Self-evaluation Report 2000–2006

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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 (RU) 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.

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1 General Introduction

1.1 Introduction

Introduction

Nikhef is the national institute for subatomic physics, in which the Foundation for Fundamental Research on Matter (FOM), the Universiteit van Amsterdam (UvA), the Free University Amsterdam (VUA), the Radboud University Nijmegen (RU) and Utrecht University (UU) participate. Nikhef co–ordinates and supports all activities in experimental subatomic physics in the Netherlands. Nikhef is located in the Science Park Amsterdam.

The history of Nikhef goes back to 1946 when FOM, Philips' Gloeilampenfabrieken and the city of Amsterdam (for the university) founded the institute for nuclear research (IKO), near the premises of Europe's first synchrocyclotron. Nikhef itself was established officially in 1975 as a joint nuclear and high–energy physics national research institute with as leading partner FOM. The nuclear research community embarked on the construction and subsequent exploitation of a series of subsequently more powerful linear electron accelerators. The research activities of the high–energy physics community were primarily focused on the CERN European particle physics laboratory near Geneva. With the shutdown of the electron linac in 1998, Nikhef redirected its focus from nuclear and high–energy physics research to accelerator–based high–energy physics research, in particular using the Large Hadron Collider (LHC) at CERN, and to research in the emerging field of astroparticle physics.

In the 2000–2006 review period, a number of experiments came to an end concluding many years of successful data–taking and data analysis: the CHORUS, DELPHI and L3 experiments at CERN and the HERA–B experiment at DESY. In addition, Nikhef's involvement in the HERMES and ZEUS experiments at DESY will end in 2007 soon after the shutdown of HERA. In view of the imminent start–up of the LHC, Nikhef is also winding down its activities in the BaBar, DØ and STAR experiments in the USA. We participated in these experiments not only because of the discovery potential they offered, but also to gain experience in B–physics, hadron collider physics and heavy–ion physics prior to the start of our LHCb, ATLAS and ALICE programs at the LHC, respectively. These three LHC experiments constitute the core of Nikhef's accelerator–based research activities. Astroparticle physics activities gradually gained momentum over the review period. The ANTARES group more than doubled in size. Nikhef has joined Pierre Auger (the large area cosmic–ray observatory near in Argentina) and Nikhef contemplates to join VIRGO (the gravitational wave laser interferometer in Italy). All these predominantly experimental research activities benefit from the expertise of Nikhef's in–house theory

Nikhef mission statement in the year 2000

To study the interactions and structure of elementary particles and fields and to co–ordinate and lead all Dutch activities in this field.

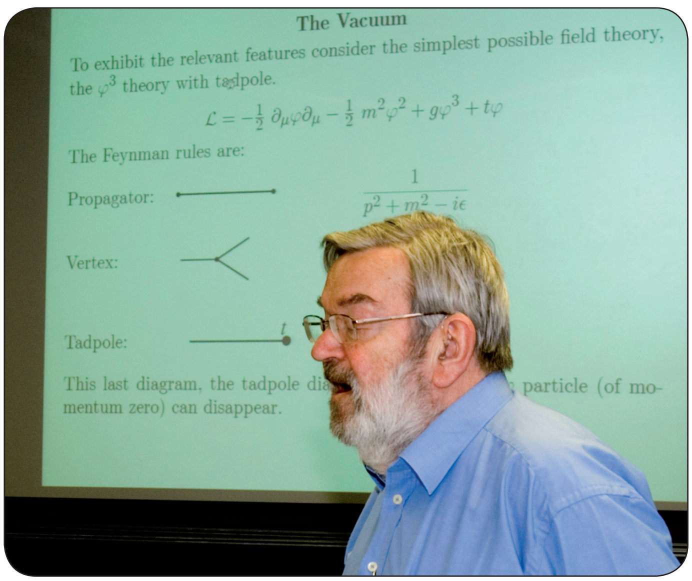

Fig. 1. Nobel laureate Prof. dr. M. Veltman lecturing on the Higgs mechanism at Nikhef.

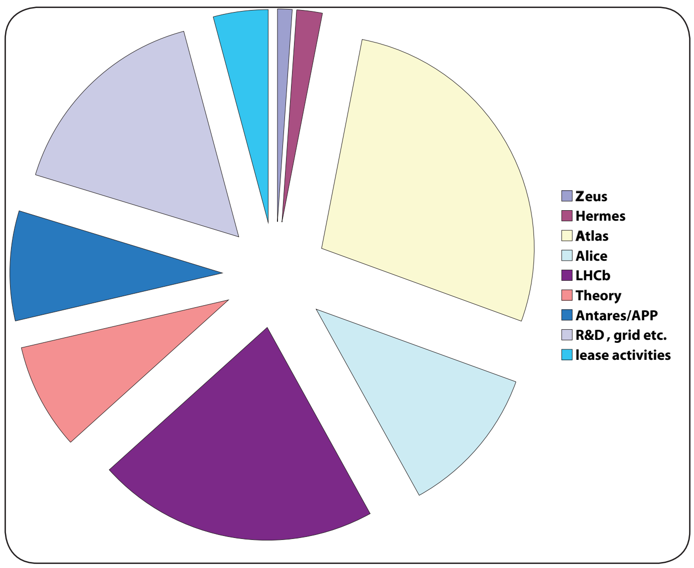

Fig. 2. Nikhef budget over the various research projects.

department. Nikhef is furthermore a partner in several national and EU subsidized R&D projects in the areas of grid computing (VL–e, EGEE and BigGrid), particle detection (RELAXD and EUDET) and astroparticle physics (KM3NeT and ASPERA).

In the 2000–2006 review period, outreach and education activities have increased significantly at Nikhef. As a result, Nikhef received much media coverage, Nikhef physicists participated in a theater play about neutrinos and Nikhef started to subsidize movies with particle physics topics as a theme. On education: Nikhef hosts the Particle and Astroparticle Physics master program (for master students) as well as the national research school for subatomic physics (for PhD students). Nikhef staff physicists lecture at all Dutch regular and technical universities with a science department and are at the forefront of numerous outreach projects for elementary school pupils, high–school students and teachers. For the general public Nikhef organizes an annual open day and Nikhef physicists give presentations at (science) museums, libraries and many other locations.

In 2006, the academic staff consisted of 132.1 fte scientists, including 60.6 fte PhD students and 14.6 fte postdoctoral fellows. Technical support was provided by well equipped mechanical, electronic and information technology departments with a total staff of 84.3 fte. Administrative and managerial support was provided by 24.9 fte. Nikhef's 2006 budget, excluding dedicated investment funding for detector construction projects and a national grid facility, amounted to 20.5 M€. Of this 20.5 M€, 63% is from structural funding by FOM, 17% is from structural funding by universities and 20% is from project funding (FOM, NWO, SENTER, EU, etc.) and industrial contracts, notably Internet Exchange housing fees.

I - Scientific groups (fte – 31.12.2006)	
Tenured staff	52.8
PhD students (4-year contract)	62.2
Post-docs (2-year contract)	20.1
Guest researchers	18
Mastergraduate students	24
Total I	*177.1*
II - Engineering support, administrative support, facility management (fte – 2006)	
Management-team	
Director	1
Institute manager	1
Personnel/HRM officer	0.8
Institute secretary	0.8
Subtotal	*3.6*
Engineering groups	
Electronic	26.7
Informatic	18
Mechanical engineering	11.8
Mechanical workshop	19.5
(project)management support	2.2
Subtotal	*78.2*
Administrative support	
Financial administration	2.8
Personnel/HRM administration	1
Library	1.2
Secretariat	3.3
Reception desk	1.2
Subtotal	*9.5*
General facility management	
Technical, building maintenance & custodial services	7.6
Purchasing	1
PR & communication	0.8
Occupational health & Safety	1
Subtotal	*10.4*
Total II	**101.7**
Total I & II	**278.8**

Table 1. An overview of Nikhef personnel in 2006.

1.2 Research programs

Figure 2 lists the annual expenses (dominated by salaries) for each program over the 2000–2006 review period. The LHC efforts (ALICE, ATLAS and LHCb specific research activities as well as generic LHC related phenomenology, grid and detector R&D projects), account for substantially more than 50% of the Nikhef expenses. The Nikhef participation in experiments at pre–LHC accelerators such as LEP, HERA, PEPII, Tevatron and RHIC, is decreasing fast. Astroparticle physics as well as grid and detector R&D related activities are steadily increasing. The latter includes R&D activities for the detector at the future linear e^+e^- collider. The remainder of this section gives a brief overview of the Nikhef research activies. A detailed description of these research activities is given in Chapters 2 and 3 of this report.

Fig. 1. Nikhef technicians working on the Silicon Tracker (SCT) for ATLAS.

Theoretical physics

Theoretical physics is a continuous and internationally recognized effort at Nikhef. Particularly noteworthy are the calculations of the four–loop beta function and the three–loop corrections to deep–inelastic structure functions using the FORM computer algebra program developed at Nikhef in earlier years. This work is indispensable for precise (few percent) predictions of processes at the LHC. Of similar importance are methods developed to include higher order corrections in the calculations and Monte Carlo simulations for the production of top quark pairs and single top at hadron colliders, thereby continuing the strong Dutch tradition in high–energy physics phenomenology.

Accelerator–based particle physics

Accelerator–based particle physics using in particular the CERN accelerator facilities near Geneva is the raison d'être of Nikhef. Hence, not surprisingly, a large fraction of Nikhef's experimental program has been driven by the CERN accelerator infrastructure, notably the neutrino beams (CHORUS), the LEP electron–positron collider (DELPHI and L3) and the LHC proton–proton collider (ALICE, ATLAS and LHCb). Other activities take place at the HERA electron–proton collider of DESY in Hamburg (HERMES and ZEUS), at a smaller scale at the Tevatron proton–antiproton collider of Fermilab near Chicago (DØ), at the electron–positron B–factory of SLAC in Stanford (BaBar) and at the RHIC heavy ion collider of BNL near New York (STAR).

The FOM program *'CHORUS: Do neutrinos have mass?'* was concluded in 2002. The principal goal of CHORUS, the observation of the oscillation of a muon–neutrino into a tau–neutrino, did not materialize. Instead CHORUS did produce a wealth of charm physics. This was only possible thanks to the fully automated emulsion scanning system developed in part at Nikhef.

The Nikhef participation in CERN's LEP program (DELPHI and L3 experiments) came formally to an end in 2004 with the termination of the FOM program *'LEP: The electro–weak interaction'*. LEP highlights include the precise measurement of the Z line shape, leading to a precise determination of the number of light neutrino species and a prediction of the top quark mass; the measurement of the W^+W^- cross section; and the search for the Higgs boson culminating into a 95% CL lower limit on the Higgs boson mass of 114.4 GeV. Indirectly the LEP measurements were acknowledged in 1995 with the discovery of the top quark at Fermilab and in the 1999 ('t Hooft and Veltman) and 2004 (Gross, Politzer and Wilczek) Physics Nobel prizes.

In anticipation of an equally successful future, a very large share of Nikhef's efforts in the 2000–2006 review period went into the construction of LHC sub–detector components and LHC physics data analysis preparations in view of three FOM programs: *'ATLAS: The exploration of new phenomena at the highest energy frontier'*; *'LHCb: The study of charge–parity violation'* and *'ALICE: The quark–gluon plasma'*. By the end of 2006 the vast majority of the LHC sub–detector hardware designed and constructed at Nikhef had been shipped to CERN to be installed in the underground caverns housing the experiments. These include: a complete endcap silicon tracker, 96 very large muon chambers and associated electronics systems and two huge endcap magnet toroids for ATLAS; a large straw–tube tracker with associated electronics and the mechanics and cooling for the vertex locator for LHCb; and the silicon strip detector for ALICE. During the construction of the LHC sub–detector systems at Nikhef, a fraction of these groups joined running experiments in the USA with comparable objectives and/or (data analysis or detector) technologies as our LHC experiments: DØ at Fermilab for ATLAS; STAR at Brookhaven for ALICE; and Babar at SLAC for LHCb. This not only resulted in novel analyses, e.g. the STAR elliptic flow analysis, but also has resulted in a large contingent very motivated PhD students. With the scheduled start of LHC experimentation later in 2007 in mind, our activities in the USA are ramping down.

In the 2000–2006 review period, Nikhef physicists were actively involved in experiments at the HERA electron–proton colliding beam facility at DESY, Hamburg via the FOM programs '*ZEUS: Structure of the proton*' and '*HERMES: Nucleon spin, flavour and glue*'. The primary results of the ZEUS experiment are beyond doubt the detailed determinations of the proton structure functions, i.e. the quark and gluon content of the proton, and their evolution as a function of the electron–proton momentum transfer. These results are a crucial input to the forthcoming interpretation of LHC data. The HERMES experiment has focused on a detailed decomposition of the nucleon spin identifying the nucleon spin contributions stemming from the intrinsic spin of the valence and sea quarks and gluons and from the orbital angular momentum of the quarks. Both the HERMES and ZEUS experiments have also given rise to a rich experimental program focused on long–lived particles using the secondary vertex tagging capabilities of silicon trackers added to these experiments during the 2001 upgrade of HERA. Both of these sub–detector systems were to a large extend designed and conceived at Nikhef and served as a stepping stone towards the very significant silicon tracker projects Nikhef embarked on for the LHC experiments. Both HERMES and ZEUS activities will come to a natural end in 2007 with the shutdown of HERA. By then the output is expected to include 15 HERMES and 21 ZEUS Dutch PhD theses.

Astroparticle physics

Dutch activities in the relatively new field of astroparticle physics started in 199x with Nikhef joining the ANTARES initiative to construct a water Cherenkov neutrino telescope in the Mediterranean Sea with as primary objective to measure the spectrum of high–energy cosmic neutrinos. Nikhef made significant contributions to ANTARES, of which the '*all–data–to–shore*' data–acquisition concept and the offline track reconstruction and visualization software are the most noticeable. Construction of the ANTARES detector started off relatively slowly, it took until 2006 to deploy

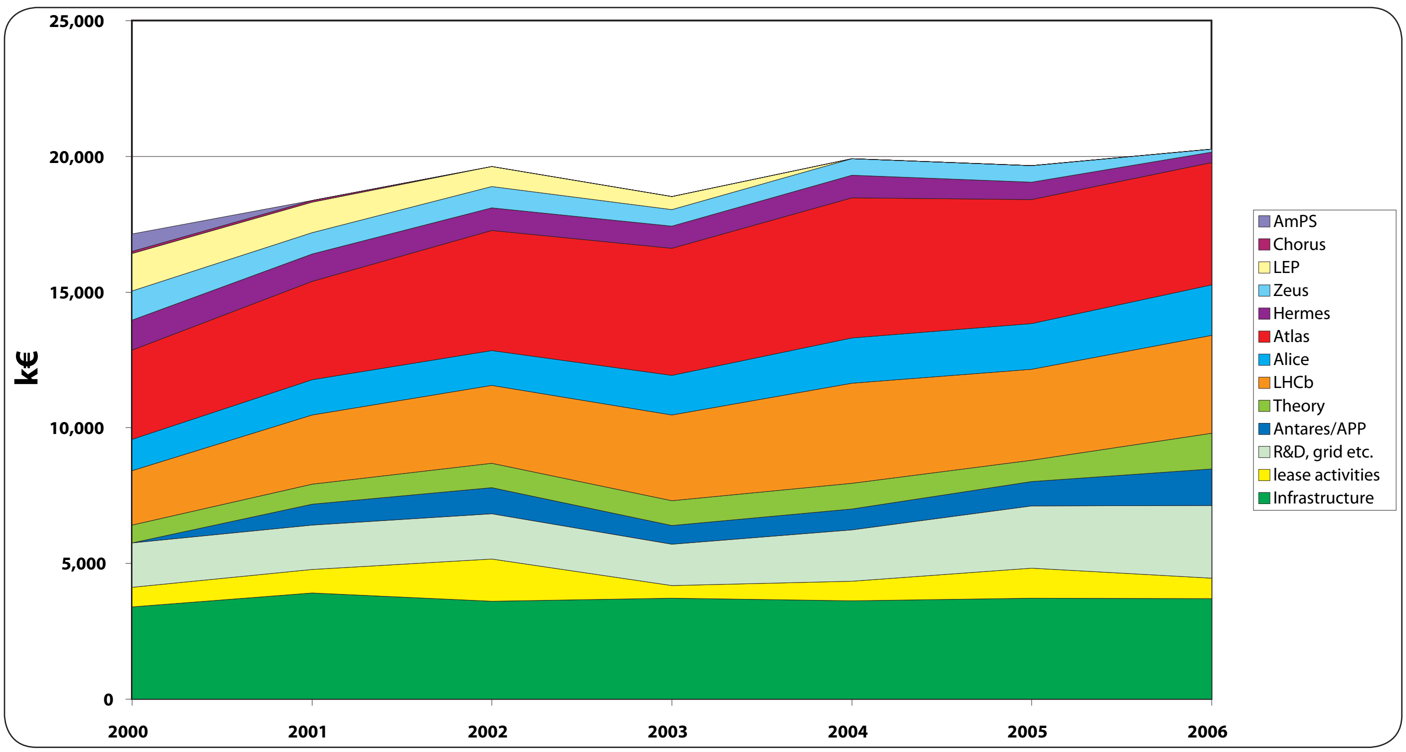

Fig. 2. Program expenses per year in the period 2000–2006.

Fig. 3. ANTARES lines waiting to be lowered into the sea.

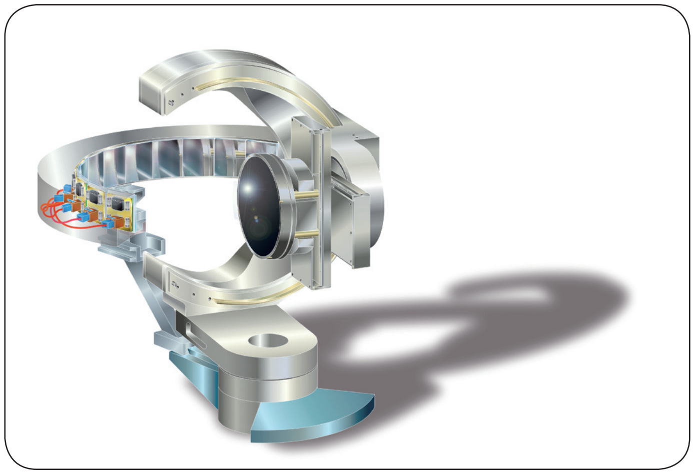

Fig. 4. Conceptual model of a RELAXD X-ray analyser.

the first 450 m real long detector line. By the end of 2006, three lines were successfully deployed and real events were recorded and astroparticle physics data analysis is ongoing. The remaining nine lines are expected to be deployed before the end of 2007, thus completing the ANTARES detector. In parallel the ANTARES group is investigating the next step: a kilometer cube detector, named KM3NeT, which received European support as a FP6-funded design study in 2006, and which was listed by the European Strategic Forum for Research Infra- structures (ESFRI) as one of the essential 35 large research instruments of the next 10 years.

In 2005 Nikhef joined, together with astronomers from ASTRON (Dwingelo) and physicists from KVI (Groningen), the Pierre Auger large area cosmic–ray observatory in Argentina as part of a national astroparticle physics plan with as central theme: *'The study of ultra–high energy cosmic rays in a multi–messenger approach'*. Based on a strong tradition in radio–astronomy, the Netherlands considers complementing the Pierre Auger observatory with radio antennas, thereby increasing the duty cycle for cosmic–ray detection with complementary technologies from the present 10% to almost 100%.

In 2006 a small team from Nikhef initiated contacts with the VIRGO laser interferometer for the detection of gravitational waves in Italy.

Detector R&D and grid computing

Subatomic physics is a technology enabled science. As such Nikhef has an extensive technical infrastructure.

Detector R&D highlights in the 2000–2006 review period include the development of gaseous detectors readout by a multipixel CMOS chip with a fully integrated gas–gain grid which yields bubble–chamber quality recordings of particle tracks; the continuous perfection of the RASNIK alignment technology in view of applications ranging from the alignment of the CLIC e^+e^- collider to the monitoring of the Earth's seismic activity; and the perfection of a CO_2–based cooling technique originally developed for the AMS satellite-based project and now used in the LHCb vertex locator. Regarding industrial collaboration Nikhef is working together with a manufacturer of X–ray equipment for material analysis (PANalytical) on the use and future perfection of Medipix technology in X–ray diffraction and X–ray fluorescence instrumentation. This has already led to a commercially available system based on Medipix technology. Further plans include setting up a production activity at the Nikhef premises in 2007 to establish a reliable supply chain for hybrid pixel detector systems. These efforts are in part financed by a subsidy from the Ministry of Economic Affairs in the Netherlands.

Grid computing has become a major effort at Nikhef. On a national level, Nikhef houses the largest number of grid researchers. Internationally, Nikhef is well recognized for security, scaling and validation software for grid operations. In 2006 the Dutch government approved the BigGrid infrastructure proposal that Nikhef, together with the Dutch computing foundation (NCF) and the Dutch bioinformatics consortium (NBIC), had submitted in 2005. BigGrid is a 29 M€ subsidy for the setting up and operation of a national grid infrastructure for a period of four years; this includes a Tier–1 center for LHC data analysis. This Dutch Tier–1 center serves the ATLAS, ALICE and LHCb experiments. BigGrid will be a general facility, open for all users in the Netherlands.

1.3 Impact: publications, citation analysis 2000-2006

In the 2000-2006 review period, Nikhef published xxx scientific articles in refereed international journals and xx PhD degrees were awarded (see Table 1). Table 2 gives a detailed breakdown of the scientific publications.

Bibliometric study

The Center for Science and Technology Studies (CSTS) of Leiden University has carried out a bibliometric study of the publications of the staff employed by Nikhef on 31 December 2006, thus reflecting the future research potential of the institute. The used method, data and detailed results are described in a separate report. The main conclusions have not yet been received.

Not yet received.

Table 1.

Not yet received.

Table 2.

1.4 Recommendations of the Evaluation Panel in 2000

An international review panel evaluated Nikhef in 2000. The overall conclusion of this panel is best summarized in their own words:

'In summary, the Panel considers that Nikhef fulfills its mission remarkably well. For a country wishing to play an active role in subatomic physics on the international scene, there is no doubt that the existence of such an Institute is an excellent, and probably the best way to operate. Over the years Nikhef has been a model of scientific excellence, efficiency and cost effectiveness recognized as such by all countries. The Panel has no hesitation in stating that Nikhef is the best way, for a country the size of the Netherlands, to organize, co–ordinate and manage its contribution to subatomic physics. This fully justifies its continued existence.'

The panel encouraged Nikhef to diversify its experimental research activities to include non–accelerator based experiments in the field of astroparticle physics. At present Nikhef is actively involved in the ANTARES water–Cherenkov neutrino telescope and the Pierre Auger large area cosmic ray observatory and Nikhef is contemplating to join the VIRGO laser interferometer gravitational wave detector. In 2004 Nikhef launched a national astroparticle physics network in which subatomic physicists and astronomers (both experimentalists and theorists) collaborate on the common research theme: *What is the origin of ultra high energy cosmic rays?*

The panel was concerned about an apparent temporary mismatch between available funds and Nikhef's obligations, notably regarding the LHCb program. This has been solved by a budget–neutral rearrangement of funds in favor of the LHCb program, enabled by the insight that some other programs had been slightly overfunded.

The panel welcomed the decision of the Nikhef ATLAS group to temporary join the DØ experiment at Fermilab, provided this effort would not jeopardize the long term success of ATLAS. Since 2000, the Nikhef ALICE and LHCb groups followed the ATLAS example by joining STAR at RHIC and BaBar at SLAC, respectively. Instead of adverse effects, we think our involvement in these experiments had a very positive impact on Nikhef.

The panel recommended installing a dedicated review committee for Nikhef's theory department. Instead we decided to embed Nikhef's theory department within a larger national theory network with a monthly symposium at Nikhef. This proved very beneficial and led amongst other to a national research agenda and the submission of a proposal for a new FOM theory program titled: *'From CMB to LHC: theoretical particle physics at the new frontier'* in early 2007.

Finally, the panel observed that Nikhef's obligations in both the LHC–experiments and other programs did not allow for enough flexibility in the R&D activities ('transitional program'). Based on this observation the Nikhef–director asked for a temporary budget increase to enable this flexibility in R&D. This eventually led to an increase of 1,36 M€ (3 million guilders), spread over the years 2003–2005, granted for a third by FOM, a third by NWO and a third by the four university partners. This has greatly improved Nikhef's capacity to pursue its R&D ambitions, particularly in detector R&D and grid research. Next to this page the letter sent by the international ECFA committee to the Minister of Education after the visit to Nikhef is reproduced. The actions as advised by the committee to Nikhef will be addressed in the Strategy Report.

1.5 Conclusions of the 2005 ECFA Visit

ECFA EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS

Minister M. van der Hoeven
Ministry of Education, Culture and Science
P.O. Box 16375
NL – 2500 BJ Den Haag

ECFA/Secr./05/1350

Geneva, 15 November 2005

Subject: <u>2005 ECFA visit to the Netherlands</u>

Dear Minister,

It was a great pleasure for the European Committee for Future Accelerators, ECFA, which I have the honour to chair, to visit the Netherlands on September 23rd and 24th 2005. ECFA visits successively the different European communities of particle physics and related disciplines, with three countries a year. On behalf of ECFA, I would like to thank the Dutch government, the Dutch physics community and in particular NIKHEF for their hospitality. After an inspiring welcome address, by Dr. C.A. van Bochove, we were guided through the Dutch activities and organization, through a series of well prepared presentations. We were also given guided tours of the NIKHEF technical departments and the facilities of the national computing centre SARA.

The committee concluded that the Dutch activities are well organized with NIKHEF as a focal-point that is well connected to the Universities, and with University faculty often in coordinating roles. This structure has produced an effective leadership allowing clear priorities to be set, in a way that is anchored in the community. The committee agreed with the prioritizations that have been made. This organization has also resulted in an international impact significantly above what would be commensurate with the available resources. The Netherlands uses well its membership of CERN and has also been strongly engaged at DESY (the German national accelerator laboratory in Hamburg); the combination of research at the LEP accelerator at CERN and the HERA accelerator at DESY has resulted in the formation of around 80 new researchers.

Overall, the committee was very impressed by the quality and impact of the Dutch activities; nevertheless it would like to indicate four areas where actions could further improve the Dutch research.

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- CAN, the recently established Committee for Astroparticle physics in the Netherlands, has defined a strategic plan, and NIKHEF has correctly given this a high priority, second only to the Large Hadron Collider at CERN. ECFA would like to emphasize the importance to ensure that existing funding-structures do not attenuate this initiative, as is often the risk for new interdisciplinary activities. It would also be good if this experimental initiative were to be backed by a corresponding increase in theoretical research.
- Europe is building up an increased networked program on accelerator R&D including CERN and DESY. It would probably be beneficial for the Netherlands if the accelerator physics at the Technical University of Eindhoven joined this activity in coordination with NIKHEF.
- The average time for doctoral (Ph.D) studies (4.7 years) is too long. We recommend this to be shortened to a maximum of 4 years. Furthermore, young people are needed to enter research for tomorrow's successes; a sufficient supply of post-doctoral fixed-term positions is therefore essential to identify these researchers who are the future of the field; there is however a tendency to reduce the number of such positions.
- Despite the ramp-down of the Dutch research at HERA in Hamburg, it would make sense to use the Dutch investment in this infrastructure for some more years, in particular for thesis work of graduate students.

The committee was impressed by the collaboration with industry on the development of pixel detectors and on grid computing. Regarding grid computing, the committee welcomes the Dutch ambitions to realize a Tier-1 for LHC data analysis as part of a large national facility serving many disciplines.

Finally I would again like to emphasize our very positive evaluation of the Dutch research on all fronts: Theoretical and experimental research, technical research and development, deployment of grid-technology, technical development together with industry, and the outreach projects, notably the successful HiSPARC project bringing modern particle physics research to high school students.

The Netherlands can be proud of their achievements in this field and of the clear evidence of high-quality leadership at all levels.

I remain, dear Minister, yours sincerely

Torsten Åkesson
Chairperson of ECFA

Cc: Prof. Dr P. Nijkamp (Chairman NWO)
Prof. Dr R.P. Griessen (Chairman FOM)

1.6 Organization

Figure 1 shows the organigram of the Nikhef collaboration.

The Nikhef director is usually appointed for 5 years. In the evaluation period a number of changes have occurred in the directorate. Per July 2001 the mandate of prof. dr. G. van Middelkoop ended. He was succeeded by prof. dr. J. Engelen, who left Nikhef per January 2004, when he was appointed Chief Scientific Officer of CERN. He was succeeded ad interim by prof. dr. K. Gaemers, until December 2004, at which date prof. dr. F. Linde was appointed as director with a mandate until and including December 2009.

The main *research* activities are organized as 'programs' which mainly follow the FOM–funding scheme. Each program has a program leader (PL), appointed by the director, who is responsible for all activities and personnel in that research line, including the share contributed by the university groups. In 2007 the programs thus defined are: ATLAS, ALICE, LHCb, Astroparticle Physics and Theory. Within the mission budget of the institute several subprograms (or projects) are defined, led by a project leader; these are 'Grid Computing and 'Detector R&D'.

The *technical* expertise is organized in four technical groups, each led by a technical group leader (TGL): computing, electronics, mechanical engineering and the mechanical workshop. These groups do not include the technical manpower at the university groups, which have a local embedding.

The *support* section, led by the institute manager, consists of the departments for financial administration, facility services, safety and working conditions, secretariat/reception and library. Two staff departments, personnel affairs and science communication, report directly to the director.

Boards, Bodies and Meetings

At the top of the hierarchy resides the Nikhef Board, consisting of six representatives of the five Nikhef partners: two members are assigned by FOM, four by each of the university partners. The Board meets twice a year. Among other tasks, the Board formally approves of the appointment of the Nikhef–director and of the yearly budget of the Nikhef collaboration.

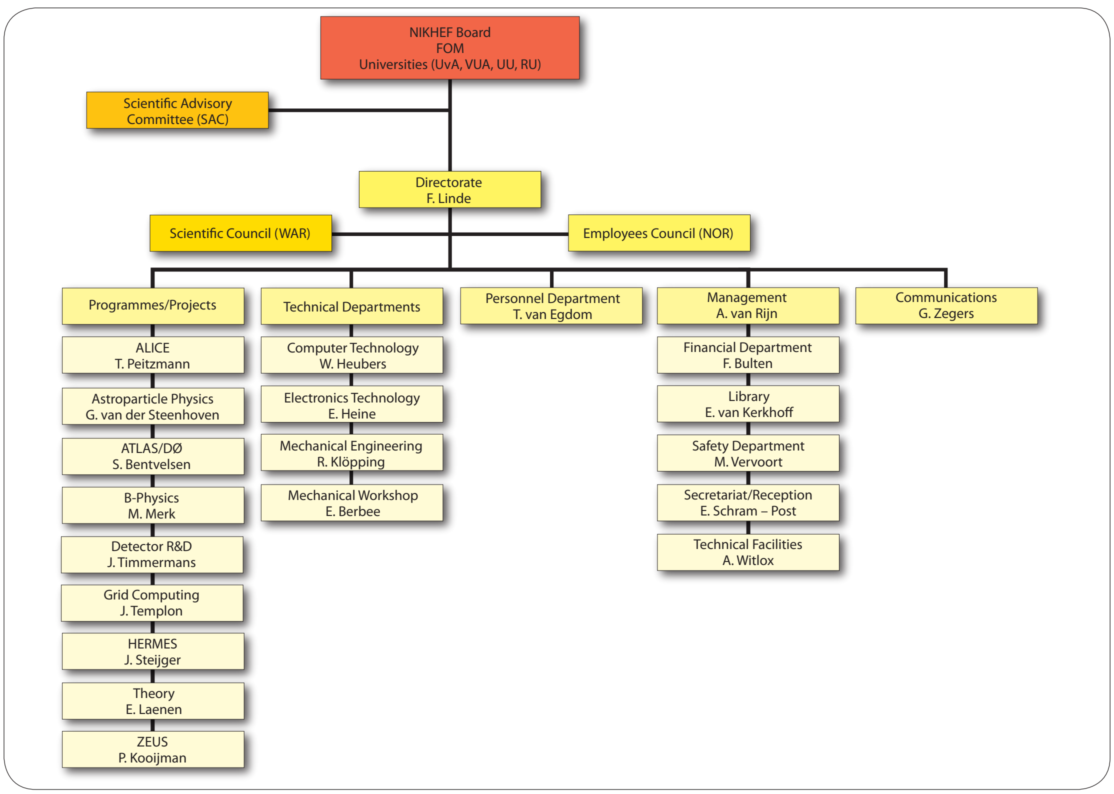


Fig. 1. Organigram of the Nikhef collaboration.

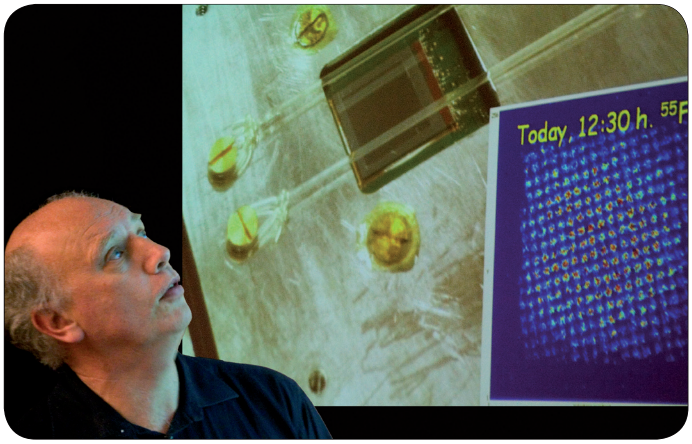


Figure 2. H. van der Graaf, giving an overview of detector R&D at the Nikhef Jamboree.

The Scientific Advisory Committee (SAC) is the external advisory body of the Nikhef Board. Members are appointed by the Nikhef Board, usually after being suggested as candidates by the Nikhef director.

Scientific policy is discussed in Nikhef's internal scientific council ('*wetenschappelijke adviesraad'* – WAR), for which members are chosen by the director and which serves as his internal advisory body. The WAR meets every two months.

For the staff meeting ('*stafoverleg'*), held in the same frequency as the WAR and actually preceding it (the day before), all scientific staff and usually the TGLs are invited to attend. The agenda usually has a large overlap with the agenda for the WAR; this enables a better and more complete contribution to the discussion, before treatment in the WAR.

Daily management of the institute takes place in the Management Team (MT), consisting of the director, institute manager and head of the personnel department, supported by the head of the secretariat. The MT meets weekly. The MT has a yearly so called '*platform*' meeting with each PL and TGL, where issues concerning the group activities, personnel and budget are discussed. In between these planned meetings are irregular 'on demand' meetings between PLs, TGLs and MT on topics requiring more immediate attention.

The director and institute manager have a quarterly meeting with the director of FOM and the FOM program manager, assigned to the institute. Quarterly meetings also take place with the directors of the other FOM institutes; these are chaired by the FOM director. The institute works council ('*Nikhef OndernemingsRaad'*– NOR), a body required by Dutch law for organisations with 50 or more employees, represents Nikhef personnel and holds meetings with the director every six weeks to discuss developments within the institute. The NOR consists of Nikhef employees who are elected by all Nikhef personnel in biannual elections. The NOR is formally consulted by the director in cases prescribed by law, in particular on safety and working conditions.

Project structure for scientific instrumentation

Since more than a decade Nikhef uses a so called '*project matrix*' structure for carrying out large scientific instrumentation projects. A project, which is usually part of a larger program, is assigned a project leader, who composes a project plan that contains – apart from technical requirements – the estimated manpower requirements and a planning with milestones. In discussions with the technical group leaders the manpower requirements are refined as is the planning. If agreed the manpower is assigned by the director.

The overall manpower planning is updated twice a year. Progress on projects is reported in the Project Plans Meeting ('*Overleg Project Plannen'* – OPP), which is held every six weeks. Manpower priorities between projects within a program are decided by the program leader; priorities between projects of different programs are decided by the director.

The 'project matrix' structure has worked quite well, although permanent attention is needed to deal with the inherent tension between the hierarchical line (technical group leaders) and the project line (project leaders). This requires clear rules, effective communication and adequate leadership.

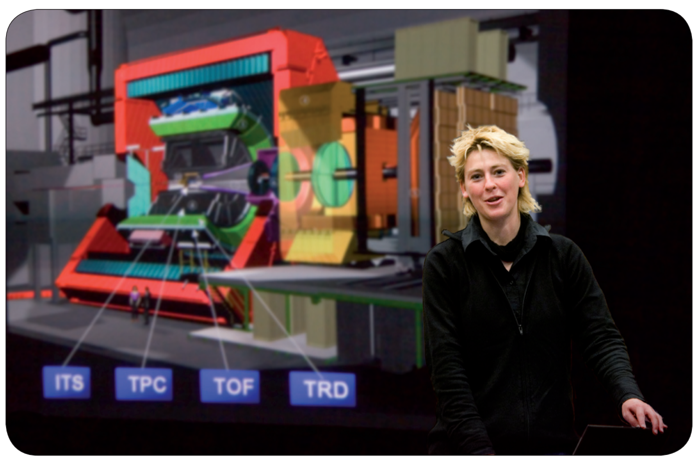


Figure 3. I. Kraus, giving an overview of the ALICE experiment at the Nikhef Jamboree.

1.7 Personnel

The number of personnel, expressed in full-time equivalents (fte) at Nikhef has gradually decreased in the period 2000–2006 as shown in Figure 1.

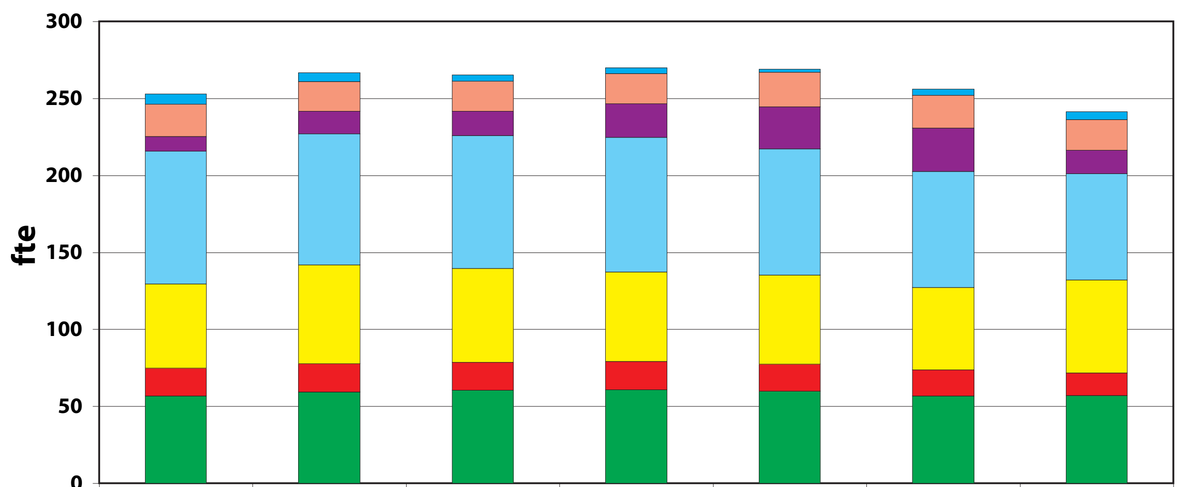
The number of permanent scientific staff has been at a stable level of about 57 fte; in the year 2006 a decrease was compensated by the joining of two university theory groups in the Nikhef collaboration. The number of postdocs varied between 15 and 20 fte yearly with a downward exception in 2006. The number of PhD students is around 60 fte, fluctuating with the Nikhef–participation in experiments in the data–analysis phase. The number is now again rising in preparation of the LHC experiments.

Noticable is the rise and fall in the number of technical staff: in 2000 about 96 fte, with a peak in 2004 of 109 fte (including about 28 fte of temporary staff) going down to about 85 fte in 2006. This is related to the construction activities for the LHC and ANTARES detectors. The number of support staff has decreased as well, but less than technical staff.

About 40% of Nikhef's permanent scientific staff, including all full professorships, is employed by the university partners. Many other staff members hold professorships at a partner university or at one of the other universities in the Netherlands. In total more than a third of the permanent staff (about 21/58) holds a professorship.

On average about 75% of PhD students are employed by FOM, the rest by universities. Postdocs are mainly employed by FOM. The majority (about 80%) of technical and support staff is employed by FOM: the 'Amsterdam' institute thereby forms the main body of the technical infrastructure of the Nikhef collaboration.

The age distribution of Nikhef for the years 2000 and 2006 is depicted in Figure 2. The shift to the older age groups of the permanent staff can be largely attributed to the technical staff, where the average age in 2000 was 46.9 years and in 2006 48.4 years, whilst the average age of scientific staff decreased from 51.1 (2000) to 49.6 (2006).



	2000	2001	2002	2003	2004	2005	2006
temporary support staff	6.7	5.7	4.1	3.8	2.0	4.2	5.2
permanent support staff	21.1	19.4	19.6	19.6	22.5	21.1	19.7
temporary technical staff	9.3	14.6	15.6	21.7	27.3	28.4	15.4
permanent technical staff	86.3	85.1	86.3	87.5	82.0	75.3	68.9
PhD students	54.7	64.0	61.2	58.0	57.9	53.4	60.6
post-docs	18.1	18.5	17.9	18.6	17.6	17.1	14.6
permanent scientific staff	56.7	59.3	60.5	60.6	59.7	56.6	56.9

Fig. 1. Ftes per personnel category 2000-2006.

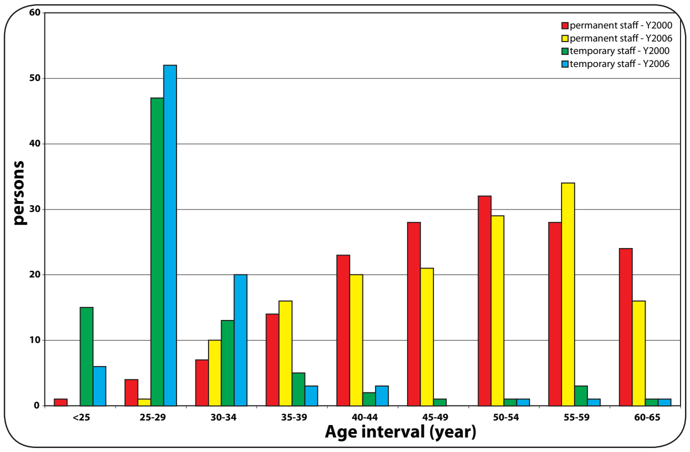


Fig. 2. Age distribution.

The average age for temporary scientific personnel has not changed significantly over the years (PhD–students: 27 years, postdocs: 34 years).

The gender distribution of Nikhef personnel (2006) is about 14% female and 86% male. In comparison with 2000 we see a growing number of female PhD students and postdocs, but the share of female permanent scientific and technical staff is still very low.

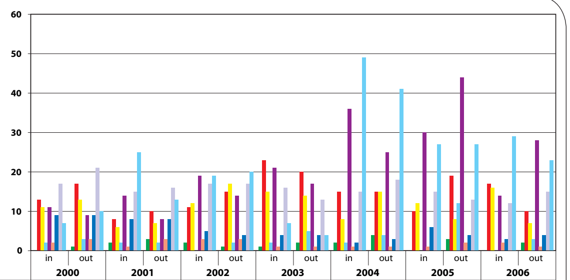
	2000	2006
permanent scientific staff	3.6%	3.6%
post-docs	4.8%	33.3%
PhD students	14.9%	16.4%
technical staff	2.1%	1.3%
support staff	33.3%	37.9%
All	**8.8%**	**14.1%**

Table 2. Percentage of female personnel.

Hiring, training, mentoring and other personnel policy issues

On average Nikhef hires about 20 to 25 people annually, half of whom are PhD students, a quarter are postdocs and one or two are new staff physicists, the remainder being replacements in the technical and support staff.

New personnel at Nikhef is attracted through advertisements on the Nikhef website and occasionally through advertisements in technical or general newspapers. For a permanent staff physicist position an advisory committee is installed, which reports to the director. Selected candidates for a such a position are always invited to give a public presentation. On average Nikhef hires one or two new staff physicists per year.



	2000 in	2000 out	2001 in	2001 out	2002 in	2002 out	2003 in	2003 out	2004 in	2004 out	2005 in	2005 out	2006 in	2006 out
permanent scientific staff	0	1	2	3	2	1	1	2	2	4	0	3	0	2
post-docs	13	17	8	10	11	15	23	20	15	15	10	19	17	10
PhD students	11	13	6	7	12	17	15	14	8	15	12	8	16	7
permanent technical staff	2	3	2	2	0	2	2	5	2	4	0	12	0	3
temporary technical staff	11	9	14	8	19	14	21	17	36	25	30	44	14	28
permanent support staff	2	3	1	3	3	3	1	1	1	1	1	2	2	1
temporary support staff	9	9	8	8	5	4	4	4	2	3	6	4	3	4
apprenticeships	17	21	15	16	17	17	16	13	15	18	15	13	12	15
master students	7	10	25	13	19	20	7	4	49	41	27	27	29	23

In general Nikhef encourages employees to follow courses and training to enhance their expertise and employability. Technical and support staff are offered courses and dedicated training facilities depending on the job. Nikhef staff in management positions (program leaders, project leaders, group leaders) may participate in management training ('managing between professionals'). Apart from the daily interactions all employees have at least once every two years a job evaluation meeting with their group leaders. In this meeting the past performance is evaluated and plans are made for the future.

For PhD students a special mentoring and monitoring scheme is in place, in the framework of the National Research School for Subatomic Physics. Their progress is monitored regularly by a so called '*C3–committee*', consisting of three members: the daily supervisor, the 'promotor', and an independent member of the Education committee of the Research School for Subatomic Physics.

PhDs can join dedicated courses on effective planning, improving presentation and communication skills, writing scientific English, structured writing, preparing for job applications and on business management.

Nikhef monitors sick leave closely. Long or frequent absence is noticed in an early stage and action is taken by the group leader. In the past six years the absence due to illness has gradually decreased from 4.7% in 2000 to 2.2% in 2006 (the percentage denotes the number of sick leave days over the total number of work days. Maternity leave is not considered as illness).

