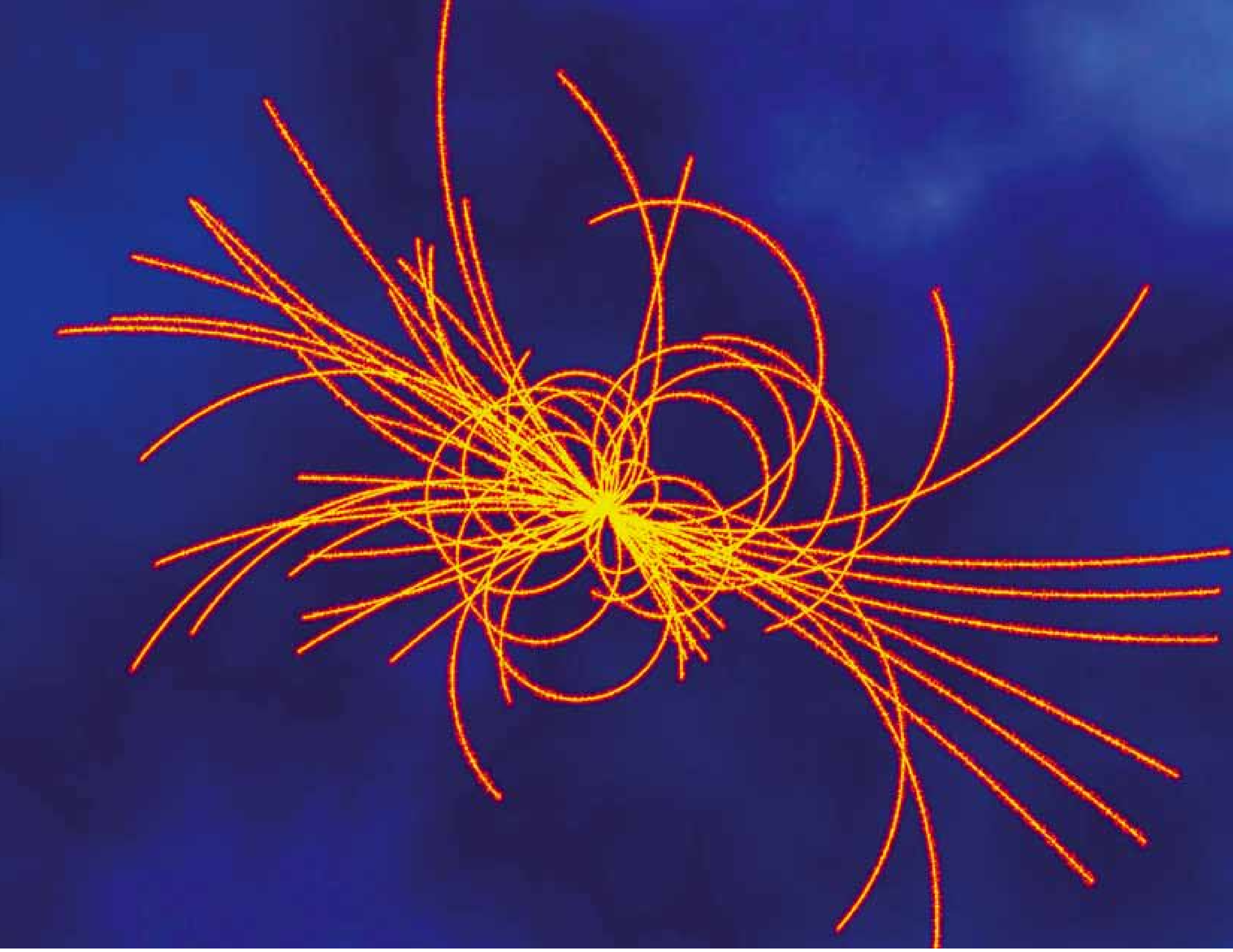


PARTICLE PHYSICS 2009.

Highlights and Annual Report

Accelerators | Photon Science | Particle Physics

Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association

Cover

Computer simulation of the decay of a Higgs particle in a high-energy physics detector.

PARTICLE PHYSICS 2009.

Highlights and
Annual Report

Contents

The year 2009 at DESY.

Chairman's foreword

The year 2009 marks not only the 50th anniversary of DESY but also the year 2 after the shutdown of HERA. We are still in the period of getting to grips with the new direction of DESY with a new focus on photon science facilities, a transition - similar to the development at SLAC – which guarantees the future of DESY as national lab.

Physics at the so-called energy frontier already has a critical other frontier, namely the limit within one single country or even a single lab can organise and facilitate an energy-frontier collider. Meanwhile, technologies have become so complex and expensive that they have to be put on the long-long-term agenda for megafacilities in Europe, in the United States or in Asia with a time horizon of more than 20 years. For us at DESY the message must be very clear: at the energy frontier we will not host a possible future linear collider, but rather will be strong partner in an international cooperation led by CERN or another institution.

With this in mind, we have to substantiate the future particle physics strategy of DESY which necessarily must be based on the three pillars (i) collaboration in international high-energy physics

It's official: DESY is full of good ideas.

Greeting international guests at the RAMIRI conference.

projects, (ii) coordination of national particle physics activities and (iii) reaching out for new frontiers in astroparticle physics.

With the Helmholtz Alliance “Physics at the Terascale” DESY has already made a very clever step ahead. The DESY management will make sure that this highly strategic alliance will get the necessary resources for the future. It is also gratifying to see the ongoing scientific harvest from HERA and that the DESY involvement at the LHC becomes more and more significant encompassing physics analysis as well as future detector upgrades. I am very optimistic that new phenomena will be discovered at this giant machine in the years to come. The design work on ILC detectors is well embedded in a global collaboration.

I am also very happy that our colleagues at Zeuthen have so successfully embarked into the astroparticle world with their very visible participation in the IceCube project. The further expansion of the astroparticle activities at Zeuthen have my full support.

For DESY the challenge is how to remain attractive for the young scientists who work in particle physics. We have many elements which are truly excellent, for instance our remarkable theory groups. Together with our large infrastructures for scientific computing and for detector design and construction as well as the direct access to the LHC experiments via our CMS and ATLAS remote control rooms we can offer a very rich, efficient and strong research environment which can easily cope with the best places in the world. Let´s work together to strengthen the role of DESY as the national hub for particle physics.

Helmut Dosch
Chairman of the DESY board of directors

Particle physics at DESY.

Introduction

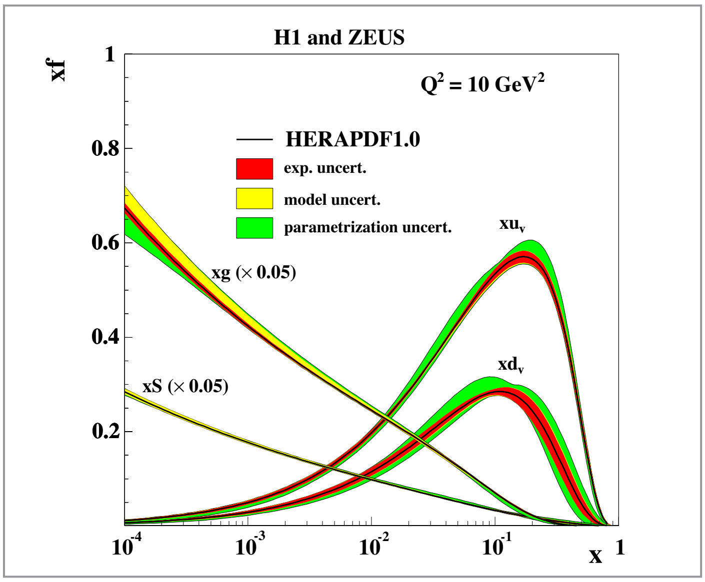
The year 2009 was very important for the future direction of Particle and Astroparticle Physics at DESY. The central event for the field: the evaluation of the programme proposals in spring. It was the peer assessment for the second period (2010 - 2014) of the Programme-Oriented Funding (PoF) of the Helmholtz Association which determines the development of our scientific programme for the next five years and beyond. In all evaluations the DESY projects received very good marks and strong endorsements by the international review panels, underlining their high estimate of our work and future plans. The very positive result of this evaluation process thus gives us a stable basis for the next years.

DESY's strategy in particle physics is to develop from HERA to the LHC and the ILC. While we are finishing the scientific harvest of the HERA experiments, we play a more and more important role in the analysis and future upgrades of ATLAS and CMS. We are also developing our central role in the preparation work on the accelerator and detector for a future linear collider.

The unique feature of DESY is that here all infrastructures required for large particle physics experiments are available: from the design and construction of new detectors to the physics analysis, comprising installations like the testbeam and of course Grid computing. Our experimental programme is complemented by a strong and broad theory group which, in addition to its successful scientific work, plays an important role in the education of young theorists in Germany and elsewhere. With new theory professors DESY now offers a unique research area on the borders between machine, experiment and theory. Just flick through the report to see some of the highlights of the stories where significant progresses were made.

An important element for future of particle physics at DESY is the Helmholtz Alliance "Physics at the Terascale". The Alliance – founded in 2007 – in funded by the Helmholtz Association and assembles all German groups performing experimental or theoretical research at the Terascale: eighteen universities, one Max Planck Institute, the research centre Karlsruhe and DESY as the leading institute. The Alliance is the most important instrument to restructure high-energy physics in Germany. After the end of the experimental programme at HERA and without a large national accelerator for particle physics on the horizon, the Alliance is a crucial tool to keep Germany's leading role in accelerator and particle physics.
The Alliance also underwent a mid-term evaluation by a panel of renowned international experts. The result of this evaluation was very positive and confirmed the need for such a structure and the success of its implementation. The review clearly recommended the continuation of the Alliance beyond the end of the approved Helmholtz funding in 2012.

The year 2009 was of course very important for DESY: we celebrated 50 proud years of research into the heart and structure of matter. Founded in 1959 almost like a bait to attract leading scientists back to Germany, it has provided outstanding results for the landscape of particle and astroparticle physics. One of the proudest chapters in DESY history is of course HERA, and the year 2009 saw the first publication of combined results from the two big HERA experiments H1 and ZEUS, a move which greatly increased precision on previous analyses.
HERA still has lively collaborations with many scientists from DESY and the partner institutes who are busy working on the scientific harvest and passing knowledge on to the next hadron machine: the LHC.



Parton distributions in the proton obtained from combined H1 and ZEUS data.

Joachim Mnich opening the international Lepton Photon Conference 2009 in Hamburg.

The Large Hadron Collider came back online in November after a year-long repair and commissioning phase. At DESY we were just as excited as our friends at CERN and users around the world to see the first collisions at 900 GeV and shortly after at 2.36 TeV recorded in the detectors. The experiment collaborations had used the extra year to get to know their detectors with cosmic data and to make some adjustments, and the well-understood detectors made it possible for LHC scientists to publish their first scientific papers in 2009, just weeks after the start-up.

While LHC groups crowded around screens in the remote monitoring rooms at DESY, the teams working on the ILC were far from idle. The concept for the International Large Detector was validated during the Lepton Photon conference that took place in Hamburg in summer, a green light for the developers of next-generation detector at DESY. Accelerators experts also performed crucial ILC parameter tests at the FLASH accelerator.

Astroparticle physicists only have one more year to wait until the IceCube neutrino telescope is fully installed. We all look forward to learning more about the elusive neutrino and along with it more about the nature of the universe. However, physicists rarely sit around and wait for news: DESY in Zeuthen has joined the Cherenkov Telescope Array project and is building parts for the gamma-ray telescopes. A combination of all of the above is the excellence initiative “Connecting Particles with the Cosmos” between DESY and Hamburg University that kicked of in 2009. We hope that this crucial multidisciplinary project will make it into the funding round of the federal ex-cellence initiatives in the future.

All this is just a rough overview of the year’s achievements in Particle and Astroparticle Physics at DESY – I would like to invite you to get a more in-depth picture on the following pages of our anniversary-year annual report. I look forward to giving you another positive review next year, when we look back at the year 2010.

Happy reading!

Joachim Mnich
Director in charge of High Energy Physics
and Astroparticle Physics

News and Events.

Happy birthday DESY.

DESY’s 50th Anniversary – DESY marks 50 years of cutting-edge research

DESY was founded in December 1959 as a German national laboratory for high-energy physics. Even before the mayors and statesmen had signed the founding documents, the site in Hamburg Bahrenfeld was bustling with activity, and the first building was already finished before DESY officially existed. This hands-on approach paired with curiosity and a pioneering spirit has accompanied the research centre all though its 50-year history and remains an essential quality today and in the future. Scientists at DESY have been investigating the structure of matter and the origin of the universe for more than 50 years. The development of increasingly powerful accelerators for particle physics research and of brilliant light sources, constantly expanding the limits of what is technically feasible, has always played a major role in DESY's history.

DESY developed from its modest beginnings into a research centre with an international reputation that now extends beyond particle physics to photon science. Its list of achievements is long, and its list of future plans even longer. Discover the gluon? Check. Understand the proton? Check. Discover oscillations of neutral b mesons, develop synchrotron radiation and free electron laser facilities? Check, check, check. And then there’s the to-do list: run the world’s most brilliant light sources, push the frontiers of accelerators and develop machines and detectors for the future will sooner or later all get check marks as well. For 2009, inaugurations of new facilities and the organisation of crucial international meetings went hand in hand with celebrations and events for DESY staff and the general public. The anniversary year was kicked off by the official handover of

DESY’s Board of Directors serve the DESY-50 birthday cake together with Nobel Laureate Professor Ada Yonath.

office from Albrecht Wagner to his successor Helmut Dosch in March. In DESY's hall 1, formerly home to the first fixed-target experiments, Wagner passed the baton to Dosch, and Dosch used it right away to conduct a DESY baton symphony.

Public lectures on DESY's history and present, a festive colloquium for Albrecht Wagner, a public photowalk followed by an exhibition are just a few of the festivities that took place throughout the year, culminating for DESY staff on 18 December with the official birthday party in hall1 and Hamburg town Hall, and for the public in the Open Day. More than 11000 people flocked to DESY and left enchanted. DESY ends the final birthday celebration in May 2010 with a visit from Chancellor Angela Merkel.

DESY's three pillars particle physics, accelerator development and photon science give the lab a firm standing in the world of research and science, and we are all curious to see what the next 50 years will bring.

In congratulating DESY on turning 50, it would be easy to reel off the milestones in particle physics, accelerator science and photon science that have happened there. But rather than do that, I'd simply like to congratulate DESY on its international spirit and openness to the broader community. It's quite an achievement for a national laboratory to establish a global stature for itself in any field. That DESY has done so in three areas of scientific endeavour is truly outstanding.

DESY's inclusiveness spans international borders, but equally importantly, it takes a broad view of domestic research. Through the Helmholtz Alliance, led by DESY, the laboratory is showing how, at a time of increasing globalization, one country can continue to play an important and coherent part in global particle physics without a major domestic frontier facility.

The end of the HERA research programme in 2007 marked a turning point for DESY. HERA was an essential machine for particle physics. Results from HERA experiments have their own merit scientifically, and they are also vital for research at the LHC – a perfect example of the links between DESY and CERN.

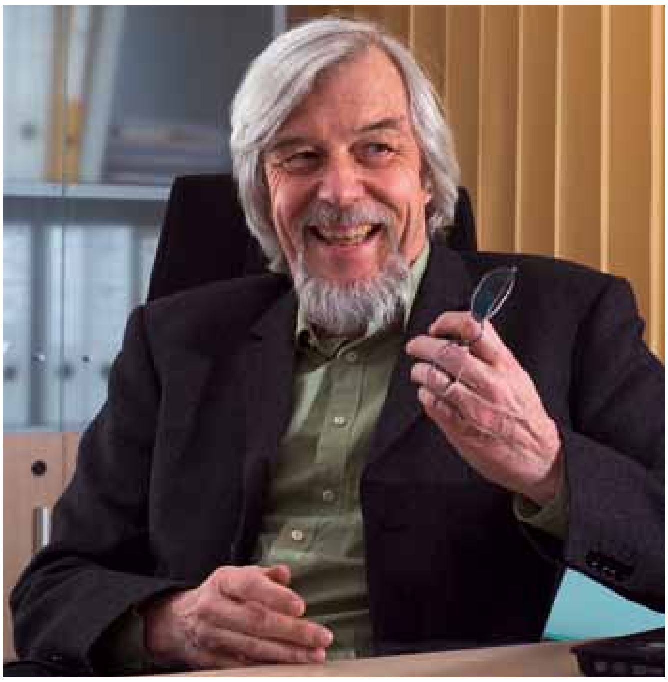
With HERA's job done, DESY's future is based on accelerator developments shared by particle physics and photon science. This has been a shrewd move for the lab, allowing it to blaze a new and innovative trail in photon science, while at the same time remaining at the forefront of accelerator and detector R&D for the future of particle physics.

The European XFEL is first and foremost a pioneering scientific instrument, but at 3.4 km in length it is also an important testing ground for the technology that could build the next frontier particle physics machine after the LHC.

I have spent the best part of 20 years of my professional life at DESY, first in the 1970s and 1980s, and then from the 1990s to the 2000s. Much of the rest of my career has been at CERN, making me a living example of the close ties that exist between the two labs. It therefore gives me great pleasure to wish DESY all the very best for this important anniversary. As long as DESY continues to show the openness, innovation and vision that it has consistently done for 50 years, the lab will be assured of a bright future.

Happy birthday, DESY, I very much look forward to many more years of fruitful collaboration!

Rolf Heuer, Director General, CERN



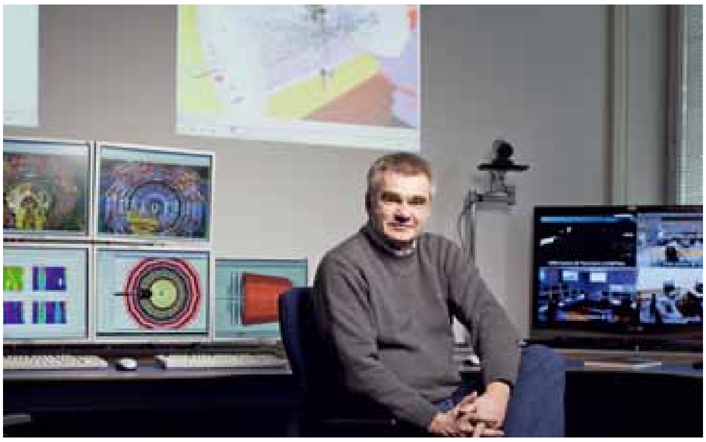
News and Events.

A busy year 2009

January

Joachim Mnich new DESY Research Director

On 1 January Joachim Mnich became the new Research Director of the high-energy physics and astrophysics sector at DESY. He is the successor of Professor Rolf-Dieter Heuer, CERN's new Director General.



Professor Joachim Mnich

"I am looking forward to the challenge of helping to shape particle physics at DESY in an international context," Mnich commented on his new position. After studying physics and electrical engineering at RWTH Aachen, he wrote his doctoral thesis at the Mark J experiment at the PETRA storage ring at DESY. After doing research at CERN at the L3 experiment, he habilitated at RWTH Aachen and accepted a professorship there in 2000. Joachim Mnich has been leading senior scientist at DESY and professor of the University of Hamburg since 2005. For two years he was head of the CMS group at DESY before becoming deputy of research director to Rolf Heuer in the DESY Board of Directors.

FLASH meets ILC

An international team attempts to run DESY's FLASH accelerator as though it were the International Liner Collider ILC. They do so by accelerating particle bunch "trains" of up to 2400 bunches with a length of 800 microseconds, at the highest possible acceleration gradient and with the highest possible reliability. These tests can only be done at FLASH, and the accelerator is pushed to the extreme.
After the team carried out first tests, feeding three times more electrons into the FLASH accelerator than usual, they achieved a breakthrough in September when they managed to shoot up to 550 electron bunches in one train through the whole accelerator. Unfortunately, the vacuum system was damaged right in front of the beam absorber and the tests had to be terminated prematurely.

The 9-mA-team in the control room.

In January, the investigations continued – with half the power, because the FLASH vacuum leak could only be fixed temporarily. After the repair and after installing an improved beam monitor, the team had for another two weeks beam time in September to finally prove that the superconducting accelerator is able to accelerate bunches at such a high rate.

February

Particle physics at DESY gets top grades from evaluation

At the end of February particle physics at DESY was put to the test for two and a half days: thirteen high-ranking scientists came to Hamburg to evaluate DESY's application for programme-oriented funding (PoF) in the field of particle physics in the Helmholtz Association. From 25 to 27 February, chaired by Michel Davier (Orsay), the international board of experts reviewed the strategic plans for the period from 2010 to 2014. The Helmholtz Association carries out research programme evaluations every five years. This was the second evaluation in the field of particle physics at DESY.

During the POF evaluation.

The evaluation is important for DESY in many respects. It confirms DESY's good worldwide reputation in the field of particle physics. After the HERA shutdown, particle physics at DESY is going through a period of transition. Thus it is important for future strategic planning to hear the opinions of internationally renowned experts. As all evaluations, it was also a good opportunity to reflect in a structured way on the future of particle physics at DESY in this period of transition, aided by panels appointed by the German Committee on Elementary Particle Physics KET and the European Committee for Future Accelerators.

March

Helmut Dosch takes the helm at DESY

Professor Helmut Dosch took office as Chair of the DESY Board of Directors on 2 March, when the outgoing DESY Director Professor Albrecht Wagner symbolically passed the baton to his successor in a handover ceremony.

Perfect handover: Albrecht Wagner passes the baton to his successor Helmut Dosch.

Helmut Dosch was born in Rosenheim (Bavaria) in 1955. The solid-state physicist used to be Director of the Max Planck Institute for Metals Research in Stuttgart and Professor at Stuttgart University. Dosch is an expert in the research of solid-state interfaces and nanomaterials with synchrotron radiation. He is also no stranger to DESY. He used to counsel the DESY Directorate as a member of the DESY Scientific Council, and, as member of the German Council of Science and Humanities, he evaluated the XFEL project which later developed into the European X-ray free-electron laser XFEL and the International Linear Collider ILC. Parallel to Helmut Dosch's start as Chairman of the DESY Board of Directors DESY also started celebrating its 50th anniversary.

DESY's Directors in front of the 50th-anniversary logo (from the left: Ulrich Gensch, Reinhard Brinkmann, Albrecht Wagner, Helmut Dosch, Christian Scherf, Joachim Mnich and Edgar Weckert).

April

Thank you and farewell, Albrecht Wagner

The research centre DESY bid farewell to its long-time Chairman of the Board of Directors, Albrecht Wagner, in a festive colloquium held on 3 April. Albrecht Wagner belonged to the DESY management for 18 years, first as research director, since 1999 as Chairman of the Board of Directors.

"Wagner has made crucial contributions towards the building of several new top-class facilities for basic research at DESY," emphasised Professor Frieder Meyer-Krahmer, State Secretary of the Federal Ministry of Education and Research. "You have rendered outstanding and lasting services to DESY and basic research in Germany and to the Federal Republic of Germany."

In 2006, Albrecht Wagner was honoured with Germany's Federal Cross of Merit, First Class, for his contributions to the research centre DESY, to Germany's reputation and to particle physics at large. Numerous honorary doctorates from universities in many countries underline the importance of Wagner's work far beyond the bounds of DESY.

Under the leadership of Wagner, decisions were made like the building of the X-ray laser European XFEL and the upgrade of the PETRA storage ring to the most brilliant synchrotron radiation source in the world, PETRA III. The global particle physics project of the future, the International Linear Collider, and the trend-setting European XFEL are facilities that will be equipped with superconducting TESLA accelerator technology. This technology was developed in an international collaboration under the direction of DESY and notably Albrecht Wagner.

Albrecht Wagner has connections to DESY since 1974. After his studies at the universities of Munich, Göttingen and Heidelberg he went to Lawrence Berkeley Laboratory (USA), the European particle physics lab CERN and conducted research at the DESY storage rings DORIS and PETRA. From 1984 to 1991, he was professor at the University of Heidelberg; in 1991 he was appointed professor at the University of Hamburg and Research Director of DESY. Since 1999, he has been Chairman of the DESY Board of Directors.

Honorary Doctorate for Volker Soergel

Professor Volker Soergel, who had been Chair of the DESY Board of Directors from 1981 to 1993, received an honorary doctorate from the University of Hamburg on 6 April at a ceremony during a colloquium in the DESY auditorium.

The Dean of the Faculty of Mathematics, Informatics and Natural Sciences at the University of Hamburg, Professor Heinrich Graener, presents the honorary doctorate certificate to Volker Soergel.

Volker Soergel was honoured for his merits in the close and successful collaboration of DESY and the University of Hamburg and for his contributions to the national and international visibility of Hamburg as a centre of science and research. Under his aegis, the electron-proton storage ring HERA was built in Hamburg, opening up a completely new way to study the structure of the proton.

More hands-on physics–upgrade of the DESY school lab

The City of Hamburg funds an up grade of DESY's school lab physik.begreifen with 400 000 Euros from Germany's federal economic stimulus package. The school laboratory is one of the most visited educational (and thus future-oriented) institutions at DESY. Established more than ten years ago, it has continuously grown and is still overcrowded. The courses for one school term are booked out immediately and the rooms are too small. There are lots of plans for the upgrade: two separate experimental labs for the quantum physics experiments, an extension to the existing building and an additional room for teachers' and educators' seminars.

There are also plans for the thematic upgrade of the hands-on physics programme. A new set of experiments which is currently being developed will be "particles and fields". The main building block for these topics is a cloud chamber, equipped with large Helmholtz magnetic coils. This will enable pupils to measure and evaluate tracks of nuclear radiation from the cloud chamber.

May

Weltmaschine goes on tour

Signs at the harbour festival

The mobile version of the Weltmaschine exhibition – an exhibition about CERN, the LHC and Germany's role in the whole project that attracted more than 30000 visitors to a subway station in Berlin in autumn 2008 – premiered at the Hamburg harbour festival in May 2009. Many of the 1.2 million festival visitors found their way to the Weltmaschine tent in the area of the harbour that was dedicated to the 2009 partner country Switzerland. Researchers from DESY, CERN and Swiss universities were on shift to explain the physics of the LHC, even during a major storm.

The Weltmachine exhibition started hitting the road in May.

Photon 09 at DESY

The international conference on the structure and the interactions of the photon including the 18th international workshop on photon-photon collisions and the international workshop on high energy photon linear colliders took place at DESY in Hamburg from 11 to 15 May.

Recent progress in understanding photon-photon and photon-proton processes were presented and the 104 participants discussed recent results on astrophysics and other related topics. This year's conference had sessions on electroweak and new physics, jets and heavy flavours, photon structure, prompt photons, small x, diffraction, and total cross sections, exclusive channels and resonances, vacuum polarisation and light-by-light scattering, low-energy photon experiments, photons in astroparticle physics and photon collider prospects.

Photon 09 participants

Happy birthday physik.begreifen

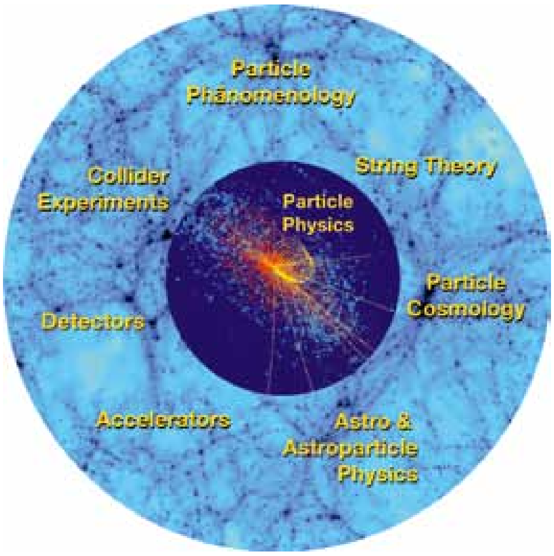
The hands-on school lab physik.begreifen at DESY in Zeuthen celebrated its 5th anniversary on 28 May with guests from politics, science and education. The DESY school labs give pupils the opportunity to immerse themselves in a physics topic in theory and practice for one day at the Zeuthen vacuum and cosmic lab. A total of 12000 pupils have experienced a great day out in the school lab during the first five years, and interest continues to rise.

Congratulations from Burkhard Jungkamp, State Secretary of Brandenburg´s Ministry for Education, Youth and Sport.

June

Gauss Alliance

In June 2009 DESY became a member of the Gauss Alliance. The Gauss Alliance is an association of large computer centres from research institutions and universities in Germany. The goal of the Gauss Alliance is to help the scientific communities in accessing and efficiently using high-performance and grid-based computing infrastructures in Germany. The Gauss Alliance will give advice to the funding agencies and to the scientific communities on how to develop, structure and organise outstanding computing infrastructures. DESY in particular actively contributes to the further development of Grid technology.



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LANDESEXZELLENZINITIATIVE HAMBURG

DESY participates in projects of the Hamburg State Excellence Initiative

The winners of the Hamburg State Excellence Initiative were named on 3 July. From a total of 21 competing applications, eight clusters of excellence and five graduate schools – institutions for the structured education of junior scientists – were selected to be funded in the coming one and a half years with 16.5 million Euros. DESY participates in six of the 13 projects covering topics ranging from nanotechnology to particle physics and cosmology.

Dr. Herlind Gundelach, Hamburg's Science Senator, Petra Herz, chairwoman of the board of the Joachim Herz Foundation, and Professor Edwin Kreuzer, chairman of the German State Rectors' Conference, presented the winning applications of the Hamburg State Excellence Initiative.

July

DESY scientist appointed Honorary Professor at BTU Cottbus

On 14 July, DESY's Wolfgang Lohmann was appointed Honorary Professor at Brandenburg University of Technology (BTU) Cottbus. The university acknowledges the scientific work of Lohmann in the field of particle physics and his long-time teaching commitment at the institutes of physics and chemistry at BTU Cottbus.

Wolfgang Lohmann is a scientist at DESY in Zeuthen and currently spokesman of the international FCAL (Forward Calorimeter) collaboration. The FCAL collaboration is involved in the development of new sensors for future detectors at the International Linear Collider, current detectors at the Large Hadron Collider and new beam diagnostics system of the free-electron laser FLASH at DESY.

Wolfgang Lohmann

Summer students on campus!

Ninety students, 75 of them in Hamburg and 15 in Zeuthen, have arrived at DESY at the end of July to participate in the eight-week DESY summer student programme. The physics students in their third to fourth year of studies come from universities in Armenia, Australia, Austria, Belgium, China, Estonia, Germany, Georgia, Greece, Ireland, India, Israel, Italy, Mexico, the Netherlands, Poland, Romania, Russia, Slovakia, Spain, Thailand, Ukraine, the United Kingdom and USA.

Summer students 2009 at DESY

The aim of the programme is to give the students the opportunity to experience the life and work in a research laboratory. The summer students join the day-to-day work of the research groups at DESY to work on specific projects: the particle physics experiments at HERA, LHC and ILC, for example, research with photons, accelerators or astrophysics. Students also participate in a lecture series about research done at DESY. The work in the groups and the lectures are complemented by visits to various experimental facilities.

Total overhaul

One of the most "ancient" buildings at DESY – laboratory building 1 – entered into a long and substantial restoration phase in July. The building will be refurbished with its long corridor, the foyer building and all the building's wings. All old windows will be replaced and all external walls will be fitted with thermal insulation; the electric system, water and heating pipes will be completely modernised. Moreover, new fire protection elements will be installed and the bits of ceiling in building 1 that contain asbestos will be removed. The restoration is financed through the Helmholtz Association and federal funds.

Building 1 in an special view from 1967.

August

DESY cavity tuning machines arrive at Fermilab

When groups from different countries collaborate in the development of a machine, the standard procedure is to send the people involved to the machines. A team of engineers and technicians from DESY, Fermilab and KEK decided to do just the opposite: they sent the machine to the people. On 3 August, two big pieces of equipment constructed by the DESY MHF-SL group went on tour to the United States – to Fermilab near Chicago. The machines in question are cavity tuning machines. They ensure that the shape of the superconducting accelerating structures, or cavities, needed for the European XFEL or the International Linear Collider ILC, corresponds exactly to the construction plan. Only this way, the electromagnetic fields within the cavity will accelerate particles.

Two essential elements are still missing in these machines: steering electronics and software. This is part of the United States' contribution to the cooperation in research with superconducting cavities, and this equipment will be added in the US.

Lepton Photon 2009
World's particle physicists gather in Hamburg

International conferences are rarely as easily summarised as Lepton-Photon or LP09, organised by DESY together with the University of Hamburg from 17 to 22 August in Hamburg. Most of the plenary talks shared the concluding sentence „We are looking forward to data from the LHC!"

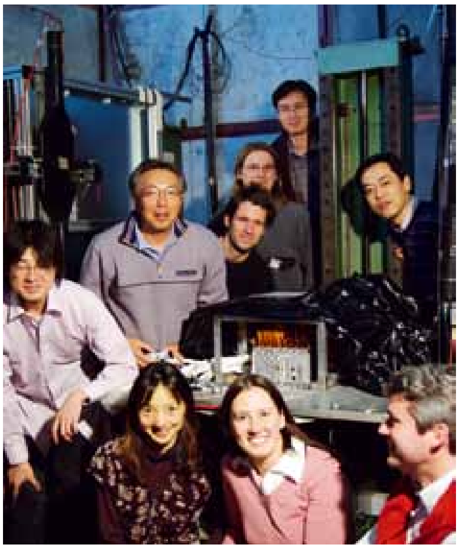
The 400 conference participants of the LP09.

Lepton Photon Symposium Poster 2009

Featuring a total of 47 presentations, 73 posters, a public lecture drawing a crowd of 350 people, and plenty of in-depth discussions, the XXIV Symposium on Lepton and Photon Interactions at High Energies (Lepton Photon 09) certainly lived up to its billing as one of the world's most important particle physics conferences. Some 400 particle physicists from around the world travelled to Hamburg's Conference Centre.

ILD validated!

During the Lepton-Photon Conference, at a meeting of the ILC Steering Committee ILCSC, two concepts for future detectors at the ILC were validated, including the concept for the International Large Detector or ILD, which has strong participation from DESY. The other validated concept called SiD has a large American contribution. A third proposal for a concept called '4th' for historical reasons was not validated. The CALICE hadronic calorimeter and the time projection chamber TPC are both subdetectors for the planned ILD.



The CALICE collaboration is part of the ILD concept.

September

Happy birthday, Lord of the (Accelerator) Rings

In September DESY celebrated the 80th birthday of Gustav-Adolf Voss, former member of the DESY Directorate and head of the accelerator division – and thus many accelerator rings. For his outstanding contributions to the conception and building of new accelerators Helmut Dosch awarded him with a golden DESY pin.

Helmut Dosch awards Gustav Voss with the golden DESY pin.

The "Lord of the Accelerator Rings" spearheaded an exceedingly productive era at DESY. The construction of the electron-positron accelerator PETRA, completed in 1978, is considered to be Voss' masterpiece. Both the calculated construction time of four years and the 100-million-Deutschmark cost were under budget by considerable margins.

Guests included Herman Winick from the SLAC National Accelerator Laboratory in Stanford, US, who knows Voss not only from their time at Harvard. At the end of the 90s, they launched the SESAME project: the first synchrotron radiation source in the Middle East. The facility in the city Allan in Jordan inherited the storage ring of BESSY-I in Berlin and was inaugurated in November 2008. The American Nobel laureate in physics, Burton Richter, who was connected live by video conference during this event, honoured Voss' achievements and visions in the field of linear accelerators.

FLASH takes charge

On the way to high beam intensities in superconducting particle accelerators, the collaboration of the DESY FLASH team and International Linear Collider colleagues achieved an important milestone in September. Pulses of 800 microseconds with an average beam current of six milliamperes at a beam energy of 800 MeV were achieved for the first time in the FLASH accelerator. For some hours of operation, with shorter pulses between 300 and 500 microseconds, the team even managed to reach the optimum particle current value of 9 milliamperes.

Before the tests could begin, the beamline to the absorber block had to be remodelled with upgrades to the vacuum system and the beam diagnostics that ensure a safe dumping of the highly intense electron beam. During the two weeks of high-current tests, the accelerator physicists first used the existing FLASH facility to accelerate pulses of 800 bunches with the highest possible charge. After reaching stable conditions with these parameters, a new photocathode laser was installed in the FLASH photoinjector, which operates with the triple frequency of the present laser, making it possible to produce 2400 pulses in one train. The combination of high electron bunch charges and long pulse trains is planned for further tests to take place after the scheduled FLASH shutdown.

When operating under full load, the accelerators will produce pulses of up to 2400 bunches in 800 microseconds at a beam current of 9 milliamperes. This will generate high collision rates at the ILC, and an amount of up to 30 000 X-ray laser flashes per second at the European XFEL and FLASH.

Accelerator control room

October

New force for the theory group

The DESY theory group has a new leading scientist to replace Peter Zerwas, who retired in 2007. Georg Weiglein joined DESY from the Institute of Particle Physics Phenomenology in Durham, UK. Weiglein will reinstate the working group on „Collider Phenomenology'' at DESY.
At the same time, Gudrid Moortgart-Pick took a post as W2 professor at Hamburg University in the framework of a common call from DESY and the university. She will also work on phenomenology at colliders, her professorship is targeted towards future project at DESY in particle physics.

New Helmholtz laboratory in HERA hall west

The detector lab for the high-energy physics groups that used to be in hall 5 to has moved to HERA hall west, home of the HERA-B detector. The laboratory now stands where HERA-B’s electronics hut used to be, and consists of parts of it – this allowed a stable and at the same time cost-effective construction of the laboratory.

The new detector laboratory in close neighbourhood to HERA-B.

In three laboratories of 70 square metres scientists and engineers develop future detectors, for example for the International Linear Collider ILC and the upgrade of the Large Hadron Collider LHC at CERN in Geneva – the sLHC. “We decided to use the HERA hall west because it is within reach for our students and guests and it is already equipped to house a detector,” says Felix Sefkow, deputy head of the FLC group. The new detector lab and existing facilities will be used for the activities within the framework of the Helmholtz Alliance and of the Cluster of Excellence with the University of Hamburg for many years.

November

DESY Open Day 2009 – a great day for everyone

At times DESY Open Day on 7 November seemed like a big funfair. There was a hustle and bustle in the tents and the halls, people were fascinated by the lectures on research, and the shuttle buses travelling on the campus were totally overcrowded. Many of the 800 helpers did not even have the chance to take a break. No matter what you pick to see, the DESY Open Day is always something special.

The DESY campus was open to the public for 12 hours. More than 13 000 visitors came to satisfy their curiosity, to broaden their horizons and simply for fun. They witnessed live research, listen to vivid explanations of research at DESY and the partner institutes. There were gummy bears on the stretching bank, chocolate marshmallows in the vacuum or the superconducting train; good examples to show that science is fun. Enthusiastic faces all around!.

In the builder's yard and the cabinetmaker's shop, in workshops and in the library, visitors had the opportunity to find out that the accelerator tunnel and science are not the only interesting things at the Hamburg accelerator centre. The main attraction was the HERA tunnel, opened especially for the occasion, with long queues at the gate.

Visitors at the ZEUS Microvertex detector.

The LHC is back

On 20 November, particle beams circulated once again in the world's most powerful particle accelerator, CERN's Large Hadron Collider (LHC). After 14 months of shutdown and repairs and a careful commissioning phase that started in summer, a clockwise circulating beam was established at ten o'clock in the evening on 20 November. Ten days later the LHC sets a new world record for beam energy with beams circulating at 1.18 TeV in both directions. Scientists in the CMS Remote Control Room at DESY watched first collisions at low energy coming in, marking important milestones on the way to the physics programme at the LHC.

The LHC control centre in Prevessin/CERN.

Precision for LHC from combined HERA data

The H1 and ZEUS collaborations have submitted three common publications, opening a new era of precision in the analysis of electron-proton data collected at the high energy collider HERA at DESY. The publications contain the result from an analysis performed by both experiments using the HERA collider data, which consists of up to 2 billion electron-proton interactions recorded over a period of 15 years between 1992 and 2007. The first of the publications, signed by 550 authors from 91 institutes and 30 countries, has now been accepted for publication by the peer reviewed Journal for High energy Physics (JHEP).

By combining their data the experiments achieve a significant increase in the sensitivity to the proton structure. The published data are of particular importance for the LHC.

The other two publications contain analyses of the events with energetic leptons in configurations that are only rarely produced in electron-proton collisions, according to the current theory of particle interactions, also known as the Standard Model. The studies, based on the full data set, observe a few spectacular events, the rate of which exceeds, but is still statistically compatible with the Standard Model prediction.

Global ILC test at KEK

Two DESY cavity packages arrived at the Japanese laboratory KEK on 3 December. They will be used for the S1-global experiment for the ILC, the demonstration of an eight-cavity cryomodule operating at an average accelerating gradient of 31.5 Megavolts per metre, the design gradient for the ILC. S1-global combines efforts and pieces of equipment from different collaborating laboratories: two superconducting cavities from DESY, another two from Fermilab, and four from KEK. They will be installed in two cryomodules, each six meters long: a new one designed and constructed in cooperation between Italy's INFN and KEK.

We turn 50! Successful past and fascinating future

DESY's anniversary year 2009 culminated in the birthday celebration on 18 December. They started in the morning, when nearly 800 DESY people gathered in hall 1. One of the guests was Ada Yonath who had just received the Nobel Prize in Chemistry. She congratulated the research centre, acknowledged the good support she got during her time as head of the Max Planck Ribosome Structure Working Group at DESY. She also gave her assistance at the party: she and the DESY Directorate cut the birthday cake, which measured one metre in width and one-and-

Signature of the State Treaty on the establishment of the foundation "Deutsches Elektronen-Synchrotron" in the Hamburg city hall on 18 December 1959.

a-half metres in length, and served it to the celebrating DESY staff. The anniversary day continued with the official part in the City Hall, where exactly on that date fifty years ago, the State Treaty on the establishment of the foundation "Deutsches Elektronen-Synchrotron" was signed.

German Research Computer QPACE is the most energy efficient in the world

The high-performance computer QPACE (QCD Parallel Computing on the Cell) , developed by an international consortium in which DESY play a central role, is the most energy-efficient supercomputer in the world. It is the top entry on the Green500 list, which provides a global ranking of energy-efficient supercomputers. QPACE was developed by an academic consortium of universities and research centres as well as the German IBM research and development centre in Böblingen within the framework of a state-sponsored research association. The QPACE core team consists of about 20 scientists and developers.

A number of scientists from DESY in Zeuthen contributed to this project. They headed the design activities and made contributions including development and implementation of the logics for a new user-optimised network, as well as design and production of a management card for the global control of the machine. The collaborators made use of their experience gained in previous projects for the development of massively-parallel computers.

OLYMPUS to replace ARGUS

The DESY directorate approved a new experiment to explore the nature of the proton: OLYMPUS. The detector consists to a large extent of the BLAST detector, operated from 2002 to 2005 at the BATES accelerator at MIT in the United States. It will be installed at the former site of ARGUS at the DORIS ring.

DORIS is one of the only facilities in the world where the pre-accelerators can be operated with both electrons and positrons. Moreover, it is possible to switch from one to the other kind of particle within ten minutes. Both kinds of particles are shot onto a hydrogen target inside the detector and possibly provide evidence of so far undiscovered higher-order contributions. OLYMPUS is a comparatively small experiment. The complete detector weighs only about 50 tons – a lightweight, compared to, for example, the 3600 tons of the HERA experiment ZEUS.

A number of small alterations to DORIS are necessary, which will only take place when DORIS does not provide beams for synchrotron radiation users. Since the use of DORIS for OLYMPUS is not possible during the operation of DORIS as a light source and the operation of PETRA III, OLYMPUS will only take data when neither accelerator is running for user operation.

The first series of measurements will start at the beginning of 2012; the second follows at the end of that year. "In these three months of measuring time we can collect enough data to learn more about the inside of the proton," says Uwe Schneekloth, one of two technical coordinators of the experiment.

Research Topics.

HERA, the strong interaction laboratory.

Studying the internal structure of the proton

The unique initial state at HERA provides an ideal QCD laboratory to probe the underlying theory as well as the structure of the proton, which is described by the structure function formalism. Hence determinations of the different structure functions have from the beginning been at the core of the HERA research programme. From these one obtains universal parton density functions, which are an essential input to any Standard Model prediction at the LHC. This analysis presents the most accurate cross section measurement to date for the inclusive neutral current process $e^+p \rightarrow e^+X$, measured in the kinematic region $12 \leq Q^2 \leq 150$ GeV^2 and $2{\cdot}10^{-4} \leq x \leq 0.1$.

The scattering of electrons on protons is a well-established method to investigate the internal structure of the proton. Early experiments demonstrated the finite size of the proton (~ 10^{-15} m) and identified its partonic content, the quarks and the gluons. Increasing centre of mass energies allowed smaller and smaller distances to be resolved in deep inelastic scattering (DIS) experiments. The distance δ probed is inversely proportional to the momentum transfer Q exchanged between the electron and proton. With HERA, distances of δ ~ 10^{-18} m can be accessed. One highlight result of H1 published in 2009 concerns a measurement of the cross section for inclusive e^+p interactions with unprecedented precision. The cross section is measured as a function of two variables, the square of the momentum transfer Q^2 and the fraction x of the proton's momentum carried by the struck quark. The phase space covers medium momentum transfers ($12 \leq Q^2 \leq 150$ GeV^2) and goes down to low x ($2{\cdot}10^{-4} \leq x \leq 0.1$). An essential aspect of this analysis is the best possible accuracy of the cross section measurement. The final uncertainties on the cross section vary between 1.3 – 2%, which is an improvement of a factor of 2 compared to previous measurements.

