Research Field Structure of Matter

Proposal for a Helmholtz Research Programme

Elementary Particle Physics

of the Helmholtz Centres
Deutsches Elektronen-Synchrotron DESY
Forschungszentrum Karlsruhe

2010 – 2014 | Coordinating Centre: Deutsches Elektronen-Synchrotron DESY
Research Field Structure of Matter

Proposal for a Helmholtz Research Programme

**Elementary Particle Physics**

of the Helmholtz Centres

Deutsches Elektronen-Synchrotron (DESY)
Forschungszentrum Karlsruhe (FZK)

2010 - 2014

Programme spokesman:
Prof. Dr. Joachim Mnich (DESY)
Coordinating Centre: DESY

Coordinator of the Research Field:
Prof. Dr. Albrecht Wagner (DESY)
Prof. Dr. Horst Stöcker (GSI)
Helmholtz Association

Mission Statement

We contribute to solving grand challenges which face society, science and industry by performing top-rate research in strategic programmes in the fields of Energy, Earth and Environment, Health, Key Technologies, Structure of Matter, Aeronautics, Space and Transportation.

We research systems of great complexity with our large-scale facilities and scientific infrastructure, cooperating closely with national and international partners.

We contribute to shaping our future by combining research and technology development with perspectives for innovative applications and provisions for tomorrow’s world.
Participating centres:

Deutsches Elektronen-Synchrotron (DESY)  Prof. Dr. Joachim Mnich  
Deutsches Elektronen-Synchrotron DESY  
Notkestr. 85  
D-22607 Hamburg  
Tel.: +49 (0)40 8998 1921  
Fax: +49 (0)40 8999 4304  
e-mail: Joachim.Mnich@desy.de

Forschungszentrum Karlsruhe (FZK)  Dr. Andreas Heiss  
Forschungszentrum Karlsruhe GmbH  
Karlsruhe Institute of Technology (KIT)  
P.O.Box 3640, 76021 Karlsruhe, Germany  
Tel: +49 (0)7247 82 5639  
Fax: +49 (0)7247 82 4972  
e-mail: andreas.heiss@iwr.fzk.de
Contents

THE RESEARCH FIELD STRUCTURE OF MATTER

THE PROGRAMME ELEMENTARY PARTICLE PHYSICS

1 Strategic significance
   1.1 Overview of the programme
      1.1.1 Status quo of the programme’s scientific context
      1.1.2 Introduction to programme topics
      1.1.3 Current and previous activities leading up to the proposed programme
      1.1.4 Expected outcomes or contributions to solving grand challenges
      1.1.5 Position of the programme in the context of international strategies
      1.1.6 Important external contributions to the programme
      1.1.7 Contribution to other programmes or to other joint cross-programme initiatives
      1.1.8 Cooperation within the programme
   1.2 Organisation of the programme
   1.3 Important infrastructures used or offered by the programme
   1.4 Proposed resources of the programme topics
   1.5 Additional resource-related information
   1.6 Overview about third party funding
   1.7 Potential developments anticipated for the programme period, future outlook
   1.8 Capital investment projects (> 2.5 M€) planned

2 Planned programme topics
   2.1 HERA
      2.1.1 Challenges
      2.1.2 Current activities and previous work
      2.1.3 Contents and goals
      2.1.4 Expected results, milestones
   2.2 LHC
      2.2.1 Challenges
      2.2.2 Current activities and previous work
      2.2.3 Contents and goals
      2.2.4 Expected results, milestones
   2.3 Preparation for a future lepton collider
      2.3.1 Challenges
      2.3.2 Current activities and previous work
      2.3.3 Contents and goals
      2.3.4 Expected results, milestones
   2.4 Theoretical Particle Physics
      2.4.1 Challenges
      2.4.2 Current activities and previous work
      2.4.3 Contents and goals
      2.4.4 Expected results, milestones
   2.5 Experimental Facilities
      2.5.1 Challenges
      2.5.2 Current activities and previous work
      2.5.3 Contents and goals
      2.5.4 Expected results, milestones
   2.6 Large-scale Facility GridKa
      2.6.1 Challenges
      2.6.2 Current activities and previous work
      2.6.3 Contents and goals
      2.6.4 Expected results, milestones
   2.7 Large-scale Facility DESY Grid Centre
      2.7.1 Challenges
      2.7.2 Current activities and previous work
      2.7.3 Contents and goals
      2.7.4 Expected results, milestones
   2.8 Summary of proposed costs of the programme topics

3 Competence provided by the participating centres
   3.1 Profiles of participating centres
      3.1.1 DESY
Contents

3.1.1  Scientific profile of DESY ................................................................. 81
3.1.2  Scientific profile of the institutes/departments/groups participating in the programme .............. 82
3.1.3  Recent and intended strategic developments ................................................ 83
3.1.4  Talent Management ............................................................................. 83
3.1.5  CVs of the principle investigators ............................................................ 87
3.1.6  FZK ..................................................................................................... 110
3.1.7  Scientific profile of FZK ...................................................................... 110
3.1.8  Scientific profile of the institutes/departments/groups participating in the programme .............. 110
3.1.9  Recent and intended strategic developments ............................................. 111
3.1.10 Talent Management ............................................................................. 112
3.1.11 CVs of the principle investigators ............................................................ 113
3.2  Evidence of scientific quality and relevance of previous work ............................................. 115
3.2.1  Quantitative indicators of DESY ................................................................ 115
3.2.2  Quantitative indicators of FZK ............................................................... 116
3.2.3  Sum of the parts of the centres ................................................................. 117
4  Appendix .................................................................................................... 118
4.1  List of Abbreviations ................................................................................. 118
5  Programme resources .................................................................................. 121
5.1  Proposed costs ......................................................................................... 121
5.2  Additional resource information for reviewers ............................................ 122
5.2.1  Resource planning of programme topics .................................................... 122
5.2.2  Current personnel capacity ..................................................................... 124
5.2.3  Resource planning of participating centres ............................................... 125
6  Performance indicators .............................................................................. 127
6.1  Performance indicators for large scale facility GridKa ....................................... 127
6.2  Performance indicators for large scale facility DESY Grid Centre ...................... 128

Additional material supporting this proposal can be found on the attached CDROM:

- Proposal for the Helmholtz Research Programme “Elementary Particle Physics” (pdf)
- Statement on the research programme by the European Committee for Future Accelerators (ECFA)
- Statement on the research programme by the German Komitee für Elementarteilchenphysik (KET)
- Statement on the research programme by the International Advisory Board of the Alliance
- Statement on the research programme by the GridKa Overview Board
- Sketch of the proposal for the Helmholtz Alliance "Physics at the Terascale"
- Full proposal "Physics at the Terascale"
- The European Strategy for Particle Physics: The CERN Council roadmap
- Proposal capital investment project "Extension of the DESY Tier-2 for LHC"
- Evaluation reports: Report 1, Report 2, Report 3
- Publications of leading scientists

Appendix
The Research Field Structure of Matter

Coordinator of the Research Field: Prof. Dr. Albrecht Wagner (DESY), until end 2008
Prof. Dr. Horst Stöcker (GSI), as of 2009

Research Field "Structure of Matter" 2010-2014

Participating Helmholtz Centres: DESY, FZJ, FZK, GKSS, GSI, HZB

I. Challenges

The challenges of this Research Field consist of

• Understanding the structure and dynamics of matter on entirely different scales of length and time, including the building blocks of matter and the fundamental forces as well as processes in the universe at the highest energies and the development of cosmic structures,

• Research on fundamental phenomena in condensed matter, plasmas, and in atoms, molecules and clusters, as well as on the structure and function of complex materials up to biomolecules.

This fundamental research, guided by acquisition of knowledge, simultaneously yields a number of incentives for technological development.

The investigation of the structure of matter requires high-technology infrastructures that are developed, built, operated and used together with national or international partners.

A core task of the Helmholtz Centres is

• The development of the required large-scale facilities and technical and scientific infrastructures and their construction, operation and scientific exploitation, as well as participation in large international projects.

The Research Field is responsible for large-scale facilities that are often unique worldwide. It therefore makes a key contribution to implementing the large-scale facility goal in the mission of the Helmholtz Association, and in doing so, it contributes critically to strengthening international visibility. The large-scale facilities are used by the Helmholtz Centres for their own research, but are available mostly to several thousand external users, from Germany and abroad.

The programme development of the Research Field "Structure of Matter" in the years 2010-2014 will be characterized mainly by the following aspects:

• Research in the programmes: elementary particle physics, astroparticle physics, hadrons and nuclei, as well as research with photons, neutrons and ions in large-scale facilities.

• Construction of two major European projects FAIR (Facility for Antiproton and Ion Research) at the GSI and XFEL (European X-ray-Free Electron Laser) in cooperation with DESY.

• Strengthening the Research Field by integrating BESSY II after the merging of BESSY and HMI to form the Helmholtz Zentrum Berlin für Materialien und Energie (HZB). By this integration the Helmholtz Association provides the entire spectrum of synchrotron radiation in one organization.
• Participation in the use of the research neutron source FRM-II in Garching. This will significantly strengthen the research with intense neutron beams.

• Change of the programme structure: the programme "Condensed Matter" will be transferred to the Research Field Key Technologies. In-house research in the programme "Photons, Neutrons, and Ions" will be further strengthened.

II. Structure and goals of the research field

The Research Field is structured into four programmes focusing on the following scientific objectives for the funding period 2010-2014.

Investigation of the building blocks of matter and in cosmology are geared towards a comprehensive and quantitative understanding of matter and its forces as well as the principles that link the smallest particles in the universe to the largest structures of the cosmos. Elementary particle physics, hadron and nuclear physics, and astroparticle physics provide answers to the central questions of current research, such as explaining the origin of mass, detecting particles that are not part of the standard model, determining the fundamental properties of nuclear matter, or explaining the origin and nature of cosmic radiation.

The programme "Elementary Particle Physics" investigates the building blocks of matter and the forces that act between them and searches for new forms of matter and the laws that have determined the development of the early universe.

The programme "Astroparticle Physics" is an area of research at the interface of astronomy, astrophysics, cosmology, and particle physics. The subjects of research extend from the origin and properties of cosmic radiation to the determination of the neutrino mass.

The programme "Physics of Hadrons and Nuclei" strives for a fundamental and deepened understanding of matter consisting of quarks and gluons. This matter includes atomic nuclei and their components, protons and neutrons, but also the quark-gluon plasma, which played an important role in the early phase of the universe.

The programme "Photons, Neutrons, and Ions (PNI)" includes the construction and operation of complex large-scale facilities and a broad spectrum of research into the properties of condensed matter and complex materials, plasmas, atoms, molecules, and clusters, which became only possible with these instruments. Starting from physics questions, experimental and theoretical activities are increasingly directed at problems in soft condensed matter, biology, and medicine. Understanding the structure and dynamics, the ordering mechanisms and electronic and magnetic properties in systems on nanometer scales is in the centre of interest. In the PNI programme, the connection between fundamental scientific questions and possible applications as well as the interaction of different scientific and technical disciplines will be emphasized in particular. Photons, neutrons, and ions in these studies are complementary tools. Further development of instruments (from particle sources to sample environments) opens up a path to a deeper understanding of matter.

The programme topic "Photons" is clearly marked by the construction and scientific use of the European XFEL, the Free Electron Laser FLASH and the storage ring PETRA III at DESY. In addition to the existing facilities DORIS and ANKA, starting in 2009, BESSY will also be integrated as an additional photon source in the Helmholtz Association.

The programme topic "Neutrons" is characterized by an intensified involvement in FRM II, operation of the Berlin-Neutron-Source BER II and the extreme sample environments available there, and intense utilization of the foreign site at SNS in Oak Ridge.

For the programme topic "Ions," the ion trap facility HITRAP and the Petawatt laser PHELIX and ISL beamlines at GSI will be fully available. A special emphasis will be given to the development of PNI-relevant installations at FAIR for experiments with highly-charged ions and antiprotons.
III. Competences and steps
The most important competences and next steps of the four programmes are summarized below.

"Elementary Particle Physics" programme
DESY – one of the worldwide leading centres in particle physics – will no longer operate its own large accelerators in the coming programme period. The goal of the programme is to ensure the future international competitiveness of German particle physics.

• Strong participation in two of the Large Hadron Collider (LHC) experiments (ATLAS and CMS). At the same time, the precision analyses of the HERA experiments will be concluded, whose results are also of great significance for the LHC analyses.

• Further expansion of the Karlsruhe grid computing centre (GridKa) at FZK, an international data and high-performance computer centre (Tier1), as well as the Tier2 centre (ATLAS, CMS, LHCb) and the analysis centre at DESY.

• Theoretical studies in close connection with experimental activity as well as research in areas at the interface of particle and astroparticle physics and in the field of string theory. The lattice-gauge theory, including R&D for novel high-performance computers, will be continued at the Zeuthen site in close cooperation with the activities at the John von Neumann Institute.

• Cooperation in further development of superconducting accelerator technology for the International Linear Collider (ILC), in which DESY plays a leading role worldwide. This follows the European Strategy for Particle Physics. Synergies between XFEL and ILC will be exploited.

• Detector development for a luminosity-upgraded LHC and for precision experiments at the ILC, contributions to development of detectors for the XFEL.

An essential instrument in the implementation of this programme is the Helmholtz Alliance "Physics at the Terascale." This Alliance with 17 German university groups, Forschungszentrum Karlsruhe, and the Max-Planck Institute for Physics combines the forces and complementary excellence in all essential fields into a long-term structure.

The programme is consistent with the European Strategy for Particle Physics, which is part of the ESFRI Roadmap.

Participating Helmholtz Centres: DESY, FZK

"Astroparticle Physics" programme

• Measurements with the Pierre Auger Observatory, which is already recording data of the highest quality, will be continued, and the plan to expand the measurements to the entire sky will be further pursued. Accompanying research includes the radiodetection of cosmic-ray showers and multi-messenger analyses.

• The IceCube neutrino telescope will be completed and therefore guarantees plenty of results in the next programme period, including the new aspect of multi-messenger analysis, the combination of neutrino astronomy with particle and gamma astronomy. In this context DESY is participating in the preparatory work for the Cherenkov Telescope Array (CTA).

• The search for Dark Matter is gaining further significance through new astronomical observations. It is planned to become a strategic field through a leading role of Forschungszentrum Karlsruhe in the European project EURECA.

• The KATRIN experiment will conduct its measurements in the next programme period. The experiment is unique worldwide and of great significance, since it has the highest sensitivity on measuring the neutrino mass or setting the best limits.
• Theoretical work in astroparticle physics will be conducted in close cooperation with the Universities of Potsdam and Karlsruhe.

The programme is consistent with the Roadmap of European astroparticle physics.

*Participating Helmholtz centres: FZK, DESY*

"Hadron and Nuclear Physics" programme

• Leading participation in the international FAIR project (Facility for Antiproton and Ion Research) at GSI. This unique accelerator complex is being built by GSI and FZJ together with national and international partners and will be operating from 2013 on.

• Participation in the planning, construction, and use of experiments at FAIR.

• Implementation of a focused experimental programme at GSI and COSY, exploiting their unique capabilities and leading towards FAIR. This is complemented by technical developments such as phase-space cooling and polarisation of antiprotons at FAIR.

• Exploitation by GSI, together with the German universities, of the ALICE detector in the Heavy Ion programme of LHC at CERN. Construction and operation of a high-performance Tier2 centre for ALICE at GSI.

• Strengthening the theoretical activities of the programme with respect to physics at ALICE and FAIR and for future hadron physics.

• Operation of EMMI (Extreme Matter Institute) in the framework of the Helmholtz Alliance "Extreme Densities and Temperatures: Cosmic Matter in the Laboratory", aiming at developing common approaches for research on matter under extreme conditions (density and temperature) in the fields of hadron and nuclear physics, atomic physics, plasma research, and astrophysics.

The programme is aligned to the Roadmap of European nuclear physics. FAIR is part of the ESFRI Roadmap.

*Participating Helmholtz Centres: GSI, FZJ*

"Photons, Neutrons, and Ions" programme

The centres participating in this programme follow their research projects with the strategic objective to fully utilize and optimize the potential of the large-scale facilities and to support the external users as effectively as possible.

At the Helmholtz Zentrum Berlin für Materialien und Energie (HZB), after merging BESSY and HMI by 1 January 2009, the potential of complementary uses of photons and neutrons to investigate e.g. magnetic materials will be utilized in particular.

**Photons:**

• Leading participation in the European X-ray laser XFEL.

• Construction of the Centre for Free Electron Laser Studies in cooperation with the Max-Planck Society and the University of Hamburg as the basis for the German utilization of XFEL. Development and construction of novel photon detectors.

• Development of PETRA III to become the world's best radiation source for hard X-rays and focusing the DORIS programme on complementary applications. Construction of a Centre for Structure and Dynamics of Condensed Matter on the Nanoscale as well as construction of the Engineering Materials Science Centre at DESY by GKSS for complementary utilization of photons and neutrons.

• Extension of the user programme at VUV-FEL FLASH by increasing the experimental capabilities and by continuous further development of the facility regarding improved stability and synchronization, seeding and the implementation of new experiments.
• Design, construction and operation of a second beam line at FLASH using the HHG (High Harmonic Generation) and a cascaded HGHG (High Gain Harmonic Generation) seeding principle (FLASHII) in order to further develop FEL techniques and to significantly enhance the user capacity of FLASH, in cooperation with BESSY/HZB.

• Expansion programme “2007 Plus” of BESSY II, especially for microscopy from the THz range to X-rays and for the generation and use of short X-ray pulses with freely selectable polarisation.

• Construction and operation of a superconducting CW linear accelerator at HZB with high current and high repetition rate, as basis for a future Energy Recovery Linac and for FEL developments, in cooperation with DESY and FZK/KIT; development and application of the superconducting undulator technology.

• Further development of ANKA as user facility in combination with the research portfolio and infrastructure available at FZK/KIT; development and application of the superconducting undulator technology.

• Further development of ANKA as user facility in combination with the research portfolio and infrastructure available at FZK/KIT; development and application of the superconducting undulator technology.

• Establishing a Centre for structural biology at DESY, together with the Research Field "Health"/"Key Technologies".

Neutrons:

• Strengthening the Helmholtz Association involvement in FRM II, construction of further instruments by the Jülich Centre for Neutron Science (JCNS), GKSS and HZB.

• Operation of BER II with the extreme sample environments available there, as well as startup of the first stage (25T) of the high-field magnet, upgrading selected instruments and neutron guides at BER II and at the cold source.

• Consolidating the JCNS outstation at the SNS in Oak Ridge, and construction of a diffractometer for non-equilibrium states of condensed matter. Construction by GKSS of the short-pulse engineering spectrometer SPES at ILL

• Participation in the development of concepts for new neutron sources (ESS) and their instrumentation.

Ions:

• For materials research, plasma and atomic physics with heavy ions at GSI, full exploration of the research potential provided by the experimental storage ring ESR, the new ion trap facility HITRAP, the new high-energy / high-power laser facility PHELIX, and the new M-branch at the UNILAC.

• Strong participation in the international FAIR project by developing the PNI-relevant installations for FAIR.

The XFEL, FELs for soft X-rays, FAIR and the ESS are parts of the ESFRI Roadmap.

Participating Helmholtz Centres: DESY, FZJ, FZK, GKSS, GSI, HZB

IV. Summary

The programmes in the Research Field “Structure of Matter” are of high international visibility and define future directions of science. The success and progress achieved in the first programme period shall be expanded.

The links with strategically important and scientifically notable partners from universities and research institutes are an important element for the successful implementation of the projects. With two approved Helmholtz Alliances, the research field is in an outstanding position here.
The Research Field “Structure of Matter” is excellently positioned within the Helmholtz Association, based on its research capabilities. It is one of the strongest attraction points for researchers from abroad and therefore makes a critical contribution to the strength of Germany as a research location. The new large instruments under construction and being planned will further contribute to keep Germany at the forefront of research.

Research Field costs

Research Field costs covered by institutional funding as requested for 2010:

<table>
<thead>
<tr>
<th>Mio. €</th>
<th>DESY</th>
<th>FZJ</th>
<th>FZK</th>
<th>GKSS</th>
<th>GSI</th>
<th>HZB</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elementary Particle Physics</td>
<td>21,2</td>
<td>8,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29,3</td>
</tr>
<tr>
<td>Astroparticle Physics</td>
<td>2,7</td>
<td>14,7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17,3</td>
</tr>
<tr>
<td>Physics of Hadrons and Nuclei</td>
<td>29,9</td>
<td></td>
<td>59,8</td>
<td></td>
<td></td>
<td></td>
<td>89,7</td>
</tr>
<tr>
<td>Research with Photons, Neutrons and Ions (PNI)</td>
<td>156,0</td>
<td>18,7</td>
<td>15,8</td>
<td>11,9</td>
<td>12,7</td>
<td>68,6</td>
<td>283,8</td>
</tr>
<tr>
<td>Non-programme bound research</td>
<td>8,1</td>
<td>2,6</td>
<td>1,2</td>
<td>0,2</td>
<td>3,6</td>
<td>2,4</td>
<td>18,1</td>
</tr>
<tr>
<td>Total</td>
<td>187,9</td>
<td>51,3</td>
<td>39,8</td>
<td>12,1</td>
<td>76,1</td>
<td>71,1</td>
<td>438,3</td>
</tr>
</tbody>
</table>
The Programme Elementary Particle Physics

1 Strategic significance

Research in elementary particle physics is motivated by the goal of attaining a fundamental description of the laws of physics, such as explaining the origin of mass and understanding the early universe and the structure of space and time, which determined the evolution of the universe from its beginning to the complex structure observed today. These topics directly relate the physics at the smallest and the largest length scales of our universe and thus link the particle and astroparticle programmes at DESY. Although fundamentally driven by the quest for knowledge, the ensuing research is performed at the edge of what is feasible technologically and hence also drives the development of technology.

With the start of CERN’s Large Hadron Collider (LHC) and preparations for the International Linear Collider (ILC) in full swing, we indeed expect revolutionary results explaining the origin of mass, unravelling the nature of dark matter and providing glimpses of extra spatial dimensions or grand unification of forces. Any of these insights would dramatically change our view of the world.

The pursuit of high energy particle physics requires accelerators capable of colliding particles at the highest energies and luminosities, complex detectors capable of recording the collision products, cutting edge information technologies like the Grid, and the development of the underlying theoretical concepts.

Particle physics has for decades been the driver for accelerator developments and continues to do so as one of the keys for our understanding of the fundamental questions of the field lies in attaining the highest possible energies. The know-how generated by focused accelerator development is of great benefit for many other fields of science. One recent example can be witnessed at DESY. Particle physicists triggered the development of superconducting accelerators to reach the TeV energy scale in electron-positron collisions. This work has led to the first VUV-FEL now operating for several years at DESY, serving a broad spectrum of users, and to the European XFEL.

Developing, building and operating accelerators and large detectors together with advanced information technology like the Grid requires and builds on high scientific and technical skills, accumulated over many years. This pool of knowledge and capability can only be provided in the framework of national laboratories such as DESY. Large-scale facilities and technical and scientific infrastructures and their construction, operation and scientific exploitation, as well as participation in large international projects are therefore core elements of the mission of the Helmholtz Association. Through their staff, technical experience and facilities laboratories such as DESY are enablers of science.

The European Strategy for Particle Physics, as approved in 2006 by CERN Council, has set the road map for the field. German particle physicists and DESY have provided major input to this strategy.

The elements of the European Strategy are: Exploitation of the LHC, followed by a linear electron-positron collider for which the ILC in superconducting technology is well prepared to serve energies of up to 1 TeV and, to reach later even higher energies, CLIC, for which R&D is being pursued. The interplay of frontier experiments, theory and technologies is a key to the development of the field. Particle physics addresses fundamental questions in basic science and at the same time will continue to have a major impact on other fields of science, on society and education. The strategy of the programme “Elementary Particle Physics” is fully aligned with this European strategy.

Particle physics has for decades been a forerunner of international co-operation; it is now becoming even more global. Through manifold, longstanding collaborations with universities and research centres in Europe and other parts of the world DESY has assumed an important
role in particle physics on an international scale. The laboratory intends to further develop these collaborations to remain an attractive research centre for partners in Europe and beyond.

Traditionally Germany, through DESY, had provided to the field world-class research facilities, such as DORIS, where B-mixing was discovered, PETRA, where the gluon was discovered, and HERA, where a precise knowledge of the structure of the proton and the strong force was achieved. The programme “Elementary Particle Physics” reflects the long-term strategy of DESY to preserve its role as one of the worldwide leading laboratories in particle physics at the high energy frontier.

The DESY programme for the next five years concentrates on physics analyses, detector operation and development, accelerator physics at the energy frontier, together with the provision and development of the necessary infrastructure. Emphasis is given to accelerator-based research at large facilities, which in general consists of projects of many years of preparation, execution and analysis, and which is thus subject of a long-term policy. The programme topics range from the completion of the analysis of HERA data, continues with the transfer of knowledge gained at HERA into the LHC physics programme through a strong participation in its experimental programme, to the preparation of future colliders, namely the ILC, and detectors. These elements will ensure that DESY remains an attractive laboratory capable of attracting the best heads in the field. This long-term experimental programme is supported by a strong theory group, which ensures that the intense and fruitful dialogue between experimentalists and theorists exemplified at HERA is further developed and applied to the next generation of experiments.

The immense computing challenges posed by modern particle physics experiments are addressed in a common effort by FZK and DESY. The particle physics programme at FZK will focus on the operation and upgrade of the powerful Grid-based Tier-1 computing infrastructure needed both for data storage and reconstruction, especially at the LHC. DESY hosts a Tier-2 centre and the national analysis facility, needed to provide users with all levels of computing service essential for working with data from modern experiments. DESY and FZK also contribute to worldwide efforts to develop tools for the Grid, in particular in the field of data storage.

In order to maintain this leadership role and to optimally position German particle physics after the end of operation of HERA in 2007 in the increasingly global environment, the Helmholtz Alliance “Physics at the Terascale” was initiated. It provides new and improved structures for particle physics in Germany through a network comprising DESY and FZK, 17 universities and one Max Planck institute as a tool for a more effective collaboration, in particular between experimentalists and theorists, e.g. for the exploitation of LHC, but also in the areas of detector development, new technologies and scientific training. More details of the structure and operation of the Helmholtz Alliance are given below.

The Alliance is a cornerstone to strengthen the strategic position of DESY in the national context. It enables DESY together with the German high energy physics community to respond coherently to the challenges of global projects and strengthens the German position in the international competition. DESY will continue to play an active role in the restructuring process for high energy physics in Germany in a sustainable way beyond the next funding period.

With the Alliance DESY is fully embedded in the overall German particle physics landscape, and continues its central role as a national laboratory for particle physics in Germany. DESY pursues this role in a dual manner: it serves as a central laboratory, which provides support and infrastructure to the community, and it constitutes an excellence centre for particle physics in Germany, combining knowledge and experience in experimental, theoretical and applied particle physics. This initiative has raised considerable interest in other countries and gained German particle physics policy substantial appraisal. Enabling the long-term sustainability of the Alliance is therefore integral part of the strategy. Extra funding for the Helmholtz Alliance is available until 2012 and DESY has made it one of its top priorities to ensure that the structures and goals of the Alliance will be sustained beyond this point.
The programme “Elementary Particle Physics” is in full agreement with the mission of the Helmholtz Association. It is consistent with the European and global strategy for particle physics and strengthened through the proposed measures. In the pursuit of the scientific and technical excellence DESY and FZK will continue to closely collaborate with and provide support for German and European universities and research institutes working at the high energy frontier. Many aspects of global management can only be dealt with strong institutions with respective large and specific infrastructure. The programmes of DESY and FZK, fully consistent with the European and global roadmaps in particle physics, further strengthen the Helmholtz-mission through manifold collaborations with German universities and on an international level.

1.1 Overview of the programme

1.1.1 Status quo of the programme’s scientific context
Over the last two decades colliders like LEP, SLC and more recently Tevatron and HERA, have vastly expanded our knowledge of the microscopic universe. They have also sharpened our view of the missing pieces of the Standard Model, and expectations. The Standard Model firmly predicts fundamentally new phenomena at the energy regime of Tera electron Volt. This so called Terascale will be investigated experimentally at the next generation of particle colliders where some of the most profound questions regarding our understanding of Nature and the Universe may be answered: (i) What is the origin of mass? (ii) Are the quarks and leptons the elementary building blocks of matter? (iii) Are the known forces unified? (iv) What is the origin of dark matter? (v) What is the origin of the matter-antimatter asymmetry in the universe?

The properties of the electro-weak force carriers clearly favour the so-called Higgs mechanism to explain the generation of mass. Its dynamic realisation is coupled to the fundamental question whether Higgs particles exist, which can only be answered at Terascale colliders. If such a Higgs particle is discovered, a plethora of new questions on its properties arises. Should the Higgs mechanism be demonstrated not to exist, the Standard Model is not able to make any prediction beyond the Terascale, and new phenomena necessarily have to arise in this energy regime.

At the Terascale we expect answers to another long-standing question, the so-called hierarchy problem. There are 16 orders of magnitude of difference between the scale of electro-weak symmetry breaking, the Terascale, and the scale where quantum gravity becomes relevant, the Planck scale, which implies an extreme fine-tuning of parameters in the current theory to be viable. Solutions to hierarchy problems should be accompanied by new particles accessible at Terascale colliders. The most prominent proposals are supersymmetry and models with extra space dimensions. Both paths offer fascinating possibilities for insight into physics at the very high scales associated with grand unification of forces and ultimately quantum gravity.

Within the supersymmetric framework, when extending the gauge couplings of the Standard Model to very high energies, the strong and electroweak forces indeed unify close to the Planck scale. This is a strong indication that supersymmetry may be manifest. However, this is only the case if the supersymmetry spectrum lies at the Terascale, just where it is also required for the solution to the hierarchy problem. Thus we expect the supersymmetric masses to be in exactly the range for a discovery and later detailed investigations at the LHC and the ILC.

The possible existence of extra spatial dimensions, beyond the hitherto observed three, captures the imagination. Within string theory such dimensions have already been extensively studied at very short distances. New theories, motivated by the hierarchy problem, suggest that the effects of extra dimensions may be visible at the length scales corresponding to the Terascale. To date gravity has not been measured in the laboratory at energy scales much above $10^{-3}$ eV. The hierarchy problem is resolved either by the large volume or the large curvature of the extra dimensions. In either case, the expected collider signatures might be clearly visible at the LHC, if such extra dimensions exist.

