NIKHEF

NIKHEF Annual Report 2004

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Publication edited for NIKHEF
Nationaal Instituut voor Kernfysica en Hoge Energie Fysica
National Institute for Nuclear Physics and High-energy Physics

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Cover:	Simulated hadronic decay of a Higgs boson
URL:	http://www.nikhef.nl

NIKHEF is the National Institute for Nuclear Physics and High-Energy Physics in the Netherlands, in which the Foundation for Fundamental Research on Matter (FOM), the Universiteit van Amsterdam (UvA), the Vrije Universiteit Amsterdam (VUA), the Radboud Universiteit Nijmegen (RUN) and the Universiteit Utrecht (UU) collaborate. NIKHEF co-ordinates and supports all activities in experimental subatomic (high-energy) physics in the Netherlands.

NIKHEF participates in the preparation of experiments at the Large Hadron Collider at CERN, notably Atlas, LHCb and Alice. NIKHEF is actively involved in experiments in the USA (DØ at Fermilab, BaBar at SLAC and STAR at RHIC) and in Germany at DESY (Zeus and Hermes). Furthermore astroparticle physics is part of NIKHEF's scientific programme, in particular through participation in the ANTARES project: a detector under construction in the Mediterranean Sea. Detector R&D, design and construction of detectors and the data-analysis take place at the laboratory located at Science Park Amsterdam as well as at the participating universities. NIKHEF has a theory group with both its own research program and close contacts with the experimental groups.

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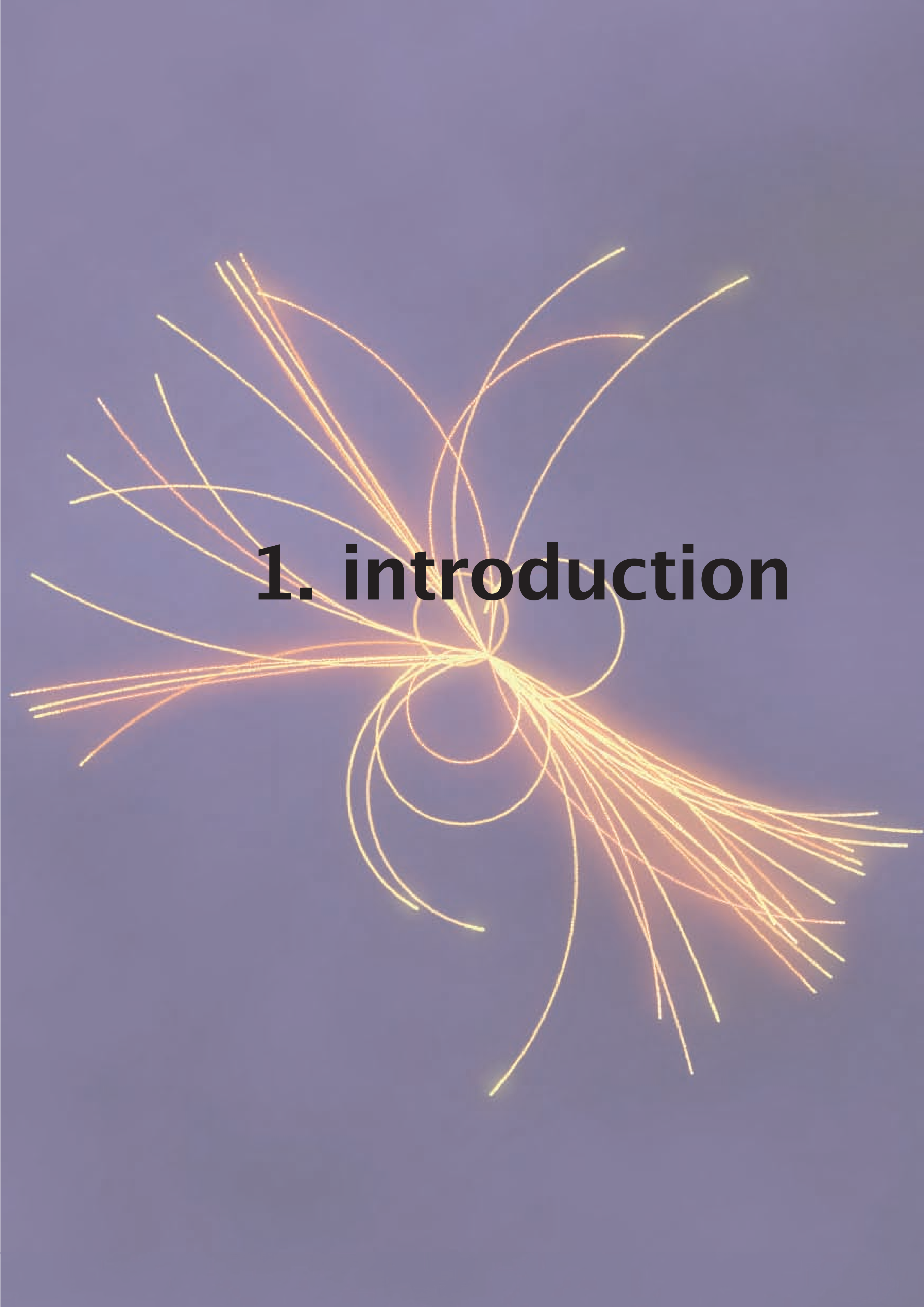
1. introduction



Report of the Director

In retrospect 2004 was a turbulent year. Foremost FOM[1] launched, debated and approved its *"Strategisch Plan 2004-2010"* the wake of which left NIKHEF with a budget reduction and the challenge to secure new funds via e.g. an *"Industrial Partnership Program"*, EU programs or ad-personam subsidies like the *"FOM Projectruimte"* and the *"NWO Vernieuwingsimpuls"*. First successes include: the preliminary EU approval of a design study for an underwater neutrino telescope (KM3NeT); the start of the Virtual Laboratory for e-science (VL-e) in which NIKHEF participates in preparation for data analysis of the large experiments at CERN's Large Hadron Collider (LHC); subsidies from several sources for the High School Project on Astrophysics Research with Cosmics (HiSPARC) and the collaboration with a former Philips subsidiary, PANalytical Almelo, on the development of silicon pixel detectors for X-ray imaging.

Today, outreach activities constitute an integral part of the NIKHEF program. Many high schools already joined the quest for the most energetic cosmic-ray in the context of NIKHEF's HiSPARC project. In June HiSPARC received the prestigious international Altran Foundation Award. In October the Dutch minister of Education, Culture and Science, M.J.A. van der Hoeven, represented the EU at the official ceremony celebrating the 50th anniversary of CERN. In November NIKHEF organized a well attended public symposium celebrating this event in Amsterdam. Throughout the year numerous high school students (and teachers) came to NIKHEF to perform small experiments, to build cosmic-ray detectors, to enroll in a master class or to simply enjoy a guided tour of NIKHEF's research activities. Vice versa NIKHEF physicists gave lively presentations on frontier research at high schools and in museums and they took part in various working groups preparing manifestations for the World Year of Physics 2005. During the traditional Dutch science week (*"Weten Week"*) in October NIKHEF opened its doors for the general public to explain and demonstrate the fascinating research projects and techniques in particle and astroparticle physics.

NIKHEF's main research ambition is to exploit the discovery potential offered by the world's flagship particle accelerator: CERN's Large Hadron Collider scheduled to start operation in 2007. In 2004 the construction of the LHC experiments progressed well. A major milestone was the installation of the first coils of the huge Atlas magnet system into the underground cavern. The magnet systems for the other two LHC experiments in which NIKHEF participates, Alice and LHCb, have been installed in their respective caverns as well. With most detector construction activities well under way or already nearing completion, most physicists are gradually shifting their focus to the event reconstruction and simulation software and physics

[1] *NIKHEF's main partner FOM, the Foundation for Fundamental Research on Matter, is the largest government-supported physics organisation in the Netherlands.*

Former NIKHEF director Jos Engelen, now CERN's Deputy Director-General and Chief Scientific Officer.

Last wire for muon chamber placed by NIKHEF's ad-interim director Karel Gaemers.

performance studies. Of particularl importance in this context, is the NIKHEF participation in the DØ, Babar and Star experiments in the United States which serve not only as LHC precursor experiments but, if nature is kind, also might yield major scientific discoveries. Another crucial ingredient towards the success of the future LHC program is GRID computing. During 2004 several data-challenges were initiated to test the performance of the world-wide available GRID infrastructure in analysing large amounts of data.

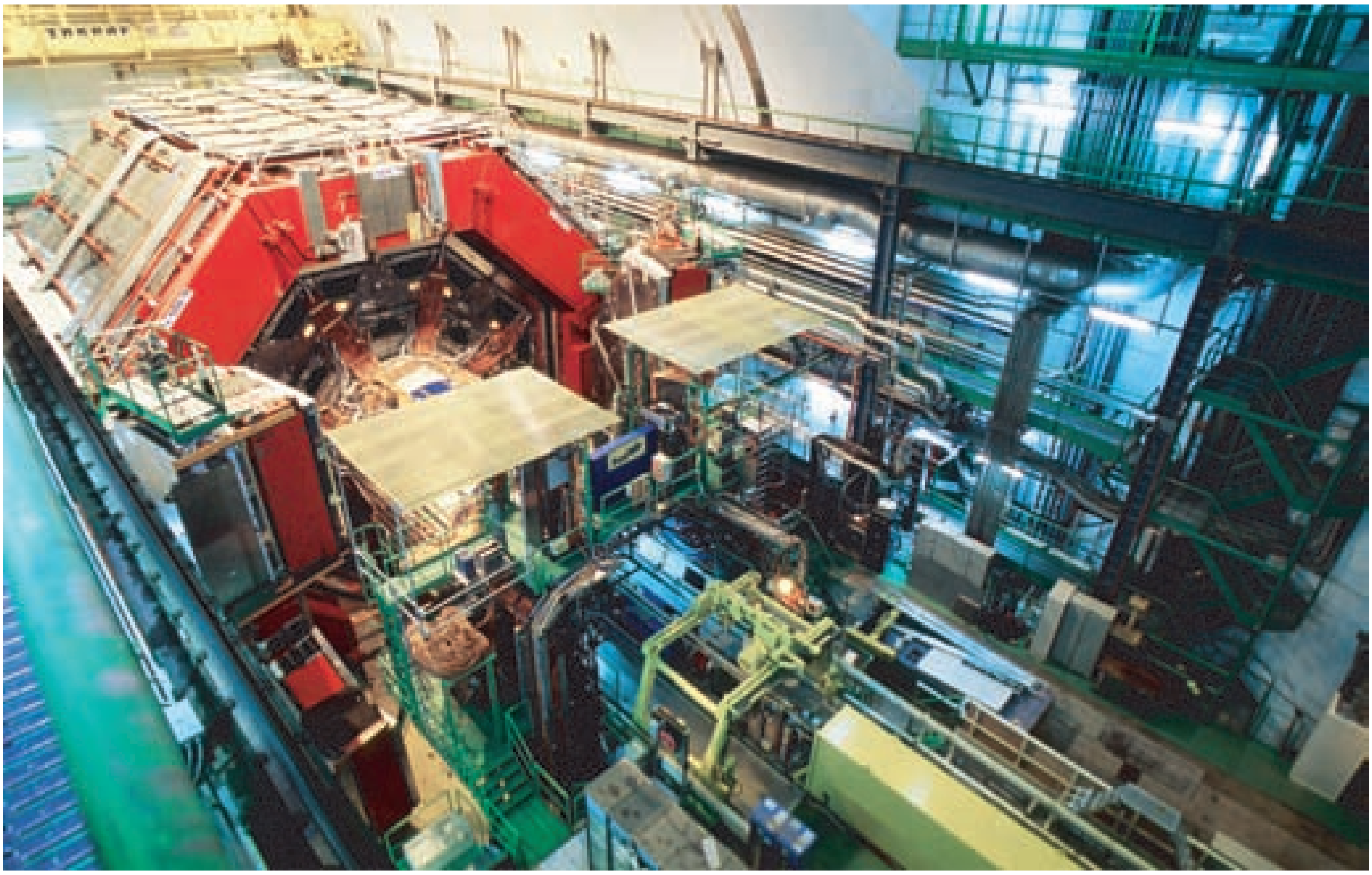
The Antares neutrino telescope under construction at the bottom of the Mediterranean Sea 40 km of the French coast is a relatively new research activity at NIKHEF in the emerging interdisciplinary field of astroparticle physics. In 2004 the first Dutch Antares PhD student received his degree! In 2005 the first full-sized detector units will be deployed. Within the Netherlands a consortium of astronomers and particle physicists from various universities and research institutes aims to broaden the Dutch role in astroparticle physics. In April NIKHEF hosted the first of a series of Astroparticle Physics Symposia which should lead to a coherent research program addressing key questions like: what are the origins of dark matter, of dark energy and of cosmic-rays?

As a joint venture of FOM and four universities (RUN, UU, UvA and VU) NIKHEF provides an excellent training environment for students. The state-of-the-art technical departments offer apprenticeships to engineering students. The Master program in Particle and Astroparticle Physics launched in 2002 has NIKHEF as its home-base. An integral part of this Master program is the highly appreciated 8-12 week stay at CERN as a summer student. In 2004 the first Master students graduated; all of them enrolled in the PhD program coordinated by the Research School Subatomic Physics. This Research School organizes the training and monitors the progress of the PhD students affiliated with NIKHEF. On average about 15 PhD degrees are awarded annually.

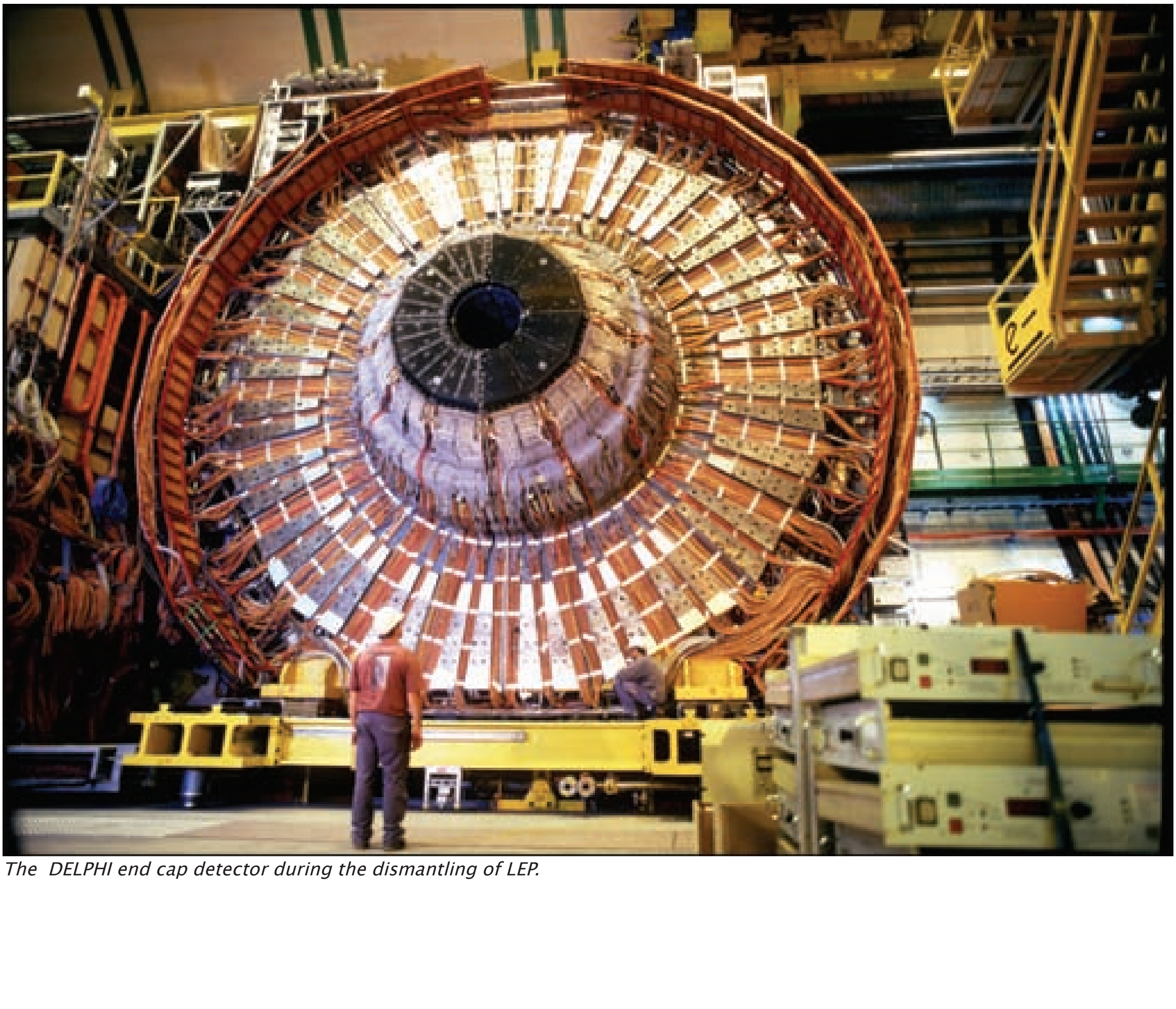
On a personal note, on January 1st NIKHEF's former director Jos Engelen started his job at CERN as Chief Scientific Officer. *Jos, all of us at NIKHEF wish you a very successful stay at CERN and please do not forget the counter on your desk ticking away the days until the first LHC proton-proton collisions!* As NIKHEF's ad interim director Karel Gaemers faced all the vicissitudes related to FOM's *"Strategisch Plan 2004-2010". Karel, I am very pleased you spearheaded this difficult task while at the same time preparing me for my task as future NIKHEF director. I hope in return you enjoyed briefly being an experimental physicist wiring the last drift tube for the Atlas muon spectrometer. We at NIKHEF wish you all the best in your new capacity as dean of the science faculty at the University of Amsterdam!*

Frank Linde

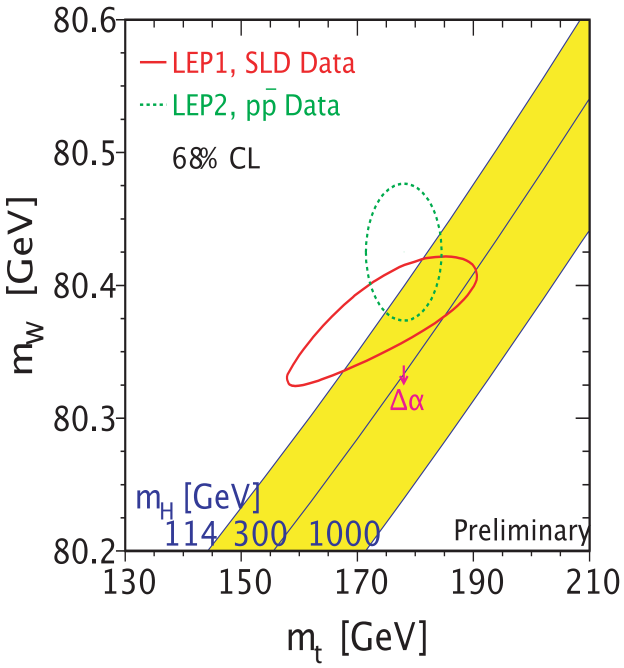
2. reviews



The L3 spectrometer.



The DELPHI end cap detector during the dismantling of LEP.



Contours at 68% Confidence Level (CL) for the top and W mass measurements in the Standard Model. The red contour corresponds to a fit to the electroweak data measured at LEP1. The green contour to the direct W mass measurement at LEP2 and the top mass determined at the Tevatron. The yellow area spans Higgs mass values from 114 to 1000 GeV.

LEP

From 1989 through 2000, four detectors at CERN collected data on e^+e^- interactions produced by the large electron-positron collider, LEP. Two of these experiments, DELPHI and L3, were supported by FOM. Important components of both detectors, as well as computer software, were developed and built by NIKHEF.

In the first phase of operation of LEP1, up to mid-1995, the centre-of-mass energy was chosen approximately equal to the mass of the Z boson in order to study its properties with high precision. Later at LEP2, the centre-of-mass energy was increased in steps to allow study of the $W^\pm$ bosons, that were produced in pairs, and to search for the Higgs boson and for new types of particles.

The precision of the measurements of Z properties surpassed all expectations. Most precise is the measurement of the mass of the Z, which has a precision of 23 ppm. Through the many, precise measurements of Z and W properties, the theory of electroweak interactions could be tested in great detail. A major success was the prediction, before its discovery, of the mass of the top quark, which enters the calculation of Z properties as a small electroweak loop correction. Similarly, an upper limit (M_H<260 GeV) is placed on the mass of the Higgs boson.

A direct search for the Higgs boson established the lower limit, M_H>114.4 GeV. The Higgs boson is the only particle of the electroweak theory that has not yet been discovered.

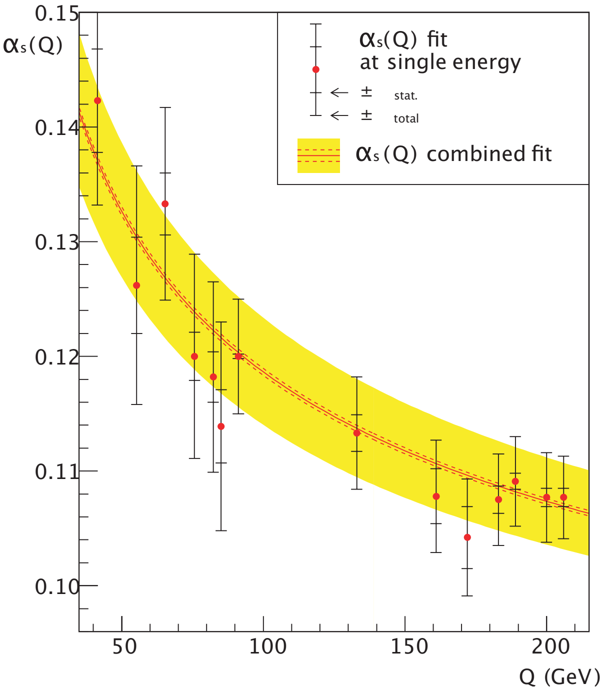
The current situation of the electroweak measurements and the W and top mass determinations is shown in the figure above.

Development and installation of silicon microvertex detectors enabled significant measurements of properties of B-mesons and the tau lepton, areas of research not foreseen at the start of the LEP programme.

Quantum Chromo-Dynamics (QCD), the other component of the Standard Model, was also tested at LEP, the lack of hadrons in the initial state providing a very clean environment for QCD studies. The strong coupling constant was measured and found to depend on the energy scale as predicted by QCD. The LEP evidence for the so-called ‘running’ of the strong coupling constant is shown in the figure on the next page. The colour structure of the final state was also found to be in accordance with the theory.

Despite intensive searches, evidence for particles or processes beyond the Standard Model was not found. The LEP data are consistent with the Standard Model.

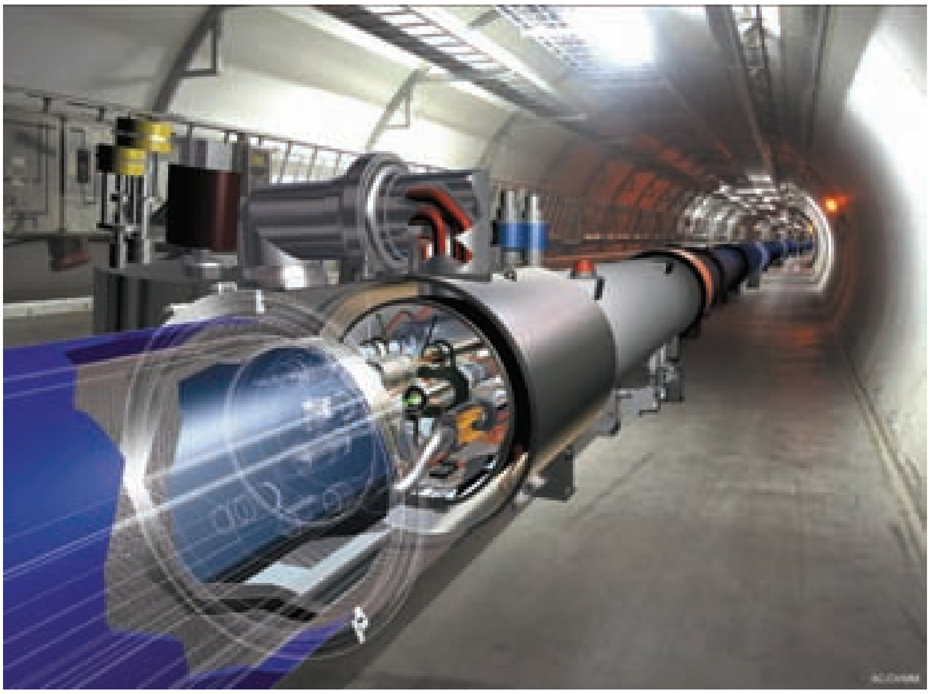
The high precision experimental tests of the Standard Model provided by the LEP experiments were acknowledged in the attribution of the Nobel prize



LEP Measurements of the strong coupling constant α_s as a function of the parameter Q that is proportional to the energy. The red line shows the expected 'running' curve in Quantum Chromo-Dynamics.

to Martinus Veltman and Gerard 't Hooft in 1999 for the electroweak Standard Model and the Nobel prize for Gross, Politzer and Wilczek in 2004 for Quantum Chromo-Dynamics.

PhD students and staff took part in all aspects of the experiments. To date, 49 Dutch PhD theses have been based on LEP results, and 5 more are expected in the near future. The total number of articles in leading scientific journals will be about 300 per experiment.



Artist's impression of the magnets in the LHC tunnel.

The Large Hadron Collider

Introduction

A major share of NIKHEF's scientific endeavour is focused on the Alice, Atlas and LHCb experiments at CERN's upcoming flagship accelerator project: the Large Hadron Collider or LHC. The LHC was first proposed in 1984, officially approved by the CERN Council in December 1994 and is presently scheduled to start operation in 2007. In operation, the LHC will be the world's most powerful accelerator, surpassing its predecessor, the Tevatron of FERMILAB near Chicago, in centre-of-mass energy by almost an order of magnitude. The LHC is likely to revolutionise our understanding of particle physics: exploring a hitherto inaccessible energy domain which allows the researchers to conclude decades of speculation and frantic searches for the elusive Higgs boson and supersymmetric partners of the Standard Model particles.

Large Hadron Collider

The LHC will be constructed in a huge 27 km circumference underground tunnel straddling the Swiss-French border near Geneva, the home of Europe's particle physics laboratory CERN. This tunnel was already excavated in the 1981-1986 period to house the LEP electron-positron collider which operated successfully from July 1989 to November 2000 at centre-of-mass energies ranging up to 210 GeV. Synchrotron radiation losses of the relatively light electrons precluded LEP operation beyond 210 GeV. Compared to electrons, protons are about 1800 times heavier, which render synchrotron radiation losses negligible for the LHC proton-proton collider. Instead, the LHC centre-of-mass limit is set by the realistically achievable bending power of the dipole magnets guiding the counterrotating proton beams around the 27 km circumference LHC ring. With 1232 superconducting 8.3 Tesla dipole magnets the highest attainable LHC centre-of-mass energy is 14 TeV. To maximize the discovery limit for hitherto unknown particles, the LHC luminosity (a measure for the proton-proton collision rate) will gradually increase from 10^{33} cm^{-2}s^{-1} during the first years of LHC operation to 10^{34} cm^{-2}s^{-1} for nominal LHC operation. Preliminary studies indicate that the LHC could eventually operate at an unprecedented luminosity of 10^{35} cm^{-2}s^{-1}. To reach these high luminosities, the spacing between successive proton bunches in the counterrotating proton beams is only 25 ns (7.5 meters). This narrows down the particle detection concepts and imposes stringent requirements on the data-acquisition electronics of the LHC experiments. Instead of proton-proton collisions, the LHC can also be configured to yield heavy-ion collisions. In this mode the centre-of-mass energy increases in proportion to the charge number Z of the heavy-ions; for example for lead-lead (Z=82) collisions the attainable centre-of-mass energy is 1130 TeV!

Apart from its geometric dimensions, the main technological challenge of the LHC, is the 15 m long

Cross section drawing of the LHC dipole magnet.

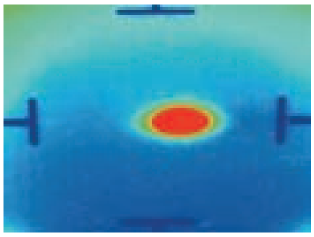
Superconducting cable showing filaments.

superconducting dipole magnet. Each dipole has to guide the counterrotating proton beams (as opposed to a counterrotating proton and an anti-proton beam); to achieve this each LHC dipole constitutes in reality two dipoles with opposite magnetic fields acting on the two separate beam pipes: one for the proton beam circulating clockwise and one for the proton beam circulating counter-clockwise. In total the 1232 dipoles require about 1200 tons of superconductor cable composed of a number of braids each consisting of filaments of niobium-titanium alloy. Intensive R&D with European industries has shown the "twin aperture" dipole magnet concept to be technically feasible and economically realizable. To limit the risks, the dipole contract has been divided between three industrial consortia: Babcock-Noell (Germany), Alston-MSA-Jeumont (France) and Ansaldo Superconduttori (Italy). Despite a number of technical and financial problems, dipole production proceeds smoothly today with more than 500 dipoles available at CERN at the end of 2004. The day-to-day status of the dipoles, and of many other components of the LHC machine, can be followed at the "LHC dashboard" on the web[1]. Once completed, the LHC with its 27 km circumference will be the largest superconducting installation in the world.

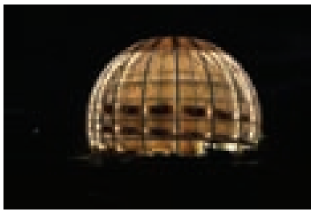
The use of superconductivity requires the dipoles to operate at a temperature of 1.9 K, about -271°C and hence even colder than outer space! This low temperature is achieved with a huge refrigeration system and a myriad of cryogenic lines circulating liquid helium through the cold mass of each superconducting dipole. At 1.9 K helium is in a super fluid state that significantly enhances its cooling capabilities; a drawback of the use of super fluid helium is that it can escape through even minute cracks in the cryostat walls. Despite stringent leak tightness requirements CERN will probably become the world's largest consumer of helium during LHC operations. The installation of the cryolines in the LHC tunnel by an industrial firm encountered a serious setback due to failures in the mechanics which allows sliding movements of the helium pipes upon cool down due to thermal contraction. At the end of 2004 the CERN management demonstrated its refreshing no-nonsense attitude by deciding to take over the repair of the cryolines already installed in the LHC tunnel in order to allow the company to concentrate on the correct and timely delivery of the remaining cryolines. This bold action of the CERN management was the only way by which the LHC schedule could be kept. CERN's Chief Scientific Officer and former NIKHEF director Jos Engelen is reminded every day of the importance of reaching LHC collisions in 2007 by an electronic display he received as a gift when he left NIKHEF in December 2003! Thus far, the cryoline problem prevented the installation of completed dipoles in the LHC tunnel, as a result of which in every available corner at the CERN site scores of fully assembled LHC dipoles can be

[1] *http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/DashBoard/index.asp.*

LHC dipole magnets waiting for installation in the tunnel.



Beam profile at the end of the transfer tunnel.



