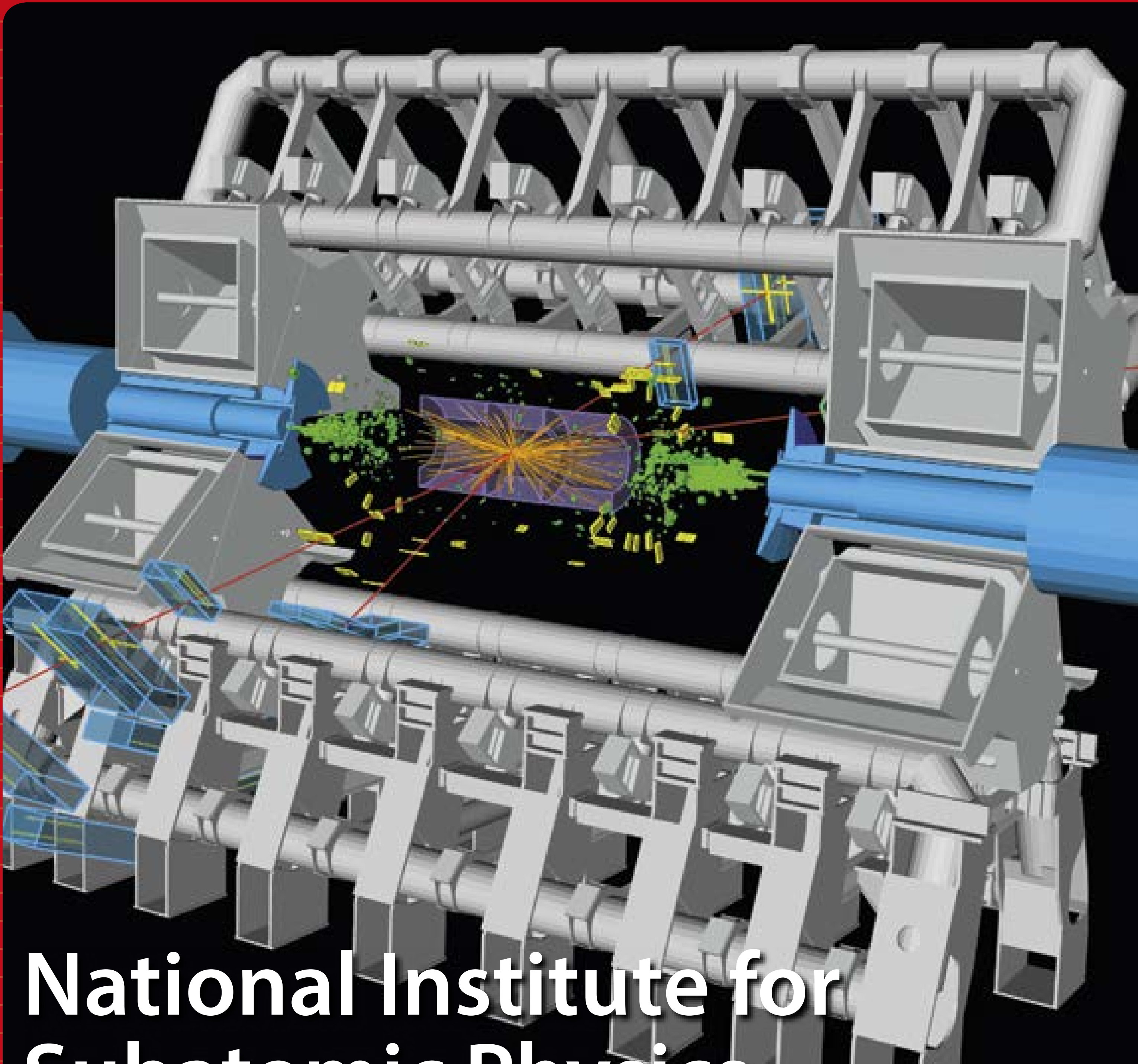
Annual Report 2012

Nikhef



National Institute for Subatomic Physics

NIKHEF

Annual Report 2012

National Institute for Subatomic Physics Nikhef

Colophon

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Front cover: Higgs event with 4 muons, compatible with the hypothesis of Z pair production where one of the Z bosons is off-shell.
Back cover: The Standard Model of particles.

Nikhef is the National Institute for Subatomic Physics in the Netherlands, in which the Foundation for Fundamental Research on Matter, the University of Amsterdam, VU University Amsterdam, Radboud University Nijmegen and Utrecht University collaborate. Nikhef coordinates and supports most activities in experimental particle and astroparticle physics in the Netherlands.

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

Contents

Introduction

"The Higgs" – is what one of the other customers exclaimed when I entered my local takeout Chinese restaurant the evening of 4 July. At home, the eight-o-clock national news opened (and continued for quite some time) with the Higgs as well. It certainly was a memorable day, the successful culmination of almost half a century of Higgs hunting. Today, six months after the Higgs discovery[1], we know its mass to a fraction of a GeV, we have measured several of its couplings, we are trying hard to assess its spin, and we have verified that its overall production rate is close to the Standard Model prediction! And while particle physicists like me are celebrating the Higgs discovery and while the general public enjoys the many public lectures, science café's and popular science publications – funding agencies once again[2] wonder whether we are done now… The answer is simple: we are not. With the Higgs being a fact we do know how particle masses can be incorporated in the Standard Model framework, but we do not have a clue about the specific particle masses. Moreover, some other subjects in particle physics remain grand challenges: the enigma of dark matter and dark energy, quantum gravity, matter-antimatter asymmetry, neutrino properties, etc. As a curious scientist I just continue on the long-time proven and immensely successful track: keep on investigating and in particular measuring! With the LHC reaching its full (design) energy in 2015 and with a blueprint for a future electron-positron linear collider in press, orders of magnitude improvement in the measurements of Higgs characteristics are feasible, as well as a first assessment of the Higgs self coupling, a direct and crucial consequence of the specific structure of the Higgs potential. I would say: stay tuned!

Apart from the monumental Higgs discovery by ATLAS and CMS, also LHCb made a major breakthrough by measuring the extremely rare branching fraction of the decay $B_s \rightarrow \mu\mu$. This decay is very sensitive to new physics phenomena beyond the Standard Model, e.g. Supersymmetry. Regretfully, the observed rate (about one in a billion) is in excellent agreement with the Standard Model prediction. Other decay channels analysed by LHCb do not yet reveal any hints of new physics either. In addition, ATLAS (and CMS) failed to observe any indication of new physics (in the LHC data accumulated so far), thereby pushing the mass limits for many hypothetical new particles to the TeV range. More progress probably has to await LHC running at the design centre-of-mass energy (14 TeV as opposed to the hitherto 7–8 TeV), foreseen to start in 2015.

1 Some purists at CERN consistently refer to the discovery of a 'Higgs-like' instead of the Higgs particle. As long as the measured characteristics of the discovered particle agree within errors with the Standard Model predictions for the Higgs particle, I consider it to be the long anticipated latter one. For me, the 'like' in Higgs-like is just a Facebook like!

2 Around 1900 many scientists considered Physics to be (nearly) complete. The following years we learned about relativity, quantum mechanics, superconductivity, neutrinos and antimatter. Just to highlight a few of the discoveries… I am already looking forward to what we will still discover in the next decade.

The mission of Nikhef is to study the interactions and structure of all elementary particles and fields at the smallest distance scale and the highest attainable energy.

Two complementary approaches are followed:

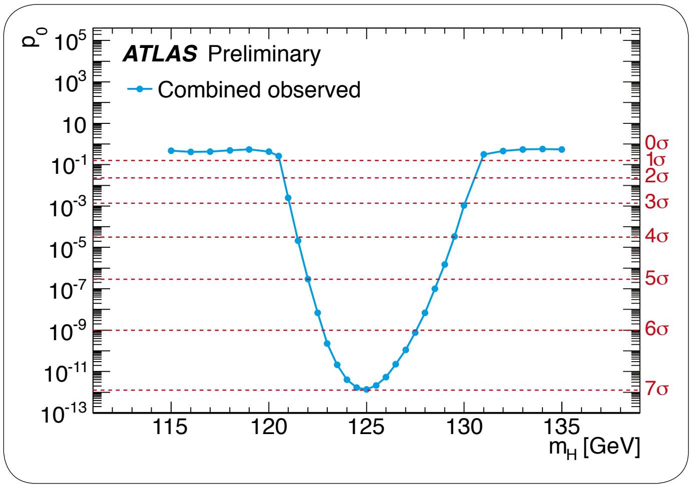
Accelerator-based particle physics
Studying interactions in particle collision processes at particle accelerators, in particular at CERN;

Astroparticle physics
Studying interactions of particles and radition emanating from the Universe.

Nikhef coordinates and leads the Dutch experimental activities in these fields. The research at Nikhef relies on the development of innovative technologies. The knowledge and technology transfer to third parties, i.e., industry, civil society and general public, is an integral part of Nikhef's mission.

Essential to the LHC success was (and still is) the flawless operation of the Worldwide LHC Computing Grid (WLCG), a network of state-of-the-art compute centres totaling 190 PB of disk space and about 180,000 CPU cores (equivalent to 0.5 million KSI2K units). One of the so called Tier-1 centres is operated jointly by Nikhef and SARA. This was made possible by the high-profile 29 M€ BiG Grid subsidy awarded in 2006 and covering the 2007–2012 period. The past years BiG Grid attracted a large and diverse scientific community, ranging from particle physics, astronomy, life-sciences and social sciences to the humanities, and offered not only Grid services, but also the High Performance Computing (HPC) Cloud environment, and the software framework Hadoop for batch processing of very large datasets. Regretfully, the BiG Grid project ended in 2012, but future structural funding of the Dutch ICT services for research has been largely secured. Meanwhile, BiG Grid marked its success by two memorable events in 2012: the *'All hands'* day for insiders in March (followed by an extremely entertaining cocktail course in the famous "House of Bols") and the *'BiG Grid & beyond'* symposium in the Beurs van Berlage on 26 September.

Leaving physics aside and switching to finances, I must conclude that 2012 was a year of extremes. The threat of budget reductions forced our funding agency FOM to revisit its spending profile. A series of –often emotional– discussions led to the decision of the FOM executive board to distribute the financial pain equally be-



Probability that the observed signals in all Higgs decay signatures simultaneously are the result of a statistical fluctuation of the background (left scale). The right scale gives the corresponding significance (number of standard deviations, σ) of the observed signal i.e. seven σ at 125 GeV.

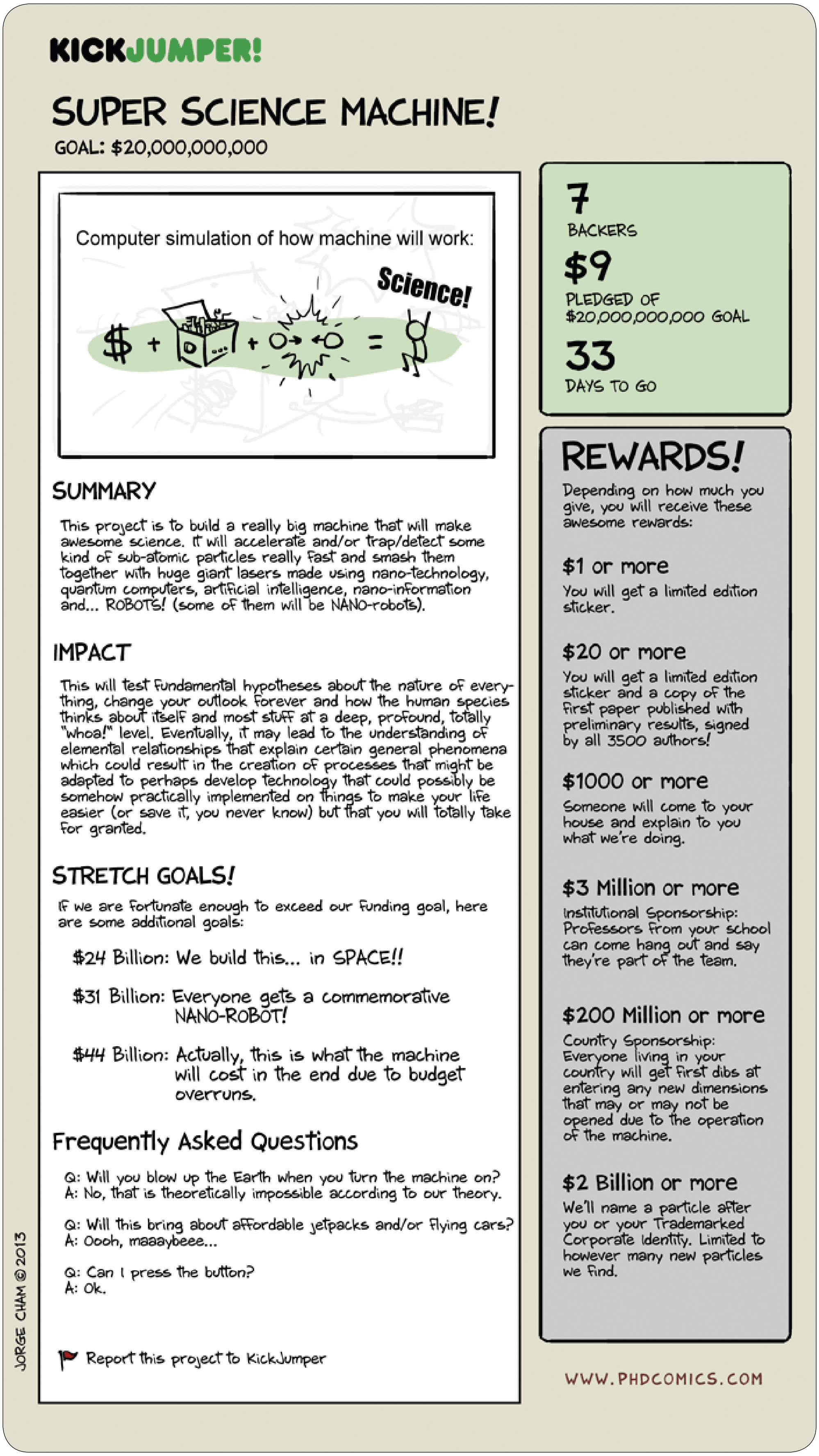
tween the three FOM institutes. Although Nikhef's research primarily produces fundamental scientific results and knowledge, it became clear in the discussions with FOM that Nikhef also contributes significantly to 'valorisation' (generating economic value). This concept, which was recently coined *"topsectorenbeleid"*, is one of the spear points of the Dutch Government.
Nikhef's pioneering activities with startup companies like Sensiflex and ASI (Amsterdam Scientific Instruments) are excellent examples hereof. Meanwhile, the FOM-institute AMOLF profited from Nikhef's startup umbrella company P2IP (Particle Physics Inside Products) via the launch of its own startup, and the Dutch chip-machine manufacturer ASML granted Nikhef a contract research project. Furthermore, Nikhef and Shell are seriously discussing a joint venture. Today, my real worry is not to collaborate with industry, but to keep it balanced. I am sure some Nikhef staff physicists already think we are devoting too much effort to industrial collaboration. I am still convinced that eventually these efforts will pay off as long as we make sure that we do not jeopardize our excellent scientific track record. Very positive news came from the European Research Council (ERC), in one round three(!) Nikhef physicists received Advanced ERC grants, the most prestigious ERC subsidy: Harry van der Graaf (innovative detector R&D), Piet Mulders and Jos Vermaseren (both in theory). Moneywise, these grants are of the same level as the highest Dutch scientific reward (the Spinozapremie) and each of them amounts to 2–3 times the Nobel prize…

In the field of astroparticle physics Nikhef's newest endeavour, the XENON direct dark matter search, received a FOM-programme subsidy, while the Virgo gravitational wave search was granted a large investment subsidy via the *'NWO-groot'* scheme. The KM3NeT deep-sea neutrino telescope project adopted the socalled string concept combined with the multi-PMT optical module as their baseline technology. This led Nikhef to step up its already substantial KM3NeT activities, notably in both its mechanics and electronics department. Together with the Auger cosmic-ray observatory, Nikhef looks forward to a discovery-rich future in the still relatively young research field of astroparticle physics.

The next few years will see some important events both in physics policy and research. In January 2013 the European Strategy for Particle Physics will be drafted. I consider this plan of great importance in particular in view of the various options for a future electron-positron machine. During its 2013–2014 shutdown period the LHC will be upgraded to allow operation at its design centre-of-mass energy of 14 TeV. Given that we already discovered the Higgs at about half of the LHC design energy and with only 1% of the planned data sample on tape, I have very high expectations of the future LHC running. In the area of astroparticle physics I hope to witness the first direct observation of a gravitational wave on Earth and it would be fantastic if XENON would discover dark matter.

Finally, for the immediate future of Nikhef: our challenge will be to find a better match between the demand for and the capacity in our technical departments. Neither continuing the extremely high workload as in 2012 is an option, nor can we afford to ignore the important demands of the LHC experiments…

Frank Linde



"Piled Higher and Deeper" by Jorge Cham www.phdcomics.com

Crowd funding, the new way to fund science?

1

1.1 Of People and Particles

Text: Laetis Kuipers

Ivo van Vulpen

Win-Win and Spin

Introduction

In the Reviews Section of the Nikhef Annual Report one normally encounters several four-page articles about scientific or technical subjects connected to one of the many fields of Nikhef's research programme. This year's discovery of the Higgs boson made the editors decide to confine the Reviews Section to the sole subject of this remarkeable scientific event. We asked Frank Filthaut and Nicolo de Groot to unveil the relation of the Higgs particle to the origin of mass and Wouter Verkerke to describe in detail what work is needed to guarantee that the fate of Higgs bosons produced in an LHC collision eventually is written down in an accepted publication. The result of their work is found in the two articles that conclude the present Reviews Section.

However, we also wanted to directly confront the reader with the enthusiasm, dedication and exertion of the scientists who participated in this enterprise. We made a selection of five involved Nikhef physicists and had them interviewed on various aspects of the discovery, the massive amount of work that preceded it, and their personal role in this research. The interviews were held by Laetis Kuipers of the *Taalcentrum VU*, while the portraits were taken by Kees Huyser.

The editors

Ivo van Vulpen works as a staff member in Nikhef's ATLAS group. "Before I joined the CERN team," Ivo says, "I had already spent four years in an earlier project investigating the Higgs boson. I was fascinated by the particle's possible existence and highly motivated to continue the search." Van Vulpen is also Assistant Professor of Physics at the University of Amsterdam. Part of his job involves teaching particle physics and explaining the Higgs mechanism in various study programmes. "I must admit that teaching the subject has made me appreciate our efforts even more, especially from a mathematical point of view. I can clearly see the beauty of finding one single, elegant solution to explain a number of fundamental issues." Other benefits following Nikhef's fundamental research concern new applications. "We have come incredibly far in terms of practical solutions," Ivo explains. "Because we were venturing into uncharted territory, we had to develop many of the tools and instruments ourselves. For instance, we built a special-purpose camera that no commercial firm could have developed on its own. Still, our main focus always lies on fundamental research: the applications were developed in the service of our core business." When it finally became evident earlier this year that the Higgs boson truly had been found, Ivo van Vulpen felt "what many people experience on the very first day following a momentous event. 'Wow, so it does exist…' is what I kept saying to myself. And the full ramifications of this wonderful new fundamental knowledge are still sinking in." Theorists claim that the Higgs particle has no spin but that it definitely has mass: enough to cause a revolution. "Finding the Higgs boson is by no means the end of particle physics," Ivo concludes, "it is a new beginning."

Pamela Ferrari

Finding the needle in the haystack

Pamela Ferrari is based at CERN, where she works as a staff member in Nikhef's ATLAS group. She has been involved in Higgs research for well over a decade. Through the years, her conviction grew that one day the Higgs boson would be discovered. Needless to say, her excitement grew, too, as overall evidence of the particle's existence became more and more robust. Pamela calls herself fortunate for being a part of it. "In my work on the WW channel," she explains, " I studied what we call *cross sections*: massive amounts of data on hits and events. Unfortunately, accumulating lots of statistics comes at a price. The data obtained are not very clean, so we had to develop ways to eliminate background noise, so to speak. At the same time, to avoid error, we literally had to retain all signals. We needed to find the right criteria to ensure increasingly efficient and powerful selection." Pamela Ferrari is currently investigating the properties of the events and their correlations. "Determining the right selection criteria may well be the hardest part of the job, but it's very exciting. The process requires a lot of creativity and deep thought. In fact, in this respect there is little difference between science and creative art. And we can now check, re-check and double-check whether what we found really is the particle that Peter Higgs predicted." After some thought, Ferrari continues: "And even if we were to find that it isn't, it would be absolutely striking because it would mean that we are dealing with completely new physics: equally revolutionary and equally challenging. And wouldn't it simply be exhilarating to see that something else is hiding just around the corner, waiting to be discovered?"

Magda Chelstowska

On the Shop Floor

Magda Chelstowska is one of Nikhef's many PhD students and a member of the ATLAS group at Radboud University Nijmegen. At CERN, she studied one of the Higgs boson's main decay modes: the WW channel. "Our group was right in the middle of things, where everything was happening", she says. "Our channel was one of the three channels where the Higgs was actually found. You can imagine the sheer thrill and excitement that all of us felt upon seeing the final results. I will always remember the shivers running down my spine." Working at the heart of the project also involved more down-to-earth tasks: talking with colleagues, producing notes, preparing publications, meeting deadlines and attending many, many conferences. "I worked ten hours a day. Life on the shop floor could be very hectic indeed, and we were working at a very high pace," Magda explains, "but without all this effort we would not have been able to do what we did. Proper science requires proper work and verification. You see, we had already gained a pretty good idea of where the Higgs boson could be found, but to prevent any bias whatsoever, we first studied the regions where it could definitely not be found. And only when we were convinced that we well and truly knew our methods, that we fully understood the detector and that we could match our data with our simulations, did we finally study the region of interest for the Higgs boson. And there it was…" After such a resounding success, people may wonder if there is life after CERN. Magda: "Oh yes, definitely. I am currently completing my dissertation and then I plan to investigate the properties of the Higgs boson. The quest simply continues."

Stan Bentvelsen

Becoming visible

Stan Bentvelsen is the programme leader of Nikhef's ATLAS group. He is one of the pioneers involved in the design, construction and installation of the Atlas detector. "To the outside world, we only became visible when the discovery of the Higgs was officially announced," he says, "but the experiment goes back more than a decade. People may not realise this, but Nikhef has always been involved as an effective and successful partner. Ours may be a small country, but it is pulling more than its weight in producing fine experts and conducting top research." To illustrate the point –and Nikhef's widely acknowledged impact– Stan mentions two specific hardware projects. "One project concerned the chambers that we built to detect muons assumed to be generated by the Higgs boson. Another is an instrument known as the inner tracker, which measures the paths of electrically charged particles. You know, it only takes a few words to say that we built the detector in Amsterdam and installed it at CERN, but this gives insufficient credit to everyone concerned. Just imagine the scale of the enterprise, the sheer creative effort it took and the dedication required from the people working on the shop floor, including those investigating channels which have not yet yielded conclusive results. Their findings are equally valuable." In terms of performance, Nikhef has gained a strong footing in the ATLAS project. "And now we have incredible amounts of data awaiting analysis. This too is something we are good at, because we have the experts and the necessary IT infrastructure." Today, Stan Bentvelsen is confident about the future. "The next step is to improve our techniques in order to conduct experiments at higher intensities. We'll remain visible for a long time to come."

photo: Thijs van den Broek

Ronald Kleiss

The tip of the iceberg

Ronald Kleiss, head of the Department of Theoretical High Energy Physics at Radboud University Nijmegen, is one of Nikhef's theorists. "Our core business," he explains, "concerns the development of a consistent theory that describes elementary particles and their behaviour. We calculate what may be expected to happen when elementary particles collide, and we make predictions on the basis of these calculations. Our work has enabled us to determine what a Higgs boson should look like, what is needed to generate it, and how it should behave. And because the proof of the pudding is in the eating, Nikhef's experimentalists have put our theory to the test. You could also say that our work has enabled them to make sense of their observations." When the Higgs discovery was made public, Ronald watched the press conference at Nikhef's headquarters in Amsterdam. "I felt elated," he says, "but I also thought 'what if this particle is not the Higgs we predicted?' This would have vast consequences for our Standard Model." He then admits to being of two minds. "To be proven right is wonderful, but it's also slightly boring. It would be far more exciting to discover that we are dealing with completely new physics." Still, whatever the future may hold, it will not be boring. "What we have discovered," Ronald states, "is merely the tip of a massive iceberg. We need to work on many topics: not only the particle's properties but also what we have termed the Higgs field. Our Standard Model predicts this field to be different from known fields such as electromagnetic fields, in that a Higgs field is always in stand-by mode. Electromagnetic fields can be 'on' or 'off', but the Higgs field is always there. We theorists definitely have our work cut out for us."

1.2 The Higgs particle and the origin of mass

Frank Filthaut & Nicolo de Groot

In 2012, the ATLAS and CMS collaborations reported the observation of a new particle in the search for the Higgs boson. Indeed the search for this particle was one of the motivations for the construction of the Large Hadron Collider. The discovery of the Higgs boson now provides one of the most tangible paths for future research that can further our understanding of particles and their interactions at the most fundamental level.

The Standard Model
The fundamental physics processes at the smallest known distances are described by the Standard Model (SM) of particle physics. It encompasses the fermions, the fundamental building blocks of all known matter: 6 quarks (found inside protons and neutrons) and 6 leptons (the electron being one of them). These particles possess internal rotation or spin of ½ . The up and down quarks and the electrons are the particles of which atoms are built up. Neutrinos we know from radioactive decays. The other fermions are heavier and can only be found inside cosmic rays or created by particle accelerators. Quarks do not appear as free particles but only in bound states called hadrons.

Three different forces, each of which is carried by a spin-1 boson, act on the matter particles. The strong nuclear interaction that binds the quarks in the protons and neutrons and the protons and neutrons inside a nucleus is carried by eight gluons. The weak nuclear interaction, responsible for radioactive beta decay, is carried by *W* and *Z* bosons and the electromagnetic interaction carried by photons. The fourth force, gravity, is not included in the SM. All matter particles have their anti-particle. These are particles with the same mass, but opposite electrical charge. The final piece of the Standard Model is the Higgs particle. This neutral particle has spin 0 and is needed to explain the mass of the other particles. The entire family of elementary particles is pictured in Fig. 1. (The concepts of spin, fermion, and boson are explained in more detail on p12 of the Annual Report 2010.)

Of the particles of the Standard Model the electron, muon and photon can be observed directly in the detector. The quarks and gluons are detected indirectly: they form jets of several hadrons. The tau lepton can decay to an electron or muon, or alternatively to a small number of hadrons. Neutrinos hardly interact at all and leave the detector unobserved. The *W* and *Z* bosons decay into pairs of fermions.

While the Standard Model has been a spectacular success in describing all elementary particle interactions with impressive accuracy down to a distance scale of attometers (10^{-18} m), there are strong hints that it is incomplete and cannot be the ultimate

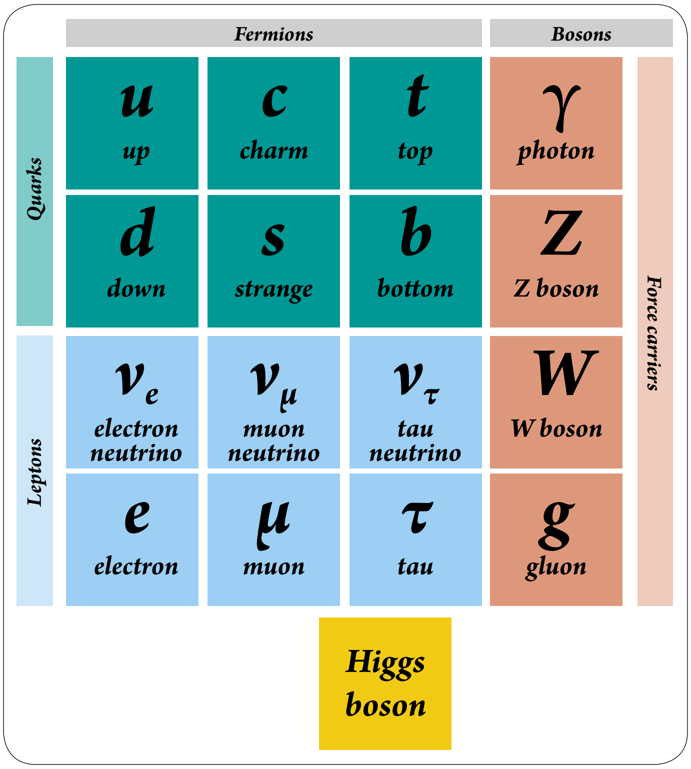


Figure 1. Elementary particles in the Standard Model. The matter particles are subdivided further into particles susceptible to the strong interaction (quarks) or not (leptons), and are arranged in three families, of increasing particle masses. The particles carrying the electromagnetic, weak, and strong forces are indicated to the right. The Higgs boson, whose existence was not established until this year, is shown as well.

theory. It does not include gravity or dark matter, it does not explain why our Universe consists of matter only, and the Higgs mass seems *unnaturally* small. A popular explanation is that the Standard Model is a low-energy limit of a more extended theory, and that if we go to higher energies we would observe new phenomena from this theory. The discovery of the Higgs particle at the LHC and the measurements of its properties will provide important clues to the hierarchy problem and what lies beyond the Standard Model.

Symmetry breaking and the origin of mass
The Standard Model is a theory based on symmetries. Every force is associated with a symmetry. With that symmetry comes a conserved quantity. For the electromagnetic force the conserved quantity is the electric charge. For the strong interaction the conserved quantity is named colour. Quarks come in three colours, labeled red, green and blue, and the force is symmetric under any permutation of these colours. Similarly, the weak interaction treats the up and down type quarks the same way, leading to a concept called isospin symmetry.

One central idea in particle physics is that of unification. The electric and the magnetic force were unified by Maxwell in the theory of electromagnetism. This led to a more elegant description of nature and a deeper understanding of the phenomena. Likewise, we would like to describe the electromagnetic force and the weak force by one theory. There is a practical problem here, however. The electromagnetic force is carried by photons which are massless particles. Consequently, the electromagnetic force has an infinite range. The weak force is carried by the *W* and *Z* particles which have a mass of almost 100 times that of the proton, and it is therefore a short-range force only. At first sight it is not obvious that these two so different forces are manifestations of the same force. This is where the Higgs mechanism comes in.

Empty space is not empty. It is filled with a field, the Higgs field. The Standard Model starts off with massless particles that travel with the speed of light. Some particles have an interaction with the Higgs field. They slow down and become massive. The stronger their interaction, the heavier they become. This is how the *W* and the *Z* particles, and also the fermions or matter particles, become massive. Others, like the photon and the gluon, don't interact at all with the Higgs field and remain massless.

When we look at the potential energy function of the Higgs field, as pictured in Fig. 2, we notice it has a funny shape. This is known as the Mexican Hat potential. The potential itself is symmetric in shape, but it does not have a minimum at a field value $\Phi = 0$. There is in fact a whole ring of possible minimum values or vacua. At very high energies, a situation which existed in the early Universe, we would not notice the *bump* in the middle. When the Universe expanded and cooled, the energy was no longer enough to overcome the bump in the middle and the Universe settled in one of the minima on the ring. The symmetry had been broken. The original Higgs field started off with four components arranged in two complex constituent fields, corresponding to four massive Higgs particles. After the symmetry breaking three of these components are absorbed by the carriers of the weak force which become the massive $W^{\pm}$ and *Z* particles. The fourth component escapes absorption and corresponds to the Higgs particle we have been looking for at the LHC. Strangely enough this theory does not predict what the mass of the Higgs boson itself should be.

Higgs production and decay

In the LHC two beams of protons collide head-on. The proton is not a fundamental particle, it is a combination of three quarks bound together by gluons and surrounded by quark-antiquark pairs. In a collision it is not possible to predict which fundamental constituents of the proton have interacted, we can only calculate the probabilities. The production of a Higgs boson goes dominantly through a process called gluon-gluon fusion. Here, two gluons collide to create an intermediate state containing top quarks which forms the Higgs boson. The top quark is very heavy and couples strongly to the Higgs.

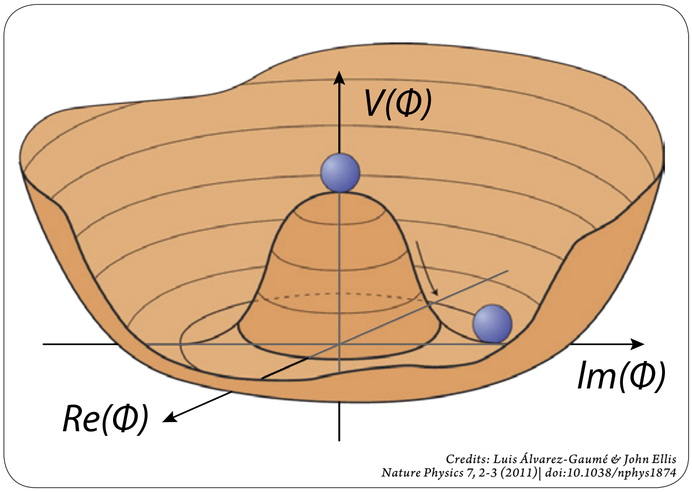


Figure 2. Potential as a function of (two of) the four Higgs field components. While in two dimensions the minimum potential is obtained in a circle, in four dimensions its equivalent is the surface of a four-dimensional sphere.

The Higgs boson itself is short lived and decays before detection. For a Higgs boson with a mass around 125 GeV, the following decay modes or channels are relevant:

- *Decay to two W bosons (WW channel).* The *W* bosons may subsequently decay to a muon or electron plus a corresponding neutrino. The experimental signature in the detector is two leptons and missing energy coming from the neutrinos. It is not possible to reconstruct the exact mass of the Higgs boson because of the neutrinos that go undetected. Instead we use the transverse mass, the combined mass of the two leptons and the missing momentum in the transverse plane, and look for an excess of events over the background from other Standard Model processes. A picture of the transverse mass is shown in Fig. 3. For searches of higher mass also the mode where one *W* decays into quarks is used. In the Standard Model the Higgs decays in 21.5% of the cases to *WW* and in 1.1% of the time to two leptons and two neutrinos.

- *Decay to two Z bosons (ZZ channel).* When both *Z* bosons decay to a pair of muons or electrons it provides an almost background-free signal. This is referred to as the golden channel. With all final state particles being observed, it provides a measurement of the Higgs mass. In the Standard Model the

Higgs decays in 2.6% of the cases to ZZ and in 0.013% in four leptons. A picture of a Higgs candidate event decaying into four muons is shown in Fig. 4.

- *Decay to two photons ($\gamma\gamma$ channel).* Since the photon is massless it does not couple directly to the Higgs and this decay proceeds through a loop of heavy charged particles like top quarks or W bosons. The decay rate is small in the Standard Model, only 0.23%, but the two photon signal is experimentally clean and allows for reconstruction of the Higgs mass.

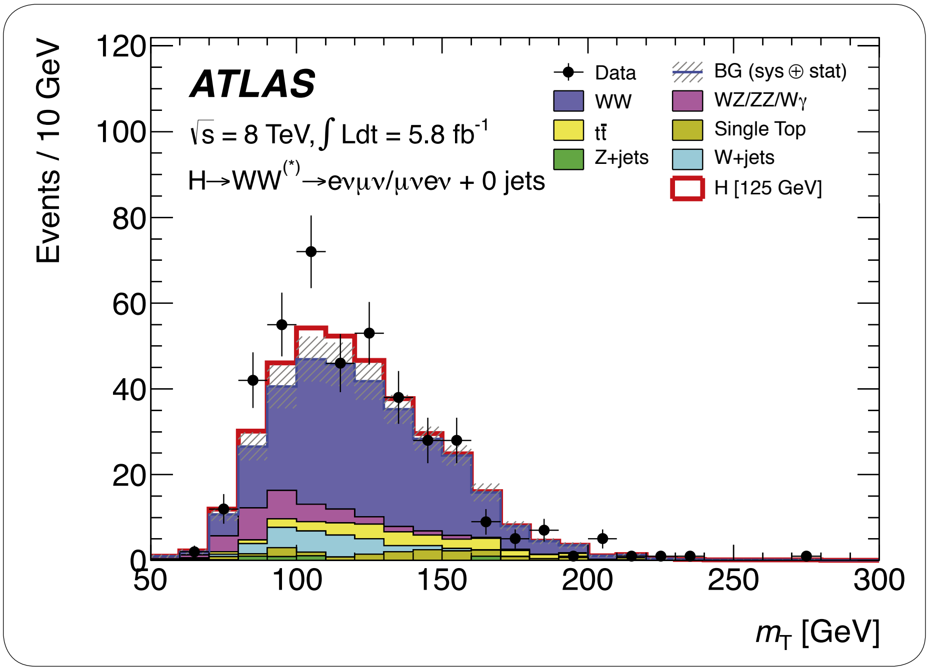


Figure 3. Transverse mass distribution obtained in the search for the Higgs boson in the decay mode $H \to WW \to \ell\nu\ell\nu$, in events with no reconstructed high transverse momentum jets. The signal prediction (shown in red) is stacked on top of the predicted backgrounds. The hashed area indicates the uncertainty on the predicted backgrounds. Figure copied from the ATLAS Higgs discovery publication.

- *Decay to two b quarks.* For a light Higgs this is the dominant decay mode, 57.7% in the Standard Model. The b quarks produce jets of particles that have to be distinguished from the jets originating from other flavors. In the gluon fusion production mode, this decay is swamped by other background, but in association with a W or Z boson or a pair of top quarks, this decay is observable above the background.

- *Decay to two τ leptons.* This decay is experimentally somewhat easier than the decay to quarks. Tau leptons decay, but their decay products can be separated from jets at a reasonable efficiency and purity. In the decay neutrinos are produced which makes this channel less suitable for a Higgs mass measurement. The expected decay rate is 6.3%.

The other decay modes either have decay rates too small to be observed or are indistinguishable from background.

In the ATLAS experiment the discovery of a Higgs-like boson in 2012 was made with three decay channels: WW, ZZ and $\gamma\gamma$. The CMS experiment has added the bb and $\tau\tau$ channels as well, but did not observe a clear excess in these. The Nikhef ATLAS group has played a major role in the discovery in the $W W$ channel and has made vital contributions to the ZZ channel (see interviews in this Annual Report).

After the discovery

With the discovery comes the question what we have really found: it is a Higgs-like particle, but is it really *the Higgs particle* of the Standard Model? The focus of the research has now shifted from discovery to understanding the nature of the new boson and in particular answering the following two questions:

- What are its quantum numbers spin and parity? Spin describes the internal rotation, parity describes what happens to a particle when the spatial components change sign, a sort of behaviour under mirror reflection. The new particle looks compatible with a Standard Model Higgs with spin 0 and positive intrinsic parity, but spin 2 or negative parity can not be excluded (yet).

- Is it the single elementary Higgs of the Standard Model, or something else? Extensions to the Standard Model predict a number of alternatives: a composite particle, an admixture with another particle, or an extended Higgs sector with five or more Higgs bosons.

The Higgs boson's spin and parity quantum numbers can be verified from the measurement of the angles between its decay products. It is expected that we will be able to provide a reasonable determination next year.