Modern cosmology has made breakthrough discoveries in recent years. Based on very precise measurements, this has led to a dramatically new and self-consistent view of the universe at large scales. Interestingly this picture makes several predictions, which imply that the Standard
Model is incomplete and which can be resolved by Terascale physics. The cosmological dark matter is most naturally explained by a weakly interacting massive particle, with a mass at or just below the Terascale. Here the most promising candidate is the supersymmetric lightest neutralino. Furthermore, cosmology requires incomplete annihilation of matter and antimatter in order to explain the dominance of matter in today’s Universe. No asymmetry of sufficient magnitude is present in the Standard Model.

The Large Hadron Collider LHC opens the Terascale physics for experimental exploration of fundamental questions. DESY is well positioned to participate in this enterprise in a key position: HERA explored the structure of protons, which now constitute the colliding beam particles at the LHC. DESY will continue to participate in precision measurements at the LHC which often depend crucially on the knowledge of the underlying hadronic environment. DESY is a member of both ATLAS and CMS, and is playing a key role in the preparations of the ILC. Through the Alliance which embraces the complete German particle physics community working at the energy frontier, all these activities are well embedded in the national landscape. The existence of a strong theory group brings together new theoretical ideas and experimental facts within the laboratory, and ensures that the analyses done at DESY are well supported theoretically. The computing support for German groups necessary to be competitive at an international level is provided by FZK and DESY. The future of the field is prepared by accelerator research for a linear collider and infrastructure support for the development and construction of large detectors at ILC and for an LHC upgrades R&D programme.

The Helmholtz Association with the centres DESY and FZK is thus centrally engaged in the physics of the energy frontier. Helmholtz is a major player in particle physics in Germany and world wide and performs in concert with the German universities.

1.1.2 Introduction to programme topics
High energy physics research at DESY is focussed on the exploration of physics at the highest available energy scales. It is cast into seven topics:

1) HERA
2) LHC
3) Preparation for a Future Lepton Collider
4) Theoretical Particle Physics
5) Experimental Facilities
6) Large-scale Facility GridKa
7) Large-scale Facility DESY Grid Centre

These programme topics are closely interrelated and build upon each other. Close connections exist between the different topics, made obvious also by the fact that many scientists work on more than one topic. The programme is well embedded into the German particle physics community.

The Helmholtz Alliance “Physics at the Terascale” plays a central role in the programme. The Alliance has been started in 2007 to restructure the German particle physics landscape and the position of DESY in this landscape after the end of HERA operation. It is a structured network, comprising DESY and FZK, 17 universities and one Max Planck Institute. It has the aim of

- fostering the collaboration between experiments, institutes, and also between experimentalists and theorists;
- providing analysis support for an optimal exploitation of LHC data;
- providing training and support for developments in the fields of accelerators, detectors, computing, and data analysis.
DESY’s background as a large laboratory that designs, builds and operates large experimental facilities and that has acquired outstanding expertise in many relevant experimental areas is a central part of the Alliance. The initiative has raised considerable interest in other countries and gained German particle physics policy a lot of appraisal.

The Alliance is organised around a number of central tasks: An analysis centre at DESY will provide focused support for analyses primarily at the LHC, with computing support given through the National Analysis Facility (NAF). A Virtual Theory Institute provides a forum for theoretical discussion and education. A Virtual Laboratory for Detector Developments is organised to improve the general detector development infrastructure. A common effort is made to improve the training of young researchers in accelerator physics. More details about the different parts of the Alliance are discussed in section 2.5 of this proposal.

Embedded into the national and international particle physics community the DESY programme for the next five years will focus on the following topics:

HERA analyses will continue well beyond 2010 providing insight to the structure of the proton and the properties of the strong force as well as the electro-weak force. Results from HERA are highly relevant in the analysis of LHC data, and so give a strong scientific motivation to complete the analysis in good time.

The LHC experiments will become the main focus of the programme over the next few years. As the HERA activities are reduced, activities at the LHC will be increased. DESY will become more and more involved in the detectors ATLAS and CMS, and in possible upgrades. Apart from its expertise in detector technologies, DESY possesses a vast experience and knowledge in the integration and commissioning of detectors it has accumulated during the HERA years. The German particle physics groups, as organised in the Alliance, participate in almost all key physics fields that can be studied with ATLAS and CMS: the search for the Higgs boson, top quark physics, searches for supersymmetry or other new physics, and much more. The contributions and support from DESY is a most valuable asset that will allow the Alliance to take a good share in the physics results that are expected during the next decade.

Major developments are expected in the development of a future lepton collider in the next few years. The ILC concept will reach maturity, and a full proposal is expected around 2012. Other technologies will see vigorous development work, particularly for the CLIC concept. DESY will continue to participate in linear collider activities with a clear focus on the further development of superconducting acceleration technologies where DESY profits tremendously from the construction of the large superconducting linear accelerator, the XFEL.

A vigorous detector development programme complements the involvement in the development of future accelerators. This programme is anchored on the one side in the Alliance, by supporting its Virtual Laboratory of Detector Technologies and on the other side in a strong involvement in the development of detector technologies and concepts for future facilities like upgrades of the LHC detectors and the ILC.

Applications of the detector development programme at DESY are not restricted to particle physics. For example the novel technology of silicon photomultiplier under study at DESY for large-scale hadron calorimeter receives interest for medical application in positron emission tomography which is part of the research programme of a Young Investigator Group (YIG) at DESY. Novel radiation hard detectors developed for application at the ILC will now be used for the LHC upgrades. The new generation of light sources under construction at DESY and elsewhere demands new technologies and detectors of similar complexity as compared to particle physics for instance in the field of data acquisition and handling. The laboratory is ideally placed to stimulate transfer of knowledge and to exploit synergies in R&D efforts for novel detectors.

Both centres, FZK and DESY will continue to expand their computing infrastructure, and serve the particle physics community, in particular as Tier-1 and Tier-2 centres for the LHC experiments. The National Analysis Facility provides vital computing resources for the Analysis Centre, which is central for the Alliance. It will continually be expanded in agreement with the
strategy to support and improve the analysis infrastructure available to researchers at DESY and at the German universities.

The DESY theory group is well positioned to contribute to the central themes of particle physics during the next few years: physics at the LHC and physics at a future electron-positron linear collider. A crucial part of these activities is the interplay between particle physics and cosmology and the development of new tools for the investigation of non-perturbative phenomena based on lattice field theory and string theory. On the phenomenological side, the complexity of the LHC data is a particular challenge.

With its four basic pillars in collider phenomenology, particle cosmology, lattice gauge theory and string theory, the theory group covers a broad and highly topical spectrum of themes in modern particle physics, well suited to address the upcoming challenges in the field. The group is deeply anchored in DESY’s experimental programme through its leading role in the Analysis Centre of the Helmholtz Alliance, the SFB TR 9 “Computational Particle Physics” and the SFB 676 on “Particles, Strings and the Early universe”. The theory group is building on well-established and vivid collaborations with local university groups in Hamburg, Berlin and Potsdam. Through all these features, the group plays a central role for theoretical particle physics in Germany and it has a very significant impact abroad that is only matched by a small number of other European institutions in the field.

In addition to the main activities forming the particle physics programme at DESY a small number of topical projects will be pursued. An example for this is the ALPS project, started in 2007, in which hypothetical weakly interacting sub-eV particles (WISPs) are searched for. The project has led to new collaborations of DESY with the Laser Zentrum Hannover and the Max-Planck-Institute for Gravitational Physics (Albert-Einstein-Institute). Activities at the low energy frontier will complement experiments at LHC. These projects are part of the programme independent research at DESY, and ensure that DESY can react to novel scientific challenges and problems quickly.

Today no one can predict what the LHC data will unveil or leave covered. Modifications to the programme and adaptations to the relative weights of its elements may be needed during the programme period. Europe, through the CERN Council Strategy group, is setting up a mechanism to manage this discussion and a process through which the roadmap can be defined, once new input is available. The national laboratory DESY will participate prominently in this process. It is vital for the success of the field and DESY that enough flexibility is maintained within the programme to allow adaption to changing boundary conditions and changing roadmaps. In particular, around the middle of the funding period discussed here results from the LHC may confirm the physics case for the ILC and pave the way for its speedy construction.

1.1.3 Current and previous activities leading up to the proposed programme

At the time when the previous proposal was written in 2004 DESY’s particle physics programme appeared significantly different from the one presented in this proposal. HERA was in full swing, several competing proposals for a linear collider existed, with one of them, the TESLA proposal, developed primarily at DESY, and no decision had been taken on an experimental programme after the HERA shutdown.

The data taking at the HERA accelerator finished on June 30, 2007. During its last years of operation the HERA collider performed extremely well. Both colliding beam experiments collected around 500 pb$^{-1}$ of high quality data. This constitutes the successful completion of 15 years of operation of the HERA collider and experiments. The analysis of the data continues and will be a key element of the next programme period.

The German particle physics community decided to strongly focus on the physics at the Terascale, which implies a focus on the exploitation of the LHC, and on the preparations for the next generation of lepton colliders. Through the contribution to the CERN budget the LHC machine and through BMBF and university funds the LHC detectors have been constructed with large contributions from Germany. The Helmholtz centre FZK contributed significantly to the computing infrastructure in Germany by setting up the Tier-1 centre.
In 2006 DESY decided to join the LHC experimental programme. This decision was driven by the desire to define a programme of highest scientific value, strongly anchored in the German particle physics community and strongly supported at the laboratory. The participation in the LHC has two components. Firstly, DESY offered to contribute to the computing infrastructure by housing Tier-2 centres for the German LHC groups, thus complementing the FZK engagement. Secondly, DESY decided to join both large LHC collaborations, ATLAS and CMS, reflecting the general situation in Germany.

In addition to the prospect of continued collaboration with a large number of German universities, in line with DESY’s mission, there is a large physics overlap of the LHC with HERA and the ILC manifested in series of international workshops. Another element in joining both large LHC collaborations is the experience made in the past, for instance at LEP and HERA, that at a later stage of the experimental programme the physics harvest considerably profits from the combination of experimental results. DESY as strong partner in both collaborations ATLAS and CMS will be ideally placed to play a strong role in this effort and hence in the exploitation of the LHC.

Since their accession both DESY groups have grown steadily and they are already well established in the LHC collaborations. Through the Alliance they are closely integrated into the German LHC community. Traditionally DESY has maintained particularly close ties to the local universities in Hamburg and in Berlin, which is also the case here. Building upon their experience from HERA and the HERA experiments, a strong focus developed on participation in the commissioning of the experiments, and on central tasks like trigger and data acquisition. Important contributions are also provided to the preparation of physics analyses. The experience and know how of operation of large infrastructures and physics analysis led to several coordinating roles of DESY physicists in the LHC experiments. This way the Helmholtz centre had a strong and highly visible impact on the successful completion of both LHC detectors. However, so far DESY has contributed to the detector hardware only at a comparatively small level.

With the end of HERA operation closer links were established between the operational teams of HERA and of the LHC. Several experienced HERA accelerator physicists participate actively in the commissioning of the LHC machine. They provided valuable advice based on their long-term experience with the superconducting proton accelerator HERA.

The engagement in the LHC will maintain DESY’s leadership role as a major laboratory for high energy physics and lay the foundation for experimentation and physics analysis at future colliders. It allows DESY to maintain and enhance its expertise in particle physics, to fulfil its role towards German universities and to remain attractive for students and scientists.

In 2004 the International Committee for Future Accelerators, ICFA, decided that the ILC be realised in superconducting technology, a technology largely developed at DESY within the TESLA collaboration. This left DESY in a unique position worldwide as the only laboratory with an operating test facility on site and a large body of experience in this technology. Great efforts have since been made to disseminate the knowledge to other labs worldwide, but DESY has remained at the focus of many developments in this area. The laboratory profits heavily from the fact that with the XFEL a large superconducting accelerator based on the TESLA technology will be built at Hamburg, and that with FLASH a small-scale accelerator is routinely operated. Both projects provide valuable information and input to the ILC project.

At the same time DESY contributed to the development of accelerator components, such as the positron source, the damping rings, the beam delivery system and the stabilisation studies through the EUROTeV project co-funded by the European Commission and coordinated by DESY. During the past few years, and following the decision to unite all LC efforts into one, the managerial structures for the ILC have been set up internationally. DESY has filled a number of important positions, and has provided support for the European director of the Global Design Effort, GDE. In 2007 with the reference design report an interim report has been published which summarises the state of the ILC project and provided a cost estimate.
Another important contribution by DESY to the ILC effort has been in the area of detector developments. DESY is participating in the development of key technologies, and is playing a central role in the definition of an integrated detector concept for the ILC. It is also making strong contributions to the management of the detector effort internationally, and coordinates many aspects of these activities in Germany. Highlights from the last few years include the commissioning of large-scale prototypes for the hadronic calorimeter, and for the time projection chamber, all within large international collaborations, but with important DESY contributions. A major success during the last years was the award of a large European contract, EUDET, to strengthen the detector development in Europe towards a linear collider. This project under the coordination by DESY has united 23 institutes from all of Europe.

Computing plays an essential role in the exploitation of the LHC, and in the preparation of the ILC or other future projects. DESY is providing for the German community large computing resources in the form of a Tier-2 centre for ATLAS, CMS and also for LHCb, and by setting up and operating a large computer farm for analysis work, the NAF.

The theory group has played a vital role in the overall programme by supporting the analysis of HERA data, contributing to the theoretical understanding of Standard Model (and beyond) processes at the LHC and the development of innovative perturbative and non-perturbative methods for field theories. It has further significantly broadened its scope during the last years. Two central recommendations of the previous evaluation have been implemented, namely the start-up of a new string theory group in Hamburg and the strengthening of activities in cosmology, in particular through the Virtual Institute VIPAC. Further highlights include the inauguration of Hamburg’s centre for mathematical physics, the successful prolongation of the SFB Transregio TR9 - “Computational Particle Physics”, and the successful application for SFB 676 “Particles, Strings and the Early Universe”, for several Helmholtz Young Investigator Groups and for a Marie Curie excellence award “2D Sigma models in String Theory”. Currently, DESY is in the process of hiring two leading scientists in the fields of collider phenomenology (Hamburg) and astroparticle physics (Zeuthen) who are expected to shape these research areas throughout the coming years. The buildup of the new phenomenology group should be essentially completed within 2009 such that it can assume its key role within the Analysis Centre of the Alliance.

In 2007 the new role of DESY after the end of HERA became more visible through the formation of the Alliance. This novel concept was awarded several millions of Euro of additional funding from the HGF to install and start these new activities. The current funding for the Alliance finishes in 2012. It will be a major goal and challenge to acquire sufficient support to continue the Alliance and its instruments beyond 2012.

1.1.4 Expected outcomes or contributions to solving grand challenges

With the proposed programme DESY will participate prominently in the LHC, and will continue to engage for the next big project in particle physics, a high energy lepton collider. Both projects jointly promise to vastly expand our knowledge about the microcosm. The LHC will help to unravel the mysteries of mass – where does mass come from? Is there a Higgs particle? – but also lead the way to finding physics beyond the Standard Model. Several models have been proposed over the last decades, many of which will have to face the experimental reality once data from the LHC start arriving. Among them is supersymmetry, a model which is particularly intriguing, but which has evaded so far any experimental confirmation. The knowledge gained should add to our understanding of the Standard Model, and help closing the last remaining holes, or the results will completely overturn our picture of the world, and force us to look for new explanations if none of the expected states are found.

Results from particle physics will have a large impact on our understanding of the cosmos. Dark matter is as mysterious as ever, although we know increasingly precisely how much dark matter there is in the universe. The LHC might shed first light on the nature of dark matter, and provide us with an explanation in terms of fundamental physics of what dark matter actually is.

These experiments at cutting edge accelerators are unthinkable without advanced computing resources, and advanced analysis tools. The large efforts spent on either development also
benefit other fields than particle physics. Examples are the development of the Grid computing infrastructure, which increasingly finds interest in other fields, or the development of many novel technologies for detectors, which are very much in demand e.g. in the area of medical diagnostics.

The results from the LHC will also be instrumental in determining the future of the field. There are many theoretical arguments that point to a sub-TeV linear collider as the right choice for the next generation lepton collider. The experimental confirmation may come from LHC results. This view is fully supported by the international community as well as scientific evaluations. As an example the German Wissenschaftsrat concluded in 2002 in its evaluation of large scientific facilities on the proposed TESLA collider, the predecessor of the ILC:

"The sub-panel stresses that the proposed linear collider will help to provide answers to fundamentally important questions in elementary particle physics and cosmology and that the collider is expected to play an important, if not decisive, role in improving understanding of the development of the cosmos and the nature of dark matter. The TESLA scientific programme complements the Large Hadron Collider (LHC) currently being built at CERN, since it is expected that the phenomena, which will be demonstrated by the LHC in the future, will be able to be explained in detail using the high measurement precision of TESLA. For this reason it is hoped that operation of both facilities will overlap."

1.1.5 Position of the programme in the context of international strategies

The international community of particle physicists has formulated a clear strategy for the next 10 - 20 years. This strategy has been independently documented in the different regions of the world and there is unanimous agreement on the key components.

In Europe a group has been charged by CERN Council to define this strategy. In a series of workshops and meetings with the community this strategy has been agreed upon, and has finally been documented in the European Roadmap for Particle Physics, prepared by CERN Council. This roadmap document has been accepted as the official European strategy by the European Commission through ESFRI.

In this document it is clearly acknowledged that “European particle physics is founded on strong national laboratories, universities and laboratories” and that the “increased globalization, concentration and scale of particle physics make a well coordinated strategy in Europe paramount”. DESY adheres to this strategy, which is reflected in the proposed programme.

The central element of this strategy is the LHC at CERN. Its successful commissioning, operation and eventual analysis of the data is the key project for the next years. The results will play a central role in our understanding of the universe and will shape the future thinking of particle physics as a whole. The LHC acquires a particular importance because after 2010 it will be the only accelerator worldwide operating at the energy frontier.

To fully exploit the investments into the LHC an upgrade of the facility will be considered in the near future. A first step will be an increase of the luminosity of the collider by an order of magnitude. Later upgrades, depending on the results, might even include an increase of the energy reach by a factor of two.

Even though the LHC is the central facility at this time, there is a clear consensus among all particle physicists, that the proton-proton collider should be supplemented by a lepton collider at appropriate energies. The choice of energy may depend on the results from the LHC, but preparations for such a facility have to be continued already now. This has been clearly recognised in all international roadmaps. For DESY this implies a lasting strong involvement in the ILC.

DESIGN has been a major contributor to the development of the ILC over the last decades. The TESLA technology was mostly developed at DESY, and allowed the proposal on an international scale of a superconducting linear accelerator. This achievement has placed DESY in a leadership position for a major future facility. The decision to pursue the ILC design in the superconducting TESLA technology consists an enormous international recognition for DESY
and, at the same time, an obligation to continue research along this line towards higher acceleration gradients.

All these projects can only be realised as strong international collaborations. The ILC project has been a pioneer in setting up a truly global project, with distributed management and distributed controls. The future of the field will to a large extend depend on whether or not these truly international projects can be made to function, and can be made to fit in with the more national and regional large laboratories like CERN, Fermilab, SLAC, KEK and others. DESY through its experience with HERA, TESLA, and, more recently, the XFEL is well positioned to contribute also to these managerial tasks through first hand experience.

1.1.6 Important external contributions to the programme

Particle physics is an international enterprise, which relies since many years on a functioning network between research centres, universities, and industrial partners. As the projects grows and becomes increasingly international the need for additional formal structures arises.

DESY is very well embedded in the German particle physics programme. Long-standing collaborations with German universities exist which contributed significantly to experiments at DORIS, PETRA and HERA. Now the Alliance provides a framework for collaboration inside Germany at the LHC experiments, detector developments and the preparation for future colliders. Locally the two DESY sites in Hamburg and in Zeuthen are closely cooperating with the University of Hamburg and the Humboldt University in Berlin, respectively. This is clearly reflected in the fact that a number of joined positions have been created in the past few years: Theoretical physics with Hamburg University, accelerator physics with the TU Berlin and astroparticle physics with Potsdam University which will have a large impact on the future research programme of the centre and the universities. Recently several Young Investigator Groups have been jointly installed between DESY and various universities, which foster the links in German particle physics. DESY is founder member of the John von Neumann-Institute for Computing which supports supercomputer-aided scientific research and development and which contributes to the lattice field theory part of this programme.

DESY, though formally a national laboratory, has traditionally had many international partners. The HERA collider was built with significant international contributions: more than 20% of the accelerator and about 60% of the experiments were financed through international contributions. The XFEL is planned as a truly international (though primarily European) project. These links have resulted not only in many international visitors, but also in significant financial contributions to DESY in the past and in the future. Both for HERA and for the linear collider DESY is cooperating with more than 100 institutions worldwide. Coordinated through the global design effort for the linear collider, DESY is closely collaborating will all major international players in the field, which include all large particle physics laboratories around the world. In recent years links to Japan have been particularly intensified.

With the engagement in the LHC programme DESY collaborates with approximately 150 institutes from all parts of the world in each of the two experiments. The already truly global collaboration for the ILC is expected to grow to a similar size.

Over the last years DESY has acquired significant third party funding. Together with the University of Hamburg a Sonderforschungsbereich was approved (SFB 676, particles, strings and the early universe). Two large contracts from the European Union could be attained, EUROTeV, in the area of ILC machine development, and EUDET, for ILC detector development. Within the FP7 framework a programme for support of detector development at the sLHC was approved, and a programme for high gradient developments for the ILC started in 2008 (ILC-HiGrade). Programmes of cooperation exist with JINR in Dubna and a number of other Russian institutions, both for HERA and for the linear collider programme. Junior research-groups become an important part of the scientific culture at DESY. Several groups from the HGF and one group funded from the DFG (Emmy Noether grant) were approved, and are making important contributions in all areas of particle physics at DESY.

DESY staff is strongly represented in numerous advisory and managerial bodies at other laboratories, and in international collaborations. DESY plays a particularly important role in the
management bodies for the linear collider, where one project manager for the ILC is from DESY, and where key positions within the GDE structure is filled with DESY staff. Strong contributions to the organisation of the detector effort at the ILC are provided by DESY scientists.

1.1.7 Contribution to other programmes or to other joint cross-programme initiatives

Fundamental questions link the physics at the smallest and the largest scales hence connecting the particle and astroparticle physics programmes. An example is the question of dark matter, which is searched for through observation of the universe and in collider experiments. The answer to this question will require concordant results from both approaches. The abundant presence in the universe of dark matter candidates, e.g. from Supersymmetry, observed at collider must be established by other observations. The theory subject “Particle Cosmology and Unification” described below in section 2.4 addresses several common physics questions.

Cross sections at the highest energies relevant for the detection and measurement of cosmic rays can be determined in collider experiments. There is also a large overlap in instrumentation between both programmes. Grid computing which is well established in particle physics becomes increasingly important for a new generation of large astroparticle detectors. On the other hand experience and knowledge gained in remote operation of large sky detectors will be relevant for future global particle accelerators and experiments.

The new generation of light sources, FLASH and in particular XFEL, require detectors of a complexity similar to particle physics detectors. Expected data rates and volumes are comparable to large particle physics experiments. The programme Photon, Neutrons and Ions (PNI) will profit from the existing extensive knowledge and experience. A common initiative has been started at DESY.

DESY which is participating in these three programmes is ideally positioned to cross-fertilize science advancements in these fields.

The non-perturbative treatment of QCD on the lattice requires continuous theoretical and algorithmic advances as well as their tests and applications on cutting edge supercomputers. To achieve this DESY collaborates with FZJ and the GSI in the John von Neumann Institute for Computing (NIC). Its facilities at Forschungszentrum Jülich (FZJ) are part of the programme Supercomputing in the Research Field Key Technologies, whereas the DESY research group is part of the programme Elementary Particle Physics in the Research Field Structure of Matter.

The GSI part of the NIC activities is covered by the Helmholtz programme Physics of Hadrons and Nuclei within the Research field Structure of Matter. Computations and data storage are distributed between Jülich and Zeuthen according to the most adequate utilization of the local infrastructure. The DESY research group within NIC continues to contribute to the development of efficient simulation software and possibly hardware for lattice field theories, organized in a simulation laboratory for lattice gauge theories.

1.1.8 Cooperation within the programme

Research in particle physics has always been a collaborative effort. This is also at DESY clearly visible, where many ties exist between the different programme topics. The long-term strategy from HERA to LHC to ILC reflects the preference in the direction DESY physicists take. Many scientists who were involved in the HERA experiments started to participate actively in the LHC activities over the last years. Several Helmholtz Young Investigator Groups and an Emmy Noether group do have research programmes spanning over two topics. The tendency will continue and increase as the HERA activities wind down. A number of researchers working on LHC are also involved in the preparations for the ILC, thus bringing valuable expertise from a recent large-scale detector construction programme to a programme still at the conceptual stage. Also a Helmholtz-Russian-Joint-Research Group established in 2007 spans from HERA to LHC and ILC. Programme topics are furthermore interrelated through the common use of infrastructures for detector development (test beam, detector laboratory) and computing as well as instruments like the analysis centre, see topic 2.5.
Within DESY numerous cooperations exist between the different research fields at DESY. Detector developments done for the ILC are finding its way into projects now starting for the XFEL. Accelerator developments done for the XFEL are of high relevance for the ILC. Common projects between the ILC and the XFEL are pursued, e.g. in the development of high quality cavities, see topic 2.3.

One of the strength of DESY is and has been the existence of a strong theory group close to an experimental centre. This is still true and valid in the time of LHC and ILC, and is heavily utilized e.g. in the formation of the analysis centre. The theory group, in particular the activities in phenomenology, form an efficient bracket for experimental topics of HERA, LHC and ILC physics analysis.

Concerning grid computing there is long-standing collaboration between FZK and DESY. This is reflected in the research topics 2.6 and 2.7 were the two centres take very important and well defined roles as Tier-1 and Tier-2 centres in the world-wide computing grid. Several initiatives on the national level with the D-Grid initiative and European scale with the EGEE Project have been jointly initiated or have major joint contributions from the two centres. With respect to data management there is a long and intense cooperation between DESY and FZK. The collaboration is fostered by the Alliance in which both centres are members.

DESY is also collaborating with other Helmholtz centres through the participation in the LHC at CERN. DESY is together with the University of Karlsruhe, now through the formation of the Karlsruhe Institute of Technology (KIT) very closely linked to FZK, member of the CMS experiment and a close collaboration has been established between all German groups. Links exist also to GSI, which is member of the ALICE collaboration and hosts a Tier-2 centre for this experiment.

As described in the previous section DESY collaborates with FZJ and GSI in the NIC. The GSI contribution is part of the Helmholtz programme Physics of Hadrons and Nuclei within the Research field Structure of Matter.

1.2 Organisation of the programme

The programme Elementary Particle Physics is subdivided into the four physics areas HERA, LHC experiments, Preparation for a future lepton collider and Theoretical Particle Physics. It is augmented by the three areas Experimental facilities, Large scale facility DESY Grid centre and Large scale facility GridKa. With the exception of the latter all programmes are based at DESY. Spokesperson is Joachim Mnich (DESY).

The research topic HERA covers the analysis of the HERA experiments HERMES, H1 and ZEUS after the completion of the measurement programme of the ep-collider HERA. The spokesperson for the programme is Carsten Niebuhr (DESY).
Important infrastructures used or offered by the programme

The research topic *LHC* is subdivided in the two experiments ATLAS and CMS where DESY physicists engage. The spokesperson is Kerstin Borras (DESY).

The research topic *Preparation for a future lepton collider* brings to bear the expertise of DESY is superconducting RF and prepares the field for the construction of future electron-positron colliders and detectors. The spokesperson is Eckhard Elsen (DESY).

The research topic *Theoretical Particle Physics* engage in a wide range of topics most of which of direct relevance for the experimental programme at the energy frontier. The spokesperson is Volker Schomerus (DESY).

The research topic *Experimental facilities* enable the development of large-scale research tools and instruments. The spokesperson is Ties Behnke (DESY).

The research topic *Large scale facility DESY Grid Centre* develops the analysis environment for LHC data and beyond. The spokesperson is Volker Gülzow (DESY).

The research topic *large scale facility GridKa* hosts the German Tier-1 centre. The spokesperson is Andreas Heiss (FZK).

Many of the research areas have recently received an additional boost as Young Investigator Groups were founded in the wake of the Helmholtz Alliance or Junior Professorships could be opened together with the Hamburg University. DESY has also been successful in attracting an Emmy Noether grant, which specially targets young female researchers. As part of these initiatives four young female scientists could be attracted to lead young research groups at DESY which constitutes half of the total number of YIGs in particle physics.

### 1.3 Important infrastructures used or offered by the programme

<table>
<thead>
<tr>
<th>Topic</th>
<th>Infrastructures used</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHC</td>
<td>Large Hadron Collider at CERN</td>
<td>Physics at the Terascale</td>
</tr>
<tr>
<td>LHC</td>
<td>LHC detectors ATLAS and CMS</td>
<td>Physics at the Terascale</td>
</tr>
<tr>
<td>LHC, Future lepton collider</td>
<td>CERN test beams</td>
<td>Detector development for LHC and ILC</td>
</tr>
<tr>
<td>Future lepton collider</td>
<td>Fermilab test beam</td>
<td>Detector development for ILC</td>
</tr>
<tr>
<td>Future lepton collider</td>
<td>DALINAC, TU Darmstadt</td>
<td>Radiation tests ILC forward detectors</td>
</tr>
<tr>
<td>Future lepton collider</td>
<td>FLASH at DESY</td>
<td>XFEL and ILC high current programme</td>
</tr>
<tr>
<td>Future lepton collider</td>
<td>Advanced Test Facility (ATF) at KEK, Japan</td>
<td>Fast ion studies, low emittance programme</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Topic</th>
<th>Infrastructures offered:</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large-scale facility GridKa</td>
<td>Tier-1 centre at FZK</td>
<td>Computing support, integrated in LHC Computing Grid</td>
</tr>
<tr>
<td>Large-scale Facility DESY Grid Centre</td>
<td>Tier-2 centre incl. NAF at DESY</td>
<td>Computing support, integrated in LHC Computing Grid, and analysis support for German groups</td>
</tr>
<tr>
<td>Experimental Facilities</td>
<td>DESY test beam</td>
<td>Detector development for LHC and ILC</td>
</tr>
<tr>
<td>Experimental Facilities</td>
<td>Alliance detector laboratory</td>
<td>Detector development and construction LHC and ILC</td>
</tr>
<tr>
<td>Experimental Facilities</td>
<td>Alliance analysis centre</td>
<td>Physics analysis HERA, LHC, ILC</td>
</tr>
</tbody>
</table>
The main instrument used by particle physics in the next few years is the LHC at CERN. DESY is participating in ATLAS and CMS. The operation of the accelerator and its experiments will be a major effort and need significant resources also from DESY. DESY will provide additional infrastructure to optimally use the LHC in the form of a remote centre, and in the form of the virtual laboratory for detector technologies and the analysis centre, both within the Alliance.

