
# Helmholtz Young Investigator Group VH-NG-303

Terascale Physics: From Data taking at LHC to Understanding at ILC

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Group Leader

**Summary Report 2007 – 2012**

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## 1 Introduction

The Helmholtz Young Investigator Group VH-NG-303 was jointly funded by DESY and the "Impuls- und Vernetzungsfonds" of the Helmholtz-Association over a period of 5 years from Mai 2007 till April 2012. In this report, a summary of the scientific activities and results of the group is presented. In total, the following researchers contributed to the activities of the group:

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|---|---|
| *Members of the group* | |
| Dr. Philip Bechtle | Group Leader |
| Dr. David Côté | Postdoc |
| Dr. Sylvie Brunet | Postdoc |
| Dr. Joao Costa | Postdoc |
| Gordon Fischer | PhD Student |
| Björn Gosdzik | PhD Student |
| Carolin Zendler[1] | PhD Student |
| Michael Böhler | Diploma & PhD Student |
| Mathias Uhlenbrock[1,2] | PhD Student |
| Sebastian Johnert | Diploma & PhD Student |
| Ivan Marchesini | PhD Student |
| Milan Zvolsky | Master Student |
| Almut Pingel | Diploma Student |
| Björn Sarrazin[2] | Diploma & PhD Student |
| Norman Jerschabek | Bachelor Student |
| *Associated Members of the Group* | |
| Dr. Takanori Kono | Postdoc |
| Dr. Nick Styles | Postdoc |
| Nicola d'Ascenzo | PhD Student |
| Peter Schade | PhD Student |
| *Additional supervised students on topics outside the group* | |
| Lea Hallermann | PhD Student |
| Isa Heinze[2] | PhD Student |
| *University Partners* | |
| Prof. Dr. R. D. Heuer | Univ. Hamburg |
| Prof. Dr. J. Haller | Univ. Hamburg |
| Prof. Dr. K. Desch[1] | Univ. Bonn |

All theses, apart from the last three PhD theses, started in 2010 and 2011, have been concluded successfully. Continuous supervision is ensured also for those students, as well at the University of Hamburg and at the University of Bonn. A full list of completed theses can be found at the end of the bibliography section.

The main focus of the activities of the group lay on data taking and data analysis at the ATLAS experiment, preparations for the International Linear Collider (ILC), and on interpretations of measurements in theories of New Physics (NP). In addition to the funding from DESY and the IVF, which was mainly spent for activities concerning data taking and commissioning of the ATLAS experiment, additional funding from the Collaborative Research Center SFB 676 of the German Research Society was successfully acquired, which funds 2 positions in the form of the project B8 jointly in the groups of J. Haller at the University of Hamburg and in the Helmholtz YIG, starting from 2008. These funds were mainly used for the development of analysis techniques for measuring NP properties, if found, and on phenomenological interpretations. The group leader of the YIG acted as co-speaker of the project B8 in the SFB 676 from 2008 to 2012.

A full list of the scientific publications of the group is given in the bibliography. First, all journal articles, public analysis notes and conference proceeding articles are given, followed by a list of all finished theses. In the following, the scientific commitments will be briefly described, followed by a very brief description of selected highlights of the scientific results within 2011 and 2012.

### 1.1 Commitments in the Context of the ATLAS Experiment

The YIG contributed to the ATLAS collaboration. Its main objective were the discovery of new fundamental structures of matter and its interaction, and solving the open questions around the nature of Dark Matter and the generation of elementary mass of elementary particles. The Young Investigator Group covered several highly visible key aspects of the operation of the detector, reconstruction of the data and analysis.

These aspects include the ATLAS Trigger Configuration, the Core Software maintenance and development, the reconstruction of $\tau$ Lepton final states and the analysis of events with $\tau$ leptons in the context of the Standard Model (SM) and Supersymmetry (SUSY) with $\tau$ leptons or electrons or muons in the final state.

