NIKHEF Annual Report 2006

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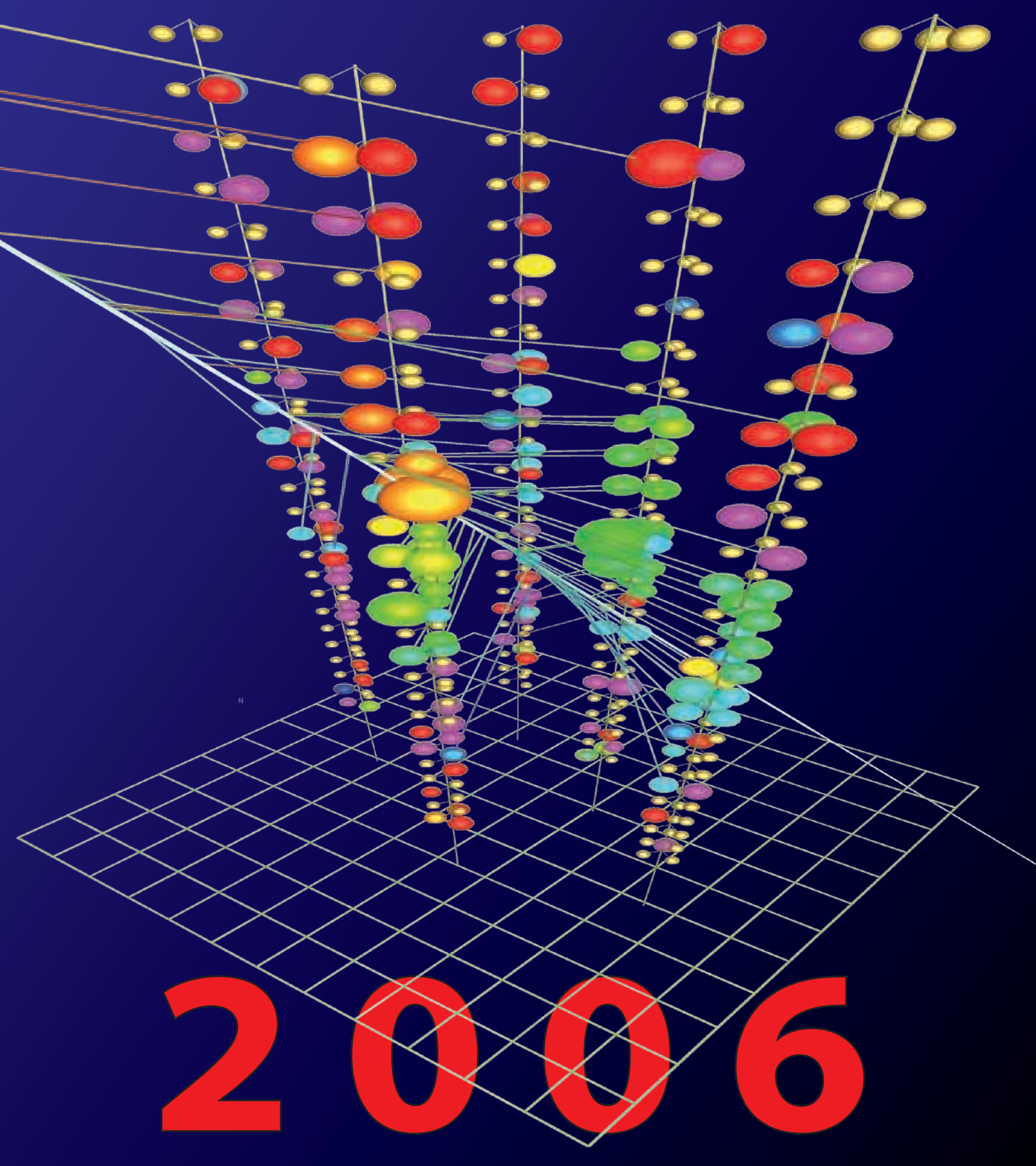

2006

Annual Report 2006

NIKHEF

Colophon

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

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

NIKHEF participates in the preparation of experiments at the Large Hadron Collider at CERN, notably ATLAS, LHCb and ALICE. NIKHEF is actively involved in experiments in the USA (DØ at Fermilab, BaBar at SLAC and STAR at RHIC) and in Germany at DESY (ZEUS and HERMES). Furthermore, astroparticle physics is part of NIKHEF's scientific programme, through participation in the Pierre Auger large area cosmic ray detection facility in Argentina and through participation in the ANTARES project: a neutrino telescope under construction in the Mediterranean Sea. Detector R&D, design and construction of detectors and the data-analysis take place at the laboratory located at Science Park Amsterdam as well as at the participating universities. NIKHEF has a theory group with both its own research programme and close contacts with the experimental groups.

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Introduction

VENI, VIDI, … VICI! These are the three, progressively more prestigious, subsidies awarded by NWO to members of the Dutch ATLAS team in 2006! In November, NWO officially granted the subsidy for a Dutch grid-based e-Science infrastructure (BIG GRID), including the Dutch compute grid facility for CERN's Large Hadron Collider (LHC) project. In June, CERN Council confirmed the foreseen November 2007 start-up date of the LHC, albeit at a disappointingly low beam energy of 450 GeV. LHC operation at the full beam energy of 7000 GeV is expected to start in March 2008. With so much excellent news, the pressure on the LHC experiments to complete their detectors in time to record first proton-proton collisions in 2007 is tangible! Throughout 2006, many pieces of LHC instrumentation were transported from the NIKHEF workshops to CERN. Beyond doubt, the most delicate were: a complete semi-conductor tracker endcap for the ATLAS inner tracking system and the silicon strip detector for the ALICE inner tracking system. Both arrived at CERN intact. The transport of the vacuum tank for the LHCb vertex locator, on the contrary, required several NIKHEF engineers to spend their summer vacation at CERN to first locate and subsequently repair leaks due to transport damage. A large fraction of two other major NIKHEF deliverables, the LHCb outer tracker and many components of the ATLAS muon spectrometer, was installed and commissioned by the end of 2006 in the underground caverns housing these LHC experiments. For the ATLAS experiment, the magnetic-field monitoring system and the RASNIK alignment systems were put to test in November when the stored energy in the huge super-conducting barrel toroids reached its design value of 1,100,000,000 Joules. Both systems performed as expected. In addition, NIKHEF PhD students were the first to reconstruct curved trajectories of cosmic-ray muons through the ATLAS muon chambers connected to the data-acquisition system, another NIKHEF deliverable already partially installed in the underground electronic area. The down-side of all this fantastic progress? The fact that the NIKHEF workshops in Amsterdam start to look a bit empty with the LHC detector components, designed and constructed at NIKHEF, now at CERN and with many of NIKHEF's technicians and engineers working at CERN on the installation and commissioning of the LHC detectors!

In 2006 the Dutch government initiated SmartMix: the chance to win a multi-million euro subsidy for collaborations between industries and research institutes aimed at either the commercialisation of knowledge or the expansion of the knowledge frontier. Perhaps surprisingly, a strong consortium, led by NIKHEF, of several (international) industries and research institutes and universities in the Netherlands entered the competition for the SmartMix subsidy with an astroparticle physics proposal with as central theme: What is the origin of ultra high energy cosmic rays? Regretfully, the SmartMix office decided to turn down this proposal (together with more than a hundred other proposals …). Nevertheless, several industrial partners decided to continue to collaborate; notably in view of the challenges and potential of the KM3NeT project, the water Čerenkov neutrino telescope in the Mediterranean Sea presently approved as a design study by the European community with NIKHEF as a participant. In 2006 ANTARES, the pilot study for such a water Čerenkov neutrino telescope, made major progress. In March, the first of the twelve 450 meter long ANTARES strings of 75 optical modules each was deployed and successfully installed at the bottom of the Mediterranean Sea off the coast of Toulon (France). Within days, muon tracks were reconstructed (Fig. 1) thanks to the concerted effort of an ex-NIKHEF PhD student now working at Fermilab near Chicago (USA) and the NIKHEF team in Amsterdam. A second string was deployed in July. All twelve ANTARES strings are expected to be deployed by the end of 2007.

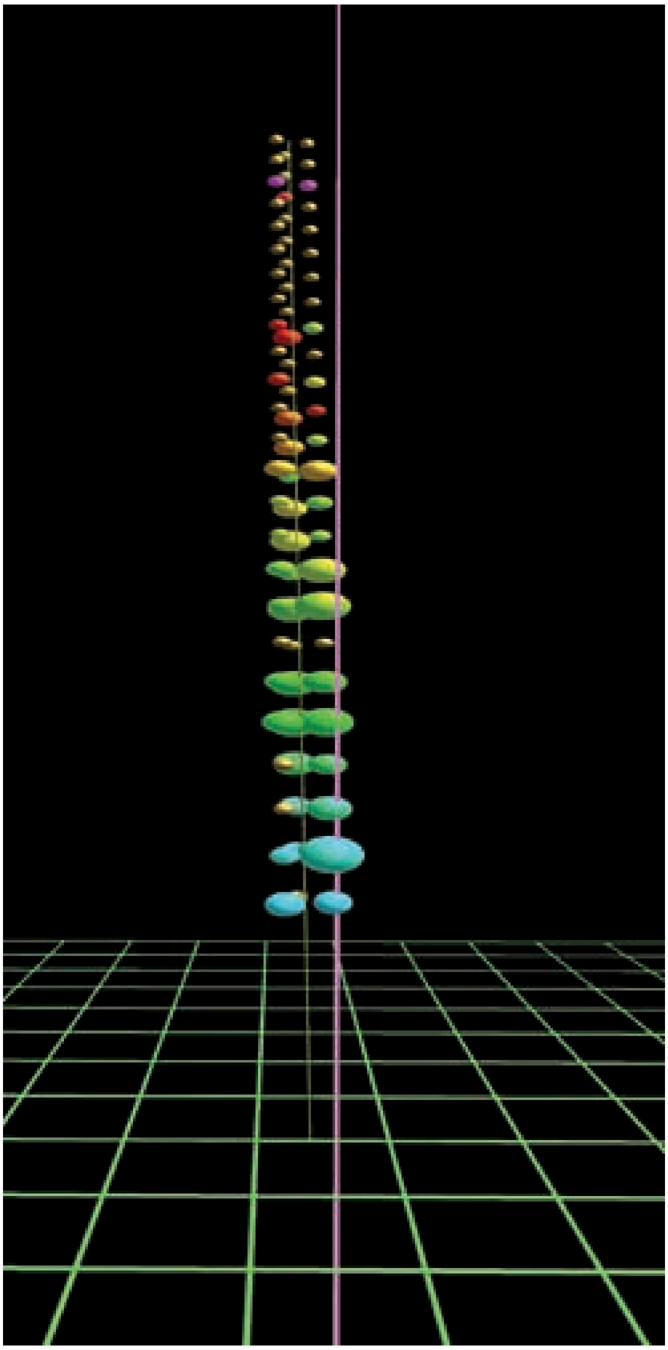


Figure 1. Muon track reconstructed with the first string of the ANTARES water Čerenkov neutrino telescope.

Despite the large efforts spent in designing, building, installing and commissioning instrumentation for LHC and astroparticle physics experiments, NIKHEF is also still involved in running experiments. In Germany, NIKHEF participates in the HERMES and ZEUS experiments at the HERA electron-proton collider. In the USA, NIKHEF physicists are active in the Babar (at PEPII, Stanford), DØ (at Tevatron, Chicago) and the STAR (at RHIC, Brookhaven) experiments. Most of these activities will soon come to a natural end either because the accelerator shuts down or because the physicists migrate to the LHC experiments in view of its higher discovery potential once its starts operation! Our R&D physicists are already looking beyond the initial LHC running by developing an innovative detection technique for LHC experiment upgrades and/or for the future linear electron-positron collider experiment. As of December, bubble-chamber quality recordings of radioactive sources like ^{55}Fe or ^{90}Sr and occasionally a cosmic ray or an alpha-article can be admired.

In retrospect, 2006 will probably be considered an important year for (European) particle physics. In July, CERN Council unanimously approved the European strategy for particle physics. This strategy was the outcome of a sequel of national and European gatherings with as key events: an open symposium in Orsay (near Paris) in January and a closed meeting of the strategy group in Zeuthen (near Berlin) in May. Dutch physicists were strongly involved throughout this process. The strategy underlines the importance of the LHC and of a future linear electron-positron collider. Moreover, the strategy recognizes the potential of the relatively new field of astroparticle physics. The European Strategy Forum on Research Infrastructures adopted the CERN document 'The European strategy for particle physics' for its own roadmap and in addition explicitly included KM3NeT as a promising future large-scale European infrastructure. KM3NeT also received a high priority in the preliminary roadmap prepared by the Peer Review Committee of the grouping of national funding agencies Astroparticle Physics European Coordination.

Also in 2006, NIKHEF employees put a lot of effort into outreach activities. Numerous people visited NIKHEF and CERN, which resulted, amongst others, in an impressive number of articles in public magazines and newspapers. Some of the photo shooting sessions led to remarkable pictures which made it to the front cover of leading Dutch science magazines such as 'Natuurwetenschap & Techniek' and 'Nederlands Tijdschrift voor Natuurkunde' as well as international magazines such as the 'CERN Courier' (Fig. 2). Theater Adhoc started shooting for its film about the Higgs odyssey and the ATLAS group completed its film 'Massa Mysterie' aimed at high school students. NIKHEF engineers put up an excellent performance during the celebration of FOM's sixtieth anniversary by winning not only the first prize but also the second prize in the 'To win the future' contest for the best physics inspired application in society. Not bad at all for a primarily fundamental-science oriented research institute like NIKHEF! The NIKHEF entrance lobby received a facelift with the addition of various stands explaining in simple terms NIKHEF's scientific endeavours. A pilot version of NIKHEF's long awaited new website was shown just before Christmas. And NIKHEF's communication department (and director) started to think about a new NIKHEF logo … For sure, these efforts will continue in 2007 and beyond!

Both NIKHEF and FOM, NIKHEF's main funding agency, invested in training programmes for our personnel in 2006. Many of NIKHEF's top echelon went to a special management training course organised by FOM. The course was rated excellent. Nevertheless, I myself am the walking proof that not everyone was able to convert the offered theory into day-to-day practice … NIKHEF itself organised a course, taught by professional actors, on presentation techniques. Also this course was very well appreciated, even some diehard opponents had to admit that they got useful advice.

A sad event took place on December 4th when Aaldert Wapstra, former director of NIKHEF's nuclear section, passed away at the age of 84. Until recently he could still be seen at the lab working

Figure 2. Endcap of the ATLAS semiconductor tracker, assembled at NIKHEF, appears in the news.

on his Atomic Mass Tables, a series that he started in 1960 (!) and of which he issued the most recent version in 2003. The series has become a desktop reference work for every nuclear physicist, and for this work he received in 2004 the SUNAMCO Medal of the International Union of Pure and Applied Physics.

Looking forward to 2007 and beyond. Next year an industrial assembly line for pixel detectors is likely to emerge at NIKHEF as a joint venture between PANalytical and NIKHEF. With the imminent turn on of the LHC, NIKHEF's investments in the construction of LHC detectors and grid computing will enter the exploitation phase. In the field of astroparticle physics both the ANTARES neutrino telescope at the bottom of the Mediterranean Sea and the Pierre Auger large area cosmic ray Observatory on the Argentinean Pampa Amarilla will be completed and many years of data taking will start. In 2007, NIKHEF will be evaluated by an international committee of renowned physicists. The outcome of this evaluation and of funding requests for a national theoretical physics programme and for a national astroparticle physics programme will have a profound impact on NIKHEF's future activities.

Frank Linde, director

Reviews

Figure 1. How the Phone Company sees you…

Figure 2. Before fiber optics there was the telegraph wire.

The Internet: a clash of cultures

Rob Blokzijl

Today we take the Internet for granted. It has always been there, and it is everywhere. We can hardly imagine a life without the Web, without e-mail, without Skype, without BitTorrent (especially our children), without whatever you can think of. Also the Internet is everywhere; on our computers be it a desktop or a laptop, on our mobile phones, on our fridges, TVs, gas stoves, door bells, you name it – it is there.

And when you think it is not there, it is just around the corner: your old fashioned analogue telephone landline terminates at a short distance from your home in a magic box around the corner and then suddenly becomes a digital, Internet Protocol (IP) based service handled by an optical fiber infrastructure. And no 'connection' exists any more – your packets are delivered on a best effort basis. Of course, you still pay for connection setup, call duration, and distance. The Phone Company has to make a buck, after all. That is their culture.

So, the Internet is everywhere, always, and it is mostly free. For a modest monthly fee one can have all the services that have ever been invented in the world of telecommunication. But – twenty years ago there was none of that. What happened between then and now? Let us go back a few years and look at the history of modern electronic telecommunications systems. As always, history explains most of todays realities.

In our case modern history of telecommunication starts in 1839, when William Cooke and Charles Wheatstone (yes, the one of the bridge) succeeded in transmitting an encoded message over an electrical subsystem (i.e. a copper wire) between Washington and Baltimore. A new age was born.

The early age of the telegraph is an interesting one: everyone and his dog invented his own, and of course the best, system. Unfortunately, these systems did not interwork. At the boundary of one telegraph system there is a man receiving incoming messages, writing them down, and transmitting them onto the next system manually. The application gateway was born!

The early telegraph system was mainly used by national governments for their normal diplomatic exchanges. And they didn't like the system: it was slow and there were too many middlemen reading their messages. In 1860 it took 17 human gateways to get a message from Berlin, the capital of the kingdom of Prussia, to the western border of the country.

So, governments got together and decided that they wanted a better system. In 1865 the International Telegraph Union was created by Governments in order to come to a single, unified International Telegraph system. And it worked. Most countries adopted the simple model: one country, one telegraph company, and the government owns and controls it. Well, that sounds familiar: it could be the Soviet Union party system, or the Dutch PTT untill the early '90s.

This was a great success. So when telephony came about in 1876, and wireless telegraphy appeared in 1896, and public radio appeared in 1920 the same model was applied. The good old International Telegraph Union changed names, its mandate was expanded several times, and it was still the governments and their state monopolies in telecommunications that called the shots. In 1947 the final reconstruction took place. The 'International Telegraph Union' was now named the 'International Telecommunications Union' (ITU), and was reconstituted under the newly formed United Nations charter

Figure 3. A black phone (or a grey one)…

Figure 4. Plus ça change…

as an International Treaty Organisation, and made a 'Member of the UN Family'. This means in practice that only UN member states can be ITU members, i.e. national governments. This is fine, as long as you as a government own and control your national phone company. This was normal in 1947, and many years to follow. In the Netherlands it has been the 'Ministerie van Verkeer en Waterstaat' (Ministry of Transport, Public Works and Water Management) that until the early 90's fully controlled the Dutch PTT.

A powerful department of civil servants, the 'Hoofddirectie Telecommunicatie en Post' (Head Directorate Telecommunications and Post), decided that your phone at home came in two colours: either grey or black. They also decided who would sit on the board of the PTT.

So far, so good. Until the late 60's we were all living in a simple but happy world. Telecoms was handled by your government, via your national phone company. And they decided what you wanted. You had a dumb terminal at home: a black telephone, or grey if you were being difficult. And the services you got where the ones provided by the network, i.e. the PTT, i.e. the Government. And nobody ever asked what you really wanted.

Then suddenly history changed on October 4, 1957, when the Soviet Union successfully launched Sputnik I. The United States president of that time, Dwight Eisenhower, decided that the US had a 'Science Gap' with the USSR, and told the military to do something about it. And thus ARPA was created: the Advanced Research Projects Agency. ARPA endeavoured on many fields of research, most of them of a fundamental nature – not military oriented. One of these projects was to investigate how to better use the scarce computing facilities in US universities. The answer was in place 20 years later: a working version of the ARPAnet, a precursor to the Internet.

ARPAnet was a revolution in telecommunication: no longer was the copper circuit the stable connection between Alice and Bob, but a service that did a best effort to deliver digital packets between two parties, without any guarantee of delivery – a best effort service.

This was the start of the 'Cultural Divide'.

The traditional phone companies on the one hand argued that no decent service could be delivered based on an a priori undetermined network service. The ARPA network researchers argued that in the first place a decent network (i.e. the phone companies) should deliver a certain quality of service, and secondly that a next layer of software would take care of packet loss anyhow. In modern terms: you will lose packets on the IP (Internet Protocol) level occasionally, but you will recover on the TCP (Transmission Control Protocol) level. Hence, we describe the Internet as TCP/IP.

Since the early 70's we have seen these interesting discussions between the phone companies, monopolists, state owned bureaucrats, and the free thinking researchers from universities in the USA. But not only in the USA: Europe has played an important role as well. One of the first theoretical studies on packet switching networks has been published in France in the 60's; a thorough study on a first implementation and operation of a packet switched network was not published in the UK for reasons of national security. This was in the 70's.

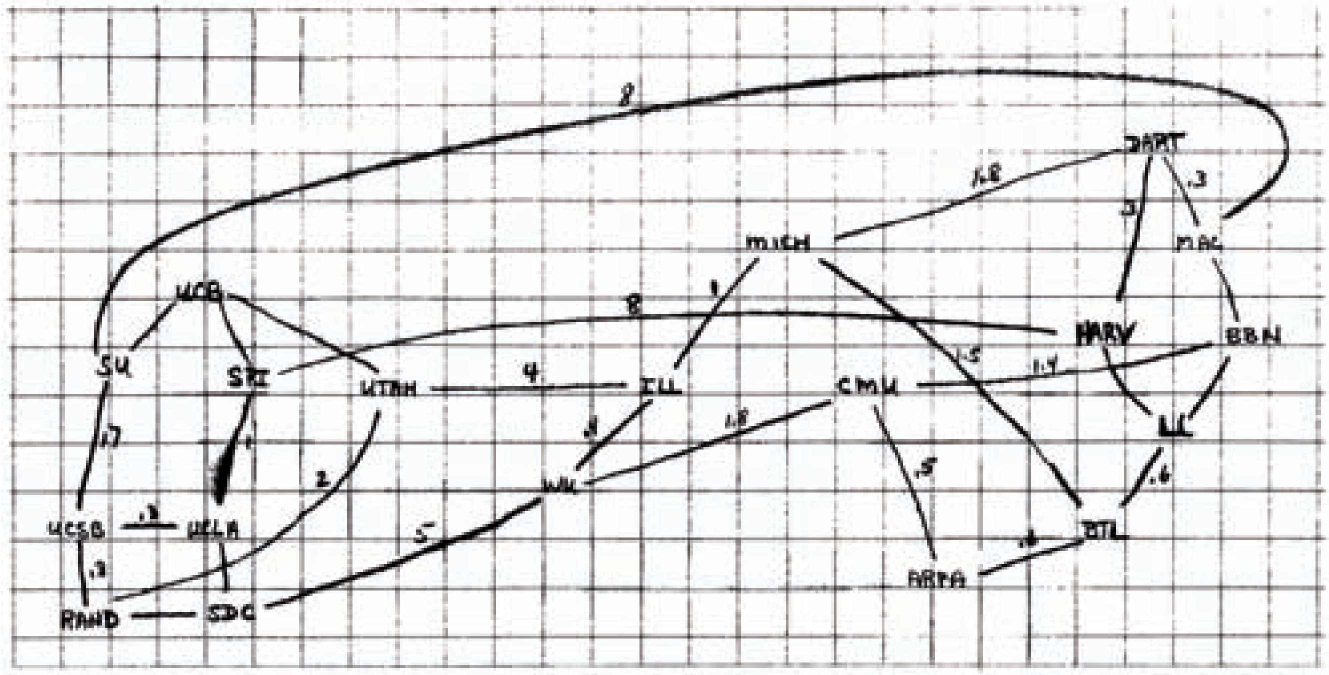


Figure 5. Sketch of the ARPAnet structure in 1969.

So, in the early 80's we had this simple situation. The research and academic world had developed a network technology that could not work according to the ITU and national governments. On the other hand these same national PTT's and governments were working on their own way of doing networking: ISO-OSI was the acronym, meaning ISO Reference Model for Open Systems Interconnection.

In those interesting years in the 80's two major developments happened:

1. The University of California at Berkeley released a version of the UNIX operation system that contained the full set of Internet protocols for free.
2. The European Commission and the US government decided that ISO OSI was the way forward, and they committed a couple of billion ECUs and USDs to the promotion and introduction.

The European PTTs were very happy.

They did not have the products or services, but the alternative, i.e. the Internet had now been officially 'verboten'. So, they could sit back and relax.

Not.

The PTT attitude was simple: we own the network, we decide what you want as services, we install that, and you have only our dumb black phone (or grey, you have a choice after all). And if you want to do different things, we don't allow that.

So, when in 1987 NIKHEF ordered a private leased line from NIKHEF to CERN from the then Dutch PTT, this was refused. It took more than 9 months, and the intervention of SURFnet and the Ministry of Economic Affairs to get this line delivered. A different culture. You don't want this, so we will not sell it to you. We have equivalent services that are a thousand times more expensive. You better buy those. And you don't know how to run a network, anyway.

This was the first time NIKHEF got to know the culture of the Elephant PTTs. And not the last time. Since NIKHEF got involved in building networks on an international scale, we have not stopped being amazed by the conservative, if not stupid attitude, of the traditional carrier service companies.

But this is not a real surprise. Today, a typical telco, that grew out of a traditional phone company, still operates on a few simple principles. The principles are way out of todays realities, but that is life in a company that got used to have a safe monopoly for at least a hundred years, protected by a friendly government.

These principles are:

1. We own the network
2. We decide what is good for you
3. So, we invent services that we will sell to you
4. And you will be happy, and you pay

These are the principles of the old culture of the black phone (or grey). Today the world is different. Now the users' principles rule:

1. You own the network, but we use it
2. We decide what we want to do with it (think: skype, web, bittorrent, etc.)
3. no thanks, we don't want your services
4. and we will pay only for transport, not services

Figure 6. The Internet now.

Now this is something new for the phone company. Users telling the company to go away. We want your transport, not your services. On the Internet we do our own services ourselves – thank you.

This is a fundamental cultural difference from the good old days. The good old days were the days with the telco principles above: we own you. The new days of the Internet are: go away, we make our own services.

What does it mean: 'Our own services'? Well, think WWW. Think Skype. Think BitTorrent, think Grid. Services invented and run by the users, not the telcos.

So, what are the telcos doing today? Simple, reinventing their old wheel. And the wheel today is called: mobile phone. At the ITU World Expo 2006 in Hong Kong you could not be seen at the Expo unless you had a new mobile phone application. Really impressive: control your gas stove at home from anywhere in the world by your mobile phone! That is what we always wanted and have been waiting for for a long time.

However, at the Peoples Republic of China pavilion, there was luckily a fresh wind: the PRC is investing umpteen billions of their yuans in 'Distributed Grid Computing'. So, what is this – a new cultural revolution?

Yes – the Chinese government is going for Grid computing. No big deal, because so is the EU. The nice thing in both cases is that the money goes to science, or at least to the requirements of science for computing. The culture might still be a bit different, but at least this time the governments of the world seem to realise that they should provide resources, and not demand politically correct outcomes. The good old telcos of this world however, the Phone Companies of the past, have not grasped their cultural problems at all. They still moan about things, no – visions, like 'Triple Play' (soooo 2 years ago), or 'convergence' (sooo last year). And today they are still thinking about a catchword for next year.

Let us hope they do not find 'Grid' as their next stock market phrase.

Grid is a development that is new and exciting as a further step forward for the Internet. WWW last century, GRID today. It is exciting that NIKHEF is at the forefront of GRID developments, as NIKHEF was one of the original developers of the World Wide Web. And one of the original builders of the Internet in Europe.

The Internet grows – in size and in functionality. The growth in size is a matter of the market today: commercial companies take care of the growth of the Internet in terms of users, bandwidth and geographical coverage.

But the growth of the Internet in functionality takes place in the old dark corners of the first Internet days: Universities and Research Institutes like NIKHEF are still at the forefront of developing new technology on the Internet. NIKHEF has this long tradition of building the Internet. From the first 64kbps international line between NIKHEF in Amsterdam and CERN in Geneva (also the first Internet connection between the two countries), up to the leading role that NIKHEF has today in new developments for GRID computing. And we should not forget that NIKHEF is a founding partner, and a prime hosting partner, of the single largest Internet Exchange in the world (AMS-IX).

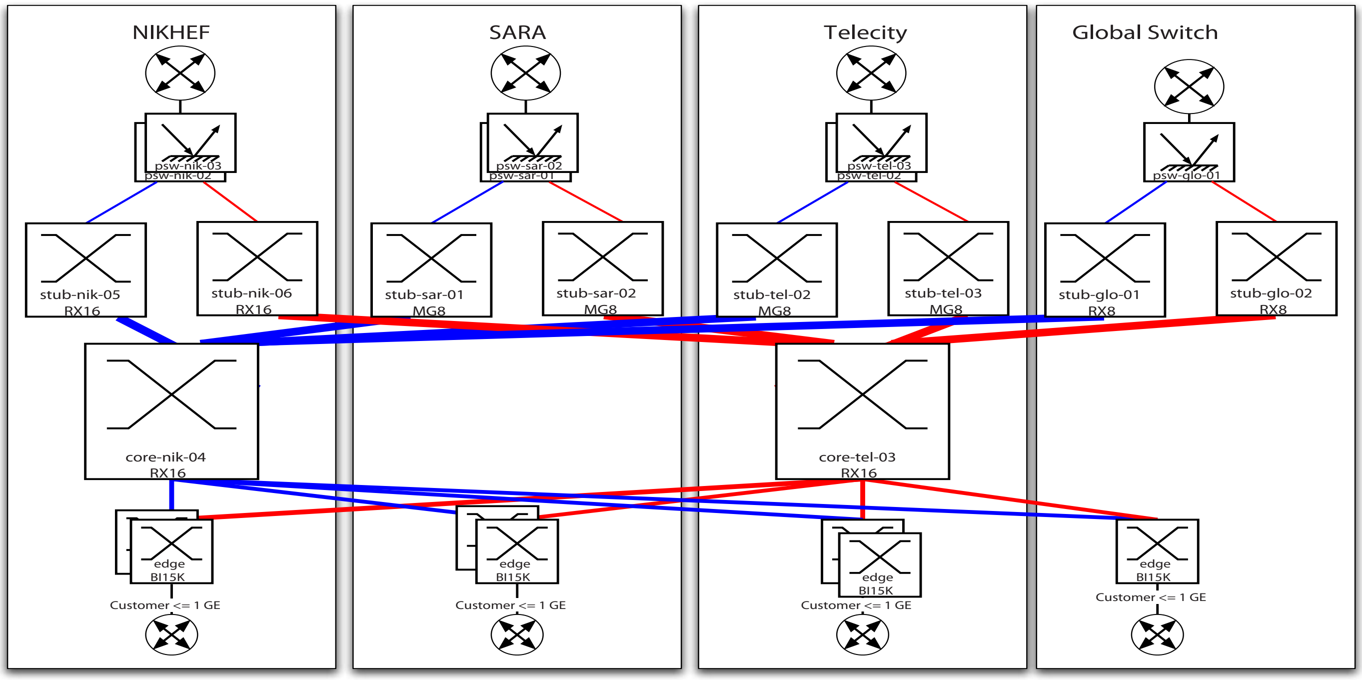


Figure 7. Topology of the AMS-IX, the largest Internet Exchange in the world.

