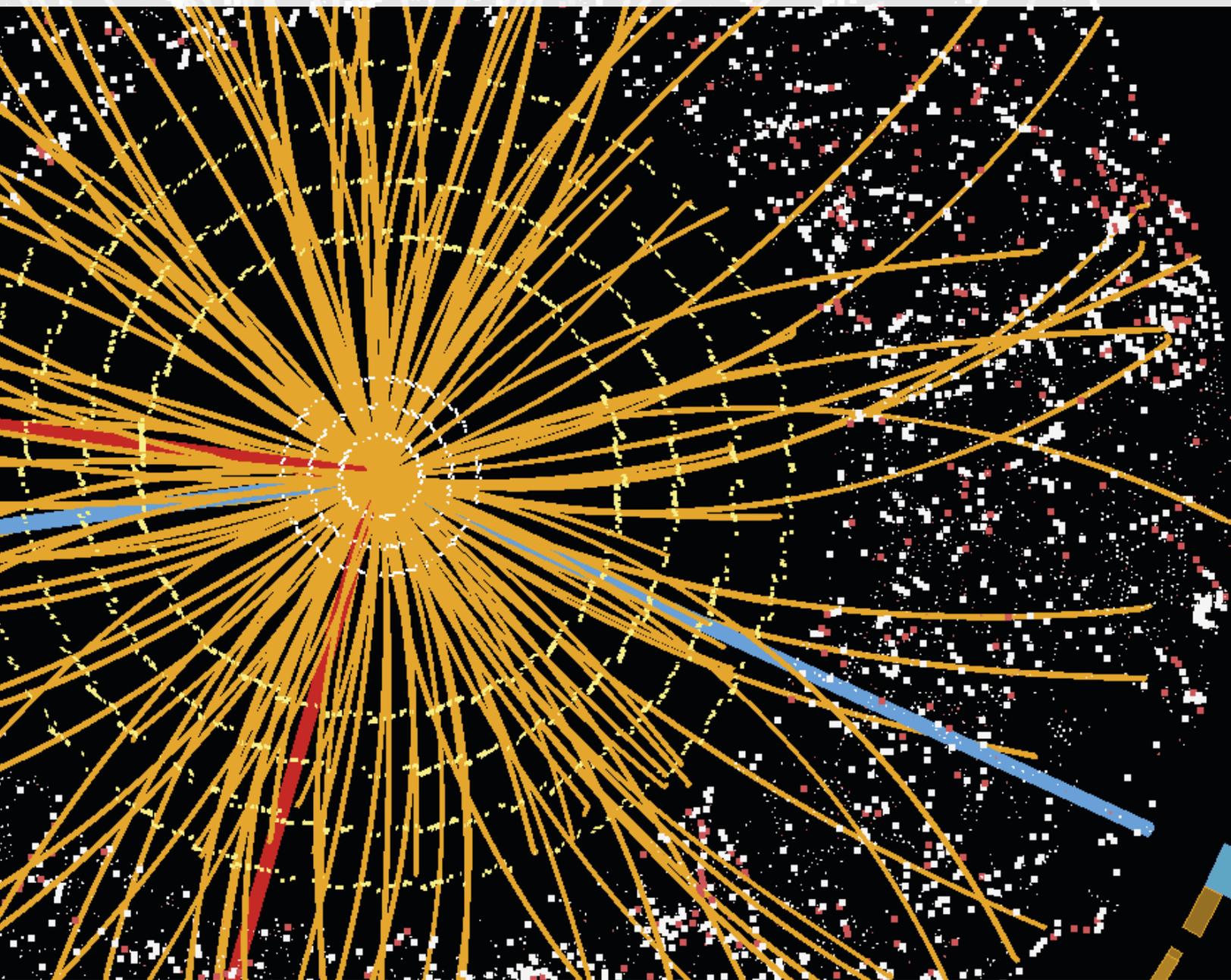


ANNUAL REPORT 2015



Ni**h**ef

National Institute for Subatomic Physics

The Nikhef institute at the Science Park in Amsterdam.



Annual Report 2015

**National Institute
for Subatomic Physics
Nikhef**



Colophon

Nikhef

Nationaal instituut voor subatomaire fysica

National Institute for Subatomic Physics

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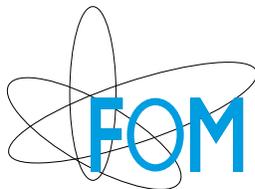
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Nikhef participates in experiments at the Large Hadron Collider at CERN, notably ATLAS, LHCb and ALICE. Astroparticle physics activities at Nikhef are fourfold: the ANTARES and KM3NeT neutrino telescope projects in the Mediterranean Sea; the Pierre Auger Observatory for cosmic rays, located in Argentina; gravitational-wave detection via the Virgo interferometer in Italy, and the 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 Amsterdam Science Park as well as at the participating universities. Data analyses make extensive use of large-scale computing at the Tier-1 grid facility operated jointly by Nikhef and SURFsara. The Nikhef theory group has its own research programme while being in close contact with the experimental groups.