More interesting is the second question. Many extensions to the Standard Model, for instance Supersymmetry, predict a modified Higgs sector or new heavy particles that would couple to the Higgs (see Annual Report 2010, p11). The LHC experiments have searched for new phenomena predicted by these models, but so far have not observed any; presently only limits on the new models have been established. In the absence of direct evidence

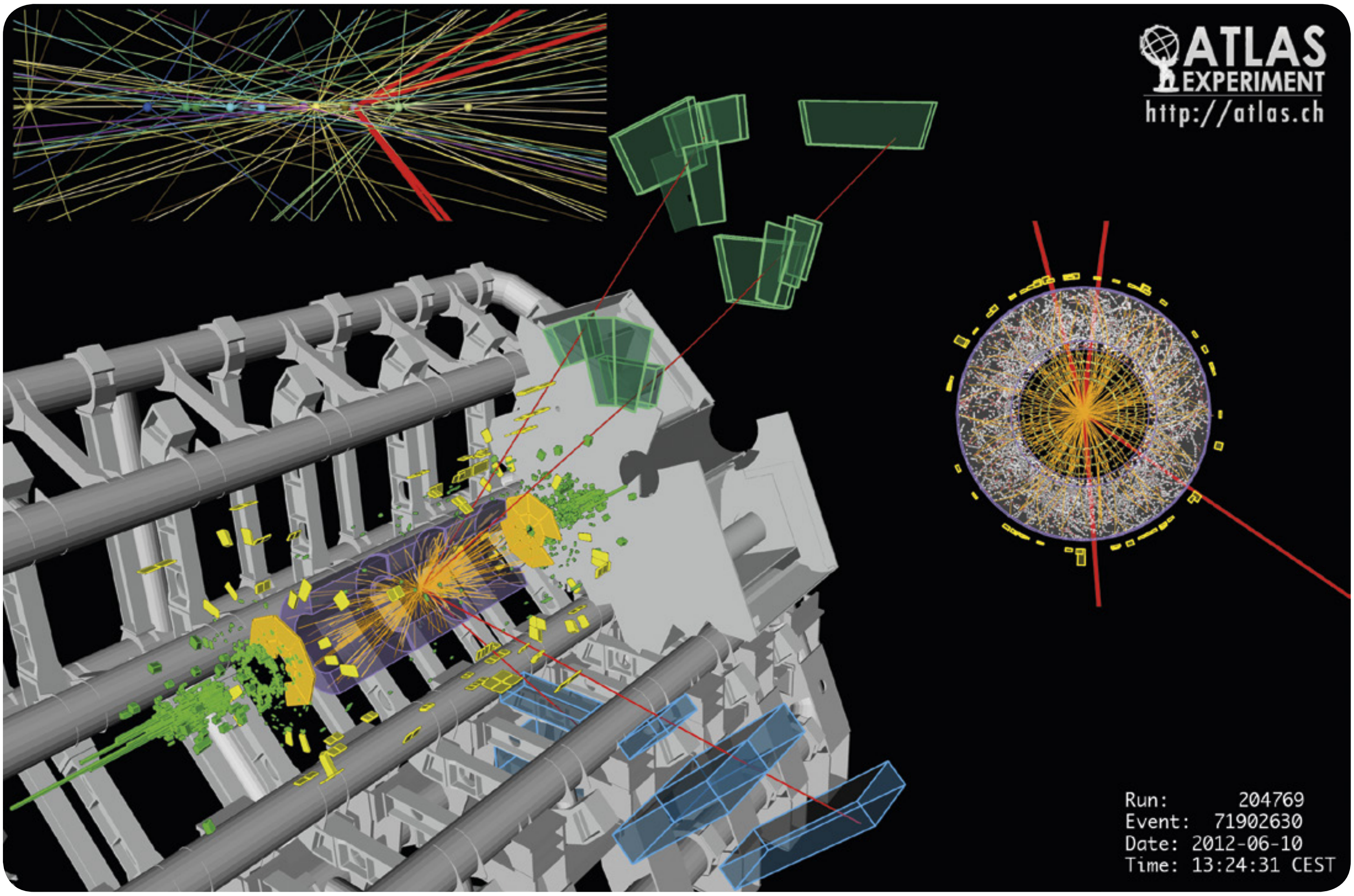


Figure 4. Graphical representation of one of the candidate events in the search for the Higgs boson in the decay mode $H \rightarrow ZZ \rightarrow \mu^+\mu^-\mu^+\mu^-$. The reconstructed muon trajectories are indicated in red. The large 3D view shows also the detector components with significant activity. The right inset shows only the measurements in the tracking detectors in the plane perpendicular to the beam direction, while the top left inset shows the measurements in the innermost tracking detectors along the beam direction (the large dots in this inset show that typically, multiple proton-proton interactions occur).

of new physics beyond the Standard Model, the Higgs particle could be a portal to new phenomena at a higher energy scale. The telltale sign of new physics would be couplings of the Higgs boson differing from those predicted by the Standard Model. Precise measurements of the couplings of the Higgs to the Standard Model particles will take several years with the LHC machine. In this sense the discovery of the Higgs this year is not the end of something, but a new beginning.

1.3 Higgs bosons tracked from production to publication

Wouter Verkerke

Our current best understanding of nature is that the mass of elementary particles is not an intrinsic property, but rather the consequence of their interaction with an omni-present field in the Universe, the so called Higgs Field. The interaction of elementary particles with this field gives these particles energy, even when at rest. It is this "energy at rest" of particles that we observe as the particle's mass following Einstein's famous equation $E=mc^2$, which relates energy to mass. While this 'aether-like' Higgs field itself is almost impossible to detect, the theory proposed by Peter Higgs predicts that this field can also manifest itself as a particle –the so called Higgs particle– and it is the existence of this *particle* that experimental physicists around the world have been aiming to prove for the last two decades.

Making Higgs bosons – The Large Hadron Collider

Higgs particles are extremely short-lived, thus to prove their existence, one should produce them, and then look for their decay products in the immediate vicinity of their production point. Higgs bosons can –like any other form of matter– be made from energy, for example in high-energy collisions of other particles. The main requirement is that the collisions should have sufficient energy to make the potentially heavy Higgs particle out of the collision energy. Here Einstein's relation $E=mc^2$ again provides guidance how much collision energy is needed to make a particle with mass m.

Early Higgs searches were performed with collisions of electrons on positrons (the anti-particle of the electron) with the LEP collider at CERN. In such collisions the particle and anti- particle fully annihilate each other and the complete collision energy is available to produce new particles, for example a Higgs boson. No Higgs bosons were found in these early experiments. The interpretation of these results was that if the Higgs boson exists, it must be heavier than 114 GeV (approximately 114 times the proton mass) as that is the maximum energy that could be made available to produce a Higgs boson at LEP.


NRC HANDELSBLAD

Woensdag 4 juli 2012 Jaargang 42 no.233 Algemeen Handelsblad (1828) en Nieuwe Rotterdamsche Courant (1844) Prijs € 2,–

Kairo is synoniem met seksueel geweld
buitenland 10

Pininfarina gaf Ferrari een gezicht
het grote verhaal 12-13

Afstudeerfilms: lelijke kinderen, dolende zielen
film 18-19

Grafische weergave van de sporen van een proton-protonbotsing in een van de deeltjesdetectoren van CERN, het deeltjesversnellerinstituut bij Genève. Foto AFP / CERN

Historische stap in het onderzoek naar de bouwstenen waaruit heelal is opgebouwd

Higgsdeeltje 'vrijwel zeker' ontdekt

Figure 1. The discovery of candidate Higgs particles generated headline news in many major newspapers.

Later searches have been performed in the collision of protons on protons. Protons are much heavier than electrons –thus allowing for more energetic collisions– but are composite particles, made of many quarks and gluons. The downside of that compositeness is that the effective collision between two protons is always between two such constituents, which each carry a variable fraction of the total proton energy. Thus, while a proton-proton collision can be made with a very high energy, the *effective* energy of a collision varies greatly from event-to-event, with only a tiny fraction resulting in truly high-energetic collisions. Furthermore, the composite nature of the protons results in enormous amounts of 'garbage' flying around in every collision. This garbage can obscure the telltale signs of a Higgs boson that might have been produced in such a collision. Nevertheless, proton-proton collisions are presently the only source of particle collisions with sufficient energy to produce Higgs bosons heavier than 114 GeV.

The latest facility to search for the Higgs boson, the Large Hadron Collider (LHC) at CERN, accelerates protons to such high speed that the energy of the motion of each proton is sufficient to create new particles with 7000 times the proton mass. Design studies for the LHC have shown that this facility can prove or disprove the existence of Higgs bosons with a mass of up to 1000 times the proton mass.

Finally, it is important to understand that the process of making Higgs bosons in high-energy proton-proton collisions is fundamentally a random process due to the quantum-mechanical nature of the physics. Even if sufficient energy is available to make a Higgs boson, it may not be created, but something else, *e.g.* a large number of lighter particles, might be created. *Essentially, anything that can happen will happen.* Thus the strategy is to collide protons on protons often enough to have 'lucky' collisions at the end of the run to prove the existence of the Higgs boson.

From detector hits to particles – Event reconstruction

Two large general-purpose experiments were built to observe these proton-proton collisions at the LHC: ATLAS and CMS. Each experiment is equipped with an array of detection systems

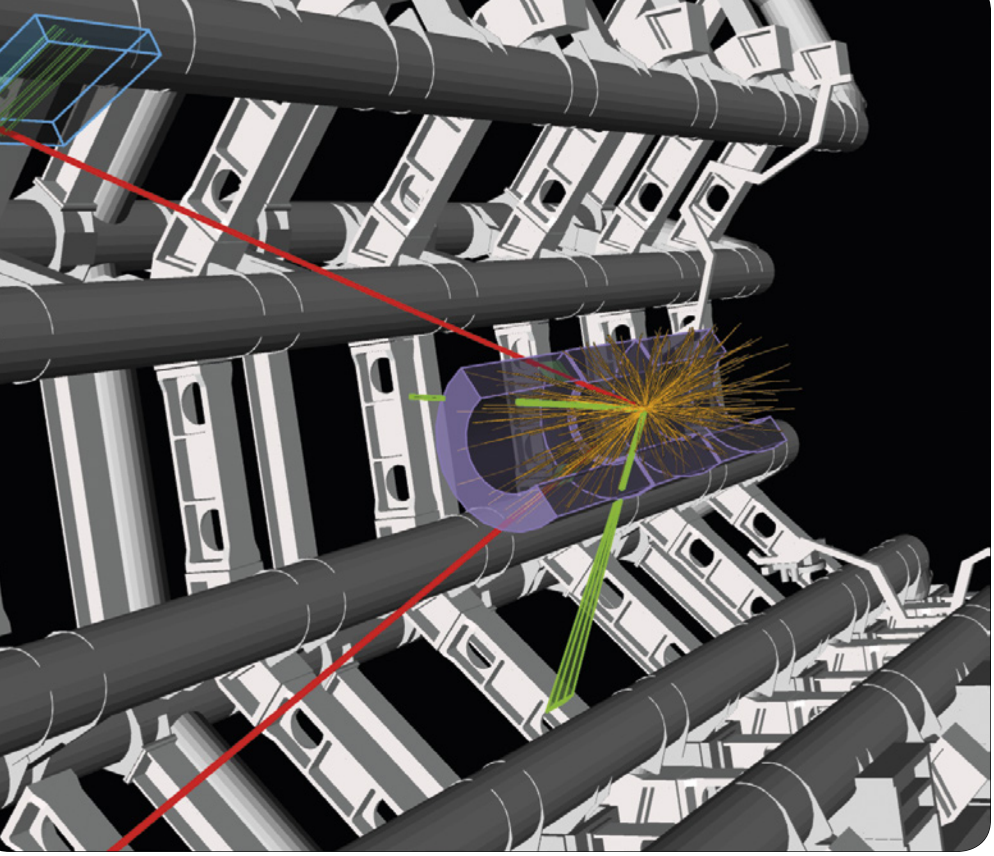


Figure 2. Reconstruction of the decay products of a proton-proton collision recorded in the ATLAS detector. In this collision four leptons were identified (highlighted as green and red tracks), a rare occurrence that is indicative of the production and subsequent decay of a Higgs boson in the collision event.

that can measure the direction, energy and momentum of most particles produced at these collisions. Each detector subsystem consists of an array of thousands to millions of identical detection units. Close to the collision point *tracking detectors* are installed that detect charged particles: each sensor unit can indicate that a charged particle passed through its (tiny) detection volume. Multiple layers of detection units –in concentric cylinders around the collision point– measure multiple space points for each particle and allow reconstructing their *trajectories*. As the detection volume is immersed in a magnetic field, such trajectories will be curved and the degree of curvature indicates the momentum (mass times velocity in classic terms) of the particle: slow particles curl a lot, fast particles will have nearly straight trajectories.

Behind the tracking systems, a layer or calorimeters is installed. Unlike the tracking detectors –which are designed to be thin and minimally obstruct the particles– these detectors are very dense and are designed to stop all particles. They convert the particle's motion energy into light, which is measured, and from which the energy of the particle is inferred.

Finally, a third layer of instrumentation behind the calorimeters measures again the trajectories of particles that are not stopped by the calorimeters. These are elementary particles of a special type –muons, siblings of electrons– that have little interaction with any type of ordinary matter – including the ATLAS detector. The mere fact that they make it beyond the calorimeter establishes their identity as muons.

A great deal of effort and ingenuity goes into establishing the particle content of each collision. The output of the ATLAS detector for each collision is a collection of thousands of tracker hits (coordinates in space through which a particle went) and hundreds of calorimeter cells (energy absorbed in a specific region of the calorimeter). The ATLAS reconstruction software analyses all these bits of information, calibrates them, and aims to reconstruct the particles originating from the collision. A typical particle will leave a dozen of tracker hits on a curved trajectory that will point to a cluster of a handful of calorimeter cells that have absorbed the energy of that particle.

In addition to direction and momentum, the identity of all particles is established, to the extent that particles left sufficiently identifying signatures in the detector. A particularly important class of particles to be identified are leptons, as these are the main messengers of Higgs boson decays. Leptons can be electrically charged –examples are the electron and its siblings the muon and tau lepton– in which case they leave characteristic detector traces. Leptons can also be neutral, the so called neutrinos, in which case they are undetectable in the ATLAS detector (neutrinos can traverse the earth without being hindered). Although undetectable individually, we can infer their presence indirectly since neutrinos are the only known undetectable particle species: the laws of energy and momentum conservation dictate that there can be no net energy flow away from the LHC beam axis in any proton-proton collision. Thus, if the summed energy of all *detected* particles in a collision nevertheless suggests that there was a net flow away from the LHC beam axis, we interpret this as a sign of the presence of a neutrino that carries away energy in the opposite direction, restoring the energy balance of the event.

Selecting interesting collisions – The trigger

Theoretical calculations of the production rate of Higgs bosons shows that at the LHC roughly one in 5 billion collisions will result in a Higgs boson. To collect a sample of a few hundred collisions with a produced Higgs boson, more than a trillion proton- proton collisions will need to be produced and examined. To meet this requirement the LHC collides protons 40 million times per second. However, it is impossible to record the detector data for a trillion collisions as each recorded collision event results in about 2 MB of data. Instead, events are preselected in real-time with a three-level *trigger system*, that rapidly examines recorded collision data and discards the large majority of events that are deemed uninteresting – for example because they lack the presence of a lepton produced in the collision. The first-level selection is built on custom hardware that reduces 40 million events per second to approximately 100,000 events per second. The next two levels are software-based and further reduce the rate to about 600 events per second, which are all stored for later detailed analysis.

Computing in practice – The GRID

Even with the aggressive data reduction through online trigger pre-selection, a few petabyte (=1000 terabyte) worth of information is produced every year the LHC runs. To reconstruct all these events about 10,000 years of computing time is needed. The LHC Computing GRID is used to store and process all this information – a network of large and small computing centers around the world, with a uniform interface that allows to operates it as a single 'super computing facility'. The backbone of the GRID are ten so called Tier-1 sites, the largest class of computing center, one of which is housed in the Netherlands at Nikhef and at SARA. These sites take care of central processing of complete data samples. Several dozen of medium-sized Tier-2 facilities complete the central computing infrastructure and allow for physics computing by individual teams of scientists. The ATLAS collaboration has access to more than 100,000 CPU cores and about 10 petabyte of storage space distributed over the various GRID sites.

Understanding what you see – Simulation

The key to interpreting LHC collision data is a detailed understanding of how various types of collisions (with Higgs boson, or without) manifest themselves in the ATLAS detector. This understanding is obtained from the study of simulated events. These studies start with a simulation of a physics process that can take place in a proton-proton collision, for example Higgs boson production. The particles that are produced in such a simulated collision are then fed into a second simulation, that of the ATLAS detector. The output of this detector simulation is so realistically detailed that it is indistinguishable from the recorded data of the ATLAS detector. Hence, the standard ATLAS reconstruction software can analyse these simulated events as if they were real data. There is of course one crucial distinction: each simulated event contains a record that explained what physics process really happened when the collision was simulated and how all observed particles are related to that. With the LHC computing grid large collections of simulated LHC collision events, either with or without Higgs boson, are prepared as the basis of the next level of studies: developing empirical algorithms that decide which collision events in the ATLAS data are most likely to contain a Higgs boson.

The needle and the haystack – Isolating collision events that may contain a Higgs boson

The Higgs boson is the chameleon of elementary particles – its decay products result in a bewildering range of vastly different signatures that will invariably look very much like the background, like ordinary collisions. Finding evidence for Higgs decays is thus akin to a painstaking search of scraps of forensic evidence in a crime scene investigation, where there is no smoking gun and no confession, but only a large number of little hints, partial finger prints, that are each on their own unconvincing, but with sufficient effort can be put together to build a convincing case.

The most promising type of decays are those in which the Higgs boson decays into other heavy particles, and subsequently into two or more high-energy leptons. These decays stand out more clearly than others, as the occurrence of two or more leptons in a collision is comparatively rare in other collisions. Unfortunately, this means that only one in about a thousand Higgs bosons that are produced inside the ATLAS detector leave hints of sufficient clarity to help to build the case of their existence. True to its chameleon-like character the precise signature of Higgs decays with two or more leptons is also not unique, but again divided over tens of distinct signatures, none of which is a priori expected to be a clear winner.

Thus, the only solution is a painstaking attempt to identify every Higgs decay signature in the data that is deemed feasible. For the discovery of the Higgs boson, twelve distinct main Higgs signatures were looked for, further subdivided in 98 detailed signatures, involving the dedicated attention of over 300 scientists in this selection and identification process alone, and resulting in over 350 pages of publicly available documentation of these search efforts.

An example – Search for Higgs decays into four leptons

Collecting evidence for Higgs bosons in a given decay signature proceeds in two steps. First, promising collision events are collected, for example by requiring the presence of multiple leptons. This reduces the event count from billions of recorded events to anywhere between a few hundred and a few thousand for a particular signature. Then, events are analysed and classified in detail to test their consistency with the presence of a Higgs boson.

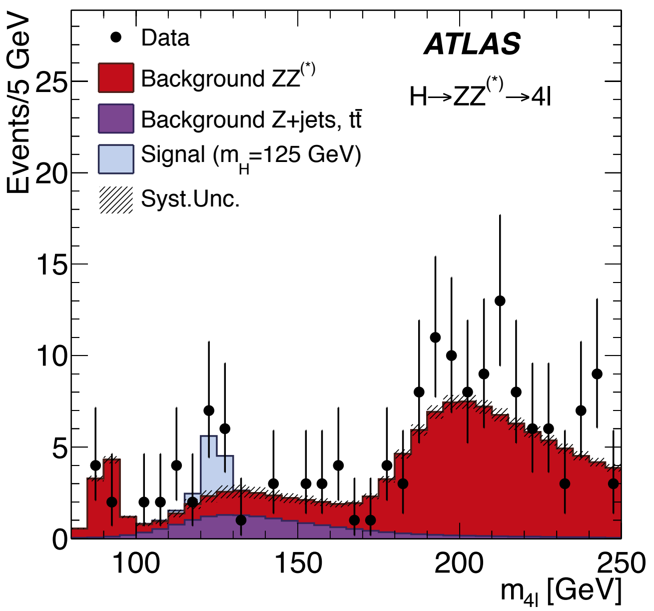


Figure 3. Distribution of the 'invariant mass' of selected collisions with four reconstructed leptons (black points). Each collision event contributes one entry in this graph and each graph point indicates the number of collision events that result in an invariant mass inside a small range. For all collision events in which the four leptons truly originate from a Higgs boson decay the 'invariant mass' will be similar, and will result in a narrow peak in the observed distribution. The data are compared to simulation predictions for all known background processes resulting in four leptons (red and purple histograms), and for a Higgs boson signal with a mass of 125 GeV (light blue histogram). The data are consistent with the existence of a 125 GeV Higgs boson.

Fig. 3 illustrates the second step for a purified sample of events that all contain four leptons. For most events in this sample, the four leptons originate from unrelated sources, but for some events they might originate from a common source: the decay of a Higgs boson into 4 leptons ($H \rightarrow ZZ \rightarrow l^+l^-l^+l^-$). To distinguish those two cases, the invariant mass of the four leptons is calculated: for all events where the four leptons truly came from a Higgs boson decay the invariant mass will be close to the Higgs boson mass, i.e. all such events will have the same value of the invariant mass. For events where the leptons came from multiple sources, the invariant mass is meaningless, and will have a random value. Thus, if there are events with Higgs boson decays into four leptons in this sample, a peak will show up in the distribution of invariant mass values, as can be seen in Fig. 3 around a mass of 125 GeV. Figure 3 also shows the results of simulation studies: the expected distribution of signal (light blue) and background (red/purple)

Is there a Higgs boson in the data? – Statistical analysis

While the signal peak in Fig. 3 is in line with expectations for a 125 GeV Higgs boson, it is also very small. It might also be the result of a statistical fluctuation of the background. After all we don't know in advance that the Higgs boson has a mass of 125 GeV, the true Higgs peak could appear anywhere in the plot according to the theory, and there are lots of little bumps all over the plot that could be interpreted as a Higgs boson signal. The final step in the Higgs discovery is thus the *statistical analysis*: we need to quantity the probability that what we observe is a background fluctuation. If that probability is high, we cannot draw any conclusions from these data. If that probability is close to zero, than that means we've discovered something new, for example the Higgs boson.

To quantify the probability of a statistical fluctuation we take the simulation predictions of the background processes *only* and run millions of simulated experiments that each collect the same number of collision events (after purification) as we observed in the data, but are known to consist only of background processes. We then count in what fraction of those millions of simulation experiments we observe a peak as large as we found in the data, or larger. This fraction is the probability that the observed peak in the data is a statistical background fluctuation. This study of the background is complicated by the fact that we don't perfectly know the properties of the background: the simulation of the background physics and the simulation of the detector introduce hundreds of smaller and larger uncertainties that must all be taken into account in the statistical analysis.

The probability that the peak at 125 GeV in Fig. 3 is a background fluctuation has been calculated to be about 1:1,000. While that may seem convincing, it actually isn't: we have to keep in mind that we look for the Higgs in thousands of places. One can compare this to rolling a dice: throwing a six four times in a row is lucky, it should happen only once every 1,296 throws on average – but it is less so if you roll ten dice at every try: the odds you'll have at least one six in every throw are rather high, about 84%, so having four throws in a row with at least one six is then nothing special, it happens in roughly half of each run of four throws.

Fortunately, there is a dozen of other decay signatures in which we are looking for the Higgs boson. Thus, if the Higgs exists it should show up in all of these decay signatures, and also with a peak consistent with the same Higgs boson mass in all signatures. This combination of signatures hugely cuts down the odds of statistical fluctuations of the background. A proper calculation of the odds of a simultaneous background fluctuation in all

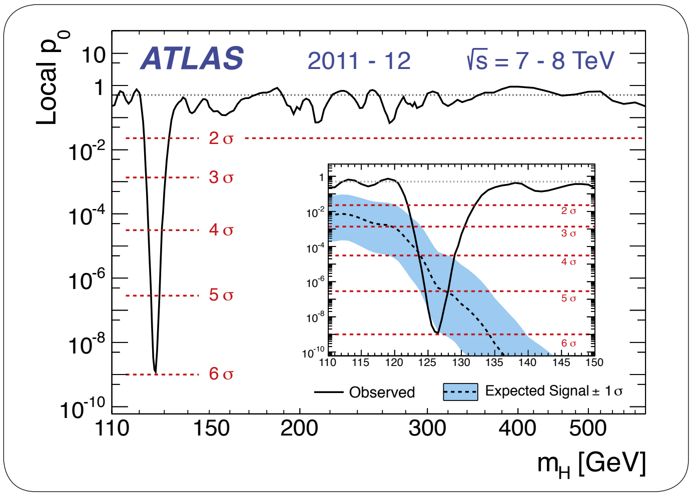


Figure 4. Probability that the observed signals in all Higgs decay signatures simultaneously are the result of a statistical fluctuation of the background. For a hypothesized Higgs boson mass of 125 GeV this probability is less than one in a billion, hence the declaration of the discovery of a new particle. The inset shows the expected outcome for simulated data with a Standard Model Higgs boson: the dashed line is the expected height of the observed peak for a Standard Model Higgs boson of various masses, the blue band indicated the uncertainty on this simulation prediction. The observed signal strength is thus consistent with the prediction within the uncertainty.

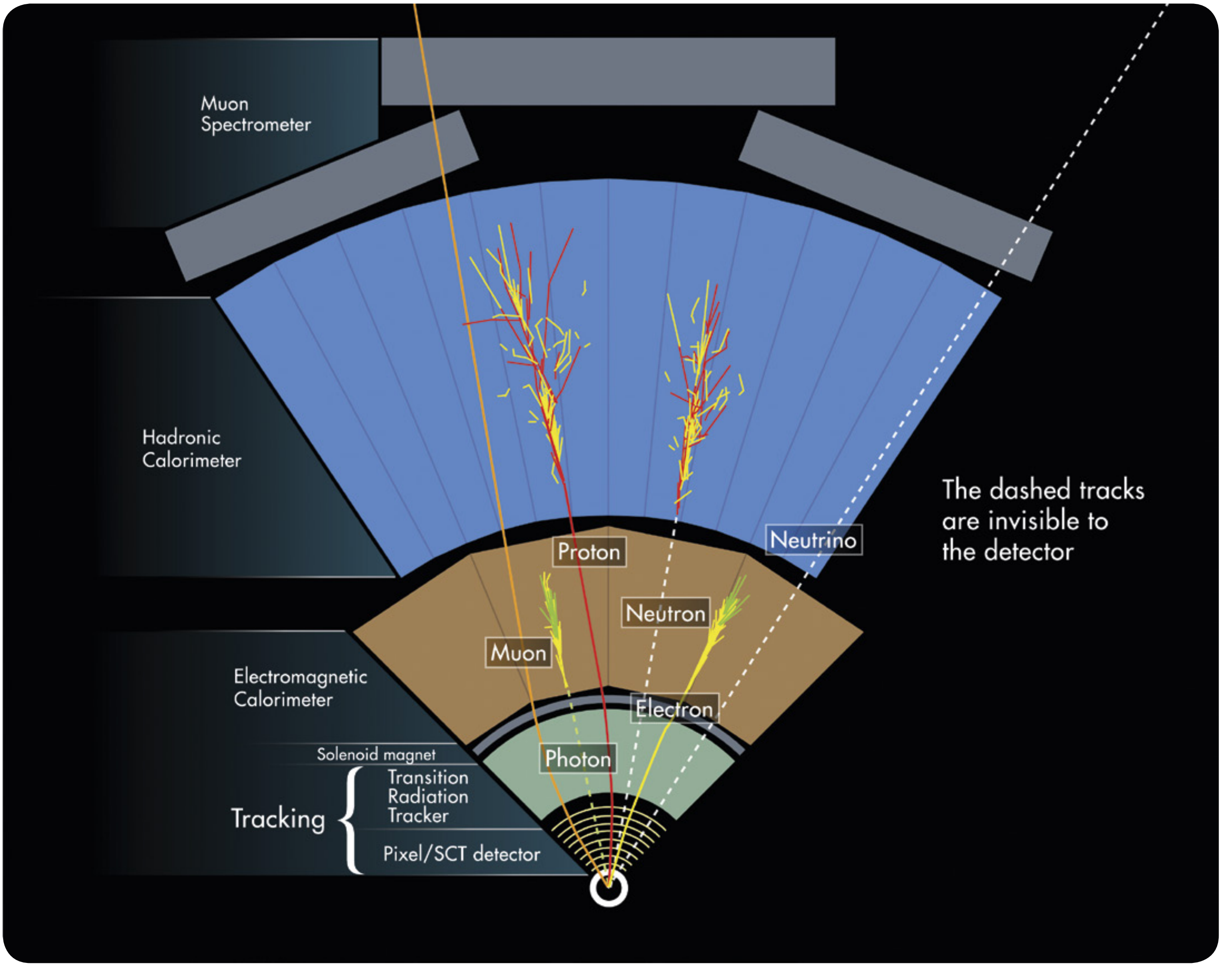
measured samples, while taking into account all known physics and detector uncertainties, is shown in Fig. 4. It shows that the odds for the background to cause a fake signature of a Higgs boson with a mass of 125 GeV in all decay signatures *at the same time* is roughly one in a *billion* – convincing scientific evidence for a discovery.

Check, double check – Blinding the data, scientific review

Given the important physics implications of a Higgs boson discovery all aspects of the analysis are thoroughly reviewed and where possible the analysis is conducted in a blind way. A blind analysis means that the criteria that are used to select the events in the data are chosen based on studies that *only* use simulated events, without a look at the data. This approach eliminates the possibility of (unintentionally) designing event selections that eliminate data events that don't meet preconceived notions of what is expected. Once the event selection strategy has been completely finalised, reviewed and approved, the recorded data are analysed with that same strategy and no further changes to the analysis strategy are made.

The scientific review of all aspects of the Higgs discovery analysis knows many components and stages. The analysis of each of the dozen Higgs decay signatures, as well as the process of the statistical combination of the signatures, is subject to a separate review. For each signature that is completed, a detailed scientific write-up is prepared, along with a draft of a journal publication. These documents are circulated to the ATLAS *Higgs physics working group* comprising more than 800 scientists and are reviewed and discussed both on dedicated discussion forums, as well as in a public meeting in which a formal 'working group' approval is given. In parallel a team of four dedicated scientists (the *Editorial Board*) follows the analysis from the very beginning, scrutinizes all aspects, and has frequent meetings with the analysis team. Once both the *Editorial Board* and the *Higgs physics working group* have approved the analysis, the draft journal paper and the detailed internal documentation are circulated to the full (3000-member) ATLAS collaboration for another 1-week round of review, ending in a collaboration-wide meeting where the analysis is presented, discussed, and if deemed ready approved. After collaboration approval, a team of two senior members of the ATLAS management will do a final reading and approval of the journal paper draft, after which the paper is submitted to a scientific journal. The journal editors will appoint two further anonymous reviewers that are not affiliated with the ATLAS collaboration for a last round of review. After the reviewers consent the result is approved for journal publication.

For the Higgs discovery analysis, both the ATLAS and CMS collaborations have prepared two long papers (about 20 pages each) documenting the full overview of the discovery analysis in either experiment, and have been published back-to-back by special arrangement.



A computer generated image showing how ATLAS detects particles.

Research

2

2.1 ATLAS
A truly remarkable year

Management: prof.dr. S. Bentvelsen (PL)
prof.dr. N. de Groot
prof.dr. ir. P. de Jong
Running Period: 1997–2015

The year 2012 clearly is the "discovery year" for the Higgs particle. On 4 July, the spokesperson of ATLAS, Fabiola Gianotti, presented evidence for a new particle with a significance of more than 5 sigma's. Also the CMS collaboration presented similar exciting results. The review articles of this annual report describe the relevance of this discovery, and present the highlights of the analysis. 2012 is also the year in which ATLAS celebrated its twentieth birthday, marking a successful period of collaboration (with healthy internal competition) among approximately 3000 authors from 174 institutions in 38 countries. The review articles in this Annual Report describe the final stage of the analysis, which was intense and beyond any national border. Nevertheless, institutes are internally recognised in their focus of research, and Nikhef plays a very visible role in a number of physics topics, including these of the Higgs search.

The Large Hadron Collider
The Higgs discovery is made possible by the excellent operation of LHC and the ATLAS detector. The detector performed remarkably well during the entire period – with approximately 95% of all the 90 million electronic channels operational. Whereas the discovery on 4 July was based on 6 fb^{-1} of data, in total the machine delivered more than 27 fb^{-1} proton-proton collisions at 7 and 8 TeV centre-of-mass energy over the last two years, which is more than anticipated. With an instantaneous luminosity reaching 7.6×10^{33} $cm^{-2}s^{-1}$, the runs in 2012 were so intense that in each bunch crossing a pile-up of 35 collisions between protons was reached (see Fig. 1).

Trigger
Events were triggered by one or a multitude of trigger items (of which more than 1000 were implemented) and produced a constant 600 Hz output rate. As this is more than can be coped with off-line, a fraction of these events will be reconstructed at a later stage with resources that are freed during shutdown. The main goal of the trigger, with new and sophisticated algorithms, is to optimise efficiency while keeping the rate under control in the harsh pile-up conditions of LHC. In December the machine stopped producing proton collisions. It will shutdown in 2013 and 2014 for an upgrade period. New collisions at full energy of 14 TeV are expected at the start of 2015, with trigger conditions even more challenging.

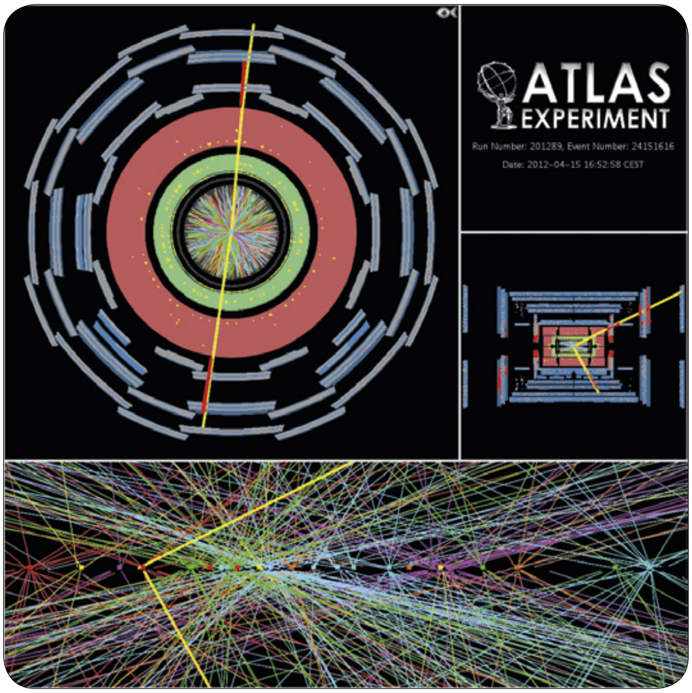


Figure 1. A candidate Z-boson event in the dimuon decay with 25 reconstructed vertices. This event demonstrates the high pileup environment in 2012 running. The vertices shown are reconstructed using tracks with transverse momentum p_T larger than 0.4 GeV.

Top physics
Nikhef plays a visible role in the study of top quarks. The cross section of strongly produced top-anti-top quark events, with a single lepton final state, was determined. Then the focus was changed to the observation of electroweak produced 'single-top' events in association with a W boson (Wt-channel), that decays with one isolated lepton. Understanding the background events with multi-jets and W+jets, is essential (Nikhef studies of these backgrounds have consumed more than 35 years of CPU power!). These studies not only test the Standard Model itself, but also give handles to the search for heavy b-quarks, for which a new limit of 870 GeV was set at 95% confidence level. It is interesting to observe that new initiatives in 'cloud computing', as an alternative to the computing GRID, were developed around these analyses.

Supersymmetry
Searches for new phenomena beyond the Standard Model have not yet observed deviations from the Standard Model predictions, and limits on such new phenomena have been set that far surpass limits from previous experiments. Results include limits on new gauge bosons W′ and Z′ below 2.5 TeV, excited quarks below 3.8 TeV, fourth generation top quark partners below 600

GeV, and extra dimensions and quantum black holes below 1.5 to 4 TeV. Tight limits are also set on Supersymmetry; in constrained models squarks and gluinos below 1.5 TeV are excluded.

Nikhef actively participates in a number of dedicated searches for Supersymmetry. These include final states with zero leptons, supersymmetric particles of the third generation, and general searches for Supersymmetry. The 2015 LHC run at full design energy will put Supersymmetry to further stringent tests.

Flavour violation

A new line of Nikhef research addresses lepton flavour violating processes. Such processes are a necessary ingredient of Leptogenesis, a theory explaining dominance of matter in the Universe. Two approaches are pursued: the search of excess of events with multiple leptons and the search of neutrinoless tau decays. To power up these analyses with the large data sample expected in 2015, the Nikhef group has developed an extension of the ATLAS first level trigger system, which will divert muon information to the topological processor. The board will be used also for other ATLAS needs such as measurement of Higgs boson decay to two tau leptons.

Future physics in ATLAS

In Fig. 2 the measured cross sections of various processes are compared to their theory predictions. It shows that the Standard Model reigns at 8 TeV – urging clarification on the Higgs particle as described elsewhere in this report.

Whereas with the current available data sets the observed quantities of the resonance particle are in accordance with the properties of a Higgs particle, further detailed studies on the Higgs are mandatory and form a central part of the future ATLAS project, next to searches for new particles and physics processes.

In order to further improve the tracking capabilities of the detector, during the coming shutdown period a new, fourth layer of pixels will be installed in the heart of ATLAS. This new detector will be operational when LHC will deliver collisions at 14 TeV. In the past year the front-end electronic chip for this new detector, FE-I4, was delivered at Nikhef, tested and found to be OK. Nikhef will also provide a 3.3 kW cooling system based on CO_2.

In the further future we prepare for an upgrade of the muon detector system, in which Nikhef will be involved in the readout. Lastly, for the high luminosity running period of the LHC, a decade from now, we have the ambition to install a new central tracking device, able to cope with the dense radiation environment.

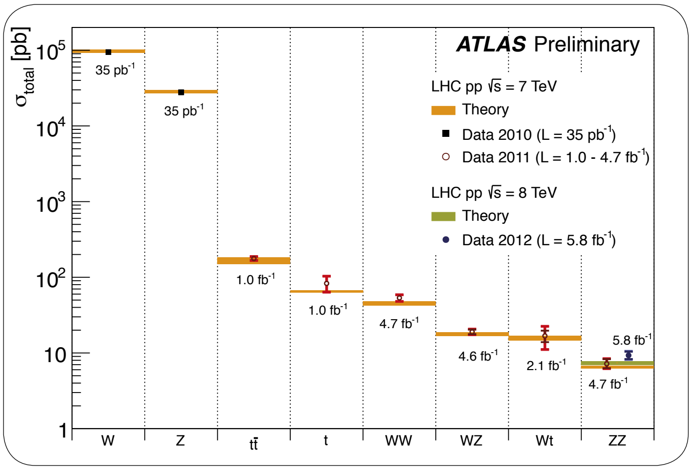


Figure 2. Summary of several Standard Model total production cross section measurements compared to the corresponding theoretical expectations. The W and Z vector-boson inclusive cross sections were measured with data of 2010. All other measurements were performed using the 2011 dataset or the 2012 dataset. The theoretical expectations were calculated at next-to-leading-order or higher.

These future high quality, high intense data sets are needed to test all possible properties of the newly discovered Higgs particle (and possibly new physics), to confront these with the phenomenology of the Standard Model and beyond.

2.2 LHCb
A deep view in the quantum structure of nature

Management: prof.dr. M.H.M. Merk (PL)
prof.dr. A. Pellegrino
Running Period: 1999–2014

The data collected with the LHCb experiment in 2011 and 2012 reveal the nature of quantum physics to an unprecedented precision. In flavour-physics, the subject studied with LHCb, precision measurements of heavy flavour particle decays are sensitive to virtual particles that occur only in quantum loops. Precise inspection of such decays should reveal the existence of new particles with masses even higher than those that can be directly produced in the collider.

The $B_s^0 \rightarrow \mu\mu$ decay
In the Standard Model the decay of a B_s^0 particle into two muons is highly suppressed due to a symmetry known as the mechanism of Glashow, Iliopoulos and Maiani (GIM). This symmetry is broken due to the fact that the different quark-types have unequal masses and consequently the decay is not fully forbidden, but it is expected to occur in 3 out of 10^9 B_s^0 decays. Such an extremely rare *B*-decay has never been observed. Due to the fact that the process is so strongly suppressed in the Standard Model theory, it is very susceptible to the existence of new particles beyond the Standard Model, as for example supersymmetric particles.

After two years of data-taking the LHCb experiment has produced approximately 2×10^{10} B_s^0 particles inside the acceptance of the detector, such that the observation of this rare decay should either be possible, or show an unexpected deviation from the prediction. To select the signal decays and suppress backgrounds a dedicated multi-variate algorithm was optimised and a blinded experiment was carried out. In the blind experiment, the selection algorithms are optimised in a process in which the outcome is hidden from the physicists in order to prevent any (unintended) biases in the analysis. Two weeks before the Hadron Collider Physics conference in Japan the analysis method was considered final and the data in the signal region were unblinded. The result revealed evidence for a $B_s^0 \rightarrow \mu\mu$ signal with a statistical relevance of 3.5 standard deviations. Fig. 1 shows a reconstructed $B_s^0 \rightarrow \mu\mu$ candidate event and Fig. 2 depicts the invariant mass distribution of reconstructed dimuon events in the region with low background level. The picture in Fig. 3 shows members of the LHCb team celebrating the publication of the result.

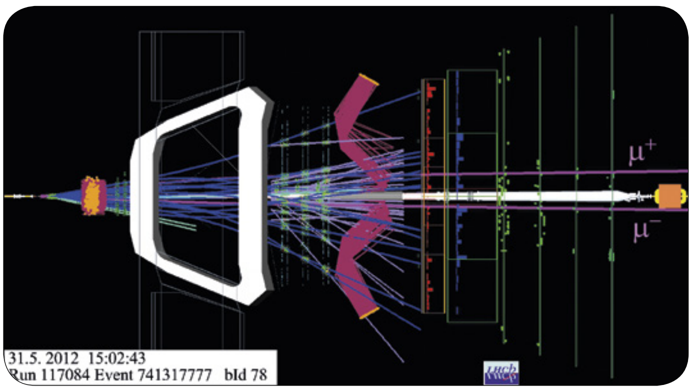


Figure 1. A reconstructed event in the LHCb detector that contains a candidate of a $B_s^0 \rightarrow \mu\mu$ decay. The purple lines indicate the reconstructed trajectories of the two muon particles.