Internet and Cultures. A world of difference. Today, there is not a single engineer or physicist on the board of KPN Telecom. There is not a single research activity in the same company, their once first class research laboratories have been sold. Directors have gained their experience in selling coffee and mars bars. And the same holds for the 'other' major phone companies in the Netherlands. Who owns Versatel today? Or is it Versatel that owns Tele2? Watch the stock tickers of your choice.

Google employs over 7000 researchers who passed a tough exam. Once employed, they are supposed to spend 20% of their time on non-Google, private, research projects. A wealth of computer science. A world of difference in a cultural sense. And yes, they do GRID computing and networking on a scale that goes far beyond LHC efforts.

Akamai, founded by two students, is competing on a grand scale with Google in the field of GRID computing and networking. They started out of MIT when over a coffee Sir Tim Berners-Lee made the flippant remark: "I can find the data - if only somebody could store it somewhere". Next, these two students took him up on his word and designed the largest data store on the Internet today. Akamai delivers your data from around the corner - and you don't know it. Whenever Bill Gates decides that you need new updates on your old Microsoft systems (if you are still using that expired technology) you probably don't know that it is coming from some room inside NIKHEF.

Nokia will sell you a mobile phone that can make phone calls. That is rather unique nowadays. A modern phone will drive your car, and your coffee machine, and your dish washer, and make porridge. It will also do your banking, read your fingerprints for our American paranoia friends, and park your car. And of course, it has a fantastic 3D display without funny glasses as in the SARA CAVE. And the Toshiba phone will transmit your favorite fragrances. And the Mitsubishi one will transmit emotions as well. And Toshiba has phones that are better than your photo camera (10 Mpx) and better than your video stuff. Live streaming from your phone at 100 Mb/s to a wall mounted display half way across the world.

Question from an elderly gentleman from a classical European Phone Company:
"How do you do all this, what are the protocols?"
Answer from the Chinese gentleman:
"We use only one protocol: IP"

That is the Internet for you.
A whole different culture.

A rack full of GRID computers.

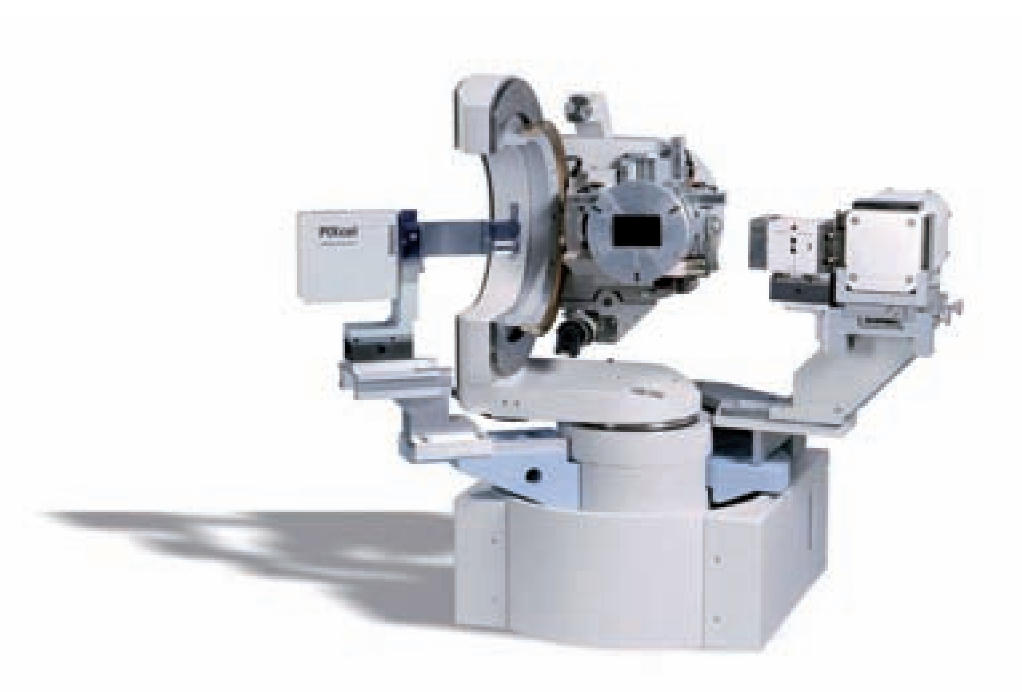


Figure 1. Recently introduced PIXcel detector system, based on single-chip Medipix2 technology, and mounted on a PANalytical X'Pert Pro XRD analysis platform.

Medipix and RELAXD: successful collaboration between Science and Industry

Jan Visschers (NIKHEF) and Klaus Bethke (PANalytical)

Introduction

Miniaturization of electronics has caused a digital revolution, providing us with cheap and powerful computers and telephones. The continuous downscaling in semiconductor technologies has enabled the particle-physics community to integrate a signal-processing circuit with hundreds of transistors into every pixel of a CMOS read-out chip. A matching sensor chip - made of very pure silicon or another semi-conducting material - is mounted on top of this CMOS chip. In this way a compact detector assembly, called a hybrid pixel detector, is obtained consisting of a sensor chip and a readout electronics chip, connected by many thousands of micro-solderbumps.

These hybrid pixel detectors were originally developed at CERN, Geneva, and in Stanford/Berkeley for particle-physics experiments. The goal of the Medipix Collaboration is to transfer these technologies to applications other than just high-energy physics.

Although not originally intended, hybrid pixel detectors also happen to function as high-performance radiation imagers. Nowadays, digital quantum cameras are being constructed that are able to use X-ray photons, neutrons, or charged high-energy particles, instead of visible light to obtain high-resolution images.

Many new applications are possible in non-destructive materials research, as well as in life sciences, such as proteomics (the study of protein structure) and pharmacological research. Ultimately, this technology also promises low-dose diagnosis and therapy for medical purposes.

Several years of intensive collaboration between NIKHEF, CERN and PANalytical B.V. have resulted in the successful market introduction in 2006 of the PIXcel detector, the first commercially available X-ray detector based on Medipix technology (see Fig. 1). NIKHEF's expertise in the field of detectors and read-out electronics has significantly facilitated the integration of the Medipix2 readout chip into PANalytical`s X-ray analysis equipment.

The PANalytical Company

PANalytical, formerly Philips Analytical, based in Almelo, the Netherlands, is now a part of SPECTRIS, the precision instrumentation and controls company, located in the UK. PANalytical is a leading manufacturer in X-ray equipment for materials analysis since 1947. It is a medium-sized company (750 employees), which develops and manufactures analytical X-ray instrumentation in two lines of business, X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF).

XRD is used to analyze the structural composition, and its relation with the properties, of various materials in a broad variety of industries such as building materials, metals, industrial minerals, semiconductors, chemicals and pharmaceuticals, new materials like nanomaterials, advanced ceramics and more recently in life sciences.

XRF is used to analyse the chemical composition of solids and liquids predominantly for quality control, in a broad variety of industries like cement, steel, aluminium and other building material and metal industries, petrochemicals, mining, industrial minerals, wafer analysis for semiconductor wafer fabs and also increasingly in the environmental field. The company gives assistance to these industries to develop and control their processes and materials

Figure 2. Close-up of a PIXcel detector. .

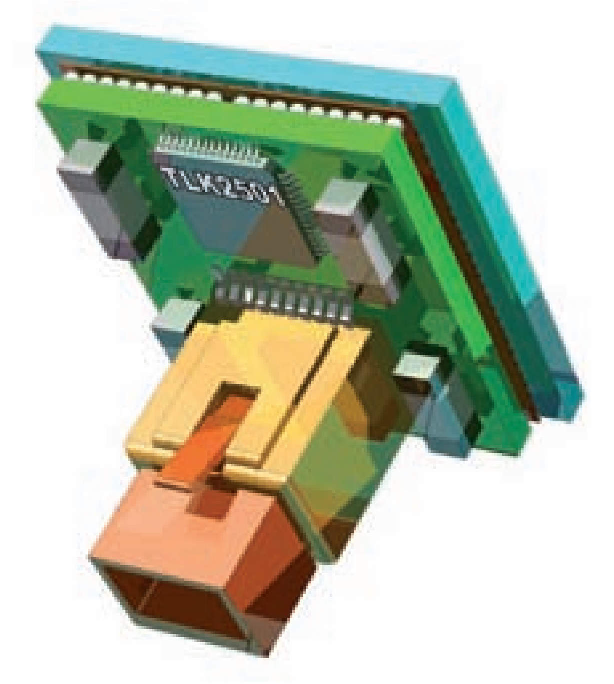


Figure 3. Design of a Quad (quadruple medipix) detector assembly with backside readout. It consists of 4 Medipix chips flip-chipped to one 3 x 3 cm^2 edgeless sensor, integrated with a commercial circuit allowing 3 Gbit/s serial data transmission.

and thereby introduce significant improvements through cost savings, energy savings, better environmental compatibility of materials and processes, and pollution control.

The Medipix Collaboration

The Medipix2 Collaboration consists of 17 leading research groups across Europe, centered at CERN, Geneva. It combines expertise from different fields of science such as: particle physics, synchrotron physics, neutron physics, electron microscopy and medical sciences. During the Medipix1 and Medipix2 projects, that started in 1995 and 2000, respectively, significant progress was made towards a new generation of quantum radiation imaging detectors: the semiconductor hybrid pixel detector. After two iterations, a commercial-grade version of the Medipix2 chip has now been achieved.

The CERN Physics Electronic Systems Support group intends to continue this successful approach through recently established Medipix3 and EUDET (Detector R&D towards the International Linear Collider) collaborations, for which already functional prototypes have been designed and manufactured.

The Medipix2 single-photon processing system provides PANalytical with cutting-edge technology for a new generation of their X-ray analysers. Agreements have been negotiated between the parties by the CERN Technology Transfer division, enabling PANalytical to gain access to this key technology while supporting the Medipix Collaboration to finance further development of chips at CERN, data-acquisition hardware at NIKHEF and data-acquisition software at the University of Naples. This agreement will give PANalytical a strong position in the market, fits perfectly into its long-term strategy, and provides it with access to world-leading groups in X-ray imaging.

The RELAXD project

Based on the Medipix2 chip technology, NIKHEF and PANalytical have initiated the project RELAXD (high REsolution Large Area X-ray Detector), aimed at large sensitive detector areas, without dead spaces, which can be read out at high speed (see Fig. 3). The project is supported by EUREKA, the European network for market-oriented R&D.

In order to construct such a large area detector, a number of separate assemblies should be tiled together, where the CMOS chips should not physically touch each other, and some area should remain available for readout drivers and other peripheral functionality. As a consequence, a 2-dimensional fan-out structure is needed (see Fig. 4), that adapts the pixel pitch of the read-out chip to a slightly larger pixel pitch in the sensor, ensuring uniform pixel sizes over the whole detector.

An important second feature is that the resultant touching sides of the quad sensor will be passivated by doping, to replace the conventional space-consuming guard-ring structure. The project involves the newest wafer-scale post-processing technologies including wafer thinning, through-wafer via etching, high-density interconnect and 3D packaging (see Fig. 5).

This solution replaces the usual wirebond connections between chip and chip carrier board by ball-grid-array (BGA)

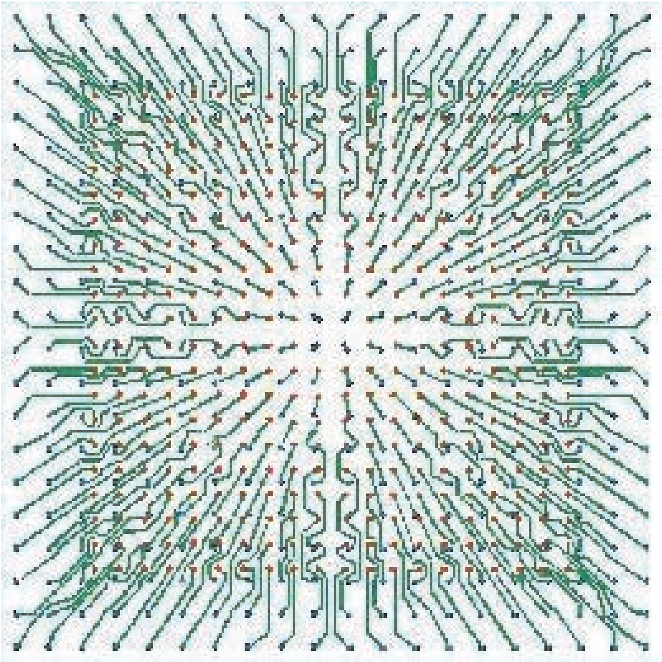


Figure 4. Principle of 2-dimensional pitch adaption between the sensor pixels (blue dots) and the read-out pixels (red dots). This re-routing pattern is applied on the backside of the sensor, and allows the medipix readout chip to be smaller in area than 1/4 of the sensor.

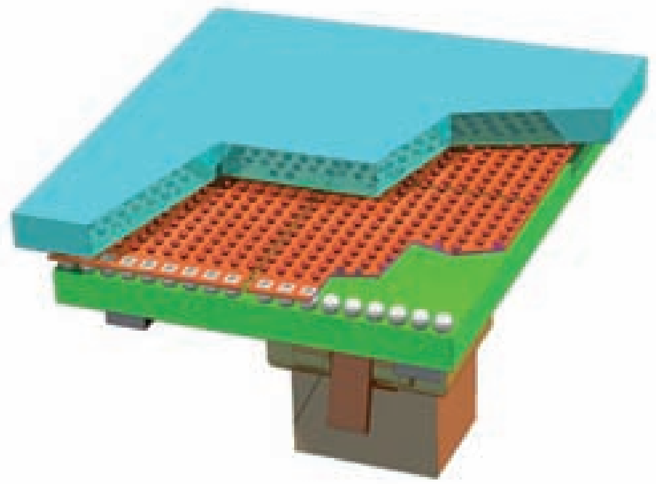


Figure 5. Principle of through-silicon via interconnect. The sensor (blue) is connected to 4 Medipix chips by (red) flip-chip solder balls. The Medipix chips (red) are connected to the printed circuit board (green) by etching holes through the Medipix chips, while on their backside contact is made via Ball-Grid-Array technology (white balls).

bonding. It is realised by engineering electrical connections through the CMOS read-out chip to the backside, and results in 4-side tilable detector micro-systems. Tiling many chips together to form a large area detector increases the amount of data that needs to be read out. For many applications the highest possible speed is needed, resulting in data rates of several Gigabits per second. Since the final detector setup needs to remain compact, it is necessary that this data rate is handled through standard high-bandwidth serial connections, e.g. Gigabit Ethernet.

Software development for data acquisition and for testing of the tiled arrays will be taken care of by PANalytical. Additionally, co-development of read-out electronics together with NIKHEF and quantitative testing on the system level belongs to the work package of PANalytical. A road map to commercialization has been introduced, with three phases that culminate in a possible product based on an array of micro-systems derived from the prototypes. After the first year of the RELAXD project, feasibility studies have given us a high confidence that first prototype modules such as shown in Figs. 3 and 5 will be working in the beginning of 2008.

In this R&D project a consortium of four partners in two countries was established, one research institution and one industrial partner in each country. Belgium contributes via the research center for micro- and nanoelectronics IMEC, Leuven, and the detector manufacturing company Canberra, Olen. The Netherlands contribute via NIKHEF, Amsterdam, a member of the Medipix Collaboration and a research institution with a key competence in detector technologies, and via PANalytical, introduced above. The EUREKA RELAXD project is funded by the Dutch and Flemish ministries of economic affairs represented by the organizations SenterNovem and IWT, respectively, as well as by the European Union (project E!3624-RELAXD).

Future prospects

RELAXD type of detectors with their unique features will enable many new applications and tremendously broaden the scope of existing ones. They will support important X-ray applications such as protein structure and function research, drug discovery and many applications in X-ray materials science, non-destructive testing, computed tomography, and synchrotron physics. Beyond X-ray applications there will be particle physics, neutron radiography and electron microscopy.

Fig. 7 shows a computer-simulated design of the core of a future X-ray analyser equipped with RELAXD technology in an arc like arrangement. We expect that - after process improvements and careful selection of cost determining designs and processes - the pixel detector technology will eventually find an entrance into the medical field. A challenge for some of the future applications will be the necessary introduction of different sensor material such as GaAs, CdZnTe or specially treated Si sensors.

A future prospect will be a continuing collaboration between PANalytical and NIKHEF in detector R&D, for instance based on Medipix3 and EUDET platforms, and in

Figuur 6: An X-ray diffractometer with on the left side the X-ray source, and on the right side a PIXcel detector. The PIXcel detector operates 'on-the-fly', acquiring dataframes continuously, while the detector is rotating around the sample holder in the center.

tiling and 3D integration of microsystems, as well as in Gas Electron Multiplier (GEM and Micromegas) technologies. It is expected that this cooperation will give rise to mutual benefits, in commercialisation for the industrial partner and in financial support for capacities and infrastructure for the research partner.

NIKHEF and PANalytical aim to continue expanding the Medipix2 technology. As a next step we intend to build up in the NIKHEF cleanrooms a production activity to process the first industrial large-wafer batch, establishing a reliable supply chain for hybrid pixel detector systems. In the longer run this may result in a commercial start-up, incubated in the Amsterdam Science Park.

The key success factor in all of this has been, and will continue to be, the strategic collaboration between all of the partners involved, both in Science and in Industry.

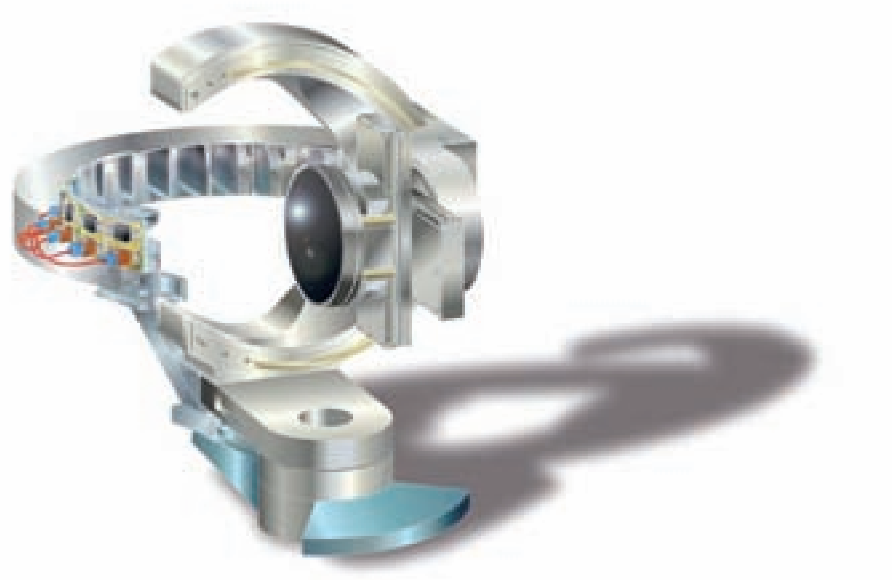


Figure 7. Conceptual computer-aided design of the core of a future X-ray analyser equipped with RELAXD technology in an arc like arrangement with respect to the object under study. The latter is in this case a semiconductor wafer (black, diameter up to 300 mm) fixed to the multi-purpose sample stage of the goniometer..

Figure 1. Aerial view of the VIRGO interferometer near Pisa, Italy. It consists of two 3 km long arms.

A Search for Gravitational Waves with VIRGO

Jo van den Brand

General Relativity is one of the most fundamental and beautiful physical theories. Yet, it is poorly tested, as compared to other fundamental physical theories as for instance quantum electrodynamics. One of the key features of general relativity is the dynamical nature of space-time itself: its curvature is a time-dependent quantity, and ripples of curvature can propagate through space with the speed of light. Such propagating curvature ripples are called gravitational waves, and their existence is one of the most important, yet untested, predictions of this theory.

In our universe, gravitational waves are produced by unique astronomical events, such as mergers of pairs of black holes or neutron stars, and supernovae explosions. Gravitational waves can be used to probe the evolution of such compact objects. The data obtained by detection of gravitational waves are entirely independent of any observation in the electromagnetic spectrum. Therefore, they are likely to lead to unique information on the nature of these compact objects. Moreover, gravitational waves propagate almost unperturbed through essentially the entire universe. This makes it in principle possible to detect gravitational waves signals emitted during the very early stages of the Big Bang. Measuring the amplitude of the waves at different frequencies should give information on matter at energies around 10^{18} GeV, a scale that will never be reached by men-made experiments.

The spectrum and amplitude of gravitational waves depend sensitively on the details of the Big Bang models, i.e. inflationary fields causing rapid expansion of the size of the universe, rapid collapse of cosmic strings, etc. Therefore, measurements of these properties of gravitational waves will represent the first direct test of Big-Bang models. Also, detection and further observation of gravitational waves would both provide important tests of the theory of General Relativity and would open a new window for astronomical observations of fascinating cosmic phenomena.

Since gravitational waves originate from sources many (millions of) lightyears away, their signal strengths at Earth are expected to be extremely weak. They cause relative displacements of free masses by distances that are a tiny fraction of the size of an atomic nucleus. Hence, enormous technological challenges have to be overcome in order to actually detect a signal. Large resources all over the world have been committed to building several types of gravitational-wave observatories that are capable of detecting this weak but fundamental phenomenon.

NIKHEF is considering to join VIRGO, a Michelson-type interferometer with a base length of 3 km. It has been built by a French-Italian collaboration at Cascina close to Pisa, and is poised to start data taking by the end of 2006. Fig. 1 shows an aerial view of the two perpendicular arms of the interferometer. At the heart of VIRGO is an ultra stable ND:YAG laser of the newest generation with 20 W power and a wavelength of 1064 nm; a 'recycling mirror' boosts the available power to several tens of kW and brings the shot noise (in strain-equivalent terms) to about 3 $\times 10^{-23}$. The laser pulse is split and both pulses travel a number of times up and down an arm after which an interference pattern is created by rejoining the pulses of both arms. Each 3 km long arm contains a Fabry-Perot cavity (finesse 50) that increases the effective interference length to about 120 km. A passing gravitational wave would distort space locally and hence change the path length of each arm differently. The resulting change in the interference pattern can then be detected. Fig. 2 shows a schematic outline of the interferometer.

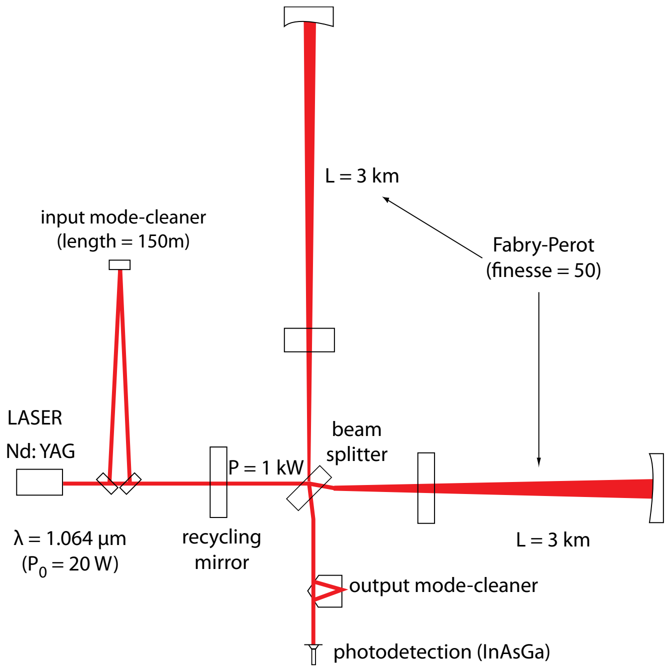


Figure 2. Schematic outline of the VIRGO interferometer showing the main optical components.

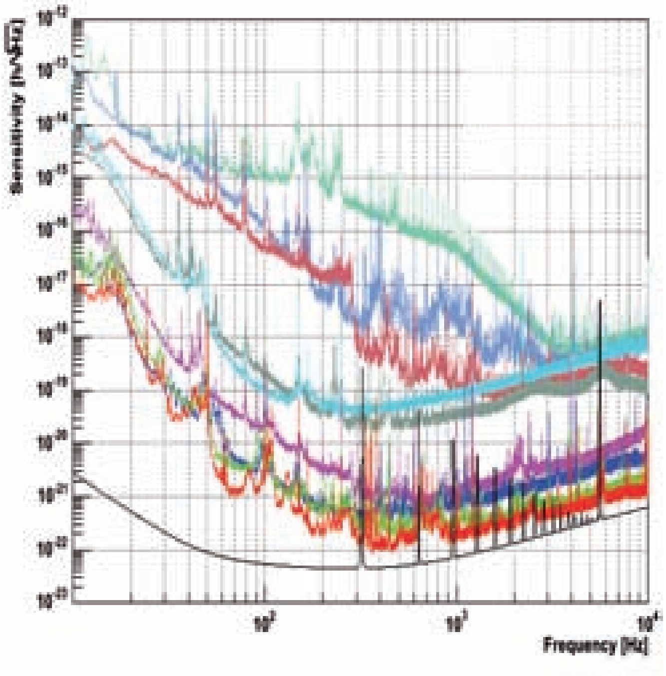


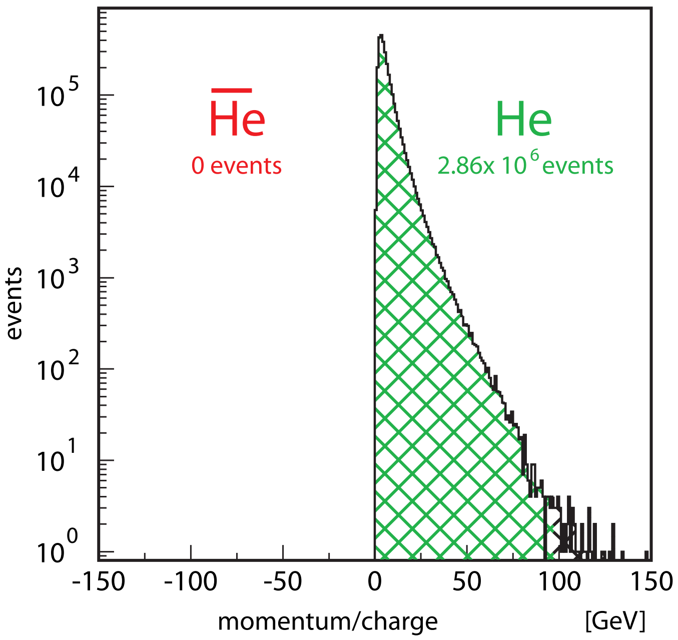
Figure 3. Progress in frequency sensitivity of the VIRGO interferometer from the start of commissioning runs in Nov. 2003 (upper green curve) to data taking runs in Jan. 2007 (lowest red curve). The solid black curve represents the design sensitivity.

Since the gravitational waves signal is weak, noise is the big enemy of the VIRGO experiment. Seismic vibrations of the ground are billions of times larger than the subatomic distance variations induced by gravitational waves. In VIRGO the seismic isolation is achieved through a chain of suspended seismic filters made of triangular cantilever blade springs. The springs provide the vertical isolation while the compound pendulum provides isolation against horizontal motions. To further reduce the seismic disturbances, this chain is attached to an actively stabilized platform that compensates for very low frequency and large amplitude oscillations. It also provides a first stage of position control down to about one micron. A second stage of position control is achieved at the end of the suspension chain by a 'marionetta' from which the mirror and a 'recoil mass' are suspended by extremely fine wires. The ultimate mirror position control is obtained through very small forces generated in a feedback loop between the mirror and the recoil mass by sets of electromagnetic actuators.

Not only noise reduction, but also perfect alignment is absolutely crucial. It is achieved by taking out a small fraction of the light at the different mirrors and sending it to quadrant diodes. The output of these diodes can be used to maintain the alignment independent of drifts of the laser itself.

NIKHEF took responsibility to improve over the present alignment capacities. In a first step, 14 new and improved electronics boards for the electronic read-out of the quadrant diodes are being built that enhance the present capabilities. NIKHEF also contributes to the understanding of thermal stabilization of the interferometer by finite-element analysis studies. NIKHEF actively participates in the analysis of the VIRGO data (see Fig. 3). In addition, we search for signals from (binary) pulsars.

Gravitational-wave astronomy will be further developed by the satellite-based interferometer project, LISA. It will have three satellites positioned in orbit around the sun, trailing the Earth by some 20 degrees. The range of sensitivity of LISA is expected to reach down to gravitational waves of frequency 10^{-4} Hz. This will enable for instance the observation of the coalescence of massive black holes.



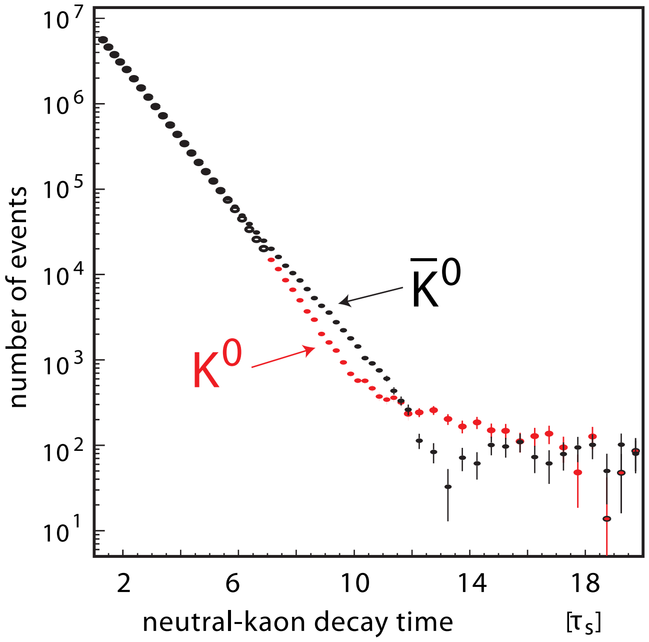


Figure 1. Observed spectrum of He nuclei in cosmic rays as seen by the AMS satellite experiment. The fact that there are no entries at the left side of the plot indicates the absence of anti-helium in cosmic rays.

Figure 2. Decay rate of kaon (K^0) and anti-kaon ($\overline{K}^0$) particles into pion pairs, as a function of the decay time. A clear difference is observed in the decay rate for particles and anti-particles.

CP Violation and the riddle of antimatter

Marcel Merk

Symmetry

The concept of symmetry is fundamental in the description of the laws of nature. For example, the symmetry that physical laws are the same in all (relativistically) moving frames (so-called Lorentz frames) leads to the theory of special relativity. The presence of a symmetry in a physical system is also connected to the existence of a conservation law; for instance, the speed of light is always constant. Alternatively, a symmetry can be related to the existence of an unobservable quantity. In the above example we realise that it is impossible to determine absolute velocity. The unobservable is zero velocity.

