NIKHEF Annual Report 2005

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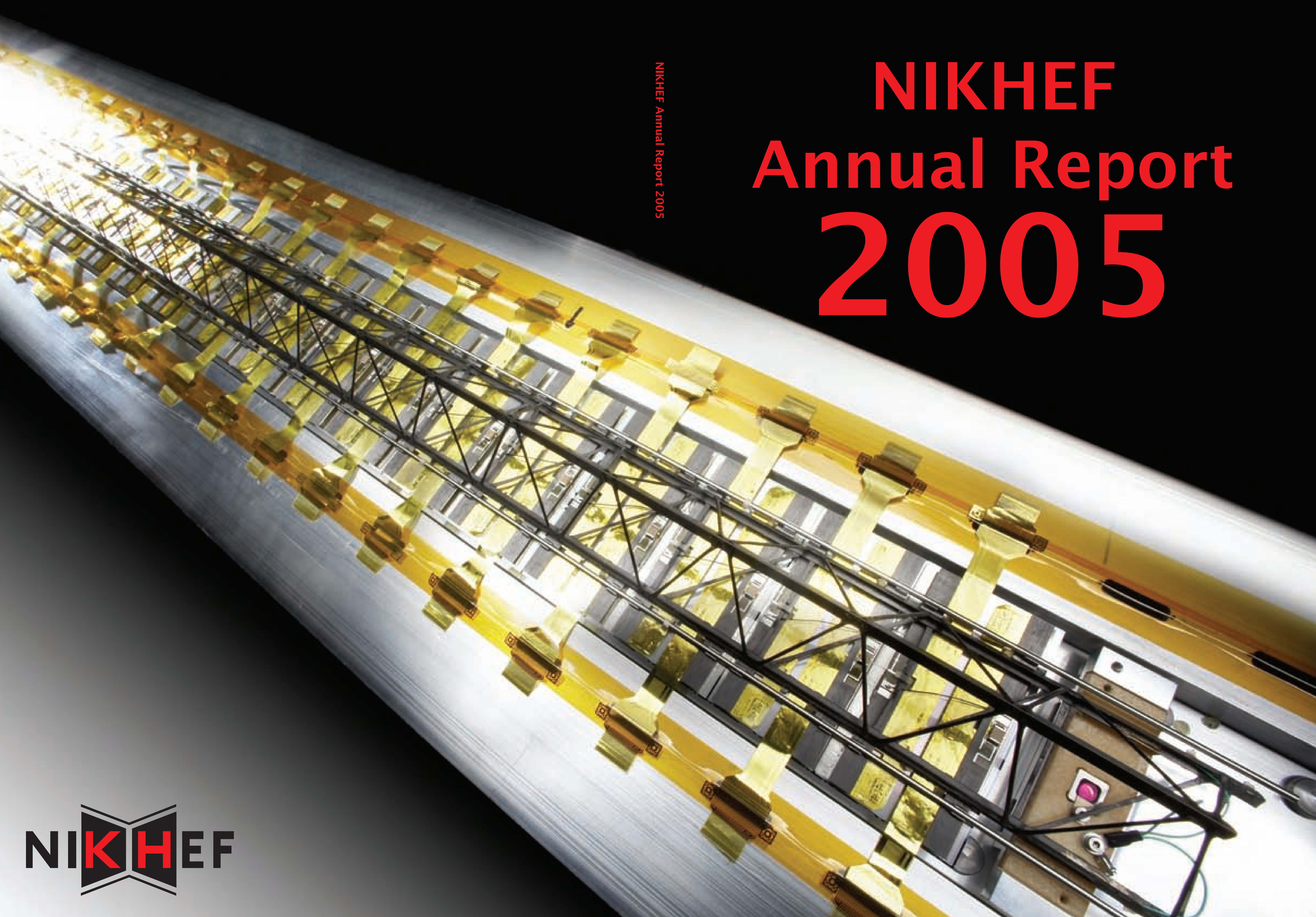

NIKHEF

Annual Report 2005

NIKHEF

Colofon

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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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 elementary particle or 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, through participation in the Pierre Auger large area cosmic ray detection facility in Argentina and through participation in the ANTARES project: a neutrino telescope 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 programme and close contacts with the experimental groups.

Contents


photo: Jan Koopstra

Introduction

Figure 1. Elementary particles from a cultural perspective (Theater Adhoc). *photo: Thomas Scholz*

Report of the Director

2005 was set aside by the United Nations as the World Year of Physics in celebration of the 100th anniversary of the Annus Mirabilis, 1905, the year in which Albert Einstein published three revolutionary papers. In “Zur Elektrodynamik bewegter Körper”, Einstein laid down his special theory of relativity, which, through the world-famous equation $E=mc^2$, concisely summarizes NIKHEF’s primary research ambition: the search for new phenomena i.e. notably particles with very high mass (m) exploiting both the world’s highest beam energy (E) colliding beam facilities and the mysterious sources in the Universe bombarding our Earth with particles with energies (E) surpassing our imagination.

From 2007 onwards, the Large Hadron Collider (LHC) at CERN (Geneva/Switzerland) will be the world’s flagship colliding beam facility. In 2005, the delay imposed by repairing defects in the LHC machine cryogenic distribution line was largely recovered. At NIKHEF, the construction of sub-detector systems for the ALICE, ATLAS (photo) and LHCb experiments made fantastic progress such that all systems are expected to be shipped to CERN in the first half of 2006 for installation and commissioning in their respective underground caverns.

NIKHEF physicists are now focusing on tomorrow’s challenges: detector simulation-, reconstruction- and visualization software and the subsequent development of optimal data analysis strategies such that NIKHEF physicists will be among the first to unveil new phenomena, expected and unexpected, in the upcoming 14 TeV center-of-mass energy LHC proton-proton collisions.

A crucial ingredient for the successful exploitation of the LHC program is the compute infrastructure. To handle the astounding annual data volume of the LHC experiments, consisting of an expected 15 million Gigabytes i.e. about 20 million CDs, CERN envisages a multi-Tier hierarchical compute grid: a Tier-0 centre at CERN connected to about ten Tier-1 centres scattered all over the world. Through a multitude of national and international grid projects over the past years, the Netherlands has become a leading player in the development of grid computing. To fully take advantage of this, NCF, NBIC and NIKHEF jointly submitted a proposal for a national grid infrastructure to serve the requirements (compute and data storage) of many scientific research labs including NIKHEF and industrial research labs such as Philips. This proposal (‘BIG GRID’) was one of the five, out of 42, recommended for funding during a high-profile “Nationaal Innovatie Event” happening on December 7th attended, amongst others, by the Dutch prime minister and the minister of Education, Culture and Science. Provided the Dutch cabinet takes over this recommendation in 2006, BIG GRID will constitute NIKHEF’s 2006 highlight and the Netherlands will become one of the LHC Tier-1 centres, thereby giving our researchers no excuse not to make the LHC experiments a major success!

Regarding the Dutch ambitions and opportunities in the relatively new and exciting field studying the mysterious sources of (energetic) particles in our Universe a document titled “Strategic Plan for Astroparticle Physics in the Netherlands” was submitted to NWO by a consortium of Dutch physicists, astronomers and space researchers. Besides the deep-sea detection of neutrinos, first pioneered by NIKHEF via the ANTARES project, this strategic plan includes the radio detection of cosmic rays and the detection of gravitational waves. In March 2005 the Netherlands officially joined the Pierre Auger Observatory (PAO), a vast (3000 km^2) surface array for the detection of ultra high-energy cosmic rays in the Pampa Amarilla (yellow prairie) in western Argentina. A possible Dutch contribution to the PAO instrumentation would be the radio detection technology developed for LOFAR. The successful exploitation of these initiatives would grant the Netherlands a visible and well-focused position in the field of astroparticle physics. A point of concern remains adequate funding for our national astroparticle physics ambitions. In the absence of options to secure structural funding, the astroparticle physics community explored many different channels to obtain subsidies. An important success herein was the EU subsidy for a design study for the follow-up of the ANTARES neutrino telescope as well as a personal subsidy for one of our young researchers via the NWO ‘Vernieuwingsimpuls’.

Throughout 2005 outreach activities were centre stage at NIKHEF. Highlights included a fantastic play featuring the neutrino particle by ‘Theater Adhoc’ (photo); a science competition (‘Eureka cup’) and a CERN master class for high-school students; the annual NIKHEF open day and many public lectures. Other memorable events were the CERN visits by the FOM council, by the Dutch minister of Education, Culture and Science, M.J.A. van der Hoeven, by various groups of university students and by Theater Adhoc which contemplates to make an artistic television movie featuring the eventual discovery of the elusive Higgs particle!

In 2005 NIKHEF’s staff association surpassed its already outstanding record as organiser of many social events throughout the year by the introduction of a novelty: a NIKHEF canoe race in the sewage canal bordering on the NIKHEF premises. Together with the technical facilities head I decided to sample the material at the bottom of this canal twice: once at the start and once near the finish. An event to forget just as fast as NIKHEF’s annual soccer match!

Figure 2. Cabling-up the ATLAS silicon tracker at NIKHEF. *photo: Peter Ginter*

Looking forward to 2006 and beyond:

- the scene appears very well-prepared for a high-profile Dutch contribution to the exploitation of CERN's LHC program: the LHC detector construction projects at NIKHEF are near completion; the BIG GRID funding recommendation brings an LHC Tier-1 center in the Netherlands within reach; many (young) researchers are now working on software, data analysis and the physics analysis strategy.

- the immediate future of astroparticle physics promises to be very exciting with the deployment of all twelve ANTARES strings before the end of 2007 and with the new research opportunities offered by the Pierre Auger cosmic-ray observatory and the VIRGO laser interferometer for the detection of gravitational waves. The long-term future of astroparticle physics in the Netherlands depends entirely on the success to secure structural funding for this research activity on a national and international level in the coming years.

Frank Linde

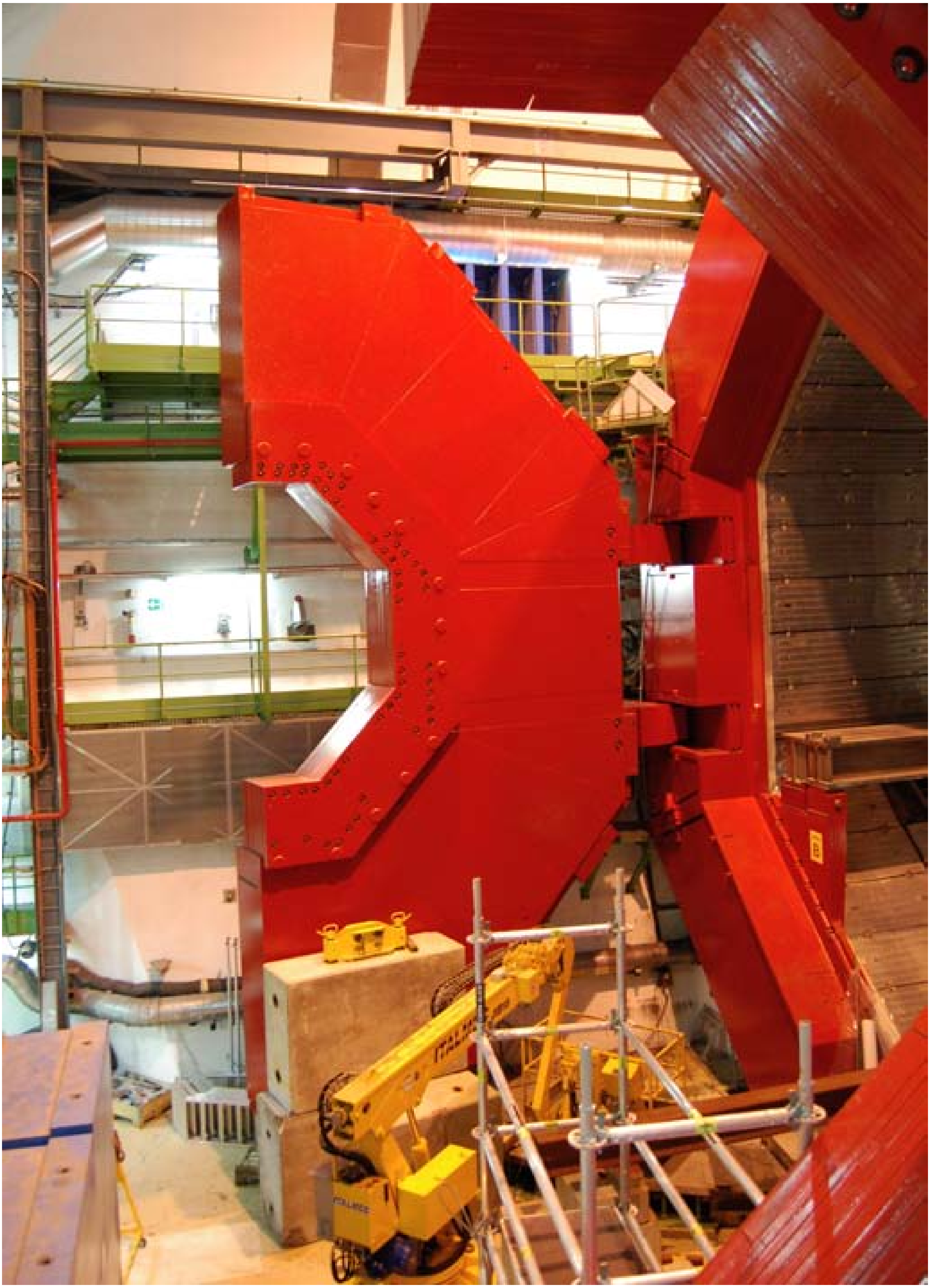


Figure 3. The ALICE detector under construction at CERN. *photo: Kees Huyser*

Reviews

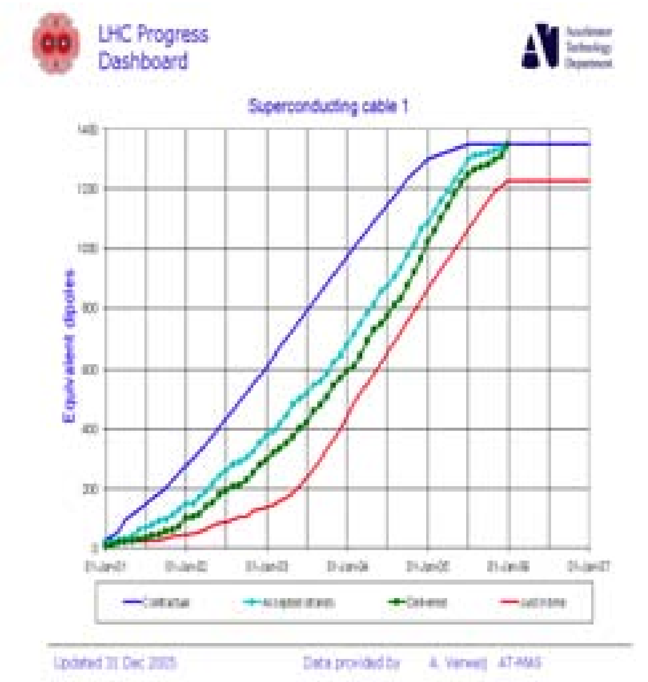


Figure 1: Progress of superconducting-cable production for the LHC magnets since January 2001.

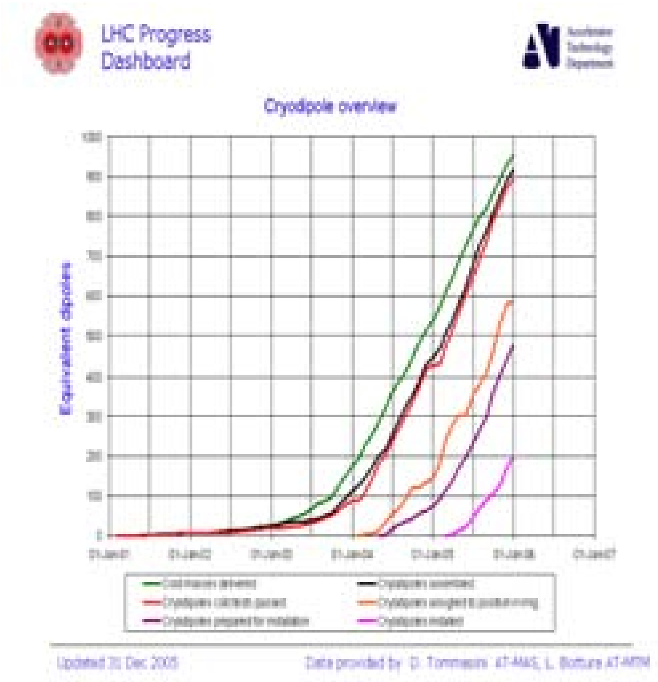


Figure 2: Progress of production and installation of the LHC cryodipoles since January 2001.

Status of the Large Hadron Collider

During the year 2005 the progress towards the realisation of the Large Hadron Collider (LHC) at CERN has been very visible. More than one quarter of the cryogenic distribution line has been installed and the first 200 cryodipoles have been put into position in the tunnel.

Introduction

The main component of the LHC is the 15 m long superconducting dipole twin magnet of which a total of 1232 are needed to close the circle in the tunnel.

This device houses two dipole magnets at a horizontal distance of 180 mm inside one iron yoke guiding counter rotating proton beams through an aperture of 56 mm for the beam pipe. At full field, 8.6 Tesla, the force loading one metre of dipole is enormous, comparable to the weight of a jumbo jet, about 400 tonnes! Steel collars (see Fig. 3) made of austenite (a special type of steel well known for its hardness caused by a high percentage of carbon), and machined to 20 micron precision, prevent the coils from moving inside their iron yoke structure.

This assembly, called the cold mass, is subsequently installed in the cryostat that will keep the magnet below 2 K at operating conditions in LHC. The dipoles guide the protons around the ring; in addition about 400 superconducting quadrupoles provide the required focusing of the beam and furthermore a large quantity of small superconducting corrector magnets is needed for the

A BIT OF HISTORY

About twenty years ago, a Long Range Planning Committee studied the physics potential of a hadron collider of the highest possible energy compatible with installation in the LEP tunnel at CERN in Geneva. The construction of the 27 km circumference tunnel for the electron-positron collider LEP was just finished and the tunnel was ready for installation of the magnets. Its internal diameter had been made sufficiently large to house in addition to LEP another collider ring. The first ideas for the Large Hadron Collider (LHC) included already superconducting magnets with two beam channels (to take counter rotating proton beams) in a single yoke. With magnet fields around 10 Tesla, a beam energy of 8 TeV could be achieved given the fixed 27 km circumference of the tunnel. Since then numerous studies and developments on superconducting magnets have taken place. The first technical design report of the LHC dates from 1991; in 1993 an external Review Committee judged the LHC design goals reasonable and realistic, while the CERN Council in 1994 approved the construction of a 14 TeV collider under certain financial constraints. At that time it was not yet known how many non-member states would contribute to this project. It would still take five years to solve problems before the final design was ready and production of components could start at an industrial scale.

Figure 3: Austenitic steel collar to hold the coils for the dipoles in position; each magnet requires about 5000 pieces.

Figure 4: First cryodipole gets lowered into the tunnel. The shaft is designed specially for the installation of the magnets.

quadrupoles (2500) and for the dipoles (3700) to correct for field imperfections at the end of the main magnets.

The superconducting cable for the coils is an niobium-titanium alloy. It consists of 36 twisted strands (diameter 15 mm), each strand being made up in turn of 8800 individual filaments, which have a diameter as small as 7 micron. A total of 7000 km cable is required for the production of all magnets. Although this cable is superconducting at 4.5 K, the LHC magnets will be cooled down to 1.9 K at which temperature helium is a superfluid and thus has a very high thermal conductivity.

This reduces the risk that a superconductor turns into normal conduction, the so called quenching phenomenon, when the current exceeds a critical level that depends on temperature and applied magnetic field. To maintain the 27 km ring at superfluid helium temperature, eight 18 kW cryoplants are distributed along the ring that provide 4.5 K helium. In order to reach 1.9 K, low-pressure heat exchangers had to be designed and built. The helium distribution lines are installed adjacent to the magnets in the tunnel and are also divided in octants. Each LHC-cell, consisting of 6 dipoles, 2 quadrupoles and stretching over a length of 107 m, is equipped with a heat exchanger and forms a closed helium loop.

Magnet production and status

The production and testing of all parts for LHC was taken up by industry in very close collaboration with CERN experts. The progress (see Figs. 1 and 2) can be followed in great detail on flow charts published on the CERN web page (http://lhc.web.cern.ch/lhc). The superconducting cable production had a slow start-up in 2001, but production finished this year. The 7000 km of cable has been provided by four companies in Europe, one in Japan and one in USA. After a long prototype phase, three European firms (in Germany, France and Italy) have taken up the production of the dipoles, which took off only beginning of 2003. At the end of 2005, 80% of the dipoles have been produced.

The cold masses are assembled at CERN in their cryostats and undergo a severe quality test during which all magnetic field properties are measured and magnets are prepared for installation in the tunnel. Testing one magnet takes about five days including the time to connect and disconnect the magnet from the test bench. Twelve test benches are running in parallel. Forty percent of the dipoles are now ready for installation. The production of the quadrupoles (France) and the corrector magnets is on schedule. Typically 80% or more is finished.

Installation in the tunnel

The installation of the helium distribution line suffered a serious drawback in 2004 after the discovery of bad quality welds and broken supports inside the vacuum vessels. Studying the problems and finding the proper repair process took several months, but once this was finished CERN together with industry made an enormous

Figure 5: View of helium distribution line already installed in the LHC tunnel.

Figure 6: Cryodipole ready to be connected to its neighbour.

effort to catch up the time lost. At the beginning of 2005, the installation of the repaired elements started and in parallel the already installed elements were repaired. By the end of 2005, 30% of the cryoline has been installed (see Fig. 5) and half of the cryoplants are in position. Testing started on the first complete sector, that is three kilometres of cryoline. First pressurisation tests have been performed. By flushing the line with room temperature helium all impurities had to be removed before cooling could start. After three days the temperature had been lowered to 10 K.

On March 7, 2005 the first dipole magnet was lowered into the tunnel (see Fig. 4). Each magnet, weighing 35 tons, is manoeuvred through the ring and put into position by specially designed vehicles and gearing equipment. The interconnection of superconducting magnets requires not only the connection of the two beam pipes, but also the pipes for the helium flow, the cryostat itself, the thermal shields, the vacuum vessel and last but not least all superconducting cables. The magnet installation process represents a very tedious and responsible job. About 200 dipoles have been installed up to the end of 2005, together with the required corrector magnets (see Fig. 6).

In addition to this activity, the development and production of numerous control systems is growing steadily. Interesting to mention here is another important part of the project, the transfer tunnels. Protons are pre-accelerated within the existing CERN accelerator complex. Two new beam lines had to be constructed to transfer the protons to the LHC, one for the clockwise direction and one for the anti-clockwise direction. The length of each transfer tunnel is approximately 2.5 km. They are equipped with about 300 normal conducting magnets (dipoles, quadrupoles and correctors) produced in Russia. The first of the two tunnels is completely equipped and tested. The commissioning of the beam line was very successful; proton beams arrived at the entrance of the LHC tunnel at the first go! The installation of magnets in the second tunnel has to wait completion since it forms the doorway to the LHC tunnel for the installation of magnets and auxiliary equipment.

Altogether the project has made enormous progress and the management has expressed great confidence that the LHC start-up will be in 2007. A review of the overall schedule is planned for spring 2006.

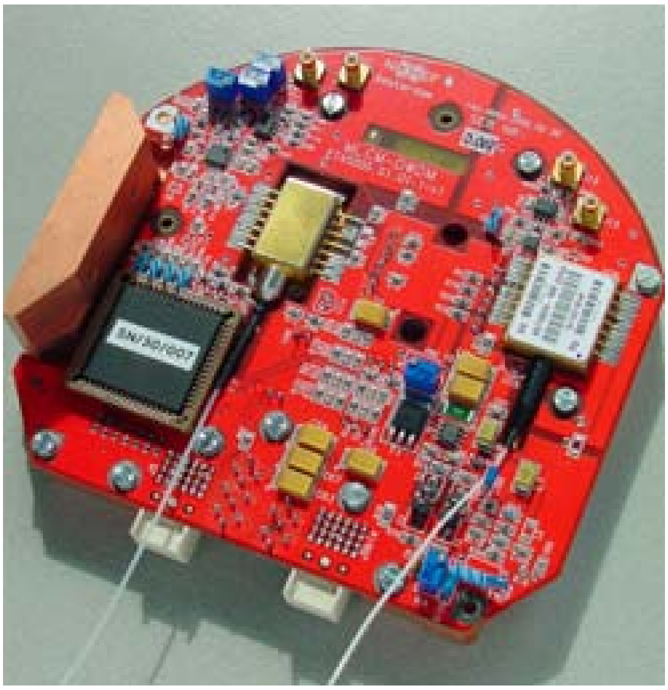


Figure 1. DWDM board equipped with a temperature-controlled laser (gold), avalanche photodiode (white), and slow-control readout chip (grey).

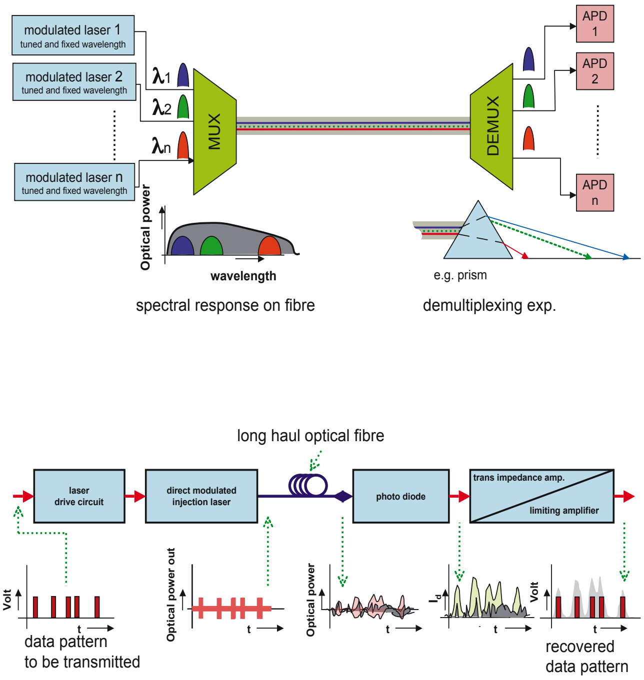


Figure 2. Top: Principle of Dense Wavelength Division Multiplexing (DWDM). Bottom: Point-to-point fibre communication.

Optical Data Transmission

Thirty years ago, in *Philips Technisch Tijdschrift* nr. 7 of 1976, it was stated that there is a possibility to transmit information over a cable by making use of light waves. The conduction should proceed over flexible hair-thin threads of glass with very high bandwidth. At that time it was possible with conventional techniques to establish 10,000 telephone connections (each 2400 bit/s signals) by modulating them and sending them over one 20 mm diameter coax cable. Depending on the application further signal amplification was needed every 5 to 25 km.

Today, the prediction of 1976 has become reality by the use of glass fibres, while the bandwidth has not even reached a maximum. One present-day fibre cable can replace 10,000 of the 20 mm coax cables employed previously. A recently accepted standard is to send 10 Gigabit/s of data, modulated on a narrow light spectrum, over a distance of 80 km without amplification.

As an example of what is possible nowadays we mention that the present commercial market provides one single optical fibre connection carrying 400 different optical narrow band spectra. Each optical band can carry completely different data protocols, modulation types and data speeds. This technology (see Fig. 1 and Fig. 2, top) is called Dense Wavelength Division Multiplexing (DWDM).

Technical progress

In a commercially available glass-fibre cable, the ones that are routed in duct pipes for example, reside 24, 48, 96, and even more, fibres per physical cable. A few years ago most fibre connections were still point-to-point connections (see Fig. 2, bottom), working at a wave length of 1310 nm, without DWDM systems. Today, due to technical developments in fibre fabrication, the application of 1550 nm wave length and the addition of DWDM technology renders the fast connections that we use worldwide for the internet. In the near future High Definition Television (HDTV) will be possible if a few parallel signals are sent, received and processed by the television set.

The revolution in data communication with fibres is mainly based on three primaries: the semiconductor laser, the signal-conducting fibres and the semi-conductor optical receivers, the photo diodes (see Fig. 1, bottom). Rather common specifications for these devices are an output power of 3 mW (4.8 dBm) for a communication laser, optical fibre loss less than 0.2 dB/km and a sensitivity of -18 dBm for the optical diode receiver.

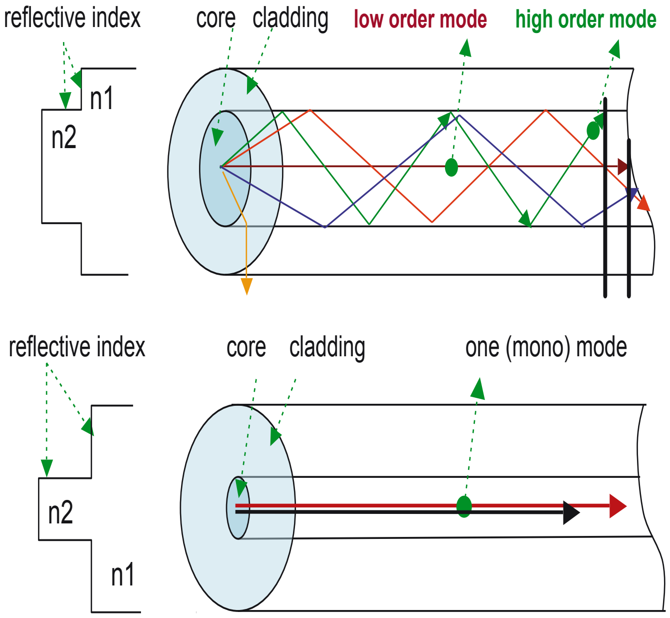


Figure 3. Top: Step-index multi-mode fibre. Bottom: single-mode fibre.

APPLICATION IN THE ANTARES DETECTOR

The NIKHEF electronic department has developed a DWDM system for use in the ANTARES detector in the Mediterranean sea. It provides a long-haul communication- and control system, lying 2300 m below sea level, with a span of 43 km to the shore station. The development and production of the electrical-to-optical and optical-to-electrical conversion board, which operates at very high frequencies, is a success. The harsh environment for the fibre cable routing and the technology to make connections in deep sea, have been subjects that required considerable technical effort. Now a 1 Gigabit/s Ethernet connection is established and data are being transported from the first detector string to the shore station.

Glass or copper

The advantages of optical data transmission via glass fibres relative to conventional copper conductors are the enormous bandwidth (a very good 'distance times bandwidth' product), low transmission loss, immunity to electromagnetic radiation, lack of crosstalk between parallel fibres, immunity to inductive interferences, and galvanic isolation between systems.

Since the fibre industry maintains a high standardisation level (by the ITU, Bellcore and EIA commissions), products of different manufacturers can easily be interfaced to different applications. The disadvantages of optical communications compared to copper transmission are the high cost for short distances, especially for low bandwidth demands, and the need of special laboratory and maintenance instruments. Obviously, the choice of the preferred technology depends on the particular needs of the intended application.

