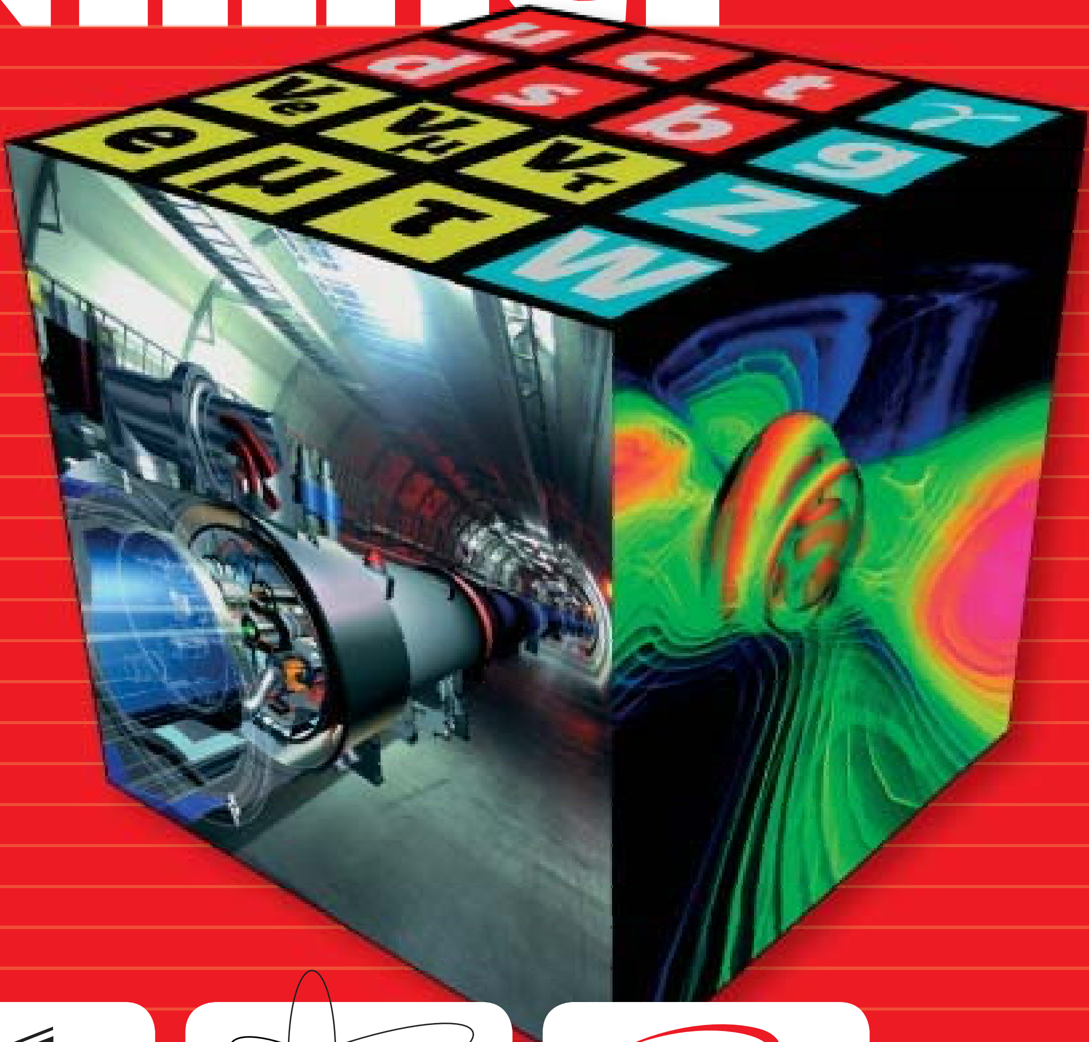
Self-evaluation
Report
2005-2010

FOM Institute for Subatomic Physics
Nikhef



NIKHEF FOM NWO

FOM-11.0936

Self-evaluation Report 2005-2010

FOM Institute for Subatomic Physics Nikhef

NIKHEF

Colophon

Publication edited for Nikhef
Nationaal instituut voor subatomaire fysica
National Institute for Subatomic Physics

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This document is produced for the NWO evaluation of the FOM Institute for Subatomic Physics. It describes the activities in the period 2005–2010. Nikhef is the National Institute for Subatomic Physics in the Netherlands, in which the Foundation for Fundamental Research on Matter, the University of Amsterdam, VU University Amsterdam, Radboud University Nijmegen and Utrecht University collaborate. Nikhef coordinates and supports the activities in experimental particle and astroparticle physics in the Netherlands. The Foundation for Fundamental Research on Matter (FOM) is part of the Netherlands Organisation for Scientific Research (NWO).

Nikhef participates in experiments at the Large Hadron Collider at CERN, notably ATLAS, LHCb and ALICE. Astroparticle physics activities at Nikhef are fourfold: the ANTARES and KM3NeT neutrino telescope projects in the Mediterranean Sea; the Pierre Auger Observatory for cosmic rays, located in Argentina; gravitational-wave detection via the Virgo interferometer in Italy, and the projects LISA and Einstein Telescope; and the direct search for Dark Matter with the XENON detector in the Gran Sasso underground laboratory in Italy. Detector R&D, design and construction take place at the laboratory located at Science Park Amsterdam as well as at the participating universities. Data analysis makes extensive use of large-scale computing at the Tier-1 facility operated by the Grid group. 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

Poster for the documentary –sponsored by Nikhef– about Peter Higgs and the hunt for the eponymous particle.
Image © Peter Tuffy | graphic design Studio HB

1.1 Introduction

FOM-Nikhef, located at the Science Park Amsterdam, is the flagship of the Nikhef Collaboration with as other members four universities: the University of Amsterdam (UvA); the VU University Amsterdam (VU); the Radboud University Nijmegen (RU); and the Utrecht University (UU). Nikhef coordinates and supports activities in experimental subatomic physics in the Netherlands. FOM-Nikhef is an integral part of the FOM organisation, the Foundation for Fundamental Research on Matter.

The history of Nikhef goes back to 1946 when FOM, Philips' Gloeilampenfabrieken (light bulb factories) and the city of Amsterdam (for the university) founded the Institute for Nuclear Physics Research (IKO), that would build Europe's first synchrocyclotron. Nikhef itself was established officially in 1975 as a joint nuclear and high–energy physics national research institute with the leading partner being FOM. The nuclear physics research community embarked on the construction and subsequent exploitation of an on–site 500 MeV electron linac (MEA) followed by a 720 MeV stretcher and storage ring (AmPS) (1992–1998). The research activities of the high–energy physics community were primarily focused on the European particle physics laboratory CERN near Geneva. With the shutdown of AmPS in 1998, Nikhef redirected its focus from nuclear and high–energy physics research to accelerator–based high–energy physics research, in particular with the Large Hadron Collider (LHC) at CERN, and to research in the emerging field of astroparticle physics.

By the end of the 2005–2010 review period, Nikhef's experimental activities were focused on three running experiments (ATLAS, LHCb and ALICE) at the LHC at CERN and four endeavours in astroparticle physics (neutrino telescopes, gravitational waves, cosmic rays and dark matter). During the review period two activities (ZEUS and HERMES) at the HERA electron-proton facility at DESY were concluded after more than a decade of successful operation. Also the three experiments (DØ, BaBar and STAR in the USA) which Nikhef joined in the nineties to gain experience (or better: to make discoveries) in hadron collider physics, B–physics and heavy–ion physics while LHC-detector construction was still in full swing, were basically terminated. Nikhef's experimental activities benefit from direct interactions with theorists of Nikhef's in-house theory department and members of Nikhef's large detector R&D group. In addition the Netherlands provides 'Tier–1' grid compute services to the LHC experiments and thereby gives the physicists at Nikhef engaged in data analysis activities access to state-of-the-art local computing services. Of course, each of these three communities (theory, detector R&D and grid computing) also pursues its own independent scientific research program. Nikhef's detector R&D activities also proved successful in attracting the interest of in-

Nikhef mission statement in the year 2007

The mission of Nikhef is to study the interactions and structure of all elementary particles and fields at the smallest distance scale and the highest attainable energy, and to connect the findings of today's research in a qualitative and preferably quantitative manner to the fierce processes occurring in the early Universe, 13.7 billion years ago.

Two complementary approaches are followed:
- Accelerator-based particle physics
  Experiments studying interactions in particle collision processes at particle accelerators, in particular at CERN;
- Astroparticle physics
  Experiments studying interactions of particles and radiation emanating from the Universe, with the Earth.

Nikhef coordinates and leads all Dutch experimental activities in these fields.

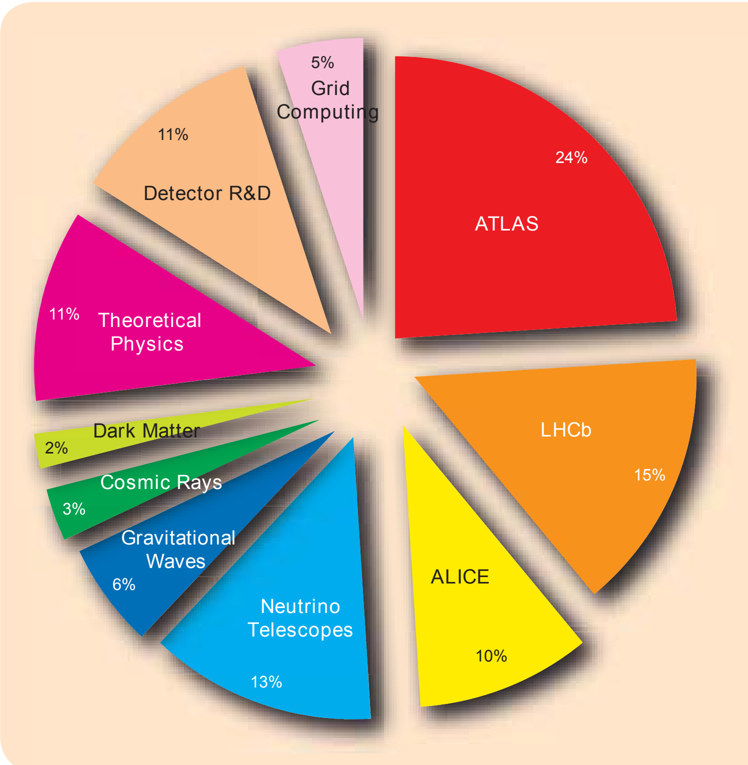

Figure 1.1.1. A breakdown of the 2010 Nikhef budget over the various research programmes.

dustrial partners. E.g. PANalytical nowadays sells a commercial product based on a detection unit co-developed by Nikhef and two start-up companies have begun to market sensors developed at Nikhef. The relative share of Nikhef's activities is shown in the pie chart (Fig. 1.1.1) for 2010. Note that the ratio for accelerator-based and astroparticle-physics experiments is now close to the 2:1 goal, as set in the Nikhef Strategic Plan 2007-2012.

In the last years education and notably outreach activities have profited from the huge media attention surrounding the start-up and running of the LHC. As a result, a very large fraction of the Dutch population is nowadays aware of Nikhef's research activities, in particular of the LHC project. Nikhef itself is very active in areas ranging from public lectures, movies (such as the "Mass Mystery" and "Higgs – into the heart of imagination" featuring Peter Higgs and a leading Nikhef physicist), masterclasses and CERN visits for secondary school teachers and students to regular interviews for newspapers, radio and television. Regarding education, Nikhef staff physicists lecture at all Dutch regular and technical universities with a science department (and sometimes even at secondary schools and primary schools). Nikhef hosts the 'Particle- and Astroparticle Physics' master programme as well as the national 'Research School for Subatomic Physics' in which about 75 PhD students are enrolled.

In the following sections of this chapter first the recommendations of the Evaluation Panel reviewing Nikhef in 2007 and the conclusions of ECFA which visited Nikhef in 2005 are presented. Next, statistical information regarding publications and PhDs is summarised. The last sections summarise Nikhef's internal organisation, personnel and financial information. Chapters 2 and 3 give the achievements and highlights of Nikhef's running and completed programmes, respectively. Chapter 4 deals with Nikhef's knowledge transfer activities. In Chapter 5 Nikhef's involvement in outreach, communication and education is summarised. Finally, in Chapter 6 Nikhef's technical and support infrastructure is presented. Even though the review only covers the period 2005–2010, often plots give information from 2000 onwards, this to reflect that many of Nikhef activities have a much longer scope than just six years.

I – Scientific (fte – 2010, FOM-Nikhef & university groups)	
Permanent scientific staff	60.1
PhD students	75.2
Post–docs	30.6
Total I	165.9
II – Management, technical and general support (fte – 2010, FOM-Nikhef)	
Management	
Director	1.0
Institute manager	1.0
Personnel/HRM officer	0.8
Subtotal	2.8
Technical	
Electronic technology	25.5
Computer technology	22.8
Mechanical engineering	16.7
Mechanical workshop	15.6
Project management	1.8
Subtotal	82.4
General	
Financial administration	3.8
Personnel/HRM administration	1.0
Library	0.6
Technical and domestic services	8.6
Secretariat and reception	4.4
PR & communication	1.8
Occupational health & safety	1.0
Education (HiSPARC)	2.3
Staff	1.3
Subtotal	24.8
Total II	110.0
Total I & II	275.8
III – Other groups (persons 2010)	
Guests (researchers, retired staff)	30.0
Master students	59.0

Table 1.1.1.
Overview of Nikhef personnel in fte (2010).

1.2 Recommendations of external evaluation boards

The NWO-international review panel evaluated Nikhef in 2007. The overall conclusion of this panel is best summarised in their own words: "The committee was very impressed with the scientific achievements of the SAF/Nikhef institute. Nikhef has an excellent reputation in particle physics as a world-class partner, with strength in breadth and depth, from detector development and construction to physics analysis, with a first class record of innovation and leadership. The close collaboration with the four Universities within the Nikhef consortium allows the Netherlands to make major contributions to large projects, and enables them to take on highly visible leadership positions. This experience is now being used in the development of a new programme in astroparticle physics, where Nikhef has established itself in a remarkably short time."

The undisputed crucial issue in this review was whether or not Nikhef would succeed to define a sustainable programme in the new and promising field of astroparticle physics without jeopardizing the full exploitation of the enormous discovery potential offered by the LHC project. To do so the panel strongly recommended an increase of Nikhef's baseline funding i.e. 'Mission' budget. This resulted in a 450 k€ structural increase of the Mission budget by FOM, and two lump sum subsidies from NWO covering each three years: 1350 k€ for 2008-2010 and 3400 k€ for 2009-2011 (strictly speaking, the 3400 k€ was not related to Nikhef's mission evaluation, but granted as so-called 'dynamiseringssubsidie'). This not only allowed Nikhef to become a prominent partner in four astroparticle physics experiments but also to replace retired personnel in its R&D and theory departments by young talented physicists, in accordance with the recommendations of the review panel. These very positive developments also indirectly led to three new FOM-programmes for Nikhef: "The origin of cosmic rays"; "Theoretical particle physics in the era of the LHC"; and "Gravitational physics – the dynamics of spacetime". Moreover, NWO awarded a large (8.8 M€) investment subsidy for the construction of KM3NeT, the next generation neutrino telescope at the bottom of the Mediterranean Sea. The only dissonant among all these positive developments is that the incidental NWO subsidies expire in 2011, which effectively would reduce the Nikhef Mission budget by about 1 M€ per 2012.

The panel encouraged Nikhef to continue to capitalise upon its knowledge transfer activities in the broadest sense i.e. both towards other research disciplines and towards industry. In the review period Nikhef established contacts with NIOZ ("Royal Netherlands Institute for Sea Research"), this led NIOZ to become a member of both the ANTARES and KM3NeT consortia working primarily on deep-sea research (ANTARES) and contributing innovative deployment concepts (KM3NeT). Through the 'BiG Grid' project –the Dutch e-science grid– Nikhef is in contact with numerous Dutch communities to provide them access to the Dutch computing grid. Vis-à-vis industry, two start-up companies are being established: one using Nikhef's renowned RASNIK alignment concept ("Sensiflex") and one ("Amsterdam Scientific Instruments", ASI) aiming to provide CMOS based imaging detectors to the light source (XFEL at DESY/Hamburg and LCLS at SLAC/Stanford) communities. Finally, Nikhef has preliminary contacts with a few, large Dutch companies such as Philips (large area X-ray detectors for medical applications) and Shell (huge sensor networks both land-based and in the deep sea).

Since the shutdown of Nikhef's 720 MeV electron accelerator complex in 1998 many review panels have repeatedly urged Nikhef to revive its accelerator technology activities (including training). Nikhef joined the 'CLIC test facility 3' (CTF3) collaboration in 2010 and will deliver alignment systems. Nikhef established contact with a Dutch industry (VDL), which delivers very high-precision prototype CLIC RF-structures to CERN. Nikhef also follows with great interest the ambition of KVI to build a compact soft X-ray Free Electron Laser (ZFEL) using CLIC technology.

A quote from the SAC report of February 2011:

"Dutch scientists, after making important contributions to the hardware, have kept their prominent position in all collaborations with a very significant (even outsized) role in producing the first physics results. They are very visible and well represented in a number of leadership and management positions, including the position of 'upgrade coordinator' in both ATLAS and ALICE. The SAC congratulates Nikhef and all LHC teams for this outstanding success and looks forward to an exciting and productive LHC exploitation, which should last well into the next decade."

A quote from the Netherlands Observatory of Science and Technology (NOWT) report "Science and Technology Indicators 2010":

"Joining forces, through specialized inter-university partnerships and other R&D networks seems to be a success formula for creating economy of scale and hence to reach world top class. A a result, some research Leading Technological Institutes (TTI's) and Nikhef have a big citation impact on international science."

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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Figure 1.2.1 Letter sent by the international ECFA committee to the Minister of Education after the visit in 2005.

- 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)

1.3 Impact: publications

In the 2005–2010 review period, Nikhef published 1280 scientific articles in refereed international journals, according to the SPIRES database, and 76 PhD degrees were awarded. See for a detailed breakdown of the scientific publications Table 1.3.1 and for breakdowns per experiment of the theses and publications Tables 1.3.2 and 1.3.3, respectively. The differences between the number of SPIRES database entries in Table 1.3.1 and that as counted by the experimental groups in Table 1.3.3 are due to differences in determination of publication dates, missing journals in the SPIRES database and conference contributions not counted in the SPIRES database.

Nikhef's scientific papers published in this period are collected in a separate document. Typically, experiments in a building phase produce relatively few papers per year, on design studies, hardware, electronics, and beam tests. Running experiments, however, produce a large number of papers per year. Apart from papers in scientific journals, specific contributions of Nikhef physicists are documented in internal notes, which are also peer reviewed. These are traditionally not listed in overviews, but are gaining importance.

PhD students at Nikhef are enrolled in the accredited Dutch 'Research School for Subatomic Physics' and follow its educational programme. Typically, 15–20 theses are produced per year. The extraordinarily low number of PhD theses in 2010 is because many were deferred to 2011 to take advantage of the first year of LHC data.

Figure 1.3.1. Cover of Science magazine showing the correlation between the origin of high-energy cosmic rays as measured by the Pierre Auger Collaboration and the location of active galactic nuclei. Image by Kelly Krause/Science.

Journal	number
Phys. Rev. D	286
Phys. Rev. Lett.	269
Phys. Lett. B	127
Eur. Phys. J	93
Nucl. Instrumen. Meth.	76
Phys. Rev. C	67
JHEP	50
Nucl. Phys.B	34
J Phys. Conf. Ser.	33
Nucl. Phys. B. Proc.	31
JINST	23
Class. Quant. Grav.	20
Astropart. Phys.	18
AIP Conf. Proc.	18
J Phys. G	14
J Cosm. Astropart. Phys.	12
Acta Phys. Polon.	9
Nucl. Phys. A	9
Comp. Phys. Comm.	7
IEEE Trans. Nucl. Sci.	7
Other	77
Total	1280

Table 1.3.1. A breakdown by journal of scientific publications in the SPIRES database.

	2005	2006	2007	2008	2009	2010	Total
ATLAS	2	2	1	2	8	3	18
LHCb	3	3	2	1	2	4	15
ALICE		1	2	3	1		7
Neutrino Telescopes	1	1	1	1	1		5
Gravitational Waves							
Cosmic Rays							
Theoretical Physics	1	2	5	2	4	1	15
Detector R&D	1		1	1	2		5
Grid Computing							
ZEUS				1			1
HERMES	2		3				5
Miscellaneous			1	5			6
Total	10	9	16	16	18	8	77

Table 1.3.2. Number of PhD theses produced per programme and per year.

	2005	2006	2007	2008	2009	2010	Total
ATLAS	35	30	38	66	51	76	296
LHCb	57	71	73	66	54	42	363
ALICE	36	35	26	16	28	33	174
Neutrino Telescopes	3	4	4	4	5	8	28
Gravitational Waves			6	14	4	19	43
Cosmic Rays			3	4	4	10	21
Theoretical Physics	19	25	26	28	40	67	205
Detector R&D	4	9	8	3	10	5	39
Grid Computing	4	3	2	4	2	2	17
ZEUS	10	2	23	7	13	11	66
HERMES	6	6	6	5	4	9	36
Miscellaneous	33	41	22	15	25	8	144
Total	207	226	237	232	240	290	1432

Table 1.3.3. Number of publications in peer-reviewed journals (incl. conference proceedings) produced per programme and per year.

Bibliometric Studies

A quote from the bibliometric study of Nikhef publications by the Centre of Science and Technology (CWTS) of Leiden University in 2007:

"Remarkably, the impact of NIKHEF is significantly above the world subfield average (FCSm) in every single year, varying between 49% and 222% above average. In the most recent year of the trend analysis, citation impact is 185% above the world subfield average, a significant difference. Moreover, NIKHEF publications are published in rather high impact journals during the whole period. In the large majority of years, NIKHEF citation impact is also significantly above the citation impact level of their journal set. On the crown indicator (CPP/FCSm), the field-normalized citation impact of NIKHEF peaks above 2.5 (150% above the world average) early on in 1989 and 1991, and very recently in 2001 and 2003."

Quotes from the Netherlands Observatory of Science and Technology (NOWT) report "Science and Technology Indicators 2010":

"Also among the non-university research institutes, we find a significant growth in output for almost all public-funded institutes, while the large R&D-intensive firms show a downward trend. Some institutes score very well with their citation impact, including two of the Dutch Technology Institutes (TTIs). This is also the case for NWO's Amolf FOM Institute, Academy's Hubrecht Institute, and Nikhef. Nikhef shows a marked increase in citation impact as well."

"Among the non-university, non-TTI institutes, with an impact score above 2, NWO's Amolf FOM Institute, KNAW-Hubrecht's Institute, and Nikhef receive twice the world average of citations."

1.4 Organisation

The Nikhef director is appointed by FOM for a 5-year term with the option of a second 5-year term. During the full period covered by this review prof.dr. F. Linde has been re-appointed as director with a mandate ending in December 2014.

The main research activities are organised as 'programmes' which follow the FOM–funding scheme. Each programme has a programme leader (PL), appointed by the director, who is responsible for all activities and personnel in his/her research line, including the share contributed by the university groups. In 2011, FOM-programmes cover: three LHC experiments (ATLAS, LHCb, ALICE); three astroparticle physics experiments: neutrino telescopes (ANTARES/KM3NeT); gravitational waves (Virgo/LISA/ET); cosmic rays (Pierre Auger Observatory); and theoretical physics. The Nikhef-mission budget is used to (temporarily) support research activities without a corresponding FOM-programme subsidy. In 2011, the Nikhef-mission budget covers: grid computing; detector R&D; and a dark matter experiment (XENON).

The technical expertise is organised in three groups, each led by a technical group leader (TGL): computing; electronics; and mechanics. 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; technical and domestic services; occupational health and safety; secretariat & reception; project management support; and library. Two other staff departments, personnel affairs and science communication, report directly to the director.

Boards, bodies and meetings

The 'Executive Board' of FOM is the main decision-making body of the foundation and is responsible for governing the affairs of the institute. Meetings with the Executive Board are scheduled when necessary, e.g. for discussions on strategic issues. The director and institute manager have a quarterly meeting with the director of FOM and the FOM programme officer assigned to the institute. Quarterly meetings also take place with the directors of all three FOM institutes and the FOM management; these are chaired by the FOM director. Once a year the directors of the FOM institutes attend a joint meeting of the Executive Boards of FOM and NWO (FOM's main funding agency).

Twice a year, FOM and the four university partners meet in the 'Nikhef board' (consisting of six members: two members assigned by FOM, and one by the governing boards of each of the four university partners). This board approves the joint scientific programme of Nikhef and the annual budgets, as provided by each partner.

The 'Scientific Advisory Committee' (SAC), consisting of six international experts[1] in Nikhef's fields of research, is the external advisory body for Nikhef and meets once a year. Members are appointed by the Nikhef board.

Daily management of the institute takes place in the 'Director's Team' (DT), consisting of the director, institute manager and head of the personnel department, supported by the head of the secretariat. The DT meets bi-weekly and organises each year a 2-day brainstorm event outside Nikhef. The DT has annual so-called 'platform' meetings 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 DT on topics requiring immediate attention.

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 bi-annual elections. The NOR is consulted by the director in cases prescribed by law, in particular on safety and working conditions.

Scientific policy is discussed in Nikhef's scientific council ('Wetenschappelijke Advies Raad' – WAR), which serves as the internal advisory body. The WAR meets every two months. For the staff meeting ('stafoverleg'), held at the same frequency as the WAR and actually directly preceding it, all scientific staff and the TGLs are invited to attend. The agenda usually has a large overlap with the WAR agenda; this enables a better and more complete contribution to the discussion, before treatment in the WAR.

Project structure for scientific instrumentation

For more than a decade Nikhef has been using a so-called 'project matrix' structure for carrying out large scientific instrumentation projects approved by the WAR. Such a project, which is usually part of a larger programme, is assigned a project leader, who composes a project plan that contains –apart from technical & financial requirements– the estimated manpower requirements and a planning with milestones. In discussions with the technical

1. Roger Cashmore (Oxford, Brasenose College), Catherine De Clercq (Brussel, Vrije Universiteit Brussel), Thomas Hebbeker (Aachen, RWTH), Yannis Karyotakis (Annecy le Vieux, LAPP), Andre Rubbia (Zürich, ETH), Jürgen Schukraft (Genève, CERN).

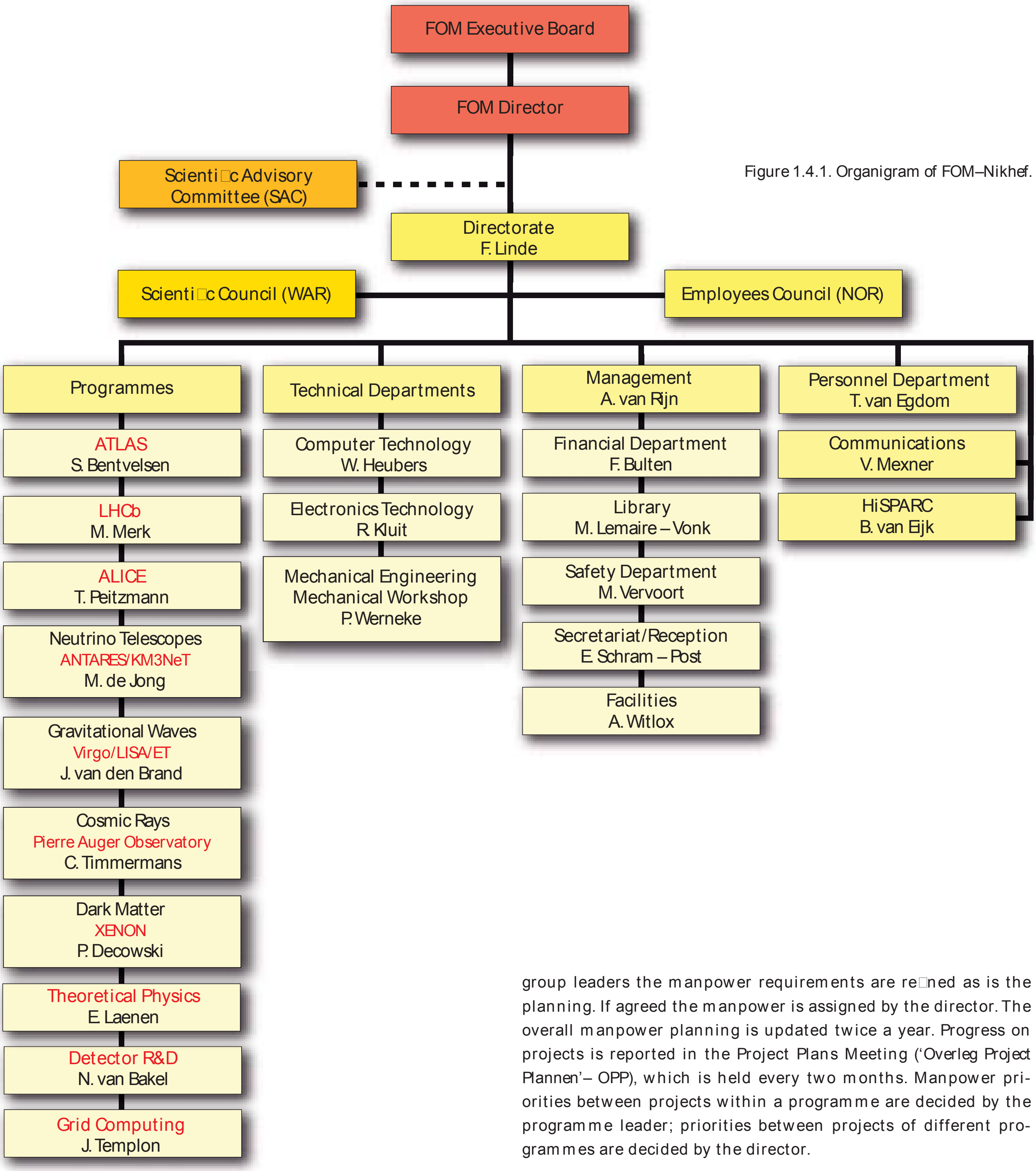


Figure 1.4.1. Organigram of FOM–Nikhef.

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 two months. Manpower priorities between projects within a programme are decided by the programme leader; priorities between projects of different programmes 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.

1.5 Personnel

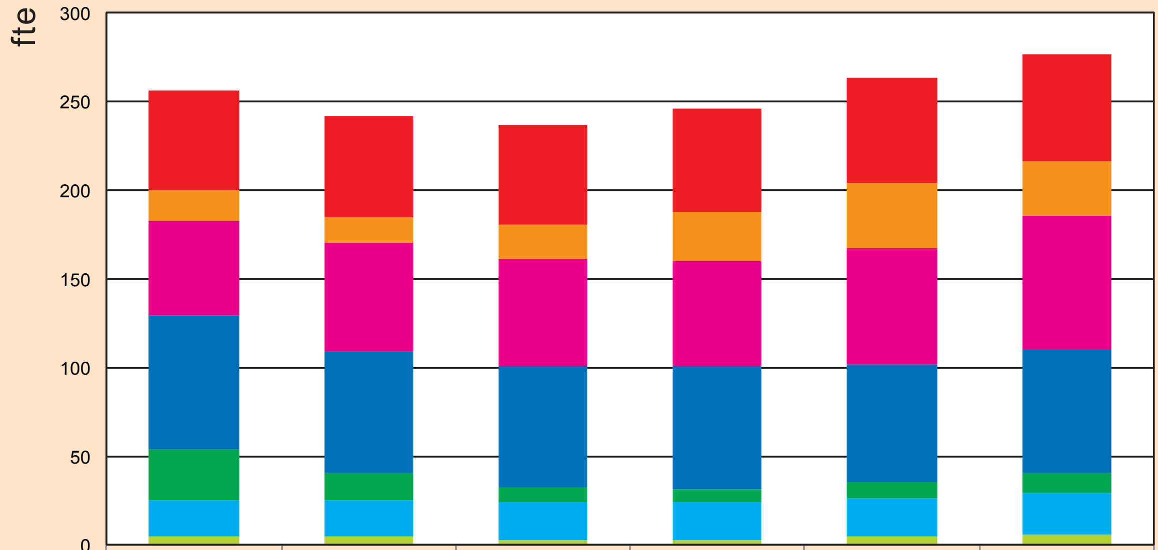
The number of personnel, expressed in full–time equivalents (fte) at Nikhef has significantly increased in the period 2005–2010 as shown in Figure 1.5.1. The number of scientific staff is now at a stable level of about 61 fte; this is including the increase in the year 2006 by the joining of two university theory groups in the Nikhef collaboration. The number of postdocs increased from 17 fte in 2005 to 31 fte in 2010; the number of PhD students increased from 53 fte in 2005 to 69 fte in 2010. Noticeable is the fall in the number of technicians from about 104 fte in 2005 to about 87 fte in 2010. This is related to the end of the construction activities of in particular the LHC detectors. The support department has gradually increased from 25 fte in 2005 to 28 fte in 2010.

About 35% of Nikhef's scientific staff, including all full professors, 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 almost a third of the scientific staff (19 out of 65 in 2010) holds a professorship. More than 80% of PhD students are employed by FOM, the others are employed by universities. Postdocs are mainly employed by FOM. The majority (about 95%) of the personnel in the technical and support departments is employed by FOM; FOM-Nikhef thereby forms the main body of the infrastructure of the Nikhef collaboration.

	2005		2010	
	%♀	#♀	%♀	#♀
Scientific staff	3.5%	2	6%	5
Postdocs	28.8%	5	14.3%	4
PhD students	13.6%	11	19.5%	19
Technical department	10.8%	8	5.5%	6
Support department	39.9%	17	27.2%	13
Total	13.8%	43	12.7%	47

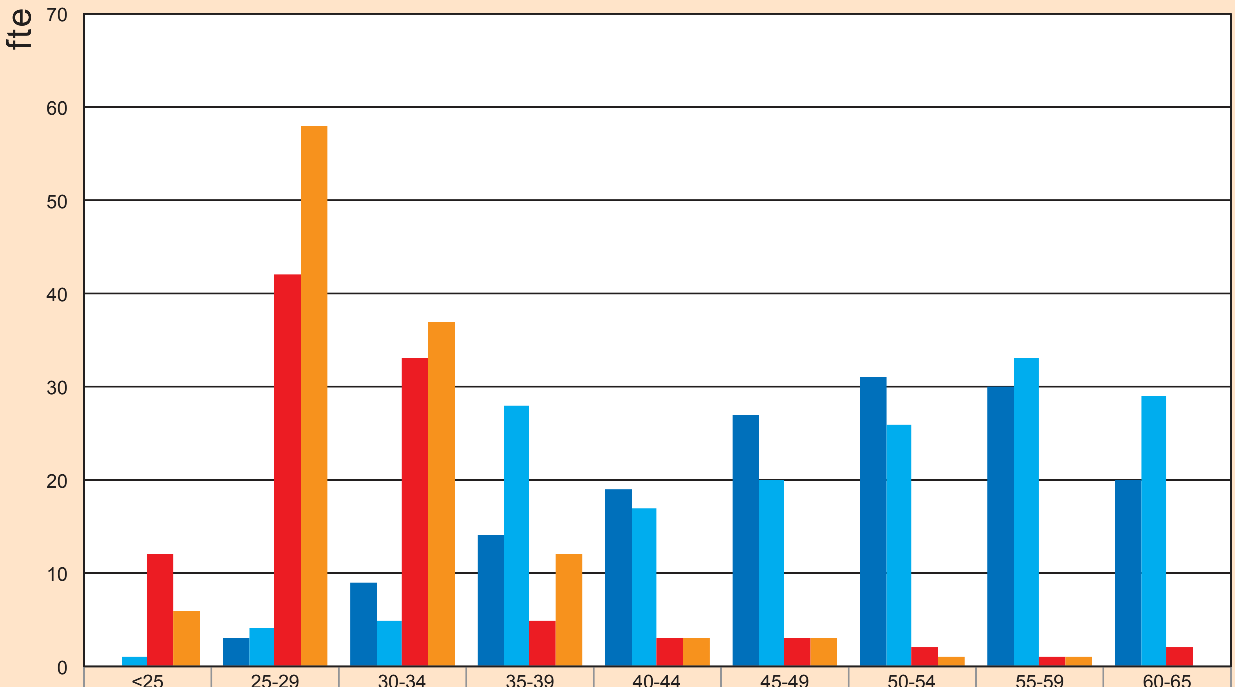
Table 1.5.1. Percentage and number of female personnel.

The age distribution of Nikhef for the years 2005 and 2010 is depicted in Figure 1.5.2. The average age in 2005 was 49.7 years and in 2010 50.0 years, whilst the average age of the scientific staff decreased slightly from 50.8 (2005) to 49.5 (2010).



	2005	2006	2007	2008	2009	2010
Scientific permanent	56.6	56.9	56	57.8	58.5	61.1
Postdocs	17.1	14.6	19.2	27.9	36.7	30.6
PhD students	53.4	60.6	60.8	59.4	66.1	75.2
Non-scientific permanent	75.3	68.9	67.8	69.6	66.2	69.1
Non-scientific temporary	28.4	15.4	8.1	6.6	9.4	11.5
Support permanent	21.1	19.7	22	22	21.5	23.9
Support temporary	4.2	5.2	2.4	2.5	4.4	5.4

Figure 1.5.1 Ftes per personnel category 2005–2010.



	<25	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-65
Permanent 2005		3	9	14	19	27	31	30	20
Permanent 2010	1	4	5	28	17	20	26	33	29
Temporary 2005	12	42	33	5	3	3	2	1	2
Temporary 2010	6	58	37	12	3	3	1	1	0

Figure 1.5.2. Age distribution.

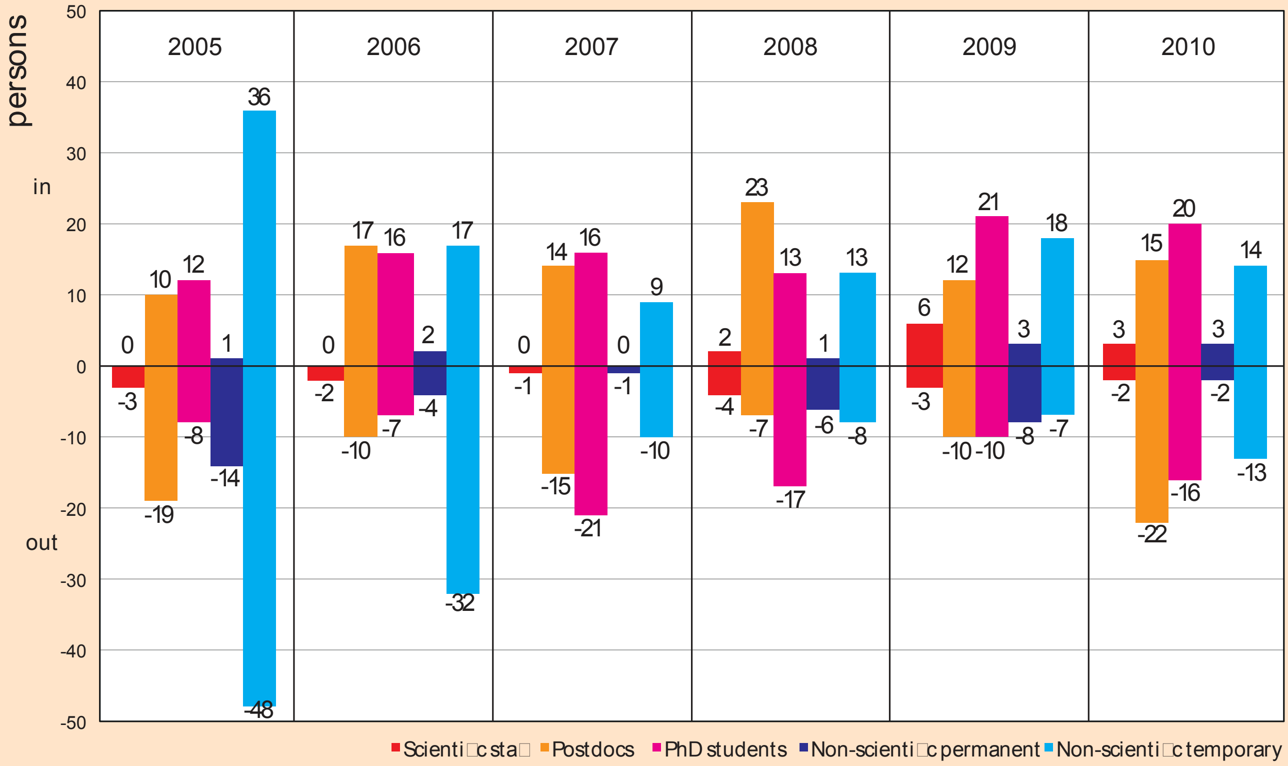


Figure 1.5.3. Mutations in the Nikhef personnel.

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

The gender distribution of Nikhef personnel (2010) is about 13% female and 87% male (Table 1.5.1) and has not changed significantly over the years. In comparison with 2005 we see a growing number of female PhD students from 7.2 fte in 2005 to 14.6 fte in 2010. The number of females in the scientific staff increased from 2 fte in 2005 to 5 fte in 2010. Regretfully the number of females in technical and support staff declined in the review period.

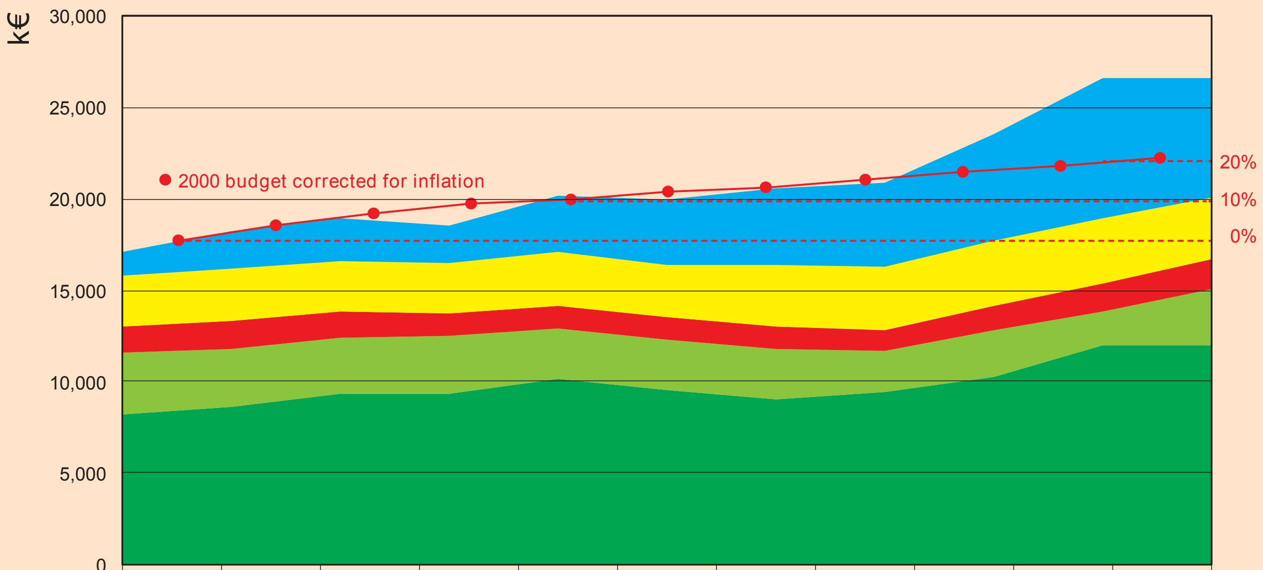
Hiring, training, mentoring and other personnel policies

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

New personnel at Nikhef is attracted through advertisements on the Nikhef website and occasionally through advertisements in technical or general newspapers. For a staff physicist position an internal advisory committee is installed, which reports to the director. Selected candidates for such a position are always invited to give a public presentation.

Figure 1.5.4. Nikhef staff cheering for the LHC start-up in 2008.

1.6 Finances



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Additional funding	1,350	2,041	2,342	2,014	2,991	3,575	4,166	4,588	5,816	7,732	6,565
Universities	2,815	2,877	2,813	2,788	2,987	2,838	3,388	3,486	3,527	3,523	3,318
FOM univ. groups	1,415	1,463	1,342	1,220	1,203	1,230	1,166	1,186	1,303	1,522	1,679
FOM-Nikhef program	3,353	3,253	3,109	3,119	2,807	2,667	2,018	2,032	2,255	1,391	2.806
FOM-Nikhef mission	8,209	8,579	9,327	9,376	10,143	9.600	9.780	9,616	10,577	12,451	12,243

Figure 1.6.1: Funding sources; the red line is the 2000 budget, adjusted for inflation (figures from the Dutch Central Statistics Bureau CBS).