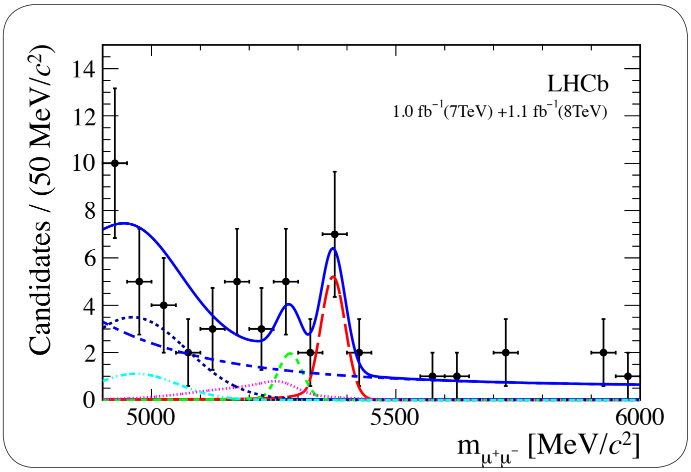


Figure 2. The invariant mass distribution of events with two reconstructed muons as observed in candidate events selected by the optimised multi-variate algorithm. The excess of events around 5370 MeV/c² corresponds to the B_s^0 mesons decaying to two muons.

With this measurement LHCb extends the search for new particles associated with new theories, to a deeper level. A popular extension of the Standard Model is Supersymmetry. In many variants of the theory the existence of supersymmetric particles would be revealed as an increase of the number of $B_s^0 \rightarrow \mu\mu$ events. The fact that the observation of LHCb is in agreement with the predictions from the Standard Model does not rule out the existence of Supersymmetry, but reduces the variety of possible realisations.

Matter–antimatter oscillations
Another intriguing aspect of quantum mechanics is that it allows neutral mesons to oscillate from a particle into their anti-particle alter-ego. This has been first observed last century for neutral kaons, and more recently for B_d^0 and B_s^0 particles. With the data recorded the past two years the LHCb collaboration has measured the mixing rate of the B_d^0 as well as B_s^0 oscillations with the highest precision to date to be respectively$(0.51 \pm 0.01) \times 10^{12}$ Hz and$(17.6 \pm 0.03) \times 10^{12}$ Hz.

Figure 3. Members of the LHCb team celebrating the publication of the paper claiming evidence for the observation of $B_s^0 \to \mu\mu$ decays.

Oscillations of particles with charmed quarks had not yet been observed before by a single experiment. In the LHC collider charmed particles are produced in unprecedented amounts and decays of excited charmed mesons $D^{*+} \to D^0\pi^+$ allow for a pure measurement of the ratio of "right sign" charm decays $D^0 \to K^-\pi^+$ over "wrong sign" charm decays $D^0 \to \overline{D}^0 \to K^+\pi^-$. Fig. 4 shows that the observed ratio of wrong-sign over right-sign events varies as function of the decay time of the charm particles, a signature of their oscillatory behaviour. With this measurement it has been established that matter–antimatter oscillations occur for all four types of neutral heavy flavour mesons.

The matter–antimatter oscillations of *B* mesons provide a precise tool to test the validity of *CP* symmetry in nature. Violations of this symmetry were first observed using kaons in 1964 and later with B^0 mesons in 2001. For the case of B_s^0 mesons the Cabibbo-Kobayashi-Maskawa mixing mechanism predicts that the CP violation induced at quantum level by the B_s^0-$\overline{B}_s^0$ amplitude to be very close to zero, as a consequence of specific parameter values in the Standard Model. Consequently, an observation of CP violation here would indicate that New Physics particles or forces would contribute. LHCb has studied these decays in detail and has reported a CP violating phase of $\phi_s = -0.001 \pm 0.105$ rad. This value is consistent with zero, an observation that disfavours the existence of particles or forces with large CP violating couplings to *b* or *s* quarks.

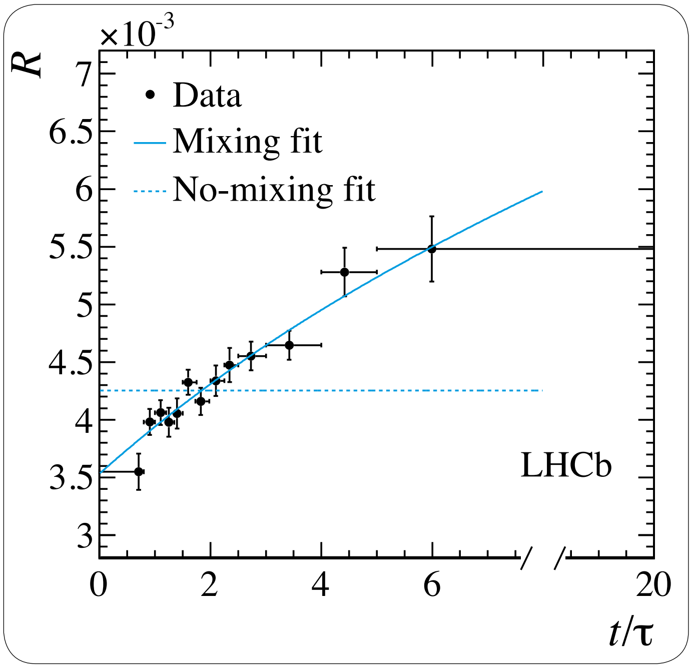


Figure 4. The decay time evolution of the ratio R of wrong-sign over right-sign charm decays (see text). The flat dashed line indicates a fit to the data for the no-mixing hypothesis.

2.3 ALICE
Relativistic heavy-ion physics

Management: prof.dr. T. Peitzmann (PL)
prof.dr. R. Snellings
Running Period: 1998–2013

The main goal of the ALICE programme is to study the strong interactions of quarks and gluons at very high temperatures and densities, as prevailed a few microseconds after the Big Bang. In particular the aim is to determine the properties of matter under such extreme conditions, and to improve our understanding of the phenomenon of confinement and the generation of mass by the strong interaction, by means of colliding heavy ions at high energy. The Nikhef heavy-ion group participates in the ALICE experiment at the LHC, where Nikhef contributed to the construction of the Silicon Strip Detector (SSD) of the Inner Tracking System (ITS). Nikhef is also taking a leading role in one of the detector upgrades of the experiment, which will further enhance the measurement capabilities in the future.

ALICE has very successfully taken data for several years, and many interesting physics results have been obtained from proton+proton, lead+lead and recently also proton+lead collisions. The Nikhef heavy-ion group is making strong contributions to several central analyses of the experiment, including studies of collective flow and the production of heavy quarks. This year two papers on the total charm production cross section in pp interactions and one paper on D meson production in lead-lead collisions were published with the Nikhef group as the main author. In this report we will highlight examples of studies on parton energy loss in the dense created medium and on the charge dependence of fluctuations of the particle numbers.

QGP-Tomography with Parton Energy Loss
Highly energetic quarks and gluons (also called *partons*) are usually measured via their fragments, which are emitted in particle *jets*. A suppression of such jets has been observed in high-energy nuclear collisions, and this phenomenon has been attributed to the energy loss of partons in the dense quark-gluon plasma. In early measurements, also those by the ALICE experiment, the measurement has been performed in an indirect way by studying the suppression of the individual fragments. In recent measurements jets have been reconstructed also in the challenging high-particle density environment of nuclear collisions, making a direct study of the suppression of jets possible.

Fig. 1 shows the nuclear modification factor R_{AA} of reconstructed jets from charged particles as a function of the transverse momentum of the jet as measured in ALICE. R_{AA} should be equal to unity, if jets are unmodified by the medium. The small value of

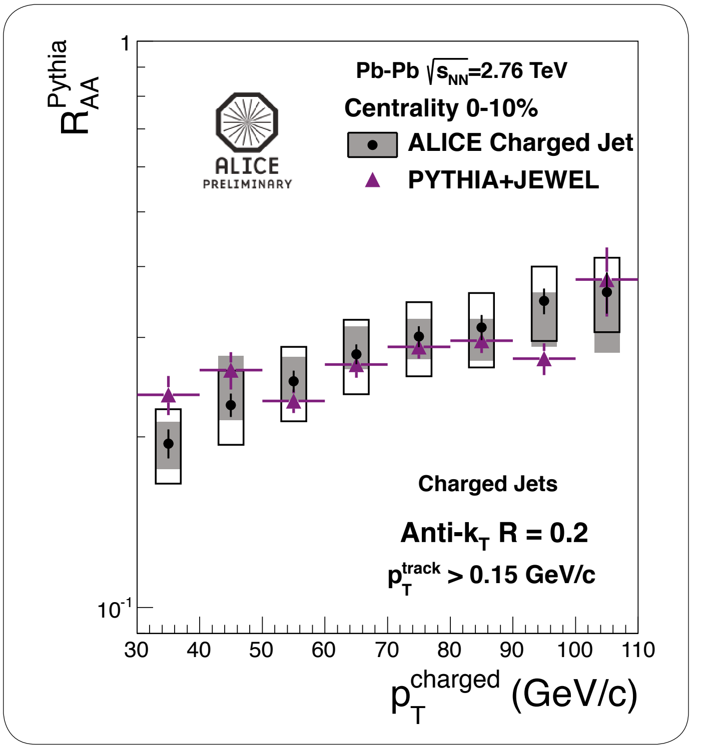


Figure 1. The nuclear modification factor for jets in central Pb-Pb collisions as a function of jet transverse momentum. The small values indicate a strong suppression of jets in these reactions compared to the expectation from pp collisions. The data are compared to a model calculation assuming energy loss of partons (quark and gluons) in a dense quark-gluon plasma.

0.2–0.3 confirms the strong parton energy loss already observed in the suppression of single hadrons also from reconstructed jets. An example of a model calculation including a dense quark-gluon plasma is also shown in the figure - it can explain the observed suppression. This indicates that the energy loss process redistributes a significant amount of momentum to large angles with respect to the jet axis. It is expected that such measurements will ultimately be useful to perform a 'tomography' of the produced matter in its early phase, i.e. to measure its density distribution.

Searching for Strong Parity Violation
Parity (*P*) and its combination with the charge conjugation (*C*) symmetries are known to be broken in the weak interaction, whereas in the strong interaction no violation of the *P* and *CP* invariances has been observed. Exact invariance leads to the *strong CP problem*, as it requires a specific fine-tuning of parameters in the theory. The possibility to observe related parity violation effects in the hot and dense hadronic matter created in nuclear collisions has been discussed for many years. In the vicinity of the deconfinement phase transition, the QCD vacuum could create

domains, local in space and time, that could lead to *CP* violating effects. This strong *CP* problem is one of the fundamental open questions of the Standard Model. These effects could manifest themselves via a charge separation along the direction of the system's angular momentum or, equivalently, along the direction of the strong ≈ 10^{14} T, magnetic field created in non-central heavy-ion collision and perpendicular to the reaction plane (the plane of symmetry of a collision defined by the impact parameter vector and the beam direction). This phenomenon is called the *chiral magnetic effect* (CME). Due to fluctuations in the sign of the topological charge of these domains, the resulting charge separation averaged over many events is zero. This makes the observation of the CME possible only via *P*-even observables, expressed in terms of two- and multi-particle correlations.

The ALICE Collaboration has studied the charge-dependent azimuthal particle correlations at mid-rapidity in Pb-Pb collisions at the centre of mass energy per nucleon pair $\sqrt{s_{NN}}$=2.76 TeV. The analysis was performed over the entire minimum-bias trigger event sample recorded in 2010 (about 13 million events). A multi-particle correlator was employed which probes the magnitude of the potential signal while at the same time suppresses the background correlations unrelated to the reaction plane. This correlator has the form $\langle\cos(\varphi_\alpha + \varphi_\beta - 2\Psi_{RP})\rangle$, where φ is the azimuthal angle of particles while the index indicates the charge or the particle type. The orientation of the reaction plane angle is represented by the Ψ_{RP}, and is not known experimentally but rather estimated by constructing the event plane using azimuthal particle distributions.

Fig. 2 presents the correlator $\langle\cos(\varphi_\alpha + \varphi_\beta - 2\Psi_{RP})\rangle$ as a function of the collision centrality compared to model calculations and results from RHIC energies. The ALICE points, shown as full and open circles for the pairs with same and opposite charge, respectively, indicate a significant difference in the magnitude but also in the sign of the correlations for different charge combinations, consistent with the qualitative expectations for the chiral magnetic effect. The effect gets more pronounced as we move from central to peripheral collisions i.e. moving from left to right along the x-axis. The results from a previous measurement of charge separation by the STAR Collaboration in Au-Au collisions at $\sqrt{s_{NN}}$= 0.2 TeV, also shown in Fig. 2 (blue stars), are similar to the LHC measurement.

The thick solid line in Fig. 2 shows a prediction for the same sign correlations due to the chiral magnetic effect at the LHC energies, based on a model that makes certain assumptions about the duration and time evolution of the magnetic field. This model

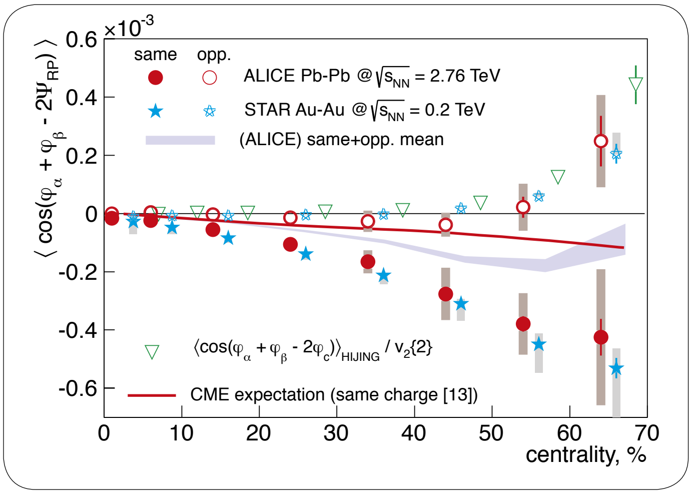


Figure 2. The multi-particle correlator $\langle\cos(\varphi_\alpha + \varphi_\beta - 2\Psi_{RP})\rangle$, which should be sensitive to parity violating effects, as a function of collision centrality.

underestimates the observed magnitude of the same sign correlations seen at the LHC. However, other calculations expect little or no change in the the chiral magnetic effect from RHIC to LHC. Conventional event generators such as HIJING, that do not include any *P*-violating effects, do not exhibit any significant difference between the correlations of pairs with same and opposite charge, which were therefore averaged in the figure (green triangles). Our results for the charge independent correlations are presented by the blue band in Fig. 2.

An alternative explanation to the chiral magnetic effect assumption was recently provided by a hydrodynamical calculation, in which the coupling between two conventional effects, a dipole flow originating from fluctuating initial conditions and local charge conservation in an anisotropically expanding medium, could potentially give a quantitative description of the centrality dependence observed.

The measurements will be extended a.o. with the analyses of higher harmonics and of correlations of identified particles. These studies are expected to shed light on one of the remaining fundamental questions of the Standard Model.

2.4 Neutrino Telescopes
ANTARES & KM3NeT

Management: prof.dr. M. de Jong (PL)
Running period: ANTARES 2001–2016
KM3NeT 2009–2020

The study of cosmic neutrinos is a key component in the field of astroparticle physics. The fruitful interplay between astrophysics and accelerator-based particle physics is exemplified by the resolution of the so-called solar neutrino problem. The potential of a neutrino telescope became evident in 1987. Eighteen hours before the arrival of the light flash from a supernova, a handful of neutrinos were detected by chance, establishing the neutrino as a viable cosmic messenger. For more than hundred years, a third cosmic messenger is known to exist. Protons and nuclei of ordinary matter emanating from the Universe spark off a sudden shower of particles in the Earth's atmosphere. These particle showers are commonly referred to as cosmic rays. The cosmic neutrinos detected so far have energies up to a few tens of MeV. They are not the subjects of this program. The angular resolution of the telescope would then be limited to 10 degrees or so. With the advent of a new generation of high-energy neutrino telescopes, the study of cosmic neutrinos with an angular resolution of about 0.2 degrees has become possible. This corresponds to about half of the apparent size of the Sun on the sky. The realisation of this perspective started in Europe with the successful deployment and operation of a prototype detector built by the ANTARES collaboration of which Nikhef is a long-standing member[1]. Today, many high-energy neutrino sources have been proposed, ranging from supernova remnants in our Galaxy to gamma-ray bursts (GRBs). It is expected that high-energy cosmic neutrinos will be detected for the first time by large neutrino telescopes, such as KM3NeT, in the next decade[2].

The feasibility of neutrino astronomy with a detector in the deep sea was proven by the successful deployment and operation of the ANTARES prototype detector. The ANTARES detector is located in the Mediterranean Sea at a depth of about 2.5 km and about 40 km from the French coast near Toulon. The construction of the ANTARES detector was completed in 2008 and since then it is operated 24 hours per day and 365 days per year, with about 10% of the time reserved for maintenance. Recently, a new memorandum of understanding has been signed through which the continuation of the operation of the ANTARES detector is ensured until 2016. Neutrinos are detected indirectly through the detection of Cherenkov light produced by relativistic muons emerging from charged current interactions of muon neutrinos in the seawater. The mixture of Cherenkov light produced by the muon, the stochastic nature of the Bremstrahlung of the muon,

1 http://antares.in2p3.fr
2 http://KM3NeT.org

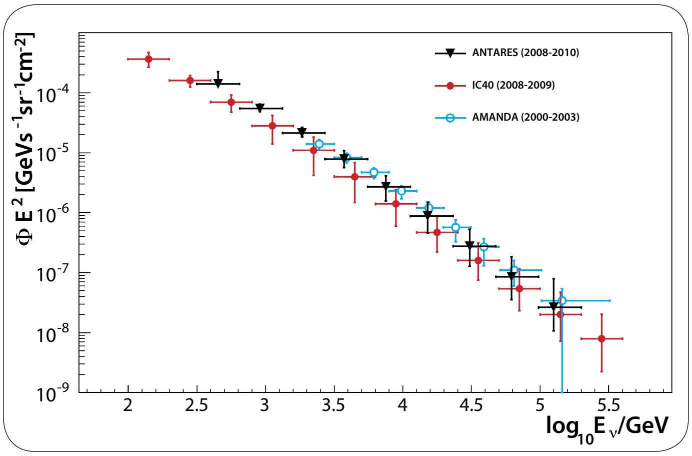


Figure 1: Energy spectrum of atmospheric neutrinos.

the scattering of light in the sea water, the optical background due to radioactive isotopes in the sea water and bio luminescence combined with the sparse sampling of the Cherenkov light with photomultiplier tubes makes the reconstruction of the muon trajectory a challenging task. Nikhef has developed the software that yields the most efficient and most accurate reconstruction of the muon trajectory. Nikhef is leading the analysis efforts for searches of point sources and provided the main author of the two published papers on this topic. In addition to the muon trajectory, the energy of the muon (and hence that of the neutrino) can be determined. From an analysis done at Nikhef, the first measurement of the energy spectrum of atmospheric neutrinos using ANTARES data has been obtained (see Fig. 1). A novel idea has been worked out at Nikhef. In this, the possibility to detect high-energy gamma rays from GRBs has been studied (see

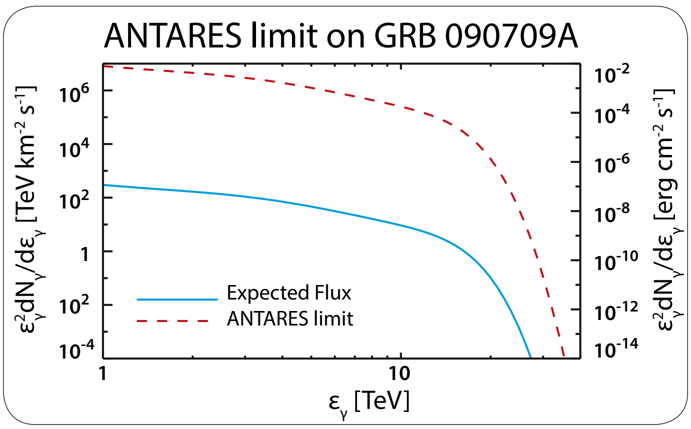


Figure 2: The 90% confidence level of the sensitivity of the ANTARES Telescope to GRB 090709A, shown as the red curve. The theoretical photon spectrum is represented by the blue curve.

Fig. 2). This preliminary study also showed that with the much larger KM3NeT detector, nearby GRBs could be seen according to current GRB models.

KM3NeT

KM3NeT is the successor of ANTARES. It has a challenging and compelling objective: The discovery of neutrino sources in the Universe. The strong scientific case of KM3NeT has been recognised in national and European roadmaps, in particular those of ApPEC, ASTRONET, and ESFRI. The infrastructure it requires will be shared by a multitude of other sciences, making continuous and long-term measurements in the area of oceanography, geophysics, and marine biological sciences possible. The feasibility of neutrino astronomy with a detector in the deep sea was proved by the successful deployment and operation of the ANTARES prototype detector. Nikhef is one of the co-founders of KM3NeT and has contributed several cost-effective design innovations, which have been adopted in the final technical solution for the telescope. These design innovations include the so-called multi-PMT optical module, the "All-data-to-shore" concept and the fibre-optic readout system. The figure of merit of KM3NeT has improved following a re-measurement of the energy spectrum of gamma-rays from the supernova remnant Vela X by the H.E.S.S. collaboration and improvements in the analysis. As a result, a 5 σ discovery can be reached within three years (compared to five years for RXJ1713). Following the discovery that the third neutrino-mixing angle (θ_{13}) is non-zero, a case study has been launched to verify the possibility of a measurement of the mass hierarchy of neutrinos with KM3NeT.

2.5 Gravitational Waves
The dynamics of spacetime

Management: prof.dr. J.F.J. van den Brand (PL)
Running period: 2010–2015

For millennia the Universe has been studied with light and other forms of electromagnetic radiation (since recently neutrinos are used as well). Gravitational wave detectors such as Virgo shown in Fig. 1, will open a new window by detecting waves in spacetime generated in the Universe. This provides unparalleled opportunities for making precision measurements in the regime of strong and dynamical gravitational fields. Such measurements would unveil any flaws in the otherwise solid and successful edifice of general relativity. Because gravitational waves penetrate all regions of time and space with almost no attenuation, these detectors can sense waves from the densest regions of matter, the earliest stages of the Big Bang, and the most extreme warpings of spacetime near black holes.

The first generation LIGO and Virgo detectors have reached excellent sensitivities. However, these sensitivities are not yet enough to detect gravitational waves and new upper limits have been published. Some of these limits like the one on the stochastic cosmic background of gravitational waves or those on the spin-down of the Crab and Vela pulsars, already restrict theoretical models and are of great astrophysical relevance.

The upgrade to 'Advanced' Virgo and LIGO will allow scanning a thousand times larger volume of the Universe. The improvements in sensitivity should guarantee the detection of gravitational waves by 2015–2016. This second generation of interferometers (Advanced LIGO, Advanced Virgo, GEO-HF and Kagra) will be implemented over the next few years.

A breakthrough in instrumentation for gravitational wave research, in which Nikhef plays the leading role, is the development of compact vibration isolation systems. Attenuation factors in excess of 10^6 are achieved within a distance of 1 m. Such systems can be used to reduce unwanted vibrations of optical components to the femtometer/$\sqrt{Hz}$ level within a limited space and at rela-

Figure 1. The Virgo gravitational wave detector near Pisa, Italy, is operated by a Dutch-French-Italian collaboration. Each interferometer arm is 3 km long. Starting in 2015, Advanced Virgo will search for gravitational wave signals together with Advanced LIGO in the U.S.A., Geo600 in Germany and Kagra in Japan.

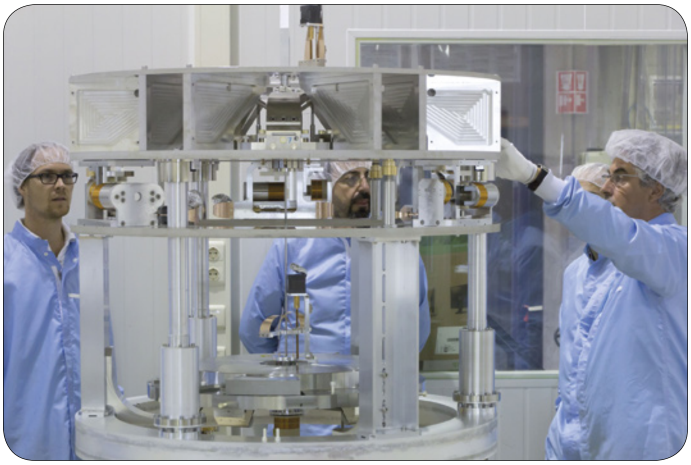


Figure 2. A prototype multi-stage displacement noise attenuation system that is under development at Nikhef for Advanced Virgo. The system will operate in vacuum and reaches operational levels of femtometer/√Hz.

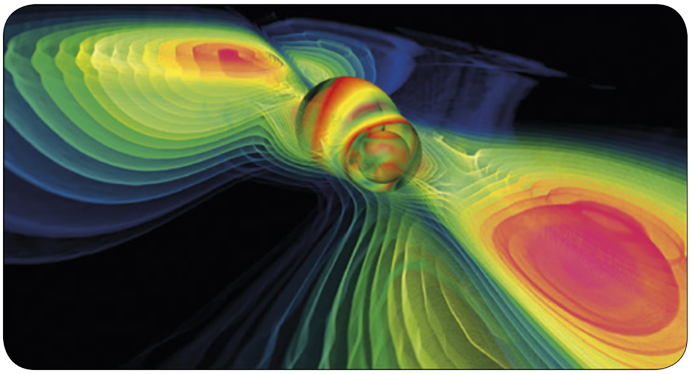


Figure 3. Coalescence of compact binaries is considered one of the most probable sources for the first direct detection of gravitational wave events. Modeling the complexity of the merger of two black holes has reached realistic levels in the last decade.

tively modest cost. Such systems have the potential to make interferometers far more robust against the influence of unwanted seismic vibrations and in this manner can significantly improve the sensitivity at low frequencies (10–100 Hz).

Our vibration isolation techniques (see Fig. 2) are now being implemented in the Advanced Virgo programme at the European Gravitational Observatory (Italy). Also Kagra, a new underground and cryogenic interferometer under construction in Japan profits from our contributions. A formal collaboration has been set-up through the ELiTES project which allows the exchange of researchers between Europe and Japan focused on the cryogenic technologies for the Einstein Telescope and Kagra gravitational wave observatories. It is a 4 years project, supported by the European Commission in March 2012.

In parallel with the instrumentation activities, Nikhef scientists are preparing so-called data analysis pipelines. Here, the most important activity concerns model-independent tests of general relativity. Fig. 3 shows gravitational radiation calculated for the coalescence of compact binaries. Such coalescing binary neutron stars and black holes offer a unique opportunity to test the strong-field dynamics of gravity. The angular motion of the binary is directly encoded in the gravitational waveform's phase, and possible deviations from general relativity, the different emission mechanisms and/or differences in orbital motion will be visible directly in the measured phase.

Possible deviations from general relativity that have been considered in the past in the context of compact binary coalescence include scalar-tensor theories, a varying Newton constant, modified dispersion relation theories, usually referred to in literature as 'massive gravity', violations of the No Hair Theorem, violations of Cosmic Censorship, and parity violating theories. However, general relativity may be violated in some other manner, including a way that is yet to be envisaged. This makes it imperative to develop methods that can search for generic deviations from general relativity. As far as waveforms are concerned, a start was made with the 'parameterized post-Einsteinian' formalism. At the same time, a sufficiently general data analysis scheme will be necessary, and Nikhef scientists recently took the first steps in that direction. The dynamics of binary coalescence are extremely rich, especially if two black holes are involved. Astrophysical black holes are predicted to be fast-spinning, causing extreme 'frame dragging' which influences the way they move around each other. If the two spins are not aligned, the orientation of the orbital plane will undergo precession, and in some cases even a tumbling motion, which modulates the phase and amplitude of the emitted waveform. General relativity makes accurate predictions for these effects, which we will be able to study in considerable detail.

The astronomers of the Radboud University Nijmegen who participate in the FOM programme became Nikhef members, and in 2012 the RU Astrophysics group joined the Virgo collaboration with the aim to lead the efforts for joint electromagnetic and gravitational wave observations and their data analysis. Currently, the efforts concentrate on assessing the actual benefit of various complementary observations, also for future space missions such as eLISA, and on developing a new optical telescope array called the BlackGEM array, dedicated to these observations.

The Nikhef/RU group organised the first Dutch Gravitational Wave Meeting in January.

2.6 Cosmic Rays
The Pierre Auger experiment

Management: dr. C. Timmermans (PL)
Running Period: 2008–2013

The Pierre Auger Experiment measures cosmic radiation of the highest energy (above 10^{18} eV) through the showers created in the atmosphere of the Earth. These measurements are performed using particle detectors at the Earth's surface and telescopes overseeing the 3000 km^2 array, which detect the fluorescence light created by air showers during dark nights.

The Pierre Auger observatory, located in the province of Mendoza, Argentina, is an excellent place to pioneer and calibrate new air-shower-detection techniques such as the detection of air showers through their emission of radio signals. The involvement of the joint Dutch group, from Nikhef and the University of Groningen, in the development of the radio technique, as well as the measurement of air shower parameters from the surface detector, originates from the desire to study the development of air showers in order to study the physics of the highest energy interactions obtainable on Earth.

Radio Signals of Air Showers

The Dutch group is a leading player in designing, deploying, running and analysing the Auger Engineering Radio Array (AERA). In 2012 all elements of stage 2 of AERA have been developed and built, and installation on site will commence in 2013. In stage 2 the number of radio stations will be expanded from 24 to 120. The Dutch group has made technical contributions in the creation of a new low power digital board that only consumes 6 W of power. This enables using a single solar panel, which means a significant reduction of costs. Furthermore, the Dutch group has designed and built a small scintillator detector, that will provide an additional trigger possibility for the radio detector station, and thus helps in understanding the nature of the radio signal.

The data of stage 1 continue to be analyzed. Especial attention is given to the parameters that are influenced by the development of air showers, such as the frequency dependence of the radio signal. Our current analysis shows the sensitivity of the radio signals to the air shower geometry. A comparison to the events for which there is fluorescence information is needed to show a dependence on the longitudinal geometry of the air shower. The Dutch group in Auger is leading these efforts.

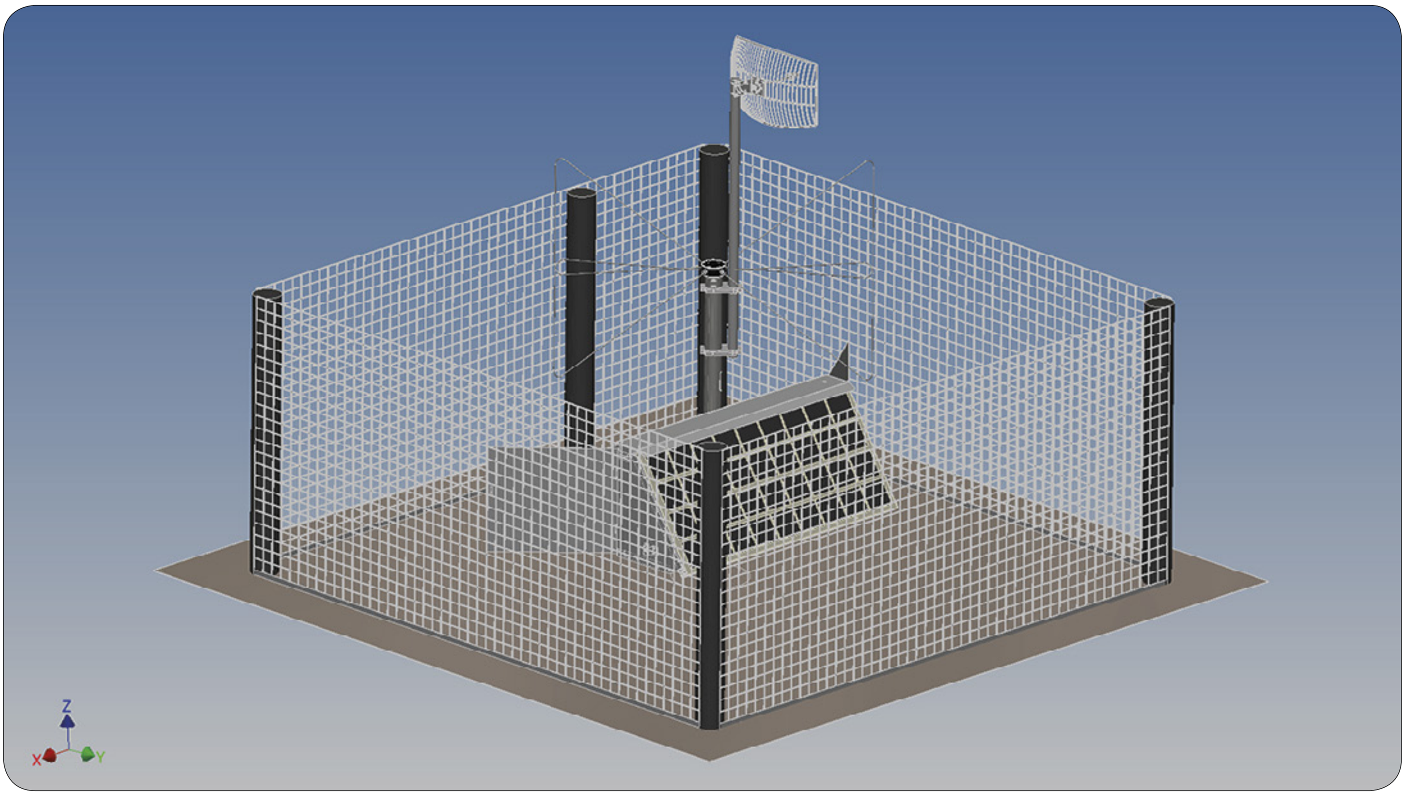


Figure 1. Design of the next generation AERA setup.

The AERA setup is, and will remain, rather sparse. This choice is made in order to cover a large area for a reasonable price. In contrast, the LOFAR radio telescope in the province of Drenthe in the Netherlands consists of a dense core of radio antennas that can be triggered externally by scintillator counters in order to measure air showers. This measurement provides information complementary to the data from Auger. The data allow for a detailed measurement of the radio lateral distribution function that can be compared to theoretical models. However, the air shower information is rather limited, therefore a detailed study of the dependence of radio on the air shower development is much better performed in Argentina. The synergy between these two experiments is exclusively studied by the Dutch Auger and LOFAR teams.

Analysis of the surface detector information

The particle measurement on Earth still contains information on the development of the air shower through the atmosphere. Intuitively, the measurement of the radius of curvature of the air shower provides information of the height of the common origin of the particles measured on Earth, and thus on the location of the initial stages of air shower development. The radius of curvature of the air shower is not a parameter that is very important for energy or directional information of the air showers. For this reason the reconstruction quality of this parameter can still be improved. In 2012 the Dutch group has, together with Argentinian groups, investigated the influence of the uncertainty of the arrival times for detectors with a low signal. By improving the model for the timing uncertainty, systematic shifts in the evaluation of the radius of curvature have been greatly reduced, which allows using the radius of curvature as a reliable parameter for more events, also at lower energies.

However, the radius of curvature is not the only composition sensitive parameter. Parameters sensitive to the muon content of air showers, such as the signal rise-time are shown to depend on the height of the shower maximum. In the upcoming year we strive to make a combination of these parameters, and compare that not only to simulations, but also to the fluorescence measurement of the air shower profile. The combination of comparisons provides the necessary theoretical background and experimental proof of the sensitivity of the measurement to the air shower development.

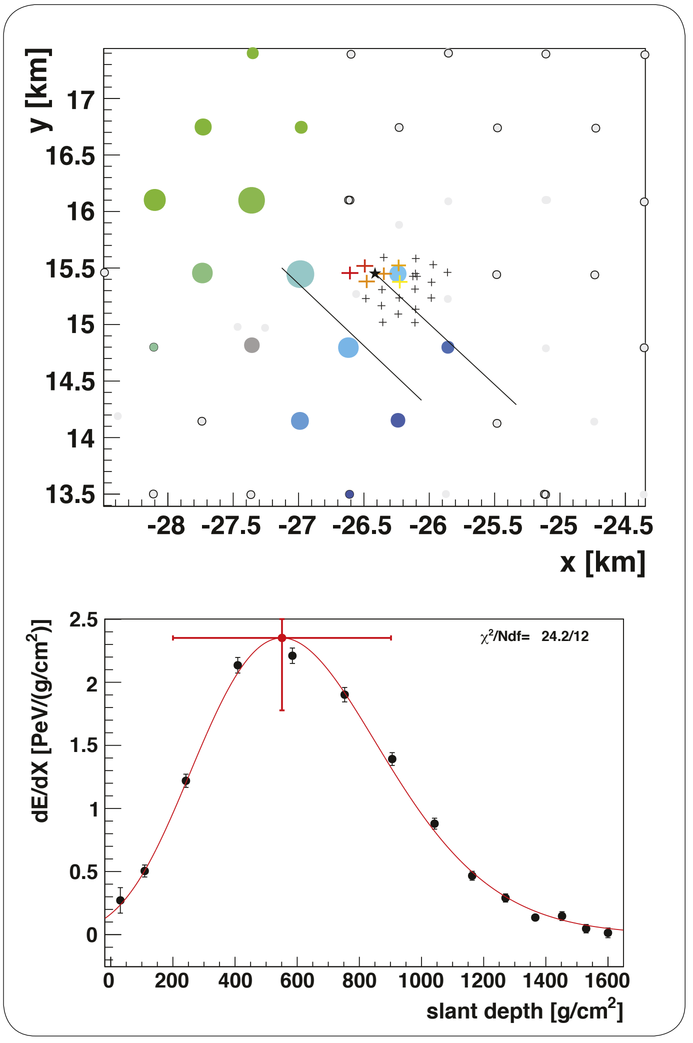


Figure 2. An event measured by the surface detector and radio (top). The size of the circles indicates the signal strength in the surface detector, whereas the colour indicates the arrival time. The coloured crosses indicate the time of the radio signal. Shower development of the same event (bottom). The shower development was reconstructed from the fluorescence telescope data of the same event as shown in the top plot.

2.7 Dark Matter
XENON & DARWIN

Management: dr. M.P. Decowski (PL)
Running Period: 2013–2018

The Dark Matter programme at Nikhef aims to detect dark matter particles in the Galaxy and was recently approved as a FOM programme. A generic class of dark matter particle candidates are called Weakly Interacting Massive Particles (WIMPs) and a global search is ongoing to detect WIMPs. Nikhef is participating in a series of experiments that are particularly well suited to detect the existence of WIMPs.

The running XENON100 experiment
XENON100 is the running dual-phase xenon experiment at the underground Gran Sasso laboratory (LNGS) in Italy. The XENON100 collaboration published the results of a blind analysis of 225 live days × 34 kg exposure in the past year. No evidence for dark matter interactions was observed. This run featured an ultra-low electromagnetic background in the energy region of interest, two orders of magnitude below any other running dark matter search experiment. The two candidate events observed in the pre-defined nuclear recoil energy range are consistent with the background expectation of (1.0±0.2) events.

The XENON100 analysis sets the most stringent limit on the spin-independent elastic WIMP-nucleon scattering cross section for WIMP masses above 8 GeV/c^2, with a minimum of 2 × 10^{-45} cm^2 at 55 GeV/c^2 (at 90% confidence level). This limit corresponds to the design goal of XENON100 and excludes a large fraction of previously unexplored WIMP parameter space, see

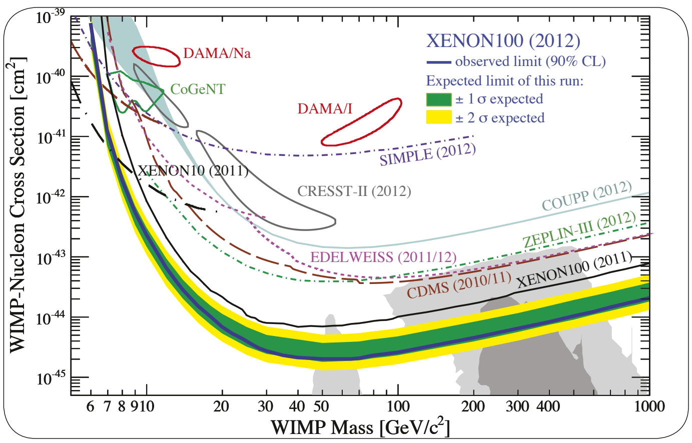


Figure 1. New results on spin-independent WIMP-nucleon scattering from XENON100. The expected sensitivity is shown by the green/yellow band (1σ/2σ) and the resulting exclusion limit (90% CL) in blue. For comparison, other experimental results are also shown, together with the regions (1σ/2σ) preferred by one class of supersymmetric models.

Fig.1. In addition, we have published an extensive report on the analysis of this detector. We plan to continue analysing the data using various other dark matter interpretations, e.g. in the framework of spin-dependent and inelastic scattering. The analysis at Nikhef is mainly focussed on understanding the recoil signal in the gas phase of the detector (the so-called S2). At the same time we plan to use the XENON100 detector in a new run to perform extensive calibration runs to improve our understanding of the systematic uncertainties and as a test-bed for XENON1T-related developments. We are improving our understanding of the response of the detector and refining our Monte Carlo simulation code, both are essential for an optimal design of XENON1T.

The next experiment: XENON1T
The XENON1T experiment is a successor to XENON100, with two orders of magnitude better sensitivity for detection of dark matter particles. To achieve this goal, several important improvements have to be made, the most significant being a much lower radioactive background from construction materials and external sources. The collaboration has spent much effort in the past year to make key decisions in the XENON1T design. Nikhef has been involved with the design of the cryostat housing the detector with the time-projection chamber and 3 t of xenon, and the vibration-free cryostat support structure. The design had to be optimised to use a minimum of low radioactivity stainless steel while achieving the mechanical specifications.

