Helmholtz Alliance - HA-101

„PHYSICS AT THE TERASCALE“

Annual Report 2014 and Final Report (April 2014)

Project Number	HA-101
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1 Summary: Project Development

1.1 Introduction

The Helmholtz Alliance "Physics at the Terascale" (www.terascale.de) is a network founded in 2007 that comprises the Helmholtz centres DESY and KIT, 18 German universities and the MPI for Physics in Munich. The aim of the Alliance is to strengthen the German particle physics community in the global competition in the field; a key element of the Alliance is communication and collaboration among the various partner institutions, between physicists working on different experiments, and between experiment and theory.
The Alliance focuses on four work packages: physics analysis ("analysis project"), grid computing ("grid project"), detector development ("detector project"), and accelerator research ("accelerator project"). In all four projects, the Alliance concentrates on scientific exchange as well as on training and education. Furthermore, dedicated Alliance fellows supported numerous existing projects, and new projects were initiated, often by means of young investigator groups initially financed by the Alliance and later made permanent by the hosting partner institution.
The original Alliance funding from the Helmholtz Impulse and Networking Fund (IVF) consisted of 5 million € per year; it was granted from project start in July 2007 to the end of 2012 (funding was maintained for 5 years, but the spending period was extended by half a year). The Helmholtz funds were supplemented by approximately twice this amount from the partner institutions, mostly in the form of (often permanent) positions. The original IVF funding came to an end at the end of 2012.
For the years 2013/14 a reduced funding of 0.5 million € per year had been granted, which was supplemented by about 1 million € from DESY base funds (used mainly for Alliance-relevant positions, computing infrastructures etc.) and by a similar amount from the university partners, mainly for the continuation of positions. About 0.375 million € per year were used for three dedicated projects described later in this report. The remaining 125000 € were used for schools, workshops, travel, etc..

1.2 8th Annual Workshop in 2014

In December 2014, the eighth annual workshop of the Alliance took place at DESY in Hamburg. Over 270 participants enjoyed three days of plenary and parallel talks and the opportunity for scientific exchange among their colleagues, indicating that even 8 years after its conception, the Alliance continues to be a relevant and attractive concept.

As in past years, the focus of the meeting was on the various Alliance projects, with parallel sessions for the analysis, grid, and detector projects. Furthermore, the various physics topics were also covered by dedicated parallel sessions on Higgs physics, physics of the Standard Model, top physics, and a session devoted to SUSY and exotics. Furthermore, a dedicated "ILC forum" was held, discussing the physics prospects for the ILC, but also the general outlook on this next big project of high energy physics. With LHC Run 2 about to begin, and with movement in Japan concerning the ILC, the presentations were accompanied by many interesting discussions!

Various high-level speakers in the plenary sessions provided their specific views on the Terascale: Former ATLAS spokesperson Peter Jenni (CERN/Freiburg) gave a historical overview of the LHC and its experiments, Markus Elsing (CERN) discussed history of and prospects for computing at the Terascale, and Thomas Gehrmann (Zurich) sketched the developments on the theory side during the Terascale years. Harry Weerts

(Argonne) described the prospects for the ILC, while Christophe Grojean (DESY) described the "world with 100 fb^{-1} of data from the LHC".
Also in view of the changes to the Helmholtz programme structure and the ideas for a new MUTLink network (see later), representatives from other communities were also invited: Christopher Wiebusch (Aachen) and Peter Braun-Munzinger (GSI) gave overviews of recent developments in astroparticle physics and from the field of hadronic and nuclear physics, respectively. Johannes Bluemer (KIT), finally, sketched the future of our fields of research inside the Helmholtz research area "Matter".

The workshop was rounded off by a satellite meeting of the PETTL project (see later in this report) and by a meeting of the NAF user committee NUC. A welcome reception, a public display of the LHC movie "Particle Fever" and a dinner at a scenic Hamburg location provided agreeable occassions for relaxation, entertainment and friendly exchange.

1.3 Project Development in 2014 and Future Directions

As in 2013, and despite the reduced funding, most Alliance projects proceeded well in 2014, and the related infrastructures continued to be heavily used by all partner institutions. Examples are the irradiation facility at KIT, the testbeam at DESY and the DESY and university Tier-2 centres plus the National Analysis Facility.

Also in 2014, the school and workshop programme of the Alliance was continued, with again many hundreds of physicists at all career levels participating in discussions, training events and scientific exchange.

An important topic discussed at the Annual Workshop and elsehwere was the future of the Terascale Alliance. There was unanimous agreement that the Terascale Alliance will need to continue, and that a strong need exists to ensure the continuation of central Alliance activities like the school programme. Currently a new organisational basis is being defined.

1.4 Sustainability Outlook

Even though the central funding of the Alliance has come to an end, the partners have agreed to fund from their own funds a core programme. DESY will support the schools and workshop programme from its own base funds at a level comparable to that of the years 2013 and 2014. All partners will continue to participate in the scientific program of the alliance through the approximately 30 tenured positions at universities and DESY. The following activities are secured:

- A constant level of training events and workshops on LHC and ILC physics and other topics (scientific and technical);
- the possiblity to support travels of Alliance members;
- the Alliance Forum;
- the maintenance of an Alliance guest and visitor programme.

In this sense – and especially considering the rather large number of tenured positions that were initally financed by the Terascale Alliance and that otherwise would not be available for HEP today – the Alliance has reached its goal of creating new structures and establishing new ways of communicating and collaborating within the German HEP community!

The potential to take up new activities or to react promptly to new developments, however, requires additional funds (for short-term manpower, for equipment which suddenly becomes necessary etc.) that are currently not available.