1.8 Finances

Funding

Nikhef as a collaboration is funded by four separate sources (Figure 1 and Table 1). The first source is the 'base' funding for the FOM–institute SAF/Nikhef; this 'base' funding is the sum of the program budget (about 25%) and the mission budget (about 75%). The second source is the FOM–funding for the three university groups (RU, UU, VU), that are part of Nikhef (historically the FOM–funds for the fourth university group (UvA) are considered to be included in the institute's budget). The third source is (the equivalent in money of) the personnel and material budget of the university groups (funded by the four universities). The fourth source is project funding from either FOM or third parties (such as the EU, NWO, the Ministry of Economic Affairs); this source also includes the income Nikhef generates from the lease of the former accelerator buildings and from housing a large part of the Amsterdam Internet Exchange.

The base funding for the institute over the evaluation period is decreasing as a consequence of the FOM strategy to declare subatomic physics a lower priority. The share of this funding has dropped from 67% to 58%.

The FOM–funding for the university groups has been relatively stable, because this is earmarked for the exploitation of the LHC experiments (till 2013 – 2015). The university contribution is also stable. It has even increased since 2006 with about half a million euro, because two theory groups (from RU and VU) have joined the Nikhef collaboration.

Nikhef is increasingly successful in acquiring support from external funds. This fourth source of money shows a significant increase: from about 1.3 M€ in 2000 (representing 8% of the total funding) to 4.2 M€ in 2006 (20% of total funding). More than half of this increase is due to Nikhef successes in obtaining project funding from FOM, but even more from *'Vernieuwingsimpulsen'* (NWO), from participation in EU sponsored projects (notably on grid deployment, detector R&D and astroparticle physics) and in national projects, funded by (a subsidiary of) the Ministry of Economic Affairs, aimed at '*valorisation*' (notably on grid research and detector R&D). The other half of this source is related to the income from the building lease activities and AMS–IX housing. Especially this last source has shown an increase from about 0,5 M€ in 2000 to about 1.4 M€ in 2006.

Expenses

Figure 2 shows the distribution of costs over the activities of Nikhef during the evaluation period. Expenses have by and large matched funding, with (slightly positive and negative) exceptions in various years. 'Expenses' in activities are defined as directly attributable costs. All remaining not directly attributable costs are defined as 'technical infrastructure/general costs'. These 'indirect costs' are at a relative stable level of 18–20%.

The graph shows nicely the decrease in activities in the former research activities at AmPS, CERN (CHORUS and LEP) and HERA (Zeus and HERMES), whilst a ramp–up for the LHC experiments can be noted (from 47% of direct expenses in 2000 to 59% in 2006). Furthermore it is clearly visible, that astroparticle physics has grown, now almost reaching the 10% level of direct costs.

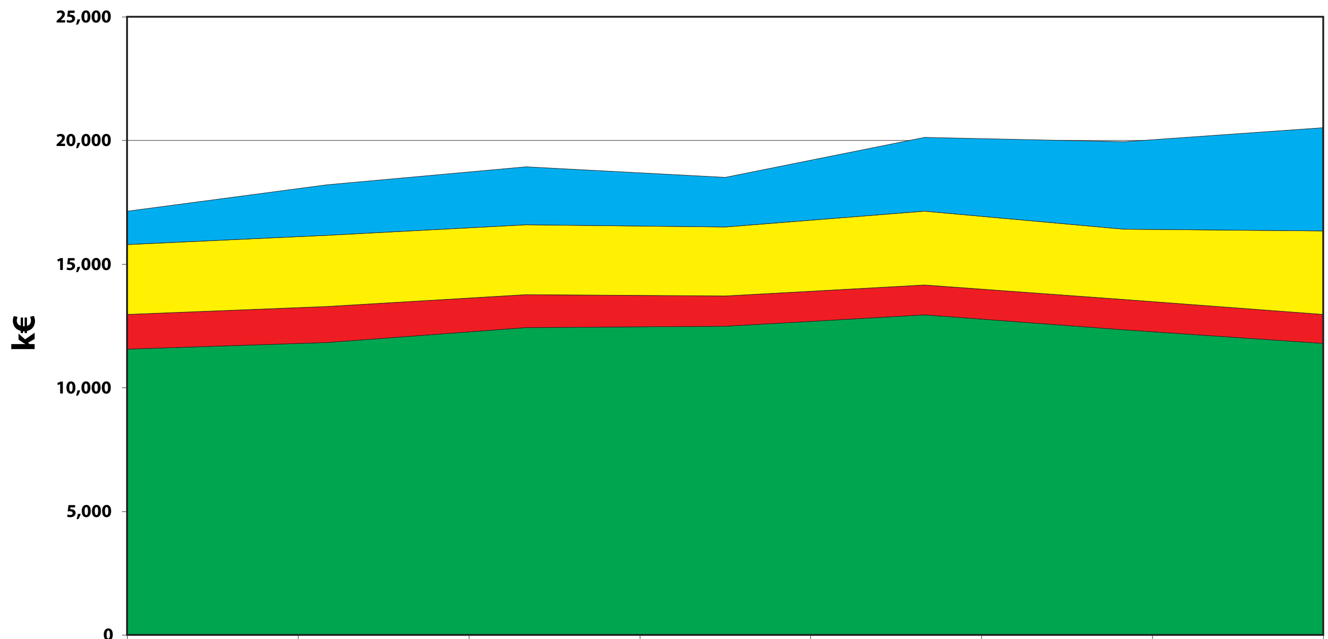
The AMS–IX housing and building lease activities require a basic maintenance budget and from time to time investments in upgrading and expanding the facilities, but still the net and cash based result over the years 2000–2006 is a sizable 4 M€, which have greatly benefited the regular research activities of Nikhef.

Investments

Table 2 shows the investment budgets (from the various sources within FOM and NWO) as granted to Nikhef in the years 2000–2007. Actual expenses usually follow the granting scheme a couple of years later. From the figures it can be derived, that Nikhef has a 'turnover' in investments of on average 2 M€ per year.

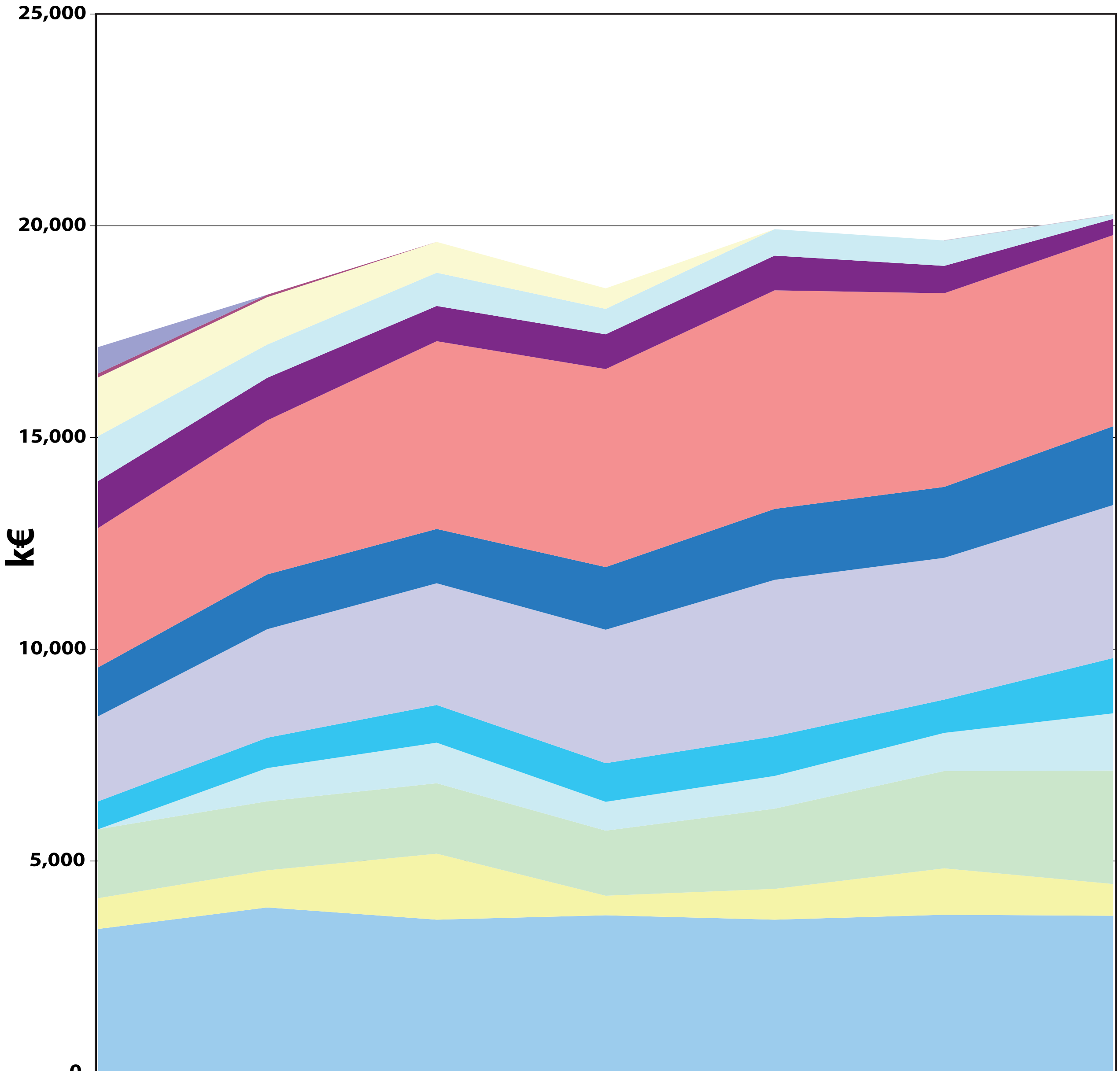
Investments funds have been largely devoted to the LHC detectors and the neutrino telescope ANTARES. Table 2 shows the expenditures in the period 1998–2006, compared with the original pledges in the Memoranda of Understanding (MoU). Most of the subsystems are now nearly completed.

Although actual costs are in most cases much higher than the MoU commitments, Nikhef has in all cases obtained enough funding to cover for these cost overruns. An example is the cost overruns in ATLAS for which in 2003 extra funding was acquired via a 'bottleneck' budget from FOM (labeled 'K&E' in Table 2). Remaining overruns are paid from exploitation budgets. For ANTARES it should be noted that due to slower deployment than originally foreseen, part of the 'savings' in off shore and on shore equipment will be needed for the over cost in common fund operations in the period 2007–2011.



	2000	2001	2002	2003	2004	2005	2006
Additional funding	1,350	2,041	2,342	2,014	2,991	3,528	4,166
Universities	2,815	2,877	2,813	2,788	2,987	2,838	3,388
FOM univ. groups	1,415	1,463	1,342	1,220	1,203	1,230	1,166
FOM institute	11,562	11,832	12,436	12,495	12,950	12,352	11,798

Fig. 1: Funding sources.



	2000	2001	2002	2003	2004	2005	2006
AmPS	634						
Chorus	88	64					
LEP	1,381	1,114	730	482			
Zeus	1,067	786	790	596	614	602	107
Hermes	1,112	1,011	831	826	820	649	384
Atlas	3,293	3,632	4,428	4,676	5,166	4,573	4,508
Alice	1,144	1,298	1,284	1,472	1,671	1,672	1,864
LHCb	2,009	2,555	2,872	3,158	3,694	3,353	3,608
Theory	665	725	890	914	942	787	1,314
Antares/APP		782	957	678	771	896	1,346
R&D, grid etc.	1,629	1,628	1,669	1,537	1,895	2,298	2,685
lease activities	726	874	1,556	463	725	1,100	743
Infrastructure	3,394	3,906	3,614	3,715	3,617	3,728	3,709

Fig. 2: Expenses Nikhef 2000–2006 per activity.

Sources		<2000	2000	2001	2002	2003	2004	2005	2006	2007
FOM/M	computing		862		120	370		170	170	170
	workshops		204		123	297	120	132		
	R&D	272			50					
	ATLAS			708	465	535				
	LHCb	1.452				31	13	406	538	462
FOM/M +	ATLAS (RU)	120			134	125	70			
universities	ALICE (UU)	193				174		20	104	107
	LHCb (VU)			101	49		90	140	56	
FOM/K&E	ATLAS					1.051				
NWO/G	ATLAS	2.133	1.089	862						
	ALICE		590		227					
	LHCb	318	454	363						
	ANTARES			1.588	1.994					
NWO/NCF	computing				140				80	100
			3.199	3.623	3.302	2.583	293	868	948	839

Table 1. Granted investment budgets 2000–2007.

Experiment		MoU commitments		spent 1998-2006	% of MoU commitments
		kCHF	k€	k€	
ATLAS	Endcap Toroids (ECT)	6,700	4,154	7,106	141%
	ECT - cost to completion	1,405	871		
	Muon Spectrometer	3,030	1,879	2,720	145%
	Inner Tracker	1,840	1,141	1,206	106%
	Trigger/DAQ	530	329	262	80%
	Cost to Completion	840	521	469	90%
	Total	**14,345**	**8,894**	**11,763**	**132%**
	% of ATLAS-detector	*2.68%*			
LHCb	Outer Tracker	3,880	2,406	2,340	97%
	Velo/Veto	1,500	930	1,200	127%
	Common Fund	1,400	868	840	97%
	Total	**6,780**	**4,204**	**4,380**	**104%**
	% of LHCb-detector	*9.00%*			
ALICE	Inner Tracker/SSD	2,010	1,246	1,218	98%
	Common Fund	225	140	141	101%
	Cost to Completion	142	88	53	60%
	Total	**2,377**	**1,474**	**1,412**	**96%**
	% of ALICE-detector	*1.89%*			
ANTARES	Off shore equipment		1,654	1,467	89%
	On shore equipment		567	394	69%
	Common fund		1,361	1,379	101%
	Total		**3,582**	**3,240**	**90%**
	% of ANTARES-detector		*17.46%*		

Table 2. Investments in LHC experiments and ANTARES versus MoU commitments.

2 Running Programmes

2.2 Physics at the TeV scale: ATLAS

Programme Organization

The programme was led by Prof. dr. F. Linde until 2005 and by Prof. dr. S. Bentvelsen since then. Nikhef has been a member of ATLAS from the beginning. The FOM programme, however, only started in 1997 and will run at least until 2015.

Research Goal

The primary research goals are to reveal and study the mechanism of electroweak symmetry breaking, responsible for giving mass to the weak gauge bosons and to the fermions, and to search for any new particles, symmetries or interactions beyond the Standard Model at the highest possible particle collider energies. In order to achieve this, the ATLAS collaboration is building a detector at the LHC, scheduled to turn on in 2008.

Research Activities

In the Standard Model of particle physics, the underlying symmetry between weak – and electromagnetic interactions is spontaneously broken by a scalar field; interactions with this field give particles a mass: this is the Higgs mechanism. Precision data from LEP show that this model is in excellent agreement with data and set limits on the mass of the Higgs boson, the quantum of the Higgs field. A major target of the ATLAS programme is to find the Higgs boson and measure its properties: mass, width, spin, and couplings.

Theories beyond the Standard Model suggest manifestations of new physics at the TeV scale, such as super symmetry or large extra dimensions. ATLAS is designed to be a general purpose detector, capable of detecting deviations from the Standard Model in a model–independent way.

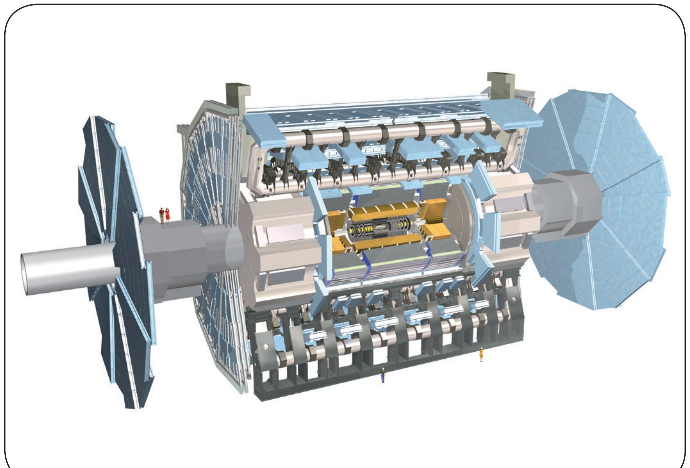


Fig. 1. The ATLAS detector.

Nikhef Research Highlights

ATLAS

- Construction of 96 precision muon chambers, plus alignment, detector control, and readout electronics.
- Construction of one endcap of the silicon strip detector.
- Manufacturing and assembly of vacuum vessels and cold mass components of the endcap toroids, in collaboration with industry.

DØ

- Participation in DØ: top quark physics and Higgs boson search.
- Important contributions to track reconstruction software in ATLAS.

The research goals are best achieved by detecting the results of particle collisions at the highest possible energies and luminosities. The LHC will provide proton–proton collisions at 14 TeV centre–of–mass energy, with luminosities of order 10^{33} $cm^{-2}s^{-1}$ initially, and 10^{34} $cm^{-2}s^{-1}$ later. The design of ATLAS is determined by the need to accurately identify and measure single particles and jets to several TeV energy, select the most interesting events from a bunch crossing rate of 40 MHz with up to 20 events per crossing and reduce these to 200 Hz, in a very harsh radiation environment.

The ATLAS detector consists of a number of particle detection systems in two magnets: a 2 T central solenoid, and a very large air core toroid with barrel and endcap components. The inner particle detector is located inside the solenoid, and consists of a silicon pixel sensor detector just outside the beam pipe, a silicon strip detector (SCT) surrounding the pixels, and a transition radiation tracker around the SCT.

All three systems have a barrel and two endcap parts. Outside the solenoid, a liquid–argon electromagnetic calorimeter measures electrons and photons, and a hadron calorimeter (scintillating tiles or liquid argon) detects isolated hadrons and hadronic jets. At the outside of ATLAS, three layers of precision muon chambers measure the trajectories of muons. A three–stage trigger and data–acquisition system selects the most interesting events, based on high–p_T leptons and jets, large missing transverse energy, and tracks that do not point to the primary vertex.

The SCT consists of a barrel with four cylinders of sensors, and two endcaps, each with nine carbon–fibre discs onto which three concentric rings of silicon detectors with their read–out electronics are mounted. In collaboration with industry, Nikhef has designed and machined the discs for both endcaps, and discs for one

Fig. 2. Nikhef PhD students working on the SCT installation at CERN.

endcap were equipped with services like cooling circuits, power tapes, and optical fibres. The read–out of the sensors involves dense analogue and digital electronics, and Nikhef has contributed to the optimization of the layout. We have manufactured 100 sensor modules at Nikhef, out of a total of 2000 needed for both endcaps, with an intrinsic mechanical accuracy of better than 10 microns. At Nikhef we fully assembled one complete endcap, in close collaboration with institutes in the U.K. responsible for the other endcap. This involved reception testing of some 1000 sensor modules (1.5 million electronic channels), precision mounting them on the discs and testing them in a specially designed test box, under ATLAS–like conditions. After passing these tests, discs were mounted in a carbon–fibre cylinder, which was also equipped with services, and tested again. In April 2006, the completed endcap was shipped to CERN, tested again and prepared for installation in ATLAS in 2007. Tests show signal–to–noise ratios as designed, and less than 0.5% of dead channels.

The key components of the muon spectrometer are the precision monitored drift tube (MDT) chambers, the alignment system to monitor the geometry, the trigger chambers, and the toroidal magnet system. Three layers of MDT chambers measure the trajectory of a muon, each chamber consists of six or eight parallel layers of 1–6 m long drift tubes, of 30 mm diameter. Nikhef has contributed to R&D for these chambers; prototypes have been subjected to a precision X–ray scan. Nikhef made the 96 large barrel outer layer (BOL) chambers, each of 5.0 × 2.2 × 0.5 m^3 size. Given the large number (40,000) of tubes and the required precision, robots were made to wire the tubes and glue the layers in a jig. Production was started in 2002, and all chambers were tested in a cosmic ray test stand at Nikhef. Early 2006 production was finished, and all chambers had been sent to CERN. There they were equipped with trigger chambers, and mounted inside ATLAS in 2006 and 2007. The chambers are now being cabled up and tested with cosmic rays. The Nikhef RASNIK alignment system is crucial in order to reach the required geometrical accuracy. In total more than 5000 RASNIKs will be used, each system consists of an illuminated mask, a lens, and a camera; image analysis then yields alignment information. Nikhef has also responsibilities in the detector control system (DCS), and has produced about 1700 magnetic field sensors.

Read–out of all detectors involves Read–Out Drivers (RODs), which push data into buffers from which the high–level trigger system can extract data. In collaboration with the Radboud University in Nijmegen, Nikhef has developed the RODs for the MDTs, and is producing all 255 of them. This involved extensive modelling of data flows in the trigger system as a whole, and optimization of components and mappings.

In 2004 various prototypes of ATLAS subdetectors, representing one complete slice of ATLAS, has been put into a test beam, and the combined performance was studied. For tracking studies, a package was developed by Nikhef, and extensive experience with tracking and alignment was gained.

Currently, ATLAS is almost completely installed and taking data with cosmic rays, in order to commission the trigger and DAQ system, and align and debug the detector. The detector is ready to be closed in September, and take first data before the end of 2007.

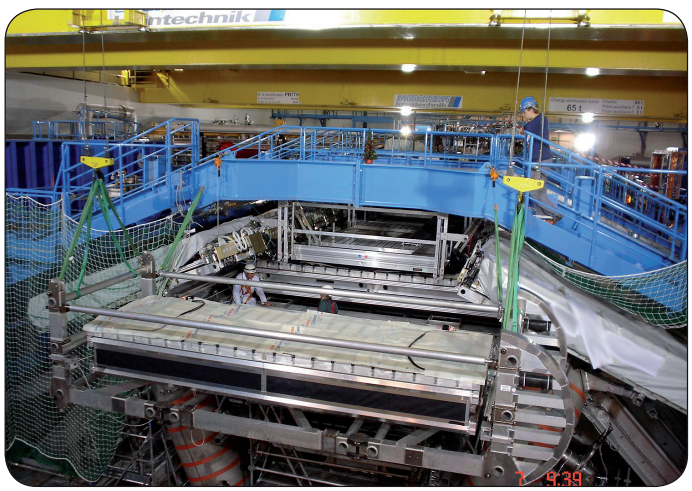


Fig. 3. A precision muon chamber built at Nikhef being installed in ATLAS.

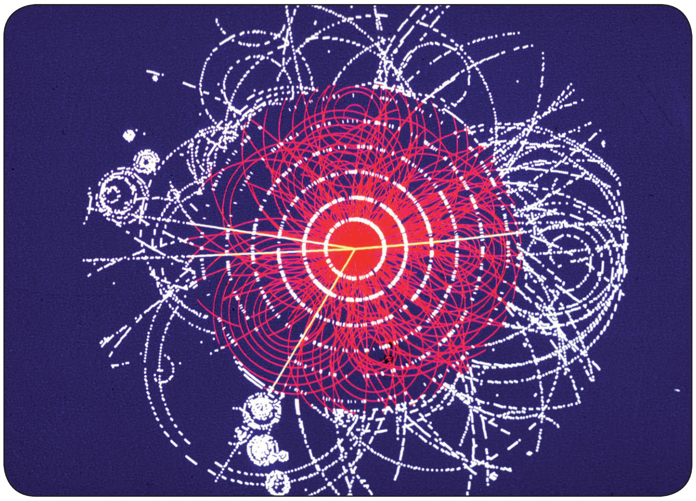


Fig. 4. Graphic display of a simulated event in which a Higgs boson is created and decays through two Z bosons into four muons.

Analysis of recorded events needs software that can extract and apply calibration corrections, and reconstruct the event. Nikhef contributes significantly to object–oriented software for tracking and vertexing, as well as to detector simulation software.

Physics analysis in ATLAS is performed in seven physics groups formed around the topics: Standard Model, B–physics, top physics, super symmetry, exotics, Higgs, and heavy ions. At the moment, ATLAS is actively and as realistically as possible preparing for analysis of first data. At Nikhef, we are interested in Higgs–boson studies and searches for physics beyond the Standard Model, and we approach these in two parallel ways: via analysis of muons, and via detailed studies of the properties of top quark pair production events. In particular, we study the reactions H→ZZ→4 muons or 2 muons and 2 *b*–quarks, Higgs production in association with a top–quark pair, super symmetry with one or two muons, and super symmetry in top–quark–like topologies. We focus on the analysis of early data, where the detector still needs to be understood, and where Standard–Model backgrounds need to be extracted from data and carefully studied. Overall, these studies show that ATLAS has excellent Higgs–boson detection capabilities for all Higgs masses up to a TeV, as well as extensive capabilities for discovery of new physics.

Future Directions

ATLAS is expected to start taking data in a technical run in 2007 and at 14 TeV in 2008. Simultaneously, our efforts in DØ, which will run until 2009, are scaled down: analyses that are still in progress, which include top–quark studies and Higgs–boson

The DØ Experiment

To gain experience and to participate in studies at the highest energy before LHC–turn on, we take part in the DØ experiment at the Tevatron, a 2 TeV proton–antiproton collider at Fermilab, Chicago.

Nikhef joined the DØ experiment in 1998. Participation in DØ has been valuable for our knowledge on Monte Carlo generators, advanced analysis techniques, reconstruction software, b–quark tagging techniques, top–quark physics, and Grid computing. At the time of our joining, DØ was preparing for a new data taking period (Run 2) at the Tevatron. The inner detector, muon system, calorimeter electronics and trigger and data acquisition systems were upgraded, a solenoid magnet was added, and data taking began in 2001. Since then, an integrated luminosity of 2 fb^{-1} has been collected, and more than 60 papers on various topics were published. Highlights include: the development of more advanced methods to measure the mass of the top quark, first evidence for single top–quark production, a first two–sided boundary for the frequency of B_s^0 oscillations, QCD studies, and limits on new physics. With 3–5 fb^{-1} of data more, DØ may be able to see first signs for the Higgs–boson in a mass range just above the LEP limit of 115 GeV, or in a window around 160 GeV. Nikhef analyses in DØ have focused on top–quark physics (cross section, mass, single top), τ production, the dynamics of *b*–quark production, and Higgs–boson searches.

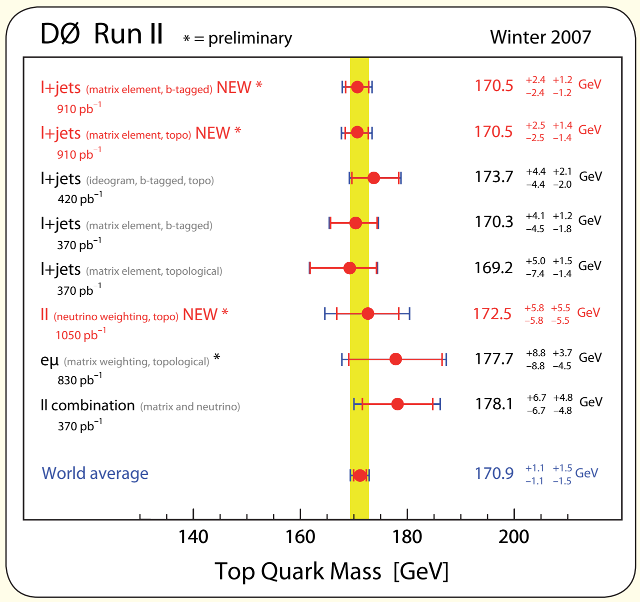


Fig. 5. DØ results on measurements of the top quark mass.

searches, will be finished and published. LHC will increase its luminosity over the years, and is scheduled to run till 2015. During this time, emphasis will be put on data collection and analysis, in order to achieve the physics goals mentioned above. Possibly the pixel detector will be upgraded in 2012. Advanced plans exist to upgrade the LHC luminosity by a factor 10 after 2015 and run a few years longer. This will need a new inner detector for ATLAS, and Nikhef is contributing to R&D activities for this. In the long term, advances in this field will depend on what experiments at the LHC will find.

Nikhef Contributions
Apart from the contributions mentioned above, and the contribution mentioned below under industrial collaborations, the computing facility SARA and Nikhef together host a full ATLAS Tier–1 GRID centre. In ATLAS, Nikhef physicists were (c.q. are) top–quark physics coordinator (S. Bentvelsen), combined muon performance group convener (P. Kluit), MC validation coordinator (W. Verkerke), ATLAS upgrade coordinator (N. Hessey), SCT endcap project engineer (P. Werneke), member of the publication committee (P. de Jong) and member of the institutional board advisory committee (S. Bentvelsen). In DØ, Nikhef has contributed beam–background monitoring equipment, but mostly computing infrastructure (Monte Carlo production on farms and on the GRID) and reconstruction and analysis software. Nikhef physicists were members of three editorial boards (S. de Jong, F. Filthaut, P. de Jong), *b*–tagging group convener and *b*–tagging validation convener (F. Filthaut).

National Collaborations
The Dutch groups within the ATLAS/DØ collaborations consist of members of the FOM institute SAF/Nikhef, the Universiteit van Amsterdam and the Radboud University Nijmegen.

International Collaborations
The ATLAS experiment is a collaboration between 161 institutes from 35 countries, and consists in total of approximately 1800 scientific authors. DØ has some 575 authors from 90 institutes in 19 countries.

Industrial collaborations
The vacuum vessels and cold mass components for the 10 m high and 5 m wide endcap toroids, designed by Rutherford laboratory (U.K.), were manufactured in the Netherlands by Schelde Exotech and Brush HMA BV, respectively. This was made possible by an innovation subsidy of 5 M*f* (2.27 M€) of the Dutch Ministry of Economic Affairs. Nikhef supervised the manufacturing and assembly and, together with Rutherford laboratory, exchanged in this context relevant expertise concerning e.g. vacuum technology, welding technology and associated quality inspection, leak testing, and choice of materials. Nikhef also closely monitored the acceptance tests.

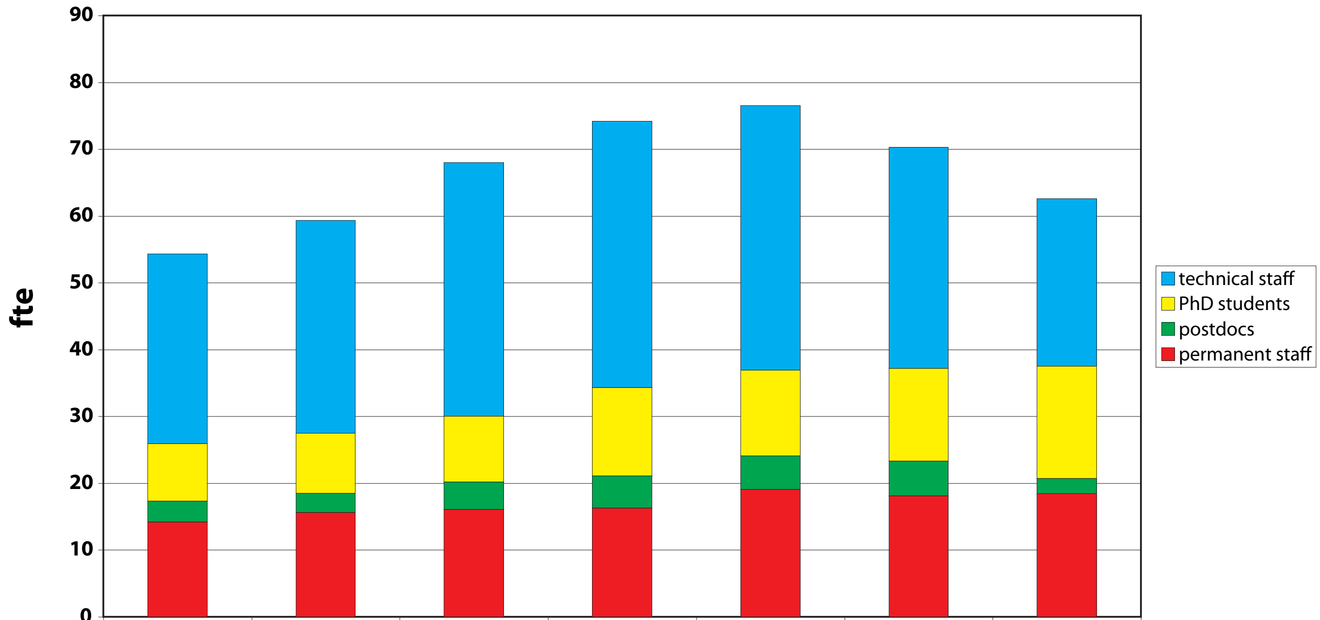
Fig. 6. An ATLAS endcap toroid magnet in its cryostat is transported at CERN.

Awards
Members of the ATLAS/DØ programme have been awarded one NWO–VICI grant (S. Bentvelsen), two NWO–VIDI grants (A.–P. Colijn, I. van Vulpen), one NWO–VENI grant (S. Klous), one EU Marie–Curie individual fellowship (S. Caron), and three FOM '*projectruimte*' grants between 2000 and 2006.

Key Publications

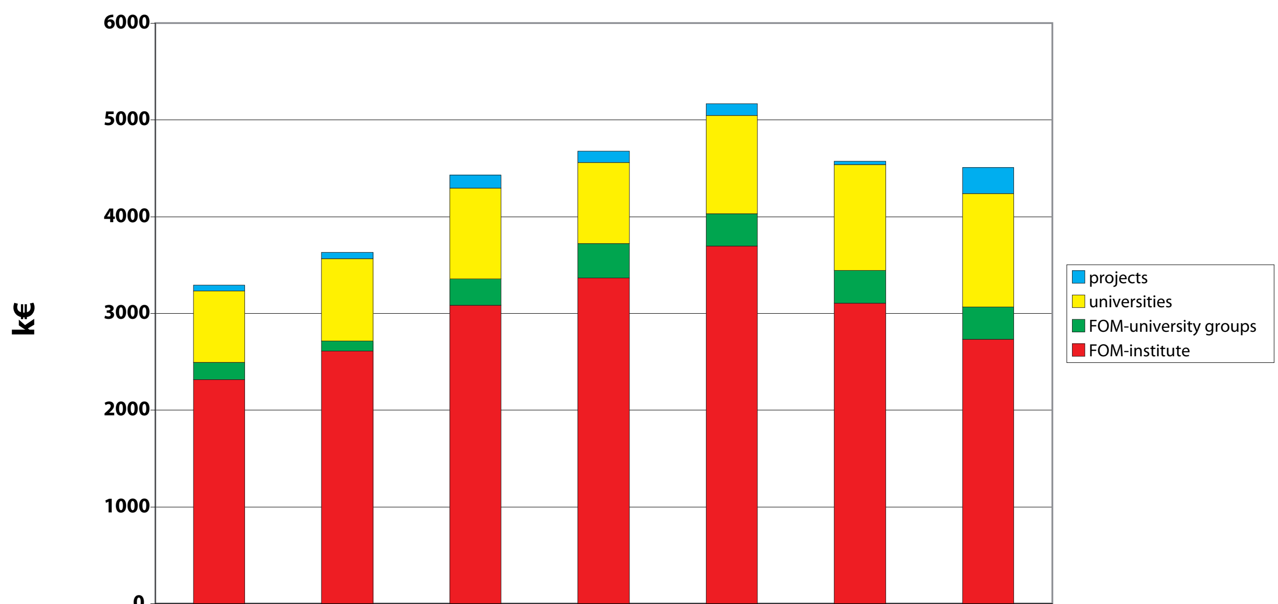
- *ATLAS technical design reports: detector and physics performance*
  CERN/LHCC **99**–14/15 (1999).
- H. Boterenbrood *et al.*
  The readout driver for the ATLAS MDT muon precision chambers
  IEEE Trans. Nucl. Sci. **53** (2006) 741.
- F. Campabadal *et al.* (ATLAS SCT Collaboration)
  Beam tests of ATLAS SCT silicon strip detector modules
  Nucl. Instr. and Meth. **A538** (2005) 384.
- V. Abazov *et al.* (DØ Collaboration)
  A Precision Measurement of the Mass of the Top Quark
  Nature **429** (2004) 638.
- V. Abazov *et al.* (DØ Collaboration)
  Direct Limits on the B_s^0 Oscillation Frequency
  Phys. Rev. Lett. **97** (2006) 021802.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff	28.4	31.8	38.0	39.9	39.6	33.1	25.1
PhD students	8.6	9.0	9.8	13.2	12.8	13.9	16.8
postdocs	3.1	2.9	4.1	4.8	5.0	5.2	2.3
permanent staff	14.2	15.6	16.1	16.3	19.1	18.1	18.4

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
projects	61	66	135	119	119	36	270
universities	738	853	939	836	1,020	1,095	1,172
FOM-university groups	180	105	270	356	334	337	334
FOM-institute	2,313	2,607	3,084	3,365	3,693	3,105	2,732

2.3 Physics with *b*–quarks: LHCb

Nikhef Research Highlights

HERA–B
- Measurement of B production cross section.

BaBar
- Measurement of CKM angle gamma.

LHCb hardware
- Construction of the Outer Tracker (OT TDR).
- Construction of the Vertex Locator (VELO TDR).

LHCb studies
- Track reconstruction (Reoptimization TDR).
- Physics studies with the B_s–meson (Reoptimization TDR).

Programme Organization

The programme was led by prof. dr. ing. J. v.d. Brand until 2005, at which point the leadership was passed on to prof. dr. M.H.M. Merk. The programme has started in 1999, and will run until 2014.

Research Goal

The absence of antimatter in the observable universe indicates that the symmetry between matter and antimatter must be broken. In the Standard Model of Particle Physics, at our present state of knowledge, this symmetry is solely broken by the presence of a complex–valued coupling between the carriers of the charged weak force and quarks. However, the resulting matter–antimatter asymmetry is far from sufficient to explain the observed abundance of matter in the universe.

The goals of this research programme are to perform precise measurements of the properties of the charged weak interaction, and to search for deviations from its (Standard Model) predictions that may shed light on the antimatter puzzle.

Research Activities

The evolution and decay of mesons containing the heavy b–quark offers a unique opportunity to study the weak interaction by utilizing the effects of quantum–mechanical interference to access the phases of its complex coupling constants. For example, the interference between two amplitudes with different weak phases introduces differences between the decay rates of B–mesons and anti–B–mesons, an effect know as 'CP' violation. In addition, the decays of B–mesons are sensitive probes of the interference of known amplitudes with novel ones, generated by processes not described by the Standard Model. Finally, in the cases where the Standard Model amplitudes are highly suppressed, there is the opportunity for large (relative) contributions of novel processes, and hence large deviations from the Standard Model predictions. Currently, there are three accelerators world–wide capable of producing B–mesons to study CP–violating effects. In 2007, the LHC will start producing unprecedented amounts of these mesons, providing a superb location for performing these measurements. To detect these particles and analyze these huge samples of data, the LHCb detector is currently under construction.

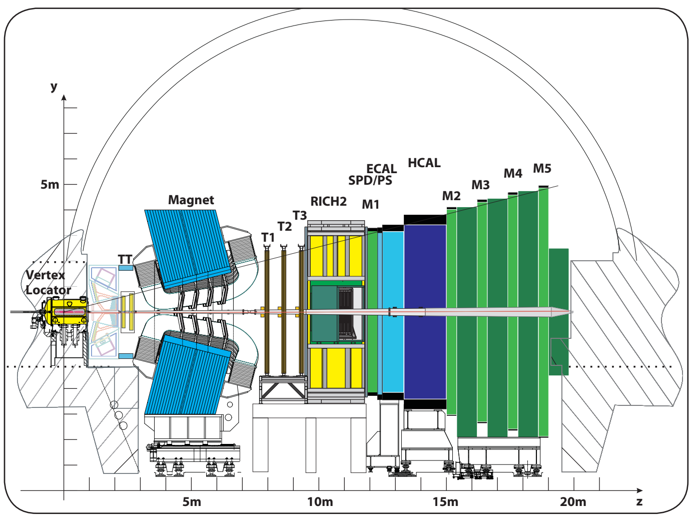


Fig. 1. LHCb detector overview.

The focus of the B-physics programme has been towards design and construction of the LHCb detector and the preparation for its exploitation and data-analysis, starting in 2007.

In LHCb all types of B–hadrons will be produced in copious amounts. The decay products of these B–hadrons generally include both charged and neutral particles. The Nikhef group focuses on the detection of charged particle trajectories, commonly referred to as 'tracking'. The tracking system of LHCb consists of several major components. The Nikhef group is involved in the construction of two of these components: the so–called vertex–locator (VELO), which surrounds the collision region, and the outer tracker (OT), which is positioned downstream of the VELO, behind a spectrometer magnet.

These detectors form the backbone of the experiment as they are the prime detectors to measure tracks and vertices of the B–decay particles. In addition to the hardware effort of designing and constructing these detectors a large part of our manpower has been devoted to the software required for these systems, to recognize the charged particles that leave trails in these detectors, and to accurately reconstruct their parameters. A physics programme

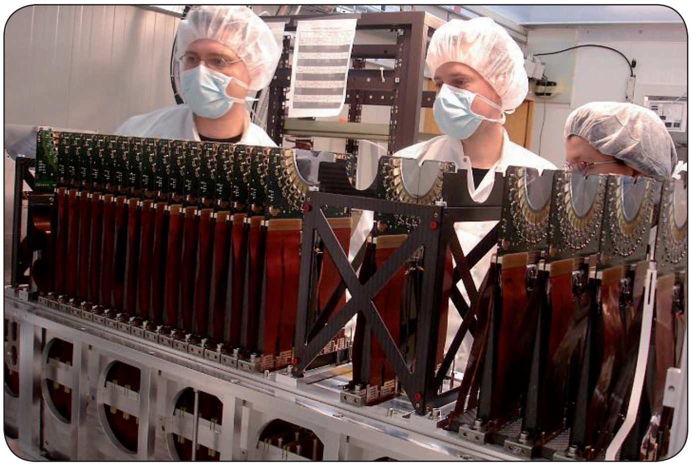


Fig. 2. The VELO and Pile–Up detector modules as installed in the first half detector.

matching these efforts is being developed. Given our activities outlined above, the programme focuses on those B–meson decays in which the final states consist of charged particles only, and which probe the transition of the *b*–quark into an *s*–quark.

The main task of the VELO is to identify and reconstruct the collision point and any displaced vertices from the decay of (amongst others) long–lived B–mesons with a resolution of several tens of µms. It consists of two moveable detector halves with 21 silicon micro–strip tracking modules, mounted in a vacuum vessel. In order to obtain optimal measurement precision the detectors are brought to a distance of 8 mm from the beam. To achieve this the detectors are mounted on a movable base plate that can retract the sensors by 30 mm in order to allow for beam injection and manipulations during ramping and tuning. The detectors are positioned by a motion control system with an accuracy of 10 µm. The actual beam position might vary from fill–to–fill and will be monitored online. The motion control system allows the system to remain centered on the position of the beam.

The detectors are operated in a secondary vacuum which is separated from the ultra high beam vacuum by a corrugated 300 µm thin $AlMg_3$ foil in order to minimize the multiple scattering of the charged particles between their production and detection. The complicated corrugated structure allows for overlap between the sensors of both detector halves and has been produced in–house by the technology of 'superplastic deformation'. Detector boxes were produced by welding the foil to 500 µm thick side walls. To avoid plastic deformations of the detector box the pressure difference between the beam vacuum and the detector vacuum is always kept to less than 5 mbar by a dedicated vacuum control system. The detector box, together with the specially designed wakefield suppressor, also serves to guide the RF field of the traversing LHC beam.

To reduce detector–aging due to irradiation the silicon sensors are cooled to a temperature below 0° C by means of an innovative cooling system that uses CO_2 as refrigerant for its good cooling properties in the required temperature domain. Nikhef is responsible for the mechanics, the vacuum technology and the cooling system of the VELO. The vertex tank has been installed around the interaction point. The open–close mechanics system and the vacuum system have been commissioned in situ. The first detector support system is, at the time of writing, almost completely equipped with silicon detectors, and will, after a metrological survey, be installed in the vacuum vessel.

Part of the VELO setup and a sole Nikhef responsibility is the Pile–Up Detector. The Pile–Up system aims at distinguishing between crossings with single and multiple visible interactions for the level–0–trigger. It uses four silicon sensors of the same type as those used in the VELO to measure the radial position of tracks in the backward direction. The Pile–Up system provides the position of the primary vertex candidates along the beam–line and also a measure of the total backward charged track multiplicity. Therefore, the Pile–Up information allows a relative luminosity measurement that is not affected by system deadtime, and monitors the beam conditions. Final commissioning of the full VELO detector will take place in the second half of 2007.

The Outer Tracker (OT) detector serves to reconstruct the momentum of the charged particles by detecting the deflection of their trajectories in the LHCb dipole magnet. The OT stations cover a large area (28 m^2 per measurement layer) and consist of gaseous straw tube detectors. The active part of the detector consists of 5 mm straw tubes (cathode), which are filled with an ionizing gas mixture (Ar/CO_2), and a 25 µm diameter tungsten wire at the center (anode). In total 256 channels are grouped in one module ($500\times34 cm^2$), facilitating the construction, assembly and maintenance of the entire detector.

Nikhef has been the leading institute in the design and R&D phase of the project which resulted in the Technical Design Report in 2001. Subsequently, Nikhef was responsible for the construction and quality assurance of half of the detector modules of the OT. During module production, stringent quality criteria were applied on the wire tension and HV behaviour of each single wire. After

Fig. 3. Installation at CERN of the wakefield suppressor on the VELO setup.

HERA–B

Operational experience with a large forward spectrometer was obtained by participating in the HERA-B experiment at DESY, Hamburg. The LHCb reoptimization of the detector in 2003 was mainly based on experience obtained in the HERA–B experiment, where it was observed that the tracking chambers located inside the volume of the large dipole magnetic field were difficult to commission for physics. In HERA–B the Nikhef group focused on tracking and contributed to the measurement of the hadronic $B\text{–}\overline{B}$ production cross section.

production, the gas–tightness of the entire module was checked, and the module was flushed with counting gas and the detector was put under high voltage for conditioning. Finally, the response to radioactive sources was checked for acceptance. The production lasted 2 years and was finalized at the end of 2005, after which the modules were shipped to CERN for installation in LHCb. Signal degradation has been observed later after irradiation with radioactive sources. This effect is under further study and possible cures are being investigated.

Nikhef is also responsible for developing, testing and assembling a large part of the readout electronics. In order to validate the combination of detector and readout electronics, four mass–production modules have been tested with a 6 GeV electron beam at the DESY–II facility in Hamburg in 2005. A large parameter space between an anode wire voltage of 1500 and 1700 V, and amplifier threshold settings between 3 and 4 fC has been identified, yielding a hit finding efficiency over 98% and a position resolution better than 200 µm, well within specifications.