Funding

The joint research programme of FOM-Nikhef and the participating university groups is funded by four separate sources (Fig. 1.6.1). The first source is the 'base'[1] funding for FOM-Nikhef; this 'base' funding is the sum of the programme budget (light green) and the mission budget (dark green). 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, acquired by FOM-Nikhef, from either FOM or third parties (such as the EU, NWO and the Ministry of Economic Affairs). This source also includes the income FOM-Nikhef generates from the lease of the former accelerator buildings and from housing customers of the Amsterdam Internet Exchange (AMS-IX) and other internet service providers.

1. The word 'base' is actually not appropriate anymore for the 'programme' part of the funding, since Nikhef had to compete for programme funding since 2008.

After a steady decrease until 2007 the 'base' funding for the institute is increasing as of 2008, due to both an increase in the mission budget and the programme budget. The mission budget has been raised permanently by FOM with about 0.5 M€, after the excellent result of the last mission evaluation (2007). NWO has for the same reason temporarily provided 0.45 M€ annually for the years 2008–2010. Another temporary, but very pleasant increase took place in 2009. In the framework of a dedicated round by NWO to make its institutes' funding more dynamic ('Dynamisering instituutsfinanciering') 3.4 M€ was allotted to Nikhef, spread over the years 2009–2011. Also new programme funding was acquired: Theory (2008–2013, 1.5 M€), Cosmic Rays (2008–2013, 3 M€) and Gravitational Waves (2010–2015, 2.1 M€).

Whilst from 2000 till 2006 the share of this 'base' funding dropped from 67% to 58% it has since more or less stabilised (57% in 2010). The FOM funding for the university groups has increased in recent years in the slipstream of the acquired programmes for Theory and Cosmic Rays, the remainder being earmarked for the exploitation of the LHC experiments (till 2013–2015). The university contribution to the funding, which had increased since 2006 with about 0.5 M€, because two theory groups from RU and VU joined the research programme, has since then declined slightly due to the less favourable financial climate at the Dutch universities and science faculties in particular. Now (2011) the prospects have improved a bit, due to 'Sectorplan' incentives (see Appendix B in the Strategy document).

Nikhef is increasingly successful in acquiring support from external funds. This fourth funding source shows a significant increase: from about 1.3 M€ in 2000 (representing 8% of the total funding) to 6.6 M€ in 2010 (25% of total funding). More than half of this increase is due to successes in obtaining project funding from FOM, 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 the data centre (AMS–IX housing). Especially this last source has shown an increase in turnover from about 0.5 M€ in 2000 to about 2.5 M€ in 2010.

All in all the Nikhef income has increased substantially (55%) over the course of 2000 to 2010. However, further analysis shows that the yearly increase more or less followed the inflation rate in the years 2000–2007, whilst only in the years since 2008 we note a real increase, which results to 27% in 2010 (compared to 2000).

Table 1.6.1 shows –from top to bottom– all grants awarded, running and completed in 2010, including their financial envelope, running period and –if not FOM-Nikhef– the name of the Nikhef partner university via which the grants have been obtained. FOM-programmes and large investment subsidies (such as BiG Grid and KM3NeT) are not included in the table. The table shows that the Nikhef collaboration is quite successful in obtaining additional project funding from various funding sources. The financial envelope of projects awarded in 2010 amounts to 4.7 M€. However, this success cannot be taken for 'granted' – it requires continuous effort in preparing project proposals.

Expenses

Figure 1.6.2 shows the distribution of costs over the joint research activities 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 other costs (which are by definition not directly attributable) are defined as 'technical infrastructure/general costs'. These indirect costs are at a relative stable level of around 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), paralleled by a ramp–up for the LHC experiments with a peak around 2005, 2006 (due to detector construction activities) and in 2010 at a stable level of about 42% of direct cost. In recent years the astroparticle physics have grown, now reaching the 20% level of direct costs. The enabling activities (Theory, Detector R&D and Grid) together make up 23% of direct cost and outreach and miscellaneous activities (including the 'tails' of closed programmes) comprise 9%.

The data centre activities (both for the grid activities and the the internet exchange) require a basic maintenance budget and from time to time investments in upgrading and expanding the facilities. In total during 1997–2010 the data centre turnover has been 16.7 M€ and the operating and investment cost have been 12.3 M€. The largest and most prominent upgrade has taken place in 2009/2010, for a total of around 5 M€. In 2010 the operating cost is at the level of 7% of Nikhef's total direct cost. The net result from the data centre activities is reinvested in the regular research activities of Nikhef.

Investments

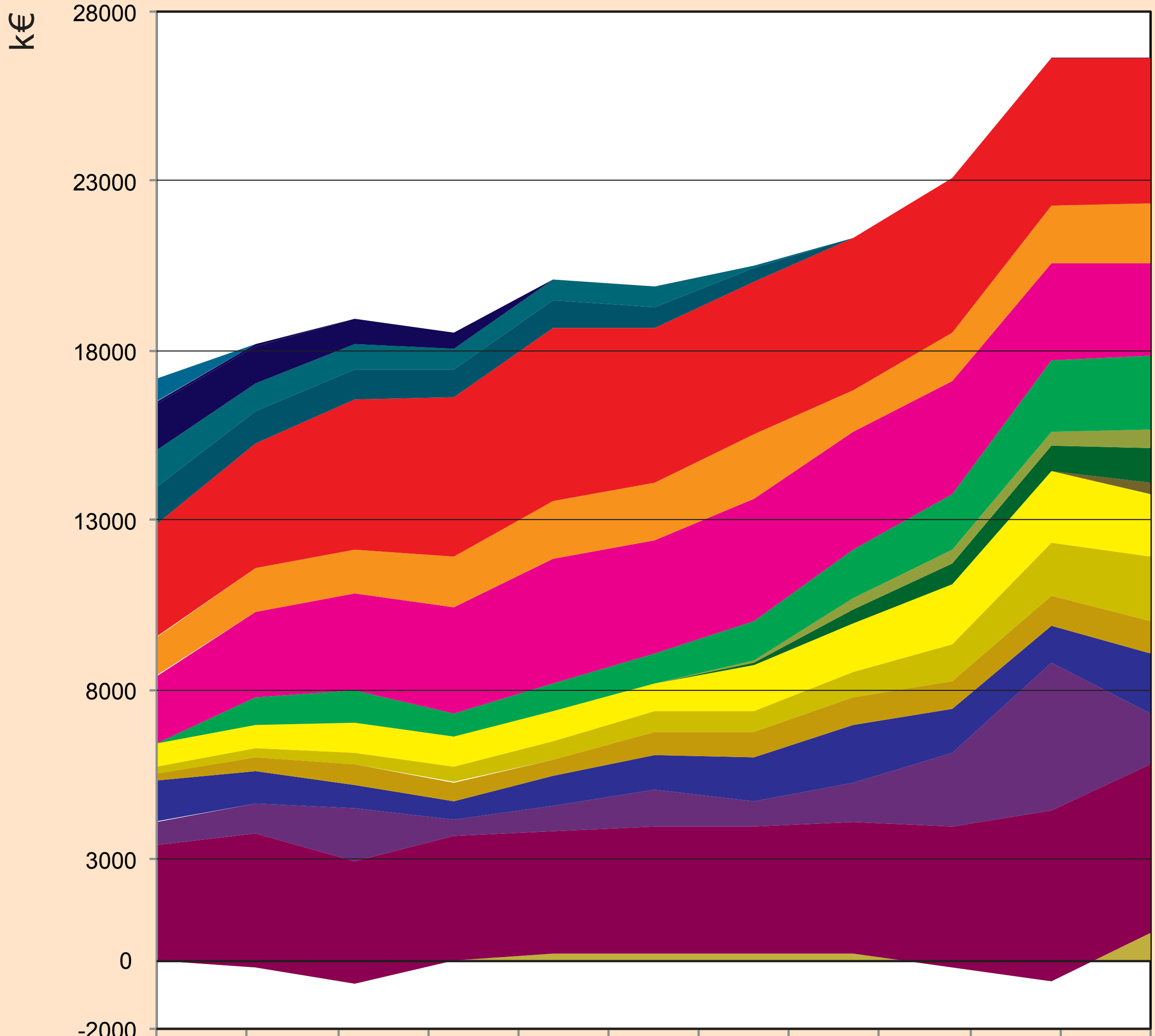
Table 1.6.2 shows the investment budgets (from the various sources within FOM and NWO) as granted to Nikhef in the years 2000–2010. Actual expenses usually follow the granting scheme, delayed by a couple of years. From the figures can be derived that Nikhef has a 'turnover' in investments of on average 2 M€ per year. In this period investment funds have been largely devoted to the LHC detectors and the neutrino telescope ANTARES. Table 1.6.3 shows the expenditures in the period 1998–2010, compared with the original pledges in the Memoranda of Understanding (MoU) for these experiments. Although actual costs are in most cases much higher than the MoU commitments, Nikhef has in all cases obtained sufficient funding to cover these cost overruns. An example is the cost overrun in ATLAS for which in 2003 extra funding was acquired via a 'bottleneck' budget from FOM (labeled 'K&E' in Table 1.6.2). Remaining overruns have been paid from exploitation budgets. Recent years show the investments for the grid infrastructure (the Nikhef part of the Dutch Tier-1, funded by BiG Grid), the prototype costs for the KM3NeT detector and for the Nikhef contribution to Advanced Virgo.

Leader	Title	Source	Period	budget (k€)	partner
Awarded in 2010					
Fleischer	Exploring a new territory of the B-physics landscape at LHCb	FOM/Pr	2010-2013	408	
Mischke	Charm content in jets	FOM/Pr	2011-2014	398	UU
Linde	Tiling appointment P. Ferrari	FOM/v	2010-2014	470	
Linde	High school teachers	FOM/EK	2010-2011	92	
Linde	Valorisation	FOM	2010-2011	200	
Linde	HiSParc nationale coördinatie fase-III	FOM/Out	2010-2013	215	
Igonkina	VIDI: Lepton flavor violation: the key towards a matter dominated Universe	NWO	2011-2016	800	
De Groot	OSAF Research school for subatomic physics – NWO graduate programme	NWO	2010-2015	800	RU
Klöpping	Holland@CERN	Senter	2010	75	
Van Bakel	Pixel innovations	STW	2010	25	
Groep	EMI: European Middleware Initiative	EU	2010-2013	189	
Groep	IGE: Initiative for Globus in Europe	EU	2010-2013	202	
Van Rijn	EGI InSPIRE: European Grid Infrastructure	EU	2010-2014	251	
Koffeman	AIDA (detector R&D)	EU	2011-2014	152	
Laenen	LHCPhenoNet	EU	2011-2015	397	
				4,674	
Completed in 2010					
Schellekens	Theme conformal field theory	FOM	2006-2010	423	
Schellekens	Standard Model interactions from open string theory	FOM/Pr	2006-2010	186	
Raven	The asymmetry between matter and antimatter	FOM/Pr	2006-2010	296	
Peitzmann	A STARry eyed look at color glass	FOM/Pr	2006-2010	260	UU
Linde	HiSParc nationale coördinatie fase-II	FOM/Out	2006-2010	242	
Linde	High school teachers	FOM/EK	2008-2010	122	
Snellings	VIDI: A new state of matter: the quark-gluon plasma	NWO	2005-2010	406	
Colijn	VIDI: Radiating top quarks	NWO	2005-2010	406	
Bouwhuis	VENI: Search for neutrinos from cosmic accelerators	NWO	2005-2010	135	
Klous	VENI: Chasing the Higgs boson with a worldwide distributed trigger system	NWO	2006-2010	141	
Visser	RelaXd	Senter	2005-2010	533	
Templon/Groep	Virtual Laboratory for e-Science	Senter	2004-2009	1,359	
Timmermans	EUDET (detector R&D)	EU	2006-2010	278	
De Wolf	KM3NeT – design study	EU	2006-2009	658	
Linde	ASPERA: astroparticle physics coordination	EU	2006-2009	218	
Hessey	sLHC: preparatory phase	EU	2007-2010	64	
Templon	Enabling Grid for e-Science (EGEE-III)	EU	2008-2010	732	
				6,459	

Table 1.6.1. Grants awarded, completed and running in 2010, including their financial envelope, running period and –if not FOM-Nikhef– the name of the Nikhef partner university via which the grants have been obtained. FOM-programmes and large investment subsidies (such as BiG Grid and KM3NeT) are not included in the table.

continued on next page

Leader	Title	Source	Period	budget (k€)	partner
Running in 2010					
Bentvelsen	Higgs or no Higgs at the LHC	FOM/Pr	2007-2011	323	
De Groot	Muons as a probe of supergravity	FOM/Pr	2006-2011	298	RU
Vermaseren	Precision phenomenology at the LHC	FOM/Pr	2008-2012	335	
De Jong, S.	Radio detection of ultra high energy cosmic rays at Auger	FOM/Pr	2008-2012	124	RU
De Groot	A search in proton- anti-proton collisions for Higgs (ASAP Higgs)	FOM/Pr	2008-2012	335	RU
Mulders	Color flow in hard hadronic scattering processes	FOM/Pr	2008-2013	331	VU
Linde	Tiling appointment O. Igonkina	FOM/v	2007-2012	310	
Van Vulpen	VIDI: Top quarks and fundamental physics at 100 zeptometer	NWO	2006-2011	406	
Van Leeuwen	VIDI: Hard probes of the Quark Gluon Plasma at the LHC	NWO	2007-2012	406	UU
Bentvelsen	VICI: Beyond the top – a new era in particle physics	NWO	2007-2013	844	
Postma	VIDI: The early Universe as a particle laboratory	NWO	2008-2013	406	
Tuning	VIDI: No GUTs, no Glory: a search for Grand Unified Theories with B-decays	NWO	2008-2013	406	
Petrovic	VENI: Search for sources of high energy cosmic rays with the ANTARES neutrino telescope and the Auger observatory	NWO	2008-2011	141	
Mischke	VIDI: Characterisation of a novel state of matter: The Quark-Gluon Plasma	NWO	2008-2013	365	UU
Heijboer	VIDI: Exploring the Cosmos with Neutrinos	NWO	2009-2014	600	
De Jong, P.	VICI: Between bottom and top: supersymmetry searches with flavour	NWO	2009-2014	1,250	
Hulsbergen	VIDI: A search for long-lived heavy particles	NWO	2010-2015	800	
Klous	Virgo on GPU	NCF	2009-2010	26	
Mischke	StG: Characterisation of a novel state of matter: The Quark-Gluon Plasma	EU/ERC	2008-2012	850	UU
De Wolf	KM3NeT-Preparatory Phase	EU	2008-2011	425	
Koffeman	MC-PAD: R&D training network	EU	2009-2012	424	
Linde	ASPERA-2: astroparticle physics coordination	EU	2009-2012	192	
Van den Brand	Einstein Telescope – design study	EU	2009-2012	200	VU
Visser	Hidralon: High Dynamic Range Low Noise CMOS sensors	Senter	2009-2012	794	
Van Beuzekom	Kenniswerkersregeling (Bruco)	Senter	2009-2010	45	
Van Eijk	HiSparc - 'betadecanen'	Univ.	2010	35	
				10,671	



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
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	4,491	4,535	4,362	4,237
ALICE	1,144	1,298	1,284	1,472	1,671	1,672	1,864	1,222	1,424	1,678	1,811
LHCb	2,009	2,555	2,872	3,158	3,694	3,353	3,608	3,473	3,333	2,846	2,675
Neutrino Telescopes		782	957	678	771	896	1,181	1,418	1,636	2,092	2,236
Cosmic Rays							50	309	442	459	537
Gravitational Waves							100	411	586	727	1,034
Dark Matter											280
Theoretical Physics	665	725	890	914	942	787	1,314	1,420	1,771	2,130	1,862
Detector R&D	240	260	358	425	484	599	657	777	1,130	1,526	1,897
Grid Computing	182	400	587	586	514	708	771	838	825	898	954
Miscellaneous	1,207	968	724	525	897	991	1,272	1,688	1,234	1,074	1,810
Lease Activities	726	874	1,556	463	725	1,100	743	1,185	2,195	4,375	1,445
Infrastructure	3,394	3,906	3,614	3,715	3,617	3,728	3,709	3,866	4,186	5,081	4,970
Deficit/Surplus		-162	-688		216	252	250	204	-211	-629	863

Figure 1.6.2: Expenses Nikhef 2000–2010 per activity (FOM–Nikhef and university groups).

Sources	Investments	<2000	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
FOM/M	Computing		862		120	370		170	170	170	170		
	Workshops		204		123	297	120	132			420		
	R&D	272			50								
	ATLAS			708	465	535							
	LHCb	1,452				31	13	406	538	462			
	KM3NeT										118	82	-11
	Advanced Virgo											237	455
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/ESFRI	KM3NeT												999
NWO/NCF	Computing				140				80	100			
	BiG Grid										840	1,300	80
			3,199	3,623	3,302	2,583	293	868	948	839	1,548	1,619	1,523

Table 1.6.2. Granted investment budgets 2000–2010.

Experiment		MoU commitments		Spent 1998-2010	% of MoU commitments
		kCHF	k€	k€	
ATLAS	Endcap toroids	6,700	4,154	7,106	141%
	ECT - cost to completion	1,405	871		
	Muon spectrometer	3,030	1,879	2,723	145%
	Inner tracker	1,840	1,141	1,207	106%
	Trigger/DAQ	530	329	391	119%
	Cost to Completion	840	521	484	93%
	total	14,345	8,894	11,911	134%
	% of ATLAS-detector	2.68%			
LHCb	Outer tracker	3,880	2,406	2,650	110%
	Vertex locator	1,500	930	1,460	157%
	Common fund	1,400	868	840	97%
	total	6,780	4,204	4,950	118%
	% of LHCb-detector	9.00%			
ALICE	Silicon Strip Detector	2,010	1,246	1,402	113%
	Common fund	225	140	141	101%
	Cost to Completion	142	88	53	60%
	total	2,377	1,474	1,596	108%
	% of ALICE-detector	1.89%			
ANTARES	Off shore equipment		1,654	1,566	95%
	On shore equipment		567	568	100%
	Common fund		1,361	1,447	106%
	total		3,582	3,581	100%
	% of ANTARES-detector		17.46%		

Table 1.6.3. Investments in LHC experiments and ANTARES versus MoU commitments.

2 Running Programmes

2.1 Physics at the TeV scale: ATLAS

Programme organisation
Since 2005, the programme leader is prof.dr. S. Bentvelsen. The FOM-programme has started in 1997, and is funded to run 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. To achieve this, the ATLAS collaboration has built a detector to record collisions at the LHC, commissioned it, and is analysing the first LHC collision data.

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 and the Tevatron show that this model is in excellent agree-

Research highlights

DØ
- Limits on the Standard Model Higgs-boson mass, improvements on these limits by better b-quark identification.
- Determination of the top-quark mass to percent level accuracy.

ATLAS
- Commissioning and operation of muon detector and silicon strip detector, development of muon track reconstruction.
- First LHC collisions: trigger and data acquisition employment, reconstruction of resonances, measurement of the charged particle multiplicity.
- Top-quark pair-production cross-section measurement at 7 TeV, first limits on new physics, such as supersymmetry, beyond those of earlier experiments.

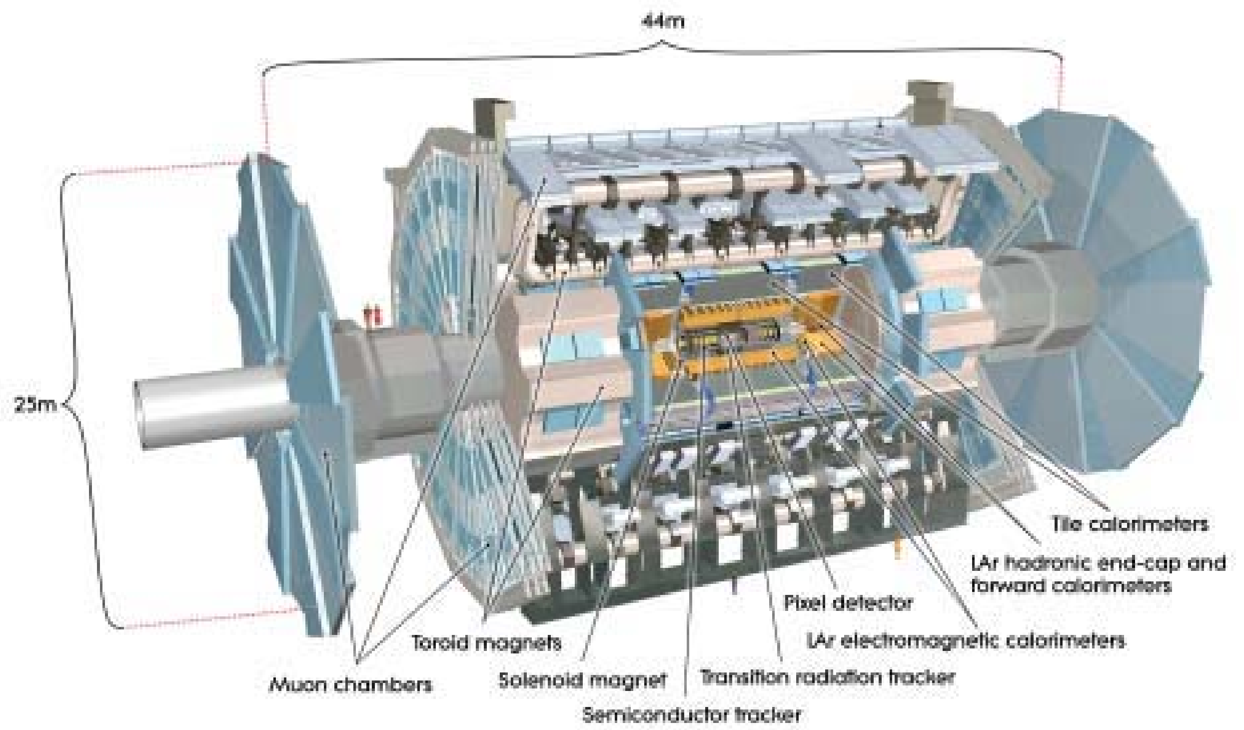


Figure 2.1.1. ATLAS detector overview: the large chambers in the outer layer of the barrel muon system and one end cap of the semiconductor tracker are Nikhef's main contributions.

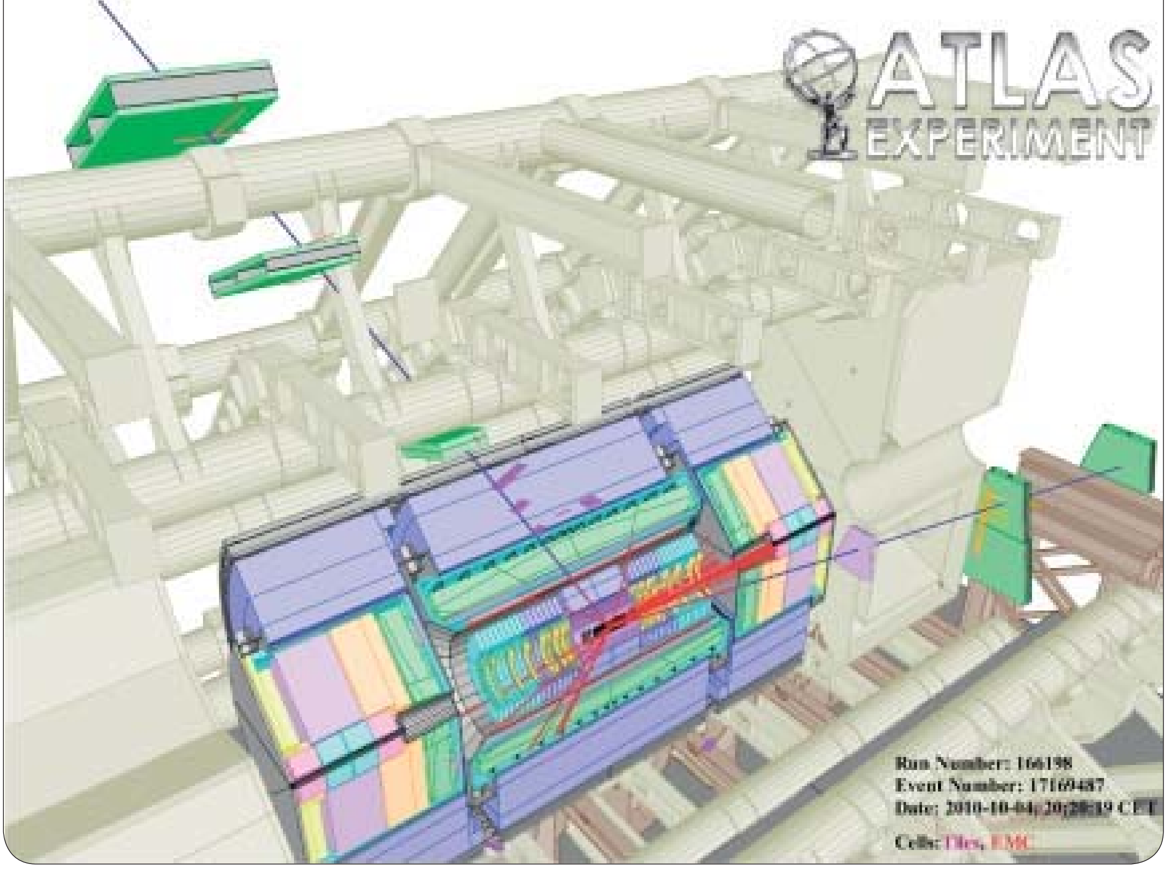


Figure 2.1.2.
ATLAS event with the highest invariant di-muon mass of the 2010 run.

ment 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.

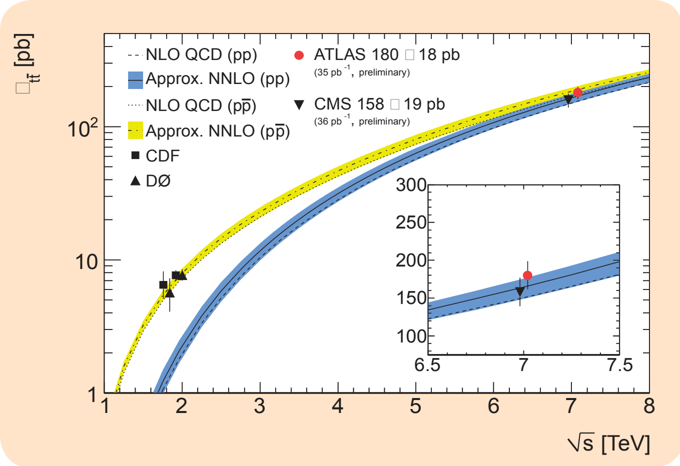
Theories beyond the Standard Model suggest manifestations of new physics at the TeV scale, such as supersymmetry (SUSY) or large extra dimensions. ATLAS is designed to be a general purpose detector, capable of detecting deviations from the Standard Model in a model-independent way.

The research goals are best achieved by detecting the results of particle collisions at the highest possible energies and luminosities. In 2010 the LHC has provided proton-proton collisions at 7 TeV centre-of-mass energy with luminosities up to 2×10^{32} cm^{-2} s^{-1}, and in the future collisions at 14 TeV with luminosities up to 10^{34} cm^{-2} s^{-1} are foreseen. 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 300 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 end cap components. The inner particle detector is located inside the solenoid, and consists of a silicon-pixel detector just outside the beam pipe, a silicon-strip detector (SCT) surrounding the pixels, and a transition radiation tracker (TRT) around the SCT. 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 transverse momentum leptons and jets, large missing transverse energy, and tracks that do not point to the primary vertex.

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. Nikhef constructed the 96 large barrel outer layer MDT chambers, each of 5.0×2.2×0.5 m^3 size, between 2002 and early 2006, and transported them to CERN. There they were equipped with trigger chambers and mounted inside ATLAS in 2006 and 2007. The cabling of all chambers (gas, power, alignment, detector control, read out) was time-consuming, and chambers were tested sector by sector in 2007 and 2008. The muon read out drivers are a Nikhef responsibility and operate according to specifications. Further Nikhef projects are the alignment hardware (RASNIK), the muon detector control system, and Hall probes to monitor the magnetic field in the muon system. The magnetic field in the end caps is provided by two large superconducting toroids of which the vacuum vessels and the cold mass components are a Dutch in-kind contribution to ATLAS. They were tested at CERN and installed in ATLAS in 2007, and operate without problems.

Muons originating from cosmic rays are a valuable calibration source for the ATLAS muon system. Nikhef scientists have invested considerable time in the muon system commissioning with cosmics between 2007 and 2009. All aspects of pattern recognition, track reconstruction, fitting, calibration and alignment were tested.

Figure 2.1.4. The top quark pair production cross section as measured by ATLAS at 7 TeV and by the Tevatron experiments at lower energies, in comparison with theoretical expectations



The SCT consists of a barrel with four cylinders of sensors, and two end caps, each with nine carbon-fibre discs onto which three concentric rings of silicon-strip detectors with their read-out electronics are mounted. Nikhef constructed 100 sensor modules and assembled one complete end cap with 1000 modules in close collaboration with institutes in the U.K. In 2006, the completed end cap was shipped to CERN and tested again, in 2007 it was mechanically integrated with the TRT, installed in the detector and cabled-up. At various stages, the detector was tested, and noise levels after integration in ATLAS were shown to be identical to those in stand-alone tests at Nikhef. A number of problems were encountered in commissioning the C_3F_8 evaporative cooling system for pixels and SCT, and Nikhef helped in finding solutions. In 2008, the detector could be operated for the first time under nominal conditions, and a series of cosmics commissioning runs showed that the detector operates better than the specifications in terms of inactive channels, hit efficiency and noise occupancy. The cosmics runs also provided a first alignment for the barrel. However, the cooling problems have led to an operating temperature somewhat higher than designed, so that possible radiation effects must be carefully monitored.

First beams and first physics results

On 10 September 2008, the LHC beams reached a beam absorber target in front of ATLAS for the first time, and an exuberant crowd in the ATLAS control room witnessed the detection by ATLAS of muons originating from that beam target. After the LHC incident in sector 3-4, ATLAS further commissioned the detector with cosmics in fall 2008 and summer 2009. On 20 November 2009, beams were back, and only a few days later first collisions at injection energy were recorded. In December, collisions at the world record centre-of-mass energy of 2.36 TeV were produced, and on 30 March 2010 the high-energy run at √s = 7 TeV started. Until the end of October 2010, ATLAS recorded 45 pb⁻¹ of data.

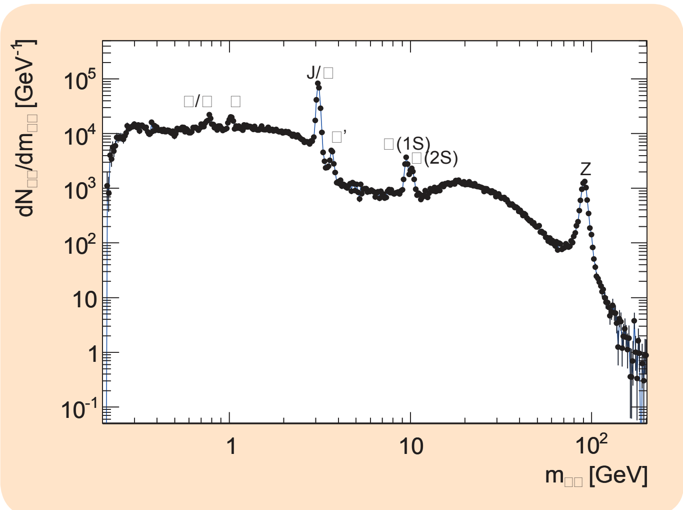


Figure 2.1.3. The preliminary di-muon mass spectrum in the 2010 ATLAS data (40 pb⁻¹ at √s = 7 TeV).

Of the LHC collisions delivered during 'stable beams' conditions, ATLAS typically collected 94% (including the begin-of-fill delay), with, depending on subdetector, between 97 and 100% of the detector channels operational. The MDT chambers, including the ones from Nikhef, perform well, and 99.5% of the channels are active. Calibration and alignment with data is still improving. In the SCT, 99.2% of all channels are operational. VCSELs, elements in the optical read out system, have shown a mortality rate beyond expectation. Luckily, for the SCT only in off-detector electronics, where they can be replaced. Similar problems affect the read out of the liquid-argon electromagnetic calorimeter, leading to 2% of dead channels, but these will be recovered in a shutdown. Noise bursts have been observed in the liquid-argon calorimeter, so that conservatively only 35 pb⁻¹ of data have been used in 2010 physics analyses, but the major part of the data lost is recoverable after reprocessing. Trigger and data acquisition systems were challenged by a steeply rising instantaneous luminosity curve (a factor 105 between March and October!) but operated effectively.

Already during the first days of data taking in 2010, the high quality of the data from the tracking detectors became clear. One of the first measurements was the determination of the charged particle multiplicity in minimum bias events, which was measured at a √s of 0.9, 2.36 and 7 TeV. The data show a higher multiplicity than that predicted by Monte Carlo models tuned to pre-LHC data. With the tracks of the inner detector, Nikhef scientists searched for resonances such as the kaon- and φ-mesons, and the Λ-baryon, proving that the magnetic field is understood and that the alignment is under control.

The muon reconstruction in the 2010 data was studied in detail by Nikhef scientists. By comparing the information from inner detector and muon chambers, the resolution can be determined. We have studied the separation of muons from decaying pions and kaons from prompt muons, and reconstructed first J/Ψ and Y-resonance peaks in the di-muon mass spectrum. Events characterised by energetic isolated muons and missing transverse energy were found, indicating production of W bosons. First cross section measurements of W- and Z production, and W production in association with jets, were published.

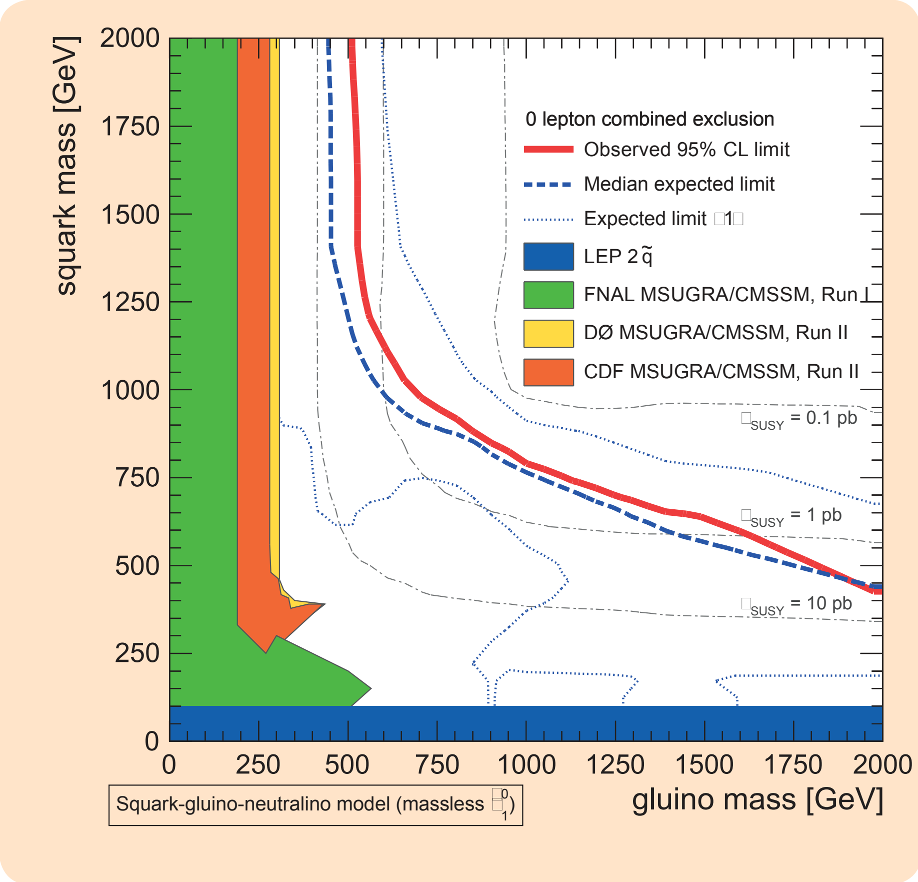


Figure 2.1.5. 95% Confidence level exclusion limits on the masses of squarks and gluinos resulting from the 2010 ATLAS data, and a comparison to earlier experiments. Masses below or to the left of the red line are now excluded. (35 pb^{-1} at $\sqrt{s}$ = 7 TeV).

The main Nikhef physics interests lie in top-quark physics, searches for new physics like supersymmetry, and searches for the Higgs boson with muons. A first measurement of the top-quark pair-production cross-section at $\sqrt{s}$ = 7 TeV was performed with 35 pb^{-1} of data, yielding 180±9(stat)±15(sys)±6(lumi) pb. Nikhef contributes to the analyses of both the semi-leptonic and the fully leptonic final states. Initial searches for supersymmetry in final states with energetic jets, significant missing transverse energy and possibly isolated leptons were performed. In the first data, no SUSY signal was found, and limits on masses of SUSY particles were set that substantially improve over the limits from the Tevatron experiments. However, the 2010 data set is small and only scratches the surface of the full LHC sensitivity. The road to Higgs boson searches in the WW and ZZ channels leads via the study of W and Z decay to muons, as discussed above; the 2010 data set is by itself too small to draw any conclusions on Higgs production. Overall, the 2010 LHC run showed that ATLAS is operating very well, and that we are on track towards reaching the physics objectives with further data.

In November 2010, ATLAS recorded more than 0.6 million lead-lead collisions. ATLAS observed a centrality-dependent di-jet asymmetry in these collisions: the transverse energies of di-jets in opposite hemispheres are observed to be more unbalanced with increasing event centrality, a phenomenon that is not observed in proton-proton collisions. In addition, the measured J/Ψ yield is found to decrease significantly from peripheral to central collisions, and the first Z bosons decaying to muons were reconstructed in heavy ion collisions.

Nikhef contributions
Apart from the contributions mentioned above, the computing centre SARA and Nikhef together host a full ATLAS Tier-1 grid centre. In ATLAS, Nikhef physicists were (c.q. are) upgrade coordinator (N. Hessey), computing coordinator (K. Bos), top-quark physics coordinator (P. Ferrari, W. Verkerke), SUSY physics coordinator (P. de Jong), combined muon performance group convener (W. Liebig), SCT end cap project engineer (P. Werneke), trigger menu coordinator (O. Igonkina), top reconstruction coordinator (I. van Vulpen), and member of the speakers bureau (P. Ferrari).

Regarding the DØ experiment, in this period Nikhef has contributed mostly computing infrastructure (Monte Carlo production on farms and on the grid) and reconstruction and analysis software. Nikhef physicists are members of various editorial boards (S. de Jong, F. Filthaut).

International collaborations
The ATLAS and DØ experiments are or were designed, constructed and operated by international collaborations. The ATLAS collaboration consists of approximately 174 institutes from 38 countries, with some 2800 scientific authors. During the period 2005–2010, the DØ collaboration has varied in size between 425 and 575 authors from 80 to 90 institutes in 19 countries.

Industrial collaborations
The vacuum vessels and cold mass components for the 10 m high and 5 m wide end cap toroids, designed by the Rutherford Laboratory (UK), were manufactured in the Netherlands by

The DØ experiment at Fermilab

To gain experience and to participate in studies at the highest energy before LHC turn-on, Nikhef joined the DØ experiment at the Tevatron, a 2 TeV proton-antiproton collider at Fermilab, 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. Since the start of 'Run 2' in 2002, DØ has collected an integrated luminosity of more than 9 fb^{-1}, and published more than 200 papers. Highlights include: searches for Higgs bosons and the exclusion of a Standard Model Higgs-boson with a mass between 158 and 175 GeV at 95% confidence level, the first two-sided interval for the frequency of B_s^0 oscillations, measurement of B_s^0 mixing parameters, advanced measurements of top-quark and W-boson masses, observation of single top-quark production, QCD studies, and limits on new physics. Nikhef analyses in DØ have focused on top-quark physics (cross section, mass, single top), τ-lepton and b-quark production, and Higgs-boson searches. The Amsterdam group left DØ in 2008, a small group from Nijmegen remains active in Higgs searches. Data taking is foreseen to end in October 2011.

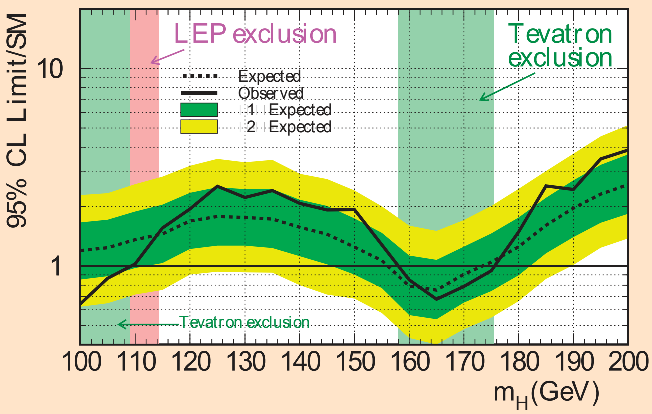


Figure 2.1.6. Upper limit on the cross section of Higgs boson production at the Tevatron, at 95% confidence level, normalised to the Standard Model value. Higgs boson masses for which the normalised cross section upper limit is smaller than one, are excluded (5.9 fb^{-1} data).

Schelde Exotech and Brush HMA. Nikhef supervised the manufacturing and assembly, and a Nikhef engineer supervised the acceptance tests at CERN.

Awards

In this period the group received two NWO-Vici grants (S. Bentvelsen, P. de Jong), two NWO-Vidi grants (I. van Vulpen, O. Igonkina), one NWO-Veni grant (S. Klous), one NWO-Rubicon grant (M. Baak), and three 'FOM-projectruimte' grants (of which one together with the theory group).