One hope in this respect focuses on the plans for the MUTLink network that is intended to be a platform for Terascale, EMMI and HAP inside the Helmholtz programme „Matter and the Universe“ and that simultaneously provides links to the universities and to the programme „Matter and technologies“. A proposal for MUTLink funding has been handed in to Helmholtz in early spring 2015; if successful, it would provide the means for new initiatives (project startup, positions etc.).

1.5 Management

In the current transition period, where the old Alliance grant has ended and a new MoU is not yet signed, the former Alliance governance structures are kept in place, and all former members of Alliance bodies were asked to remain in their respective positions.
Therefore, the Project Boards are still responsible for the Alliance research topics, have a steering and monitoring function and provide the management with first-hand information about ongoing activities, plans and ideas. The Management Board has the overall executive power, while the Institute Assembly, with one representative per partner institute, forms the Alliance “parliament” and decides about structures and general directions.

2 Main Scientific Achievements and the Alliance Research Projects

2.1 Main Scientific Achievements

Despite the shutdown of the LHC, the year 2014 was full of excited anticipation: for the LHC Run 2 of the LHC, for news from the ILC project, and for the final LHC Run 1 results.
While all current measurements hint to the Standard Model character of the Higgs boson discovered in 2012, both experimentalists and theorists in the Alliance and elsewhere are preparing for ever more scrutiny of the new particle using the new LHC data that will come in in 2015 and new and refined theoretical tools and predictions. Alliance members are at the forefront of this research, as they are in the efforts toward the realisation of the ILC or of the Belle II experiment.
The ILC technical design report (TDR), which was published in 2013, contains numerous significant contributions made by Alliance physicists on the physics, on the machine and on the detectors. Since the vote of the Japanese community for a specify potential construction place (the Kitakami mountain region in the Iwate prefecture), site-specific work has started, and again Alliance members are deeply involved in this work which, hopefully, will lead up to a decision to build the ILC in Japan.

Due to the diverse nature of the Alliance and the specific organisation of our field of research – collider-based high energy physics – it is rather complicated to give a list of the main scientific achievements of the Alliance. It should, however, be stressed again, that it is the networking and communication among the Alliance partners that are considered to have had the most significant impact on the field, providing a noticable boost to the German contributions in the internationally organised research in particle physics. This effect – though difficult to measure – was and is felt by Alliance partners and by peers from other countries alike.

The following short sections on the four projects of the Terascale Alliance also contain the most significant results obtained in the past 7 or so years, without claiming or even aiming at completeness. For a more technical overview of achievements, the reader is referred to the previous annual reports and their publication lists.

2.2 The Analysis Project

The Analysis Project Board aimed at supporting and coordinating analysis activities within the German LHC and ILC community. This was done by running an Analysis Centre, supporting analysis working groups, and running a virtual theory institute. In the past years, the Analysis Project Board members were: Herbi Dreiner (Bonn), Martin Erdmann (Aachen), Stefan Gieseke (KIT), Michael Kobel (Dresden), Klaus Moenig (DESY), Thomas Schörner-Sadenius (DESY), Peter Uwer (Berlin), Stephanie Hansmann-Menzemer (Heidelberg), Georg Weiglein (DESY).

The Analysis Centre was specifically running working groups on Monte Carlo (MC) generators, parton distribution functions (PDFs), statistics tools and SUSY/BSM parameter fits. These topics were chosen for several reasons: First, they are experiment-independent, i.e. developments here are beneficial not only for one of the LHC experiments or only the ILC community, but for several of them. They also provide natural connections between experiment and theory. And finally, in all these areas significant expertise was available at DESY. Therefore, most groups had at their hearts one DESY scientist who, together with other designated colleagues, formed the nucleus of the group and aimed at attracting collaborators from other German institutes. In the case of the Monte Carlo group a young investigator group at KIT was established in addition.

The Monte Carlo group worked specifically on aspects of Monte Carlo tuning, on parton shower developments and on specific Monte Carlo generators. The group also provided support to the whole German community in questions related to the basics and to the application of Monte Carlo generators; a significant contribution in this respect were the Monte Carlo schools, which were held on an annual basis at varying Alliance partner institutions, attracting, over the years, close to 500 physicists. The Monte Carlo schools will also be maintained in the future.

The objective of the SUSY/BSM parameter fitting working group – a joint effort by theorists and experimentalists – was to provide optimal means to fully exploit available and future data with respect to supersymmetry and other new physics models. The group produced fits to LHC SUSY searches and contributed to the exclusion of numerous specific models and predictions. During the course of the Terascale Alliance, the group became part of a larger effort centered at the CERN LHC Physics Centre.

Like the MC group, the statistics tools group aimed at providing support to the whole community in terms of statistics tools and methods; main efforts in achieving this objective were schools on statistics (ranging from basics to rather advanced issues), or informal statistics discussions open to everybody that were organised and supervised by acknowledged experts. The statistics tools group in the Analysis Centre also supported numerous well-known statistics projects and software packages, ranging from the "Bayesian Analysis Toolkit" BAT - a statistical analysis package heavily used by the LHC collaborations – to TMVA (a toolkit for multi-variate analysis). The support was given in the form of manpower funded by the Analysis Centre or through direct contributions, e.g. DESY fellows or other junior physicists who contributed part of their working time.

Members of the PDF working group held core responsibilities in the efforts that, during the course of the Alliance, became the AB(K)M PDF set and the HERAFitter project. Both projects are now well established in the community, and the HERAFitter tool is used by many LHC physicists for performing precision QCD analysis of the proton’s

parton distribution functions. Both projects were not only driven by Alliance members (mostly from DESY), but also profited immensely from Alliance support in terms of funding and manpower. The support for HERAFitter continues even today in the form of two FTEs.
Another focus of the PDF group was the education aspect; like the MC and statistics tools group, the group performed several schools, educating young scientists and attracting them to this specific aspect of high energy physics at the Terascale.