Dispersion

When one sends an optical signal through a glass fibre cable different components of the input signal may arrive at different times at the end of the cable. This phenomenon is called dispersion and its size depends on the structure of the cable. The dispersion has two origins. Firstly, there is the modal dispersion: different wave lengths in the light spectrum travel with different speeds through the glass material of the core.

A second contribution to dispersion is due to the diameter of the core: each ray of light travelling inside the cable can follow various trajectories, which causes differences in arrival time for an optical pulse consisting of many individual rays. These dispersion phenomena degrade the electrical signal output of the receiving diode used for electrical data recovery. A proper choice of the type of fibre cable is therefore needed to optimize performance.

Fibres

There are two main types of fibre: the multi-mode and the single-mode glass fibres. The multi-mode fibre (see Fig. 3, top) has an overall cross section of 125 μm and a core of 50 or 62.5 μm. A semiconductor laser or Light Emitting Diode (LED) generates an optical signal that is injected into the fibre and then mainly propagates through the fibre core. For short distances, e.g., inside buildings and small plants, a wave length of 850 nm is commonly used.

For long haul distances, metropolitan networks and beyond, single-mode fibre (see Fig. 3, bottom) is used with a cross section of 125 μm and a core of 9 μm. Because of these dimensions the optical signal is propagated through the fibre with less reflections and the dispersion is therefore much smaller than that caused by different ray trajectories in the multi-mode fibre.

Moreover, by proper design of the fibre the modal dispersion can be tuned to zero for a certain wave length,

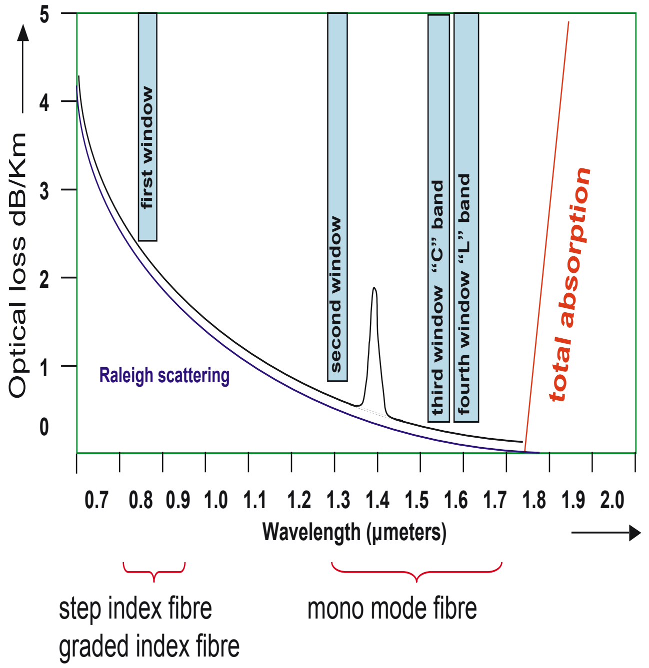


Figure 4. Optical power attenuation curve.

Figure 5. An 8-channel DWDM multiplexer with fibres attached.

e.g. 1310 nm or 1550 nm. If one operates such a fibre, e.g. tuned for 1310 nm, outside this ‘zero-dispersion wave length’, this results in a dispersion with a typical value of 18 ps/nm/km for a common type of fibre.

Signal amplification

The optical loss curve of a fibre shows low attenuation at wave lengths between 1310 and 1550 nm (see Fig. 4). Also the low dispersion of the optical signal in single-mode applications is very advantageous. The 1550 nm spectrum is favourable because all-optical-amplifiers work in this wave-length domain. Their active bandwidth is a favourable addition for economical and reliability reasons. Long haul distances are covered, while all optical signals, independent of modulation methods or protocols, and all channels in a DWDM system are amplified without optical-to-electrical and electrical-to-optical conversions. Optical amplifiers compensate for possible bandwidth loss and signal-quality degradation, e.g., there is no addition to the time jitter of the signal. A commonly used optical amplifier is the Erbium-Doped Fibre Amplifier (EDFA).

Components

For the implementation of optical network architectures many components are available and in development. The most important ones are:

- The Optical Add and Drop Multiplexer (OADM). It adds or withdraws a predefined optical DWDM channel to or from the common fibre for DWDM transport.
- Optical isolators. They are needed in fibre networks to prevent signal backscattering.
- Three- or four-way optical circulators. These are used for routing control, e.g. if bidirectional signals are present on a single fibre.
- Polarisation-maintaining fibres and dispersion-compensating fibres. These are used to restore signal properties.
- Mirrors. They are often used in time-dependent measurements.

Other commonly used components are attenuators for signal tuning, optical switches, wave-length lockers and signal splitters. Many of these devices are now being developed with planar technology like in conventional chip fabrication. This makes production in large quantities possible.

A further very important development is the so called Micro Electro Mechanical System (MEMS), which uses micro-machined mirror arrays to reflect light to different points in an array, e.g., for switching it to a predefined fibre. The tilt angle of a micro mirror is set by an electrostatic force underneath the mirror.

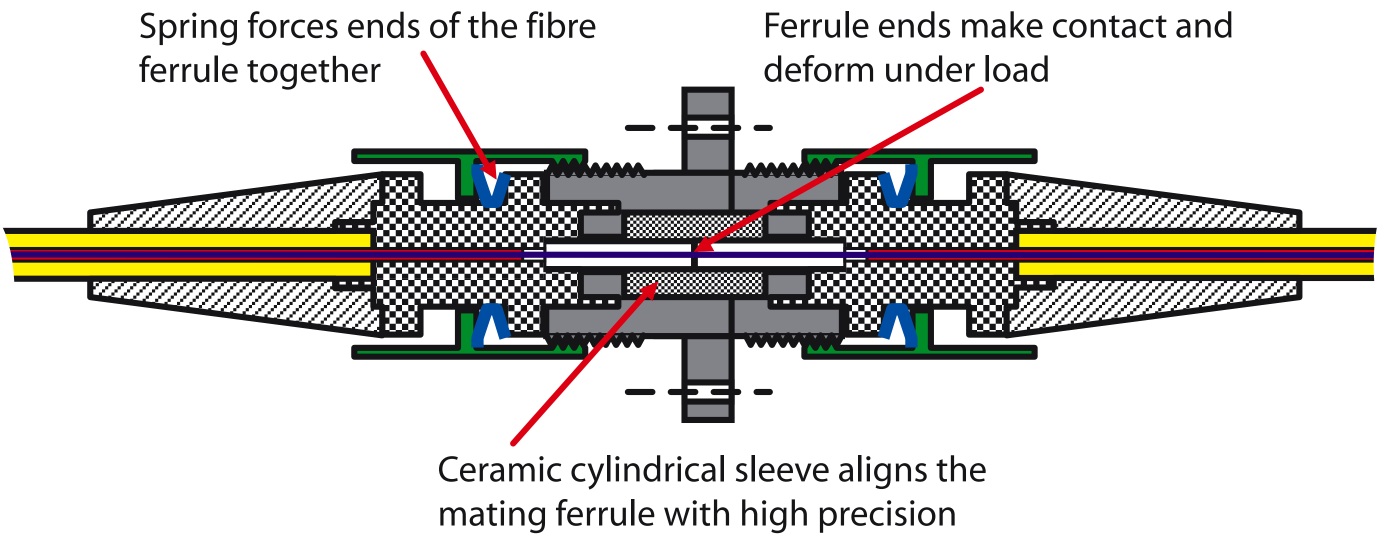


Figure 6. Optical connector.

Building optical networks

There are two main methods to interconnect fibres: optical connectors and optical splices. For both devices the requirement is to keep optical losses minimal.

A wide variety of optical connectors is available (see Fig. 6). The quality of the connector depends on the alignment precision of the fibre cores. Two fibre ends with similar connectors are joined under slight pressure by a mating adapter. Especially in single-mode fibre (9 µm core) with its own high mechanical tolerances, intensive cleaning of the end faces is needed before the connection can be made. With such connections the optical loss can be reduced to almost 0.5 dB. Optical microscopes are needed for the highly essential inspection of the connector end faces.

The use of optical splices needs special and expensive equipment. In this technique two fibres are automatically aligned and then melted together with an arc. These fusion splices produce optical losses of less than 0.005 dB.

The most frequently used fibre is made of pure silica glass and is very fragile. Therefore, much attention has to be paid not only to the mechanical protection of glass fibres, giving the fibre its major strength, but also to the mechanical manipulations and routing of glass fibre cables. Propagation of light in a fibre is based on Snellius laws. As a consequence, bending a fibre too tightly or squeezing it will cause a tremendous optical loss since the maximum reflection angle is crossed. Manipulation technologies for these items differ substantially from copper wire systems.

Therefore, the availability of various specialised skills are a condition to successfully exploit and develop this optical technology.

Optical sensing

Another interesting application of optical fibre technology is in the field of optical sensing. Sensors based on photonic technology can measure physical quantities like pressure, strain, temperature and chemical parameters like pH, salinity, et cetera. In such sensors, the quantity to be measured is transformed into a change in an optical parameter, like optical power, wave length, polarisation or travelling time. This change is then transformed by a detector into an electrical signal representing the measured parameter. The fibre itself can be used for this transformation, or special elements, called ‘modulators’, can be employed. Special optimized fibres, having e.g. scintillating properties under nuclear radiation, are also promising candidates for nuclear applications. In general terms, photonic technology provides the opportunity not only for data- and telecommunications, but also for advanced sensing.

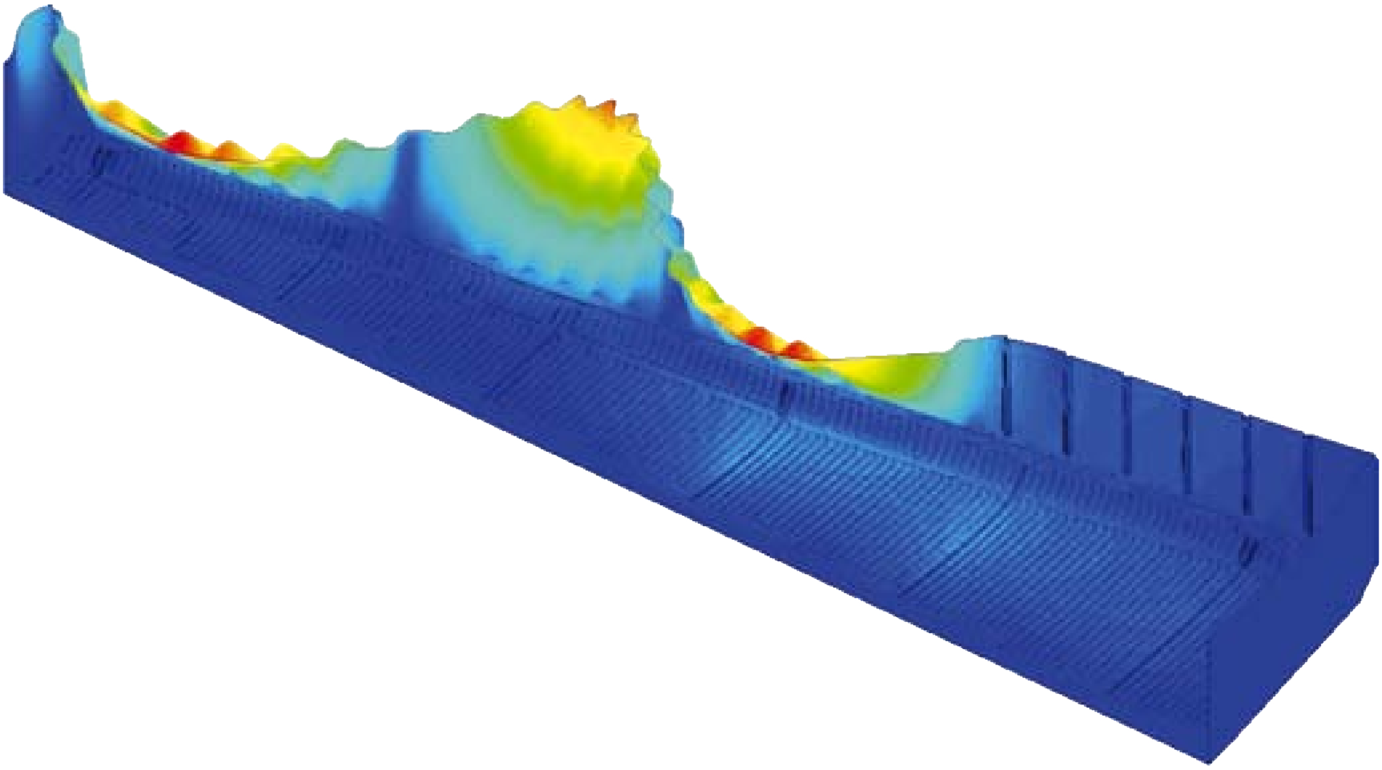


Figure 1. Vibration mode calculated with FEM for the top foil of a vacuum box in the LHCb Vertex Locator. The frequency is 107 Hz.

Finite-Element Methods in Engineering and Development

In recent years finite-element methods (FEM) for simulation of the behaviour of, e.g., mechanical structures, have become an important tool for designers to evaluate properties of the structure in a premature state. Within a time of 20 years, in which several major breakthroughs occurred, FEM developed from a toy just for specialists into a method accessible for many engineers.

First, interactive post processing options for interpretation and presentation of the calculations got facilitated by the availability of cheap graphical workstations. A short time later, flexible preprocessing was implemented by the possibility to exchange information between FEM and modern modeler systems for Computer Aided Design (CAD).

Though these developments greatly enhanced the ease-of-use, even more achievements have been made in the complexity of the processing itself.

Solving equations

In the finite-element method the solution of the relevant (partial) differential equations that govern the behaviour of mechanical structures, is obtained by converting them into a (linear) system that can be solved numerically.

Today a wide range of versatile solvers and specialised solvers is available on a commercial basis for both linear and non-linear problems. It is possible to simulate the behaviour of complex static structures, including non-linearity; examples are geometrical and contact problems, and physical problems involving non linear material behaviour. But also dynamic simulation is possible with complex transient input behaviour like earthquake shocks and crash analyses. Also the determination of buckling and post buckling of slender structures, heat transfer (radiation, conduction and convection), fluid dynamics with heat transfer, mould-flow simulation for cast products, sheet metal forming, and less trivial: the simulation of force fields (electric, magnetic and gravitation), are examples of what is treated in present-day applications of FEM. A recent development in this area is the simulation of all kinds of coupled problems, of which the so called fluid-structure interaction is a good example. Here a flow solver is coupled with a structural solver in which the fluid flow and the deflection of the structure influence each other. This coupling occurs for instance in the simulation of a sail boat sail under wind pressure.

Restrictions

All these possibilities excite mechanical engineers to a large extent, but two main drawbacks have stayed the same over the years. Firstly, highly skilled and experienced engineers are necessary to reliably exploit finite-element methods, though amateurs (e.g., by the help of wizards) can easily reach nice looking results. The latter can be helpful to obtain general information about different design options but may be hazardous to base final design upon. As an example, recently accidents occurred in which balconies were breaking from houses and roofs collapsing under snow loads. Secondly there is always a

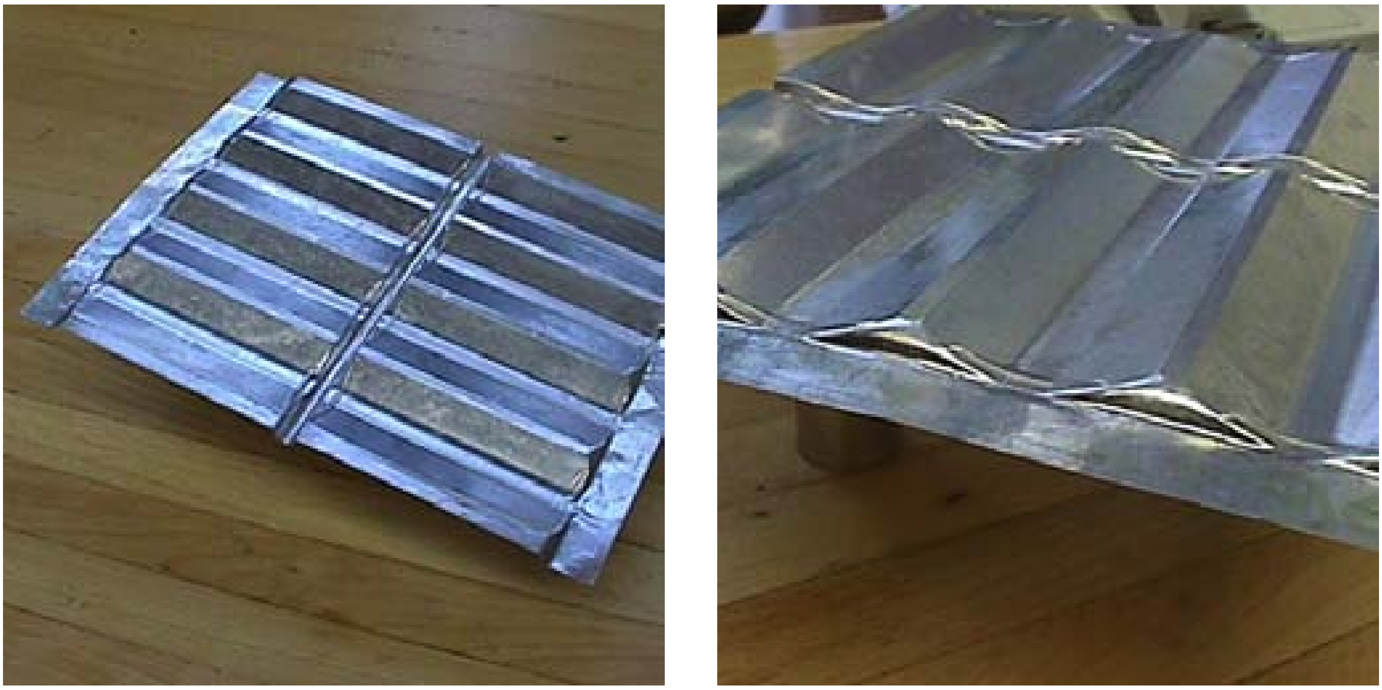


Figure 2. Left : one of the first attempts to manufacture the vacuum foil of the vertex detector. Right: close-up of this foil showing the cracks caused by too much local deformation.

lot of expertise needed for the correct interpretation of the calculations. In fact this problem is another reason for the accidents just mentioned.

FEM at NIKHEF

At NIKHEF, finite-element methods have been used for many years in mechanical design. Many of the applications and tools mentioned above have been employed in the design of instrumentation for physics experiments. An example is given in Fig. 1, which shows a vibration mode calculated with FEM for a detector box of the LHCb Vertex Locator.

The coming years a new and important step in further applying FEM at NIKHEF will be made. For the LHCb Vertex Locator very thin specially shaped foils were made to separate the LHC beam vacuum from the detector vacuum. This foil was developed by trial and error (see Fig. 2) for an intermediate step in the development), and it took several years to find a production process for this technique, which is called super plastic sheet metal forming (SPF). Our aim is to be able to simulate this SPF-process with FEM in the near future. The SPF process is not very endurable and therefore we are not able to make foils in a reproducible way. Many of them have been thrown away before we were left with a few good ones. Luckily we need only a few of them. With good simulation models we would not have been spending so much time, money and effort in obtaining the four foils needed.

SPF research project

A PhD research project was started in 2005 to model the SPF process and thus to reduce the costs of future products made by super plastic forming. The aim is to simulate the manufacturing process using FEM in order to gain a better insight into the forming possibilities of such thin foil products. State-of-the-art FEM computer codes are directly applicable to solve problems like this. But especially material models, including the appropriate material constitutive equations, used by FEM-solvers are not available. In addition, many other modelling problems arise when one wants to simulate SPF work because the discontinuity of the process is influenced by a large number of parameters.

In the research project special attention will be given to the manufacture of foils for future Vertex Detectors. The goal of this research is to determine a design strategy for developing this kind of foils. Such a strategy should exclude as much as possible that the user needs to perform extensive optimization steps or complex forming analyses. The idea is rather to find a set of rules that one can use in developing these thin foils. Spin-off from this research project can be expected since industrial interest for SPF is growing.

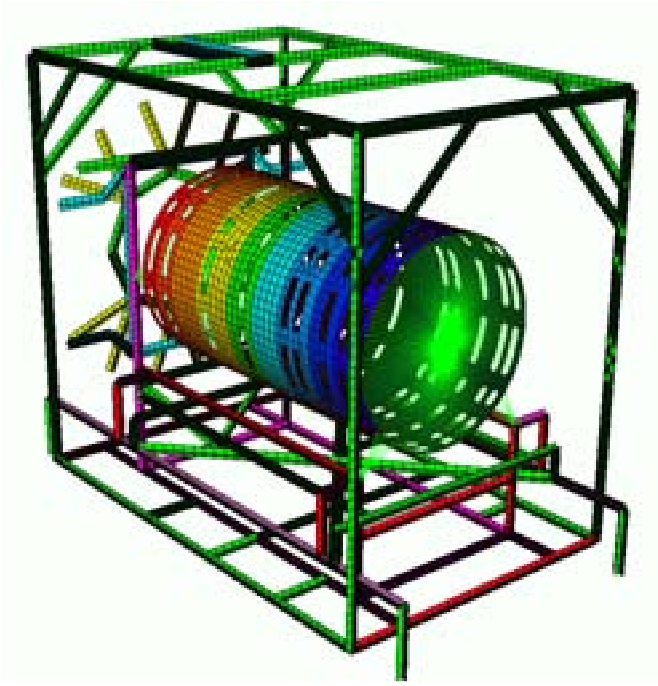


Figure 3. The test model (left) and the FEM model (right) for the transport of the Atlas ECT detector developed and produced at NIKHEF.

Two main subjects will be studied in the research project:

- Simulation of forming processes, especially SPF with large deformations and strains. This requires appropriate finite-element analysis software and, of course, theoretical knowledge. For the calculations we will employ two different codes: DiekA, which is developed by the University of Twente, and the commercial software package ABAQUS. To obtain reliable results, we need a thorough understanding of material parameters, the sensitivity of the computed results to these parameters, and the possibilities and limits of the finite-element software.

- Optimization of the topology of vacuum foils employed in vertex detectors, with the objective to minimise the thickness in radiation length. This optimization process must communicate with the manufacturing process in such a way that the final product meets the requirements posed by both physicists and engineers. Moreover, sufficient wake-field suppression can be an additional constraint; such a requirement would make the task a complex multi-objective optimization problem.

Other FEM applications at NIKHEF

We made FEM simulations for the transport of the ATLAS SCT-cylinder from Amsterdam, where it was assembled, to the ATLAS cavern at CERN. To make sure that the cylinder loaded on a truck lorry would survive any possible traffic actuation due to road imperfections or traffic incidents a FEM model was built and verified under transport conditions (see Fig. 3) For that purpose we performed a test ride with a dummy cylinder, equipped with sensors and a movie camera. The measured data were used to validate the results calculated with the FEM model. With the latter the engineers could then specify the right suspension for the cylinder in the lorry. No more test rides were necessary, which saved a lot of time and money.

For the Alpha Magnetic Spectrometer (AMS), a project for the International Space Station (ISS), NIKHEF made the design for the cooling system (see Fig. 4) for the silicon detectors. Part of the cooling system is the evaporator, for which the difference in temperature between assembling conditions and working conditions can be as large as 60 K (from +20° to -40° C). The temperature of -40° C will be the working temperature of the cooling pipes. Contraction of the pipe material will lead to displacements and stress in the assembly. The displacement of the exit Clamp Base due to a deformation of the cooling pipes of 1.8 mm, induced by a 60 K temperature difference, was calculated to be 0.69 mm.

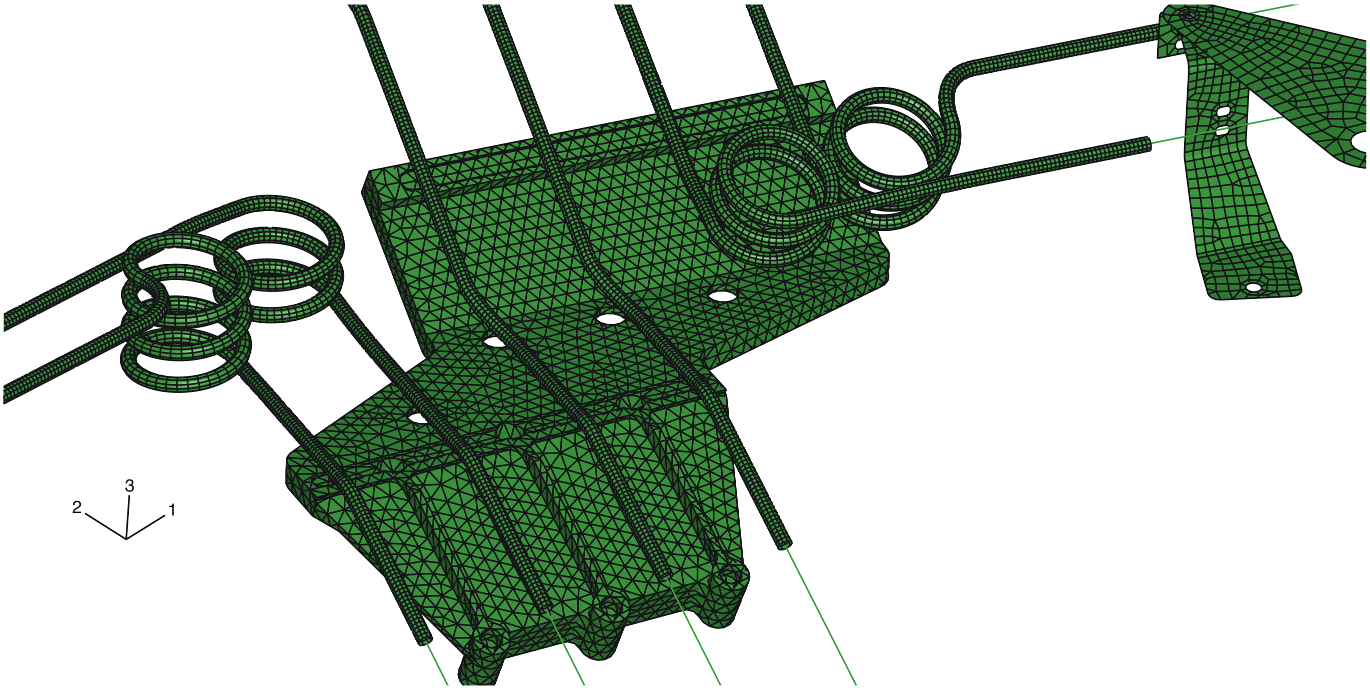


Figure 4. Part of the cooling system for the AMS in the International Space Station.

Conclusion

FEM has developed into a mature and versatile tool engineers can not do without. Already at present, but certainly in the very near future, its application will make a lot of prototyping obsolete. Though prototyping will always be needed for verification of the simulations, it will be less costly and can be rather simple. This will reduce development time and can increase quality. FEM can be risky in the hands of users who are not aware of what they are doing. Integration of FEM with CAD can reduce this problem but expert designers can not be missed in an organisation where FEM is chosen as one of the core technologies for the support of Engineering and Development.

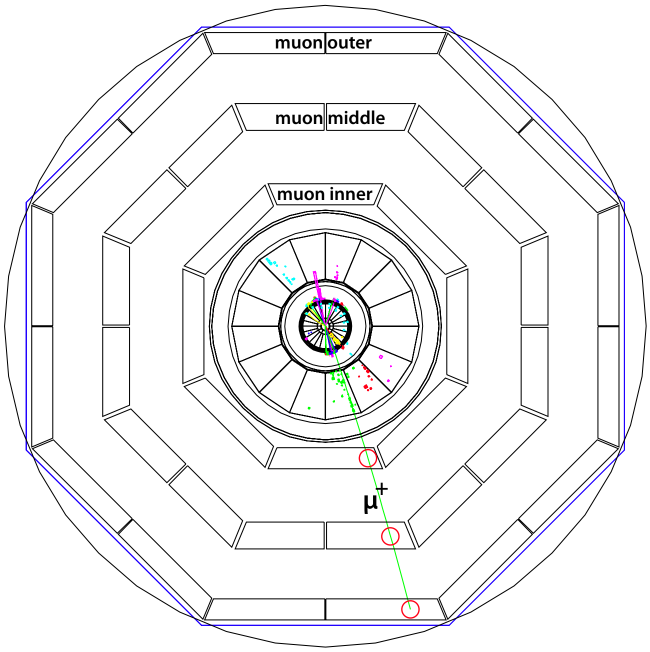


Figure 1. A muon event in the L3 experiment. The curvature of the muon track (green curve) is a measure for its momentum.

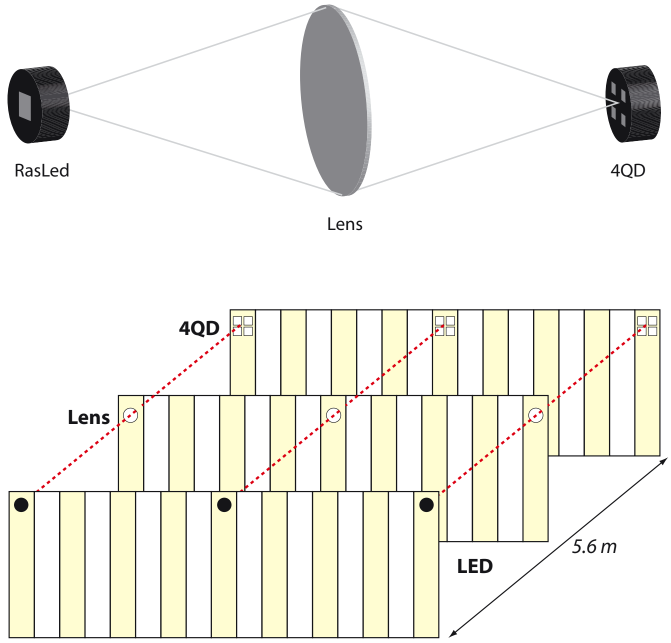


Figure 2, top. Principle of the RASNIK four-quadrant system (4Q). The image of the LED is projected onto the 4Q photo diode. Bottom: Wire positioning in the L3 muon chambers. The middle wire support should be well in line with the outer two. The alignment is monitored by means of 3 RASNIK systems.

The RASNIK Alignment System

Alignment systems are an essential element in high-energy physics equipment. For the L3 experiment NIKHEF has successfully contributed with the RASNIK ('Red Alignment System NIKhef') technology. Today an extension of this system with pixel chips is in wide use in several experiments at the LHC.

Detector Alignment

For the L3 experiment, operational at CERN from 1989 to 2000, NIKHEF has contributed 32 large drift chambers to the muon spectrometer. The muon chambers formed three coaxial cylinders which were placed in a large solenoid magnet. Due to the Lorentz force, the muon tracks are curved, and the radius of curvature is a measure for the muon momentum. This radius can be measured by recording three points of the track, by three chambers (see Fig. 1).

