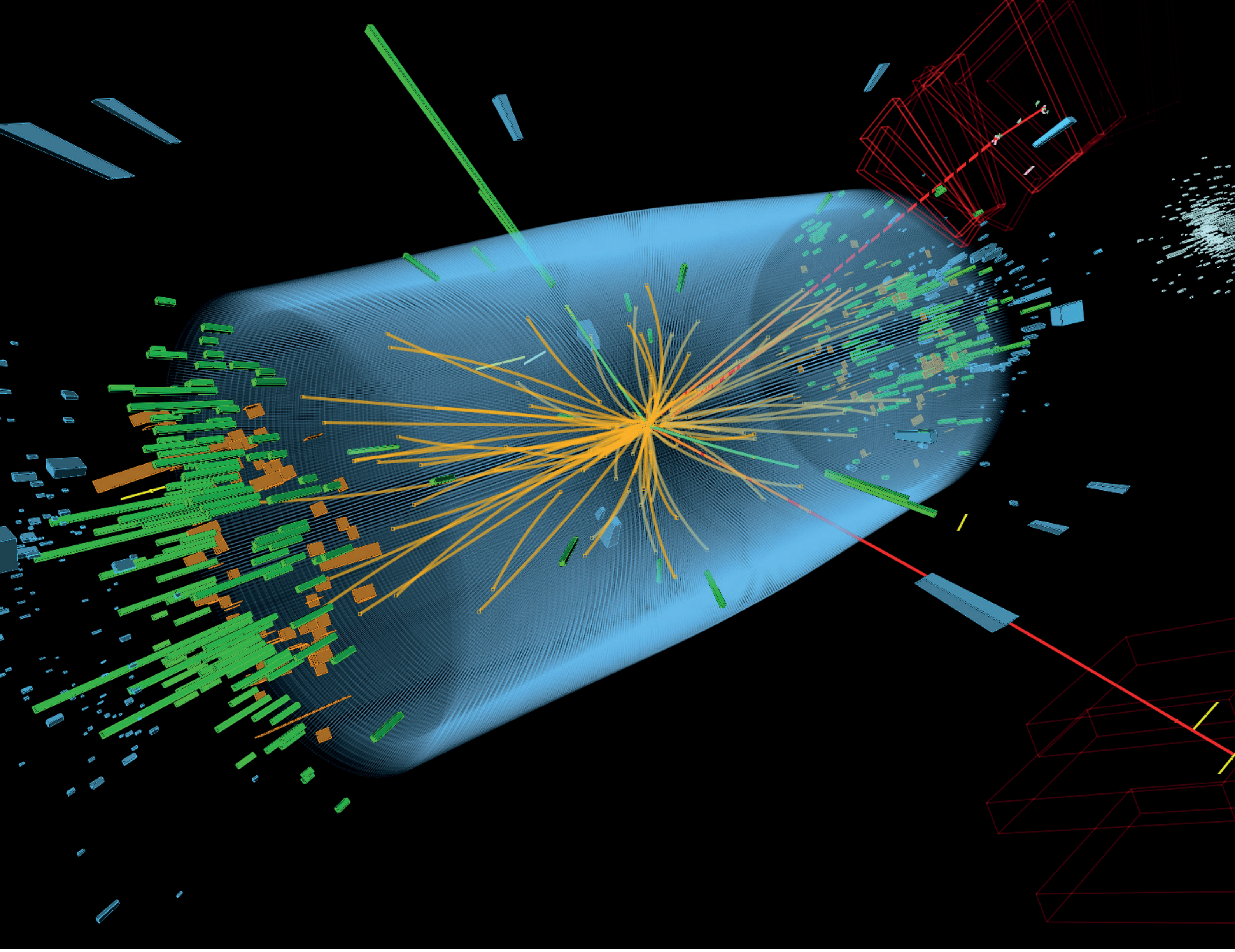

PARTICLE PHYSICS 2012.

Highlights and Annual Report

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

Cover

Picture of a Higgs particle decaying in two electrons and two muons. This event was recorded with the CMS detector at CERN. (Credit: CERN)

PARTICLE PHYSICS 2012.

Highlights and Annual Report

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Chairman's foreword

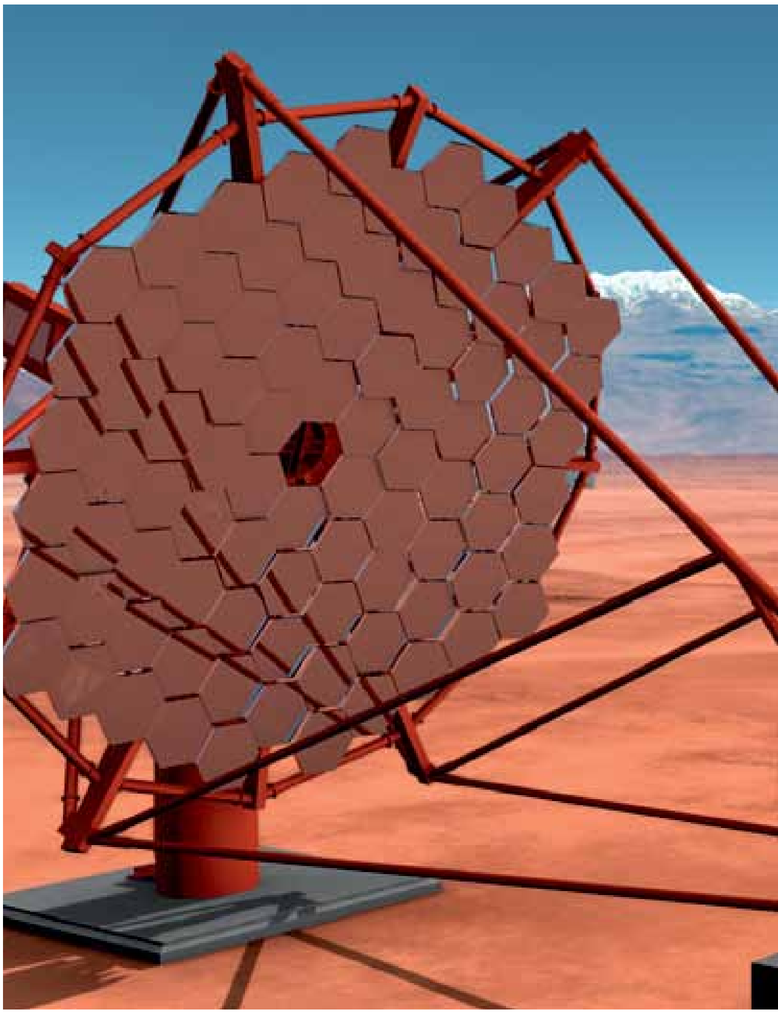
Without any doubt, the discovery of the long-sought Higgs particle at the CERN research centre near Geneva in July 2012 is one of the top scientific highlights of the last years, which will decisively shape the future of particle physics. We are proud that, through our participation in the experiments at the Large Hadron Collider (LHC) at CERN, we are part of the global endeavour that resulted in this spectacular discovery. Contributing to the LHC, in particular to the upgrade programmes of the ATLAS and CMS detectors, will be one of DESY's key priorities for the years to come.

One hundred years ago, in 1912, two other discoveries dramatically influenced the scientific world: the observation of cosmic rays by Victor Hess and the discovery of X-ray diffraction by Max von Laue. Both physicists were pioneers in their respective field. While the study of cosmic radiation stimulated many developments in particle and astroparticle physics, X-ray diffraction opened a new gateway into the world of molecules and atoms.

DESY´s light sources PETRA III and FLASH as well as the European XFEL X-ray laser are the most advanced X-ray facilities built on Max von Laue's legacy. These modern research facilities enable leading-edge research ranging from physics, chemistry and biology to materials and life sciences, and support application-driven research for our society's needs, for instance in the fields of energy, environment, key technologies and health.

The European XFEL is DESY's priority project. DESY contributes significant resources to this international prestige project on German ground. As major cooperation partner, we are responsible for the superconducting accelerator, which, in a 2 km long tunnel, supplies the tailored 17,5 GeV electron bunches for the X-ray lasing process. The construction of the European XFEL accelerator is well under way and will be finished in the second half of 2015. This is a huge effort for our laboratory, in particular for the machine division, the administration and the DESY infrastructure. Together with our partners, we are currently working out the best conditions and appropriate governance frame for the future operation of the European XFEL.

In October 2012, we ended user operation at the DORIS III synchrotron radiation facility. The remaining weeks of DORIS operation were dedicated to the OLYMPUS experiment, which was set up to shed light on the startling discrepancy, discovered at Jefferson Lab in the USA, in the ratio of the electric to magnetic elastic form factors for electron scattering off protons. As far as we can see today, the experiment ran extremely well and produced unique data. DORIS was a most successful research infrastructure, serving as a world-leading collider for particle physics and a European workhorse for synchrotron radiation. Over its entire



A possible design of the Cherenkov Telescope Array (CTA)
(Image: DESY/Milde Science Comm./Exozet)

On 19 September 2012, German Federal Chancellor Angela Merkel, Hamburg's First Mayor Olaf Scholz, Nobel Prize laureate in Chemistry Ada Yonath and DESY Director Helmut Dosch symbolically christened the experimental hall of PETRA III, the world's most brilliant X-ray source, after the physics pioneer Max von Laue.

lifespan of almost four decades, it generated an immense scientific output. Today, demonstrating the impact that research infrastructures have on science, economy and society to policy-makers and funding agencies has become ever more important. We have therefore launched a socio-economic study covering the complete lifetime of DORIS.

DESY is striving to further enhance its collaboration with German universities. DESY is the national hub for two Helmholtz alliances in particle and astroparticle physics, thereby establishing an interactive network between all major German universities and Helmholtz research centres that are active in these fields. DESY´s role herein has been further strengthened. The two key projects, the LHC at CERN and the IceCube neutrino telescope at the South Pole, are producing inspiring scientific results, which are boosting such research. DESY's future weight at the LHC will critically hinge on its role in the LHC detector upgrade programme. DESY is currently organizing the necessary resources for its contribution to the ATLAS and CMS upgrades at the LHC.

The new partnership with the University of Hamburg, PIER, is gathering momentum. The new PIER Helmholtz Graduate School was launched at the end of October, with strong support by the Helmholtz Association and the Joachim Herz Foundation.

To ensure that DESY research remains at the forefront of science, it is mandatory to promote young talents and offer equal opportunities at DESY. Ten young investigator groups are currently carrying out research at DESY in close collaboration with our partner universities. Four of the young investigators are women. One of them is Kerstin Tackmann, who has been significantly involved in the discovery of the Higgs-like boson at the LHC and recently earned the Hertha Sponer Award 2013 of the German Physical Society (DPG). I am sure that others will follow her example.

I would like to thank all collaborators and colleagues for their fruitful work.

Helmut Dosch
Chairman of the DESY Board of Directors

Particle physics at DESY.

Introduction

4 July 2012: Announcing the discovery of a Higgs-like particle at the LHC at CERN

Particle physics in 2012 was marked by a centennial discovery: a new fundamental particle, a Higgs boson, was observed at the Large Hadron Collider (LHC) at CERN near Geneva. It was a truly remarkable, worldwide event on 4 July, when the ATLAS and CMS collaborations presented their results at CERN and in live transmissions to all major particle physics laboratories. The audience in the crowded DESY auditorium burst out in spontaneous applause, as did people in many places around the globe. This discovery raised extraordinary public interest and received unprecedented news coverage – at least for a scientific event. I am sure that it will give a boost to our field, and I am very glad that we at DESY were able to contribute in various, important ways to this success.

The observation of a Higgs boson was the first fundamental discovery at the LHC, but the accelerator and experiments are only at the beginning of their scientific career. So far, a bit more than half of the full collision energy of 14 TeV has been reached, and about 1% of the total luminosity projected at the end of the high-luminosity phase around 2030 has been collected. This shows that the potential for further fundamental discoveries is still large. The LHC has now entered its first long shutdown, during which the machine and experiments will be prepared for operation at full collision energy.

DESY scientists and technicians are much in demand in important sectors of the ATLAS and CMS experiments, contributing their experience from the construction and long-time operation of the detectors at DESY’s former HERA accelerator. DESY is determined to play an important role, commensurate with its mission as national laboratory for particle physics, in the further improvement of the LHC and the detectors. This holds, in particular, when a fundamental renewal and upgrade of the experiments for the high-luminosity phase will be required at the end of this decade.

In parallel to the exploitation of the LHC, the preparations for the next “world machine” are progressing. The discovery of a Higgs boson gave an enormous boost to the International Linear Collider (ILC), at which the properties of this fundamental and very special particle could be precisely studied in a way complementary to the LHC. Japanese particle physicists have expressed strong interest to host the ILC in Japan and have given highest priority to the project. The technical design report (TDR) for the machine and detector baseline documents (DBD) for two experiments were submitted and are currently being evaluated. DESY scientists made many key contributions to these reports and to the

15 December 2012: Handing over the draft of the ILC TDR to the ILC Steering Committee (Photo: Nobuko Kobayashi)

underlying scientific and technical effort on the machine and detectors. With the completion of the TDR, the ILC project enters a new phase, which is reflected by the newly founded linear collider organization, which combines all worldwide efforts on linear colliders.

DESY enjoys a long-standing collaboration with Japan, and the most recent example is our participation in the Belle collaboration at the SuperKEKB facility. As part of a German consortium consisting of nine universities and research institutes, we are contributing to the design and construction of the vertex detector using a technology that is a spin-off from the ILC detector R&D. This ambitious project has made good progress and DESY, with its key expertise and competencies, is becoming an indispensable partner.

On 2 January 2013, the DORIS accelerator was shut down after almost 40 years of operation. For the last experiment, OLYMPUS, this marked the end of three months of very successful data taking. The experiment, which profited from the very good collaboration between the experimentalists and the DORIS operation crew, reached its luminosity goal thanks to the unique capability of DORIS to provide intense beams of electrons and positrons. The data are now being carefully analysed, and the collaboration is working hard to achieve its goal of measuring the ratio of elastic electron–proton to positron–proton scattering with unprecedented precision.

Intriguing results have also been obtained in astroparticle physics. The IceCube neutrino detector at the South Pole observed two very energetic events providing first hints at extragalactic neutrinos. More data are eagerly awaited to confirm this important observation. DESY's future project in astroparticle physics is the Cherenkov Telescope Array (CTA). The preparations for this large international gamma-ray observatory are progressing well. A first prototype of the mid-sized telescopes, which will be constructed at DESY, is being set up in Berlin.

At DESY, we are preparing for the next five-year funding period, which will start in 2015. Our future in particle physics will focus on the LHC and on electron–positron physics at Belle II and at the ILC, all topics closely accompanied by and with strong support of our theory group. We will further develop our particle physics infrastructure, for instance the computing support. All this is well aligned with the German and the European Strategy for Particle Physics, the latter of which was developed in 2012 and is scheduled for approval by the CERN Council in the spring of 2013. Both strategies assign highest priority to the LHC and give strong support for a linear collider as the next "world machine".

With this annual report, we look back at a very interesting and eventful year in particle and astroparticle physics at DESY. We are living in an exceptional time indeed, with exciting opportunities for our field on the horizon.

Joachim Mnich

Joachim Mnich
Director in charge of Particle Physics
and Astroparticle Physics

Helmholtz Alliance.

Physics at the Terascale

The Helmholtz Alliance "Physics at the Terascale" brings together physicists in the field of high-energy particle physics from DESY, KIT, MPI Munich and 18 German universities. All share a common interest in the physics of the LHC and ILC. The Alliance members are theoretical as well as experimental physicists. The Alliance has become a major part of the particle physics landscape in Germany.

High-energy physics is a truly international endeavour. The big experiments at major collider facilities like the LHC or the planned ILC have thousands of members from countries all around the world. Working in these experiments not only means working at the forefront of science and technology, but also participating in an exciting, truly global enterprise.

The Alliance was formed to support the German high-energy physics community beyond the actual involvement in specific experiments. It provides the means for collaborations between experimental and theoretical physicists, as well as experimental infrastructure for new developments, available for common use. Training young physicists who are just entering the field is an essential component of the Alliance.

The Alliance builds on already existing and very efficient structures such as those for the LHC experiments. It adds a common and very strategically oriented layer that brings together universities, research centres and different experiments. In this way, the Alliance brings a new quality of cooperation to the German high-energy physics community, designed to make particle physics in Germany even more visible internationally and to optimize the impact of German contributions to major international projects. It has also enabled a new level of cooperation between the universities and the Helmholtz research centres in Germany. The Alliance was launched in 2007 and receives its current funding from the Helmholtz Association. This support allows its partners to hire strategically placed experts and thus bring missing expertise to Germany, as well as to invest in infrastructure and common activities that are open to all partners. Obtaining funding for these purposes would be essentially impossible through other means.

CERN Director-General Rolf-Dieter Heuer addresses the participants of the annual workshop of the Terascale Alliance in December 2012.

German groups are playing an important and very visible role in the analyses of the LHC data. The discovery of a Higgs-like particle by the LHC experiments, ATLAS and CMS, was the most prominent achievement in 2012. This is a success for the Alliance as well. A multitude of other physics results were published in 2012, which provide input for the combined analyses of the theorists and experimentalists of Alliance working groups. These working groups are active in the fields of new physics phenomena and especially complex analyses, such as measuring the mass of tau lepton pairs or utilizing the central jet veto to study specific production processes (vector boson fusion).

The Alliance is organized in four working areas: analysis, computing, detectors and accelerators. Over the first years of the Alliance, the large infrastructure projects in the detector area were installed and are now available to all partner institutions. Their use is significant in particular in the context of the LHC upgrade projects.

The accelerator project bundles the involvement of the German groups in the preparations for the next big project in particle physics, a linear electron–positron collider. In addition, it has established a strong activity in an area of novel accelerator technologies, namely plasma accelerators.

In 2012, the analysis project was clearly dominated by the high number of publications of the LHC experiments and especially by the discovery of the Higgs-like particle. Many studies are in progress to combine the results from different experiments and interpret the data in the context of different theoretical models. Progress has also been made in optimizing the legacy of HERA results for input to LHC analyses. A major challenge has been to provide adequate computing to the LHC community. The Alliance has invested heavily in the Tier-2 centres, which are part of the Worldwide LHC Computing Grid (WLCG). In addition, physics analysis is being supported by the National Analysis Facility (NAF) at DESY.

Education plays a big role in all of the research areas of the Alliance. In 2012, a total of 17 schools and workshops with over 1000 participants were organized. The participants ranged from Bachelor students to senior physicists. The schools and workshops allow young researchers to gain experience in different data analysis techniques (e.g. simulation and data analysis tools, statistics), learn about accelerator and detector techniques, and exchange ideas with colleagues from other institutions.

The Alliance triggered a process by which the community as a whole agreed on which areas to support, where to invest and where to place resources. The Alliance thus gave a big boost to a common German particle physics infrastructure and community. One of the big successes of the Alliance is that a significant part of these activities – and many of the people – will remain available beyond the initial Alliance funding period, which ended in 2012. The Helmholtz Association will provide some additional funding for the years 2013 and 2014. Hence, the Alliance will continue at least for another two years. These limited funds will allow the continuation of the networking activities and the school and workshop programme. In addition, it has been decided to fund three projects from the analysis, computing and detector development areas for two years.

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Weltmaschine.

Bringing particle physics into people's minds

In 2008, a position specifically aimed at facilitating CERN and LHC communication with the German public was set up under the auspices of the DESY public relations (PR) department, with funding from the German Federal Ministry of Education and Research (BMBF) and the Helmholtz Alliance "Physics at the Terascale". The main task of this "LHC communication coordinator" is the promotion of CERN and the LHC and especially of the German participants in this global endeavour. The coordinator is responsible for a travelling exhibition, the maintenance of a website and the organization of LHC-related events. These activities are substantially raising the public's awareness and interest in the LHC in Germany.

The mobile exhibition "Weltmaschine" at the Deutsches Röntgen Museum in Remscheid

2012 will go down as the year of the discovery of the Higgs particle – or at least of the Higgs-like particle. Not only scientists but also the public were highly interested when the spokespersons of the ATLAS and CMS experiments claimed, on 4 July, the observation of a new boson very similar to the long-sought Higgs particle.

For the German LHC communications team too, the year´s activities peaked on that historic day: the discovery of the Higgs-like particle earned huge media coverage. A joint press release of DESY, the FSPs ("BMBF Forschungsschwerpunkte") ATLAS and CMS, the German committee for particle physics (KET) and the Max Planck Institute for Physics in Munich, coordinated by DESY PR and the LHC communication coordinator, raised broad interest and inspired virtually every newspaper in Germany to cover the event. A live stream of the CERN seminar into the DESY auditorium – with subsequent interviews and discussions of press and media representatives with DESY scientists, telephone interviews with news agencies and more – completed the day of the discovery. The news clippings collected from July to September 2012 filled almost 600 pages, while those from October to December amounted to only 170. Analysing not only the quantity but also the tone of the articles shows that particle physics has attracted more and more public interest and is now part of the public's general knowledge.

The mobile exhibition “Weltmaschine” at the science night in Berlin on 2 June 2013

More occasions for people to ask questions were, for example, the public lectures connected with the mobile exhibition “Weltmaschine”. This exhibition was originally built in 2008 and shown in the subway station “Bundestag” in Berlin. After a resounding success – with more than 30 000 visitors in five weeks and a great deal of press attention to particle physics and the LHC – the exhibit was transformed into a mobile version. In 2012, this mobile exhibit was shown in Tübingen, Remscheid, Berlin and Munich. In Tübingen and at the Deutsches Röntgen Museum in Remscheid, in particular, the exhibit was a big success. In Tübingen, more than 500 – instead of the expected 80 – visitors attended the opening ceremony. In Remscheid, each and every one of the six public lectures held in three months – organized in cooperation with University of Wuppertal – was jam-packed. The lasting high demand for the exhibition together with the large number of visitors convincingly demonstrates the high interest of the general public in the field of particle physics and the LHC.

The website www.weltmaschine.de worked again perfectly as a central starting point for the general public and for journalists. The web portal enabled people to learn the latest news and find background information and pictures about the Higgs-like particle, CERN and the LHC in general. www.weltmaschine.de was launched in parallel with the start-up exhibition in Berlin. It focuses on German LHC research activities, with a wealth of background material.

Since 2008, the German CERN and LHC communication coordinator has been helping to raise an ever-increasing awareness of the LHC and generate keen interest among the public in keeping abreast of all the latest news concerning the LHC. Together with the German Executive LHC Outreach Group (GELOG), with delegates of the four LHC experiments, German institutions and CERN, the communication coordinator is pursuing the two main goals of the project: to make people aware of the cutting-edge research performed at the LHC and maintain the visibility of the German institutions involved.

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http://www.weltmaschine.de

News and events.

News and events.

A busy year 2012

January

20 years of DESY in Brandenburg

On 1 January 1992, the Institute of High-Energy Physics (IfH) of the former GDR Academy of Sciences was officially united with the DESY research centre in Hamburg. Twenty years later, on 31 January 2012, about 350 DESY staff members and guests celebrated the anniversary of this fruitful research unification with a symposium in Zeuthen.

In the course of the German reunification, the former GDR research centres had been evaluated by the German Council of Science and Humanities. The council acknowledged the high scientific level of IfH Zeuthen and, in 1991, recommended its continuation as part of DESY. In cooperation with the Zeuthen scientists, DESY developed a concept for the future of the institute. On 11 November 1991, a state treaty between the Federal Republic of Germany and the federal states of Hamburg and Brandenburg sealed the integration of IfH Zeuthen into DESY. The association allowed the preservation of large parts of the institute and opened up long-term future prospects for the Zeuthen scientists.

Sabine Kunst, Minister of Science, Research and Culture of Brandenburg, stressed the importance of DESY in Zeuthen.

February

Hamburg mayor visits DESY

Olaf Scholz, First Mayor of the Free and Hanseatic City of Hamburg, visited DESY on 15 February to learn more about the current plans and projects of Hamburg's largest research centre.

After discussions with the DESY Board of Directors, Scholz visited the DESY school laboratory "physik.begreifen", where he witnessed the good atmosphere and the commitment and concentration of fourth-graders doing vacuum experiments, and of upper secondary school pupils carrying out electron experiments.

Scholz personally performed some vacuum experiments together with Karen Ong, the head of the school lab. He also emphasized his appreciation that DESY's top-level research is not carried out in an ivory tower but takes place in a process of lively communication with the city of Hamburg, its citizens and local companies.

Olaf Scholz, First Mayor of Hamburg, at the DESY school lab

March

DESY and KEK intensify cooperation

DESY and the Japanese accelerator centre KEK intend to intensify their long-standing cooperation. The first joint workshop of the two institutes, which covered the complete range of DESY and KEK research fields, revealed extensive synergetic potential in the fields of materials science and other applications of synchrotron radiation as well as in particle physics and accelerator technology.

Science at DESY is subdivided into three research fields – particle physics, accelerator development and photon science. In particle physics, the two institutes look back on roughly 40 years of cooperation, including DESY's current participation in the Belle II experiment at KEK. Both centres are also working together to enhance superconducting accelerator technologies towards the realization of the International Linear Collider (ILC).

The first laboratory-wide joint workshop explored additional fields of cooperation. To this end, a high-ranking Japanese delegation travelled to DESY in Hamburg together with the KEK directorate. During one day, the representatives of both centres discussed additional cooperation possibilities. Multiple synergies could be exploited in the fields of photon science and detector development, amongst others, in which DESY and KEK have complementary strengths.

Participants in the joint KEK–DESY workshop

European particle physicists bundle detector development

European particle physicists take another step towards joining forces for the construction of detectors at particle accelerators. The 26-million-euro project AIDA (Advanced European Infrastructures for Detectors at Accelerators) will advance a common European infrastructure for detector development, including shared standards for sensor development, testing and data evaluation. More than 80 institutes from 23 countries are participating in the project, which is coordinated by CERN, Switzerland. The first annual meeting, with more than 150 participants, took place at DESY in Hamburg on 28–30 March 2012.

The four-year project is to deliver concrete installations, such as a series of standardized "telescopes" used to measure test beams and to gauge detector components. A prototype telescope has already been created within the framework of the forerunner project EUDET, and is being used successfully at DESY and CERN.

The CMS detector at the LHC (Photo: CERN)

April

Physics Olympiad at DESY

From 10 to 15 April, 15 pupils came to DESY to showcase their physics skills in a selection round for the International Physics Olympiad. After solving theoretical and experimental tasks, five participants were selected to represent Germany in the 43rd International Physics Olympiad, which took place in Estonia in summer 2012.

The annual national selection contest in Germany is coordinated by IPN – Leibniz Institute for Science and Mathematics Education at the University of Kiel in cooperation with the ministries of education of the German federal states and with financial support from the Federal Ministry of Education and Research (BMBF). The tests for the competition were developed by a team of DESY scientists and the IPN competition management, and corrected by former Physics Olympiad participants.

Alongside the written tests, a framework programme offered the young physicists the opportunity to learn more about research at DESY. A further highlight was a visit to the largest model railway in the world, “Miniatur Wunderland” in the historical Hamburg warehouse district, including a glimpse behind the scenes. At the prize presentation, the five members of the German national team were selected, and two other participants received an invitation for a DESY internship of several weeks in recognition of their remarkable achievements.

Participants in the 2012 selection round for the International Physics Olympiad at DESY

Cosmic super-accelerators surprise scientists at South Pole telescope

The most powerful particle accelerators are found in space: some of the subatomic particles that rain down from space on the Earth’s atmosphere have energies up to one hundred million times higher than those created in the Large Hadron Collider (LHC) at CERN, the most powerful accelerator on Earth. How these cosmic rays are accelerated to such high energies it still something of a mystery, however.

Using the world’s largest neutrino telescope, IceCube in Antarctica, scientists have investigated one of the possible types of cosmic super-accelerators – gamma-ray bursts – and discovered that they are probably not the main source of the highest-energy cosmic rays. This result calls for a re-evaluation of one of the two leading hypotheses on the origin of extremely energetic cosmic particles, as the international team lead by Nathan Whitehorn from the University of Wisconsin (USA) reported in the scientific journal *Nature*. The IceCube collaboration comprises around 40 institutes from 10 countries, among them eight German universities and DESY.

The IceCube team investigated around 300 gamma-ray bursts from the period from 2008 to 2010. If gamma-ray bursts are indeed sources of high-energy cosmic particle radiation, neutrinos produced alongside the gamma rays should also reach the Earth directly, as they are electrically neutral and not deflected by magnetic fields. Surprisingly, within the two-year investigation period, IceCube found not a single neutrino matching one of the 300 gamma-ray bursts explored. The current models of cosmic-ray and neutrino production in gamma-ray bursts therefores need to be reworked.

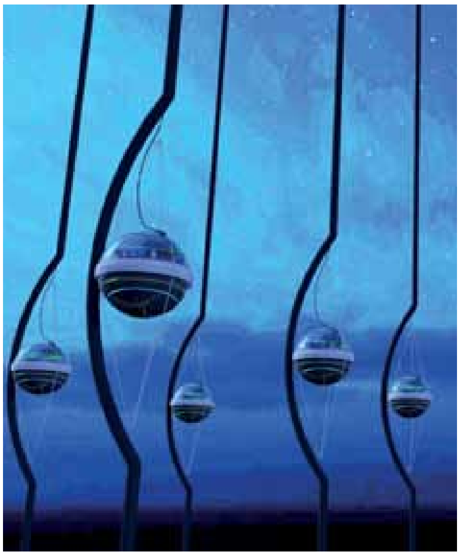


Illustration of the IceCube sensors (photomultipliers), more than 5000 of which are deployed up to 2.5 km deep in the Antarctic ice (Image: NSF/J. Yang)

German–South African Year of Science launched

On 16 April, Germany's Minister of Education and Research Annette Schavan and South Africa's Minister of Science and Technology Naledi Pandor launched the German–South African Year of Science 2012/2013 in Cape Town, South Africa. The topic of the month – and one of the seven central themes of the Year of Science – was astronomy. DESY scientist Christian Spiering, chairman of the German Committee for Astroparticle Physics (KAT), attended the opening ceremony to present the German–South African cooperation in astroparticle physics and the future Cherenkov Telescope Array (CTA), which the South African region bids to host.

CTA is planned as an arrangement of 50 to 80 telescopes, which will record the flashes of Cherenkov radiation emitted by high-energy gamma rays hitting the Earth's atmosphere. The five telescopes of the forerunner instrument H.E.S.S., which was erected in Namibia under German leadership, already detected 85 cosmic gamma-ray sources, including residues of stellar explosions, binary star systems and the powerful jets shooting out of the centres of active galaxies.

Namibia bids to host CTA, and is receiving strong support from South Africa. CTA is on the European priority list of future large-scale projects of ESFRI, the European Strategy Forum on Research Infrastructures. German institutes participating in this international project are DESY, the Max Planck Institute for Nuclear Physics in Heidelberg, the Max Planck Institute for Physics in Munich, the universities in Berlin (HU), Bochum, Dortmund, Erlangen, Hamburg, Potsdam, Tübingen and Würzburg as well as the Heidelberg observatory.

German Federal Minister of Education and Research Annette Schavan and her South African counterpart Naledi Pandor with a model of CTA (Photo: Deutsch-Südafrikanisches Jugendwerk e.V. (DSJW))

May

FLASH passes ILC performance test

In May 2012, a team of ILC and DESY accelerator experts descended on the FLASH control room to bring the superconducting linear accelerator closer to ILC properties, delivering a wealth of data and interesting results for FLASH and the ILC.

The overall goal of the studies was to run DESY's FLASH facility with long bunch trains and heavy beam loading, with cavities at the top of their gradients. Tuning FLASH for maximum performance is an intricate interplay of information, with signals being fed back and forward to each individual cavity. For the ILC, all the cavity gradients should be as constant and stable as possible during the 800 μs beam pulse, and the team managed this better than planned. FLASH itself was modified before the ILC studies. It now has a control mechanism that can ramp down radio frequency power if cavities approach their quench limit, and the electron gun can produce 800 μs bunch trains.

PIER

Helmholtz Association funds PIER Graduate School

The Helmholtz Association pledged to support the PIER Graduate School with a total of 2.4 million euro for six years. The PIER Graduate School offers excellent training for doctoral students in a unique environment, thus attracting young talents from all over the world to Hamburg. It is part of the new Partnership for Innovation, Education and Research (PIER) of the University of Hamburg and DESY, which covers four research fields: particle and astroparticle physics, nanosciences, photon science, and infection and structural biology.

As a multidisciplinary umbrella structure, the PIER Graduate School will expand the existing high-quality doctoral training at the University of Hamburg and DESY in the PIER research fields, creating optimal structures and parameters with transparent access information and services for doctoral students. It will also promote an intensive exchange among doctoral students and with representatives of business and industry. Contact fairs, recruiting events and a mentoring programme will encourage PIER doctoral students to actively plan their future careers. Within the framework of cooperations with international universities and research centres, the PIER Graduate School will provide structured exchange programmes for doctoral students and facilitate joint graduations. Coaching, childcare offers and financial support for travelling with family will help the reconciliation of work and family life. In addition, the Helmholtz Association will fund two scholarships within the PIER Graduate School, one of them for excellent female scientists. The Joachim Herz Foundation will contribute five scholarships per year for outstanding doctoral students.

May

Russian and German partners collaborate on data management and analysis

European XFEL, DESY, Forschungszentrum Jülich and the Kurchatov Institute in Moscow will cooperate in developing IT solutions for large scientific facilities. A memorandum of understanding on a collaboration to devise new data management and data analysis solutions was signed in Berlin on 22 May during the closing event of the German–Russian Year of Education, Science and Innovation 2011–2012.

Experiments at new large-scale research facilities, such as the European XFEL X-ray laser, produce enormous amounts of data that need to be stored, maintained and made available for analysis. This challenging task requires new ways to manage data and to provide computing infrastructure that will support scientists during and after their experiments. The European XFEL can serve as a pilot project for further collaboration between the involved partners in this area.

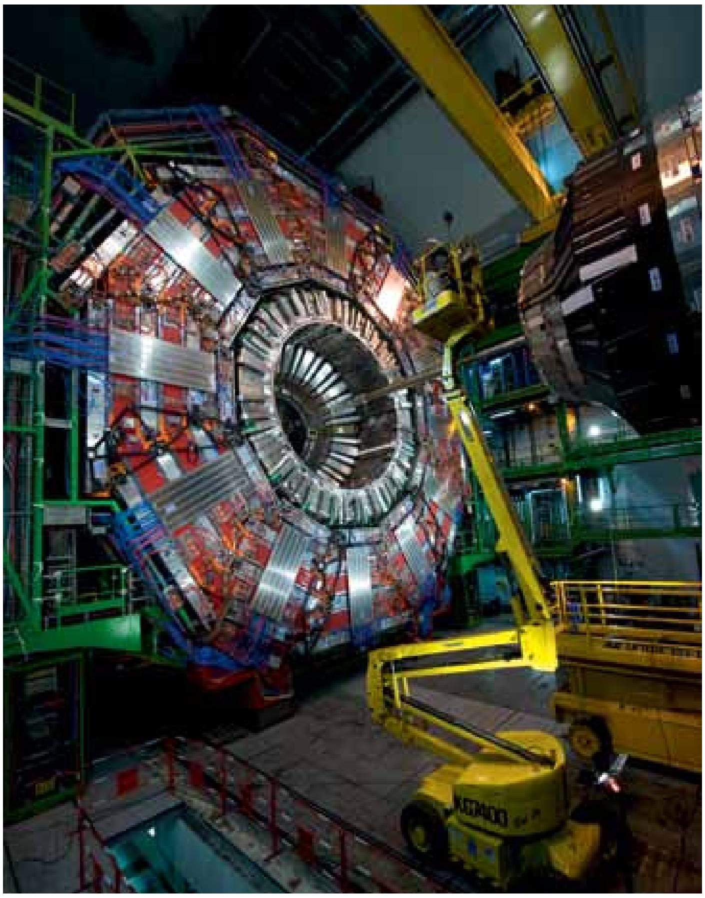
DESY has been operating a large Tier-2 computing architecture for several years in the framework of the LHC computing, and will contribute its expertise towards developing such solutions for the European XFEL.

Signing the "Memorandum of Understanding on collaboration to develop data management and data analysis solutions for large-scale scientific experimental facilities" on 22 May 2012 in Berlin (Photo: BMBF)

New Helmholtz platform for detector technologies

The Helmholtz Association is building a new platform for the further development of detector technologies and detector systems. Nine Helmholtz institutes, among them DESY, are participating in the project, which also integrates the competence of eleven universities and seven research institutes from Germany and abroad. The Helmholtz Association is funding the detector initiative as a portfolio theme with 13 million euro from 2012 to 2016.

The objective of the new research platform is to create the bases and technologies to develop highly integrated photon and particle detectors, to optimize data transfer and data evaluation and to design and build exemplary detector prototypes. One major R&D topic is silicon detectors, which are needed at the European XFEL and the LHC. The focus here will be on increasing the integration level. This type of detector could have a wide range of applications extending way beyond basic research.



The CMS detector at the LHC (Photo: CERN)

June

European XFEL tunnel construction completed

The European XFEL X-ray free-electron laser reached an important milestone: the construction of the network of tunnels – which has a total length of nearly 5.8 km and extends 3.4 km from the DESY site to Schenefeld in Schleswig-Holstein – was completed. The event was celebrated on 14 June with more than 400 participants, including guests from politics and science as well as staff from collaborating companies.

The tunnel boring crew in front of the cutting wheel of AMELI

With an investment volume of more than one billion euro, including 240 million euro for the construction of the tunnels and other underground buildings, the new international research facility is one of the largest scientific projects on German territory. Starting in 2015, the European XFEL will generate laser-like X-ray flashes that will enable completely new insights into the nanoworld. DESY is the main shareholder of the European XFEL company.

Tunnel construction began in July 2010 with the main accelerator tunnel using the tunnel boring machine TULA (“Tunnel for laser”). In January 2011, the second machine, AMELI (the German acronym for “At the end there will be light”), started to excavate the five photon tunnels leading into the experimental hall. This was a difficult mission: given the special layout of the tunnel system, the 160-tonne colossus had to be repeatedly relocated and prepared for the next section. TULA completed its work in August 2011. With the completion of the last tunnel section, the mission of AMELI came to an end in June 2012.

Helmholtz Association funds commercialization of new electronics industry standard

Controlling modern accelerators demands extremely precise and fast technology that can process numerous data sets in parallel. To this end, DESY developed a new generation of control electronics for FLASH and European XFEL. After implementation of this low-level radio frequency (RF) system, which is based on the electronic standard MTCA.4, the new standard proved to be so multifunctional that it is being prepared for commercialization and application in industrial enterprises and large-scale research projects. The costs of about 4 million euro for the two-year project are borne by the Helmholtz Association through the Helmholtz Validation Fund, DESY and partners from industry.

With linear accelerators, it is not possible – as with storage rings – to measure a parameter in one particle round and regulate it in the next. Instead, the data from a particle bunch already traversing the accelerator must be used to determine the starting values for the next bunches. To this end, DESY developed a control hardware that acts on subsequent particle bunches within the same bunch train. Such a system must be able to very quickly process a wide range of data in parallel. To control the RF for the linear accelerator of the European XFEL, developers used the new electronics standard MTCA.4, which was elaborated within the PCI Industrial Computers Manufacturers Group (PICMG) with significant participation of DESY and adopted in October 2011.

Together with seven industrial companies, DESY is now further developing the modules, which will be made available on a license basis, and optimizing them for industrial application. In addition, the product line will be completed and extended for special industrial requirements. DESY and the involved companies will also offer extensive counselling to promote the implementation of the new industrial process control standard.

DESY’s fast control electronics has great potential for applications in industry.

June

Musical superstrings

On 22 June, the “Particle Partitas” were performed in the DESY auditorium – a musical journey through the history of physics, with a violin playing the leading role.

This special combination of music and science was created by three experts in their trade. The particle physicist Brian Foster, who works at DESY and the University of Hamburg within the framework of a Humboldt professorship, presented the milestones and visions of the future of particle physics. The renowned composer and artist Edward Cowie, inspired by the world of fundamental building blocks, wrote a series of eight short musical pieces for violin. The violinist and Classical Brit Award winner Jack Liebeck gave musical life to the physics topic.

As Foster announced, the event will be the first of a series involving a lecture followed by a concert from international artists.

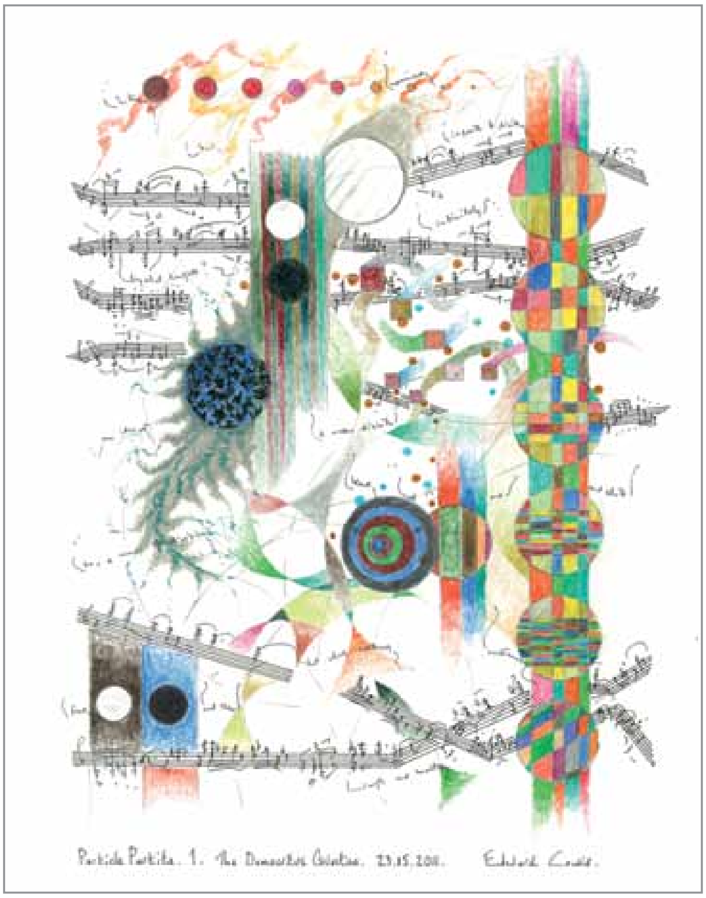


Illustration of composer and artist Edward Cowie for the first piece of Particle Partitas: “The Democritus Question”

Ground-breaking ceremony for future gamma-ray telescope

Construction of a telescope prototype for the planned Cherenkov Telescope Array (CTA) gamma-ray observatory started with a ground-breaking ceremony in Berlin. A mechanical prototype of a medium-sized CTA telescope – one of the three types of telescopes planned for CTA – will be built at the research campus in Berlin Adlershof. After laying of the foundations, the components of the prototype will be mounted, followed by a data-taking programme to understand the properties of the prototype in detail, optimize the control and safety systems and work on calibration aspects.

Simulation of the CTA telescope prototype at the Adlershof campus in Berlin

The CTA observatory, which is one of DESY’s future projects, will be used to study cosmic particle accelerators, such as supernova explosions, binary star systems or active galactic nuclei, with unprecedented sensitivity. It is being built by an international consortium of more than 1000 members from 27 countries. DESY is responsible for the design and construction of the mechanical structures and control systems for the medium-sized telescopes, which have a mirror diameter of 12 m, and coordinates their overall construction. Moreover, DESY contributes to the control and monitoring systems of the planned telescope array, to the electronics and the optimization of CTA performance as well as to computing-intensive simulations and analyses.

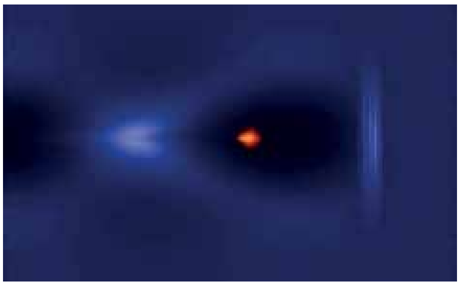
The CTA group at DESY in Zeuthen cooperates closely with the University of Potsdam and the Humboldt University in Berlin within the framework of the Berlin Brandenburg Cluster, and is a member of the Helmholtz Alliance for Astroparticle Physics in the fields of high-energy sources and search for dark matter.

New virtual institute for plasma acceleration

The Helmholtz Association is funding a new “virtual institute” at DESY that will advance a novel accelerator technology. Plasma wakefields have the potential to accelerate particles over very short distances, thus offering a promising technology for future accelerator applications. The newly established virtual institute “Plasma wakefield acceleration of highly relativistic electrons with FLASH” will do basic research to explore the possibilities of using the extremely high electric fields created in a plasma to reliably accelerate high-energy electrons. The Helmholtz Association will fund the virtual institute for a period of five years.

A plasma is a highly excited state of ionized matter, with electrons moving freely between the atomic nuclei. It is, for example, generated by an intense laser beam or by a particle beam in a gas. Initial experiments at other institutes to use such fields for particle acceleration produced very promising results.

One of the major challenges is to inject a particle bunch into the plasma at exactly the right time for it to be accelerated – an experiment that has not been carried out so far. This is one of the topics of the new virtual institute, which involves DESY, the University of Hamburg, the Max Planck Institute for Physics in Munich, the John Adams Institute (UK) and the accelerator centres SLAC, LBNL (both USA) and CERN. The scientists will inject the electron beam of the FLASH II accelerator into a plasma cell, thereby accelerating it using the plasma. At one of the experimental setups, the plasma will be created by the particle bunch itself; in another approach, it will be produced by an extremely intense laser. Further experiments are also planned at the Relativistic Electron Gun for Atomic Exploration (REGAE) at DESY in Hamburg and at the PITZ photoinjector test facility at DESY in Zeuthen.



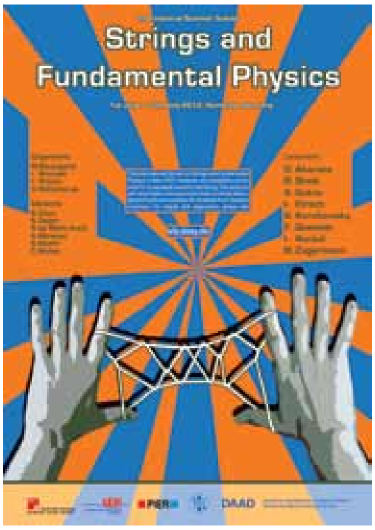
Simulation of an electron bunch in a laser-driven plasma wave

July

String theory summer school

For two weeks in July, 120 students from all continents attended the “International School on Strings and Fundamental Physics” organized by the University of Hamburg and DESY.

With their enthusiasm, the participants themselves ensured that the summer school was a great success. Coordinators and participants benefitted to the same degree. The students had the opportunity to network, and the coordinators came in contact with young talents who are otherwise difficult to reach. As said Bryan Larios, a master student from Honduras: “The summer school showed that students from poor countries may also work at high-standard research centres. They just have to get the opportunity.”



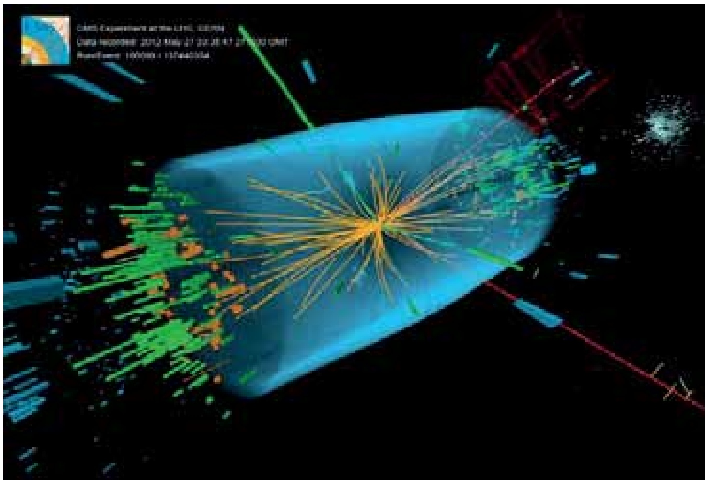
To organize their attendance was not always easy for the participants. Some came from countries where research institutes do not have the means to bear the costs for international conferences or schools. Thanks to funding from the PIER partnership of the University of Hamburg and DESY, the German Academic Exchange Service (DAAD), the Hamburg LEXI Excellence Cluster “Connecting Particles with the Cosmos” and DESY, participants from economically weak countries received travel grants.

The summer school covered topics of fundamental and advanced string theory. The lectures and seminars were held by internationally renowned scientists. Among the highlights of the school were the students’ talks, which resulted in interesting discussions and provided starting points for future cooperation. As Mexican doctoral student Liliana Vazquez Mercado put it: “The school was great, with excellent speakers and interesting people from all over the world. DESY was the perfect location for this event.”

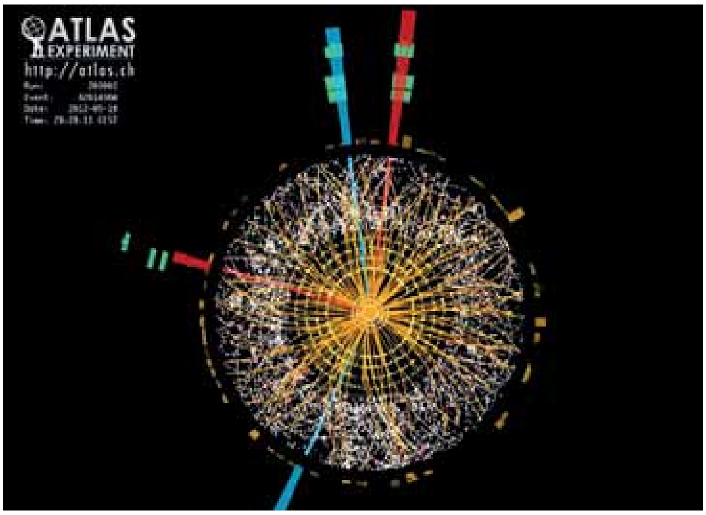
July

New particle observed at the LHC – more evidence for Higgs particle

On 4 July, the ATLAS and CMS collaborations at CERN presented their latest results on the search for the Higgs boson. Both LHC experiments detected a so far unknown particle in the mass region of 125 to 126 GeV. The scientists denoted their findings as still preliminary. The probability that this was no new particle but a statistical fluctuation was lesser than one in a million, however. The particle might be the long-sought Higgs boson, which explains how elementary particles acquire mass.