Detector developments as planned in this programme for LHC upgrades and a future lepton collider rely on particle test beams, in particular the facilities at CERN and Fermilab are relevant. For the development of radiation hard sensors, in particular for forward detectors at the ILC, it is planned to use the DALINAC facility at Darmstadt.

Future accelerator developments profit from the availability of the FLASH accelerator on the DESY site, originally developed and constructed in the framework of the TESLA linear collider project and now used to a large fraction as a high performant X-ray laser for photon research. This superconducting linear accelerator provides valuable input and research opportunities for many questions related to the ILC. Another facilities which are will be used for ILC development by DESY scientists is the advanced test facility, ATF, at KEK.

Infrastructures offered through this programme include the large computing facilities at FZK and DESY, as well as other experimental facilities at DESY. They are described in detail in the respective research topics.

1.4 Proposed resources of the programme topics

All resource information given in this proposal follow the specifications of the Helmholtz Association. For the research topics HERA, LHC, Preparation for a Future Lepton Collider, Theoretical Particle Physics and Experimental facilities only 80% of the financial and manpower projections, based on 2009 costs, are reported. The remaining 20% are considered to be part of the programme independent research which is not subject to this evaluation. For the large-scale facilities, GridKa and DESY Grid Centre, 100% of the financial and manpower projections are reported, based on 2009 costs.

![Proposed programme costs in 2010 by topics](image_url)
For additional resource information including investments and the whole period, see 5.2.1 Resource planning of programme topics.

1.5 Additional resource-related information
For detailed information to large-scale facilities see 6 Performance indicators for large-scale facility.

1.6 Overview about third party funding
The subdivisions of bars denote the personnel categories scientists, doctoral students and scientific support personnel (from bottom to top). For additional information see 5.2.2 Current personnel capacity.
The anticipated developments of the programme are embedded into the fabric of European Strategy for particle physics. As such it addresses the optimal exploitation of the HERA data at a level and detail of analysis that cannot be anticipated to date. Likewise the programme has to be ready to accept the challenge of operating more sophisticated detectors at an upgraded LHC machine. As the decision for an upgrade is likely to be taken around the turn of the decade it falls well into the current funding period and may necessitate extra investments. Likewise the findings of the LHC could point to the fast implementation of an ILC-like electron-positron collider with specific requirements for the detector. DESY must be ready for these scenarios.

Below a few initiatives are sketched which address these anticipated developments. They are integrated in the respective programme topics described in chapter 2 but need additional funding through the annual research field budget increment (bonus award): on average an annual budget increment of 600 k€ is required, which results in a cumulative increase of 9 M€ over the five year period.

**Sustaining the structures of the Helmholtz Alliance**

The new structures put in place in Germany through the Helmholtz Alliance “Physics at the Terascale” are successful and must be sustained. DESY plays a central role in the Alliance, which is a key instrument to ensure the leading position of the laboratory to the benefit of particle physics in Germany in general. Instruments set up at DESY in the framework of the Alliance requiring additional funds include the Analysis Centre with the National Analysis Facility and the Detector Laboratory with its infrastructures. In addition, the Alliance comprises a broad education programme for young researchers encompassing schools lectures and a fellow programme opening new opportunities at DESY and German universities. These measures include also promotion of equal opportunity tailored to tear down barriers in particle physics particular for young women. The additional funds for all these instruments discontinue in the year 2012 with the end of the Alliance funding period but the successful model of the Alliance as a nation-wide organisation form for large-scale research must be continued beyond this point.
An additional amount of 1.5 M€ per year is necessary starting mid 2012.

**Long-term availability of HERA data**
The unique data sets collected by the HERA experiments represent the dividend of a large financial and scientific investment over a period of two decades. In the coming years the HERA collaborations will continue to extract many physics results from these data. Increasingly, the collaborations will carry out this work jointly. This significantly increases the precision of the results and maximizes the effectiveness of the effort. Consequently a gradual transition from proprietary to public access to the data will occur which will eventually bring about complete open access the HERA data. As a result it will later on be possible to analyse HERA data beyond the lifetime of the presently existing collaborations as new questions or ideas arise from future scientific advances. It is proposed to start a programme to make the organizational and intellectual preparations for the long-term preservation of the experimental know how. It should be noted that open access to High Energy Physics data has never been achieved so far. Discussions on a possible collaboration with other high-energy experiments at the Tevatron and the B-factories have started and a first workshop at DESY is planned. This work will be carefully coordinated with the Alliance for Permanent Access to scientific knowledge in Europe (APA).

An additional amount of 0.1 M€ per year is necessary starting 2010.

**Scientific computing**
In order to support the planned activities of the HERA collaborations it is proposed to set up a development programme for software concepts and solutions for long-term data preservation for particle physics experiments. The project will be addressed in close collaboration between FZK and DESY. In accordance with their respective roles in the computing model FZK will give emphasis to the persistency of raw data and DESY will concentrate on analysis data. It should be noted that due to good scientific practice guidelines from the national german science council. User data, for instance in the framework of the NAF, used for publications have to be made available for at least 10 years after their initial creation. DESY and FZK are collaborating actively with the HERA experiments and others in developing the necessary strategies, the concepts including meta data systems and software components.

In addition there is the general data management challenge in particle physics. With SRM/dCache DESY is contributing as part of the collaboration with FNAL and NordGrid a major middleware component to the LHC computing which is in use by the majority of the Tier-1 and the Tier-2 centres. The further upgrade of this data management package and, in particular in preparation for sLHC, the extension of the scalability to much higher data quantities and data bandwidth into and out of the data management system is still a real challenge. DESY as the developer and FZK as a first test group are actively working on this data handling programme which makes these sites very visible.

An annual budget increase of 0.1 M€ is necessary starting 2010.

**Upgrades of LHC detectors**
Intense R&D efforts have started for upgrades of the LHC accelerator and experiments around 2016 (sLHC). The DESY ATLAS group participates in R&D projects for the upgrade of the ATLAS silicon pixel detector. DESY’s R&D effort comprises Monte Carlo simulations and a detector system integration project; see Section 2.2.3 for further details. The R&D work, in close collaboration with leading German pixel detector institutes (University of Bonn, TU Dortmund, MPP and HLL Munich) and other national and international partners, will lead to a Technical Design Report around 2011 and detector construction around 2014. After the R&D phase DESY plans to participate in the detector construction.

Also for CMS preparation for a high luminosity phase at the LHC has started based on a similar schedule as for ATLAS. DESY intends to participate in close collaboration with the universities of Aachen, Hamburg and Karlsruhe in an R&D programme for the upgrade of the CMS tracker. The three universities played a leading role in the development and construction of the currently installed tracker. In a first phase DESY will contribute to the design of the tracker with the aim to minimize the material budget and to explore available materials and technologies for silicon sensors for application in the harsh radiation environment. In a later stage of the project DESY
will participate in the prototyping of modules and contribute to the integration of the new tracking detector.

This activity will foster DESY’s leadership position in detector development and construction and intensify the collaboration with university groups both in Germany and internationally.

An annual budget increase of 0.1 M€ is necessary starting 2010.

**Linear Collider accelerator and detector**

The imminent construction of the XFEL provides a natural ground for development of SRF cavities for the ILC. DESY will profit from the synergy between the two facilities and will advance the accelerating gradient of the cavities. This synergy extends further to the construction of the XFEL itself. The experience from the single tunnel layout for the XFEL is vital input for the ILC and its costs. The control concepts of the XFEL (and FLASH) are of direct relevance for the ILC.

Detector developments for the next large accelerator facility at the moment are focused on technological studies, and individual feasibility demonstrations. In a few years the need will arise to move to integrated tests of more than one technology, more than one component at one time. This will require the appropriate prototype components, but it will also require the coordinated development of data acquisition systems, of readout hardware and software, and coordinated efforts to collect and analyse large amounts of data. To make this large and distributed programme possible a central place of coordination is needed, which could take the form of a project office for a detector at a future linear collider. If DESY could obtain the funds to operate such a centre, it would put DESY at a central place in the development and integration of an ILC detector, certainly for Europe, maybe even beyond Europe, and also at the same time ensure that the German community has a strong role in this endeavour to play.

An additional amount of 1 M€ is necessary for the entire five year period.

**Strengthening international and cross-programme collaboration**

There is the strong intention to further develop the already existing global collaboration in particle physics as well as to other programmes, in particular astroparticle physics. As an example we mention here a planned initiative of the DESY theory group on gravitino dark matter search.

New results from satellite experiments, FGST and PAMELA, and from the LHC are expected to yield important information about the nature of dark matter in the universe during the next years. In the DESY theory group the hypothesis of decaying gravitino dark matter has been developed, which leads to characteristic signatures in all these experiments. In close collaboration with the new Institute for the Physics and Mathematics of the Universe (IPMU), Tokyo, DESY plans to play a leading role in the analysis of the new data and the study of implications for physics beyond the standard model. There is a close connection with the IPMU also in the area of string theory. The collaboration with the IPMU will be strengthened by joint postdoc offers as well as mutual extended visits of staff, postdocs and graduate students.

This initiative requires additional resources for manpower. An additional amount of 0.15 M€ per year is necessary starting 2010.

**1.8 Capital investment projects (> 2.5 M€) planned**

**Ongoing projects:**

There is no ongoing large capital investment project in this programme.

**Proposed projects:**

A proposal has been submitted to extend the Tier-2 centres at DESY for the three LHC experiments ATLAS, CMS and LHCb. The executive summary of this proposal is cited below and the full proposal together with the evaluation reports can be found on the attached CDROM.
Executive summary:
"Extension of the DESY Tier-2 for LHC".

DESY is supporting the three LHC Experiments ATLAS, CMS and LHCb with a full Tier-2 each. The centres are being setup on both DESY sites Hamburg and Zeuthen and being managed as a shared resource. With the Tier-1 centre at GridKa, hosted by the Research Centre Karlsruhe, and the Tier-2 centre for the Alice experiment, based at the GSI in Darmstadt, the concentration of important resources on major national HGF Lab’s in Germany to the benefit of productivity and reliability is fulfilled as requested by the Ministry BMBF and the Helmholtz-Society. This Proposal has to be seen in the context of the Helmholtz Alliance “Physics at the Terascale” and is an extension of that concept to the DESY sites.

The proposed extension of the DESY Tier-2 covers the three topics:
- Central Data store: 3 PB mainly in 2010/11 for analysis data
- Extension of the Grid-Analysis Farm for ATLAS, CMS and LHCb
- Required infrastructure (racks, cooling, network)

In total 4.8 Mio € are requested distributed over the programme period. This consist about half of the necessary investment to fulfil the pledges required to develop the Tier-2 centres in pace with the anticipated increase in the amount of LHC data.

Planned projects:
DESY is preparing two more capital investment projects to be submitted during the coming funding period. They are based on R&D projects proposed in this programme and are intended to provide the required resources for construction. Details of the proposals as well as the total financial volume depend on the results of the ongoing R&D work and the global developments in the field.

“Upgrade of the LHC detectors ATLAS and CMS”
DESY intends to submit a proposal to fund the participation in future LHC detector upgrades. The DESY involvement in upgrades of ATLAS and CMS will take place in close collaboration with the German university groups and optimally exploit the infrastructures of the Helmholtz Alliance. Details of the proposal are being discussed. The main investments are foreseen starting in 2012.

“Preparation of ILC cavity production”
If the global strategy for particle physics converges on the fast implementation of the ILC DESY intends to prepare the infrastructure for superconducting accelerator components. Such a decision could be envisaged around the middle of this funding period. The extension of the infrastructure would profit from and is well matched to the production timelines of components for the European XFEL.
2 Planned programme topics

2.1 HERA

Spokesperson of the topic: Carsten Niebuhr

Contributing centres: DESY

Personnel (2010): 20 scientists, 12 doctoral students, 4 scientific support personnel

Contributing principal investigators: Cristinel Diaconu, Eckhard Elsen (see also 2.3), Achim Geiser, Alexandre Glazov (see also 2.2), Tobias Haas, Hannes Jung (see also 2.2), Wolf-Dieter Nowak, Klaus Rith, Thomas Schörner-Sadenius (see also 2.5). YIG: Katerina Lipka (see also 2.2).

2.1.1 Challenges

Relevance

Results from the unique electron-proton collider HERA, operating between 1992 and 2007, are in many respects irreplaceable and complementary to those from LEP and Tevatron, which collide electrons and positrons and protons and anti-protons, respectively. Data taking of the colliding beam experiments H1 and ZEUS and of the fixed target experiment HERMES using polarised leptons ended in summer 2007. HERA-B, the second fixed target experiment made use of the proton beam halo and ceased operation in 2003 after a redirection of its physics programme from studies of CP-violation in the B-system towards investigations of heavy quark production in proton-nucleus interactions that are now nearing completion. Electron-proton scattering at high momentum transfer, also called Deep-Inelastic Scattering (DIS) is ideally suited to study in particular the proton structure and the dynamics of the strong interaction because it involves a clean leptonic probe and a hadron in the initial state. The high beam energies, resulting in a centre-of-mass energy of 320 GeV, give access to a phase space several orders of magnitude larger than in previous fixed-target experiments.

The data collected by H1 and ZEUS and by the fixed-target experiment HERMES are used to address a very large variety of physics topics ranging from electroweak phenomena and searches for physics beyond the Standard Model at the energy frontier to precision measurements of the proton structure and the study of QCD dynamics. Over the years many aspects of the Standard Model were investigated and several hundred publications were produced by the HERA collaborations on these topics. They comprise of very fundamental discoveries such as the strong rise of the structure function $F_2$ at low $x$ at high energies, the observation of a large diffractive component in DIS at high $Q^2$, the demonstration of the running of the strong coupling constant in a single experiment, the absence of right-handed currents in the HERA energy range or the precision determination of the net contribution of quarks to the total spin of the nucleon.

1 The figures given here for scientists and scientific support personal reflect FTE from DESY only, see 1.4.
Most published results are still based on a fraction of the available data sample only. The final analysis of the full HERA data will in the coming years provide high precision results in the area of proton structure and QCD, a high precision measurement of the strong coupling constant, improved determinations of the weak couplings of the u- and d-quark and a deeper and more quantitative understanding of the phenomenon of diffraction.

The LHC presently is the main focus of the entire particle physics community. The HERA data are an essential ingredient to untangle the complexity of the final state. The deep connection between the HERA results and the physics at the LHC has been worked out over many years in the framework of the HERA-LHC workshop. A follow-up study group (PDF4LHC) involving all LHC and HERA experiments and including theorists has recently been initiated to continue this successful collaboration. It will provide a framework for the extraction of the best possible parton density functions (PDFs) from the combination of all available data.

**Challenges**

In order to obtain optimal precision the final HERA analyses must be based on complete and homogenous data sets. This requires the final reconstruction of the order of $10^9$ events per experiment exploiting the best knowledge of the detectors. For the HERA II data-taking period (2002-07) the experiments have made substantial investments in detector upgrades. These new detector components such as the new or modified silicon based vertex detectors, the new H1 very forward proton spectrometer, the cavity polarimeter and the HERMES recoil detector have to be perfectly calibrated and aligned before the final reconstruction. However, the ultimate precision will in many cases only come from the combination of H1 and ZEUS results. This will not only reduce the statistical errors but in several cases also will lead to a substantial reduction of systematic errors by cross calibration of the complementary detectors as was recently exemplified by a combination of inclusive HERA I cross section measurements.

For most physics analyses the study of systematic effects necessitates the production of large amounts of simulated events, which by far exceeds the locally available computing capacities. Therefore the mass production of Monte Carlo events has meanwhile been ported completely to the Grid with its large distributed CPU resources. Presently the access to the Grid is rather straightforward but for the future it must be guaranteed that sufficient CPU resources remain available for the HERA experiments even after the start-up of the LHC.

Although the analysis of the HERA data is expected to conclude by the end of the funding period in 2014, a need to reanalyse the data might arise even later. This could for example be triggered by new and unexpected findings at the LHC needing confirmation from ep data in the areas of the underlying QCD or searches or by the availability of higher order theoretical calculations, which would lead to a further reduction of systematic errors. Thus a framework for long-term archiving and retrieval of the HERA data must be provided. At the same time the data should also be made publicly available to the entire scientific community. This has never been achieved before in high energy physics. Discussions on a possible collaboration with other high-energy experiments at Tevatron and the B-factories have started.

This programme has to be performed in competition for resources with the LHC start-up. According to recent surveys done within the collaborations the number of physicists available for data analysis from the institutes collaborating with DESY is expected to decrease roughly linearly with time from now on. For the collaborating external institutes in H1 and ZEUS this corresponds to a reduction from about 100 FTEs in 2008 to roughly 65 FTEs per experiment by 2010. The contribution of the DESY physicists to the analysis efforts is essential to achieve the main physics goals outlined in the following. Hence, a constant share of the DESY groups has to be maintained during the new funding period. The collaborations will also take advantage of the close integration of HERA and LHC physics studies within the analysis centre.

**2.1.2 Current activities and previous work**

After giving account of the data taken at HERA and of the ongoing preparations for final analyses this section outlines the status of the main physics topics where analyses are presently being performed.
Data taking at HERA II
The combined HERA data collected at nominal proton energy by H1 and ZEUS correspond to a luminosity of approximately 1 fb$^{-1}$. As a result of several modifications and improvements to the accelerator and the detectors a very high level of performance and operation efficiency was reached in the last years of operation. In addition to the quantitative improvement over HERA I, the HERA II data were taken with longitudinally polarised lepton beams made possible by the installation of spin rotators around the interaction regions of H1 and ZEUS during the HERA upgrade shutdown. A polarisation of 30-40% was regularly achieved. The HERA II luminosity is roughly equally balanced between positive and negative lepton charges and the two polarisation states, which is important for electroweak measurements.

The last three months of HERA operation were devoted to a special run at reduced proton beam energy in order to measure the longitudinal structure function $F_L$. This structure function is a fundamental observable in QCD that so far had never been measured at low $x$. It allows a direct and independent determination of the gluon density at small $x$ without model assumptions providing an important consistency check for perturbative QCD calculations. First results in a restricted kinematic range have already been published by H1 and results in the full accessible phase space from both collaborations are expected in the coming months.

Preparations for final physics analyses
Many preliminary results using the full HERA datasets have been presented already at conference over the last years. Currently the collaborations are working on the final calibration of the detectors and are preparing the Grand Reprocessing of their large event samples consisting of more than $10^9$ events in order to obtain homogenous data sets for the final physics analyses. The rate of production of the required Monte Carlo samples on the GRID routinely reaches the level of 200 million events per month and is still growing. In several areas the work on combining H1 and ZEUS results has successfully started and has led to first promising results. Most of the analyses listed below require intense collaboration with the theory group.

Physics beyond the Standard Model
In the LHC era the HERA data are no longer at the energy frontier. Hence it is expected that limits set by the HERA experiments on new physics will be quickly superseded by the LHC. However, interesting event signatures beyond Standard Model expectations have been observed in the HERA data. Already a long time ago, for example, H1 had observed an excess of events with isolated leptons, missing transverse momentum and a hadronic system at high transverse momentum in positron-proton data. Limits on a variety of phenomena have been set from around 300 GeV in direct up to a few TeV in indirect searches for contact interactions, leptoquarks, extra dimensions or supersymmetric particles. To further increase the sensitivity combined analyses based on a total luminosity of 1 fb$^{-1}$ are being performed for most of the physics channels. Examples are the search for multi-electron events or for events with an isolated lepton plus missing transverse momentum. So far no significant signal beyond the Standard Model expectation has been observed in the combined data sets and improved limits on couplings or masses have been derived. It is expected that all final HERA analyses on physics beyond the Standard Model (BSM) will be published by 2009.

Proton structure and PDFs
The unique initial state at HERA provides a QCD laboratory to probe the underlying theory as well as the structure of the proton, which is described by the structure function formalism. Hence determinations of the different structure functions $F_2$, $xF_3$ and $F_1$ are at the core of the HERA research programme. From these one obtains universal parton density functions (PDFs), which are an essential input to any Standard Model prediction at the LHC. From the structure function $F_2$ most of the information on the sea-quark distributions arises, $xF_3$ gives access to the valence quarks at high $x$ and $F_1$ is important for the determination of the gluon at low $x$. Both H1 and ZEUS are currently working on the analysis of the lower-energy proton beam data sets taken at the end of the HERA running in order to extract the longitudinal structure function $F_L$, which has never been measured at small $x$. First results have already been published by H1. A ZEUS publication is expected by the end of 2008.
H1 and ZEUS are also jointly working on the final combined analyses of the HERA I inclusive DIS data, which will be published soon. A very significant step in PDF precision was recently achieved when a next-to-leading order (NLO) QCD fit to the combined preliminary HERA I neutral current (NC) and charged current (CC) inclusive data of H1 and ZEUS was performed. The resulting HERA-only PDFs have a precision comparable to or better than the results from up-to-date global fits. Global fits have the disadvantage that they combine the data of a wide variety of data with very different systematic errors. Hence, the HERA-only PDFs form an important independent PDF set which quickly gained international recognition. They are about to be released as HERAPDF0.1 in the Les Houches Accord PDF interface LHAPDF. Similarly, based on a fraction of the available data set, the combination of neutral current polarised e+p and e+p cross sections was used for a preliminary extraction of the structure function xF_5, which is sensitive to the distribution of valence quarks in the proton.

**Strong coupling constant α_s**
The strong coupling constant α_s in QCD is one of the fundamental parameters of the Standard Model. Even though it is called a constant it depends on the energy scale at which it is probed. This energy dependence, a phenomenon also called “running”, is a direct consequence of the non-abelian nature of QCD and leads to the phenomenon of asymptotic freedom. The determination to a precision of 1% or better is one of the highest priority goals of the HERA programme. Such a precision is important not only for calculating QCD cross-sections but also sheds light on physics at the energy scale of Grand Unified Theories (GUTs), where the three forces of the Standard Model are expected to unify. At HERA jet measurements provide sensitivity to the PDFs as well as to the strong coupling constant α_s. Both collaborations have measured inclusive and multi-jet cross sections and determined α_s with an experimental error close to or better than 1%. First fits to the combined HERA I data of H1 and ZEUS have been already performed. However, the present results are still dominated by theoretical scale uncertainties which are typically 3-5 times larger.

**Heavy flavour**
Heavy flavour physics at HERA explores the charm and beauty contents of the proton and the photon as well as the production and fragmentation of charmed and beauty particles. The charm contribution to the NC cross section at low x is about 20 - 30% while beauty contributes only about 1%. So far the measurements at HERA relied on extracting the charm contribution by explicit charm meson reconstruction. A large number of measurements using a wide variety of mesons and in many different regions of phase space were performed this way. From these first results on the charm structure function F_{c\bar{c}} were obtained and compared to perturbative QCD calculations. Also, the fragmentation of charm quarks was studied in detail. More recently lifetime tagging of heavy quarks is used to obtain larger and more inclusive samples. The collaborations are also working on combining their data in order to both reduce the statistical errors as well as to cross-calibrate their measurements. They are also making use of the increased statistics of the HERA II data in combination with the greatly improved instrumentation of the experiments to allow for more differential comparisons and to extend the covered phase space.

**Spin Structure of the nucleon**
The primary goal of the HERMES experiment is the investigation of the spin structure of the nucleon. It has contributed and will further contribute novel and often pioneering results to a deeper understanding of this important aspect of nucleon structure. Despite enormous worldwide efforts by several spin experiments and substantial theoretical progress over more than 20 years it is still not fully understood how the nucleon spin 1/2 is shared between the contributions of intrinsic and orbital angular momenta of its constituents, i.e., the quarks and gluons. Data from HERMES allow constraining three of these contributions. Flagship results are the HERMES measurements of the inclusive double spin asymmetries from a longitudinally polarised deuterom target which provided the so far most precise value for the fractional contribution of quark spins to the nucleon spin of about 33% with an experimental relative error of about 7.5%, and the most precise leading-order determinations of the helicity-weighted distributions for up, down and strange quarks from double-spin asymmetries in semi-inclusive
polarised deep inelastic scattering from longitudinally polarised atomic hydrogen and deuterium targets. Measurements of double spin asymmetries for hadrons with large transverse momenta indicate that the contribution from gluon spins is probably very small. The envisaged determination of Generalized Parton Distributions (GPDs) from exclusive processes will allow determination of the quark total and orbital angular momentum contribution.

Electroweak physics
The data taken with polarised lepton beams during the HERA-II running period open a unique window on electroweak physics in the so-called space-like sector. This should be seen in contrast to LEP, Tevatron and the LHC where the heavy bosons are produced either as time-like or as real particles. Hence the measurements done in the electroweak sector at HERA, even though not as precise as those coming from these other machines, nevertheless check an important, previously unexplored, sector of the theory and are therefore complementary. In addition the variable scale \( Q^2 \) allows probing electroweak interactions all the way from a region where the electromagnetic interaction dominates to \( Q^2 \approx 10^4 \text{ GeV}^2 \) where both weak and electromagnetic interactions become of equal strength. The measurement of the cross section of the charged current interaction that involves the exchange of W bosons, as a function of the polarisation of the lepton beam for the two different lepton charges has enabled a textbook measurement, which directly demonstrates the absence of right handed charged currents in the HERA energy range and allows to set a lower limit on the mass of right handed W bosons of the order of 200 GeV. The first combination of H1 and ZEUS data on the polarisation asymmetry in NC e+p and in e+p scattering demonstrates parity to be violated down to distances as small as 10^{-18} \text{m}.

Furthermore the cross sections of electroweak processes depend on the quark densities of the proton and on the electroweak coupling constants of the quarks to the gauge bosons. A combined QCD and electroweak fit to HERA I and to a fraction of the HERA II data made a determination of the axial and vector couplings of u- and d-quarks possible. The preliminary results are compatible with the values expected in the Standard Model and resolve an ambiguity, which was still present in the corresponding measurements from LEP. In addition the measurements allow a determination of the W propagator mass, which in the framework of the Standard Model can also be translated into an indirect determination of \( \sin^2 \Theta_W \). Improved results are expected from the ongoing analyses of the complete HERA data.

Low-x physics and diffraction
A substantial fraction of the total cross section in hadron-hadron scattering is due to soft diffractive reactions, which are described in Regge theory. Among the important discoveries at HERA is a significant fraction of events with a large rapidity gap that involve a hard scale, which indicates the presence of hard diffraction. Diffractive events with a hard scale can be used to investigate the low-x structure of the proton and the behaviour of QCD at high densities and recently have received interest as they may provide a clean environment to study the Higgs boson at LHC. The observation of hard diffraction at HERA has significantly advanced the QCD interpretation of diffraction in terms of quarks and gluons. Diffractive parton distribution functions (DPDFs) have been obtained from combined QCD fits to the inclusive diffractive and semi-inclusive data on diffractive dijet production. While this success confirms theoretical expectations that hard-scattering factorisation holds in diffractive DIS, it is well known that factorisation does not apply in hadron-hadron collisions as becomes evident when comparing predictions based on HERA DPDFs with measurements of diffractive dijet production at the Tevatron. Recent results on factorisation in semi-inclusive diffractive photoproduction help to understand this disagreement, but still need further clarification.

Additional interesting investigations include the production of leading baryons and vector mesons and the study of Deeply Virtual Compton Scattering (DVCS). Substantial improvements both in statistical precision and in kinematic coverage in particular at small \( x_{\text{ip}} \) are expected from the analysis of the full HERA II data collected with the forward proton spectrometers of H1.

Hadronic final state
HERA is an ideal place to study parton dynamics and to perform precision QCD measurements in a well-defined environment. A large variety of detailed studies of the structure of the hadronic
final state like event shapes, jet physics, search for instantons, prompt photons and particle production have been performed and important progress has been made. HERA offers the unique possibility to test the universality of fragmentation and hadronisation by measurements of fragmentation functions, particle spectra and energy flow. The investigations of the hadronic final state also enable measurements of the unintegrated parton distribution functions (uPDF) at small $x$, which are essential for a proper description of final states also at LHC.

Furthermore HERMES explores many details of hadron structure, hadron production and hadronic interactions with electromagnetic probes at centre-of-mass energies of about 7 GeV. High precision data on multiplicities for charged and neutral pions and kaons, protons and antiprotons will serve as input for an improved determination of PDFs and fragmentation functions in this kinematic domain.

Eventually, results from the collider experiments can be combined with the measurements of the transverse momentum dependent PDFs obtained at larger $x$ at HERMES.

2.1.3 Contents and goals
The data taken by the HERA experiments over a period of 15 years are truly unique. The HERA collaborations are currently working intensively to analyze these data. Many final results, in particular on electroweak measurements and searches for physics beyond the Standard Model, will be published by the end of 2009. H1 and ZEUS expect to produce each about 15 to 20 papers a year in 2008 and 2009 and HERMES about half as much. However it will take a long time and a major effort to extract all the information and to understand the ramifications. This applies predominantly to those cases where the analysis is dominated by systematic effects. However, the configurations probed in lepton-proton collisions are so unique that it cannot be completely excluded that HERA could be sensitive to new physics even in the LHC era. There are also a few anomalies on the level of 2 to 3 standard deviations in the HERA data that warrant a careful analysis of the combined data sets of H1 and ZEUS. One example is the class of events with two or more high momentum leptons. This kind of events is expected in the Standard Model but they are very rare. With additional information from LHC this topic could become of interest once again. Hence it is of supreme importance to conclude all searches for new physics based on the combined H1 and ZEUS data as quickly as possible but to keep the data and the know how in that area alive in order to be able to react quickly when new LHC results arrive.

The following paragraphs describe into which directions the activities in the different areas will develop and outline their main physics goals.

Long-term preservation and public access to the HERA data
The HERA data are the harvest of a very large financial and scientific investment. They cannot be replaced in any foreseeable future. The HERA collaborations are investing a large effort to perform a complete analysis of these data and extract as much information as possible. However, it is clear that some analysis avenues will remain unexplored due to lack of manpower and other resources. It is therefore mandatory that the data be transformed into a format that will be accessible for an indefinite period. The data should also be made publicly accessible so that the intellectual leverage of the entire scientific community can be brought to bear. This is a challenging project since it involves preserving not only the data but also the knowledge base about a large and very complicated accelerator/detector complex at the same time and it has never been achieved in High Energy Physics. First efforts are on their way in collaboration with the Tevatron experiments and the B-factories. By the time the analysis of the data by the collaborations themselves concludes at the end of the funding period, the goal of a long-term publicly available data format has to be achieved.