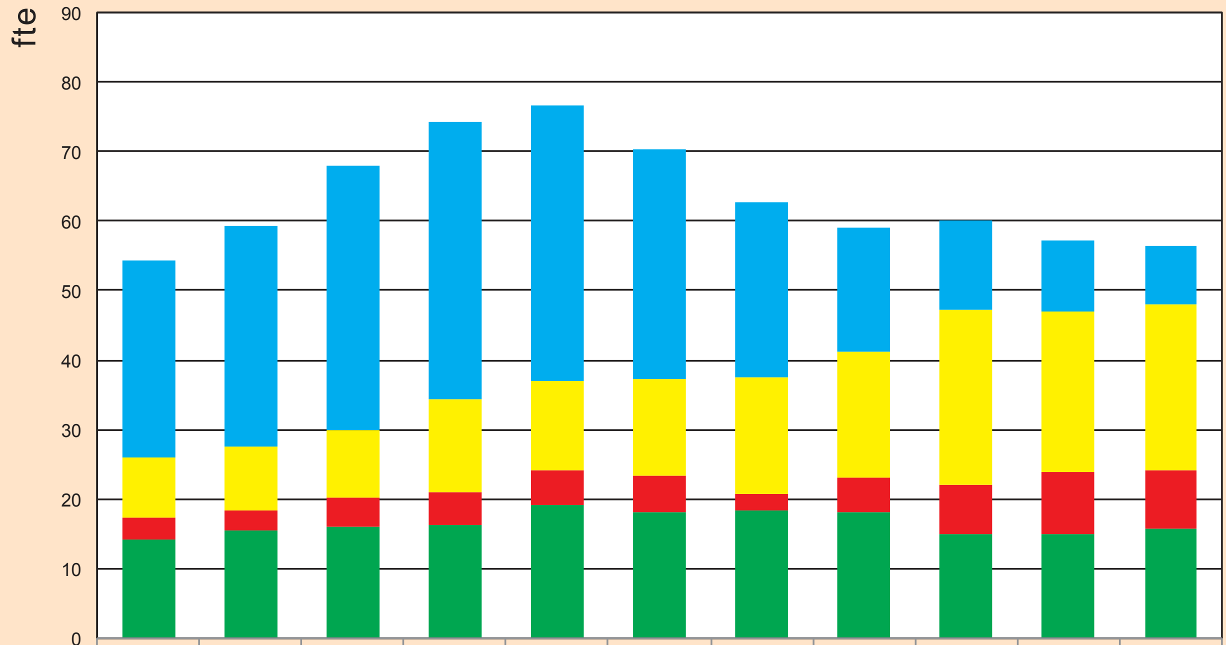
Key publications

DØ

- V. Abazov (et al.) (DØ Collaboration), Direct Limits on the B_s^0 Oscillation Frequency, Phys. Rev. Lett. 97 (2006) 021802
- V. Abazov (et al.) (DØ Collaboration), Evidence for production of single top quarks and first direct measurement of $|V_{tb}|$, DØ Collaboration, Phys. Rev. Lett. 98 (2007) 181802
- V. Abazov (et al.) (DØ Collaboration) and T. Aaltonen (et al.) (CDF Collaboration) Combination of Tevatron Searches for the Standard Model Higgs Boson in the WW Decay Mode, Phys. Rev. Lett. 104 (2010) 061802

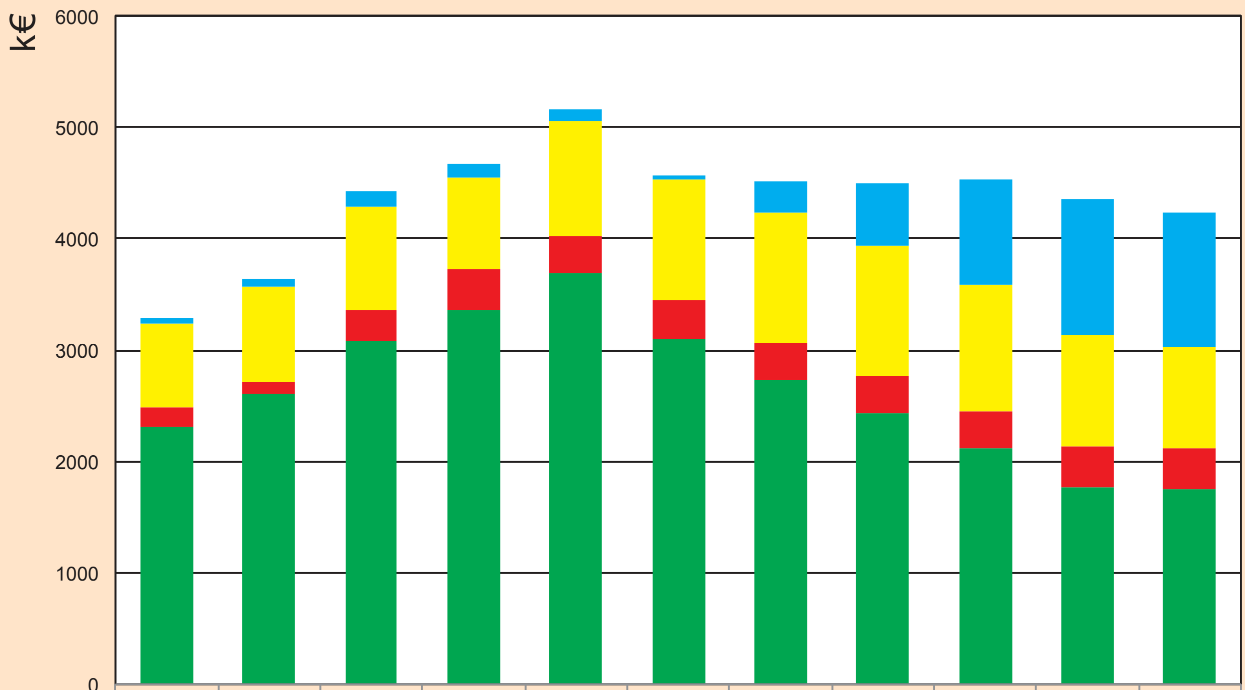
ATLAS

- G. Aad (et al.) (ATLAS Collaboration), Expected Performance of the ATLAS Experiment – Detector, Trigger and Physics, CERN-OPEN-2008-020, arXiv: 0901.0512
- G. Aad (et al.) (ATLAS Collaboration), The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003
- G. Aad (et al.) (ATLAS Collaboration), Measurement of the top quark-pair production cross section with ATLAS in pp collisions at $\sqrt{s}$ = 7 TeV, arXiv: 1012.1792 (2010), accepted by EPJC



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians	28.4	31.8	38.0	39.9	39.6	33.1	25.1	17.9	12.9	10.4	8.4
PhD students	8.6	9.0	9.8	13.2	12.8	13.9	16.8	18.1	25.2	23.0	23.9
Postdocs	3.1	2.9	4.1	4.8	5.0	5.2	2.3	5.1	7.0	9.0	8.5
Staff	14.2	15.6	16.1	16.3	19.1	18.1	18.4	18.0	15.1	14.9	15.7

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects	61	66	135	119	119	36	270	557	953	1,236	1,204
Universities	738	853	939	836	1,020	1,095	1,172	1,177	1,124	997	919
FOM-university groups	180	105	270	356	334	337	334	331	339	353	361
FOM-Nikhef	2,313	2,607	3,084	3,365	3,693	3,105	2,732	2,426	2,119	1,776	1,753

Table II – Budget

2.2 Physics with b–quarks: LHCb

Programme organisation

Since 2005 prof.dr. M.H.M. Merk is the programme leader. The FOM-programme has started in 1999, and is funded to 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 the Standard Model predictions that may shed light on the antimatter puzzle.

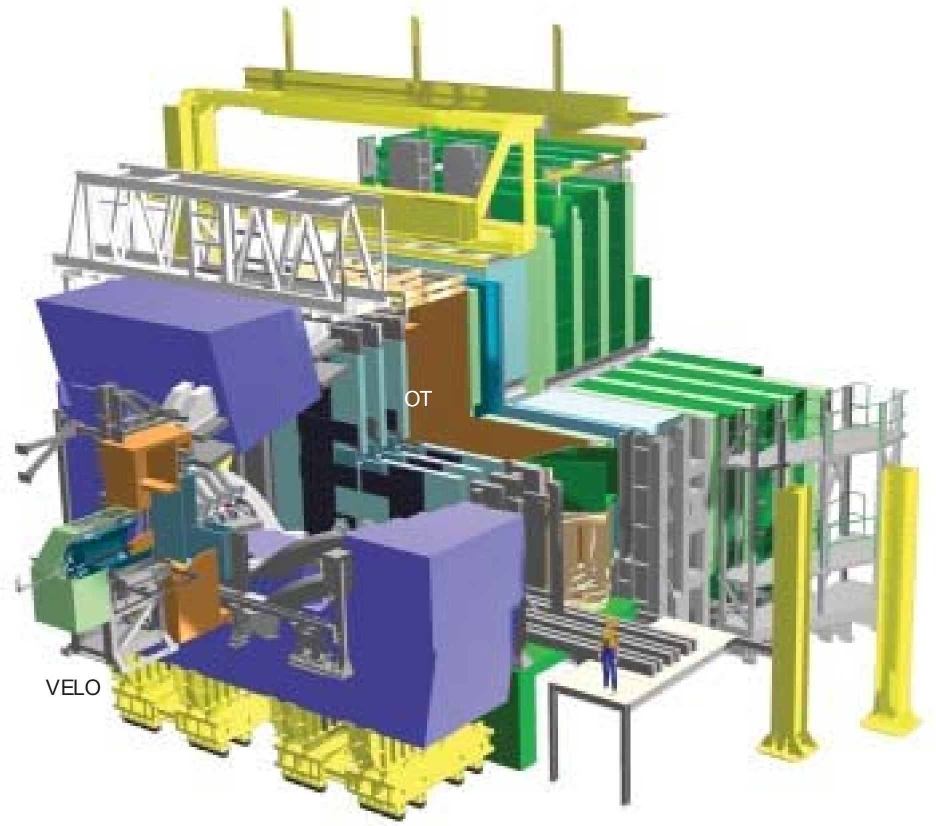


Figure 2.2.1. LHCb detector overview with indicated Nikhef's main contributions: the Vertex Locator (VELO) and Outer Tracker (OT) stations.

Research highlights

BaBar

- Detection of the lowest mass particle of the bottomonium family, called the η_b.

LHCb

- Commissioning of the outer-tracker and vertex-locator detectors.
- Track reconstruction and aligment.
- First physics studies with the B_s–meson.

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.

In LHCb all types of B–mesons are produced copiously. The decay products of these B–mesons 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 was 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 products. In addition to the hardware effort of designing and constructing these detectors a large part of our manpower was devoted to developing software for these systems, to recognise the charged particles that leave trails in these detectors, and to accurately reconstruct their parameters. 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. The Kalman track-fitting reconstructs the particle trajectories over a distance of about 10 metres with a precision of 8 μm at the vertex position and of 80 μm at the downstream end of the spectrometer. This same fitting method is also used in the High Level Trigger system of the experiment.

A Nikhef physics programme matching these efforts is now underway. 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.

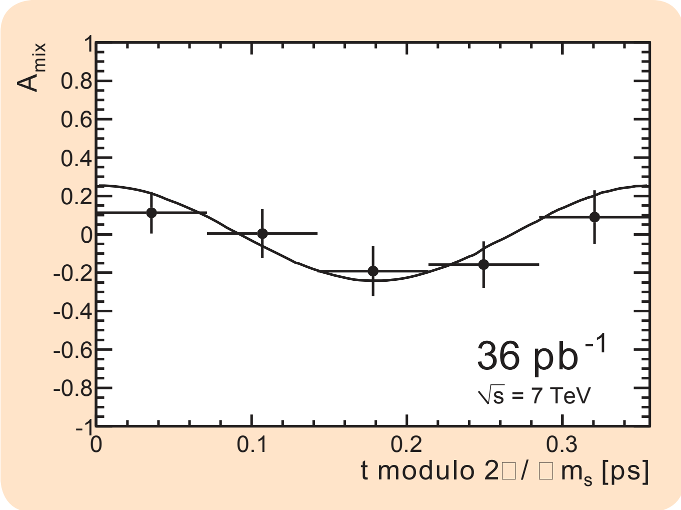


Figure 2.2.2. The mixing asymmetry A_{mix} for the decay of the B_s^0 meson: proportional to the difference between the number of events in which the produced matter(antimatter) B_s^0 particle had the same identity during its decay, and the number of events in which it had not, as a function of its lifetime, folded in one oscillation period.

Detector developments

The main task of the VELO is to reconstruct and identify the collision point and any displaced vertices from the decay of (amongst others) long–lived B–mesons with a resolution of several tens of microns. It consists of two moveable detector halves with 21 silicon micro–strip tracking modules, mounted in a vacuum vessel. 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 to allow for beam injection and manipulations during ramping and tuning. The detectors are positioned by a motion control system with an accuracy of 5 μm. The actual beam position varies from fill–to–fill, an online monitoring process follows the beam location by reconstructing the event-by-event vertex positions.

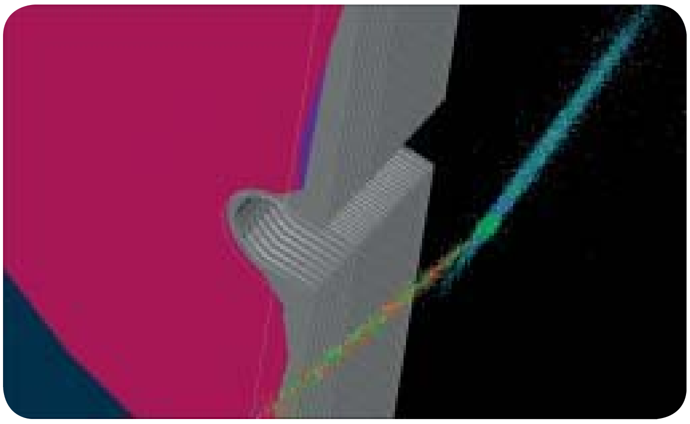


Figure 2.2.3. LHC beams as seen by the VELO (view compressed in z).

The detectors are operated in a secondary vacuum, which is separated from the ultra high beam vacuum by a corrugated 300 μm thin aluminium-alloy foil to minimise 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. Detector boxes were produced by welding the foil to 500 μm thick side walls. To avoid 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.

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. Nikhef is responsible for the mechanics, the vacuum technology and the cooling system of the VELO. The vertex tank was installed early 2007. The open–close

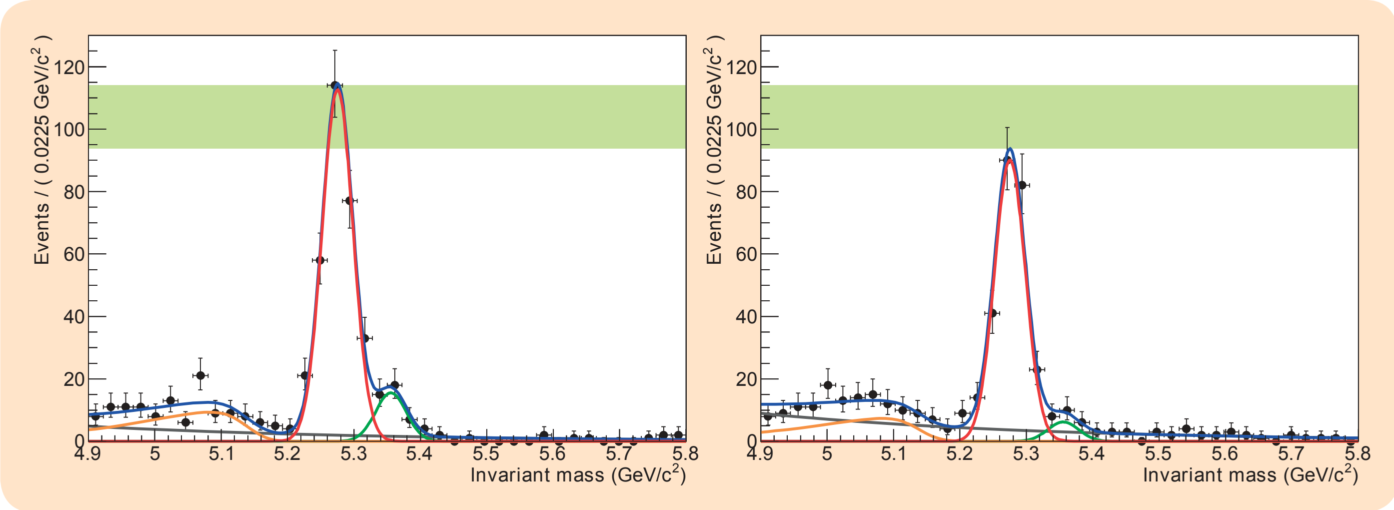


Figure 2.2.4. CP-violation, as seen in the decay B→K π. B→K$^+$π$^-$(left) and B→K$^-$π$^+$ (right). The fit disentangles the B_d (red) and B_s (green) contribution. The different yields between the left and right figures are predominantly due to the large CP asymmetry in these decays.(35 pb^{-1} at √s = 7 TeV)

mechanics system and the vacuum system were commissioned in situ. The last part of the detector support system, completely equipped with silicon detectors and metrologically surveyed, was installed in the vacuum vessel in October 2007.

In collaboration with the ASIC laboratory in Heidelberg a radiation hard read-out chip based on 0.25 μm CMOS technology was developed, with analogue front-end, buffer memory, serial read out and prompt binary outputs. The chip is used in all silicon-based sub-detectors of LHCb.

The 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 centre (anode). In total 256 channels are grouped in one module (500×34 cm^2). This modular structure facilitated the construction, assembly and maintenance of the entire detector.

Nikhef has been the leading institute in the design and R&D phase of the OT project. Subsequently, Nikhef was responsible for the construction and quality assurance of half of the detector modules of the OT. The production took two years and was finalised at the end of 2005, after which the modules were shipped to CERN for installation in LHCb. The installation of the OT was completed in 2007.

Signal degradation has been observed later after irradiation with radioactive sources. However, this effect seems to be under control after adding O_2 to the gas mixture.

Nikhef was also responsible for developing, testing and assembling a large part of the OT read–out electronics. To validate the combination of detector and read–out electronics, four mass–production modules were 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 of over 98% and a position resolution better than 200 μm, well within the specifications.

In the following years the detector was calibrated and the momentum measurement procedure has been fully commissioned. The detector timing has been tuned to provide a precise reference time (t_0) and the drift-time relationship (r-t) has been established.

First beams

On 22 August 2008 the LHC injection system was tested by colliding protons on a beam absorber target. This beam dump provided an intense source of muons that traversed the LHCb detector and were detected with the VELO. The events provided a first calibration of this detector with beam. The detector was fully commissioned during 2009, where a major activity was to time-align the VELO detector read out with respect to the beam crossing time. The Nikhef group members have developed an automated procedure to find the optimal timing resulting in a signal-over-noise value of about 20. These data were used to determine the alignment of the individual silicon measurement planes to about 5 μm.

On 20 November 2009, the first beams were injected into the LHC ring with an energy of 450 GeV. Interactions of the beam with remnant-gas atoms in the beam vacuum were observed in so-called beam gas events the next day. After both beams had been captured in stable orbits the first collisions were observed on 23 November by an excited crew in the LHCb control room. The resulting data were fully reconstructed on the computing grid infrastructure and available for the physics users in the home institutes only one hour after they were collected by the experiment. On 14 December, the proton beams were accelerated to a world-record energy of 1.18 TeV, providing collisions at a centre of mass energy of 2.36 TeV. These data were used to further tune the reconstruction and physics algorithms. Well-known particles such as the long-living K^0_s-meson and the Λ-baryon as well as the neutrally decaying π^0 were identified. The reconstructed mass of the K^0_s-meson in this run was determined to be 497.2 ±0.2 MeV, close to the known mass of 497.7 MeV, indicating that the calibration and the alignment of the tracking systems were then already close to the required precision. The detector is further validated with these first data. The VELO cluster finding efficiency turned out to be 99.8% with a best hit resolution of 4 μm. The primary vertex is reconstructed with a precision of 15 μm in X- and Y-directions and about 90 μm in the Z-direction, resulting in an impact parameter resolution of about 20 μm. This is somewhat worse than Monte Carlo predicts, but further improvements are expected with an improved alignment and material description.

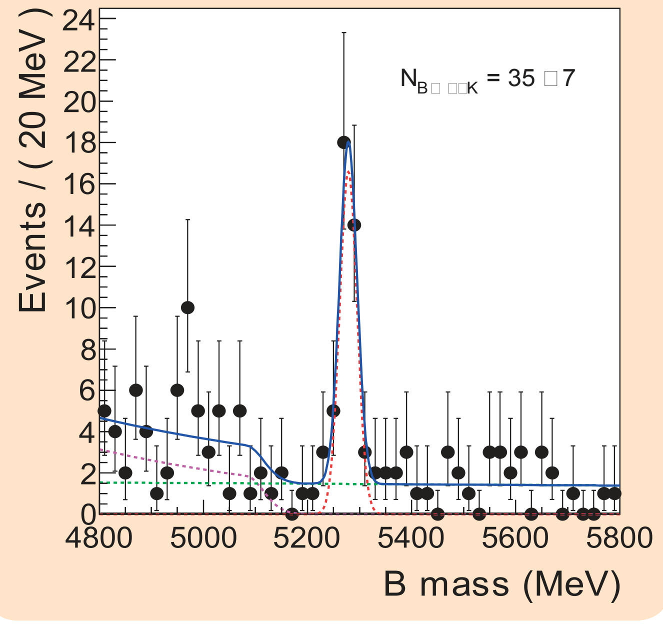


Figure 2.2.5. Observation of one of the rarest B-decays: $B^+ \to K^+\mu^+\mu^-$ at LHCb. (37 pb^{-1} at $\sqrt{s}$=7 TeV)

The BaBar experiment at SLAC

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

The experience gained at BaBar has been valuable for setting up the analysis chain for the LHCb data. 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 $B^0 \to D^*\pi$. Data-taking ended on 7 April 2008.

The OT detector has routinely taken data during the whole 2010 data taking period, with less than 1% of dead channels and very low noise (less than 1% of the average occupancy). The low discriminator thresholds have guaranteed high drift-cell efficiency (>98%). Time offsets and time-to-space calibrations have been performed and the results stored in the reconstruction database. The spatial alignment of the various detector layers with respect to each other and of the whole OT with respect to the other LHCb subdetectors has been determined with a precision of about 100 μm in the X-coordinate (dipole bending). The alignment of individual straw-tubes modules is still ongoing. A resolution of 250 μm has been obtained, close to the one expected from beam tests (200 μm), the discrepancy presumably being due to imperfections in the module-to-module alignment. The LHCb detector is therefore ready for the task ahead.

In 2010, LHCb collected about 38 pb^{-1} of physics data, at different settings of the LHC machine, most notably increasing instantaneous luminosities up to 1.6×10^{32} $cm^{-2}s^{-1}$, close to the LHCb design luminosity (2×10^{32} $cm^{-2}s^{-1}$).

From the first data production cross sections are determined and the first papers are in the process of being published or have been published already. In the sample of 2010, B-mesons have already been fully reconstructed and the first sign of CP-violation at LHCb has been observed in $B \to K\pi$. The Nikhef group has been very active in the analysis, most notably in the tracking and alignment software and in the analysis of rare and CP-violating decays.

Nikhef contributions

The prominence of the Nikhef group in the above LHCb topics can be recognised from the fact that Nikhef was deeply involved in the original OT and VELO technical design reports. Nikhef has provided a project leader for the OT project (A. Pellegrino), deputy–project leaders of the VELO project (E. Jans and M. van Beuzekom) and convenors of physics analysis groups (G. Raven and now W. Hulsbergen). M. Merk has been Track–Fit coordinator and Off–line Reconstruction Coordinator, J. van den Brand was VELO–coordinator at the time of the development of the vertex tank. P. Koppenburg is now responsible for Operations. Moreover, Nikhef physicists are members of the Editorial Board.

International collaborations

The BaBar and LHCb experiments are or were designed, constructed and operated by international collaborations. The BaBar collaboration consisted of approximately 550 physicists from 10 countries. The LHCb collaboration currently consists of 731 participants from 15 countries.

Awards

In this period the group received two NWO-Vidi grants (N. Tuning and W. Hulsbergen) and a ‘projectruimte’ grant for a project with the theory department.

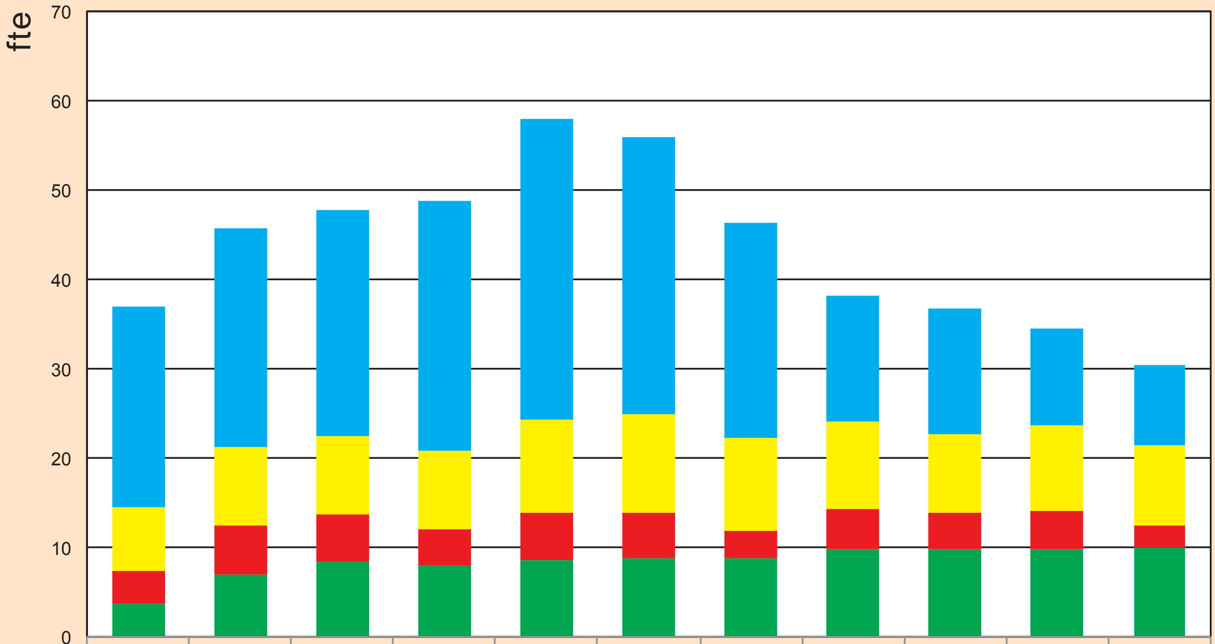
Key publications

BaBar

- Bernard Aubert (et al.) (BaBar Collaboration), Observation of a broad structure in the $\pi^+\pi^-$ J/Ψ mass spectrum around 4.26-Gev/c^2, Phys.Rev.Lett. 95 (2005) 142001
- Bernard Aubert (et al.) (BaBar Collaboration), Evidence for D^0-D^0 Mixing, Phys.Rev.Lett. 98 (2007) 211802
- Bernard Aubert (et al.) (BaBar Collaboration), Search for lepton flavor violation in the decay $\tau^\pm \to \mu^\pm\gamma$, Phys.Rev.Lett. 95 (2005) 041802
- Bernard Aubert (et al.) (BaBar Collaboration), Search for lepton flavor violation in the decay $\tau^\pm \to e^\pm\gamma$, Phys.Rev.Lett. 96 (2006) 041801
- Bernard Aubert (et al.) (BaBar Collaboration), Measurements of the $B \to X(s)$ gamma branching fraction and photon spectrum from a sum of exclusive final states, Phys.Rev. D72 (2005) 052004

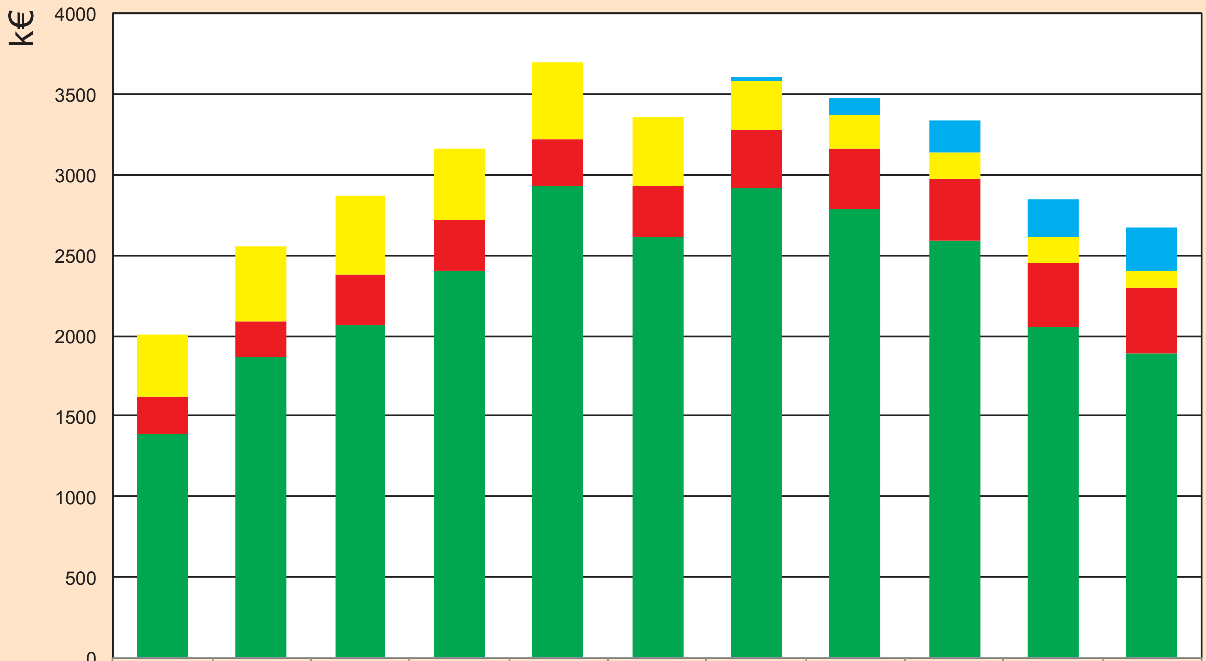
LHCb

- A.Augusto Alves (et al.) (LHCb Collaboration), The LHCb Detector at the LHC, JINST 3 (2008) S08005,2008
- R. Aaij (et al.) (LHCb Collaboration), Measurement of σ $(pp \to b\bar{b}X)$ at $\sqrt{s}$=7 TeV in the forward region, Phys.Lett. B 694 (2010) 209
- Fabian Jansen (et al.) (LHCb Outer Tracker Collaboration), Construction, installation and commissioning of a high-efficiency and high-resolution straw tube tracker for the LHCb experiment, Nucl. Instrum.Meth. A617 (2010) 23
- Van Lysebetten (et al.) (LHCb-VELO Collaboration), Commissioning and operation of the vertex locator (VELO) at the LHCb experiment, Nucl.Instrum.Meth. A617 (2010) 67
- R. Aaij (et al.) (LHCb Collaboration), Prompt K^0_s production in pp collisions at $\sqrt{}_s$=0.9 TeV, Phys. Lett. B693 (2010) 69



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians	22.4	24.4	25.2	27.9	33.7	31.0	24.0	14.0	14.0	11.0	9.0
PhD students	7.2	8.8	8.8	8.8	10.3	11.1	10.4	9.7	8.8	9.5	9.0
Postdocs	3.7	5.5	5.4	4.0	5.4	5.1	3.1	4.6	4.0	4.3	2.4
Staff	3.7	7.0	8.3	8.0	8.5	8.8	8.8	9.8	9.9	9.8	10.0

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects							30	103	190	237	268
Universities	392	467	490	436	470	430	301	210	165	155	110
FOM-university groups	226	227	319	320	299	316	363	377	384	399	408
FOM-Nikhef	1,392	1,861	2,063	2,402	2,925	2,607	2,914	2,783	2,594	2,055	1,889

Table II – Budget

2.3 Relativistic heavy–ion physics: ALICE

Research highlights

STAR
- Measurement of azimuthal correlations of forward neutral pions in d+Au collisions.

ALICE
- Commissioning of the Silicon Strip Detector.
- Elliptic flow analysis and first publication from heavy-ion beam time.

Programme organisation

Since 2002 prof.dr. T. Peitzmann is the programme leader. The FOM-programme has started in 1998, and is funded to run 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 group has played a leading role in the design, testing 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

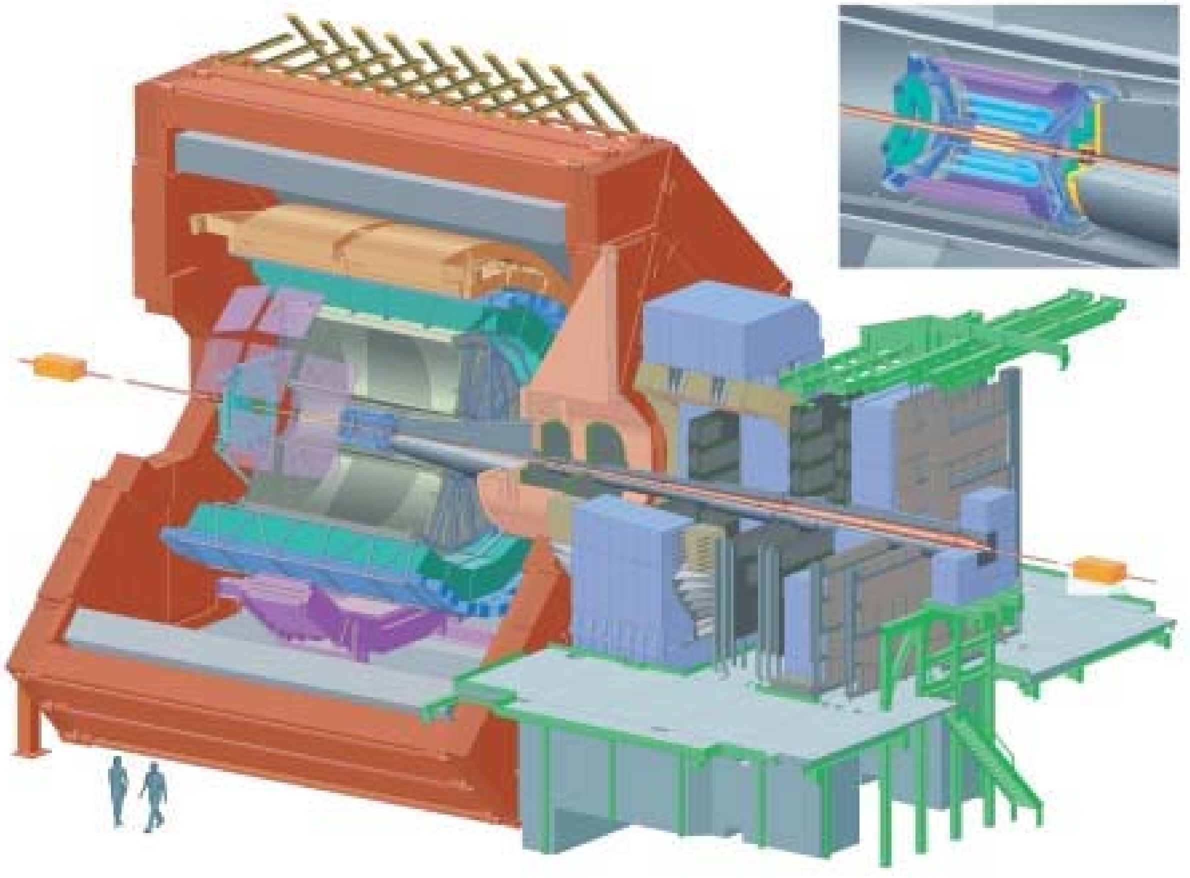


Figure 2.3.1. A schematic view of the ALICE experimental setup. The picture on the upper right shows an enlarged view of the Inner Tracking System (ITS), which contains significant contributions from Nikhef in its two outer layers, the Silicon Strip Detector (SSD).

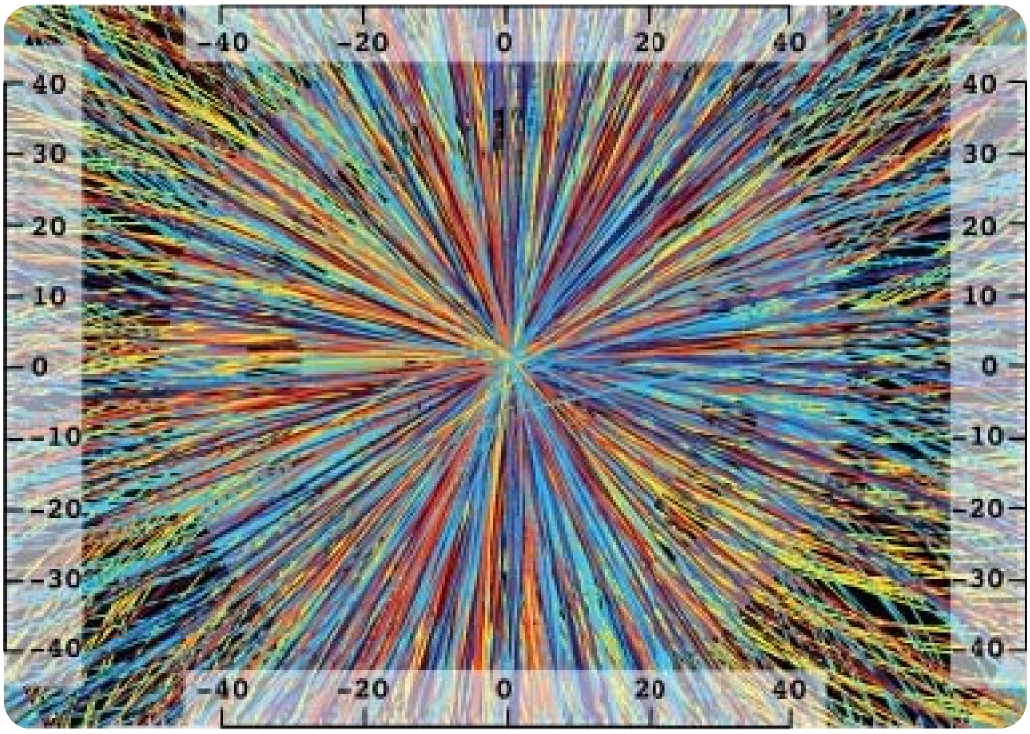


Figure 2.3.2. A single central Pb+Pb collision as measured by the central detectors of ALICE. The colours of the tracks indicate different particle properties such as momentum and charge. The scale of the transverse dimensions is indicated in cm.

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. At the end of 2006 the SSD was shipped to CERN. 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 Nikhef.

Based on cosmics measured with the ALICE-like test set-up in Utrecht a first gain calibration (same value for all 1698 modules) of the SSD was performed. When more and more data became available, first cosmics in ALICE, later proton-proton (p+p) and finally lead-lead (Pb+Pb), the gain calibration could be refined down to the level of individual chips (22632 chips), leading to a spread of less than 1%. Using straight tracks from cosmics passing twice through each layer, the internal alignment of the SSD could be checked. It confirmed the measurements of the module positions done at Nikhef during ladder assembly. When aligning the SSD with the rest of the ITS and the TPC, it turned out to be necessary to correct for the Hall effect in the silicon sensors –an effect of a few microns– to finally achieve a position resolution of individual hits of 20 μm.

Very recently, the group has started an initiative to develop a highly granular electromagnetic calorimeter as an upgrade for ALICE for forward rapidity measurements, an activity, which builds upon experience in the STAR experiment with forward measurements.

First physics measurements at LHC

The main purpose of the ALICE experiment is to measure interactions of high–energy heavy ions at the CERN LHC, however, it is also measuring p+p interactions. Since the start of LHC operations in November 2009 ALICE has taken data of proton-proton collisions, first at the injection energy of 2×450 GeV and later at a centre of mass energy of 2.36 TeV. From the first data at 900 GeV ALICE has measured the charged particle multiplicity leading to the very first physics publication from LHC. In the following, the ALICE experiment has both performed a number of measurements at these early energies as well as at the recently achieved energy of 7 TeV and has further prepared the measurements in heavy-ion collisions.

The performance of the detector as a whole and of the SSD in particular during the beam time was excellent. The ratio of antiprotons to protons in p+p collisions has been one of the first published results. Results of spectra of pions, kaons and protons (identified via energy loss in the ITS) in 900 GeV p+p collisions have been obtained, and the data analysis of 7 TeV p+p collisions is ongoing. Already from the very first week of heavy-ion beams a number of interesting papers have been published. The Nikhef group has had a strong role in the first measurement of elliptic flow in heavy-ion collisions at LHC. Elliptic flow had been found to be astonishingly large at RHIC and from that large value it was concluded that the viscosity of the produced matter must be extremely small, which has attracted a lot of theoretical interest. Expectations for the much higher LHC energy were unclear, as different physics effects could have caused an increase as well as a decrease of viscosity. The performed measurements clearly indicate a stronger integral elliptic flow, which also requires an extremely low viscosity. Also, measurements of the effect of jet quenching in hadron distributions at high transverse momentum have been performed.

The STAR experiment at BNL

The group has contributed significantly to analysis of elliptic flow, jet quenching and heavy-flavour production within the STAR experiment. In the final phase the activities have been reduced and have focused on measurements at large rapidities in search of the Colour Glass Condensate. A PhD student of the group has made substantial contributions to the detector used for these measurements (the Forward Meson Spectrometer) and to the corresponding Monte Carlo simulations and data analysis.

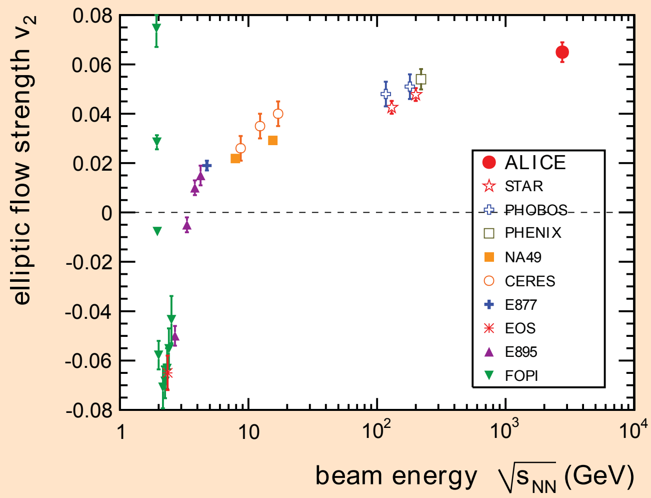


Figure 2.3.3. The strength of elliptic flow in Pb+Pb collisions as measured by the ALICE experiment at the highest available beam energy compared to data at lower energies. The integrated elliptic flow v_2 is higher than the value at RHIC, which was already seen as astonishingly large. In the common interpretation of this phenomenon such a large value of v_2 requires a strongly interacting system with an extremely low viscosity ('perfect fluid').

Also here an even stronger effect as compared to lower energy was observed. Already from these very early results it is clear that very dense, strongly interacting matter is produced in heavy-ion collisions at LHC. The interpretation of these measurements will require further quantitative theoretical work.

Nikhef contributions

Nikhef developed the electronics of the SSD end cap and produced the end cap 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. After the installation Nikhef was responsible for the commissioning of the detector and had strong contributions in the calibration of the SSD and also in general to the alignment of the whole ALICE detector setup. Nikhef has developed analysis methods and software for elliptic flow, which enabled us to measure anisotropic flow at the LHC, a few days after the data became available. This resulted in the first publication based on heavy-ion collisions at the LHC. Nikhef has contributed to software development for simulations and analysis of heavy flavour hadrons and has taken a leading role in the corresponding analyses. Furthermore the Nikhef group is involved in particle identification using specific energy loss measured in the ITS.

Nikhef scientists occupy a number of important positions within the ALICE collaboration: G-J Nooren is SSD project leader, M. van Leeuwen is coordinator of the Particle Identification Task Force and member of the Physics Board, T. Peitzmann is upgrade coordinator, R. Kamermans † was and T. Peitzmann is management board member, and Paul Kuijer was deputy spokesperson.

International collaborations

The group has been involved in several international collaborations, in particular the ALICE collaboration, involving 104 institutes from 30 countries and more than 1000 members. Since 2002 the group has collaborated in the STAR experiment (51 institutions from 12 countries, with a total of 545 collaborators), this effort is terminated in 2011.

Awards

In this period the group received two NWO-Vidi grants (A. Mischke and M. van Leeuwen), an ERC starting investigator grant (A. Mischke) and a FOM 'projectruimte' grant.