Another well known example is a system of particles in which the interactions are symmetric under translation of these particles. For such a system conservation of momentum is found to be valid. The unobservable quantity in this case is the location of an absolute origin of space.

Charge-Parity (CP) symmetry is the technical term for the symmetry in which the laws of physics are identical for matter particles and for antimatter particles. If CP symmetry is present we can not make an absolute definition of what is matter and what is antimatter. The unobservable quantity thus can be called 'matterness'.

A general theorem states that any field theory that respects the laws of relativity theory always obeys symmetry under *simultaneous* Charge-inversion (C), Parity inversion (P) and Time reversal (T), together known as CPT symmetry. It was long believed that all theories describing particle interactions should be also symmetric under *individual* C, P and T reversal. This implies that positive and negative charge, left and right handedness, and the direction of time, can only be defined relatively, not in an absolute sense.

Violation of symmetries

It has been shown in 1964 by the Russian physicist Andrei Sacharov that the existence of our matter-dominated universe can only be explained if the symmetries under both C and CP inversion, are broken. In other words, the laws of nature must be able to act differently on matter and on antimatter particles. Then, these asymmetric processes must also have acted in the early hot phase of the universe, in such a way that only matter-particles survived. The fact that indeed antimatter does not occur in significant amounts in the universe has been demonstrated by the AMS satellite experiment, (see Fig. 1).

Of the known fundamental interactions between elementary particles only the weak nuclear force is observed to violate symmetry under Parity inversion. In 1957 the Chinese/American physicist Chien-Shiung Wu demonstrated that radioactive decay, which is mediated by the weak interaction, is not left-right symmetric. A year later Goldhaber and collaborators showed that neutrinos produced in radioactive decays always have a spin vector pointing in a direction opposite to their momentum vector. In other words, the weak interaction operates in a left-handed way, allowing to make an absolute definition of handedness. The fact that right-handed neutrinos are *never* produced in these decays is referred to as maximal violation of parity.

In 1964 the group of Christenson, Turlay and the later Nobel-prize winners Cronin and Fitch, demonstrated with an experiment

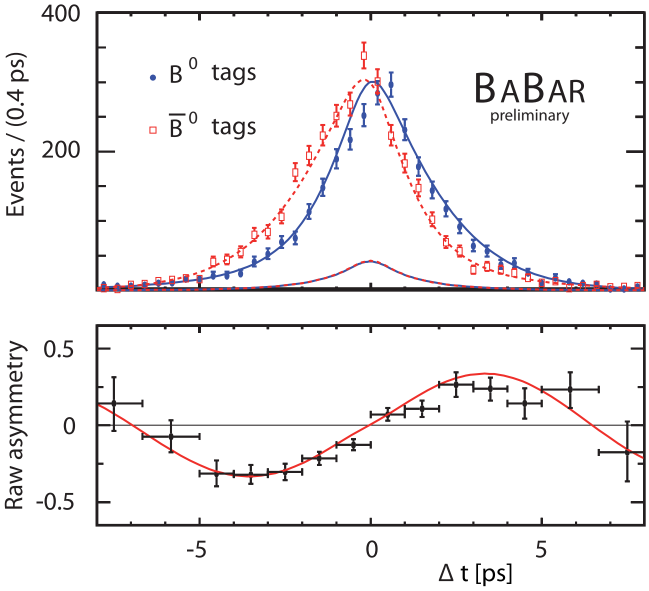


Figure 3. Decay rate of tagged B-mesons (B^0) and anti-B mesons ($\bar{B}^0$) into a $J/\psi K_s$ final state (upper panel). The difference between the curves, illustrated by the asymmetry in the lower panel, indicates a large violation of CP symmetry in this decay mode.

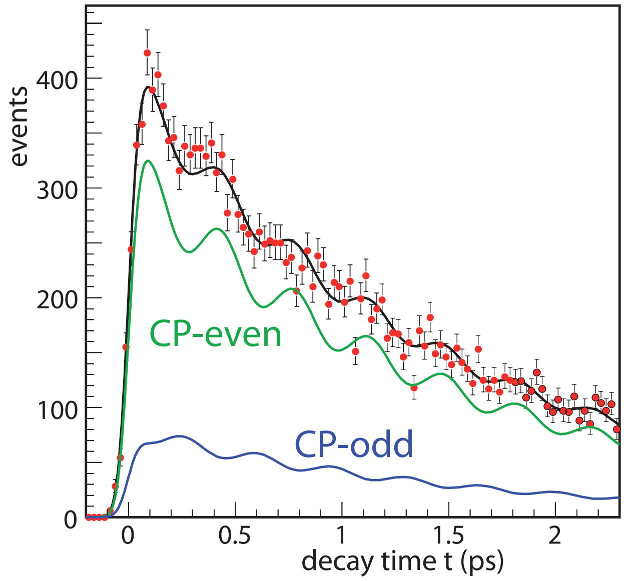


Figure 4. Simulated decay rate of B_s mesons to $J/\psi\varphi$ particles assuming the presence of a new source of CP violation that causes the oscillations in the decay distribution. The open symbols illustrate the expected statistical accuracy of the LHCb experiment after one year of data taking.

involving neutral strange mesons, the K^0 particles, that the weak interactions between the quarks violate not only symmetry under Charge and Parity reversal, but also, for a tiny fraction, violate symmetry under their combined operation: CP. This is illustrated by the observation that the decay rate of kaon particles to a positive and a negative pion is not the same as that of an anti-kaon to a positive and a negative pion. This so-called asymmetry, as observed by the CPLEAR collaboration, is illustrated in Fig. 2.

Although it has been known since 1964 that the weak interaction violates CP symmetry, the underlying mechanism remained unclear. New, hitherto unknown, forces acting between the quarks, the building blocks of the mesons discussed above, have been considered as a possible origin of the observed asymmetries.

B-mesons

In 1999 the experiments BaBar (at SLAC, Stanford, USA) and Belle (at KEK, Tsukuba, Japan) observed violations of CP symmetry in neutral *B*-meson decays. Neutral *B*-mesons consist of a beauty quark together with a down quark. In this case decays were considered in which the produced particles in the final state are their own anti-particles. This allows to do a beautiful interference experiment: a *B*-meson can either directly decay, or it can first oscillate into an anti *B*-meson and decay consecutively into the final state. Comparison of the process of the initially produced *B*-particles to the mirror process of the anti-*B* particles shows a clear difference, as illustrated in Fig. 3. This difference is the manifestation of CP violation: matter particles decay differently than antimatter particles.

The interference experiment shows more: the observed asymmetry is consistent with the hypothesis that the quantum mechanical amplitude of the weak interaction for anti-particles is the complex conjugate of that of matter particles. In other words, the weak force is modeled with a complex coupling strength! This is a quantum mechanical phenomenon for which there is no classical equivalent.

The question rises whether this newly discovered behaviour of the weak interaction can also explain the baryon asymmetry in the universe. This is the observation that matter dominates practically completely antimatter in the universe, whereas one can assume that the universe started of with equal amounts of matter and antimatter.

Asymmetries in the universe

Consider that in the early, hot universe, matter and antimatter particles - e.g. quarks and anti-quarks - were in equilibrium with light according to interaction: $q\bar{q} \rightleftarrows \gamma\gamma$. As soon as the universe cooled down the annihilation of matter with antimatter into light occurred at a higher speed than the reverse reaction. Finally all particle - antiparticle pairs annihilated into photons.

The presence of a surplus of matter in the universe today indicates a surplus of matter at the time of 'freeze-out'. The amount of surplus of matter particles can be obtained from the present-day ratio of light particles (photons) in the universe to the amount of matter (stars, galaxy's, etc.). Observations with satellite experiments have shown that this ratio is 10^9. This implies that in the initial phase of the universe the laws of nature must have produced *one* additional matter particle for 10^9 pairs of matter and antimatter particles. Can

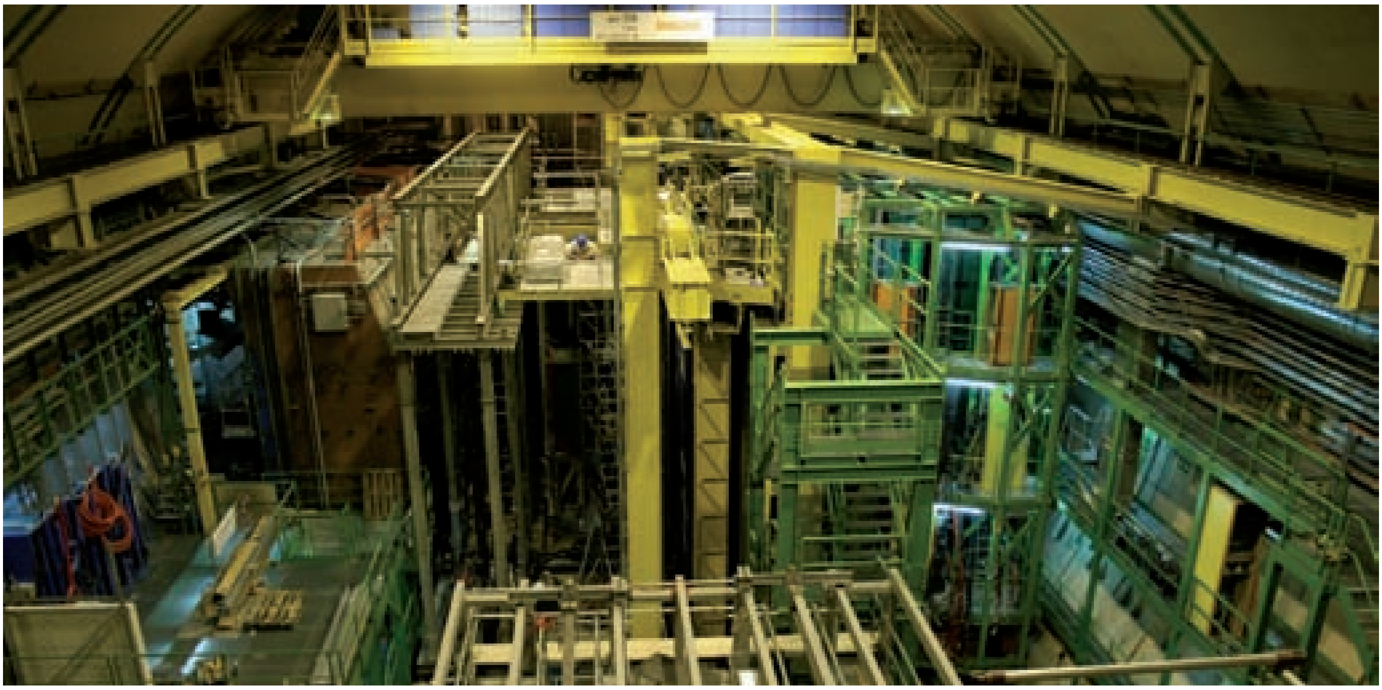


Figure 5. The LHCb spectrometer during installation at one of the collision points of the Large Hadron Collider. The experiment is situated 100 meter underground.

such an asymmetry be produced by the weak interaction that takes place between quarks? Current theoretical models fall short by many orders of magnitude to explain such an asymmetry.

This leads to the question whether there are more sources of CP violation in the electroweak interaction. The research contains two general directions. The first direction looks for CP violation between leptons instead of quarks, the second one looks for new interactions between quarks.

New searches

The investigation of CP violation occurring in lepton interactions leads to experiments with neutrinos. The recent observation of neutrino oscillations implies that neutrino particles are not massless. The existence of neutrinos with non-zero mass in turn leads to the possibility that CP-violating interactions can occur between leptons in a similar way as between quarks. These experiments, however, are difficult and have not yet been realised.

The search for new interactions, affecting CP asymmetries between the quarks, will start in the experiments at the Large Hadron Collider (LHC) at CERN, Geneva. In the case that new particles are discovered at LHC, the corresponding interactions are generally also expected to affect the complex coupling constants present in several *B*-meson decay modes. One of the studied decays is the decay of a B_s (*b*-quark and $\bar{s}$-quark and vice-versa) particle into a J/ψ ($c\bar{c}$-quarks) particle and a φ ($s\bar{s}$-quarks) particle. This decay is equivalent to the decay in which the BaBar and Belle experiments observed CP violation in the weak interaction as described in the Standard Model. However, in the case of the B_s meson decay the predicted CP violation in the Standard Model is approximately zero. Hence, a positive observation of CP-violation in this decay would indicate that physics beyond the description of the Standard Model is at work.

Simulations (see Fig. 4) have demonstrated that experiments at the LHC collider should be able to observe possible deviations from the Standard Model if new interactions are present. In particular the LHCb experiment, in which NIKHEF plays a leading role, is specially designed to hunt for new phenomena in the decays of *B*-particles. A picture of the detector under construction in shown in Fig. 5. The Monte-Carlo simulation presented in Fig. 4 shows that, if these CP-violating interactions are present, the LHCb experiment is in the position to measure them and make a big step on the way to solve the riddle of the antimatter mystery.

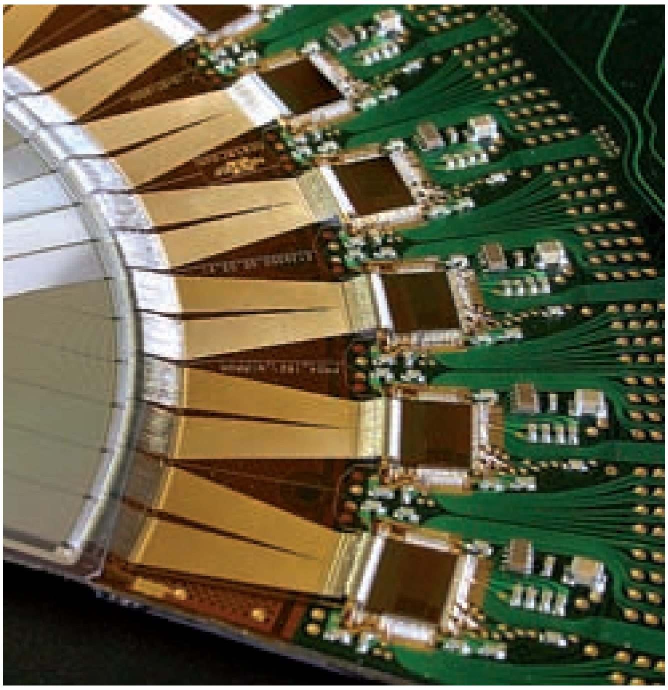


Figure 1. Silicon detector with front-end electronics for the LHCb Vertex Locator.

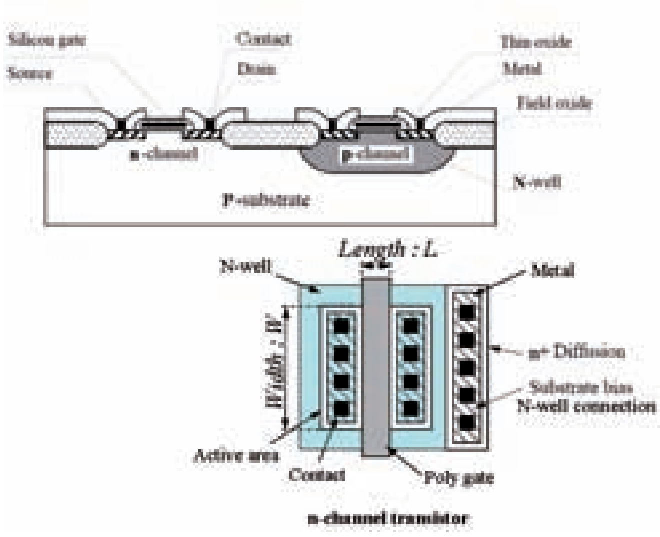


Figure 2. CMOS N- and P-channel transistor.

Integrated Circuits

Ruud Kluit

Introduction

In modern electronic products and equipment integrated circuits (ICs) constitute a major part of the employed components. In the race to build small, low-power, light-weight products with increasing functionality in an economically affordable manner, the integration of many functions in one small component is extremely important. Therefore, industry is pushing this technology further and further.

In building large particle detectors for subatomic physics experiments we can benefit from the progress in this technology, in particular at locations where we need high spatial accuracy for particle-track measurements. Here, many detector channels are placed in a small volume, for instance close to the point where particle beams collide and the track density is consequently very large.

As an illustration of the dimensions involved, consider a tracking detector based on a matrix of silicon pixel chips with 256x256 pixels each. If the pixel size is 60x60 μm^2, this chip will have 65536 pixels on an area of about 2.5 cm^2. In such a case each pixel, which is a sensitive detector channel, requires a signal amplifier, signal processing, storage of the detected signal and configuration functions to tune and optimise the detection capabilities. In addition, a complete chip can require circuits for data compression and data transmission.

Requirements

The front-end electronics (the chips) of the sensors reside often inside the detector volume and therefore their mass must be kept to a minimum since the presence of material will disturb the particle tracks that need to be measured. As a consequence, many particles will hit or pass through the electronics and can damage or influence its behaviour. This makes it necessary to design radiation-tolerant or radiation-hard electronics that is able to function under these harsh conditions.

Due to the mentioned requirements, many detectors for LHC experiments (see Fig. 1 for a recent example) could not have been built if the designers would not have been able to use IC technology in the electronics that reads out the sensors. For the next generation of electronics in particle detectors, for instance in LHC upgrades and new experiments, one requires further integration, less power dissipation and better radiation tolerance.

Working principle

An IC is a physical component that houses more than one different functional circuit, which in turn uses transistors as primary components. Let us focus on the Complementary Metal On Semiconductor (CMOS) technology for ICs, where in fact the metal is now replaced by poly-crystalline silicon.

A transistor (see Fig. 2) has four terminals: Source, Drain, Gate and Substrate, the latter being basically the wafer or chip. One can say that the gate is used to control the current that can flow from drain to source, and that it requires less current for changing the gate voltage than the resulting change in drain-source current. When no gate voltage is applied the NMOS transistor does not conduct, whereas the PMOS transistor does, and with gate voltage the NMOS is 'off' and the PMOS is 'on'. With these components one can build logic cells like NAND and NOR gates and inverters, and with these cells one can subsequently design microprocessord and memory circuits, and also signal amplifiers.

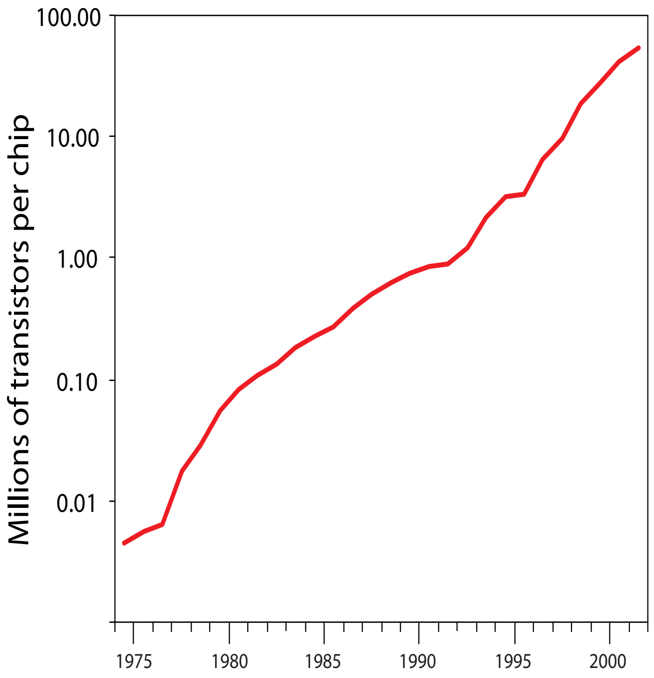


Figure 3. Moore's law, predicting the doubling of the number of transistors per chip every two years.

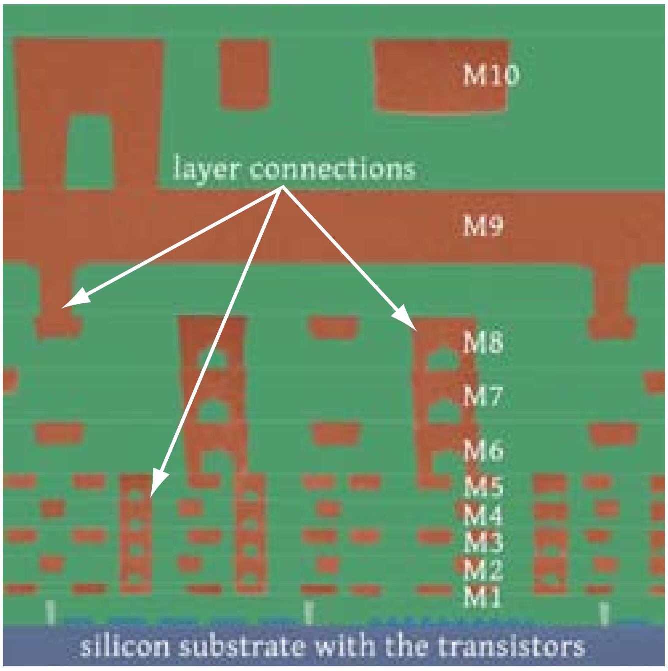


Figure 4. Example of a cross-section of a chip with 10 metal layers The smallest line width is 0.12 µm.

Technology progress

The minimum Gate length L (see Fig. 2) is used as a measure for the technology size. In 1996 we designed circuits using a 0.8 µm CMOS technology. Due to innovations in the chip industry the minimum feature size happens to reduce by about a factor 0.7 every two years. In the past the PC market was a driving force, but presently the telecommunication (mobile phones) and consumer electronics (mobile equipment, games) also require state-of-the-art ICs. The technology scaling (the number of transistors per chip doubles every 24 months, see Fig. 3) was predicted already in 1965 by Gordon Moore, cofounder of Intel. It is expected to be valid until around 2020 when the 3-5 nm size is reached. Then, other approaches than the presently employed ones are required to shrink the devices or to add more components on a chip. Already a lot of effort is put in the way interconnects between circuits are handled: more ICs in one package, stacking of chips and the integration of more technologies in one chip (e.g. optical and electrical, CMOS and bipolar) to build three-dimensional structures.

Fig. 2 shows a wafer (substrate) cross-section of a typical CMOS transistor with the source and drain area's connected to a metal layer, and poly-crystalline silicon for the transistor gate. Modern technologies avail of up to 10 layers of metal to design a circuit on a chip, which makes more efficient use of the silicon for transistors possible (Fig. 4).

Presently, in 2006, the 130nm CMOS technology is well 'characterized'. This means that the designer has enough reliable technology information to calculate the behaviour of the circuit and that good simulation models are available for verification of the design before production. Since the production costs are rising for each technology generation (in 2006 about 270 k€ for a small prototype production of 130nm CMOS with five metal layers), verification becomes a major part of the design time. Hence, we try to benefit as much as possible from educational programmes, which reduce the costs of IC prototyping and production, and we combine as many projects as possible on a wafer in one production, for prototypes and mass production. The production quantities are in general not more than 10-50 thousand, whereas the chip industry deals with millions of chips. This means we are a negligibly small participant in the IC world, but we do want to follow the industry's state of the art.

ICs at NIKHEF

At NIKHEF we follow the industry in using available IC technologies that are used for commercial purposes, are easy to access, and are well characterized. A specific requirement for our detector electronics is that it must be radiation tolerant. This we can realise by using design techniques that have been proven to increase resistance against radiation damage. The picture in Fig. 5 shows a specific D-flip-flop designed with the use of enclosed transistors instead of the linear layout shown in Fig. 2. This layout avoids radiation-induced leakage current between source and drain of the transistor. An advantage of the shrinking size of transistors is that they become less sensitive to radiation damage, but on the other hand more sensitive to single event set-ups, like bit-flips. Such events even happen due to cosmic radiation at ground level in PC's, albeit very rarely. This phenomenon is also taken into account when designing circuits for particle detectors.

Once a chip has been produced, it must be characterized properly before it can be used on many sensors in an experiment. This

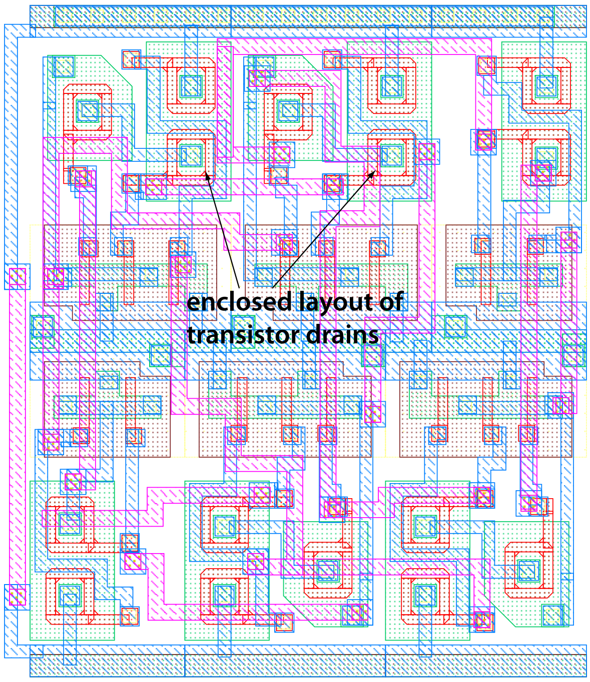


Figure 5. Layout of radiation-tolerant D-flip-flop in 130nm CMOS technology.

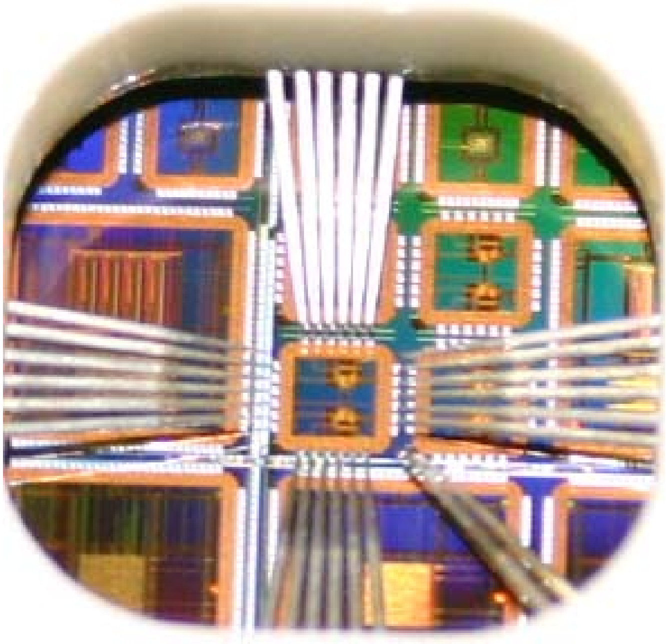


Figure 6. Probe needles make contact to a chip under test on a multi-project production wafer.

requires special test equipment and methods like a wafer-prober (Fig. 6) and automated test environments for what we call 'larger' production quantities (thousands). Inside our international physics community we share this kind of equipment to reduce costs.

Collaborations

For every new generation of IC technology the specific characteristics need to be examined. Therefore, close collaboration with other IC-design groups in the subatomic physics community is necessary, also for exchanging design experience, sharing common circuits in different ICs and support for design tools, which are increasing in number and complexity.

The NIKHEF electronics department worked together in IC projects with the Heidelberg ASIC labor and LEPSI/IN2P3 Strasbourg, in projects for CERN and DESY. For new experiments new collaborations are being formed, but the CERN micro-electronics group is always a central point for new technologies, sharing of experience, and the organization of (prototype) productions. In addition, we share experience in this field with other Dutch research institutes like the Netherlands Institute for Space Research SRON, the MESA+ Institute for Nanotechnology at the University of Twente, and the University of Eindhoven. Naturally, we regularly present our work in conferences and the relevant literature.

For the design software NIKHEF is member of the Euro Practice organisation that delivers complete commercial IC design tools for educational and research programs. The combination of the IC technologies and the software enables us to develop state-of-the-art detectors for sub-atomic physics that provide the best possible research opportunities for physicists and students.

Prospects

For IC designers exciting future projects are new particle detectors, for which prototypes of readout electronics need to be developed with properties that never have been demonstrated before. This is not only interesting for the engineers and physicists, but also for the IC foundry. A NIKHEF design went into production in 2006 (Fig. 7). Its purpose is to measure the track of a particle through a thin (1 mm) gas layer above the chip by measuring the drift time of the induced charge in the gas that is drifting to sensitive pixels. The chip has an array of 16x16 pixel cells and is designed in 130 nm CMOS technology with eight metal layers. The goal of this design is to demonstrate the detector principle by building a small detector with this chip. This would be a starting point for an upgrade of detectors of the present LHC experiments and also for detectors for future experiments.

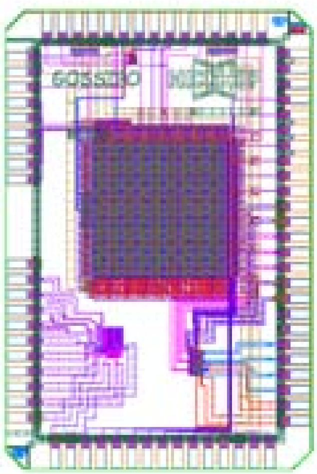


Figure 7. NIKHEF prototype chip (2x3mm^2) for a 16x16 pixel particle detector using a gas layer, designed in 130 nm CMOS technology.

Research

A technician working on the ALICE Silicon Strip Detector in the Utrecht clean room.