In addition to the construction of both the VELO and OT tracking detectors, a large part of our manpower has been devoted to the software required for these systems, and to recognize the charged particles that leave trails in these detectors, and to accurately reconstruct their parameters. Based on experience obtained in the HERA–B experiment, the group has provided pattern recognition algorithms for the Outer Tracker detector as well as algorithms that connect track segments in the VELO to those in the Outer Tracker. In addition, Nikhef was the main author of a Kalman track fitting algorithm used in the standard reconstruction sequence of LHCb. This activity has benefited from our experience gained in the BaBar experiment, particularly in the determination and implementation of possible detector misalignments. As a result, Nikhef has provided the leader of the track reconstruction task force.

The reconstruction algorithms were used in order to further optimise the layout of the tracking system in LHCb. Based on Monte Carlo studies it was decided in September 2003 to reduce the number of detector stations in the main tracker from 11 to 3 and to reduce the number of silicon planes in the vertex detector from 25 to 21. This optimization was driven by the requirement to reduce the amount of material present in the set–up in order to improve the physics performance. As benchmarks of the physics performance two B_s–meson decay studies done by Nikhef were presented to demonstrate the physics sensitivity of the LHCb experiment. The first decay, a B_s–meson into a D_s–meson and a kaon can be used to measure the CKM–angle γ; the second decay, a B_s–meson into a J/Ψ and a Φ meson can be used to search for interactions beyond the framework of the Standard Model.

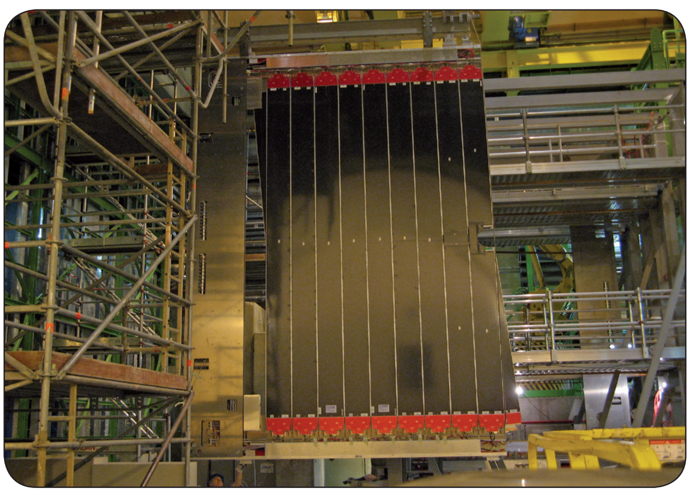


Fig. 4. Outer Tracker modules mounted in an C–frame at Nikhef.

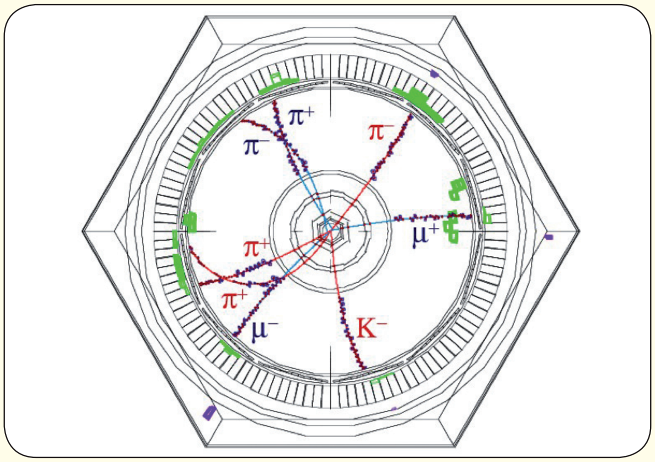


Fig. 5. A "golden" BaBar event. An electron and positron annihilate at the center of the vertex detector in this cross–sectional view, producing a B and a $\overline{B}$ meson. One of them decays into a pair of muons and a pair of pions (blue tracks), while the other (the "tagging" B) decays into a kaon and three pions (red tracks).

BaBar

The group joined the BaBar collaboration at SLAC, Menlo Park at the end of 2002. This enabled the group to perform initial measurements already prior to the LHC startup, gaining important experience with the analysis of large samples of B–mesons.

The experience gained at BaBar is part of the preparations for the analysis of the LHCb data. The group is preparing several analyses, all of which aim at the study of the transition between the heavy *b*–quark and the *s*–quark. In this respect, LHCb has an advantage compared to BaBar: it has access to decays of the so–called B_s–meson, a bound state of a *b*– and an *s*–quark.

We contributed to the BaBar tracking software, alignment and operation of the vertex detector of the experiment, and obtained the first constraint on the CKM angle γ through the determination of the CP asymmetry in the decay of $B^0 \rightarrow D^* \pi$.

Future Directions

The BaBar experiment is scheduled to take data until 2008. Combined with the start–up of the LHC collider end of 2007, our participation is foreseen to end in 2008. The LHCb experiment is, at the time of writing, nearing the completion of its construction. Initial collisions at low energy are scheduled for the fall of 2007, during which the detector will be commissioned. Collisions at the nominal energy are expected to start in the spring of 2008, at which time the collection of physics data will start in earnest.

Nikhef Contributions

The prominence of the Nikhef group in the above LHCb topics can be recognized from the fact that Nikhef was the main author of the OT technical design report, contributed several chapters to the VELO technical design report and the 're–optimization' physics technical design report. In addition Nikhef currently provides the project leader of the Outer Tracker project (A. Pellegrino), the deputy–project leader of the VELO project (E. Jans) and the convenor of the of the 'propertime and mixing' group (G. Raven), one of the five analysis groups in LHCb. M. Merk has been Track–Fit coordinator and Offline Reconstruction Coordinator, J. van de Brand was VELO–coordinator. Moreover, Nikhef physicists are members of the Editorial Board. Apart from the Nikhef contributions to LHCb as mentioned above, Nikhef participated for HERA–B in the construction of the Outer Tracker, composed of large Honeycomb Wire Chambers and in the design and production of First–Level Trigger boards. Moreover, the Nikhef Utrecht group participated in the construction of the Inner Silicon Tracker.

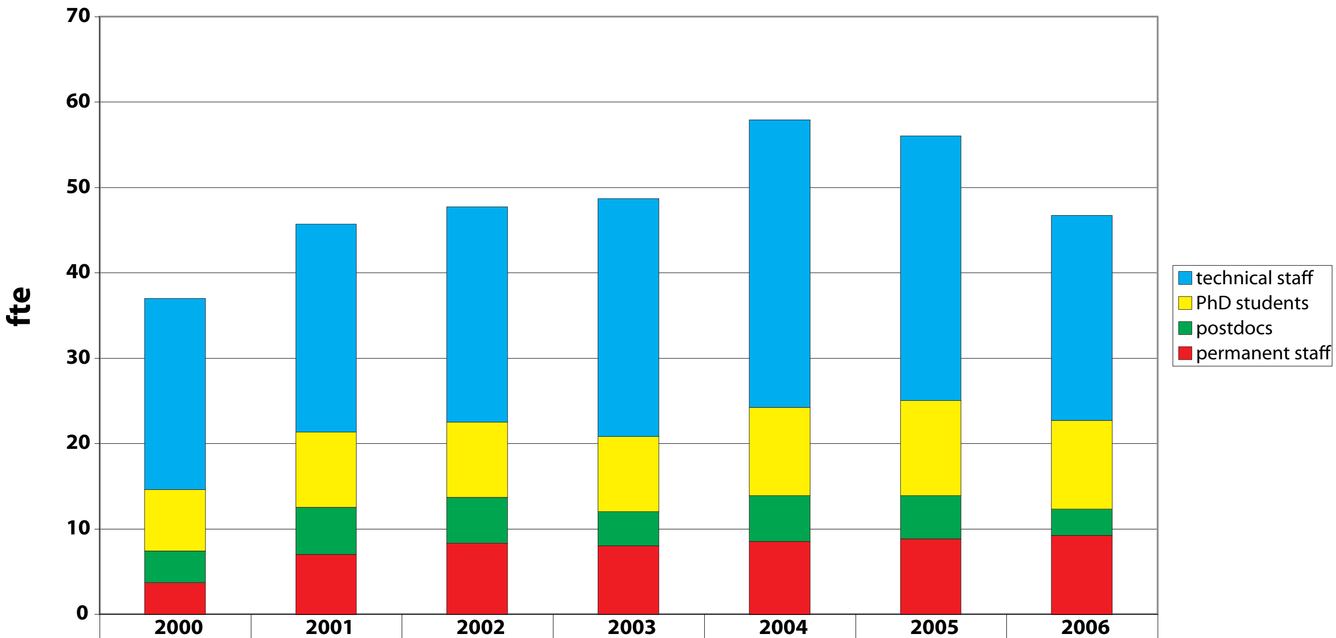
International Collaborations

The HERA–B, BaBar and LHCb experiments are designed, constructed and operated by international collaborations. The HERA–B collaboration consisted of 240 physicists from 13 countries. The BaBar collaboration consists of approximately 550 physicists from 10 countries. The LHCb collaboration currently consists of 670 participants from 14 countries.

Key Publications

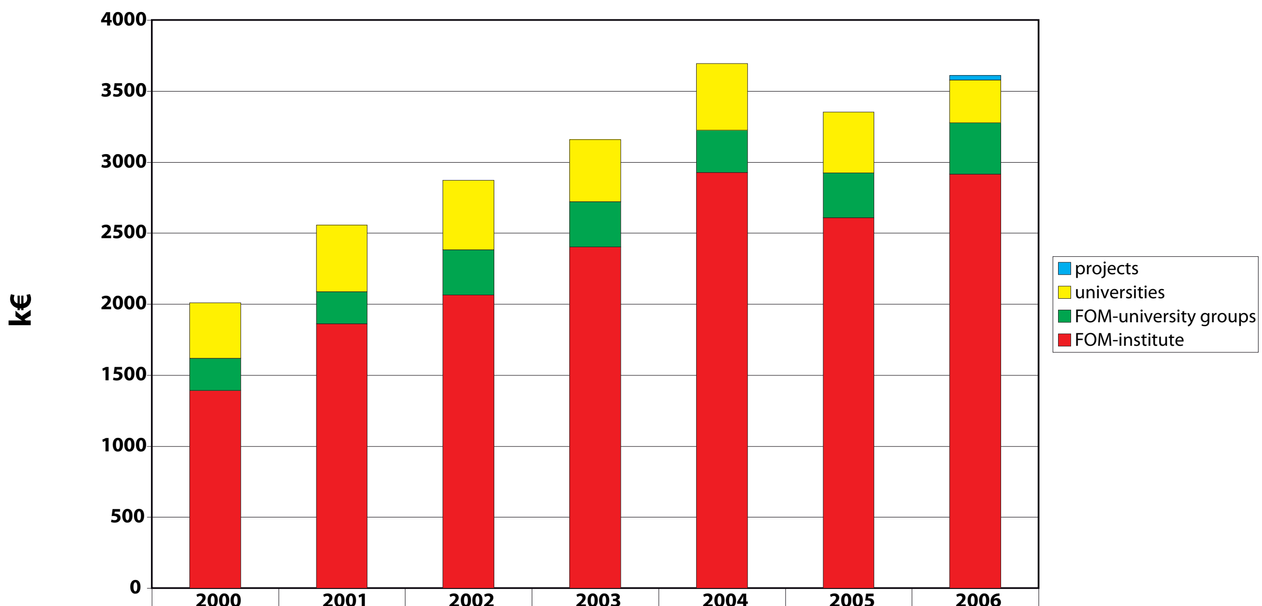
- O. Long, M. Baak, R.N. Cahn, and D. Kirkby.
  Impact of tag side interference on time dependent CP asymmetry measurements using coherent B^0 anti–B^0 pairs
  Phys. Rev. **D68** 034010, 2003.
- B. Aubert *et al.* (BaBar collaboration)
  Measurement of Time-Dependent CP Asymmetries in $B^0 \rightarrow D^{*\pm}\pi^{\mp}$ Decays and Constraints on sin($2\beta+\gamma$)
  Phys. Rev. Lett. **92** 251801, 2004.
- I. Abt *et al.* (HERA–B Collaboration)
  Measurement of the $b\overline{b}$ production cross–section in 920–GeV fixed target proton nucleus collisions
  Eur. Phys. J. **C26** 345, 2003.
- LHCb Technical Design Reports:
  - TDR5: VELO, CERN–LHCC–2001–011
  - TDR6: Outer Tracker, CERN–LHCC–2001–024
  - TDR9: Reoptimized detector: design and performance, CERN–LHCC–2003–030
  - TDR10: Trigger System, CERN–LHCC–2003–031

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff	22.4	24.4	25.2	27.9	33.7	31.0	24.0
PhD students	7.2	8.8	8.8	8.8	10.3	11.1	10.4
postdocs	3.7	5.5	5.4	4.0	5.4	5.1	3.1
permanent staff	3.7	7.0	8.3	8.0	8.5	8.8	9.2

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
projects	0	0	0	0	0	0	30
universities	392	467	490	436	470	430	301
FOM-university groups	226	227	319	320	299	316	363
FOM-institute	1,392	1,861	2,063	2,402	2,925	2,607	2,914

2.1 Relativistic Heavy-Ion Physics: ALICE

Nikhef Research Highlights

STAR

- Elliptic flow measurements.
- Neutral pion and direct photon measurement.

ALICE

- Construction of the Silicon Strip Detector.
- Implementation of elliptic flow analysis software.

Programme Organization

Prof. dr. A. Buijs was group leader of the heavy–ion group until the end of 2001, dr. P. Kuijer followed until the end of 2002, when the leadership was taken over by prof. dr. T. Peitzmann. The programme was started in 1998 and runs until 2013.

Research Goal

The research focuses on experimental studies of the thermodynamics of strongly interacting matter in high–energy collisions of heavy nuclei. The goal is to study the quark–gluon plasma, a state of extremely high density and temperature. It will provide crucial information on one of the fundamental interactions, the strong interaction, under conditions that cannot be studied elsewhere. The quark–gluon plasma is expected to have existed very shortly after the Big Bang.

Research Activities

The ALICE experiment will measure interactions of high–energy heavy ions at the CERN LHC. The group has played a leading role in the design, test and construction of the Silicon Strip Detector (SSD), which constitutes the two outer layers of the Inner Tracking System (ITS) of the ALICE detector. It is a crucial part of the overall charged particle tracking and therefore relevant for all measurements involving charged particles. In particular, the ITS, and with it the SSD, are important for the measurement of short–lived particles, such as so–called strange and charmed particles. The high multiplicities of produced particles in the heavy–ion collisions require a large number of independent read–out channels (about 2.5 million). The ALICE experiment is dedicated to measure also very low–momentum particles, which would be significantly disturbed by dead material such as support structures. Knowledge about those low momentum particles is crucial to obtain information about the bulk (i.e. thermodynamic) properties of the system. Therefore, the SSD was designed with as little dead material as possible – in the final design an extremely lightweight detector was achieved. The SSD was assembled in Utrecht, and all components were successfully tested. On December 12, 2006 the SSD was shipped to the CERN research centre.

The SSD project is a collaborative effort of institutes in Helsinki (Finland), Kharkov and Kiev (Ukraine), Nantes and Strasbourg (France), St. Petersburg (Russia), Trieste (Italy), Utrecht and Amsterdam. The project leadership is performed jointly by a person from Strasbourg and by a local group member.

Recently, the group has significantly increased efforts to prepare for the future analysis with the ALICE detector. Analysis tools for elliptic flow measurements have been developed and implemented in the ALICE software framework. Elliptic flow is one of the key observa-

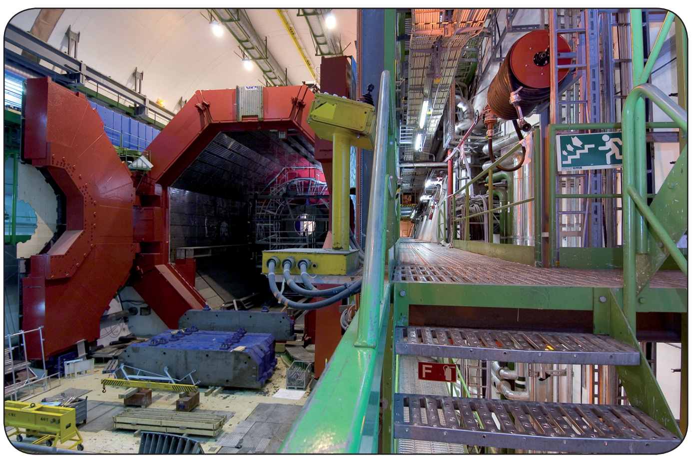


Fig. 1. Installation of the coils for the ALICE experiment.

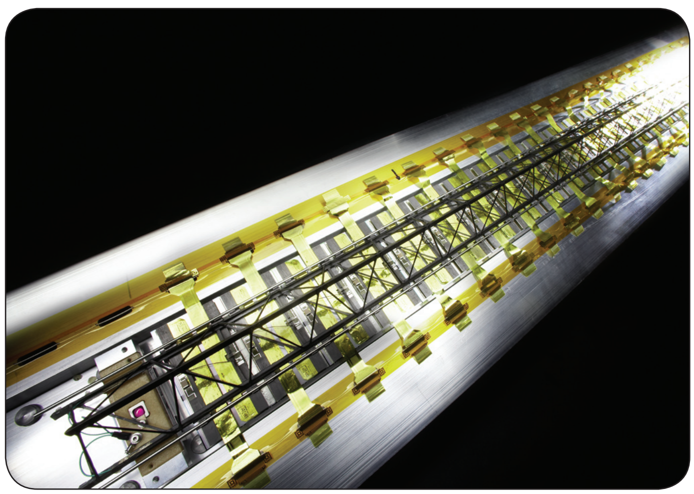


Fig. 2. A Silicon Strip Detector ladder for the ALICE detector. The carbon fiber structure carries 22 double-sided silicon strip detectors.

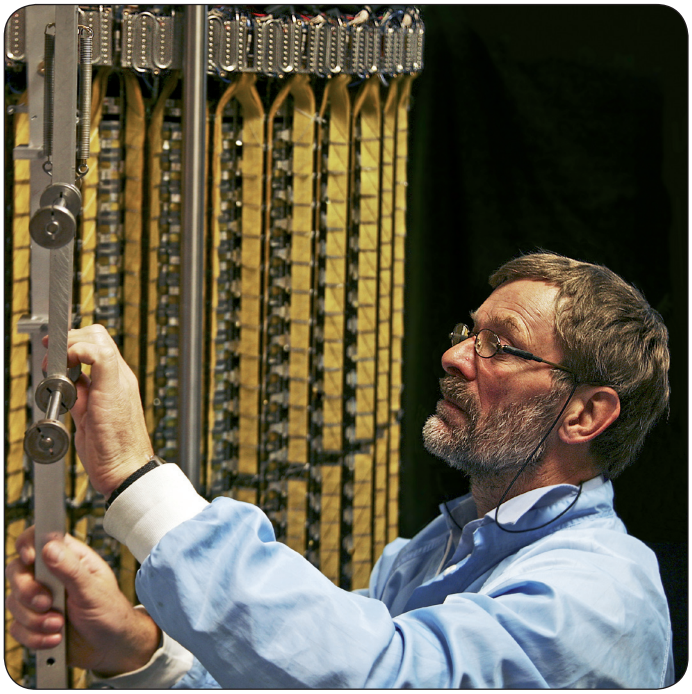


Fig. 3. The Silicon Strip Detector during its completion at Utrecht University. The detector consists of two concentric cylindrical layers of silicon strip sensors, mounted on carbon fiber structures.

bles in the physics of heavy–ion collisions. It is the azimuthal asymmetry in particle distributions generated by the thermal pressure in a very early stage of the collision and can thus provide information on the thermal properties of this early state. It can furthermore be investigated already from the first data to be taken. Simulations of elliptic flow have been performed, that have demonstrated a very good sensitivity of the detector to this observable.

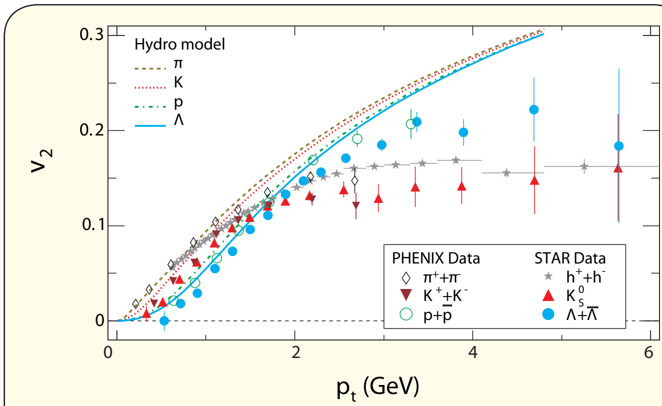


Fig 4. Elliptic flow strength V2 as a function of transverse momentum for identified particles as measured at RHIC. At low transverse momentum the pattern of elliptic flow is well reproduced by hydrodynamic calculations (lines).

Future Directions

In the coming years the group will concentrate on the exploitation of the ALICE experiment. The activities within the STAR experiment will be continued until the individual research projects (in particular PhD theses) have been completed. The activities within

STAR experiment

The ALICE group is also active in data taking and analysis within the STAR experiment, which is running at the RHIC accelerator at Brookhaven National Laboratory. Observations by STAR include a.o. the large magnitude of elliptic flow, the strong suppression of jet production, the consistency of integrated hadron ratios with a production from hadronization in a thermal system and a strong baryon enhancement at intermediate transverse momentum. Those results have led to the current interpretation of the matter produced as being a strongly interacting, opaque liquid with extremely low viscosity.

The large acceptance STAR detector is particularly well suited to study azimuthal correlations as used for the analysis of elliptic flow and of di–jet structures. Our group has therefore concentrated on two main avenues: the analysis of elliptic flow and studies of high transverse momentum probes involving the recently added electromagnetic calorimeter.

The studies of elliptic flow have shown in particular that:

- elliptic flow is large, indicative of strong partonic interactions at the early stage of the collision (in ideal hydrodynamics a thermalization time smaller than 1 fm/c is required);
- at low transeverse momentum ($p_{T)}$ elliptic flow for all measured particles is well described by boosted thermal (i.e. hydrodynamic) particle distributions;
- in the intermediate p_T range the elliptic flow strength is approximately proportional to the number of constituent quarks in the hadrons considered;
- and elliptic flow is sizable up to $p_T = 7$ GeV, indicating strong parton energy loss.

Regarding the Electromagnetic Calorimeter (EMC) our group has significantly contributed to the completion of the detector itself and to its commissioning and debugging. Our group was the first to present results on identified particles measured with this detector leading to the presentation of preliminary data on direct photon production (an extremely difficult measurement) by one of our PhD students at Quark Matter 2006, the most important conference in the field.

ALICE will include:

- contributions to integration and commissioning of the SSD detector;
- contributions to alignment of the SSD;
- development and test of analysis software for elliptic flow analysis;
- analysis of elliptic flow and related two–particle and multi–particle correlation analyses.

Nikhef Contributions

Nikhef developed the electronics of the SSD endcap and produced the endcap modules, did most of the ladder production (mounting of detector modules, i.e. sensors with front–end electronics, on carbon fibre structures including cabling), performed mechanical and electronic measurements of the ladders. Furthermore Nikhef has contributed to software development for elliptic flow simulations and analysis. In STAR R. Snellings was convenor of the spectra physics working group and T. Peitzmann is convenor of the high-p_T physics working group. In ALICE P. Kuijer was and G. Nooren is SSD project leader, R. Kamermans is management board member.

National Collaborations

The group at Nikhef works in close collaboration with the Subatomic Physics Institute at the UU.

International Collaborations

The group has been involved in several international collaborations. Within the ALICE collaboration (104 institutes from 30 countries and more than 1000 members) –the focal point of our efforts– we have so far concentrated on development, construction and test of the Silicon Strip Detector. Early in this period the group was involved in the first generation heavy–ion experiments (NA49, NA57, WA98), mainly concentrating on data analysis. Within the NA57 experiment we have also been involved in silicon detector developments. Since 2002 the group collaborates in the STAR experiment (51 institutions from 12 countries, with a total of 545 collaborators) to maintain a strong position in physics analysis until data taking in ALICE starts.

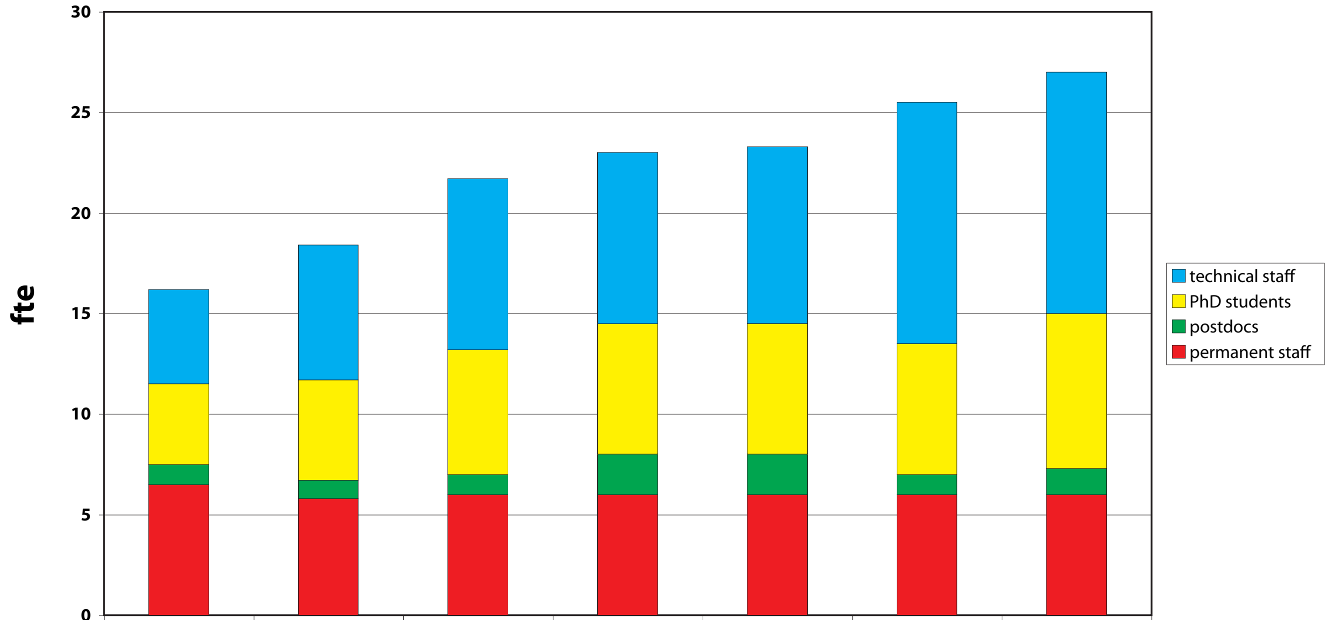
Awards

In this period the group has received a '*Springplank*' and a NWO–VIDI (Raimond Snellings) and a NWO–VENI fellowship (André Mischke, UU), and two 'projectruimte' grants from FOM.

Key Publications

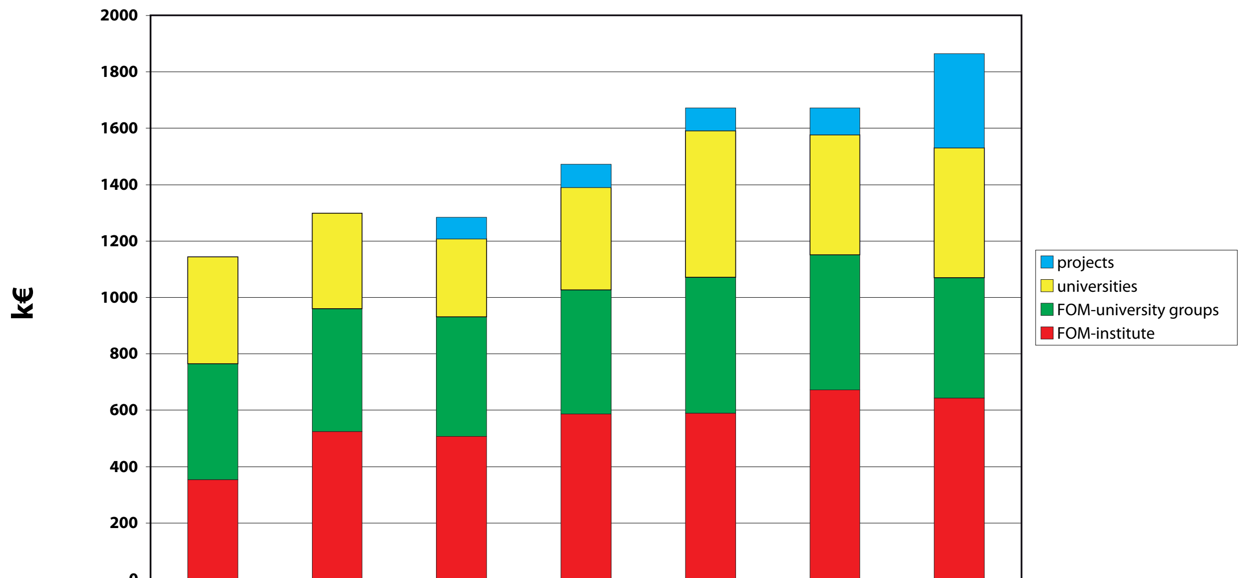
- M.M. Aggarwal *et al.* (WA98 Collaboration)
  Observation of direct photons in central 158A GeV $^{208}Pb+^{208}Pb$ collisions
  Phys. Rev. Lett. **85** (2000) 3595.
- K.H. Ackermann *et al.* (STAR Collaboration)
  Elliptic flow in Au+Au collisions at $\sqrt{s_{NN}}$ = 130 GeV
  Phys. Rev. Lett. **86** (2001) 402.
- C. Adler *et al.* (STAR Collaboration)
  Disappearance of back–to–back high p_T hadron correlations in central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
  Phys. Rev. Lett. **90** (2003) 082302.
- J. Adams *et al.* (STAR Collaboration)
  Evidence from d+Au measurements for final state suppression of high p_T hadrons in Au+Au collisions at RHIC
  Phys. Rev. Lett. **91** (2003) 072304.
- J. Adams *et al.* (STAR Collaboration)
  Experimental and theoretical challenges in the search for the quark gluon plasma: The STAR Collaboration's critical assessment of the evidence from RHIC collisions
  Nucl. Phys. **A757** (2005) 102.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff	4.7	6.7	8.5	8.5	8.8	12.0	12.0
PhD students	4.0	5.0	6.2	6.5	6.5	6.5	7.7
postdocs	1.0	0.9	1.0	2.0	2.0	1.0	1.3
permanent staff	6.5	5.8	6.0	6.0	6.0	6.0	6.0

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
projects	0	0	77	83	81	96	335
universities	380	338	277	363	519	425	459
FOM-university groups	410	436	424	440	482	480	427
FOM-institute	353	524	506	586	589	671	643

2.4 Neutrino Astroparticle Physics: ANTARES

Programme Organization

The research programme has been led by prof. dr. M. de Jong, who was elected as deputy spokesperson of the ANTARES collaboration in 2005. Since then prof. dr. G. van der Steenhoven has taken over as programme leader. The programme runs from 2001 until 2007.

Research Goal

The primary objective of the research programme is to measure the spectrum of high–energy cosmic neutrinos. Searches will be performed of neutrino point sources, and relics of dark matter particles. For this purpose a 0.04 km^3 neutrino telescope (ANTARES) is being built on the bottom of the Mediterranean Sea, off the coast near Toulon. At the same time, the development of a substantially larger km^3–sized neutrino telescope will be initiated in a European framework (KM3NeT).

Research Overview

A cosmic neutrino observatory will represent one of the key instruments needed for the advancement of *astroparticle physics*, a new interdisciplinary research field at the interface of astronomy and physics. More in particular, the observation of (ultra) high energy neutrinos from the universe will provide information on the unknown origin of high energy cosmic rays, the nature of cosmic acceleration mechanisms, and the composition of dark matter. Neutrinos have substantial advantages as compared to other particles when addressing these issues, as they are uncharged and have virtually no mass. As a result neutrinos are neither bent by intergalactic magnetic fields, nor absorbed by interstellar clouds. Hence, neutrinos can be traced to their (cosmic) origin, which is impossible – or at least very difficult – for other particles. This feature enables the association of cosmic neutrinos with known optical sources, i.e. the discovery of neutrino point sources is anticipated. Once discovered, the yield and energy spectrum of neutrinos emitted by such sources can be compared to their electromagnetic emission, thus providing immediate information on cosmic acceleration mechanisms, the origin of cosmic rays and – if peaked in a certain energy region – on the existence and composition of dark matter.

Nikhef Research Highlights

- Successful deployment and operation of the prototype instrumentation line in 2005.
- Successful implementation of the innovative 'All-Data-to-Shore' concept for the readout of ANTARES.
- Reconstruction of the first muon tracks within 24 hours after the successful deployment of the first line.
- Development of novel dedicated triggers to search for neutrinos from Gamma Ray Bursts or Monopoles.

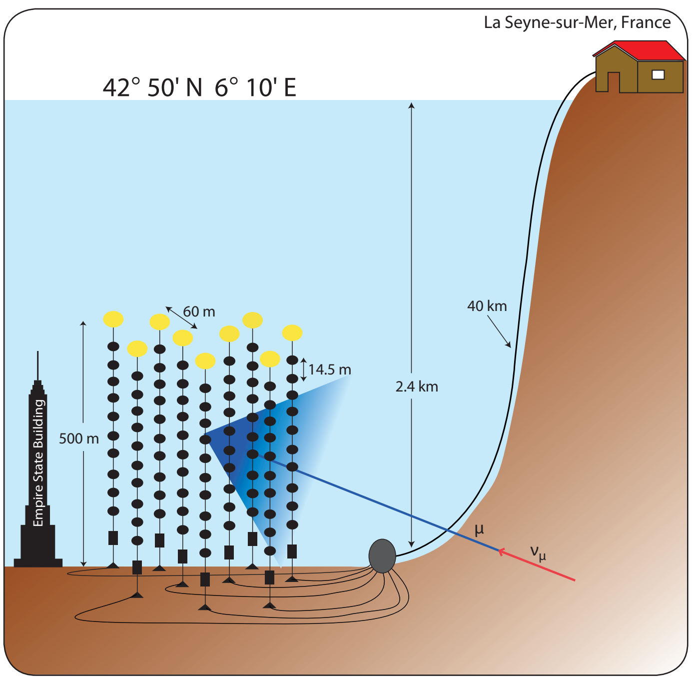


Fig. 1. Detection principle of the ANTARES neutrino telescope.

Fig. 2. The platform carrying the first detector line of ANTARES is loaded onto the sea vessel 'CASTOR', prior to its deployment in the Mediterranean Sea.

Fig. 3. Deployment of one of the 25 stories of the first ANTARES detector line. A story is seen to consist of three glass spheres each housing a large photomultiplier tube. At the centre of each story a titanium cylinder contains all readout and control electronics.

Cosmic neutrinos can be detected by large detector arrays in highly transparent media such as sea water or polar ice. The detection principle is based on the rare occurrence of an interaction of a high energy neutrino with a nucleon in the vicinity of the detector. In such a *charged–current* interaction a muon is produced that is emitted in approximately the same direction as the incident neutrino. The produced charged muon will propagate through the transparent water (or ice) with the velocity of light in vacuum, which is larger than the velocity of light in water. As a consequence the muon will emit Cherenkov light, which can be detected by an array of light–sensitive detectors. Because of the large transparency of sea water, the detector array can have a relatively large spacing with distances between adjacent detector lines of approximately 70 m.

Research Activities

In 2001 the construction of the ANTARES deep–sea neutrino telescope started with the deployment of an electro–optical cable between a site in the Mediterranean Sea, 40 km off the French coast near Toulon, and the shore station in La Seyne–sur–Mer. In 2002 the end of the cable was brought to the surface, connected to the so–called junction box (a deep–sea multiplexer unit to which all the detectors lines are connected) and redeployed. Since that time the junction box and the electro–optical cable have operated properly. As a next step, two prototype lines were deployed in 2003: a short instrumentation line and a line with 15 optical modules. These prototype lines revealed some shortcomings, such as optical transmission losses and several leaks that required design changes. Nevertheless, it has been possible to measure the counting rates due to bioluminescence for several months.

In 2004 the ANTARES design was finalized. In its final design ANTARES consists of 12 detector lines covering a total effective volume of about 0.04 km^3. Each line has a total height of about 450 m and is fixed to the sea bed by an anchor that also contains the connector for the deep sea signal and power cable. The lines are held nearly vertical by syntactic–foam buoys at the top. A line has a total of 75 photomultipliers housed in glass spheres, which are referred to as optical modules. The optical modules are designed to detect the Cherenkov light emitted by the muons propagating through the sea water. The sea bed at the ANTARES site has a depth of about 2500 m, while the optical modules are positioned at depths between 2400 m and 2000 m. As the lines are flexible they move in the sea current. The positions of the optical modules are measured with a system of acoustic transponders and receivers together with several tilt meters and compasses on each line.

The final development phase of ANTARES started with the construction of a new prototype instrumentation line that included several optical modules. This so–called 'MILOM' line was deployed in early 2005 and connected shortly thereafter to the junction box using a Remotely Operated (submarine) Vehicle. The MILOM

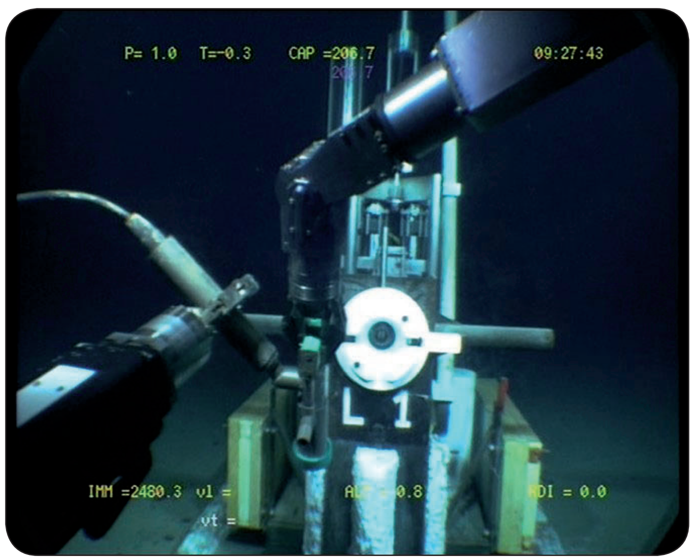


Fig. 4. The anchor of the first detector line of ANTARES after its deployment on the bottom of the Mediterranean Sea at a depth of 2480 m. Also seen are the arms of the the remotely operated submarine vehicle (ROV), which are in the process of connecting line 1 to the shore station.

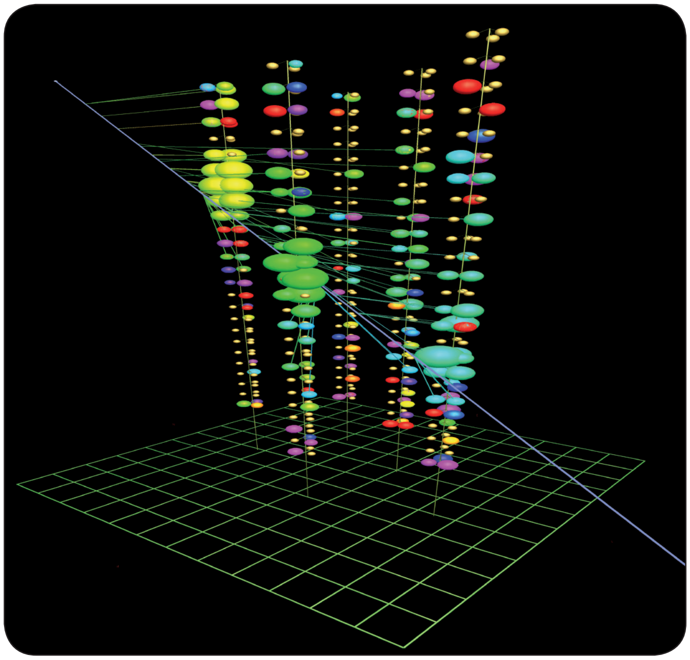


Fig. 5. One of the first reconstructed events in the five current ANTARES detector lines. The coloring of the optical modules is a measure of the timing of the signal, while the purple line represents the muon track.

line has been in operation until it was recovered in Spring '07. Following this success, the first of the series of 12 detector lines was deployed in early 2006, and connected to the shore station several weeks later. The 2nd detector line was deployed and put into operation in the fall of 2006, while the 3rd line followed near the end of 2006. Early 2007 two more lines were deployed and connected to the shore station, resulting a fully operational 5-line neutrino telescope by Febr. 2007 (see Fig. 5).

First muon tracks were reconstructed (using software developed by Nikhef graduate students) within 24 hours after the connection of the first detector line to the shore station. The data confirm the excellent timing (of less than 1 ns) and position resolution (better than 20 cm) that is needed to operate ANTARES as a flexible neutrino telescope with a pointing accuracy of 0.3 degree or less.

The first data also gave evidence of unexpected variations in the background light recorded in the deep sea environment, which is caused by various life forms. This observation of a variable *bioluminescence* has attracted considerable attention among marine biologists.

Nikhef contributions

Nikhef has played a leading role in the development of the ANTARES neutrino telescope. Financially it contributed 3.2 M€, which represents 16% of the total investment required. The following detector components were developed and constructed at Nikhef: an optical–fiber based data–communication system (DWDM), a passive off–shore cooling system, power modules for the detector strings and the off–shore electronics, and the on–shore readout system. The reliable operation of the first detector lines demonstrated the success of these engineering projects.

Moreover, at Nikhef the special so–called 'All–Data–to–Shore' system was developed for the readout of ANTARES. Within this concept, all data recorded by the optical modules are transported to shore using modern fiber–optic based technologies. In the shore station various trigger algorithms can be implemented in software to further filter the data. This system allows for a flexible trigger and reduced backgrounds when applied to the various neutrino point–source searches.

During the ANTARES construction phase several tracking and search algorithms have been developed (and tested by means of Monte Carlo simulations) at Nikhef. This has resulted in software filters that can be used to search for Gamma Ray Bursts and Monopoles.

The Netherlands is actively participating in the governance of the

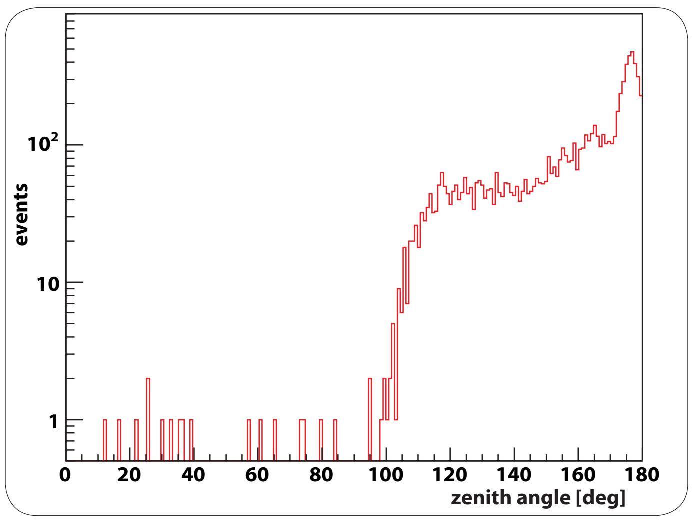


Fig. 6. Distribution of the reconstructed zenith angles with the Antares neutrino telescope. The events below 90 degrees are neutrinos that traversed the Earth.

ANTARES collaboration by providing the deputy spokesperson (M. de Jong) since 2005, the coordinator of the Neutralino Working Group (G. van der Steenhoven) since 2005, and several (rotating) members of the Publication Committee (M. de Jong, P. Kooijman, G. van der Steenhoven, E. de Wolf), Conference Committee (M. de Jong and G. van der Steenhoven) and Search Committee (E. de Wolf).

Future Directions

Given the successful operation of the first ANTARES detector lines in 2006, it is realistic to expect the completion of the detector in 2007. Once complete, the full deep–sea neutrino telescope will be operated for 5 years or more in an effort to map the Southern neutrino sky, which is complementary to the ongoing measurements of the AMANDA–IceCube collaboration aimed at mapping the Northern neutrino sky. At the same time the preparations for the construction of a km^3–sized neutrino telescope in the Mediterranean Sea have been initiated. This project, known under the name KM3NeT, will have an effective area that is a factor 20 (or more) larger than that of ANTARES. The KM3NeT collaboration has been formed in 2005 (with substantial Dutch participation) and receives EU funding of about 9 M€ in 2006 – 2009 for a design study. First neutrinos could be observed by KM3NeT in 2012.

National Collaborations

The Dutch research effort within the ANTARES collaboration is led by Nikhef with significant support from the University of Amsterdam and – more recently – the nuclear physics research institute KVI of the University of Groningen.

International Collaborations

In the ANTARES collaboration 18 research groups, originating from 6 countries (France, Germany, Italy, the Netherlands, Russia and Spain) collaborate.

Industrial Collaborations

The development of the *Dense Wave–length Division Multiplexing* system for data transport from the optical modules in the sea to the shore has been carried out in close collaboration with Baas R&D, a subsidiary of Baas Group. This Dutch company has a track record in developing fiber–optic networks.

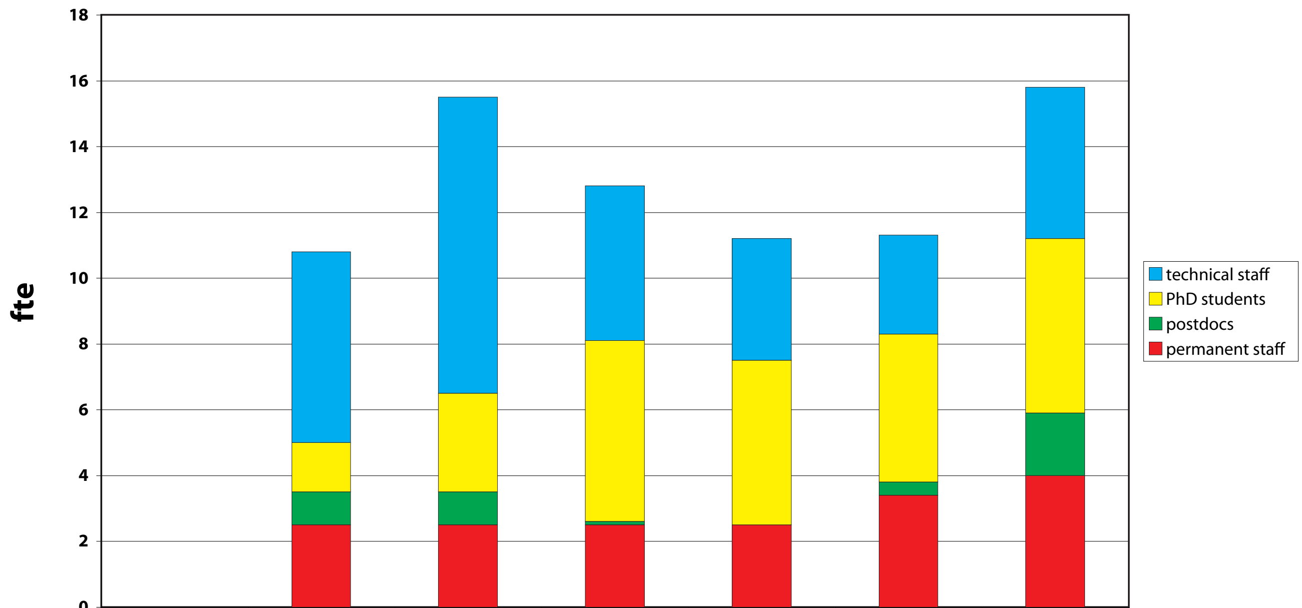
Awards

Ronald Bruijn received the 2003 price for the best master thesis at the Universeit van Amsterdam. His subject was a study of the muon–energy reconstruction using neural networks. Mieke Bouwhuis received the 2006 award of the Dutch Physical Society for the best popular account of a recent PhD thesis in physics or astronomy. She also received an NWO–VENI fellowship that enables her to continue her research in the area of time–variable neutrino point sources for three years.

