Helmholtz Russia Joint Research Group HRJRG-002
Physics Analysis and Calorimetry at the Terascale

Activity Report 2009

Participating Institutes:

Deutsches Elektronen-Synchroton. DESY, Hamburg
Institute for Theoretical and Experimental Physics, ITEP, Moscow
Moscow State University, MSU, Moscow
Moscow Engineering Physics Institute, MEPHI, Moscow

Group Members of the HRJRG:

Principle Investigator (Germany):	Dr. Kerstin Borras (DESY)
Principle Investigator (Russia):	Dr. Roman Mizuk (ITEP)
Group Leaders:	Dr. Felix Sefkow (DESY)
	Prof. Dr. Michael Danilov (ITEP)
	Dr. Michael Merkin (MSU)
	Prof. Dr. Boris Dolgoshein (MEPHI)
Key Researcher:	DESY: 1, ITEP: 1,
Post Doctoral Fellows:	DESY: 2, MSU: 2
Graduate Students:	DESY: 3, ITEP: 1, MEPHI: 1, MSU: 1

The concept of Helmholtz Russian Joint Research Groups was launched with the primary goal to promote the scientific cooperation with Russia and to provide attractive research conditions for young scientists in the field of particle physics. The Helmholtz Russian Joint Research Group HRJRG-002 was approved in September 2007. The program started on the 1st of November 2007. In total the group consists of 20 members from DESY and the three Russian Institutes.

Description of goals of the group:

The Helmholtz Russia Joint Research Group HRJRG-002 continues the long-lived and very fruitful cooperation between DESY and Russian Institutes beyond the common efforts for HERA experiments and their final data analysis, physics and detector R&D towards new activities imminent at the LHC, e.g. the CASTOR Calorimeter and with the HCAL project for the future ILC. Within the project several excellent young scientists and students are supported, opening the possibility for a future career in high energy particle physics.
The combination of physics in data analysis and in phenomenological calculations as well as with detector activities pursued in this Joint Research Group makes the project extraordinary and exceptional.

Main Activities of the group in the year 2009:

The goals of the phenomenological calculations pursued in this HRJRG are to obtain predictions for a number of new processes, to study the theoretical uncertainties of the achieved predictions and to implement the processes into Monte Carlo simulation generators, which are relevant for physics analysis of data from HERA, the Tevatron and the LHC. Since the start of the group several processes have been investigated and the results have been successfully published. Among these are the prompt photon hadro-production, the inclusive W- and Z-Boson production also in accosciation with quark-antiquark pairs, production of the (yet undiscovered) Higgs-Boson in connection with bottom-quark or top-quark production, as well as forward jet production. Latter one is an important ingredient for the physics analysis of the data from the CASTOR calorimeter at LHC.

The year 2009 was very exciting for the project of the CASTOR calorimeter. After having identified a temporary solution for the problems for the Photo-Multipliers (PM) in the readout caused by the unexpectedly high magnetic stray field, the production went on full speed. Here the group of MSU played a key role, since they had agreed to produce the needed new PMT bases and they succeeded within an extremely short time. While preparing the full calorimeter, also a test beam program for the new configuration had to be performed. Finally on the 25th of June 2009 the fully operational calorimeter was installed in CMS. Being then integrated into the data readout stream of the CMS experiment and it is now permanently taking data with all CMS components. In the beginning the calorimeter had to be supervised by a dedicated CASTOR expert in 24h on 7 days a week basis, which was a severe load for the small CASTOR group. Finally the calorimeter could now be fully integrated within the general group for hadronic calorimeter (HCAL) in CMS and is supervised by these shifts which were enforced by some CASTOR group members. This achievement was only possible with the dedicated effort by the MSU group who developed the CASTOR slow control and integrated it into the HCAL slow control. During times of no data taking, the response of the calorimeter is monitored by a LED system, to which the ITEP group crucially contributed.

Unfortunately the LHC running scheme did not start with the design energy of 7 TeV per beam and with very low beam intensities. The CASTOR and CMS data which have been taken in November and December 2009 during the initial running of LHC with the injection energy of 0.9 TeV ans 1.18 TeV, were analyzed and the result on ratios in terms of energy flow in the forward direction pre-approved by the CMS collaboration. Now the calibration has to be finalized in order to proceed towards a very early publication. Another fast publication concerns the analysis of forward jets in the CASTOR calorimeter, which will give insight into the proton parton evolution scheme at very small momentum fractions x, where saturation effects are expected to occur. Preparations with simulated events are well in progress.
A third analysis aspect is given by the underlying event structure and multi-parton interactions at the LHC, where CASTOR can deliver crucial input. The charged particle production in the collisions is here a key ingredient. A new PhD student at ITEP is studying these spectra from different collider experiments on a general basis in order to identify new regularities. This will also open the possibility to produce predictions for LHC.