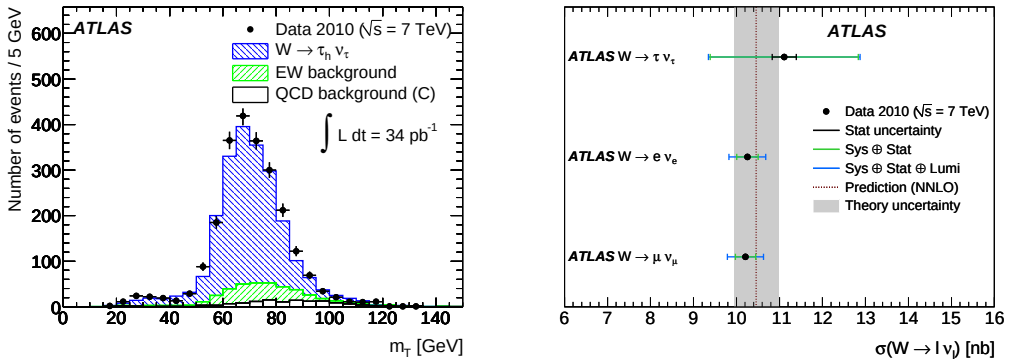
### 1.2 Commitments in the Context of the Proposed ILD Experiment

The activities of the group in the area of the ILC concentrated on the following aspects: The analysis potential in the areas of SUSY precision measurements and the precision measurement of of Triple Gauge Couplings (TGC), and the potential of measuring the the beam polarizations in the collision from data. In addition, a group member was involved in the CALICE collaboration.

## 2 ATLAS Core Software and Physics Analysis Tools

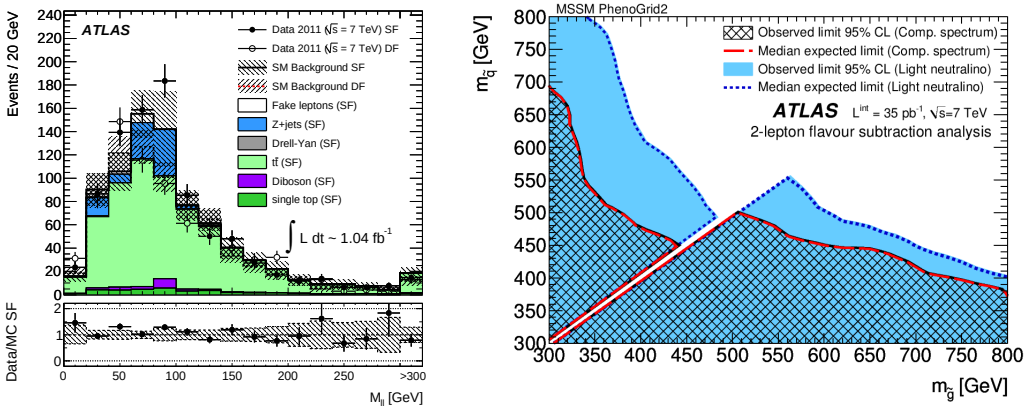
The recent efforts on the ATLAS core software and the work on tools for physics analysis have focused on three areas: Running the ATLAS Tier0, where the de-

[1]Members of the university partner group of the University of Bonn
[2]PhD Thesis still ongoing and still supervised




(a) (b)

Figure 1: *Results from the analysis of $pp \to WX \to \tau\nu_\tau X$ events. In (a), the transverse mass distribution is shown, which can be used to prove that a very pure signal is found after selection. In (b), the measured cross-section times branching fraction of the $W \to \tau\nu_\tau$ production is compared to the experimentally much less challenging electron and muon channels [32].*




(a) (b)

Figure 2: *Results from the search for SUSY with 2 same-flavor leptons in the final state. In (a), the di-lepton mass distributions for same and different flavor are displayed, showing no excess over the expected background. In (b), the resulting limit on a phenomenological SUSY model is shown [29, 33].*

tector calibration and data reconstruction is performed, improving the so-called job transforms, which are providing a common interface to ATLAS reconstruction and analysis jobs on all platforms, and creating the autconfiguration tool [27], which was and is essential for the consistent analysis of data and Monte Carlo, automatically taking all correct configuration settings for all data periods into account (such as magnetic field configuration, detector geometry, etc.). Group member David Cote was the first Tier0 coordinator, a tradition within the group which is currently filled with group member Joao Costa.