Tracks of the newly discovered particle in the CMS detector
(Image: CMS collaboration, CERN)



Tracks of the newly discovered particle in the ATLAS detector
(Image: ATLAS collaboration, CERN)

More than 700 German scientists work at ATLAS and CMS, including about 400 young scientists. The analysis presented on 4 July was based on the data collected at the LHC in 2011 and 2012, and only included certain decay possibilities of the new particle, especially two that gave a particularly clear image of the particle. Further analyses for other decay channels were being prepared.

The seminar “Update in the search for the Higgs boson” on 4 July was broadcast from CERN to the jam-packed DESY auditorium, where a magnum bottle of champagne was later popped to celebrate the discovery.

Minjie Yan wins Otto Stern Prize for the best diploma thesis

She probably is the diploma physics student coming from the most distant country to Hamburg, and she most certainly is the best: on 11 July, Minjie Yan from China was awarded the Otto Stern Prize for the best diploma thesis in the physics department of the University of Hamburg.


Minjie Yan

The recently graduated physicist wrote her thesis within DESY's linear accelerator research group FLA, where she tested improved electron beam diagnostics for the FLASH accelerator. She is the second student ever to be distinguished with the Otto Stern Prize in this field.

DESY summer student programme 2012

About 100 undergraduate students from 33 countries attended the DESY summer student programme 2012 from 17 July to 6 September. The students came to DESY in Hamburg and Zeuthen to gather practical experience in different fields of research. For seven weeks, they worked with DESY scientists in different projects in accelerator, particle and astroparticle physics as well as photon science. Around 40 lectures, aiming to impart physics basics as well as special aspects important for DESY research, complemented the lab work. The cultural and scholarly exchange were equally important.

The programme was very well received by the students, who especially appreciated the international atmosphere at DESY and the suitable mixture of practical work and lectures on topics that are usually not presented in such a comprehensive manner in university courses. Many participants considered coming back to DESY as doctoral students or postdocs. Educating and promoting young scientists is a central part of DESY's mission.


DESY summer students 2012

August

Consular Corps of Hamburg visits DESY

The Consular Corps of Hamburg and Hamburg's First Mayor Olaf Scholz visited DESY on 21 August. About 60 consuls took a tour of the DESY campus, including the X-ray radiation sources PETRA III and FLASH.


Hamburg's First Mayor Olaf Scholz and India's Consul General in Hamburg Murugesan Subashini (Image: DESY/Lars Berg)

"Modern technologies of all kinds have no foundations on which to stand without basic research," Scholz said during the visit. "DESY is a scientific nerve centre that enjoys a worldwide reputation for research of the highest class." Helmut Dosch, the Chairman of the DESY Board of Directors, thanked the city of Hamburg for its continuous support of DESY, and the consular service for its essential contributions to cultivating relations between nations, which also benefit DESY with its global scientific connections and more than 3000 guest scientists coming every year from all over the world. With nearly 100 consulates, Hamburg is one of the largest consulate locations in the world.


The Consular Corps of Hamburg on its DESY visit

August

DESY extends cooperation with Thailand

DESY will strengthen its cooperation with scientists in Thailand, with the aim to expand the exchange of knowledge, experience, equipment, staff and students. In the presence of HRH Princess Maha Chakri Sirindhorn, DESY Director Helmut Dosch and representatives of the Thai Synchrotron Light Research Institute, the Thailand Center of Excellence in Physics and the Thai National Science and Technology Development Agency signed a corresponding memorandum of understanding in Bangkok on 27 August.

The extension of cooperation involves all research fields of DESY: accelerator physics, photon science, particle physics and astroparticle physics. It will consolidate the traditionally good relations between DESY and research institutes in Thailand. As Helmut Dosch underlined, Thailand is a dynamic country with a very high scientific potential.

DESY and its Thai partners already agreed on various cooperations in the past, for example at the PITZ photoinjector test facility in Zeuthen or for the support of young Thai students in the DESY summer student programme.

A framework agreement on an extended cooperation of DESY with scientists in Thailand was signed on 27 August in Bangkok.

September

German Federal Chancellor Merkel visits DESY

On 19 September, German Federal Chancellor Andrea Merkel visited DESY. Together with Hamburg's First Mayor Olaf Scholz, Nobel Prize laureate in chemistry Ada Yonath and DESY Director Helmut Dosch, she symbolically christened the experimental hall of PETRA III, the world's most brilliant X-ray source, after the physics pioneer Max von Laue.

PETRA III is "in the truest sense of the word a brilliant example" for the further development of Laue's method, Angela Merkel emphasized in her address. "PETRA III extends, in a remarkable way, the world of research and knowledge for which Max von Laue laid the foundation stone one hundred years ago." DESY possesses the outstanding ability to employ its large-scale facilities to address important questions of humanity, and thus enhance the benefit of the individual, Merkel said. "Germany needs top-level research like what is done here. Germany needs your knowledge and ideas for tomorrow's technologies and markets."

Chancellor Merkel also underlined the importance of progress in basic research as breeding ground for the technologies and innovations of tomorrow. "Progress in basic research paves the way for economic and social progress. This is, of course, extremely important for a nation lacking in raw materials like Germany. This is why basic research is crucial for us. It is the key for Germany's future prosperity." According to Merkel, DESY offers the best conditions for global research cooperation. "In the field of basic research in the natural sciences, DESY plays a leading role in the world. And it is an attractive location for state-of-the-art large-scale facilities," Chancellor Merkel said.

Federal Chancellor Angela Merkel, DESY Director Helmut Dosch, Nobel laureate Ada Yonath and Hamburg's First Mayor Olaf Scholz unveil the name "Max von Laue" on the wall of the PETRA III experimental hall.

October

New German particle physics brochure

What is happening in Germany in the field of particle physics and what are the perspectives for the coming years? A new brochure (in German) by the German Committee for Elementary Particle Physics (KET) provides an overview on current projects, demonstrates the far-reaching impact of particle physics research on society and presents the German physicists' strategy for the future.

Within the German particle physics scene, DESY plays an important role as a national laboratory and coordination centre.

PIER Helmholtz Graduate School awards first scholarships

The first round of scholarship awards within the new PIER Helmholtz Graduate School was completed in October 2012. Seven outstanding candidates were awarded a three-year grant for their doctorate. Hong-Guang Duan, Nele Müller, Özgür Mehmet Sahin, Matthias Schlaffer and Clemens Wieck received a Joachim Herz grant, Alena Wiegandt and Cornelius Gati a Helmholtz grant. The scholarship holders will conduct their PhD in one of four PIER research fields.

A total of 36 young scientists from Germany and abroad had applied for the PIER scholarships. The best 16 of them were invited to present they work in public lectures in front of a committee of ten top-class scientists. The scholarships were presented on 31 October by the chairwoman of the Joachim Herz Stiftung, Petra Herz, and the representative of the Helmholtz Association, Ilja Bohnet.

From left to right: Hong-Guang Duan, Özgür Sahin, Alena Wiegandt, Clemens Wieck, Matthias Schlaffer, Cornelius Gati, Nele Müller (awardees), Stefanie Tepaß (PIER Helmholtz Graduate School), Petra Herz (Joachim Herz Foundation) and Ilja Bohnet (Helmholtz Association)

PhD thesis award 2012

The PhD thesis award 2012 of the Association of the Friends and Sponsors of DESY (VFFD) was shared by Katarzyna Anna Rejzner and Arik Willner.

Katarzyna Anna Rejzner

Arik Willner

Katarzyna Anna Rejzner from Poland studied in Cracow, and then started her doctoral studies on gauge theories at the II Institute of Theoretical Physics at the University of Hamburg. Despite their high predictive value, gauge theories present a series of unsolved problems related to the auxiliary parameters that are required for their formulation. An important question is whether the theories' predictions depend on the rather arbitrary choice of these auxiliary parameters. Rejzner developed a mathematically precise version of a formalism devised by Soviet physicists Batalin and Vilkovisky, showing that the choice of the auxiliary parameters does not play a decisive role. As a consequence of her work, a consistent quantification of gravity – one of today's major unsolved problems in physics – now seems to be within reach.

Arik Willner studied in Kassel and Hamburg, where he obtained his doctoral degree working on the possibilities of seeding free-electron lasers. These novel research facilities emit extremely intense ultrashort X-ray flashes. However, the beam pulse quality is subject to statistical fluctuations if nothing is done to specifically prevent the effect. One possible countermeasure is seeding, which consists in inducing the laser process with a weak beam pulse of the required wavelength. Producing such seeding pulses in the wavelength range from 10 to 100 nm is very difficult, however, especially when thousands of these pulses are needed every second, as is the case at FLASH. Arik Willner was able to solve this problem in his PhD thesis, thereby significantly advancing the technology.

The PhD thesis award of the Association of the Friends and Sponsors of DESY includes a prize money of 3000 euro. The association presents the prize every year for one or two outstanding PhD theses.

DESY passes Helmholtz midterm evaluation

DESY successfully passed an intermediate assessment in the second round of the programme-oriented funding (POF II) of the Helmholtz Association, which took place in November 2012. DESY scientists produced impressive achievements, acknowledged Janos Kirz from Lawrence Berkeley National Laboratory (USA), Chairman of the DESY Scientific Council, on the occasion of the midterm evaluation.

As one of the 18 research centres of the Helmholtz Association, DESY applies for funding for its research programmes within the Association's programme-oriented funding every five years. In the current POF II period from 2010 to 2014, DESY participates in the programmes elementary particle physics, astroparticle physics and photon/neutron/ion science in the research field "Structure of Matter".

DPG awards Max Born Prize to Max Klein

The German Physical Society (DPG) awarded the Max Born Prize to Prof. Max Klein for his fundamental experimental contributions to the revelation of proton structure through deep-inelastic scattering.

Max Klein

In the past 40 years, Max Klein concentrated in particular on investigating the inner structure of the proton. In the 1990s, he played a decisive role in the discovery of a surprisingly large gluon component within the proton. Gluons are important for the generation of Higgs bosons, a promising candidate of which was detected in July 2012 at CERN.

After first experiments in Dubna, Klein joined experiments at DESY and CERN in the 1980s. Since 1985, he has been a member of the H1 collaboration at DESY's HERA storage ring. As the head of the H1 collaboration from 2002 to 2006, he guided the project into a new era of precision measurements of the proton structure and tests of the Standard Model of particle physics. Since 2006, Klein has been working in the UK, where he holds the Chair for Particle Physics at the University of Liverpool. Throughout his career, Klein has been a tireless forerunner in the field of lepton–nucleon scattering, and he is now playing a leading international role in the planning of a next-generation scattering experiment.

DESY school labs participate in first Helmholtz Day

On 20 November, the 25 school labs of the Helmholtz Association organized the first nationwide Helmholtz Day, a new type of event dedicated to Hermann von Helmholtz (1821–1894). The namesake of the Helmholtz Association was one of the last prominent polymaths. However, his many pioneering findings are often not associated with him.

Several hundred pupils took part in the first Helmholtz Day. The DESY school labs in Hamburg and Zeuthen each welcomed a class of sixth-graders, who were first introduced to Hermann von Helmholtz's research work and then had the opportunity to do vacuum experiments. Each participant received a Helmholtz T-shirt as a souvenir.

Pupils with vacuum half-shells at the DESY school lab in Zeuthen

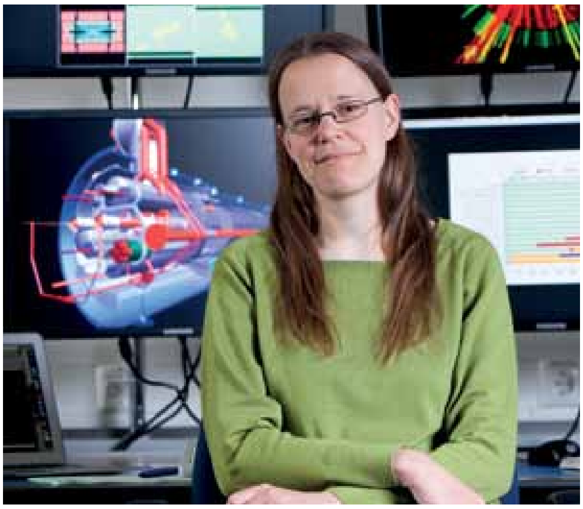
"It is important to ask the right questions" was Hermann von Helmholtz's research motto, which he applied in his investigations of phenomena in optics, acoustics, geology, meteorology and thermodynamics. The ophthalmoscope he developed for retina examinations is still in use today, and the conservation of energy rule, the formulation of which he decisively shaped, is one of the central laws of physics.

Through the experiments at the Helmholtz school labs, pupils learn to make out the essential questions in order to better understand and be able to analyse natural-science theories. The staff members of the Helmholtz school labs convey a better understanding of scientific thinking to the pupils and offer them an insight into work in a scientific profession. The aim of the labs is to arouse or deepen the interest of young people for the natural sciences in order to secure the next generation of scientists.

Pupils at the DESY school lab in Hamburg watching a chocolate marshmallow in a vacuum

Hertha Sponer Prize 2013 for Kerstin Tackmann

The German Physical Society (DPG) awarded the Hertha Sponer Prize to DESY physicist Kerstin Tackmann “for her outstanding work on the way to the detection of the Higgs boson at the Large Hadron Collider (LHC) at CERN. As a leading scientist, she made decisive contributions to the detection of a new particle decaying into two photons. This new particle is a promising candidate for the Higgs boson, which would complete the Standard Model of elementary particle physics”. The award will be presented in March 2013 at the DPG annual meeting in Dresden.



Kerstin Tackmann

Kerstin Tackmann studied physics in Dresden, where she graduated in 2004. In 2008, she obtained her PhD at the University of California, Berkeley. She then went to CERN and joined the ATLAS group. As from 2011, she is heading a Helmholtz Young Investigators Group at DESY, which is working on the search and detection of the Higgs boson and participating in the development work for the ATLAS detector upgrade.

With the Hertha Sponer Prize, the DPG honours female scientists for outstanding research in physics. The prize, which amounts to 3000 euro, is awarded annually to encourage young female physicists and attract more women to physics. Hertha Sponer (1895–1968) was a German physicist who made important contributions to molecular physics and spectroscopy, among others.

December

Proton collisions at LHC end with new record

In December, the LHC concluded its last round of proton–proton collisions with an intensity record of 2748 particle bunches circling in opposite directions – twice as many as before. “The accelerator and the detectors worked extremely well,” DESY particle physics director Joachim Mnich said on the occasion. “The LHC has already written history with the discovery of the new Higgs-like particle.” In July, the CMS and ATLAS collaborations had announced the observation of a new particle that was very similar to a Higgs boson. “With the collisions measured in ATLAS and CMS until December, we should be able to more precisely identify the particle we have seen in the data obtained until July,” said Mnich.

View into the LHC tunnel
(Photo: CERN)

About 150 DESY scientists participate in the two large LHC experiments, each of which recorded several billion proton–proton collisions in the past three years. DESY also provides substantial storage and computing capacity for the data analysis, which is being used by German and international groups.

6th annual workshop of the Helmholtz Alliance “Physics at the Terascale”

The 6th annual workshop of the Helmholtz Alliance “Physics at the Terascale” took place at DESY in Hamburg on 3–5 December. About 320 participants attended the workshop, reviewing the achievements of the past years and looking towards future activities planned in the framework of the prolonged Alliance. The Alliance triggered a process by which the community as a whole agreed on which areas to support, where to invest and where to place resources. The Alliance thus gave a big boost to a common German particle physics infrastructure and community. One of the big successes of the Alliance is that a significant part of these activities – and many of the people – will remain available beyond the initial Alliance funding period, which ended in 2012. The Helmholtz Association will provide some additional funding for the years 2013 and 2014. These limited funds on top of the base-funded scientific infrastructure will allow the continuation of the networking activities and the school and workshop programme. In addition, it has been decided to fund three projects from the analysis, computing and detector development areas for two years.

Research topics.

The charm of HERA.

Revelations from charm quarks in deep-inelastic scattering

Quarks, the constituents of nuclear matter, carry a “flavour” quantum number. One of these flavours is known as “charm”. Despite being heavier than the proton, charm quarks are produced abundantly in electron–proton collisions at large momentum transfer – a consequence of the quantum properties of such reactions in the context of the theory of quantum chromodynamics (QCD). The combination of all available measurements from the H1 and ZEUS experiments at DESY's former HERA accelerator results in a precise determination of the charm quark contribution to the proton structure functions, which in turn leads to a competitive measurement of the charm quark mass, and, finally, to a reduction of the uncertainties of cross section predictions for *W* and *Z* bosons at the LHC.

Deep-inelastic scattering (DIS) of electrons off protons at the HERA collider is well suited to studying the properties of QCD. At energy scales significantly larger than the proton mass, processes with quarks carrying “heavy flavour” quantum numbers such as charm (m_c ~ 1.5 GeV) contribute significantly to inclusive quantities like the reduced cross section, σ_{red}, which is related to the proton structure functions. In the case of charm, this contribution can reach up to 36% in reactions at the highest measured energy transfer. A good understanding of the influence of the charm quark mass on the experimental and theoretical treatment of such quantities is thus of great importance, and can yield significant insights as shown below.

In order to study the charm contribution, events containing charm quarks in the final state must be tagged and separated from other processes. This can be achieved experimentally in various ways, which differ in their systematic uncertainties. Eight such measurements by the H1 and ZEUS collaborations have recently been combined to yield a result with strongly reduced overall uncertainties (Fig. 1). This uncertainty reduction is due not only to a combination of the statistical uncertainties, but also to a reduction of the systematic uncertainties through cross-calibration of the different measurements.

Just as in quantum electrodynamics, where, due to quantum screening effects, the electron charge can depend on the energy or distance scale at which it is measured, the charm quark mass can depend on the energy scale in the QCD treatment. The details of the dependence hinge on the “scheme” within which it is evaluated. When the MSbar running-mass definition in the fixed-flavour number scheme at next-to-leading order is used, a fit of QCD cross section predictions to the combined charm data yields a measurement of the charm quark mass “at its own scale” of

$$m_c(m_c) = 1.26 \pm 0.05_{exp} \pm 0.04_{th}\ \text{GeV},$$

where the first uncertainty is experimental and the second theoretical. This is in good agreement with the world average of 1.275 ± 0.025 GeV derived from completely different processes.

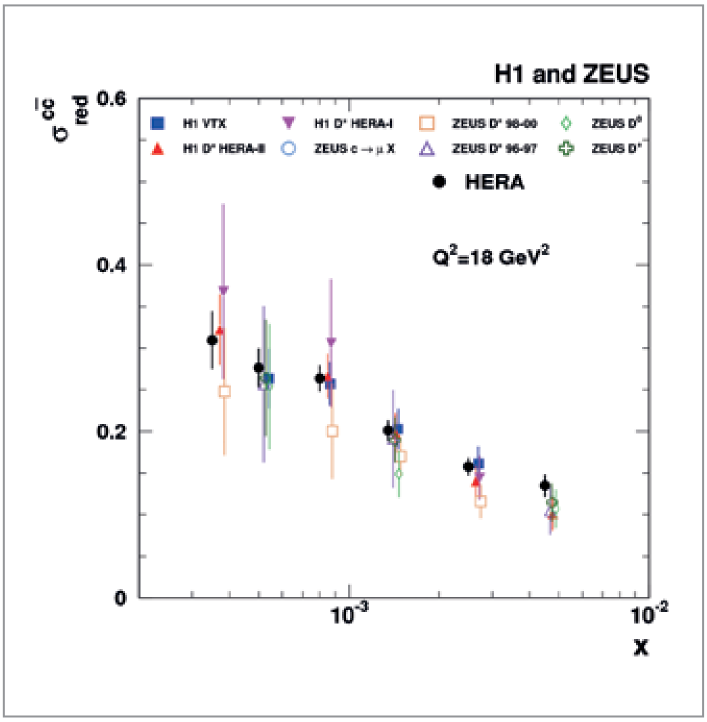


Figure 1

Example of the combined reduced cross sections σ_{red}^{cc} (black filled circles) as a function of the Bjorken scaling variable *x* for photon virtuality $Q^2 = 18\ \text{GeV}^2$. For comparison, the input data from the eight different measurements are also shown.

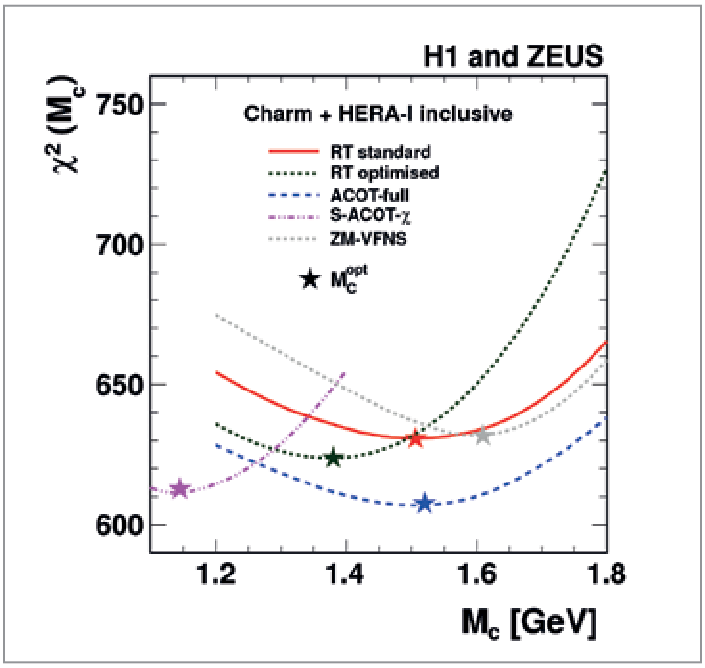


Figure 2

The values of χ^2 for the PDF fit to the combined HERA inclusive DIS and charm measurements. As explained in the text, different schemes are used in the fit and represented by lines with different styles. The values of the optimal charm mass parameter for each scheme are indicated by stars.

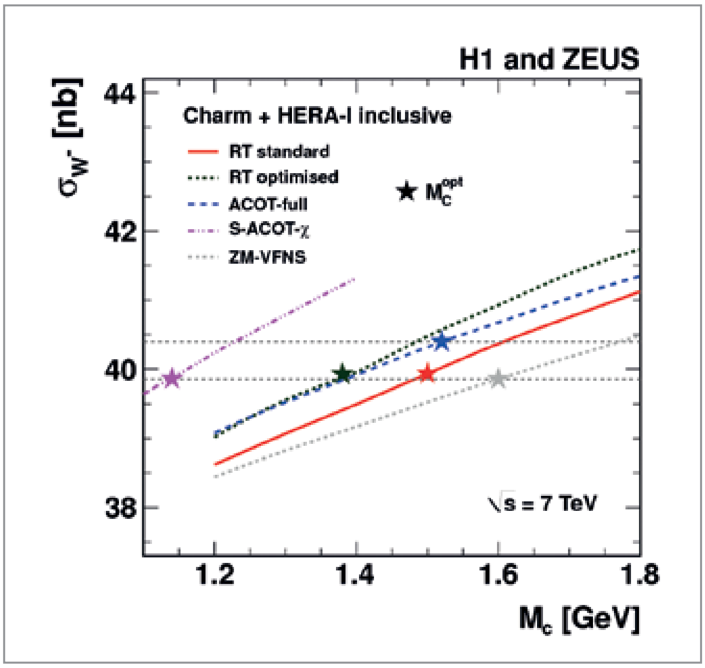


Figure 3

Cross section predictions for W^- production at the LHC as a function of the charm mass at next-to-leading order, using the same schemes as in Fig. 2. The optimal mass parameter for each scheme as obtained from Fig. 2 is again indicated by a star.

Most cross section predictions for proton–proton collisions, e.g. at the LHC, use parton density functions (PDFs, which give the probability to find quarks or gluons carrying a given fraction of the proton momentum) that are derived within the variable-flavour number scheme, in conjunction with the “pole” mass definition for the charm quark. As shown in Fig. 2, fits to the HERA charm (and inclusive) data, which use variants of this scheme, can lead to quite different optimal values for the related charm mass parameter. This reflects the theoretical uncertainty of the charm quark mass determination within this scheme. This charm mass parameter, in turn, influences the determination of the PDFs, and therefore the predictions of e.g. cross sections for the production of *W* and *Z* bosons, the carriers of the weak interactions, at the LHC.

Figure 3 shows an example of the mass dependence of such predictions for W^- bosons. Interestingly, when choosing the optimal value of the charm mass parameter obtained from the HERA fit for each of the scheme variants, as indicated by the stars and the two horizontal lines, the cross section predictions are much closer to each other than when a single fixed mass is chosen for all schemes (which can be seen as the difference between rising lines at a single fixed mass). Making the first choice thus substantially reduces the uncertainty of the cross section predictions from the ensemble of these schemes due to the value of the charm quark mass.

This result illustrates how HERA measurements at relatively low energies compared to the LHC can have a significant and direct impact on the interpretation of measurements at the LHC. A further combination of the measurements presented here with other measurements such as jet production has the potential to produce similar constraints also for the production of other final states, such as the top quark or Higgs boson.

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H1 and ZEUS Collaborations, DESY-12-172, accepted by Eur. Phys. J. C.

HERA: the proton microscope.

Deep-inelastic scattering at small distances

In the HERA storage ring, electrons collided with protons head-on and at high energies. The HERA experiments H1 and ZEUS study these collisions, particularly those in which the electron is deflected to large angles to probe the proton at distances much smaller than its diameter and thereby reveal its constituents – quarks and antiquarks. Large-angle scattering can also demonstrate the unification of electromagnetic and weak force.

More than 100 years ago, Ernest Rutherford performed his famous experiment on the scattering of alpha particles when passing a gold foil. The detection of alpha particles scattered at very large angles led to the discovery that the positive charge in the gold atoms is all concentrated in a small volume, the nucleus. Later, it was found that nuclei are not elementary particles, but are made of protons and neutrons, where the proton itself is the simplest possible nucleus, namely that of the hydrogen atom. The proton and the neutron themselves are composed of quarks, antiquarks and gluons. At HERA, electrons and their antiparticles, positrons, were used to probe the composition of the proton at very small distances. The reaction of highly energetic electrons or positrons with protons is termed “deep-inelastic scattering”. There are two basic types of reactions, as illustrated in Fig. 1: “neutral current” reactions, in which the scattered electron or positron is detected, and “charged current” reactions, in which the electron or positron changes into a neutrino or antineutrino, respectively. The neutrinos and antineutrinos escape detection.

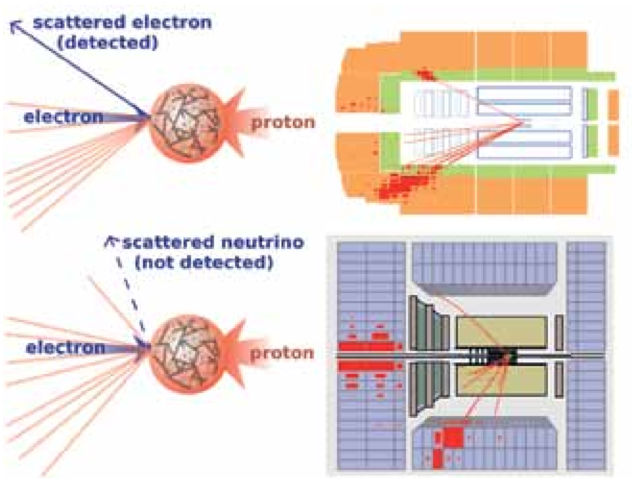

Figure 1

Electron–proton scattering events with a scattered electron (top) and a scattered neutrino (bottom)

To look at small distances, a large change in momentum of the scattered electron or positron is required. In Fig. 2, the probability of the reaction is shown as a function of the momentum transfer squared. The largest momentum transfer measured at HERA corresponds to a distance of about 10^{-18} m, a fraction of 1/1000 of the proton radius. One can see that reactions at small momentum transfer happen with much higher probabilities than those at large momentum transfer, corresponding to small distances. Also, at small momentum transfer, the neutral current reaction (shown in blue) has a much higher probability than the charged current

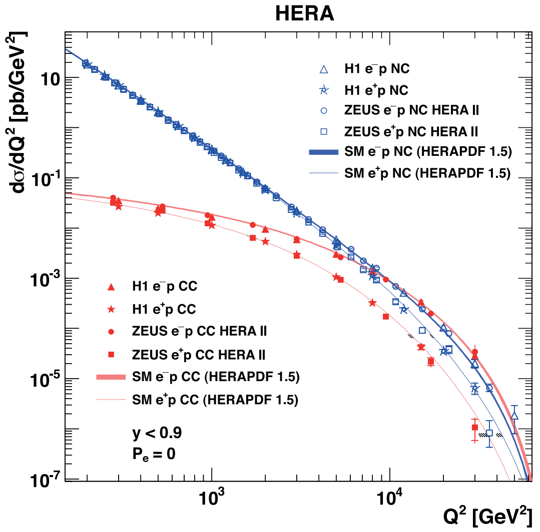

Figure 2

HERA cross section measurements probing small distances reaction (shown in red). At large momentum transfer, the picture changes: the two types of reactions have similar probabilities. The charged current reaction corresponds to the weak force, whereas the neutral current reaction corresponds to the electromagnetic force. The effect of these forces becoming similar in strength at small distances is a consequence of the unification of the electroweak forces. The corresponding theory of electroweak interactions was derived by Sheldon Lee Glashow, Abdus Salam and Steven Weinberg, and honoured with the Nobel Prize in Physics in 1979. Their theory predicted the existence of heavy particles, the $W^{\pm}$ and Z^0 bosons, long before they were discovered in 1983. At HERA, Z^0 bosons are rather challenging to observe, as discussed in another article in this annual report.

At large momentum transfer, one can also see another effect: the probability of the reaction depends on the type of the probe, electron or positron. This difference is related to the participation of the Z^0 boson in the reaction and to the fact that there are different types of quarks and antiquarks inside the proton. The valence quarks are responsible for the overall charge of the proton. In contrast, the sea quarks come in pairs of quarks and antiquarks, such that the overall sum of their charge cancels. The difference between electron and positron neutral current reactions is sensitive to the valence quarks alone, whereas the average of electron and positron reactions probes the sum of valence and sea quarks. Figure 3 shows the difference between electron and positron scattering. It varies depending on the fraction of the proton’s momentum that participated in the interaction. The electron–positron difference is largest for reactions in which about one fifth of the proton enters the reaction. In other words, the valence quarks typically carry a large fraction of the proton’s momentum. In contrast, sea quarks typically carry a small fraction of the proton’s momentum. Figure 4 shows a different view of the proton, in which the spin of the probe is exploited. Electrons and positrons have an intrinsic rotation, their spin. At large momentum transfer, the interaction with protons depends not only on the particle type, electron or positron, but also on the orientation of their spin. The difference between reactions with left-handed and right-handed spin orientation is rather small and thus difficult to measure. Similar to the average of electron and positron reactions, the spin difference is sensitive to the sum of sea and valence quarks. Figure 4 shows that the spin difference rises towards small fractions of the proton’s momentum, a clear indication that sea quarks contribute.

Finally, when also looking at the charged current reaction, one gains sensitivity to another property of quarks and antiquarks, their flavour. Direct measurements of reactions involving charm-flavoured quarks are discussed in another article of this annual report. Taking all the information extracted from the HERA data together, one obtains a detailed picture of the proton, where the various types of quarks and antiquarks are disentangled into parton density functions. The nucleus, first seen by Rutherford, has by now revealed a good part of its secrets, thanks to the small distances that become accessible with the HERA microscope.

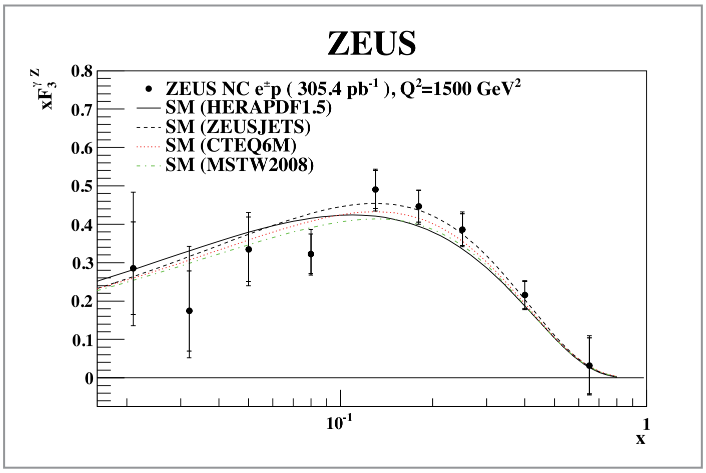

Figure 3

Difference between electron and positron scattering in neutral current reactions

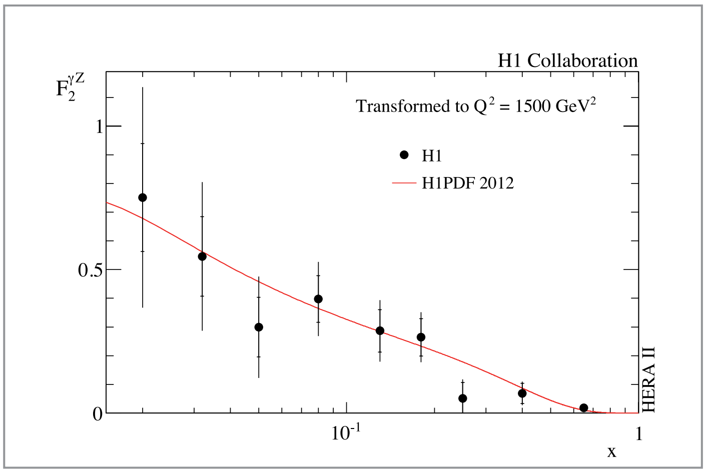

Figure 4

Difference between neutral current reactions when using left-handed versus right-handed probes

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Z^0 bosons at HERA.

Looking for a needle in a haystack

The Z^0 boson is an elementary particle that, together with the *W* boson, mediates weak interactions. It is electrically neutral and its own antiparticle. At the HERA collider, the Z^0 boson was observed both as a real particle and indirectly, as a carrier of the weak force between colliding electrons and protons. These measurements test the predictions of the Standard Model of particle physics, or more specifically, electroweak theory.

The Z^0 boson is among the heavyweights of elementary particles. Its discovery in 1983 by the UA1 and UA2 collaborations at CERN was honoured with the Nobel Prize in Physics in 1984. With a mass of 91.2 GeV/c^2, the Z^0 boson is almost 100 times as massive as the proton – heavier even than an iron atom. Its mass is important, since the Z^0 acts as the force carrier of the short-range fundamental force known as the weak force: the high mass of the Z^0 limits the range of the force. This large mass also makes the Z^0 difficult to produce at HERA. Only a handful have been observed in all the data gathered in 1996–2007.

The ZEUS collaboration measures the production of Z^0 bosons in events in which the proton remains intact and the Z^0 decays into quarks. Each of these quarks produces a jet (spray of particles), which is then observed in the ZEUS detector (Fig. 1). The sought-after signal for the production of a real Z^0 is a peak at the mass of the Z^0 in the distribution of the invariant mass of the two jets from the Z^0 decay.

The two-jet mass distribution recorded by the ZEUS experiment does indeed show such a peak (Fig. 2). The mass of the Z^0 boson is reconstructed from its decay products. A

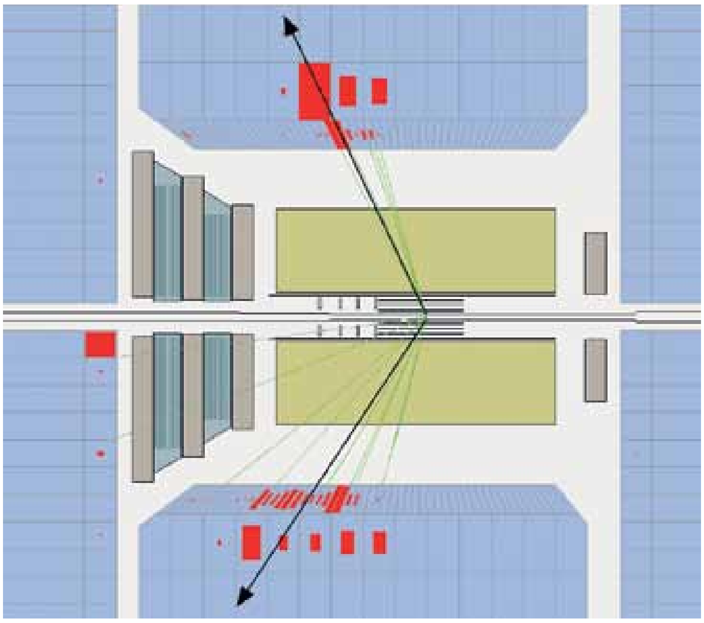

Figure 1

Real Z^0 production and decay into two quark jets in the ZEUS detector. The scattered electron is seen close to the beam pipe.

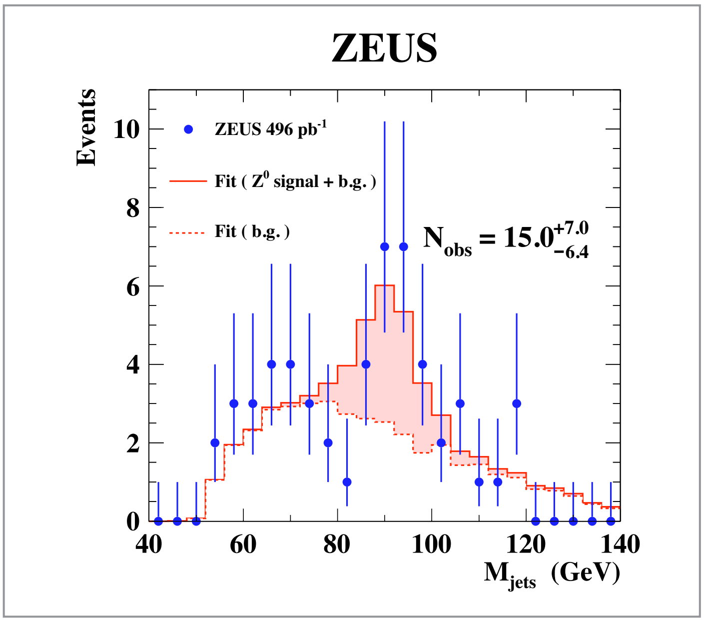

Figure 2

Experimental evidence for real Z^0 production

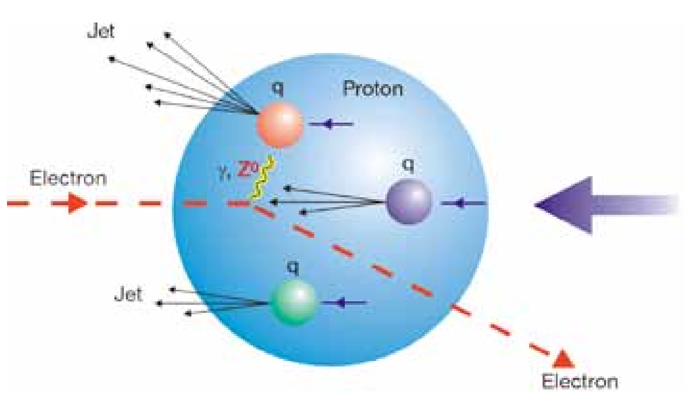

Figure 3

Neutral current interactions at HERA

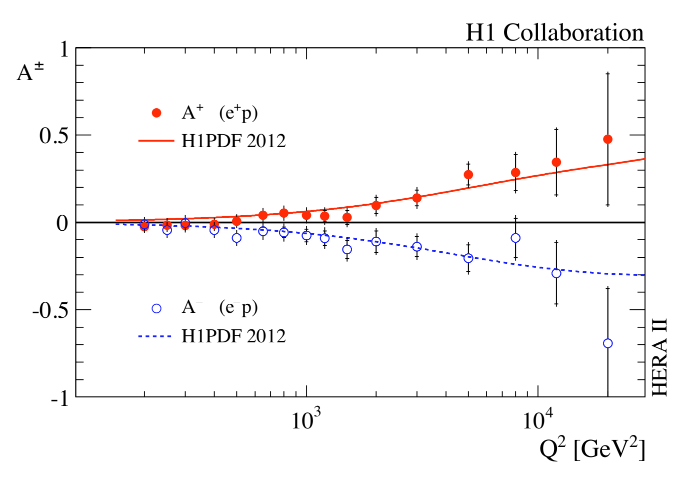

Figure 4

Polarization asymmetry for electron and positron beam

clear Z^0 mass peak with a total number of 15 Z^0 events is observed near 91.2 GeV/c^2. This is the first measurement of the real Z^0 boson in electron–proton scattering. It is the rarest process ever measured at the HERA collider. Still, this small number of observed candidates is in agreement with expectations – a big success of the theory of electroweak interactions in electron–proton collisions.

The Z^0 also shows up as a virtual particle – a transmitter of the weak force, a similar role to that played by the *W* bosons in radioactive decays. The exchange of Z^0 bosons is called "weak neutral current". Such currents were first observed in 1974 at CERN in neutrino–proton reactions. At HERA, where electrons or positrons collide with protons, the Z^0 exchange is more difficult to measure. Other neutral current reactions, in which a photon is exchanged instead of a Z^0 boson, have a much higher probability to occur. Figure 3 shows the neutral current reaction as it would happen at HERA. Here, a photon or a Z^0 boson is emitted from the electron and interacts with a constituent of the proton, causing the electron to change its momentum. This change is called a squared momentum transfer, Q^2. Only when the momentum transfer is large, is the contribution of the Z^0 to the neutral current interaction process significant. In order to disentangle the contributions of the photon and the Z^0 in the exchange, certain distinguishing properties of the weak force, for example parity violation, must be measured.

The electrons (or positrons) circulating in the HERA ring were polarized, meaning that their spins had a specific orientation relative to their flight directions. The spin corresponds to an intrinsic rotation, either clockwise or anticlockwise. A change in parity is equivalent to flipping the rotation direction. For the electromagnetic force – the photon exchange – parity is conserved so that the probability of the interaction does not depend on the spin orientation. In contrast, for weak forces, the interaction probability differs for left-handed and right-handed interactions. This difference is said to be “parity violating”.

A direct measure of parity violation, and thus of the weak effects, in neutral current scattering at HERA is the spin asymmetry, which is the difference between probabilities of a specific interaction occurring for different polarizations of the incoming beam. The H1 and ZEUS collaborations both measured such an asymmetry. The result from the H1 experiment is shown in Fig. 4. The asymmetry depends on the momentum transfer. It is zero for small values of Q^2 and grows with increasing Q^2, which shows that parity violation in this reaction is due to the exchange of a heavy particle, in fact, the Z^0. The predictions derived on the basis of electroweak theory are in agreement with the HERA measurements, which is another big success of the theory. The 1967 vintage Standard Model of particle physics is still getting it right after all these years! So far, the Standard Model has withstood all tests that experimenters have devised, including the prediction of the Higgs boson, which was discovered in 2012 at the LHC.

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Catch me if you can.

Kinematically complete event reconstruction in deeply virtual Compton scattering

The HERA experiment HERMES has delivered an entire saga of pioneering measurements, which shed light on the decomposition of the proton spin and the multidimensional structure of the proton. The final upgrade of HERMES was the addition of a detector to measure the momenta and angles of recoil protons from hard exclusive reactions such as deeply virtual Compton scattering (DVCS). This process constitutes the rare case in which the proton remains intact and a single photon, carrying intrinsic information about the proton kinematic structure, is emitted. The recoil detector was crucial for eliminating background from events in which the proton had been excited to a Δ^+ resonance. One highlight in this endeavour is presented here: the beam helicity asymmetry in DVCS.

Hard exclusive reactions and nucleon tomography

Deep-inelastic scattering of point-like electrons off protons is a clean tool for studying the structure of the proton, a complex object made of quarks and gluons. The energy of the impinging particles is so large that the strong ties between the quarks inside the proton are almost always broken up: the proton fragments into other particles.

In less than one of 10 000 electron–proton collisions, the nucleon remains intact, instead emitting a single highly energetic photon – a process termed deeply virtual Compton scattering, or DVCS. Only the longitudinal momentum of one of the quarks is altered. From the study of the trajectory of the photon, we can infer the magnitude and direction of the change in quark momentum. But how do we know the proton did not break up? We must have sufficient information about the event to deduce that no other particles emerge from the interaction apart from the photon, electron and proton, as is expected for DVCS.

For more than a decade, theoretical physicists have been proposing that experimentalists measure this hard exclusive process, since the data could yield an interesting constraint on generalized parton distributions (GPDs). GPDs are effectively three-dimensional maps of the nucleon in longitudinal and transverse position space ("nucleon tomography"). Global interest in GPDs is high, not least because of their potential to access the illustrious orbital angular momentum of partons and thus possibly solve the longstanding puzzle of the origin of nucleon spin.

DVCS events and the HERMES recoil detector

To measure DVCS, the HERMES experiment used the spin-polarized positron (electron) beam of HERA at DESY. Electrons from the beam with an energy of 27.6 GeV scattered off protons at rest. HERMES was one of the two pioneering experiments to measure DVCS in 2002. The other facilities that measure DVCS explore different kinematic regions (Jefferson Lab in the USA, the HERA collider experiments and recently COMPASS at CERN).

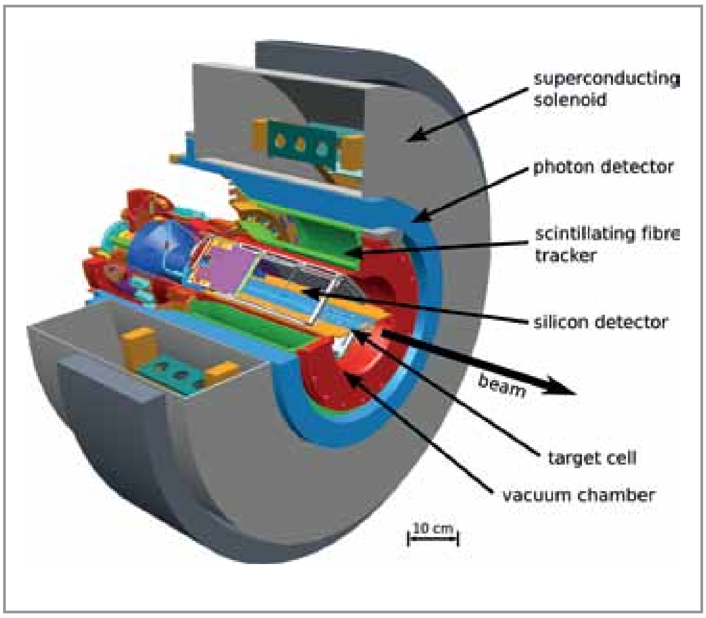

Figure 1

Schematic view of the HERMES recoil detector

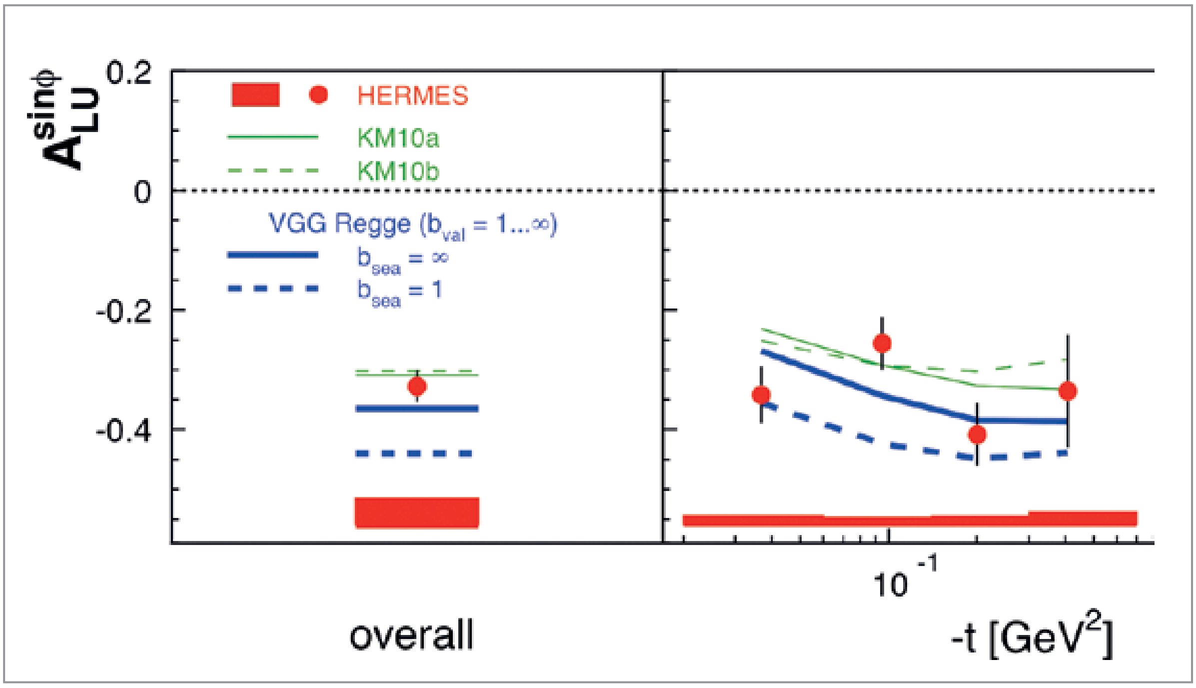

Figure 2

Beam helicity asymmetry amplitude in DVCS

Before 2006, HERMES could only detect the scattered electron and the DVCS photon, while the intact proton escaped detection. Nonetheless, exclusive events could still be separated from those in which the proton fragmented, using the information contained in the reconstructed momenta of the photon and electron. However, a complication arose: the scattering could excite the proton into its heavier brother, the Delta (Δ^+) particle. Since the intact proton was not detected, the "proton case" could not be distinguished from the "Delta case", the latter amounting to 12% on average according to a Monte Carlo simulation. These contaminating events remained part of the event sample prior to 2006. A pure "proton case", however, is desirable for establishing "proton tomography" before considering other, likely more complicated cases such as the Delta.