Further, more dedicated working groups existed that were designed to work – maybe even only for a limited time – on very specific questions that touched upon the current research interests of the LHC experiments and theory, and that combined colleagues from several institutes and from both experiment and theory. In short, the following groups were formed and maintained for some time:

- The “Central Jet Veto” group aimed at methods to identify the vector boson fusion production reaction for Higgs bosons;
- the group on “Higgs boson production in association with heavy quarks” also worked in the field of Higgs physics, trying to establish signals that are most profitable in conjunction with heavy quarks;
- the “M-tau-tau” group focused on final states of Higgs-boson production with two tau leptons. The group is still active;
- the group “Neutrino masses and lepton-flavour violation at the LHC” investigated very specific scenarios of new physics beyond the Standard Model.

These working groups typically consisted of members from both LHC experiments and theorists and where meant to develop common tools for data analysis and to understand theoretical problems in the analysis. The groups typically met during the yearly Alliance meetings and in many cases also in between.

The Analysis Centre also acted as a general forum for sharing information and for communicating, and consequently, one of the main tasks of the Centre was the organisation of meetings, of workshops and schools, and of a rich guest programme that also included the “Theorist of the Month” programme conducted at DESY. These activities are described below.

2.3 The Grid Computing Project

The Grid Project of the Terascale Alliance has significantly contributed to the grid infrastructure in Germany. The Alliance made major contributions in the area of Tier-2s at the university sites Aachen, Freiburg, Göttingen, Munich and Wuppertal, and it closely collaborated with DESY and the Max-Planck-Institute for Physics in Munich (Tier-2 centres for ATLAS, CMS and LHCb) and with KIT (German Tier-1 GridKa).

In 2013 and 2014 the grid project continued its work, focusing the available interim funding on five work packages:

- WP1 “Development of reliable and high performance access to LHC data through the dCache project”
- WP2 “Performance monitoring of grid jobs, sites and services”
- WP3 “Virtualisation techniques and the management of job submission and workflows in distributed computing infrastructures”
- WP4 “Improvement of networking connections in Germany and the international connectivity”
- WP5 “General support for site operations, training and schools”

Project partners are RWTH Aachen, DESY, Wuppertal, Göttingen, KIT and LMU München. The work packages are discussed in detail in Sect. 3.3.

Project coordination and advisory role for German HEP computing

Computing and the distributed computing infrastructure of the grid are of strategic importance for the success of the LHC and other HEP experiments. Germany is taking a leading role in worldwide grid computing, providing substantial capacity with a very reliable performance.

In the recent past, the mandate of the Grid Project Board was extended (and the board called „Computing Board"), turning it into a communication and coordination forum for all German HEP computing aspects. This change clearly acknowledges the expertise and impact of the Terascale computing efforts. The Computing Project Board is advising the German representation of the particle physics community ("Komitee für Elementarteilchenphysik", KET) in all matters related to computing.

The members of the original Terascale Grid Project Board were: Andreas Heiss (KIT), Arnulf Quadt (Göttingen) Günter Duckeck (LMU München), Günter Quast (KIT), Markus Schumacher (Freiburg), Matthias Kasemann (DESY), Thomas Kress (RWTH Aachen), Volker Gülzow (DESY), Christian Zeitnitz (Wuppertal).

For the extended mandate additional representatives from German Tier-2 computing centers as well as from other experiments joined: Torsten Harenberg (Wuppertal), Hartmut Stadie (Hamburg), Michael Schmelling (Heidelberg), Peter Malzacher (GSI), Stefan Kluth (MPI München), Thomas Kuhr (KIT).

In 2013 the status and prospects of computing for data analysis in Germany was discussed by the Computing Board during a workshop in Wuppertal. In April 2014, a further two-day workshop focused on the broader topic of HEP related software and computing developments in Germany. Topics discussed included GPU- and ARM-processing, cloud computing, WAN data access, multicore, multithreading and parallel programming projects, use of HPC computing, modern tracking algorithms developments and implementations, analysis framework developments, detector alignment and event displays. The status of various projects was also presented in parallel sessions at the annual Terascale workshops in December 2013 and 2014.

The Computing Board also delivered a report on the status and outlook of computing needs for HEP in Germany. The report describes in detail the German infrastructure for LHC computing and its usage and the needs of the experiments for the next five years. It includes the estimates for data analysis of the Belle-2 experiment. This planning was updated in fall 2014 to reflect recent developments and changes in schedule.

Summary

The requirements for technical data analysis tools for the Tier-2 centres and the NAF are growing strongly, driven by the upcoming LHC Run 2 and the Belle-2 experiment. Based on past experience, the experiments are constantly evolving their analysis concepts, making ever more use of dynamic data allocation to storage and CPU recource centers. The efficient management of large amounts of data and their analysis require the deployment of sophisticated storage solutions. New search and access methods for data reduction, strategies for efficient utilization of fast and reliable networks, and tools for dynamic data management and use of data caching were developed and are deployed for the start of LHC Run 2. The Terascale grid project played a key role by contributing to the developments and the deployment of the updated infrastructure tools for HEP data analysis in Germany.

2.4 The Detector Development Project

Detector development within the Alliance was and is coordinated by the Detector Project Board. The members of this board are Alexander Dierlamm (Karlsruhe), Doris Eckstein (DESY), Eckhard Elsen (DESY), Lutz Feld (Aachen, Chair), Ariane Frey (Göttingen), Hans Krüger (Bonn), Hans-Christian Schultz-Coulon (Heidelberg), Felix Sefkow (DESY), Stefan Tapprogge (Mainz).

One of the main achievements of the detector project – as of the whole Alliance – is the networking and communication across experiments and across institutes. There are now many new connections and collaborations that did not exist, and in fact would have been rather unusual, before the Alliance.