An accurate measurement of the muon momentum requires not only a good position resolution of the chambers and a precise knowledge of the magnetic field; also the position of the middle chamber with respect to the inner and outer chamber should be known, in the bending direction, with a precision of 20 μm. Technically it is hard to position and to permanently keep the chambers fixed within this tolerance. Instead, the position of the middle chamber, relative to the inner and outer chamber has been monitored permanently, and the alignment data were used to correct the track curvature. After proper calibration of the alignment systems, the muon momentum measurements do not depend on the chamber positions.

The essential sensor of the RASNIK system, as applied in the L3 muon spectrometer, is a four-quadrant photo diode. The light from a source with a well-defined square geometry is projected, by means of a simple positive lens, onto this sensor (see Fig. 2, top). The ratio of the four currents from each diode segment is a measure for the image position with respect to the sensor, and therefore a measure for the alignment of the source, the lens and the sensor (see Fig. 3). By connecting light sources to the inner chambers, lenses to the middle chambers and sensors to the outer chambers, the relative positions of the middle chambers can be monitored and corrections can be applied in computing the track curvatures (see Fig. 2, bottom).

Precision

By applying modulation on the LED light sources, and by using analog multiplexing in the read-out system of the (amplified) current signals from all individual photo diode segments, drift in the systems was virtually eliminated, and the systems could work in daylight. A precision of 10 μm has been reached, in terms of a lens displacement, in the directions perpendicular to the optical axis (see Fig. 4). The errors were due to image blurring (diffraction, off-focus and non-sphericity of the lens), and due to non-homogeneous light-emitting surfaces. After careful calibration, precisions of 1 μm could be reached.

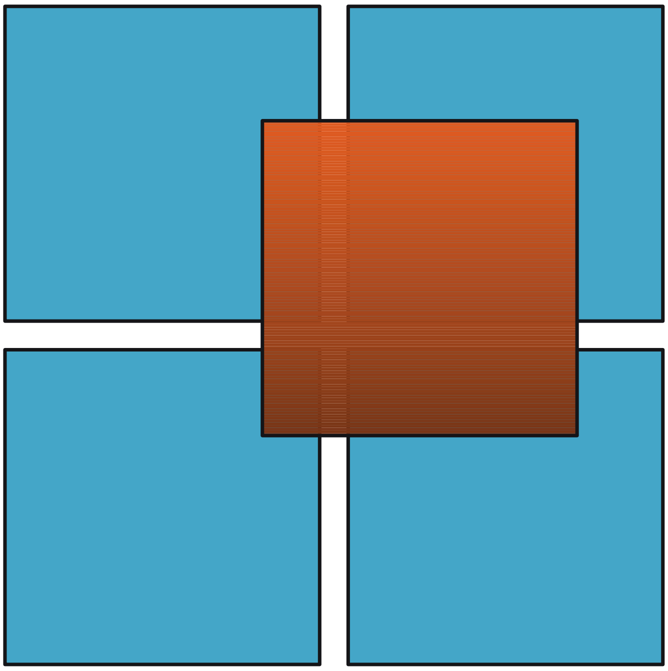


Figure 3. The image position follows from the currents through the four diode quadrants.

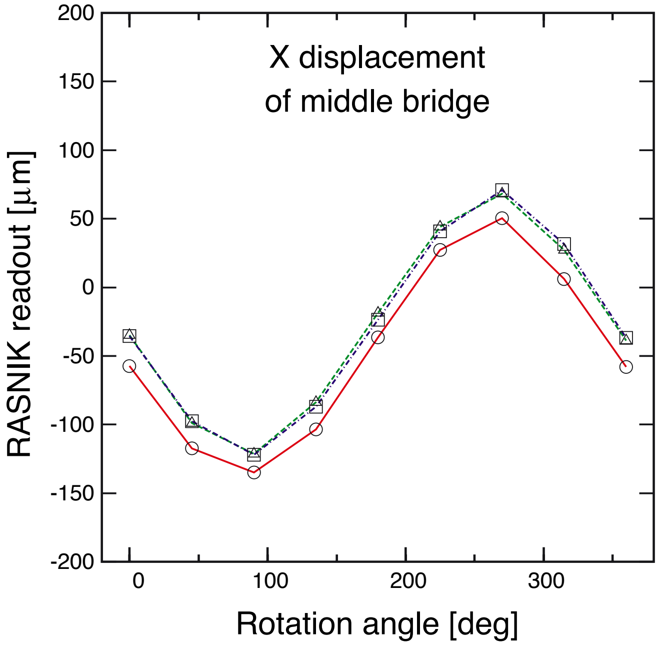


Figure 4. The read-out values of three RASNIK systems in a chamber, when rotating the chamber 360 degrees around an axis parallel to the wires. The three systems agree within 20 µm over a range of 200 µm.

In practice, both systematic and statistical errors are larger: variations in the refraction index of the ambient air, which are generated due to temperature gradients and air convection, are the dominant contributions to the ultimately attainable accuracy.

Thanks to their low costs and high precision, RASNIK systems were also applied as wire 'straightness monitor'. The 6 m long wires in the L3 drift chambers, accurately suspended at both ends, required an additional fixation in the centre in order to limit the wire sag and to prevent deflection due to electrostatic forces. The 'middle bridge' needed therefore to be placed in line with the outer two. For this purpose three RASNIK systems were applied. From the internal consistency of the thus obtained redundant data the required precision of the system, including mechanical aspects, could be achieved.

RASNIK systems in the ATLAS detector

In 1993 the concepts for the large muon spectrometer of the ATLAS experiment (see elsewhere in this Annual Report) were established. The principle of a 'floppy floating' chamber, combined with high-precision monitoring of position and geometry was enthusiastically adopted: some 7000 RASNIK systems were foreseen to be applied. In the L3 detector the range of the RASNIK systems was limited by the size of the four-quadrant photo diode (fiducial surface 2.5 mm^2). In ATLAS, the required range of several alignment systems is up to 20 mm due to expected variations in the position of the chamber. These uncertainties are caused by magnetic forces on the toroid coils, and by several mechanical tolerances in chamber supports. Consequently, large and expensive four-quadrant sensors would be required, and the two-dimensional (scanning) calibration procedure would be a major project by itself. Instead, an alternative was developed that employs new low-cost (video) CCD chips. The square homogeneous light source was replaced by a coded mask, illuminated from behind, and this object is projected onto the CCD.

The video signal from the CCD chips is converted into image frames by means of a frame grabber in a pc. In an on-line image analysis, four parameters per image are calculated: both transverse image positions, the image scale and the image rotation around the optical axis (see Fig. 6). In theory any pattern could be used as image object. Black-white contours, though, contribute efficiently to image position information.

The chess-board pattern (see Fig. 5), proposed by NIKHEF technician Henk Groenstege, has shown to perform outstandingly, a better one was never found. The total contour length, in both directions, is maximal given the minimal chess field pitch, required for non-sharp images. In each 9th row or 9th column, an 8-bit digital code is applied, representing the coarse image position; over a large surface the coded pattern in a small section is thus unique. The fine position is obtained from the black-white contours.

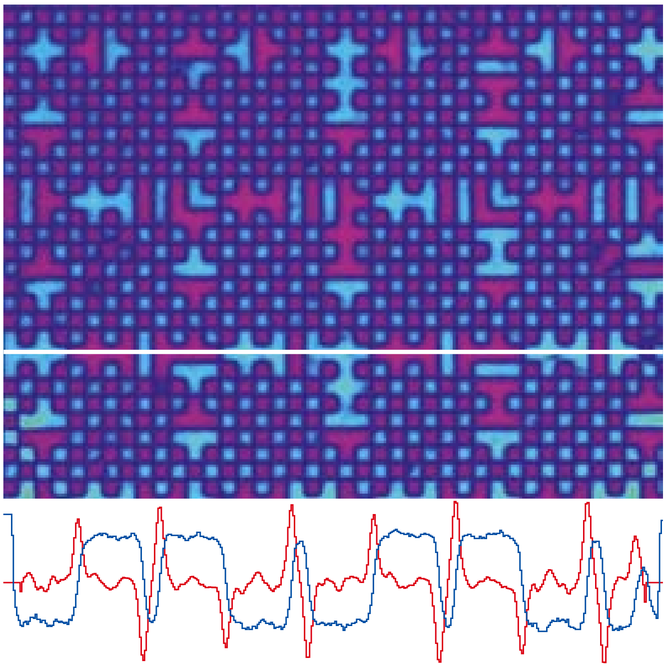


Figure 5. Typical (false colour) image from a CCD-RASNIK system. The light intensity, local at the white horizontal line is plotted (blue). After differentiation peaks appear corresponding to contour positions (red). The fine image position, as well as the image scale, is derived from these peak positions.

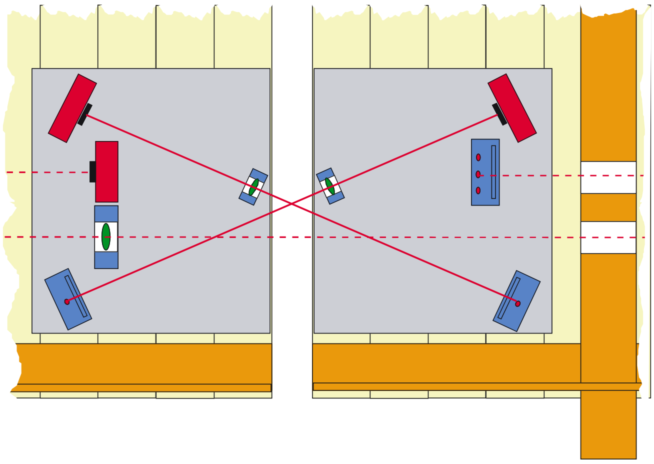


Figure 6. The Praxial alignment systems, placed at two adjacent chamber corners. These symmetrical systems measure three translations and three rotations of one corner with respect to its adjascent corner. As a result, the position of a chamber with respect to its neighbour chamber is known with redundancy.

The precision of the CCD-RASNIK system is determined only by the precision of the coded mask. These are manufactured by the chip industry, and contour precisions as good as 5 nm are possible. We have measured the intrinsic precision of RASNIK by placing a mask directly against the CCD, recording contact shadow images. Here, a precision of 50 nm per image was obtained for both transverse positions, a precision in the scale of 5 x 10^{-5}, and a precision of the image rotation of 0.02 mrad. The errors, both random and systematic, of practical RASNIK systems are determined entirely by the properties of the ambient light-transmitting medium.

In ATLAS, CCD-RASNIK systems are used as 'projective' systems, pointing towards the interaction point. The straightness of muon tracks can directly be compared with the local projective RASNIK systems, thus providing a straightforward chamber alignment correction. For the projective systems, the range of the RASNIK systems (determined only by the size of the masks) is as large as 50 x 50 mm^2.

Similar to the use in the L3 chambers, the 'InPlane' RASNIK systems are applied to monitor the chamber sag in the ATLAS detector. In addition, by applying two diagonal systems, the torsion of the chambers is measured with the same image sensors. The relative position of two adjacent chambers is measured by means of 'proximity' systems and 'praxial' systems (see Fig. 6).

In ATLAS, a total of 7000 CCD-RASNIK systems are applied. By means of a hierarchy of multiplexers, all sensors are read out sequentially by 6 pc's within 15 minutes. The corresponding light sources are powered only at the time of the measurement, thus minimising the required power. The price of the read-out system, after optimizing, is dominated by the cost of cables.

Outlook

For future linear colliders, new alignment systems are required. For the alignment, e.g. in CLIC, of 15.000 accelerator elements of 2.4 metre long, 30.000 low-cost RASNIK systems are needed, as well as some 600 systems with a distance of 100 m between mask and sensor. The latter would require an expensive lens of 1 metre diameter. An alternative is studied in which the lens is replaced by a hole, and the light source by a laser. The position of the diffraction pattern on the image sensor is a measure for the alignment, as before. Finally, alignment systems with sub-nanometre precision are required for the beam steering elements, since seismic noise causes the (nanometre wide) beams not to collide. This high precision may be possible with a RASNIK system using a four-quad photo diode sensor with quadrants of only 1 x 1 μm^2, in combination with a focused laser beam.

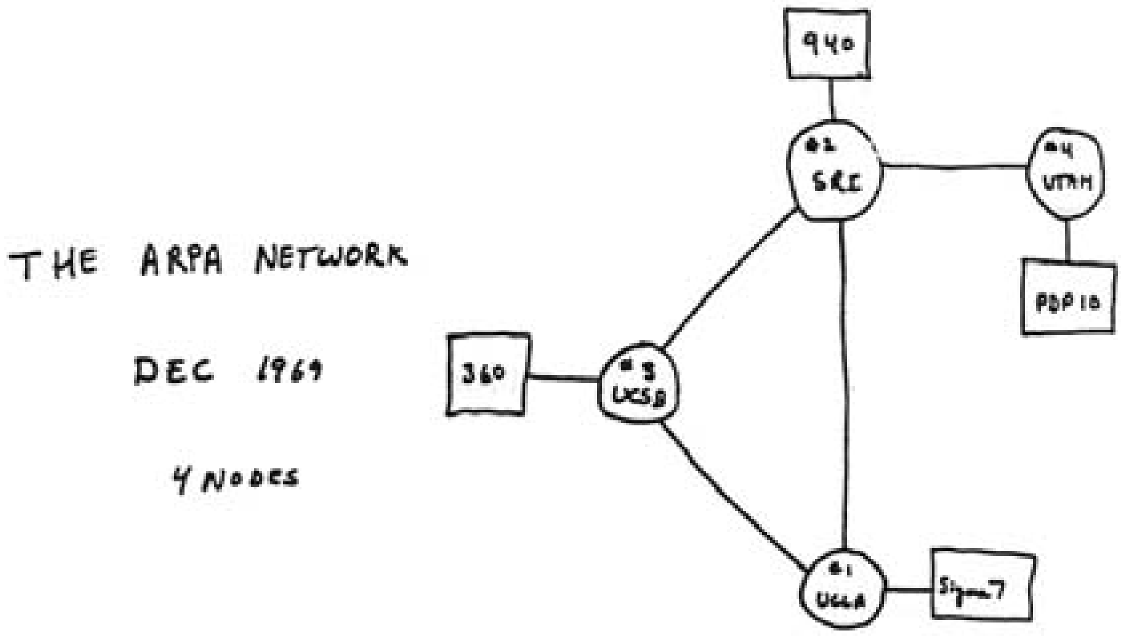


Figure 1. Sketch of the first ARPA network (predecessor of Internet), implemented in 1969 between four American universities.

The Internet – How big is it anyway?

A recent article in a quality newspaper had the title "Internet growth comes to a halt, but the Web is still growing". This title poses a few questions, the most interesting one being how to measure the size of the Internet. Since the Internet is not a centrally managed system this question is not easy to answer. One can only try to measure the actual size by looking at various parameters from the edges of the Internet. So, let us have a look at some of these parameters and try to draw conclusions.

The start of what we now know as the Internet can be traced back to December 1969 when a couple of universities in the USA connected their computers. Figure 1 gives the original network topology, and we can see that the size of the Internet was 4. Since those days the network has grown in size.

One of the early approaches to get a feeling of the size of the Internet has been to count the number of hosts connected to the net. In the early days of the net this was rather straightforward: almost all computers were directly connected to the Internet and they all had a unique Internet Protocol (IP) address and a unique domain name.

The Domain Name System (DNS) contains a distributed database coupling these addresses and names. In 1990 the late Eric Wassenaar of NIKHEF wrote the famous 'host' program that undertook a systematic walk through this database and counted the number of host entries.These counts have been done on a monthly basis for more than 10 years by NIKHEF and more recently by the RIPE NCC. Two numbers illustrate this:

2 October 1990	31,724
31 December 2005	14,981,314

A few comments on these results are appropriate.

In the first place these numbers refer to the geographical area of Europe, the Middle East and Central Asia. Secondly, while the first number gives a rather accurate description of the actual size of the Internet, the more recent number does not. This is caused by the fact that large numbers of computers nowadays are hidden by Network Address Translation (NAT) equipment and no longer appear in the DNS. One can think of compute farms or home equipment as examples. Finally, the total number of domain names in the global DNS today is about 80,000,000. Not all of them are active and contribute to the size of the Internet.

Let us now look at another parameter. The Internet is built by interconnecting networks owned and operated by Internet Service Providers (ISP). How many ISPs are there? This seems a rather easy question to answer: an ISP needs IP address blocks and the only way to get them is to join one of the 5 regional IP address registries. The combined membership of these registries today is about 10,000 ISPs. So, the Internet consists of about that number of networks, one might conclude.

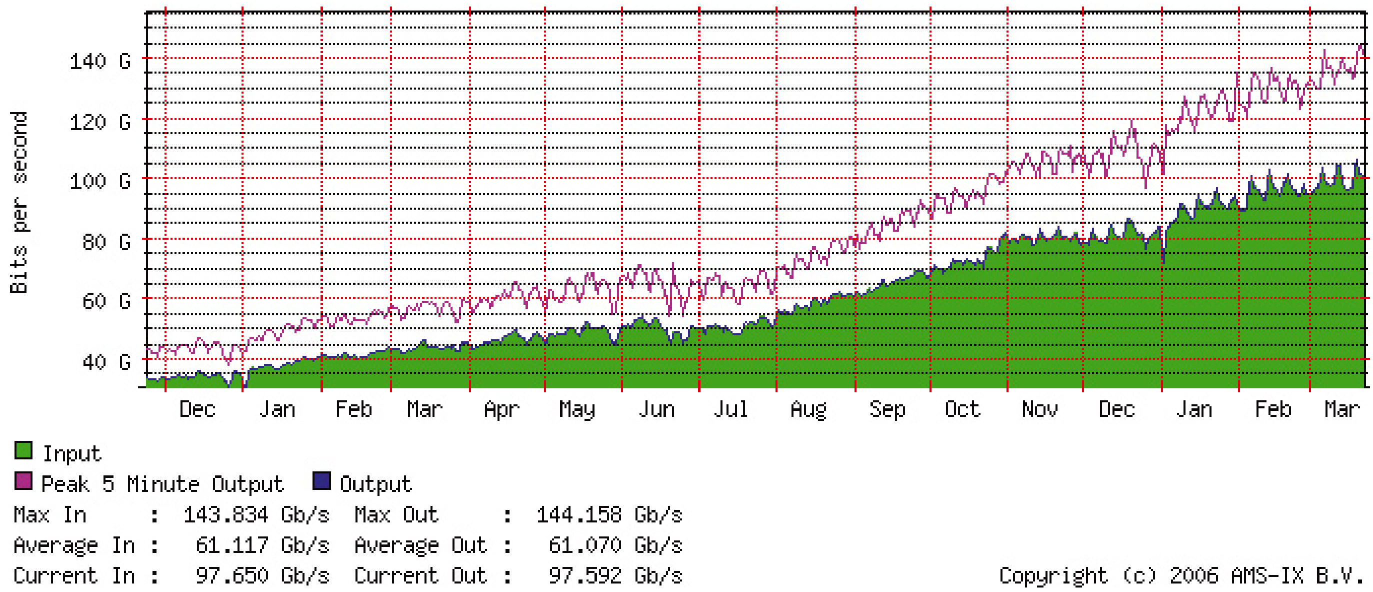


Figure 2. Data rates in 2004-2006 at the AMS-IX internet exchange point hosted by NIKHEF.

However, life is more complicated. Behind many of these ISPs reside other networks that do not deal directly with the regional registries, but do have their own networks. They just get their address blocks from upstream providers. To get an indication of how many of those exist we have to look at the routing system of the Internet. Routing on the Internet is again a distributed system. The basic principle is again simple: each network announces its existence to its neighbours, and the neighbours propagate this knowledge to their neighbours. After a while convergence takes place and a steady state is reached. If one now examines the routing tables, one can get a more complete picture of the interconnected networks.

The state of the global Internet routing table on 4 February 2006 tells us that 87,940 networks are announced by 21,423 ISPs. It is of interest to compare this with the global telephone system where there are less then 500 independent operators, highly regulated by the International Telecommunications Union (ITU) of the United Nations.

It is also of interest to note that the total announced IP address space amounts to 1,487,343,776 addresses. The equivalent number in the telephone system is approximately 1,000,000,000.

So, we have 21,423 ISPs that make up the global Internet by interconnecting their networks. There are various ways of doing this, the main ones being either direct connections or joining an Internet eXchange Point (IXP). An IXP is a neutral, common facility where several ISPs meet and connect their networks. The Amsterdam Internet Exchange (AMS- IX) is a good example of such an exchange point. The AMS-IX has currently 240 member networks and is one of the largest exchange points in the world. NIKHEF is home to about 100 of these ISPs and provides both AMS-IX connectivity and private interconnections. It is interesting to note that in 2005 more than 300 of these private interconnections were established at NIKHEF.

Let us now look at another parameter: traffic volume. How much traffic is there on the Internet? This question is easy to answer: nobody knows. However, we can have a look at various aspects of this question and come up with some interesting numbers.

In the first place traffic over the AMS-IX. Today the peak is at 140 Gbits/s, with the minimum value at 50 Gbits/s. The growth over 2005 was a factor 4. More details are shown in Fig. 2.

What is all this traffic? The major component today exists of peer-to-peer network traffic, in other words downloads of music and films. It is interesting to observe that many ISPs are trying to stop this traffic because their infrastructure cannot cope with the loads. ISPs can analyse the data content of IP packets and block e.g. BitTorrent packets. BitTorrent is a popular download mechanism. However, new versions of this application use encryption of their packets which circumvents ISP blocking of this

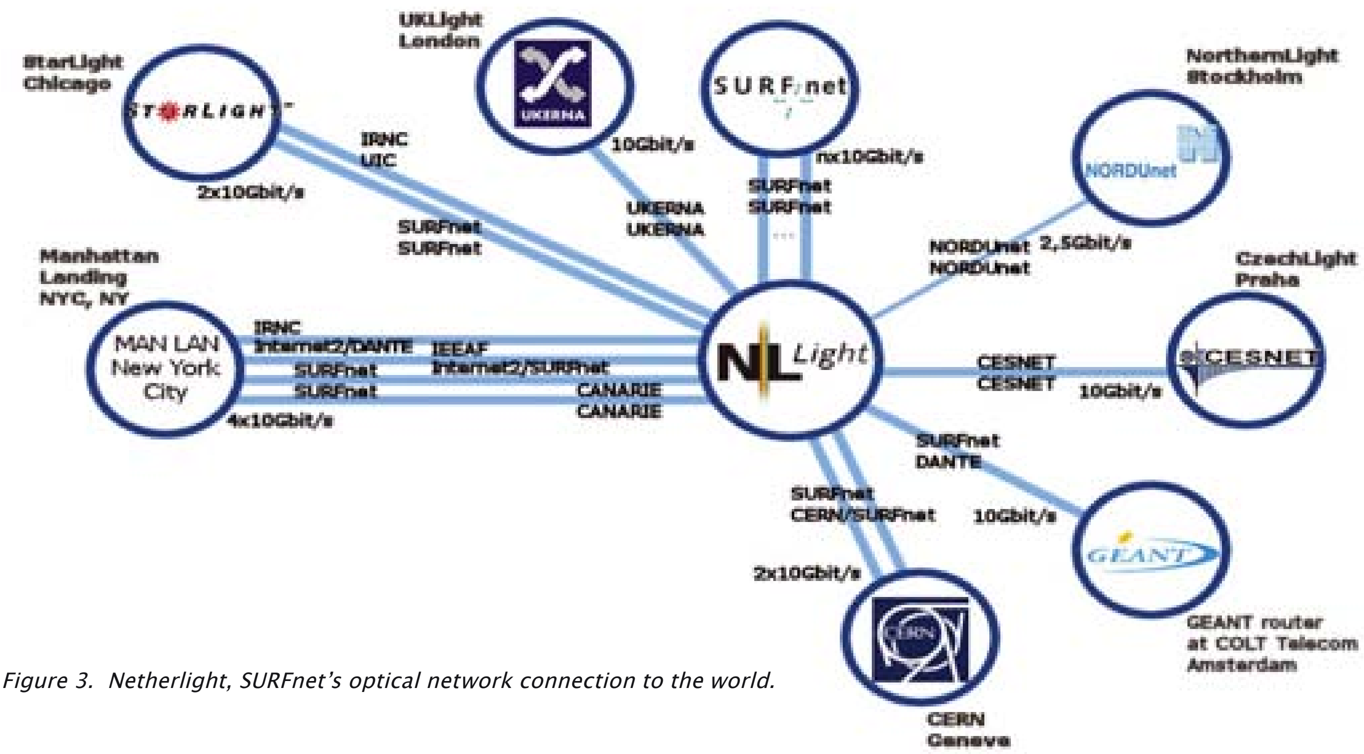


Figure 3. Netherlight, SURFnet's optical network connection to the world.

type of traffic. An interesting side effect is that law-enforcement agencies that do traffic sniffing suddenly find it impossible to analyse most of the Internet traffic. A blessing in disguise, according to some.

To transport all this traffic bandwidth is needed. So, how much bandwidth is there on the Internet? This varies dramatically. For example, it is not uncommon for a NIKHEF user to have 8 Mbits/s as a connection to the home. In Japan or Korea she could have 1 Gbits/s for the same price, whereas many African countries have less than 8 Mbits/s as total international connectivity. Pricing is even more divergent: 1 Mbits/s costs typically US$ 5 per month internationally, whereas in many African countries this will be US$ 15,000 per month. This is sometimes called the digital divide, but it is clearly more an economic divide. One of the roots of the African problem lies in the monopoly position of national telecommunication companies.

NIKHEF started international networking in the early 80's with 1200 bits/s connections. Today this has grown to a grand total of 30 Gbits/s thanks to the good works of SURFnet, our national academic and research network. SURFnet has built an optical network (see Fig. 3) that is the most advanced network of its kind in the world. NIKHEF is connected at 10 Gbits/s for general Internet connectivity. In addition to this SURFnet provides 10 Gbits/s to CERN in Geneva (Switzerland) and 10 Gbits/s via ESnet to Fermilab in Chicago (U.S.A.).

We started with the question of how big the Internet is. We have seen that this question is not straightforward to answer; therefore the real answer might well be: 42.