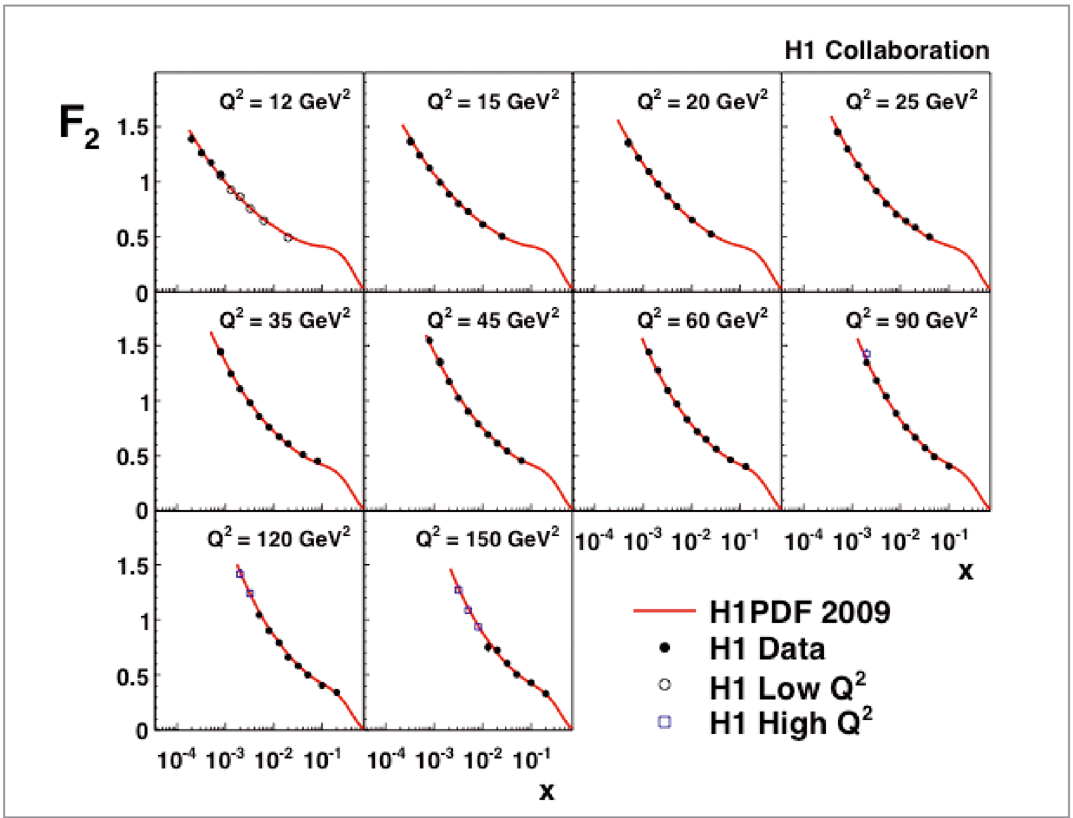


Figure 1

Measurement of the proton structure function F_2 as a function of x for different values of Q^2. The curve represents the H1PDF 2009 QCD fit.

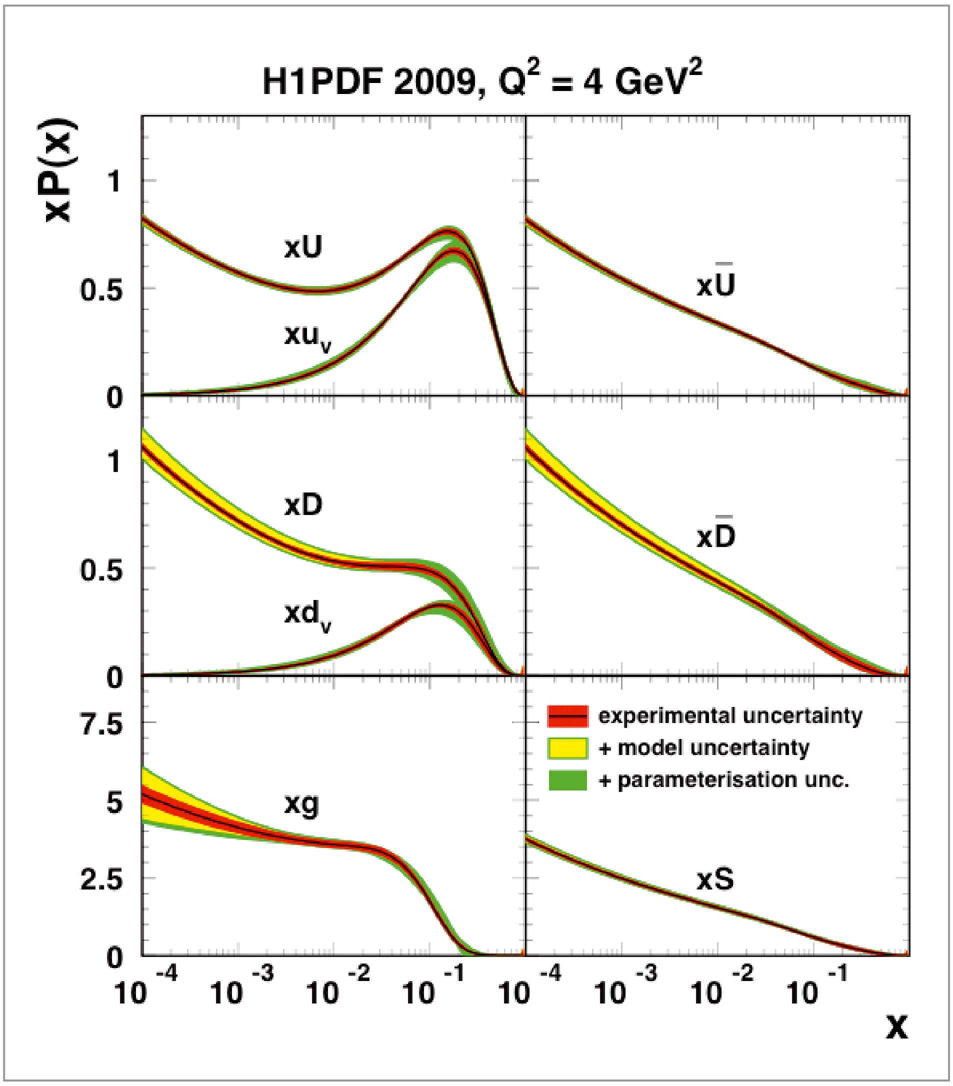


Figure 2

Parton distributions as determined by the H1PDF 2009 QCD fit at $Q^2 = 4$ GeV^2. The bands show the size of the different sources of uncertainties.

From the measured double differential cross section $\sigma(x,Q^2)$ the proton structure function $F_2(x,Q^2)$ is derived. This function describes the momentum distributions of the partons (PDFs) in the proton probed at a scale Q^2. The measured structure function F_2 is shown in figure 1 as a function of x for 10 bins in Q^2. For each Q^2 bin there is a strong rise of the structure function for $x \to 0$, which indicates a large sea quark density. The rate of the rise increases with increasing Q^2, which is a signature of a large gluon density.

The new medium Q^2 data discussed above together with already published H1 data for higher Q^2 Neutral Current (NC) and Charged Current (CC) scattering are used as sole input to a next-to-leading-order (NLO) QCD analysis. In this analysis the parton distributions, which cannot be predicted by QCD, are parameterised at a starting scale Q_0^2. The evolution to other scales is then governed by the principles of QCD. In the fit to the measured $F_2(x,Q^2)$ the PDF parameters are then determined. The very good description of the data by this fit, as seen in Fig. 1, clearly supports the underlying QCD principles.

The parton density functions resulting from the QCD fit are shown in Fig. 2 for a resolution scale of $Q^2 = 4$ GeV^2. The uncertainties in all different PDFs have been reduced significantly compared to previous determinations. It is remarkable that due to the high precision of the measured cross sections the experimental uncertainty is for all PDFs in most regions of x small compared to the total uncertainty. The model- and parametrisation uncertainties dominate in general the total error on the PDFs.

These PDFs constitute up to now the most accurate determinations of the parton distributions in the proton from a single experiment. This will be of very high value concerning the physics interpretations of any forthcoming LHC results. In order to predict cross sections at LHC energies PDFs have to be evolved from the HERA region to the very high scales at LHC. The precision of the PDFs achieved in this analysis and the proof of the validity of the QCD evolution scheme achieved here will allow accurate predictions for cross sections at LHC, for example for the production of the Higgs boson in gluon gluon fusion processes.

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Authors and References:

H1 Collaboration

Eur. Phys. J. C64 561(2009)

The strength of the strong force.

How sticky is the gluon?

Being one of the four fundamental forces in nature, the strong interaction between quarks results from the exchange of gluons that couple to the colour charge of the quarks. Quantum Chromodynamics (QCD), the theory of the strong force, predicts how the strength of the colour force, which is characterised by the strong coupling constant α_s, depends on the distance between the partons. At HERA, the measurement of the rate of jet production as a function of the resolution parameter Q that corresponds to the momentum transfer between electron and scattered quark, provides a fundamental test of the details of QCD. Increased statistics has enabled improved measurements of inclusive jet, 2-jet and 3-jet cross sections, which are used to extract the strong coupling constant with significantly reduced error.

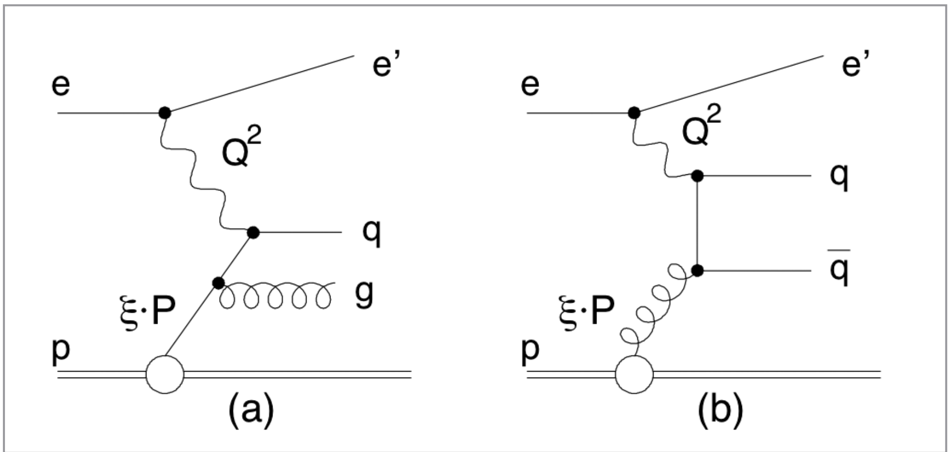

Figure 1

Two processes contribute to jet production in deep-inelastic lepton-proton scattering at order $O(\alpha_s)$: (a) QCD Compton scattering and (b) boson-gluon fusion.

In neutral current (NC) deep-inelastic scattering (DIS) the quark that is struck by the exchanged photon may radiate additional high-energy gluons in a way similar to how accelerated electrons radiate photons. The probability for such processes is proportional to the value of the strong coupling constant α_s. One of the specific features of the strong interaction is that α_s decreases as the distance between the partons becomes smaller, leading to what often is referred to as "asymptotic freedom". At large distances, however, the force gets so strong that the struck quark and any radiated energetic gluon cannot escape from the proton as free particles. This characteristic facet of QCD is known as "confinement": instead of coloured partons a number of colourless particles grouped into so-called jets emerge from the interaction and only those can be detected by experiments. Jet production at HERA therefore provides an important testing ground for Quantum Chromodynamics (QCD). While inclusive DIS only can yield indirect information on the strong coupling via scaling violations of the proton structure functions, the production of jets allows a direct measurement of α_s. At leading order (LO) in the strong coupling constant α_s jet production in DIS proceeds via the so-called QCD-Compton (Fig. 1a) and boson-gluon fusion (Fig. 1b) processes.

The H1 collaboration has recently published two jet measurements which mainly differ in the range of the negative four momentum transfer squared Q^2 that is covered by the two analyses. In the first publication, ratios of jet cross sections to the corresponding NC DIS cross sections are measured in the region $150 < Q^2 < 15000$ GeV^2. These normalised cross sections benefit from a partial cancellation of experimental and theoretical uncertainties. The measurements are then compared with perturbative QCD (pQCD) predictions at next-to-leading order (NLO) corrected for hadronisation effects, and α_s is extracted

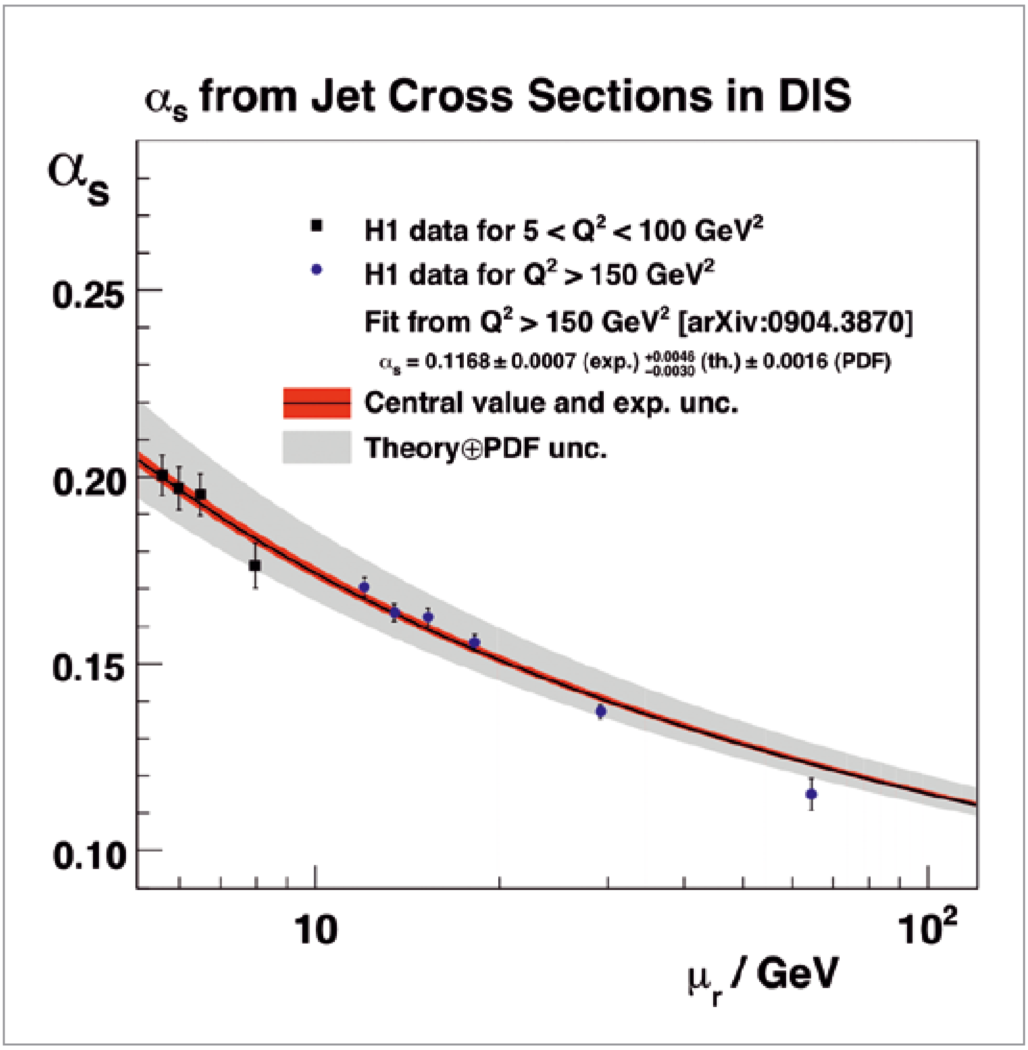

Figure 2

Values of the strong coupling constant evolved from the scale M_Z to the average μ_r in each region for the two analyses described in the text. The solid line shows the two-loop solution of the renormalisation group equation using only the high Q^2 data. Very good agreement with the low Q^2 results can be observed.

from a fit of the predictions to the data. This experimentally most precise determination of $\alpha_s(M_Z)$ yields:

$$\alpha_s(M_Z) = 0.1168 \pm 0.0007 \text{ (exp.) } {}^{+0.0046}_{-0.0030} \text{ (th.) } \pm 0.0016 \text{ (PDF).}$$

The largest contribution to the total error by far is of theoretical origin and is dominated by the renormalisation scale dependence, which is used to estimate the effect of missing higher orders beyond NLO in the pQCD prediction. This measurement improves the experimental precision on α_s determinations from other recent jet measurements at HERA. The result is competitive with those from e^+e^- data and is in good agreement with the world average.

In the second publication, new measurements of the inclusive jet, 2-jet and 3-jet production cross sections, as well as the ratio of 3-jet to 2-jet cross sections, are performed in the range $5 < Q^2 < 100$ GeV^2, where the QCD-Compton process dominates. Compared to earlier HERA measurements in this kinematic range the larger data set together with improved understanding of the hadronic energy measurement help to significantly reduce the total uncertainty of the cross section determination. The precision of the measurements is typically in the range from 6 to 10 %. As for the high Q^2 data the results are compared with perturbative QCD predictions at NLO corrected for hadronisation effects, and α_s is extracted from a fit of the predictions to the data. The extracted value of the strong coupling constant

$$\alpha_s (M_Z) = 0.1160 \pm 0.0014\text{(exp.) } {}^{+0.0093}_{-0.0077} \text{ (th.) } \pm 0.0016 \text{ (PDF)}$$

is consistent with the value determined from the high Q^2 jet cross sections as can be also inferred from Fig. 2, where the individual measurements are shown as a function of the renormalisation scale μ_r for both analyses. The measurements allow the running of the strong coupling to be tested down to the limits of the perturbative calculation. Together with the high Q^2 measurements these data test the running of α_s in the range of renormalisation scale between about 6 and 70 GeV.

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The Standard Model at highest Q^2.

Final results on neutral- and charged current cross sections in electron-proton scattering.

In HERA II the number of recorded electron-proton collisions was 10 times larger than in HERA I. In 2009 ZEUS published the measurement of the neutral- and charged-current cross sections using these data. The results are the key ingredient to separate up- and down-type valence quark distributions in the proton and to perform the most precise measurement of the parity-violating structure function xF_3.

In the Standard Model of particle physics the electromagnetic and the weak forces are described as two manifestations of one fundamental underlying symmetry principle. At HERA one observes these manifestations in the form of the neutral-current (NC) and charged-current (CC) interactions. Neutral currents are mediated by neutral bosons, the massless photon and the very heavy Z boson. Charged currents are only mediated by the heavy charged $W^{\pm}$ bosons. These exchanges lead to very different configurations in the detector and very different dependences on the momentum transfer. In neutral-current events one observes the scattered electron. NC events are balanced in the transverse plane. The cross section falls very rapidly with the fourth power of the momentum transfer. In contrast, CC events have large missing transverse momentum due to the

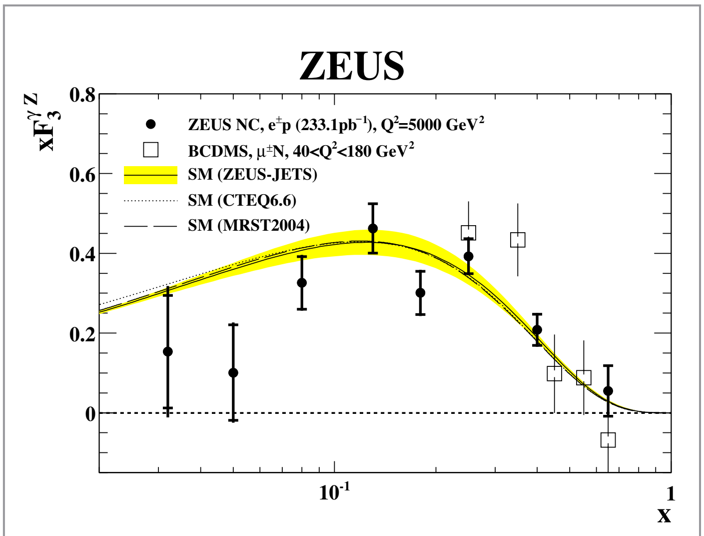

Figure 1

The structure function $xF_3^{\gamma Z^0}$ plotted as a function of x at fixed Q^2. The closed circles represent the ZEUS data. The open squares are the only other data available from the BCDMS collaboration. The inner error bars show the statistical uncertainty while the outer ones show the statistical and systematic uncertainties added in quadrature. The curves show the predictions of the Stabdard Model evaluated using the ZEUS-JETS PDFs with the shaded band indicating the uncertainties

neutrino, which escapes undetected. At low energy, the cross section is strongly suppressed relative to the neutral current one. But its decrease with energy is less dramatic. At values of the momentum transfer comparable to the mass of the heavy bosons, the two cross sections are of similar magnitude.

Precise measurements of the cross sections for these two types of processes with different lepton flavours and with different polarisations of the lepton beam are at the core of the HERA II programme. In 2009, ZEUS completed the analysis of the HERA II electron-proton data. This sample is a factor 10 larger than the previously analysed HERA-I electron-proton sample. Fig. 1 shows the parity-violating structure function xF_3, which was extracted from the new measurements and from the previously published analysis of the HERA I positron-proton data. The quantity xF_3 is the charge-weighted difference of quark and anti-quark distributions in the proton. This difference is equivalent to the valence quarks. The structure function xF_3 would be zero except for the presence of Z exchange. As can be seen, the quality of the data is a vast improvement over the only other previously available results, which are from the BCDMS collaboration. Thus these results provide information of unprecedented quality about the valence quark content in the proton. Scientifically, this information stands by itself. However, it is also of crucial value for analyses at the LHC where solid information about valence quark distributions is required to interpret measurements performed at the highest reachable energies.

In the static picture, the proton is composed of two up quarks and one down quark. In terms of parton densities, this would correspond to the case of up-type quarks carrying exactly two thirds of the momentum and down-type quarks the remaining one third. In the dynamic QCD picture of the proton, which also includes gluons, the situation is more complex. However, it is important to establish how the simple basic ideas translate to the complete QCD picture. Hence, in addition to separating the valence quarks, one should also separate up- and down-type quarks. This is achieved using measurements of the CC cross sections. In electron-proton collisions, the exchange proceeds via W^- bosons and, correspondingly, in positron-proton collisions it proceeds via W^+ bosons. These bosons couple only to up- and down-type quarks respectively. Hence, comparing measurements done using electron-proton and positron-proton samples, one separates up- and down-type quarks. The effect is demonstrated in Fig. 2 where the CC cross section is shown as a function of the Bjorken scaling variable x in 9 different bins of Q^2 up to the highest values reachable at HERA. It can be seen that the data are in good agreement with the Standard Model descriptions shown as the continuous lines. This in itself is a beautiful confirmation of the Standard Model. In addition it is noteworthy to consider the relative magnitude of the dashed and the dotted red lines. They correspond to the up- and down-type quark contributions to the total CC cross section. At the highest values of Q^2, the contribution to the CC cross section coming from down-type quarks completely dominates the cross section, just as one would expect if there were only valence quarks. At the smallest value of Q^2 the up-type quarks still dominate but there is also a sizeable down-type contribution which comes from the sea quarks.

Together with positron-proton data one thus obtains a clean separation between the different ingredients in the proton. The corresponding analyses will be published during 2010 thus providing a complete and consisting picture of deep inelastic scattering on the proton in the complete HERA kinematic region.

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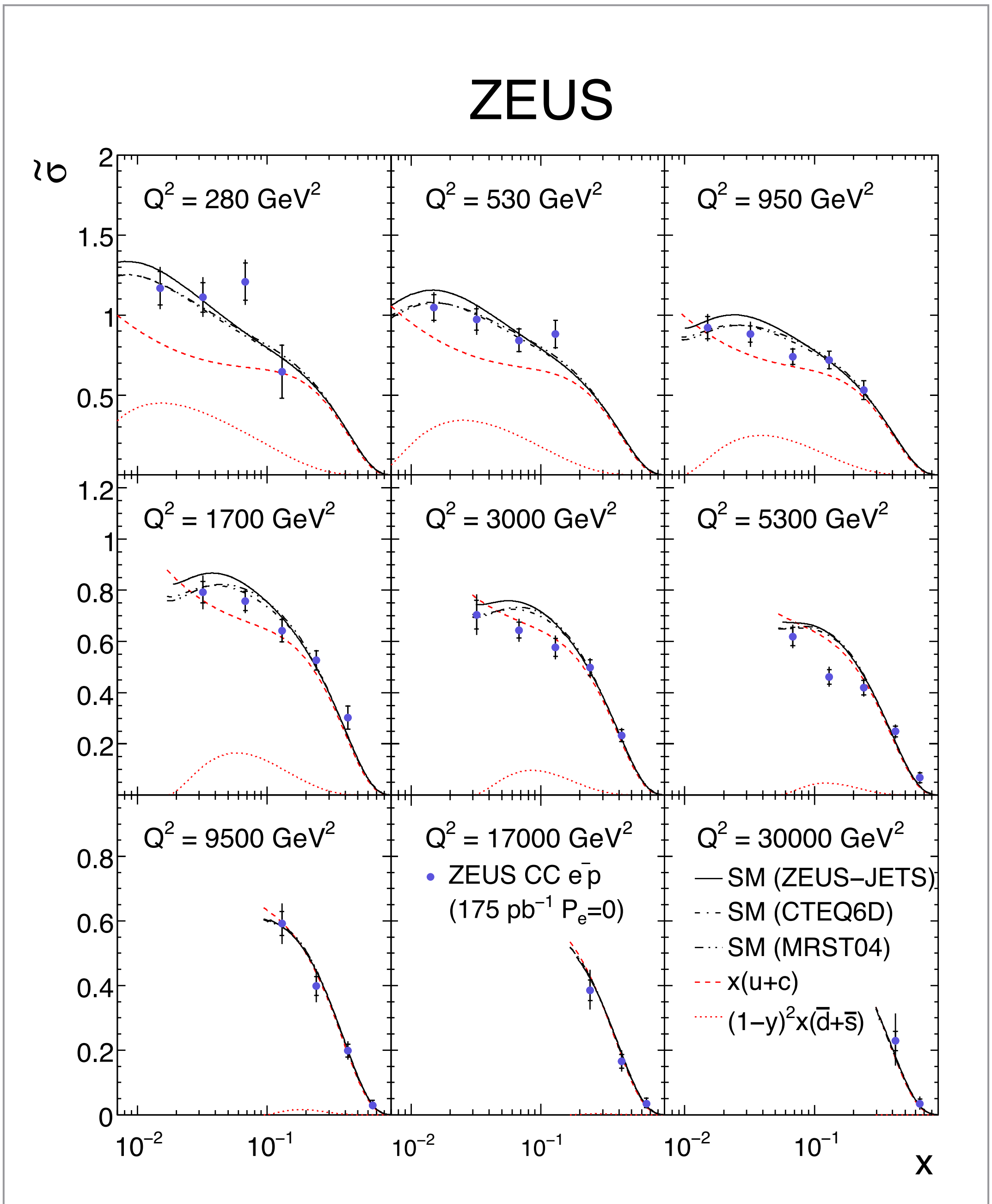

Figure 2

The e^-p CC DIS reduced cross section plotted as a function of x for fixed Q^2. The circles represent the data points and the curves show the different predictions of the Standard Model evaluated using the ZEUS-JETS, CTEQ6D and MRST04 PDFs. The dashed and dotted lines show different contributions of the PDF combinations $x(u + c)$ and $(1 - y)2x(\bar{d} + \bar{s})$, respectively

Diffraction described by perturbative QCD.

A consistent treatment of diffraction at HERA in terms of perturbative QCD

In a recent publication the ZEUS collaboration showed that all diffractive processes at HERA could be consistently described in the framework of perturbative QCD with no need for suppression mechanisms. This work paves the way for future studies at the LHC where diffractive scattering will provide a very clean laboratory for searches for new physics.

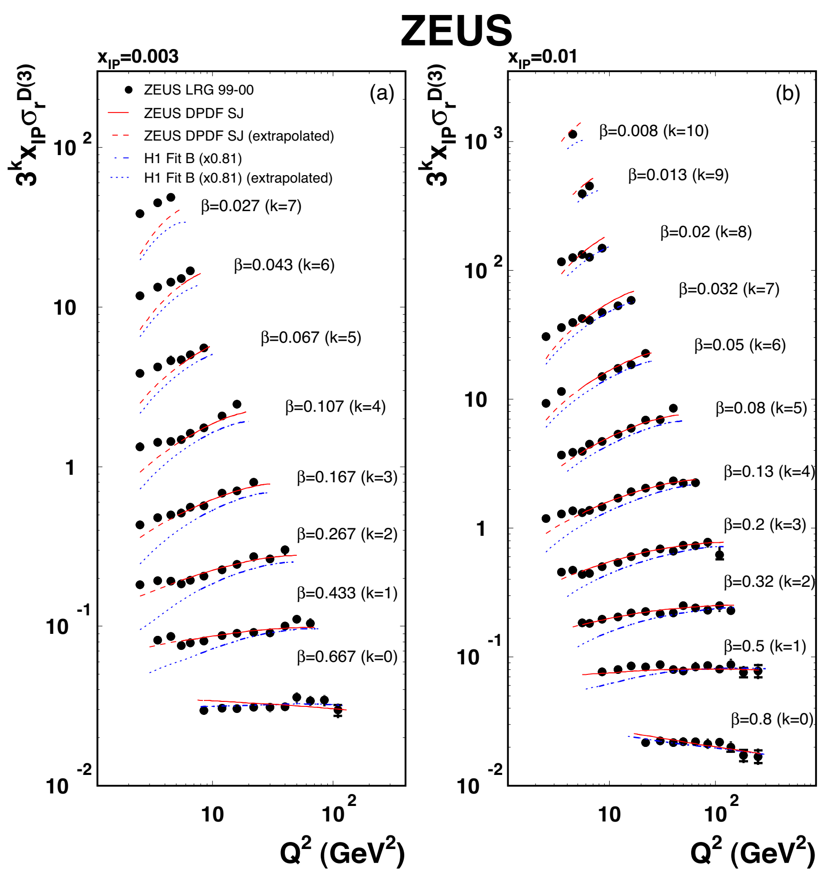

Figure 1

The fit ZEUS DPDF SJ (continuous line) and H1 Fit B (dashed–dotted line) compared to the ZEUS LRG data at (a) x_P = 0.003 and (b) x_P = 0.01 as a function of Q^2 for different β values. Where visible, the inner error bars show the statistical uncertainties and the full bars indicate the statistical and systematic uncertainties added in quadrature. The H1 predictions are corrected to $M_N = m_P$ via the scaling factor 0.81. The dashed (dotted) lines represent the DGLAP extrapolation beyond the ZEUS (H1) fitted region.

The process of diffractive scattering has been known for a long time and has been extensively studied in hadron-hadron collisions. It was phenomenologically described in terms of Regge theory and seen as a soft phenomenon that would not be present in hard interactions. Therefore, it came as a surprise when a sizable diffractive contribution, amounting to as much as 15%, was found in Deep Inelastic Scattering (DIS) at HERA through the observation of large-rapidity-gap events. In these processes, the proton escapes intact even though the point-like photon interacted with a small configuration inside the proton.

In the naïve picture of deep-inelastic interactions, such processes do not occur with a sizeable rate because the proton is described as a gas of uncorrelated quarks and gluons. The photon knocks out one of these partons, leaving behind a colored state, and hadronisation occurs between the struck parton and the proton remnant, effectively filling the “gap” between struck quark and remnant with hadrons. The existence of a large diffractive component at high Q^2, or equivalently, the presence of rapidity gaps, shows that the structure of the proton is indeed not gas-like. Strong correlations exist between partons that make the proton “grainy,” so that the interactions

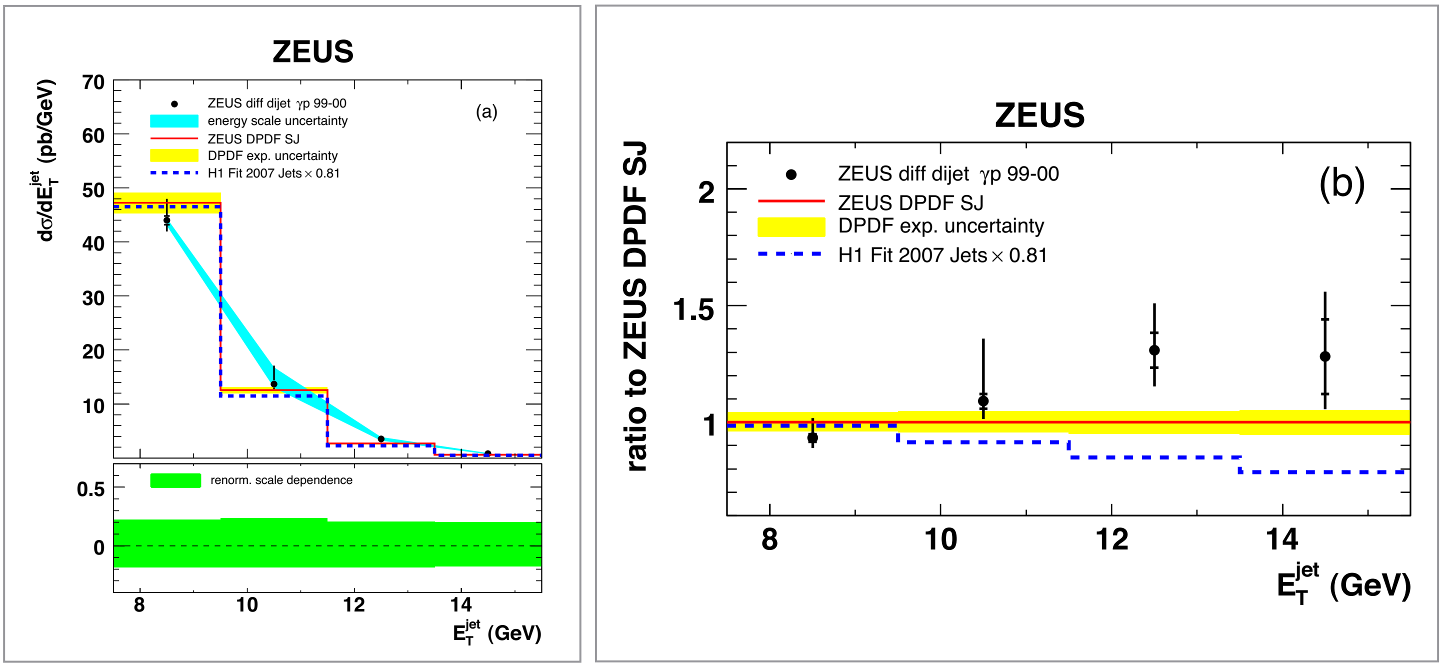

Figure 2

(a) ZEUS DPDF SJ predictions compared to the ZEUS diffractive dijet photoproduction data as a function of E_{jet}. The predictions from H1 Fit 2007 Jets are also shown, corrected to $M_N = m_p$ via the scaling factor 0.81. (b) Ratio of the data and of the H1 predictions to ZEUS DPDF SJ predictions.

take place between the photon fluctuating into a quark-antiquark pair and a colour-less correlated state made of more than one parton inside the proton. In QCD this state comprises at least two gluons and is sometimes called the Pomeron.
One key question related to diffractive scattering is the following: Is this picture of the diffractive exchange universal? Expressed in other words: Is it a generic property of the proton independent of the probe or does it depend on the probe or other details of the scattering process? The answer to this question is of great interest for experiments at the LHC where the magnitude of the diffractive cross section to be expected is not known and where diffractive processes are being considered as a particularly interesting, clean environment in which to look for new physics.

In a paper published in 2009, the ZEUS collaboration could show that all the diffractive phenomena at HERA can consistently be described by perturbative QCD. For this purpose, a QCD fit of diffractive parton distribution functions (DPDFs) was performed to the reduced diffractive DIS cross-section and to diffractive dijet data. In this fit the behaviour of the observable quantities as functions of relevant scale parameters such as momentum transfer, Q^2, or jet transverse energy, E_T, is described by the QCD evolution equation, commonly called the Dokhshitzer-Lipatov-Altarelli-Parisi (DGLAP) equation. As shown in Fig. 1 this procedure yields a good description of the ZEUS data except at values of Q^2 below 10 GeV^2.

If DPDFs are universal, then one can use them to make predictions for other processes such as hadron-hadron collisions at the Tevatron or at the LHC. However, older results from the CDF collaboration at the Tevatron indicate that diffractive processes are much less abundant in a hadron-hadron environment than one would expect from the HERA data. If this is indeed true, one needs to invoke additional mechanisms that suppress the underlying diffractive exchange thus spoiling the simple picture. In the analysis discussed here, the ZEUS collaboration showed that the DPDFs extracted in deep inelastic scattering can also be used in real photon-photon collisions to describe diffractive dijet events. This is illustrated in Fig. 2, which shows the cross section for dijet production in real photon-proton collisions (photoproduction) as a function of the transverse energy of the jets. The prediction obtained from the DPDFs gives an excellent description of the data with no need to invoke any suppression mechanisms. Why would this result be relevant for hadron-hadron collisions? The reason is that the real photon, which on the one hand can be seen as the point-like carrier of the electromagnetic force, according to the Vector Dominance Model (VDM), also very much behaves like a hadron. This is intuitively clear from Heisenberg's uncertainty principle that states that the quasi-real photon ($\Delta Q \approx 0$), which has a small extension in momentum space, must have a large extension, Δx, in configuration space.

Thus, it is firmly established that DPDFs from HERA are universal and are applicable at the LHC. These results pave the way for further studies at the LHC, or at a future electron-ion collider, at which diffractive scattering will provide a very clean laboratory to test many aspects of the Standard Model and also to search for new physics.

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HERA combined results.

H1 and ZEUS predict Standard Model physics at the LHC with unprecedented precision

At HERA a new level of experimental precision is obtained from the combination of data sets from the H1 and ZEUS experiments. Thus the structure of the proton is measured with unprecedented precision down to values of Bjorken-x ≈ 10^{-5}. Also, searches for events with isolated leptons are presented in a coherent analysis. The combined analyses ensure the optimal output from the experimental programme.

High-energy physics experiments address fundamental questions using large facilities and complex detectors, which often use innovative detection techniques. It is usual to build and operate more than one such detector at the same accelerator, to confront, compare and eventually combine the measurements. Combining measurements made by similar detectors becomes feasible and ultimately mandatory when these detectors are well understood and tested with many physics analyses.

So far, individual measurements investigating a plethora of different processes have been published by H1 and ZEUS in more than 400 scientific articles. Recently, three common publications were accepted by the Journal of High Energy Physics (JHEP). In these publications a new paradigm is addressed by combining the H1 and ZEUS data in coherent analyses.

The structure of the proton at unprecedented precision

One of the papers submitted for publication recently by the H1 and ZEUS collaborations contains a combination of more than 1402 individual measurements from 14 publications to obtain 741 cross section measurements with unprecedented precision. All available data on neutral and charged current interactions taken during the first phase of HERA running from 1992 – 2000 are used. The data cover virtualities of the exchanged bosons from 0.2 GeV^2 up to the highest values reachable at HERA of around 30000 GeV^2 and values of Bjorken x from 0.2×10^{-6} to almost 1. Thus, these data extend from regions where perturbative QCD was never tested to the electro-weak regime. At very small values of Bjorken-x, $x < 10^{-2}$, no other measurements exist. In this region the gain of the combination is impressive: the individual measurements were dominated by systematic errors, which are drastically reduced down to as little as 1%. Using these new data, a new set of parton distribution functions (HERAPDF 1.0) has been extracted. It is shown in Fig. 1 (left). This partonic content is universal and can be used to make predictions for other processes involving protons, for example cross sections in pp collisions at the LHC.

One such prediction in the Standard Model is the production of single weak bosons at the LHC as shown in Fig. 1 (right). This process can be seen as a “standard candle” and will be used for a luminosity determination. The precision of the corresponding theoretical predictions is dominated by the uncertainties originating from the knowledge of the proton parton distributions, which in turn come from the HERA measurements.

Ultimately, these measurements by H1 and ZEUS provide the standard candle against which any new phenomenon at the LHC in the mass range of up to a few hundred GeV will have to be compared. The new physics may well be in this range, in which case a precise knowledge of the production cross section would be absolutely crucial to explore the properties of these new particles.

Events with high energy leptons

New physics is predicted by many theoretical extensions of the Standard Model. According to these extensions, a peak in a mass spectrum or a deviation in a clever variable should be observable. However, new physics can also manifest itself beyond the “standard predictions” and show up as spectacular events, in regions of the phase space where only very few events should be seen according to the Standard Model. Events with energetic isolated leptons are an example of such a golden channel. They provide a clean signature and they benefit from robust predictions.

At HERA, as early as ten years ago, events with one isolated electron or muon and missing transverse momentum were reported. In the Standard Model this topology is explained by the production of a W boson, which decays to an energetic charged lepton and a neutrino. Initially a discrepancy with the Standard Model was observed by H1 amounting to as much as three standard deviations with no effect seen in ZEUS. In order to clarify this point a common analysis was undertaken. Combining the results leads to a decreased significance of the observed excess for events with large hadronic transverse

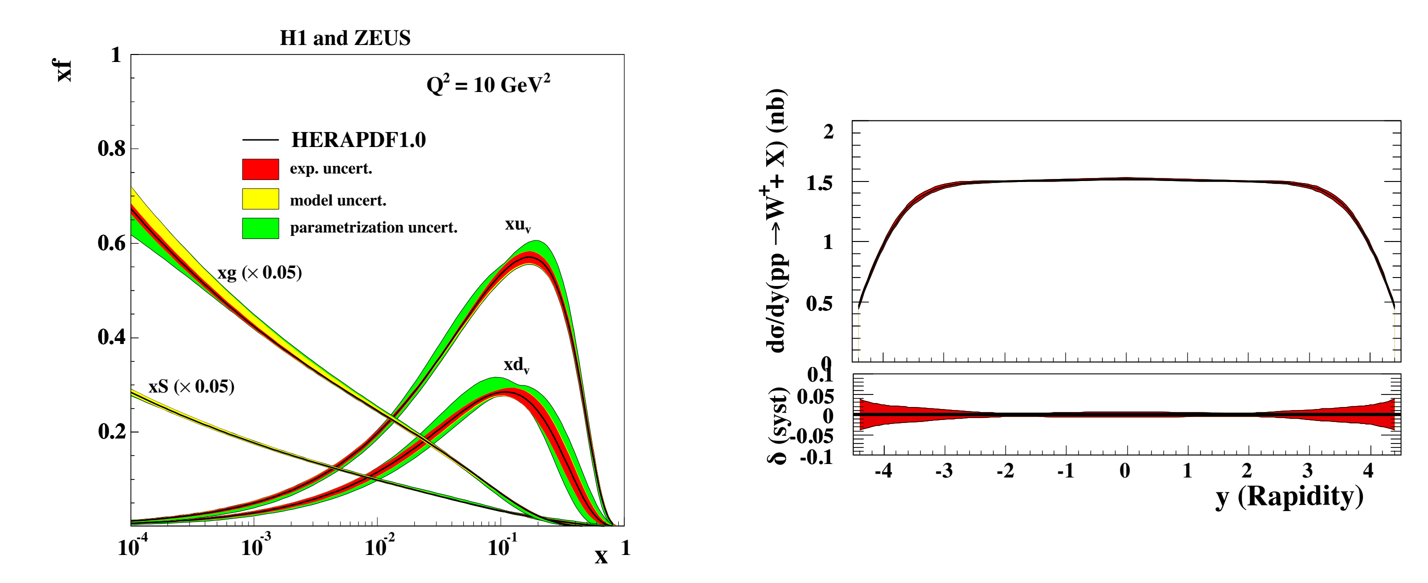

Figure 1

Left: The proton parton densities extracted from the combined H1 and ZEUS measurements, displayed for a virtuality $Q^2 = 10$ GeV^2. Right upper plot: The prediction for the production cross section of single W^+ bosons at the LHC af 14 TeV. Right lower plot: The cross section uncertainty which comes from the PDF uncertainty in the combined H1 and ZEUS analysis.

momentum to a level below two standard deviations, on the other hand it improves significantly the measurement of the W cross section. Thus this measurement becomes an important confirmation of the weak sector of the Standard Model in a unique configuration.

Events with more than one charged lepton are dominantly produced by photon-photon collision, the photons originating from the colliding electron and the protons. In individual analyses H1 and ZEUS found a few hundred events containing several leptons, both electrons and muons, at high transverse momentum with some events where the scalar sum of the lepton momenta exceeds 100 GeV. In a combined analysis, 7 events are observed in this region in e^+p collision for an expectation of 1.94±0.17, while no such event is observed in e^-p collisions for a similar expectation. The observation of the excess in e+p collisions is still compatible with the Standard Model and is interpreted as a statistical fluctuation. However, this observation stimulates discussions, since one could also attribute the excess to a bi-lepton resonance such as a doubly charged Higgs boson, H^{++}, produced predominantly in electroweak interactions thereby providing unique constraints on the gluon content of the proton in a region that is crucial for the precision physics at LHC.