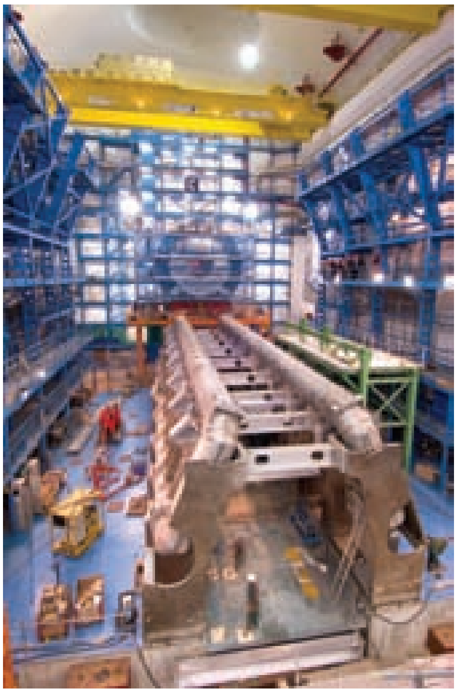
"Globe de l'Innovation"

found today. Operation of the LHC makes full use of the accelerator infrastructure already available at CERN. The protons begin their journey in the ion source just before a LINAC which injects them via the Booster complex into CERN's workhorse accelerator: the Proton Synchroton. In the Proton Synchroton the protons are collected into packages ("bunches") and accelerated to an energy of 26 GeV to be fed into the Super Proton Synchroton. In the Super Proton Synchroton the protons are further accelerated to an energy of 450 GeV and finally, via newly build transfer lines, injected into the LHC. The LHC accumulates protons until the design current of about 0.6 Amperes is reached upon which the protons are accelerated to their collision energy of 7 TeV. At design luminosity, the stored energy in each proton beam is approximately 400 MJ which is equivalent to the kinetic energy of a 15.000 ton ship cruising at 15 knots! In November 2004, a major milestone was passed when the first proton bunches meeting the LHC specification were sent along the transfer line to come within meters of the LHC tunnel. A photograph of the beam profile recorded at the end of the transfer line is shown above. Plans to operate the CERN accelerator complex from a control room from within the refurbished "Globe de l'Innovation" had to be abandoned because of cost reasons favouring the old CERN Prevessin control room. Instead, the Globe de l'Innovation will house CERN's Microcosm exhibition in the future.

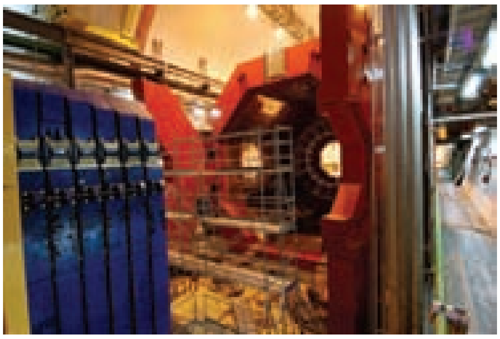
LHC Experiments

Five experiments are scheduled to collect data during LHC operations: the general purpose experiments Atlas and CMS; the B-physics experiment LHCb; the heavy-ion experiment Alice and the total cross-section experiment Totem. NIKHEF participates in Alice, Atlas and LHCb. Alice and LHCb are located in underground caverns previously occupied by the LEP L3 and Delphi experiments (in both of which NIKHEF groups participated in the past), respectively. Even though the construction of sub-detector equipment for both of these experiments is still in full swing in the participating institutes, the experimental magnets have been installed already in the caverns. For the Atlas experiment a huge new cavern had to be excavated. The civil engineering of the Atlas cavern started in 1999 and was handed over to the Atlas collaboration in February 2003. With the installation of the first, out of eight, superconducting coils comprising the Atlas barrel toroid in November 2004 a major milestone was passed. The expectation is that all three experiments with NIKHEF participation will finish construction early 2007 and be ready to record first proton-proton collisions later in 2007.

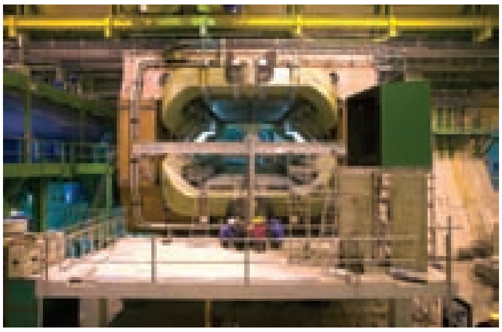
The enormous annual data samples to be collected during LHC operation (about 20 PB/year, equivalent to 25 million CDs) require a novel approach vis-à-vis data processing and data storage. In the LEP era, a single large computing facility at the CERN site served



View into the ATLAS cavern where the experiment is being assembled.



Magnets for the ALICE experiment are put into position.

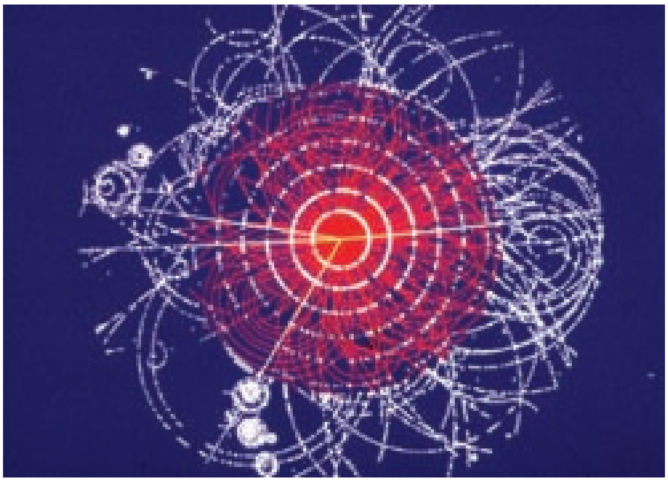


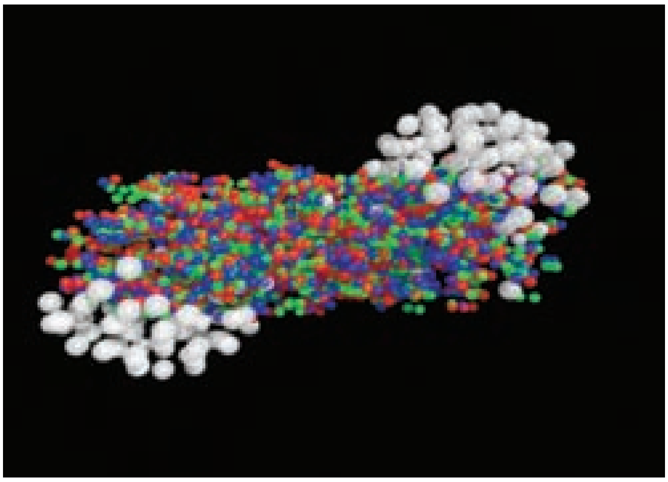
Installation of the spectrometer magnet of LHCb.

the computing needs of the experiments. Instead, the LHC computing model relies on a geographically distributed architecture with a so-called Tier-0 facility at CERN connected via high-bandwidth (10-100 Gb/s) Tier-1 facilities in different countries, including the Netherlands. A multitude of smaller Tier-2 facilities, serving primarily as physics analysis centres, are connected to each Tier-1 facility. The Tier-0 and Tier-1 facilities together take care of data storage, data reconstruction and data simulation. The Tier complex is operated as a computer GRID. Nikhef is, via its participation in the national Virtual Laboratory for e-Science (VL-e) and the European EGEE project, an important GRID software development centre. In 2004, Nikhef participated in various CERN initiated data challenges by means of which the community intends to gradually increase the handled data volume to cope with the 20 PB/year once LHC data taking and data analysis takes off in 2007.

LHC Physics Program

The high centre-of-mass energy of LHC proton-proton interactions allows probing a completely new territory. The most exciting LHC result would be a surprise discovery of a new process or a new type of particle. Such a discovery could revolutionize our understanding of the structure and the evolution of the Universe since the beginning of time coined the “Big Bang”. Even though surprises are impossible to predict, a tantalizing possibility would be the creation and subsequent decay of mini-black holes hinting at the existence of extra spatial dimensions. Less revolutionary, but nevertheless still Nobel-prize deserving, would be the discovery of particles that classify as dark matter constituents. Dark, as opposed to ordinary, matter is a collective name for the unknown substance predicted to exist by astronomers based e.g. on the radial dependence of rotational velocities in galaxies. Dark matter is predicted to make-up about 23% of the Universe, the remaining consists of ordinary matter (about 4%) and dark energy (about 73%).
The LHC will almost certainly put an end to the long standing mystery of the mechanism responsible for the breaking of the electroweak symmetry, leaving the carrier of the electromagnetic force, the photon, massless while endowing the carriers of the weak force, the W- and Z-boson, with a large mass. The most elegant mechanism explaining the electroweak symmetry breaking is the Higgs mechanism that predicts the existence of a spinless massive particle: the Standard Model Higgs boson. The kinematics of the LHC proton-proton collisions permit the discovery of a Higgs boson with a mass of up to 1000 GeV, well in excess of the present 95% confidence level upper limit on the Standard Model Higgs boson of 219 GeV. Once discovered, various decay properties of the Higgs boson can be measured, which should lead to a better understanding of not only the masses of the force carriers but also of the masses of heavy matter particles like the bottom- and top-quark and possibly the tau-lepton.





Example of a simulated proton-proton collision with the production and decay of a Higgs boson.

Computer simulation of the creation of a quark-gluon plasma in heavy-ion collisions.

The LHC data also allow to probe deeper into a mystery touching upon the very reason of our existence: the fact that in our universe, 13.7 billion years after its beginning, matter apparently dominates anti-matter by a large factor. The origin of this asymmetry can be studied by detailed measurements on bound states comprising bottom-quarks and is the prime motivation behind the design of the LHCb experiment.

The operation of the LHC as a heavy-ion collider should yield an unprecedented nuclear matter density in which the quarks and gluons are no longer confined to the inside of composite particles like protons and neutrons but form a type of “deconfined” matter referred to as the quark-gluon plasma. This new state of matter is predicted to exist by the theory of strong interactions, Quantum Chromo-Dynamics, and was the state of matter a few microseconds after the Big Bang. Today the quark-gluon plasma might still exist in the core of very dense stars. The observation and study of the quark-gluon plasma is the aim of the experiment dedicated to the study of heavy-ion collisions: the Alice experiment.

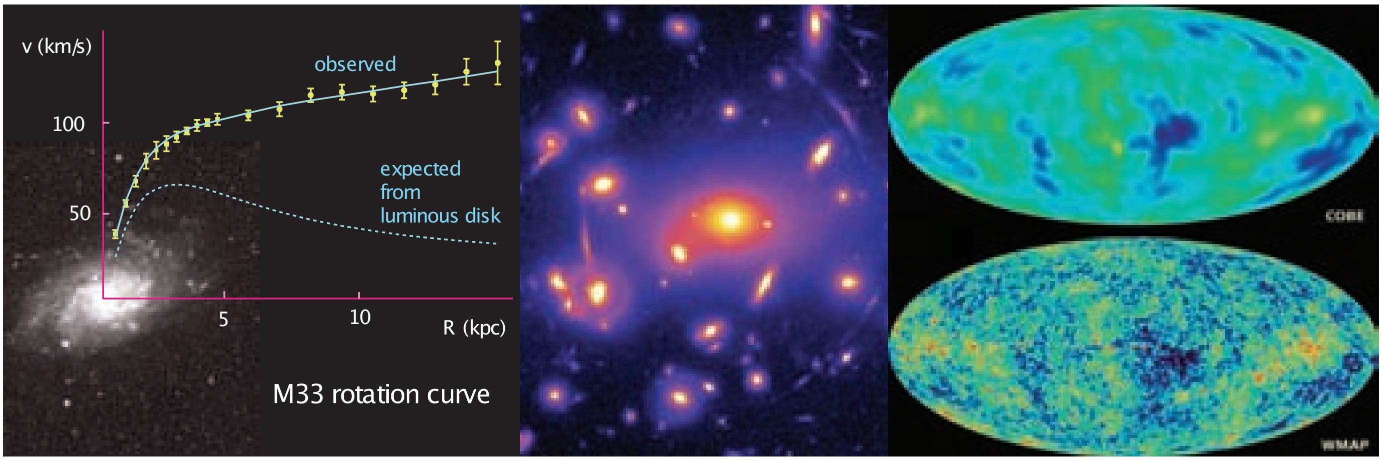


Figure 1 Three pieces of observational evidence supporting the existence of dark matter in the universe. On the left the discrepancy between the observed and expected rotational velocities is displayed, in the middle a picture of gravitational lensing is shown, while on the right the temperature fluctuations occurring in the cosmic microwave background are shown.

Astroparticle Physics

In recent years astroparticle physics has emerged as a highly promising interdisciplinary research field that brings together expertise developed in physics and astronomy with the objective of addressing a number of key questions in science:

- *What is the nature of dark matter?*
- *What is the nature of dark energy?*
- *What is the origin of the highest-energy cosmic rays?*
- *What is the origin of the structure of the universe?*

An answer found to any of these questions, even a partial one, will represent a major break-through at the frontier of scientific investigations. Finding a constituent of dark matter, a field-theoretical explanation of dark energy, a source of ultra high-energy cosmic rays, or the first unambiguous observation of gravitational waves, will each mark the beginning of an entirely new field of research ranging from 'Dark Matter Physics' to 'Gravitational Wave Astronomy'. The aforementioned questions will be discussed briefly in somewhat more detail, especially focusing on possible future research opportunities.

The nature of dark matter

Evidence for the existence of large amounts of dark matter in the universe comes – amongst others – from the measured rotational dynamics of and velocity dispersion in galaxies, observations of the relative velocities of galaxies in a cluster, and from gravitational lensing in clusters of galaxies (see figure 1). In fact, all current estimates, including those derived from satellite-based observations of the cosmic microwave background radiation, indicate that dark matter constitutes about 23 ± 4% of the total energy content of the universe. It has been suggested that a large fraction of dark matter consists of the so-called *lightest supersymmetric particles*. These hypothetical particles (also known as neutralinos) arise in *supersymmetry,* a theoretical framework that goes beyond the Standard Model of particles and fields. In order to obtain evidence for the predicted existence of neutralinos and measure their mass various methods have been introduced in the last couple of years:

- In direct searches it is tried to measure the recoil energy deposited by a passing neutralino in a very well shielded (underground) detector. Well-known experiments of this type are (amongst others) DAMA, CDMS and Edelweis-II.
- In satellite-based searches gamma rays, positrons or antiprotons are observed originating from the annihilation of a pair of neutralinos in a large celestial body such as the sun. This method has yielded first (unconfirmed) evidence for the existence of a 50 – 200 GeV neutralino using data obtained by the EGRET (γ's), BESS (e^+'s), HEAT and AMS-02 (antiprotons) satellites.
- In an indirect search the neutrinos emitted in the decay of W-bosons produced in the annihilation of a pair of neutralinos are detected. This method has the advantage that high-energy neutrinos need to

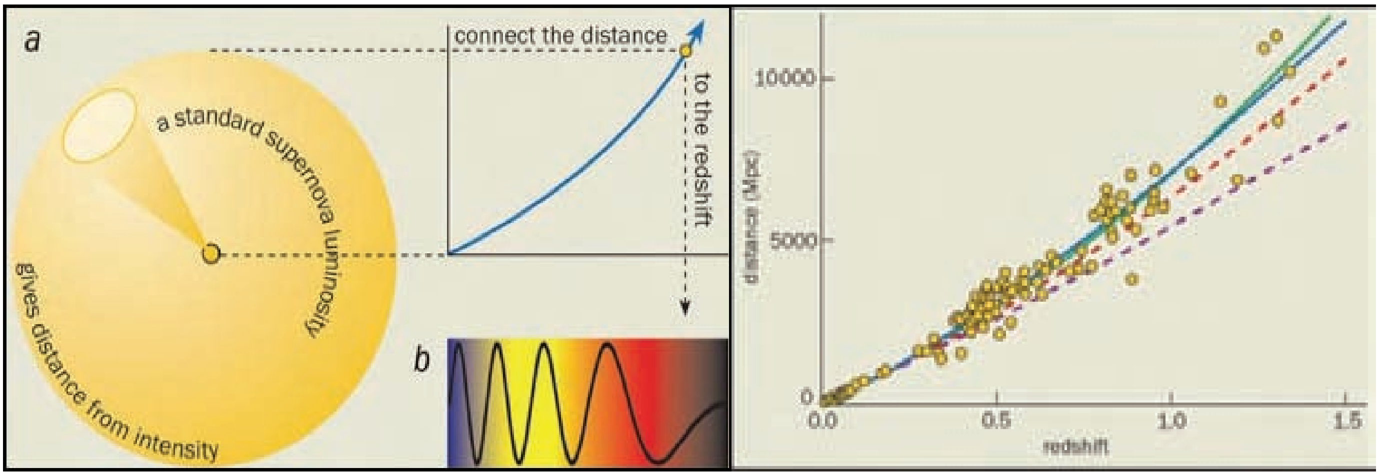


Figure 2 As the luminosity of type-Ia supernovae is well known, the apparent luminosity gives a measure of the distance (plotted on the y-axis) which can be compared to the redshift (plotted on the x-axis). While the left panel illustrates the concept, the right panel shows the actual data in comparison to various model calculations that include an accelerated expansion of the universe. The dashed purple line has no accelerated expansion included.

be observed, which makes it possible to use the new deep-sea neutrino detectors such as ANTARES, which is presently under construction, for this purpose.

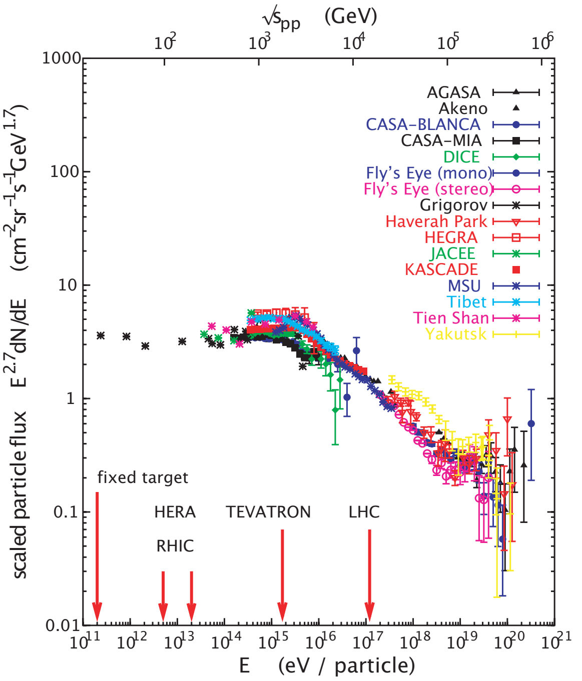
The nature of dark energy

The primary evidence for the existence of dark energy comes from observations of distant type-Ia supernovae that appear dimmer than they would be if the expansion of the universe was decelerating under the pull of gravity alone (see Fig. 2). Other evidence for the existence of dark energy comes from the number density of galaxy clusters, large scale density fluctuations and the number of strong gravitational lenses. By combining information derived from the red shifts of distant type-Ia supernovae (which – to be precise – gives a value for the *difference* between the amount of dark energy and dark matter) and the data obtained on the temperature fluctuations of the cosmic microwave background by the COBE and WMAP satellites (which gives a value for the *sum* of the amount of dark energy and dark matter), it is found that dark energy constitutes an astonishing 73% of the total energy content of the universe. This implies that normal (baryonic) matter only accounts for at most 4% of the universe. In order to make progress in understanding the nature of dark energy several research projects have been initiated:

- Cosmological arguments imply that the relative amount of dark energy and dark matter is changing while the universe is expanding. To verify this prediction, it is of importance to measure the red shifts of type-Ia supernovae out to very large distance scales (i.e. red shifts). Optical astronomy programs of this kind, known as GOODS and ESSENCE, have been started.
- Improved cosmic microwave background measurements will be performed by the PLANCK satellite that is presently under construction. With PLANCK the temperature fluctuations will be measured to a precision of 10^{-6} at an angular resolution of 5 arc minutes.
- A possible source of dark energy is the energy that – according to quantum mechanics – is contained in the vacuum. Unfortunately, simple estimates of this vacuum energy result in a value that is 120 orders of magnitude larger than the (dark) energy observed in the universe. Theoretical astroparticle physics research is needed to investigate whether the presence of a Higgs field or supersymmetry are able to resolve this discrepancy.

The origin of the highest-energy cosmic rays

The atmosphere of the earth is continuously bombarded by protons and heavier atomic nuclei – the so-called cosmic rays – which are causing air showers of secondary particles. The extent of the air showers, i.e. the spatial spread of the secondary muons reaching the surface of the earth is used to determine the energy distribution of the original cosmic rays hitting the earth. Whereas the steeply falling energy spectrum of cosmic



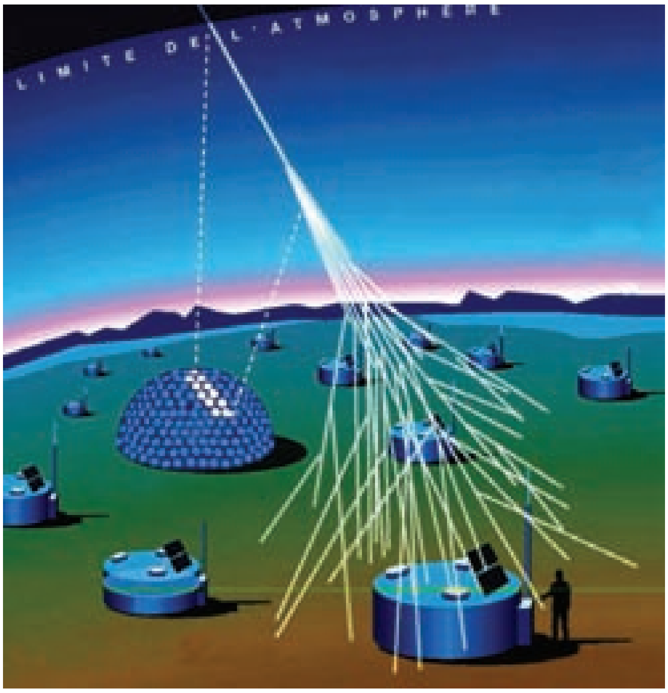


Figure 3 In the left-hand panel the energy spectrum of cosmic rays above 10^{11} eV is shown. The spectrum is scaled by a power of 2.7 in order to make the various features better visible. The data above the GZK limit ($5x10^{19}$ eV) are not fully consistent. In this domain new data with much better statistics will be collected by the Pierre Auger Observatory, of which a schematic picture is shown in the right-hand panel.

rays is well measured, many questions remain:

- What is the origin of ultra high-energy cosmic rays, having energies in excess of 10^{16} eV? What is the nature of the cosmic acceleration mechanism(s) that give rise to such high energies?
- Does the cosmic ray spectrum extend beyond the highest possible energy a proton can maintain in the universe due to collisions with the cosmic microwave background radiation (which will result in the production of pions above such energies)? If cosmic rays are observed above this so-called GZK (Greisen, Zatsepin and Kuzmin) limit, can they be attributed to entirely novel phenomena?

In order to answer these questions more detailed experimental information on the nature of cosmic rays must be obtained, for which several opportunities exist:

- Unambiguous experimental data on ultra-high energy cosmic rays need to be obtained in order to establish beyond doubt whether or not the GZK limit is exceeded. Such measurements will be obtained by the Pierre Auger Observatory (PAO), which is presently under construction in Argentina.
- The development of extended air showers can be measured over many orders of magnitude through radio detection of cosmic rays. The directional sensitivity of radio detection makes it possible to search for anisotropies in the cosmic ray spectrum, and the ability to reconstruct the spatial development of air showers makes it possible to study – under special conditions – cosmic neutrinos. Projects of this type are LOFAR, RICE and ANITA.
- In order to identify specific astrophysical sources that can be associated with high energy cosmic rays, one needs to observe cosmic neutrinos that are not affected by large intergalactic magnetic fields. This opportunity is offered by the new deep-sea neutrino telescopes, such as ANTARES and KM3NeT, that are presently being developed. As these detectors (and similar ones in Antarctica) will have a reasonable (0.2 to 2.0 degrees) angular resolution, it will be possible to use them for searches of neutrino point sources.

The origin of the structure of the universe

The universe is believed to originate from an initial super dense and hot phase, the so-called “Big Bang”. The stars, galaxies and clusters of galaxies observed today – 13.7 billion years later – must have formed later from early density fluctuations. Also, the observed dominance of matter over anti-matter requires the existence of some asymmetric processes in the early phases of the universe. These issues are studied in cosmology, but there are a number of projects that (partially for historical reasons) belong to astroparticle physics:

- The temperature fluctuations of the cosmic microwave background as measured by the satellites COBE and WMAP provide information on the age of the universe, its curvature, expansion rate and several other cosmological parameters. More importantly, the successor of WMAP, the PLANCK satellite, will – because of its improved angular resolution – be able

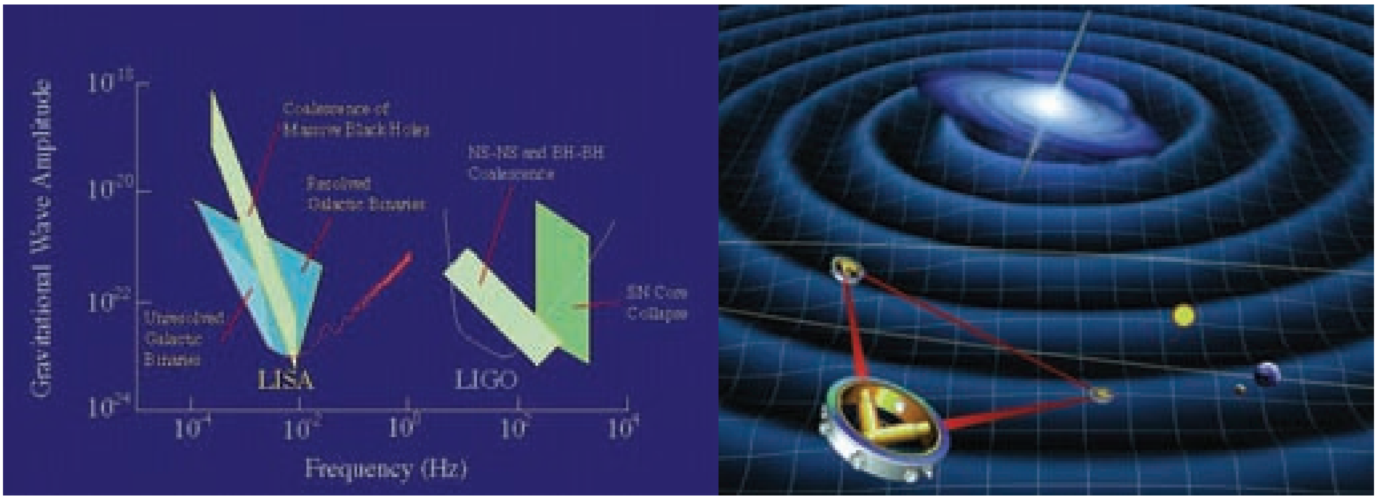


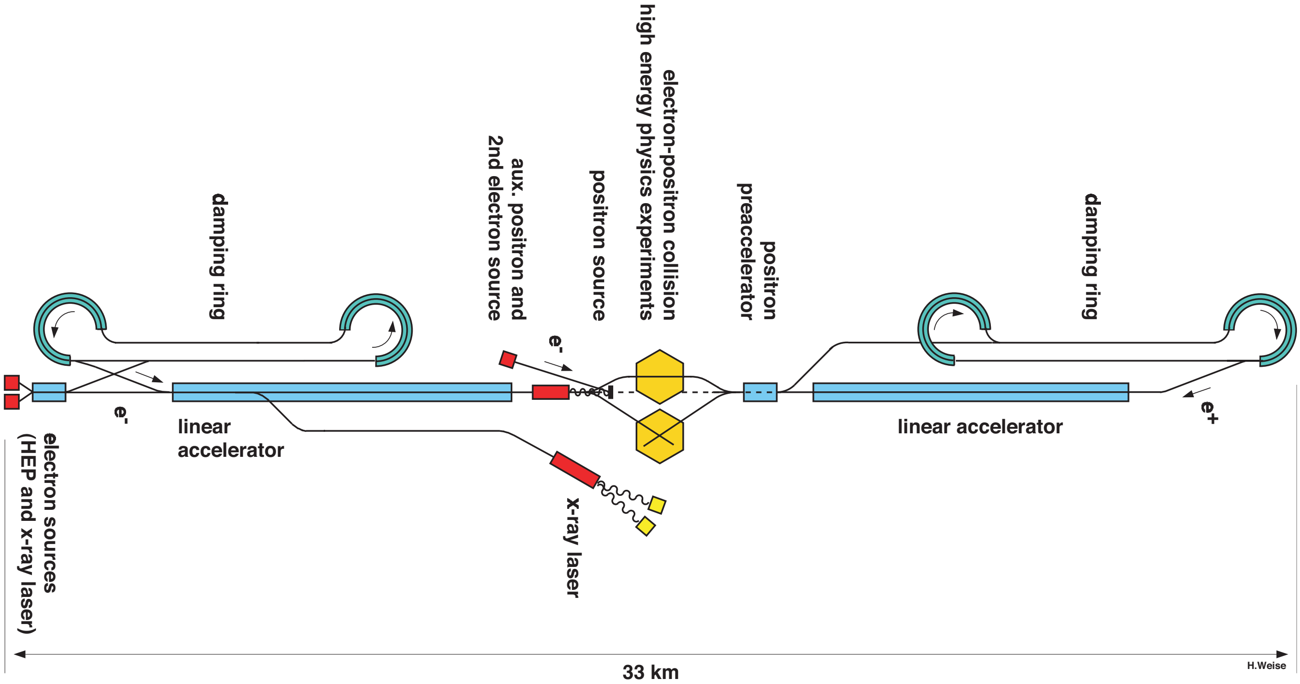
Figure 4 In the left-hand panel the estimated amplitudes of gravitational waves emitted by various astrophysical sources are plotted as a function of the frequency of the gravitational wave. This amplitude or sensitivity corresponds to twice the relative length change (ΔL/L) of a given detector (arm) due to the passing of a gravitational wave. The red (blue) curve gives the lower sensitivity limit of LISA (LIGO). In the right-hand panel the configuration of the three satellites constituting the LISA gravitational wave observatory is schematically shown. The relative distance between the three satellites is approximately $5x10^6$ km.

to probe the period of exponential inflation of the universe. As inflation has presently no firm theoretical foundation in physics, PLANCK has the potential of causing a break-through in this field.

- Gravitation plays a central role in the evolution of the universe. It is well-described by general relativity, but it is unclear how general relativity acts at the quantum level (which has an immediate impact on models of the early universe), One of the – only indirectly confirmed – predictions of general relativity is the existence of gravitational waves. If such waves are observed directly – which in itself would be a major success – it not only proves the validity of the framework of general relativity, but it also represents the start of 'Gravitational Wave Astronomy'. Because of the extreme weakness of the gravitational interaction, such waves propagate essentially unperturbed through the entire universe. Hence, the observation of gravitational waves makes it possible to probe the universe to the earliest time scales. Experiments designed to observe (and hence discover!) gravitational waves include resonant detectors such as Explorer, Mini-Grail and Nautilus, and interferometers such as VIRGO, LIGO (see figure 4) and LISA. The sensitivity of the LISA and LIGO gravitational wave observatories is shown in the left-hand panel of figure 4.