The annual detector workshop of the Alliance is a popular and unique forum to further foster this collaborative spirit. At the workshop, detector developments within the Alliance are presented and the challenges of future projects are discussed. In 2014 the workshop was held at Göttingen University[1] (3-7 March 2014). With 64 participants it was again very well attended. This time the focus was put on „Detector Development for ILC“, „Active pixels and 3D Integration“, and a joint session with the PETTL project (see below) on the upgrades of the ATLAS and CMS outer trackers. The workshop was accompanied by a school on „TCAD Simulation of Silicon Sensors“, which was attended by 22 participants.
Based on the very positive feedback from the community it is planned to continue the series of Terascale detector workshops beyond the end of Helmholtz funding for the Alliance. The detector workshop 2015 already took place at Humboldt University Berlin[2] (2-6 March 2015).

A further area where the Alliance had a massive impact is that of maintenance of existing infrastructures, and the erection of new ones. Examples to be mentioned are the chip design facilities in Bonn and Heidelberg, the silicon sensor facility in Hamburg, or the facilities for gaseous detectors in Aachen. Although these facilities are predominantly used by the respective local groups, it is fair to say that numerous detector development activities in German would not have been – and still would not be – possible without the support from the Alliance – the Alliance decidedly advanced the field of detector development in Germany!

During its extension into the years 2013 and 2014, one project from the area of detector development is funded by the Alliance. It has been selected by the international advisory panel from a number of very good proposals. The title of this project is ‘Enabling Technologies for Silicon Microstrip Tracking Detectors at the HL-LHC’, abbreviated as „PETTL“ (see below, Sect. 3.1). Results of previous work have been described in earlier annual reports.

2.5 The Accelerator Physics Project

The accelerator physics project in the Alliance started with two objectives, namely to engage in the training of students in accelerator science and to maintain and advance the scientific expertise in superconducting radio-frequency (RF) acceleration that had been accumulated within the TESLA collaboration and subsequently was foreseen for the International Linear Collider ILC. For that matter and as an initial step, the university

[1] https://indico.desy.de/conferenceDisplay.py?confId=9389
[2] https://indico.desy.de/conferenceDisplay.py?confId=10967

base was to be broadened and Hamburg University was provided with a young investigator (“Young Investigator Group”, YIG) position with tenure option at DESY. This widely visible signal and continuing support from both KET and the Alliance led to a broader recognition of accelerator physics as an enabling science for progress in particle physics, which today is exemplified by the foundation of the Komitee für Beschleunigerphysik as a body to promote the scientific goals of accelerator research, including novel accelerator concepts.

While an excellent researcher could be attracted from Berkeley for the YIG position mentioned above, Hamburg University opened a full professorship for novel accelerator physics and DESY started to open its infrastructure for experiments in novel accelerator concepts. In particular the unique features of the electron bunches at the FLASH user facility made it possible to plan a major installation on fundamental beam-driven experiments at DESY, which is now under way as the FLASHForward experiment. FLASHForward will inject ultra-short electron bunches from FLASH into a dedicated plasma cell and shape and measure beam properties in a reproducible fashion. Beyond FLASHForward, DESY has started to engage in a major facility and collaboration in the Helmholtz ARD programme.

The research on superconducting RF is home to DESY and profits from the synergy with the construction of the European XFEL. The contributions of the universities of Wuppertal and Hamburg and of DESY to this topic inside the Alliance were fundamental in establishing one of the primary goals of the ILC Technical Design, an accelerating gradient in excess of 30 MV/m. Bonn university provided access to the ELSA accelerator for e.g. polarisation and beam dynamics studies.

Last but not least the Alliance fostered the training of students: the two Alliance accelerator schools, the accelerator sessions at the annual meetings and the exchange of personnel between institutes contributed to establishing the accelerator topic at the relevant level, a progress that is widely acknowledged today.

3 Reports from Specific Funded Projects

3.1 The “PETTL” Project

The tracking detectors of the ATLAS and CMS experiments have shown excellent performance in LHC Run 1 and are expected to continue to do so during LHC operation at design luminosity. Both experiments will, however, have to exchange their tracking systems when the LHC is upgraded to the high-luminosity LHC (HL-LHC) around the year 2024. The new tracking systems need to operate in an environment in which both the hit densities and the radiation damage will be about an order of magnitude higher than today. In addition the new trackers need to contribute to the first-level trigger in order to maintain a high data-taking efficiency for the physics processes of interest. Novel detector technologies have to be developed to meet these very challenging goals.

The German groups active in the upgrades of the ATLAS and CMS tracking systems have formed a collaborative "Project on Enabling Technologies for Silicon Microstrip Tracking Detectors at the HL-LHC" (PETTL), which was supported by the Terascale Alliance during the years 2013 and 2014. The involved groups were from RWTH Aachen University, Humboldt University Berlin, DESY, University of Freiburg, Hamburg University, and from the Karlsruhe Institute of Technology. The aim of the project was to share experience and to work together on key areas of mutual interest during the R&D phase of the upgrades.

Five work packages have been selected: Exchange of experience, Radiation Hardness of Silicon Sensors, Low-Mass System Design, Automated Precision Assembly Procedures, and Irradiations. Three workshops have been organized in the course of this project: 28 February – 1 March 2013 at Mainz University, 6-7 March 2014 at Göttingen University, and 1-3 December 2014 at DESY Hamburg. The following examples may give a flavour of the obtained results.

Within the work package “Exchange of Experience”, experts from both experiments reported on their experience gained during the development and construction of the current ATLAS and CMS tracking detectors. A list of ‘lessons learned’ was synthesized from these reports and made available to the groups. In a second step the ongoing activities and plans for the tracker upgrades were confronted with these lessons such that weaknesses of these developments could be spotted and addressed.

