Annual Report 2013

Nikhef

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National Institute for Subatomic Physics

NIKHEF

Annual Report 2013

National Institute for Subatomic Physics Nikhef

Colophon

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National Institute for Subatomic Physics

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Front cover: The Lagrangian for the Standard Model
Back cover: The Standard Model of particles since the discovery of the Higgs boson

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 *e*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 SURFsara. Nikhef has a theory group with both its own research programme and close contacts with the experimental groups.

Contents

Introduction

8 October 2013 at Nikhef: most of us and some (distinguished) guests are gathered in front of a large TV screen to watch the Physics Nobel prize 2013 announcement. After a long delay[1] the verdict finally comes: to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*. To celebrate this memorable event champagne bottles are uncorked. The first time an experiment Nikhef participates in and co-founded (ATLAS) is explicitly referred to in a Nobel prize quote! And despite that, some of us (including me) had hoped for more: tribute to the huge experimental endeavour to actually confirm the theoretical hypothesis of Englert and Higgs. After all: that is why it took the Nobel committee almost fifty years to award this Nobel prize. Anyway, the good news is that the experimentalists and/or CERN still stand a good chance to get one of the future Physics Nobel prizes *"for the discovery of the first fundamental scalar particle ..."*. Meanwhile, many characteristics of the discovered particle have been measured and are (albeit sometimes within large uncertainty) consistent with the corresponding theoretical prediction for the Higgs particle.

Not surprisingly, the LHC and in particular the discovery of the Higgs particle attracted once again a lot of media attention. I particularly liked the score of the annual *Serious Request* auction to help poorly nourished children in Africa. Nikhef had offered a guided tour to CERN. This item attracted huge interest and was finally sold as one of the top items at almost € 8000, well above a helicopter ride and lunch with our Defense Minister and a golden record of celebrated Dutch singer Jan Smit.

During a full, and freezing, week in January 2013 in Sicily, the European Strategy for Particle Physics was updated to take into account the impressive progress (in particular, but not only, the discovery of the Higgs particle) made since it was formulated for the first time in 2006. The meeting itself was very animated, notably vis-à-vis long-term future projects at the CERN premises like the Compact Linear Collider (CLIC) and a 80–100 km circumference proton-proton collider (VLHC). Also, possible European contributions to projects elsewhere like the International Linear Collider (ILC) and long-baseline neutrino facilities were discussed. For the immediate future the continuation of the LHC project was unanimously attributed the top priority. This strategy update was subsequently adopted by a special CERN Council meeting in Brussels on 30 May 2013, in the presence of representatives of the European Commission.

Nikhef staff eagerly await the announcement of the 2013 Nobel prize for Physics. Seated second from right is Martinus Veltman, the 1999 Physics Nobel prize laureate.

For Nikhef, 2013 was an eventful year. In February, we received the sad news that Ger van Middelkoop, a two times director of Nikhef, suddenly and unexpectedly passed away at age 75. Late 2013, the decision was taken to demolish large parts of the former accelerator complex at Nikhef to make room for a new large data centre as well as to house ARCNL, the *Advanced Research Centre for NanoLitography*. One of Nikhef's security wizards left Nikhef to take up a job on the hack-team of Dutch telecom provider KPN. Shortly after, he made it (once again!) to the national news. In November Groningen University applied to become a member of the Nikhef consortium, while Leiden University announced that desire already earlier. As a result, all regular (*i.e.* non-technical) universities in the Netherlands with a physics curriculum will soon collaborate within Nikhef. In 2013 our main funding organisation approved a proposal to continue our LHC-related activities until 2021 (at least), which allows us to maintain a strong presence in the ATLAS, LHCb and ALICE experiments. Regretfully, another large and very prestigious funding proposal aiming to broaden Nikhef both content-wise (research programs) and people-wise (in particular including several astronomy groups), was rejected. Some of our start-up activities experienced difficulties in keeping the cash flow balanced, but they all survived the year. Shell and Nikhef officially signed a contract on the development of state-of-the-art seismic sensor networks, a direct result of Nikhef's expertise in this field gained while working on the Virgo gravitational-wave detector.

1 Apparently, they could not find Peter Higgs. Very much in line with the generations of experimental particle physicists who have frantically hunted after the Higgs particle for almost 50 years!

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 radiation 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.

Largely due to the urgent construction work for the KM3NeT and Advanced Virgo projects, but also due to Nikhef's ambition to expand its collaboration with industries like ASML and Shell, our technical departments became severely overloaded. As a result we experienced several animated and emotional Project Planning meetings. And despite the promises I made in my introduction to Nikhef's 2012 Annual Report, the LHC experiments regretfully received once again little technical support. An exception was the CO_2-based cooling system for the ATLAS vertex detector which was delivered and installed at CERN in 2013. Luckily, the work on the projects Advanced Virgo and XENON1T will wind down by summer 2014, while work for Shell will become the responsibility of InnoSeis B.V., a new start-up firm. So I am convinced that in the course of 2014 the technical workload will gradually become manageable. Provided, of course, we carefully scrutinise any new commitments!

Looking ahead, science-wise 2014 is going to be a strange year since almost all of Nikhef's experimental activities are in a construction or maintenance phase. The LHC complex is being prepared for 13–14 TeV operations (almost twice the centre-of-mass energy in previous years), scheduled to start in 2015. The Virgo laser interferometer is undergoing a major upgrade with the aim to increase its sensitivity such that several dozens of gravitational waves ought to be detected annually starting in 2016 (a rate that is 2–3 orders of magnitude larger than in past years). XENON1T construction work will be completed in 2014 and by the end of 2015 the experiment is expected to achieve a sensitivity at least one order of magnitude better than that of any other existing direct dark matter search experiment. Finally, KM3NeT will construct many and deploy some 800 meter long detector strings in 2014 at two locations: off the coast of Sicily (Italy) and Toulon (France). With those, KM3NeT will begin in 2015 to record neutrino interactions in the Mediterranean deep-sea using the innovative multi-PMT concept.

I am eagerly looking forward to see these experimental endeavours going online and I hope Nature will be kind enough to grant us at least one revolutionary discovery: *Supersymmetry, Dark Matter, Gravitational Waves* or best of all the *entirely unexpected!*

Frank Linde

An Open Day participant searching for particles of the Standard Model.

Reviews

1

1.1 Passion for Physics and Education

Marcel Vreeswijk

Education and research: making a difference

Introduction

Although Nikhef's mission statement does not explicitly mention teaching as one of the institute's objectives and efforts, this does not mean that education in the broadest sense of the term is not part of its daily work. Many Nikhef members divide their time between research and educational activities like teaching and tuition. Not only because their research can not exist without the continuous influx of young talent, but also because of their urge to convey their passion for physics to next generations of researchers. Education is the most important precursor of scientific craftsmanship, and Nikhef physicists contribute to it on many levels, ranging from secondary education, academic Bachelor's and Master's courses to PhD programmes.

Since the educational efforts of Nikhef collaborators has hardly received detailed and personal attention in past issues of our Annual Report, the editors include a series of interviews on the subject in this year's Review Section. We asked involved Nikhef physicists, a high school teacher and a Master's student to expand on their contributions, their way of working, and why interest in physics is so contagious. The interviews were held by Laetis Kuipers from *Taalcentrum VU*, and the portraits were taken by Marco Kraan.

The editors

In addition to working as a researcher at Nikhef, Marcel Vreeswijk operates as Director of UvA's Bachelor's Programme in Physics and Astronomy. "I have always liked the combination", he says, "simply because I like working with students. It never tires me. I have always been fascinated by the interplay of various forces, be it in the field of education or in my own discipline when I investigate top quarks. I am in a fortunate position. My work allows me to introduce fascinating new physics and new theory into the physics curriculum and it also allows me to train and select excellent students for future research work." UvA's Bachelor's Programme is a broad and comprehensive programme, designed to cater not only to the very best students and future top researchers, but also to those who will likely find jobs elsewhere. Vreeswijk: "We offer students a highly differentiated programme, and we go to great lengths to make sure that they get exactly what they need. We have developed a special Honours programme that offers extra courses to those who can handle the challenge, we provide extra help and tuition to those who need it, and we closely monitor student progress. Our carefully designed tutor system is second to none and has definitely proven its worth. Our approach reduces the gap that students generally experience upon making the move from secondary school to university. In addition, we have introduced what we call our 'matching programme', in which we invite secondary school pupils to come and taste the flavour of all that we have to offer. Our efforts help us not only to reduce drop-out levels in the first year but also to instil a strong sense of discipline in our students. This will stand them in good stead when they taste the freedom and the large number of choices we offer them in later stages of our Bachelor's and Master's programmes." With the development of the Amsterdam Faculty of Sciences, a revolutionary new cooperation project between UvA and VU University, Marcel Vreeswijk admits to having his work cut out for him: "There's never a dull moment in my job, but I love it."

Lars Aalsma

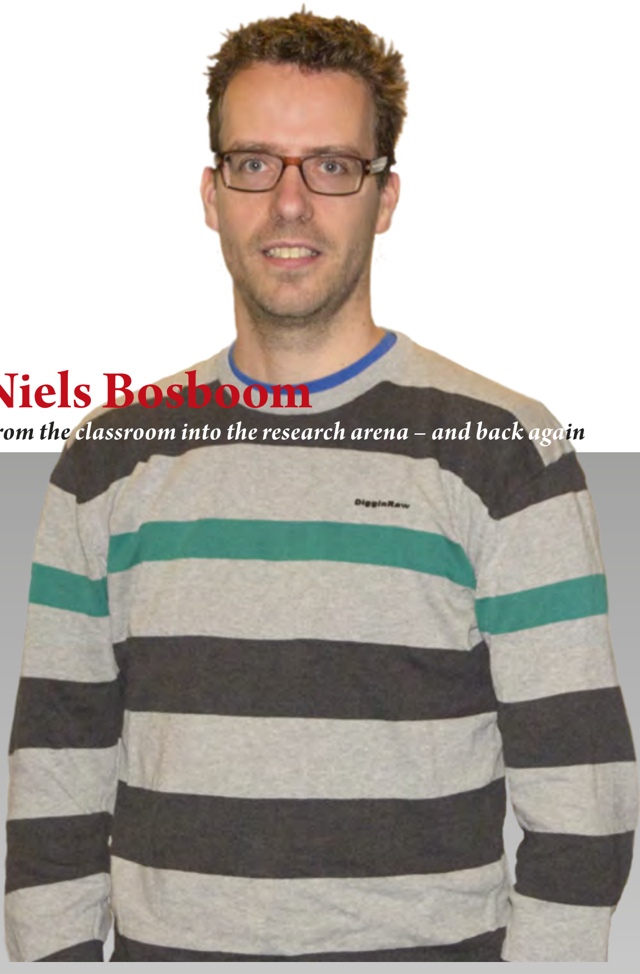
The fun of teaching

Lars Aalsma is one of the many talented and highly motivated Master's students enrolled in UvA's Physics & Astronomy programme. He also operates as a teaching assistant in this programme, lecturing to Bachelor's students. Nikhef's educational team considers itself very fortunate in having him on board. Aalsma: "Even though I did not have any teaching experience prior to my application, at least not in the area of physics, I was nevertheless eager to take on the challenge." In fact, he admits that he likes the job even better than he thought he would. "What I very much appreciate is the interactivity involved in teaching and tutoring physics students. We are a like-minded group of people who share a deep interest in the wondrous world of physics. Of course, I was a bit nervous the very first time I had to address a group of students, but I quickly noticed that it was not only my audience who could learn things from me: I was also learning a lot myself. For instance, when I focus on the development of academic skills or when I explain how students should conduct and write about scientific research, I must make sure that I brush up my own skills, too. I want to practise what I preach. And the very best moments are those when I succeed in getting students truly interested in a particular topic. I like fuelling people's curiosity." Having experienced himself exactly how much hard work is needed to complete a first year at university, Aalsma recognises not only what newcomers are faced with from the moment they arrive, but also when they start struggling. "This is the moment when I, as a tutor, can make a real difference in offering these students my advice and assistance. Of course, I try to motivate people to stay, but what I find most important is helping them to make well-considered decisions, for instance when they start wondering whether the physics programme is in fact the right choice or whether opting for a different science discipline would actually be better." As for his own future, Lars is still considering his next step: a move into theoretical or into experimental physics, or perhaps a combination of the two. He is, however, certain about one thing: his wish to combine research and teaching.

Sijbrand de Jong

Broadening the knowledge base

Nikhef's Sijbrand de Jong is a man of many talents. He is the Dutch scientific delegate at CERN, he is Ambassador to the Dutch Annual Academic Prize Foundation, and he is professor of Experimental Physics at Radboud University Nijmegen. He is also Director of the Radboud Pre-University College of Science and its Regional Support Points. Offering programmes and activities to assist secondary schools and complement their science curriculum, the College is a one-stop 'education-and-research' shop for pupils and teachers alike. De Jong: "As a researcher, I have always been driven purely by my own curiosity, by the need to discover how the world works and by my wish to determine the basic ingredients of the universe. It is precisely this curiosity-driven factor that strongly links my research work to my education efforts. I am a bit of a missionary: I want to share my knowledge with the rest of the world, and I particularly want to communicate that a tremendous sense of gratification can be found in the acquisition of new knowledge." With his academic lectures and the many guest lectures he delivers outside university, De Jong caters to a highly diverse audience. He finds that his enthusiasm and his love for the subject under investigation lie at the heart of his teaching. "Of course," he continues, "I always try to adapt my approach to relate to my audiences' worlds, be it the world of advanced physics students or the world of teenagers. For instance, to improve pupils' understanding of complex numbers, phases and equalizers, I let them use their iPhones and iPods for a hands-on experiment." Another key element of De Jong's education mission concerns broadening the knowledge base of secondary school science teachers. "In any form of education," he says, "having a wide knowledge base is crucial. It allows instructors to develop approaches that fit the learning styles of the adolescents and teenagers they are teaching. In my view, however, today's secondary school science teachers often lack sufficient knowledge about certain topics in the field of 'new' science. In addition, they often lack the scientific background needed for the development of a large knowledge base. This is exactly why our Pre-University College of Science has developed its proactive initiatives: we want them to pay off in the new secondary school curricula."



Niels Bosboom

From the classroom into the research arena – and back again

Working as an enthusiastic physics teacher at the Minkema College for Secondary Education in Woerden, Niels Bosboom is one of the lucky few to have been selected for participation in FOM-Nikhef's Teachers in Research programme. The project was launched in 2008 with the aim of offering secondary school science instructors the opportunity to join Nikhef's research teams for a period of one year. The main objectives of this popular and successful programme are to stimulate and nourish contact between academia and secondary education, to broaden the knowledge base and research skills of instructors working in the field, and ultimately to harvest new generations of science students. "One day a week," says Bosboom, "I would travel to Amsterdam, first to brush up on the necessary literature and subsequently to focus on my specific area of interest: data analysis and simulations. I closely cooperated with our team's PhD student, who was involved in creating test fields and measurement setups. In this way, we contributed to each other's success." For Bosboom, the added value of Nikhef's Teachers in Research programme has proven to be the applicability of his newly acquired knowledge and skills in his classes. "And what is more," he adds, "it has allowed me to communicate my enthusiasm and to show my pupils that well-organised team efforts, hard work, concentration and dedication ultimately pay off. I was greatly pleased to notice that this had a direct effect on the quality of my pupils' final profile reports." One example that Bosboom mentions to illustrate the point is his school's bionic eye project: "In this project, pupils are using a low-resolution camera to test their subjects, but they keep running into all kinds of technical difficulties. To solve these, they have contacted a German professor, who is now assisting them." Another example he mentions is the long-standing HiSPARC project: "This is a fascinating project in which secondary schools and academic institutions cooperate in measuring cosmic rays with extremely high energy." He then continues: "And of course I shouldn't forget CERN's most recent initiative scheduled for 2014, in which schools will be offered a chance to use part of the beam line for their own investigations." According to Bosboom, establishing a network within the FOM-Nikhef and the CERN teacher programmes is of invaluable importance. "I have noticed," he explains, "that many of my colleagues tend to be confined to their classrooms and their schools. This is a great pity, because it prevents them from grabbing the many opportunities available to them to make maximum use of excellent networks. Moreover, it prevents them from creating added value for their schools and their pupils. We need to stimulate cooperation projects. Their worth cannot be stressed enough."

Text interviews: Laetis Kuipers

1.2 My Higgs Story

Martinus Veltman

The 'real' history of the Higgs particle differs substantially from the usual published accounts. In this note the history as experienced by the author will be presented. Of course, history is not absolute, and depends on the personal experience of who is presenting the subject. The discovery of the Higgs particle at CERN must be seen as a (provisional) end of a hundred years of physics. A century of theory and experiment. The usual public presentations do not reflect in any way this impressive history.

The start of the story is the theory of Abraham and Lorentz (1904). In that theory the electron is seen as a small charged sphere. The self-energy of the electron is the energy of such a sphere assuming that this energy is zero if the radius is infinitely large. If that radius goes to zero then this energy will become infinitely large inversely proportional to this radius. One speaks of a linear divergency. This energy is positive, because energy must be supplied to compress the little sphere. The electron is in the first instance seen as a point particle, and the smearing out to a sphere is called a regulator mechanism with the radius as regulator parameter.

This insight remained unchanged for some 35 years. Quantum mechanics did not really produce any change, but the extension of quantum mechanics to quantum field theory made a difference. Field theory as described by Heisenberg and Pauli (1929) differs from simple quantum mechanics because processes in which particles are produced (such as emission of a photon by an atom) can be studied. The problem with self-energy remained, except that the degree of divergence changed from linear to logarithmic (Weisskopf 1939). The regulator mechanism remained a usually ignored worry, one crudely truncated the occurring divergent integrals. Pauli, understanding that this is nonetheless a crucial part of the theory developed a consistent method with Villars (1949). The point is that quantum electrodynamics is gauge invariant, and any regulator mechanism must also be gauge invariant because else gauge invariance (that guarantees conservation of electric charge) will be lost.

Divergencies

The next essential and in fact brilliant step was taken by Kramers, professor at the University of Leiden. The calculations in quantum field theory were everywhere plagued by occurring divergencies. According to Kramers that needed not to be any problem as long as there was no direct conflict with experiment. The electron self-energy is an example: while we know very precisely what the mass of an electron is (that is thus including the contribution of the self-energy), we do not know what we started with. Even if the self-energy is infinite then we still have the

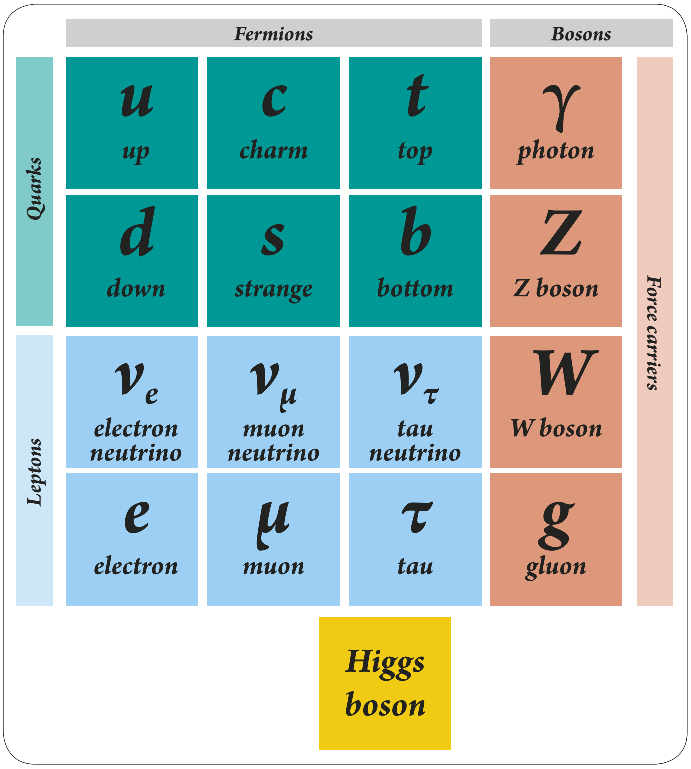


Figure 1. Elementary particles in the Standard Model. The matter particles are subdivided further into particles susceptible to the strong interaction (quarks) or not (leptons), and are arranged in three families, of increasing particle masses. The particles carrying the electromagnetic, weak, and strong forces are indicated to the right.

situation that the observed mass is the sum of something that is unknown (the 'bare' mass, the mass of the electron exclusive the self-energy) and something that is infinite (the self-energy). It is not possible to say precisely what this self-energy should be. According to Kramers the infiniteness of the self-energy is simply irrelevant. By assuming that initially the 'bare' mass is infinite as well, with opposite sign, there is no problem. Slightly differently formulated: the theory cannot predict the mass, because nobody knows the mass of an uncharged electron. It sounds so simple, yet it made all the difference.

The big question is now where all these infinities occur. If all infinities can be compensated by a specific assumption concerning the available free parameters, then after that the theory can predict measurable quantities. A theory where this is possible is called a renormalizable theory.

After the war the research concerning field theory restarted slowly. There were two experiments that presented measure-

Figure 2. Peter Higgs at the Bahnson Institute of Field Physics at the University of North Carolina in Chapel Hill, 1965

ments that could not be explained by regular quantum mechanics, namely the Lamb shift (Lamb and Retherford, 1947) and the anomalous magnetic moment of the electron (Kusch and Foley, 1948). These discoveries were debated at a conference at Shelter Island (near New York) in 1947. People understood that these effects had something to do with quantum field theory. Kramers came with his idea concerning the absorption of infinities in the free parameters of the theory, and participants such as Bethe, Feynman, Schwinger and Weisskopf, next to Tomonaga in Japan, took up this idea and developed the renormalizable theory of quantum electrodynamics. It was truly a revolution.

In 1959 these developments surfaced in Utrecht, where I started working on a thesis under the supervision of Leon Van Hove. Field theory fascinated me, and I started studying the big problem of the day: the theory of weak interactions (keywords: neutron decay, muon decay, neutrinos). Everybody else at the Institute did statistical mechanics, a subject that never aroused any interest in me. That made for some peace. Concerning the weak interactions, the leading phenomenological theory was that of Feynman and Gell-Mann (1958) and this theory predicted the existence of vector bosons, something like photons, but charged and massive. That was internationally seen the grand subject, but if you are young (ahum) that does not bother you. Anyway, there was barely any progress. I also did not get very far.

Even so, I started something that was in any case field theory, namely unstable particles. Apart from electron, neutrino, photon, graviton and proton all particles are unstable, and in fact the field theory for unstable particles was not well developed. At the time all field theory was perturbation theory, meaning theory based on the smallness of a parameter, the coupling constant, and everything was computed in successive approximations in this parameter. Thus given the coupling constant g (in electromagnetism that is the electric charge e) compute experimentally observable results in lowest order in g and subsequently in order g^2 et cetera.

Renormalizability

Perturbation theory in the case of unstable particles is a doubtful scheme. If all coupling constants are zero all particles are stable. If the coupling constants are now switched on then everyone and his brother becomes unstable, and that is simply not a continuous transition. You thus cannot develop in the coupling constant around the value zero. This had a relatively heavy consequence: the usual formalism was useless. What to do?

In those days one used the formalism to arrive, finally, at Feynman rules that could be used to do calculations. The conclusion is simple: start directly with these Feynman rules and forget the canonical scheme. In the end, if you want to learn to use a bicycle, you do not need to know anything about bicycle fabrication. In this rather naive manner I made nonetheless an important breakthrough. Later I started to work on Yang-Mills theories and there the official formalism is useless as well.

Thus the procedure was as follows. Start with writing down a Lagrangian based on the phenomenology of the situation to be described. Subsequently write directly the Feynman rules suggested by that Lagrangian, a relatively simple task. However, after that there is a problem: how do we know that the theory so obtained is correct? Correct means here that probability is conserved and causality is respected. In the traditional approach these properties are normally built-in in the formalism, but this was no longer true. In my thesis (1963) I investigated this aspect, namely unitarity (= conservation of probability) and causality of a theory generated by a set of Feynman rules. The title: *Unitarity and Causality in a renormalizable field theory with unstable particles*. The article was ready in 1960, but Van Hove felt that I should do some additional work. Well, I followed Van Hove to CERN, and spent most of the ensuing seven years doing phenomenological type of work. That turned out to be time well spent, I knew what I was talking about.

In that period, outside my vision, the theory of superconductivity was developed, and Higgs c.s. wrote their articles. In 1968, meanwhile returned to Utrecht, I started to work on Yang-Mills theories. The phenomenology of the weak interaction suggested (to me) that this theory should be some kind of a Yang-Mills theory. Let me make it clear what that is: electromagnetism is a gauge theory satisfying some symmetry (the theory is invariant under gauge transformations) that subsequently generates a conservation law. For electromagnetism this is conservation of electric charge. A Yang-Mills theory can be seen as a generalization of this idea to a theory with additional, charged 'photons'. The gauge invariance is generalized. This is literally what Yang and Mills did.

The photon couples to every charged particle, in particular to the charged 'photons'. There arises a complex scheme of particles interacting with one another that no one understood very well. It also seemed irrelevant, as nobody ever saw charged photon-like particles. The gauge invariance also ruined the usual standard formalism. What I did was simply assigning masses to those 'charged photon colleagues', the rest remained unchanged. The usual theory was irrelevant to me and of no interest. In the following I will call these 'new photons' vector bosons.

The theory appeared superficially as a non-renormalizable theory. Up to that time quantum electrodynamics was the only renormalizable theory that was of some physics relevance, but not many people had worried about formal aspects like gauge invariance. There were things such as the Feynman or Landau gauge but no one had made any thorough analysis of that. In other words, the massive Yang-Mills type theories that might be of relevance to weak interactions constituted unknown territory. It should be added that the theory looked very complicated, involving very large expressions. The territory appeared quite uninviting.

There were many infinities, but thanks to the gauge symmetry many of these infinities cancelled. The main new idea that I had was now to construct new Feynman rules so that these cancellations were directly contained in those new rules. The experimental predictions of the theory should thereby not change. The new rules that I discovered showed a remarkable new particle: that new particle did occur internally in the Feynman diagrams, but was never actually produced. Such a particle is called 'ghost' particle. In hindsight I discovered that Feynman in a lecture in Poland (1962) had already introduced such a ghost when considering the massless Yang-Mills theory and gravitation (also a gauge theory). Feynman's treatment was limited to the lowest but one order in perturbation theory, which limitation was due to the fact that he did not know how to prove unitarity etc. for perturbation theory in general order. That now was precisely what was demonstrated in my thesis.

It turned out that the theory with the new Feynman rules was almost renormalizable. The remaining infinities were a consequence of the above mentioned introduction of masses for the vector bosons. I was wrestling with that for a few years, meanwhile streamlining and simplifying the theory.

The σ-model

In 1957 Schwinger published an impressive article in which he introduced the so-called σ-model. That was about pions and their interactions, and in addition there was a new spinless particle, the σ-particle. The theory had a certain symmetry, but I do not want to enter into this. The interaction of the σ-particle with itself had as a consequence that a new vacuum came into existence, with an energy lower than that of the 'empty' vacuum, and with an everywhere present σ-field. Thus, if the universe starts in the first instance with the usual empty vacuum then it will decay directly to the σ-vacuum. In fact this σ-model was literally the same as the Higgs related part of the Standard Model. Schwinger used this σ-vacuum as a mass generating method (by coupling particles to the background σ-field). In particular Schwinger used this vacuum to generate a mass for the muon. I knew the σ-model, and when the Belgian student Hugo Strubbe asked in 1970 if he could come to work on the σ-model at the Institute I reacted positively.

In the summer of 1969 or 1970 Glashow suggested to me to use the σ-model to generate masses for the vector bosons, but I answered that I was not yet ready for that. In Utrecht Strubbe gave a seminar about his work, and my then student 't Hooft had the idea (see the book of Frank Close, *The Infinity Puzzle*; 't Hooft mentions Ubbink who is not a particle physicist but he probably meant Strubbe) to introduce this model in order to generate masses for the vector bosons. In that he succeeded beyond the wildest expectations, and the replacement of my rather manual procedure by this σ-vacuum construction led to the disappearance of the last non-renormalizable divergencies of the Yang-Mills theory.

The development since then was as follows. First a model had to be found for the weak interactions. It turned out that there was already such a model (Weinberg 1967) but, and I cite Weinberg *"The model lay dormant"*, a somewhat bizar excuse for a period of four years in which Weinberg himself did not even mention the model once. For the strong interactions the relevant theory was called quantum chromodynamics (QCD), a pure Yang-Mills theory with quarks and massless gluons (Fritzsch, Gell-Mann and Leutweiler, 1973).

The Higgs particle, in fact nothing else but the σ-particle of the σ-model seems now to have been seen experimentally at CERN. A stunning success of the renormalization idea.

What now about Higgs? The contribution of Higgs (1964) was related to a development in the domain of superconductivity. The history is complicated, and in particular the contribution of Anderson is rarely mentioned.

The theory of superconductivity was in 1964 reasonably well developed, and one of the results was that an electromagnetic field inside a superconductor had a finite range. A field with finite range is in quantum field theory a field of which the corresponding particle has a finite mass, and it thus seemed that a photon developed a mass when inside a superconductor. This inspired Higgs to concentrate on the question of how to give a mass to the photon. A method is, just as I did, to simply assign a mass to the photon. But that would mean that the photon would have a mass outside the superconductor as well, while one would really rather have something that would lead to a mass as a consequence of the superconduction. The alternative procedure is to have a background field inside the superconductor, and then generate mass a la Schwinger by coupling the photon to that field. This is the method used by Higgs.

Degrees of freedom

In that construction there appears a particular feature, namely the question of degrees of freedom. A massless photon has two degrees of freedom: polarization along or opposite to the direction of motion of the photon. A massive spin-1 particle has three degrees of freedom. In the case of a massive spin-1 particle one can through a Lorentz transformation go to the rest system of the particle, and as is well-known from atomic physics such a particle has three degrees of freedom. Thus something happened with the degrees of freedom in the Higgs procedure, one new degree was added to the photon. Well, the background field has charge (the photon couples to it), but a charge can be positive or negative thus that field has two degrees of freedom. One of them is moved to the photon, the other remained as a particle. Without entering in any detail it follows that the Higgs construction produces an extra particle. This then is the Higgs particle. The idea to generate photon mass through a background field was in addition to Higgs published by several authors (Brout and Englert, Guralnik, Hagen and Kibble), but they did not emphasize the occurrence of a new particle.

The Higgs procedure was reasonably well-known, especially because this procedure broke the Goldstone theorem. That theorem says that when creating a mass through a field in the vacuum there arises necessarily a massless particle. In the case of the Higgs construction the theorem is not applicable because of the disappearance of a degree of freedom of the Higgs field. I remember that I, when discussing 't Hooft's article with him, said that it seems that this had something to do with the Goldstone theorem, unknown to both of us. We looked to one another and I said something like *"your theory is ok in any case, thus leave this question for what it is"*. As often, ignorance is the basis of progress. Of course, as should be, we have recognized the work of Higgs *et al.*, and in particular Kibble is cited in 't Hooft's article.

Higgs work had further consequences. Kibble at the Imperial College in London generalized the work of Higgs to a system with three vector particles, a substantial step in the direction of the construction of a model for weak interactions. His model was not very realistic, but Weinberg passing on his way to a Solvay conference in Brussels wrote an improved version inspired on a model by Glashow. And thus Weinberg appeared in Brussels with his well-known article. At that conference Englert actually stated explicitly that such models are renormalizable. But nobody knew what to do, because the standard theory did not work for Yang-Mills type theories. That was in 1967. After the work by 't Hooft in 1971 the interest renewed.

In conclusion, the importance of the Higgs construction is that it made the theory of Yang-Mills fields renormalizable. Observable results can be calculated and compared with experiment, and that has happened in a multitude of ways in the last 40 years, up to and including the recent discovery of the Higgs particle. I interpret the 2013 Nobel prize as a just recognition of this achievement.

1.3 Wireless seismic sensing: a Nikhef–Shell collaboration

Jo van den Brand (Nikhef) & Wim Walk (Shell)

"Gravitational Physics" is part of the astroparticle physics program of Nikhef and has as goal the first direct detection of gravitational waves. The equipment required for this research is immensely complex and involves high-tech systems to allow precise determination of seismic fields, advanced vibration isolation systems, sensor and actuator development, optimal control, and state-of-the-art laser and optical technology.

First generation interferometers (Virgo, LIGO, and GEO600) were realised and are now upgraded to 'Advanced' detectors expected to be operative by around 2015 with sufficient sensitivity to allow the first observation of gravitational waves. Einstein Telescope (see Fig. 1) constitutes a natural evolution to improved performance. With sensitivity ten times better than advanced detectors, this third generation gravitational-wave observatory will be able to explore a region of the Universe with a radius of billions of light-years, by collecting thousands of gravitational-wave events per year of observation.

Seismic noise affects Einstein Telescope both by shaking the suspension points of mirrors and by moving directly the mirrors through the Newtonian attraction by the soil mass (*i.e.* gravity-gradient noise). By going underground both effects are reduced especially at low frequency (2–3 Hz).

Newtonian noise can be further suppressed by measuring correlated motion in seismic fields with arrays of seismic sensors. Such arrays will allow subtraction of gravity-gradient noise both in Advanced Virgo and Einstein Telescope.

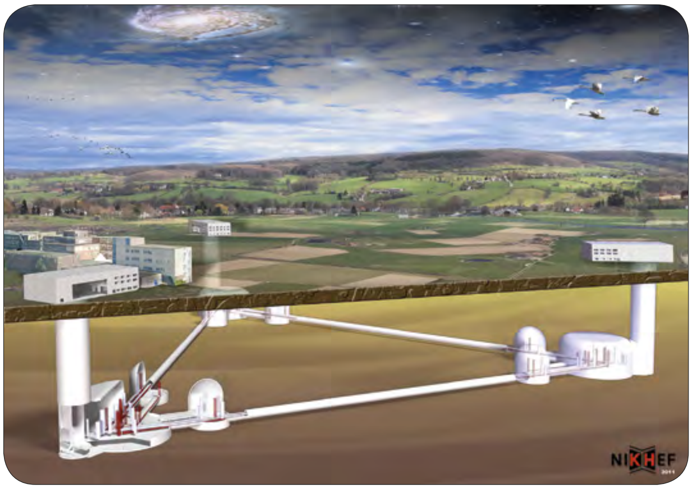


Figure 1. Artist's view of the Einstein Telescope observatory, composed of three superposed interferometric detectors, arranged underground in a triangle. Each interferometer has two 10 km arms, coinciding with two sides of the triangle. The instrument will be built at a depth of at least 150 m.

Figure 2. Impression of a wireless sensor node. Each node features a sensitive seismic sensor connected to a data acquisition system. Nodes communicate via proprietary wireless radio protocols.

As an example of the pioneering nature of its research, Nikhef itself develops the state-of-the-art ultra-low power wireless digital seismic sensor nodes (see Fig. 2). Nikhef avails of adequate 'in-house' expertise and strong mechanical, electronics, and computing departments. Moreover, for a variety of projects expertise is available from Nikhef's R&D group and from experimental physicists in the Gravitational Physics group.

Quality seismic data as well as the cost-efficient, flexible deployment of seismic sensor networks are important in the oil and gas industry. Responding to the energy challenge requires discovering ever deeper and more complex reservoirs, as well as reservoirs in tight rock systems. The prime motivation for Shell is to enable the realisation of unprecedented mega-node seismic sensor networks for oil and gas exploration. Through its collaboration with Nikhef and its spin-off InnoSeis, Shell seeks to identify and acquire valuable contributions to these technology intensive exploration processes.

Today's standard approach to network deployment is to connect each sensor to the network via cables to enable the acquisition of seismic data and distribution of power. Current trends in seismic surveys and the increasing demand for more detailed imaging of subterranean structures indicate that the size of the seismic networks will need to increase. Cabled systems do not scale cost effectively. They are inhibited in their growth due to the increasing cost and complexity of deployment, maintenance and transportation associated with the cables.