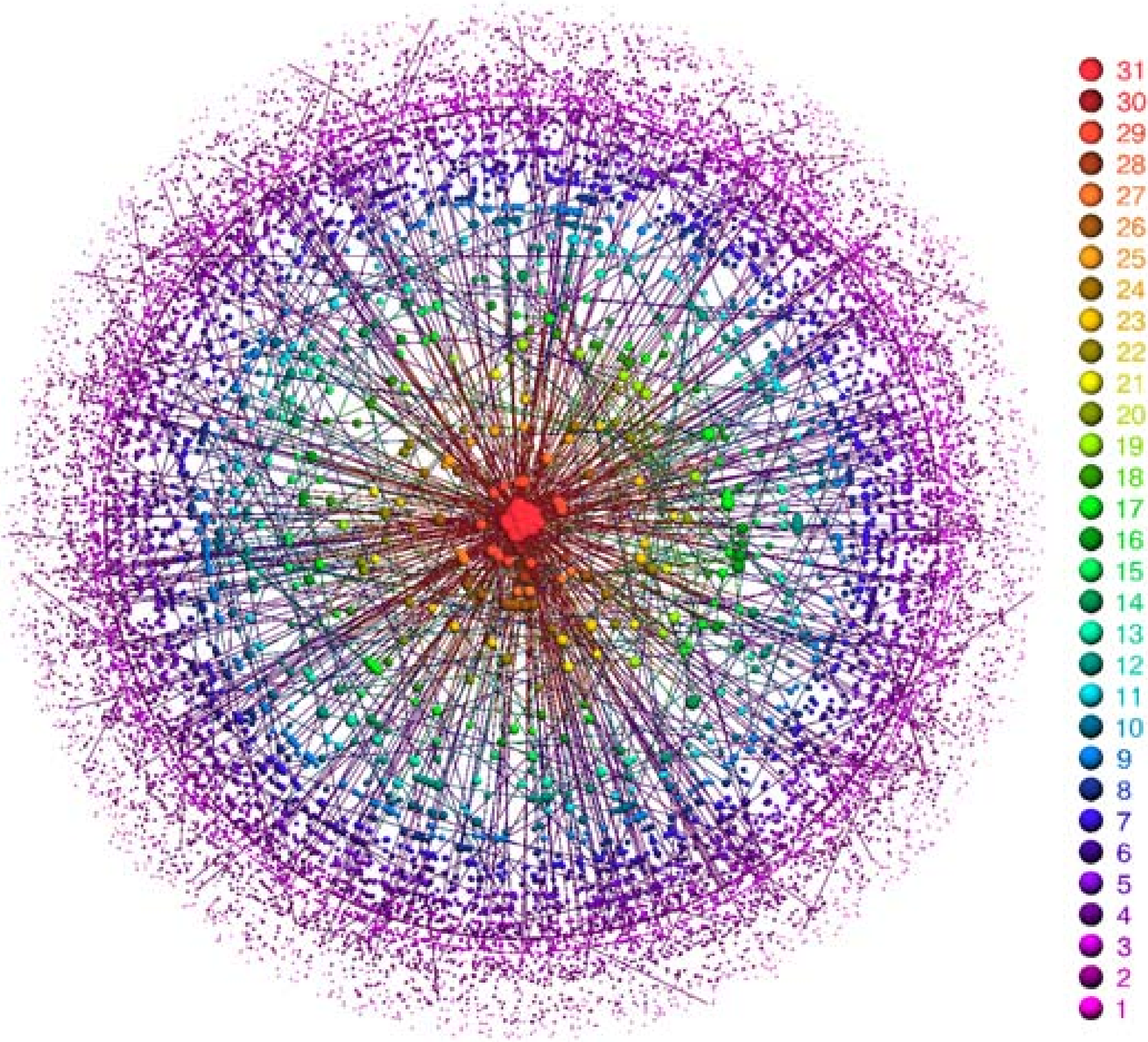
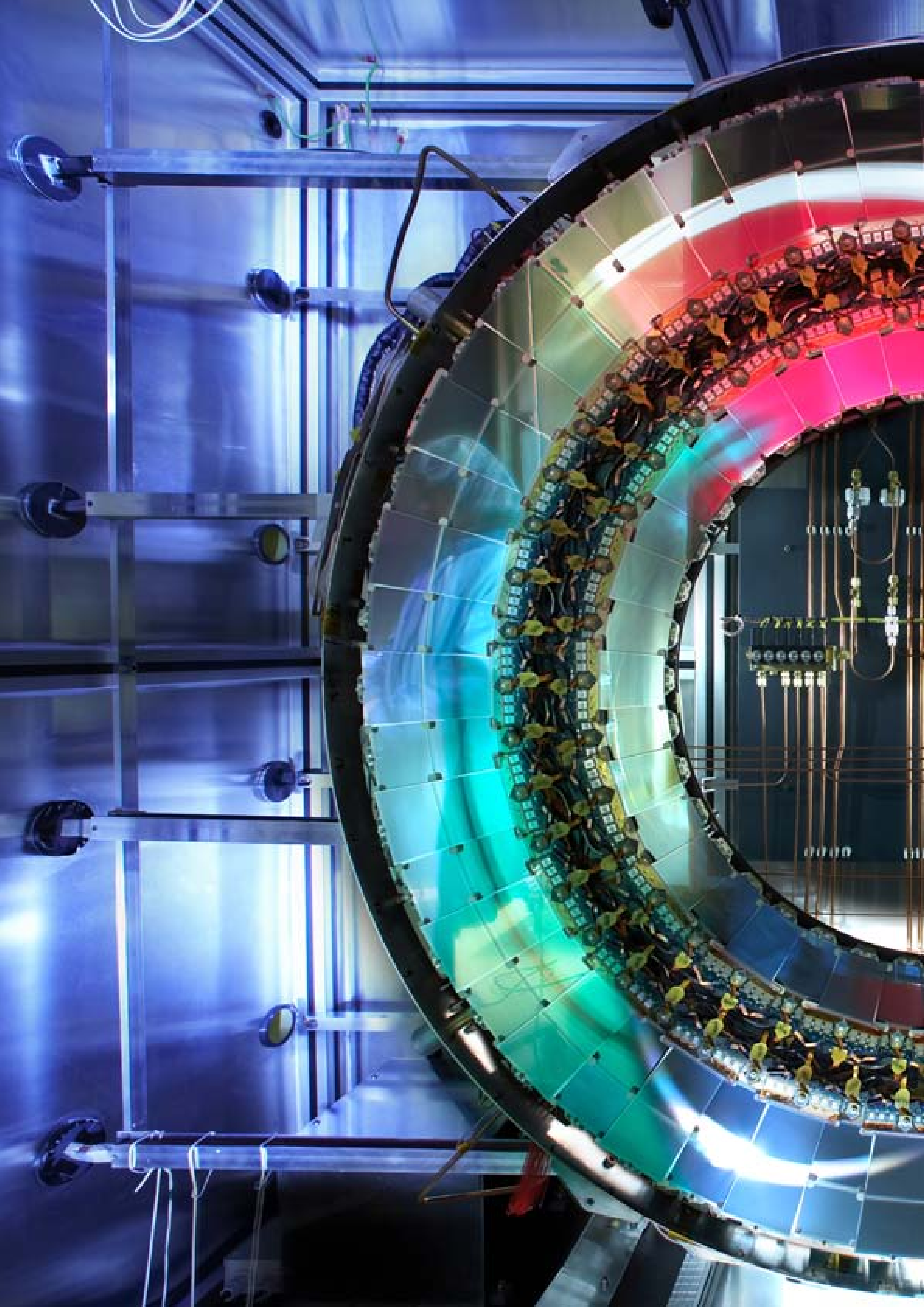
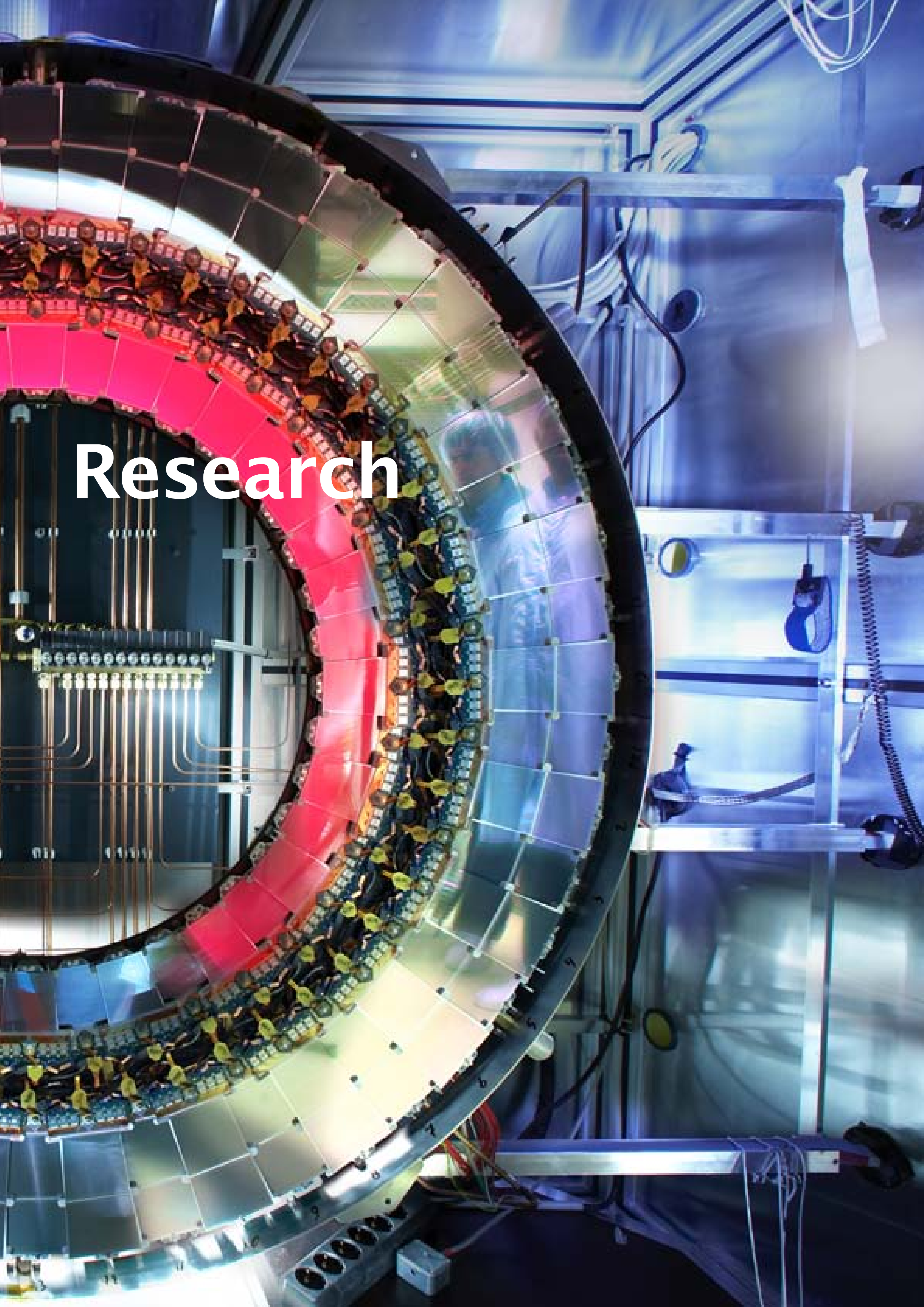


Figure 4. An IP-address map by DIMES (http://www.netdimes.org).



Research



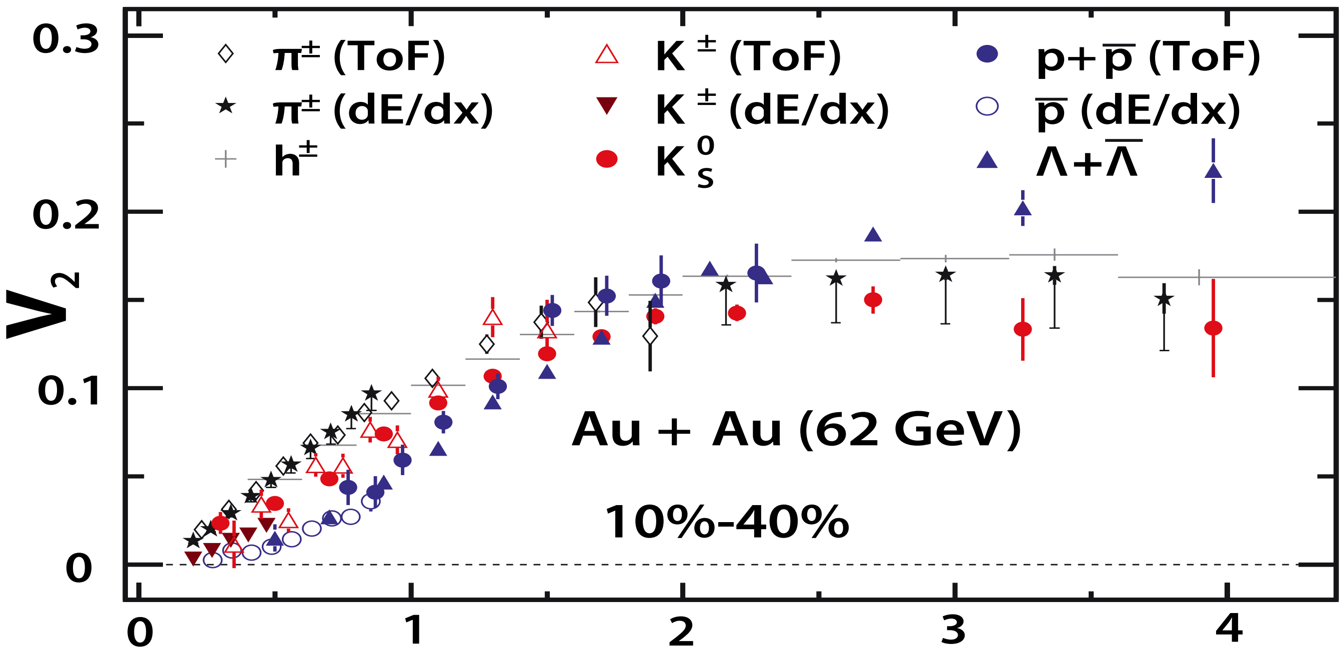


Figure 1. Elliptic flow strength v_2 as a function of transverse momentum for different particle species in semi-central Au+Au collisions at 62 GeV.

ALICE

Introduction

In the standard model of particle physics quarks and gluons are the fundamental constituents of protons and other similar particles, called hadrons. These constituents, however, have not been observed as free particles. Their mutual interaction, the strong interaction, confines them within the hadrons.

The theory of the strong interaction, Quantum Chromo Dynamics (QCD), predicts the existence of a new form of matter at high density and temperature, called a Quark Gluon Plasma (QGP), where the quark and gluon degrees of freedom are liberated instead of being confined within hadrons. In collisions of heavy-ions of very high energies in particle accelerators experimentalists attempt to create this new state of matter and study its properties.

The NIKHEF heavy-ion group is participating in the ALICE experiment at the future LHC collider at CERN, Geneva. The group has a leading role in developing and building a Silicon Strip Detector (SSD) as part of the Inner Tracking System (ITS) of ALICE and is preparing the future analysis with the ALICE detector. Furthermore, the group is involved in data taking and analysis in the STAR experiment at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. In the following some highlights of these activities are discussed.

Results from STAR

A major analysis focus has been the investigation of azimuthal asymmetries of the distribution of particles produced in a heavy-ion collision, in particular the so-called elliptic flow. The excited matter produced in a non-central heavy-ion collision has an asymmetric, almond-like transverse shape. This asymmetry in shape leads to a pressure gradient that depends on the azimuthal angle, which in turn produces an asymmetry in the emission pattern of particles. The strength of this asymmetry can be best characterised by a second order Fourier coefficient v_2.

Recently, such an analysis has been performed on data obtained at a beam energy of $\sqrt{s_{NN}}$ = 62 GeV, somewhat below the maximum energy of $\sqrt{s_{NN}}$ = 200 GeV at RHIC. Some of the results are displayed in Fig. 1, which shows v_2 as a function of transverse momentum p_T for different identified hadrons. The general behaviour is already known from analysis of the data at the maximum beam energy: v_2 increases with p_T, and the particular shape of this increase is different for the different hadrons.

At low p_T this pattern reflects the mass of the hadrons, and it is very nicely explained by hydrodynamic motion. The best theoretical description of the data is obtained, if one assumes the produced matter to undergo a quark-

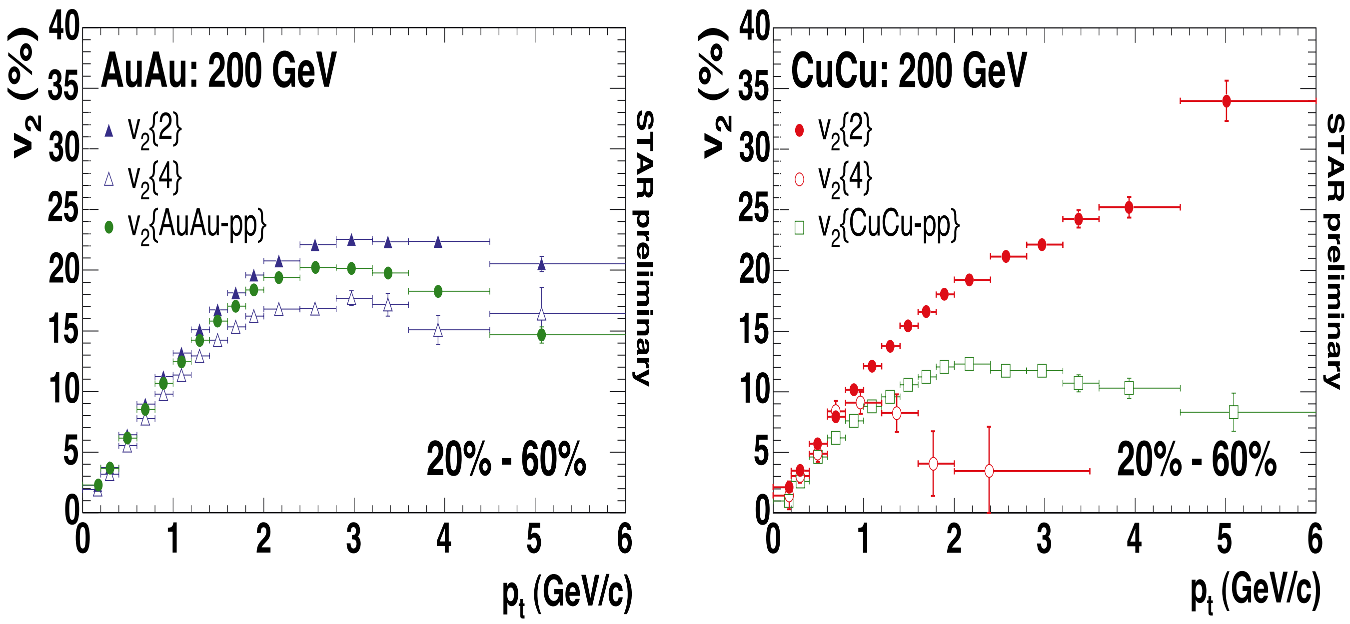


Figure 2. Elliptic flow strength v_2 as a function of transverse momentum for Au+Au and Cu+Cu collisions at 200 GeV extracted with different methods.

gluon-plasma phase followed by a transition to confined hadronic matter. This transition was observed first at the maximum RHIC energy, and similar conditions are obviously already generated at the lower beam energy.

A lot of systematic checks are underway to consolidate this important observation. One of these is documented in Fig. 2, which shows v_2 as a function of transverse momentum for Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}}$ = 200 GeV extracted with different methods. The analysis of elliptic flow essentially measures correlations between the emitted particles. Because of this, the result is not only sensitive to the true collective motion, but also to other correlations which may, e.g., originate from jets produced in the collisions. The different methods exhibit a very different sensitivity to these unavoidable correlations and can therefore test the magnitude of their influence. It can be seen in the left panel that the differences between the different analyses are small for Au+Au reactions, which makes the results easier to interpret than those from Cu+Cu reactions, which show large differences as seen in the right panel. These differences are the subject of further ongoing studies.

Status of the ALICE silicon strip detector

This year saw the start of mass production of all subsystems for the SSD. The responsibility of NIKHEF is in the integration of modules on ladders on the support structure of the ITS and the complete read-out chain from the front-ends onwards. In the successful ITS beam-test in 2003 all these components have shown to operate as expected.

A highlight for the NIKHEF ALICE programme was the completion of the first SSD ladder (see Fig. 3). Twenty-two doublesided detector modules were positioned on the assembly bench with an accuracy of a few micrometers. Then they were glued to the carbon-fibre ladder-frame and the hybrids were connected to the cooling tubes. Later, the 44 ladder cables were soldered to the hybrids and connected to the EndCap boards. The accuracy of the positioning machine is about 2 μm, the finally achieved accuracy, after hybrid and cable connection, is slightly worse. After completion the module positions are determined with a 3D measuring machine. In this way the sensor positions will be known in the experiment with the required 10 μm precision.

Another important activity in Amsterdam is the mass production of EndCaps. Because of the rather high power density, the boards consist of an aluminium core with copper-on-kapton circuits glued onto it. The aluminium core is thermally connected to a water cooling circuit, which also cools the front-ends on the ladders.

The ASICs ALABUF and ALCAPONE are wire bonded onto these boards, whereas the SMD-components are soldered. Zero-insertion-force connectors allow the thin

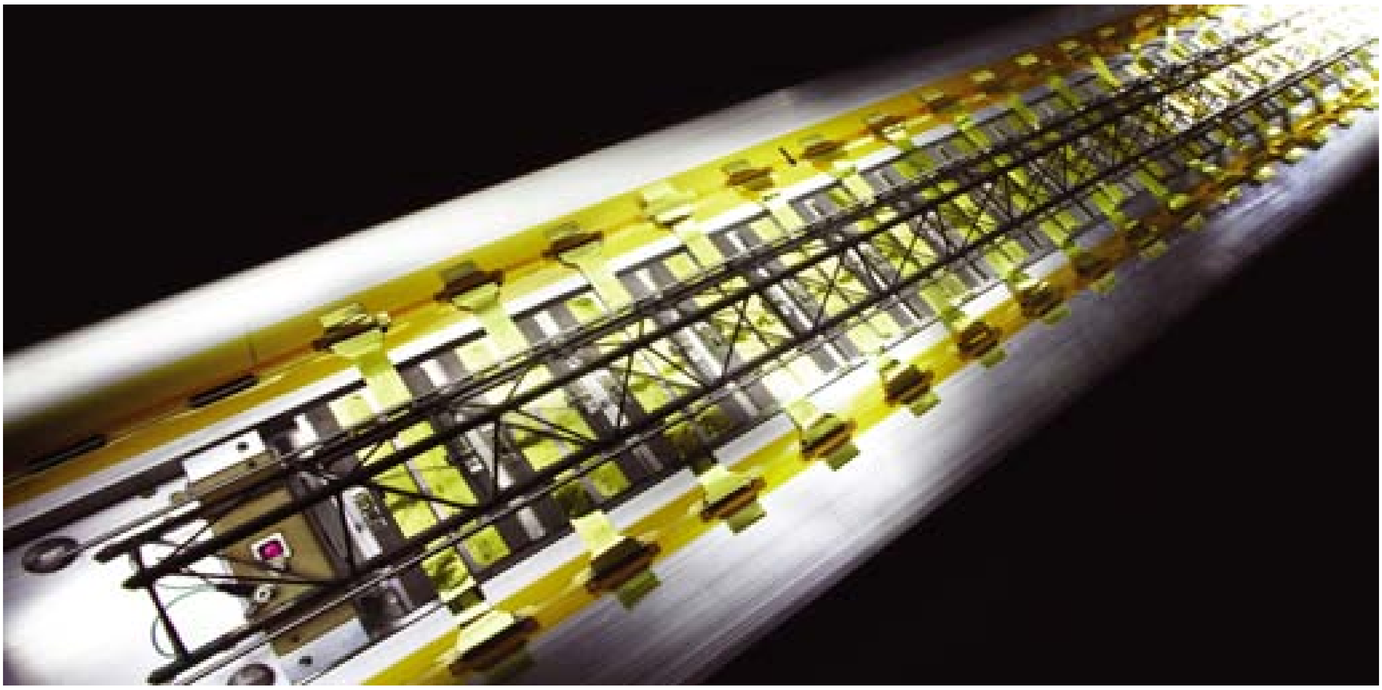


Figure 3. A ladder of the ALICE silicon strip detector with mounted detector modules.

ladder cables (aluminium-on-kapton) to be connected. The high yield of the ASIC production allows the use of untested chips, with only one fifth of the boards to be repaired. About 70% of the required number of boards is available for mechanical integration. Some 10% of the EndCaps is fully completed.

In parallel the analysis of the first data is already being prepared through software development and Monte-Carlo simulation. Elliptic flow has proven to be a very useful observable. While it may be carried to high levels of sophistication, already a simple analysis will provide crucial information for understanding the collision dynamics. Thus the group has concentrated on this observable for its first analysis steps. Simulations using the newly developed software components have already shown that the sensitivity of the ALICE detector to elliptic flow will be very good.

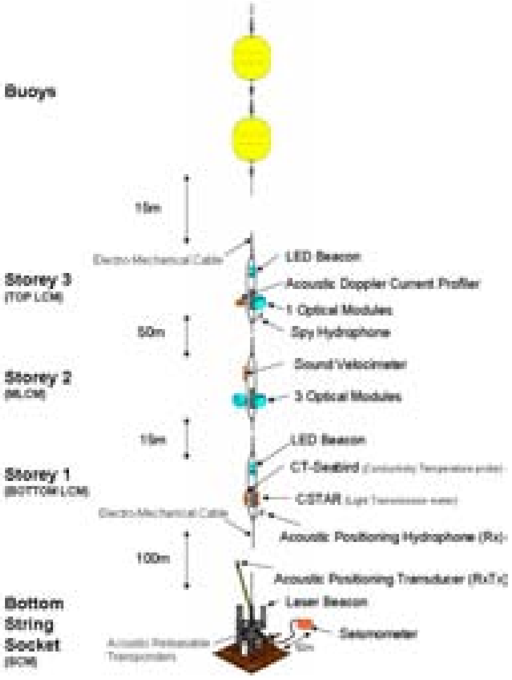


Figure 1: Schematic drawing of the instrumentation line ('MILOM') that has been deployed and operated by the ANTARES collaboration in 2005.

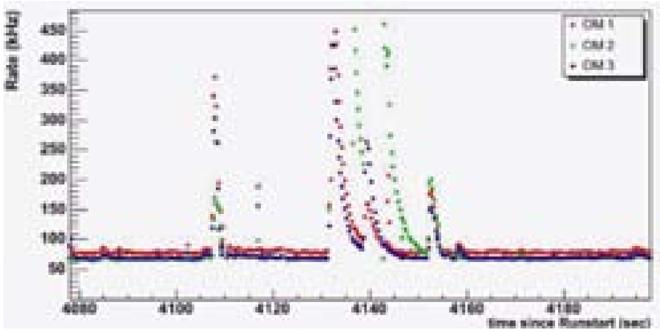


Figure 2: Count rates observed with the three optical modules (OM1, OM2 and OM3) of the instrumentation line. The count rates are plotted as a function of time. While on average the count rates amount to about 70 kHz, during short periods of strong bioluminescence a dramatic increase of the rate is observed.

Astroparticle Physics

In 2005 enormous progress has been made towards establishing Astroparticle Physics as a new interdisciplinary research programme in the Netherlands. In a joint effort, involving research groups from ASTRON, KVI, NIKHEF, SRON and several universities, a strategic plan has been developed for this field, which has been submitted to NWO. This national strategic plan for astroparticle physics is focussing on one research topic: the origin of (ultra) high-energy cosmic rays.

This central theme is addressed by exploiting various techniques for which considerable expertise exists in the Netherlands:

- radio detection of cosmic rays;
- deep-sea neutrino detection;
- gravitational wave detection.

In such a multi-messenger approach various aspects of the central research question can be addressed independently. Radio detection of cosmic rays enables the study of the actual development of the extended air showers in the atmosphere and the chemical composition of the incident cosmic particles. Deep-sea neutrino detection will make it possible to identify the astrophysical (point) sources from which the cosmic rays originate, while gravitational waves give – once they are detected – information on the nature of these (compact) astrophysical objects. In each case the proposed observational strategy involves both facilities that give fast access to data (such as the Pierre Auger Observatory, ANTARES and Mini-Grail, respectively) and future facilities for which research and development work has to be carried out (such as LOFAR, KM3NeT and LISA, respectively).

The Strategic Plan for Astroparticle Physics in the Netherlands was well received, and has already led to several new initiatives. Two examples are mentioned. In 2005 the Netherlands Ultra-high energy Cosmic-ray Collaboration (NUCC) was formed involving researchers from ASTRON, KVI, NIKHEF and the Radboud University, which – as one national team – joined the Auger collaboration. The Pierre Auger facility in Argentina, which was inaugurated in the autumn of 2005, presently represents the most advanced cosmic-ray observatory in the world. It was specifically designed to observe the highest-energy cosmic rays with energies in excess of 10^{18} eV. Within Auger the Dutch team will focus on implementing the distributed radio detection technique developed for LOFAR. As a second example the efforts to set up a research group studying gravitational-wave physics can be mentioned. In collaboration with NIKHEF and SRON a group at the Vrije Universiteit prepared a letter of intent for data-analysis activities of the future LISA space-based laser interferometer. The same group also established initial contacts with the Italian-French VIRGO collaboration. Both LISA and VIRGO are state-of-the-art gravitational-wave detectors based on laser interferometry, covering complementary frequency ranges.

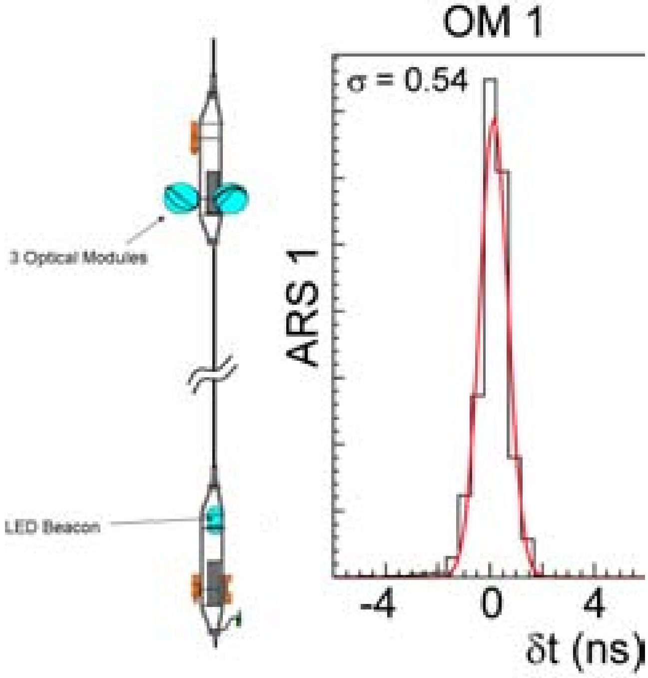


Figure 3: Some results obtained with the mini-instrumentation line of the ANTARES experiment. The schematic drawing in the left-hand panel shows how the time spectrum displayed in the other panel has been measured. A LED light beacon illuminates the optical modules, which yield – after correction for cable length differences – the time spectrum shown in this figure. The observed time resolution (labeled as 'σ') is about 0.5 ns.

Figure 4: Picture taken of the first fully equipped detector line (LINE 1) of the ANTARES neutrino telescope. The line consists of 25 floors that contain three optical modules each.

The ANTARES project

The development of deep-sea neutrino telescopes represents the largest NIKHEF contribution to the national astroparticle physics programme. In 2005 important steps have been taken towards realisation of the first telescope in the Mediterranean Sea in the framework of the ANTARES project. Most importantly, a so-called mini-instrumentation line ('MILOM') has been successfully deployed in the sea near Toulon (see Fig. 1). This instrumentation line has been used to measure and monitor various parameters related to the physical orientation of the cable, the seawater properties, bioluminescence and seismic events. Moreover, the line was equipped with optical and acoustical instruments enabling a determination of the time and position resolution of the neutrino telescope.

Since the spring of 2005 the instrumentation line has been in operation. After a few months the count rates observed in the (three) optical modules had gone down to about 70 kHz (see Fig. 2), the value typically assumed in the design of ANTARES. Moreover, by making use of a LED beacon, the time resolution was observed to be well below 1 ns (see Fig. 3). Together with the observed position resolution of less than 20 cm, it follows that the anticipated angular resolution of the ANTARES neutrino telescope will be 0.3 degree or less. This is considerably better than the angular resolution values quoted by competing experiments.

The successful operation of the instrumentation line also demonstrated that the data-acquisition system – based on the all-data-to-shore concept developed at NIKHEF – worked properly. This concept is based on two key ingredients: a high-bandwidth optical data transfer system for which the so-called Dense-Wavelength Division Multiplexing (DWDM) technique is used (see the Review section of this Annual Report) and an advanced software trigger. In 2005 a new trigger algorithm for point-source searches was developed which increased the anticipated efficiency of the system substantially.

Near the end of the year, the first fully equipped detector line was ready for deployment (see Fig. 4).

Figure 1. Dr. Sandra Muijs reflected in one of the discs of the Semiconductor Tracker (SCT).

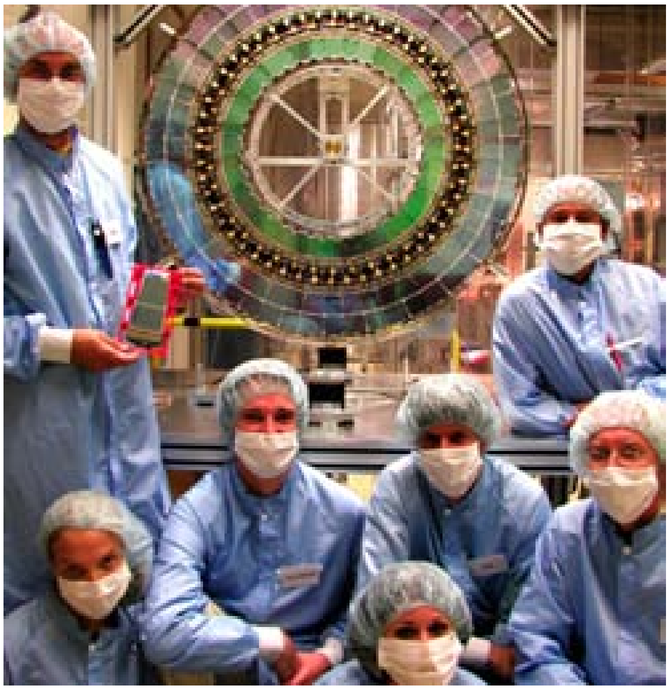


Figure 2. NIKHEF employees posing in front of the Semiconductor Tracker (SCT).

ATLAS

It is expected that in 2007, the Large Hadron Collider (LHC) at CERN will deliver first proton-proton collisions at the ultra-high energy of 14 TeV. The construction of the ATLAS experiment, which will detect and analyse these collisions, is in full swing. The eight coils of the large barrel air-core toroidal magnet have been installed. The central solenoid, together with the barrel electromagnetic and hadronic calorimeters, have been moved to their final position.

NIKHEF is responsible for the assembly of one complete endcap of the semiconductor tracker (SCT) (see Fig. 1) for ATLAS, which consists of some 1000 modules (1.5 million electronic channels) with silicon strip sensors for charged particle detection, mounted on nine carbon-fibre discs. A hundred modules have been produced at NIKHEF, the remaining were assembled at collaborating institutes.