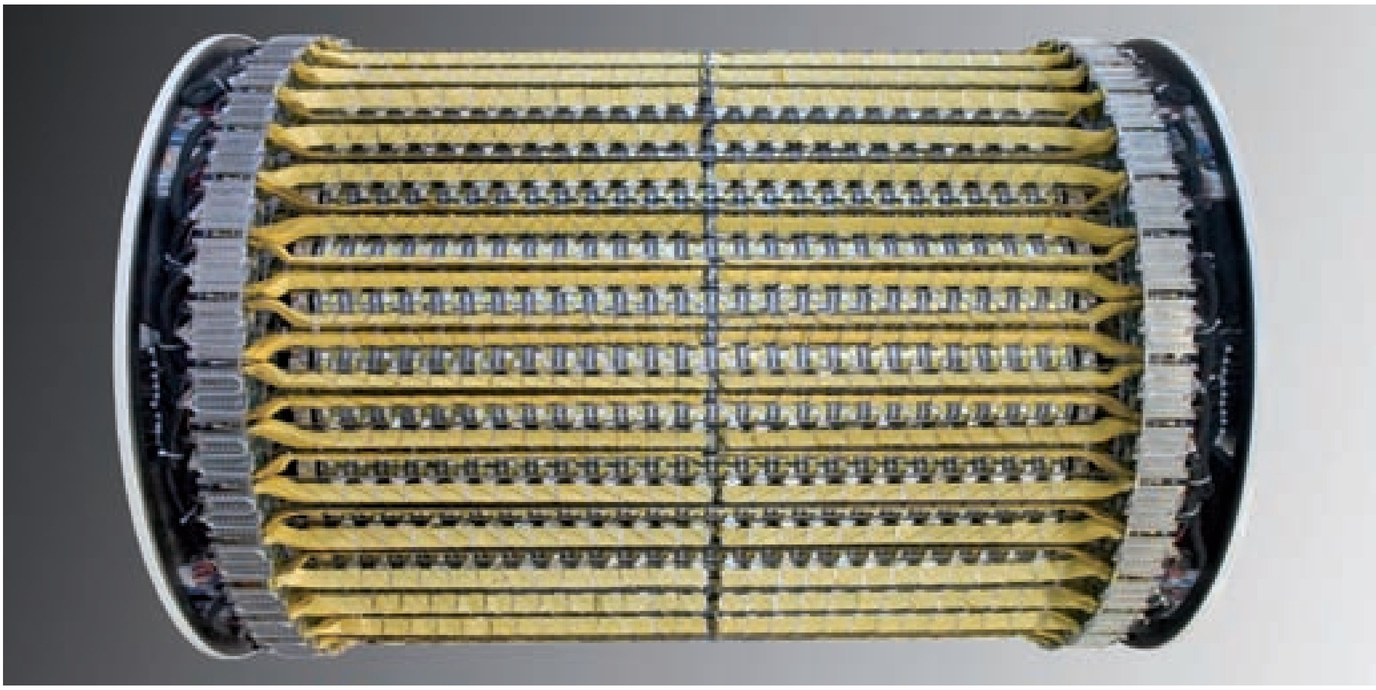


Figure 1. Completed assembly of the ALICE Silicon Strip Detector. Visible are the ladders of the outer barrel with the yellow readout cables that collect the signals of the 2.5 million individual strips. At the left and right side of the barrel are two rings of end-cap electronics, which were designed and built at NIKHEF.

ALICE

Colliding ultra-relativistic heavy nuclei in particle accelerators does enable us to create and study a novel state of matter called the Quark-Gluon Plasma (QGP). It is believed that this primordial state of matter filled the Universe in the first few microseconds after the Big Bang, before the phase transition to the present hadronic state of matter took place.

The highest heavy-ion collision energies available to date are provided by the Relativistic Heavy Ion Collider (RHIC) at Brookhaven. The experiments carried out at this collider have shown that an extremely dense and hot medium with unique properties is indeed created in gold on gold collisions at a collision energy of 200 GeV per nucleon. In the coming years the Large Hadron Collider (LHC) at CERN will provide lead on lead collisions at an unprecedented energy of 5500 GeV per nucleon.

The NIKHEF heavy-ion group participates in the STAR experiment at RHIC and in the ALICE experiment at the LHC. In 2006, the activities of the group were focused on the assembly and testing of the two outer layers of silicon strip detectors (SSD) of the ALICE inner tracker system (ITS). In addition to this hardware effort, the NIKHEF group continued with the analysis of current STAR data and with the development of software to analyze the future LHC data from ALICE.

By the end of 2006, the full assembly of SSD layers was shipped from Utrecht to CERN where they will be integrated in the ALICE detector before the summer of 2007. The timely achievement of this milestone concludes a phase of design, testing and assembly, spanning almost ten years of effort in close collaboration with institutes in Finland, France, Italy, Russia and the Ukraine. The final assembly of the two SSD layers has partly been carried out at NIKHEF, both in Amsterdam and Utrecht, and partly at SUBATECH (IN2P3) in Nantes. A more detailed account of the NIKHEF contribution to the SSD assembly is given below.

In total, 64 out of 80 ladders with 25 SSD detector modules each were assembled at NIKHEF. This ladder assembly continued until November 2006, with peak production rates of four ladders per week. The 16 ladders from Nantes were shipped to NIKHEF where they were measured mechanically and had their final check. About 50% of all produced ladders showed defects which could be solved by a variety of post-treatments, ranging in difficulty from relatively simple interventions up to the replacement of an entire detector module. In the course of the year it became clear that a considerable number of detector modules suffered from excessive noise. The cause was quickly found in a crash research program carried out in cooperation with INFN in Trieste. The remedy requires an additional voltage to be applied between the sensor bias and the ground of the front-end chips. To achieve this, a modification of hundreds of Supply Cards was necessary. Because of the different mode of operation the affected modules had to be grouped together onto ladders which are serviced by the modified electronics. These ladders will be operated with the compensation voltage only after installation in ALICE. However, extensive tests on a set of selected ladders showed that the noise is indeed much reduced without unwanted side-effects.

Fig. 1 shows the completed SSD. On December 12, 2006 the SSD was shipped to CERN where it arrived on December 14. After further tests, the detector will be rotated to the horizontal position and be integrated with the ITS drift detector before installation in ALICE.

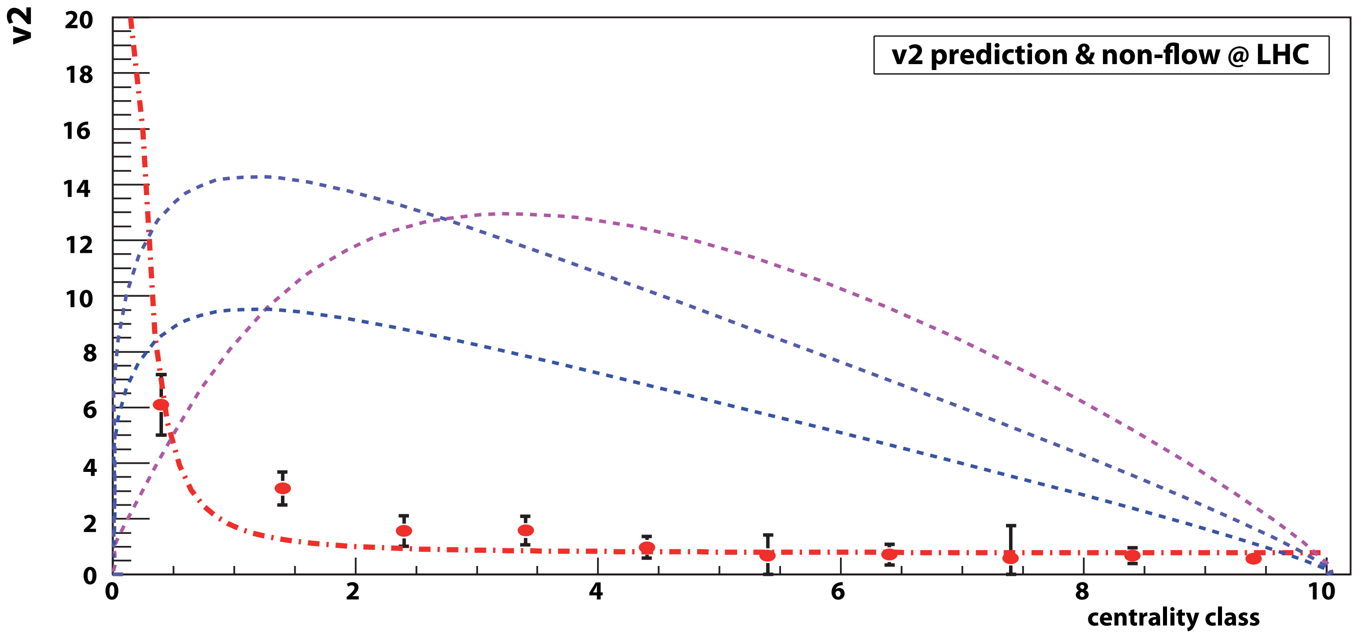


Figure 2. Elliptic flow coefficient v_2 versus the event centrality class, defined such that larger values correspond to more central events. The dashed curves represent three model predictions for the elliptic flow expected at LHC. The data points show non-flow contributions estimated from a simulation of the ALICE experiment. The dashed-dotted curve corresponds to a parameterization of the non-flow effects.

The physics focus of the NIKHEF group is oriented toward the measurement of collective phenomena in particle production from the dense medium produced in heavy-ion collisions at the LHC. Such phenomena are a prominent feature of heavy-ion collisions and are therefore relatively easy to detect. The theoretical interpretation of results from RHIC indicate that by these measurements profound insight can be gained in the behavior of matter at extremely large densities and temperatures.

Of particular interest are azimuthal correlations, which originate from the pressure gradients in the azimuthally asymmetric interaction region of non-central heavy-ion collisions. This anisotropic collective behavior is called elliptic flow. The measurement of elliptic flow gives, under certain model assumptions, access to the equation of state and transport properties of the medium produced in the collision. For instance, the discovery of the perfect fluidity of the medium created in gold on gold collisions at RHIC is largely based on detailed measurements of elliptic flow and their interpretation in terms of relativistic hydrodynamics.

Detailed simulations were performed to investigate the feasibility of an elliptic flow measurement in ALICE. One of the largest experimental uncertainties in the flow measurement is due to azimuthal correlations from sources other than collective flow like momentum conservation, resonance decays, jets and mini-jets. In particular the contribution from jets is expected to be a dominant source of non-flow effects at the LHC.

Fig. 2 shows the result of a feasibility study based on a simulation of the ALICE experiment. The simulated lead on lead collisions used for this study are basically a superposition of many nucleon-nucleon collisions and contain a large amount of randomly distributed jets. Since collective flow is absent in these events, the elliptic flow strengths obtained from an analysis of the sample are entirely due to correlations induced by the presence of jets. The strengths of these non-flow effects are shown by the data points and by the dashed-dotted curve in the figure. The dashed curves show model predictions of the strength of genuine elliptic flow in lead on lead collisions at the LHC.

From this result it is concluded that jet contributions to the azimuthal correlations are small compared to those from elliptic flow, provided that the event is not very peripheral or very central. Flow measurements like those performed at RHIC are therefore not obscured by the abundant jet-structures that are present at the LHC.

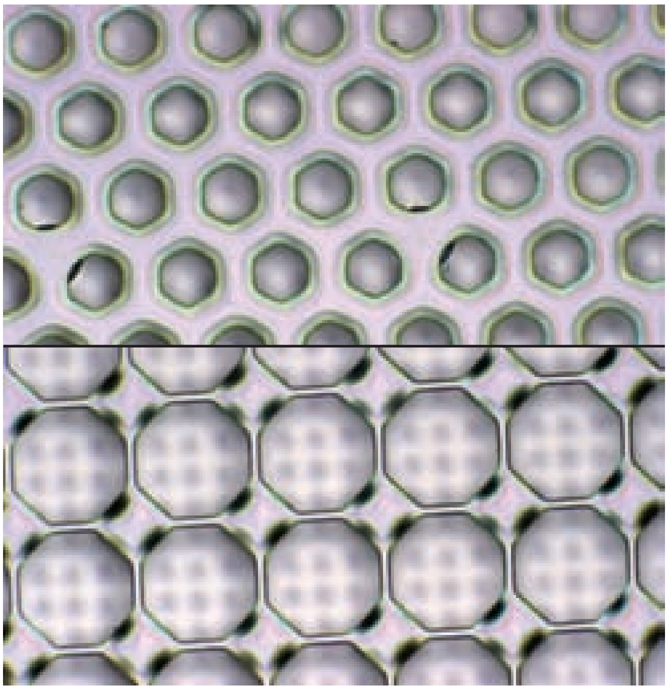


Figure 1. Some of the various Ingrid patterns used for the measurements. Note that the insulating pillars do not create local losses.

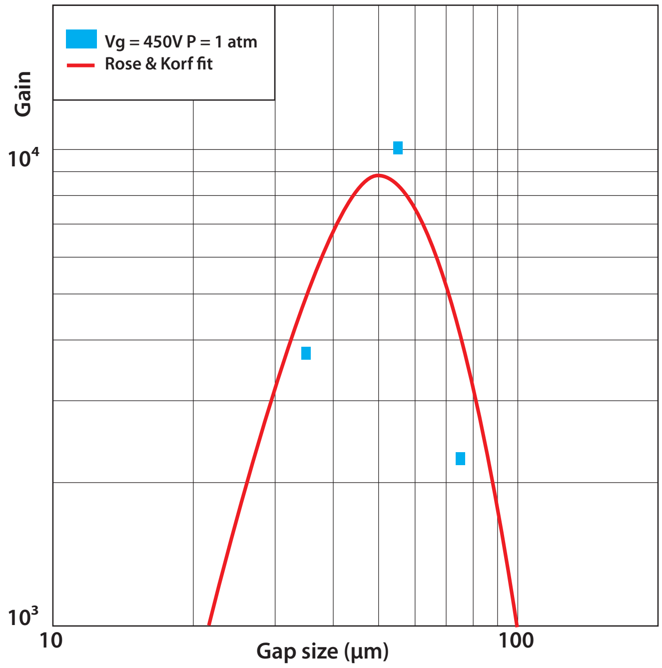


Figure 2. Measurement of the gas gain as function of the gap height, compared with model expectations.

Detector Research & Development

The group was active in three main R&D areas:

- The development of gaseous detectors readout by specially developed multipixel CMOS chips with fully integrated gas-gain grid;
- The development of hybrid CMOS pixel detectors for X-ray imaging applications (see the feature article "Medipix and RELAXD" in the Reviews section of this Annual Report);
- The development of various alignment systems based on RASNIK (see also the 2005 Annual Report).

Progress on Ingrids/GridPix detectors and discharge protection.

The concept of pixel readout of gas-filled detectors was validated in 2004 by combining a Micromegas amplification grid with a Medipix2 CMOS chip as a pixel segmented anode. The fine granularity offered by the pixel matrix results in improved spatial resolution and 2-track separation compared to a 'traditional' pad readout. Furthermore, the good single (primary) electron efficiency (>90%) can improve the energy-loss measurement through a cluster-counting technique.

As a possible solution for the fabrication of larger pixelised Micro Pattern Gas Detector (MPGD) elements, the group proposed the integration of the Micromegas amplification grid and the CMOS readout chip (Ingrid) by means of wafer postprocessing technology: the structure of a thin (1 µm) aluminium grid is fabricated on top of an array of insulating (SU8) pillars of typically 50 µm height, which stand on the CMOS chip. This structure thus forms a 'monolithic' detection and readout device. This work is done in close collaboration with the MESA+ institute of the University of Twente. Results from a a first working Ingrid were published in 2006. Several Ingrids of different geometry, shape and pitch of the grid holes, and multiplication gap thickness (pillar height), see Fig. 1, 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 in the gas gain is reached for a gap thickness around 50 µm (at fixed grid voltage), in agreement with expectations from model calculations (see Fig. 2).

In the framework of the EUDET project (detector R&D program towards a Linear Collider detector) the TimePix chip was developed as a modification of the earlier used Medipix2 chip. The TimePix not only provides a high-granularity x-y coordinate readout, but each 55x55 µm^2 pixel also measures the arrival time of the charge on the pixel, thus providing a third coordinate (z) measurement. The new chip design (by the CERN Microelectronics group) was submitted to the foundry early July and 12 wafers arrived in September. Initial electronic characterization tests of the chip show that it behaves according to specs. The yield of good chips on a wafer is very satisfactory (typically 70-80%).

Unlike setups where a (triple-)GEM structure is used as gas multiplier, the electric field just above the CMOS readout chip in our setup with a Micromegas (or Ingrid) multiplication stage is about an order of magnitude higher. This increases the probability of discharges, damaging irreversibly the CMOS chip. Two possible solutions are being investigated.

In the first method we investigated the use of a highly resistive layer of 4 µm of amorphous silicon (aSi) with a resistivity of ~ 10^{11} Ω.cm covering the chip. The expected effect is a limitation of the current of large avalanches (e.g. discharges). First tests with and without such a protection layer deposited on a non-pixelated

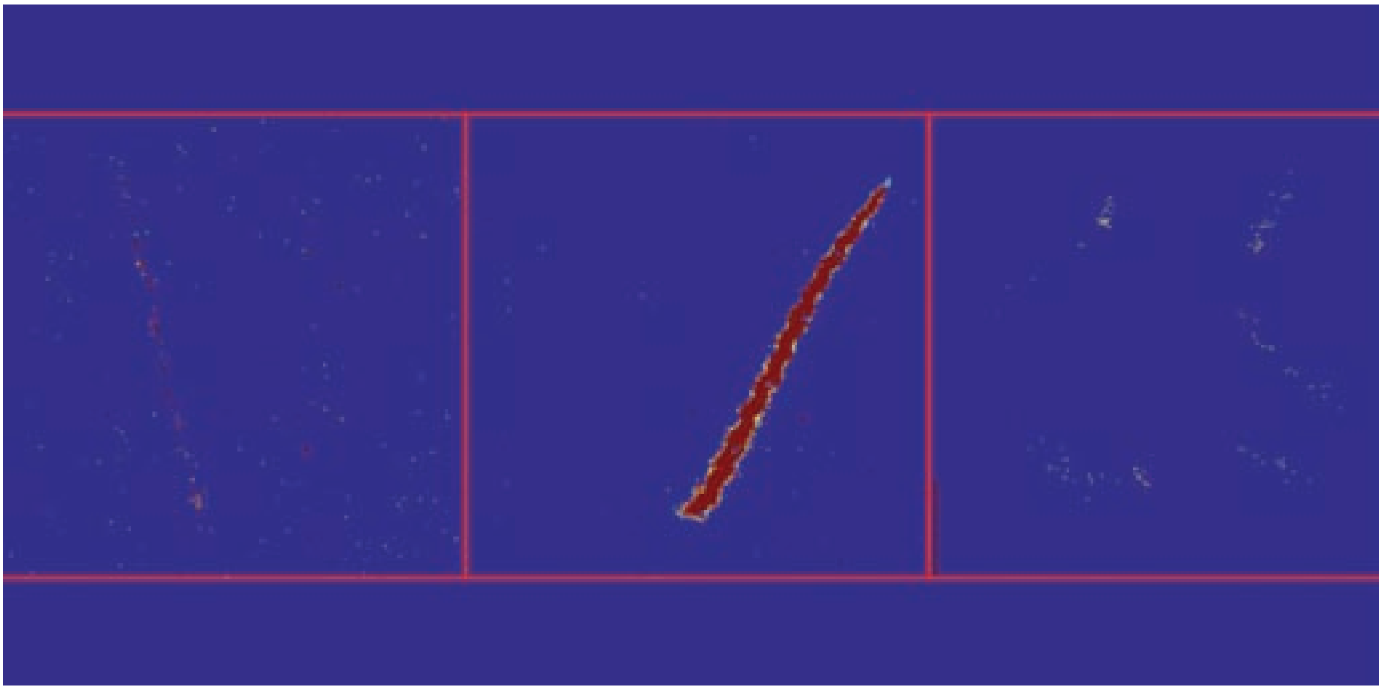


Figure 3. Examples of tracks recorded with the newly developed TimePix chip; left: 'random' track during rather long 'acquisition' of 1 sec. The color code indicates the amount of charge collected on each pixel; middle: same from a (heavily ionising) α particle; left: tracks from cosmic muons in 'triggered' mode, where now the color code indicates the time of arrival of the signals on the pixels. The picture is integrated over 700 seconds, but the actual 'active' time of the detector during each trigger was only 150 μs.

anode showed that in a 80/20 Ar/Isobutane gas mixture the 'unprotected' detector gain could not be raised above about 20,000 before the occurrence of discharges, while a 'protected' detector could reach gains of half a million. Just before the end of 2006, a first 'protected' TimePix chip with a Micromegas as gas gain grid became operational in a small drift chamber (15 mm drift gap) filled with a 80/20 He/Isobutane gas mixture. First examples of observed charged particle tracks are shown in Fig. 3.

A second possibility to protect the readout chip is to fabricate a 2-stage Ingrid structure using the same wafer postprocessing technique. Two layers of metallic grids and insulating pillars are superposed. The 'top' gap can then be used as main amplification grid, while the 'lower' gap just above the CMOS chip can be operated at a much lower field strength, sufficient to extract the avalanche charge created in the 'top' gap onto the anode. A first fabrication attempt of such a double-grid structure was successful (see Fig. 4).

GOSSIP

With a 1 mm thin layer of gas, the GridPix detector can be applied as vertex detector, as an alternative for the widely applied silicon detectors. In a small test chamber, the pulse-height spectrum of Fig. 5 has been measured, confirming that a good efficiency can be combined with a fast detector response.

For a future upgrade of the ATLAS experiment, anticipating on the extreme radiation levels at the Super-LHC, concept studies were carried out in the application of Gas On Slimmed Silicon Pixel (GOSSIP) concerning cooling, mechanical suspension and data processing architecture.

Gossipo chip design

The Gossipo-1 'Multi Project Wafer' chip was made in 130 nm technology. The chip included several preamp-shaper-discriminator channels, optimized for the extreme small source capacity of the future GridPix detectors. The chips performed as hoped for. A power dissipation of only 2 μW per pixel appeared possible. By using the 'triple well' technology, a better separation between analog and digital signals was possible. The minimal setting of thresholds was indeed determined by the preamp noise only: digital interference was negligible.

With the Gossipo-2 chip, the arrival time of individual primary electrons can be measured (see the article 'Integrated Circuits' in the Reviews Section). Each pixel contains a 700 MHz clock which is only active, for a short (interpolating) period, after being activated by an avalanche. This chip will contain 16x16 pixels, and it will be tested as a real GridPix detector.

RASNIK alignment systems

USB-RASNIK

The installation of RASNIK systems in ATLAS progresses well (see 'ATLAS nearing completion' in this section). A new application has been proposed that monitors the sag of roof constructions. Such a RasIce system could generate an alarm in case of an overload of snow. This proposal has won the 3rd price in the 'Nieuwe Ideeën' contest, initiated by the University of Amsterdam, and has resulted in commercial interest: prototypes of low-cost RASNIK components, based on webcam sensors, suitable for mass production, have been made.

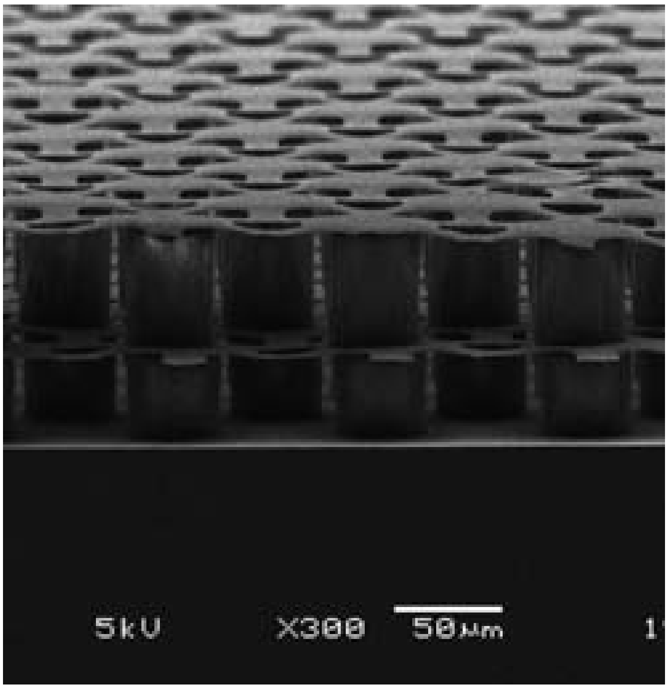


Figure 4. Photograph of a first trial to fabricate a double-grid structure (TwinGrid).

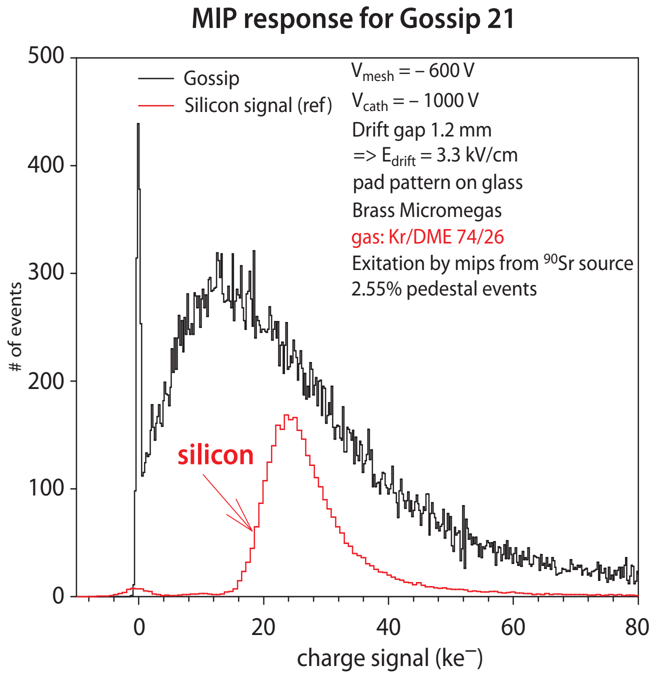


Figure 5. Measured pulse-height spectrum of a Micromegas detector with a drift gap of 1.2 mm, irradiated with electrons from a ^{90}Sr source. From this measurement the efficiency of the future Gossip detectors can be derived.

RasClic

For the alignment of the future Compact Linear Collider (CLIC) at CERN, a special long-distance RASNIK system has been developed. It consists of a laser of which its (divergent) beam illuminates a plate with a 50 mm Ø hole. An image pixel sensor, placed 50 m behind the plate records the typical diffraction pattern. The position of this pattern on the sensor is a direct measure for the alignment of the laser, the central hole and the image sensor.

Since a precision of order 1 µm (in terms of image position on sensor) is expected, the light beam should travel through vacuum in order to prevent light beam deflection due to variations in the air density. The 'RasClic' set up at CERN is shown in Fig. 6; the precision is much better than required for CLIC, and the instrument could be applied as seismometer if images could be processed with a speed of 25 Hz or more. With this idea, Marc Kea and Henk Groenstege won the 1st price of the contest 'Win de Toekomst', organized in the framework of FOM's 60th anniversary.

Fig. 6. The 'RasClic' setup at CERN.

Figure 1. The Piere Auger Observatory in Argentina uses a hybrid combination of particle detection (foreground) and air fluorescence detection (background).

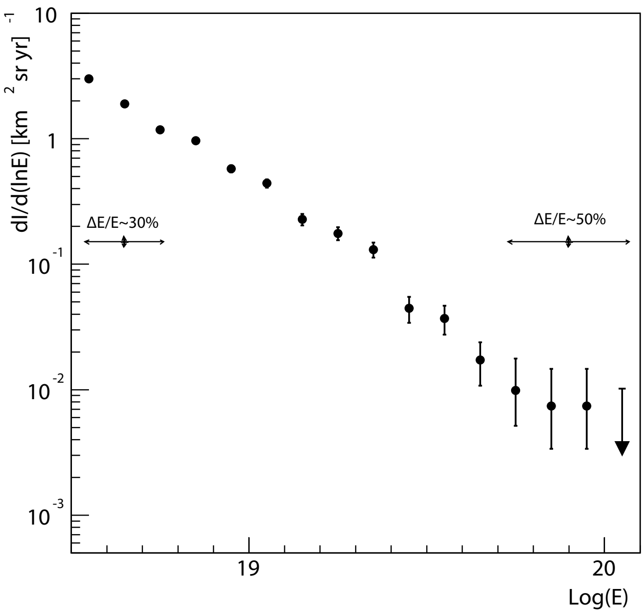


Figure 2. Intensity of ultra-high energetic cosmic rays as a function of energy, measured at the Pierre Auger Observatory.

The Pierre Auger Observatory

The Pierre Auger Observatory will consist of a northern and southern site. The northern site will be constructed near Lamar, Colorado, USA. The nearly completed southern site is located on the pampa near Malargüe, Argentina (35°27'S, 69°35'W, 1400 metres altitude). When finished, it will consist of 4 fluorescence detectors and 1600 watertanks (see Fig. 1) on a surface area of 3000 km^2.

The purpose of the Pierre Auger observatory is to measure the flux, nature and origin of the highest energetic particles ever observed: Cosmic rays of energies above 10^{18} eV (UHECR). First results have already been published. The energy-spectrum is shown in Fig. 2. The energy calibration of all events originates from the so-called hybrid events, from which the correlation between the particle density at 1000 metres from the shower core and the energy, as reconstructed from the fluorescence information, is measured.

A first result on the nature of cosmic rays is given in our publication of a 95% upper limit of a 16% contribution of photons above 10 EeV. The photon fraction at high energies will be crucial in examining proposed top-down models on the origin of UHECR. Other searches on the origin of UHECR are performed. The AGASA collaboration published a 4.5σ excess near the galactic centre. Our search with four times as much data shows no excess in this region, severely limiting a possible flux from the galactic centre.

The initial Dutch contribution consisted of building tank-microT-PCB's (tank power control board), which have all been delivered to the collaboration. The main R&D interest of the participating Dutch groups lies in the development of Radio detection of showers induced by UHECR. The NIKHEF contribution to this R&D is focused toward creating a high-speed, low-power data-acquisition unit, a prototype of which originates from the electronics development for the HiSPARC project. The other national partners, KVI and ASTRON, are responsible for wireless data transmission and antenna design, respectively. This division of tasks allows an optimal use of the strength of each partner.

In mid-October a working radio antenna with readout was assembled in Nijmegen and moved to Dwingeloo for first measurements. This setup, as well as two others, was moved to Argentina for measurements on site using three radio antennas, which are read-out by the HiSPARC-prototype scopes, using long cables. Our program included not only using the ASTRON-built LOFAR antennas, but also reading out the log-periodic-dipole antenna's from Karlsruhe/Aachen in order to have an independent check of our data acquisition as well as a measurement on the relative antenna performances.

The data are stored on laptops which allow to easily transport and analyze them. The analysis of these data will take some time, and the first results on background and possible coincidences with the Auger watertanks are not expected before early 2007.

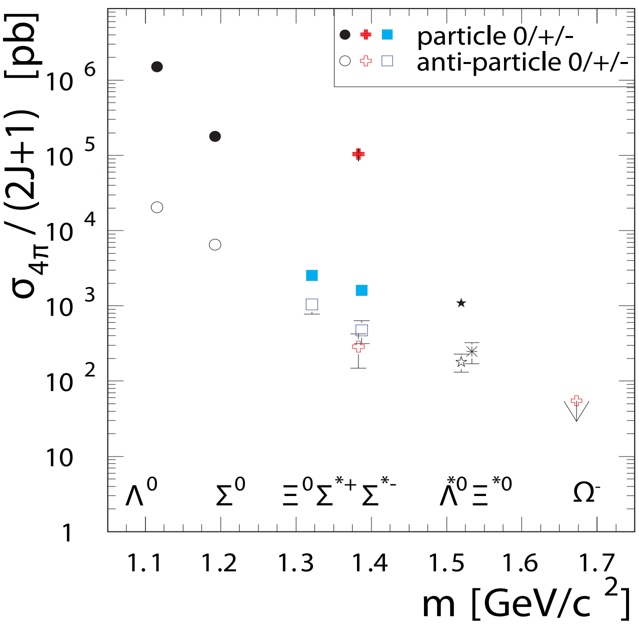


Figure 1. Production cross section of hyperons measured in HERMES, extrapolated to full (4π) acceptance.