For the purpose of studying the pure "proton case", the HERMES apparatus was upgraded in the winter of 2005/06 with the addition of a recoil detector (Fig. 1). The new device, which surrounded the proton target, could detect the recoiling protons emerging under steep angles and with low momenta, and thereby suppress the "Delta case" to a level below 0.2%.

Beam helicity asymmetry in DVCS

In the analysis, selected events were sorted into two containers, or bins, according to the sign of the polarization of the positron beam. The event counts were then used to compute the difference in count rates: the beam helicity asymmetry. The asymmetry is then subjected to a harmonic analysis with respect to the azimuthal angle ϕ between the plane defined by the three-momenta of the incoming and scattered electrons and that defined by the three-momenta of the photon and the proton. The resulting sin ϕ modulation is shown in Fig. 2 in bins of $-t$ (the square of the four-momentum transferred to the proton) and as "overall" value (integrated over the accepted phase space by HERMES). The amplitude extracted without recoil proton detection (not shown here), which includes Delta events, is 20% smaller in magnitude.

The figure also indicates the predictions of theoretical models as blue bands. One of the model variants describes the new HERMES data fairly well, even though slightly overshooting them in magnitude. The green curves are results from a global fit to previous measurements of DVCS, which take into account various experiments. The new results from HERMES will serve as a valuable and much awaited input for future global fits of DVCS data, and thus a step towards a clear three-dimensional picture of the proton.

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Reference:

HERMES Collaboration, Beam-helicity asymmetry arising from deeply virtual Compton scattering measured with kinematically complete event reconstruction, JHEP 10 042 (2012)

The Higgs at last (?)

Is the hunt for the Higgs boson successfully concluded?

On 4 July 2012, the CMS and ATLAS collaborations at the LHC at CERN revealed that they had both observed a new boson whose properties are compatible with the Higgs particle predicted by the Standard Model of particle physics. This discovery is the culmination of decades of work by many thousands of physicists and engineers, and marks the beginning of a new era in high-energy physics. Dedicated Higgs analysis teams at DESY played a leading role in the discovery and are now working intensely to unravel the secrets of the new particle, and to test whether it really is the elusive Higgs boson.

Since the 1960s, when the Higgs mechanism was introduced into the Standard Model (SM) as a way to explain how elementary particles acquire mass, physicists have been searching for evidence that it is indeed the correct explanation of particle mass. Since the Higgs mechanism predicts the existence of a spin 0 boson (a.k.a. the Higgs boson), the discovery of such a boson with the right properties would be a convincing confirmation.

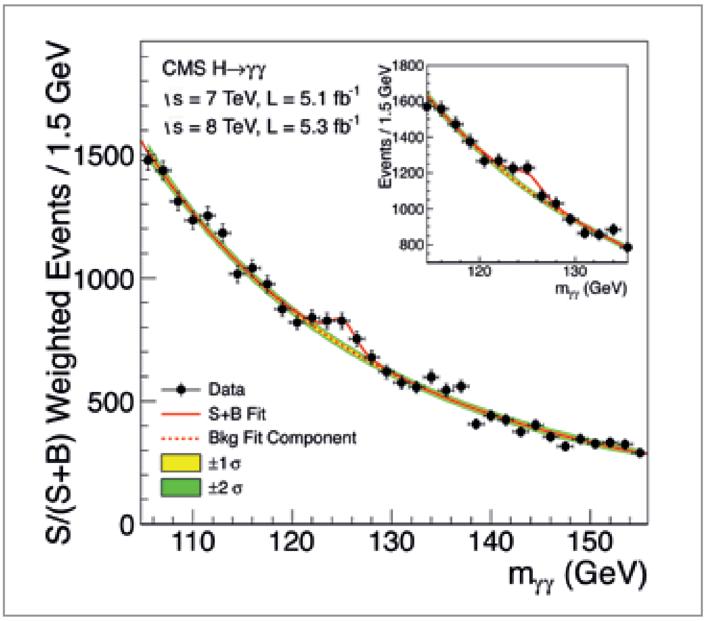

Figure 1

Diphoton mass distribution, from the CMS $H \rightarrow \gamma\gamma$ analysis, showing a weighted and unweighted sum of different photon categories

This discovery may have happened in the summer of 2012, when the ATLAS and CMS experiments reported convincing evidence for a new particle with at least some of the predicted properties of the SM Higgs boson at a mass of about 125 GeV. The observations were based on a combination of measurements of several decay channels. Figure 1 shows the resonance as a visible excess in the diphoton invariant mass spectrum. Figure 2 quantifies the excess in the combination of the three most sensitive search channels as the probability that a background fluctuation could cause the observed excess vs. mass. At 125 GeV, this probability is a minuscule 10^{-9}, convincing evidence that the data encompass something new. DESY contributed significantly to the discovery in the diphoton channel (ATLAS) and the two tau lepton channel (CMS).

Current Higgs measurements

Since July 2012, the exceptional performance of the LHC has provided the ATLAS and CMS experiments with more than a two-fold increase in data, whose analysis strongly confirms the July discovery and has allowed for the exclusion at the 95% confidence level of additional SM Higgs-like resonances in a large mass range (~110–500 GeV).

The new data is also opening the door to the rigorous study of the properties of the newly found particle. For example, the SM predicts the relative decay rates of the Higgs boson into different channels. Thus, an important early test is a comparison of the actual rates with the SM predictions. Figure 3 shows the strength of the signal of measured decay modes normalized to the SM prediction. The overall compatibility with the SM prediction is good (within 2σ) although the measurement uncertainties are still large. The

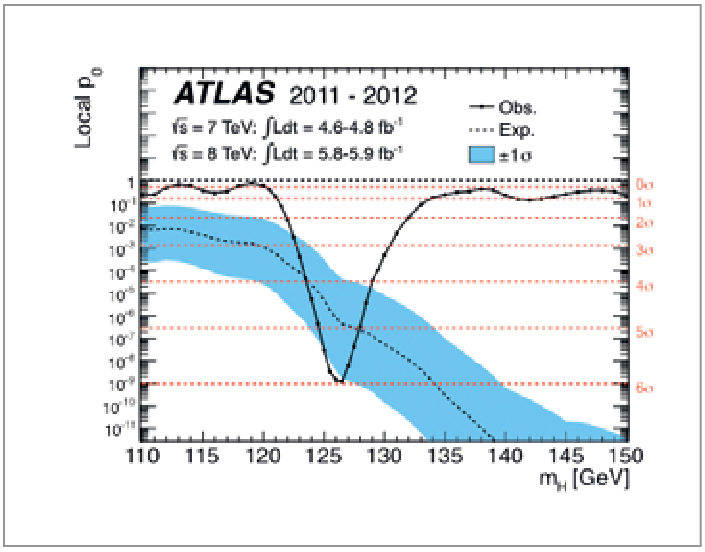

Figure 2

Local probability (p_0) of a background-only hypothesis to be consistent with ATLAS data, for the combination of the $H \to \gamma\gamma$, *ZZ* and W^+W^- analyses

physics community will be closely monitoring the evolution of these measurements, since a deviation with respect to the SM could signal the advent of an even more exciting era in particle physics.

Probing the fermionic decays (i.e. decays into lepton or quark pairs) of the new particle is another crucial test of its compatibility with the SM Higgs boson. The SM predicts that the strength of the Higgs coupling to a fermion should depend on the fermion's mass and that the Higgs boson decays preferably into the heaviest fermions, if kinematically allowed. Thus, about 6% of all decays should be into pairs of the heaviest leptons, i.e. tau lepton pairs.

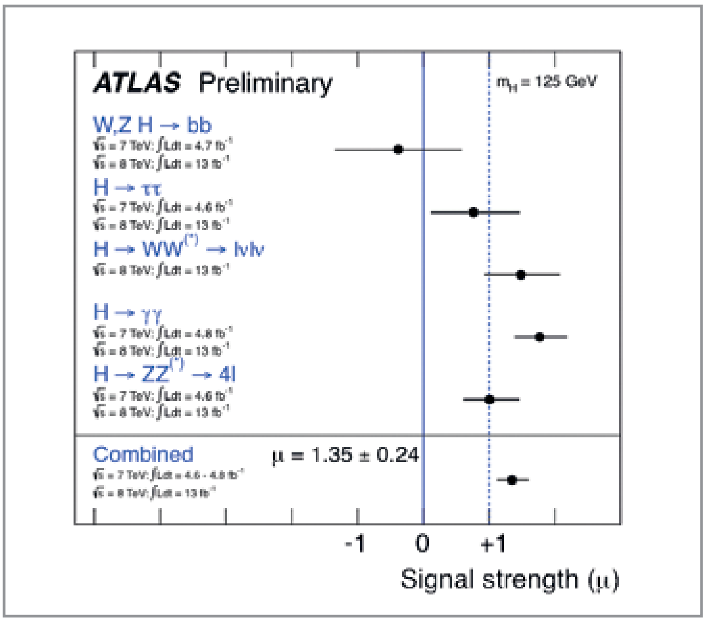

Figure 3

Signal strength observed in different Higgs search channels by the ATLAS collaboration. The combination of the different channels is also shown at the bottom and compared to the SM expectation (dashed line at 1).

The DESY CMS group is heavily involved in the analysis of this decay mode. Optimized algorithms for the reconstruction of hadronic tau decays have existed for some time; however the leptonic decay modes of the tau had not been studied in detail until the DESY CMS group jumped in to fill the gap.

As expected by the SM prediction, the LHC data have so far not shown a compelling signal in the fermionic decay modes. For example, the CMS Collaboration has measured the value of the signal strength, normalized to the SM prediction, in the $H \to \tau\tau$ decay channel to be 0.7 +/- 0.5. The uncertainty is too large to claim an observation but with additional data, the signal should soon emerge if the SM is correct.

Fermionic decays are also ideal probes of an extended Higgs sector, such as that predicted by the minimal supersymmetric extension of the Standard Model (MSSM). The DESY CMS group is strongly contributing to searches for an extended sector in both the tau lepton pair channels and the *b* quark pair channels, the latter being studied for the first time at the LHC. The current measurements already exclude significant parts of the MSSM parameter space and, together with the earlier measurements from LEP at CERN, effectively rule out the low-mass region up to about 120 GeV for the mass of additional neutral MSSM Higgs bosons (Fig. 4).

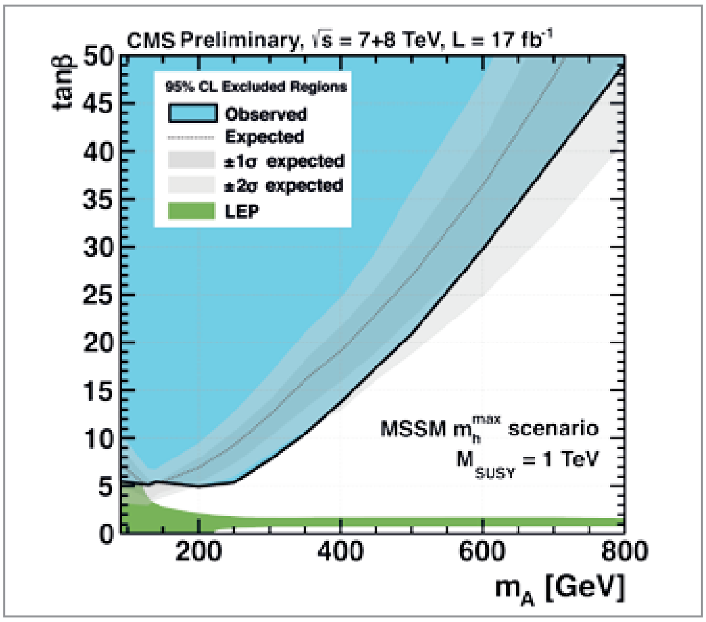

Figure 4

The region in the plane excluded by the CMS search for neutral MSSM Higgs bosons in the *tt* decay channel. Here, tan β denotes the ratio of vacuum expectation values of two Higgs doublet in MSSM, and m_A is the mass of the neutral CP-odd Higgs boson.

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High-luminosity physics.

ATLAS and CMS study the opportunities and challenges posed by the LHC upgrades

After the “Phase 1” upgrade in 2018, the LHC will operate at three times the collision rate of the present machine and achieve its design centre-of-mass energy of 14 TeV. The additional collision rate and higher energy will give physicists the opportunity to cover substantially more territory in the search for new physics. In 2022, the LHC will be further upgraded to operate at about eight times the present luminosity. This upgraded machine, known as the “High-Luminosity LHC” (HL-LHC), will provide a huge data set and thereby even more exciting new opportunities to explore the physics frontier. The increased collision rates will, however, pose significant experimental challenges. The ATLAS and CMS groups at DESY are hard at work studying the measurement potential in the harsh environment of the new machine.

Designing detectors for high luminosity

In 2012, the LHC produced an average collision rate of about 20 proton–proton interactions every 25 ns. Due to detector limitations, all 20 interactions are superimposed (or “piled-up”) on each other in the event record. This complicates the online selection of interesting interactions as well as their offline reconstruction and, ultimately, the extraction of physical information (and therefore possible discoveries) from the data. After the upgrades, the average number of piled-up events will increase at first to about 50 and then to about 140 collisions per event, and the analysis of the data will become even more difficult. Figure 1 shows an example of how a simulated HL-LHC event in the upgraded ATLAS tracker would look.

The tracking detectors will be improved by increasing their granularity and adding more detector planes, but the performance of the new detectors needs to be evaluated by carefully simulating their response to these complex events and going through the exercise of extracting physical information from the simulated data. After all, if the efficiency for finding interesting signals doesn’t increase much, increasing the collision rate won’t buy very much. Fortunately, as illustrated below, the studies show the opposite: the planned detectors will be sufficiently powerful to allow the extraction of the desired information without undue efficiency loss. Thus, the enormous data sets offered by the upgraded machine can be put to good use.

The ATLAS and CMS groups at DESY are studying specific examples of the sorts of measurements that are being planned for the upgraded detectors. The CMS group chose to study the discovery potential for a particular variant of a supersymmetric model. Supersymmetry (SUSY) is one of the foremost theoretical contenders for fixing certain problems in the Standard Model of particle physics and for explaining dark matter. The ATLAS group focused instead on an important issue concerning the Higgs boson. Theoretically, the Higgs boson is a consequence of the Higgs field which, if it exists, is responsible for conferring mass on all massive elementary particles. This raises a question: can we associate our newly discovered boson to this field, and thus truly call it a Higgs boson? The measurement of the so-called Higgs self-coupling should answer that question.

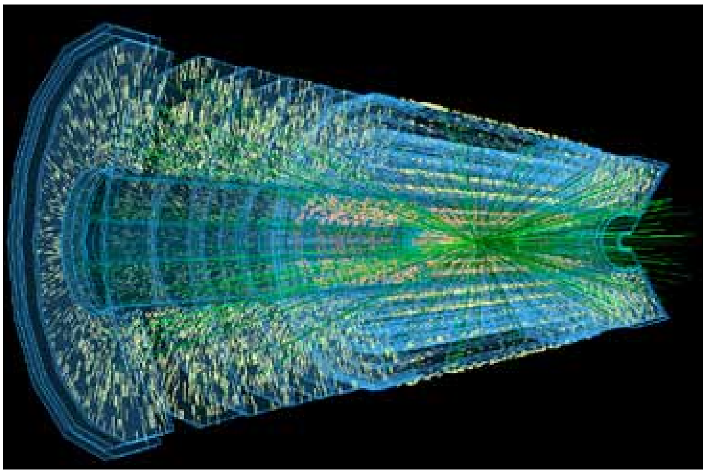

Figure 1

High-luminosity event simulated in the baseline layout for the ATLAS tracker upgrade, showing particle tracks and hits in the pixel and microstrip subdetectors

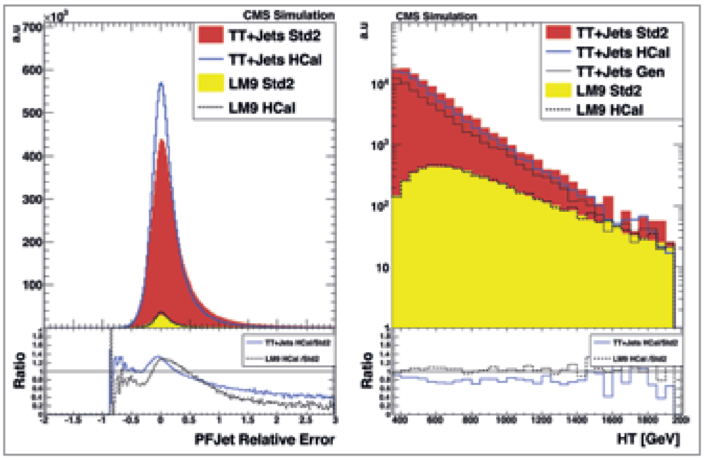

Figure 2

Distributions of the relative uncertainty on the transverse momentum measurements for jets using the particle flow algorithm (left) and the HT distribution (right). The dominant background of top pair events with multiple jets (TT+Jets) is compared to a certain supersymmetric signal (LM8). The present geometry (Std2) and the improved geometry after the pixel detector and hadronic calorimeter upgrade (HCal) are shown. On the right, the black line shows, for comparison, the input distribution before detector simulation. After the Pixel+HCal upgrade, the measured HT is in closer agreement.

Third-generation SUSY searches at CMS

The search for light third-generation squarks is of great and fundamental interest. The CMS group at DESY is evaluating the performance of such a third-generation SUSY search with detector simulations in a high pile-up environment for the standard and the upgraded geometry of the CMS pixel detector and the hadronic calorimeter (HCal). The search targets the decay products of stops and sbottoms, and the final state consists of a single lepton, missing transverse energy (MET) and a high jet multiplicity. The heavy-flavour content of an event is measured using b-tagging methods.

The analysis selects signal events with significant hadronic activity, quantified by the scalar sum (HT) of the transverse momenta of selected jets. The missing transverse energy is calculated with the CMS particle flow algorithm combining information from different sub-detectors to reconstruct all visible particles. The study is performed using full simulations of the standard and the upgraded detector geometry at an LHC with a centre-of-mass energy of $\sqrt{s}$ = 14 TeV and 25 ns bunch crossing, and assuming an average of 50 pile-up interactions per event as expected after the Phase I upgrade (Fig. 2).

The upgraded detector is shown to improve the measurement of the transverse momenta of jets in the particle flow algorithm, which in turn improves the HT resolution. For the major background to the third-generation SUSY search, namely events with top quark pairs, the signal-to-background ratio is improved in the HCal geometry relative to the standard geometry in the large-MET, large-HT region of the event selection. The HCal upgrade improvements come from a reduction of out-of-time pile-up energies, an improvement in the signal-to-noise ratio and a finer granularity of the detector readout.

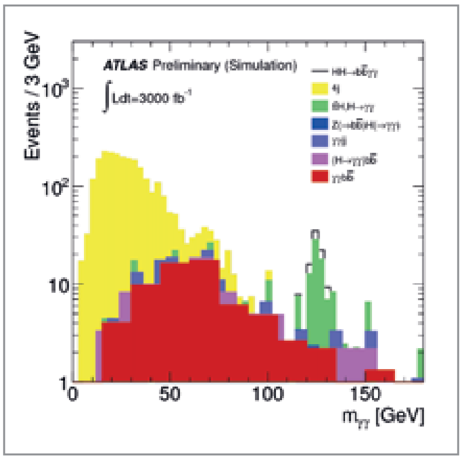

Figure 3

Diphoton distribution, taken from generator level events smeared to account for detector effects, for $HH \rightarrow bb\gamma\gamma$ signal and various backgrounds, in 3000 fb^{-1} of HL-LHC collisions

Higgs measurements at the HL-LHC

Measurements of the couplings and spin parity of the recently discovered Higgs-like boson that can be made using the anticipated 300 fb^{-1} LHC data set will already give strong indications regarding the specific nature of this particle. However, establishing with certainty whether this particle is truly compatible with a Standard Model Higgs boson will require the full 3000 fb^{-1} of the HL-LHC data set. This huge data set will allow not only significantly increased precision for the measurements that are currently possible, but also exclusive measurements of otherwise inaccessible, low branching ratio final states.

The planned measurements will provide insight into specific Higgs boson couplings. Of particular interest is the Higgs boson self-coupling, since it is linked to the Higgs potential and therefore gives insight into whether the Higgs field indeed fulfils its specific role in electroweak symmetry breaking. The Higgs self-coupling can be probed through measurements of Higgs pair production where production channels with and without Higgs self-interactions interfere destructively and thus cause large variations in the total cross section for different self-coupling strengths.

This is a highly challenging measurement, even at the HL-LHC, as the Higgs pair production cross section is about a thousand times smaller than that of a single Higgs boson. Nevertheless, initial studies in the $HH \rightarrow bb\gamma\gamma$ channel indicate, as illustrated in Fig. 3, that a signal can be seen, and show that a ~30% overall sensitivity to the Higgs self-coupling strength can be achieved if the individual sensitivity from the $bb\gamma\gamma$ channel can be matched from a combination of other channels, and combined across the ATLAS and CMS experiments.

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Boosted top quark resonances.

The search for the heaviest particles at the high-energy frontier

After three years of successful LHC operation, the Standard Model of particle physics seems more solid than ever. But what about physical phenomena beyond the verified theories? The heaviest of all known elementary particles, the top quark, could be connected with such new phenomena. If so, the new particles must be heavy and have highly energetic decay products. The reconstruction of such objects leads to analyses at the very highest energy edge of high-energy physics.

New physical phenomena at high energies?

If the boson discovered at the LHC in 2012 proves to be the Higgs boson, all elementary particles of the Standard Model will have been found. If a particle not described by the Standard Model does indeed exist, it is very likely to be heavier than anything known today – otherwise it would probably have already been seen. Several theoretical extensions to the Standard Model do predict such particles, and also predict that they might be in the form of top quark resonances, i.e. particles that decay into pairs of the heaviest known elementary particle together with its antiparticle: a top and an antitop quark (denoted $t\bar{t}$). A group at DESY has focused on the search for heavy top quark resonances using data from the ATLAS detector at the LHC.

Properties of the top quark

Top quarks (and antitop quarks) decay in 10^{-24} s, and almost always into a b quark and a W boson. The W boson in turn decays either into a charged lepton and a neutrino (a leptonic decay) or into a pair of lighter quarks (a hadronic decay). Top quarks are detected through their decay products. Quarks from the decay give rise to jets: collimated sprays of hadrons in the detector. Charged leptons have distinct signatures in the detector from which they can be identified, and the neutrino, which doesn't interact with the detector material, is indirectly measured as “missing” momentum. For the analysis described here, one of the top quarks is required to decay leptonically and the other hadronically. The sought-after events thus contain four jets, one charged lepton and missing momentum.

Boost!

Top quark pairs created by known mechanisms are typically produced with very little kinetic energy (i.e. at threshold) and decay nearly at rest. Since, in such cases, the four jets produced in the decays fly off in very different directions, they can be relatively easily reconstructed. We refer to such decays as “resolved”. In contrast, top quarks that are the decay products of a much heavier particle will fly away from each other with very high momentum (they are said to be “boosted”). Consequently, the decay products of the boosted quarks will tend to emerge from the interaction in nearly the same direction, so that jets from boosted hadronic decays will tend to merge into a single jet. The biggest challenge of the analysis is to distinguish such merged jets from ordinary single jets. To do so, the mass of the jet is checked. If it is high, the jet is more likely to have come from a boosted top quark. The jet's substructure is also checked for other subtle effects that allow a merged jet to be distinguished from an ordinary jet.

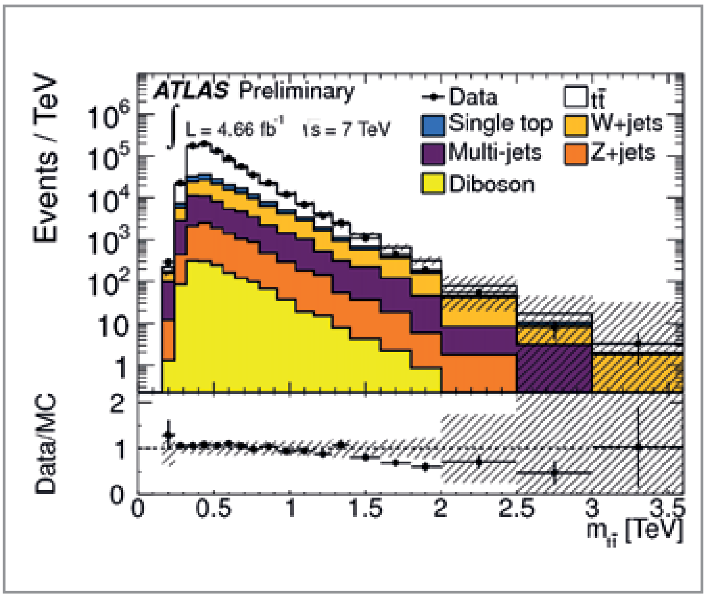

Figure 1

Top: Invariant mass of the reconstructed $t\bar{t}$ pairs and expected contributions from the Standard Model. The latter are divided into different categories based on the origin of the particles.

Bottom: Ratio of the data to the Standard Model prediction. No hints of $t\bar{t}$ resonances can be seen.

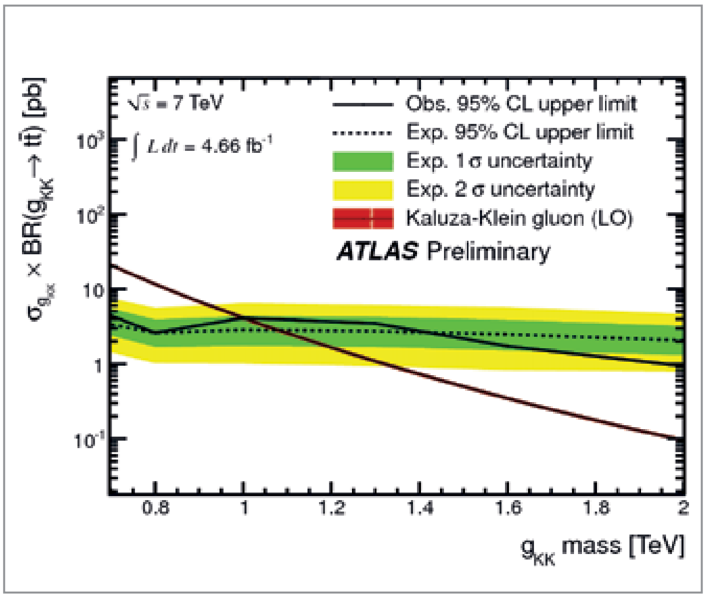

Figure 2

Upper limit on the production rate of the hypothetical Kaluza–Klein gluon (g_{KK}), a $t\bar{t}$ resonance, as a function of the $t\bar{t}$ invariant mass ($m_{t\bar{t}}$). The upper line is the theoretical production rate. For mass values at which the observed upper limit is below the prediction, the existence of a Kaluza–Klein gluon is excluded.

The search

After a sample consisting of both resolved and boosted top pairs has been isolated, it is checked for evidence of top quark resonance production by looking at the invariant mass spectrum of the $t\bar{t}$ pair. A resonance will show up as a bump in the spectrum – i.e. a rate in excess of the Standard Model prediction in a localized region of mass. If, however, the $t\bar{t}$ pair is only produced as predicted by the Standard Model, the $t\bar{t}$ mass spectrum will fall smoothly with increasing mass, as shown in Fig. 1.

We can conclude from Fig. 1 that the production rate of $t\bar{t}$ resonances, if any, is too low to be detected. Since we know our detection efficiency, we can set an upper limit on the rate (or, more precisely, the cross section) and compare this limit with the expectations of the models. The upper limits derived from the boosted sample, together with the predictions of one model (involving a “Kaluza–Klein gluon”, or KK gluon for short) can be seen in Fig. 2. The measurement rules out the model for any mass below about 2 TeV. If only the resolved decays had been used, a much weaker mass limit of about 1 TeV would have resulted. For exploring high mass, the techniques developed in this analysis for dealing with boosted states are clearly the way to go.

Towards a boosted future

The analysis described above is based on ATLAS data from 2011. A much larger data sample from 2012 is now being analysed, which opens the door to exploring even higher masses. We also eagerly await the start of data taking at a much higher centre-of-mass energy in 2015, after the ongoing upgrade of the LHC is completed. The higher LHC energy will dramatically increase the rate of boosted top quarks and the boosted analysis will become even more important.

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The ATLAS semiconductor tracker.

Operation and performance studies of the ATLAS SCT at DESY

The ATLAS inner detector (ID) consists of three parts: a silicon pixel detector, a semiconductor tracker (SCT) made from silicon microstrips and a transition radiation tracker (TRT) made from gaseous straw tubes. At the end of 2011, DESY officially joined the ATLAS SCT group to strengthen the tracker upgrade effort at DESY. Besides playing a leading role in operating and calibrating the SCT, DESY is involved in long-term performance studies, such as the evaluation of radiation damage in the high-radiation environment of the LHC and the proper modelling of radiation damage in Monte Carlo simulations of the detector. In addition, the DESY group is commissioning a new sonar system to monitor the gas composition in all inner detector components.

Only a few months after the successful turn-on of the LHC in 2010, the ATLAS and CMS experiments published their first high-precision measurements. In summer 2012, a fantastic breakthrough in the field of particle physics was recorded: the discovery of a new particle, so far consistent with the Standard Model Higgs boson. These remarkable achievements would have been impossible without the excellent performance of the LHC and the outstanding efficiency of both experiments in the first two years of data taking.

The ATLAS ID is responsible for measuring particle tracks with high precision. It is the innermost detector of ATLAS and measures 1.5 m in radius and 7 m in length. As shown in Fig. 1, it is composed of three subdetectors: the pixel detector is innermost, followed by the main subject of this article, the SCT, and finally the TRT, all of which are contained in a solenoidal magnet with a field of 2 T.

At the end of 2011, DESY officially joined the ATLAS SCT group and currently, ten DESY physicists are participating in SCT-related projects, including development of the offline monitoring and calibration system, investigation of radiation damage issues, implementation of radiation damage models in the detector simulation and participation in offline ID quality assurance shifts.

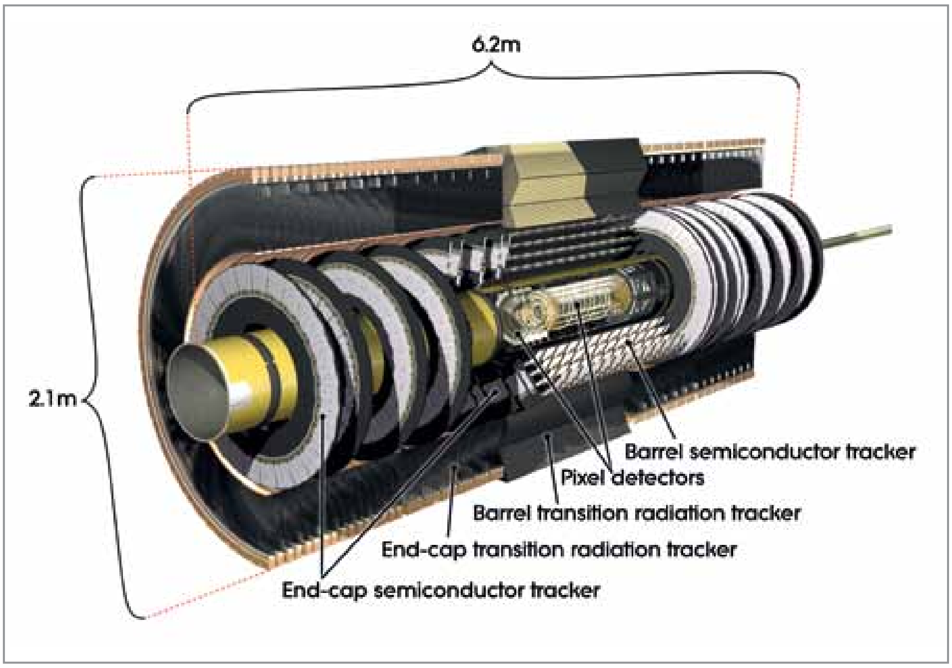

Figure 1

The current ATLAS inner detector (ID), composed of pixel detector (silicon pixels), semiconductor tracker (SCT, silicon microstrips) and transition radiation tracker (TRT, gaseous straw tubes)

Figure 2

The central (barrel) part of the SCT prior to installation

Operation of the ATLAS SCT

The LHC produces a prodigious interaction rate: counter-rotating bunches of protons pass through each other in the ATLAS intersection region at a rate of 20 MHz, and up to 40 interactions occur in each bunch crossing. In this demanding environment, the SCT modules are required to provide excellent spatial resolution (16 µm), a hit efficiency of more than 99% and an extremely low noise occupancy of $5x10^{-4}$. To maintain the highest possible data quality, a calibration procedure is performed with the collected data, and updated calibrations are made available within 48 h of the time the data is taken for input into the reconstruction programs. The calibration procedure updates all the key variables needed to monitor long-term performance, namely, noisy-strip inventory, count of dead strips and chips, noise rates, raw occupancy, efficiency and readout error rate.

Since summer 2012, DESY has been responsible for maintaining the underlying software infrastructure of the calibration loop and is the first point-of-call in case of problems. The base version of the calibration code was extensively rewritten and, after commissioning by DESY, became operational at the end of 2012. The new code is significantly more efficient and provides even faster feedback than the former version.

Radiation damage in Monte Carlo simulations

The SCT was designed to operate for 10 years, but it nonetheless slowly deteriorates primarily due to radiation damage. Radiation damage causes an increase in detector noise, higher leakage current and a decrease of the charge collection efficiency. Careful monitoring of these effects and predicting their impact on detector performance are essential. The DESY ATLAS group has therefore introduced a model of the most important cause of the symptoms listed above, i.e. charge trapping, into the simulation framework. Charge trapping occurs because of defects in the crystal structure of the silicon caused by interactions of passing particles. With the new code, the degradation of detector performance with increasing radiation can now be accurately predicted.

Gas monitoring in the ID cooling system

DESY is also involved in the commissioning of a sonar system designed to monitor the gas composition in the ID cooling system and to detect possible leaks of the coolant into the air surrounding the ID. The composition of the cooling system gas can be inferred from measurements of the pressure, temperature and speed of sound of the gas. The first sonar sensor was brought into operation in late 2012 and is now routinely analysing the SCT cooling gas. Two additional sonars will be installed and commissioned during the LHC shutdown in 2013 and 2014. The testing of the underlying software is in progress and the new system is currently being integrated in the detector control system.

During the upcoming shutdown, DESY physicists will extend their work of 2012 to prepare for the future challenge of even higher interaction rates and a near doubling of the LHC centre-of-mass energy.

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The top quark and its properties.

The heaviest elementary particle opens a window to new physics

The top quark is the heaviest known elementary particle and will therefore almost certainly play a special role in the search for new physics. The LHC at CERN presents a unique opportunity to exploit this potential. The Helmholtz Young Investigators Group (YIG) “Approaching the Fundaments of Physics using Top Quarks at the LHC” is participating in this exciting exploration.

Despite the enormous success of the Standard Model (SM), open questions suggest that undiscovered physics lies beyond. Such “beyond the Standard Model”, or “BSM”, physics, if it exists, will most likely be discovered in the form of heavy particles with strong couplings to the heavy particles of the SM. A promising research path is therefore a detailed study of the production and properties of the heaviest known particles, namely the Higgs-like boson itself and the heaviest of all known elementary particles, the top quark. Using data from the ATLAS experiment to do just that is the focus of the YIG. More specifically, we are contributing to measurements of top quark polarization, of charge asymmetries in the production of top–antitop quark pairs ($t\bar{t}$) and of $t\bar{t}$ spin correlations.

One interesting open issue involves the production asymmetry of $t\bar{t}$ pairs: Tevatron studies show a deviation of the measured asymmetry from SM predictions. The YIG is contributing to a different but complementary measurement that should help to understand the deviation.

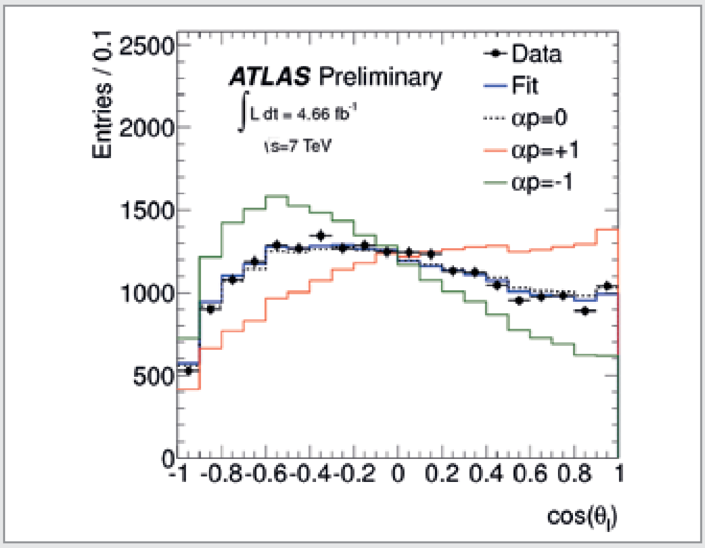

Figure 1

Cosine of the angle of the lepton in the top quark rest frame, with respect to the top quark direction in the $t\bar{t}$ rest frame, for $t\bar{t}$ events with one final-state electron. Shown are distributions for different top quark polarization hypotheses as well as a fit to the data.

Another way to explore the Tevatron asymmetry riddle is to measure top quark polarization. Many BSM models that predict a sizeable $t\bar{t}$ production asymmetry at the Tevatron also predict a measurable polarization at the LHC, while the SM predicts no polarization. The YIG is pursuing this measurement and has already contributed to the first result, which was shown at the Top2012 conference in fall 2012. Figure 1 shows the spectrum of an angle whose distribution is sensitive to the polarization together with predictions. The measurement is compatible with the SM expectation, although the verdict is still out.

The YIG is also contributing to the precision measurement of the spin correlation between top and antitop quarks. This study will provide complementary insights to those of the Tevatron measurements.

In 2022, the LHC, together with the ATLAS and CMS detectors, will be upgraded to prepare for a higher-luminosity environment. This includes the complete replacement of the ATLAS tracking system. The YIG is contributing to the optimization of the design of the new tracker through detailed simulations, studies of tracking and vertexing performance and the development of improved cluster splitting algorithms.

Reference: http://atlas.desy.de/e168372/e168375/

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Helmholtz Young Investigators Group
“Approaching the Fundaments of Physics Using Top Quarks at the LHC”

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Proton structure from deep-inelastic scattering and proton collisions.

Advancing the interpretation of the LHC data

The project “Determination of the proton structure using data from deep-inelastic scattering at HERA and proton–proton collisions at LHC” started in 2011. Its goal is the determination of heavy quark masses, the strong coupling constant (α_S) and the parton distribution functions (PDFs) in a most coherent manner by simultaneously exploiting the deep-inelastic scattering (DIS) data from HERA and the measurements from the LHC.

QCD analysis framework HERAFitter

The novel open-source program HERAFitter provides a basis for comparisons of different theoretical approaches and can be used for direct tests of the impact of new experimental data in QCD analyses through a coherent treatment of the data and theory calculations. Originally developed by the H1 and ZEUS collaborations and used for determination of HERAPDF sets, HERAFitter has been extended to the LHC experiments and to the implementation of additional phenomenological approaches. The HERAFitter program is released [1] and widely used by the LHC experiments, e.g. to determine the strange quark distribution in the proton [2].

Measurement of the running charm quark mass

Charm quark physics (and in particular the value of the charm quark mass) is the key issue in the QCD analysis of the proton structure. Experimental measurements of charm production usually suffer from phase space limitations, and theory has to be used to extract the charm cross section in the full phase space. In close collaboration with the ABM PDF group at DESY in Zeuthen, a comprehensive analysis of charm production in DIS was performed [3] to determine the running mass of the charm quark, $m_c(m_c)$, at NLO and approximate NNLO. The analysis accounts for the full correlation of the phase space correction with both $m_c(m_c)$ and the PDF.

A further study [4] includes the combined HERA charm measurements [5] into the ABM scheme of global QCD analysis for the simultaneous determination of the PDFs, $m_c(m_c)$ and the study of the correlation between $m_c(m_c)$ and the value of α_S. The results are consistent with and of comparable precision as the world average.

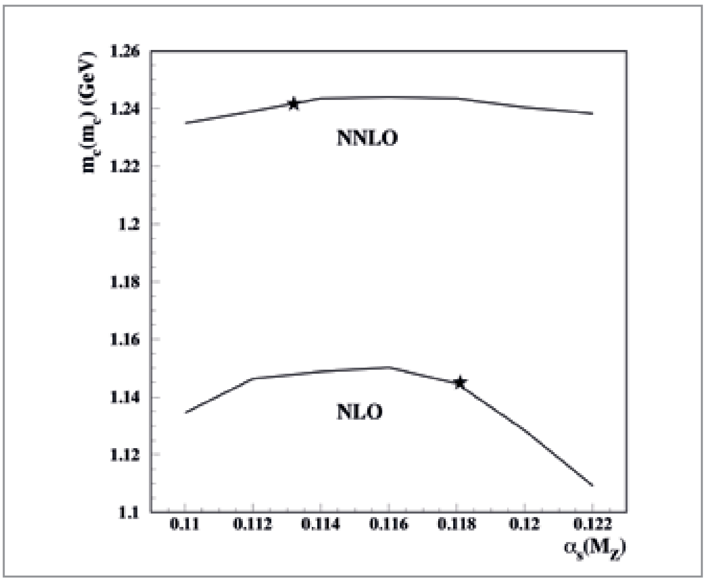

Figure 1

Dependence of the charm quark mass, obtained in the QCD fit, on the assumption on α_S evaluated at the scale of the Z boson mass. The central values for results at NLO and NNLO are indicated by the symbols.

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QCD and proton structure from HERA to the LHC.

Improving the description of the proton

Although designed primarily for the discovery of the Higgs boson and physics beyond the Standard Model, the LHC is basically a “QCD machine” operating in a new energy regime. Consequently, the LHC experiments are confronted with much higher rates of events containing multiple jets, vector bosons and top quarks than the expected rates due to the new physics processes. The full discovery potential of the LHC therefore depends on reliable predictions for signal and background processes. Measurements of several observables in different regions of phase space are required in order to extract complementary information on the fundamental parameters of the theory used to describe the background. Most of these observables are interconnected by their sensitivity to the proton structure, which is expressed in terms of parton distribution functions (PDFs). DESY groups within the CMS and ATLAS experiments are contributing significantly to measurements of the production of electroweak bosons, top quark pairs and events with jets, with the goals of pinning down the fundamental parameters of QCD and obtaining deeper insights into the parton distributions and parton dynamics within the proton. This work is realized in close collaboration with theorists at DESY and other institutes.

Quark distributions using electroweak boson production at the LHC

The strange quark distribution plays an important role for a variety of physics processes, but is not known precisely. It was measured in fixed-target and neutrino experiments with large uncertainties due to a lack of understanding of fragmentation and nuclear effects. The ratio of *W* boson and *Z* boson production cross sections at the LHC is sensitive to the flavour decomposition of the quark sea. Such measurements are being included into the QCD analysis together with the deep-inelastic scattering (DIS) data from HERA to provide constraints on the strange quark distribution [1]. For this purpose, the open-source program HERAFitter developed at DESY was used.

Top quark production at the LHC and precision tests of QCD

Top quark pair production is described in the framework of perturbative QCD and plays a key role in testing various aspects of the QCD factorization theorems. The values and accuracy of the top mass and strong coupling constant measurements determine the precision of many Standard Model predictions and, in turn, the reliability of searches beyond the Standard Model. The DESY CMS group is deeply involved in measuring differential distributions of top pair cross sections [2] and top quark properties. The high precision of the experimental measurements of top pair cross sections is used to put constraints on the top quark mass and, for the first time, to determine the strong coupling constant [3] (Fig. 1). Simultaneous determination of the top quark mass, strong coupling constant and PDFs is a subject of a current study.

QCD at highest energies

The parton densities obtained from a fit to the inclusive DIS cross sections measured at HERA rise steeply towards small values of the fraction of the proton momentum carried by the partons. The cross section for jet production calculated with these parton densities also rises towards small transverse jet

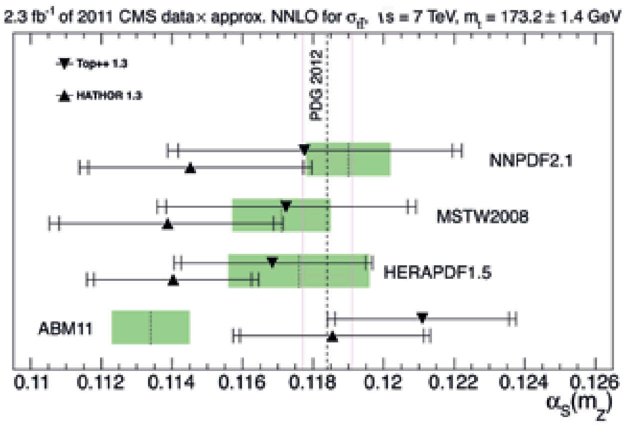

Figure 1

Strong coupling constant measurements, determined from inclusive top quark pair production cross sections. The acronyms next to each data point designate which PDF set is used.

momenta and eventually exceeds the total inelastic proton–proton cross section. A measurement that tests the theoretical predictions in the region of small transverse momenta was proposed [4] (Fig. 2) and is currently being performed using low p_t charged particle jets (minijets) and tracks in CMS.

While the inclusive minijet cross section yields information on the transition from a perturbative (high p_t) to a non-perturbative (small p_t) phase, measurements of the hadronic final state are mandatory for an understanding of the parton radiation pattern, which drives the parton evolution as described by the parton density functions. The energy density in an area away from a jet system in the central region is especially sensitive to parton radiation. This energy density has been measured for the first time in a region close to the proton beam direction using the CASTOR calorimeter (built with major contribution from DESY), which covers a region not previously accessible [5].

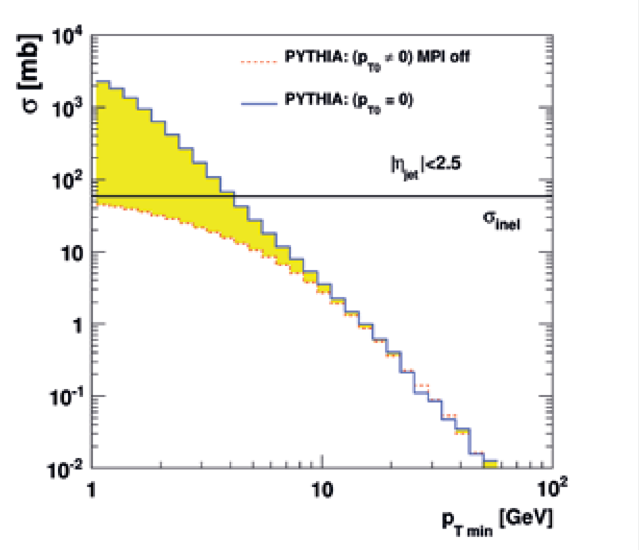

Figure 2

Cross section for minijets as a function of transverse momentum

In order to reduce the sensitivity to the absolute energy calibration of the calorimeter, the ratio of energy density in events with a jet in the central detector to that obtained in minimally biased events has been measured. The dependence of this energy density as a function of the proton–proton centre-of-mass energy is shown in Fig 3. In an environment in which the parton densities are large, more than one partonic interaction can occur. The measured energy density is compared to predictions, which include such multiple partonic interactions (MPI). While models including the concept of MPI can be made to describe the measurement, the predictions without MPI fail to describe the data.

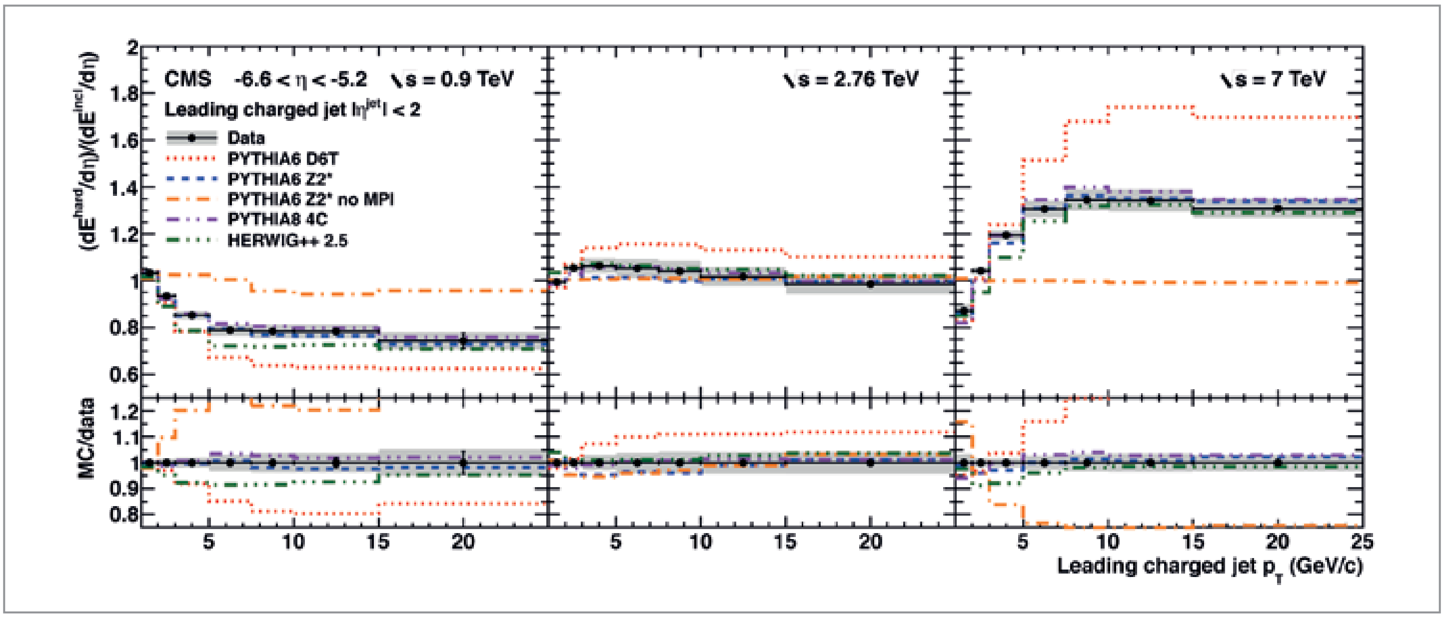

Figure 3

Energy density ratio measured for three different centre-of-mass energies

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Supersymmetry.