Parton distributions and QCD
Traditionally parton density functions are obtained from QCD fits to the inclusive deep inelastic scattering cross sections. However, other observables such as jet cross sections both in deep inelastic scattering as well as in photoproduction and heavy quark production cross sections can potentially be integrated into such fits. This requires consistent theoretical calculations to at least NLO in QCD for all observables. For the totally inclusive case, calculations up to next-to-
next-to-leading order (NNLO) exist. For jets and for heavy quark production the situation is more complicated. Both jet and heavy quark production cross-section calculations exist only up to NLO. In the case of heavy quark production additional complications arise due to the mass of the quarks and the corresponding production thresholds. A fully consistent fit requires calculations in the so-called variable flavour number scheme (VFNS) with proper treatment of the heavy quark masses to at least NLO. Combining as much data as possible it will be possible to determine parton density functions at the percent level or even below. This translates into a precision of 1-2% for predictions for standard model processes at the LHC.

Another topic of investigation is the analysis of the validity of the evolution scheme in QCD. For the fits discussed above the validity of the perturbative evolution equation is a necessary ingredient. The evolution scheme applied at HERA is based on the so-called DGLAP equations. However, it is expected that there are deviations from this scheme at very small values of $x$ where large logarithmic corrections should be taken into account. This goes under the name of BFKL evolution. Very high precision $F_2$ data might provide hints whether BFKL evolution is relevant in the HERA kinematic regime and hence important for the extrapolation of the HERA PDFs to LHC energies. Other observables such as forward-going jets or single hadrons at low-$x$ and low-$Q^2$ are also sensitive to these low-$x$ phenomena.

**Strong coupling constant $\alpha_s$**

The strong coupling constant $\alpha_s$ can be obtained from QCD fits to both inclusive and exclusive data with an experimental precision below 1%. However, the current measurement precision is limited to about 2-3% by insufficient theoretical understanding of the scale dependences. These scale dependences can be reduced by an improved understanding of how to choose the proper scale for each process under study or by using NNLO theoretical calculations since these have smaller dependences on the specific scale choice than the NLO calculations. It is not likely that dedicated new calculations will become available any time soon. However, there is significant theoretical progress within the LHC context on semi-automatic QCD calculations. These new techniques should also result in higher order QCD calculations for other processes such as electron-proton scattering. Restricting the analysis to the highest $Q^2$ values where the scale dependencies are significantly reduced is another avenue to reach a smaller total error opened up by the availability of the high statistics HERA II data.

**Heavy flavour physics**

In previous HERA measurements the charm contribution was mainly extracted by exclusive reconstruction of charm mesons. The improved tracking capabilities of the upgraded detectors open up the possibility to rely more on inclusive lifetime tagging methods. These techniques increase the available sample sizes but also require a detailed understanding of the tracking systematics of the detector. Therefore both collaborations are and will be improving their calibration and their tracking codes. Together with theoretical progress on a consistent treatment of the heavy quark thresholds and the heavy quark masses it will be possible to extract the charm and beauty structure functions $F_2^{cc}$ and $F_2^{bb}$ with uncertainties well below 5% and 15% respectively. These observables will eventually become essential ingredients in global QCD fits and help to further reduce the error on the PDFs, in particular of the gluon.

**Electroweak physics**

It is expected that the electroweak measurements will be concluded by the end of 2009. However, QCD and electroweak combined fits performed on the HERA I data provided the most precise extraction of the vector and axial vector couplings of the $u$- and $d$-quarks. These fits will be redone once the H1 and ZEUS combined HERA II results will be available.

**Diffraction**

Low-$x$ physics and diffraction are of considerable interest also at the LHC because diffraction might provide a unique clean environment to study complicated processes such as Higgs production. Nevertheless making precise predictions for diffractive processes at the LHC remains a challenge. Both H1 and ZEUS have explored a number of different techniques to make further progress in this area. The cleanest and most promising technique involves tagging the forward-going protons. The forward proton spectrometers of H1 collected data during HERA II running and provide large samples. They will yield substantial improvements both in
statistical precision and in kinematic coverage in particular at small $x_{ip}$. Of particular interest is a measurement of the $t$-dependence since it contains important dynamical information that is essential for tests of QCD models.

Other methods to measure diffractive processes make use of the unique signature of the hadronic final state of these events in the main detectors. These methods have good statistical power but theoretical and systematic uncertainties arise when results from different methods are combined. Further progress needs to be made on reducing these uncertainties so that all data sets can eventually be combined and exploited to obtain diffractive PDFs. These should be usable, with additional theoretical input, to also understand diffractive scattering processes at the LHC and possibly open up an avenue to investigate new processes at the LHC in the clean environment of diffractive scattering.

Furthermore, the measurement of vector meson production and the study of Deeply Virtual Compton Scattering (DVCS) will provide experimental sensitivity to the so-called Generalized Parton Distributions (GPDs), which contain important information about correlations between partons inside the proton.

**Low-x physics and hadronic final states**

Previous HERA I studies show that the details of QCD dynamics at low $x$ can be investigated by exploring the hadronic final state. The HERA II data will be used to extend hadronic final state measurements into previously unexplored regions of phase space. These will provide important results on factorisation, hadronisation universality, the behaviour of partons at very small $x$, multiple interactions, underlying events and eventually also on the underlying QCD evolution mechanisms. These results will have a major impact on the interpretation of LHC data.

**Transverse-momentum dependent parton distribution and fragmentation functions**

While unpolarised parton distributions are known with rather high precision and also the helicity-dependent quark distributions have been explored in some detail, several other important parton distribution (and fragmentation) functions, in particular for the transversely polarised nucleon, are still badly known or even completely unknown. Examples are the quark transversity distribution (the third quark distribution function required for a complete leading-twist description of nucleon structure), the Sivers quark distribution, found to be related to quark orbital motion, and the Collins (polarised) quark fragmentation function. Information on such distributions will be obtained from the unique HERMES data on semi-inclusive production of pions, kaons and (anti)protons on a transversely polarised proton target. This data will allow to determine final cross section asymmetries as major input to global fits of above mentioned previously unknown transverse-momentum dependent quark distribution and fragmentation functions and to determine the tensor charge, i.e., the first moment of the transversity distribution. A combination of the transverse momentum dependent PDFs as measured by HERMES with those measured at much smaller $x$ by the collider experiments is a unique challenge. It offers to cover a much larger range in $x$ and parton flavour and will combine the different attempts to describe the small and large $x$ behaviour of the final state. A smooth transition from the standard DGLAP range with soft gluon resummation to the small $x$ range with BFKL/CCFM resummation can be obtained.

**Exclusive processes and Generalized Parton Distributions**

The partonic structure of the nucleon has traditionally been described in terms of PDFs. In recent theoretical developments these have been conceptually subsumed within the broader framework of GPDs, which also describe elastic form factors and hard exclusive reactions. These distributions allow one to obtain a 3-dimensional picture of the nucleon, correlating the longitudinal momentum fraction of partons with their transverse distance from the nucleon's centre. Furthermore, moments of certain GPDs were found to relate directly to the total (including orbital) angular momentum carried by partons in the nucleon. GPDs are accessible through exclusive processes that involve at least two hard vertices, yet leave the target nucleon intact. There are four twist-2 quark-chirality conserving quark GPDs. Exclusive vector meson production is sensitive to the two polarisation-independent distributions, pseudo-scalar meson production to the two polarisation-dependent distributions and exclusive production of photons (DVCS) to all four distributions. The main focus of the work to be accomplished by HERMES in
the coming years will be the analysis of the pioneering data on DVCS and exclusive production of pseudo-scalar and vector mesons taken with the Recoil Detector as the latest upgrade of the HERMES apparatus. Due to the detection of the recoiling nucleon, respectively nucleus, the huge data set recorded with unpolarised proton and deuterium targets will be essentially free of admixtures from resonance contributions and background from semi-inclusive reactions.

The analysis of this data will be supplemented by a refined re-analysis of previous data for exclusive processes on unpolarised, longitudinally and transversely polarised targets and the extraction of the various cross section asymmetries with respect to beam charge and beam and target polarisation. A main goal is the first direct (leading-order) determination of the all-flavour combination for the GPD $H$ measured over the HERMES kinematic range. Subsequently, constraints for at least the valence $(u,d)$ quark GPDs $H$ and $E$ will be extracted in the kinematic domain of the HERMES experiment. Depending on the level of the theoretical description reached, this knowledge on GPDs can then be used to evaluate the (presently unknown) $u$- and $d$-quark total angular momentum contribution to the nucleon spin. Using the 2007 HERMES precision result on intrinsic spin contribution of all quarks, also the unknown quark orbital momentum contribution can be determined.

Further progress and hence milestones in the later years depend on the development of a 'global GPD fit' code, using as input all this data together with corresponding data for exclusive processes from the HERA collider experiments and present and future experiments at other facilities. The development of such a global GPD fit is planned in cooperation between HERMES, the DESY theory group and the University of Glasgow.

**2.1.4 Expected results, milestones**

The analysis of the HERA data will conclude within the funding period 2010-14. Hence the work outlined above will essentially shape the legacy of HERA. It can be classified in two broad categories - statistics limited analyses and precision analyses.

Studies limited by the statistics of the data, in particular searches for physics beyond the Standard Model will be essentially completed within the current funding period. For such analyses, the results will be given in terms of exclusion limits for new physics processes. For direct searches these limits extend to the kinematic limit of HERA, which allows exclusion of objects with masses up to roughly 300 GeV. For indirect searches these limits will extend to several TeV, in some channels reaching as high as 10 TeV.

On the other hand, the precision analyses requiring detailed systematic studies will reach well into the new funding period. One important element of the Alliance is the analysis centre where physicists working on HERA and on LHC are closely collaborating. This will ensure that on the way to achieving ultimate precision several intermediate results with increased accuracy and extended phase space coverage will be made public in accordance with the requirements of the LHC experiments. Upon completion of the analyses, the final results of these studies will be summarized in a series of comprehensive summary papers. More specifically the following milestones concerning the final HERA results are foreseen:

- Publish the H1/ZEUS combined measurements of the inclusive cross sections by 2011,
- Publish the first experimental determination of the nucleon's tensor charge by 2012,
- Publish HERA parton-density distributions with a precision of better than 1% from combined H1/ZEUS fits including inclusive, jet and heavy quark data by 2013,
- Extract a value of the strong coupling constant $\alpha_s$ with 1% precision by 2013,
- Publish a determination of the generalized parton distributions and the total angular momentum of up and down quarks by 2013,
- Convert the HERA data into a format with indefinite lifetime and make them publicly accessible by 2014.

In addition, further studies will be carried out to determine the electroweak couplings of the light quarks to 10% precision, to extract the charm and beauty structure functions, $F_2^{cc}$ and $F_2^{bb}$ with highly improved precision, to get better understanding on issues of universality and factorization and to gain deeper insight into the mechanisms involved in diffractive scattering.
2.2 LHC

Spokesperson of the topic: Kerstin Borras

Contributing centres: DESY

Personnel (2010): 39 scientists, 20 doctoral students, 9 scientific support personnel

Contributing principal investigators: Alexandre Glazov (see also 2.1), Johannes Haller, Hannes Jung (see also 2.1), Matthias Kasemann (see also 2.6), Wolfgang Lohmann (see also 2.3), Rainer Mankel, Mike Medinnis, Andreas Meyer, Klaus Möning, Thomas Naumann, Wolfram Zeuner.

YIG: Philip Bechtle (see also 2.3), Ulrich Husemann, Katerina Lipka (see also 2.1), Isabell Melzer-Pellmann (if approved, see also 2.5), Alexei Raspereza (if approved).

Topic costs 2010: 5,455 M€

2.2.1 Challenges
Relevance
The LHC programme is expected to deliver a fundamentally new understanding of particle physics. A new energy frontier will be reached at the LHC and there are great hopes for discoveries and for hints towards the answers of the fundamental questions described in Chapter 1. For this reason DESY is participating strongly in this endeavour. This engagement will maintain DESY’s role as a major laboratory for high energy physics and lay the foundation for experimentation and physics analysis at future colliders. It allows DESY to enhance its expertise in particle physics, to fulfil its role towards German universities and to remain attractive for students and scientists.

The strategic decision of DESY to join both large LHC experiments, ATLAS and CMS, reflects the situation in the German particle physics community, which concentrates its main efforts in these two experiments, and allows DESY to support the German groups most effectively. At a later stage, when physics results might be combined as it was done at LEP and is in progress for HERA, DESY will be in an optimal position to nurture this effort. The DESY groups are integrated into the national groups and are associated members of the BMBF Förderschwerpunkte (FSP) 101 (ATLAS) and 102 (CMS). In total 18 German University groups and institutes including DESY participate in ATLAS and Germany provides 11% of the yearly funding, being the 2nd largest group within the collaboration. In CMS six German University groups and institutes are engaged and Germany delivers about 6% of the yearly funding, which is the 4th largest contribution to the CMS collaboration.

2 The figures given here for scientists and scientific support personal reflect FTE from DESY only, see 1.4.
The LHC experiments are the next step towards the understanding of the fundamental laws of physics and constitute the main pillar of the programme Elementary Particle Physics, in accordance with the global strategy. It is commonly anticipated that in a few years an initial picture of physics at the Terascale will have emerged. DESY plans to participate in the work to achieve this goal by contributing to the operation of the experiments and especially to data analysis. For the latter a strong synergy with the theoretical particle physics group can be exploited.

The expertise and knowledge gained at HERA will be transferred to support physics analysis, detector operation and improvements at the LHC. The profound skills in data analysis will enrich and inspire the analysis strategies at the LHC. It is DESY’s strategy for the next funding period to increase the LHC activities while the HERA activities ramp down.

It is commonly believed that some important aspects cannot be addressed with the LHC because the predicted rates of the interactions needed for these studies are far too low. Therefore an upgrade of the LHC towards higher luminosity, and possibly also higher energy, is considered as one cornerstone in the global strategy.

The involvement of DESY in the LHC programme is the key element to maintain an attractive in-house research programme in particle physics for the coming funding period and beyond.

**Challenges**

ATLAS and CMS are large acceptance general purpose detectors optimized for the study of the rare collisions processes described above. Both experiments are comprised of three major detector systems: a system for tracking charged particles in the region closest to the beam (the inner detector) followed by calorimetry for identifying energetic photons, electrons, and jets of hadrons as well as measuring their energies and finally a system for detection and identification of muons.

The ATLAS and CMS detectors each provide of order 100 million detector signals per collision. The unprecedented event rates and event data sizes place yet unseen demands on the data acquisition and triggering systems as well as the offline computing infrastructure.

Taking into account the long lead time needed for any significant detector upgrade, plans have to be prepared now for measurements with an upgraded LHC, possibly with a 10 times increased luminosity, called sLHC, and maybe also at a higher energy. Such a scenario would increase the accessible range for discoveries dramatically. A ten-fold increase of the luminosity by itself would increase the reachable energy range for discoveries by roughly 30%. The higher luminosity would also provide the necessary amount of data for reducing many data-driven systematic uncertainties as these usually scale with the size of the control sample. For an upgraded LHC the detectors and the computing as well as analysis techniques will need improved performance and first preparations and studies are starting now worldwide.

DESY joined the two experiments at a point at which the collaborations existed already more than a decade. Both detectors had been completely designed and were being assembled. The major challenge at that time was to still make a significant impact to the experiments and to achieve high visibility. The long-standing experience in construction and operation of large accelerator and detector facilities at DESY together with the well trained scientific and technical personal matched very well the needs of the collaborations and allowed the two groups to quickly make important contributions.

In close collaboration with the nearby University of Hamburg and Humboldt University Berlin, as well as other German groups involved in the LHC experiments, DESY soon took on important responsibilities and central coordination roles in the general areas of detector installation and operation, data preparation and software infrastructure, and the preparation of physics analyses. In addition, the groups are becoming active in the research and development efforts needed for the detector upgrades for operation at the sLHC.

A challenge faced by the DESY LHC groups is to take advantage of DESY’s unique character as a national high energy physics laboratory to support the German groups within the LHC collaborations and within the scientific community world-wide. Germany has contributed
substantial funds towards the construction of the LHC and the two experiments. The German groups have made major investments to the LHC programme. It is essential that they are well positioned to benefit from this investment. The DESY LHC groups are working in the context of the Alliance to achieve this goal in three ways: working to ensure a smooth liaison between the DESY Tier-2 centre and the respective collaborations and contributing to the operation of the NAF; contributing manpower and expertise to the analysis centre; actively promoting the establishment of virtual laboratories for detector development specifically aimed at the sLHC upgrade.

After the LHC begins regular operation, it will be necessary to maintain a significant presence at CERN. This has to be balanced against the need to maintain a strong core group at DESY to support the activities mentioned above as well as to support the important task of student education. Regular exchange of DESY physicists working at CERN and frequent visits of them at DESY will guarantee a vivid transfer of knowledge in both directions between the working groups at CERN and at DESY. With the establishment of a remote centre at DESY the needs for CERN presence will be reduced. The centre will also help to keep close contact with developments at the experiments on a daily basis.

Based on the broad HERA expertise in operating and monitoring of various detector components as well as in data analysis and computing, DESY is well prepared to meet these challenges.

2.2.2 Current activities and previous work
The detailed programme of the two DESY LHC groups concentrates on physics analyses and on support for the commissioning and operation of the detectors. For both experiments the current activities can be classified into four groups:

a) Physics Analyses and contributions to the Analysis Centre
b) Coordination tasks
c) Trigger, data acquisition and monitoring
d) Computing and software

To a lesser extend DESY contributes to detector development and construction, especially in the forward region, where the experiments were not yet complete.

In addition to these direct contributions to the experiments, DESY has agreed to take on a supporting role for the German groups working at the LHC in the context of the Alliance. Of the four research topics of the Alliance, three are relevant for the LHC. Data analysis proceeds in the context of the analysis centre (see details in section 2.5). Detector R&D and development for the upgrade of the LHC is planned taking into account both the use and the provision of infrastructure for the virtual laboratory for detector development (see details in section 2.5). Grid computing and the use of the NAF (see details in section 2.7) will ease the timely completion of physics analyses for their publication.

a) Physics analysis
The main motivation for DESY to participate in the LHC experiments is the very compelling Terascale physics programme. The analysis of the LHC data may lead to exciting new insights and discoveries. Participation in physics analyses is an essential cornerstone for the education of diploma and master students, PhD students and postdocs. Both the ATLAS and the CMS group are active in physics analyses that may answer fundamental questions in particle physics. DESY’s analysis efforts can be divided into searches for new physics beyond our present knowledge and Standard Model physics. The physics analysis work is performed in close collaboration with groups from the University of Hamburg and Humboldt University in Berlin.

The theory of supersymmetry (SUSY) is currently the most conclusive model of physics beyond the standard model. SUSY models solve key questions that cannot be answered within the Standard Model. This makes SUSY searches one focus point of essentially all German physics groups.
DESY’s expertise in experimental searches for SUSY is complemented by the vast experience of the DESY theory group in SUSY calculations. Some SUSY models are characterized by final states that contain a large number of tau-leptons. One of the YIGs in ATLAS therefore concentrates on these final states with tau-leptons and has taken a leading role in optimizing the tau-lepton reconstruction in ATLAS. Further efforts include searches in the framework of gauge mediated SUSY breaking and techniques to extract SUSY parameters from experimental data. Within the CMS group one application for a YIG to search for SUSY signatures using highly energetic jets has been submitted recently.

The discovery of a Higgs boson, whether in the Standard Model or in theories beyond the Standard Model, is one of the main goals of the LHC experiments. Depending on the success of an application for a new YIG, the CMS group will become active in this important field of LHC physics. Expertise acquired in searches for the Higgs boson at LEP and in the preparation of the physics programme of the ILC will allow contributing significantly to the exploration of electroweak symmetry breaking.

Excellent understanding of Standard Model processes is crucial for the success of the LHC physics programme – with a strong theory group and the HERA expertise DESY is an excellent position to play a leading role.

Standard Model reactions have large event rates compared to the rare interactions of new physics and represent an important background from which the signals of new physics have to be singled out. The analysis of known processes helps to interpret the signals seen in the new detectors and with their understanding to achieve excellent performance soon after the LHC start-up. Standard Model processes provide “standard candles” that will be used to normalize new physics processes. On the other hand precise knowledge of these reactions can provide indirect constraints on new physics, similar to the way limits on the Higgs mass were derived from LEP precision measurements. The ATLAS and CMS groups work on a variety of Standard Model analyses, top-quark physics, production of W and Z bosons, interactions at small momentum transfer and the description of the underlying event.

The top-quark is the heaviest quark in the Standard Model. Its mass is intriguingly close to the electroweak scale; therefore the top-quark plays a key role in theories beyond the Standard Model that could explain electroweak symmetry breaking. After the top-quark discovery in 1995, the basic properties have been studied at the Tevatron on relatively small data samples. The LHC will be a “top-quark factory” where DESY will be able to test the role of top-quarks in the Standard Model and beyond. Due to the large top-quark mass, top-quark events feature a complicated event structure that makes them a prominent background in many searches but also an ideal tool for detector calibration.

The DESY groups are involved in studies of the strong production of top-quark pairs as well as electro-weak production of single top-quarks. Both the ATLAS and the CMS group strengthen their efforts with new YIGs. The work of the ATLAS YIG is built on the top-quark physics experience at the Tevatron and the CMS YIG works on exploiting HERA results to improve top-quark measurements at the LHC using precision measurements of the proton structure. Both ATLAS and CMS profit from the expertise on higher order calculations of top-quark production in the DESY theory group.

Further Standard Model analyses have close connections to HERA physics, so that the groups can transfer their experience in a very direct way. Processes in which a W or Z boson is produced are sensitive to PDFs. The final accuracy of the PDFs extracted from HERA data will have a crucial impact on the systematic uncertainties of the measurements at the LHC. W and Z production, also in association with additional jets of hadrons, are valuable tools for detector calibration and Monte Carlo event generator tuning. With their high event rates they represent considerable backgrounds both to searches for new physics and top-quark analyses.

Physics with data from detectors in the forward region of the LHC spans a broad variety of QCD related topic. Most prominent is small-x physics including diffraction, which represent one of the major topics at HERA. Since this forward physics has a natural continuation at the LHC, HERA
experts are involved in the construction and the data analysis of the CASTOR calorimeter in CMS and the ALFA detector in ATLAS.

Topics which can be addressed with the data of the CASTOR calorimeter are the parton densities in the proton at very low Bjorken-$x$, where the data can distinguish between different parton evolution schemes and possibly unveil saturation effects necessary to tame the growth of the number of partons seen at HERA. Closely connected to this topic are multi-parton-interactions in a proton-proton collision. This effect needs to be understood as it entails offsets in the particle multiplicity and energy in an event and hence is relevant for discovery physics.

The ATLAS group contributes to the luminosity detector ALFA, which measures the absolute luminosity, needed for all cross section measurements as normalization. At the same time, by operating detectors so close to the beam, ALFA will also provide first insights into diffractive signatures.

In addition the ATLAS group is maintaining the interfaces between Monte Carlo generators and the ATLAS software and a member of the group is co-chairing the ATLAS generator group. In this context, physicists from DESY work on validation and tuning of generators in close collaboration with the Monte Carlo group of the analysis centre.

Summary
With the selection of topics in physics analyses the LHC groups at DESY successfully cover the full range of energies, from low energy Standard Model phenomena through Higgs production towards highly energetic SUSY searches. The ingredients and tools used bridge the activities at HERA through the LHC towards a future linear electron positron collider.

b) Coordination tasks
Due to the special expertise and abilities of the DESY staff physicists, who have operated and coordinated several different detector components in the HERA experiments, the activities within the DESY LHC group concentrate in areas that are essential for commissioning and operating the experiments in hardware and software. It was possible for several members of the DESY LHC groups to take responsibilities in central coordinating tasks in the ATLAS and CMS collaborations.

Two prominent examples are the areas of technical coordination and computing for CMS, both being on the first level of the CMS management and therefore also included in the management board.

In his role as the deputy technical coordination one DESY CMS physicist is responsible for all activities taking place in the experimental hall. During the construction of the detector up to 100 persons are working in the cavern at the same time, which demands a high level of monitoring and coordination of all processes. Several times technicians from DESY helped for a few months to finalize detector components like the endcaps of the electromagnetic calorimeter. Presently the detector has been closed for first data taking. The group will profit from the experience gained during the CMS installation process for modification, repair and installation work during upcoming shutdowns, which are scheduled for several months per year. Also on the side of the LHC machine DESY has contributed to the commissioning by sending physicists of the accelerator group to CERN.

Since 2007 DESY is leading the collaboration wide CMS computing project. This project is responsible to coordinate the worldwide Grid resources at the Tier-0, Tier-1 and Tier-2 centres as well as the regular data processing, Monte Carlo production and the provisioning of analysis resources. Important milestones were the tests of the infrastructure and the data production in preparation for the start of data taking.

DESY is also co-leading two further projects: the CMS-wide Data Quality Monitoring & Certification project and the Calibration & Alignment project. The commissioning of CMS and the data analysis rely crucially on the success of these projects. Extensive tests demonstrated that CMS is well prepared to monitor the quality of data and to perform the detector calibration and alignment within very short turn-around times to meet the requirements for data
reconstruction. DESY also contributes one of the co-project managers of the CASTOR calorimeter.

Within the ATLAS collaboration the DESY ATLAS group fulfils coordinating responsibilities in several areas. The group responsible for the definition and implementation of the derived physics data is co-chaired by a member of the DESY group as well as the group responsible for the trigger configuration. The DESY ATLAS group also has responsibilities for Monte Carlo generators in ATLAS. One member of the group coordinates the implementation of the interfaces between the generators and the ATLAS software and another member co-chairs the ATLAS generator group.

c) Trigger, data acquisition and monitoring

Trigger

At the LHC the interaction rate is extremely high. At design luminosity there are about 20 minimum bias events per bunch crossing every 25 ns, while the rate of interesting events may be only a few per day or even less. The experiments are able to record a data rate of only about 100 Hz. This large difference makes triggering at the LHC a real challenge. Both experiments operate a multi-level trigger system. The first level is built from custom-designed electronics and produces trigger decisions at the full 40 MHz LHC bunch crossing rate. The higher levels run on standard PCs, which are installed in processor farms comprising several thousand CPUs each connected to the data sources. In both experiments DESY contributes to parts of the central trigger operation, namely the trigger configuration and monitoring.

In ATLAS the first level trigger hardware contains a large number of programmable elements, which must be configured at the beginning of data-taking runs. The higher-level trigger processes are built from hundreds of different software packages, all of which have adjustable parameters that must be set at start-up time. Furthermore, the software, which steers the execution of processes, must be configured in a flexible way to allow evaluation of an arbitrary number of different signatures. Finally, it must be possible to change the pre-scale factor of each trigger signature as a run progresses and the luminosity falls. The DESY group is involved in all of these areas as well as the overall coordination of the trigger core software group whose domain includes trigger configuration and trigger steering.

The DESY and Humboldt groups are jointly responsible for coordinating the monitoring activities of the ATLAS trigger. Monitoring infrastructure is being deployed both in the online environment for immediate feedback and control as well as in the Tier-0 centre and CERN Analysis Facility for more extensive checks of the trigger.

In CMS members of the DESY group are delivering essential contributions to the run control and monitoring software of the higher level trigger supervisor, which is used to operate the numerous units of the filter farm. The concept of the software was developed in 2006 and is since then in continuous operation enabling further improvements and extensions. A second activity in this area concerns the development and implementation of the configuration database, which ensures coherence between the two levels of filtering in CMS and which will be used in future for the data quality monitoring and also in physics analyses.

Data Quality Monitoring and Data Certification

DESY is co-leading the CMS-wide Data Quality Monitoring (DQM) and Data Certification project. This supervision of the detector status via monitoring the detector response to event signals is of central importance to guarantee optimal data quality already during data taking. The project comprises the monitoring of the data online in real-time processing with instantaneous graphical displays, the further processing through the reconstruction up to the archiving (offline) and the data certification for physics analyses.

Members of the DESY CMS group provide the infrastructure for the different monitoring tasks. One example is a graphical user interface for the collected monitoring information that is accessible worldwide. Meanwhile the overall framework has been designed and is in the process of being implemented. It is adapted to the needs of the collaboration via regular system tests. For the forthcoming data taking periods these implemented tools are to be automated to cope with the increasing flow of data.
Remote Control Centre at DESY
In 2008 a remote control centre has been set up at DESY. It comprises facilities for performing DQM shifts and a video conferencing system with permanent connection to the control room at the CMS experiment and to the control room on the Meyrin site of the CERN area. In addition there are connections to the control room at Fermi National Accelerator Laboratory in the US. The DESY CMS group has taken over the responsibility to monitor the data quality during the morning shifts in the regular system tests with cosmic muons and also in the forthcoming initial data taking. In these shifts the DESY remote centre has been used and adjusted to the needs. The remote centre has been proven to be completely functional now and will be regularly employed in the forthcoming data taking. It is planned to enlarge the scope of the remote centre and include tasks like calibration and alignment, supervision of computing activities and performance control of sub-detectors.

This facility will help DESY and the members of the German Universities and institutes to fulfil the requirements for being an author of the CMS collaboration, which demands on average 25% of the working time for CMS service, while reducing travel costs for performing shifts at CERN.

Summary
The high level of coordinating responsibilities within the LHC collaborations demonstrates clearly that the expertise of the DESY physicists is very welcomed in the experiments. The diversity of the engagements reflects an optimal use of the competence available at DESY. The chosen contributions in the central areas for commissioning, operation and monitoring provide crucial input for the experiments, which is connected with a very high visibility.

d) Computing and Software
The field of computing and software is one of the main challenges for the LHC experiments. The DESY LHC groups deliver essential contributions to the realization of the complicated computing models.

A major hardware contribution of DESY to the LHC experiments is the operation of the Tier-2 centres, which is described in detail in section 2.7. The Tier-2 centres are grouped in so called clouds around a Tier-1 centre from which they receive their data. The Tier-1 centre at FZK is the relevant centre in the case of DESY. The DESY groups participate in the operation of the cloud and the data distribution within it. Within CMS DESY is responsible for the installation of the CMS software at all Grid centres outside of the US. The installation team is coordinated by DESY and installs new software releases in more than 50 centres within typically less than 24 hours.

ATLAS computing activities
The DESY ATLAS group is responsible for the ATLAS user support of the NAF. Members of the group install the latest software releases, register accounts and help users with ATLAS specific problems. One group member also chairs the NAF user committee and is a member of the ATLAS Germany computing board that decides about the distribution of data in Germany.

An important DESY activity is the participation in the management and monitoring of the ATLAS worldwide data distribution as core service of the experiment. This also includes a contribution to the development of data distribution software tools. A member of the DESY group is responsible as librarian in the release management of the ATLAS offline software.

The data format written out by the ATLAS reconstruction is too space consuming for data analysis. For this reason smaller data formats are being defined. A member of the DESY group is co-coordinating this project and the DESY group contributes to the format definition for top-quark physics, supersymmetry and tau-lepton analyses.