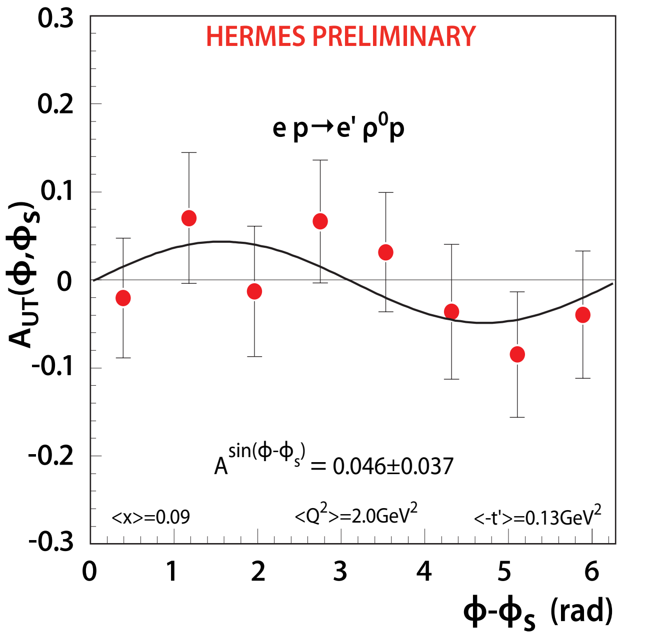


Figure 2. Measured values of the asymmetry A_{UT} -integrated over kinematical variables- versus the relevant angle φ-φ_s. Here φ and φ_s are the azimuthal angles of, respectively, the ρ^0 production plane and the target spin with respect to the lepton scattering plane. The curve represents the extracted sin(φ-φ_s) component of the asymmetry, which is sensitive to the value of J^q.

The HERMES Experiment

In 2006 HERMES took the opportunity to change its experiment for the last time. HERMES will focus its efforts until the final shutdown of HERA, mid 2007, on the measurement of Generalized Parton Distribution functions (GPDs). To this end a recoil detector was added to the experiment. At the same time the analysis of the data taken in the previous years, was forged ahead.

Nucleon Spin

Since the EMC-experiment made us aware of the fact that only about 30% of the nucleon spin can be attributed to the spin of the quarks which make up the nucleon, much research was devoted to the question how the spin is distributed between the different partons. The polarization of Λ particles created in the collision of polarized leptons and protons, can be correlated to the polarization of the *s*-quarks with respect to that of the *u*-quarks in the proton, when the Λ is produced in the target fragmentation region. On the other hand, when the Λ is produced in the current fragmentation region, its polarization is due to the spin of the struck (u-)quark.

Information on the process of fragmentation of quarks and gluons into observable hadrons can be obtained by measuring baryon production in high energy experiments. Hyperons are especially interesting as they contain a strange valence quark which is not present in the target nucleon. At present no calculable theoretical description of this process exists, and it is assumed that baryons and mesons are produced by a similar mechanism during the fragmentation process. Therefore, the (phenomenological) LUND model of fragmentation is used in a Monte Carlo simulation to determine the fraction of hyperons that are produced directly in the fragmentation and from decays of heavier hyperons. The production rates of hyperons of different strangeness content and spin have been measured (see figure) and are compared to the results of the Monte Carlo simulation.

The transverse target spin asymmetry in exclusive ρ^0 production

In addition to the available information about the quark helicity contribution to the nucleon spin Σ^q, measurements of J^q, the quark total angular momentum, will provide a way to determine the unknown contribution of the quark orbital momentum L^q. Calculations based on Generalized Parton Distributions show that the transverse target spin asymmetry A_{UT} in exclusive ρ^0 production is sensitive to J^q.

Preliminary results for this asymmetry, based on the data taken during the 2002-2004 period (see figure), have already been compared with GPD based calculations for different values of J^q. Although the measurements are consistent with these calculations, the statistical uncertainties are yet too large to make a sharp distinction between different values of J^q. The data taken in the year 2005 at least double the amount of statistics available for this analysis.

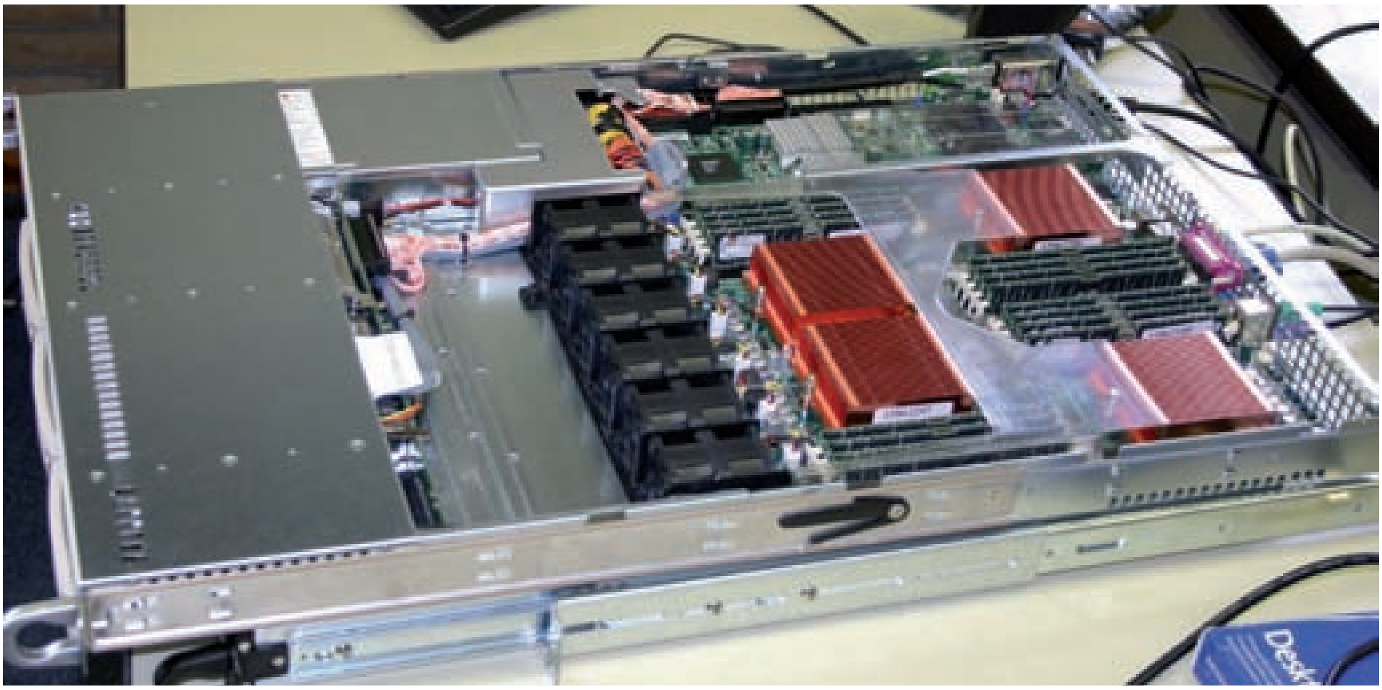


Figure 1. The 4-Opteron computer on which a multi-threaded version of FORM is being tested.

Theory

Research in the NIKHEF theory group in 2006 continued to cover a diverse set of areas in theoretical particle physics. Below we review some highlights, beginning with phenomenology.

The s- and t-channel single top-quark production processes were included in the MC@NLO Monte Carlo simulation framework. This process, of which evidence was reported by the DØ collaboration, allows direct measurement of the CKM element V_{tb}, and is sensitive to various forms of new physics. The inclusion is an important step toward this goal.

A global fit to mostly deep-inelastic scattering data was performed using a next-to-leading-order (NLO) calculation enhanced by next-to-leading logarithmic BFKL resummation. A marked improvement over the purely NLO fixed-order approach was found.

Development of the FORM program, used for many of the most challenging calculations in perturbative quantum field theory, continued apace this year. A multi-threaded version, which exploits the opportunities of computers with multiple computing cores, is near completion, and performs well on a specially acquired 4-processor machine (see Fig. 1).

A study of the matrix element of the electromagnetic current between pion states was done in lattice QCD at finite temperature ($T = 0.93\ T_c$), allowing extraction of the electromagnetic vertex function under conditions relevant to heavy-ion collisions.

A very promising approach to describe particle behaviour and collective effects in a hot or dense medium is the 2-particle irreducible (2PI) action method (see Fig. 2). In the past year possibly serious problems regarding renormalization were resolved for relevant field theories.

In the area of string theory, much progress was made by members of our group on understanding the link of string theory to lower-scale physics. A quite exhaustive and systematic study allowing for a great variety of D-brane configurations led to numerous examples of string vacua that resemble the Standard Model, as well as several kinds of unification models that contain the Standard Model.

The characteristics of proton acceleration in astrophysical sources were studied, in particular the energy and rapidity distributions of secondary pions and kaons produced in these circumstances.

In cosmology, progress was made towards embedding inflation in realistic particle physics models such as grand unified theories and string theory. It was shown that the (gravitational) couplings between the inflaton fields and other fields, for example the Standard Model fields, constrain these models severely. In particular, so-called VSI solutions to higher-dimensional Einstein equations were found and studied. These solutions are also novel, exact solutions of supergravity and string theory.

Understanding systems of particles in curved spacetimes involves finding constants of motion, which is in general a non-trivial task. Methods to find these were extended to situations with external abelian and non-abelian gauge fields.

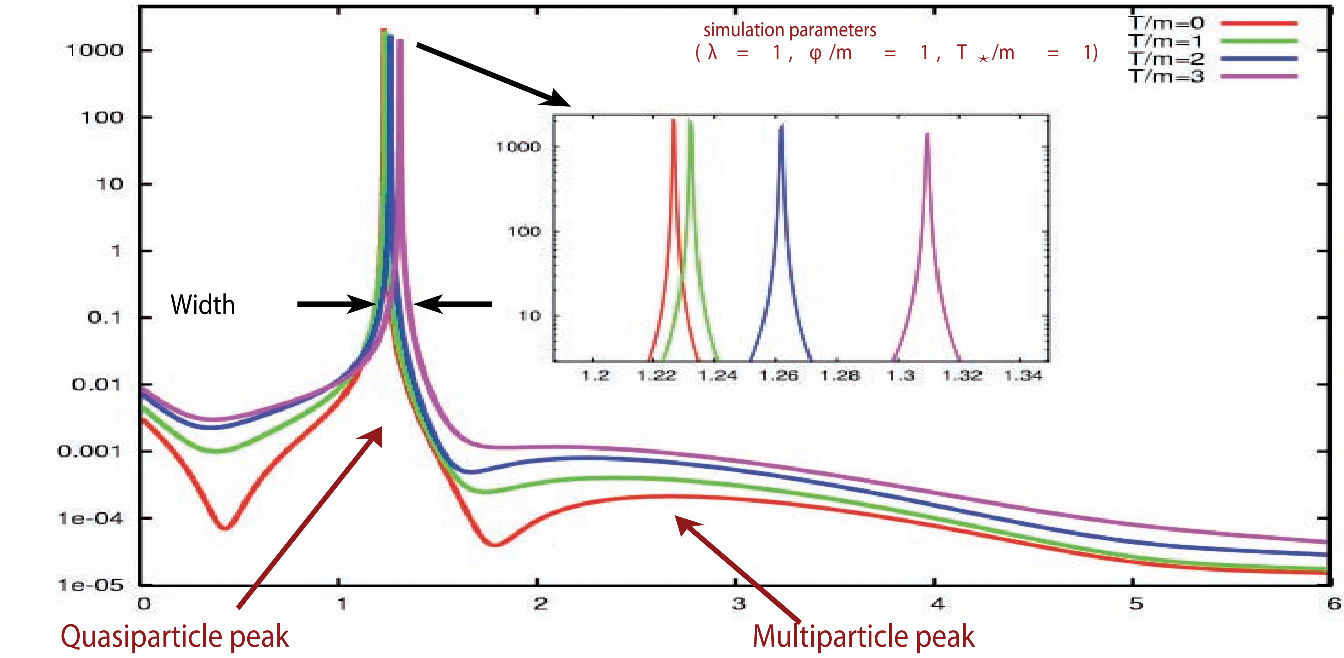


Figure 2. Quasiparticle properties in a scalar theory can be captured by the spectral function. The center and width of the peak tell us about the mass and stability of the quasiparticle. These change with increasing temperature, as a result of the interactions with the medium.

Other news

A number of other noteworthy issues deserve mention.

A prestigious Humboldt Prize was awarded by the Alexander von Humboldt Foundation to Jos Vermaseren for his work on precision QCD. The prize will enable him to spend a year doing research at DESY Zeuthen and the University of Karlsruhe.

In 2006 staff members of the group have been active in teaching in the NIKHEF topical lectures, the 2006 AIO/OIO school for theoretical PhD students (van Holten, Schellekens), and organizing a workshop 'Beyond the Standard Model' at Bad Honnef (van Holten). Outreach activities consisted of organizing a symposium for highschool students (van Holten), and contributing to a student symposium at Delft University (Laenen).

Staff members have also been teaching university courses in Nijmegen (Beenakker, Kleiss, Schellekens), Leiden and Delft (van Holten), Utrecht (Laenen) and Amsterdam (Koch).

Two new initiatives were started in 2006 by theory group members. The first are the twice-a-year NIKHEF Academic Lectures. Lecture sets consist of four 45-minute lectures, geared towards NIKHEF scientists from PhD students to staff, on topics relevant to the research program of the institute. This year's topics were the Standard Model (Laenen), and Supersymmetry and GUTS (Schellekens). The second new initiative are the monthly Theory Meetings, in which theorists from all Dutch groups gather to discuss, work, collaborate, generate ideas etc. The National Seminar on Theoretical High-Energy Physics also continues to be held at NIKHEF, and attracts good attendance.

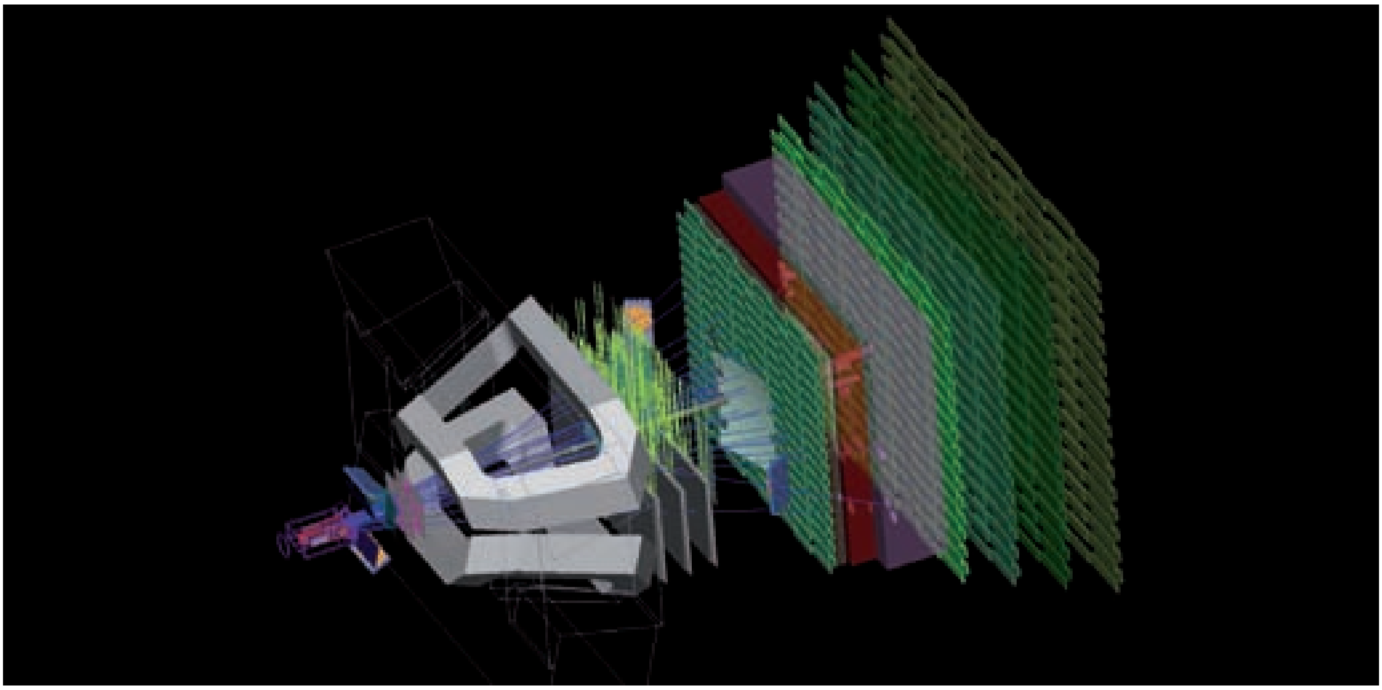


Figure 1. Simulated B-decay event in the LHCb detector. The blue lines indicated the charged particle trajectories that are detected with the tracking detectors.

Tracking in LHCb

The proton-proton collisions in the Large Hadron Collider will produce *B* and $\overline{B}$-particles with a rate of 100 kHz, thus providing a factory of *B*-hadrons. In particular the *B*-mesons, particles consisting of a *b*-quark and a light *u*, *d* or *s*-quark, are a possible source for manifestations of new physics laws. To search for deviations from the Standard Model, specific rare *B*-decay processes must be selected and reconstructed with the experiment. The physics program in LHCb, one of the four experiments at the LHC collider, aims to study the decays of these *B*-mesons. A simulation of a *B*-decay event inside the LHCb experiment is shown in Fig. 1.

NIKHEF focuses on a subset of *B*-decay events in which the decay products only include charged particles. The detection of these charged particles, generally referred to as tracking, is done with detector systems constructed at NIKHEF: the Vertex Locator and the Outer Tracker.

With the Outer Tracker detector the trajectories of charged particles in the 0.5 Tesla magnetic dipole field of LHCb are reconstructed. By comparing the observed curvature in the known magnetic field, the Outer Tracker provides a measurement of the particle momenta with a relative precision of 0.5% which in turn leads to a precise reconstruction of the invariant mass of *B*-decay event candidates. In this way the Outer Tracker provides an important ingredient to distinguish signal events from background events and allows to select rare *B*-decays produced in the collider. Fig. 2 shows as an illustration a simulation of the reconstructed mass peak for the signal decays $B_s \rightarrow K^-\pi^+$ as compared to specific background decays $B_d \rightarrow K^-\pi^+$.

The Outer Tracker detector consists of 56,000 gaseous straw tube detectors covering 12 layers with a detection surface of 30 m^2 per layer. It measures ionizations of gas atoms produced by charged particles traversing the detector. Testbeam experiments have demonstrated that the particle trajectories can be measured with a precision of 200 μm. The complete detector is constructed in a modular way, allowing for easy installation and maintenance. The detector modules have been constructed and tested at NIKHEF and are currently being installed in the experiment. A crucial aspect in the installation is the positioning and alignment of these large detectors. Optical survey inspections have shown that the first of these large detector planes has been positioned in the experimental setup with a precision of 1 mm. Software simulations have shown that such an alignment is sufficient for pattern recognition programs to correctly find the tracks. A further alignment will be obtained from the data using a dedicated alignment fitting program called 'Millipede'.

The Vertex Locator exploits the fact that the average *B*-meson lifetime is 1.5 ps, such that *B*-decay vertices are generally displaced by several mm from the from the primary event vertex. This signature allows firstly, to preselect *B*-events in an online trigger procedure, secondly to suppress further backgrounds by requiring that all *B*-decay products must originate from this seperated vertex, and thirdly to measure the individual lifetime of each *B*-decay event.

The Vertex Locator contains 21 silicon-strip detector stations with strips measuring the *r* and φ coordinates of traversing particles. In order to obtain highest precision, the Vertex Locator detectors are positioned at 8 mm distance to the beam line. They are placed in a vacuum container, only separated from the beam vacuum by a 0.3 mm thick aluminium window. Since the aperture of the LHC

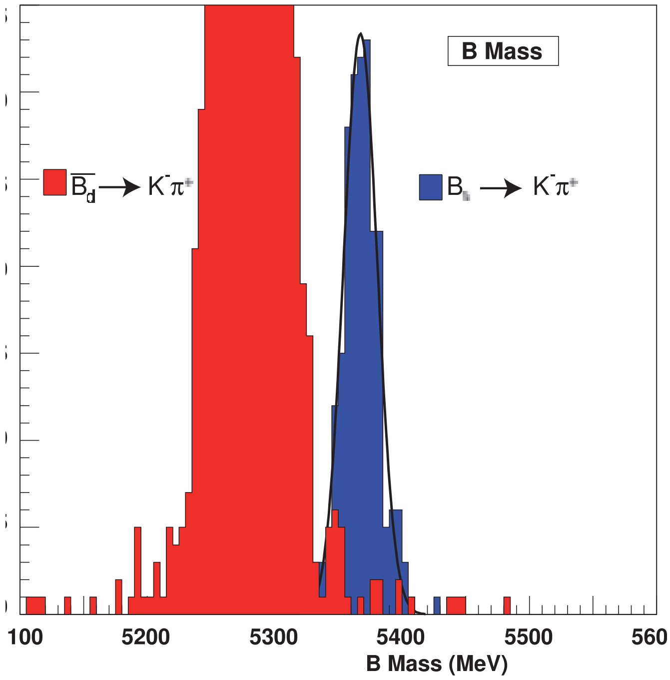


Figure 2. Mass separation between the signal decay $B_s \rightarrow K^-\pi^+$ *and the background decay* $\overline{B}_d \rightarrow K^-\pi^+$*. The mass resolution of the signal* B *decay is expected to be 13 MeV.*

Figure 3. Silicon detection stations being installed in the Vertex Locator support frame.

beam during injection is more then 8 mm this vacuum container with the detectors must be retracted during beam injection. A stepping motor system has been constructed that positions the detector planes in each fill with a reproducibility of 10 µm. Due to their positioning close to the colliding beams the detectors suffer from a large irradiation dose. To avoid damage to the detectors they are cooled to a temperature of -5°C. A prototype of the CO_2 based binary-phase cooling system has been successfully tested in a testbeam experiment at CERN.

The Vertex Locator testbeam experiment is the last validation test before installation in the experiment. The experiment includes 6 stations with final detectors as well as the final electronics (see Fig. 3). The traversing particle trajectories are reconstructed with a prototype version of the software that will be used in the final experiment.

The software required to reconstruct particle trajectories from the detector hits has been improved to adapt for possible detector misalignments. The tracks are fitted with a 3-dimensional Kalman-filter fit method and extrapolations in the magnetic field are performed with a fifth-order Runge Kutta extrapolation method. The fit accommodates non-ideally positioned detector elements as trajectories in space. In the fitting procedure these detection trajectories are compared to the particle trajectories, which results in an unbiased estimator for the particle trajectory. The fitting method incorporates multiple-scattering kinks along the trajectory and yields an average impact parameter resolution of 40 µm. Together with the reconstructed momentum of the particles *B*-decay lifetimes can be reconstructed with a precision of approximately 40 fs.

Figure 1. The first detector line of ANTARES shortly before it is being loaded onto the deployment vessel. On the left the yellow buoy is visible that keeps the line vertically in the sea water.

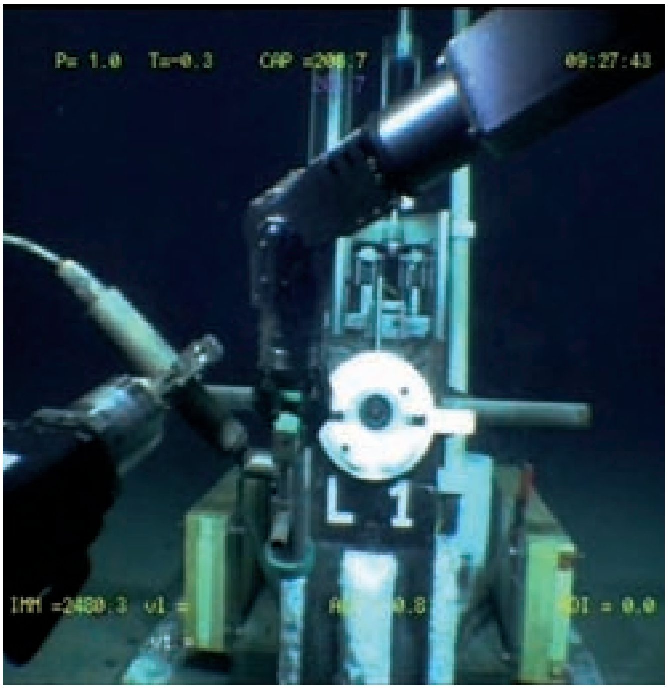


Figure 2. The anchor of the first detector line of ANTARES after its deployment on the bottom of the Mediterranean Sea at a depth of 2480 m. The mechanical arms of the 'Remotely Operated Vehicle' (ROV) are clearly visible on the picture in front of the anchor.

ANTARES

The year 2006 represents an important milestone for the ANTARES neutrino detector project. In this year the first three detector lines were deployed, and the first muon tracks have been reconstructed. In fact, it can be stated that the operation of ANTARES as a high energy neutrino telescope has begun.

Scientifically, the observation of high-energy neutrinos on the Northern hemisphere is eagerly awaited, as it enables the search for neutrinos originating from the galactic centre. Following the first observations of high-energy gamma rays from the galactic center a few years ago (by the HESS telescope), it has been speculated that the first neutrino point sources are likely to be discovered in this part of the sky. The observation of neutrino point sources would represent a scientific break-through as it could be used to address several key issues at the interface of astronomy, cosmology and physics. These issues include the origin of ultra-high energy cosmic rays, the mechanism of cosmic acceleration processes and the nature of dark matter.

The detection principle of ANTARES is based on the observation of Čerenkov light emitted by a muon produced when a neutrino interacts with an atomic nucleus in the earth. As the direction of the produced muon is almost the same as that of the original neutrino, the orientation of the muon track can be used to identify the direction of the neutrino. In order to observe and measure the timing of the Čerenkov photons the detector needs to be built in a transparent medium. At the same time the photo-sensitive detectors need to be shielded from other light sources. These requirements can be met by building a neutrino telescope on the bottom of the sea at a depth of several kilometers, where daylight does not penetrate.

Unfortunately, muons are also copiously produced in the atmosphere when a high-energy proton from space hits the outer layers of the atmosphere. Some of these muons propagate through the sea water and thus cause a background in the detector. However, atmospheric muons can be distinguished from those produced in neutrino interactions by their direction. As only neutrinos are able to penetrate the entire earth, any muon track originating from below the horizon must be attributed to an incident neutrino. At the same time the down going (atmospheric) neutrino tracks can be used to commission and test the detector.

The detector lines of ANTARES have a total length of 450 meter and carry 75 light-sensitive detectors each. By measuring the timing of the Čerenkov photons, the angle of the muon track with respect to the detector cable can be calculated. In this way the full muon track can be reconstructed. Once complete, the detector will consist of 12 detector lines, of which the first 3 were deployed in 2006. The detector is expected to be fully operational near the end of 2007 or early 2008.

After deployment each detector line is connected to the shore station by means of a submarine operation. A few hours later, the detector line is powered up and the readout process can be initiated. In this way, the first muon tracks could be reconstructed within 24 hours after the connection of the first line. These developments demonstrated the successful operation of the readout system, which was developed by the NIKHEF team in the ANTARES collaboration. Despite relatively high background rates caused by deep-sea life forms (known as bioluminescence) it has been possible to transport all data from the photo-sensitive detectors to the shore station.

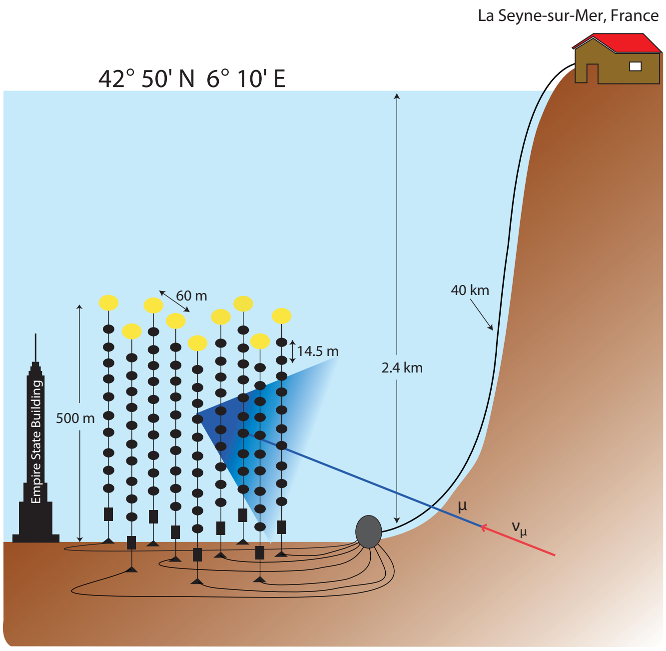


Figure 3. Detection principle of the ANTARES neutrino telescope as explained in the text.

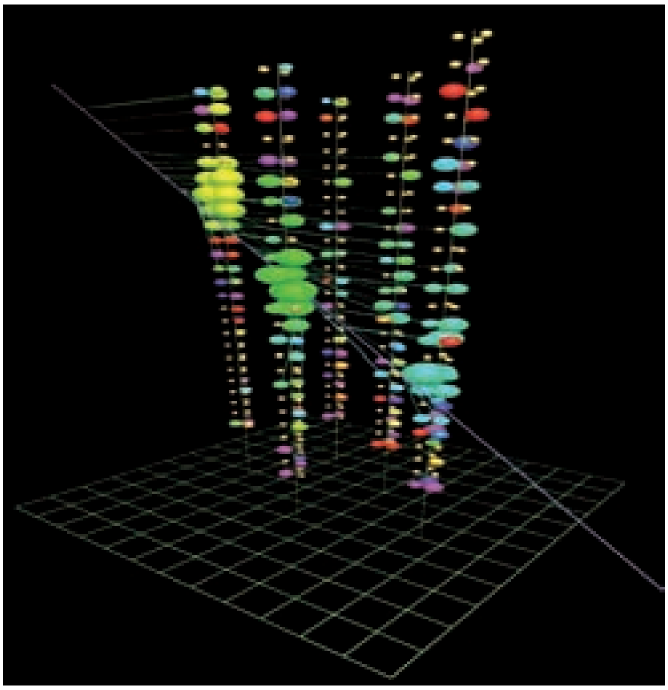


Figure 4. One of the first reconstructed events in the five current ANTARES detector lines.

Using the data collected by the first detector lines a large number of muon tracks has been reconstructed. Obviously, most tracks were down going and could be associated with atmospheric muons, but at the same time a fair number of up going muon tracks has been identified that can be associated with neutrino events. Hence, the operation of ANTARES as a neutrino telescope has successfully started.