Hunting Supersymmetry with the CMS detector

2012 was an exciting year for Supersymmetry. The experimental data provided by the LHC has excluded many, previously well regarded, assumptions and simplifications about the nature of Supersymmetry, while new ideas became important for the ongoing searches for phenomena beyond the Standard Model of particle physics. The latest data now make it possible to extend the searches into regions of higher, unexplored masses and to processes with low cross section.

A supersymmetric world

Even after the discovery of the Higgs boson, the Standard Model of particle physics raises many puzzling questions. Examples are the hierarchy problem, which is related to the question why the energy scale of the weak interaction is so much smaller than the Planck scale, and the possible unification of the strong and the electroweak forces. Another open question is the nature of dark matter, which is needed for example to describe the movement of stars in spiral galaxies and which seems to be by far more abundant than the visible matter in our universe.

Supersymmetry, or SUSY, predicts partner particles to all known elementary particles and provides an elegant explanation for many of the pressing questions in physics and cosmology. The postulated SUSY particles have the same properties as their Standard Model partners except for their spin, but they must be heavier since otherwise they would have already been observed.

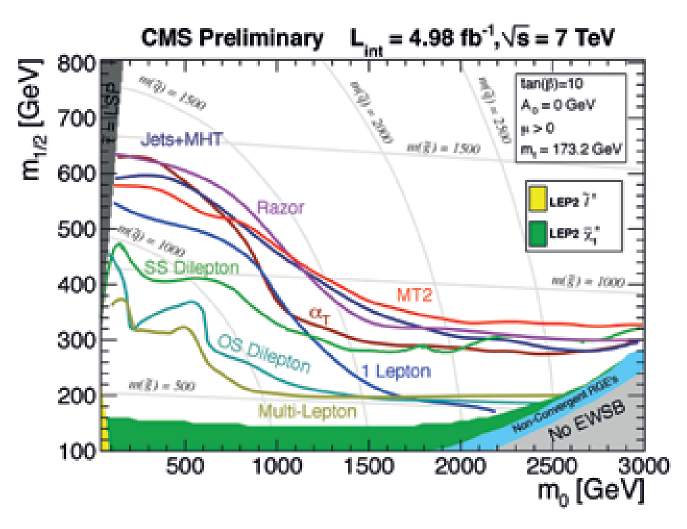

Figure 1

Observed limits from several 2011 CMS SUSY searches plotted in the CMSSM (m_0, $m_{1/2}$) plane

While the concept of Supersymmetry itself allows for an elegant extension of the Standard Model, many details of such models cannot be deduced from first principles. In particular, the masses of the new particles are unknown and additional assumptions are used to fill this lack of knowledge. One popular approach is the Constrained Minimal Supersymmetric Standard Model (CMSSM), which assumes that at a sufficiently high energy scale all the scalar particles have the same mass m_0, and that the SUSY partners of all the gauge bosons, the gauginos, have the same mass $m_{1/2}$.

Another assumption, R-parity conservation, guarantees that SUSY particles always decay directly or through cascades of supersymmetric particles into the lightest SUSY particle (LSP). The LSP is stable and therefore a viable candidate for dark matter. As a neutral particle it escapes direct detection, but it can still be seen indirectly because it typically carries a large amount of momentum transverse to the beam direction. The total transverse momentum must be conserved, and the missing momentum due to the escaping LSPs can be deduced from the measurement of the transverse momentum of all the other particles.

The main production process of SUSY particles at the LHC is through gluinos and squarks, the SUSY partners of gluons and quarks. Given R-parity conservation, these are produced in pairs and decay eventually into quarks, leptons and the LSP. Common to all SUSY events are multiple jets from these decays and missing transverse momentum due to the escaping LSPs.

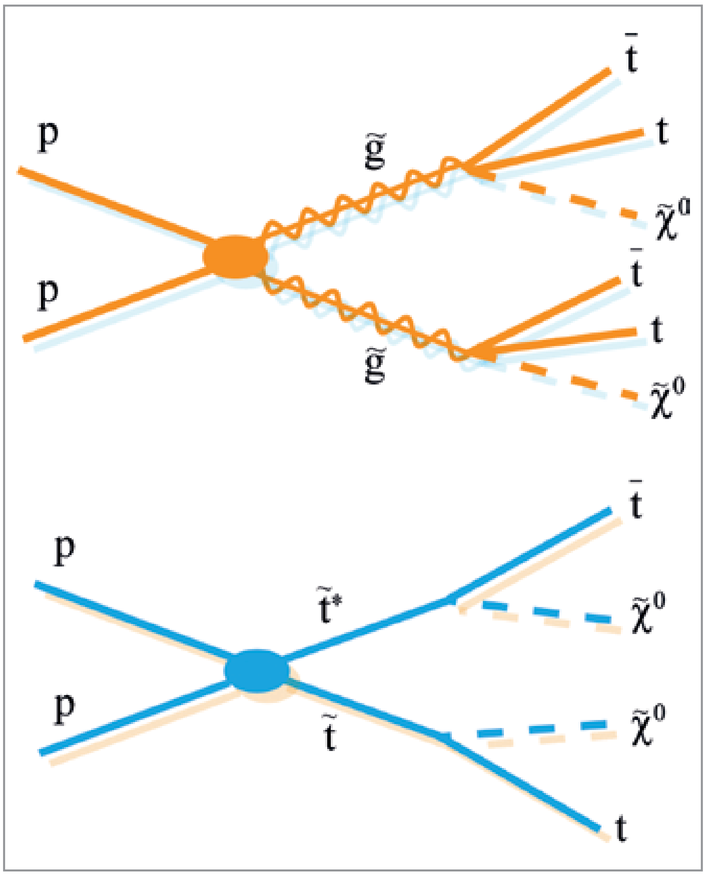

Figure 2

A sketch of two simplified models. The upper diagram describes the production of a gluino pair that decays into two LSPs and four top quarks. The limit derived for this process with 2011 data is shown in Fig. 3. The lower diagram describes the direct stop production. The CMS SUSY group at DESY is currently analysing 2012 LHC data for this process.

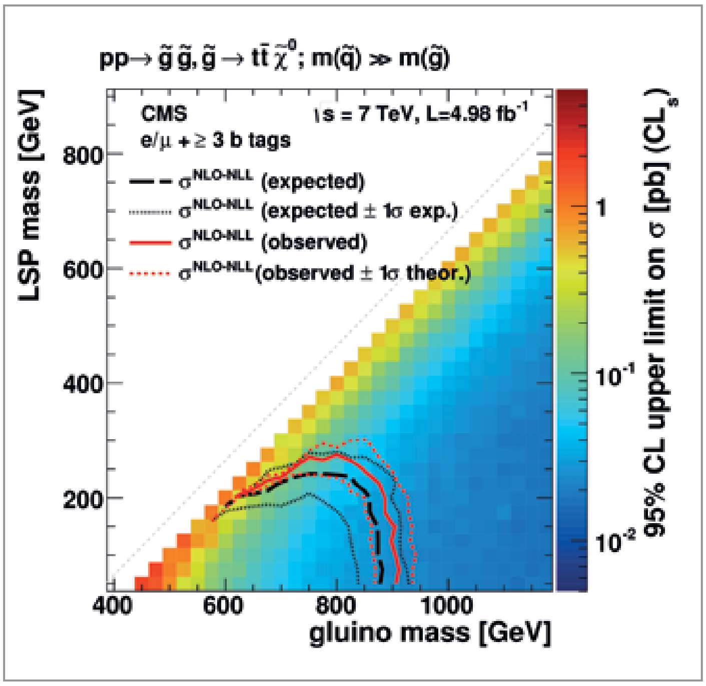

Figure 3

Observed limits for the gluino-mediated stop production in decays with one lepton. Gluinos are produced in pairs and decay into two top quark jets and the LSP, which escapes detection, leading to significant missing transverse momentum.

LHC at 7 TeV

During 2011, the CMS experiment recorded proton–proton collision data at a centre-of-mass energy of 7 TeV. Several CMS groups have analysed these data for hints of Supersymmetry. A large number of searches for different final states and with different search methodologies have been published during 2012. The combined results are shown in Fig. 1. At DESY, a Helmholtz Young Investigator Group has specialized in searches for decay channels with exactly one muon or electron, *b* jets and a large amount of missing transverse momentum. A large part of Standard Model physics is suppressed by this choice, and many different SUSY scenarios can be investigated.

It is important to present the results of searches for new physics in a most general way. For this purpose, simplified models have been defined (Fig. 2). They describe a single aspect of a supersymmetric process, typically concentrating on the mass differences between SUSY particles. With such an approach, additional assumptions, as needed for example to define the CMSSM, can be avoided. Figure 3 shows the excluded mass range for such a simplified model. It describes the gluino-mediated stop production with four top quarks in the final state, as illustrated in the upper diagram of Fig. 2. In the CMS detector, the decay products of the four top quarks, here *b* jets and leptons, can be observed.

LHC at 8 TeV

Up to now, the results of all SUSY searches are consistent with the Standard Model of particle physics. One may be worried about the *naturalness* of supersymmetric models if the masses of SUSY particles are orders of magnitude larger than their Standard Model partners. Nevertheless, it is sufficient that only the SUSY particle masses of the third generation, stop and sbottom, are small. In such a scenario, the hierarchy problem can still be solved and the large masses of the gluino and the first- and second-generation squarks explain the lack of observation.

In this case, the large amount of LHC data collected in 2012, about four times more than in 2011, opens a new window for the discovery of Supersymmetry: the direct stop production (Fig. 2 bottom). Depending on the stop mass, the cross section for this process can be small and the high background from Standard Model physics makes the stop search an ambitious project, which can nevertheless be pursued thanks to the steady refinement of analysis techniques. These analyses are still ongoing, with first results expected to become available during 2013. They are even more promising for the energy upgrade of the LHC, which will almost double the centre-of-mass energy.

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Optical femtosecond synchronization.

Long-term stable laser-to-laser synchronization for FLASH and the European XFEL

To fully exploit the time resolution of X-ray free-electron lasers (FELs), it is mandatory that the synchronization of the FEL accelerator, both with its external seed and with the laser systems of the experiments, have an accuracy and stability on the femtosecond time scale. This is well beyond the reach of conventional RF-based schemes and can only be achieved using direct optical methods.

One of the distinguishing features of FELs is their ability to produce intense X-ray light pulses with the extremely short durations needed to study processes that occur on atomic time scales, i.e. within a few femtoseconds (10^{-15} s) or less. These pulses allow “flashing” atomic and molecular processes to reveal internal dynamics in unprecedented detail. To fully exploit this unique capability, it is not only mandatory to stabilize the timing of the FEL pulses themselves to the femtosecond level, but equally important to synchronize them with other time-critical systems to the same accuracy. Prominent examples of such external systems are the probe lasers used to measure a sample after its excitation by the FEL pulse and the laser systems used to “seed” the FEL process.

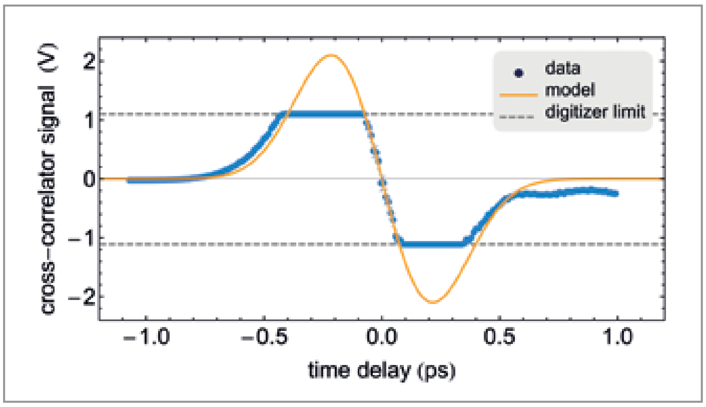


Figure 1

Error signal from a two color balanced optical cross-correlator used to lock an external Ti:sapphire laser to the optical reference clock train at FLASH. The sensitivity, i.e. the slope at zero time delay, is 0.063 fs/mV.

For FLASH and the European XFEL, a novel laser-based synchronization system has been developed, which first enhanced and will eventually replace the established conventional RF-based system step by step.

In the new scheme, short infrared laser pulses produced by extremely low-noise, erbium-based master laser oscillators (MLOs) are distributed in actively length-stabilized, and therefore also transit time-stabilized, fiber-optical links. A key feature of the system is the ability to directly synchronize secondary pulsed laser systems, such as the probe lasers mentioned above or the slave laser oscillator at the European XFEL, to the MLO optical reference clock train without the intermediate RF-based timing detector otherwise required.

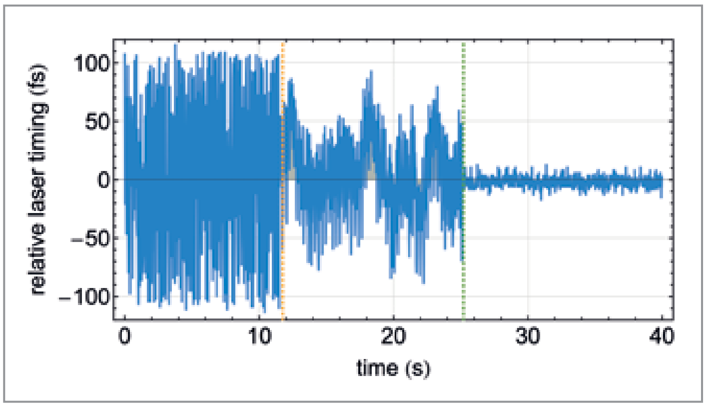
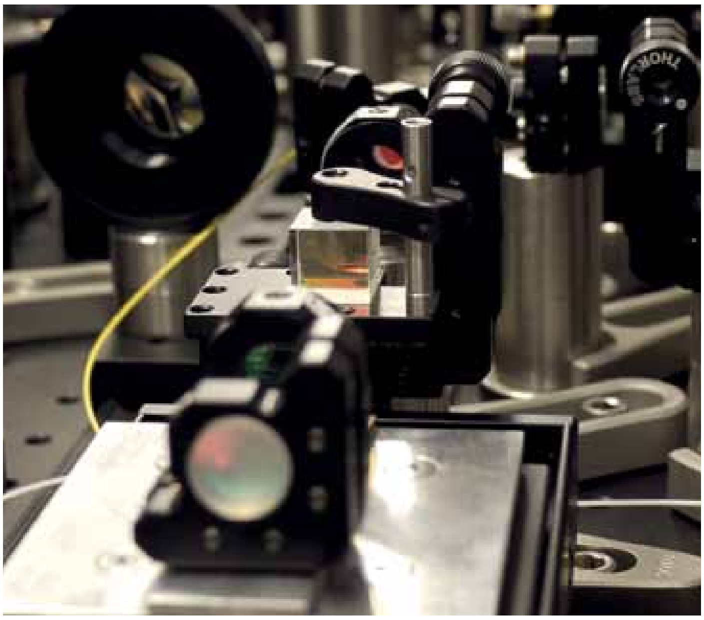


Figure 2

Switching the synchronization of the FLASH pump–probe laser from an RF-based system (soft loop parameters up to 12 s, tighter parameters after 12 s) to the new all-optical scheme (after 25 s)

The essential components of such a direct optical lock are balanced optical cross-correlators (OXCs), which mix the clock pulse and the secondary pulse in nonlinear crystals and thus produce so-called error signals that are extremely sensitive to the relative time difference between the two laser systems. An example of such a signal is shown in Fig. 1. The sensitivity of the signal (i.e. the slope at the zero-crossing), 0.063 fs/mV, is more than ten times better than that achieved



with unaided RF-based systems. This extreme sensitivity places considerable demands on the baseline stability of the laser's synchronization before the optical stabilization loop can take over. Figure 2 illustrates the gain in stability obtained by switching the synchronization of the FLASH pump–probe laser from the standard RF-based system to the all-optical scheme. The timing jitter, measured with a second independent OXC, decreases from an initial 75 fs to less than 5 fs (rms) after switching to the optical system.

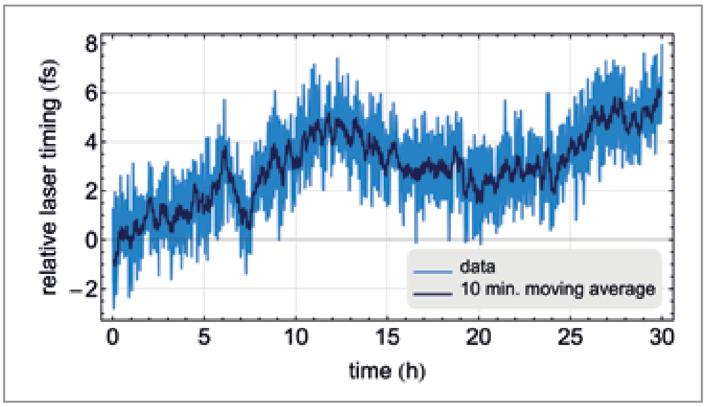


Figure 4

Out-of-loop measurement of the relative timing accuracy of two laser oscillator systems (MLO and SLO), which are optically locked with the OXC technique. The timing walk-off over 30 h is less than 6 fs.

At the European XFEL, the optical synchronization system is required to keep the electron injector in lockstep with timing-critical user experiments over a distance of more than 3 km. To achieve this, the main MLO, located in the injector building, is complemented by a secondary, or "slave", laser oscillator (SLO) installed in the experimental hall. MLO and SLO must run synchronously with femtosecond accuracy over hours and days.

Figure 3

Partial view of an optical delay line for scanning the timing of the two laser systems for the calibration shown in Fig. 1

In a first laboratory experiment, we demonstrated that the optical mixing technique using OXCs can maintain the synchronization of two such master oscillators to the required level over more than a full day. The two lasers were synchronized using one OXC while a second OXC was used to measure, independently from the feedback system, the timing difference between them. The results shown in Fig. 4 and 5 demonstrate the performance of the technique. Over 30 h, the mean timing of the two laser pulse trains does not walk off by more than 6 fs, the time it takes light to travel just less than 2 µm in free space. The distribution of the instantaneous jitter of the two clock pulse trains with respect to each other is shown in Fig. 5. Obviously both systems are jumping between two discrete states, possibly related to mechanical vibrations in the laboratory. However, the states are only about 1 fs apart with less than 1 fs residual width.

The two experiments shown here clearly demonstrate the superior performance of the direct optical locking scheme and point out the direction of how to fully exploit the time resolution provided by the ultrashort X-ray FEL pulses to study processes on atomic time scales.

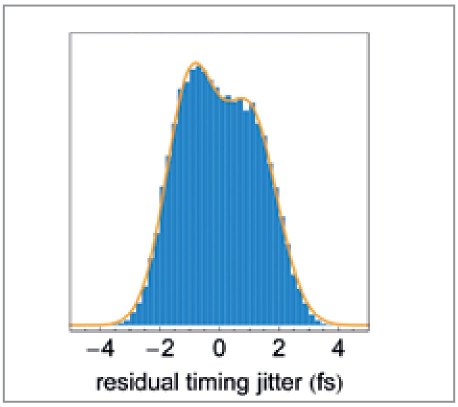


Figure 5

Distribution of the instantaneous jitter between the two oscillators (MLO and SLO) from Fig. 4. The systems seem to hop between two discrete states about 1 fs apart. The residual jitter is less than 1 fs.

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Towards the industrialization of high-gradient cavities.

The extra spin on superconducting RF cavities

The discovery of a Higgs-like particle at the LHC in summer 2012 has prompted considerable interest in the timely construction of the International Linear Collider (ILC) – the ideal facility for exploring the new particle with high precision. According to plan, the ILC will be an e^+e^- collider with centre-of-mass energies of initially 500 GeV. The Japanese particle physics community unequivocally made the construction of the facility their highest priority, a move that was enthusiastically welcomed internationally. The ILC will require the production of thousands of high-gradient superconducting RF cavities. The construction of the European XFEL places DESY and its collaborators in industry at the forefront of the technological development of accelerating cavities.

Cavities for the ILC

The ILC [1] will, according to plan, start at a centre-of-mass energy of 500 GeV and have the potential for an energy upgrade. It will be the ideal facility for exploring the newly discovered Higgs-like particle with high precision. At the heart of the facility is a linear accelerator based on 1.3 GHz superconducting niobium cavities operating at a field of 31.5 MV/m and beyond. This field is considerably higher than that applied in any existing superconducting accelerator and exceeds the field of the accelerator modules for the European XFEL by almost 50%. Nonetheless, the experience gained in the preparation of the construction phase of the European XFEL has made Europe a key player in the advanced development of superconducting cavities.

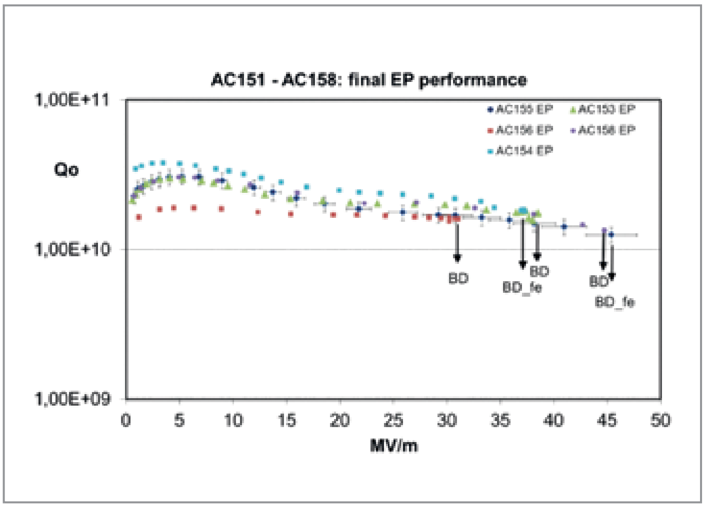

Figure 1

Quality factor (Q_0) as a function of the accelerating field for cavities treated at DESY [3]

Europe's position has been further strengthened thanks to the ILC-HiGrade [2] grant of the Framework Programme 7 of the European Commission, which enabled the production of an additional 24 cavities over and above the 800 needed for the European XFEL. The additional cavities will allow a detailed investigation of performance limitations and of ways to increase the accelerating field to a value suitable for the ILC.

Figure 1 shows the performance of cavities [3] produced according to the European XFEL recipe. Quality factors (Q_0) of better than 10^{10} were obtained for fields of up to 45 MV/m. This is a major improvement over previous efforts and a demonstration of the considerable potential of this technique. For 1.3 GHz superconducting RF cavities, a high quality factor ($>10^{10}$) leads to high power efficiency. In principle, the axial accelerating electric fields can be increased to the maximum value of the associated magnetic field (critical field) on the surface of the superconductor, which sets the fundamental performance limit for the technology and corresponds to roughly 55 MV/m for these TESLA-shape cavities. Any foreign material or irregularities of the surface structure will reduce this limit and eventually lead to either a Q-drop and thermal breakdown (quench) or electron loading and radiational activation due to excessive parasitic field emission. The chemical processing of the cavities used for the test shown in Fig. 1 was done at DESY. The processing included a key treatment step: the electropolishing of the cavity's inner surface followed by proper rinsing.

DESY has developed several tools for locating surface irregularities on the finished cavities. These include an automated optical inspection tool for testing a complete nine-cell cavity (OBACHT), which was commissioned in 2012 and is now routinely operated for quality assessment (Fig. 2).

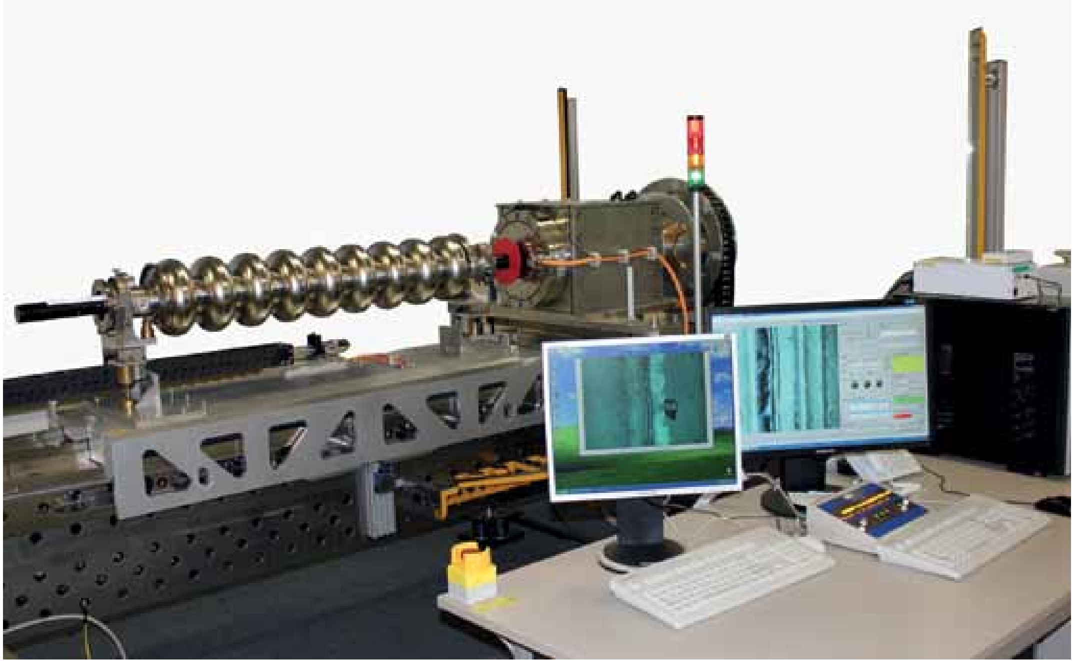

Figure 2

The automated cavity inspection tool, OBACHT, in operation. The cavity slides over a rod that houses the high-resolution camera. The rotation drive in the background enables an azimuth scan of the full surface.

Another tool, the “Second Sound” system, locates the position of a quench by tracing the phase transition of superfluid helium at the niobium surface. These tools are already proving their worth as the series production of cavities for the European XFEL begins.

The cavity database

To build the ILC efficiently, large industrial contributions will have to come from the Americas, Europe and Asia. All regions have taken steps to engage industry in the manufacture of cavities. Meanwhile, the number of qualified cavity vendors has risen from two in 2006 to five in 2012. A vendor becomes qualified when his production procedure is shown to satisfy a set of quality criteria that reflects the world’s best knowledge on preparation and treatment of niobium surfaces. These rules have been defined by the cavity database group [4], whose membership is drawn from all of the geographical regions and which is charged with monitoring progress worldwide.

Figure 3 summarizes one aspect of the progress made: the yield of cavities capable of accelerating at 28 MV/m or even 35 MV/m has risen over the past few years. After including a second short electropolishing step (as in Fig. 3), the yield of high-performance cavities produced in industry has reached the required standard for the ILC, i.e. 90%. Since this observation is based on a small number of measurements, the arrival of 800 new cavities for the European XFEL together with the ILC-HiGrade cavities will provide a welcome basis for more profound studies. It will be particularly interesting to assess whether the second treatment step is really necessary – if not, considerable cost savings could be made.

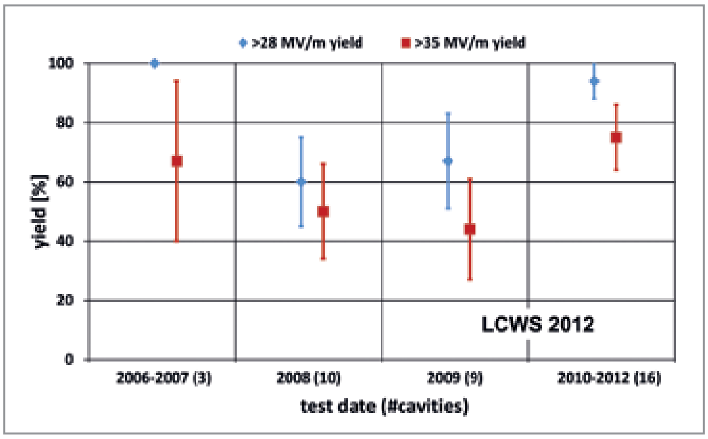

Figure 3

Yield of cavities reaching two thresholds in accelerating fields. The cavities have received one or two treatments. The results summarize the worldwide activities documented in the cavity database.

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[1] N. Walker, N. Phinney, N. Toge, editor. International Linear Collider Reference Design Report, Volume 3: ACCELERATOR. International Linear Collider Collaboration (2007) and E. Elsen et al., editors. International Linear Collider, a technical progress report, DESY-11-041

[2] For more information on the ILC-HiGrade programme see: ilc-higrade.eu

[3] D. Reschke et.al, “Results on large grain nine-cell cavities at DESY: Gradients up to 45 MV/m after electropolishing,” Proceedings of SRF2011, Chicago, IL USA, p. 490 (2011)

[4] For more information on the cavity database see: newsline.linearcollider.org/readmore_20091029_ftr1.html

ILC design integration.

Collaborative engineering on a global scale

The planned International Linear Collider (ILC) will be a truly global project. Scientists from more than a dozen countries are contributing to the global design effort, which will culminate in the publication of the ILC technical design report (TDR) in 2013. DESY's design integration activities collect the design contributions from all over the world and ensure they fit well.

From design to integrated design

In summer 2013, the five-year long technical design phase of the ILC will come to its conclusion with the publication of the ILC TDR. Volume 2, "The ILC Baseline Design", presents the complete design of the entire accelerator complex. It describes the accelerator site with its tunnels, caverns and shafts, the layout and composition of the different accelerator sections, and the various individual core components, such as accelerator modules, RF cavities, klystrons and different types of magnets. The baseline design describes the geometry of the planned facility, defines its functions and properties that are needed for e.g. electrical, thermal and physics simulations, and provides a cost estimate and an implementation plan.

One of the major challenges in the design process is to integrate the various contributions and ensure the overall design is complete, correct and consistent. For example, when developing the first layouts of the accelerator beamlines, the dimensions of the various future components have to be estimated. These assumptions must be matched with the components' detailed engineering designs, which are evolving in different laboratories around the world. The sequencing of components in the 3D design models of the beamlines has to be identical with their optics simulation models, and component types and counts have to match the assumptions in the cost estimate. For beamlines with tens of thousands of components, this is no easy task. Not only that, the design must be further optimized: beamlines from different accelerator sections need to be arranged in the most compact manner possible, so they can cost-effectively share the same tunnel. Tunnel diameters have to fit all beamlines and infrastructure, but for cost reasons, they must also be as small as possible. Through this entire process, all information on changes must propagate and be cross-checked whenever any part of the design evolves.

Lattice integration: the soul of a new machine

The so-called lattice, which describes the sequence of components in the various beamlines, is the heart and soul of an accelerator design. The design integration process therefore centres on the lattice. Scientists from all over the world have invested many years of work into the design, simulation and optimization of the lattices for the different ILC accelerator beamlines: the electron and positron sources, the damping rings, the transfer lines and bunch compressor systems, the main linear accelerators and the beam delivery system, which eventually produces the particle collisions. In early 2012, these different accelerator sections were finally fitted together into one large, all-encompassing lattice for the whole accelerator. Three-dimensional visualizations of all beamlines were created to ensure that no gaps nor overlaps between the beamlines were present.

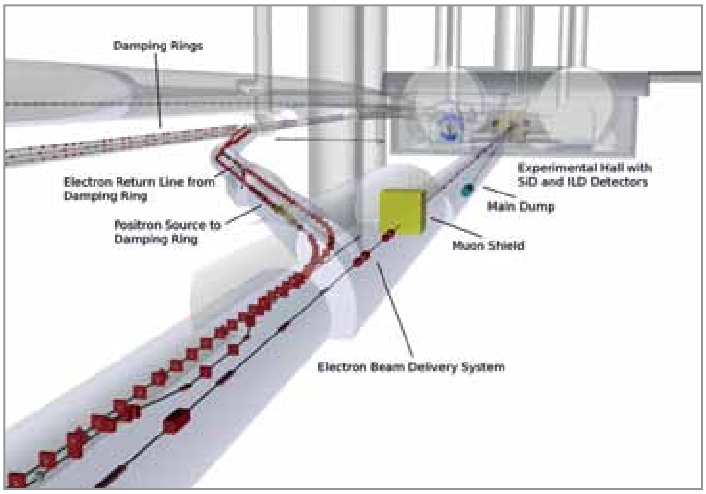

Figure 1

Compact beamline configuration in the ILC central region thanks to effective design integration

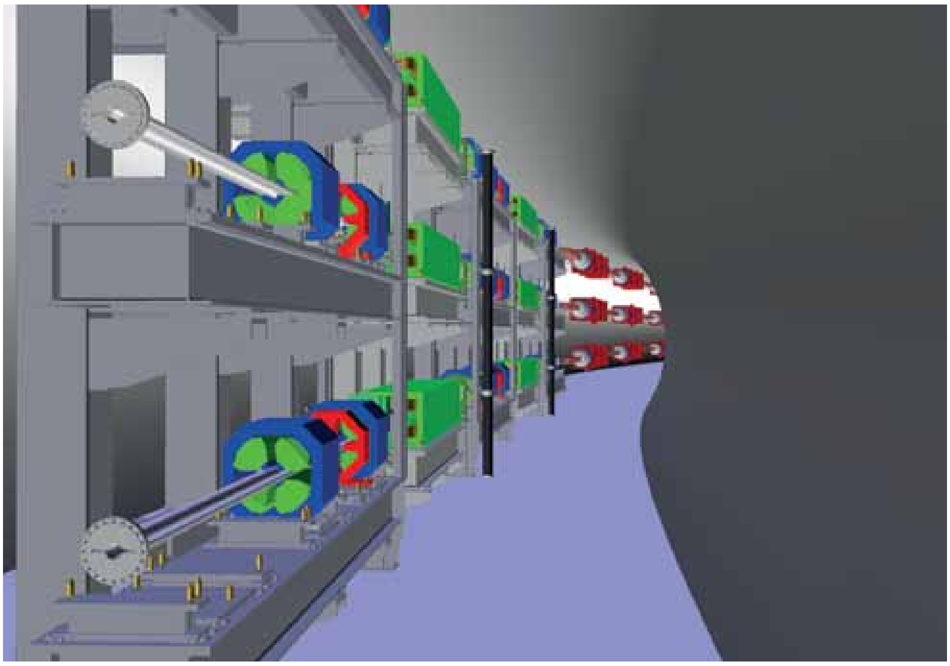

Figure 2

A view into the damping-ring tunnel showing detailed engineering models of beamline magnets and support structures, and “placeholder” visualization models further down the beamline. The detailed magnet model and the lattice data were created by a group from Cornell, the tunnel model at CERN and the lattice visualization at DESY.

This initial integration was followed by an iterative optimization, in which beamlines were adapted to the tunnel design. The integrated lattice was translated into sets of coordinates, which were coordinated with the civil construction group to ensure consistency between accelerator and tunnel geometries. If possible, beamlines were moved and adjusted in the layout to reduce the required tunnel cross sections, ensure that all components would be accessible and make sure that transportation and emergency escape routes would not be blocked by beamlines. Figure 1 shows an example of a particularly crowded area that was optimized during the design integration.

Zooming in: from tunnels to single components

The lattice initially contained very general “placeholder” descriptions for the various components, which defined their basic optical properties and estimated maximum dimensions. Several special devices, such as beam dumps, targets, and instrumentation, were also incorporated into the lattice. When detailed designs and prototype devices had been developed, the information in the lattice was refined with actual physical dimensions and properties, and it was checked that the real components fit their foreseen spaces in the beamlines (Fig. 2). Their properties were used to determine e. g. power consumption and heat loads, which were in turn used to design the required installations and supply lines of the general infrastructure.

Accurate and up-to-date component counts based on the lattice served as input for the installation planning and cost estimation teams. All the information is captured in technical specifications and cost roll-ups, in 3D models and design drawings, in parameter lists and simulation results. The information is interlinked, and is accessible throughout the entire project via DESY’s web-based engineering data management system (EDMS).

An integrated vision

3D visualization is a very special tool in the design process, because it stimulates imagination as no other design format can. For the ILC global design effort, automated procedures have been developed for generating visualization models of the accelerator from the lattice. The accelerator models have then been combined with architectural designs to obtain an impression of the emerging facility. In DESY’s virtual-reality room, one can now walk or fly through more than 30 kilometres of virtual tunnels and caverns filled with virtual cryomodules, magnets and detectors, and get an impression of the magnificence of this scientific adventure and the elegance of its design.

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Beams on.

Linear collider detectors under test

DESY's detector developers are preparing the instruments needed for a demanding high-precision physics programme at a future linear collider such as the International Linear Collider (ILC). The need to reach the highest possible granularity and resolution while minimizing the material budgets of trackers and the size of calorimeters is pushing the development of novel technologies. Advances in ultralight vertex detectors, gaseous tracking, hadron calorimetry and beam polarimetry are leading the field in core components. For all of them, the moment of truth comes when prototypes are subjected to beam tests, which reveal their functionality at system level under realistic conditions. A few examples are reported here.

Testing the prototype TPC

Efforts in gaseous tracking at DESY currently focus on studies of a large prototype of a time projection chamber (LP TPC). The LP, with its diameter of 770 mm and length of 610 mm, can accommodate seven readout modules of a size comparable to the ones planned for the final TPC.

Conventional TPCs use multiwire structures for gas amplification, which are unsuited for ILC applications. Therefore, novel approaches, aimed specifically at meeting the demanding precision requirements of the ILC, are being studied. Several prototypes of micromesh ("Micromegas") and gas electron multiplier (GEM) foil structures have been constructed and tested. Besides the traditional pad readout, a pixel readout is also under test, as are several readout electronic developments.

The integration of up to seven modules on the endplate of the LP provides a good test of mechanical design options. Another major concern being addressed using the LP is the field homogeneity at the borders of the modules; the goal is to reach a homogeneous field configuration over the whole endplate.

Measurements with the LP TPC are being performed in the test beam area T24/1 at DESY, where electron and positron beams from 1 to 6 GeV are available. This area hosts a sophisticated infrastructure with all the equipment needed to operate and study a gaseous detector, including a 1 T magnet mounted on a movable stage, a high-voltage system and a gas system that includes a slow control setup.

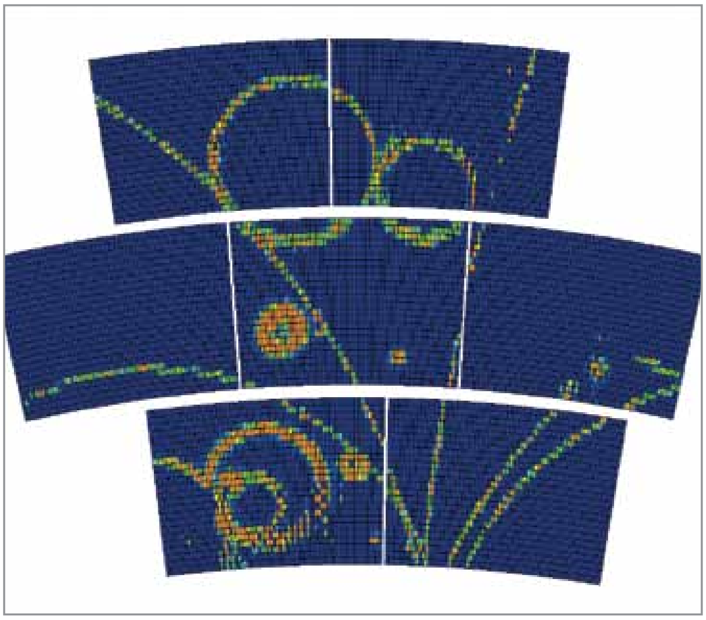

Figure 1

Event display recorded with seven modules equipped with Micromegas in the LP TPC in the test beam setup at DESY

Figure 2

Installation of an HCAL readout layer with 576 scintillator tiles and SiPMs into the CALICE tungsten stack in the SPS beam at CERN

Calorimetry-related activities

In the field of calorimetry, DESY, together with five other German groups, is driving the application of novel solid-state photosensors, so-called SiPMs, as a means of achieving a very finely segmented readout of scintillator-based detectors: the hadron calorimeter (HCAL) has a cell size of 3 x 3 cm^2, and the cell size of electromagnetic calorimeters is up to four times smaller.

Coping with the unprecedented channel density presents major challenges to the integration of the detector electronics into the detector volume. The electronics for readout, calibration, signal digitization and zero suppression must be squeezed in and realized within a tiny power budget. The first steps of data reduction require excellent control of the detector operation, which must be tested in beam conditions.

In 2012, a first such detector layer was exposed to hadron beams and successfully delivered data. Thanks to the timing capabilities of the electronics, the data provide information about the time evolution of hadron showers.

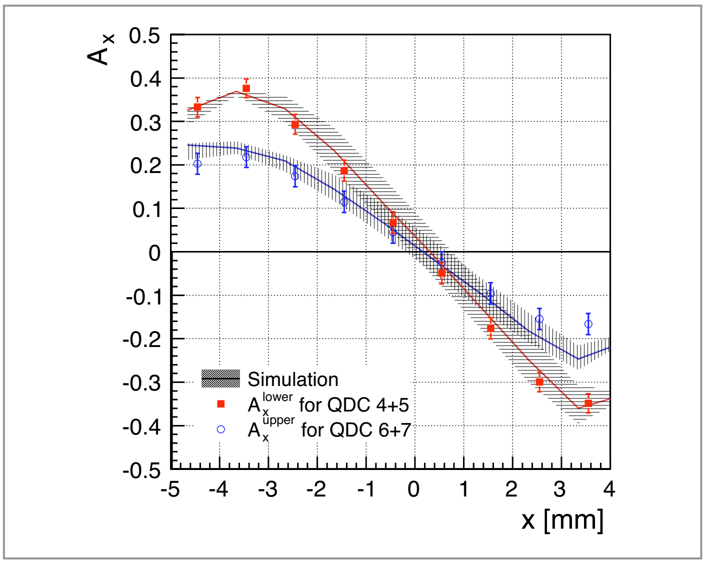

Figure 3

Measured light yield asymmetries in the laser Compton polarimeter compared to simulation [From JINST 7 P01019 (2012)]

Polarization measurements

DESY is developing laser Compton polarimeters for the precise measurement of polarization on both sides of the collision point of a linear collider. Past experience has shown that the linearity and alignment of the detector used to measure the Compton-scattered electrons (or positrons) are the dominant sources of systematic uncertainty. A robust, radiation-hard and well-established approach based on gas Cherenkov detectors makes use of the proportionality between the emitted Cherenkov light and the number of electrons passing any of the 1 x 1 cm^2 wide (in this case) gas-filled channels facing the Compton interaction point.

A prototype with two such channels was built and operated in test beams at DESY and at the ELSA stretcher ring in Bonn, Germany. One result of the tests was the successful demonstration of a novel alignment method that exploits the characteristic pattern of Cherenkov light inside each channel. The results demonstrate that the alignment precision is sufficient to reach the overall precision goal of the polarimeter.

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Particle physics beyond the LHC.

A linear collider could provide a view of physics well beyond the LHC

The discovery of a Higgs-like particle at CERN in summer 2012 has changed the world of physics. One of the most fundamental and vexing questions of nature seems close to being answered. The LHC experiments at CERN will spend the next years trying to consolidate the discovery and answer as many questions posed by the Higgs as possible. Why then are physicists convinced that they need another, different, collider to unravel this and more secrets of nature? Physics at extremely small distances is very complex and requires many different means to explore it. An electron–positron collider such as the International Linear Collider (ILC) would be a unique complement to the LHC, since it would enable different approaches to the study of nature and answer questions the LHC is unable to address. In the course of the preparation of the technical design report (TDR) for the ILC, intense studies have been performed to understand the physics potential of such a machine and to quantify the gain compared to the LHC.

Physics at the ILC

Physics at an electron–positron linear collider is precision physics. The ILC and its experiments have been designed with precision measurements foremost in mind. The physics potential of the ILC is huge. It has access to the full range of Higgs properties, including the Higgs self-coupling. By looking at precision observables, it will be sensitive to many new models of physics, either through the direct discovery of new states or through the indirect search for new physics.

Higgs branching ratios

Determining the branching ratios of the Higgs boson into the different elementary particles is a key to understanding the Higgs mechanism. At an electron–positron collider, such a measurement can be done independently of model assumptions and without assuming particular properties of the Higgs boson. A key capability of a detector for this measurement is the ability to separate the different final states. The excellent secondary vertex reconstruction of the ILD detector enables a pure and efficient separation of $h \rightarrow bb$ or $h \rightarrow cc$ final states. In the past, these measurements were studied for a 250 and 500 GeV collider. A new study has been performed for a 1 TeV machine. The invariant mass distribution, after application of the *b*-tagging algorithm, is shown in Fig. 1. An integrated luminosity of 1 ab^{-1} will permit the decay into *b* quarks to be measured to better than 1% and the decay into *c* quarks to 3.9%. The polarization of the beams plays an important role in this analysis since it helps to reduce the backgrounds significantly.

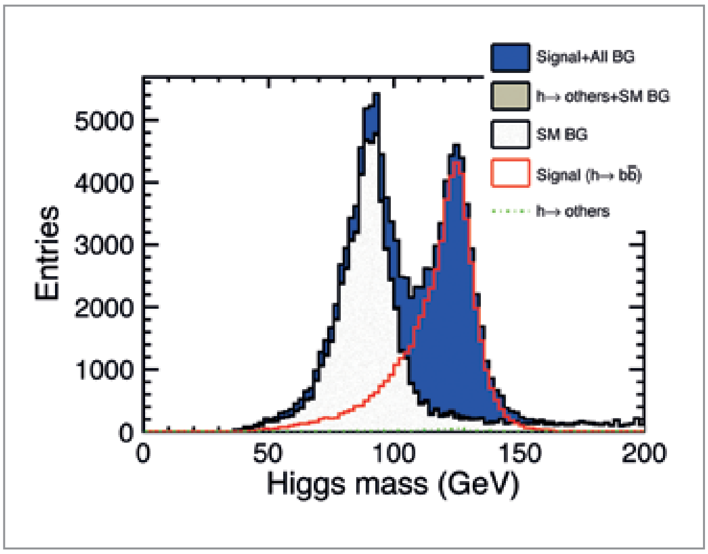

Figure 1

Reconstructed invariant mass distribution for a 125 GeV Higgs boson after applying the *b*-tagging algorithm

Polarizations in *WW* decays

At the ILC, both the electron and the positron beams will be polarized and thus provide the means to selectively enhance or suppress particular Standard Model processes; this ability will play a crucial role in many Standard Model and “beyond the Standard Model” analyses. The measurement of the polarization will be done on a bunch-by-bunch basis with Compton polarimeters. This will be complemented by the measurement of the *WW* cross section. The decay spectrum of the *WW* has a strong angular dependence because of the polarization. This can be used to determine the absolute value of the luminosity-weighted beam polarization. An optimized combination of like-sign and unlike-sign polarized beams can be used to determine the beam polarization to better than 0.2%. The achievable precision is shown in Fig. 2.

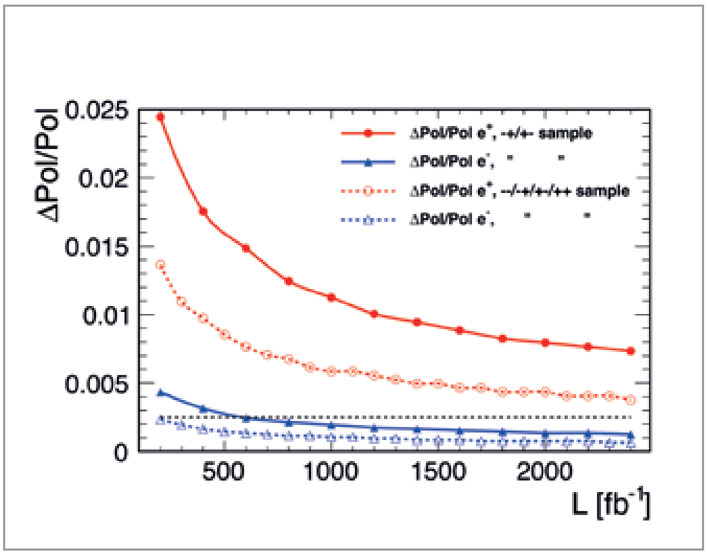

Figure 2

Relative error of the polarization, measured in *WW* events. Compared are results from two samples. The ultimate precision can be achieved (dashed lines) for a sample where 20% of all data are accumulated with both beams polarized in the same direction, and 80% with oppositely polarized beams.