In 2005, all the services to each disc have been completed. This involved mounting and testing cooling circuits, as well as routing and testing both the electrical (power distribution) and optical (data communication) cabling. So far seven discs (see Fig. 2) have been fully equipped with detector modules, and these have been successfully tested in ATLAS-like conditions. For this purpose, a disk test box and a C_3F_8 evaporative cooling machine were built. The number of defective channels is below 0.5%, and the detector noise is as expected. At present, three discs have been installed in the endcap cylinder itself, and were successfully tested. Mounting of further cabling and cooling pipes on the cylinder is in progress. In the next months, the remaining two discs will be equipped with modules, and six more discs will be integrated into the endcap cylinder before departure for CERN. Upon arrival, reception tests will be performed to check for any transit damage. Subsequently, integration into an endcap of the Transition Radiation Tracker (TRT), which surrounds the SCT, can begin. The other components of the inner detector are also progressing well.

Of the 96 ATLAS precision muon chambers assembled in Amsterdam between 2002 and 2004, 93 have already been shipped to CERN. Before departure, sets of five chambers were routinely tested in a cosmic-ray test stand. After arrival at CERN, the chambers are tested again, and mounted with RPC trigger chambers in a

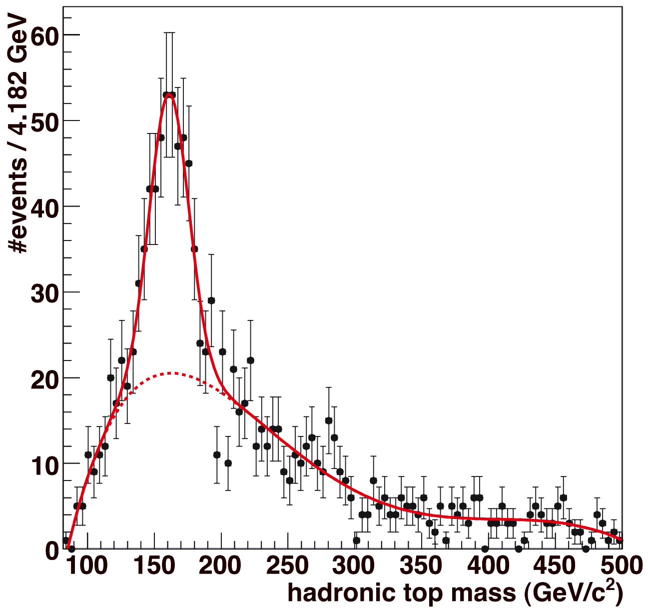


Figure 3. Result of a NIKHEF study of the possibilities of top-quark event selection with early data, without explicit b-quark identification. Shown is the invariant mass of 3 jets corresponding to one top quark, a clear peak is visible on top of the background.

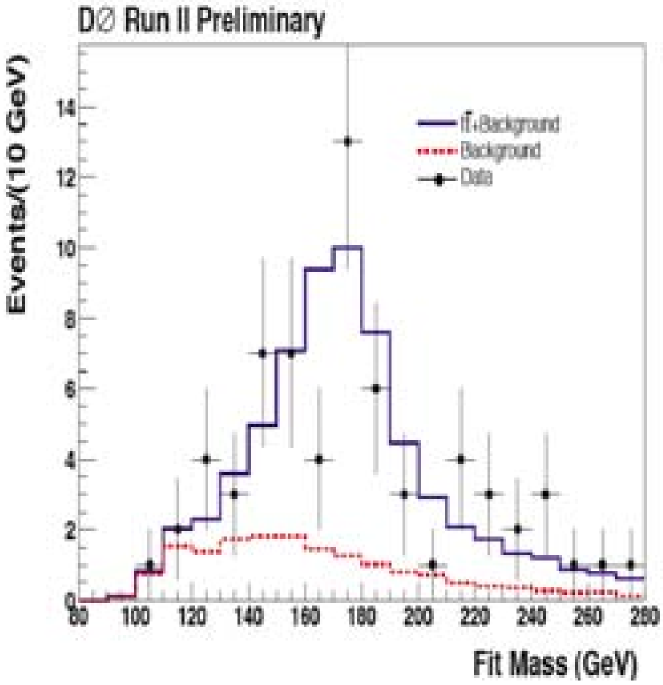


Figure 4. The distribution of fit masses of top events selected in the lepton plus jets channel. This selection includes b-tagging of jets. The dashed histogram is the prediction of the background. The full histogram is signal plus background for the best fitted top mass of m_t=170.6 ± 4.2 (stat) ± 6.0 (syst) GeV.

common support. In december 2005, the first chambers were installed in ATLAS, and first data with cosmic ray muons in the cavern have been taken. First components of the detector control system have been installed. A final design of read-out driver and buffer electronics has been made.

The main goals of ATLAS are to definitively prove the existence or non-existence of the last missing element of the successful standard model, the Higgs particle, and to search for new phenomena, such as supersymmetry, 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 events, and a NIKHEF study has shown that a clean sample can be selected with early data, even without b-quark recognition (which needs a well-calibrated detector), see Fig. 3. In fact, the top-quark sample can be used to study b-quark recognition, as well as the calibration of the energy of jets produced by quarks. The group is further interested in searches for Higgs bosons and new phenomena, notably through top-like final states, and with high-p_t isolated muons.

At this moment physics at the energy frontier is done at the Tevatron collider at Fermilab near Chicago, where protons and anti-protons collide at a centre-of-mass energy of 2 TeV. NIKHEF physicists participate in the DØ experiment, which collected so far more than 1 fb^{-1} in Run 2 and published 29 papers. Using Neural Networks the NIKHEF group attained spectacular improvements in b-quark tagging and tau-lepton identification. These tools are used to measure top quark properties and search for the Higgs boson. Hints of Higgs bosons may be observed for masses up to 170 GeV, before the LHC results become available. The preliminary state-of-the-art combined top quark mass measurement by DØ and CDF (the competitor experiment at the Tevatron) is 172.7 ± 2.9 GeV.
Fig. 4 shows the distribution of fit masses of top events in the DØ detector.

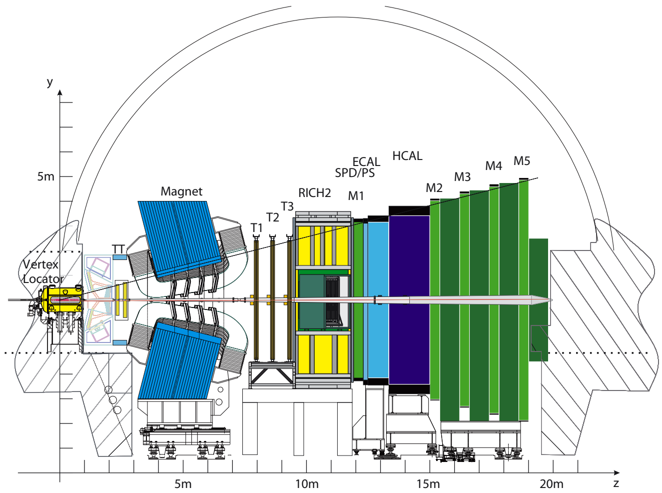


Figure 1. Side view of the LHCb detector, shaped like a forward spectrometer, since at LHC-energies B-hadrons are predominantly produced in the forward cone.

Figure 2. Outer Tracker quarter-station with detector modules, pre-assembled at NIKHEF for test purposes.

B-Physics

Constructed by a worldwide collaboration involving 46 institutions from 15 countries, LHCb is one of the four experiments that will be installed at the Large Hadron Collider (LHC). It is dedicated to study CP violation and other rare phenomena observable in the decays of B hadrons. While present-day B-meson factories produce few $b\bar{b}$ events per second, at the nominal LHCb luminosity of 2 $\times 10^{32}$ cm^{-2} s^{-1} 10^5 $b\bar{b}$ events per second will be produced.

The decay rates of the B^0 meson (the combination of a b-quark and a d-quark) to a number of final states has recently been shown by the BaBar and Belle experiments to differ from the corresponding decay rates of the $\bar{B}^0$ anti-meson. In general, this asymmetry between matter and anti-matter (known as CP-violation) manifests itself as the appearance of complex factors in quark-flavor changes described in the Standard Model (SM) by the CKM matrix, which relates the quark mass eigenstates to the quark electroweak eigenstates. It has not yet been observed for B_s mesons, the combination of b- and s-quarks. The LHCb experiment is particularly suited to study the decay of B_s mesons. Moreover, since the study of the B-meson sector is a place where the SM theoretical predictions can be precisely compared to the experimental results, it is also an ideal ground to identify deviations from the SM and signs of new physics.

As a preparation for LHCb running, NIKHEF participates in the BaBar experiment running at the Stanford Linear Accelerator Center (SLAC) in Palo Alto, U.S.A. In addition to the discovery of direct CP-violation in the decay of B^0 mesons, the more than 300 fb^{-1} thus far recorded allowed BaBar to harvest a large variety of physics results, resulting in 56 scientific publications in 2005.

The LHCb experiment has entered the crucial phase of the preparation for the installation of the sub-detectors at the Point 8 of the LHC, close to Ferney-Voltaire in France. The NIKHEF contribution is concentrated around the main topic of tracking. The tracking system of the LHCb detector, shown in Fig. 1, is divided in a silicon vertex detector close to the interaction region, a dipole magnet, and a tracking system behind the magnet: from the deflection of the charged particles in the magnetic field, the momentum of charged particles is determined. The tracking system behind the magnet is divided in two parts: a small silicon detector at high rapidity in the highest particle-flux region, and a gaseous straw tube detector, the Outer Tracker (OT), covering most of the LHCb acceptance. NIKHEF plays a leading role in the construction of the OT, of the VErtex LOcator (VELO) and the Pile-Up detector, and to the development of the tracking software. The performance of the vertex and tracking system is crucial in order to obtain the accuracy in the extrapolation of tracks to the decay vertex needed to provide the necessary B_s lifetime resolution.

In addition, for the reconstruction of various final states with a large number of tracks ($B_s^0 \rightarrow D_s^- \pi^+$, with $D_s^- \rightarrow K^+K^-\pi^-$; $B_s^0 \rightarrow J/\psi\varphi$, with $J/\psi \rightarrow \mu^+\mu^-$ and $\varphi \rightarrow K^+K^-$; etc.), a high track-reconstruction efficiency is mandatory.

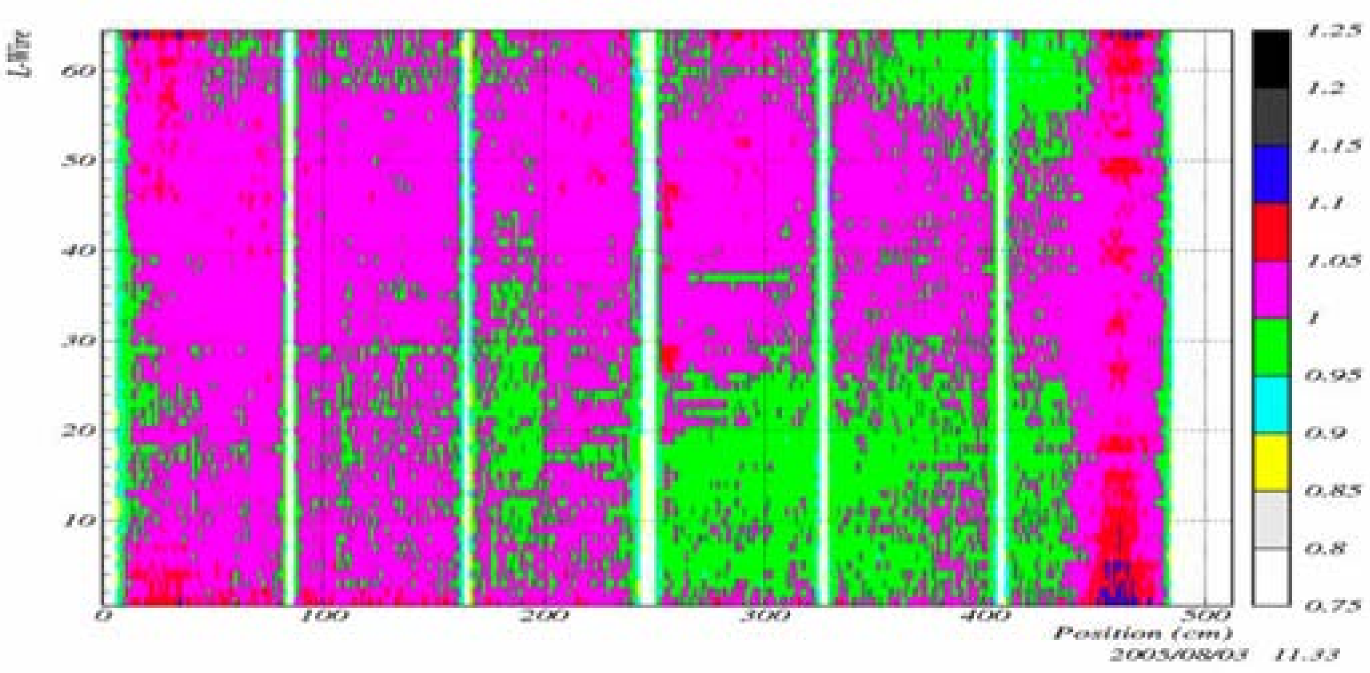


Figure 3. Result of a scan of the entire module surface in pixels of 0.5 cm²: the gap in the middle and the two groups of wire locators at each side are clearly recognisable.

The OT detector is divided in three tracker stations. Each station comprises two vertical layers and two layers with a stereo angle of ±5° (x-u-v-x), arranged in four independently movable units, as shown in Fig. 2.

A layer consists of 14 long F-modules (500 x 34 cm^2) and 8 short S-modules above and below the beam pipe. Each detector module consists of two staggered mono-layers of 64 straws. The anode is 25 μm thick gold-plated tungsten wire, whereas the cathode is made of a carbon-doped (XC) kapton straw and of aluminum at the outside for electrical shielding. The wires are read out at the two ends, resulting in a total of 256 channels per module and approximately 56,000 readout channels for the whole detector.

The year 2005 saw the completion of the mass production of all detector modules: in total, the OT contains 96 short S-modules and 168 long F-modules, of which 130 were produced at NIKHEF. During module production, stringent quality criteria were applied on the wire tension and HV behaviour of each single wire. After production, the gas-tightness of the entire module is checked, and the module is flushed with counting gas and put under high voltage for conditioning. Finally, the response to radioactive sources was checked for acceptance. The entire surface in pixels of 0.5 cm^2 of both module mono-layers was scanned with a 20 mCu ^{90}Sr source to determine the uniformity of the response (see Fig. 3). Defects of various nature, like missing wire locators, poor gas flow, damaged wire surface, or deformed straws could be detected. Apart from few initial modules, no module was rejected. In total less than 0.1% of all channels exhibit a response deviating by more than 25% from the nominal value.

In order to validate the combination of detector and front-end electronics, four mass-production modules have been tested with a 6 GeV electron beam at the DESY-II facility in Hamburg. The performance of the OT was measured for values of the high voltage ranging between 1200 and 1700 V and of the amplifier threshold ranging from 1.5 to 5.5 fC. Resolutions of 200 μm and efficiencies close to 100% were achieved for high-voltage values above 1550V.

In summary, LHCb is an experiment at the LHC dedicated to study CP violation and other rare phenomena in B hadron decays. An excellent vertex and momentum resolution are key ingredients for the success of the LHCb physics performance. NIKHEF has a leading role in the construction of the OT, Pile-Up and VELO system and in development of the tracking software. All activities are progressing well and the experiment will be ready for the first LHC collisions in 2007.

Figure 1. The new Grid cluster.

Figure 2. Dr. Kors Bos thinking about e-Science infrastructure.

The Grid and the Physics Data Processing Group

2005 was a very productive and active year for the NIKHEF grid group and for our partners at SARA as well. At NIKHEF, the old 50-node DØ farm computers (purchased in 2000) were finally retired from production use and have found new life as test machines in various capacities; the computing capacity was (more than) replaced by a 28-node Dell cluster (see Fig.1). This system included several terabytes of disk space and a very nice console switch, which we are considering purchasing for all our machines. SARA installed a ten-terabyte addition to the grid-enabled storage in response to problems with data access encountered in early 2005.

The grid software efforts this past year were mainly focused on operational hardening and automation; as the scale of the systems continues to increase, manual intervention becomes ever more impractical.

Our participation in the Dutch national e-Science project, ‘VL-e’, reached its highest level so far with the addition of two new staff members in this area. They are concentrating on packaging the VL-e software and on coordinating the activities of the various developer groups constructing this software. During 2005 NIKHEF has also established links through VL-e with such groups as the DANS (Data Archival and Networked Storage) initiative of the Royal Dutch Academy of Sciences (KNAW), the National Library of the Netherlands (KB), Philips Research and Shell.

In the fourth quarter of 2005, we wrote (see Fig. 2), together with partners from the Dutch bio-informatics project NBIC and the scientific computing foundation NCF, a proposal for a national e-Science infrastructure, which was submitted to the Dutch science foundation NWO. The proposal has been approved for 30 million euro, and includes a full Tier-1 for ATLAS, ALICE, and LHCb for four years, a data centre for LOFAR and infrastructure for the Dutch biomedical community. We expect final government approval in early 2006.

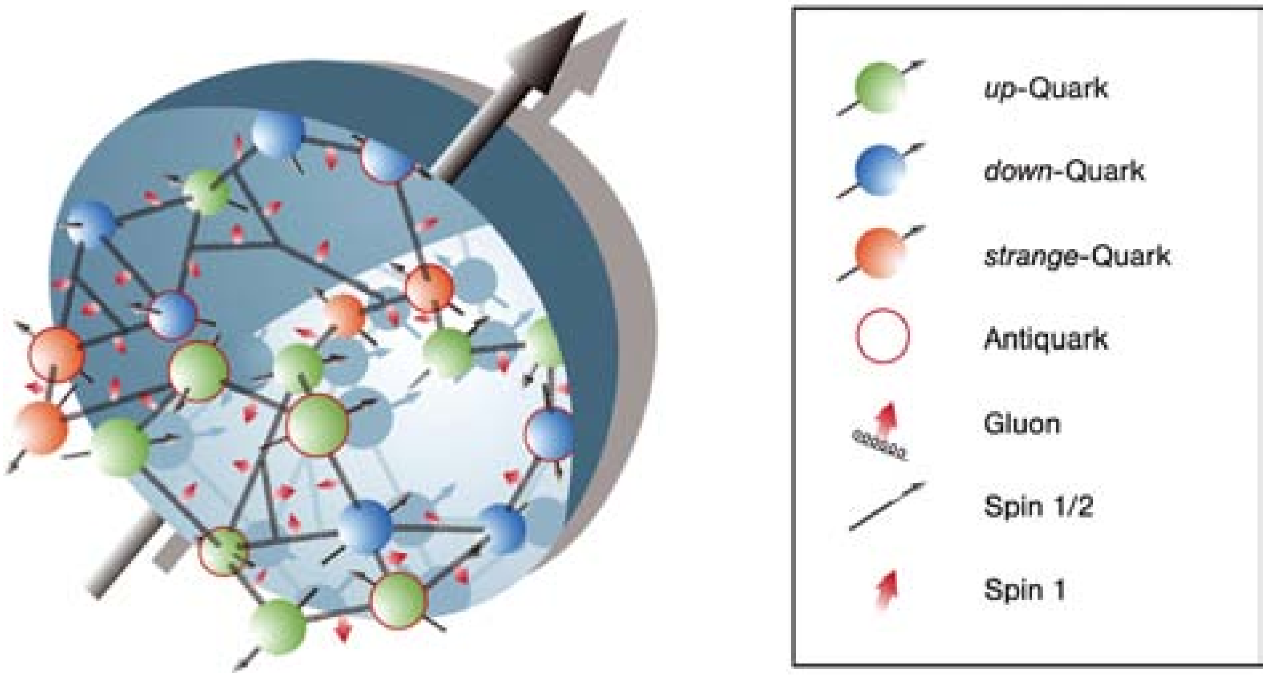


Figure 1. The more one zooms in on the proton the more details become visible. The valence quarks reside in a sea of virtual quarks and anti-quarks held together by gluons. *Illustration: DESY*

In Search of the Spin of the Nucleon with HERMES

Where is that spin?

Only a small percentage of the visible mass in the universe can be attributed to the mass of nucleons and electrons. It is the dynamics of quarks and gluons, the constituents of the nucleon, that must be understood to explain the origin of the mass of the nucleon and by that also the origin of the mass of the visible matter in the universe. In this respect the spin of the nucleon plays an important role.

In the EMC-experiment at CERN in 1988 it became already clear that the spin of the valence quarks is only responsible for approximately 30% of the spin of the proton. Since that time worldwide much research has been done in order to discover how the spin of the proton can be explained from the dynamics of its constituents. It seems that both the spin of the valence quarks, the gluons and also the orbital momentum of quarks and gluons contribute to it. In the past it was already established that the sea quarks (occurring in quark-antiquark pairs, see Fig. 1) contribute hardly to the proton spin. Other contributors to the nucleon spin are therefore necessary and thus form the subject of experimental searches.

NIKHEF is involved in investigations related to several aspects of the nucleon spin, in particular two subjects have been studied, i.e., photon-gluon fusion and transversity. These studies are carried out at the HERMES experiment, which uses polarised electron and positron beams of the HERA electron-proton collider of DESY in Hamburg. Information on the spin structure of the proton can be obtained by scattering of polarised electrons and positrons off polarised targets.

Transversity

One of the manners to describe the internal structure of nucleons is by using distribution functions. These functions contain information on how the total momentum and spin of the nucleon is carried by the quarks and gluons from which it is built. By carrying out deep-inelastic scattering experiments off a nucleon prepared in different spin states, different distribution functions can be identified. The most important ones of these are the three distribution functions called q, Δq and δq. Only about the third one, the 'transversity' distribution function δq, practically nothing is known.

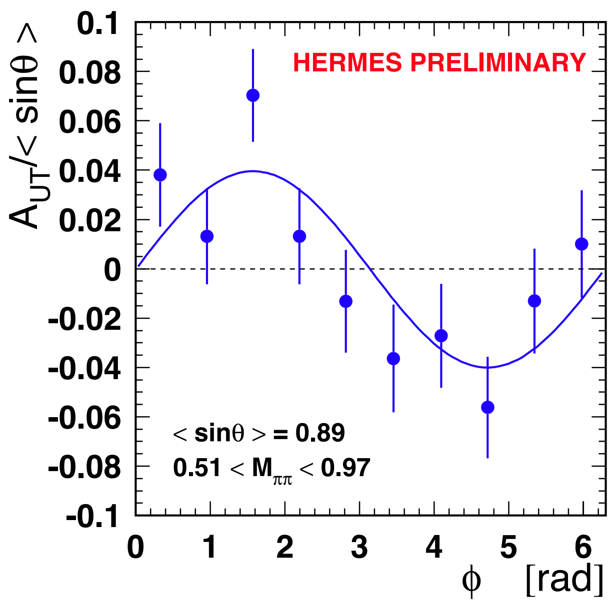


Figure 2. Asymmetry A_{UT} measured at HERMES in the azimuthal (Φ) distribution of pion pairs produced in deep-inelastic scattering from a transversely polarised hydrogen target. The sine modulation is directly dependent on the 'transversity'.

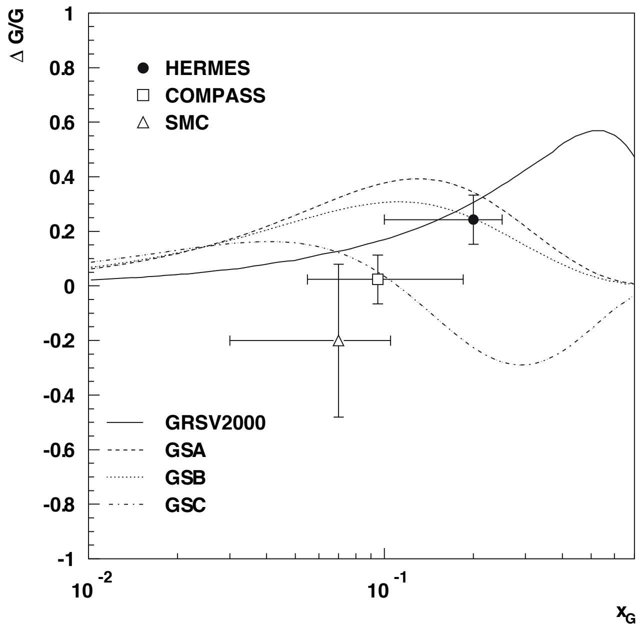


Figure 3. The gluon momentum fraction x_G. The results of three different experiments (SMC, COMPASS, HERMES) are compared to curves representing various theoretical calculations.

Transversity describes the distribution of transversely polarised quarks in a transversely polarised nucleon. At the HERMES experiment δq is examined by deep-inelastic scattering of electrons off a transversely polarised hydrogen target. An asymmetry in the azimuthal angle distribution of the detected hadrons that emerge from the scattering process can then be related to δq. Last year such an asymmetry has been measured by HERMES for the first time for pions. An alternative method is to look for the same type of asymmetry in the production of pion pairs. This method has a number of advantages, of which the most important is that the measured asymmetry is related to δq in a simpler manner. Preliminary results (see Fig. 2) indicate that this method can also be very well used to measure transversity.

Photon-gluon fusion

The determination of the gluon contribution to the proton spin, or the measurement of the gluon polarisation in the proton, is particularly difficult because gluons are uncharged. As a result, the reaction yield is dominated by contributions from the (charged) quarks. However, the latter contributions can be strongly reduced by selecting events where two pions are produced that each carry a large momentum in the direction perpendicular to the beam direction. In this way the contribution of the so called photon-gluon fusion process becomes relatively large, and it is also very probable that the gluon actually participated in the scattering process. Nevertheless, the contributions from the remaining background processes are still far from negligible and therefore they had to be estimated with the help of exhaustive Monte-Carlo simulations.

These measurements and analyses have led to values for the gluon polarisation of ΔG/G = 0.24±0.09 (stat) ±0.01 (syst) with estimated model uncertainties ranging from -0.30 to +0.10. This is the first rather precise measurement of ΔG/G (see Fig. 3), where also the uncertainty due to various model assumptions has been estimated with great care. The conclusion is that the gluon polarisation contributes to the proton spin, but is certainly not dominant. That means that the quarks (and gluons) probably possess also a non-negligible orbital momentum. In order to prove this conjecture new measurements are necessary.

Figure 1. Picture of the InGrid wafer. There are 19 fields each with a different grid geometry. Note the individual anode and grid connections at the edge of the wafer.

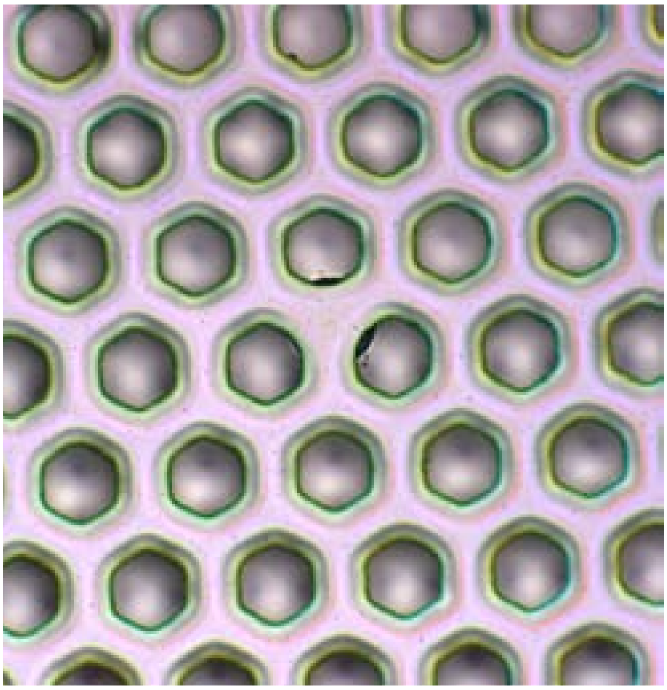


Figure 2. The InGrid pattern which was used for the measurements. Note the slightly hexagonal holes (hole pitch 60 μm). The insulating pillars (diameter 30 μm) are centred between three adjacent holes, and are just visible. No local loss of sensitivity is expected.

Detector R&D

The two main R&D topics of the group in 2005 were:

- the development of a wireless time projection chamber (TPC) that is directly read out by specially developed multipixel CMOS chips with fully integrated gas-gain grid.
- the development of hybrid CMOS pixel detectors for X-ray imaging applications.

A third topic that was defined in 2003 at the start of the R&D project, the development of vertex detector systems based on monolithic CMOS pixel detectors, was still 'on hold' because of lack of available person power.

GridPix, Ingrid, TimePix, Gossip

After the initial breakthrough in 2004 of detecting minimum ionising particles in a small prototype TPC with a Micromegas foil as gas multiplication grid on top of the Medipix2 pixel read-out chip as anode, these studies were continued with modified geometries, different gas mixtures and with 'triggered' operation of the Medipix readout for increased efficiency. Most of these tests had a very short lifetime due to hitherto unexplained damage of the Medipix chips, although very likely this was due to discharges. A possible solution to this problem is under study, by depositing an amorphous silicon layer on the CMOS read-out chip, with a thickness of some 4 μm and a volume resistance of 0.2 GΩ/cm.

The following step in the development is the integration of a Micromegas type of grid (Ingrid) in wafer post-processing technology. This work is done in collaboration with the group of Prof. J. Schmitz of the MESA+ institute at the University of Twente. A 50 μm thick layer of SU-8 photoresist is deposited and exposed (to pattern the pillars that should support the grid) on top of a 4″ silicon wafer, with a 0.2 μm layer of aluminium as (dummy) anode material. On top of this a (0.8 μm thickness) pure aluminium layer is deposited and patterned to form the grid. The last step in the process consists of the removal of the unexposed SU-8. This first Ingrid, a 4″ wafer with 19 fields of 15 mm diameter each having different geometries of pillars and grid holes, is shown in Figs. 1 and 2. It was successfully operated as a detector and the very precise and uniform geometry of such a grid led to an unprecedented energy resolution of 6.5% RMS (see Fig. 3) and a gas gain variation over the fiducial area within ±5%. These results were accepted for publication in NIM.

In 2005 the EUDET project, a detector R&D program towards a Linear Collider detector, in the EU Framework Programme 6, was approved. Together with groups from CEA Saclay, CERN and University of Freiburg, NIKHEF receives funding and is responsible for the development of the TimePix readout chip. The chip will be based on the Medipix2 chip, where the hit counter actually present in each pixel, will be used to count clock pulses, from the moment a pixel 'sees' a hit. This will then allow a 3D reconstruction of the primary ionisation clusters formed by the minimum ionising particles traversing the gas volume of the detector. It is expected that a first version of this chip will be available towards the end of 2006.