Presently the LHC machine operation has restarted with an even higher beam energy of 3.5TeV and the CASTOR calorimeter is continuously taking data. A preliminary schedule for the LHC running foresees further data collection at 3.5 TeV until approximately end of 2011. With an about one year long shut down the LHC beam lines will be prepared for higher beam energies and intensities. Due to this new LHC schedule it will not be possible to collect the necessary data for the envisaged physics analyses, especially for the small-x studies for the proton structure. Nevertheless it is hoped to achieve some first results which might give indications for the proton parton evolution scheme, however with larger systematic uncertainties and with not as small momentum factions x as with 7 TeV beam energy.

In 2009 the linear collider group completed the beam test program with the 8000 channel, cubic-metre prototype of a highly granular hadron calorimeter (HCAL) with SiPM read-out, continued the analysis of test beam data from the previous campaigns at CERN and Fermilab, and commissioned the first module of a new, realistic second generation prototype with integrated read-out electronics and calibration system.

During the five week data taking campaign in May 2009 at Fermilab, the HCAL prototype was combined with a prototype of an electromagnetic calorimeter with tungsten absorber sheets and scintillator strip active layers, built in Japan and read-out by so-called MPPCs, photo-sensors which are very similar to the Russian SiPMs used in the HCAL and also in the steel scintillator-strip tail-catcher backing up the two calorimeters for leakage detection. ECAL and HCAL were using the same read-out and slow control electronics provided by DESY.

Emphasis was put on the collection of low energy hadron data, in the range 1-20 GeV, where uncertainties in the simulation are large and experimental data promise to constrain the models significantly. First checks indicate a high quality of the data.

In the data analysis important new results were obtained and presented at major conferences. We highlight two results which have a particular relevance for particle flow and high granularity. The transverse profiles of hadronic showers were measured and found to be reasonably well reproduced, once saturation effects in the scintillator and pulse shaping in the electronics are properly taken into account. The transverse extension of showers influences the capability to separate particles from each other and reconstruct them individually. The result thus lends support to the predicted jet energy performance of such a calorimeter at the linear collider.

An important contribution to the energy resolution of the calorimeter for single hadrons originates from fluctuations in the electromagnetic fraction of the shower, to which in addition the response is higher than for the pure hadronic part. This can be partially corrected for if the electromagnetic part is recognized by its higher energy density and re-weighted. The technique is called software compensation, it is used in existing experiments and is expected to be more efficient for calorimeters with finer segmentation. Indeed, it was found that already a simple weighting procedure improved the hadronic energy resolution in test beam data from 61% to 49%/sqrt(E).

In the context of the evaluation of detector concepts for the linear collider by an international panel of experts, the question was studied how the large number of about 8'000'000 channels can be handled in real collider detector. It could be demonstrated that using innovative methods like the auto-calibration of the SiPM gain, or the reconstruction of track segments inside hadronic showers, the necessary precision can be achieved and maintained. It was a strong asset of the study that the methods could be exercised and validated using test beam data from different sites and transporting calibrations from one to the other.

This was one of the last cornerstones of establishing the SiPM technology for a linear collider experiment. The future studies will concentrate on verifying the particle flow performance using multi-particle events and event mixing techniques.

For a realistic detector proposal, it is essential to demonstrate that the tremendous integration challenges which come along with the extremely fine segmentation can be mastered without degrading the performance by dead spaces for support structures, readout lines and services. In 2009 the first fully functional version of an

integrated chip became available, which includes pre-amplifier, self-trigger, time and amplitude digitization, pipelines and digital processing. The group developed a printed circuit board which integrates the ASICs into the detector volume and couples the electronics to the tiles. It also features an optical calibration system with embedded LEDs. The system was successfully commissioned using the first prototype series of scintillator tiles and MRS-APDs. LED light was injected and single photo-electron signals were resolved in the internally digitized data. An absorber structure prototype with minimized dead spaces and the required mechanical tolerances has also been produced.
In 2010, the commissioning will continue using positrons from the DESY test beam. The board and the external interfaces will be redesigned to accommodate the final chip and tile and other optimizations. These interfaces are a preparation for the test of a tower structure in 2011.