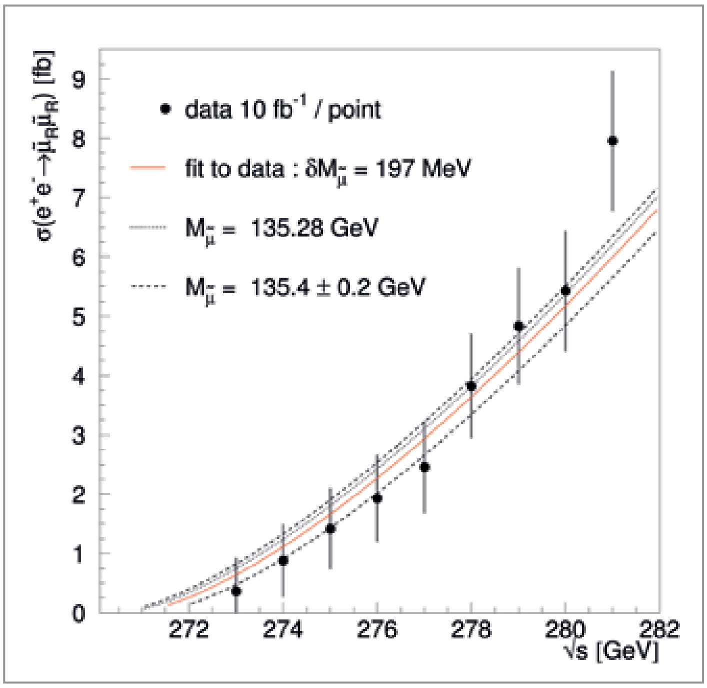

Figure 3

Cross section as a function of centre-of-mass energy of the supersymmetric partner of the muon. Indicated is the result of the fit to the threshold, as the solid line, and the error band, as the dashed line.

Threshold scans at the ILC

A useful feature of electron–positron colliders is their capability to perform threshold scans. The centre-of-mass energy of the collider can be finely tuned to scan, for example, across a resonance. This can be very useful in the detailed study of known or new particles. In Fig. 3, the cross section for $e^+e^- \rightarrow$ *smuon smuon* is shown as a function of the centre-of-mass energy of the collider. A fit to this distribution would yield a precise determination of the mass of this state.

In summary, recent work has reconfirmed the physics potential of an electron–positron collider. The well-known tunable initial state of a linear collider coupled with an excellent detector for reconstructing final states will enable precision measurements that extend well beyond the reach of the LHC. This article highlighted only a few examples, selected from those with strong contributions from DESY physicists. A much more complete picture of the physics reach of the ILC can be found in the ILC TDR.

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The ILC technical design report.

A milestone towards the next big project in particle physics

The International Linear Collider (ILC) is a proposed electron–positron collider for the energy range of 200 to 500 GeV (centre-of-mass) with upgrade options towards 1 TeV. The ILC technical design report (TDR) describes the physics opportunities in the light of the recent results from the LHC, as well as the technical design of the accelerator systems and the particle detectors. The publication of the TDR is an important milestone towards the next big global project in particle physics, and coincides with the regional updates of particle physics strategy and the recent proposal from the Japanese high-energy physics community to host the ILC in Japan. The technical design of the accelerator has been brought to a level that allows a reliable cost evaluation and sets the stage for the engineering design towards possible construction.

The physics challenge

The properties of the Standard Model Higgs boson are theoretically completely known. It is therefore straightforward to settle the question of whether the observed particle is the simplest incarnation of the Higgs mechanism or, rather, belongs to a more complex underlying structure. A complex structure might manifest itself as a deviation of the observed couplings of the Higgs to other particles. Given the mass of the recently discovered Higgs-like particle found at the LHC, these couplings could be studied with high precision at a 250 GeV centre-of-mass energy electron–positron collider, although higher energies would be required to explore the Higgs self-coupling. The planned ILC with an energy of 500 GeV is ideally suited for this research, which may be carried out in stages of increasing energy.

The Japanese initiative to host the ILC is timely and well justified by the current physics landscape: an electron–positron collider promises a rich physics programme today and ideally complements the measurements foreseen at the LHC. Both facilities would contribute to an understanding of the high-energy frontier.

The initiative is also timely since the TDR [1] for the ILC was completed in 2012. The TDR presents a solution for a cost-effective linear collider operating at up to 500 GeV and upgradeable to 1 TeV.

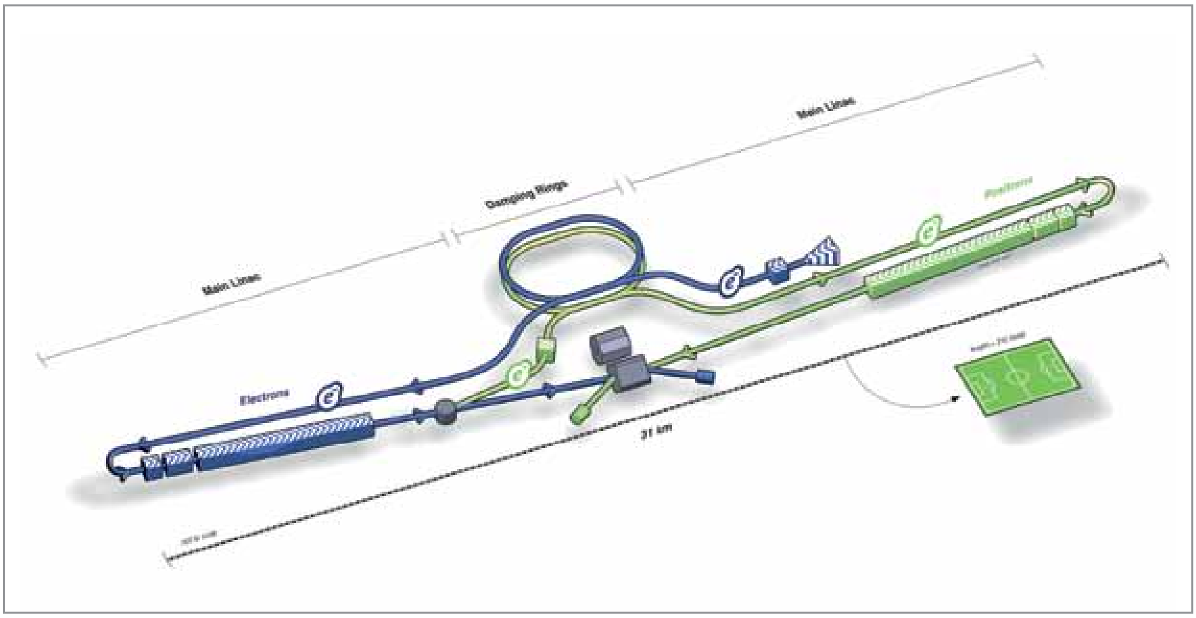

Figure 1

View of the proposed ILC (Image: ILC GDE)

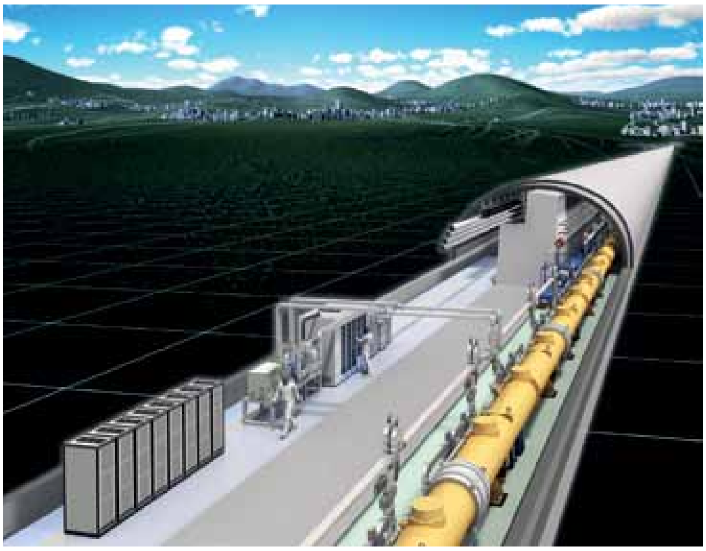

Figure 2

Artist's view of the ILC in the Japanese tunnel configuration ("Kamaboko") (Image: Rey.Hori/KEK)

The accelerator design

Figure 1 shows a sketch of the main ILC layout. The two ~11 km long linear accelerators deliver beams to the collision point with a small horizontal crossing angle of 14 mrad. The electron and positron sources, the damping rings and the interaction region with the detector hall and infrastructure are concentrated in the central region. The ILC has evolved from the design presented in the reference design report [2] through R&D results on high-risk items. In addition, the re-evaluation of cost–performance trade-offs and detailed considerations of site-specific requirements have led to a more realistic design.

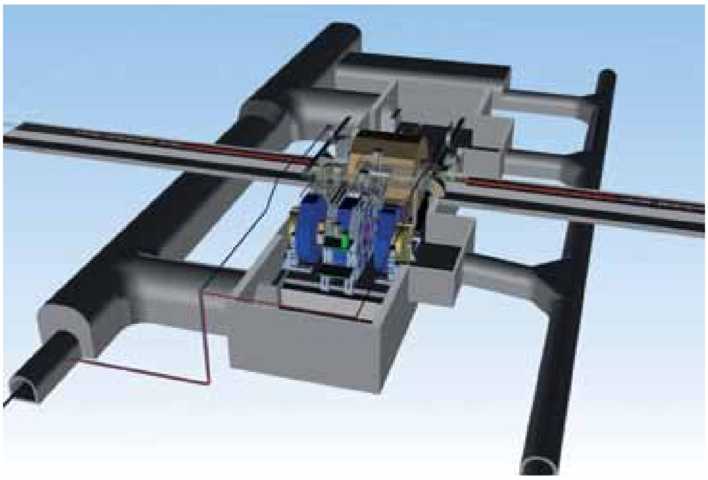

Figure 3

3D model of the underground experimental cavern with two detectors in "push-pull" configuration (Image: DESY)

The design needs to be refined once the final site has been chosen, after which there will be a period of detailed engineering work prior to construction. Two sites are under study in Japan; both are in mountain regions and therefore impose special requirements on the ILC layout. Access to accelerator tunnels and caverns under mountains is impractical through vertical shafts, horizontal access tunnels are more cost-effective. The logistics of the site access requires careful planning of the installation schemes and timelines of both accelerator and detector infrastructure. The tunnel configuration for the main linear accelerators is shown in Fig. 2. The "Kamaboko"-shaped tunnel is divided by concrete shielding along the middle axis. This provides safe maintenance access to the klystrons and modulators while the machine is operating.

The detector integration

Figure 3 shows a 3D model of a conceptual design of the underground area around the interaction point. The two detectors, SiD (front) and ILD (back), share one interaction region and are mounted on a movement system that allows "push and pull" of the detectors within a short time of around one day. Reliable alignment of the 15 000 t masses to sub-millimetre precision is a challenge in itself; solutions have been developed at a conceptual level.

The physics challenges and the special boundary conditions of the envisaged sites put requirements on the engineering design of the detectors. The TDR contains the detailed baseline descriptions (DBD) of the two envisaged experiments, ILD and SiD. Both detector concepts have been validated for the ILC on the basis of their Letters of Intent [3, 4]. The conceptual design of the detectors has now been brought to a level of realism where the influence of the support structures, cables and service paths on the physics performance has been tested in full detector simulation studies with realistic data flows including digitization and reconstruction steps. A set of physics benchmark reactions has been used to test and optimize the detector design for the physics requirements of the ILC.

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OLYMPUS.

Data taking and detector performance

The goal of the OLYMPUS experiment is to quantify the effect of two-photon exchange in elastic lepton–proton interactions by precisely measuring the ratio of the positron–proton and electron–proton elastic scattering cross sections. The experiment was performed using the intense beams of electrons and positrons stored in the DORIS ring, an internal unpolarized hydrogen gas target and the former BLAST detector from the MIT-Bates Linear Accelerator Center. The detector parts had been shipped to DESY, re-assembled and commissioned in the DORIS hall. Data taking took place in 2012.

The OLYMPUS experiment aims to measure the ratio of the positron–proton to electron–proton elastic scattering cross sections in order to determine the contribution of multiphoton exchange to electron–proton scattering. The motivation for the measurement is an observed deviation from unity in the electric to magnetic form factor ratio of the proton determined in polarization transfer measurements performed at Jefferson Lab in the USA, in apparent contradiction with measurements made using the Rosenbluth separation technique. Since the Rosenbluth formula assumes that only one photon is exchanged between the electron and the proton, higher-order radiative corrections, particularly multiphoton exchanges, are the likely source of the discrepancy. The measurements at DORIS were performed with the former MIT BLAST detector, which had been transferred from MIT to DESY and re-assembled in the DORIS hall.

In 2012, the OLYMPUS team very successfully took data over a four-week period in February and a second period of

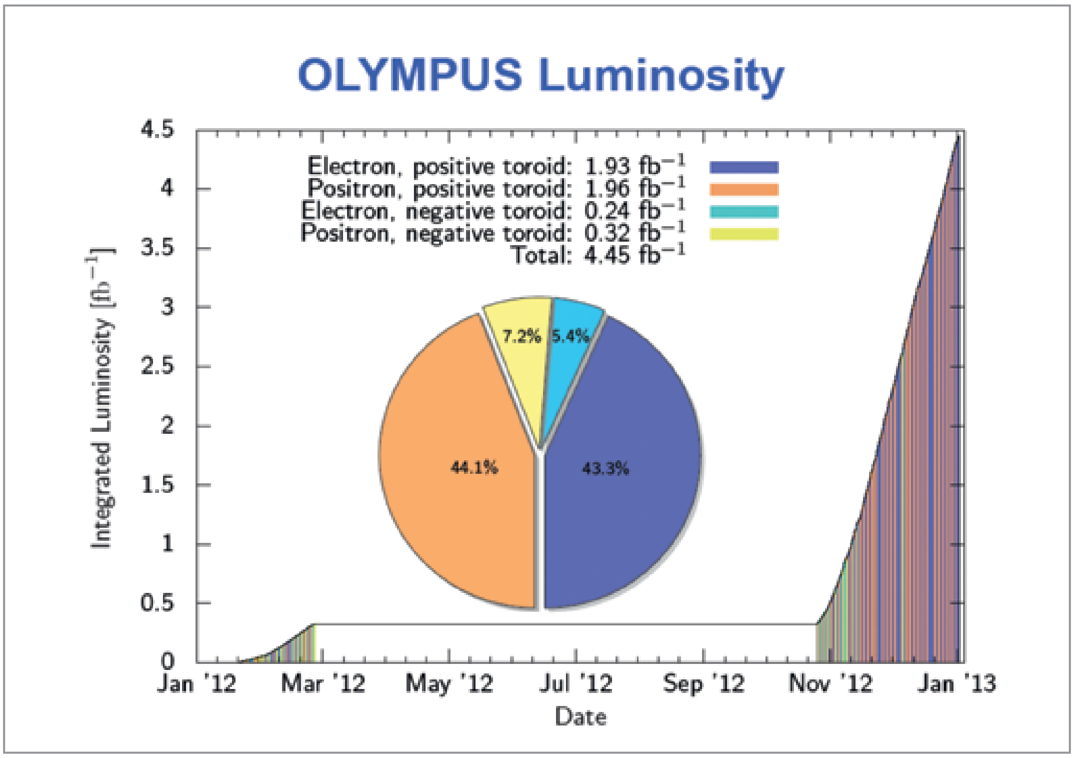

Figure 1

Integrated luminosity as a function of date and fraction of data taken under the specified conditions. The colours indicate the different beam species and magnetic field polarities.

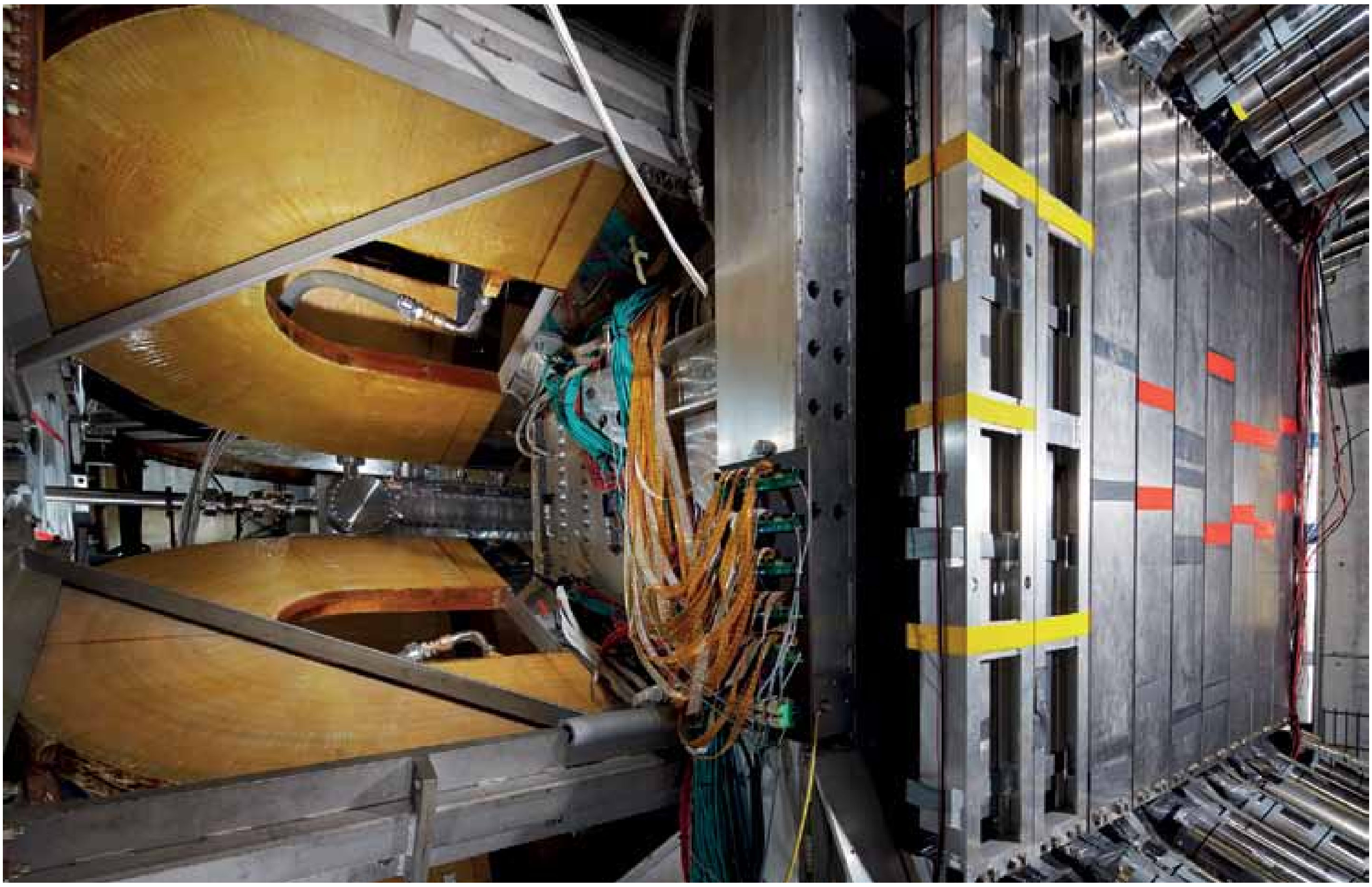

Figure 2

Picture of the OLYMPUS detector showing the target chamber in the beamline, the drift chamber and time-of-flight detectors

slightly over two months, from October to early January 2013, at which time the DORIS accelerator was definitively shut down. Throughout the OLYMPUS running period, DORIS was operated with both electron and positron beams. The beam species was changed daily in order to reduce possible systematic biases. The very efficient operation of the detector and the excellent performance of the accelerator were the major ingredients for the successful data taking periods. Despite a disappointing integrated luminosity from the first run due to an internal gas leak, the integrated luminosity ultimately reached 4.45 fb^{-1}, well above the design goal for the experiment of 3.6 fb^{-1}, thanks to the fact that DORIS was operated in top-up injection mode during the second run and thus allowed the target density to be increased beyond the design value. Since the DORIS shutdown, further steps have been taken to improve the calibration and understanding of the detector: a one-month-long cosmic-ray data taking run was made, the detector positions were optically surveyed, and the magnetic field was completely remapped.

The main focus has now shifted to the analysis of the data. In essence, the two-photon exchange contribution will be determined by counting the number of electron–proton and positron–proton elastic scattering events as a function of the scattering angle, normalizing them to their respective luminosities, and then calculating the ratio of these normalized counts. Three independent methods are used to determine the luminosity: the first, a computation involving the beam current plus gas flow and temperature, the second from Moller/Bhabha scattering off the hydrogen electrons, and the third from elastic *e–p* scattering at low angles, where the two-photon exchange contribution to the cross section is negligible. The results will be compared with Monte Carlo studies that include radiative corrections and a detailed description of the detector performance. The detector acceptances, efficiencies and luminosity will have to be understood at the one-percent level, although some potential biases will cancel when the ratio is taken.

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Reference:
http://web.mit.edu/OLYMPUS

DESY @ Belle I and II.

Joining the exploration of flavour at the terascale

A recent extension to the rich particle physics programme at DESY is its participation in the Belle II experiment, which is presently under construction at the SuperKEKB facility in Japan. Together with seven German university groups and MPI Munich, DESY will contribute a novel pixel vertex detector. The ambitious goal of the upgrade of the former KEKB collider is an increase of the instantaneous luminosity by a factor of 40 to 8 x 10^{35} $cm^{-2}s^{-1}$ by exploiting the so-called nanobeam scheme. The new machine will have a strong impact on the inner Belle II detector components through tight space constraints and significantly higher background levels. The DESY group is responsible for several key activities related to these challenges. In summer 2012, the group also joined the Belle I collaboration and thus gained access to a huge, high-quality data set collected in the years 1999–2010.

In 2011, DESY joined the Belle II collaboration, which is presently upgrading the former Belle detector to fully exploit the enormously increased instantaneous luminosity that will be provided by the upgraded SuperKEKB asymmetric electron–positron collider at KEK in Japan. This next-generation B factory will complement the exploration of new physics beyond the Standard Model currently being carried out at the energy frontier by the experiments at the LHC.

The German institutes are contributing to the experiment by developing and constructing a new type of pixel vertex detector (PXD), based on the DEPFET detector concept originally developed for the ILC. One of the main features of the PXD is its very low material budget. This is particularly important since the decay products of B mesons typically have rather low momenta. A four-layer double-sided silicon strip detector (SVD), which is being designed by KEK and HEPHY in Vienna, Austria, will surround the two-layer PXD. Together the two systems form the Belle II vertex detector (VXD) (Fig. 1, left).

The most challenging SuperKEKB components are the new superconducting final-focus magnets (QCS), because they must provide enough focussing strength to squeeze the beams to the required nanometre scale. Consequently, they impose tight space constraints that considerably complicate the installation scheme of the VXD. In the original plan, the VXD was to be connected to one of the QCS magnets outside the Belle II detector and then moved together with the QCS into the central drift chamber (CDC). In order to avoid the risk of damaging the fragile VXD during this delicate

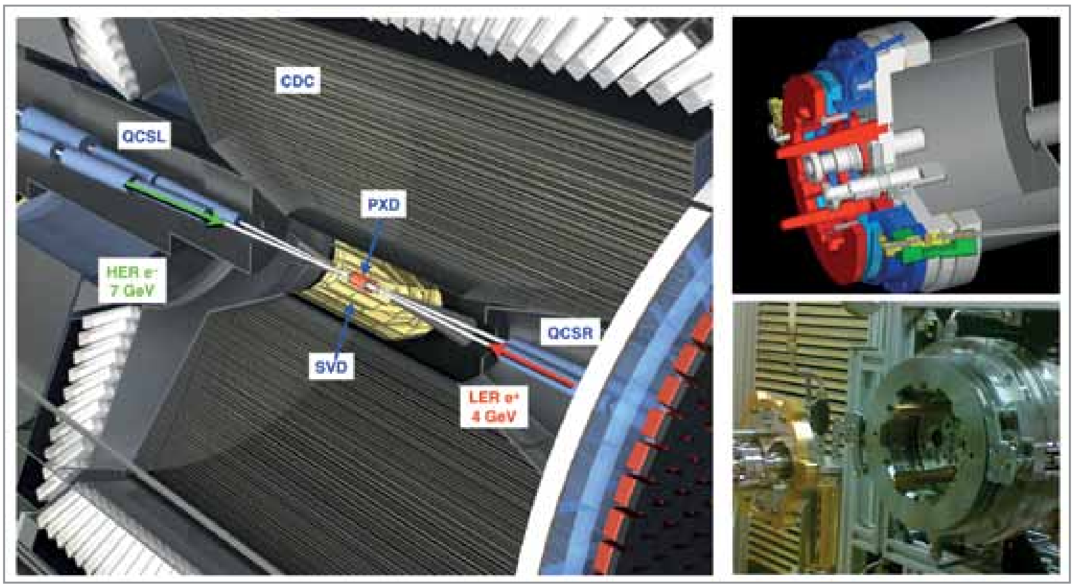

Figure 1

Left: Schematic view of the interaction region indicating the narrow space available between the superconducting final-focus magnets (QCSL, QCSR) and the pixel vertex detector (PXD) and silicon strip detector (SVD) surrounded by the central drift chamber (CDC). Right: CAD drawing and prototype of a hydraulic remote vacuum connection system designed at DESY, which would allow an independent installation of the vertex detector and QCS magnets, not possible in the original installation scheme.

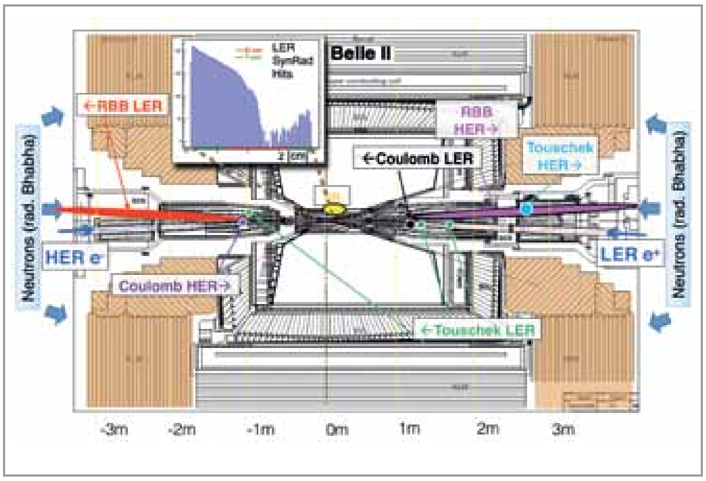

Figure 2

Locations where, according to simulations, background particles of various sources will hit the beam pipe close to the interaction point. The insert shows the expected distribution of synchrotron photon hits along the beam pipe inside the PXD.

operation, DESY designed a novel hydraulic remote vacuum connection system that will allow installation of the VXD in the CDC before the vacuum connection to the QCS is remotely closed. Figure 1 (right) shows the principle of the design together with a prototype, which is presently undergoing extensive tests at DESY.

Another expected consequence of the modified accelerator design is a large increase of background in the detector. Figure 2 indicates the most prominent of the locations where, according to simulations, background particles will hit the beam pipe close to the interaction point. DESY is responsible for the very time-consuming simulation of the background contribution from synchrotron radiation. The inset in Fig. 2 shows the distribution of simulated hits along the central beam pipe inside the PXD. These results give crucial feedback to the SuperKEKB machine group responsible for finalizing the challenging design of the interaction region.

For optimal performance, both PXD and SVD will be operated at the rather low temperature of -25°C. Therefore, two-phase evaporative CO_2 cooling will be used. The CO_2 system for Belle II is the result of a common development with the ATLAS-IBL group (CERN, NIKHEF), which faces very similar cooling requirements. DESY is in charge of building a thermal mock-up to verify and optimize the overall cooling concept for the VXD (Fig. 3).

The completion of the common PXD+SVD beam test, which is now in preparation at the DESY test beam, will be an important milestone for the project. The goal of the test is to evaluate all relevant system aspects under realistic conditions, including the slow control software concept, in whose development DESY is playing a pivotal role.

The study of CP-violating effects requires very accurate reconstruction of the decay vertices of B mesons and their antiparticles by the VXD. It is therefore important to align and calibrate all tracking detectors as precisely as possible. Building on its extensive experience with alignment and calibration of tracking detectors in H1 and CMS, whose alignments are based on the MillePede algorithm and the general broken line (GBL) concept, the DESY group is leading the collaboration-wide effort to align and calibrate the Belle II tracking system.

In July 2012, DESY also joined the Belle I collaboration and thus gained access to a huge data set corresponding to an integrated luminosity of about 1 ab^{-1}. As a contribution to the recently initiated Belle data preservation effort, DESY will provide storage space for a second copy of all Belle I physics data. In addition, DESY is providing Grid infrastructure and is offering newly installed NAF 2.0 CPU resources for data analysis. Having the full data locally available at DESY is particularly important for DESY's recently started first Belle physics analysis: a study of the energy dependence of the weak mixing angle by measuring a tiny forward–backward asymmetry of muon pairs with very high precision. The experience gained with the Belle I data will be very valuable as a preparation for future measurements at Belle II.

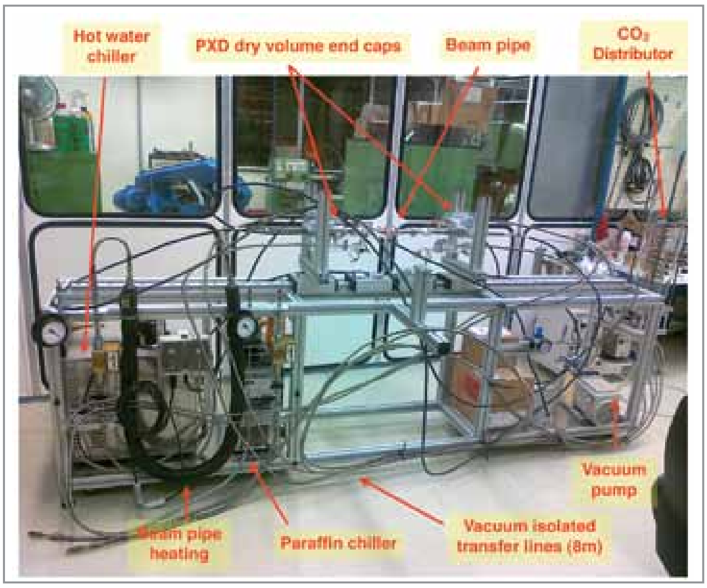

Figure 3

Thermal mock-up of central beam pipe and inner detector to study the overall cooling concept for the VXD, which is based on CO_2 cooling.

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Any Light Particle Search II.

ALPS prepares for its second stage

The masses and coupling of the many proposed dark-matter particle candidates span a wide parameter range. Two classes of candidates stand out because of their convincing physics case and the variety of experimental and observational probes: weakly interacting massive particles (WIMPs), such as neutralinos, and very weakly interacting slim (i.e. ultralight) particles (WISPs), such as axions. The direct production and detection of WISPy dark-matter candidates in the laboratory is the aim of the ALPS experiment at DESY.

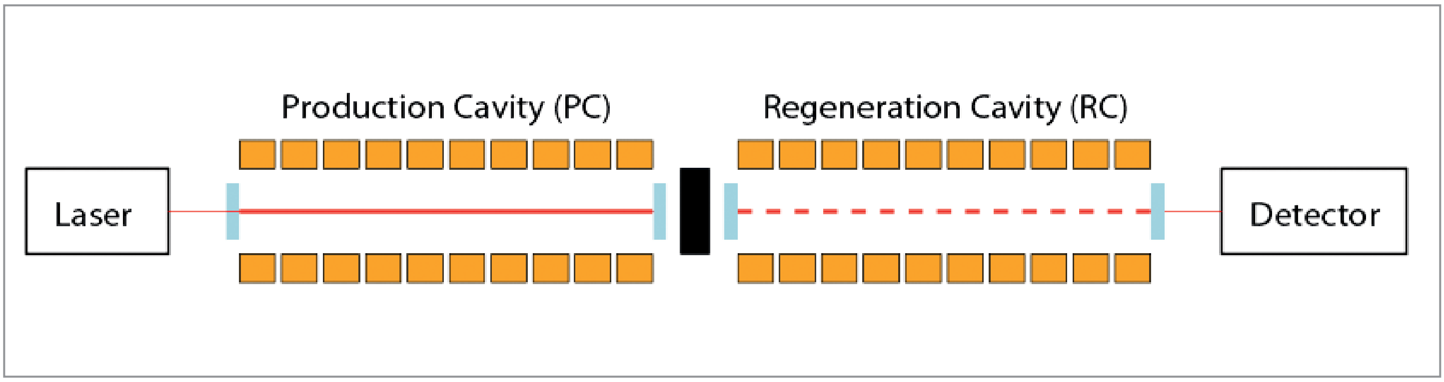

Figure 1

Schematic view of a light-shining-through-a-wall experiment such as ALPS-II

ALPS is based on the light-shining-through-a-wall (LSW) technique (Fig. 1). Laser photons sent towards a wall can oscillate into the hypothetical WISPs (generation side); the latter will traverse the wall because of their tiny interaction probability, and can then oscillate back into photons behind the wall (regeneration side). A clear observation of light generated on the very well shielded regeneration side could only be explained by yet unknown WISPs that have passed the wall.

In 2010, ALPS published the still world-leading exclusion limits on two of the best-motivated WISPs: axion-like particles (ALPs) and hidden-sector photons (HPs). This was achieved by exploiting a resonant optical cavity with 1.2 kW of circulating power in green (532 nm) laser light on the production side, a superconducting HERA dipole magnet to supply a strong magnetic field of 5 T – a necessary ingredient for photon–ALP oscillations to occur in vacuum – and a low-noise commercially available cooled CCD camera, on which any produced light would be focused, as the detector.

Since then, the physics case for WISPs has been growing even stronger. In fact, it became evident that ALPs with masses and couplings not far beyond the presently explored parameter regions not only qualify as cold dark matter candidates, but also occur quite naturally in extensions of the Standard Model expected from string theory. Moreover, photon–ALP–photon oscillations in cosmic magnetic fields have been shown to be a possible explanation of the seemingly anomalous transparency of the universe for very high energy photons. This transparency had been inferred from gamma-ray spectra of distant active galactic nuclei.

Encouraged by these developments, the ALPS collaboration, which currently includes members from the Albert Einstein Institute (AEI) in Hannover, DESY and the University of Hamburg, is preparing a new version of ALPS with greatly enhanced sensitivity.

The ALPS-II experiment plans to use:

> Infrared (1064 nm) laser light in the production cavity with a circulating power of 150 kW (thus benefiting from the experiences of gravitational-wave interferometers, which are operated at the same wavelength),

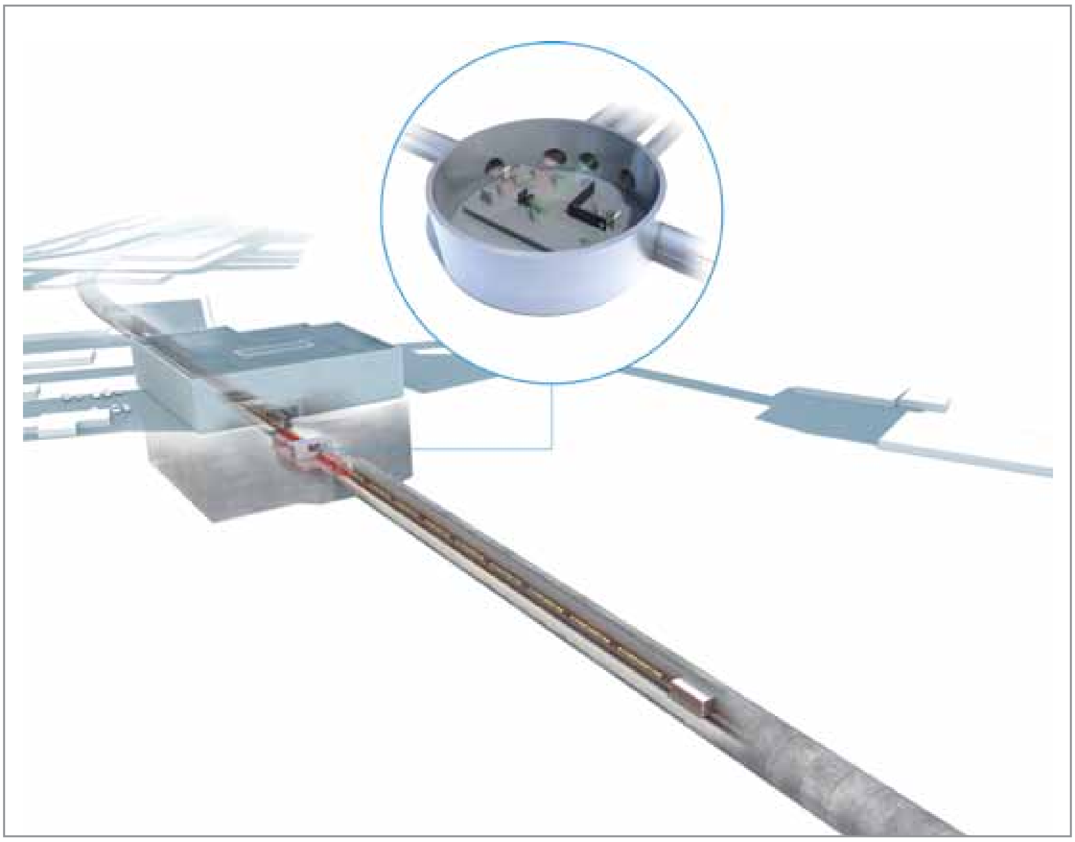

Figure 2

Artist's view of the ALPS-IIc setup, showing a straight section of the HERA tunnel equipped with 10 + 10 HERA dipoles. The middle part, accommodating the central breadboard including the "wall", is highlighted.

> A second cavity on the regeneration side behind the wall, mode-matched to the production cavity by green (532 nm) light to enhance the back-conversion probability of WISPs into photons,

> 10 + 10 straightened HERA dipoles (orange squares in Fig. 1) in one of the straight sections of the HERA ring (Fig. 2) to increase the magnetic length,

> A superconducting transition edge sensor (TES) as the detector to count single infrared photons in a nearly background-free environment.

The planned enhancements will enable access to parameter regions of WISPs suggested by dark-matter, low-energy incarnations of string theory and the anomalous transparency of the universe for very high energy photons.

ALPS-II will be realized in three phases:

> ALPS-IIa will prove the feasibility of the optical system, including the TES detector. Both cavities will have lengths of about 10 m. Data taking is foreseen for 2014.

> ALPS-IIb will consist of 100 m long cavities installed in the HERA tunnel. Its main goal is a demonstration that the planned optical system can be made to work reliably in the HERA tunnel. This test is a necessary ingredient for a decision on the installation of the 10 + 10 straightened HERA dipole magnets required for the final stage. ALPS-IIb is to be concluded in early 2016.

> ALPS-IIc will finally allow the search for ALPs and other WISPs to begin in 2017, assuming the construction of European XFEL at DESY remains on schedule.

Important milestones towards the realization of ALPS-II were reached in 2012. Infrared laser light was successfully locked in ALPS-IIa. Details of the laser concept were tested at the AEI in Hannover. A very cost effective method to straighten the HERA dipoles was experimentally verified with the magnet used by ALPS-I. Crucial components of the TES detector system, such as an adiabatic demagnetization refrigerator (ADR), were installed in ALPS-IIa.

Most importantly, a technical design report for ALPS-II was submitted to the DESY Physics Research Committee in August 2012 and successfully reviewed in November 2012. It describes in detail how to combine existing infrastructure at DESY (HERA dipole magnets, long straight sections in the HERA tunnel, cryogenics) with world-leading expertise in laser technology (derived from experience at gravitational-wave interferometers) and new optical detectors (superconducting single-photon counters) to achieve sensitivities in WISP searches several orders of magnitude better than any existing laboratory experiment. ALPS-II could be realized at comparably modest costs, but the impact of any discovery could hardly be overestimated.

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Diamonds are a physicist’s best friend.

Putting diamonds to work as particle detectors

When people hear the word “diamond,” they may think of gemstones, or industrially produced diamonds for cutting tools. However, high-purity synthetic diamonds are also useful as sensors for particle detection, most notably under conditions when other detectors perform less well: diamond sensors are more robust, have faster response and are more radiation tolerant than other types of sensors.

The diamonds used for particle detection are produced in poly- or monocrystalline form by chemical vapour deposition (CVD) by Element Six Technologies (www.e6.com). When grown using this process, they can be up to 10 cm square for polycrystalline diamonds (1 cm square for monocrystalline) and about half a millimetre thick. A single-crystal CVD diamond is shown in Fig. 1.

The application of diamond sensors for accelerator instrumentation is a rapidly evolving field, specifically in the area of beam conditions monitoring and the protection of accelerator and detector components susceptible to radiation. Along this line, the CMS-FCAL group at DESY in Zeuthen has developed several detector systems with diamond sensors, which are now in routine use at the LHC and at FLASH. The group is also in the process of designing upgrades for the existing systems as well as new systems for proposed accelerators.

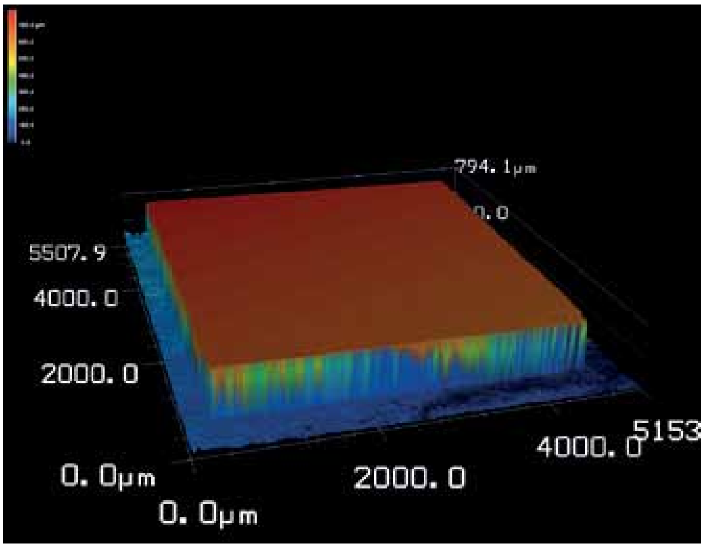

Figure 1

Laser microscope scan of single-crystal CVD diamond

At CERN’s experiment CMS, the BCM1F fast beam conditions monitor has been operating since the startup of the LHC. BCM1F comprises eight single-crystal diamond detectors installed in two planes with four sensors each on either side of the interaction point. Six additional diamond sensors are installed around the LHC ring (Fig. 2). The detectors measure the rate of particles originating from various sources: interactions of beam particles with remnant gas atoms in the vacuum chamber, unidentified falling objects (UFOs) in the vacuum chamber or, for CMS, from proton–proton collisions. These count rates are turned into beam quality and luminosity measures, which are sent to the LHC and CMS control centres. They are of invaluable importance for maintaining the smooth running conditions needed for high-quality data. The LHC is currently undergoing an upgrade to run at higher energies and luminosities. When it turns back on in two years, the operational radiation environment will be even more challenging. The BCM1F system is therefore being upgraded to cope with the expected higher rates and to improve redundancy.

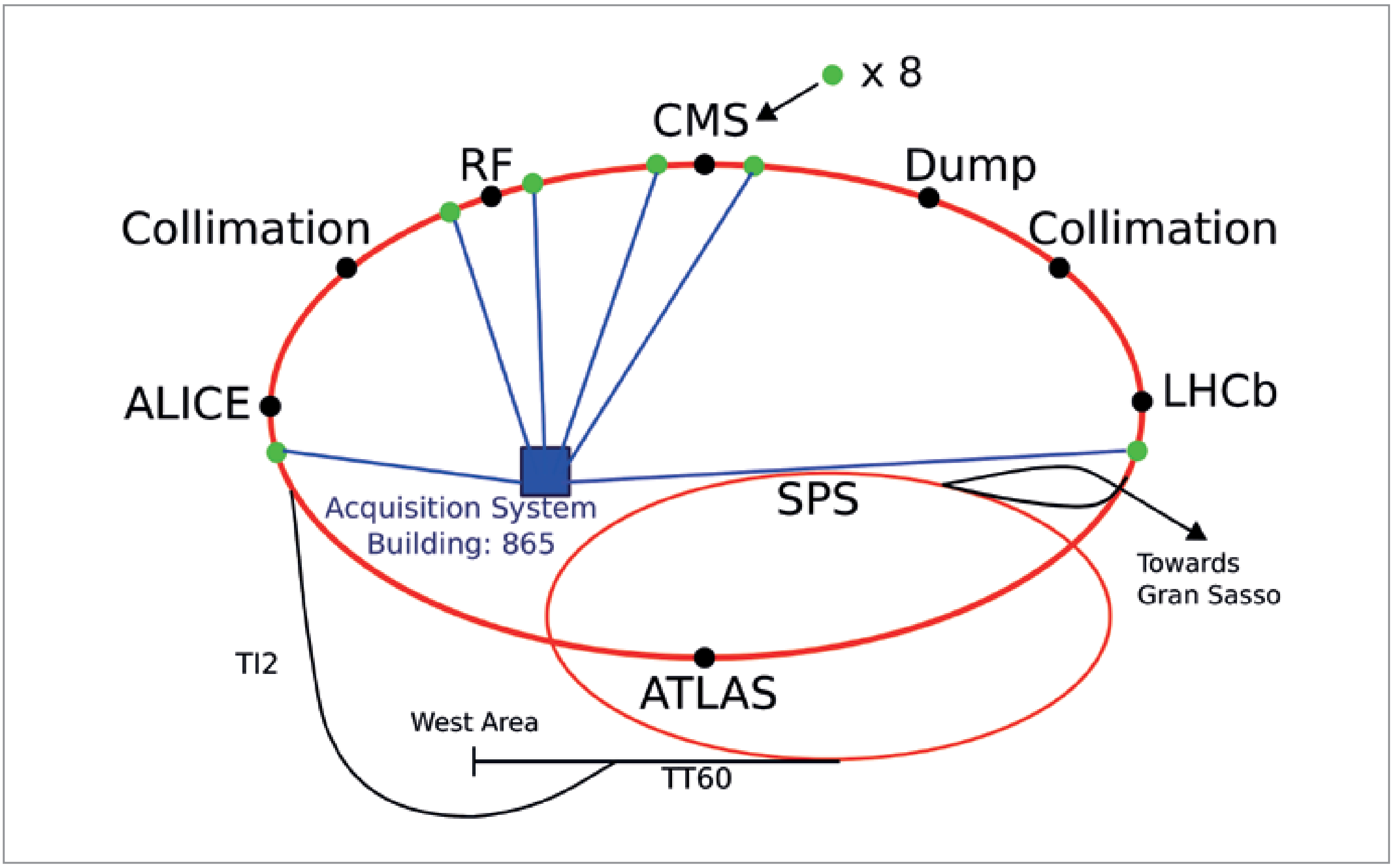

Figure 2

Locations of diamond sensors (green dots) installed at the LHC. All data are sent via optical links to the central acquisition system.

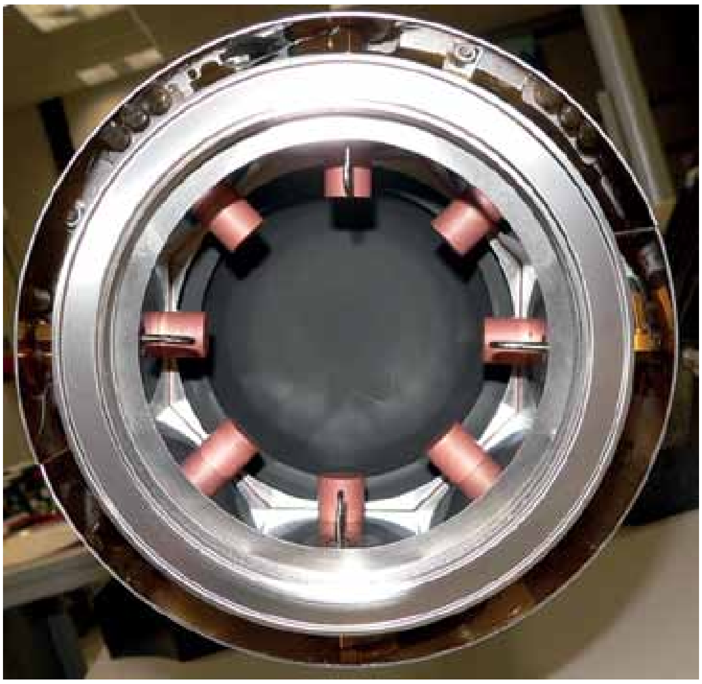

Figure 3

Diamond–sapphire installation for FLASH

Polycrystalline diamond and sapphire sensors are also used in the beam halo monitoring system installed in FLASH at DESY, as shown in Fig. 3. This system prevents beam particles from scraping the beam pipe downstream of the undulator, and thereby, keeps the vacuum conditions from deteriorating to the point where accelerator operation becomes impossible. Similar systems are being constructed for the FLASH II beamline and are in the design stage for the European XFEL. In addition, diamond sensors are being considered for the instrumentation of the very forward regions of a future linear collider detector.

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LHC detector development.

ATLAS and CMS are paving the way to discoveries

The LHC experiments ATLAS and CMS performed superbly in 2012. Each collected 23 fb^{-1} of data with an efficiency well above 95%. The LHC was then shut down in February 2013 to upgrade the experiments and the LHC itself for running at higher energies and higher data rates when operation resumes in 2015. Further upgrades aimed at maintaining the excellent performance of the detectors and preparing for even higher data rates are also being planned. DESY is engaged in several silicon-sensor-based detector upgrade projects for both experiments, including the replacement of the CMS pixel detector in 2016. Both ATLAS and CMS are investigating ways to improve the radiation hardness of sensors and replace their current trackers for the high-luminosity LHC in 2022.

CMS pixel upgrade for 2016

The CMS pixel detector was optimized for operation under LHC design parameters but, since the LHC will soon be exceeding some design parameters by a factor of two, its performance will start to suffer. It will also be approaching the end of its useful life. To continue to exploit the remarkable performance of the LHC, CMS will replace the current pixel detector with an improved version. To improve resolution and redundancy, the new detector will have four instead of three concentric barrel layers and three instead of two end cap disks on either end. It will also use improved readout chips, more efficient powering and a much lighter mechanical support structure.