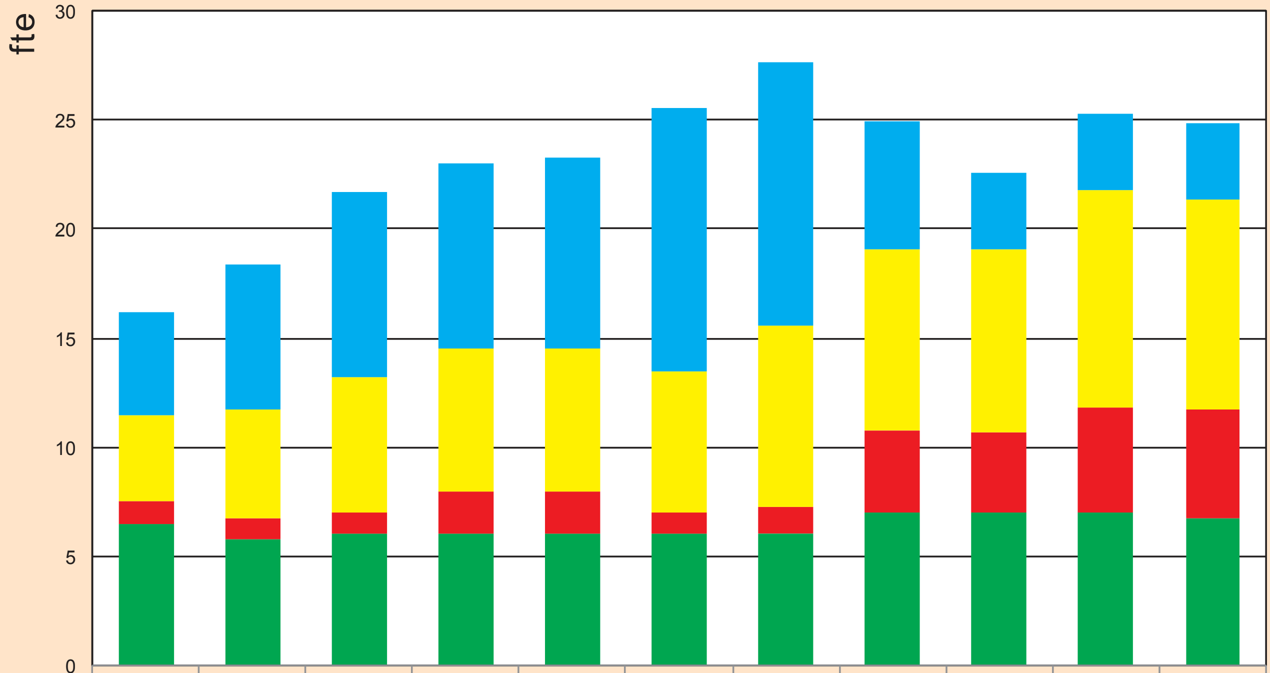
Key publications

STAR

- 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

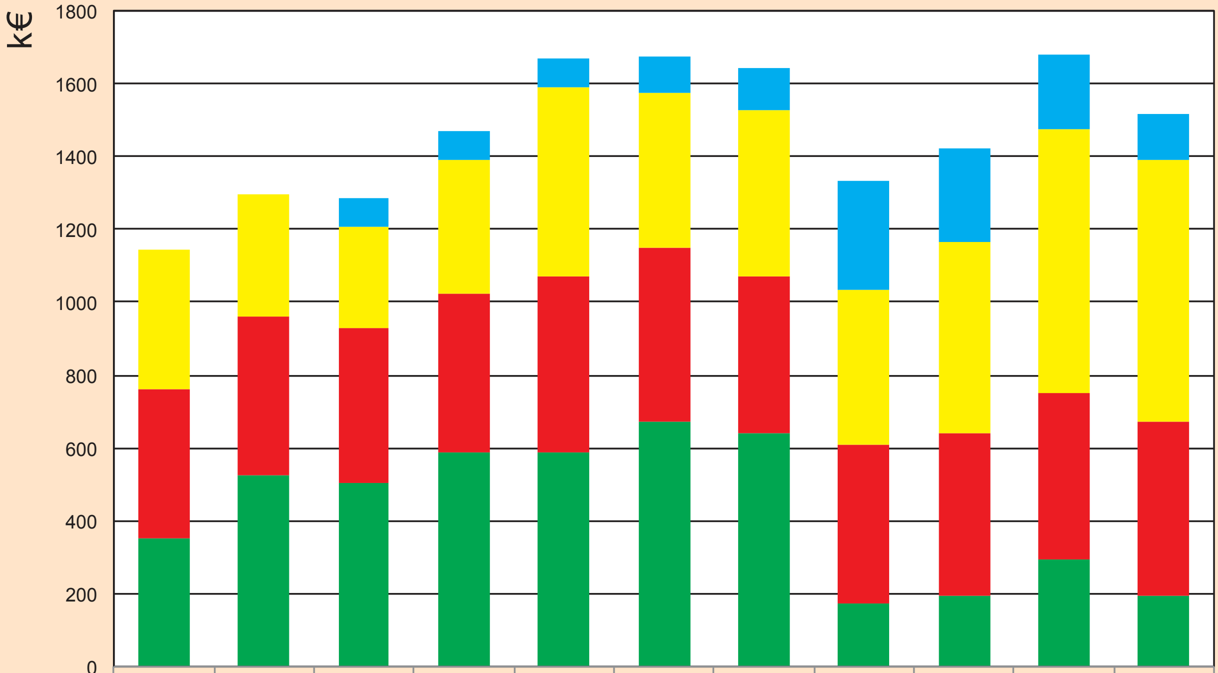
ALICE

- K. Aamodt (et al.) (ALICE Collaboration), First proton-proton collisions at the LHC as observed with the ALICE detector: measurement of the charged-particle pseudorapidity density at $\sqrt{s}$ = 900 GeV, Eur. Phys. J. C65 (2010) 111
- K. Aamodt (et al.) (ALICE Collaboration), Charged-particle multiplicity density at midrapidity in central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, Phys. Rev. Lett. 105 (2010) 252301
- K. Aamodt (et al.) (ALICE Collaboration), Elliptic flow of charged particles in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, Phys. Rev. Lett. 105 (2010) 252302



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians	4.7	6.7	8.5	8.5	8.8	12.0	12.0	5.8	3.5	3.5	3.5
PhD students	4.0	5.0	6.2	6.5	6.5	6.5	8.3	8.3	8.4	10.0	9.6
Postdocs	1.0	0.9	1.0	2.0	2.0	1.0	1.3	3.8	3.7	4.8	5.0
Staff	6.5	5.8	6.0	6.0	6.0	6.0	6.0	7.0	7.0	7.0	6.7

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects			77	83	81	96	112	299	257	204	124
Universities	380	338	277	363	519	425	459	426	526	721	721
FOM-university groups	410	436	424	440	482	480	427	436	444	461	474
FOM-Nikhef	353	524	506	586	589	671	643	173	197	292	197

Table II – Budget

2.4 Neutrino telescopes: ANTARES and KM3NeT

Programme organisation

Prof. dr. G. van der Steenhoven was programme leader until 2008, then after his departure to Twente University prof. dr. M. de Jong took over. The programme runs from 2008 to 2013.

Research goal

The primary objective of the research programme is to measure the spectrum of high–energy cosmic neutrinos with the ANTARES detector. Searches are performed of neutrino point sources, and relics of dark matter particles. At the same time, the development of a substantially larger km^3–sized neutrino telescope is initiated in an European framework (KM3NeT).

Research activities

ANTARES

The neutrino telescope ANTARES has matured from a design in 2004 to a fully operating detector in 2010. It is located at the bottom of the Mediterranean Sea 40 km south of Toulon at a depth of about 2500 m. It is a pilot project that aims to show the feasibility of detection of cosmic neutrinos using the sea as a detection medium. These neutrinos are detected through the muon they produce when interacting in or close to the detector. These muons being charged and travelling at velocities higher than the speed of light in the sea water emit Cherenkov light. Detection of this light with an array of photo-sensors allows the direction of the muon and therefore the neutrino to be reconstructed.

Research highlights

- Successful deployment of the 12 ANTARES detector lines.
- Successful implementation of the innovative ‘All–Data–to–Shore’ concept for the read–out of the detector.
- First neutrino sky map analysis.
- Development of prototype detector unit for KM3NeT.

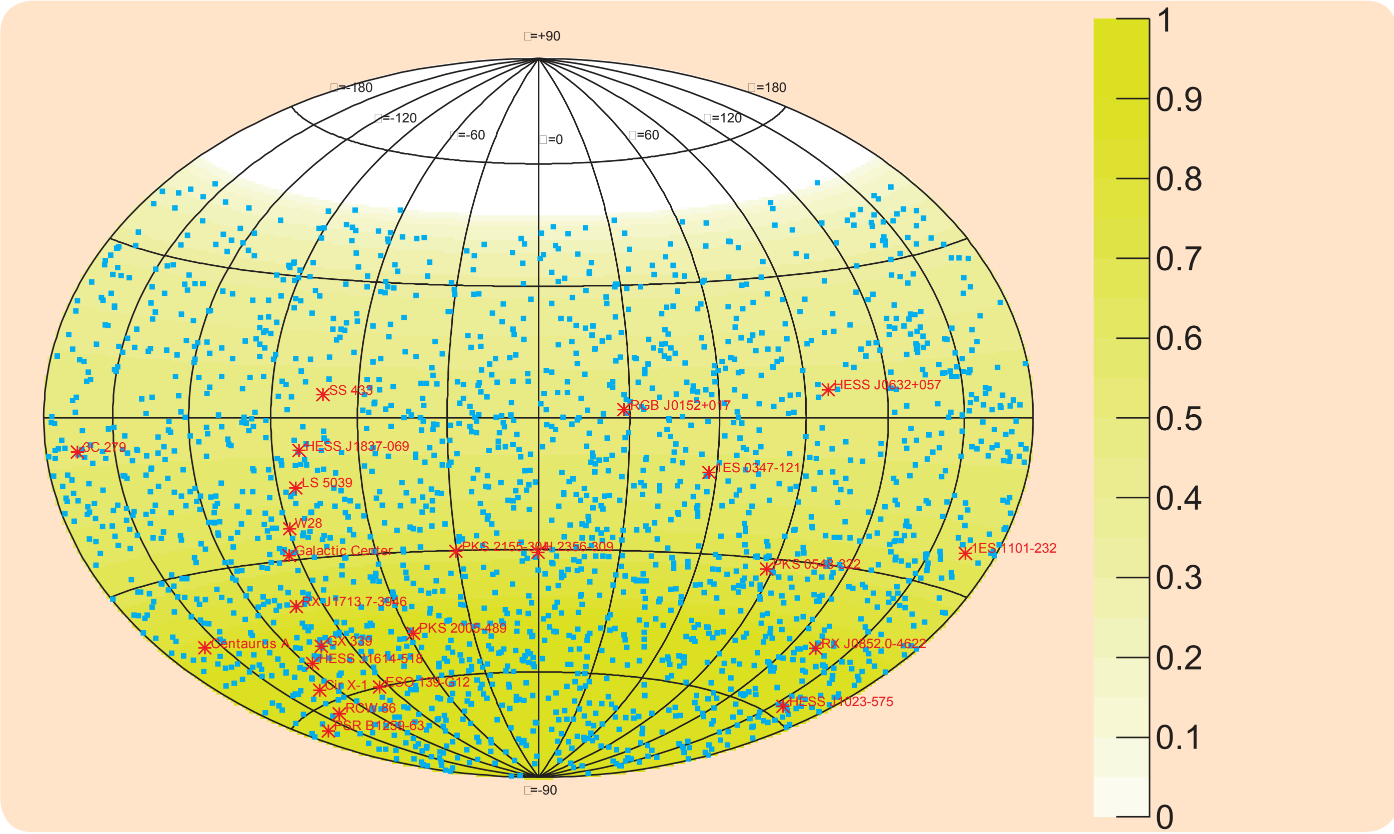


Figure 2.4.1. Celestial coordinates of 2040 selected neutrino candidates used for the point source search. Due to the optimised selection criteria, the events in the sky map mostly consist of mis-reconstructed muons (40%) and atmospheric neutrinos (60%). 24 source candidates are also shown in red. The yellow shading indicates the fraction of time available for observation (i.e. below the horizon). (ANTARES 2007–2008 preliminary data)

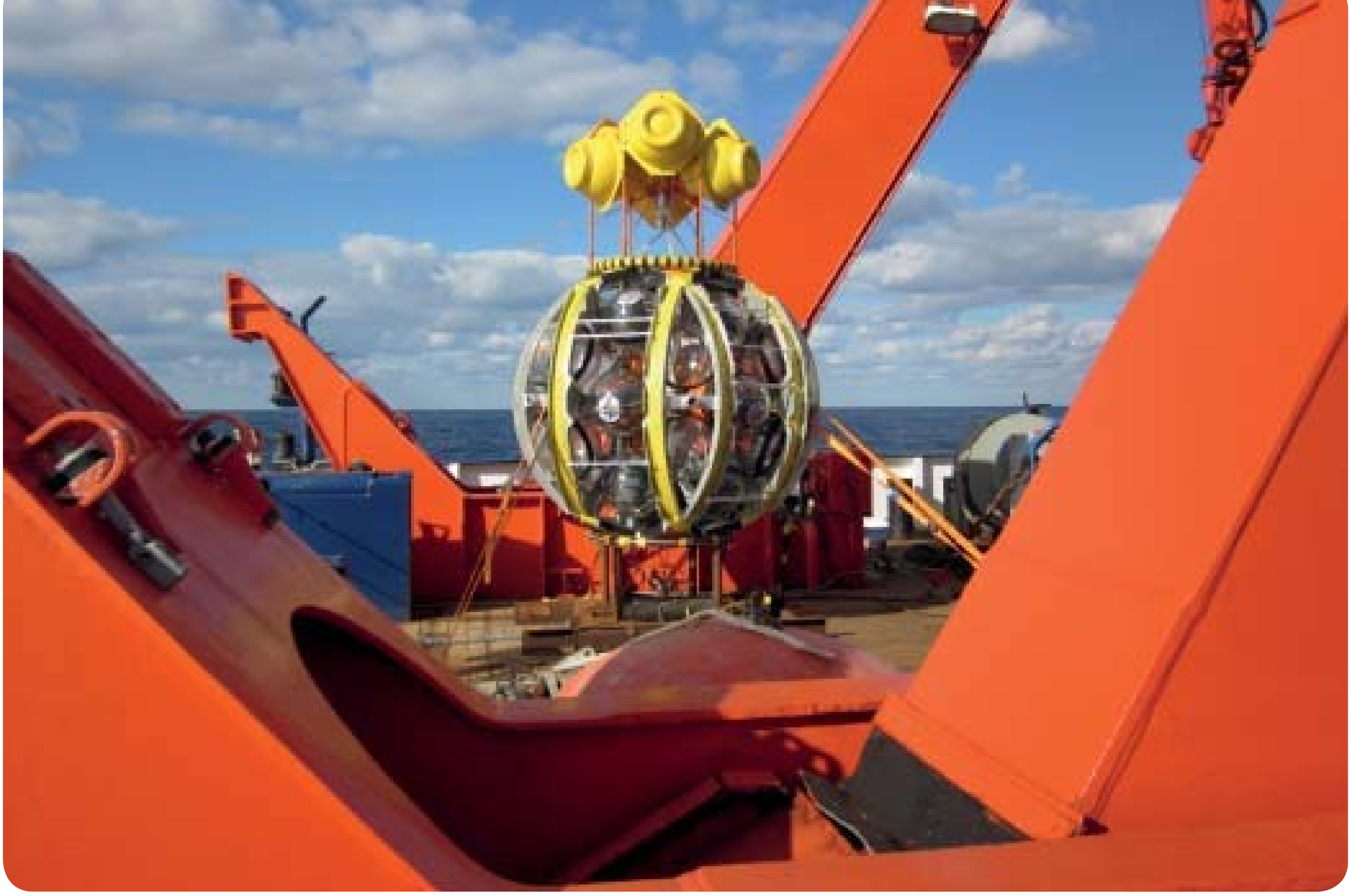


Figure 2.4.2. Launcher tests for prototype KM3NeT instrumentation lines.

The first detector line became operational in March 2006 and this was the culmination of several years of research and testing that allowed for the validation of the different subsystems of the detector. In addition many measurements of the deep-sea environment were made to be sure of the feasibility of the project. Understanding the behaviour of the first detector line and reconstructing the first tracks of muons passing the line were the subjects of Nikhef thesis; the first one in ANTARES to report on data taken with the telescope. It showed that the measured flux of muons, originating from interactions of cosmic rays above the detector, was as expected and so one could conclude that the experimental apparatus was well understood. This was only achieved after a re-evaluation of the angular acceptance of the optical sensors. In the following two and a half years the remaining 11 lines with optical sensors and one line with sensors for tracking the deep sea environment were installed.

The Nikhef group initially concentrated on track reconstruction software and with the algorithms described in the first ANTARES thesis it was possible to double the sensitivity of the detector, compared to what was thought to be achievable. This algorithm has since been revisited and further optimisation has led to a further increase in sensitivity. Using the tracking algorithm it has been shown that the sea allows for a significantly better directional accuracy than that possible in the competing experiments in the South Polar icecap, AMANDA and IceCube.

The search for neutrino signals from annihilation of dark matter particles in the Sun and the centre of our Galaxy was the subject of a study at Nikhef. The analysis shows that with only a short exposure of about 60 days with a half built detector, the sensitivity of ANTARES is already competitive with the presently published results.

The detection of relativistic monopoles in the ANTARES detector was investigated early on at Nikhef. The study of detection of monopoles travelling at velocities below the Cherenkov threshold, where monopole induced δ-ray production extends the sensitivity of the detector, was started. This method has been used in 2010 to set the best flux limit for relativistic monopoles.

Additional subjects being covered are the search for neutrinos from Gamma-Ray-Bursts (GRBs) and investigations of the chemical composition of charged cosmic rays in the energy range around 1 PeV.

Recently an analysis of around 2000 neutrino events in ANTARES has produced the best flux limits for neutrinos emanating from sources in the southern sky. This part of the sky of course incorporates the centre of our Galaxy. Having the centre of our Galaxy in its field of view makes the ANTARES neutrino telescope unique. Unfortunately, no sources have been found (2% of the background-only experiments is expected to yield a significance higher than the most significant 'hot-spot' found in the data). Competitive limits on the neutrino flux have been set for a number of source candidates. This work is continued with two more years of data to be analysed. The same data-set of selected up-going neutrino events is also being used to search for correlations with the highest energy cosmic-ray events detected by the Pierre Auger Observatory.

KM3NeT

Having demonstrated that the technique of a deep-sea neutrino telescope is feasible, a design study was started for a truly large volume telescope: KM3NeT. The seeds for this project were already sown in 2003 when the Nikhef group organised the first workshop on very large volume neutrino telescopes. During the design study that followed several unique techniques were developed at Nikhef. The optical sensor was redesigned to incorporate many small photomultipliers in a single pressure resistant housing, thus reducing the number of pressure resistant vessels and pressure transitions by a factor of three while keeping the sensitivity identical to the traditional solution using large area photomultipliers. A fibre-optic read out using state-of-the-art reflective electro-optical amplifying modulators was designed, which allows for the power hungry communications lasers to be placed only on shore. Finally, a pressure balanced oil filled cable housing 12 optical fibres and two copper conductors in a 6 mm diameter tube is under construction. This allows for efficient extraction of fibre read out at every optical sensor.

Together with the Royal Netherlands Institute for Sea Research (NIOZ), a method has been developed to deploy KM3NeT detector strings. This 'launcher' was successfully tested in a sea campaign in Greece in December 2009.

Work is also ongoing at Nikhef on developing reconstruction techniques dedicated for use with the KM3NeT detector design. These studies show that, due to the good optical properties of water, angular resolutions as small as 0.1° will be achievable.

At present the design of the detector is being finalised and the estimates are that a detector of around six cubic kilometres will be feasible. This is almost an order of magnitude larger than the IceCube detector, that has recently been installed in the icecap of the South Pole.

International collaboration

Nikhef is well represented in the committees of ANTARES, with a member of the steering committee and members of the conference and publication committees.

During the negotiations for obtaining funding for KM3NeT developments in the European Framework programmes 6 and 7, for KM3NeT design study and preparatory phase, E. de Wolf was one of the key negotiators. Funding for the programmes was obtained and KM3NeT is on the roadmap of the European Strategy Forum for Research Infrastructures (ESFRI). In the preparatory phase P. Kooijman is one of the European coordinators of the work packages on production preparation.

In 2010, the KM3NeT consortium defined the technology of the research infrastructure following the Technical Design Report and concluding validation tests conducted after.

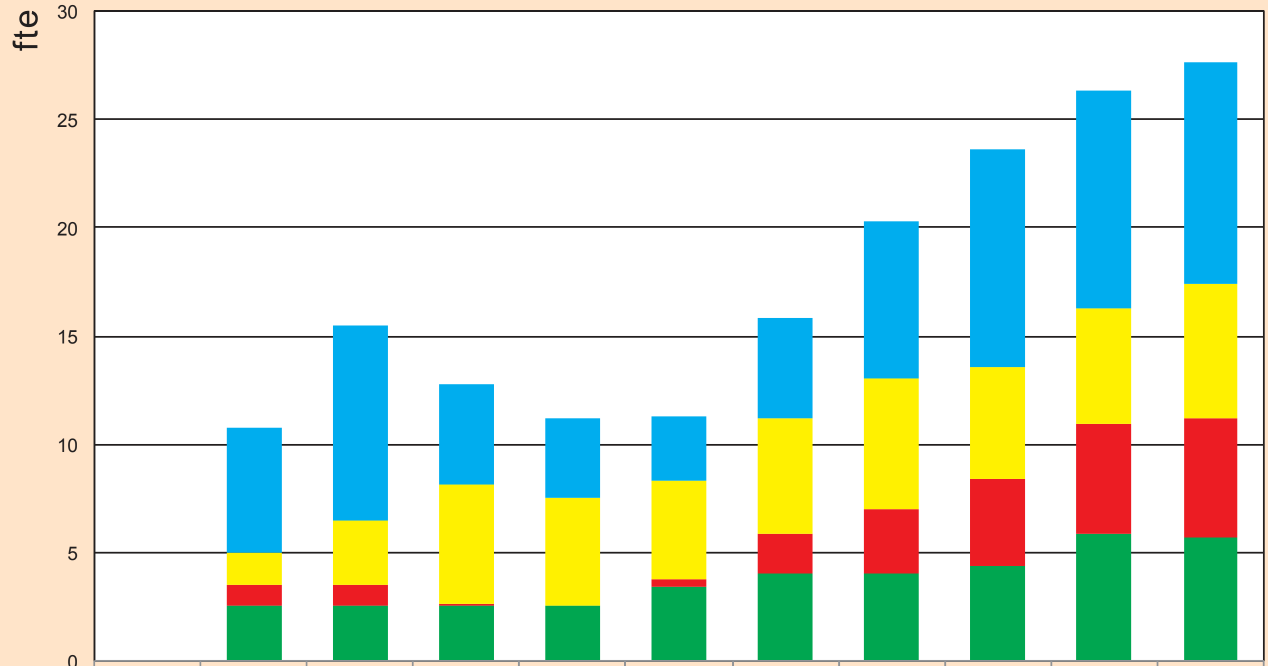
Awards

M. Bouwhuis and J. Petrovic received NWO-Veni grants in 2005 and 2008, respectively. A. Heijboer was awarded a NWO-Vidi grant in 2009. The minister of OCW decided on basis of the advice of NWO and SenterNovem to finance in total five research facilities, as selected by the so-called commitee Van Velzen, KM3NeT is one of them. Those projects were earlier been put on the European Roadmap by the European Strategic Forum for Research Infrastructure (ESFRI).

KM3NeT in the Netherlands, a collaboration of Nikhef, KVI and the marine research institute NIOZ, received in total a funding of 8.8 M€.

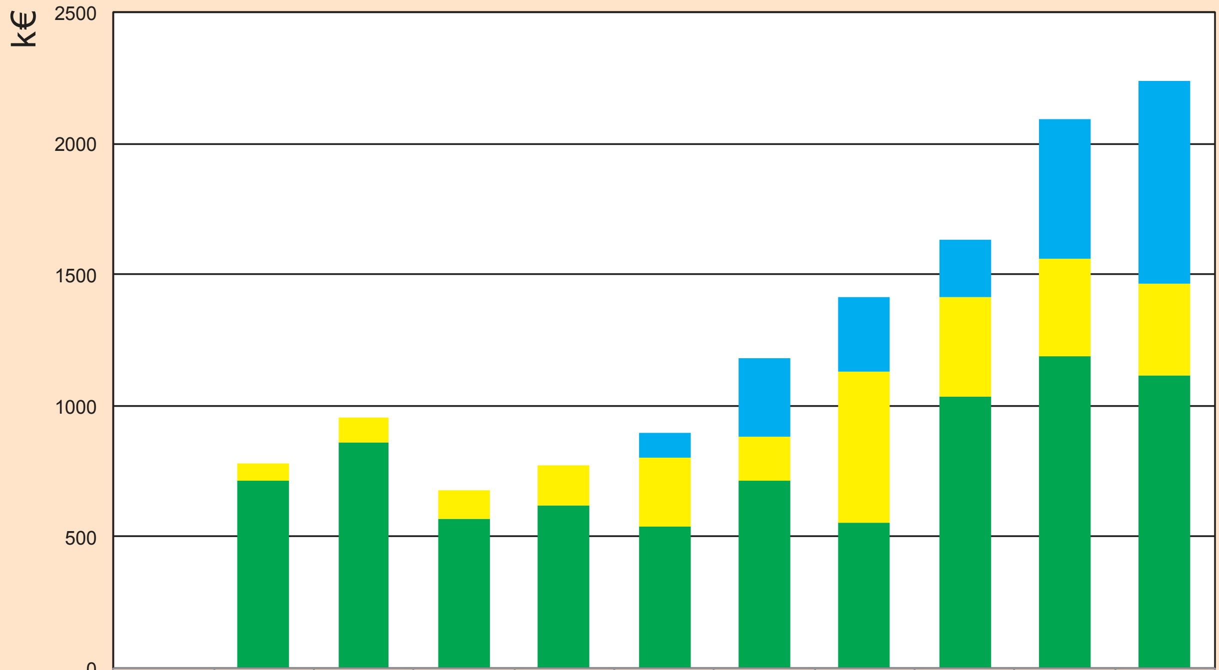
Key publications

- J.A. Aguilar (et al.) (ANTARES Collaboration), Zenith distribution and flux of atmospheric muons measured with the 5-line ANTARES detector, Astroparticle Physics 34 (2010) 179
- J.A. Aguilar (et al.) (ANTARES Collaboration), Performance of the front-end electronics of the ANTARES Neutrino Telescope, Nucl. Instr. and Meth. A622 (2010) 59
- J.A. Aguilar (et al.) (ANTARES Collaboration), Measurement of the atmospheric muon flux with a 4 GeV threshold in the ANTARES neutrino telescope, Astroparticle Physics 33 (2010) 86 (erratum: Astroparticle Physics 34, 3 (2010) 185)
- M. Ageron (et al.) (ANTARES Collaboration), Performance of the First ANTARES Detector Line, Astroparticle Physics 31, 4 (2009) 277
- M. Ageron (et al.) (ANTARES Collaboration), Studies of a full scale mechanical prototype line for the ANTARES neutrino telescope and tests of a prototype instrument for deep-sea acoustic measurements, Nucl. Instr. and Meth. A581 (2007) 695



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians		5.8	9.0	4.7	3.7	3.0	4.6	7.3	10.0	10.0	10.2
PhD students		1.5	3.0	5.5	5.0	4.5	5.3	6.0	5.2	5.4	6.2
Postdocs		1.0	1.0	0.1		0.4	1.9	3.0	4.0	5.0	5.5
Staff		2.5	2.5	2.5	2.5	3.4	4.0	4.0	4.4	5.9	5.7

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects						95	297	285	224	532	770
Universities		70	95	107	153	258	166	581	373	373	352
FOM-university groups											
FOM-Nikhef		712	862	571	618	543	718	552	1,039	1,187	1,114

Table II – Budget

2.5 Gravitational physics – the dynamics of spacetime: Virgo

Programme organisation
The research programme is being led by prof.dr. J.F.J van den Brand. The programme runs from 2010 to 2015.

Research goal
The primary objective is the first direct detection of gravitational waves, primarily with the Virgo detector near Pisa in Italy. This is a 3 km laser interferometer designed to measure the stretching and squeezing of spacetime due to gravitational waves, to a relative accuracy of 10^{-22}. Searches are being performed for gravitational waves from inspiraling and colliding binary neutron stars and black holes, continuous waves from pulsars, supernovae, and primordial backgrounds.

Research highlights

- Successful upgrade of Virgo to Virgo+ in 2008.
- Development of a data analysis pipeline to search for gravitational waves from fast-spinning neutron stars that are part of a binary system.
- Characterisation of gravity gradient noise in 3rd generation detectors (like the Einstein Telescope).
- Development of methods for doing cosmology with gravitational waves, e.g. studying dark energy with Einstein Telescope.

Research overview
Einstein's theory of general relativity revolutionised our understanding of space, time, and gravitation. The curvature of spacetime dictates the way in which matter and energy flow through it, and the latter in turn determines the curvature. For the first 60 years, almost all tests of general relativity involved stationary gravitational fields –the equivalent of doing experiments in electrostatics and magnetostatics. However, a core aspect of the theory is that gravitation is a dynamical phenomenon. This is exemplified by its prediction of gravitational waves: disturbances in spacetime curvature which propagate at the speed of light. The first indirect evidence for their existence came with the discovery of the Hulse-Taylor binary pulsar, whose orbital motion is changing in close agreement with general relativity if gravitational waves are being emitted.

Figure 2.5.1. The Virgo interferometer.

With the advent of a new class of gravitational-wave detectors, gravitational physics is about to change in a dramatic way. These are kilometer-scale interferometers which look for the tidal effects induced by passing gravitational waves, with a sensitivity to relative length changes $\Delta L/L < 10^{-22}$: Virgo near Pisa in Italy), LIGO in the US, and GEO in Germany. A first direct detection of a gravitational-wave signal is expected to happen around the middle of the decade. When this happens, we will finally have empirical access to the strong-field dynamics of gravity.

The Virgo experiment consists of a Michelson laser interferometer made of two orthogonal arms, each with a length of 3 km. Virgo is sensitive between a few tens of Hz up to a few kHz. Prime sources in this window include neutron stars in the Milky Way producing continuous gravitational waves, as well as inspiraling and colliding stellar mass binary black holes and neutron stars in other galaxies. Searches are also performed for unmodeled bursts coming from supernovae and other short-lived sources such as cusps in cosmic strings, and primordial gravitational waves arising from phase transitions shortly after the Big Bang.

In the past years, there has been much research and development for the Laser Interferometer Space Antenna (LISA), a large space-based observatory consisting of three spacecraft in heliocentric orbits, keeping a triangular configuration at distances of 5 million kilometre from each other. LISA is a collaborate effort of NASA and ESA, with a projected launch date shortly after 2022. It will probe the low-frequency range, from 10^{-4} Hz to 10^{-1} Hz; among other sources, it will be able to measure the inspiral and merger of supermassive binary black holes anywhere in the visible Universe.

Finally, a design study was recently concluded for a large European ground-based gravitational-wave observatory called Einstein Telescope (ET). ET is envisaged to consist of multiple interferometers with 10 km arm length, arranged in a triangle, in an underground facility. It will have a 10 times better sensitivity than Advanced Virgo and will be able to pick up sources at cosmological distances.

Research activities

During 2007–2008, Virgo performed its first science run, partially in conjunction with a LIGO run. After that the Virgo collaboration carried out an upgrade, termed Virgo+. In this upgrade, the laser power was increased and thermal compensation systems were installed. The design sensitivity was reached, and a second science run was performed in 2009–2010. Around that time, preparations were made for another upgrade to so-called Advanced Virgo, which will be finished by 2014.

The first detections will likely be made by Advanced Virgo and LIGO, but the existing interferometers have already yielded interesting astrophysical results by providing upper limits. From the search for continuous waves, it was established that no more than 4% of the energy emitted in the Crab pulsar's spin-down is emitted as gravitational radiation. The searches for short-duration signals have helped in the characterisation of gamma-ray bursts. The search for stochastic gravitational-waves led to constraints on certain models of baryogenesis.

The latency in data analysis has steadily decreased, so that it is now possible for gravitational-wave researchers to alert conventional astronomers when a candidate event is seen in the interferometer's data stream.

Figure 2.5.3. A seismic isolation system for optical benches. In the horizontal direction, the attenuation is done by three inverted pendula, in the vertical direction by a system of blade springs.

In May 2008, ET received 3 M€ from the European Commission within the Seventh Framework Programme (FP7) for a preliminary design study to define the specifications for the required site and infrastructure, and the new technologies and total budget needed. The study can be considered an important step towards the third generation of gravitational-wave observatories.

Nikhef contributions

In the 2008 upgrade to Virgo+, Nikhef took responsibility for the front-end electronics for angular alignment of the various mirrors, as well as for the input mode cleaner (IMC). The IMC is a 144 m long high finesse cavity that is used to filter out unwanted modes of the laser beam before it is injected into the interferometer proper. It also represents the first stage in the frequency stabilisation of the carrier wave.

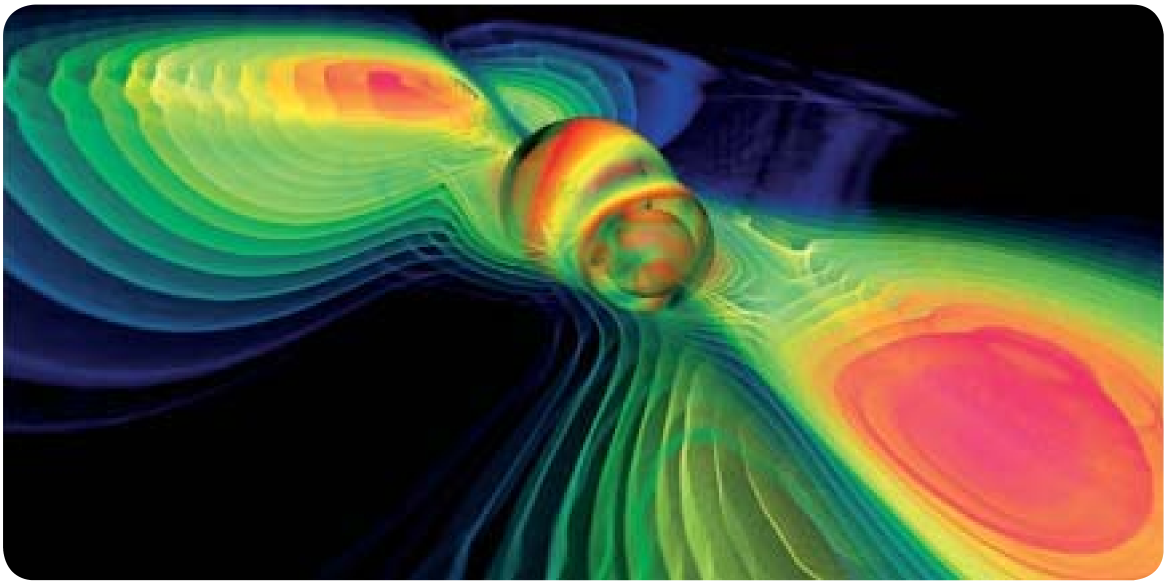


Figure 2.5.2. The gravitational waves emitted during the inspiral and merger of two black holes will give us direct empirical access to the strong-field dynamics of gravity. (Picture credit: AEI Potsdam.)

Figure 2.5.4. Underground infrastructure research (programme leader J van den Brand in the centre with a white tag) for the Einstein Telescope at a depth of 1480 metres in the Homestake Mine (South Dakota). The Homestake Mine is famous for being the site at which the solar neutrino problem was first discovered.

The end mirror of the IMC was suffering from low optical quality of both substrate and coating, which led to significant scattering losses. In addition, the weight of the mirror and its reference mass was too small, making the system sensitive to radiation pressure effects resulting in control problems. Nikhef has replaced the entire IMC end mirror system. A heavier and better-quality end mirror, part of the suspension system, and reaction mass were installed. The installation of the device took place in September 2008.

As part of the preparations for Advanced Virgo, Nikhef built a seismic isolation system for optical benches, where the horizontal damping is done by inverted pendula and the vertical damping by a system of geometric anti-springs. Furthermore, cryo-links were designed which will dramatically improve the quality of the vacuum by freezing out water vapour. As for the Virgo+ upgrade, Nikhef also designed the alignment electronics for Advanced Virgo. Finally, a prototype for a phase camera was built, which produces a phase map of the laser beam's cross-section.

Nikhef is a leading contributor to the ET-design study, by its involvement in the science case, and by being in charge of the infrastructure design and site selection. In this context, seismic measurements were performed around the world. Nikhef researchers also used finite element methods to model gravity gradient noise, which will be a limiting factor to ET's sensitivity at very low frequencies.

On the data analysis front, Nikhef has been involved in the search for continuous waves from fast-spinning neutron stars, and more recently also the effort to detect and study short-duration signals from coalescing compact binaries. For continuous waves, Nikhef researchers have developed an algorithm which automatically takes into account the Doppler modulation in signals from neutron stars that are part of a binary with unknown orbital elements. For coalescing binaries, the emphasis is on parameter estimation, i.e., the reconstruction of a source from the signal. An in-depth study was performed to understand the effects of instrumental calibration errors on parameter estimation. A start was also made with the development of algorithms to find possible deviations from General Relativity by looking at gravitational waves from binary coalescences as seen in Advanced Virgo. It also was shown how inspiraling binaries as seen in LISA and ET can be used as 'standard candles' to study the nature of dark energy.

Finally, Nikhef theorists have developed a promising new way to model the waveforms produced by so-called extreme mass-ratio inspirals, whereby a stellar mass object moves around a super-massive black hole before eventually getting swallowed. Such events are prime sources for LISA.

National collaborations

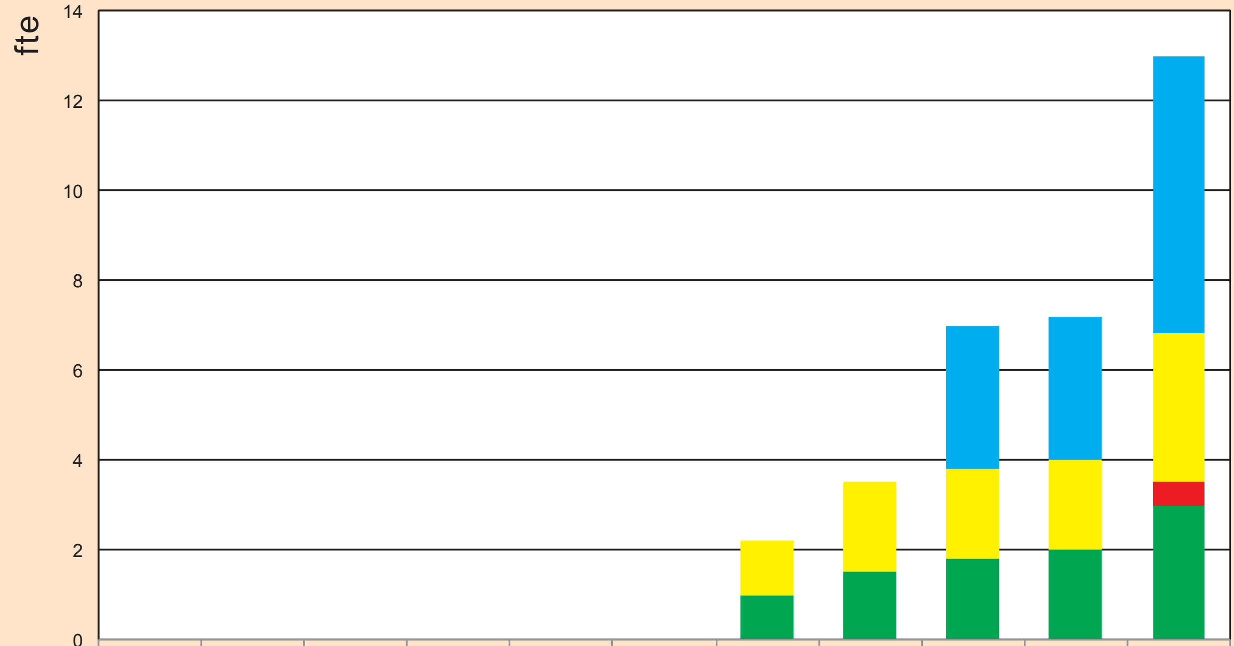
The Nikhef gravitational physics group receives technical support from the VU University Amsterdam. In its theory and data analysis projects, it collaborates with individuals from the universities of Leiden and Nijmegen.

International collaborations

The Virgo Collaboration closely collaborates with the LIGO Scientific Collaboration in the US, sharing the data from the different detectors. Together the collaborations have more than 800 members worldwide. The Einstein Telescope effort is a project of eight European research institutes.

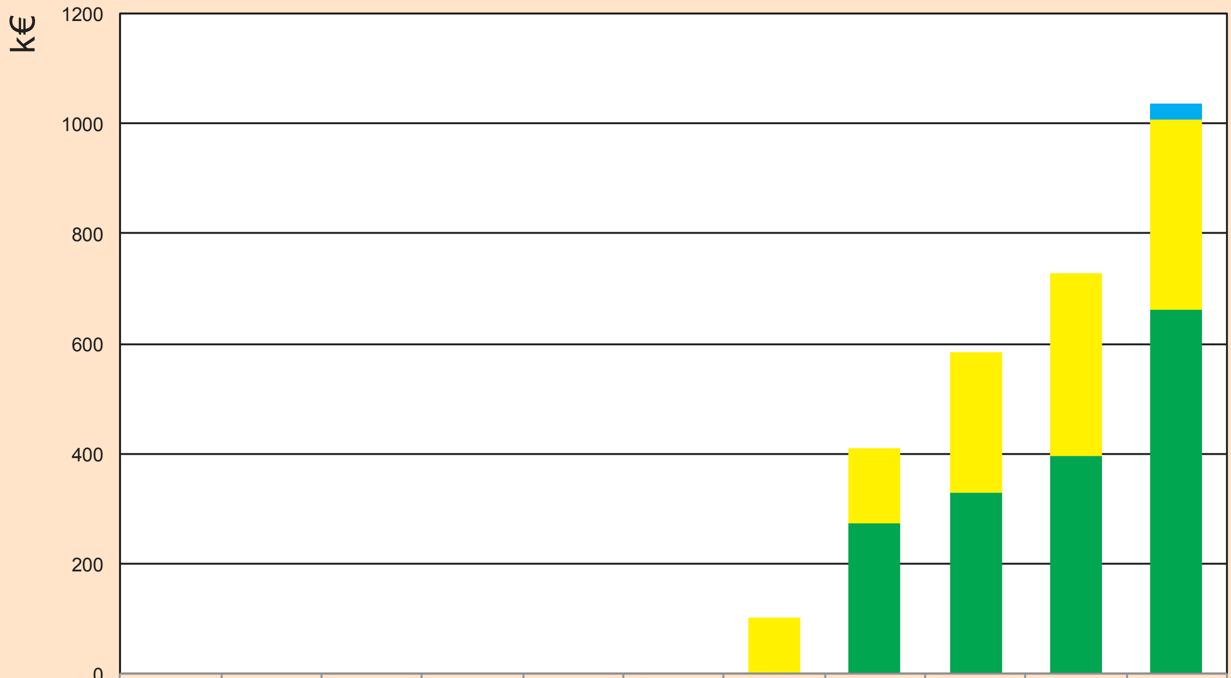
Key publications

- LIGO Scientific Collaboration, Virgo Collaboration, An upper limit on the stochastic gravitational-wave background of cosmological origin, Nature 460 (2009) 990
- LIGO Scientific Collaboration, Virgo Collaboration, Searches for gravitational waves from known pulsars, Astrophys. J 713 (2010) 671
- LIGO Scientific Collaboration, Virgo Collaboration, Search for gravitational waves from compact binary coalescence in LIGO and Virgo data from S5 and VSR1, Phys. Rev. D82 (2010) 102001
- C. Van Den Broeck, M. Trias, B.S. Sathyaprakash, and A.M. Sintes, Weak lensing effects in measuring the dark energy equation of state with LISA, Phys. Rev. D81 (2010) 124031
- M. Punturo et al., The Einstein Telescope: A third-generation gravitational wave observatory, Class. Quantum Grav. 27 (2010) 194002



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians									3.2	3.2	6.2
PhD students							1.2	2.0	2.0	2.0	3.3
Postdocs											0.5
Staff							1.0	1.5	1.8	2.0	3.0

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects											26
Universities							100	136	258	333	348
FOM-university groups											
FOM-Nikhef								275	328	394	660

Table II – Budget

2.6 Cosmic rays: Pierre Auger Observatory

Programme organisation

The FOM programme “The origin of Cosmic Rays” was awarded in 2008 and runs until 2013. The Dutch coordinator for the Pierre Auger Observatory is prof.dr. A.M. van den Berg (KVI/ University of Groningen), and the Nikhef project leader is dr. C.W.J.P. Timmermans.

Research goal

The primary objectives of the programme are: (i) the search for the sources of cosmic rays; (ii) the study of the primary composition of cosmic rays and (iii) the study of the interactions of fields and particles with ultra-high-energy cosmic rays (UHECRs), between their sources and detection on Earth. The Pierre Auger experiment studies air showers induced by protons, heavy atomic nuclei, neutrinos, and gamma-rays, at energies above 10^{17} eV.

Research activities

One of the key unresolved issues in astroparticle physics concerns the origin of cosmic rays with very large energies. Cosmic rays are a collective name for a variety of subatomic particles that are continuously bombarding the outer layers of the Earth’s atmosphere. While the Sun is a well-known source of low-energy cosmic rays, the origin of particles with energies in excess of 10^{12} eV has not yet been unambiguously identified. Supernovae explosions, for instance, are commonly believed to be the source of cosmic rays with energies up to 10^{15} eV, but so far it has not been possible to prove this by observation. Beyond this energy domain cosmic-ray particles most likely originate from extra-galactic sources at very large distances. Some of these particles are reaching energies well in excess of the highest energies that can be produced in the most advanced man-made particle accelerators. In fact, cosmic rays are the only observed ultra-high energy (UHE) particles on Earth, i.e. with energies in excess of 10^{16} eV. Still, the acceleration mechanism(s) leading to such ultra-high energies and their sources remain largely unknown. The search is carried out using the Pierre Auger Observatory, which is located in western Argentina near the city of Malargüe. The Pierre Auger Observatory consists of 1600 particle detectors, located on a total area of 3000 km^2, at ground level detecting the tail of the extended air-shower resulting from cosmic rays. This particle detector array is overlooked by 27 optical telescopes, which record the fluorescence light generated in air showers.

Figure 2.6.1. A particle detector in the foreground and two radio detection stations in the background.

Research highlights

- Measurement of a cutoff in the energy spectrum of Ultra High Energy Cosmic Rays (UHECRs).
- Determination of the composition of cosmic rays at extreme energies.
- Measuring the non-isotropic arrival distribution of UHECRs.
- Radio detection of Cosmic Rays.
- First measurement of the effect of charge excess at the air-shower front in radio.