At ITEP a new version of the SiPM detector has been developed. The sensitive area has been increased from $1mm^2$ to $1.3mm^2$. The number of pixels increased from 556 to 796. A new high precision package for the SiPMs has been developed and constructed, which can be used both for the new version and for the previous version of SiPMs. The new package has been extensively tested and verified to satisfy the requirements. Thus a SiPM detector with the external dimensions $2.8x4.0x1.5mm^3$ has been developed. Its mechanical and electrical properties have been tested.
Also a new setup for the measurements of the new SiPM parameters has been developed at ITEP, which allows to measure 15 detectors simultaneously. In addition a thermostat-based setup for the long-term stability measurements of the SiPMs has been designed, constructed and commissioned. In total 255 SiPMs can be tested in the new setup simultaneously at elevated temperature.

In the area of R&D for optimizing the scintillator tiles a new version for a casting form of next iteration of the scintillator tile layout has been constructed. Up to now 2000 tiles have been produced using this new casting form. Furthermore different possibilities for a direct scintillator tile read-out (i.e. without a wave-length shifting fiber) have been studied at ITEP.

At MEPhI, investigations with a pilot batch SiPMs with large area for direct scintillator tile readout have been carried out. The SiPMs had a rectangular shape $2x5mm^2$ and 1000 read-out pixels in total. The structure of the detectors was p-over-n, which is optimal for the detection of blue light. The light detection efficiency was found to be in agreement with the expectations. Unfortunately, poor amplitude resolution and high dark rate didn't allow to determine the light yield of the SiPM-tile system. The new construction of SiPMs has been designed and a next batch was produced. The sensitive area of the new detectors is $2x7.5mm^2$ with 1500 pixels. The main characteristics of the new SiPMs measured at MEPhI are: a working point below 70V, a light detection efficiency for the 435 nm light of 15-20%, a gain of $>10^6$, with an optical cross-talk of as low as 10%, at a dark rate of 2-3MHz. The amplitude resolution allows to resolve individual photo-electon peaks. The detectors have also been tested at DESY in assembly with $30x30x3mm^3$ tiles and a light yield of 46 pixels per Minimum Ionization Particle has been measured.
Using such a unique elongated shape of the SiPM will possibly provide a good uniformity of the light yield over the whole tile area. The measurements of the tile uniformity are still to be performed. The technical requirements for the SiPMs for the direct readout of the tiles are yet to be determined. The goal is to develop a suitable technology for the mass production of detectors of this type.

Achievements within the Group in the Year 2009:

During the year 2009 two PhD students, one from ITEP and one from DESY, finished their work and passed successfully their defence. Both have now excellent positions with foreign institutes: one is employed by a US University to work at CERN on the data analysis of the CMS experiment and the other one pursues phenomenological calculations at the University of Madrid. A third PhD student is about to finish within the next two months. Replacements for the students have been successfully found in Russia.

This HRJRG offered two phenomenologists within the group to pursue their studies with a good financial basis, which is not the usual case. They succeeded to publish their important results in several publications, a very good foundation for their future carreer.

One PostDoc Fellow from DESY accomplished to obtain a position in the analysis center of the Helmholtz Terascale Alliance. During half of his time he is allowed to pursue data analysis in an experiment, which he does within our HRJRG with CASTOR calorimeter data.

On the senior side one key researcher from DESY became spokesman of the CALICE collaboration and the principal investigator at DESY is leading now the whole CMS group at DESY.

On a more personal basis it has to be noted, that with the personal grants this HRJRG opened for three members the possibility to further increase their family life with a new baby, without having to worry about their professional position.

Developments within the Group HRJRG-02:

A third annual meeting of the group took place at DESY on the 24th of February 2010. The meeting was preceded by an international workshop on Silicon Photo-Multipliers at DESY and offered several members of the group to participate in an international event for the first time.
During the past lifetime of this HRJRG two upgrade projects for CMS detector components began to study the use of SiPMs for their purpose. One project is the upgrade of the CMS HCAL, analogous to the HCAL effort in CALICE , and one is connected with the CMS Muon detector, but closely related to the HCAL upgrade. The SiPM workshop was organized to foster the experience exchange between the experts of these different communities. The participation was overwhelming with more than 45 registrants from 20 different institutes and 8 different countries. The different projects have been presented with their specific technical challenges. Also institutes and companies presented characterization studies for various new SiPM sensors and triggered lively discussions. At the end of the workshop time was foreseen for discussions on closer collaboration. One specific project got already some third party funding and is about to start soon.

This HRJRG-002 will finish by end of October 2010. It is planned to keep the close collaboration and to intensify it possibly with a common project for SiPMs in the detector upgrade projects in the CMS experiment.