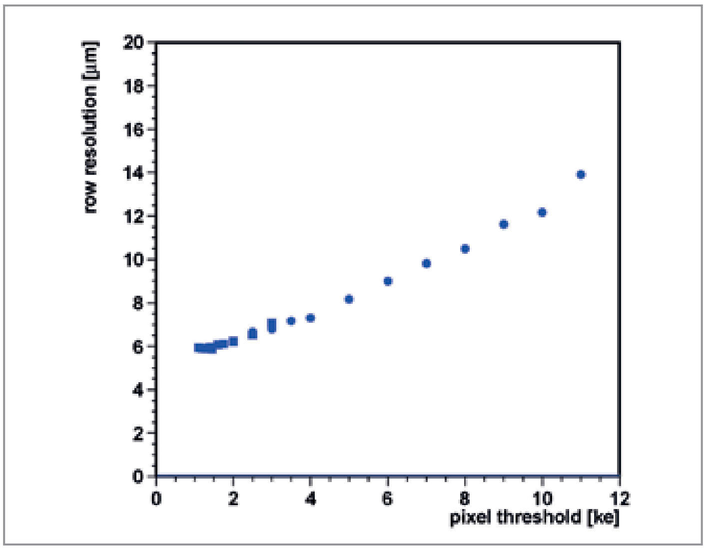

Figure 1

Resolution of a pixel sensor equipped with the new readout chip versus pixel threshold. The new chip can operate down to a threshold of 1600 electrons compared to the 3000 electron threshold of the old chip.

DESY, together with the universities in Aachen, Hamburg and KIT in Karsruhe, will build and calibrate the outermost layer of the barrel, which comprises 512 identical detector modules. Preparations for module production and testing are under way. For example, the DESY CMS group, together with the electronics research group, investigated bump bonding technologies and is currently setting up the infrastructure for module production. In addition, DESY determined the efficiency and resolution of the first prototypes of a new readout chip (ROC) using the DESY 6 GeV electron test beam and a EUDET pixel telescope copy as an external reference. Figure 1 shows the measured resolution as a function of the internal threshold. The new ROC can be operated with a threshold of 1600 electrons compared to the 3000 electron threshold of the old ROC. This results in better hit efficiency and a resolution down to 6 µm.

CMS silicon strip tracker for HL-LHC

Present planning calls for the LHC to be transformed into the high-luminosity LHC (HL-LHC) which, when it starts operation in 2022, will deliver an instantaneous luminosity of $5 \times 10^{34}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, five times higher than the LHC design luminosity. The radiation level will increase accordingly. This has necessitated research into improving the radiation hardness of detectors. DESY and the University of Hamburg are contributing by characterizing irradiated sensor test structures of various materials and thicknesses in terms of noise, dark current and efficiency in order to find a sensor material that fits the needs for the HL-LHC already in 2013. Design challenges of the new CMS tracker include the needs to operate at -20°C, to minimize material budget and to provide trigger information for added rate suppression at high luminosity. The detector modules must be rigid, but as light

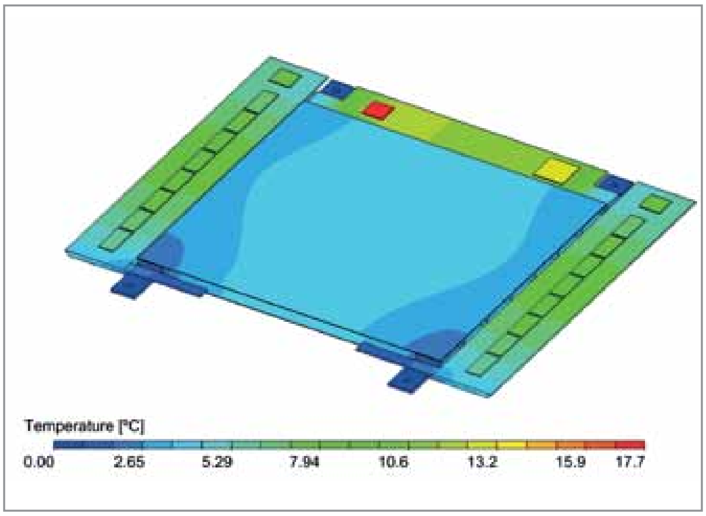

Figure 2

Thermal finite element analysis of a detector module with trigger capability. The maximum temperature difference between the cooling blocks and the DC-DC power chip is 17.6°C.

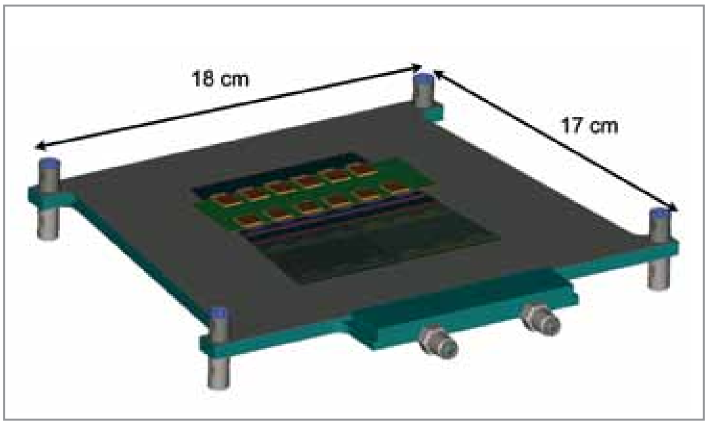

Figure 3

Petalet mechanical drawing

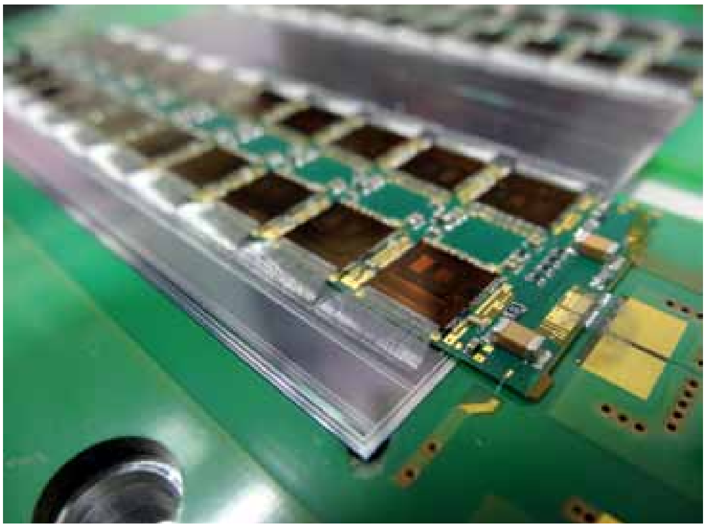

Figure 4

ATLAS single-sided silicon strip module for the HL-LHC detector upgrade

as possible. The modules are being designed and optimized for thermomechanical properties using electronic design tools. Figure 2 shows the results of a thermal finite element analysis of one design under study. The module shown has a sensitive area of 10 x 10 cm^2 and is capable of providing trigger information at each HL-LHC bunch crossing.

ATLAS silicon strip tracker for HL-LHC

The DESY ATLAS group is engaged in the preparatory research needed for the HL-LHC ATLAS tracker upgrade. DESY will not only build detector modules, but also carry out the macro assembly of a full silicon strip end cap made of seven disks with 2 m diameters. Each disk will be subdivided into 32 wedge-shaped petals. Petals are very light support structures made of a carbon honeycomb material core sandwiched between carbon fibre facings. Single-sided silicon strip modules are glued onto the electrical tapes attached to the carbon fibre facings. Titanium cooling tubes in the centre will provide sufficient cooling of the sensors and the readout electronics glued to the top of the sensors. In cooperation with the universities in Freiburg and Berlin, DESY specifically contributes to the R&D for the petals, including electronics development, module production, mechanics design and test beam studies.

A small-scale prototype called a “petalet” was designed and is being constructed to study petal-specific features while planning for a larger prototype for a later stage of the project. Figure 3 shows a mechanical drawing of a petalet with end cap modules. A single-sided silicon strip module for the ATLAS tracker upgrade is shown in Fig. 4. The electrical performance of this module was shown to be well within specifications.

Synergies and common infrastructure

Both detector development groups benefit from DESY’s membership in the two LHC collaborations since it allows for an exchange of experience within DESY and for the sharing of expensive infrastructure, such as wire bonding machines, probe stations and a CO$_2$ cooling plant.

A mechanical and thermal test stand was set up for thermal measurements of temperature profiles and mechanical deformations to an accuracy of 10 µm. The first module prototypes of CMS and ATLAS will be built and measured in these test setups in 2013.

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Power, ground and electromagnetic interference.

Design strategies for electronic systems

Scientific instruments must often detect small signals in the vicinity of large switching currents. This is particularly true for the CALICE-AHCAL calorimeter, where sensitive electronics must operate in the midst of 3 kA of current that is abruptly switched on and off at a rate of 5 Hz. Good overall performance requires that the sensitivity of the calorimeter electronics to this alternating current as well as the disturbance caused by the switching on systems external to the calorimeter be minimized. For AHCAL, the strategy for doing so focuses on controlling the current loops, enclosing them within small volumes and minimizing the currents induced into the infrastructure.

High-energy physics and photon science collaborations develop detectors with enormous channel counts and high, power-hungry, data rates. A particular problem for one such detector, CALICE-AHCAL, is that the requirements on the homogeneity of the calorimeter together with a lack of active cooling place particularly severe constraints on the tolerable amount of generated heat. Power consumption (and therefore heat generation) is minimized by switching the currents of the front-end electronics on only for the short interval of beam delivery by the accelerator, 600 μs, and off for the rest of the repetition cycle of 200 ms. For the four million channels, the switched current reaches 3 kA. As shown in Fig. 1, the calorimeter is a stainless-steel structure with gaps for layers of scintillators and their readout electronics. Each layer of about 2 m^2 contains 2000 channels with just 40 μW each.

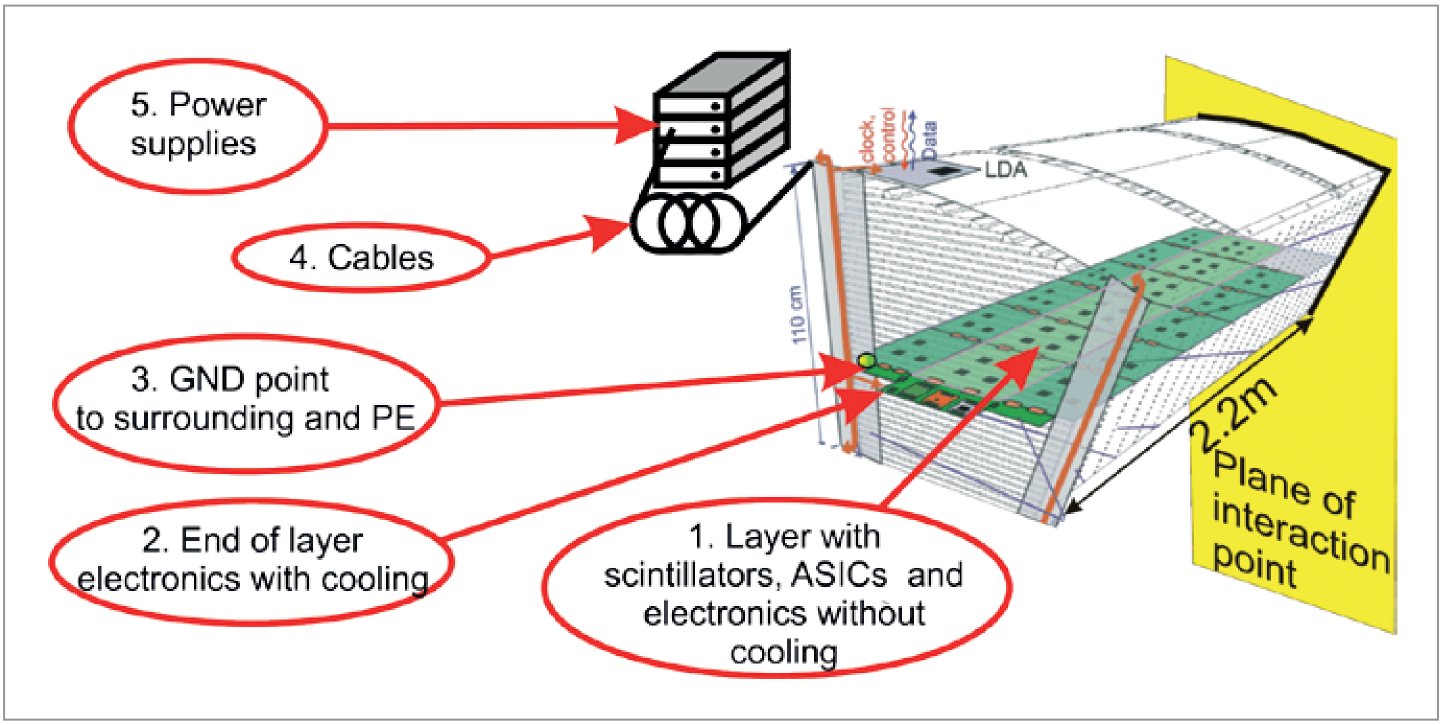

Figure 1

CALICE-AHCAL: detector system for a hadron calorimeter at the ILC. The ovals show the elements that must be considered when optimizing the power/GND system and the noise of the whole detector (ILD).

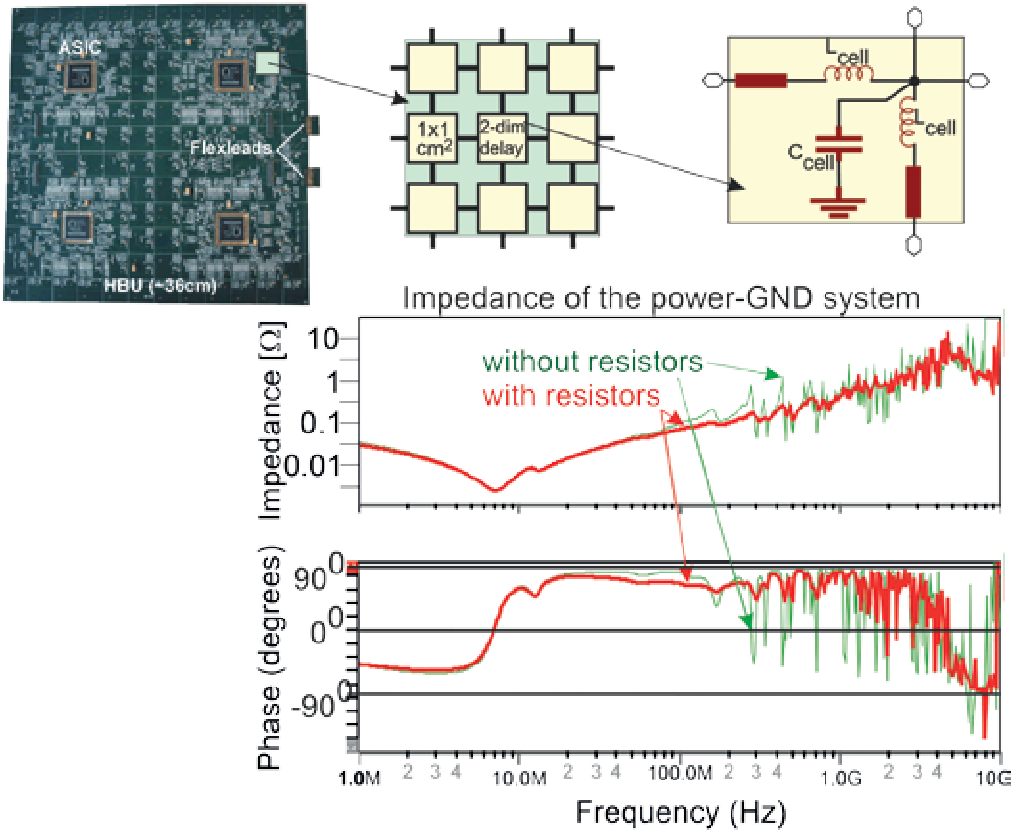

Figure 2

Optimizing the noise suppression of a PCB design.

Top: simulation scheme for a PCB with a small distance of the power layer to the GND layer. Bottom: simulated impedance for a PCB with capacitors and resistors.

To minimize heat production, the switching must be abrupt. The resulting sharp switching edges will generate Fourier components in the spectrum of currents starting from the repetition frequency of the beam, 5 Hz, far into the 100 MHz regime. In the AHCAL concept, the current loops are closed in geometrical regions much smaller than the wavelengths of the frequencies. For the high frequencies, the loops are closed within the calorimeter layers near each circuit switching current. For lower frequencies, the large electronic components are placed at the end of the calorimeter or even outside the detector. As indicated in Fig. 1, the proper control of the currents requires that the system design include the front end, the on-detector control, the choice of a grounding point, the cabling and the power supplies in the off-detector rooms.

The technique for minimizing the impact of the high frequencies is shown in Fig. 2. A specific layer structure of the printed circuit boards (PCBs) and a choice of different capacitors and resistors provide the needed low impedance, < 0.1 Ω, and fulfil the requirement that the phase shift not be near ±90°. The needed studies for the design were done with realistic simulation models for the components in the PSPICE simulation program, with appropriate differential equations (VHDL-AMS) and a model representing the (36 cm)^2-sized PCB by small two-dimensional elements. Adding resistors into the power/ground (GND) system was found to greatly reduce large excursions in the impedance as shown in the plot of Fig. 2. In a real system operated at a large test beam facility, the power/GND-system was found to suppress the noise very well (no debugging was even needed!). The real behaviour of the PCBs is expected to be less ideal, and the currents induced into the full calorimeter structure have been estimated to be a few Amperes of the switched 3 kA. Similar simulations of the control electronics and cabling schemes demonstrated the need for charge storage and filters at different locations of the calorimeter, as well as the careful design of the cabling and the floating of power supplies.

This current control technique is also being applied to X-ray camera systems that will take 1 Mpx pictures of 20 x 20 cm^2 at a rate of 3520 pictures/s (AGIPD) and have a current consumption of 1 kA for possible use at the European XFEL.

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P. Göttlicher for the CALICE collaboration, 2013 JINST 8 C01042

Plasma trimming.

Electron acceleration using density-tailored capillary discharge waveguides

Specific shaping and precise knowledge of transverse and longitudinal density profiles in targets used for plasma wakefield acceleration are crucial prerequisites for the generation of reproducible electron beams needed by upcoming experiments at FLASH and REGAE. The targets employed, capillary discharge waveguides, are a few centimetres long but only a few hundred micrometres in diameter. The wakefields generated within these capillaries facilitate acceleration gradients of more than 10 GV/m and intrinsically generate electron bunches with femtosecond duration. Results from the first tests at DESY and at the Lund Laser Centre in Sweden are presented below.

Relativistic particle acceleration in plasmas

Acceleration of charged particles based on charge separation induced in plasmas is a novel concept, the investigation of which has made remarkable progress in the past few years. Plasma accelerators use high-intensity laser pulses or high-current-density particle beams to ionize a gaseous target material and locally push the generated plasma electrons outward while ions remain confined due to inertia. The induced charge separation, which propagates with the generating beam, can give rise to field gradients above 10 GV/m and thus accelerate electrons to GeV energies in a few centimetres, some two to three orders of magnitude shorter than is common in radio frequency accelerators.

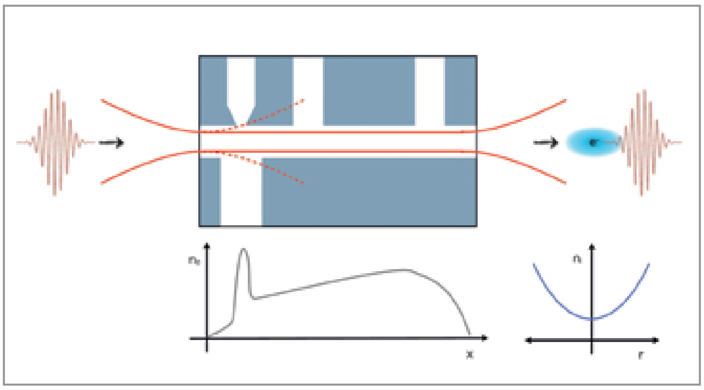

Figure 1

A laser-guided pulse (red solid lines) through a capillary discharge waveguide (CDWG) in contrast to a non-guided pulse (dashed red lines). The plot on the lower right qualitatively indicates the required transverse plasma density profile for guiding (blue line). On the lower left is an example of the longitudinal density profile generated in the CDGW (grey line).

Transverse density shaping with HV discharges

When using laser beams for wakefield generation, the interaction distance of the beam with the gas target is usually limited to a few Rayleigh lengths around the focus, since the intensity diminishes drastically as illustrated in Fig. 1. Increasing the interaction length of the laser with the gas target effectively results in increasing the acceleration length.

To do so, the laser must be guided through the capillary by generating a transverse refractive-index profile similar to that used in gradient fibre optics. The change in refractive index is realized by shaping the transverse temperature and thereby the gas density distribution with a high-voltage (HV) plasma discharge of about 20 kV and 300 A. The energy transferred into the system leads to nearly full ionization and strong heating of the gaseous target media in the central region, while the capillary walls remain at ambient temperature and cool the plasma. The resulting temperature and gas density profile is strongly time-dependent and only exhibits the desired density profile (shown in Fig. 1) in a short time window.

This is indicated in Fig. 2, where the transmission efficiency of a laser beam through the capillary discharge waveguide (CDWG) is plotted versus time together with the time-dependent discharge current. While the transmission through a 200 µm diameter capillary with 15 mm length is about 40% of the intensity of the unperturbed laser beam without discharge, the throughput can be increased to nearly 100% with a discharge-induced transverse density modulation. As can be seen during the initial phase, just after ignition the transmission decreases to about 30% before a guiding channel forms.

The profiles of the guided beams observed at the capillary exit are illustrated in the two inserts in Fig. 2. While in the non-guided case, the whole capillary exit is inhomogeneously illuminated and has several hotspots caused by internal reflections off the rough capillary walls, a well guided transmitted beam shows a nice mode quality with little distortion and a size that is comparable to the focal spot size. It should be noted that even though the energy transmission stays at almost 100%, spatial distortions of the transmitted beam can be observed. Thus the time window for optimum guiding of the laser beam is effectively about 20 ns.

Injection and acceleration using a longitudinal taper

In addition to the transverse density profile for laser guiding, multiple gas inlets to the capillary allow the tuning of the longitudinal density profile variation of the local gas density. In the example shown in Fig. 1, the capillary (dark blue structure) has three gas inlets connecting from the top and an outlet to the bottom. The gas inlet with the nozzle on the left, together with the outlet below it, serve as a free-flow gas jet, which allows the generation of either sharp density spikes or a local introduction of a dopant gas species with a different ionization potential. Both methods facilitate controlled, spatially confined injection and placement of electrons within the wakefield and subsequently the reduction of shot-to-shot variations.

Once injected, a controlled linear increase of the gas and thus plasma density in the acceleration region (compare to Fig. 1) prevents the electrons from outrunning the accelerating field and allows for acceleration to higher energies. After acceleration, a controlled release of the electron beam into the vacuum supports cooling the transverse electron motion and reduces the divergence of the beam.

Two electron spectra of beams obtained in recent experiments at the Lund Laser Centre using specific density-tailored CDWGs are presented in Fig. 3. To create this image, the electron beam is dispersed by a permanent magnet to produce an energy-resolved spectrum along the horizontal axis of the image, while information about the transverse coordinate and beam divergence can be gleaned from the vertical distribution. As can be seen from the two different spectra, charge distributions with various features that reflect different acceleration conditions can be characterized.

Tweaking the electron beams resulting from plasma acceleration as well as investigating the acceleration process and controlling the plasma parameters, such that reproducible beams are generated, will continue to be a major activity in the quest to make plasma wakefields a key component of particle accelerators.

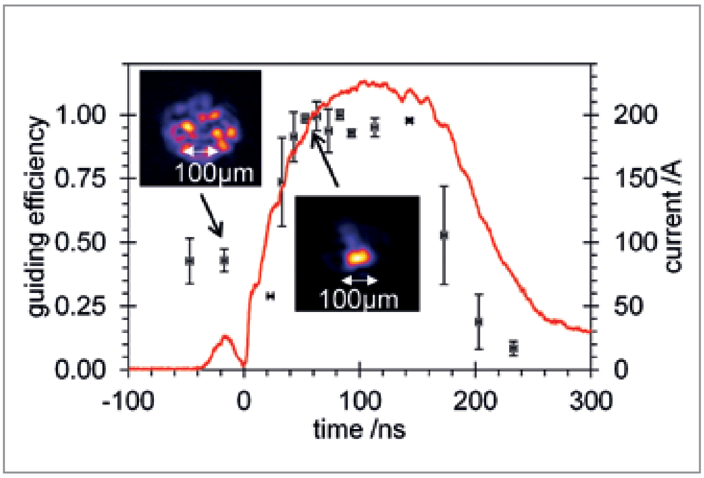

Figure 2

Guiding efficiency (black, with error bars) for a laser beam transmitted through a CDWG. Also plotted are the current waveform of the discharge (red solid line) and two images of the laser beam profile at the capillary exit.

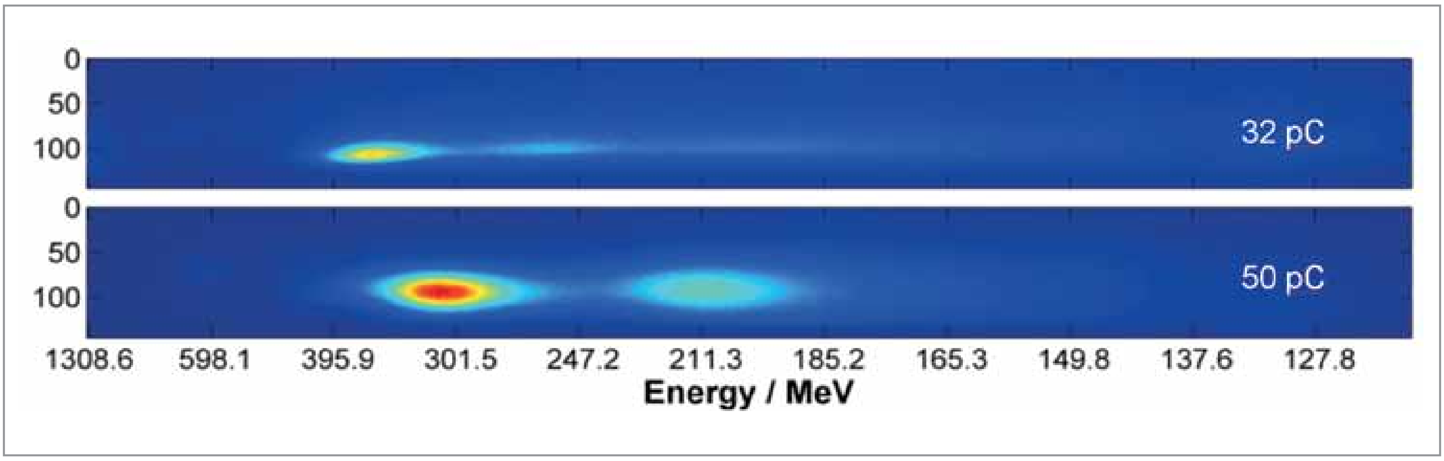

Figure 3

Electron energy spectra of two beams accelerated at the Lund Laser Centre. In the top image, the beam shows a spectrum with a quasi mono-energetic feature and a longer low-energy tail. The lower image shows a double-peaked spectrum.

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Tossed from wave to wave.

Assessing staged plasma acceleration

Since the demonstration of GeV beam generation on centimetre scales, plasma acceleration is considered a promising technology for future compact particle accelerators. However, before this technology can climb the energy ladder towards the TeV frontier, staging of plasma acceleration modules must be mastered. Simulation studies for future experiments at DESY reveal constraints on current staging schemes and show that further refinement of the technique is necessary to facilitate low-emittance beams from compact staged plasma acceleration.

Principle of plasma acceleration

Today's sources of laser or charged particle beams readily attain intensities sufficient to excite large-amplitude plasma waves if focussed onto appropriate gas targets. These plasma waves, propagating with the velocity of the drivers, are capable of carrying longitudinal fields ("wakefields") of a magnitude on the order of 100 GV/m [1]. Such wakefields allow for an energy gain that, for a given acceleration length, can be orders of magnitude higher than in conventional accelerators.

Because of its potential to render possible short and affordable linear accelerators, plasma acceleration has been experiencing a rising scientific interest and progress in the last decades. As a consequence, the stability, energy and energy spread of plasma-accelerated electron beams have improved significantly, and various methods to trap electrons from the plasma background into the wake have been developed. While these injection techniques may create intrinsically short (~10 fs) electron beams, which e.g. can be utilized to generate brilliant X-ray radiation [2], most methods offer only limited control over the amount of injected charge, the initial and final transverse phase space distribution and the current profile of the beam.

External beam injection and staged laser wakefield acceleration

A yet to be demonstrated approach of injecting a well-defined electron bunch from a conventional source into a laser-driven plasma wave (dashed box in Fig. 1) is currently being prepared at the REGAE and FLASH accelerators at DESY. These experiments will not only feature a high degree of control over the injection process and the final beam parameters, but also allow for an analysis of concepts of staged plasma acceleration [3].

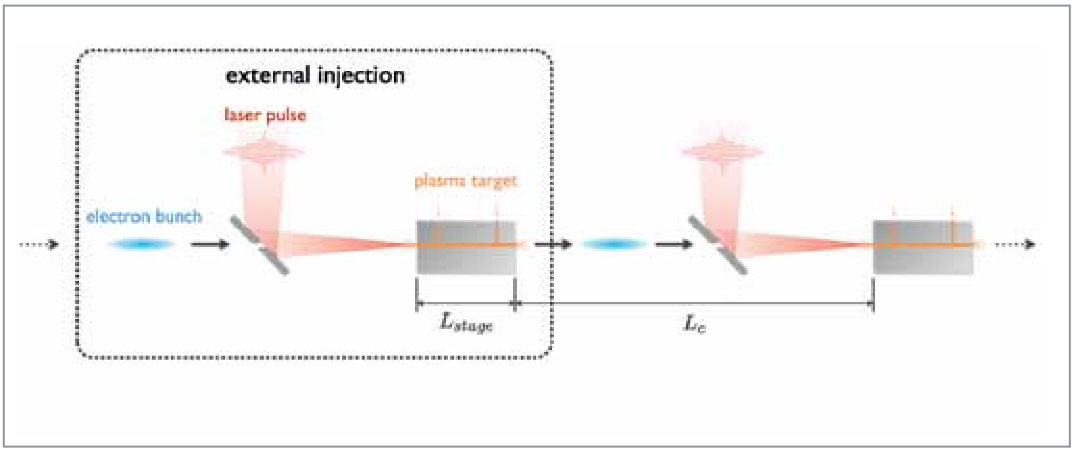

Figure 1

Scheme for external injection and staged laser-driven plasma-based acceleration

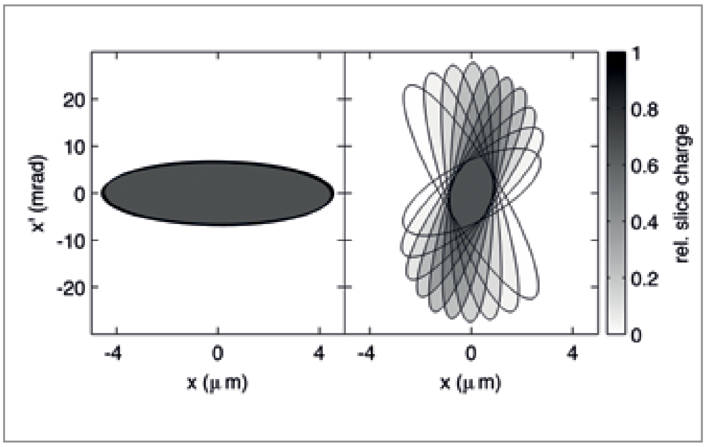

Figure 2

Slice ellipses in transverse trace space (slope and coordinate) before (left) and during propagation in a plasma module (right). The oscillation phases of the various time slices decohere with respect to each other, causing projected emittance growth.

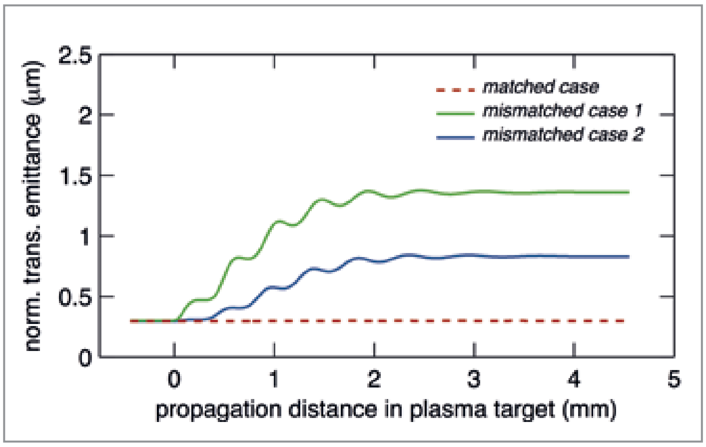

Figure 3

Simulated evolution of the transverse normalized emittance of beams injected into a laser-driven plasma wave

Staging of plasma accelerators, e.g. for laser drivers, will be necessary if energies beyond the 10 GeV regime need to be attained, since the energy gain in a single stage is fundamentally limited by the depletion of the driver energy. Such acceleration in a series of plasma modules involves the ejection and injection of electron beams from and into plasma targets (Fig. 1).

Current considerations for staging schemes favour 10 GeV modules with a length of L_{stage} ~ 1 m and a coupling distance of L_c ~ 1 m using plasmas with a density of ~10^{17} cm^{-3} [2]. The coupling distance in these designs is essentially given by the minimum laser focussing length and has a comparable length to the plasma stage itself. This is vital since a much longer coupling distance would start to dominate the total length and thus reduce the effective gradient.

Emittance growth in staged plasma acceleration

Particle-in-cell simulations using the OSIRIS code for the REGAE external-injection experiments suggest that long matching sections for the electron beams between the stages or yet to be developed adiabatic matching techniques in the plasma are required in order to mitigate significant deterioration of beam quality from transverse emittance growth [4]. The transverse emittance is equivalent to the transverse phase space volume of a beam.

The reason for this is explained as follows: an electron beam injected into a plasma wave will undergo betatron oscillations in the strong focussing fields of the plasma waves, which can be of the same order of magnitude as the longitudinal wakefields. Since the longitudinal dimensions of the plasma wave are on the order of 100 µm, a 10 µm long bunch will experience a significant variation of the focussing fields along the axis, and the betatron oscillations in various time slices of the beam will decohere rapidly with respect to each other, eventually causing substantial growth of the projected emittance (Fig. 2). For finite-length bunches, this can only be suppressed if the bunch is matched into the focussing wakefields (Fig. 3).

Bunches that are ejected from one stage, *n*, and drift freely between stages *n* and *n*+1 will enter the subsequent stage (*n*+1) with a mismatch, which even for ~10 cm coupling distances increases the emittance by an order of magnitude during the traversal of a single module.

Thus, new matching techniques need to be developed to facilitate the design of compact staged plasma accelerators.

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IceCube.

Neutrino astrophysics and particle physics at the South Pole

IceCube is the first cubic-kilometre-scale neutrino telescope and thus the first with sensitivity to high-energy neutrinos from distant cosmic sources. In 2012, IceCube provided the first hints of extraterrestrial neutrinos: two events with energies of about a million GeV, which were probably not generated in the Earth's atmosphere. No indications have been found of the super-heavy magnetic monopoles predicted by grand unified theories, but limits on their fluxes have been improved by a factor of a hundred. Last but not least, the year 2012 opened a new venture for IceCube: the study of neutrino oscillations.

The IceCube neutrino observatory has two components: the neutrino telescope IceCube in the deep Antarctic ice and the surface detector IceTop. IceCube comprises 5160 light sensors (or digital optical modules, DOMs) on 86 strings. A quarter of the DOMs were assembled at DESY. The DOMs are arranged at depths between 1.4 und 2.4 km and record the Cherenkov light emitted by charged particles, such as would be generated by neutrino interactions, passing through the array. In addition to the assembly of the DOMs, DESY in Zeuthen plays an important role as European Tier-1 centre and second data archive, the first being in Madison, USA.

Two PeV events: cosmic or terrestrial?

The standard signature for a neutrino reaction is a muon emerging from a muon neutrino interaction and passing the detector from below. Two years ago, the collaboration succeeded in clearly identifying another much trickier signature: an isolated particle shower ("cascade"), which is usually caused by an electron neutrino or tau neutrino interaction.

Since high-energy cascade events can be fully contained in the detector volume, their energies can be measured more precisely than those of muons. A precise energy measurement is particularly important in the search for diffuse fluxes of extraterrestrial neutrinos, since such neutrinos are distinguished by their higher energy compared to atmospheric ones. A report on an analysis of the PeV energy range (1 PeV = 10^6 GeV) using the 2010/2011 data set, which was released in June 2012, describes two fully contained cascade events (Fig. 1), which together constitute a 2.8σ excess over the expected background. The origin of the two events is being further investigated in two DESY analyses, which focus on the energy range of a few hundred TeV. The first of these (using 2008 data with a cascade signature) showed a 2.2σ excess (3 events) over the expected rate. The second one (using 2009 data) will be released in May 2013. Meanwhile, a search for energetic muon tracks yielded a 2.1σ excess (RWTH Aachen). Taken together, these three results might be a first glimpse into the neutrino sky at high energies. A second analysis of the 2010/11 data (UW Madison) reveals additional hints. The year 2013 might provide the definite answer.

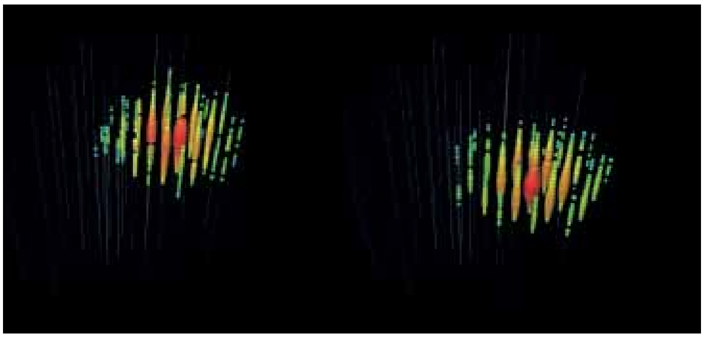

Figure 1

Two events with energies of 1.0 and 1.1 PeV. The sizes of the symbols indicate the charge registered in the corresponding DOM, the colour indicates the arrival time of the light.

GUT magnetic monopoles

Most versions of grand unified theories (GUTs) predict the existence of extremely heavy magnetic monopoles with masses of up to 10^{19} GeV. Velocities for cosmic GUT monopoles must be small compared to the velocity of light, since none of the known cosmic magnetic fields could boost them to relativistic speeds. According to a prediction of the early 1980s, these monopoles could catalyse the decay of protons along their path. Particles generated in the decay would emit Cherenkov light. Since GUT monopoles would need milliseconds to cross IceCube, far longer than the microseconds needed by relativistic particles, they could in principle be distinguished from the latter. However, background due to muons and dark-noise counts over a millisecond time frame poses a considerable challenge (Fig. 2).

Other candidates for slowly moving particles are SUSY Q-balls (extremely heavy candidates for dark matter) and lumps of strange quark matter, the so-called nuclearites. The discovery of any of these objects would have a significant impact on particle physics, on cosmology and possibly on the question of dark matter. In two recent analyses performed at DESY and at RWTH Aachen, no slowly moving, bright particles have been found. This translated into an upper limit to their cosmic abundance that is about a factor hundred better than any previous limit.

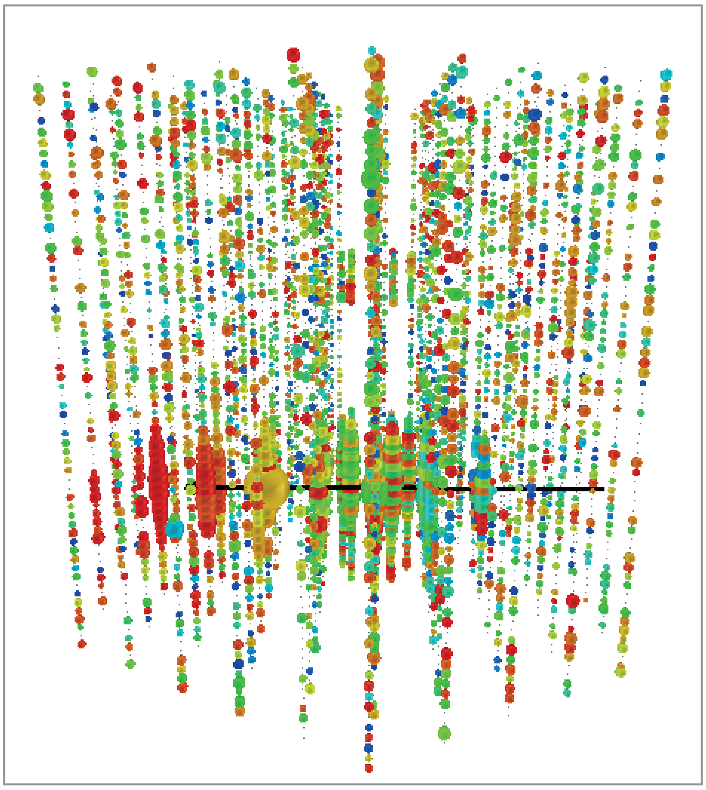

Figure 2

Event view of a simulated GUT magnetic monopole in IceCube. It is accompanied by signals from dark-noise counts and from several muons, which hit the detector during the millisecond the monopole needs to cross the full array.

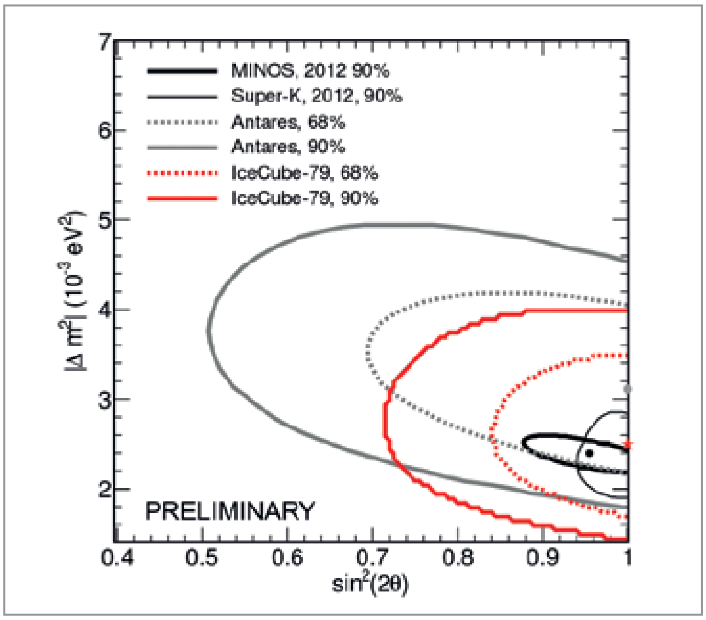

Figure 3

Constraints to mass difference Δm_{23}^2 and mixing angle $\sin^2\theta_{23}$ obtained with DeepCore. Our data are compared to the best data from underground detectors. Ongoing analyses will considerably improve the present DeepCore constraints.

Neutrino oscillations

Atmospheric neutrinos constitute the ultimate background to the search for extraterrestrial neutrinos. More than 150 000 of them have been recorded with IceCube. The measured energy spectrum extends up to 400 TeV and fully agrees with the predicted spectrum of neutrinos from the decay of π and K mesons. This fact constrains predictions of a possible contribution from charm particle decay (and hence constrains the corresponding cross sections for charm production).

Recently, we demonstrated the ability of the tightly spaced inner array of IceCube, called DeepCore, to observe the effect of neutrino oscillations at low energies, which up to now has been the exclusive province of low-threshold underground detectors. Neutrino oscillations are a consequence of the fact that neutrinos have mass – a first step beyond the Standard Model of particle physics. Figure 3 shows the constraints on the space spanned by the two parameters relevant for neutrino oscillations: the square of the mass difference between the two neutrino mass states and the mixing angle, which describes how strong the oscillations are. With the proposed PINGU detector (about 20 additional strings in the inner part of IceCube), the threshold would be reduced to a few GeV, which would possibly enable the study of matter effects of neutrino oscillations, and thereby possibly the determination of the mass hierarchy (i.e. which neutrinos is the heaviest, which the second heavy and which the lightest).

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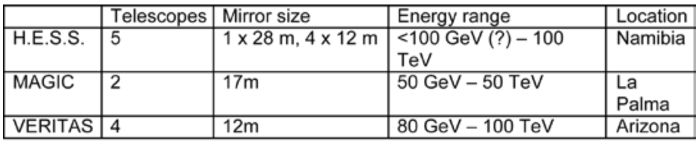
H.E.S.S., MAGIC, VERITAS and Fermi.

Ground-based and satellite-borne gamma-ray astronomy

Gamma-ray astrophysicists at DESY actively contribute to all major experiments currently operating in the field of gamma-ray astronomy. The DESY campus in Zeuthen unifies the know-how on Cherenkov telescopes, covering the energy range between 0.1 TeV and 100 TeV, and space-borne instruments, which image the sky above 10 MeV. The wide coverage of hardware, analysis and astrophysical expertise provides an ideal framework for this leading institute in the field. In 2012, all three ground-based observatories underwent major upgrades that will substantially improve their sensitivities.

The H.E.S.S., MAGIC and VERITAS Cherenkov telescope systems map out cosmic accelerators in the TeV sky. They differ technically in their mirror dish sizes, camera layouts, telescope counts and locations (either northern or southern hemisphere), the latter defining which targets can be observed (Table 1).



	Telescopes	Mirror size	Energy range	Location
H.E.S.S.	5	1 x 28 m, 4 x 12 m	<100 GeV (?) – 100 TeV	Namibia
MAGIC	2	17m	50 GeV – 50 TeV	La Palma
VERITAS	4	12m	80 GeV – 100 TeV	Arizona

Table 1: Specifications of the three Cherenkov telescope systems

The H.E.S.S. experiment

Its southern hemisphere location permits the H.E.S.S. experiment to observe the inner Milky Way and its dozens of TeV gamma-ray sources. With its two different mirror sizes, H.E.S.S. is the only “hybrid array”. The large H.E.S.S. II telescope, inaugurated in September 2012, will allow the energy threshold of the array to be lowered and thereby to open an unprecedented energy window on the inner Milky Way. For instance, pulsars are abundant in the inner Milky Way, but are yet to be detected by H.E.S.S. The DESY group is involved in the maintenance and operation of the data acquisition system and the commissioning of the new five-telescope system (Fig. 1). An upgrade of the H.E.S.S. I cameras is foreseen for 2015.

The main physics topic of the H.E.S.S. group at DESY in Zeuthen is pulsar wind nebulae (PWN). Two of these giant clouds of electron–positron plasma were among the science highlights of H.E.S.S. in 2012. One of them, Vela X, is located only a few hundred parsecs from the Earth and has a size four times larger than the apparent size of the moon. The other one resides in the Large Magellanic Cloud, around the most energetic pulsar known, and is the farthest PWN ever detected. The DESY group is working on a systematic study of the population of PWNs, their general attributes and their time evolution.

The MAGIC observatory

Unlike H.E.S.S., MAGIC has been focusing on the low-energy regime ever since its first large telescope was installed in 2004. The addition of a nearly twin telescope in 2008 brought the observatory to its full potential. MAGIC boasts the lowest threshold of all Cherenkov telescopes and has been exploiting it to close the energy gap between satellite- and ground-based observations. This singular feature led to the only phase-resolved very high energy (VHE) pulsar spectra, and to the detection of the farthest active galactic nucleus in this energy band. In 2012, the observatory resumed observations after an upgrade, which provided extremely fast

Figure 1

The five-telescope H.E.S.S. experiment in Namibia

Figure 2

Replacement of the MAGIC-I camera

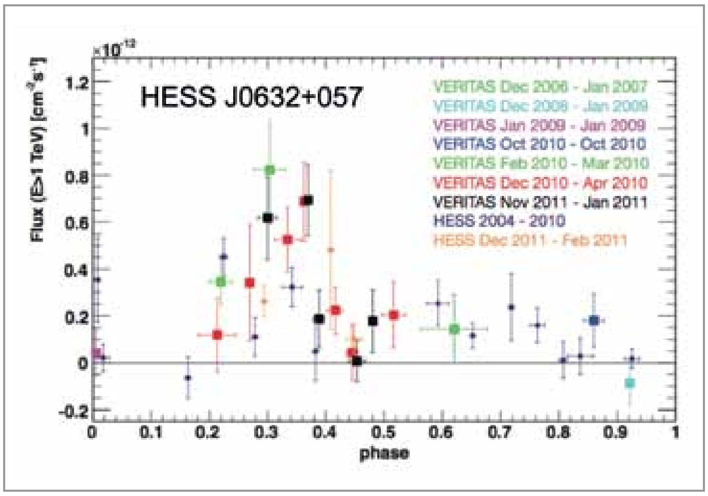


Figure 3

A multi-year observation of binary system HESS J0632+057 with H.E.S.S. and VERITAS reveals a periodic activity around orbital phase 0.3.

readout electronics, a larger field of view and a new camera for the first telescope (Fig. 2).

The DESY group is dedicated to the observation and broadband modelling of active galactic nuclei and supernova remnants (SNR), as well as to the measurement of the diffuse electron spectrum. Major results of 2012 are the discovery of a new blazar (BL Lac object 1ES 1727+502) and the study of the SNR W51C. The DESY group succeeded in modelling the broadband spectrum of W51C with a hadronic emission model. Since the emission was known to be in the interaction zone between the SNR and a nearby molecular cloud, we could infer that it is accelerating cosmic rays up to an energy of 50 TeV. This result contributes significantly to the understanding of the origin of galactic cosmic rays.