Seismic studies cover an exploration area of thousands of square kilometers. Fig. 3 shows how images of rock layers below the ground are obtained by distributing about one million wireless sensor nodes on the surface. The ground is then excited by

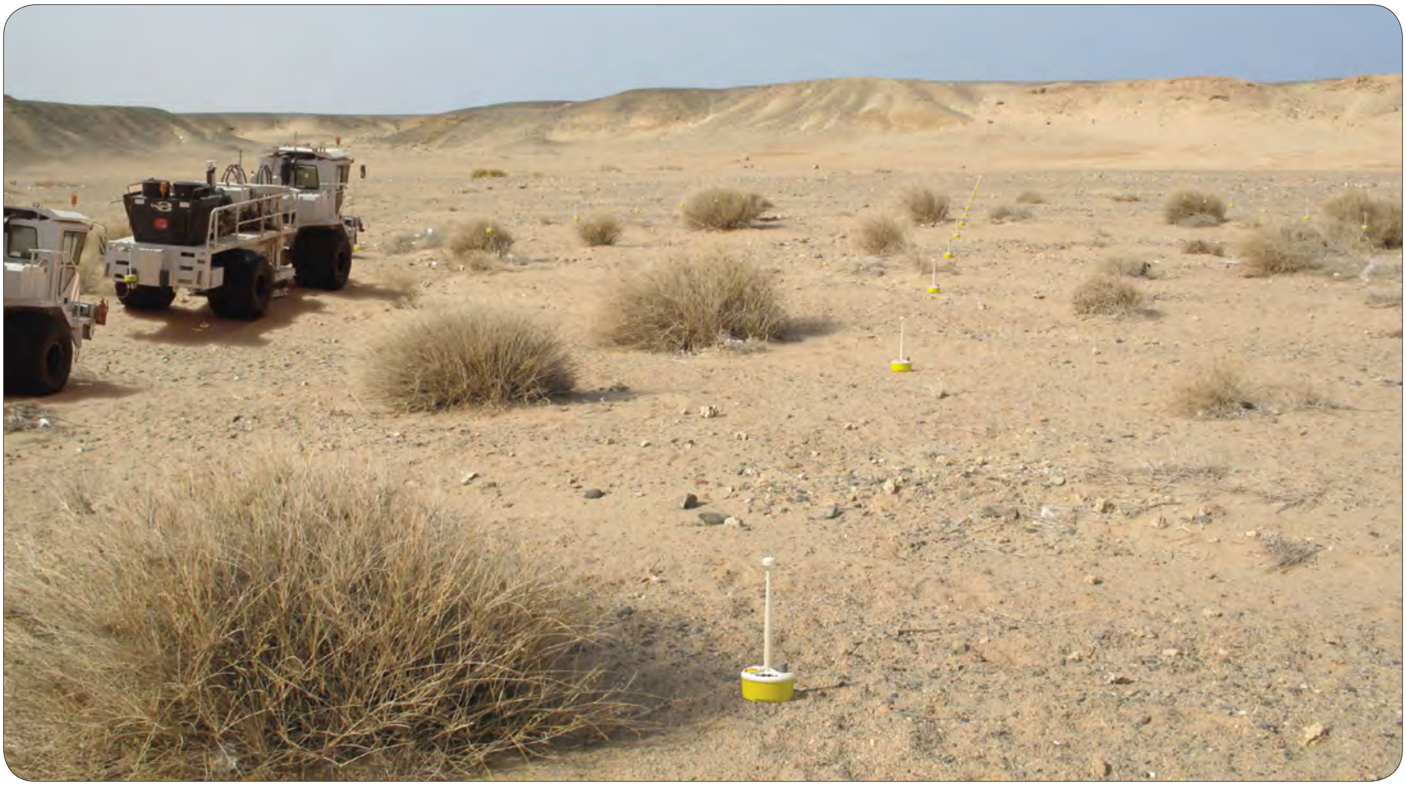


Figure 3. Artist's impression of a future geophysical survey of a potential site that hosts oil or natural gas. Vibroseis trucks visible on the left excite the ground, while wireless sensor nodes are placed in a grid on the surface to detect reflected waves.

a number of Vibroseis trucks, that lower vibrating platforms to the ground to emit seismic waves. These waves bounce off layers of rock when they transition between rock layers, and when rock properties change. The sensor network records the reflected waves. Wireless mesh communication is employed to collect status and trace data and route these to the data collection center doghouse. A patent for the TDMA (Time Division Multiple Access) protocol has been submitted and is part of the agreement signed by Shell and Nikhef.

While initially geophones are foreseen as sensors, accelerometer research based on MEMS (Microelectromechanical systems is the technology of very small devices) is carried out by Nikhef in collaboration with scientists from MESA+ at the University of Twente. The principle of increasing the sensitivity of the sensor by lowering its resonance frequency with antispring technology has been demonstrated. A patent application for this new technology is in preparation.

Dedicated electronics are required for the operation and readout of our MEMS sensors. For the development of proprietary ASICs, Nikhef participates in the SENSEIS collaboration with Shell, ST Microelectronics, InnoSeis and the University of Twente. In 2013 SENSEIS was approved for funding in the call for Advanced Instrumentation by the prestigious Topsector HTSM (High Tech Systems & Materials)

Following Nikhef's mission evaluation in 2010, knowledge and technology transfer to third parties, *i.e.* industry, civil society and general public, is now explicitly included as part of Nikhef's mission. The collaboration with Shell allows Nikhef to contribute to the Dutch Topsectors *Energy* and *HTSM*.

Research

2

2.1 ATLAS
Harvesting LHC Run 1

Management: prof.dr. N. de Groot (PL)
prof.dr.ir. P. J. de Jong (PL)

When on 8 October the 2013 Nobel Prize in Physics was awarded to Peter Higgs and François Englert, the quotation read: *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which was recently confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*. Although the work of Higgs, Brout and Englert dated from 1964, only the experimental discovery of the new particle in 2012, and the measurements of its properties in the past year, gave the solid ground on the basis of which the Nobel Prize could be awarded. For this, the European Physical Society honoured ATLAS and CMS, together with Higgs and Englert, with the EPS high energy physics prize.

Although both ATLAS and CMS are collaborations of a large number of physicists, Nikhef students, postdocs and staff played an important role in various analyses in ATLAS that led to the discovery of the new particle, and to the proof that this new particle is indeed a Higgs boson. As a recognition of this on national level, Frank Linde and Stan Bentvelsen received, for the Dutch ATLAS group, the Physica Prize of the Dutch National Physical Society and the Physica Foundation.

Harvesting 'Run 1'
'Run 1' of the LHC, at 7 and 8 TeV center-of-mass energy, formally ended on 14 February 2013 when the beams were dumped and the LHC went into a two-year shutdown. The collected luminosity of 5 fb^{-1} at 7 TeV and 20 fb^{-1} at 8 TeV exceeded initial expectations, proved that the ATLAS detector is operating well, and led to a wealth of physics results. Nikhef has contributed to the muon system, the silicon strip detector and to the trigger and readout system and takes part in their operation. Physics-wise we concentrate on top quark physics, Higgs physics, and searches for new physics signals beyond the Standard Model.

In 2013, two ATLAS collaboration workshops were held at Nikhef. In April 2013, some 150 ATLAS supersymmetry searchers visited Nikhef for a workshop to discuss getting the most out of Run 1 supersymmetry analyses and prepare for the next run, and in May about 70 ATLAS members gathered at Nikhef to discuss the H→WW analysis.

Top quark physics
In the analysis of top quark pair production, the focus of the group has been on the estimation of backgrounds from QCD multijet events and from W and Z production in association with jets. The developed methods have been used in several ATLAS papers. In 2013 the group has shifted attention to single top quark production, in particular to the process of associated W plus top production. In the semileptonic decay mode of the top quark the Wt cross section was measured to be in agreement with the Standard Model prediction, although still with large systematic uncertainties. The analysis was also used to set a limit on excited b quarks decaying to a W boson and a top quark. A summary of ATLAS single top quark production cross section measurements is shown in Fig. 1.

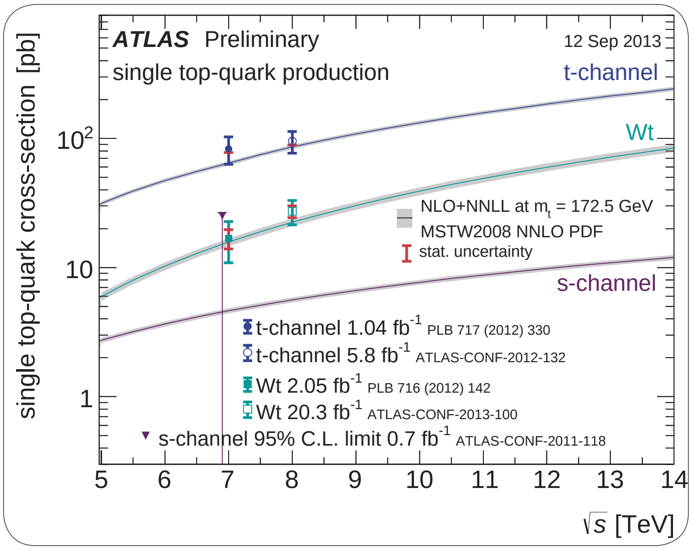


Figure 1. Summary of ATLAS single top quark production cross section measurements.

Is the new boson a Higgs boson?
In 2013 the ATLAS group has built on the discovery of a Higgs boson in 2012. The full 2011-2012 dataset is more than double in size than that of the discovery, which allowed us to study the properties of the new particle. Using the angular correlations between the decay products in WW and ZZ decay modes we were able to determine the quantum numbers spin and parity of the new particle. With the larger dataset we measured the couplings to the W and Z boson with greater precision and established that this is indeed the long sought Higgs boson. Fig. 2 summarizes the measured production strength of the Higgs boson in various decay channels.

We also contributed to the first measurement of an alternative production mode of a Higgs boson through the fusion of vector bosons. We started a new line of research on the production of the Higgs boson in association with a pair of top quarks. This channel offers the possibility of a direct measurement of the coupling

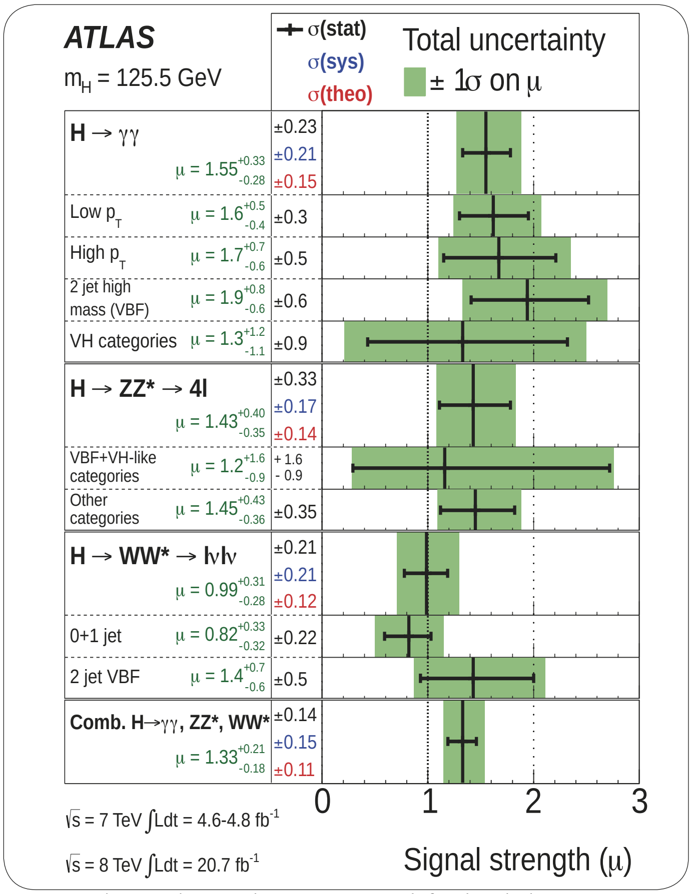


Figure 2. The signal strength parameter μ is defined such that μ=0 corresponds to the background-only model and μ=1 to the size of the Higgs boson signal predicted by the Standard Model.

between the Higgs boson and a top quark. Also we studied the frequency of double parton interactions as a potential background to double Higgs production. These analyses will become particularly relevant for Run 2 of the LHC. In 2013 the ATLAS experiment observed the first decay of the Higgs boson into tau leptons.

Searches for physics beyond the Standard Model

The discovery of the Higgs boson has opened new possibilities for the search for a signal of new physics. New physics should not lead to large quantum corrections to the mass of the Higgs boson. These corrections could be many orders of magnitude larger than the measured Higgs mass of about 125 GeV. An important question is therefore: *Why is the Higgs so light?* A new symmetry of nature called supersymmetry could explain the low mass of the Higgs boson, if the new particles predicted by supersymmetry are not too heavy. The Higgs discovery and the measured Higgs mass might be seen as new guiding principles to search for new physics. On the other hand the Higgs boson can be regarded as a new tool to search for new physics. New particles might show up in the decay of the Higgs boson or might be produced in association with Higgs bosons. These studies are just beginning.

The 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 2.9 TeV, excited quarks below 3.8 TeV, fourth generation top quark partners below 650 GeV, and extra dimensions and quantum black holes below 1.5 to 4 TeV.

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. Fig. 3 shows exclusion limits on a supersymmetric model in which pairs of gluinos (the partners of gluons) are produced, which each decay to a pair of top quarks and a neutralino; the strongest limit is derived by an analysis led by Nikhef. Run 1 has set significant limits on supersymmetry; in constrained models squarks and gluinos below approximately 1.5 TeV are excluded. The 2015 LHC run at full design energy will put supersymmetry to further stringent tests.

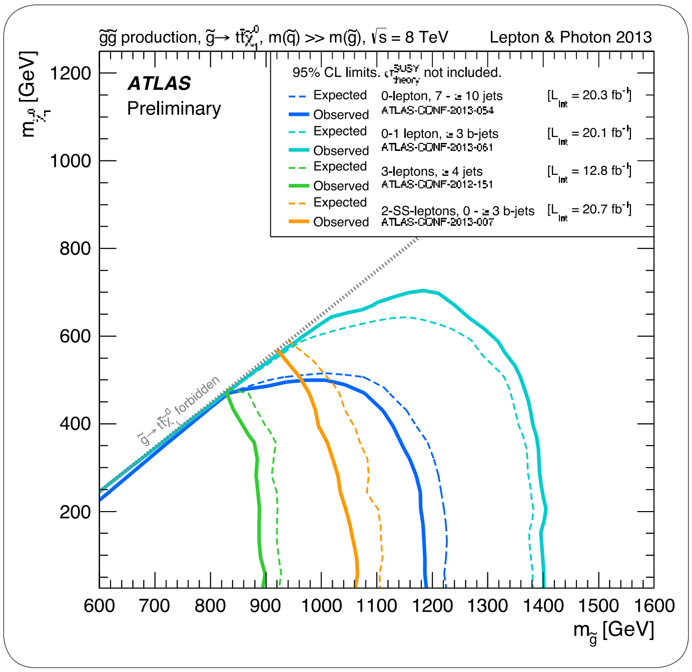


Figure 3. Exclusion limits on gluinos decaying to a top quark pair and a neutralino. For light neutralinos, gluinos with a mass below 1400 GeV are excluded in this model.

One of the fundamental questions of particle physics is whether elementary particles such as leptons and quarks are really elementary. To test this hypothesis we look for *excited states* of these particles. In particular, excited charged or neutral leptons would result in an experimental signature with three or more normal leptons. The available data allow to make first statements on the existence of excited neutrinos and excited taus. So far no evidence of such events was found above background level.

Nikhef has initiated a new research line in ATLAS looking for lepton flavour violating processes in tau decays. While experimentally very challenging, an observation of such decay would indicate new physics beyond the Standard Model.

Future physics in ATLAS

In the 2013–2014 LHC shutdown, LS1, the LHC machine will prepare for future operation at higher energies, but also ATLAS is upgrading the detector for running in 2015 and beyond at nominal LHC luminosity. Nikhef is involved in various projects in LS1. The ATLAS pixel detector is extended with an additional layer of silicon sensors, the insertable B-layer (IBL), closer to the interaction point. Nikhef has constructed a cooling plant for the IBL, based on evaporative CO_2 cooling, a Nikhef expertise since several years. The plant has been delivered to CERN, as shown in Fig. 4, and will be commissioned in 2014.

The level-1 trigger will have to cope with significantly larger collision rates in Run 2, which implies that it will have to become smarter. ATLAS tries to achieve this in the form of a topological trigger that will enable ATLAS to trigger at the first level on smart combinations of objects. Nikhef develops 'momentum imbalance' reconstruction algorithms to be run on the new topological trigger in order to improve searches for supersymmetry. Nikhef has also constructed a board that will enable the feeding of muon detector information to the topological trigger, which is important for triggering on events with Higgs boson candidates, as well as on events with a signature expected for lepton flavour violation. Furthermore, Nikhef is active in upgrades of the readout system.

In Run 2, which will last from 2015 to 2018, the LHC is expected to deliver some 150 fb^{-1} at a centre-of-mass energy of at least 13 TeV. The higher energy will be very beneficial for searches for new massive particles. After Run 2, the LHC will shutdown for an extended period again (LS2) in order to upgrade the LHC injectors and prepare for luminosities exceeding the design luminosity. ATLAS will replace a layer of endcap muon chambers by a layer of new chambers in micromegas technology, to improve triggering on muons in the forward region. Nikhef is involved in the readout of the new system, which will be based on a new design with high-speed optical links, configurable in a flexible way. This will also be used for the trigger system of the electromagnetic calorimeter and serve as a prototype for a readout of the full detector after future upgrades.

The European Strategy for Particle Physics has prioritized the full exploitation of the LHC up to a delivered luminosity of 3000 fb^{-1}. This is achievable with a significant upgrade of the accelerator and the detectors after 2023, in a project known as HL-LHC. The Nikhef ATLAS group has participated in physics studies for the HL-LHC upgrade, in particular in searches for supersymmetry, Higgs production and WW scattering. The HL-LHC will demand a new inner detector for ATLAS, based on all-silicon sensors, able to stand the higher instantaneous and integrated luminosity and the corresponding radiation dose. Nikhef is involved in design studies and simulation, as well as in the design of an endcap strip detector, with the aim to construct one complete endcap detector at Nikhef.

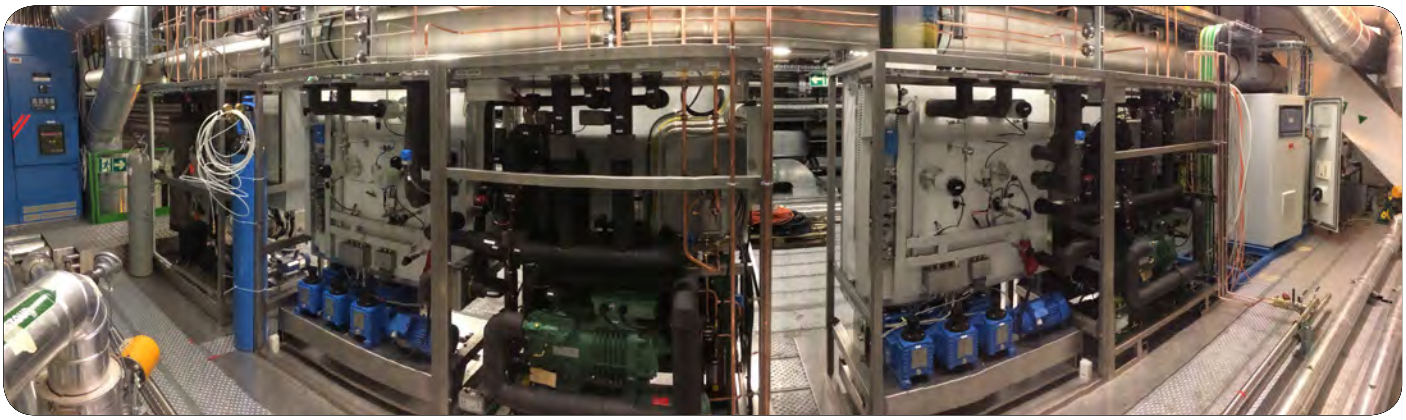


Figure 4. The CO_2 cooling plant for the IBL, constructed at Nikhef, installed in the ATLAS service cavern.

2.2 LHCb
New Physics in the Loop?

Management: prof.dr. M.H.M.Merk (PL),
prof.dr. A. Pellegrino

After collecting a wealth of collision data at the LHC in 2011 and 2012, 2013 was a year of harvesting results for the LHCb collaboration. In 2013 the collaboration published 76 articles with new observations including a 'world-best' measurement. The research focuses on the topic of flavour physics, the physics of interactions between different quark types. Flavour physics is the domain of the weak force, carried by either the charged W^+ and W^- bosons ('the charged current'), or the neutral Z^0 boson ('the neutral current').

In the Standard Model, the flavour-changing charged currents are the source of an asymmetry between matter and antimatter (CP violation); flavour changing neutral currents are forbidden at first order, leading to the phenomena of rare decays. The goal of the LHCb experiment is to confront Standard Model predictions with precision measurements of both CP violating processes as well as rare decays. Of particular interest are processes with large higher-order quantum loop corrections, as these may be sensitive to contributions from particles or force carriers that are not included in the Standard Model.

CP Violation

Nobel prize winning discoveries of CP violation were made in 1964 in neutral K_s mesons and in 2001 in B^0_d mesons. In 2013 LHCb observed for the first time CP violation using B^0_s mesons,

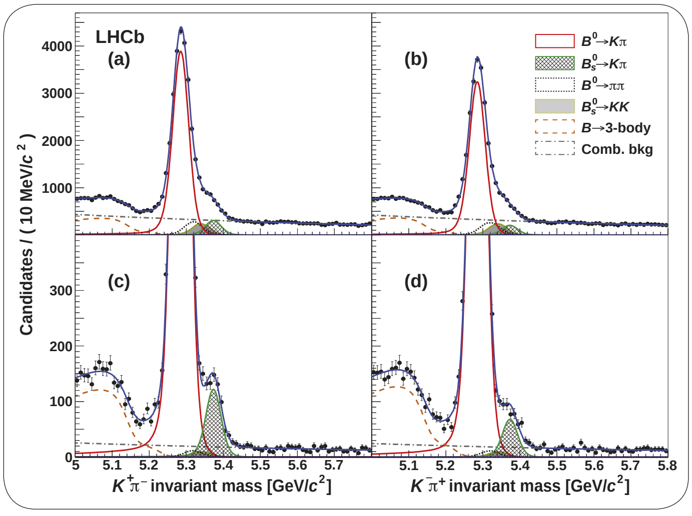


Figure 1. Measurements of the decays (a) $B^0_d \to K^+\pi^-$, (b) $B^0_d \to K^-\pi^+$, (c) $B^0_s \to K^+\pi^-$ and (d) $B^0_s \to K^-\pi^+$. The red curves in the top plots illustrate the CP asymmetry for these B^0_d decays, while the green curves in the bottom plots show the, even larger, asymmetry for B^0_s decays.

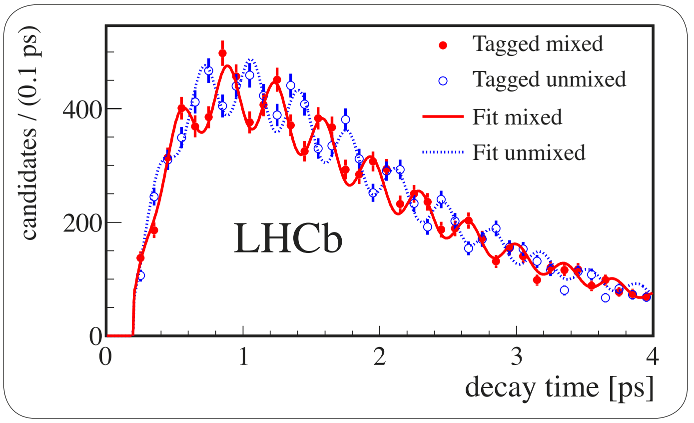


Figure 2. Observation of B^0_s to anti-B^0_s oscillations as function of the decay time. The red data points represent the cases where a B^0_s has mixed into an anti-B^0_s or vice versa, while the blue points represent the unmixed cases. The corresponding curves represent the fitted theory prediction including experimental dilution effects.

particles consisting of a second (s) and a third generation (b) quark. This observation of CP violation is illustrated in the bottom plots of Fig. 1, from which it was derived that the neutral B^0_s mesons have a (28±4)% higher probability to decay into a $K^+\pi^-$ final state than into the antiparticle conjugated final state $K^-\pi^+$. The above observation of CP violation assumes that any instrumental asymmetries for detection of positive and negative particles are well understood.

Alternatively, CP violation is studied as a function of the decay-time of B^0_s and $\overline{B}^0_s$ mesons. In that case a decay-time dependent CP violation signal can occur related to the quantum mechanical phenomenon that a B^0_s meson can oscillate into an $\overline{B}^0_s$ meson before decaying. The observations of such flavour oscillations with LHCb are shown in Fig. 2 resulting in a mixing frequency Δm_s=18 ps^{-1}. With this frequency, B^0_s mesons can either directly decay to the final state or first oscillate into their anti-particle and subsequently decay to the final state. The quantum mechanical interference of these two amplitudes allows to determine the magnitude of the CP violating parameters in the theory. This method is applied to two different decay modes: in the first mode ($B^0_s \to J/\psi\,\phi$) the relevant parameter of the Standard Model, ϕ_s, predicts no CP violation, while in the second mode ($B^0_s \to D^\mp_s K^\pm$) a large CP asymmetry, γ, is expected. The result of 2011 LHCb data of the $B^0_s \to J/\psi\,\phi$ measurements is shown in Fig. 3, together with those of other experiments. The plot shows that the measurement is consistent with no CP violation in this decay channel, as is predicted by the Standard Model. We expect to publish the, still blinded, results of 2012 data this winter, tripling the data-statistics. The analysis method of the $B^0_s \to D^\mp_s K^\pm$ data has been

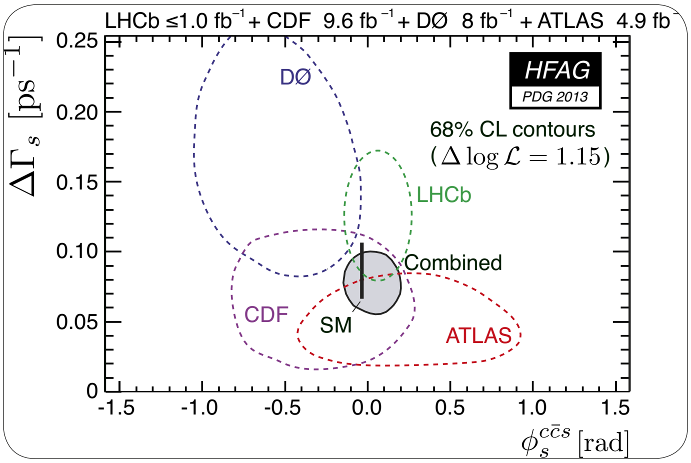


Figure 3. Contour plot of the allowed values of the CP violation parameter ϕ_s plotted versus the B^0_s lifetime parameter $\Delta\Gamma_s$. The combined measurements of LHCb, CDF, D0 and ATLAS are found to be in agreement with the Standard Model prediction.

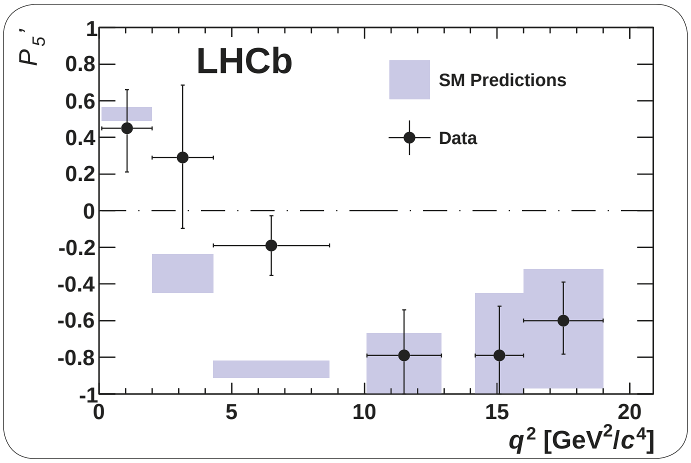


Figure 5. Measurement of the angular observable p_5' obtained with $B^0_d \rightarrow K^* \mu^+ \mu^-$ decays as function of the square of the invariant mass of the di-muon pair. The data show a discrepancy with the Standard Model prediction in the second and third bin of the plot, locally corresponding to 3.7σ.

prepared in 2013 and we are eagerly looking forward to publish the first results of this decay channel this winter.

Rare Decays

The so-called GIM mechanism invokes a Standard Model symmetry to predict that an interaction between two quarks of different flavour and the same charge is (to lowest order) not allowed. The most prominent examples of such an interaction are decays of the B^0_d and B^0_s particles into two muons. Fig. 4 shows the status for the search of these very rare decays with the LHCb experiment yielding a signal of 4σ significance for the B^0_s decay and 2σ for the B^0_d decay. A combination with measurements of the CMS experiments leads to the discovery of B^0_s (more than 5σ significance) while the B^0_d zero signal is still not significant. The relative ratio of the B^0_d and B^0_s decays is a sensitive parameter in the search of signals from physics beyond the Standard Model.

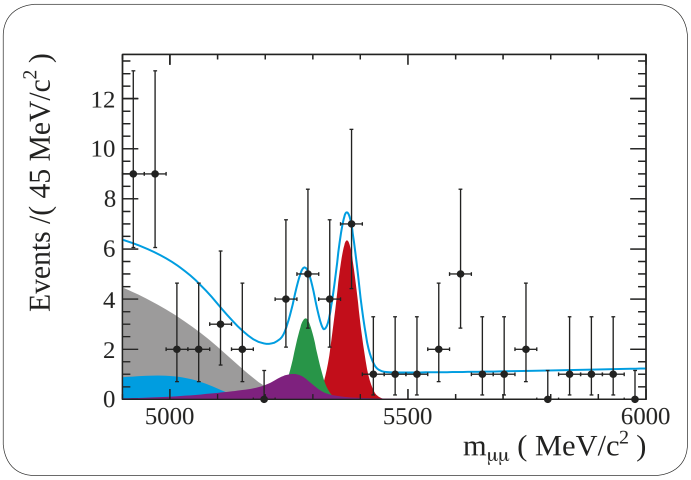


Figure 4. The observed mass spectrum of $\mu^+\mu^-$ decay candidates that are produced from a secondary vertex, as seen with the LHCb detector. The black points represent the data and the blue curve is a fit yielding a 4σ signal observation of $B^0_s \rightarrow \mu^+\mu^-$ (red surface) and 2σ for $B^0_d \rightarrow \mu^+\mu^-$ (green surface). The other coloured surfaces represent different background contributions.

An intriguing signal is observed in rare decays of the type $B^0_d \rightarrow K^* \mu^+ \mu^-$. In these decays the angular distribution of the particles in the final state provide means to test the Standard Model theory. No significant deviation from the Standard Model prediction is shown apart from an observable called p_5', an angular observable constructed to minimize uncertainties due to unknown form factors. Fig. 5 shows the distribution of this particular variable as a function of the invariant mass of the muon-pair produced in the decay. The results, based on the 2011 data, show a 3.7σ deviation from the Standard Model prediction in the lower q^2 region of the plot. The forthcoming results of the 2012 data should clarify whether this is a statistical fluctuation or perhaps a first glimpse of physics beyond the Standard Model. In the latter case a virtual heavy Z′ boson could explain the observed signal.

2.3 ALICE
The LHC heavy-ion programme

Management: prof.dr. R. Snellings (PL)

ALICE (A Large Ion Collider Experiment) is designed to address the physics of strongly interacting matter, and in particular to study the properties of the Quark-Gluon Plasma (QGP), using proton-proton, proton-nucleus and nucleus-nucleus collisions at the CERN LHC.

Prior to the start-up of the LHC heavy-ion programme, the nature of the QGP as an almost perfect liquid emerged from the experimental investigations at the SPS (CERN) and at RHIC (Brookhaven National Laboratory). ALICE has confirmed this basic picture, observing the creation of hot hadronic matter at unprecedented values of temperatures, densities and volumes. The measurements of the ALICE experiment have exceeded the precision and kinematic reach of all significant probes of the QGP that had been measured over the past decade. These physics results have been achieved by ALICE after only two years of Pb–Pb running and one p–Pb run, demonstrating its excellent capabilities to measure high-energy nuclear collisions at the LHC.

Current status of heavy flavour in ALICE
One of the physics analyses performed by the Nikhef group is the production of mesons containing charm quarks to study the modification of the yield when the partons are produced in and traverse through the hot and dense matter. We performed the first measurement of the production yield of D^* mesons in lead-lead collisions at 2.76 TeV. The D^* particle production in lead-lead collisions is normalised by the production in proton-proton interactions to quantify the nuclear modification.

This normalised yield, plotted in Fig. 1, clearly shows a suppression as a function of the centrality of the collision. In addition, these measurements compared to model calculations suggest that beauty production is less suppressed in lead-lead collisions compared to prompt charm production. Less suppression for heavier quarks (beauty quarks are much heavier than charm quarks) was predicted due to the so-called dead cone effect.

To clarify whether the observed suppression is an initial or final state effect, the Nikhef group performed in 2013 the measurement of D^* meson production in proton-lead collisions, which provide an essential reference for understanding the measurements in lead-lead collisions. The observed lack of significant suppression in the yield of D^* in proton-lead collisions proves that the observed suppression of D^* meson production in lead-lead collisions is indeed due to final state effects.

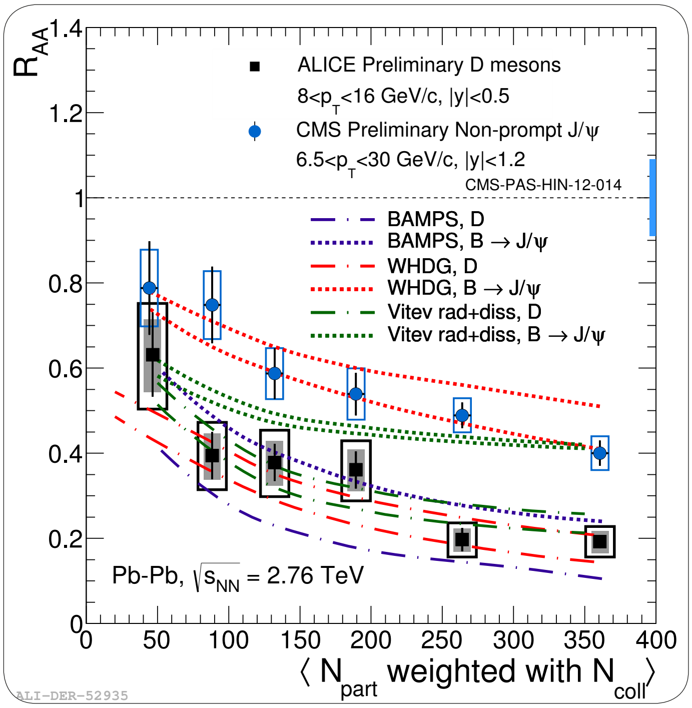


Figure 1. The energy loss of prompt D mesons (black symbols) and J/ψ from beauty decays (blue symbols) in hot QCD matter is quantified using the nuclear modification factor R_{AA}, which is shown as a function of the collision centrality.