Key Publications

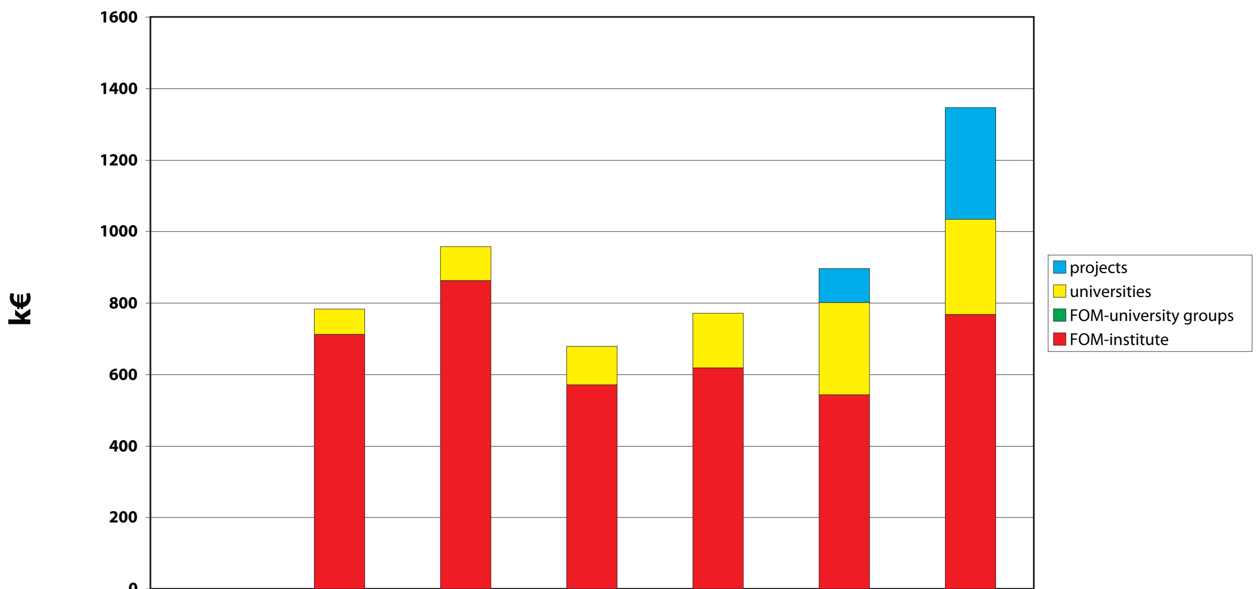
- J.A. Aguilar *et al.* (ANTARES Coll.)
  Transmission of light in deep sea water at the site of the ANTARES neutrino telescope
  Astroparticle Physics **23** (2005) 131.
- M. Bouwhuis
  Neutrinoflitsen uit het heelal
  Nederlands Tijdschrift voor Natuurkunde **72** (2006) 74.
- J.A. Aguilar *et al.* (ANTARES Coll.)
  First results of the Instrumentation Line for the deep–sea ANTARES neutrino telescope
  Astroparticle Physics **26** (2006) 314.
- J.A. Aguilar *et al.* (ANTARES Coll.)
  The data acquisition system for the ANTARES neutrino telescope
  Nucl. Instr. Methods **A570** (2007) 107.
- G. Giacomelli and P.M. Kooijman
  ANTARES Collaboration detect its first muons
  CERN Courier **46** (Sept. 2006) 24.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff		5.8	9.0	4.7	3.7	3.0	4.6
PhD students		1.5	3.0	5.5	5.0	4.5	5.3
postdocs		1.0	1.0	0.1	0.0	0.4	1.9
permanent staff		2.5	2.5	2.5	2.5	3.4	4.0

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
projects		0	0	0	0	95	312
universities		70	95	107	153	258	266
FOM-university groups		0	0	0	0	0	0
FOM-institute		712	862	571	618	543	768

2.5 Theoretical Physics

Programme Organization

Since 2005 the research programme has been led by prof. dr. E. Laenen, who succeeded the programme leader prof. dr. J.W. van Holten. The present programme began in 1999 and ends in 2007. A joint follow–up programme with a number of universities will be submitted in 2007.

Research Goal

The theory group at Nikhef aims to push forward the frontiers of knowledge in theoretical particle physics and its applications to astrophysics and cosmology. It focuses on exploring new concepts and ideas related to the elementary constituents of matter and carriers of force, inspiring experimental verifications of these ideas, and enabling detailed comparison between theoretical concepts and experimental data.

Research Activities

One of our research areas, pursued by B. Schellekens and collaborators during the last decade, has been the use of interacting two–dimensional conformal field theory for the construction of theories of open and closed strings. In theories of this type the closed strings produce gravitational interactions, whereas the open strings are responsible for all gauge interactions, in particular those of the Standard Model.

During the first part of this period they developed a systematic approach to deal with rational conformal field theory (RCFT) on two–dimensional surfaces with boundaries and/or without orientation. These surfaces describe the propagation through space–time of open and/or unoriented strings. The formalism allows the computation of the particle spectrum for a large class of open string theories.

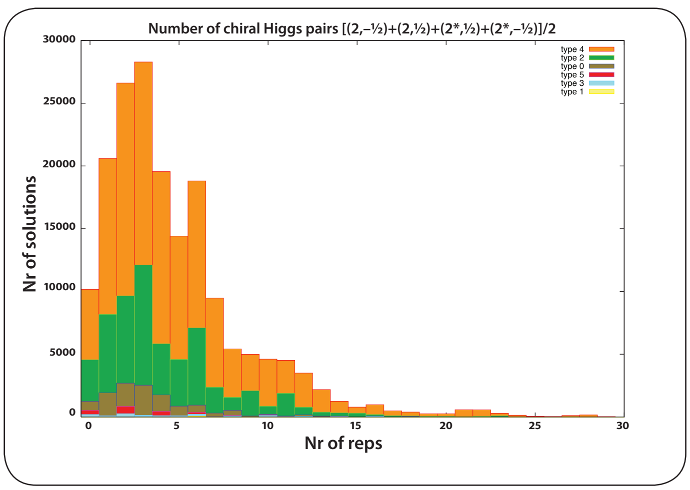


Fig. 1 Distribution of the number of supersymmetric Higgs pairs for the complete database. Colors indicate different brane realizations of the Standard Model.

Nikhef Research Highlights

- Complete calculation of next–to–next–to–leading order QCD splitting functions.
- Finding thousands of Standard Model–like spectra among string vacua.
- Construction of new anomaly–free non–linear supersymmetric gauge theories.
- Lattice calculation of charged pion electro–magnetic form factor.
- Joint threshold– and recoil resummation.
- Release of FORM computer program, version 3.

In the last three years they have started to apply this formalism to the construction of string theories that precisely match the Standard Model interactions and its chiral matter. This made it possible to find, for the first time in open string constructions, spectra that are chirally identical to that of the supersymmetrized Standard Model.

In total more than 200.000 distinct string spectra with Standard Model features were found. They all include the gauge interactions of the Standard Model and three families of quarks and leptons. This extensive database, the only one of its kind in the world, is now being used for further study, for example to examine the possibility to generate Majorana masses for right–handed neutrinos, needed to realize the see–saw mechanism in string theory.

Research of J.W. van Holten, his students and collaborators in the period 2001–2006 has covered a range of different topics, most of them connected with supersymmetry. The main effort has been in the area of effective field theories. In collaboration with S. Groot Nibbelink and T.S. Nyawelo he constructed and analyzed a new class of anomaly–free non–linear supersymmetric gauge theories in which some of the known quarks and leptons are pseudo–Goldstone fermions. As a new line of research, with an eye to possible applications in cosmology and the description of many–particle dynamics in quantum field theory, they started the development of relativistic supersymmetric fluid dynamics.

Effective field theories are also used to model the evolution of the

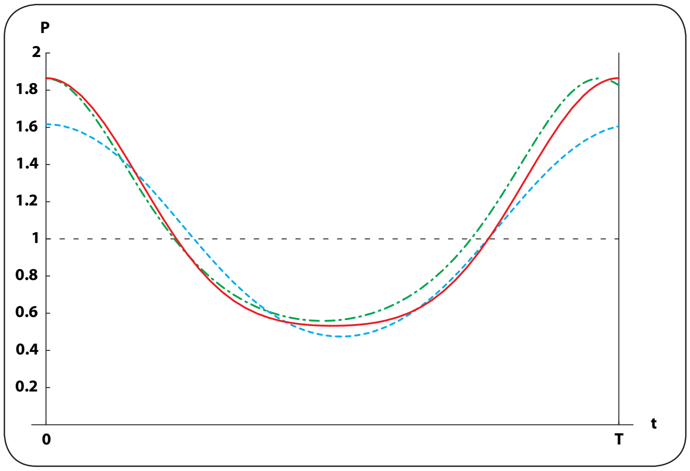


Fig. 2. Power emitted as gravitational radiation by orbiting mass in Schwarzschild geometry as a function of time t in one orbital period T. Black dotted: circular orbit (reference), green: elliptic orbit (Kepler), blue: elliptic orbit, first–order geodesic deviation, red: elliptic orbit, second–order geodesic deviation.

universe at large, such as in inflation and quintessence models. In this connection he has investigated the properties and use of scalar field theories connected with spontaneous symmetry breaking (Goldstone– and Higgs–type fields).

A development that is presently receiving follow–up is work with R. Colistete and R. Kerner on an alternative formulation of perturbation theory for solving equations of motion in general relativity. This is particularly useful for the computation of orbits of masses in large–scale external fields, such as those of black holes. This will allow them e.g. to compute gravitational radiation from such motion.

J. Vermaseren's research in the period covered has mostly concentrated on the calculation of the three–loop QCD splitting functions and coefficient functions for deep inelastic scattering. These quantities are indispensable for the determination of the parton distribution functions inside the proton to the 1–2% level. Any calculation of effects at the LHC that needs an accuracy at the level of a few percent will need these results. The calculation took about 20 man–years over a period of 10 years. The results have already had a great impact on many approximative methods used in QCD, showing some of them to be incomplete. It has also revealed unexpected structures in perturbation theory, and enabled improvement of resummation accuracies, allowing e.g. new estimates of the Higgs production cross section. The mathematical methods developed in the course of this effort have spawned further work in higher order perturbation theory.

This effort was only possible due to significant enhancements to the computer algebra program FORM, of which Vermaseren is the author. During this time, version 3 of this program was released, allowing a whole new generation of calculations.

E. Laenen has concentrated on the phenomenology of the Standard Model, in particular issues involving perturbative QCD. Part of his research improves perturbative predictions of rates, shapes and distributions of observables at hadron colliders. Higher–order corrections can however be large when a kinematic edge such as phase–space boundary or a heavy–particle production threshold is involved, and thus endanger the quality of the prediction. Together with his collaborators Laenen has sought to 'resum' a variety of such large logarithmic terms to all orders, and thereby restore predictive power to the perturbative approach. He has shown how to resum threshold logarithms to next–to–next–to–next leading level for the Drell–Yan and the Higgs production process, how to resum jointly both threshold and zero–recoil logarithms for prompt photon and heavy–quark production, as well as how to sum large associated constant terms.

Another research focus of his has been top–quark physics, in particular hadron collider production characteristics. Early on in the period he developed a method to estimate second–order perturbative corrections, and applied them to top–quark pair production.

More recently, his efforts have centered on the not–yet–observed production of single top quarks through the weak interaction. Laenen and collaborators performed the first fully differential next–to–leading–order calculation for this reaction. Last year, this

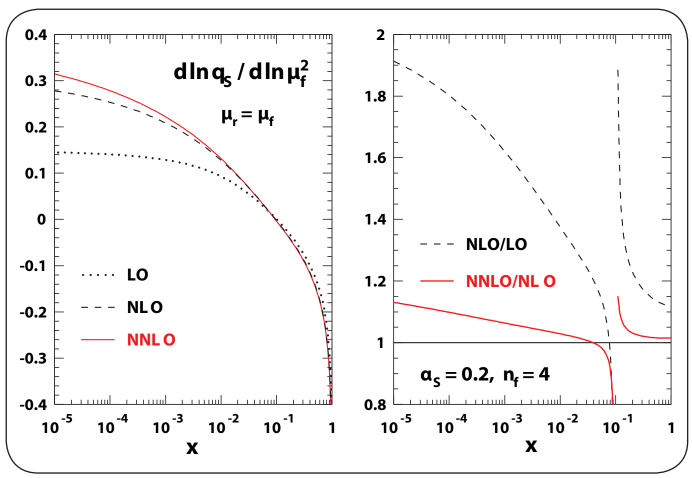


Fig. 3. The perturbative expansion, as a function of Bjorken x, of the scale derivative of the single quark density, resulting from the 1–, 2– and 3– loop splitting functions.

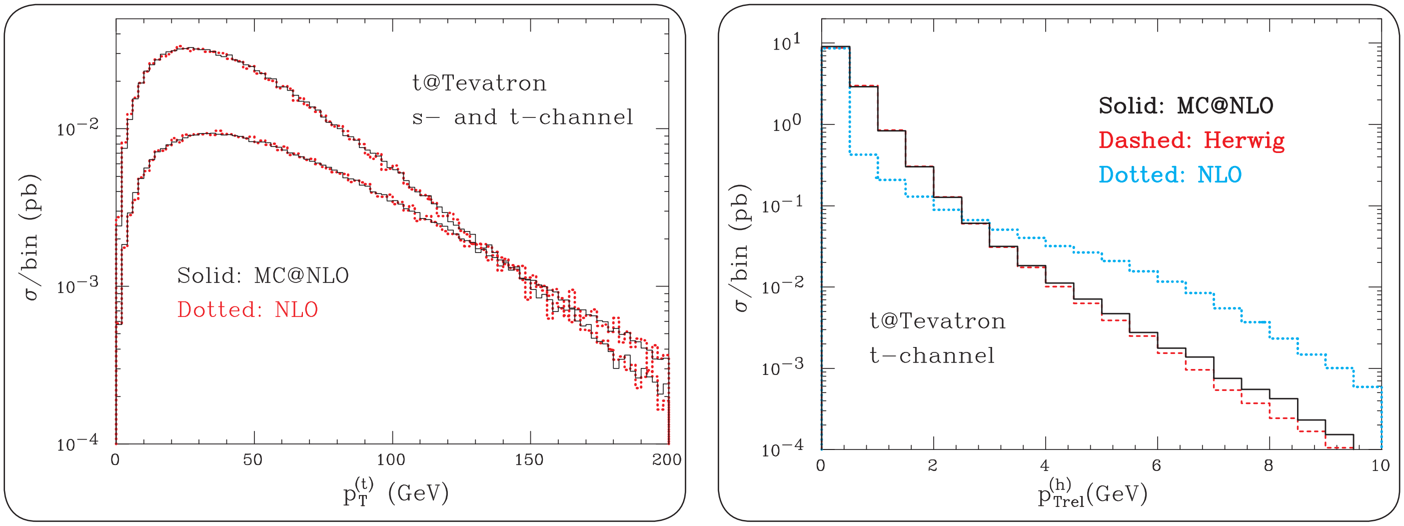


Fig. 4 Left: prediction of the transverse momentum spectrum of the top quark production by the weak interaction in two different production channels; the NLO and the MC@NLO framework agree. Right: momentum transverse to the main jet direction for the hardest jet in single top events; the MC@NLO prediction has the best aspects of NLO and HERWIG.

process was included into the MC@NLO next–to–leading order Monte Carlo simulation frameworks. As a result, both theorists and experimenters can now compute highly accurate and realistic predictions for single–top production, as well its backgrounds.

Over the last years, J. Koch has studied the structure of mesons in lattice QCD making use of the TERAS supercomputer at SARA. The electromagnetic form factor of a free charged pion was calculated in quenched QCD. While initial feasibility studies reported in the literature had been carried out for pions with a mass of the order of 1 GeV, masses as low as 360 MeV can now be treated. Different methods to extrapolate to the physical pion mass, based on chiral perturbation theory, were considered. The obtained form factors confirmed the phenomenological vector–meson dominance model.

QCD predicts that hadronic matter undergoes a phase transition when it is exposed to extreme conditions, i.e. high temperature and/or high baryon density. To investigate possible changes in the internal structure of a pion below the critical temperature, the pion electromagnetic vertex was calculated just below the critical temperature for the phase transition. No significant changes were found in the corresponding vertex function, a finding that contradicts most predictions based on effective models. Calculations were also carried out above the critical temperature for the correlators of a quark–antiquark pair with quark quantum numbers. These data are currently being analyzed. To achieve higher accuracy, one needs not necessarily go to larger lattices, but can also use improved lattice actions and concomittant improved operators. It is being investigated how such improvement can be carried out for the quark conserved vector current in calculations of matrix elements below and above the critical temperature.

Future Directions

Research in the theory group in the near future will continue along the lines indicated above. Applications of results obtained and methods developed promise a fruitful harvest. This applies to research in finite temperature QCD, and certainly to collider phenomenology, with the LHC startup being near. Also the research in string theory promises important new insights in the near term in how it is linked to weak–scale physics. Looking further ahead, members of the theory group have, together with colleagues from many Dutch universities, submitted a focused and coherent FOM program proposal centered around the question which theoretical particle physics model can explain present and future collider data as well as cosmological observations. A FOM program proposal to continue the string theory research is also foreseen.

National Collaborations

Individual collaborations exist with theorists at the universities of Leiden, Amsterdam and Utrecht.

Particle theorists in the Netherlands meet a few times a year at Nikhef for a day of seminars to learn about the latest developments in the field. Quite recently the theory group has started to host 'Theory Meetings', in which attendants are encouraged to start or continue a collaboration, discuss, share expertise, etc.

International Collaborations

Members of the theory group collaborate with theorists in Europe, the USA, Asia, and Australia.

Awards

FOM projectruimte projects were awarded to B. Schellekens, for research on linking string theory to weak scale physics, and to E. Laenen and T. Peitzmann, for a project on detecting the colour glass condensate.

J. Vermaseren won in 2006 the Humboldt Prize from the German Humboldt Stiftung for his groundbreaking research on high–order radiative corrections.

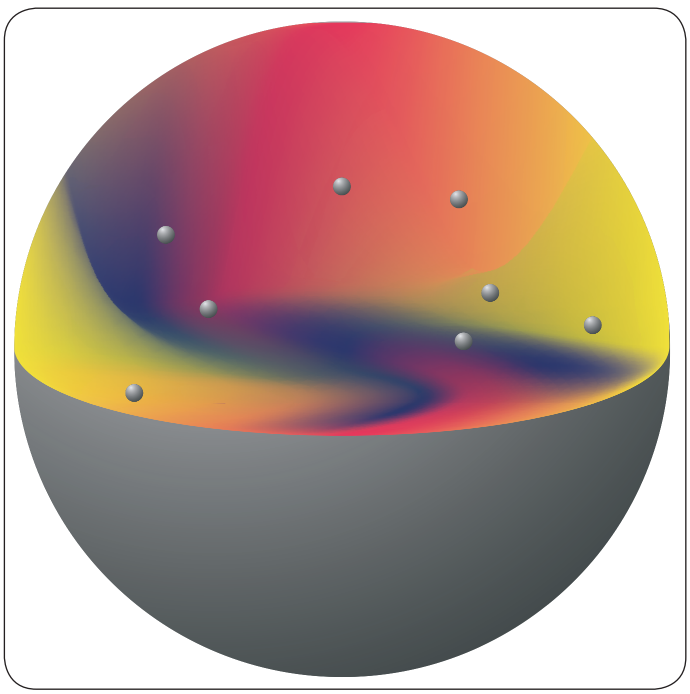
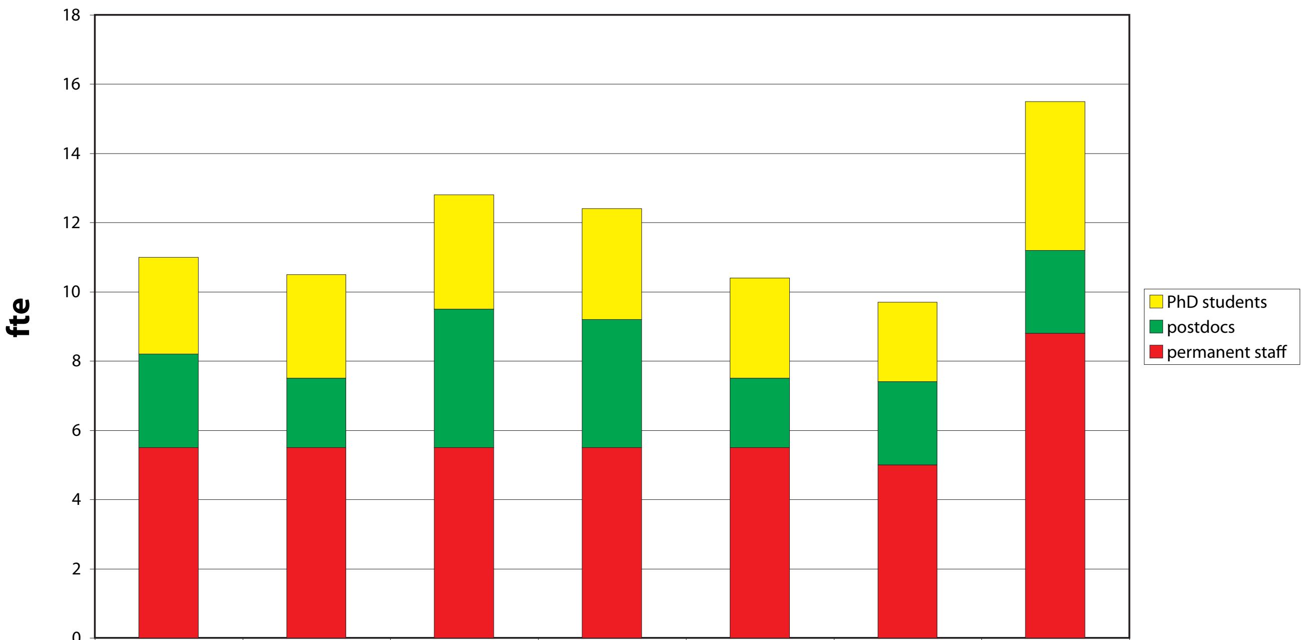


Fig. 5. An impression of a fluid moving on a sphere where the scalar fields live. The relativistic fluid mechanics and supersymmetric extensions are described in the PhD thesis of Tino Shawish Nyawelo.

Key Publications

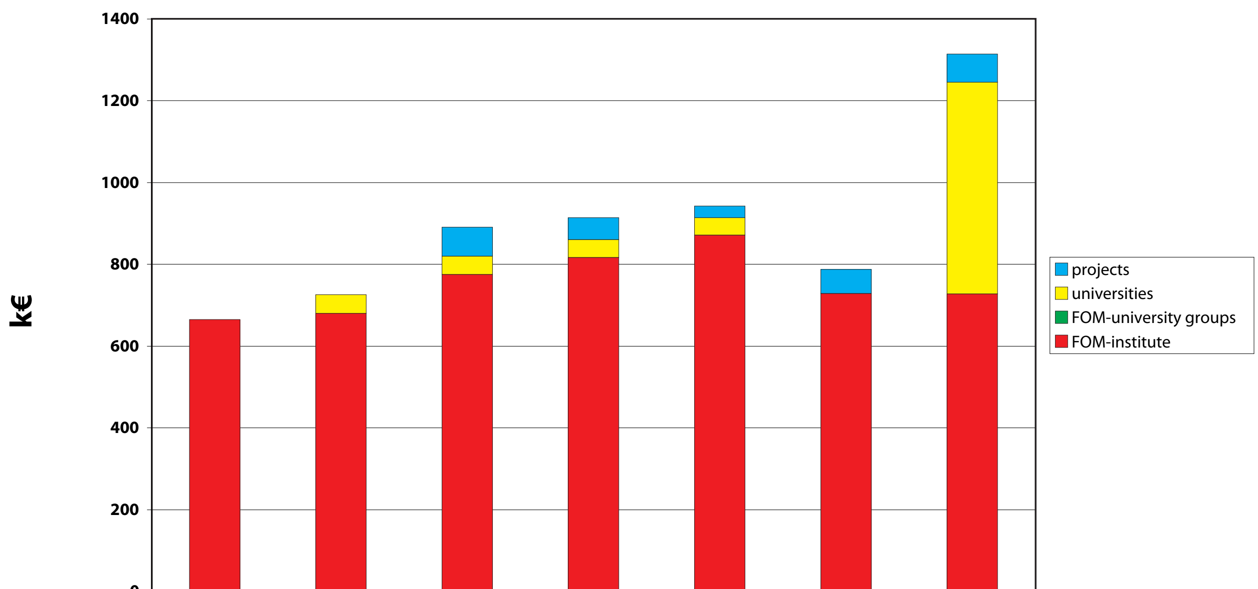
- T.S. Nyawelo, J.W. van Holten and S. Groot Nibbelink
  Superhydrodynamics
  Phys. Rev. **D64** (2001) 021701.
- J.W. van Holten
  Cosmological Higgs fields
  Phys. Rev. Lett. **89** (2002) 201301.
- S. Moch, J.A.M. Vermaseren, A. Vogt
  The three–loop splitting function in QCD: the non–singlet case
  Nucl. Phys. **B688** (2004) 101.
- A. Vogt, S. Moch, J.A.M. Vermaseren
  The three–loop splitting function in QCD: the singlet case
  Nucl. Phys. **B691** (2004) 129.
- J. Fuchs, L.R. Huiszoon, A.N. Schellekens, C. Schweigert, J. Walcher
  Boundaries, crosscaps and simple currents
  Phys. Lett. **B495** (2000) 427.
- T.P.T. Dijkstra, L.R. Huiszoon, A.N. Schellekens
  Supersymmetric standard model spectra from RCFT orientifolds
  Nucl. Phys. **B710** (2005) 3.
- E. Laenen, G. Sterman, W. Vogelsang
  Recoil and threshold corrections in short–distance cross sections
  Phys. Rev. **D63** (2001) 11401.
- S. Frixione, E. Laenen, P. Motylinski, B.R. Webber
  Single–top production in MC@NLO
  JHEP **0603** (2006) 092.
- J. van der Heide, J.H. Koch, E. Laermann
  Pion structure from improved lattice QCD: Form–factor and charge radius at low masses
  Phys. Rev. **D69** (2004) 094511.
- J. van der Heide, J.H. Koch, E. Laermann
  Electromagnetic vertex function of the pion at T>0
  Eur. Phys. J. **C48** (2006) 589.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
PhD students	2.8	3.0	3.3	3.2	2.9	2.3	4.3
postdocs	2.7	2.0	4.0	3.7	2.0	2.4	2.4
permanent staff	5.5	5.5	5.5	5.5	5.5	5.0	8.8

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
projects	0	0	70	54	28	59	69
universities	0	45	45	43	43	0	518
FOM-university groups	0	0	0	0	0	0	0
FOM-institute	665	680	775	817	871	728	727

2.6 Detector R&D

Nikhef Research Highlights
- Production of commercial grade Medipix2 chips.
- Detection with Micromegas + Medipix readout.
- First working electron multiplier grid produced in wafer post-processing.
- 3D particle tracking with Timepix readout.
- Development of a 100 meter long alignment system for CLIC, capable of detection of 'humming' of the earth.

Programme Organization
The programme was led by prof. dr. G. van der Steenhoven until summer 2004 and by dr. J. Timmermans since then. The programme has started officially in 2003.

Research Goal
The primary research goal at the start is detector development for a large, general purpose experiment at the International Linear Collider. The programme is divided into:
- development of a 'digital TPC', where gas multiplication is done via MPGD (Micro Pattern Gas Detector) systems like Micromegas or GEM and the charge collected on CMOS pixel readout chips;
- development of 'monolithic' CMOS sensors for vertex detector systems;
- the continuation of the successful development of hybrid CMOS pixel detectors for X-ray imaging through participation in the Medipix Collaboration at CERN.

The third topic was included because of the large overlap in the technologies used, and the outlook to use these 'enabling technologies' in future LHC detector upgrades.

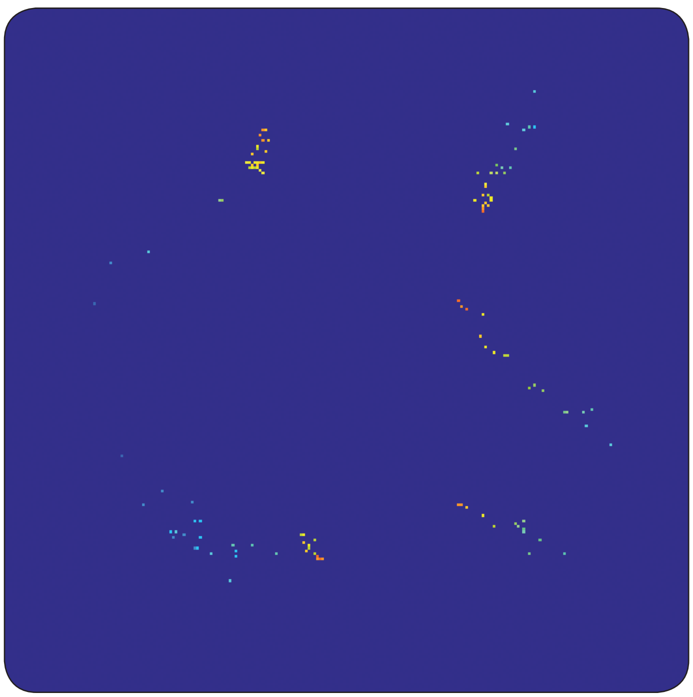


Fig. 1. Tracks from cosmic muons in 'triggered' mode with the TimePix chip. The color code indicates the arrival time of the signals on the pixels.

Research Overview
One of the concepts for central tracking in a general purpose detector at a future Linear Collider consists of a Time Projection Chamber (TPC) with a readout endplate fully covered with pads of a typical size 2×6 mm^2 and where the gas multiplication is obtained with MPGD's instead of MultiWire Proportional Chambers (i.e. grids instead of wires). Due to the much increased readout granularity a big improvement in track-parameter resolution and double-track separation is to be expected compared to previously operating large TPC's as e.g. at LEP. The Nikhef R&D group proposed to go even one step further and try to profit from recent developments in readout circuits for pixel (vertex) detectors at LHC and X-ray imaging. The idea was to use CMOS pixel readout chips as active anode in a gaseous detector (like a TPC) wit MPGD's as gas multiplier. This would allow the detection of single primary ionisation clusters created by the charged particles traversing the (large) gaseous drift volume. In addition to a very good spatial resolution for the reconstructed track points, also a big improvement in the measurement of the energy loss dE/dx is to be expected. The limiting factor is the effectiveness of reconstructing the initial primary ionisation clusters due to diffusion along the drift path. In addition to the initial plan of 'proof-of-principle" experiments using existing pixel readout chips and GEM or Micromegas gas multiplication structures, a collaboration with the MESA+ institute of the University of Twente was started to develop the integration of the gas multiplication structure with the CMOS readout chip using wafer post-processing techniques.

If successful, larger scale integration of many single-chip structures will have to be built. This will require fast, multi-chip readout technologies and through-silicon-via connections of the chip I/O to backplane support pcb's carrying fast communication logic.

This is being pursued in the RELAXD project for developing large-scale, edgeless tiled X-ray imaging devices.

Because of limited person power, the programme line "development of 'monolithic' CMOS sensors for vertex detectors" was staged. Instead, along the same principle of pixelised readout of gaseous detectors, the concept of very light-weight, thin gas detectors (about 1 mm gas thickness) with high-resolution, time-resolved pixel readout (Gossip) is being investigated as possible replacement for vertex detector layers at a luminosity upgraded super-LHC.

Another activity within the Detector R&D group is on developments based on the RASNIK alignment systems. The most challenging is the so-called RasClic alignment system for the future Compact Linear Collider (CLIC). This consists of a (divergent) laser beam illuminating a plate with a 50 mm ø hole at a distance of 50 m and an image pixel sensor placed at 50 m behind this plate to record the typical diffraction pattern. A precision in the order of 1 μm is expected.

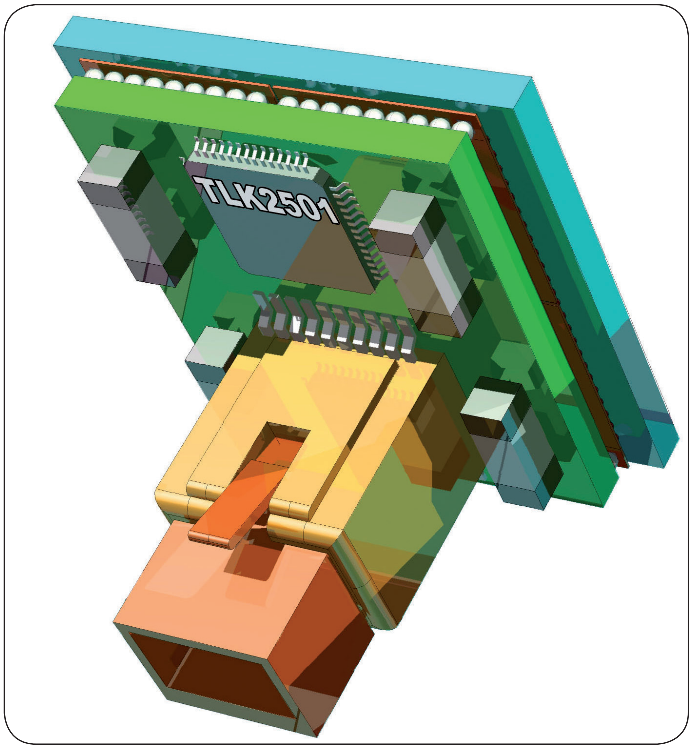


Fig. 2. Quad medipix assembly with backside readout as developed for the RELAXD project.

Research Activities

Pixel readout of gaseous detectors

Initial 'proof-of-principle' results on detecting photon conversions from an ^{55}Fe source were obtained in 2003 and beginning of 2004 in a small TPC with a triple-GEM stack as gas multipliers and a Medipix2 CMOS pixel readout chip as anode, having 256x256 pixels of 55×55 μm^2. Due to diffusion in the 10 cm drift region, in between the GEMs and between the last GEM and the pixel anodes, the initial charge cluster was spread out over 100-200 pixels. The triple-GEM stack was replaced by a single Micromegas grid at 50 μm distance from the anode and a smaller drift gap of about 1 cm employed. Sharp images of the ^{55}Fe photon conversions were recorded. These results were presented at the Vienna Conference on Instrumentation in February 2004. Shortly after, by increasing the gas gain from the Micromegas grid to about 20,000, nice images of minimum ionising particle tracks from a ^{90}Sr source and from cosmics were observed.

End 2004, in collaboration with the group of prof. dr. J. Schmitz at MESA+, University of Twente, the development of a wafer post-processing technology for the production of Micromegas-like structures on top of wafers of CMOS chips was started. After many production process iterations the first working structures on dummy wafers were delivered and many detailed measurements of gas gain, energy resolution and gain uniformity were published.

In 2005 and 2006, several integrated grids of different geometry, shape and pitch of the grid holes and multiplication gap thickness were produced and tested with various gas mixtures. Energy resolution and gas gain were measured as a function of the grid parameters and compared with model calculations.

Also in 2004 the group proposed a modification of the Medipix2 chip, called TimePix, in which the clock signal (50-150 MHz) would be distributed to every pixel on the matrix. The 14-bit counter already present in every pixel, instead of counting hits in the 'imaging' operation mode, would count clock pulses from the moment a pixel is 'hit' until a common stop signal defined by the end of the shutter time, thus providing a 3^{rd} coordinate measurement through the drift time measurement. Most of the existing functionality of the chip and its pixel geometry would be kept. This proposal was included in the EUDET project and receives EU funding from 1st January 2006 for 4 years. A full-reticle engineering run of 12 wafers was submitted in Summer 2006 and was very successful. The chip works according to specifications and the yield of good chips is quite satisfactory (about 70%). First results with the TimePix chip as active anode have been obtained in a small test chamber with

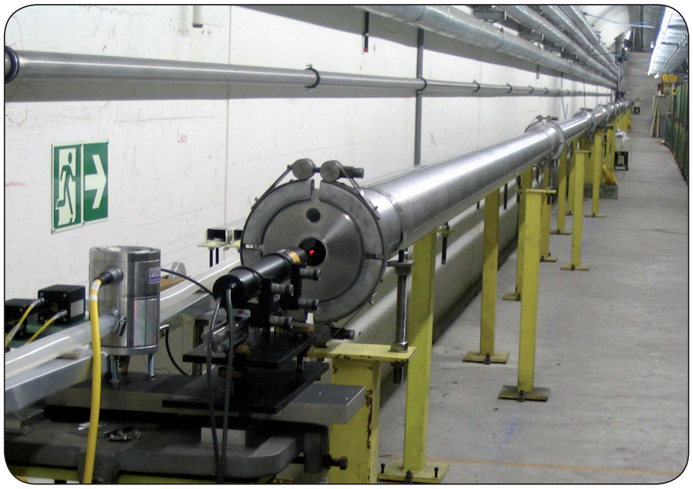


Fig. 3. The RasClic set-up at CERN.

15 mm of drift space.

One problem remains: the electric field strength just above the chip is very high (about 80 kV/cm) and there is a finite probability of a discharge (or very large signal charge) that can damage one or more pixels or even the whole chip. Several attempts were made protecting the top surface of the chip with a 4 μm thick, highly-resistive amorphous silicon layer. The first tested TimePix chip was protected this way and had a live-time under high-voltage of 40 days, much longer than previously used unprotected (Medipix2) chips. A second possibility of fabricating a double integrated grid (with the high field region in between them) is being investigated.

For a future upgrade of the ATLAS experiment, anticipating on the extreme radiation levels at the super-LHC, concept studies are being carried out in the application of thin gas layers with pixel readout as vertex detector elements. Pulse height measurements from a 1.2 mm thick detector confirmed that a good efficiency can be combined with a fast detector response. Deep sub-micron (130 nm CMOS technology) is being developed for this application. The preamp-shaper-discriminator channels have been optimised for the extreme small source capacity of the detector pixels; a power dissipation of 2 μW per pixel appeared possible. The design for a new 16×16 channel test chip is ready, in which each pixel is equipped with a 700 MHz clock, which is only active during a short (interpolation) period.

X-ray imaging
Nikhef is participating in an international collaboration to develop a high spatial, high contrast resolving CMOS pixel read-out chip working in single photon counting mode. During this Medipix2 project, that started in 2000, significant progress was made towards a new generation of quantum radiation imaging detectors: the semiconductor hybrid pixel detector. After two iterations, a commercial-grade version of the Medipix2 chip has now been achieved.

Based on the Medipix2 chip technology, the project RELAXD (high REsolution Large Area X-ray Detector) was started, aimed at producing large sensitive detector areas, without dead spaces, which can be read out at high speed. In order to construct such a large area detector, a number of separate assemblies should be tiled together. As a consequence, a 2-dimensional fan-out structure is needed that adapts the pixel pitch of the read-out chip to a slightly larger pixel pitch in the sensor, ensuring uniform pixel sizes over the whole detector. An important second feature is that the resultant touching sides of the quad sensor will be passivated by doping, to replace the conventional space-consuming guard-ring structure. The project involves the newest wafer-scale post-processing technologies including wafer thinning, through-wafer via etching, high-density interconnect and 3D packaging.

Software development for data acquisition and for testing of the tiled arrays, development of read-out electronics and quantitative testing on the system level is planned to be done in the Netherlands. A road map to commercialization has been introduced, with three phases that culminate in a possible product based on an array of micro-systems derived from the prototypes. After the first year of the RELAXD project, feasibility studies have given us a high confidence that first prototype modules will be produced and tested in the beginning of 2008.

RasClic
A test setup is installed at CERN. Because of the expected precision of order 1 μm the light beam should travel through vacuum to prevent distortions due to variations in air density. The diffraction pattern images are currently being processed at a speed of 12 Hz. This allows the instrument to be used as a seismometer. Earthquakes have already been seen in the data as well as the 'humming' of the earth.

Future Directions

The prime task is to demonstrate a viable solution to the discharge problem in Micromegas-like gas multiplication structures, to prevent damaging the CMOS readout chips. In parallel, several technological developments will continue to produce larger scale systems of multiplication grids integrated with CMOS readout chips: on the one hand based on TimePix chips for TPC like applications (EUDET/

ILC) and secondly, with newly developed CMOS chips in 130 nm (and later 90 nm) technology for detector upgrades at the super-LHC.

The current developments within the RELAXD project are indispensable, not only for achieving large, edgeless X-ray imaging detectors, but also to apply them in large scale system integration for future tracking detectors at ILC and super-LHC.

The development of long-distance alignment systems for CLIC (RasClic) can lead to hitherto unexpected applications in seismographic systems with unprecedented precision.

Nikhef Contributions

- Nikhef contributed to the Medipix chip design, the design and fabrication of carrying pcb's for single, four and eight chips and the design, fabrication and control of the interface box between the chip and the readout computer;
- Nikhef played and plays a pioneering role in the detection of minimum ionising particles using (integrated) MPGD's and CMOS pixel readout chips;
- RASNIK alignment systems have been invented and developed at Nikhef and were/are applied in large quantities in e.g. the L3 experiment at LEP and Atlas at LHC. The current development for alignment systems over large distances of about 100 m is also led by Nikhef.

J. Visschers is deputy spokesperson of Medipix2, J. Timmermans is tracking coordinator of EUDET and deputy European convenor of the LC-TPC collaboration.

Knowledge Transfer

For the RELAXD project a consortium of four partners in two countries was established, one research institution and one industrial partner in each country. Belgium contributes via the research center for micro- and nanoelectronics IMEC, Leuven, and the detector manufacturing company Canberra, Olen. The Netherlands contribute via Nikhef and via PANalytical, formerly Philips Analytical. The EUREKA RELAXD project is funded by the Dutch and Flemish ministries of economic affairs represented by the organizations SenterNovem and IWT, respectively, as well as by the European Union (project E!3624-RELAXD).

National Collaborations

A close collaboration exists with the MESA+ Institute of the University of Twente, groups of prof. dr. J. Schmitz and prof. dr. B. Nauta.

International Collaborations

The group is intensively collaborating within the EU funded EUDET project (groups from Universities of Bonn and Freiburg (D), CEA Saclay (F) and CERN), within the Medipix2 and Medipix3 collaborations. The Medipix2 Collaboration consists of 17 leading research groups across Europe, centered at CERN, Geneva.

Industrial collaborations

The RELAXD project funded by Senter Novem (Ministry of Economic Affairs) is a collaboration between NIKHEF and IMEC Leuven (B) as knowledge institutes and industrial companies: PANalytical Almelo (NL) and Canberra Olen (B).