The VERITAS experiment

VERITAS has four telescopes in the northern hemisphere and combines a high sensitivity at low energies with good sky coverage. Its cameras were successfully upgraded with high-efficiency photomultipliers in 2012 in order to lower the energy threshold and thereby increase the sensitivity for the detection of fainter sources and objects at larger cosmological distances. A further increase in sensitivity was achieved by using sophisticated analysis methods for both VERITAS and the Cherenkov Telescope Array (CTA), developed in the framework of a Helmholtz Young Investigators Group. A more than 30% improvement in observing time for weak gamma-ray sources and a better low-energy response were achieved.

The main astrophysical mystery addressed by the VERITAS group is the mechanism by which particles are accelerated to extremely high energies in binary systems and active galactic nuclei. A joint observation programme of VERITAS, H.E.S.S. and the Swift X-ray telescope on the binary system VER J06322+057/HESS J0632+057 (Fig. 3) provided a rich data set that is revealing details of the acceleration process, such as the cooling time scales and the dependence on the astrophysical environment. The Helmholtz Young Investigators Group mentioned above is further developing methods to survey the high-energy sky in both space and time.

The Fermi gamma-ray space telescope

The Fermi Large Area Telescope (LAT) has been observing the gamma-ray sky since 2008 with unprecedented sensitivity. One of the research highlights in 2012 was the detection of the so-called pion bump in the energy spectrum of SNRs, a direct proof of the hypothesis that SNRs are accelerators of cosmic rays and a significant step towards a quantitative understanding of cosmic-ray acceleration. Another research highlight was the detection of the extragalactic background light (EBL) at ultraviolet frequencies. The EBL density was inferred from the absorption features imprinted in the gamma-ray spectra of extragalactic sources. The measured EBL density constrains the contribution of active galactic nuclei and low-metalicity stars to the EBL in the early universe.

The Fermi group at DESY participated in both discoveries and played a leading role in the detection of the EBL. Other activities include the study of the extragalactic gamma-ray background and of the gamma-ray emission in bow shocks of runaway stars.

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The Cherenkov Telescope Array.

Major steps at DESY towards a future gamma-ray observatory

The Cherenkov Telescope Array (CTA) is a next-generation gamma-ray observatory. It will provide unprecedented, deep insights into the non-thermal high-energy universe. It will serve a wide astrophysical community as an observatory for studying energetic particle accelerators in supernova remnants and active galaxies, for exploring transient sources such as distant gamma-ray bursts and for conducting highly sensitive searches for emissions from dark-matter particles. CTA will deliver its first scientific data after 2016. DESY is one of the strongest institutions in the CTA consortium.

Ground-based gamma-ray observatories are sensitive to high-energy photons with energies starting from 10 GeV and up to at least a few hundred TeV. Gamma rays emitted by astrophysical sources such as supernova remnants initiate extended particle showers when they enter the Earth's atmosphere. The measurement of the Cherenkov light produced by the secondary electrons and positrons of such a shower can be used to determine the direction and energy of the initial gamma ray. CTA will have a sensitive area for the observation of high-energy gamma rays of more than 10^6 m^2. The sensitivity of CTA will be an order of magnitude better than that of existing observatories, such as H.E.S.S., MAGIC or VERITAS, and will cover a wider energy range.

According to plan, CTA will comprise two arrays, one in the northern and the other in the southern hemisphere. Both CTA arrays will consist of a few very large central telescopes embedded in an array of medium-sized telescopes. In the southern observatory, these will be surrounded by an array of small dishes, with an area of a few km^2. The central telescopes are primarily for measuring gamma rays with energies up to 100 GeV with high efficiency, while the larger array will provide high-performance coverage of the energy range from 100 GeV to 10 TeV. The additional array of the southern observatory will be used to catch the rare, bright showers with energies of about 100 TeV. CTA is currently in the preparatory phase. Construction will begin in 2015, and the first scientific data will be acquired after 2016, if all goes according to plan.

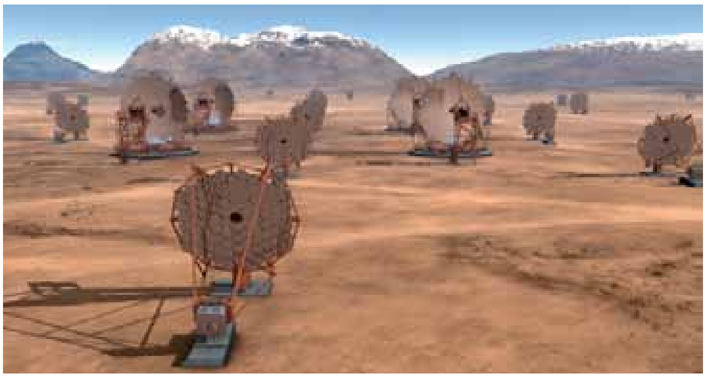

Figure 1

Artists view of an array layout using real designs for the different telescopes (Image: DESY/Milde Science Comm./Exozet)

Figure 2

Mechanical prototype of the CTA medium-sized telescope at Berlin Adlershof. Eventually, the prototype will consist of a tower, a 40-tonne movable optical dish with mirrors and a dummy Cherenkov camera at a distance of 16 m from the center of the dish.

The CTA group at DESY is leading the efforts in several key aspects of the development, optimization and construction of the instrument. The approximately 40 medium-sized telescopes with an effective mirror area of 100 m^2 are the core of the observatory. The DESY CTA group carries the overall project responsibility for these medium-sized telescopes and is also responsible for their mechanical design and for the drive system. A full mechanical prototype was built in Berlin Adlershof and was used to verify the design and to establish a cost-efficient production process with industrial partners. The telescope prototype is an ideal test bed for the CTA array control, which is being developed under the leadership of the DESY group.

CTA will observe astrophysical objects with a wide range of characteristics and therefore very different sets of demands will be placed on the instrument. The DESY group uses detailed Monte Carlo simulations to optimize and study the performance of CTA for the detection of these objects. By leveraging the knowledge already gained through the operation and development of the current telescopes as well as by adapting analysis tools designed for the existing instruments, the group is rapidly gaining a detailed understanding of the sensitivity and capabilities of the future CTA.

The site search process will be finished within the next year. Sites in six countries in the southern and northern hemisphere are being characterized with ground-based measurements of key parameters, such as cloudiness, wind speed and light pollution, which are then compared to satellite data and simulations. A concept of site development is being worked out, and a verification process of cost implications of the site choice has started.

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Deciphering the mysterious.

Theoretical astroparticle physics

Dark matter, gamma rays from astroparticle sources and the wave–particle interactions of energetic charged particles are the main research topics in theoretical astroparticle physics at DESY in Zeuthen.

Indirect detection of dark matter

Dark matter constitutes about a quarter of the mass/energy content of the universe. If it is composed of weakly interacting massive particles, it could be indirectly detected through Standard Model particles produced in the decay or annihilation of dark matter. We have analysed VERITAS observations of the Coma cluster of galaxies. The Coma cluster is a nearby example of the largest structures in the universe and is of interest for its dark-matter content, the nature of which is one of the most important questions in modern astrophysics. The resulting limits on the self-annihilation of dark matter are most constraining for dark-matter particles with a mass more than a thousand times higher than that of a hydrogen atom.

Because their conventional gamma-ray emissions are extremely weak, dwarf satellite galaxies near the Milky Way are of particular interest for indirect searches for dark matter. We were able to demonstrate that care must be exercised in deriving limits on dark-matter annihilation, not only because the gamma-ray intensity profile must be explicitly accounted for, but also because dependencies on the particulars of the dark-matter distribution function need to be considered. A decisive question is whether the dark-matter distribution is isotropic or enhanced in the direction of the in-fall toward the centre of the galaxy in question. If Sommerfeld enhancement is expected, knowledge of the dark-matter distribution function is indispensable for estimating its effect.

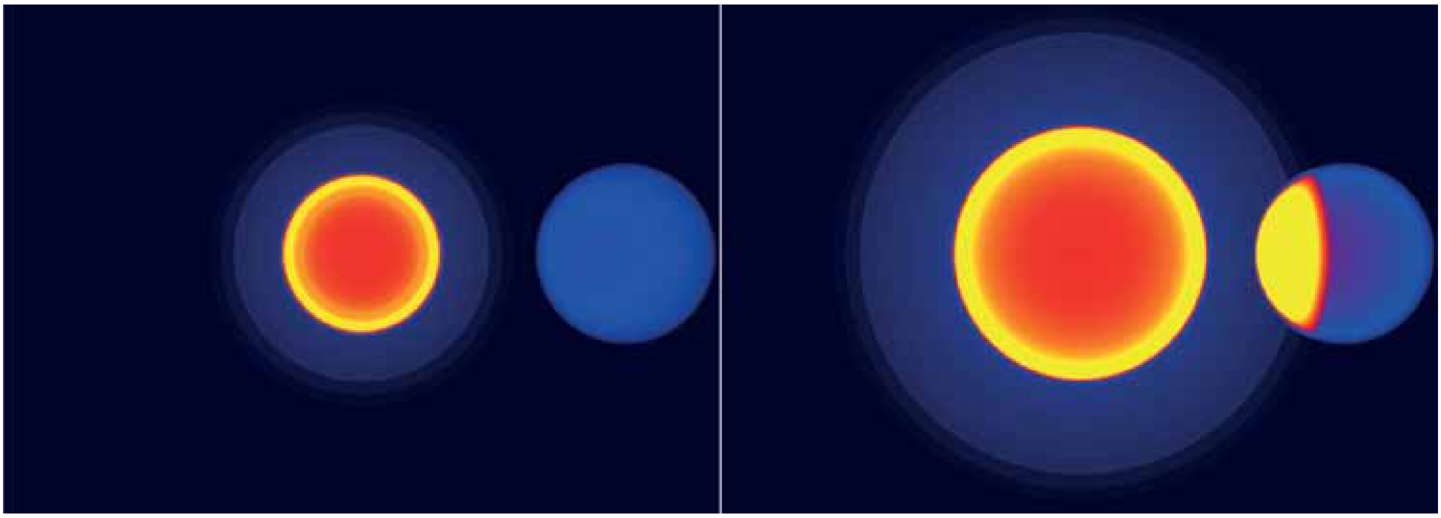

Figure 1

Cosmic rays escaping from a supernova remnant and illuminating the dilute interstellar medium and a nearby molecular cloud. Snapshots after 400 (left) and 1000 years (right).

Cosmic-ray acceleration in supernova remnants

In 2012, we celebrated the centenary of the historic balloon flight during which the Austrian scientist Viktor Hess made his discovery of cosmic rays, which eventually earned him the Nobel Prize in Physics. Some four decades later, another Nobel laureate, Enrico Fermi, proposed the first theory of cosmic-ray acceleration by magnetic fields in the interstellar medium. His theory was based on new ideas by Hannes Alfven, who was later awarded a Nobel Prize for plasma physics studies. However, that was only the beginning of the story. Many years later, the origin of cosmic rays and their acceleration and propagation in our galaxy remains a mystery. An efficient first-order Fermi mechanism known as diffusive shock acceleration is among the proposed acceleration schemes. According to the proposal, acceleration occurs in conjunction with the blast waves of supernova remnants, thus making them prime candidates for the principal sources of cosmic rays in our galaxy.

Proving that supernovae provide the galaxy with the bulk of cosmic rays is very hard, however, and entails the demonstration that both nuclei and electrons are accelerated. Electrons are efficient emitters, and thus the current observations already show substantial evidence of electron acceleration. The detection of accelerated nuclei is more problematic. Nuclei such as protons produce pion decay emission in collisions of cosmic rays with material at rest. The neutral pions subsequently decay into two gamma rays. A target material for producing such collisions could be the plasma of the supernova remnant or the surrounding interstellar medium. However, in many cases the supernova remnant expands into the caverns created by the winds of progenitor stars (stars that explode), so that the surrounding plasma is not dense enough to produce an observable flux of pion-decay gamma rays. In this case, nearby gas clouds and cloudlets of molecular gas could serve as a target for cosmic rays that escape from a supernova remnant.

We are investigating such systems with the help of numerical solutions of cosmic-ray transport coupled to hydrodynamical descriptions of the evolution of supernova remnants. Figure 1 shows two snapshots of the gamma-ray intensity that would result from the interaction of escaped cosmic rays with a nearby molecular cloud (located to the right of the supernova remnant). The weak halo around the remnant is due to the interaction of escaping cosmic rays with the surrounding dilute plasma. The upcoming Cherenkov Telescope Array (CTA) observatory will be able to observe these systems. Studies of their spectra will tell us a lot about diffusive properties of the media and transport of cosmic rays in the vicinity of the source.

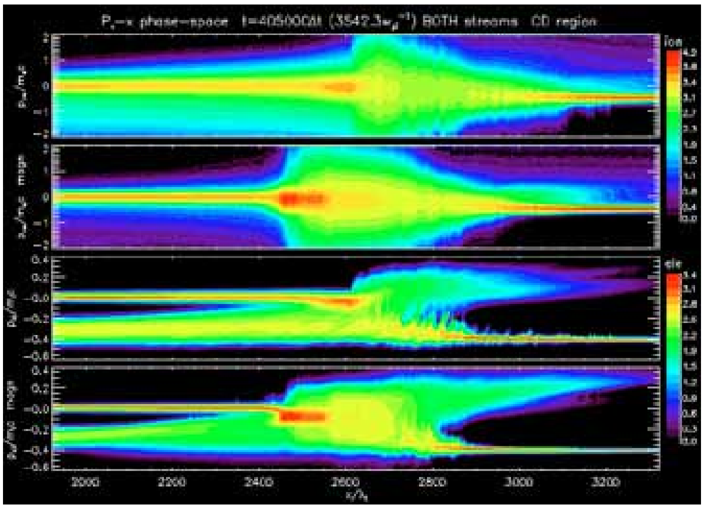

Figure 2

Phase space distribution of electron–ion plasma around two proto-shocks

Kinetic simulations of cosmic-ray acceleration at shocks

Shocks in space environments are collisionless, meaning that collective electromagnetic interactions, rather than two-body collisions, provide the exchange of energy and momentum of particles and hence the compression of plasma at the shock. These processes can be studied with kinetic simulations, which have the advantage of keeping track of the distribution function of all particles involved. Figure 2 shows an example of the phase space distribution of the two-shock system formed after the collision of two electron–ion plasma clouds with a density contrast of a factor of 10.

A variety of kinetic instabilities operate in the collision region. Since pre-acceleration of particles is needed for their injection into Fermi-type acceleration processes, the momentum distribution of electrons and ions behind the proto-shocks is of particular interest. In the unmagnetized systems as well as in proto-shocks with parallel magnetic fields, we observed no development of spectral tails in the electron distributions, however since the ion distributions had not generally become fully isotropic by the end of the simulations, no definitive statement could be made. Most of the pre-acceleration is expected to arise at the shock transition itself, where strong and turbulent electric and magnetic fields are present. Simulations of systems with perpendicular magnetic field are in progress.

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A la recherche de l'Higgs perdu.

We've got the Higgs – what now?

The year 2012 saw the spectacular discovery at the LHC at CERN of a new particle that to our present knowledge is compatible with being a scalar, i.e. spinless, particle known as a boson, with all the properties predicted by the electroweak Standard Model of particle physics in the 1960s. Though the measurements indicate that the new particle is indeed the Standard Model Higgs boson, the data are not yet precise enough to conclusively settle the issue. If it is the Higgs boson, or very much like it, it is also the remnant of the Higgs field, which pervades the whole universe and has the heavy responsibility of imparting mass to all elementary particles. The Higgs boson's ability to confer mass comes from a very important property of the Higgs field: it couples to all elementary particles with a strength proportional to the mass of the particle. Therefore, it couples only negligibly to electrons, but quite strongly to the heavy electroweak force carriers (gauge bosons), $W^{\pm}$ and Z, and the top quark.

One of the main open questions in particle physics relates to the properties of the potential of the Higgs field: in contrast to the gauge fields, the minimum of the Higgs field is not at zero (Fig. 1). This non-zero vacuum expectation value is responsible for electroweak gauge invariance being intact despite having a spectrum of excitations that does not reflect electroweak symmetry (e.g. the massive electroweak gauge bosons, $W^{\pm}$ and Z). In the theoretical description of the potential of this non-zero Higgs field, quantum fluctuations due to the Heisenberg uncertainty principle cause the potential, as described in the Standard Model, to be unstable. Indeed, given the most recent data from the top and Higgs mass measurements, the outer rim of the potential appears to turn over at very high energies due to such quantum fluctuations, and therefore the potential is unstable. This implies that the vacuum we are presently in is not the true vacuum of the universe and that our universe could decay into its true vacuum, thereby destroying all known structures! This state of affairs is called a metastable vacuum state. Fortunately for us, the lifetime for such a "vacuum decay" is larger than the age of the present universe. However, up to now it is not clear in the theory if the Higgs field could have found the vacuum it is now in, given the potential the Standard Model gives it!

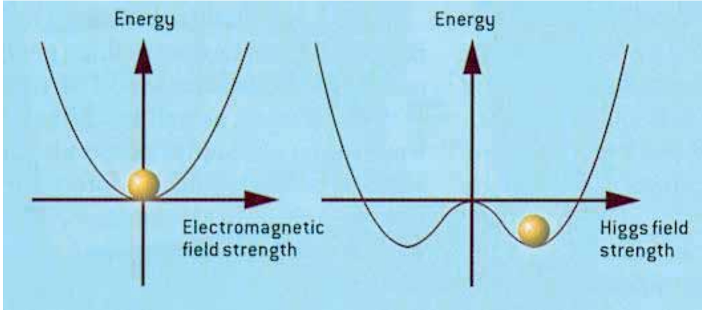

Figure 1

The non-vanishing ground state of the Higgs field

Another important point related to the instability of the Standard Model description of the Higgs potential is variously named the hierarchy, fine tuning, or vacuum stability problem of the Higgs and the electroweak Standard Model. Together with the gravitational evidence for the existence of dark matter, it is one of the strongest motivations for suspecting fascinating physics beyond the Standard Model (BSM). BSM models, most of which introduce new symmetries, new interactions and particles, are called supersymmetric models, little Higgs models, extra dimensions, composite models etc. Generically they predict the existence of many particles between a hundred GeV and several TeV of mass. The details of their properties, such as spins, couplings and mass patterns, depend on the specific setup of the corresponding model. Two examples, the minimal supersymmetric model (MSSM) and a generic little Higgs model, are shown in Fig. 2.

Since the discovery of the Higgs-like particle in 2012 was the sensational event in the field, most theoretical studies concentrated on the interpretation of BSM models in the light of the LHC Higgs measurement. Figure 3 shows an example of a specific little Higgs model (from arXiv:1212.5930), where the yellow and green areas indicate regions of the parameter space of this model that are still allowed by the data at 95% and 99% confidence level, respectively. The blue region leads to a better fit of the little Higgs model to the data than the Standard Model does.

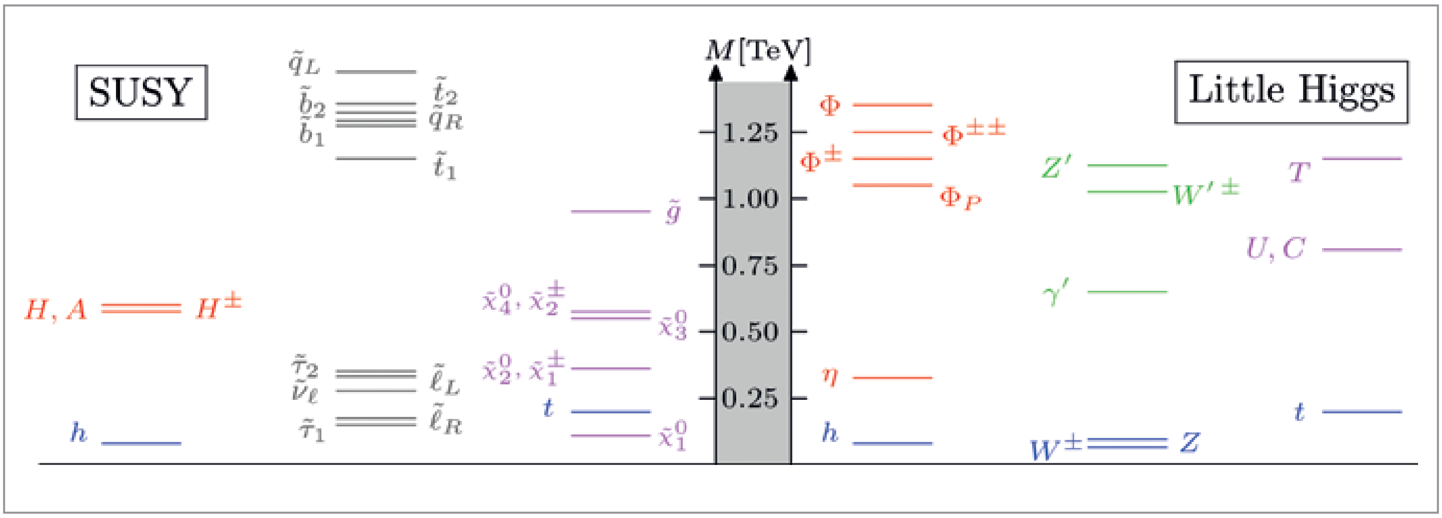

Figure 2

Spectra of additional particles predicted by two BSM models: a supersymmetric model and a little Higgs model

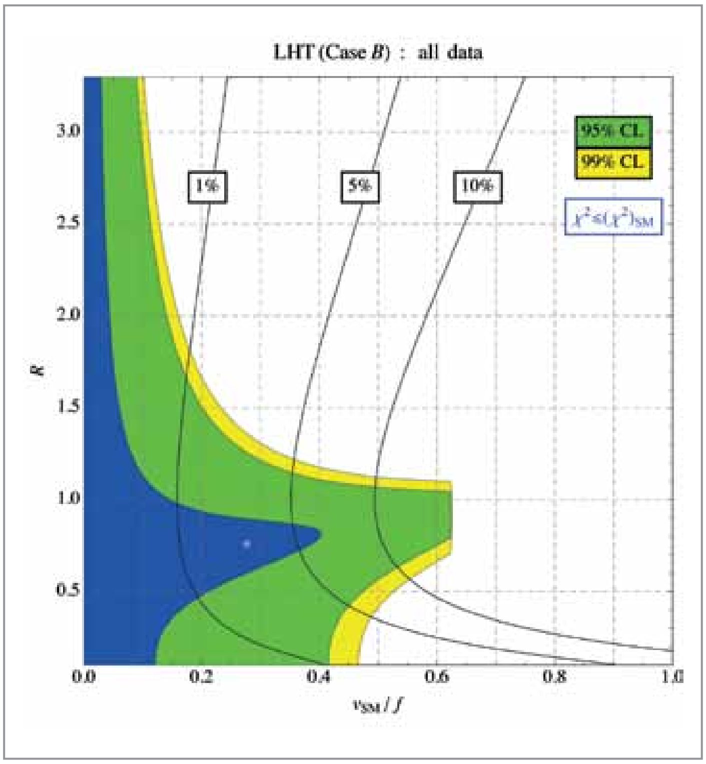

Figure 3

Example of an exclusion region from LHC Higgs data for a parameter space of a BSM model (the littlest Higgs model)

Until now, the LHC Higgs measurements – as spectacular as they are – are not very precise, so most of the constraints on BSM models still come from precision electroweak measurements from earlier collider experiments like LEP, SLC and Tevatron. We therefore eagerly await the analysis of more of the LHC data taken in 2012. Searches for other predicted particles (Fig. 2) have so far failed to yield any evidence for their existence. Unfortunately, in the hadronic environment of the LHC, any BSM particle produced will likely be “coloured” (i.e. carry the colour quantum number, like quarks). Discriminating the signals of coloured particles from Standard Model backgrounds is theoretically and experimentally extremely challenging. For examples, see arXiv:1204.6264, arXiv:1206.2146, and arXiv:1212.5559.

At the end of 2012, depending on the analysis, between one quarter and one half of the data from the LHC 2012 run had been completely analysed. Unless the analysis of the Higgs decay channels in the remaining 2012 data set gives a big boost in precision and hence information, no ground-shaking discovery can be expected in the searches for heavy particles until after the LHC restarts in early in 2015 at full energy, and thereby opens a vast new territory for exploration and the exciting possibility of discovering new particles, new interactions, or new forms of matter.

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Precision calculations, algebraic summation and integration.

Towards the mathematical structure of the microcosm

Analytic calculations of Feynman diagrams of the Standard Model at higher loop order are organized in a unique way with iterated integrals or indefinitely nested sums providing the most elementary representation. Recently, several new function spaces of these integrals and sums have been revealed. They are characterized in terms of "word" structures similar to those found in the genetic code.

At present high-energy colliders such as the LHC, the measurements of observables that describe many inclusive processes have reached a precision of 1% or better. From these measurements, one can extract the fundamental parameters of the Standard Model, such as the strong coupling constant $\alpha_s(M_Z^2)$, the *W* boson and heavy quark masses, and the parton distributions of the nucleon. Usually, the experimental constraints on these parameters come from a series of precision measurements, which require careful fits that also properly treat the systematic uncertainties. On the theory side, highly accurate cross section calculations must be provided. Depending on the process, a large number of two- and three-loop Feynman integrals might be needed. In many of the present cases, the diagrams calculated have one or two different mass scales. The solutions are given in terms of multidimensional integrals with integrands that vary strongly within the range of integration.

The best way of computing the needed integrals is by analytic integration. This works in the case of widely inclusive processes to two- and three-loop orders in the massless and the single-mass cases. Important examples are the splitting functions and massless and massive coefficient functions in deep-inelastic scattering, the *Z* peak in e^+e^- annihilation and in the Drell–Yan process as well as the inclusive $W^\pm$ and *Z* boson production cross sections at proton–proton colliders.

The demand for such computations has spurred the development of new algorithms and mathematical technologies by close collaborations of physicists working in quantum field theories and mathematicians working in computer algebra, combinatorics and algebraic geometry, since methods from all these fields are involved. These efforts led to the elucidation of very special classes of new mathematical numbers and functions.

The integration of the Feynman integrals may be performed by transforming them into multiply nested sums through higher transcendental functions or Mellin–Barnes integrals [1]. Often these sums may be solved using mathematical packages like Sigma [2]. The results are then given in the more simple cases as harmonic sums

$$S_{b,\vec{a}}(N) = \sum_{k=1}^{N} \frac{(sign(b))^k}{k^{|a|}} S_{\vec{a}}(k)\,.$$

Likewise, one may use other techniques, like Risch algorithms and the method of hyperlogarithms, to arrive at iterated integrals of the kind

$$H_{b,\vec{a}}(x) = \int_0^x d\,z f_b(z) H_{\vec{a}}(z)\,.$$

Here, we call $a_i \in \vec{a}$ a *letter* and $\vec{a}$ a *word*, given by a certain ordered set of letters. In the case of these specific sums and integrals, we iterate e.g. the concrete letters $(\mathrm{sign}(b))^k/k^{|a|}$ resp. $f_b(z)$ on a simpler sum or integral. Given these structures, the specific sequence of letters implies the corresponding algebras of these quantities, so-called shuffle algebras. In addition, structural relations among these quantities exist. By applying all such relations, one may represent the large variety of the harmonic sums and integrals over rather compact bases. Also special classes of numbers occur that are represented by the iterated integrals at argument, $x = 1$. In the simplest case, these are the multiple zeta values.

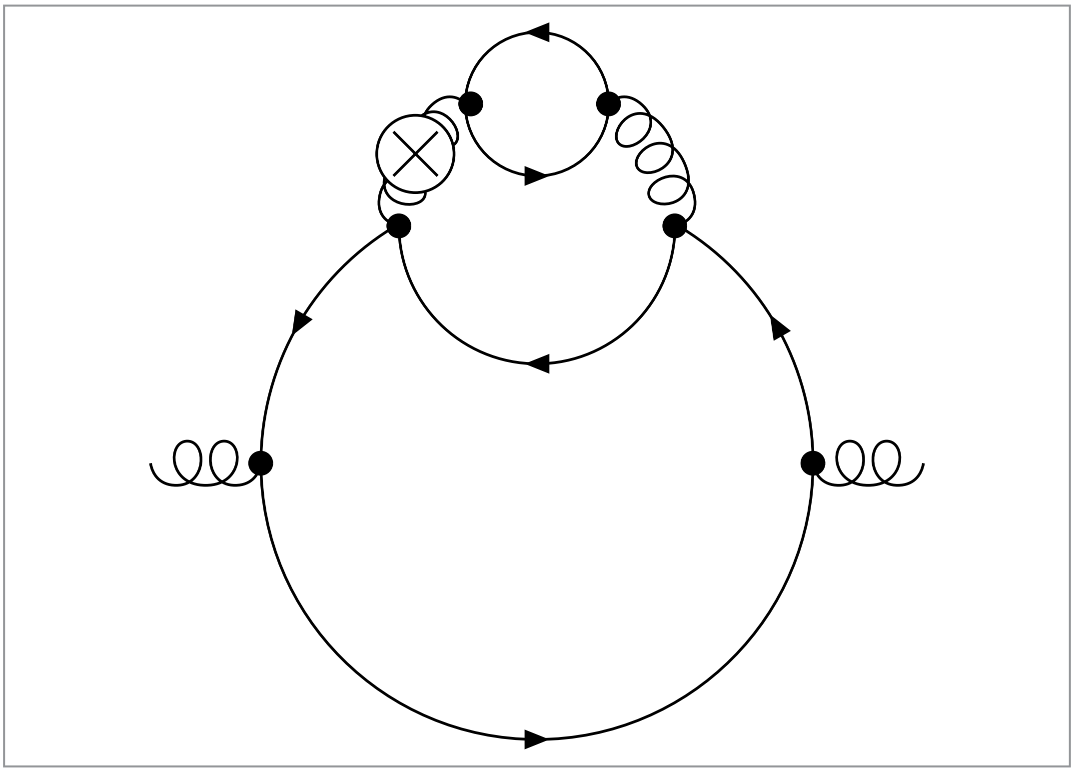

Figure 1

Example of a three-loop Feynman diagram (Courtesy A. Hasselhuhn)

It turns out that, in the case of the nested sums representing Feynman integrals, rational representations are followed by harmonic sums, which are a part of the so-called generalized sums [3] and cyclotomic sums [4]. The latter are a subset of the generalized cyclotomic sums. This class has a further extension, which also allows for binomial and inverse binomial terms $\binom{2i}{i}$. Figure 1 shows a typical three-loop graph with two massive lines of equal mass. Besides rational expressions and harmonic sums, the result for this integral also contains binomial sums

$$
\begin{aligned}
&I(N) = \\
&-\frac{1}{5}\frac{1}{\varepsilon(N-1)N(N+1)^2(N+2)} \\
&-\frac{2^{-2N-7}(N-3)}{(N+1)(2N-3)(2N-1)}\binom{2N}{N} \\
&\times\sum_{i_1=1}^{N}\frac{2^{2\mathrm{i}_1}\left(i_1!\right)^2}{\left(2\mathrm{i}_1\right)!i_1^2}\left[S_1\left(\mathrm{i}_1\right)-\frac{1}{i_1}\right] \\
&+\frac{7\cdot 2^{-2N-7}(N-3)}{(N+1)(2N-3)(2N-1)}\binom{2N}{N}\zeta_3 \\
&+\frac{P(N)}{7200(N-1)^2N^2(N+1)^3(N+2)(2N-3)(2N-1)} \\
&\qquad\quad\left(-3N^2+N-56\right)S_1(N)
\end{aligned}
$$

with $P(N)$ a polynomial and $\varepsilon = D-4$ the dimensional parameter. For single massive three-loop diagrams, the number of contributing letters needed to express the iterative integrals can be larger than thirty.

Feynman integrals give, in a fascinating way, birth to whole new classes of special functions. With growing complexity, i.e. when going to higher loops, more legs and allowing for more mass scales, even richer algebraic structures are expected in the corresponding calculations. One may hope that the unique mathematical structure of two-loop graphs with more legs will be found by applying summation and integration methods in a systematic way.

The “atoms” of these function spaces act like “letters” in building “words”. This is either realized in terms of iterated integrals or sums. However, the concrete realization is of secondary interest for a wide host of properties of these quantities, and the primary role is played by the sequence of letters itself. This is very similar to the realization of the genetic code in the life sciences. Therefore, one could call the above-mentioned structures observed in the Feynman diagrams the “genetic code of the microcosm”. In this way, analytic calculations in relativistic quantum field theories exhibit a deep connection to genetics. Exchanging the mathematical insights already gathered by the two disciplines would be exciting and of benefit to both.

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Gamma-ray lines from dark matter.

What they can tell us about Supersymmetry

A good signature for the widespread annihilation or decay of dark-matter particles would be a sharp peak in the energy spectrum of gamma rays, i.e. an excess of monochromatic gamma rays. The observation of such a peak would reveal a wealth of information with major impact on both particle physics and astrophysics. Currently, a spectral feature around 130 GeV in the gamma-ray spectrum measured by the Fermi Large Area Telescope is under active debate, and it is intriguing to compare its characteristics with the expectations for supersymmetric dark matter.

Astronomical observations on vastly different length scales, ranging from individual galaxies to the large-scale structure of the observable universe, are providing convincing evidence for the existence of a non-luminous form of matter, usually called dark matter. In addition, the amount of baryonic matter inferred from the abundances of light nuclei and the anisotropies in the cosmic microwave background radiation suggests that dark matter is non-baryonic.

Intriguingly, all known properties of dark matter are consistent with a new species of electrically neutral particles that are stable or extremely long-lived compared to the age of the universe. If this species has a mass and interaction strength typical for the weak interactions, it must have been produced in the early universe through thermal freeze-out with an abundance of the correct order of magnitude to match cosmological observations. Such particles arise within well-motivated extensions of the Standard Model. The most prominent example is the neutralino of the minimal supersymmetric extension of the Standard Model (MSSM). Another possible candidate from the MSSM is the gravitino, which can also be produced thermally in the early universe and be quasi-stable on cosmological timescales. Both possibilities are currently being tested at the LHC.

The annihilation or decay of dark-matter particles can lead to characteristic signatures in the cosmic radiation. A particularly striking signature would be a signal in the monochromatic gamma rays that arise from two-body annihilation or decay into photons. Under certain circumstances, three-body final states can also feature a characteristic gamma-ray spectrum. The observation of such a spectral feature in the cosmic gamma-ray flux at weak-scale energies could reveal a wealth of information about dark matter. The position and strength of the line would reveal the dark-matter mass and its partial cross section into monochromatic gamma rays. The spatial distribution of the signal would discriminate between decaying and annihilating dark matter, and could even be used to determine the actual distribution of dark matter within the central parts of the galaxy as well as its substructure.

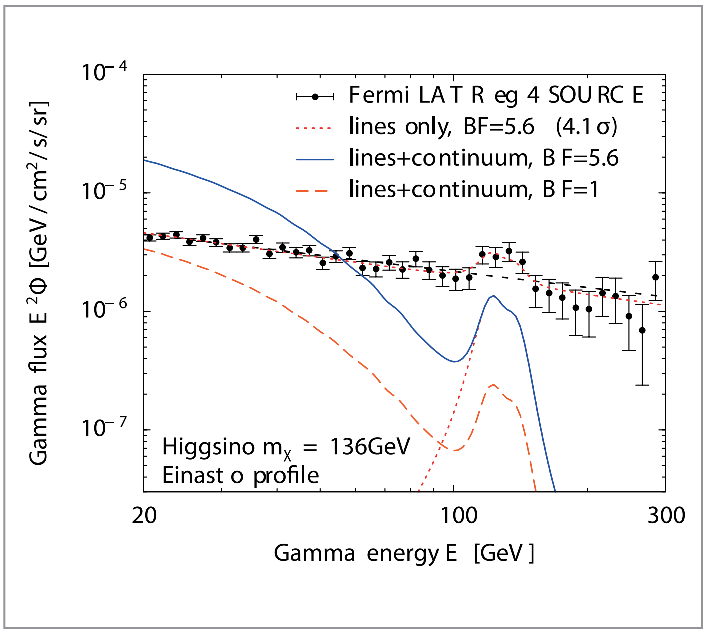

Figure 1

Fermi data [3] showing an excess at 130 GeV and prediction for Higgsino dark matter

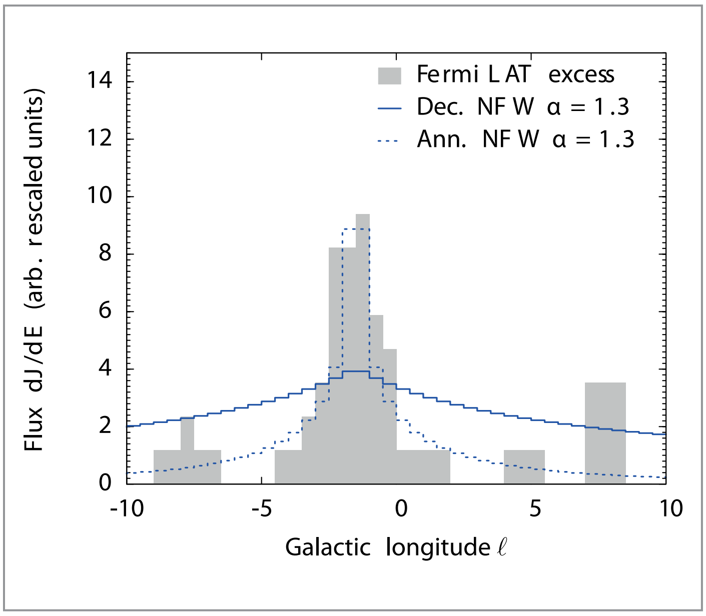

Figure 2

Spatial profile around the galactic centre [5] and expectations for annihilating or decaying dark matter

Over the past years, the Large Area Telescope (LAT) on board the Fermi satellite [1] has observed the gamma-ray sky in the energy range from 20 MeV to 300 GeV with unprecedented accuracy. Recently, an analysis based on optimized search regions around the galactic centre using 43 months of data has reported tentative evidence for a gamma-ray feature around 130 GeV [2,3]. This observation has triggered an active debate, and is being scrutinized by the Fermi collaboration.

It is intriguing to compare this observation with features expected for supersymmetric dark matter. In particular, important constraints arise from annihilation or decay into weak gauge bosons or Higgs bosons as well as fermions. Typically, these channels dominate over the production of monochromatic photons, since dark matter is electrically neutral and annihilation into photons arises only at the loop level. For example, for neutralino dark matter, the branching ratio into monochromatic photons is at the permille level, while it can rise to up to 3% for decaying gravitino dark matter. The subsequent decay and fragmentation of e.g. *W* bosons leads to a broad spectrum of gamma rays in the range 10–100 GeV, limiting the allowed amount of continuum emission from dark matter. We find that, to explain the Fermi excess, a branching ratio into monochromatic photons of more than half a percent is necessary [4]. This excludes Higgsino- and Wino-like neutralino dark matter as an explanation. Similar constraints arise from the flux of antiprotons produced by the *W* bosons.

In view of the limited statistics, it is premature to draw a firm conclusion about the spatial distribution of the excess. Nevertheless, it has been found to be compatible with the radial dependence expected for conventional Navarro–Frenk–White or Einasto profiles in the case of annihilating dark matter [5]. In contrast, for decaying dark matter, these profiles would lead to a much broader emission and a significant contribution from the galactic halo. The absence of a feature around 130 GeV away from the galactic centre therefore disfavours explanations based on decaying dark matter.

In the near future, the H.E.S.S. II Cherenkov telescope will test the apparent excess in the Fermi data, and offer the possibility to search for gamma-ray lines at TeV energies. The planned Cherenkov Telescope Array (CTA) and the satellite mission Gamma-400 also have an excellent potential to search for gamma-ray lines. Whether the Fermi excess is real or not, it has exemplified how much we can learn about dark matter by searching for features in the gamma spectrum.

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From bubbles to high-energy collisions.

Modern mathematics in particle physics

Quantum gauge theories are incredibly successful in describing nature down to the very smallest scales that we can reach in high-energy collisions. But even after many decades of experience with gauge theories, the scientific community struggles to obtain accurate numerical predictions. Precision computations using conventional approaches need massive computer algebra, in which thousands of terms must be evaluated, and the answers they provide can fill dozens of pages – if they can be written out on paper at all. Yet, closer studies of the expressions obtained often reveal an astonishing simplicity. In a few cases, modern mathematical methods have been employed to reduce many pages of formulas to just a few lines. Since we usually expect that calculations and results possess similar complexity, scientists from all over the world are now searching for radically different and more economic ways to perform gauge theory computations.

In the last decade, developments in string theory have clarified powerful new hidden symmetries of gauge theory, which have allowed us to solve a few problems that seemed hopelessly complicated at the end of the last century. The relation between string theory and gauge theory is based on the so-called gauge-string correspondence of Juan Maldacena. String theory is a deformation of gravity. Hence, in certain regimes, it can be studied with the geometric techniques of Einstein's theory of general relativity. If string theory is to teach us about the scattering of particles, what geometric problem should we look at? The answer is quite beautiful – scattering becomes a minimal-area problem in the geometric regime of string theory.

Minimal-area problems are very common in everyday life. Imagine a wire that has been bent into some circular shape and dipped into a soapy solution. When we hold this wire parallel to the ground, a soap bubble will hang down from it, pulled by the gravitational attraction of the earth. The area of the bubble depends on the shape and size of the circular wire in a complicated but calculable manner. String theory has developed a very similar picture for scattering amplitudes.

Consider for example a scattering process involving *N* gluons with four-momenta $p_i, i = 1, \ldots, N$. In string theory, we are now instructed to build a wire in four-dimensional space by placing the momenta one after another such that the tail of

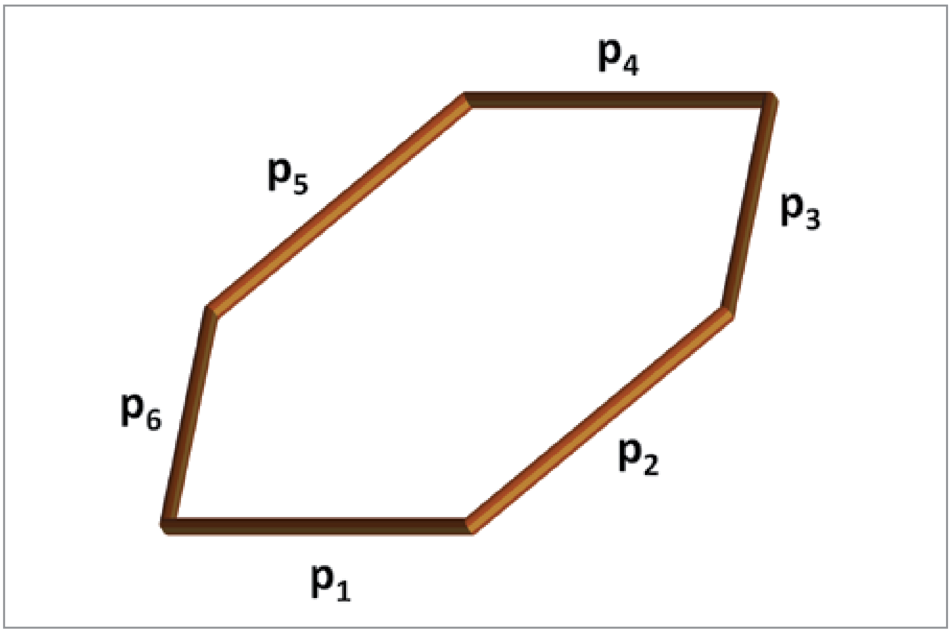

Figure 1

Gluon momenta p_i are placed such that the tail of p_{i+1} starts at the head of p_i. The resulting figure forms a closed wire with piecewise linear sections.

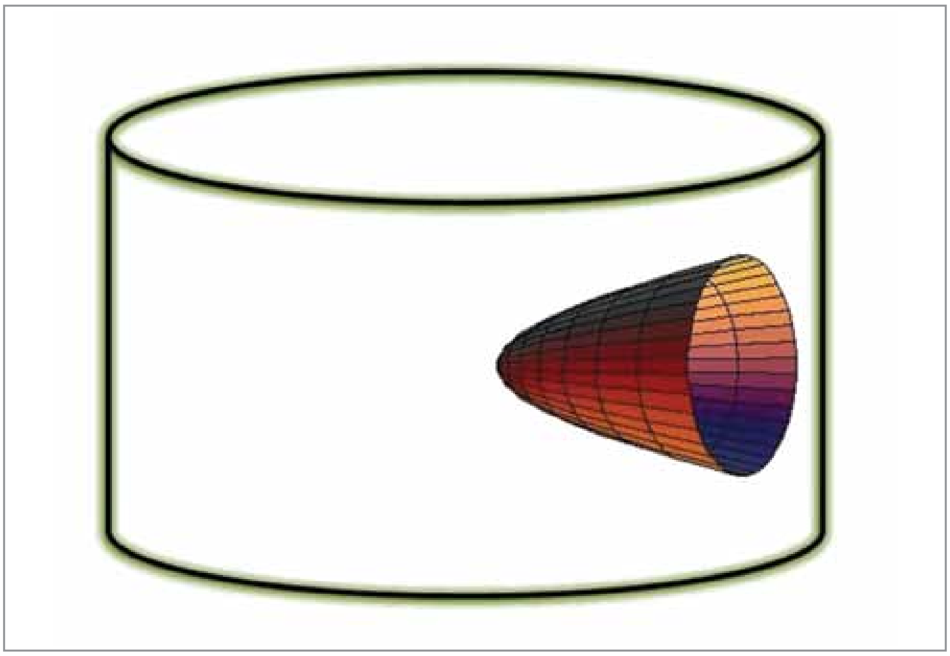

Figure 2

A minimal-area surface (“bubble”) forms in a five-dimensional space (cylinder) when a circular wire is placed onto the four-dimensional boundary (of the cylinder). The gravitational attraction of a heavy object in the centre of the five-dimensional space pulls the surface towards the interior.

p_{i+1} starts at the head of p_i (Fig. 1). Since momentum is conserved, the wire will close up to form a ring with piecewise linear sections. To obtain the scattering amplitude, we are told to put this wire onto the four-dimensional boundary of a special five-dimensional space that has been curved by the presence of a three-dimensional “black hole” in the centre of the space (Fig. 2). The gravitational attraction from the black hole pulls the bubble that is suspended by the wire into the five-dimensional space. Its area, *A*, depends on the momenta, p_i, of our gluons and is believed to agree with the cross section in a particular limit of gauge theory.

The computation of the area, $A = A(p_i)$, and hence of the cross section, is a standard geometric problem. But it is not yet the formulation of scattering amplitudes that seems most useful. Mathematicians have actually suggested a reformulation, in which the area of the bubble is identified with the vacuum energy of a one-dimensional quantum system. As in any other dimension, such a quantum system may be characterized by its particle spectrum, the masses, m_ν, and interactions. In the present context, we assume that these particles move along a one-dimensional circle of radius *R*. In quantum theory, the vacuum of such a model is a complicated state, which in most cases possesses non-zero (Casimir) energy *E*. This energy depends on the masses and interactions of the particles. Mathematicians were able to design the particle spectrum with mass parameters $m_\nu = m_\nu(p_i)$ and interactions such that the vacuum energy $E(m_\nu)$ matches the area $A(p_i)$ of the “bubble” described in the previous paragraph. This one-dimensional quantum system is computationally more accessible than the original minimal-area problem.

Particle physicists and string theorists of the University of Hamburg and DESY have joined forces to exploit this remarkable new description of scattering processes in order to develop a supersymmetric cousin of quantum chromodynamics. In particular, they were able to develop a novel procedure to evaluate the string-theoretic description of scattering amplitudes in the high-energy limit of strongly coupled gauge theory (1207.4204[hep-th]). Results of this type nurture our hope that it might be possible to calculate cross sections in gauge theory for all values of the coupling constant. Much more work, both at weak and strong coupling, is needed to accomplish this ambitious goal. Nevertheless, over the last few years, progress has been so rapid that an international annual conference series has been devoted to this task. In March 2012, the conference Amplitudes 2012 was hosted by the high-energy theory groups of the University of Hamburg and DESY. Since 1 January 2013, the DESY theory group is also coordinating the European training network GATIS (Gauge Theory as an Integrable System) with a closely related focus (see: http://gatis.desy.eu).

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Non-perturbative Higgs boson mass bounds.

Constraining the Standard Model

This article discusses non-perturbative Higgs boson mass bound calculations by the NIC group using lattice field theory methods. The results help to constrain the validity range of the Standard Model and, in particular, the existence of a heavy fourth fermion generation.

The Standard Model (SM) of particle physics is by now very well explored and tested. The only missing link in the SM is the Higgs boson – in fact a central part of the SM, since it is believed to provide masses to a number of elementary particles (Fig. 1). The missing link may now have been found, given the discovery by the LHC experiments of a "Higgs-like" boson in July 2012. Although the mass of the Higgs boson cannot be predicted by the SM itself, theoretical bounds on its mass can be computed. To this end, it is sufficient to look at only a certain part of the SM, namely the Higgs–Yukawa sector. In the Higgs–Yukawa model, all gauge bosons, i.e. the photon and the vector bosons, are neglected, as is the strong interaction. In this way, the Higgs–Yukawa model can be studied with non-perturbative lattice field theory techniques by putting the theory on a four-dimensional grid of discretized space-time points, which leads to non-perturbative results for the Higgs boson mass bounds.