Further insight into the properties of the medium can be obtained by investigating the elliptic flow (v_2) of heavy-flavour hadrons. If heavy-quarks re-interact strongly with the medium, the elliptic flow of heavy-flavour hadrons should reflect the spatial azimuthal anisotropy of the medium, similar to light hadrons. Therefore, measurements of v_2 at low transverse momentum provide information on the degree of thermalisation. The Nikhef group measured for the first time in heavy-ion collisions the v_2 of prompt D^* mesons. A non-zero magnitude of v_2 with a significance of 5.7σ is observed for $2 < p_T < 6$ GeV/c, compatible with that of light hadrons within the uncertainties. This suggests that D mesons interact strongly with the medium at low p_T. However, measurements with much higher statistics, in particular at lower p_T, are required to draw firm conclusions about charm quark thermalisation in the hot medium created at the LHC.

We can further study the production and subsequent fragmentation of heavy-quarks in more detail by investigating azimuthal correlations between the electrons from heavy-quark decays and charged hadrons. With the large amount of proton-lead collisions measured in Spring 2013, the azimuthal correlations can be studied differentially as a function of the multiplicity

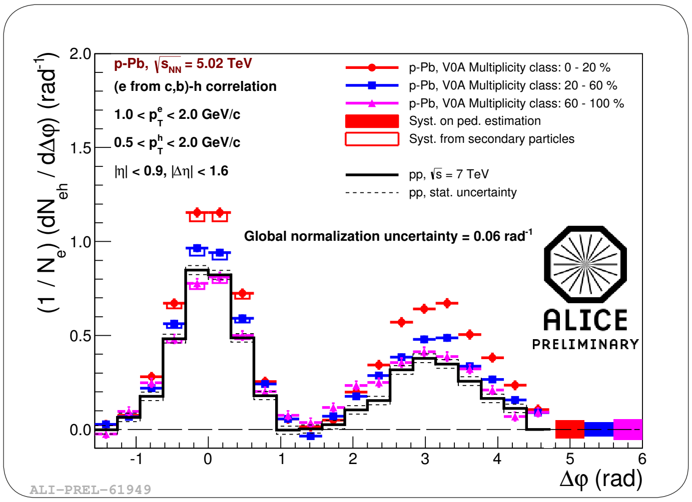


Figure 2. Azimuthal angular correlations between electrons from heavy flavour decays and charged hadrons in proton-proton and proton-lead collisions.

of the charged particles produced in these collisions. Flavour conservation implies that heavy quarks are always produced in pairs. Momentum conservation requires that these pairs are correlated in relative azimuth ($\Delta\phi$) in the plane perpendicular to the colliding beams. Fig. 2 shows the measured azimuthal correlation as function of multiplicity in proton-lead collisions and, in addition, in minimum bias proton-proton collisions. We observe an enhancement of heavy-flavour azimuthal correlation in high-multiplicity events compared to low-multiplicity events as well as compared to the yield in proton-proton collisions. This enhancement, the so-called near side and away side ridge, is not observed in theoretical models such as PYTHIA. Further measurements and theoretical developments are needed to clarify whether this is an initial state or final state effect such as the elliptic flow observed in lead-lead collisions.

New Inner Tracking System

Despite the current state of the art measurements there are several frontiers, including high precision measurements of rare probes over a broad range of transverse momenta, for which the current experimental setup is not fully optimised. ALICE is therefore preparing a major upgrade of its apparatus, planned for installation in the second long LHC shutdown (LS2) in the years 2018–2019.

At this moment the main particle tracking device in the ALICE experiment is limited to a readout rate of approximately 500 Hz for lead-lead collisions. The ALICE upgrade will modify the detector such that it will be able to record all Pb–Pb interactions (50 kHz) which the LHC will deliver. Besides a two orders of magnitude increase in data collection speed a new, high-resolution, low-material thickness Inner Tracking System (ITS) will improve the tracking precision significantly and allow access to B mesons and the Λ_c baryon which cannot be separated from background with the current set-up. The improved tracking system will be positioned closer to the interaction region by reducing the diameter of the LHC beam pipe. This new detector, in combination with an upgraded Time Projection Chamber (TPC) and upgraded data acquisition, will allow us to collect about ten billion (10^{10}) lead-lead interactions in the period 2019–2021, two orders of magnitude more data than would be possible without the upgrade. Detailed simulations have shown that the improved resolution and significant increase in statistics will allow the ALICE experiment to address the main questions about heavy flavour thermalisation and in-medium energy loss.

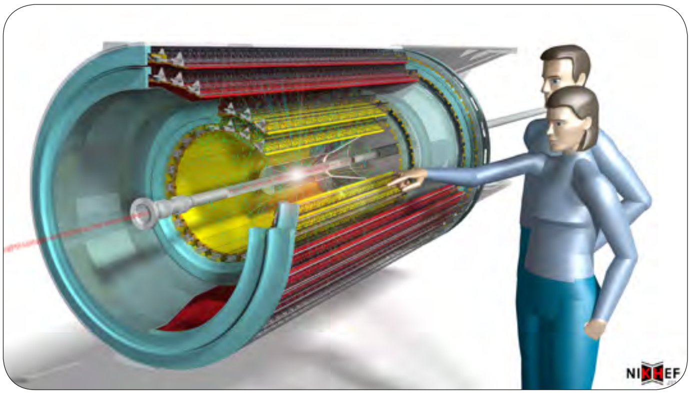


Figure 3. Artist impression of the future ALICE inner tracking system.

In 2013 Nikhef has joined the ALICE inner tracking system upgrade programme. Nikhef will benefit from its experience gained with the design and production of the existing ITS to optimise the new system using modern technology. Only by integrating the power regulators into the sensor ASIC and by using a serial powering scheme the material used in the active volume can be reduced to the required amount. In addition, Nikhef will design and build a cooling system based on CO_2 evaporative cooling. The institute has ample experience with such systems, both for experimental and industrial environments. An evaporative cooling system can achieve a high cooling power with much less cooling liquid than the currently used water cooling system, thus reducing the amount of material used. During the production phase Nikhef will assemble a significant fraction of the detection staves for the two outer layers, using components produced in other laboratories, and assure the quality of the final product in accordance with the foreseen project leadership of Nikhef.

2.4 Neutrino Telescopes
KM3NeT & ANTARES

management: dr. A. Heijboer (PL)

Neutrino astronomy at Nikhef

The neutrino telescope programme at Nikhef comprises data analysis from the running ANTARES detector and the construction of the next generation neutrino telescope: KM3NeT. ANTARES has been taking data since 2007 and is planned to keep running through 2015. The Nikhef group has played a key role in developing the data acquisition software and has been a main contributor in the data analysis and physics output. In particular, the Nikhef group was responsible for the papers on point source searches.

The successor project to ANTARES, KM3NeT, has achieved much in 2013. In January, KM3NeT made the transition from a consortium to a collaboration. A management structure has been put in place to construct the first phase of the KM3NeT detector.

The ambition of the collaboration is to construct a neutrino telescope consisting of more than 600 strings; this is now known as 'KM3NeT phase 2'. This size is dictated by the main science goal, which is the detection of neutrinos from galactic supernova remnants. These objects are thought to produce the bulk of the cosmic rays detected on Earth; this hypothesis could be confirmed by a discovery of the associated neutrinos. Distributing the detector over multiple sites (in France, Italy and Greece) will allow maximal use of potential funding while taking into account geographical constraints. Studies have shown that distributing the detector in this way will not significantly affect the physics potential.

Currently, funds are available to construct a first fraction of the total detector. The funding scheme imposes that the money is spent on a short timescale. This motivates the near-term goal to construct roughly 30 strings, most of which will be deployed near Sicily, Italy.

Figure 1. Exploded view of a KM3NeT Optical Module. Visible are (from top to bottom the glass feed-trough, the 14 mm thick glass sphere, the 3D printed structure supporting the PMTs, the aluminum cooling structure, fan-out boards (green), CLB (red), and the power board (dark green). On the left, the titanium collar is shown which holds the sphere and attaches to two Dyneema ropes which make up the string.

Nikhef contributions to KM3NeT

A team from Nikhef designs the optical network for the readout. In this design, each Optical Module (OM) sends its data to shore using a specific wavelength. This technique, called dense wavelength division multiplexing, was already employed succesfuly in ANTARES. In KM3NeT, one optical fibre in the main cable to the shore can accommodate the data from four detector strings. This reduces the cost of the main cable to shore and optimises the reliability by having few active components in the sea. As the detector is expected to keep operating for at least 15 years, much attention has been given to reliability, in particular to the lifetime and long-term stability of the optical transceivers in the OMs.

Nikhef also develops the firmware for the central logic board inside the OM. A system called 'White Rabbit' is implemented to establish inter-OM clock synchronization. This is crucial since the reconstruction of neutrinos in the detector is based on the accurate information of the arrival time of the Cherenkov photons. Algorithms for packaging and sending the data, as well as for receiving (slow control) commands from the shore are also being implemented.

The 'bases', which provide the high voltage to the photomultiplier tubes (PMT), as well as amplification and discrimination of the PMT signals, form another innovative Nikhef design. The bases provide a low-power high voltage supply, combined with compact design so that 31 of them can be fitted in the OM. This is achieved by means of two ASICs, which were also designed in house. In 2013, after successful prototyping, the ASICs have been produced, packaged and tested in an engineering run, which has yielded more than enough units for phase-1. Two separate fan-out boards collect the signals from the PMTs. KVI/CART has recently taken responsibility for designing this board and managing the production in industry. The order to produce all boards needed in phase-1 will be given soon.

Nikhef engineers have designed a major chunk of the mechanical structures in the detector. Some examples are the 3D-printed structure that holds the PMTs in place inside the sphere to the ropes that support string, the oil-filled vertical cable that houses the optical fibres and power leads, the glass feed-throughs (penetrators) which have to withstand the pressure of about 300 bars —they are are all designed, built and tested at Nikhef. In most cases, these in-house designs are much cheaper than standard marine components. As a result, the cost of the optical module is dominated by the PMTs, which maximises the physics potential. An exploded view of an optical module showing many of Nikhef's contributions is shown in Fig. 1.

The first Optical Module

In April of 2013, the first KM3NeT optical module was deployed near Toulon, France (see Fig. 2) and connected to the ANTARES infrastructure, which provides the link to the shore. Moments later, all 31 channels were providing data. The analysis of the data taken by the OM has illustrated the efficacy of the multi-PMT design to identify Cherenkov light from high energy charged particles (muons) in backgrounds produced by radioactive decays and bioluminescence. This is shown in Fig. 3 (left), which shows the event rate as a function of the number of simultaneously firing PMTs. The data are described by a simulation, which shows that the only possible source of high-multiplicity events are atmospheric (down-going) muons. The contributions from decaying ^{40}K and random coincidences of single-photon backgrounds are also understood relatively well and indicated in the figure. In Fig. 3 (right), muon events have been isolated by requiring at least six PMTs to be hit. As the muons are down-going, the Cherenkov light will be detected on the upper PMTs. This is clearly shown in the figure, which illustrates the directional sensitivity of the multi-PMT OM. Some of the remaining discrepancies between the simulation which are apparent in this figure are

Figure 2. First KM3NeT optical module, about to be deployed near the ANTARES detector.

due to shadowing of the titanium structure, which is part of the ANTARES line, but is not simulated. The directional sensitivity which is evident from this data, will enhance the reconstruction performance of the KM3NeT detector.

The Discovery of Cosmic Neutrinos

Besides the progress of KM3NeT, 2013 has also been an exciting year for the field of neutrino astronomy in general. In the November issue of Science magazine, the IceCube collaboration published an analysis showing a 4.3 sigma excess of events compatible with a high energy cosmic neutrino flux. The origin of these neutrinos is still unknown. An intriguing (though not very significant) conglomeration of events is present near the Galactic Center. In a Northern Hemisphere detector, the neutrinos will be up-going, which allows to achieve better angular resolution and a lower energy threshold by exploiting muon neutrinos. It has been pointed out that a large detector in the Mediterranean will be instrumental in studying this signal. The KM3NeT collaboration is currently studying the science reach of one or two 'building blocks' of 115 strings for such a signal with high priority. Such a detector would be an intermediate step between the currently funded phase-1 and the full KM3NeT detector (phase-2). It is expected that such a detector can study the IceCube signal with enough accuracy (*e.g.* angular resolution) to yield vital, additional information on the souces of the cosmic neutrinos.

The usefulness of a Northern Hemisphere detector is further illustrated by a recent ANTARES result, which adresses a particular hypothesis about the IceCube signal, namely that the conglomeration of events near the Galactic Center could be due

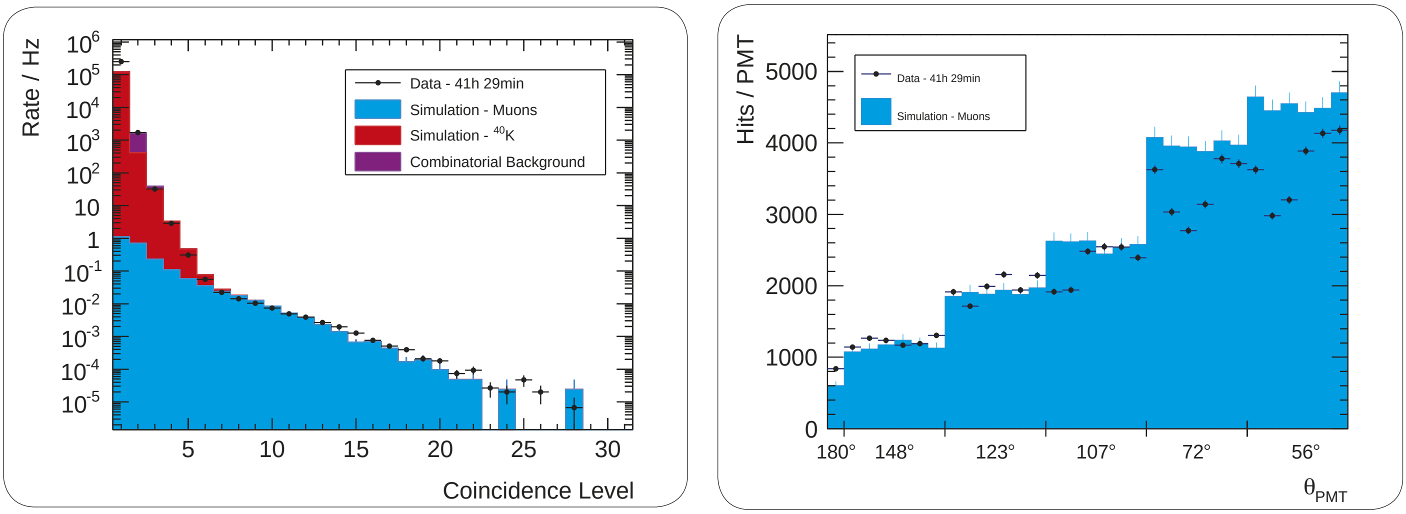


Figure 3. Left: the rate of events observed by the OM as a function of the PMT multiplicity (see text). Right: the zenith angle of the PMTs that detect light in events with a PMT multiplicity above 6. The PMTs at the top of the OM see more light from the down-going muons.

to a single point source. The ANTARES point source search analysis (in which the Nikhef group has been playing a dominant role since several years) has been applied to six years of data (2007–2012). No significant excess was found, which allows to set a limit which is stringent enough to exclude the presence of a point source in the IceCube 'hot spot' region with sufficient strength. Hence, despite its small size, ANTARES is still contributing important information on the Southern Sky.

2.5 Gravitational Waves
The dynamics of spacetime

Management: prof.dr.ing. J.F.J. van den Brand (PL)

The main objective of the program is to find direct experimental evidence for the existence of gravitational waves, ripples in spacetime that are emitted by accelerating bodies. This will once and for all prove that gravity is a dynamic phenomenon. With data from gravitational waves one can further probe the astrophysics of extreme objects, cosmology, and the nature of general relativity, which allows the first experimental steps on the path to quantum gravity.

Advanced Virgo, a major upgrade of the laser interferometer at Pisa in Italy, is expected to detect gravitational waves for the first time in the next several years, along with similar projects as LIGO in the U.S., GEO-HF in Germany, and Kagra in Japan. Scientists of the FOM Gravitational Physics Program are responsible for a number of key sub-systems of Advanced Virgo:

- Vacuum-cryolinks are needed to achieve the required sensitivity of $3\times10^{-24}/\sqrt{\text{Hz}}$ at 200–400 Hz. To avoid that the fluctuating index of refraction of the residual gas in the interferometer arms will lead to unacceptable frequency noise in the interferometer output, ultra-high vacuum in the 10^{-10} mbar region must be achieved in the vicinity of the high-quality optics. To achieve this goal, Nikhef has designed four cryolinks in close cooperation with Dutch industry.
- Seismic isolation systems have been developed to suppress seismic displacement noise entering the optical tables that contain sensors used for longitudinal and angular alignment of the core optics of Advanced Virgo. Fig. 1 shows EIBSAS, a single-stage vibration attenuation system used to isolate Virgo's external injection bench to picometer/$\sqrt{\text{Hz}}$ levels in all six degrees of freedom. Multi-stage seismic isolation systems are effective in realizing vibration-free environments at femtometer/$\sqrt{\text{Hz}}$ levels for optical tables placed in-vacuum.

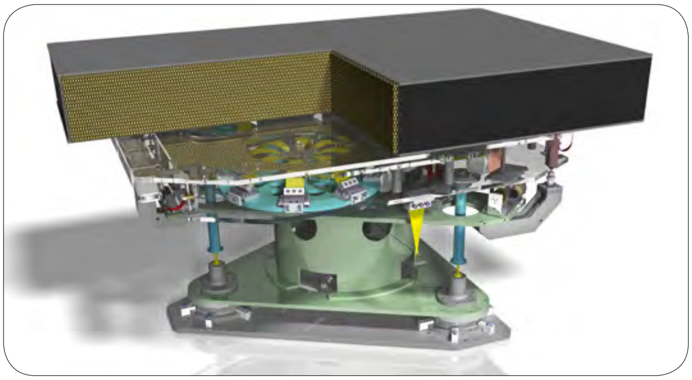


Figure 1: Installation of the EIBSAS vibration isolation system in Advanced Virgo. EIBSAS was developed at Nikhef and allows for damping vibrations with more than 60 dB in 6 degrees of freedom.

- Optical systems can detect radiation modulated at specific frequencies to allow a precise angular alignment of the optical components with respect to one another. Phase cameras have been developed that can measure the amplitude and phase of carrier and side-band laser light. Information from these sensors is used for adaptive corrections to deformation and index of refraction changes in Virgo's main optical elements due to thermal effects.

In addition to the development of instrumentation, preparations were made for the scientific exploitation of the detector. A strong analysis group is in place and Nikhef scientists coordinate important activities, such as the compact binary coalescence (CBC) analysis group for LIGO and Virgo. This allows to answer important questions, such as *"Will we make a census of black holes, i.e. can we use gravitational waves to count the number of coalescent black holes?"* and *"What is the equation of state of neutron stars?"*. Furthermore, colliding neutron stars and black holes will be used as cosmic markers to study the structure and evolution of the Universe on the largest length scales. Moreover, these binary systems provide a unique 'laboratory' for studying the dynamics of spacetime itself, which will allow tests of general relativity theory in an unprecedented way: alternative theories of gravity like scalar-tensor models or theories with a massive graviton may be excluded (or confirmed!), and it becomes possible to search for low-energy signatures of quantum gravity.

Several developments in 2013 assure a bright future of the discipline. The Einstein Telescope shown in Fig. 2 is proposed as a gravitational-wave observatory of the third generation. Nikhef scientists have made important contributions to the design study funded within the FP7. In addition, in November 2013 the European space agency ESA approved *e*LISA, an interferometer in space that is to be launched in 2034. *e*LISA will operate at much lower frequencies than the ground based observatories. It will be able to sense fusion of supermassive black holes occurring almost anywhere in the Universe, and may detect gravitational waves that were generated immediately after the Big Bang.

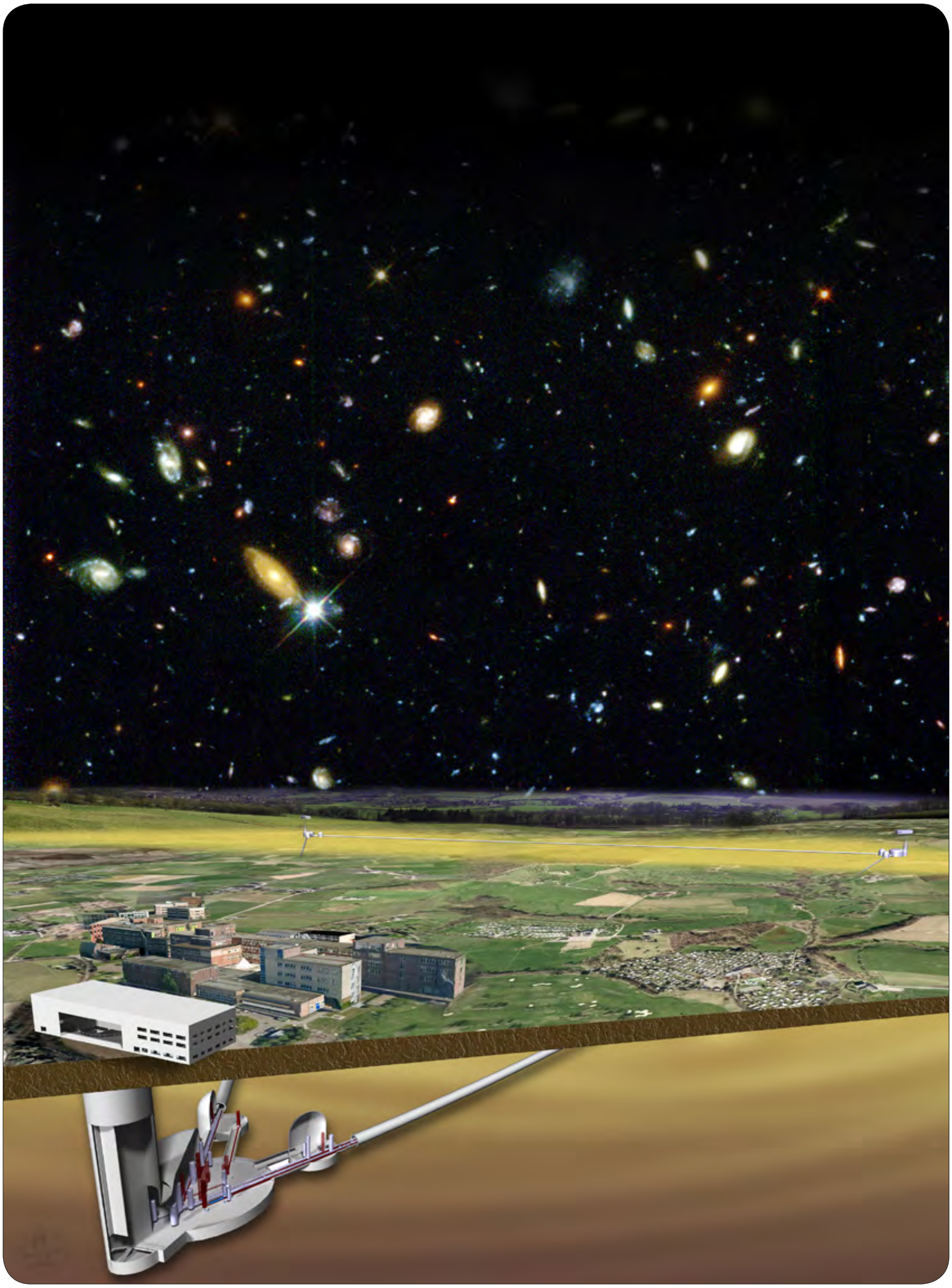


Figure 2: Einstein Telescope is a third generation gravitational wave observatory. The triangular observatory with 10 km arm length is placed underground at a depth of a few hundred meters.

2.6 Cosmic Rays
Pierre Auger Observatory

Management: prof.dr. S.J. de Jong (PL)

Ultra-high-energy cosmic rays are charged particles that are emitted by yet unknown sources in the universe and cause extensive air showers when they hit the Earth's atmosphere. The highest energy cosmic rays have interactions in the atmosphere that exceed the LHC collision energy by one and a half orders of magnitude. The Pierre Auger Observatory (Auger) is the world's largest cosmic ray observatory located on 3000 km^2 near Malargüe in the province of Mendoza in Argentina measuring cosmic rays with energy above 10^{18} eV. Baseline Auger consists of a surface detector that is comprised of 1660 water Cerenkov tanks that count particles in the tail of the air shower, and a fluorescence detector consisting of 24 fluorescence telescopes that register the light emitted by nitrogen molecules that are excited by the air shower. A small part of the observatory has been enhanced by infill water Cerenkov tanks at smaller inter-tank distances and three high elevation fluorescence telescopes to reduce the energy threshold by an order of magnitude, and by charged particle detectors buried underground for detection of the muon component in the air showers. The water Cerenkov tanks and fluorescence telescopes all perform well and the muon detection enhancement is being commissioned.

A consortium of Dutch groups from Nikhef, the University of Groningen and the Radboud University Nijmegen is participating in the Pierre Auger Collaboration since 2005. Besides analyzing the Auger surface and fluorescence detector data, the Dutch group pioneers the "radio dectection", which is a complementary technique to measure ultra-high-energy cosmic rays by detecting the radio frequency radiation emitted by the air shower.

The origin of ultra-high-energy cosmic rays

The Pierre Auger Collaboration had already shown definitively that the energy spectrum of cosmic rays exhibits a sharp drop around 10^{20} eV. This drop is compatible with the Greisen-Zatsepin-Kuz'min cut-off caused by the universe becoming opaque due to resonant collisions between ultra-high-energy protons and the photons of the cosmic microwave 2.7 K background radiation. However, new measurements of the nuclear composition of cosmic rays show a change from a proton-like composition at energies up to $10^{18.5}$ eV towards heavier nuclei at $10^{19.5}$ eV. This may hint at a maximum energy that can be reached by cosmic accelerators, where highly electrically charged nuclei are accelerated to higher energies than protons. Several phenomenological groups have shown that a spectrum of nuclei both fits the composition measurement and the energy spectrum of ultra-high-energy cosmic rays well. However, the evidence is far from conclusive.

Figure 1: AERA-2 radio detector station. The butterfly shape antenna just above the numbered plate receives the signals from air showers. The system is solar powered and the electronics is fit in the box behind the solar panel. The antenna on top of the pole is for the wireless communication to and from the station. The fence is to keep larger sized animals from damaging the station.

A search for neutrons shows that it is very unlikely that there are a few isolated strong sources in our galaxy that produce cosmic rays with energies around 10^{18} eV; hence, also the protons at this energy are very likely extra-galactic. This result is confirmed by limits from searches for photons at energy around 10^{18} eV and by a recent result from the Pierre Auger Collaboration that shows that the observed large scale isotropy is not compatible with protons with energies around 10^{18} eV originating from galactic sources.

New limits were published for neutrinos in the energy range for which they are expected from Greisen-Zatsepin-Kuz'min interactions with similar sensitivity as competitor observatories and just above the abundance at which they may be expected.

Radio detection of cosmic rays

Together with German and French groups, the Dutch group has established the Auger Engineering Radio Array (AERA), originally with 24 antenna stations and in summer 2013 enlarged with 100 additional ones. Half of the new stations are equipped with small scintillator trigger counters that enable triggering at the station level, while the other half is equipped with a large buffer memory that allows it to use the Auger surface detector and fluorescence detector triggers. As a result many trigger strategies can be compared and efficiencies measured with the enlarged set-up with a guaranteed large data set for simultaneous radio detection and surface and/or fluorescence detection in the near future.

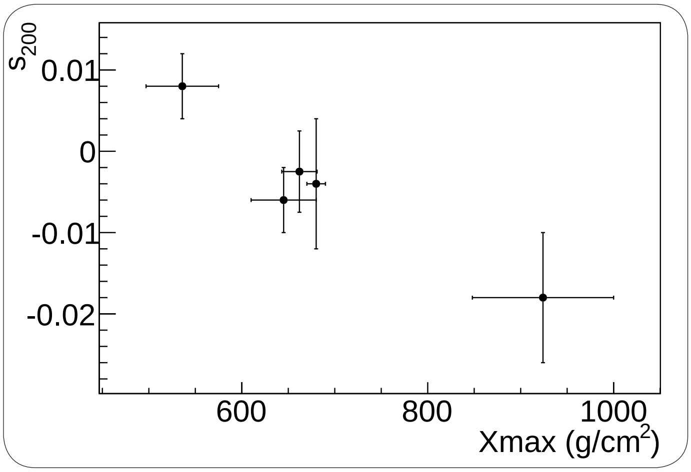


Figure 2: Depth of air shower maximum, Xmax, as measured by the Auger fluorescence detector versus slope of the signal frequency spectrum at 200 m from the shower axis, S_{200}, as measured with radio detection. Xmax is currently the best estimator for the composition of the incoming cosmic ray.

Fig. 1 shows a picture of one of the 100 stations installed in 2013. The Dutch group is also involved in using the core of the LOFAR radio telescope for the detection of cosmic rays. The energy range for detection in LOFAR is typically just below the Auger energy range, but the detection uses a very large density of radio stations, typically many hundreds. This allows for a precise determination of the lateral distribution of the signal around the air shower axis.

Composition of ultra-high-energy cosmic rays

It is crucial to know the composition, preferably on an event-to-event basis, to unravel the origin of cosmic rays at the highest energy. Such measurements are not available towards the highest observed energy and in the lower energy regime the composition determination is almost exclusively based on the single technique of fluorescence detection. The fluorescence telescopes operate only in dark nights, which is only about 10% of the total clock time. The Dutch group focuses on composition determination, both using the Auger surface detector and with radio detection. These provide both a better duty cycle and independent methods to check and calibrate the fluorescence telescopes.

PhD Guus van Aar was able to show in a preliminary result that the surface detector has a composition sensitivity with a resolution that is about two times worse than that of the fluorescence detector, but is better than the average separation between protons and iron and has a 24/7 duty cycle. This has been presented to the collaboration and will soon be published in an internal note.

Stefan Grebe obtained his PhD with a thesis that shows for the first time a composition measurement based on the pulse shape of the radio signal measured by a single station compared to fluorescence composition measurements, see Fig. 2.

By a detailed comparison of the lateral signal distribution with simulation on data of the LOFAR core, postdoc Stijn Buitink was able to show a first preliminary composition determination with a resolution similar to that of the Auger fluorescence detector.

Preparing for the future

In 2013 the Pierre Auger Collaboration prepared an upgrade proposal for the Pierre Auger Observatory beyond 2015. The upgrade is aimed at collecting more information on the composition at the highest energy. It entails faster electronics for the surface detector to be able to distinguish individual muons hitting the water Cerenkov tanks and dedicated muon detectors shielded by enough material to eliminate the electronic component in the air shower at the detector. Both these upgrades are aimed at a composition measurement that is slightly less precise than that of the fluorescence detector, but with a duty cycle approaching 100%.

At the end of 2013 five radio detector stations have been equipped with an antenna that is sensitive also to the vertical polarisation. If this shows successful the aim is to extend AERA with at least another 35 stations that measure all three polarisations.

2.7 Dark Matter
XENON & DARWIN

Management: dr. M.P. Decowski (PL)

The nature of dark matter is one of the biggest problems in modern physics. Nikhef is participating in the XENON-series of direct detection dark matter experiments that are particularly well suited to search for the Weakly Interacting Massive Particle (WIMP), a leading dark matter candidate particle. XENON100 is the running experiment which has published important constraints on WIMP parameters and we are currently constructing the XENON1T experiment which will allow a two orders of magnitude more sensitive search. We are also building a local xenon R&D laboratory to explore future detection techniques and investigate properties of xenon.

XENON100 Data Analysis

The XENON collaboration is continuing to record data with the XENON100 detector at the Gran Sasso underground laboratory (LNGS) in Italy and analyzing the data. The data-sets are typically subdivided into runs, *i.e.*, periods of time when the detector is running uninterrupted. The latest such run was completed in 2012, with a total of 225 days of dark matter data. The collaboration used these data this year to publish spin-dependent WIMP-neutron and WIMP-proton scattering results, see Fig. 1. Other papers focussed on refinements in the analysis procedures and understanding of the detector. We expanded a detailed paper describing the analysis procedures of XENON100 to include the latest run. We finalized the analysis, and published a paper that describes the response of the XENON100 dark matter detector to nuclear recoils and one that details our neutron backgrounds. These results are important for further understanding of XENON100 and for optimization of the XENON1T detector.

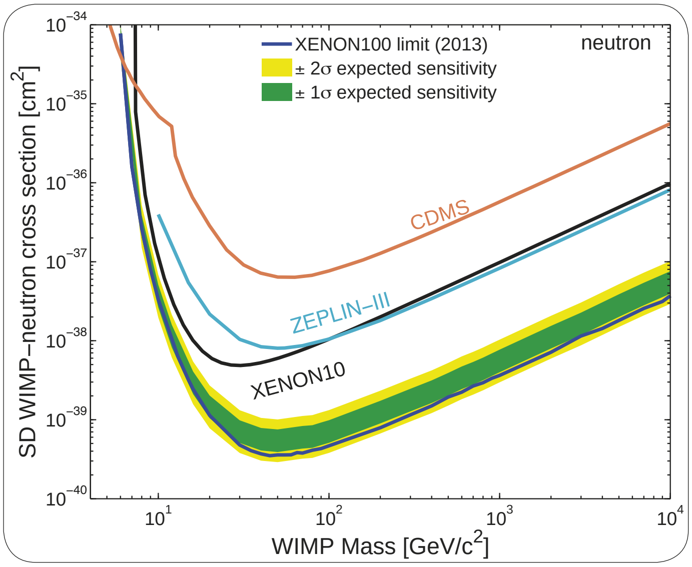


Figure 1. Results on spin-dependent WIMP-neutron scattering in XENON100. The coupling cross section is shown as a function of the WIMP mass. The expected sensitivity is shown by the green/yellow band (1σ/2σ) and the resulting exclusion limit (90% CL) in blue. For comparison, other experimental results are also shown. This is presently the most competitive result on WIMP-neutron scattering. XENON100 also published similar, less competitive, results for WIMP-proton scattering.

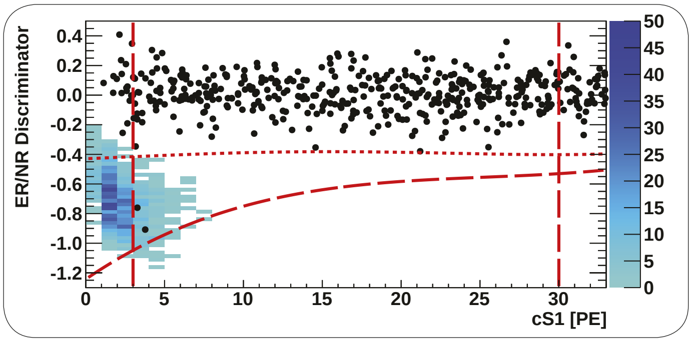


Figure 2. The electron/nuclear recoil (ER/NR) discrimination parameter plotted against a measure of the deposited event energy cS1. Observed events are shown by the black dots; the band with a discrimination value around zero is due to electron recoil events. Nuclear recoils are expected to occur in the region enclosed by the red dashed lines. The blue area shows the simulated event distribution expected for a 8 GeV/c² mass WIMP with a cross section of 3×10^{-41}cm², as allowed by recent CDMS-Si and CoGeNT results. 223^{+303}_{-85} events should be visible in the XENON100 225-day data-set, whereas only two events, with one expected background, are actually observed.

A new dark matter run was started in April 2013 after a number of months of detector improvement work. Apart from accumulating more dark matter data, the main purpose of this run will be to obtain an even better detector understanding through the use of new calibration sources. One source in particular that the collaboration wants to use is a ^{88}Y-Be source providing low-energy mono-energetic neutrons. This would allow the collaboration to experimentally confirm XENON100's low-mass WIMP detection capability. 2013 saw a number of experimental results claiming to detect these so-called low-mass WIMPs. The problem is that XENON100 does not observe a signal compatible with low-mass WIMPs at the same interaction cross section, see Fig. 2, and the present analysis excludes these claims to a high degree. The ^{88}Y-Be source would provide an important verification and calibration of our low-mass WIMP detection capability.