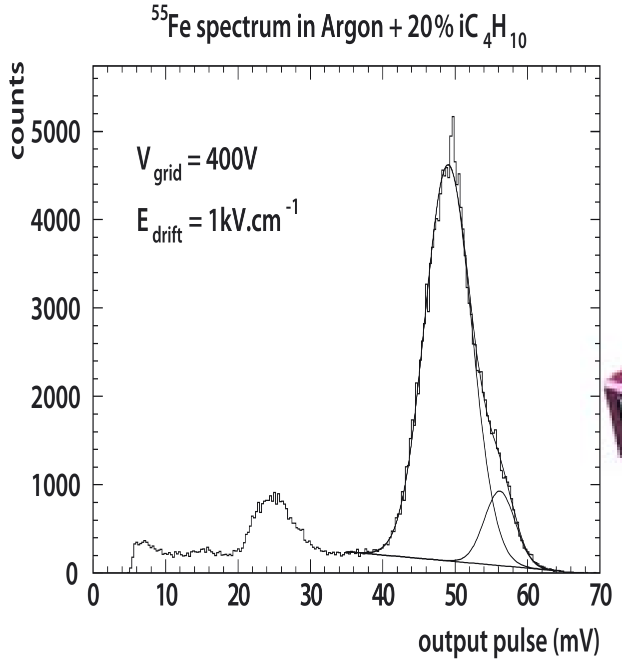


Figure 3. Measured pulse height from a ^{55}Fe source for an Argon/Isobutane 80/20 mixture; the curves show the results of the fit to the pulse shape, showing the 5.9 and 6.5 keV lines and their superposition on a linear 'background'.

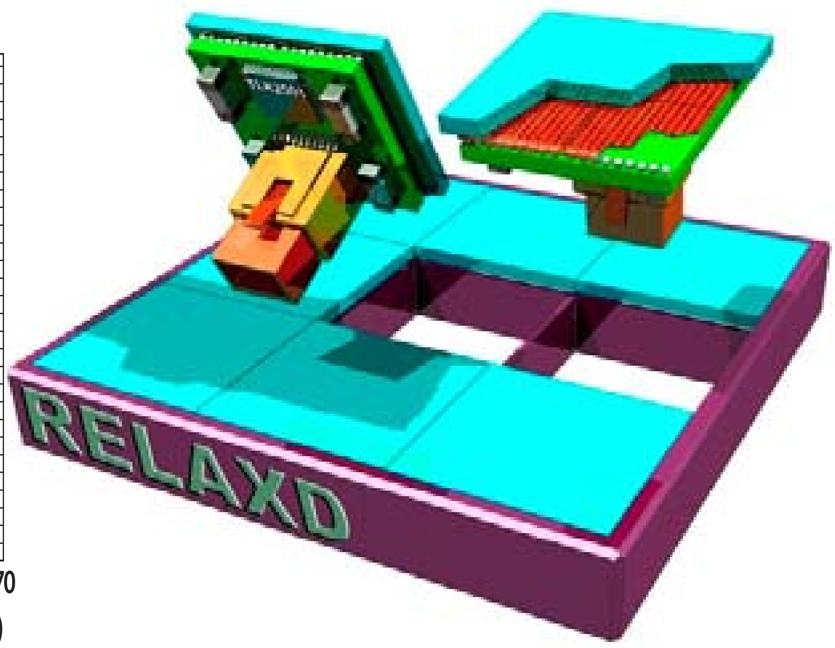


Figure 4. Artist impression of the modular RELAXD X-ray imager, consisting of 9 tiled microsystems of 3x3 cm^2 each. Every microsystem contains a 0.25 megapixel sensor diode, 4 Medipix-2 chips, and a 3.125 Gbit/s serial readout circuit.

Another variant of the GridPix principle consists of the Gossip ('Gas On Slimmed Silicon Pixel') detector, where the 'thinned' CMOS pixel readout chip + grid is operated with only 1 mm thick gas layer. Such a detector can possibly be used as a vertex detector in high-radiation environments as e.g. a luminosity upgraded Large Hadron Collider (SLHC). Work is in progress to design a new (very low noise) input stage for the corresponding pixel readout chip in 130 nm CMOS technology. Also ageing measurements were done to test a prototype detector with a Micromegas covered 'dummy' anode under high-rate conditions. After a charge exposure of 0.3 Coulomb/mm^2 deposits of carbon polymer on the anode are clearly visible, that lead to significant gain losses, but the detector was operating stably during the whole exposure. It is estimated that with a GridPix/Gossip type of detector the ageing rate is ≈ 400 times less than with classical wire chambers.

Medipix developments

In the framework of generic detector research and development, NIKHEF participates in the Medipix Collaboration at CERN. This is a multidisciplinary consortium of 18 research institutes and university groups, who together pursue the further development of CERN-invented hybrid pixel detector technologies. Not only medical applications are targeted, but all X-ray imaging, computed tomography, diffraction, fluorescence and small-angle scattering techniques applicable in medicine, pharmacology and proteomics, industrial process monitoring and quality control, active dosimetry and safety monitoring equipment, e.g., luggage control.

NIKHEF plays a major role in this consortium, developing and delivering to all members readout interfaces and firmware, as well as the chipboard carriers. Also NIKHEF has contributed to the deep-submicron circuit design for the Medipix2 chip, which has been mainly designed at CERN in 250 nm technology. At present we are involved in Multi-Project-Wafer submits in 130 nm technology, as a preparation for the downscaling of the Medipix2 chip to a future full-reticule Medipix3 chip in 130 nm technology. Our focus is on ultra-high bandwidth serial readout over copper wires. In collaboration with the IC-design group of Prof. B. Nauta at Twente University, Enschede, a breakthrough was obtained by transporting 5 Gbits/s over 30 meters of standard coaxial cable, a 'world best', resulting in a publication submitted to the IEEE Journal of Solid-State Circuits.

Of course, this generic type of research can not be solely funded from our High-Energy Physics budgets, and we have been quite active, and successful, in locating alternate funding sources. The most recent success is an Eureka Project named 'high-Resolution Large-Area X-ray Detector' (RELAXD) funded by the Dutch ministry of Economic Affairs (Senter-Novem), its Flemish counterpart (IWT) and the European Union. In this project, industries and knowledge institutes work together on R&D towards a mass-manufacturable modular X-ray detector microsystem. Partners on the Dutch side are NIKHEF as

Figure 5. Several chip carrier boards. Starting from top-right and going clockwise, the original CERN-developed single-chip carrier and 3 NIKHEF developed carriers: an octal chip carrier fitted with a quad Medipix assembly, a single-chip carrier developed for PANalytical, and a first RELAXD carrier board for quad Medipix assemblies, fitted with a quad assembly.

the knowledge institution on detector technologies and PANalytical, Almelo, a manufacturer of industrial X-ray equipment. On the Flemish side IMEC in Leuven acts as the knowledge institution with a huge experience in Microsystems, and Canberra Semiconductor, Olen is a manufacturer of semi-conducting radiation detectors. The project will run for 4 years and will lead to pre-production prototypes demonstrating completely new technologies. These new technologies will include edgeless sensors, two-dimensional pixel pitch redistribution, three-dimensional stacking of sensor, readout ASIC, and high-bandwidth readout, and high-bandwidth serial readout with standard protocols. These new technologies are also expected to be very useful for future generations of detectors in High-Energy Physics.

Further activities include a collaboration with the protein crystallography group of Prof. J.P. Abrahams of Leiden University, on the application of arrays of Medipix chips inside a cryo-electron-transmission microscope.

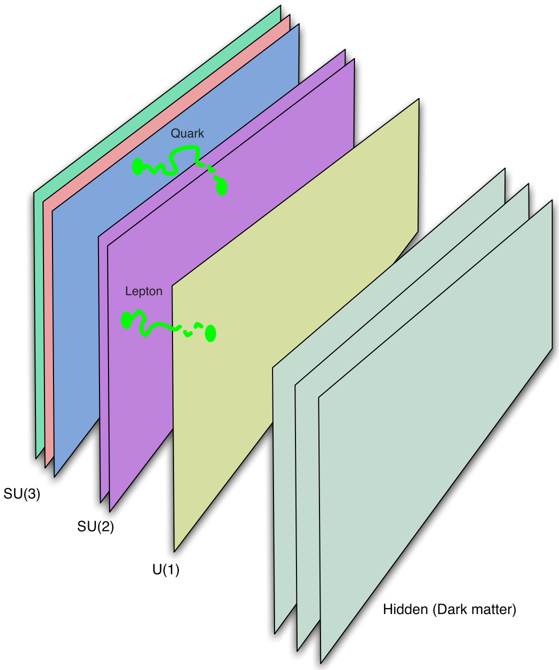


Figure 1. Standard Model brane configuration.

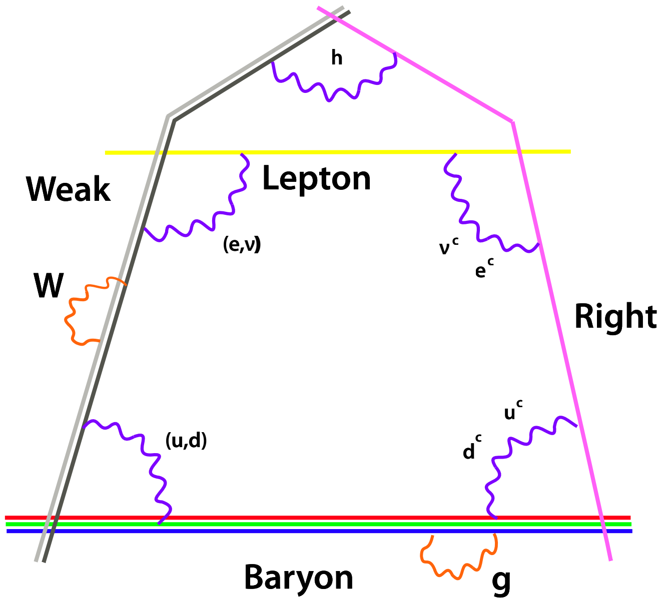


Figure 2. Brane realization of Standard Model particles.

Theory: The Standard Model from Open Strings

The activities of the theory group cover a wide range of topics in particle physics and astrophysics. This year we focus on one of those activities, a research project aimed at understanding what we can learn about the standard model from string theory.

String Theory: A theory of gravity *and* particle physics

Two monumental achievements of physics in the last century are general relativity and quantum mechanics. However, it has been known for a long time that serious problems arise when one tries to combine the two. These problems seem to become important if processes are considered where gravity acts at extremely short distances, near the Planck length (about 10^{-33} cm). Although this is of no immediate experimental concern, it has long been felt that this problem may give a clue about a new underlying theory, which in its turn may have other implications that are more easily accessible to experiment.

Traditional theories of gravity treat fundamental particles generically as 'matter', and do not impose any constraints on it other than conservation of energy. However, string theory is different. In string theory objects interact gravitationally by interchanging closed loops of strings. This picture implies that string gravity can only couple to matter that itself is made of strings. This imposes severe restrictions on the allowed matter, and implies that it is far from obvious that the presently known 'Standard Model' of quarks, leptons and their strong and electroweak interactions can actually be coupled to string gravity. In principle this provides therefore an opportunity to falsify string theory which would not normally be available in a theory of quantum gravity: if there is a fundamental obstruction to obtain the standard model, then the entire theory will have to be rejected.

Already since the early days of string theory, two main types of strings are known: closed and open strings. Gravity is always due to closed strings, but in principle there are two possibilities for the standard model matter (the quarks, leptons, and the gauge bosons: the photon, the gluons and the Z, $W^{\pm}$ vector bosons); either they are realized as closed strings, like gravity, or as open strings.

Search for The Standard Model from Strings

A realisation of all interactions in terms of closed strings initially seemed the more attractive option, and was indeed the first one pursued after 1985. It quickly became clear that there are many choices for the six-dimensional compactification manifold needed to lower the canonical space-time dimension of string theory, ten, to four. Each choice corresponds to a different string theory vacuum with a different spectrum. Among the many possibilities,

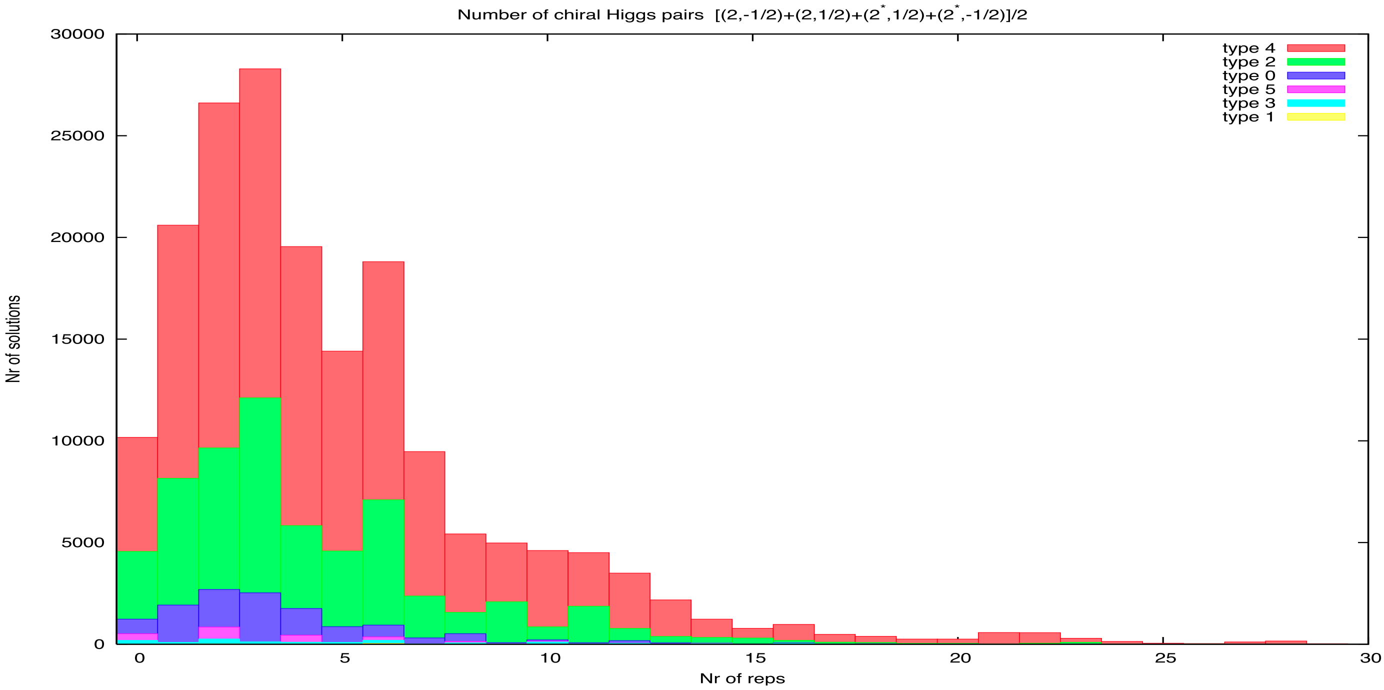


Figure 2. Distribution of the number of supersymmetric Higgs boson pairs.

a few were found that had more or less the right features. This closed-string approach is by no means ruled out, but has ran into a few serious difficulties.

Open string realisations became especially popular due to the 'brane world' idea, where our universe is a three-dimensional membrane moving through a higher dimensional space-time.

Starting around 1996 there have been attempts to obtain a more or less realistic spectrum from open strings, but despite a large amount of work no examples were found that completely satisfied even the rather mild criteria one might impose in an initial search: a stable solution whose chiral spectrum is identical to that of the standard model.

Recent NIKHEF results

During the last decade of last century a group at NIKHEF collaborating with other institutes developed a systematic way of dealing with a much larger class of possibilities. At the end of 2003, in view of the difficulties other methods encountered, it was decided to try applying these techniques to the construction of realistic open string models. The result was astonishing. It turned out that the desired spectra were not only present, but abundantly so.

Fig. 1 is an 'artist's impression' of the kind of brane configurations searched for. In reality the branes lie on top of each other in our four-dimensional Minkowski space, and intersect each other in the extra six dimensions. The number of intersections determines the number of quarks and leptons in the spectrum.

In total more than 200.000 distinct string spectra with Standard Model features were found. They all have the gauge interactions and quarks and leptons of the Standard Model, but they do in general have additional gauge bosons and non-chiral matter. But more differences will become apparent once additional physical quantities are computed. In particular, these string theories are expected to have different Yukawa couplings, and hence to lead ultimately to different predictions for the quark and lepton masses. There are also differences in the number of candidates for Higgs bosons, as the distribution of Fig. 2 shows.

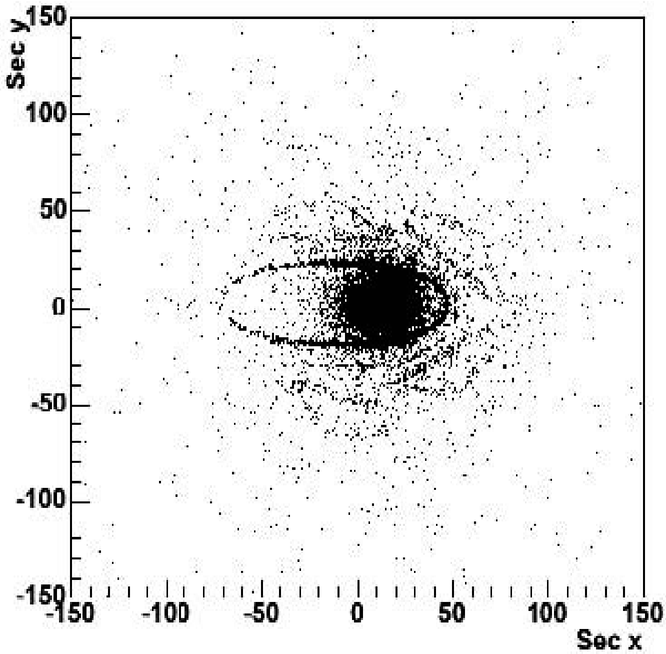


Figure 1. Secondary vertices, reconstructed with the ZEUS Micro Vertex Detector.

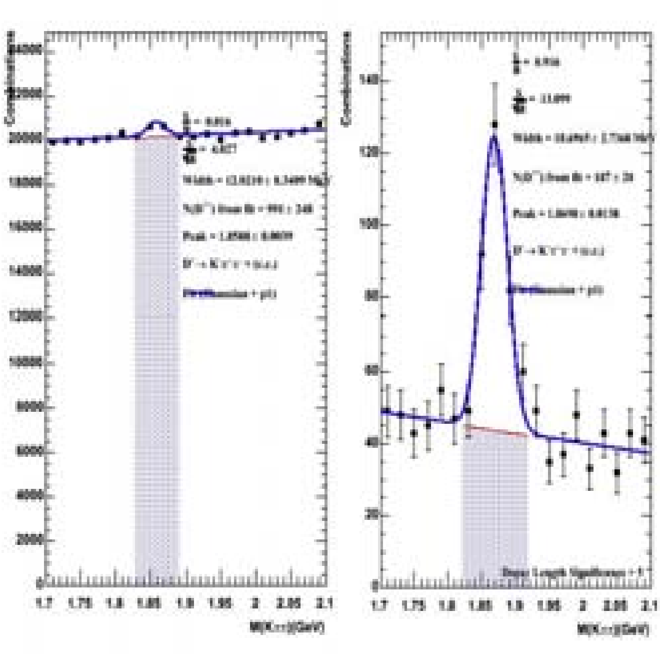


Figure 2 . D^+ invariant mass distribution before (left) and after (right) selection on Decay Length Significance > 5.

Searching Charmed Mesons with ZEUS

ZEUS is located at the DESY accelerator centre in Hamburg (Germany) at the electron-proton collider HERA. In 2005 electron-proton collisions were provided that allow the study of deep inelastic scattering.

One of the most important tasks of ZEUS is to measure the charm contribution F_2^{cc} to the proton structure function F_2. The ZEUS group at NIKHEF is concentrating on this topic trying to take full advantage of the ZEUS Micro Vertex Detector (MVD) which was built at NIKHEF and installed in the centre of the ZEUS detector in 2001.

In order to measure F_2^{cc} heavy, charmed mesons have to be selected. When heavy quarks are produced in a collision they hadronise immediately and make pairs with other quarks: $c\bar{u}$ (D^0) or $c\bar{d}$ (D^+). Both of these two D mesons decay very fast and very close to the interaction point, to pions (π) and kaons (K) of which the trajectories are measured and used to reconstruct the original D mesons. The decay point (displaced secondary vertex) is very close to the interaction point (primary vertex). Such vertices can be reconstructed using the MVD which is the first detector outside the beam pipe. In Fig. 1 you can see displaced secondary vertices reconstructed, using a software package written and developed at NIKHEF. The beam pipe, the interaction point and the MVD-ladders can be seen. Good reconstructed vertices allow to define and compute selection variables as the signed decay length, the decay length error, the lifetime, etc. In Fig. 2 the D^+ invariant mass distributions are shown before and after selection based on the Decay Length Significance.

The considarably enlarged signal-to-background ratio proves that the charmed mesons can be selected in an analysis that is based on the data from the vertex detector. When more data are available and analysed, foreseen for 2006, it will be possible to determine the cross section for charm production in deep inelastic scattering.

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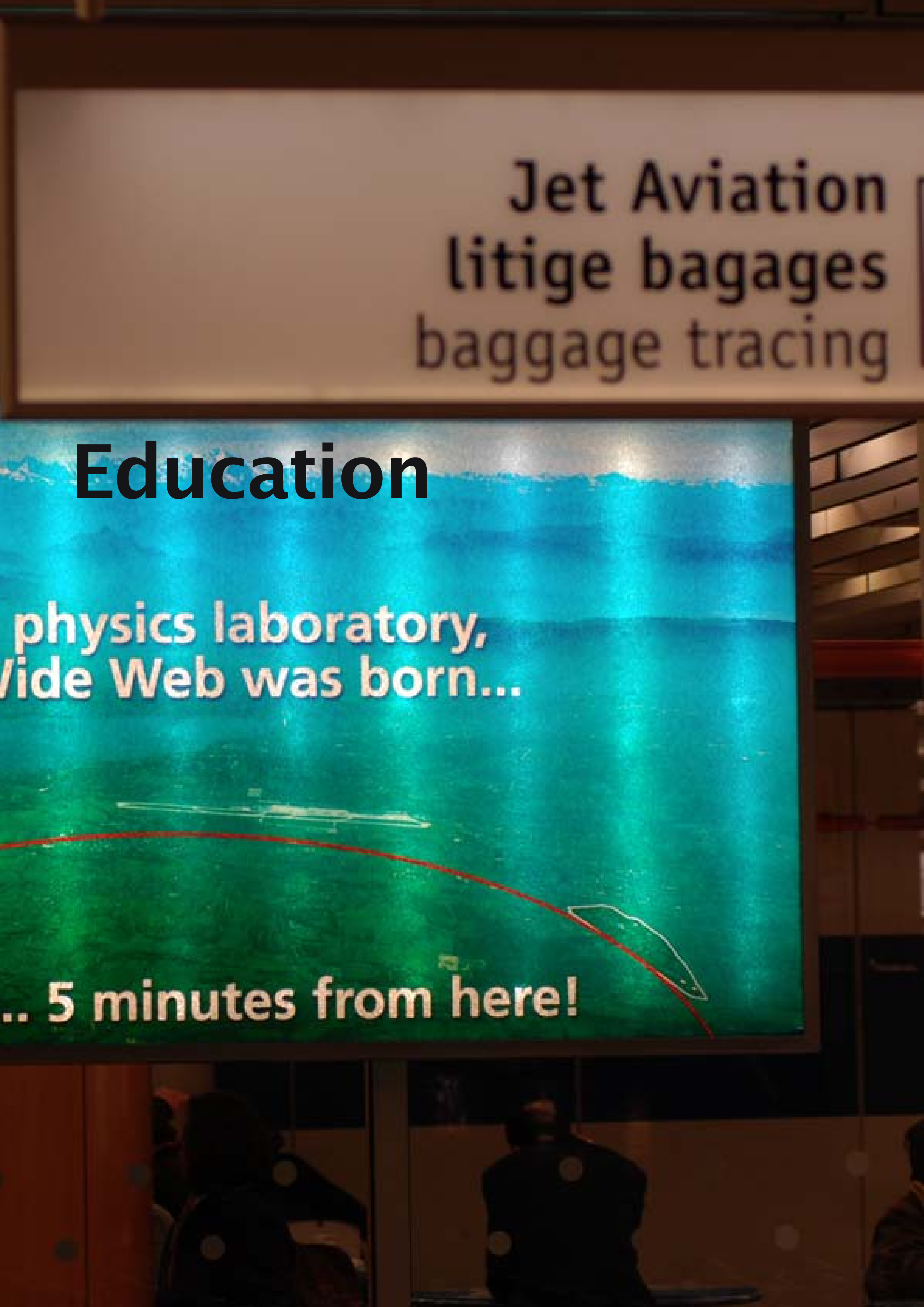
Education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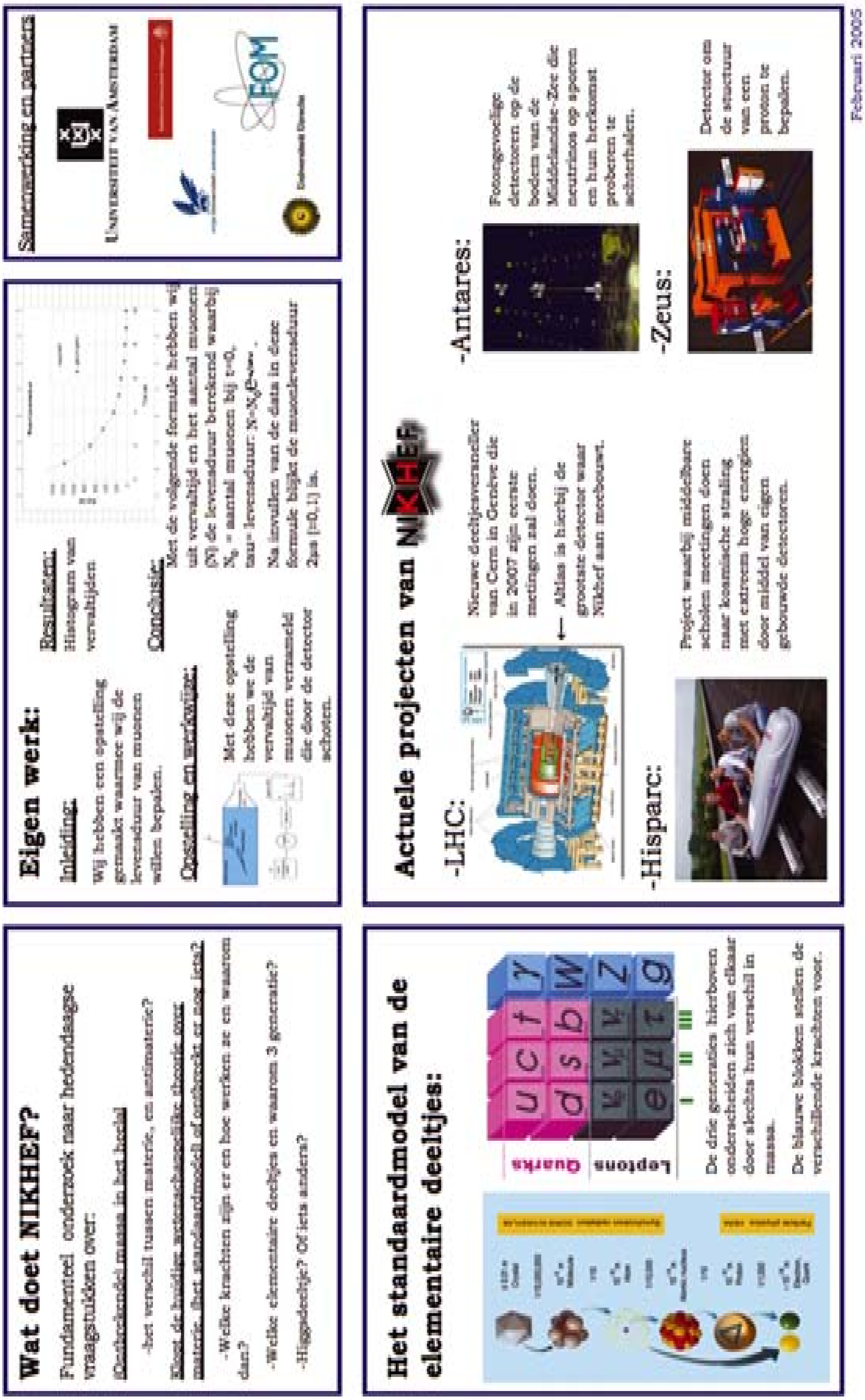


Figure 1. New this year were two high-school students, who spent a whole week at NIKHEF on a course called 'snuffelstage'. They summarised their work in a poster.

Figure 2. Part of the manual how to build a cloud chamber.

Figure 3. The cloud chamber made its way to a physics teachers' conference as well.

Interactions with High Schools

High-school teachers as well as students are often contacting NIKHEF for advice and support. In 2005 around ten schools were guest at NIKHEF to hear and see what we do. The programme of such a visit typically features a lecture, a movie and a tour.

Dutch high-school students perform a research project in their final year, called the 'profielwerkstuk'. This project is sometimes the reason for a visit; sometimes students decide after the visit to perform their research here. On our website students can find background information on (astro)particle physics, as well as ideas for suitable research projects. In 2005 seven students decided to carry out their project at NIKHEF on a topic in particle physics.

Relatively new are projects in which a school can actively work with a particle detector, for example by using the spark- or cloud chamber, or participate in the HiSPARC project (see under Outreach). Next year more information on building a spark- and cloud chamber will be published on the website. It is also possible to borrow one from NIKHEF. This year, articles published on the website Natuurkunde.nl directed teachers to this possibility to get particle physics in school. Additionally they were shown at the annual conference for physics teachers. Muon life-time measurements are also performed in cooperation with high schools.

Observing Subatomic Particles

It is fascinating to know that we are bombarded continuously by particles coming from the universe, the cosmic radiation. These particles come and go continuously around and through our body and we can demonstrate this beautifully with a cloud chamber.

Manual "How to build a cloud chamber", H. Tiecke 2006

Figure 1. Masterstudents doing their computer assigments.

Master of Science in Particle and Astroparticle Physics

This year four students of the master programme Particle and Astroparticle Physics graduated at the University of Amsterdam, one of them with highest grades (cum laude). After their graduation they all became PhD students at NIKHEF in the ATLAS and LHCb experiments. In September 2005 a new cohort of students started the master programme, among them students from the University of Amsterdam (UvA), the Vrije Universiteit Amsterdam (VUA), Utrecht University (UU) and Greek universities in Athens and Thessaloniki.

The objective of the two-year master programme is to teach students theoretical and experimental skills in (astro)particle physics and to train them working in the large international research groups typical for this field of research. All compulsory courses and many optional courses are given by university and FOM staff of NIKHEF. For the first time the master programme became accessible as part of the master programme Experimental Physics of Utrecht University. In Nijmegen the first student of the new master programme graduated this year. Also he continued to do a PhD in particle physics. Two more physics students and one computer science student are active in the Nijmegen group.