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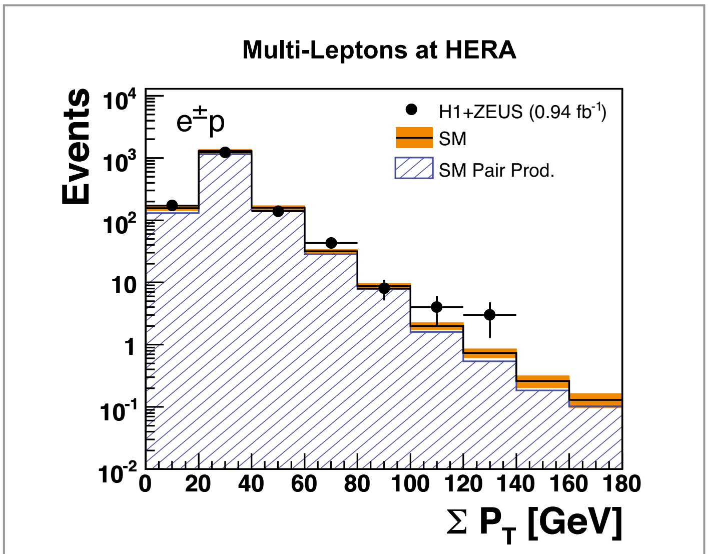

Figure 2

The distribution of the scalar sum of the leptons measured in multi-lepton events by the common H1 and ZEUS analysis. In the regions at $P_T > 100$ GeV, 7 events are detected for 1.9±0.2 predicted in e^+p collisions, while no event is observed in e^-p collision for a similar expectation.

Deeply virtual Compton scattering at HERMES.

Accessing the angular momentum of quarks in the nucleon

Hard exclusive leptoproduction of real photons (Deeply Virtual Compton Scattering, DVCS) is one of the cleanest ways to access Generalized Parton Distributions (GPDs). The theoretical framework of GPDs can provide a three-dimensional representation of the structure of hadrons at the partonic level. The HERMES experiment collected a unique data set on DVCS using the HERA 27.6 GeV polarised electron or positron beams with both beam helicities, and longitudinally and transversely polarised or unpolarised gas targets (H, D or heavier nuclei). The azimuthal asymmetries measured at HERMES allow access to information related to GPDs and as a result to the total angular momentum of quarks in the nucleon.

For the last two decades the internal structure of the nucleon has been intensively studied with the HERA accelerator at DESY. The HERMES experiment was built to get insight to the spin structure of the nucleon. At present many experiments including HERMES have demonstrated that only about 1/3 of the nucleon spin can be attributed to quark spins. Possible explanations could be non-vanishing contributions from gluon total and quark orbital angular momenta. The understanding of this 'missing part' of the nucleon spin is one of the most intriguing tasks of modern particle physics. The partonic structure of the nucleon has traditionally been described in terms of parton distribution functions. In recent theoretical developments these have been conceptually subsumed within the broader framework of Generalized Parton Distributions (GPDs), which also describe elastic form factors and hard exclusive reactions. These distributions allow to obtain a three-dimensional picture of the nucleon, correlating the longitudinal momentum fraction of partons with their transverse distance from the nucleon's centre. Furthermore moments of certain GPDs were found to relate directly to the total (including orbital) angular momentum carried by partons in the nucleon. GPDs are accessible through exclusive processes that involve at least two hard vertices, yet leave the target nucleon intact. In Deeply Virtual Compton Scattering (DVCS), the incoming lepton interacts via a virtual photon with a quark inside the nucleon, which radiates a real photon. A competing process is the Bethe-Heitler process, in which the real photon in the final state is emitted by the incoming or outgoing lepton. The two processes are experimentally indistinguishable and therefore interfere.

At HERMES energies the contribution from the Bethe-Heitler process dominates the ones from DVCS and interference, which are those of interest. In order to gain access to these small contributions, asymmetries, i.e. ratios of counting rates, can be extracted from data. The difference of the number of events with, e.g. different helicity or charge state, enters in the numerator and its sum in the denominator. In this way effects from the geometric and kinematic acceptance cancel to a certain degree. HERMES is a unique experiment because it used electron and positron beams with both beam helicities provided by HERA and operated unpolarised and longitudinally polarised hydrogen and deuterium targets and transversely polarised hydrogen target. Due to this fact, for unpolarised hydrogen and deuterium targets three different asymmetries could be accessed. Two of them are sensitive to the interference term and one to the squared DVCS amplitude. The results are fitted the azimuthal angle ϕ between the lepton scattering plane and the photon production plane (the transverse target-spin direction). The various asymmetry amplitudes extracted from HERMES data are shown in Fig. 1.

Most of the amplitudes measured are compatible with zero. The beam-charge asymmetry amplitude $A_C^{\cos\phi}$ and the beam-spin asymmetry amplitude $A_{LU,I}^{\sin\phi}$, sensitive to the interference term, show a significant non–zero value. In contrast, the amplitude $A_{LU,DVCS}^{\sin\phi}$, sensitive to the squared DVCS amplitude, is found to be compatible with zero. Different asymmetry amplitudes measured at HERMES are sensitive to different GPDs and therefore provide severe constraints on GPD models. Within these models the present results can be combined with measurements of other asymmetry amplitudes or various other observables to access the total angular momentum of quarks inside the target nucleon, to better understand the spin structure of the nucleon.

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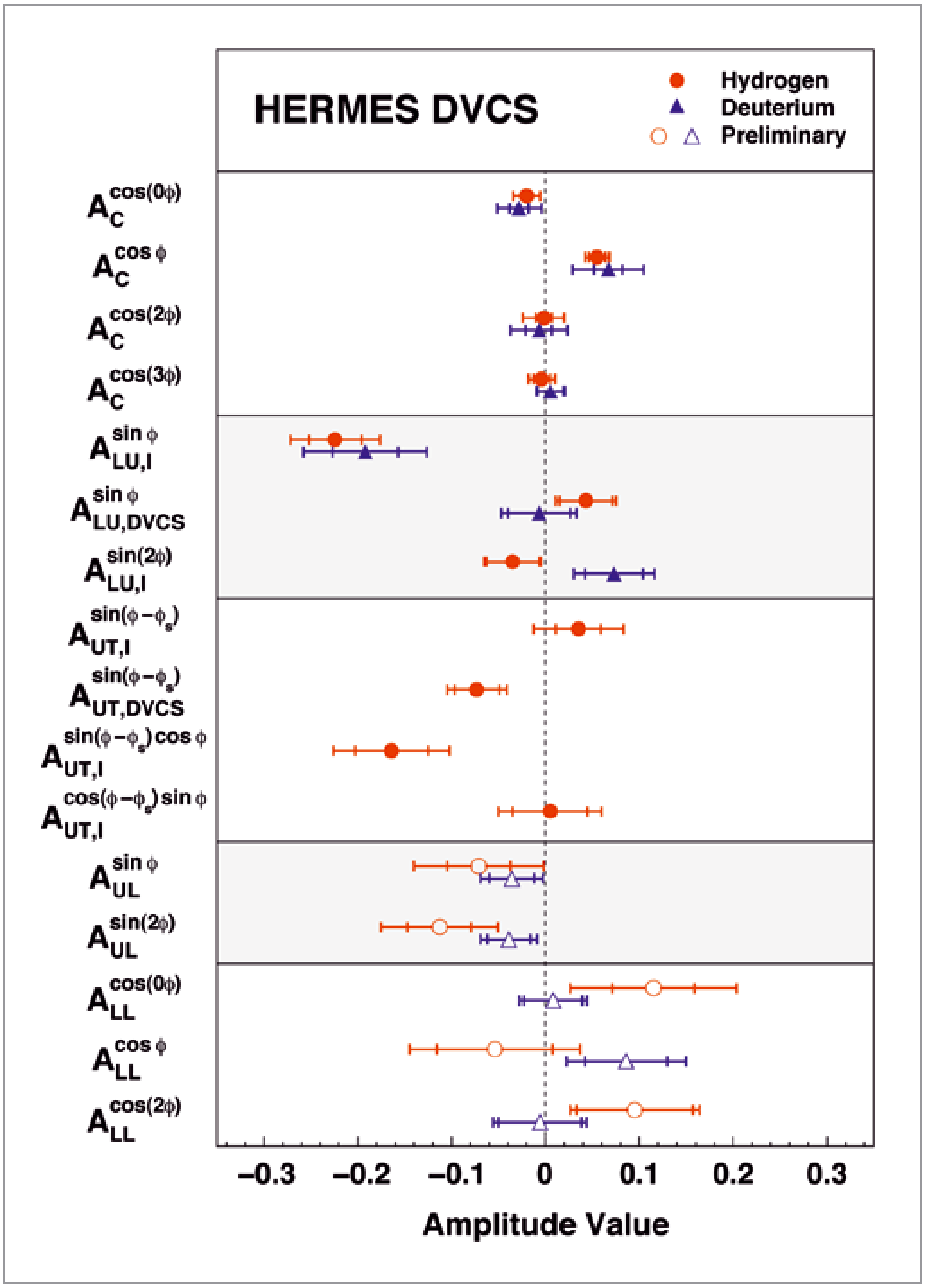

Figure 1

Asymmetry amplitudes measured at HERMES. By full (open) symbols published (preliminary) results are presented. Data collected with hydrogen (deuterium) target are shown by circles (triangles). The inner (full) error bars represent statistical (systematic) uncertainty. Amplitudes are grouped according to various experimental conditions, where A_C refers to the beam-charge asymmetry and A_{XY} refer to beam (X) and target (Y) polarisation states where U stands for unpolarised, L and T stand for longitudinal and transverse polarisation, respectively.

Orbiting quarks and the Sivers effect.

Isolating contributions to the proton's spin

Scattering the 27.6 GeV leptons of HERA from a nuclear-polarised proton target provides insights in the spin structure of the proton. From 2002 until 2005 HERMES injected transversely polarised protons into the storage-cell target internal to the HERA lepton ring. The azimuthal distribution of final-state pions and charged kaons about the direction of the virtual photon exchanged was analysed to isolate the Sivers effect, the latter being closely tied to orbital angular momentum of quarks inside the proton and thus to one unknown contribution to the proton spin.

The exploration of the tiniest building blocks of matter is the core task of the experiments performed at DESY with the HERA accelerator. For sake of simplicity, we can imagine the nucleon as made of a bunch of partons, quarks and gluons, very tightly joined together. In a typical deep-inelastic scattering collision, the nucleon races fast in one direction to meet an electron coming in from the opposite direction. Each of the partons carries a fraction x of the momentum of the nucleon, so that they all add up to make a prodigious total momentum. Nowadays, we know accurately how the total momentum is shared among the partons. But the structure of the nucleon is much more intricate and fascinating. Partons do not move all in the same direction in an orderly manner. They wander around also in directions transverse to the nucleon's path. We would like to have a picture of the nucleon in all directions. We want to know the shape of the nucleon in momentum space: does it look like a pancake, or a bagel, or something weirder? Moreover, nucleons have spin, which roughly means that the partons inside the nucleon collectively spin or revolve to generate the total spin of the nucleon. One of our goals is to pin down how much of the proton spin is built up by the partonic spins or their orbital angular momentum.

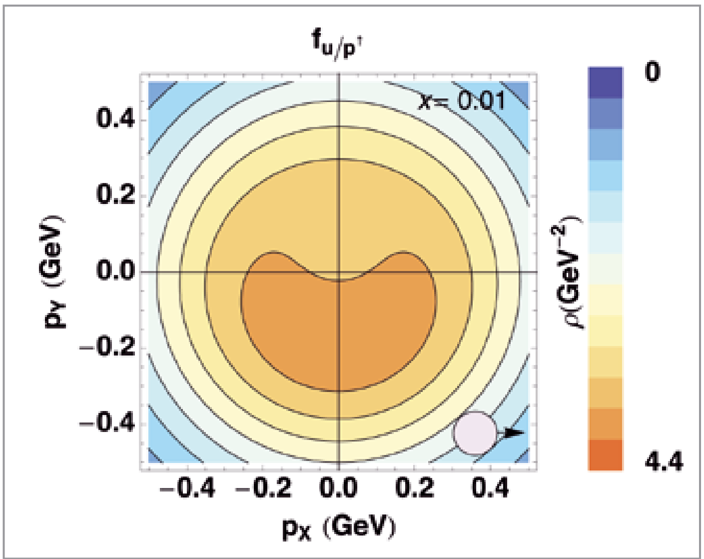

Figure 1

Sivers distribution of up quarks as expected in a model calculation. For a proton polarised to the right more quarks are found moving downward (i.e., they are found with negative momentum in the y-direction) than moving upwards.

There can be correlations of all kinds between the spin of the nucleon, the spin of the partons, and their momenta. Each kind of correlation can teach us something new about the way partons are organised inside the nucleon and can help us estimate how large the contribution of partonic angular momentum to the spin of the nucleon is.

The present article presents a measurement related to a specific correlation between the spin of the nucleon and the momentum of the partons. This kind of correlation is called Sivers function and is strongly related to the orbital angular momentum carried by the partons. Fig. 1 shows an example how theorists picture this correlation. It depicts the momentum density of up quarks in a nucleon moving out of the page that has its spin directed to the right. In this case up quarks with a fixed momentum fraction x are more likely to be found moving downward than upward.

In a concrete experiment it is not possible to directly observe how partons are moving inside the nucleon. Rather, we see the effect of the primordial partonic motion through the distribution of the debris after a deep-inelastic collision. We keep the nucleon polarised in, e.g. the upward direction, we point the beam of electrons into it and we look at distortions in the ensuing shower of particles. If we notice that some particles prefer to go to the left of the plane formed by the proton spin and the beam direction, we conclude that a nonzero Sivers

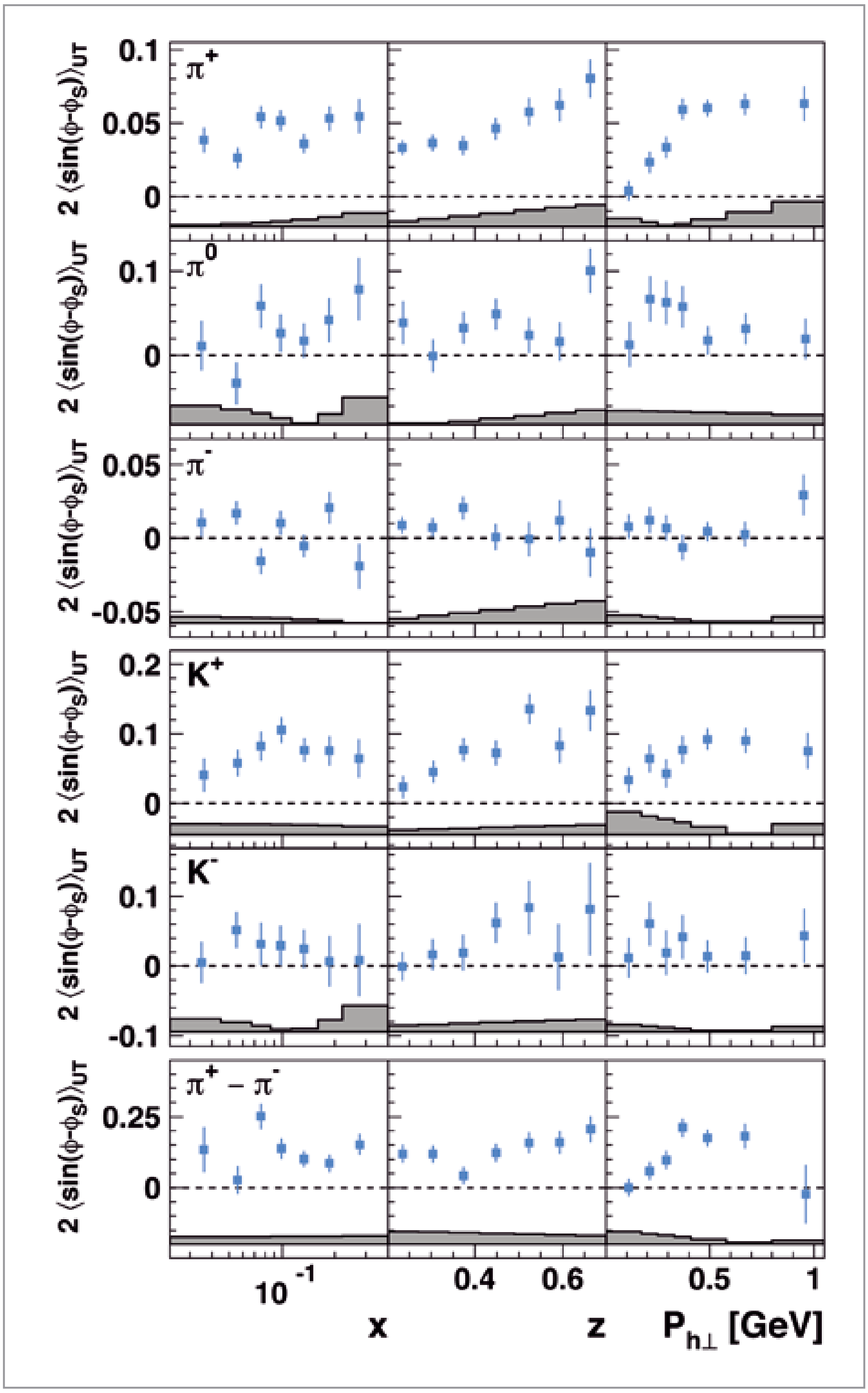

Figure 2

Sivers asymmetry amplitudes for pions, charged kaons, and the pion-difference asymmetry (as denoted in the panels) as function of the proton's longitudinal momentum fraction x carried by the struck quark, the energy fraction z of the virtual photon carried by the detected hadron, and the hadron's transverse momentum with respect to the direction of the virtual photon.

function is involved.The HERMES experiment is one of the few experiments worldwide where the Sivers effect can be measured, because it was designed to perform semi-inclusive deep-inelastic scattering off nuclear-polarised targets. A few years ago, HERMES presented the first-ever measurement of the Sivers effect. The results reported in this article are shown in Fig. 2. We dramatically improved the statistical precision on the measurement for charged pions, and for the first time we present the Sivers asymmetries for neutral pions, kaons, and the pion-difference. The qualitative features of the asymmetries measured are still to be fully understood. For instance, while the results for pions can be understood using present models for the Sivers function, it is a bit unexpected to see the positive kaons' asymmetry being even larger than the one for positive pions.

An intriguing property of the Sivers function is that it is expected to change according to the way we "look at it." If we use deep-inelastic scattering the Sivers function is expected to have the opposite sign as compared to the Drell-Yan process where one uses a beam of hadrons instead of leptons. If this QCD expectation is confirmed, it will mark a great success of the theoretical framework we use to interpret these experiments.

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Data preservation in high-energy physics.

New ICFA study group formed to investigate future analysis of past data

Data from high-energy physics (HEP) experiments are collected with significant financial and human effort, when at the same time there is no coherent strategy for long term data preservation. An inter-experimental study group on data preservation and long-term analysis in HEP was convened at the end of 2008 and held a series of workshops in 2009.

The scientific potential of a high-energy physics experiment is in principle defined and exhausted within the lifetime of the collaboration. However, given the continuous improvement in areas of theory, experiment and simulation – as well as the advent of new ideas or unexpected discoveries – the need to re-analyse old data may arise. As experimental complexity and the associated costs continue to increase, many present-day experiments will provide unique data sets that are unlikely to be improved upon in the foreseeable future. The close of the current decade will see the end of data taking at several large facilities and the collaborations are now confronted with the question of how to preserve their scientific heritage.

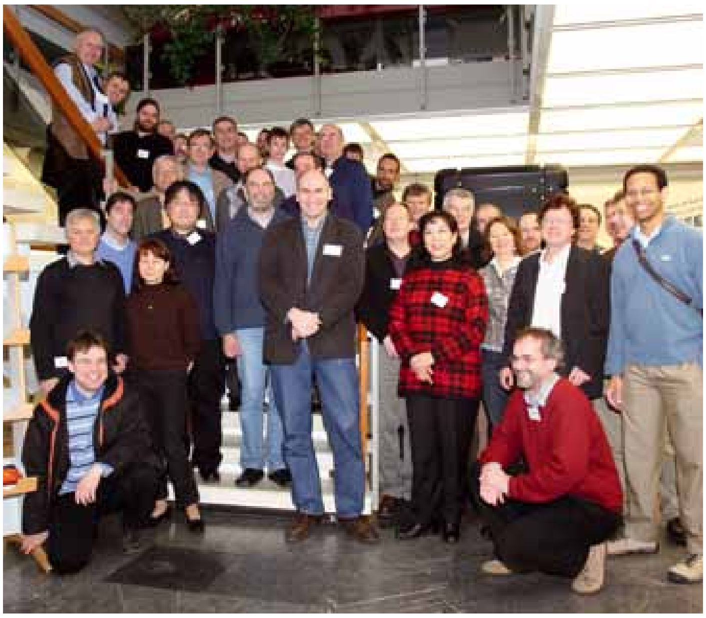

Figure 1

Participants of the first workshop on data preservation and long term analysis in high energy physics, held at DESY, 26-28 January 2009.

To address this specific issue in a systematic way, a study group on data preservation and long term analysis in high-energy physics (DPHEP) was formed at the end of 2008. The collider experiments BaBar, Belle, BES-III, CLEO, CDF, D0, H1 and ZEUS, as well as the associated computing centres at SLAC, KEK, IHEP, Fermilab and DESY are all represented, together with CERN, in the group steering committee. A series of workshops was held in 2009 to investigate the issues and options for data preservation. The DPHEP effort has since been endorsed by the International Committee for Future Accelerators (ICFA) and the first recommendations of the group were published in December 2009.

The inaugural DPHEP workshop took place 26–28 January 2009 at DESY, where the aim was to survey the current status in HEP in terms of data preservation. Participants of the workshop are shown in Fig. 1. Current analysis models, details on data and Monte Carlo production as well as estimates for storage requirements were presented, where it became clear that no long-term analysis model was foreseen by any of the experiments. While storage technology should not pose problems given the data volumes involved, good communication between the experiments and the computer centres will be the key issue as the collaborations wind down their activities.

Concerning software, the ROOT analysis environment used by most HEP experiments offers many advantages in documentation and support. The use of crucial inherited libraries and commercial software that are no longer officially maintained is most likely to cause problems in the future. Modern techniques of software emulation, such as virtualisation, may offer promising features. Previous experience with old experiments clearly shows that a complete re-analysis of experimental data has only been possible when all of the ingredients could be accounted for, as exemplified in a recent successful re-analysis of JADE data. A Monte Carlo event is shown in the revitalised

JADE event display in Fig. 2. The situation regarding the LEP data is less clear and the recovery of all information may become impossible within a few years from now, if no effort is made to define a consistent and clear stewardship of the data.

The scientific value of long-term analysis was examined in a recent survey by the PARSE-Insight project, where around 70% of over a thousand HEP physicists regarded data preservation as very important or even crucial. There is also an increasing awareness within funding agencies regarding the preservation and stewardship of scientific data, in particular with issues pertaining to open access.

Four working groups have been formed within the DPHEP initiative: physics cases; preservation models; preservation technology; governance. At the second DPHEP workshop, which took place 26-28 May 2009 at SLAC, the first report of the group was written, following the structure of these working groups. The main recommendations of the report may be summarised as follows:

1. Data preservation beyond the end-date of experiments opens up future scientific opportunities and urgent action is needed now.

2. Different levels of preservation and usability are possible. The preservation of the full analysis capability of experiments is recommended, including reconstruction and simulation software.

3. The technological aspects are well within the reach of the large HEP computing centres and the most efficient solution would be the creation of a data archivist position, charged with the preservation of data analysis capabilities.

4. Close collaboration is required between experiments, laboratories and funding agencies, where a clear and internationally coherent policy should be defined and implemented.

5. An international data preservation forum is proposed as a reference organisation.

A follow-up workshop was held at CERN, 7-9 December, preceded by a public symposium. Progress reports from the experiments were given and, like at the first workshop, presentations from fields outside of HEP such as astrophysics contributed to the discussions and provided useful hints as to the critical points in the organisation of such projects. A second DPHEP report is in preparation, which will include concrete examples of preservation projects and crucially, estimates for the necessary funding of such initiatives in the long term.

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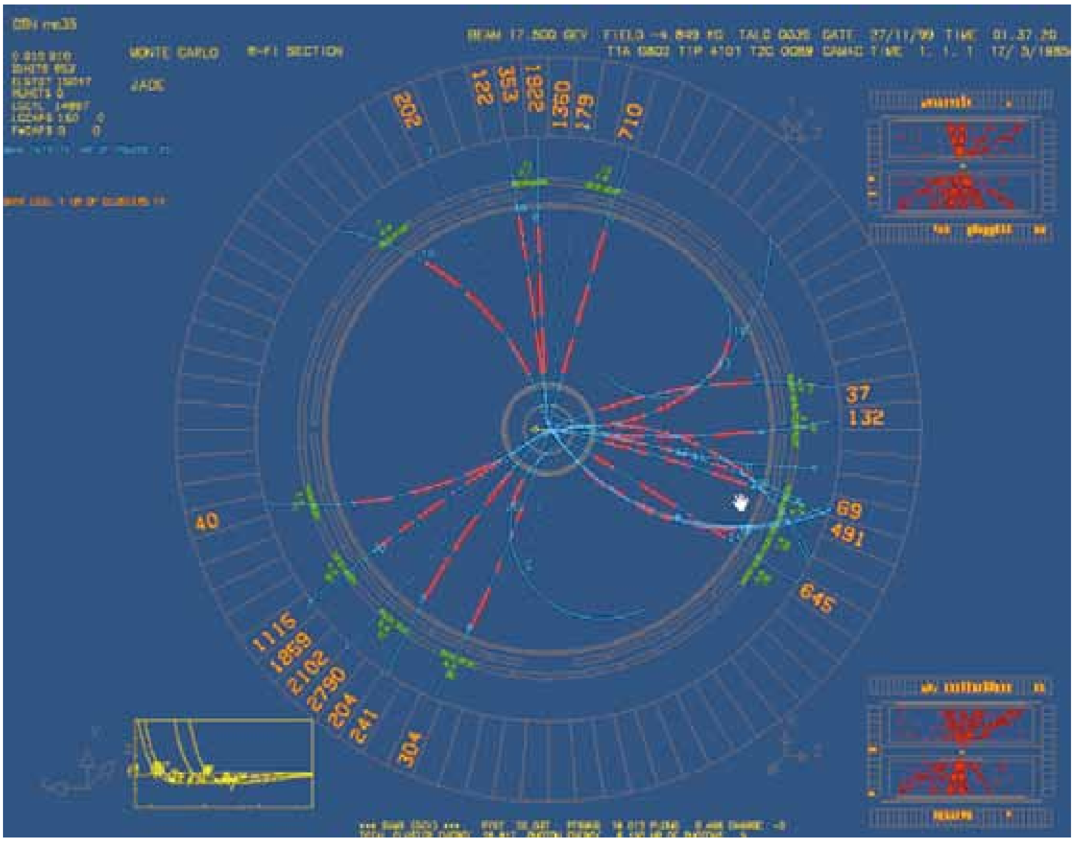


Figure 2

A simulated event in the JADE detector, generated using a refined Monte Carlo program and reconstructed using revitalised software more than 10 years after the end of the experiment. (Courtesy S. Bethke).

The first ATLAS paper on LHC data.

A major milestone is reached

The Large Hadron Collider (LHC), the latest and most energetic particle collider in the world, is located at CERN, near Geneva. The LHC produced its first proton-proton collisions at a centre-of-mass energy of 900 GeV in November 2009. The ATLAS collaboration collected half a million records of the collisions, and from them produced its first physics result: a precise measurement of charged-particle production in proton-proton collisions at 900 GeV. The measurement was published by the journal Physics Letter B.

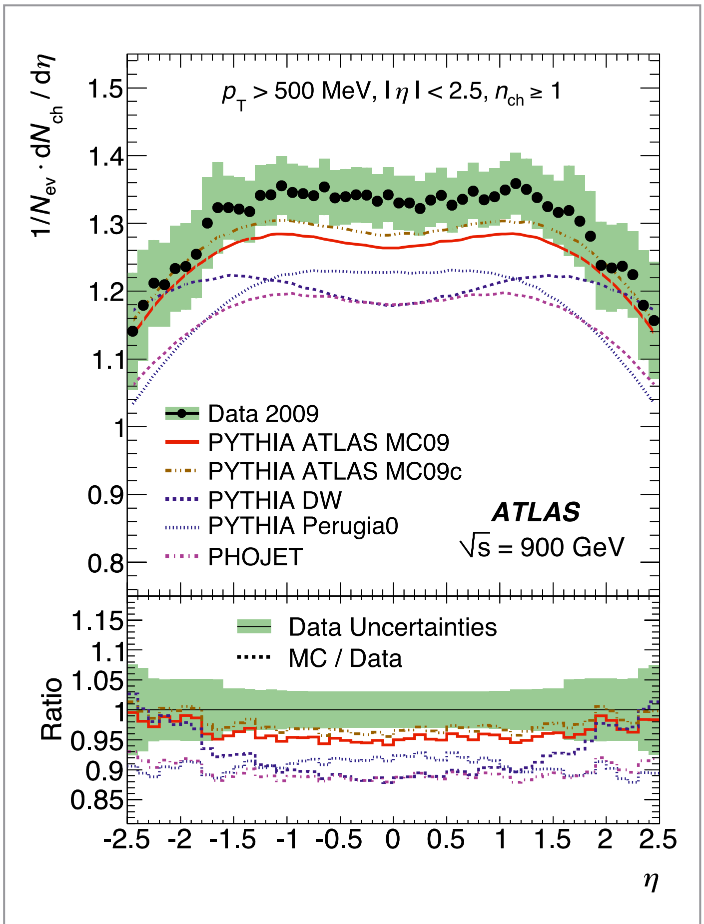


Figure 1

(upper) The charged particle multiplicity vs. η together the predictions of several models. (lower) The ratio of measured data to model predictions vs. η. The green bands indicate the total uncertainties of the measurement.

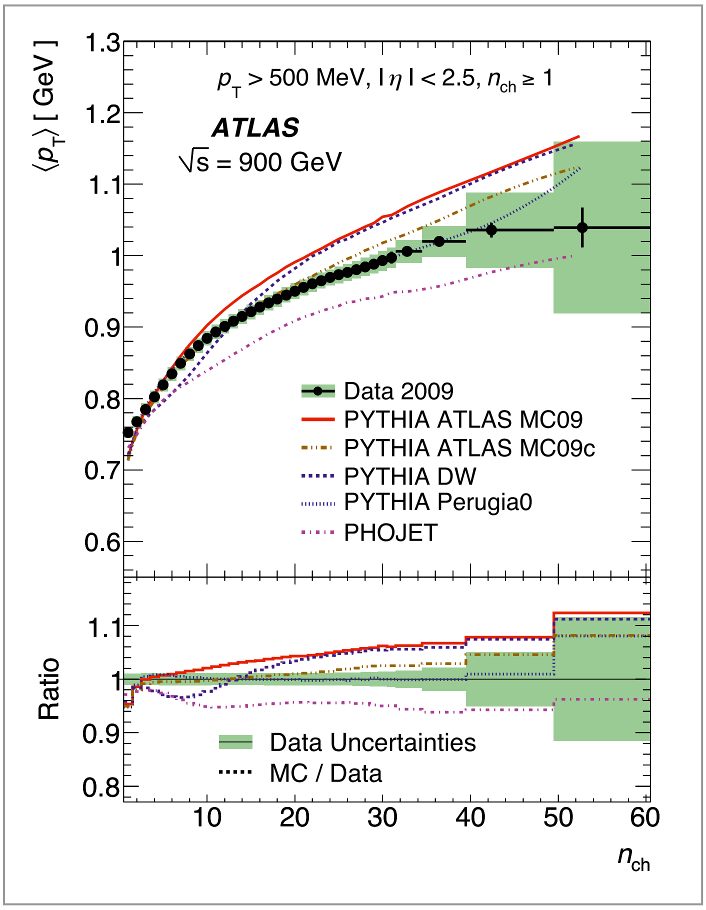
The measurement is ultimately the product of the work of more than 2500 physicists from 38 countries who, together with an army of engineers and technicians, built the detector, wrote the reconstruction and analysis software and are now operating the detector and data processing systems. Since joining the ATLAS collaboration in 2006, DESY physicists have contributed significantly in several areas including triggering, the data-processing software, Monte Carlo software and the analysis of the measurement discussed here. The analysis was done in part on the National Analysis Facility at DESY.

The LHC is designed to collide proton beams at a centre of mass energy of 14 TeV. The proton beams are first injected into the LHC with a beam energy of 450 GeV and in normal operation, would be accelerated to higher energies before they are given over to the experimental collaborations for detailed studies of the collisions. However, in November 2009 the LHC was still being commissioned and as part of the procedure, the beams were allowed to collide at injection energy for several hours. The experimental collaborations used the opportunity to check the response of their detectors to collisions for the first time and to collect the event sample used for the measurement discussed here.

Particle production in proton-proton collisions is described by phenomenological models which are based on the well established theory of strong interactions: QCD. The models form the basis of Monte Carlo event generators which, together with a detector simulation program, generate events which model the detector response to real collisions. The models contain several parameters which are tuned to provide a best match

Figure 2

(upper) The mean p_T of charged particles vs. charged multiplicity, along with several model predictions. (lower) The ratio of measured data to model predictions vs. charged multiplicity. The green bands indicate the total uncertainties of the measurement.



to a large number of collision data sets from several particle experiments performed in the last decades.

The first ATLAS physics publication shows a comparison of the 900 GeV data to the phenomenological models A small team of highly motivated physicists worked around the clock on the final data analysis and the production of a paper describing their results: a survey of charged particle production at a centre of mass energy of 900 GeV.

When charged particles traverse the inner part of the ATLAS detector, they leave behind measurable hits in silicon detectors which are connecting into tracks by the reconstruction programs. Two of the parameters which describe the tracks are of particular interest for this measurement: the transverse momentum (p_T) and the pseudorapidity (η). The transverse momentum is the momentum of the track perpendicular to the beam direction. The pseudorapidity is a measure of the track's polar angle, relative to the beam axis (tracks emerging perpendicular to the beam have $\eta = 0$).

The distribution of the numbers of tracks in the selected events, and the p_T and η distributions of tracks were extracted from the data, corrected for inefficiencies and compared to the corresponding distributions from the phenomenological models whose parameters were tuned to fit existing data sets. Fig. 1 shows the charged particle multiplicity as function of η normalised to the number of events fulfilling the event selection criteria. As can be seen in the figure, an average of 1.333±0.003(stat)±0.040(syst) charged particles is observed in an η interval of 1 about η of 0. This is a larger density than predicted by any of the models shown on the figure by between 5% and 15%.

In Fig. 2, the mean p_T of charged particles in events is plotted versus the particle multiplicity, n_{ch}, of the same events. The predictions of several models are also shown. This distribution is sensitive to the distribution of colour charges in the final state. It is best described by another parameter set – called Perugia 0. Since none of the parameter sets shown in the figures describe the distributions sufficiently well, the models must be further tuned. The ATLAS analysis strategy of minimising the influence of models on the presentation of results, coupled with the high precision of the data make the measurement particularly useful for model tuning.

The LHC is now regularly colliding protons at a centre of mass energy of 7 TeV. The next ATLAS physics publication will probably be a repeat of the analysis described here using the first collected events. The measurement will provide a first glimpse at collisions at the energy frontier and further input for tuning the models. The DESY group is playing a significant role in this essential second step towards the fascinating discoveries to come.

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Taking aim.

The ATLAS trigger

The efficient selection of extremely rare interactions amidst an enormous background of ordinary processes is the principal task of the ATLAS trigger system: the trigger examines 40 million events per second and selects only 200 of them for offline analysis. The trigger comprises three successive levels: the first is built of custom-designed electronics and the two higher levels are large clusters of high-performance computers. Determining the mix of trigger algorithms to be run is the province of the Trigger Menu group. Providing and maintaining the enormous number of needed parameters is a task of the Trigger Configuration group. Trigger performance monitoring is the responsibility of the Trigger Monitoring group. The DESY/ATLAS group is making prominent contributions in all three of these areas.

The ATLAS physics programme and the trigger menu

The ATLAS physics programme calls for the study of many known and hypothesised fundamental processes. Each such process produces events with a unique set of detector responses (a signature) which can be exploited by the trigger system to distinguish it from the huge background. Sophisticated algorithms are designed to select each signature efficiently while strongly rejecting background. Each event is processed through a menu consisting of hundreds of chains of such algorithms. Many such trigger menus are needed to match the large variety of expected running modes for commissioning and for amassing collision data at both low and high LHC energies and at both low and high LHC collision rates.

The start-up trigger menus had already been defined well before the first LHC operation in late 2008 and were refined based on experience with first operations. These further efforts have resulted in significant performance improvements and in more realistic menu compositions.

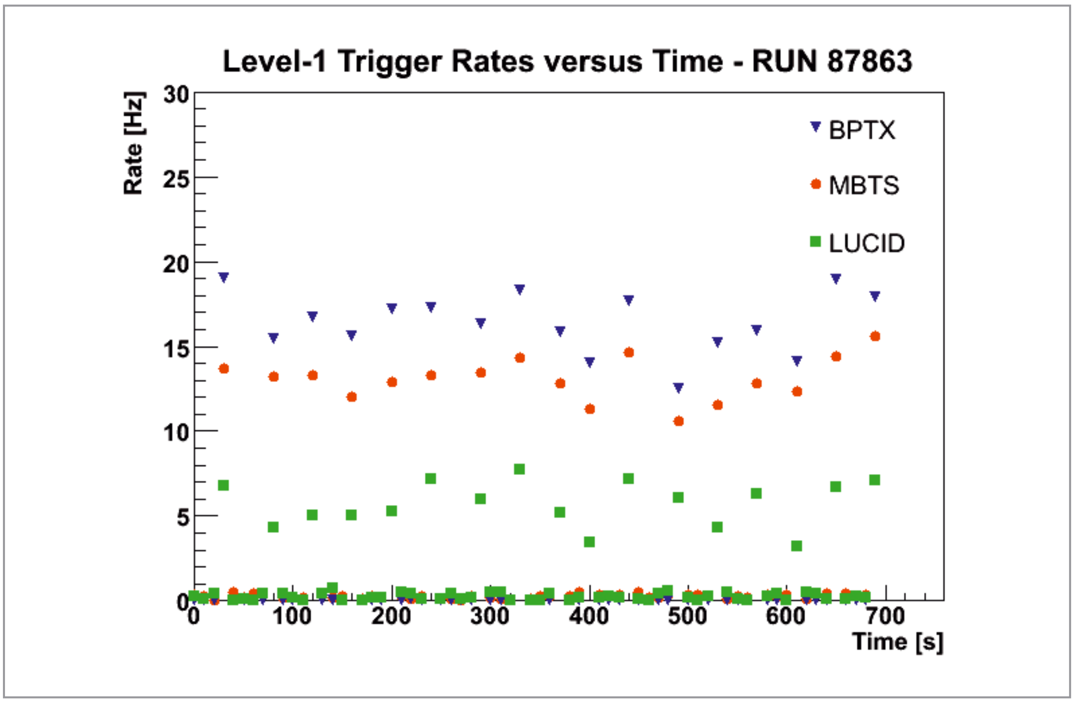

Figure 1

Trigger rates from 3 ATLAS detectors vs. time. The rate-spikes at 40 second intervals correspond to proton injections into the LHC.

Configuring the trigger

The ATLAS trigger configuration group provides several essential services and tools: the maintenance and preservation of the full inventory of ATLAS trigger menus, graphical user interfaces for accessing the configuration database, interfaces for retrieving trigger configurations both online and offline, tools for uploading predefined configurations into the database and a mechanism for initialising offline analysis programs.

The online system must supply the three trigger levels with thousands of parameters and provide mechanisms for changing between configurations. At run start-up, the configuration for a specified menu is retrieved and downloaded. While a run is in progress and without halting the data acquisition, sets of chain scaling factors (which affect the relative chain rates) can be changed to adjust for decreasing LHC collision rate or changes in detector conditions. These capabilities proved crucial during the second half of 2009, when the daily ATLAS data taking programme was in constant flux.

Monitoring trigger performance

A sensitive indicator of the health of the system is the trigger rate. A dip in trigger rate could indicate the failure of a detector component or the loss of processing power at the higher level. A sudden rise could indicate the appearance of noise. The trigger monitoring group provides the infrastructure needed to assemble very fine-grained rate information from thousands of sources and present it to the experts both in the control room and anywhere in the world via the web. An example from 10 September, 2008 is shown in Fig. 1. The plot shows trigger rates from 3 ATLAS detectors. The rate spikes occurring every 40 seconds correspond to proton injections into the LHC.

The trigger rate monitoring is complemented by hundreds of histograms of parameters derived in the higher level trigger processors as the trigger decision is being formed. An example is shown in Fig. 2 which shows a histogram of the spatial positions of collisions in the plane transverse to the beam direction for one of the first LHC collision runs in December 2009. The histogram was quickly made available to the ATLAS experts who could then rapidly assess an essential parameter affecting performance: the beam position. The histogram contents are gathered from thousands of processor nodes once per minute, added together and presented to the experts in the control room through graphical user interfaces. They are also automatically scrutinised by software which decides, for example by comparing the actual plots to references, whether they might be indicating problems. The decisions from many histograms enter into a so-called trigger data quality flag which is combined with flags from other systems to produce the global online trigger data quality flag. The online flag is combined with an offline flag generated during the first reconstruction pass of the data and presented to a human expert who then makes the final decision on suitability of the data for further analysis.

Looking forward

The ATLAS trigger system was right on target during the 2008 LHC start-up period. During the shutdown in 2009, the trigger systems were further honed and are now fully prepared to take aim at the exciting physics programme the LHC is starting to offer.

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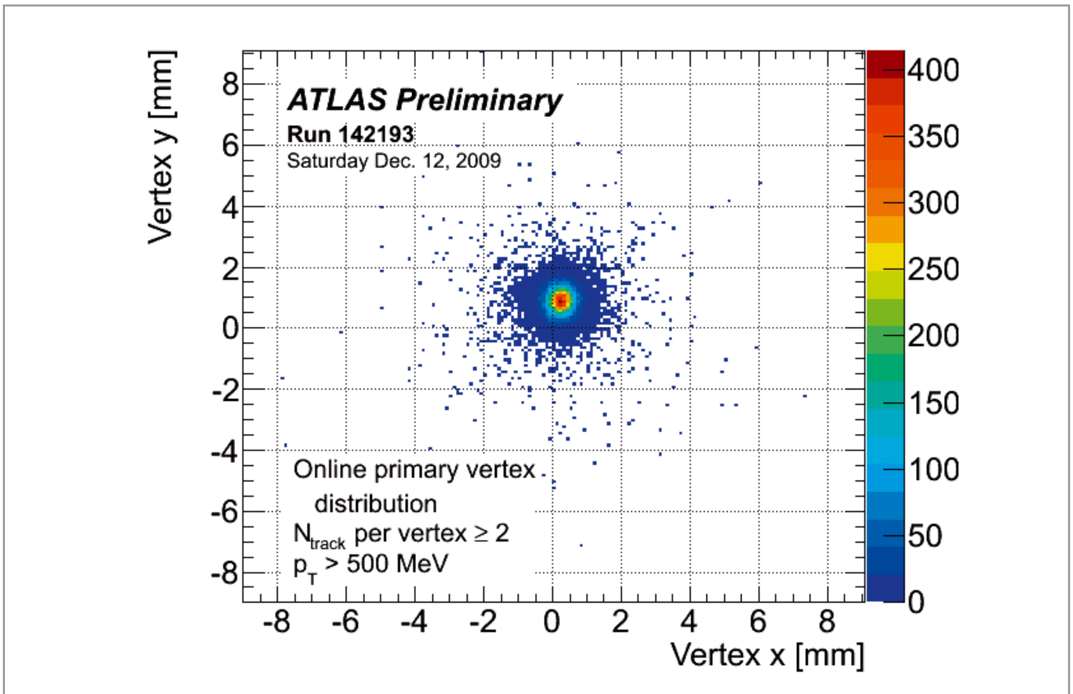


Figure 2

The spatial position of collision points in the plane transverse to the beam.