Construction of XENON1T

This year's focus was the design and start of construction of the XENON1T experiment, see Fig. 3. The construction of the water tank and the support building started in September 2013 and is nearing completion. The vibration-free cryostat support structure for which Nikhef carries responsibility, is presently being

Figure 3. Rendering of the XENON1T detector. The xenon target and TPC are inside a 1.4 m-diameter cryostat housed in a 10 m-diameter water tank.

constructed at an external company and will be shipped to LNGS in early 2014. Nikhef has also designed the mechanical structures for the automated calibration system that will deploy various calibration sources around the detector. Finally, we participated in a critical design review of the cryostat itself. Based on this review several important design modifications were performed.

Another effort for which Nikhef carries responsibility is the software-based event trigger and event builder as part of the XENON1T data-acquisition system. We completed a prototype of the system, including all necessary components. At the heart of the system is an open-source document database called MongoDB, which allows very efficient lookup of event fragments to make trigger decisions and event building. The focus will now shift to performance improvements and stress testing. The detector is still on schedule to start operation in early 2015.

Finally, the XENON collaboration is also exploring the option to increase the xenon target mass of the XENON1T detector from

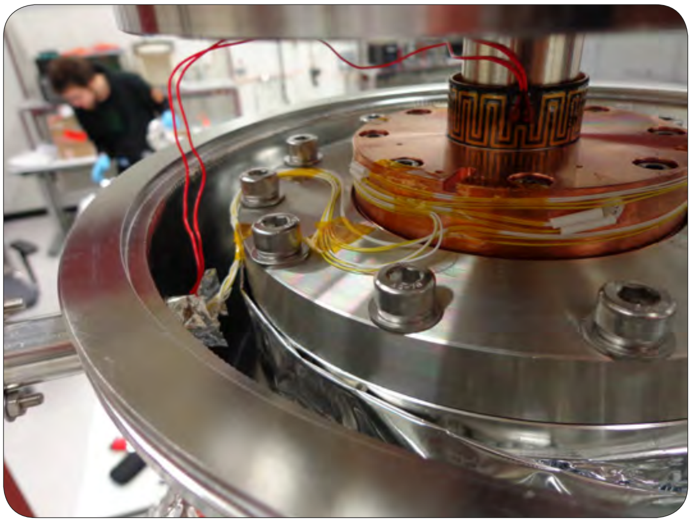


Figure 4. A picture of the heat-band around the XAMS cold-head used for xenon R&D at Nikhef.

3.5 tons to 7–8 tons as a future upgrade (called XENONnT). We aim to design XENON1T to allow the reuse of as many components as possible for XENONnT. All of the mechanical components that Nikhef is responsible for are already designed with XENONnT in mind.

The Dark Matter group is building a small dual-phase liquid xenon TPC at Nikhef. The project is called XAMS (*'Z-ahm-s'*) and will allow us to test new detection technologies in a xenon detector and to study the general properties of xenon. This is important for analysis of dark matter data coming from detectors such as XENON100 and XENON1T. We procured and assembled the cryostat and gas system to liquify and purify xenon in the past year. In November we successfully liquified xenon, an important milestone, and started the design of a xenon TPC. We hope to commission this small detector in early 2014.

2.8 Theoretical Physics

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

The Nikhef theory group this year had many members, thanks to grants obtained in the previous years. As a result, research in the group, including that of the VU University and Radboud University partners, ranged far and wide. New developments took place in B-physics, Higgs and top physics, new physics possibilites, quantum chromodynamics methods and results, cosmology, black hole physics, supergravity and string theory. Below we review these developments, in this order.

Research summary

The rare decay $B_s^0 \to \mu^+\mu^-$ is one of the most promising processes to test the quark-flavour sector of the Standard Model. Although still affected by sizable uncertainties, measurements of the $B_s^0 \to \mu^+\mu^-$ branching ratio by the LHCb and CMS collaborations were highlights of this year, with results in the ballpark of the Standard Model. In the comparison of the measured branching ratio with the theoretical prediction, subtle effects arising from the quantum-mechanical B_s^0–$\bar{B}_s^0$ mixing have to be taken into account. However, this phenomenon offers also a new observable, the effective $B_s^0 \to \mu^+\mu^-$ lifetime $\tau_{\mu+\mu-}$, and a CP-violating asymmetry $\mathcal{S}_{\mu+\mu-}$. A detailed analysis was performed, which explored the complementarity of these observables with respect to the conventional branching ratio information. Scenarios of physics beyond the Standard Model were considered where these observables allow a discrimination between model-independent effective operators and their CP-violating phases. In specific models with tree-level flavour-changing neutral currents mediated by a new heavy neutral gauge boson, striking patterns and correlations among these observables were pointed out. These first studies illustrate the power of $\tau_{\mu+\mu-}$ and $\mathcal{S}_{\mu+\mu-}$ to fully exploit the physics potential of $B_s^0 \to \mu^+\mu^-$, thereby putting exciting new topics on the agenda of the LHC upgrade era.

The important production of the Higgs boson in association with a top quark pair was explored. It allows the extraction of SM Yukawa coupling to the top quarks. In addition, more differential observables could tell us about the coupling structure. This mode is however notoriously difficult to detect given the complexity of the final state (high jet multiplicity) and given that it is affected by QCD backgrounds ($t\bar{t}$+jets) with much larger production rates. It was shown that the sensitivity to its presence can be significantly enhanced by means of the so-called matrix element reweighting method. In particular, this method is able to efficiently reduce the combinatorial problem arising from the jet multiplicity in the final state. Assuming SM production rates for signal and background processes, this matrix-element-based analysis leads to an expected 3σ (resp. 5σ) observation in the di-leptonic channel for a luminosity of 120 fb^{-1} (resp. 420 fb^{-1}) at 14 TeV.

Work continued on a novel method for computing two-loop scattering amplitudes in QCD. The calculation of two-loop QCD amplitudes will be necessary for precision phenomenology at the LHC in its second run. The advantage of the formalism being pursued over the more traditional approach of Feynman diagrams is the substantial reduction of diagrams that need to be evaluated in order to compute full amplitudes. For typical processes, the reduction is from several thousands of Feynman diagrams to on the order of 20–50 basis diagrams. The approach uses complex analysis (illustrated in Fig. 1) to determine the coefficients of these basis diagrams out of tree-level scattering amplitudes. This year the formalism was extended to two-loop double-box integrals with four massive external legs.

Various new developments took place regarding the FORM program and its applications. Partly in a collaboration with Tilburg University, new methods were developed for simplifying very large expressions for repeated and fast numerical evaluation,

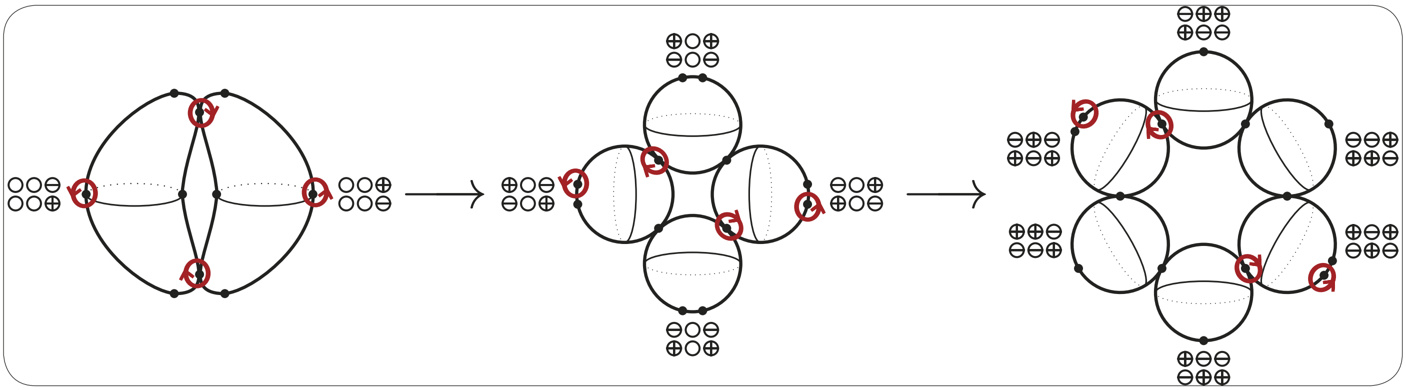


Figure 1. In two-loop maximal unitarity, two-loop QCD amplitudes are determined from products of tree-level amplitudes by evaluating the latter along specific complex integration contours, shown in red.

improving on e.g. Horner schemes. Among many other topics, this is very important in high energy physics for the efficient use of higher order calculational expressions, sometimes gigabytes in size, in QCD and electroweak theory.

Theoretical models that go beyond the Standard Model of electroweak interactions often predict the existence of so-called supersymmetric particles. At the Large Hadron Collider (LHC) a dedicated search programme is therefore devoted to finding these heavy supersymmetric particles. To provide theoretical predictions that are sufficiently stable and reliable, advanced resummation techniques for calculating the sizable quantum corrections are required. This year a big step was taken towards achieving the next level of precision in this context, *i.e.* performing the resummation at next-to-next-to-leading accuracy, which should become the new precision standard for the upcoming LHC searches.

Parton showers based on 2→3 dipole transitions rather than the more traditional 1→2 have recently been developed, having the advantage of more accurate kinematics, and possibly better imitation of exact calculations. The extension of such antenna-based showers to include exact next-to-leading QCD corrections, and the assessment of the optimal evolution variables was achieved in the VINCIA framework, for the case of electron-positron collisions.

The flavour dependence of the unpolarized transverse-momentum-dependent parton distribution functions (TMD PDFs) and fragmentation functions (TMD FFs) was studied. TMD distributions yield in a sense three-dimensional pictures in momentum space of hadronic structure, in contrast to the usual one-dimensional collinear parton distribution and fragmentation functions, and allow the study of cross sections for processes sensitive to the transverse motion of partons. An important question concerns their possible flavour dependence. This year this issue was studied in detail, assuming gaussian parametrizations for unpolarized TMDs from Semi-Inclusive Deep Inelastic Scattering (SIDIS) data collected at the HERMES experiment at DESY.

To further study TMD's, with which one can describe azimuthal asymmetries in processes with polarized particles in the initial or final state, process dependent effects have to be taken into account. A systematic classification was given for gluons, where it was possible to isolate the process dependence. Furthermore it was shown that in the Drell-Yan process for specific azimuthal asymmetries the proton correlators become colour entangled. Thus it is still possible to write the cross section as a product of two TMD PDFs, but it leads to additional colour factors. It was shown that this implies additional calculable colour factors in the corresponding cross section, which in specific cases may involve an additional sign flip.

Gluons inside an unpolarised hadron can be linearly polarised, if one takes into account their transverse momentum with respect to the direction of motion of the parent hadron. This still unknown, nonperturbative distribution, corresponding to an interference between +1 and −1 gluon helicity states, could form a valuable addition to the analysis methods currently used to determine the quantum numbers of the newly found boson at the LHC. During this year it was shown how the linear polarisation of gluons can be directly probed in dijet or heavy quark pair production in electron-hadron collisions, and in quarkonium production experiments at the LHC. This might also be relevant for Higgs production studies.

Turning to cosmology, one may consider whether the Standard Model Higgs field can drive inflation. Such Higgs inflation is possible if it is non-minimally coupled to gravity. This set-up thus relates electroweak scale quantities (measured at the LHC) with inflationary scale observables (extracted from the Cosmic Microwave Background). However, a meaningful comparison is only possible if quantum corrections are taken into account. In a careful study some of the subtleties involved in this calculation were discussed, thereby resolving various conflicting/wrong statements in the literature.

Hints of anomalies in the Cosmic Microwave Background (CMB) data from the Planck satellite motivated a search for possible explanations. If real, it is likely that features in the inflation model are responsible for these anomalies. It was found that even a very mild influence of extra (heavy particle) degrees of freedom during inflation might explain these anomalies and therefore their effect is potentially observable. This aspect might be a new window to the study of high energy theories through observations in in this era of precision cosmology.

The amount of dark energy and dark matter, different relics from the early universe, differ by a factor 5. It might be that dark and ordinary matter originated from the same mechanism. In such an 'Asymmetric Dark Matter' scenario, the dark matter relic abundance arises from an excess of dark particles over dark antiparticles. This excess is converted dynamically to the particle-antiparticle asymmetry of ordinary matter, by early universe processes. Possible connections of asymmetric dark matter to neutrino mass-generation mechanisms were explored, and it was investigated whether the capture of dark matter in neutron stars can constrain the asymmetric dark matter scenario. Also a review was given of various model-building and phenomenological aspects of this scenario.

The collective dynamics of scalar fields in a homogenous and isotropic universe was studied. Analytical solutions of the Friedmann equation for pure scalar cosmologies were constructed, some exact, and many using a newly developed perturbative approach. A number of general theorems concerning these solutions were established. In particular, the Hubble parameter representing the fractional rate of change of the universe can never increase during the evolution of such a universe; and if the scalar potential has a region of negative values, eventual collapse of the universe becomes inevitable.

In a very comprehensive study the present state of affairs of the predictability of the Standard Model itself, and possibly new physics was reviewed. In particular, the possibility of a huge 'landscape' of possibilities of possible universes was discussed from both top-down and bottom-up perspectives, including the issue of anthropic arguments.

Black holes, which lie at the intersection of quantum mechanics and general relativity, provide a particularly fertile testing ground for many ideas in string theory. Since the 1970s, it has been known that black holes should radiate with a temperature related to their mass and an entropy related to their area. The latter may actually also be seen as a statistical entropy, arising from string theory microstates, just as macroscopic properties of a gas arise from their microscopic description. This remarkable connection can be tested for many types of black hole solutions, where small corrections to black hole entropy become important. This was done via possible higher derivative couplings, arising from quantum effects, in the effective four dimensional Lagrangian allowed by supersymmetry.

It was also found that a class of supergravity interactions based in turn on a very large class of higher-derivative couplings, involving as a special case a supersymmetric version of a topological (Gauss-Bonnet) invariant will not contribute to the entropy of supersymmetric black holes. This restricts the relevant four-dimensional contributions to black hole entropy to a minimal set of holomorphic interactions in the effective action.

Scalar particles in supergravity theories, though difficult to treat, do possess a geometric description with only certain interactions, lessening the complications. In less supersymmetric situations their analysis is more difficult. Usually, one is concerned with the so-called 'flat directions' of the potential for the scalar fields, corresponding to their massless excitations. This year an interesting feature of these flat directions was discovered in both five and ten dimensions. When black hole solutions preserve a sufficient amount of supersymmetry, the flat directions actually remain flat and their corresponding particles remain massless even after the addition of more complicated higher-derivative interactions.

Other more explicit links between 4D supergravity and string theory have been explored, motivated by the discovery of a new family of supergravity theories with maximal supersymmetry, the so-called gauged SO(8) supergravities, parametrized by a quantity ω. To understand the origin of this family, an eleven dimensional perspective was chosen, the highest possible in this case, where supergravity is unique and possibly a low energy limit of string/M-theory. In this way it could be studied whether the 4D theories for any ω could be recovered by dimensional reduction from 11D. There are strong indications at present that this is only possible for special values of ω.

In three dimensions, various highly supersymmetric theories have been of major interest in recent years with the aim of developing a description of multiple M2-branes: extended objects of two spatial dimensions believed to play a key role in M-theory, similar to the role of one dimensional strings in string theory. To couple them to supergravity requires a fully developed formulation of 3D supergravity-matter systems. A construction of a new formulation of three-dimensional supergravity with conformal symmetry was achieved, as well as a whole new set of 3D supergravity actions. These may be important to describe M2-branes dynamics.

Other news

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, and elsewhere. Their informal character, with ample time for discussion and collaboration, is very fruitful. The national Seminar on Theoretical High-Energy Physics continues to be held at Nikhef and to attract excellent speakers.

Outreach activities of the theory group include the HiSPARC project as well as members giving lectures to high-school students and many other interested groups. At the Nikhef open day, the group hosts 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 Detector Research & Development group remained on novel gaseous pixel detectors (GridPix) and semiconductor detectors for particle tracking, with the aim of developing new detectors for Nikhef's (astro-) particle physics programmes. We collaborated with several internal and external groups both in the design and construction of pure scientific instrumentation, and on its development into commercial applications (valorisation).

Together with the Nikhef ATLAS group we hired a PhD student to investigate self-triggering and on-chip pattern recognition for use in, for example, the ATLAS L1 trigger. With the Nikhef Dark Matter group we continued construction of a test facility to investigate various detector technologies at liquid xenon temperatures. Through the Nikhef gravitational-waves group we are involved in the development of sensing systems to align Virgo's optical test masses and to compensate possible mirror abberations. This collaboration also resulted in a grant within the High Tech Systems and Materials (HTSM) programme to develop ultra-sensitive accelerometers for future gravitational-wave detectors. These accelerometers will have applications outside our field, and this is one example of the group's involvement in valorisation: the development of scientific instrumentation towards commercial applications.

The compostion of the group changed over 2013. The R&D group has welcomed new staff member Els Koffeman; together with Philips we are working with two students in the INFIERI Initial Training Network on cutting edge technology in telecommunications, photonics and electronics; and the number of students with a Master project in detector development is increasing. Moreover, Harry van der Graaf started his ERC Advanced Grant programme and hired a postdoc and two PhD students to study the physics of ultra-thin membranes to develop new types of particle detectors.

Semiconductor Detectors

About ten years ago Nikhef started developing timing circuitry for pixelated particle detectors. The Timepix3 chip, which became available in the second half of 2013, is the latest member of a succesful pixel chip family. This radiation hard ASIC containing 64,000 pixels was developed together with CERN and the University of Bonn. The timing resolution (1.56 ns) has been improved compared to the previous version of the Timepix chip by almost a factor of ten and this gives a large improvement in the z-resolution for our Gridpix detectors discussed in the next section. Other novelties of this chip are that it offers simultaneous time-of-arrival and time-over-threshold measurements in

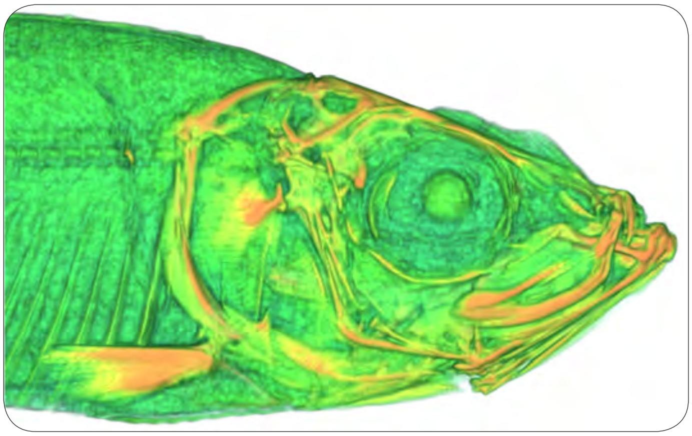


Figure 1. Reconstruction of a frozen fish with conventional computed tomography at Nikhef. Material resolution can be added with spectroscopic pixel detectors with more intelligent pixels, which are currently under development, leading to real colour computed tomography.

each pixel, and it has a data-driven readout with a rate capability of up to 80 MHits/s. To cope with the full data-stream of about 6 Gbit/s an FPGA based readout system (SPIDR) has been developed. This system controls the Timepix3 chip, packs the output data and sends it over a 10 Gbit/s ethernet network to the data acquisition. Testing of the Timepix3 chip, for which the SPIDR readout is essential, is in full swing and the chip performs according to specification. The first particle tracks with a micromegas foil mounted on top of the chip have been recorded.

For the upgrade of their vertex detector, the LHCb collaboration decided in 2013 to use silicon hybrid pixel technology. This requires the development of a new pixel ASIC in a 130 nm CMOS (complementary metal-oxide-semiconductor) technology, called VeloPix. The VeloPix design has started. It is based on our Timepix3 developments, but has a 8 times higher hit rate capability and features an output bandwidth of almost 20 Gbit/s. This enormous bandwidth requires the development of a new high speed serialiser. Submission of the full scale VeloPix is foreseen for the second half of 2014.

These developments of more intelligent readout chips for particle tracking detectors can also be utilized in imaging applications. X-ray imaging is based on the measurement of the properties of an X-ray beam transmitted through an object. In conventional X-ray imaging only the intensity (number of photons) is measured, but with our novel pixel chips X-ray detectors have spectral resolution as well, while keeping an appropriate spatial resolution. Energy sensitivity allows to do material resolved imaging by measuring differences in the energy dependence of the X-ray cross sections of different materials. When applied to Computed

Tomography (CT), it also helps minimizing (or even eliminating) beam hardening artifacts, which are due to the fact that conventional systems still cannot take into account the polychromatic nature of the tube spectrum in the reconstruction algorithms. It is also believed that new detectors will improve other issues, such as signal-to-noise ratio and dose reduction. Hence, spectral CT is considered to be the future of X-ray imaging.

Gaseous pixel detectors

The gaseous GridPix detector is based on a fine-granularity pixel chip that is able to record the time of arrival of the incoming signal. Thanks to the small pitch of the pixel cells (55 × 55 μm^2), the detector collects the individual electrons that are liberated in the gas volume by a traversing charged particle as illustrated in Fig. 2. This kind of tracking detector, collecting all information that can be deduced from the ionization trail of a charged particle in gas, has a wide range of applications like the time projection chamber of the proposed experiment at the International Linear Collider (ILC), the first level triggering of the ATLAS inner detector and in proton therapy. In the framework of developing the Timepix3 chip, the Gossipo-2 prototype chip has been designed, consisting of a matrix of only 16×16 pixels. We used it as the basis for a complete GridPix detector, where we profit from its upgraded time measurement properties. In 2013 the detector has been completed and subsequently tested in a testbeam at DESY. The aim of the testbeam experiment was to measure the angular resolution of the reconstructed tracks from data of the Gossipo-2 detector. We recorded 300k triggers in the 1.3 mm high drift space using tracks of several GeV electrons under angles between 2° and 47°. A preliminary analysis yielded a resolution of 3° for angles up to 30°. At larger angles the error increased in combination with a systematic deviation towards the smaller angles.

Over the last two years we realized that our GridPix technology can contribute to the development of instrumentation for cancer treatment. An increasing number of patients could benefit from the use of proton beam therapy for tumor irradiation. However, the full potential of proton beam therapy relative to X-ray irradiation is not yet fully exploited. Proton beam therapy offers the possibility to prevent the irradiation of critical tissues surrounding a tumor much better than one can achieve with X-rays. However, this benefit can only be exploited properly if one has sufficiently detailed information about the proton-stopping-power distribution in the patient, to make sure the protons mainly target the tumor cells.

Currently, such information is deduced from X-ray CT attenuation images. As the physics of attenuating X-rays differs significantly from the stopping of protons, this information is of limited value. Using proton radiographs in combination with the already available X-ray CT data, we can improve the resolution of the proton-stopping-power distribution for deep-seated tumors from 1 cm to 1 mm.

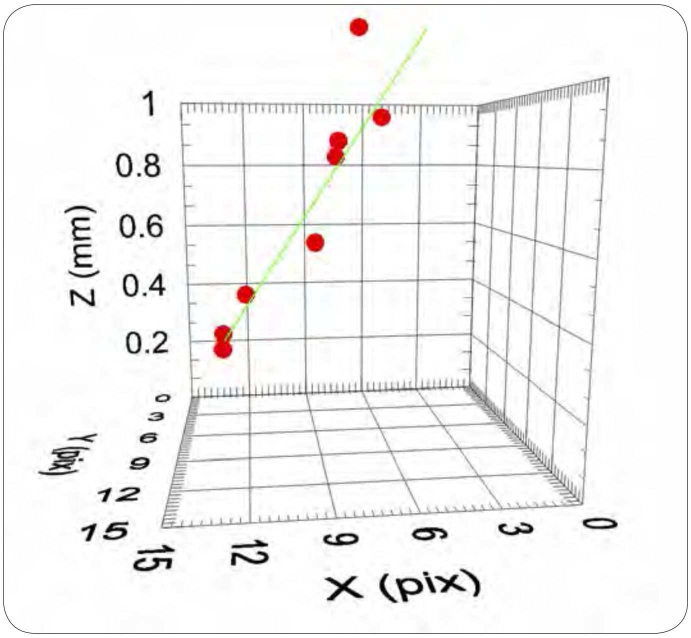


Figure 2. A reconstructed electron track (green line) with a 32° angle in the Gossipo-2 detector. The red dots are the measured positions of the liberated electrons.

In the Netherlands, Nikhef and KVI have joined forces to work on new detection systems for proton beam therapy. We have developed a prototype proton beam radiography system that consists of two GridPix based tracking devices and one calorimeter to determine the deposited energy in a patient. The tracking devices are GridPix based time-projection-chambers that provide unambiguous 3D tracks of protons before and after transmission of the patient. In combination with the deposited energy this provides the best possible data to reconstruct the most-probable-path of the proton through the patient, and as such an accurate proton-stopping-power map.

Accelerator alignment

Over the last 15 years Nikhef has developed several optical alignment systems for *e.g.* the alignment of the ATLAS detector elements. Currently, we are investigating whether these alignment systems can be developed further for the pre-alignment of accelerator structures of a future linear collider. Linear colliders require accurate pre-alignment of the accelerator sections (10 μm

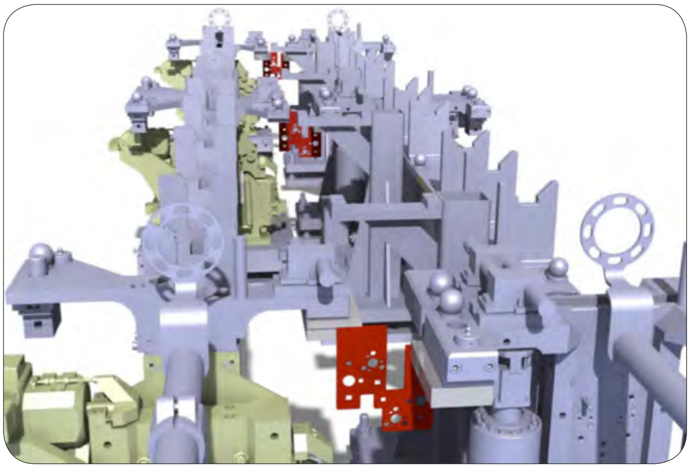


Figure 3. The CLIC alignment mock-up (4m) at CERN, with in red the mechanical mounts that hold the optical alignment systems

per 200 m). We aim to validate our new optical alignment system for large mechanical structures –the so-called RasDif system– and, eventually, to out-perform the conventional stretched wire systems. The RasDif system has already achieved sub-micron alignment accuracy at a test bench at CERN over 140 meters. The system is a 3-point straightness monitor consisting of a monochromatic light source, a diffraction plate and a pixel image sensor. By monitoring the position of a diffraction pattern on the image sensor, a measure for the relative positions of the three components is obtained.

Another test bench has been constructed in 2013 in collaboration with the Compact Linear Collider (CLIC) alignment group at CERN. This mock-up with two CLIC accelerator sections of 2 m each is shown in Fig. 3 and will be used in the coming year to test the performance of various alignment systems over shorter distances. At the beginning and end of each of these CLIC sections, our optical alignment systems have been installed. In addition, proximity alignment systems have been installed between the main beam and the drive beam. This small optical alignment system of 60 mm length ensures the correct distance between the two CLIC beams. This is relevant since precise timing of the delivery of the electrons by the RF drive beam to the accelerating cavities in the main beam is important.

2.10 Grid Computing
Large-scale scientific computing

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

For the grid facilities at Nikhef, 2013 was a year of business mostly as usual, the notable exception being a marked increase in the amount of non-HEP computing work performed on our grid cluster. Given the close of the BiG Grid project as well as the European middleware projects (EMI and IGE), which had funded much of our development work, 2013 gave our group an opportunity to refine the focus of our research activities.

Facilities

The grid facilities at Nikhef continued to run smoothly (99% availability) this year. Usage was also high, with only 2.4% of the computing power going unused. Fig. 1 shows how the computing power of the Nikhef grid cluster was used in 2013. In May, new capacity was installed, a large fraction of which replaced out-of-support hardware purchased in 2009; the rest (purchased via a subsidy from the national e-infrastructure operated by SURF) was used to expand capacity available to non-HEP experiments, whose usage of the facility expanded to 13% in 2013. A further expansion is expected soon, as LOFAR data processing on the grid begins in earnest early next year.

The grid group took increasing responsibility for the 'stoomboot' cluster, used mostly by Nikhef physicists for data analysis tasks. Main activities here were improving the scheduling, taking into account the wide range of activities for which stoomboot is used, and in improving access to data via both the network (mostly to grid storage at Nikhef and SARA) and via the `glusterfs` distributed file system.

Activities in support of Users

Activities regarding the Nikhef stoomboot cluster have already been mentioned above. Most of the effort went into understanding and correcting stability problems with the `glusterfs` distributed file system, via which much of the data was being analyzed. Work on improving the *performance* is still in progress.

Work on *multiprocessing* (for lack of a better term) continues to increase. Pilot studies on GPU use were undertaken in the context of the KM3NeT, LHCb and ATLAS experiments. Exploratory work on more traditional multiprocessing (parallelization across multiple cores and machines) was performed in the context of solid-state physics research undertaken in support of new-detector development, understanding how to optimize deployment and production for computing work using the VASP electronic structure code.

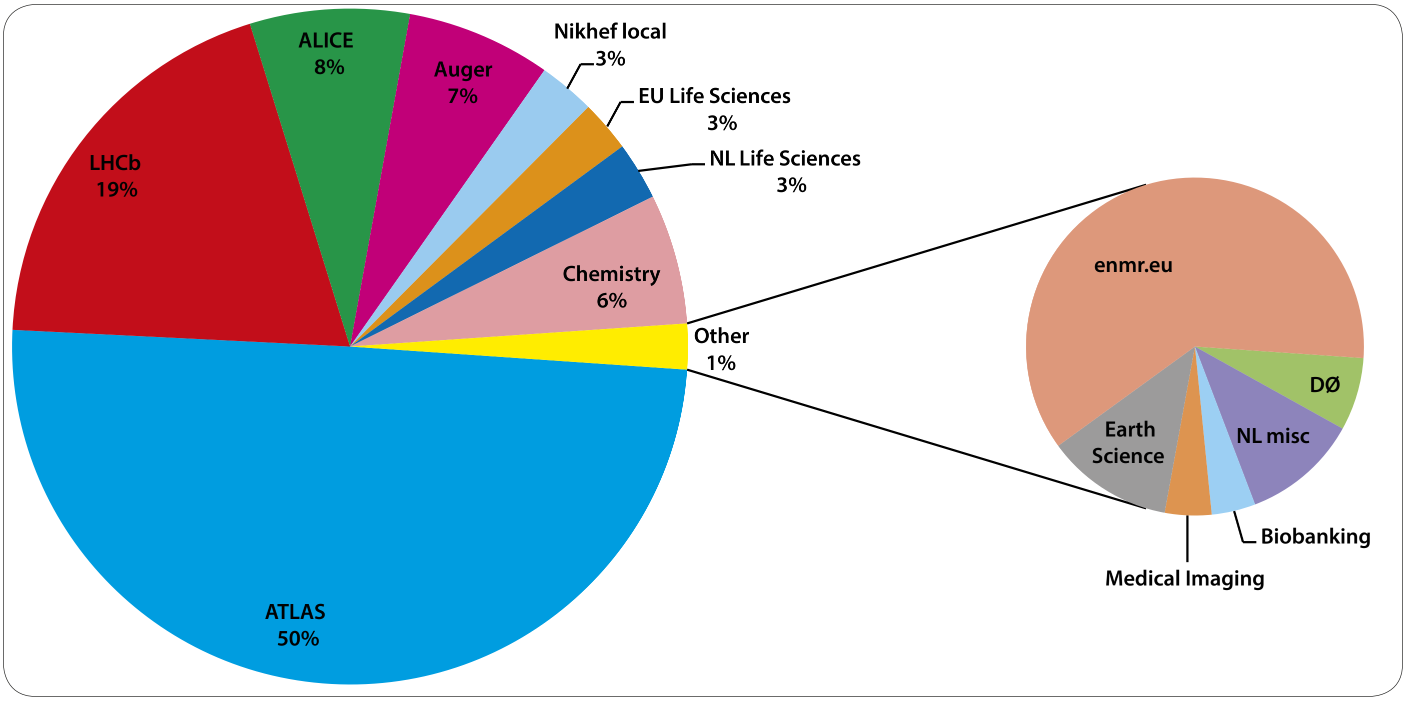


Figure 1. Usage of computing resources on the Nikhef grid cluster in 2013.

The first jobs from the Virgo (gravitational waves) group have been sighted on the Nikhef grid cluster, following on from discussions last year. Virgo intends to run their general-relativity simulation codes on the grid. Collaboration with the Nikhef XENON group on data management continues.

CHEP 2013
The 20th International Conference on Computing in High Energy Physics (CHEP 2013) was organized by our group (conference chair David Groep) and held in Amsterdam (*Beurs van Berlage*). Many contributions addressed issues of high-performance computing on multi-core machines, and dealing with extreme data volumes ('big data'). The conference was well attended (479 participants) and extremely well received by the attendees, despite the fact that many colleagues from US national laboratories (such as FNAL) were unable to attend due to the US government shutdown.

Figure 2. The CHEP 2013 conference in the Beurs van Berlage in Amsterdam.

Computer Science Research
Daniela Remenska's PhD project (our group collaborating with prof.dr. Henri Bal at the Free 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 are based. Currently her research focuses on forging a bidirectional link between the UML diagrams used by software engineers to specify software design, and the formal-method model representation of the software, in which verification can be carried out. Such a link will allow systems to be verified during the design stage, without the burden of constructing yet another representation of the program (in the formal-methods language).

National e-science infrastructure
This year, the SURF foundation assumed responsibility for the Dutch national e-science infrastructure (formerly operated by the BiG Grid project co-directed by Nikhef). One of the most visible changes was a major overhaul of the procedures for submission and review of requests for computing resources on the infrastructure. The simplifications resulted in a marked increase in the number of active users on the infrastructure; as discussed above this is immediately apparent from the usage statistics of our own grid cluster, which is operated as part of the Dutch national e-science infrastructure.

Nikhef is also involved in the NetherLands e-Science Center (NLESC), another element of the national e-science infrastructure. The NLeSC consists mainly of a team of e-science engineers who work on a wide variety of projects across many disciplines, the common feature being the enabling of new research via use of software, computing, storage, and network infrastructures. Nikhef contributes a member of the e-science *"Integrator"* team, a group of senior scientists deeply involved in computing for diverse fields such as High Energy Physics, Astronomy, Cognition, Genetics, and Water Management. This group is sufficiently broad *and* deep to significantly influence the national scientific computing agenda.

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.

The national e-science infrastructure funds development work at Nikhef as well, mainly in the area of *scalable multi-domain security.* One can think of this as an academic equivalent to *"sign on using your Google credentials"* —in our case, it's *"sign on using your institutional credentials"*, the idea being that when you are employed as a scientist at a research institute in the Netherlands, this status should grant you immediate access to a variety of electronic resources, without having to first *"register"* and *"create an account"*. Nikhef is active in this area both as a policy maker (how secure do institutional credentials need to be before you can trust them?) and as technology producer, constructing software enabling cross-institute collaborations based on the technology described above. Via funding provided by the European Grid Infrastructure (EGI), Nikhef also assumes primary responsibility for these policy tasks at the European level, along with major responsibility for coordination of the cyber security of the EGI.

Other Activities

Given sufficient funding, we plan to engage with the KM3NeT and LHCb groups at Nikhef surrounding optimization of their trigger software, the expectation being in both cases that there is much to gain from restructuring of the code and/or pursuing a move to newer hardware. There are also plans for a significant expansion of the stoomboot cluster, both in the sense of more job slots for the current activities, as well as a segment dedicated to parallel workflows such as those being run by the Nikhef Detector R&D group. Data management work will continue with the XENON group, who have also indicated interest in our GPU research. Finally we are closely following the (inter)national developments aimed at the Horizon2020 EU program, with the aim of making significant contributions, for example in the area of Identity Federations, an area both of Nikhef expertise and specific EU focus, given that most ESFRI projects are requesting this technology.