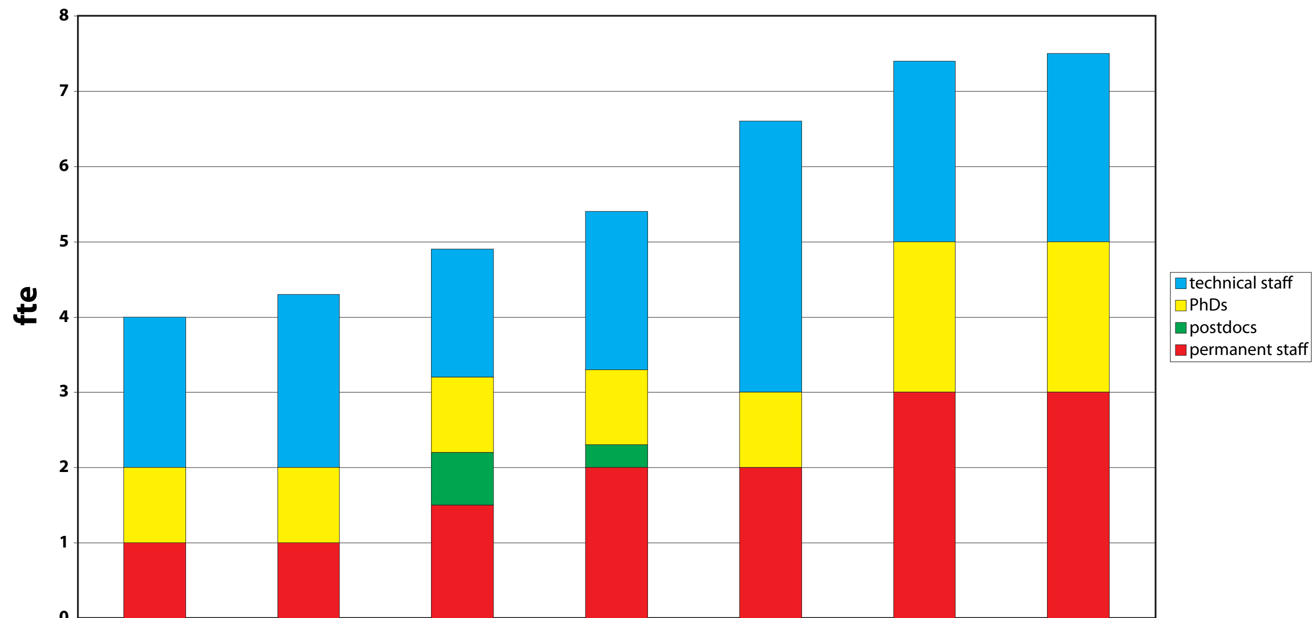
Awards

3rd prize Science Park Competition 2006 "*Nieuwe Ideeen*": RasIce: a monitor system for sag of roof constructions
1st prize FOM60 Competition 2006 "*Win the Future*": RasClic: a new seismograph

Key Publications

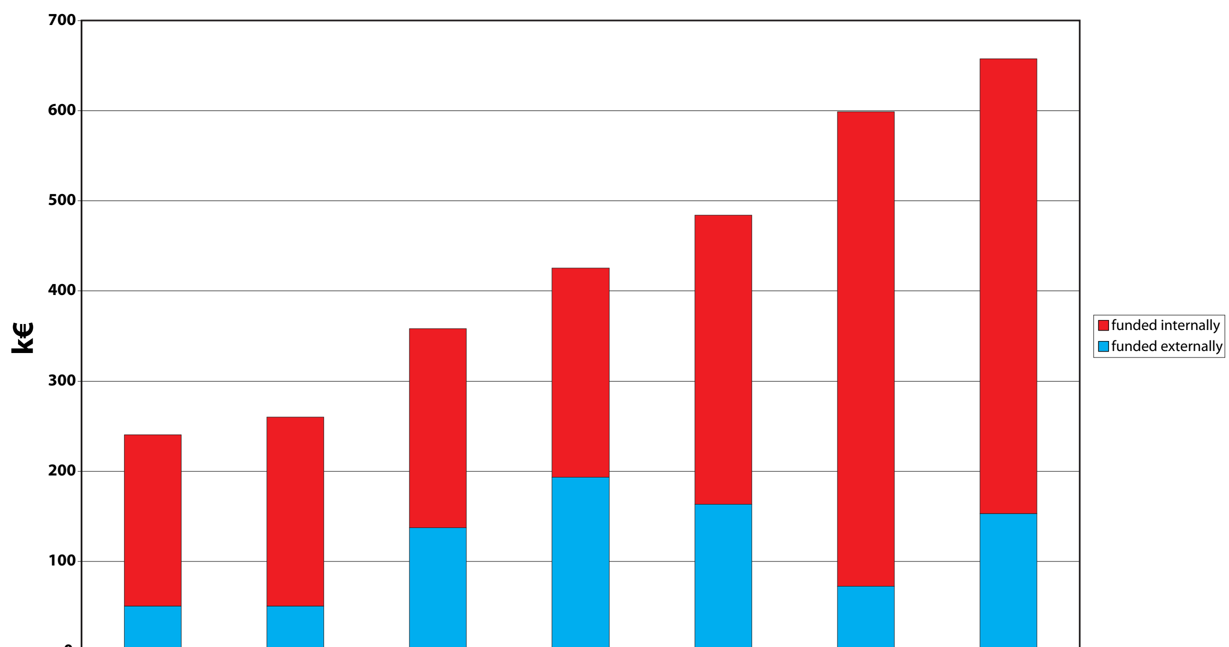
- P. Colas *et al.*
  The readout of a GEM- or Micromegas-equipped TPC by means of the Medipix2 CMOS sensor as direct anode
  Nucl. Instrum. Meth. **A535** (2004) 506.
- M. Campbell *et al.*
  The Detection of single electrons by means of a Micromegas-covered MediPix2 pixel CMOS readout circuit
  Nucl. Instrum. Meth. **A540** (2005) 295.
- M. Chefdeville *et al.*
  An electron-multiplying 'Micromegas' grid made in silicon wafer post-processing technology
  Nucl. Instrum. Meth. **A556** (2006) 490.
- J.R. Schrader *et al.*
  Pulse-width modulation pre-emphasis applied in a wireline transmitter, achieving 33 dB loss compensation at 5 Gb/s in 0.13 μm CMOS
  IEEE J. Solid State Circuits **41** (2006) 990.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff	2.0	2.3	1.7	2.1	3.6	2.4	2.5
PhDs	1.0	1.0	1.0	1.0	1.0	2.0	2.0
postdocs			0.7	0.3			
permanent staff	1.0	1.0	1.5	2.0	2.0	3.0	3.0

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
funded internally	190	210	221	232	321	527	504
funded externally	50	50	137	193	163	72	153

2.7 Physics Data Processing: Grid Computing

Nikhef Research Highlights
- Successful completion of the European DataGrid project.
- Won grant of 29 M€ for BIG GRID infrastructure proposal.
- Established funding for the local LHC Tier-1.
- First release of Virtual Laboratory middleware.

Programme Organization
In the period 2000–2003, this activity was led by dr. K. Bos, from 2004 onwards by dr. J. Templon.

This programme is not associated with a specific FOM programme, so there are no official starting or ending dates. National funding of this effort started in 2000, with significant EU funding arriving in 2001. Funding from the Dutch national BIG GRID project is guaranteed until 2010.

Research Goal
The primary goal of the Physics Data Processing project is to meet the LHC data processing needs via the use of distributed and grid computing techniques. We pursue this goal by constructing an LHC Computing Grid (LCG) Tier–1 site in Amsterdam, via software development and engineering, and via creation of a generic e–Science infrastructure in the Netherlands, serving a broad range of scientific communities.

Research Overview
Grid computing involves realizing a global, well–connected infrastructure of tens of thousands of computers, and tens of petabytes of mass storage. A software layer is needed in order to coordinate the activities of these computers, according to the users' desires, as well as to coordinate the activities of the users, who are sharing the facility. Grid computing also has implications for the construction of user software; these implications range from trivial to far–reaching, depending on the amount and type of data processing the programme is doing. Finally there is engineering research needed in understanding how to efficiently operate the large amount of computer hardware involved at some of the larger sites. Nikhef participates in most of these research areas.

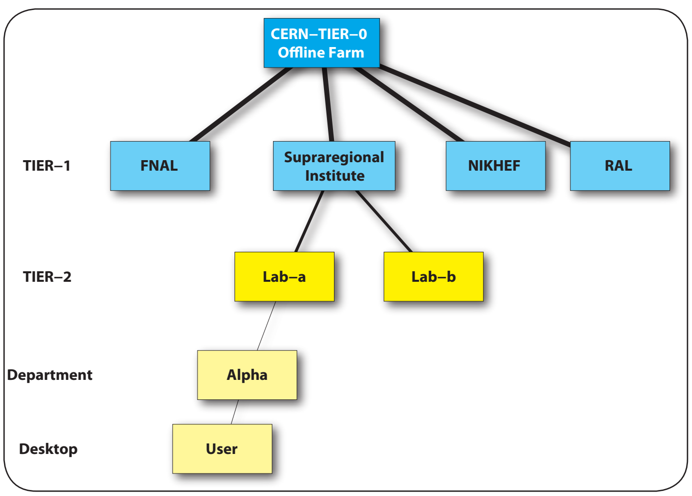


Fig 1. Hierarchy of Grid Centers for LHC computing.

Research Method
For our software–engineering and grid–usage research lines, our primary research method is the classic engineering cycle : define, design, develop, and test. We operate a mid–sized grid facility at Nikhef, large enough so that the 'test' phase of this cycle will locally encounter most of the scaling problems associated with grid computing at production scale. The presence of this facility also provides a testbed for our operational activities (aimed at large–scale facility operations).

Research Activities
Selected to host the first Global Grid Forum (today: Open Grid Forum) in Amsterdam, Nikhef established itself as the grid expertise centre in the Netherlands, and one of the primary knowledge hubs in the European arena. Nikhef was one of the five core partners in the European Data Grid project, which ended in early 2004. This project successfully demonstrated the ability of running a grid serving multiple user communities, spanning a continent and tens of computer centers, containing hundreds of processors. Nikhef made important contributions in facility operations (resulting in the 'Quattor' tool now used at many grid sites) and fundamental contributions in the area of authentication and authorization, resulting in the LCAS/LCMAPS framework, which is now standard at all sites in the LHC computing grid.

The LCG, which is the successor to the EU DataGrid infrastructure, today exceeds 200 sites, 20,000 processors, and mediates access to many petabytes of storage, making it the largest operational grid in the world. Nikhef, together with the national high–performance computing and networking centre SARA, which is located close by, gives a sizeable contribution to LCG, and will at the start of LHC data taking provide the largest Tier–1 capacity for ATLAS in Europe

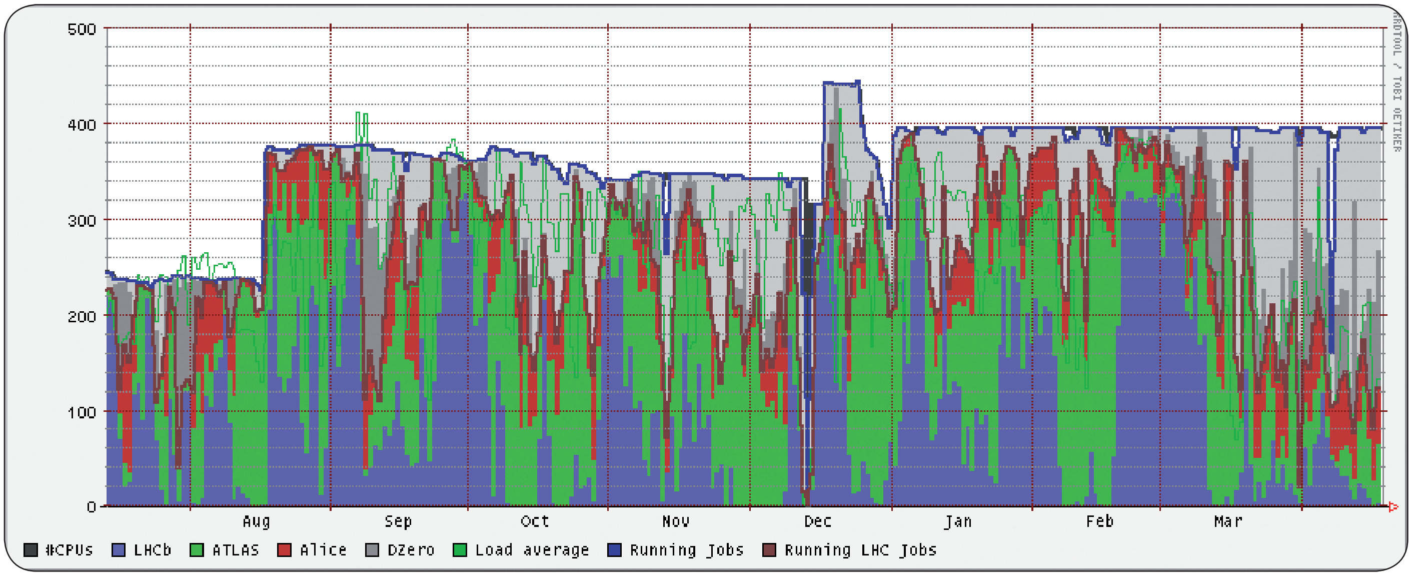


Fig.2. Number of running Grid jobs at any time for the period July 2006–April 2007.

– 13% of all ATLAS Tier–1 resources worldwide – whilst also catering for LHCb (25% of all Tier–1 capacity) as well as ALICE. While computing capacity is roughly shared between Nikhef and SARA, SARA will handle the bulk of the storage for the Dutch Tier–1, in view of their longstanding expertise in this area. In 2006, the first tests simulating the raw data chain from detectors at CERN to tapes at the Tier–1 centers was tested; with 154 MB/s average rate, SARA exceeded the target of 120 MB/s.

Prioritization of computing work amongst researchers in the same experiment is becoming increasingly important as the LHC turn–on approaches. Nikhef has played a leading role in the European effort to realize a working system for grid–wide computational priority management. As of this writing, all the necessary components of the system (including the critical task start–time estimation program, produced in our group at Nikhef) have been delivered, allowing large–scale grid–wide tests to start in early 2007.

Nikhef also plays a leading role in the Dutch national e–Science project 'VL–e' (Virtual Laboratory for e–Science). Software engineers at Nikhef produced the first 'Proof–of–Concept' release of the VL–e software stack in 2005, and users from Dutch hospitals are sharing the Nikhef computer facilities with the high–energy physicists. Furthermore our colleagues in the social sciences have recently begun archiving e.g. scanned images from the pages of ancient bibles on our grid storage systems.

Future Directions

Nikhef is one of the three partners in the Dutch National BIG GRID project, a 29 M€ infrastructure effort that includes funding for the Dutch Tier–1. This project runs until 2010, which roughly coincides with the end of the EU 'EGEE' project and Dutch National VL–e project, both of which our group participates in. The first 'big' year for the LHC experiments will be 2008. All these factors lead us to expect that until 2009, our current lines of research will remain relevant and viable.

After 2008, we expect that the operations part will become increasingly less research–oriented; however the need for research into effective large–scale usage of grid computing is likely to become much more important, and we expect to play a large role here, both for LHC computing as well as for a broader scientific community in the Netherlands. Our research in authentication and authorization is internationally recognized; Nikhef is a world leader in this area and we intend to continue this track as well. Finally, our main focus will remain unchanged: to achieve a working grid computing infrastructure with satisfied users. Our experience is that this focus rather effortlessly generates relevant research topics.

Nikhef Contributions

Apart from the mentioned activities, J. Templon is the representative from High Energy Physics in the European DataGrid Architecture Task Force. D. Groep is chairing the International Grid Trust Federation and is Area director for Grid Security of

Fig. 3. Artist's impression of the Grid.

the Open Grid Foundation. Coordinator of the ATLAS Computing Operations is K. Bos, who is also chairing the LHC Computing Grid Deployment Board.

Knowledge Transfer

Gridforum NL, national Grid tutorials (together with SARA), leadership of 'Data Intensive Sciences' and 'Scaling and Validation' programs in the Dutch National Virtual Laboratory (VL–e) project.

National Collaborations

The group collaborates intensively with SARA, Philips, ASTRON, Academisch Medisch Centrum Amsterdam and DANS (Data Archiving and Networked Services).

Fig. 4. Grid Admin Nerd Group (GANG) event at Nikhef. People from industry work together with scientist of Nikhef, UVA and SARA to construct a grid in a single day using 25 laptops.

International Collaborations

This includes: Enabling Grids for E–science in Europe (EGEE), LHC Computing Grid, International Grid Trust Federation (chaired by Nikhef staff), e–Infrastructures Research Group (eIRG), Open Science Grid (US) and the Globus Project.

Industrial collaborations

The group has Philips as a partner in Big Grid.

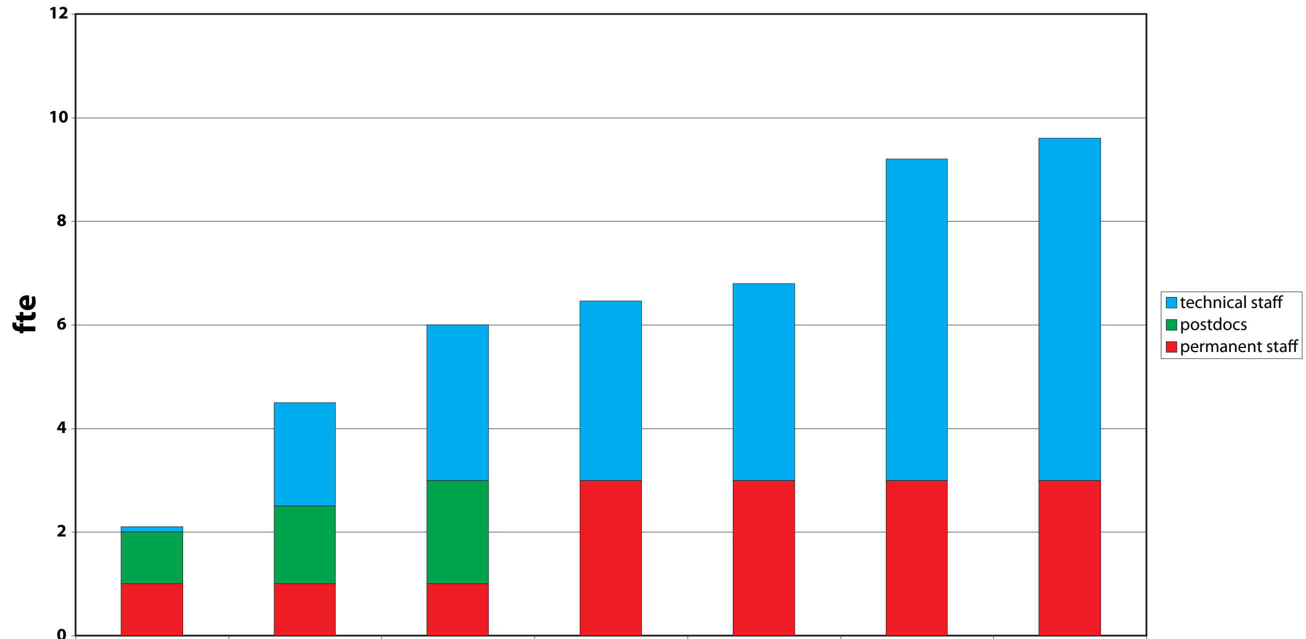
Awards

S. Klous has won a NWO–VENI grant in 2006.

Key Publications

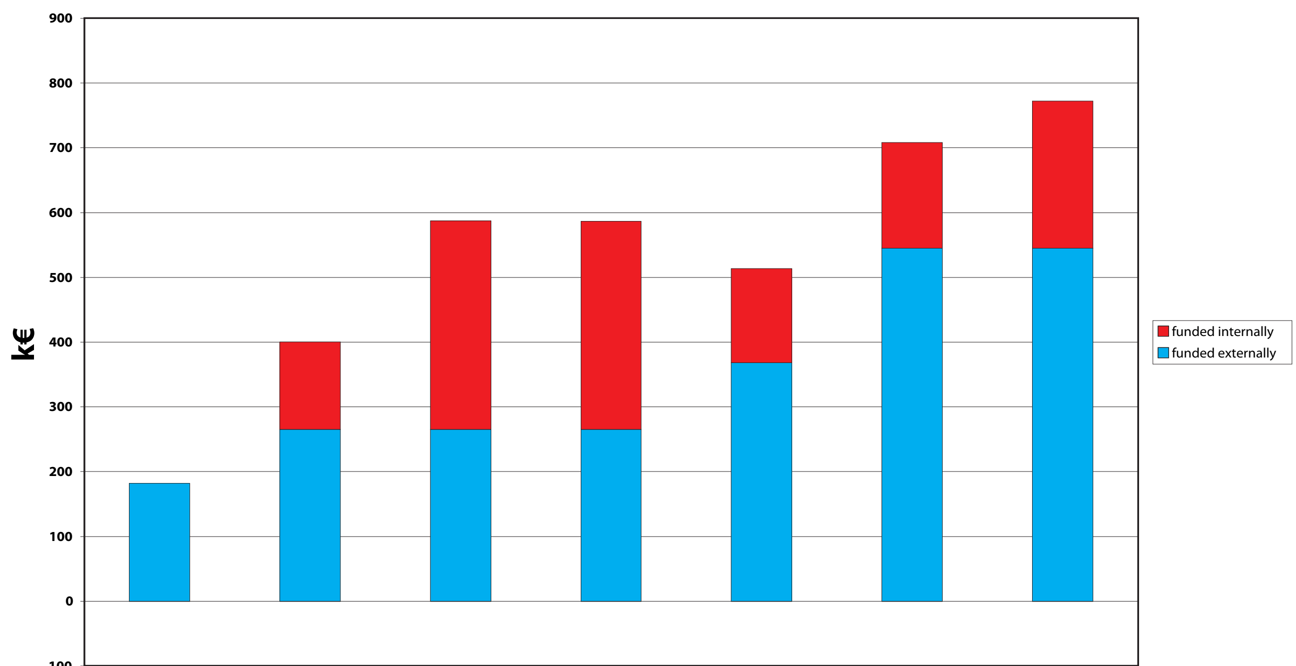
- D. L. Groep, J. Templon, C. Loomis
  Crunching real data on the Grid: practice and experience with the European DataGrid
  Concurrency and Computation: Practice and Experience **18**(9) (2006) 925.
- S. Burke *et al.* (K. Bos, D. L. Groep, W. van Leeuwen, J. Templon)
  HEP Applications and Their Experience with the Use of DataGrid Middleware
  Journal of Grid Computing **2**(4) (2004) 369.
- Th. Roeblitz *et al.*
  Autonomic Management of Large Clusters and Their Integration into the Grid
  Journal of Grid Computing **2**(3) (2004) 247.
- R. Alfieri *et al.*
  Authentication and Authorization Mechanisms for Multi–domain Grid Environments
  Journal of Grid Computing **2**(4) (2004) 301.
- D. O'Callaghan *et al.* (D. L. Groep)
  International Grid CA Interworking, Peer Review and Policy Management through the European DataGrid Certification Authority Coordination Group
  Lecture Notes in Computer Science **3470** (2005) 285.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff	0.1	2.0	3.0	3.5	3.8	6.2	6.6
postdocs	1.0	1.5	2.0				
permanent staff	1.0	1.0	1.0	3.0	3.0	3.0	3.0

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
funded internally	0	135	322	322	146	164	227
funded externally	182	265	265	265	368	545	545

Fig.4. The Grid ‘freecard’.

3 Exploratory Programmes

3.1 New Astroparticle Physics Initiatives: Cosmic Rays and Gravitational Waves

Programme Organization

The Nikhef Astroparticle Physics research programme is led by prof. dr. G. van der Steenhoven. The Auger project leader is dr. Ch.W.J.P. Timmermans, while the Virgo team is led by prof. dr. ing. J.F.J. van den Brand.

In 2005–2006 the research efforts in astroparticle physics were expanded when Nikhef physicists joined the Pierre Auger collaboration and expressed the intention of joining the Virgo collaboration. While the Pierre Auger Observatory aims to measure the cosmic ray spectrum out to the highest possible energies, the Virgo laser interferometer has been built to search for direct evidence of gravitational waves.

The Pierre Auger Observatory

The Pierre Auger observatory has been set up to measure the origin and composition of the highest energy particles ever observed: cosmic rays with energies above 10^{18} eV. For this purpose an array of 1600 water tanks is being built covering an area of 3000 km^2 in western Argentina. In the water tanks the Cherenkov light emitted by muons produced when a cosmic ray hits the outer layers of the atmosphere is observed. In addition, huge light sensitive detectors measure the fluorescence produced by air showers.

Fig. 2. A water tank of the Pierre Auger Observatory with – in the background – the mountain tops of the Andes in Argentina.

The Dutch team in the Auger collaboration consists, apart from Nikhef, of groups from KVI, ASTRON and the Radboud University. In 2006 the team has produced a set of about 100 micro–electronics boards for the readout of the water tanks. Moreover, an R&D project has been initiated aimed at radio detection of air showers

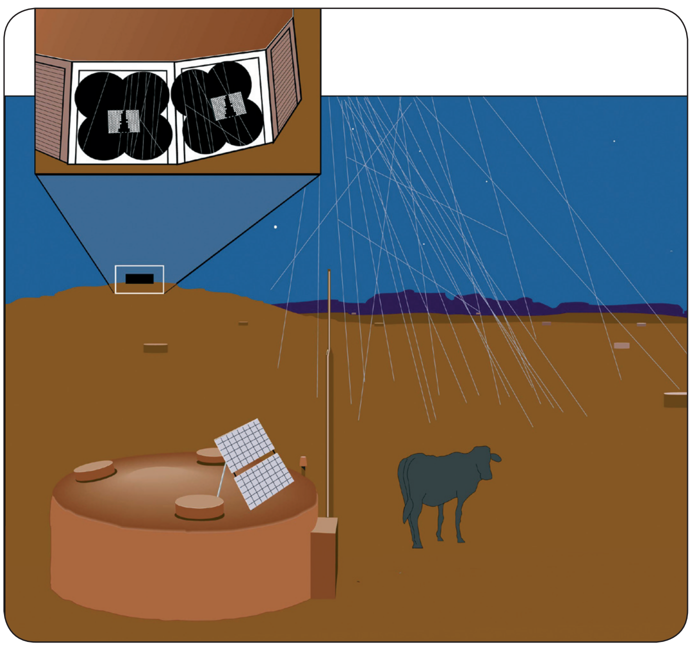


Fig.1. Principle of operation of the Pierre Auger experiment, using fluorescence detectors, to detect ultraviolet light emitted by air showers, and surface detectors, to record particles as they traverse water–filled tanks.

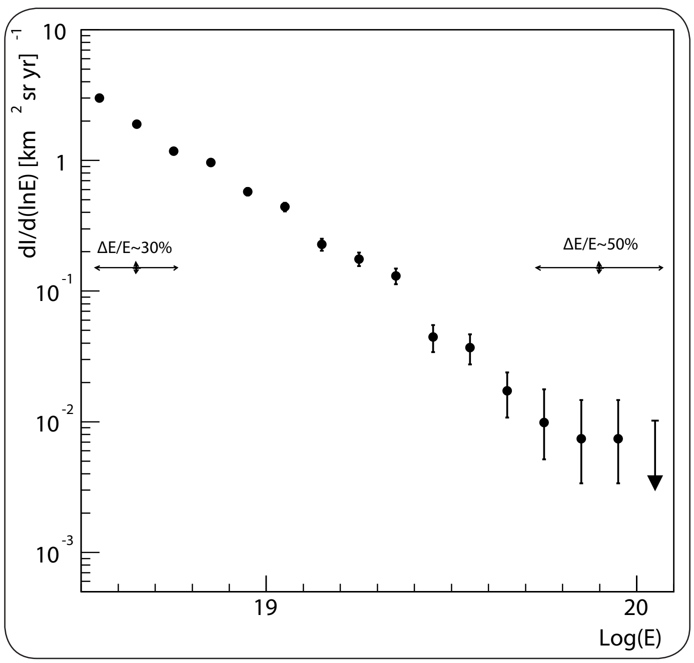


Fig. 3. Intensity of ultra–high energetic cosmic rays as function of energy, as measured at the Pierre Auger Observatory.

Fig. 5. *The Virgo interferometer near Pisa, Italy. Both arms of the interferometer, each with a length of 3 km, can be seen.*

induced by extremely high–energy cosmicrays. For this purpose a new antenna design (led by ASTRON), a low–power wireless data transmission system (KVI) and a high–speed low–power data acquisition unit (Nikhef) needs to be developed. Near the end of 2006 a prototype radio antenna and readout system were shipped to Argentina for first tests.

First data on the energy spectrum of very high energy cosmic rays have already been published by the Auger collaboration, although the full detector array will only be completed near the end of 2007.

The Virgo interferometer

General Relativity (GR) is one of the fundamental theories of physics. One of the key features of GR is the dynamical nature of space–time itself: its curvature is time dependent, and ripples of curvature can propagate through space–time with the speed of light. Such propagating curvature–ripples are called gravitational waves (GWs), and their existence is one of the most important, yet untested, predictions of GR. In our universe, GWs are produced by unique astronomical events, such as mergers of black holes or neutron stars, and super–novae explosions. The observation of GWs is entirely independent of any observation in the electromagnetic spectrum, and is therefore likely to lead to unique information on

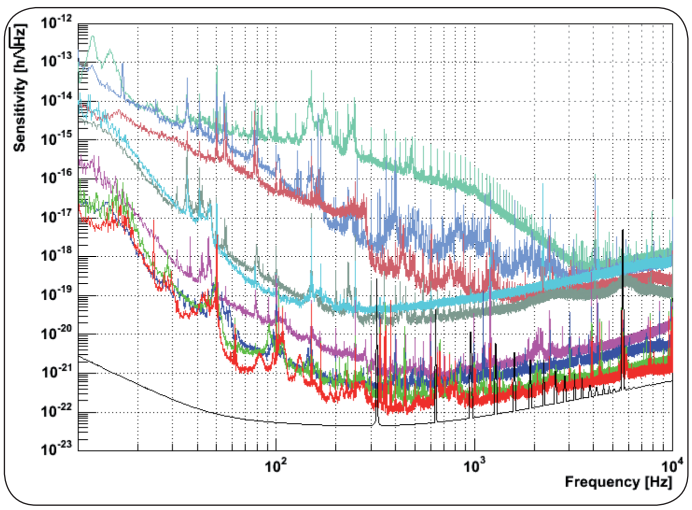


Fig. 6. *Progress in frequency sensitivity of the Virgo interferometer from the start of commissioning runs in Nov. 2003 (upper green curve) to data taking runs in Jan. 2007 (lowest red curve). The solid black curve represents the design sensitivity.*

such compact objects. Moreover, as GWs propagate almost unperturbed through the universe, it is in principle possible to detect GW–signals emitted during or shortly after the Big Bang.
As the spectrum and amplitude of GWs sensitively depend on the details of Big Bang models, i.e. inflationary fields causing a rapid expansion of the universe, such data will enable direct tests of such models. The detection of GWs would thus not only provide a crucial test of general relativity, but would also open a new window for astronomical observations.

However, GW–signals are expected to be extremely weak (causing relative displacement of free masses by distances that are a tiny fraction of the size of an atomic nucleus), and thus enormous technological challenges have to be overcome in order to detect them.

Nikhef has expressed interest to join the Virgo collaboration, which has developed a Michelson type interferometer with a base length of 3 km. Virgo has been built by a French–Italian collaboration at Cascina close to Pisa. In the Virgo interferometer a laser pulse is split and travels a number of times up and down each arm after which it creates an interference pattern with the other pulse. A change in the path length due to a passing gravitational wave will result in a change of the interference pattern. The Nikhef team intends to contribute to the alignment and thermal stabilization of the interferometer. In addition, Nikhef will participate in the data analysis.

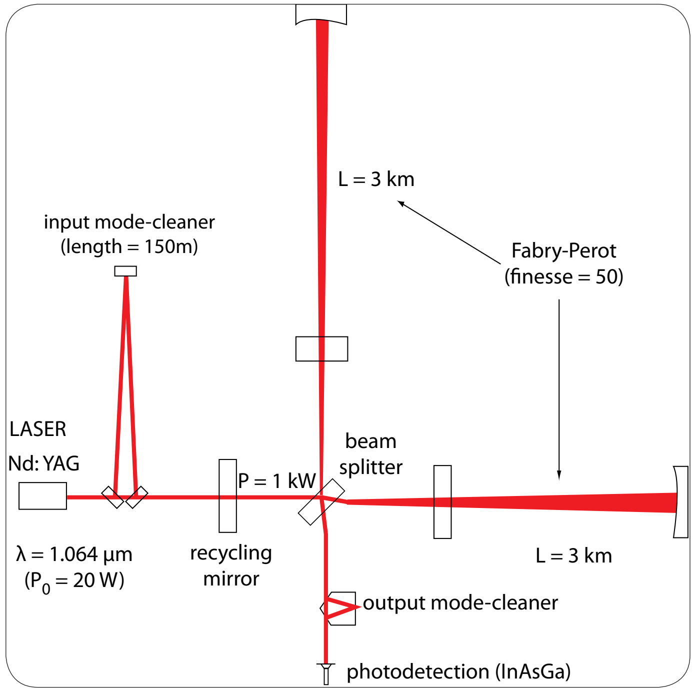


Fig. 7. Schematic outline of the Virgo interferometer showing its main optical components.

4 Completed Experiments

4.1 Nucleon Dynamics: AmPS

Programme Organization

The programme consisted of two subprogrammes: ITF, led by dr. C.W. de Jager and subsequently by prof. dr. ing. J.F.J. van den Brand, and EMIN, led by dr. L. Lápikas. This programme started in 1987 with the formal approval for the construction of the Amsterdam Pulse Stretcher (AmPS) accelerator. The programme came to an end in 2001.

Research Goal

The aim of the experiments with AmPS was twofold: to study the high–momentum and high–energy components of (inter)nucleon wave functions in nuclei via one–nucleon and two–nucleon knock-out reactions, and to study the spin degrees of freedom in nuclei, as well as the neutron electric form factor.

Research Overview

In the AmPS facility, the (polarized) electron beam from the Nikhef MEA accelerator was stored and extracted at energies up to 720 MeV. Experiments were carried out in the period 1992–1998, with an extracted beam in the experimental hall EMIN and with the stored beam in the Internal Target Facility (ITF) hall. The results of the experiments with AmPS have been extensively described in the previous NWO Evaluation Report 1994–2000, and subsequently in the Final Report for the Dutch Foundation FOM, "*Results of the AmPS program*", 2001.

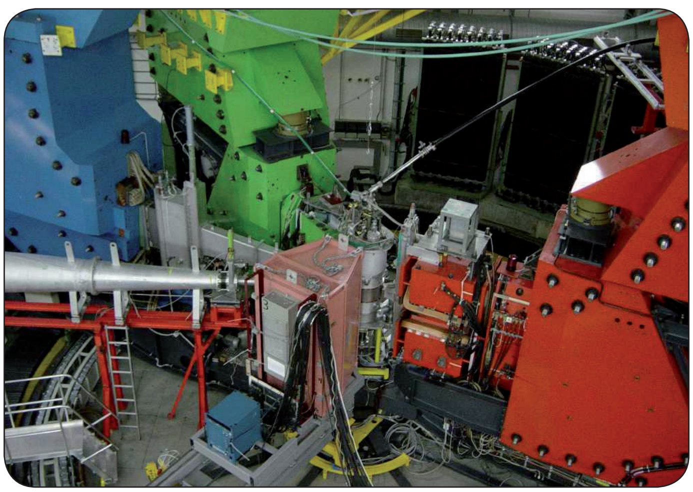


Fig. 1. Triple coincidence setup of the (e,e'pn) experiment in the A1 hall at MAMI, Mainz. The (blue) spectrometer at the left detects scattered electrons, the HADRON3 detector (center front) measures protons, while the (black) time-of-flight units measure the neutrons.

Nikhef Research Highlights

- Nucleon–nucleon correlations studied with electron-induced two-nucleon knockout.
- High-precision determination of the proton spectral function of nuclei.
- Measurement of the neutron charge form factor.
- Measurement of the spin structure of the deuteron.

Research Activities

The previous NWO evaluation report contained an output survey for the AmPS programme amounting to 69 publications and 29 theses. In the present evaluation period an additional number of 36 publications and 7 theses has completed the analysis of this work. With the closure of AmPS in 1998 several high–tech pieces of instrumentation became available for use in experiments elsewhere. The Atomic Beam Source, which had served in the Nikhef Internal Target Facility, was shipped to the MIT/Bates accelerator (USA), where it was employed in the BLAST programme as polarized target for spin–dependent electron scattering experiments. The large-acceptance magnetic spectrometer BigBite was sent to Jefferson Lab in Newport News (USA), where it is currently still being used in electron-scattering experiments in Hall A. The HADRON3 detector, which observed protons in knockout reactions in the EMIN hall, was transported to the MAMI accelerator facility in Mainz (Germany). Here, Nikhef physicists initiated and led an experiment that studied the electron–induced knockout of a proton–neutron pair from ^{3}He. In this triple coincidence experiment ^{3}He(*e,e'pn*) the scattered electrons were detected in a magnetic spectrometer of the Mainz A1 hall, the protons by the large–acceptance HADRON3 detector provided by Nikhef, and the neutrons by a 16.5 m^2 time–of–flight wall built by a Tübingen/Glasgow collaboration (see Fig. 1). Of special interest is the comparison between these data and similar ones that were obtained with AmPS via the reaction ^{3}He(*e,e'pp*). As Fig. 2 shows, there is a remarkable difference in the momentum dependence of these two sets of data. One of the causes of this difference is the fact that both reactions have a different sensitivity to nucleon–nucleon correlations in the initial–state wave function, i.e. *pp* versus *pn*, which is related to the isospin dependence of the nucleon–nucleon force at short internucleon distances.

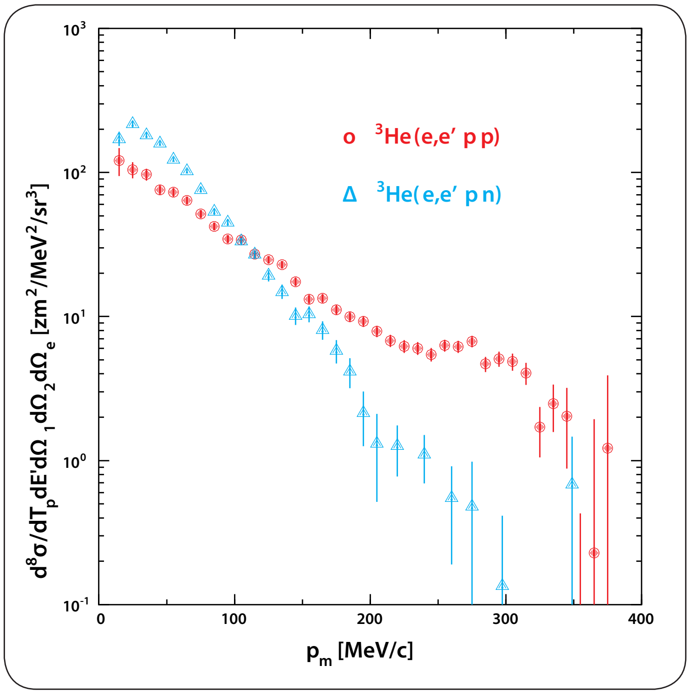


Fig. 2. Triple coincidence cross sections for the reaction ^{3}He(e,e'pn) (red), kinematically scaled to previously measured data for the reaction ^{3}He(e,e'pp) (blue).

Future Directions

In the nineties of the past century FOM made the decision to no longer support this field of physics. Consequently, at Nikhef, no further research in this direction is being considered.

National Collaborations

In the AmPS experiments, Nikhef physicists from the FOM institute SAF/Nikhef, Free University Amsterdam (VUA) and Utrecht University cooperated with physicists from Delft Technical University, and KVI (Groningen).

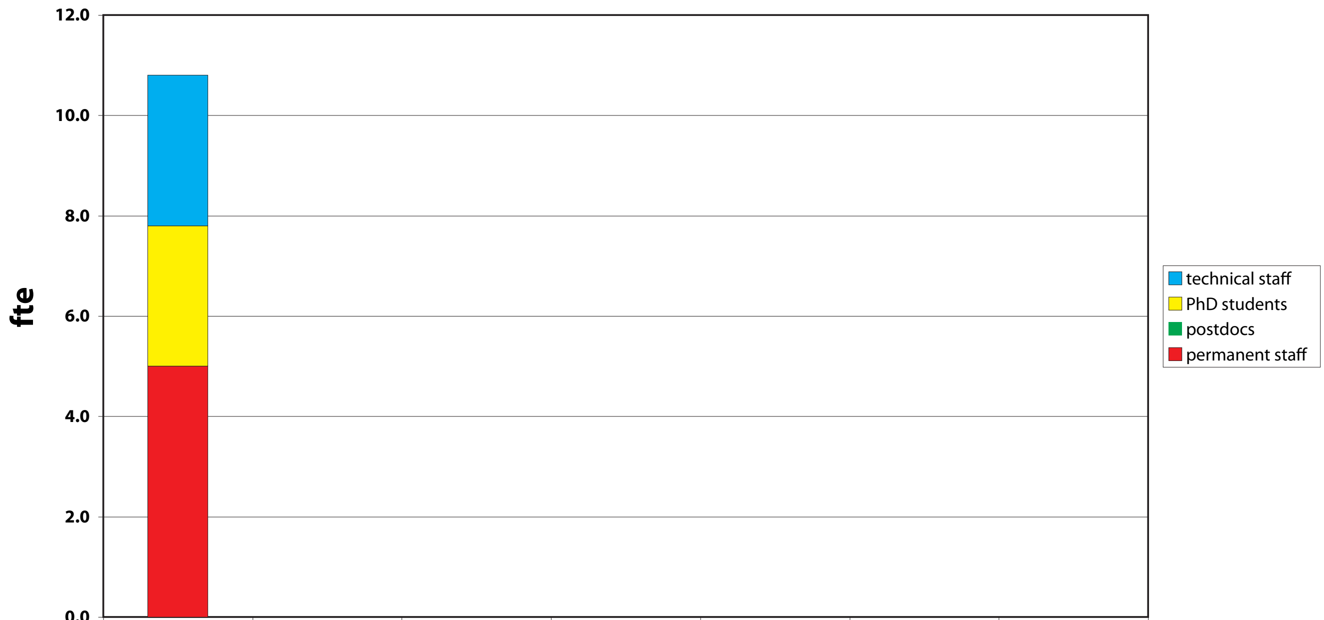
International Collaborations

In the experiments carried out with AmPS 39 groups from 14 different countries participated. The experiment at Mainz was a joint effort between the Universities of Mainz and Tübingen (Germany), Glasgow (UK) and Nikhef, with theoretical support from the Jagellonian University, Cracow (Poland) and the Ruhr Universität, Bochum (Germany). Its spokesman was E. Jans (Nikhef).

Key Publications

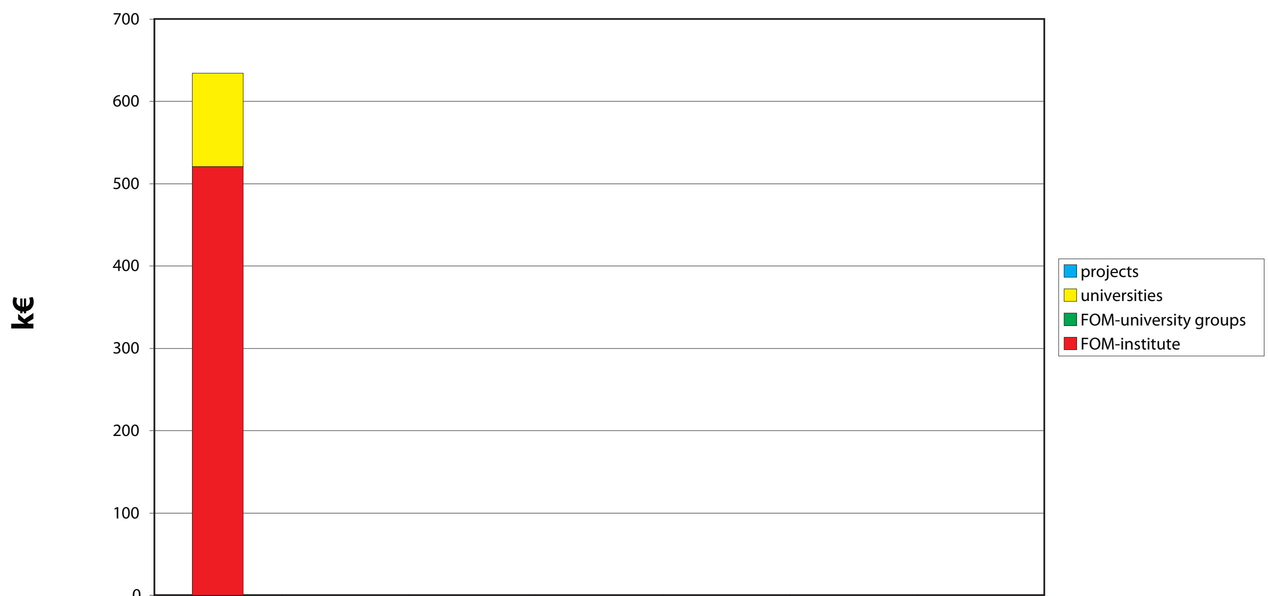
- I. Bobeldijk *et al.*
  High–momentum protons in ^{208}Pb
  Phys. Rev. Lett. **73** (1994) 2684.
- C.J.G. Onderwater *et al.*
  Dominance of $^1S_0$ proton pair emission in the ^{16}O(e,e'pp) reaction
  Phys. Rev. Lett. **78** (1997) 4893.
- L. Lapikás *et al.*
  Transparency of ^{12}C for protons
  Phys. Rev. **C61** (2000) 064325.
- I. Passchier *et al.*
  The charge form factor of the neutron from the reaction $^2\vec{H}(\vec{e},e'n)p$
  Phys. Rev. Lett. **82** (1999) 4988.
- M. Ferro–Luzzi *et al.*
  Measurement of tensor analyzing powers for elastic electron scattering from a polarized ^{2}H target internal to a storage ring
  Phys. Rev. Lett. **77** (1996) 2630.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff	3.0						
PhD students	2.8						
postdocs	0.0						
permanent staff	5.0						

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
projects	0						
universities	113						
FOM-university groups	0						
FOM-institute	521						

4.2 Precision Electroweak Physics: LEP

Programme Organization

The LEP programme consisted of two experiments: DELPHI led subsequently by dr. J. Timmermans and dr. P. M. Kluit and L3 led by dr. G. J. Bobbink and dr. W. J. Metzger. The FOM LEP programme ended in 2004; a final report was submitted.

Research Goal

The main goal of the LEP programme is to perform precision measurements and tests of the electroweak theory, search for the Higgs–boson and look for new physics. LEP was expected to answer questions like: what is the number of neutrino families? What are the masses of the Z and W–bosons? What are the basic couplings of the fermions (quarks and leptons) to the gauge bosons? Do the gauge–bosons couple to each other as predicted by the electroweak theory? What is the value of the strong coupling constant and does it run as a function of energy as predicted by Quantum Chromo Dynamics (QCD)? And last but not least: are there new (such as the Higgs or e.g. supersymmetric) particles?

Research Overview

Nikhef participated in the DELPHI and L3 experiments. In the first stage of the experiments, the electron–positron collider LEP was run at a centre–of–mass energy around the Z–mass (91 GeV), in the second stage at energies above the W^+W^- threshold (161–209 GeV). In the period 2000–2006 data were taken, analyzed and in total about 200 articles were published in journals by each experiment.

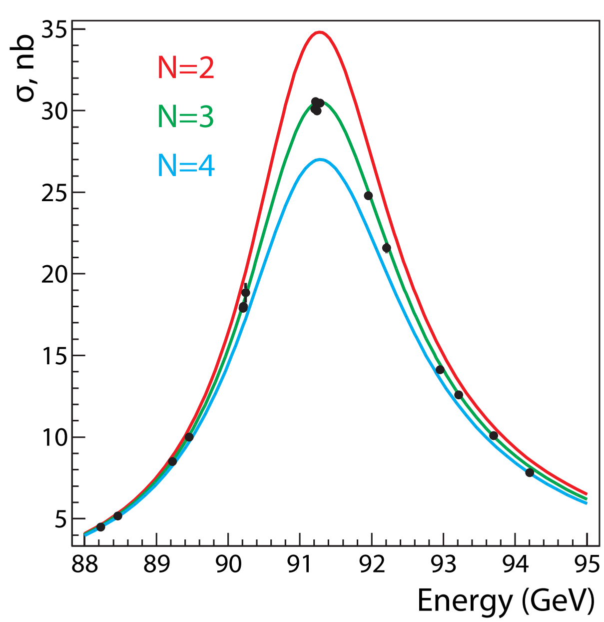


Fig. 1. The LEP Z line–shape measurements compared to the predictions for 2, 3 and 4 light neutrino species.