Fig. 2 shows the close-to-final design of the XENON1T experiment inside a 10 m diameter water tank as additional shielding against external neutrons. The experiment is now going through a safety review process, including seismic safety. Once completed, we will start construction in the spring of 2013 in Hall B of LNGS with the erection of the water tank and the Nikhef-supplied cryostat support structure. The goal is to complete the detector in 2014 and start taking physics data in 2015.

The future dark matter experiment: DARWIN
The DARWIN experiment will be the ultimate direct detection dark matter experiment as it will become limited by the irreducible background coming from solar neutrinos. The goal of the experiment is to build a detector with 10–20 ton xenon and argon WIMP-targets with ultra low background materials. As part of the DARWIN consortium, we are continuing to investigate GridPix as a direct charge readout system, this could potentially lower the energy threshold and radioactive background.

We have started to assemble a test facility, called XAMS, to investigate GridPix and other technologies at liquid xenon tem-

Figure 2. Illustration of the XENON1T detector, to be constructed at the underground Gran Sasso laboratory (LNGS) in Italy. The cryostat with the dual-phase xenon time-projection chamber is in the middle of a 10 m diameter water tank. The detector contains about three tons of xenon of which one ton is used as the WIMP target.

peratures in a dual-phase TPC setting. Many of the components have already been delivered and we expect to start the liquefaction of high purity xenon in early 2013. This new test facility is housed in the CryoLab at Nikhef.

Finally, we were recently awarded a FOM *"Vrije Programma's"* grant with a running period of six years. The programme has strong experimental and theoretical components and allows us to fully participate in dark matter research.

2.8 Theoretical Physics

Management: prof.dr. E. Laenen (PL)

This year has been a banner year for the Nikhef theory group, in which both the amount of external funding and the number of members increased significantly. Before turning to these matters, let us review research conducted in the group, which includes that of the VU University Amsterdam and Radboud University Nijmegen partners.

Research summary

The rare decay $B_s^0 \to \mu^+\mu^-$ is one of the key processes for testing the Standard Model (SM). In a paper published in Physical Review Letters, it was pointed out that this channel offers a new theoretically clean observable, the effective lifetime $\tau_{\mu+\mu-}$. This quantity, which gives new sensitivity to physics lying beyond the SM, is accessible thanks to the sizable decay width difference $\Delta\Gamma_s$ of the B_s-meson system that was established by LHCb in the spring of 2012. It was shown, in general terms, that $\Delta\Gamma_s$ leads to subtleties in the interpretation of experimental results in terms of B_s decay branching ratios. This is also the case for $B_s^0 \to \mu^+\mu^-$, where $\Delta\Gamma_s$ lifts the SM reference value of the branching ratio by about 10%. The $\Delta\Gamma_s$ shift is particularly relevant in view of the recent 3.5σ evidence for $B_s^0 \to \mu^+\mu^-$ reported by LHCb, with a first experimental branching ratio of $(3.2^{+1.5}_{-1.2}) \times 10^{-9}$, while the theoretical SM prediction taking $\Delta\Gamma_s$ into account reads $(3.54\pm0.30) \times 10^{-9}$. The measurement of $\tau_{\mu+\mu-}$ to complement the branching ratio is an exciting new topic for the future upgrade of the LHC experiments and may still reveal a large New-Physics contribution. Another analysis focused on $B_s \to D_s^{(*)\pm}K^{\mp}$ decays, exploring the impact of $\Delta\Gamma_s$ for the exploration of CP violation at LHCb. These projects were carried out in collaboration between members of the theory and LHCb groups.

Spin-entangled decays in scattering events at the Large Hadron Collider (LHC) were analysed, and a very generic algorithm to keep track of spin correlation effects in Monte Carlo events at a greater accuracy was proposed, and implemented. The results and accompanying software (MadSpin) have important implications for the physics programme carried on at the LHC, in particular to separate rare signal events from large QCD background events.

The expected polarisation of the top produced in the decay of a scalar top is surveyed. The polarisation depends on the mixing in the stop and neutralino sector as well as on the kinematics, the mass difference between stop and neutralino. It was found that mixed stop behave more like righthanded stops due to the larger hypercharge that enters the stop/top/gaugino coupling. Different lab frame observables are discussed that are found to be a faithful probe of polarisation. In addition the effect of polarisation is illustrated on the energy and transverse momentum distributions. It is shown that for negative polarisations the spectra are softened considerably, especially for large mass differences between the stop and neutralino.

Dimension-six sources of parity- and time-reversal violation (or equivalenty CP violation) beyond the Standard Model were investigated. These sources are being searched for by various electric-dipole-moment experiments all over the globe. A framework, based on effective field theories, has been built in which hadronic and nuclear PT-odd observables can be calculated in a unified and systematic way. This framework has been used already for several calculations.

To help unravel possible physics beyond the Standard Model, a project was started that aims at putting in place a machinery of cleverly constructed sum rules: fast diagnostic tools that can be used to translate the findings at LHC energies into conclusive statements about (properties of) the underlying higher-energy physics. In this way specific models or generic hypotheses that are common to new-physics models such as unification and universality properties can be tested.

To study transverse momentum dependent parton distribution functions (TMD PDFs), which are useful to describe azimuthal asymmetries, mostly in processes with polarised particles in the initial or final state, process dependent effects have to be taken into account. A systematic classification of quark TMD PDFs was given, including process dependence in calculable factors depending on the colour flow in the hard process. This was achieved by defining a finite number of TMD PDFs of definite rank, of which the rank 0 functions are the (three) well-known collinear PDFs, while the rank 1 functions include among others the time-reversal odd (T-odd) Sivers and Boer-Mulders functions, important to describe single spin asymmetries. An important new result is that the full treatment of transversely polarised quarks in transversely polarised hadrons requires three (universal) rank two TMD functions, all of them being T-even. The list of leading quark TMD PDF's for spin-½ hadrons was thus completed, while results for spin 1 hadrons were also included.

FORM version 4.0 was released this year. It represents several years of work and includes many new features. It is also open source. It may well contain the first efficient open source implementation of factorisation of multivariate polynomials. As part of a new project Monte Carlo tree search algorithms were used to simplify output expressions so that resulting numerical programs

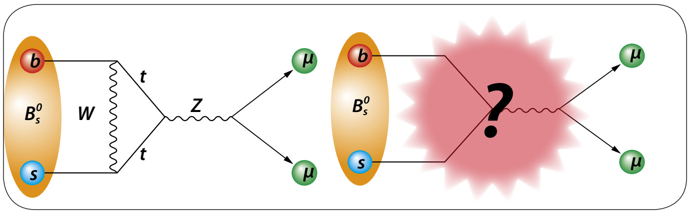


Figure 1. Standard Model and possible New Physics contributions to rare decay $B_s \rightarrow \mu^+\mu^-$.

will be significantly faster. These algorithms are unprecedented in computer algebra and will be part of the soon-to-be-released version 4.1 of FORM. They have been tested already in the calculation of the full one loop electroweak corrections to the reaction $e^-e^+ \rightarrow t\bar{t}\gamma$ which was also completed.

Prompt photon production in fixed target or collider experiments has traditionally been an important QCD testing ground, with a phenomenological relevance of its own. The impact of the soft-gluon resummation effects, in particular the inclusion of leading soft-collinear terms, was assessed for the production via fragmentation, which involves keeping track of many colour structures. The effects were found to be mild, but not negligible.

QCD has a deconfined phase at high temperature. The thermodynamics of its quenched version has been analysed by lattice simulations with good precision, and gives rise to a pronounced plateau, starting just above the critical temperature and extending to about four times the critical temperature. This behaviour is a conundrum, unexplained by perturbative methods. Moreover, it shows up for any number of colours. A simple Landau-Ginzburg approximation to the effective potential reproduces this salient fact quite well, with just one free parameter.

In the framework of Higgs inflation, the role of the inflaton is played by the Standard Model Higgs boson. To confront this model to observations, a precise description, including quantum effects, is needed. As an intermediate step in this programme the effective action for the abelian-Higgs model in an expanding Universe was calculated.

If inflation is driven by the sgoldstino field, a necessary ingredient of any supersymmetric extension of the standard model, its predictions are very robust. It was pointed out by researchers in the group that the reason is that the sgoldstino dynamics decouples from the low energy physics. Concrete implementations of this idea were formulated.

Inflation with a pseudo-scalar inflaton can lead to a copious production of massless gauge quanta. This can lead to an equilateral non-Gaussian component to the power spectrum. However, it was estimated that in such models the power spectrum increases beyond the critical bound set by the non-detection of primordial black holes. A new variant of this model was proposed that produces massive gauge quanta. In this case, a local non-Gaussian component to the power spectrum is generated and black hole bounds are parametrically satisfied.

The physical demands for any sensible SM extension were translated to the language of noncommutative geometry. This is a relatively new and promising framework to do particle physics in, yielding a limited number of viable theories. From this point of view, it was concluded that the SM needs to be extended with right-handed neutrinos, and that the minimal supersymmetric extension of the SM, does not satisfy our demands. To do so requires a slightly bigger particle content than the MSSM provides.

Discrete symmetries are often invoked in ideas about extensions of the standard model, to argue that certain undesirable processes (for example, the decay of the proton) are forbidden. However, quantum gravity usually breaks discrete symmetries, because of the "no-hair" theorem of black holes. Black holes cannot carry discrete charges, and therefore cannot preserve them. There is one potential exception: it was demonstrated two decades ago that discrete subgroups of spontaneously broken *U(1)* symmetries can be respected by quantum gravity. In string theory the same problem and the same way out exists, in principle. There are usually several *U(1)*'s that get a mass because of two-point couplings to axions. To investigate if a discrete subgroup remains, one has to check if those axion couplings have common integer factors, which is not obvious because a priori these couplings are real numbers. We studied this for a special class of string theories, open strings built using discrete two-dimensional field theories. We developed a method to extract the information in all such constructions, and applied it to several classes of supersymmetric extensions of the Standard Model.

In the context of BPS black holes and the so-called OSV conjecture, the relation between N=2 supergravity effective actions and the topological string was discussed and clarified.

The properties of nonlinear sigma models in 2+1 dimensional AdS and the restrictions imposed upon them by Supersymmetry were analysed. 2+1 dimensional AdS is rather special as there are multiple formulations of N-extended Supersymmetry for each N>1. The results for N=3,4 are especially stringent and mirror similar developments found in recent years for 3+1 and 4+1 dimensional AdS. This classification may potentially be useful for applications to the AdS/CFT correspondence.

The thermal partition function of quantum field theories on arbitrary stationary background spacetime was studied, with arbitrary stationary background gauge fields, and in the long wavelength expansion. It was demonstrated that the equations of relativistic hydrodynamics are significantly constrained by the requirement of consistency with any partition function. In particular, the universal part of the equilibrium partition function characteristic of a theory with multiple abelian U(1) anomalies was computed in arbitrary even spacetime dimensions. In this way, all the known results on these transport coefficients were rederived. This has recently been conjectured to be linked to the anomaly polynomial of the theory. Furthermore the local description of anomaly induced transport in terms of a Gibbs current was linked to the more global description in terms of the partition function.

Various sectors of the Supersymmetry algebra of N=1 supergravity in 4 dimensions were explored. By a change of variable in the path integral formulation of the theory, three different sectors of the algebra were isolated, generated by a scalar, a pseudo-scalar and a vector generator, respectively. Interestingly, the scalar sector was shown to be sufficiently big to constrain the Lagrangian of the theory to the form previously derived from the full Poincare superalgebra.

With holographic renormalisation techniques the finite part of the on-shell action for a higher-spin theory in AdS3 (spin-3 in particular) was computed, and with this, in turn, the two point correlation functions for operators dual to spin-3 fields in AdS3. Subsequently, the on-shell action for AdS3 was analytically continued to compute the on-shell action for spin-3 fields in 3d de Sitter space, and the two point correlators fields for operators dual to spin-3 fields dS3 were computed. These results point towards a real central charge in the dual CFT as opposed to a problematic imaginary central charge, suggested in the literature.

The work of Bekenstein and Hawking in the 1970s showed that black holes have thermodynamic behaviour, and one can associate a thermodynamic temperature and entropy to black holes in the quantum theory of gravity. Members of the group endeavour to probe these concepts beyond the semiclassical approximation, and to compute exact quantities in the full quantum theory. In particular, for black holes in string theory answers can be compared to the corresponding answers found by statistical mechanics applied to string theory. In a series of papers, the gravitational and statistical aspects of black hole entropy in string theory were explored.

Other news

This has been a remarkable year for the Nikhef theory group, because the size, stength and external funding of the group increased significantly. Per 1 March, Bernard de Wit and his group funded by his ERC Advanced Grant, a VENI grant, and a *Projectruimte* moved from Utrecht University to Nikhef. Also Jos Vermaseren and Piet Mulders were awarded ERC Advanced Grants. The latter moved his residence and that of his group to Nikhef, adding further to the size and strength of the group. Thus, the group now hosts no less than three ERC Advanced Grant holders. In addition, *Projectruimte* grants were awarded this year to Marieke Postma and Piet Mulders.

Robert Fleischer was appointed, per March 1, Extraordinary Professor of Theoretical Physics at the VU University Amsterdam, to a chair on *'High-Energy Physics with an Emphasis on B Physics'*.

The monthly Theory Center Meetings, a key element of the FOM program *"Theoretical Particle Physics in the Era of the LHC"*, continue to be well-attended, strengthening interaction among theorists in the Netherlands. The student-only seminar remains very popular. The national Seminar on Theoretical High-Energy Physics continues to be held at Nikhef and attracts good speakers and excellent attendance. Eric Laenen was a speaker at a KNAW symposium on Higgs physics. For the Nikhef Academic Lectures Piet Mulders presented a number of lectures on Dirac and Majorana fermions.

Outreach activities of the theory group include HiSPARC as well as giving lectures to high-school students and other interested groups. At the Nikhef open day, the group hosted a *"Big Bang Theory Corner"* to answer many questions from visitors.

2.9 Detector R&D

Management: dr. N.A. van Bakel (PL)

The focus of the group in 2012 remained on research towards new detector technologies for future particle physics experiments. Novel *micro pattern gas detectors* (MPGD) and semiconductor detectors under development for accelerator based research find new applications in particle-astrophysics experiments and industrial instrumentation. The group is also involved in valorisation: further development of scientific instrumentation towards commercial applications.

Gaseous Detectors

The GridPix detector is a pixelated readout chip with a gas amplification grid on top. This family of detectors allows a 3-D track reconstruction of ionising radiation. The *x-y* position is given by the pixel matrix and the *z* position is derived from the time of arrival of the drifting ionisation charge. The first GridPix detectors (MPGD) have been fabricated in 2006 by developing MEMS techniques compatible with CMOS post processing. Some of the post-processing steps were done on single Timepix readout chips limiting the mass production of these novel devices. This method delivered sufficient quantities in the initial phase of GridPix R&D but since 2010 an effort is ongoing towards mass production of GridPix devices. The goal is to complete all post-processing on full size 200 mm Timepix wafers to ensure the production of numerous spark proof GridPix detectors of high quality and reliability. In collaboration with the MESA+ institute at the University of Twente, IZM Fraunhofer Institute in Berlin, and Bonn University a number of GridPix batches on wafer scale have been fabricated in 2012. Major advances in the production process and quality control have been demonstrated and provided new ideas to further improve the technology. Finite element simulations yield a better understanding of the thermal stress in the different materials of the GridPix, especially needed for applications in noble liquid environments for Dark Matter searches. Currently even full *ceramic* GridPix devices are considered, where ceramic materials cover the metal grid and replace the SU8 pillars to achieve even better spark protection and for operation in cryogenic environments.

The so called IZM3 batch provided enough GridPix detectors to organize a beam test at the SPS North area (H4) providing a beam of 150 GeV muons. The set-up in Fig. 1 shows a beam telescope consisting of four GridPix detectors in a row. Each detector has only a 1 mm gas layer over the GridPix structure and is mounted on an individual rotation stage to position the detectors under an angle with respect to the beam axis while keeping the detectors aligned. This will allow to measure e.g. the position and angular

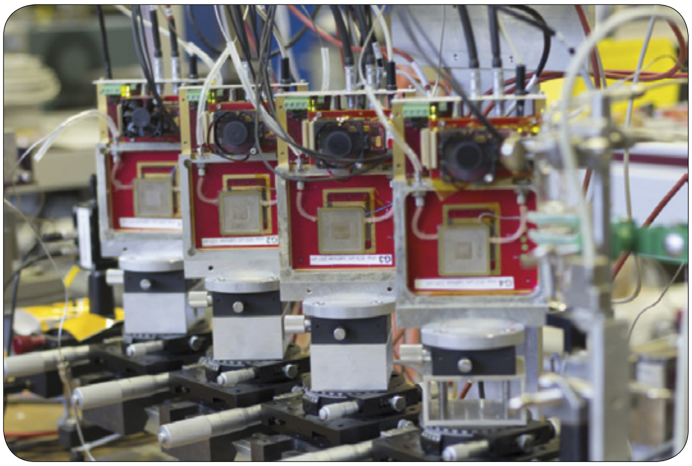


Figure 1. The GridPix beam telescope, designed and built at Nikhef, has been shipped to CERN in November 2012 where it was installed at the SPS test beam. The individual detectors are readout with 'Relaxd boards' and the high-grid-voltage is provided by 'miniHV' voltage supplies. Both instruments have been developed within Nikhef's Electronics Department.

resolution, efficiency and two-track separation of the GridPix detectors. In addition, GridPix detectors with longer drift lengths up to 16 mm have been tested in collaboration with A. Romaniouk's group at CERN. These Time Projection Chambers (TPC) with longer drift lengths have potential applications in e.g. a future upgrade of the Atlas L1 trigger. Allowing fast and efficient recognition of tracks and determination of their properties could give a fast trigger on tracks with high transverse momentum.

Semiconductor Detectors

The granularity of particle detectors is ever increasing and hence many detectors adopt a pixel architecture. The Nikhef R&D and electronics group are actively involved in the design and characterisation of pixel sensors and readout chips. Given the complexity of these chips, we collaborate with other institutes and universities on the design. Most notably we work with the CERN PH/ESE group on the design of the Timepix-3, which is a follow up of the Timepix chip that is successfully used in many applications. The Timepix-3 consists of a matrix of 256×256 active pixels with a size of 55×55 μm^2 and is built in a 130 nm CMOS technology.

In the framework of the Timepix-3 chip, Nikhef and Bonn University developed the GOSSIPO-4 prototype chip to test a series of circuits and a new high density Standard Cell Library developed at CERN. While Timepix-3 is a general purpose chip, the focus of the GOSSIPO series of chips is mainly on gas detector readout, e.g. GridPix and large volume TPCs. The 3-D tracking potential of GridPix has been demonstrated using the TimePix chip with a time resolution of 10 ns. An improved

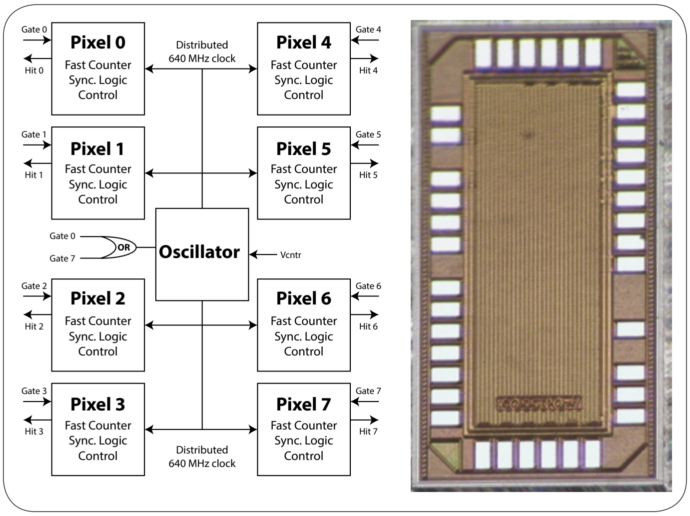


Figure 2. The block diagram shows the Super Pixel concept realised in GOSSIPO-4 chip, a 4×2 pixel chip of 2×1 mm². The main feature is that the oscillator is shared among 8 different pixels. This saves power and area but increases the problems with the synchronisation.

Time to Digital Converter (TDC) is needed to achieve better track reconstruction. A factor 10 gain in timing resolution is an essential improvement for the drift time determination, and thereby for the position resolution (in the drift direction) of gaseous detectors.

Many different TDC architectures are possible to achieve such resolution, but for area and power consideration it has been decided to use an oscillator that provides a fast clock (640 MHz) combined with a counter. There are two main concepts that will be tested with GOSSIPO-4; the first one is a new structure called *Super Pixel*, in which one oscillator provides the clock for high resolution time measurements in 8 different pixels. This solution has been adopted to reduce area and power consumption but it introduces a new level of complexity since the fast clock has to be generated free of glitches and distributed to 8 pixels. The second novelty is the Phase Locked Loop (PLL) controlled oscillator. In order to reduce differences in the oscillation period caused by process and temperature variation, a PLL locked to a 40 MHz reference clock is placed at the periphery of the chip to provide a control voltage compensating these variations. GOSSIPO-4 has been submitted in 2012 and is currently being characterised at Nikhef.

Many features of the Timepix-3 are identical to the pixel chip called VeloPix which is developed for the VErtex LOcator upgrade (VELO) of the LHCb experiment thereby bringing IP developed mainly for non-HEP applications in the Medipix collaboration back to the core business of Nikhef. One of the main features of the Timepix-3 chip is a much faster front-end (peaking time < 25 ns) and fast time digitiser (TDC) in each pixel with a resolution of 1.6 ns to record the arrival time of the particle. Besides the arrival time of the hit, each pixel also measures the signal charge by determining the time where the signal is over threshold.

Another major improvement in Timepix-3 is that the zero-suppression of the data is now done on chip. This gives an enormous reduction in data volume and thereby an increased track readout rate compared to the non-zero-suppressed frame-based readout as used in the current version of the Timepix chip. In addition to the sparsification of the data, the chip can operate in a triggerless, data driven readout mode. This means that each hit is immediately sent off chip without waiting for a trigger/shutter signal.

The Timepix-3 will be submitted early 2013 and has hit rate capability of 40 million hits per second. Once submitted, the same design team will work on the VeloPix chip which has to operate in the vacuum of the LHCb experiment at only 5 mm from the colliding proton beams. The chips closest to the beam have to handle a hit rate of about 500 million hits/s. This requires the development of on chip drivers for high speed serial links. Being close to the beam the VeloPix will face a radiation dose reaching 500 Mrad during the life time of the experiment and has to be robust against radiation induced single event upsets.

2.10 Grid Computing

Management: dr. J.A. Templon (PL), ing. W. Heubers

Facilities

The grid facilities at Nikhef ran well this year, thanks to past investments made in facility monitoring, and in improvement and automation of fault-recovery procedures. Fig. 1 shows how the computing power of the Nikhef grid cluster was used in 2012. The year saw major upgrades in the area of networking and virtualisation within the facility. Nearly all grid services now run within a fully virtualised environment which supports advanced virtual machine management such as live migration, simplifying system maintenance and improving overall availability. The networking improvements are mainly targeted at making it possible to isolate users/groups into separate virtual LANs. This isolation will eventually make it possible to shift security measures from the software layer into the hardware (network) layer, which provides both performance and ease-of-use advantages to the user.

Middleware

Our middleware products are in active use by grid projects around the world. Active development on these products is decreasing, due to both the level of maturity reached by the software, as well as the end of the European middleware projects that have funded these developments for the last ten years. Nikhef will continue to maintain these products as long as "relevant customers" (for example, grid infrastructures for physics research) continue to use them.

Activities in support of Users

Together with the Nikhef Computer Technology group we significantly improved *'stoomboot'* –a computing cluster service provided to Nikhef physicists. Scheduling of user jobs was completely revamped, based on our experience with the larger grid cluster. Data access was vastly improved by deprecating the previous NFS storage in favour of a new cluster file system based on GlusterFS. GPU computing is also being jointly investigated by the CT and Grid groups, exploring the potential benefit for the Virgo and ANTARES experiments.

We are collaborating with Nikhef staff involved in Virgo, to run their general-relativity simulation codes on the grid. For the XENON experiment, we have implemented a service to transfer their data onto the grid, and provided a proof-of-concept for analysis of these data.

The Virgo general-relativity work is one of several recent experiments to request use of more powerful machines for their jobs. These jobs make simultaneous use of many cores and often request large amounts of RAM. We have provided this computing service to our colleagues from LOFAR and to a life-sciences group at the Technical University of Delft. The LHC experiments at CERN are experimenting with many-core computing. We expect that they will soon be ready to try this on the grid; our newest round of computing hardware acquisition has anticipated this development.

Via the BiG Grid project we are contributing components for the distributed-computing infrastructure for several non-HEP groups: Humanities and Social Science (DANS in The Hague, the CLARIN ESFRI project, and the Max Planck Institute for Psycholinguistics), Quantum Chemistry (Leiden), Life Sciences (Academic Medical Center of Amsterdam).

This year we have been preparing for the 20th edition of the conference on Computing in High-Energy Physics (CHEP), which will be held in the Beurs van Berlage in Amsterdam in October 2013.

Research

Daniela Remenska's PhD project (our group collaborating with prof.dr. Henri Bal at the VU University of Amsterdam) concerns using formal methods to verify soundness of design in distributed systems. Her studies are carried out on LHCb's DIRAC system, on which their computing operations is based. Currently her research focuses on constructing the formal models directly from UML diagrams, which allows systems to be verified during the design stage.

One part of Hurng-Chun Lee's PhD project (our group collaborating with the Nikhef ATLAS group) involves investigating the suitability of so called high-performance cloud systems for data analysis purposes in high-energy physics. He managed to achieve good performance for analysis, however the scalability was rather poor, due to the architecture choices usually made for cloud systems. A detailed report will appear in his PhD thesis in 2013.

BiG Grid

The end of 2012 marks the end of the BiG Grid project. The successes achieved thanks to this project were celebrated in the Beurs van Berlage in Amsterdam on 26 September 2012[1]. BiG Grid was a 28.8 M€ project funded by a Dutch government call in 2006, targeting large-scale research infrastructures. The project was jointly submitted by Nikhef, the Netherlands Bioinformatics Consortium NBIC, and the Dutch Foundation for Scientific Computing NCF. The Dutch National Supercomputer Center SARA played a key role as an operational partner.

1 http://www.biggrid.nl/big-grid-and-beyond-26-september-2012/
The presentations are available from that page, as well as some short films about BiG Grid.

BiG Grid has played a central role in the development of the Dutch national large-scale computing infrastructure. It has funded the Netherlands Tier-1 center for LHC computing (jointly operated by Nikhef and SARA), high-performance grid computing sites at the University of Groningen and the Philips Research Campus in Eindhoven, a set of 'Life Science Grid' clusters placed mainly at universities and research hospitals, a High-Performance Cloud and a Hadoop facility. It has also supported scores of researchers in making the transition from their desktops onto the national infrastructure. This work has been carried out via several routes, ranging from the highly-rated operations groups at Nikhef and SARA, teams of support specialists also at Nikhef and SARA, direct funding for e-science work within the user groups, or via the eBioGrid project.

One of the aims of BiG Grid was to realize a stable funding construction to assure continuation of the infrastructure after the project ended. This construction has been realized with the merger of the SARA foundation into the Surf foundation, which is already responsible for the Dutch National research network infrastructure, SurfNet. SurfSARA will continue to fund the Netherlands Tier-1 LHC computing center, as well as e-science research activities carried out at Nikhef. The new construction also involves the Netherlands e-Science Center (NLeSC). Jeff Templon has been named one of the NLeSC *integrators*, *"top researchers from a variety of disciplines who have broad experience and understanding of the possibilities of e-Science"*. These integrators help steer the development activities of NLeSC.

Future Activities

Given the end of the BiG Grid project as well as the approaching end (spring 2013) of two European middleware projects, we reviewed our activities in terms of relevance, impact, and match with the current group members. A decision was taken to, for the coming several years, focus our activities in *a)* scaling R&D and *b)* scalable multi-domain security. The scaling work involves computing problems generated by an increase in the scale of some aspect of the problem. A current example is the ceiling on processor clock speed; applications can no longer be made significantly faster by increasing the CPU speed. Expansion in the number of CPU cores has been the answer, however the number of cores per physical machine has grown to the point that program architectures need to change. Scalable multi-domain security refers to enabling groups of researchers to collaborate across institutions and computing infrastructures, while retaining the necessary resources and data privacy. This is a challenging area of interest not only for high-energy physics, but for any collaborations spanning a significant number of collaborators or institutes (such as most ESFRI projects).

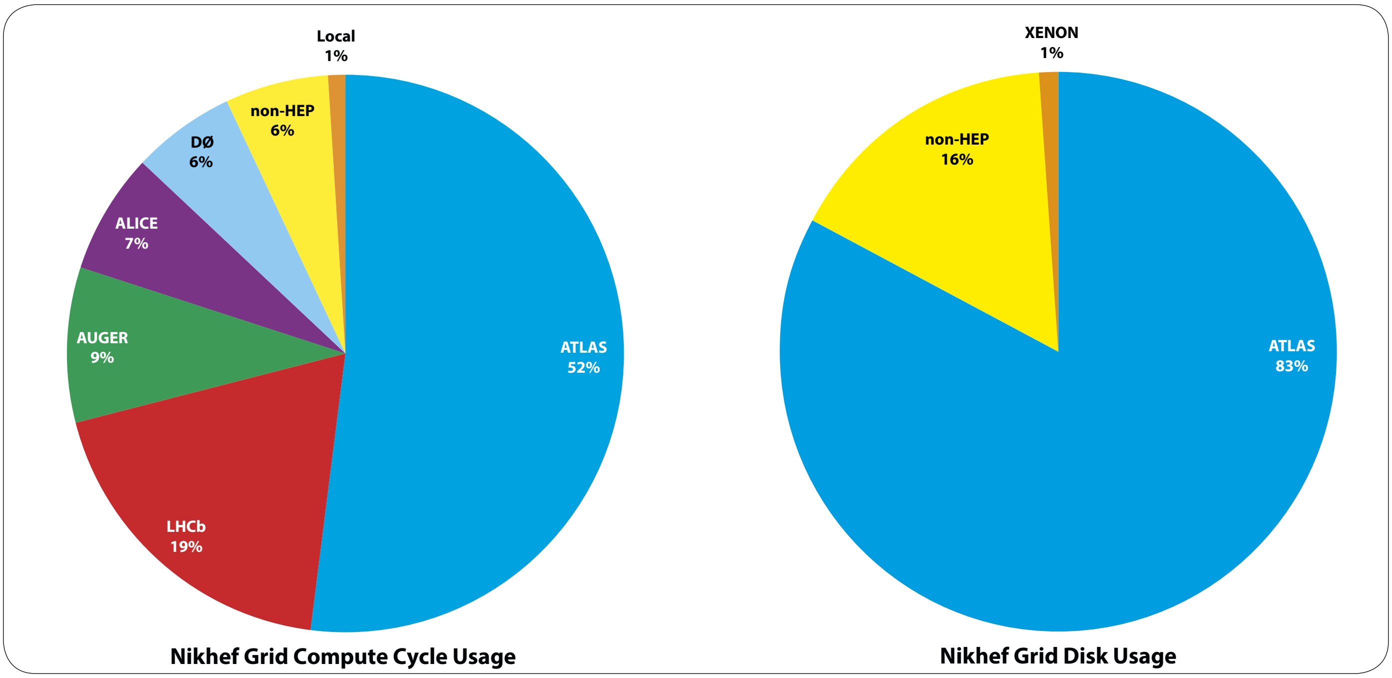


Figure 1. Usage of computing resources on the Nikhef grid cluster in 2012. Of the non-HEP cycles, 70% were consumed by various life sciences groups, 20% by quantum chemistry, the remaining ten percent were used by a wide variety of groups. Of the disk usage, about 50% of non-HEP usage is by LOFAR and the other half by various life sciences groups.

3

Output

3.1 Publications

ATLAS/DØ
ATLAS Collaboration: G. Aad (*et al.*); R. Aben, L.J. Beemster, S. Bentvelsen, E. Berglund, G.J. Besjes, G.J. Bobbink, K. Bos, H. Boterenbrood, S. Caron, M.A. Chelstowska, A.P.Colijn, M. Consonni, C. Daum, P.C. van der Deijl, C. Deluca, P.O. Deviveiros, A. Doxiadis, B. van Eijk, P. Ferrari, F. Filthaut, S. Gadatsch, H. Garitaonandia, R. van der Geer, D.A.A. Geerts, M. Gosselink, H. van der Graaf, N. de Groot, F. Hartjes, N.P. Hessey, O. Igonkina, P. de Jong, M.S. Kayl, Z. van Kesteren, P.F. Klok, S. Klous, P. Kluit, A.C. König, F. Koetsveld, E. Koffeman, A. Koutsman, E. van der Kraaij, H. Lee, R. van der Leeuw, T. Lenz, F. Linde, G. Luijckx, J. Mahlstedt, G. Massaro, J. Mechnich, A. Muijs, I. Mussche, L. de Nooij, J.P. Ottersbach, P. Pani, O. Peters, E. van der Poel, M. Raas, A. Reichold, M. Rijpstra, N. Ruckstuhl, G. Salamanna, A. Salvucci, R. Sandstroem, J. Snuverink, D. Ta, C.J.W.P. Timmermans, M. Tsiakiris, E. Turlay, W. Verkerke, J.C. Vermeulen, M. Vranjes Milosavljevic, M. Vreeswijk, I. van Vulpen
Diffractive Measurements in ATLAS
AIP Conf. Proc. **1441** (2012) 181

W and Z production measured using the ATLAS detector and impact on parton densities of the proton
AIP Conf. Proc. **1441** (2012) 190

ATLAS measurements of electroweak boson production cross sections
AIP Conf. Proc. **1441** (2012) 607

ATLAS measurements of isolated photon cross-sections
AIP Conf. Proc. **1441** (2012) 610

Inclusive b-jet production in ATLAS
AIP Conf. Proc. **1441** (2012) 622

B and D hadron production and prospects in ATLAS
AIP Conf. Proc. **1441** (2012) 699

Search for R-parity violating Supersymmetry and long lived particles with the ATLAS detector
AIP Conf. Proc. **1441** (2012) 710

Exotics searches for new physics with the ATLAS detector
AIP Conf. Proc. **1441** (2012) 728

Standard model Higgs boson searches in ATLAS
AIP Conf. Proc. **1441** (2012) 735

Top Quark Production Measurements at ATLAS
AIP Conf. Proc. **1441** (2012) 738

Top quark mass and top properties at ATLAS
AIP Conf. Proc. **1441** (2012) 742

Elliptic and higher order flow measured in a large phase space in $\sqrt{s_{NN}}$=2.76 TeV lead-lead collisions
AIP Conf. Proc. **1441** (2012) 780

ATLAS measurements of jet suppression in heavy ion collisions
AIP Conf. Proc. **1441** (2012) 835

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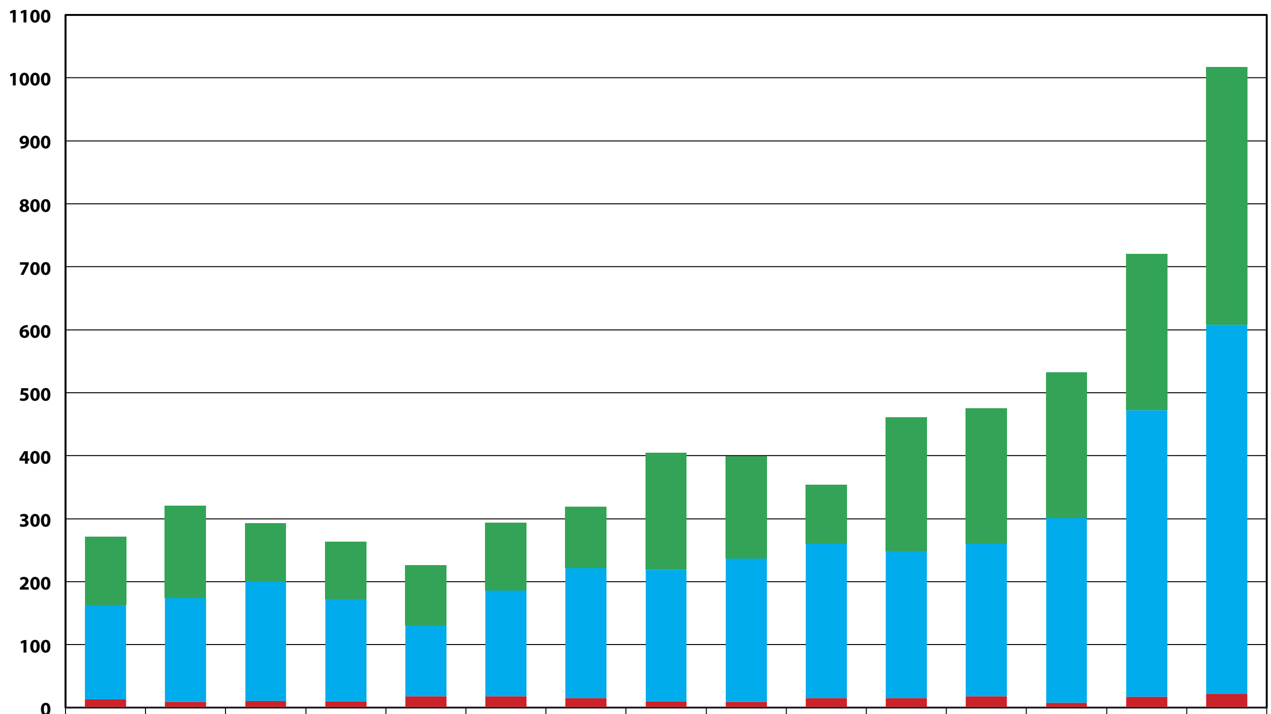


	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Talks	109	147	92	91	95	108	97	186	162	93	212	215	231	248	410
Publications	150	165	190	163	113	168	207	209	228	246	234	243	293	455	589
Theses	13	9	11	10	18	18	15	10	9	15	15	18	8	17	22

Figure 1. Nikhef's scientific output in the last 15 years.

3.2 Theses

Folkert Koetsveld
Searching for Supersymmetry in the first LHC data with ATLAS
Radboud Universiteit Nijmegen, 23 January 2012
Promotores: N. de Groot, P.J. de Jong

Naomi van der Kolk
To flow or not to flow: a study of elliptic flow and nonflow in proton-proton collisions in ALICE
Universiteit Utrecht, 25 January 2012
Promotores: Th. Peitzman, R.J.M. Snellings

Egge Freek van der Poel
Muon performance studies in ATLAS towards a search for the Standard Model Higgs boson
Universiteit van Amsterdam, 26 January 2012
Promotores: F.L. Linde, P.M. Kluit

Reinier de Adelhart Toorop
A flavour of family symmetries in a family of flavour models
Universiteit Leiden, 21 February 2012
Promotores: J.W. van Holten, F. Bazzocchi

Ante Bilandzic
Anisotropic flow measurements in ALICE at the Large Hadron Collider
Universiteit Utrecht, 7 March 2012
Promotor: R.J.M. Snellings

Marek Chojnacki
Measurement of pions, kaons and protons with the ALICE detector in pp collisions at the LHC
Universiteit Utrecht, 3 May 2012
Promotores: R.J.M. Snellings, R. Kamermans†
Copromotores: G.J.L. Nooren, M. van Leeuwen

Melvin Michael Meijer
A $WH \rightarrow \tau\nu b\mathrm{b}$ *Higgs search with the D∅ detector at the Tevatron: How to find the Higgs at the end of a circular collider*
Radboud Universiteit Nijmegen, 25 June 2012
Promotor: S.J. de Jong
Copromotor: F. Filthaut

Nicole Manuela Ruckstuhl
Muon signatures in ATLAS: a search for new physics in $\mu^{\pm}\mu^{\pm}$ *events*
Universiteit van Amsterdam, 28 June 2012
Promotor: S.C.M. Bentvelsen
Copromotor: I.B. van Vulpen

Dimitrios Palioselitis
Measurement of the atmospheric neutrino energy spectrum
Universiteit van Amsterdam, 2 July 2012
Promotor: P.M. Kooijman
Copromotor: M.P. Decowski

Ioannis Malamos
Reduction of one and two loop amplitudes at the integrand level
Radboud Universiteit Nijmegen, 2 July 2012
Promotores: R.H.P. Kleiss, C.G. Papadopoulos, R. Pittau

Harm Schoorlemmer
Tuning in on cosmic rays: Polarization of radio signals from air showers as a probe of emission mechanisms
Radboud Universiteit Nijmegen, 14 September 2012
Promotor: S.J. de Jong
Copromotor: C.W.J.P. Timmermans

Barbara Storaci
First determination of the fragmentation fraction ratio of f_s/f_d *with tree level hadronic decays at 7 TeV pp collisions*
Vrije Universiteit Amsterdam, 19 September 2012
Promotor: M.H.M. Merk
Copromotor: N. Tuning

Menelaos Tsiakiris
Top quark pair production cross-section in proton-proton collisions at $\sqrt{s} = 7$ *TeV*
Universiteit van Amsterdam, 19 September 2012
Promotor: S.C.M. Bentvelsen
Copromotores: P. Ferrari, S. Klous

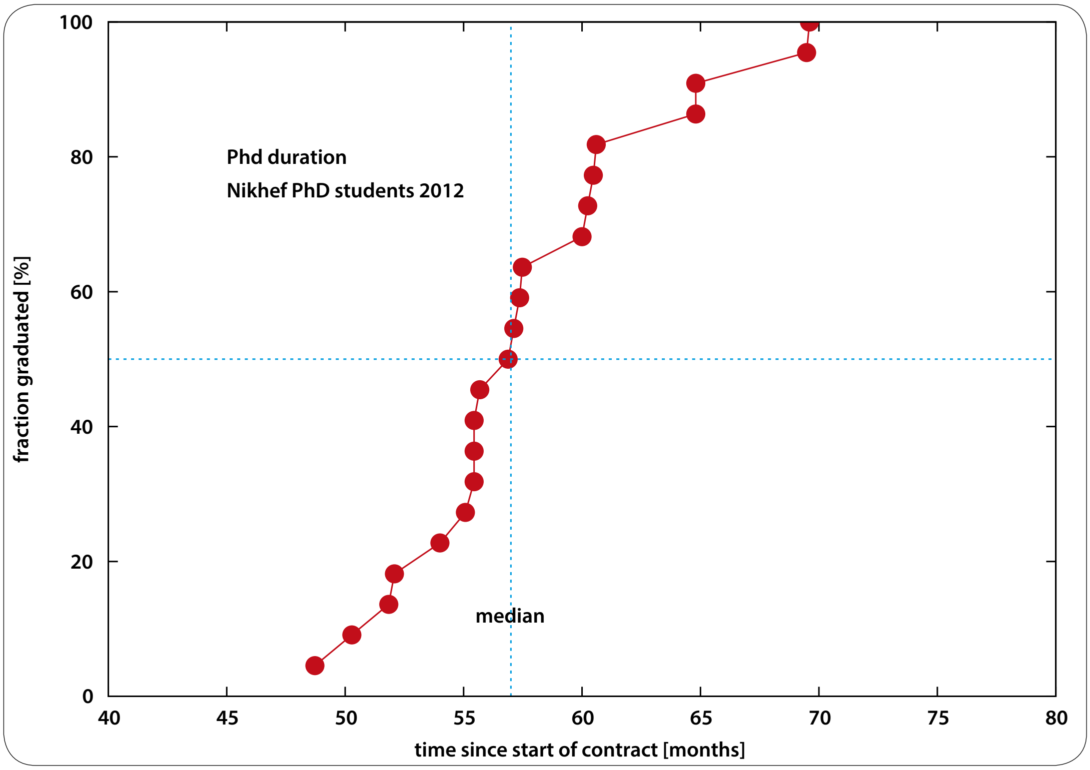


Figure 1. Fraction of PhD students working at Nikhef that graduated in the year 2012 as a function of time since the start of their thesis contract. The median PhD duration is 57 months (4.8 year).