3

Output

3.1 Publications

ATLAS/D0

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, E.J. Buis, S. Caron, M.A. Chelstowska, A.P. Colijn, M. Consonni, V. Dao, P.C. Van Der Deijl, C. Deluca, P.O. Deviveiros, A. Doxiadis, B. van Eijk, P. Ferrari, F. Filthaut, C.Galea, 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, I. Mussche, L. de Nooij, J.P. Ottersbach, P. Pani, E. van der Poel, M. Raas, A. Reichold, M. Rijpstra, N. Ruckstuhl, A. Salvucci, J. Snuverink, D. Ta, M. Tsiakiris, E. Turlay, W. Verkerke, J.C. Vermeulen, M. Vranjes Milosavljevic, M. Vreeswijk, I. van Vulpen

Measurements of top quark pair relative differential cross–sections with ATLAS in pp collisions at $\sqrt{s}$=7 TeV
Eur. Phys. J. **C 73** (2013) 2261

Search for pair–produced massive coloured scalars in four–jet final states with the ATLAS detector in proton–proton collisions at $\sqrt{s}$=7 TeV
Eur. Phys. J. **C 73** (2013) 2263

Measurement of the flavour composition of dijet events in pp collisions at $\sqrt{s}$=7 TeV with the ATLAS detector
Eur. Phys. J. **C 73** (2013) 2301

Jet energy measurement with the ATLAS detector in proton–proton collisions at $\sqrt{s}$=7 TeV
Eur. Phys. J. **C 73** (2013) 2304

Single hadron response measurement and calorimeter jet energy scale uncertainty with the ATLAS detector at the LHC
Eur. Phys. J. **C 73** (2013) 2305

Jet energy resolution in proton–proton collisions at $\sqrt{s}$=7 TeV recorded in 2010 with the ATLAS detector
Eur. Phys. J. **C 73** (2013) 2306

Measurement of the $t\bar{t}$ production cross section in the τ + jets channel using the ATLAS detector
Eur. Phys. J. **C 73** (2013) 2328

Multi–channel search for squarks and gluinos in $\sqrt{s}$=7 TeV pp collisions with the ATLAS detector at the LHC
Eur. Phys. J. **C 73** (2013) 2362

Measurement of k_T splitting scales in $W \rightarrow \ell\nu$ events at $\sqrt{s}$=7 TeV with the ATLAS detector
Eur. Phys. J. **C 73** (2013) 2432

Search for a light charged Higgs boson in the decay channel $H^+ \rightarrow c\bar{s}$ in $t\bar{t}$ events using pp collisions at $\sqrt{s}$=7 TeV with the ATLAS detector
Eur. Phys. J. **C 73** (2013) 2465

Measurement of the inclusive jet cross–section in pp collisions at $\sqrt{s}$=2.76 TeV and comparison to the inclusive jet cross–section at $\sqrt{s}$=7 TeV using the ATLAS detector
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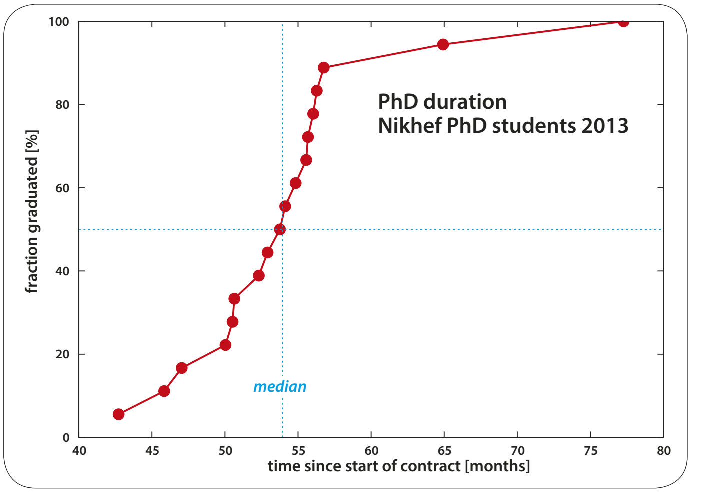


Figure 1. Fraction of PhD students working at Nikhef that graduated in the year 2013 as a function of time since the start of their thesis contract. The median PhD duration is 54 months (4.5 year).

3.2 Theses

Glenn Vanbavinckhove
Optics measurements and corrections for colliders and other storage rings
Universiteit van Amsterdam, 16 January 2013
Promotor: J.J. Engelen
Copromotor: L.R. Evans

Wilco Johannes den Dunnen
Polarization effects in proton-proton collisions within the Standard Model and beyond
Vrije Universiteit Amsterdam, 15 February 2013
Promotores: D. Boer, P.J.G. Mulders

Tri Laksmana Astraatmadja
Starlight beneath the waves: In search of TeV photon emission from Gamma-Ray Bursts with the ANTARES Neutrino Telescope
Universiteit Leiden, 26 March 2013
Promotor: M. de Jong

Raoul Stefan de Rooij
D^{*+} production in proton-proton and lead-lead collisions, measured with the ALICE experiment at the CERN-Large Hadron Collider
Universiteit Utrecht, 14 May 2013
Promotores: R.J.M. Snellings, R. Kamermans†
Copromotores: A. Mischke, A. Grelli

Alexandr Vladimirovich Kozlinskiy
Outer Tracker calibration and open charm production cross section measurement at LHCb
Vrije Universiteit Amsterdam, 22 May 2013
Promotor: M.H.M. Merk
Copromotor: Th.S. Bauer

Mark Gerrit Beker
Low-frequency sensitivity of next generation gravitational wave detectors
Vrije Universiteit Amsterdam, 28 June 2013
Promotor: J.F.J. van den Brand
Copromotor: H.J. Bulten

Lisa Christina Hartgring
Top Quark Spin and QCD Corrections in event generation
Universiteit van Amsterdam, 5 July 2013
Promotor: E.L.M.P. Laenen

Mikolaj Krzewicki
Anisotropic flow of identified hadrons in heavy-ion collisions at the LHC: from detector alignment and calibration to measurement
Universiteit Utrecht, 11 July 2013
Promotores: T. Peitzmann, R.J.M. Snellings
Copromotor: M. Botje

Stefan Grebe
Finger on the pulse of cosmic rays – dependence of the radio pulse shape on the air shower geometry
Radboud Universiteit Nijmegen, 9 September 2013
Promotor: S.J. de Jong
Copromotor: C.W.J.P. Timmermans

Sander Johannes Nicolaas Mooij
Effective theories in cosmology
Universiteit van Amsterdam, 24 September 2013
Promotor: E.L.M.P. Laenen
Copromotor: M.E.J. Postma

Magda Chelstowska
The road to the discovery of the Higgs boson in the $H \to WW^{(*)} \to \ell\nu\ell\nu$ channel
Radboud Universiteit Nijmegen, 25 September 2013
Promotor: N. de Groot
Copromotor: F. Filthaut

Jan Gerard Weenink
Gauge invariance and frame independence in cosmology
Universiteit Utrecht, 30 September 2013
Promotor: E.L.M.P. Laenen
Copromotor: T. Prokopec

Serena Oggero
Beauty in the crowd: Commissioning of the LHCb Pile-Up detector and first evidence of $B_s^0 \to \mu^+\mu^-$
Vrije Universiteit Amsterdam, 3 October 2013
Promotores: M.H.M. Merk, A. Pellegrino
Copromotor: M.G. van Beuzekom

Marta Verweij
Modelling and measurement of jet quenching in relativistic heavy-ion collisions at the LHC
Universiteit Utrecht, 7 October 2013
Promotores: R.J.M. Snellings, R. Kamermans†
Copromotor: M. van Leeuwen

Samo Jordan
Globally and locally causal dynamical triangulations
Radboud Universiteit Nijmegen, 16 October 2013
Promotor: R. Loll

Hurng-Chun Lee
Single top quark production at the LHC: Data processing and cross section measurement
Universiteit van Amsterdam, 29 October 2013
Promotor: S.C.M. Bentvelsen
Copromotores: M. Vreeswijk, J.A. Templon

Tjonnie Guang Feng Li
Extracting physics from gravitational waves: testing the strong-field dynamics of general relativity and inferring the large-scale structure of the universe
Vrije Universiteit Amsterdam, 20 November 2013
Promotor: J.F.J. van den Brand
Copromotor: C.F.F. Van Den Broeck

Stefan Rechenberger
Quantum Einstein gravity : the metric and the foliated formulation.
Radboud Universiteit Nijmegen, 21 November 2013
Promotor: R. Loll
Copromotor: F.S. Saueressig

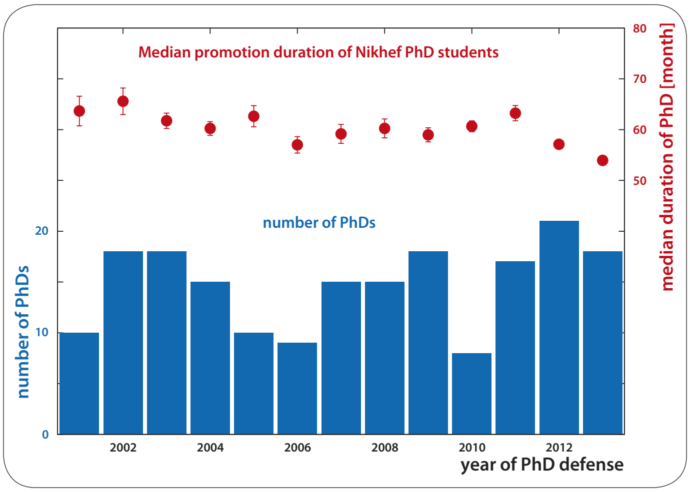
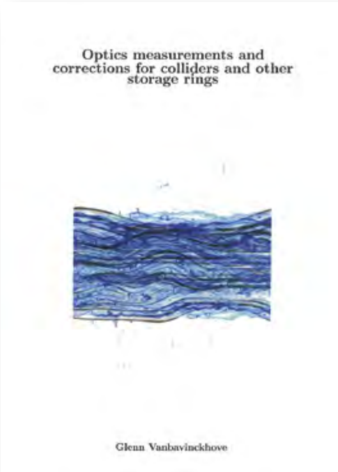
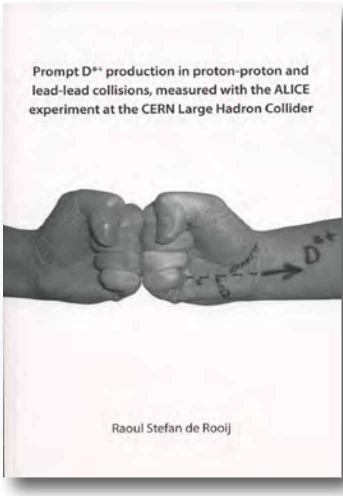


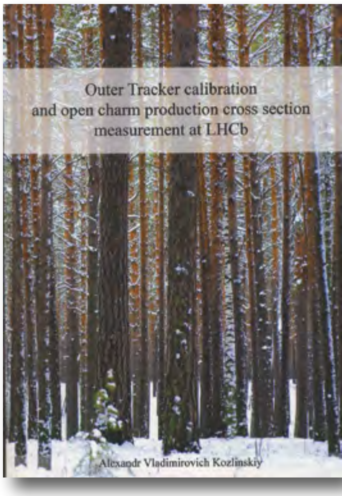
Figure 2. Median PhD duration of Nikhef PhD students since 2001 as a function of graduation year. The error bars represent the median absolute deviation (MAD)/√(n-1). The histogram gives the total number n of PhDs in each year.

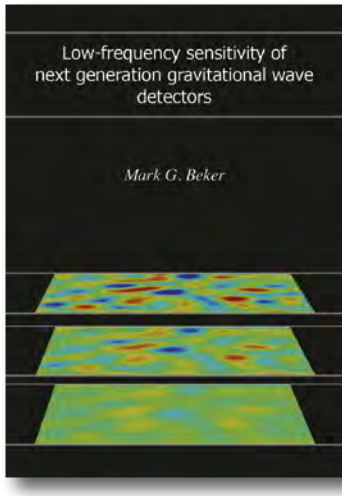

Optics measurements and corrections for colliders and other storage rings
Glenn Vanbavinckhove

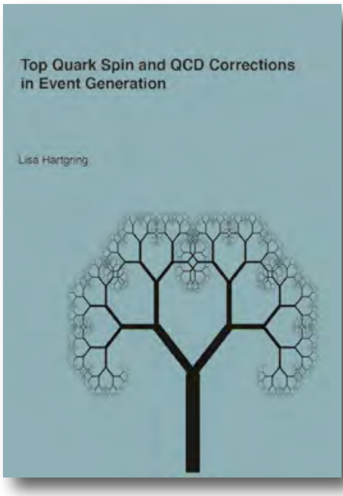

polarization effects in proton-proton collisions within the standard model and beyond
wilco den dunnen


Starlight beneath the waves
In search of TeV photon emission from Gamma-Ray Bursts with the ANTARES Neutrino Telescope
Tri L. Astraatmadja


Prompt D*+ production in proton-proton and lead-lead collisions, measured with the ALICE experiment at the CERN Large Hadron Collider
Raoul Stefan de Rooij

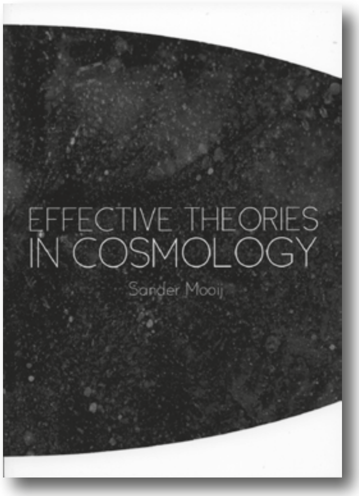

Outer Tracker calibration and open charm production cross section measurement at LHCb
Alexandr Vladimirovich Kozlinskiy

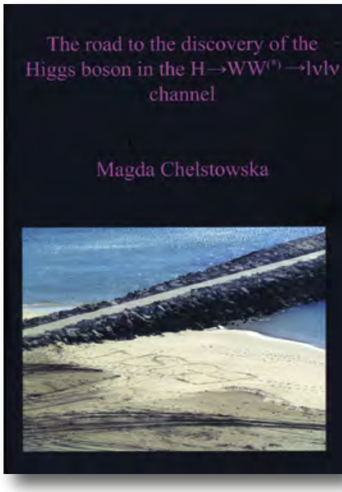

Low-frequency sensitivity of next generation gravitational wave detectors
Mark G. Beker


Top Quark Spin and QCD Corrections in Event Generation
Lisa Hartgring

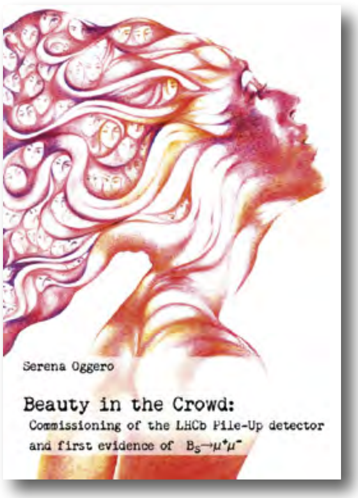

Anisotropic flow of identified hadrons in heavy-ion collisions at the LHC:
from detector alignment and calibration to measurement
Mikolaj Krzewicki

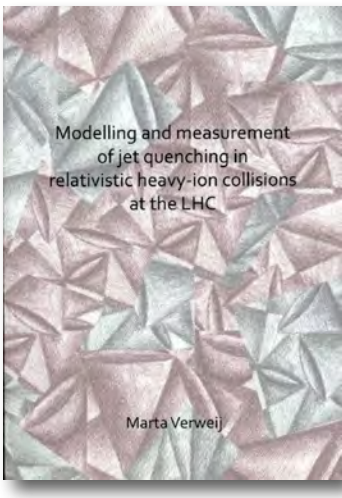

Stefan Grebe
Finger on the pulse of cosmic rays


EFFECTIVE THEORIES
IN COSMOLOGY
Sander Mooij


The road to the discovery of the Higgs boson in the $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ channel
Magda Chelstowska

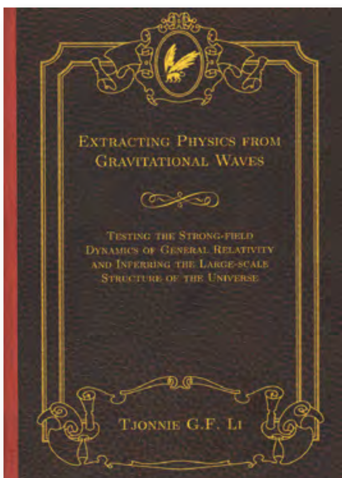

Gauge Invariance
and
Frame Independence
in Cosmology
Jan Weenink

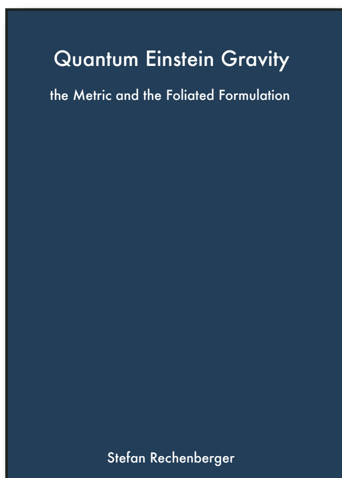

Serena Oggero
Beauty in the Crowd:
Commissioning of the LHCb Pile-Up detector
and first evidence of $B_s \rightarrow \mu^+\mu^-$


Modelling and measurement
of jet quenching in
relativistic heavy-ion collisions
at the LHC
Marta Verweij


Globally and Locally Causal
Dynamical Triangulations
Samo Jordan


SINGLE TOP QUARK PRODUCTION
AT THE LHC
- DATA PROCESSING AND CROSS SECTION MEASUREMENT -
HURNG-CHUN LEE


EXTRACTING PHYSICS FROM
GRAVITATIONAL WAVES
TESTING THE STRONG-FIELD
DYNAMICS OF GENERAL RELATIVITY
AND INFERRING THE LARGE-SCALE
STRUCTURE OF THE UNIVERSE
TJONNIE G.F. LI


Quantum Einstein Gravity
the Metric and the Foliated Formulation
Stefan Rechenberger

3.3 Talks

ATLAS
Aben, R.Z., Search for a Higgs boson in fermion modes using the ATLAS detector, Pheno2013, Pittsburgh, USA, 2013-05-06

Bentvelsen, S., Higgs status and prospects at LHC, Workshop Noncommutative Geometry and Particle Physics, Leiden, The Netherlands, 2013-10-14

Besjes, G.J., Estimating the SM background for supersymmetry searches: challenges and methods, 21st Int. Workshop on Deep-Inelastic Scattering and Related Subjects, Marseille, France, 2013-04-23

Caron, S., Exploring all possible regions of Supersymmetry with ATLAS, HEP colloquium, University Brussel, Brussels, Belgium, 2013-03-01

Higgs and Searches for new physics, BLV Conf. 2013, Heidelberg, Germany, 2013-04-09

Dao, V., Search for the Higgs boson in fermionic channels with the ATLAS detector, Conf. SUSY 2013, Trieste, Italy, 2013-08-26

Deluca, C.D., Searches for gluino-mediated production of third generation squarks with the ATLAS detector, 21st Int. Workshop on Deep-Inelastic Scattering and Related Subjects, Marseille, France, 2013-04-23

Filthaut, F., Physics Harvest at the Large Hadron Collider, Physics Colloquium, NTNU Trondheim, Trondheim, Norway, 2013-02-15

Gadatsch, S., Combination of Higgs results, Physics@FOM, Veldhoven, The Netherlands, 2013-01-23

Measurements of the Higgs Boson Couplings using the ATLAS Detector, NNV Fall Meeting, Lunteren, The Netherlands, 2013-11-01

Measurements of the Higgs Boson Main Coupling Properties using the ATLAS Detector, Workshop on Weak Interactions and Neutrinos, Natal, Brazil, 2013-09-17

Groot, de, N., Physics at the LHC, Quantum Universe 3, Groningen, The Netherlands, 2013-03-28

The discovery of the Higgs boson, Lunchlezing studentenvereniging de Leidsche Flesch, Leiden, The Netherlands, 2013-04-10

Igonkina, O., ATLAS trigger menu and performance in 2012-2013 and prospects for 2015, IEEE Conf., Seoul, South Korea, 2013-11-01

Jong, de, P.J., New Particle Searches at the Large Hadron Collider, Workshop on Non-commutative Geometry, Leiden, The Netherlands, 2013-10-14

The 2013 Physics Nobel Prize, Kavli Institute of Nanoscience, TU Delft, Delft, The Netherlands, 2013-10-31

Kuijer, P.G., Physics for Alice Upgrades, Heavy Flavour and QCD Phase Structure in High Energy Collisions, Berkeley, USA, 2013-11-21

The Ridge and More in Alice, Int. Conf. on the Initial Stages of High Energy Nuclear Collisions, Illa da Toxa, Spain, 2013-09-09

Lenz, T., Study of Higgs boson production in bosonic decay channels at the LHC, Rencontres du Vietnam, Quy Nhon, Viet Nam, 2013-08-14

Mahlstedt, J., Search for excited leptons in ATLAS, NNV Fall Meeting, Lunteren, The Netherlands, 2013-11-01

Searches for New Phenomena in Events with Multiple Leptons with the ATLAS Detector, 5th Workshop of High Energy Physics in the LHC Era, Valparaíso, Chile, 2013-12-16

Nooij, de, L., Underlying event and Multiple Parton Interactions with hard probes with ATLAS and CMS, workshop QCD@LHC, Hamburg, Germany, 2013-09-02

Pani, P., Searches for direct pair production of third generation squarks with the ATLAS detector, 21st Int. Workshop on Deep-Inelastic Scattering and Related Subjects, Marseille, Marseille, France, 2013-04-25

Salvucci, A., Observation of a Higgs-Like particle in the search for the Standard Model Higgs Boson in the $H\rightarrow ZZ^{(*)}\rightarrow 4\ell$ with the ATLAS detector at LHC, Physics@FOM, Veldhoven, The Netherlands, 2013-01-23

Recent Higgs$\rightarrow ZZ^{(*)}\rightarrow 4\ell$ Results: latest results from the search for the Standard Model Higgs Boson with the ATLAS experiment at LHC, Les Rencontres de Physique de la Vallée d'Aoste 2013, La Thuile, Italy, 2013-02-27

Verkerke, W., Discovery of a new particle at LHC: Higgs or Not?, Physics@FOM, Veldhoven, The Netherlands, 2013-01-23

Profiling and systematic uncertainties, Graduierten Kolleg Freiburg - Physik an Hadron-Beschleunigern, Lenzkirch-Saig, Germany, 2013-09-30

Profiling and systematic uncertainties, Graduierten Kolleg Freiburg - Physik an Hadron-Beschleunigern, Lenzkirch-Saig, Germany, 2013-10-01

RooFit and RooStats - a framework for advanced data modeling and statistical analysis, ROOT Users workshop, Amsterdam, The Netherlands, 2013-10-15

RooFit status and plans, ROOT Users workshop, Saas Fee, Switzerland, 2013-03-14

Status of top quark physics, 25th Rencontres de Blois on Particle Physics and Cosmology, Blois, France, 2013-05-28

Verlaat, B.A., Dimensioning of CO_2 cooling pipes in detector structures, Forum on Tracking Detector Mechanics, Oxford, United Kingdom, 2013-06-20

Novel technologies and materials for thermal management, ECFA High Luminosity LHC Workshop, Aix les Bains, France, 2013-10-02

Vulpen, van, I., Analysis walkthrough, Helmholtz Alliance Introductory Statistics School, DESY, Hamburg, Germany, 2013-03-18,

Introduction to Root and statistics tutorial, HASCO summerschool 2013, Göttingen, Germany, 2013-07-07

LHCb
Beuzekom, van, M.G., The upgrade of the LHCb Vertex Locator, Vertex 2013, Lake Starnberg, Germany, 2013-09-17

De Bruyn, K.A.M., Studies of CP Violation in B Hadron Decays, SUSY 2013, Trieste, Italy, 2013-08-26

Dettori, F., Performance of the LHCb detector during the LHC proton runs 2010-2012, 13th Vienna Conf. on Instrumentation, Vienna, Austria, 2013-02-14

Rare B decays, VI Italian workshop on pp physics at LHC, Genova, Italy, 2013-05-08

Very rare B decays at LHCb, 14th Int. Conf. on B-Physics at Hadron Machines - Beauty 2013, Bologna, Italy, 2013-04-09

Hulsbergen, W.D., Flavour in the era of the LHC, WHEPP 2013, Puri, India, 2013-12-14

Indirect CP violation in the B_s system at LHCb, Moriond QCD 2013, La Thuile, The Netherlands, 2013-03-12

Jans, E., Operational aspects of the VELO cooling system of LHCb, Vertex 2013, Lake Starnberg, Germany, 2013-09-19

Martinelli, M.M., The LHCb Upgrade, Beauty 2013, Bologna, Italy, 2013-04-12

Tracking and Alignment at LHCb, Int. Conf. on Astroparticle, Particle, Space Physics and Detectors for Physics Applications, Como, Italy, 2013-09-23

Merk, M.H.M., The Relativistic Quantum World part 1, Lecture Maastricht University, Maastricht, The Netherlands, 2013-09-16

The Relativistic Quantum World part 2, Lecture Maastricht University, Maastricht, The Netherlands, 2013-09-23

The Relativistic Quantum World part 3, Lecture Maastricht University, Maastricht, The Netherlands, 2013-09-30

The Relativistic Quantum World part 4, Lecture Maastricht University, Maastricht, The Netherlands, 2013-10-07

Voordracht voor Rotarians, Maastricht, Maastricht, The Netherlands, 2013-11-25

Oggero, S., The B_s meson decay in two muons: a search for rare beauty, Physics@FOM, Veldhoven, The Netherlands, 2013-01-22

Snoek, H.L., The LHCb VELO: Performance and Radiation Damage, 9th Int. "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors, Hiroshima, Japan, 2013-09-02

Tuning, N. Status Report, 114th LHCC, Geneva, Switzerland, 2013-06-12

Studies of the properties and decays of the B_c meson at LHCb, EPS HEP 2013, Stockholm, Sweden, 2013-07-18

The Performance and Radiation Hardness of the Outer Tracker Detector for LHCb, 13th Topical seminar on Innovative Particle and Radiation Detectors (IPRD13), Siena, Italy, 2013-10-08

ALICE

Bertens, R.A., v_2 of particles and jets: probing the QGP at the ALICE detector, NNV Fall Meeting, Lunteren, The Netherlands, 2013-11-01

Christakoglou, P., Angular correlations at the LHC with ALICE, 13th Zimanyi winter school on heavy ion physics, Budapest, Hungary, 2013-12-03

Angular correlation studies in lead-lead and proton–lead with ALICE, IX Workshop on Particle Correlations and Femtoscopy, Catania, Italy, 2013-11-05

Charge-dependent azimuthal correlations, QGP physics school, Siena, Italy, 2013-07-09

Results on angular correlations with ALICE, Strangeness in Quark Matter, Birmingham, United Kingdom, 2013-07-22

Kuijer, P.G., Recent Results of the Alice Experiment, Workshop on Nuclear Physics XIV, Havanna, Cuba, 2013-02-06

Leeuwen, M. van, Hard Probes of the Quark Gluon Plasma, Int. School on Quark-Gluon Plasma and Heavy Ion Collisions: past, present, future, Siena, Italy, 2013-07-09

Luparello, G., Measurement of D meson production in proton–lead collisions with the ALICE detector, Strangeness in Quark Matter, Birmingham, United Kingdom, 2013-07-26

Performance of ALICE silicon tracker detector, 22nd Int. Workshop on Vertex Detectors, Lake Starnberg, Germany, 2013-09-16

Mischke, A., Charm and heavy-flavour decay lepton production and flow at the LHC, SaporeGravis Workshop, I3 Hadron Physics Program I3HP3 of EU 7th Framework Programme, Nantes, France, 2013-12-03

Getting a flavour of the primordial matter in the early universe, seminar, Institute of Physics, Slovak Academy of Science, Bratislava, Slovakia, 2013-04-10

Heavy quarks as a probe of the Quark Gluon Plasma, seminar, Department of Physics and Astronomy, Utrecht, The Netherlands, 2013-06-20

Hot QCD matter under extreme condition: quest for the Quark Gluon Plasma properties, seminar, Polish Academy of Sciences, Crakow, Poland, 2013-09-20

Open Heavy Flavour, 2nd Int. Conf. on New Frontiers in Physics (ICNFP 2013), Kolymbari (Crete), Greece, 2013-09-04

Studying hot QCD matter at the CERN-LHC with heavy quarks, 21st Int. Workshop on Deep-Inelastic Scattering and Related Subjects, Marseilles, France, 2013-04-24

Nooren, G., First results of beamtests of a MAPS based ElectroMagnetic calorimeter, 11th Int. Conf. on Large Scale Applications and Radiation Hardness of Semiconductor Detectors RD13, Florence, Italy, 2013-05-05

Peitzmann, T., Upgrades and performance, Invited talk at Large Hadron Collider Physics Conf. - LHCP 2013, Barcelona, Spain, 2013-05-18

Upgrades: physics case and plans, LPC prospectives days in HI physics, Clermont-Ferrand, France, 2013-03-01

Bevor die Kerne wurden: Das Quark-Gluon Plasma, Invited talk at Symposium "Facetten moderner Kernphysik", Münster, Germany, 2013-10-25

Prototype studies for a forward EM calorimeter in ALICE, CHEF 2013 - Calorimetry for High Energy Frontier, Paris, France, 2013-04-24

The Forward Calorimeter Project, Workshop on Results and prospects of forward physics at the LHC, Geneva, Switzerland, 2013-02-12

The Forward Calorimeter Proposal in ALICE, III Workshop on QCD and Diffraction at the LHC joint with LHC Forward Physics and Diffraction WG meeting, Cracow, Poland, 2013-11-19

Upgrade of the ALICE experiment, Invited talk at 2nd Int. Conf. on New Frontiers in Physics (ICNFP 2013), Kolymbari (Crete), Greece, 2013-09-03

Zhou, Y., Anisotropic flow of identified particles in Lead–lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ALICE detector, Int. Conf. on Strangeness in Quark Matter, Birmingham, United Kingdom, 2013-07-23

Dark Matter

Colijn, A.P., Catching dark matter in the wild - underground dark matter detection experiments, Physics@FOM, Veldhoven, The Netherlands, 2013-01-22

The XENON1T experiment, 21st Int. Conf. on Supersymmetry and Unification of Fundamental Interactions, Trieste, Italy, 2013-08-29

Decowski, M.P., Direct Detection Dark Matter Experiments, Amsterdam-Paris-Stockholm meeting, Stockholm, Sweden, 2013-03-25

Overview of Directe Detection Dark Matter Experiments, Closing in on Dark Matter, Aspen, CO, USA, 2013-01-28

The Search for Dark Matter Particles, Colloquium at Free University Brussels, Brussels, Belgium, 2013-10-18

The missing Universe - what is dark matter?, Noncommutative Geometry and Particle Physics, Leiden, The Netherlands, 2013-10-14

Detector R&D

Graaf, van der, H., Micro Pattern Gas Detectors: status, outlook and new applications, ICATPP 2013, Villa Olmo, Como, Italy, 2013-09-25

The Tipsy single soft photon detector and the Trixy ultrafast tracker, Fast timing in light-production-based detectors, Ajaccio, Corsica, Italy, 2013-04-29

Tipsy & Trixy: Applications of Dynode Vacuum Amplifiers in Radiation Technology, Special Focus Workshop "Towards 10 ps…" IEEE/NSS, Seoul, South Korea, 2013-10-27

Ultrafast dynode electron multiplying detectors, CMOS Emerging Technology Symposium, Whistler, Canada, 2013-07-19

Ultrafast dynode electron multiplying detectors, seminar at TRIUMF, Vancouver, Canada, 2013-07-23

Koppert, W.J.C., GridPix Detectors: Production and Characterisation, Vienna Conf. on Instrumentation, Vienna, The Netherlands, 2013-02-12

Schioppa, E.J., Combined X-ray CT and mass spectrometry for biomedical imaging applications, 2013 Int. Workshop on Radiation Imaging Detectors, Paris, France, 2013-06-27

Gravitational Waves

Agathos, M., TIGER: A data analysis pipeline for testing GR with gravitational waves from coalescing binaries, 20th Int. Conf. on General Relativity and Gravitation and 10th Amaldi Conf. on Gravitational Waves, Warsaw, Poland, 2013-07-12

Using GW to determine the EOS of neutron stars, SRON mini-symposium on Gravitational Waves, Utrecht, The Netherlands, 2013-06-18

What do gravitational waves have to say about neutron stars?, 17th Symposium on Astroparticle Physics in the Netherlands, Nijmegen, The Netherlands, 2013-05-30

Agatsuma, K., Local control optical lever for iKAGRA payloads, Elites 2nd general meeting, Tokyo, Japan, 2013-12-05

Ambrosi, d', G., Beyond ISCO orbits for EMRIs, NNV Fall Meeting, Lunteren, The Netherlands, 2013-11-01

Beker, M., Newtonian Noise Subtraction, GW Advanced Detector Workshop, Elba, Italy, 2013-05-20

Advanced Virgo MutiSAS + Control, GW Advanced Detector Workshop, Elba, Italy, 2013-05-20

Bertolini, A., Update on Einstein Telescope site issues, Elites 2nd general meeting, Tokyo, Japan, 2013-12-04

Suspensions and seismic isolation in cryogenic environment, Elites 2nd general meeting, Tokyo, Japan, 2013-12-05

Blom, M.R., Kick off for Advanced Virgo: New seismic attenuation system for the next generation gravitational wave detector, Physics@FOM, Veldhoven, The Netherlands, 2013-01-22

New in-air seismic attenuation system for the next generation gravitational wave detector, 10th Amaldi Conf. on gravitational waves, Warsaw, Poland, 2013-07-09

New in-air seismic attenuation system for the next generation gravitational wave detector, 13th TAUP Conf., Pacific Grove, USA, 2013-09-11

Brand, van den, J.F.J., Development of a position sensor with femtometer resolution, Measuring by light, Shell Conference, Rijswijk, The Netherlands, 2013-11-22

Status talk on site studies for Einstein Telescope, Leibniz University Hannover, Einstein Telescope 5th General Meeting, Hannover, Germany, 2013-10-22

Detecting vibrations in spacetime, University of Groningen, Groningen, The Netherlands, 2013-03-21

Broeck, Van Den, C.F.F., Measuring the neutron star equation of state with gravitational waves, 18th Symposium on Astroparticle Physics in the Netherlands, Leiden, The Netherlands, 2013-10-23

Probing dynamical spacetime with gravitational waves, IVth School of Astroparticle Physics, Observatoire de Haute-Provence, St. Michel l'Observatoire, France, 2013-06-05

TIGER: A data analysis pipeline for testing GR with advanced gravitational wave detectors, Gravitational Wave Tests of Alternative Theories of Gravity in the Advanced Detector Era, Bozeman, USA, 2013-04-15

Testing general relativity with advanced gravitational wave detectors, Workshop on Science with the First Gravitational Wave Detections, South Padre Island, USA, 2013-05-22

What will be the first source detected by LIGO-Virgo?, 20th Int. Conf. on General Relativity and Gravitation and 10th Amaldi Conf. on Gravitational Waves, Warsaw, Poland, 2013-07-11

Del Pozzo, W., Strong field tests of GeneralRelativity, GW Advanced Detector Workshop, Elba, Italy, 2013-05-23