Nikhef Research Highlights

- Precise measurement of the properties of the weak gauge bosons W and Z, and the gauge structure of the electroweak theory.
- Data show that there are 3 light neutrino species.
- Through radiative corrections LEP is sensitive to heavy particles: correct prediction of top quark mass and prediction of Higgs–boson mass.
- Search for the Higgs–boson: no discovery and lower limit of 114.4 GeV at 95% CL. Also limits on many models of physics beyond the Standard Model.
- Results on Quantum Chromo Dynamics, bottom–quark and tau–lepton physics.

Research Activities

One of the main results of LEP is the determination of the number of light neutrino species by measuring the Z–line shape, i.e. the cross section as a function of the centre–of–mass energy. The final Z–line shape is shown in Fig. 1, and compared to the prediction for 2, 3 and 4 neutrino species. The number of neutrino species was determined to be 2.9841 ± 0.0083, compatible with three neutrino families.

One of the most accurately measured quantities at LEP is the mass of the Z–boson of 91187.5 ± 2.1 MeV. To achieve a precision of 23 ppm not only the tidal effect of the moon had to be taken into account, but also the water level in Lake Geneva, and the passing of TGV trains close to CERN.

The LEP experiments also measured to high accuracy the basic couplings of the Z–boson to leptons (electrons, muons, tau's) and quarks (up–type and down–type).

In the electroweak model the couplings for lepton species are identical. Lepton universality was tested at the 3 per mille level.

The electroweak model predicts the existence and magnitude of the interactions between the gauge–bosons. This can be tested by measuring the cross section for W–pair production as a function of the energy and the differential cross sections as function of the W–production and decay angles. In Fig. 2 the LEP W–pair cross–section measurements and the predictions from the electroweak model are shown.

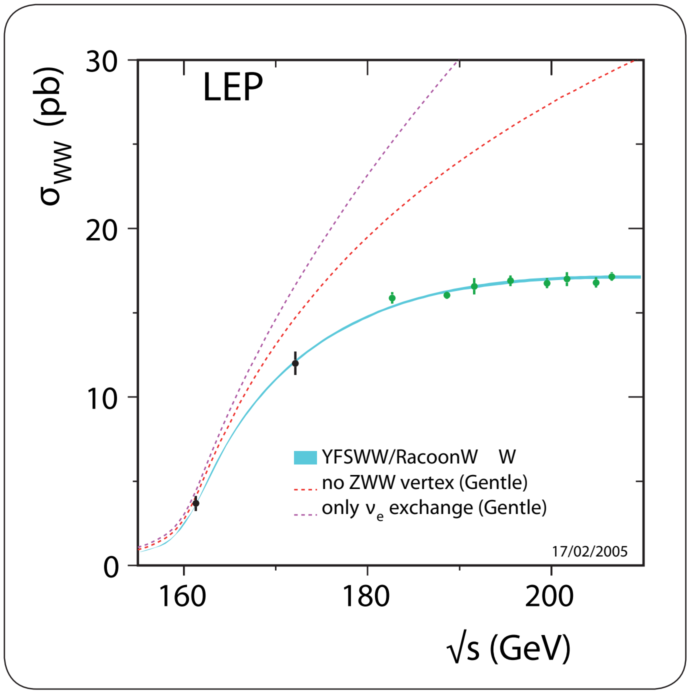


Fig. 2. The LEP W–pair cross–section (2005) compared to the electroweak model and without interactions between the gauge–bosons.

The absence of interactions between the gauge–bosons is clearly ruled out by the data. More information on the precise values of these gauge couplings is obtained from angular analyses. With the selected samples, the W–boson mass has been determined to be 80.376 ± 0.033 GeV; Nikhef has pioneered advanced techniques to minimize both the statistical and the systematic error.

Of particular interest is the indirect constraint on the mass of the Higgs–boson that can be derived from the LEP data. The coupling constants of the Z are e.g. sensitive through radiative corrections to the top–quark and Higgs–masses; the theory behind these calculations was honored by a Nobel Prize given to Martinus Veltman and Gerard 't Hooft in 1999.

Fig. 3 shows the Standard Model relation between the W–boson mass, the top–quark mass, and the Higgs mass, and the LEP1+SLD and LEP2+Tevatron measurements. The combined electroweak fit to all measurements tells us that the mass of the Higgs–boson is lower than about 150 GeV at 95% CL.

At LEP a large effort was put into the search for yet unobserved particles. In particular particles predicted by supersymmetric theories and the undiscovered Higgs particle.

No new particles were observed. The combined LEP lower limit on the Higgs mass is 114.4 GeV at 95% CL.

The theory of the strong interactions QCD was also put to severe tests and the group structure $SU(3)_c$ established. One striking prediction from QCD is the running of the strong coupling constant as a function of the energy. In Fig. 4 the LEP measurements for the strong coupling constant and the QCD prediction are shown. These measurements confirmed the theory behind asymptotic freedom, leading to a Nobel Prize for Gross, Politzer and Wilczek in 2004.

Finally it must be said that, due to the introduction of silicon microvertex detectors, LEP was able to perform precision measurements in unexpected areas such as B (bottom–quark) and τ–physics. These include measurements of B–mixing, lifetimes, excited states and rare decays, and τ–lifetime, branching fractions, and decay dynamics.

Future Directions

Further research in high energy e^+e^- physics will require the construction of a linear collider. The International Committee for Future Accelerators ICFA is coordinating this world wide effort;

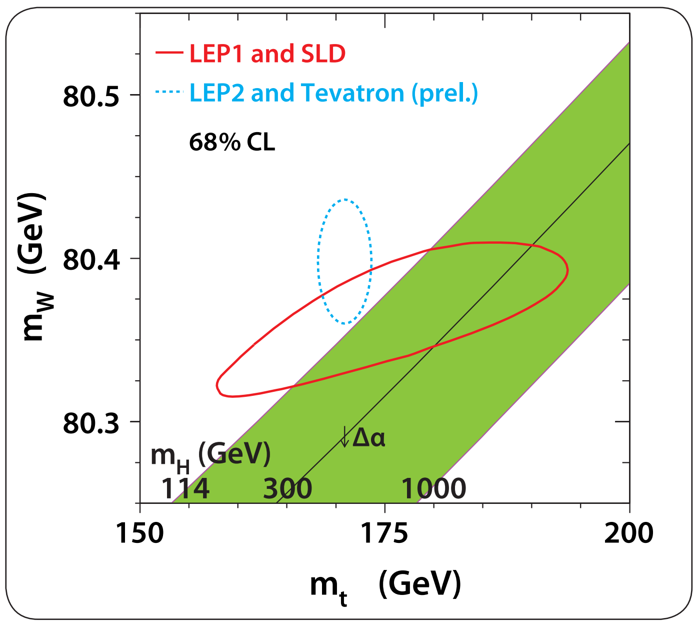


Fig. 3. The Standard Model relation between W–boson mass, top–quark mass, and Higgs–boson mass, and the results of the electroweak fit to LEP1 and SLD data and direct measurements from LEP2 and the Tevatron. A Higgs–boson lighter than 114 GeV is excluded by direct searches at LEP.

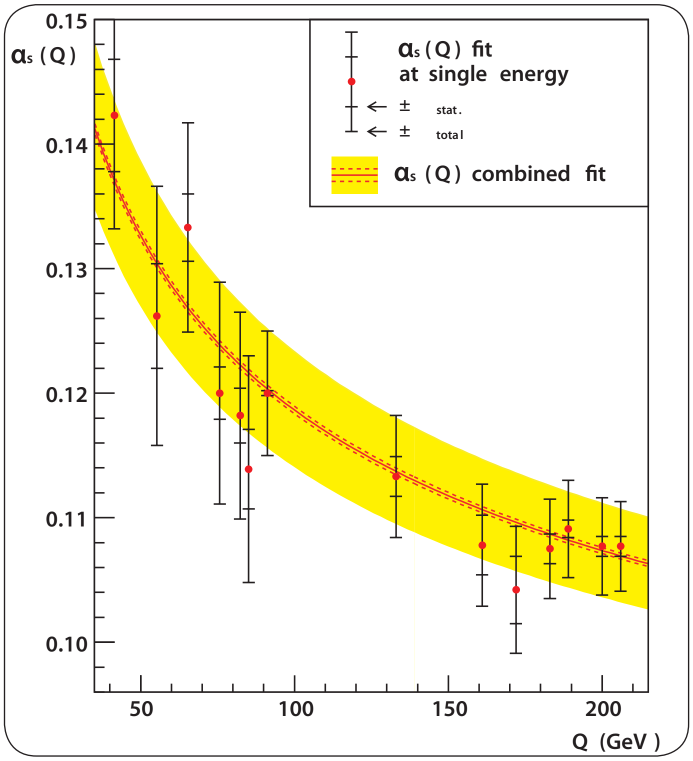


Fig. 4. The LEP measurements of the strong coupling constant α_s, and its variation with the scale Q.

in 2003, Nikhef organized the 4th ECFA/DESY workshop on physics and detector for a linear collider.

Nikhef Contributions

Nikhef played an important role in the construction and upgrade of the detectors and the running of the experiments. For DELPHI, Nikhef was an important partner in the Ring Imaging Cherenkov detector project, and built the Inner Detector; for L3 Nikhef built muon chambers including the RASNIK alignment system, the silicon luminosity monitor, and precision mechanics for the silicon microvertex detector. Physicists and PhD students played a key role in the analysis and publication of physics results, in this review period in particular in W boson physics and Higgs searches. The physics topics covered by PhD theses range from Z, W, B–physics, QCD studies to two-photon physics. In L3 P. de Jong was convenor of the W–physics group and was member of the LEP W–physics steering group. Convenor of the DELPHI B–oscilllations and lifetimes was P. Kluit, D. Reid was DELPHI τ–physics convenor and F. Filthaut was convenor of the L3 fermion pair-production physics group. Chairman of the L3 management board was G. Bobbink. J. Timmermans is DELPHI spokesperson since 2002.

International Collaborations

In the DELPHI and L3 collaborations about 100 institutes from 40 countries collaborate.

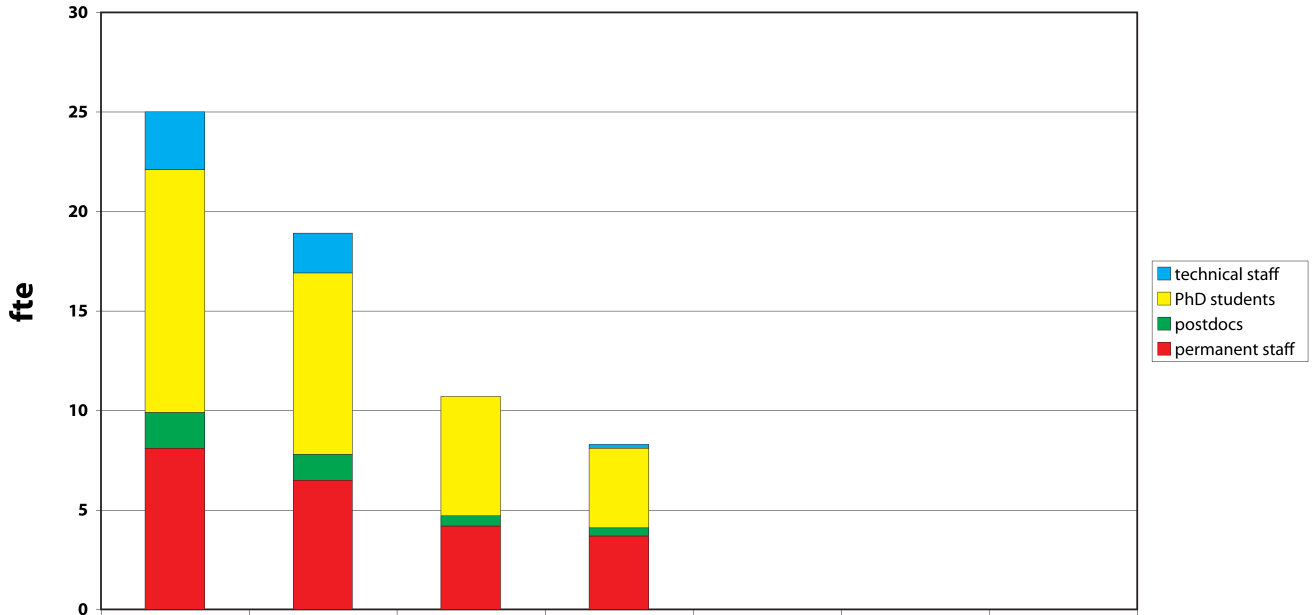
Awards

P. de Jong obtained in 1999–2003 a FOM ‘Springplank’ position. Several PhD students obtained prestigious CERN and Fermilab fellowships.

Key Publications

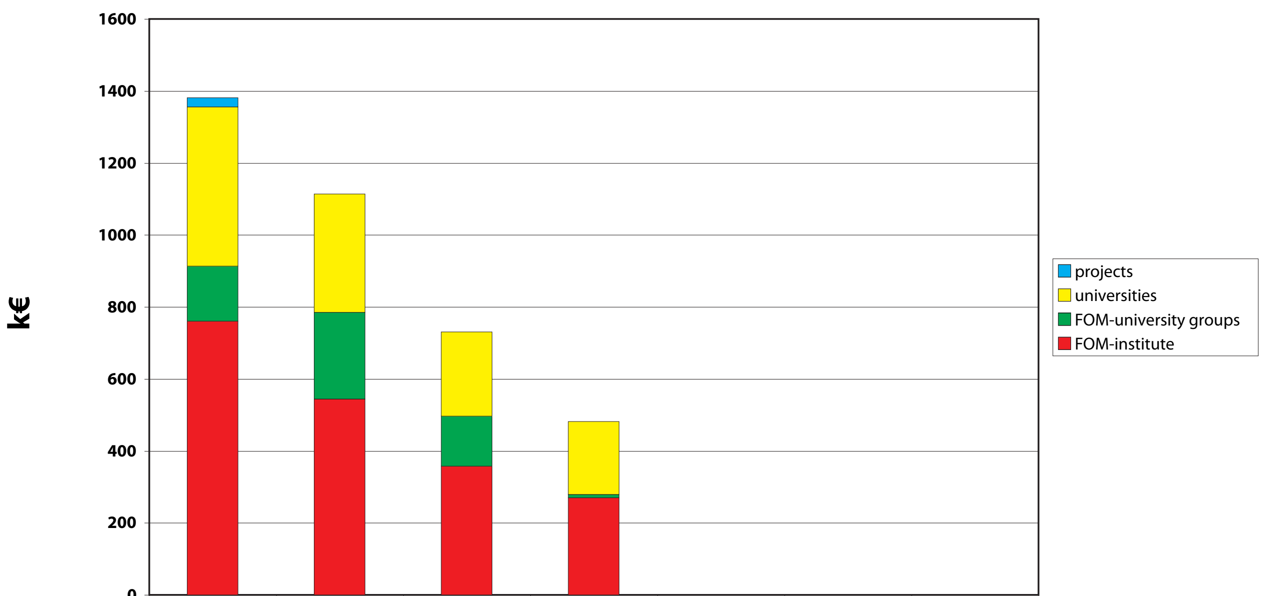
- A. Heister *et al.* (ALEPH, DELPHI, L3 and OPAL Collaborations)
  Search for the Standard Model Higgs Boson at LEP
  Phys. Lett. **B565** (2003) 61.
- S. Schael *et al.* (ALEPH, DELPHI, L3, OPAL, SLD Collaborations, LEP Electroweak Working Group, and SLD Electroweak and Heavy Flavor Group)
  Precision Electroweak Measurements on the Z Resonance
  Physics Reports **427** (2006) 257.
- J. Alcaraz *et al.* (ALEPH, DELPHI, L3, and OPAL Collaborations)
  A Combination of Preliminary Electroweak Measurements and Constraints on the Standard Model
  hep–ex/**0612034** (2006)
- M. Acciarri *et al.* (L3 Collaboration)
  QCD studies in e+ e– annihilation from 30–GeV to 189–GeV
  Phys. Lett. **B489** (2000) 65.
- P. Abreu *et al.* (DELPHI Collaboration)
  Determination of |Vub| / |Vcb| with DELPHI at LEP
  Phys. Lett. **B478** (2000) 14.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff	2.9	2.0	0.0	0.2			
PhD students	12.2	9.1	6.0	4.0			
postdocs	1.8	1.3	0.5	0.4			
permanent staff	8.1	6.5	4.2	3.7			

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
projects	25	0	0	0			
universities	442	329	233	203			
FOM-university groups	153	241	139	9			
FOM-institute	760	544	358	270			

4.3 Neutrino Scattering: CHORUS

Nikhef Research Highlights
- Neutrino oscillation exclusion limits.
- Neutrino–induced charm production measurements.
- Neutrino charged current nuclear structure function measurements.

Programme Organization
The programme was led by dr. R. van Dantzig. Nikhef joined the CHORUS research programme at CERN in 1992 with a small team. The programme formally ended in 2002. However, data analysis and publication continued up to this year.

Research Goal
The principal aim was to detect neutrino (ν) oscillations, in particular a muon–neutrino (ν_μ) oscillating to a tau–neutrino (ν_τ). The observation of this phenomenon would be a discovery of prime importance implying that neutrinos are massive particles, with far reaching consequences for particle physics and possibly for cosmology. If not observed in the accessible window of the difference in neutrino mass squared, $\Delta m^2_{\mu\tau}$ of order eV^2, and small mixing, upper limits were to be obtained on the probability of $\nu_\mu \rightarrow \nu_\tau$ oscillation at the level of a few times 10^{-4}. The study of neutrino–induced production of short–lived charmed particles was foreseen from the outset. In particular, this concerned neutrino–induced production of short–lived particles containing a charm–quark. Both charged and neutral charmed particles could be observed with unprecedented precision. The CHORUS programme thus originally had two main branches, oscillation physics and charm physics; Nikhef has added neutrino nuclear total cross–section and structure function measurements.

Research Overview
The CHORUS experiment had excellent prospects for the discovery of neutrino oscillations, provided that mixing would be small and Δm^2 would be large (of order eV^2), rendering neutrinos a significant dark matter component. On the other hand, in spite of long–standing indications in solar neutrino data, it was not at all certain that neutrino's have mass – and thus would oscillate – at all.

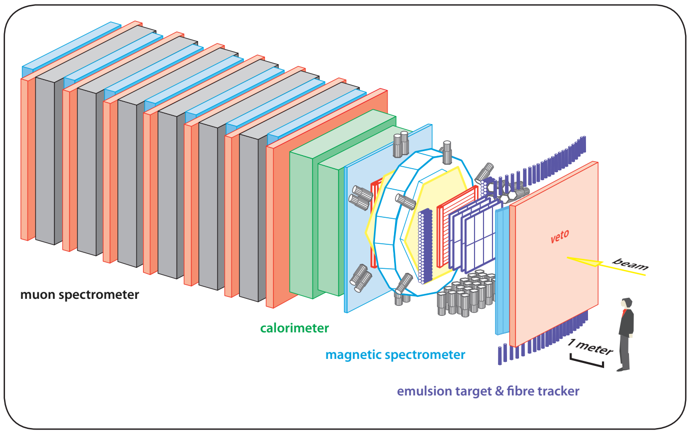


Fig. 1. Chorus Detector, the neutrino beam comes from the right.

The experimental approach was a challenging combination of two widely different detection techniques: registration of tracks in photographic emulsion and electronic tracking. The key was a *kink* decay signature of a tau–particle produced in a tau–neutrino interaction inside the 800 kg emulsion, here used both as target and as tracking device. The neutrino beam for the experiment contained no tau–neutrinos. If observed, any tau–neutrino thus could have made its appearance only through the oscillation phenomenon. Main data taking took place between 1994 and 1998.

Read–out of the photo–emulsion to search for the tau–signature was like looking for a needle in a haystack. It became only possible thanks to the development in CHORUS of fully automatic microscope scanning systems of high speed, together with strategies on 'where to look' using the electronic tracking information.

Research Activities
Before the period under review the main CHORUS result on the oscillation search was derived from the absence of any tau–signature after extensive exposure to the CERN neutrino beam. In the year 1997 this led to a stringent upper limit on the $\nu_\mu \rightarrow \nu_\tau$ oscillation probability ($P_{\mu\tau}$) in the CHORUS sensitivity region, improved in 2001 to $P_{\mu\tau} < 3.4 \times 10^{-4}$ (90% CL). This upper limit result has been used as constraint in different flavour mixing schemes. Surprisingly, in 1998 the absence of neutrino oscillation signals became supported by the discovery of neutrino oscillations in a quite different oscillation region, at large mixing and small Δm^2 (about 3×10^{-3} eV^2). This result occurred in data on atmospheric neutrinos, induced by cosmic rays, from the Super–Kamiokande detector in Japan. Later, this discovery was confirmed and extended by other experiments. Since then a mostly consistent picture of neutrino oscillations has emerged, which, nevertheless, is still incomplete. Worldwide, new experiments are on the way to answer the current questions.

With regard to charm physics Nikhef has pioneered analysis of charm production in the calorimeter – used as (lead) target – as well as inside the emulsion stack.

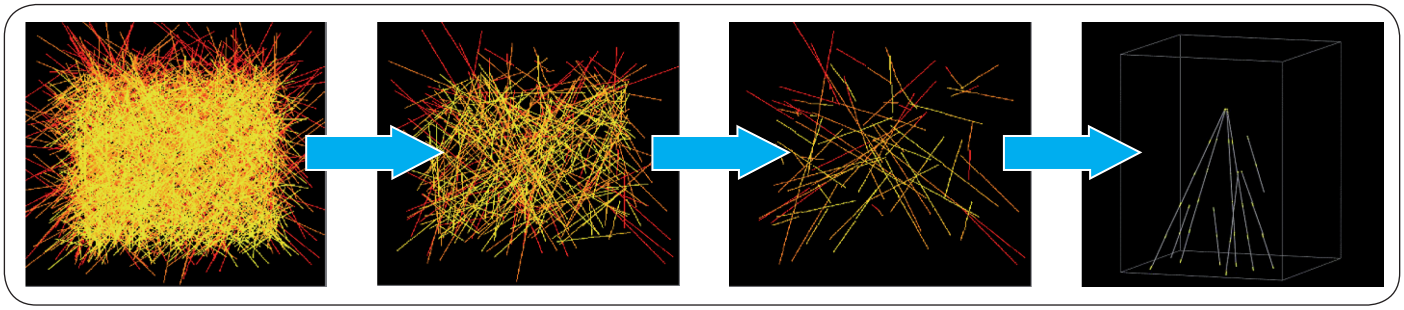


Fig. 2. Emulsion tracks from the haystack to the needle: the interaction vertex; the result of automatic scanning and analysis software.

Concerning charm physics with emulsion events, an exceptional event of diffractive charm production had been detected and studied along with charm production in emulsion in one of the Nikhef PhD–projects. Specifically, D^0–neutrino production cross–sections were measured as a function of energy and for different decay modes; ultimately this study was based on 10^3 identified D^0's from 10^5 general ν_μ charged–current (CC) events. The cross–section ratio of charged over neutral D–mesons was measured as well as the semi–leptonic branching fraction of D–mesons in ν_μ charged–current interactions, and a value was derived for the $|V_{cd}|$ matrix element.

Based on only electronic events from 5×10^6 *di–muon* triggers, various charged–current neutrino cross–sections were measured, for example on J/Ψ production. The charm–quark distribution in lead (calorimeter as target) was obtained in deep–inelastic charged–current –neutrino scattering as part of a second PhD–project. The electronic detector with a four–target–setup allowed studying the Z/A dependence for neutrino–nucleus CC–scattering total cross–sections. Differential cross–sections and nuclear structure functions on lead were measured with high statistical accuracy for deep–inelastic charged–current neutrino and anti–neutrino scattering in a third PhD–project.

Nikhef contributions

Nikhef has contributed technically to the CHORUS detector by building a tracker with the in–house developed 'honeycomb chambers' and dedicated electronics. It contributed further to the infrastructure by a fully automatic microscope system as part of the CERN–Nikhef Emulsion Scanning Facility and by the development of scanning and analysis software, with results written–up recently in a fourth PhD–project.

Knowledge Transfer

There were several spin–off projects with long term benefits. In the frame of an EU–project, a research grant from the Dutch Ministry of Economic Affairs allowed participation in the development of the read–out of a neutrino–target/detector with thin scintillating fibres. This project has grown later into a successful collaboration between Nikhef, CERN and PANalytical (previously Philips Analytical) in the MEDIPIX project, to develop high–resolution X–ray cameras for radiation imaging in materials analysis (XRD and XRF) a.o. in life sciences. These cameras are based on large area semiconductor pixel detectors with integrated miniaturized electronics.

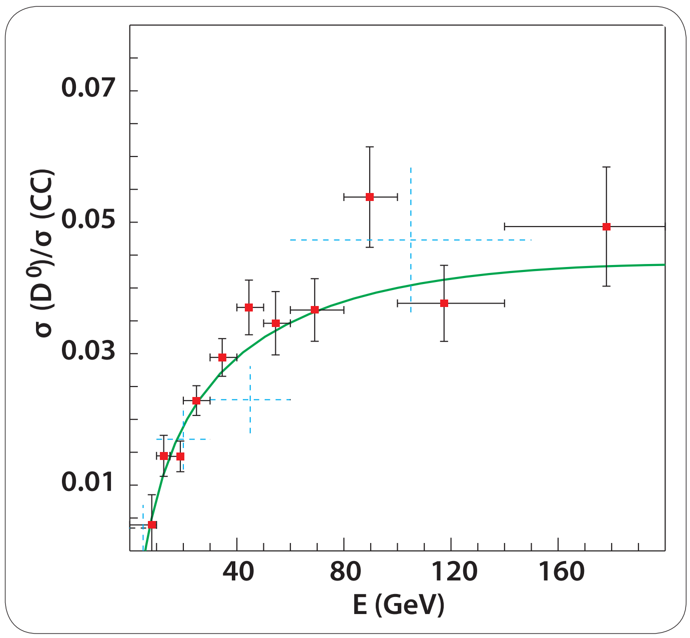


Fig. 3. Energy dependence of neutrino induced neutral charm (D^0) production relative to the total charge–current cross section. The full data points show the CHORUS measurements, the dashed crosses FNAL–E531 results. The curve represents a model calculation.

International collaborations

CHORUS was an international collaboration of 25 teams with in total 130 physicists from Europe, Russia, Japan and the USA. On distributed computing for data analysis and data simulation there was collaboration with the Computer Science department of UW–Madison on the application of the Condor system (M. Livny c.s.).

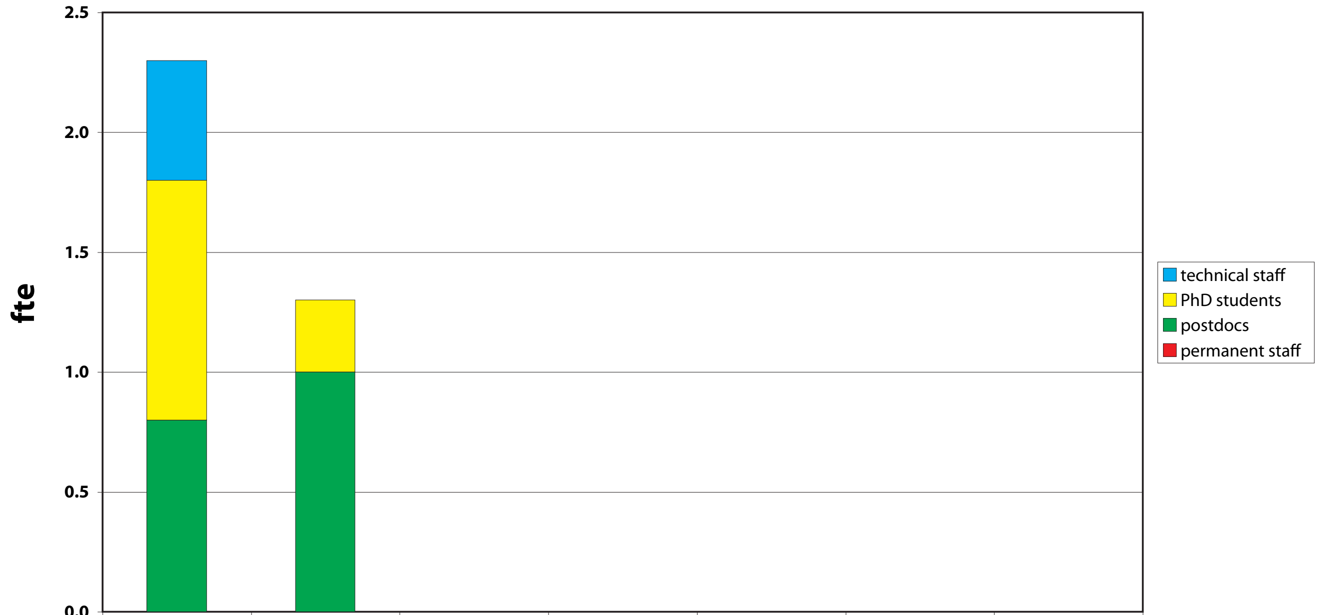
Industrial Collaborations

Concerning the optics, mechanics and control of the CERN–Nikhef scanning microscopes there were several international collaborations with industries coordinated at CERN.

Key publications

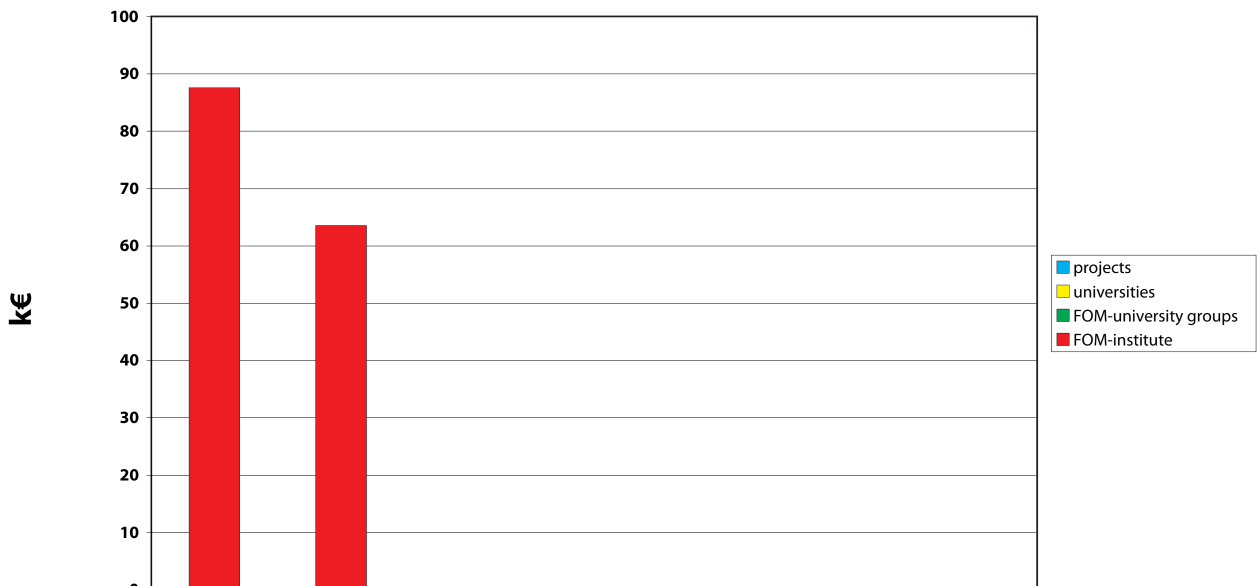
- E. Eskut *et al.*
  New results from a search for $\nu_\mu \rightarrow \nu_\tau$ *and* $\nu_e \rightarrow \nu_\tau$ *oscillation*
  Phys. Lett. **B497** (2001) 8.
- G. Onengut *et al.*
  Measurements of D^0 *production and of decay branching fractions in neutrino–nucleon scattering*
  Phys. Lett. **B613** (2005) 105.
- G. Onengut *et al.*
  Measurement of D^{*+} *production in charged–current neutrino interactions*
  Phys. Lett. **B614** (2005) 155.
- A. Kayis–Popaksu *et al.*
  Measurement of the Z/A dependence of neutrino charged–current total cross–sections
  Eur. Phys. J. **C30** (2003) 159.
- G. Onengut *et al.*
  Measurement of nucleon structure functions in neutrino scattering
  Phys. Lett. **B632** (2006) 65.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff	0.5	0.0					
PhD students	1.0	0.3					
postdocs	0.8	1.0					
permanent staff	0.0	0.0					

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
projects	0	0					
universities	0	0					
FOM-university groups	0	0					
FOM-institute	88	64					

4.4 The Nucleon Spin Structure: HERMES

Programme Organization
Prof. dr. G. van der Steenhoven has led the programme, followed by dr. J.J.M. Steijger from 2005 onwards. The group was formed in 1995 to carry out the FOM–HERMES programme. This programme was formally concluded at the end of 2006. A final report was submitted in 2007.

Research Goal
The HERMES experiment was conceived to study the spin structure of the nucleon with the polarized electron or positron beam of HERA (DESY, Hamburg) and a (nuclear) polarized gas target, internal to the accelerator. The structure of the nucleon is formally described by five distribution functions: the gluon density distribution G, its spin distribution ΔG, the quark distribution q, and its helicity (longitudinal spin) Δq and transversity (transverse spin) δq distributions. The number–density distributions are the subject of other experiments. The goal of the HERMES experiment is to determine the helicity distribution more accurately than is already known, and to provide early measurements of the transversity and gluon spin distributions.

Research Overview
Deep–inelastic scattering is a particular powerful technique to measure the spin–dependent distribution functions. The sensitivity to the quark–spin is derived from the use of a polarized beam and polarized target nucleons. When the quark spins contribute to the nucleon spin, the former are also polarized, and their relative orientation can be determined by measuring the difference between the scattering with beam and target polarizations parallel and anti–parallel. When also the hadronic final state is detected, information on the flavour of the struck quark can be deduced.

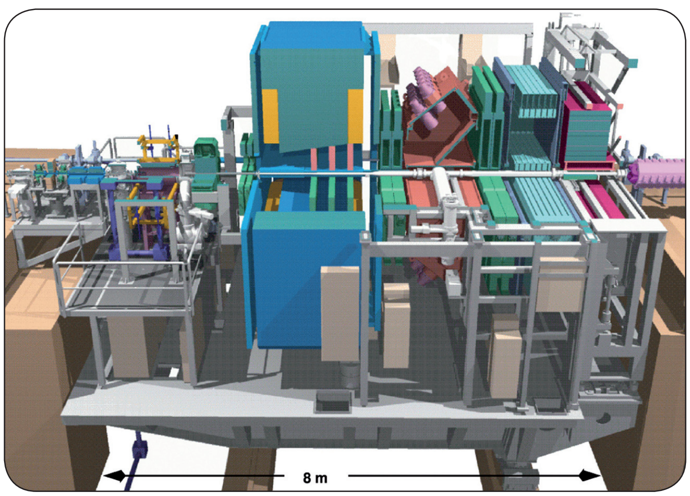


Fig.1. The HERMES Detector at DESY.

Nikhef Research Highlights
- Development of two new, pioneering detector systems: the Vertex Chambers and the Lambda Wheels.
- Determination of the flavour decomposition of the quark contributions to the nucleon spin.
- Direct estimate of the gluon contribution to the nucleon spin.
- Development of independent measurements of transversity.
- Contributions to the study of hadronization.

The research executed by the HERMES collaboration is organized in three periods set apart by differences in the experimental setup. In the first period the target consisted of different gases, of which the nuclei were polarized in a direction parallel to the beam line. In this configuration the helicity distributions are easily accessible. In the second period the target nuclei were polarized in a direction perpendicular to the beam–facilitating the measurement of the transversity distributions. HERMES operated with this setup in the years 2001–2005. At the beginning of 2006 a new detector (the recoil detector) was installed, optimizing the experiment for the study of Generalized Parton Distribution functions (GPDs), which, among others, open a window on the contribution of the orbital angular momentum of the partons (quarks and gluons) to the spin of a nucleon.

Research Activities
The number densities of both gluons and quarks have extensively and successfully been studied by, among others, HERA collider experiments. The quark helicity distribution and its flavour decomposition is determined by HERMES. Final results have recently become available from this collaboration. This result states that the quarks contribute $\Delta\Sigma_q$=0.330 ±0.011 (theory) ±0.025(exp.) ±0.028 (evolution) to the nucleon helicity. The flavour decomposition has shown that the contribution of the strange–quarks is small and consistent with zero. This rules out one important explanation of the deficit of the quark contribution to the nucleon spin which needs a substantial negative polarization of the strange–quarks. The small value of the strange–quark polarization is confirmed by experiments in which the polarization transfer from the beam to a Lambda particle is determined.

Lambda particles have the desirable property that their polarization can be deduced from the angular distribution of their decay products. This property was used to measure the polarization of

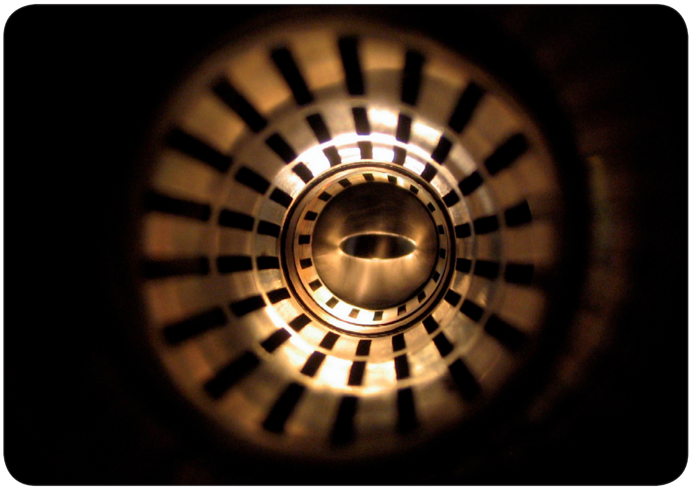


Fig 2. Entrance for the beam to the target cell. The HERMES target is an open–ended tube with elliptical cross section. In the centre of the tube gas is admitted, which is pumped out at both ends by a powerful pumping system.

Lambda particles produced on an unpolarized target. The degree of polarization transferred from the beam to the Lambda particles produced from the remnants of the target nucleon, is proportional to the degree to which an *s*–quark in the nucleon is polarized along the direction of the spin of the *u*–quark.

The Lambda particles in this experiment were reconstructed using the *Lambda Wheels* detector installed in 2001. Although this instrument does not provide a momentum measurement, Lambda particles could be reconstructed from a proton, measured and identified by the HERMES spectrometer, and a track measured in the new detector. In spite of the unknown momentum and unidentified pion, the invariant mass resolution is only about a factor of 4 worse, compared to that of a Lambda reconstructed from a decay completely measured in the full spectrometer. This is the price paid for the larger, and more symmetric acceptance of the Lambda Wheels.

The contribution to the nucleon spin attributable to the gluon spin can be deduced indirectly from QCD fits to observed deviations from scaling, i.e. the Q^2–dependence of the structure functions. Unfortunately, these fits are poorly constrained due to the limited range in the Bjorken scaling variable x and in Q^2. A direct measurement of this contribution can be made if a process can be identified that has a gluon in the initial state. Photon–gluon–fusion is such a process, measurable in lepton scattering. The final state consists of a quark–antiquark pair emitted back to back in the photon–gluon centre of momentum system. These quarks hadronize to hadrons with a large transverse momentum, which can be detected. Several background processes contribute to the same final state, but are not sensitive to the gluon polarization. These contributions are estimated from a Monte Carlo simulation, and subtracted.

A final value for the small and positive gluon contribution, including a careful analysis of the errors due to the background subtraction, will be ready for publication soon.

The (quark) transversity is the distribution about which very little is known presently. The transversity distribution function is chiral–odd. Chirality is an approximate quantum number for quarks which is conserved in hard QCD and electroweak processes, and can therefore not be measured in isolation in deep–inelastic processes. In semi–inclusive deep inelastic scattering the cross section contains terms that are sensitive to the product of the chiral–odd transversity and an (also chiral–odd) fragmentation function. The product therefore is chiral–even and can be measured.

Six different combinations of the polarization of the beam and the target can be measured in several processes each giving rise to a different combination of the transversity distribution function and a fragmentation function allowing the determination of the transversity h_1 alone. HERMES has chosen the azimuthal single–spin asymmetry in hadron production, and in the production of hadron–pairs. The function h_1 can be subsequently used to

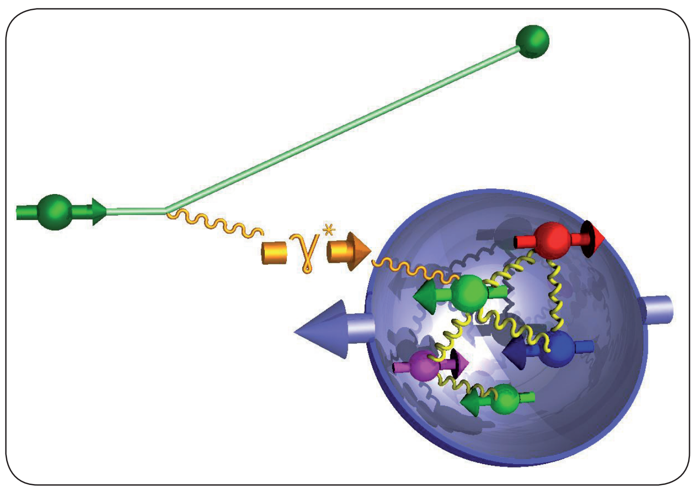


Fig. 3. Artist's impression of a deep–inelastic scattering event. A beam lepton (green) scatters off a nucleon (blue), emitting a virtual photon (gold). The photon is absorbed by a quark (coloured sphere inside the nucleon) or a gluon (yellow wavy lines). The arrows on the spheres show the direction of their spin.

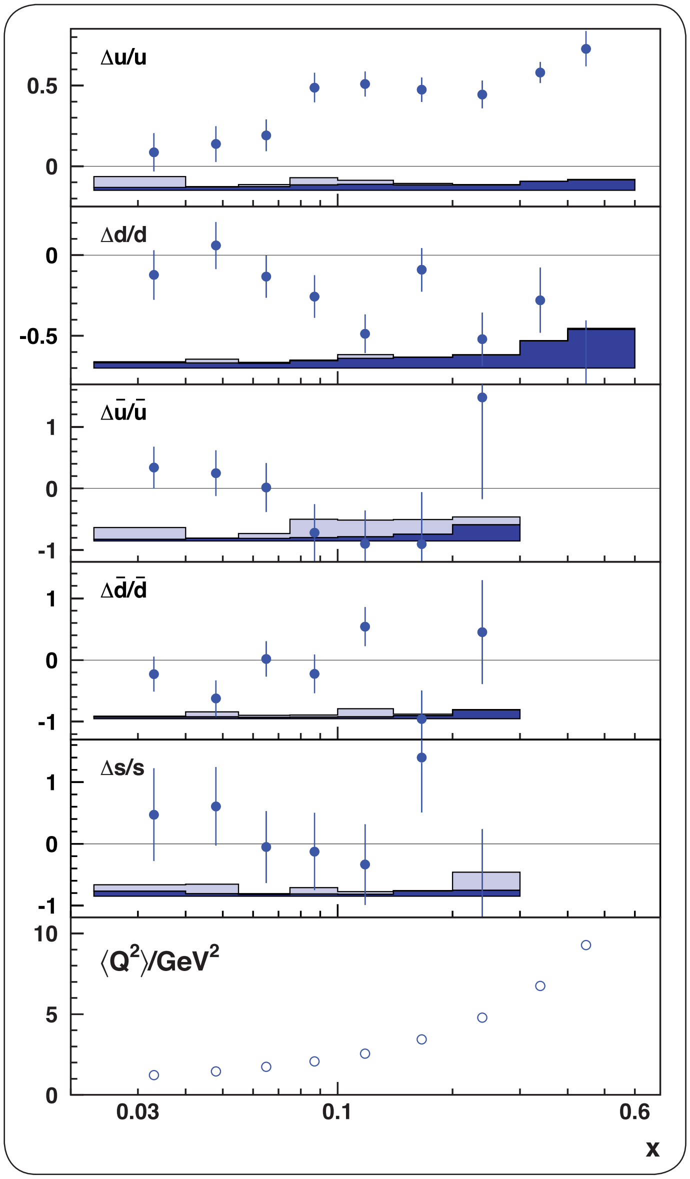


Fig. 4. The polarization of quarks of different flavour is shown as a function of x , the fraction of the nucleon momentum carried by the quark. The error bars are statistical uncertainties, the bars below the points show the systematic uncertainty. Light blue those due the uncertainty in the fragmentation models, dark blue from Born asymmetry.

determine the transverse quark polarization $\delta\Sigma_q$ analogous to the determination of $\Delta\Sigma_q$ from the polarized distribution function g_1. Polarization can also be transferred to a Lambda particle produced on a transversely polarized target with an unpolarized beam. The degree of (transverse) polarization transferred from this target is proportional to the product of the transversity distribution and a different fragmentation function. These experiments show a small but measurable signal, proportional to the transversity distribution, the interpretation of which is currently under study.

The final, unknown, contribution to the nucleon spin is the orbital momentum carried by its constituents. Calculations based on Generalized Parton Distributions show that the transverse target spin asymmetry A_{UT} in exclusive ρ^0 production is sensitive to the total angular momentum J^q of the quarks. It is necessary to separate the asymmetry caused by the exchange of a longitudinally polarized (virtual) photon from that by transversely polarized photons, because only the former is sensitive to J^q. A comparison of data with GPD model predictions allows to obtain a value for the total angular momentum of the quarks.

Understanding hadronization, the process in which a quark struck in a hard scattering, interacts with other (virtual) partons leading to the emission of one or more hadrons, is a prerequisite for e.g. the flavour decomposition of the nucleon spin. In this analysis the hadron type observed in the experiment serves as a tag of the flavour of the struck quark. Hadronization in free space was studied thoroughly in electron–positron collisions, but these experiments do not provide information on the time evolution of the process. Semi–inclusive deep inelastic scattering experiments on nuclei of different sizes can, because of the difference between nuclear matter and empty space, fill this gap. Data have been acquired on many different nuclei ranging from hydrogen to xenon which will be published in the near future.

Nikhef Contributions

Nikhef designed and built and built various detector systems. In the early phases of the experiment (before 2000) a large MSGC-based vertex detector was developed, and a large part of the EM-calorimeter of HERMES was built. After the year 2000 a wheel-shaped silicon detector array was built, called the Lambda Wheels, which is installed inside the high vacuum of the accelerator. The experience gained in the construction of this detector was used for an other, larger scale, silicon array in the recoil detector, installed at the start of 2006, by a group of institutes under the leadership of Glasgow University. An algorithm was developed to extrapolate tracks originating from detached vertices, as e.g. is the case for the Lambda decay products, correctly to the vertex. This extrapolation is complicated by the presence of the (transverse) holding field, necessary for the transversely polarized target. The Nikhef group also pioneered the first very fast (less than a single revolution of the beam) radiation monitor capable to dump the lepton beam in HERA. This system is in continuous operation since 2002, and protects sensitive detectors from the high doses that accompany an unintended loss of beam.