In order to develop sufficiently radiation-hard silicon sensors both experiments have performed extensive measurement campaigns on test structures and sensor prototypes. Within the PETTL project, the results of these independent measurements have been compared by experts from both experiments. This has resulted in a much improved mutual understanding of these results. The combined results have then been used to improve the models of radiation damage in silicon.

The silicon sensors have to be mounted with a high precision of the order of 10 micrometers in order to achieve the necessary track measurement accuracy. While the mounting structures in the ATLAS and CMS trackers are different it is very instructive to compare the requirements and the solutions followed in the two experiments. Moreover there has been a collaborative attempt to develop a precise assembly scheme for silicon sensor modules. This included studies on novel gluing techniques, which will allow the collaborations to substantially increase the assembly rate.
In summary, the PETTL project was very successful in establishing a fruitful exchange between the groups from the two experiments as well as in strengthening the link between DESY and the University groups. This collaboration will continue beyond the formal end of the Alliance.

3.2 The „Semi-inclusive and Inclusive Hard Scattering Processes“ Project

During the years 2013 and 2014, the analysis project ``Semi-inclusive and inclusive hard scattering processes'' made essential field-theoretic, phenomenological and experimental contributions to precision particle physics at the LHC and HERA. By collaboration of institutions at six German sites (Freiburg, Hamburg, Mainz, Karlsruhe, Wuppertal, Zeuthen) a far deeper understanding has been obtained on the Drell-Yan process and hadronic weak boson production at the LHC, giving new insight into the nucleon's light-quark structure. Large progress has been made on heavy-quark production at HERA and LHC (up to the 3-loop QCD corrections) and on the deeper understanding of various top-quark production processes and of the top-quark mass. Furthermore, jet production at LHC has been explored in much greater detail. All these processes contributed to the improvement of the accuracy of the parton distribution functions (PDFs), the strong coupling constant $\alpha_S(M_Z^2)$, and the heavy-quark masses for charm, bottom and top in exclusive and inclusive processes.

Di-muon production, Drell-Yan process and weak boson production
One major goal of the project consisted in determining the different sea-quark flavor distributions at higher accuracy, combining recent data obtained at the LHC, Tevatron, and at fixed-target experiments. In particular, the so far poorly known strange-sea distribution has now been obtained with smaller errors. It was found to be consistent with the strange-sea suppression observed in earlier experiments on di-muon production in neutrino-nucleon deep-inelastic scattering (DIS). The theoretical framework of the analysis including the updated next-to-next-to-leading-order (NNLO) corrections to the charged-current heavy-quark DIS Wilson coefficients has been published as an open-source code.

Also the valence-quark distributions have been improved by using precise measurements of different LHC processes, in particular the muon charge asymmetry in W-boson production. Here, for the first time, the associated production of W bosons and charm quarks at the LHC was used to directly probe the strange-quark distribution in CMS and ATLAS. New modules in *HERAFitter*, which were developed for this analysis, have been used. A combination of these data with further data from the LHC has shown that the results are compatible. The inclusion of data from neutrino experiments gave invaluable insights into the strange-quark distribution and its constraints from different sources.

The sensitivity of the parton distribution functions to the published Drell–Yan cross-section measurement using the 2011 LHC data set was tested using *HERAFitter*, and a strategy was devised on how to optimize the analysis for the 2012 data. In particular, the single-differential cross-section measurement as a function of the di-lepton mass using the 2011 data was extended to two double-differential measurements as a function of mass and rapidity and as a function of mass and the pseudorapidity difference between the two decay leptons. The former double-differential measurement is predominantly sensitive to PDFs, while the latter is sensitive to electroweak corrections.

Heavy quarks in DIS
The analytic calculation of the 3-loop corrections of the heavy-flavor Wilson coefficients for the deep-inelastic structure function $F_2(x,Q^2)$ in the region $Q^2 >> m_Q^2$, with m_Q the heavy quark mass, and the 3-loop transition coefficients in the variable flavor number scheme made further progress. The corrections are needed to perform consistent NNLO QCD analyses of the deep-inelastic scattering world data. Moreover, the $O(\alpha_S^2)$ heavy-flavor corrections for deep-inelastic charged-current scattering were calculated and are ready for experimental analysis. First measurements of charm-quark production at HERA were included into the simultaneous determination of the charm-quark mass and parton distributions and used for for the first ever measurement of the charm-quark mass running.

Top-quark pair production
The pole mass of the top quark was determined by using the LHC measurements of the top-quark pair production cross section, and, alternatively, by exploring the top-quark decay kinematics. The LHC measurements of inclusive jet and top-quark pair production were used to determine the strong coupling constant at next-to-leading order (NLO) and NNLO, respectively. Within the project, the phenomenological tools were created to include the measurements of the differential top-quark pair production into a QCD analysis at NNLO, and the potential of top-quark pair production measurements to improve the accuracy on the gluon distribution at high x was demonstrated.

Single top production
Comprehensive cross-section measurements of single top-quark production in the t-channel were carried out. Due to the bottom quark in the initial state, the inclusive cross section of this process is sensitive to the b-quark density. When separating top-quark and top-antiquark production, the cross sections are sensitive to the u-quark and d-quark PDFs in an x range between 0.02 and 0.5. Taking the ratio of the cross sections reduces the experimental uncertainties through cancellation. In addition to the inclusive cross-section measurements also differential cross sections in top-quark (top-antiquark) p_T and |y| were provided. The analysis uses ATLAS data recorded in the year 2011 at a center-of-mass energy of 7 TeV. Both the measurement of the cross-section ratio and the differential cross sections in single top-quark production are the first measurements of these quantities ever and have been pioneered by the Wuppertal group, with the idea of making these measurements available to further constrain PDFs. The PDFs that agree best with these measurements are those of Alekhin, Blümlein, Moch (Phys.Rev. D86 (2012) 054009), which are not based on LHC data.