Hennes, E., Design aspects of vertically soft cryogenic suspensions, Elites 2nd general meeting, Tokyo, Japan, 2013-12-05

Status of Nikhef activities on crystalline suspensions, GW Advanced Detector Workshop, Elba, Italy, 2013-05-24

Heijningen,van, J., OSEMS on the payload prototype of the TYPE B/Bp suspension for KAGRA, Elites 2nd general meeting, Tokyo, Japan, 2013-12-05

Meidam, J., TIGER: A method for testing the strong-field dynamics of General Relativity with gravitational waves., NNV Fall Meeting, Lunteren, The Netherlands, 2013-11-01

Rabeling, D., ET Seismic surveys, GW Advanced Detector Workshop, Elba, Italy, 2013-05-20

Veitch, J., Parameter estimation for compact binary coalescence signals with LIGO-Virgo, 20th Int. Conf. on General Relativity and Gravitation and 10th Amaldi Conf. on Gravitational Waves, Warsaw, Poland, 2013-07-11

What will advanced detectors teach us about compact binaries, and how?, seminar, Cardiff, United Kingdom, 2013-04-12

Grid Computing

Dok, van, D.H., Experiences with moving to open source standards for building and packaging, 20th Int. Conf. on Computing in High Energy and Nuclear Physics, Amsterdam, The Netherlands, 2013-10-17

Keijser, J.J., A gridified version of 'rsync', EGI Community Forum 2013, Manchester, United Kingdom, 2013-04-12

Data Management for Digital Archivists, EGI Community Forum 2013, Manchester, United Kingdom, 2013-04-10

Dealing with a decommissioned SE, EGI Community Forum 2013, Manchester, United Kingdom, 2013-04-10

Remenska, D., From UML to Process Algebra and Back: An Automated Approach to Model-Checking Software Design Artifacts of Concurrent Systems, NASA Formal Methods Symposium, Moffett Field, CA, USA, 2013-05-14

Templon, J.A., Creating the Dutch National e-Infrastructure for Research, Int. Symposium on Grids and Clouds (ISGC 2013), Taipei, Taiwan, 2013-03-21

Miscellaneous

Decowski, M.P., Recent Results from the KamLAND-Zen Experiments, TAUP 2013, Asilomar, CA, USA, 2013-09-10

Status of Neutrinoless Double Beta Decay Experiments, Invisibles13 Workshop, Durham, United Kingdom, 2013-07-17

Jansen, S., Measuring properties of EeV cosmic rays using sub-μ eV photons, or: how to span 24 orders of magnitude with a wire., NNV Fall Meeting, Lunteren, The Netherlands, 2013-11-01

Vervoort, M.B.H.J., Risk Assessment of Occupational Used Nanomaterials – A comparison of Risk Assessment methods in order to determine the risk of Occupational used nanomaterials in a research environment, Dritte Hochschultagung 'Sichere gesunde Hochschule', Dresden, The Netherlands, 2013-09-18

Risk Assessment of Occupational Used Nanomaterials – A comparison of Risk Assessment methods in order to determine the risk of Occupational used nanomaterials in a research environment, NVVA (Nederlandse Vereniging Voor Arbeidshygiene)-symposium, Zeist, The Netherlands, 2013-04-17

Neutrino Telescopes

Samtleben, D.F.E., The High Energy Neutrino Sky as seen by ANTARES, Neutrino Telescopes, 25th Rencontres de Blois on Particle Physics and Cosmology, Blois, France, 2013-05-29

Schulte, S., Update on the ANTARES full-sky neutrino point source search, Neutrino Telescopes, Int. Cosmic Ray Conf., Rio de Janeiro, Brazil, 2013-07-08

Visser, E.L., Neutrinos from the Milky Way, Neutrino Telescopes, 18th Symposium on Astroparticle Physics in the Netherlands, Leiden, The Netherlands, 2013-10-23

Neutrinos from the Milky Way, Neutrino Telescopes, Physics@FOM, Veldhoven, The Netherlands, 2013-01-22

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Ambrosi, d', G., A song of waves and stars, PhD Day, Utrecht, The Netherlands, 2013-09-27

Neutron Stars? May be…, Postgraduate AIO/OIO School 2013 Theoretical High Energy Physics (THEP), Doorn, The Netherlands, 2013-02-18

Buffing, M.G.A., How to observe color in hadronic interactions if you are color-blind, NNV Fall Meeting, Lunteren, The Netherlands, 2013-11-01

Universality of TMD distribution functions, 21st Int. Workshop on Deep-Inelastic Scattering and Related Subjects, Marseille, France, 2013-04-24

Universality of gluon TMD distribution functions, QCD Evolution Workshop, Newport News, Virginia, USA, 2013-05-08

Using color to zoom in on quarks and gluons in a proton, DRSTP Postgraduate School, Doorn, The Netherlands, 2013-02-11

Butter, D.B., The N=2 Gauss-Bonnet and other higher derivative terms from conformal supergravity, The String Theory Universe, 19th European Workshop on String Theory, Bern, Switzerland, 2013-09-03

The N=2 Gauss-Bonnet invariant from conformal supergravity, Int. Workshop on Supersymmetries and Quantum Symmetries, JINR, Dubna, Russia, 2013-08-01

Ciceri, F.P.Y., Towards an N=4 conformal supergravity action, DRSTP THEP school, Doorn, The Netherlands, 2013-02-19

Contillo, A., Functional Renormalisation Group approach to Horava-Lifshitz gravity, University of Salerno, Salerno, Italy, 2013-10-02

Renormalization group flow of Horava-Lifshitz gravity at low energies, Asymptotic Safety seminar, Radboud University, Nijmegen, The Netherlands, 2013-11-04

The Asymptotic Safety guide to the Universe, University La Sapienza, Rome, Italy, 2013-10-10

The paradigm of Asymptotic Safety as a guiding principle to the early universe dynamics, Conf. LOOPS13, Waterloo, Canada, 2013-07-26

Cooperman, J.H., Renormalization of Entanglement Entropy and the Gravitational Effective Action, High Energy Physics Colloquium, Nijmegen, The Netherlands, 2013-09-09

De Bruyn, K.A.M., Hunting Penguins: Precision Measurements in the B Meson System, TU Dortmund, Dortmund, Germany, 2013-10-30

Fleischer, R., Probing New Physics with $B^0_s \to \mu^+\mu^-$, Portorož 2013 - Probing the Standard Model and New Physics at Low and High Energies, Portorož, Slovenia, 2013-04-15

Probing New Physics with $B^0_s \to \mu^+\mu^-$, Towards the Construction of the Fundamental Theory of Flavour, Munich, Germany, 2013-12-10

Theory Issues of Precision B Physics in the LHC Era, B-Physics School, Neckarzimmern, Germany, 2013-02-13

Towards New Frontiers in Precision B Physics: Theoretical Challenges and Perspectives, seminar at the Center for Particle Physics of Marseilles (CPPM), Marseille, France, 2013-06-17

Holten, van, J.W., Nobelprijs 2013, Faculteitsseminarium University Leiden, Leiden, The Netherlands, 2013-10-15

Scalar Cosmology, ApPEC APP meeting, Madrid, Spain, 2013-10-18

Scalar Cosmology, Workshop Beyond the Standard Model, Bad Honnef, Germany, 2013-03-20

Kasemets, T., Double parton distributions under evolution, MPI@LHC 2013, Antwerp, Belgium, 2013-12-05

Knegjens, R.J., A New Window for New Physics in B_s decays to two muons, Physics@FOM, Veldhoven, The Netherlands, 2013-01-23

B_s Effective Lifetimes: phenomenology with a non-zero B_s decay width difference implications workshop, CERN, Switzerland, 2013-10-14

Phenomenology with a non-zero B_s lifetime difference, Beauty 2013, Bologna, Italy, 2013-04-12

Laenen, E., Perturbation Theory to All Orders for Collider Physics, University of Edinburgh, Higgs Centre, Edinburgh, United Kingdom, 2013-02-01

Recent Developments in QCD Resummation, University of Valencia, Valencia, Spain, 2013-10-22

Recent Developments in Top Quark Physics, Universita di Roma "La Sapienza", Rome, Italy, 2013-04-29

Resummation in Gauge Theories, School for Analytical Computing in THEP, Atrani, Italy, 2013-10-01

Some Recent Developments in Top Quark Physics, University of Glasgow, Glasgow, United Kingdom, 2013-01-30

Summary Talk, Int. Workshop on Top Quark Physics, Durbach, Germany, 2013-09-19

Larsen, K.J., From Trees to Two Loops by Maximal Unitarity, Albert-Ludwigs Universität, Freiburg, Freiburg, Germany, 2013-06-04

From Trees to Two Loops by Maximal Unitarity, LHCPhenonet Workshop on Particle Physics, Buenos Aires, Argentina, 2013-04-24

From Trees to Two Loops by Maximal Unitarity, University of California, Los Angeles, Los Angeles, USA, 2013-04-16

Maximal Unitarity at Two Loops, Polylogarithms as a Bridge between Number Theory and Particle Physics, Durham, United Kingdom, 2013-07-12

Maximal Unitarity at Two Loops, The Geometry and Physics of Scattering Amplitudes, Stony Brook, USA, 2013-12-13

Loll, R., Causal Dynamical Triangulations and Time, Conf. Quantum Gravity in Paris 2013, Paris-Orsay, France, 2013-03-18

Causal Dynamical Triangulations without Preferred Foliation, 20th Int. Conf. on General Relativity and Gravitation, Warsaw, Poland, 2013-07-11

Causal Dynamical Triangulations without Preferred Foliation, Conf. Loops 2013, Perimeter Institute, Waterloo, Canada, 2013-07-25

Causal Dynamical Triangulations: Creating Spacetime Dynamically, Erlangen University, Erlangen, Germany, 2013-06-18

Constructing the Quantum Universe from Causal Dynamical Triangulations, University of Groningen, Groningen, The Netherlands, 2013-02-25

Quantum Gravity from Causal Dynamical Triangulations, Lecture Course, 2nd Erlangen Fall School on Quantum Geometry, Erlangen, Germany, 2013-10-01

Quantum Gravity from Causal Dynamical Triangulations, Perimeter Institute, Waterloo, Canada, 2013-05-23

Quantum Gravity on Your Desktop: The Emergence of Spacetime, IMAPP annual meeting, Radboud University, Nijmegen, The Netherlands, 2013-06-20

Quantum Gravity, Lecture Course, Theoretical High Energy Physics School 2013 of the Dutch Research School for Theoretical Physics (DRSTP), Doorn, The Netherlands, 2013-02-11

Mulders, P.J., Intrinsic transverse momenta at high energies, Invited talk at the Multiparton dynamics working group meeting (QCD@LH2013), Hamburg, Germany, 2013-09-02

Quantum Chromodynamics at Work, Invited talk at the Quantum Universe (QU3) meeting, Groningen, The Netherlands, 2013-03-27

TMDs of definite rank for quarks and gluons, Invited talk at the QCD Evolution Workshop 2013, Newport News, USA, 2013-06-05

TMDs: Theory and Phenomenology, Invited talk at the 13th Int. Conf. on Meson-Nucleon Physics and the Structure of the Nucleon (MENU2013), Rome, Italy, 2013-10-01

The role of transverse momenta and spins in QCD at high energies, Theory seminar, Physics Department, Roma University La Sapienza, Rome, Italy, 2013-02-11

Universality of azimuthal and spin asymmetries, 9th Circum-Pan-Pacific Symposium on High Energy Spin Physics, Ji'nan, China, 2013-10-30

Universality of azimuthal asymmetries at high energies, Indiana-Illinois Workshop on Fragmentation Functions, Bloomington, USA, 2013-12-13

Wilson lines off the light-cone in TMD PDFs, Invited talk at the Lightcone 2013, Skiathos, Greece, 2013-05-21

Nawata, S., Knot homologies and super-A-polynomials, seminar at Universidad Computense Madrid, Madrid, Spain, 2013-01-15

Quantum 6j-symbols for $U_q(sl_N)$, seminar on Elliptic Integrable Systems and Hypergeometric Functions at KdV Institute, Amsterdam, Amsterdam, The Netherlands, 2013-04-15

Chern-Simons theory and knot invariants, seminar at McGill University, Montreal, Canada, 2013-06-19

Chern-Simons theory, quantum knot invariants and volume conjectures, seminar at University of Warsaw, Warsaw, Poland, 2013-12-05

Knot homologies and extensions of volume conjectures, Serminar on Geometry and Mathematical Physics at KdV Institute, Amsterdam, The Netherlands, 2013-11-12

Knot homology and 3d gauge theory, seminar at Steklov Mathematical Institute, Moscow, Russia, 2013-09-10

Mirror symmetries from knots, Workshop on Knots and physics 2013 at University Amsterdam, Amsterdam, The Netherlands, 2013-09-27

Petraki, K., Asymmetric Dark Matter, seminar, Cambridge, United Kingdom, 2013-11-15

Asymmetric Dark Matter, seminar, Lancaster, United Kingdom, 2013-11-25

Cosmology and phenomenology of asymmetric dark matter models, Conf. SnowDARK 2013, Utah, USA, 2013-03-22

Pisano, C., Collins effect in pp → pion jet X at RHIC, Indiana-Illinois Workshop on Fragmentation Functions, Bloomington (Indiana), USA, 2013-12-13

Probing the linear polarisation of gluons inside the proton at the LHC, NNV Fall Meeting, Lunteren, The Netherlands, 2013-11-01

Reys, V.R., The kinetic multiplet in N=2, d=4 supergravity, Postgraduate AIO/OIO School 2013 Theoretical High Energy Physics, Doorn, The Netherlands, 2013-02-14

Rietkerk, R.J., Spin correlations with Higgs bosons, Postgraduate AIO/OIO School 2013 Theoretical High Energy Physics (THEP), Doorn, The Netherlands, 2013-02-18

Rijken, T., Baryon-baryon Interactions, The Strangeness Nuclear Physics School 2013, J-PARC (Tokai) and Tohoku University (Sendai), Tokai and Sendai, Japan, 2013-02-14

Baryon-baryon interactions, Workshop Nuclear equation of state and hyper nuclear physics, Yukawa Inst. of Theor. Physics, Kyoto University (YITP), Kyoto, Japan, 2013-01-18

ESC08-models of Baryon-baryon Interactions, Flavor SU(3) Meson-exchange viewpoint, HPCI & iTHES Workshop, RIKEN, Tokyo, Japan, 2013-12-12

ESC08-models of Baryon-baryon Interactions, Flavor SU(3) Meson-exchange Viewpoint, Workshop Hadron-Physics at J-PARC, Tokai, Japan, 2013-02-12

Extended-soft-core Baryon-baryon Model ESC08. Flavor SU(3) Meson-exchange viewpoint, Strangeness Nuclear Physics Workshop 2013, Xiamen, China, 2013-12-14

Nijmegen Baryon-baryon 8Flavor SU(3) Extended-Soft-Core ESC08c, Meson-exchange viewpoint, Tokyo-Institute of Technology (TIT), Tokyo, Japan, 2013-02-07

Saueressig, F., Asymptotically Safe Gravity – A pedagogical introduction, HEP Colloquium, Radboud University (RU), Nijmegen, The Netherlands, 2013-05-13

Asymptotically Safe Gravity – A pedagogical introduction, Rijksuniversiteit Groningen (RUG), Groningen, The Netherlands, 2013-06-03

Asymptotically Safe Gravity – A pedagogical introduction, Technische Universität München (TUM), München, Germany, 2013-05-02

Asymptotically Safe Gravity – A pedagogical introduction, Utrecht University (UU), Utrecht, The Netherlands, 2013-06-05

Black holes in Asymptotically Safe Gravity, Loops 13 Conf., Perimeter Institute, Waterloo, Canada, 2013-07-23

Black holes in Asymptotically Safe Gravity, University of Sussex, Brighton, United Kingdom, 2013-08-15

Schellekens, A.N., Discrete Symmetries in Discrete Orientifolds, S.N.S. seminar, Pisa, Italy, 2013-05-23

The Standard Model in the Multiverse, NNV Fall Meeting, Lunteren, The Netherlands, 2013-11-01

Signori, A., Does the transverse motion of quarks depend on their flavor?, NNV Fall Meeting, Lunteren, The Netherlands, 2013-11-01

Exploring the flavor dependence of unpolarized TMDs, QCD Evolution Workshop, Thomas Jefferson National Accelerator Facility, Newport News, VA, USA, 2013-05-06

Exploring the flavor dependence of unpolarized TMDs, Structure of Nucleons and Nuclei Workshop, Como, Italy, 2013-06-11

Flavor dependence of unpolarized Fragmentation Functions, Indiana-Illinois Workshop on Fragmentation Functions, Bloomington, IN, USA, 2013-12-13

From quarks to TMDs: a transverse look into hadrons, Pavia, Italy, 2013-12-19
TMDs: a transverse look into hadrons, DRSTP Theoretical High Energy Physics (THEP) school 2013, Doorn, The Netherlands, 2013-02-19

Vidotto, F., A covariant prospective on singularity resolution, LOOPS13, Waterloo, Canada, 2013-07-25

A new twist on spin connection, EFI Winter Conf. on Canonical and Covariant LQG, Tux, Austria, 2013-02-26

Atomism and Relationalism as guiding principles for Quantum Gravity, Philosophical Foundations of Quantum Gravity, University of Illinois, Chicago, USA, 2013-09-27

Infinities as a measure of our ignorance, Workshop "Infinities and Cosmology" DAMTP, Cambridge, United Kingdom, 2013-03-21

Maximal acceleration in covariant loop gravity and singularity resolution, 20th Int. Conf. on General Relativity and Gravitation, Warsaw, Poland, 2013-07-10

Spinfoam and Cosmology, APC, Paris, France, 2013-06-27

Waalewijn, W.J., Calculating track-based observables for the LHC, BOOST 2013 Conf., Flagstaff (Arizona), USA, 2013-08-14

Correlations in Double Parton Scattering, MPI@LHC 2013, Antwerp, Belgium, 2013-12-05

Wit, de, B., Subleading corrections to BPS black hole entropy; Higher-derivative N=2 supersymmetric invariants and the 5D-4D connection, Iberian Strings 2013, IST Lisboa, Portugal, 2013-01-22

On shell or off shell; Is that the question?, Workshop 'Toine 60', Leuven, Belgium, 2013-03-16

A Superspace Odyssey, Workshop 'Adventures in Superspace', McGill University, Montreal, Canada, 2013-04-19

Deformed gauged SO(8) supergravities and their possible embedding in M-theory, Workshop 'Topics in Holography, Supersymmetry and Higher Derivatives', Texas A&M University, College Station, USA, 2013-04-23

The construction and use of N=2 supersymmetric higher-derivative couplings, Workshop 'Meeting on Branes, Strings and Higher Derivatives', Texas A&M University, College Station, USA, 2013-04-25

Deformed gauged SO(8) supergravities: What can they tell us about M-theory?, SFB Space-Time-Matter, Albert-Einstein Institut, Golm, Germany, 2013-06-04

Deformed gauged SO(8) supergravities: What can they tell us about M-theory?, McGill University, Montreal, Canada, 2013-07-29

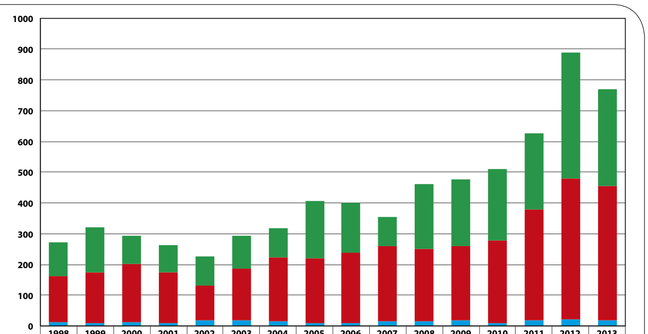
On supersymmetric black holes, in 'Frontiers of quantum gravity and cosmology', Stanford University, Palo Alto, USA, 2013-09-12

Deformed gauged SO(8) supergravities: What can they tell us about M-theory?, CEA, Saclay, France, 2013-09-25

Deformations of special geometry: searching for the topological string, Workshop 'Geometry of Strings and Fields', Galileo Galilei Institute for Theoretical Physics, Arcetri, Florence, Italy, 2013-10-02

Deformations of special geometry: searching for the topological string, Conf. Frontiers and new perspectives in geometry and physics, Euler Institute, St. Petersburg, Russia, 2013-10-14

On supersymmetric black holes, Mini-symposium, University of Groningen, Groningen, The Netherlands, 2013-10-18



	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Talks	109	147	92	91	95	108	97	186	162	93	212	215	231	248	410	316
Publications	150	165	190	163	113	168	207	209	228	246	234	243	270	361	458	435
Theses	13	9	11	10	18	18	15	10	9	15	15	18	8	17	22	18

Figure 1. Nikhef's scientific output in the last 16 years. Note that the numbers of publications (red) for the years 2010-2012 have been adapted (lowered) to reflect the new criteria for eligibility employed since 2013.

3.4 Posters

ATLAS
Besjes, G.J.
Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in 20 fb^{-1} of $\sqrt{s}$=8 TeV pp collisions
LHCP 2013, Barcelona, Spain, 2013-05-14

Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in 20 fb^{-1} of $\sqrt{s}$=8 TeV pp collisions
Lepton-Photon 2013, San Francisco, USA, 2013-06-24

Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in 20 fb^{-1} of $\sqrt{s}$=8 TeV pp collisions
SLAC Summer Institute 2013, Menlo Park, CA, USA, 2013-07-11

Gadatsch, S.
Combined Measurements of the couplings of the Higgs boson in ATLAS
European school for HEP, Parádfürdö, Hungary, 2013-06-09

Mahlstedt, J.
Limit Setting on new BSM models
European school for HEP, Parádfürdö, Hungary, 2013-06-08

The ATLAS Hadronic Tau Trigger
CHEP 2013, Amsterdam, The Netherlands, 2013-10-14

Pani, P.
Search for a heavy SUSY partner of the top quark using multivariate techniques in ATLAS
Physics@FOM, Veldhoven, The Netherlands, 2013-01-22

Search for a heavy SUSY partner of the top quark decaying to a chargino and a b-jet in ATLAS
European school for HEP, Parádfürdö, Hungary, 2013-06-08

for the ATLAS collaboration
Search for direct top squark pair production in final states with one isolated lepton
Int. Conf. ICNFP13, Crete, Greece, 2013-08-31

for the ATLAS collaboration
The ATLAS Semiconductor Tracker: operations and performance
IEEE/NSS/MIC, Seoul, South Korea, 2013-10-30

Salvucci, A.
The new Higgs particle in the $H \to ZZ^* \to 4\ell$ searches with the ATLAS detector
EPS2013, Stockholm, Sweden, 2013-07-18

Detector R&D
Breur, P.A.
Explaining a modulation in the activity of radioactive sources
INFIERI summer school, University of Oxford, Oxford, United Kingdom, 2013-07-15

Gajanana, D., *et al.*
WDM modulator circuit for high energy physics applications
Technical University of Eindhoven, Eindhoven, The Netherlands, 2013-11-25

Tsigaridas, S.
Intelligent 3D tracking with GridPix detectors
INFIERI summer school, University of Oxford, Oxford, United Kingdom, 2013-07-15

Gravitational Waves
Ambrosi, d', G.
Beyond ISCO orbits for EMRIs
School of Gravitational Waves, Warsaw, Poland, 2013-07-04

Veitch, J. and C. Messenger
Avoiding selection bias in gravitational wave astronomy
20th Int. Conf. on General Relativity and Gravitation and 10th Amaldi Conf. on Gravitational Waves, Warsaw, Poland, 2013-07-08

Grid Computing
Remenska, D., *et al.*
Round-tripping DIRAC: Automated Model-Checking of Concurrent Software Design Artifacts
CHEP2013, Amsterdam, The Netherlands, 2013-10-14

HiSPARC
Hart, R.G.K., *et al.*
The HiSPARC Control System
14th Int. Conf. on Accelerator & Large Experimental Physics Control Systems, San Francisco, USA, 2013-10-10

LHCb
Tolk, S. for the LHCb Collaboration
First evidence for the decay $B_s \to \mu^+\mu^-$
CERN, Geneva, Switzerland, 2013-03-13

Miscellaneous
Verlaat, B.A., L.Zwalinski, J.Daguin, J.Godlewski, H.Postema, J.Noite, M.Ostrega, O. Crespo-Lopez, P.Petagna, P.Tropea
CO_2 cooling for silicon detectors
Conf. on Future Perspectives in High-Energy Physics 2013, "Physics in the LHC era", Tblisi, Georgia, 2013-10-13

Theoretical Physics
Ambrosi, d', G.
Beyond ISCO orbits for EMRIs
Trends in Theory 2013, Dalfsen, The Netherlands, 2013-05-16

Buffing, M.G.A.
Gluons in high-energy scattering processes: Playing with color
Trends in Theory 2013, Dalfsen, The Netherlands, 2013-05-17

Ciceri, F.P.Y.
N=4 conformal supergravity actions
Trends in Theory 2013, Dalfsen, The Netherlands, 2013-05-17

Knegjens, R.J.
In Pursuit of New Physics with B_s Mesons
Trends in Theory 2013, Dalfsen, The Netherlands, 2013-05-17

Nauta, L.J.
Enlightening Dark Matter
Trends in Theory 2013, Dalfsen, The Netherlands, 2013-05-17

Reys, V.R., and S. Murthy
Steps towards a non-renormalization theorem for black hole entropy
Trends in Theory 2013, Dalfsen, The Netherlands, 2013-05-17

Rietkerk, R.J.
Spin correlations with Higgs bosons
Trends in Theory 2013, Dalfsen, The Netherlands, 2013-05-16

Spin correlations with Higgs bosons
UvA PhD symposium, Amsterdam, The Netherlands, 2013-05-23

Rottier, O.G.
One Loop Corrections at Future Linear Colliders
Trends in Theory 2013, Dalfsen, The Netherlands, 2013-05-17

Signori, A.
Transverse motion of quarks: what's its flavor?
Trends in Theory 2013, Dalfsen, The Netherlands, 2013-05-17

3.5 Jamboree

By the end of each year Nikhef physicists and technicians gather in a two-day Annual Meeting traditionally called Jamboree. The 2013 edition of this event was held in one of the main lecture halls in the new building of the Faculty of Science of the University of Amsterdam, opposite Nikhef. Organisers were Els Koffeman and Stan Bentvelsen. Reports were given about the status of Nikhef's various programmes and projects both by staff members, postdocs and young students.

Monday 16 December 2013

Introduction

10:30 *Welcome*, Stan Bentvelsen

ATLAS

10:40 *ATLAS: introduction and highlights*, Paul de Jong
10:55 *Measurement of the differential cross section of phi(1020) production*, Lucie de Nooij
11:10 *Higgs production and properties measurements*, Valerio Dao
11:30 *Searching for a scalar top quark partner*, Priscilla Pani
11:45 *Lepton flavour violating tau decays and new Level 1 trigger capabilities*, Saminder Dhaliwal

Dark Matter

12:00 *Dark Matter Program Overview*, Patrick Decowski
12:20 *Multiple scatterings in WIMP searches?*, Matteo Alfonsi

Detector R&D

14:00 *Detector R&D Overview*, Niels van Bakel
14:20 *Status and progress of MEMBrane*, Shuxia Tao
14:35 *Energy sensitive pixel detectors for X-ray imaging applications*, Enrico Schioppa
14:50 *Tracking in 1 μl of gas*, Fred Hartjes

LHCb

15:20 *Introduction and Overview*, Niels Tuning
15:36 *From neutral B's to a muon pair*, Siim Tolk
15:52 *The B_s mixing phase*, Roel Aaij
16:08 *Search for long-lived exotic particles*, Maurizio Martinelli
16:24 *The LHCb Upgrade*, Eddy Jans

Miscellaneous

16:40 *Nikhef and its neighbours: developing Amsterdam Science Park*, Arjen van Rijn
17:00 *Summary*, Frank Linde

Tuesday 17 December 2013

Virgo

09:20 *Status update*, Jo van den Brand
09:30 *Instrumentation for Advanced Virgo*, Alessandro Bertolini
09:45 *Status gravitational wave analysis*, Chris Van Den Broeck

ALICE

10:00 *The ALICE program*, Raimond Snellings
10:05 *ALICE upgrades*, Paul Kuijer
10:40 *Charm in ALICE*, Chiara Bianchin
11:00 *Correlations in ALICE*, Misha Veldhoen

Computing

11:20 *Overview*, Jeff Templon
11:40 *Towards automated model-checking of concurrent software designs*, Daniela Remenska

Auger

12:00 *Status of Auger*, Sijbrand de Jong
12:20 *Ultra-high-energy cosmic ray composition*, Guus van Aar

Theory

14:00 *Nikhef theory in 2013*, Eric Laenen
14:20 *A theorist in the Wild West of LHC observables*, Wouter Waalewijn
14:40 *New Flavour Sensations*, Kristof De Bruyn
15:00 *Black hole entropy and effective Lagrangians*, Daniel Butter

ANTARES & KM3NeT

15:40 *Neutrino astronomy overview*, Aart Heijboer
16:00 *Search for neutrinos from the galaxy*, Erwin Visser
16:20 *Results from a Prototype KM3NeT Optical Module*, Tino Michael

Miscellaneous

16:40 *Summary on "Physics in 2025" by committee Dijkgraaf*, Sijbrand 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 2013 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 2013, still running grants, and recently completed grants awarded in earlier years.

NWO Grants
Jeroen van Tilburg (LHCb) was awarded a Vidi grant for his proposal *"The high-precision frontier in beauty and charm decays"*. Over a period of five years, he receives in total about 800 k€ from NWO to start his own research group. The Vidi grants awarded by NWO are aimed at young excellent researchers with several years of successful postdoctoral research experience.

Tjonnie Li (Gravitational Waves) obtained funding in the framework of the Rubicon programme of NWO for his proposal *"Luisteren naar de kernen van botsende neutronensterren"* (Listening to the cores of colliding neutron stars). For a period of 24 months, he will conduct research at the LIGO Laboratory, California Institute of Technology, USA. With Rubicon, NWO creates for scientists who have recently gained their PhD the opportunity to acquire research experience at internationally renowned institutes abroad.

FOM Grants
In September, FOM granted a large research programme to Nikhef: *"LHC Physics – the Dutch participation."* The programme, running from 2014 up to and including 2021, is the integral continuation of the three currently separate FOM-programmes ATLAS, LHCb and ALICE. The total grant amounts to 16.9 M€, to fund 40 PhD students, 13 postdocs, secondment costs, travel budgets, and Nikhef's contribution to maintenance and operations of the detectors.

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

- To Bob van Eijk (ATLAS) & Stan Bentvelsen (ATLAS) for their proposal *"Splitting the Higgs: the connection to dark matter"*, amounting to about 400 k€ to fund one PhD position for the duration of four years and one postdoc position for two years;
- To Pamela Ferrari (ATLAS) for *"CP violation in the Higgs sector"*, amounting to 396 k€ to fund one PhD position for the duration of four years and one postdoc position for two years;
- To Frank Filthaut (ATLAS) & Nicolo de Groot (ATLAS) for their proposal *"Higgs as a portal to new physics"*, amounting to 396 k€ to fund one PhD position for the duration of four years and one postdoc position for two years;

Figure 1. Frank Linde (left) and Stan Bentvelsen (right) received the Physicaprijs 2013.

- To Andre Mischke (ALICE) for *"A charming way to disentangle initial- and final-state effects at the LHC"*, amounting to 270 k€ to fund a PhD position for four years;
- To Frank Saueressig (Theoretical Physics) for *"Black hole dynamics in asymptotically safe quantum gravity"*, amounting to 398 k€ to fund one PhD position for the duration of four years and one postdoc position for two years.

Other Dutch Awards & Grants
Frank Linde (Nikhef director) and Stan Bentvelsen (ATLAS) were awarded the prestigious *'Physicaprijs 2013'* for their contributions to the discovery of the Higgs particle with the ATLAS detector. This prize is awarded once per year to an eminent physicist working in the Netherlands by the *'Nederlandse Natuurkundige Vereniging'* and the *'Stichting Physica'*.

Nicolo de Groot (ATLAS) and Frank Filthaut (ATLAS) won the Radboud Science Award. This award supports initiatives to translate research into teaching programmes for elementary school children. The award winners have contributed to the discovery of the Higgs particle with the ATLAS detector. They receive 10 k€ for their school project to let children discover why elementary particles have mass.

Niels van Bakel (Detector R&D) together with Jo van den Brand (Gravitational Waves) and Alessandro Bertolini (Gravitational Waves) and colleagues from the University of Twente received a grant from the technology foundation STW for their proposal *"SENSEIS: Silent sensors for stellar echo's and seismic surveys"*. This STW grant in the framework of the topsector HTSM (High Tech Systems & Materials) amounts to 495 k€, while industrial partners contribute another 270 k€ to the project. The SENSEIS project will develop ultra-sensitive readout electronics for seismic sensor networks. These will be used in gravitational waves research projects, but can also be utilized in survey networks for oil and gas exploration.

The HiSPARC project (High School Project on Astrophysics Research with Cosmics) received 50 k€ via the *'Sectorplan Natuur- en Scheikunde'* from the Dutch Ministry of Education, Culture and Science. The grant is awarded for outreach activities.

European Awards & Grants

A new COST Targeted Network was approved under the name of *"Next Generation of Young Scientist: towards a contemporary spirit of R&I (Sci-GENERATION)"*, with Andre Mischke (ALICE) being co-applicant. COST (European Cooperation in Science and Technology) is one of the longest-running European frameworks supporting cooperation among researchers across Europe. Sci-GENERATION is a new COST initiative that aims at elaborating contemporary scientific thought and thereby disseminating a new spirit of research and innovation in Europe. The targeted network receives 500 k€ over a period of five years.

The Nikhef theory group is one of the node leaders of the newly installed Marie Curie Initial Training Network *"HIGGSTOOLS: The Higgs quest – exploring electroweak symmetry breaking at the LHC"* and receives over a period of four years about 250 k€. These transnational networks focus on a joint research training programme to make research careers more attractive to young people.

A European Marie Curie *'International Incoming Fellowship'* grant of 183 k€ was given to Daniel Butter (Theoretical Physics) for his postdoc project *"HYPERGRAV: The last piece of the puzzle: Off-shell hypermultiplets in string theory and complex geometry"*. This grant is meant for experienced researchers based in non-European countries willing to receive research training in and collaborate with a host institution based in Europe.

Kasper Larsen (Theoretical Physics) received a European Marie Curie *'Intra European Fellowship'* grant for a two-year postdoc project with title *"2LoopAccuracy4LHC"* at the ETH Zurich, Switzerland. The fellowship is designed for researchers willing to develop their career in Europe outside their home country.

An ERC Proof of Concept Grant was awarded to Andre Mischke (ALICE) and colleagues Jan Visser (Detector R&D) and Hugo de Jong (University Medical Centre Utrecht) for their project *"High Sensitivity Mammography with a new generation of silicon pixel sensors"*. They receive 150 k€ over a period of 12 months. ERC grant holders can apply for this additional funding to establish the innovation potential of ideas arising from their ERC-funded frontier research projects.

Via Nuffic (the Netherlands organisation for international cooperation in higher education) the BND graduate school of subatomic physics has applied for an ERASMUS Intensive Programme of the European Commission and receives about 35 k€ to bring together students and teaching staff from higher education institutions of at least three participating countries.

Diego Martinez Santos (LHCb) received the 2013 Young Experimental Physicist Prize from the High Energy Particle Physics Division of the European Physical Society. He was awarded the prize for his outstanding contributions to the trigger and commissioning of the LHCb experiment, and the analyses leading to the first evidence for the rare decay $B^0_s \rightarrow \mu\mu$. The prize is assigned to young experimental physicists for outstanding work in the field of Particle Physics and/or Particle Astrophysics.