Between 2005 and 2010, the Pierre Auger experiment clearly reconfirmed the cut-off in the energy spectrum of incoming cosmic rays. The discussion now focuses on the nature of this cut-off. This cut-off could be mainly due to the GZK-effect, i.e. the energy loss of protons through interactions with the cosmic microwave background, or to a limit of the astronomical accelerators, which might show up by a gradual change in the composition (nuclear charge) of cosmic rays at the highest energies.

Furthermore, the collaboration discovered that the distribution of arrival directions of cosmic rays with an energy larger than 5.5×10^{19} eV is not isotropic. The nature of the clustering or the sources of cosmic rays is still under debate. Our science publication of 2007 showed a correlation with the local distribution of active galactic nuclei, but depending on the composition of the cosmic rays, it is not excluded that the flux is dominated by a few nearby sources.

To resolve this fundamental question, the determination of the composition of the highest energetic particles is essential. The Pierre Auger Observatory uses optical telescopes to detect the fluorescence light emitted in air showers to study the shower

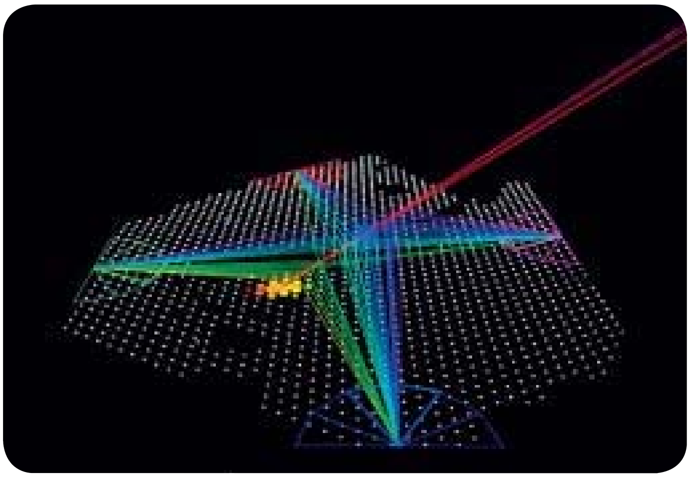


Figure 2.6.2. An air shower recorded by the Pierre Auger Observatory particle detector array and by the four eyes of the fluorescence telescope system. The colour-coding of the lines towards these four eyes indicates the movement of the shower as it penetrates the atmosphere. The colour-coding of the particle detectors is a measure of the relative timing for the detection of secondary particles in these detectors.

development, which is the main handle for the determination of the composition of the primary cosmic rays. The disadvantage of this method is that it only works in clear moonless nights, thus about 10% of the time. Due to the small flux of UHECRs, this uptime limits the composition measurement to cosmic rays with energies well below the cut-off in the energy spectrum. And, as a matter of fact, until today no data has been obtained with the fluorescence detectors at energies larger than 5.5×10^{19} eV, thus where the anisotropy starts and where correlations with astronomical objects can be made. The data obtained just below this energy indicates a change in composition from light (proton-like) to heavy (iron-like).

The detection of coherent radio emission from air showers provides a complementary handle on the shower development, with an uptime of nearly 100%. However, this technique is still under development. In 2005 scientists from Nikhef, KVI/University of Groningen, and the Radboud University have been invited to participate in the Pierre Auger collaboration to lead the development of radio-detection at the Pierre Auger Observatory. Our main effort is aimed at advancing the radio technique to be able to measure the development of air showers at the highest energies as a complementary tool for the determination of the composition of cosmic rays at the highest energies.

Radio detection of cosmic rays

Huge numbers of electrons and positrons are present in a highly energetic air shower. The main mechanism by which these particles emit coherent radiation is by their movement in the Earth's magnetic field. There are two complementary views of the main emission mechanism. The macroscopic view describes the effect of the magnetic field on these moving charged particles as a current perpendicular to this field and to the direction of the incoming cosmic ray. In a microscopic view the individual particles are created and absorbed while gyrating in the Earth's magnetic field. In both models the shower front is well defined leading to coherent radiation in the 20–100 MHz regime. Thanks to the radio development within the Pierre Auger Observatory, we now have reached a point where predictions from these two different models are quite similar, and both are in agreement with observations.

The Nikhef group, as part of the Dutch effort, has set out to establish the radio technique in Argentina by measuring the radio signal of air showers in time-coincidence with the particle detectors of the Pierre Auger Observatory. We have set up an initial array of three radio detector stations in the Pierre Auger Observatory that we have operated between 2007 and 2009. The read out of the stations was triggered using a small particle detector, that was located at our central station near the array. The data from this setup have shown that it is possible to operate low noise radio detector stations, which are sensitive to the galactic radio background, in the Pierre Auger Observatory. Using logarithmic periodic dipole antennas, the setup was capable of measuring radio signals induced by air showers, and the cosmic-ray arrival direction as reconstructed from the radio signals agreed with the reconstruction using the information from the particle detector array of the Pierre Auger Observatory.

Unexpectedly, the data from this setup also revealed a secondary mechanism by which an air shower generates a radio signal. This mechanism originates from the excess of negative charge in the front of an air shower, as first described by Askaryan in 1962. This charge excess causes a dipole effect, which leads to radio

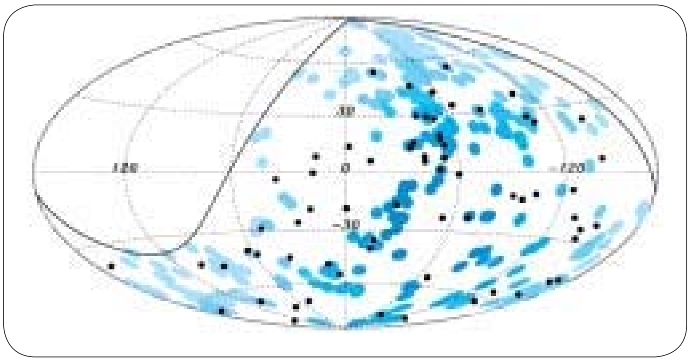


Figure 2.6.3. The 69 arrival directions of cosmic rays with an energy larger than 55 EeV detected by the Pierre Auger Observatory up to 31 December 2009 are plotted as black dots in an Aitoff-Hammer projection of the sky in galactic coordinates. The solid line represents the border of the field of view of the observatory for zenith angles smaller than 60°. Blue circles of radius 3.1° are centred at the positions of the 318 AGNs in the VCV catalog that lie within 75 Mpc and that are within the field of view.

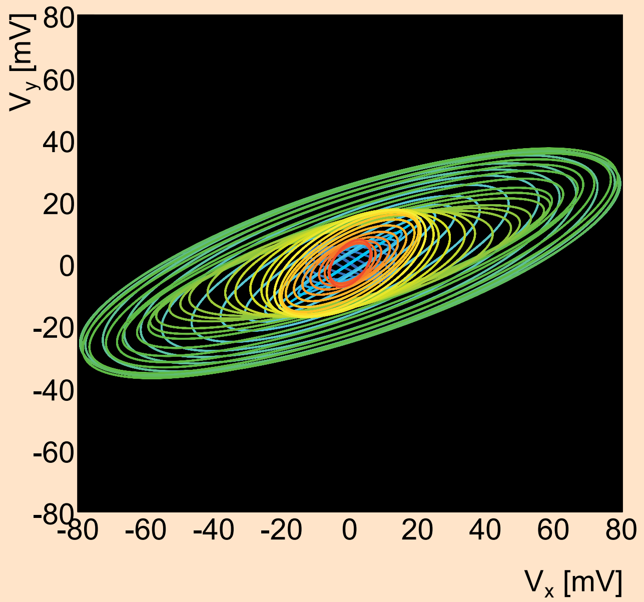


Figure 2.6.4. Polarisation ellipse of a measured radio signal as a function of colour-coded time. The horizontal axis shows the pulse height in the East-West direction, and the vertical axis shows the North-South polarisation. The signal starts at the blue-end, expands and ends at red.

emission. However, the polarisation pattern is different from the main geomagnetic contribution. A Nikhef-initiated polarisation dependent analysis of the data has clearly revealed, for the first time ever, the existence of this effect occurring in air showers.

As a next step towards a large detection array, we have developed a radio detector station that uses solar power and digital electronics very close to the radio sensor. The main challenges of this setup are the suppression of pulsed (self-induced) noise, which influences the capability of using the radio signal to trigger the read out, as well as the limited power available to amplify, digitise, store and send the data. Nikhef has contributed to this setup by developing a low-power, passively cooled digitiser with an onboard CPU, whereas KVI/University of Groningen delivered a low-noise highly efficient photo-voltaic system. Even though this setup (MAXIMA) was too small to exploit self-triggering of cosmic rays, we were able to record air-shower induced radio signals from this setup by triggering the read out of each individual station using a small local particle detector. This setup has produced data of much higher quality than our original setup, and the next development of a 20 km^2 radio detector setup is therefore based upon these stations.

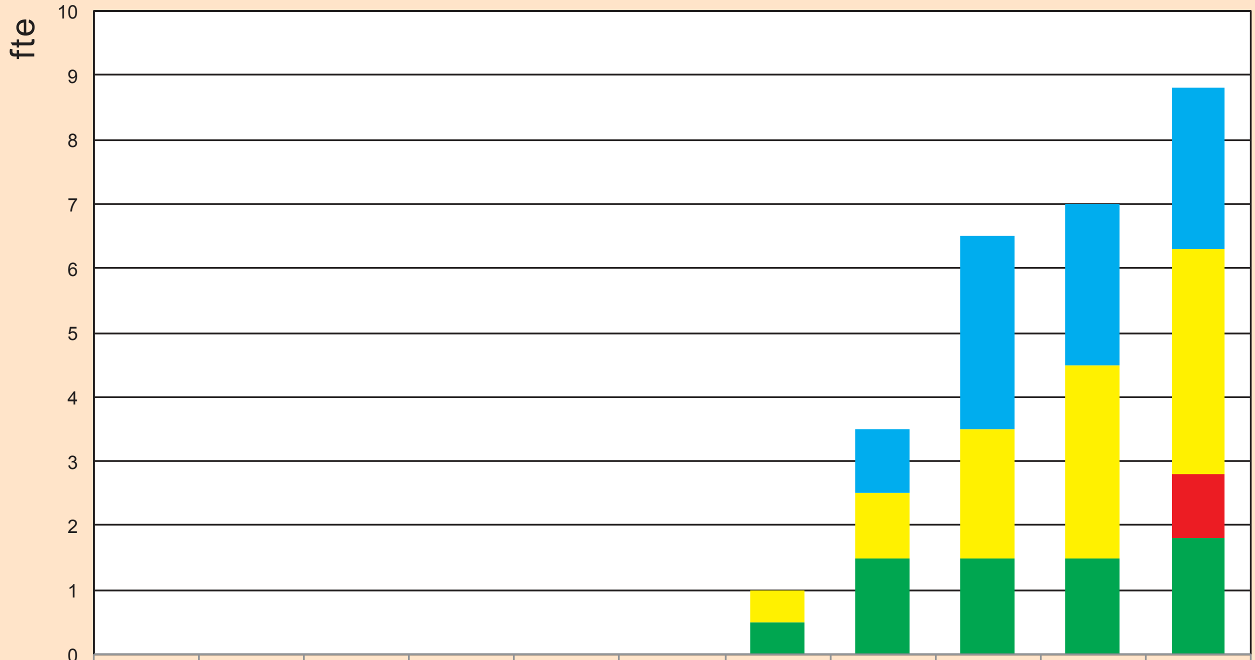
The next challenge for creating a large detector is the development of a low-power high-throughput self-managing communication system. We have found experts outside the Nikhef collaboration with whom we are developing such a completely new type of data communication system for sensor networks. This development may not only be beneficial for radio detection as this can be applied to other purposes as well (e.g. an early-warning system for catastrophic events).

Awards

In this period the group received a 'projectruimte' grant together with KVI/University of Groningen and the astrophysics group of the Radboud University. In 2007, J. Petrovic received a NWO-Veni for combining Pierre Auger Observatory and ANTARES research. In 2007, the EPS outreach prize was awarded to C. Timmermans for initiating HiSPARC, a cosmic ray outreach project in the Netherlands. In 2009, the Dutch annual academic prize was awarded to "Cosmic Sensation", which set out to translate cosmic ray research to a large audience. The team of Cosmic Sensation was composed of honours students and scientists of the Radboud University and was led by S. de Jong.

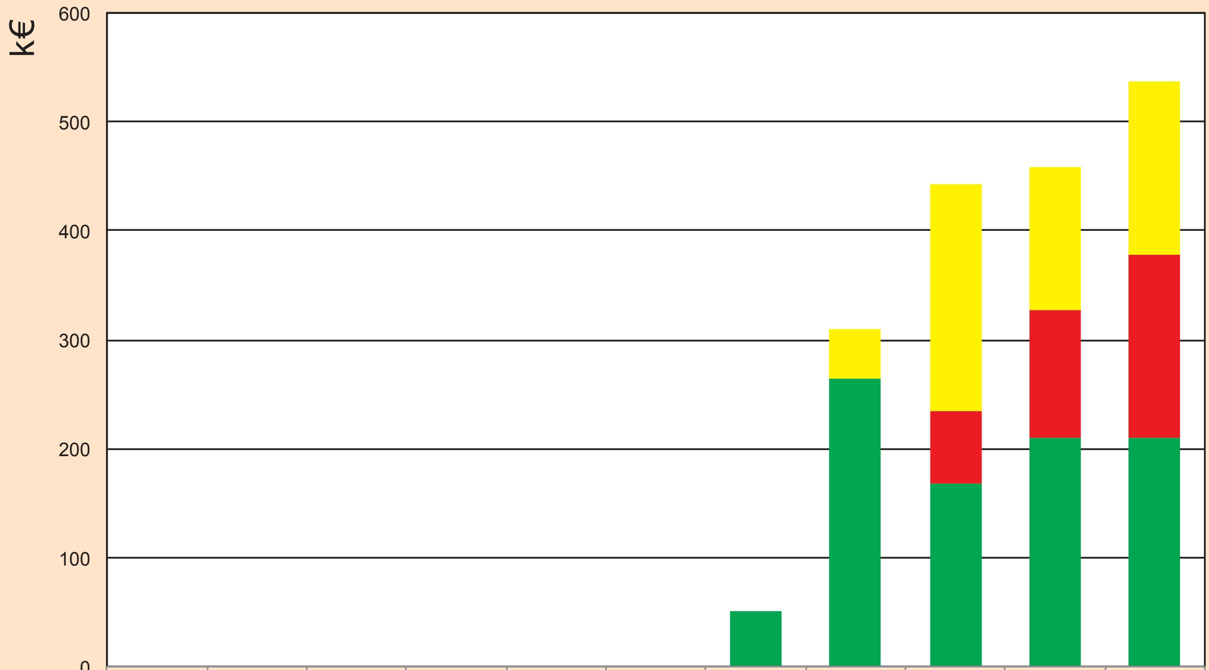
Key publications

- J. Abraham (et al.) (The Pierre Auger Collaboration) Correlation of the highest energy cosmic rays with positions of nearby active galactic nuclei, Science 318 (2007) 938
- J. Abraham (et al.) (The Pierre Auger Collaboration) Observation of the Suppression of the Flux of Cosmic Rays above 4×10^{19} eV, Phys. Rev. Lett. 101 (2008) 061101
- J. Abraham (et al.) (The Pierre Auger Collaboration) Measurement of the Depth of Maximum of Extensive Air Showers above 10^{18} eV, Phys. Rev. Lett. 104 (2010) 091101



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians								1.0	3.0	2.5	2.5
PhD students							0.5	1.0	2.0	3.0	3.5
Postdocs											1.0
Staff							0.5	1.5	1.5	1.5	1.8

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
projects											
universities								45	208	132	159
FOM-university groups									66	117	168
FOM-Nikhef							50	264	168	210	210

Table II – Budget

2.7 Theoretical physics

Programme organisation

The programme leader at Nikhef is prof.dr. E. Laenen. The award of the FOM programme "Theoretical Particle Physics in the Era of the LHC" in 2007 (ending in 2014) has been very important for the theory group at Nikhef. By funding five PhD and five postdoctoral fellowships at six participating institutes it jump-started a network-based effort in addressing the question of what is behind the Standard Model via the three themes of precision predictions, discrete symmetry violation, and new particle production. The group also has a direct link with the Gravitational Waves programme, of which prof.dr. J.W. van Holten is a member.

Research goal

The Nikhef theory group in Amsterdam pursues its own research objectives, supports, informs and learns from experimental efforts. It also actively participates in teaching efforts at Nikhef through lab-wide lecture courses and mentoring of Master students, PhD students and postdocs. In recent years, aided by the FOM programme, it increasingly acted as host and coordinator of efforts in the theoretical particle physics phenomenology. The group consists of five staff members, and about 5–10 PhD students and postdocs. A number of Master students have recently also joined in publications. Its research objective is to describe and explain the properties and interactions of elementary particles, chiefly in the framework of quantum field theory. This entails both the construction and evaluation of models, as well as the developments of analytical and computational tools thereto.

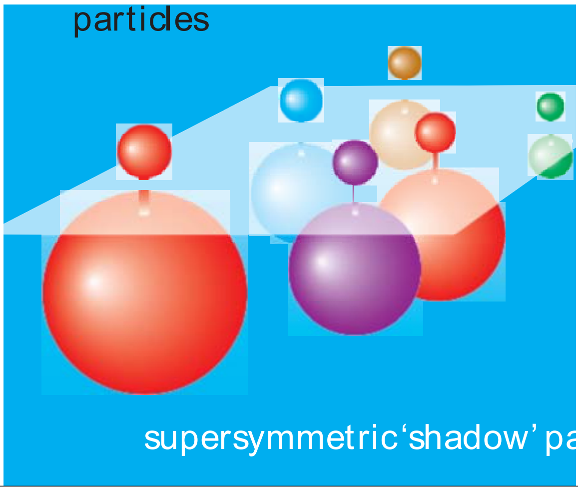


Figure 2.7.1. In supersymmetry theory all particles (bosons and fermions) have a –more massive– partner with the same quantum numbers except spin. Hence all bosons have a supersymmetric fermion partner and vice-versa.

Research highlights

- The continuing output from the heroic efforts by Vermaseren, Moch and Vogt that produced the spectacular results of the 3-loop QCD splitting functions in 2004.
- The classification of enormous numbers of solutions for the string theory landscape by Schellekens and collaborators, allowing statistical analysis on occurrance of features such a gauge groups and numbers of fermion families.
- The open sourcing of symbolic manipulation program FORM, with strong support of Nikhef management; a crucial step to make FORM viable for the long term.

Research activities

The following projects have been pursued:

Standard Model-like theories from string theory

- Majorana neutrino masses incorporated into conformal field theory based framework.
- Predictions for models with 3 families now no longer unusual.

Top quark physics

- Single top production included in MC@NLO (Three Standard Model channels, plus one with charged Higgs).
- Single top production studied for SUSY-QCD model with Dirac gluino.

Cosmology

- Many approaches tested for theoretical consistency (hybrid inflation, string based), showing inflation to be an discriminator between various new physics models.

Gravitational waves

- Combined analytical-numerical approach developed for binary star system emitters.

Beyond the Standard Model

- Next-to-leading order (NLO) plus next-to-leading logarithmic (NLL) resummed production cross sections of squarks and gluinos derived.
- Charged Higgs production built into MC@NLO.
- Extra-dimensional models with soft walls designed and consistency criteria defined.

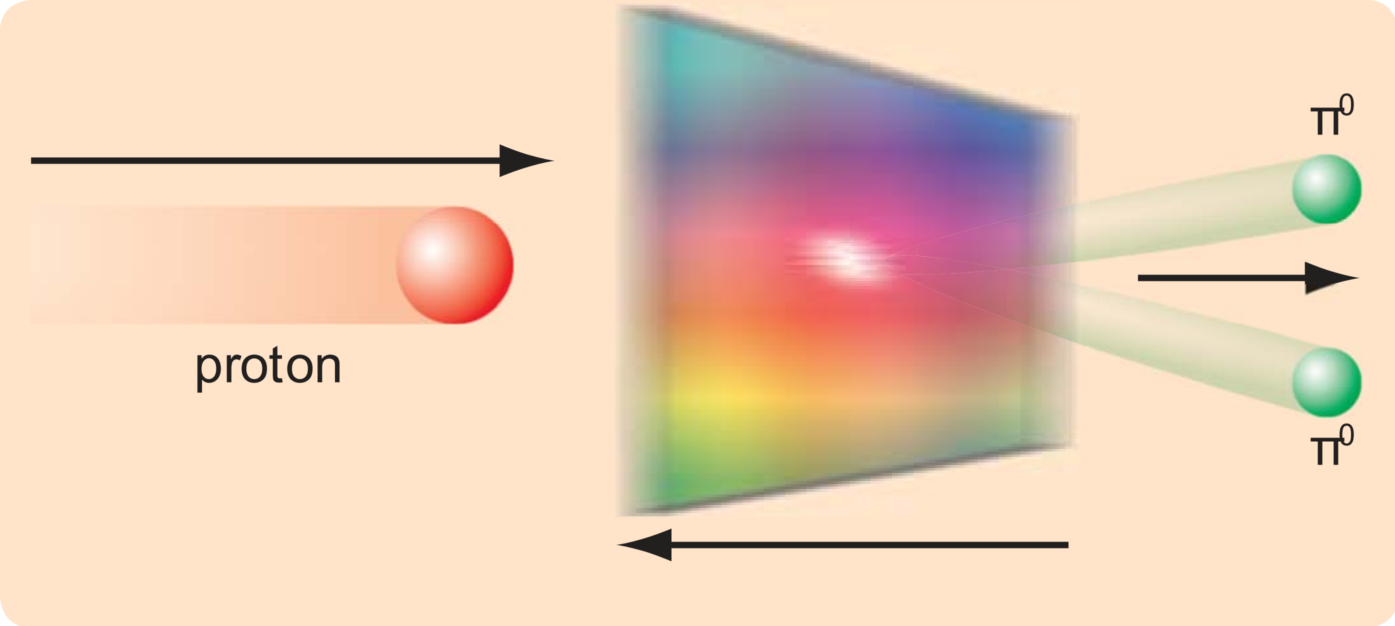


Figure 2.7.2. Colour glass condensate in proton-ion collisions. The nucleus is Lorentz contracted along the direction of motion. The term 'colour' refers to the colour charge of quarks and gluons, 'glass' to the behaviour of this disordered state (a solid on short time scales, but a liquid on longer time scales) and 'condensate' to the very high density of the gluons.

QCD predictions and tools

- Development of tFORM started.
- NNNLO corrections to F2 and F3 coefficient functions computed.
- Heavy quark PDFs defined according to FONLL scheme.
- 3-loop quark and gluon form factors computed.
- NLO predictions for vector bosons plus jets (background for top physics and new physics searches) computed and included into Blackhat.
- NLO predictions made and automation achieved through GRACE, GOLEM and SAMURAI approaches.
- Resummation approaches extended to NNLL. Extension of web exponentation derived from two to any number of external lines. Classification and resummation of sub-eikonal terms achieved using both path-integral and diagrammatic methods.

Mathematical physics

- Data mine created for multiple zeta values.
- Nonrelativistic Chern-Simons vortices on torus studied.

B-physics and CP violation

- New strategy proposed for reducing the uncertainty in the measurement of the rate for $B_s^0 \rightarrow \mu^+\mu^-$ at LHCb – one of the key processes to search for New Physics.
- Shown that $B_s^0 \rightarrow J/\psi\, K_S$ helps exploration of CP violation in B_d^0–$\bar{B}_d^0$ mixing.
- Shown that $B_s^0 \rightarrow K^+K^-$ offers interesting observables to search for new physics, and points to CKM angle γ in agreement with Standard Model.

Special emphasis has been put on collaboration between theorists and experimentalists with other groups within the Netherlands:

Joint publications between different institutes in the FOM programme that involve Nikhef

- Family symmetries (Bazzochi (VU), Adelhart Toorop).
- Squark-gluino production (Niessen, Beenakker (RU), Laenen).

FORM, tFORM	Vermaseren (et al.)	Symbolic manipulation program; its multi-threaded version. Used by theorists worldwide for computing collider signals and many other applications.
GOLEM, SAMURAI	Reiter (et al.)	One-loop diagrams; one loop scattering amplitudes in dimensional regularisation.
Spinney; Haggies	Reiter (et al.)	For spinor helicity calculation; for generating optimised numerical codes from mathematical expressions.
Blackhat	Forde (et al.)	NLO calculations for a vector boson plus up to four jets.
Madgraph 5, Feynrules	Herquet (et al.)	Automated computation of many processes, requiring only the Lagrangian as input.
Kac	Schellekens	For computing “fusion rules” in conformal field theory.
MC@NLO	Frixione, Webber, Laenen (et al.)	Nikhef group members added the single top production processes to this framework.

Table 2.7.1. Important software (contributed to) by group members.

Joint publications and projects of theorists and experimenters

- B-physics (Fleischer and LHCb staff members).
- Colour glass condensate PhD project (Laenen and Peitzmann (STAR, UU)).

National and international collaborations

The Nikhef theory group hosts the monthly Theory Centre Meetings, where staff, postdocs, PhD and Master students from many Dutch universities interact, discuss and collaborate on questions relevant for collider and astroparticle physics. These meetings, featuring also advanced lectures on relevant topics, have become a fixture on the Dutch theoretical physics calendar. Nikhef also hosts the National THEP seminar twice a year. At present the group is a full node in the FP7 training network 'LHCPhenoNet'. It was a subnode in the FP7 training network 'HEPTOOLS', until completion of this programme in 2010. Group members have research collaborations with colleagues all over the world.

Guests

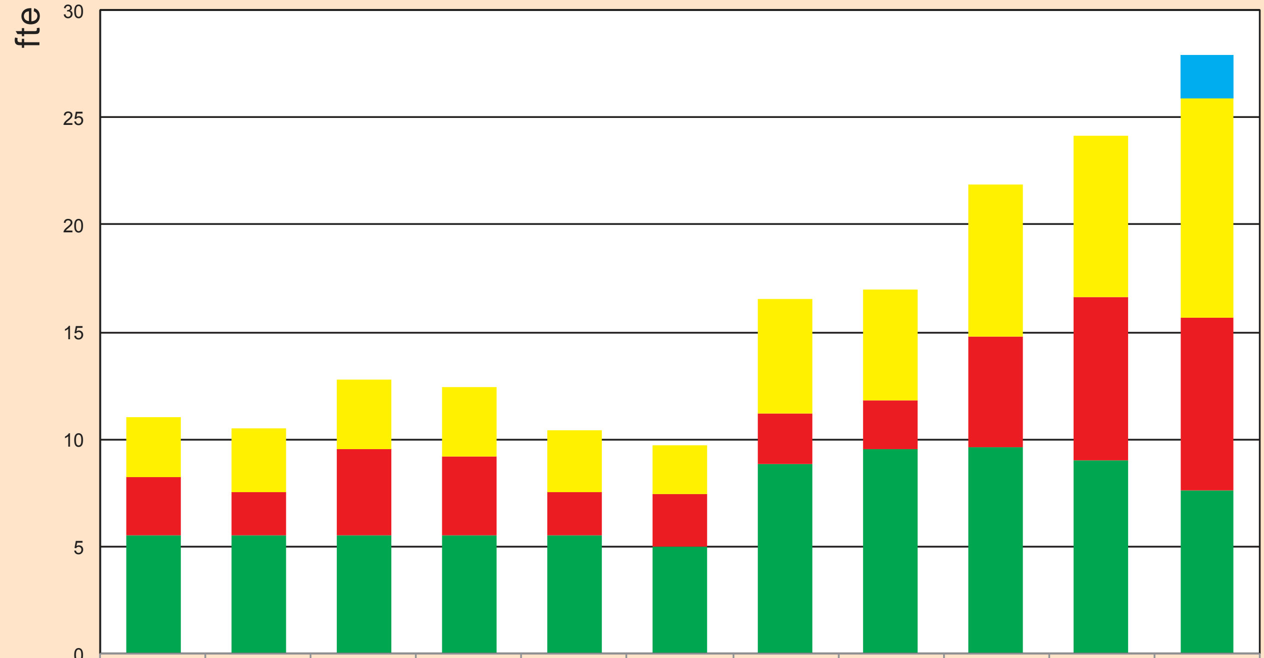
More than the other physics groups at Nikhef, the theory group has a tradition of inviting guest scientists for longer-term visits for the purposes of collaboration and extended discussions. During 2009-2010 the number of foreign guests was 20 with affiliation: University Pierre et Marie Curie–Paris VI, University of Tours (France), University of WÜrzburg, DESY Zeuthen, University of Aachen, University of MÜnchen (3) (Germany, Physics Department-IIT Mumbai (2), University of Madras-Chennai (India), University of Torino (Italy), CERN (2) (Switzerland), University of Liverpool (3) (UK), SUNY Buffalo, Fermilab (US) and University of Hanoi (Vietnam).

New staff and awards

R. Fleischer joined the group per September 2009, thereby strengthening the efforts in precision predictions and in the physics of flavour and CP violation. M. Postma, working in the area of inflationary cosmology and its relation to particle physics, joined the group on a 5 year NWO-Vidi grant in 2008. FOM 'Projectruimte' grant proposals have been awarded to Schellekens (2005), Laenen (2005, with experimental physics colleague), Vermaseren (2007), Fleischer (2009). In 2006 Vermaseren was awarded the Humboldt research prize, enabling him to spend extended periods in DESY Zeuthen, and Karlsruhe. Postdocs C. White (2008) and M. Herquet (2010) were awarded Marie Curie Fellowships.

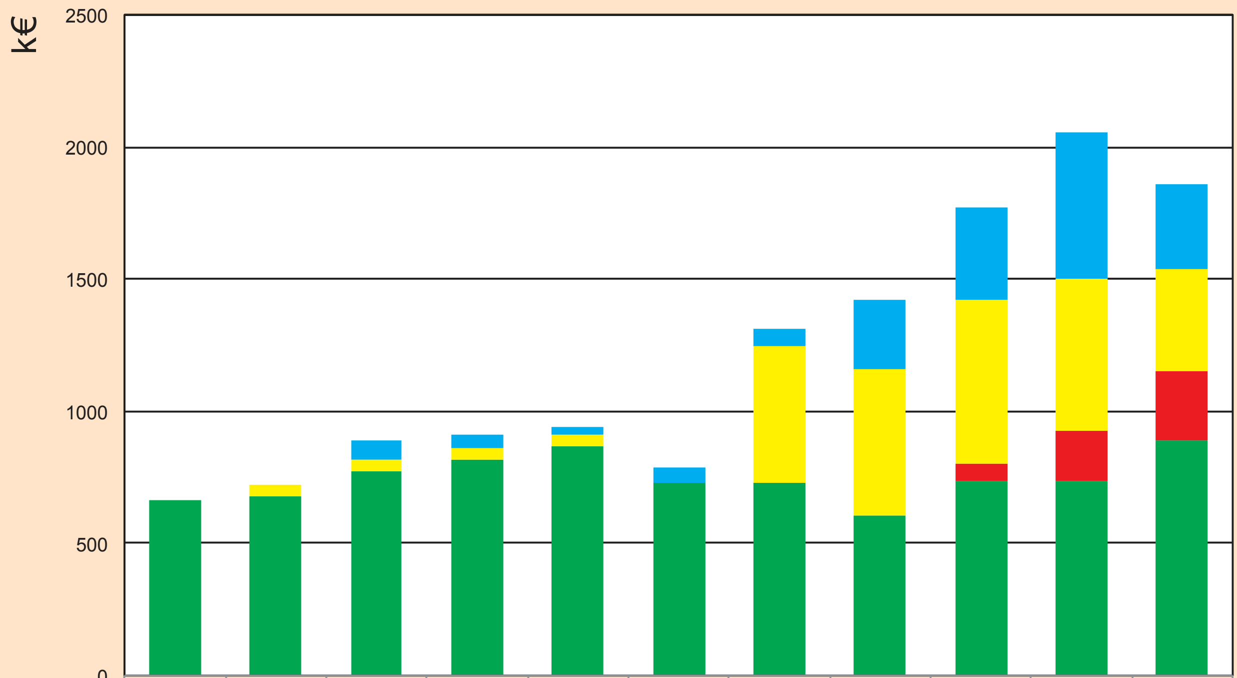
Key publications

- T. Dijkstra, L. Huiszoon, A. Schellekens, Supersymmetric Standard Model spectra from RCFT orientifolds, Nucl.Phys. B710 (2005) 3
- S. Moch, J. Vermaseren, A. Vogt, The Third-order QCD corrections to deep-inelastic scattering by photon exchange, Nucl.Phys. B724 (2005) 3
- R. Jeannerot, M. Postma, Confronting hybrid inflation in supergravity with CMB data, JHEP 0505 (2005) 071
- S. Frixione, E. Laenen, P. Motylinski, B.R. Webber, Single-top production in MC@NLO, JHEP 0603 (2006) 092
- W. Beenakker, S. Brensing, M. Kramer, A. Kulesza, E. Laenen, I. Niessen, Soft-gluon resummation for squark and gluino hadroproduction, JHEP 0912 (2009) 041
- R. Fleischer, N. Serra, N. Tuning, A New Strategy for Bs Branching Ratio Measurements and the Search for New Physics in $B^0_s \to \mu^+\mu^-$, Phys.Rev. D82 (2010) 034038



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians											2.0
PhD students	2.8	3.0	3.3	3.2	2.9	2.3	5.3	5.2	7.1	7.5	10.2
Postdocs	2.7	2.0	4.0	3.7	2.0	2.4	2.4	2.3	5.2	7.6	8.1
Staff	5.5	5.5	5.5	5.5	5.5	5.0	8.8	9.5	9.6	9.0	7.6

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects			70	54	28	59	69	262	350	552	323
Universities		45	45	43	43		518	549	621	577	384
FOM-university groups									66	192	268
FOM-Nikhef	665	680	775	817	871	728	727	609	734	734	887

Table II – Budget

2.8 Detector R&D

Programme Organisation

The programme was led in 2005–2008 by dr. J. Timmermans, in 2009 -2010 by prof.dr. F. Linde and since November 2010 by dr. N.A. van Bakel. The programme has started officially in 2003 as Nikhef programme, funded out of the mission budget.

Research Goal

The focus of the Nikhef R&D group has been on the further development of gaseous and silicon detectors for charged particles and X-rays with pixelated read out at multi-gigabit per second read out rate. The context of the programme has been both the preparation for a new generation of experiments at the e^+e^- linear collider (ILC or CLIC) as well as intrinsic detector R&D with foreseen applications only on a long term basis. Collaborations with industrial partners are actively pursued.

The group has been active in the following R&D areas:

- Gaseous detectors read out by specially developed multi-pixel CMOS chips with fully integrated gas-gain grid;
- Hybrid CMOS pixel detectors for X-ray imaging applications;
- Alignment systems based on RASNIK;
- Compact read out electronics based on Medipix & Timepix ASICs;
- CO_2 detector cooling.

Moreover, in the evaluation period the group has seen growth in the number of staff members as well as of PhD and master students.

Research highlights

- Production of GridPix, a novel Micro Pattern Gas Detector on a CMOS pixel read out chip, with wafer post-processing technologies.
- Construction and testing of a large prototype Time-Projection-Chamber (TPC) for a future linear collider.
- Development of a compact 1 Gbit/s read out system for the Medipix2 and Timepix micro-chips.
- Development of a Timepix read out ASIC (Application Specific Integrated Circuit) within the Medipix collaboration.
- Successful ending of the RelaXd project; development of a compact 1 Gbit/s read out system for the Medipix2 and Timepix chips.
- New R&D projects: the Hidralon project in close collaboration with Philips Healthcare and a chip design project with Bruco in the framework of the 'Kenniswerkersregeling'.

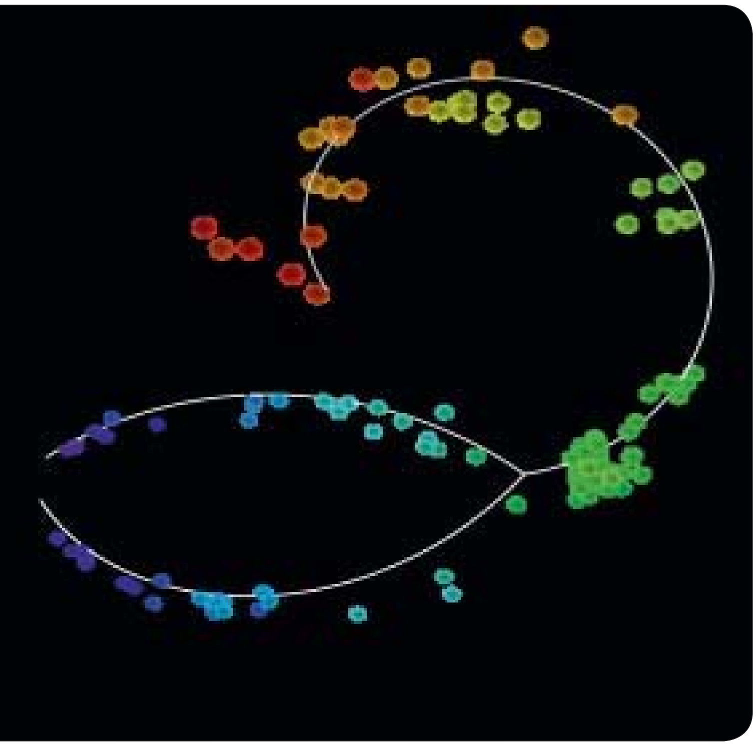


Figure 2.8.1. The tracks of an electron and an electron-positron pair resulting from the decay of a ^{24}Na nucleus, recorded with the GridPix detector. The drift time, proportional to the perpendicular coordinate, is indicated by colour. Each hit pixel can be associated with a single electron, created along the path of the energetic particles.

Research Activities

Gaseous detectors

As a possible solution for the fabrication of larger pixelated Micro Pattern Gas Detector (MPGD) elements, the group proposed the integration of the amplification grid with the read out chip by means of wafer post-processing and MEMS (micro-electro mechanical systems) technology: a thin (1 μm) aluminium grid is fabricated on top of an array of 50 μm long pillars placed on a CMOS chip. This structure forms a 'monolithic' detection and read out device, called GridPix, and the fabrication process has been developed in close collaboration with the MESA+ institute of the University of Twente. Several GridPix's of different geometry, shape and pitch of the grid holes, and multiplication gap thickness (pillar height) were produced and tested with various gas mixtures. Energy resolution and gas gain were measured as a function of the grid geometry parameters. As an example, a maximum gas gain is reached for a gap thickness around 50 μm (at fixed grid voltage), in agreement with expectations from model calculations.

Achieving sufficient protection against discharges has been an enormous breakthrough. Initially, this has been realised by means of 15–20 μm thick amorphous silicon layers on the CMOS read out chip. Later, another high-resistive material Si_3N_4 (silicon nitride) has been successfully applied resulting in a 7 μm thick protection layer. Further developments of the GridPix production process to improve performance and yield have been a continuous effort. GridPix detectors with only a thin layer of gas covering the pixel chip could be an alternative for Silicon sensors, now widely applied in tracking detectors. A beam telescope has been assembled consisting of three GridPix detectors, having a drift gap of 1 mm. The telescope was placed in the H4 testbeam at CERN to measure the basic operational parameters of the MPGD detectors, such as position resolution, angular resolution, efficiency and double track separation. This showed the superior 3D angular track resolution of this type of detector. While the full analysis of the abundance of data is still in progress, preliminary analysis has resulted in a position resolution of 15 μm and a track detection efficiency of 99%. With an angular resolution of 0.6° a single gas layer GridPix detector could provide momentum information for the ATLAS Level-1 trigger.

GridPix could provide better radiation tolerance, and be much lighter compared to semiconductor detectors. The crucial feature of 'ageing' has been studied with some encouraging results. In 2010 the ATLAS Executive Board has reviewed the possible benefits and will support this R&D effort for a duration of three years to demonstrate and quantify performance, cost and reliability, with the remark that silicon sensors remain the ATLAS baseline solution.

Several projects have evolved last year as a spin-off from the gas detector and read out ASIC efforts within the group. Integrating a UV-photon sensitive CsI photocathode on top of a grid structure enables high resolution imaging of single UV-photons. This detector operated reliably with He/isobutane gas mixtures and attained sufficient charge gain. Another application uses a GridPix detector with a 2 cm drift gap, called PolaPix, to detect cosmic x-rays. By reconstructing the direction of the ejected electrons the associated polarisation angle of the x-rays can be determined. A new R&D activity is part of a DARWIN design study, planning to use GridPix in dual phase noble liquid detectors to detect rare processes like dark matter interactions. A first experimental setup has been assembled to operate a GridPix detector under cryogenic conditions. In the framework of the European EUDET R&D project towards a future Linear Collider detector, Nikhef initiated the development of the Timepix chip as a modification of the earlier used Medipix2 chip. The Timepix not only provides a high-granularity x-y coordinate read out, but each 55×55 μm² pixel also measures the arrival time of the charge on the pixel, thus providing the third spatial coordinate (z).

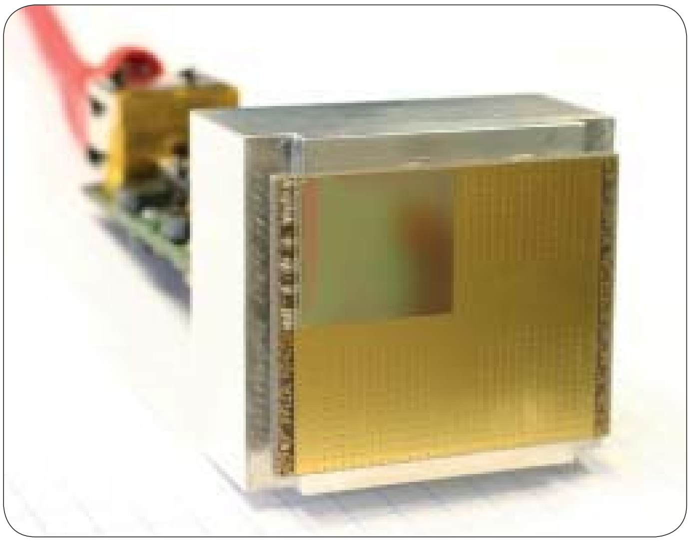


Figure 2.8.2. RelaXd quad chipboard with high-speed read-out module.

The group is participating in the Linear Collider TPC (LCTPC) collaboration, which pursues R&D for a large Time-Projection Chamber (TPC). The performance goals for such a TPC are an order of magnitude better momentum resolution than obtained at LEP. In collaboration with CEA Saclay an 8-fold GridPix detector system has been prepared, and mounted on an endplate module for the EUDET Large Prototype TPC test facility, installed inside a 1 T solenoid at a 6 GeV electron test beam at DESY. Stable data taking has been achieved in 2010 with satisfactory operation of the detector demonstrating the anticipated high granularity.

Semiconductor detectors

Silicon hybrid pixel detectors with Medipix read out have been used to measure local space vectors for particle trajectories instead of points. One setup consisted of two hybrid detectors closely assembled into a vertical stack. This 2-sensor system demonstrated a first volumetric pixel (voxel) with full parallel read out, providing precision tracking, even at high densities of incident particles. Secondary 'delta' electrons have been observed, which have a high probability to create corrupted position measurements along the trail. If these can be recognised in a fitting procedure, an improved precision may be achieved.

Another effort is aimed at characterizing edgeless sensors. Dicing techniques are compared in the quest for smoother edges to reduce leakage currents in the active pixel matrix. This programme started with silicon sensors in the ReLaXd project and has been extended towards heavier materials like gallium-arsenide and cadmium-telluride in cooperation with Philips Healthcare in the Hidralon project for the use in medical interventional X-ray imaging. Specifically, the reduction of the inactive edge of the sensor is under study to enable tiling with a minimum of dead area between the tiles. A proof of principle has been established with significant reduction of the guard rings surrounding the active area of silicon pixel sensors. For a 300 μm thick silicon sensor the guard ring has been reduced from 500 μm to about 50 μm from the sensor edge,

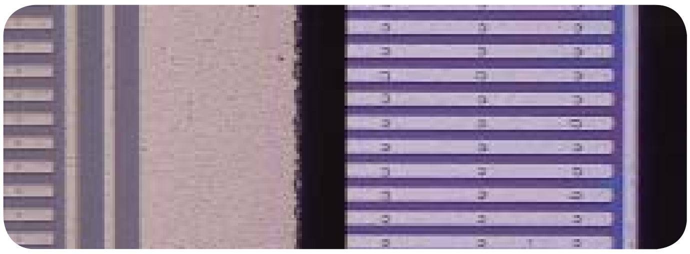


Figure 2.8.3: Comparison between edges and guard ring structures of silicon sensors: a sensor with conventional guard ring diced with a blade (left) and one cut out by deep reactive ion etching and a narrow guarding structure (right).

decreasing the dead area from 7% to 1%. Two such sensors were placed side by side in a test beam at CERN and revealed a dead-area of only 90 µm between the two modules.