To analyse high energy physics data it is necessary to compare them with simulated data. A subgroup of the DESY ATLAS group is responsible for the interfaces between the event generators and the ATLAS simulation software. A serious problem in the event simulation is the huge CPU time needed to simulate electromagnetic showers. The H1 experiment at HERA has developed methods to reduce the simulation time significantly. Members of the DESY group are implementing these methods into the ATLAS software to speed up the detector simulation.
CMS Tracker Alignment
DESY is co-leading the CMS-wide Calibration and Alignment project. Here the participating group members contribute to the alignment of the tracker, in close cooperation with the University of Hamburg.

With more than 20,000 silicon sensors the CMS tracker is one of the most complex tracking devices ever built. The performance of such a device is crucially determined by the knowledge of the position and orientation of the individual modules, best within the order of microns. The calibration of the position parameters, called alignment of the tracker, reaches its ultimate precision with the analysis of the tracks inside the tracker itself. Here the formidable mathematical problem appears to determine roughly 50,000 free parameters with data sets containing a few millions of reconstructed tracks. In this new complexity the Millepede-II algorithm developed at the University of Hamburg has been shown to be promising. The goal of this activity is the completion and implementation of a system that routinely achieves a precision of 10 \( \mu m \) for the complete CMS tracker. This should be accomplished within the usual data taking operation and with prompt reconstruction in quasi real-time. Comprehensive tests during the data taking with cosmic muons on a regular basis have successfully validated the concept.

Summary on Software and Computing:
The two LHC groups at DESY contribute in essential fields to the computing of the experiments. Especially they work at the interface between the experiments and the Tier centres to facilitate an efficient running of the DESY Tier-2-centres and the NAF.

e) Detectors
So far the LHC groups at DESY contribute to detector components only to a small extent. As the central detectors were in their last stage of construction these smaller activities are related to detectors in the forward regions. In ATLAS there is the support for the ALFA detector, in CMS these are the contributions to the Beam Condition Monitor (BCM) and the CASTOR calorimeter.

ALFA at ATLAS
For the normalization of any cross section measurement the luminosity must be known as precisely as possible. The most precise luminosity determination in ATLAS will be done with special detectors 240 m away from the interaction point called ALFA. This detector system measures the absolute luminosity in special low luminosity runs with parallel beams using the well calculable Coulomb scattering. In order to detect the beam protons scattered in the Coulomb region, the sensors have to be placed extremely close to the beam. Therefore these detectors, consisting of several planes of scintillating fibres, are mounted in so called “Roman pots” which can be retracted from the beam during injection and are brought into their measurements position only when acceptable beam conditions are reached. With the absolute normalization in the low luminosity runs the other ATLAS luminosity detectors, which are sensitive to the relative luminosity only, are calibrated for their use in normal running conditions at nominal luminosity. Eight independent detectors are needed for the final operation. One detector has been finished as a prototype. The full detector will be built in 2009 with installation and operation starting in 2010.

The DESY ATLAS group contributes to the construction of the ALFA detector and later analysis of its data within an international group. From Germany the Humboldt University and the University of Gießen participate in this detector. One part of the DESY contribution is the precision metrology of the measurement planes. Very high precision is needed to relate the counting rate of the detector to the calculated cross section. Another task of DESY is the machining of some part of the titanium support structures. They are pre-fabricated in industry using electro-erosion and then finally machined in the DESY workshops. Fast scintillation detectors for triggering are also built at DESY.

In summer 2008 the first complete detector was tested in a test beam at CERN, under the coordination of a member of the DESY group. After the installation of the detector in the shutdown 2009/2010 DESY plans to contribute to the commissioning and operation of the detector and plan to take a leading role in the data analysis.
Beam Condition Monitor at CMS

Beam Condition Monitors (BCM) are installed just outside the beam-pipe on both sides of the interaction point. They will monitor the beam conditions inside the CMS experiment to protect the detector, in particular the tracker, against radiation damage. They deliver information to the machine for improving the beam conditions especially during injection and data taking. The system is also connected to the LHC beam abort system. As sensors scintillators and CVD (chemical vapor deposition) diamonds are used.

DESY contributed to the tests of diamond sensors for the BCM. This work is based on developments for the linear collider done in the FCAL collaboration (see chapter 2.3). The system, based on single crystal CVD diamonds, was commissioned and installed in the CMS detector. It was operational at the LHC start-up, and first signals of beam halo particles were recorded with the first circulating LHC beam on 10th of September 2008. The readout software is now in the commissioning phase and the data analysis under development.

The current BCM is designed for the very early phase of LHC operation at low luminosity. At higher LHC luminosities, expected after 2009, the scintillators must be replaced with radiation hard sensors. Also, parts of the electronics are not sufficiently fast to allow bunch-by-bunch monitoring. Hence, replacements of components of BCM will be unavoidable soon. Our goal is to contribute with the expertise acquired within FCAL to ensure the operation of CMS under good beam conditions, essential to collect data at maximal luminosity. The BCM commissioning is pursued in close collaboration with the University of Karlsruhe and CERN.

CASTOR Calorimeter at CMS

About 14.4 m away from the interaction point the CASTOR calorimeter will be installed on one side of the experiment, where it enlarges the available kinematic phase space considerably. In this forward region it has to withstand extremely high particle fluxes. Therefore the calorimeter had to be designed very radiation hard and its operation will already provide insight to the conditions expected for the upgraded LHC accelerator. Due to its forward location the CASTOR calorimeter can be used to address questions in QCD, which are also studied at HERA.

The CASTOR calorimeter has two project managers, one of them is a DESY physicist. At DESY the project is pursued in a joined effort from DESY and Moscow State University. The funding contribution is financed with contributions from a new Helmholtz-Russian-Joint-Research Group (HRJRG-02), which also comprises a related project from the ILC-HCAL (see section 2.3.3) and is thus networking between activities for HERA, LHC and ILC in one group. The contributions from DESY and Moscow State University are on the construction of the mechanics, the production of front-end electronics, software for the data acquisition, the slow control and the data base. DESY physicists also participate in the preparation, data taking and analysis of test beam measurements at CERN and optimize the simulation code. Studies and preparations for physics analyses are well under way.

Recently two scientists from the University of Karlsruhe, working on the phenomenology of cosmic ray showers and a Monte Carlo generator, have decided to join this effort, since CASTOR data can provide input for the energy scales in cosmic ray showers. In cooperation with the Institute for Experimental Nuclear Physics of the University of Karlsruhe they have submitted an application for the funding of a postdoc and hardware contribution.

Summary on Detectors:

Scientists of the DESY LHC groups successfully participate in detector projects in the forward regions of the experiments. They are all motivated by close collaborations with other activities at DESY. Both, the CASTOR calorimeter and the ALFA detector are strongly tied up with HERA physics topics and technologies, while the Beam Condition Monitor successfully employs technologies developed for the forward instrumentation of a detector at a future electron positron collider.

2.2.3 Contents and goals

As described above the DESY LHC groups have taken responsibilities in several central areas of the ATLAS and CMS experiments. The goal for the coming years is to finalize ongoing developments and implementations and to enter operation mode. This includes continuous
supervision and maintenance of the DESY hardware contributions as well as refinements of the tools based on the experience gained during data taking and continuous adaptation to the increase of luminosity.

In the focus, however, will be the strong participation in the physics harvest of the LHC. Hence, for the coming programme period DESY intends to strengthen the activity in physics analysis and to continue and to develop the responsibilities assumed in detector operation. In addition DESY plans to contribute to the R&D phase for detector upgrades and to prepare for detector construction, both in close collaboration with the German LHC groups.

a) Physics analysis
The LHC is built to explore unknown territory, which makes it difficult to predict in detail how physics analysis will look like in the next funding period; however, the main directions are clear.

Both groups prepare for searches of supersymmetry and, if the YIG application is successful, the CMS group will also work on Higgs searches. These searches will continue in a large part of the allowed parameter space until new particles or effects are found somewhere. At this time the strategy will change. If new particles are found it is essential to measure their properties and couplings as precisely as possible. This programme will strongly restrict the class of models that can explain the current problems of particle physics and cosmology and will constrain parameters within these models. In parallel, searches for further new particles will still go on to complete the spectrum, however, these searches will be guided by the new effects possibly found already.

The programme to investigate Standard Model processes will continue. Background processes must be studied for searches as well as for measurements of new particles. The parton distribution functions must be known as precisely as possible to interpret absolute and differential cross sections in terms of couplings and finally also precision measurements inside the Standard Model can give important information on new physics. Predictions of any model for LHC data can only be done using Monte Carlo generators. The groups will therefore, in close collaboration with the analysis centre, continue to work on such generators especially on their tuning.

Independently of the new physics found the top-quark will remain interesting. Due to its large production cross section, well defined topologies and decays involving neutrinos it will be an important background and a source for calibration and monitoring events. Because of its large mass the top couplings carry information about electroweak symmetry breaking and the top mass is of utmost importance to calculate loop corrections to the properties of other particles especially if, as e.g. in supersymmetry, the Higgs mass can be predicted in terms of other model parameters.

The ATLAS and CMS groups at DESY have laid the foundations to successfully participate in LHC analyses covering a broad range of topics both in searches for new physics and in Standard Model physics. Currently the groups are involved in preparatory work to be ready for the first LHC data. In order to efficiently pursue the data analyses toward the timely publication of new results both the use and the provision of support for the analysis centre is one cornerstone in the physics analysis concept. Relying in the LHC data analysis on the competence made available through the analysis centre will enhance the visibility of German physics contribution within the large international collaborations.

Especially once high luminosity data samples are available the synergies with the programme of the DESY theory group can be exploited. For example theorists in Zeuthen work on higher order calculations of PDFs and of top-quark production and a theorist is employed by the analysis centre to work on Monte Carlo generators all in direct connection to the LHC Standard Model programme.

During the funding period physics analysis to extract new physics knowledge from the LHC data will be DESY’s top priority. Standard Model processes can be analysed with the high statistics available soon after regular data taking has started and will be used for detector calibration. Searches for supersymmetric signals and the Higgs-boson will dominate the activities in physics
analysis on a longer timescale. With the analysis centre a central source of competence for the education and training of students as well as for support for individual user requirements is provided. This will effectively enhance the performance of physics analyses in Germany and may lead to high visibility in the international competition within the large collaborations of ATLAS and CMS. An important task of DESY is to sustain the analysis centre after the end of the Alliance.

b) Coordination tasks
Presently the level of coordinating responsibilities of the DESY LHC groups to the experiments is extraordinarily high compared to the level of funding and manpower contribution. The usual practise in particle physics experimental collaborations foresees a regular rotation of such coordination responsibilities with the goal of an equal distribution to all institutes. For the funding period we aim at keeping the level of important coordination responsibilities to at a high level. The deputy Technical Coordinator in CMS, represented by a DESY physicist, has taken up the responsibility as Technical Coordinator for the upgrade at LHC. Within the current European Framework Programme (FP7) the sLHC pp project, a preparatory phase, was approved to create and install the necessary infrastructure for an upgrade of the LHC.

c) Trigger, data acquisition and monitoring

Trigger
Continuous work on the trigger is required to ensure smooth data taking during increasing luminosity and changing machine conditions and to adapt to an evolving physics programme when new effects are found.

The evolution of the trigger implies that the configuration system and monitoring will also evolve. Although DESY responsibilities in the area of infrastructure development will lessen, the operation and monitoring of the trigger will require substantial effort. We thus foresee that the DESY ATLAS group will continue to contribute to the trigger but with less emphasis on infrastructure development and more emphasis on the evolution of the trigger algorithms and on trigger operation – specifically monitoring shift work. ATLAS is currently preparing the basis for enabling remote monitoring and the DESY group is planning to integrate its activities into the LHC centre at DESY.

With the increase of the LHC luminosity the CPU power available for data acquisition and high level trigger farms in the ATLAS and CMS experiments need to be enlarged to their design levels. DESY is expected to contribute to the purchase of the additionally needed hardware.

Finally we note that the options for upgrading the first level trigger to allow it to cope with the increased luminosity of the sLHC are being studied. One possibility would be the addition of a tracking component in the pixel detector to increase the selectivity of the muon trigger. Such a trigger would require close (on-detector) coupling with the pixel detector itself and its development would have to be considered in conjunction with the pixel upgrade discussed below. That work would also be well embedded in the Alliance. The Universities of Heidelberg and Mainz are already involved in the ATLAS trigger. It would thus be natural for DESY to also contribute in this area.

Data Quality Monitoring
Within the area of DQM and tracker alignment the present work at CMS concentrates on the design and development phase. Within the funding period these activities will move towards streaming, operation and production with the necessary regular adaptations to new developments. In future the areas will be expanded to provide also data quality monitoring for physics analysis groups. Also the data certification on the different levels of the Tier-0, Tier-1 and Tier-2 have to be developed for data as well as for Monte Carlo generated event samples. The three areas of DQM, higher level trigger and alignment can be connected with a strong synergy between each other like for example data quality monitoring for the alignment or taking over concepts of the HLT supervisor for the DQM structure.

The expertise obtained in the present activity for the tracker alignment will be employed to also conduct studies for the expected performance of different possible layouts for an upgraded tracker.
Remote LHC centre
The present available remote centre for CMS has been proven to be a valuable tool to perform shift and monitoring duties. In the future the CMS centre may be further developed into a more general remote centre. Such a general LHC centre could serve for monitoring and operation tasks for CMS as well as for ATLAS. Also activities for the LHC machine could be embedded in a more general LHC remote centre following the lines of a Global Detector Network as described in section 2.5.3.

d) Software and Computing
DESY has extensive experience in high energy physics data analysis and the coordination of computing, the goal is to take responsibility in areas of coordination and organisation of distributed data analysis. This experiment wide responsibility extends the role of operating the Tier 2 centre and the NAF for the Germany based LHC data analysis.

The needs for evolution in the ATLAS computing domain are similar to those for the trigger. In particular the content of the compressed data format will need to be continuously adapted to adjust to higher data-rates. With improved knowledge on Terascale physics and detector performance, the amount of information per event stored will be reduced. Grid operation will also face new challenges. New data will be processed and old data will need to be reprocessed at the same time. The needs for datasets will change repeatedly and significant manual intervention will be required. Given its particular responsibilities in the NAF, DESY must anticipate a significant manpower commitment in this area.

Work on the Monte Carlo generators must continue. There is a strong focus on Monte Carlo generators within the Alliance and the DESY LHC groups will promote the use of such developments in the collaborations.

Tracker Alignment
Presently the Tracker Alignment relies strongly on data which have been taken during the integration phase in standalone operation mode and on the data taken during the cosmic runs. The strategies to be followed with collision data are under study with simulated events. Certainly with the arrival of more and more data also the work in this area similar to the one in the area of data quality monitoring, will move from the design and implementation phase towards the streaming operation with high reliability. Since several German groups are participating in the tracker project it is envisaged to improve in a common effort the present algorithms and to develop new strategies with large data sets and extensive fitting procedures.

The expertise obtained in the present activity for the tracker alignment will be employed to also conduct studies for the expected performance of different possible layouts for an upgraded tracker.

e) Detector upgrades
The intense particle flux at the sLHC design luminosity of $10^{35} \text{cm}^{-2} \text{s}^{-1}$, ten times larger than the LHC design luminosity, poses major challenges for the inner detectors at both ATLAS and CMS. The experiments need to cope with a significant increase in occupancy and to control radiation damage to the detectors. At the same time the inner detector material budget must be reduced. In ATLAS the complete inner detector will be replaced with an all-silicon tracker. Also a replacement of the CMS all-silicon tracking detector with a new design is inevitable. These detectors are foreseen for installation around 2016. This funding period will be used for R&D, the design of tracking detectors with substantial reduced material budget and prototyping of the critical detector components.

R&D towards the exchange or modification of detectors for sLHC has already started within the collaborations. The upgrade of the tracking systems is one prominent area, in which most of the German groups in both ATLAS and CMS are very active. German ATLAS activities concentrate mainly on the pixel detector at inner radii while the CMS effort goes into the strixel detector, a silicon strip detector located at medium radii which has variable strip lengths from very short pixel-like up to the usual strip lengths. In addition to these two tracking system upgrades DESY will follow up smaller-scale upgrade projects, for example the upgrade of the BCM in CMS, the
ALFA detector in combination with further extension detectors at ATLAS and an effort aiming for an improved muon-track trigger in CMS.

All detector upgrade projects will be pursued in close collaboration with German universities exploiting the infrastructures of the virtual detector laboratory of the Alliance. DESY is contributing to the virtual detector laboratory with its unique infrastructure as explained in research topic 2.5. In particular DESY will provide an electron test beam for tests of sensors and sensor modules. Experienced DESY personnel will support organizing and conducting the measurements. A key element of the test beam infrastructure is the EUDET telescope, comprised of high-resolution silicon pixel sensor planes.

For the tracker upgrade proposals are submitted by the ATLAS and CMS collaborations. The ATLAS proposal is approved and the CMS proposal is currently under review.

**ATLAS pixel upgrade**

DESY plans to participate in R&D towards the ATLAS inner detector replacement with two projects: Monte Carlo simulation studies to optimize the design of the inner detector and a generic R&D project in the field of silicon detector system integration. This R&D programme is part of the programme of the YIG “Top as Key to LHC Physics” and well embedded both in the ATLAS collaboration, including leading German ATLAS institutions, and the Alliance.

The simulation studies will be carried out in the framework of an R&D proposal for planar pixel sensors. The R&D proposal is supported by an international group of 14 institutions including Humboldt University Berlin, University of Bonn, TU Dortmund, and MPP/HLL Munich. The goals of the MC studies are to optimize the design of the upgraded pixel detector with respect to number and radii of detector layers, pixel sizes, sensor thickness and sensor overlap. DESY will work on realistic studies that take into account the expected pile-up due to an average of 400 simultaneous interactions per bunch crossing. This will require re-optimization of algorithms for charge clustering, track finding, and the identification of jets containing long-lived B-hadrons (b-tagging) or possibly novel approaches to tracking and b-tagging.

The system integration project addresses a common problem in future particle physics detectors: reducing the amount of non-detector material in the tracking volume while increasing the number of readout channels. A key approach followed both for sLHC and ILC is to reduce the number of power lines by powering detector modules in series or via DC-DC coupling. For these novel powering schemes it is important to consider system integration aspects as soon as possible. We propose to develop a silicon detector powering solution suited for the ATLAS pixel detector upgrade in close collaboration with the University of Bonn and other partners. The project is well embedded in the Alliance also beyond the ATLAS collaboration with a similar project for the CMS tracker upgrade pursued at RWTH Aachen. We will also investigate possible R&D projects towards improved optical data transmission for future particle physics experiments. Such an optical data transmission system must be suited for both the transmission of data and control signals, allow for GHz bandwidth and withstand high radiation dose.

The DESY ATLAS group has started to help with the commissioning of the present ATLAS pixel detector. Apart from being an important service task for the ATLAS collaboration, this commitment will also provide hands-on experience with the requirements and problems of the present pixel detector that will be invaluable for working on the detector upgrade. We have taken responsibility for calibration and monitoring tasks for the present detector and will contribute to shifts when data taking starts.

The current R&D proposals aim at Technical Design Reports around 2011 and detector construction around 2014. The exact timing depends on the sLHC start-up time which can only be fixed once first running experience with the LHC is gained. After the R&D phase, we plan to contribute to the construction of the upgraded ATLAS pixel detector, in close collaboration with other German institutions working on the planar pixel sensor proposal and other ATLAS pixel detector upgrade proposals.
CMS tracker upgrade
The upgrade of the CMS tracker will be a major R&D effort by the Universities of Aachen, Hamburg and Karlsruhe. These universities played a leading role in the development and construction of the currently installed tracker. In the first years of data taking these groups will acquire unique expertise in operating and characterising the performance of the current full-silicon tracker. Physicists from DESY are currently included in the tracker alignment effort.

The participation of DESY in the CMS tracker upgrade will be based on two pillars:

1. Mechanical and thermal FE calculations to minimize the material budget:
The calculations will be done in close collaboration with the German university groups being committed in the module design, detector cooling and power management. In addition, these activities will be accompanied by physicists performing Monte-Carlo simulations, similar to the simulations described in the ATLAS tracker upgrade, to optimise the CMS tracker design for the physics challenges at sLHC. In a later stage of the upgrade project DESY will also substantially contribute to the integration of the new tracking detector.

2. R&D to explore available materials and technologies for silicon sensors for application in the harsh radiation environment at the sLHC and to develop, construct and test of prototype detector components. The activities of the DESY group will be focused in a first phase on sensor design, sensor characterisation and irradiation studies. In a second phase also prototyping of modules will be considered.

This research work will be pursued in the framework of the “Central European Consortium”, which is within CMS a cooperation of several institutes, including the participating German groups. It will be embedded in the general CMS tracker upgrade programme. A Technical Design Report is expected around 2012.

ALFA and further detectors for diffraction at ATLAS
It is foreseen that the ALFA detector will be installed by the beginning of the funding period. The remaining tasks will be the commissioning of the detector, its operation, and especially the analysis needed for the extraction of the luminosity for ATLAS. The DESY group intends to contribute in all of these areas.

Inside ATLAS a proposal is currently being written for additional detectors to measure diffractive events. These detectors would not only give access to the standard QCD aspects of diffraction but would also allow the study of diffractive production of high mass objects such as the Higgs or supersymmetric particles. These processes are very rare, but extremely clean and would allow the measurement of certain properties of the produced particles including their masses with high precision.

One part for this detector, FP420, consists of silicon detectors housed in a movable beam pipe 420 m downstream of the interaction point. The special experience coming from the large programme of diffractive physics carried out at HERA would be of substantial benefit for this project. In addition, the movable beam pipe planned for FP420 was invented by DESY and has been used already in the ZEUS detector. Furthermore, since the FP420 project will use silicon pixel detectors, there would be significant synergies with the proposed pixel R&D project.

DESY is considering contributing to this project on a smaller level in collaboration with German universities. As of today a group at the University of Gießen is interested in contributing to the project.

R&D for upgraded Beam Condition Monitors at CMS
Studies will be done on the radiation hardness of GaAs, single and polycrystalline diamond and quartz sensors. The research will be performed with partners, e.g. IAP Freiburg, JINR Dubna (Russia), for the sensor production, and within the EU supported project CARAT for the test and characterisation of sensors. The goal is to obtain large-area sensors that withstand the dose rates expected near the beam-pipe of LHC for a reasonable time. These sensors may be used in case the current design must be changed, as well as for the replacement of the scintillators or to instrument dedicated devices at very small polar angles. The research work overlaps to a large extend with the R&D for e+e− linear collider detectors. A redesign for operation at high
luminosity will be done and the essential new components, i.e. sensors front-end and back-end electronics, will be developed together with partners in the BCM group. The upgrade to a diamond pixel sensor telescope is just studied and will be pursued in case of benefit for physics.

The present collaboration with the University of Karlsruhe and CERN will be continued. For example joint measurements in the high intensity beams in Karlsruhe are planned. The activities might be strengthened by a young investigator group in close cooperation with the University of Karlsruhe in the context of measurements for the Higgs-boson. The application has been submitted lately.

Fast muon track trigger in CMS

Within the CMS collaboration the muon detector community is considering an upgrade to improve the muon trigger capabilities at the first level. At RWTH Aachen options are studied for a fast muon track tag to be installed just outside of the CMS solenoid. This would help to connect tracks in the inner tracker with the tracks in the outer muon chambers. The goal will be to use the information of this new detector together with the tracker in the first level trigger. In a later stage this development may contribute to a first level track trigger. It turns out that the radius where the outer layer of the hadronic calorimeter is located is well suited. Since the detector technologies under study at Aachen (scintillators and Silicon photomultiplier readout) are very similar to the technology chosen for the hadronic calorimeter for a future electron positron collider (see chapter 2.3), this project represents a potential candidate for a fruitful collaboration between calorimetry and muon detection, between communities in LHC, ILC and HERA and at the same time optimizes the use of resources. The expertise and interest of DESY are focused in the system aspects of a detector component with Silicon photomultiplier readout, for example in the interplay of the sensors with the electronics, in the calibration and monitoring methods and in the detector integration with the support, the supply and services. In a first stage a test stand with a complete CMS readout will be set up which would make it possible to contribute to a monitoring system. The activities of the RWTH Aachen and DESY are complementing each other.

Goal for detector upgrades

The main goal for the envisaged detector activities is the joint effort and the support of the German particle-physics community in their R&D and construction activities for an upgraded LHC. Since most of the German Universities and Institutes are involved in a new tracker design, it is natural to devote the main emphasis to this area. Several activities can be followed up in parallel for ATLAS and CMS at the same time, taking advantage from the infrastructure of the virtual detector laboratory of the Alliance.

2.2.4 Expected results, milestones

With the LHC starting next year we expect major physics results in the next funding period. Details cannot be predicted since the new physics scenario that nature has chosen is unknown. However a scenario with a light Higgs is likely and will be used for the estimate of time scales. In addition, the work of the DESY groups is embedded in the collaborations and dependent on the LHC performance, so that DESY only has a limited influence on the time scales.

If the operation of the LHC is halted for an upgrade after some years of running the new detectors have to be ready by this date. Some milestones have been set to reach this final goal. With these assumptions the expected results and milestones can be summarised as:

- By 2010 stable operation of the LHC and the detectors at luminosities of a few times $10^{33}$ cm$^{-2}$s$^{-1}$. This will allow for detector calibration and alignment using Standard Model processes and to obtain first estimates of multi-parton interactions and the underlying event. Also, it is expected to have first indications on answers to fundamental questions.

- By 2011 more precise measurements of Standard Model and new physics processes may start. After proof of principle of detector technologies projects for LHC detector upgrades will be determined.

- In 2012 the nominal LHC luminosity $10^{34}$cm$^{-2}$s$^{-1}$ should be reached. It is expected to obtain an initial picture of the Terascale physics (Higgs, SUSY) allowing to consolidate
the global particle physics strategy and to decide on the future direction and projects concerning the upgrade of the LHC and a future electron positron collider.

- In the second half of the funding period, 2012-2014, LHC physics analyses will be continued and improved. In addition, production of detector replacements will take place and R&D for detector upgrades will be ongoing, with construction starting towards the end of the funding period.

DESY’s role and mission
With the outlined scientific activities and goals DESY’s role as the central laboratory for particle physics in Germany will be ensured. Even without an accelerator installation on site a research laboratory has an important role to play. Due to the long years of HERA operation the DESY staff is especially experienced in detector operation, data processing and physics analysis. As compared to universities research laboratories like DESY are characterised by their large fraction of permanent staff without teaching duties, being available for long-term service tasks, coordination and project management. Such tasks are difficult to fulfil for university groups. DESY offers special infrastructure and knowledge that was built up during HERA running in areas like computing or test beams.

In closely cooperating with the German universities and institutes DESY will take a fair share in the service tasks und upgrade activities, providing infrastructure and engineering, usually not easily available outside research laboratories and profound competence in physics data analysis. Education and training for young scientists starting with the level of diploma students up to young investigator groups is a pronounced goal embedded in all activity areas with hands-on thesis work and specialised topical workshop meetings.
2.3 Preparation for a future lepton collider

Spokesperson of the topic: Eckhard Elsen

Contributing centres: DESY

Personnel (2010)\(^3\):
- 20 scientists,
- 6 doctoral students,
- 6 scientific support personnel

Contributing principal investigators: Ties Behnke (see also 2.5), Wilhelm Bialowons, Frank Gaede (see also 2.7), Wolfgang Lohmann, Sabine Riemann, Felix Sefkow, Nick Walker, Hans Weise.

YIG: Philip Bechtle (see also 2.2), Erika Garutti, Jenny List.

Topic costs 2010: 3,535 M€

2.3.1 Challenges

Relevance

Progress in particle physics is closely coupled to the availability of accelerators and high-resolution detectors. The scientific community has identified an electron-positron collider operating at energies close to the scale of electroweak symmetry breaking as the next big step following the LHC. Such a collider represents a huge investment both in know-how and technology, and in resources. Planning and realisation of such a project proceeds in a truly international context, both for the accelerator itself, and for the experiments to eventually optimally exploit the facility.

The particle physics community has very clearly and repeatedly stated its scientific need for a high-energy lepton collider, like the ILC, which naturally complements the physics reach of the LHC. The physics interplay between the two approaches has been documented in various in-depth studies. The need for a lepton collider has been formally repeated in statements of the US EPP2010 committee, of the European CERN Council strategy group, and in Asia through statements by ACFA and others. The commitment of the community to the project is evidenced by the focus on one technology, on one project, and by the fact that the participating institutes agreed to operate within global management structures to pursue and advance the project.

These statements underline the scientific desire and necessity of exploring nature at high-energy scales with as many different and independent means as possible. Lepton colliders constitute a particularly clean and powerful tool and significantly extend the scientific reach of the LHC. Major scientific breakthroughs are expected from the combination of LHC and lepton collider data.

The International Linear Collider, ILC, is the most mature project for such a collider. In 2007 the ILC Reference Design Report, RDR, has been published. It describes a collider with an initial centre-of-mass energy of 500 GeV. The collider is upgradable to 1 TeV. From the start DESY has been strongly engaged in this project. Today DESY is tightly integrated into the international structures of the ILC, which have been created under the leadership of ICFA, and which resulted in the formation of the Global Design Effort, GDE, in 2004, and in the formation of the

\(^3\) The figures given here for scientists and scientific support personal reflect FTE from DESY only, see 1.4.
research directorship for the experimental programme in 2007. These global structures coordinate the required progress in accelerator and detector technology.

Challenges
The international community has set itself a schedule, which aims for completion of the preparatory work for the ILC by 2012. Following the release of the RDR in 2007 the accelerator goes through an intense technical design phase. Detailed plans for the accelerator are being worked out under the leadership of the GDE. Until 2010 the most pressing technical questions will be addressed. Until 2012 a complete proposal will be presented which is developed to a point where the ILC project could be proposed as a real project. Work on the detectors has to be in step with this schedule. The experimental community has organised itself around detector concepts, which are precursors to detector collaborations, and R&D groups focussed on specific technologies.

To advance both aspects – accelerator and detectors – to the point where a proposal can be submitted requires significant conceptual and technical work. A prominent aspect is the development of reliable high gradient cavities, a project, in which DESY plays a decisive role. Other aspects of the collider have to be advanced just as well, and require excellent technical work and good international coordination. The detector necessitates considerable technological progress to yield the high precision instrument required. In addition the transition from a detector concept to a realistic and fully integrated detector design has to be made.

DESY will continue to engage decisively in the management of the GDE to work towards realization of the collider, and to collaborate closely with one of the ILC detector concepts, the ILD group.