4

Nikhef & Society

4.1 Outreach & Communication

In February 2013, the first three-year running period of the LHC concluded very successfully and the LHC entered its first long shutdown for consolidation and maintenance. This shutdown period has provided unique opportunities for visits to the underground facilities at CERN, which are not possible during LHC operation. Making use of this, Nikhef organised in 2013 numerous guided tours at CERN for various groups of widely different origin. A group of Dutch journalists from print, radio and online media were treated to a dedicated two-day National Media Visit by Nikhef and CERN. Furthermore, excursions for KNAW, FOM and university board members were arranged. The general public as well as school children and teachers had ample opportunities for visits, too.

Certainly the most extraordinary way to offer a trip to CERN occurred in an auction for a good cause. Every year before Christmas, 3FM Serious Request, a partnership between the Dutch radio station 3FM and the Dutch Red Cross, raises money to fight some humanitarian crisis. Amongst the various fund raising activities is an auction of unique items and experiences. This year Nikhef offered for the first time an unforgettable trip to CERN as auction item, which raised the amazing amount of € 7700. The happy buyer will be taken on a very special tour around CERN beginning of 2014.

Another highlight of the year 2013 was the assignment of the Nobel Prize in Physics to particle physics. François Englert and Peter Higgs were jointly awarded the prize *" for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*. This announcement was celebrated in the particle physics community in the Netherlands and around the world, and widely covered in the national and international media.

Every year, Nikhef organises a variety of activities for different target audiences (general public, decision makers and opinion leaders, media, students and teachers) to explain what Nikhef's particle and astroparticle physics research entails and how the technical departments support this research by designing, constructing and operating cutting-edge instrumentation. The communications department initiates many of these activities, but also relies on Nikhef staff and PhD-students' much appreciated dedication to reach 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 2013 is given. For education activities please refer to section 4.2.

Nikhef & the general public
Nikhef engages with the general public on various occasions. Numerous outreach talks were again given by Nikhef scientists all across the Netherlands and throughout the year, for example in the context of KIJK Live!, Kennis op Zondag, Paradisolezing, just to name a few (for a full list please refer to section 4.5).

A prime occasion for the general public to become familiar with Nikhef is, of course, the annual Open Day which is always organised together with the other institutes at Science Park Amsterdam. This year's Open Day was held on Saturday 5 October during the *"Weekend van de wetenschap"* (Weekend of science) with the central theme *"Schatkamer van de wetenschap"* (Treasure room of science). For more details and some impressions, please find a report in pictures in this chapter.

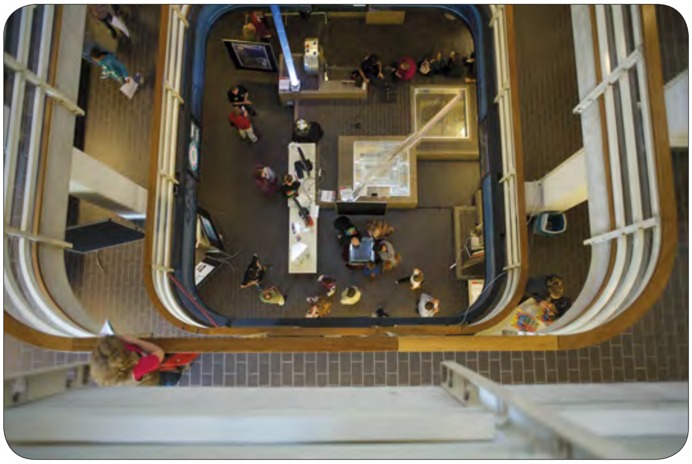
Nikhef & art
This year, quite exceptionally, the research Nikhef is involved in was also expressed in works of art. Since the summer, pictures of Nikhef's research projects can be found in the *"Steps of Science"* by Nienke Korthof. Laid in the stone paving, these lenticular tiles with ultra-short animations form a walk of fame of the scientific studies of all institutes located at the Science Park Amsterdam.

In September, the second edition of the Science Park Amsterdam Film Festival (SPAFF) took place, a collaboration of Science Park, the various institutes and organisations located at Science Park, and curator Jan van den Berg (Theater Adhoc). At Nikhef, three screenings of two different documentaries were each briefly introduced by a Nikhef scientist.

In November, Jan van den Berg's theater performance *"Higgs"* premiered in the Netherlands. In a mix of facts and fiction combined with a good sense of humour, Jan van den Berg tells his story about how he, a theater- and filmmaker, followed the quest of the scientists for the Higgs particle. He is touring his play until next year, and has invited Nikhef scientists to join him on stage for an interview at the end of the performances.

Internet & social media
The homepage of the Nikhef website has undergone some visual changes to make the content more accessible for visitors. Furthermore, to provide more insight into the organisation, a brief history of the institute and a list of all former directors were added to the website. The makeover was completed by adding a few stories about Nikhef employees and their work, and implementing a new image bank where Nikhef's research and other activites are highlighted in pictures.

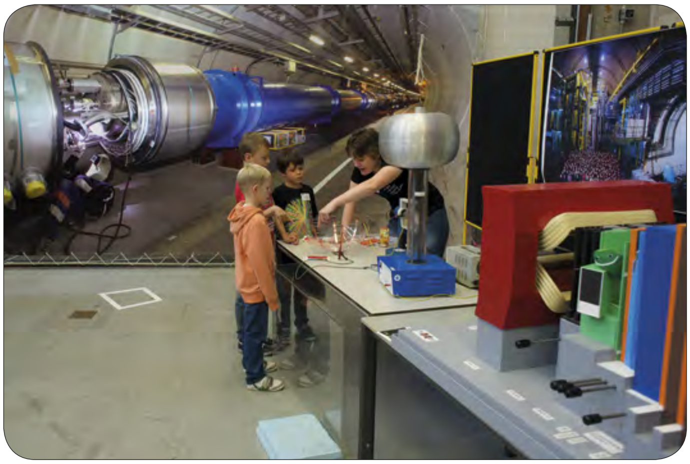
Open Day 2013 in pictures



In the main hall, interested people learn all about Nikhef's astroparticle physics research and experience how cosmic rays are made visible in a cloud or spark chamber.

Guided tours through the data centre at Nikhef are much appreciated (see picture) and the four mini lectures about topics like the Standard Model, gravitational waves or proton therapy are well attended (not shown).

In the workshop, visitors are invited to do their own little experiments and people can ask all their questions to the many Nikhef volunteers easily recognizable with their colourful open day T-shirts.



The principle of particle acceleration is demonstrated in front of a giant poster of the LHC accelerator. Further exhibits and demonstrations are set up by the LHC research groups and the technical departments.

Children go treasure hunting in search for all the elementary particles that form the particle zoo, i.e. the Standard Model of particle physics.

The young visitors enjoy themselves when soldering their own electronic gadgets (see picture) or building meccano models (not shown).

In 2013, Nikhef's social media channels got the attention of a wider public. The Nikhef Facebook page went from 50 to more than 200 likes and there were more interactions with followers. Twitter followers grew from 150 to more than 500. Nikhef was mentioned frequently especially around the Open Day and in connection with the Nobel Prize for Physics.

Nikhef & decision makers and opinion leaders

Nikhef took several opportunities to showcase the benefits of particle physics research to opinion leaders and decision makers, both at national and international levels.

In May 2013, the CERN Council held an extraordinary session in Brussels to mark the launch of the updated European Strategy for Particle Physics. The Nikhef communication department participated in a working group of the European Particle Physics Communication Network to organise a series of targeted communications activities around the Council meeting, such as a press conference, a working lunch in the European Parliament, a panel discussion followed by a reception, a working lunch with the European Competitiveness Council, all backed up by a brochure and a small exhibition. The objective was to foster appreciation for particle physics, its beneficial impact on society, and the value of international collaboration in science.

Furthermore, the long shutdown at CERN was a unique opportunity to organise visits to the underground experimental areas and the LHC tunnel for this target group. Nikhef, in collaboration with CERN, has offered guided tours to delegations of KNAW, FOM, and board members of universities. Further visits in 2014 are being planned for members of the royal family, members of ministries or parliament, NWO, and other committees.

Nikhef & the media

In October, Nikhef in collaboration with the CERN press office invited Dutch journalists from print, radio and online media to pay a visit to CERN, in particular to the underground facilities which are accessible at the moment during the long shutdown of the LHC. Nine journalists, from prestigious national newspapers to specialised science-oriented media, accepted this invitation (see Fig. 1). The two-day programme consisted of visits to the LHC tunnel and to the underground caverns of the experiments ATLAS, ALICE and LHCb, a general introductory talk to CERN, and ample time for one-on-one interviews as well as for informal chats with Nikhef scientists.

The objective of these National Media Visits (offered by CERN for all Member states) is to familiarise, or re-familiarise, journalists with CERN and the LHC, while introducing them to CERN personnel from their own countries. The Dutch Media Visit was much appreciated by the journalists in this respect, and was also followed by good media coverage in the days and weeks after the visit.

Throughout the whole year, Nikhef-related research appeared in many articles in various newspapers and magazines (e.g. Trouw, Algemeen Dagblad, Volkskrant, NRC, Telegraaf, Technisch Weekblad, NWT, regional newspapers). There were also interviews with Nikhef researchers on several radio programmes (e.g. Labyrint Radio, BNR Nieuwsradio).

Especially the Nobel Prize for Physics 2013, which was awarded to François Englert and Peter Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles"*, got a lot of media attention. The Nobel Prize Committee also praised the experimentalists' efforts by adding *"and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments*

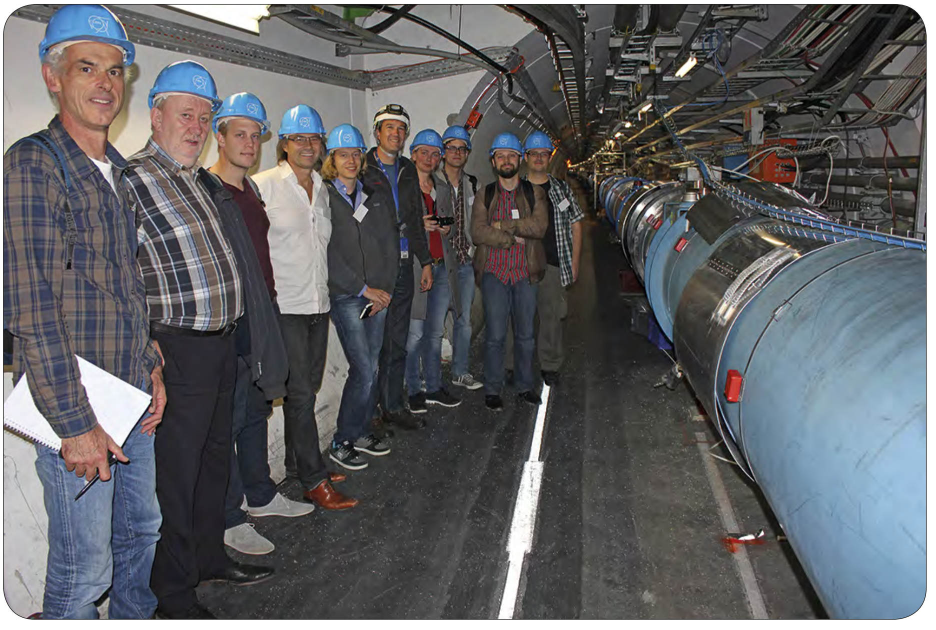


Figure 1. Dutch journalists on a CERN visit inspect the LHC tunnel.

at CERN's Large Hadron Collider". The contribution of Nikhef physicists, who play an important role in the ATLAS experiment, was named in several articles and programmes.

Another highlight of media coverage was for sure the Klokhuis broadcast *"Het kleinste deeltje"* (The smallest particle) in their series *"Zoek het uit!"* (Investigate it!). This series about scientific research in the Netherlands is intended for children. Klokhuis filmed for two days at CERN, above and below ground, featuring Nikhef researchers Ivo van Vulpen and Rosemarie Aben (see Fig. 2).

Much of the media coverage either follows one of the press or news releases Nikhef regularly issues, or results from requests by journalists who approach Nikhef researchers for interviews and background information.

Nikhef & science communication networks

Nikhef's communication department works together with national and international communication networks to develop, coordinate, and organise communication activities concerning 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

- Communication departments of institutes and organisations at Science Park Amsterdam;
- Communication departments of the FOM institutes and the central FOM office;
- Platform Wetenschapscommunicatie (PWC) – An association for science communication staff.

Figure 2. Klokhuis presenter Nienke de la Rive Box is flanked by Nikhef researchers Rosemarie Aben and Ivo van Vulpen during filming for the broadcast "Het kleinste deeltje" (The smallest particle).

4.2 Education

Nikhef is very committed to educating young people and to stimulating their interest in science and technology. From the very young, budding physicist to the PhD students, there are appropriate programmes for each age group. The teachers are not forgotten either, they can participate in various activities as well.

Nikhef & Primary schools

The *'Techniek Toernooi'* is a tournament for primary schools in which young students are introduced to scientific problems in a playful fashion. Traditionally, many members of the Nikhef staff participate in the jury of academic staff that judges the results of the competition.

Nikhef & Secondary schools

Every year Nikhef makes a great effort to introduce secondary school students to particle and astroparticle physics. Through the Nikhef website schools can apply for a Friday afternoon visit, which contains a lecture by a Nikhef scientist, a film and a guided tour. This year, the Friday afternoon visits were attended by more than 250 students. Over 20 secondary school students were helped 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.

In March over 60 students participated in the International Masterclass on Particle Physics held at Nikhef both in Amsterdam and Nijmegen. This yearly event is organised simultaneously in many particle-physics institutes across the world and includes lectures, exercises and a live video conference with CERN to share the results of the day with students at the other institutes. This year, for the first time the exercises were based on real Higgs data.

Nikhef & HiSPARC

The High School Project on Astrophysics Research with Cosmics (HiSPARC) offers 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 2013, the HiSPARC detector network consisted of approximately 100 stations throughout the country. Also in 2013, the HiSPARC network in England has been expanded considerably. The English network now includes clusters around the cities of Bristol, Birmingham and Durham. The cluster in Aarhus, Denmark, is providing data with high efficiency.

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 2013 there were several activities for teachers.

In the academic year 2012/2013 five teachers participated in the teacher-in-research programme (*'Leraar in Onderzoek'*), which was made possible by FOM and Nikhef. These teachers were supervised by staff members and they all carried out a separate piece of research within the HiSPARC project. In cooperation with the UvA and Bètasteunpunt Amsterdam (the Its Academy), Nikhef organised a teachers course about particle physics. The course (six evenings spread over six weeks) was attended by 20 teachers, all of whom valued it highly.

In September Nikhef and CERN organised the annual Dutch CERN Teacher Programme. This year, 13 teachers visited CERN and attended this special programme, consisting of a four-day trip instead of the usual three days in former years. Due to the LHC shutdown, the teachers had the special opportunity to go underground and inspect the ATLAS and CMS detectors at close range.

Master's programmes at Nikhef

All four universities, UU, UvA, RU and VU, offer a two year Master's programme focused on the research done at Nikhef. In the first year, the programme typically consists of lectures on Particle Physics and Astroparticle Physics. These lectures include Higgs physics, physics beyond the Standard Model, Cosmology, Field Theory, CP violation etc., as well as advanced experimental tools like statistical data analysis, detector issues and R&D and a C++ course. The various aspects of experimental particle physics are combined in a small project, and this year a Cherenkov detector was built to measure cosmic tracks.

During their second year the students work on their own research project in one of the groups at Nikhef. In 2013 more than 20 new students enrolled in the first year of the Master's programme, among them students from other European countries like Luxembourg, Greece and the Czech Republic. One student from Pakistan enrolled in the Erasmus Mundus programme for China, Nepal, Bangladesh and Pakistan. A total number of 23 students graduated in 2013 (see section 5.6).

Research School Subatomic Physics

All PhD students at Nikhef receive academic training through the Research School Subatomic Physics (*'Onderzoeksschool Subatomaire Fysica'*, OSAF). In 2013, 18 PhD degrees were obtained by students from OSAF. The number of new PhD registrations in 2013 was 22. The *'Jan Kluyverprijs'* for the best English summary of a PhD thesis was awarded to Sander Mooij.

The BND summer school (Belgium, the Netherlands, Germany) was held in August in Brussels, Belgium, and organised by the Vrije Universiteit Brussel. There were a record number of 72 participants. The school was again supported with a grant from the EU Erasmus Life Long Learning programme.

OSAF organised three topical lectures in 2013. The subjects were statistics, dark matter and accelerators.

HiSPARC in pictures

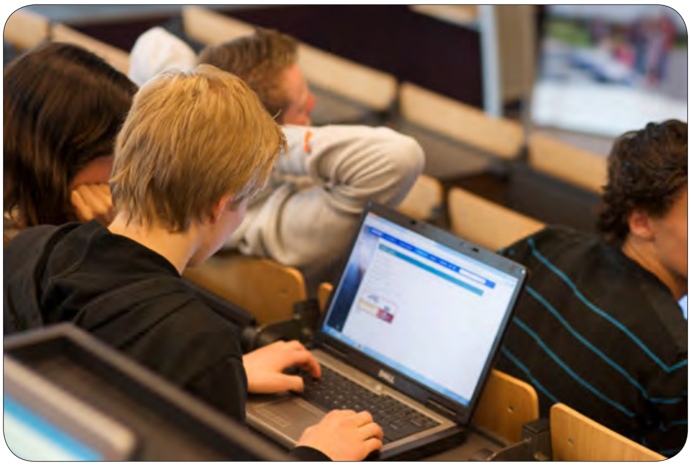


Figure 1. Each year HiSPARC organises a symposium at which students can present their 'profielwerkstuk' (research project). The group with the best project and presentation wins a trip to CERN.

Figure 2. The assembly of the detectors takes place at Nikhef or one of the universities (Radboud Universiteit Nijmegen, VU Amsterdam, Universiteit Utrecht, Rijksuniversiteit Groningen).

Figure 3. The students and their mentors install the HiSPARC detectors on the roof of their school.

Figure 4. The five teachers who participated in the teacher-in-research programme ('Leraar in Onderzoek'); in the background a few HiSPARC detectors are visible in their ski-box enclosures.

4.3 Knowledge Transfer
Valorisation & Spin-off Activities

It has been an exciting year for the startup companies AmsterdamScientific Instruments (ASI) and Omics2Image (Omx2i). To gain traction for a high-tech spinout in a global market is a serious challenge. Finding a 'killer application' for their platform technology has brought them many industrial and academic trials to demonstrate a specific proof of principle or demonstrate their existing products.

Mass Spectrometry Imaging is believed to have a large impact in the Life Sciences arena. This potential has been recognised, since Omx2i is engaged via specific partnership projects with a few of the key market leaders. Omx2i also won several business plan contests amongst which the *NGI Venture Challenge* and the *Benelux Venture Forum* pitching contest. ASI has added additional sales over the result of 2012, together with trials on CT imaging in dental research, agrofood and even in the area of art authentication. Both companies have been preparing for the attraction of investment funds in order to accommodate growth. Since the technologies and application domains of both companies are well aligned, the shares of both companies have been transferred to a joint new holding company, ASIH (ASI Holding B.V.), of which Particle Physics Inside Products (P2IP B.V.), the joint initiative of FOM and 1&12 Investment Partners, is the majority share holder.

Sensiflex, the other startup in the P2IP portfolio, had a quiet year. Sensiflex aims at selling the Rasnik alignment system in non-scientific domains. Besides a few projects, discussions with a civil construction company are ongoing to strengthen the partnership.

The company InnoSeis has been established mid 2013. InnoSeis aims to market technologies spinning out of Nikhef's gravita-

Figure 2. Wim Walk (Shell) and Frank Linde (Nikhef) just after signing the collaboration agreement on the TremorNet project (16 October 2013). Also visible are (from left to right) Jo van den Brand (Nikhef and InnoSeis), Mark Beker (InnoSeis) and Maurice Benning (Shell).

tional wave instrumentation activities. The company has been subcontracted in the framework of the TremorNet project, a co-operation contract agreed between VU, Nikhef and Shell, on the delivery of a proof-of-concept low power wireless seismic sensor network. Moreover, InnoSeis has acquired orders for calibration of seismic sensors in their unique vibration-free environment.

Also in 2013 another startup company has been established, NoZAP, aiming at developing live streaming television on demand. A Nikhef engineer with expertise in grid development and operations (in particular the networking aspects) is involved in this company.

In 2013, Nikhef continued to carry out a (mechanical) engineering project for ASML, which was acquired in 2012. This project will be completed early 2014.

One (European) patent application, jointly with VU University, was filed in 2013: *'Position based broadcast protocol and timeslot schedule for a wireless mesh network'*.

Nikhef continued its long standing research relation with PANalytical. And finally, Nikhef's datacenter activities (in particular for customers of the Amsterdam Internet Exchange, AMS-IX) have further increased.

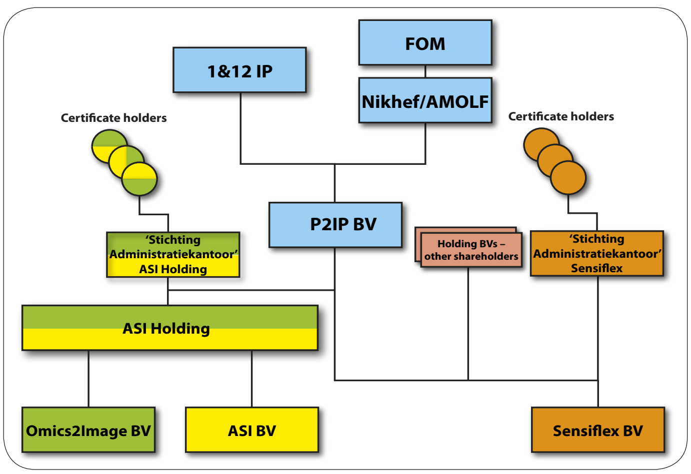


Figure 1. The current legal structure around Nikhef's start-ups.

4.4 Memberships‡

Annual Conference on Large Hadron Collider Physics (LHCP)
P. Koppenburg (Program Committee)

ApPEC - Particle Astrophysics and Cosmology Theory (PACT)
J. van Holten (board member)

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)

Committee Dijkgraaf
S. de Jong

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. Bentvelsen, N. de Groot, 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 Physical 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)
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 – Review Committee silicon tracking detector system for the Compressed Baryonic Matter experiment
G. Nooren

Helmholtz Alliance for Astroparticle Physics, Germany (HAP)
E. de Wolf (Advisory Board)

Istituto 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 Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions
M. van Leeuwen (International Advisory Committee)

International Particle Physics Outreach Group (IPPOG)
S. Caron

International Grid Trust Federation
D. Groep (chair)

‡ *as of 31 December 2013.*

International Union for Pure and Applied Physics - Commission on Astroparticle Physics
J. Hörandel

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

InterActions
V. Mexner

International Society for General Relativity and Gravitation
J. Veitch

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 (board member)

Platform Universitaire Natuurkunde (PUN)
S. Bentvelsen, N. de Groot

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

Steunpuntenraad
S. de Jong (chair)

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), A. van Rijn (treasurer), M.Vreeswijk (editorial board), S. de Jong (editorial board)

Stichting Natuurkunde Olympiade Nederland
E. de Wolf (board member)

Stichting Physica
P. Mulders (treasurer)

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

Aben, R.Z., Higgs: Wat en Hoe - Paradisolezing, Paradisolezing in de serie: Aap, Noot, Higgs, Amsterdam, The Netherlands, 2013-02-10

Het kleinste deeltje, Cinekid festival, premiere klokhuisserie: Zoek het uit!, Amsterdam, The Netherlands, 2013-10-23

Bentvelsen, S., De ontdekking op CERN, Triangulum, Apeldoorn, The Netherlands, 2013-01-10

Observation of the Higgs (?) particle, Physics@FOM , Veldhoven, The Netherlands, 2013-01-21

Ontdekking van het Higgs deeltje, Paradiso lezing Aap, noot, Higgs, Amsterdam, The Netherlands, 2013-02-10

Symmetrie in de natuurkunde, Science Cafe, Nijmegen, The Netherlands, 2013-03-11

Ontdekking van het Higgs deeltje, Rotary Diemen, Diemen, The Netherlands, 2013-03-17

De jacht naar het Higgs deeltje, Natuurwetenschappen Diligentia, Den Haag, The Netherlands, 2013-04-08

De ontdekking van het Higgs, NNV jaarvergadering, Delft, The Netherlands, 2013-04-19

Brand, van den, J.F.J., Gravitatiegolven – de dynamica van ruimtetijd, Sterrenkundevereniging Galileo, KNVWS afd. Zuid-Limburg, Sterrenwacht Limburg, Heerlen, The Netherlands, 2013-10-12

Gravitatiegolven – de dynamica van ruimtetijd, Koninklijke Maatschappij voor Natuurkunde, Diligentia, Den Haag, The Netherlands, 2013-11-18

Gravitatiegolven – de dynamica van ruimtetijd, Vereniging voor Experimenteel Radio-Onderzoek Nederland, afd. West-Friesland, Hoorn, The Netherlands, 2013-12-17

Colijn, A.P., Help! Waar is ons Heelal?, Dark Matter, Science cafe, Nijmegen, The Netherlands, 2013-11-18

Het Higgs deeltje, Dark Matter, Europese Science Olympiad (EUSO) reünisten, Amsterdam, The Netherlands, 2013-10-04

Decowski, M.P., Donkere Materie, Science Cafe, Amsterdam, The Netherlands, 2013-03-07

Neutrino Oscillation and Neutrino Applications to Understand Earth's Geology, De Leidsche Flesch Student Association, Leiden, The Netherlands, 2013-03-27

Filthaut, F., De ontdekking van het Higgsdeeltje, Weer- en Sterrenkundevereniging Thales, Zwolle, The Netherlands, 2013-03-28

Het Higgsdeeltje, een jaar later, Weer- en Sterrenkundevereniging Eemsmond, Appingedam, The Netherlands, 2013-10-02

Groot, de, N., De ontdekking van het Higgboson, RU Lustrum, Nijmegen, The Netherlands, 2013-06-02

Deeltjesdetectoren, RU Nijmegen, masterclass, Nijmegen, The Netherlands, 2013-06-04

CERN en de ontdekking van het Higgsboson, Maritime Research Institute Netherlands, Wageningen, The Netherlands, 2013-06-10

De ontdekking van het Higgsboson, RU alumnidag, Nijmegen, The Netherlands, 2013-10-05

De ontdekking van het Higgsboson, een pre-nobel lezing, Koninklijk Genootschap Physica, Alkmaar, The Netherlands, 2013-10-07

Holten, van, J.W., Speciale Relativiteitstheorie, Scholierenvoordracht, Leiden, The Netherlands, 2013-02-01

Igonkina, O., Particle physics, School visit, Amsterdam, The Netherlands, 2013-06-28

Jong, de, P.J., Fysica bij de LHC, NSA Symposium, Amsterdam, The Netherlands, 2013-03-20

Jong, de, S., Higgs and health, TEDx, Nijmegen, The Netherlands, 2013-02-02

De Wiskunde achter de Higgs: de kracht van symmetrie en statistiek, Nationale Wiskunde Dagen, Noordwijkerhout, The Netherlands, 2013-02-02

Cum Laude PWS prijs 2013 voor het N&T profiel, Stedelijk Gymnasium, Nijmegen, The Netherlands, 2013-03-04

NiNa en de quantumwereld, ThiemeMeulenhoff, Soest, The Netherlands, 2013-03-23

Beta in het Dagelijks leven, Boekpresentatie Beta in het dagelijks leven, Soest, The Netherlands, 2013-04-18

Openingstoespraak, Wiskundedialoog, Nijmegen, The Netherlands, 2013-05-13

Profielwerkstuk en wetenschap, PWS dag Raaijland college, Venray, The Netherlands, 2013-08-20

Openingstoespraak, NLT cluster Nijmegen, Nijmegen, The Netherlands, 2013-08-23

Openingstoespraak, Excellentie programma, Nijmegen, The Netherlands, 2013-09-10

CERN, Alumni programma, Nijmegen, The Netherlands, 2013-10-05

Kosmische straling, Triangulum sterrenkundige vereniging, Apeldoorn, The Netherlands, 2013-10-10

CERN, Alumni programma, Geneve, Switzerland, 2013-10-17

Elektriciteit voor 4 VWO, Woudschoten Natuurkunde Didaktiek, Noordwijkerhout, The Netherlands, 2013-12-14

Laat, de, A.P.L.S., Kosmische straling in de bovenbouw, Woudschoten Natuurkunde Didactiek Conferentie, Noordwijkerhout, The Netherlands, 2013-12-13

Linde, F.L., Higgs, NASK Congres, 's Hertogenbosch, The Netherlands, 2013-01-18

Wetenschap & Religie, Zuiderpoort gemeente Almere, Amsterdam, The Netherlands, 2013-03-03

Science Park Amsterdam, Nationale roadmap grootschalige onderzoeksfaciliteiten symposium, Amsterdam, The Netherlands, 2013-03-06

Higgs, NiNa bijeenkomst natuurkunde docenten, Utrecht, The Netherlands, 2013-04-10

De jacht op de Higgs, NNV Fysica 2013, Delft, The Netherlands, 2013-04-19

Higgs, De Leidsche Flesch Student Association, Leiden, The Netherlands, 2013-05-15

Microcosmos-CERN, CERN-bezoek FOM bureau, Utrecht, The Netherlands, 2013-06-03

De Deeltjes Dierentuin, minilezing Nikhef Open Dag, Amsterdam, The Netherlands, 2013-10-05

The Wild World of Subatomic Particles, Bright Horizons Rhone cruise, 2013-12-01

The Story of the Higgs, Bright Horizons Rhone cruise, 2013-12-02

The Mystery of Dark Matter, Bright Horizons Rhone cruise, 2013-12-03

Particle Physics and You!, Bright Horizons Rhone cruise, 2013-12-04

Merk, M.H.M., Het Antimaterie Mysterie, Voordracht voor KNVWS afdeling Leiden, Leiden, The Netherlands, 2013-10-29

Het Antimaterie Mysterie, Voordracht voor KNVWS afdeling Nijmegen, Nijmegen, The Netherlands, 2013-04-24

Higgs: De Oorsprong van Massa, Voordracht voor Rotarians, Maastricht, Maastricht, The Netherlands, 2013-11-25

Mischke, A., Tomography of the Quark Gluon Plasma, Seminar, French-Dutch Academy, Amsterdam, The Netherlands, 2013-01-23

Understanding the Universe, Annual General Conference, Academia Europaea, Wroclaw, Poland, 2013-09-17

Rijn, van, A.J., e-Infrastructure Commons 2020: Integrated services via interoperable infrastructures, e-IRG Workshop, Vilnius, Lithuania, 2013-11-04

Samtleben, D.F.E., Help! Waar is ons Heelal?, Science Cafe Nijmegen, Nijmegen, The Netherlands, 2013-11-18

Schultheiss, N.G., Deeltjesfysica en relativiteitsleer voor VWO+, Woudschoten Natuurkunde Didactiek Conferentie, Noordwijkerhout, The Netherlands, 2013-12-14

Snoek, H.L., The LHCb experiment, Visit of Honour students from Rijksuniversiteit Groningen, Geneva, Switzerland, 2013-08-27

Templon, J.A., Supporting Research met de Nederlandse nationale e-infra, Kerngroep vergadering SURF Special Interest Group "Research Support", Utrecht, The Netherlands, 2013-06-27

Tuning, N., Higgs en de Kosmos, Open Kringavond, Doopsgezinde Kerk, Aalsmeer, The Netherlands, 2013-02-19

Introduction to HEP and LHCb, Visit of Students from Radboud University Nijmegen, Geneva, Switzerland, 2013-04-30

Vreeswijk, M., Tentamenlade, ICAB-conference, Nijkerk, The Netherlands, 2013-05-22

Vulpen, van , I.B., De ontdekking van het Higgs boson, Science Symposium Raayland college, Venray, The Netherlands, 2013-01-17

De ontdekking van het Higgs boson, Viva Fysica, Amsterdam, The Netherlands, 2013-02-01

Zoektocht naar de elementaire bouwstenen van de natuur, Honours studenten bijeenkomst Leiden, Leiden, The Netherlands, 2013-04-23

De ontdekking van het Higgs boson, KIJK Live! bijeenkomst, Amsterdam, The Netherlands, 2013-10-02

De ontdekking van het Higgs boson, KIJK Live! bijeenkomst, Groningen, The Netherlands, 2013-10-06

The discovery of the Higgs boson, Symposium studievereniging Leidsche Flesch, Leiden, The Netherlands, 2013-11-27

Zoektocht naar de bouwstenen van de natuur, Lezing technici Science Park Amsterdam, Amsterdam, The Netherlands, 2013-12-10

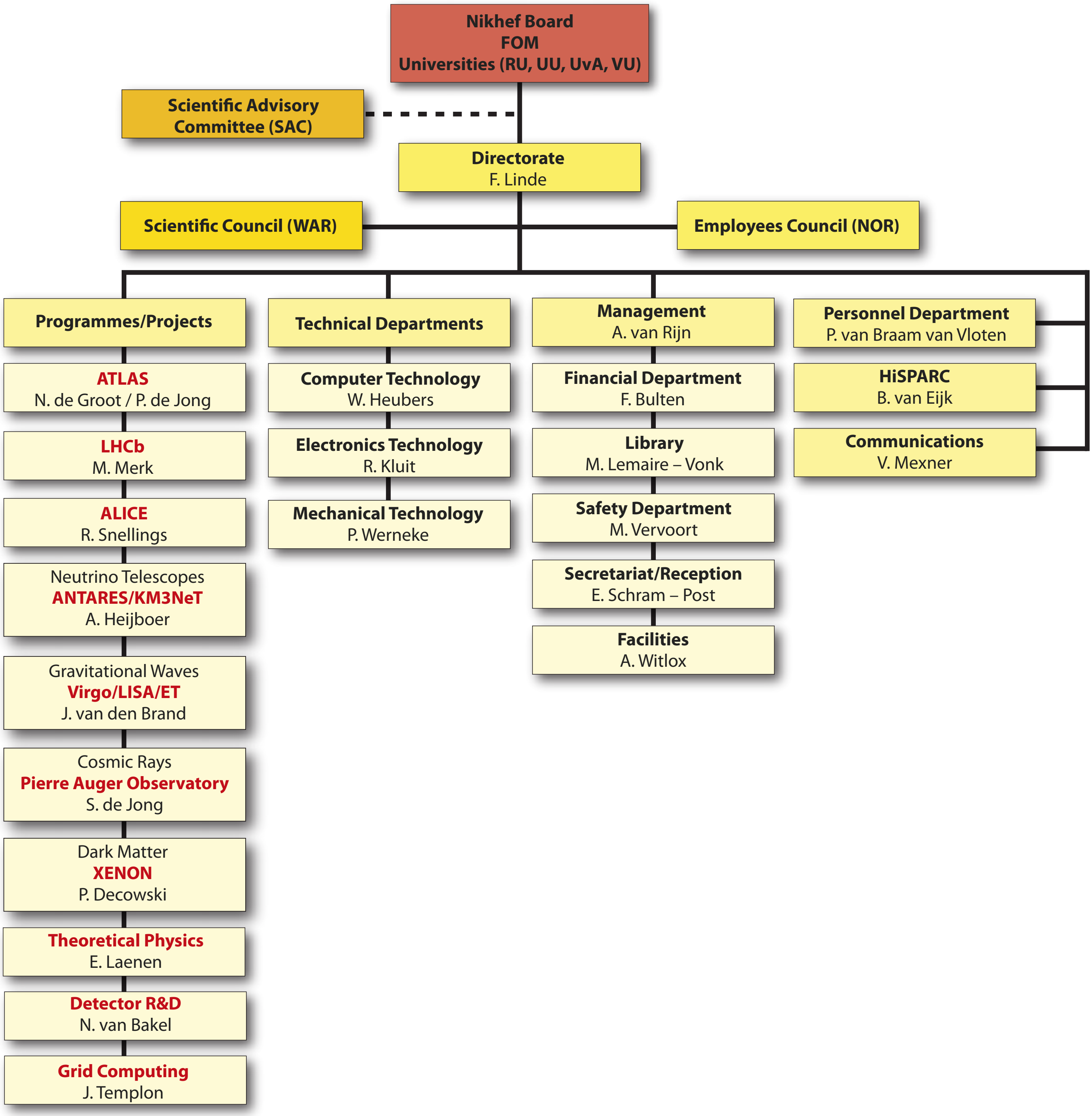
Wit, de, B.Q.P.J., De ontdekking van het Higgs-deeltje, Centrale Commissie voor Interkerkelijk Vormingswerk (CCIV), Bussum, The Netherlands, 2013-10-17

Nikhef staff member Hella Snoek is interviewed on the terrace of the CERN cafetaria during the 2013 Dutch National Media Visit.