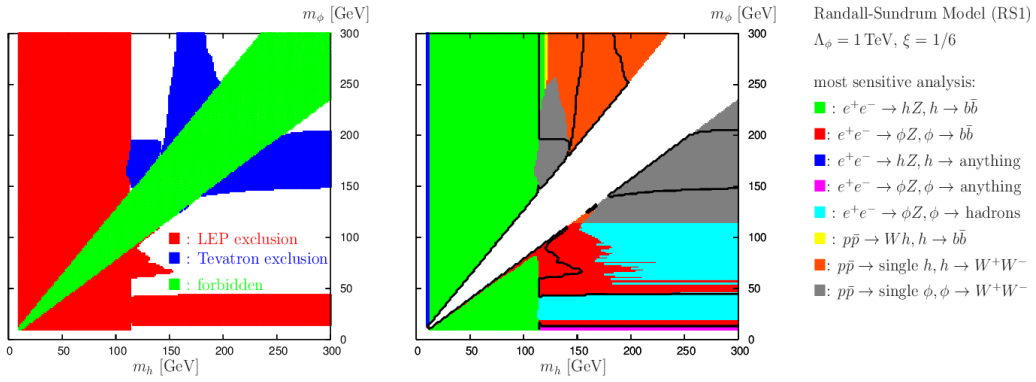



Figure 3: *Analysis of a Randall-Sundrum model using data from LEP and the Tevatron. The left plot shows the excluded and allowed parameter space, while the right plot shows which analysis in which production and decay channel, model independently included in* `HiggsBounds`*, delivers the strongest constraint [26].*

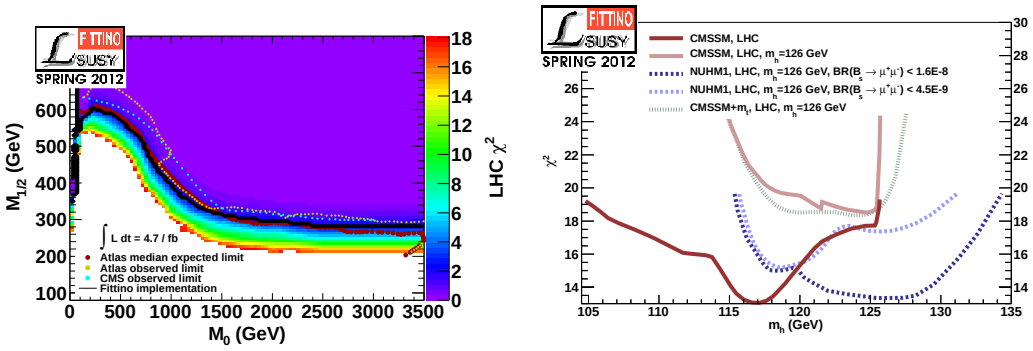
## 3 ATLAS Analyses

The achievements of the group in the years 2011 and 2012 comprise the following results: In the area of Standard Model measurements, the group concentrated on physics with $\tau$ leptons and performance measurements of the $\tau$ reconstruction and ID. Detailed data-driven measurements of the so-called fake-rate of QCD jets faking $\tau$ leptons in reconstruction and ID were performed and published in [30]. Measurements of the cross-section times ranching fraction $\sigma \times$BR were obtained for the two most prominent SM channels of $\tau$ production at the LHC, $Z \to \tau\tau$ [24, 37] and $W \to \tau\nu_\tau$ [32]. An example of the results of the latter are given in Fig. 1. These are interesting because the large mass of the $\tau$ with respect to the electron and muon could make the appearance of NP in loops more prominent. In both cases, the SM was confirmed. Work on a much more precise measurement of BR($W \to \tau\nu_\tau$)/BR($W \to \mu\nu_\mu$), based on a new innovative technique, is still ongoing.

In the area of SUSY searches, the group continued its deep involvement in the di-lepton analyses, using the flavor subtraction technique to obtain a very clean spectrum of the di-lepton invariant mass. The advantage of this technique is that it allows to directly measure properties of the potentially discovered NP, instead of a pure discovery of an excess beyond the SM. This work unfortunately did not lead to a discovery of New Physics, but to constraints on the SUSY parameter space, as published in [28, 29, 33, 34].