The start of the Large Hadron Collider at CERN is imminent. First beams have been circulating and first results from proton-proton collisions at very high energies will become available within a few years. These results will be used to optimize the required physics capability of the linear collider. If the LHC confirms e.g. the existence of a low-mass Higgs, and possibly even of new physics in the few-hundred GeV energy regime, the ILC in its currently proposed form will be the machine to build. Since many years such is the theoretical expectation. Should the LHC exclusively point to larger energy scales beyond the reach of an ILC the technology is not at hand. At CERN intense R&D is under way to take the two-beam acceleration concept to a stage of maturity. With considerably higher gradients the CLIC concept strives to reach energies of several TeV for lepton collisions.

The initial physics harvest from the LHC will help guide the field. The choices range from an even stronger concentration on LHC and its upgrades to a rapid implementation of the ILC. Else a period of consolidation has to be foreseen to advance the CLIC concept to a stage ready for implementation. This discussion, which is expected to take place during the funding period discussed in the report, will impact the programme at DESY and its partners.

On a longer perspective the field will have to advance new accelerator concepts to fulfil the physics demands for physics at extreme energies. No concept has reached a stage of maturity that could provide a simple selection mechanism to date. Nonetheless several studies are pursued in various laboratories, based on concepts like plasma wakefield acceleration, or for muon colliders. DESY is not yet strongly engaged in these studies. However an exploratory effort is under discussion to start in the second half of the funding period in close cooperation with the University Hamburg and the Helmholtz Alliance.

DESY is committed to remain at the forefront of particle physics and will maintain its leadership position in the development of linear colliders and its application.

2.3.2 Current activities and previous work
DESY is strongly engaged in the development of the ILC accelerator and of the detectors at a linear collider. Its prominent role in Europe is largely owed to the success of the superconducting RF technology that has been advanced to maturity within the TESLA collaboration centred at DESY and was adopted in 2004 by an international selection process.
In Germany, DESY is the home laboratory for universities engaging in the ILC, both for the accelerator and for the experimental programme.

DESY's strong position derives also from the European Free Electron Laser, XFEL, which is under construction at DESY and is based on the same technology. Design choices and eventually construction experience of the XFEL are major inputs to the discussions of the ILC. With FLASH, a linear accelerator in SRF technology is in routine operation on the DESY campus. It can be viewed as a prototype of the ILC, which provides already now operating experience and initial feedback on performance and reliability of components. At FLASH modern controls and monitoring systems are being developed which will eventually be carried over to the ILC. Over the last years intense consultations between the XFEL/FLASH- and the ILC-community have taken place. In particular, the aspect of costing for the ILC is profiting heavily from the XFEL project and the related industrialization studies.

Naturally a major focus of the scientific accelerator work at DESY over the past years has been the development of cavities with high gradient. Together with industry and with other laboratories systematic investigations have been carried out on the performance of cavity cells, on the preparations and the fabrication process. While significant progress has been made the production goals for the high-gradient ILC type cells have not yet been reached. Consequently the topic remains in focus for the next few years.

The work towards realization of the ILC is coordinated internationally by the GDE, which receives support from the participating laboratories. The European ILC Director and one of the three ILC Project Managers are two exposed positions, which are supported through this mechanism. The team is complemented by of a number of senior DESY staff members in key GDE assignments.

Beyond the dominant SRF engagement complementarily supported by EU programmes CARE and more recently ILC-HiGrade, DESY has contributed decisively to studies on damping rings for the ILC, to fast ion studies, to electron cloud studies, to beam simulations, to the development of a positron source and to metrology and stabilization studies. These latter activities have been supported by the EU Design Study EUROTeV. All these contributions draw heavily from the experience in operating lepton accelerators at DESY and the synergy with the construction of FLASH and XFEL projects.

The development of accelerator technology is supplemented by a vigorous programme to develop the experimental capabilities to eventually exploit the ILC. Realistic studies for an ILC detector require considerable investments in basic and advanced detector technologies. DESY plays a central role in a number of R&D collaborations: VERTEX, LC-TPC, FCAL and CALICE. In addition DESY contributes to the investigation of beam diagnostics like the measurement of beam polarisation, and to the design of the interaction region of the machine. The experimental programme is completed by a strong involvement in the study of the physics at a linear collider, both from the experimental and from the theoretical side. Many of the activities are part of the European programme EUDET, and are integrated within Germany in the activities of the Helmholtz Alliance “Physics at the Terascale”.

The focus of the work of the last funding period since 2005 has been on the development of basic technologies. For the TPC the concept of a gas-electron multiplier (GEM) based readout has been proven to be feasible, and basic performance parameters have been measured. The concept of a tile-calorimeter-readout based on Silicon photomultipliers has been demonstrated, and first results from a prototype in a hadronic test beam have been obtained. A demonstrator Silicon pixel detector telescope based on the MAPS technology has been built and has been successfully exposed to test beams at DESY and CERN. Various sensor technologies, selected for extreme radiation hardness, have been studied within the FCAL group, and, in particular, promising results for a diamond-based technology have been obtained.

Building upon these results, the different projects will start to move towards more sophisticated prototypes, which will address not only basic technological questions, but also start to address questions of compactness, integration and general usability within a colliding beam experiment. The goal will be to advance the different projects to a point where towards the end of the
funding period a decision could be taken, based on scientific grounds, on the application of these different detector concepts to a detector at the ILC. Many of the technologies developed have found a broad interest outside the immediate lepton collider community. Examples are the VERTEX detector technologies, which are used in the STAR experiment at Brookhaven National Laboratory, and are being proposed for the upgrade of the Belle experiment in Japan, or the application of the tile calorimeter technology to medical imaging applications.

The physics potential of a linear collider has been further explored over the past few years. A focus was the investigation of possible signals of supersymmetric particles, and of the role of the ILC in search for dark matter. To make such studies possible major efforts were spent on developing adequate software systems, and on providing samples of simulated and reconstructed events to the community.

DESY contributes to technological developments within the projects, but also contribute its experience in the management and coordination of large-scale projects, and offers to serve as an integration and management centre for these activities. In the past DESY has successfully assumed this role in the construction of the EUDET test beam facility, in the construction of the EUDET telescope, the LC-TPC large prototype integration, and the integration of the test beam effort within the CALICE collaboration.

In 2007 an international coordination of the detector activities was initiated with the nomination of a research director for the linear collider. S. Yamada from KEK was chosen to be the first director of the research programme. His first task is the organization of detector concept groups for the ILC, and of a stringent review process of the proposed detectors. To this end the community has been invited to submit letters of intent for experiments at the ILC, which are due in 2009, and which will be reviewed by an international review body. DESY is participating in a central position in one of the proposed concepts, the ILD detector.

2.3.3 Contents and goals

The activities for the linear collider address both detectors and machine and are detailed below. In addition DESY fulfils a special role in Europe as a centre for machine and detector activities. This role originates from the TESLA collaboration that established a European network for linear collider research. It lead to the construction of TTF (now FLASH), the TESLA proposal for a combined linear collider with integrated X-ray free electron laser, the XFEL project and strongly influences the activities for the ILC. DESY fills this obligation for the community by engaging prominently in the global management activities for the ILC and by coordinating European projects for accelerator and detector developments.

ILC Management

Following the publication of the RDR the management of the ILC has entered a new phase. The lab-centred structure, geared towards a quick completion of a conceptual report like the RDR, has been replaced by a more conventional project management structure. Under the leadership of the GDE (B. Barish, director, and three regional directors) a project team has been established, with three project managers (N. Walker, DESY, M. Ross, FNAL (chair) and A. Yamamoto, KEK). A clearly prioritised list of R&D topics has been identified and the responsibilities have been distributed to the collaborators around the world according to the available resources and technical capabilities.

With the developments for TESLA and FLASH DESY is well poised and naturally committed to support the GDE management team, and to assist the GDE in its job of developing and establishing appropriate management structures that may eventually take the project towards realization.

The DESY Project Manager is responsible for the accelerator systems, i.e. sources, damping rings, bunch compressors, main linear accelerators, beam delivery systems, final focus and beam dump. While some of these systems are being pursued at DESY others are coordinated abroad, notably in the UK at Daresbury laboratory. There is also considerable overlap in some areas in conjunction with the R&D project CLIC at CERN and whenever possible one tries to pool the effort. Inevitably the task of the project management entails a fair number of visits to the remote laboratories.
DESY is also frequented by the other two Project managers. The Japanese Project Manager, charged with the responsibility of SRF systems, necessarily pays a large numbers of visits to DESY in addition to holding regular phone conferences. The cavity R&D activities and the industrialisation process of cavity production at DESY are the two key areas of interest for the ILC. It is a considerable challenge to fulfil the need for establishing a smooth production goal for the XFEL with the technically somewhat more ambitious demands for the ILC. With the EU-support from the ILC-HiGrade programme a plan has been developed which is beneficial for both XFEL and ILC and taps many of the same resources. It is very helpful in this context that the liaison person to the TESLA Technology Collaboration, which supports generic R&D on SRF technology, is also hosted at DESY.

The chair of the Project Management team, M. Ross, is responsible for the civil construction and the conventional facilities for the ILC. He is thus much concerned with the process of site specification and site selection. The current baseline of the ILC foresees two parallel tunnels more than 100 m deep. With the beam being accelerated in one tunnel the other tunnel houses the RF supplies and cooling water. Such an arrangement may not turn out to be the most cost effective solution. Efforts have been launched to explore sites near surface (shallow sites) where part of the high-power infrastructure could be placed above ground. DESY commands significant expertise and experience from the site exploration of the TESLA project and subsequently the XFEL. The XFEL opted for a single tunnel solution with the cavities suspended from the ceiling. It is hence natural that the technical boundary conditions for a shallow site and particular a single tunnel approach will thus be developed with considerable engagement form DESY. The EU-programme ILC-HiGrade is supporting these activities. A candidate shallow site is currently being advertised near the Dubna in Russia where the ground is favourable and the infrastructure of a large laboratory (JINR) is located nearby.

As a result of these studies it is expected that the cost estimate for the realisation of the ILC will receive further input. Critical design decision can be revisited and reconsidered. It is expected that cost management figures from the construction of the XFEL will be incorporated into the overall estimate. DESY is in a unique position to contribute the experience from a real project in the same technology.

**Detector programme**

The experimental programme at the ILC relies on excellent detectors, which are capable of reconstructing the event with great precision. The clean nature of the events at the ILC and the nearly background free environment make it possible to envisage novel detector concepts, geared toward precision, efficiency and speed. For more than 5 years intense and internationally coordinated efforts are under way to develop technologies, which can be proposed for an experiment at the ILC. Even though the focus of many of these developments is a linear collider their application may be more general. They originate from or trigger themselves other projects even outside of particle physics. An example is Silicon based photomultipliers, which have been brought to maturity through the demands of a calorimeter for the ILC. Today they are applied even in medical physics. DESY encouraged this development by establishing a group of young investigators. Vertex detector technologies developed for the ILC find applications in other projects. Conversely, the extremely active and fast moving industry contributes new technologies, which then find applications also as detectors in particle physics.

Many of the technologies need many years to mature and to be fully characterised. A strong and long-term detector effort therefore is considered essential for a laboratory like DESY. The activities proposed in the following sections are selected in a balance between technological interest and relevance, and the particular strengths of a laboratory like DESY. Developments which needs significant infrastructure, and which need long and stable support are often difficult to realise at a university, and can be more easily done at a laboratory. Integration of different components, the organisation of collaborative efforts etc. are tasks where DESY contributes significant experience. For the linear collider this orientation is visible in the fact that DESY is participating in basic R&D for Silicon photomultiplier or vertex detector technologies, but is also
coordinating the LC-TPC test beam effort or the CALICE – HCAL test beam effort and installation.

**Vertex Detector**

The vertex detector at the ILC detector delivers high-resolution information about decay vertices and supplements the information from the main tracker on track parameters. Currently various candidate technologies are being investigated for an ILC vertex detector, of which none has reached the maturity for a proposal.

A major challenge over the next few years will be to advance as many technologies as possible to a point where a complete ladder can be built to ILC specifications, and to define and setup a procedure to compare the different technologies under well defined conditions. DESY as an institute which has experience in silicon detector construction (e.g. at the HERA experiments), but which has no strong connection to any single technology, can support and coordinate this effort, leading eventually to a reduction of the number of technologies, and possibly the selection of a baseline technology.

As part of and integrated into the activities of the HGF Alliance Detector laboratory DESY can support the development of many of the central services needed to eventually operate the detector. Examples are powering and cooling schemes, which have to be an integral part of any design from the very early stages.

**Tracking Detector:**

Over the past few years DESY with partners of the LC-TPC collaboration has constructed a large TPC prototype. This detector can be operated with different readout systems, and is designed to fit inside a large bore superconducting magnet available at the test beam at DESY. By the start of the HGF funding cycle in 2010 it is expected that this prototype has been exposed to a first series of test beam experiments, scheduled for late 2008 and 2009, and that results from this first round of measurements are available. Subsequently the existing prototype will then be equipped with readout systems of increasing sophistication. Major goals are:

- Design and operation of a readout module with significantly reduced material. While current systems contribute around 30% of a radiation length, this should be reduced to less than 10%.
- Design and operation of a silicon based endplate with fine-grained pixel readout.
- Design and construction of readout electronics, which can be integrated into the endplate, including cooling and auxiliary services such as testing, calibration and alignment.

As part of this effort, the large prototype might be moved to a hadronic beam facility after 2010, either at CERN, or at Fermilab, depending on availability and other external conditions. This would allow also the more detailed test of the response of the system to a hadronic beam environment, the test under high-rate conditions, and the experimental verification of the particle identification capabilities of the TPC.

DESY will participate in the CERN based RD51 initiative, aiming at advancing the state of micro-pattern gas detectors. In close cooperation with RD51 new developments of these basic detectors will feed into the plans for the large prototype, and will influence the detailed research plans.

**Hadronic Calorimetry**

During the past three years a prototype of a hadronic calorimeter, large enough to fully contain hadronic showers at energies of up to 100 GeV, has been designed and built at DESY in an international collaboration. Together with a prototype of a sampling electromagnetic calorimeter and a muon detector, this prototype has been exposed to particle beams first at CERN, and since 2008, at Fermilab. With this prototype the fundamental operation of a large-scale tile based sampling calorimeter read out with Silicon based photomultipliers has been established, and the basic performance parameters have been validated. The analysis of the large body of
data collected through 2008, and, in a different configuration, during 2009, is expected to continue until the end of 2009 at least.

By the beginning of the next funding cycle in 2010, the design of the next generation of test modules should be advanced enough that a decision on the construction of a realistic prototype module can be taken. Different from the current prototype, the next generation module will be designed with real space considerations in mind, integrating the readout electronics into the sensitive layers, and with a realistic mechanical structure, including realistic support structures, dead zones, and other imperfections.

For the next years the design of the module is scheduled, together with the construction of small-scale mechanical and electrical prototypes, which will demonstrate the feasibility of the design. This work is in part financed by the European Commission within the EUDET programme. After 2010 construction of a full module could then proceed, equipped with a large enough set of sensors to fully contain again a hadronic shower. This module would then be exposed to beam, to study its performance, and to validate the basic design.

After a roughly two years construction period, this module could become operational towards the middle of the next funding cycle, and could be a cornerstone of an integrated test beam experiments, described later in this document, to demonstrate experimentally the feasibility of particle flow at a lepton collider.

**Forward Instrumentation**

The forward region in the detector at the ILC is rather special. A good detection system is needed for many physics channel to make the detector as hermetic as possible. On the other hand the very complex geometry of the interaction region with two beams crossing at a small angle, and the large beam induced background rates make this a very difficult region for experimentation. At DESY the design of the two detector systems closest to the beam in the forward direction, the LumiCAL and the BeamCAL, are studied. A major focus of the development is the search for appropriate sensors, which are radiation hard and at the same time, offer enough granularity to reach the performance goals. In an international collaboration a design for the two devices is being developed. Over the next few years the design should have matured enough, including a high speed compact readout system, that a concrete proposal can become part of the detector proposal scheduled for 2012. To reach this goal, the following steps have to be taken:

- production and test of sensors with appropriate pad structure
- design and production of an integrated readout chip for approx. 100 channels
- development of a high speed optical readout system
- performance studies in a test beam

After having established the fundamental performance a prototype calorimeter is scheduled to be designed and built during the remainder of the funding cycle, and should be available for extensive beam tests by 2014.

**Software**

An important part of the design work of a detector at a future large facility is a powerful software system, which allows physicist the easy access to simulated data, and which allows the flexible simulation and study of different detector models. DESY together with SLAC has developed a rather generic data model for Linear Collider studies, which is in use around the world by most groups involved in these studies. Built upon this model, DESY has developed a modular analysis framework, which is used to develop a full suite of reconstruction software, and which is currently being used as a basis for a rather major production of simulated event files, which will be used in the ongoing detector optimization.

Over the next years, the framework will be continuously improved and adapted to the needs of the user. On the scale of the next finding cycle, an in-depth review of the software will be done, and the underlying design will be adapted to latest developments in software development. This primarily concerns the input output system which is currently being used, and which lacks many
features. Over the next few years studies will be done to implement a more modern underlying IO system, without impacting the existing large base of developed software packages.

An important and central issue of the simulation of detector is the management of the geometry information for the detector. At the moment no coherent geometry source exists, which allows the consistent detector description in simulation, reconstruction, and eventually CAD based design. It is planned to study the possibility to extend the current geometry model to a more complex and powerful system, which will be able to answer to the needs of the different user communities, and at the same time allow the consistent description of the detector. This work is foreseen in cooperation with the DESY computing groups, and with groups from CERN.

**ILD: a detector concept at the ILC**

Over the last year the international community has started an initiative to develop integrated detector concepts for the ILC. While such efforts have been ongoing locally for a long time, it is only now that they have reached a certain international recognition, and that a clear time line has been developed. By the time the next finding cycle will start, the concept groups will have delivered letters of intent (LOI) to the ILC management, in which the outlines of the proposed detector concepts are elaborated. These LOI’s are due in March of 2009. They will then be evaluated by an international advisory group (IDAG).

DESY participates in the ILD concept group. The ILD concept is based on the mostly Asian GLD detector concept, and the LDC detector, which has been developed based upon the TESLA project in Europe. DESY is playing a central role in this detector group, both by contributing to the organization of the study, and by participating in a significant way in performance studies of the proposed detector.

By 2010, the ILD concept should have been evaluated by the IDAG. If this evaluation has been passed successfully, ILD will then study in more detail the performance of the proposed detector, based upon simulation studies, and investigate the engineering of this large facility. The latter aspect is particularly important since the proposed design of the ILD calls for two detectors sharing one interaction region in a push-pull configuration. This setup puts very stringent and novel requirements on the overall engineering, which may in the end define how well the detector as a system can perform. A careful and complete engineering study is needed and planned for the first part of the next funding cycle, to answer whether or not push-pull is feasible. In step with the proposed time line for the ILC accelerator project, the concept will be developed into a full proposal by 2012, to be submitted to the international funding agencies.

To reach this goal, a coordinated effort is needed to address the most pressing engineering questions. This requires detailed engineering of the different sub-systems, but also a realistic study of the integration of the sub-systems into a complete detector.

**Accelerator programme**

**Preparing the accelerator technology**

The HEP accelerator programme at DESY will address the readiness of the ILC and in particular its operation at the highest gradients. As LHC results become available the ILC project is ready to pass the acceptance test in the global community as is expected from the current understanding of physics. With such a favourable decision DESY will be a strong partner in and contributor towards the realisation of the project independent of its location.

In the meantime DESY operates FLASH as a user facility for VUV research, which can provide valuable feedback on SRF electron linac operation. There is thus considerable interest both from user interested in high intensities, from XFEL and from the ILC to establish the high-current operation mode at the highest gradients for FLASH. High current operation is mandatory for the ILC in order to attain the advertised luminosities. An international working group has been established that eventually operate FLASH under presently extreme conditions with 1 ms long bunch trains consisting of 3000 bunches of more than 1 nC charge. Under these conditions the source, the transport systems and the power distribution are put under strong demands. The low-level RF system (LLRF) will employ feedback systems to control the distribution of RF power and phase to enable smooth operation and beam transport – a key requirement for the XFEL and ILC.
Pushing the SRF cavity gradient

Over the course of the funding cycle the XFEL will mass-produce some 800 cavities for use in the electron linac of the XFEL facility. These cavities and their production cycle are largely identical to the anticipated production scheme for the ILC with the exception of the lower gradient specification. It is the goal of the high gradient programme to develop a processing method that is compatible with the XFEL production goals and cost and reaches operational gradients of 31.5 MV/m reliably and reproducibly. Such gradients have been multiply established in prototypes. However, the production method itself is not yet sufficiently characterized to guarantee the high gradient at high yield.

Recently a new optical inspection system has been developed by the University of Kyoto and KEK (Japan) to investigate the inner surface of a 9-cell cavity structure. A second prototype of that camera is now at DESY and will be used to characterize the surface structure and defects with the hope to establish a correlation with cavity breakdowns localized from a temperature profiling methods. The optical inspection can be applied to the warm cavity and is thus expected to provide much faster feedback on the quality of a given cavity.

In more general terms, the high gradient programme aims at defining and controlling the production parameters for Niobium cavities such that the ILC requirements can be fulfilled. Corresponding measures are being implemented. This feedback will be made available to industry such that the quality standards are established at the origin of the cavities. With the success of this programme the XFEL profits from the availability of a large number of cavities with sufficient operating margin and the option to go to smaller wavelength by increasing the energy of the beam in the undulator.

This activity will be supported by the ILC-HiGrade programme.

Positron source and polarisation

The positron production scheme foreseen for the ILC has only recently been demonstrated in a test experiment at the end of the SLAC linac: a high-energy electron beam is run into a short wavelength helical undulator to generate circularly polarised multi-MeV photons. The photons are subsequently converted in a thin target to polarised positrons, which are then captured. Regarding the physics potential of lepton colliders, polarisation of both beams and flexible spin manipulation are most valuable. DESY physicists have participated in these measurements and demonstrated both the production yield of the positrons and their polarisation.

The scheme will be used in the ILC. A 4 m prototype of the helical undulator has been produced in England. The ILC requires 100-200 m helical undulator to satisfy the intensity needs. The target has to be laid out as a water-cooled, rapidly spinning spoke wheel to distribute the heat load. DESY scientists have calculated the expected energy deposits and radiation doses. With this knowledge it is possible to design capture and to pre-acceleration sections after the target.

DESY plans to continue the research on the efficiency of the target and capture section to improve the overall positron yield. At the same time the positron polarisation can be increased to levels exceeding 60% by collimation of either the photon beam before it hits the target or by collimation of the emerging positron beam.

Polarisation transport from the source to the interaction region has been a special interest of the DESY groups in the past. It is planned to continue these activities in the framework of the Positron Source Collaboration. Both analytical calculations and detailed Monte Carlo simulations will be carried out which is possible since recently polarisation has been implemented in the Geant 4 code.

Polarimetry

The final precision of many measurements depends on a precise knowledge of the beam parameters of the collider. Among the most important ones is the degree of polarisation of the lepton beams, initially only electrons, eventually both electrons and positrons, in the interaction region. This is done with a dedicated polarimeter, which has positions both upstream and downstream of the interaction point. Two polarimeters are needed since in the interaction and in
the transport of the beams from the location of the polarimeters to the interaction point the
degree of polarisation might change slightly.

DESY contributes decisively to the polarimeter design and draws heavily from the experience
acquired during many years of running of polarimeters at HERA and from the SLD polarimeter
operated at SLAC in the 1990ies. The ultimate precision to be obtained at the ILC however is
significantly better than what has been previously achieved, thus requiring significant
development work. This work includes the design of the setup used to measure the polarisation
– both the machine related aspects as well as the detector related aspects – and the
development of appropriate detectors and analysis strategies to reach the desired precision.

The know-how obtained in this work will be very valuable for other applications, e.g. for the
CLIC concept, or at other lower energy lepton accelerators.

**Beam Dynamics**

DESY has engaged in accelerator systems development in the past, most notably recently
through the EUROTeV programme. EUROTeV will end 2008 and the resources are not
available to contribute to the understanding of damping rings, beam transport and stability
requirements at the same level and the same breadth – a work that has to be taken over by ILC
groups abroad.

DESY has developed a high level of competence in beam simulation codes, in particular the
Merlin C++ environment, which is used by physicists in other laboratories. DESY will seek to
support this activity both for the German universities and the larger accelerator community by
providing “system level support” for the usage of the code. The scale of that activity largely
depends on available funds.

**Novel particle accelerator schemes**

With the emergence of physics results from LHC the HEP community will be challenged to
decide on the parameters of the next project. Given the solid physics case for the ILC DESY
rests its policy on the rapid realisation of the ILC in the next decade.

Should nature choose not to comply with these expectations the CLIC concept may come to
bear or truly novel acceleration concepts will be demanded. Among the novel concepts two
approaches have shown spectacular gradients in a small setup: plasma wakefield acceleration
and laser based acceleration in dielectrics or nano-scale structures. Key experiments have
been carried out at Berkeley, SLAC, Paris and MPI Munich. The SLAC experiment
demonstrated energy doubling by transferring via a plasma the energy of the head of the bunch
to the tail at incident energies of almost 50 GeV.

It would be premature to engage in these activities with a large experimental programme.
Nonetheless DESY foresees to explore novel acceleration technologies towards the second half
of this funding cycle in order to be ready to eventually launch a new exploratory experimental
programme in accelerator research, should the need arise. Such an activity will be imbedded in
the Helmholtz Alliance “Physics at the Terascale” and will be implemented in close collaboration
with German institutes. For this funding cycle it is foreseen to carry out initial simulation studies.

### 2.3.4 Expected results, milestones

The overarching goal of the accelerator programme is to seek readiness for implementation of
the International Linear Collider. The current timelines for an implementation of the ILC span the
Technical Design Phases I and II of the GDE i.e. from now to 2010 and then on to 2012. The
latter date is the target for presentation of the machine design for scrutiny and approval.

The most prominent contribution of DESY will be the development of an industrial process that
provides high-gradient SRF cavities at acceptable yield. DESY is closely collaborating with the
KEK laboratory and several US institutions to achieve this goal.

DESY will also contribute to the refinement of controls system, in particular of the demanding
LLRF control. For the polarised positron source DESY will contribute to an optimized design and
fully engineered positron source. This work will be pursued in an international collaboration, in
particular with partners in the UK.
The FLASH facility provides an excellent testing ground for the performance of the accelerator under beam loading and with parameters similar to those of the ILC.

Starting from the review of the experimental programme in 2009 a solid and viable experimental programme for the ILC will be defined, and substantiated by appropriate prototyping and testing work. The technologies pursued by DESY will make the transition from experimental technologies to mature technologies, which can be proposed for a realistic and fully costed detector. Major milestones will be the construction and operation of a generation of engineering type prototypes, and the integration of these prototypes into an overall detector concept with help of the ILD project office, in international collaboration.

Scientifically major progress is expected during these years. On a technical side, particle flow as a viable reconstruction scheme for the ILC will have been established and experimentally verified by 2014. Maybe most important though will be that first results from the LHC will become available during this cycle. Its interpretation will play a major role in the definition of the linear collider, or, more generally, for the future of this project as a whole. Through its participation in both the ILC and the LHC projects DESY is in a strong position to participate centrally in the process, and to help shaping the future of particle physics.

DESY’s role and mission
The accelerator and detector plans at DESY are well aligned with the global plans and developments in the field. DESY makes available the tools and infrastructure as required for the experimental progress. The tasks tackled are often much too large to be supported by an individual university. The lessons learnt in these activities serve to provide the technological base for the decisions on the future directions of particle physics.
2.4 Theoretical Particle Physics

Spokesperson of the topic: Volker Schomerus

Contributing centres: DESY

Personnel (2010)\(^4\):
- 28 scientists,
- 8 doctoral students,
- 2 scientific support personnel

Contributing principal investigators: Wilfried Buchmüller, Rainer Sommer, Jörg Teschner, N.N. (successor Peter Zerwas).

YIG: Laura Covi, Sven-Olaf Moch.

Topic costs 2010: 3,427 M€

2.4.1 Challenges

Relevance

The central themes in current theoretical particle physics are the investigation of non-perturbative features of the Standard Model and the exploration of possible avenues to shorter distances beyond the Standard Model. The latter activities are dominated by the ideas of supersymmetry and unification, which are supported by the symmetries and the particle content of the Standard Model, the amazingly precise unification of gauge couplings in its minimal supersymmetric extension, and the smallness of neutrino masses. Unification with gravity can then be achieved in the framework of string theories. Lattice gauge theories and string theories provide important techniques to treat non-perturbative aspects of non-Abelian gauge theories, which are responsible for confinement in QCD, properties of the strongly coupled quark-gluon plasma, masses and couplings of hadrons needed in flavour physics, the electroweak phase transition and baryon and lepton-number changing processes in the high-temperature phase of the Standard Model.

The LHC will open up the new territory of TeV scale physics, where the onset of new physics is expected. In particular, the mechanism responsible for electroweak symmetry breaking that is ultimately related to the understanding of the origin of the masses of all elementary particles will manifest itself at the TeV scale. It may give rise to one or more new elementary scalar particles, the Higgs bosons, to a new kind of strong interaction or to other possibly unexpected phenomena. Furthermore, it is expected that experiments at the TeV scale will be sensitive to effects of new physics contributions that stabilise the huge hierarchy between the weak and Planck scales. Prime candidates for physics beyond the Standard Model (SM) are supersymmetry, which postulates a symmetry between fermions and bosons and embeds space-time into a "superspace", or additional dimensions of space, which may either be very small or even infinitely large.

The well-established standard models in particle physics and cosmology will also be probed by new experiments in astroparticle physics. New results from satellite experiments, including FGST, PAMELA and PLANCK, will provide crucial information on the composition of the cosmological energy density, and the distribution and properties of dark matter in the universe, possibly related to supersymmetry. Many theorists hope that new results from collider and satellite experiments will allow us to identify the nature of dark matter within the next few years.

\(^4\) The figures given here for scientists and scientific support personal reflect FTE from DESY only, see 1.4.
Challenges
The central themes in current theoretical particle physics and the experimental particle physics programme at DESY determine also the programme of the DESY theory group: physics at the LHC, a future electron-positron linear collider and HERA. A crucial part of these activities is the interplay between particle physics and cosmology and the development of new tools for the investigation of non-perturbative phenomena based on lattice field theory and string theory.

On the phenomenological side, the complexity of the LHC data is a particular challenge. The interpretation of experimental signals in terms of new physics requires the control of standard model processes with very high precision and close collaboration between theorists and experimentalists. Expertise in particle physics, astrophysics and cosmology will be needed to make use of all data, which are relevant to solve the dark matter puzzle. Knowledge about the phenomenology of physics beyond the standard model as well as supersymmetry and grand unification are the basis for attempts to embed the standard model into string theory. Last but not least, advanced methods and high-performance computing are required to evaluate hadronic observables with controlled errors.