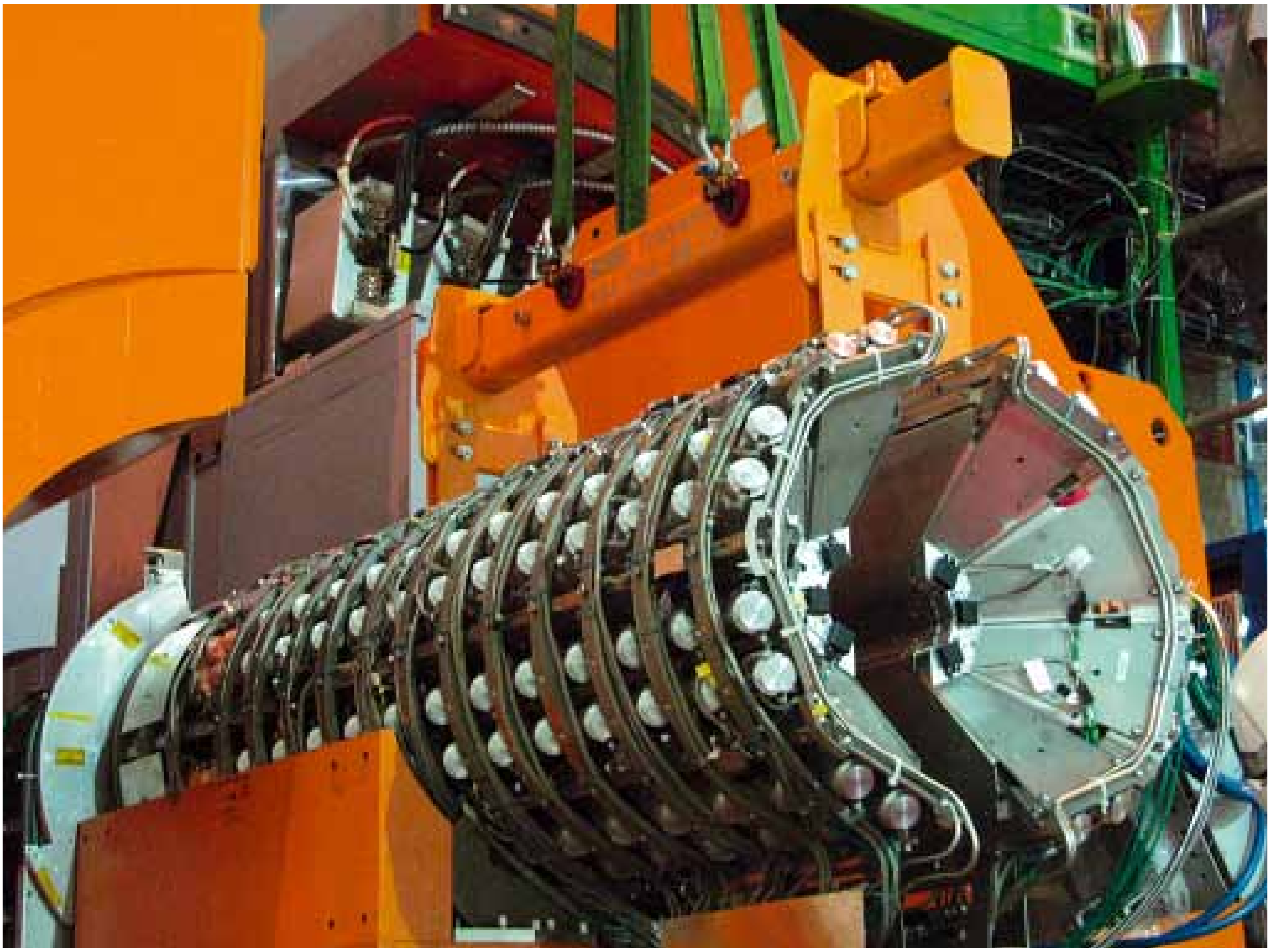
CMS: Ready for collisions.

Detector completed and well prepared

The CMS experiment is one of the two multi-purpose experiments at the Large Hadron Collider at CERN. The group from DESY is contributing in key positions to the construction and the commissioning of the detector, the development of the software, the computing, and not least, the analysis of the data. In 2009, the first proton-proton collision data were recorded, analysed and published, proving that the CMS experiment is in magnificent shape, ready for the discovery of new physics at the energy frontier.

Figure 1

The CASTOR Calorimeter during the mounting in the CMS Detector.



In the Compact Muon Solenoid Collaboration scientists from more than 150 institutions throughout the world share a common research effort to explore a new scale in fundamental physics. The CMS detector is a 12000-ton instrument based on a large high-field superconducting magnet. The inside of the solenoid magnetic coil comprises a silicon tracking system, an electro magnetic crystal calorimeter and a hadronic calorimeter. The compact iron return yoke is instrumented with detectors for the precise measurement of muons.

Instrumentations close to the beam pipe complement the CMS detector, such as the CASTOR Calorimeter, and the Beam Condition Monitor, systems to both of which the DESY group has made major contributions.

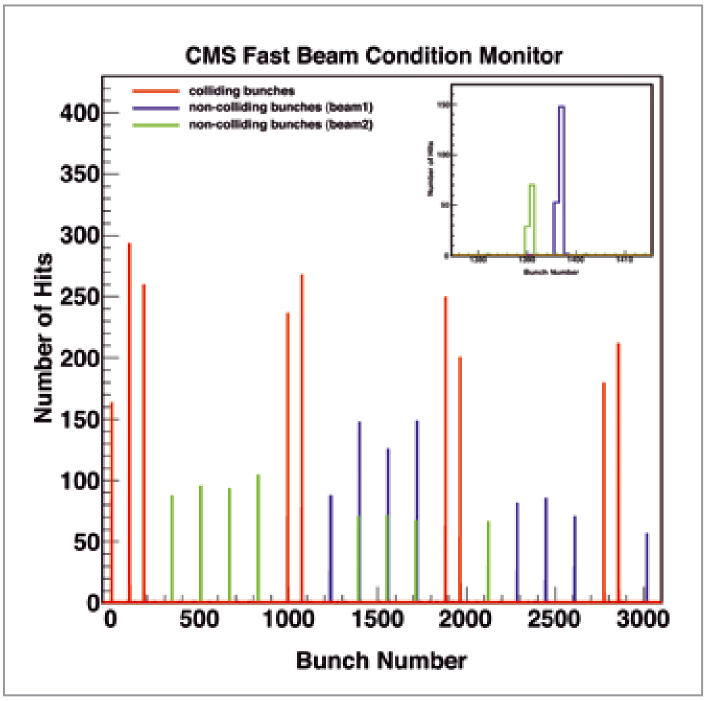


Figure 2

Bunch structure data from a run with proton proton beams in the LHC. Those entries coming from bunches with proton collisions are marked in red.

The assembly of the CMS experiment had been completed in 2008. Subsequently, throughout spring and summer 2009, the CMS experiment was regularly operated using cosmic ray muons, in preparation for the recording and analysis of collisions data. The recorded data are of invaluable use for the refinement of the trigger, the computing and the software infrastructure, the detector calibrations and alignments, as well as the analysis procedures. The insights from this commissioning phase were summarised in a series of detailed publications, describing the alignment and calibration efforts, as well as the achieved detector performance benchmarks and resulted in several physics papers.

The CMS group at DESY achieved key contributions to the commissioning efforts, taking lead roles in the areas of calibration and alignment, data quality monitoring, technical coordination and computing. Several members of the DESY group are coordinators in these areas, carrying CMS-wide responsibilities. The CMS group runs a remote operation center at DESY in which daily shifts for the monitoring of the CMS data quality and for computing operations are performed. DESY is a Tier-2-site for LHC-computing and our group is thus directly involved in the data processing chain.

An important milestone for the DESY group was the installation and commissioning of the CASTOR calorimeter. This calorimeter is situated about 14 m away from the interaction point, close to the beam pipe. It widens the phase space for physics analyses considerably, as it measures particles and jets that are produced under very small scattering angles. A photograph taken during the mounting of this device in the CMS detector is shown in Fig.1.

The CASTOR calorimeter was integrated into the readout system of the CMS experiment and participated in the regular data taking. A first physics analysis looking at the energy flow is well in progress and passed successfully the stage of a pre-approval.

Another DESY contribution to the CMS detector is the first Beam Condition Monitor BCM1F. Considerable effort was made to develop the readout software to ensure storage and publishing of relevant data and a detailed trail of the history in case of a beam loss or beam abort.

The detector was fully operational when LHC was filled with colliding proton beams for the first time in November 09. During the data taking period of the LHC the system was fully active and the beam halo was permanently monitored. Counting rates of the different detectors were used in the run-control to watch the beam conditions inside the CMS detector and to ensure stable data taking.

The TDC signals were recorded in time intervals corresponding to LHC orbits. The counting rate as a function of the time is shown in Fig. 2. The signal nicely resolves the halo from single bunches, in this case 16 x 16, demonstrating the potential of the beam halo monitor BCM1F to flag critical bunches in case of dangerous beam conditions.

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CMS collaboration

CMS: Results from first physics data.

First collision data show good detector performance

The physics activities of DESY at the CMS experiment span the following four areas: measurement of top quarks, QCD studies, Higgs discovery and SUSY searches. The top quark measurements and searches concentrate on final states including leptons. The QCD studies have a focus on the forward detector region, in which DESY is also contributing to the detector instrumentation.

CMS, like the other experiments at the LHC, was delivered the first proton-proton collision data in November 2009. In December, the centre of mass energy of the two proton beams in the LHC was ramped for the first time to the value of 2.36 TeV, marking the world record for 2009. Fig.1 displays one of the first multi-jet events recorded in the CMS experiment at this centre of mass energy.

In December 2009, CMS recorded in total about 350.000 and 20.000 minimum bias events from proton-proton collisions at a centre of mass energy of 900 GeV and 2360 GeV, respectively, with all detectors in operation. As one of the highlights of these data samples, a first J/ψ candidate event was reconstructed through its decay into two opposite charged muons. The event is sketched in Fig. 2. The two muons are clearly visible as reconstructed tracks in the inner tracker, reaching further into the outer muon system.

CMS physics analyses are based on the reconstruction and identification of physics objects, such as charged tracks from hadrons, leptons and jets. The DESY group contributes to the refinement and optimisation of physics object re-construction and identification tools in three main areas, namely studies of jet and missing energy reconstruction algorithms, the reconstruction of charged tracks, and the identification of long-lived particles using the reconstruction of secondary displaced vertices. In 2009, the physics profile of the DESY group was increased significantly, as two new Young Investigator Groups joined the CMS group at DESY. With the advent of proton-proton collisions data the analysis efforts at CMS and at DESY got into full swing. In a first step all groups engaged in reconstructing physics signals from the first run. Comparisons with distributions predicted by MC simulations showed amazingly good agreement.

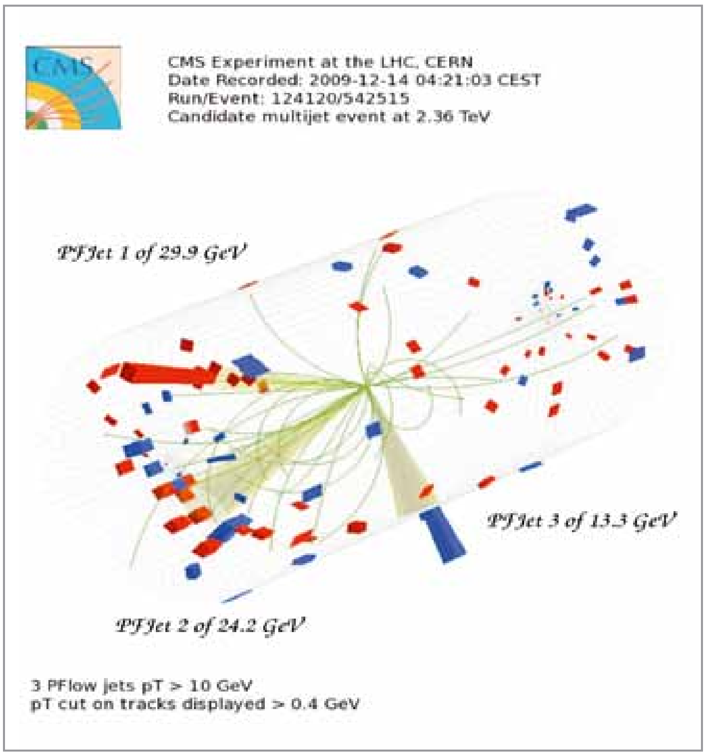

Figure 1

Display of one of the first multi-jet events, measured in the CMS experiment at a centre of mass energy of 2.36 TeV.

Using the data, the properties of jets and missing energy distributions were studied in detail with different jet and energy reconstruction methods, i.e. from calorimeter energy depositions, from combined calorimeter and tracker information, and from particle flow candidates. Fig. 3 contains two of the measured distributions. The data (points) agree very well with the prediction from Monte Carlo simulations, indicating that both the physics distributions and the detector performance are amazingly well understood.

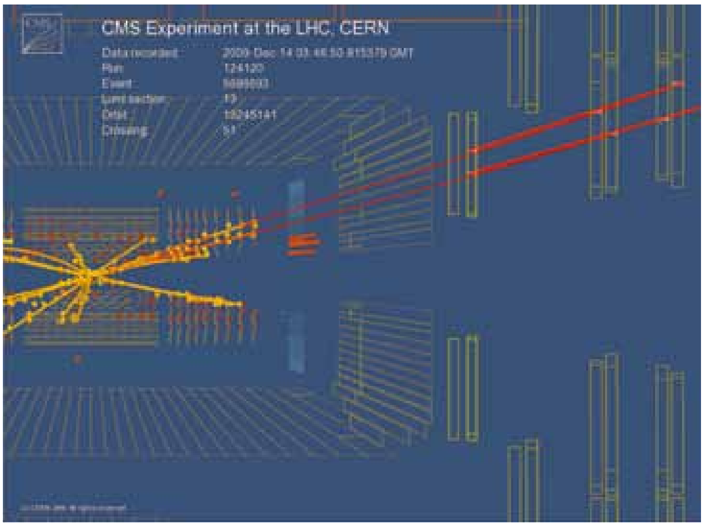

Figure 2

A di-muon event recorded in the CMS experiment at a proton-proton center of mass energy of 2.36 TeV. The invariant mass of the two opposite charged muons is 3.03 GeV, consistent within detector resolution with the mass of the J/ψ meson.

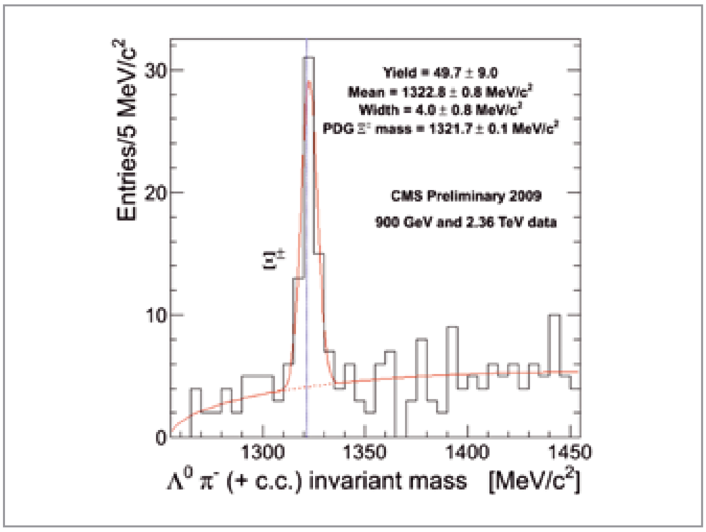

Figure 4

Charged Ξ baryon resonance as reconstructed from charged tracks in the decay into $\Xi \rightarrow \Lambda^0\,\pi$ and $\Lambda^0 \rightarrow p\pi$.

To study the performance of the CMS tracking system, a number of hadronic resonances, such as K^0_S and Λ^0 were reconstructed, using the excellent CMS tracking devices. The DESY group contributed to the effort of tracking studies, performed the reconstruction of K* and Ξ resonances and contributed to the preliminary distributions provided to the public.

The reconstruction of the Ξ baryon is particularly challenging since both a charged particle and a neutral particle decay have to be detected in the tracker. In Fig. 4 the invariant mass spectrum of charged Ξ baryons reconstructed in cascade decay chain, $\Xi \rightarrow \Lambda^0\,\pi$ where $\Lambda^0 \rightarrow p\pi$ is shown. In the 2009 CMS collisions dataset a sample of 50±9 charged Ξ baryon candidates was reconstructed with a mass resolution of 4.0±0.8 MeV and a central value of 1322.8±0.8 MeV consistent with the Particle Data Group value.

In summary, from the CMS data recorded in 2009 a large number of impressive analysis results were achieved from in a re-markably short amount of time. The DESY group was able to provide significant contributions to these achievements, and is now eagerly engaged in the analysis of the 2010 data which are recorded at an unprecedented center-of-mass energy of 7 TeV.

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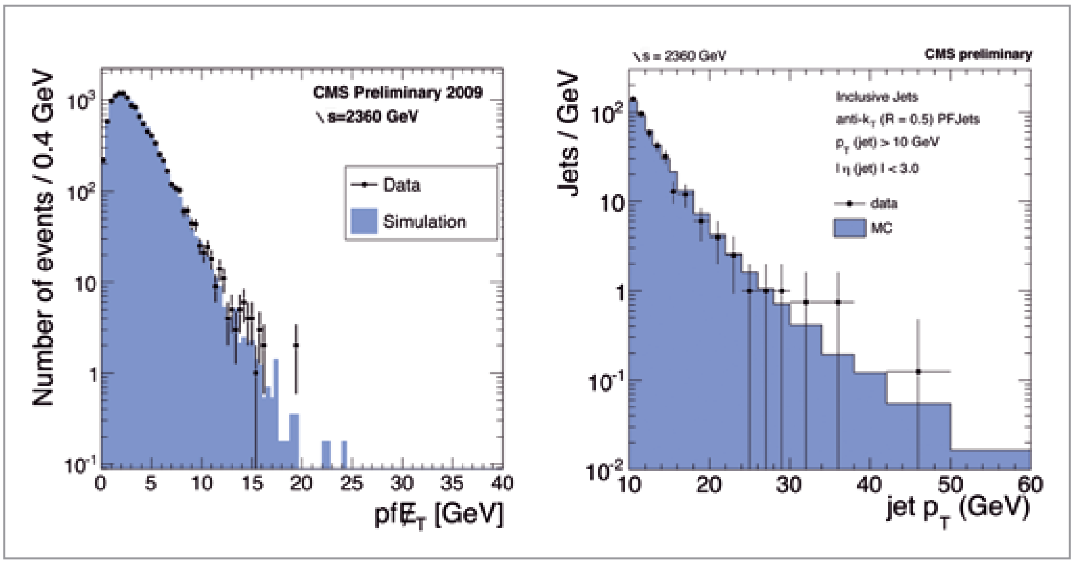

Figure 3

Particle flow distributions as measured at a center of mass energy of 2.36 TeV, a) the transverse momentum of jets, b) the distribution missing transverse energy. The prediction from the PYTHIA Monte Carlo simulation is shown in the blue histograms

The DESY Grid Infrastructure.

Global computing for e-science

Grid computing has become a key technology for the computing in e-science. Since 2004, DESY operates a Grid infrastructure. Originally targeting at particle physics experiments of LHC, HERA, and ILC, communities such as the photon science have recently been included. Complementary to the batch-oriented Grid infrastructure, the National Analysis Facility (NAF) was set up at DESY. Together they form the “DESY Grid Centre”.

When talking about computing today, the word "Grid" appears almost immediately. The term Grid was introduced by Foster and Kesselman in the mid 90s. In analogy to the power grid, which provides electrical power in a standardised way to everyone, they proposed a computing infrastructure which creates a universal resource of computing power for users. The computing resources, consisting of computers, data storage, and networks, are distributed world wide. The usage of the resources is managed by means of services which can be accessed by the internet. The key concept of the Grid is the formation of so-called Virtual Organizations (VO), in which users utilise common computing resources by sharing certain rules, as done in big collaborations.

In order to meet the vast computing demands of the LHC experiments, the world-wide LHC Computing Grid (WLCG) was invented. It was set up pioneering the EU project EGEE (Enabling Grids for e-Science), which was started in 2005, to build and to operate a global Grid infrastructure for the science communities.

Even before the start of EGEE it had become clear that major computing and storage resources for the future can only be expected in the Grid. Hence DESY's Grid activities started in 2004 with a small installation of Grid services and resources. The main intention at that time was to study the feasibility of large-scale Monte Carlo production for H1 and ZEUS, which had fully relied on distributed computing models until then. Moreover, the upcoming ILC community demanded computing and storage resources, and communities such as the Astroparticle physics collaboration IceCube and the International Lattice Data Grid (ILDG) asked for Grid access.

Since 2005 DESY is a member of the German/Switzerland (DECH) federation of EGEE and operates a large Grid infrastructure. DESY is also founding member of the national D-GRID initiative. In its participation in WLCG DESY acts as a German Tier-2 centre for the ATLAS, CMS, and LHCb. DESY has been facing steadily growing computing demands of various science communities with very different requirements and use cases as well as computing strategies and traditions. In particle physics, collaborative work in a global context is well established since long whereas the synchrotron light experiments are just entering the transition region from purely local to mostly global computing approaches with huge amounts of data.

The Grid infrastructure is well suited for centrally controlled and batch-like data processing and for massive Monte Carlo production campaigns. The LHC experiments and other HEP and non-HEP communities have utilised the Grid over the last years. LHC data are distributed over a multi-layer (tier) structure with CERN as the central and unique producer of data (Tier-0), 11 Tier-1 centres which hold copies of the raw data, and almost 100 Tier-2 centres. As a Tier-2 centre, DESY holds data which are relevant for analysis.

The DESY Grid Infrastructure

In order to make maximal use of installed resources and available manpower while remaining scalable, flexible and open for new communities, DESY is running one Grid infrastructure for all supported Virtual Organizations (VO). It is based on the most recent gLite middleware - the software developed by the EGEE project to implement services, protocols and interfaces - and contains all node types to make it a complete Grid infrastructure with all mandatory services. VO-specific unique core services are VOMRS/VOMS to manage VO members and catalogue services (LFC). Core services with multiple instances are the workload management (WMS), proxy server (PX), and information services (BDII). Resources are provided by computing elements (CE) and Storage Elements (SE). The SEs are based on dCache. Many of the services run multiple instances to ensure performance and reliability.

The DESY Grid resources are located at the two DESY sites in Hamburg and Zeuthen. Per job slot 2GB of memory and 15GB of local disk space are provided on compute nodes - called Worker Nodes (WN). DESY operates a tape back-end to the SEs of 2PB. The WNs are installed in batch farms.

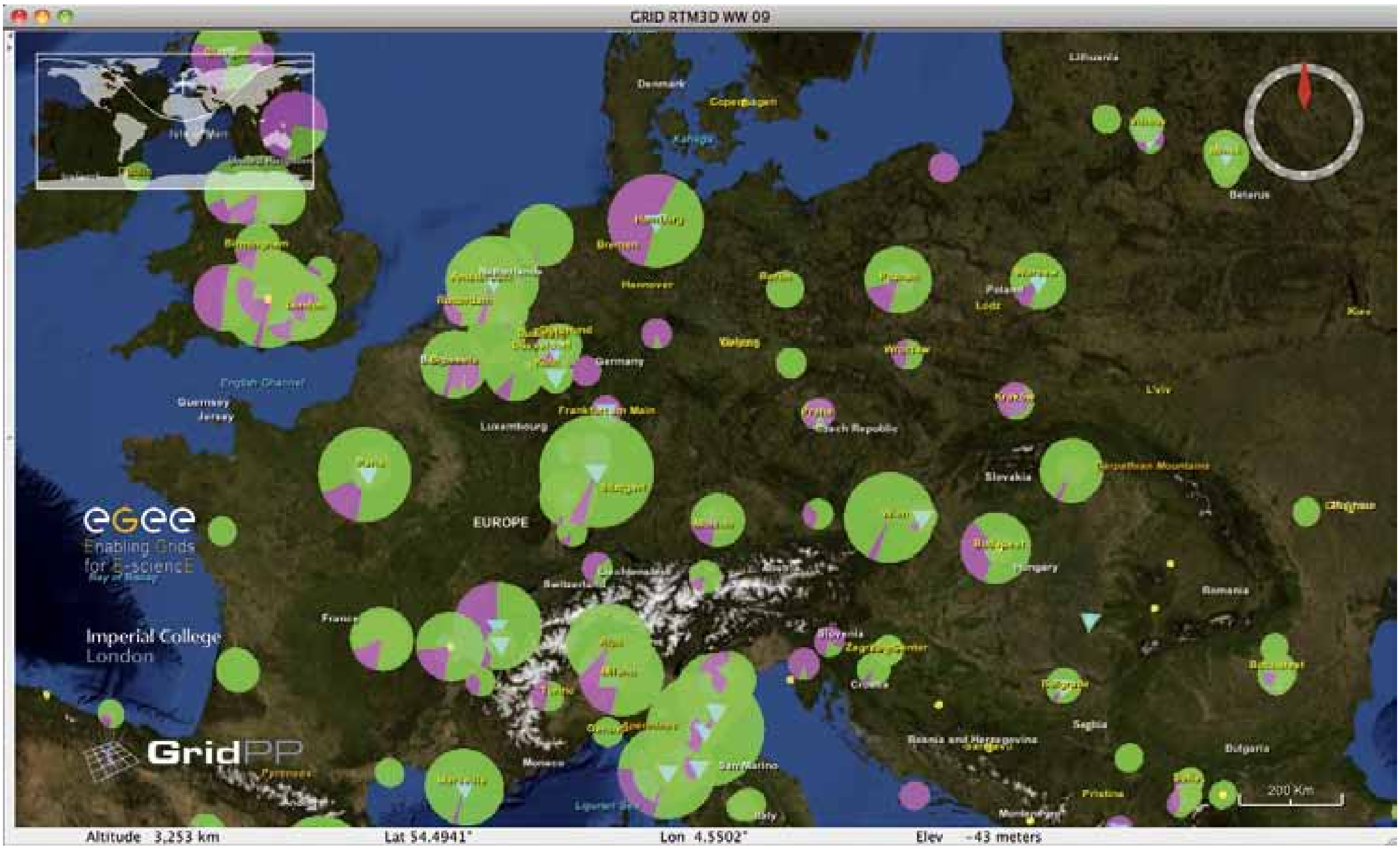

Figure 1

EGEE Grid sites in central Europe. The circle area scales with the number of resources at the site. The fraction of running (scheduled) jobs is indicated in green (magenta). Triangles show sites with work load management services.

Since resources are funded by different projects according to their objectives, resource usage is steered by a scheduling system: WNs are not dedicated to VOs or users. Instead, the scheduler will prioritise queued jobs according to the user's VO membership, roles and groups, taking into account the VOs resource usage in a certain period (typically some weeks). On the other hand the utilisation is maximised if not all VOs submit jobs. The SE usage is managed by providing explicit storage areas (directories) for VOs and their groups.

DESY is the home for VOs of HERA (H1 or HONE, ZEUS, HERMES), linear collider community (ILC, CALICE), astroparticle (ICECUBE), lattice QCD ILDG and photon science (European XFEL). All Grid cores services are provided at DESY. DESY supports VOs of LHC hosted at CERN (ATLAS, CMS and LHCb), astroparticle (CTA), and bioinformatics BIOMED.

The HERA experiments have massively used Grid resources mainly to produce Monte Carlo events world-wide. Their VOs are constantly utilising a good fraction of the resources at DESY. For ILC event simulation campaigns for detector studies were carried out exclusively on the Grid. Comparable resources would not be available on local resources. The CALICE collaboration as well as other groups are using the Grid to store their testbeam data which allows for seamless access from all over the world.

Tier-2

DESY committed to provide computing and storage resources for ATLAS, CMS, and LHCb as a Tier-2 centre according to the Memorandum of Understanding (MoU) with WLCG. Furthermore DESY operates VO specific Grid services such as VOBoxes, PhEDEx for the CMS data transfer system, an Oracle-based tag database for ATLAS and various Squid servers to cache conditions data for ATLAS and CMS.

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Site	Job slots	Hosts	Disk Space
DESY-HH	4236	373	1 PB dCache (w/o HERA data)
DESY-ZN	670	94	1 PB dCache

Figure 2

Overview of the resources at both DESY sites

The National Analysis Facility at DESY.

Providing analysis resources for LHC and ILC

The global structure of the DESY Grid offers resources which are perfect for batch-like computing but imposes a significant overhead for analysis work. In order to allow German HEP users efficient data analysis, DESY has set up the National Analysis Facility (NAF) which complements the Grid. The Grid Infrastructure and the NAF are based on and coupled via the data which is distributed via the Grid.

NAF layout and building blocks

In the framework of the Helmholtz Alliance "Physics at the Terascale", the National Analysis Facility was designed and built starting end of 2007 at DESY to complement the DESY and German Grid infrastructure. Key design criteria for the NAF are:

- Interactive access to large scale computing resources coupled experiment data. All data are at hand for analysis without any need for data moving.
- New tools, like parallel analysis frameworks or powerful databases.
- A seamless integration of Grid authentication and authorisation methods with local systems.
- Additional Grid resources, dedicated to the Terascale Alliance for batch processing. Support and documentation.

A schematic view of the NAF and its building blocks is shown in Fig. 1.

Grid: dCache storage and Grid cluster

The Grid dCache storage is the main import, export and exchange system for data. It should be identically accessible from all systems in the NAF. In agreement with the experiments, existing SEs are used which are equipped with more space to hold additional data. A first consequence of this is that normal Grid users (e.g. not part of the Alliance) can also access this data. Special areas in the SE can however be configured with for Alliance users only. The Grid infrastructure was extended to offer Alliance users additional resources for batch processing, with prioritised access to Grid resources. Both the data management and Grid submission methods are completely identical for the NAF and the non-NAF part of the dCache or Grid.

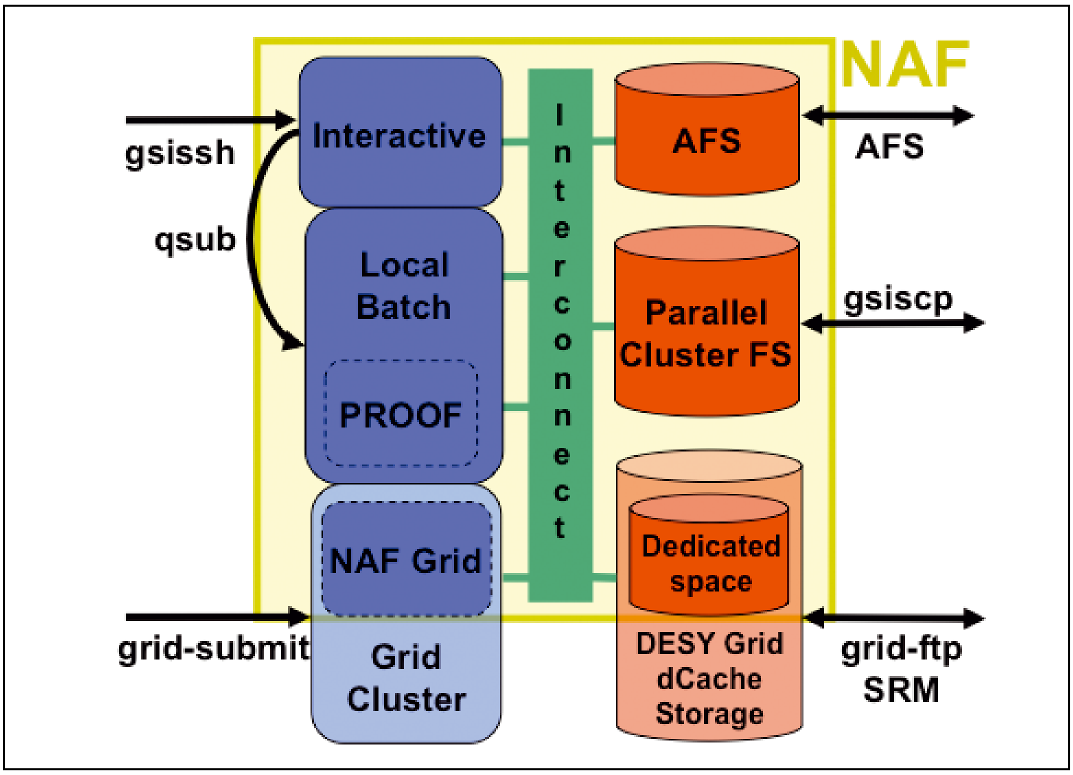

Figure 1
Schematic view of the NAF building blocks.

Figure 2

The NAF is used by members of the LHC and ILC experiments working in partner institutes of the Terascale Alliance.

Interactive, Local Batch and PROOF

Some parts of the analysis work are not well suited for the batch-oriented Grid. Therefore additional complementary computing resources are made available in an interactive cluster with an attached batch system – about 1500 CPU cores – allowing for local job submission. Users log into work group servers which provide environments for developing and short testing. For longer jobs, users may use the local batch farm, though the Grid is still recommended for traditional batch processing. In the last years, PROOF – the Parallel ROOT Facility – has been developed at CERN for fast interactive analyses of data. A priori, PROOF contrasts traditional batch facilities. However, with SGE as a batch resource management system, the NAF can integrate both: by the use of a so-called parallel environment, users may reserve many CPU slots which are spread over many machines. They will be used to run PROOF workers on them. This allows for a proper accounting and resource usage monitoring.

AFS and Parallel Cluster FS

From the interactive and local cluster machines in the NAF, not only the dCache SE is available, but also two additional spaces: an AFS based-space and a parallel cluster file system implemented using Lustre. AFS is used in the NAF to host the user's home directories as well as group directories for their software installation. The cluster file system Lustre fulfils a different role: it is intended to serve as a fast scratch space that contains data which is analysed very often and at a very high throughput rate. The Lustre file systems can only be accessed from the interactive and local cluster machines of the NAF. The network backbone for Lustre is based on the fast InfiniBand technology. The size of the Lustre file system is around 100 TB.

Authentication in the NAF

Locally, authentication is done via Kerberos. As all NAF users have Grid certificates (X509), the NAF hides the Kerberos layer from the users. Instead, they use proxy certificates, which are automatically converted to Kerberos tokens. To complete this Kerberos-X509 integration, the NAF ensures the availability of a valid proxy certificate while users are logged into the NAF

Running experience

Around 400 users are registered on the NAF, the majority from institutes outside of DESY, which makes clear that DESY is offering a service for the national HEP community. In retrospect, this also reinforces the decision to not build on the existing DESY infrastructure for interactive computing, but to build something new, with the only legacy of components of the DESY Grid infrastructure.

Support and documentation

The users' acceptance is fostered by the good support and documentation in and around the NAF. The operators provide documentation about the basic functionalities of the NAF. In addition to the expert level support, they also provide a first level support for all fabrics related issues. Experiments also have organised their own support and documentation for specific issues.

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dCache.

Storage management at the petascale

In 2009 dCache, the WLCG storage-backbone software got ready for the planed 18 months sustained LHC operation, by applying professional release and quality management to its deployment process. Moreover, by providing standard industry technology beyond WLCG requirements, other data intensive projects, like the European-XFEL or the Swedish National Infrastructure for Computing (SNIC), joined the dCache user community or committed to use dCache to manage their data in the near future.

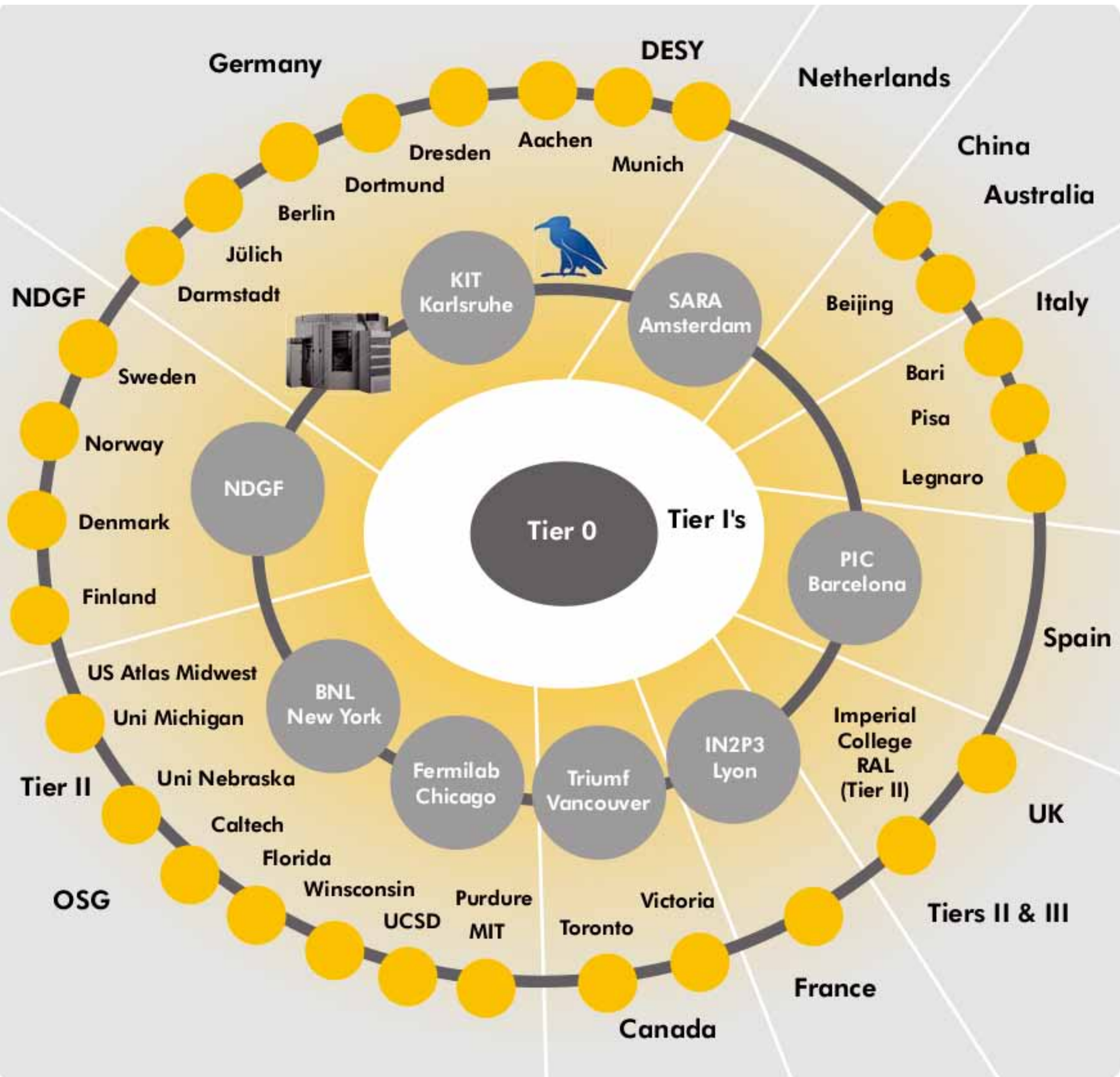

Figure 1
Worldwide distribution of dCache instances in the context of the LHC

The dCache software enhancements

2009, in order to compete with storage solutions provided by other laboratories and by industry, the rich portfolio of features of dCache has been extended by two more standard data access interfaces: WebDAV to support web browsers and desktop environments for interactive use, and the NFSv4.1 file system interface to cover worker nodes and large scale batch systems.

In its core functionality, dCache stores data reliably on a huge set of heterogeneous commodity storage systems under a single file system tree. Attached to a tape or backup system, dCache migrates data to such systems for archiving purposes or to free space on disk. If data are needed, which does no longer reside on fast media, dCache re-fetches this data from the attached system and makes it available again to the end-user. For redundancy reasons or to improve data access performance, dCache can create more than one copy of a defined set of files.

Collaboration and dCache support model

Beginning of 2010, the dCache collaboration composed of DESY, Fermilab and the Nordic Data Grid Facility, NDGF has been expanded by the Swedish National Infrastructure for Computing, SNIC. Their plan is to build the Swedish National storage infrastructure on top of the dCache software. Being part of the collaboration gives them the advantage of getting more influence on the direction dCache will take in terms of technology, deployment and release procedures.

In addition to the core dCache collaboration other groups and organisations support dCache in different ways. In 2009 the interaction with those groups could be significantly improved by establishing clear communication channels through the dCache.org infrastructure, described below. In Germany, the D-Grid Integration Project, as well as the Helmholtz Alliance "Physics at the Terascale" are supporting dCache development at DESY and system administration at the various German data centers. The latter builds the "German dCache Support Group", coordinating activities, like regular information ex-changes, tutorials and workshops. In the US, the Open Science Grid (OSG) initiative deploys dCache trough the Virtual Data Toolkit (VDT), their data management base system. The first level support for the North European countries is completely covered by the Nordic Data Grid Facility.

The dCache.org infrastructure

dCache.org is the project part filling the gap between the dCache software and the deployable dCache system. It is primarily funded by DESY and provides standard interfaces to the developers and customers. It covers the overall project management which includes representing 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 in the future European Middleware Initiative (EMI). Finally, dCache.org collects requirements of potential customers and presents solutions.

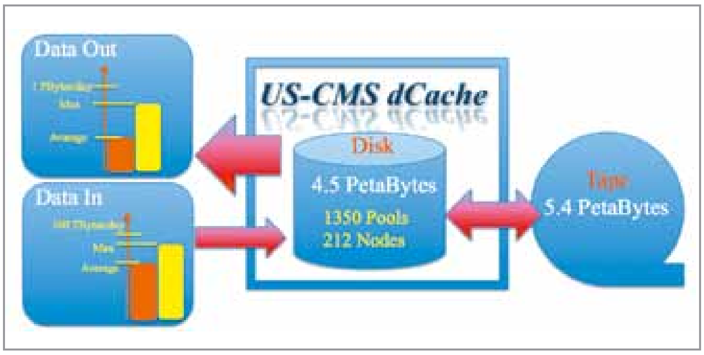

Figure 2

The US-CMS dCache instance in Chicago is the largest dCache installation in the world.

Deployment

At the time being, dCache is primarily used in the context of the LHC and High Energy Physics storage. Eight out of the eleven LHC Tier-1 sites in the US, France, Spain, Canada, Northern Europe, the Netherlands and Germany run dCache, as well as about 40 Tier-2 centers around the world. In total, about 50 Petabytes of data is already stored in dCache installations, being more than 50% of the entire LHC data.

In order to allow those sites to plan their software upgrades properly and still being compliant with the WLCG requirement of not applying new software during the first run period, dCache.org introduced the concept of a Golden Release in 2009. A Golden Release is guarantied to be supported for at least a year and no new feature will be added to such a branch. However dCache.org regularly provides patches if needed. Outside of the Golden Release, new releases offering new functionalities are published as before. dCache is the only WLCG software provider, offering such a service to its costumers.

New dCache communities and the European Middleware Initiative

In 2009 new communities and groups have shown interest in using dCache as their primary storage management technology. At DESY, PETRA III and CFEL will use dCache to access the backend tape system and the European-XFEL is describing dCache in their computing TDR as their preferred storage system. LOFAR, the Dutch based Low Frequency Array Antenna project is using dCache at sites in Amsterdam and Jülich; the Swedish National Infrastructure for Computing recently decided to build a national wide dCache infrastructure for data intensive communities. These developments are inspiring dCache to intensify its move towards industry compliant access mechanisms. This approach is appreciated by the European Middleware Initiative (EMI), which is going to fund dCache till about 2013. dCache will be part of the middleware bundle provided by EMI to the European Grid Infrastructure (EGI) and other interested customers.

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New accuracy reached at FLASH .

Electron beam timing with femtosecond precision

Novel laser-optical beam arrival time monitors at FLASH measure the timing of individual electron bunches with unrivaled accuracy of a few femtoseconds. Using these monitors in a fast feedback system allowed to stabilise the timing of the bunches within along bunch train to about 40 fs. A combination of the timing feedback and a compression feedback based on coherent radiation considerably improved and stabilised the FEL output power over the entire bunch train.

Ultrashort high-brightness X-ray pulses have been a dream in many disciplines of science. Free-electron lasers are capable of generating such an X-ray beam, but in contrast to conventional synchrotron light sources the X-ray pulse duration is in the femtosecond range rather than in the nanosecond or picosecond range. The major challenge associated with ultrashort light pulses is a correspondingly precise synchronisation of the kilometer-long linear accelerator driving the FEL. Conventional radio frequency (RF) synchronisation methods are inadequate for that purpose because of temperature-dependent length variations of the coaxial cables guiding the RF to the superconducting cavities. An alternative is a laser-optical synchronisation system in which the periodic pulse train from an infrared fiber laser is distributed in the accelerator tunnel via optical fibers. The core part of the scheme is an erbium-doped soliton fiber laser producing the periodic train of infrared pulses (λ = 1550 nm, σ_t < 100 fs). The precisely controlled repetition rate is 216.7 MHz, the sixth sub-harmonic of the 1300 MHz accelerating radio frequency of FLASH. The laser pulses are distributed along the accelerator via glass fibers whose optical length is stabilised by a feedback loop. For this purpose, the laser light is partly reflected at the end of the fiber link, travels back through the fiber and is then optically cross-correlated with the incoming laser pulse train. The signal from the cross-correlator is utilised to correct for fiber length changes by means of a piezo-electric fiber stretcher and a mechanical delay stage.