In 2006 preparations for the next generation of deep-sea neutrino telescopes have also been initiated. A European collaboration has been formed, known under the name KM3NeT, which receives support from the 6th EU framework program to carry out a design study. The goal of this study is to arrive at a cost-efficient design of a deep-sea neutrino telescope in the Mediterranean Sea that surpasses ANTARES by a factor of 20 or more in effective volume. The design study, in which NIKHEF is strongly involved, has been officially started in the spring of 2006. The Dutch contribution to KM3NeT is focused on a new design of the optical module and the information technology. The design study will be concluded in 2009.

Figure 1. Installation of one of the NIKHEF muon chambers in the ATLAS experiment.

ATLAS nearing completion

The installation of the ATLAS detector, which will observe proton-proton collisions at a centre-of-mass energy of 14 TeV at the Large Hadron Collider at CERN, Geneva, progressed well through 2006 and is now nearly completed. NIKHEF is responsible for several major detector projects: a semiconductor tracker endcap, for precision measurements of charged tracks near the interaction point, large precision drift chambers that are used to reconstruct muon tracks, and various electronic components of the read-out system. In addition, NIKHEF has played a leading role in the development of tracking software and in the preparation of the analysis of the first data. Our goal is to find the elusive Higgs boson and signatures of new phenomena like supersymmetry.

In January 2006, not a single detector component made by NIKHEF had been installed in the ATLAS experiment yet, although 96 large muon chambers produced at NIKHEF had been shipped to CERN. These chambers, measuring about two by five meters each, count in total some 40,000 drift tubes. They are able to reconstruct the track of a muon with a precision of about 20 micrometers. This year, a team of NIKHEF scientists and technicians has installed and connected all chambers in ATLAS. Tests have shown only few problems, and the chambers have taken first data from cosmic rays.

On November 9th of 2006, a current of 20,000 Ampere was sent through the ATLAS barrel toroid coils for the first time, thus bringing into operation the world's largest superconducting magnet system. The magnetic field of this system curves muon trajectories, which makes it possible to measure the muon momentum with the muon chambers. During the toroid power-up tests, we have observed deformations of the chambers of the order of 100 micrometers, just as predicted, with our RasNik alignment system. This system, developed at NIKHEF (see Annual Report 2005), is being used throughout the ATLAS muon system and is currently being installed in the detector.

Another major NIKHEF responsibility is that of the Muon Read-Out Drivers (MROD). These are electronics boards containing roughly 3500 electronic components. We need over 200 boards to read out the muon system. In 2006 we performed extensive testing of the prototype boards at NIKHEF and at CERN. Only minor problems, which could be remedied in the firmware, were found. It was shown that the MROD output links are able to run at 50 MHz rather than at 40 MHz, which leads to an increase in bandwidth of the full system by 25%. In October 2006 a pre-series of 15 production modules was received. After correcting some small errors, a full MROD crate has been made operational at NIKHEF. Twelve MROD boards will be installed at the ATLAS pit and used in the commissioning of the muon detector.

NIKHEF has assembled one complete endcap of the semiconductor tracker (SCT) for ATLAS, which consists of some 1000 modules (1.5 million electronic channels) with silicon strip sensors for charged particle detection, mounted on nine carbon-fiber discs.

Early 2006, the last discs were equipped with sensors and all discs were mounted inside the endcap cylinder. In parallel, the cylinder was equipped with services, such as cooling circuits, power cables, and optical fibers for data communication. All sensors were then extensively tested in ATLAS-like conditions. For this purpose, a large test box and a C_3F_8 evaporative cooling machine were built. The number of defective channels is below 0.5%, and the detector noise is as expected. On April 19th and 20th, the endcap, mounted

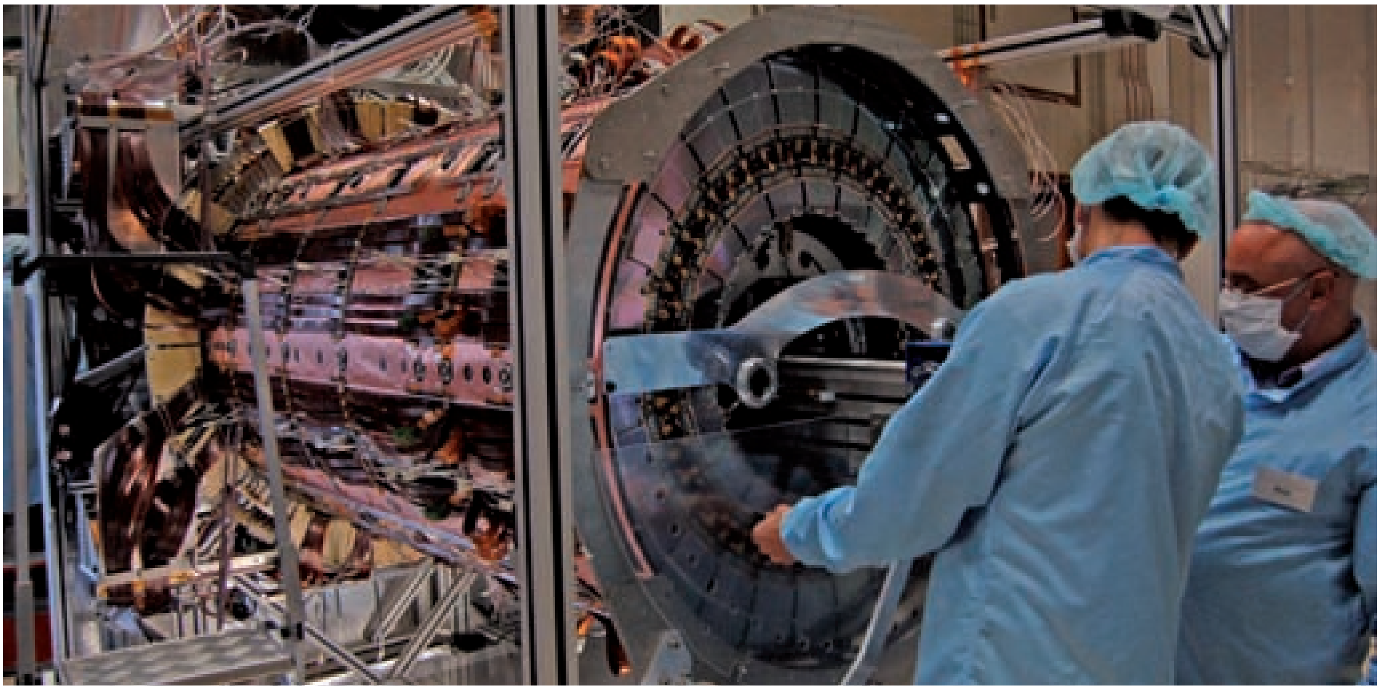


Figure 2. Installation of a semiconductor tracker (SCT) disc in the endcap cylinder.

in a transport frame, was transported to CERN, and located in a cleanroom in the surface area of the ATLAS pit. Various tests were performed upon reception to check for transportation damage, but no damage was found. The cylinder was subsequently further prepared for mounting inside an endcap of the Transition Radiation Tracker (TRT), and for installation in the pit early 2007. The other endcap is in a similar state, whereas the barrel SCT and TRT were already integrated, tested with cosmic rays, and mounted in ATLAS in the summer of 2006. NIKHEF has also re-joined the group building the silicon pixel detector, in order to help getting that detector ready for installation inside the SCT in spring 2007.

The relevance of the ATLAS research was well recognized by our funding agencies. In 2006 we welcomed the award of one NWO VICI grant (Bentvelsen), one VIDI grant (van Vulpen), one VENI grant (Klous) and 2 FOM projectruimte proposals (Bentvelsen & Kleiss and de Groot).

Physics Highlights from the DØ experiment

In preparation for the LHC, and to do physics at the high-energy frontier before LHC starts, NIKHEF physicists participate in the DØ experiment at the Tevatron (Fermilab, Chicago) where proton-antiproton collisions take place at 2 TeV. The total delivered luminosity to DØ in run 2 now exceeds 2 fb^{-1}, and some 50 papers have been published or have been accepted for publication. In March 2006, DØ was the first experiment to set an upper limit on the frequency of oscillations between B_S mesons and their anti-particles $\overline{B}_S$ mesons; the oscillation frequency is constrained to be between 17 and 21 ps^{-1} at 90% confidence level. The NIKHEF group is working on muon and tau reconstruction and *b*-quark tagging. A significant increase in *b*-tagging performance has been achieved with neural networks. This boosts the search for Higgs bosons. Apart from the Higgs boson search in the channels where the Higgs is produced in association with a W or a Z boson, NIKHEF analyses focus on the top quark mass, the jet energy scale, extra dimensions, and *b*-quark production mechanisms.

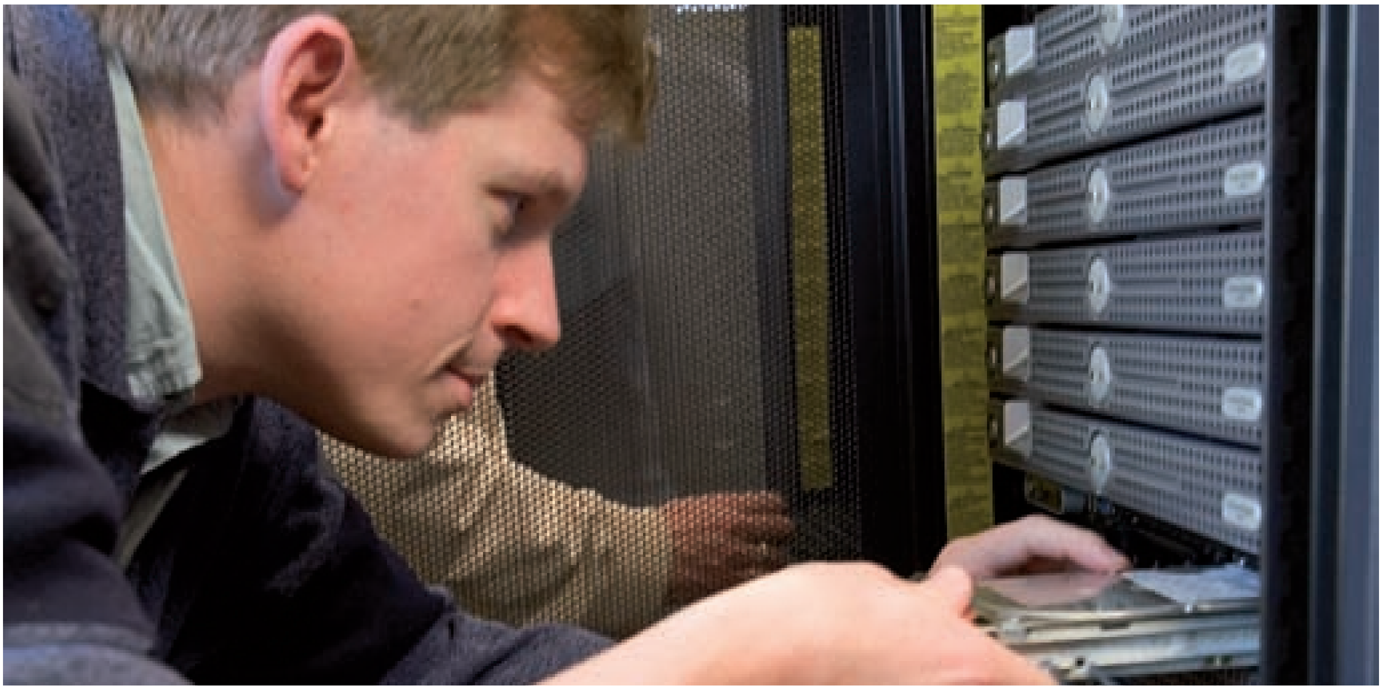


Figure 1. Installing new hardware into one of the Grid nodes.

The Grid and the Physics Data Processing Group

In the past year, investments in various areas made by our group have begun to seriously pay off.

The most important of these was the final government approval of the BIG GRID infrastructure proposal that NIKHEF, together with the Dutch Computing Foundation NCF and the Dutch Bioinformatics consortium NBIC, had submitted last year. This proposal was funded for essentially the full amount. The resulting 29 M€ provides four-year full funding for an LHC Tier-1 computing center for the ATLAS, ALICE, and LHCb experiments, a storage and computing infrastructure for the LOFAR radio astronomy experiment, and further facilities for the life sciences and social sciences.

In anticipation of the LHC turn-on next year, the resource capacities at NIKHEF and SARA are being rapidly expanded, on the order of a factor 3 for computing and a factor 10 for storage.

Several group members have received prestigious professional appointments during 2006. Sander Klous received a VENI fellowship to support his proposal of doing ATLAS remote triggering via grid technology; David Groep was appointed area director for Security in the Open Grid Forum, an international grid standards organization; and Jeff Templon was appointed to the EGEE (flagship 6th framework EU grid project) Technical Coordination Group.

The Dutch national e-Science project, 'VL-e' continues to make progress; NIKHEF staff associated with VL-e released the first version of the project middleware during 2006. Our colleagues at DANS (Data Archival and Networked Storage), responsible for archiving of social-science results, stored their first data on the grid during 2006.

Some numbers indicating the scale of the operations here during 2006:

- number of DØ Monte-Carlo events our group generated: 32,437,271;
- years of computer time provided to the LHC experiments: 226
- number of grid jobs run : 320,000;
- amount of LHC data permanently stored : 40 terabytes (together with SARA).

During the coming year, effort will be focussed on the large increase in computing and storage resources in the Tier-1, in preparation for LHC turn-on in late 2007.

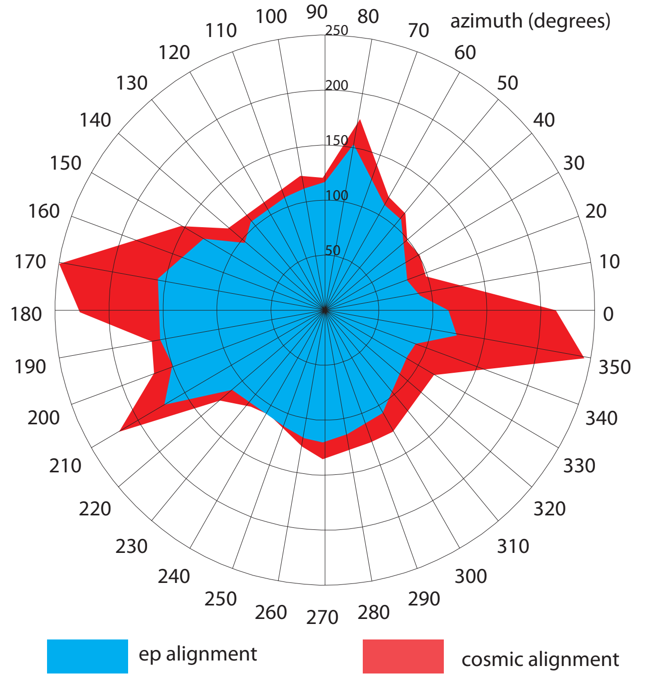


Figure 1. The impact parameter resolution as a function of azimuth for data after alignment with cosmic ray particles and after alignment using ep data.

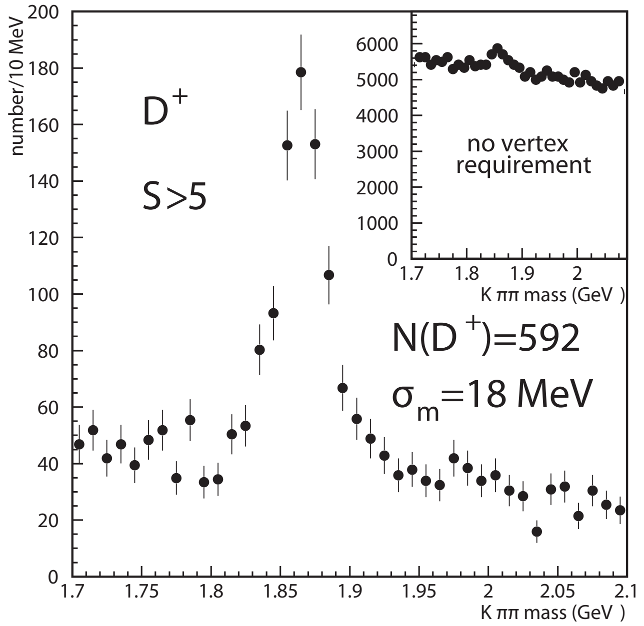


Figure 2. Charged charm meson reconstruction from its decay into Kππ.

Perfecting the ZEUS detector

In the ZEUS experiment, 2006 has been spent in optimizing the microvertex detector, while the data have steadily been streaming in. In order to obtain a significant improvement in the measurement of the charm- and possibly the bottom-quark structure functions it is necessary to collect a large amount of data and combine this with the best possible reconstruction of the events.

The accelerator has performed very well on the first score having provided an integrated luminosity of some 250 pb^{-1}. The main emphasis of the analysis group has been producing the best possible reconstruction. Most notably, a programme of alignment of the silicon microvertex detector has been carried out. Up to now the alignment had only been performed with cosmic-ray particles. Although this provides very clean data, it has its disadvantages: cosmic rays come predominantly vertically from above and so tend not to provide any information for the alignment of the detector modules that cover the sides of the interaction region.

Now that the accelerator has started producing large quantities of data with little background (in contrast to the first years of running with the microvertex detector) it has become possible to select events of relatively low multiplicity and use them to align the full detector. This has been a major effort and has taken the best part of the year to come to the final alignment. This has produced a pronounced improvement in the accuracy with which tracks can be reconstructed. As is shown in Fig. 1 the accuracy for the reconstruction of the impact parameter of a track with respect to a vertex has improved from 200 micron to around 100 micron. Especially for tracks in the horizontal direction the improvement is very significant.

In the 2005 Annual Report we already showed that the use of the microvertex detector gave pronounced improvement in the reconstruction of events containing charm particles. Now, we have indications that the resulting charm signals will become even more significant. To further improve the reconstruction of charm particles several new algorithms have been developed. One of these, where the decay products of the charm particle are combined into a single 'track' that is then fitted to the primary vertex, where a selection can be made on the goodness of fit, has already (with the old alignment) led to an increase in signal-to-noise ratio of almost a factor two without loss of events. A result is shown in Fig. 2 where the new algorithm was used to extract the $D^{\pm}$ signal. The amount of data used for this figure is about one tenth of the final sample.

The ZEUS collaboration is now busy reanalyzing all its data with the renewed alignment of the microvertex detector and is preparing for the best charm structure function measurement ever in the coming year.


PORT

Education & Outreach

Figure 1. Properly dressed members of the jury of the 'Techniek Toernooi ' take their jobs very seriously, and have fun!

Figure 2. Students figuring out which particles they observe during the second European Master class at NIKHEF in March 2006.

Education

Students & schools

Particle physics is a complex but interesting subject for high school students. In 2006 seven schools visited NIKHEF, sometimes requested by teachers; sometimes students brought their class and teacher with them. On mostly Friday afternoons, visiting students attend lectures, watch a documentary on particle physics and get a tour at NIKHEF, meanwhile having the opportunity to ask all their questions.

The 8th of June 2006 the second edition of the 'Techniek Toernooi' was organised. This is a match for primary school kids on several subjects and started in the World Year of Physics 2005. More than 400 children of sixty primary schools travelled to the 'Land van Ooit' in Drunen, with more than a hundred ideas, installations and prepared works. Five NIKHEF professors participated in the jury, making all kids happy with a certificate and some with a prize as well.

For high school students we had the following activities:

- A new possibility for the general public as well as for high schools is to have a physicist lecturing e.g. at school. On our website we published a tool that teachers or students can use to apply for a lecture on a particle physics topic. Our goal is to encourage the interactions between scientists and high-school students. We hope that the lectures are an additional tool that high schools will embrace. Note that this initiative is not only open to high schools, but to other organisations as well.

- Teachers regularly borrow our cloud and spark chambers. Currently, our muon lifetime device is being modified for transport to schools as well.

- The 'profielwerkstuk' is a research project that students have to perform in their final year at Dutch high school. In 2006 ten students performed a project on (astro)particle physics, either at NIKHEF or at school with help from NIKHEF.

- In March the second European Master class on Particle Physics for high school students was organised. Sixty students tried to figure out whether the real events displayed were muons, tau particles or something else. The final video conference connection with quiz, with the other groups of students following simultaneously a similar master class elsewhere in Europe, was a bit long. However, most students stayed to discuss the results and hear what their colleagues thought about the events they analysed.

- During the Open Day in October we tried to attract more young visitors than in previous years by publishing a Quantum Quiz especially for students of age 12–18. An extra incentive for them to walk around was the iPod they could win.

A new initiative is our participation in the curriculum development of physics taught at high schools. NiNa (Nieuwe Natuurkunde) is the name of the new physics curriculum, and NLT (Natuur, Leven en Techniek) is a new subject students and schools can choose to offer and to follow. All courses are under construction. Working groups of teachers and institutes are developing readers and other material. NIKHEF participates in three modules: Quantum and Relativity, and Cosmic rays, both for NiNa, and a module on astroparticle physics for NLT. Through these initiatives we develop a good connection with Dutch physics education and solid ground for more physics students and more physics interest and knowledge in society.

Figure 3. A high level of concentration is needed when you are soldering…

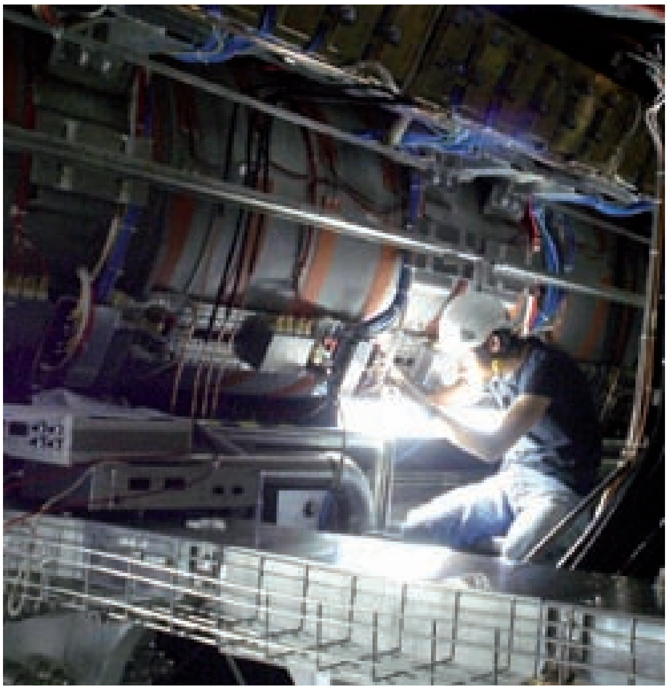


Figure 4. One of our PhD students working in the heart of the ATLAS detector.

HiSPARC

The HiSPARC project, where universities and scientific institutes such as NIKHEF work together with high schools to unravel the mysteries of cosmic rays, e.g. their origin, is continuously expanding. Six new detectors have been constructed in 2006. To accommodate the growing numbers of participants new hard- and software has been developed. The new data-acquisition system is capable of sampling the detector output at a considerably higher resolution for considerably lower costs.

With more than 40 detector stations, and counting, the amount of data stored increases rapidly. Since all data are accessible through the internet, efficient and easy-to-use tools are needed to search the database and study the results. A basic analysis tool to estimate the position and direction of the cosmic-ray shower displayed on Google-maps is used to inspire the students. This tool has been successfully introduced at the third high-school symposium for students held in Amsterdam. To support the teachers and students new material has been made available through a Virtual Learning Environment.

Cosmic rays do not stop at the border and in September the second international Cosmic Ray School Project meeting took place in Lisbon. This was a follow up of the meeting of 2005 organized in Amsterdam. Under the name of 'Eurocosmics' projects from all over Europe work together to set up a collaboration to use each other's expertise. In the coming year this collaboration will be extended and intensified.

Master of Science in Particle and Astroparticle Physics

Thirty master students of four different Dutch universities and three foreign universities are currently enrolled in the master programme Particle and Astroparticle Physics. Ten of them are female, a remarkably large fraction for Dutch standards. Together they represent a new generation of (astro)particle physicists.

Fifteen of them are second-year students, of which seven spent several weeks at CERN, working on projects in various research groups. The inspiring, international environment of CERN made them enthusiastic for a career in particle physics research. In September this year, they felt well prepared to start their one-year master thesis research work in the various groups at NIKHEF.

The first-year students followed the programme of physics courses, among which courses in particle physics, particle detection and statistical data analysis, all given by lecturers working as senior physicists at NIKHEF. In the traditional NIKHEF project, they practice on a small scale working in a typical research environment of a particle physics experiment. This year, their task is to upgrade the HiSPARC detectors.

Research School Subatomic Physics

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

Figure 5. Students at the 2006 Summerschool in Bad Honnef.

Throughout the year, the members of the research school's board organize one or two interviews ('C3 gesprekken') with each PhD student and his/her promotor and thesis advisor to monitor the progress of his/her research project and his/her participation in the Topical Lectures and the BND summerschool.

The 2006 BND summerschool was held in Bad Honnef near Bonn. The main focus was on the strong interactions. The school was widely appreciated by the 43 (14 Belgian, 18 Dutch and 11 German) registered particpants. It was organized by prof. Achim Stahl and Aachen University.

As usual, also in 2006 three Topical Lectures were organized: one dealing with statistical methods, one on astroparticle physics and one on precision tests of the Standard Model at low energies. The typical attendance of the Topical Lectures was 20–25 PhD students during the morning sessions (lectures) and 15–20 PhD students during the afternoon sessions (exercises).

Regarding administrative matters: 69 PhD students were enrolled in the Research School in December 2006 and 9 PhD students graduated in 2006. Also in 2006 the school was re-approved by the Royal Dutch Academy of Sciences (KNAW) for a period of 5 years.

Since December 2004 prof. Nicolo de Groot from the Radboud Universiteit Nijmegen is secretary and the coordination of the school is in the hands of the Radboud Universiteit.

Outreach

Science Communication

To structure our outreach efforts we are developing a communication plan. Furthermore, we are working on communication strategies for the start-up of the LHC and astroparticle research activities occurring in the Netherlands. Some of the projects that the science information office has worked on in 2006 will be discussed below in some more detail.

The design and implementation of a novel NIKHEF website is a large project, which has so far remained rather invisible to NIKHEF employees because its launch is planned for 2007. The new design includes a separation between local information on the intranet and a site for the general public.

We updated the design of the NIKHEF central entrance. Information on each of the current NIKHEF projects has been visualised on new information panels in the NIKHEF entrance hall. Although the panels contain some written information on the projects, the primary goal is to draw the attention and curiosity of visitors with attractive graphics. The panels can be carried to schools or conferences as well, and free cards of these panels are available in both Dutch and English. This is the first step in creating a NIKHEF style in our building, publications, and so forth. All these changes to a single NIKHEF brand will continue in 2007.

Students do not always believe what professors tell them during high school master classes…

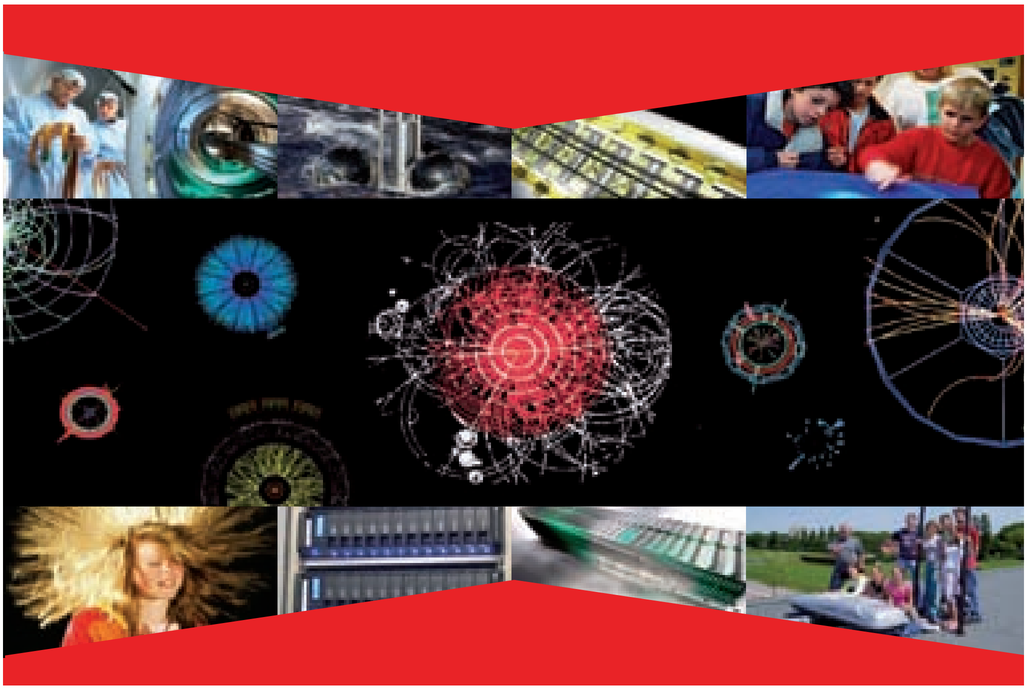


Figure 6. NIKHEF has isssued some free postcards, high-lighting the different experiments and groups; the 'general' postcard is shown above.

Media

Ongoing business consists of preparing news items for the website and for our funding agency FOM and our university partners, press releases, talking to reporters and photographers visiting NIKHEF and CERN, editing papers of those reporters, and of course talking to NIKHEF employees to hear what is going on! We keep reporters and photographers informed on our scientific progress, and they contact us themselves as well. The publications resulting from contacts with the media appear on our website as well as on paper in the library.

A group of ten Dutch science reporters visited CERN early June to see for themselves how interesting and extraordinary this place is. The aim was to show them around, so that they have a better impression on what they will be writing about when the LHC will be turned on. The day was very successful with a very busy programme in which we managed to see, amongst others, ATLAS, LHCb, the bending magnets. Some reporter comments: "You know it is big, but now that you see it you think, yes, it is really big…" And: "When you read an article there is always a point where readers think: no, you haven't really been there. We can now write without readers thinking that". The visit was an initiative of CERN, FOM and NIKHEF, and has resulted in a lot of publicity.

Specialties

The long awaited movie about the Higgs search was finished after one day of extra shooting at NIKHEF in May 2006: 'Het Massa Mysterie'. The DVD consists of eighteen minutes about the Higgs search, theory and construction of the detectors, and features many NIKHEF employees.

Theatre group Adhoc is planning to make a documentary on the Higgs particle, featuring Peter Higgs and co-workers. NIKHEF contributes to the making of this movie, which is due to be on air by 2008.

In 2006 FOM celebrated its 60th birthday. NIKHEF participated in the birthday manifestation on the 20th of November in the Kurhaus (Scheveningen). Two out of of three NIKHEF PhD students managed to reach the final match 'Win de toekomst' on this day. On November 25th FOM personnel celebrated the anniversary in an ear-shattering evening in DeFabrique in Maarssen.