The master programme is intended as the incubator for talented future (astro)particle physicists, while simultaneously the experience with working in an international environment should give them sufficient skills for a career elsewhere in society. Among the students enrolled in the programme since its beginning in 2002, one is taking simultaneously part in the master Astronomy and Astrophysics of UvA. His research project will be in the field of astroparticle physics. Two students have opted for a special version of the master programme: after one year of disciplinary physics courses and a shorter research project at NIKHEF, they take courses in communication and education followed by a practical training, mostly in teaching physics at high schools.

Publications

B. M'Charek, *The selection of* $B_s^0 \rightarrow D_s^{+(-)} K^{-(+)}$ *events in LHCb*, Master Thesis, VU
Z. van Kesteren, *Angular orientation reconstruction of a Hall sensor calibration setup*, Master Thesis, UvA
A. Koutsman, *Pulse Analysis for ATLAS MDT Twin Tubes*, Master Thesis, UvA
J. Amoraal, *Panning for the Golden Decay* $B_s \rightarrow J/\psi\varphi$ *at LHCb*, Master Thesis, UvA
S. Cohen, Y. Grange, M.C. Takes, *Coach: Construction Of A Gaseous Čerenkov detector*, NIKHEF project.
E. Jansen, *Visualization and Alignment of the Muon Chambers at the H8 Combined Testbeam*, Master thesis, RU

Figure 1. Researchschool 2005.

Research School Subatomic Physics

The research school for subatomic physics organises each year academic training courses ('Topical Lectures') and, in collaboration with Belgian and German research groups, a summer school ('BND Summer school') for PhD students.

The 2005 BND summer school was held in "de Krim" on the island of Texel. The location did not provide the same level of interesting distractions as the 2004 edition in downtown Gent, which improved lecture attendance in the morning sessions. Helped by a week of glorious weather and a social programme including a day of golf, the school was widely appreciated by the 40 (10 Belgian, 21 Dutch and 9 German) registered participants. The school was organised by Prof. S. Bentvelsen and the University of Amsterdam.

Also in 2005 three Topical Lectures were organised: one dealing with Monte-Carlo calculations, one on cosmology and one on supersymmetry. 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: 59 PhD students were enrolled in December 2005 and 10 PhD students graduated in 2005.

The research school was reviewed by an international panel in May and received a very positive report. The request for renewal of the recognition of the research school by the royal Dutch Academy of Sciences (KNAW) was filed in December 2005. Since December 2004 Prof. N. de Groot from the Radboud University Nijmegen is secretary and the Radboud University is 'penvoerder' of the school.

Outreach

Figure 1. Very young 'scientists' in the Fun Lab during the Open Day.

Figure 1. Coming and going Science Information Officers Gabby Zegers and Jacques Visser, September 2005.

Science Information Services

The year 2005 has been a turbulent year full of outreach activities, mainly due to the initiative to announce the year 2005 as the World Year of Physics. NIKHEF was involved in a lot of activities in both national and international projects. Besides the extra activities within the scope of the World Year of Physics we had to deal with our usual business. A newly written and designed brochure has replaced the NIKHEF brochure 'NIKHEF Update'. The new ATLAS film about the efforts of NIKHEF in this experiment progressed steadily this year. The film crew has taken shots at NIKHEF and at CERN and the finishing touch will soon take place. Regularly, contacts with the media and meetings with other institutes inside and outside the Netherlands have taken place.

In 2005 more than 40 articles, intended for the general public, were published concerning NIKHEF related subjects. Thanks to the data- and photo base of CERN and the image bank of Interactions.org we are able to provide journalists, teachers and students with relevant photographs, graphics and so on. We also participate in the international outreach committees EPPOG and ATLAS. Due to the overload of outreach activities NIKHEF has decided to expand the employment rate of the science information officer from 0.5 to 1 fte. In September Gabby Zegers has been appointed and next year she will be succeeding Jacques Visser who was the NIKHEF science information officer for more than sixteen years.

Figure 1. The Eureka Cup for high-school students was held at the Science Park.

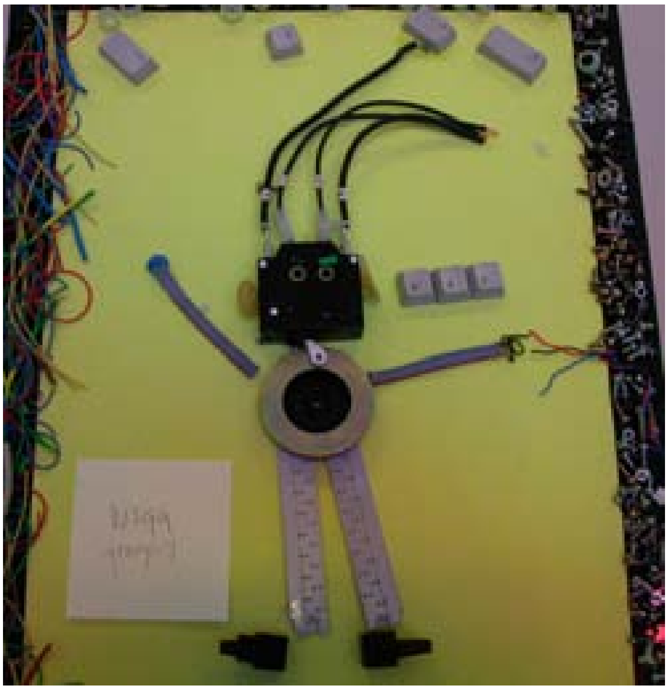


Figure2. The technics tournament led to a great deal of nice works by primary-school kids, now published in a booklet.

World Year of Physics

In 1905 Albert Einstein wrote his legendary articles that provided the basis of three fundamental fields in physics: the theory of relativity, quantum theory and the theory of Brownian motion. The World Year of Physics in 2005 provided the opportunity to celebrate the 100th anniversary of this miraculous year.

Particle-Physics Masterclasses

Professor M. Kobel from the Universität Bonn initiated the European particle physics master class project. All member states of CERN were asked to participate. The idea behind these master classes is to expose high-school students to particle-physics lectures given by active scientists, and to let them perform analyses on data from real particle-physics experiments. At the end of the day, like in an international collaboration, the participants joined in a video conference to discuss and combine the results.

For the Netherlands NIKHEF co-ordinated the Dutch contributions. The universities of Amsterdam, Utrecht and Nijmegen each participated in this event together with six locations elsewhere in Europe. The master classes were a great success and are recommended to be continued.

Quantum Diaries

Quantum diaries is a collaborative blogging project where 32 particle physicists from around the world are blogging their professional and personal lives as part of the World Year of Physics. Involved in this effort are CERN, SLAC, Fermi lab, KEK, NIKHEF, JINR, and many other physics labs around the world. From NIKHEF Maaike Limper, Frank Linde and Alex Koutsman participated. They regularly described their vicissitudes on their web log. For more details see the site:
http://www.quantumdiaries.org.

National Initiatives

From the start (in 2004) NIKHEF has been involved in the organisation of the World Year of Physics in the Netherlands. Several working groups were established and in three of them NIKHEF was active.

Primary schools: Techniek Tournooi

Dr. Els de Wolf was a member of the working group primary school. It organised the technics tournament in the amusement park "Land van Ooit". More than 700 children, teachers and parents participated. The youngest

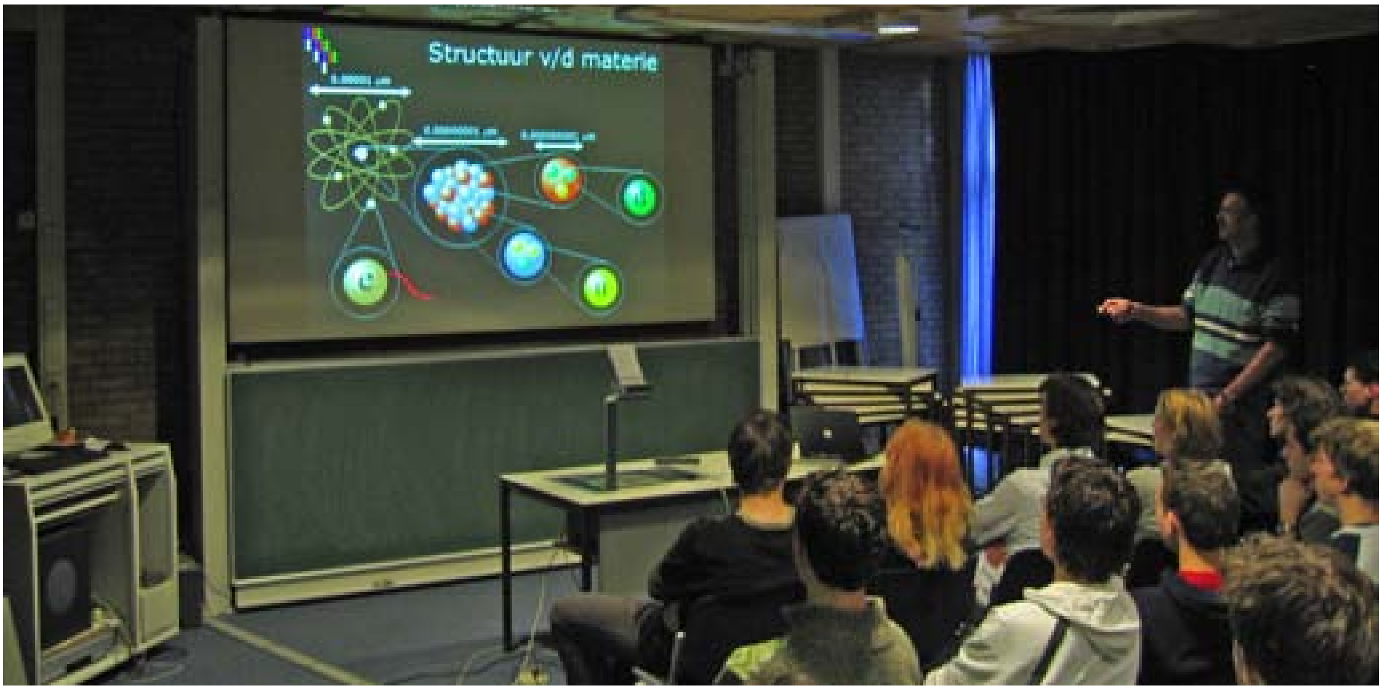


Figure 3. Masterclass held at NIKHEF.

children competed by building sand castles, paper bridges and the biggest soap bubble. The older ones produced a piece of work about science and technology. The makers of the twenty best pieces of work received a price and their work has been published in a booklet and was exposed in an exhibition at NIKHEF.

High schools: Eureka Cup

The activities in this project were mainly intended to trigger curiosity, to show the fun of solving scientific and technical problems, and to increase insight in physics experiments. In parallel, laboratory visits and lectures on selected topics were organised for the participants. Jacques Visser of NIKHEF was one of the organising members. In front of the NIKHEF building at the Science Park Amsterdam more than 250 high-school students from first to fourth grade were in competition for the Eureka Cup. Prizes were awarded for the best water rocket, the longest chain reaction, recognition of persons by various sensors, and astronomical parallax measurements.

The main public event: Science Unlimited

The main physics event, tentatively termed 'Science Unlimited' took place in the centre of Amsterdam at the Science Museum Nemo. Dutch universities and institutes like NIKHEF developed exhibits and demonstrations of physical phenomena. In addition, industry provided examples of modern technology, illustrating the link between science and its application in everyday life. In parallel, selected scientists in an adjacent auditorium gave public lectures. The event lasted a whole week in the second half of June 2005. Jacques Visser was a member of the organising committee and NIKHEF participated in the exhibits as well as in the lectures given. Prof. F. Linde and Prof. B. van Eijk both took care of one lecture in the afternoon on Friday and Saturday. Exhibits from NIKHEF were the (cosmic) spark chamber, the cloud chamber and a full working unit of the HiSPARC cosmic ray project. During this week the Science Museum was admission free and open from 10 AM to 10 PM. A total of thirty NIKHEF employees were present at our exhibit. More than 15,000 people visited the Science Unlimited event in spite of the national train strike on Friday and the tropical heat on Sunday.

Figure 1. Jan van den Berg, the bear (Hannie van den Berg) and the elementary particles during the Adhoc show.
photos: Joep Lennarts

Adhoc Science Theatre

October 8, the Dutch theatre group Adhoc gave a show about elementary particles at one of NIKHEF's former accelerator buildings. A stage occupied by large colourful cubes, carrying the symbols of particles and forces of the Standard Model, formed the base onto which presenter Jan van den Berg showed the basic relations in particle physics and the weird phenomena of quantum mechanics in a light and playful way.

The show was especially focused on the neutrino. Using video fragments of his visit to the Super-Kamiokande neutrino detector in Japan, a scale model of the mountain housing the detector and a glass of water symbolising the big volume of pure water of the detector, we were introduced into the technique of Čerenkov light detection. Meanwhile, Hannie van den Berg, impressive in a huge bear suit, represented Jan's encounter with a real bear on his mountain trip to Super-Kamiokande.

The relation to another small-scale world was made by an interview about molecular biology with Ronald Plasterk, director of the Hubrecht Laboratory in Utrecht. Chromosomes, DNA, RNA, how far can we go down in size? Not too far, in fact. Altogether an evening rousing the imagination of the laymen public about a world far beyond visual reality.
One day before, mathematician Lex Schrijver was guest in the show, and October 9, nanoscale specialist Kobus Kuipers was invited at NIKHEF. Maarten de Jong explained the mysterious characteristics of the neutrino in Radio Kootwijk on September 17. A movie based on the Higgs particle is now in preparation by Adhoc.

An evening rousing the imagination of the laymen public about a world far beyond visual reality.

Figure 1. The open day at NIKHEF made a lot of children wonder how...

National Science Week - Open Day

Since 1970 NIKHEF takes part in the National Science Week together with other institutes in the Science Park Amsterdam. In 2005 the Open Day took place on Saturday October 22. The World Year of Physics inspired the NIKHEF activities and various posters of the World Year of Physics could be seen all over the place. The theme of the National Science Day this year was “Know your nuclear forces”. It was used for several demonstrations and lectures. Prof. S. Bentvelsen gave the main lecture, of which the subject was ‘nuclear force’. The coffee corner was transformed together with the Spectrum area in a big ‘Science Cafe’, where movies from NIKHEF and CERN about our work in particle physics were shown. We even presented a draft version of the new ATLAS video, which concentrates on the in-house construction of the muon chambers.

In the Spectrum physicists demonstrated all kinds of mind-provoking and interesting physics experiments. In between, mini lectures were given: Prof. J. van Holten talked about gravity, Prof. P. Mulders about electromagnetism and Prof. F. Linde about the weak and strong nuclear forces. In the mechanical department we displayed muon chambers, detector parts and photos. Videos were shown about the experiments. Furthermore there was a demonstration with the test arrangement of the muon chambers.

As for so many years we created again a ‘Fun Lab’ for young children, where they built their own electronic toys, like ‘disco brooches’, ‘light organs’ and the very popular ‘bedroom alarm’. This last toy warns you when one of your parents sneaks into your bedroom. The Fun Lab is such an enormous success that for several years NIKHEF organised an additional Fun Lab at the central restaurant of the Science Park Amsterdam. A few thousand people, pupils, students, families and individuals visited NIKHEF. We had around twenty percent more visitors than last year. We owe this success mainly to the enthusiasm and effort of the NIKHEF employees. The remarks of the public were, as each year, very positive.

Figure 1. High-school students at work for HiSPARC.

HiSPARC

After winning the Altran Award in 2004, HiSPARC concentrated on the design and development of a new set-up for the data acquisition in 2005. This was necessary because the existing system was not suited for mass production and relatively expensive. Both features form an obstacle for expansion and therefore an update of the electronics was needed. The electronic department of NIKHEF hopes to have the design ready by autumn 2006.

In March, NIKHEF hosted a successful international workshop of Cosmic Ray School projects. Representatives of projects in 12 countries including the USA met for two days to exchange experiences and to discuss possibilities for collaboration in the future. As a result two HiSPARC teachers went to a workshop organised by the CROP project in Nebraska, USA. A follow-up of the workshop is planned in Lisbon, Portugal in 2006 parallel to the 20th European Cosmic Ray Symposium.

Also in March, the second HiSPARC student conference was held. Approximately 90 high-school students and teachers from 10 different schools attended, workshops were given for and by students about several topics around cosmic rays. The quality of the contributions was impressive.

In October Prof. A. Watson, among others spokesman of the Pierre Auger Observatory, paid a visit to the project in Nijmegen. At a special symposium teachers and students spoke with Prof. Watson about their contribution to the project. Prof. Watson stated that to his knowledge HiSPARC is the only school project capable of making a contribution to science.

Dr. C. Timmermans presented the first scientific results of the HiSPARC project at the International Cosmic Ray Conference 2005 in Pune, India. Both in Nijmegen and Amsterdam triple events with estimated primary energies of more than 10^{19} eV were recorded. This comes close to the energy range of the ultra high energetic cosmic rays that HiSPARC eventually aims to detect.

To calculate the energy of the incoming primary particles, software is made available on the web to be used by

students and teachers. There is an ongoing activity in several school projects, where students either perform experiments or look into the HiSPARC data. Some teachers are very active in monitoring the data and looking for interesting events.

Also in 2005, LOFAR radio antennas were placed at the Radboud University Nijmegen to study the possibilities of joint detection with the two sensors. To minimize the amount of data to be stored, a triggered read out of the LOFAR antennas is necessary. The technical feasibility of this set-up was demonstrated in the past period. The LOFAR antennas allow for a better energy estimation of the primary particle. The set-up also opens the way for a collaboration with the LOFAR@school project to further increase the visibility of HiSPARC.

After the rapid expansion of the detector network especially in the HiSPARC cluster Amsterdam, progress slowed down somewhat in the second half of this year. In total approximately seven new stations were installed. The focus in 2005 was primarily on methods of data analysis and the development of classroom material.

In the school years 2004-2005 and 2005-2006 HiSPARC received support from the Platform Bèta-Techniek. This contribution is to be used partly for the development of modules for a new integrated science course for high schools. To this end teachers and members of the HiSPARC team developed paper- and web based material. A successful pilot version of an Electronic Learning Environment (ELO) has been launched at two high schools.

The World Year of Physics meant more attention than usual for science and technology by the media. One of the highlights for HiSPARC was an article in Science. The journal wrote about the apparent popularity of cosmic ray projects with high schools all around the world. Other media, especially local newspapers wrote regularly about HiSPARC. In November HiSPARC participants could be heard on national radio.

Figure 1. The 'Natuurwetenschappelijke Studievereniging Amsterdam' (NSA) visits CERN.

CERN visits

Frank Linde, in his quantum diary weblog:
"Thursday April 21, the Dutch minister of Education, Culture and Science, Mrs. M.J.A. van der Hoeven, came for the third time to CERN. The previous visits were cut short by a crisis in the Dutch government and by KLM, the Dutch airline company, respectively. This third visit was a major success! The minister was very well prepared, showed a genuine interest in our field of research and nevertheless did not shy away from asking critical questions. The highlights of the visits were a tour of the ATLAS cavern and the closing session featuring an open discussion with Dutch personnel working at CERN. For those following minister van der Hoeven on television: watch her wearing the colourful ATLAS scarf; she received it as a present of the CERN director general Robert Aymar."

Between November 9 and 13, a group of 25 students from the "Natuurwetenschappelijke Studievereniging Amsterdam" (NSA) visited CERN. The trip, organised by Joris Hartman and Stan Bentvelsen, included a visit to the ATLAS and CMS detectors, the LHC magnet site, various construction halls and presentations by several international speakers.

The FOM board and chairmen of 'werkgemeenschapscom missies' paid a two-day visit to CERN, guided by scientific director Jos Engelen. Lectures and discussions on the mission of CERN, the highlights and ambition of NIKHEF at CERN, more specific on the search to find the Higgs particle, and the necessary computer network, GRID, were alternated by a visit to the halls where detectors are being built. The whole industry involved in these experiments became clearly visible to the guests, who where able to see the magnets for the LHC accelerator and ATLAS being constructed. Finally, the LHC tunnel was entered, where 'the real thing' will happen in 2007.

Early 2005 a couple of high-school students were able to pay a visit to CERN. That visit was still part of the 50 year CERN activities that took place in 2004. NIKHEF organised part of the visit. Seven HOVO 'students' visited CERN in March. On April 5 and 6, twenty students from the honours programme of the Radboud University Nijmegen followed.

Figure 2. The FOM board visits CERN, April 2005. *photo: CERN*

Impressive, to see the building of the ATLAS detector yourself. Impossible to imagine its size!

Very inspiring!

We should go more often on a working visit!

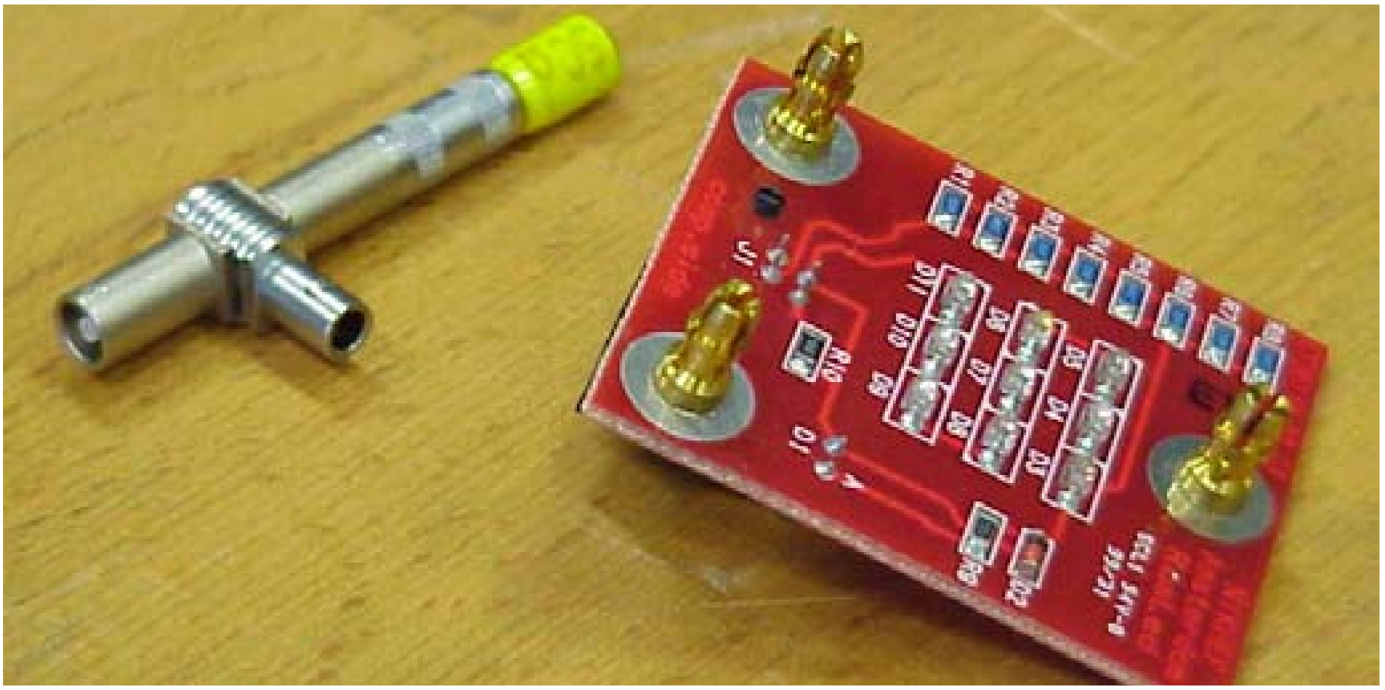


Figure 1. The RasLed, a part of a RASNIK alignment system.

Industry

Industrial Liaison

On February 10, NIKHEF organised a suppliers meeting on the theme Industrial Liaison in cooperation with Dutch Scientific. Many research institutes like CERN, ESRF, EFDA need to reinvest the money they are receiving from member states back into these member states. For this purpose, a network of Industrial Liaison Officers tries to contact many firms in their respective countries.

The suppliers meeting of February 10 was joined by 45 Dutch firms representing many different disciplines, e.g. vacuum expertise, materials knowledge, special fabrication and forming technologies, electronics, data acquisition, communication technology.

The programme was set up in two parts. A few specialised talks by NIKHEF experts and a visit in groups to selected NIKHEF sites: clean rooms, workshops, research laboratories, computer farm, GRID demo. This was also the opportunity for some firms to get acquainted with new techniques developed at NIKHEF, and to consider their potential for industrial application. As examples we mention: CO_2-cooling, detector development and Rasnik alignment.

Knowledge Management in the Electronic Department

This year representatives of the technical departments of the faculty of physics of the University of Amsterdam visited NIKHEF. The programme existed of half a day presentations about the institute and its departments (engineering, electronic, mechanic and computer technology) and a guided tour through the various departments of NIKHEF. During the breaks and during the tour, ideas were exchanged about ways of working, technical issues, organisation problems, etc.

Networking days with third parties, like the electronic department of a university or with industrial parties, are one way to exchange knowledge. Collaborations with third parties belong to the normal activities of an electronic department notably in the field of outsourcing. The electronic department organises every year one or two days to establish these relations.

Figure 1. The logo of the InterActions Collaboration.

Figure 2. The InterActions Collaboration at the INFN Frascati Laboratory in March 2005.

The InterActions Collaboration

In 2005 the collaboration has 21 members, representing the world's most important particle-physics laboratories in Europe, North America and Asia. The group meets twice a year at member state laboratories or at a particle-physics conference. At these meetings the present members report on the well-being of their institute and discuss the communication challenges they are facing. As it turns out, most of the laboratories and institutes struggle with the same issue: how to reach their target audience. Together, the members must confront the challenging future of particle physics. With cut backs in funding and new large projects in the making, a worldwide particle-physics communication strategy is necessary. During these visits strategic communication and practical tools are discussed.

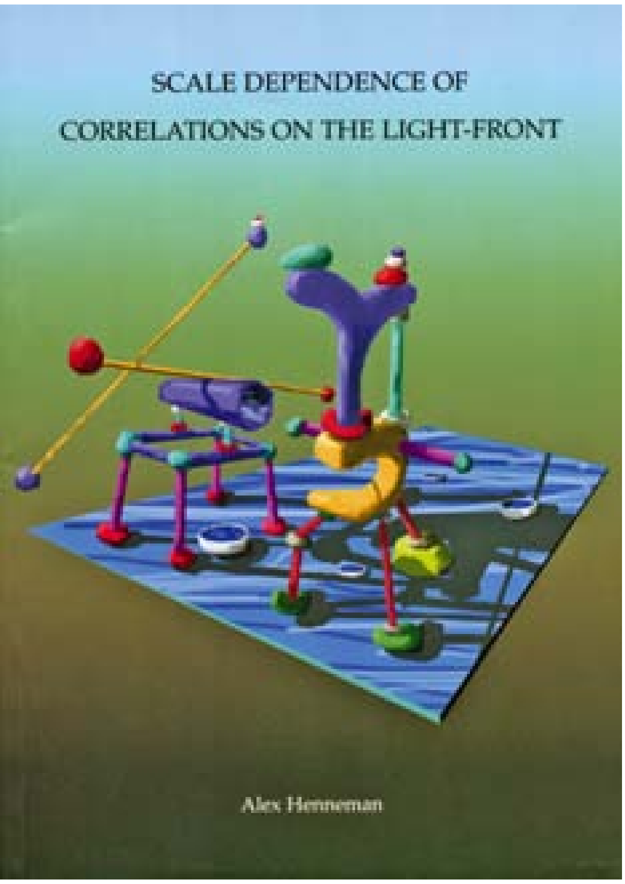
An example of the need for strategic communication is the ILC project. To convince governments of the necessity of this future accelerator, communication to these parties must start long before an actual decision will be taken. The InterActions Collaboration meeting in August 2005 at Snowmass, Colorado, was focused on this topic.

For the World Year of Physics 2005 the InterActions Collaboration worked together on the successful Quantum Diaries (www.interactions.org/quantumdiaries). Quantum Diaries is a website that followed physicists from around the world as they experience the World Year of Physics 2005. Through their bios, videos, photos, and blogs, the diarists offered a personal look at the daily lives of particle physicists. Representing NIKHEF, physics student Alex Koutsman, graduate student Maaike Limper and director Frank Linde, blogged throughout the year.

Mission: *Not only to support the international science of particle physics but to set visible footprints for peaceful collaboration across all borders.*

It was in Hamburg, 2001, that the heads of the communication departments of CERN, DESY, Fermi lab, Jefferson Lab, INFN Gran Sasso and SLAC formed the InterActions Collaboration. Its goal: to support particle physics worldwide by working together on strategic communication.
Anne Mieke van den Bergen represents NIKHEF at the biannual meetings.