Outlook

Many excellent research opportunities exist in the rapidly developing field of astroparticle physics research. In some of these projects Dutch institutions are already playing an important role (LOFAR, ANTARES, mini-GRAIL and the precursor mission of LISA, LISA-pathfinder). Given the discovery potential of the astroparticle physics projects, it is desirable to prepare a coherent research plan for a strong and visible Dutch involvement in this newly emerging field at the interface between physics and astronomy.



Sketch of the overall layout of the linear collider as it was orginally proposed for the TESLA project (the second interaction region with crossing angle is optional and not part of the baseline design).

The International Linear Collider

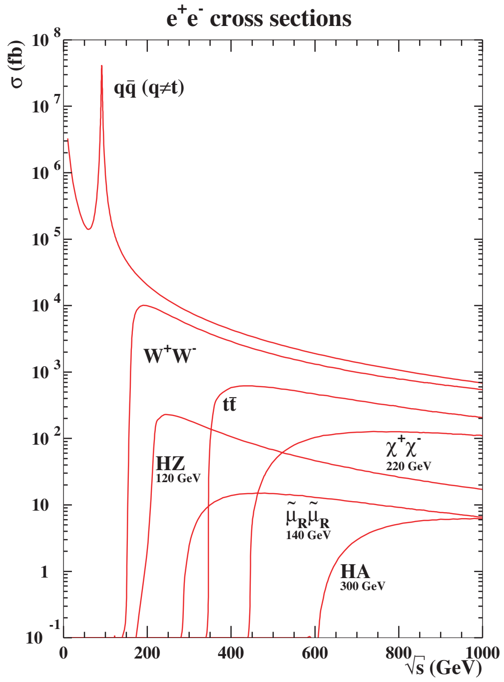
There is a worldwide consensus in the particle physics community that the next major accelerator after the Large Hadron Collider (LHC), still under construction at CERN, should be a linear e^+e^- collider. As its baseline option, the total energy of the colliding electrons and positrons should be 500 GeV and the luminosity (a measure of the collision rate) should be above 10^{34} $cm^{-2}s^{-1}$, at least a 100 times more than that reached at the LEP2 collider at CERN, which ended operation in 2000. The energy reach should be upgradeable to about 1 TeV. In summer 2004, after a recommendation of the International Technology Review Panel, the International Committee on Future Accelerators (ICFA) took the decision that this new machine, the International Linear Collider (ILC), should be built using superconducting technology for the accelerating cavities. This technology has been successfully developed at DESY (Hamburg) and a complete Technical Design Report[1] for such a machine, was already produced in 2001.

The scientific case

Over the past thirty years experiments at particle accelerators have firmly established the Standard Model of particle interactions. It describes the fundamental particles and the physics laws that govern matter, energy, space and time. All matter particles of the theory (three families of quarks and leptons) have been discovered and the properties of the force–carrying particles (the gluon for the strong force, the photon for the electromagnetic force and the W and Z gauge bosons for the weak force) are now well known. The unification of the electromagnetic and the weak forces (“electroweak” interaction) explains the close connection between the photon and the W and Z bosons, and has been experimentally verified to very high precision at LEP. The (large) mass of the W and Z bosons can be understood through an electroweak symmetry breaking mechanism, which is associated to the Higgs field permeating all space. Three of its four components lead to the massive W^+, W^- and Z bosons. The fourth component gives rise to a new boson, the Higgs particle, which has so far escaped detection. All the properties of the Higgs boson are precisely predicted by the Standard Model, except its mass.

The Higgs particle is expected to play a central role in the experimental program of the ILC. At 500 GeV collision energy a Standard Model (SM) Higgs boson of mass up to 400 GeV can be observed. This is well above the upper limit of about 200 GeV obtained from precision measurements at LEP. If a Higgs boson exists in this mass range it will for sure be discovered at the LHC (and possibly already at the Fermilab Tevatron collider). However, previous experience has shown that proton–(anti)proton colliders and e^+e^- colliders are complementary. The W and Z bosons were discovered at the Sp$\bar{p}$S collider of CERN in the early eighties. But precision measurements at LEP of the properties of the Z and W bosons really established the Standard

[1] *http://tesla.desy.de/tdr/*



Cross-sections for several representative processes at the ILC.

Computer simulation of the decay of a Higgs particle in the TESLA detector.

Model, allowing a precise prediction of the top quark mass and to constrain the Higgs boson mass. Even if the Higgs is already discovered at the LHC, the clean experimental conditions of the e^+e^- collider allow precise determination of its properties like mass, width, spin, decay branching fractions. In addition, the ILC offers the unique possibility to establish the coupling of the Higgs boson to itself.

The precision of the measurements will be vital for the full understanding of the origin of mass. If the electroweak symmetry is broken in a more complicated way than predicted by the Standard Model, high precision measurements of the top quark mass and W mass from threshold scans and of the electroweak mixing angle from a high statistics run at the Z mass, will strongly constrain the alternatives.

The Standard Model, however, fails to predict *exact* unification of the three forces at a scale of about 10^{16} GeV. To achieve that, new physics at a scale of a few hundred GeV up to one TeV is required. New physics in a similar energy range is also needed to solve the so called *hierarchy problem*, i.e. finding a solution to limit the masses of the Higgs, W and Z bosons, which would otherwise rise to the Planck scale (10^{19} GeV) due to quantum fluctuations.

One possibility to solve these problems is the existence of Supersymmetry (SUSY). It predicts many new particles, a partner for each of the matter and force particles of the Standard Model that we know today and a total of five Higgs bosons. Each fermion has a boson superpartner and vice versa. Despite extensive searches in past and present experiments, no sign of these particles has yet been observed. Although there is a large spectrum of masses for these supersymmetric particles, depending on the values of the parameters of the theory, again the ILC is complementary to the LHC in the sense that precision measurements of the masses and other properties of the particles accessible in the energy range of the ILC, will allow an accurate determination of the parameters of the theory. One very intriguing possibility is to investigate whether the lightest supersymmetric particle could be a candidate for the dark matter in the universe. This neutral particle (*neutralino*) can be precisely studied at the ILC.

The Linear Collider facility

The baseline machine should operate as an e^+e^- collider up to a maximum energy of 500 GeV. The actual operating point will in first instance be dictated by the maximum of the Higgs production cross-section. The peak luminosity should be above 10^{34} $cm^{-2}s^{-1}$, which would allow to collect an integrated luminosity of 500 fb^{-1} in the first four years. This would make the ILC a true Higgs factory with about 10.000 Higgs bosons produced per year. The beam energy precision should be better than 0.1%, which is required to do precision measurements of the Higgs and top quark masses. An important parameter is the degree of

A 9-cell superconducting cavity developed at DESY.

polarisation of the electron beam, which is expected to be 80%. History has shown that it is very desirable to have two interaction regions for two experiments, to allow independent measurements and cross-checks of (unexpected) results. One of these interaction regions should then have a crossing angle between the incoming beams to allow for the possibility of a γγ collider. As was done at LEP2, the machine should be able to operate at 91 GeV at the peak of the Z production cross-section, albeit with a lower luminosity, for short detector calibration runs.

The machine should be upgradeable to a total energy of 1 TeV with a foreseen integrated luminosity of 1000 ab^{-1} over a period of 3-4 years. Presently existing prototype superconducting cavities have reached an accelerating field of over 35 MV/m, which would correspond to a total energy of 800 GeV. Vigorous R&D is going on to improve on these performance figures.

Several other options of running are planned. One is the doubling of the integrated luminosity over two years after the initial 500 fb^{-1} period of four years. Another unique possibility would be to polarise also the positron beam. An e^+ polarisation degree of at least 50% is anticipated. As already mentioned, several very important measurements could be done at the WW threshold with a luminosity of a few 10^{33} $cm^{-2}s^{-1}$, allowing e.g. a W mass determination with a precision better than 10 MeV, and at the Z peak ("Giga-Z" option) with a luminosity of several 10^{33} $cm^{-2}s^{-1}$. With a second interaction region with crossing beams at an angle of few tens of mrad, (polarised) γγ or eγ collisions at 80% of the maximum e^+e^- energy and 30-50% of the luminosity would be possible. This option would be much helped with the operation of the ILC as an e^-e^- collider, which has intrinsic physics interest on its own.

ILC detectors

The experimental conditions at the e^+e^- linear collider are very clean as compared to hadron colliders, permitting a much more detailed understanding of the interactions and the possibly new physics. This however presents much larger challenges to the detectors than those at the earlier e^+e^- colliders LEP and SLC. E.g. the precise understanding of the nature of the Higgs boson requires an accurate and unambiguous measurement of its decay branching fractions. This can be done by identifying the different decay particles of the Higgs boson recoiling against a pair of muons from the accompanying Z decay.

Very precise 3D pixel vertex detectors will allow the tagging of b and c quarks in these Higgs decays with high efficiency and purity. The vertex information needs to be complemented by a momentum measurement for charged particles an order of magnitude more precise than achieved before, using tracking detectors surrounding the vertex detector and by highly granular calorimeters for a precise and complete reconstruction of the jets originating from particles decaying. The

Over 300 physicists and engineers gathered in Paris in April 2004 for the International Linear Collider Workshop, discussing the physics, detectors and machine options for the Linear Collider.

aim is to obtain a two-jet invariant mass resolution comparable to the natural widths of the W and Z bosons.

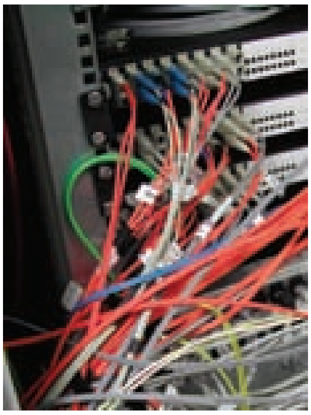
At present three detector concepts are being studied. While there is a broad agreement on the main detector requirements as sketched above, details on the design characteristics and performance are being simulated, prototypes developed and being tested. The various choices range between a large gaseous tracking detector (Time Projection Chamber) and an all-Silicon tracking detector, between a highly-granular Si-W electromagnetic calorimeter and one with scintillators as the active medium and between an analog or digital read-out solution for the hadron calorimeter. The magnetic field strength in these different detector concepts varies between 3 and 5 Tesla.

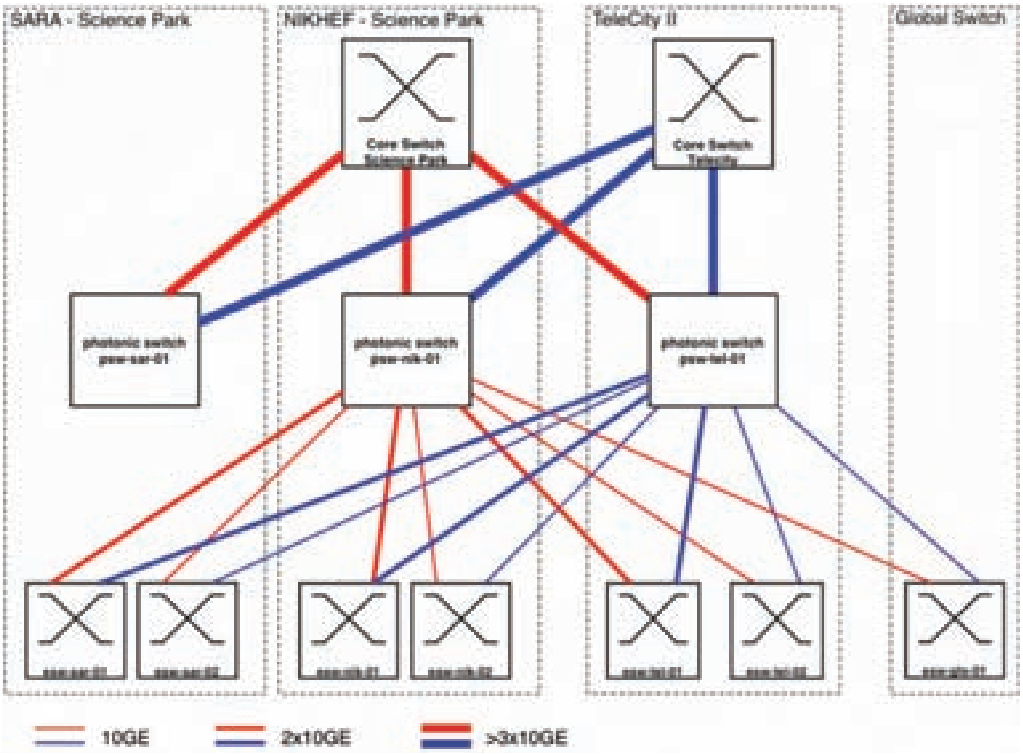
Organisation of the ILC program

The International Linear Collider Steering Committee (ILCSC) has established a framework for a truly worldwide international organisation that will develop the design of the ILC. Prof. Barry Barish has been appointed (in March 2005) as director of the Global Design Effort for the ILC. The goal is to complete a detailed Technical Design Report by 2007, and to begin the process for site proposals also by 2007, followed by a site selection and approval of international roles and responsibilities by governments in 2008. As a first step it is aimed to complete the accelerator conceptual design report (CDR) by end 2005/early 2006, including site requirements and an initial cost and schedule plan.

Following the time line for the Global Design Effort, and in close collaboration with it, it is planned to have preliminary costing, performance estimates and necessary R&D plan for the existing detector concepts ready by the time of the accelerator CDR, in 2006. More detailed CDR's for the experiments are then called for at the time of the accelerator TDR (2007) and Letters of Intent for experiment proposals in 2008.

All these activities for the moment take place at (major) accelerator labs and physics institutes all over the world, with regular international workshops and conferences.





25 Years of Internet Activities at NIKHEF

Internet, and networking in general, has a long history at NIKHEF. From an acoustic 110 bits per second (bps) modem 35 years ago to Gigabit networking today has been an interesting growth path. In this article we shall describe some of these developments. We shall also give an overview of current Internet related activities.

Networking for NIKHEF started in 1980 with the installation at CERN of a remote batch station. A group of NIKHEF physicists working on one of the ISR experiments at CERN had the need to make use of the computing power of the NIKHEF CDC 6400 mainframe in Amsterdam. This was implemented by connecting two Modcomp II computers via the public telephone network. The Modems used were 110 bps acoustic modems. Data input went via a punch card reader, data output went to a line printer. Sending input while printing output was not a good idea: the sound of the printer interfered with the acoustic modems.

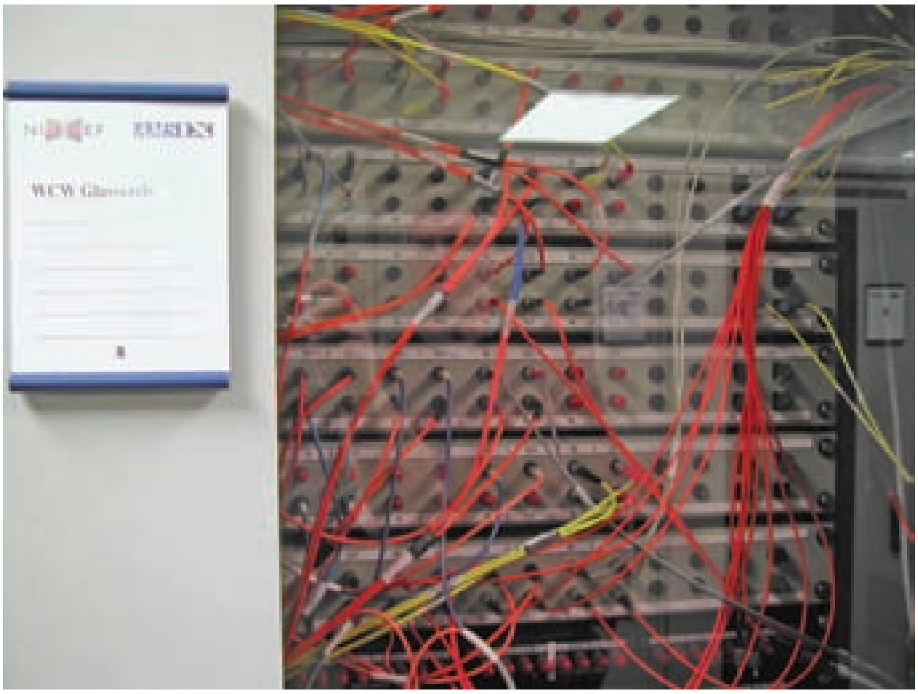
1980 was also the year when the first interactive service between NIKHEF and CERN was installed. A terminal and a 1200 bps modem made it possible to dial in into the WYLBUR service on the CERN IBM mainframes. This was for some time a very popular service. It was also a considerable boost for the NIKHEF phone bill.

In 1983 the first real networking equipment was installed: a Camtec X.25 PAD connected to the Norsk Data Nord-100 CE frontend computer. The network connections went via the public X.25 network of the PTT: Datanet-1. The box made the first real interactive services and file transfers possible between NIKHEF and CERN. Connections to DESY and SLAC followed later. Network bandwidth: 2400 bps.

1985 saw the birth of the first campus network: WCWLAN. A 10 Mbps ethernet using the Internet protocols TCP/IP. This brought the first electronic mail services to NIKHEF since it connected to the EUnet services at the CWI. Also USEnet News was introduced.

The use of these network services saw a steady growth over the next years. Also the costs grew steadily: these costs were related to the volume of the traffic. In 1989 a point was reached where it became more cost effective to go away from public dial-up services and rent private lines. Combining the requirements of NIKHEF, CERN and via CWI the EUnet services enabled the acquisition of a leased line between NIKHEF and CERN. The bandwidth was 64 kbps and the delivery time of the line was 9 months. This was obviously a whole new ball game for the Dutch PTT. In this year NIKHEF went away from traditional UUCP addressing and introduced domain names: nikhef.nl was born.

The next few years the Internet in Europe really took off. Many networks popped up and were interconnected. Most of these interconnections took place in Amsterdam since the combination of networking for particle physics (NIKHEF) and networking for computer science (CWI) made Amsterdam a natural hub for the



Internet in Europe. In 1991 NIKHEF becomes a customer of SURFnet, the academic and research network in the Netherlands. SURFnet from this date on provides all external networking for NIKHEF. This is also the year that NIKHEF's own private networks come to an end.

Now we make a big jump in time and we will have a look at the networking situation at NIKHEF in 2004. NIKHEF networking services have seen a steady growth: today we are still connected to SURFnet, however the current bandwidth is 1 Gbps. In the near future this will be upgraded to 10 Gbps. SURFnet also provides additional dedicated bandwidth to CERN (10 Gbps) and FNAL (10 Gbps).

The role of Amsterdam and NIKHEF as an important hub in the global Internet has also evolved on a grand scale. The few network interconnections of the early days have today evolved in a set of so called Internet Exchange Points (IXP), that all have a point of presence at NIKHEF. In 2004 we play host not only to the Amsterdam Internet Exchange (AMS-IX), but also to the Netherlands Internet Exchange (NL-IX), the Xchangepoint Europe (XPE), and the Packet Exchange. Together they constitute the largest concentration of Internet Service Providers (ISP) in the world. The oldest and largest of these IXPs is the AMS-IX - a direct descendant of the early NIKHEF activities in this field. Started in 1996, AMS-IX today interconnects more then 200 Internet Service Providers from all over the world.

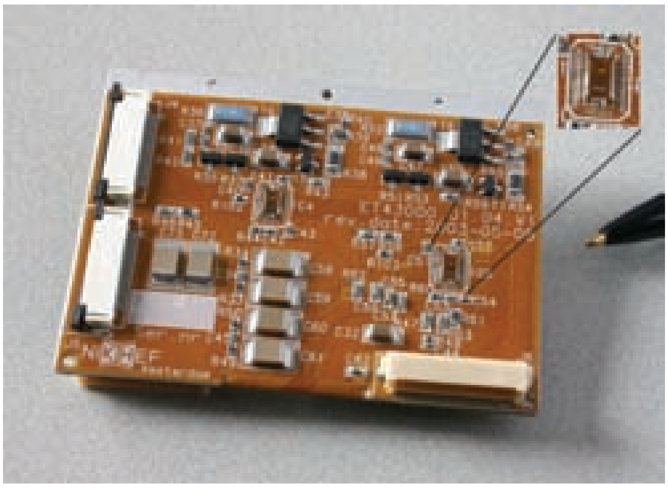
The underlying technology of the AMS-IX consists of a mix of high powered Ethernet switches and optical switches. At the end of 2004 this infrastructure switched over 50 Gbps of traffic at peak hours, using about 10% of the total capacity.

For comparison, it is interesting to note that these figures are comparable with the networking requirements of the LHC experiments combined.

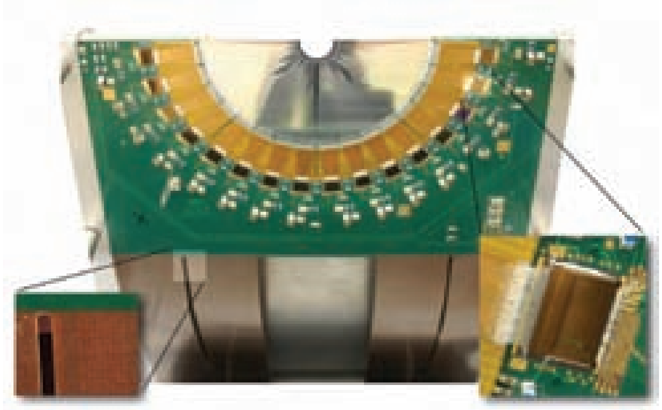
Apart from involvement with the basic infrastructure of the Internet, NIKHEF is also participant in a few key services such as naming and addressing on the Internet.

The Internet works with numbers: the IP addresses. However, users prefer names as defined in the Domain Name System (DNS). So, a mapping takes place between numbers and names. This is the job of the DNS: a distributed, hierarchical database system that consists of a set of about half a million servers worldwide. At the top of this hierarchy sit the so called root servers that tie the system together. NIKHEF plays host to two of such servers: the K-root operated by the RIPE NCC in Amsterdam, and the F-root operated by the Internet Systems Consortium in California.

Next to the root servers, NIKHEF is also hosting top level domain servers for Germany, the UK and Russia.



Example PCB with SMD and 2 wire bonded chips for ALICE.



Prototype LHCb-VELO hybrid. Left insert: meshed copper planes. Right insert: Beetle chip.

Printed circuit boards in high energy physics: from simple carrier to crucial component

ALICE

Printed circuit boards (PCBs) are commonly used in electronics for high energy physics. Starting from a simple interconnecting plate made from phenol paper with a single connection layer in the 1960's, printed circuit boards have evolved to complex multilayer boards made from various base materials carrying many surface mounted devices (SMD) and wire bonded chips. In addition PCB designs are often constrained by environmental requirements, like thermal conductivity, vacuum compatibility and high voltage isolation.

LHCb-VELO

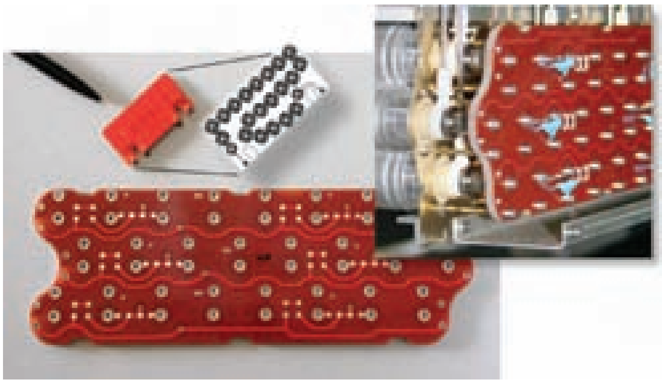
For the LHCb-Vertex project a detector hybrid has been designed which carries 16 Beetle chips reading out 2048 strips of a silicon detector. As the hybrid is operated in vacuum, heat generated by the Beetles has to be taken out by conduction through the PCB material. Base material for this hybrid is a polyimide (Kapton^{TM}) multilayer partially glued to an aluminium surface.
A total of 64 high speed analog and 256 differential digital signal channels are connected by means of flexible flatcables through vacuum. To ensure vacuum compatibility provisions were made, e.g. embedded meshed copper planes.

ATLAS MDT

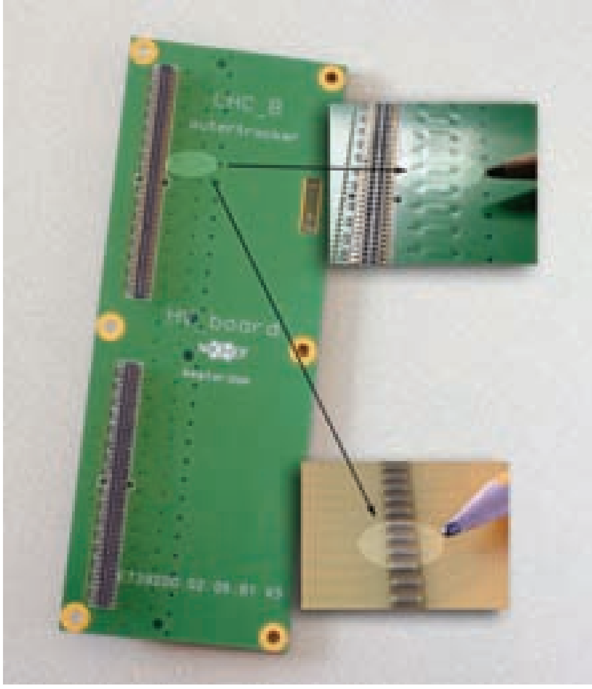
In the ATLAS muon drift tube test setup a two sided read-out is accomplished by combining two tubes connected via a delay line. A delay of 11 ns is needed with signals at high voltage (3000 Vdc).
This is accomplished by a PCB with planar coils and well defined parasitic capacitance. A 4-layer prototype with 22 coils is tested. The successor of this delay line is a detector end plate for 24 tubes with 12 integrated 5 ns delay lines. It consists of a stackable 6-layer PCB with some external HV parts and 144 embedded planar coils and parasitic capacitors.

LHCb Outertracker

The LHCb-outertracker consists of 50.000 small tubes containing a centre wire connected at high voltage (2000 Vdc). Large capacitors are needed to couple out the detector signals. The technological challenge is to place these relatively large capacitors close to the detector between high density signal wires. Due to small dimensions and high voltage, isolation by air is not sufficient. Therefore capacitors are embedded into the PCB. The high voltage boards with 32 capacitors each are successfully tested for low signal noise and low leakage current.



Above: prototype ATLAS-MDT delayline with 22 embedded coils
Below: detector endplate with 12 integrated delay lines
Right insert: endplate mounted on a stack of drift tubes.



Frontend high voltage board for the LHCb outertracker with embedded HV-capacitors highlighted.

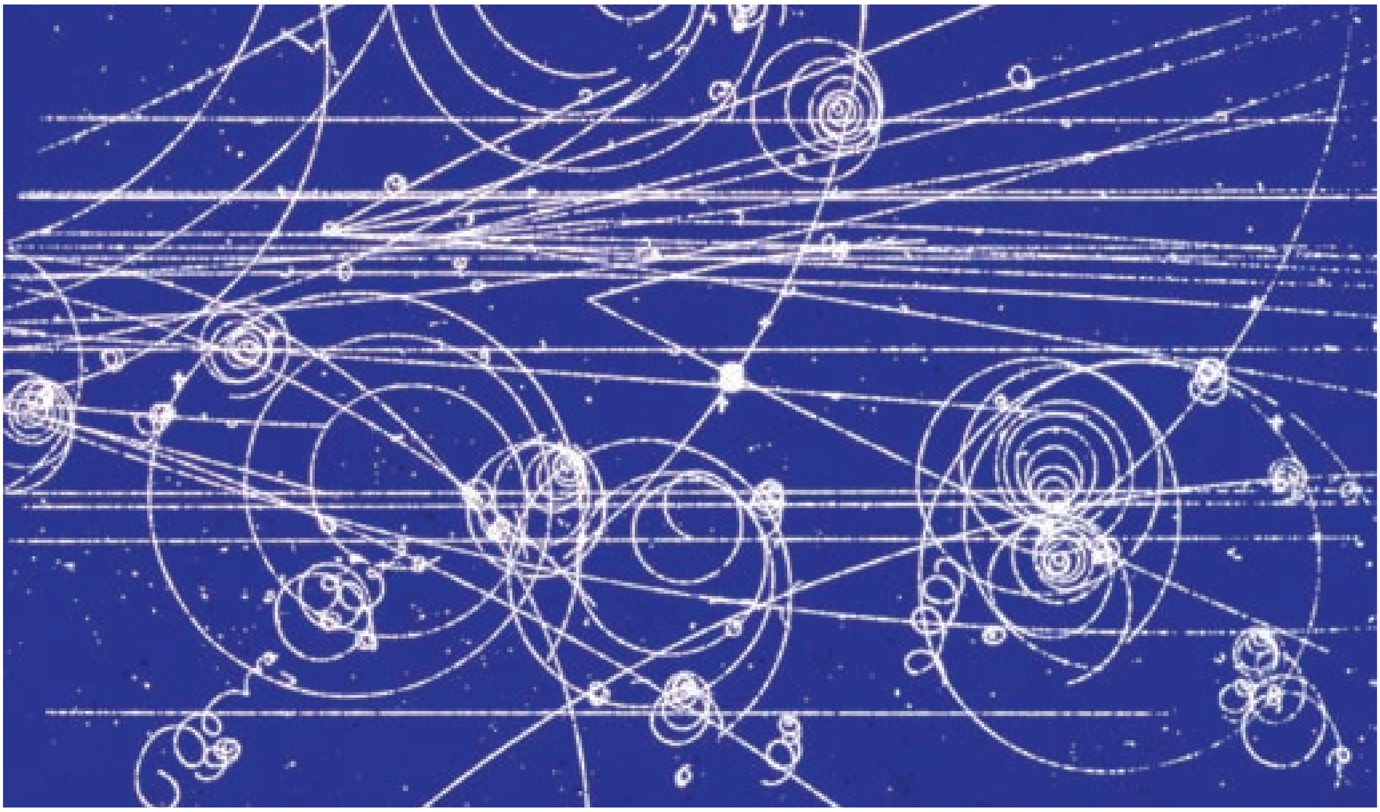
Mechanical precision support structures very demanding

The size of the experiments under construction for the Large Hadron Collider at CERN is enormous.

The ATLAS detector for example has a cylindrical shape, 45 meter long, 22 meter in diameter and weighs 7000 tons. The detector is assembled of hundreds of subdetectors. What one often not realizes is that very stringent requirements are put on the accuracy of the assembly of subdetectors as well as on the complete assembly.