John Philip Ottersbach
Muons in early ATLAS data: from first collisions to W^+W^- production
Universiteit van Amsterdam, 25 September 2012
Promotor: S.C.M. Bentvelsen
Copromotor: P.M. Kluit

Martin Fransen
Gridpix: TPC development on the right track. The development and characterisation of a TPC with a CMOS pixel chip read out
Universiteit van Amsterdam, 26 September 2012
Promotores: F.L. Linde
Copromotor: H. van der Graaf

Ido Mussche
Measurements on top quark pairs in proton collisions recorded with the ATLAS detector
Universiteit van Amsterdam, 9 October 2012
Promotor: S.C.M. Bentvelsen
Copromotor: P. Ferrari

Daan van Eijk
Ageing and the decay of beauty: Radiation hardness of the LHCb outer tracker and time-dependent CP violation using $B_s \rightarrow J/\Psi\Phi$ decays
Vrije Universiteit Amsterdam, 15 October 2012
Promotores: M.H.M. Merk, H.G. Raven
Copromotor: N. Tuning

David Boudewijn Reinder Alexander Fokkema
The HiSPARC cosmic ray experiment: Data acquisition and reconstruction of shower direction
Universiteit Twente, 17 October 2012
Promotor: B. van Eijk
Copromotor: J. Steijger

Agnes Irene Maria Niessen
Improving predictions for SUSY cross sections: Soft-gluon resummation for SUSY-QCD
Radboud Universiteit Nijmegen, 8 November 2012
Promotor: R.H.P. Kleiss
Copromotor: W.J.P. Beenakker

Gijs van den Oord
Recursion, Monte Carlo, and vector boson scattering at hadron colliders
Radboud Universiteit Nijmegen, 15 November 2012
Promotor: R.H.P. Kleiss
Copromotor: S.C.M. Bentvelsen

Marcel Johannes Petrus Raas
Jet multiplicities in the $W \rightarrow \mu\nu_\mu$ process in proton-proton collisions at 7 TeV
Radboud Universiteit Nijmegen, 29 November 2012
Promotor: N. de Groot
Copromotor: F. Filthaut

Marten Jan Bosma
On the cutting edge of semiconductor sensors. Towards intelligent X-ray detectors
Universiteit van Amsterdam, 21 December 2012
Promotor: E.N. Koffeman
Copromotor: M.G. van Beuzekom, J. Visser

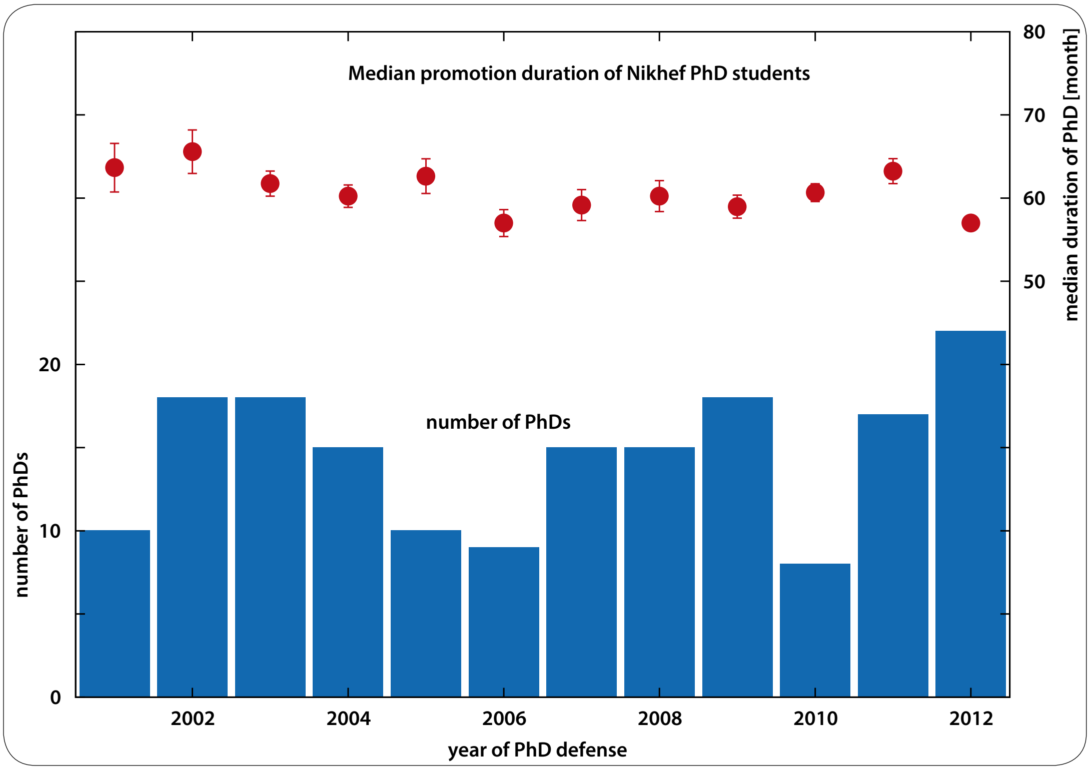
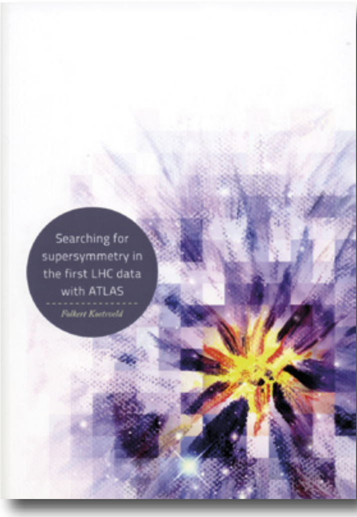
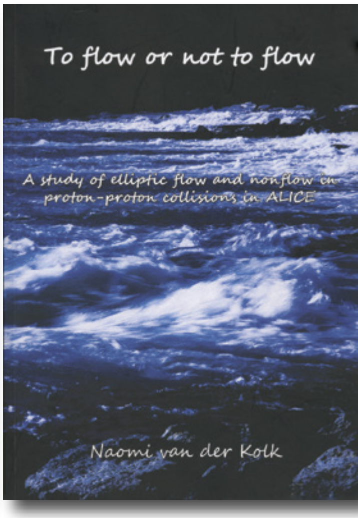


Figure 2. Median PhD duration of Nikhef PhD students since 2001 as a function of graduation year. The error bars represent the median absolute deviation (MAD)/√(n-1). The histogram gives the total number n of PhDs in each year.


Searching for supersymmetry in the first LHC data with ATLAS


To flow or not to flow
A study of elliptic flow and nonflow in proton-proton collisions in ALICE
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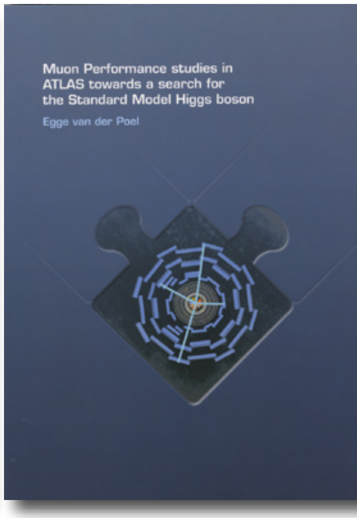
Muon Performance studies in ATLAS towards a search for the Standard Model Higgs boson
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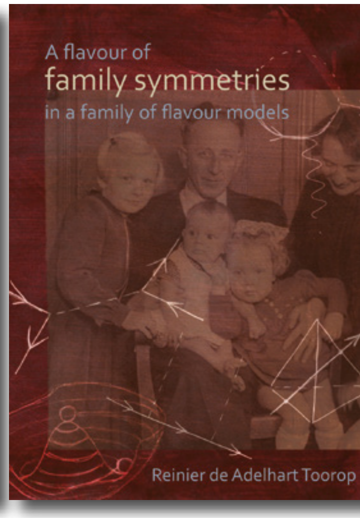
A flavour of family symmetries in a family of flavour models
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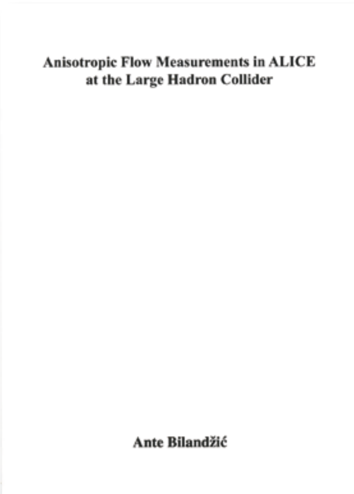
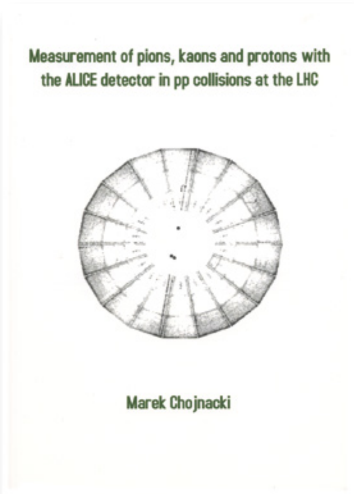
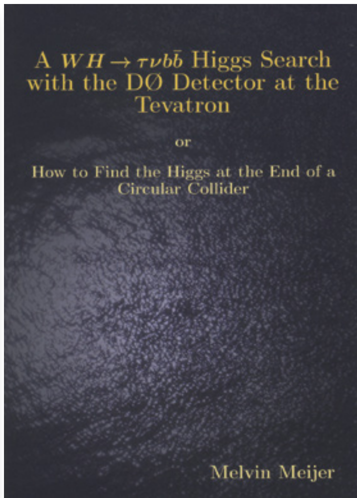
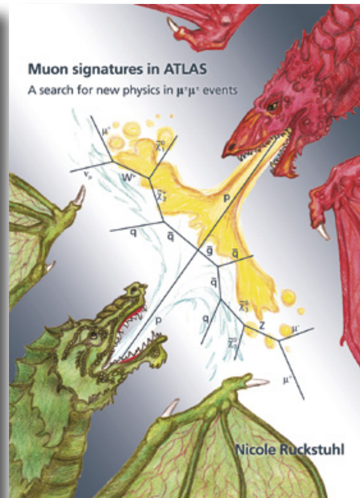
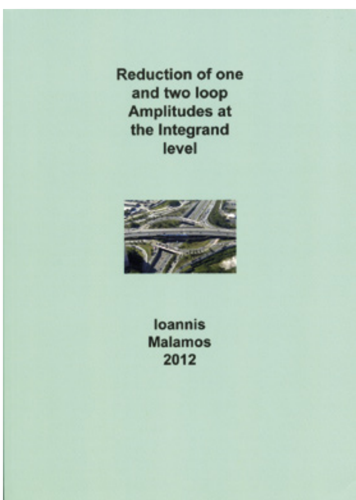
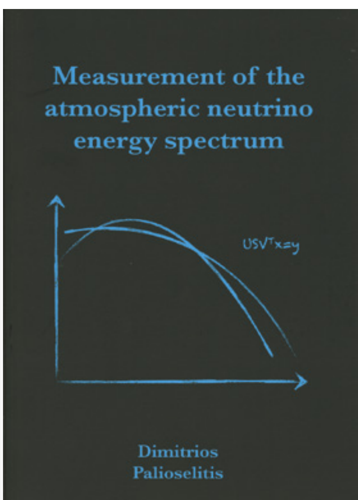

Anisotropic Flow Measurements in ALICE at the Large Hadron Collider
Ante Bilandžić

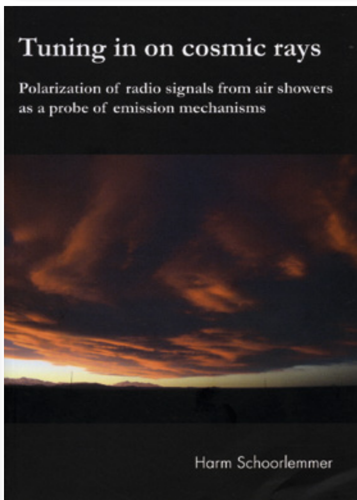

Measurement of pions, kaons and protons with the ALICE detector in pp collisions at the LHC
Marek Chojnacki


A $WH \to \tau\nu b\bar{b}$ Higgs Search with the DØ Detector at the Tevatron
or
How to Find the Higgs at the End of a Circular Collider
Melvin Meijer


Muon signatures in ATLAS
A search for new physics in $\mu^{+}\mu^{+}$ events
Nicole Ruckstuhl


Reduction of one and two loop Amplitudes at the Integrand level
Ioannis Malamos
2012


Measurement of the atmospheric neutrino energy spectrum
$USV^{T}x=y$
Dimitrios Palioselitis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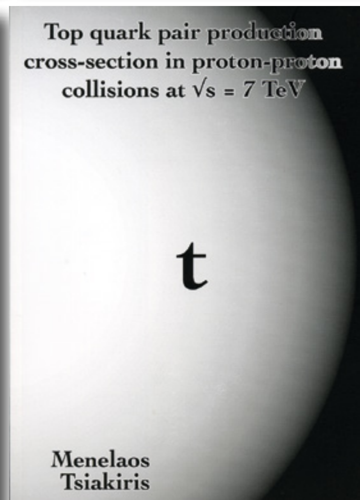
Top quark pair production cross-section in proton-proton collisions at $\sqrt{s}$ = 7 TeV
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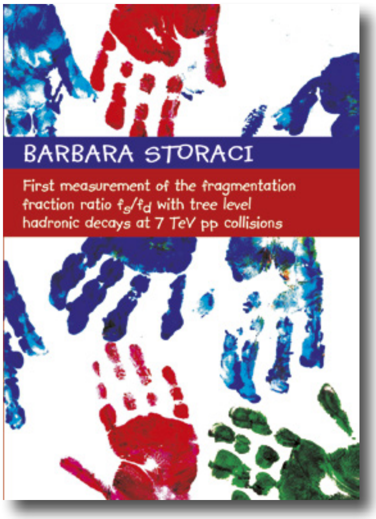
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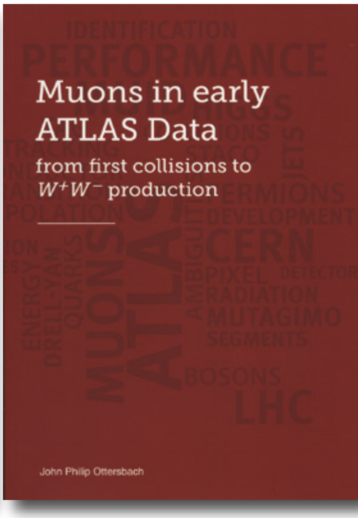
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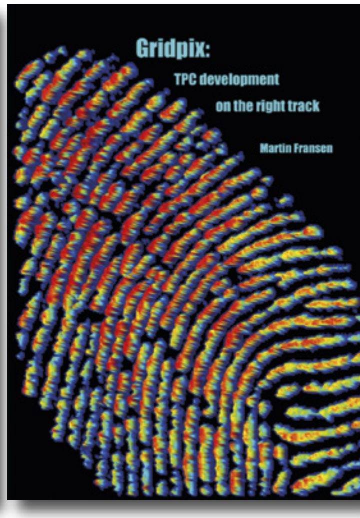
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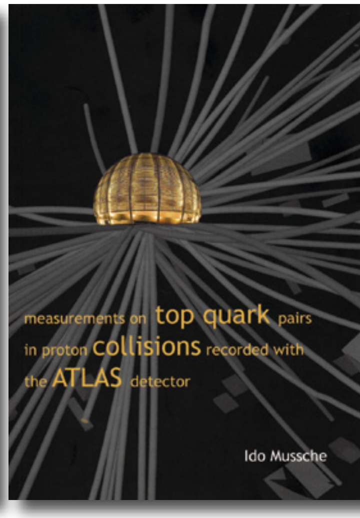
measurements on top quark pairs in proton collisions recorded with the ATLAS detector
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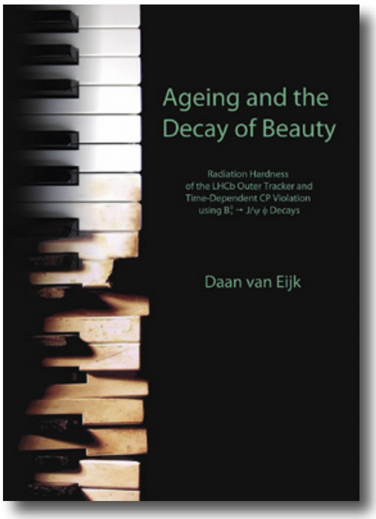
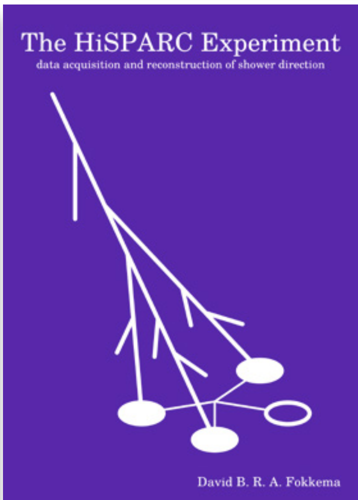
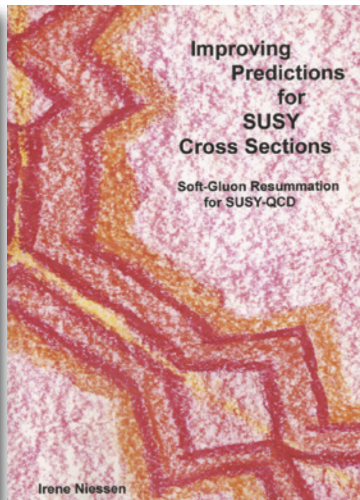
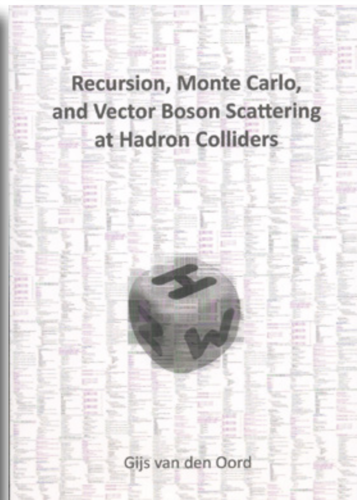
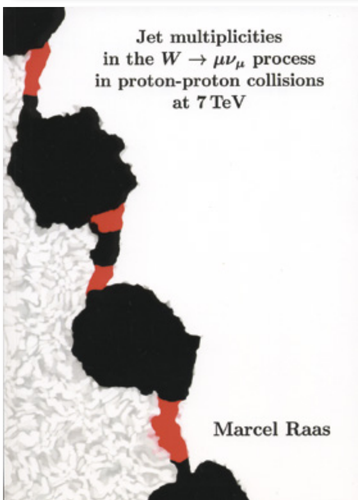
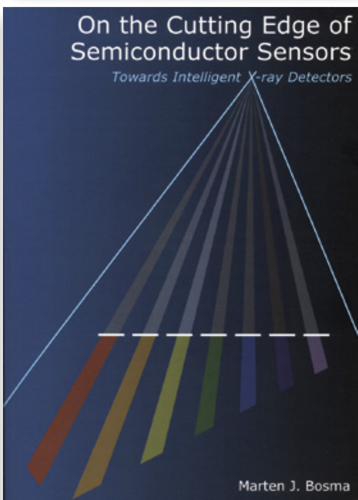

Ageing and the Decay of Beauty
Radiation Hardness of the LHCb Outer Tracker and Time-Dependent CP Violation using $B_s^0 \to J/\psi\,\phi$ Decays
Daan van Eijk

The HiSPARC Experiment
data acquisition and reconstruction of shower direction
David B. R. A. Fokkema

Improving Predictions for SUSY Cross Sections
Soft-Gluon Resummation for SUSY-QCD
Irene Niessen

Recursion, Monte Carlo, and Vector Boson Scattering at Hadron Colliders
Gijs van den Oord

Jet multiplicities in the $W \to \mu\nu_\mu$ process in proton-proton collisions at 7 TeV
Marcel Raas

On the Cutting Edge of Semiconductor Sensors
Towards Intelligent X-ray Detectors
Marten J. Bosma

3.3 Talks

ATLAS/DØ

Bentvelsen, S.C.M., Physics at the LHC, Colloquium University of Groningen, Groningen, The Netherlands, 14 March 2012

Physics at the LHC, Colloquium University of Groningen, Groningen, The Netherlands, 22 March 2012

Caron, S., Recent constraints on WIMP dark matter from detection and production experiments, Physikalisches Kolloquium, University of Freiburg, Freiburg, Germany, 9 January 2012

Higgs, SUSY or something else, First results of the LHC, Physics@FOM, Veldhoven, The Netherlands, 17 January 2012

ATLAS inclusive searches for SUSY and Dark Matter, Workshop on LHC implications, Geneva, Switzerland, 13 July 2012

Results from the LHC: ATLAS, DarkAttack 2012 Conf., Ascona, Switzerland, 16 July 2012

Chelstowska, M., Search for the SM Higgs Boson in the $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$, Physics@FOM, Veldhoven, The Netherlands, 17 January 2012

Search for the SM Higgs Boson in the $H \rightarrow WW^*$ decay mode with 4.7 fb^{-1} of ATLAS data at $\sqrt{s}=7$ TeV, CIPANP 2012, St. Petersburg, Florida, USA, 29 May 2012

Observation of an excess of events in the search for the SM Higgs Boson in the $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ decay mode with the ATLAS detector, NNV Fall Meeting, Lunteren, The Netherlands, 2 November 2012

Ferrari, P., Higgs measurements and perspectives, From Higgs to Dark Matter, Geilo, Norway, 17 December 2012

Filthaut, F., The Hunt for the Higgs Boson, Colloquium Eindhoven University of Technology, The Netherlands, 22 March 2012

Search for the Higgs Boson: Discovery in Sight!, Physica 2012 symposium, Enschede, The Netherlands, 30 May 2012

Observation of an excess in the search for the Standard Model Higgs boson in the $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ decay mode with the ATLAS detector, SUSY 2012 Conf., Beijing, China, 13 August 2012

The discovery of the Higgs boson, NNV Fall Meeting, Lunteren, The Netherlands, 2 November 2012

b-Jet tagging in proton-(anti-)proton collisions, 5th Int. Workshop on heavy quark production in heavy-ion collisions, Utrecht, The Netherlands, 15 November 2012

Groot, de, N., Deeltjesfysica, Lunchlezing Leonardo (studievereniging natuurwetenschappen), Nijmegen, The Netherlands, 6 February 2012

How the Higgs was found, Huygens colloquium, Nijmegen, The Netherlands, 3 September 2012

Hessey, N.P., General Considerations for Low Mass Systems, PIER Workshop on Non-Sensitive Materials in High Energy Physics, Hamburg, Germany, 13 September 2012

Igonkina, O., LHC performance, Fysica–Chemie 2012, University of Twente, Enschede, The Netherlands, 30 May 2012

Chasing the anti-matter, FOM/v symposium, Woerden, The Netherlands, 8 June 2012

Jong, de, P.J., Looking further than the Standard Model with the LHC, Fysica–Chemie 2012, University of Twente, Enschede, The Netherlands, 30 May 2012

Supersymmetry searches at the LHC, Int. symposium on Physics in Collision 2012, Strbske Pleso, Slovakia, 14 September 2012

Motivations and recent results on Supersymmetry searches at the LHC, DESY Physics seminar, Hamburg, Germany, 16 October 2012

Motivations and recent results on Supersymmetry searches at the LHC, DESY Zeuthen Physics seminar, Zeuthen, Berlin, Germany, 17 October 2012

Kluit, P.M., Beyond the Standard Model Higgs Boson Searches with ATLAS, Int. Conf. Beyond The Standard Model of Particle Physics, Qui Nhon, Viet Nam, 19 July 2012

Leeuw, van der, R.H.L., Jets + missing ET SUSY searches in ATLAS, Recontres de Physique de La Vallée d'Aoste, La Thuile, Italy, 1 March 2012

Ta, D.B., Single top quarks with ATLAS @ the LHC Physics@FOM, Veldhoven, The Netherlands, 17 January 2012

Single top quarks @ LHC, TOP 2012 - 5th Int. Workshop on Top Quark Physics, Winchester, United Kingdom, 19 September 2012

Single top quarks @ LHC, ULB-VUB seminar, Brussels, Belgium, 23 November 2012

Tal Hod, N., Search for heavy resonances, and resonant diboson production with the ATLAS detector, Hadron Collider Physics Symposium 2012, Kyoto, Japan, 13 November 2012

Verkerke, W., Advanced statistics for discoveries, PhD training VUB/ULB, Brussels, Belgium, 24 April 2012

Advanced statistics for discoveries, PhD training VUB/ULB, Brussels, Belgium, 25 April 2012

Top quark property measurements (ATLAS/CMS), Physics at the LHC 2012, Vancouver, Canada, 7 June 2012

Vulpen, van, I.B., The search for the Higgs boson, Ehrenfest Colloquium Leiden University, Leiden, The Netherlands, 8 February 2012

The discovery of the Higgs boson, Physics Colloquium Groningen University, Groningen, The Netherlands, 29 November 2012

LHCb/BABAR

Beuzekom, van, M.G., VeloPix ASIC developments for the LHCb VELO upgrade, 6th Int. Workshop on Semiconductor Pixel Detectors for Particles and Imaging, Inawashiro, Japan, 5 September 2012

Dettori, F., Rare charm decays, 5th Int. Workshop on Charm Physics (CHARM2012), Honolulu, USA, 15 May 2012

Eijk, van, D., CP violating phases in neutral meson oscillations, BEACH 2012, Wichita, USA, 24 July 2012

Heijne, V.A.M., Search for long-lived exotic particles at LHCb, Dark Forces at Accelerators, Frascati, Italy, 17 October 2012

Search for long-lived exotic particles at LHCb, NNV Fall Meeting, Lunteren, The Netherlands, 2 November 2012

Jans, E., VELO Operations and Performance in 2011, 7th Workshop on Advanced Silicon Radiation Detectors, Ljubljana, Slovenia, 29 February 2012

Koppenburg, P.S., B physics from LHCb, $B_s \rightarrow \mu\mu$ and $K^*\ell\ell$, 4th SuperB Collaboration Meeting, Physics Meeting, Elba, Italy, 31 May 2012

Lambert, R.W., Heavy Flavour Physics, an introduction and review, Lake Louise Winter Institute, 2012, Lake Loiuse, Canada, 21 February 2012

Merk, M.H.M., Physics with b-quarks: LHCb, restricted ECFA Review of the Netherlands, Amsterdam, The Netherlands, 17 February 2012

CP Violation at LHCb, Int. Symposium on Symmetries in Subatomic Physics, Groningen, The Netherlands, 19 June 2012

CP Violation at LHCb, Seminar Radboud University, Nijmegen, The Netherlands, 11 July 2012

Oggero, S., Very rare decays at LHCb, DISCRETE 2012, Lisbon, Portugal, 4 December 2012

Raven, G., B physics at the LHC, Physics@FOM, Veldhoven, The Netherlands, 17 January 2012

CP Violation (I), CERN summer student lectures, Geneva, Switzerland, 6 August 2012

CP Violation (II), CERN summer student lectures, Geneva, Switzerland, 6 August 2012

CP Violation (III), CERN summer student lectures, Geneva, Switzerland, 7 August 2012

CP Violation (IV), CERN summer student lectures, Geneva, Switzerland, 7 August 2012

Measurement of the CP-violating phase φ_s in the B_s system at LHCb, CKM 2012, Cincinnati, USA, 29 September 2012

Schiller, M.T., Measurements of CKM angle γ from tree-dominated decays, Flavor Physics and CP Violation Conf. (FPCP) 2012, Hefei, Anhui Province, China, 22 May 2012

Tuning, N., LHCb: Indirect Searches for New Particles, Fysica–Chemie 2012, University of Twente, Enschede, The Netherlands, 30 May 2012

Heavy Flavor Physics Results from LHC, SLAC Summer Institute, Menlo Park, USA, 23 July 2012

ALICE/STAR
Bertens, R.A., ϕ-meson anisotropic flow measured by ALICE for Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, WPCF 2012, Frankfurt am Main, Germany, 10 September 2012

Botje, M.A.J., QCD evolution with QCDNUM, Proton Structure in the LHC Era, DESY, Hamburg, Germany, 22 October 2012

Christakoglou, P., Overview of results from ALICE at the LHC, Int. Conf. on New Frontiers in Physics, Chania, Greece, 12 June 2012

Balance function studies at the LHC, Workshop, Chania, Greece, 12 June 2012
Charge dependent azimuthal correlations with the ALICE detector at the LHC, P- and CP-odd effects in hot and dense matter, BNL, New York, USA, 25 June 2012

Balance function studies at the LHC, VIII Workshop on Particle Correlations and Femtoscopy, Frankfurt, Germany, 12 September 2012

Charge correlations and balance functions at the LHC, Winter school on heavy ion physics, Budapest, Hungary, 4 December 2012

Kuijer, P.G., Status and Plans of ALICE, Physics at LHC 2012, Vancouver, Canada, 4 June 2012

Leeuwen, van, M., Forward Physics with the FOCAL upgrade, Hot and Dense QCD in the LHC era, meeting of the ERC-StG HotLHC, Santiago de Compostela, Spain, 9 February 2012

Overview of jet quenching in heavy ion collisions, Workshop Jet Modification in the RHIC and LHC Era, Wayne State University, Detroit, USA, 20 August 2012

Mischke, A., Open heavy flavour RAA in ALICE, 50th Int. Winter Meeting on Nuclear Physics, Bormio, Italy, 25 January 2012

Heavy-flavour production in heavy-ion collisions at the CERN-LHC, Excellence Cluster Universe Colloquium, Munich, Germany, 10 October 2012

Overview on heavy flavour measurements at the CERN-LHC, 10th Int. Conf. on Quark Confinement and the Hadron Spectrum (Confinement 10), Munich, Germany, 11 October 2012

Round Table discussion on "'Quark Gluon Plasma: What have we learnt so far?"', 10th Int. Conf. on Quark Confinement and the Hadron Spectrum (Confinement 10), Munich, Germany, 12 October 2012

Heavy flavour production at the LHC, 2nd Zimanyi Winter School, Wigner Research Center for Physics of the Hungarian Academy of Sciences, Budapest, Hungary, 3 December 2012

Peitzmann, T., Results on heavy-ion collisions from the ALICE experiment, Physics@FOM, Veldhoven, The Netherlands, 17 January 2012

The ALICE Upgrade Programme, DIS2012, Bonn, Germany, 28 March 2012

Upgrade of the ALICE experiment, Quark Matter 2012, Washington, USA, 17 August 2012

Snellings, R.J.M., How do I measure anisotropic flow and estimate flow fluctuations, Seminar Johann Wolfgang Goethe University, Frankfurt, Germany, 30 January 2012

Angular Correlations at the LHC from ALICE, Rencontres de Moriond, La Thuile, Italy, 14 March 2012

The "Little Bang" at RHIC and the LHC, Seminar University of Padova, Padova, Italy, 22 March 2012

Bulk Properties of the Quark-Gluon Plasma, QNP 2012, Palaiseau, Paris, France, 17 April 2012

Anisotropic Flow at RHIC and at the LHC, ICFP, Kolymbari, Greece, 11 June 2012

Anisotropic Flow at the LHC as measured by ALICE, Probing the extremes of matter with heavy-ions, Erice, Italy, 24 September 2012

Verweij, M., Jet Reconstruction in Heavy-Ion Collisions with ALICE, Hot and Dense QCD in the LHC Era, Santiago de Compostela, Spain, 9 February 2012

Measurement of jet spectra in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV with the ALICE detector at the LHC, 5th Int. Conf. on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions, Cagliari, Italy, 31 May 2012

Measurement of jet spectra with charged particles in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV with ALICE, Quark Matter 2012, Washington DC, USA, 18 August 2012

Zhou, Y., Anisotropic flow of identified particles in $\sqrt{s_{NN}}$=2.76 TeV Pb-Pb collisions with the ALICE detector, NNV Fall Meeting, Lunteren, The Netherlands, 2 November 2012

Neutrino Telescopes
Astraatmadja, T.L., Detecting TeV γ-rays from GRBs with km^3 neutrino telescopes, Physics@FOM, Veldhoven, The Netherlands, 18 January 2012

Detecting TeV γ-rays from GRBs with km^3 neutrino telescopes, Max-Planck-Institut für Astronomie (MPIA), Heidelberg, Germany, 13 February 2012

Neutrino telescopes as γ-ray telescopes: Searching for TeV photon emission from Gamma-Ray Bursts with the ANTARES Neutrino Telescope, 16th Symposium on Astroparticle Physics in the Netherlands, Amsterdam, The Netherlands, 11 May 2012

Samtleben, D.F.E., The underwater Neutrino Telescopes ANTARES and KM3NeT, 16th Symposium Astroparticle Physics in the Netherlands, Amsterdam, The Netherlands, 11 May 2012

The High Energy Neutrino Sky as seen by ANTARES, Conf. Planck 2012, Warsaw, Poland, 30 May 2012

Gravitational Waves
Agathos, M., TIGER: A Bayesian method for testing general relativity using gravitational waves from compact binary systems, 13th Marcel Grossmann Meeting, Stockholm, Sweden, 5 July 2012

Measuring the equation of state of neutron stars with direct gravitational wave observations, NNV Fall Meeting, Lunteren, The Netherlands, 2 November 2012

Beker, M.G., Newtonian noise simulations and subtraction for ET and Advanced Virgo, GWADW 2012, Hawaii, USA, 17 May 2012

Status of Advanced Virgo and its compact seismic isolation technology, Stanford University, Paolo Alto, USA, 23 May 2012

Seismic noise, and simulations and subtraction of Newtonian noise for ET, Marcel Grossman 2012, Stockholm, Sweden, 6 July 2012

Bertolini, A., Composite crystalline mirror suspension for cryogenic detectors, ELiTES: First Collaboration Meeting, Tokyo, Japan, 3 October 2012

Blom, M.R., Commissioning and performance of the external injection bench seismic attenuation system for the Advanced Virgo gravitational wave detector, 12th Pisa Meeting on Advanced Detectors, La Biodola, Italy, 1 June 2012

Brand, van den, J.F.J., Mitigating External Forces, Round Table Discussion, Gravitational Waves Advanced Detector Workshop, Waikoloa, Hawaii, USA, 15 May 2012

Achievements of the Initial Gravitational Wave Detectors, ELiTES: First Collaboration Meeting, Tokyo, Japan, 3 October 2012

Nikhef - Kagra Gravitational Wave Experiment, Tokyo University, Tokyo, Japan, 5 October 2012

Vision talk on site studies, Einstein Telescope 4th General Meeting, Leibniz University Hannover, Hannover, Germany, 4 December 2012

Del Pozzo, W., Fundamental physics, astrophysics and cosmology with gravitational waves, Second Quantum Universe Symposium, University of Groningen, Groningen, The Netherlands, 4 April 2012

Testing General relativity using Bayesian model Selection, GW New Horizons Workshop, Hannover, Germany, 8 June 2012

Hennes, E., Noise issues in vibration sensing and isolation for Advanced Virgo, Gravitational Wave Advanced Detector Workshop, Waikoloa, Hawaii, USA, 14 May 2012

Site selection and Newtonian noise studies for the Einstein Telescope, ELiTES: First Collaboration Meeting, Tokyo, Japan, 3 October 2012

Li, T.G.F., TIGER: A data analysis pipeline for testing general relativity using compact binary coalescence, Gravitational-wave Physics & Astronomy Workshop 2012, Hannover, Germany, 4 June 2012

Gravitational waves as independent cosmological probes, 13th Marcel Grossmann Meeting, Stockholm, Sweden, 3 July 2012

A data analysis pipeline for testing general relativity using gravitational wave signals from binary neutron star and black hole mergers, NNV Fall Meeting, Lunteren, The Netherlands, 2 November 2012

Nelemans, G., eLISA, First Dutch Gravitational Wave meeting, Amsterdam, The Netherlands, 19 January 2012

Gravitational wave astrophysics, Virgo week, Virgo/EGO, Cascina, Italy, 29 February 2012

The importance of complementary electro-magnetic observations to GW detections, APP symposium, De Rode Hoed, Amsterdam, The Netherlands, 10 May 2012

Galactic binaries, LISA Symposium, Paris, 23 May 2012

Gravitational waves, Blandford Symposium, University of Groningen, Groningen, The Netherlands, 24 October 2012

Rabeling, D.S., Long term site characterizations for Einstein Telescope, ET general meeting, Hannover, Germany, 4 December 2012

Shah, S.,Synergy between EM and GW measurements, First Duch Gravitational Wave meeting, Amsterdam, The Netherlands, 19 January 2012

Sluys, van der, M., Compact binaries and gravitational waves, Astrophysics colloquium, ESO Vitacura office, Santiago, Chile, 20 March 2012

Compact binaries and gravitational waves, Astrophysics colloquium, Centro de Astrofisica, Universidad de Valparaíso, Chile, 21 March 2012

Using astrophysical knowledge in gravitational-wave data analysis of binary inspirals, Virgo week, Pisa, Italy, 25 June 2012

The formation of double white dwarfs, EuroWD12, Krakow, Poland, 16 August 2012

Van Den Broeck, C.F.F., Strong-field tests of general relativity, Physics@FOM, Veldhoven, The Netherlands, 23 January 2012

Astronomy, cosmology, and fundamental physics with Einstein Telescope, Testing the strong-field dynamics of general relativity with advanced gravitational wave detectors, Kona, Hawaii, USA, 19 May 2012

Astronomy, cosmology, and fundamental physics with Einstein Telescope, Gravitational Wave Physics and Astrophysics Workshop, Hannover, Germany, 4 June 2012

Astrophysics, cosmology, and fundamental physics with gravitational waves, VESF School on Advanced Gravitational Wave Detectors, Cascina, Italy, 18 October 2012

Probing the dynamics of spacetime with gravitational waves, CoCoNuT meeting, Palma de Mallorca, Spain, 24 October 2012

Veitch, J., Listening for new physics with gravitational waves, University of Massachussetts, Amherst, USA, 16 March 2012

What can we measure with CBC parameter estimation, Rattle and Shine, Kavli Institute for Theoretical Physics, Santa Barbara, USA, 3 August 2012

Cosmic Rays

Grebe, S., Spectral index analysis of the data from the Auger Engineering Radio Array, ARENA Conf., Erlangen, Germany, 19 June 2012