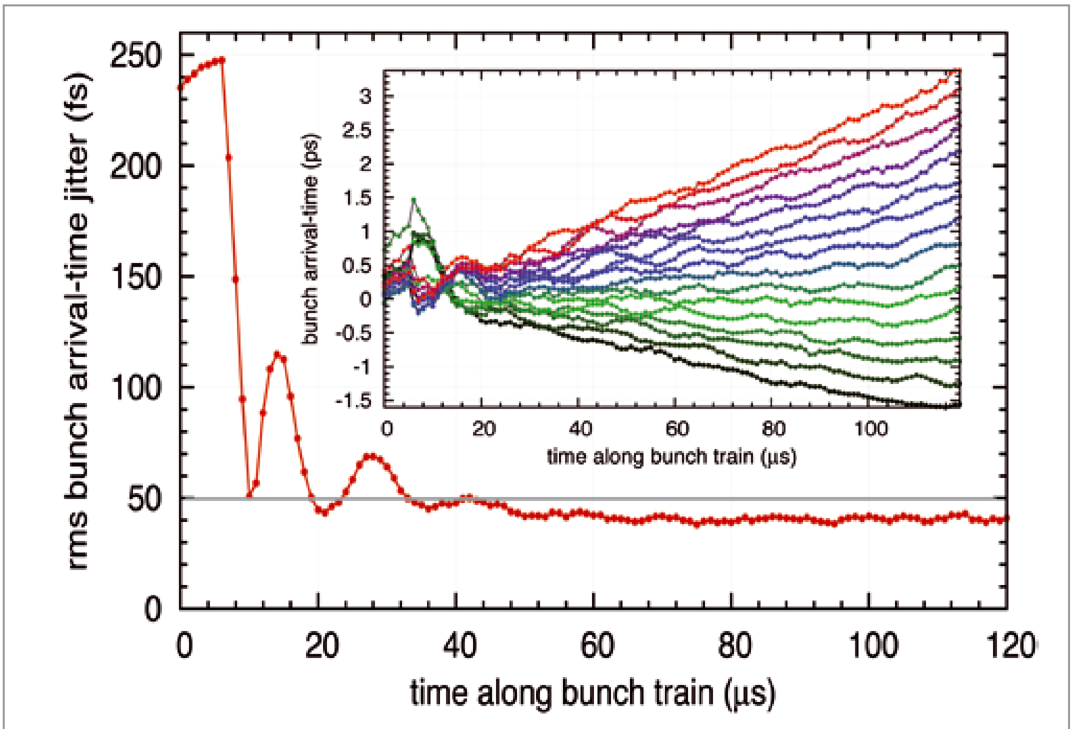

Figure 1

Effect of the bunch arrival-time feedback on the arrival-time jitter for a train of 120 bunches. Inset: imprinting arbitrary slopes in the timing along the bunch train.

As a first application of the laser-optical synchronisation system being installed at FLASH, we have implemented two laser-driven beam arrival time monitors in the linac tunnel and carried out measurements on the time resolution that can be achieved. The Beam Arrivaltime Monitor (BAM) is a novel electro-optic detection device developed in our group, which was presented in the Annual Report 2006: the bipolar signal from a broadband electron beam pickup electrode (bandwidth larger than 10 GHz) is sampled by one of the pulses of the periodic infrared laser pulse train at the end of a stabilised fiber link. In an electro-optic modulator (EOM), the sampling laser pulse receives an amplitude modulation depending on its timing with respect to the voltage signal of the beam pickup. To achieve high sensitivity and to minimise the dependence on bunch charge variations, the relative timing of the bunched electron beam and the laser pulse train is chosen such that the scanning laser pulse coincides with the zero-crossing of the pickup signal. A small shift in the bunch arrival time moves the zero-crossing position, and consequently the laser pulse amplitude is modulated in the EOM. By comparing the intensity of the sampling pulse to that of the unaffected laser pulses in the train, the electron bunch arrival time can be determined with an accuracy that is far better than the time duration of the pickup signal itself.

Two beam arrival time monitors were installed in a 60 m long straight section of the accelerator. Each monitor was supplied with laser pulses through its own stabilised fiber-link. The difference signal of both detectors has an rms variation of only 8.5 fs. Thus the BAM resolution amounts to $8.5 / \sqrt{2} = 6$ fs. This a world record for timing measurements in a linear accelerator and a factor of 10 better than the precision achieved in previous arrival time measurements using an electro-optic crystal inside the electron beam pipe.

One of the BAMs was utilised to establish an arrival-time feedback acting on the RF field amplitude of the first accelerating module. This possibility is unique to superconducting accelerators owing to the long duration of the RF pulse (1 ms at FLASH). Fig. 1 shows the effect of the feedback on the arrival-time jitter along the bunch train: the feedback loop reduced the timing jitter from 240 fs to about 40 fs.

The feedback also permits to generate pre-defined arrival-time patterns along the bunch train. The inset in Fig. 1 shows some examples. These may turn out useful for pump-probe experiments at the FEL, allowing for delay scans within a single bunch train. The bunch compression process in the magnetic chicanes depends sensitively on the RF phase during bunch crossing. Phase fluctuations, caused either by fluctuations of the incoming RF or by arrival time jitter of the electron bunches, lead to a stronger or weaker compression of the bunch, which can be detected by monitoring the intensity of coherent radiation. The measured coherent radiation power was utilised in a second feedback loop to stabilise the RF phase in the first accelerating resonator module. This feedback reduced the beam phase jitter from 0.2° to 0.025°.

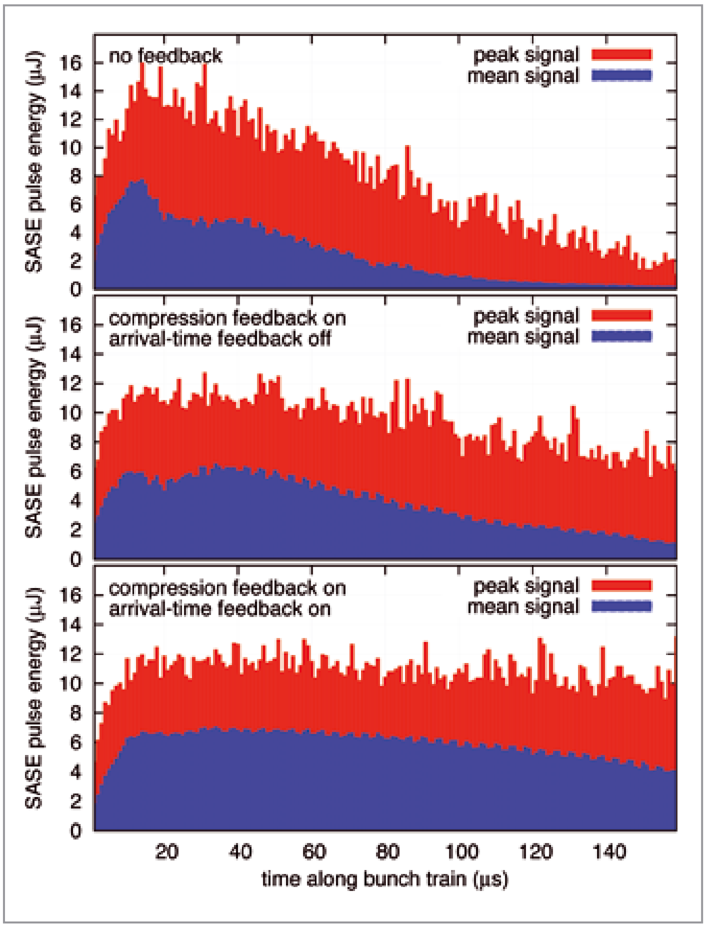

Figure 2

Evolution of FEL pulse energy along the bunch train. Top: no feedbacks, center: with bunch compression feedback, bottom: with bunch-compression and arrival-time feedback.

Combining timing and phase feedback loops resulted in a significant improvement of the FEL pulse energy stability. Fig. 2 shows the FEL pulse energy distribution along the bunch train for three different feedback configurations (no feedbacks, only bunch compression feedback, both feedbacks active). Without any feedback, the FEL pulse energy decreased gradually along the bunch train. After activating both stabilisation loops, the average pulse energy was more than doubled and remained on a high level over the entire bunch train. Furthermore, the pulse energy fluctuations along the train were reduced significantly to a value of about 20% which corresponds to the level of statistical fluctuations in the Self-Amplified Spontaneous Emission (SASE) process.

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Unexpected patterns.

Microstructures in the electron bunches of FLASH

Microbunching Instabilities in the electron bunches driving an X-ray or VUV free electron laser have been considered for quite some time. They are potentially a detrimental factor for the FEL process and might disable diagnostic methods. Since the typical wavelengths of these instabilities are far too short to be observed directly in the charge distribution of the bunch, indirect methods using coherent bunch radiation have to be used to explore them. At FLASH, we studied coherent radiation from the UV to the IR region and determined the strength of the microbunching phenomenon from 0.3 to 20 μm . These unique data are of vital importance for the validation of microbunching models and simulations and a benchmark for the extrapolation to other machines eg. the European XFEL.

The electron bunches leaving the injector of FLASH are about 6 picoseconds long and have a peak current of 50-100 A, which is far too low for the FEL gain process. Therefore they are longitudinally compressed by a two-stage method: (1) an energy chirp is generated by off-crest acceleration in the superconducting cavities, the electrons at the bunch head receiving a smaller energy gain than those at the tail, and (2) the beam is passed through two magnetic chicanes where the leading lower-energy electrons travel on a longer path than the trailing higher-energy electrons. The compressed bunches are characterised by a very narrow leading spike with a peak current above 1000 A and a long tail. The magnetic bunch compression, though necessary for generating the high peak current needed in the FEL process, is accompanied with undesirable side effects. Theoretical studies predict a microbunching instability in the magnetic chicanes, due to the combined action of space charge forces, coherent synchrotron radiation and longitudinal dispersion. In this process, purely statistical fluctuations of the charge density can be amplified to a significant level. The amplification factor strongly depends on the wavelength of the fluctuation and the properties of the magnetic chicanes. At LCLS, strong microbunching at visible wavelengths was observed which in consequence prohibited the use of conventional beam-imaging diagnostics and also compromised the FEL process itself. Several high-resolution techniques have been used by our group at FLASH in the past years to determine the longitudinal bunch charge distribution: in the electro-optic (EO) detection of individual electron bunches we have achieved a world-record time resolution of 50 femtoseconds, the limitation being given by the material properties of the electro-optic GaP crystal. A direct visualisation of the bunch profile was achieved with a transverse-deflecting microwave structure (TDS). Bunch features as short as 25 fs could be resolved, and a time-resolved phase space analysis was carried out. Both the EO and the TDS techniques, however, have reached their resolution limit, hence micrometer-substructures in the bunch (time scales of 10 fs or less) are inaccessible with these time-domain methods. Spectroscopy of coherent transition radiation (CTR) is an alternative, frequency-domain method. While it does not allow for a direct reconstruction of the time profile, it offers the unique possibility of identifying microstructures down to visible wavelengths.

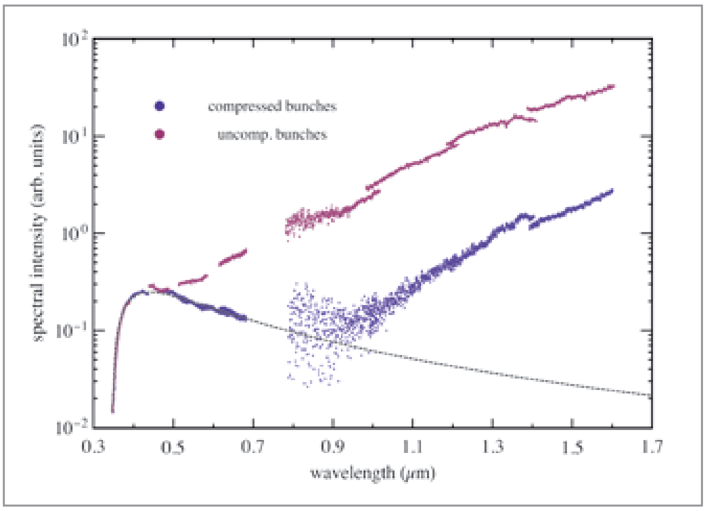

Figure 1

Spectral intensity of visible and near-infrared transition radiation. Blue dots: longitudinally compressed electron bunches, FEL operation mode. Red dots: uncompressed electron bunches. The dashed black curve shows the characteristics expected for incoherent TR.

Coherent transition radiation is produced on an off-axis screen by single electron bunches that are picked out of a long bunch train by a fast kicker magnet. The CTR leaves the electron beam pipe through a 0.5 mm thick diamond window featuring a high transmission from visible light up to millimetre wavelengths. The radiation passes through a 20 m long evacuated beam line equipped with focusing mirrors, and is guided to a laboratory outside the accelerator tunnel. It can be measured using a broadband infrared (IR) spectrometer which has been developed in our group and which is described in the Annual Report 2008. With two selectable grating sets, the wavelength range from 3 µm to 23 µm can be explored. In order to extend the spectral range to shorter wavelengths, we used two commercial spectrometers for the near infrared (NIR) and for visible light (VIS). The NIR spectrometer covers the wavelength range from 800 to 1600 nm, the NIR spectrum is recorded with an InGaAs line array camera, the VIS spectrometer covers the wavelength range from 300 to 700 nm and is equipped with an image-intensified CCD camera with S20 photocathode. Fig. 1 shows the transition radiation spectrum in the range 0.35 µm < λ < 1.6 µm, as measured with the VIS and NIR spectrometers under normal FEL operating conditions (compressed bunches). In the visible range up to 0.7 µm, the data are consistent with the expectation of fully incoherent radiation (dashed line). It falls off as λ^{-2}, the sharp cut-off at 0.35 µm is due to the UV edge of the optics used. Above λ = 1 µm an exponential rise of the radiated intensity is observed which marks the onset of coherent emission. As mentioned above, compressed bunches exhibit a sharp leading spike in their current profile which itself is a strong source of coherent radiation. This is not the case for uncompressed bunches which are accelerated on-crest in the RF cavities upstream of the magnetic chicanes. Nevertheless, these bunches radiate much stronger coherently in the VIS and NIR regime than compressed bunches. The onset of coherent emission is shifted to about 450 nm (Fig. 1), a clear indication for the presence of microstructures in the regime of visible and near infrared wavelengths.

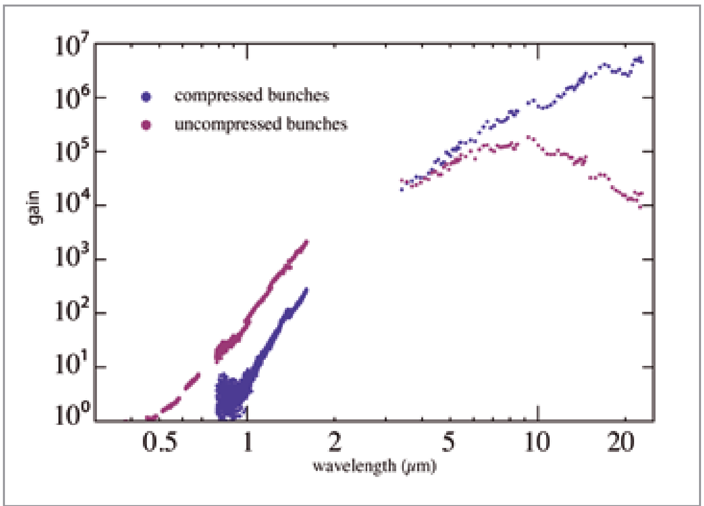

Figure 2

The gain factor (the ratio between coherent and incoherent radiation) as a function of wavelength. Blue dots: longitudinally compressed electron bunches, FEL operation mode. Red dots: uncompressed electron bunches.

For a quantitative description of the phenomenon, we define a gain factor as the ratio between total and incoherent radiation. This factor describes how much initial statistical fluctuations are amplified by the microbunching process and is a key quantity for theoretical models. In Fig. 2 we show this gain as a function of wavelength for the data obtained with the VIS and NIR spectrometers, now combined with previous data measured with the IR spectrometer at wavelengths from 3 µm to 23 µm, again for compressed bunches and uncompressed bunches. For the first time, such gain curves have been measured over an extended wavelength range which spans almost two orders of magnitude. They are complemented by additional data taken with different settings of the magnetic chicanes which are not shown here. For the uncompressed bunches, the gain rises exponentially above a certain short wavelength threshold and reaches a peak value of about 10^5 at a wavelength of 8 µm. These data are of vital importance for the detailed understanding of the microbunching process and a bench mark for analytical models as well as numerical simulations.

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Workshop on the Microbunching Instability III, Rome, Italy, March 24-26

Towards the energy frontier.

Inspect, diagnose and improve

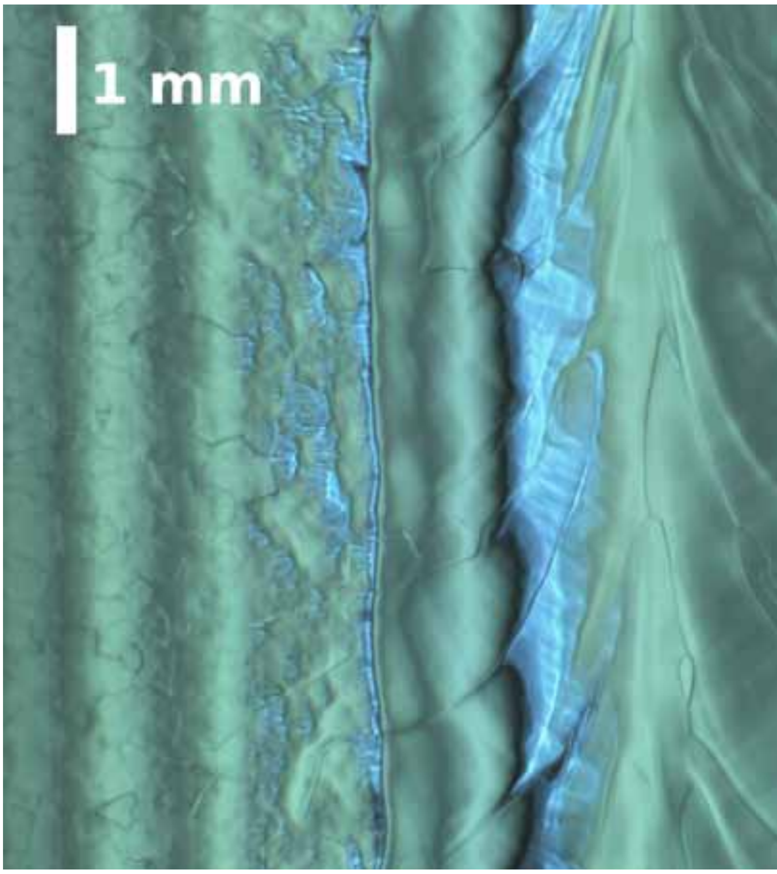
The planned International Linear Collider (ILC) will employ superconducting cavities operated at 1.3 GHz to accelerate electrons. These resonators feature a remarkable Q-value of 10^{10} and are operated with long RF pulses of typically 1 ms duration. This technique has been well established in the international TESLA collaboration largely hosted at DESY, is routinely used at the FLASH facility and constitutes the basis of the electron acceleration for the European XFEL. In contrast to the latter machine the ILC must use the highest possible accelerating gradients to be cost effective. Such high-gradient cavities are available in prototypes, but cannot currently be produced with high yield. The efforts in 2009 have concentrated on identifying some of the limiting features in this process.

Look in the mirror

The advantage of using superconducting cavities is their power efficiency. Effectively the cavity is filled before the bunch train enters the cavities and the beam takes the power out of the stored reservoir, which has to be replenished in between individual bunches. The maximum attainable field is given by the critical B-field of the superconductor. It may be affected by impurities at lower gradients where the heating in a normal conducting area causes a temperature rise above the critical value. Field emission can be a cause of breakdown when the bombardment from an emitter leads to localised heat injection. Surface features such as micrometer-sized defects are supposedly causing excessive B-field and initiate the transition to the normal conducting phase and hence a quench. In fact, the current state-of-the-art is typically characterised by quenches as the major cause for gradient limitation of well-produced and prepared cavities.

The examination of the inner cavity surface is not trivial: good cavities have a very smooth surface with optical properties resembling those of a mirror. The access to the 9-cell cavities is geometrically restricted. A collaboration of the University of Kyoto and KEK in Japan has developed a lighting system with a CCD camera that is able to record pictures of the cavity surface with high contrast. The inspected area can be illuminated with selectable illumination angles. A detailed analysis of the shadows cast by the surface features even enables a reconstruction of the depth or height of those features in the Niobium. Features of a few micron can still be resolved with the camera introduced on the axis of the cavity.

DESY has obtained such a camera, which has been used extensively on the cavity samples available for inspection. This vast body of information has been visually analysed. The most



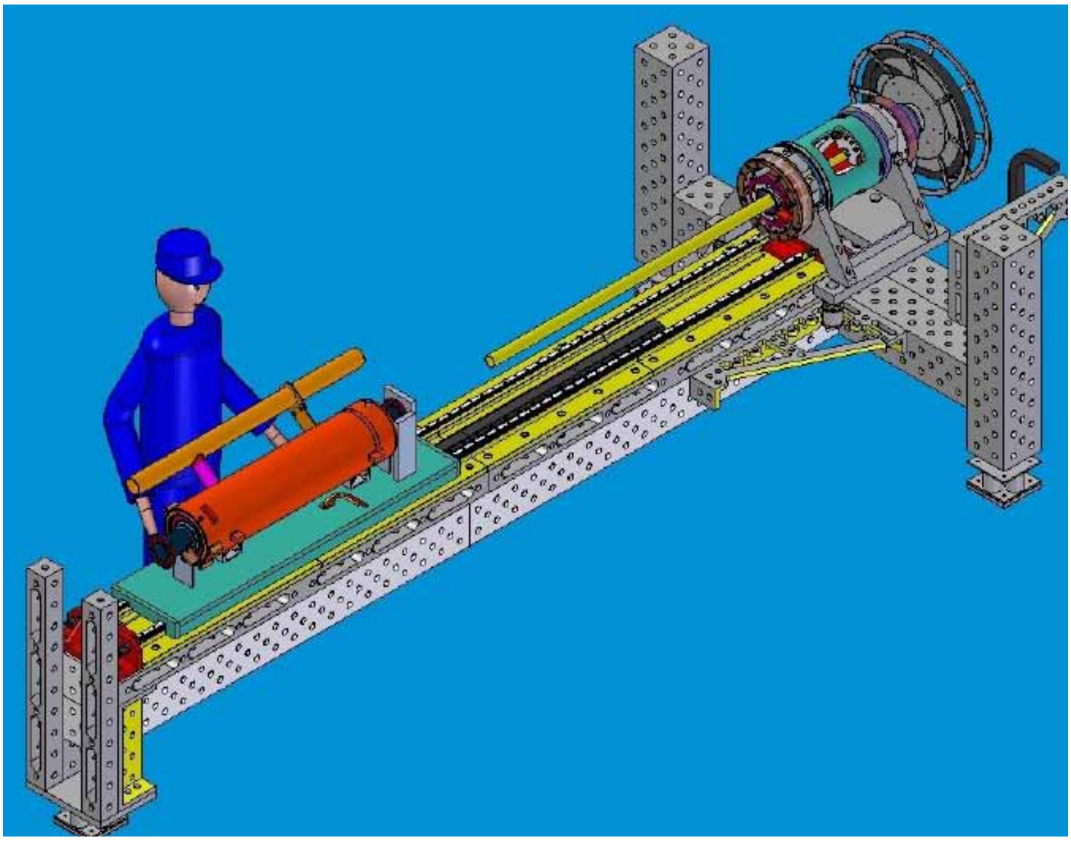


Figure 2
The sketch of the robot for optical cavity inspection.

revealing results were obtained when correlating the optical analysis with detailed temperature mapping by resistors attached to the outside of the cavities. There are several cavities that expose features of several 10 µm diameter which coincide with the hottest spot in the temperature map. Eventually the cavity quenches at this location. On the other hand there are many features, typically along the welding seam between cavity half-cells along the so-called equator (Fig. 1). These structures are clearly visible; however, they do not cause a quench. Clearly, it is essential to categorise the features properly and to learn discern the harmless ones.

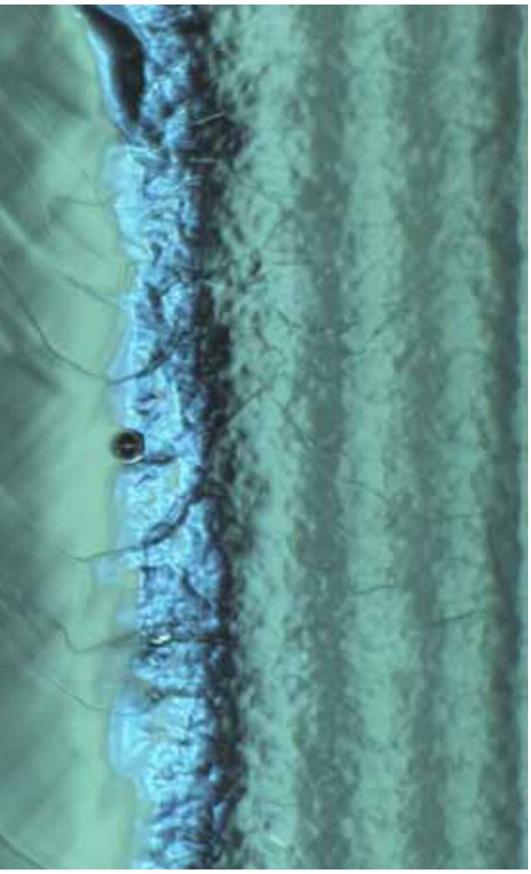


Figure 1
The welding seam of two half-cells with an enclosed defect.

Towards a camera robot

The optical inspection is without a doubt a powerful tool to diagnose and categorise the quality of the produced cavities. The main limitation results from the time required to record both the equator and the iris of the cavity, typically a period of two days. An automated setup will be able to catalogue the surface much faster. Such a robot has been designed and is displayed in Fig. 2. The cavity will be mounted on a sledge driven by a linear motor. At the same time the camera can be rotated by 360°. The robot will be commissioned in 2010.

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The International Linear Collider.

Design, decide and reconsider

As the LHC delivers first collisions at TeV energies expectations run high for new physics to emerge at the Terascale. Supersymmetry is an attractive theory for such new physics that offers compelling explanations to overcome the shortfalls of the Standard Model beyond the scale of electroweak symmetry breaking. It is also well understood that the Terascale discovery potential of the LHC will be both augmented and complemented by an e+e- linear collider which hence has long been identified as the next large project of particle physics. A Global Design Effort (GDE) coordinates the progress of the International Linear Collider (ILC). Based on the TESLA 1.3 GHz superconducting technology it will have an initial energy reach of 500 GeV centre of mass, which can be extended to 1 TeV in a subsequent phase. The e+e- interaction region accommodates two detectors in a push-pull configuration. The design for machine and detectors has been well documented in the Reference Design Report (RDR) in 2007. The ensuing Technical Design Phase serves to consolidate this design by 2012 with DESY an important contributor.

ILC design

The layout of the ILC is sketched in Fig. 1: electrons and positrons are generated at the central campus, 'cooled' in their 6 km damping ring and transported 15 km to the beginning of their respective superconducting linac where they are accelerated to an energy of 250 GeV.
The resulting high-energy, tiny-emittance electron and positrons beams are then focused down to a few nanometers in height and brought into collision at the centre of a complex multifaceted high-precision detector.

The critical R&D on superconducting RF continues to attract attention worldwide and particularly at DESY. In addition GDE activities in 2009 were focused on reconsidering the design choices with a view on proposing cost-optimised alternatives. Such modifications have been identified and were brought forward for further study. Specifically, an overall reduction in the underground civil engineering volume by ~40% has been achieved, predominantly by the removal of the so-called service tunnel which ran the entire length of the machine.

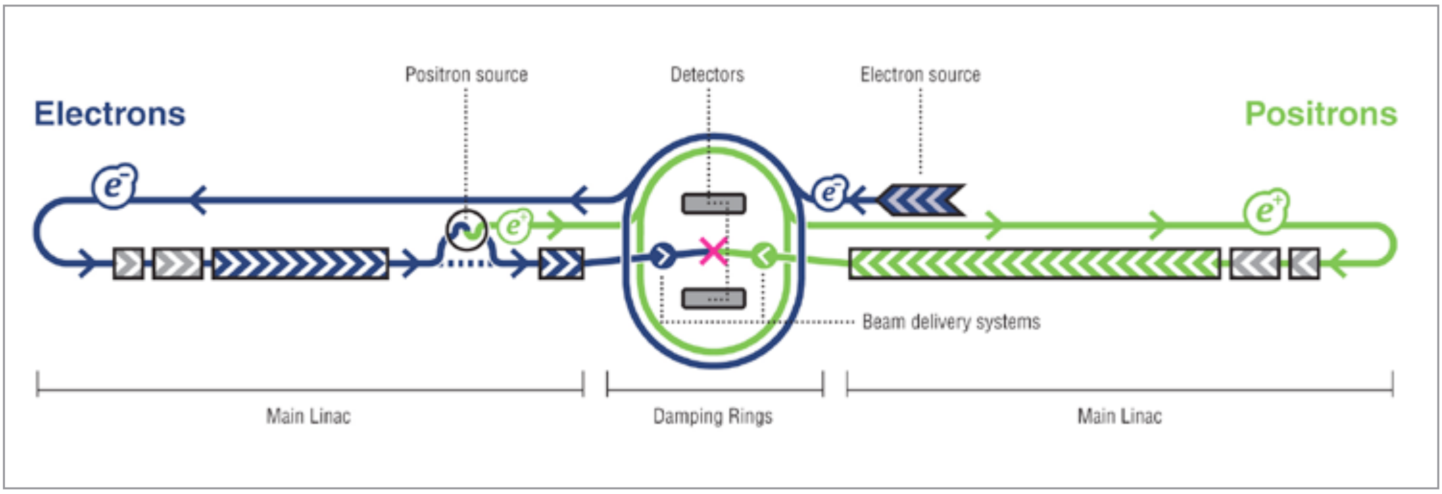

Figure 1

The schematic layout of the ILC with the Central Campus housing Damping Rings and Detector Hall as defined in the Reference Design Report.

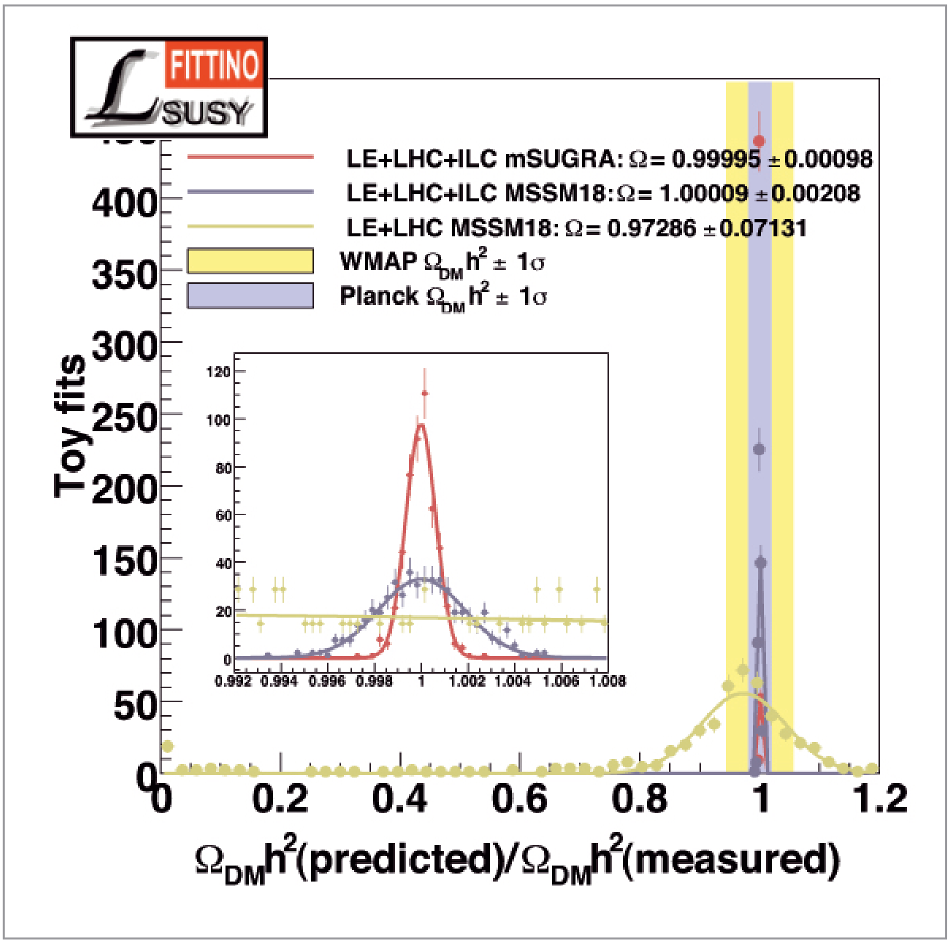

Figure 2

One of the mysteries of modern physics is the apparent abundance of dark matter in the universe. Supersymmetric theories offer an explanation. The theory may be experimentally accessible at both the LHC and the ILC. This figure shows the improvement in the precision provided by the ILC in this study compared to the LHC alone.

This has been made possible in part by the development of novel concepts for the RF power distribution. The RF-distribution, another cost-driver, has been re-examined for cost savings and an alternative scheme has been brought forward that utilises half the installed RF power whilst maintaining the luminosity.

This ambitious proposal is currently being jointly examined by the accelerator and physics community with the goal to conclude in early 2011 so that the engineering and cost work required for the publication of the Technical Design Report can be completed by 2012.

Experimentation at the ILC

The high precision offered by the ILC collider needs to be matched with sophisticated experiments to resolve the expected new physics. Following the RDR release in 2007 several detector concept groups have formed to prepare integrated detector designs. In 2009 three of these groups submitted letters of intent. A thorough review by independent experts recommended two concepts to continue towards a full technical design, ILD and SiD.

The letter of intent for ILD has been supported by almost 800 physicists worldwide and DESY is a strong contributor to this concept. ILD features a combined TPC and Silicon based tracking system, a high-resolution calorimeter and utilises the Particle Flow Technique to reconstruct the final state. The performance of the detector has been assessed in simulation studies of benchmark physics reactions. Some of the benchmark reactions push the resolution of the tracker for final states such as $e^+e^- \rightarrow ZH$, with the Higgs boson H decaying invisibly. Other reactions, e.g. studies in the context of Supersymmetry rely on the capability of the detector to measure precisely energy and direction of jets, thus stressing the performance of the calorimeter. Such studies of physics reach necessitate the simulation of a full detector and indicate nicely how and where the ILC complements the anticipated measurements at the LHC. An example of the results of such studies is shown in Fig. 2.

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Reference:
http://www.linearcollider.org

ILC goes 3D.

A virtual tour of next-generation accelerators

What the International Linear Collider ILC will finally look like is far from having been decided yet. But the current best guess how it may look can be seen in a new Virtual Reality showroom at DESY, where users can virtually take a walk through the tunnel and get first-hand experience of their future working environment.

Visualising complex beamline designs, animating installation procedures and virtually walking through planned facilities – 3D modelling is a powerful and important tool with a broad range of applications in accelerator and detector development: 3D visualisation enables inspection and compliance analysis of interfacing systems and components. Simulations enable early verification of safety and transportation concepts. Digital humans, so-called avatars, can be inserted into accelerator models to perform reachability and field-of-sight studies for installation works. Movies of transport and installation procedures can be created for staff training. And ultimately, stereo projection can be used to inspect and simulate designs and processes in virtual environments. 3D modelling helps discovering and resolving design issues earlier and leads to large savings in time and cost.

Promoting the benefits of 3D modelling, DESY has developed and established a collaborative design process, which enables laboratories around the globe to jointly develop 3D models of next-generation projects – such as the planned ILC.

Particle accelerators and detectors are complex facilities, which consist of many sub-systems. They include buildings and tunnels, accelerator and detector systems, supply lines and other technical infrastructure. Several independently working groups, often located at different collaborating institutes, design and develop the various sub-systems. In this process, each group creates and maintains 3D models of their individual sub-systems. These models are restricted to one sub-system each and show the equipments, assemblies and supply lines of e.g. the water distribution system, the ventilation system, a beamline element, or an RF unit.

Figure 1

Digital human at work at the ILC accelerator, cone of view indicated

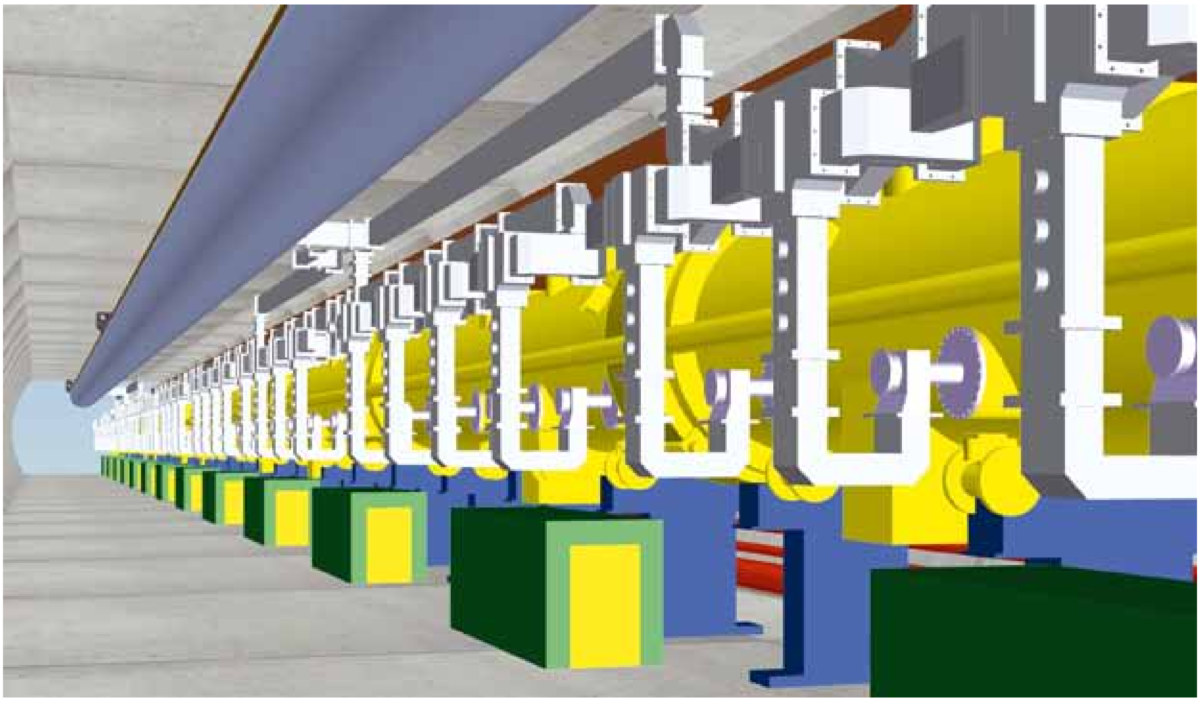

Figure 2
ILC in 3D – this is what it will look like

At DESY, an integration team puts together all the individual sub-system models into a so-called master model, which shows the entire facility. The master model is needed for coordination purposes: it should for example ensure that the various systems have compatible interfaces, and make sure all the components fit into their complex environments. The master model is also the basis for subsequent simulations, such as installation and safety procedures.

Working groups usually have their design tool environments in place. This includes 3D CAD systems, which may be different at different labs, and which are incompatible by nature. At DESY, a process has been developed which enables integrating 3D sub-system models from different working groups into a master model. It is independent of the design tools in use: the participating institutes provide their component models in a neutral 3D format to DESY, where the models are integrated into the master model. The master model is then published in an Engineering Data Management Systems, EDMS. The EDMS is a web-based information system through which all collaboration partners can access, review and work with the 3D models and their accompanying documentation. Changes, however, should only be made only by the original authors, to avoid confusion and the evolution of incompatible parallel versions. The good thing about the EDMS: any user, also users without CAD systems, is able to access the 3D models with the system's web-based viewers.

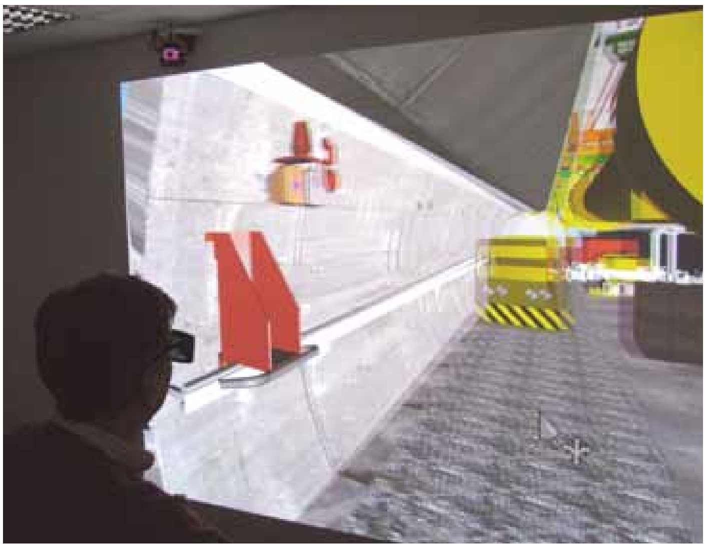

Figure 3
Observer in Virtual Reality room

The collaborative design process was first developed at DESY for the European XFEL project. At XFEL, more than a dozen working groups maintain more than 100 sub-system models, which are updated into the master model on a weekly basis. The process has then been extended to the global design effort (GDE) of the planned ILC, where an initial model of an equipped tunnel segment was produced end of 2009.

The virtual tour of the ILC was presented at the “ILC Accelerator Design & Integration” workshop at DESY in December, where it was well accepted and received a lot of attention. Complementing technical design documents, the virtual accelerator offers realistic perceptions of dimension and space and stimulated lively communication. It makes the ILC appear a little bit closer, as now it can be “seen”. And with contributions from STFC in Daresbury, FNAL in Chicago, CERN in Geneva and DESY, the ILC 3D master model is also as a truly global design effort a prototype for the “real” accelerator.

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Extreme precision.

Forward-looking calorimeters

The forward region in a detector at the linear collider is a very special region. It is needed to measure key quantities – luminosity is best measured from bhabha-pairs going forward, the beam parameters can be estimated from the forward going beam-strahlung – and it closes the gap in the region between the main detector components and the beam pipe. The region is also very special because the environment is extremely hostile for any sort of detector. Radiation doses are extreme, backgrounds from different sources threaten to kill any signals, and space is very limited.

The FCAL collaboration with members from 16 institutes around the world has set itself the goal of developing instruments which can survive in this environment and still provide precision measurements. The challenges-high precision shower reconstruction for luminosity measurements (LumiCal), extreme radiation hardness for beam monitoring (BeamCal) and fast readout for both-will be best met by very compact cylindrical sampling calorimeters with tungsten absorber layers interspersed by pad-structured sensors.

In 2009 a range of different sensor options have been explored. The most promising option for the LumiCal is standard silicon technology, as the radiation is moderate, and fast and precise detectors are essential. Novel materials, e.g. gallium-arsenide (GaAs), artificial single- and polycrystalline diamonds and sapphire, are investigated for the BeamCal.

The most recent Silicon sensors have been produced by Hamamatsu Photonics and have been characterised by a collaboration of the Institute of Nuclear Physics PAN (Cracow), DESY (Zeuthen) and Tel Aviv University.

BeamCal sensors are studied in the laboratory and in an ongoing test-beam programme. The currently most promising sensor material is GaAs. Sensors, as shown in Fig. 1, are produced in an Institute of the Sibirian Academy of Science in collaboration with JINR Dubna. These sensors have been successfully operated and meet all requirements. Diamond sensors are even radiation harder, but high cost currently exclude large scale use.

Based on the expertise acquired a new beam-halo monitor for the FLASH accelerator has been developed, and operated successfully in the 9 mA test-run. Sapphire sensors, albeit of excellent radiation hardness, need more investigations in particular to enhance the signal size.

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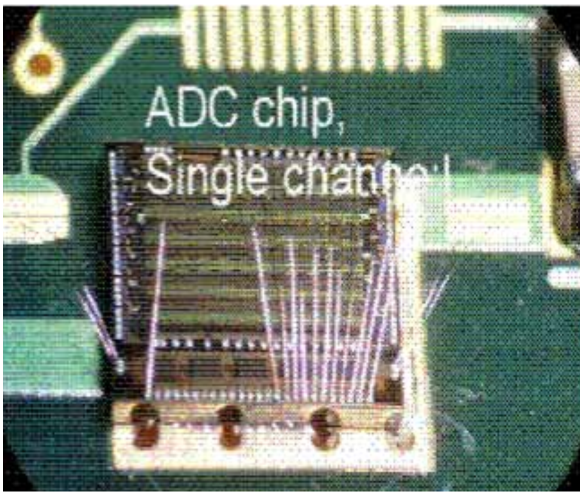

Figure 1
(left) Photo of a GaAS sensor prototype for BeamCAL.(right): An 8 channel front end ASIC prepared for test.

Beautiful spin.

Positrons for the linear collider

The physics reach of a linear collider will profit enormously from the possibility to polarise the beams. This will help to understand difficult signatures, and disentangle parity-related properties of new particles or interactions. Whereas the means to produce highly polarised electron beams are at hand, it is a challenge to provide the intense polarised positron beam needed. A promising method is based on the creating of polarised photons in a helical undulator using the high-energy electron beam. Hitting a thin target, these photons create polarised e^+e^- pairs. The critical points of polarised beams for a linear collider are the positron source itself, in particular the long-term survival of the target, and the collection and acceleration of the polarised positrons. For the physics is it essential that the polarisation of the beam is precisely known at the interaction point.