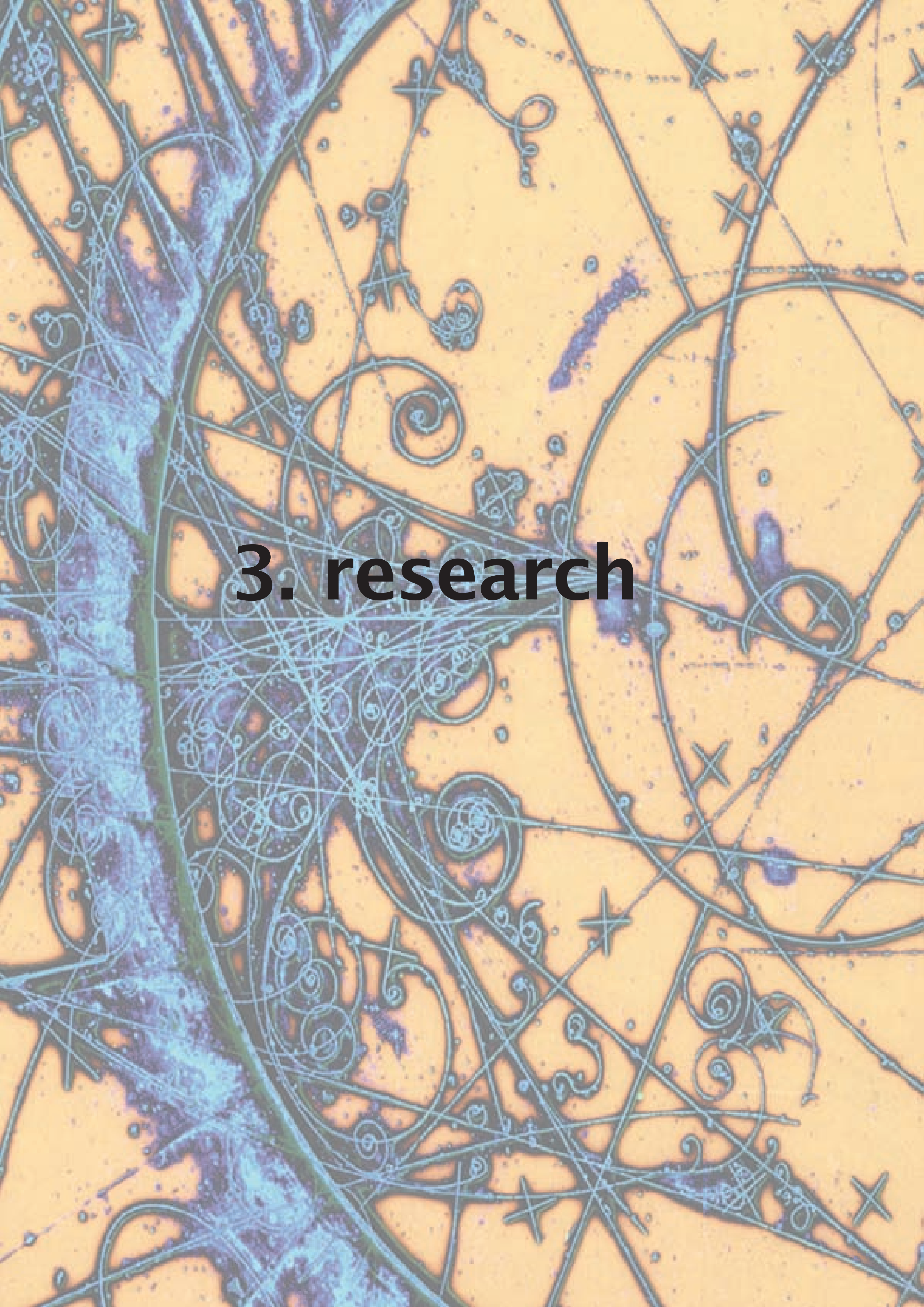
One of these subdetectors is the silicon tracker. Layers of silicon detectors surround the point where the beam particles collide. These detectors determine the trajectory of the charged particles produced in the collision with an accuracy of 10-20 micron.

But only when the mechanical support structures fulfil very stringent requirements on flatness, rigidity and stability this goal can be achieved.



Production of particles by 16 GeV negative pions in the first CERN liquid hydrogen bubble chamber.

The majestic spiral galaxy M81.



3. research

Inauguration of the ATLAS-MDT barrel organ at the occasion of the first shipment of ATLAS MDT chambers to CERN.

Parts of the ATLAS detector are being assembled in the experimental area, 65 m below the surface. In the wall (just below the 'C') the hole, where the particle beam enters the hall, is visible.

ATLAS: construction in full swing

A highlight for the NIKHEF ATLAS programme in 2004 was the completion of the mechanical assembly of ATLAS precision muon chambers in Amsterdam. On October 5th, technicians glued the last layer of aluminium drift tubes on the 101st and final chamber to be assembled at NIKHEF. Ninety-six of these chambers make up the full set of the 'Barrel Outer Large' chambers, which comprise the major part of the third and outer layer of the detectors in ATLAS that measure the direction and momentum of the muons.

During three years of chamber assembly, following many years of R&D work, 42000 'monitored drift tubes', 30 mm in diameter, five meter long and a wall thickness of 0.4 mm, have been produced.
A semi-automatic wiring machine equipped the tubes with a total of 200 km of tungsten sense wire, as well as 84000 end-plugs. The tubes were then subjected to a number of tests on the precision of the wire location and wire tension, leak tightness under three bar pressure, and the ability to stand high voltage on the sense wire with small dark current. Tubes passing the quality tests were glued into layers of up to 72 tubes in parallel; the full muon chambers consist of two sets of three layers of tubes, separated by a spacer.

To measure high-momentum muons accurately at the LHC, precision and control have been the key words in chamber assembly. Within the chamber dimensions of up to five by two meters, the tubes needed to be mounted with a precision of 20 microns. To achieve this, precision jigs were used on a granite table inside a temperature- and humidity-controlled clean room, and tube positions were constantly monitored during assembly, exploiting the NIKHEF RASNIK alignment system.

As from October, sets of five chambers are being routinely tested in a dedicated cosmic-ray test stand, into which the ATLAS muon-detector control system, the RASNIK alignment system, and the ATLAS read-out electronics are also integrated. Since December, batches of chambers are shipped to CERN, where they are mounted together with trigger chambers, the RPC's, in a common support. The first of these assemblies will be mounted in the ATLAS experimental area mid-June 2005.

The second large ATLAS detector construction project at NIKHEF is one end-cap of the semiconductor tracker (SCT), which consists of some 1000 modules with silicon strip sensors for charged particle detection, mounted on nine light and strong carbon-fiber disks. Hundred modules have been made at NIKHEF, and have undergone tests on mechanical accuracy and electrical performance. The other modules are being delivered from other institutes; each module is subjected to an acceptance test. The disks have been manufactured, and are now being prepared for module mounting. This involves mounting and testing of cooling pipes, optical and electrical cabling on the disks, and construction of a cold test box for the fully equipped disks.

Muon detectors, produced by NIKHEF, are tested before they are shipped to CERN. With cosmic muons the position resolution of each individual channel is measured. At the left, above the table, an LED-display shows the trajectory of a muon.

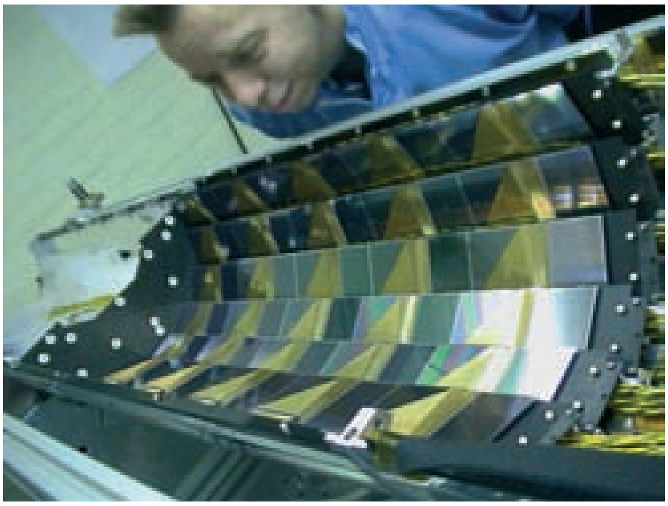
One of the goals of ATLAS is to definitively prove the existence or non-existence of the last missing element of the successful Standard Model: the Higgs particle. The ultra-high collision energy of the LHC will also give the opportunity to ATLAS to search for new phenomena, such as super-symmetry, extra space-time dimensions, or other new physics. NIKHEF is preparing simulation, event reconstruction and analysis software, with emphasis on rapid commissioning of the ATLAS detector. In particular we are interested in top quark production events, which also give excellent physics opportunities with first data.

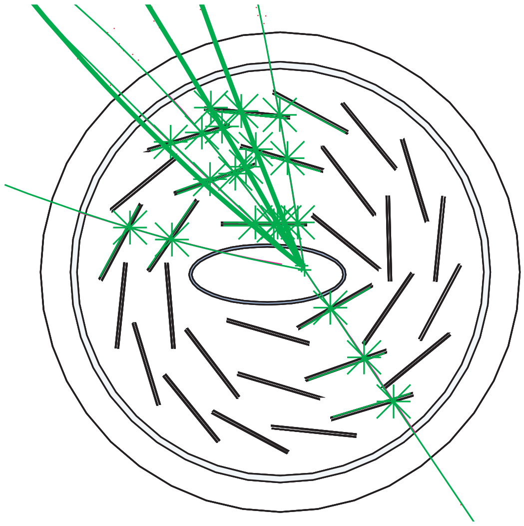
In preparation for the LHC, and to do physics at the high-energy frontier before LHC starts, NIKHEF physicists participate in the DØ experiment at the Tevatron (Fermilab, Chicago: proton-antiproton collisions at 2 TeV). In 2004 the total delivered luminosity in run 2 tripled to 450 pb^{-1}, and first papers on this dataset have been published. These include studies of properties of bottom quarks, quantum chromodynamics, and backgrounds to Higgs production. Furthermore, the most precise measurement of the top quark mass has been published in Nature.

Large Hadron Collider

At the European Laboratory for Particle Physics (CERN) the construction of the Large Hadron Collider is advancing well. It is expected that in 2007 first proton-proton collisions at the ultra-high energy of 14 TeV will be delivered. The construction of the ATLAS experiment, which will detect and analyse these collisions, has made good progress in 2004: the infrastructure of the experimental hall has been completed, and the installation of the spectrometer magnets has started.

Components of the ATLAS detector are under construction at various locations in the world, or have already been completed. In a dedicated test beam, a representative subset of ATLAS ingredients has been tested successfully, combining all detector elements.





The silicon strip detector during construction. On the right a reconstructed Deep Inelastic Scattering (DIS) event in the detector, with in the center the elliptical beampipe; the crosses on the lines represent the signals in the individual silicon sensors.

ZEUS takes data in 2004

The ZEUS experiment is located at the electron proton collider HERA in Hamburg (Germany). HERA restarted operation in 2001, after an upgrade of the accelerator. The goal of the upgrade was to increase the luminosity of the machine. Until the beginning of 2004 operation of the accelerator proved to be far more difficult than expected and almost no data could be collected. In 2004 most of the problems were solved and colliding beams were provided on a regular scheme from January until mid August.

After a foreseen shutdown for yearly maintenance the accelerator switched from positron to electron beams colliding with protons as requested by the ZEUS experiment.

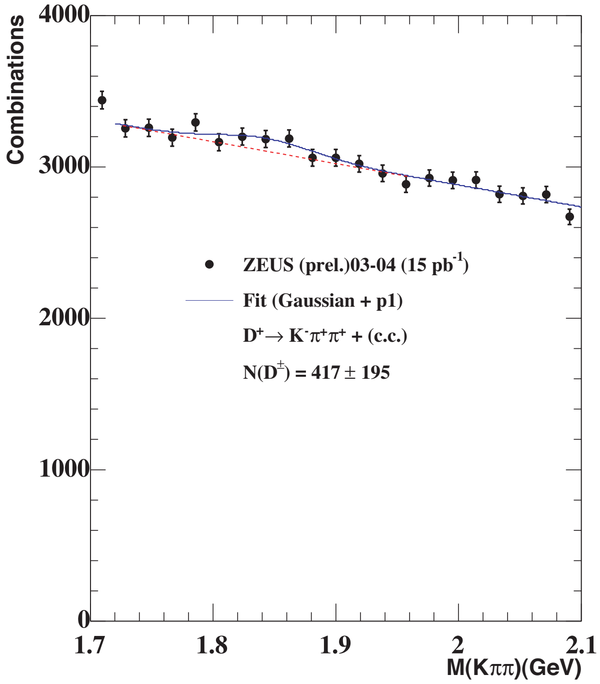
The ZEUS experiment

The ZEUS experiment is composed of subdetectors that are built in cylinder like shells around the interaction region. From the inside out the experiment starts measuring the tracks of charged particles, with a high resolution silicon strip detector. This detector was completed in 2001 and for a large part designed and built by NIKHEF. The performance of this detector is very good and reliable. The momentum of the tracks is subsequently measured with the help of a wire chamber, inside the magnetic field of 1.5 Tesla. Due to the poor background conditions given by the HERA machine, the operation voltage of this chamber had to be reduced and this led to a somewhat reduced efficiency at the trigger level. Just outside this combined tracking system a sampling calorimeter provides the energy measurement of all particles except the muons (that traverse the calorimeter and continue their journey into the muon chambers) and neutrinos (that escape the detector without leaving any trace). Although the calorimeter has already been in operation since 1991, it still works extremely reliably.

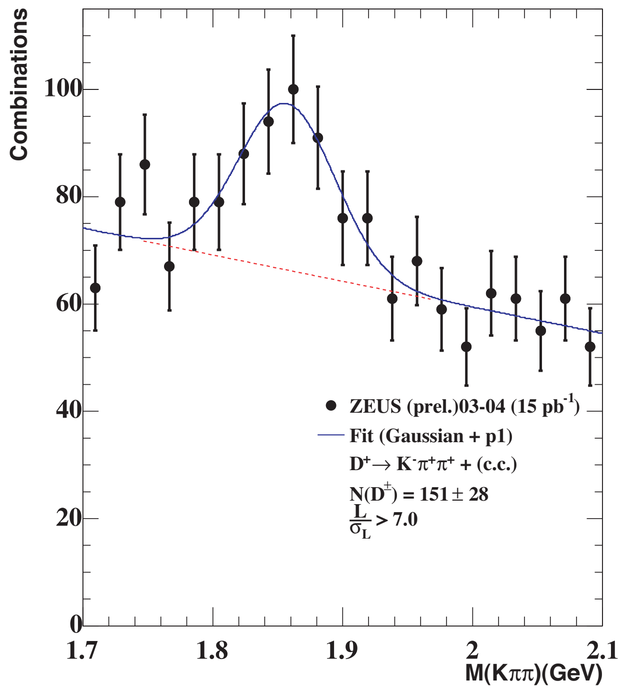
Charmed mesons

At HERA the electron serves as fine resolution probe to look inside the proton. The center-of-mass energy of the electron-proton collisions is 320 GeV. At present the main goal of the ZEUS experiment is to explore the contribution of heavy quarks to the structure of the proton.

The production process of heavy quarks can be quite well described by the so called boson gluon fusion: A photon radiated by the electron scatters with a parton (this is either a quark or a gluon) inside the proton. In the final state a charm or bottom quark pair can be formed. Once these heavy quarks are produced they immediately hadronise: pairing up with other quarks in the fragmentation phase. For the charm quark it means that it will form a $c\bar{u}$ combination in 56% of the cases (called a D^0 meson) and a D^+ ($c\bar{d}$) meson in 24% of the cases. Each of these are unstable and will decay shortly after their production into stable decay products. These decay particles like pions and kaons are observable



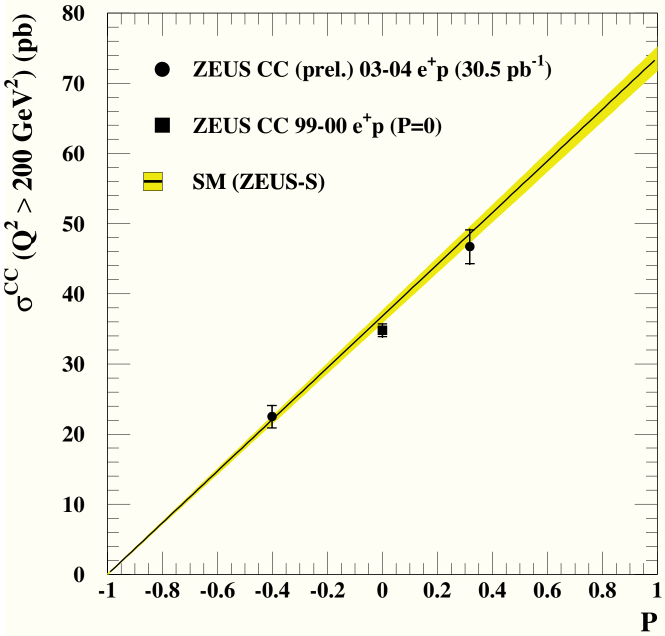
M(Kππ) invariant-mass distribution. The quoted number of D-mesons, decaying into (Kππ), is a result of a Gaussian fit to the signal and a first-order polynomial for the background.



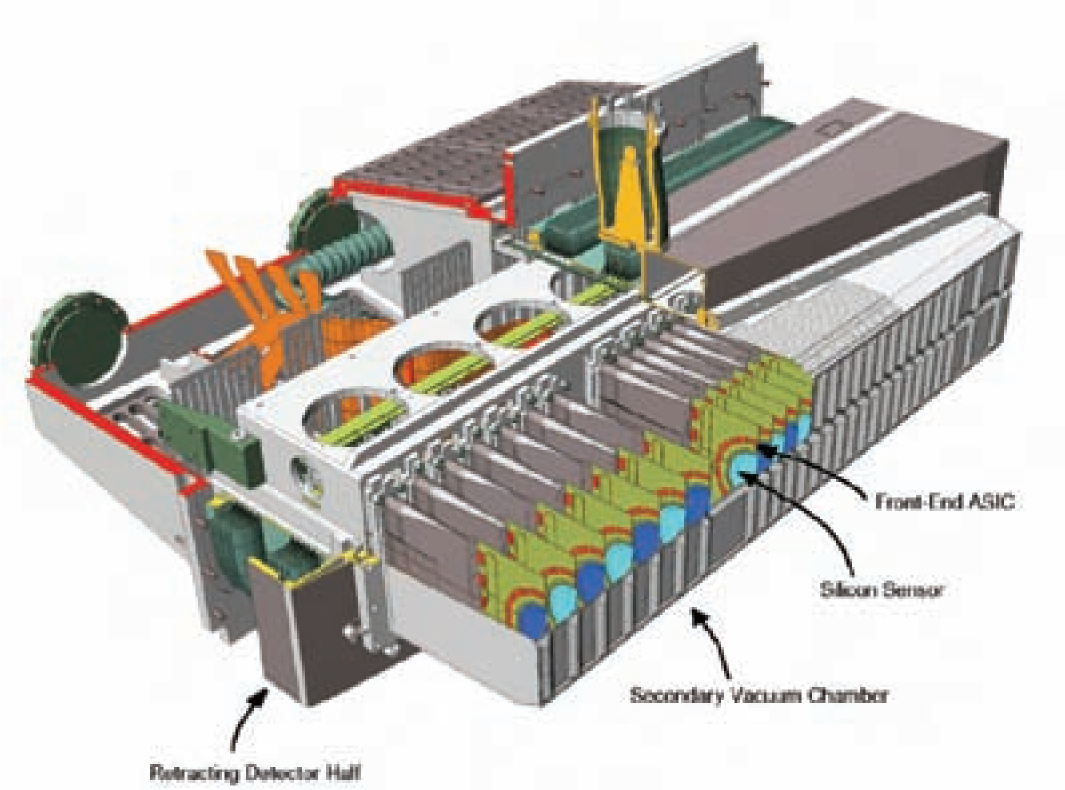
The same data as shown in the left figure, but now the information of the vertex detector is used for the reconstruction of of the decay of the D-meson. Demanding a decay length significance of $L/\sigma_L > 7$ provides a very clean D-signal.

charged particles. If the tracks they follow are reconstructed accurately the decay point of the charmed meson can be deduced from their common origin. On average this decay point is only a few hundred micrometer away from the primary collision point where most other tracks come from.

In 2004 the charm production deep inelastic scattering was measured with this separated vertex reconstruction method for the first time. Although the data sample is still somewhat small, the measurement of the D^+ meson was successful and this result has been submitted to the summer conference ICHEP-04 in Beijing. A comparable method was also used to tag the decay of B-mesons into at least one muon.



First cross section measurement with polarised beams. The Standard Model predicts the cross section of charged current e^+p scattering as a function of the longitudinal polarisation. With negative polarisation (P=-1) this cross section should go to zero. From the data it can be concluded that the exchange of the left handed W boson dominates the cross section. The influence of the proton structure is obtained from earlier data and fixed target data and is described in the 'ZEUS-S fit' for 'standard'.



Schematic picture showing one VELO detector half with the detector modules, the secondary vacuum chamber and the support mechanics.

B-Physics program: status and physics goals

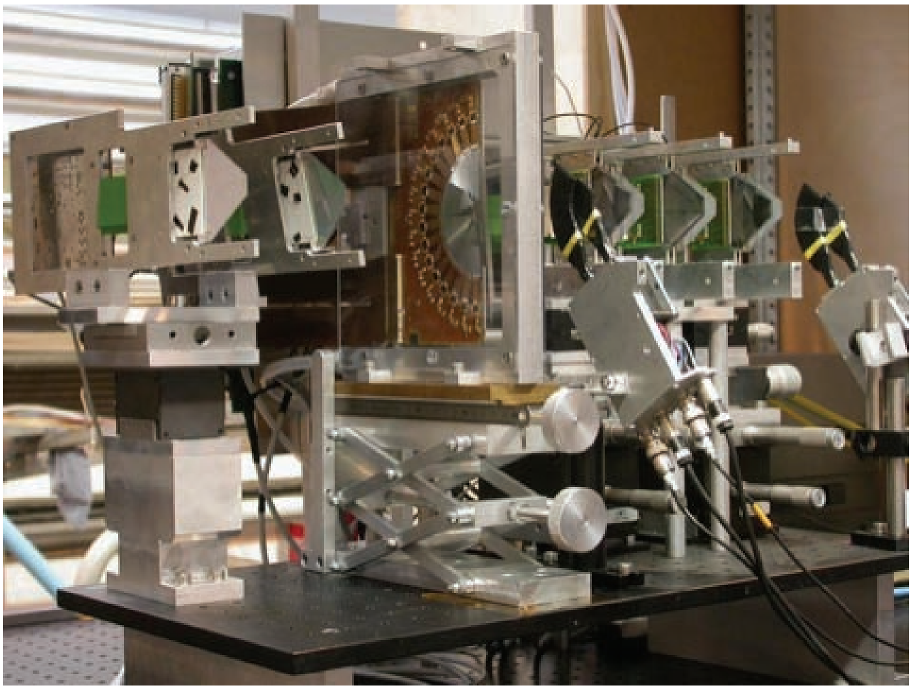
LHCb is a dedicated experiment at the Large Hadron Collider (LHC) to study CP violation and other rare phenomena in B-hadron decays. The B-meson sector is a place where theoretical predictions can be precisely compared with experimental results. CP violation is described in the Standard Model by a single complex phase in the CKM matrix, which relates the mass eigenstates to the electroweak eigenstates in the quark sector.

As preparation for LHCb running, NIKHEF participates in the BaBar experiment at the Stanford Linear Accelerator Center in Palo Alto, U.S.A. BaBar has a rich physics program, witnessed by the about 50 scientific publications in 2004, the most significant event being the discovery of *direct* CP violation in the B-sector.

The LHC will collide proton-proton bunches at 40 MHz with a center-of-mass energy of 14 TeV. The LHC design luminosity is 10^{34} $cm^{-2}s^{-1}$ which means more than 20 proton-proton interactions per crossing, since the inelastic proton-proton cross section is 80 mb. Beams will be defocused at the LHCb interaction point to achieve a luminosity of 2 x 10^{32} $cm^{-2}s^{-1}$. Even at this moderate luminosity, LHCb will produce about 10^5 $b\bar{b}$ events/s (compared to a few $b\bar{b}$ events/s at BaBar). The events will be dominated by single interactions, optimizing the physics output.

To overconstrain the relevant observables, LHCb will have to reconstruct many final states with different topologies: $B^0 \rightarrow \pi^+\pi^-$, $B^0 \rightarrow K^+\pi^-$, $B^0_s \rightarrow \pi^+K^-$, $B^0_s \rightarrow K^+K^-$, $B^0_s \rightarrow D_s^-\pi^+$, $B^0_s \rightarrow D_s^{\pm}K^{\mp}$, $B^0{}_s \rightarrow J/\psi\varphi$, $B^0_s \rightarrow \varphi\varphi$, $B^0 \rightarrow K^{*0}\gamma$, *etc.* Final states with hadrons require an efficient and robust trigger for non-leptonic decays, where often decays with 3 or 4 charged tracks need to be reconstructed and therefore a high track reconstruction efficiency is mandatory. Channels with B^0_s need an excellent proper time resolution to resolve the high frequency B^0_s - $\bar{B}^0_s$ oscillation. These last points constitute significant detector challenges and are the area of focus of the NIKHEF B-physics group.

The NIKHEF contribution to LHCb concentrates on tracking, both hardware and software. The vertex locator (VELO) has to provide precise measurements of track coordinates close to the interaction region. It is optimized to give the best impact parameter resolution with the smallest amount of material. The VELO consists of 21 silicon stations placed along the beam direction and its information is used in the level-1 trigger. This device contains 3 additional silicon disks that are used in the level-0 trigger to reject multiple proton-proton interactions. The sensors are placed at a radial distance of 8 mm from the beams and can be retracted during injection. To minimize the material between the interaction region and the detectors, the silicon sensors are inside a thin aluminium box with a pressure less than 10^{-4} mbar. The side of the box facing the beam also shields the sensors against RF pickup. Each of the 21 VELO stations consists of two sensors, 300 μm thin, one with r-strips, the other with ϕ strips. The strip



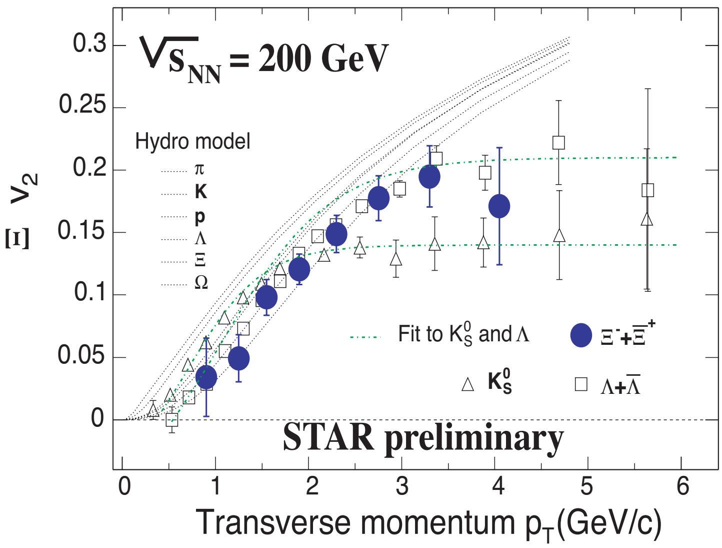
Picture of the VELO test beam set-up showing a complete detector module and various silicon detector sensor prototypes.

pitch varies from 35 to 102 μm. The expected impact resolution is 30 μm. The VELO data represent 180,000 read-out channels. The sensors are equipped with Beetle front-end chips, largely developed at NIKHEF.

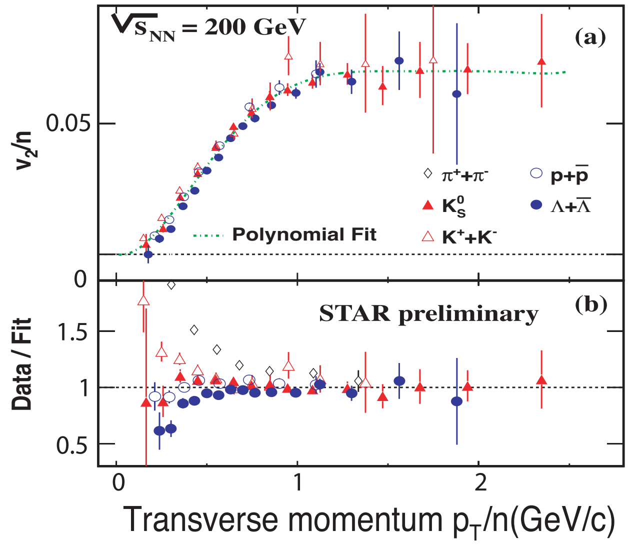
Besides the VELO, NIKHEF plays a leading role in the large tracking stations that are equipped with 5 mm diameter straw tubes, arranged in 4 double layers.

The performance of the tracking system with simulated events has been studied extensively at NIKHEF: on average 27 tracks, which traverse the full spectrometer, are reconstructed per event. The efficiency is 94% for tracks above 10 GeV and the momentum resolution is 0.4%. The resolution on the impact parameter of the tracks with respect to the primary vertex peaks at 20 μm and its average is 40 μm.

In summary, LHCb is a dedicated experiment at LHC to study B-physics with a dedicated trigger, and excellent vertex and momentum resolution and particle identification. The construction is progressing well and the detector will be ready for the first LHC collision in 2007.



Azimuthal dependence of the particle yield, characterized by the largest Fourier coefficient v_2, as a function of the transverse momentum p_T. At low p_T the various particle species follow the characteristic mass dependence as expected from a collectively expanding system (hydrodynamical model predictions). However, at transverse momenta above 2 GeV/c the flow seems to depend more on the type of particle (baryon or meson) than on its mass.



Baryon meson scaling is shown by dividing the Fourier coefficient v_2 and the transverse momenta by the number of quarks in the hadron (two for mesons and three for baryons). This leads to an universal curve above p_T/n = 0.6 GeV/c for the different particle species. This scaling law is accounted for naturally in models of hadron formation by constituent quark recombination or coalescence.

Heavy-Ion Physics

Introduction

The strong force is one of the four fundamental forces in Nature. The underlying theory of the strong force, QCD, is well established even though its fundamental degrees of freedom, the quarks and gluons, can not be observed as free particles due to confinement. The confinement of quarks and gluons inside a hadron is from first principles still poorly understood. At high temperatures and densities QCD predicts the existence of a deconfined form of matter, called a Quark Gluon Plasma (QGP), where the quarks and gluons are the relevant degrees of freedom. Heavy-ion collisions at the highest energies available provide a unique tool to create and study this new phase of QCD matter and thus may provide better understanding of the fundamental properties of the strong force.

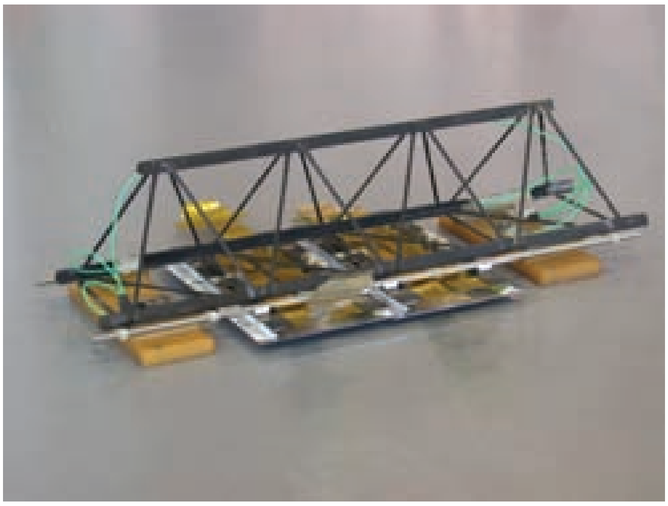
The study of high energy heavy-ion collisions is currently performed at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory and in the near future at the Large Hadron Collider (LHC) at CERN. At RHIC the Dutch heavy-ion group (NIKHEF/UU) collaborates within the STAR experiment and at the LHC within ALICE.