Spectral index analysis of the data from the Auger Engineering Radio Array, NNV Fall Meeting, Lunteren, The Netherlands, 2 November 2012

Dark Matter

Alfonsi, M., XENON Dark Matter programme: from XENON100 to XENON1T, VIII Int. Workshop on the Dark Side of the Universe, Armação de Búzios, Brazil, 14 June 2012

GridPix application to dual phase TPC, 6th Symposium on large TPCs for low energy rare event detection, Paris, France, 19 December 2012

Decowski, M.P., Detecting Dark Matter, AUC Who's in Town Lecture Series, Amsterdam, The Netherlands, 3 December 2012

Schön, R., Einsatz eines GridPix-Detektors für die Suche nach dunkler Materie, Spring meeting of the DPG, Göttingen, Germany, 27 February 2012

Operating the GridPix detector in dark matter search experiments, Pisa Meeting on Advanced Detectors, Isola d'Elba, Germany, 25 May 2012

Theoretical Physics

Artoisenet, P.A., Gluon fragmentation into charmonium at NLO, LHCphenonet Annual Meeting 2012, Chester-le-Street, United Kingdom, 21 March 2012

MadWeight: a tool for matrix element method, The 2012 FeynRules/MadGraph School on LHC Phenomenology, Natal, Brazil, 4 October 2012

Rare SM Processes in LO and NLO, MC generators and future challenges, a joint ATLAS/CMS/LPCC workshop, Geneva, Switzerland, 21 November 2012

Broek, van den, T.C.H., Noncommutative geometry and Supersymmetry, Physics@FOM, Veldhoven, The Netherlands, 17 January 2012

Noncommutative geometry and (N =1) Supersymmetry, A Neapolitan Workshop on Noncommutative Geometry, Napels, Italy, 20 September 2012

Noncommutative geometry and (N =1) Supersymmetry, DRST PhD Day, Utrecht, The Netherlands, 12 October 2012

Buffing, M.G.A., Color flow of quarks and gluons in high-energy collisions, DRSTP Postgraduate School, Driebergen, The Netherlands, 30 January 2012

Transverse weighting for quark correlators, QCD Evolution Workshop, Newport News, USA, 15 May 2012

Using color to zoom in on quarks and gluons in a proton, NNV Fall Meeting, Lunteren, The Netherlands, 2 November 2012

D'Ambrosi, G., Gravitational Waves in EMRI Systems, DRSTP PostGraduate School, Driebergen, The Netherlands, 30 January 2012

Dunnen, den, W., Can the LHC tell us the parity of the Higgs?, Physics@FOM, Veldhoven, The Netherlands, 17 January 2012

Can the LHC tell us the parity of the Higgs, Theoretical Particle Physics meeting, Nikhef, Amsterdam, The Netherlands, 24 February 2012

Linearly Polarized Gluons and the Higgs Transverse Momentum Distribution, XXth Int. Workshop on Deep-Inelastic Scattering and Related Subjects (DIS 2012), University of Bonn, Bonn, Germany, 29 March 2012

Can the LHC tell us the parity of the Higgs?, Universität Tübingen, Tubingen, Germany, 8 December 2012

Fleischer, R., On Branching Ratios of B_s Decays and the Search for New Physics in $B^0_s \to \mu^+\mu^-$, 4th Workshop on Theory, Phenomenology and Experiments in Flavour Physics, Capri, Italy, 13 June 2012

Penguin Effects in $\phi_{d,s}$ Determinations, CKM 2012 - 7th Int. Workshop on the CKM Unitarity Triangle, Cincinnati, Ohio, USA, 29 September 2012

Theory News on $B_{s(d)} \to \mu^+\mu^-$ Decays, CKM 2012 - 7th Int. Workshop on the CKM Unitarity Triangle, Cincinnati, Ohio, USA, 1 October 2012

Hartgring, L.C., NLO Matching for Antenna Showers, Lund University, Lund, Sweden, 6 March 2012

NLO Matching for Antenna Showers, LHC Phenonet, Durham, United Kingdom, 21 March 2012

Holten, van, J.W., Majorana fermions, DRSTP school Soft Condensed Matter and Statistical Physics, Driebergen, The Netherlands, 22 March 2012

Extreme Mass Ratio Binaries, IRGAC Conferentie, Paraty, Brazil, 1 August 2012

Elementaire deeltjes, Woudschoten Conferentie, Noordwijk, The Netherlands, 15 December 2012

Jordan, S., A second order phase transition in CDT, Conf. CDT and Friends, Nijmegen, The Netherlands, 11 December 2012

Knegjens, R.J., An exploration of $B_s \to J/\Psi s\bar{s}$, 4th Workshop on Theory, Phenomenology and Experiments in Flavour Physics, Anacapri, Italy, 12 June 2012

Lessons from B_s Lifetimes, Int. School of Subnuclear Physics, Erice, Italy, 26 June 2012

Laenen, E., Next-to-eikonal exponentiation, Workshop Soft-Collinear Effective Theory, Madrid, Spain, 28 March 2012

Next-to-eikonal exponentiation, Teilchentee Seminar, University of Heidelberg, Germany, 3 May 2012

Standard Model limits: QCD at the LHC, 5th Int. Symposium on Symmetries in Subatomic Physics, University of Groningen, The Netherlands, 19 June 2012

Top quark, Graduiertenkolleg Seminar, University of Mainz, Germany, 4 July 2012

Top quark physics, Lectures at Cargese Summer School, Cargese, France, 30 August 2012

The theory of single-top production, DESY Theory Workshop, Hamburg, Germany, 27 September 2012

Loll, R., Quantum Spacetime, from a Practitioner's Point of View, MultiCosmoFun '12 (Conf. on Multiverse and Fundamental Cosmology), Szczecin, Poland, 14 September 2012

Quantum Spacetime, from a Practitioner's Point of View, Workshop "Models of Gravity", Bremen, Germany, 5 October 2012

Quantum Gravity from Causal Dynamical Triangulations – Whence and Whither, NORDITA Scientific Program and Workshop "Perspectives of Fundamental Cosmology", Stockholm, Sweden, 9 November 2012

Mooij, S.J.N., Higgs in the Sky, Physics@FOM, Veldhoven, The Netherlands, 17 January 2012

Inflation in and beyond the Standard Model, THEP Seminar Radboud University, Nijmegen, The Netherlands, 30 January 2012

Sgoldstino inflation, SCIPP Seminar, Santa Cruz, USA, 17 May 2012

Sgoldstino Inflation, TEP Seminar UCLA, Los Angeles, USA, 29 May 2012

Sgoldstino Inflation, Theory Seminar UCSD, San Diego, USA, 15 June 2012

Sgoldstino Inflation, Theoretical Physics Seminar, Argonne, USA, 19 June 2012

Effective Action for the Abelian Higgs Model in FLRW, Non-Equilibrium Field Theory in Cosmology workshop, Leiden, The Netherlands, 20 July 2012

Effective Action for the Abelian Higgs Model in FLRW, Theory Seminar Laboratoire APC, Paris, France, 18 September 2012

Effective Potential and Gauge Invariance in FLRW, Theory Seminar Orsay, Paris, France, 19 September 2012

Effective Potential and Gauge Invariance in FLRW, UKcosmo Imperial College, London, United Kingdom, 20 September 2012

Effective Potential and Gauge Invariance in FLRW, Theory Seminar IFT, Madrid, Spain, 8 October 2012

Effective Potential and Gauge Invariance in FLRW, Theory Seminar, Granada, Spain, 9 October 2012

Effective Potential and Gauge Invariance in FLRW, Theory Seminar LMU, Munich, Germany, 27 November 2012

Mulders, P.J., Theory Overview of Transverse Momentum Dependent Distribution and Fragmentation Functions, XX. Int. Workshop on Deep Inelastic Scattring and Related Subjects, Bonn, Germany, 26 March 2012

Defining TMD Correlators, Workshop on QCD Evolution 2012, Newport News, USA, 14 May 2012

TMDs: Theory and Phenomenology, Int. School on Prospects in QCD at future electron-proton and electron-ion colliders, Orsay, France, 5 June 2012

Universality of TMD correlators of definite rank, Int. Conf. on QCD and Nucleon Structure, QCD-N'12, Bilbao, Spain, 22 October 2012

Murthy, S.V., Localization and exact holography, String theory seminar at UvA, Amsterdam, The Netherlands, 6 March 2012

Exact quantum entropy of black holes, Seminar at University of Minho, Braga, Portugal, 27 April 2012

Some progress in the computation of exact black hole entropy, Newton Institute (Cambridge) Conf. on branes and black holes, London, United Kingdom, 28 May 2012

Quantum black holes, wall-crossing and mock modular forms, Meeting on Quantum algebra, Quantum geometry and Quantum information, Tallinn, Estonia, 11 July 2012

Mock modular forms in physics, Mathematics Colloquium at UvA, Amsterdam, The Netherlands, 5 September 2012

Quantum black holes, wall-crossing and mock modular forms, Rencontres Theoriciennes, Paris, France, 15 November 2012

Some progress in exact quantum black hole entropy, Indian Strings Meeting 2012, Puri, India, 19 December 2012

Some progress in the understanding of exact quantum black hole entropy, Seminar at Institute of Mathematical Sciences, Chennai, India, 24 December 2012

Rietkerk, R.J., Improving predictions for multi-leg processes at next-to-leading order, NNV Fall Meeting, Lunteren, The Netherlands, 2 November 2012

Rijken, T., Recent Nijmegen Extended-Soft-Core models ESC08, Meson-exchange viewpoint, Int. Workshop: Hyperon-Hyperon Interactions and Searches for Exotic Di-Hyperons in Nuclear Collisions, Brookhaven, USA, 2 March 2012

Baryon-baryon (S=0,–1,–2,–3,–4) Interactions. Flavor SU(3) Nijmegen Extended-Soft-Core ESC08, 20th Int. IUPAP Conf. on few-Body problems in Physics (FB20), Fukuoka, Japan, 21 August 2012

ESC08 models of baryon-baryon Interactions, 12th Int. Workshop on Strangeness Nuclear Physics (SNP12), Neyagawa, Osaka, Japan, 28 August 2012

Schellekens, A.N., Discreet Steps in the Landscape, CERN Theory seminar, Geneva, Switzerland, 11 April 2012

Discrete Symmetries in Discrete Orientifolds, String Pheno 2012 Conf., Cambridge, United Kingdom, 29 June 2012

Discrete Symmetries in Discrete Orientifolds, CERN String Phenomenology Workshop, Geneva, Switzerland, 16 July 2012

Vidotto, F., Spinfoam and Cosmology, Nordita Program, Stockholm, Sweden, 14 January 2012

Vries, de, J., Time-Reversal Violation in Nucleons and Nuclei, Seminar, Radboud University Nijmegen, Nijmegen, The Netherlands, 19 November 2012

Time-Reversal Violation in Light Nuclei in Effective Field Theory, Seminar, Ruhr-Universität-Bochum, Bochum, Germany, 6 December 2012

Wit, de, B., The 4D/5D connection, black holes and higher-derivative couplings, Mathematics and Applications of Branes in String and M-Theory, Isaac Newton Institute, Cambridge, United Kingdom, 14 March 2012

Deformations of special geometry; in search of the topological string, Branes and Black Holes (a London Satellite Meeting of the Isaac Newton Institute), King's College, London, United Kingdom, 31 May 2012

Beauty, consistency and eternal bliss, Symmetries, Unification and the Search for Quantum Gravity, Albert-Einstein Institut, Golm, Germany, 7 September 2012

The 4D/5D and 4D/3D connections, BPS black holes and higher-derivative couplings, Black Holes in Supergravity and M/Superstring Theory, Albert-Einstein Institut, Golm, Germany, 11 September 2012

The Ultimate Vacuum, 'The Quantum Quest: a Fascinating Journey', Solvay Workshop, Brussels, Belgium, 6 November 2012.

Gauged SO(8) supergravities, Indian String Meeting 2012, Puri, India, 18 December 2012

Detector R&D

Bakel, van, N., The TimePix detector at the X-ray Correlation Spectroscopy instrument at LCLS, 11th Int. Conf. on Synchrotron Radiation Instrumentation, Lyon, France, 10 July 2012

Graaf, van der , H., RasClic status: TT1 'LongBaseline RasDif', RasChain and the pre-alignment of the QD0's, CLIC-MDI, CERN, Geneva, Switzerland, 4 May 2012

The Tipsy single soft photon detector and the Trixy ultrafast tracking detector, iWoRID2012, Figueira da Foz, Portugal, 4 June 2012

The Tipsy single soft photon detector and the Trixy ultrafast tracking detector, IEEE-NSS 2012, Anaheim, USA, 1 November, 2012

Proposal for the construction procedures for the NSW chambers, ATLAS-NSW Workshop, Frascati, Italy, 29 November 2012

The Tipsy single soft photon detector for the readout of LXe/LAr dark matter TPCs. Sixt Symposium on Large TPCs for Low Energy Rare Event Detection, Paris, France, 18 December 2012

Koppert, W.J.C., High Precision Measurements of Track-segments of Ionising Particles with GridPix Detectors, Physics@FOM, Veldhoven, The Netherlands, 18 January 2012

GridPix Detectors: Functionality and Operation, EDIT 2012, Fermilab, Chicago, USA, 20 February 2012

Schioppa, E.J., Construction and test of an X-ray CT setup for material resolved 3D imaging with Medipix based detectors, Int. Workshop on Radiation Imaging Detectors – IWORID 2012, Figueira da Foz, Portugal, 2 July 2012

Timmermans, J., A Time Projection Chamber for a future linear e^+e^- collider, DESY Joint Instrumentation Seminar, Hamburg, Germany, 14 September 2012

Zappon, F.Z., GridPix detectors: functionality and operation, EDIT 2012, Fermilab, Chicago, USA, 17 February 2012

Grid Computing

Groep, D.L., The EUGridPMA and the Classic Authentication Profile 4.4, Asia Pacific Grid Policy Management Authority, Taipei, Taiwan, 28 February 2012

Introduction of SHA-2 in the EGI Infrastructure, 26th EUGridPMA Plenary Meeting, Lyon, France, 17 September 2012

Koeroo, O.A., Identities, Roles and Unix(like) systems, GlobusEUROPE, Prague, Czech Republic, 17 September 2012

gLExec: install, configuration and use, EGI-TF, Prague, Czech Republic, 20 September 2012

Argus EES, EGI-TF, Prague, Czech Republic, 20 September 2012

Security Training: Wrap up, EGI-TF, Prague, Czech Republic, 21 September 2012

Templon, J.A., Scalable proxy cache for Grid Data Access, Conf. on Computing in High Energy Physics (CHEP), New York, USA, 24 May 2012

Miscellaneous

Decowski, M.P., Recent Results from the KamLAND-Zen Experiment, Colloquium at Saclay, Paris, France, 2 May 2012

Deceitful Neutrinos, Fysica–Chemie 2012, University of Twente, Enschede, The Netherlands, 30 May 2012

Majorana Neutrino's en Donkere Materie, KNAW mini-symposium, Amsterdam, The Netherlands, 31 May 2012

Jong, de, S.J., Nikhef, rECFA visit to the Netherlands, Nikhef, Amsterdam, The Netherlands, 17 February 2012

Radio detection of cosmic rays, Topical lectures Cosmic Rays, Nikhef, Amsterdam, The Netherlands, 23 March 2012

Cosmic rays, Nikhef Scientific Advisory Committee, Amsterdam, The Netherlands, 26 April 2012

Linear Collider: ILC and CLIC, Workshop Future Nikhef Activities, NIOZ, Texel, The Netherlands, 22 May 2012

Metzger, W.J., BEC and jets at the Z pole, VIII Workshop on Particle Correlations and Femtoscopy, Frankfurt, Germany, 14 September 2012

Bose-Einstein Correlations and jet structure of hadronic Z decays, XLII Int. Symposium on Multiparticle Dynamics, Kielce, Poland, 18 September 2012

Verlaat, B.A., Evaporative CO_2 cooling for thermal control of scientific equipments, SLAC Advanced Instrumentation Seminars, Menlo Park, USA, 28 March 2012

TRACI, a multipurpose CO_2 cooling system for R&D, 10th IIF/IIR Gustav Lorentzen Conf. on Natural Working Fluids, Delft, The Netherlands, 26 June 2012

Design considerations of long length evaporative CO_2 cooling lines, 10th IIF/IIR Gustav Lorentzen Conf. on Natural Working Fluids, Delft, The Netherlands, 26 June 2012

Cooling experience with the LHCb VELO and spin-offs, Forum on Tracking Detector Mechanics, CERN, Geneva, Switzerland, 4 July 2012

HiSPARC

Eijk, van, B., Studium Generale 'Einstein ingehaald door neutrino?', Universiteit Twente, Enschede, The Netherlands, 21 february 2012

Montanus, J.M.C., Modeling cosmic air showers, NNV Fall Meeting, Lunteren, The Netherlands, 2 November 2012

3.4 Posters

ATLAS/DØ
Pani, P.
Track-based alignment of the ATLAS Inner Detector: implementation and performance
Int. Conf. on Computing in High Energy and Nuclear Physics (CHEP 2012), New York, USA, 24 May 2012

ALICE/STAR
Nooren, G.J., *et al.*
An extreme granularity electromagnetic calorimeter using monolithic pixels for future forward measurements in ALICE
Quark Matter 2012, Washington DC, USA, 16 August 2012

Zhou, Y., *for the ALICE Collaboration*
Anisotropic flow of φ meson in Pb-Pb collisions at $\sqrt{s_{NN}}$ *= 2.76 TeV with the ALICE detector*
Quark Matter 2012, Washington D.C., USA, 16 August 2012

Neutrino Telescopes
Astraatmadja, T.L., *on behalf of the ANTARES Collaboration*
Neutrinos from GRBs and their detection with ANTARES
International Astronomical Union (IAU) Symposium No. 279, Death of Massive Stars: Supernovae and Gamma-Ray Bursts, Nikko, Japan, 12 March 2012

Detecting TeV photons from GRBs with km^3 *neutrino telescopes*
International Astronomical Union (IAU) Symposium No. 279, Death of Massive Stars: Supernovae and Gamma-Ray Bursts, Nikko, Japan, 12 March 2012

Gajanana, D., *et al.*
ASIC Design in the KM3NeT detector
Topical Workshop on Electronics for Particle Physics (TWEPP 2012), Oxford, UK, 20 September 2012

Wolf, E. de, *on behalf of the KM3NeT Consortium*
KM3NeT Photonic Readout and DAQ System
12th Pisa Meeting on Advanced Detectors , La Biodola, Isola d'Elba, Italy, 20 May 2012

on behalf of the KM3NeT Consortium
The KM3NeT Digital Optical Module
Neutrino 2012 Conference, Kyoto, Japan, 3 June 2012

Gravitational Waves
Hennes, E.
Demonstrating passive seismic isolation using anti-spring technology
Physics@FOM, Veldhoven, The Netherlands, 17 January 2012

Demonstrating passive seismic isolation using anti-spring technology
First DSPE conference (Dutch Society for Precision Engineering), Deurne, The Netherlands, 4 September 2012

Li, T.G.F.
TIGER: A Data Analysis Pipeline for Testing General Relativity Using Compact Binary Coalescence
Rattle and Shine: Gravitational Wave and Electromagnetic Studies of Compact Binary Mergers, Santa Barbara, USA, 30 July 2012

Dark Matter
Schön, R.
Using a GridPix detector in dark matter search
Physics@FOM, Veldhoven, The Netherlands, 17 January 2012

Theoretical Physics
Buffing, M.G.A., P.J. Mulders
Gluons in high-energy scattering processes and color gauge invariance
Physics@FOM, Veldhoven, The Netherlands, 18 January 2012

Detector R&D
Gajanana, D., *et al.*
Irradiation tests on InP based Mach Zehnder Modulators
Topical Workshop on Electronics for Particle Physics (TWEPP 2012), Oxford, UK, 18 September 2012

Irradiation studies on InP based Mach Zehnder Modulators
17th Annual Symposium of the IEEE Photonics Benelux Chapter, Mons, Belgium, 29 November 2012

Grid Computing
Remenska, D., Bal, H., Willemse, T., Templon, J., Verstoep, K.
Analysis of DIRAC's behavior using model checking with process algebra
Conference on Computing in High Energy Physics (CHEP), New York, USA, 21 May 2012

3.5 Jamboree

By the end of each year Nikhef physicists and technicians gather in a two-day Annual Meeting traditionally called Jamboree. The 2012 edition of this event was held at Utrecht University and organised by Panos Christakoglou, Marco van Leeuwen and Raimond Snellings. Location was the more than 500 years old *kapittelzaal* of the Dom Church, presently in use as the aula of the university. In this historical surroundings reports were given about the status of Nikhef's various programmes and projects both by staff members, postdocs and young students.

Figure 1. The Jamboree was held in the more than 500 years old chapter house or 'kapittelzaal' of the Dom Church.

Obviously, there was ample attention for this year's discovery of the Higgs boson in which the ATLAS group is involved, but also the other two Nikhef groups at CERN (ALICE and LHCb) offered results from many new analyses. The broad scope of Nikhef's research program was further reflected in talks with subjects ranging from *"quadrupole deformation of coalescing binary stars"* to the technique of subtracting earth crust movements from the –already ultra stable– Virgo data. Various speakers amazed us with unconventional items in their presentations: we saw a rotating 3D-voxel measured with X-rays, an anxiously looking team of XENON physicists at the unblinding of their data in a Mediterranean hotel, and we finally listened to an audible signal of *B*-meson oscillations.

Monday 10 December 2012
Introduction
09:30 *Welcome speech*, Jaap Dijkhuis
09:45 *Nikhef status and plans*, Frank Linde

ANTARES/KM3NeT
10:00 *Search for Neutrino Point Sources with ANTARES*, Claudio Bogazzi
10:25 *Status KM3NeT*, Dorothea Samtleben

AUGER
11:05 *Results from Auger in 2012*, Charles Timmermans
11:30 *Radio Detection of Cosmic Rays: Progress at AERA and links to LOFAR*, Anna Nelles

Computing
11:55 *Introduction*, Jeff Templon
12:00 *GPU computing*, Jan Just Keijser
12:10 *Computing overview*, Jeff Templon
12:30 *BiG Grid & Beyond*, Arjen van Rijn

Dark matter
13:40 *XENON*, Patrick Decowski

Detector R&D
14:10 *Overview*, Niels van Bakel
14:25 *GridPix Detectors: Production and Testbeam Results*, Wilco Koppert
14:45 *The color of X-rays*, Enrico Schioppa
15:05 *Photonic integration*, Deepak Gajanana
15:15 *Tipsy & Trixy & ERC plans*, Harry van der Graaf

Theory
15:50 *Theory in 2012*, Eric Laenen
16:00 *NLO matching for Antenna showers*, Lisa Hartgring
16:20 *Baryogenesis and Dark Matter*, Kalliopi Petraki
16:40 *Black hole thermodynamics and macrostates*, Ivano Lodato
17:00 *The MSSM as a geometric theory*, Thijs van den Broek

Tuesday 11 December 2012
ATLAS
09:00 *Introduction*, Nicolo de Groot
09:10 *Atlas running and multi leptons*, Pier-Olivier Deviveiros
09:25 *Single top quark in ATLAS*, Hurng-Chun LEE
09:40 *Higgs to four muons*, Antonio Castelli
09:55 *Higgs properties and status*, Elina Berglund
10:10 *Susy searches*, Carolina Deluca
10:25 *Hardware activities for the next two years*, Gerjan Bobbink

ALICE
11:00 *ALICE in 2012*, Thomas Peitzmann
11:10 *Jet measurements in Pb-Pb*, Marta Verweij
11:30 *D-meson measurements in pp and Pb-Pb*, Alessandro Grelli
11:50 *Flow of identified particles*, Grazia Luparello
12:10 *The forward calorimeter (FoCal) project: status and plans*, Elena Rocco

LHCb
13:30 *Introduction, status and upgrade*, Marcel Merk
13:50 *New CP violation measurements*, Rob Lambert
14:10 *The very rare decay* $B_s \to \mu\mu$, Francesco Dettori
14:30 *The* B_s *mixing phase* Φ_s, Jeroen van Leerdam
14:50 *Measurement of angle* γ, Manuel Schiller

Gravitational waves
15:30 *Advanced Virgo*, Johannes van den Brand
15:45 *Probing dynamical spacetimes with gravitational waves*, Chris Van Den Broeck
16:00 *Post-mortem of a binary neutron star merger*, Tjonnie Li

Future activities
16:20 *Future activities: Summary of the Texel and Cracow meetings*, Paul de Jong

3.6 Awards & Grants

Every year numerous Nikhef members make a great effort to apply for grants or compete for awards. Below, the proposals honoured and the awards received in 2012 are listed. Please refer to Section 5.4 for a full overview (including precise amounts) of all current grants regarding Nikhef, namely newly awarded grants in 2012, still running grants and recently completed grants awarded in earlier years.

NWO Grants

NWO honoured the proposal *"Advanced Virgo – Probing the dynamics of spacetime"* of Jo van den Brand (Gravitational Waves) with a grant of 2 M€ in the framework of the *'Investeringen NWO-groot'* (Investment subsidy NWO large). The aim of this programme is to stimulate investments in innovative scientific equipment or data of national or international importance.

Alessandro Grelli (ALICE) received a Veni grant of 250 k€ for his proposal *"Research into a new state of matter"*. The Veni grant offers researchers who have only recently completed their doctorates the opportunity to develop their ideas during three years.

Hans Montanus (HiSPARC/LiO) received an NWO grant called *'Promotiebeurs voor Leraren'* (PhD Grant for Teachers). The secondary school that employs him will receive approximately 110 k€ to enable Montanus for a period of four years to perform part-time research at Nikhef on *"Jets in cosmic air showers"* under the supervision of Bob van Eijk.

Two Nikhef proposals were included in the National Roadmap for Large-Scale Research Facilities, namely *"Dutch contributions to the detector upgrades of the Large Hadron Collider experiments at CERN"* and *"KM3NeT: the next generation neutrino telescope"*. Only the best projects with the greatest potential for science and society were selected.

FOM Grants

A new FOM research programme *"The Missing Universe: What is the subatomic constituent of Dark Matter?"* has been established under the leadership of Patrick Decowski (Dark Matter). FOM awarded a budget of 2 M€ for the period 2013–2018. These so-called free programmes are available for promising research initiatives of excellent quality.

Four FOM-*'projectruimte'* grants were awarded to Nikhef researchers:

- to Olga Igonkina (ATLAS) for her proposal *"Search for tau decays to a muon and a photon to understand the lack of anti-matter in the universe"*;
- to Piet Mulders (Theoretical Physics) for his proposal *"Quantum chromodynamics at work in the Higgs sector"*;
- to Thomas Peitzmann (ALICE) for his proposal *"Thermal photon measurements in ALICE: probing the initial temperature of the quark-gluon plasma"*;
- and to Marieke Postma (Theoretical Physics) for her proposal *"Keeping track of time during inflation"*.

These grants are meant to fund PhD (and sometimes postdoc) positions and each amount to about 400 k€.

Jo van den Brand and Henk Jan Bulten (Gravitational Waves) received 256 k€ of funding for a PhD position on *"Wireless seismic-sensor networks"* from the programme *"Computational Sciences for Energy Research"*. This programme, which is executed by FOM, is part of a new public-private partnership between Shell and NWO. It facilitates PhD positions in the Netherlands for students who will afterwards continue their career at the Shell Technology Centre in Bangalore, India.

Other Dutch Awards & Grants

Nikhef received together with AMOLF and CWI a grant of nearly 400 k€ in total from SURFnet for a joint proposal for improving their ICT-infrastructure. The grant was awarded within the framework of the Campus Challenge that was organised by SURFnet en SIDN (*'Stichting Internet Domeinregistratie Nederland'*).

European Grants

Three ERC Advanced Grants were awarded to Nikhef researchers. This prestigious grant is given by the European Research Council to exceptional individual researchers to pursue cutting-edge ground-breaking projects that open new directions in their

Figure 1. This is what more than 6 M€ looks like! Harry van der Graaf (left), Piet Mulders (2nd left) and Jos Vermaseren (right) each brought home an Advanced ERC Grant.

respective research fields or other domains:

- Harry van der Graaf (Detector R&D) receives nearly 2.5 M€ for his highly innovative proposal *"MEMS-made Electron Emission Membranes"*;
- Piet Mulders (Theoretical Physics) is granted more than 2 M€ for his proposal *"Quantum Chromodynamics at Work"*;
- the proposal *"Solving High Energy Physics Equations using Monte Carlo Gaming Techniques - HEPGAME"* of Jos Vermaseren (Theoretical Physics) was honoured with more than 1.7 M€.

An *"INFIERI"* grant of 404 k€ was given to Nigel Hessey (ATLAS). INFIERI is a European Marie Curie *"Initial Training Network"*. These transnational networks focus on a joint research training programme to make research careers more attractive to young people. Nikhef will use the grant to fund two PhD students for three and two years, respectively.

Wouter Waalewijn (Theoretical Physics) received a European Marie Curie *"International Incoming Fellowships"* grant of 183 k€ for his postdoc project *"Precise Predictions for Higgs and New Physics Signals with jets at the Large Hadron Collider"*. This grant is meant for experienced researchers based in non-European countries willing to receive a research training in a host institution based in Europe.

Other awards & grants

Andre Mischke (ALICE) received a Van Gogh grant (together with prof.dr. Jörg Aichelin, SUBATECH) of 5 k€ from the *'Frans-Nederlandse Academie'* (French-Dutch Academy), a bilateral organisation that supports more and better collaboration between France and the Netherlands in education and research. The aim of this grant is to facilitate the exchange of Dutch and French researchers working within one research project.

Figure 2. Andre Mischke (2nd from the right) received a Van Gogh Grant, awarded by the 'Frans-Nederlandse Academie'.

Antonio Pellegrino (LHCb) received a grant from the Brazilian *Ministério da Ciência, Tecnologia e Inovação* in the framework of a programme called *"Science without borders"*. It is meant to encourage foreign scientists to spend time in Brazil and Brazilian students, engineers and researchers to visit foreign institutes. The grant finances for a period of three years some travel costs and daily allowances for these exchanges between Nikhef and Brazil.

Eric Hennes (Mechanical Technology) won the *"Best demonstration award"* at the DSPE-Conference (Dutch Society on Precision Engineering).

4

Nikhef & Society

4.1 Outreach & Communication

After decades of research at different institutes and experiments all over the world, on 4 July 2012, ATLAS and CMS at CERN organised a joint colloquium and press conference, where the two experiments' spokespersons announced they had discovered a Higgs-like boson. Nikhef organised a national media event, and all the main Dutch television news channels and more than 15 newspaper journalists attended this event to follow the presentation and subsequent press conference and ask questions and interview Nikhef scientists. Following this news and the media event, more than 100 articles were published in national and regional newspapers and magazines. More than 20 news reports appeared on TV and radio that night, in such different programes as Nieuwsuur, Hart van Nederland, RTL Nieuws and NOS Journaal.

Figure 2. Children could construct their own Meccano models at the Open Day, but some needed a little help...

For the occasion, Hannie van den Bergh and Jan van den Berg, film makers of the documentary *"Higgs: into the heart of imagination"*, travelled to Sicily together with Nikhef's ATLAS programme leader Stan Bentvelsen and a film crew to interview prof.dr. Peter Higgs on the eve of the discovery. Van den Berg filmed and edited a number of extra scenes that have now been added to the film. The extended version of the film was broadcast on the day of the discovery. It has also appeared on a special edition of the DVD.

Every year, Nikhef organises a variety of activities for different target audiences (media, general public, students and teachers) to explain what Nikhef's particle and astroparticle research entails and how the technical departments support all these research endeavours. The communications department initiates many of these activities, but also relies on Nikhef staff and PhD-students' much appreciated dedication towards reaching out to the different target audiences about our research projects. Additional activities are based on enthusiastic initiatives of individual Nikhef members. Below, a comprehensive overview of all communication activities during 2012 is given. For education activities please refer to section 4.2.

Figure 1. Nobel Prize winner Gerard 't Hooft (wearing a Standard Model tie!) was interviewed by Dutch televison at the Nikhef Higgs media event.

Nikhef & the general public

This year, Nikhef again participated in the organisation of the annual Science Park Amsterdam Open Day for the general public, which took place in October during the Dutch Science Month. On the Open Day, all institutes on the Science Park opened their doors to people of all ages who are interested in science and want to find out more about it. At Nikhef people visited the exhibits and demonstrations in the main hall and the workshop set up by the LHC detector research groups, the astroparticle physics project groups, and the technical, computer infrastructure and theoretical physics departments. ATLAS hosted an ATLAS control room with live displays from the actual ATLAS control room at CERN. The Mechanical Technology group presented the newest additions to their impressive arsenal of milling and turning equipment and reintroduced the *'Amsterdammertjes'* which people were able to bring home with them. Children were able to participate in a search for particles, including the newly found Higgs boson. They were also able to construct their own electronic gadgets and Meccano models. Two mini lectures about the Higgs discovery were organised. The lectures, *"Higgs: Mass hysteria about the mass mystery"* about how it was discovered and *"The invisible Higgs – how do you prove the existence of something you can't see"*, drew a full house of visitors. In addition, there were two other lectures about topical subjects, *"The Little Big Bang"* about research at ALICE, and *"Dark Matter"*.

Figure 3. PhD student Tjonnie Li (left) explains a detector part during the Nikhef Open Day.

Figure 4. Physicist and author Walter Lewin signing copies of his book after his colloquium.

Outreach talks

In 2012, Nikhef scientists travelled all across the Netherlands and beyond to give numerous outreach talks at different venues and for many different audiences (see section 4.4 for a complete list). Frank Linde gave four lectures on *'Bright Horizons'*, a scientific cruise through Germany and Switzerland. The talks were about quantum questions, the past and present at CERN, particle physics matters and astroparticle physics. Many Higgs lectures were given in 2012 by invitation of amongst many others, the Nederlandsch Natuur- en Geneeskundig Congres, Kennis op Zondag (NWO) and the KNAW Higgs symposium. Andre Mischke gave a lecture (*"Quark soup in the lab"*) at Bessensap, the NWO event where science meets the press.

Internet & social media

The Nikhef website was updated with a brand new homepage which was a welcome improvement from the old homepage, showing a more transparent Nikhef: it is now clearer in one glance what Nikhef does and what it stands for. Also, news, events and jobs at Nikhef are now more prominently visible on the homepage.

At the end of 2011, the Nikhef blog – *"Blogging at Lightspeed"*, was 'opened' for Nikhef employees, the press and the general public to find out more about Nikhef and its research and researchers. Blog posts were added all year long, and especially around important milestones, such as the Higgs discovery.

Nikhef continued making progress on the social media field in 2012. Nikhef's Twitter account @nikheftweets went from 100 to almost 300 followers. Nikhef's Facebook page went from 50 to more than 110 likes.

Special events

On 8 May, prof.dr. Walter Lewin, the Dutch-American physicist who is famous for his inspiring lectures with fun demonstrations, visited Nikhef to give a colloquium entitled *"The Birth and Death of Stars"*. After the colloquium Lewin answered questions from the audience and signed copies of his new book *"Gek op natuurkunde"*, the Dutch translation of *"For the Love of Physics"*.

Two Dutch popular science books on particle physics were also published in 2012, namely *"Higgs – Het elementair abc van een elementair deeltje"* by Govert Schilling, and *"De deeltjesdierentuin"* by Jean-Paul Keulen. To both books several Nikhef scientists contributed by giving interviews, answering questions, or proofreading the manuscript.

In September, Science Park Amsterdam, together with film maker Jan van den Berg organised the Science Park Amsterdam Film Festival (SPAFF). Nikhef hosted the viewings of three movies, among which *"Higgs: Into the heart of imagination"*.

Guided tours at Nikhef and at CERN

Nikhef organises guided tours for everybody interested in the research performed at the institute. Visitors are welcome to join the Friday afternoon visits programme which is routinely offered twice per month and comprises a lecture, the viewing of a film, and a tour of the institute. Special guided tours are set up upon request. Among the many visitors were groups from SURFnet, the NWO communications department and international physics students.

Figure 5. PhD student Daniel Geerts (left) gives a guided tour to high school students. Here he explains the cosmic-ray muon chamber set-up.

Figure 6. Nikhef staff member Ivo van Vulpen (right) is interviewed by Dutch television about the discovery of the Higgs boson.

Moreover, there is a lot of interest in CERN visits by various Dutch groups. Nikhef supports these visits by providing Dutch speaking guides and lecturers from a pool of Nikhef employees stationed at CERN. In some cases, these CERN visits are in addition sponsored financially by Nikhef. Nikhef also organised two separate CERN visits by the first prize winners of the *'Nationale Wetenschapsquiz'* (National Science Quiz) junior and senior. Frank Linde joined writer and science journalist Govert Schilling at CERN to give him a private tour of the facilities.

Nikhef & the media

Nikhef issued one press release and more than ten news releases, concerning, among many other subjects, the discovery of the Higgs boson, Dark Matter research and new tests for the Standard Model of Particle Physics. Press releases are sent out to a long list of TV, radio, newspaper and magazine press offices and journalists, whereas the news releases are distributed using the social media channels Twitter and Facebook. The communication department is deliberately selective in choosing items that are sent out as press releases, in order to build and maintain a credible relationship with the (science) press.

Nikhef scientists contributed to many articles in various newspapers and magazines (NRC Handelsblad, Trouw, Volkskrant, Natuurwetenschap & Techniek, Kijk, and many more), and regularly gave interviews on radio programmes (e.g., Radio 1 Journaal, BNR Nieuwsradio).

Especially for the Higgs seminar Nikhef scientists were interviewed on TV (NOS journaal, RTL Nieuws, Nieuwsuur). VPRO Labyrint, a TV programme about science on national TV, sent a film crew to the Gran Sasso laboratory to document the search for dark matter there. They interviewed three researchers, among whom Nikhef programme leader Patrick Decowski.

Nikhef & science communication networks

Nikhef's communication department works together with national and international communication networks to develop, coordinate and organise communication activities about science in general and particle and astroparticle physics in particular.

International networks

- *EPPCN* – The European Particle Physics Communication Network;
- *InterActions* – A collaboration of communicators for particle physics worldwide.

National Networks

- *Science Park Amsterdam* communication departments;
- *FOM* meeting with the various communications departments of the FOM institutes;
- *Platform Wetenschapscommunicatie* (PWC), an association for science communication staff.

4.2 Education

Nikhef is committed to educating young people and to stimulating their interest in science and technology. From the very young, budding physicists to the PhD students, there are appropriate programmes for each age group. Teachers can participate in various activities as well.

Nikhef & Primary schools

The *'Techniek Toernooi'* is a science tournament for primary schools, where the academic world of science meets that of the primary schools. Traditionally, many members of the Nikhef staff participate in the jury of academic staff that assesses the designs. In 2012, the children in the age group between 4 and 12 years were challenged in different ways to use materials such as cardboard, sand, aluminium, water or bricks for building constructions.

Several Nikhef scientists presented a lecture in the popular series *'Wakker Worden Kinderlezingen'* for children between 8 and 12 years at the NEMO science museum. In 2012 Frank Linde gave a lecture about the origin of lightning and Marcel Vreeswijk talked about the question why people float on the Dead Sea.

Nikhef & Secondary schools

Every year, Nikhef puts a lot of effort into introducing secondary school students to particle and astroparticle physics. Through the Nikhef website schools can apply for a Friday afternoon visit, which consists of a lecture by a Nikhef scientist, a film and a guided tour. In 2012 the Friday afternoon visits were attended by more than 300 students. Furthermore, fourteen secondary school students were assisted by Nikhef scientists to carry out their *'profielwerkstuk'* (research project). Apart from this, several schools were visited by Nikhef staff members for private lectures. Nikhef also supported numerous CERN visits of secondary school students by providing Dutch guides for tours.

On 2 March 2012 35 students participated in the yearly International Masterclass on Particle Physics held at Nikhef. After various lectures about the basics and the history of particle physics, CERN and other related subjects, the students start their own bit of research with real data from the Large Hadron Collider at CERN. The day is concluded with a live video conference with CERN to share the results of the day with students at other participating institutes.

Nikhef & HiSPARC

The High School Project on Astrophysics Research with Cosmics (HiSPARC) gives students a chance to participate in real scientific research. Schools can take part in the project and their students work together in building a detector that is designed to detect high-energy cosmic rays. In 2012, the HiSPARC detector network consisted of over 90 stations throughout the country. A start was made with building a network of HiSPARC detectors in Great Britain, with the first system going online in October in Bristol. More are expected to follow soon.

Figure 1. Masterclass students perform research with real data from the Large Hadron Collider at CERN.

In April, HiSPARC organised the annual HiSPARC Symposium intended for students and teachers. It is an extensive programme that consists of lectures, workshops and presentations of *'profielwerkstukken'* by the students themselves. The best *'profielwerkstuk'* is awarded with a trip to CERN, a prize made possible by the *'Nederlandse Natuurkundige Vereniging'* (NNV, the Dutch Physical Society).

Nikhef & Teachers

Nikhef reaches out to teachers, keeping them informed on the latest developments in physics, which they can pass on to their students. In the academic year 2011/2012 the FOM teacher-in-research programme (*'Leraar in Onderzoek'*, LiO) continued. Five new LiOs were selected and two LiOs prolonged their contract with a second year. Of the seven teachers one was stationed at KVI (Groningen), the others were based at Nikhef (Amsterdam). All teachers were supported by staff members and all had their own research activities within the HiSPARC project.