CERN visits

Besides the mentioned media visit in June, other groups visited CERN this year. In March 2006, part of the NIKHEF staff visited CERN for two days. After being impressed by the ATLAS detector and the bending magnets, they went skiing as well. It was a good opportunity to see what our colleagues are working on when they are not at NIKHEF. As usual, students of the UvA, HOVO (elderly) and Honours students visited CERN as well.

Open Day

The open day was held on Saturday the 21st of October 2006, in the National Science Week, and together with all other institutes at the Science Park. We estimate that between one and two thousand people visited NIKHEF. Early birds were kept outside until noon, where they were entertained by a musical family with their instruments and songs. During the day the musicians directed visitors to activities which were not so busy. A new and quite successful initiative.

Figure 7. NIKHEF support staff visited CERN in March. Here they pose after a visit to the LHC magnet facility.

At four o'clock, the musicians took care of the winner of the Quantum Quiz for high school students: Jurjen Boog, student at the OSG De Meergronden in Almere, 17 years old. Approximately fifteen students seriously filled in the quiz.

13:00–13:15	Piet Mulders, Energie, massa en deeltjes
13:45–14:00	Jan Willem, van Holten, Rimpels in de ruimte
14:30–14:45	Frank Linde, Het Bernini Mysterie: tussen fantasie en werkelijkheid

Programme of the mini-lectures on the Open Day 2006

Several short lectures were held in the lecture room on the third floor. This was quite successful, as the room was filled for all three talks. The lecture by Frank Linde, on the book 'Angels and Demons' by Dan Brown, had been announced beforehand in a Dutch newspaper (NRC) and was given twice because of the enormous public interest.

In the Spectrum, physics experiments were shown by enthusiastic employees. At first, the Van de Graaff generator was considered a bit frightening, but after a few demonstrations, the kids forgot about their fear and enjoyed their hair being pulled up by some strange force. Dutch television (Talpa) used this as a preview of the National Science Week 2006.

Although a lot of our products were transported to CERN during 2006, we managed to exhibit many interesting displays and demonstrations on our research projects. Next year we will figure out a way to let people walk around in NIKHEF, so that they see all the interesting parts. One possibility is to offer a guide. This may be helpful for people that want to know more about our research, but do not dare to ask too much. The remarks on the open day were generally very positive.

Outreach collaborations

We communicate with other science communicators in the Netherlands as well as at the Science Park Amsterdam to coordinate activities and requests. Furthermore, we attend international outreach meetings with the same purpose.

LHC communication

NIKHEF participates in the Large Hadron Collider experiments, and therefore also in their outreach activities. ATLAS has an outreach group meeting twice a year in the ATLAS week. Outreach material is developed at these meetings, for example the ATLAS puzzle, which was finished and for sale this year.

We regularly have contacts with other outreach officers of the experiments that NIKHEF participates in (LHCb and ALICE), as well as with the CERN communication office. Press releases are communicated beforehand, and if suitable we prepare local versions of them to be launched at the same time.

InterAction Collaboration

The 22 members of the InterAction collaboration meet twice a year at member laboratories or at a particle physics conference. At these meetings the present members report on their institute, discuss the communication challenges they are facing and strategic communication and practical tools are discussed.
In 2006 the InterAction Collaboration met at KEK (Japan) and DESY (Germany). The KEK meeting dealt exclusively with the International Linear Collider (ILC) communication. At DESY, LHC, ILC press

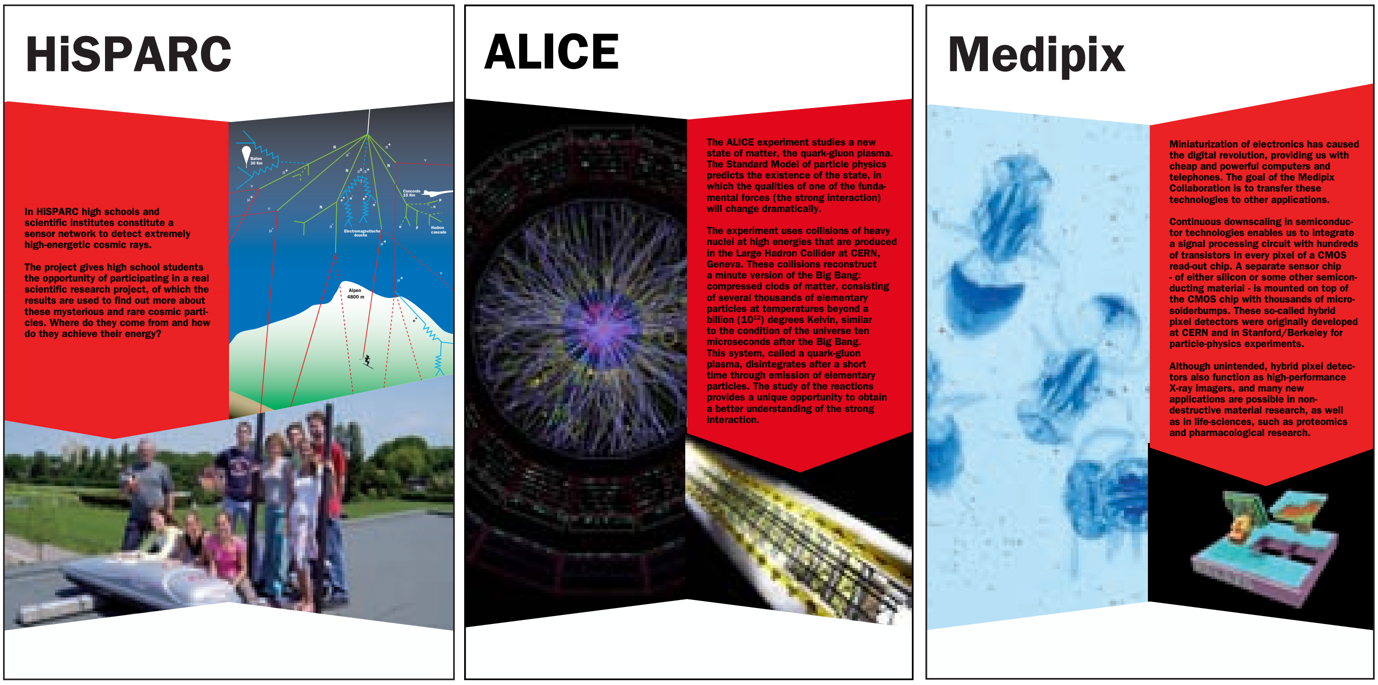


Figure 8. NIKHEF free postcards, high-lighting the different experiments and groups.

release workshop, and communicating with lab's neighbors were important items on the agenda.

The website www.interactions.org is going strong, featuring a news wire, image bank, daily news articles and many more resources for communicators of particle physics. Other examples are a website for the communication about the LHC at CERN (www.interactions.org/LHC), joint press releases and reaching out to the physics community and science writers through the Interactions.org news wire.

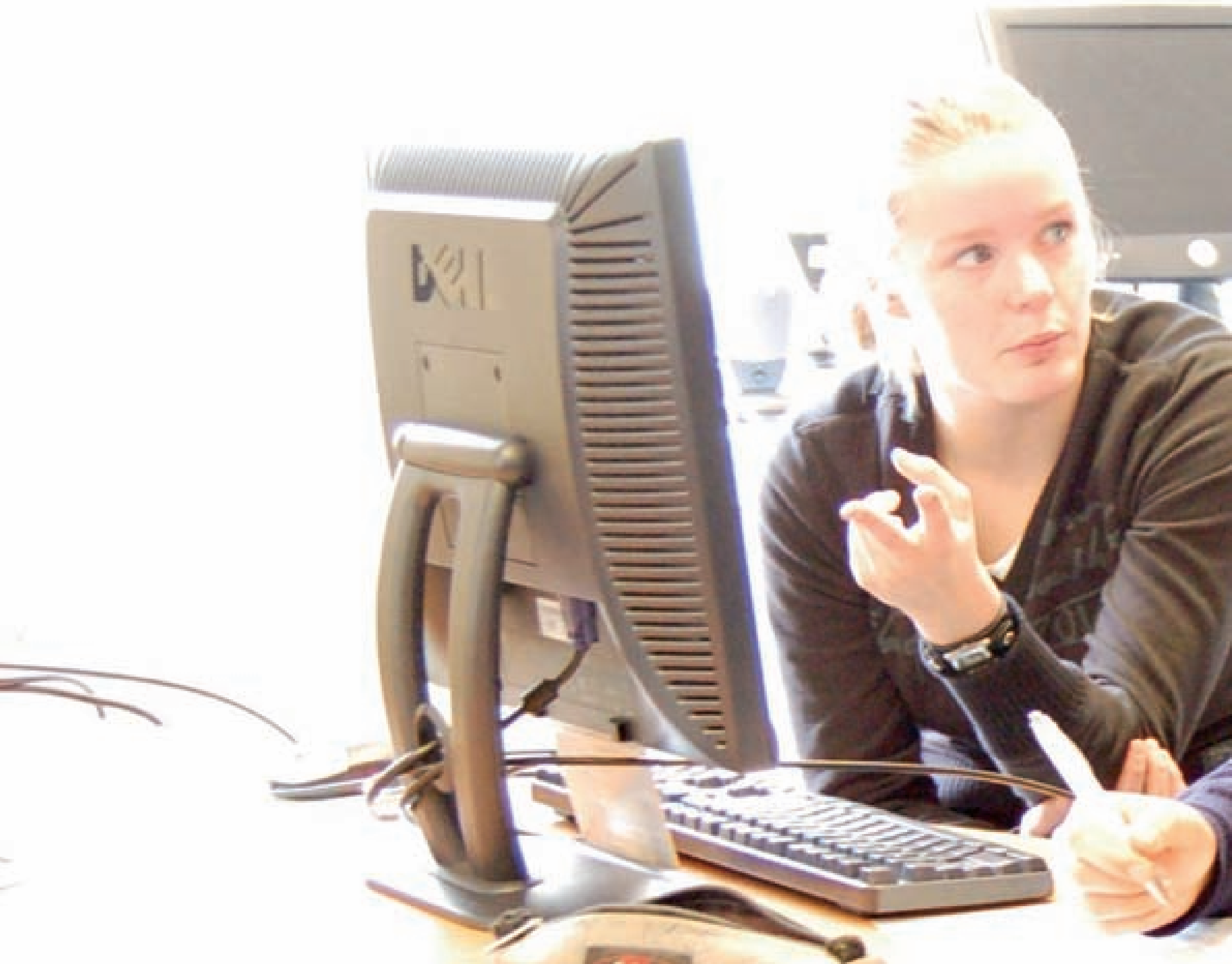
EPPOG

The European Particle Physics Outreach Group (EPPOG) concentrates on the development of hands-on physics tools for students and the general public.

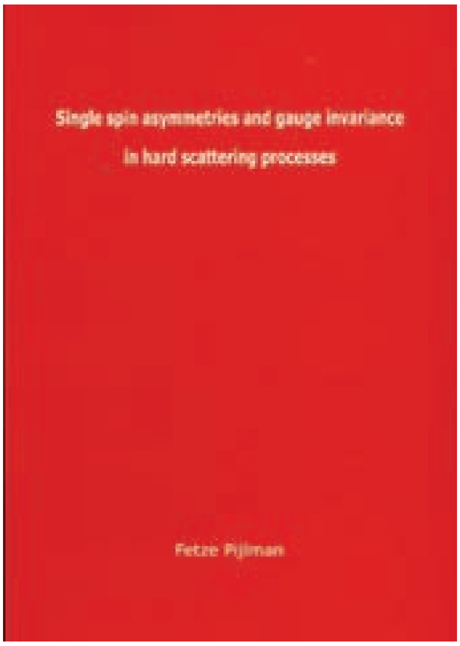
This year two meetings were held, one in London and one at CERN. One of the main topics was trying to find a way to realize exhibitions in science museums together with the European Network of Science Centres and Museums (ECSITE) and national initiatives. We are discussing with the Dutch Science Centre NEMO about starting an exhibition on (astro) particle physics. EPPOG also coordinates the European Master classes each year in March, and communicates about student material and local projects, such as the use of spark and cloud chambers and muon detection devices.

Figure 9. Reporters at CERN are impressed: "You know it is big, but now that you see it you think, yes, it is really big…"

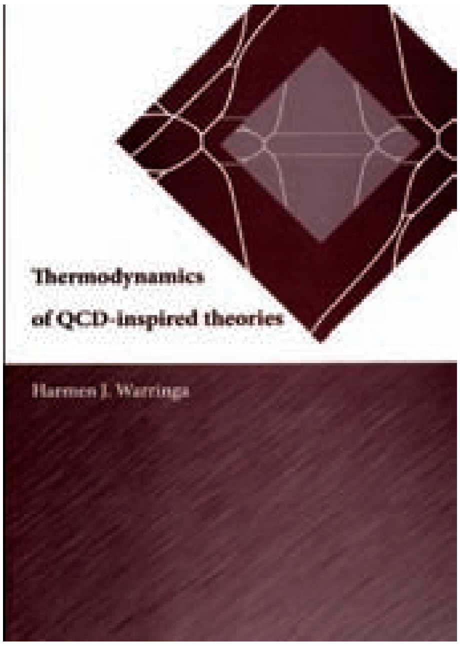

De stille kracht
De kracht die ons met beide benen op de grond houdt is zo alledaags, dat hij alleen nog opvalt als je van je fiets valt. Maar voor wetenschappers is het een hoofdbreker: zij proberen rimpelingen van de zwaartekracht in het laboratorium te vangen.
De onmetelijke lichtheid van de zwaartekracht
'Wij zouden nu deeltjes kunnen gaan vinden waar de theorie geen raad mee weet. Dat is natuurlijk prachtig'
Sander Klous zoekt mee naar mysterieus Higgs-deeltje
Giga-apparaat jaagt op minideeltje
In de ingewanden van
CERN
Oerknalsoepmeter
Jarenlang sleutelden wetenschappers op de zevende
etage van het Buijs Ballotlaboratorium in Utrecht aan
het Internal Tracking System, een onderdeel van de
ALICE-detector. Inmiddels wacht het in Genève op
installatie in de Large Hadron Coll
De melkweg gezien vanaf de zeebodem
Trouw
ZON GEEFT SCOOTMOBIEL PIT
OP JACHT NAAR
ONBEKENDE DEELTJES



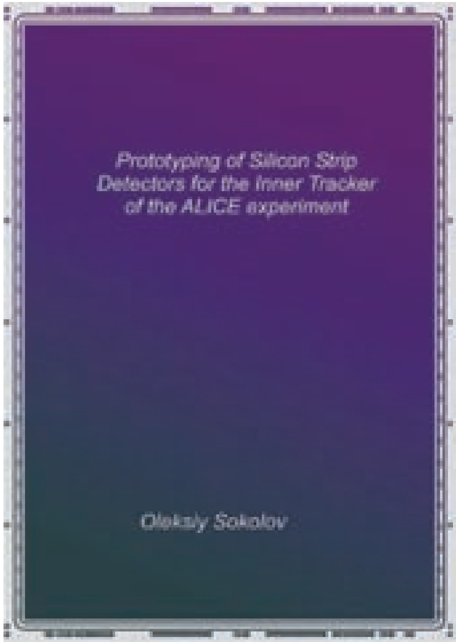
Theses, Publications & Talks



Vrije Universiteit Amsterdam, 10 January 2006



Vrije Universiteit Amsterdam, 28 February 2006



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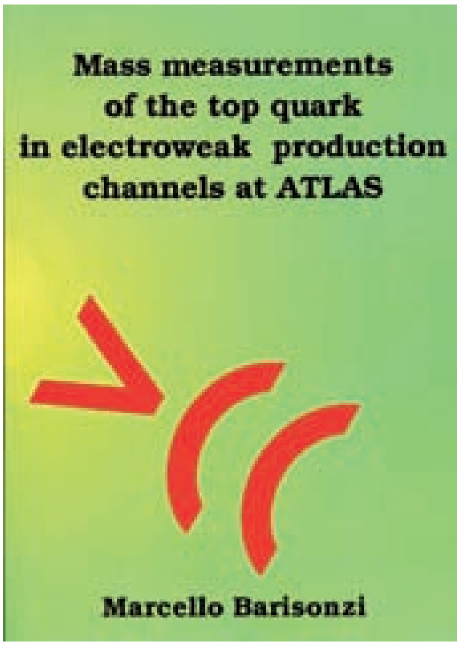

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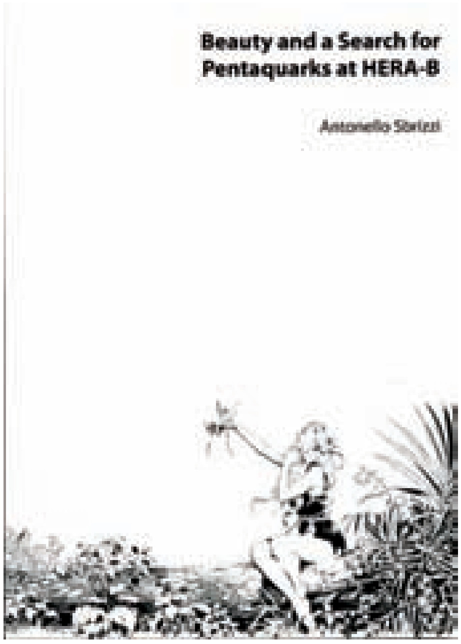

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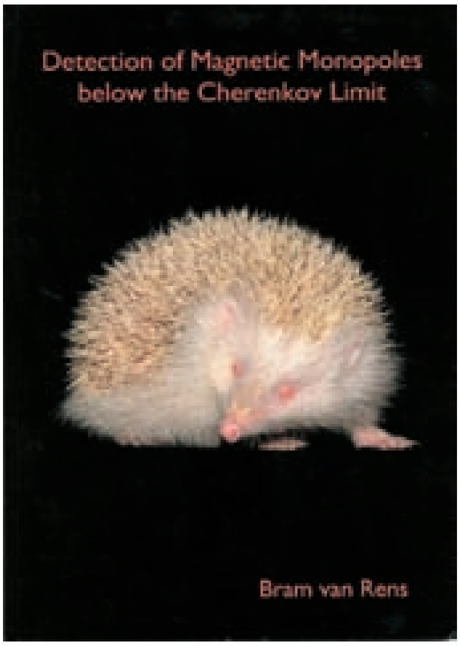

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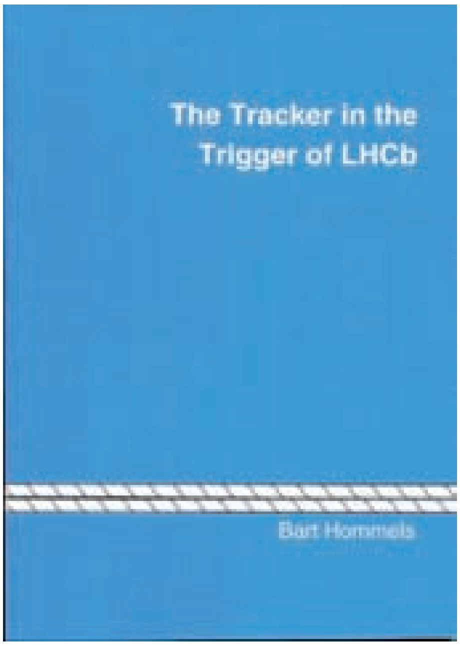

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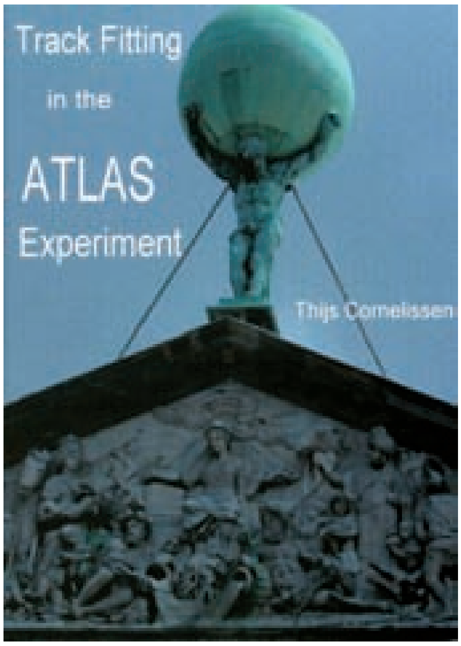

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Theoretical and Experimental Challenges of Semi–Inclusive Deep Inelastic Scattering, Workshop on Inclusive and Semi–Inclusive Spin Physics with High Luminosity and Large Acceptance – TJNAF, Newport News, USA, 14 December 2006

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Do vortons form? 30 years of cosmic strings, Lorentz Center, Leiden, The Netherlands, 6 September 2006

Density perturbations in SUSY hybrid inflation with cosmic strings, Galileo Galilei Institute, Florence, Italy, 25 October 2006

Schellekens, A.N., Beyond the Standard Model, AIO–School THEF (10 lectures), Zeist, The Netherlands, 23 January 2006

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Sightseeing in the Landscape, Ecole Polytechnique, Paris, France, 26 April 2006
Sightseeing in the Landscape, Landelijk Seminarium THEF, Amsterdam, The Netherlands, 19 May 2006

Sightseeing in the Landscape, Workshop on String Vacua and the Landscape, Trieste, Italy, 31 May 2006

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The why and how of three loop QCD, DESY, Zeuthen, Germany, 30 November 2006

The mathematics of Feynman diagrams, University of Eindhoven, Eindhoven, The Netherlands, 13 December 2006

Detector R&D

Chefdeville, M.A., The pixel readout of gaseous detector, Third symposium on large TPC for low energy rare event detection, Paris, France, 12 December 2006
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Discharge Protection and Ageing of Micromegas Pixel Detectors, IEEE–NSS Conference, San Diego, USA, 29 October 2006

Gromov, V.V., Prototype of the Front–end Circuit for the GOSSIP (Gas On Slimmed Silicon Pixel) Chip in the 0.13µm CMOS Technology., Inst. de Fisica Corpuscular and University of Valencia, Valencia, Spain, 28 September 2006

Schrader, J.H.R., Wireline equalization using pulse–width modulation, IEEE Custom Integrated Circuits Conf., San Jose, USA, 10 September 2006

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Direct readout of gaseous detectors with tiled CMOS pixel circuits, 10th Topical Seminar on Innovative Particle and Radiation Detectors, Siena, Italy, 2 October 2006

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ZEUS

Grigorescu, G., Heavy Flavour Production in ep Collisions, 13th International QCD Conference, Montpellier, France, 3 July 2006

Keramidas, A., Heavy flavour production in ep collisions, XXXVI International Symposium on Multiparticle Dynamics, Rio de Janeiro, Brazil, 2 September 2006

Koffeman, E.N., Experience with the ZEUS vertex detector, Vertex Workshop 2006 , Perugia, Italy, 25 September 2006

Figure 1. Harry van der Graaf, giving an overview of detector R&D at the NIKHEF Jamboree.

Figure 2. Ingrid Kraus, giving an overview of the ALICE experiment at the NIKHEF Jamboree.

NIKHEF Jamboree 2006

Monday 18 December 2006

09:30 Welcome (Frank Linde)
09:35 LHC status (Jos Engelen, CERN)
10:00 ATLAS (Stan Bentvelsen)
- ATLAS overview (Wouter Verkerke)
- Tracker and Tracking for ATLAS (Wolfgang Liebig)
- Status of the ATLAS muon spectrometer (Zdenko van Kesteren)

11:30 DØ (Stan Bentvelsen)
- DØ (Sijbrand de Jong)
- Top mass measurement in DØ (Pieter Houben)

12:00 Theory (Eric Laenen)
- A tool to study matter in extreme conditions: The 2PI effective action (Alejandro Arrizabalaga)
- MC@NLO and single top production (Patrick Motylinski)

14:15 Dark Matter: Shaping Cosmic Structure (invited) (Rien van de Weygaert, RUG)
15:30 Astro Particle Physics (Gerard van der Steenhoven)
- Introduction (Gerard van der Steenhoven)
- First muon tracks in Antares (Ronald Bruijn)
- KM3NeT (Els de Wolf)
- Pierre Auger Observatory (Charles Timmermans)
- Status of Virgo (Thomas Bauer)

Tuesday 19 December 2006

09:30 LHCb & Babar (Marcel Merk)
- Overview (Marcel Merk)
- The Advent of the Vertex Locator (Eddy Jans)
- First vertices in the Vertex Locator (Aras Papadelis)
- Tracking with a realistic detector geometry (Edwin Bos)

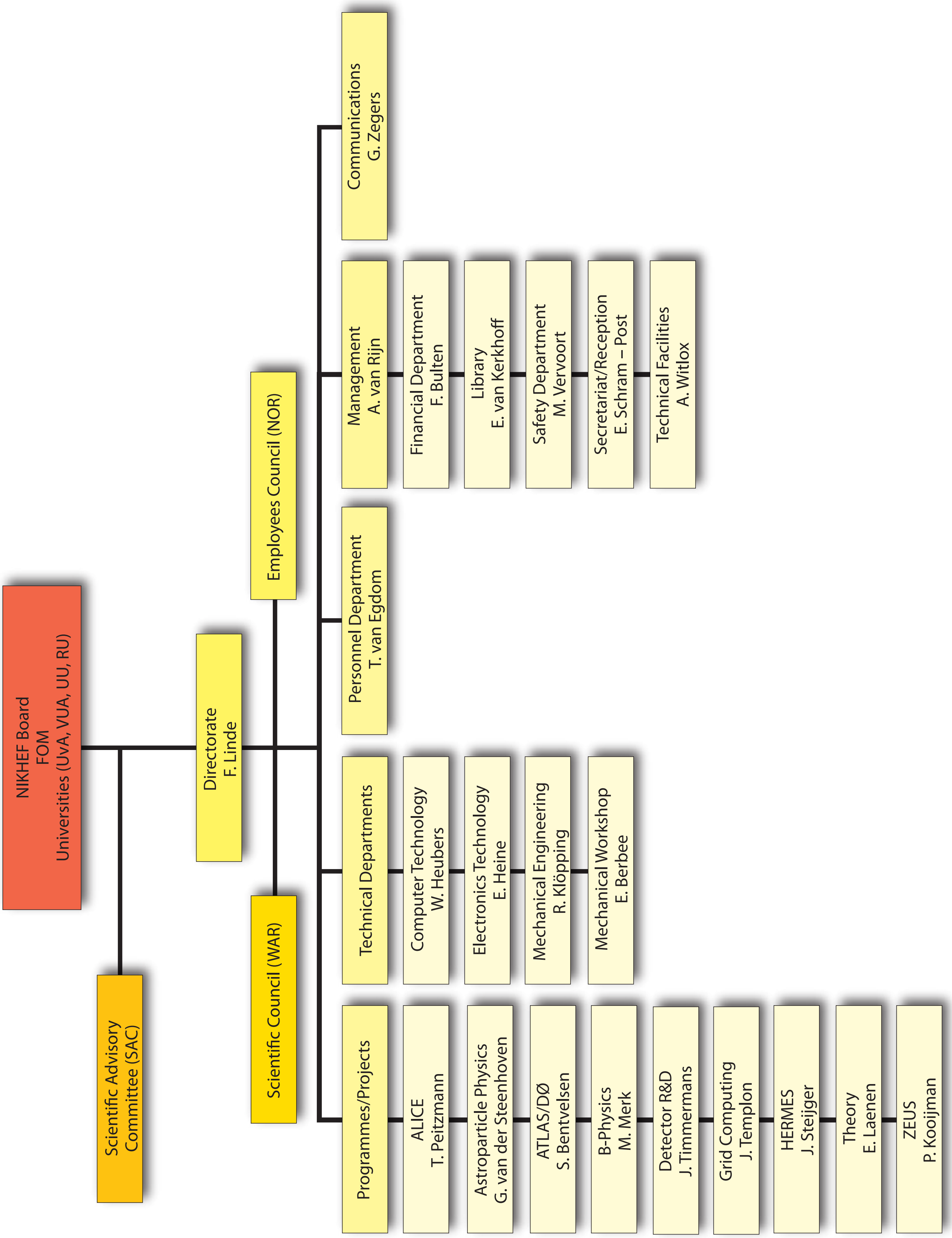
11:15 Grid (Jeff Templon)
11:35 ALICE STAR (Paul Kuijer)
- Introduction (Raimond Snellings)
- Neutral mesons and direct photons in STAR (Martijn Russcher)
- ALICE overview (Ingrid Kraus)
- ALICE SSD status (Stephane Plumeri)

14:00 HERMES
- Transverse Target Spin Asymmetry in Exlusive ρ^0 Production (Jeroen Dreschler)

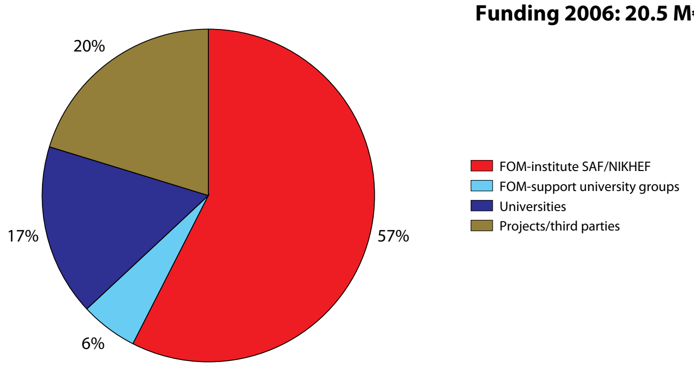
14:20 ZEUS (Gabriel Grigorescu)
14:40 Master Project - HiSparc (Lucie de Nooij)
14:55 NWO visitatie (Leo Wiggers)
15:45 R&D (Harry van der Graaf)
16:05 LHC upgrade (Nigel Hessey)
16:35 Summary talk (Frank Linde)

Resources

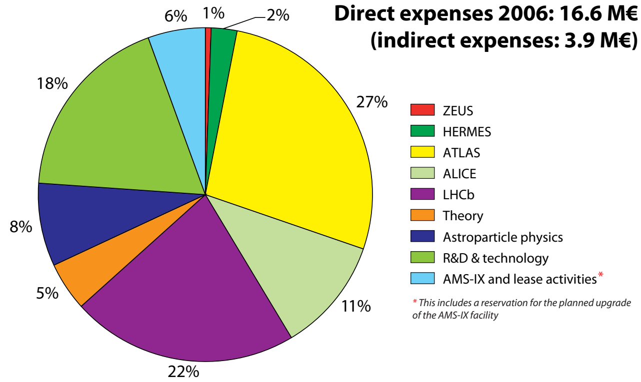
NIKHEF Organization



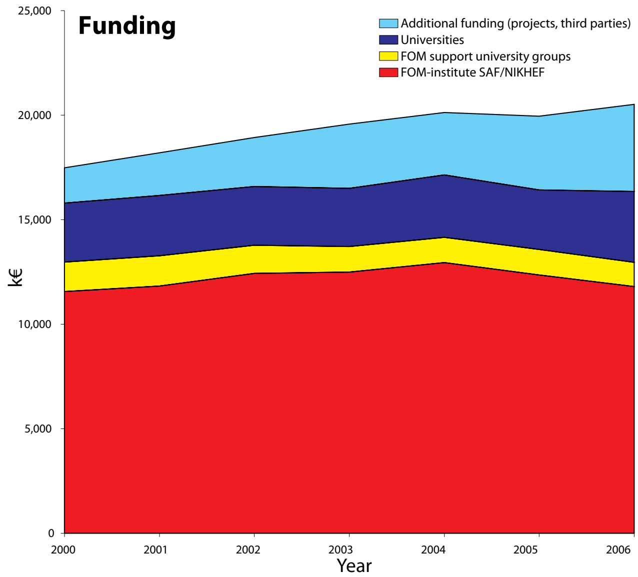
Funding 2006: 20.5 M€



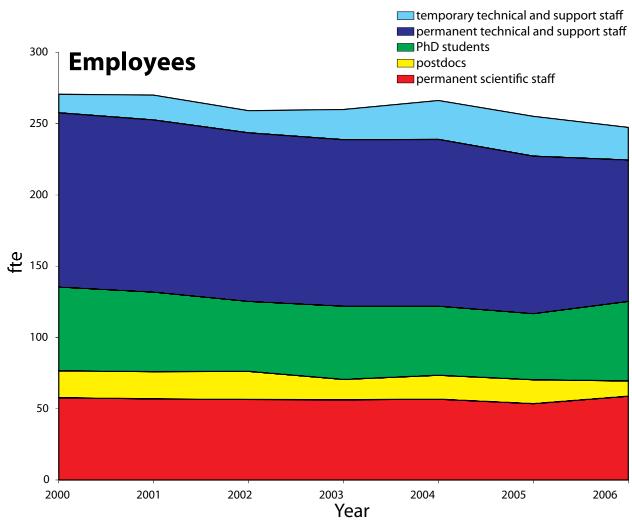
Direct expenses 2006: 16.6 M€ (indirect expenses: 3.9 M€)



Funding and Expenses



In 2006 the funding of NIKHEF has increased with about half a million euro, particularly through the universities: per 2006 two theory groups (at the Vrije Universiteit and at the Radboud Universiteit) have joined the NIKHEF collaboration. The institute's funding from FOM is now at the level of 11,8 M€, including partial compensation for 'Soest VI' (FOM's strategy document for the years 2005–2010, which encompasses a further reduction of NIKHEF's base budget). As in the previous year NIKHEF has succeeded in 2006 in balancing this downward trend with external (mostly non-structural) funding for a total of 4,2 M€. These external sources consist of fees from customers of the Internet Exchange housing facility (1.45 M€), rental income (0.5 M€) and project funding from various sources (FOM, NWO, SENTER, EU, etc.). This funding will continue to be needed in order for NIKHEF to at least maintain its current level of activities.