Star experiment

Recent findings at RHIC have established, in heavy-ion collisions, the creation of a strongly interacting dense system that cannot be described in terms of ordinary colour neutral matter. This is supported by the observation of strong collective expansion ("flow") of the system, evidence of approximate thermalization, and by the observed large energy loss of high momentum quarks and gluons, evidence for the enormous density produced in these gold-gold collisions.

In such a dense system, multiple interactions of quarks and gluons become important and may introduce particle production mechanisms that are absent in elementary collisions such as electron-positron or proton-proton. In the latter two, particle production is understood as a stepwise process. In the initial hard collision, the high momentum quarks or gluons are produced that turn into hadrons by "fragmentation".

The fragmentation process, which cannot be calculated from first principles, is described by a universal fragmentation function. It is established that in these elementary collisions baryon (three-quark states) production is suppressed compared to meson (two-quark states) production. However, in heavy-ion collisions at RHIC it is observed that at intermediate transverse momenta the baryon-meson ratio is above unity. Recently, detailed measurements of the identified particle yields at intermediate transverse momentum as function of azimuthal angle with respect to the reaction plane, have provided better understanding of this different particle production mechanism.



Test assembly of two silicon strip detectors on their carbon fiber support structure.

Analog signals from the Silicon Strip Detector are digitized with the help of custom designed front-end readout modules, FEROM.

Further study of the coalescence mechanism in heavy-ion collisions could explain the observed hadronic flow as being built up from the flow of the constituent quarks. Therefore, if this mechanism is confirmed, it would provide a strong argument in favour of the observation of deconfinement at RHIC.

Alice experiment

For the first time a small version of the Alice Inner Tracking System (ITS) was tested in a particle beam at the CERN SPS accelerator. Although it will still take a year before the full version of the ITS will be ready, the test already included the first production modules of components from sensors up to the DAQ system. The test showed that all sub-systems, silicon pixel, silicon drift and silicon strip detectors, can be operated together without mutual interference.

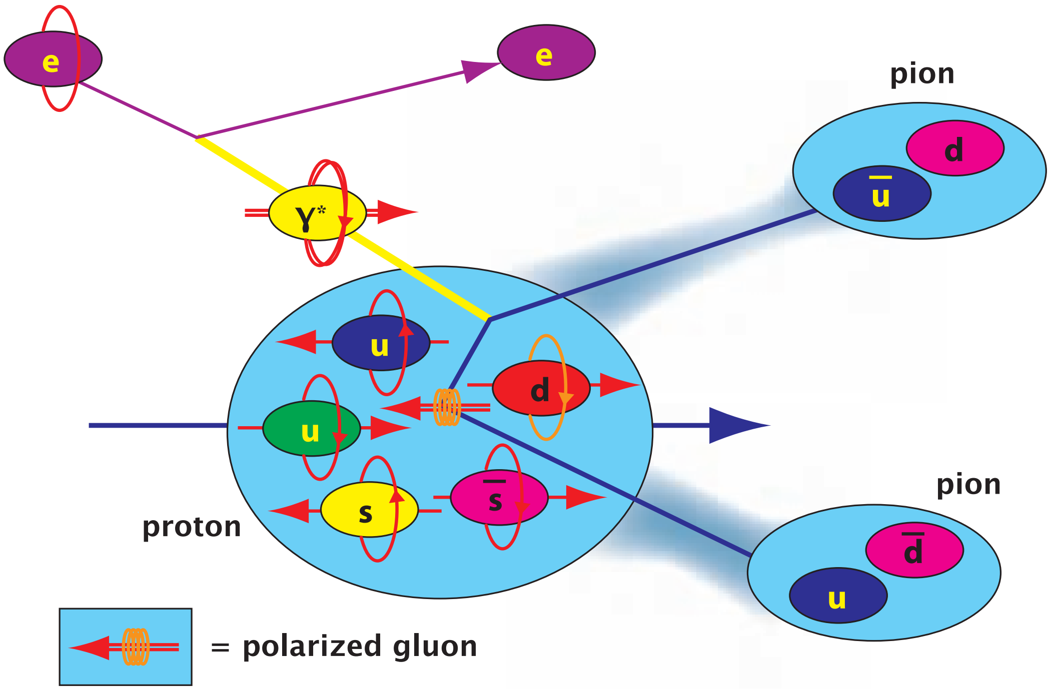
NIKHEF has been involved in all aspects of the design of the silicon strip detector (SSD) system from its beginning and has taken responsibility for the production of the electronics for the read-out chain and for the final assembly of the system. A small section of the complete assembly of modules on its support structure has successfully been tested. A total of 1600 detection modules will be assembled in the same manner. Each module is mounted on light weight carbon fiber support structures with an accuracy better than 0.01 mm. Special care was taken to make the structure as light as possible in order to influence the trajectory of the particles as little as possible.
The SSD read-out electronics consists of three devices:

The first device consists of amplifiers and analog storage in a custom made chip that was designed and produced by the French participants in the SSD project. These chips are mounted directly on the sensor and connected using light weight cables produced in Ukraine.

The EndCap device is mounted outside the active volume of the SSD. It controls the front-end and further amplifies the analog signal. NIKHEF has designed two custom chips (ASICS) in order to be able to service all 1600 front-end modules in the limited space available.

Finally the analog signals are converted to digital information and sent to the Alice data acquisition system by the front-end read-out module (FEROM), which was designed by the IGF at Utrecht University. This system includes 1600 fast analog to digital converters operating in parallel to process the data quickly enough.

The beam-test in 2004 has shown that the whole read-out chain works.



The photon-gluon fusion process in action. A photon (γ) interacts with a gluon, after which a process called fragmentation occurs symbolized by the blue mist. This results in two particles flying away from the original proton.*

HERMES: the proton spin puzzle

Since a few decennia it is known that nucleons are made up of quarks (1964) bound together by gluons (1973), each of which have an intrinsic angular momentum. A precise understanding of how these angular momenta combine to the angular momentum of the nucleon has yet to be achieved. Around 1980, it became clear that the sum of the angular momenta of the quarks accounted for about only 20% of that of the nucleon, leaving 80% to be contributed by the intrinsic spin of the gluons and the orbital angular momentum of the quarks and gluons. This problem is also known as the proton-spin puzzle.

The contribution from the gluon spin can a.o. be deduced from the study of the photon-gluon fusion process. Two signatures for this process exist: the production of charm quarks or two hadrons with a high transverse momentum. Both options are explored in the NIKHEF group. In each of the two cases the final state is not unique, and other processes have to be subtracted. This situation is the origin of a large theoretical systematic uncertainty on the result apart from the experimental systematic and statistical uncertainties.

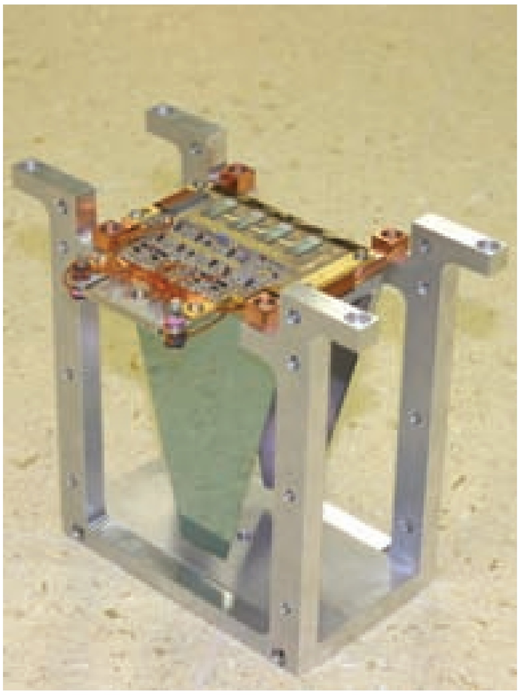
The study of charm production in photon-gluon fusion resulted in the discovery of a hitherto neglected background process with a large negative asymmetry. The background process contributes an unknown amount to the positive asymmetry due to the photon-gluon fusion process so that it is only concluded that the gluon polarization is positive.

An extensive Monte Carlo study was initiated in the NIKHEF group, with the aim to get a realistic estimate of this theoretical systematic uncertainty in the case of the high-transverse momentum pairs. With the new PYTHIA-6 code more processes could be handled with a better accuracy than could be done before. The result of this study is that a smaller fraction of the experimental asymmetry than previously thought, is due to the photon-gluon fusion process, but that on the other hand this number is now more reliable. A value for the gluon polarization measured with this process is expected soon.

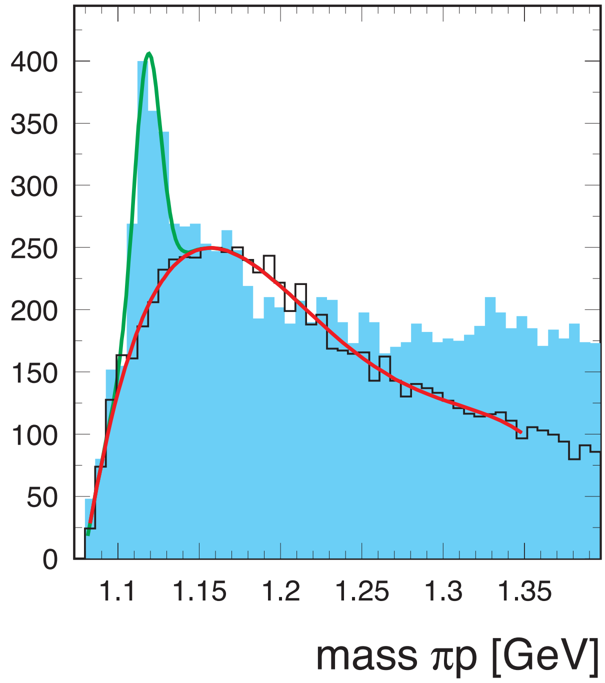
First data from the Lambda Wheels

In the previous years the NIKHEF group developed and installed a new silicon detector in the front region of the HERMES experiment. This detector is geared towards the detection of decay products from relatively long-lived particles, where the NIKHEF group has special interest in Λ particles. These particles are very similar to nucleons, where one of the quarks has been replaced by a strange quark, which enjoys only a passing existence in the nucleon.

Monte Carlo studies show that a large fraction of the Λ particles are produced by the decay of heavier products of the primary interaction. Λ particles, however, which are produced in the target fragmentation region, are predominantly produced in the interaction of the beam with the target nucleons which makes the interpretation



Lambda wheels are assembled from several wedge-shaped silicon sensors bonded to their front-end readout electronics.

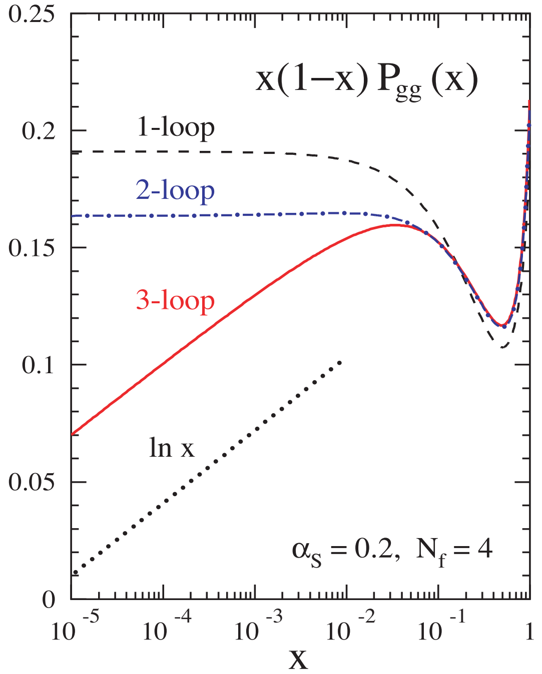


The invariant mass distribution of the (πp) system. The red curve is the result of a random combination of a pion and proton track while the blue histogram only contains data obtained with Lambda Wheels. The peak at 1.115 GeV represents the Λ-signal.

of the experimental results a great deal easier. Precisely those can be reconstructed from the data collected with the new silicon detector, which is therefore known as the Lambda Wheels. This is of interest as the Λ polarization in this domain gives information on the relative spin orientation of the sea and valence quarks in the proton.

The Λ particles are not observed directly, because they are neutral and leave no ionization. In addition, the majority has already decayed before they reach the detector. The Λ and its momentum have therefore to be reconstructed from the measured properties of its decay products: a proton and a pion. The proton is likely to be detected in the HERMES spectrometer while the pion from a Λ produced in the target fragmentation region is most probably seen only in the Lambda Wheels detector. The Λ particle is solely reconstructed reliably when both tracks are precisely measured in the same coordinate system.

This year the Lambda Wheels detector was successfully operated and aligned in the HERMES coordinate system. We also succeeded in developing a reconstruction algorithm such that the first sample of Λ particles could be selected.



Expansion of the gluon-gluon splitting function for four light quark flavors and a typical value of the strong coupling constant α_S.

From left to right: Tim Jones, co-author of the 2-loop β function, David Gross, co-author of the 1-loop β function, Oleg Tarasov, co-author of the 3-loop β function and Jos Vermaseren (NIKHEF), co-author of the 4-loop β function of QCD, calculated with Vermaseren's FORM program.

Theory: towards supersymmetry?

The main effort of the theory group continues to concern the elementary particles and their interactions. In connection with the ongoing experimental program at NIKHEF, research is being carried out to provide the theoretical framework for the analysis of the experiments and to develop models for a coherent and fundamental understanding. As has come into focus increasingly over the last years, research in physics on subatomic scales also intersects with the physics on very large scales, astrophysics and cosmology. This aspect is increasingly reflected in the activities of the theory group.

Physics of the Standard Model

In the collisions of hadrons with extremely high energies, such as at LHC, the structure of hadrons will be probed at a scale that is smaller then ever before. It is crucial for the interpretation of these experiments that the perturbative aspects of QCD are handled to a high accuracy. Calculations of the splitting functions and coefficient functions to three loops have been completed – a landmark achievement. These results make it possible to determine the parton distribution functions to an unprecedented accuracy and shed light on the convergence rate of the QCD expansion. Over the last years a state-of-the art computer program, FORM, has been developed at NIKHEF which generates and calculates the extremely large number of diagrams with a complicated singularity structure that arise in this connection.

Another QCD aspect that is of great relevance for QCD processes at high energy scales is the summation of soft gluon radiation processes. The mechanism is analogous to the radiative corrections in electromagnetic processes, where an arbitrary number of soft photons have to be taken into account to reduce the QED description to the classical results. However, the QCD situation is far more complicated since the gluons, due to confinement, couple increasingly strongly to their emitters as they become softer. Nevertheless, these contributions could be summed up for processes where heavy quarks are produced. This will significantly increase the accuracy of top quark production calculations and provide a firmer theoretical background for the search for the Higgs particle.

Research on non-perturbative QCD has continued by making use of lattice methods. It was investigated whether hadron properties change as the temperature of the surrounding matter approaches the transition to the quark-gluon plasma. No significant changes were found for the internal structure of the pion just below the critical temperature. These calculations are only possible with high performance parallel computing and the availability of the TERAS cluster at SARA in Amsterdam was crucial.

Quantum gravity, cosmology and astrophysics

A 'supersymmetry' between bosons and fermions can solve, amongst others, the unification of all gauge

The ‘TERAS’ super-computer cluster at SARA in Amsterdam, used for non-perturbative QCD calculations.

forces, the quantization of gravitation and the existence of dark matter in the universe. The construction of gauge-unification models was investigated that yield alternatives to the standard super-phenomenology and where supersymmetry is broken at low energies. A first step was made towards the construction of a super-symmetric form of relativistic hydrodynamics, an important element in cosmological models of the early universe. It was found in a simple model that non-linearities make it difficult to quantize such hydrodynamical theories.

Gravitation becomes important on the Planck scale and is thus relevant for understanding the early universe or for the description of black holes. String theory is a candidate for a theory of quantum gravity and it is one of the challenges to fit the particles of the Standard Model into such a theory as well. Based on large scale computer calculations, it was shown that there is a larger class of accessible string models. A supersymmetric Standard Model candidate in open string theory was found, along with a large group of models with similar features.

Grid Admin Nerd Group (GANG) event at NIKHEF. People from IBM, Logica CMG, and Philips Research work together with scientists from NIKHEF, the University of Amsterdam, and SARA, to construct a grid in a single day using 25 laptops.

GRID, world wide computing

Introduction

The *Physics Data Processing* (PDP) project is primarily concerned with the problems of computing for the LHC experiments. These experiments have chosen to use the techniques of *grid computing* to organize the immense quantities of storage and processing power needed to accomplish the LHC computing task. These techniques are applicable to a wide range of scientific disciplines — earth observation, computational chemistry, bioinformatics, and astroparticle physics are already using grid techniques — hence the PDP group works with collaborators in some of these disciplines as well.

The activities of the group are organized along three broad lines: *applications*, *infrastructure*, and *software*.

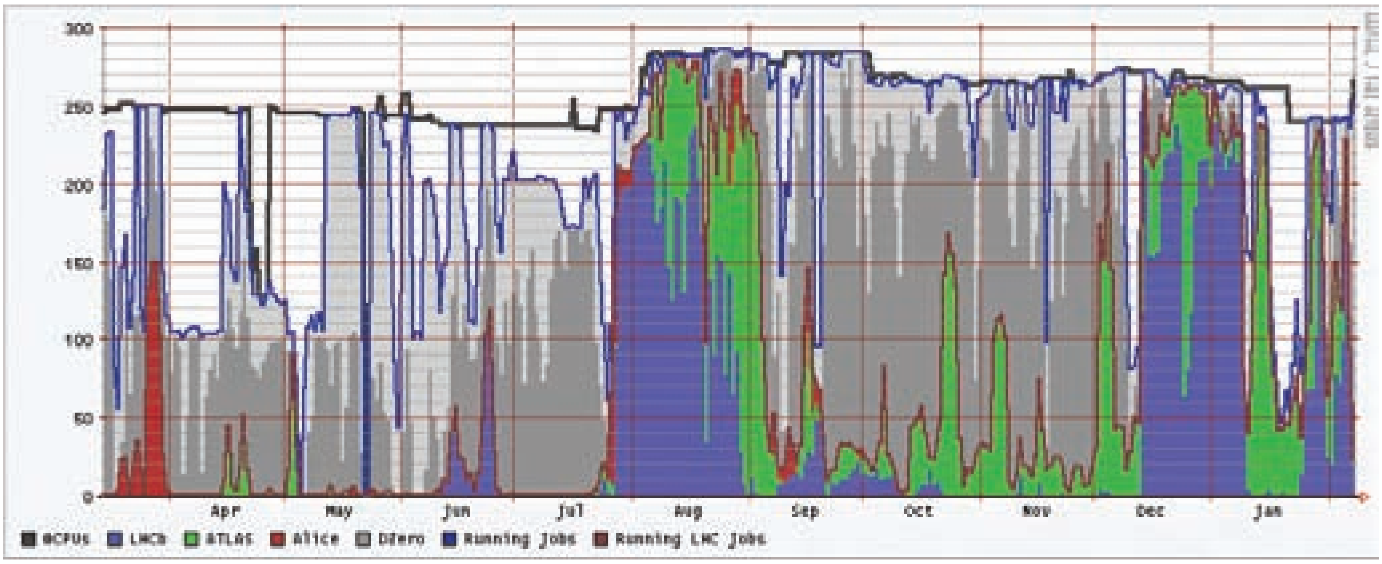
Applications

Computing on grid infrastructures requires a new approach to programming and usage patterns. Grids are fairly new and hence it is not immediately apparent how to organize various classes of computing work. Several members of the PDP group are addressing this by working together with NIKHEF physicists and scientists at other Dutch research institutes to bring their computing to the grid and gain experience on how to do it in the most effective fashion. Aside from the LHC experiments, these investigations involve the DØ and ANTARES experiments, earth observation (KNMI), and radio astronomy (LOFAR). Industrial interest is growing, and NIKHEF has hosted some special events for our industrial partners.

Infrastructure

The computing plans of the LHC experiments envision a hierarchical "tier" structure. Tier-0 is CERN, the data producer. Copies of the raw LHC data will be archived at about ten large "Tier-1" centres, which will also support large scale computing activities such as reprocessing of the raw data. NIKHEF (in cooperation with the Dutch National Supercomputing Center SARA, located about 50 m from NIKHEF) will be one of these Tier-1 centres. Discussions are under way with other communities (e.g. LOFAR & bioinformatics) on how the Tier-1 facility could be part of a general e-Science Resource Center for Dutch science located in the Science Park Amsterdam.

This Tier-1 activity involves the operation and maintenance of a farm of a few thousand commodity PCs and hundreds of terabytes of storage. Well-established cluster-computing techniques cannot be simply scaled up to this level; several members of the PDP group are working on new techniques that will address these "scaling violations". This group is in essentially daily contact with a similar group at SARA. 2004 is the first year that the LHC experiments have started to use the grid infrastructure on a massive scale, as can been seen from the statistics figure. The



LHC-grid statistics.

dark solid line represents the number of CPUs in our grid production facility. Any white area under the dark solid line represents idle capacity. The dark grey area is computing done for the DØ experiment, the primary-coloured areas are for the various LHC experiments, and the light grey is from all other computing load. From the amount of white area, one can see that since July 2004 the farm at NIKHEF has been essentially always full. A full cluster helps greatly in identifying and addressing scaling problems; during 2004 we have expanded our operational limits from about 50 machines to about 150 (the scaling problems are mostly related to number of machines and number of jobs, not to processing power). We plan to add new machines to expand this scale in the coming two years in a gradual ramp up to 2007, when the LHC turns on.

Software

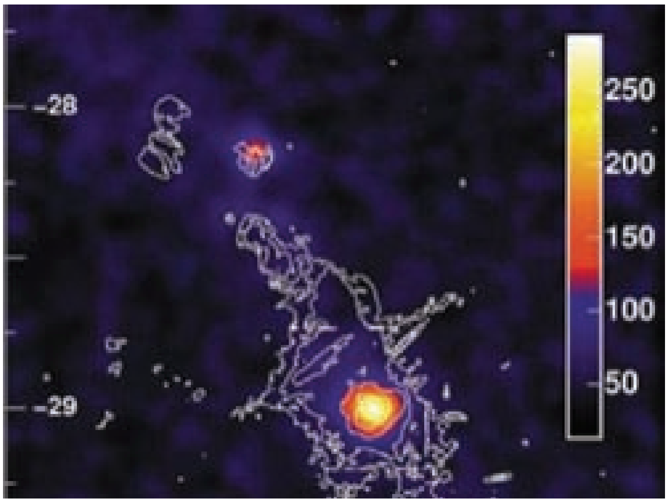
Our software projects are mainly concerned with forming user communities (like "the ATLAS LHC experiment") on grid infrastructures in a secure and efficient fashion. Security is important since the work will be done on resources owned by many different organizations; one must ensure that people using these machines are actually authorized to do so, that one of these organizations can verify that the work actually originated from a valid member of an accepted user community, and that all activity can be traced if needed. Efficiency is important since we want it to be just as easy to run computing tasks on the grid as it is on locally-owned machines. In 2004 NIKHEF contributed several security- and organization-related software packages (e.g. LCAS/LCMAPS) to the LHC computing grid project.

Further software in support of infrastructure operation has also been contributed, and widely adopted among the other Tier-1 centres.

Projects

The group's work is supported by the European sixth framework EGEE project, as well as the Dutch BSIK VL-e project. NIKHEF also provides the leadership for the subprograms "Scaling and Validation" and "Data Intensive Sciences" within VL-e.

Deployment of the ANTARES prototype line; two frames each with three photo sensors packaged in glass spheres are visible. Read-out electronics is contained in a titanium cylinder visible in the middle of the frame.



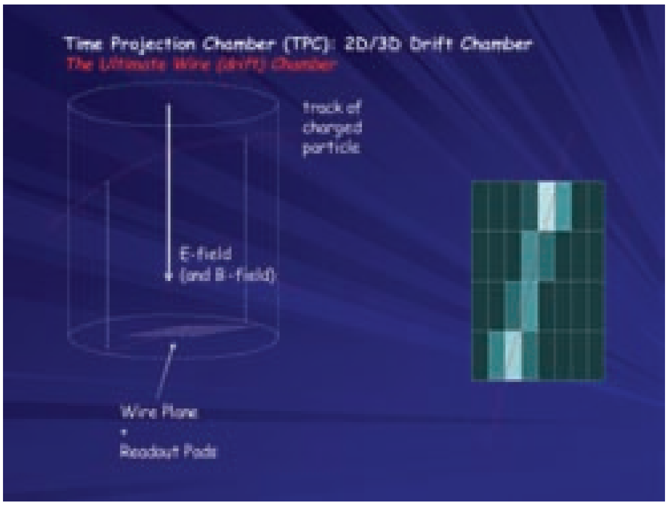
Gamma ray sources in the Galactic centre. Observed by the HESS telescope in Namibia. Will ANTARES observe neutrinos from there?

ANTARES: neutrinos and the sea

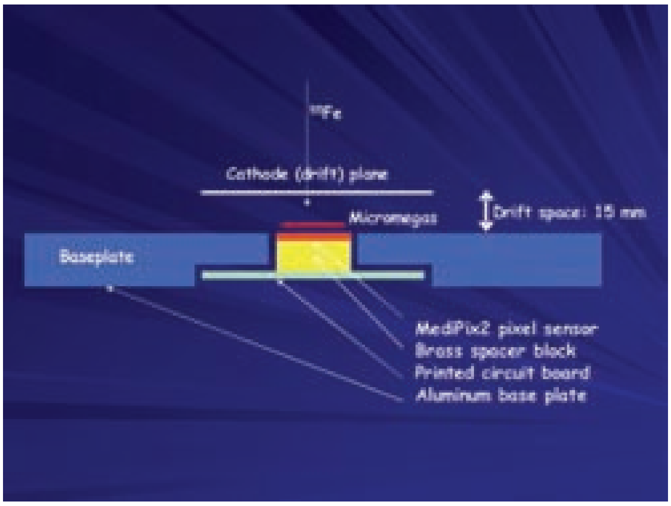
Recently, the possibility to detect very high energy particles from the universe opened up a new and challenging field — named Astroparticle Physics — with exciting potential for major discoveries. These "cosmic messengers" are gamma rays, charged particles, neutrinos or as yet unknown particles. Their energies extend above 10^{21} eV, many orders of magnitude higher than those produced by accelerators on earth. How and where these particles are accelerated to such energies is unknown, but the acceleration process may involve some of the most violent astrophysical sources in the Universe, such as Gamma Ray Bursts and/or massive black holes. Their origin could also be the decay of dark matter particles or exotic massive particles produced in the early universe. Their propagation through the universe is to be understood. Coherent detection of the different types of cosmic messengers will be vital for understanding why and where they reached such extremely high energies.

High energy cosmic messengers - and in particular cosmic neutrinos - are difficult to detect. This is the challenge of the ANTARES project. Since neutrinos hardly interact with matter, most of them will travel unnoticed through a detector. Hence, a large detection volume is required to enhance the chance to detect some. The ANTARES neutrino telescope will employ a large volume of deep-sea water of the Mediterranean Sea for this purpose. A small number of the many neutrinos traversing the earth will interact with matter in the sea bed or with the sea water itself and produce an electrically charged particle, a muon. This muon transmits on its way through the sea water blue (Čerenkov) light, that can be detected by highly sensitive light sensors. Since the muon continues in almost the same direction, the information of neutrino direction is preserved, thus revealing the direction in which the source of the neutrino should be searched for. On completion, the ANTARES neutrino telescope will exist of twelve vertical lines with in total 900 light sensors. The light sensors are packaged in water tight glass pressure spheres which are mounted in titanium frames attached to the lines. The 350 m long lines will be anchored on the sea bed at a depth of 2400 m at an in-between distance of 60 m. A buoy at the top of a line must keep the line in vertical position.

This year the prototype phase of the ANTARES telescope is almost finished. A final test is foreseen in the spring of 2005. Evaluation of a prototype line revealed that the employed electro-optical cable withstood insufficiently the high pressure of the sea water; one of the optical fibres appeared to be damaged. The cable manufacturer has designed a new cable, that will be tested in situ. The cable with 75 glass pressure vessels will be deployed at the ANTARES site. For this cable test, NIKHEF has designed and built an autonomous purpose-built read-out system. In the mean time the mass production of all parts of the telescope is in full swing. All parts are ready to be assembled in the first two lines of the ANTARES telescope.



The Time Projection Chamber (TPC). In the right-hand side of the picture, the typical charge distribution, measured on the readout pads, is indicated.



The layout of the test chamber. Particles passing the drift volume of 14x14x15 mm³ can be detected.

TimePix: Innovations in gas-filled detectors

The history of gas-filled wire chambers, commonly used in particle physics experiments, starts with the invention of the Geiger tube in 1908. Essential for these detectors is the strong electric field close to the wire surface. Free electrons, created along the path of a fast passing charged particle, drift towards the wire and cause an electron avalanche since the electrons gain sufficient energy, between collisions, to free another electron from a gas molecule. A single free electron can therefore cause an electron avalanche, resulting in a measurable charge pulse.

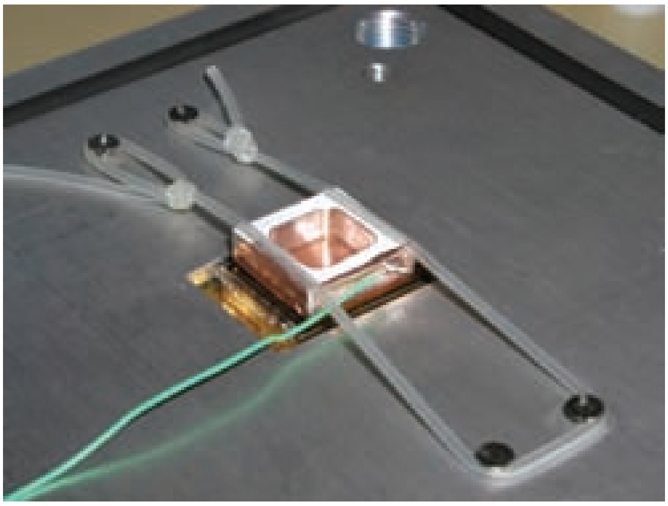
Technically it is rather hard to construct a plane of parallel wires with a pitch less then 1 mm. This is a severe limit to the *granularity* of a gaseous detector, and observing smaller details in the pattern of free electrons is problematic.

In 1995, Giomataris and Nobel laureate Charpak invented the Micromegas: it is a thin metal foil with a large number of small holes. At the bottom side of the foil, thin insulating (kapton) pillars are fixed with a length of about 50 μm. When placed on a flat conductive (anode) plane, the distance between the foil and the anode plane is defined precisely by these pillars. When some 400 V is applied between the foil and the anode plane, an electron avalanche occurs when a free, drifting electron enters a hole in the Micromegas. The combination of the Micromegas and the anode can thus replace a wire plane.