Instead of the yearly mastercourse held at Nikhef, physics teachers could attend in 2012 a *'Netwerkbijeenkomst deeltjesfysica voor docenten'* (Network meeting particle physics for teachers), which was organised in Castricum in April by the *'Steunpunt Natuurkunde Amsterdam'*. Marcel Vreeswijk gave a lecture on particle physics. The meeting was attended by 24 teachers.

Figure 2. Students enrolled in the MSc in Particle and Astroparticle Physics built a 4 multi-wire proportional chamber cosmic muon detector.

For the third time since 2010, Nikhef organised together with CERN a 3-day Dutch CERN teachers programme. In 2012, the programme took place at the end of September and the 20 available places were quickly filled after a selection from about 40 applications. The teachers attended lectures from scientists working at CERN and followed guided tours through several CERN experimental halls and other venues.

MSc in Particle and Astroparticle Physics

In the two year Masters programme offered by Nikhef, students can specialise in the field of Particle and Astroparticle Physics. In the first year, the programme comprises besides lectures a small project in which the students are introduced to all aspects of experimental particle physics. This year a detector consisting of 4 multi-wire proportional chambers was built with the aim to measure cosmic-muon tracks. In their second year the students work on their own research project in one of the groups at Nikhef.

In 2012, nine new students enrolled in the first year of the Masters, among them two students from other European countries. One student from Germany and one from Portugal enrolled in the programme as ERASMUS student for six months. A total number of 13 students graduated in 2012. Of these students, six continued their career in industry or as entrepreneur, one as a physics teacher and six chose a position as a PhD student at Nikhef or abroad.

Research School Subatomic Physics

All PhD students at Nikhef receive academic training through the Research School Subatomic Physics (*'Onderzoeksschool Subatomaire Fysica'*, OSAF). In 2012, PhD degrees were obtained by 22 students from OSAF. The number of new PhD registrations in 2012 was also 22. The *'Jan Kluyverprijs'* for the best summary of a PhD thesis was given to Daan van Eijk.

The BND summer school (Belgium, the Netherlands, Germany) was held in September/October in Bonn, Germany. The summer school was organised this year by the University of Bonn. There were 63 participants. The school was again supported with a grant from the EU Erasmus Life Long Learning programme.

OSAF organised three topical lectures in 2012. The subjects were cosmic rays, nuclear physics and the Higgs particle.

4.3 Knowledge Transfer

Valorisation & Spin-off Activities

In 2012, the Nikhef startup company *Amsterdam Scientific Instruments* (ASI), which aims at developing and commercialising Medipix based particle detection equipment, has grown substantially. In its first full year of operations the company gained good market traction where it sold several systems to a number of high-profile customers around the world. By the end of 2012 the number of employees has grown from 1 to 5 fte and is expected to grow in 2013. The company established its own lab facility on the ground floor of the former University of Amsterdam 'Astronomy' building, adjacent to Nikhef. In fact, Nikhef's valorisation partner, *1&12 Ventures*, decided to move into that very same floor with all its activities.

Nikhef's second startup *Sensiflex*, which aims at selling the Rasnik alignment system in non-scientific domains, experienced a year full of challenges. Circumstances led the CEO of the company to resign. The ad interim management has been asked by the share holders to come up with a plan to rescope the company in a such a way that the initial market interest from the civil construction industry can be turned into a profitable business model.

A milestone in 2012 was the entry of our colleague FOM-institute AMOLF into the investment company *Particle Physics inside Products* (P2IP). AMOLF also obtained a seat in the Board, which –per ultimo 2012– consists of Gerrit Jan Bolderman and Chatib Sjarbaini (1&12), Bart van Leijen (AMOLF), Hendrik van Vuren (FOM) and Arjen van Rijn (Nikhef). Hans Roeland Poolman (1&12) is P2IP director. Soon after the entry of AMOLF another spin-off company was established with P2IP participation, *Omics2Image*, which aims at developing and selling biomolecular imaging equipment.

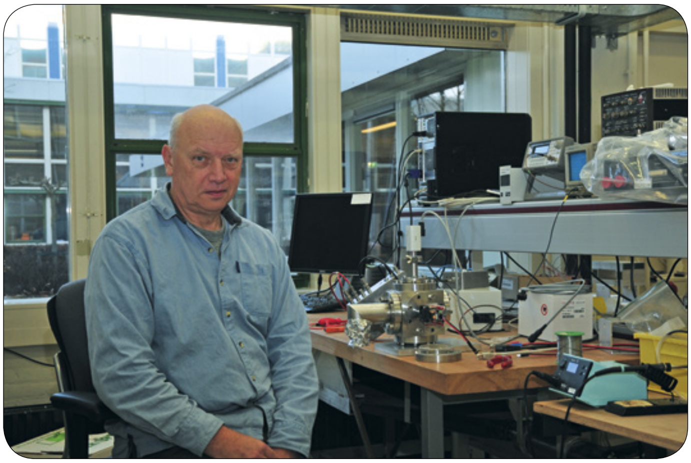


Figure 1. Harry van der Graaf, whose Rasnik alignment system forms the base one of the products of Sensiflex.

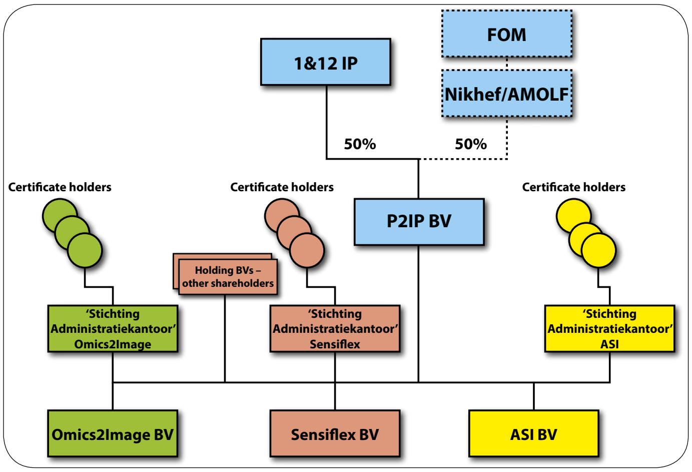


Figure 2. The current legal structure around Nikhef's start-ups.

During the year P2IP has followed various leads and prospects. It assisted in writing an STW valorisation proposal on CO_2 cooling. Although the technology was considered interesting, unfortunately the grant was not awarded. Other alternatives for a road-to-market are still considered. Furthermore, P2IP discussed possibilities of network resource scheduling software, developed in Nikhef's grid computing group .Talks with various large and small companies have demonstrated interest from the industry.

In 2012, Nikhef acquired a contract for a (mechanical) engineering project for *ASML*. Most of the work will be carried out in 2013. Furthermore, in 2012 discussions with *Shell Exploration and Production* have intensified regarding collaboration on the development of instrumentation for a wireless seismic sensoring network (a spin-out of Nikhef's involvement in gravitational wave detection experiments).

One (Dutch) patent application was filed in 2012: '*Tipsy: Photon detector with high time resolution and high spatial resolution*'.

Nikhef continued its long standing and fruitful research relation with *Panalytical*, now also in closer collaboration with our startup ASI. And finally, Nikhef's datacenter activities (in particular for customers of the *Amsterdam Internet Exchange*, AMS-IX) have further increased. In December, after a rigorous audit, the Nikhef facility has again qualified as 'AMS-IX certified' datacenter.

4.4 Memberships*

ASPERA
F. Linde (Governing Board)
H. Demonfaucon (joint secretariat)

Astroparticle Physics European Coordination (ApPEC)
P. Kooijman (scientific advisory committee),
F. Linde (steering committee)

BEAUTY, Int. Conference on B-Physics at Hadron Machines – International Advisory Committee
R. Fleischer (co-chair)

Big Grid – Directorate
F. Linde, A. van Rijn

Computer Algebra Nederland – Board
J. Vermaseren

CERN Council
S. de Jong

CERN European Strategy Group
S. de Jong, F. Linde

e-Infrastructure Reflection Group (e-IRG)
A. van Rijn (Dutch delegate)

EUROCOSMICS
B. van Eijk (chair)

European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT) – Scientific Board*
P. Mulders

European Committee for Future Accelerators (ECFA)
S. de Jong, M. Merk, F. Linde (restricted ECFA), Th. Peitzmann

European Particle Physics Communication Network (EPPCN)
G. Bobbink , V. Mexner

European Physical Society
E. de Wolf (Executive Committee, Physics Education Board)
B. van Eijk (HEP Board)

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

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

European Research Council – Advanced Grants panel PE2
S. de Jong

FOM
Th. Peitzmann, S. Bentvelsen (Board)
E. de Wolf (Adviescommissie FOm/v programma)
W. Beenakker, R. Kleiss, E. Laenen (chair) (network Theoretical High Energy Physics)

Fonds Wetenschappelijk Onderzoek, Vlaanderen – Expertpanel Physics
E. de Wolf

FP7 Marie Curie Actions "Initial Training Networks" – Mathematics-Physics Panel, EU Research Executive Agency
A. Mischke

Gesellschaft für Schwerionenforschung, Darmstadt – Program Advisory Committee
Th. Peitzmann

Gesellschaft für Schwerionenforschung, Darmstadt – Review Committee silicon tracking detector system for the Compressed Baryonic Matter experiment
G. Nooren

Insituto Nazionale di Fisica Nucleare (INFN)
F. Linde (member Technical Scientific Committee)

Institute of Research in Mathematics and Physics (IRMP) – Université Catholique de Louvain
E. Laenen (Scientific Advisory Committee)

International Particle Physics Outreach Group (IPPOG)
S. Caron

International Union for Pure and Applied Physics (IUPAP)
P. Mulders (Liaison for the Netherlands)

International Grid Trust Federation
D. Groep (chair)

Int. Workshop on Heavy Quark Production in Heavy-Ion Collisions
Paul Kuijer, Andre Mischke (co-chairs)

* *as of 31 December 2012.*

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

InterActions
V. Mexner

KNAW – Commissie Evaluatie Wetenschappelijk Ruimteonderzoek in Nederland
S. de Jong

KNAW – Advisory Committee on Higher Education
B. de Wit

Landelijk coördinatorenoverleg HiSPARC
B. van Eijk (chair), J. van Holten

LHCPhenoNet ITN network
E. Laenen (Supervisory Board)

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

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

Nederlands Tijdschrift voor Natuurkunde – Editorial Board
P. Decowski

Nederlandse Natuurkundige Vereniging (NNV)
S. de Jong, E. de Wolf (deputy chair)

Nederlandse Natuurkundige Vereniging (NNV) – Advisory Board
M. Vreeswijk

Nederlandse Natuurkundige Vereniging (NNV) – Sectie Onderwijs en Communicatie
S. de Jong (vice chair)

Nederlandse Natuurkundige Vereniging (NNV) – Sectie Subatomaire Fysica
J. van Holten, I. van Vulpen (secretary), E. Koffeman (deputy chair)

Netherlands eScience Center
J. Templon (eScience Integrator)

Nuclear Physics European Collaboration Committee (NuPECC)
R. Snellings

Open Grid Forum CA – OPS working group
D. Groep (co-chair)

Particle Physics Inside Products (P2IP BV)
A. van Rijn (member of the board)

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

Platform Bèta Techniek – Ambassador
F. Linde, E. de Wolf

Sectorplan committee for Physics and Chemistry (Commissie Breimer)
B. de Wit

Stichting Conferenties en Zomerscholen over de Kernfysica (StCZK)
S. de Jong, P. Mulders

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

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

Stichting Industriële Toepassing van Supergeleiding
B. van Eijk

Stichting Natuurkunde.nl
F. Linde (chair), M. Vreeswijk (editor)

Topsector High Tech Systems & Materials (HTSM) – Scientific Committee and Roadmap Circuits & Components Committee
N. van Bakel

University of Edinburgh – Higgs Centre
E. Laenen (associate member)

Vereniging Gridforum Nederland
A. van Rijn (treasurer)

Worldwide LHC Computing Grid
J. Templon (Management Board)

Young Academy of Europe
A. Mischke (chair)

4.5 Outreach Talks

Beker, M.G., Gravitatiegolven, de dynamica van ruimtetijd, Leidse Weer- en Sterrekundige Kring, Leiden, The Netherlands, 23 October 2012

Luisteren naar het Heelal, Koninklijke Nederlandse Vereniging voor Weer- en Sterrenkunde, Galaxis, Den Bosch, The Netherlands, 19 December 2012

Bentvelsen, S.C.M., De deeltjesversneller in Genève, KNAW Higgs Symposium, Amsterdam, The Netherlands, 11 January 2012

Op jacht naar het Higgs deeltje, KSG de Breul, Zeist, The Netherlands, 14 March 2012

Op jacht naar het Higgs deeltje, Natuurkundig Genootschap, Rotterdam, The Netherlands, 20 March 2012

De ontdekking van het Higgs deeltje, Kennis op Zondag, Den Haag, The Netherlands, 7 October 2012

De Large Hadron Collider in actie, 104e NNGC congres 'Higgs, Majorana en de Kosmos', museum Boerhave, Leiden, The Netherlands, 27 October 2012

De ontdekking van Higgs, Chemische Kring, Utrecht, The Netherlands, 29 October 2012

Brand, van den , J.F.J., Gravitational Wave Experiments, Astronomical Society 'Zaanstreek', Zaanstreek, The Netherlands, 26 January 2012

Recent Developments in Gravitational Physics Experiments, AWSV Metius, Alkmaar, The Netherlands, 30 November 2012

Bulten, H.J., Wireless Seismic-sensor Networks, DevLab Café colloquium, Eindhoven, The Netherlands, 25 May 20125

Chelstowska, M., PhD student impressions, rECFA (restricted European Committee for Future Accelerators), Amsterdam, The Netherlands, 17 February 2012

Christakoglou, P., ALICE in a nutshell, Amsterdam, The Netherlands, 29 November 2012

Colijn, A.P., Help! Waar is ons Heelal?, Science Park Colloquium, Amsterdam, The Netherlands, 2 February 2012

Dark Matter, Kronig lezing, TU Delft, Delft, The Netherlands, 5 June 2012

Donkere Materie, Nikhef Open Dag, Amsterdam, The Netherlands, 6 October 2012

Higgs, Science Café IJburg, Amsterdam, The Netherlands, 22 November 2012

Dark Matter, Marie Curie lustrum, Radboud University, Nijmegen, The Netherlands, 28 November 2012

Decowski, M.P., Detecting Dark Matter, AUC Who's in Town Lecture Series, Amsterdam, The Netherlands, 3 December 2012

Eijk, van, B., HOVO college, Teyers Museum, Haarlem, The Netherlands, 3 april 2012

HOVO college, Teyers Museum, Haarlem, The Netherlands, 10 april 2012

HiSPARC, The Red Maids' School, Bristol, United Kingdom, 22 october 2012

Elementaire deeltjes, Cygnus Gymnasium & Pieter Nieuwland College, Amsterdam, The Netherlands, 31 october 2012

Elementaire deeltjes: het verband tussen heel klien en heel groot, Bonhoeffer College, Castricum, The Netherlands, 18 december 2012

Eijk, van, D., Deeltjesfysica op CERN, Studium Generale Amersfoort, Amersfoort, The Netherlands 8 April 2012

Filthaut, F., Computers bij experimenten in de deeltjesfysica, TU/e guest lecture, Eindhoven, The Netherlands, 10 January 2012

De ontdekking van het Higgsdeeltje, boekpresentatie, Amersfoort, The Netherlands, 29 September 2012

Geer, van der, R., De ATLAS-detector, Visit of high school students, Geneva, Switzerland, 22 February 2012

De ATLAS-detector, Visit of high school students, Geneva, Switzerland, 13 March 2012

De ATLAS-detector, Visit of Delft University students, Geneva, Switzerland, 18 June 2012

De ATLAS-detector, Visit of Junior College Utrecht students to CERN, Geneva, Switzerland, 12 November 2012

Groot, de, N., Het Higgsdeeltje, het ontbrekende puzzelstuk, Soeterbeeckt Programma, Nijmegen, The Netherlands, 7 March 2012

Het Higgsdeeltje, het ontbrekende puzzelstuk, Natuurkundig Genootschap Utrecht, Utrecht, The Netherlands, 3 April 2012

Mysterie van de Zwaartekracht, TASA (Turkish Academic Student Association), Nijmegen, The Netherlands, 16 May 2012

Deeltjesfysica, Masterklas Radboud University, Nijmegen, The Netherlands, 29 June 2012

Higgs, Open dag lustrum Radboud University, Nijmegen, The Netherlands, 24 November 2012

How the Higgs was found, Shell, Amsterdam, The Netherlands, 19 December 2012

Hartgring, L.C., Het Higgs Boson, Brainwash, Amsterdam, The Netherlands, 2 August 2012

Holten, van, J.W., Elementaire deeltjes, HOVO college, Haarlem, The Netherlands, 13 March 2012

Speciale relativiteitstheorie, Einstein's verjaardag, Leiden, The Netherlands, 14 March 2012

Kosmologie, HOVO college, Haarlem, The Netherlands, 24 April 2012

Neutrino's, Paradiso symposium, Amsterdam, The Netherlands, 27 May 2012

Jong, de, S.J., Nieuwe beta curricula in het VO, introductielezing voor schoolleiders in de regio Nijmegen, Radboud University, Nijmegen, The Netherlands, 17 January 2012

Deeltjes onderzoek op CERN, Raayland Science dag, Nijmegen, The Netherlands, 26 January 2012

Inleiding discussie energie, Jonge Democraten, Nijmegen, The Netherlands, 1 February 2012

Higgs of de nieuwe aether, Valuascollege, Venlo, The Netherlands, 1 March 2012

Quantumwereld 1, NiNa nascholings cursus, Radboud University, Nijmegen, The Netherlands, 6 March 20126

Quantumwereld 2, NiNa nascholings cursus, Radboud University, Nijmegen, The Netherlands, 13 March 2012

Quantumwereld 3, NiNa nascholings cursus, Radboud University, Nijmegen, The Netherlands, 20 March 2012

Quantumwereld 4, NiNa nascholings cursus, Radboud University, Nijmegen, The Netherlands, 27 March 2012

Aansluiting VO-WO, workshop Conferentie Beta Techniek, Rotterdam, The Netherlands, 29 March 2012

Masterclass CERN, SSgN, Nijmegen, The Netherlands, 4 April 2012

Pre-University en Talentenprogramma, Krimpenerwaard College, Krimpen aan de IJsel, The Netherlands,14 May 2012

Linear Collider: ILC and CLIC, Workshop Future Nikhef Activities, NIOZ, Texel, The Netherlands, 22 May 2012

De uitspraak, Girls summer camp, Radboud University, Nijmegen, The Netherlands, 5 June 2012

Radboud pre-University College of Science, platform VO-HO, Nijmegen, The Netherlands, 6 June 2012

Significantie, CITO, Arnhem, The Netherlands, 5 September 2012

Radboud PUC of Science en de nieuwe beta programma's, docentenbijeenkomst, Radboud University, Nijmegen, The Netherlands, 26 September 2012

Wat Nijmegen voor de RU en de RU voor Nijmegen kan doen, senaatsdiscussie met de burgemeester van Nijmegen, Nijmegen, The Netherlands, 1 October 2012

Higgs of de nieuwe aether, Radboud Alumni dag, Nijmegen, The Netherlands, 6 October 2012

Het NLT lustrum boek, bijeenkomst met schoolleiders, Radboud University, Nijmegen, The Netherlands, 12 October 2012

Masterclass natuurkunde, Nijmeegse 2-daagse, Nijmegen, The Netherlands, 16 October 2012

The Physics of Ultra High Energy Cosmic Rays, FOM programmainterview, FOM, Utrecht, 6 November 2012

Quantumwereld 1, NiNa nascholings cursus, Radboud University, Nijmegen, The Netherlands, 6 November 2012

Quantumwereld 2, NiNa nascholings cursus, Radboud University, Nijmegen, The Netherlands, 13 November 2012

Quantumwereld 4, NiNa nascholings cursus, Radboud University, Nijmegen, The Netherlands, 27 November 2012

Koeroo, O.A., Public Key Infrastructure: How does it work?, Hogeschool van Amsterdam, Amsterdam, The Netherlands, 22 February 2012

Public Key Infrastructure: How does it work?, Hogeschool Zuyd, Heerlen, The Netherlands, 28 March 2012

XACML: Transitions, Platform Identity Management Nederland: XACML practical experiences, Utrecht, The Netherlands, 26 April 2012

Security Drills in a Grid Environment, TERENA: 36th TF-CSIRT Meeting, Amsterdam, The Netherlands, 11 May 2012

Nikhef & Grid Computing Security, Fox-IT, Delft, The Netherlands, 17 August 2012

Public Key Infrastructure: How does it work?, Hogeschool Zuyd, Heerlen, The Netherlands, 24 October 2012

Public Key Infrastructure: A cheezy Man-in-the-Middle attack hack, Hackalong, Schiphol-Rijk, The Netherlands, 2 November 2012

Laat, de, A.P.L.S., Kosmische straling, Medewerkersavond, Sonnenborgh, Utrecht, The Netherlands, 18 September 2012

Laenen, E., Het onstaan van massa in het Standaard Model van elementaire deeltjes, KNAW Higgs Symposium, Amsterdam, The Netherlands, 11 January 2012

Hett Standaard Model, Convocatie Centaurus, KNVWS, Nijmegen, The Netherlands, 7 March 201

Linde, F., Neutrino's, sneller dan het licht?, Amsterdam Chemisch Dispuut, Amsterdam, The Netherlands, 24 January 2012

Neutrino's, sneller dan het licht?, Science Café Wageningen, Wageningen, The Netherlands, 23 February 2012

Neutrino's & Higgs, Nationaal Ruimtevaart Museum, Lelystad, The Netherlands, 1 March 2012

Neutrino's, sneller dan hun schaduw?, Science Café Nijmegen, Nijmegen, The Netherlands, 12 March 2012

Waar komt de bliksem vandaan?, Wakker worden lezing, NEMO Science Centre, Amsterdam, The Netherlands, 18 March 2012

Quantum World - CERN - Valorisation - Astroparticles, Bright Horizons Rhine cruise, The Netherlands, Germany & Switzerland, 12-18 April 2012

Discussie panel Wetenschapsdiner, NWO, Den Haag, The Netherlands, 1 October 2012

Higgs, KPMG, Amstelveen, The Netherlands, 10 October 2012

Wetenschap & Religie, Zuiderpoort, Almere, The Netherlands, 2, 9 & 30 October 2012

Deeltjes botsen, Mensa Oktoberweekend 2012, Elspeet, The Netherlands, 2 November 2012

Higgs, Natuurkunde.nl sponsorevent, Nikhef, Amsterdam, The Netherlands, 8 November 2012

Higgs & nut deeltjesfysica, DeForum-filmtheater, Hilversum, The Netherlands, 13 November 2012

Higgs, Science Café Deventer, Deventer, The Netherlands, 12 December 2012

Higgs, Winterlezing, Zaanland Lyceum, Zaandam, The Netherlands, 18 December 2012

Loll, R., Mysterious Quantum Spacetime: Why 3+1 sometimes equals 2, Lustrum Marie-Curie Student Associations, Radboud University, Nijmegen, The Netherlands, 28 November 2012

Mysterious Quantum Spacetime: Why 3+1 sometimes equals 2, Lise Meitner Lecture of the Austrian and German Physical Societies, Vienna, Austria, 30 November 2012

Merk, M.H.M., Mysterieuze Materie, Past Rotary Club Maastricht, Maastricht, The Netherlands, 23 April 2012

De Ontdekking van het Higgs Deeltje, Studium Generale Universiteit Maastricht, Maastricht, The Netherlands, 11 October 2012

Mischke, A., Journey to the Big Bang, Visit of a schooldelegation from Copenhagen, Utrecht, The Netherlands, 1 January 2012

Quarks en de oerknal, Voorlichtingsdag, Faculty of Science, Utrecht, The Netherlands, 17 March 2012

Wat is Quark Soep?, NWO Bessensap, Den Haag, The Netherlands, 4 June 2012

A landmark on the way to the big bang, European Science Forum - Passion for Science (ESOF 2012), Dublin, Ireland, 14 July 2012

Mooij, S.J.N., How many Higgs in Higgs?, NerdNite, Amsterdam, The Netherlands, 28 September 2012

Mulders, P.J., Neutrino's, nog steeds ongrijpbaar?, Ned. Ver. Weer en Sterrenkunde Galaxis, Den Bosch, The Netherlands, 21 March 2012

Het (ongrijpbare) neutrino, Ned. Ver. Weer en Sterrenkunde Jean Delsing, Venlo, The Netherlands, 28 September 2012

Sluys, van der, M., Wij zijn gemaakt uit sterrenstof!, Publieksavond, Radboud University, Nijmegen, The Netherlands, 27 January 2012

De Zon, Sonnenborgh – museum & sterrenwacht, Utrecht, The Netherlands, 16 February 2012

De Zon, Publieksavond, Radboud University, Nijmegen, The Netherlands, 30 March 2012

Compacte dubbelsterren, Sterrenwacht Halley, Heesch, The Netherlands, 28 April 2012

Compacte dubbelsterren en gravitatiegolven in ons heelal, Astra Alteria, Putten, The Netherlands, 21 May 2012

De Zon, Sonnenborgh – museum & sterrenwacht, Utrecht, The Netherlands, 10 October 2012

Compacte dubbelsterren en gravitatiegolven in ons heelal, Thales, Zwolle, The Netherlands, 18 October 2012

Sterren, sterrenstelsels en gravitatiegolven, Publieksavond, Radboud University, Nijmegen, The Netherlands, 26 October 2012

Snellings, R.J.M., Duizenden mini oerknallen per seconde; hoe en waarvoor?, Open day Utrecht University, Utrecht, The Netherlands, 31 March 2012

Oermaterie, KNAW, Amsterdam, The Netherlands, 21 May 2012

Verkerke, W., De ontdekking van het Higgs deeltje, Science Café Leiden, Leiden, The Netherlands, 11 September 2012

Vreeswijk, M., Deeltjes en Interacties - een masterclass voor docenten, Netwerkbijeenkomst deeltjesfysica voor docenten, Castricum, 26 April 2012

Waarom drijf je in de dode zee?, NEMO Science Centre, Amsterdam, 18 November 2012

Vulpen, van, I.B., De zoektocht naar het Higgs boson, KNAW Higgs symposium, Amsterdam, The Netherlands, 11 January 2012

Zoektocht naar de elementaire bouwstenen van de natuur, Volksuniversiteit Soest, Soest, The Netherlands, 14 February 2012

Zoektocht naar de elementaire bouwstenen van de natuur, Leiden Honours students meeting, Leiden, The Netherlands, 15 June 20125

The discovery of the Higgs boson, Scientific highlight, FNWI colloquium University of Amsterdam, Amsterdam, The Netherlands, 3 September 2012

Zoektocht naar de elementaire bouwstenen van de natuur, Avondlezing Probusclub Aerdenhout, Aerdenhout, The Netherlands, 20 September 2012

The quest for the Higgs boson, 'Who's in town' lecture series, Amsterdam University College, Amsterdam, The Netherlands, 25 September 2012

Zoektocht naar de elementaire bouwstenen van de natuur, 104ᵉ NNGC congres 'Higgs, Majorana en de Kosmos', museum Boerhave, Leiden, The Netherlands, 27 October 2012

Wit, de, B.Q.P.J., De LHC deeltjesversneller: waarom en hoe?, IC-67, Vught, The Netherlands, 21 June 2012

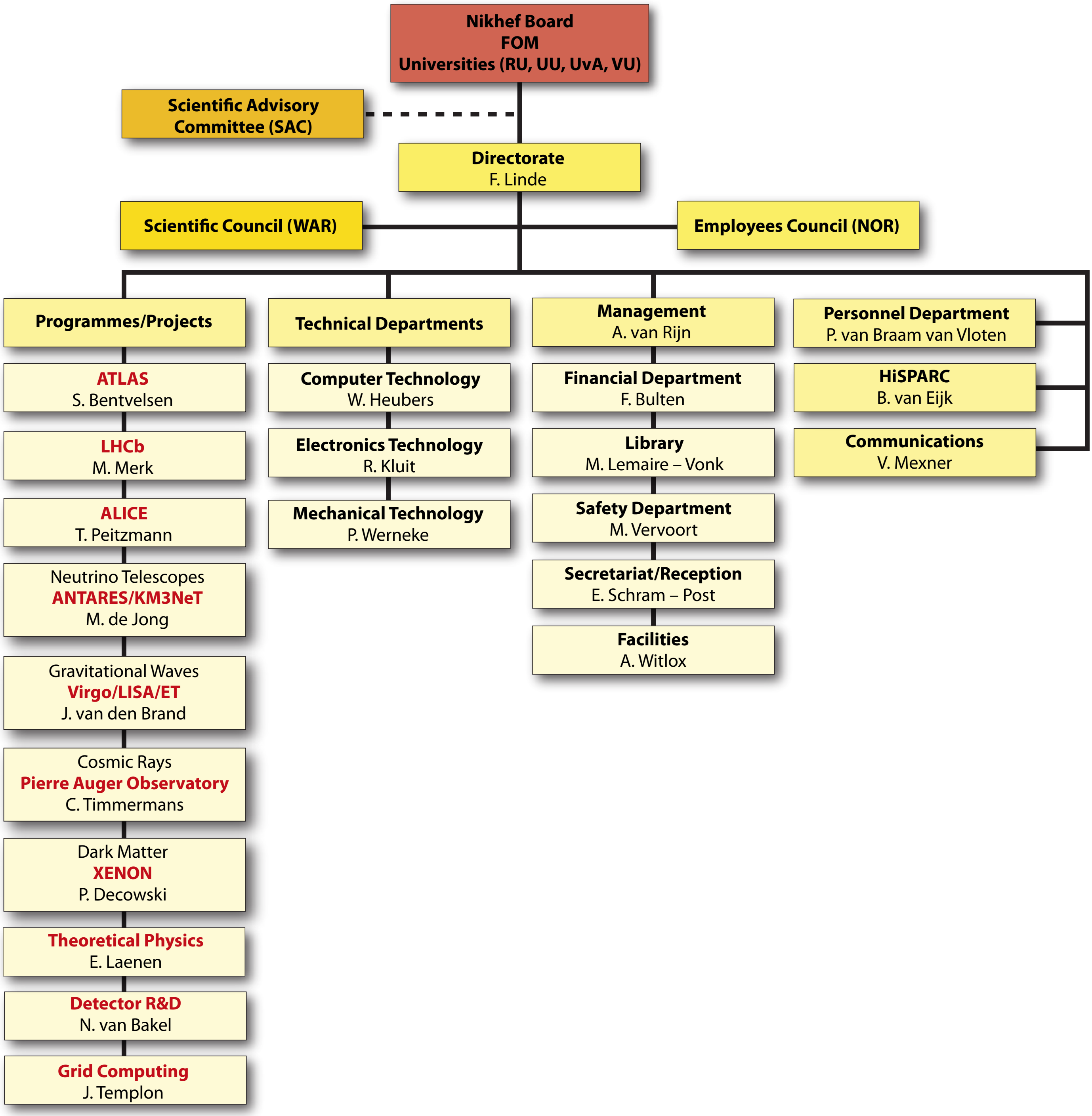
Op zoek naar het Higgs-deeltje, Dolderse Wetenschappers, Den Dolder, The Netherlands, 9 November 2012

Nikhef's valorisation and industry partners.

Resources

5

5.1 Organigram*



* *as of 31 December 2012.*

5.2 Organisation*

Nikhef Board
C.C.A.M. Gielen (Radboud University Nijmegen)
C.L.A. Hooijer (secretary, FOM)
H. Irth (VU University Amsterdam)
N.J. Lopes Cardozo (chair, FOM)
G.F.B.P. van Meer (Utrecht University)
K.J. Schoutens (University of Amsterdam)
W. van Saarloos (FOM)

Management Team
P. van Braam van Vloten
F. Linde
A. van Rijn

Scientific Advisory Committee (SAC)
C. De Clercq (Vrije Universiteit Brussel, Brussels)
Y. Karyotakis (chair, LAPP, Annecy le Vieux)
T. Nakada (EPFL, Lausanne)
A. Rubbia (ETH, Zürich)
J. Schukraft (CERN, Geneva)
C. Spiering (DESY Zeuthen, Berlin)
B. Webber (University of Cambridge, Cambridge)

Employees Council (NOR)
R. Aben (vice secretary)
J. Dokter
R. Hart (secretary)
J.J. Keijser
K. Oussoren (vice chair)
W. Verkerke
W. Vink
R. Walet
L. Wiggers (chair)

CERN Contact Commissie
S. Bentvelsen (secretary)
S. de Jong (chair)
R. Kleiss
F. Linde
M. Merk
Th. Peitzmann

Dutch Research School Theoretical Physics
W. Beenakker (Educational Board)
J. van Holten (Educational Board)
R. Kleiss (Governing Board)
E. Laenen (Governing Board)
P. Mulders (Educational Board)

Scientific Council (WAR)
S. Bentvelsen
A. van den Berg (KVI, Groningen)
J. van den Brand
B. van Eijk
H. van der Graaf
N. de Groot
M. de Jong (staff meeting)
P. de Jong (chair)
S. de Jong
E. Koffeman
E. Laenen
F. Linde
M. Merk
Th. Peitzmann
A. van Rijn (secretary)
J. Templon
R. Timmermans (KVI, Groningen)
N. Tuning (staff meeting)
L. Wiggers

Onderzoekschool Subatomaire Fysica – Onderwijscommissie
S. Bentvelsen
J. Berger (secretary)
J. van den Brand
P. van Braam van Vloten (personnel)
B. van Eijk
N. de Groot (chair)
P. de Jong
S. de Jong
E. Koffeman
E. Laenen
F. Linde
M. Merk
P. Mulders
Th. Peitzmann
G. Raven
A. Schellekens
R. Snellings

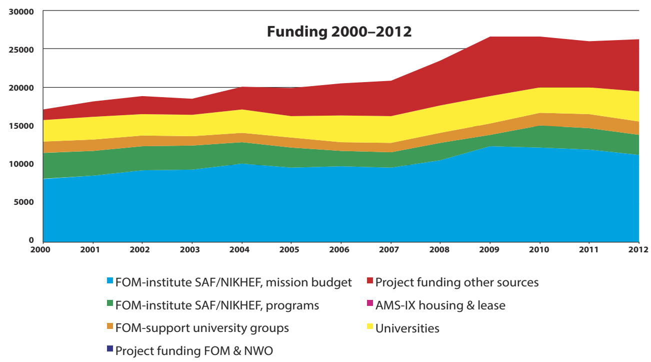
Committee for Astroparticle Physics in the Netherlands (CAN)
J. van den Brand
P. Decowski
J. Hörandel (chair)
D. Samtleben
C. Timmermans
C. Van Den Broeck (vice chair)

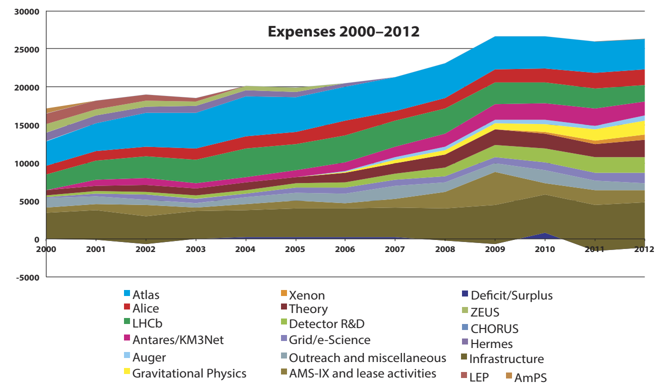
* *as of 31 December 2012.*

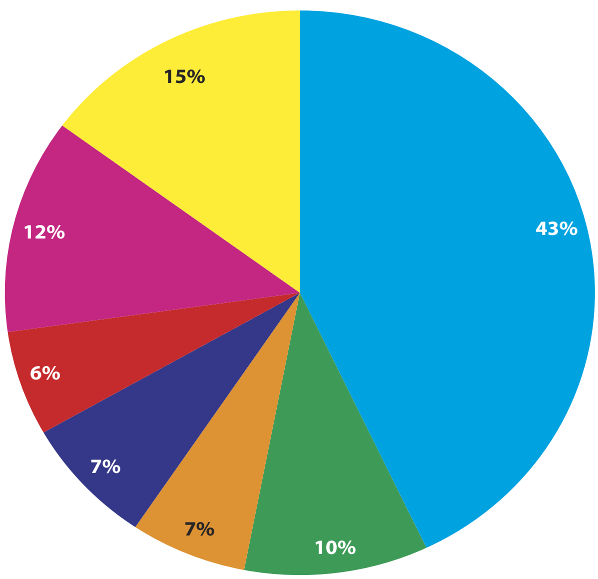
5.3 Funding & Expenses

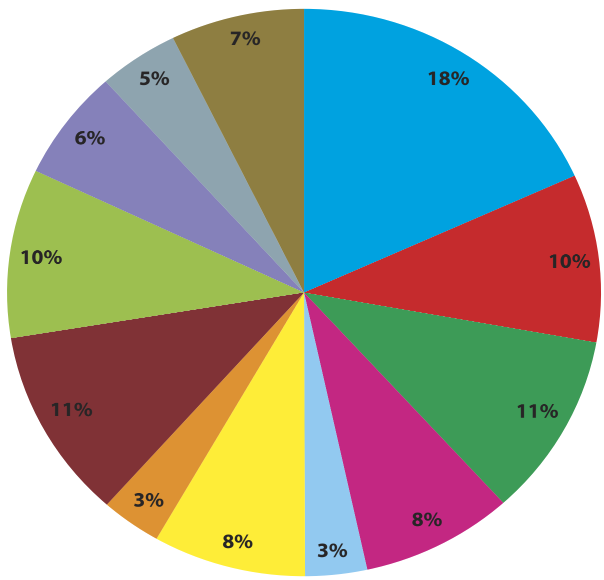
From the income perspective the year 2012 shows a decline in mission budget, now that the temporary increase from the *'Dynamisering instituutsfinanciering'* ended in 2011. A new FOM-programme (Dark matter) has been acquired in 2012, starting in 2013 and running for six years. Also many other grants have been awarded, which will appear mostly in the budget figures as of 2013, in particular several ERC Advanced Grants and an *NWO-Groot* investment subsidy for Advanced Virgo. Further details can be found in section 3.6 'Awards and grants' of this Annual Report. The turnover in contracts with customers of the Internet Exchange datacenter facility has also increased (to about 2.8 M€). All in all the 2012 funding level of the Nikhef collaboration is slightly higher than the level of 2011: 26.3 M€ versus 26.0 M€.

The expenses for accelerator-based particle physics (ATLAS, LHCb and ALICE) have slightly decreased to 38% (2011: 41%), with an emphasis on scientific staff (notably PhD students). The astroparticle physics activities are stable at about 22% of expenses, including a growing involvement in the XENON experiment. The enabling activities (theory, grid and detector R&D) have grown to 27% of expenses, whilst outreach and the lease activities make out the remainder (11%) of the direct costs. Infrastructure costs have been relatively high, in particular due to the investment in workshop equipment and the necessary re-furbishment. These costs largely explain the deficit in 2012. Not included in the graph are investments in BiG Grid funded equipment, KM3NeT prototype detector and Advanced Virgo, budgeted at about 3.5 M€ in 2012.









5.4 Grants

In the table below we show from top to bottom all grants awarded in 2012, running grants and completed grants awarded in earlier years, including their financial envelope, running period and –if not the FOM institute– the name of the Nikhef partner university via which the grants have been obtained. FOM programmes and large investment subsidies (such as BiG Grid and KM3NeT) are not included in the table. More information on some the grants of 2012 can be found in section 3.6 'Awards and grants'.

In 2012 the Nikhef collaboration has been extremely successful in obtaining additional project funding from various sources. The financial envelope of projects awarded in 2012 amounts to 12.9 M€, about 9 million more than in 2011. Most striking are four ERC Advanced Grants, one of which has been transferred in March 2012 from Utrecht University to Nikhef. It will be hard to repeat this funding success in the following years.