A large portion of the work on the analysis went into studies on Monte Carlo generators for the signal process. The studies resulted in a change of the default Monte Carlo from the leading-order generator *AcerMC* to the next-to-leading-order generator *POWHEGBOX*. In the future, the analysis will be performed in a similar manner on the 8 TeV data set.

Heavy final states
The NLO QCD corrections to hadro-production of $W^+W^-bb(bar)$ and tt(bar)bb(bar) matched to parton showers through the *PowHel* method (*HELAC-NLO+POWHEGBOX*) were studied. In particular, as for tt(bar)bb(bar), an analysis according to cuts provided by the CMS experimental group at DESY aimed at both optimizing these cuts and at providing theoretical predictions at the hadron level, also including MPI effects, for this relevant background to tt(bar)H. As for $W^+W^-bb(bar)$, a comparison activity started aimed at comparing *PowHel* predictions, also including single resonant and non-resonant diagrams, with *POWHEGBOX* predictions of tt(bar)➔ $W^+W^-bb(bar)$, including NLO top decays as obtained by the group of P. Nason. This activity aimed at understanding the effects of resonance treatment and parton shower on predictions for the W-b invariant mass.

Analysis of LHC jet data
Further progress has been made in analyzing hadronic jet production at the LHC at NLO. The work is composed of two parts: First, further developments of the *fastNLO* tool allowed us to prepare a more generic package, the *fastNLO* toolkit (version 2.3), separating the access to its fast interpolation capabilities from the individual implementation used with the *NLOJet*++. Subsequently, the new version has been interfaced to the *DiffTop* package for fast repetitions of the cross-section calculation of differential top-quark pair production at approximate NNLO order. In addition, the new *fastNLO* version has been integrated into the *HERAFitter* project, replacing the previous less flexible one.

As a second part, the tool development has been accompanied by work on the experimental side to ensure the usability and completeness of the experimental data for the inclusion into combined fits. Within the CMS collaboration this lead to a publication in which the potential of inclusive jet data to reduce the gluon PDF uncertainty at high momentum fractions x is demonstrated.

The high potential of the LHCb heavy-flavor production measurements for reducing the uncertainty of the gluon distribution has been demonstrated. At medium values of x, the measurements of inclusive jet production at the LHC could be shown to improve the uncertainty on the gluon and light-quark distributions. In the region of very high x, which is particularly important for searches for physics beyond the Standard Model, the uncertainty of the gluon distribution is particularly large. For the jet analysis it is expected that the present analysis scheme can be extended to NNLO upon the arrival of the NNLO di-jet QCD corrections, which will be finished in one year's time. This analysis will then provide competitive determinations of the strong coupling $\alpha_S(M_Z^2)$ and a significant improvement on the gluon distribution function.

Two collaboration meetings were held in November 2013 and 2014 at Liebenberg Castle and Berlin-Brandenburg Academy of Sciences to discuss work progress and results.

3.3 The Grid Project „Performance optimisation for the present and next generation HEP data analysis on the grid“

WP1 - Development of reliable and high-performance access to LHC data through the dCache project (Aachen, DESY, Wuppertal)
DESY is coodinating the dCache project and at the same time is also the main German dCache development site. For LHC Run 2 the data management models changed towards a „mesh network topology“ with a stricter separation of tape-based and disk-based storage. The developments of new data access and transfer protocols were completed and deployed in all German WLCG sites.
The use of intelligent, self-organizing storage area network with data tiering as a backend for dCache enabled storage systems was investigated in Wuppertal. The high-performance access to frequently used data and to data-sets accessed less frequently, which are automatically stored on lower-cost disk drives, was investigated. Extended dCache support to all German HEP grid sites together with hands-on tutorials for dCache administrators during the annual GridKa School and special dCache workshops was provided by Aachen.

WP2 - Performance monitoring of grid jobs, sites and services (Göttingen)
The distributed HEP grid computing systems are increasing in complexity because of the inclusion of more heterogenous resource infrastructures. The new HappyFace system has been successfully integrated with a new strategy to allow seamless displays of the information and the status of both the monitoring resources and the direct access to the grid user applications and the grid collective services in the ATLAS computing system.
To improve stability and reliability of the computing infrastructure, a feature selection method by support vector machines was applied to the extraction of components in the infrastructure. The „Adaptive Neuro Fuzzy Inference System“ (ANFIS) was used for the prediction of the service response time and failures for short and long periods. An evaluation of the approaches is performed on real monitoring data from the WLCG Tier-2 center GoeGrid. The results demonstrate high efficiency of both approaches in comparison to known methods.

WP3 - Virtualisation techniques and the management of job submission and workflows in distributed computing infrastructures (KIT, LMU München)

A prototype cloud system was installed at KIT to develop and adapt interfaces for the experiment workflows management system to virtual resources and to gain operational experience. All CMS- and grid-specific services were operated in a virtualized environment based on OpenStack. This test was extended to a test system of a new HPC cluster at Freiburg university towards the end of the project. Both the local OpenStack and the Freiburg cluster have been integrated into the workflow management system. In addition to the pure provisioning of CPU resources, remote access to CMS data and stage-out of results to WLCG sites were demonstrated.
The LMU group participates in the development and operation of the "HammerCloud" system, the tool for systematic tests of remote infrastructures for grid jobs. It is used in ATLAS and other experiments for a wide range of different aspects in job and workflow management. It is an essential prerequisite for the investigation and deployment of new workflows, such as jobs using wide-area IO or alternative data access protocols.