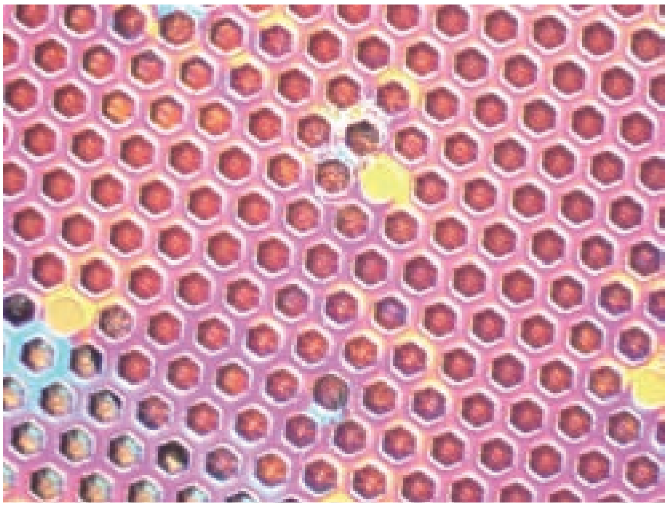
For experiments at the future International Linear Collider (ILC), the so-called Time Projection Chamber (TPC) is a good candidate for measuring the tracks of charged particles. It consists of a large gas-filled volume in which a homogeneous electric field is created by a field cage, with a wire plane at one side. Electrons, created along the track of a fast particle passing the gas volume, will drift along the electric field lines towards the wires. Typical charge signals appear on the read-out pads, from which the projected track can be calculated. By measuring the time between the crossing of the particle and the avalanches on the pixels, the third coordinate can be obtained. The result is a three-dimensional image of the track.

The very high track densities expected at the future colliders require new read-out techniques. In recent TPCs, the wire planes have been replaced by Micromegas foils. To fully employ the potential granularity, each hole should be associated with its own read-out chain consisting of the sensing pad and amplifier circuitry. This could be realised by using a pixel chip as anode, with its pixel pattern matching the hole pattern of the Micromegas.

For testing this new read-out we built a small TPC in which we applied the Medipix-2 pixel sensor. This chip, which has been developed for X-ray imaging, contains 256x256 pixels with a dimension of 55x55 μm^2. Each pixel contains an amplifier and discriminator, as well as a counter. By reading the counter content of all



The Micromegas is mounted in a small frame, and pressed onto the Medipix chip.



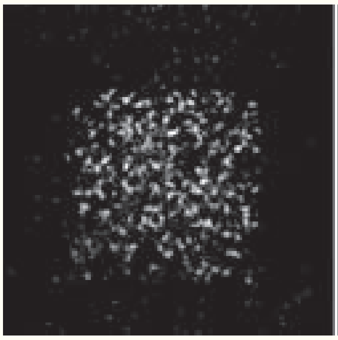
First prototypes of InGrid, in which a perforated membrane is suspended by insulating pillars.

pixels, an X-ray image can be recorded. Together with a bumb-bonded (pixel) sensor, the Medipix-2 chip forms a complete X-ray detector. In our application we used the ‘naked’ Medipix chip.

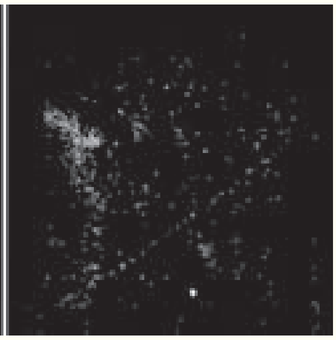
We irradiated the chamber to 5.9 keV X-ray quanta from an ^{55}Fe source. After absorption of a quantum, two clouds of primary electrons are produced, each containing some 110 electrons. With only a gas gain of 600, the clouds are clearly visible.

With an increased gas gain, tracks from muons created by cosmic rays were detected. The combination of a pixel sensor with a gas amplification gap forms a device that could provide track data with unprecedented precision. These results were presented at various conferences on instrumentation and vertex detectors.

Together with the MESA+ institute of the University of Twente, we are developing the technology to cover chip-containing wafers with a Micromegas. This would eventually result in monolithic devices forming an ‘Integrated Grid’ (InGrid) read-out system for gaseous detectors.



The image of some ^{55}Fe quanta. The double cloud structure, left by a photo-electron and an Auger-electron, is clearly visible.



Track image of a minimum-ionising muon, created in a cosmic ray event. The pattern of electron clusters along the track is clearly visible.

Assembly of the LHCb outer tracker in a NIKHEF cleanroom.

4. education

"Het Pand", a beautifully restored Dominican monastery of the 13th century presently serving as the conference center of the Rijksuniversiteit Gent.

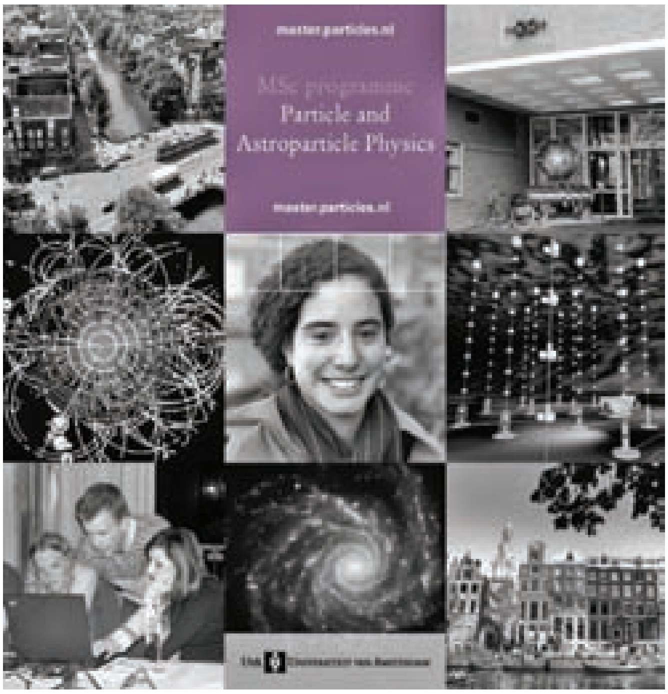
Research school subatomic physics

The research school for subatomic physics organizes each year academic training courses ("Topical Lectures") and, in collaboration with Belgium and German research groups, a summer school ("BND Summer school") for PhD students. Throughout the year, the members of the research school's board organize 1-2 interviews ("C3 gesprekken") with each PhD student and his/her promotor and thesis advisor to monitor the progress of his/her research project and his/her participation in the Topical Lectures and the BND summer school.

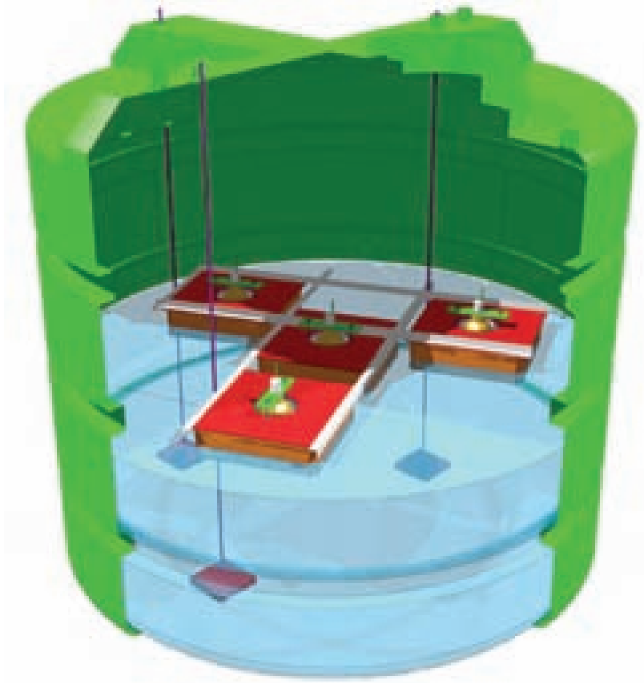
A novelty of the 2004 BND summer school (6-17 September) was its location: not somewhere quiet in the middle of nowhere but smack in the center of the lively town of Gent in Belgium. The 41 registered PhD students were housed in university dormitories and the lectures took place in "Het Pand", a beautifully restored Dominican monastery of the 13th century presently serving as the conference center of the Rijksuniversiteit Gent. The excursion was memorable as well: a tour of Gent's medieval center by kayak! Despite the questionable quality of the water in Gent's canals, nobody fell ill. PhD students and lecturers alike rated this BND summer school, scientific program, location, excursion and the local organizer (Prof. dr D. Ryckbosch), as excellent. Hence a tradition to follow for future BND summer schools!

As usual, also in 2004 three Topical Lectures were organized: one dealing with the physics of the quark-gluon plasma; one on CP violation and one aimed at hands-on experience in Feynman calculus by means of the computer algebra program FORM. The typical attendance of the Topical Lectures was 20-25 PhD students during the morning sessions (lectures) and 15-20 PhD students during the afternoon sessions (exercises).

Regarding administrative matters: 53 PhD students were enrolled in December 2004 and 15 PhD students graduated in 2004 of which one received the cum laude judicium. In December 2004 Prof. dr N. de Groot from the Radboud Universiteit Nijmegen was appointed as secretary. In view of this and in view of the required renewal of the recognition of the research school by the royal Dutch academy of sciences (KNAW), the board decided to also transfer the "penvoerderschap" to the Radboud Universiteit Nijmegen.



Advert poster for the master programme in particle physics and astroparticle physics by the University of Amsterdam.



Overview drawing of a water Čerenkov detector, built by three students as part of their master study.

Master of Science in Particle and Astroparticle Physics

In 2004 the first master student graduated in Particle and Astroparticle Physics at the University of Amsterdam. She is now a PhD student in the ATLAS group of NIKHEF.

Two years ago NIKHEF staff employed by the University of Amsterdam or the Free University in Amsterdam started a new master programme to educate students in experimental (astro)particle physics research. The objective of the programme is to teach students theoretical and experimental skills and to train them working in the large international research groups typical for the field of particle physics.

The curriculum includes courses in particle physics, astroparticle physics, particle detection, statistical data analysis and programming C++. Training in communication and education skills is an integral part of the programme. All mandatory courses and many optional courses are given by NIKHEF staff in the studio classroom of the institute.

In the NIKHEF project students are confronted with the many aspects of defining a research question and building an experiment that could give the answer to that. Together they design and build a particle detector, develop simulation programs, take data, develop a data analysis programme and write a scientific report about their results. Although supervised by NIKHEF staff, they are themselves responsible for the planning and management of the project and the definition and assignment of tasks. After having finished the project they make a user guide for high school students that can use the experiment at NIKHEF for their research project (in Dutch: profielwerkstuk). Each year another project is defined: a water Čerenkov detector to show the presence of cosmic muons, a detector to measure the velocity of cosmic muons and this year a gas Čerenkov detector to measure the energy of cosmic muons.

In the summer following their first year, students take part in the CERN summer student programme. During two or three months in the summer they work in one of the experimental teams at CERN at their own project and follow a series of lectures of scientists from around the world. Finally, in their second year students do a MSc research project in one of the groups at NIKHEF.

The master programme should become the incubator for talented future (astro)particle physicists, while the experience with working in an international environment should give them enough skills for a career elsewhere in society. The intention is to make it a national master programme by including more universities. First contacts with the University of Utrecht about this were already positive.

Koen and Martien from Het Amstel Lyceum in Amsterdam have, as part of their 'profielwerkstuk', assisted in building the cosmophone for the open day at NIKHEF. During that day they explained lively to the many visitors how cosmic rays can be measured.

Interaction with High Schools

'Zur Geschwindigkeit bewegter Myonen', this is the title of one of the 'profielwerkstukken' – research projects by high school students – done at NIKHEF in 2004 by a student of Barlaeus Gymnasium in Amsterdam: a wink to the famous paper of Einstein *'Zur Elektrodynamik bewegter Körper'.*

In their final year, Dutch high school students do a research project, in Dutch called a *profielwerkstuk*. They are free to choose their research subject provided that it fits in their exam 'profile' – the curriculum of their school exam. Regularly, NIKHEF is approached by high school students with physics in their curriculum with the request to allow them to do their research project at NIKHEF. These requests range from "Can we measure neutrino oscillations at NIKHEF" to "Can we measure the speed of light at NIKHEF". The first request came from a group of four high school students from the Candea College in Duiven (NL) that had read about the ANTARES neutrino telescope project at the website of natuurkunde.nl. When they realised that at that moment the only operational neutrino detector was in Japan, they made an effort and found sponsors (amongst them FOM, Stichting Physica and Stichting Weten) for a visit to SuperKamiokande. To prepare for their visit they were introduced in neutrino physics by members of the ANTARES group at NIKHEF. The results of their quest for neutrino's is described in a nice report with the title *'Drie keer niks, een onderzoek naar het ongrijpbare neutrino'.*

The challenging requests by the high school students indicate that they find modern fundamental physics quite appealing but that they have little or no idea about how difficult it is e.g. to measure a seemingly easy to measure quantity like the velocity of a particle. At NIKHEF we offer high school students the possibility of fundamental research with equipment made available for this purpose.

In 2004, seven groups of one to three high school students visited NIKHEF to do the research for their profielwerkstuk. Occasionally they were assigned to specific projects, but most of them decided to verify the theory of Special Relativity by measuring the velocity of cosmic muons. For that purpose they made use of an experimental setup of scintillator plates and photo multipliers. After a short introduction into particle physics and special relativity, at the first day of their visit, students familiarise themselves with the experimental setup and the electronics involved. They calibrate the detector and collect data for their analysis. At home they work out the formulae involved to extract the velocity of the cosmic muons from the recorded signals. At the second day of their visit they analyse their data using a special computer program and their formulae. The result is that they measure that cosmic muons have a velocity of about 96% of the velocity of light in vacuum and realize that the formulas from classical mechanics don't work for these particles. To see Special Relativity at work is very much appreciated by the high school students.

Marleen Rijksen zittend op een van der Graaff generator.

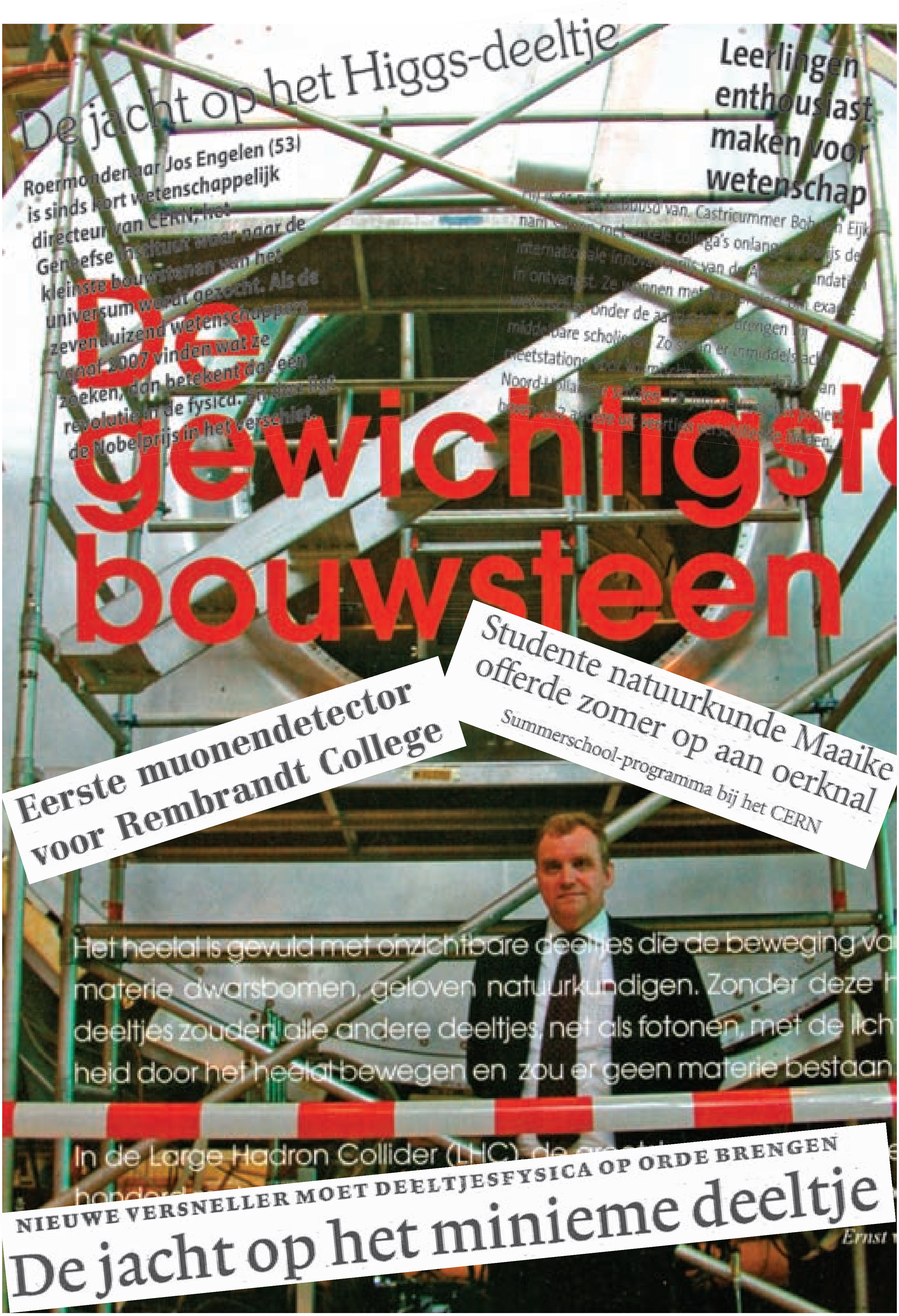
5. outreach

Gedurende het jaar 2004 heeft een drietal gebeurtenissen binnen het NIKHEF extra aandacht van de pers getrokken.

Allereerst werd prof. dr J.J. Engelen, directeur NIKHEF in 2002 en 2003, per 1 januari 2004 benoemd als wetenschappelijk directeur van CERN hetgeen aanleiding heeft gegeven tot meerdere interviews aan diverse Nederlandse dagbladen.

In de zomer werd het HiSPARC project beloond met de internationale Altran Foundation Award; mede dankzij de zeer enthousiaste deelname van vele scholen verspreid over heel Nederland is er een levendige belangstelling bij de pers.

Tot slot heeft het vijftigjarig bestaan van CERN in het najaar de nodige aandacht getrokken waardoor het totaal aantal publicaties in de pers circa 75 is geworden.


De jacht op het Higgs-deeltje
Leerlingen enthousiast maken voor wetenschap
De
gewichtigst
bouwsteen
Eerste muonendetector voor Rembrandt College
Studente natuurkunde Maaike offerde zomer op aan oerknal
Summerschool-programma bij het CERN
NIEUWE VERSNELLER MOET DEELTJESFYSICA OP ORDE BRENGEN
De jacht op het minieme deeltje

HiSPARC, scholier én wetenschapper

In het High School Project on Astrophysiscs Research with Cosmics (HiSPARC) werken scholieren en leraren van middelbare scholen samen met wetenschappers om de oorsprong te zoeken van hoogenergetische kosmische straling. Het project heeft een druk en succesvol jaar achter de rug. Het netwerk van deeltjesdetectoren is in 2004 fors uitgebreid zodat er nu in heel Nederland zo'n 30 detectorstations staan op de daken van scholen en universiteiten, alle gebouwd door middelbare scholieren. Een aantal scholen staat op de wachtlijst om een detector te gaan bouwen. Om het uitgebreide netwerk te coördineren is in februari 2004 een nationale projectcoördinator aangesteld, gefinancierd door het FOM en gehuisvest op het NIKHEF. Dit jaar zijn ook de eerste wetenschappelijke resultaten geboekt. In Nijmegen zijn enkele drievoudige coïncidenties waargenomen en geanalyseerd.
Deze analyse is beschreven in een artikel in het decembernummer van het Nederlands Tijdschrift voor Natuurkunde. In hetzelfde artikel staat ook de analyse van de coïncidenties tussen twee detector stations in het Nijmeegse cluster, resulterend in een eerste HiSPARC meting van een interessant gedeelte van het kosmische deeltjesspectrum. Een belangrijk doel voor het komende jaar is dat leerlingen een rol gaan spelen in deze analyse.

In juni heeft HiSPARC de internationale Altran Foundation Award 2004 in ontvangst mogen nemen. Een internationale jury koos het Nederlandse project uit 163 Europese en Amerikaanse inzendingen en honoreerde HiSPARC onder andere vanwege *het actief betrekken van docenten en scholieren bij wetenschappelijk onderzoek.* De prijs bestaat uit een jaar ondersteuning van experts uit de Altran Groep. De mensen van Altran leveren o.a. een wezenlijke bijdrage bij de ontwikkeling van verbeterde en goedkopere elektronica en het opzetten van een database.
In het HiSPARC project werken onderzoekers nauw samen met de natuurkunde leraren van alle deelnemende scholen. Dit gebeurt op allerlei manieren. Sinds deze zomer zijn er op het NIKHEF twee leraren die één dag in de week op het NIKHEF aan het HiSPARC project werken. In Nijmegen gebeurt dit al langer. Daarbij geven mensen van het HiSPARC team regelmatig workshops en gastlessen, zoals bijvoorbeeld op de jaarlijkse landelijke bijeenkomst van natuurkundeleraren, de Woudschoten conferentie. Afgelopen zomer heeft ook de eerste landelijke HiSPARC leraren workshop plaatsgevonden op het NIKHEF. Deze werd bijgewoond door zo'n 40 leraren en was een groot succes.

Het succes van HiSPARC is niet onopgemerkt gebleven. Het winnen van de Altran Award heeft geresulteerd in een artikel in Nature. Maar ook de nationale pers liet zich niet onbetuigd. Naast vele artikelen in lokale bladen kon men dit jaar ook in de Volkskrant, NRC en het Parool lezen over HiSPARC. Ook in het maandblad Natuurwetenschap & Techniek stond een uitgebreid artikel. In totaal zijn er het afgelopen jaar meer dan 50 artikelen verschenen en bovendien was HiSPARC te zien op TVNH.

Nationale Wetenschapsdag, Open Dag NIKHEF

NIKHEF neemt al meer dan twintig jaar samen met de andere instituten op het Science Park Amsterdam deel aan de Nationale Wetenschapsdag. Deze ‘Open Dag’ heeft dit jaar plaatsgevonden op zaterdag 23 oktober en is door de afdeling Voorlichting samen met leden van de wetenschappelijke en technische groepen georganiseerd. De voorbereidingen zijn al in het voorjaar begonnen en dit jaar is er speciale aandacht besteed aan het 50-jarige bestaan van CERN.

Voor scholieren uit het voorgezet onderwijs is een quiz bedacht. Deze quiz bevatte multiple choice vragen over deeltjesfysica en CERN. De quiz stond op de NIKHEF website en met enig speurwerk waren alle antwoorden te vinden op de websites van NIKHEF en CERN. De eerste prijs was een verzorgde reis van twee dagen voor twee personen naar CERN in Genève. De winnaar van de quiz was de 17 jaar oude Johan Smits. Hij had maar één antwoord van de 21 vragen fout. Hij gokte erop, zoals hij zelf zei, dat de variaties in de energie van de LEP bundel veroorzaakt werd door het elektriciteitsnet en niet door de maanstand. Johan heeft zijn prijs ontvangen tijdens het speciale symposium dat in Amsterdam ter gelegenheid van de 50ste verjaardag van CERN is georganiseerd (zie elders in dit jaarverslag). Als reisgenoot heeft hij een vriendje uitgekozen (en niet zijn jongere zusje zoals zijn moeder graag had gewild).

Op het NIKHEF is voor de Open Dag een kleine tentoonstelling ingericht in het kader van 50 jaar CERN. Uit alle hoeken en gaten zijn detectoronderdelen, prototypen van detectoren, oude bellenvatfoto’s en oude apparatuur verzameld en tentoongesteld. Buiten waren bij de ingang van het NIKHEF al een grote RF-cavity van de LEP versneller en een twee meter hoog aluminium model van de ATLAS endcap toroide opgesteld. Van CERN zelf hebben we veel oude foto’s en posters via het web kunnen downloaden, die op de tentoonstelling zijn opgehangen. Aan de vele bezoekers hebben we als aandenken echte bellenvatfoto’s cadeau meegegeven. De centrale lezing van het Science Park Amsterdam ging over de 50 jarige geschiedenis van CERN en werd gegeven door professor Frank Linde, die aan het eind van dit jaar de nieuwe directeur van NIKHEF is geworden.

Meer dan 1500 mensen hebben NIKHEF gedurende de Open Dag bezocht. Zoals alle andere instituten op het Science Park Amsterdam werden we verondersteld om 12 uur open te gaan. Echter al om half elf arriveerden de eerste bezoekers. Hoewel nog niet alles was ingericht was de koffie wel klaar.

Ruim 80 medewerkers waren aanwezig om het bezoek te informeren over ons werk in Amsterdam en in het buitenland. We hadden ook nog een extra programma georganiseerd voor een reisgezelschap van twintig personen, omdat zij enige weken later een bezoek zouden brengen aan CERN. Naast de 50 jaar CERN tentoonstelling in het Spectrum waren in de centrale hal en de grote montage hal van de mechanische afdeling stands ingericht met detectoronderdelen en posters

van de verschillende onderzoeksprojecten van NIKHEF. Tevens werden op verschillende plaatsen demonstraties gegeven en films vertoond.

Ook dit jaar hadden we, naast de extra exposure voor het 50-jarige bestaan van CERN, weer een speciale aandachtstrekker. In het midden van de centrale hal was een kamer gebouwd met lengten van drie meter in de vorm van een kubus. Dit was de kosmofoon, een door een computer gestuurd kosmisch muziek instrument. Op het dak en onder de vloer van de kosmofoon zaten plastic scintillatoren, die de muonen uit de kosmische straling detecteerden. Afhankelijk van de energie van de muonen produceert de computer een toon. Veel beat, weinig klassiek maar wel een publiekstrekker.

Voor families met kinderen richten we elk jaar een “Pretlab’ in. In het Pretlab kunnen 6 tot 12 jarigen hun eigen elektronische speeltjes maken. Onder toezicht van medewerkers van de elektronica groep worden ‘disco broches’, ‘lichtorgels’ en het bijzonder populaire ‘slaapkamer alarm’ gemaakt. Dit laatste speeltje waarschuwt je als een van je ouders stiekem de slaapkamer in wilt sluipen. Het Pretlab is zo’n enorm succes dat NIKHEF nu al jaren ook zo’n Pretlab in het centrale restaurant voor alle andere kinderen op het Science Park organiseert.

Het aantal bezoekers op de Open Dag is de afgelopen jaren min of meer constant gebleven. Die paar duizend bezoekers bestaan uit families, studenten, scholieren en individuen uit alle lagen van de bevolking. Wij danken dit succes voornamelijk aan de inzet en het enthousiasme van onze NIKHEF-medewerkers. De opmerkingen van de bezoekers varieren van ‘heel tevreden’ tot ‘zeer enthousiast’. Deze reacties zijn voor ons weer een stimulans om met het organiseren van dit soort gebeurtenissen een klein beetje bij te dragen aan onze verantwoording naar het publiek.

Het vijftigjarig bestaan van CERN in Amsterdam

In oktober 2004 heeft CERN, het Europees centrum voor deeltjes onderzoek in Geneve, het vijftigjarig bestaan gevierd.

In 1954 was Nederland één van de twaalf Europese landen die CERN, Conseil Européenne pour la Recherche Nucléaire, hebben opgericht. Inmiddels is CERN uitgegroeid tot het grootste onderzoekcentrum op het gebied van deeltjesfysica in de wereld, waarvan twintig landen lid zijn en waarmee een dertigtal landen geassocieerd zijn.

Het NIKHEF, de thuisbasis van de Nederlandse deeltjesfysici, heeft bij deze gelegenheid een symposium georganiseerd op 5 november in de Aula van de Universiteit van Amsterdam. Circa 300 belangstellenden, waaronder medewerkers en oud-medewerkers van NIKHEF, bestuursleden van universiteiten, NWO en FOM, luisterden naar een viertal voordrachten, waarin verschillende facetten van de betekenis van CERN werden toegelicht. De sprekers werden ingeleid door de dagvoorzitter, prof. dr W. Hoogland, decaan van de beta fakulteiten van de Universiteit van Amsterdam.

Prof. dr J.J. Engelen, wetenschappelijk directeur van CERN en voormalig NIKHEF directeur, sprak over de ontstaansgeschiedenis van CERN ten tijde van de Koude Oorlog en de rol die CERN nu vervult als wereldlaboratorium.

De huidige directeur van NIKHEF, prof. dr F.L. Linde, liet enkele van de meest recente ontdekkingen bij CERN de revue passeren en lichtte een tipje van de sluier op over de spannende dingen die gaan komen in de zeer nabije toekomst, als de nieuwe versneller, de Large Hadron Collider (LHC), operationeel wordt.

Dr R. Cailliau, medewerker van CERN en 'co-developer' van het World Wide Web, memoreerde de heroische tijden toen de nieuwste supercomputers bij CERN in bedrijf werden gesteld, de overgang naar het PC tijdperk en de ontwikkeling van het World Wide Web door CERN rond 1992, alsmede de komst van de GRID technologie.

Tot slot sprak dr D. Hoekzema, natuurkundeleraar en projectleider 'Moderne Natuurkunde voor het VWO', over de belangstelling voor deeltjesfysica bij scholieren en in het bijzonder over de enthousiaste ervaringen die scholieren opdoen bij een excursie naar CERN. Onder het genot van een drankje werd de middag afgesloten met een zeer geanimeerde informele discussie.

Bij de officiële ceremonie op 19 oktober in Genève waren staatshoofden, ministers en officiële vertegenwoordigers uit vele landen aanwezig. Namens Nederland, als voorzitter van de Europese gemeenschap, sprak Mevrouw Van der Hoeven, Minister van Onderwijs, Cultuur en Wetenschap, de speech uit, waarvan hieronder een deel is weergegeven.

Het vijftigjarig bestaan van CERN in Genève

Ladies and gentlemen,
It is a great honour and pleasure for me to speak to you today. I do so on behalf of the president of the European Council, who is still recovering from severe illness.

[...]
More than anything else, CERN is an inspiring example of what European cooperation and joining forces can achieve. In the last fifty years, CERN has shown how Europe can set up large and complex research infrastructures that exceed the capacity of individual countries. CERN is also a model for centres of excellence.

So I see CERN as an excellent example of cooperation and joining forces. Which are precisely the themes which we want to put on the research, innovation and technology agenda. Both at national level, and in the European Union.