Particle physics in the next decade requires broad research in theory, including collider physics, cosmology, string theory and lattice gauge theory. Also important is the training of graduate students and postdocs. To meet these challenges, a number of key initiatives are envisaged for the next funding period:

• Strengthen collider phenomenology with a leading role in the Analysis Centre of the Helmholtz-Alliance in Hamburg and Zeuthen.
• Install new Junior Research Groups at the interface of main current research activities.
• Maintain activities in particle cosmology at current level after VIPAC phase-out.
• Continue to develop the “Zentrum für Mathematische Physik (Hamburg)” as a leading interdisciplinary centre for mathematical physics and string theory.
• Maintain the position of Zeuthen as a leading centre for research and training in lattice field theory (NIC and theory group) and precision collider phenomenology.
• Develop a centre for Theoretical Physics with Hamburg University as one component of a new particle physics cluster in Hamburg.

The planned new activities in theoretical astroparticle physics will further enhance the current interactions between particle and astroparticle physics at DESY.

2.4.2 Current activities and previous work
The DESY theory group, in collaboration with local universities and the particle physics group of the John-von-Neumann Institute for Computing (NIC), pursues a vigorous and broad research programme which rests on four pillars: collider phenomenology (Hamburg, Zeuthen), particle cosmology (Hamburg), lattice gauge theory (Zeuthen) and string theory (Hamburg). The group’s dual strategic role is characterized on one hand by its contributions to the particle physics programme of DESY. On the other hand, through its post-doc/guest programmes and the organization of various scientific events, the theory group provides a service to German particle physics and represents a leading centre for theoretical physics in Europe.

Through its research activity in collider phenomenology, the theory group is deeply rooted in DESY’s long term particle physics programme. In particular, it plays a key role in the analysis centre of the Helmholtz Alliance. Central research topics in collider phenomenology are QCD and standard model processes at HERA and the LHC, Higgs physics and supersymmetry at LHC and ILC, and precision predictions for colliders, including novel tools for perturbative computations using massive computer algebra. In the area of particle cosmology, current activities concern the matter-antimatter asymmetry, in particular leptogenesis, dark matter, inflation and cosmic neutrinos. Closely related are studies of very weakly interacting ‘hidden sector’ particles and work on phenomenological aspects of grand unified theories (GUTs), as well as their embedding into the heterotic string. Non-perturbative dualities between (supersymmetric) gauge theories and string theory are the main theme of the string group. Research
Planned programme topics

includes the high-energy limit of QCD and properties of strings in Anti-de-Sitter spaces. The lattice field theory groups at NIC/DESY develop advanced technology for non-perturbative computations in QCD, effective theories and the Higgs sector of the Standard Model with applications to precision calculations for phenomenology and to strong interactions in the Higgs sector.

Thereby, the scientific programme of the theory group ranges from (supersymmetric) standard model physics at present colliders to the description of new physics, both at future colliders and in cosmology. Developing (universal) computational methods is a second important aspect of the group’s profile. From conventional perturbation theory, over precision calculations to the most advanced tools in non-perturbative studies (lattice gauge & string theory), the toolkit includes all technologies that are relevant in today’s high energy theory.

Over the past decades, the DESY theory group has developed a vivid and highly successful collaboration with the local universities in Hamburg, Berlin and Potsdam. Currently, many joint research projects are supported by the Sonderforschungsbereich 676 “Particles, Strings and the Early Universe” and the Transregio 09 “Computer-gestützte Theoretische Teilchenphysik”. The benefits of the interaction are mutual. On one hand, the well-matched research activities at the local universities are vital for DESY’s theory group in sustaining its very broad research programme that covers all aspects of modern particle physics. More specifically, the research groups in astroparticle models, QCD, mathematics and string phenomenology at Hamburg University, and the research groups in lattice gauge theory and phenomenology at Humboldt University share many interests, run common workgroups, seminars and colloquia. On the other hand, staff members of the DESY theory group contribute significantly to teaching activities, in particular at graduate and postgraduate level. With frequent lectures on advanced topics in particle physics, the organization of national and international schools/workshops (see below), and by advising numerous graduate students, DESY plays a key role in creating a unique and widely recognized training centre for theoretical particle physics in Europe. On the more advanced level, the theory group sustains a very active and highly competitive fellowship programme. Among postdocs from around the world, the theory group is highly appreciated for its timely research profile, the close interaction between its different branches and with the experimental programme. Former postdocs and junior staff members of the theory group can be found in particle physics research groups all over Europe and beyond, where many of them hold key positions. Through all these activities, the group contributes significantly to shaping theoretical particle physics in Germany and it has a substantial impact abroad that is only matched by a small number of other European institutions in the field.

The DESY theory group is part of several existing networks, which cover all aspects of the current research and shape the group’s national and international interaction. These include the

• SFB Transregio 09 “Computergestuetzte Theoretische Teilchenphysik”, DESY Theory contributes to 5 projects,
• Coordination of European Collaborations in LQCD; ALPHA & ETMC-collaboration.
• Virtual Institute for Particle Cosmology, with Bonn U, Heidelberg U, LMU München,
• “Zentrum fuer Mathematische Physik” with Hamburg U, bi-weekly colloquium, visitor programme, 2-3 workshops/year,
• SFB 676 “Particles, Strings and the Early Universe”, DESY Theory contributes 7 projects
• Management of German nodes in EU training networks: HEPTOOLS, FLAVIANET.
• John-von-Neumann Institute for Computing (NIC). DESY Theory contributes a particle physics research group, computing resources, SFB participation (TR-55).

A close cooperation with the new “Institute for Physics and Mathematics of the Universe” in Tokyo is planed. The theory group also organizes and hosts a large number of regular conferences, schools and workshops, e.g. the annual DESY theory workshop, the conference “Loops and Legs”, the “String Steilkurs”, the school “Lattice Practices” and “Computer algebra &
Particle Physics”. During the last 5 years, the group hosted a total number of 11 international conferences, 20 workshops and 7 schools.

A few highlights of the past research illustrate the broad activities of the theory group. In the area of collider physics, precise predictions for important processes in the Standard Model and in various extensions of it have been obtained and state-of-the-art methods for multi-loop and multi-leg processes have been developed. Outstanding results are the computation of the complete perturbative QCD corrections to next-to-next-to-leading order for the evolution of parton distribution functions of the proton. These are needed for precision analyses of HERA data and indispensable for predictions of the parton luminosity at LHC from global analyses. Precise QCD corrections to structure functions in deep-inelastic scattering have also been employed in an extraction of the strong coupling constant at an unprecedented accuracy of 1%. Research for the ILC has led to the complete next-to-next-to-leading order QED corrections to Bhabha scattering establishing an accuracy of 1 per mille (or better) for precision luminosity measurements at electron-positron colliders and meson factories.

Theoretical work done at DESY has also played a key role for the determination of the CKM matrix, through state of the art predictions of higher order contributions to flavour-changing-neutral-current processes (rare B-decays, neutral meson mixings). Furthermore, influential results on minimal flavour violation were published.

In the area of cosmology, it has been shown that unstable gravitinos can provide a consistent cosmology including leptogenesis, primordial nucleosynthesis and dark matter, with specific predictions for LHC and satellite experiments. In the framework of orbifold compactifications a consistent embedding of the supersymmetric standard model into the heterotic string has been obtained.

The area of lattice gauge theory could, for the first time, develop a complete strategy for treating b-quarks on the lattice with control of all systematic errors. Based on finite size scaling technologies, this will allow for high precision B-physics computations. Furthermore, a detailed investigation of the advantages of the twisted mass formulation of lattice QCD has resulted in the formation of a large European collaboration, ETMC, addressing many aspects of QCD starting from this formulation.

Finally, the new string theory group, with leading expertise in particular on curved string backgrounds, has been successfully installed. Recent applications include the study of time dependent backgrounds and the first construction of string theories in (lower dimensional) Anti-de Sitter geometries. These activities were awarded a Marie-Curie excellence grant.

2.4.3 Contents and goals
The following section shall discuss the four main topics separately. Their embedding into the unifying blueprint of the theory group was explained in the previous section. Some of the specific interrelations will be pointed out as we proceed.

Collider Phenomenology
The goals stated below are part of the programme of providing theory support for the Analysis Centre. They will involve a close interaction between theorists and experimentalists.

While the high energy reach of the LHC will allow the exploration of TeV scale physics, the LHC experiments are significantly more complex than any previous particle physics experiment. Identifying the nature of physics at the TeV scale will require intense collaborative efforts between experimentalists and theorists. On the theoretical side, high-precision calculations of SM processes are needed to distinguish possible signals of new physics from SM backgrounds. Possible hints of new physics need to be compared with different models of physics beyond the SM, taking into account the possibility that new physics could manifest itself in unexpected ways that go beyond our present imagination. With its expertise in all areas of particle physics and its close links to the Analysis Centre and to the experimental groups at DESY and the University of Hamburg, the DESY theory group is ideally placed to take a very strong role in the exciting enterprise of unveiling the nature of physics beyond the SM.
In the first phase of LHC data taking, the primary goal will be to understand Standard Model physics before any discoveries of new effects can be made. Precise predictions will be worked out for processes that will ultimately be used as "standard candles" for the luminosity determination at the LHC as well for processes that can serve to determine the jet energy scale and, at a later stage, to measure the parton distribution functions at the LHC.

The correct identification of signals of new physics at the LHC requires precise theoretical predictions for both signal and background processes. While quantum effects of the strong interaction have been intensively studied for signal processes in some BSM scenarios, electroweak quantum corrections can also be very important. Precise predictions involving both types of corrections will be obtained, and the remaining theoretical uncertainties for the relevant processes will be quantified. Since most of the interesting signals at the LHC have backgrounds involving multi-particle final states, for these processes an accurate modelling of the strong interaction, of SM-type electroweak corrections, but also of possible new physics contributions will be carried out. In fact, the main background for determining the properties of supersymmetry at the LHC would most likely be supersymmetry itself.

In order to achieve the above goal, new methods and algorithms for multi-leg and multi-loop processes in the Standard Model and beyond must be developed. This will be pursued in a model-independent approach, making extensive use of computer algebra tools. An outcome will be numerical programmes, which can be used by the experimentalists at the LHC to help analyse and interpret the data. It is planned to not only develop these theory tools for experimental analyses, but also to provide long-term support.

Data from HERA plays a key role for validating theoretical tools for the LHC, especially in the sector of strong interactions, which are considerably more complex in pp than in ep interactions. Furthermore, HERA data remains a key input for the determination of precise parton densities, until the LHC will eventually be able to improve this precision. The close connections of the DESY theory group with HERA experimentalists are a major asset for providing support in the ongoing analysis of data from the high-luminosity HERA run 2, so as to maximise the impact of these data on physics at the LHC.

A particular focus of the investigations at the LHC will be on possible manifestations of the electroweak-symmetry-breaking mechanism. This will involve predictions for relevant observables that probe the Higgs sector of the SM and its extensions and that could ultimately be used to distinguish between different possible mechanisms of electroweak symmetry breaking. In particular, the aim will be to obtain improved theoretical predictions for Higgs boson production processes, decay rates and transverse momentum distributions, including strong and electroweak corrections and taking into account CP-violating effects. In this context also the phenomenology of more exotic models of new physics will be studied, for instance mixing of the Higgs boson with the radion, a state predicted in models with large extra dimensions. The interplay of the Higgs sector with other sectors in new physics scenarios will be analysed, for instance Higgs boson decays into supersymmetric particles or other new states as well as the decays of new particles into Higgs bosons.

Strategies for identifying the nature of new physics and for precisely determining its underlying structure will be developed. Extracting properties of new states, for instance couplings, spin and CP properties, from the LHC data will often require certain theoretical assumptions concerning the properties of the new states, their mass hierarchies, etc. The goal is to interpret possible signals of new physics with as little model assumptions as possible. The results obtained from the LHC data in this way, which will be incorporated as they arise, will be confronted with different models, taking into account information from the flavour sector, from experiments performed at lower energies, as well as implications from cosmology. These analyses will be crucial on the way to establish a particular scenario of new physics, to decipher its underlying structure (in the case of supersymmetry, for instance, to determine the supersymmetry-breaking mechanism) and to reveal the possible nature of candidates for dark matter in the universe.

Once the energy scale of new physics is identified, this will lead to a strong effort in planning and designing the next generation of particle physics experiments. In this context the possible
interplay will be studied of results obtained at the LHC and at future facilities, such as an electron-positron linear collider or an electron-proton collider (making use of the LHC proton beam).

**Particle Cosmology and Unification**

The interface of particle physics and cosmology has rapidly gained importance during the past decade. Current activities concern several central questions of this field: matter-antimatter asymmetry, dark matter, inflation and cosmic neutrinos.

Detailed studies have been carried out on the connection between neutrino properties and matter-antimatter asymmetry for baryogenesis via leptogenesis. In the next years, conceptual and quantitative aspects of leptogenesis will be studied in detail with the goal of achieving a full quantum mechanical description of baryogenesis. Constraints on neutrino masses and mixings from leptogenesis are relevant for the experimental neutrino programme in Hamburg and Zeuthen. Inflation, a likely phase of the early universe before baryogenesis, provides a successful description of the cosmic microwave background data. However, many conceptual problems are still unsolved. Future activities at DESY will concern in particular the embedding in supergravity and string theories (see String Theory).

An attractive dark matter candidate is the gravitino, the superpartner of the graviton. At DESY a model for quasi-stable gravitinos has been developed which leads to a consistent cosmology including leptogenesis, primordial nucleosynthesis and dark matter. In the near future several predictions of the model will be tested at LHC and by the FGST satellite. Several implications of decaying gravitino dark matter, including anti-proton flux, still have to be worked out. Also important are signatures at LHC and ILC for various next-to-lightest superparticles, such as scalar tau-lepton, scalar top, scalar neutrino, higgsino (see Collider Phenomenology). Several phenomenological analyses are currently being carried out by experimental groups in Hamburg and Zeuthen.

In the next decade, a number of increasingly sensitive detectors for ultra high energy cosmic rays (Pierre Auger Observatory, IceCube, ANITA) will be operated, enabling the detection of extremely energetic cosmic neutrinos via neutrino-nucleon scattering. With these detectors, the era of extragalactic neutrino astronomy may start. Observation of these neutrinos would provide an opportunity for particle physics even beyond the reach of the LHC. The DESY theory group will continue to study particle physics implications as well as astrophysical and cosmological aspects of these cosmic neutrinos (see Collider Phenomenology).

The symmetries and the particle content of the standard model, and in particular the unification of gauge couplings in its supersymmetric extension, point towards grand unified theories (GUTs). Together with gravity, GUTs can be embedded into string theory. This leads to predictions for cosmology and particle physics, such as the existence of new very heavy, or very light particles.

At DESY, unified theories in six dimensions have been studied as an intermediate step between the standard model and the heterotic string (see String Theory). It has been shown that this leads to a successful phenomenology of quark-lepton Yukawa couplings, with specific features in the neutrino sector and characteristic predictions for proton decay. In the next years detailed studies will be carried out concerning the stabilization of the extra dimensions, cosmological effects of the corresponding moduli fields and the possible patterns of supersymmetry breaking.

A characteristic feature of standard model embeddings into string theory is the prediction of a ‘hidden sector’ of particles, which have only very weak interactions with ordinary particles. At DESY it has been demonstrated that in the context of specific, semi-realistic string compactifications some of the hidden sector particles may be very light, with masses in the sub-eV range, and that their interactions with the standard model particles, in particular through kinetic mixing with the photon, may be sizeable. These studies of the mass spectrum in the hidden sector and the kinetic mixing with the visible sector will be continued and extended towards realistic compactifications of the heterotic string (see String Theory). The laser experiment ALPS at DESY has a considerable discovery potential for light hidden sector
particles. The theory and phenomenology of light very weakly interacting particles will be further developed in the next years.

**Lattice Field Theory**

The lattice field theory groups at DESY and NIC play a most important and visible role in the world-wide lattice community through their development of advanced methods, computational strategies and algorithms for non-perturbative field theories. They are intimately connected with the University groups in Germany and several other European countries; three European collaborations (ALPHA, ETMC and QCDSF) are coordinated from Zeuthen. Their present emphasis lies on algorithms for simulation and analysis of QCD including two generations of sea quarks as well as applications relevant for experiments from HERA to LHC and Super-B factories.

The physics projects require computing resources at the forefront of supercomputing. Following the recommendation by the Senate of the Helmholtz association, these resources are realized in coordination with the research field “key technologies”. Within the John von Neumann Institut for Computing (NIC), the cooperation between DESY, FZ Jülich and GSI, DESY groups continues to contribute to the development of efficient software and possibly hardware for lattice field theories. In the future the DESY contribution will be organized in a Simulation Lab for lattice gauge theories. It will build on the available expertise in computers and QCD algorithms to assist the German lattice community in an efficient use of special as well as commodity computers. Performance analysis for future installations as well as a continued development and support of the international lattice data grid are carried out by the simulation laboratory. It will further run small scale installations of high-end parallel computers for performance and algorithm studies as well as to support local smaller scale projects of students. In this respect as well as through the organization of workshops and tutorials it assists the German universities in educating students in high performance computing in lattice QCD. Given their organization as European collaborations, the DESY and NIC research groups will also contribute to and profit from the planned European initiatives for supercomputing.

Research focuses on a quantitative precise understanding of QCD in its non-perturbative domain (e.g. confinement, chiral symmetry breaking, low energy parameters, vacuum polarisation function) and on applications, which are relevant to precision phenomenology. The determination of fundamental QCD parameters ($\alpha_s$, quark masses) is carried out with the best control of systematic errors and will eventually yield determinations at the 1% level and for $\alpha_s(M_Z)$ with even higher precision. It will provide the input parameters for perturbative QCD and will yield an interesting comparison with the HERA analysis of $\alpha_s$, with obvious implications for many applications including the unification of forces.

A restriction of scenarios for physics beyond the Standard Model or possibly the discovery of new physics contributions can be achieved by combining high precision experimental data for decays of flavoured mesons with lattice computations of the relevant matrix elements. The impressive results of the B-factories and of the Tevatron will be significantly improved by LHC, LHCb and future Super-B factories. In order to match this precision, the lattice groups will study Kaon-, D- and B-meson decays with up to one hadron in the final state using advanced technologies such as non-perturbative Heavy Quark Effective Theory and finite size scaling developed by DESY and university partners. Linear lattice spacing effects will be absent in the used discretisations.

A computation of moments of twist-2, polarised and unpolarised nucleon structure functions with (close-to) physical quark masses will allow for comparisons to the HERA PDFs. Providing constraints on their parameterisations will be an important result of this project. Also the challenging singlet moments and generalized parton distribution functions will be investigated.

Triviality bounds and the width of the Higgs boson are studied in Higgs-Yukawa models with exact lattice chiral symmetry, which represents a formidable improvement of older results in the literature. Electroweak symmetry breaking, to be investigated at LHC and ILC, may turn out to be a non-perturbative phenomenon, for example in the form of walking technicolor. The lattice
field theory technology developed for QCD, once suitably adapted, will be essential for a theoretical study of such scenarios.

**String Theory**

As an interdisciplinary field of basic research, string theory currently addresses two distinct and fundamental problems of modern theoretical physics: The unification of all interactions, including gravity, and the physics of strongly interacting quantum field theories. Accordingly, two very different types of compactifications are being studied. In the context of unified theories, the 10-dimensional string background must be compactified to a 4-dimensional Minkowski or cosmological space-time. For applications to 4-dimensional gauge theories (without gravity), on the other hand, compactifications to 5-dimensional Anti-deSitter (AdS) geometries are relevant.

The fundamental parameter of string theory is the string length (or tension). Understanding stringy physics in compactifications with small length scales, in cosmological backgrounds or in strongly curved AdS spaces often requires treating the string length non-perturbatively. In applications of AdS compactifications to 4-dimensional gauge theory, the string length is directly related to the field theory (`t Hooft) coupling.

DESY’s string theory group has leading expertise, in particular in the non-perturbative treatment of the string length. Therefore it is in an excellent position to address some of the most profound problems in strongly curved or singular compactifications (i.p. phenomenologically relevant orbifolds, see also Particle Cosmology and Unification), in time-dependent backgrounds (i.p. cosmological space-times with big bang singularities), and in strongly curved AdS geometries (i.p. gauge theories at finite ‘t Hooft coupling, see Lattice filed theory).

Throughout the next funding period, the construction of string theory in AdS geometries along with applications to gauge theory will remain in the focus of the string theory group. Recent progress in the computation of non-protected quantities, such as anomalous dimensions and matrix elements, will be extended to the relevant 5-dimensional AdS geometry. In addition, the group has recently initiated the study of novel target space dualities for AdS geometries. Like the more conventional T-dualities of string theory, these are expected to provide new computational tools for non-perturbative effects in AdS backgrounds. The dualities will be investigated further in a 3-dimensional toy model and the 5-dimensional context that is relevant for maximally supersymmetric 4-dimensional Yang-Mills theory. Such target space dualities might also turn out to be a key ingredient in proving the equivalence between string and gauge theory. Part of this research will be pursued in collaboration with other members of Hamburg’s centre for mathematical physics (joint with Hamburg University).

Applications of AdS compactifications to 4-dimensional gauge theories, in particular to QCD and certain supersymmetric extensions thereof, have received enormous attention lately. They range from computations of the cusp anomalous dimension in supersymmetric Yang-Mills theory (as a function of the coupling) to the viscosity of a Quark Gluon plasma. DESY’s string theory intends to study novel (integrable) structures in perturbative gauge theory (see ‘loops and legs’ in Collider Phenomenology), e.g. implications of the newly discovered dual conformal symmetry. It is also planned to apply advanced methods of string theory (see previous paragraph) to the computation of scattering amplitudes. For some quantities, exact results are expected, at least in the planar limit. Special attention will be paid to the high energy sector of QCD, a topic that is pursued in close collaboration with the QCD group at Hamburg University.

### 2.4.4 Expected results, milestones

In the following we shall list the central results that are expected within the next funding period. If completion before the end of the funding period is expected, some earlier dates are given. Several of the expected milestones require collaboration between different research groups within DESY and with local universities.

The area of collider phenomenology will confront theory predictions with early LHC data in pursuit of possible manifestations of the physics responsible for electroweak symmetry breaking and for stabilising the gauge hierarchy. This will take into account information from the flavour sector, from experiments performed at lower energies, as well as implications from cosmology along. These activities will build on in-house expertise in precise determinations of parton
distribution functions at the LHC, in the calculations of scattering amplitudes for higher order radiative corrections of the strong and electroweak interactions for massive particle production (Higgs, top-quarks, W/Z-bosons, supersymmetric particles, ...), where application of new string theory inspired methods is envisaged (Collider Phenomenology/String Theory).

An important topic at the interface of particle cosmology and collider physics is the hypothesis of decaying gravitino dark matter. New data from the satellite experiments FGST and PAMELA and from the LHC will be studied with respect to the implications for the breaking of supersymmetry. In the area of unified theories string vacua with GUT structure, which contain the supersymmetric standard model, will be compared in different approaches (orbifolds, Calabi-Yau compactifications, F-theory).

In lattice gauge theory, realistic simulations of lattice QCD addressing a large set of observable with two generations of quarks close to their physical masses and with small lattice spacings and two different discretisations will lead to a control of systematic errors. In the years 2013-2014 the computation of the fundamental parameters of QCD and flavour physics matrix elements will reach a precision around one percent, including all sources of systematic errors, while twist-2, polarised and unpolarised non-singlet moments of parton distribution functions will be controlled at the 5-10% level.

The solution of string theory in 5-dimensional Anti-deSitter compactifications is one central goal of the string theory group. Implications for perturbative and non-perturbative gauge physics, such as e.g. manifestations of integrability and enhanced symmetries, shall be studied along with applications to the high energy sector of QCD (String Theory/Collider Phenomenology).
2.5 Experimental Facilities

Spokesperson of the topic: Ties Behnke
Contributing centres: DESY
Personnel (2010)\(^5\):
3 scientists,
0 doctoral students,
4 scientific support personnel

Contributing principal investigators: Ingrid Gregor, Isabell Melzer-Pellman (see also 2.2), Thomas Schörner-Sadenius (see also 2.1).

Topic costs 2010: 0.597 M€

2.5.1 Challenges

Relevance

DESY as a large research laboratory in Germany has in the past and intends to continue so in the future provided support for the construction of large and sophisticated detector systems, and supported analysis efforts for complex data. In the past this has been done so for experiments at the DESY accelerators, and thus filled naturally a role expected from the host laboratory for large infrastructures. In the future with no major facilities for Particle Physics operating any more on site, DESY will have to re-define its role and find new ways to efficiently support particle physics and the construction and building of large detector systems.

The construction of detector systems plays a central role in particle physics. It is central for the German programme that a strong capability of detector development and construction be in existence, and be maintained over long period. While at universities significant work has been carried out in the past and important contribution e.g. to the LHC experiments have been realised, it is difficult to maintain detector development and building facilities beyond the scope of individual projects. DESY as a research laboratory has a unique position to maintain and make available detector development and test infrastructures over long time, and carry over know how and facilities from one project to the next.

DESY in addition to its well developed general technical infrastructure has a unique test beam facility to offer to its users, offering three electron or positron beams of up to 6 GeV energy distributed into four experimental areas. Next to CERN which has beam facilities for even higher energies and different particles (hadrons, muon and neutrinos) DESY is currently the only laboratory in Europe which can deliver high energetic particles in the multi-GeV range.

Challenges

DESY sees its role in the development of a scientifically first class core group of people experienced in the development and construction of detectors, and in the provision of infrastructure resources, which are difficult or impossible to realise at a university. The people involved will need to be part of challenging and advanced detector projects, to attract top people to the laboratory and, with some fraction of their time, to support and operate the general infrastructure at the laboratory. The detector laboratory and the analysis centre setup in the context of the Helmholtz Alliance are examples of such constructs. Only with the end of the HERA experiments is DESY in a position to develop and provide a significant programme in this direction.

\(^5\) The figures given here for scientists and scientific support personal reflect FTE from DESY only, see 1.4.
2.5.2 Current activities and previous work

In the past DESY has supported collaborating institutions with the construction and the building of detector components. Large-scale production of components, and the coordination and integration of components built elsewhere into the final detectors have typically been done at DESY. During the operation of the large detectors DESY has supported the experimental groups in many aspects of detector operation, of maintenance, and of engineering support for the experiments.

Currently DESY is involved in active detector development projects for a future lepton collider, and for LHC detector upgrades.

For a future lepton collider, DESY has been the coordinator of major developments, like the CALICE hadronic calorimeter, and the combined test beam experiment, or the LC-TPC large prototype construction work. Through the EUDET programme DESY has developed and made available infrastructure for use at test beams, and managed and coordinated several test beam campaigns at DESY and at other laboratories. DESY makes available to external groups a number of infrastructure installations. It provides three electron test beams, which are in high demand among experimental groups. It offers other infrastructure like high field test facilities, and other installations. The well-developed infrastructure of shops and experimental facilities are available within the constraints of the DESY programme.

For the data analysis project, DESY has set up an analysis centre to support physicists from German groups on general data analysis issues and to ensure a leading role of German particle physics in the global context and a major share of the key physics results of the LHC. The analysis centre has the tasks of

- providing education and training for German particle physicists in analysis-related issues through schools, workshops, and seminars;
- providing user support in areas of general interest like MC generators, PDFs, statistics, software, and others;
- strengthening the collaboration between different institutes working on related analyses, between the experiments, and also between experiment and theory.

Currently, the analysis centre hosts three groups working in the fields of Monte Carlo generators, statistics tools, and parton distribution functions. So far the groups have already (or are about to) organize introductory schools into their subjects for Ph.D. students and young postdocs. With more than 100 participants and overall excellent feedback these events were a great success and confirm the attractiveness of an analysis centre at DESY.

In addition to these education events, the groups and their members have research programmes of their own, aiming at delivering significant contributions to the data analysis projects at HERA, the ILC and, chiefly, the LHC:

- The Monte Carlo group is focusing on the tuning and validation of Monte Carlo generators. In addition, the group is working on the development of new parton-shower models, the further development of specific generators like CASCADE, and the evaluation of PDF sets particularly suited for the use in Monte Carlo generators (the PDF4MC project).
- The Statistics Tools group is concentrating on the development of statistics tools necessary for successful data analysis at the LHC and their implementation in software frameworks.
- The PDF group activities build on in-house expertise in the analysis of DIS structure function data from HERA and on precise theoretical predictions for hard scattering processes. The group will also assist in the precision determination of the parton luminosity at the LHC.

The analysis centre and its groups are supported by DESY physicists working for the centre a fraction of their time. In addition, of four positions initially funded by the Helmholtz Alliance...
“Physics at the Terascale”, two are secured as tenure track by DESY and already filled (one to act as leader of the analysis centre, the other to support the Monte Carlo group). The future of the two remaining positions has yet to be decided.

2.5.3 Contents and goals

Test Beams at DESY

For many years DESY has operated three electron test beams. These beams have a limited energy of at most 6 GeV, but are well suited for the investigation of detector components, for the integrating of components with the DAQ systems, and for studies, which do not require a hadron beam. In the last year alone 10 groups from 11 countries have experimented at the DESY test beams, for a total of 6000 hours of beam time.

Supported by the EUDET programme and by the Helmholtz Alliance DESY has upgraded the three test beam lines. In one line a superconducting magnet and other infrastructure helpful for the test of tracking detectors has been installed. This beam line will be made available to the experimental community for dedicated tests of tracking detectors, starting in 2008. It will be first used by the LC-TPC collaboration, to do extensive tests on the large-scale TPC prototype under development. For this in addition to the magnet the area is equipped with a sophisticated movable table, a gas infrastructure, and a central slow controls system to easily monitor and control the installation. In addition the test beam area is going to be equipped with a remote control and monitoring system, which will enable groups to operate and supervise equipment in the area from remote, away from the DESY site.

Remote Control Centre

Increasingly experiments already during the development phase are planned and executed by international collaborations, spread over many countries and many continents. To make a shared development and shared test easier, the concept of the “Global Detector Network” has been developed. Through dedicated and safe connections, the control of an experiment can be done remotely, monitoring can be performed remotely, and discussions between partners are made easier even if not all partners are at one place. DESY is actively pursuing this remote control scheme. In 2008 a remote centre for the CMS experiment (see 2.2) and a remote control facility for detector development projects have been set up and put into operation. Their functionality will be expanded over the years and applied to other remote experiments.