The ReLaXd project is a collaborative effort with industry, PANalytical in the Netherlands, IMEC research centre and Canberra in Belgium, to develop a high-speed X-rays imager. The Nikhef participation focuses on the development of detector units that can be tiled at all four sides into larger surfaces and can be read out at a multi-gigabit per second rate. This requires replacing the wire-bond read-out at the side of the chip by Through-Silicon-Vias; a ball-grid-array attached to the bond-pads at the front of the chip. To minimise the area between the tiles, edgeless sensors have been designed by Canberra. The first devices have been made and tested. The performance of the edge-pixels in the various configurations has been studied. The multi-gigabit per second read out is being developed in collaboration with PANalytical. The frame rate was increased to about 100Hz and full communication with the chip is being implemented in the onboard field-programmable gate array (FPGA). This system is now the baseline read-out at Nikhef for all Medipix related experiments with gas and semiconductor detectors.

In the fall of 2009 a collaboration between Bruco, an ASIC design house specialised in mixed signal design, and Nikhef started under the 'Kenniswerkers regeling'. Within the collaboration two projects were defined. In the first sub-project we designed and tested a prototype chip in a 130 nm technology which proved that it is possible to transfer data over micro twisted pair cables of 2 m with speeds in excess of 8 Gbit/s. The typical application for such links are the inner detectors of collider experiments where optical transmission might not be feasible due to the harsh radiation environment. With some small design modifications speeds of 10 Gbit/s seem possible.

The second sub-project consisted of extensive studies to optimise the read out architecture of pixel detector read-out chips. A strong reduction in the data volume has been obtained by implementing sparse read out, i.e. only those pixels are read out which have a hit. A further reduction in the amount of data was achieved by clustering hits from adjacent pixels which allows removal of redundant address and timing information. The studies have shown that it is possible to read out more than 500 million pixel hits per second with a loss of less than 1%.

Optical alignment for a Linear Collider (CLIC)

A new cooperation between Nikhef and CERN is the so-called RasClic optical alignment system, for pre-alignment of accelerator elements at a future e^+e^- linear collider (notably for CLIC), and to monitor the position of the final focus quadrupoles on each side of the detector.

RasClic is a laser-based three-point alignment system, derived from the short-range system RASNIK but using diffraction rather than imaging, dedicated to the alignment of ILC/CLIC elements and monitoring slow oscillations resulting from earthquakes ('earth hum'). A patent for both applications has been submitted; earth hum wave packets were first observed on 12 September 2007. Several test benches have been commissioned at Nikhef and CERN to study short and long range alignment with sub-micrometer precision. Observed precision of the 91 m prototype at CERN is below 200 nm per measurement, with improved light insertion by optical fibre. Recent upgrades are an extension to 140 m (projected 500 m), increased measurement repetition rate from average 12.5 Hz to stabilised 62.5 Hz, temperature monitoring of the environment for drift correction, and improved pattern analysis; target precision is from 10 down to 1 nm.

CO_2 cooling

The group has been involved in developing cooling equipment for the Alpha Magnetic Spectrometer experiment (AMS: designed to search in space for dark matter, missing matter and antimatter at the international space station ISS), and the LHCb experiment at LHC. Both experiments have detector cooling based on an evaporating cooling cycle. Using liquid CO_2 as a cooling fluid, allows the experiments to work with high pressure, small sized tubing and thus low-weight systems. As a consequence of working with high pressure one can regulate the cooling temperature of the detector at 0.3 °C over a distance of 60 m.

Due to the success of this cooling systems for AMS and LHCb, CO_2 cooling has acquired popularity at various institutes and universities. In July 2009 a collaboration has started between institutes and universities that have interest in cooling plants with CO_2 as cooling fluid.

Nikhef Contributions

Nikhef contributed to Medipix the design and fabrication of carrying PCBs for single, four and eight chips and the design, fabrication and control of the interface box between the chip and read-out computer. Nikhef played and plays a pioneering role in the detection of minimum ionizing particles using (integrated) MPGDs and CMOS pixel read-out chips. RASNIK alignment systems have been invented and developed at Nikhef and were/are applied in large quantities in e.g. the ATLAS experiment at LHC. For XFEL detector R&D activities DESY has expressed interest in acquiring a CO_2-cooler based on the Nikhef design.

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

National Collaborations

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

In a multidisciplinary collaboration with the Faculty of Electric Engineering of the University of Twente (prof. dr. ir. Bram Nauta) two PhD projects were completed, funded by STW and industrial grants.

International Collaborations

The group is involved in international collaborations: the EU-FP6 funded EUDET project; with groups from the universities of Bonn and Freiburg, CEA Saclay and CERN, and the Medipix2 and Medipix3 projects. The Medipix2 Collaboration consists of 17 leading research groups across Europe, centred at CERN.

The ReLaXd project funded by SenterNovem, an agency of the Dutch Ministry of Economic Affairs, is a collaboration between Nikhef and IMEC Leuven, as knowledge institutes, and industrial companies: PANalytical and Canberra.

The Hidralon project is pursued in close collaboration with manufacturers e.g. Philips Healthcare and Orbotech and other research groups such as the Delft University of Technology and the Fraunhofer Institute.

Awards

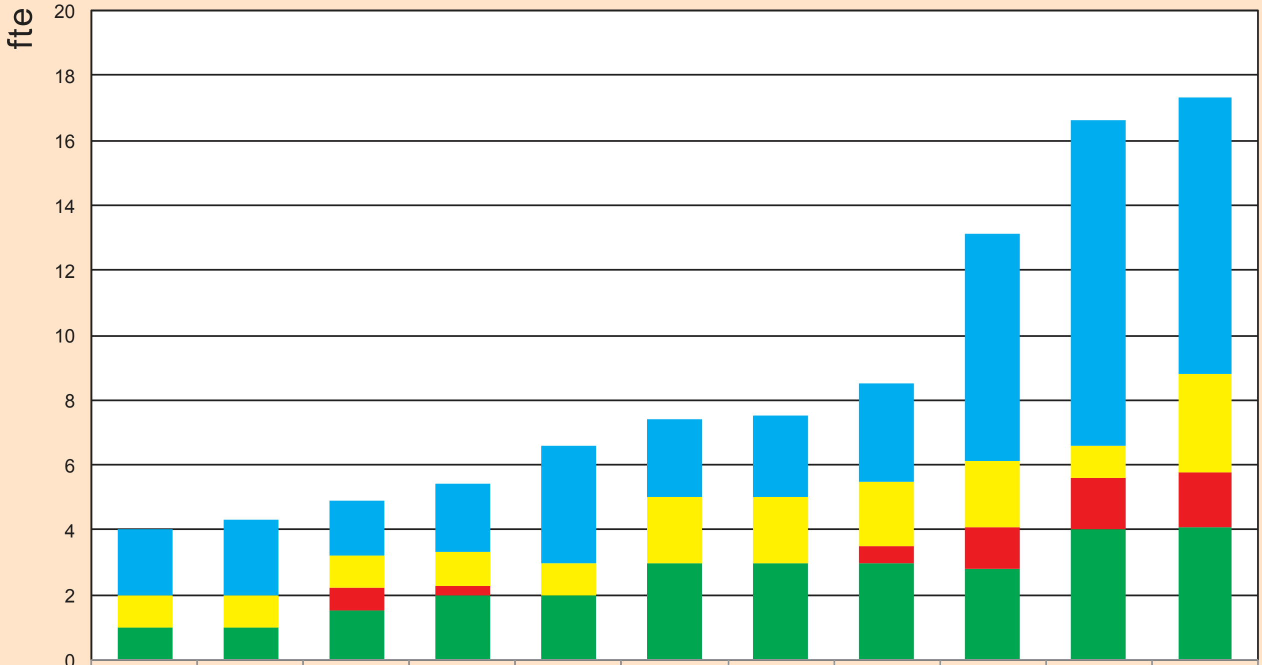
A valorisation grant of the Technology Foundation STW was received by N. van Bakel and J Visser (R&D) for their proposal “Hybrid Pixel Detector Arrays for Industrial and Photon Science Instrumentation” to develop pixel detectors for other applications in the framework of a Nikhef spin-off company.

For the semiconductor detector developments, two projects with Nikhef involvement were rewarded by SenterNovem: the ReLaXd project (with PANalytical, Canberra and IMEC) and the Hidralon project (with a large European consortium in which Nikhef predominantly works with Philips Healthcare).

SenterNovem accepted a Nikhef proposal in 2009 for its ‘Kenniswerkers Regeling’. This enables two engineers of the company Bruco to work for a period of 18 months on two pixel-detector projects at Nikhef.

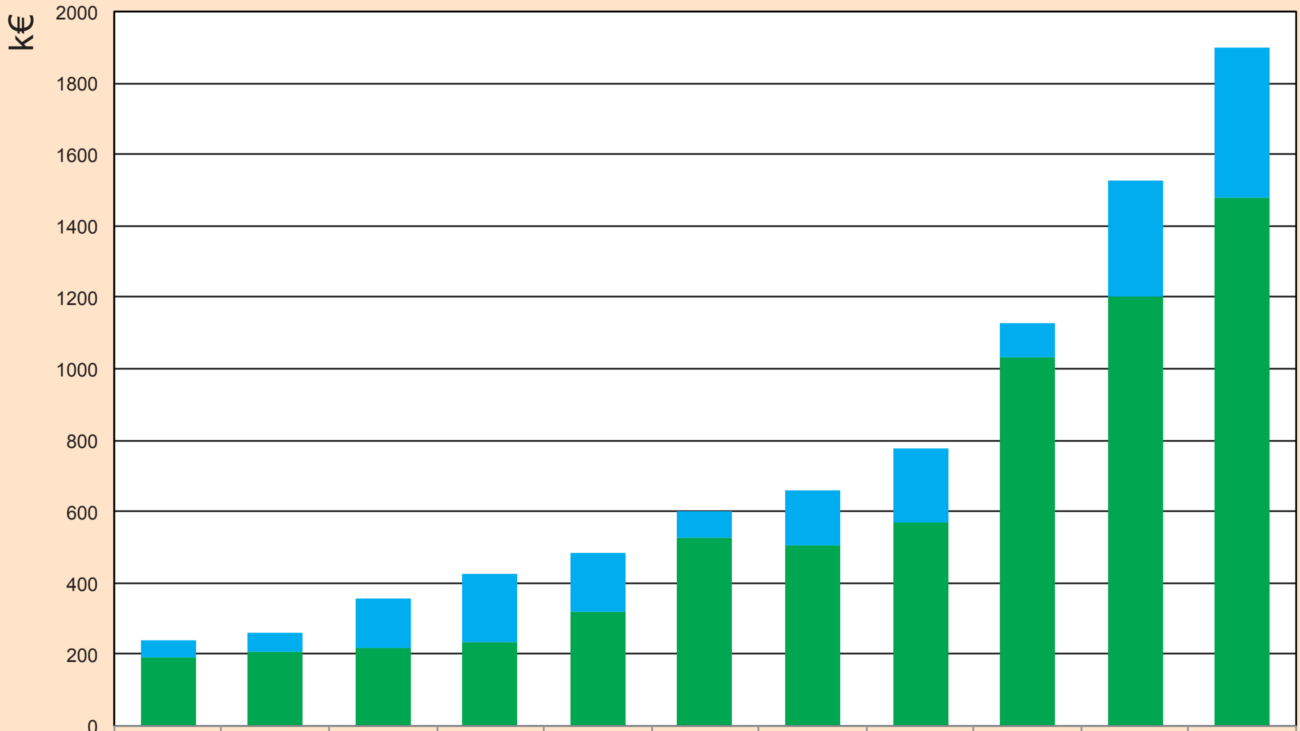
Key Publications

- T. Tick (et al.), J Visser, Status of the timepix MCP-HPD development, J Instr. 5 (2010) C120205
- H. van der Graaf, New results of GridPix TPCs, J Phys. : Conf. Series 179 (2009) 012008
- H. van der Graaf, Novel gas-based detection techniques, Nucl. Instr. Meth. A 604 (2009) 5
- M. Chefdeville (et al.), An electron–multiplying ‘Micromegas’ grid made in silicon wafer post–processing technology, Nucl. Instrum. Meth. A 556 (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



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians	2.0	2.3	1.7	2.1	3.6	2.4	2.5	3.0	7.0	10.0	8.5
PhD students	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	3.0
Postdocs			0.7	0.3				0.5	1.3	1.6	1.7
Staff	1.0	1.0	1.5	2.0	2.0	3.0	3.0	3.0	2.8	4.0	4.1

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects	50	50	137	193	163	72	153	208	100	325	418
FOM-Nikhef	190	210	221	232	321	527	504	569	1,030	1,201	1,479

Table II – Budget

2.9 Physics data processing: Grid computing

Programme organisation

Since 2004 dr. J.A. Templon is the programme leader. This Nikhef programme is not associated with a speciﬁc FOM programme, but is funded out of the mission budget. The activity started in 2000. Since 2001 approximately 75% of the funding for this activity comes from external sources such as EU-Framework programmes or national (Dutch) subsidies for e-infrastructure deployment and research. As of this writing, funding is assured through the end of 2012.

Research goal

The high-energy physics community requires a very-large-scale computing infrastructures to accomplish its research goals. As one of Nikhef's 'enabling technology' programmes, the Grid Computing programme is aimed at understanding how to build and operate such an infrastructure, and in addition to make the resulting infrastructure generally accessible to other research communities with signiﬁcant computing needs. A strength of the Nikhef programme is that we not only work to understand how to build and operate the infrastructure; we actually do it: one of the activities of the group is to operate a signiﬁcant component of the Dutch LHC Tier-1 computing centre. This aspect distinguishes the research at Nikhef from academic research on distributed computing being done in a university setting.

Figure 2.9.1. Grid computers inside the new Nikhef data centre, commissioned in 2009.

Research highlights

- Realisation of Dutch LHC Tier-1 facility.
- Realisation of global grid trust network.
- Realisation of sustained end-to-end data transfers at the 10 Gbit/s level (LHC data from pit to disk server at Tier-1).
- Expanding regime of stable systems operation by orders of magnitude.

Research activities

The Nikhef grid 'site' (collection of storage and computing resources) are connected to various computing grids comprising hundreds of other sites, serving the work of thousands of users to hundreds of thousands of computer processor cores and tens of thousands of Terabytes of storage. This ecosystem presents many directions in which one could pursue research. The Nikhef group focuses on three rather practical research questions:

- How to construct (the various pieces of) the grid so that they can function at the required scale;
- How to provide secure access to grid resources;
- What 'design patterns' are appropriate for using grid computing infrastructures.

Our primary research method is the classic engineering cycle: deﬁne, design, develop, and test. The facility that we operate at Nikhef is 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.

Scaling and validation of grid infrastructures

The scale of the European research grid (ﬁrst under the pan-European grid infrastructure EGEE; now EGI), and the Worldwide LHC Computing Grid (WLCG) has increased enormously during the evaluation period 2005-2010. In 2005, these grids were just beginning to evolve from research testbeds into real production infrastructures. Since then, the local resources expanded by a factor 10 in computing and a factor of one hundred in both storage and (networking) bandwidth. The WLCG 'Service Challenges' were the core of a two year programme to accomplish this evolution, running from November 2004 until April 2007 (which was at that time the target date for the start of LHC operations). During this critical period, global deployment was to a large extent coordinated by our group member K. Bos in his role as chair of the Grid Deployment Board of the WLCG. At the beginning of 2005, the grids were 'blind': operational status of the sites was not being monitored, and the system for usage accounting was in the prototype stage. Nikhef

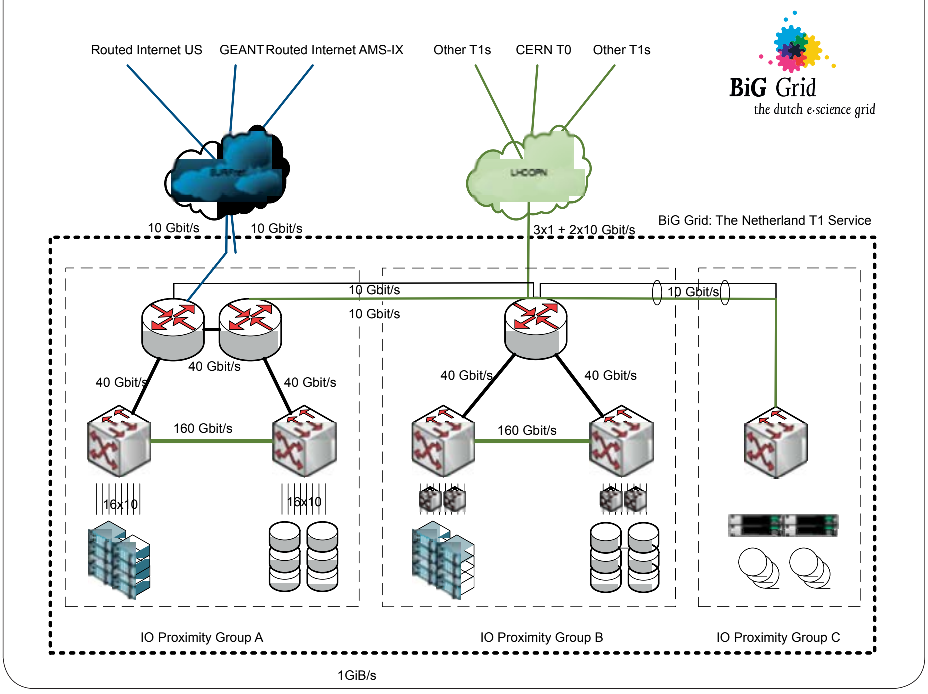


Figure 2.9.2. Network connections schematic for the Dutch LHC Tier-1. Proximity group 'A' is physically housed at Nikhef, B and C at SARA.

played an important role in the development and establishment of the accounting and especially the monitoring infrastructure, which by the end of the evaluation period is a well-established part of both WLCG and EGI.

The transition to a production infrastructure meant that in addition to an increase in the scale of the system at all levels, the expectations on system reliability increased. To meet this goal (97% availability) at these scales, a number of actions were taken. At the site level, an automated monitoring system (Nagios) was deployed that integrates local tests of the system with those collected by the grid-wide monitoring system (the first version of which was deployed in 2005). The number of local tests has steadily increased over time as we learn which conditions signal an impending problem with one of the services. The monitoring system in some cases takes preventive action such as setting a malfunctioning machine offline. This is necessary since the system operates 24×7 whereas the operators do not. Most grid services are now run in virtual machines, which greatly facilitates the task of installation and maintenance. Many core services are now replicated, sometimes via providing multiple front-ends (e.g. our four gatekeepers accepting computing tasks) and sometimes via a failover configuration (e.g. the LDAP servers providing the back end of our Network Information Service).

A crucial scaling occurred in our internal network infrastructure. This scaling was largely unanticipated, as the LHC experiments severely underestimated the bandwidth requirements between grid storage and their computing tasks. While we had planned for an internal 10 Gbit/s backbone, parts of the system ultimately required upwards of 100 Gbit/s, which in turn required a major redesign of the site network. A related issue is the emerging 'crisis' in data management; at current scales, new paradigms in data access and management are required. Research on these paradigms is discussed below.

Providing secure access to grid infrastructures

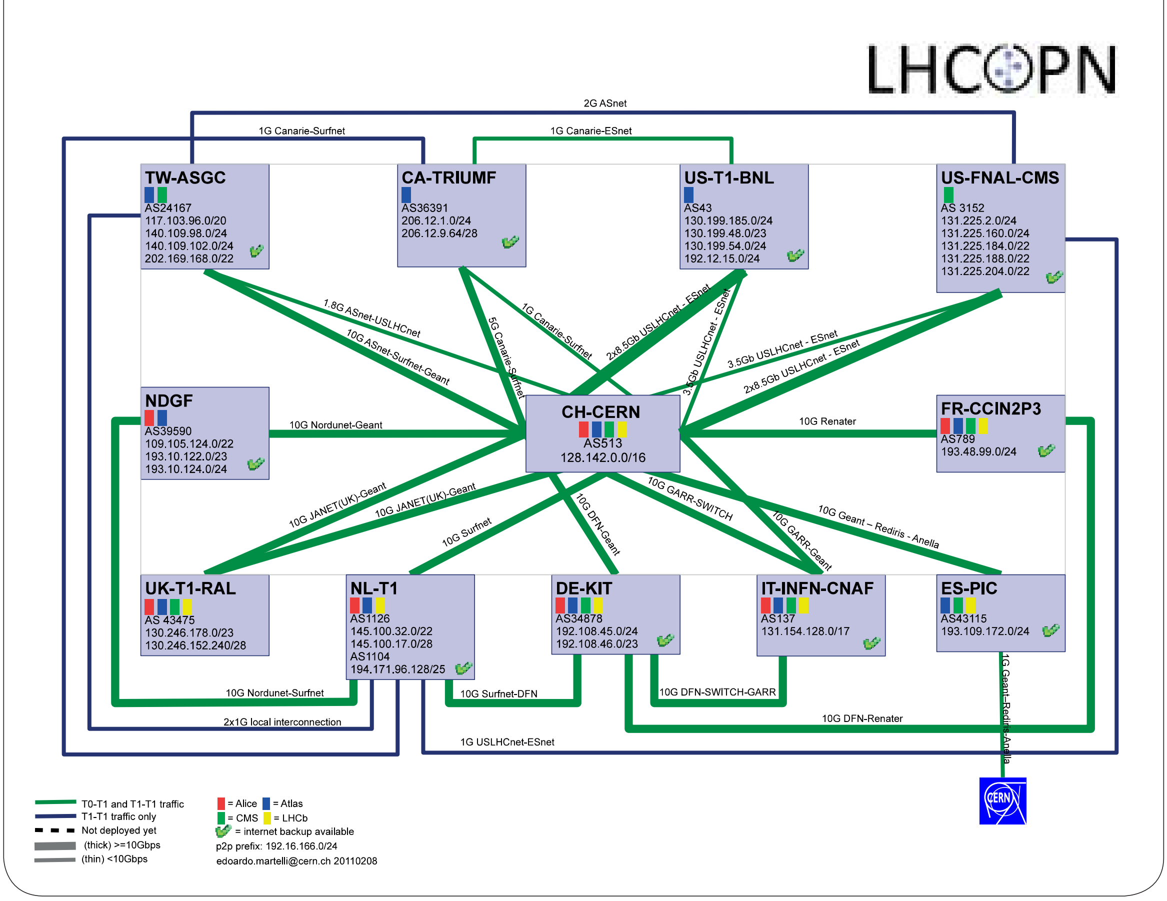
One of the major achievements during this period was the founding of the International Grid Trust Federation (IGTF) in 2005. Cooperation amongst grid users and sites distributed around the world, requires a system for identifying users and sites, in a fashion secure enough to satisfy all involved. The WLCG is an extremely valuable target for cybercriminals due to the large amount of computer processors and especially due to the aggregate bandwidth out of the system. The degree of trust internal to a computing grid is rather high, which requires a high level of security at the boundaries – hence the importance of this issue. Nikhef played a leading role in the founding of the IGTF.

During this period, the experience gained from the grid testbeds was used to develop a coherent security architecture for the European grid infrastructures. Nikhef was part of the team defining this architecture, and our group is responsible for developing several software components implementing various pieces of this architecture. gLExec is a program to make the required mapping between the grid world and the Unix notion of users and groups, and has the capacity to enforce that mapping by modifying the user and group identity of gLExec and any processes spawned through gLExec. The gLExec mechanism for local execution of grid tasks and the Site Central Authorization Service (SCAS) server for providing authorization decisions on resource requests have both been implemented and deployed on the production grid systems. gLExec is also being used as a core component at several US grid sites. As of this writing, the advanced Execution Environment Service is still under development. This component is of interest in providing advanced capabilities such as executing grid jobs within user-specified virtual machines (private clouds).

Grid design patterns

The LHC Tier-1 service is funded by the Dutch national grid project (BiG Grid). The proposal for this project was submitted to the Dutch government in 2005 by Nikhef, the Netherlands

Figure 2.9.3. Diagram of the LHC optical private network. Note the number of links per site: CERN has the most with 11, followed by the Dutch Tier-1 (NL-T1) with 6, the rest having four or less.



Bioinformatics Consortium (NBIC), and the Dutch National Computing Foundation (NCF). BiG Grid's main goal is to provide enabling computing technology to Dutch scientists from any field. Nikhef's main participation in this project, aside from operating a significant fraction of the computing, is in making the connection between users and the grid. Large-scale use of distributed computing resources is significantly different than analysing data in spreadsheets on a desktop computer.

During this period we have collaborated with several groups, most notably the Max Planck Institute for Psycholinguistics (authentication and authorization frameworks), LOFAR (data archives and high-bandwidth data transfers), and the Academic Medical Centre in Amsterdam. The challenge is to find 'design patterns' that are reusable for a large class of users, and also to know where to draw the line: especially in the area of data access, one size certainly does not fit all. Whereas high-energy physics projects try to organise their data mostly as large (> 1 Gigabyte) files, the medical community prefers relational database systems, and workers from computational chemistry tend to produce very large numbers of very small (kilobyte) files.

This is illustrative of the data 'crisis' referred to above; in addition to issues surrounding the different storage paradigms used by different communities, there is also the issue of how to best distribute data to optimise both ease of access and efficiency of storage. The LHC experiments' initial attempts in these areas have failed miserably. These early attempts were based on pre-placement of data, in anticipation of expected heavy usage. It proved impossible to make accurate predictions about the frequency of access to data; hence most of the data stored at WLCG sites was never being accessed, and many user jobs ran at low CPU utilisation while waiting for data. In 2010 our group built a prototype data-prefetcher for the LHCb experiment that addresses the latter problem. We expanded this effort based on discussions at a data management workshop we hosted in Amsterdam in June 2010. The current work in this area is based on ideas from web proxy caches and content-delivery networks.

Nikhef contributions

The prominence of the Nikhef group in the above grid topics can be recognised from the fact that Nikhef was one of the five core partners in the first European grid project, the European Data Grid (EDG). Nikhef was also heavily involved in constructing the first EGEE proposal, provided the majority of the writing team for the BiG Grid proposal, and was responsible for the bid book, which led to the establishment of EGI.eu headquarters in Science Park Amsterdam.

During the review period Nikhef has provided: representation in the EGEE Project Technical Forum and Technical Coordination Group (J. Templon); Area Director for Security and Open Grid Foundation (D. Groep); chair of the WLCG Grid Deployment Board (K. Bos); chair of the International Grid Trust Federation (D. Groep); members of the BiG Grid Executive Team (A. van Rijn, D. Groep, and J. Templon); member of the BiG Grid Directorate (F. Linde); the ATLAS computing coordinator (K. Bos) and the EGI.eu Executive Board (A. van Rijn).

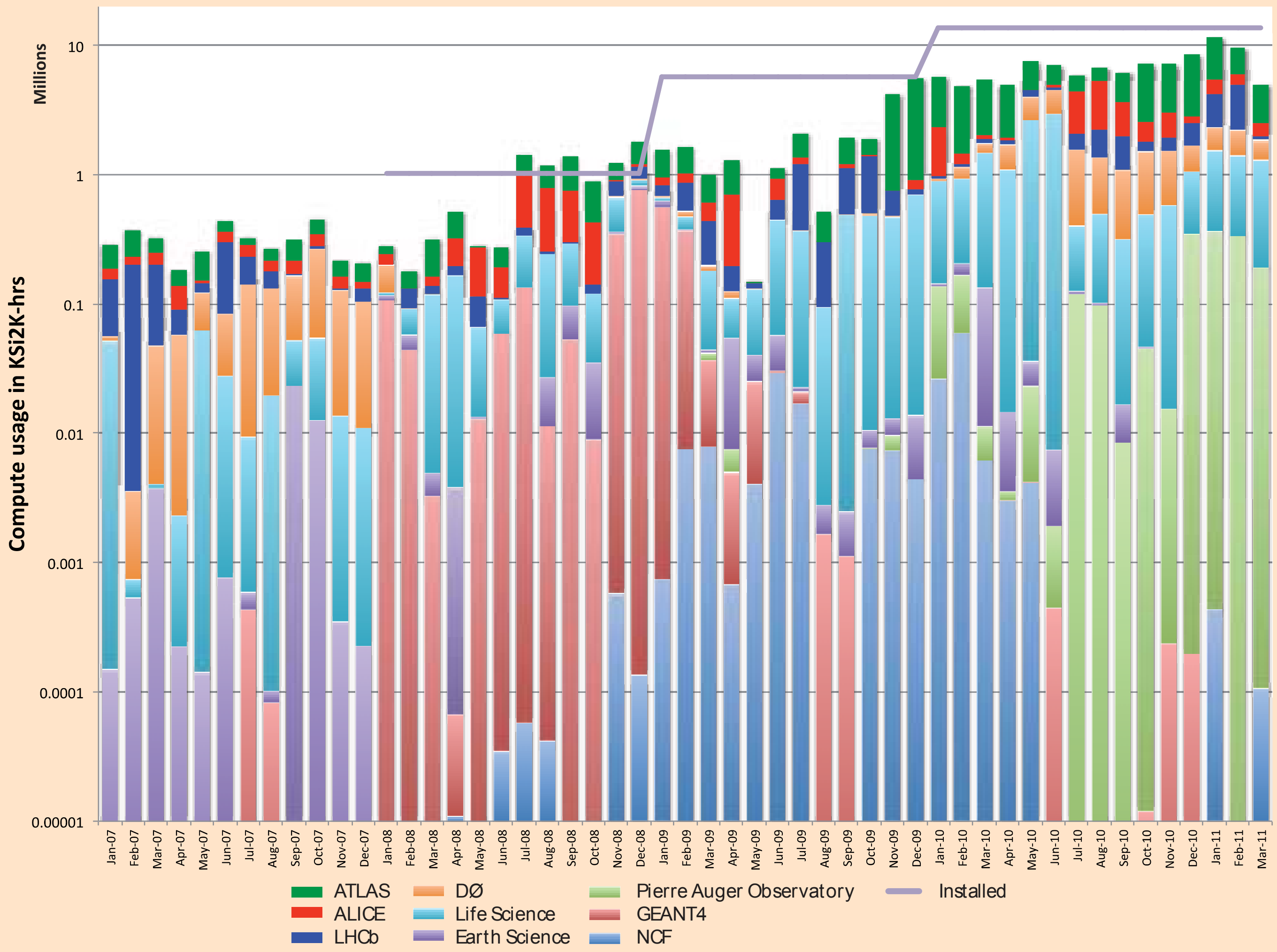


Figure 2.9.4. Computing done on Dutch 'BiG Grid' resources since the start of that project. Computing resources include the LHC Tier-1 centre (at Nikhef and SARA), computer centres at the university in Groningen and the High Tech Campus of Philips in Eindhoven, as well as the Life Science Grid clusters at various universities and research hospitals in the Netherlands. The gray line shows the total amount of resources installed: about 5000 cores.

National collaborations

See also the descriptions of the BiG Grid work. In addition to these, we collaborate with SARA on operating the Dutch LHC Tier-1 centre, with Philips Research in Eindhoven on grid site operations, and the Dutch Royal Library on data centre operations.

International collaborations

Grid by nature has an international orientation, as one of its primary functions is to federate computing resources from many geographically distributed locations. WLCG currently consists of over four hundred sites, including all continents except Antarctica. WLCG supports the computing of the LHC experiments, which are also based on international collaborations. We are a member of the European Grid Initiative (located at the Science Park Amsterdam), the European Middleware Initiative, and the Initiative for Globus in Europe. During the evaluation period, in addition to the LHC experiments we support, we provided signi□cant computing power for international efforts in drug discovery (WISDOM) and biomolecular NMR data analysis (eNMR).

Key publications

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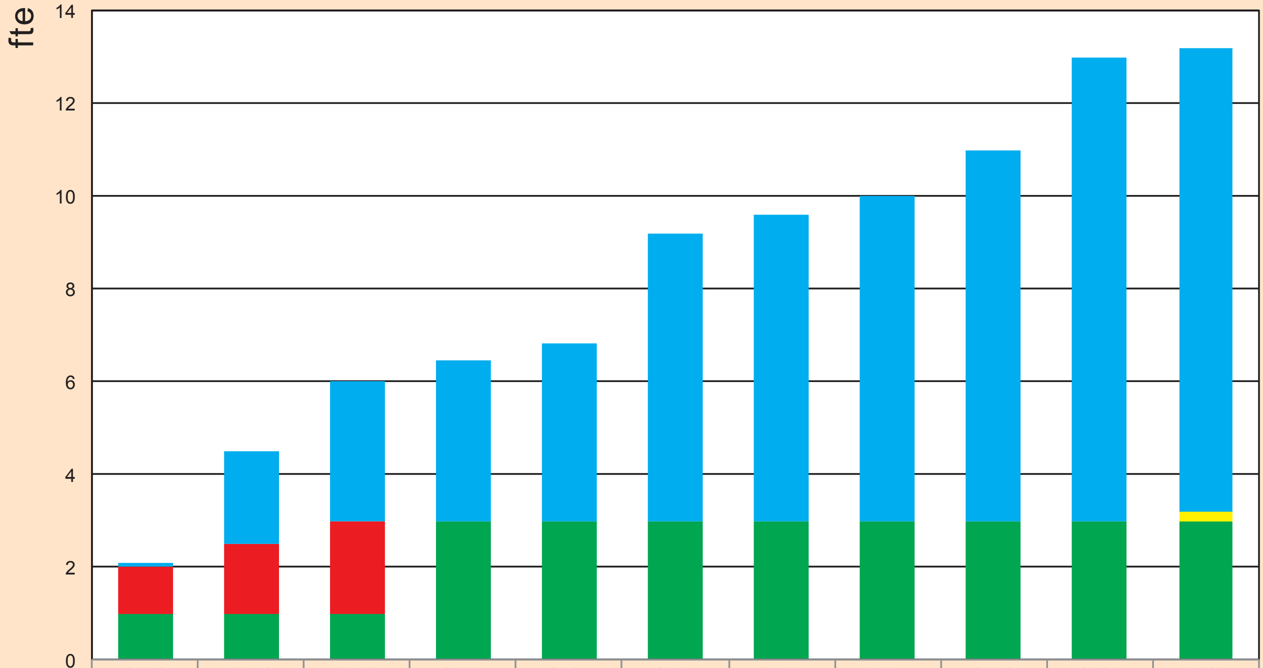
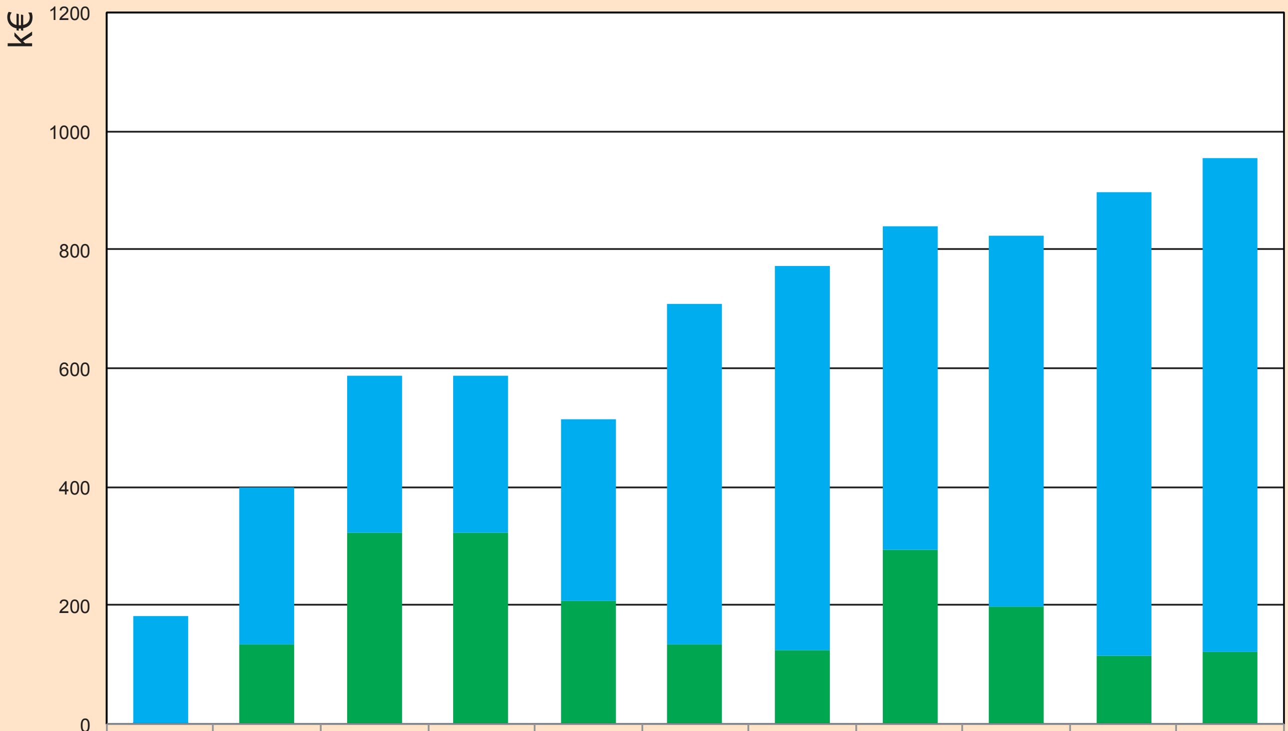
- H. Li, D.L. Groep, L. Wolters, Mining performance data for metascheduling decision support in the Grid, Futur. Gener. Comp. Syst. 23 (2007) 92
- S. Klous et al. (S. Klous, J. van den Brand), Transparent access to Grid resources for user software, Concurr. Comput.-Pract. Exp. 18 (2006) 787
- D.L. Groep, J.A. Templon, C. Loomis, Crunching real data on the Grid: practice and experience with the European DataGrid, Concurr. Comput.-Pract. Exp. 18 (2006) 925
- G. Garzoglio et al. (D.L. Groep, O. Koeroo), De□nition and Implementation of a SAML-XACML Pro□le for Authorization Interoperability Across Grid Middleware in OSG and EGEE, J. Grid Comput. 7 (2009) 297



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians	0.1	2.0	3.0	3.5	3.8	6.2	6.6	7.0	8.0	10.0	10.0
PhD students											0.2
Postdocs	1.0	1.5	2.0								
Staff	1.0	1.0	1.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Table I – Manpower



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects	182	265	265	265	305	574	648	544	627	783	832
FOM-Nikhef		135	322	322	209	135	123	294	198	116	122

Table II – Budget

3 Completed Programmes

3.1 HERA experiments: ZEUS and HERMES

Programme organisation

Prof.dr. P. Kooijman has led the Nikhef ZEUS programme and dr. J.J.M. Steijger the HERMES programme. Both FOM programmes, ZEUS and HERMES, have formally ended at the end of 2006 and final reports were submitted in 2007.

Research goal

The goal of the ZEUS experiment was to investigate the quark and gluon structure of the proton, and to study the influence of Quantum Chromo–Dynamics (QCD) on the evolution of this structure. The HERMES experiment was conceived to study the spin structure of the nucleon with the polarised electron or positron beam of HERA and a (nuclear) polarised gas target, internal to the accelerator.

Research activities

For 15 years, electrons and protons collided at extremely high energies inside the 6.3-kilometre-long HERA particle accelerator ring at DESY, Hamburg. Research operation was concluded in summer 2007 with the shutdown of HERA. The evaluation of the recorded data, however, is still continuing. The analysis is providing a comprehensive overall picture of the proton and the forces acting within it – with a precision that won't be matched easily by any other particle accelerator in the world for years to come. The determined distribution functions of quarks and gluons inside the proton have proven to be invaluable for calculating detection limits for the LHC.

Figure 3.1.1. HERA accelerator at DESY, Hamburg, with the experimental halls indicated.

Research highlights

ZEUS:
- Final measurement of proton structure function F_2 and determination of F_L.
- Determination of gluon and quark distributions in the proton
- Measurement of the charm structure function.
- Measurement of the polarisation dependence of the charged current cross section for positron– and electron proton scattering.
- Observation of diffractive scattering of the virtual photon.

HERMES:
- 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 hadronisation.

The HERA accelerator and experiments

The HERA storage ring facility at DESY was the only one in the world in which two different types of particles were accelerated separately and then brought to collision. Here electrons –or their antiparticles, the positrons– collided with hydrogen nuclei, i.e. protons from the hadron family, which are nearly 2000 times heavier. In these electron-proton collisions, the point-like electron acts like a tiny probe that scans the inside of the proton and reveals its inner structure. The higher the energy of the particle collision, the deeper physicists are able to gaze into the proton, and the more details are revealed.

The HERA storage ring passes through four large underground halls, one at each point of the compass. Here, seven stories below the surface, stood the detectors used by international research teams to investigate the minutest building blocks of matter. In 1992, the first two HERA experiments went into operation, ZEUS in the South Hall and H1 in the North Hall. Both general purpose experiments observed the high-energy collisions of electrons and protons to unravel the internal structure of the proton and the mysteries of Nature's fundamental forces. The HERMES experiment started taking data in the East Hall in 1995. It used the (polarised) HERA electron beam to investigate the intrinsic angular momentum –the spin– of protons and neutrons. From 1999 to 2003, the HERA-B experiment used the proton beam from the storage ring in HERA's West Hall to shed light on the properties of

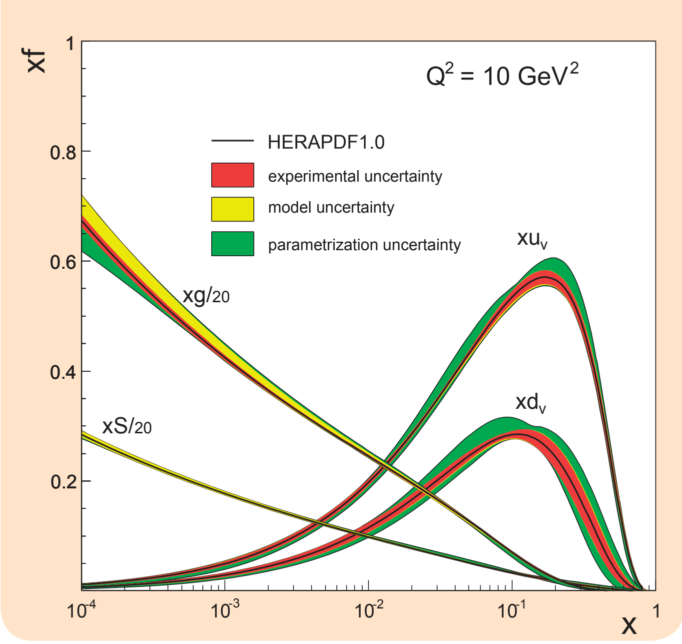


Fig. 3.1.2. Gluon and quark distribution functions from a combined analysis of the ZEUS and H1 collaborations. Note the continuing rise at low-x of the gluon distribution (xg) and the sea quarks (all other quarks (xS) apart from the valence u and d quarks: xd_v and xu_v).

heavy quarks. Nikhef has been participating in ZEUS, HERMES and HERA-B. The HERA-B experiment stopped already in 2003 and will not be discussed here further.

Research overview

The large detectors were in operation until mid-2007, and recorded large amounts of data. During that time, many of the insights provided by HERA found their way into the physics textbooks. Active data taking has been completed, but the HERA experiments are continuing with the analysis in this decennium.

The ZEUS (and H1) results have led to a radically different picture of matter at short distances. It has become clear that at short distances and small x, which corresponds to short time fluctuations, the physics is dominated by gluons. The extremely high density of gluons leads to novel and previously unexpected effects, such as a high rate for diffractive processes (where the proton remains intact), even at high momentum transfer between electron and proton. The theoretical understanding of the results is still in development, but will likely result in radically new ways of understanding matter at short distances. Today, driven by the HERA data, theorists discuss the possible presence of an underlying ‘colour glass condensate’ at the heart of all matter. Others discuss the possible deep connection between diffractive processes and gravitational interactions, seeing links between string theories and supersymmetric versions of QCD. The most important results from HERA –the observations of the strong rise of the structure functions at small x and the large diffractive cross section– therefore represent a beginning to a wholly new understanding of Nature. Furthermore, for the first time the behaviour of the coupling constant as a measure of the strength of the strong force, over a broad range of energies was measured in single experiments. At large momentum transfers the strong force becomes increasingly weak (an effect described as ‘asymptotic freedom’ of the quarks). These results confirm the behaviour of the strong force as predicted in 1973 ago by David Gross, David Politzer and Frank Wilczek. These three physicists were awarded the Nobel Prize in 2004.