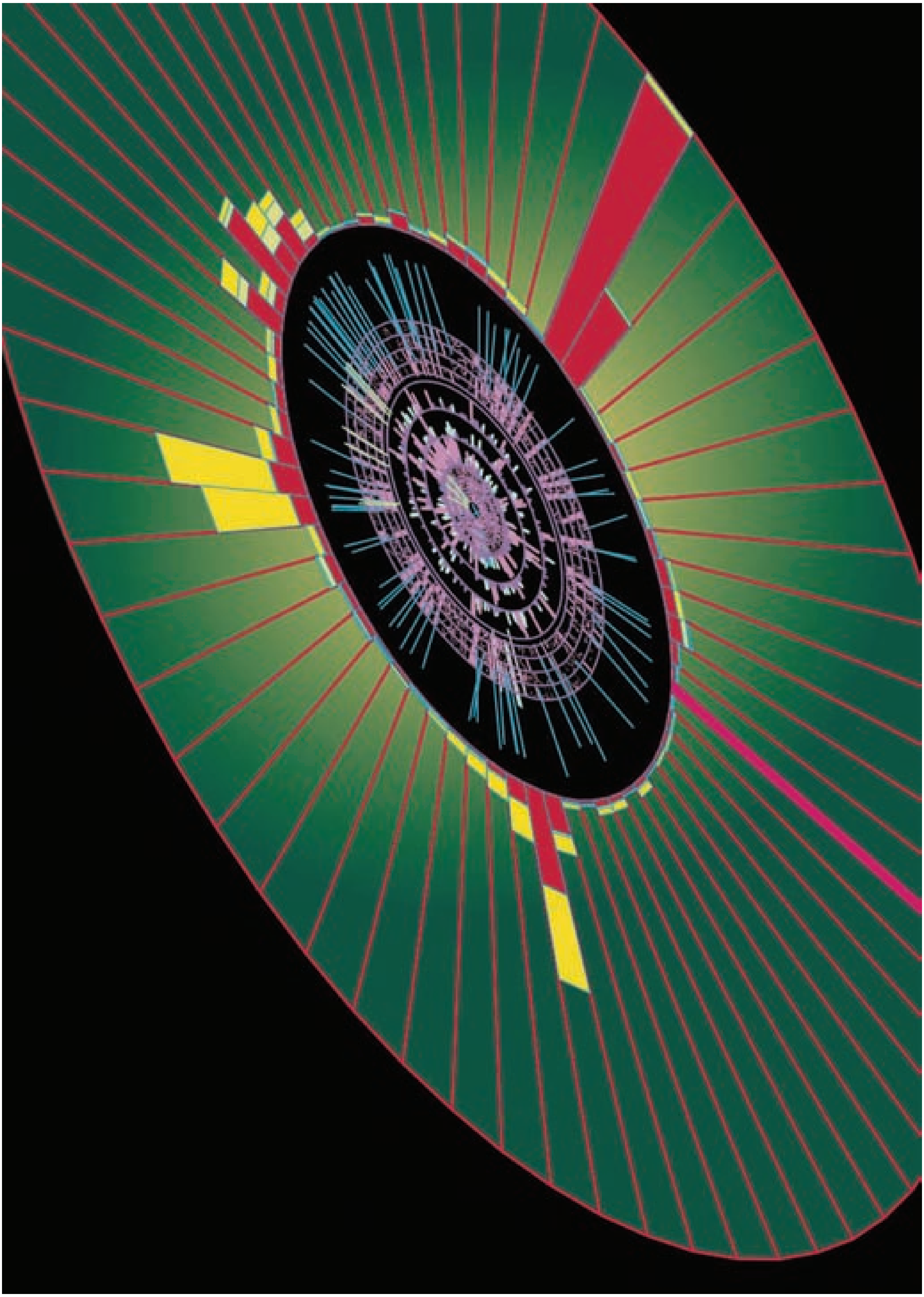
And we are making progress. On a national level I would like to point at the Dutch Innovation Platform. This platform has been set up to stimulate innovative cooperation between private companies, universities and research institutes, and to join forces in the area of innovation.

[...]
The Communication sets out the elements relevant to establishing a true European research area. And there are a lot of them. Among other things, European centres of excellence and European technological initiatives must be created. Europe must also be able to attract the best researchers. The European research area needs coordination of national programmes and should encourage mechanisms to promote excellence.

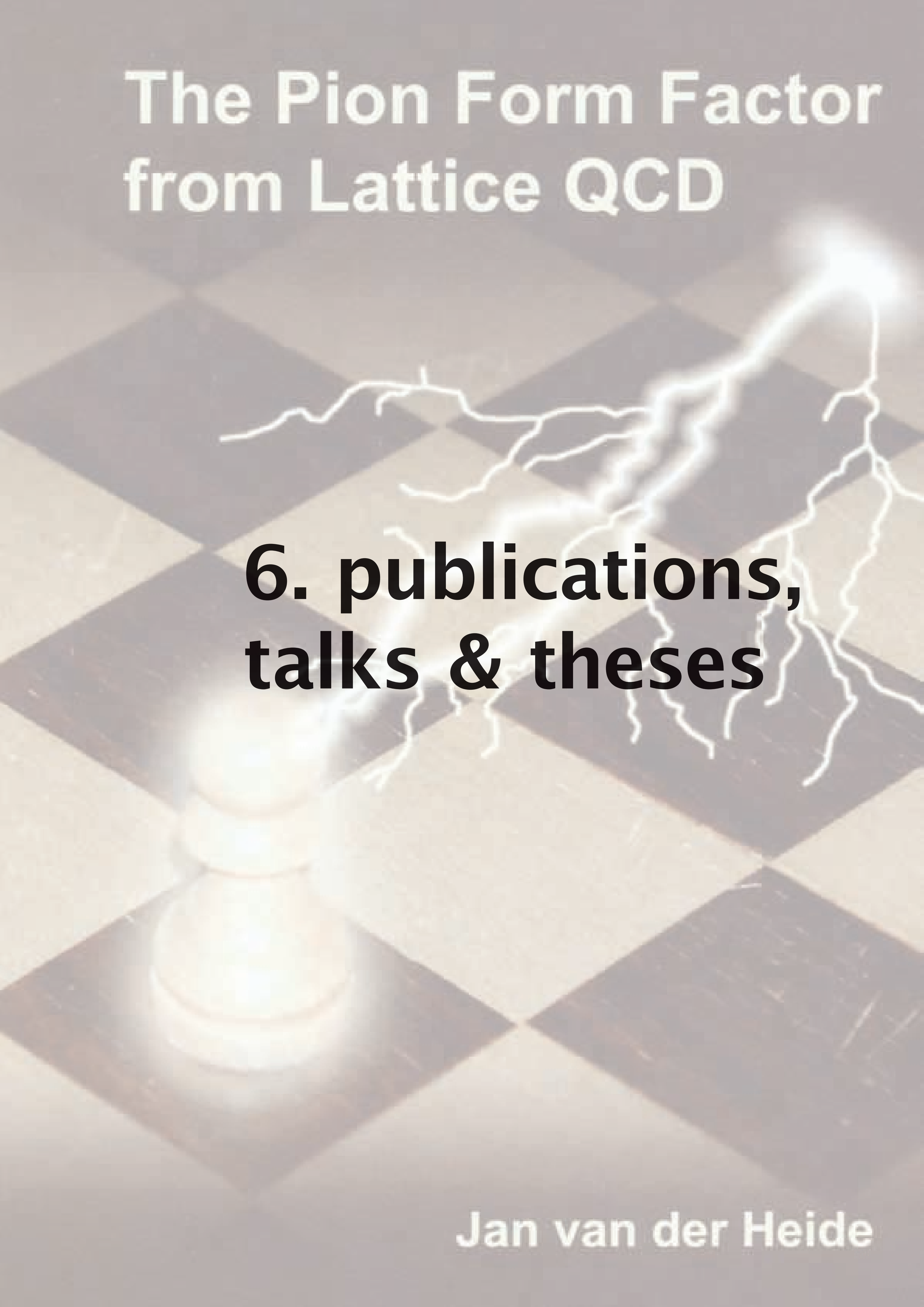
Last but certainly not least, Europe needs state-of-the-art infrastructures. CERN has been such an infrastructure for fifty years. And one can see what this has produced. Not only three Nobel Prize winners but also an invention we cannot even imagine doing without today – the world wide web. That has given us a taste for even more. That's why we see developing more infrastructures like CERN as a real challenge. Maybe not as big but just as effective. Which is also why during the Informal Competitiveness Council we discussed how to better coordinate our efforts in the context of the European Union. I am pleased that the European Strategy Forum for Research Infrastructures has now begun to develop a strategic roadmap for European infrastructures for the next ten years.

[...]
In the Netherlands –and now I am speaking as a Dutch minister– we are joining in the celebrations to the full. Because if one thing has become clear, it is that Dutch particle physics owes a great debt to CERN and has in its turn contributed a fair share to CERN. We are celebrating the anniversary in the Netherlands with a scientific symposium and with special activities for youngsters.

Because we need young people for tomorrow's breakthroughs in physics. I wish CERN and the physics community great success. Here's to another fifty years!



A pair of top quarks reconstructed in the DØ experiment at Fermilab. This end view shows the final decay products: an electron (red towers), a neutrino (pink), and four jets of particles.



6. publications, talks & theses

Publications

DØ

DØ Collaboration (P.W. Balm, F. Blekman, K. Bos, P. de Jong, O. Peters, L. Phaf, W. van Leeuwen, M. Vreeswijk, S.N. Ahmed, S.J. de Jong, S. Duensing, F. Filthaut, N.A. Naumann, D. Wijngaarden)

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Nature **429** (2004) 638-642

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L3 Collaboration (G. Bobbink, J.A. van Dalen, M. Dierckxsens, F. Filthaut, Y. Hu, P. de Jong, W. Kittel, A. Koenig, F. Linde, W. Metzger, A.J. Muijs, T. Novak, B. Petersen, D.J. Schotanus, C. Timmermans, R.T. van der Walle)

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NA49 Collaboration (M. Botje, M.A. van Leeuwen)

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D.A. Wijngaarden

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F. Filthaut

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S. de Jong

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G. van der Steenhoven

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G. Raven

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E. Maddox

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D. Groep

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E. Laenen

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CERN
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P. Kluit

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R&D

H. van der Graaf

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CMOS sensor as direct anode
Vienna Conference on Instrumentation, Vienna, 16-21 February 2004

The detection of single electrons using the MediPix2/ Micromegas assembly
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A. Fornaini

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L. Lapikás

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E. Jans

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Lectures

G. van der Steenhoven

The quark structure of the nucleon
FANTOM Study Week on QCD at low energies
Emmen (NL), 24-28 May 2004 (3 lectures)

G. Raven

CP Violation

MICAS graduate school, Universite Libre, Brussel, 20-22 April 2004

D. Groep

DataGrid practice and experience
Gastcollege SDE, UvA Grid Master opleiding, UvA, Amsterdam 27 Januari 2004

Introduction to Grid Computing
Guest lecture at LIACS, Leiden University, Leiden, NL
13 September 2004

T. Peitzmann

Ultrarelativistic Heavy-Ion Collisions, Lecture at the International Summer School on Subatomic Physics
Beijing University, 25-30 August 2004

Ultrarelativistic Heavy-Ion Collisions, Lecture at the Joint Belgian /Dutch/German Summer School on Particle Physics
Gent, Belgium, 6-7 September 2004

F. Linde

Calorimetry, Lecture at the Joint Belgian /Dutch/German Summer School on Particle Physics
Gent, Belgium, 6-7 September 2004

W. Verkerke

Data analysis
Lecture at the Joint Belgian /Dutch/German Summer School on Particle Physics
Gent, Belgium, 6-7 September 2004

Theses

Bakel, Niels Anton van

The silicon vertex detector for LHCb : interaction with the LHC beams and the design of a radiation hard front-end chip
Vrije Universteit Amsterdam 17 December 2004

Baldew, Vinod

Measurement of the W boson mass and width with the L3 detector
Universiteit van Amsterdam 24 September 2004

Balm, Paul Wijnand

Measurement of the B_d^0 lifetime using $B_d^0 \rightarrow J/\psi K_S^0$ decays at DØ
Universiteit van Amsterdam 8 December 2004

Dierckxsens, Mark

Measurement of the Triple Gauge-Boson Couplings in e^+e^- Collisions at LEP
Radboud Universiteit Nijmegen 13 January 2004

Duensing, Silke

Measurement of $\sigma(p\bar{p}\rightarrow Z0)$ x BF $(Z0\rightarrow\tau\bar{\tau})$ at the DØ detector at $\sqrt{s}$ = 1.96 TeV at the Tevatron
Radboud Universiteit Nijmegen 8 April 2004

Grijpink, Sjors Johannes Louis Assuerus

Charged current cross section measurement at HERA
Universiteit van Amsterdam 7 April 2004

Heide, Johannes van der

The Pion Form Factor from Lattice QCD : a non-perturbative study at zero and finite temperature
Universiteit van Amsterdam 2 December 2004

Heijboer, Adriaan Jacob

Track reconstruction and point source searches with ANTARES
Universiteit van Amsterdam 8 June 2004

Iersel, Miranda van

Aspects of Bound-State Calculations in Light-Front Dynamics
Vrije Universiteit Amsterdam 19 October 2004

Maddox, Erik

Study of heavy quark production at HERA using the ZEUS microvertex detector
Universiteit van Amsterdam 7 December 2004

Nyawelo, Tino Shawish

Non-linear field theory with supersymmetry: hydrodynamics and sigma models
Vrije Universiteit Amsterdam 27 April 2004

Phaf, Lukas Kaj

Top quark production at hadron colliders
Universiteit van Amsterdam 19 May 2004

Schagen, Sven

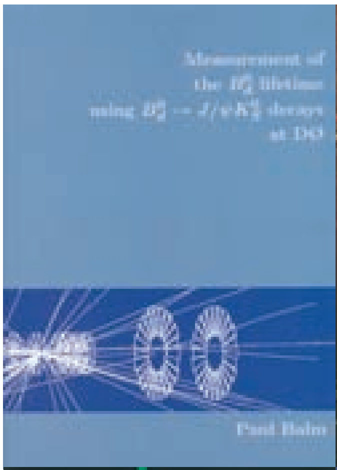
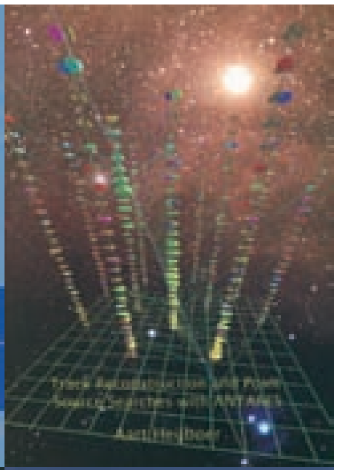
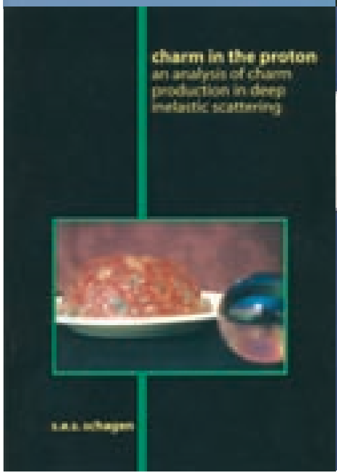
Charm in the Proton, an analysis of charm production in deep inelastic scattering.
Universiteit van Amsterdam 23 January 2004

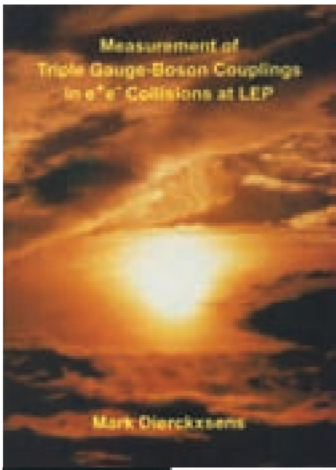
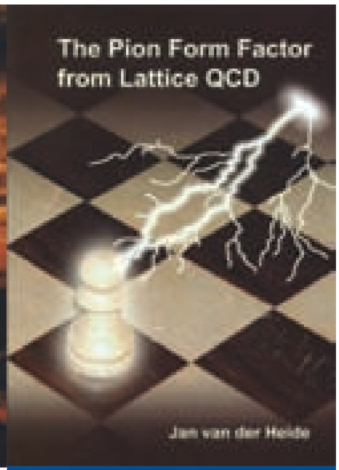
Steenbakkers, Martijn Franciscus Maria

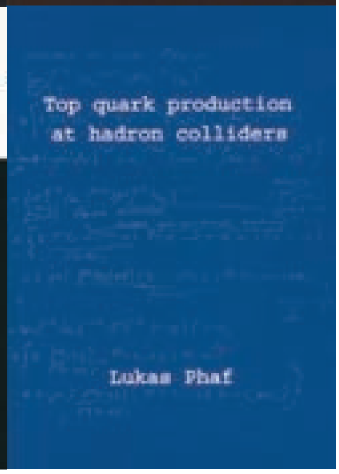
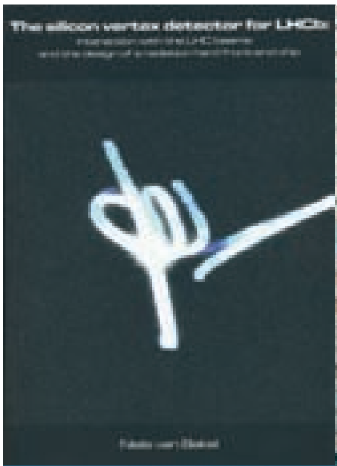
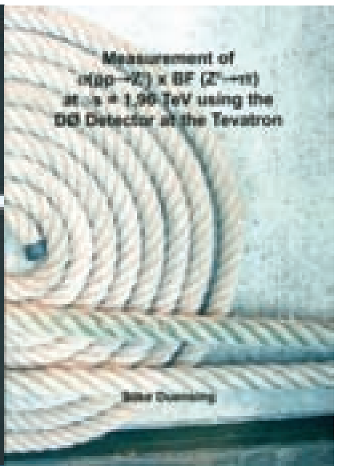
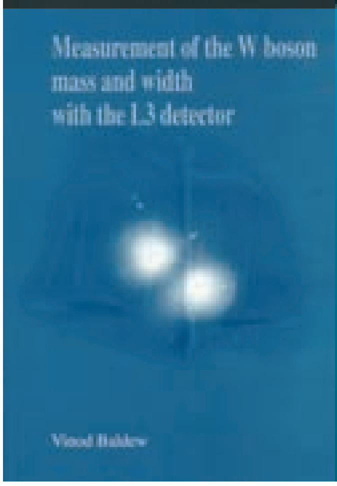
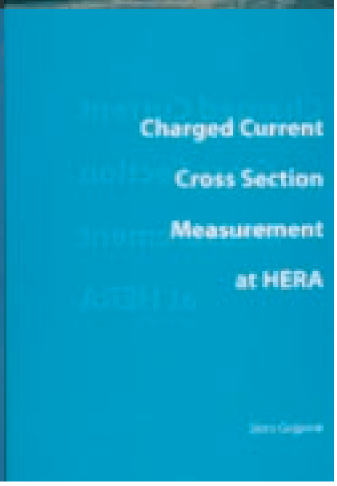
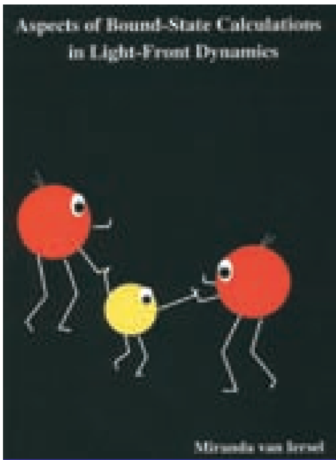
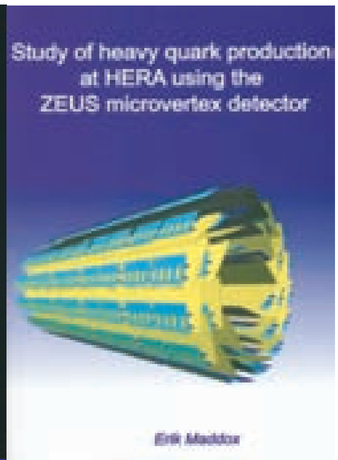
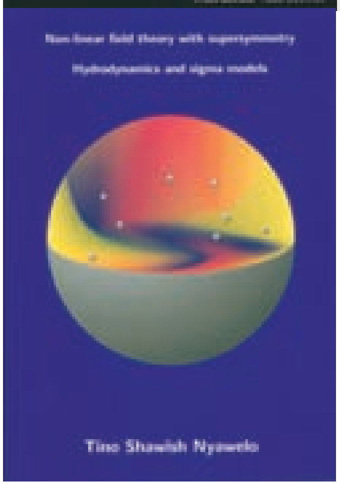
Quasi-free π^0 and π^- electroproduction on ^{4}He in the delta-resonance region
Vrije Universiteit Amsterdam 21 January 2004

Tvaskis, Vladas

Longitudinal-transverse separation of deep-inelastic scattering at low Q^2 on nucleons and nuclei
Vrije Universiteit Amsterdam 6 December 2004


Paul Balm


charm in the proton
an analysis of charm
production in deep
inelastic scattering


Measurement of
Triple Gauge-Boson Couplings
in e+e- Collisions at LEP
Mark Dierckxsens

The Pion Form Factor
from Lattice QCD
Jan van der Heide


Top quark production
at hadron colliders
Lukas Phaf

The silicon vertex detector for LHCb:

Measurement of
DØ Detector at the Tevatron

Measurement of the W boson
mass and width
with the L3 detector
Vinod Baldew

Charged Current
Cross Section
Measurement
at HERA

Aspects of Bound-State Calculations
in Light-Front Dynamics
Miranda van Iersel

Study of heavy quark production
at HERA using the
ZEUS microvertex detector
Erik Maddox

Tino Shawish Nyawelo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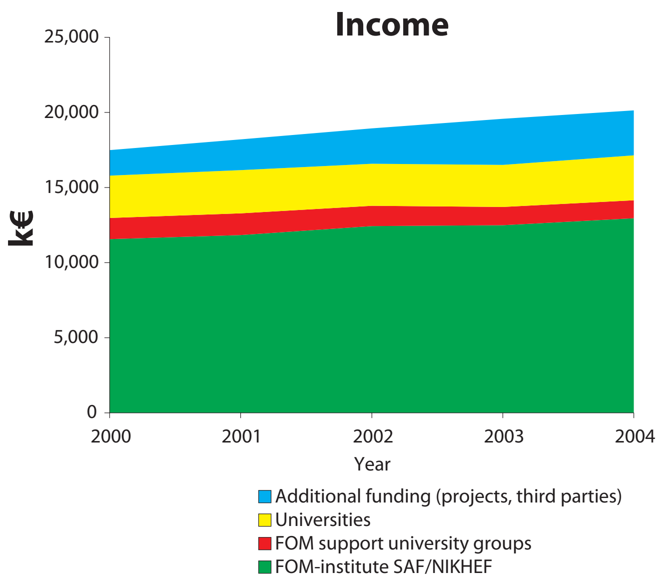
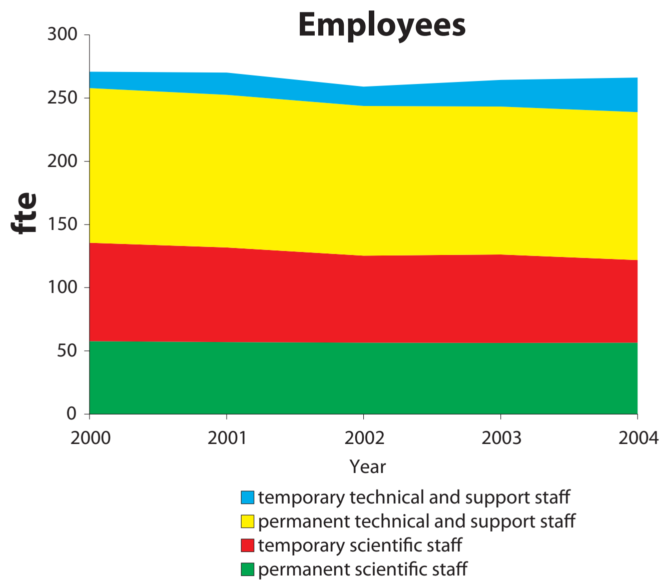
2004
FOMOLYMPICS
NIKHEF

7. resources & personnel

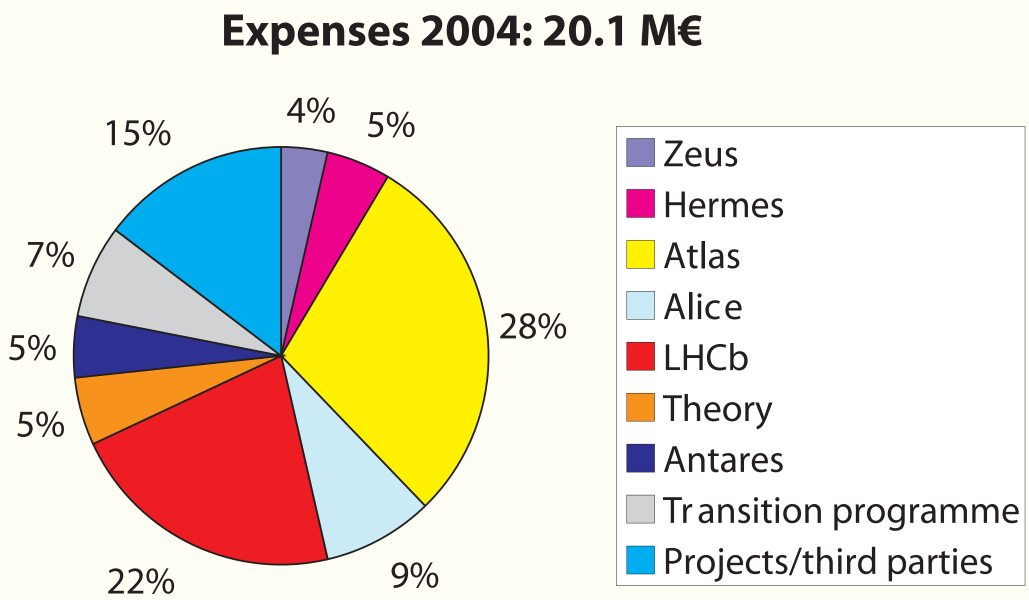
Internet connection equipment from one of the service providers located at NIKHEF.





In the past five years the total income of NIKHEF has increased slightly (17.5 million in 2000, 20.1 million in 2004), which is largely due to the increase in external (project) funding (1.3 million in 2000, 3 million in 2004).

The number of NIKHEF employees has been reasonably stable over the years with a slight increase in temporary technical personnel in recent years, due to the large technical commitments in the preparations of the LHC experiments. In 2004 the number of ftes was about 266.



The NIKHEF income for running costs in 2004 was 20.1 million Euro. 14.1 million from FOM, 3 million through the partner universities and 3 million from third parties and projects. Almost 60% was devoted to the LHC experiments: Atlas 28%, LHCb 22% and Alice 9%.

Personnel

1. Experimental Physicists

Anastasoaie Drs. Mw. M.	KUN	ATLAS
Apeldoorn, Dr. G.W. van	UVA	B-Phys
Baak, Drs. M.	VU	B-Phys
Bai, Drs. Mw. Y.	FOM	Alice
Barisonzi, Drs. M.	UT	ATLAS
Barneo González, Drs. P.J.	Guest	Other Projects
Bauer, Dr. T.S.	FOM-UU	B-Phys
Bentvelsen, Prof. Dr. S.C.M.	FOM-UVA	ATLAS
Berg, Drs. P.J. van den	FOM	ATLAS
Blekman, Drs. Mw. F.	FOM	ATLAS
Blok, Dr. H.P.	VU	HERMES.
Bobbink, Dr. G.J.	FOM	ATLAS
Bos, Drs. E.	FOM	B-Phys
Bos, Dr. K.	FOM	Other Projects
Botje, Dr. M.A.J.	FOM	ALICE
Bouwhuis, Drs. Mw. M.C.	FOM	ANTARES
Brand, Prof. Dr. J.F.J. van den	VU	B-Phys
Bruin, Drs. R.	UVA	ANTARES
Bruinsma, Ir. P.J.T.	Guest	ANTARES
Bulten, Dr. H.J.	VU	B-Phys
Caron, Dr. S.	FOM	ATLAS
Chefdeville, Drs. M.A.	FOM	ATLAS
Colijn, Dr. A.P.	UVA	ATLAS
Colnard, Drs. Mw. C.M.M.	FOM	ANTARES
Coppola, Dr. N.	FOM	ZEUS
Cornelissen, Drs. T.G.	FOM	ATLAS
Dantzig, Dr. R. van	Guest	Other Projects
Demey, Drs. M.	FOM	HERMES
Diddens, Prof. Dr. A.N.	Guest	Other Projects
Djordevic, Drs. M.	KUN	ATLAS
Dreschler, Drs. J.	FOM	HERMES
Duinker, Prof. Dr. P.	Guest	Other Projects
Eijk, Prof. Dr. Ing. B. van	FOM	ATLAS
Eijndhoven, Dr. N. van	UU	Other Projects
Eldik, Dipl. Phys. N. van	FOM	ATLAS
Engelbertink, Dr. G.A.P.	FOM	Other Projects
Engelen, Prof. Dr. J.J.	UVA	Other Projects
Erné, Prof. Dr. Ir. F.C.	Guest	Other Projects
Fabbri, Dr. R.	FOM	HERMES
Ferreira Montenegro, Drs. Mw. J.	Guest	Other Projects
Filthaut, Dr. F.	KUN	ATLAS
Galea, Drs. Mw. C.F.	FOM	ATLAS
Gorfine, Dr. G.	FOM	ATLAS
Graaf, Dr. Ir. H. van der	FOM	ATLAS
Grebenyuk, Drs. O.	FOM	ALICE
Grigorescu, Drs. G.T.	FOM	ZEUS
Groep, Dr. D.L.	FOM	Other Projects
Groot, Prof. Dr. N.	KUN	ATLAS
Hartjes, Dr. F.G.	FOM	ATLAS
Hegeman, Ir. J.G.	UT	ATLAS
Heijne, Dr. Ir. E.H.M.	Guest	Other Projects
Hesselink, Dr. W.H.A.	VU	HERMES
Hessey, Dr. N.P.	FOM	ATLAS
Hommels, Ir. L.B.A.	FOM	B-Phys
Houben, Drs. P.W.	FOM	ATLAS
Jans, Dr. E.	FOM	B-Phys
Jong, Dr. M. de	FOM	ANTARES
Jong, Dr. Ir. P.J.	FOM	ATLAS
Jong, Prof. Dr. S.J.	KUN	ATLAS
Kamermans, Prof. Dr. R.	FOM-UU	ALICE
Keramidas, Drs. A.A.	FOM	ZEUS
Ketel, Dr. T.J.	FOM-VU	B-Phys
Klok, Drs. P.F.	FOM-KUN	ATLAS
Kluit, Dr. Drs. P.M.	FOM	ATLAS
Koffeman, Dr. Ir. Mw. E.N.	FOM	ZEUS
König, Dr. A.C.	KUN	ATLAS
Konijn, Dr. J.	Guest	Other Projects
Kooijman, Prof. Dr. P.M.	UVA	ZEUS
Kuijer, Dr. P.G.	FOM	ALICE
Laan, Dr. J.B. van der	FOM	Other Projects
Lapikás, Dr. L.	FOM	HERMES
Laziev, Drs. A.E.	Guest	HERMES
Li, Drs. Z.	KUN	Other Projects
Linde, Prof. Dr. F.L.	FOM	DIR
Lingeman, Dr. E.W.A.	Guest	Other Projects
Massaro, Dr. G.G.G.	FOM	ATLAS
Merk, Prof. Dr. M.H.M.	FOM	B-Phys
Middelkoop, Prof. Dr. G. van	Guest	Other Projects
Mischke, Dr. A.	FOM-UU	ALICE
Muijs, Mw. Dr., A.J.M.	FOM	ATLAS
Nardulli, Drs. J.	FOM-VU	B-Phys
Nat, Drs. P.B.	FOM	HERMES
Naumann, Drs. A.	FOM	ATLAS
Nooren, Dr. Ir. G.J.L.	FOM-UU	ALICE
Novak, Drs. T.	KUN	ATLAS
Papadelis, Drs. E.A.	FOM	B-Phys
Peitzmann, Prof. Dr. T.	UU	ALICE
Pellegrino, Dr. A.	FOM	B-Phys
Pohl, Prof. Dr. M.	KUN	Other Projects
Raven, Dr. H.G.	VU	B-Phys
Reischl, Drs. A.J.	FOM	HERMES
Rens, Drs. B.A.P. van	FOM	ANTARES
Rodriques, Dr. E.M.	FOM	B-Phys
Sbrizzi, Drs. A.	FOM	B-Phys
Schotanus, Dr. D. J.	KUN	Other Projects
Schrader, Ir. J.H.R.	FOM	Other Projects
Simili, Drs. E.	FOM	ALICE
Snellings, Dr. R.J.M.	FOM	ALICE
Snoek, Drs. Mw. H.L.	FOM	B-Phys
Snuverink, Ir. J.	FOM	ATLAS
Sokolov, Drs. A.	UU	ALICE
Souvorov, Dr. V.	Guest	B-Phys
Steenhoven, Prof. Dr. G. van der	FOM	HERMES
Steijger, Dr. J.J.M.	FOM	HERMES
Templon, Dr. J.A.	FOM	B-Phys
Tiecke, Dr. H.G.J.M.	FOM	ZEUS
Tilburg, Drs. J.A.N.	FOM	B-Phys
Timmermans, Dr. C.W.J.P.	FOM	ATLAS
Timmermans, Dr. J.J.M.	FOM	Other Projects
Toet Dr. D.Z.	Guest	Other Projects
Tuning, Dr. N.	FOM-VU	B-Phys
Vankov, Drs. P.H.	FOM	B-Phys
Vázquez Acosta, Dr. Mw. M.L.	FOM	ZEUS
Verkerke, Dr. W.	FOM	ATLAS
Vermeulen, Dr. Ir. J.C.	UVA	ATLAS
Visschers, Dr. J.L.	FOM	Other Projects
Vreeswijk, Dr. M.	UVA	ATLAS
Vries, Drs. G. de	UU	ANTARES
Vries, Dr. H. de	FOM	B-Phys
Vulpen, Dr. I.B. van	FOM	ATLAS
Wahlberg, Drs. H.	UU	B-Phys
Wang, Drs. Q.	KUN	Other Projects
Wapstra, Prof. Dr. A.	Guest	Other Projects
Wiggers, Dr. L.W.	FOM	B-Phys
Wilden, Dr. L.H.	FOM	B-Phys
Wijngaarden, Drs. D.A.	Guest	ATLAS
Witt Huberts, Prof. Dr. P.K.A.	Guest	ANTARES
Wolf, Dr. Mw. E. de	UVA	ZEUS
Woudstra, Dr. Ir. M.J.	FOM	ATLAS
Ybeles Smit, Drs. G.V.	FOM	HERMES
Zupan, Drs. M.	FOM	B-Phys