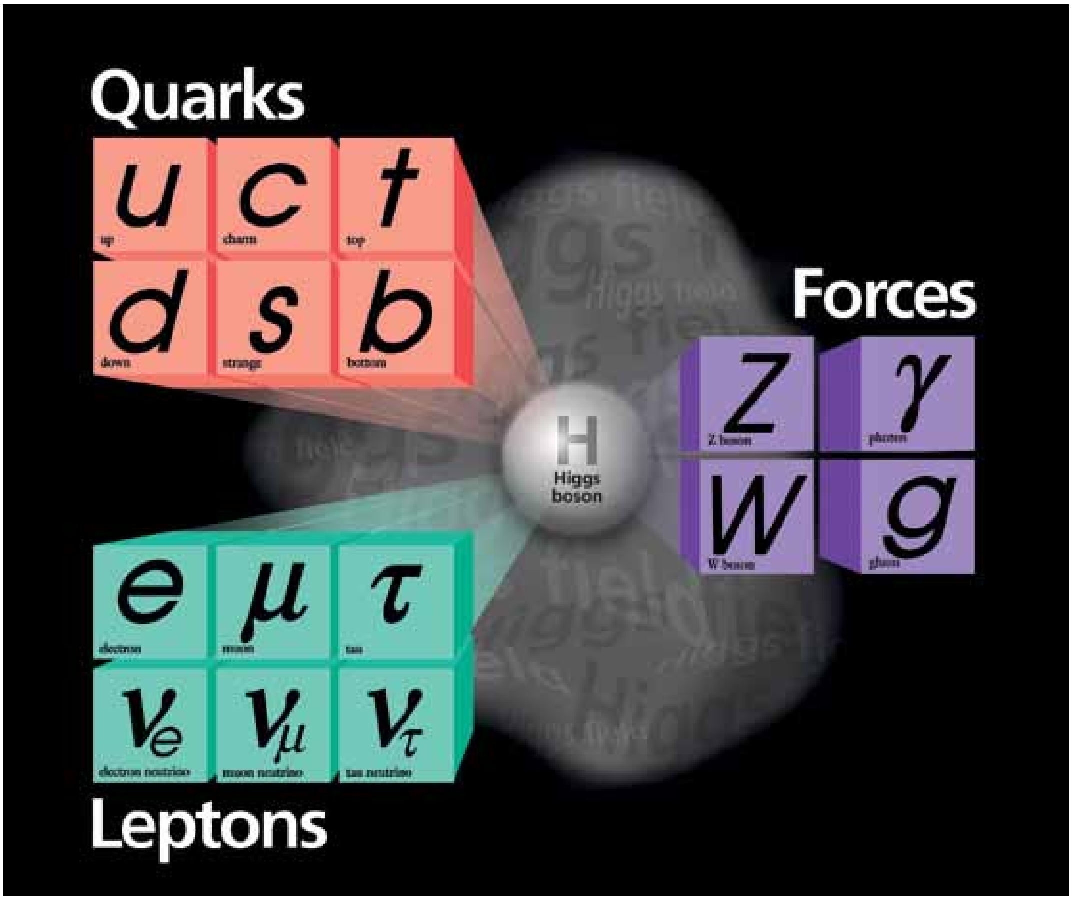

Figure 1

The Higgs boson as the central part of the Standard Model providing mass to elementary particles

The Higgs–Yukawa sector of the SM describes the generation of fermion masses via the non-vanishing vacuum expectation value (*vev*) acquired by the Higgs field. In principle, the relevant couplings of the theory, namely the quartic self-interaction of the Higgs field and the Yukawa coupling between the Higgs field and the fermions, can grow strong. This happens when the masses involved are large enough to enter a regime in which perturbation theory might fail to analyse the situation.

There are indeed examples where the applicability of perturbation theory is questionable. The first is the upper Higgs boson mass bound, which is based on triviality arguments. Here, the Higgs boson mass can become large and give rise to a sufficiently strong value of the quartic coupling that perturbation theory may no longer work. The second is the lower Higgs boson mass bound, which is based on vacuum instability arguments. It is unclear whether the latter instability is an artefact of applying perturbation theory at large values of the Higgs field at which an expansion around the minimum of the effective potential is no longer justified. A third example is provided by the possibility of a heavy fourth generation of quarks, which offers the attractive possibility to explain the baryon asymmetry of the universe. However, large fermion masses lead to strong values of the Yukawa coupling, and perturbation theory shows large corrections indicating that it may fail to give the correct answer.

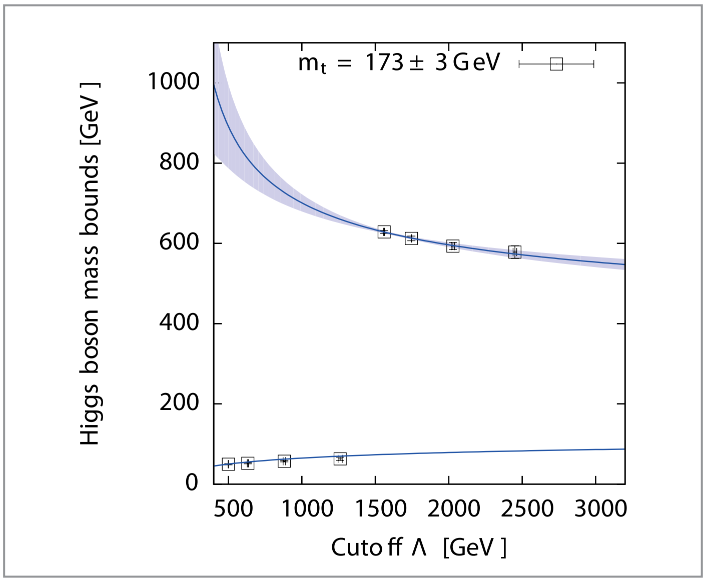

Figure 2

Cut-off dependence of the upper and lower Higgs boson mass bounds for a fermion mass of about ~ 173 GeV

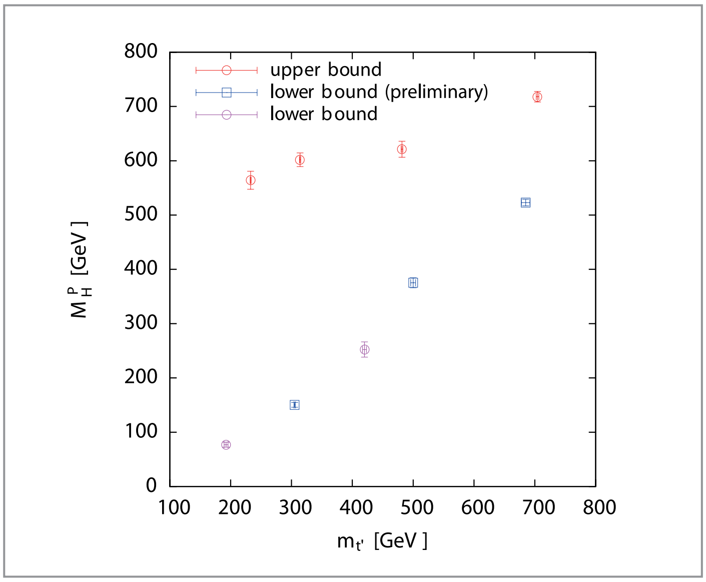

Figure 3

Fermion mass dependence of the lower and upper Higgs boson mass bounds at a cut-off of about 1.5 TeV

Therefore, non-perturbative lattice field theory simulations are mandatory when addressing the Higgs boson mass bounds. Lattice computations became possible when a lattice modified chirally invariant formulation of Higgs–Yukawa theories on the lattice was found. Figures 2 and 3 show the results of the Higgs boson mass bound calculations performed by the NIC group.

The graphs in Figs. 2 and 3 have a very interesting interpretation in the light of the SM and also of the fourth fermion generation. Concerning the SM, a Higgs boson mass of about 125 GeV seems to just escape the Higgs boson mass bounds. This leaves open the possibility that the SM is valid up to very high energies. On the other hand, a fourth fermion generation seems to be ruled out for fermion masses larger than about 300 GeV. Combining this with the LHC observation that the existence of additional quarks with masses smaller than about 500 GeV is excluded, one finds that a simple extension of the SM with a fourth fermion generation is not compatible with the experimental finding of a 125 GeV Higgs boson mass.

An open question is whether the Higgs boson mass bounds shown in Figs. 2 and 3 could change when higher-dimensional terms are added to the theory, such as a $\lambda_6 \Phi^6/\Lambda^2_{cut}$ term. Preliminary analyses by the NIC group indicate that when the coupling λ_6 assumes a value of $\lambda_6 \geq 0.1$, the perturbative corrections start to become large and perturbation theory is not adequate to analyse the situation. Again non-perturbative lattice calculations will be necessary to test the stability of the Higgs boson mass bounds. The NIC group is actively pursuing such computations, and it will be very interesting to see whether the Higgs boson mass bounds can be altered.

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The DESY Grid Centre.

Providing for the computing needs of national and global communities

The discovery of a “Higgs-like” particle by the LHC experiments marked 2012 as a truly extraordinary year for high-energy physics (HEP). The DESY Grid Centre, comprising the Grid infrastructure and the National Analysis Facility (NAF), is contributing significantly to the LHC effort and also provides resources for other HEP and non-HEP groups.

The decisive role of Grid computing for the LHC was explicitly acknowledged by the ATLAS and CMS collaborations when they presented their evidence for a Higgs-like particle in the CERN auditorium in July 2012. Several other HEP groups as well as groups from other fields of science also rely heavily on Grid resources. DESY operates Grid sites in Hamburg (DESY-HH) and Zeuthen (DESY-ZN). It participates in the EU European Grid Infrastructure project (EGI) [1] and is a member of the National Grid Initiative (NGI-DE).

The DESY Grid user community

Within the Worldwide LHC Computing Grid (WLCG) [2], DESY serves as a Tier-2 centre for ATLAS and CMS and several other communities. In Grid jargon, a user community is normally registered as a “virtual organization” (VO). DESY is the home of a number of global VOs, including ILC, ATLAS, CMS, LHCb, Belle, IceCube, CTA and also some non-HEP VOs. In addition to being a multi-VO site, DESY was the biggest Tier-2 site for CMS in Europe in 2012 in terms of delivered CPU time.

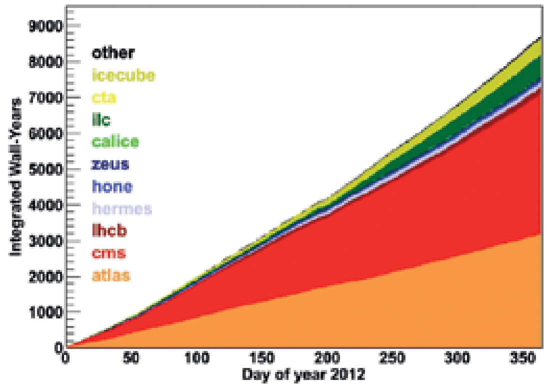


Figure 1

Accumulated time spent on DESY Grid and NAF resources in 2012, detailed for the different virtual organizations. Although ATLAS and CMS consumed most of the resources, other communities such as HERA, ILC and astroparticle physics also used substantial fractions of the resources.

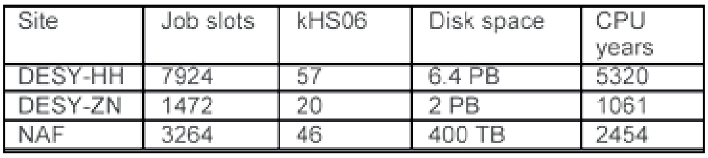
The HERA experiments continue to use Grid resources for Monte Carlo production. ILC event simulation campaigns for detector studies were also carried out on the Grid. The CALICE collaboration and the AIDA groups use the Grid to store and analyse their test beam data. The Zeuthen site operates as a Tier-1 centre for the IceCube project and runs large-scale Monte Carlo simulations for CTA. DESY is also participating in the Belle II experiment at KEK in Japan, which will start data taking in 2017, and consequently supports the Belle VO by providing computing and storage resources, in particular disk space for storing Belle data to prepare physics analyses for Belle II. DESY will participate in a Belle II Monte Carlo campaign, followed by a data challenge, in spring 2013.

The Grid

DESY operates a single Grid infrastructure, which includes all the node types needed to provide the mandatory services expected of a complete Grid infrastructure for all supported VOs. Virtualization technologies are exploited for most of the Grid services in order to increase reliability, scalability and flexibility.

Several upgrades were carried out in 2012. The deployment at DESY of the CERN virtual machine file system (CVMFS) for ATLAS in 2012 helped to overcome severe bottlenecks in software provisioning by providing a caching mechanism for the software needed by Grid jobs. For the Belle VO, an initial order of storage resources of 100 TB was installed by the end of 2012. A total of 400 TB of Belle data will be stored at DESY by the end of 2013. Computing resources for the Belle II

Monte Carlo campaign will be made available in spring 2013. Following the requests of the experiments, the Grid computing resources at DESY were massively increased to about 8000 job slots at DESY-HH (Table 1). Finally, in order to improve the CPU efficiency of the Grid, an alternative scheduler, which maximizes occupancy of available jobs slots, was developed and put into operation.



Site	Job slots	kHS06	Disk space	CPU years
DESY-HH	7924	57	6.4 PB	5320
DESY-ZN	1472	20	2 PB	1061
NAF	3264	46	400 TB	2454

Table 1: Overview of the resources at both DESY sites

The NAF

The National Analysis Facility (NAF) [4] was set up in the context of the Helmholtz Alliance "Physics at the Terascale" with the goal of offering the best possible data analysis infrastructure for German high-energy physicists working on the LHC and the ILC. It includes both a batch-like DESY Grid infrastructure and an interactive facility.

In 2012, the NAF was an important platform for many LHC analyses and has proven to be an important link in the LHC analysis chain, augmenting the Grid infrastructure not just for groups working at DESY but also for the German HEP community. The interactive data analysis capabilities of the NAF, now enjoyed by the LHC communities, will soon also be enabled for Belle (II).

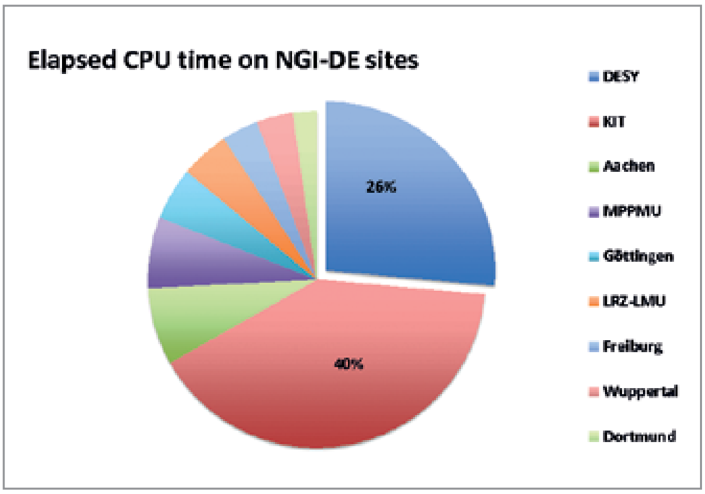


Figure 2

Relative elapsed CPU time on NGI-DE in percent. Roughly a quarter of the German Grid computing was done at DESY.

2012 was a fruitful year for LHC data collecting and, as a result, usage of NAF resources had to be increased. The purchase of the required additional resources is planned in collaboration with representatives of the experiments. By the end of 2012, the CPU and storage resources of the NAF reached the values shown in Table 1. In Hamburg, the SONAS storage appliance provided by IBM is replacing Lustre as a fast cluster file system, and the existing Lustre service in Hamburg will be decommissioned in 2013. To improve performance for compilation, the CVMFS was also introduced to the NAF. The ratio of total resource usage by internal DESY groups to that of external users remained unchanged in 2012 at about 25%. This clearly shows that the NAF is first a facility for the whole German LHC community, and as such is very well received.

Through dialogues with users, it became clear that some of the fundamental concepts and decisions that influenced the initial design in 2007 were no longer valid. Examples include the choice of graphical tools and distributed setup. Therefore, a blueprint for a new design, called NAF 2.0, was formulated and endorsed by the user communities. The work for a remodelling of the NAF started in 2012, and the full migration will be completed in 2013.

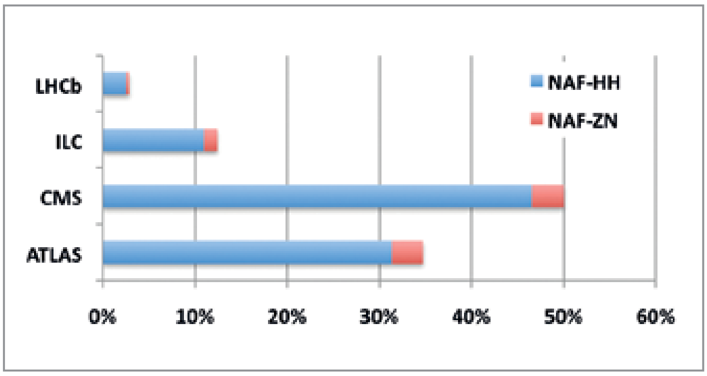


Figure 3

Distribution of NAF usage by virtual organization. The CMS group at the University of Hamburg added its own resources to the NAF.

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References:

[1] http://www.egi.eu
[2] http://lcg.web.cern.ch/lcg
[3] http://naf.desy.de

The Helmholtz “big data” project and the dCache scientific cloud.

Coping with huge data sets

The Helmholtz Association’s “Large Scale Data Management and Analysis” (LSDMA) portfolio extension was launched in 2012 and provides German laboratories and universities with support for data storage and analysis as well as moderate funding for development. The principal beneficiary of the DESY funding share is dCache. The dCache system was initially designed for high-energy physics experiments and has since evolved into a generic scientific cloud storage system, which caters to several scientific communities. dCache software is currently deployed at more than 60 sites worldwide and distributed through channels that include the Unified Middleware Distribution (UMD) of the European Grid Infrastructure (EGI). In 2010, dCache became a partner in the European Middleware Initiative (EMI) and, in 2012, a member of LSDMA.

LSDMA

The major objective of the Helmholtz Association’s LSDMA portfolio extension is the development and deployment of infrastructure to support the analysis of existing data from a wide range of scientific communities. The basic motivation is best expressed by one of its founding ideas: “Our vision is a scientific e-infrastructure that supports seamless access, use, re-use, and trust of data. In a sense, the physical and technical infrastructure becomes invisible and the data themselves become the infrastructure.” The LSDMA collaboration comprises four Helmholtz centres and seven universities, which together receive a total of more than 13 million euro over a five-year period. The DESY share is just below 2.5 million euro.

The dCache system enhancements

The increasing number of interested new scientific communities and a rapid change in storage technology motivated the dCache collaboration to undertake new developments in various strategic areas. Most of these efforts are funded through LSDMA. Examples include:

> A pluggable authentication system, which eases the integration of dCache into existing infrastructure,
> An http-based storage federation system, which enables the worldwide federation of heterogeneous storage endpoints into a single file system accessible through any browser or other http(s)–enabled client,
> A “multi-Tier storage” system to optimize data placement among base storage technologies, i.e. spinning disks, solid-state disks and tape systems based on a client-specified access profile,
> The integration (in collaboration with the University of Applied Science, HTW, in Berlin) of standard access mechanisms such as NFS and WebDAV to offer cloud storage protocols such as the Amazon-S3 pseudo-standard and the CDMI industry standard.

The collaboration and dCache.org

The dCache collaboration comprises computer scientists from Fermilab, the Nordic e-Infrastructure of Computing (NeIC, formerly NDGF), the Swedish National Infrastructure of Computing (SNIC), DESY and, since 2012, HTW in Berlin (essentially through the LSMDA project).

Following the end of Helmholtz funding for the German dCache support group in 2012, most of the German partners are nevertheless continuing to collaborate within that well-established structure. Examples include: the organization of a “dCache day” during the GridKA School of Computing, contributions to the annual European dCache workshops and an agreement with the organizers of the International Symposium for Grids and Clouds (ISGC) to co-locate a dCache workshop with the ISGC in March 2013 in Taipei.

The link between the distributed code development and networking activities discussed above is the largely DESY-funded group dCache.org, which provides standard interfaces to developers and customers. It covers overall project management and represents dCache in various forums, e.g. the Grid Deployment Board, the OSG External Software Group, the German DGI-II and “Physics at the Terascale” as well as EMI and EGI.

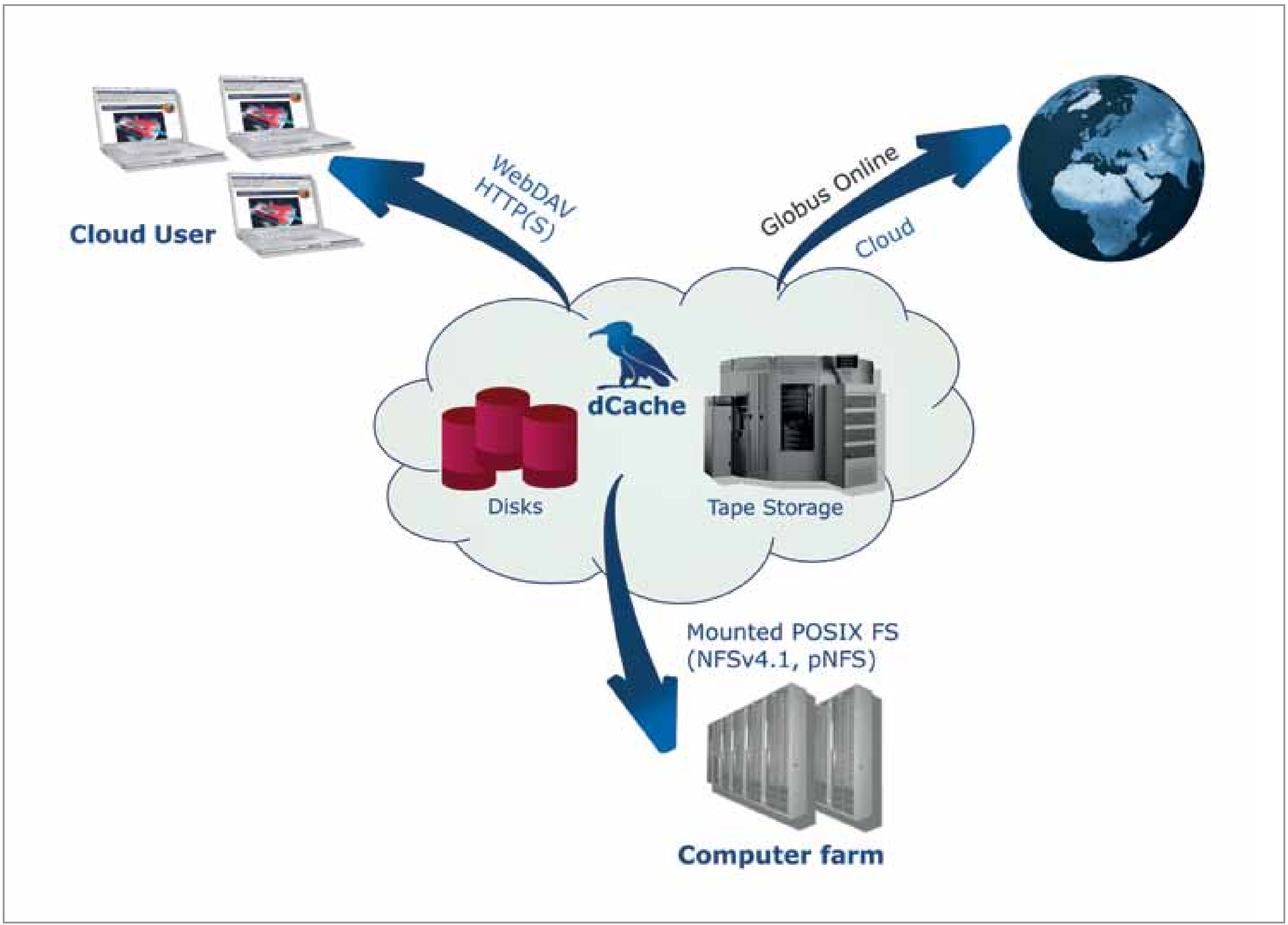

Figure 1

The DCache scientific cloud

Deployment

Most dCache installations still operate in the context of the Worldwide LHC Computing Grid (WLCG). Eight of eleven LHC Tier-1 sites in the USA, France, Spain, Canada, Northern Europe, the Netherlands and Germany run dCache, as do 40 Tier-2 centres worldwide. The two new Russian Tier-1 centres in Moscow and Dubna are also considering dCache. In total, more than 100 PB of data are stored in dCache installations, roughly 50% of the entire LHC data set. Meanwhile, other scientific communities are catching up. At Fermilab, the Intensity Frontier groups and, in Europe, the storage technology evaluation groups of the European Data Project (EUDAT) are evaluating dCache for their customers. At DESY, the dCache team is tuning the software to cope with the performance and feature requirements of PETRA III, CFEL and the European XFEL. LOFAR, the Dutch-based Low Frequency Array Antenna project, is using dCache at sites in Amsterdam, and both Forschungszentrum Jülich and SNIC are running a dCache infrastructure for data-intensive communities. Two international companies, one in Switzerland and one in the California Bay area, are negotiating commercial licenses.

dCache at DESY

The dCache operations team (DOT) at DESY in Hamburg operates five dCache instances. Three are Grid-enabled, two of which are dedicated to LHC experiments and their virtual organizations (ATLAS, CMS). The third mainly serves ILC and the photon science experiments. All three use the same access scheme but talk to different computing infrastructures, such as the LHC Tier-2 centre and the National Analysis Facility (NAF) at DESY. The two non-Grid-enabled instances are used by the local HERA experiments. By the end of 2012, the total disk capacity of dCache at DESY exceeded 8 PB.

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Data preservation and the legacy of HERA.

Leading the way in the global data preservation initiative

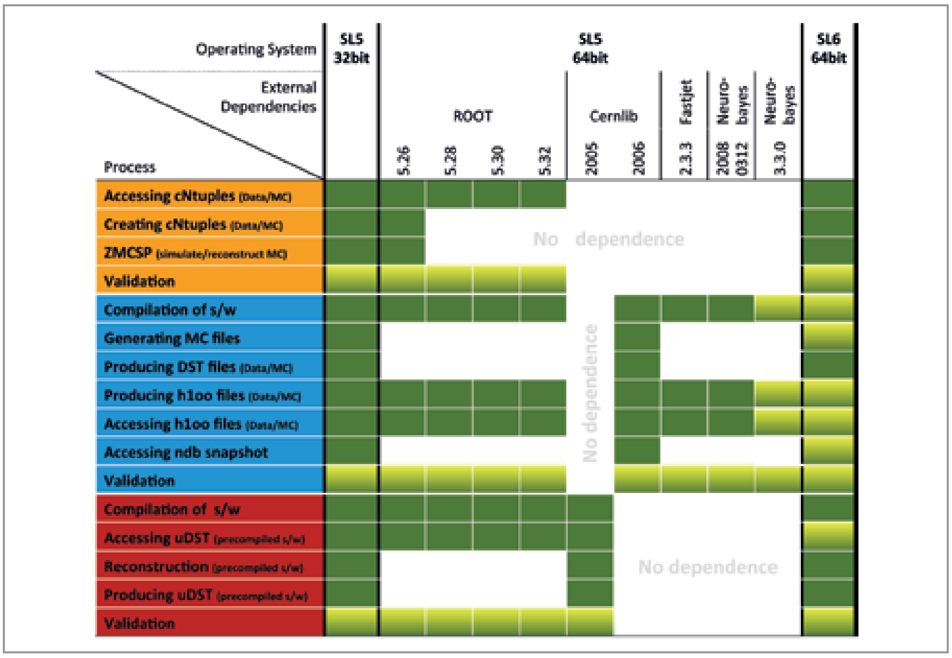
The year 2012 was a busy period in the emerging field of data preservation in high-energy physics (HEP). Following the publication of a large-scale report providing recommendations to the international study group on data preservation in high-energy physics, DPHEP, will, in 2013, transform itself into a collaboration. Since 2008, DESY has been making leading contributions to DPHEP, and is continuing to investigate and develop novel solutions to the complex problems associated with data preservation in in high-energy physics.

The international DPHEP study group achieved a milestone in May 2012 with the publication of its large-scale report. The report, which is the culmination of three years of work, contains comprehensive updates from all participating labs and experiments, as well as a detailed look at the future working directions. As a major player in DPHEP, DESY provided many key contributions. A central message is that data preservation in HEP is not possible without long-term investment in both hardware and human resources. With this in mind, DPHEP will evolve to a new collaboration structure in 2013, with a central project manager position initially based at CERN. Following the transition, DESY will continue to contribute to DPHEP by developing generic solutions of interest to the general DPHEP community. The participants of the sixth DPHEP workshop held in Marseille in November 2012 are shown in Fig. 1.

Besides describing the many projects taking place within the community, the DPHEP report includes a comprehensive evaluation of the physics case for data preservation. Given that no successor to HERA has yet been approved, this is particularly relevant to the unique data collected by the H1, ZEUS and HERMES experiments. It is well known that HERA collision data are important for understanding the structure of

Figure 1

Participants of the sixth DPHEP workshop, which was held at the Centre de Physique des Particules de Marseille in November 2012



Operating System	SL5 32bit	SL5 64bit									SL6 64bit
External Dependencies		ROOT				Cernlib		Fastjet	Neuro-bayes	Neuro-bayes	
Process		5.26	5.28	5.30	5.32	2005	2006	2.3.3	2008 0312	3.3.0	
Accessing cNtuples (Data/MC)	🟩	🟩	🟩	🟩	🟩						🟩
Creating cNtuples (Data/MC)	🟩	🟩									🟩
ZMCSP (simulate/reconstruct MC)	🟩	🟩									🟩
Validation	🟨	🟨	🟨	🟨	🟨						🟨
Compilation of s/w	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟨	🟨
Generating MC files	🟩						🟩				🟨
Producing DST files (Data/MC)	🟩						🟩				🟩
Producing h1oo files (Data/MC)	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟨	🟨
Accessing h1oo files (Data/MC)	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟨	🟨
Accessing ndb snapshot	🟩						🟩				🟨
Validation	🟨	🟨	🟨	🟨	🟨		🟨	🟨	🟨	🟨	🟨
Compilation of s/w	🟩	🟩	🟩	🟩	🟩	🟩					🟩
Accessing uDST (precompiled s/w)	🟩	🟩	🟩	🟩	🟩	🟩					🟨
Reconstruction (precompiled s/w)	🟩					🟩					🟩
Producing uDST (precompiled s/w)	🟩					🟩					🟩
Validation	🟨	🟨	🟨	🟨	🟨	🟨					🟨

Figure 2

Current results of the validation framework from the ZEUS (orange), H1 (blue) and HERMES (red) experiments, where different operating systems and versions of the external dependencies are examined. Successful test results are indicated in green, where those still requiring attention are shown in yellow.

the proton in terms of parton distribution functions and are therefore a crucial input for Standard Model predictions at the LHC. The HERMES data provide unique input to the study of generalised parton functions, which are important for exploring the spin structure of the proton. Future theoretical models or novel analysis techniques may allow further exploitation of the data in ways not possible using today's predictions or methods.

Preserving the HERA data is a two-step process; first, the data must be prepared in the desired format. Only then can the archival storage system, which is currently under development, be installed. The choice of data format depends on the desired DPHEP preservation level; more flexibility requires more investment, but ultimately yields more return. In the case of H1 and HERMES, which aim for a complete level-four preservation, the final data was prepared in 2012. By early 2013, ZEUS is expected to follow. The conversion of the current dCache-based storage system employed by all HERA experiments to an archival system will provide a smooth transition between the current active analysis phase (live collaboration) and the data preservation phase. The need for the rapidly aging hardware of the experiments is being eliminated by moving the HERA data storage to a dedicated space within the DESY dCache. This is particularly important for HERMES, which has recently migrated its full measurement and Monte Carlo data and has thereby retired many old servers. After successfully testing its software as described below, HERMES is now in a position to use DESY-IT centrally managed services (batch farm, storage) without the need for dedicated hardware and human resources. This is particularly important given that the collaboration officially ended in 2012.

Preserving only the data is not enough. Only by preserving the software and environment can the capability to perform analyses be secured. Past efforts employing a naive virtualization approach have not always guaranteed success. Therefore, the development of the software preservation system is being pursued at DESY by all experiments and in close cooperation with DESY-IT. The validation system at DESY is renowned in the HEP community as a concrete solution to the problem. The production version of the system was deployed in 2012 with SLD5/32-bit as a common baseline operating system. Newer, 64-bit versions as well as newer versions of external software such as ROOT were successfully tested. The validation tests, which are still under development, have already aided software and operating system migrations and have identified bugs in the experimental software of the collaborations. The progress of the validation system is illustrated in Fig. 2.

Finally, significant progress in areas of documentation and metadata is being made. All collaborations have now migrated their webpages to a virtual system maintained by DESY-IT, once again removing the need for dedicated hardware. The storage of the internal notes of all HERA collaborations has been completed by the DESY Library INSPIRE team, in a project now being repeated by other HEP collaborations. A recent effort has consolidated the available HERA-related theses in the INSPIRE database and further projects are in the pipeline, including the storage of preliminary results and publication draft versions in INSPIRE. A huge amount of non-digital documentation has been organized and archived in dedicated storage space in the DESY Library. It is worth noting that this work has uncovered many forgotten Master's and Ph.D. theses, which provide unique documentation on the formative years of the HERA experiments and amount, in the case of H1, to 20% of the total.

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Bye-bye SPIRES.

Obituary to a reliable companion

In early spring 2012, the web interface of the well-known SPIRES database was put offline after 38 years of reliable and indispensable service to the high-energy physics (HEP) community. SPIRES-HEP was, and its successor INSPIRE still is, the first choice of reference for publications for the HEP community, covering not only journal articles and preprints but also conference proceedings, technical reports, theses and other "grey" literature. The value of the information is enhanced by thorough proof-reading.

It started in 1974 as a bibliographic database, SPIRES-HEP, hosted at SLAC. But the service of providing information on articles published in HEP dates back even further. Since 1963, DESY had been publishing printed books, the High Energy Physics Index, with listings of scientific literature (Fig. 1). They comprised publication notes of preprints (exchanged by major institutions via snail mail) and journal publications, which were categorized by subject and indexed as well as assigned with keywords.

Meanwhile, a similar service was being provided by SLAC, so when the SLAC library decided to turn its printed listings into an electronic database, it was a natural decision to join forces. Enrichment of the data, which requires knowledge of the subject (indexing and classification) as well as content-based selection of articles, has since been done at DESY.

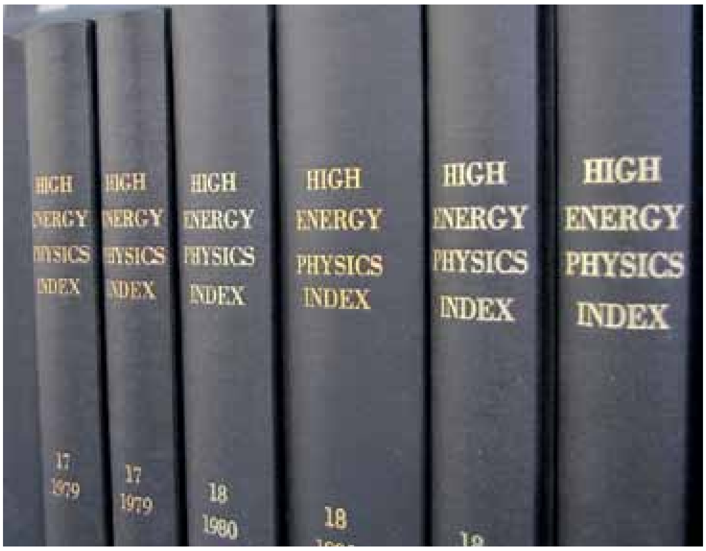

Figure 1

The HEP index published from 1963 to 1996 at DESY

In the mid 1980s, the SLAC computing moved to an IBM VM/CMS system, which enabled the possibility to query the SPIRES-HEP database remotely by sending an email to the QSPIRES server. Not only was information about literature provided, but several databases like CONF, EXP, INST, HEPNames and JOBS followed and Fermilab joined the team.

Things changed drastically and rapidly in the early 1990s: in August 1991 Paul Ginsparg started the first e-print archive at hep-th@xxx.lanl.gov. This arXiv preprint server became immensely successful and heavily interlinked with SPIRES. Shortly after the first WWW server, developed by Tim Berners-Lee at CERN, went live in June 1991, SPIRES became the first web server outside Europe on 12 December 1991. Functionalities of the web server constantly improved until full-texts from arXiv could be harvested via SPIRES.

The basic architecture of the database did not change even after hardware upgrades, so, up until the very end, some parts of the software ran via an IBM VM/CMS emulation tool. Increasing amounts of data and added requirements for classification and enrichment eventually made the maintenance of the database a cumbersome task. Requirements for a modern web interface with faster search and more functionality were also quite obvious; a clear need for a modern software engine was therefore identified.

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Hello INSPIRE.

The new HEP information system

In 2007, the SPIRES labs – DESY, Fermilab and SLAC – joined efforts with CERN to form a collaboration aimed at developing the successor of the aged SPIRES system. One of the main requirements was to incorporate a fast and scalable database engine, which would accommodate the needs of SPIRES and provide a modern interface for users. CDS Invenio, developed and maintained at CERN, was a perfect candidate for this, so, after several years, an Invenio-based system has been developed, which was named INSPIRE (INvenio + SPIREs).

Following alpha- and beta-testing, which consisted of a period of running both systems in parallel for the purpose of testing and gathering user feedback, the service was completely switched over to the new system in 2012, and INSPIRE became the main platform. On top of the usual high-quality metadata, INSPIRE enables several new features. It provides a detailed view of the record including the abstract, which is now an integral part of the metadata, extracted figures and a full list of references, not only those to records in INSPIRE (Fig. 1).

Diffractive W and Z Production at the Fermilab Tevatron

Phys.Rev. D82 (2010) 112004

Figure 1

INSPIRE record with metadata and plots

The metadata are more flexible, e.g. records can be related; this is used to combine chapters of a book or establish a structure for institutions. New types of information can be added, for example ISBN identifiers to identify books and make them citable in the longer term. References can be extracted from the full-text file of an article. This will ultimately lead to an increase in the completeness of citations. Full texts are stored in the system when available, thus enabling full-text searches and the display of text snippets.

Author identification is another big step. Based on names, affiliations and fields of research, authors are clustered and people represented in the HEPNames database are asked to claim their papers, a process which has proven very successful. For the first time, this allows us to relate a person (with email, institutional history and fields of interest) with the author and his or her publication history and citation summary.

Already existing workflows are largely improved. DESY has always indexed articles by assigning keywords. This process has now been automated and standardized. In addition, it has been enhanced as a means to help in the selection of articles relevant for HEP. In this way, more journals and arXiv categories can be browsed, articles selected and publication notes can be added, making INSPIRE not only a worthy successor of SPIRES, but in many ways a new HEP information system.

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LEXI.

Cluster of Excellence on the final straight

In 2009, the city-state of Hamburg launched an excellence initiative, dubbed LEXI, to stimulate promising research networks in Hamburg. The Cluster of Excellence “Connecting Particles with the Cosmos” was formed to create an interdisciplinary research structure by combining local expertise on accelerator and detector physics, particle physics, astrophysics and astroparticle physics with cosmology, string theory and mathematical physics. As reported in previous years, several young investigators groups and a large variety of additional activities and projects were initiated and supported by the cluster. A key element of this funding model is its large flexibility in distributing resources, which allows fast response to new developments in the different areas of research.

Intensifying collaboration between the different fields is one of the main goals of the cluster. Like in the past, in the final year of funding a certain fraction of the resources available to the cluster was also used to support new and promising initiatives at the interface of several research areas.

A prime example is the topic of dark matter, which has been introduced to explain several astrophysical observations and which has strong relations to many areas of the cluster. Understanding the nature of dark matter is one of the most important open issues in physics today. Although particle physics offers several potential explanations of this phenomenon, none of those could be demonstrated to exist in nature so far. Among the well-motivated dark-matter candidates from particle physics are axions and other very weakly interacting slim particles (WISPs), e.g. axion-like particles (ALPs) or hidden photons (HPs). The dominant interactions of ALPs and HPs with Standard Model particles arise from couplings to photons. Recently, it was shown that a large and yet unexplored region in the parameter space spanned by photon coupling strength and ALP or HP mass could in principle give rise to cold dark matter. Figure 1a shows this region together with the area that has already been excluded by the ADMX experiment at Lawrence Livermore National Laboratory (USA) and by a variety of other experiments.

In order to explore the region of even smaller HP masses and photon coupling strength, a new pilot experiment has been set up by members of DESY, the University of Hamburg and the MPI for Radio Astronomy in Bonn. Jointly funded by LEXI, the SFB 676 and PIER, the WISP Dark Matter eXperiment (WISPDMX) utilizes a former HERA 208 MHz proton ring cavity as microwave resonator (Fig. 1b) for the conversion of HPs to ordinary photons. Depending on the results of this pilot study, an advanced experiment could be envisaged, aiming at a scan through a larger mass range by employing the H1 solenoid magnet to perform the first definitive axion dark-matter search below 2 µeV. The sensitivity that could be reached by such an experiment is also indicated in Fig. 1a.

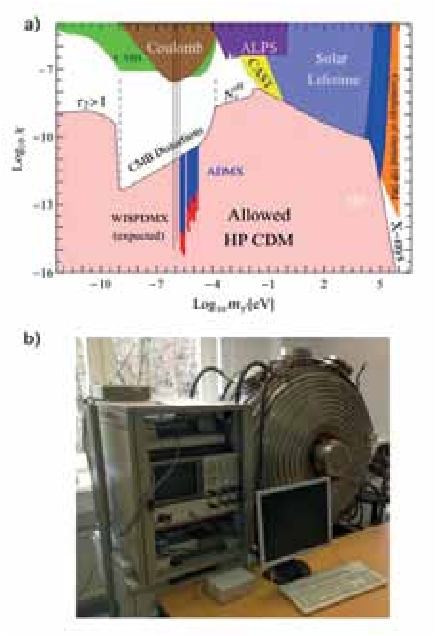

Figure 1

a) Allowed parameter region of coupling strength versus mass for hidden photon cold dark matter (HP CDM). The sensitivity reach of the WISPDMX search is indicated.

b) Experimental setup of the WISDMX pilot experiment, which utilizes a former HERA 208 MHz proton cavity.

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Reference:

http://desy.de/~ringwald/axions/talks/wispdmxmeeting.pdf

Global detectors – global infrastructure.

A magnet from the Far East

The development of modern detectors needs excellent infrastructure. In Europe, the Advanced Infrastructure for Detectors at Accelerators (AIDA) project, which is partially funded by the European Union, is working to improve the European infrastructure for advanced detector development. AIDA serves all interested parties, primarily the LHC and linear collider communities. With the help of AIDA funds, a large-volume superconducting magnet at DESY, together with its cooling system, was upgraded in collaboration with the Japanese centre for particle physics, KEK.

PCMAG: A magnet for detector studies

New detectors often need to be tested in strong magnetic fields. For this purpose, a 1 T superconducting magnet was loaned by KEK to DESY as part of the EUDET programme and installed in the DESY test beam area. The magnet, originally developed for a balloon-based experiment, is mounted on a versatile movable stage and can house experiments of up to 70 cm in diameter and 1 m in length in a strong magnetic field. During its first years of operation, it was cooled from a liquid-helium reservoir, which needed periodic refilling. However, since the filling procedure was both error-prone and expensive, KEK proposed that the magnet be converted to liquefy its own helium. The conversion was carried out in 2011–12 by Toshiba in Japan: two cryo-coolers, which continuously cool helium gas to liquid-helium temperature in a closed-circuit system, were installed on the magnet. Together, they provide enough cooling power to operate the magnet without further external cooling.

Figure 1

Close-up view of the two cryo-coolers installed on the PCMAG magnet. The coolers are pneumatically operated and operate as a closed system.

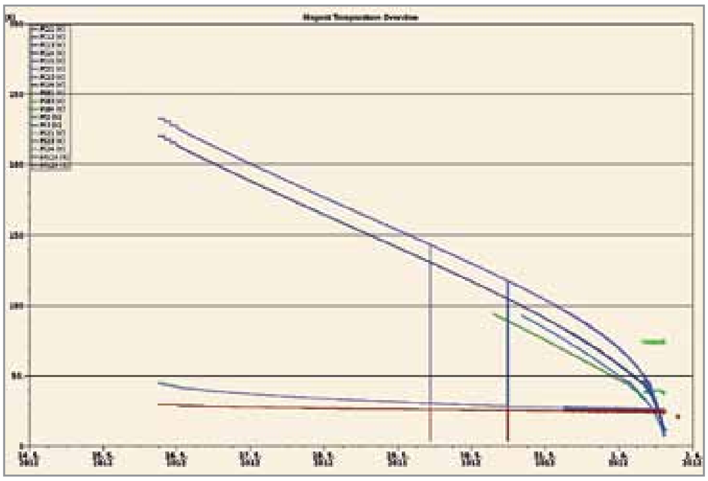

Figure 2

Temperature measured at the coil of the PCMAG during the first cool-down

The newly modified magnet was re-installed at DESY in late spring 2012 in a common effort of KEK and DESY engineers, and successfully cooled for the first time at the end of May 2012. It has since been operating continuously, without problems or downtimes.

This magnet is an excellent example how a European initiative like AIDA helps to improve key infrastructure at DESY and at the same time utilizes the close and excellent relationship between DESY and international partners like KEK.

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SFB 676: Particles, Strings and the Early Universe.

Collaborating to unravel the structure of matter and space-time

The collaborative research centre SFB 676, which is funded by the German Research Foundation (DFG), conducts a research programme at the interface of particle physics, string theory and cosmology. It is carried out within the long-standing collaboration of DESY with the physics and mathematics departments at the University of Hamburg. One of the highlights of 2012 was the measurement of the mixing angle θ_{13} in neutrino oscillations.

Neutrino flavour oscillations were established during the past two decades, but not all parameters describing the mixing had been measured. Until recently, evidence of non-zero mixing angles had been found for $\theta_{12} \approx 30°$, from solar and reactor neutrino experiments (together with the "solar" mass splitting difference $\delta m^2 = m_2^2 - m_1^2 = 7\times10^{-5}$ eV^2), and for $\theta_{23} \approx 45°$, from atmospheric and long-baseline neutrino experiments (together with the "atmospheric" mass splitting difference $\Delta m^2 = m_3^2 - m_{1,2}^2 = 2\times10^{-3}$ eV^2). Concerning θ_{13}, only an upper limit had been given by the CHOOZ reactor experiment.

The difficulty in measuring θ_{13} lies in its smallness compared to the other two angles. The first hints of a non-zero θ_{13} started to emerge in 2008 from a detailed analysis of solar and long-baseline reactor data [1], which, when combined with the early appearance data from the MINOS long-baseline accelerator experiment [2] in 2009, became a 2σ indication, and then 3σ evidence in 2011 when the low-background appearance data from the T2K experiment [3,4] were included. In 2012, the short-baseline reactor experiments Daya Bay [5] and RENO [6] finally established $\theta_{13} > 0$ at $\sim5\sigma$, by observing ν_e disappearance from near to far detectors, and measured $\sin^2 \theta_{13} \simeq 0.023 \pm 0.003$ and $\sin^2 \theta_{13} \simeq 0.029 \pm 0.006$, respectively. Consistent indications were also found in the Double Chooz reactor experiment with a far detector only ($\sin^2 \theta_{13} \simeq 0.028 \pm 0.010$) [7].

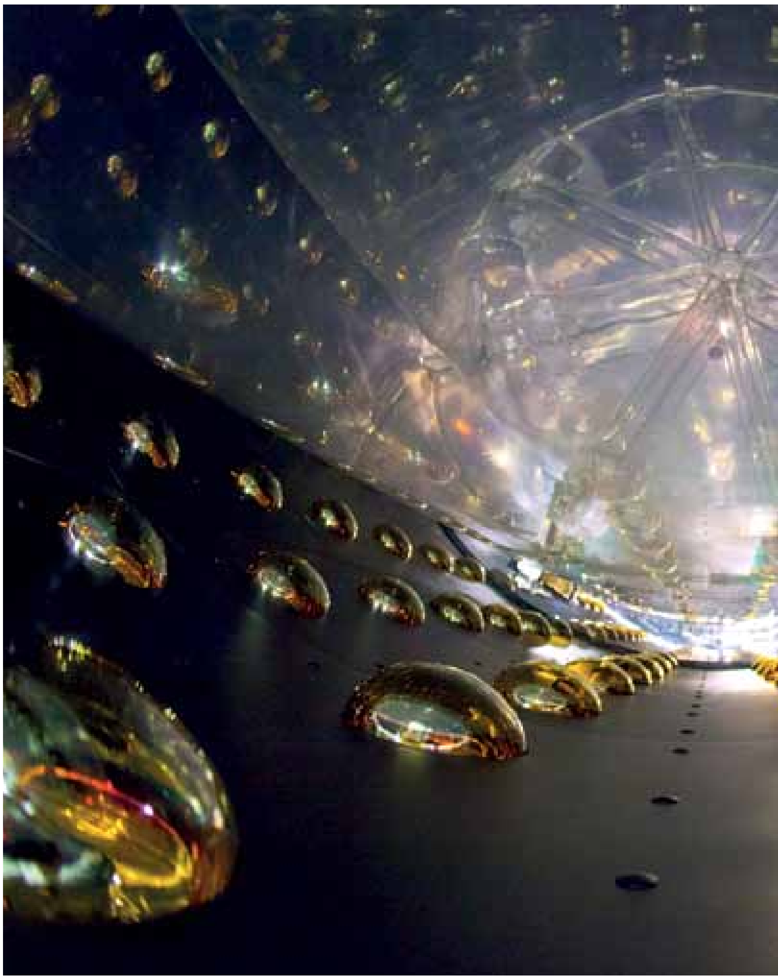

Figure 1

The two antineutrino detectors in Daya Bay Hall 1, shown here prior to the pool being filled with ultrapure water

θ_{13} was the last unmeasured neutrino mixing angle, and its measurement is of fundamental importance. All three mixing angles must be non-zero for a CP-violating phase to exist. This is considered to be the key to an explanation of the matter–antimatter asymmetry of the universe [8]. Furthermore, the value of θ_{13} is crucial for the planning of future large neutrino experiments to measure leptonic CP violation. The measurement of θ_{13} thus marks the beginning of a new era in neutrino physics.

The measurement directly relates to the research activity of the B3 project “Neutrinos in the Standard Model” of the SFB 676 and, in particular, to its participation in the European project LAGUNA-LBNO (Large Apparatus for Grand Unification and Neutrino Astrophysics – Long Baseline Neutrino Observations), which is investigating the possibility to build a large underground neutrino detector in Europe to determine the neutrino mass hierarchy and the CP-violating phase.

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