WP4 - Improvement of networking connections in Germany and the international connectivity (DESY, KIT)
The original LHC data model has evolved away from a strict hierarchical model; analysis data are accessed remotely from any site world-wide. For data analysis the LHC open network environment ("LHCone") complements the LHCOPN which connects CERN and the Tier-1 centers. LHCone is providing entry points into a network that is private to the LHC Tier-1/Tier-2/Tier-3 sites for data analysis. The LHCone is connecting more than 120 sites world-wide; in Germany DESY, KIT, GSI, RWTH Aachen, and University of Wuppertal participate. Software-defined networking is a research activity performed within LHCone. It will allow central control of network traffic without requiring physical access to the networking hardware.
This work package was performed by the project partners without project support.

WP5 - General support for site operations, training and schools (KIT, all sites)
The German dCache support team provides support to German dCache users. The annual International GridKa Computing School is attended by more than 130 participants. It is one of the leading summer schools for advanced computing techniques in Europe and is jointly organized by KIT and the Terascale Alliance.
This work package was performed by the project partners without project support.

4 Schools and Workshops

4.1 Events in 2014

Like the years before, 2014 was full of events, addressing again several hundreds of members of the Alliance. The following table gives an overview. All in all, almost 800 physicists from all career levels participated in and contributed to Alliance events – not counting the close to 300 participants of the annual meeting held at Hamburg from 1-3 December[3].

Name	Date	Place	Participants
Fast Monte Carlo in HEP	14-16 January	Zeuthen	32
7th Terascale Detector Workshop	3-7 March	Göttingen	64
Monte Carlo School	10-14 March	Hamburg	35
Introduction to the Terascale	17-21 March	Hamburg	31
Statistics School „Measurement Time“	31 March – 4 April	Hamburg	52

[3] The list of workshops, and the total count of events over the entire Alliance lifetime, does not contain small working group meetings or numerous conferences and workshops that were organisationally supported by the Alliance – of which hundreds have taken place.

Linear Collider Forum	29-30 April	Bonn	32
Parton Showers, Event Generators and Resummation	11-13 June	Münster	47
C++ School 2014	16-20 June	Hamburg	38
Advanced Programming Concepts 2014	23-27 June	MPI Munich	36
Beam Telescopes and Testbeams for Detector R&D	30 June – 2 July	Hamburg	57
Linear Collider School	11-15 August	Chiemsee	42
GPUs in HEP*	10-12 September	Pisa, Italy	78
Workshop on Vector-Like Quarks	15-16 September	Hamburg	29
Proton Structure in the LHC Era	29 September – 2 October	Hamburg	36
BSM Parameter Fitting Workshop	29-30 September	Hamburg	20
Higgs-mass precision calculations workshop - KUTS2*	20-22 October	Hamburg	21
Hamburg Higgs Workshop	22-24 October	Hamburg	61
Future Physics With HERA Data	11-13 November	Hamburg	72
8th Annual Terascale Meeting	1-3 December	Hamburg	274
Mtautau Workshop	3-4 December	Hamburg	10

Table 1: Overview of Alliance workshops and schools in 2014. The events marked with an asterix (*) were events organised by other entities but supported by the Terascale Alliance.

These high numbers of events and participants – which have basically been constant over the past few years – once again demonstrate the attractiveness of the Alliance and its concepts to the community of particle physicists in Germany – and beyond.

4.2 Summary of Alliance Events since 2007

All in all, far more than 200 events[4] (schools, workshops, seminars, working group meetings etc.) were held by the Alliance since its foundation until the end of funding in 2014. They attracted an estimated 7500 physicists from all career levels.
The education and networking / communication effects of these events are clearly the most significant result of the Alliance, and the Alliance management is working towards maintaining the offered programme at approximately the same level, now based on DESY base funding.

4.3. Future Developments

At the end of 2014, the responsibility for the organisation of Terascale events changed from Thomas Schörner-Sadenius, now acting as Scientific Manager of the Alliance, to Isabell Melzer-Pellmann, a senior staff member of DESY, and Kerstin Hoepfner, senior staff member at RWTH Aachen.

5 Backbone Activities and Networking

As described before, in the year 2014 only moderate funding from Helmholtz was available. These funds were used for the projects described in Sect. 3 (375000 €) and for maintaining a moderate backbone of Alliance measures – mainly the organisation of events, travel support for Alliance members, and a guest and visitor programme.
In the following few paragraphs, a few of the networking and backbone activities will be described, focusing on a summary of the full Alliance lifetime from 2007 until today.

[4] A comprehensive list of schools and workshops can be found on the Alliance web page www.terascale.de . The DESY INDICO system houses the numerous smaller meetings, working group meetings and seminars held by the Alliance.

5.1 Promotion of Early-Career Researchers

The promotion of early-career researchers was of central interest to the Alliance. Consequently, numerous measures were taken to support young scientists.

Roughly 550 students have finished their Ph.D. thesis at one of the Alliance institutes during the past 7 years. They all had the benefit of the huge Alliance network and of the far-reaching programme of events they could participate in. There is probably not a single Ph.D. student who graduated during the past 7 years who has not been to at least one Alliance school and to most of the Annual meetings of the Alliance! With this experience of a great and diverse network of first-class research institutions, the young scientists are optimally prepared for successful careers.

The Alliance, in the two rounds of its fellowship programme, directly funded more than 200 person-years of these fellows, which certainly enjoy a high reputation as they underwent a strict selection procedure and contributed to one of the many highly visible Alliance projects. And like all the post-docs, they benefited from the Alliance programmes (training, workshops, travel support, guest and visitor programme). The fellow positions were complemented by a number of technical positions (engineers and technicians) that the Alliance funded or supported over the years.