2. Theoretical Physicists

Arrizabalage, Dr. A.	FOM
Dijkstra, Drs. T.P.T.	FOM
Fuster, Drs. Mw. A.	FOM
Gaemers, Prof. Dr. K.J.F.	UVA
Gato-Rivera, Dr. Mw. B.	Guest
Holten, Prof. Dr. J.W. van	FOM
Kleiss, Prof. Dr. R.H.P.	KUN
Koch, Prof. Dr. J.H.	FOM-UVA
Koers, Drs. H.B.J.	UVA
Laenen, Prof. Dr. E.	FOM
Motylinski, Drs. P.	FOM
Mulders, Prof. Dr. P.J.G.	VU
Pijlman, Drs. F.	VU
Postma, Dr. Mw. M.E.J.	FOM
Schellekens, Prof. Dr. A.N.J.J.	FOM
Veltman, Prof. Dr. M.J.G.	Guest
Vermaseren, Dr. J.A.M.	FOM

Vogt, Dr. A.	Guest
Warringa, Drs. H.	VU
Wit, Prof. Dr. B.Q.P.J. de	UU

3. Computer Technology Group

Akker, T.G.M. van den	FOM
Blokzijl, Dr. R.	FOM
Boterenbrood, Ir. H.	FOM
Damen, Ing. A.C.M.	FOM
Geerts, M.L.	FOM
Grijpink, Dr. S.J.L.A.	FOM
Harapan, Drs. D.	FOM
Hart, Ing. R.G.K.	FOM
Heubers, Ing. W.P.J.	FOM
Huyser, K.	FOM
Klous, Dr. S.	FOM
Koeroo, Ing. O.A.	FOM
Kuipers, Drs. P.	FOM
Leeuwen, Drs. W.M. van	FOM
Michielse, Dr. Ir. P.H.	Guest
Oudolf, J.D.	Other
Salomoni, Drs. D.	FOM
Schimmel, Ing. A.	FOM
Starink, Dr. R.	FOM
Tierie, Mw. J.J.E.	FOM
Venekamp, Drs. G.M.	FOM
Wijk, R.F. van	FOM

4. Electronics Technology Group

Berkien, A.W.M.	FOM
Beuzekom, Ing. M.G.van	FOM
Boer, J. de	FOM
Boerkamp, A.L.J.	FOM
Evers, G.J.	FOM
Fransen, J.P.A.M.	FOM
Gotink, G.W.	FOM
Groen, P.J.M. de	FOM
Groenstege, Ing. H.L.	FOM
Gromov, Drs. V.	FOM
Haas, Ing. A.P. de	FOM
Heine, Ing. E.	FOM
Heutenik, B.	FOM
Hogenbirk, Ing. J.J.	FOM
Jansen, L.W.A.	FOM
Jansweijer, Ing. P.P.M.	FOM
Kieft, Ing. G.N.M.	FOM
Kluit, Ing. R.	FOM
Koopstra, J.	UVA
Kroes, Ir. F.B.	FOM
Kruijer, A.H.	FOM
Kuijt, Ing. J.J.	FOM
Mos, Ing. S.	FOM
Peek, Ing. H.Z.	FOM
Reen, A.T.H. van	FOM
Reus, D.P.	FOM
Schipper, Ing. J.D.	FOM
Sluijk, Ing. T.G.B.W.	FOM
Stolte, J.	FOM
Timmer, P.F.	FOM
Tona, Y.	FOM
Verkooijen, Ing. J.C.	FOM
Vink, Ing. W.E.W.	FOM
Zwart, Ing. A.N.M.	FOM
Zwart, F. de	FOM

5. Mechanical Engineering Group

Arink, R.P.J.	FOM
Band, H.A.	FOM
Boer Rookhuizen, H.	FOM
Boucher, A.	FOM
Buskop, Ir. J.J.F.	FOM
Diepen, Ing. L.S. van	FOM
Doets, M.	FOM
Duisters, D.H.	FOM
Klöpping, Ir. R.	FOM
Korporaal, A.	FOM
Kraan, Ing. M.J.	FOM
Lassing, P.	NWO
Munneke, Ing. B.	FOM
Riet, Ing. M.	FOM
Schuijlenburg, Ing. H.W.A.	FOM
Snippe, Ir. Q.H.C.	FOM
Thobe, P.H.	FOM
Verlaat, Ing. B.A.	FOM

6. Mechanical Workshop

Arends, Mw. W.	FOM
Atehortua Escobar, Mw. B.E.	FOM
Berbee, Ing. E.M.	FOM
Beumer, H.	FOM
Boer, R.P. de	FOM
Bozkus, B.	FOM
Bron, M.	Other
Brouwer, G.R.	FOM
Buis, R.	FOM
Ceelie, L.	UVA
Cohen, Mw. S.	FOM
Filina, Mw. T.	Guest
Gesser, M.R.	FOM
Homma, J.	FOM
Jansen, F.M.	FOM
Jaspers, M.J.F.	UVA
John, D.	FOM
Keiser, P.C.H.	FOM
Kirillov, V.	Guest
Kok, J.W.	FOM
Kuilman, W.C.	FOM
Lavrentyev, V.	Guest
Leguyt, R.	FOM
Leter, C.E.D.	FOM
Martis, J.	FOM
Mul, F.A.	FOM-VU
Nieuwenhuizen - Oskam, Mw. W.	FOM
Overbeek, M.G. van	FOM
Peters - Müllenberg, Mw. A.G.H.	FOM
Petten, O.R. van	FOM
Rem, Drs. Ing. N.	FOM
Rietmeijer, A.A.	FOM
Roeland, E.	FOM
Rövekamp, J.C.D.F.	UVA
Veen, J. van	FOM
Willemse, M.A.	FOM

7. Management and Administration

Berg, A. van den	FOM
Bergen, Mw. A.M. van den	Guest
Boeding, A.P.M.	Guest
Bulten, F.	FOM
Colle, Dr. J.J.H.C.	Guest
Derlage, R.W.N.	Guest
Doest, Mw. C.J.	FOM
Dokter, J.H.G.	FOM
Echtelt, Ing. H.J.B. van	FOM
Egdom, T. van	FOM
Faassen, Mw. N.F.	FOM
Greven-v.Beusekom, Mw. E.C.L.	FOM
Heuvel, Mw. G.A. van den	FOM
Hidden, F.J.	Guest
Kerkhoff, Mw. E.H.M. van	FOM
Kesgin-Boonstra, Drs. Mw. M.J.	FOM
Kleinsmiede - van Dongen, Mw. T.W.J. zur	FOM
Langelaar, Dr. J.	Guest
Langenhorst, A.	FOM
Lemaire-Vonk, Mw. M.C.	FOM
Mors, A.G.S.	FOM
Mulders, Mw. S.A.M.P.	FOM
Noordkamp, B.S.	Guest
Pancar, M.	FOM
Rijksen, C.	FOM
Rijn, Drs. A.J. van	FOM
Schram - Post. Mw. E.C.	FOM
Spelt, Ing. J.B.	FOM
Tánczos, Dr. Mw. I.C.	FOM

Vervoort, Ing. M.B.H.J.	FOM
Visser, J.	FOM
Vries, W. de	FOM
Werneke, Ing. P.J.M.	FOM
Wild, P.M. van der	Guest
Willigen, E. van	FOM
Witlox, Ing. W.M.	FOM
Woortmann, E.P.	FOM

8. Apprentices in 2004

Aguilar Sanchez, J.A.	Antares
Ahmahdi A.,	Mechanical Workshop
Bansi S.,	Staff
Bekkum, E.M.W. van	Mechanical Engineering
Berg, B.C.J. van den	Other Projects
Berkman, S.	Technical Facilities
Berlijn, T.	Theory
Blok, J.L.	Atlas/DØ
Boellaard, C.J.A.	Other Projects
Bos, E.	Atlas/DØ
Bosdriesz, E.	Other Projects
Brak, M.	Theory
Brandt, O.	Other Projects
Breukink, R.W.	Atlas/DØ
Chourak, H.	Electronics Technology
Cottini, N.	Antares
Dernier, M.J.L.	Electronics Technology
Dijk, R.M.	Other Projects
Eijk, C.J.	Electronics Technology
Elbers, M.C.	Zeus
Ennes, P.	Atlas/DØ
Geerdink, J.	Atlas/DØ
Harracha, F. el	Technical Facilities
Haverhoek, J.D.	Other Projects
Henze, E.	Mechanical Workshop
Hoek, Mw. S. van	Other Projects
Hooft van Huysduynen, L.	Other Projects
Horssen, P. van	Other Projects
Horst, T. van der	Electronics Technology
Jansen, P.N.J.M.	Electronics Technology
Keiser, P.C.H.	Mechanical Workshop
Kerkoerle, T.J. van	Other Projects
Kerssens, R.	Electronics Technology
Kesteren, Z. van	Atlas/DØ
Klarenbeek, J.J.F.	Other Projects
Koekoek, G.	Theory
Koopmans, Mw. K.	Other Projects
Koutsman, A.J.	Atlas/DØ
Kouwenberg, S.	Mechanical Workshop
Lascaris, E.	Other Projects
Leeuwen, Mw. V.C.P. van	Atlas/DØ
Limper, Mw. M.	Atlas/DØ
Losekoot, G.	Other Projects
M'charek, Mw. B.	B-Physics
Meijer Timmerman Thijssen, R.	Other Projects
Molina - Clemente, N.	Theory
Mooij, S.J.N	Other Projects
Mulders, G.D.	Other Projects
Mussche, I.	Other Projects
Nooij, Mw. L. de	Other Projects
Otto, J.	Electronics Technology
Overes, Mw. F.	Other Projects
Papadelis, A.	B-Physics
Parker, A.	Atlas/DØ
Plas, B.A. van der	Zeus
Putten, S. van der	Other Projects
Reingoud, G.C.	Mechanical Workshop
Rijpstra, Mw. M	Theory
Rövekamp, R.M.	Computer Technology
Schie, H.G.M. van	Other Projects
Schotten, S.	Other Projects
Slooten, E.	Other Projects
Smits, P.	Other Projects
Stavenga, G.C.	Theory
Swenne, M.	Computer Technology
Takes, M.C.	Antares
Til, S. van	Other Projects
Tramper, F.	Other Projects
Visser, G.	Electronics Technology
Vries, M. de	Mechanical Engineering
Waaldewijn, W.J.	Theory
Winkel, C.D.	Computer Technology
Witteveen, Mw. M.L.M.	Other Projects
Woerdings, F.	Technical Facilities
Wong, C.C.K.	Electronics Technology
Zevenbergen, P.H.A.	Other Projects

9. They left us

Antony, A.T.	Computer Technology
Bagaturia, Dr. Iuri	B-Physics
Bakel, Dr.ing. N.A. van	B-Physics
Balm, Dr. P.W.	Atlas/DØ
Banfi, Dr. A.	Theory
Bansi, S.H.	Algemeen
Barneo González, Drs. P.J.	Other Projects
Boer, Ir. Y.R. de	Mechanical Workshop
Born, E.A. van den	Electronics Technology
Boudreault, Dr. G.	Other Projects
Buitenhuis, W.E.J.	Technical Facilities
Dabrowska, A.	B-Physics
Dalhuisen, J.M.	Electronics Technology
Dasgupta, Dr. M.	Atlas/DØ
Eijk, Dr. ir. R.M. van der	Computer Technology
Ferreira Montenegro, Mw. drs. J.	Other Projects
Geer, R. van der	Mechanical Workshop
Geerinck, Ir. J.	Staff
Gosselink, M.	Mechanical Workshop
Griffioen, Dr. K.A.	Hermes
Guz, Dr. Y.	B-Physics
Hagedorn, J.	Mechanical Workshop
Heide, Dr. ir. J. van der	Theory
Heijboer, Dr. A.J.	Antares
Henze, E.	Mechanical Workshop
Hollenberg, P.A.M.	Electronics Technology
Hunen, Dr. J.J. van	B-Physics
Jansen, P.N.J.M.	Electronics Technology
Klous, Drs. S.	B-Physics
Kramer, R.P.	Staff
Laziev, Drs. A.E.	Hermes
Lefevere, Y.	Mechanical Engineering
Liem, Ing. A.M.H.	Mechanical Engineering
Luigjes, J.A.	Atlas/DØ
Luijckx, Ir. G.	Atlas/DØ
Maas, Dr. R.	Other Projects
Maddox, Dr. E.	Zeus
Metzger, Dr. W.J.	Other Projects
Mexner, Mw. Dr. V.	Hermes
Nyawelo, Dr. T.S.	Theory
Otto, J.	Electronics Technology
Phaf, Dr. L.K.	Atlas/DØ
Putte, Dr. ir. M.J.J. van den	Other Projects
Rabenecker, S.	B-Physics
Reischl, Dipl. Phys. A.J.	Hermes
Rummel, Ch.	B-Physics
Schagen, Dr. S.E.S.	Zeus
Scholte, Dr. ir. R.C.	Mechanical Workshop
Shao, Prof. dr. B.	B-Physics
Silva - Marcos, Dr. J.I.	Theory
Steenbakkers, Dr. ir. M.F.M.	Computer Technology
Stoffelen, N.	Mechanical Workshop
Tvaskis, Dr. V.	Hermes
Vink, N.M.	Mechanical Workshop
Vogt, Dr. A.	Theory
Vonk, A.	Mechanical Workshop
Wang, S.	B-Physics
Winkel, C.D.	Computer Technology
Witt Huberts, Prof. Dr. P.K.A. de	Antares

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Woordenlijst

ALICE Experiment bij de LHC-versneller op het CERN. ALICE onderzoekt het quark-gluonplasma.

ANTARES Europees experiment op de bodem van de Middellandse Zee. ANTARES zoekt naar extreem energierijke neutrino's uit de kosmos.

ATLAS Experiment bij de LHC-versneller op het CERN. ATLAS zoekt naar het Higgsdeeltje.

antideeltje Bij ieder deeltje hoort een antideeltje dat dezelfde massa heeft, maar waarvan verder alle eigenschappen tegengesteld zijn. Als een deeltje en zijn antideeltje elkaar ontmoeten, vernietigen zij elkaar. Daarbij komt energie vrij waaruit weer nieuwe deeltjes kunnen ontstaan.

antimaterie Materie die bestaat uit antideeltjes.

anti-quark Het anti-deeltje van een quark. Wordt aangeduid met een streepje boven de quarknaam.

annihilatie Proces waarbij een deeltje en zijn anti-deeltje elkaar ontmoeten en vernietigen. Er komt energie vrij.

atoom Atomen zijn de bouwstenen van de chemische elementen. Elk element bestaat uit karakteristieke atomen, zuurstof bestaat uit zuurstofatomen, ijzer uit ijzeratomen enzovoorts.

atoomkern De atoomkern, binnenin het atoom, bestaat uit neutronen en positief geladen protonen. De eenvoudigste atoomkern is de waterstofkern die uit een enkel proton bestaat.

BABAR Experiment bij de B-fabriek op SLAC.

baryon Baryonen zijn opgebouwd uit drie quarks. Zij vormen een sub-groep van de zogenaamde hadronen; deeltjes die gevoelig zijn voor de sterke kracht. Een proton is een baryon net als een neutron. Baryonen hebben halftallige spin.

Big Bang Zie oerknal

BNL Brookhaven National Laboratories (Brookhaven/New York).

boson Deeltjes met heeltallige spin. Een foton is een boson.

B-mesonen B-mesonen zijn deeltjes die bestaan uit twee quarks, waaronder ten minste één bottom-quark. (Zie: quarks.)

bundel Een pakketje deeltjes dat door een deeltjesversneller reist.

calorimeter Detector waarmee vastgesteld wordt wat de oorspronkelijke energie van een deeltje was.

CCD Charge Coupled Device; matrix van lichtgevoelige punten die gebruikt wordt in bijvoorbeeld videocamera's.

CERN Europees centrum voor deeltjes onderzoek. Oorspronkelijk: Conseil Européen pour la Recherche Nucléaire.

collider Versnellerring waarin deeltjes in tegengestelde richting draaien en op een aantal punten frontaal botsen.

DØ Experiment bij de Tevatron collider van Fermilab bij Chigaco in de Verenigde Staten.

DELPHI Experiment bij de LEP-versneller op het CERN.

DESY Deutsches Elektronen-Synchroton; versnellerinstituut in Hamburg.

dradenkamer Detector voorzien van vele draden die de passage (plaats en eventueel tijd)van geladen deeltjes registreert.

elektrisch veld Krachtveld dat wordt opgewekt wanneer er deeltjes met elektrische lading aanwezig zijn. Het veld beïnvloedt de beweging van elektrisch geladen deeltjes.

elektromagnetisch spectrum Het hele gebied van elektromagnetische golven (straling) dat loopt van de zeer lange (laag frequente) radiogolven, via infraroodstraling, zichtbaar licht, ultraviolette straling tot en met de zeer kortgolvige (hoog frequente) röntgen- en gammastraling.

elektron Het elektron is een negatief geladen deeltje. Het draait in atomen om de atoomkern heen. Voor zover wij weten heeft het geen inwendige structuur: het is niet opgebouwd uit kleinere bouwstenen. Samen met zijn zwaardere 'broers', het muon en het tau-deeltje, behoort het tot de zogenaamde leptonen.

elektronvolt De energie die aan een elektron wordt toegevoegd als het een potentiaalverschil van 1 Volt overbrugt.

elektrozwakke kracht Natuurkundig model waarin de elektromagnetische en de zwakke kracht onder één noemer zijn gebracht.

elementair deeltje Deeltje zonder meetbare inwendige structuur dat de fundamentele bouwsteen vormt voor ingewikkelder structuren, zoals de ons omringende materie.

energie De energie van een deeltje met rustmassa m en snelheid v bestaat uit: bewegingsenergie $E = {}^{1}/{}_{2}mv^2$ (bij snelheden die veel kleiner zijn dan de lichtsnelheid), interne energie ($E = mc^2$) en uit potentiële energie (bijvoorbeeld wanneer een elektrisch geladen deeltje zich in een elektrisch veld bevindt).

eV Elektronvolt; de energie die aan een elektron wordt toegevoegd als het elektron een potentiaalverschil van een Volt doorloopt.

fermion Alle deeltjes met halftallige spin worden fermionen genoemd.

foton Licht en andere vormen van elektromagnetische straling kun je ook opvatten als een stroom deeltjes. Zulke lichtdeeltjes, fotonen, zijn ook de dragerdeeltjes van de elektromagnetische kracht.

GeV Giga-elektronvolt, een miljard elektronvolt.

gluon Krachten worden bewerkstelligd door het uitwisselen van deeltjes. Voor de elektromagnetische kracht zijn dit fotonen. De gluonen zijn de dragerdeeltjes van de sterke kracht.

GRID De gridtechnologie maakt het mogelijk netwerken van computers te bouwen die zich gedragen als virtuele supercomputers met grote rekenkracht.

hadron Alle deeltjes die gevoelig zijn voor de sterke kracht worden hadronen genoemd (naar het griekse woord voor krachtig). De hadronen zijn ook gevoelig voor de andere natuurkrachten (zwakke, elektromagnetische en zwaartekracht).

HERA Hadron Electron Ring Anlage; versneller bij DESY.

HERMES Experiment bij de HERA-versneller bij DESY.

Higgsdeeltje Deeltje dat nodig is om te verklaren waarom elementaire deeltjes en dragerdeeltjes van de krachten elk een specifieke massa hebben.

HiSPARC HiSPARC is een project waarbij middelbare scholen samen met wetenschappelijke instellingen een netwerk vormen om kosmische straling met extreem hoge energie te kunnen meten..

hoge energiefysica Natuurkundig onderzoek waarin elementaire deeltjes en hun wisselwerkingen via natuurkrachten onderzocht worden. De naam is afgeleid van het feit dat deeltjes eerst versneld moeten worden tot een hoge energie om tijdens botsingen elementaire deeltjes te kunnen produceren.

instabiel Een instabiel deeltje vervalt en gaat daarbij spontaan over in andere deeltjes.

impuls De hoeveelheid beweging in een bepaalde richting. Als de snelheden veel kleiner zijn dan de lichtsnelheid dan geldt: impuls = massa x snelheid

impulsmoment Mate van draaibeweging van een deeltje of een lichaam. Voor deeltjes wordt het gemeten in heeltallige of halftallige veelvouden van de planckconstante h gedeeld door 2π. Dit wordt ook wel spin genoemd.

keV Kilo-elektronvolt; duizend elektronvolt.

kleurkracht De sterke kracht, die er voor zorgt dat quarks altijd in groepjes van twee of drie aan elkaar gekluisterd zitten. In de theorie van de kleurkracht (quantumchromodynamica) kan ieder quark één van drie kleuren aannemen: rood , blauw of groen. Door middel van gluonen wisselen de deeltjes voortdurend kleurlading uit.

kortlevend Een kortlevend of instabiel deeltje gaat spontaan over in andere deeltjes en heeft een beperkte levensduur.

kosmische straling Kosmische straling bestaat uit energetische deeltjes die vanuit de kosmos op aarde terechtkomen. Deze deeltjes zijn meestal atoomkernen (protonen), maar het kunnen ook elektronen, gammastralen of neutrino's zijn.

L3 Experiment bij de LEP-versneller op het CERN.

LEP Large Electron Positron collider; deeltjesversneller bij het CERN waarin elektronen op hun antideeltjes botsen.

lepton Leptonen zijn ongevoelig voor de sterke kracht. Het elektron en zijn zwaardere broers, het muon en het taudeeltje, zijn leptonen. Bij elk van hen is een bijbehorend neutrino.

LHC Large Hadron Collider; versneller bij CERN waarin protonen op protonen botsen.

LHCb Experiment bij de LHC-versneller. LHCb onderzoekt symmetrieschending in de natuur.

massa Onder invloed van de zwaartekracht leidt massa tot gewicht; in de relativiteitstheorie is massa equivalent met energie.

meson Deeltje dat is opgebouwd uit een quark en een anti-quark. Het lichtste meson is een pion. Pionen zijn opgebouwd uit (anti)up-en(anti)down-quarks. Mesonen zijn gevoelig voor de sterke kracht en hebben een heeltallige spin.

MeV Mega-elektronvolt; een miljoen elektronvolt.

muon Zwaardere broertje van het elektron (ongeveer tweehonderd maal zo zwaar). Net als het elektron draagt het muon negatieve elektrische lading en heeft het halftallige spin.

natuurkrachten 1) De elektromagnetische kracht en 2) de zwakke kracht, die samen onder een noemer zijn gebracht in de elektrozwakke kracht. 3) de sterke kernkracht en 4) de zwaartekracht.

NIKHEF Nationaal Instituut voor Kernfysica en Hoge Energie-Fysica

neutrino Een massaloos of zeer licht deeltje. Neutrino's voelen alleen de zwakke kracht en treden daardoor nauwelijks in wisselwerking met materie. Neutrino's doorkruisen in enorme aantallen - vrijwel onopgemerkt - ons heelal.

neutron Neutraal bouwsteen van de atoomkernen. Een neutron zelf bestaat uit drie quarks: twee downquarks en een upquark.

oerknal Volgens deze theorie ontstonden tijd, ruimte en deeltjes (energie) tijdens de oerknal. Daarna rekte de ruimte steeds verder op en ordende materie zich tot (uiteindelijk) clusters van sterrenstelsels, sterrenstelsels, sterren en planeten.

PHENIX Experiment bij de RHIC-versneller op BNL.

pion Deeltje met een massa tussen die van het elektron en het proton in. Overbrenger van de sterke kracht tussen hadronen. Er is een positief geladen, een negatief geladen en ook een elektrisch neutraal pion. Pionen bestaan uit een (anti)up- en een (anti)down-quark.

positron Antideeltje van het elektron. Heeft dezelfde massa als het elektron en dezelfde spin, maar is positief geladen. Als elektron en positron elkaar ontmoeten vernietigen zij elkaar en komt energie in de vorm van lichtdeeltjes vrij.

proton Positief geladen bouwsteen van de atoomkern. Een proton bestaat uit drie quarks: twee upquarks en een downquark.

QCD QuantumChromoDynamica; wiskundig model dat de wisselwerking van de sterke kernkracht beschrijft.

quarks Elementaire deeltjes. Er zijn zes quarks. De up- en downquarks zijn de bouwstenen van protonen en neutronen, en daarmee van de ons omringende materie. Verder zijn er nog het strange-, charm-, top- en bottomquark.

RASNIK Red Alignment System NIKhef; een uitlijnsysteem waarin een gecodeerd optisch patroon door middel van een lens wordt afgebeeld op een CCD-camera.

RHIC Relativistic Heavy Ion Collider; deeltjesversneller bij BNL.

Science Park Amsterdam
Science Park Amsterdam is de vestigingsplaats van onder andere een aantal internationaal gerenommeerde onderzoeksinstituten, waaronder NIKHEF.

siliciumdetector Siliciumdetectoren zijn gebouwd om geladen deeltjes te meten en men kan daarmee met grote precisie de baan van de deeltjes bepalen.

SLAC Stanford Linear Accelerator Center (Stanford/Californië).

snarentheorie Theorie waarin deeltjes worden voorgesteld als strak gespannen snaren. Als de snaren trillen representeren zij een deeltje.

spin Draaibeweging ofwel impulsmoment van deeltjes. Voor elementaire deeltjes gelden de wetten van de quantummechanica: zij vereisen dat de draaibeweging gequantiseerd is en alleen voorkomt in veelvouden van een constante. Deze constante is de Planck-constante gedeeld door 2π. De spin van deeltjes kan heeltallig zijn (0,1,2,3,4,...) of halftallig ($^1/_2$, $^3/_2$, $^5/_2$, ...).

Standaard Model Het Standaard Model is een theorie waarbij drie van de vier natuurkrachten - sterk, zwak en elektromagnetisch - samen met de elementaire deeltjes zijn ondergebracht in één model.

STAR Experiment bij de RHIC-versneller op BNL.

sterke kracht De kracht die protonen en neutronen in de atoomkern bijeen houdt. In dit geval door uitwisseling van pionen. Meer algemeen: de kracht die tussen hadronen werkt. Op een lager niveau, als we spreken over quarks, wordt de sterke kracht beschreven als een kleurkracht en de wisselwerking van lijmdeeltjes (gluonen).

supergeleidend Een supergeleidend materiaal heeft geen elektrische weerstand waardoor er zeer sterke magneetvelden mee opgewekt kunnen worden.

synchrotron Ringvormige versneller.

tau-deeltje Zwaarste broertje van het elektron en het muon. Gedrieën behoren zij, met de bijbehorende neutrino's, tot de leptonen.

TeV Tera-elektronvolt; een triljoen (duizend miljard) elektronvolt.

Tevatron Versneller van Fermilab bij Chicago waarin protonen op antiprotonen botsen.

vacuüm Lege ruimte. In feite nooit echt leeg; door energiefluctuaties kunnen er steeds kortstondig paren van een deeltje en een antideeltje ontstaan.

veld Een verschijnsel dat van tijd en plaats afhangt. Je kunt denken aan een temperatuurverdeling of aan het zee-oppervlak. In een veld zitten vaak golfbewegingen. Wisselwerkingen tussen deeltjes kun je beschrijven met behulp van krachtvelden. Men spreekt bijvoorbeeld van een elektrisch veld of een zwaartekrachtveld.

versneller Apparaat om energie aan deeltjes toe te voegen.

vertexdetector Vertexdetectoren zijn zo nauwkeurig dat bij botsingen de sporen van geladen deeltjes totaan het punt waarop ze zijn ontstaan met grote precisie kunnen worden bepaald.

wisselwerking Uitwisseling van dragerdeeltjes ten gevolge van een van de natuurkrachten.

World Wide Web Op het Web kan informatie via het internet snel en systematisch opgezocht worden.

W-deeltje Geladen dragerdeeltje van de zwakke kracht.

Z-deeltje Neutraal dragerdeeltje van de zwakke kracht.

ZEUS Experiment bij de HERA-versneller in Hamburg.

zwaartekracht Kracht waarmee (zware) objecten elkaar aantrekken. De zwaartekracht is evenredig met de massa van de objecten en omgekeerd evenredig met het kwadraat van hun onderlinge afstand.

zwakke kracht Werkt alleen op zeer korte afstanden en is zeer zwak. Alle bekende deeltjes zijn er gevoelig voor. De zwakke kracht is verantwoordelijk voor (radioactief) verval van deeltjes.