HERMES studies the origin of nucleon spin, i.e. the spin of the protons and neutrons. Experiments carried out at the CERN and SLAC research centres in the mid-1980s had already determined that the three main components of the nucleon –the valence quarks– together account for only around one-third of the total spin. The HERMES collaboration attempted to find out where the other two-thirds come from by sending the longitudinally or transversely polarised electrons or positrons from the HERA storage ring through a gas-filled cell. There, the particles collide with the gas atoms, which are also longitudinally polarised. Because the type and frequency of the collisions depend on the polarisation of the nucleon components, the particle reactions observed enable the scientists to determine where the nucleon spin actually originates from. During HERA’s first operational phase, HERMES completed its first assignment, which was to measure the individual contributions made to the nucleon spin by each of the various types of quark. Using measurements on longitudinally polarised gases, the HERMES collaboration provided the world’s first model-independent determination of the separate contributions made to the nucleon spin by the up-, down-, and strange quarks. The results reveal that the largest contribution to the nucleon spin comes from the valence quarks. The up quarks make a positive contribution as their spin is preferably aligned with the spin of the nucleon, while the down quarks provide a contribution with opposite sign. The polarisations of the sea quarks are all consistent with zero – an especially important result. Under the assumption that all types of quark behave in the same way dynamically inside the nucleon, previous experiments had led to the conclusion that the strange quarks play a significant, canceling, role in the nucleon spin. The HERMES results now show that the polarisations of the sea quarks are all small: there is thus little evidence for such a cancellation between the contributions of valence and sea quarks. The HERMES measurements prove that the spin of the quarks generates less than half of the spin of the nucleon, and that the quark spins that do contribute come almost exclusively from the valence quarks. HERMES also found a direct indication that the gluons make a small but positive contribution to the overall spin. HERMES thus succeeded in taking an initial and important step toward the solution of the spin puzzle.

Nobel Laureate Frank Wilczek on the HERA measurements:

“The most dramatic of these specific experimental tests, that protons viewed at ever higher resolution would appear more and more as field energy (soft glue), was only clearly verified at HERA twenty years later.”

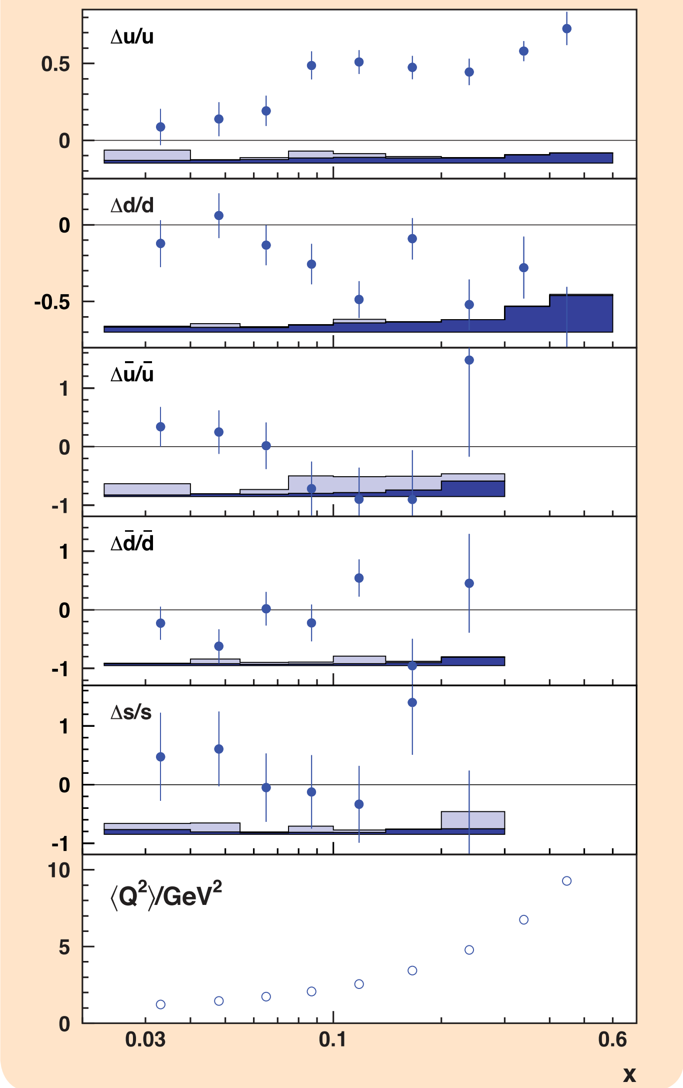


Fig. 3.1.3. Model-independent determination by HERMES of the separate contributions made to the nucleon spin by the up, down and strange quarks. The largest contribution to the nucleon spin comes from the valence quarks (u and d), with the up quarks making a positive contribution, the down quarks a negative one.

Nikhef contributions

In ZEUS Nikhef has contributed heavily to the design and building of the uranium calorimeter, was responsible for the read out of the calorimeter, the second-level trigger based on the information of the calorimeter and the overall second-level trigger of the experiment. At the upgrade a complete renewal of the vertex detector has taken place, in which the wire-chamber was replaced by silicon-strip detectors by Nikhef in collaborations with other institutes. Also tracking reconstruction software was largely written by Nikhef physicists.

During the course of the experiment the Nikhef group has provided several coordinators of physics groups. J. Engelen was coordinator of the photon structure group. P. Kooijman was coordinator of the proton structure group on three separate occasions. L. Wiggers was (joint) trigger coordinator for almost the full running time of the experiment. H. Tiecke was project leader of the microvertex construction., N. Brummer has been Monte Carlo coordinator for several years. R. Yoshida was calorimeter coordinator, P. Kooijman was convenor of structure functions sessions at several conferences.

In HERMES Nikhef has contributed to part of the lead-glass calorimeter, a tracking detector based on Multi Strip Gas Chambers, a silicon-strip detector system in the accelerator vacuum and a beam loss monitor system. J. van den Brand was spokesman of the collaboration in 1994 and 1995, G. van der Steenhoven has been chair of the editorial board and W. Hesselink was convenor of the charm analysis group.

International collaborations

The ZEUS collaboration has currently 385 members on the authors list from 62 institutes in 18 countries. The HERMES collaboration consists of 126 members from 24 institutes in 10 countries.

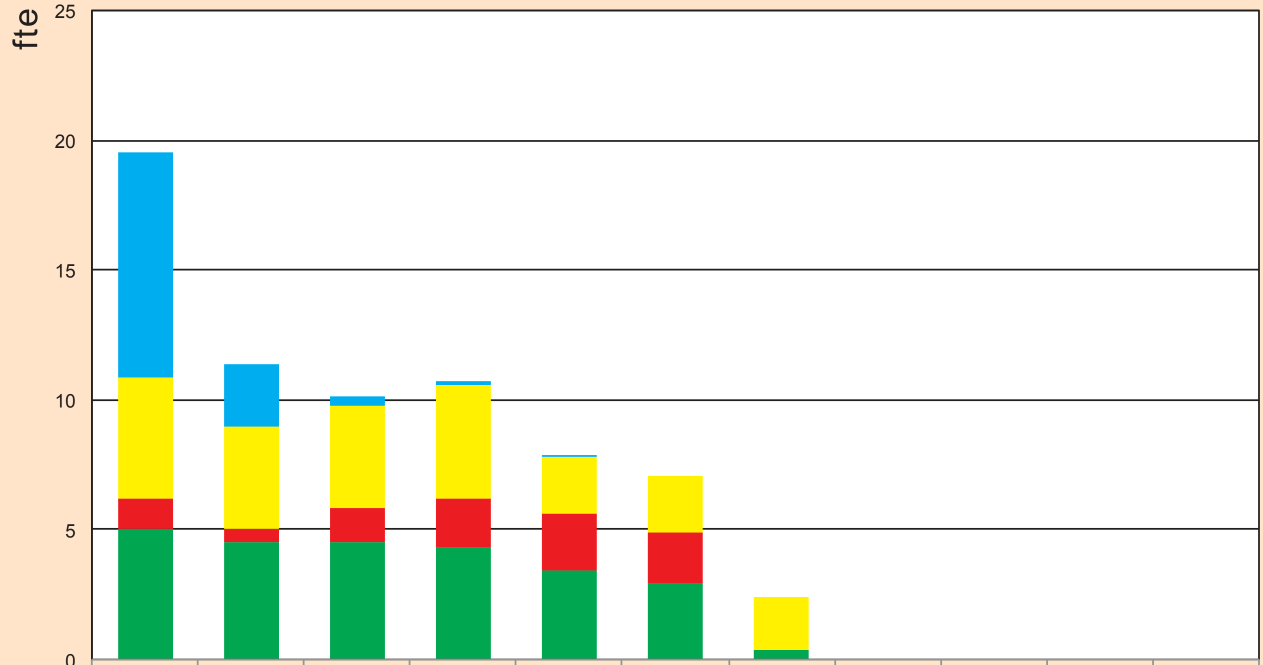
Key publications

ZEUS

- F.D. Aaron (et al.) (H1 and ZEUS collaboration), Combined Measurement and QCD Analysis of the Inclusive e±p Scattering Cross Sections at HERA, JHEP 1001 (2010) 109
- S. Chekanov (et al.) (ZEUS collaboration), Measurement of the Longitudinal Proton Structure Function at HERA, Phys. Lett. B682 (2009) 8
- S. Chekanov (et al.) (ZEUS collaboration), Measurement of D mesons production in deep inelastic scattering at HERA, JHEP 0707 (2007) 74
- S. Chekanov (et al.) (ZEUS collaboration), Measurement of charged curent deep inelastic scattering cross sections with a logintudinalluy polarised electron beam at HERA, Eur. Phys. J. C61 (2009) 223
- S. Chekanov (et al.) (ZEUS collaboration), Measurement of hig Q**2 neutral current deep inelastic e-p scattering cross sections with a longitudinally polarised electron beam at HERA, Eur. Phys. J C62 (2009) 625

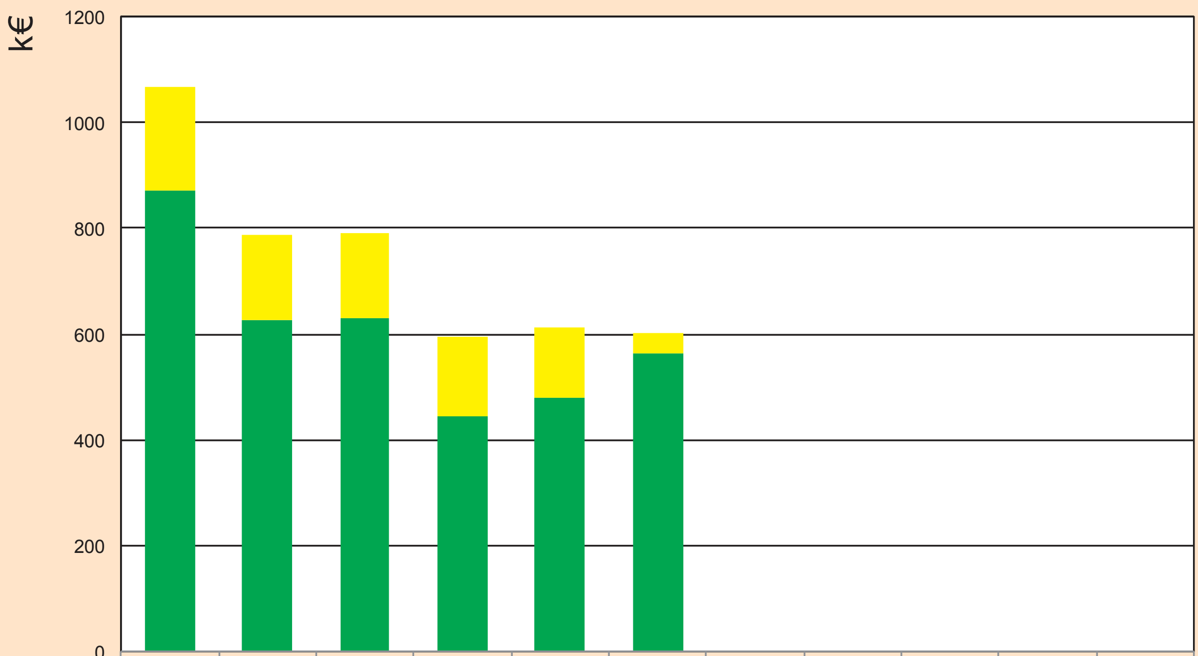
HERMES

- Airapetian (et al.) (HERMES Collaboration), Effects of transversity in deep-inelastic scattering by polarized protons, Phys. Lett. B693 (2010) 11
- Airapetian (et al.) (HERMES Collaboration), Observation of the Naive-T-odd Sivers Effect in Deep-Inelastic Scattering, Phys. Rev. Lett. 103 (2009) 152002
- Airapetian (et al.) (HERMES Collaboration), Measurement of Azimuthal Asymmetries With Respect To Both Beam Charge and Transverse Target Polarization in Exclusive Electroproduction of Real Photons, JHEP 0806 (2008) 066
- Airapetian (et al.) (HERMES Collaboration), Measurement of Parton Distributions of Strange Quarks in the Nucleon from Charged-Kaon Production in Deep-Inelastic Scattering on the Deuteron, Phys. Lett. B666 (2008) 446
- 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



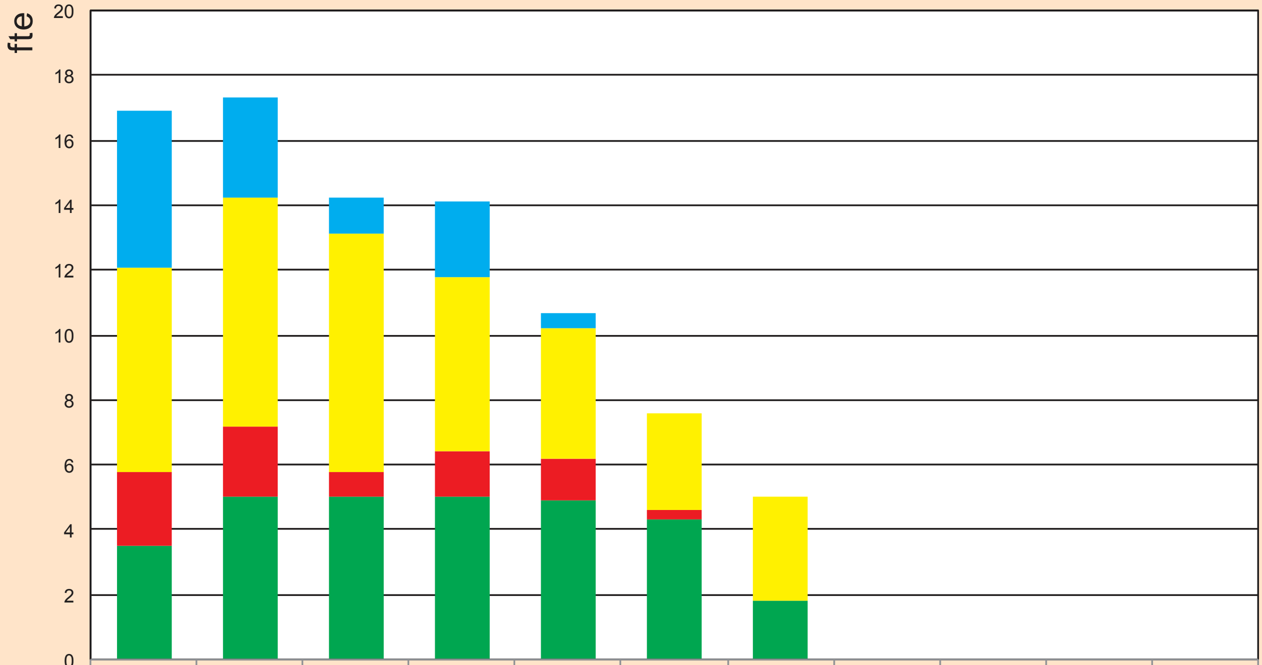
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians	8.6	2.4	0.3	0.1	0.1						
PhD students	4.7	4.0	4.0	4.4	2.2	2.2	2.0				
Postdocs	1.2	0.5	1.3	1.9	2.2	2.0					
Staff	5.0	4.5	4.5	4.3	3.4	2.9	0.4				

Table I – Manpower ZEUS



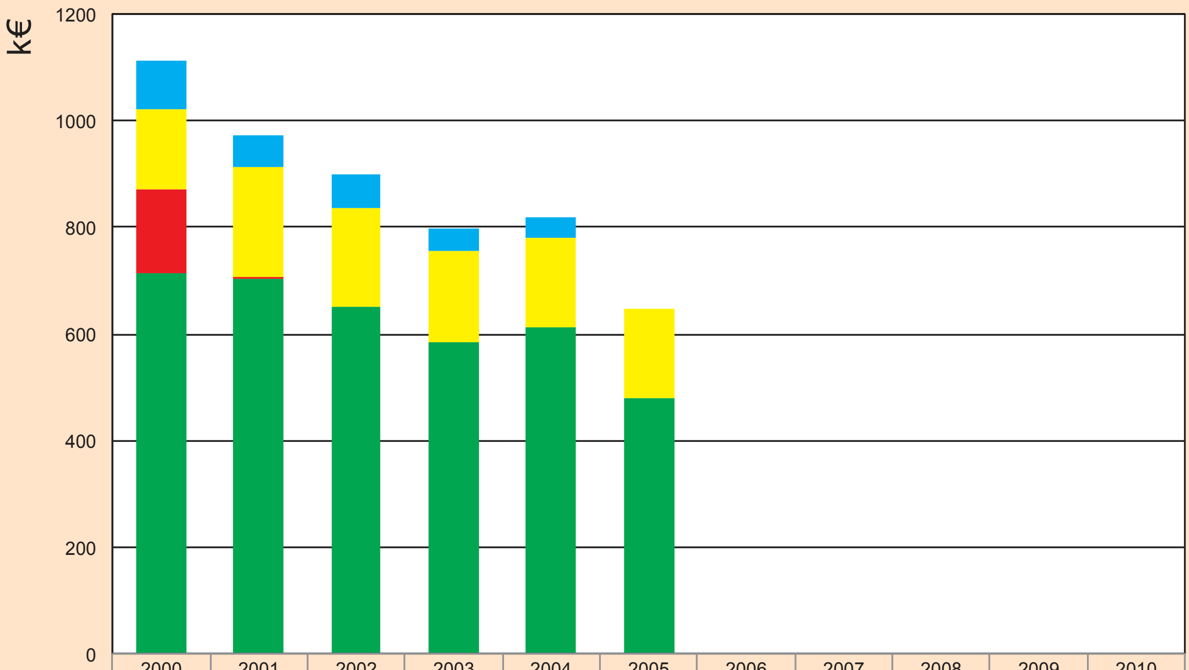
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects											
Universities	197	161	160	153	133	40					
FOM-university groups											
FOM-Nikhef	870	625	630	443	481	562					

Table II – Budget ZEUS



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Technicians	4.8	3.1	1.1	2.3	0.5						
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					
Staff	3.5	5.0	5.0	5.0	4.9	4.3	1.8				

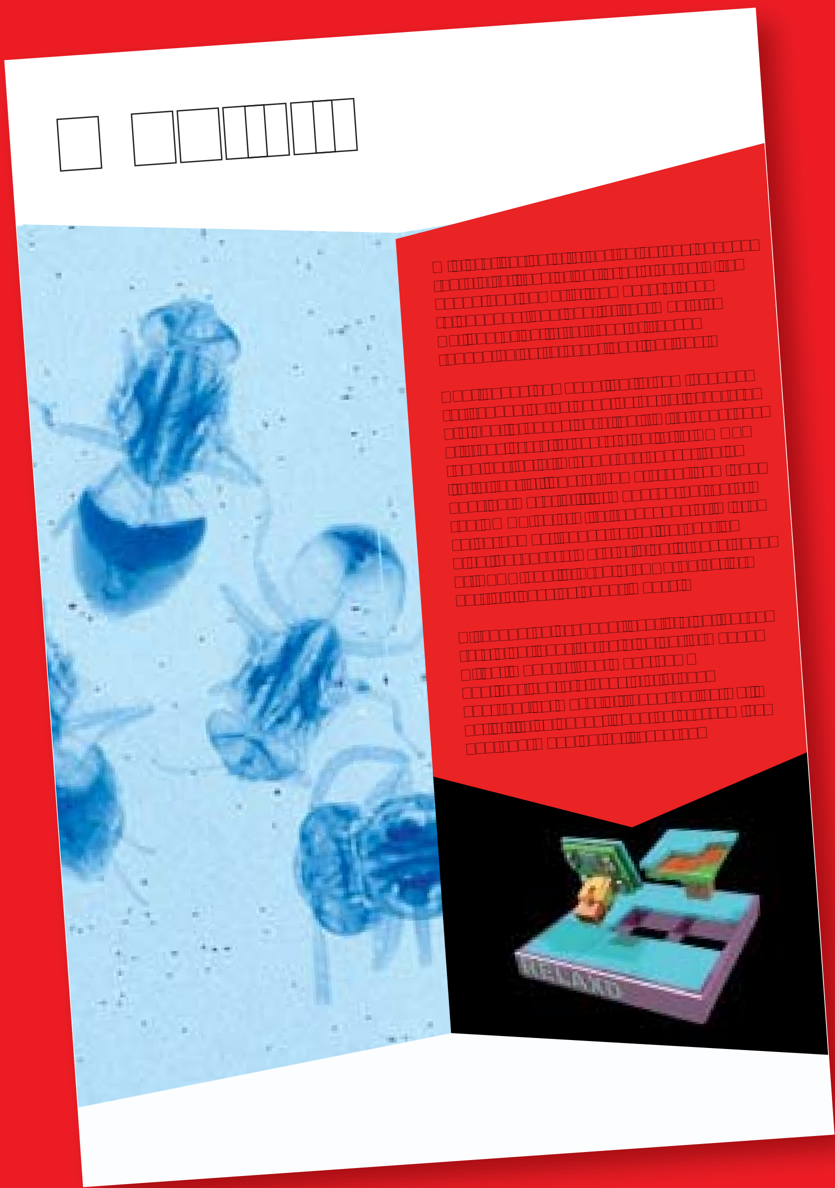
Table I – Manpower HERMES



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Projects	90	59	63	41	38						
Universities	150	209	185	170	170	170					
FOM-university groups	159	1									
FOM-institute	713	703	651	586	612	479					

Table II – Budget HERMES

4 Knowledge Transfer



4.1 Knowledge transfer

Introduction

In the past years Nikhef's awareness of the importance of knowledge transfer to 'third parties' (including industry and other scientific organisations) has increased. Stimulated by the political climate, both NWO and FOM have defined policies and programmes on innovation and 'valorisation' (the translation of knowledge into technology to create commercially viable products or services) and funds have been available, in particular 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 past decade, broadly categorised 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 Hadron Collider experiments. They relate mostly to our electronic and mechanical (engineering) expertise.

The RASNIK alignment technology has obtained its firm place in scientific instruments such as the ATLAS and the LHCb detectors. RASNIK has been brought to the attention of the non-HEP world, for instance via contests. A proposal to explore the use of RASNIK in the realm of buildings (sensing the deformations of a snow–covered roof, 'Rasice') won a Science Park Amsterdam innovation award (May 2006) and a proposal to use RASNIK for seismic registrations won an award at FOM's 60th anniversary (November 2006). In September 2007 a (Dutch) patent was filed on RASNIK and this patent was awarded in March 2009. Recently RASNIK has become the central product of a spin-off company called Sensiflex, which aims at using the technology for non-scientific applications, particularly in aligning building structures. A large Dutch based engineering company has already bought several RASNIK systems via Sensiflex and intends to use it on a worldwide scale as a lower cost replacement of its current alignment solutions. To this end a licensing agreement between Nikhef and Sensiflex has been drafted and a position as shareholder is considered. A Nikhef staff member is considering being involved in the (technology) management of the spin-off.

A modified RASNIK implementation is now also being investigated as the alignment tool for CERN's next linear collider CLIC, as part of Nikhef's commitment in the CLIC-CTF3 collaboration.

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 since 1947 a leading manufacturer in X–ray equipment for materials analysis. 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 in 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 read–out chip into PANalytical's X–ray analysis equipment.

Figure 4.1.1. Nikhef technician Gerrit Brouwer installs a Sensiflex RASNIK system in the Rotterdam Weena tunnel.

Another example of technology transfer is the Hidralon project in which Nikhef collaborates with Philips Healthcare to study edgeless sensors made of Cadmium-Telluride (CdTe) to more efficiently detect X-rays of around 100 keV. First studies are

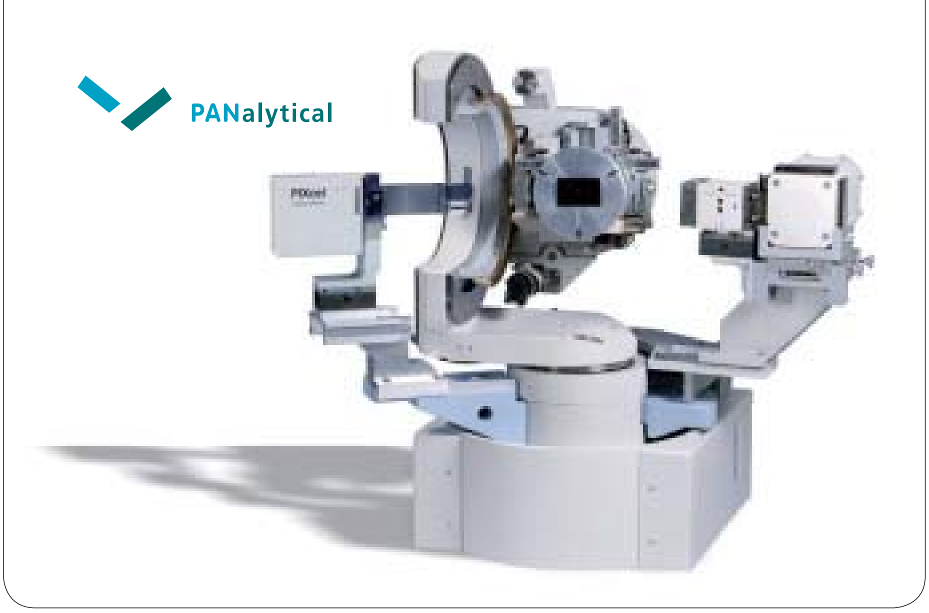


Figure 4.1.2. A PIXcel detector system, based on single-chip Medipix2 technology, mounted on a PANalytical X'Pert Pro XRD analysis platform.

done on silicon sensors, while the material on CdTe is being designed and produced. For the production of CdTe sensors Nikhef works together with various suppliers.

The involvement in Medipix has created yet another spin-off, called Amsterdam Scientific Instruments, aimed at producing pixel detection units. For this initiative a valorisation grant from STW (the Dutch Technological Sciences foundation) has been awarded in December 2010, the first STW-grant in Nikhef's history. Also here Nikhef is considering a position as shareholder. Two Nikhef R&D staff members are involved in this activity.

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. CO_2 cooling is now also considered in various other instruments. A patent application, jointly with CERN, is in preparation.

It should be mentioned here that Nikhef's Industrial Liaison Officer and the heads of technical departments have regularly organised '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.

From 8 to 11 November 2010, the Nikhef Industrial Liaison Officer also organised the 'Holland@CERN' exhibition during which 27 Dutch companies presented their products and expertise to a large crowd at CERN. This event was subsidised by "agentschap NL" a subsidiary of the Ministry of Economic Affairs.

Networking – the Amsterdam Internet Exchange

Internet, and networking in general, has a long history at Nikhef. From an acoustic 110 bits per second (bit/s) modem 35 years ago to Gbit/s 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 bit/s. The year 1985 saw the birth of the first campus network, a 10 Mbit/s 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 kbit/s and the delivery time of the line was nine months.

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

Figure 4.1.3. Holland@CERN; an exhibition of 27 companies at CERN from 8–11 November 2010.

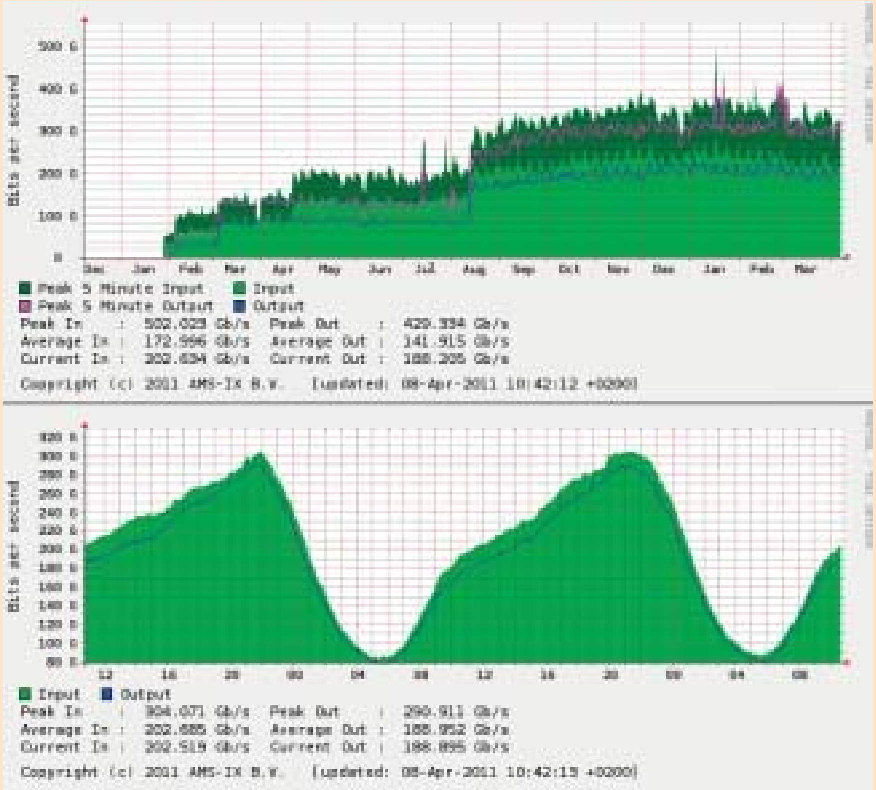


Figure 4.1.4. AMS-IX data traffic flowing through Nikhef. Top is the aggregated yearly throughput, bottom is a snapshot of the throughput on a typical day, 8 April 2011.

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, but now with a current bandwidth of 10 Gbit/s. SURFnet also provides additional dedicated bandwidth to CERN (10 Gbit/s) 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 than 400 Internet Service Providers ('AMS–IX members') from all over the world, housed at eight sites in Amsterdam of which Nikhef is still one of the largest in terms of internet traffic. Currently Nikhef houses equipment of about 120 customers, generating a turnover of about 2.5 M€ per year.

Nikhef also participates 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 also hosts 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) and its successor project 'Virtual Laboratory for e-Sciences' (VL-e, running from 2004 to 2009), led by prof.dr. L.O. Hertzberger of the University of Amsterdam.

Since then Nikhef has built up a very strong position in grid projects, both internationally (EDG and the successive EGEE–projects) and nationally (VL, VL–e) culminating in 2006 in the 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. By the end of 2010, this BiG Grid infrastructure was considered a part of the total 'e-Infrastructure' (which also comprises the research network and the high performance computing), that in the near future will be coordinated and operated nationally under the umbrella of SURF. A taskforce with high-level membership from SURF and NWO jointly has drafted a proposal for structural funding for such an e-Infrastructure, which is now being considered for approval by the relevant ministries.

Finally, it is worth mentioning, that under the auspices of BiG Grid and with strong involvement of Nikhef a bid book was prepared to host the head office of the European Grid Initiative (EGI) in Science Park Amsterdam. In March 2009 Amsterdam was selected out of eight competing bids from all over Europe. After almost a year's preparation, EGI.eu was incorporated as a foundation under Dutch law on 8 February 2010. Currently 22 staff are employed by EGI.

5 Outreach & Education

5.1 Outreach & education

Introduction

To explain to a broad audience what kind of research Nikhef does and why, a variety of outreach, communication and education activities are organised by Nikhef every year. In return, these activities increase Nikhef's visibility for the general public, the media, the funding agencies, potential industrial partners and future employees and students. The following section gives an account of Nikhef's achievements in the period 2005-2010 in the field of outreach, communication and education.

Figure 5.1.2. PhD students Egge van der Poel and Lucie de Nooij were interviewed in the TV talk show 'De Wereld Draait Door' in 2010. In the middle is host Matthijs van Nieuwkerk, on the right is prof.dr. Robbert Dijkgraaf, president of the Royal Netherlands Academy of Arts and Sciences (KNAW).

Outreach

Website

A completely redesigned and improved website was launched in October 2008. The website has been split into public web pages to address different external target groups, and web pages for Nikhef users where all departments can store and exchange their internal information. The website is continuously being further refined.

Open day and outreach talks

Every year Nikhef welcomes the general public for an open day in October. This event is part of the annual Dutch Science Month ('Oktober kennismaand') and is organised together with the other institutes at the Science Park Amsterdam. In the past years, several thousands of people have visited these events.

Nikhef scientists have given numerous outreach talks for the general public, at science cafes, museums, science associations, cultural organisations, universities and schools. To name one example, Nikhef physicists participated in the European Researchers' Night in September 2010. During this event several European institutes, such as CERN, presented their research via live video connections to the general public in different European cities. The Nikhef scientists commented on topics related to particle physics and answered questions from the local audience.

Figure 5.1.1. Nikhef staff member Fred Hartjes installing a spark chamber at the NEMO science centre.

Exhibits

Nikhef has developed a number of dedicated exhibits and displays for outreach purposes in the past years. For the start-up of the LHC event in 2008 large prints of the ATLAS experiment and of the LHC tunnel were produced and placed inside and outside the Nikhef building. In the ceiling of the main hall a display of the LHC was installed, with four screens representing the interactions points on which (live) collisions in the experiments are projected. Mock-ups of the ATLAS and the LHCb experiment were ordered to be able to explain the experiments to visitors. Furthermore, three mobile spark chambers were built which can be borrowed by schools or brought along to outreach talks at other locations. In 2010, a large spark chamber installation developed and built at Nikhef was installed in the main hall, and a similar set-up has been donated to the NEMO science museum in Amsterdam where it is a prominent part of the new permanent 'Ruimtedouche' (Cosmic Shower) exhibit.

Figure 5.1.3. Young scientists at work at the 'Techniek Toernooi'.

Guided tours at Nikhef and at CERN

Countless guided tours have been organised at the institute in the past years. People interested in Nikhef's research have always been welcome to join the Friday afternoon visits programme which is regularly offered. Furthermore, special guided tours were set up on request, such as in 2010 for a delegation of the National Natural Science Foundation of China (NSFC) on invitation of NWO.

Moreover, Nikhef has supported numerous CERN visits of various Dutch groups by providing Dutch speaking guides and sometimes in addition financial sponsoring.

Media

In the past years, Nikhef's research has garnered a considerable amount of media coverage in newspapers, magazines, on TV and in radio programmes. The majority of the articles were about physics research conducted at CERN, but programmes such as HiSPARC, KM3NeT and ANTARES were also often the focus of attention.

There were two major events that made for the most extensive national media coverage in the history of Nikhef. On 10 September 2008, the Nikhef communications department organised an LHC start-up event that proved to be very popular among journalists. Nearly every Dutch newspaper or science and technology related magazine covered the news of the first proton beams in the LHC, and several TV crews visited Nikhef. This event even made it to the eight o'clock news that evening. The 'First Physics' event on 30 March 2010 received comparable media coverage. A national news TV crew (NOS) visited Nikhef to film the champagne corks popping after witnessing the LHC's first proton collisions on screen. On and around that date, no less than 15 different radio programmes featured Nikhef researchers. Two Nikhef PhD students were invited by the popular prime-time TV talk show 'De Wereld Draait Door' to explain on camera what these first proton collisions meant for physics.

Nikhef issues approximately ten press releases each year, often in collaboration with other institutes or universities. The communications department deliberately only selects items which are newsworthy for journalists, in order to build a credible relation between Nikhef's communications department and the (science) press. As a result, many journalists are able to find the institute when they need information about (astro)particle physics or if they need to speak to an expert in the field.

Education

Nikhef invests in educational projects at all levels. Between 2005 and 2010, the following projects were organised or supported by Nikhef.

Primary-school children

Since its first edition during the World Year of Physics in 2005, Nikhef physicists participate in the organisation of the 'Techniek Toernooi', a yearly national science tournament for primary-school children to compete on technical constructions and experiments. Since 2009, three additional regional satellite tournaments take place, thus doubling the number of participating children to nearly two thousand.

Figure 5.1.4. Secondary school students Jacek Smit (left) and Matthijs Kuik (right) won a visit to CERN with their presentation at the HiSPARC 2010 Symposium.

year	total	male	female	% female	foreign	% foreign
2005	11	9	2	18%	2	18%
2006	11	7	4	36%	1	9%
2007	6	4	1	17%	0	0%
2008	15	10	5	33%	2	13%
2009	25	23	2	8%	8	32%
2010	15	13	2	13%	5	33%
total	83	66	16	19%	13	16%

Table 5.1.1. Inflow of the Master's programme Particle and Astroparticle Physics.

Secondary school students

Between 2005 and 2010, Nikhef has welcomed over a thousand secondary school students for a visit to the institute. In total around 70 secondary school students have carried out their 'profielwerkstuk' (dedicated science project in their final school year) at Nikhef, growing from ten students in 2006, to over twenty in 2010. Nikhef scientists have visited numerous secondary schools to give lectures. And Nikhef members have guided many secondary school groups during their CERN visits.

Since 2005, Nikhef has organised a yearly European Masterclass on Particle Physics in collaboration with the European Particle Physics Outreach Group (EPPOG). More than 200 secondary school students between 16 and 18 have participated in this event over the last years.

Figure 5.1.2. Nikhef staff member Ivo Vulpen was interviewed for national television at the LHC start-up.

Nikhef is in charge of the central coordination of HiSPARC (High School Project on Astrophysics Research with Cosmics) which is run by a collaboration of universities and scientific institutes founded in 2002. Within this programme secondary school students are given the opportunity to build their own cosmic ray detector and subsequently to analyse data from this detector. The network of detectors has grown from 40 in 2006 to nearly 90 in 2010 located at more than 70 secondary schools and a few other locations divided over several regional clusters in the Netherlands. Several detectors abroad were connected to the HiSPARC database through the international collaboration EuroCosmics. A yearly HiSPARC symposium is organised, attended by on average 150 participating secondary school students.

Secondary school teachers

Since 2008, FOM finances a programme ('Leraar in Onderzoek', LiO) which enables secondary school teachers to take part in scientific research by spending one day per week on research at one of the FOM institutes under supervision of scientific staff. Every year between 6 and 7 teachers are assigned, the majority of them is stationed at Nikhef and works on topics within HiSPARC.

Nikhef has organised several excursions for secondary school teachers to CERN between 2005 and 2010. Since 2010, these CERN visits for teachers have been turned into an official Dutch CERN teachers programme, embedded in CERN's international effort to train secondary school teachers.

Bachelor- & master students

Many Nikhef staff members are faculty members or hold special professor positions at a university, taking part in the regular teaching programmes at Bachelor and Master level or lecturing more advanced particle physics classes.

In 2002, a new two-year Master's programme in Particle and Astroparticle Physics was introduced by Nikhef and its university partners UvA and VU. In the period 2005 to 2010, on average 14 students per year participated in the programme.

Graduate school

The Research School for Subatomic Physics (OSAF) has been set up by the universities within the Nikhef collaboration and the Nikhef laboratory, with the Radboud University Nijmegen as the official secretary for OSAF. In 2010, OSAF was one of the ten research schools in the Netherlands that received a grant from the new NWO Graduate Programme. The NWO committee in particular mentioned the 'impressive proposal' from OSAF.

Professors of the subatomic and astroparticle physics groups at the VU University Amsterdam, University of Amsterdam, Utrecht University, Leiden University and the Radboud University are connected to the Graduate School.

Mission/aim of the graduate school

The mission of OSAF is the training of PhD candidates in subatomic physics to the highest international standard. OSAF is part of Nikhef and the scientific focus of the research training offered to the PhD candidates therefore coincides with the mission and research programme of Nikhef.

Supervision

Students typically have a daily supervisor and a thesis advisor. The latter is always a professor at the university that will award the PhD degree. At the beginning of the PhD a training and supervision plan is prepared. This should specify on which experiment the student will work, who the thesis advisor and daily supervisor are, how frequently the student meets with his advisors (at least twice a month) and which courses will be part of the PhD training. The training and supervision plan is discussed with the student before it is signed. At this point the requirements for a PhD thesis are also explained. Progress is monitored in so-called C3 interviews. The student, the supervisor(s) and an independent member of the education committee meet and discuss the progress of the thesis work, training of the student future plans and evaluate if the supervision is adequate. C3 interviews contain both a look at past performance and a discussion of future steps. C3 interviews are held after 6, 12, 24, and 36 months. The independent member of the education committee reports at the meeting of the full committee on the progress of the student.

When the 6 months interview leads to serious doubt about the students' ability to complete the PhD, progress can be monitored more closely and a go/no-go decision could be taken within the first 12 months. The independent member can also advise to replace the supervisor in case of problems with the supervision.

Education programme

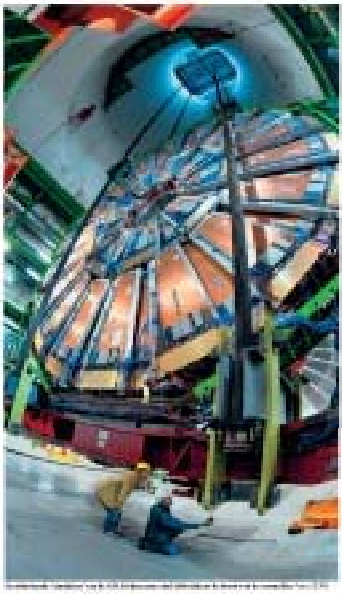
PhD students attend six topical lectures. These are three-day intensive courses, taught by scientists from the OSAF or international experts on topics relevant to subatomic physics. The first two years PhD candidates attend a two-week summer school that is jointly organised between Germany, Belgium and the Netherlands. The third year an international school is attended. In principle the candidate can propose a school, provided it is a good match with the research programme and at the appropriate level. Most choose to attend the CERN European School of Physics. Others have opted in recent years for schools at the Stanford Linear Accelerator Center in California, at Fermilab near Chicago, in Mexico and in Colombia. Next to the scientific training, students can follow a number of courses, including general courses offered by FOM to PhD candidates.

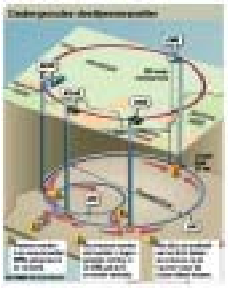
International activities

There is a strong international component to the educational programme which follows naturally from the international nature of our research programme. Apart from participating in the CERN summer school, students can present at scientific meetings at the host laboratory and frequently attend one or more meetings abroad to discuss with their international colleagues. The PhD candidates typically spend 12–18 months at CERN or another laboratory in a fully international setting. At least one of the mandatory summer schools is in Belgium or Germany. Collaboration meetings of their experiments are at various international locations. As specified, in their third year they are allowed to participate in an international school, while in their final year they are encouraged to attend an international conference and present their results.

Deeltjesfysica Grootste deeltjesversneller ter wereld gestart, op zoek naar het 'Higgsdeeltje'

Na twintig minuten zijn ze halverwege





Een zinloos, zwart, gapend gat

Ontdekkingen over de oerknal kan fundament onder religies wegslaan.

Deeltjesversneller start en 'de wereld vergaat niet'

De CERN gaat morgen in Genève de oerknal nabootsen.

Zwitserland Elementaire deeltjes onder de grond

Knallend naar de Big Bang

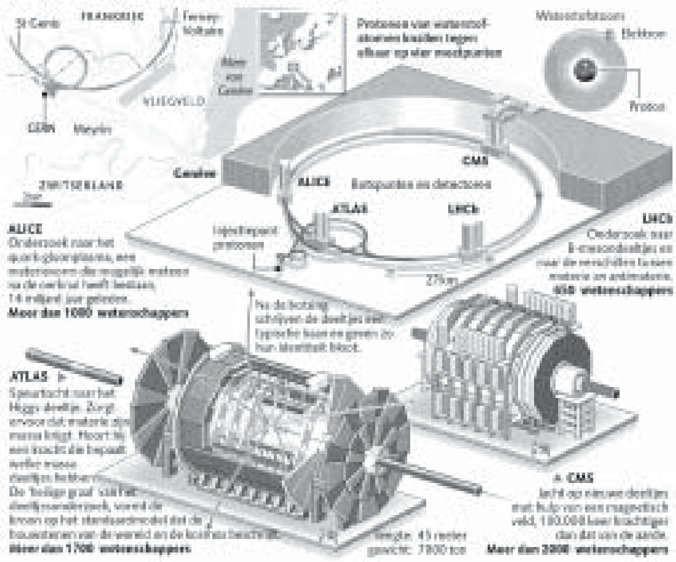
Aan de LHC werkten ruim 200 Nederlandse onderzoekers mee.