		Awarded			
Leader	**Title**	**Source**	**Period**	**Budget k€**	**Partner**
Igonkina	Search for tau decays to a muon and a photon to understand the lack of anti-matter in the universe	FOM/Pr	2012-2016	400	
Peitzmann	Thermal photon measurements in ALICE: probing the initial temperature of the quark-gluon plasma	FOM/Pr	2012-2016	394	UU
Mulders	Quantum chromodynamics at work in the Higgs sector	FOM/Pr	2012-2016	379	VU
Postma	Keeping track of time during inflation	FOM/Pr	2012-2016	385	
Van den Brand	Wireless seismic sensors	FOM/Shell	2013-2017	256	
Van den Brand	Advanced Virgo – Probing the dynamics of spacetime	NWO	2012-2014	2,000	
Grelli	VENI: Research into a new state of matter	NWO	2012-2016	250	UU
Heubers	The 'Research Campus' (with Amolf and CWI)	SURFnet	2013-2014	100	
Waalewijn	PRECISIONJETS4LHC: Precise Predictions for Higgs and New Physics Signals with jets at the Large Hadron Collider	EU	2013-2015	183	
Hessey/Visser	INFIERI: INtelligent Fast Interconnected and Efficient Devices for Frontier Exploitation in Research and Industry	EU	2013-2017	404	
De Wit	AdG: Supersymmetry: a window to non-perturbative physics	EU/ERC	2010-2015	1,910	UU
Mulders	AdG: Quantum Chromodynamics at Work	EU/ERC	2013-2018	2,069	VU
Van der Graaf	AdG: MEMS-made Electron Emission Membranes	EU/ERC	2013-2018	2,396	
Vermaseren	AdG: Solving High Energy Physics Equations using Monte Carlo Gaming Techniques – HEPGAME	EU/ERC	2013-2018	1,739	
				12,865	
		Running			
Leader	**Title**	**Source**	**Period**	**Budget k€**	**Partner**
Mulders	Color flow in hard hadronic scattering processes	FOM/Pr	2008-2013	331	VU
Fleischer	Exploring a new territory of the B-physics landscape at LHCb	FOM/Pr	2010-2013	408	
Mischke	Charm content in jets	FOM/Pr	2011-2015	398	UU
Van den Broecke	Binary black holes as laboratories for fundamental physics	FOM/Pr	2011-2015	354	
P. de Jong	Mind the gap! Generalizing dark matter searches at the LHC.	FOM/Pr	2011-2015	264	
Linde	Tiling appointment P. Ferrari	FOM/v	2010-2014	470	
Linde	Tiling appointment M. Postma	FOM/v	2013-2017	326	
Linde	High school teachers	FOM/EK	2010-2013	92	
Linde	Valorization	FOM	2010-2013	200	
Linde	HiSPARC nationale coördinatie fase-III	FOM/Out	2010-2013	215	
Postma	VIDI: The early universe as a particle laboratory	NWO	2008-2013	406	
Tuning	VIDI: No GUTs, no Glory: a search for Grand Unified Theories with B-decays	NWO	2008-2013	406	
Mischke	VIDI: Characterisation of a novel state of matter: The Quark-Gluon Plasma	NWO	2008-2014	365	UU
Heijboer	VIDI: Exploring the Cosmos with Neutrinos	NWO	2009-2014	600	

P. de Jong	VICI: Between bottom and top: Supersymmetry searches with flavour	NWO	2009-2014	1,250	
Hulsbergen	VIDI: A search for long-lived heavy particles	NWO	2010-2015	800	
Klous	Virgo on GPU	NCF	2009-2012	26	
Igonkina	VIDI: Lepton flavor violation: the key towards a matter dominated universe	NWO	2011-2016	800	
De Groot	OSAF Research school for subatomic physics – NWO graduate programme	NWO	2010-2015	800	RU
Snellings	VICI: A new state of matter: The Quark Gluon Plasma	NWO	2012-2016	1,500	UU
Visser	New Detector Systems for Biomedical Imaging (together with Amolf)	STW	2012-2016	300	
Van Bakel/Visser	Valorisation grant 2nd phase (Amsterdam Scientific Instruments)	STW	2012-2013	200	
Mischke	StG: Characterisation of a novel state of matter: The Quark-Gluon Plasma	EU/ERC	2008-2013	850	
Groep	EMI: European Middleware Initiative	EU	2010-2013	189	
Groep	IGE: Initiative for Globus in Europe	EU	2010-2013	202	
Van Rijn	EGI InSPIRE: European Grid Infrastructure	EU	2010-2014	251	
Koffeman	AIDA (detector R&D)	EU	2011-2014	152	VU
Laenen	LHCPhenoNet	EU	2011-2015	397	
Van den Brand	ELiTES: ET-LCGT Interferometric Telescopes: Exchange of Scientists	EU	2012-2016	32	
Hessey	TALENT: Training for cAreer deveLopment in high-radiation ENvironment Technologies	EU	2012-2016	545	
Laenen/Artoisenet	PROBE4TeVSCALE: Resolving short-distance physics mechanisms in hadron collisions at TeV scale energies	EU	2012-2014	192	
J. Visser	Hidralon: High Dynamic Range Low Noise CMOS sensors	Senter	2009-2012	794	
Van Eijk	HiSPARC – 'betadecanen'	Univ.	2011–	30	
				14,145	

Completed

Leader	**Title**	**Source**	**Period**	**Budget k€**	**Partner**
Vermaseren	Precision phenomenology at the LHC	FOM/Pr	2008-2012	335	
Van den Berg / Timmermans	Radio detection of ultra high energy cosmic rays at Auger	FOM/Pr	2008-2012	124	RU
S. de Jong	A search in proton- anti-proton collisions for Higgs (ASAP Higgs)	FOM/Pr	2008-2012	335	RU
Linde	Tiling appointment O. Igonkina	FOM/v	2007-2012	310	
Bentvelsen	VICI: Beyond the top – a new era in particle physics	NWO	2007-2012	844	
Van Leeuwen	VIDI: Hard probes of the Quark Gluon Plasma at the LHC	NWO	2007-2012	406	UU
Petrovic	VENI: Search for sources of high energy cosmic rays with the ANTARES neutrino telescope and the Auger observatory	NWO	2008-2012	141	
De Wolf	KM3NeT – Preparatory Phase	EU	2008-2012	447	
Koffeman	MC-PAD: R&D training network	EU	2009-2012	424	
Linde	ASPERA-2: astroparticle physics coordination	EU	2009-2012	192	
Van den Brand	Einstein Telescope – design study	EU	2009-2012	200	UU
				3,758	

5.5 Personnel*

ATLAS

Aben	MSc.	R.Z. (Rosemarie)	FOM
Angelozzi	MSc.	I. (Ivan)	FOM
Beemster	MSc.	L.J. (Lars)	FOM
Bentvelsen	Prof.dr.	S.C.M. (Stan)	UvA
Berge	Dr.	D. (David)	UvA
Berglund–Scherwitzl	Dr.	F.E. (Elina)	FOM
Besjes	MSc.	G.J. (Geert-Jan)	RU
Bobbink	Dr.	G.J. (Gerjan)	FOM
Butti	MSc.	P. (Pierfrancesco)	FOM
Caron	Dr.	S. (Sascha)	RU
Castelli	MSc.	A. (Antonio)	FOM
Chelstowska	MSc.	M. (Magda)	FOM
Croft	MSc.	V.A. (Vince)	FOM
Dao	MSc.	V. (Valerio)	FOM
Deigaard	MSc.	I. (Ingrid)	FOM
Deijl	MSc.	P.C. van der (Pieter)	UT
Deluca Silberberg	Dr.	C. (Carolina)	FOM
DeViveiros	Dr.	P.O. (Pier-Olivier)	FOM
Dhaliwal	MSc.	S.K. (Saminder)	FOM
Ferrari	Dr.	P. (Pamela)	FOM
Filthaut	Dr.	F. (Frank)	RU
Gadatsch	MSc.	S. (Stefan)	FOM
Geer	MSc.	R. van der (Rogier)	RU
Geerts	MSc.	D.A.A. (Daniel)	FOM
Groot	Prof.dr.	N. de (Nicolo)	RU
Hessey	Dr.	N.P. (Nigel)	FOM
Igonkina	Dr.	O.B. (Olga)	FOM
Jong	Prof.dr.ir.	P.J. de (Paul)	UvA
Karastathis	MSc.	N. (Nikos)	other
Klok	Drs.	P.F. (Peter)	FOM
Kluit	Dr.drs.ir.	P.M. (Peter)	FOM
Koffeman	Prof.dr.ir.	E.N. (Els)	FOM
König	Dr.	A.C. (Adriaan)	RU
Koutoulaki	MSc.	A. (Afroditi)	FOM
Lee	MSc.	H.C. (Hurng-Chun)	FOM
Leeuw	MSc.	R.H.L. van der (Robin)	FOM
Lenz	Dr.	T. (Tatjana)	FOM
Mahlstedt	Dipl. Phys.	J. (Joern)	FOM
Mechnich	Dipl. Phys.	J. (Jörg)	other
Nooij	Drs.	L. de (Lucie)	FOM
Oussoren	MSc.	K.P. (Koen)	FOM
Pani	MSc.	P. (Priscilla)	FOM
Salvucci	MSc.	A. (Antonio)	RU
Slawinska	Dr.	M.K. (Magdalena)	other
Struebig	Dipl. Phys.	A.H. (Antonia)	FOM
Ta	Dipl. Phys.	D.B. (Duc)	FOM
Tal Hod	Dr.	N. (Noam)	FOM
Valencic	MSc.	N. (Nika)	FOM
Verkerke	Dr.	W. (Wouter)	FOM
Vermeulen	Dr.ir.	J.C. (Jos)	UvA
Vranjes Milosavljevic	Dr.	M. (Marija)	FOM
Vreeswijk	Dr.	M. (Marcel)	UvA
Vulpen	Dr.	I.B. van (Ivo)	UvA
Weits	MSc.	H. (Hartger)	FOM
Woerden	MSc.	M.C. van (Marco)	CERN
Wollenberg	MSc.	W. van den (Wouter)	UT

LHCb

Aaij	MSc.	R.J.M. (Roel)	FOM
Ali	MSc.	S. (Suvayu)	FOM
Bauer	Dr.	T.S. (Thomas)	FOM
Bruyn	MSc.	K.A.M. de (Kristof)	FOM
Coco	Dr.	V.A.G. (Victor)	FOM
David	MSc.	P.N.Y. (Pieter)	FOM
Dettori	Dr.	F. (Francesco)	FOM
Eijk	Dr.	D. van (Daan)	other
Farinelli	MSc.	C. (Chiara)	FOM
Heijne	MSc.	V.A.M. (Veerle)	FOM

* *as of 31 December 2012.*

Overview of Nikhef personnel in fte (2012)

I – Scientific groups (fte – 2012, institute & university groups)	
Permanent scientific staff	60.1
PhD students	92.0
Post–docs	31.0
Total I	**183.1**
II – Management, technical/engineering and general support (fte – 2012, institute)	
Management team	
Director	1.0
Institute manager	1.0
Personnel/HRM officer	1.0
Subtotal	**3.0**
Technical/engineering support	
Electronics technology	28.6
Computer technology	23.1
Mechanical technology	28.8
Subtotal	**80.5**
General support	
Financial administration	3.8
Personnel/HRM administration	1.0
Library	0.6
Technical and domestic services	9.8
Secretariat and reception desk	3.9
PR & communication	3.2
Occupational health & safety	1.0
Staff	0.4
Subtotal	**23.7**
Total II	**107.2**
Total I & II	**290.3**
III – Other groups (persons 2012)	
Guests (researchers, retired staff)	68
Master students	34
Apprentices	18

Heit		J. (Joren)	other
Holtrop	Prof.dr.	M.W. (Maurik)	other
Hulsbergen	Dr.	W.D. (Wouter)	FOM
Jans	Dr.	E. (Eddy)	FOM
Ketel	Dr.	T.J. (Tjeerd)	other
Koopman	MSc.	R.F. (Rose)	FOM
Koppenburg	Dr.	P.S. (Patrick)	FOM
Kozlinskiy	MSc.	A. (Alexandr)	FOM
Kroon	Ing.	B.W.H.J. van der (Boudewijn)	FOM
Lambert	Dr.	R.W. (Rob)	FOM
Leerdam	MSc.	J. van (Jeroen)	FOM
Martinelli	Dr.	M. (Maurizio)	FOM
Martinez Santos	Dr.	D. (Diego)	FOM
Merk	Prof.dr.	M.H.M. (Marcel)	FOM
Nakayama	Dr.	H. (Hiro)	other
Oggero	MSc.	S. (Serena)	FOM
Onderwater	Dr.	C.J.G. (Gerco)	RuG
Pellegrino	Prof.dr.	A. (Antonio)	FOM
Raven	Prof.dr.	H.G. (Gerhard)	VU
Schiller	Dr.	M.T. (Manuel)	FOM
Syropoulos	MSc.	V. (Vasiliis)	FOM
Tolk	MSc.	S. (Siim)	FOM
Tsopelas	MSc.	P.C. (Panos)	FOM
Tuning	Dr.	N. (Niels)	FOM
Wiggers	Dr.	L.W. (Leo)	FOM

ALICE

Bertens	MSc.	R.A. (Redmer)	UU
Bjelogrlic	MSc.	S. (Sandro)	FOM
Botje	Dr.	M.A.J. (Michiel)	FOM
Caliva	MSc.	A. (Alberto)	FOM
Christakoglou	Dr.	P. (Panos)	FOM
Dubla	MSc.	A. (Andrea)	UU
Kuijer	Dr.	P.G. (Paul)	FOM
Lapointe	Dr.	S.L. (Sarah)	FOM
Leeuwen	Dr.ir.	M. van (Marco)	UU
Lodato	MSc.	D.F. (Davide)	UU
Luparello	Dr.	G. (Grazia)	FOM
Mischke	Dr.	A. (Andre)	UU
Nooren	Dr.ir.	G.J.L. (Gert-Jan)	FOM
Peitzmann	Prof.dr.	T. (Thomas)	UU
Perez Lara	MSc.	C.E. (Carlos)	FOM
Reicher	MSc.	M. (Martijn)	UU
Rocco	Dr.	E. (Elena)	FOM
Rodriguez Manso	MSc.	A. (Alis)	FOM
Schee	MSc.	W. van der (Wilke)	UU
Snellings	Prof.dr.	R.J.M. (Raimond)	UU
Thomas	MSc.	D. (Deepa)	UU
Veldhoen	MSc.	M. (Misha)	FOM
Verweij	MSc.	M. (Marta)	UU
Yang	Dr.	H. (Hongyan)	FOM
Zhang	MSc.	C. (Chunhui)	UU
Zhou	MSc.	Y. (You)	FOM

Neutrino Telescopes

Bogazzi	MSc.	C. (Claudio)	FOM
Bormuth	MSc.	R. (Robert)	other
Gaemers	Prof.dr.	K.J.F. (Karel)	other
Heijboer	Dr.	A.J. (Aart)	FOM
Jong	Prof.dr.	M. de (Maarten)	FOM
Kooijman	Prof.dr.	P.M. (Paul)	UvA
Michael	Dipl. Phys.	T. (Tino)	FOM
Samtleben	Dr.	D.F.E. (Dorothea)	UL
Schulte	Dr.	S. (Stephan)	FOM
Steijger	Dr.	J.J.M. (Jos)	FOM
Visser	MSc.	E.L. (Erwin)	FOM
Wolf	Dr.	E. de (Els)	UvA

Gravitational Waves

Agathos	MSc.	M. (Michail)	FOM
Beker	Ir.	M.G. (Mark)	FOM
Bertolini	Dr.	A. (Alessandro)	FOM
Blom	MSc.	M.R. (Mathieu)	FOM
Brand	Prof.dr.ing.	J.F.J. van den (Jo)	VU
Bulten	Dr.	H.J. (Henk)	VU
D'Ambrosi	MSc.	G. (Giuseppe)	FOM
Del Pozzo	Dr.	W. (Walter)	FOM
Elsinga		R. (Rogier)	other
Heijningen	Ir.	J.V. van (Joris)	FOM
Janssens	MSc.	S.M.J. (Stef)	CERN
Jonker	Drs.	R.J.G. (Reinier)	FOM
Li	MSc.	T.G.F. (Tjonnie)	FOM
Masserot		A.A. (Alain)	other
Meidam	MSc.	J. (Jeroen)	FOM
Nelemans	Prof.dr.	G.A. (Gijs)	RU
Pacaud		E.G.M. (Emmanuel)	other
Pollice		C. (Claudio)	other
Rabeling	Dr.	D.S. (David)	FOM
Shah	MSc.	S. (Sweta)	FOM
Sluys	Dr.	M.V. van der (Marc)	other
Van Den Broeck	Dr.	C.F. (Chris)	FOM
Veitch	Dr.	J.D. (John)	FOM

Cosmic Rays

Aar	MSc.	G.A. van (Guus)	RU
Berg	Dr.	A.M. van den (Adriaan)	RUG
Falcke	Prof.dr.	H. (Heino)	RU
Freivogel		B.W. (Ben)	UvA
Grebe	MSc.	S. (Stefan)	FOM
Hörandel	Prof.dr.	J.R. (Jörg)	RU
Jansen	MSc.	S. (Stefan)	FOM
Jong	Prof.dr.	S. de (Sijbrand)	RU
Nelles	MSc.	A.F. (Anna)	FOM
Palioselitis	Dr.	D. (Dimitrios)	other
Timmermans	Dr.	C.W.J.P. (Charles)	FOM

Dark Matter

Alfonsi	Dr.	M. (Matteo)	FOM
Colijn	Dr.	A.P. (Auke Pieter)	UvA
Decowski	Dr.	M.P. (Patrick)	UvA
Tiseni	MSc.	A. (Andrea)	FOM

Theoretical Physics

Artoisenet	Dr.	P. (Pierre)	FOM
Banerjee	MSc.	N. (Nabamita)	FOM
Beenakker	Dr.	W. (Wim)	RU
Bonocore	MSc.	D. (Domenico)	FOM
Broek	MSc.	T.C.H. van den (Thijs)	FOM
Buffing	MSc.	M.G.A. (Maarten)	VU
Butter	Dr.	D.P. (Dan)	FOM
Ciceri	MSc.	F.P.M.Y. (Franz)	FOM
Falgari	Dr.	P. (Pietro)	other
Fleischer	Prof.dr.	R. (Robert)	FOM
Gato-Rivera	Dr.	B. (Beatriz)	other
Hartgring	MSc.	L.C. (Lisa)	FOM
Holten	Prof.dr.	J.W. van (Jan-Willem)	FOM
Kleiss	Prof.dr.	R.H.P. (Ronald)	RU
Knegjens	MSc.	R.J. (Rob)	FOM
Kuipers	Dr.	J. (Jan)	other
Laenen	Prof.dr.	E.L.M.P. (Eric)	UvA
Larsen	Dr.	K.J. (Kasper)	FOM
Lodato	MSc.	I. (Ivano)	FOM
Maio	Dr.	M. (Michele)	other
Mooij	Drs.	S.J.N. (Sander)	FOM
Mulders	Prof.dr.	P.J.G. (Piet)	VU
Murthy	Dr.	S.V. (Sameer)	FOM
Nawata	Dr.	S. (Satoshi)	FOM

Ortiz Cabello	MSc.	P. (Pablo)	FOM
Petraki	Dr.	K. (Kallia)	FOM
Postma	Dr.	M.E.J. (Marieke)	FOM
Reys	MSc.	V. (Valentin)	FOM
Rietkerk	MSc.	R.J. (Robbert)	UvA
Sahoo	Dr.	B. (Bindusar)	FOM
Schellekens	Prof.dr.	A.N.J.J. (Bert)	FOM
Signori	MSc.	A. (Andrea)	VU
Smith	Prof.dr.	J. (John)	other
Veltman	Prof.dr.	M.J.G. (Martinus)	other
Vermaseren	Dr.	J.A.M. (Jos)	FOM
Vogt	Prof.dr.	A. (Andreas)	other
Vries	MSc.	J. de (Jordy)	other
Weenink	MSc.	J.G. (Jan)	UU
Wit	Prof.dr.	B.Q.P.J. de (Bernard)	FOM
Tsinikos		I. (Ioannis)	other
Vlaar		S.H. (Shannon)	other

Detector R&D

Bakel	Dr.	N.A. van (Niels)	FOM
Beuzekom	Dr.ing.	M.G. van (Martin)	FOM
Boer Rookhuizen	Ing.	H. (Herman)	FOM
Bosma	Dr.	M.J. (Marten)	other
Graaf	Dr.ir.	H. van der (Harry)	FOM
Hartjes	Dr.	F.G. (Fred)	other
Koppert	MSc.	W.J.C. (Wilco)	FOM
Schioppa	MSc.	E.J. (Enrico)	FOM
Schön	Dipl. Phys.	R. (Rolf)	FOM
Timmermans	Dr.	J.J.M. (Jan)	other
Tsagri	Ir.	M. (Mary)	FOM
Visser	Dr.	J. (Jan)	FOM
Zappon	MSc.	F. (Francesco)	FOM

Grid Computing

Baan Hofman (CT)		W.M. (Wilco)	FOM
Bos	Dr.	K. (Kors)	other
Dok (CT)	Drs.	D.H. van (Dennis)	FOM
Gabriel (CT)	Dr.	S. (Sven)	FOM
Groep	Dr.	D.L. (David)	FOM
Keijser (CT)	Drs.	J.J. (Jan Just)	FOM
Koeroo (CT)	Ing.	O.A. (Oscar)	FOM
Remenska	MSc.	D. (Daniela)	FOM
Salle (CT)	Dr.	M. (Mischa)	FOM
Starink (CT)	Dr.	R. (Ronald)	FOM
Suerink (CT)	Ing.	T.C.H. (Tristan)	FOM
Templon	Dr.	J.A. (Jeff)	FOM
Verstegen (CT)	Ing.	A.C.Z. (Aram)	FOM

HiSPARC

Dam		K. van (Kasper)	FOM
Eijk	Prof.dr.ing.	B. van (Bob)	FOM
Fokkema	Dr.	D.B.R.A. (David)	FOM
Laat	MSc.	A.P.L.S. de (Arne)	FOM
Montanus	Drs.	J.M.C. (Hans)	other
Schultheiss	Ing.	N.G. (Nicolaas)	other
Veen	MSc.	C.G. van (Norbert)	FOM
Vulpen	MSc.	M.J. van (Matthijs)	FOM
Zonneveld		R. (Rickie)	FOM

Mechanical Technology

Band	Ing.	H.A. (Hans)	FOM
Berbee	Ing.	E.M. (Edward)	FOM
Boer		R.P. de (René)	FOM
Brouwer		G.R. (Gerrit)	FOM
Buis		R. (Rob)	FOM
Ceelie		L. (Loek)	FOM
Doets		M. (Martin)	FOM
Driel		B.S. van (Brian)	FOM
Hennes	Drs.	E. (Eric)	FOM
Jaspers		M.J.F. (Michiel)	UvA
John		D.M. (Dimitri)	FOM
Kok		J.W. (Hans)	FOM
Korporaal		A. (Auke)	FOM
Kraan	Ing.	M.J. (Marco)	FOM
Kuilman		W.C. (Willem)	FOM
Leguyt		R. (Rob)	FOM
Munneke	Ing.	B. (Berend)	FOM
Overbeek		M.G. van (Martijn)	FOM
Petten		O.R. van (Oscar)	FOM
Rietmeijer		A.A. (Arnold)	FOM
Roeland		E. (Erno)	FOM
Roo	B.Eng.	K. de (Krista)	FOM
Rosing	Dr.ir.	R. (Richard)	FOM
Rovekamp		J.C.D.F. (Joop)	FOM
Snaijer	B.Eng.	A.D. de (Ad)	FOM
Verlaat	Ing.	B.A. (Bart)	FOM
Walet	Ing.	R.C. (Rob)	FOM
Wees		D. van (Dave)	FOM
Werneke	MSc.	P.J.M. (Patrick)	FOM

Electronics Technology

Berkien		A.W.M. (Ad)	FOM
Borga	B.ICT	A.O. (Andrea)	FOM
Buurmans	Ing.	J. (Jeroen)	FOM
Cano Manchebo		J. (Javier)	other
Fransen		J.P.A.M. (Jean-Paul)	FOM
Gajanana	MSc.	D. (Deepak)	FOM
Gebyehu	Ir.	M. (Mesfin)	FOM
Gotink		G.W. (Wim)	FOM
Groen		P.J.M. de (Piet)	FOM
Groenstege	Ing.	H.L. (Henk)	FOM
Gromov	Ir..	V. (Vladimir)	FOM
Heijden	Ing.	B.W. van der (Bas)	FOM
Heine	Ing.	E. (Eric)	FOM
Hogenbirk	Ing.	J.J. (Jelle)	other
Ietswaard		G.C.M. (Charles)	FOM
Jansen		L.W.A. (Luc)	FOM
Jansweijer	Ing.	P.P.M. (Peter)	FOM
Kaper		M. (Mark)	other
Kieft	Ing.	G.N.M. (Gerard)	FOM
Kluit	Ing.	R. (Ruud)	FOM
Koopstra		J. (Jan)	FOM
Kuijt	Ing.	J.J. (Jaap)	FOM
Mos	Ing.	S. (Sander)	FOM
Peek	Ing.	H.Z. (Henk)	other
Schipper	Ing.	J.D. (Jan David)	FOM
Schmelling	Ing.	J.W. (Jan-Willem)	FOM
Sluijk	Ing.	T.G.B.W. (Tom)	FOM
Snoek		G.D. (Gerben)	other
Tamminen		V.E. (Viivi)	other
Timmer		P.F. (Paul)	FOM
Veenstra		L.F.K. (Leo)	other
Verkooijen	Ing.	J.C. (Hans)	FOM
Vink	Ing.	W.E.W. (Wilco)	FOM
Visser	Ing.	G.C. (Guido)	FOM
Wang		W. (Wei)	other
Wijnen	Ing.	T.A.M. (Thei)	RU
Zivkovic	Dr.ir.	V. (Vladimir)	FOM
Zwart	Ing.	A.N.M. (Albert)	other

Computer Technology

Akker		T.G.M. van den (Theo)	FOM
Beveren	Ing.	V. van (Vincent)	FOM
Boterenbrood	Ir.	H. (Henk)	FOM
Bouwens	Dr.	B.T. (Bram)	FOM
Bouwhuis	Dr.	M.C. (Mieke)	FOM
Damen		A.C.M. (Ton)	FOM
Harapan	Drs.	D. (Djuhaeri)	FOM
Hart	Ing.	R.G.K. (Robert)	FOM

Heubers	Ing.	W.P.J. (Wim)	FOM
Kan		A.C. van (André)	FOM
Kerkhoff		E.H.M. van (Ellie)	FOM
Kuipers	Drs.	P. (Paul)	FOM
Leeuwen	Drs.	W.M. van (Willem)	other
Oudolf		H. (Jan)	other
Schimmel	Ing.	A. (Fred)	FOM
Tierie		J.J.E. (Joke)	FOM
Wal	B.ICT	B. van der (Bart)	FOM
Wijk		R.F. van (Ruud)	other

Management and Administration

Azarfane		M. (Mohamed)	other
Azhir		A. (Ahmed)	FOM
Berg		A. van den (Arie)	FOM
Berger		J.M. (Joan)	FOM
Bonam	B.Com	S. (Surya)	FOM
Braam van Vloten	MSc.	P. van (Pieter)	FOM
Bulten	bc.	F. (Fred)	FOM
Demonfaucon	MA	H. (Hélène)	FOM
Dokter		J.H.G. (Johan)	FOM
Echtelt	Ing.	H.J.B. van (Joost)	FOM
Haan–Hekkelman		W.R. de (Wijnanda)	FOM
Huyser		K. (Kees)	FOM
Kleinsmiede–van Dongen		T.W.J. zur (Trees)	FOM
Klöpping	Ir.	R. (Rob)	FOM
Langenhorst		A. (Ton)	FOM
Lapikás	Dr.	L. (Louk)	other
Lemaire–Vonk		M.C. (Maria)	FOM
Linde	Prof.dr.	F.L. (Frank)	FOM
Matthesius		K.H. (Karin)	FOM
Mexner	Dr.	I.V. (Vanessa)	FOM
Mors		A.G.S. (Anton)	FOM
Oosterhof–Meij		J.E.G. (Annelies)	FOM
Pancar		M. (Muzaffer)	FOM
Rem	Drs.ing.	N. (Nico)	FOM
Richmond	Ir.	E.M. (Edwin)	other
Rijksen		C. (Kees)	FOM
Rijn	Drs.	A.J. van (Arjen)	FOM
Sande		M. van der (Melissa)	FOM
Schram–Post		E.C. (Eveline)	FOM
Vervoort	Ing.	M.B.H.J. (Marcel)	FOM
Vreeken		D. (Daniel)	other
Willigen		E. van (Ed)	FOM
Witlox	Ing.	A.M. (Arie)	FOM
Woortmann		E.P. (Eric)	FOM

Miscellaneous

Engelen	Prof.dr.	J.J. (Jos)	UvA

5.6 Master students

In 2012, 13 students graduated from the Masters programme Particle and Astroparticle Physics, see Table 1. For more information about the Masters programme, please refer to Section 4.2.

Date	*Name*	*University*	*Master thesis title*	*Supervisor(s)*	*Group*
9-1-2012	Bouwe Andela	UvA	Massive neutrinos and Z'	J.W. Van Holten	Theoretical Physics
27-1-2012	Hartger Weits	UT	Measurement of CP violation in the analysis of $B^0 \rightarrow J/\Psi K_S$ decays with the 2010 LHCb data.	W. Hulsbergen B. van Eijk	LHCb
31-1-2012	Panagiotis Tsopelas	UU	Applying GridPix as a 3D particle tracker for proton radiography	J. Visser S. Brandenburg (KVI)	Detector R&D / KVI
17-4-2012	Marco van Woerden	UvA	Study of the response to isolated muons from collisions of the ATLAS Tile Calorimeter's gap/crack cells	H. Wilkens (CERN) I. van Vulpen	CERN/ATLAS
1-7-2012	Jeroen Snijdewint	UvA	Monte Carlo Studies on the Uncertainty and Background Analysis of the ANTARES and KM3NeT Neutrino Telescopes	J. Steijger	Neutrino telescopes
24-7-2012	Vasileios Syropoulos	UvA	Measurement of $\Delta\Gamma_d$, from the Effective Lifetime Ratio of $B_d \rightarrow J/\Psi K^0_s$ and $J/\Psi K^{0*(892)}$, with the LHCb 2011 data	W. Hulsbergen	LHCb
1-8-2012	Redmer Bertens	UU	Anisotropic flow of ϕ-mesons in $\sqrt{s_{NN}}$=2.76 TeV collisions at ALICE	R. Snellings	ALICE
7-8-2012	Loran de Vries	UvA	Search for a correlation between HiSPARC cosmic-ray data and weather measurement	B. van Eijk	HiSPARC
27-8-2012	Philipp Frings	UvA	CP Violation in D^0 Decays – A Signal of New Physics?	R. Fleischer	Theoretical Physics
29-8-2012	Brent Huisman	UvA	Proton Imaging with GridPix Detectors	J. Visser S. Brandenburg (KVI)	Detector R&D / KVI
1-9-2012	Isha Savani	UvA	Angular Observables of $B^0 \rightarrow K^*0\ (\rightarrow K^+\pi^-)\mu^+\mu^-$ from Quantum Field Theoretical Methods	M. Merk P. Mulders J. van Leerdam	Theoretical Physics / LHCb
2-9-2012	Adriaan ter Braack	UvA	Testing General Relativity with Gravitational Waves from Compact Binaries: The TIGER-method	C. Van Den Broeck	Gravitational Waves
24-9-2012	Maria Tselengidou	UvA	Measuring proton decay in ice	P. Kooijman	Neutrino telescopes

Table 1. Master students who graduated in 2012.

5.7 Apprentices

The presence of high quality technical departments at Nikhef allows us to offer interesting internship positions for students in secondary (MBO) and higher (HBO) vocational education. The table below lists the apprentices who finished their training period in 2012 in the departments Computer Technology (CT), Electronics Technology (ET) and Mechanical Technology (MT).

Date	*Name*	*School*	*Subject / Title*	*Supervisor(s)*	*Group*
Jan. 2012	B. Harteloh	HBO Hogeschool van Amsterdam	Analysis, assembly and testing of demonstration passive seismic attenuators	E. Hennes	MT
Jan. 2012	L. de Leeuw	MBO ROC van Amsterdam	Bronhouder	O. van Petten	MT
Feb. 2012	F. van Son	HBO Hogeschool van Amsterdam	Design Tester for KM3NeT PMT base	P. Timmer	ET
June 2012	H. Harteloh	HBO Hogeschool van Amsterdam	Design plan for Virgo Cryolink water inlet system	K. de Roo	MT
June 2012	E. Huang	MBO Horizon College Hoorn	Outreach gadget: simple & low cost particle detector	H. Verkooijen	ET
June 2012	J.J. van Bergen	MBO Nova College Haarlem	Grid Security Challenge	O.Koeroo	CT
July 2012	D. Giesen	MBO ROC van Amsterdam	Roteerhouder	O. van Petten	MT
Dec. 2012	D. van Wees	HBO Haagse Hogeschool	Analysis and testing of MEMS accelerometer with anti-spring	E. Hennes	MT

Table 1. Apprentices who finished their training period at Nikhef in 2012.

Glossary

G

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

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

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

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

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

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

Antiproton
The antiparticle of the proton.

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

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

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

Baryon
See Particles.

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

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

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

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

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

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

Collider
See Accelerator.

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

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

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

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

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

Electron
See Particles.

ET
Einstein Telescope. Design project for a third generation gravitational wave observatory consisting of three –underground and typically 10 km long– cryogenic xylophone interferometers in a triangular shape.

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

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

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

FTE (Full Time Equivalent)
Unit of manpower.

Gluon
See Particles.

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

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

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

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

Higgs boson
A particle predicted in 1964 independently by theoreticians Brout, Englert and Higgs in order to explain the mechanism by which particles acquire mass. In 2012 the ATLAS and CMS experiments at the LHC announced the discovery of a particle with mass 125 GeV that fits the properties of this Higgs boson. The particle plays a central role in the Standard Model of elementary particle phyisics.

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

ILC
International Linear Collider, now under study. A possible

future electron–positron accelerator, proposed to be built as an international project.

KSI2K
The Kilo SpecInt 2000 (KSI2K) is a unit in which integer computing power is expressed. It is only partially correlated with computing speed.

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

KM3NeT (Cubic Kilometre Neutrino Telescope)
Planned European deep–sea neutrino telescope with a volume of at least one cubic kilometre at the bottom of the Mediterranean Sea.

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

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

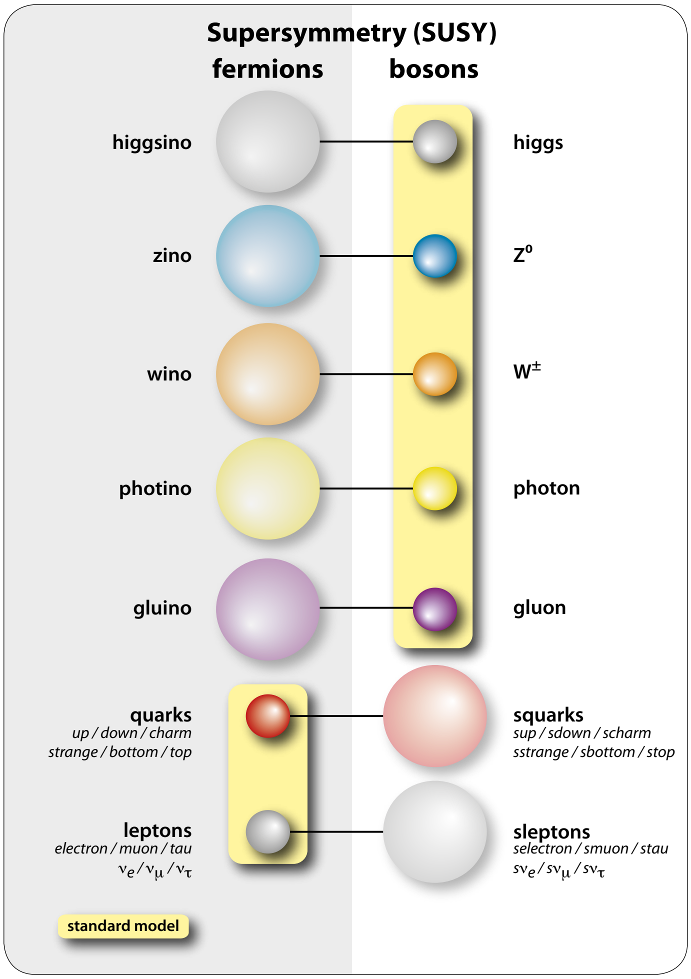
Lepton
A class of elementary particles that includes the electron. Leptons are particles of matter that do not feel the strong force *(see also Particles).*

LHC (Large Hadron Collider)
CERN's accelerator which started in 2008.

LHCb (Large Hadron Collider beauty)
One of the four major experiments that uses the LHC.
Linac
An abbreviation for linear accelerator.

LISA (Laser Interferometric Space Array)
ESA/NASA mission concept; three spacecraft, orbiting around the Sun as a giant equilateral triangle 5 million km on a side. Superseded by ESA only eLISA mission

eLISA (evolved LISA)
ESA only gravitational wave space mission, orbiting around the Sun as a giant equilateral triangle 1 million km on a side. Formerly known as NGO (New Gravitational Wave Observatory). Candidate for launch in 2028.



Supersymmetry; for every type of boson there exists a corresponding type of fermion with the same mass and internal quantum numbers, and vice-versa.

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

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

Meson
See Particles.

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

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

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

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

NWO
The Netherlands Organisation for Scientific Research funds thousands of top researchers at universities and institutes and steers the course of Dutch science by means of subsidies and research programmes

Nucleon
The collective name for protons and neutrons.

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

Photon
See Particles.

Pierre Auger Observatory
International experiment in Argentina to track down the origin of ultra–high–energy cosmic rays.

Pion
See Particles.

Positron
The antiparticle of the electron.

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

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

Quark
The basic building block of matter (see also Particles).

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

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

Relaxd (high-REsolution Large-Area X-ray Detection)
EU–funded development of the large area fast detector system using Medipix technology.

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

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

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

Spin
Intrinsic angular momentum of a particle.

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

STAR
Experiment at RHIC.

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

Supersymmetry
Supersymmetry (often abbreviated SUSY) is a symmetry that relates elementary particles of one spin to other particles that differ by half a unit of spin and are known as superpartners.

SURFnet
Networking organisation in the Netherlands.

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

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

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

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

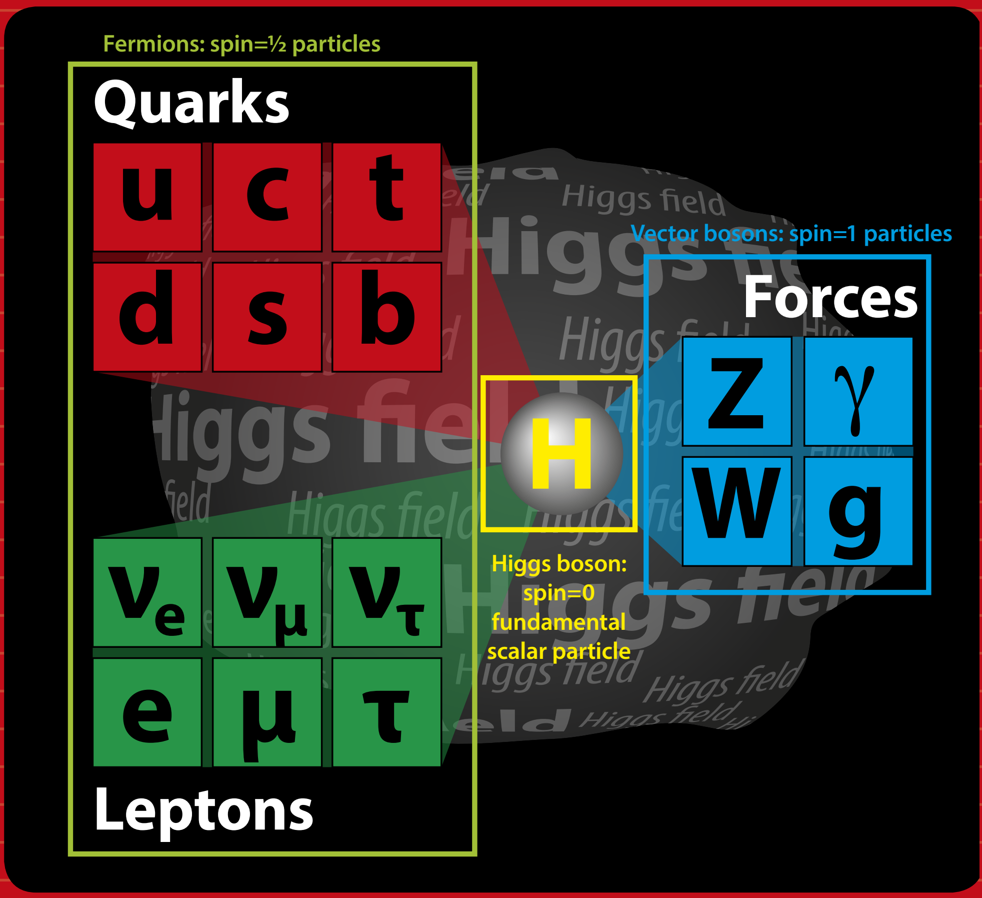
Virgo
Detector near Pisa for gravitational waves: a Michelson laser interferometer made of two orthogonal arms, each 3 km long.

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

WIMP
Weakly Interacting Massive Particles are the most compelling candidates for *dark matter* particles. They can interact with normal matter through the weak nuclear force and through gravity and are often inherent to models extending the *Standard Model.*

XENON
A series of experiments aiming at direct detection of Weakly Interacting Massive Particles (*WIMPs*). The detectors are located in the Gran Sasso laboratory in Italy and use xenon as the target material.

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


Fermions: spin=½ particles
Quarks
u c t
d s b
νe νμ ντ
e μ τ
Leptons
Higgs boson: spin=0 fundamental scalar particle
H
Vector bosons: spin=1 particles
Forces
Z γ
W g
Higgs field

NIKHEF