Besides the Alliance fellows, the Alliance fundedsix young investigator groups (YIGs), typically for a duration of initially five years and in exchange for the tenure commitment on the part of the hosting institution. The following YIGs were installed:

Name	Host institute	Status
Stefan Giesecke	KIT	tenured
Jens Osterhoff	DESY	tenured
Steffen Schumann	Göttingen	Professor
Arno Straessner	Dresden	Professor
Peter Uwer	Berlin	Professor
Wolfgang Wagner	Wuppertal	Professor

Numerous further (mostly technical or functional) positions that were initially funded by the Alliance have also been tenured at DESY (6), Bonn (3), Goettingen (1), Mainz (1), Siegen (1), Wuppertal (4), Würzburg (1). All in all, the Alliance has created 22 tenured positions and thus has developped considerable leverage in the field.

5.2. Grants and Awards

Numerous high-level grants and awards were given to Alliance members in the course of the past 7 years. They are too many to be mentioned here; instead, a selection of the most prominent examples shall be given here.

- As of 1 January 2009, Prof. Dr. Rolf-Dieter Heuer (previously DESY) was elected CERN Director General.
- DESY physicist Kerstin Tackmann (DESY) received the Hertha Sponer Prize of the German Physical Society (DPG) in 2013; she also received the Bjørn H. Wiik Prize. In 2014 Tackmann was awarded the IUPAP Young Scientist Prize in Particle Physics.
- DESY physicist Kerstin Borras was elected CMS Deputy Spokesperson for the years 2014 and 2015.
- Prof. Karl Jakobs (Freiburg) received the 2015 Stern-Gerlach medal of the German Physical Society (DPG).

- Dr. Kevin Kröninger (then Goettingen, now Dortmund) received the 2008 Otto Hahn Medal.

5.3 International Networking, Guests and Visitors, Theorist of the Month

An important part of the Terascale networking was the guest and visitor programme, one building block of which was the „Theorist of the Month“. The Theorist of the Month typically spent about a week at DESY or any other of the Alliance institutes to intensify the scientific exchange on ongoing projects and to educate his colleagues on his / her specific field of expertise. During the visit, typically one or two seminars are given, and numerous informal discussions took place that very often triggered increased collaboration and concrete projects.
For various reasons, the programme was run at a reduced level in 2014. The following table lists the theorists that visited DESY in 2014.

Theorist of the Month	Home institute	Time at DESY
Jeppe Anderson	University of Durham, UK	30 June – 4 July
Jesse Thaler	MIT, USA	2 – 6 June
Stefan Weinzierl	Mainz University	7 – 11 April
Howard Baer	University of Oklahoma, USA	17–21 March

The „Theorists of the Month“, however, were not the only visitors and guests that the Alliance invited and supported. Numerous other physicists – too many in fact to be mentioned – spent time at partner institutions or were invited from abroad to spend time within the Alliance network in order to work on common projects. This exchange, which even in the time of reduced Alliance funding could be maintained at a reasonable level, significantly contributed to the lively academic atmosphere of the Alliance.

A further part of the international networking was the very large number of Alliance physicists that were invited to international conferences to report on their projects. These were also often supported from Alliance funds.

5.4 Outreach

In 2014, no outreach activities were supported anymore by the Alliance. In former years, numerous activities were directly supported by the Alliance, e.g. the Weltmachine exhibition, the particle physics Master Classes, and others. These were reported upon in previous annual reports.

5.5 Equal Opportunities and Dual Career

In 2014, due to the reduced Alliance funding, no equal-opportunity or dual-career measures were supported anymore by the Alliance.
In the years before, from 2008 to 2012, six dual-career measures were supported in Berlin, Bonn, Freiburg, Hamburg, Karlsruhe and Wuerzburg, for durations of typically three and up to five years.

5.6 Interim Professorships etc.

During its course, the Alliance financed substitutes for their scientific managers at the Universities of Bonn and Wuppertal, and professors from Mainz and Hamburg have been funded to spend one year at CERN.

Several guest scientist had been invited and partially funded by the Alliance to work concrete projects for durations of up to half a year; the details can be found in the individual annual reports of the past years.

5.7 Other Support Activities

Other support activities comprise (list not exhaustive) numerous conferences and workshops in Germany in the field of particle physics, the arXiv preprint server operated by Cornell University, data network costs, and support for the university Tier-2 centres.

6 Personnel

Except for a very small number of persons funded by the Alliance within the three projects sketched above (3 Ph.D. students, 2 scientists and one technician), no explicit funding for personnel was available in 2014. Therefore, in the following table, we only report on other personnel involved in the Helmholtz Alliance projects in 2014:

	Male	Female
Diploma / Master students	152	35
Ph.D. students	217	69
Post-docs	144	44
Senior scientists	111	26
Technical staff (technicians, secretaries etc.)	66	10

The following table shows an overview of personnel employed by the Alliance from 2007 – 2014 (specified are person years financed by the Alliance):

	Number
Ph.D. students	104
Scientists	254
Technical staff	44

Finally, the following table summarises the numbers of personnel involved in the Helmholtz Alliance projects in 2007 – 2014 (again person years are specified):

	Number
Diploma / Master students	1150
Ph.D. students	1971
Post-docs	1406
Senior scientists	700
Technical staff	463

7 Publications and Dissertations

The complete list of Alliance-related publications for 2014 is attached to this report. In total there were 441 papers published in refereed journals, not counting the very many preprints (which mostly turned into publications), internal reports and other papers.

43 Ph.D. thesis on directly Alliance-related topics were completed in 2014 (and one habilitation thesis), 8 of them by female scientists. A total of 242 such dissertations were finished during the course of the Alliance, as were 23 habilitations.

The complete overview of publications obtained during the lifetime of the Alliance from 2007 – 2014 can be taken from the previous annual reports. All in all, we can report on more than 2600 (4500) refereed publications (preprints).