The number of employees within the NIKHEF collaboration has decreased in 2006 from 255 fte to about 248 fte, largely due to retirement of personnel and ending contracts of temporary (mainly technical) staff. We observe a slow increase of temporary scientific staff (PhD students and postdocs) to prepare for the analysis phase of the LHC experiments.

From the expenses in 2006 27% was consumed by the ATLAS program, 22% by LHCb and 11% by ALICE, in total 60% for the LHC experiments. The HERA experiments are now coming to an end, representing only 3% of the expenses. Astroparticle physics activities have increased to 8%, due to NIKHEF's participation in the EU funded 'KM3NeT'-project.

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Astroparticle Physics European Coordination
F. Linde (steering committee)
G. van der Steenhoven

Committee for Astroparticle Physics in the Netherlands
S. de Jong
F. Linde
P. Mulders
G. van der Steenhoven (chair)

Board of Computer Algebra Nederland
J. Vermaseren

Wetenschappelijke Adviescommissie KVI, Groningen
G. van der Steenhoven

NWO Bestuur Exacte Wetenschappen
R. Kamermans

Adviescommissie FOM/v programma
E. de Wolf (chair)

NNV Board
G. van der Steenhoven (treasurer)
P. Mulders (secretary)
E. de Wolf

NNV Sectie H
E. Koffeman
P. Kluit

NNV Sectie Onderwijs en Communicatie
S. de Jong (vice chair)

Redactie Nederlands Tijdschrift voor Natuurkunde
S. de Jong
P. Mulders

Program Advisory Committee Gesellschaft fur Schwerionenforschung, Darmstadt
T. Peitzmann

KNAW Raad voor Natuur- en Sterrenkunde
F. Linde
T. Peitzmann

Worldwide LHC Computing Grid Management Board
J. Templon

European Particle Physics Outreach Group
G. Zegers

InterActions
A. van den Bergen

Stichting Quality Assurance Netherlands Universities Evaluation Committee Liberal Arts and Sciences
N. de Groot

Personnel

Experimental physicists

Amoraal, drs. J.M	FOM	B-Physics
Anastasoaie, mevr. drs. C.M.	FOM-RU	ATLAS/DØ
Ancu, drs. L.S.	RU	ATLAS/DØ
Baak, drs. M.A.	FOM	B-Physics
Bai, mevr. drs. Y.	FOM	ALICE
Bauer, dr. T.S.	FOM	B-Physics
Benedosso, mevr. drs. F.	UU	ALICE
Bentvelsen, prof. dr. S.C.M.	UvA	ATLAS/DØ
Berg, drs. P.J. van den	FOM	ATLAS/DØ
Blok, dr. H.P.	GST	HERMES
Bobbink, dr. G.J.	FOM	ATLAS/DØ
Boer, dr. F.W.N.	GST	Other Projects
Bos, drs. E.	FOM	B-Physics
Bos, dr. K.	FOM	Other Projects
Botje, dr. M.A.J.	FOM	ALICE
Bouwhuis, mevr. dr. M.C.	FOM	Astroparticle Physics
Braidot, drs. E.	FOM-UU	ALICE
Brand, prof. dr. ing. J.F.J. van den	VU	B-Physics
Bruijn, drs. R.	UvA	Astroparticle Physics
Bruinsma, ir. P.J.T.	GST	Other Projects
Bulten, dr. H.J.	VU	B-Physics
Chefdeville, drs. M.A.	FOM	Other Projects
Colijn, dr. A.P.	UvA	ATLAS/DØ
Colle, dr. J.J.H.C.	GST	HiSPARC
Colnard, mevr. drs. C.M.M.	FOM	Astroparticle Physics
Coppens, mevr. drs. J.M.S.	FOM	Astroparticle Physics
Cornelissen, drs. T.G.	FOM	ATLAS/DØ
Dantzig, dr. R. van	GST	Other Projects
Decowski, dr. M.P.	FOM	Astroparticle Physics
Demey, drs. M.	GST	HERMES
Djordjevic, drs. M.	GST	ATLAS/DØ
Doxiadis, drs. A.D.	FOM	ATLAS/DØ
Dreschler, drs. J.	FOM	HERMES
Duinker, prof. dr. P.	GST	Other Projects
Eijk, prof. dr. ing. B. van	FOM	ATLAS/DØ
Eijndhoven, dr. N. van	UU	ALICE
Eldik, dipl. phys. N. van	FOM	ATLAS/DØ
Engelen, prof. dr. J.J.	UvA	Other Projects
Ennes, drs. P.	FOM	ATLAS/DØ
Ferreira Montenegro, mevr. drs. J.	GST	Other Projects
Filthaut, dr. F.	RU	ATLAS/DØ
Galea, mevr. drs. C.F.	FOM	ATLAS/DØ
Gosselink, ir. M.	FOM	ATLAS/DØ
Graaf, dr. ir. H. van der	FOM	ATLAS/DØ
Grebenyuk, drs. O.	FOM	ALICE
Grigorescu, drs. G.T.	FOM	ZEUS
Groep, dr. D.L.	FOM	Other Projects
Groot, prof. dr. N. de	RU	ATLAS/DØ
Harmsma, ir. S.	FOM	Astroparticle Physics
Hartjes, dr. F.G.	FOM	ATLAS/DØ
Hegeman, ir. J.G.	UT	ATLAS/DØ
Heijne, dr. ir. E.H.M.	GST	Other Projects
Herzberger, prof. dr. L.O.	GST	Other Projects
Hesselink, dr. W.H.A.	GST	HERMES
Hessey, dr. N.P.	FOM	ATLAS/DØ
Hoogland, prof. dr. W.	GST	Other Projects
Houben, drs. P.W.H.	FOM	ATLAS/DØ
Hulsbergen, dr. W.	GST	B-Physics
Igonkina, mevr. dr. O.B.	GST	ATLAS/DØ
Ivan, ir. C.G.	FOM-UU	ALICE
Jans, dr. E.	FOM	B-Physics
Jansen, drs. E.	FOM	ATLAS/DØ
Jansen, ir. F.M.	FOM	B-Physics
Jong, prof. dr. S.J. de	RU	ATLAS/DØ
Jong, prof. dr. M. de	FOM	Astroparticle Physics
Jong, dr. ir. P.J. de	FOM	ATLAS/DØ
Kamermans, prof. dr. R.	FOM-UU	ALICE
Keramidas, drs. A.A.	FOM	ZEUS
Kesteren, drs. Z. van	UvA	ATLAS/DØ
Ketel, dr. T.J.	FOM-VU	B-Physics
Kirby, dr. M.H.	FOM-RU	ATLAS/DØ
Klok, drs. P.F.	FOM-RU	Other Projects
Klous, dr. S.	FOM	ATLAS/DØ
Kluit, dr. drs. P.M.	FOM	ATLAS/DØ
Koetsveld, drs. F.	FOM-RU	ATLAS/DØ
Koffeman, mevr. prof. dr. ir. E.N.	FOM	ATLAS/DØ
Kolk, mevr. drs. ing. N. van der	FOM	ALICE
Koenig, dr. A.C.	RU	ATLAS/DØ
Konijn, dr. J.	GST	Other Projects
Kooijman, prof. dr. P.M.	UvA	Astroparticle Physics
Koutsman, drs. A.J.	FOM	ATLAS/DØ
Kraaij, drs. E.E. van der	FOM	ATLAS/DØ
Kraus, mevr. dr. I.C.	FOM	ALICE
Kuijer, dr. P.G.	FOM	ALICE
Laan, dr. J.B. van der	FOM	Other Projects
Lapikás, dr. L.	FOM	HERMES
Li, drs. Z.	RU	Other Projects
Liebig, dr. W.	FOM	ATLAS/DØ
Liempt, drs. F.J.P. van	FOM	HiSPARC
Lim, ir. G.M.A.	UvA	Astroparticle Physics
Limper, mevr. drs. M.	UvA	ATLAS/DØ
Linde, prof. dr. F.L.	FOM	Directorate
Lingeman, dr. E.W.A.	GST	Other Projects
Lysebetten, mevr. dr. A. Van	FOM	B-Physics
Magrath, mevr. MSc C.A.	UvA	ATLAS/DØ
Mangano, dr. S.	FOM	Astroparticle Physics
Massaro, dr. G.G.G.	FOM	ATLAS/DØ
M'charek, mevr. drs. B.	VU	B-Physics
Merk, prof. dr. M.H.M.	FOM	B-Physics
Metzger, dr. W.	GST	Other Projects
Middelkoop, prof. dr. G.	GST	Other Projects
Nardulli, drs. J.	FOM-VU	B-Physics
Nat, drs. P.B. van der	FOM	HERMES
Nooren, dr. ir. G.J.L.	FOM-UU	ALICE
Ordonez Sanz, drs. G.	RU	ATLAS/DØ
Papadelis, drs. E.A.	FOM	B-Physics
Peitzmann, prof. dr. T.	UU	ALICE
Pellegrino, dr. A.	FOM	B-Physics
Petrovic, mevr. dr. J.	FOM	Astroparticle Physics
Plumeri, dr. S.	FOM-UU	ALICE
Pree, drs. T.A. du	FOM	B-Physics
Presani, mevr. drs. E.	FOM	Astroparticle Physics
Putten, drs. S. van der	FOM	Astroparticle Physics
Raven, dr. H.G.	VU	B-Physics
Rens, ir. B.A.P. van	GST	Astroparticle Physics
Reischl, drs. A.J.	GST	HERMES
Rijpstra, mevr. drs. M.	FOM	ATLAS/DØ
Rodrigues, dr. E.M.	FOM	B-Physics
Russcher, drs. M.J.	FOM-UU	ALICE

Schrader, ir. J.H.R.	GST	Other Projects
Simili, drs. E.L.	FOM-UU	ALICE
Simioni, drs. E.	FOM-VU	B-Physics
Snellings, dr. R.J.M.	FOM	ALICE
Snippe, ir. Q.H.C.	FOM	Other Projects
Snoek, mevr. drs. H.L.	FOM	B-Physics
Snuverink, ir. J.	FOM	ATLAS/DØ
Steenhoven, prof. dr. G. van der	FOM	Astroparticle Physics
Steijger, dr. J.J.M.	FOM	HERMES
Tanczos, mevr. dr. I.C.	FOM	HiSPARC
Templon, dr. J.A.	FOM	Other Projects
Timmermans, dr. C.W.J.P.	FOM	ATLAS/DØ
Timmermans, dr. J.J.M.	FOM	Other Projects
Toet, dr. D.Z.	GST	Other Projects
Tomasek, ing. L.	GST	Other Projects
Tuning, dr. N.	FOM-VU	B-Physics
Vankov, drs. P.H.	FOM	B-Physics
Verkerke, dr. W.	FOM	ATLAS/DØ
Vermeulen, dr. ir. J.C.	UvA	ATLAS/DØ
Visschers, dr. J.L.	FOM	Other Projects
Vreeswijk, dr. M.	UvA	ATLAS/DØ
Vries, dr. H. de	FOM	B-Physics
Vulpen, dr. I.B. van	FOM	ATLAS/DØ
Vykydal, drs. Z.	GST	Other Projects
Wang, drs. Q.	RU	Other Projects
Wiggers, dr. L.W.	FOM	B-Physics
Wijnker, drs. G.P.J.C.	FOM	Astroparticle Physics
Witt Huberts, prof. dr. P.K.A. de	GST	Astroparticle Physics
Wolf, mevr. dr. E. de	UvA	Astroparticle Physics
Ybeles Smit, drs. G.V.	FOM	B-Physics
Zupan, drs. M.	FOM	B-Physics

Theoretical physicists

Arrizabalaga, dr. A.	FOM
Beenakker, dr. W.J.P.	RU
Boer, dr. D.	VU
Bomhof, drs. C.	FOM-VU
Boomsma, MSc. J.K.	VU
Dijkstra, drs. T.P.T.	GST
Fuster, mevr. drs. A.	FOM
Gaemers, prof. dr. K.J.F.	UvA
Gato-Rivera, mevr. dr. B.	GST
Gmeiner, dr. F.K.	FOM
Holten, prof. dr. J.W. van	FOM
Kleiss, prof. dr. R.H.P.	RU
Koch, prof. dr. J.H.	FOM
Koekoek, drs. G.	VU
Koers, drs. H.B.J.	UvA
Laenen, prof. dr. E.L.M.P.	FOM
Motylinski, MSc. P.	FOM
Mulders, prof. dr. P.J.G.	VU
Postma, mevr. dr. M.E.J.	FOM
Rijken, dr. T.A.	RU
Schellekens, prof. dr. A.N.J.J.	FOM
Veltman, prof. dr. M.J.G.	GST
Vermaseren, dr. J.A.M.	FOM
Wessels, drs. E.	FOM-VU
White, dr. C.D.	FOM
Wit, prof. dr. B.Q.P.J. de	UU

Figure 1. Nobel prize laureate prof. Tini Veltman (left) hands over the first prize of the FOM competition 'Win the future' to Marc Kea (right). Technician Henk Groenstege and TU Delft student Marc Kea -who both work at NIKHEF- won with their project 'RasClic: a new seismograph'.

Computer Technology Group

Akker, T.G.M. van den	FOM
Blokzijl, dr. R.	GST
Boterenbrood, ir. H.	FOM
Damen, ing. A.C.M.	FOM
Deurzen, dr. P.A.J. van	GST
Dok, drs. D.H. van	FOM
Geerts, M.L.	FOM
Harapan, drs. D.	FOM
Hart, ing. R.G.K.	FOM
Heubers, ing. W.P.J.	FOM
Huyser, K.	FOM
Kan, A.C. van	FOM/Rijnhuizen
Keijser, drs. J.J.	FOM
Koeroo, ing. O.A.	FOM
Kuipers, drs. P.	FOM
Leeuwen, drs. W.M. van	GST
Michielse, dr. ir. P.H.	GST
Oudolf, J.D.	QUADO
Schimmel, ing. A.	FOM
Starink, dr. R.	FOM
Tierie, mevr. J.J.E.	FOM
Venekamp, drs. G.M.	FOM
Wijk, R.F. van	FOM

Electronics Technology Group

Berkien, A.W.M.	FOM
Beuzekom, dr. ing. M.G. van	FOM
Fransen, J.P.A.M.	FOM
Gotink, G.W.	FOM
Groen, P.J.M. de	FOM
Groenstege, ing. H.L.	FOM
Gromov, drs. V.	FOM

Haas, ing. A.P.J. de	FOM
Heine, ing. E.	FOM
Hogenbirk, ing. J.J.	FOM
Jansen, L.W.A.	FOM
Jansweijer, ing. P.P.M.	FOM
Kieft, ing. G.N.M.	FOM
Kluit, ing. R.	FOM
Koopstra, J.	UvA
Kruijer, A.H.	FOM
Kuijt, ing. J.J.	FOM
Mos, ing. S.	FOM
Peek, ing. H.Z.	FOM
Reen, A.T.H. van	FOM
Schipper, ing. J.D.	FOM
Sluijk, ing. T.G.B.W.	FOM
Stolte, J.	FOM
Timmer, P.F.	FOM
Tona, Y.	FOM
Verkooijen, ing. J.C.	FOM
Vink, ing. W.E.W.	FOM
Zwart, ing. A.N.M.	FOM
Zwart, F. de	FOM

Mechanical Engineering Group

Arink, R.P.J.	GST
Band, ing. H.A.	FOM
Boer Rookhuizen, ing. H.	FOM
Buskop, ir. J.J.F.	FOM
Doets, M.	FOM
Klöpping, ir. R.	FOM
Korporaal, A.	FOM
Kraan, ing. M.J.	FOM
Munneke, ing. B.	FOM
Schuijlenburg, ing. H.W.A.	FOM
Thobe, P.H.	FOM
Verlaat, ing. B.A.	FOM

Mechanical Workshop

Berbee, ing. E.M.	FOM
Boer, R.P. de	FOM
Brouwer, G.R.	FOM
Buis, R.	FOM
Ceelie, L.	UvA
Homma, J.	FOM
Jaspers, M.J.F.	UvA
John, D.	FOM
Kok, J.W.	FOM
Kuilman, W.C.	FOM
Leguyt, R.	FOM
Mul, F.A.	FOM-VU
Overbeek, M.G. van	FOM
Petten, O.R. van	FOM
Rietmeijer, A.A.	FOM
Roeland, E.	FOM
Roevekamp, J.C.D.F.	UvA

Management and Administration

Barneveld, mevr. K.M. van	FOM
Berg, A. van den	FOM
Bergen, mevr. A.M. van den	FOM
Bulten, F.	FOM
Dekker, mevr. C.E.	FOM
Dokter, J.H.G.	FOM
Echtelt, ing. H.J.B. van	FOM
Egdom, T. van	FOM
Faassen, mevr. N.F.	FOM
Greven-Van Beusekom, mevr. E.C.L.	FOM
Heuvel, mevr. G.A. van den	FOM
Kerkhoff, mevr. E.H.M. van	FOM
Kesgin-Boonstra, mevr. drs. M.J.	FOM
Kleinsmiede-van Dongen, mevr. T.W.J. zur	FOM
Langenhorst, A.	FOM
Lemaire-Vonk, mevr. M.C.	FOM
Mors, A.G.S.	FOM
Pancar, M.	FOM
Rem, drs. ing. N.	FOM
Rijksen, C.	FOM
Rijn, drs. A.J. van	FOM
Schram-Post, mevr. E.C.	FOM
Spelt, ing. J.B.	FOM
Vervoort, ing. M.B.H.J.	FOM
Vreeken, D.	QUADO
Werneke, ing. P.J.M.	FOM
Willigen, E. van	FOM
Witlox, ing. A.M	FOM
Woortmann, E.P.	FOM
Yilmaz, E.	QUADO
Zegers, mevr. drs. G.E.	FOM

Apprentices in 2006

Aaij, R.J.M.	ATLAS/DØ
Adelhart Toorop, R. de	Theory
Blankers, T.	Astroparticle Physics
Blom, M.R.	Astroparticle Physics
Bos, mevr. E.M.	Other Projects
Bosma, M.J.	Other Projects
Cohen, S.	B-Physics
Cottini, N.	Astroparticle Physics
Derkx, X.C.B.L.	Theory
Dernier, M.J.L.	Electronics Technology
Ebeling, R.P.	Astroparticle Physics
Egmond, E. van	Mechanical Engineering
Elbers, M.C.	ZEUS
Evangelatou, D.	Other Projects
Fransen, M.	ATLAS/DØ
Geer, R. van der	ATLAS/DØ
Grange, Y.G.	Astroparticle Physics
Hartman, J.	Other Projects
Heijden, B.W. van der	Electronics Technology
Hervy, W.	Personnel Department
Hessels, C.	Electronics Technology
Hessey, M.S.	ATLAS/DØ
Holten, E.F. van	HiSPARC
Jong, R.A. de	Computer Technology
Kappel, M.F.J. van	Theory
Kea, M.J.	ATLAS/DØ
Keune, A.	B-Physics
Khafaji, Salar Al	ATLAS/DØ
Klerks, E.P.	ATLAS/DØ
Klomp, M.	Electronics Technology

Figure 2. Wim Beenakker proudly shows his 'Teacher of the Year' award.

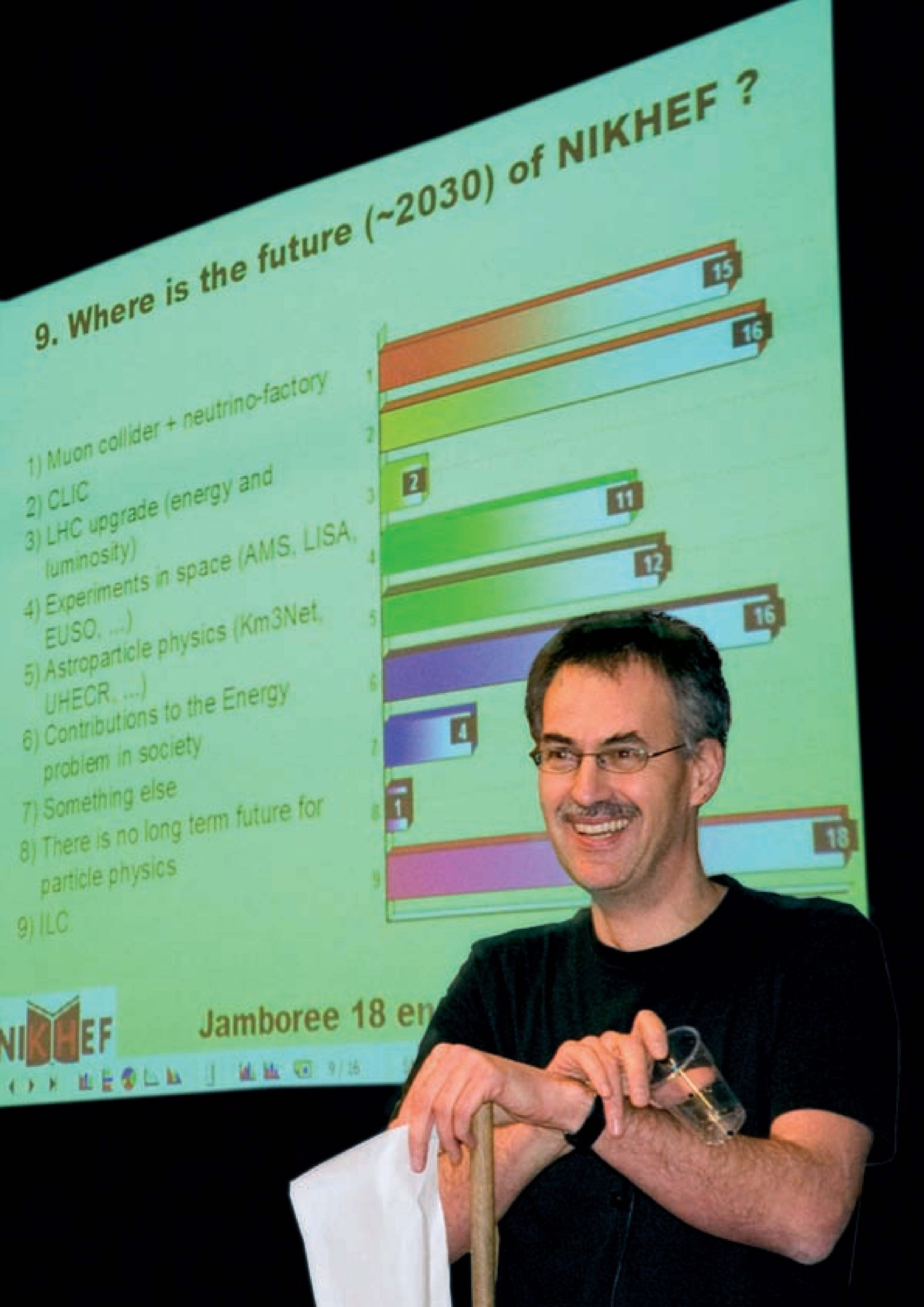
Kok, mevr. M.	ATLAS/DØ
Kok, M.O. de	Theory
Koot, M.R.	Computer Technology
Kuijken, mevr. I.	Other Projects
Lascaris, E.	Theory
Leerdam, J. van	ATLAS/DØ
Meeroeksom, mevr. Sudatip	Technical Facilities
Meester, S.	Astroparticle Physics
Mous, I.V.N.	Other Projects
Mussche, I.	Other Projects
Nederveen, M.B.	ATLAS/DØ
Nooij, mevr. L. de	B-Physics
Osei, B.	Electronics Technology
Plas, B.A. van der	ZEUS
Poel, E.F. van der	ATLAS/DØ
Pottelberghe, M.J.M.L van	ATLAS/DØ
Ruckstuhl, mevr. N.M.	ATLAS/DØ
Scholten, S.	B-Physics
Schuurmans, D.	Mechanical Engineering
Spaargaren, B.	Computer Technology
Til, S. van	Other Projects
Torres Celis, mevr. P.C.	ATLAS/DØ
Tsiakiris, M.	Other Projects
Versloot, T.W.	B-Physics
Watson, E.R.R.	Technical Facilities
Witteveen, mevr. M.L.M.	Other Projects
Zebeda, G.	Technical Facilities

They left us

Apeldoorn, dr. G.W. van	B-Physics
Arink, R.P.J.	Mechanical Engineering
Atehortua Escobar, mevr. B.E.	Mechanical Workshop
Beek, R.M. van	Mechanical Workshop
Beumer, H.	Mechanical Workshop
Blokzijl, dr. R.	Computer Technology
Brantjes, R.N.	Other Projects
Bron, M.	Mechanical Workshop
Caron, dr. S.	ATLAS/DØ
Chen, M.	B-Physics
Cornelissen, drs. T.G.	ATLAS/DØ
Dijkstra, drs. T.P.T.	Theory
Djordjevic, drs. M.	Other Projects
Duisters, ing. C.H.	Mechanical Engineering
Geer, R. van der	ATLAS/DØ
Groot Nibbelink, dr. S.	Theory
Heijden, B.W. van der	Electronics Technology
Henze, E.	Mechanical Workshop
Heutenik, B.	Electronics Technology
Horvathy, dr. P.	Theory
Jansen, F.M.	Mechanical Workshop
Kaan, ir. A.P.	B-Physics
Kop, A.	Mechanical Workshop
Lascaris, E.	HiSPARC
Lavrentyev, V.	Electronics Technology
Losekoot, mevr. G.	ATLAS/DØ
Michalowski, dr. J.J.	B-Physics
Mischke, dr. A.	ALICE
Muijs, mevr. dr. A.J.M.	ATLAS/DØ
Nawrot, dr. A.	B-Physics
Novak, drs. T.	Other Projects
Otto, J.	Electronics Technology
Peters-Muellenberg, mevr. A.G.H.	Mechanical Workshop
Reischl, dipl. phys. A.J.	HERMES
Rens, dr. ir. B.A.P. van	Astroparticle Physics
Reus, D.P.	Electronics Technology
Sbrizzi, dr. A.	B-Physics
Schrader, ir. J.H.R.	Other Projects
Silva-Marcos, dr. J.	Theory
Sluijk-Bark, mevr. M.H.	Electronics Technology
Stoffelen, N.	Mechanical Workshop
Suerink, T.C.H.	Other Projects
Thomasson, P.B.	Mechanical Workshop
Tiecke, dr. H.G.J.M.	ZEUS
Torres Celis, mevr. P.C.	Mechanical Workshop
Visser, J.	Staff
Vries, drs. G. de	Astroparticle Physics
Wapstra, prof. dr. A.H.	GST † 4-12-2006
Willemse, M.A.	Mechanical Workshop
Zajac, R.	B-Physics
Zeng, M.	B-Physics

Award Winners

Wim Beenakker	Teacher of the year, Radboud Univ. Nijmegen
Mieke Bouwhuis	Nederlands Tijdschrift voor Natuurkunde - 1st prize
Harry van der Graaf	SciencePark Competition 'Nieuwe Ideëen' - 3rd prize
Henk Groenstege	FOM60 competition 'Win the future' - 1st prize
Henk Groenstege	SciencePark Competition 'Nieuwe Ideëen' - 3rd prize
Marc Kea	FOM60 competition 'Win the future' - 1st prize
Justus Koch	Teacher Award 2006, Natuurw. Studiever. Amsterdam
Justus Koch	Teacher Award 2006, Fac. of Sciences, Univ. van Amsterdam
Antonello Sbrizzi	Van Coeverden Adrianistichting Research Award
Bart Verlaat	FOM60 competition 'Win the future' - 2nd prize
Jos Vermaseren	Humboldt Research Award
Jan Visschers	SciencePark Competition 'Nieuwe Ideëen' - 3rd prize


9. Where is the future (~2030) of NIKHEF ?
1) Muon collider + neutrino-factory
2) CLIC
3) LHC upgrade (energy and luminosity)
4) Experiments in space (AMS, LISA, EUSO, ...)
5) Astroparticle physics (Km3Net, UHECR, ...)
6) Contributions to the Energy problem in society
7) Something else
8) There is no long term future for particle physics
9) ILC
15
16
2
11
12
16
4
1
18
NIKHEF
Jamboree 18 en
9/16