G. van der Steenhoven has been chairman of the Editorial Board and W.H.A. Hesselink was convenor of the charm analysis group.

Knowledge Transfer

Nikhef assisted Glasgow University in the development of the silicon detector for the Recoil Detector.

National Collaborations

In the HERMES programme, physicists from the FOM institute SAF/Nikhef cooperated with physicists from the Free University (VUA) in Amsterdam.

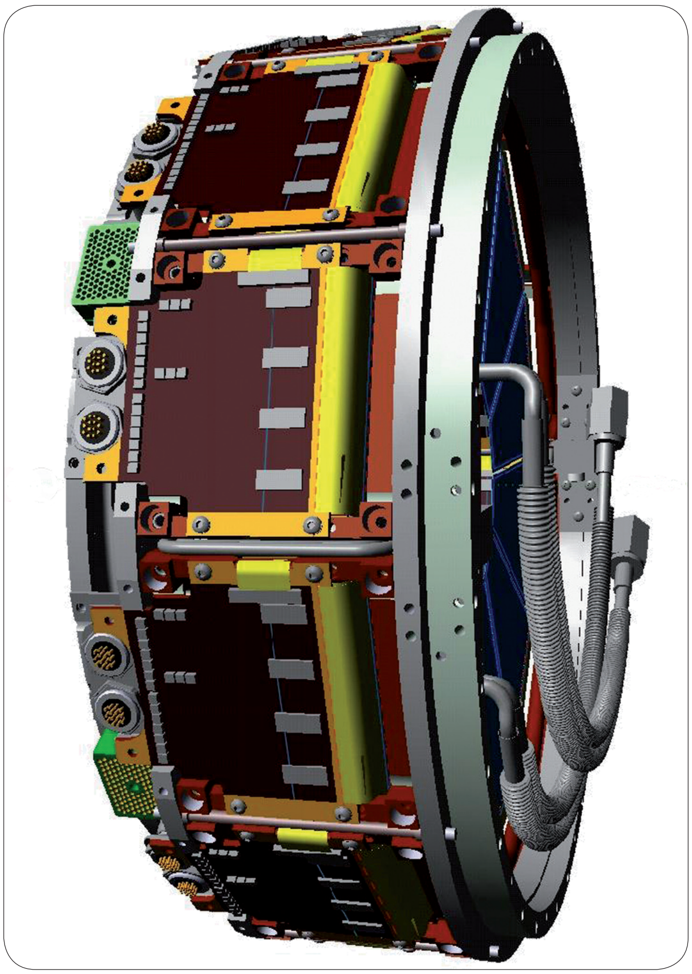


Fig. 5. Artist's impression of a Lambda Wheel.

International Collaborations

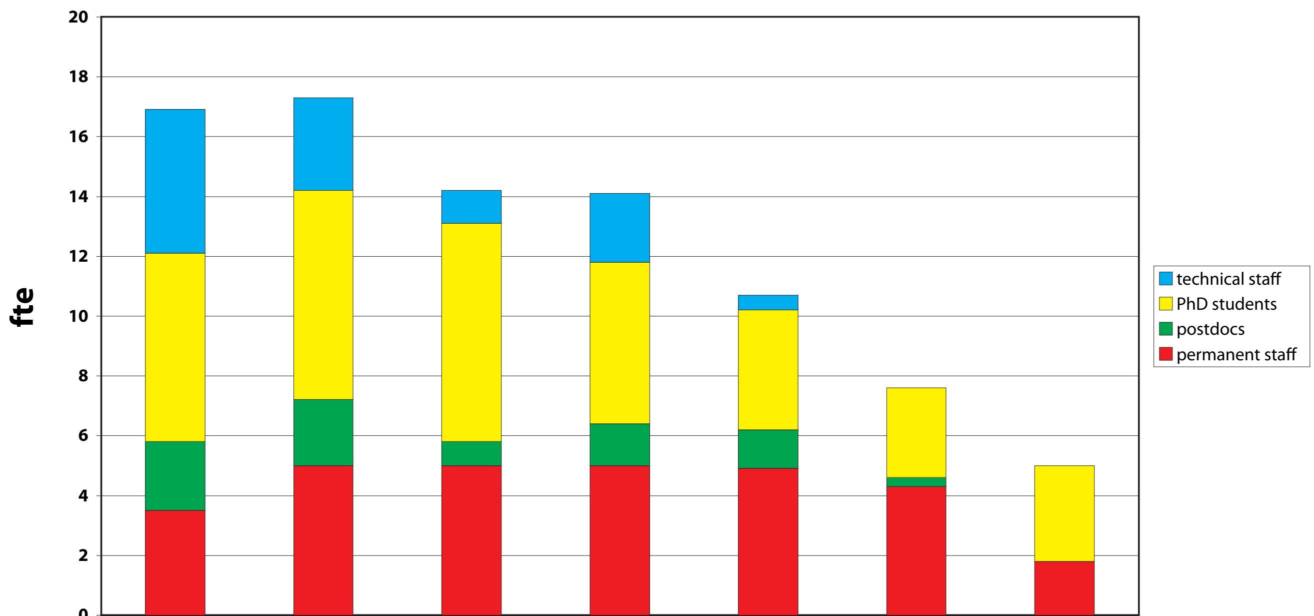
The Lambda Wheels were constructed in cooperation with the Petersburg Nuclear Physics Institute (PNPI, Russia) and the Friedrich–Alexander–University of Erlangen–Nürnberg (Germany). Several members of the Nikhef group in HERMES have also been involved in related experiments carried out in Hall C at Jefferson Laboratory in Virginia.

The HERMES collaboration consisted of about 185 physicists from 31 institutes in 10 countries (2002 data).

Key Publications

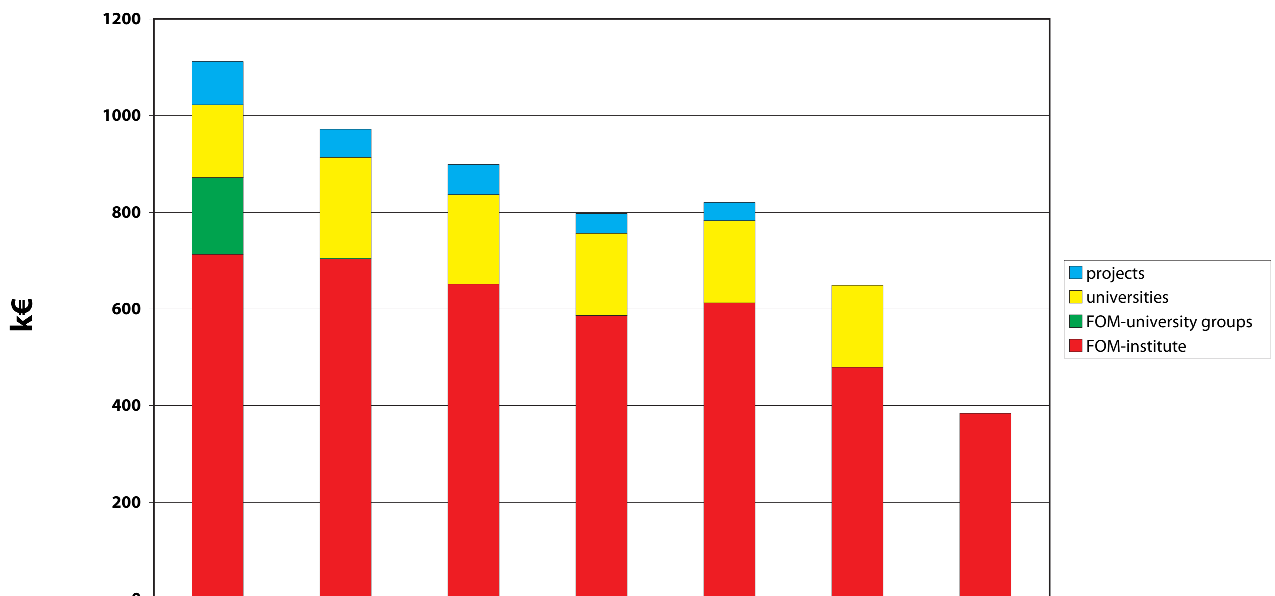
- A. Airapetian *et al.* (HERMES Collaboration)
  Precise determination of the spin structure function g_1 of the proton, deuteron, and neutron
  Phys. Rev. **D75** (2007) 012007.
- A. Airapetian *et al.* (HERMES Collaboration)
  Quark Helicity Distributions in the Nucleon for up, down, and strange Quarks from Semi–inclusive Deep–inelastic Scattering
  Phys. Rev **D71** (2005) 012003.
- A. Airapetian *et al.* (HERMES Collaboration)
  Single–Spin Asymmetries in Semi–Inclusive Deep–Inelastic Scattering on a Transversely Polarized Hydrogen Target
  Phys. Rev. Lett. **94** (2005) 012002.
- A. Airapetian *et al.* (HERMES Collaboration)
  Measurement of Single–spin Azimuthal Asymmetries in Semi–inclusive Electroproduction of Pions and Kaons on a Longitudinally Polarized Deuterium Target
  Phys. Lett. **B562** (2003) 182.
- A. Airapetian *et al.* (HERMES Collaboration)
  Measurement of the Beam–Spin Azimuthal Asymmetry associated with Deeply–Virtual Compton Scattering
  Phys. Rev. Lett. **87** (2001) 182001.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff	4.8	3.1	1.1	2.3	0.5	0.0	0.0
PhD students	6.3	7.0	7.3	5.4	4.0	3.0	3.2
postdocs	2.3	2.2	0.8	1.4	1.3	0.3	0.0
permanent staff	3.5	5.0	5.0	5.0	4.9	4.3	1.8

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
projects	90	59	63	41	38	0	0
universities	150	209	185	170	170	170	0
FOM-university groups	159	1	0	0	0	0	0
FOM-institute	713	703	651	586	612	479	384

4.5 The Proton Structure: ZEUS

Programme Organization
Prof. dr. P. Kooijman has led the programme. The FOM programmme ZEUS has formally ended at the end of 2006. A final report was submitted in 2007.

Research Goal
The goal of the ZEUS experiment is to investigate the quark and gluon structure of the proton, and to study the influence of Quantum Chromo–Dynamics on the evolution of this structure.

Research Method
The experiment was performed at the HERA accelerator at the DESY research laboratory in Hamburg. Electrons of 27.5 GeV are brought into collision with protons of 900 GeV. By observing the angular distributions of the particles emanating from the interaction the structure of the proton can be unravelled. The ZEUS detector is a multi–purpose magnetic detector that is placed at one of the interaction points of the storage rings. The detector and storage ring complex became operational in the year 1991 and have continually been producing data up to the present day, with the exception of the year 2001 when the complex was shut down for a major accelerator and detector upgrade.

Research Activities
The year 2000 was noteworthy in the life of the ZEUS experiment as it was the first year that the HERA collider attained its design yearly integrated luminosity of 100 pb^{-1}. This was followed in 2001 by a shutdown in which the detector was upgraded by the addition of a silicon strip microvertex detector. This occurred in

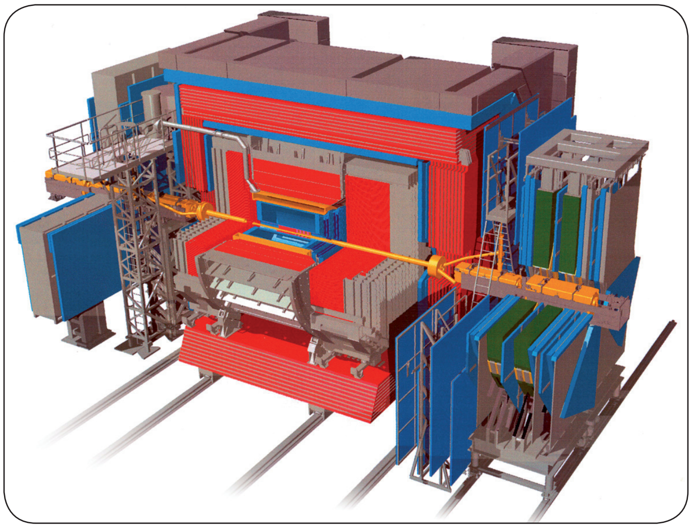


Fig 1. The ZEUS detector.

Nikhef Research Highlights
- Final measurement of proton structure function F_2.
- Determination of gluon and quark distributions in the proton.
- Building and commissioning of the micro-strip vertex detector.
- Measurement of the charm structure function.
- Measurement of the polarisation dependance of the charged current cross section for positron and electron-proton scattering.
- Observation of diffractive scattering of the virtual photon.

conjunction with an upgrade of the collider, which should have provided an increase of a factor of three to five in the yearly integrated luminosity. To achieve this, a major rebuild of the interaction region optics was undertaken. Unfortunately, the years 2002 and 2003 yielded almost no usable luminosity at all due to fierce and unforeseen background problems. By the end of 2004 the problems were finally overcome and since then the collider has produced excellent data albeit at a rate of only 30% above the rate in the year 2000.

Although the review period has not been a particularly satisfactory one for HERA, the microvertex detector of the ZEUS experiment has performed in an excellent way. This detector, which was built at Nikhef in collaboration with institutes from Germany, Italy and England, has performed up to and beyond specification. It has remained in perfect shape even throughout the period of vicious backgrounds in 2002 and 2003. The detector was designed to allow a cleaner measurement of the production of charm and bottom particles in the *ep* collisions. The latter subject unfortunately will only be able to be studied in a limited way due to the lack of data. For the measurement of charm however it is now really starting to show its potential. The Nikhef group has concentrated on the reconstruction of the charm events using this detector. By employing novel vertexing and analysis techniques we have been able to obtain a marked increase in efficiency and reduction of background for charm particle signals. One particular example is shown in Figure 4. Given the performance of the microvertex detector, a significant measurement of the bottom cross section could have been made with sufficient luminosity.

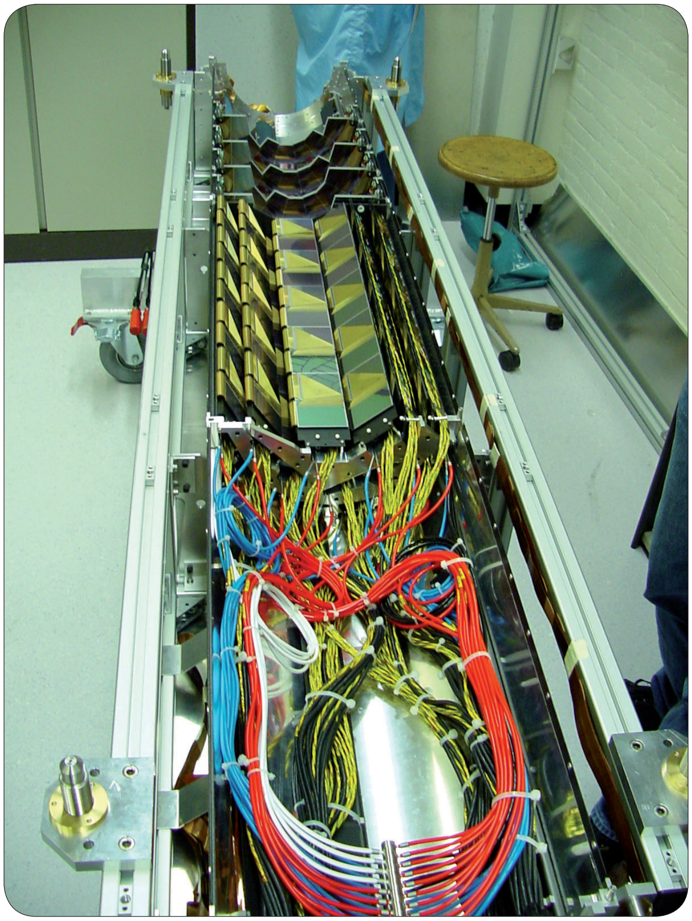


Fig. 2. The microvertex detector.

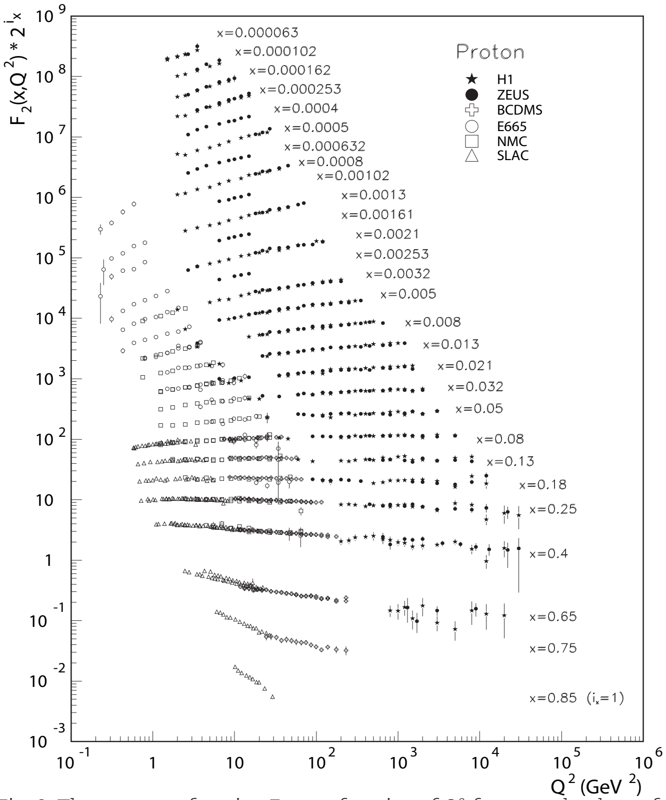


Fig. 3. The structure function F_2 as a function of Q^2 for several values of x. This figure is taken from the latest publication of the Particle Data Group. It contains data from fixed target experiments and the H1 experiment at HERA in addition to our measurements. The range in both Q^2 and x has been increased by three orders of magnitude.

Future Directions

After running in 2007 at reduced proton beam energy (for the measurement of the longitudinal structure function F_L), the experiment will stop taking data in July 2007 and the Nikhef group will finalize the charm analysis. After publication we will withdraw from the collaboration. Worldwide, there are no further plans for a dedicated ep scattering facility. The LHC will give further information on proton structure functions.

Nikhef Contributions

In this review period, Nikhef was responsible for the building of the microvertex detector. It also provided the framework for the analysis of the ZEUS data in terms of QCD, through the QCDNUM programme. The analysis of the inclusive structure function data and its interpretation in terms of QCD together with the analysis of the microvertex detector data have been the major achievements of the group. Before 2000, Nikhef built half of the forward and rear calorimeter, the second level calorimeter trigger, and part of the presampler detector. N. Coppola was run coordinator for several running periods. Both E. Tassi and P. Kooijman were physics coordinators of the DIS group. E. Koffeman was tracking coordinator, N. Brummer MC coordinator and L. Wiggers trigger convenor.

International Collaborations

The ZEUS collaboration is an international collaboration of 53 institutes from 17 different countries. The number of scientists involved in 2004 was 330.

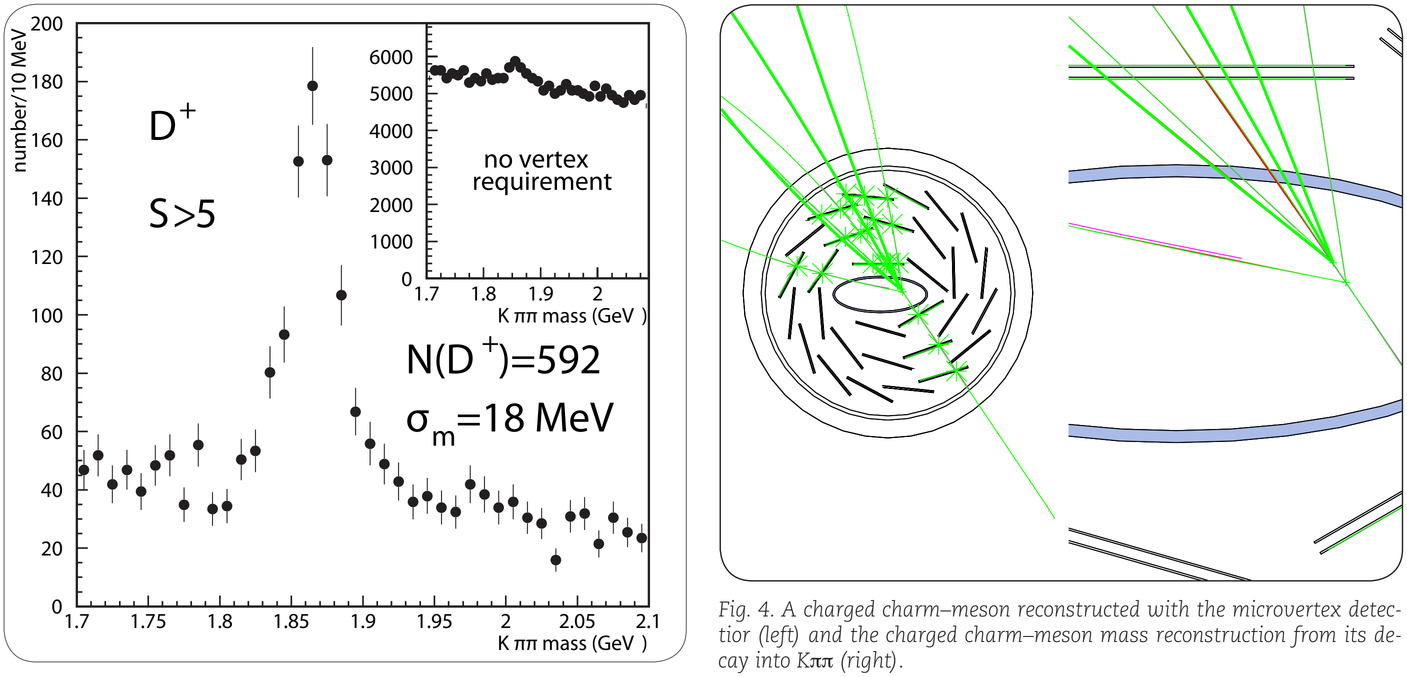
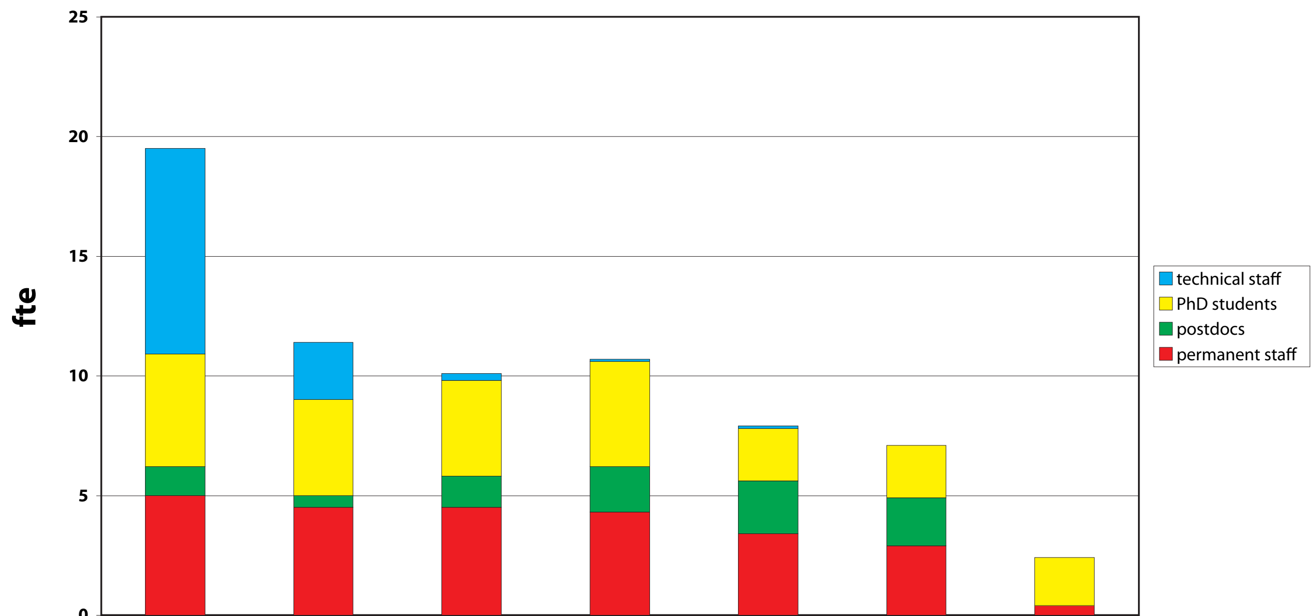


Fig. 4. A charged charm–meson reconstructed with the microvertex detector (left) and the charged charm–meson mass reconstruction from its decay into Kππ (right).

Key Publications

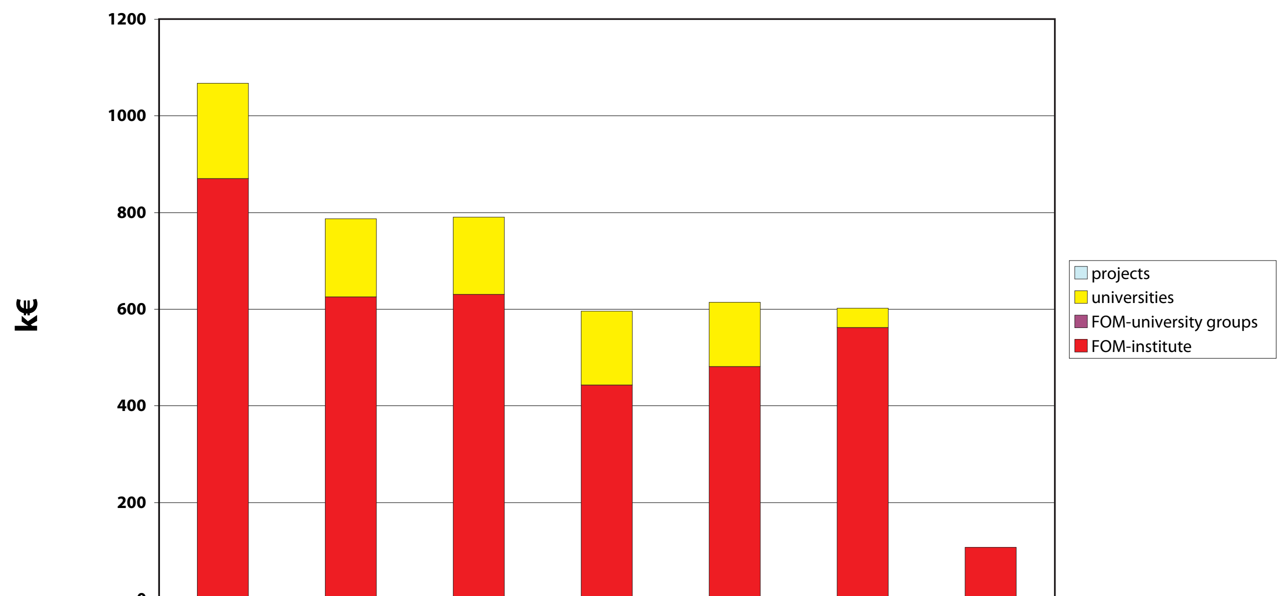
- S. Chekanov *et al.* (ZEUS Collaboration)
  Measurement of the neutral current cross section and F_2 structure function for deep inelastic e^+p scattering at HERA
  Eur. Phys. J. **C21** (2001) 3, 443.
- S. Chekanov *et al.* (ZEUS Collaboration)
  Measurement of high–Q^2 e^-p neutral current cross sections at HERA and the extraction of xF_3
  Eur. Phys. J. **C28** (2003) 2, 175.
- S. Chekanov *et al.* (ZEUS Collaboration)
  A ZEUS next–to–leading–order QCD analysis of data on deep inelastic scattering
  Phys. Rev. **D67** (2003) 012007.
- S. Chekanov *et al.* (ZEUS Collaboration)
  A next–to–leading order QCD analysis of inclusive cross section and jet–production data from the ZEUS experiment
  Eur. Phys. J. **C42** (2005) 1.
- M. Botje
  A QCD analysis of HERA and fixed target structure function data
  Eur. Phys. J. **C14** (2000) 285.

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006
technical staff	8.6	2.4	0.3	0.1	0.1	0.0	0.0
PhD students	4.7	4.0	4.0	4.4	2.2	2.2	2.0
postdocs	1.2	0.5	1.3	1.9	2.2	2.0	0.0
permanent staff	5.0	4.5	4.5	4.3	3.4	2.9	0.4

Table II – Budget



	2000	2001	2002	2003	2004	2005	2006
projects	0	0	0	0	0	0	0
universities	197	161	160	153	133	40	0
FOM-university groups	0	0	0	0	0	0	0
FOM-institute	870	625	630	443	481	562	107

5 Knowledge Transfer

5 Knowledge Transfer

Introduction

In the past years Nikhef's awareness of the importance of knowledge transfer to 'third parties' (including industry and other scientific organizations) has increased. This paralleled the change in the political climate in The Netherlands, where we have also seen an upsurge of interest in the relation between knowledge and economic growth. Words like 'knowledge economy', 'innovation' and '*valorisation*' (the translation of knowledge into technology in order to create commercially viable products or services), have become commonplace. More importantly, the government has made funds available (largely provided by the nation's return on natural gas sales) for investing in the 'knowledge infrastructure'.

Based on Nikhef's strong technological skills a growing number of opportunities have been used in the 2000–2006 period, broadly categorized in two areas: instrumentation and networking & computing.

Instrumentation

Almost all projects and activities in this area are by–products of our detector R&D for the large Large Hadron Collider experiments. They relate mostly to our electronic and mechanical (engineering) expertise.

The *RASNIK* alignment technology has gathered its firm place in scientific instruments like the Atlas detector and the LHCb detector. It is now also being investigated as the alignment tool ('RASCLIC') for CERN's next linear collider. Outside the science domain the technology has recently gained fresh attention. A pro-

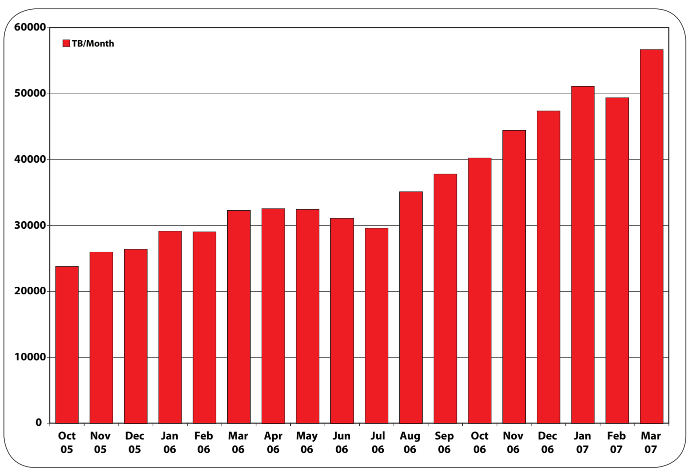


Fig. 1. Accumulated AMS–IX traffic (TB/month), with current average rates of 120 Gb/s and peak rates of 260 Gb/s.

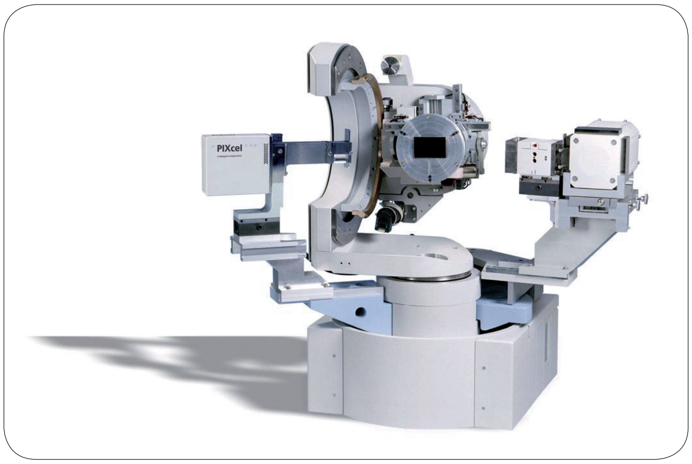


Figure 2. Recently introduced PIXcel detector system, based on single-chip Medipix2 technology, and mounted on a PANalytical X'Pert Pro XRD analysis platform.

posal to explore the use of RASNIK in the realm of buildings (sensing the deformations of a snow–covered roof, 'RASICE') has won a Science Park Amsterdam innovation award (May 2006). And a proposal to use RASNIK for seismic registrations has won an award at FOM's 60th anniversary (November 2006). These awards allow this technology to be brought closer to marketable products.

One of the most successful examples of technology transfer –to a company called PANalytical– has resulted from Nikhef's involvement in the *Medipix* collaboration. PANalytical (formerly Philips Analytical, Almelo, the Netherlands, and now part of SPECTRIS, UK) is a leading manufacturer in X–ray equipment for materials analysis since 1947. It is a medium sized company (750 employees) which develops and manufactures analytical X–ray instrumentation in two lines of business, X– Ray Diffraction and X– Ray Fluorescence. Several years of intense collaboration, starting 2001, between Nikhef and PANalytical, have resulted in the successful market introduction (in 2006) of the PIXcel detector, the first commercially available X–ray detector based on Medipix technology. Nikhef's expertise in the field of detectors and read–out electronics has significantly facilitated the integration of the Medipix2 readout chip into PANalytical`s X–ray analysis equipment.

Other examples of technology transfer to non–particle physics domains are the (mechanical engineering) activities for the Dutch Belgian Beamline (Dubble) at the ESRF (Grenoble) and the mechanical design of the cooling circuit of the AMS experiment, resulting in firm knowledge of the intricacies of CO_2 cooling, which expertise was subsequently used in the LHCb Vertex locator cooling system.

Fig.3. Updating a Grid node.

It should be mentioned here that Nikhef's Industrial Liaison Officer and the heads of technical departments have regularly organized 'network meetings' with related technical departments of other institutes and with companies. Aim of these meetings is to inform industry about new scientific instrumentation projects and to exchange knowledge and expertise on (new) technologies.

Networking – the Amsterdam Internet Exchange

Internet, and networking in general, has a long history at Nikhef. From an acoustic 110 bits per second (bps) modem 35 years ago to Gigabit networking today has been an interesting growth path. Networking for Nikhef started in 1980 with the installation at CERN of a remote batch station. In 1983 the first real networking equipment was installed. The network connections went via the public X.25 network of the Dutch national telecom company, with a network bandwidth of 2400 bps.

The year 1985 saw the birth of the first campus network, a 10 Mbps ethernet using the Internet protocols TCP/IP. This brought the first electronic mail services to Nikhef since it connected to the EUnet services at the adjacent Centre for Mathematics and Informatics (CWI). In 1989 a point was reached where it became more cost effective to go away from public dial–up services and rent private lines. Combining the requirements of Nikhef, CERN and via CWI the EUnet services enabled the acquisition of a leased line between Nikhef and CERN. The bandwidth was 64 kbps and the delivery time of the line was 9 months. In 1985 Nikhef introduced domain names: www.nikhef.nl was born.

The next few years the Internet in Europe really took off. Many networks popped up and were interconnected. Most of these interconnections took place in Amsterdam since the combination of networking for particle physics (Nikhef) and networking for computer science (CWI) made Amsterdam a natural hub for the Internet in Europe. In 1991 Nikhef became a customer of SURFnet, the academic and research network in the Netherlands. Today we are still connected to SURFnet, however with a current bandwidth of 1 Gbps. SURFnet also provides additional dedicated bandwidth to CERN (10 Gbps) and many other sites.
The role of Amsterdam and Nikhef as an important hub in the global Internet has also evolved from the few network interconnections of the early days into a set of so called Internet Exchange Points (IXP). The oldest and largest of these IXPs is the AMS–IX – a direct descendant of the early Nikhef activities in this field. Started in 1996, AMS–IX today interconnects more then 250 Internet Service Providers ('AMS–IX members') from all over the world, housed at four sites in Amsterdam of which Nikhef is the largest in terms of internet traffic. Currently Nikhef houses equipment of nearly a hundred ISPs (AMS–IX members), generating a turnover of about 1.4 M€ per year.

Nikhef is also participant in a key service on the Internet. Whereas the Internet works with numbers (IP addresses), users prefer names. These are defined in the Domain Name System (DNS), a distributed, hierarchical database system, mapping names and numbers, that consists of a set of about half a million servers worldwide. At the top reside the so called root servers that tie the system together. Nikhef –quite uniquely– hosts two of such servers: the K–root operated by the RIPE NCC in Amsterdam, and the F–root operated by the Internet Systems Consortium in California. Nikhef is also hosting top level domain servers for Germany, the UK and Russia.

Grid Computing

Nikhef's involvement in the computing infrastructure needed for particle physics experiments has always been strong. Around 2000, when the first discussions started at CERN on using grid technology for the data analysis of the LHC experiments, Nikhef decided to join the flagship EU project 'Datagrid' (or EDG), as one of the six main partners. In this project Nikhef's involvement and expertise in networking were elegantly combined with the experiences gained in a national 'knowledge infrastructure' project, titled 'Virtual Laboratory' (VL, running from 1998 to 2003), led by prof. B. Hertzberger from the University of Amsterdam.

Since then Nikhef has built up a very strong position in grid projects, both internationally (EDG, EGEE–1, EGEE–2) and nationally (VL, VL–e) culminating in the recent acquisition of the BIG GRID project, funded with almost 29 M€, aimed at building an e–Science infrastructure in The Netherlands for a variety of sciences.

The national grid projects all have industrial involvement. In fact, in the VL–e project Nikhef is responsible for the subprogram 'scaling and validation' which also includes industries like IBM and LogicaCMG. In the BIG GRID project a prominent role will be fulfilled by Philips Research, which, stimulated by the successful grid usage in the VL–e project, has offered to house a large fraction of the BIG GRID infrastructure on the Philips Eindhoven campus, in the framework of their 'Open Innovation' strategy.

In 2003 Nikhef was one of the founding fathers of 'Gridforum Nederland', which is one of the first official 'affiliates' of the Open Grid Forum (formerly called Global Grid Forum). Gridforum Nederland currently has about 100 members both from the research area and from industry (e.g. IBM, HP, LogicaCMG and various SMEs). Gridforum Nederland is aimed at transferring knowledge on grid technology by way of organizing tutorials, masterclasses, 'business days', evening lectures etc.

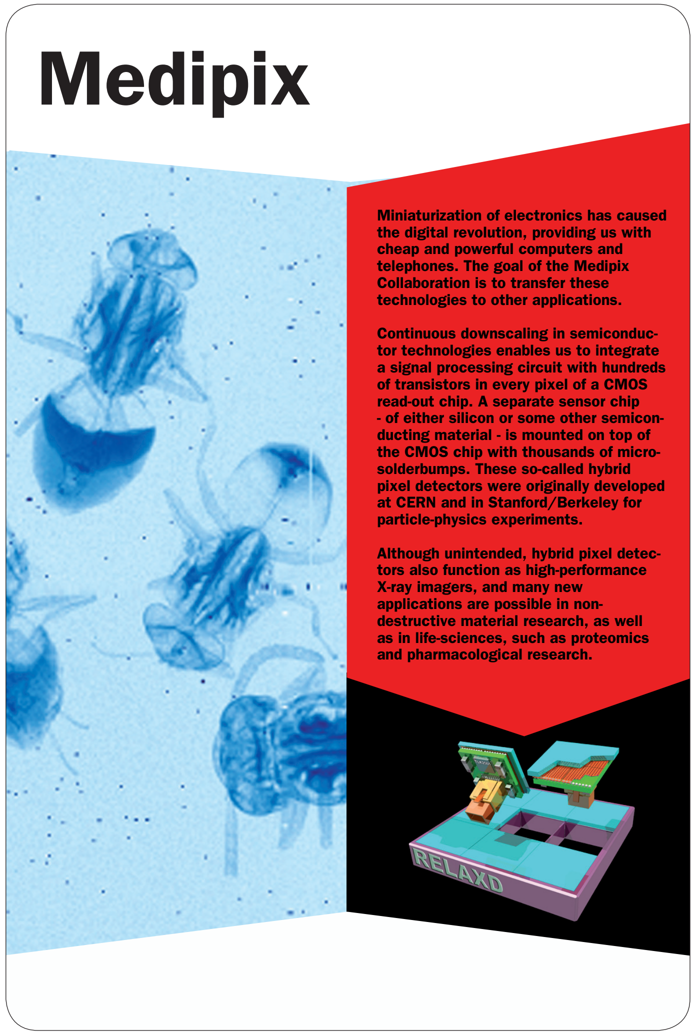


Fig.4. The medipix 'freecard'.

6 Education & Outreach

6.1 Education & Outreach

Introduction

Outreach activities explain the public as well as funding agencies what we do and why we do it. In return, outreach and education activities increase Nikhef's visibility, funding, and human–capital influx. We collaborate in (inter)national outreach committees to share ideas and coordinate science communication.

Outreach activities

Open Day

During the traditional Dutch science week ('*WetenWeek*') in October Nikhef opens its doors for the general public. This open day is organized annually together with all institutes at the Science Park , and is visited by 3500 people.

World Year of Physics 2005

From the start in 2004 Nikhef has been involved in the organization of the World Year of Physics 2005 in the Netherlands. In three working groups Nikhef participated: '*Techniek Tournooi*', Eureka Cup, and the main public event: Science Unlimited. The European particle physics master class started in this year as well. The InterAction Collaboration worked together on Quantum Diaries (www.interactions.org/quantumdiaries). Representing Nikhef, physics student A. Koutsman, graduate student M. Limper and director F. Linde, blogged throughout the year 2005.

Visits to CERN

Nikhef supported numerous visits to CERN. Dutch reporters and photographers, the Dutch Minister of Education, the FOM Board, the NWO board, the '*Stichting Nationale Computerfaciliteiten*' (NCF), the collaborating university boards and student groups, varying from high school students to Honours and HOVO (elderly) students, were guided by Nikhef staff on their visits to CERN.

Media

The science information office expanded its contacts with the media during the last years, by e.g. organizing a guided visit to CERN in 2006. The result is clearly visible in the number of 'popular' publications on Nikhef–related topics, which increased by one order of magnitude in the last two years.

Movies and public entertainment

An award winning documentary on the ATLAS experiment was prepared: "*Het ATLAS experiment*". In addition, we worked on a movie on the Higgs search. This movie was finished in May 2006 and is called "*Het Massa Mysterie*". The DVD deals with the Higgs search. Additionally, Nikhef employees participate in Science

Fig. 1. In 2005 members of the NWO-board visited CERN.

Cafes (Nijmegen) and in theatre shows (e.g. Theater Adhoc, 2005), lectures (musea, schools, clubs).

Education

Research at Nikhef relies on highly qualified researchers and technical support. To a large extent the human potential for Nikhef is shaped by the educational system up to university level. Nikhef invests in special educational projects on all levels, as well as visits of students to Nikhef and CERN, and facilities such as: lectures on request, borrowing equipment and performing research at Nikhef.

Primary schools

Nikhef participates in the national '*Techniek Toernooi*', a match for primary school children on several technical and artistic tasks. This started in the World Year of Physics in 2005 and was repeated in 2006.

High Schools

Starting in the summer of 2002 the *High School Project on Astroparticle Research of Cosmics* (HiSPARC), started constructing a network of cosmic ray detectors all over the Netherlands. This project, both scientific and educational, is designed as an open network that other schools and academic institutions can join. The goal of HiSPARC is to involve high school students and their teachers directly in all stages of scientific research. Presently over 40 high schools are involved, clustered around six universities all over the Netherlands. Every year the participating schools organize a HiSPARC student conference. Universities, scientific societies, industry, schools and private organizations have financially supported the project.

Fig. 2. The Dutch Minister for Education, Culture and Science, Mrs. Maria van der Hoeven, gave a speech on the occasion of CERN's 50th anniversary.

The successful approach of HiSPARC is supported by the '*Platform Bèta–Techniek*' of the Ministry of Science and Education. Three high school teachers have participated as researcher and developer on part–time funded positions at Nikhef. Their contribution has allowed the development of supporting background material for schools. HiSPARC received the prestigious international Altran Foundation Award in June 2004.

Starting in 2005, Nikhef participates in the European Master Class on Particle Physics for high school students. In 2006 the master class was repeated and even more successful. The Eureka Cup, a competition around topics as 'build the highest water rocket', intended to trigger curiosity and show the fun of solving technical and scientific problems, was held next to the Nikhef building. This event also started in 2005, and will be repeated in 2007.

Nikhef participates in the development of the novel physics curriculum for secondary schools in the Netherlands since 2006. NiNa ('*Nieuwe Natuurkunde*'/New Physics) is the name of the restyled physics curriculum, and NLT ('*Natuur, Leven en Technologie*'/Nature, Life and Technology) is a new optional subject at high school.

Bachelor and Master students

Several Nikhef staff members are faculty members at a university, taking part in the regular teaching programmes at Bachelor and Master level. Some of the FOM employed Nikhef staff hold special professor positions, also at universities that are not part of Nikhef, usually lecturing more advanced particle physics classes, on (inter)national technical and regular universities.

In 2002 Nikhef staff employed by the Universiteit van Amsterdam or the Free University Amsterdam started a new two year master programme to educate students in experimental (astro)particle physics research. Since the start of the programme in 2002, a remarkably high percentage – for Dutch standards – of 30% of the students enrolled, were female. The Radboud University Nijmegen Nikhef staff runs a particle physics master track in the physics and astronomy master programme.

PhD students

The research school for subatomic physics organizes annually academic training courses and, in collaboration with Belgian and German research groups, a summer school for PhD students, since 1996. Goal is the coordination of all PhD students in particle physics, amounting to approximately 60 students in total each year. The research school was reviewed by an international panel in May 2005 and the Royal Dutch Academy of Sciences (KNAW) has renewed the accreditation of the school for 4 more years in 2006.

Collaborations on communication

We collaborate in several communication efforts to share ideas and to coordinate activities. With cutbacks in funding and the start of new large international projects, a worldwide particle physics communication strategy is necessary. Participation in (inter)national communication committees provides tools to map out communication strategies for Nikhef.

National

We participate in the national science communicators group '*Platform voor Wetenschaps Communicatie*' and in the Science Park Amsterdam Communicators Group, both since they started in the eighties.

International

Nikhef participates in the Large Hadron Collider experiments, and therefore also in their outreach activities.

The European Particle Physics Outreach Group (EPPOG) concentrates on the development of hands–on physics tools for students and the general public and meets twice a year. Nikhef participates in EPPOG from the start in 1997.
For detailed information see www.cern.ch/eppog.