The Virtual Laboratory for Detector Developments

For the Helmholtz Alliance the development of advanced detector projects is a central topic. To support German institutions with this the Alliance wants to improve the general infrastructure available in Germany for such projects. Infrastructure available at different places in Germany are improved with help from the Alliance and made available to a large community than just the local one. Facilities for the development of advanced chips are built up and improved at the University of Bonn and of Heidelberg. DESY provides its technical facilities and detector development facilities to the Alliance partners.

Part of this is a team of engineers well trained in questions relevant for detector development which are available not only to DESY scientists, but also to other partners of the Alliance. These teams of engineers typically team up with one of two physicists and work for some time on a specific topic identified within the Helmholtz Alliance. As an example this team developed and built the infrastructure needed to operate the large TPC prototype. This project is pursued in Germany by three Universities and DESY. This team also designed and built the mechanical support structure and the movable stage for the CALICE test beam, which eventually was used to combine the electromagnetic calorimeter, built in France, the hadronic calorimeter, primarily built at DESY, and a tail catcher into one experiment. In the future this group will also support developments for the LHC experiments. Discussions are ongoing on an involvement in the development of the tracking system upgrades at the ATLAS and CMS detectors, and other projects might develop.

The virtual laboratory for detector developments is a central part of the Helmholtz Alliance, and an important stepping stone for DESY to continue its evolution towards a central infrastructure and support laboratory for experimental high energy physics in Germany.
A Project Office for an ILC detector at DESY

Many of the linear collider related R&D programmes now under way will reach preliminary conclusions on the use of different technologies by the beginning of the next decade. The next step in development of a detector for a future facility will be to submit the proposed technologies to a system test, where questions of combined performance, but also of system integration and system management can be addressed. These tests require a complex infrastructure and the coordination of many different groups. DESY proposes to establish an ILC project office for detector integration initially at DESY, later possibly distributed over several laboratories. The purpose of this office is to develop a strategy for a system integration test, to apply for and manage common resources to setup this infrastructure, and to manage the use of this facility. It is clear that DESY alone will not be able to develop and operate such an ambitious facility. However with the installation of a core office at DESY contributions from other partners can be acquired and the project as a whole can be advertised.

The goal of this project would be to start the construction of a test beam facility, most probably at CERN, within the first few years of the funding cycle, depending on the funding. The facility would consist of the infrastructure needed to operate a detector slice consisting of a vertex tracker, a TPC prototype, and a calorimeter module. The detectors would be identical or based on the different prototypes developed over the years within the different R&D projects. The main challenge of the project would be to built up and operate a magnet system so that the tracker–calorimeter complex can be operated in a strong magnetic field.

The project office would be set up initially at DESY since here infrastructure exists to perform initial tests, and to commission the entire chain of detectors to be used in the study. In addition DESY can provide a large volume superconducting magnet, which can be used to test the setup in a magnetic field – though without beam.

The project office would also be used to ensure that a minimum set of standards is established between the different participating groups, to ensure interoperability of the components. One of the concrete projects would be to follow up and propose a common DAQ architecture, based on the work started in the context of the EUDET project.

Analysis Centre

For the future of the analysis centre, a number of activities are foreseen: One of the primary tasks of the analysis centre will be the organization of education events like school, workshops, and seminars. Building on the success of the schools that have already taken place, all three groups have concrete ideas for future events with both general and more specialized scopes. Besides the schools, a number of smaller workshops addressing the more expert physicist are foreseen. In addition, the analysis centre is planning a series of seminars on topics of general interest.

Another tool to be used by the groups and the analysis centre in general are discussion weeks. For these, a small number of experts (typically 1-3) will be invited to the analysis centre in order to work together with DESY colleagues and physicists from other institutes on a dedicated issue for a short period of time. The first such event has taken place and been observed with great interest from the community, and a significant number of future discussion weeks on a variety of topics are currently being planned. The discussion weeks will help maintain DESY’s position as the central German particle physics laboratory through the people they attract and the knowledge they help to build up within the analysis centre.

In contrast to the education, discussion and research aspects of the analysis centre, the service and support function for the German particle physics community still has to be defined and evolved. Currently, ideas on how to provide support in the fields connected to the three groups are being implemented, and the question of more general user support for physicists involved in the LHC and ILC experiments is being discussed. In addition to the service function, also the issue of collecting and documenting knowledge will be approached.

Considering the expected long lifetime of the LHC the continuous involvement of additional permanent or tenure track staff also after the end of the Helmholtz Alliance is mandatory for the
intended sustainability of the analysis centre and community of German LHC activities, and a prerequisite for successful networking inside the German community.

In addition to DESY-related staff, efforts to attract more physicists from other institutes working on issues related to the analysis centre or its groups will be undertaken, with the aim of strengthening the centre and the coherence of German particle physics activities.

2.5.4 Expected results, milestones

• Throughout the period of this funding cycle DESY intends to operate the test beams. A continuous effort will be made to maintain and improve, if possible, the beam lines.

• The remote control centres will continue to operate for the next few years.

• The virtual detector laboratory for detector technologies is currently being setup, and will increase its operation through the next few years. It is expected that it will reach its full strength in 2010.

• The analysis centre will become, within the next few years, the central hub for all analysis-related issues of the German particle physics community, providing education, expertise and a network of activities and knowledge.

• A major milestone will be the end of the Helmholtz Alliance in 2012. A major goal will be to continue the activities beyond the end date of the Helmholtz Alliance, and make them part of the core DESY programme.
2.6 Large-scale Facility GridKa

Spokesperson of the topic: Andreas Heiss

Contributing centres: FZK

Personnel (2010): 15 scientists, 0 doctoral students, 16 scientific support personnel

Contributing principal investigators: Holger Marten, Jos van Wezel.

Topic costs 2010: 8,160 M€

Preamble
Computing is of strategic importance for Particle Physics research and its development will be highly relevant for the future of this field. German research groups are very active in many international Particle Physics experiment collaborations, including the four experiments ALICE, ATLAS, CMS and LHCb at the Large Hadron Collider (LHC). These experiments produce exceptional amounts of data and thus demand computing resources beyond the reach of typical university computing centres.

In chapters 2.6 and 2.7 the large-scale computing facilities at FZK and at DESY are discussed. They cannot be seen independent of each other and they have to be considered in the context of grid-based computing of a whole variety of particle physics experiments in general and certainly in the context of the Tier structure in the "Worldwide LHC Computing Grid" (WLCG). For the sake of this document, a brief overall introduction for both chapters is given here.

FZK and DESY are running large computing and storage infrastructures for many particle physics experiments. In particular FZK and DESY are part of the Worldwide LHC Computing Grid Infrastructure (WLCG). The WLCG is organized in a distributed tier structure with CERN, the Tier-0, as the main data source. The Tier-0 distributes a copy of experiment data to 11 worldwide Tier-1 centres. In Germany, the Grid Computing Centre Karlsruhe (GridKa), built and operated by FZK, has taken the responsibility of a WLCG Tier-1 centre. On the Tier-1 sites, bulk analysis, reprocessing and storage of certain data, for example raw and simulated, takes place. Some of these data sets are finally used for the real scientific end user analysis which is carried out on many Tier-2 centres around the world. DESY has taken responsibility for a large Tier-2 in Germany, serving the LHC experiments ATLAS, CMS and LHCb and for a national Analysis Facility (NAF) for the German scientists. This means that GridKa and DESY have to provide the Particle Physics community with a full operational compute and storage resource centre on a 24x7 basis for at least 15 years, according to the pledges, made in the Worldwide LHC Computing Grid (WLCG) memorandum of understanding between FZK, DESY and CERN.

In addition to the LHC-experiments, GridKa and DESY are supporting many other particle physics experiments that are mentioned in the specific chapters.

GridKa and DESY are both very active in the Grid Projekt EGEE (Enabling Grids for E-sciencE) project, the largest multi-disciplinary grid infrastructure in the world, co-funded by the European Commission. They are members of the distributed Regional Operations Centre (ROC), collaborating with the Helmholtz Centre GSI, the Fraunhofer-Institutes for Algorithms and Scientific Computing (SCAI) and for Techno- und Wirtschaftsmathematik (ITWM) as well as the

---

8 The figures given here for scientists and scientific support personal reflect FTE from DESY only, see 1.4.
Large-scale Facility GridKa

Swiss National Supercomputing Centre (CSCS). In addition GridKa and DESY have taken a very active role in the German national Grid initiative D-Grid on the particle physics community level as well as on the core infrastructure level.

2.6.1 Challenges
At the request of, and in close collaboration with the German Particle and Nuclear Physics community, the Forschungszentrum Karlsruhe (FZK) has taken on the task of developing, installing and operating a Regional Data and Computing Centre for the German Particle Physics research community, the Grid Computing Centre Karlsruhe, GridKa. The aim of GridKa is to provide a computing environment capable of meeting the challenges posed by the computing requirements of Particle Physics experiments and in particular the LHC experiments, thus assuring competitive computing resources for the German research groups collaborating in these experiments.

As a Tier-1 centre within the Worldwide LHC Computing Grid (WLCG), it significantly contributes to the computing infrastructure of the LHC project and is of outstanding importance for the data analyses of the four experiments. It is responsible for storing and processing the raw data taken at CERN, distributing data to associated German and European Tier-2 centres and storing simulated data generated at Tier-2 centres. In addition to the CPU and storage resources, GridKa provides central grid services like file catalogues, resource brokers, databases and file transfer services with a very high reliability. These services are used by users and other resource centres in the German-Swiss region of the EGEE project and by other associated WLCG grid sites.

GridKa will further increase its resources to meet the future demands of the experiments and will remain fully functional for at least 15 years after the start of LHC data taking, providing efficient access to data and computing power in a worldwide framework for thousands of collaborators in more than 50 countries.

2.6.2 Current activities and previous work
The GridKa project is divided into three phases, given by the time scale of the WLCG project:

Phase 1: Development and construction of prototypes
Phase 2: Installation of the LHC Computing Production Facility, 2006-2008
Phase 3: Maintenance and operation, 2008 until end of LHC data analysis.

During this phase of the project, LHC groups used GridKa for Monte Carlo simulation of LHC physics events and the response of their detectors to these physics processes. “Data Challenges”, large-scale tests of increasing size and complexity, were performed to test the experiment software and computing models. GridKa contributed in these LCG-wide challenges and used the results to optimize and tune its computing environment.

The already running non-LHC experiments CDF, D0, Compass and Babar have been utilising GridKa as a data centre since 2001 and GridKa gained valuable experiences from their computing tasks.

At the end of phase 1 in 2005, approximately 20% of the CPU resources and 10% of the storage resources required for the LHC experiments at LHC start-up in 2008 were installed.

Main objective of phase 2 was the installation of the initial full production facility needed at the time of the LHC start-up. During this phase, the CPU resources for LHC have been increased by approximately a factor of 6 while the disk and tape resources have been scaled by a factor a 10. The resources for the non-LHC experiments have been increased moderately during this period. In 2007, extra funding from the Federal Ministry of Education and Research (BMBF) in the context of the German Grid Initiative D-Grid allowed to further increase the resources of GridKa. These additional resources are integrated into the GridKa computing environment and can be used by users belonging to the High Energy Physics Community Grid project but are shared with other D-Grid communities.
The enhancement of the Local Area Network (LAN) and Wide Area Network (WAN) infrastructure of GridKa during phase 2 was an important step heading for reliable services for LHC data taking. WAN connections are realised using several redundant edge routers. In addition to a direct 10 Gbit/s link to CERN using the LHC Optical Private Network (OPN) infrastructure, GridKa has direct 10 Gbit/s links to the WLCG Tier-1 centres CNAF (Italy), SARA/NIKHEF (Netherlands) and IN2P3 (France), which also serve as backup-links to CERN. To the DFN X-WIN (German national research network) backbone, GridKa is also connected by a 10 Gbit/s link which is used mainly for the data transfer between GridKa and Tier-2 centres. In addition, direct 1 Gbit/s connections exist to the Tier-2 centre in Prague (Czech Republic) as well as to Poznan (Poland).

While the non-LHC experiments continued their data processing during Phase 2, the LHC-experiments intensified their WLCG wide tests. Regularly, “Data and Service Challenges” of different kind were performed. Main focus was to test the data distribution from CERN to the Tier-1 centres and also to their associated Tier-2 sites. Recent tests finally included all components of the experiments’ computing models. The complete chain from the data acquisition at the detector, distribution and processing of raw data as well as distribution of processed data for analyses to the Tier-2 sites has been tested at full scale during the Common Computing Readiness Challenge 2008 where GridKa participated with great success.

The increased load on grid services like file catalogues or information systems as well as the storage systems during the last years helped to discover and understand scalability issues of the services and also weaknesses in the experiments’ computing models. These issues have been addressed using different techniques to implement load-balanced and redundant setups in consideration of the forthcoming higher load on the services due to LHC startup and the local CPU and storage upgrades.

Phase 3: Maintenance and operation, 2008 until end of LHC data analysis.

With the beginning of LHC data taking in 2008, Phase 2 has ended and GridKa is ready to serve the LHC Particle Physics Community with reliable CPU and storage resources as well as grid services. As of October 2008, GridKa operates approximately 1200 compute nodes corresponding to 6300 CPU cores, 220 file servers for local and dCache grid-enabled storage as well as 50 servers providing grid services like compute elements, resource brokers, workload management systems, catalogues, information systems and databases.

The end of Phase 2, however, does not imply that GridKa’s resources are already fully scaled to the future needs of the LHC experiments. There will be a massive increase of the resources during the next years to enable the analysis of growing data samples from the LHC experiments.

The computing centre infrastructure is permanently improved and adapted to the forthcoming needs. GridKa’s resources and services are supported by a 24h x 7d on-call service guaranteeing immediate response to problems outside of office hours.

Management and representation within WLCG

From the beginning, an effective project structure has been set up for GridKa, consisting of a Technical Advisory Board (TAB) and an Overview Board (OB). These boards consist of computing experts from the different particle physics experiments, the German Committee for Elementary Particle Physics (KET) and for Hadrons and Nuclei (KHK) and of representatives of DESY, GridKa and the BMBF. The TAB discusses and reviews requirements of the experiments and the technical realization of GridKa. The OB reviews and agrees on the project plan, including the required human and financial resources. Since time scale and milestones of the setup of GridKa are largely driven by the WLCG project, GridKa representatives are consequently members of several boards governing and reviewing WLCG, the Project Overview Board (POB), the Grid Deployment Board (GDB), the Management Board (MB), the Computing Resources Review Board (CRRB) and the Computing Resource Scrutiny Group (C-RSG).

Affiliated projects, knowledge transfer and education

The Strategic Helmholtz Alliance “Physics at the Terascale” is a structured research network comprising 17 universities, two Helmholtz institutes and one Max Planck Institute.
was founded in 2007 to improve structures for particle physics in Germany, intensify the collaboration between the partners and thus strengthen the position of German groups in the international research field of Particle Physics. As the German Tier-1 centre, GridKa plays an important role in the research topic “Grid Computing” of the Alliance and benefits from the improved knowledge transfer between the partners. It is represented in the Grid Project Board of the Alliance.

Grid Computing is by now a well-established technology proven to work for large collaborations of thousands of people handling Petabytes of data. Since 2003, the aim of the GridKa School (Grid Computing School Karlsruhe) is to educate scientists of many disciplines in the techniques of Grid Computing. The School is organized by GridKa and courses are offered in collaboration with scientists and generally acknowledged computing specialists of several universities and the Helmholtz centres DESY and GSI.

Meanwhile, the GridKa School is an international event with participants from many countries, several research fields and the industry. In 2008, the year of the LHC start, the GridKa school is held in collaboration with the Helmholtz Alliance “Physics at the Terascale” and runs special courses on grid usage and the computing models of the LHC experiments.

The GridKa-CA, the German Grid Certification Authority, is internationally accredited since 2002 and issues X.509 certificates for German users. It is member of the EUGridPMA, the European Grid Policy Management Authority that collaborates with the IGTF (International Grid Trust Federation). Certificates issued by the GridKa-CA are accepted at all computing centres in the WLCG.

FZK participates in the project "Enabling Grids for E-Science" (EGEE) which is funded by the European Commission since 2004 and brings together experts from 27 countries with the aim to provide researchers in academia and industry with access to major computing resources, independent of their geographic location. Meanwhile phase 3 of the project has started and EGEE runs the largest multi-disciplinary grid infrastructure in the world. GridKa is part of this infrastructure and scientists from FZK work actively on different topics within EGEE.

The Global Grid User Support team, working in close collaboration with the GridKa project, develops and maintains the central help desk system for the EGEE infrastructure which integrates the support efforts throughout the project and provides the single point of contact for users requiring support in using the EGEE grid (see http://www.ggus.org). Additionally the support team provides the regional help desk for the German/Swiss federation and a help desk application for the ENOC group within EGEE. Currently another help desk application for the LHCOMP group of the EGEE project is being developed and implemented.

2.6.3 Contents and goals
With the start of the LHC, the main installation phase of the GridKa project has ended and GridKa is ready to serve the LHC Particle Physics Community with sufficient CPU and storage resources for the first year of LHC as well as reliable grid services. During the following years, GridKa has to further increase its storage resources to store the growing data volumes to be produced by the LHC experiments. CPU resources will be increased to cope with the increasing demand of computing power to process new data and regularly reprocess raw data from preceding collider runs.

A comparatively moderate increase of the CPU and storage resources for the non-LHC Particle Physics experiments during the next years allows German groups participating in these experiments to be competitive in their work fields and continue data processing at GridKa until a few years after the end of data taking at the respective experiment.
This figure shows the total resources of GridKa required in the next years. Included are resources to be pledged to the LHC experiments according to the WLCG Memorandum of Understanding as of April 2008, resources for the non-LHC experiments and those dedicated to users from the German Grid initiative D-Grid. (The numbers for the year 2014 are estimates for internal planning as there are no official requirements posed by the LHC experiments up to now.)

When planning the deployment of new storage and CPU resources much effort is taken to evaluate new technologies and hardware considering not only technical but also economical aspects, e.g. power consumption and density (compute power or storage per floor space unit). Results of tests and studies of hardware are communicated with other IT centres e.g. at the HEPiX forum, an organisation formed by High Energy Physics and Nuclear Physics laboratories and institutes and many others to enhance the information exchange between specialists in scientific computing.

After the start of the LHC, the reliability of the computing services and resources is crucial for the LHC physics community to be able to quickly do analyses on the data and publish first results. The expected load on the WLCG sites is higher than before real data has arrived since physicists have a high interest in getting real data for analysis as quick as possible. The main goal of GridKa during this phase is to provide reliable resources and services and it is expected that much manpower is required to sustain a high service quality and reliability during the next years. Also the services are now in a production ready state, further developments are necessary to improve scalability and reliability. Given the enormous increase of the CPU and storage resources during the years following the LHC start-up, scalability has to be focussed on when planning and implementing grid and storage services and resources. In particular the setup of the grid-enabled dCache storage system used at GridKa needs to be planned carefully to ensure the scalability of the system. The reliability of many essential grid services can be improved by applying new technologies such as virtualization and redundant setups with automatic failover of service components. Currently and in the next years, it is the aim of GridKa to evaluate such techniques and use them to further improve the service reliability.

In parallel to these efforts undertaken at the WLCG computing facilities, the developers of grid and storage services will continue improving their software and adapting it to the future needs of...
the experiments. Continuous testing of new software releases at large scale computing facilities is indispensable to assure a high quality and prove scalability.

The permanent increase of resources and the improvement of services is a WLCG wide effort and not limited to GridKa alone. GridKa collaborates with several national particle physics groups and grid sites at universities and other institutions. There is a particularly intensive and good cooperation between GridKa, operating a very large dCache installation, and DESY, developing this software. In general, the collaboration within Germany has been intensified in 2007 when the Strategic Helmholtz Alliance “Physics at the Terascale” was founded.

On the international scale, GridKa collaborates with several centres of similar size: RAL (UK), IN2P3 (F), INFN (I), CERN (CH), SARA/NIKHEF (NL), TRIUMF (CA), PIC (E), ASGC (TW), NDGF (Scandinavia), BNL and FNAL (USA). These collaborations make GridKa an interesting place to work for young researchers from Germany and other countries.

2.6.4 Expected results, milestones
As explained in the previous chapters, GridKa will continue upgrading its resources according to the pledges agreed on in the Memorandum of Understanding of the WLCG. Although, the LHC experiments’ activities will dominate at GridKa during the following years, non-LHC experiments will be served as long as data analyses are done. The Technical Advisory Board reviews and discusses the future resource requirements of the experiments every year and communicates the agreed numbers to the Overview Board where the final decision is made. The GridKa Overview Board will also decide on future motions of other experiments or experimental groups requesting resources, taking into account the resource requirements of the experiments already using GridKa as well as the funding situation. In particular, at the time of writing this proposal, a request for compute and storage resources at GridKa from the German physics groups working in the Belle collaboration has been submitted to the Overview Board.
2.7 Large-scale Facility DESY Grid Centre

Spokesperson of the topic: Volker Gülzow

Contributing centres: DESY

Personnel (2010)\(^7\):
- 10 scientists,
- 0 doctoral students,
- 5 scientific support personnel

Contributing principal investigators: Frank Gaede (see also 2.3), Patrick Fuhrmann, Matthias Kasemann (see also 2.2), Peter Wegner.

Topic costs 2010: 3,370 M€

2.7.1 Challenges
The computing requirements for particle physics are largely defined by the needs of the current or planned large experiments and the collaborations, i.e. HERA- and LHC-experiments for this funding period. The underlying architecture is the computing Grid.

DESY is part of the overall “tier-ed” computing structure of the LHC where it assumes various roles. A particular focus at DESY is storage and fast access of large-volume data together with the relevant meta-data for analysis. A National Analysis Facility (NAF) hosted at DESY and supported by physics analysis experts supplements the activities in the Worldwide LHC Computing Grid Project (WLCG) and sets DESY aside from other Tier-2 centres for LHC.

The NAF has been implemented in the framework of the Helmholtz Alliance “Physics at the Terascale”. It comprises the computing infrastructure for a large analysis centre at DESY to furnish German scientists with batch and interactive LHC data analysis capabilities. The WLCG Grid resources in contrast do not allow interactive access. The NAF extends its services beyond the LHC: currently ILC MC-simulations, HERA-analysis and the computing needs of theory groups in Germany are supported. The NAF addresses in particular smaller research groups at universities and provides them with the possibility and access to resources, they could not support on their own.

Grid infrastructure is also provided for the HERA experiments H1 and ZEUS, for IceCube, ILC, CALICE and theory groups, in particular Lattice QCD. In the nomenclature of the LHC data model DESY assumes the Role of a Tier-0, Tier-1 and Tier-2 for the HERA experiments who are among the first to exercise the Grid with physics data. The analysis of the HERA data will continue for several more years and will require sophisticated support. DESY has set up a software development programme to contribute actively in the Grid development for high-energy physics. The focus is on efficient large volume data management, which is central to the success of the Grid paradigm. The dCache package makes DESY a major developer and contributor to LHC-Grid endeavour.

The DESY computing programme for particle physics is fully embedded and aligned with the Helmholtz Alliance and national/international projects.

The challenges for the next years are:

- Operation and extension of a large Grid-based computing- and storage farm including a Tier-2 centre and the NAF to furnish efficient services to the LHC experiments ATLAS,

---

\(^7\) The figures given here for scientists and scientific support personal reflect FTE from DESY only, see 1.4.
CMS and LHCb, and to ILC, CALICE, to the HERA-experiments, IceCube and the theory groups.

- Operation of a fully functional Grid for the non-LHC experiments of particle physics in Germany.
- Development, support and dissemination of the data management software package dCache, analysis software packages and Grid software.

2.7.2 Current activities and previous work
For many years DESY has been running large computing- and storage systems for numerous HEP experiments, in particular the HERA-Experiments H1 and ZEUS. To support the particle physics groups in Germany and collaborating partners DESY has set up and is operating a large-scale computing infrastructure using Grid-technology. This huge facility currently hosts and serves many Virtual Organisations (VO) including H1, ZEUS, ILC, CALICE, ICECUBE, ILDG. In addition, DESY is supporting the VO’s ATLAS, CMS and LHCb, hosted by CERN. This large facility is operated using the gLite middleware and the dCache storage management software. It is part of the Worldwide LHC Computing Grid (WLCG) and can be accessed from all over the world. All Grid resources are continuously monitored worldwide by LCG-mechanisms and DESY has achieved an excellent performance profile over the past years. As part of the worldwide administration of the Grid, DESY operates over 30 central servers handling services such as the resource broker and workload management systems, replica catalogues or metadata catalogues.

DESY Normalised CPU time per VO
CUSTOM VO's. February 2008 - August 2008

In addition to the LHC Tier-2 activities the large-scale facility is used as the computing platform for the National Analysis Facility (NAF) located at DESY. In the framework of the Helmholtz Alliance "Physics at the Terascale" the NAF enables German research groups from the LHC experiments, the ILC and the theory groups to analyse data and run simulations interactively. The NAF itself comprises at least the size of a full Tier-2 in terms of computing power. The NAF is in particular intended to support smaller university groups in their sophisticated analysis of e.g. LHC data.

DESY has placed special emphasis on hosting the data of the experiments and thus anticipates analysis benefits for the scientists. The required storage technology is considered a true challenge. DESY is designing and hosting a reliable and multi-level storage system that ranges from a high performance LUSTRE based file system down to huge tape libraries.
Excellent connectivity on a local area network as well as on the wide area network is a prerequisite. The two DESY sites in Hamburg and Zeuthen are linked via a 10 Gigabit/s VPN (Virtual private network) whilst connectivity to the outside world is handled via a 10 Gigabit/s access to the national research and education Network X-WiN. In addition DESY has a 10 Gigabit/s VPN link to the GridKa Tier-1 centre as the main data source for the LHC analysis.

Running such a complex grid based system needs reliable and error tolerant software. DESY is contributing to the worldwide set of middleware components with the dCache software to handle large amounts of data.

The storage technology dCache is commonly used by the LHC HEP community to manage data of the order of several Peta Bytes per single instance. It handles disk space and allows access to a variety of tertiary storage back-ends. In addition to about 70 Tier-2 LCG sites, the main dCache users in terms of data storage size are eight Tier I centres, namely TRIUMF (Canada), BNL (US, New York), the Fermi National Laboratory (US, Chicago), IN2P3 (France), PIC (Spain), GridKa (Germany), NDGF (Finland, Sweden, Denmark, Norway) and SARA (Netherlands). For the coming years dCache is expected to manage the largest share of LHC data outside CERN.

The dCache technology addresses the desire of public laboratories to purchase low cost storage hardware to huge amounts of data reliably. The dCache technology is operating system and storage hardware agnostic. It bundles heterogeneous storage systems in one huge storage area under a single unique file system tree. It allows fine-grained steering of data streams and is optimised for high throughput I/O. Furthermore it supports various brands of tertiary storage systems at its data back-end. Despite of representing a full-fledged LHC “storage element” it is not limited to this use pattern.

The dCache software is provided by a international group of developers from DESY, the Fermi National Laboratory (FNAL), the Nordic DataGrid Facility (NDGF) and others. DESY plays a leading role in this informal collaboration:

- DESY provides the necessary infrastructure in order to manage and distribute a professional software system. DESY hosts the central dCache code repository to be used by all partners, to manage releases, versions and patches. DESY provides a complete and entirely automated regression test suite for the various dCache sub-packages as well as the automated building system and the placement of the dCache package at dCache.org. DESY organises weekly developers phone conferences with all partners to co-ordinate coding efforts and planning for future features. Moreover, DESY offers a set of virtual machines running the most recent dCache system. Those machines are used by CERN to evaluate gLite dCache interoperability.
- DESY organises the dCache customer support for all non US laboratories as well as, due to a special agreement, for the Brookhaven National Laboratory. In this context DESY produces and collects documentation to install and run a dCache instance. This information is published through web pages at dCache.ORG, hosted by DESY. DESY offers weekly video conferences, inviting LHC dCache Tier-1 centres and large Tier-2's to discuss operational issues. Storage experts of the LHC experiments are asked to call-in when needed. The dCache team at DESY is member of the German Storage Support group of the Alliance “Physics at the Terascale” as well as a member of the D-Grid DGI II Project.
- DESY is responsible for developing the central dCache components as well as the dCache deployment and installation software. This includes the communication kernel, various implementations of the file system engine, the dCache core and the information system.
- DESY provides the overall dCache project management. This includes, software management, contact to the CERN Storage System Deployment group as well as to the LHC experiments. The leader of the dCache project represents dCache in the US, Open Science Grid (OSG) executive board.
2.7.3 Contents and goals
The large-scale computing and data facility at DESY is seen as one of the key elements in particle physics for DESY. The provision of this complex machinery to the scientific community is a key element of the DESY HEP strategy. DESY assumes the role of a data- and analysis centre for a whole set of HEP experiments and supports various virtual organisations. This demand poses a considerable challenge for the data management software developer, the system architect and resource provider since commercial solutions either do not exist or are not affordable. In addition to the stored data large databases for meta-data have to be maintained for the experiments such as calibration data or tag-data.

Consequently the primary goals of the DESY computing programme for particle physics are:

• upgrading the large-scale computing and data facility according to the WLCG pledges and the requirements of other experiments
• providing a full Grid infrastructure for the non LHC experiments from particle physics in Germany
• coordinating, upgrading and continuously developing the NAF according to the needs of the German research groups
• maintaining DESY as a primary centre for analysis of LHC data in Germany
• maintaining the outstanding position of DESY in development of data management software.

High-bandwidth wide area networks constitute a key infrastructure for maintaining a leading role in LHC distributed computing. The 10 Gb/s connection between the sites Hamburg and Zeuthen and 10 Gb/s connections dedicated to FZK and to DFN X-Win will facilitate the successful operation of WLCG Tier-2 centres at DESY for the coming next years. According to the WLCG MoU pledges an extension of the wide area connectivity will be necessary by 2012.

2.7.4 Expected results, milestones
DESY will continuously upgrade the Computing facility according to the following figure:

The numbers shown include the Grid requirements of all VO’s, mainly the LHC experiments, the HERA experiments ILC/CALICE and IceCube.

The requirements are paced by the schedule of the LHC; a huge upgrade step is foreseen for the luminosity upgrade. The analysis of the HERA experiments is expected to fade out in the
2012 timeframe, the required computing resources from then on are considered to be at negligible level. In contrast the computing requirements for the ILC will drastically increase for Monte Carlo simulations; the current ILC schedule foresees a technical design study for 2012.

Since the dCache is in operation on so many sites as a critical resource, DESY has special responsibility to coordinate and arrange support and push further development. An expert team, distributed over key sites, is required to support the dCache operation and to further develop the system over the next few years.

2.8 Summary of proposed costs of the programme topics

For additional information see 5.2.3 Resource planning of participating centres.