Een miljard botsingen per seconde

Wat in 1964 begon met een artikel van anderhalf kantje in een vakblad, mondt vandaag uit in het grootste wetenschappelijke experiment ooit. De natuurkundige Jos Engelen (58) leidt op researchinstituut CERN in Genève dit superonderzoek.

De oerknalmachine speurt naar de kleinste deeltjes

De Large Hadron Collider versnelt twee bundels met protonen in een ring, omtrek 27 kilometer. Zo'n 9300 magneten koelen deze deeltjes op een temperatuur van 271 graden Celsius onder nul door de vacuüm gezogen ring, waar ze met bijna de snelheid van het licht frontaal op elkaar botsen. De eerste momenten direct na de oerknal worden zo nagebootst.



Gelukzalig gevoel bij zoektocht naar bouwsteentje

Het deeltje van Peter Higgs, en anderen

Wetenschappers dolblij nu proef in speurtocht naar oerknal eindelijk is geslaagd

'Belangrijkste feit sinds landing op de maan'

Dat opent een deur naar onbekend terrein.

Deeltjesfysica Europees Centrum voor deeltjesonderzoek heeft na acht jaar weer een versneller

Ring waar het kouder is dan in het heelal

Zoeken naar de bouwsteentjes van de kosmos

In Genève gaan experts vandaag voor het eerst deeltjes laten botsen bij hoge energie. Een handleiding

Deeltjesversneller met succes opgestart

6 Technical and Support Infrastructure

6.1 Technical facilities

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

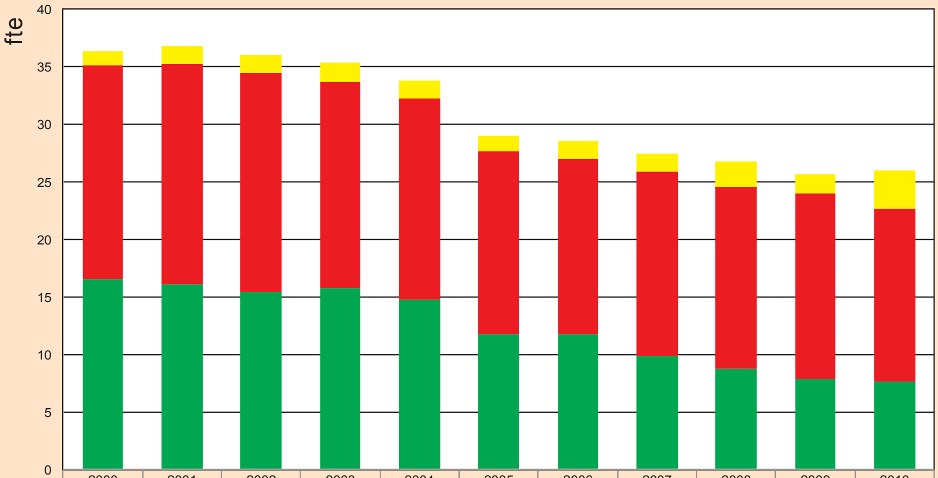
The first is a large 170 m², ISO-class 10.000 clean room, constructed inside the big assembly hall of the mechanics workshop. It has been used for construction of about 100 large Muon Drift Tube (MDT) chambers for the ATLAS detector at CERN. Currently it is being used for building instrumentation for Advanced Virgo, even reusing the large granite table, used to glue the ATLAS MDT chambers. The room is temperature and humidity controlled.

The second is located in a former experimental hall: a large 270 m² clean room 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 an 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 silicon chips and wafers. The facilities have been extensively used in the years 2000–2007 for assembling ZEUS, HERMES, ATLAS, LHCb and ALICE vertex modules. The foundations of this clean room area allow for extremely vibration–free positioning of any equipment. In 2007 a refurbishment was carried out, 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. The facility is shared with PANalytical for their Medipix-2 based detector production line. Per ultimo 2010 the most important facilities in this area are:

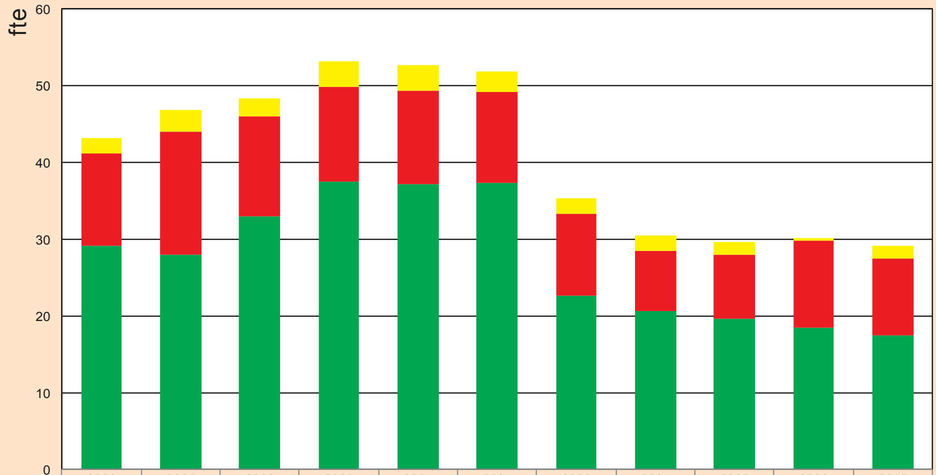
- a 15 m² ISO-class 1.000 clean room with separate airlock and overpressure system for gas detector assembly purposes;
- a 15 m² ISO-class 1.000 clean room containing two semi–automatic probe stations; a Süss PA300PS-MA and a Micro Manipulation 8860 to probe wafers up to 300 mm and 200 mm diameter respectively. In this room is also located a FEI Phenom scanning electron microscope;
- a 35 m² ISO-class 10.000 temperature controlled clean room, housing a large Wenzel 3D-coordinate measurement machine;
- a 30 m² ISO-class 10.000 room for detector module assembly and quality testing room;
- a 40 m² die–bonding and wire–bonding room, two with an automatic wedge–wedge bonders; a Hesse & Knipps BJ815 and a Delvotec 6320 to automatically bond wires for effective pitches down to 40 μm and a TPT HB16 semi–automatic ball-wedge bonder for deep access configurations and small pitch down to 25 μm;
- a 30 m² ISO-class 10.000 clean room, containing a smaller Zeiss 3D-coordinate measurement machine and a plasma cleaner to clean surfaces before die-bonding and wire-bonding.

Figure 6.1.1.
Assembly of the seismic attenuation system for the external injection bench of Advanced Virgo in one of Nikhef's clean rooms.



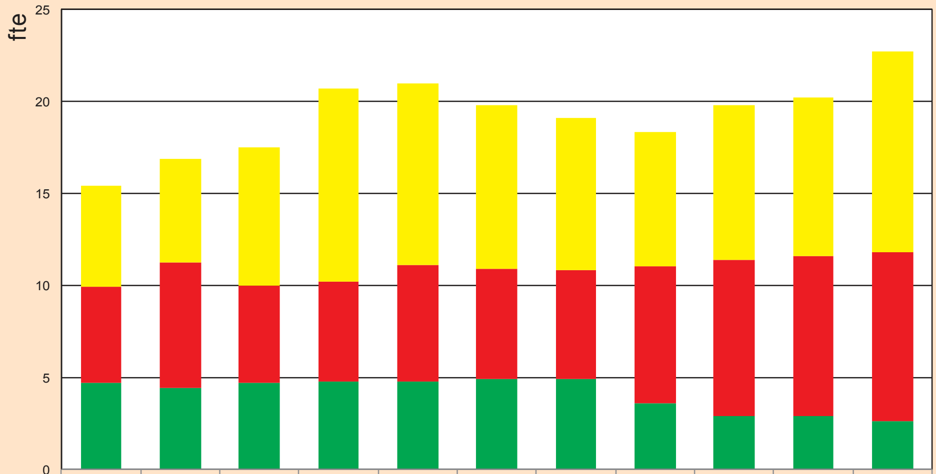
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
WO	1.2	1.6	1.6	1.6	1.6	1.3	1.5	1.5	2.3	1.7	3.4
HBO	18.6	19.1	19	17.9	17.5	16	15.3	16	15.8	16.1	15
MBO	16.5	16.1	15.4	15.8	14.7	11.7	11.7	9.9	8.7	7.9	7.6

Figure 6.1.2.
Electronics technology manpower 2005–2010.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
WO	2.1	2.9	2.4	3.3	3.3	2.7	2	2	1.8	0.4	1.7
HBO	12	16	13	12.4	12.2	11.9	10.6	7.8	8.3	11.3	10.1
MBO	29.1	27.9	33	37.5	37.2	37.3	22.7	20.6	19.6	18.5	17.4

Figure 6.1.3.
Mechanical technology manpower 2005–2010.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
WO	5.5	5.7	7.5	10.5	9.9	8.9	8.3	7.3	8.4	8.6	10.9
HBO	5.2	6.8	5.3	5.4	6.3	6	5.9	7.4	8.5	8.7	9.2
MBO	4.7	4.4	4.7	4.8	4.8	4.9	4.9	3.6	2.9	2.9	2.6

Figure 6.1.4.
Computer technology manpower 2005–2010.

6.2 Electronics technology

Technical Group Leader: ing. R. Kluit

The main task of the Electronics Technology Department is to design, build, maintain and support electronic systems for read–out and processing of the data of detectors in close collaboration with the experimental physicists involved. Efficient, short communication lines have proven to be essential when designing this kind of complicated, very specific instrumentation.

Significant contributions to the present LHC (ATLAS, LHCb and ALICE) experiments have been made and the systems are now in use. In addition, for ANTARES and KM3NeT electronics was developed, which is already in use or will be used in a deep-sea environment.

Electronic parts in the LHC experiments are exposed to ionizing and non-ionizing radiation. This required the use of specific design techniques for front-end ICs and other electronics for data acquisition- and control systems installed on the detector. In the development phase also prototypes equipped with commercially available components were irradiated and tested. The validated systems turn out to function as expected in the harsh radiation environment in the LHC experimental caverns.

Fiber optic communication systems, with Dense Wavelength Division Multiplexing (DWDM), enable high data-rate communication under sea, as has been demonstrated in the last years. This technology can also open new opportunities for successive or upgraded experiments at accelerators.

The IC-design technology that is required to design radiation tolerant front-end parts is also applied in areas with specific demands, like low-power, low-cost (large quantities), where also high integration-density is required. This underlines the importance of investing in IC-design technology and skilled designers for the department.

The PCB-design process has been evaluated and improved, the process is set up now such that outsourcing of the PCB production and board assembly matches industry work methods smoothly.

Figure 6.2.1.
Optical marine cable prototype ready for pressure test at 5km below sealevel.

Table 6.2.1. Electronics contributions.

Experiment	Subsystem	Technologies used
ATLAS	Muon detector data acquisition Alignment and detector control	FPGAs and data communication Alignment system, CAN bus and sensors
ALICE	Inner-tracker read out & control	Full custom ICs, low power and in small volume
LHCb	Vertex & Pile-up detector read out	Front-end IC, read out and data-communication, FPGAs
ANTARES/KM3NeT	Data-acquisition, detector front-end and power	Optical communication network, IC for PMT read out, low power DC/DC conversion & HV supplies
R&D	Gas-detector tracking systems	Full custom ICs for sensor read out and small high-speed data acquisition with FPGAs.

6.3 Mechanical technology

Technical Group Leader: ing. P. Werneke

In this section the activities are described of the Mechanical Engineering Department and the Mechanical Workshop. The close collaboration that already existed between those groups, has now been formalised by merging them in one group Mechanical Technology (MT).

The main task of the MT is to develop, design, and realise mechanical solutions for the mostly large, international projects that Nikhef participates in. They concern detectors with different sensitive mediums, each with their different requirements and construction methods. A relatively new development at the MT is the construction of gravitational-wave detectors. This requires a new field of expertise: the seismic isolation of large optical elements.

A wide range of mechanical technologies has been used for the different projects: light and stiff construction, vacuum, CO_2 cooling, cryogenic techniques, special welding and gluing techniques, wire bonding, high-pressure applications, etc. The detectors have found their way deep underground, in the desert, in space or a few kilometres below sea level.

The MT has pioneered in the application of new and often light materials and composites. These have found their way into the present LHC particle detectors. Herewith we opt for carbon fibre fortified synthetic materials or construction foam. This requires a sound characterisation of materials, for instance research into the influence of heat and humidity on stability.

Other research is aimed at the weldability of titanium welding tubes with extremely thin walls. The mechanical technicians have computer-driven metal working machines at their disposal. Parts and assemblies are checked to the micrometer level. Assembly is often done in cleanrooms.

With the use of mathematical models and special software (finite element analysis) the characteristics of the designs can be predicted very accurately. However, during realisation still questions will remain. Were the required specifications indeed met? Could we make the constructions even stiffer, more precise or with even less material? Is the heat on detectors being carried off sufficiently? Are electrical or magnetic fields adequately shielded? Intuition and experience of the technical staff plays a crucial role in the realisation of the projects.

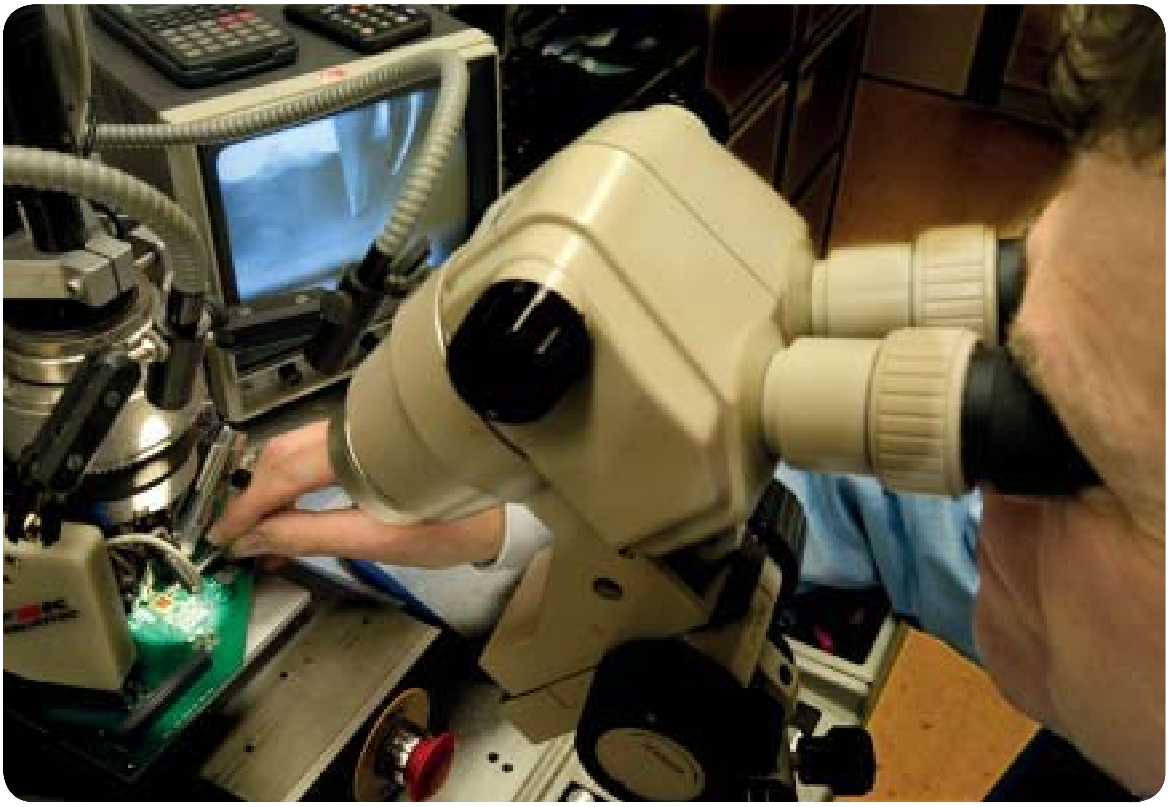


Figure 6.3.1.
Wire bonding.

Experiment	Subsystem	Technologies used
ATLAS	Muon detector	Precision engineering, light and stiff construction, finite element analyses, precision machining and assembly, tooling, 3D-coordinate measuring, procurement, installation.
	Inner detector	Precision engineering, light and stiff carbon fiber construction, finite element analyses, wire bonding, precision machining and assembly, tooling, 3D-coordinate measuring, procurement, cooling, installation.
LHCb	Outer tracker	Precision engineering, light and stiff construction, finite element analyses, wire bonding, precision machining and assembly, tooling, 3D-coordinate measuring, procurement, installation.
	Vertex locator	Precision engineering, light and stiff construction, finite element analyses, wire bonding, precision assembly, 3D-coordinate measuring, vacuum, welding, CO^2 cooling, sensing & control, installation.
ALICE	Inner tracker	Precision engineering, light and stiff construction, finite element analyses, wire bonding, precision assembly, 3D-coordinate measuring, installation.
ANTARES		Thermal analyses and cooling.
KM3NeT		Development and realisation of the optical modules prototypes, high-pressure, finite element and thermo-mechanical analyses, hydro-dynamics, optics, 3D-coordinate measuring.
Virgo		Precision engineering, light, stiff and stable construction, finite element and thermo-mechanical analyses, precision assembly, optics, vacuum, welding, cryogenics, sensing & control, 3D-coordinate measuring, installation.
Pierre Auger Observatory		Thermal analyses and cooling.
XENON		Cryogenics, finite element and thermo-mechanical analyses, development of stable mechanics.
Detector R&D		Precision engineering, light and stiff construction, precision assembly.

Table 6.3.1. Technologies used in the experiments.

6.4 Computer technology

Technical Group Leader: 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 projects.

The focus of the CT effort in the past years moved from writing software for scientific instruments like those for the LHC detectors towards deploying an infrastructure for storage and analysis of massive amounts of data produced by these instruments. Until recently CT software engineers were set to work at CERN to install and test their software for read-out and control systems of the ATLAS and LHCb detectors on the spot. Nowadays their work is directed to support the running experiments remotely and participating in new developments initiated by the R&D and other groups at Nikhef.

Grid computing has become a mature activity at Nikhef in the past years. The CT contributes a substantial amount of manpower to the activities of the Physics Data Processing (PDP) group, which is described in more detail in the relevant chapter of this report. Worth mentioning here is that CT local system management benefits from the knowledge transfer from the colleagues working in the PDP projects. An excellent example of this cooperation is the deployment of a shared identity management and user administration system on the interface of the distributed grid and local ICT environments. This identity system not only provides us with an automated user administration coupled to the database of the human resource department, but also levelled Nikhef up to the status of a 'trusted site' inside the Dutch SURFnet federation and other international federations.

The CT group implemented major upgrades in the local ICT infrastructure. The most important ones were the replacement of the core and backbone network router to be able to fulfil the always growing demands for more internal and external network bandwidth, the installation of a high-availability central file server and the deployment of a powerful cluster for the mail services. To facilitate the demands from our scientific users for compute and storage capacity fully integrated in the local desktop environment, we have installed a computer cluster with associated data storage servers.

Figure 6.4.1. Nikhef is an AMS-IX certified data centre.

Since 1995, when Nikhef started to offer housing services for the first customers of the Amsterdam Internet Exchange (AMS-IX), the demands put on the availability have increased dramatically. At the same time the demands for more floor space, racks, power and cooling capacity keep on growing. Nikhef has decided to continue its computer housing services for at least five more years and started an upgrade project for the facility. This upgrade included the construction of a new computer room situated on the second floor in the building to locate racks for Nikhef internal ICT services and grid-related compute and storage capacity. The main components of the upgrade were: a second no-break power feed and an upgrade of the existing one, a new cooling system on the roof of the building, a new monitoring and control system, extension of the floor space, additional services such as a gas-suppression system, more advanced security and last but not least a reorganisation of the support groups. As a result of all these investments we now have a stable and up-to-date facility. Furthermore Nikhef has been officially certified as an AMS-IX housing site and expansion of the grid infrastructure is guaranteed for years to come.

6.5 Management & support

Institute Manager: drs. A. van Rijn

Whilst the personnel officer 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, project management support and several staff members.

The main tasks of the secretariat (3.3 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 (1.1 fte) handles all incoming general phone calls and monitors admittance to the Nikhef building, with special emphasis on checking admittance to Nikhef's data centre 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 important (to illustrate: in 2010 Nikhef sent out more than 500 invoices, for a total amount of 6.8 M€). Externally acquired projects, often with different rules regarding accountability, makes project administration an increasingly complex activity.

Figure 6.5.1. Nikhef staff gathering in front of the building for a fire drill.

Technical and domestic services (THD, 8.6 fte) are responsible for building maintenance and installations, (such as clean room control, heating, cooling, power). This includes a 7×24 hours standby service. Nikhef's THD also has important responsibilities for several installations, shared with neighbouring institutes and for other common 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). Since 2009, after the refurbishment of the data centre, including separation of the cooling system, one THD member is dedicated to the maintenance of the data centre installations (head of the data centre technical services). The safety officer (1.0 fte), whose tasks include radiological and environmental safety, is responsible for safety and for taking all necessary measures to ensure healthy working conditions. Nikhef has a team of about 17 employees trained in first aid, fire extinguishing and accident prevention. Nikhef's safety officer is also the central (WCW) coordinator for environmental affairs.

For the general (WCW) tasks Nikhef receives a financial compensation equivalent to about 2 fte. Nikhef also provides the project manager (0.8 fte), who coordinates most of the area development of WCW on behalf of the land owner (NWO). The project manager is supported by the Nikhef-secretariat (0,5 fte). For these tasks Nikhef is financially compensated by NWO.

The library (0.6 fte) provides access to all relevant journals in the field. Following trends in electronic publication Nikhef management has since 2007 carried out a significant (50%) reduction in both the space and the personnel available for the library.

One staff member (1,0 fte) serves as Industrial Liaison Officer and also provides support to the Nikhef body for project planning and support. Another staff member (0,8 fte), physically embedded in the electronics department, serves as project manager for a large part of Nikhef's KM3NeT technical commitments.

For outreach and science communication 1.8 fte is available, a 0.9 fte communication officer and a 0.9 fte graphical designer. For the HiSPARC project 0.8 fte of coordinating effort is available. In 2010, 11 secondary-school teachers were active in this project (totalling 1.5 fte). The HiSPARC activities are funded separately by FOM.

Appendices

A Conferences & workshops organised by Nikhef

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

7th Middleware Security Group multi project meeting, 14–15 December 2005, Amsterdam, D. Groep, 26 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

Virgo Collaboration Meeting, 3–5 July 2006, Nikhef, Amsterdam, J. van den Brand, 60 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

HEAP meeting, 19–20 February 2007, E. de Wolf, 100 participants

ACAT 2007, XI International Workshop on Advanced Computing and Analysis Techniques in Physics Research, 23–27 April 2007, B. van Eijk, J. Vermaseren, 100 participants

2nd ASPERA 'Roadmap' Workshop on European strategy for astroparticle physics, 20–21 Sep 2007, Felix Meritis, Amsterdam, G. van der Steenhoven, 172 participants

KM3NeT Workshop on the Conceptual Design Report, 12–16 November 2007, Nikhef, E. de Wolf, 40 participants

12th EUGridPMA Plenary Assembly, 14–16 January 2008, Amsterdam, D. Groep, 45 participants

GEE JRA1 All Hands meeting, 20–22 February 2008, Amsterdam, O. Koeroo, 33 participants

Micro-Pattern Gas Detectors (RD-51) Workshop, 16–18 April 2008, Nikhef, Amsterdam, H. van der Graaf, P. de Jong, 96 participants

Strong and ElectroWeak Matter, 26–29 August 2008, Science Park Amsterdam, E. Laenen, 105 participants

Einstein Telescope Governing Council meetings, 5 September 2008 and 10 September 2010, Nikhef, Amsterdam, J. van den Brand, 15-20 participants

LSC/VIRGO joint meeting, 22–25 September 2008, De Duif, Amsterdam, J. van den Brand, 195 participants

EUDET Annual Meeting, 6–8 October 2008, Nikhef, Amsterdam, H. van der Graaf, J. Timmermans, 70 participants

Underground Site Construction Meeting, COB meeting with industry (EU-FP7-infrastructure), 8 October 2008, Nikhef, Amsterdam, J. van den Brand, 25 participants

Quattor Working Group, 27-29 October 2008, Amsterdam, D.Groep, 25 participants

ASPERA R&D meets industry event, 28 October 2008, R. van der Meer, 35 participants

4th ATLAS Tracker Upgrade Workshop, 3–7 Nov 2008, Amsterdam, N. Hessey, 162 participants

EGI Council Meetings, 29 May 2009, 9 July 2009, 3 February 2010, 3 March 2010 and 25 November 2010, Science Park, Amsterdam, A. van Rijn, 40 participants

Vertex 2009, 13-18 September, Putten , E. Koffeman, A.P. Colijn, M. van Beuzekom, 50 participants

LHCb VeloPix Module Construction kick-off meeting, 9 November 2009, Nikhef, M. van Beuzekom, 25 participants

LHCb Tier-1 Jamboree, 21–22 March 2010, Nikhef, J. Templon, 40 participants

1st EGI Operational Security Coordination Team meeting, 22–23 March 2010, Amsterdam, S. Gabriel, 33 participants

WLCG Grid deployment board, 23 March 2010, Nikhef, J. Templon, 40 participants

KM3NeT general meeting by Work Package F/L - Production preparation, 5–7 June 2010, Nikhef, E. de Wolf, 80 participants

KM3NeT strategic board (SPB) meeting, Nikhef, 7 June 2010, Nikhef, E. de Wolf, 20 participants

KM3NeT ASC meeting, 7 June 2010, Nikhef, F. Linde, 15 participants

Jamboree on Evolution of WLCG Data & Storage Management - Jamboree WLCG, 16–18 Jun 2010, Nikhef, K.Bos, J. Templon, 100 participants

KM3NeT work Package D - Strategic Issues, 21–22 June 2010, Nikhef, M. de Jong, 40 participants

EGEE-III Final Review, 23–24 June 2010, Science Park Amsterdam, A. van Rijn, 40 participants

EGI Technical Forum 2010, 14–17 September 2010, Beurs van Berlage, Amsterdam, D. Groep, T. Suerink, A. van Rijn, 500 participants

ATLAS Trigger Workshop, 18–22 Oct 2010, Purmerend, O. Igonkina, 80 participants

HEAP meeting, 2 November 2010, Science Park Amsterdam, E. de Wolf, 100 participants

ANTARES Collaboration meeting, 22–24 November 2010, Nikhef, Amsterdam, P. Kooijman, 83 participants

LHCb HLT Workshop, 24–25 November 2010, Nikhef, G. Raven, 30 participants

Figure A.1. Poster for the 18th VERTEX workshop which was organised by Nikhef in 2009. Photo © Jacco Herzog

B Memberships of (inter)national committees & boards

ASPERA
F. Linde (2006–2010) (Governing Board)
R. van der Meer (2007–2010) (Joint Secretariat)
G. van der Steenhoven (2006) (Joint Secretariat)

Astroparticle Physics European Coordination (ApPEC)
P. Kooijman (2007–2010) (peer review committee)
F. Linde (2005–2010) (steering committee)
G. van der Steenhoven (2006–2007)

BEAUTY Intern. Conference on B-Physics at Hadron Machines International Advisory Committee
R. Fleischer (2009–2010)

Board of Computer Algebra Nederland
J. Vermaseren (2007–2009)

BiG Grid Executive Team
D. Groep
A. van Rijn (chair)
J. Templon (2008)

Big Grid Directorate
F. Linde
A. van Rijn (2009–2010)

CERN Council Strategy Group
S.J. de Jong (2005–2007)
F. Linde (2005–2007)

CERN Large Hadron Collider Committee (LHCC)
S. de Jong (2005–2008)

CERN SPS Committee
P. Kooijman (2006–2010)

Committee for Astroparticle Physics in the Netherlands (CAN)
J. van den Brand (2008)
M. de Jong (2008)
S. de Jong (2007–2008)
F. Linde (2007–2008)
R. van der Meer (secretary) (2007–2008)
P. Mulders (2007–2008)
G. van der Steenhoven (2007)
E. de Wolf (2008)

Committee Sectorplan Physics
F. Linde (2007)

Computer Algebra Nederland – Board
J. Vermaseren (2010)

Computing Resources Scrutiny Group (LCG C-RRB advisory group)
D. Groep (2008)

DESY Hamburg – Program Review Committee
J. Timmermans (2005–2010)

Deutsche Physikalische Gesellschaft Hadronen Physik – Scientific Advisory Committee
J. Koch (2005–2008)

Scientific Advisory Committee Deutsche Forschungsgemeinschaft “Gravitational Wave Physics” (Germany)
J.W. van Holten (2005–2006)

Development and Commissioning of LOFAR for Astronomy Review Committee (DCLA review)
G. van der Steenhoven (2007)

Dutch Research School Theoretical Physics – Educational Board
P. Mulders (chair) (2007–2008)
E. Laenen (2007–2008)

EGEE Technical Management Board
J. Templon (2008)

EGI Organisational Task Force
A. van Rijn (chair) (2009–2010)

EGI.eu Executive Board
A. van Rijn (vice-chair) (2010–)

EUROCOSMICS
B. van Eijk (chair) (2009–2010)

European Committee for Future Accelerators (ECFA)
v. Middelkoop (2005)
R. Kamermans † (2005)
S. de Jong (2005–2010)
M. Merk (2006–2010)
F. Linde (2005–2010) (restricted ECFA)
Th. Peitzmann (2006–2010)

European Particle Physics Communication Network EPPCN
G. Bobbink (2008–2010)
G. Zegers (2008)
V. Mexner (2010)

European Particle Physics Outreach Group
G. Zegers (2006–2008)
V. Mexner (2009–2010)
H. Tiecke (2005–2006)

European Physical Society
E. de Wolf (2008–2010) (Physics Education Board)
F. Linde (2006) (High Energy Physics Board)
B. van Eijk (2007–2010) (High Energy Physics Board)

European Physics Journal – Scientific Advisory Committee
P. Mulders (2007–2010)

European Policy Management Authority for Grid Authentication in e-Science (EUGridPMA)
D. Groep (chair) (2005–2010)

European Research Council – Advanced Grants panel PE2
S. de Jong (2009–2010)

European Science Foundation – Physical and Engineering Sciences Unit
R. Kamermans † (2005–2010)

FOM Governing Board
J. Engelen (2005–2008)
S. de Jong (2005–2010)
S. Bentvelsen (2009–2010)

FOM Committees
E. de Wolf (2007–2010) (Adviescommissie FOM/v programma)

FOM network Theoretical High Energy Physics
P. Mulders (chair) (2005-2008), E. Laenen (chair) (2008–2010)

Fonds Wetenschappelijk Onderzoek Vlaanderen – Expertpanel Physics
E. de Wolf (2009–2010)

Gesellschaft für Schwerionenforschung Darmstadt – Program Advisory Committee
Th. Peitzmann (2006, 2008–2010)

GridKa Overview Board Karlsruhe
K. Bos (2005–2010)

Helmholtz-Alliance for Physics at the Terascale – International Advisory Board
K. Bos (2007–2010)

Landelijk co-ordinatorenoverleg HiSPARC
B. van Eijk (chair)
J. van Holten (2009–2010)

International Grid Trust Federation
D. Groep (chair) (2005–2010)

InterActions
A. van den Bergen (2005–2008)
G. Zegers (2008)
V. Mexner (2009–2010)

IPPP Steering Committee Durham (UK)
N. de Groot (2005–2006)

Jefferson Lab (USA) Programme Advisory Committee
E. Jans (2005)

JINR Scientific Council Dubna (Russia)
G. van Middelkoop (2005)

Kamer Natuurkunde (VSNU)
G. van der Steenhoven (2007)

KNAW Raad voor Natuur- en Sterrenkunde
F. Linde (2007)
Th. Peitzmann (2007)

KVI Groningen – Scientific Advisory Committee (WAC)
P. Mulders (2008–2010)
G. van der Steenhoven (2007)

Laboratori Nazionali del Gran Sasso, L'Aquila – Scientific Committee
F. Linde (2005–2010)

Laboratori Nazionali di Frascati, Frascati – Scientific Committee
G. van Middelkoop (2005)
F. Linde (2006–2010)

Laboratoire de l'Accélérateur Linéaire, Orsay – Scientific committee
F. Linde (2008–2010)

Natuur Leven Technologie – Regionaal Steunpunt Arnhem-Nijmegen
S. de Jong (2010)

Nederlands Tijdschrift voor Natuurkunde – Redactie
S. de Jong (2006–2010)
M. Decowski (2009–2010)

Nederlandse Natuurkundige Vereniging (NNV) – Board
G. van der Steenhoven (treasurer) (2005–2006) (executive board member)
P. Mulders (secretary) (2005–2009)
E. de Wolf (2003–2007) (executive board member)
E. de Wolf (2008)
J. van Holten (2009)
S. de Jong (2009)

Nederlandse Natuurkundige Vereniging (NNV) – Secties
J. van Holten (2010)
P. Kluit (2007–2010)
E. Koffeman (2007–2010) (Sectie Subatomaire Fysica)
S. de Jong (vice chair) (2008–2010) (Sectie Onderwijs & Communicatie)
S. de Jong (2010)
P. Mulders (secretary) (2010)
E. de Wolf (deputy chair) (2010)

Nijmegen Centre for Advanced Spectroscopy – Supervisory Board
F. Linde (chair) (2009–2010)

Nuclear Physics European Collaboration Committee (NuPECC)
Th. Peitzmann (2006–2010)
G. van der Steenhoven (2005)

Onderzoekschool Subatomaire Fysica – Onderwijscommissie
Th. Bauer
S. Bentvelsen
J. Berger (secretary) (2009–2010)
J. van den Brand
T. van Egdom
B. van Eijk
N. de Groot (chair)
P. de Jong
S. de Jong
M. Kesgin (secretary) (2007)
J. Koch
E. Koffeman
E. Laenen
F. Linde
M. Merk
P. Mulders
Th. Peitzmann (2008–2010)
E. Schram-Post (secretary) (2008)

Open Grid Forum Standards Function Security Area (2008)
D. Groep (director) (2006–2010)

PDF4LHC (Parton Density Functions for the LHC) workshop series – Organising committee
M. Botje (2009–2010)

Platform Bèta Techniek – ambassadeur
F. Linde
E. de Wolf (2007–2010)
G. van der Steenhoven (2007)

International Workshop on Radiation Imaging Detectors – Scientific Advisory Committee
J. Visschers (2009–2010)

Programme Committee of the First workshop on Security Trust and Privacy in Grid Environments (STPC 2008)
D. Groep (2008)

Scientific Advisory Committee of the International Workshop on Radiation Imaging Detectors
J. Visschers (2008)

Réseaux IP Européens (RIPE)
R. Blokzijl (chair) (2005–2010)

SPSC–CERN
P. Kooijman (2005–2006)

Stichting Conferenties en Zomerscholen over de Kernfysica (StCZK)
G. van der Steenhoven (2007),
S. de Jong
P. Mulders (2007–2010)

Stichting Cosmic Sensation
S. de Jong (chair, secretary and treasurer) (2009–2010)

Stichting Hoge-Energie Fysica
J. van den Brand
R. Kleiss
F. Linde (chair)
Th. Peitzmann (2008)
A. van Rijn (treasurer) (2007–2010)

Stichting Industriële Toepassing van Supergeleiding (2008)
B. van Eijk (2008–2010)

Stichting Natuurkunde.nl
G. van der Steenhoven (2007)
Stichting Physica
G. van der Steenhoven (2006–2007)

Stichting Quality Assurance Netherlands Universities Evaluation Committee Liberal Arts and Sciences
N. de Groot (2006–2007)

Techniek Toernooi
E. de Wolf (chair) (2008–2010)

Thomas Jefferson National Accelerator Facility Newport News –Program Advisory Committee
P. Mulders (2008–2010)

Vereniging Gridforum Nederland
A. van Rijn (treasurer) (2007–2010)

Virtual Laboratory for e-Science VI-e
A. van Rijn (2009–2010) (Directorate)

Worldwide LHC Computing Grid Management Board
J. Templon (2007–2008)

C 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 uses the LHC.

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 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 interactions of high-energy cosmic neutrinos.

Antimatter
Every kind of matter particle has a corresponding antiparticle. Charged antiparticles have the opposite electric charge as 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.

ASPERA
Sixth Framework Programme for co-ordination across European funding agencies for financing astroparticle physics. The seventh Framework Programme started in 2009 and is called ASPERA-2.

ATLAS (A Toroidal LHC ApparatuS)
One of the four major experiments that uses the LHC.

BaBar
Detector at SLAC's B Factory. Named for the elephant in Laurent DeBrunhoff's children's books.

Baryon
See Particles.

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 centimetres long and can be just a few μm in diameter.

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

BNL (Brookhaven National Laboratories)
Laboratory at Long Island, New York, 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.

CLIC (Compact LInear Collider)
A 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.

Colour glass condensate
Representation of atomic nuclei travelling near the speed of light as Lorentz contracted spheres along the direction of motion before collision, where ‘colour’ refers to the type of charge that quarks and gluons carry as a result of the strong nuclear force and ‘glass’ to the behaviour of this disordered state: a solid on short time scales but a liquid on longer time scales.

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.

DO (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. See also WIMP.

Decay
Any process in which a particle disappears and in its place two or more different particles appear.

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. Examples are the ATLAS, the ALICE and the LHCb detectors.

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, involving more than 90 institutions over 30 countries worldwide, to provide a Grid infrastructure, available to scientists 24 hours a day. The programme ended on April 30 2010. Its tasks are taken over by the European Grid Infrastucture (EGI), located at Science Park Amsterdam.

Electron
See Particles.

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

EGI
A foundation to create and maintain a pan-European Grid Infrastructure (EGI) in collaboration with National Grid Initiatives (NGIs) and European International Research Organisations (EIROs), to guarantee the long-term availability of a generic e-infrastructure for all European research communities and their international collaborators. Its mission is to enable access to computing resources for European researchers from all fields of science, from High Energy Physics to Humanities.

EUDET (European Detector R&D towards the International Linear Collider)
EU–funded R&D project for research on future ILC detectors, ending in 2011.

eV (Electronvolt)
A unit of energy or mass used in particle physics. One eV is extremely small, and units of million electronvolts, MeV, thousand MeV = 1 GeV, or million MeV = 1 TeV, are more common in particle physics. The latest generation of particle accelerators reaches up to several TeV. One TeV is about the kinetic energy of a flying mosquito.

Fermion
General name for a particle that is a matter constituent, characterised by spin in odd half integer quantum units (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.

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).

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 to the mechanism by which physicists think particles acquire mass.

HiSPARC (High School Project on Astrophysics Research with Cosmics)
Cosmic-ray experiment with schools in the Netherlands.

ILC (International Linear Collider)
A possible future electron–positron accelerator, proposed to be built as an international project.

Jet
The name physicists give to a cluster of particles emerging from a collision or decay event all traveling in roughly the same direction and carrying a significant fraction of the energy in the event.

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.

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.

LEP
The Large Electron–Positron collider at CERN which ran until 2000. Its tunnel has been reused for the LHC.

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 accelerator that started in 2008.

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

Linac
An abbreviation for linear accelerator.

LIGO (Laser Interferometer Gravitational-Wave Observatory)
A facility to detect astrophysical gravitational waves consisting of two widely separated installations in Hanford, Washington and Livingston, Louisiana, operated in unison as a single observatory.

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. The exploratory LISA Pathfinder is due to be launched in 2011.

LOFAR (Low Frequency Array)
First radio telescope of a new generation of astronomical facilities, mainly in the Netherlands. Started in 2010.

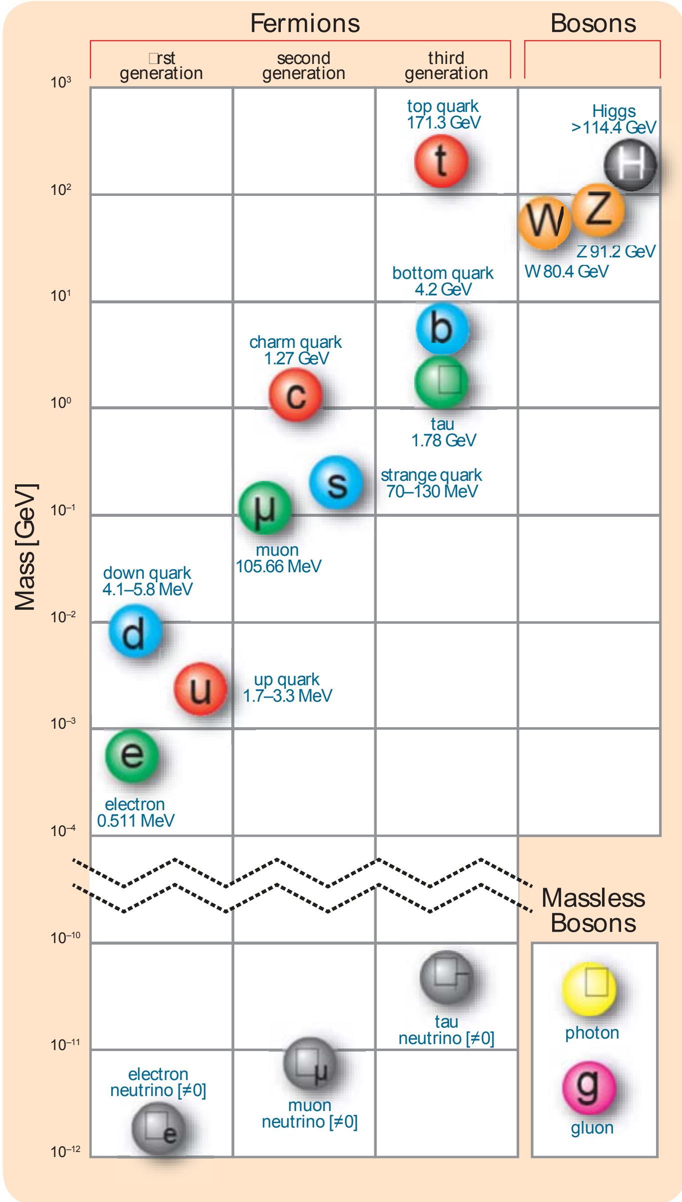


Figure C.1. The Standard Model particles (neutrino masses only indicative).

Medipix

A family of photon counting pixel detectors based on the Medipix CMOS read-out chips that can be provided with a signal from either a semi-conductor sensor or ionisation products in a gas volume. The detectors are developed by an international collaboration, hosted by CERN, and including Nikhef. Medipix-3 is the prototype that is currently in the development phase.

Meson

See Particles.

Momentum

Momentum is a property of any moving object. For a slow moving object it is given by the mass times the velocity of the object. For an object moving at close to the speed of light this definition gets modified according to Relativity Theory. The total momentum is a conserved quantity in any process.

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.

NWO

The Netherlands Organisation for Scientific Research is funding thousands of top researchers at universities and institutes and is steering Dutch science by means of subsidies and research programmes

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 bottom (or beauty). The leptons are electron and electron neutrino, muon and muon neutrino, τ and τ-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 gluons and 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.

Photon
See Particles.

Pierre Auger Observatory (PAO)
International experiment in Argentina to track down the origin of ultra-high-energy cosmic rays.

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 also 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.

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 also Forces).

Superconductivity
A property of some materials, usually at very low temperatures, that allows them to carry electricity without resistance. When starting a current flow in a superconductor, it will keep flowing for ever —as long as it is kept cold enough.

Supersymmetry
Supersymmetry (often abbreviated SUSY) is a theory that predicts the existence of heavy 'superpartners' to all known particles. It will be tested at the LHC.

SURFnet
Organisation providing the research network in the Netherlands.

Tevatron
Fermilab's 2-TeV proton–antiproton accelerator near Chicago.

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

Trigger
An electronic system for spotting potentially interesting collisions in a particle detector and triggering the detector's read-out system.

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.

WIMP (Weakly Interacting Massive Particle)
A hypothetical particles that has a non-zero mass and only participates in weak nuclear interactions. Dark matter may be composed of WIMP’s.

XENON
The XENON experiment searches for dark matter with liquid xenon as target material for finding WIMPs; is installed at the Gran Sasso underground laboratory in Italy.

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

Zeus
Collider experiment at DESY’s HERA, was running till July 2007.

NIKHEF FOM NWO