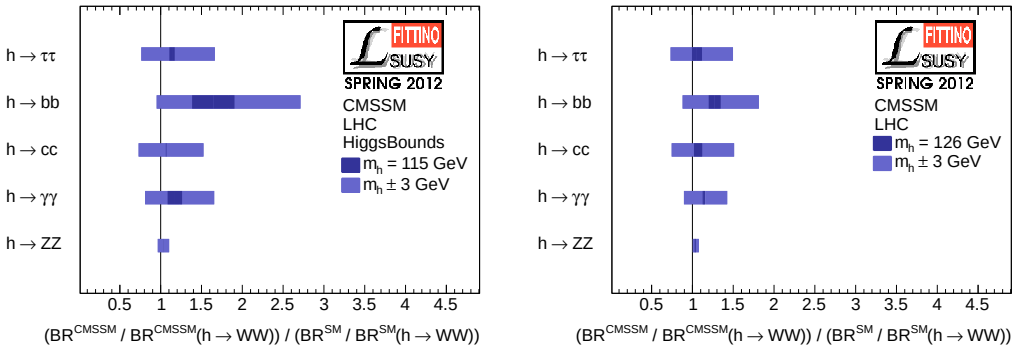
## 4 New Physics Parameter Determination

As in the years before, the work on the interpretation of New Physics models concentrated on the `HiggsBounds` and `Fittino` projects. `HiggsBounds` was significantly enhanced by new functionalities and is currently updated to include all available direct searches for Higgs-like states at LEP, the Tevatron and the LHC [26]. An example of the use of `HiggsBounds` to set limits on a Randall-Sundrum model is shown in Fig. 3. `Fittino` [25, 31, 38] was also further developed to include a representation of up-to-date LHC SUSY searches and a large




(a) (b)

Figure 4: *(a) shows the result of the re-implementation of the inclusive ATLAS search used for setting exact limits on SUSY parameters in the Fittino project. An exact agreement between the official result and the free implementation is found, validating the use of the free implementation for setting limits on other models and parameter ranges than the ones directly tested within ATLAS. In (b), the resulting $\chi^2$ profile for different masses of the lightest SUSY Higgs boson are shown, clearly indicating that $m_h \approx 125\,\text{GeV}$ is not preferred by constrained SUSY models [38].*




(a) (b)

Figure 5: *The allowed range of ratios of Higgs branching fractions with respect to the nominal SM values for the same $m_h$. In (a), for the current Higgs limits, and in (b) for a potential value of $m_h = 126\,\text{GeV}$. A wide allowed range is observed within the allowed SUSY parameter space, taking constraints from direct SUSY searches, astrophysics, cosmology and precision results into account. This shows that measurements of ratios of branching fractions, at LHC or potentially much more precisely at a linear collider, still have a huge potential for constraining SUSY even in simple models like the CMSSM [38].*

amount of cosmological and precision observables. It is used to study the implications of a possible Higgs-like state at around $m_h = 125\,\text{GeV}$ (see Fig. 4) and to show that the possible future measurement of Higgs branching fractions can still have a significant effect on constraining the SUSY parameter space even for very constrained models like the CMSSM (see Fig. 5).

In addition, the group used its expertise in interpretations to contribute to general recommendations for the interplay between theory and experiment in the LHC era [35, 36].

## 5 Other Activities

The group has been strongly involved in setting up a cosmic ray detector for the use in high schools. The project is now fully integrated into a Germany-wide "Netzwerk Teilchenwelt" and run by DESY Physik Begreifen.

## 6 Summary

In summary, while no signs of New Physics have been found to date, the group contributed to the advancement of constraining the available parameter space of SUSY models, both by providing experimental results and by the means of phenomenological interpretations. In addition, tools for the interpretation of data are provided, important contributions to the ATLAS data taking and analysis software have been developed, SM measurements have been made, and contributions to the broader understanding of the possible experimental program at the ILC have been made.

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