5

Resources

5.1 Organigram*



* *as of 31 December 2013.*

5.2 Organisation*

Nikhef Board
C.C.A.M. Gielen (chair, Radboud University Nijmegen)
C.L.A. Hooijer (secretary, FOM)
H. Irth (VU University Amsterdam)
N.J. Lopes Cardozo (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)
F. Gianotti (CERN, Geneva)
N. Glover (IPPP, Durham)
J. Mnich (DESY, Hamburg)
T. Nakada (EPFL, Lausanne)
A. Rubbia (chair, ETH, Zürich)
J. Schukraft (CERN, Geneva)
C. Spiering (DESY Zeuthen, Berlin)

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)
N. van Bakel
S. Bentvelsen
J. van den Brand
S. Caron
P. Decowski
H. Falcke
P. de Jong
S. de Jong
E. Koffeman
E. Laenen
F. Linde
M. Merk
J. Messchendorp (KVI, Groningen)
G. Onderwater (KVI, Groningen)
Th. Peitzmann (chair)
G. Raven
A. van Rijn (secretary)
R. Snellings
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)

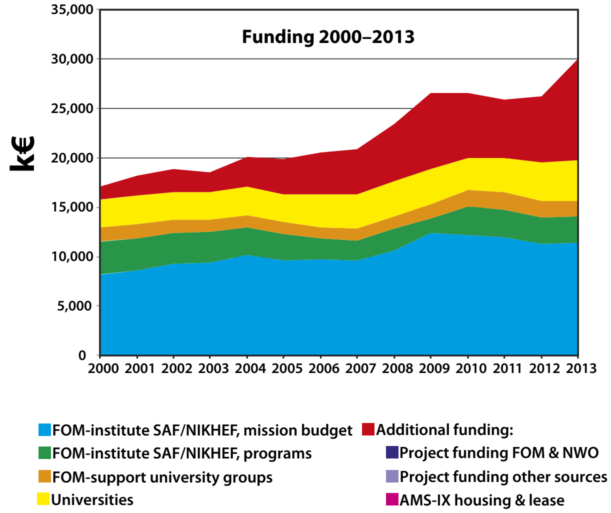
* *as of 31 December 2013.*

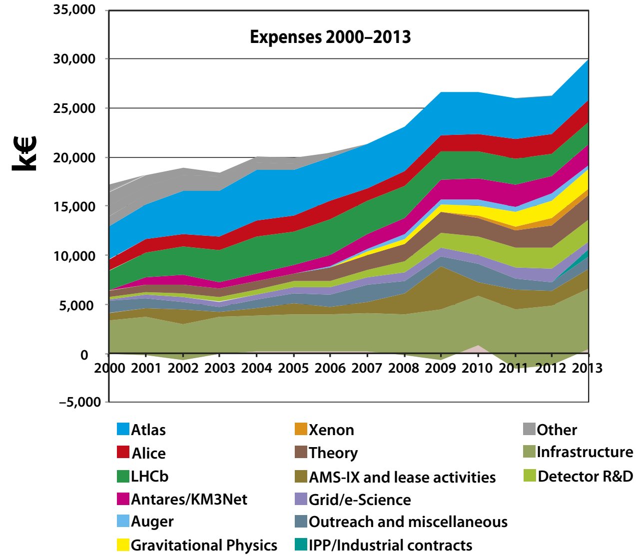
5.3 Funding & Expenses

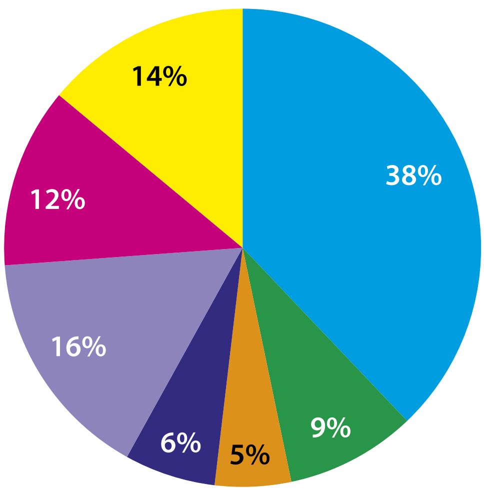
The 2013 funding level of the Nikhef collaboration is considerably higher than last year: 30.1 M€ versus 26.3 M€. The four ERC grants acquired in 2012 explain the majority of this sharp increase in income. Furthermore, the Dark Matter FOM-programme, acquired last year, appears in the funding this year. Two FOM-programmes have been acquired in 2013, which will appear in the books as of 2014: a large 16.9 M€ programme for LHC physics (2014 – 2021, this programme is the continuation of the current ATLAS, LHCb and ALICE programmes) and a 1.2 M€ theoretical programme (2014–2018) entitled *'Quantum gravity and the search for quantum spacetime'*, acquired by Renate Loll from Nikhef partner RU.

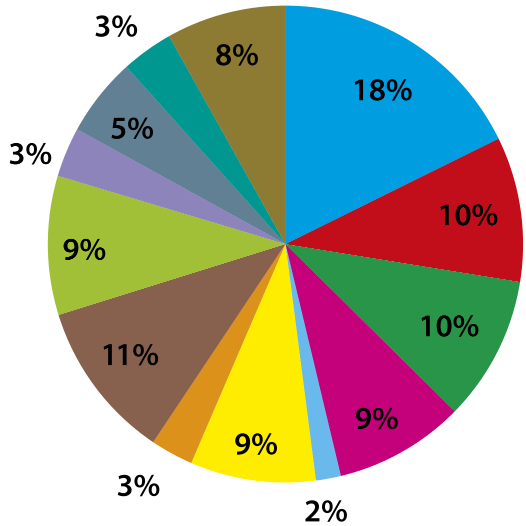
The expenses for accelerator-based particle physics (ATLAS, LHCb and ALICE) have stabilised on 38%, with an emphasis on scientific staff (notably PhD students). The astroparticle physics activities, in which construction activities are large, have consumed about 23% of expenses. The enabling activities (theory, grid and detector R&D) have grown to 28% of expenses, whilst industrial activities, outreach and the lease activities make out the remainder (11%) of the direct costs.

Not included in the graph are investments in SURF funded equipment for the national e-infrastructure, KM3NeT detector and Advanced Virgo, together budgeted at about 3.6 M€ in 2013.









5.4 Grants

In the table below we show from top to bottom grants awarded in 2013, 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 are not included in the table. More information on some of the grants of 2013 can be found in section 3.6 'Awards & Grants'.

In 2013 the Nikhef collaboration has again been successful in obtaining additional project funding from various sources. The financial envelope of projects awarded in 2013 amounts to 5 M€, about 8 million less than the extremely successful year 2012, but still more than in 2011.

Awarded					
Leader	**Title**	**Source**	**Period**	**Budget k€**	**Partner**
Van Eijk / Bentvelsen	Splitting the Higgs: the connection to dark matter	FOM/Pr	2013–2017	400	
Filthaut / De Groot	Higgs as a portal to new physics	FOM/Pr	2013–2017	396	RU
Mischke	A charming way to disentangle initial- and final-state effects at the LHC	FOM/Pr	2013–2017	270	UU
Ferrari	CP violation in the Higgs sector	FOM/Pr	2014–2018	396	
Saueressig	Black hole dynamics in asymptotically safe quantum gravity	FOM/Pr	2014–2018	398	RU
(Various)	FOM/v projects	FOM	2013–2016	425	RU
Van Tilburg	VIDI: The high-precision frontier in beauty and charm decays	NWO	2013–2018	800	
Van Bakel	SENSEIS: Silent sensors for stellar echo's and seismic surveys	STW	2014–2018	495	UT
Butter	HYPERGRAV: The last piece of the puzzle: Off-shell hypermultiplets in string theory and complex geometry	EU	2014–2016	183	
Laenen	HIGGSTOOLS: The Higgs quest - exploring electroweak symmetry breaking at the LHC	EU	2014–2017	251	
Mischke	ERC PoC: High Sensitivity Mammography with a new generation of silicon pixel sensors	EU	2014–2015	149	UU
Van Eijk	HiSPARC - 'betadecanen'	Univ.	2013–2014	50	
Van den Brand	TremorNet	Shell	2013–2014	783	VU
				4,996	
Running					
Leader	**Title**	**Source**	**Period**	**Budget k€**	**Partner**
Fleischer	Exploring a new territory of the B-physics landscape at LHCb	FOM/Pr	2010–2014	408	
Mischke	Charm content in jets	FOM/Pr	2011–2015	398	UU
Van Den Broeck	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	FOM/v	2010–2014	470	
Linde	Tiling appointment	FOM/v	2013–2017	326	
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/IPP	2013–2017	256	
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	
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
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	
Heubers	The 'Research Campus' (with Amolf and CWI)	SURFnet	2013–2014	100	
PDP group	Contribution to the national e-infrastructure	SURFsara	2013–2014	1,545	
Van Rijn	EGI InSPIRE: European Grid Infrastructure	EU	2010–2014	251	
Koffeman / Hessey	AIDA (detector R&D)	EU	2011–2014	152	
Laenen	LHCPhenoNet	EU	2011–2015	397	
Van den Brand	ELiTES: ET-LCGT Interferometric Telescopes: Exchange of Scientists	EU	2012–2016	32	VU

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	
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	
				24,614	

Completed

Leader	Title	Source	Period	Budget k€	Partner
Mulders	Color flow in hard hadronic scattering processes	FOM/Pr	2008–2013	331	VU
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	
Van Bakel / Visser	Valorisation grant 2nd phase (Amsterdam Scientific Instruments)	STW	2012–2013	200	
Klous	Virgo on GPU	NCF	2009–2013	26	
J. Visser	Hidralon: High Dynamic Range Low Noise CMOS sensors	Senter	2009–2012	794	
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 Eijk	HiSPARC - 'betadecanen'	Univ.	2011–2012	30	
				3,941	

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
Besjes	MSc.	G.J. (Geert-Jan)	RU
Bobbink	Dr.	G.J. (Gerjan)	FOM
Brenner	MSc.	L. (Lydia)	FOM
Butti	MSc.	P. (Pierfrancesco)	FOM
Caron	Dr.	S. (Sascha)	RU
Castelli	MSc.	A. (Antonio)	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
Galea	Dr.	C.F. (Cristina)	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
Kluit	Dr.drs.ir.	P.M. (Peter)	FOM
König	Dr.	A.C. (Adriaan)	RU
Koutoulaki	MSc.	A. (Afroditi)	FOM
Lenz	Dr.	T. (Tatjana)	FOM
Mahlstedt	Dipl. Phys.	J. (Joern)	FOM
Nelles	MSc.	A.F. (Anna)	FOM
Nooij	Drs.	L. de (Lucie)	FOM
Oussoren	MSc.	K.P. (Koen)	FOM
Pani	MSc.	P. (Priscilla)	FOM
Sabato	MSc.	G. (Gabriele)	FOM
Salvucci	MSc.	A. (Antonio)	RU
Slawinska	Dr.	M.K. (Magdalena)	FOM
Struebig	Dipl. Phys.	A.H. (Antonia)	FOM
Tal Hod	Dr.	N. (Noam)	FOM
Toptop	MSc.	K. (Koral)	FOM
Valencic	MSc.	N. (Nika)	FOM
Verkerke	Dr.	W. (Wouter)	FOM
Vermeulen	Dr.ir.	J.C. (Jos)	UvA
Vranješ Milosavljević	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
David	MSc.	P.N.Y. (Pieter)	FOM
De Bruyn	MSc.	K.A.M. (Kristof)	FOM
Dettori	Dr.	F. (Francesco)	FOM

* *as of 31 December 2013.*

Overview of Nikhef personnel in FTE (2013)

I – Scientific groups
(fte – 2013, institute & university groups)

Permanent scientific staff	67.2
PhD students	96.0
Post–docs	40.0
Total I	**203.2**

II – Management, technical/engineering and general support (fte – 2013, institute)

Management team	
Director	1.0
Institute manager	1.0
Personnel/HRM officer	1.0
Subtotal	**3.0**
Technical/engineering support	
Electronics technology	25.8
Computer technology	22.1
Mechanical technology	25.8
Subtotal	**73.7**
General support	
Financial administration	3.8
Personnel/HRM administration	1.0
Library	0.6
Technical and domestic services	6.8
Secretariat and reception desk	3.9
PR & communication	2.9
Occupational health & safety	2.0
Staff	2.4
Subtotal	**23.3**
Total II	**100.0**
Total I & II	**303.2**

III – Other groups (persons 2013)

Guests (researchers, retired staff)	93
Master students	65
Apprentices	12

Heijne	MSc.	V.A.M. (Veerle)	FOM
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
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
Oggero	Dr.	S. (Serena)	other
Pellegrino	Prof.dr.	A. (Antonio)	FOM
Raven	Prof.dr.	H.G. (Gerhard)	VU
Schiller	Dr.	M.T. (Manuel)	FOM
Snoek	Dr.	H.L. (Hella)	FOM
Syropoulos	MSc.	V. (Vasiliis)	FOM
Tilburg	Dr.	J.A.N. van (Jeroen)	FOM
Tolk	MSc.	S. (Siim)	FOM
Tsopelas	MSc.	P.C. (Panos)	FOM
Tuning	Dr.	N. (Niels)	FOM
Vries	MSc.	J.A. de (Jacco)	FOM
Wiggers	Dr.	L.W. (Leo)	FOM

ALICE

Bertens	MSc.	R.A. (Redmer)	UU
Bianchin	Dr.	C. (Chiara)	UU
Bjelogrlić	MSc.	S. (Sandro)	FOM
Botje	Dr.	M.A.J. (Michiel)	FOM
Caliva	MSc.	A. (Alberto)	FOM
Christakoglou	Dr.	P. (Panos)	FOM
Dobrin	Dr.	A.F. (Alexandru)	UU
Dubla	MSc.	A. (Andrea)	UU
Grelli	Dr.	A. (Alessandro)	UU
Keijdener	MSc.	D.L.D. (Darius)	other
Kofarago	MSc.	M. (Monika)	other
Kuijer	Dr.	P.G. (Paul)	FOM
Leeuwen	Dr.ir.	M. van (Marco)	FOM
Leogrande	MSc.	E. (Emilia)	UU
Lodato	MSc.	D.F. (Davide)	UU
Luparello	Dr.	G. (Grazia)	FOM
Maarel	MSc.	J. van der (Jasper)	FOM
Mischke	Dr.	A. (Andre)	UU
Mohammadi	MSc.	N. (Naghmeh)	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
Veldhoen	MSc.	M. (Misha)	FOM
Yang	Dr.	H. (Hongyan)	FOM
Zhang	MSc.	C. (Chunhui)	UU
Zhou	MSc.	Y. (You)	FOM

Neutrino Telescopes

Bormuth	MSc.	R. (Robert)	UL
Heijboer	Dr.	A.J. (Aart)	FOM
Jong	Prof.dr.	M. de (Maarten)	FOM
Jongen	MSc.	M.H.G. (Martijn)	FOM
Kooijman	Prof.dr.	P.M. (Paul)	UvA
Michael	Dipl. Phys.	T. (Tino)	FOM
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
Agatsuma	Dr.	K. (Kazuhiro)	FOM
Ambrosi	MSc.	G. d' (Giuseppe)	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 Jan)	VU
Heijningen	Ir.	J.V. van (Joris)	FOM
Janssens	MSc.	S.M.J. (Stef)	CERN
Jonker	Drs.	R.J.G. (Reinier)	FOM
Meidam	MSc.	J. (Jeroen)	FOM
Nelemans	Prof.dr.	G.A. (Gijs)	RU
Van Den Broeck	Dr.	C.F. (Chris)	FOM
Veitch	Dr.	J.D. (John)	FOM

Cosmic Rays

Aar	MSc.	G.A. van (Guus)	
Berg	Prof.dr.	A.M. van den (Adriaan)	RUG
Falcke	Prof.dr.	H. (Heino)	RU
Hörandel	Dr.	J.R. (Jörg)	RU
Jansen	MSc.	S. (Stefan)	FOM
Jong	Prof.dr.	S. de (Sijbrand)	RU
Timmermans	Dr.	C.W.J.P. (Charles)	FOM

Dark Matter

Alfonsi	Dr.	M. (Matteo)	FOM
Bertone	Dr.	G. (Gianfranco)	UvA
Colijn	Dr.	A.P. (Auke Pieter)	UvA
Decowski	Dr.	M.P. (Patrick)	UvA
Tiseni	MSc.	A. (Andrea)	FOM
Tunnell	Dr.	C.D. (Chris)	FOM

Theoretical Physics

Artoisenet	Dr.	P. (Pierre)	FOM
Beenakker	Dr.	W. (Wim)	RU
Bonocore	MSc.	D. (Domenico)	FOM
Buffing	MSc.	M.G.A. (Maarten)	VU
Butter	Dr.	D.P. (Dan)	FOM
Ciceri	MSc.	F.P.M.Y. (Franz)	FOM
Fleischer	Prof.dr.	R. (Robert)	FOM
García Echevarría	MSc.	M. (Miguel)	other
Contillo	Dr.	A. (Adriano)	RU
Cooperman	Dr.	J.H. (Joshua)	FOM
Gryb	Dr.	S.B. (Sean)	RU
Holten	Prof.dr.	J.W. van (Jan-Willem)	FOM
Inverso	MSc.	G. (Gianluca)	FOM
Kleiss	Prof.dr.	R.H.P. (Ronald)	RU
Knegjens	MSc.	R.J. (Rob)	FOM
Laenen	Prof.dr.	E.L.M.P. (Eric)	FOM
Larsen	Dr.	K.J. (Kasper)	FOM

Lodato	MSc.	I. (Ivano)	FOM
Loll	Prof.dr.	R. (Renate)	RU
Mirsoleimani	MSc.	S.A. (Ali)	FOM
Mulders	Prof.dr.	P.J.G. (Piet)	VU
Nawata	Dr.	S. (Satoshi)	FOM
Ortiz Cabello	MSc.	P. (Pablo)	FOM
Petraki	Dr.	K. (Kallia)	FOM
Pires	MSc.	L.P.M.P. (Luis)	RU
Postma	Dr.	M.E.J. (Marieke)	FOM
Reys	MSc.	V. (Valentin)	FOM
Rietkerk	MSc.	R.J. (Robbert)	UvA
Ritzmann	Dr.	M.M. (Mathias)	FOM
Ruijl	MSc.	B.J.G. (Ben)	FOM
Saueressig	Dr.	F.S. (Frank)	RU
Schellekens	Prof.dr.	A.N.J.J. (Bert)	FOM
Signori	MSc.	A. (Andrea)	VU
Taanila	MSc.	O.K.T. (Olli)	FOM
Vermaseren	Dr.	J.A.M. (Jos)	FOM
Vidotto	Dr.	F.V. (Francesca)	RU
Volponi	MSc.	M. (Marco)	FOM
Waalewijn	Dr.	W.J. (Wouter)	FOM
Wiechers	MSc.	M. (Michael)	UvA
Wit	Prof.dr.	B.Q.P.J. de (Bernard)	FOM
Zanusso	Dr.	O. (Omar)	RU

Detector R&D

Bakel	Dr.	N.A. van (Niels)	FOM
Beuzekom	Dr.ing.	M.G. van (Martin)	FOM
Graaf	Dr.ir.	H. van der (Harry)	FOM
Hartjes	Dr.	F.G. (Fred)	other
Koffeman	Prof.dr.ir.	E.N. (Els)	FOM
Koppert	MSc.	W.J.C. (Wilco)	other
Prodanović	MSc.	V. (Violeta)	FOM
Schioppa	MSc.	E.J. (Enrico)	FOM
Schön	Dipl. Phys.	R. (Rolf)	FOM
Tao	Dr.	S. (Shuxia)	FOM
Theulings	Ir.	A.M.M.G. (Annemarie)	FOM
Timmermans	Dr.	J.J.M. (Jan)	other
Tsagri	Ir.	M. (Mary)	other
Tsigarídas	MSc.	S. (Stérgios)	FOM
Visser	Dr.	J. (Jan)	FOM

Grid Computing

Groep	Dr.	D.L. (David)	FOM
Remenska	MSc.	D. (Daniela)	FOM
Templon	Dr.	J.A. (Jeff)	FOM

HiSPARC

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. (Niek)	other
Veen	MSc.	C.G. van (Norbert)	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. (Robert)	FOM
Ceelie		L. (Loek)	FOM
Doets		M. (Martin)	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
Kroon	Ing.	B.W.H.J. van der (Boudewijn)	FOM
Kuilman		W.C. (Willem)	FOM
Leguyt		R. (Robert)	FOM
Munneke	Ing.	B. (Berend)	FOM
Overbeek		M.G. van (Martijn)	FOM
Petten		O.R. van (Oscar)	FOM
Rietmeijer		A.A. (Arnoldus)	FOM
Roeland		E. (Erno)	FOM
Roo	B.Eng.	K. de (Krista)	FOM
Rövekamp		J.C.D.F. (Joop)	FOM
Verlaat	Ing.	B.A. (Bart)	FOM
Walet	Ing.	R.C. (Rob)	FOM
Werneke	MSc.	P.J.M. (Patrick)	FOM

Electronics Technology

Amico		A. d' (Antonio)	FOM
Berkien		A.W.M. (Ad)	FOM
Borga	B.ICT	A.O. (Andrea)	FOM
Buurmans	Ing.	J. (Jeroen)	FOM
Fransen		J.P.A.M. (Jean-Paul)	FOM
Gajanana	MSc.	D. (Deepak)	FOM
Gebyehu	Ir.	M. (Mesfin)	FOM
Gotink		G.W. (Wim)	FOM
Groenstege	Ing.	H.L. (Henk)	FOM
Gromov	Ir.	V. (Vladimir)	FOM
Heijden	Ing.	B.W. van der (Bas)	FOM
Ietswaard		G.C.M. (Charles)	FOM
Jansen		L.W.A. (Luc)	FOM
Jansweijer	Ing.	P.P.M. (Peter)	FOM
Kieft	Ing.	G.N.M. (Gerardus)	FOM
Kluit	Ing.	R. (Ruud)	FOM
Koopstra		J. (Jan)	FOM
Schipper	Ing.	J.D. (Jan David)	FOM
Schmelling	Ing.	J.W. (Jan-Willem)	FOM
Schreuder		F.P. (Frans)	FOM
Timmer		P.F. (Paul)	FOM
Verkooijen	Ing.	J.C. (Hans)	FOM
Vink	Ing.	W.E.W. (Wilco)	FOM
Visser	Ing.	G.C. (Guido)	FOM
Wijnen	Ing.	T.A.M. (Thei)	RU
Živković	Dr.ir.	V. (Vladimir)	FOM

Computer Technology

Akker		T.G.M. van den (Theo)	FOM
Baan Hofman		W.M. (Wilco)	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
Dok	Drs.	D.H. van (Dennis)	FOM

Gabriel	Dr.	S. (Sven)	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
Keijser	Drs.	J.J. (Jan Just)	FOM
Kerkhoff		E.H.M. van (Elly)	FOM
Kuipers	Drs.	P. (Paul)	FOM
Oudolf		H. (Jan)	other
Sallé	Dr.	M. (Mischa)	FOM
Schimmel	Ing.	A. (Alfred)	FOM
Starink	Dr.	R. (Ronald)	FOM
Suerink	Ing.	T.C.H. (Tristan)	FOM
Tierie		J.J.E. (Joke)	FOM
Verstegen	Ing.	A.C.Z. (Aram)	FOM
Wal	B.ICT	B. van der (Bart)	FOM

Management & 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
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
Keijer		K.E.F. (Koen)	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
Romeyn		R.A. (Rosa)	ZZP-er
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 2013, 23 students graduated from the Master's programme Particle Physics and Astroparticle Physics, see Table 1. For more information about the Master's programme, please refer to Section 4.2.

Date	Name	University (honours)	Master thesis title	Supervisor(s)	Group
28 February 2013	Liselotte Heukelom	UvA	In search of the smuon	P.J. de Jong	ATLAS
31 May 2013	Aagje Hendriks	UvA	A Search for the Higgs Boson in the Decay to b-Quarks with the ATLAS Detector	I.B. van Vulpen A.P. Colijn	ATLAS
31 May 2013	Ioannis Tsinikos	UvA (cum laude)	Spin Correlations at Hadron Colliders	E.L.M.P. Laenen M. Vreeswijk	ATLAS Theory
31 May 2013	Jacco de Vries	UvA (cum laude)	First Observation of the Decay $B_c^+ \to B_s^0 \pi^+$	N. Tuning S.C.M. Bentvelsen	ATLAS
21 June 2013	Jins de Jong	RU	Hybrid renormalization and the ß-functions of the real scalar Higgs Lagrangians from the scalar spectral action	W. Beenakker W. van Suijlekom	Theory
26 June 2013	Johnny Zhan Wu	UU	Blast-Wave model fit for identified particle spectra and elliptic flow	R. Snellings Y. Zhou	ALICE
15 July 2013	Lydia Brenner	UU	Elliptic flow of inclusive electrons at 2.76 TeV lead-lead collisions with ALICE detector	R. Snellings A. Grelli	ALICE
24 July 2013	Alexandru-Ionut Babeanu	UU	Electromagnetic shower recognition with a forward calorimeter for the ALICE experiment	T. Peitzmann D. Lodato	ALICE
24 July 2013	Alexandros Apostolou	UU	Data analysis from the beam test at DESY for the Focal Prototype	T. Peitzmann G.J. Nooren	ALICE
27 July 2013	Jasper van der Maarel	UU	Azimuthal angular correlations of heavy flavour decay electrons and charged hadrons in proton-proton collisions at $\sqrt{s} = 7$ TeV using the ALICE detector	A. Mischke D. Thomas	ALICE
31 July 2013	Naghmeh Mohammadi	UU	Azimuthal angular correlations between heavy flavour electrons and charged hadrons in semi-central lead-lead collisions at 2.76 TeV at ALICE	A. Mischke D. Thomas	ALICE
31 July 2013	Margot Brouwer	UvA	Dark Matter Indirect Searches with Dwarf Spheroidals: Prospects for GAMMA-400	G. Bertone C. Weniger	GRAPPA
31 July 2013	Athanasios Chouliaras	UvA	Higgs Spin and Parity Determination Using the Decay Channel $H \to ZZ^* \to 4\ell$ with the ATLAS Detector	I.B. van Vulpen P.J. de Jong	ATLAS
31 July 2013	Suzanne Klaver	UvA (cum laude)	A Search for Long-Lived Neutralinos in LHCb	W. Hulsbergen P.J. de Jong	LHCb
31 July 2013	Jesse Mesman	UvA	Branching Fraction Measurement of the $B_s^0 \to \overline{D}^0 K_S^0$ Decay	W. Hulsbergen I.B. van Vulpen	LHCb
14 August 2013	Martijn van Beek	RU	The Effects of Dark Matter on Gravitational Lensing Properties of Galaxy Clusters	W. Beenakker/G. Lewis (University of Sydney)	Theory
18 August 2013	Gerard Smit	UU	Eccentricity fluctuations in the overlap region of simulated lead-lead collisions	R. Snellings T. Peitzmann	ALICE
30 August 2013	Marco Tompitak	VU (cum laude)	Neutron star deformability	C. Van Den Broeck	Theory Grav. Waves
30 August 2013	David Hohn	UvA	Higgs Spin and Parity Determination Using BDTs with the ATLAS Detector	P. Ferrari S.C.M. Bentvelsen	ATLAS
30 August 2013	Matthijs Muller	UvA	A Higgs Boson Search	M.Vreeswijk	ATLAS
31 August 2013	Martijn Jongen	RU (cum laude)	Quantum Field Theory on a Random Lattice	R. Kleiss	Theory
27 September 2013	Ching Bon Lam	UT	Interactions of Particles with Momenta of 1–10 GeV in a Highly Granular Hadronic Calorimeter with Tungsten Absorbers	A.Lucaci-Timoce B. van Eijk	CLIC
31 December 2013	Sander Breur	UvA	The Performance of Nal(TI) Scintillation Detectors	A.P. Colijn I.B. van Vulpen	ATLAS

Table 1. Master's students who graduated in 2013.

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 2013 in the Electronics Technology (ET) and Mechanical Technology (MT) departments.

Date	Name	School	Subject / Title	Supervisor(s)	Group
25 January 2013	Brian van Driel	MBO ROC van Amsterdam	Service paal	O. van Petten	MT
28 May 2013	Jack Geurtsen	HBO Haagsche Hogeschool	Stress maximization of monocrystalline silicon cantilever blades	E. Hennes	MT
7 June 2013	Simon Hoogland	MBO Horizon College Hoorn	HiSPARC PMT base	H. Verkooijen	ET
28 June 2013	Floris Romeijn	MBO ROC van Amsterdam	Demo opstelling voor thermo-elastische demping	O. van Petten	MT

Table 1. Apprentices who finished their training period at Nikhef in 2013.

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.

D0 (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 physics. In 2013 Englert and Higgs received the Nobel Prize "*for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider*".

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.

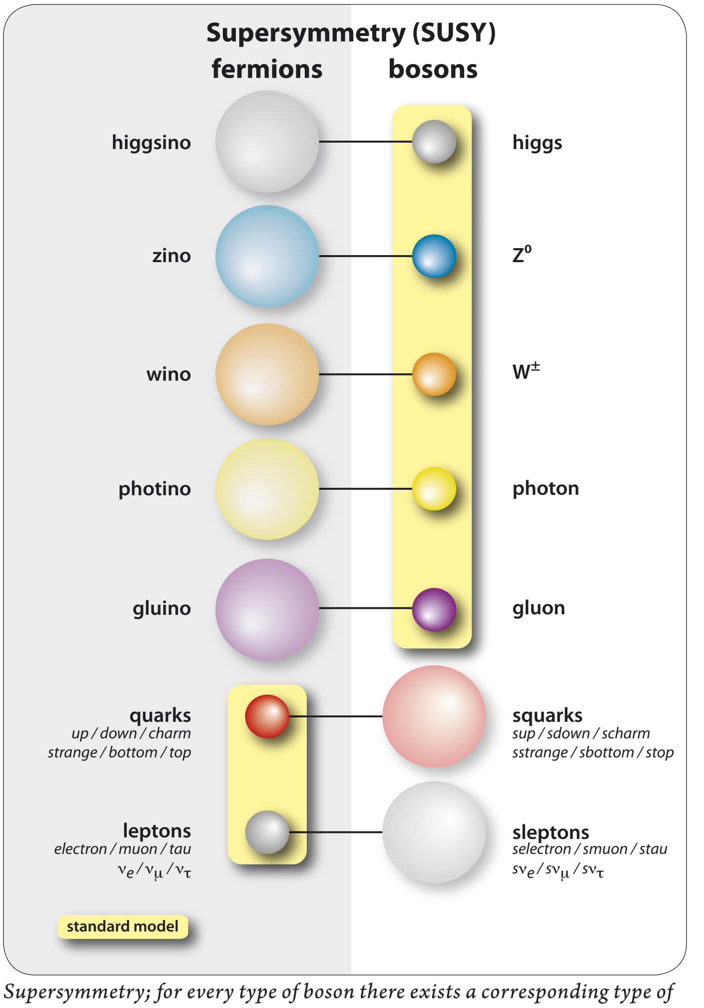
LEP
The Large Electron–Positron collider at CERN which ran until 2000. Its tunnel has been reused for the LHC.

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.

HL-LHC (High Luminosity Large Hadron Collider)
Proposed upgrade of CERN's LHC to increase its luminosity (rate of collisions) by a factor of 10 beyond its design value.

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



Supersymmetry; for every type of boson there exists a corresponding type of fermion with the same mass and internal quantum numbers, and vice-versa.

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 *e*LISA 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.

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.

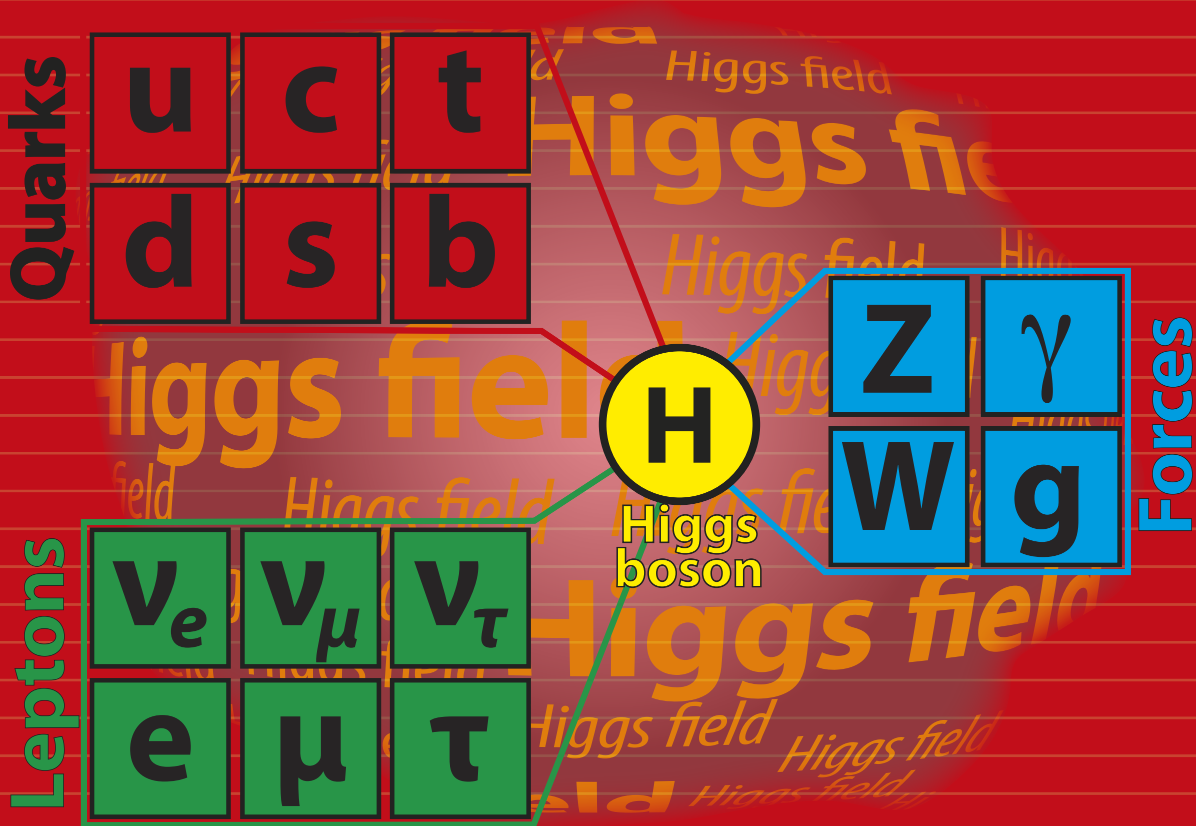
Virgo
Detector near Pisa for gravitational waves: a Michelson laser interferometer made of two orthogonal arms, each 3 km long.

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.


Quarks
u c t
d s b
Leptons
ν_e ν_μ ν_τ
e μ τ
H
Higgs boson
Forces
Z γ
W g
Higgs field

NIKHEF