The international Positron Source Group with members from all laboratories participating in the linear collider preparation is developing the design of the positron source. Different approaches are studied to develop ways to produce a high intensity polarised positron beam. In 2009 the DESY-Zeuthen part of this group developed the simulation program PPS-Sim based on Geant4. It allows evaluating efficiently the particular positron production including yield and polarisation for a specific source design. With this it is possible to study and to compare different options for the target, the optics to collect the positrons behind the target and the first stage of acceleration. An important part of this tool is Geant4 with polarised processes, which has been developed as part of the project and which is implemented in the official Geant4 version. The Zeuthen group is actively supporting the development of Geant4, e.g. providing maintenance of the polarisation extension. In addition, the precision to describe bremsstrahlung and pair-production at high energies has been studied and substantially improved.

For the positron source design, radiation aspects are also important. Due to the high particle flux the target and the surrounding components will be highly activated. Remote handling facilities and special shielding are needed. This is not only a cost factor, but also essential for the maintenance of the machine. The group is developing the tools for the evaluation of radiation and residual dose rates for source components and accelerator elements in the source region.

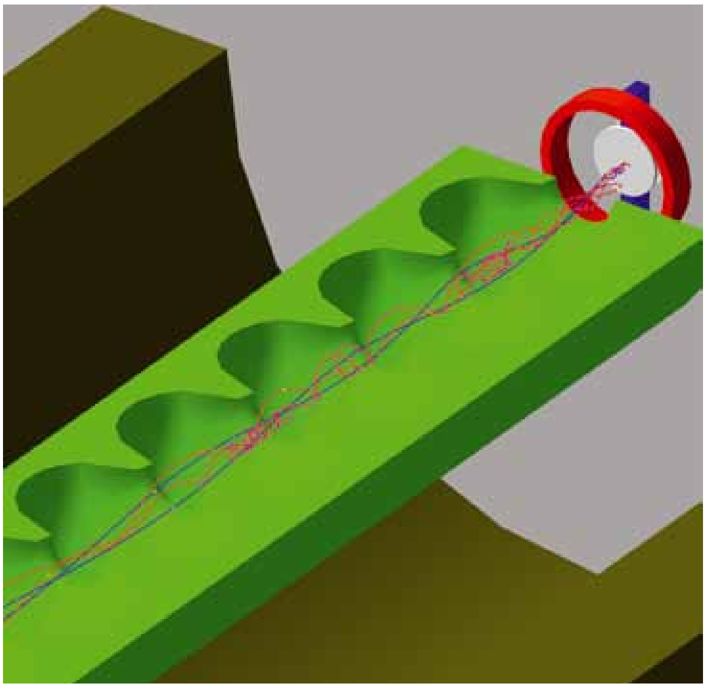

Figure 1

Electrons (red) and positrons (blue) spiraling through the first acceleration structure of the positron source.

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Going granular.

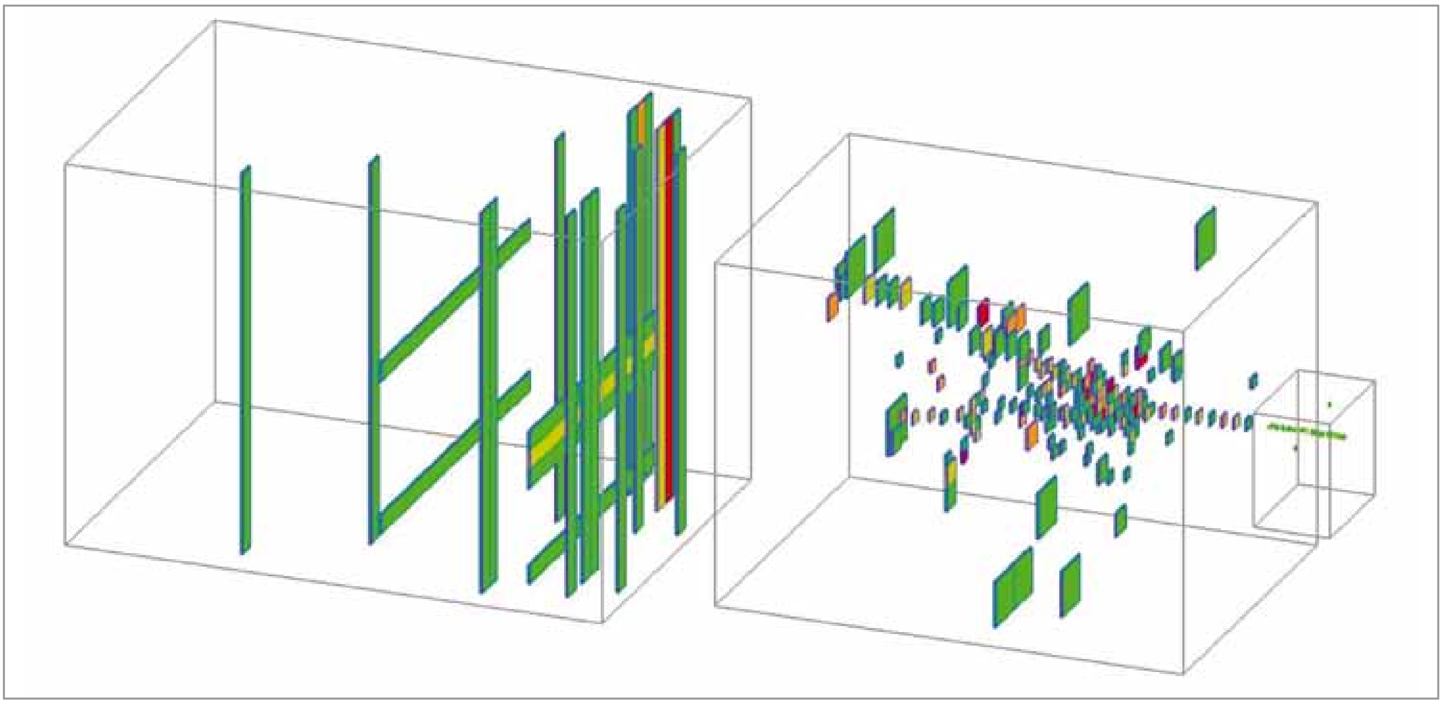
Calorimeters meet tracking

Calorimeters are at the core of a detector for the linear collider. DESY has been for many years at the forefront of developing novel granular hadronic calorimeters. This work is done in the context of the CALICE collaboration, led since 2009 by a DESY physicist.

In 2009 a major test beam experiment was completed. The one cubic-meter prototype was extensively tested in hadron beams at Fermilab, together with an prototype of the electromagnetic calorimeter, and a tail catcher. While the hadronic calorimeter equipped with small scintillator tiles readout with Silicon based photo multipliers (SiPM), has been built by DESY, the electromagnetic calorimeter and the tail catcher were provided by outside collaborators. All shared the same DESY-built electronics, developed in cooperation between Orsay and DESY.

A special emphasis of the 2009 data taking was on low-energy hadron data, below 20 GeV. Uncertainties in the simulation are large in this regime, and experimental data promise to constrain the models. Significant progress was made in the understanding of the data, and the subsequent analysis. The transverse profiles of showers in the HCAL was studied in detail, and found to be well described by the simulation. This is very relevant for studies of the anticipated particle flow performance, and gives confidence into the results.

The electromagnetic component present in each hadronic shower is an important contribution to the overall resolution of the device. Since the response of the calorimeter to electrons and hadrons is different, the energy resolution can be improved significantly if the different parts can be identified, and are calibrated individually. This so-called software compensation has been successfully demonstrated in the prototype. Applying it to data the measured resolution has been improved from 61 to 49%/√E.



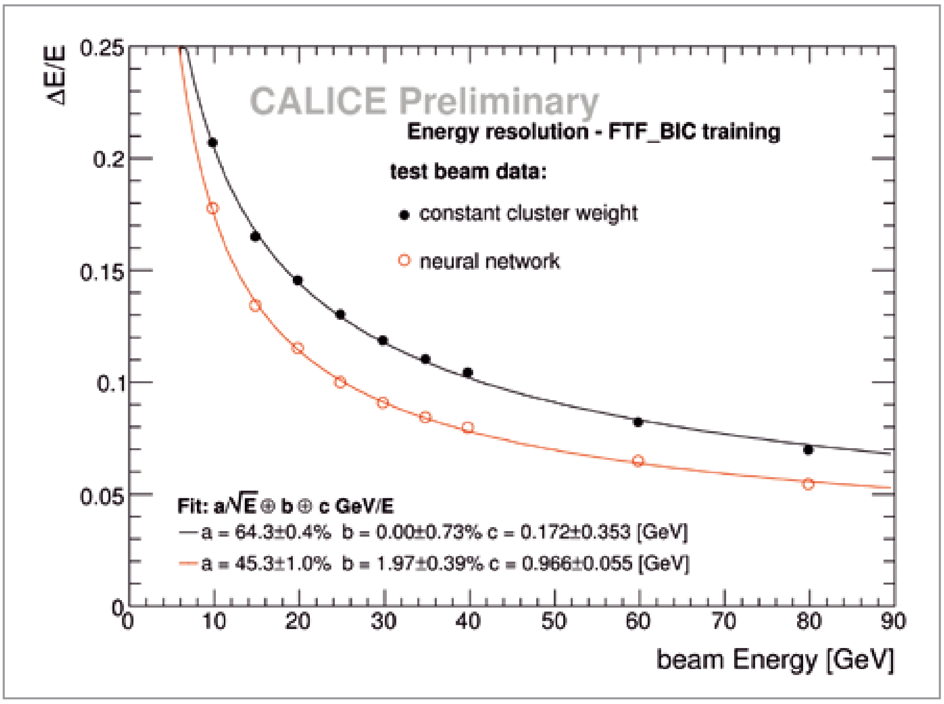


Figure 2

Energy resolution measured in test beam data, before and after applying the reweighting technique mentioned in the text.

A major challenge for these highly granular calorimeters is the calibration. Actual experience was collected with the prototypes, and was applied to a simulation study of the complete detector, with several millions of channels. It could be demonstrated that using innovative methods like the gain auto-calibration capability of the SiPM, or the reconstruction of track segments inside hadronic showers, the necessary precision can be achieved and maintained. It was a strong asset of the study that the methods could be exercised and validated using test beam data from different sites. A convincing proof of the robustness of the system was the demonstration that the calibration could be successfully transported from one experimental site at CERN to another at Fermilab.

For a realistic detector proposal, it is essential to demonstrate that the tremendous integration challenges which come along with the extremely fine segmentation can be mastered without degrading the performance by dead spaces for support structures, readout lines and services. In 2009 the first fully functional version of an integrated chip became available, which includes pre-amplifier, self-trigger, time and amplitude digitisation, pipelines and digital processing. The group developed a printed circuit board, which integrates the ASICs in the detector volume and couples the electronics to the tiles. It also features an optical calibration system with embedded LEDs. The system was successfully commissioned using the first prototype series of scintillator tiles and photo sensors. LED light was injected and single photo-electron signals were resolved in the internally digitised data. An absorber structure prototype with minimised dead spaces and the required mechanical tolerances has also been produced.

Figure 1

Event display of an hadronic interaction in the CALICE prototype. Visible are (from the right) signals in the electromagnetic calorimeter, the hadronic calorimeter, and the tail catcher.

In 2010, the commissioning will continue using positrons from the DESY test beam. The board will be redesigned to accommodate the final chip and tile, and several will be equipped with tiles and sensors and assembled in a more than 2 m long row, to verify that the large areas of a collider detector can be read without losses in signal quality or introducing heat dissipation problems. In parallel, the external interfaces will be redesigned to match the tight spatial constraints demanded by a hermetic detector covering the full solid angle, and already necessary to build a stack structure with relatively find longitudinal pitch. These interfaces are a preparation for the test of a tower structure in 2011.

With these studies the DESY group as part of the CALICE collaboration is making major progress on the way to develop and demonstrate these novel highly granular calorimeters. These devices allow the topological reconstruction of showers, and require techniques better known from tracking systems than from previous calorimeters to fully exploit the information they provide. The major challenge of the next few years will be to show that these fascinating devices can be built on a large scale for affordable costs, so that they can become part of the baseline detector proposal.

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https://twiki.cern.ch/twiki/bin/view/CALICE/WebHome

Moving around.

Tracking in large volumes

Tracking in a detector for a future electron positron linear collider is a very challenging task. It plays a central role in the overall event reconstruction concept, requiring both high efficiency, and excellent resolution. Since a number of years a time projection chamber (TPC) is under development at DESY, which is designed to meet the ambitious ILC goals. The main innovation of the proposed chamber is the gas amplification system, which is based on micro pattern gas detectors. These devices were invented at CERN about 15 years ago, and have seen an increasing use ever since.

In 2007 an international collaboration has been formed, LCTPC, with the goal of developing this TPC. DESY is a key member in this collaboration, and is developing and providing major infrastructure for the group. A central part is a sophisticated installation in one of the DESY test beams, which provides a test environment for studying advanced TPC concepts. The area has become operational in late 2008. In 2009 major upgrades have added a remote controllable movable stage, an external Silicon tracker, a cosmic ray trigger, and other devices. Major contribution to this infrastructure have come from the EUDET programme and from the Helmholtz Alliance “Physics at the Terascale”.

A major piece of equipment provided by DESY is the flexible TPC field cage. This lightweight structure has been designed at DESY, and was built by an external company. It has been designed in a way to accept different readout systems, and to enable the direct comparison of different TPC technologies. Three different types of readouts have been tested: Groups from Saclay and Canada provided a micromegas-based readout module, groups from Japan and China a GEM-based one, and groups from Bonn University and NIKHEF a system based on a pixelated silicon readout ship, the timepix chip. All groups took significant amounts of data under different conditions, and were able to do some first preliminary analyses of resolution and other relevant quantities.

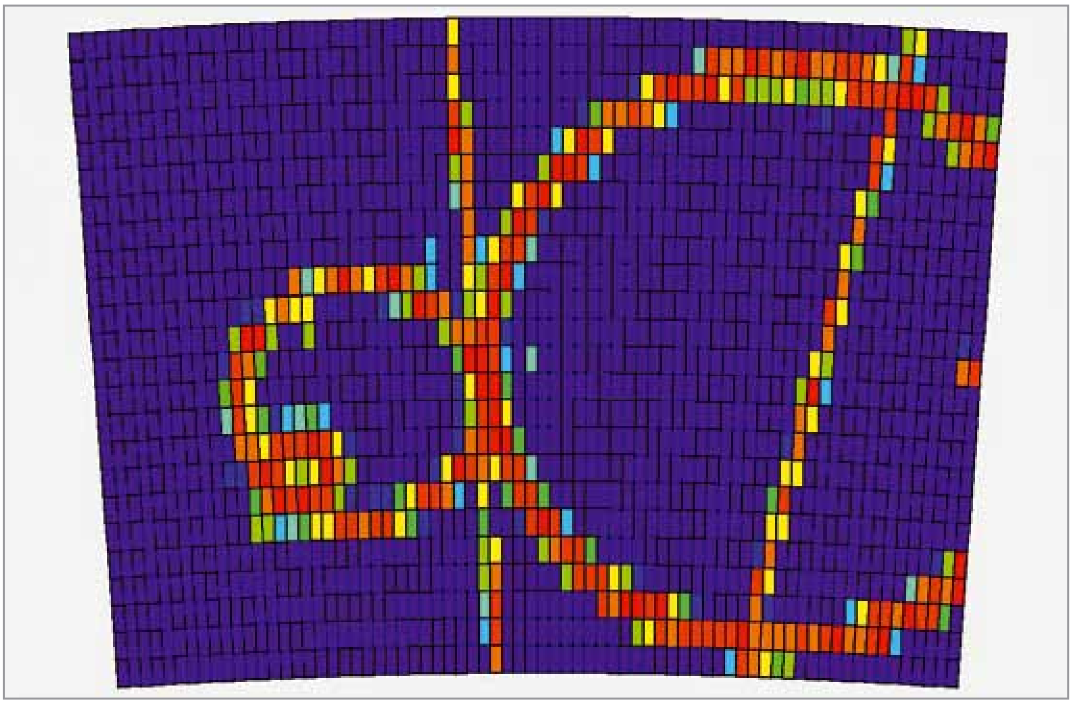

Figure 1

Picture of a low energetic particle seen in the TPC prototype.

Figure 2

Photograph of the magnet mounted inside the stage, with the TPC installed inside the magnet.

The DESY group is – apart from operating the infrastructure and providing basic services to the visiting groups – developing a GEM-based second generation readout module. A new way to mounting GEM foils was developed, which provides self supporting GEM stacks, removing dead areas and promising high precision mounting structures. These structures have been developed and tested for a smaller test chambers, were they were extensively studied using cosmic rays. The technology is now transferred to a module for the large prototype, where it will see first beam in 2010.

The success of a collaborative endeavour depends on software as well as on the hardware. The analysis of the data collected with the TPC setup is done by different groups around the world. A system which provides easy access and easy analysis is therefore crucial. The MarlinTPC system, originally developed at Bonn University, was taken over by the DESY group and reached a first release stage. The software provides a modular approach to event reconstruction, and has pre-programmed central tools like hit finding, track fitting, and others. The software framework is based on the MARLIN system, which has been developed in the ILC community, and which is also used by the wider ILD concept group. During 2009 most of the functionality needed could be provided within this system. Under development is a flexible data base interface, needed to store and manage conditions data from the experiment. Data from the different experiments are routinely stored on the GRID, and thus made available nearly in real time to every collaborator around the world. Over the next 2-3 years the TPC test beam will be operated nearly continuously. The TPC will be equipped with a total of seven readout modules, in different technologies. The main goals of the next few years are to demonstrate that a multi-module system can be operated, and can provide high precision data. Apart from testing the mechanical structures this also implies that calibration strategies be developed, and that corrections routines are available which take into account the field in the superconducting magnet and its distortions. It is expected that by 2012 complete data will be available for the different technological options under discussion, namely GEM, micromegas, and pixel-based readout. It is planned to develope and test advanced endplates made from low-mass materials.

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ILCSoft.

Software tools for ILC detector R&D

Monte Carlo simulation techniques are an indispensable tool for the development of particle detectors for new accelerators. ILCSoft is a complete software framework for simulation and analysis of physics events for ILC detector R&D. The tools are developed at DESY in close collaboration with other international partners. They have been successfully used in studies performed for the Letter of Intent (LOI) submitted for the ILD detector concept, and in various ongoing testbeam programs for ILC detector R&D.

Overview

The ILCSoft framework is based on LCIO, a software package that provides both, a persistency file format for Linear Collider detector studies as well as a hierarchical event data model as shown in Fig. 1. Developed as a joint project between DESY and SLAC, it is now widely used and defines the de facto standard for ILC-related detector R&D work. The core of the ILCSoft framework is defined by Marlin, a modular C++ application framework that uses LCIO as its transient and persistent event data model. Marlin allows the distributed development of reconstruction and analysis algorithms. It is highly flexible and is configurable through the use of XML steering files that allow the specification of global and per-module run time parameters. Marlin is complemented by a number of software tools: GEAR, which provides the high level view of the detector geometry and materials as needed during reconstruction and analysis; LCCD, a conditions data toolkit that provides access to the conditions data of test beam experiments via an abstract interface to an underlying MySQL database; and CED, a fast 3D event display for visualisation of event data and reconstruction algorithms.

The Mokka application, which is based on the geant4 toolkit, is used for the simulation of the detector response to particles created in the interaction. It poses a flexible description of the detector's geometrical and material properties, this is interfaced to GEAR and thus available at the reconstruction level. This flexibility allows for the scaling of the sub detectors in a coherent way, a feature massively exploited in the detector optimisation phase.

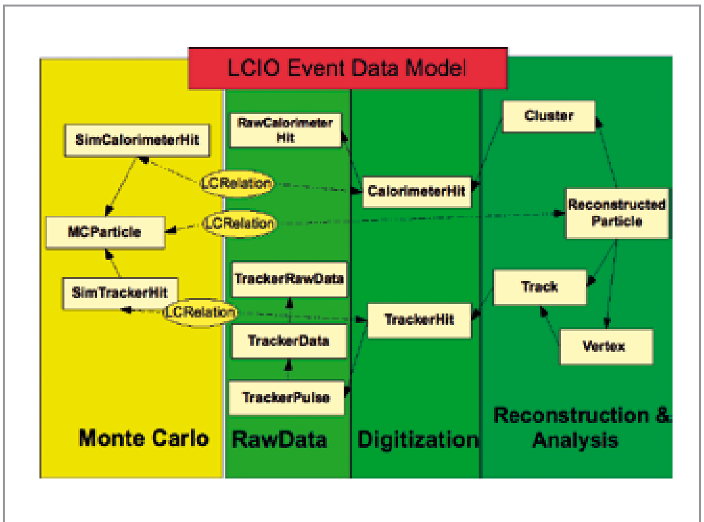

Figure 1

Hierarchical event data model defined in LCIO

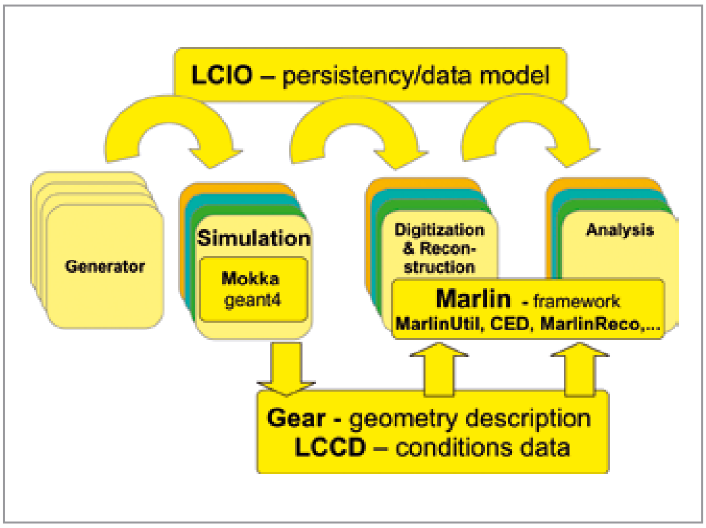

Figure 2

Overview of the software tools in LHCSoft

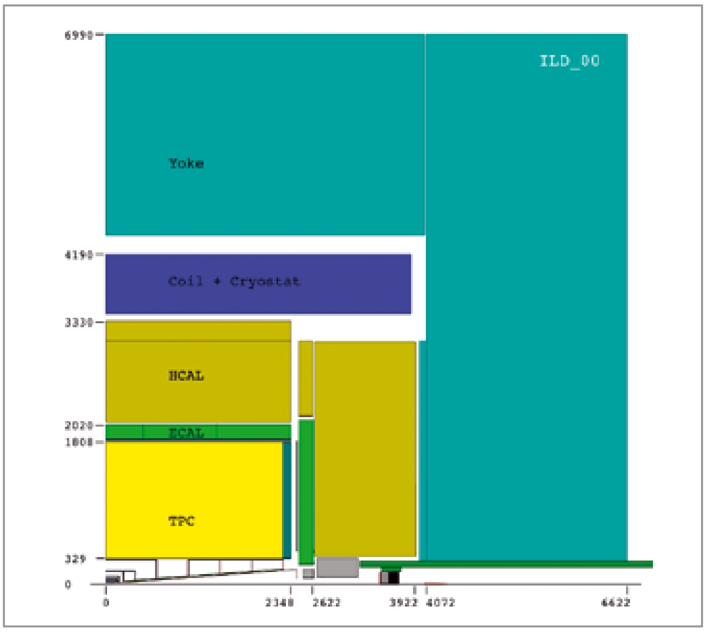

Figure 3

Quadrant view of the ILD_00 model as implemented in Mokka

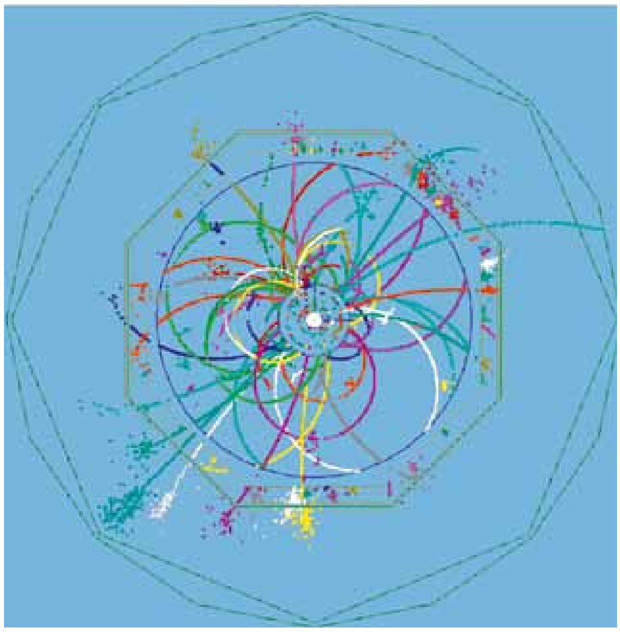

Figure 4

ttbar event simulated and fully reconstructed

Fig. 2 shows an overview of the main tools provided in ILCSoft and how they are used at the main stages of high energy physics Monte Carlo data processing: generation, simulation, reconstruction and analysis. The core framework is completed by a number of auxiliary tools, such as RAIDA for histogramming and the utility package MarlinUtil. ILCSoft depends on a small set of external packages that are widely used in the field, e.g. ROOT, gsl and CLHEP.

Application of ILCSoft

ILCSoft is the software framework of the ILD detector concept working group, being used for detector optimisation and physics studies. It is also used by the international testbeam collaborations CALICE, LC-TPC and EU-Pixeltelescope, the CLIC detector working group and in parts by the SID detector concept.

For ILD a full set of reconstruction algorithms have been developed in the framework. The plug-in-based design of Marlin supports this distributed development of algorithms, and also allows for the comparison of different algorithms at runtime. For example, one can run two tracking algorithms each producing independent collections of reconstructed tracks. Digitisation is performed in the MarlinReco package. This converts the output from simulating the interaction of particles with the detector material into realistic measurements. To this end, the subdetector resolutions established in testbeam experiments are applied in a parametrised way. MarlinReco also contains pattern recognition and track fitting algorithms originally developed at LEP for the reconstruction of long-lived charged particles. The ILD concept with its precision tracking and highly granular calorimeters is specifically optimised for the particle flow algorithm, i.e. the reconstruction of single particles via the reconstruction of calorimeter showers and their combination with tracks, so as to reach an unprecedented jet energy resolution. The Marlin package PandoraPFA currently provides the best implementation of the particle flow algorithm. Vertex reconstruction and identification of heavy flavor jets is performed in the LCFIVertex package. This set of tools has been used heavily together with Mokka in order to try and find the optimal layout of the ILD detector for writing the Letter of Intent (LOI). For this LOI an ILD model, including dead regions, support material and realistic resolutions was implemented in Mokka, as shown in Fig. 3.

Together, more than 50 million Monte Carlo events were fully simulated and reconstructed for the final ILD model and its detector variants. This was done for a set of defined benchmark reactions – typically corresponding to an integrated luminosity of 500 fb^{-1}, or more, and a sufficiently large set of standard model events for background estimation. Fig. 4 shows an event display of one of these events. Given that such a massive production requires a considerable amount of computing re-sources – about 3min./event – this was only possible using the Grid. The largest part of this production has been done on the DESY Grid centre, whilst the rest was performed at a handful of other European Grid sites.

With this sample of Monte Carlo events it was possible to demonstrate the extensive physics capabilities of the ILD detector, which in turn contributed to the successful validation of the ILD LOI.

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The IceCube neutrino telescope.

Searching for cosmic neutrinos at the South Pole

High-energy neutrinos must be emitted as a by-product of collisions of charged cosmic rays with matter. Since they can escape much denser celestial bodies than light, they can be tracers of processes which stay hidden to traditional astronomy. At the same time their extremely low reaction probability makes their detection extraordinarily difficult. Realising the dream of high-energy neutrino astronomy requires detectors of a cubic kilometer scale or beyond. After five years of construction, such a device – IceCube – is going to be completed in January 2011.

When fully installed in January 2011, IceCube will consist of 86 strings equipped with a total of 5160 photomultipliers in glass spheres, lowered to depths between 1.4 and 2.4 km in the Antarctic ice shield. The total equipped volume is one cubic kilometer. In a furious Antarctic season 2009/10, twenty strings have been installed, on top the 59 deployed in the previous five seasons. Fig. 2 shows an artist's view of the detector. Six central strings have been added to the original design. These narrow-spaced strings form "DeepCore", a sub-array with a lower energy threshold than the rest of IceCube. IceCube is complemented by a surface detector, IceTop, which consists of ice tanks recording the Cherenkov light of air shower particles passing the tanks.

DESY has assembled 1250 optical modules and developed the front-end electronics located at the surface which allows communication with the detector deep in the ice. DESY's main contributions to maintenance and operation of the experiment are Monte-Carlo mass simulation, including the coordination of German GRID computing and building up the European data centre.

The main physics goal of IceCube is the search for sources of extraterrestrial high-energy neutrinos. The traditional method is to look for upward going muons generated in neutrino interactions close to or within the detector. For IceCube, this means looking to the Northern hemisphere. The background

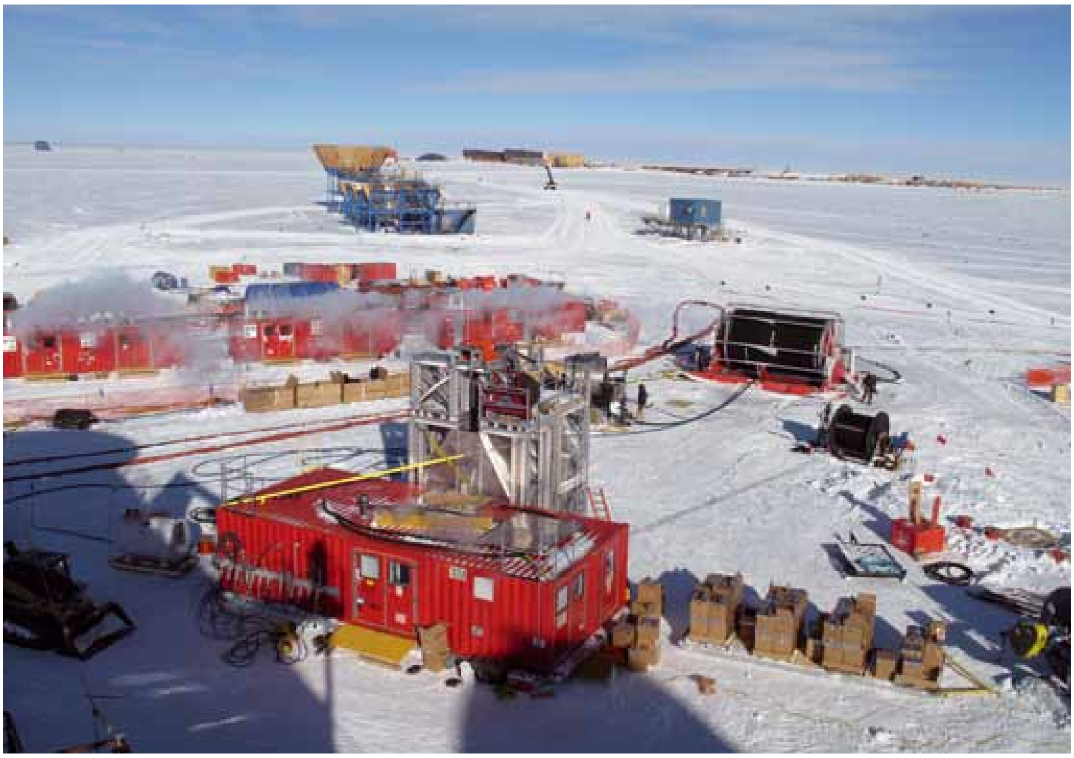

Figure 1

View to the IceCube drilling and deployment camp, with heaters, pumps and the drilling hut in the foreground and a radio telescope and the South Pole station in the background.

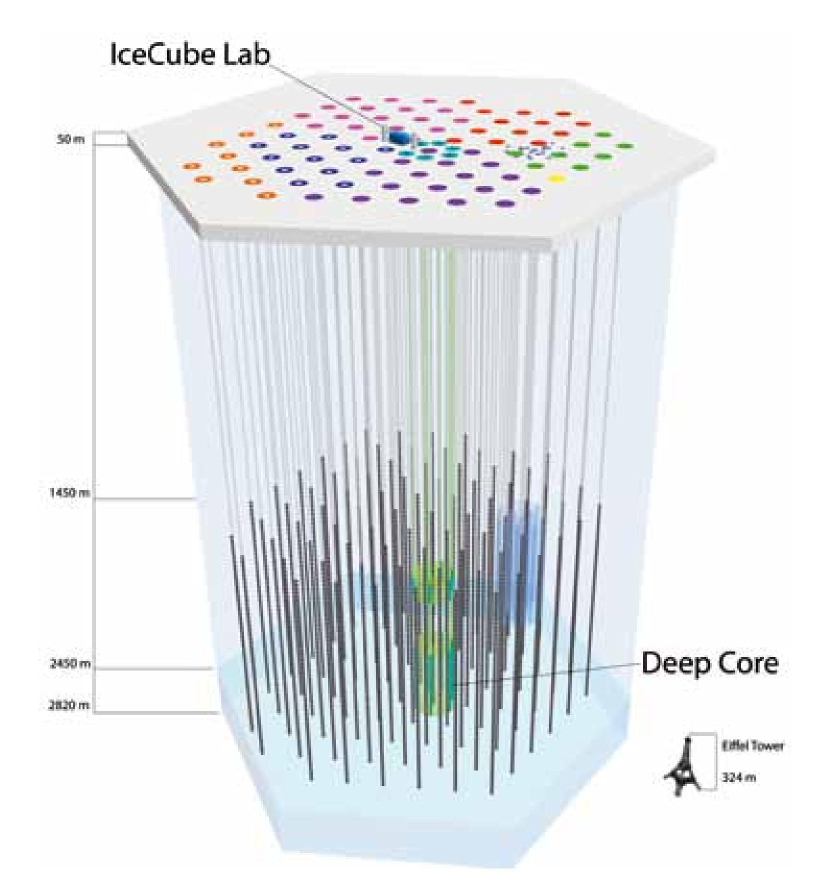

Figure 2

Artist's view of IceCube. The DeepCore array replaces AMANDA, IceCube's predecessor which was decommissioned in May 2009. At the surface: the air shower detector IceTop

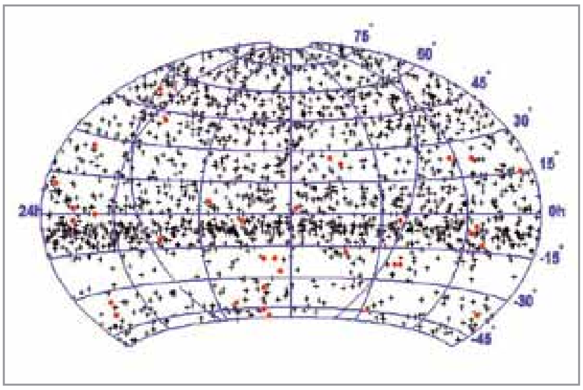

Figure 3

Thirty five events of the Air shower experiments Auger and HiRes ($E>10^{19.5}$ eV, red dots) on the background of the IceCube sky map with 1885 events (crosses). Data are from 2007.

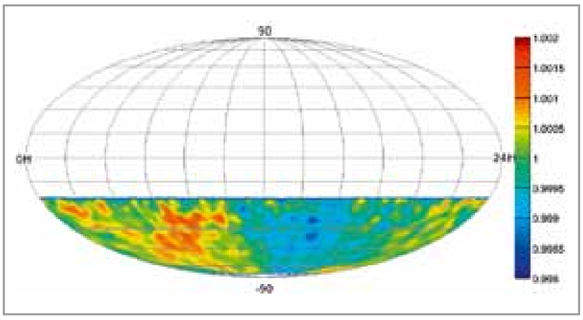

Figure 4

IceCube sky map of downward moving muons.

to extraterrestrial neutrinos consists of neutrinos generated by cosmic rays collisions in the Earth's atmosphere. AMANDA and IceCube have registered several 10^4 of such atmospheric neutrinos, with a rich potential for addressing questions of particle physics. However, no statistically significant excess of neutrinos from a certain direction has been observed, neither in the sky map of seven years of AMANDA operation nor in the first data taken with IceCube.

Fig. 3 shows the sky map derived from one year operation of IC-22 (22 string configuration operated in 2007). The analysis has been tailored in a way that also part of the Southern sky (above the horizon at the South Pole) is included. The crosses are IceCube neutrino candidates, the red dots mark the directions of 35 charged cosmic rays with highest energy which have been registered by the Auger and HiRes cosmic ray detectors. A slight correlation between IceCube neutrino events and the cosmic ray events is observed, with 60 IceCube events in a 3° neighbourhood of the Auger/HiRes events instead of 43.5 expected for accidental coincidences. More IceCube data and the expected new Auger data will tell whether this 2.4σ effect is more than just a statistical fluctuation.

Looking above horizon and lowering the energy threshold down to the TeV range, one obtains a sky map of punch-through muons from air showers. The showers are due to the interaction of cosmic rays which have entered the atmosphere from the Southern hemisphere. The resulting sky map (Fig. 4) shows a large-scale anisotropy on the per-mille level. A similar effect has been observed by low-threshold cosmic ray detectors on the Northern hemisphere. With IceCube, it is measured for the first time at the South. Covering the full sky and adding the huge statistics expected from the coming years of IceCube operation will help to distinguish between different hypotheses on the origin of the anisotropy: Is it due to large-scale magnetic fields which bundle cosmic rays? Is it due to a few nearby sources of cosmic rays? In the latter case IceCube may contribute to the identification of the sources of cosmic rays – paradoxically not via neutrinos, but via muons from cosmic rays itself!

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http://icecube.wisc.edu

One hundred eyes.

The Cherenkov Telescope Array CTA – the future of gamma-ray astronomy

The impressive results of the ground-based very high-energy gamma-ray instruments H.E.S.S., MAGIC and VERITAS have generated a huge interest in both the astrophysics and particle physics communities. A consortium of institutes plans CTA, the Cherenkov Telescope Array. The goal is to design, construct and operate this next-generation observatory providing a sensitivity improvement compared to current instruments of one order of magnitude, an enlarged energy range, a significantly improved angular resolution, and nearly full-sky coverage with arrays on both hemispheres. CTA is currently in the preparatory phase working on R&D and is planning to build prototypes. The start of the construction is planned for 2013.

Very high-energy (VHE) gamma-ray astronomy studies the universe at energies above several GeV up to a few hundred TeV. The majority of the observed photons are produced by the most extreme non-thermal processes known, taking place in extraordinary environments such as remnants of stellar star explosions, ultra-relativistic jets emerging near super-massive black holes, and gamma-ray bursts. CTA will be a unique tool for VHE astronomers and will likely provide the key observations for the understanding of long standing questions of astrophysics like the nature of gamma-ray bursts, the process of jet formation near active galactic nuclei and the origin of cosmic rays, including the enigmatic ultra-high energy cosmic rays with energies beyond 10^{20} eV.

The nature of dark matter is one of the most important scientific questions today. CTA will be the most sensitive instrument to measure gamma rays from dark-matter annihilation as predicted by Supersymmetry (SUSY). A positive signal will provide information about the cross-sections and the cosmological distribution of dark matter. Important constrains on the nature of dark-matter will be set for the case of a non-detection.

CTA will be built in two arrays, on the Northern and Southern hemisphere. Each CTA array will consist of a few very large central telescopes providing excellent efficiency below 100 GeV, embedded in an array of medium sized telescopes giving high performance in the energy range from 100 GeV to 10 TeV, surrounded by a few-km^2 array of small dishes to catch the bright but rare showers at a few 100 TeV: altogether more than fifty telescopes. An artist's view of one array is shown in Fig. 1.

CTA is promoted by all European groups participating in VHE astronomy, with a large number of new partners from all over the world. CTA is on the list of projects on the roadmap of the European Strategy Forum for Research Infrastructures (ESFRI). ApPEC and ASTRONET, the European committees of the astroparticle and astronomy community have given CTA top priorities.

The following basic parameters of the CTA arrays will be established within a design study in the years up to 2012 in order to understand performance and costs:

- Characteristics and availability of site candidates
- An optimal array layout
- Small prototype series of components such as mirrors, photo sensors, electronics, drive systems and mid-size and small telescopes
- A detailed design for telescopes and equipment
- A plan how to operate the facility as observatory
- A model and prototype how to handle and analyse the data.

Figure 1

An artist's view of a CTA array with a mix of different telescopes

The DESY group in Zeuthen joined the CTA consortium three years ago. We play a role in CTA commensurate to Helmholtz centers: a strong, sustainable partner in large infrastructure projects that gives a solid support for universities. VHE astronomy is an important component of a multi-messenger programme that is a part of DESY's programme in astroparticle physics.

During the R&D and prototype phase the CTA group at DESY contributes in these fields: physics analysis and optimisation of the CTA array performance with Monte Carlo methods. An intense, Grid-based simulation effort is needed to perform array optimisation and prepare physics analysis. We started a design study for the mechanical construction of telescopes with a diameter of 12 metres to establish how we can, with industrial partners, take responsibility to build such a telescope. The DESY group in Zeuthen is working on the design of the dish structure carrying the mirrors (with partners at Argonne and Saclay) and the mount that drives the telescope. We are developing a high-voltage system for the phototubes in the camera and have started a design study of a digital trigger system of CTA. To maximise the scientific output, the CTA facility will operate as an open observatory, providing observation time and data to a wide community. In collaboration with partners in Erlangen and Berlin, a prototype system for the array operation and control system for CTA shall be designed and developed.

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www.cta-observatory.org

Decaying superWIMPs.

Signatures of decaying dark matter in cosmic rays?

Many well-motivated particle physics scenarios predict that dark matter particles decay with a lifetime much longer than the age of the universe. Recently reported excesses of cosmic ray positrons (+ electrons) can be interpreted in terms of such decays. This interpretation will be tested by upcoming cosmic gamma ray and neutrino observations.

There is overwhelming evidence for dark matter in the universe that is not made of any known elementary particle. Unraveling its particle nature is one of the most exciting goals of present-day particle physics and cosmology. It is generally expected that this endeavour can only succeed by putting together many different signatures – indirect signals in cosmic rays from dark matter annihilation or decay, direct signals from galactic dark matter particles in earthbound detectors, and detection of dark matter particle candidates at accelerators.

Theoretical particle physicists have proposed many candidates for the constituents of dark matter. The best motivated occur in extensions of the Standard Model (SM) which have been proposed in order to solve other problems besides the dark matter puzzle. In this respect, local supersymmetric extensions of the standard model, which aim at a solution of the hierarchy problem and at a grand unification of all forces, provide very interesting dark matter candidates, notably neutralinos and gravitinos, the superpartners of the SM neutral bosons and the graviton, respectively. In fact, neutralinos are very natural and popular candidates for the dark matter since they have interactions of electro-weak strength and their masses are expected around the weak scale, ~100 GeV, leading to the fact that their relic density resulting from freeze-out in the early universe is just in the right ball-park as required by observation. They belong to the class of WIMP – weakly interacting massive particle – dark matter. For WIMPs, however, stability, or at least lifetime much longer than the age of the universe, has to be imposed by a symmetry such as *R*-parity in the case of the supersymmetric SM: otherwise their mass and coupling would imply a lifetime of order 10^{-25} s. This is not necessary for gravitinos, which belong to the class of superWIMPs – super-weakly interacting massive particles: owing to their extremely weak, gravity-like interactions, they live very long, even in the absence of a stabilising symmetry. In fact, in supersymmetric scenarios with small *R*-parity violation, gravitinos in the mass range from 100 GeV to 1 TeV are viable candidates for dark matter and provide a consistent thermal history of the universe, including successful leptogenesis and big bang nucleosynthesis [arXiv: 0903.1813,arXiv:0910.1870]. Other very well-motivated potentially late-decaying superWIMP candidates are hidden-sector U(1) gauge bosons or gauginos, where the decay rate is suppressed by a possibly tiny kinetic mixing between a hidden U(1) gauge group and the U(1) of hypercharge [arXiv:0909.0515,arXiv:0910.5625].