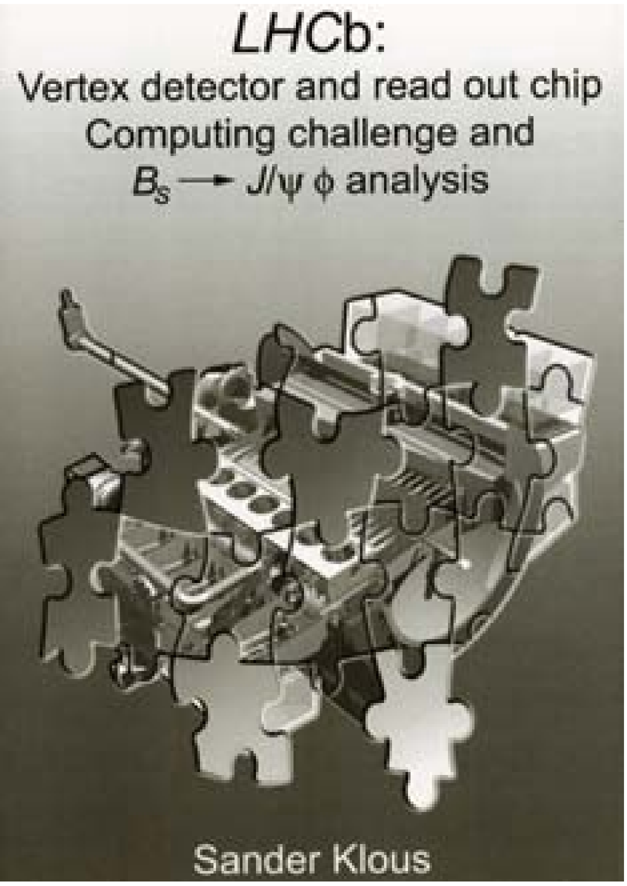
Theses, Publications & Talks



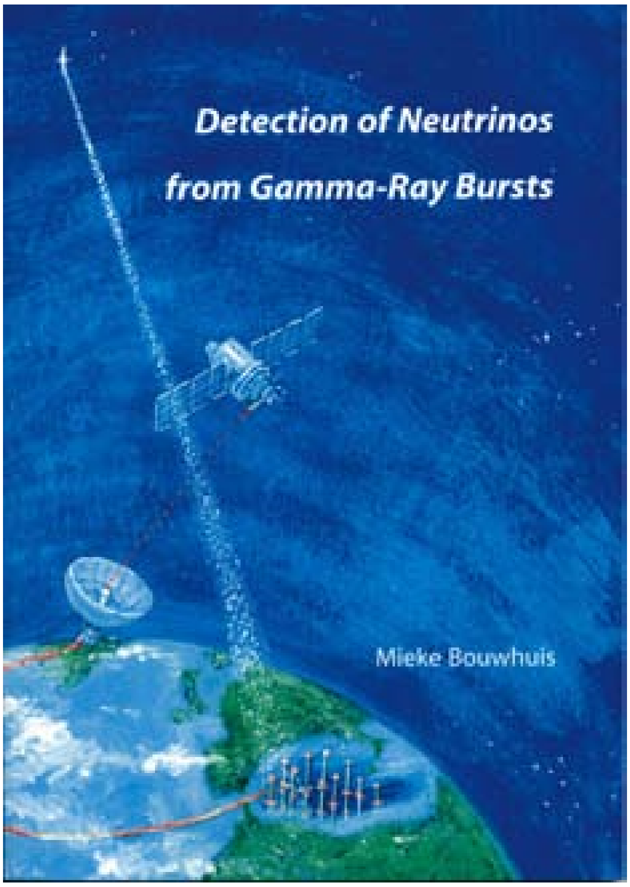
Vrije Universiteit Amsterdam, February 2

Vrije Universiteit Amsterdam, March 3

Twente Univers



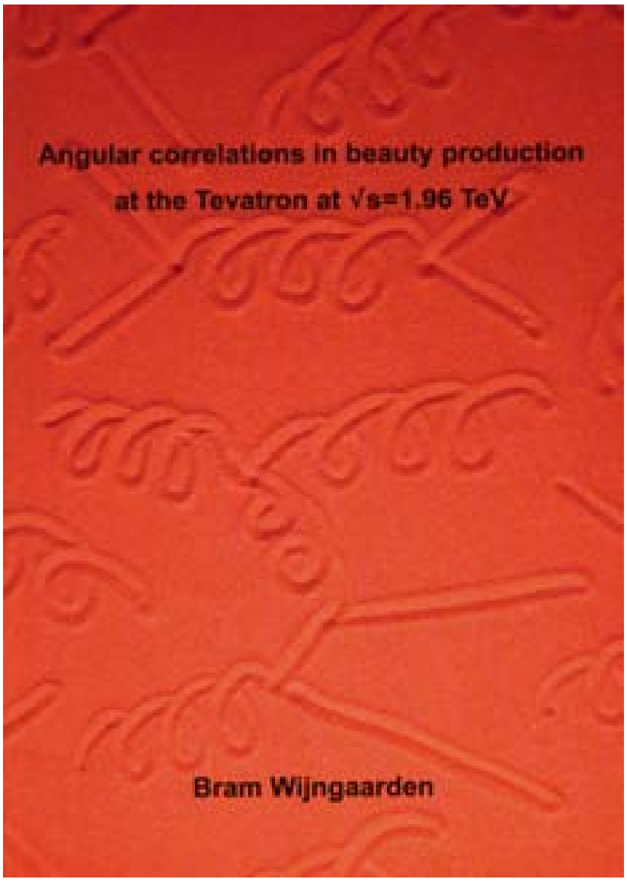
Vrije Universiteit Amsterdam, May 31



University of Amsterdam, July 7

Utrecht University

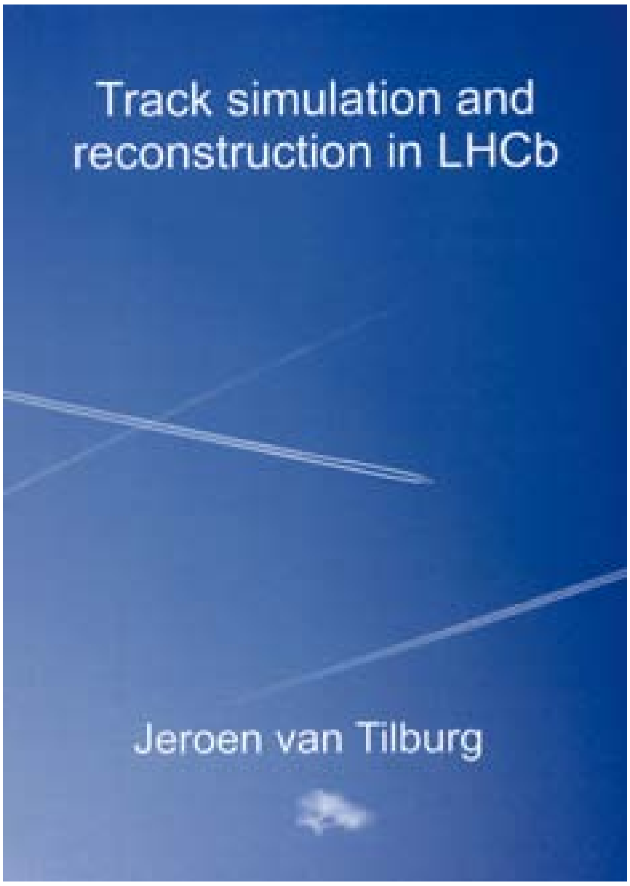
sity, June 2



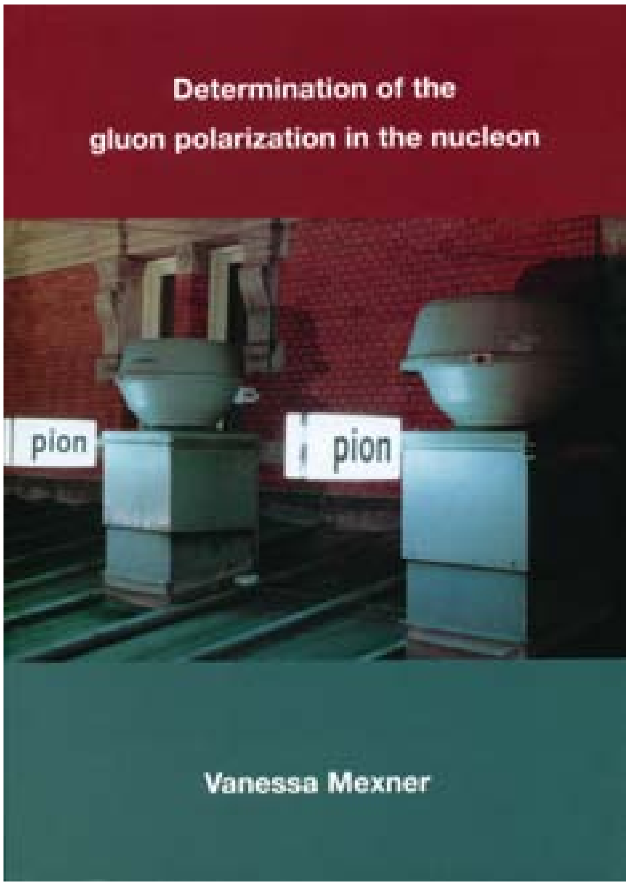
Radboud University Nijmegen, June 21

University of Amsterdam, April 1

y, September 7



Vrije Universiteit Amsterdam, October 11



University of Amsterdam, December 20

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Papadelis, A., Observation of Anomalous bias dependent cluster centroid shifts in the LHCb Velo detector, Vertex 2005, November, Chuzenji Lake, Nikko, Japan

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Exploring the Cosmos with the Amanda/IceCube Neutrino Observatory, Physics colloquium NIKHEF, December, Amsterdam

Addressing a Hot Item with a Very Cool Experiment : First light in IceCube, General Physics colloquium, May, Utrecht

Aspects of Modern Physics, General physics evening lecture, Utrecht University, October, Utrecht

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Gluon saturation, Workshop NL-Muenster on RHIC/Alice physics, April, Twente University, Enschede

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Top quarks at the LHC, Landelijk Seminarium Theoretische Fysica, December, Amsterdam

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The cosmic web of strings, From Strings to Cosmic Web, November, Groningen

Schellekens, B., Supersymmetric Standard Model Spectra from RCFT Orientifolds, February, Tor Vergata, Rome, Italy

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Sightseeing in the Landscape, Paris area common seminar, Institute Henri Poincare, November, Paris, France

String Theory, Marie Curie Colloquium, Radboud Universiteit Nijmegen, December, Nijmegen

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Prospects of FORM, ACAT05, DESY, May, Zeuthen, Germany

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Detector R&D

Chefdeville, M., Recent results of GridPix detectors, 9th ICATPP, October, Como, Italy

An electron-multiplying ‘Micromegas’ grid made in wafer post-processing technology, SAFE 2005, Annual Workshop on Semiconductor Advances for Future Electronics and SENSORS, November, Veldhoven

Graaf, H. van der, Recent GridPix results: an Integrated Grid (InGrid) and an ageing test of a Micromegas chamber, PSD7, September, Liverpool, UK

GOSSIP: a vertex detector combining a thin gas layer as signal generator with a Si pixel readout, TIME workshop, October, Zürich, Switzerland

Gromov, V., Performance of the Bandgap Reference circuit, designed in a commercial 0.13 μm CMOS Technology, 11th Workshop on Electronics for LHC and future Experiments - LECC 2005, LECC 2005, September, Heidelberg, Germany

Putten, S. van der, Tracking cosmics: Recent results from a Micromegas-covered MediPix2 pixel CMOS readout circuit in a mini-TPC, 7th International Workshop on Radiation Imaging Detectors, July, Grenoble, France

Schrader, J.H.R., Jitter Limitations on Multi-Carrier Modulation, IEEE Int. Symp. Circuits and Systems, May 2005, Kobe Japan

Equalization of Skin Effect Loss Dominated Channels using Pulse-Width Modulation Pre-Emphasis, ProRISC 16th Annual Workshop on Circuits, Systems and Signal Processing, November, Veldhoven

Timmermans, J., Readout of a TPC by Means of the MediPix CMOS Pixel Sensor, LCWS 2005, March, Stanford, UK

Review Tracking and Vertexing, LCWS 2005, March, Stanford, USA

Readout of a TPC using the Medipix2 CMOS pixel sensor, Int. TPC R&D meeting, March, Berkeley, USA

Digital TPC developments at NIKHEF, ECFA Linear Collider workshop, November, Vienna, Austria

CMOS Transmitter using Pulse-Width Modulation Pre-Emphasis achieving 33dB Loss Compensation at 5-Gb/s, Symp. VLSI Circuits, June 2005, Kyoto Japan

Delay 25 an ASIC for timing adjustment in LHC. 11th Workshop on Electronics for LHC and future Experiments, September 2005, Heidelberg

Visschers, J.L., Single-photon sensitive imaging with hybrid pixel detectors, Detector Seminar ESA-ESTEC, January, Noordwijk

Pixel Detectors for X-ray Applications, XFEL brainstorm meeting, January, Woudschoten

Hybrid Pixel Detectors for X-ray Imaging, Symposium Medical Imaging, KVI, March, Groningen

Detector Development together with Industry, ASTP-seminar WTCW-Z009, May, Amsterdam

Hybrid Pixel Detectors and High-bandwidth Readout, current status and future trends, European Detector Forum, May, Strassbourg, France

Hybrid Pixel Detector R&D at NIKHEF and CERN, Philips Applied Technologies, November, Eindhoven

MEDIPIX: Een Foton-tellende Beeldopnemer voor Rontgen- en andere Ioniserende Straling, Innovatie Platform Bijeenkomst, December, Maarssen

GRID

Bos, K., NIKHEF and LCG, Super Computing 2005, November, Seattle, USA

The LHC Data and Computing Grid, Grid@Large workshop, August, Lisbon, Portugal

Groep, D., EUGridPMA overview and status, 4th EUGridPMA Plenary Meeting, January, Marseille, France

Grids: van onderzoek tot onderzoeksfaciliteit, Presentation at the NWO ICT Theme Day, February, The Hague

The Virtual Laboratory for E-Science, European Grid Conference 2005 Industry Forum, February, Amsterdam

The EUGridPMA and Grid Federations, GGF CAOPS WG, March, Seoul, Korea

EUGridPMA, Grid Authentication in Europe, EUGridPMA Plenary Meeting, May, Tallinn, Estonia

IGTF Federation, GGF CAOPS WG, June, Chicago, USA

The International Grid Trust Federation, TERENA TF-EMC2, September, Barcelona, Spain

The EUGridPMA and Grid Security, EIROforum Grid Group plenary assembly, September, Geneva, Switzerland

Namespace Constraints Policy Requirements and Proposal, A New GGF CAOPS Working Document, October, Boston, USA

The International Grid Trust Federation, GGF Security Area Plenary meeting, October, Boston, USA

The NIKHEF Data Processing Facility, Leiden Institute for Advanced Computing Studies (LIACS), Grid Seminar Series, November, Amsterdam

The EUGridPMA and the IGTF, First APGridPMA Plenary Meeting, November, Beijing, China

The International Grid Trust Federation, UK Presidency e-IRG Meeting, December, London, UK

Templon, J., ICT Onderzoek en Grids, Presentation at the NWO ICT Theme Day, February, The Hague

Informatieversnellers: Computers en Fysica, VivaFysica Lezing, Universiteit van Amsterdam, January, Amsterdam

Techniek en Achtergronden van Grids, KNCV congres, April, Wageningen

Connecting LRMS to GRMS, HEPiX Spring Meeting, May, Karlsruhe, Germany

Venekamp, G., Glexec, 4th EGEE Conference, MWSG, October, Pisa, Italy

Miscellaneous

Groot, N. de, Summary of EHEF group research activities, IMAPP Colloquium, Radboud Universiteit Nijmegen, April, Nijmegen

De Einstein Code, Master Class, Radboud Universiteit Nijmegen, March, Nijmegen

Hochs, P., Bridging the Mathematics-Physics Culture Gap with The Mass Gap Problem, IMAPP Colloquium, Radboud Universiteit Nijmegen, December, Nijmegen

Holten, J.W. van, HiSPARC, Niels Bohr Colloquium, University of Copenhagen, February, Copenhagen, Denmark

HiSPARC, Colloquium University of Bonn, June, Bonn, Germany

HiSPARC, DESY Colloquium, June, Hamburg, Germany

HiSPARC, Colloquium DESY, June, Zeuthen, Germany

HiSPARC, Op jacht naar de kosmische straling, Woudschoten Conferentie, December, Noordwijk

Jans, E., Electro-induced two-nucleon knockout experiments on ^{3}He, ECT workshop on “Probing microscopic structure of the lightest nuclei in electron scattering at JLab energies and beyond”, July, Trento, Italy

Jong, S. de, Proficiat, Albert Einstein!, Science Café Nijmegen, February, Nijmegen

De Einstein Code, Master Class, Radboud Universiteit Nijmegen, March, Nijmegen

Ontcijfer het geheim van de kosmos, Master Class, Radboud Universiteit Nijmegen, March, Nijmegen

Leer elementaire deeltjes herkennen, Master Class, Radboud Universiteit Nijmegen, March, Nijmegen

Deel je kennis met Europa, Master Class, Radboud Universiteit Nijmegen, March, Nijmegen

Test of the EW sector of the SM, HEP2005 Int. Europhysics Conference on High Energy Physics, EPS, July, Lisboa, Portugal

Het heelal: een zwarte gatenkaas, Science Café Nijmegen, September, Nijmegen

Bridging the Mathematics-Physics Culture Gap with The Mass Gap Problem, IMAPP Colloquium, Radboud Universiteit Nijmegen, December, Nijmegen

Kittel, W., Beyond the Gaussian Approximation (Experimental Review), 4th Workshop on Particle Correlations and Femtoscopy, August, Kromeriz, Czech Republic

Some Open Questions in Bose-Einstein Correlations, 5th Budapest Winter School on Heavy Ion Physics, December, Budapest, Hungary

Kleiss, R., Proficiat, Albert Einstein!, Science Café Nijmegen, February, Nijmegen

De Einstein Code, Master Class, Radboud Universiteit Nijmegen, March, Nijmegen

Linde, F., Scientific program at NIKHEF, KVI colloquium, March, Groningen

Waar komt de bliksem vandaan?, Teylers museum, March, Haarlem

Kleiner dan atomen, CERN masterclass, March, Amsterdam

Scientific program at NIKHEF, WZI colloquium, April, Amsterdam

Big Bang in het laboratorium, Science Unlimited, June, Amsterdam

Kleine deeltjes, grote experimenten, HOVO cursus, August, Leiden

Kleine deeltjes, grote experimenten, Triangulum, September, Apeldoorn

Scientific program at NIKHEF, AMOLF colloquium, September, Amsterdam

Electroweak Physics, BND summerschool, September, Texel

De sterke kernkracht, NIKHEF open dag, October, Amsterdam

Inleiding elementaire deeltjesfysica, Vereniging voor technische physica, November, Delft

The fabulous four, NEMO beta festival, December, Amsterdam

Metzger, W., Introduction to jet physics in e^+e^- annihilation, 5th Budapest winter school on heavy ion physics, December, Budapest, Hungary

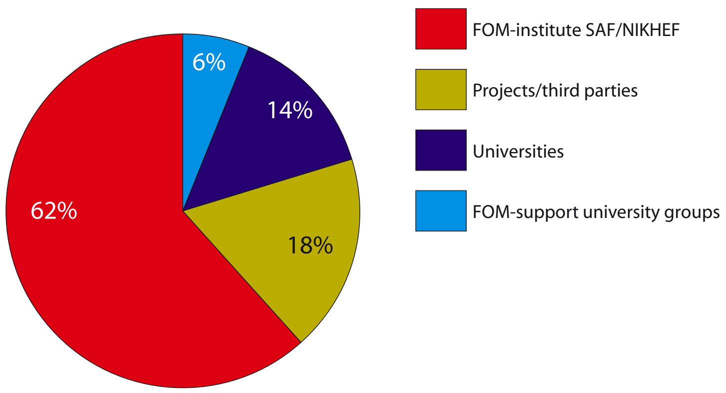
Bose–Einstein Correlations in e^+e^- Annihilation and $e^+e^- \rightarrow W^+W^-$, 4th Workshop on Particle Correlations and Femtoscopy, August, Kromeriz, Czech Republic

Timmermans, C., Science and outreach: the HiSPARC project, 6th two-yearly symposium of the Dutch Research School of Theoretical Physics, May, Dalfsen

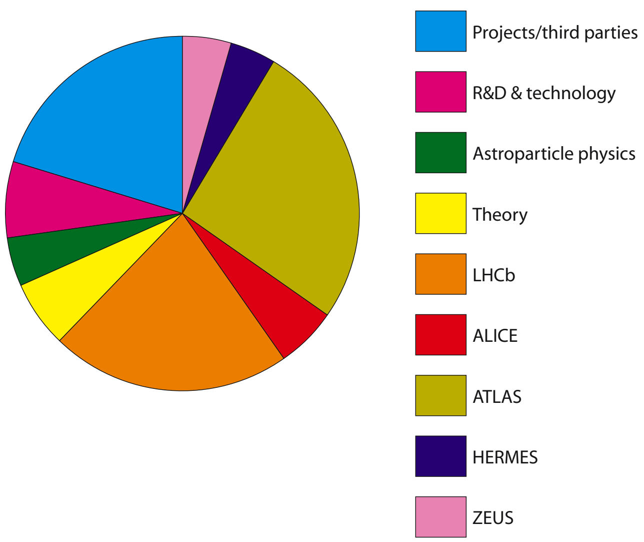
Setup and first results of the HiSPARC experiment, ICRC 2005, 29th Int. Cosmic Ray Conference, August, Pune, India

Resources & Personnel

Income 2005: 19.9 MEUR



Direct expenses 2005: 16.3 MEUR (indirect expenses: 3.6 MEUR)



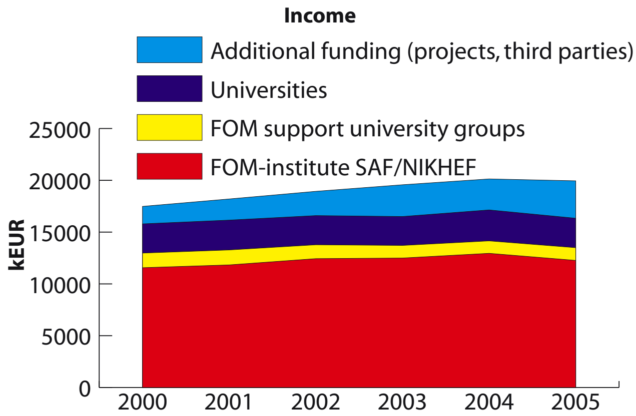
Resources

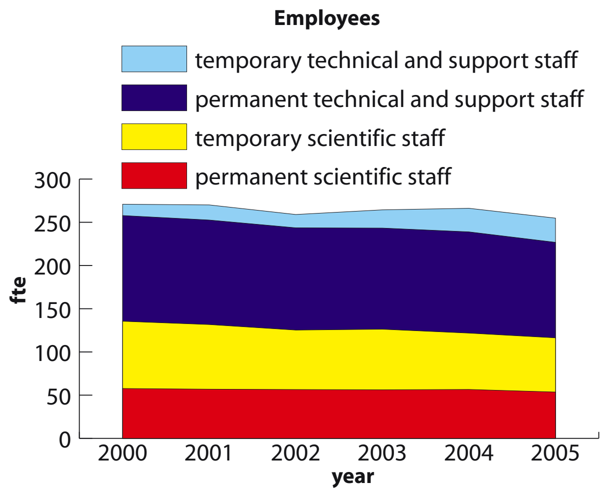
In 2005 the total NIKHEF income has nearly stabilised. This is due to an increased external funding (3.6 M€ compared to 3.0 M€ in 2004), which compensated the decrease in 'base' funding from FOM. The external sources consist of fees from customers of the Internet Exchange housing facility (1.3 M€), rental income (0.5 M€) and project funding from various sources (FOM, NWO, SENTER, EU, etc.). For the coming years the base funding from FOM will further decrease, which will –if not balanced by increased income from other sources– necessitate measures of reducing personnel and material costs of NIKHEF activities.

The number of employees of the NIKHEF collaboration has decreased in 2005 to about 255 fte, largely due to retirement of (technical) personnel. The number of temporary technical and support staff has not changed. Looking backward we observe that 2004 has shown the peak in the number of technical staff working on the realisation of the LHC detectors.

From the direct expenses in 2005 28% was consumed by the ATLAS programme, 21% by LHCb and 10% by ALICE, in total almost 60% for the LHC experiments. 'General' R&D, including the (not externally funded part of the) grid and pixel-detector activities comprised 8% of the budget.

Astroparticle physics (ANTARES) is still at a 5% level, but needs additional funding to grow into a larger fraction of the NIKHEF scientific program.





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Kuijt, Ing. J.J.	FOM
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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

Mechanical Engineering Group

Arink, R.P.J.	GST
Band, H.A.	FOM
Boer Rookhuizen, H.	FOM
Buskop, Ir. J.J.F.	FOM
Doets, M.	FOM
Duisters, D.H.	FOM
Klöpping, Ir. R.	FOM
Korporaal, A.	FOM
Kraan, Ing. M.J.	FOM
Lassing, P.	GST
Munneke, Ing. B.	FOM
Riet, Ing. M.	GST

Schuijlenburg, Ing. H.W.A.	FOM
Thobe, P.H.	FOM
Verlaat, Ing. B.A.	FOM

Mechanical Workshop

Atehortua Escobar, Mw. B.E.	FOM
Beek, R.M. van	FOM
Berbee, Ing. E.M.	FOM
Beumer, H.	FOM
Boer, R.P. de	FOM
Bron, M.	Other
Brouwer, G.R.	FOM
Buis, R.	FOM
Ceelie, L.	UvA
Filina, Mw. T.	GST
Henze, E.	FOM
Homma, J.	FOM
Jansen, F.M.	FOM
Jaspers, M.J.F.	UvA
John, D.	FOM
Kok, J.W.	FOM
Kop, A.	FOM
Kuilman, W.C.	FOM
Lavrentyev, V.	GST
Leguyt, R.	FOM
Mul, F.A.	FOM-VU
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
Stoffelen, N.	FOM
Willemse, M.A.	FOM

Management and Administration

Barneveld, Mw. K.M. van	Other
Berg, A. van den	FOM
Bergen, Mw. A.M. van den	GST
Bulten, F.	FOM
Colle, Dr. J.J.H.C.	GST
Dekker, Mw. C.E.	Other
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
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.	GST
Langenhorst, A.	FOM
Lemaire-Vonk, Mw. M.C.	FOM
Liempt, Drs. F.J.P. van	FOM
Mors, A.G.S.	FOM
Noordkamp, B.S.	GST
Pancar, M.	FOM
Rijksen, C.	FOM
Rijn, Drs. A.J. van	FOM
Schram-Post. Mw. E.C.	FOM
Spelt, Ing. J.B.	FOM
Tanczos, Dr. Mw. I.C.	FOM
Vervoort, Ing. M.B.H.J.	FOM
Visser, J.	FOM
Vreeken, D.	Other
Werneke, Ing. P.J.M.	FOM
Willigen, E. van	FOM
Wilt, P.M. van der	GST
Witlox, Ing. W.M.	FOM
Woortmann, E.P.	FOM
Yilmaz, E.	Other
Zegers, Drs. Mw. G.E.	FOM

Apprentices in 2005

Aaij, R.J.M.	B-Physics
Aarts, A.A.A.	ATLAS
Agarwal, A.	Mechanical Engineering
Ali, S.	Mechanical Workshop
Amoraal, J.M	B-Physics
Berlijn, T.	Theory
Blok, J.L.	ATLAS
Blom, M.R.	B-Physics
Bos, E.M.	Other Projects
Bosma, M.J.	ATLAS
Breukink, R.W.	ATLAS
Burnet, J.	Technical Facilities
Chourak, H.	Electronics Technology
Cohen, S.	B-Physics
Cottini, N.	ANTARES
Egmond, E. van	Mechanical Engineering
Elbers, M.C.	ZEUS
Ennes, P.	ATLAS
Fransen, M.	ATLAS
Frederix, R.H.	Theory
Geers, A.J.	Other Projects
Grange, Y.G.	ANTARES
Hartman, J.	Other Projects
Haverhoek, J.D.	Other Projects
Heijden, B.W. van der	Electronics Technology
Horssen, P. van	Other Projects
Horst, T. van der	Electronics Technology
Jairam, D.	Technical Facilities
Jankowski, M.	B-Physics
Keune, A.	Other Projects
Klomp, M.	Electronics Technology
Koutsman, A.J.	ATLAS
Kuckulus, F.	Mechanical Workshop

Kuijken, I.	B-Physics
Lascaris, E.	Theory
Maccione, Luca	ANTARES
M'charek, B.	B-Physics
Mous, I.V.N.	Other Projects
Mussche, I.	B-Physics
Pal, B.	Mechanical Engineering
Plas, B.A. van der	ZEUS
Pottelberghe, M.J.M.L van	ATLAS
Putten, S. van der	ATLAS
Rijpstra, M.	Theory
Rövekamp, R.M.	Computer Technology
Schuurmans, D.	Mechanical ngineering
Swenne, M.	Computer Technology
Takes, M.C.	ANTARES
Terlouw, B.	HERMES
Til, S. van	ATLAS
Torres Celis, P.C.	ATLAS
Versloot, T.W.	B-Physics
Visser, G.	Electronics Technology
Waaldewijn, W.J.	Theory
Wong, C.C.K.	Electronics Technology

They left us

Arends, Mw. W.	Mechanical Workshop
Arink, R.P.J.	Mechanical Engineering
Atehortua Escobar, Mw. M.L.	Mechanical Workshop
Baak, Drs. M.	B-Physics
Barisonzi, Drs. M.	ATLAS
Benmbarek, M.	Mechanical Workshop
Blekman, Dr. Mw. F.	ATLAS
Boeding, A.P.M.	Other Projects
Boer, J. de	Electronics Technology
Boerkamp, A.L.J.	Electronics Technology
Bos, Mw. M.	Secretariat / Reception
Boucher, A.	Mechanical Engineering
Bouwhuis, Dr. Mw. M.C.	ANTARES
Bozkus, B	Mechanical Workshop
Castillo Catellanos, Dr. J.E.	ALICE
Cohen, Mw. S.	Mechanical Workshop
Coppola, Dr. N	ZEUS
Coulon, J.M.	Other Projects
Derlage, R.W.N.	Other Projects
Diepen, Ing. L.S. van	Mechanical Engineering
Doest, Mw. C.J.	Technical Facilities
Esch, J.A.W.P.	Other Projects
Evers, G.J.	Electronics Technology
Fabbri, Dr. R.	HERMES
Fransen, M.	Mechanical Workshop
Geer, R. van der	Mechanical Workshop
Gesser, M.R.	Mechanical Workshop
Gorfine, Dr. G.	ATLAS
Gosselink, M.	Mechanical Workshop
Grijpink, Dr. S.J.L.A.	Computer Technology
Guz, Dr. Y.	B-Physics
Hari Dass, Prof. Dr. N.D.	Theory
Hesselink, Dr. W.H.A.	HERMES
Hogenbirk, Ir. R.S.	Electronics Technology
Hommels, Ir. L.B.A.	B-Physics
Hooft van Huysduynen, L.	ATLAS
Jansen, P.N.J.M.	Electronics Technology
Keiser, P.C.H.	Mechanical Workshop
Kirillov, V.	Mechanical Workshop
Kroes, Ir. F.B.	Electronics Technology
Lassing, P.	Mechanical Engineering
Laziev, Drs. A.E.	HERMES
Leeuwen, Drs. W.M. van	Computer Technology
Leter, C.E.D.	Mechanical Workshop
Luigjes, J.A.	ATLAS
Martis, J.	Mechanical Workshop
Middleton, Dr. D.G.	Transition Programme
Mischke, Dr. A.	ALICE
Mulders, Mw. S.A.M.P.	Secretariat / Reception
Naumann, Dr. N.A.	ATLAS
Nieuwenhuizen-Oskam, Mw. W.	Mechanical Workshop
Pijlman, Drs. F.	Theory
Rem, Drs. Ing. N.	Mechanical Workshop
Riet, Ing. M.	Mechanical Engineering
Salomoni, Drs. D.	Computer Technology
Schenk, Mw. E.L.	Secretariat / Reception
Schotanus, Dr. D.J.	Transition Programme
Snippe, Ir. Q.H.C.	Mechanical Engineering
Sokolov, Drs. A.	ALICE
Stoffelen, N.	Mechanical Workshop
Suvorov, Dr. V.	B-Physics
Tilburg, Dr. J.A.N. van	B-Physics
Veen, J. van	Mechanical Workshop
Vries, Drs. G. de	ANTARES
Warringa, Drs. H.	Theory
Wilden, Dr. L.H.	B-Physics
Woudstra, Dr. Ir. M.J.	ATLAS
Zeng, M.	B-Physics
Zwart, F. de	Electronics Technology