Fig. 3. HiSPARC detectors in a demonstration set-up in Nikhef's hall.

The European astroparticle physics community started an outreach committee as well in 2006, in which Nikhef participates. This outreach group is part of ERA–NET project ASPERA. For detailed information see www.aspera–eu.org.

In 2001, the world wide InterAction Collaboration was formed. Nikhef has joined the InterAction Collaboration in 2003. At the meetings, held twice a year, the members report on their institute and discuss the communication challenges they face.
For detailed information see www.interactions.org.

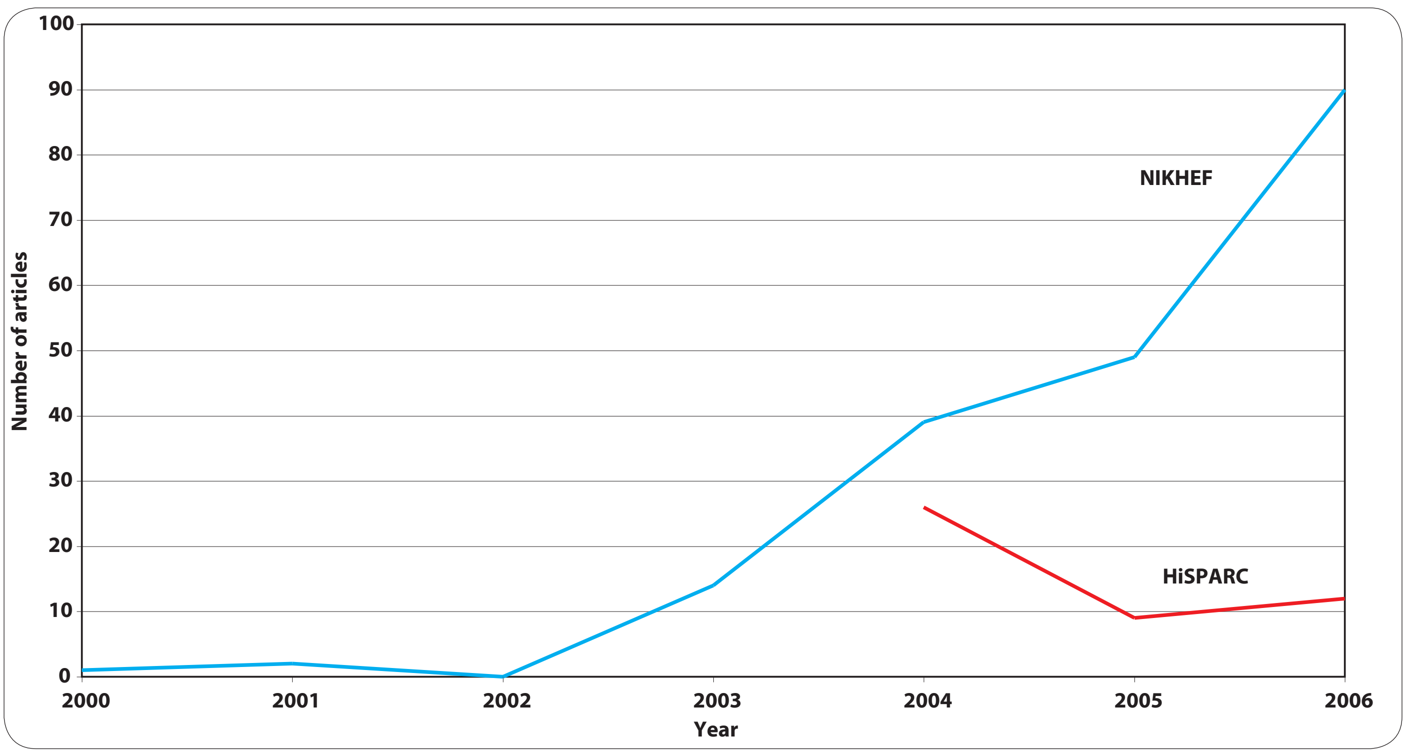


Table 1. Publications 2000–2006.

7 Technical and Support Infrastructure

7.1 Technical Facilities

Nikhef avails over a wide variety of laboratory facilities. Apart from about ten 'general purpose' lab rooms for R&D, Nikhef has three clean room facilities.

The first is a large 170 m², class 10.000 cleanroom, constructed inside the big assembly hall of the mechanics workshop. It has been used for construction of about 100 large Muon Drift Tube modules for the ATLAS detector at CERN. Still inside is robotic equipment to insert wires in the drift tubes, tension and seal them. Also a very large granite table is still there, used to glue the finished and tested tubes together into large modules, with precisions of 20 µm. The room is temperature and humidity controlled.

The second is located in a former experimental hall: a large 270 m² cleanroom area divided over 4 separate rooms. It has been built for assembly and testing of the straw–tube outer tracker modules for the LHCb experiment at CERN. The area is largely empty now, and has ISO qualification of 10.000, with temperature and humidity control.

The third clean area is the 'Silicon Alley', in which facilities are concentrated for handling and testing Si–chips and wafers. The facilities have been extensively used in the past years for assembling ZEUS, HERMES, ATLAS, ALICE and LHCb vertex modules. The foundations of this clean room area allow for extremely vibration–free positioning of any equipment. Per ultimo 2006 the most important facilities in this area are:

- a 32 m², ISO class 1.000 clean room with separate airlock and overpressure system (temporarily converted into a wafer–probing room at class 10.000) containing a semi–automatic probe station (Micro Manipulation 8860) to probe wafers up to 200 mm diameter;
- a 36 m², ISO class 10.000 clean room, in use for a large 3D measurement machine, temperature controlled.
- a 32 m² detector module assembly and quality testing room, ISO class 10.000;
- a 38 m² subdetector assembly and testing room, ISO class 10.000;
- a 40 m² die–bonding and wire–bonding room, with an automatic wedge–wedge bonder (Delvotec 6320) to automatically bond wires for effective pitches down to 40 µm;
- an unclassified clean room, containing a smaller 3D measurement machine.

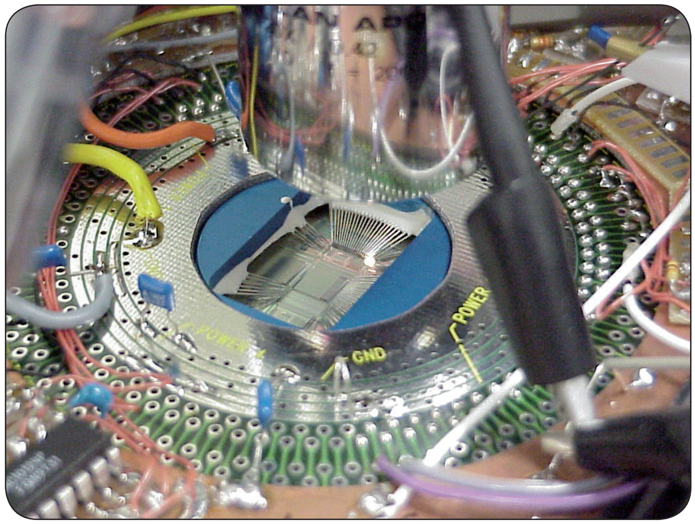


Fig. 1: Wafer test at the probe station.

Currently an upgrade of the 'Silicon Alley' is planned, which encompasses both improvements in the physical layout (such as restoring the class 1.000 clean room by relocating the wafer probing to a new location) and investments in diagnostic and assembly equipment for detector R&D.

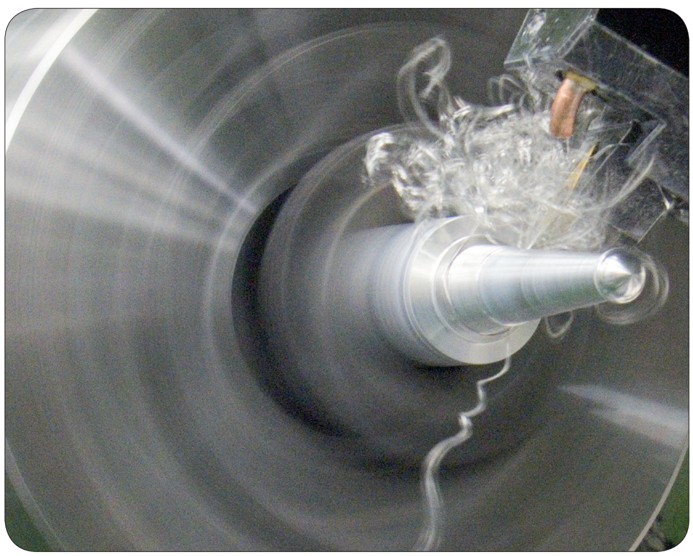


Fig.2: CNC-machined part made by the Mechanical Workshop.

7.2 Electronics Technology

Department Head: ing. E. Heine

The main task of the Electronic Technology Department is to design, build, maintain and support electronic systems for readout and processing of the data of detectors in close collaboration with the experimental physicists involved.

The emphasis in the department is on the field of micro–electronics in front–end electronics and on data handling and data communication with computer farms. This requires a variety of skills ranging from photonics, printed circuit designs, field programming arrays and micro–electronic designs to the use of high–level simulation tools and high–end equipment.

To cope with the ever more advancing technology courses have been provided, both internally (Xilinx Virtex4 2005) and externally (Digital Modulation – PATO 2005, micro–electronics – Lausanne, optical communication – TU/e). Cooperation has been established with universities on specific knowledge areas, in particular optical communication (TU/e) and chip design (University of Heidelberg, SRON, CERN en UT). If possible local industry is involved for outsourcing PCB production, assembly or co–design and co–production projects. The department avails of a wide range of general and specialised equipment and facilities, such as a climate chamber for testing electronics (range –45 °C to 180 °C), specialized high frequency oscilloscopes, an optical time domain reflectometer, a semiconductor characterization system, an infrared camera, a fiber welding system, a network analyzer, a bit error rate tester and various other equipment.

The department consists of 25 ftes: 4% at university level, 68% at '*HBO*'–level (higher vocational education) and 28% at '*MBO*'–level (intermediate vocational education).

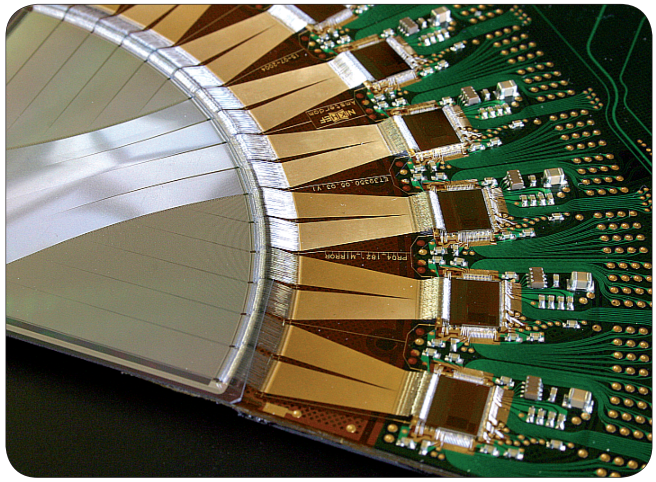


Fig.1. Silicon detector with front-end electronics for the LHCb Pile-Up system.

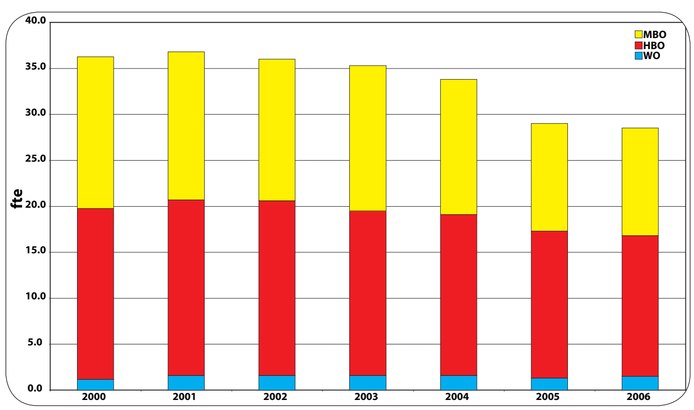


Fig.2. Manpower 2000–2006

7.3 Mechanical Engineering Department

Department Head: Ir. R. Klöpping

The main responsibilities of the Mechanical Engineering Department are mechanical engineering and development. A new design begins with a set of requirements, which need to be defined in close cooperation with the physicists. Often, the problem has to be re–analysed and tentative prototypes have to be constructed and tested to determine or refine the requirements.

For engineering purposes finite–elements modelling is used. For design purposes the department uses a CAD/CAE system to model, analyse, simulate and compose mechanical hardware. In the end stage of this process production drawings are made for components to be manufactured.

Special expertise has been built up around non–solid state detector parts and mechanical structures for carrying detector parts. Motion control and measuring and control of processes (LabView) are also part of the competences. The department avails of applied knowledge on physical principles in areas such as thermodynamics and fluid dynamics, (geometrical 3D) measuring, vacuum technology, system dynamics, kinetics, electricity and magnetism. For knowledge on other areas and for getting access to highly specialised competences cooperation is sought with other laboratories, universities and scientific institutes.

The department consists of 10 fte, 10% educated at university level, 70% at '*HBO*'–level and 20% at '*MBO*'–level. Normally one or two '*HBO*'–students per year follow a training period at the department.

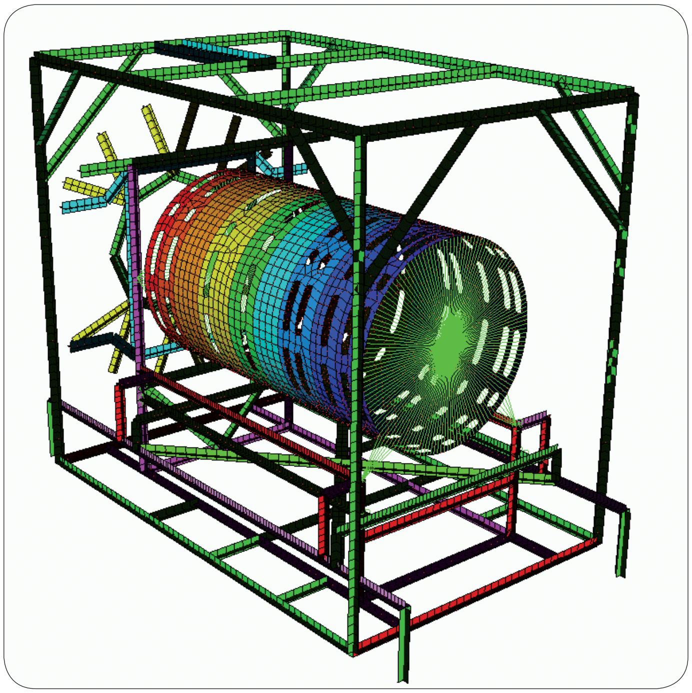


Fig.1. The finite–element model for the transport of the ATLAS endcap SCT detector developed and produced at Nikhef.

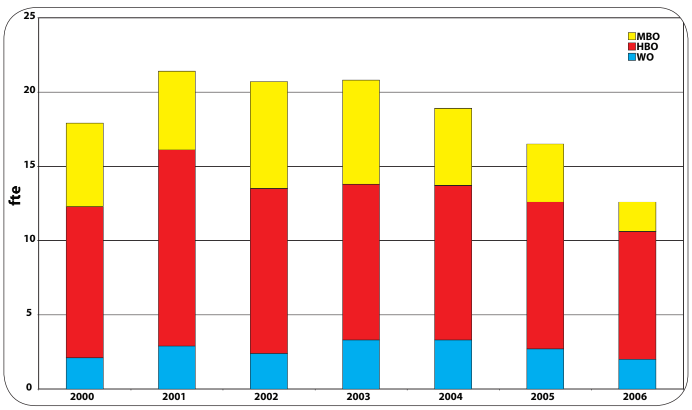


Fig.2. Manpower 2000–2006

7.4 Mechanical Workshop

Department Head: ing. E.M. Berbee
The Mechanical Workshop develops and builds various types of detectors, produces high–precision parts for those and builds production lines in cleanroom circumstances, including test and measuring equipment for quality control. Further skills are computer–controlled machining, wire bonding, knowledge of composites and other ‘new’ materials, cooling systems for electronics, outsourcing of parts, machining and 3D measuring up to object sizes of 2000 mm, orbital–, tig– and plasma welding, gluing methods with tooling and superplastic forming of thin plate for obtaining more precision and less mass of the constructions.

The main responsibility of the Mechanical Workshop for the last six years has been developing prototypes and building and integrating of detector parts for the LHC experiments. This work has been carried out by a core group of very skilled, very experienced and internationally co–operating technicians. Moreover, a large additional workforce was required, for which approximately 60 starting technicians, students and apprentices were temporarily employed. Assisted by the experienced technicians they learned how to accurately construct, test and operate the mechanical components of the complex detector systems.

At the highest point of the workload (end 2004) the department consisted of 32 fte. Now the department has 16 fte: 12% at the level of ‘*HBO*’) and 88% at the level of ‘*MBO*’.

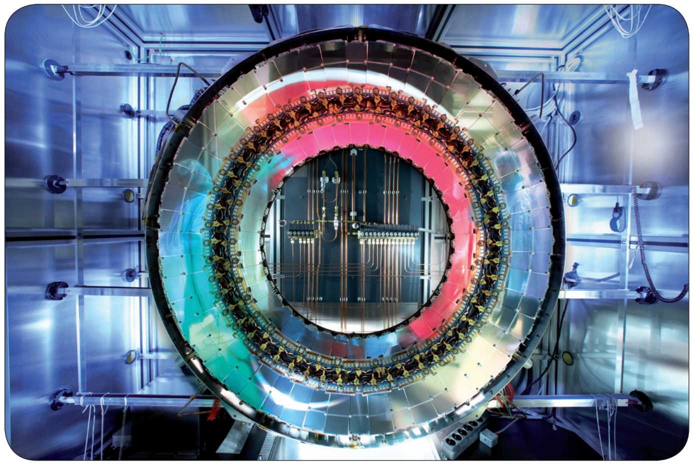


Fig.1. A carbon fiber disc fully mounted with silicon detectors for the ATLAS central tracking system.

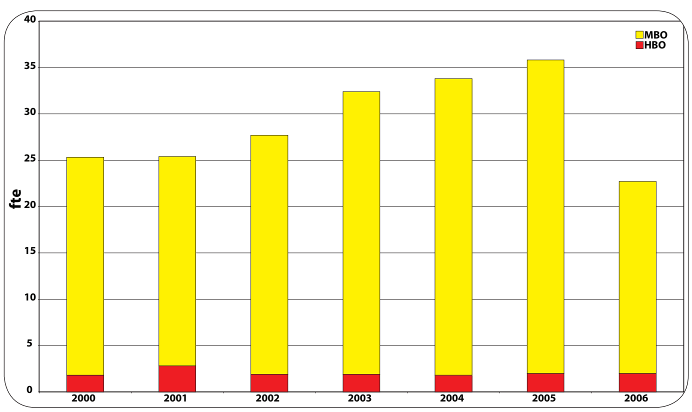


Fig.2. Manpower 2000–2006

Fig.3. A hands-on approach to leadership; Nikhef’s director, F. Linde, working on a detector part.

7.5 Computer Technology Department

Department Head: ing. W.P.J. Heubers

The Computer Technology Department (CT) is responsible for the ICT infrastructure at Nikhef and contributes with technical manpower to the scientific programs. The CT has also taken responsibility for the daily operational support of the AMS–IX housing facility at NIKHEF. The CT software engineers participate in the development of the software for control and data–acquisition systems of scientific instruments like the LHC particle detectors and the ANTARES neutrino telescope. The CT engineers design and implement applications based on commercially available packages, like PVSS and LabView running on the Windows platform for production and control systems of the detectors. The CT develops software running at Linux computers and embedded systems of the readout electronics and integrates these software modules into the data–acquisition systems of the detectors at CERN and other sites.

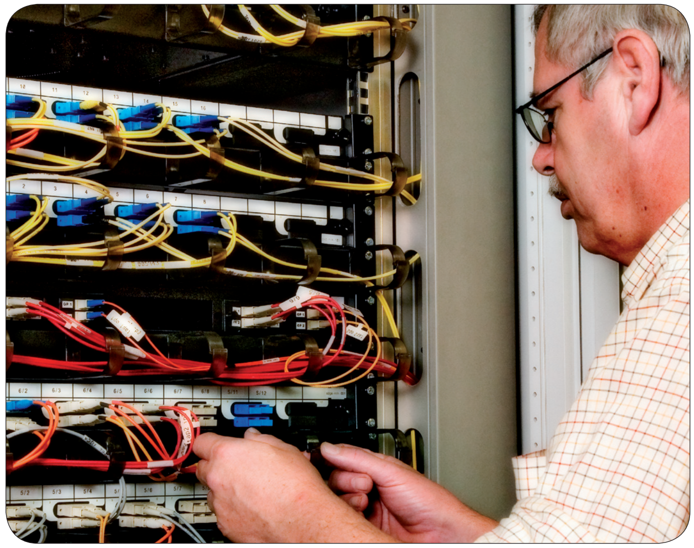


Fig.1. AMS-IX intelligent hands.

As from the year 2000, the CT has put an increasing effort into the support of grid computing projects under the supervision of the Physics Data Processing project group. The main goal of this activity is to set up the Tier–1 infrastructure for the LHC Computer Grid (LCG) at Nikhef and SARA. This activity ranges from purchasing, installing and configuring compute clusters and massive disk storage and network devices to the development and testing of middleware software for grid services and security infrastructure.

Following the expansion of the Internet Exchange the department's computer housing facility has undergone several extensions and upgrades in the review period. One of the milestones has been the installation of a no–break installation (batteries and diesel generator) at the end of 2002. Nikhef's own essential servers are also connected to this no–break installation. The experience gained with housing the AMS–IX facility has shown to be very relevant for Nikhef's ambitions in grid computing, due to the large coherence in demands for Tier–1 housing and the AMS–IX facility, especially with regard to cooling and power infrastructure.

The Computer Technology Group consists of about 20 fte, of which 40% at university level, 40% at '*HBO*'–level and 20% at '*MBO*'–level.

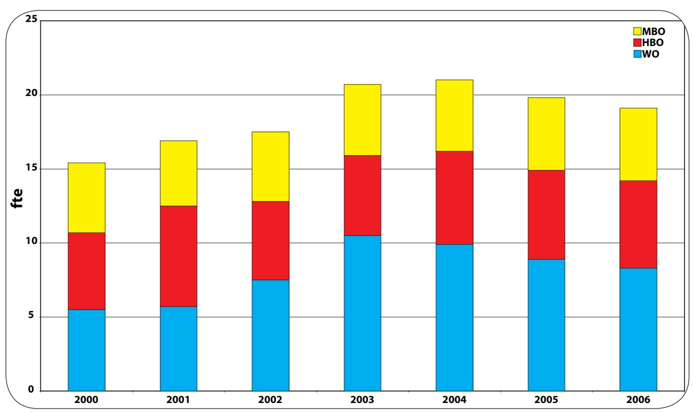


Fig.2. Manpower 2000–2006

7.6 Management & Support Division

Institute Manager: drs. A. van Rijn
Whilst the personnel office and the science communication officer report directly to the Nikhef director, the support division is headed by the institute manager. It consists of the secretariat (including reception desk), financial administration, technical and domestic services, library and two separate staff members: the safety officer and the (scientific) project coordinator.

The main tasks of the secretariat (3.2 fte) are providing management support to the director, institute manager and programme leaders, handling travel requests of Nikhef personnel (about a thousand per year), managing agendas and supporting various boards and meetings. The reception desk (1.0 fte) handles all incoming general phone calls and monitors admittance to the Nikhef–building, with special emphasis on checking admittance to Nikhef's AMS–IX housing facility.

The financial administration (FA, 3.8 fte) includes ordering goods, checking invoices, charging the appropriate budgets and project administration. The bookkeeping is done on a FOM–wide system. The FA has much experience in handling transport (imports and exports) and in administrating VAT. The management of debtors (accounts receivable) is becoming more important (to illustrate: in 2006 Nikhef sent out more than 400 invoices, for a total amount of almost 5 M€). Externally acquired projects, often with different rules regarding accountability, makes project administration an increasingly complex activity.

Technical and domestic services (THD, 7.1 fte) are responsible for building maintenance and installations, (such as clean room control, heating, cooling, power), some of which are shared with adjacent institutes. This includes a 7×24 hrs standby service. Nikhef's THD has also responsibilities for the maintenance of important infrastructures on the western part of the Science Park (also indicated as WCW area), such as the 10 kV system on the premises and all other underground infrastructure (water, gas, fiber ducts).

The library (1.2 fte) provides access to all relevant journals in the field. Following trends in electronic publication Nikhef management is currently planning a significant reduction in both the space and the personnel available for the library.

The project coordinator (1.0 fte) is responsible for the coordination of technical (instrumentation) projects in the production phase. He is currently seconded to CERN to lead the ATLAS SCT installation engineering.

Fig.1. Fire-extinguisher training at Nikhef.

The safety officer, whose job includes radiological and environmental safety, (1.0 fte) is responsible for safety and for taking all necessary measures to ensure healthy working conditions. Nikhef has a team of about 20 employees trained in first aid, fire extinguishing and accident prevention. Nikhef's safety officer is also the central (WCW) coordinator for environmental affairs.

8 Conferences & Workshops

8 Conferences & Workshops organized by Nikhef

GGF1: First Global Grid Forum and European Datagrid Conference
4–9 March 2001, WTCW, Amsterdam
K. Bos, A. van Rijn, M. van den Berg
376 participants

ICHEP 2002: 31st International Conference on High Energy Physics
25–31 July 2002, RAI, Amsterdam
G. van Middelkoop, S. Bentvelsen, P. de Jong, J. Koch, E. Koffeman, E. Laenen, F. Linde, G. van der Steenhoven, A. van Dulmen
880 participants

IWORID 2002: 4th International Workshop on Radiation Imaging Detectors
8–12 September 2002, NIKHEF, Amsterdam
J. Visschers, A. Fornaini, S. Muijs, J–R. Schrader, D. San Segundo Bello, A. van Rijn, C. Doest, A. Donkerlo
100 participants

4th ECFA/DESY Workshop on Physics and Detectors for a 90–800 GeV Linear e^+e^- Collider
1–4 April 2003, NIKHEF, Amsterdam
J. Timmermans, F. Linde, S. de Jong, M. Pohl, P. Kluit, A. van Rijn
255 participants

HEPiX/HEPNT and Large Scale Cluster Computing Workshop
19–23 May 2003, NIKHEF, Amsterdam
W. Heubers, P. Kuipers, E. Schram–Post, C. Doest
65 participants

International Summer School on Particle and Nuclear Astrophysics
17–29 August 2003, Nijmegen
G. van der Steenhoven, P. Mulders, J. Kuijpers, O. Scholten
65 participants

VLVνT: Workshop on Technical Aspects of a Very Large Volume Neutrino Telescope in the Mediterranean Sea
5–8 October 2003, NIKHEF, Amsterdam
E. de Wolf, A. van Rijn, U. Katz (Erlangen)
100 participants

LECC 2003: 9th workshop on electronics for LHC experiments
29 September – 3 october 2003, NIKHEF, Amsterdam
L. Wiggers, A. Pellegrino, A. van Rijn, M. van Beuzekom, R. Kluit
145 participants

Fig. 1. Poster LECC2003.

First National Astroparticle Physics Symposium
26 April 2004, NIKHEF, Amsterdam
F.L. Linde, G. van der Steenhoven
125 participants

EGEE 2004: Enabling Grids for E–science
22–26 November 2004, The Hague
K. Bos, A. van Rijn, J. Wolfrat (SARA), M. Leenaars (NCF), J. Dyer (EGEE/Terena), L. Bos (MCC)
434 participants

Fig. 2. ZEUS Collaboration week October 2005.

Alice Collaboration week
13–16 June 2005, Academiegebouw Utrecht
P. Kuijer, A. Portier, K. Oskamp
146 participants

ANTARES Physics Analysis Workshop
27–30 September 2005, NIKHEF, Amsterdam
M. de Jong, E. de Wolf
30 participants

ZEUS Collaboration Week
8–13 October 2005, NIKHEF, Amsterdam
P. Kooijman, E. Koffeman
116 participants

EUDET–JRA2 Meeting
4–5 January 2006, NIKHEF, Amsterdam
J. Timmermans, H. van der Graaf
30 participants

French–Dutch Workshop on Photodetection
7 February 2006, NIKHEF, Amsterdam
S. Katsenavas, G. van der Steenhoven
20 participants

Workshop on joint R&D projects for future neutrino telescopes
10 May 2006, NIKHEF, Amsterdam
G. van der Steenhoven
15 participants

KM3NeT Photonics Workshop
21–22 June 2006, NIKHEF, Amsterdam
E. de Wolf
39 participants

2nd International Summer School on Astroparticle Physics
29 August – 8 September 2006, Arnhem
G. van der Steenhoven, P. Mulders, J. Kuijpers, R. Timmermans
65 participants

9 Glossary

9 Glossary

Accelerator
A machine in which beams of charged particles are accelerated to high energies. Electric fields are used to accelerate the particles whilst magnets steer and focus them.
A collider is a special type of accelerator where counter–rotating beams are accelerated and interact at designated collision points.
A synchrotron is an accelerator in which the magnetic field bending the orbits of the particles increases with the energy of the particles. This keeps the particles moving in a closed orbit.

ALICE (A Large Ion Collider Experiment)
One of the four major experiments that will use the *LHC*.

AmPS (Amsterdam Pulse Stretcher)
Storage and stretcher ring for 720 MeV electrons, built (1989-1992) and operated (1992-1998) at NIKHEF. It provided an extracted beam with currents up to 10 μA and duty factor over 50%, and a stored polarized electron beam with currents up to 110 mA.

AMS–IX (Amsterdam Internet Exchange)
The main place in the Netherlands for Internet Service Providers to interconnect and exchange IP traffic with each other at a national or international level.

Annihilation
A process in which a particle meets its corresponding antiparticle and both disappear. The resulting energy appears in some other form: as a different particle and its antiparticle (and their energy), as many mesons, or as a single neutral boson such as a Z^0–boson. The produced particles may be any combination allowed by conservation of energy and momentum.

ANTARES (Astronomy with a Neutrino Telescope and Abyss Environmental Research)
Large area water *Cherenkov* detector in the deep Mediterranean Sea near Toulon, optimised for the detection of muons resulting from collisions of high–energy cosmic neutrinos with water.

Antimatter
Every kind of matter particle has a corresponding antiparticle. Charged antiparticles have the opposite electric charge to their matter counterparts. Although antiparticles are extremely rare in the Universe today, matter and antimatter are believed to have been created in equal amounts in the *Big Bang*.

Antiproton
The antiparticle of the proton.

ApPEC (Astroparticle Physics European Coordination)
Consortium of national funding agencies aiming to develop long–term strategies in the field.

Aspera
Sixth Framework Programme for co–ordination across European funding agencies for financing astroparticle physics.

ATLAS (A Toroidal LHC Apparatus)
One of the four major experiments that will use the *LHC*.

BaBar
B–$\overline{B}$ (anti–B) detector at SLAC's B Factory. Named for the elephant in Laurent DeBrunhoff's children's books.

Bates
(No acronym) The Massachusetts Institute of Technology Bates Linear Accelerator Center.

Beam
The particles in an accelerator are grouped together in a beam. Beams can contain billions of particles and are divided into discrete portions called bunches. Each bunch is typically several centimeters long and can be just a few μm in diameter.

B Factory
SLAC's electron–positron collider, built to produce B–mesons, started in 1999.

Big Bang
The name given to the explosive origin of the Universe.

BNL (Brookhaven National Laboratories)
Laboratory where the *RHIC* accelerator is located.

Boson
The general name for any particle with a spin of an integer number (0, 1 or 2…) of quantum units of angular momentum. (named for Indian physicist S.N. Bose). The carrier particles of all interactions are bosons. Mesons are also bosons.

Calorimeter
An instrument for measuring the amount of energy carried by a particle.

Cherenkov radiation
Light emitted by fast–moving charged particles traversing a dense transparent medium faster than the speed of light in that medium.

CHORUS (CERN Hybrid Oscillation Research Apparatus)
Experiment at CERN.

CLIC (Compact LInear Collider)
A site–independent feasibility study aiming at the development of a realistic technology at an affordable cost for an electron–positron linear collider for physics at multi–TeV energies.

Collider
See *Accelerator*.

Cosmic ray
A high–energy particle that strikes the Earth's atmosphere from space, producing many secondary particles, also called cosmic rays.

CP violation
A subtle effect observed in the decays of certain particles that betrays nature's preference for matter over antimatter.

CWI
Dutch Centre for Mathematics and Computer Science, Amsterdam

DØ (named for location on the Tevatron Ring)
Collider detector, studies proton–antiproton collisions at Fermilab's Tevatron.

Dark matter
Only 4% of the matter in the Universe is visible. The rest is known as dark matter and dark energy. Finding out what it consists of is a major question for modern science.

D–brane
In string theory, a higher dimensional membrane that provides an anchoring surface for strings.

Detector
A device used to measure properties of particles. Some detectors measure the tracks left behind by particles, others measure energy. The term 'detector' is also used to describe the huge composite devices made up of many smaller detector elements.

Dipole
A magnet with two poles, like the north and south poles of a horseshoe magnet. Dipoles are used in particle accelerators to keep the particles on a closed orbit.

EGEE (Enabling Grids for E–SciencE)
An EU–funded project led by CERN, now involving more than 90 institutions over 30 countries worldwide, to provide a seamless Grid infrastructure that is available to scientists 24 hours a day.

Elliptic Flow
When two heavy nuclei collide in the center of the *STAR* detector, the initial shape of the collision zone is usually an ellipse. Pressure in the liquid seeks to make the matter round, and so makes the liquid flow faster in the shorter direction. This elliptic flow can be measured in the speed and direction of the particles when they reach the detector, and the flow is largest when many particles are emitted from a given collision. The number of particles emitted depends on the intensity of that collision: how 'head–on' the collision between the two nuclei was.

Endcap
Detector placed at each end of a barrel–shaped detector to provide the most complete coverage in detecting particles.

EUDET (European Detector R&D towards the International Linear Collider)
EU–funded R&D project for research on future *ILC* detectors.

EUnet
European UNIX network, Europe's largest Internet Service Provider.

eV (Electronvolt)
A unit of energy or mass used in particle physics. One eV is extremely small, and units of million electronvolts, MeV, or thousand million electronvolts, GeV, are more common in particle physics. The latest generation of particle accelerators reaches up to several million million electronvolts, TeV. One TeV is about the energy of motion of a flying mosquito.

Fermion
General name for a particle that is a matter constituent, characterized by spin in odd half integer quantum units (1/2, 3/2, 5/2...). Named for Italian physicist Enrico Fermi. Quarks, leptons and baryons are all fermions.

Forces
There are four fundamental forces in nature. Gravity is the most familiar to us, but it is the weakest. Electromagnetism is the force responsible for thunderstorms and carrying electricity into our homes. The two other forces, weak and strong, are connected to the atomic nucleus. The strong force binds the nucleus together, whereas the weak force causes some nuclei to break up. The weak force is important in the energy–generating processes of stars, including the Sun. Physicists would like to find a theory that can explain all these forces in one common framework. A big step forward was made in the late 1970s when the electroweak theory uniting the electromagnetic and weak forces was proposed. This was later confirmed in a Nobel prize–winning experiment at CERN.

FTE (Full Time Equivalent)
Unit of manpower

GeV
See *Electronvolt*.

Globus
Grid middleware toolkit development in the USA.

Gluon
See *Particles*.

Gravitational wave
The gravitational analog of an electromagnetic wave whereby gravitational radiation is emitted at the speed of light from any mass that undergoes rapid acceleration.

Grid
A service for sharing computer power and data storage capacity over the Internet.

Hadron
A subatomic particle that contains quarks, antiquarks, and gluons, and so experiences the strong force. (See also *Particles*)

HERA
Hadron–Electron Ring Accelerator at DESY.

HERA–B
Fixed–target experiment at DESY, to investigate *CP violation* in the B–meson.

HERMES
DESY fixed–target experiment to explore spin.

High–Energy Physics
A branch of science studying the interactions of fundamental particles; called 'high–energy' because very powerful accelerators produce very fast, energetic particles probing deeply into other particles.

Higgs boson
A particle predicted by theory, linked with the mechanism by which physicists think particles acquire mass.

HiSPARC (High School Project on Astroparticle Cosmic Rays)
Cosmic–ray experiment with schools in the Netherlands.

ILC
International Linear Collider, now under study. A possible future electron–positron accelerator, proposed to be built with international participation.

Kaon
A meson containing a strange quark (or antiquark). Neutral kaons come in two kinds, long–lived and short–lived. The long–lived ones occasionally decay into two pions, a CP–violating process. (See also *Particles*)

KM3Net (Cubic Kilometre Neutrino Telescope)
Planned European deep–sea neutrino telescope with a volume of at least one cubic kilometre at the bottom of the Mediterranean Sea.

LCAS (Local Centre Authorization System)
System to verify the *GRID* authorization.

LCG (LHC Computing Grid)
The mission of the LCG is to build and maintain a data–storage and analysis infrastructure for the entire high–energy physics community that will use the LHC.

LCMAPS (Local Credential MAPping Service)
Provides all credentials necessary to access *GRID* services within a centre.

LEP
The Large Electron–Positron collider, which ran until 2000.

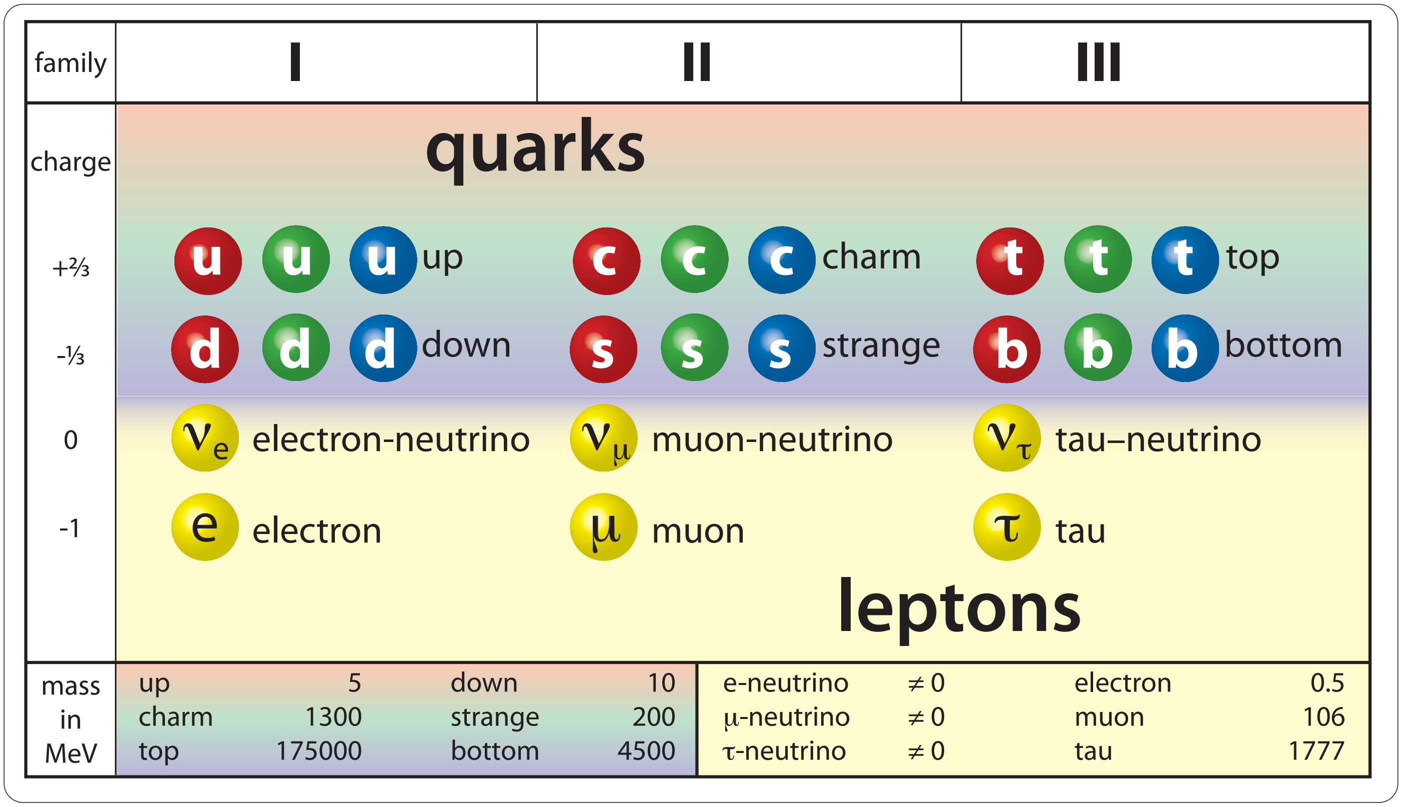


Fig. 1. The Standard Model.

Lepton
A class of elementary particles that includes the electron. Leptons are particles of matter that do not feel the strong force. (see also *Particles*)

LHC (Large Hadron Collider)
CERN's next big accelerator.

LHCb (Large Hadron Collider beauty)
One of the four major experiments that will use the *LHC*.

Linac
An abbreviation for linear accelerator.

LISA (Laser Interferometric Space Array)
ESA/NASA mission, the first space–based gravitational wave observatory; three spacecraft, orbiting around the Sun as a giant equilateral triangle 5 million km on a side.

Lofar (Low Frequency Array)
First radio telescope of a new generation of astronomical facilities, mainly in the Netherlands.

Muon
A particle similar to the electron, but some 200 times more massive. (See also *Particles*)

Muon chamber
A device that identifies muons, and together with a magnetic system creates a muon spectrometer to measure momenta.

Neutrino
Uncharged, weakly interacting lepton, most commonly produced in nuclear reactions such as those in the sun. There are three known flavours of neutrino, corresponding to the three flavours of leptons. Recent experimental results indicate that all neutrinos have tiny masses. (See also *Particles*.)

NLO (Next–to–Leading Order)
Second order calculations in perturbative *QED* and *QCD*.

Nucleon
The collective name for protons and neutrons.

Particles
There are two groups of elementary particles, quarks and leptons, with three families each. The quarks are named up and down, charm and strange, top and beauty (or bottom). The leptons are electron and electron neutrino, muon and muon neutrino, tau and tau neutrino. There are four fundamental forces, or interactions, between particles, which are carried by special particles called bosons. Electromagnetism is carried by the photon, the weak force by the charged W and neutral Z bosons, the strong force by the gluon; gravity is probably carried by the graviton, which has not yet been discovered. Hadrons are particles that feel the strong force. They include mesons, which are composite particles made up of a quark–antiquark pair, and baryons, which are particles containing three quarks. Pions and kaons are types of meson. Neutrons and protons (the constituents of ordinary matter) are baryons; neutrons contain one up and two down quarks; protons two up and one down quark.

Pierre Auger Project
(No acronym) International experiment in Argentina to track down the origin of ultra–high–energy cosmic rays.

Photon
See *Particles*.

Pion
See *Particles*.

Positron
The antiparticle of the electron.

Quantum electrodynamics (QED)
The theory of the electromagnetic interaction.

Quantum chromodynamics (QCD)
The theory for the strong interaction analogous to QED.

Quark
The basic building blocks of matter, see *Particles*.

Quark–gluon plasma (QGP)
A new kind of plasma, in which protons and neutrons are believed to break up into their constituent parts. QGP is believed to have existed just after the Big Bang.

RASNIK (Red Alignment System NIKHEF)
Optical alignment system where a pattern is projected by a lens on a CCD and deviations measured.

RELAXD
EU–funded development of the large area fast detector system using Medipix technology.

RHIC
Brookhaven's Relativistic Heavy Ion Collider; began operation in 2000. RHIC collides beams of gold ions to study what the universe looked like in the first few moments after the Big Bang.

RICH (Ring Imaging CHerenkov)
A kind of particle detector that uses the light emitted by fast–moving charged particles as a means of identifying them.

RIPE (Réseaux IP Européenne)
A collaboration between European networks which use the *TCP/IP* protocol suite. RIPE NIC is an IP registry, allocating Internet Protocol numbers to the European region.

SARA
Academic Computing Services of Amsterdam.

Scintillation
The flash of light emitted by an electron in an excited atom falling back to its ground state.

Solenoid
An electromagnet produced by current flowing through a single coil of wire. Many particle detectors are surrounded by a solenoidal magnet, since this produces a fairly uniform magnetic field within.

Spectrometer
In particle physics, a detector system containing a magnetic field to measure momenta of particles.

Spin
Intrinsic angular momentum of a particle.

Standard Model
A collection of theories that embodies all of our current understanding about the behaviour of fundamental particles.

STAR
Experiment at *RHIC*.

String Theory
A theory of elementary particles incorporating relativity and quantum mechanics in which the particles are viewed not as points but as extended objects. String theory is a possible framework for constructing unified theories that include both the microscopic forces and gravity. See *Forces*.

Supersymmetry
A theory linking matter and forces.

SURFnet
Networking organisation in the Netherlands.

Synchrotron
See *Accelerator*.

TCP/IP *(Transmission Control Protocol / Internet Protocol)*
Suite of communications protocols to connect hosts on the Internet, invented in 1981.

TDR (Technical Design Report)
The blueprint for an (LHC) sub detector system.

Technology transfer
The promotion and dissemination of technologies, developed originally for scientific research, to third partied for socio–economic and cultural benefits.

TeV.
See *Electronvolt*.

Tevatron
Fermilab's 2–TeV proton–antiproton accelerator.

Tier–1
First tier (category) in the *LHC* regional computing centers. Tier–0 is the facility at CERN taking, reconstructing and storing the data.

Trigger
An electronic system for spotting potentially interesting collisions in a particle detector and triggering the detector's readout system to record the data resulting from the collision.

Valorisation
French term for dissemination and exploitation of results.

Vertex detector
A detector placed close to the collision point in a colliding beam experiment so that tracks coming from the decay of a short–lived particle produced in the collision can be accurately reconstructed and seen to emerge from a 'vertex' point that is different from the collision point.

Virgo
Detector near Pisa for gravitational waves: a Michelson laser interferometer made of two orthogonal arms, each 3 km long.

W–boson
A carrier particle of weak interactions; involved in all electric–charge–changing weak processes.

Z^0–boson
A carrier particle of weak interactions; involved in all weak processes that do not change flavour and charge.

ZEUS (Not an acronym, but goes with HERA)
Collider experiment at DESY's *HERA*.