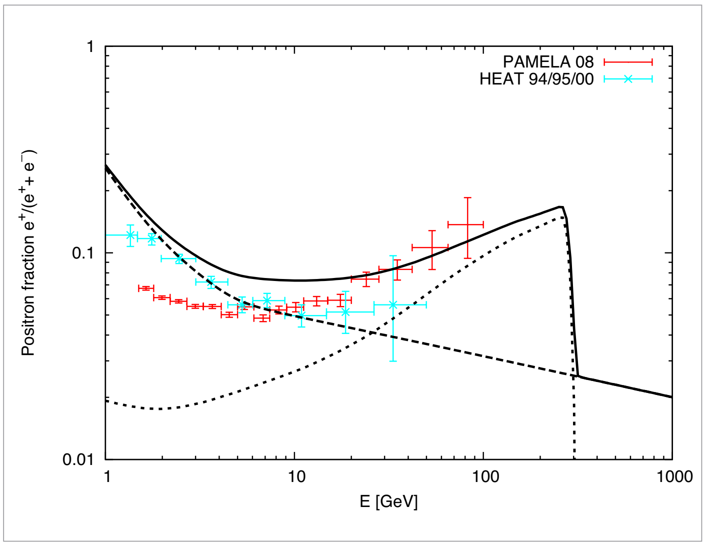

Figure 1

The observed cosmic ray positron fraction exceeds at high energies the expectation from spallation of primary cosmic rays in the Milky Way disc (falling dashed line). This rise may originate from the decay of a gravitino with mass ~ 600 GeV and lifetime ~ 1.5 x 10^{26} s (rising dashed line).

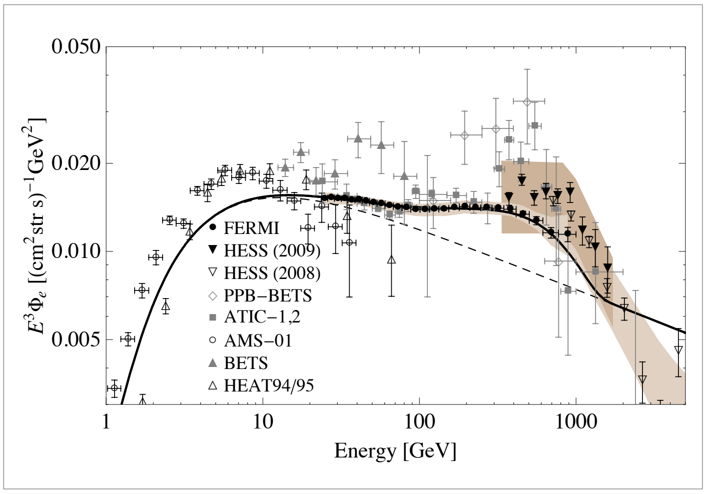

Figure 2

The observed cosmic ray $e^+ + e^-$ flux displays, in the 10 ÷ 1000 GeV range, an excess over the conventional expectation (dashed line). It may be matched by invoking in addition a decaying (e.g. via $\chi \to \mu^+ \mu^- \nu$) superWIMP of mass ~ 3.5 TeV and lifetime ~ 1.1 x 10^{26} s (solid line).

Very recently, the interest in decaying dark matter increased dramatically, after reports of apparent cosmic ray excesses observed by the PAMELA, Fermi-LAT, and H.E.S.S. collaborations in high-energy positron (Fig. 1) and electron and positron (Fig. 2) spectra, compared to the expectation from secondary production of positrons due to the collision between primary protons and the interstellar medium within our galaxy. The quantification of these excesses is still quite uncertain, not only because of quite large systematic uncertainties. A very conventional astrophysical source for them could be nearby pulsars and/or supernovae remnants. However, these observations have inspired theorists to search also for pure particle physics models which accommodate all results.

Generically, interpretations in terms of WIMP annihilation seem to be disfavoured, since the magnitude of the observed excesses appear to require either a huge enhancement of the local density of dark matter, which is at variance with recent numerical simulations of the latter, or a huge enhancement of the annihilation cross section over the one expected for a thermal relic. This constraint is relaxed in decaying dark matter scenarios, where the positrons may be produced in the decay of a superWIMP, e.g. of a gravitino (Fig. 1) or a hidden gaugino. In this case, the magnitude of the excess requires the lifetime of the superWIMP to be of order ~ 10^{26} s, while the fact that the excess in the e^+ and e^- data extends to about a TeV (Fig. 2) necessitates a quite large superWIMP mass of a few TeV [arXiv:0906.1571]. This might be easily realised in hidden gaugino scenarios [arXiv:0903.3625,arXiv:0912.4496]. For a decaying gravitino dark matter scenario, on the other hand, the observed fluxes can only be matched by invoking also additional astrophysical sources [arXiv:0906.1187]: thermal leptogenesis and universal boundary conditions at the scale of grand unification restrict the gravitino mass to lie below 600 GeV.

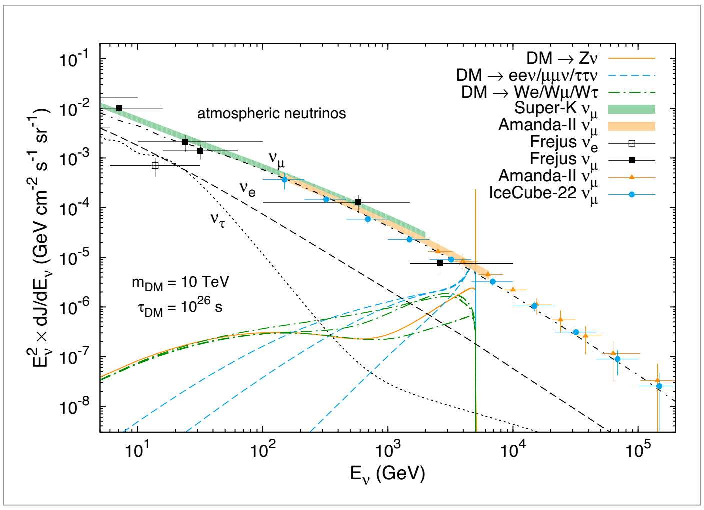

Figure 3

Neutrino spectra of a decaying superWIMP compared to the expected background.

The key to understand the origin of the excesses seems to lie in a multi-messenger approach: one has to search for signatures in radio waves, in synchrotron radiation [arXiv:0905.4952, arXiv:0912.1203], in neutrinos [arXiv:0912.3521] (Fig. 3), in anti-protons, and in gamma rays. In fact, if decaying dark matter is the right explanation of the excesses observed in cosmic ray positrons, a dipole-like anisotropy in the gamma-ray signal is predicted that could be observable in the near future by Fermi [arXiv:0909.3514,arXiv:0912.4504].

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J/ψ photoproduction at HERA.

Evidence for colour-octet processes

The cross section of inclusive J/ψ photoproduction is for the first time calculated at next-to-leading order within the factorisation formalism of nonrelativistic quantum chromodynamics, including the full relativistic-corrections due to the intermediate ${}^1S_0^{[8]}$, ${}^3S_1^{[8]}$, and ${}^3P_J^{[8]}$ color-octet states. A comparison to recent H1 data suggests that the color-octet mechanism is indeed realised in J/ψ photoproduction, although the predictivity still suffers from uncertainties in the color-octet long-distance matrix elements.

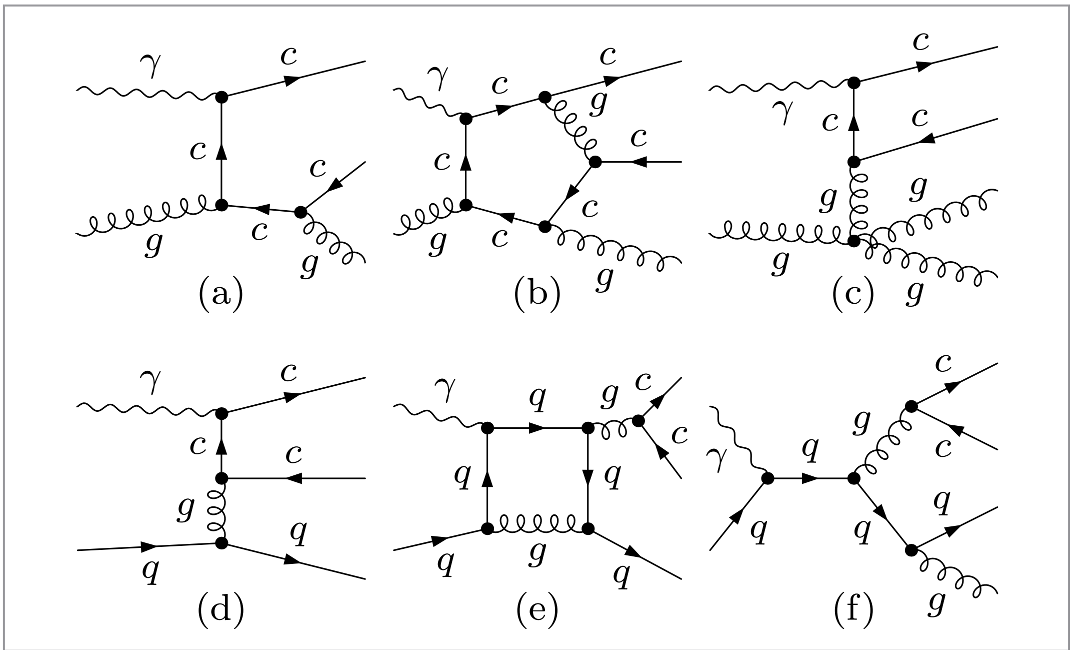

Figure 1

Sample diagrams contributing at LO (a and d) and to the virtual (b and e) and real (c and f) NLO corrections.

Since the discovery of the J/ψ meson, in 1974, charmonium has provided a useful laboratory for quantitative tests of quantum chromodynamics (QCD) and, in particular, of the interplay of perturbative and nonperturbative phenomena. The factorisation formalism of nonrelativistic QCD (NRQCD) provides a consistent theoretical framework for the description of heavy-quarkonium production and decay. This implies a separation of process-dependent short-distance coefficients, to be calculated perturbatively as expansions in the strong-coupling constant α_s, from supposedly universal long-distance matrix elements (LDMEs), to be extracted from experiment. The relative importance of the latter can be estimated by means of velocity scaling rules; i.e. the LDMEs are predicted to scale with a definite power of the heavy-quark (Q) velocity v in the limit $v \ll 1$. In this way, the theoretical predictions are organised as double expansions in α_s and v. A crucial feature of this formalism is that it takes into account the complete structure of the $Q\overline{Q}$ Fock space, which is spanned by the states $n = {}^{2S+1}L_J^{[a]}$ with definite spin S, orbital angular momentum L, total angular momentum J, and color multiplicity $a = 1, 8$. In particular, this formalism predicts the existence of colour-octet (CO) processes in nature. This means that $Q\overline{Q}$ pairs are produced at short distances in CO states and subsequently evolve into physical, colour-singlet (CS) quarkonia by the nonperturbative emission of soft gluons. In the limit $v \to 0$, the traditional CS model (CSM) is recovered in the case of S-wave quarkonia. In the case of J/ψ production, the CSM prediction is based just on the ${}^3S_1^{[1]}$ CS state, while the leading relativistic corrections, of relative order $O(v^4)$, are built up by the ${}^1S_0^{[8]}$, ${}^3S_1^{[8]}$, and ${}^3P_J^{[8]}$ ($J = 0,1,2$) CO states.

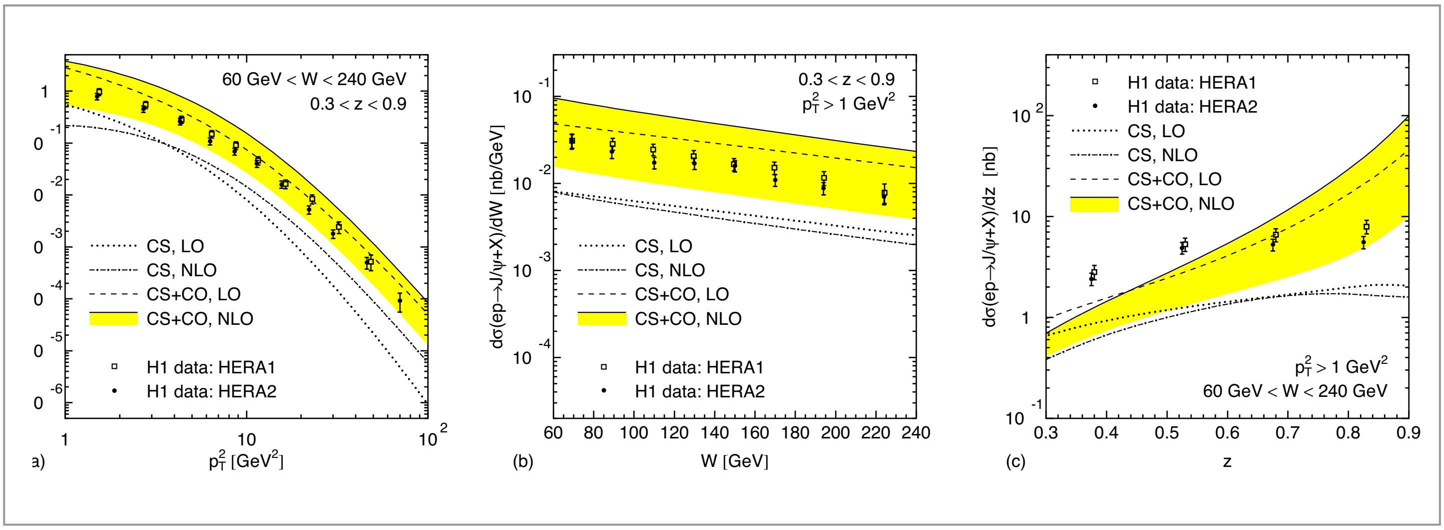

Figure 2

(a) p_T^2, (b) W, and (c) z distributions of inclusive J/ψ photoproduction at LO and NLO in the CSM and full NRQCD in comparison with H1 data [arXiv:hep-ex/0205064,arXiv:1002.0234 [hep-ex]]. The yellow bands indicate the theoretical uncertainty due to the CO LDMEs.

Fifteen years after the introduction of the NRQCD factorisation formalism, the existence of CO processes and the universality of the LDMEs are still at issue and far from proven, despite an impressive series of experimental and theoretical endeavors. The greatest success of NRQCD was that it was able to explain the J/ψ hadroproduction yield at the Fermilab Tevatron, while the CSM prediction lies orders of magnitudes below the data, even if the latter is evaluated at next-to-leading order (NLO) or beyond. Also in the case of J/ψ photoproduction at DESY HERA, the CSM cross section significantly falls short of the data, as demonstrated by a recent NLO analysis using up-to-date input parameters and standard scale choices, leaving room for CO contributions. Similarly, the J/ψ yields measured in electroproduction at HERA and in two-photon collisions at CERN LEP2 were shown to favor the presence of CO processes. As for J/ψ polarisation in hadroproduction, neither the leading-order (LO) NRQCD prediction, nor the NLO CSM one leads to an adequate description of the Tevaton data. The situation is quite similar for the polarisation in photoproduction at HERA.

In order to convincingly establish the CO mechanism and the LDME universality, it is an urgent task to complete the NLO description of J/ψ hadro- and photoproduction, regarding both J/ψ yield and polarisation, by including the full CO contributions at NLO. While the NLO contributions due to the ${}^1S_0^{[8]}$ and ${}^3S_1^{[8]}$ CO states may be obtained using standard techniques, the NLO treatment of ${}^3P_J^{[8]}$ states in $2 \to 2$ processes requires a more advanced technology, which has been lacking so far. In fact, the ${}^3P_J^{[8]}$ contributions represent the missing links in all the previous NLO analyses, and there is no reason at all to expect them to be insignificant. Specifically, their calculation is far more intricate because the application of the ${}^3P_J^{[8]}$ projection operators to the short-distance scattering amplitudes produce particularly lengthy expressions involving complicated tensor loop integrals and exhibiting an entangled pattern of infrared singularities.

This technical bottleneck, which has prevented essential progress in the global test of NRQCD factorisation for the past fifteen years, is overcome here for the first time [arXiv:0909.2798 [hep-ph]]. Example Feynman diagrams for partonic LO subprocesses as well as virtual- and real-correction diagrams are shown in Fig. 1.

The H1 measurements of the cross section distributions in J/ψ transverse momentum p_T, photon-proton center-of-mass energy W, and fraction z of the photon energy transferred to the J/ψ meson (in the proton rest frame) are compared with the new NLO predictions in full NRQCD in Fig. 2 (a)–(c), respectively. For comparison, also the default predictions at LO (dashed lines) as well as those of the CSM at NLO (dot-dashed lines) and LO (dotted lines) are shown. Despite the caveat concerning our limited knowledge of the CO LDMEs at NLO, we conclude that the H1 data show clear evidence of the existence of CO processes in nature, as predicted by NRQCD, supporting the conclusions previously reached for hadroproduction at the Tevatron and two-photon collisions at LEP2.

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Parton distributions for the LHC.

Precision predictions for Terascale physics

Parton distributions are an indispensable ingredient for theoretical predictions of particle production at the LHC. Universality of QCD factorisation allows for their determination in global fits to experimental data. Precision analyses of parton distributions including QCD radiative corrections at the next-to-next-to leading order in perturbation theory can be used to provide cross section predictions at LHC energies with well-quantified uncertainties.

The property of QCD factorisation rests on the fact that one can separate the sensitivity to dynamics from different scales due to the renormalisation group equation, which governs mass singularities. A cross section of some hadronic final state X in, say, proton-proton scattering is expressed in terms of parton distribution functions (PDFs) in the proton and some hard short-distance cross section for parton scattering. The PDFs describe the hadron momentum carried by a quark or gluon. They are essentially non-perturbative objects, because the proton is a complicated bound state governed by non-linear gluon couplings in a Yang-Mills theory. Modern parameterisations of parton distributions from global fits account in particular for the effects of experimental errors and come with the according uncertainties. Much of the needed experimental information originates from deep-inelastic scattering (DIS) data on structure functions from the HERA experiments and from fixed targets.

In arXiv:0908.2766 [hep-ph] precision PDFs have been determined in a next-to-next-to-leading order (NNLO) QCD-analysis of DIS world data, Drell-Yan- and di-muon data along with a careful study of the heavy flavor effects in DIS structure functions.

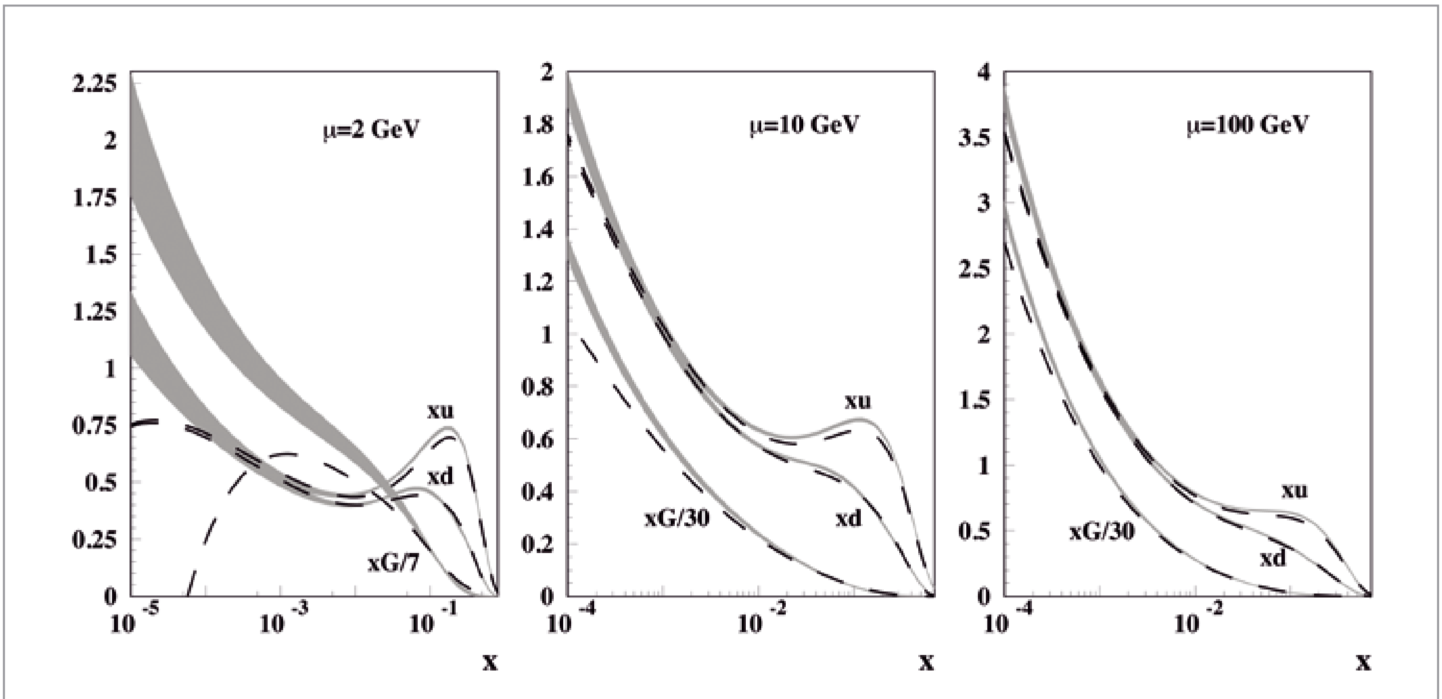

Figure 1

Light Parton Distributions

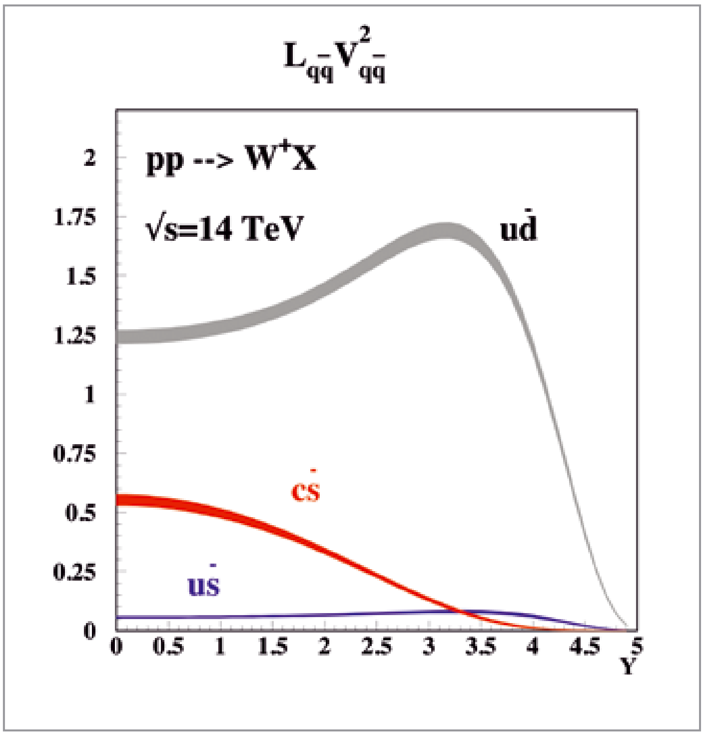

Figure 2

Parton luminosity for pp → W⁺ X.

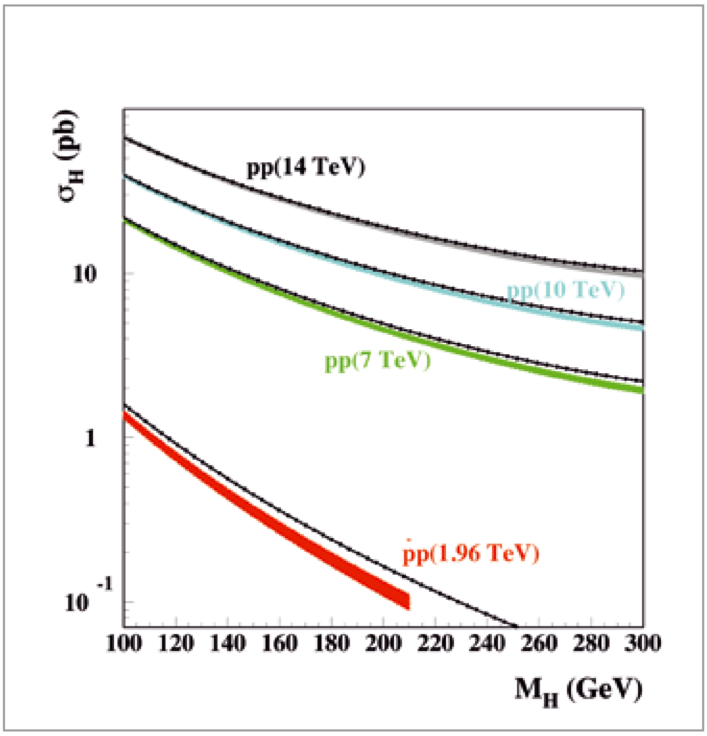

Figure 3

Higgs boson production

Correlated errors have been taken into account whenever available. In Fig. 1 the scale evolution of the light parton distributions are shown (bands) and compared to the MSTW08 distributions (lines).

The precision of the DIS world data has reached a level which requires NNLO perturbative QCD predictions both for PDF determinations and measurements of the strong coupling constant $\alpha_s(M_Z)$. In arXiv:0908.2766 [hep-ph] the PDF-evolution is performed in the $N_f = 3$ fixed-flavour scheme, and supplementary sets of PDFs in the 4- and 5-flavour schemes are derived from the results in the 3-flavour scheme using matching conditions. The charm-quark DIS contribution is calculated in a general-mass variable-flavour-number scheme interpolating between the zero-mass 4-flavour scheme at asymptotically large values of momentum transfer Q^2 and the 3-flavour scheme at the value of $Q^2 = m_c^2$. The strong coupling constant is measured at an accuracy of ≃ 1.2% with a value of $\alpha_s(M_Z) = 0.1135 \pm 0.0014$ in the fixed-flavour scheme and $\alpha_s(M_Z) = 0.1129 \pm 0.0014$ in the variable flavour scheme. This compares to a previous non-singlet analysis, based on widely different data in hep-ph/0607200, where $\alpha_s(M_Z) = 0.1134 \pm 0.0021$.

The implications of the accuracy of the PDFs for a standard candle process as pp → W⁺ X at LHC for individual flavor combinations is shown in Fig. 2. A rather high precision is reached over the whole kinematic range. Another application concerns the prediction of the total Higgs boson production cross section due to gluon-gluon fusion for different collider energies shown in Fig. 3. Comparison to MSTW08 yields a satisfactory agreement with the present analysis at lower Higgs-boson masses for the LHC energies, while some deviations are visible e.g. for larger mass values.

Of course, all observed differences have to be considered in view of the statistical and systematic accuracies finally to be obtained in the experimental measurements.

The PDFs of arXiv:0908.2766 [hep-ph] allow for detailed simulations of the different inclusive processes at the LHC and are of central importance in monitoring the luminosity. Further refinements will be obtained from the combined H1 and ZEUS data and partial data from Tevatron. With the start of data taking at the LHC precision measurements of inclusive processes at hadron colliders open up the opportunity to further improve the understanding of the PDFs of nucleons at the NNLO level.

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From string geometry to strong force.

How spin chains enter particle physics

According to modern ideas of string theory, the Standard Model of particle physics might be considered as the holographic image of some 5-dimensional string theoretic world. The picture suggests entirely new ways to think about elementary particles and it provides very surprising new calculational tools for gauge theories that are borrowed from the theory of one-dimensional spin systems.

Gauge field theory provides a tremendously successful mathematical framework to describe nature in all areas of physics. The Standard Model of particle physics, for example, is predicting detailed features of high-energy collisions with incredible accuracy. To obtain such precise numerical predictions from gauge field theories, however, remains a mayor challenge that drives entire research fields. Besides many technical problems there is a central conceptual issue to overcome: in quantum field theories, the fundamental constituents often depend on the strength of the coupling. The phenomenon is well known e.g. from Quantum Chromodynamics (QCD). At high energies, the behavior of QCD is efficiently analysed in terms of quarks and gluons. But when we pass to low energies, these constituents confine into hadrons. The transition from high energy (small coupling) to low energy (large coupling) is still very poorly understood.

There is a seemingly unrelated fundamental problem of physics that is receiving considerable attention. Einstein's theory of general relativity (GR), our well-tested model of space-time, cannot be quantised, at least not perturbatively in Planck's constant. Therefore, GR is commonly regarded as an effective large distance description of space-time geometry, one that requires appropriate modification at smaller scales. This is where string theory comes in to help, by providing a consistent fundamental model of space-time geometry. Clearly, strings perceive space-time quite differently form point particles, in particular when their length l_s is of the order of a typical length scale R of the background geometry. These differences enable string theory to build a quantisable model of space-time geometry. On the other hand, understanding string geometry in the regime where $l_s/R \sim 1$ is a daunting task. It has challenged string-theorists for almost three decades now. Over the years, an impressive toolkit has been put together that provides access to qualitative and quantitative aspects of string geometry.

Before we explain some of these tools, let us outline a surprising development that relates the two very distinct topics we sketched above. While studying higher dimensional black holes, the string theorist Juan Maldacena, IAS Princeton, proposed that gauge field theories may admit an equivalent formulation through strings which propagate in some carefully chosen 5-dimensional curved background. According to his conjecture, the gauge theory coupling λ is related to the ratio l_s/R of the string length l_s and the background's curvature radius R. Maldacena's correspondence links two of the most fundamental problems of modern physics: Understanding stringy corrections to space-time geometry simply becomes another way to think about the dependence of gauge field theory on the coupling λ. If we take into account how much progress string theorists have made in understanding string length effects, the change of perspective promises fruitful applications to gauge field theory. The harvesting has just begun. We shall describe some of the recent progress it has brought, after a quick glance into the relevant toolkit.

A single string is a one-dimensional quantum system whose understanding is fundamental for string theory. In particular, it is of considerable interest to determine the energy spectrum of the string's vibrational modes. This spectrum is strongly affected by the curvature radius R of the underlying background geometry. In computing such curvature effects, string theorists can profit from expertise gathered in a very different area of physics, namely from the study of quantum spin chains. The famous Heisenberg model, for example, is a one-dimensional array of spins that interact through a characteristic spin-spin coupling between nearest neighbors. The eigenvalues of the associated Hamiltonian were first determined by Hans Bethe in 1931. Bethe's solution was just the first step in a long and successful development. As the field progressed, we have learned how to determine the spectrum of many one-dimensional quan-

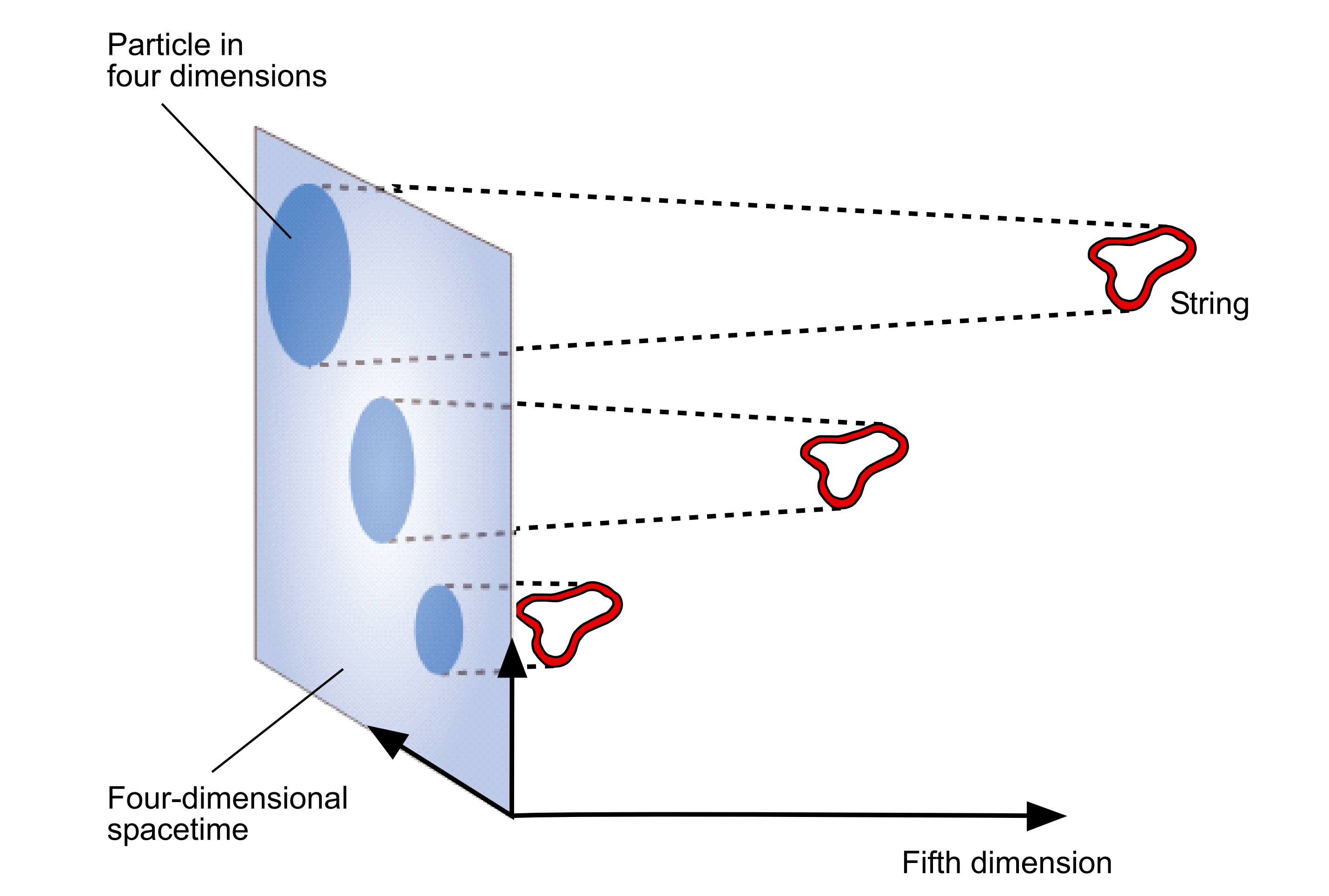

Figure 1

Ordinary gauge field theories, such as QCD, may admit an equivalent formulation through strings, which propagate, in some carefully chosen 5-dimensional curved background

tum systems by solving a particular class of non-linear integral equations (NLIE), see for example [arXiv:0902.4825,0910.3173].

Putting all these elements together, we arrive at a remarkable conclusion: If Maldacena's proposal is correct then we should be prepared to use methods from the theory of one-dimensional quantum systems in four-dimensional gauge theory calculations! Recently, this surprising insight has been beautifully illustrated by a first concrete example. It involves a (maximally) supersymmetric cousin of QCD. According to a celebrated recent proposal [arXiv:0901.3753,0902.4458] certain quantities in this theory are controlled by a new set of NLIE which resemble those found in one-dimensional spin chains. While the equations have not been derived from string theory yet, they have undergone extensive tests. Since the conjectured NLIE determine gauge theory data for arbitrary values of the gauge coupling [arXiv:0906.4240], their predictions may be compared to results of more traditional, though extremely involved, precision computations in weakly coupled gauge field theory. The agreement is impressive.

Of course, much work is needed to extend the applicability of such novel techniques to other quantities, such as e.g. scattering amplitudes, and less supersymmetric gauge theories. This task calls for new developments in the theory of one-dimensional quantum systems. Actually, the strings that appear in the context of supersymmetric gauge theory possess important features that distinguish them form the quantum systems that are usually investigated in condensed matter theory. In the Heisenberg chain, for example, spins take their value in a 2-dimensional representation of the spin algebra. The generalisation that is relevant to supersymmetric gauge theories would roughly amount to choosing spins in infinite dimensional representations of some superalgebra. DESY's theory group has completed pioneering work on the study of such more general one-dimensional quantum systems. In particular, members of our group have determined the spectrum of some supersymmetric one-dimensional systems as a function of the parameter l_s/R [arXiv:0809.1046,0908.0878,1001.1344]. The lessons learned from such investigations lead to significant advances in the theory of spin chains. But, more importantly, they possess the potential to revolutionise the way we treat and think about gauge theory.

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Results from non-perturbative QCD.

Low-energy pion scattering

The quarks and gluons of QCD are strongly interacting at low energies and confined into hadrons. Pions, the lightest hadrons on the other hand interact more and more weakly at low energies, enabling a perturbative treatment of their interactions, encoded in a chiral effective Lagrangian. Parameters in this Lagrangian are here computed through numerical ab-initio "simulations" of the quark and gluon Lagrangian of QCD. Our results, compared to pion scattering experiments, show that indeed we understand this intricate dynamical interplay. This step is important as non-perturbative QCD is almost always with us in the interpretation of high energy collider experiments.

The force that binds the quarks and gluons together – the strong interaction – is theoretically described by quantum chromodynamics (QCD). While it is weak at short distances (asymptotic freedom), at distances of 0.5 fm and larger the quarks interact extremely strongly, in fact so strongly that they will never be seen as particles but rather are confined in bound states leading to the observed hadron spectrum.

Since the interaction between quarks becomes so strong at large distances, analytical methods such as perturbation theory fails to analyse QCD. A method to nevertheless tackle the problem is to formulate QCD on a 4-dimensional, Euclidean space-time grid. This setup allows for a rigorous definition of QCD and enables us to perform numerical computations, usually called "simulations".

These simulations are extremely expensive, needing Petaflop computing and even beyond, a regime of computing power we just reach today. In the past, lattice physicists had to work with a number of limitations when performing numerical simulations. For a long time the quarks were treated in a crude so-called quenched approximation, where their dynamics is distorted. In a next step, the lightest quarks, the up and down, were taken into full consideration, even if their masses were still unphysically large.

Nowadays the three lightest quarks are included. In addition, their simulation is performed in almost realistic conditions: masses are close to their physical values, the lattice sizes reach about 3 fm linear extent and the lattice spacing is becoming smaller and smaller. The change of the simulation landscape

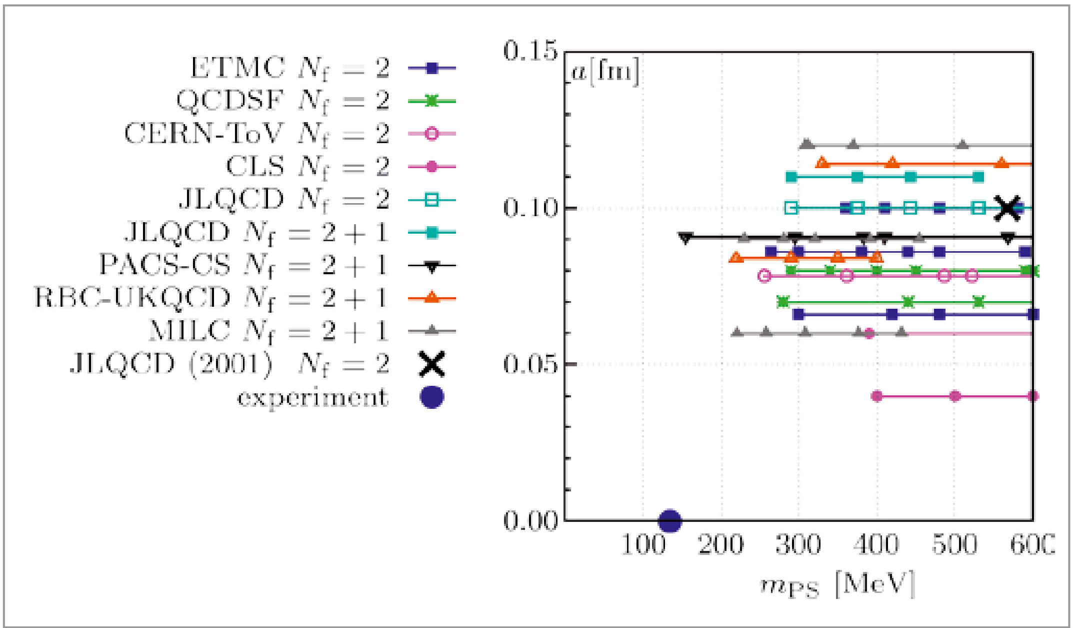

Figure 1

The values of the lattice spacing a and pion masses $m_\pi = m_{PS}$ as employed presently in QCD simulations by various collaborations as (incompletely) listed in the legend.

is illustrated in Fig.1 (arXiv:0810.5634[hep-lat]), where the blue dot indicates the physical point i.e. a zero value of the lattice spacing and the experimental pion mass of 140 MeV. Most of the simulations now go well beyond what could be reached in 2001 (the black cross) demonstrating the progress in algorithms enabling realistic simulations.

As an example of results of lattice simulations performed by the John von Neumann Institute for Computing (NIC) research group, we discuss a determination of so-called low energy constants of chiral perturbation theory (ChPT). Due to the phenomenon of spontaneous chiral symmetry breaking, the pions can be interpreted as the Goldstone bosons in QCD and indeed, the pions are the lightest hadrons observed experimentally. ChPT provides a systematic expansion of QCD at low energy and small quark masses, encoded in an effective Lagrangian. In different orders of this expansion unknown parameters, "low energy constants", appear which cannot be computed within ChPT itself but need alternative methods to be determined.

on the other hand, they can be obtained very precisely from lattice simulations. Determinations of the low energy constants in the above mentioned quenched approximation had been performed early by the Alpha Collaboration (arXiv:hep-lat/0006026). Now the European Twisted Mass Collaboration (ETMC), has determined them realistically with two dynamical quarks as shown in Fig. 2. The symbols denote different lattice results and the curves represent fits to the ChPT formulae (arXiv:0911.5061[hep-lat]).

The low energy constants can in turn be used to compute pion scattering, in particular the scalar a_0^0 and tensor a_0^2 S-wave pion scattering lengths as shown in Fig. 3 (arXiv:0911.1416[hep-ph]). Our results with their small errors are depicted as the light green ellipse. An independent calculation of the scattering length a_0^2 by the NIC research group (arXiv:0909.3255[hep-lat]) is shown as the light blue band.

The accurate results described here could be achieved due to a long lasting effort of the group in conceptual improvements

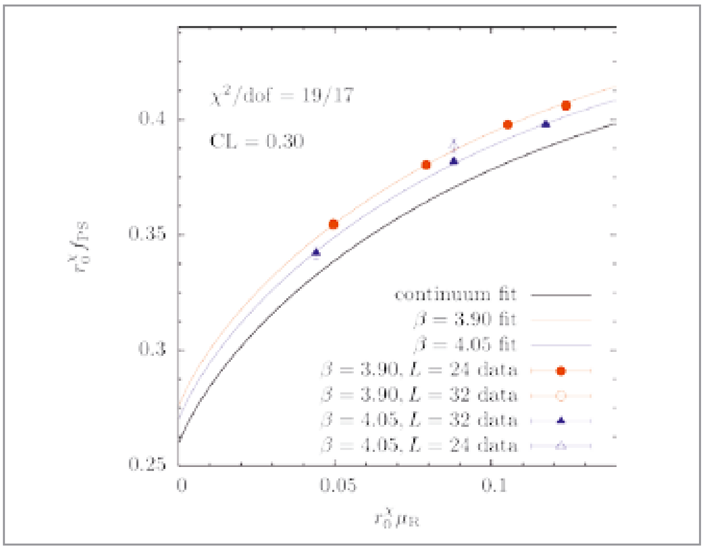

Figure 2

The pion decay constant fPS in units of the static force parameter $r_0^\chi \approx 0.5$ fm as a function of the quark mass μ_R.

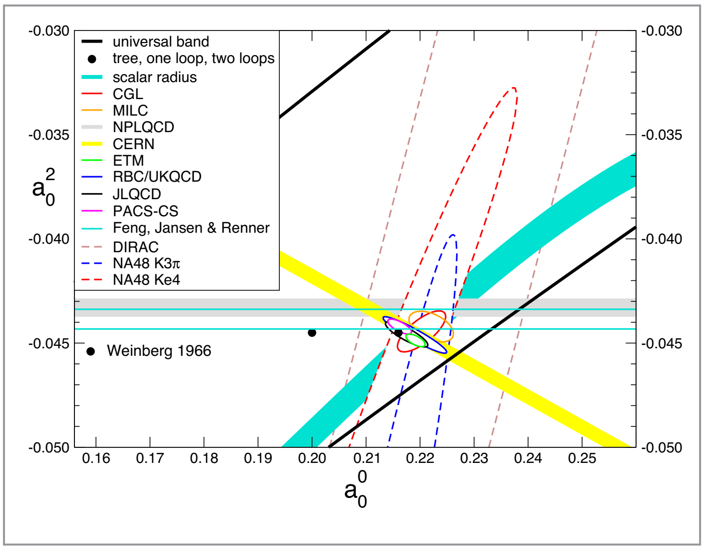

Figure 3

Experimental and theoretical results for the S-wave pion scattering lengths.

Lattice techniques provide a perfect tool to compute these low energy constants directly from QCD. With the mentioned progress of lattice simulations it has now become possible to approach a regime of pion masses where the ChPT expansion becomes applicable. Thus we can confront lattice QCD results with the analytical formulae derived in ChPT and determine the desired low energy constants through appropriate fits.

Suitable quantities for such a comparison are the pion mass m_π and the corresponding decay constant f_π. Their quark mass dependence can, on the one hand, be computed in ChPT and

such as an acceleration of the continuum limit and non-perturbative renormalisation. Also the supercomputer resources of the NIC have been indispensable, in particular the 72 rack BG/P installation at the Forschungszentrum Jülich, which together with the GSI and DESY forms the NIC.

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The Alliance "Physics at the Terascale".

Exploring new territories together

In 2007 18 German universities, the Max Planck Institute in Munich, and the Helmholtz centres Karlsruhe and DESY joined forces in the Helmholtz Alliance "Physics at the Terascale". The stated goal of this alliance is to enhance the common efforts to explore the physics at the Terascale using accelerators. This complements the existing research structures, which are organised around single experiments. The current focus on activities is on exploiting the physics potential of the LHC accelerator, but an additional important aspect is the investigation of the next step, e.g. a linear collider (LC), as well. The Alliance is organised around four topics: analysis, computing, detectors, and accelerators. Activities in all four areas are organised and coordinated among the partners. In 2009 the Alliance reached its halfway point and was subjected to an intense review by independent experts.

A key part of the Alliance "Physics at the Terascale" are common infrastructures, which are shared by all partners. These shared infrastructures consists of actual hardware and – mostly – of people, spread around different locations. The first two years of the alliance were used to build up these infrastructures, find the right people, and setup structures so that partners can use these new installations. This phase has been mostly finished in 2009, with nearly all positions filled, and most major investments either done or well under way. The emphasis now is shifting from building up the infrastructures to using them. This is particularly timely since in 2009 the LHC collided for the first time proton beams at high energies, and started to provide data to the collaborations.

A central component of the Alliance is the analysis center, which is hosted by DESY. The analysis center organises training events and workshops for members of the Alliance, in particular aiming at young researchers and students. This is especially important at a time where, due to the reorganisation of the university courses, less time is available for in-depth lectures on topics like particle physics. These training events are much appreciated and complement the training students receive at the universities. In 2009 the analysis center organised 8 schools, which were attended by close to 1000 students from all over Germany. The analysis center is also the place where important developments for all members of the LHC and LC communities are done and made available to the community. Areas where activities have started are the development of statistical tools, the development of Monte Carlos, and the analysis of parton density functions (PDF), from HERA data to be used at the LHC. In all cases working groups have been formed and the work has started. The analysis center is seeking a close cooperation with similar groups at CERN and elsewhere, to optimally contribute to the LHC and LC programmes.

In order to establish a close and fruitful discourse between theoretical and experimental physicists from the LHC experiments ATLAS and CMS, topical working groups, which had been formed already before the start of the alliance, have been continued in the framework of the Alliance. The aim is the exchange of ideas and new developments, which are of interest to the whole community.

With the help of the Alliance a distributed system of Tier-2 centres has been established in Germany, providing the required computing infrastructure needed for the LHC experiments. These centres have been established over the first two years of the alliance and started their regular operation with the beginning of the LHC data taking in November 2009. In addition to the handling of the actual experiments data, they contribute significantly to the production of large Monte Carlo sets. The national analysis facility (NAF) has been setup at DESY, providing computing resources to members of the ATLAS and CMS community for the analysis of LHC data. In particular for smaller universities who cannot afford significant local clusters, and the overhead connected with such an installation, the NAF offers an easy and effective way to participate in the LHC analysis.

Major infrastructure has been installed in a number of German universities to support detector development projects. At Bonn and Heidelberg the already existing chip development capacities have been extended and are now available to partners of the Alliance. At Karlsruhe a high-dose radiation facility is being

Figure 1

Map of Germany showing the location of the partners of the Helmholtz Alliance "Physics at the Terascale"

operated and – through Alliance funding – made available to all Alliance partners. At DESY engineering and general detector development resources are available and are used for Alliance projects. In 2009 a number of new projects, which are of strategic interest to the German community, were identified and which receive initial funding through the Alliance.

The goal of the Alliance is to help re-inforcing accelerator science in Germany at the university level. This is achieved by supporting the training of students in accelerator science at the universities and in special accelerator schools, This activity aims at a network of accelerator physicists throughout the alliance partners in order to strengthen the accelerator science and provide a long term perspective for the this field in Germany. At the University of Hamburg a young investigator groups in novel accelerator science will be established and the search for a leader of this group has started.

The Alliance is supporting its work by a number of supporting measures. In several cases young researchers from overseas could be attracted to Alliance positions by using the dual career programme of the Alliance. In this programme a position for the spouse of an Alliance member could receive some support to obtain a position even in a field outside the Alliance. In a number of cases short term positions could be funded through the alliance to allow high ranking members of the Alliance to accept management level positions for some time at one of the large experiments at CERN.

In its nearly three years of existence the Alliance has become a accepted and visible part of the German research landscape in particle physics. It allows the community to react quickly to challenges, and it improves the cohesion between the partners as a whole. The success of the programme has also been acknowledged by the reviewers of the midterm evaluation, which was done at the end of 2009 under the leadership of Prof. Jos Engelen. The reviewers congratulate the Alliance on its success, and strongly recommends that a way be found to ensure that the structures and the activities of the Alliance can be continued after the end of the current funding period, at the end of 2012. For DESY the Alliance is a key component to ensure its role as a central laboratory for particle physics in Germany, and to ensure that the activities at DESY are well aligned with those of the German community.

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Connecting particles with the cosmos.

Collaboration between DESY and Hamburg University excels

In January 2009 the state of Hamburg launched the Excellence Initiative in order to stimulate research networks in Hamburg. DESY is involved in six research collaborations that were selected among 21 competing applications to be funded for an initial period of one and a half years. Connecting Particles with the Cosmos is one of eight selected "Clusters of Excellence" that comprises physicists, astrophysicists and mathematicians from Hamburg University and DESY. The aim is to create an interdisciplinary research cluster, which combines unique expertise on accelerator and detector physics, particle physics, astro- and astroparticle-physics with cosmology, string theory and mathematical physics.

Current research on the fundamental laws of nature is a highly interdisciplinary effort requiring experimental data and theoretical insights from multiple fields including accelerator and detector physics, particle physics, astrophysics, cosmology, string theory and mathematics. The logo of the cluster Connecting Particles with the Cosmos as shown in Fig. 1 outlines the seven research areas that are centred on the common subject of particle physics. The research programme of the cluster, which is led by Prof. Peter Schleper from Hamburg University focuses on the following key questions:

- What is the mechanism of electroweak symmetry breaking?
- Does the world become supersymmetric at the TeV scale?
- What is the nature of dark matter?
- Is String Theory the basis of Particle Physics and Cosmology?

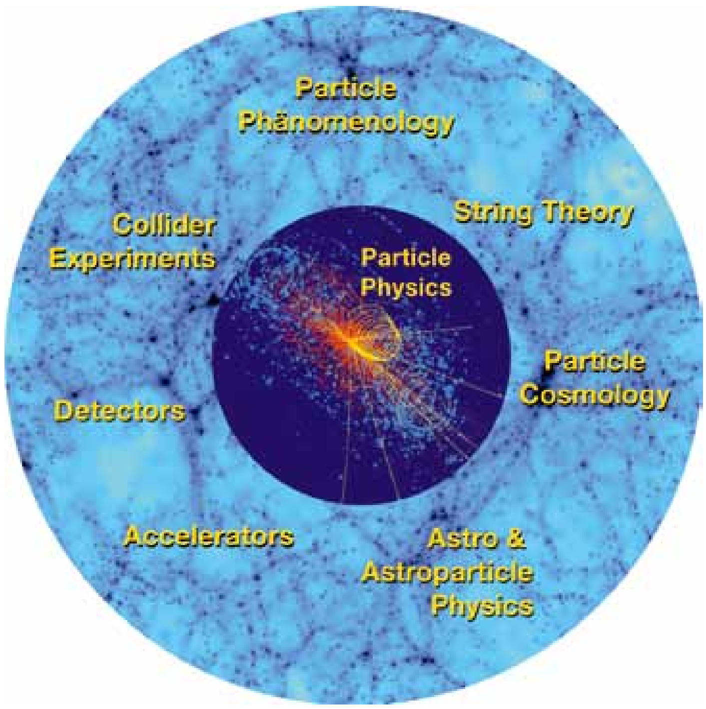

Figure 1

The logo of the cluster "Connecting Particles with the Cosmos", outlining the seven research areas that are centred on the common subject of particle physics.

The kick-off meeting took place at the beginning of November and marked the official start of the cluster (see Fig. 2). The invited speakers Sergio Bertolucci (CERN research director), Marcella Carena (University of Chicago and Fermilab) and Nobel prize winner Gerard 't Hooft (Spinoza Institute, Utrecht) set the scene by giving a stimulating overview of the open questions in the field of science, followed by presentations of young researches, who introduced the subjects of all seven research areas of the cluster.

The funding provided by the state of Hamburg for the cluster amounts to 1.8 MEuro until the end of 2010 with a possible extension by further two years pending a review that will take place in autumn of 2010. These funds are commonly shared by Hamburg University and DESY and are being used to shape the local research structures, for applying a dedicated staffing and appointing strategy along the scientific goals of the cluster and for investments into strategic projects. At Hamburg University several currently vacant professorships in the associated research areas are in the process of being re-appointed. This situation opens up the possibility to create a coherent research network on specific strategic topics. Therefore, as an accompanying measure, the cluster in particular supports the hiring of young researches who will complement such activities by working as the interface between the different research areas. Several young investigator groups have already been created along these lines and promising young scientists have been appointed as group leaders. An example for such a young investigator group is the group on “Cosmological background fields and search for dark matter in the early universe”, which investigates signatures of dark matter in diffuse radiation background fields produced in the early Universe. This group will also explore the complementarity of indirect searches with searches at colliders for new physics. Close co-operations with astrophysics facilities – especially the Hamburg Observatory – are also being exploited.

Figure 2

A large audience of scientists from the Hamburg area and several very distinguished invited speakers at the inaugural meeting, listening to an introduction to the scientific subjects of the cluster.

A prominent example for interdisciplinary research is the quest for understanding the nature of dark matter. Although its existence is strongly motivated by astrophysics and cosmology, there is still a lack of direct experimental evidence. This is a strong motivation for a number of experiments in astroparticle physics as well as at the Large Hadron Collider. A young investigator group of the cluster has just started to work on the theoretical aspects of dark matter at the interface between LHC physics and cosmology. Since the topic of dark matter is a particularly promising and rich field of physics with still growing experimental and theoretical activity at an international level, a special visitor programme has been launched within the framework of the cluster to foster scientific exchange between physicists working on this subject.

Figure 3

Kick-Off workshop Poster 2009

Another essential element of the cluster is building up infrastructures for R&D projects in the area of accelerator research and detector development and construction. One example is the improvement of diagnostic tools to gain better understanding of the physics processes involved in performance variations and limitations of high gradient cavities for the ILC. Another example is complementing and strengthening the structures created within the virtual detector laboratory of the Helmholtz Alliance by investing in the common infrastructure required, for example for LHC detector upgrade projects, which are jointly pursued by DESY and Hamburg University.

With research groups in Hamburg active in all relevant fields, the cluster is in an excellent position to play a leading role in the worldwide research programme on particle physics and its connection to cosmology.

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The ALPS Experiment.

Hidden sector lightweights do not light up ALPS

The ALPS collaboration searches for photon oscillations into “Weakly Interacting Sub-eV Particles” (WISP). Inside a superconducting HERA dipole magnet a “light shining through the wall” experiment with resonant laser power build up is setup on the DESY site. Several upgrades of the experimental setup permit to perform measurements, which sets now the most stringent purely laboratory constraints on the existence of low mass axion-like particles, hidden photons and minicharged particles.

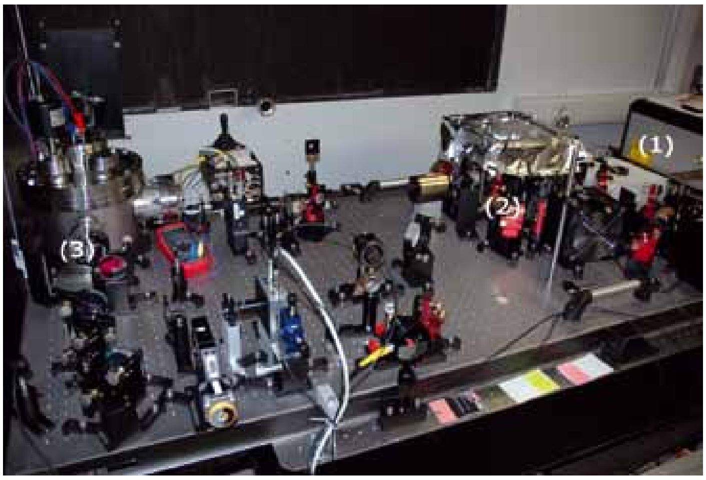

Figure 1

Photo of ALPS laser bench with setup for the resonant cavity. From right to left: (1) infrared laser (used also for the advanced LIGO set-up), (2) resonant second harmonic generation and (3) outer end of resonant ALPS cavity with vacuum vessel containing the coupling mirror.

String theory motivated extensions of the Standard Model often predict a rich low-energy phenomenology with very weakly interacting low mass particles living in “hidden sectors”, beyond the Standard Model. These particles are called WISPs (weakly interacting sub-eV particles) and could also explain unresolved phenomena like dark matter and dark energy.

The ALPS (Any Light Particle Search) experiment at DESY searches for such particles with unprecedented accuracy. These suspected hidden world particles are less than a billionth of the mass of the electron and they hardly interact with our matter. In search for these hidden particles, ALPS performs a “light shining through the wall” experiment. An intense laser beam is sent inside a vacuum tube through a superconducting HERA dipole magnet with a built-in optically opaque wall in its centre. In case WISPs do exist, single photons from the laser beam could transform in the strong magnetic field of the HERA magnet to these particles and traverse the wall. On the other side of the wall they could be revealed because some of them transform again back into photons. These can be detected at the end of the magnet with a camera, Fig. 2.

The ALPS experiment, approved in the year 2007, is installed around a 9 m long and 5 Tesla strong spare HERA dipole magnet in the former HERA magnet test hall on the DESY site. In a

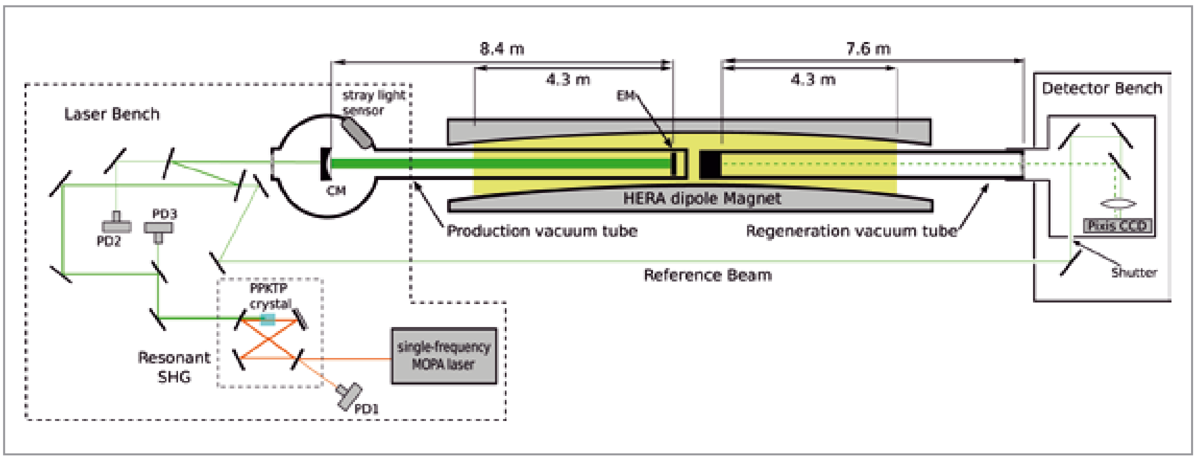

Figure 2

Schematic view of the ALPS LSW experiment.

Figure 3

Photo of the end mirror holder with the adopted squiggle motors, suitable for high vacuum and operational under a 5 Tesla magnetic field.

continuous effort the performance and capability of the setup was steadily improved. An important and crucial milestone was the successful installation of a Fabry-Perot resonator in the superconducting HERA magnet. Between two mirrors, one on the laser bench and the other in the middle of the HERA magnet, the laser light is reflected back and forth (Fig. 2). By adjusting the frequency of the injection laser one achieves a resonant laser power build-up in the ALPS experiment. Initially the mirrors of the optical cavity were situated outside the vacuum tube. This results in a power build-up of around 40, limited by the losses due to absorption and scattering in the two windows of vacuum tube. By placing the complete cavity including both mirrors inside the vacuum the internal losses of the cavity were reduced by an order of magnitude. This required a rebuild of the setup with an enlarged vacuum system comprising a vacuum vessel, which contains the coupling mirror (CM), on to the laser bench, Fig. 1. A crucial development for this successful upgrade was the modified squiggle motor shown in Fig. 3 for the precise mirror steering in middle of magnet, which slides through the production tube to the middle of the magnet.

As prime photon source ALPS uses an advanced 1064 nm laser system, providing 30 W infrared laser light with excellent beam parameters. To match the detection efficiency of the CCD camera the infrared laser light is converted by means of a non-linear crystal into green laser light (Fig. 1). In order to increase the conversion efficiency a folded ring shaped resonator was built around the nonlinear PPKTP crystal. While the production cavity is kept in resonance by a feed-back loop acting on the frequency of the primary laser, the ring shaped resonator is locked by another electronic feed-back loop which adjusts the resonator length in order to keep it resonant with the incident infrared laser light. This elaborated and sophisticated laser setup works very reliably and provides more than 1 kW of green laser power inside the production tube.

Another successful upgrade was the installation of the new PIXIS 1024B camera. It operates at -70°, shows a high quantum efficiency for green light and superb low dark current and read-out noise. It permits the measurement of very low photon fluxes with just a few photons per hour, provided that they are focused essentially into a single known pixel of the CCD.

ALPS achieved and even surpassed the high-flying aims lined-out in the Letter of Intent enabling the experiment to take in the year 2009 physics data with remarkable limits on the probability of photon-WISP-photon conversion of a few 10^{-25}, yielding the most sensitive laboratory measurement on WISP production (Fig. 4). However, no light generated by WISP production was seen by ALPS and therefore yet no evidence for the existence of WISPs was found.

Furthermore ALPS deployed a new method to cover regions of insensitivity caused by incoherence of the photon- and WISP wave functions. Filling about 0.1 mb of Argon gas into the production and regeneration tube changes the refraction index and shifts the oscillation poles, orange graph (ALPS-gas) in Fig. 4.

Further significant increases in the sensitivity will require a substantial upgrade of the experimental setup. Four basic frontiers are obvious: stronger magnets, more laser power, better detectors and resonant regeneration techniques, which means building an optical cavity in the regeneration tube behind the wall. ALPS has laid firm foundations to address these issues. A very crucial ingredient is the successful collaboration with the laser experts of the laser-interferometer experiments searching for gravitational waves. The mid-term goal is to probe parameter regions for WISPs suggested by puzzling astrophysical observations. A corresponding experimental proposal is being drafted.

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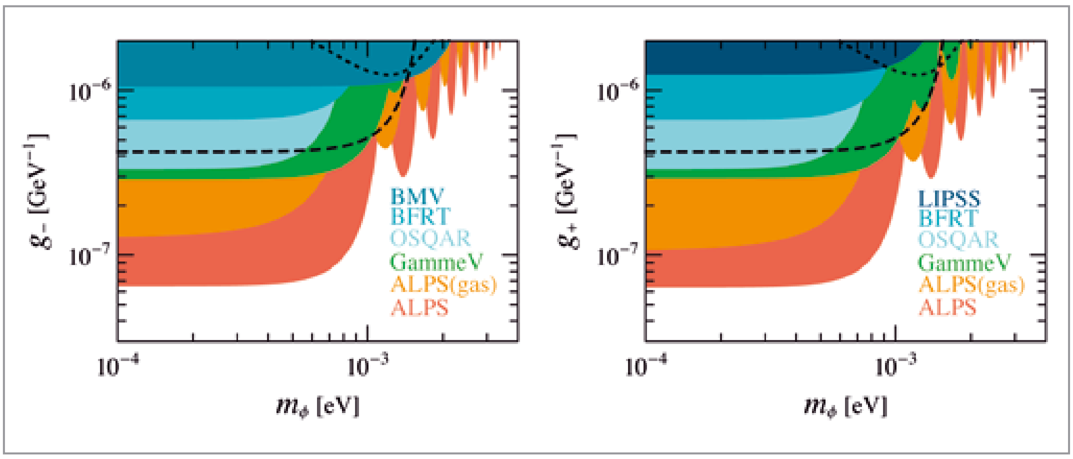

Figure 4

Exclusion limits for pseudoscalars (left) and scalar (right) axion-like particles of ALPS and other experiments..

OLYMPUS.

A new experiment at DORIS

The OLYMPUS experiment at DESY has been proposed to measure the ratio of unpolarised positron-proton and electron-proton elastic scattering cross sections to quantify the effect of two-photon exchange, which is widely considered to be responsible for the discrepancy between measurements of the proton electric to magnetic form factor ratio with the Rosenbluth and polarisation transfer methods. The experiment uses intense beams of electrons and positrons stored in the DORIS ring, an unpolarised internal hydrogen target and the existing BLAST detector from the MIT-Bates Linear Accelerator Center. OLYMPUS has been approved and preparations of the experiment have started.

Recent determinations of the proton electric to magnetic form factor ratio from polarisation transfer measurements at JLAB indicate an unexpected and dramatic discrepancy with the form factor ratio obtained using the Rosenbluth separation technique in unpolarised cross section measurements. This discrepancy has been explained as the effects of multiple photon exchange beyond the usual one-photon exchange approximation in the calculation of the elastic electron-proton scattering cross section. Since most of our understanding on the structure of the proton and atomic nuclei is based upon lepton scattering analysed in terms of the single-photon approximation it is essential to definitively verify the contribution of multiple photon exchange.

In 2007, the OLYMPUS collaboration submitted to DESY a letter of intent to carry out an experiment to definitely determine the contribution of multiple-photon exchange in elastic lepton-nucleon scattering. The most direct evidence for multiple-photon exchange would be a deviation from unity in the ratio of positron-proton to electron-proton elastic cross sections. The experiment would utilise intense beams of electrons and positrons in the DORIS ring incident on an internal hydrogen gas target at a beam energy of 2.0 GeV. For this experiment the existing Bates Large Acceptance Spectrometer Toroid (BLAST) from MIT and an unpolarised internal gas target (Fig. 1) is used.

The letter of intent was favourably reviewed by the DESY Physics Research Committee at its autumn 2007 meeting. By May 2008, the experiment had been studied by the DESY machine group and it was determined that the experiment was feasible. It was established that the proposed experiment can be installed and commissioned in parallel with existing light source operation at DORIS, but will require dedicated data taking time. A formal proposal was submitted to the PRC in the autumn of 2008, favourably reviewed, and formally approved by the DESY Directorate, conditional upon the funding to be secured and a running schedule to be worked out. After a technical review and the approval of the funding request by the U.S. Department of Energy and the National Science Foundation, the experiment was finally approved in December 2009.

The OLYMPUS collaboration comprises of about fifty physicists from fifteen institutions in Germany, Italy, Russia, Armenia, the United Kingdom and the United States.

The OLYMPUS detector essentially consists of the former BLAST detector, with a few upgrades. The various detector components are: a target chamber (with thin exit windows) GEM tracking detectors and drift chamber inside the toroid magnet, surrounded by time-of-flight counters. Luminosity monitors will be located in the rear direction (Fig. 2).

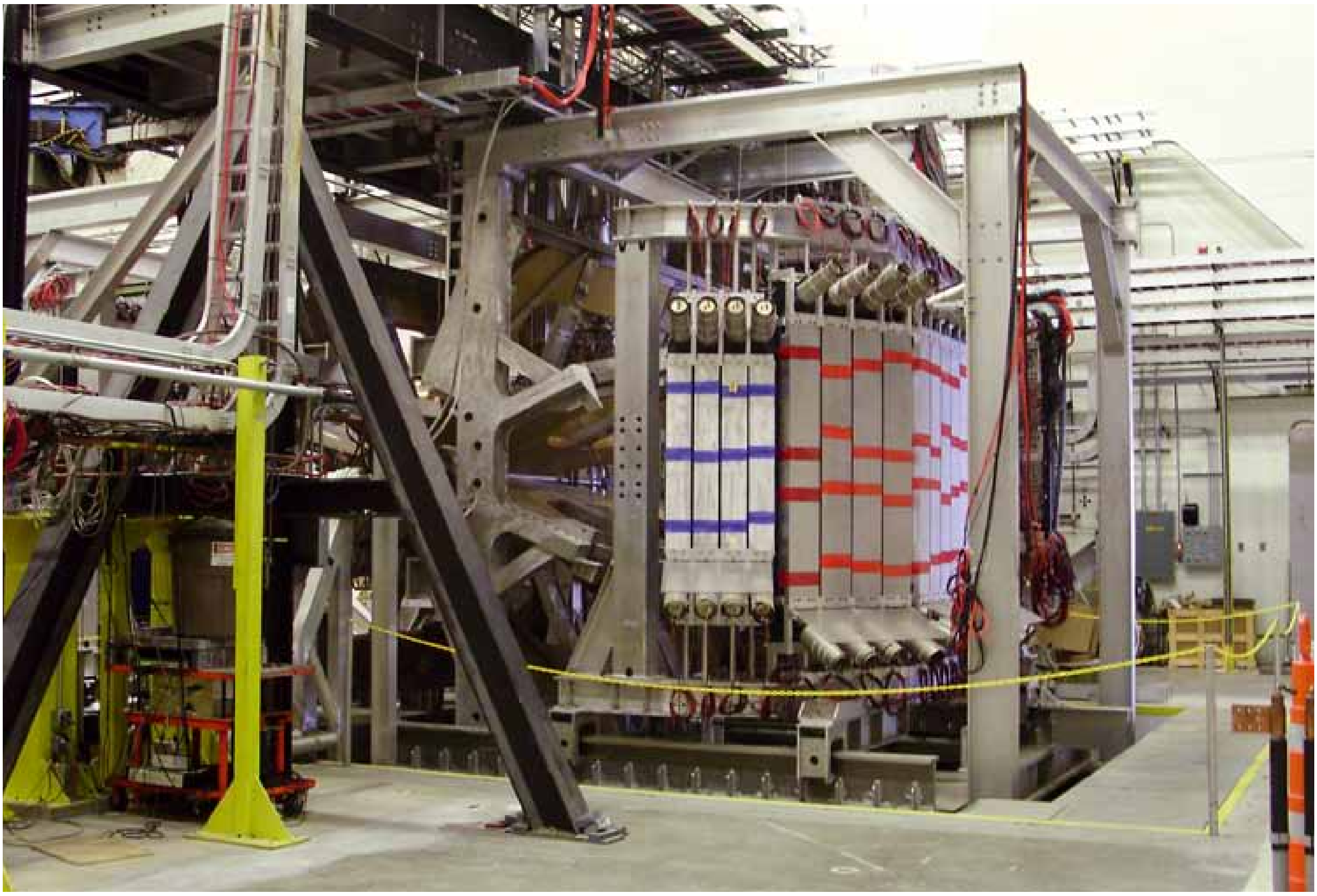

Figure 1

The OLYMPUS (former BLAST) detector at MIT-Bates before its disassembly

The schedule is summarised as follows:

- Disassemble and ship the OLYMPUS detector in spring 2010
- Ship the OLYMPUS target chamber, beam line and luminosity monitor in autumn 2010
- Modify the DORIS beam line and install the OLYMPUS target in winter 2010/2011
- Assemble the OLYMPUS detector in summer/autumn 2010
- Commission the complete OLYMPUS detector in winter/spring 2011
- Move the complete detector into the beam position in summer 2011
- Commission the complete experiment with beam in autumn 2011
- Take data in 2012 in two separate running blocks

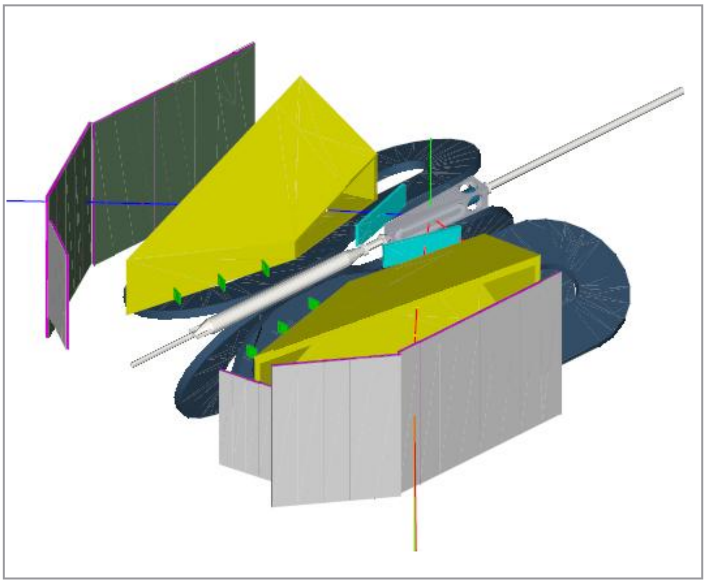

Figure 2

Schematic view of Olympus Detector: the target chamber and beam line in the center, surrounded by GEM tracking detectors (light blue), drift chambers (yellow) and time-of-flight counters (grey). The coils on the bottom side are shown in blue.

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Readout systems with high bandwidth.

Electronics development with high-performance FPGAs

FPGA based readout systems with high-speed serial links are an attractive solution to cope with the expected high data rates from future detectors for particle physics and photon science. Modern high–performance FPGAs can easily process data rates of up to several 100 GBit/s and transfer data via several Multi-Gigabit connections to standard IT-equipment.

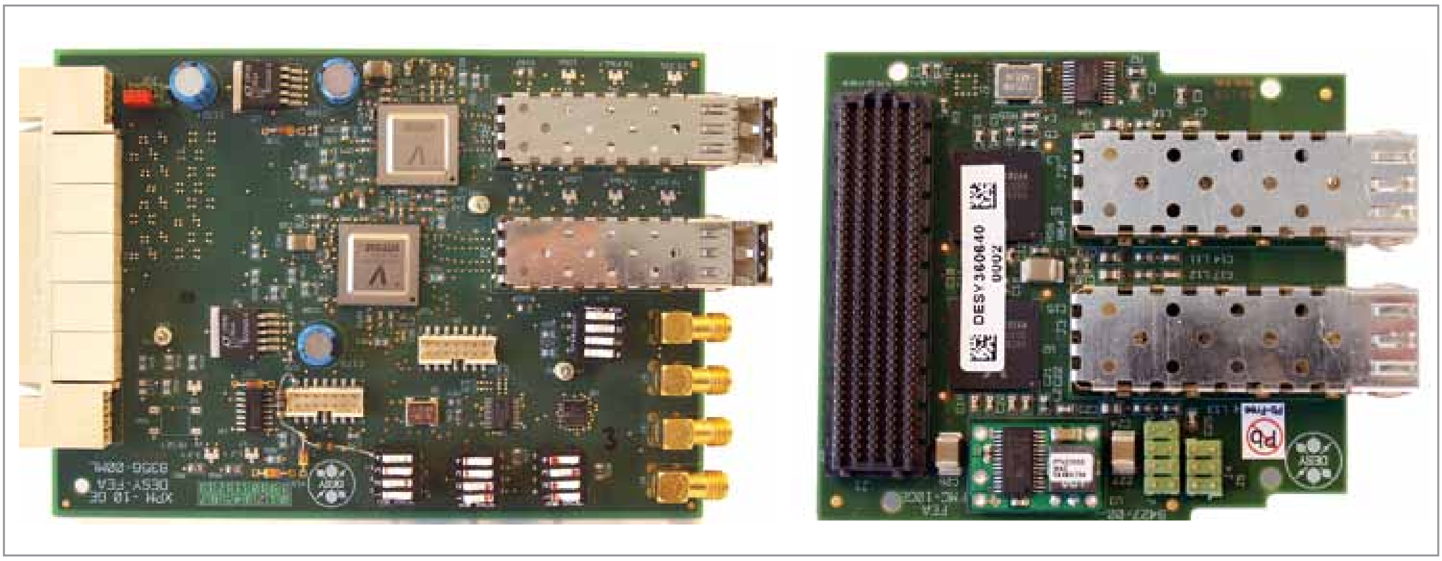
10G Ethernet

DESY is participating in the development of a readout system for 2-D Pixel detectors at the XFEL. Three consortia are developing these Megapixel X-Ray cameras, which are designed to take up to 5000 pictures per second at a frame rate of 4.5 MHz and a resolution of up to 14 bits. The resulting data rates out of the front-end are in the range of 80 – 120 GBit/s. All three detectors foresee to use sixteen 10 GBit Ethernet links to transfer the image data from the camera-head to a first processing stage, called train builder. This device reassembles the partial images of each link to full pictures and collects consecutive frames before sending them for a common analysis to a node of a processor farm. DESY developed a two-channel 10Gbit Ethernet card as a design prototype for the detector read-out and the train builder.

The Design goal of our development was to realise a 10GBit Ethernet board with low risk and low budget in relatively short time and to focus the development on the demands of routing high speed differential signals of up to 10 GBit/s on a standard PCB. This goal was achieved with the development of an adapter card to a suitable FPGA-evaluation board with two independent 10 GBit Ethernet-channels. To get a better understanding of the design limits the two channels were routed differently. This approach allowed creating, testing and debugging the firmware independently of the hardware. As standard communication protocol between the FPGA and a commercial PC we designed an UDP stack as firmware for the FPGA.

Figure 1

10GBit Ethernet Adapter card in XPM format (left) and FMC format (right)



All quantitative tests of the board were very successful. After an optimisation of transfer parameters we achieved for the FPGA-to-FPGA communication bit error rates of better than 10^{-15} at data transfer efficiencies of about 99% via an optical fibre from and to the FPGA. These measurements were repeated in a temperature-range of 20°C to 70°C and did not show any significant dependence. Between the FPGA and a LINUX PC with a commercial 10GBit Ethernet card a throughput of more than 7GBit/s was realised before packets started to get lost. Comparable figures were also achieved in a PC-to-PC communication. The experience gained from the successful prototype went into a redesign in the form-factor FMC (FPGA Mezzanine Card). FMC is a relatively new and compact standard (VITA57) for mezzanine cards optimised for communication with high-performance FPGAs. This board will be used for tests with a prototype version of the train builder.

DESY Advanced Mezzanine Card (DAMC)

Modern control and data acquisition (DAQ) and systems for accelerators and detectors have high requirements on system availability, scalability and bandwidth. Similar requirements exist in the Telecommunication industry where the ATCA (Advanced Telecommunications Computing Architecture) and µTCA Standards have been developed recently. Focused primarily on pure digital applications this standard is based on Gigabit serial communication links and has several advantages like shelf management, redundancy, hot swap capability and scalability. Future control- and DAQ Systems for accelerators and detectors will be based on this attractive architecture. Examples are the beam control systems for the XFEL, upgrades for LHC Detectors as well as the ILC.

To investigate the potential of µTCA for analogue Input/Output DESY has started already at an early phase to develop a µTCA board. As a universal, compact and economical solution this board aims at several applications for control and DAQ systems at the XFEL accelerator and its beam lines. The first generation of the DAMC is a single size board based on a Virtex-5 FPGA, equipped with 256 MBit of DDR2 memory. It has a custom made interface to an I/O mezzanine card, supports 4 lane PCI Express as well as 1GBit Ethernet and implements the module management in IPMI. A two channel 100 Msample ADC/DAC mezzanine card handles analogue input and output as well as signal conditioning.

Based on the experience obtained during operation at the FLASH accelerator at DESY a new version of the board was developed, which will improve the versatility and overcome the limitations of the first generation by additional features. It is already compliant with the new standard xTCA for Physics, which extends and improves the µTCA standard for measurement applications. As a double size board with a possible extension by a rear transition module (µRTM) of the same size the real estate has been quadrupled.

This approach allows for modular systems, where analogue or digital rear transition Input/Output as well as signal conditioning measures can be separated from the FPGA based front module. Additionally the new board can be extended by a VITA 57.1 compliant FMC. For external communication four optical Gigabit links are available at the front panel. The DDR2 memory size has been doubled to 512 MBit and the interfaces to the back plane have been improved and became more flexible to allow for better inner-crate communication.

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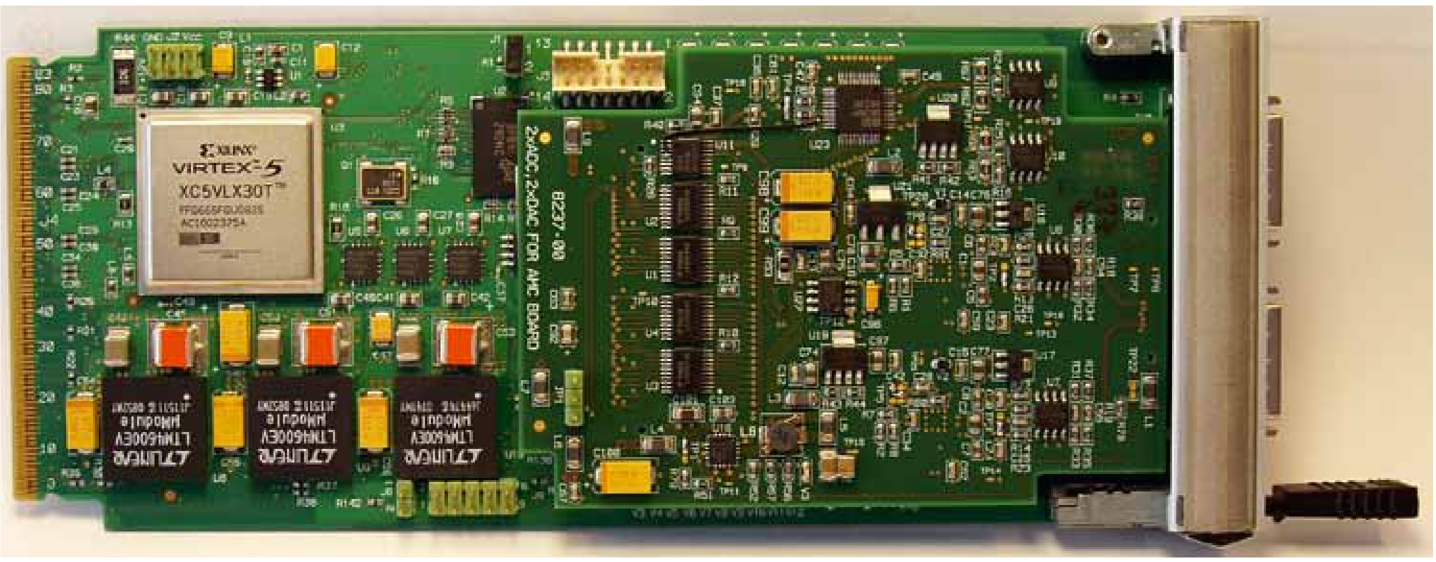
Figure 2

First generation DESY Advanced Mezzanine Card (DAMC)



INSPIRE.

A new HEP information platform

INSPIRE is the successor of the high quality High Energy Physics (HEP) database SPIRES, which is an effort of SLAC, DESY and FERMILAB, joined by CERN. This project brings together the contents and experience of the by far most useful HEP Information system and a modern advanced bibliographic database. DESY will continue to feed valuable data into the new system and will operate the German mirror, once the new system is in production.

The SPIRES-HEP database stores bibliographic information about the literature in the field of High Energy Physics since 1974. Today the service is being run by SLAC, DESY and Fermilab and is providing high quality metadata with human-proofed publication information, links to full text, author affiliations and much more.

In 2007 the four high-energy physics laboratories ran a user poll to analyse the current state of HEP information systems [arXiv:0804:2701]. The poll respondees represented about 10% of the active HEP community worldwide, and the results showed that SPIRES and arXiv together are the most popular information systems in the HEP community, with about 90% of respondees using either of both, and SPIRES being dominant with 48.2% users (see Fig. 1).

Nevertheless being such a veteran system, SPIRES now suffers from its aging technology, resulting in scalability and maintenance issues. Since 2007 the collaboration has been working on development of the successor of SPIRES, called INSPIRE, which combines the high quality metadata in SPIRES with the fast and scalable software of CDS Invenio, developed and maintained at CERN. During 2009 the system has gone through final stages of development, and a beta-test of the system is planned in the beginning of 2010.

The DESY Library contributes substantially to strategic planning, assessment of enrichment and administration of harvesting of the bibliographic data into INSPIRE, which includes tasks such as preprint to journal matching, maintenance of standardised institution naming, and tagging of core HEP articles and gray literature. Moreover, a keywording ontology developed and maintained by DESY Library is to date a unique reliable source of high energy physics keywords based on contents and assigned by experts in each corresponding field. Within this framework, an automatic keywording procedure has been deployed which uses the said ontology to provide keywords for daily harvested preprints. Also, DESY provides mirroring for the INSPIRE services.

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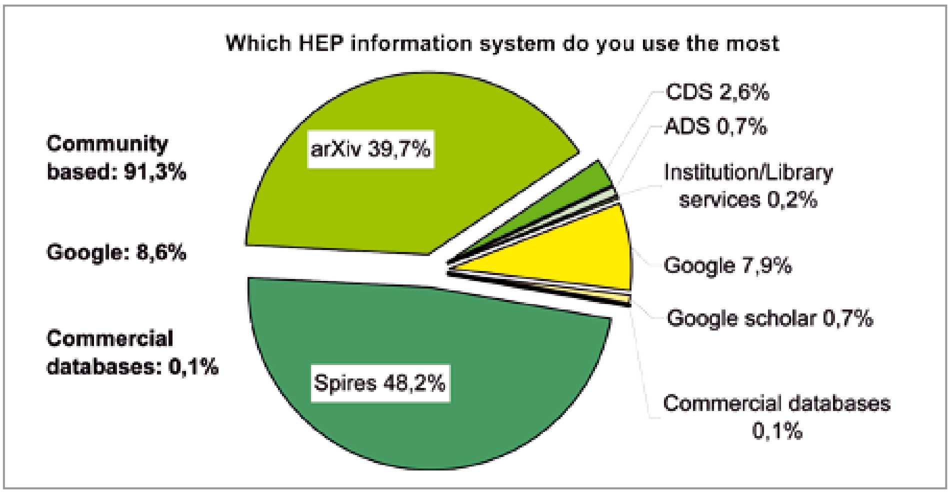

Figure 1

Favorite information resources for HEP scholars.

SCOAP3.

Open Access Publication in high-energy physics

The Sponsoring Consortium for Open Access Publication in Particle Physics (SCOAP3) aims at transforming the HEP publication landscape into open access publishing (OA). This will be feasible by redirecting subscription money. A staff member of the DESY library represents Germany in the SCOAP3 steering committee.

Since the mid sixties when HEP scientist sent their preprints to HEP groups all over the world, they were always on the front of OA. With arXiv.org most HEP publications are already publicly available for all users free of charge via the internet. Nevertheless traditional journals, publishers and their services are important to ensure the high quality standards by peer-review. Moreover, the arXiv still does not cover all HEP articles.

Driven by the ever-rising costs of journals and the growing awareness to grant everybody free access to knowledge gained by publicly funded research, the call is getting louder to push the OA movement further. An ambitious objective came up in 2006/07, to completely transform the HEP publishing into OA which is facilitated by three specific features:

- The groups of authors and readers are essentially the same.
- The majority of all publications in the HEP area are concentrated in six journals from three publishers.
- The SPIRES database provides – through input done by the DESY library – the information, which articles are HEP and, by the exact assignment of authors and affiliations, the share of each country in HEP publishing.

Through long term commitments of the SCOAP3 funding partners and a tendering procedure it is expected that many publishers enter into negotiations to turn their high quality journals into OA journals. In return, subscriptions will become obsolete. Already by the tendering procedure itself, the actual costs for publishing HEP articles will become more transparent. Moreover, the sheer importance of the sponsoring consortium will lead to a stronger position in the price negotiations with the publishers. Besides the big HEP laboratories each country will contribute according to its share of HEP publishing. Today already 68.8% of the aimed budget of 10 million Euros is pledged.

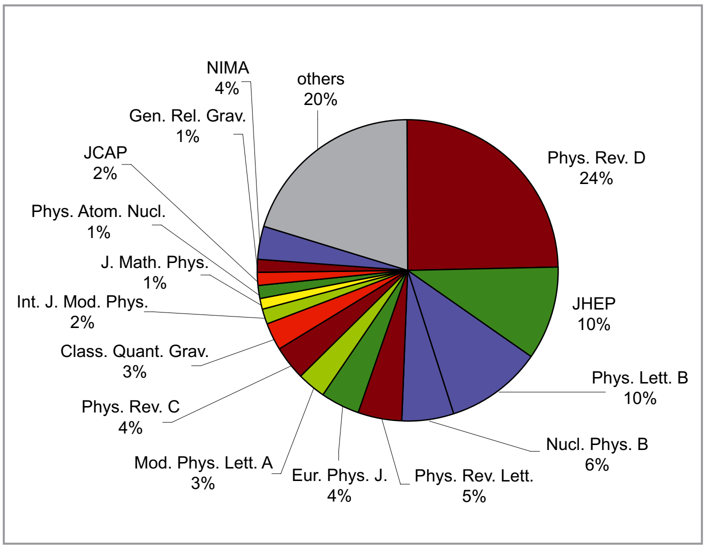

Figure 1

Distribution of HEP articles by journals (publishers are marked by colors, dark red: APS, dark green: Springer, blue: Elsevier, green: World Scientific, red: IOP, yellow: AIP)

For Germany the funding agencies are the Helmholtz-Gemeinschaft (HGF), the Max-Planck-Gesellschaft (MPG), and the Technische Informationsbibliothek Hannover (TIB) for the universities.

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www.scoap3.org

References.

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