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Introduction

Again this was a remarkable year for Nikhef, with existing and new challenges, changes of various kinds and lots of scientific excitement. With almost 100 PhD students and 30 postdocs and a large staff of senior scientists, engineers, technicians and support staff, Nikhef is a very dynamic institute with a challenging mission and an excellent international reputation.



During this year the Transition of NWO started. The current FOM organization will be split in two with the granting part in the new domain 'Natural and Mathematical Sciences'. The part of FOM that now supports the FOM institutes will become part of the new NWO Institute Organization unit that will support all NWO institutes. We are involved in discussions how to shape the new organization, with special emphasis on the position of the institutes.

Nikhef too made a number of organizational changes. Els Koffeman has joined the Management Team with special attention for scientific instrumentation. Regular meetings with all programme leaders (OPL) have been introduced to optimize the portfolio of the institute. The Scientific Council (WAR) is a renewed think tank that monitors the quality of our science and has an open eye for new ideas and initiatives. A Grant Office is put in place that evaluates proposals and organizes internal reviews before submission, with the aim to reach a higher success rate. These bodies have settled in their roles during the year. It is my impression that with these new initiatives

in combination with regular project leader meetings, works council meetings (NOROV) and staff meetings, our internal discussions are well taken care of. One of the pleasures for me is to present my personal view in regular '*spiegelmomenten*' in the Spectrum hall. In the course of the year I reviewed ongoing activities at the institute, news from the technical groups and science collaborations, outreach, safety etc.

One of the priorities are the plans and ambitions for a renovation of the institute building in Amsterdam. A number of technical installations have come to the end of their lifetime – or are simply absent like the top-cooling in the N-building. Not only that, we need a facelift to get rid of a stuffy atmosphere, to increase the transparency and intellectual climate of the building and to create a modern scientific environment. Although the realization of this programme may still take some time, we have started a number of pilot projects. Most visible is the Spectrum hall itself

Nikhef mission

The mission of the National Institute for Subatomic Physics 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.

that has undergone a drastic facelift and has become a pleasant place, while at the same time showing the urgency for further renovation. But be patient!

Above all, the science and technology of Nikhef, with Nikhef people, makes our institute so special. This book proudly reports on all our activities in 2015. Three of our top scientists are interviewed on the challenges in physics beyond the discovery of the Higgs particle. There is an article about the Nobel Prize in neutrino physics and we follow the story of the careers of four former Nikhef PhD students. You can also read updates of the activities of the science groups, theory and R&D, knowledge transfer, education and outreach.

The real excitement is in the experimental programs. The LHC was restarted after a period of two years of silence. The obtained results are solid new physics results and offer room for new speculations. ALICE has advanced in their understanding of the quark-gluon plasma. LHCb made a number of observations that are not understood in terms of the Standard Model of particle physics. ATLAS reports even on potential new resonances. We all look forward to more data as the story of the LHC at the highest energies has only just begun.

The astroparticle physics experiments have been very active in 2015 as well. On 11 November the inauguration of the XENON1T experiment took place in Gran Sasso, Italy. On 16 November Nikhef signed a declaration of intent to continue the Pierre Auger Observatory in Argentina for another ten years. On 3 December the first detection line of the KM3NeT neutrino telescope was successfully launched in the Mediterranean Sea. Also the last parts of the advanced Virgo detector built at Nikhef, were transported to Cascina to be installed, by Nikhef scientists, members of the tightly collaborating Virgo/LIGO consortium.

In the coming years the potential for finding new physics is high. Next year we will report on the spectacular discovery of gravitational waves that were publicly announced on 11 February 2016. It may be that particle physics shows even more surprises in the next years. The science at Nikhef is very much alive!



Stan Bentvelsen

Multidisciplinary approach

Characteristic for Nikhef is a multidisciplinary approach in the field of particle and astroparticle physics. Scientists and engineers from university partners and the FOM institute work together to investigate the smallest building blocks of matter and their mutual forces. It positions Nikhef as one of the few institutes in the world in the field of particle physics capable of developing scientific theories, performing data analysis and constructing instrumentation. This, combined with the wide pallet of knowledge and expertise, is the origin of Nikhef's strong reputation, both nationally and internationally.

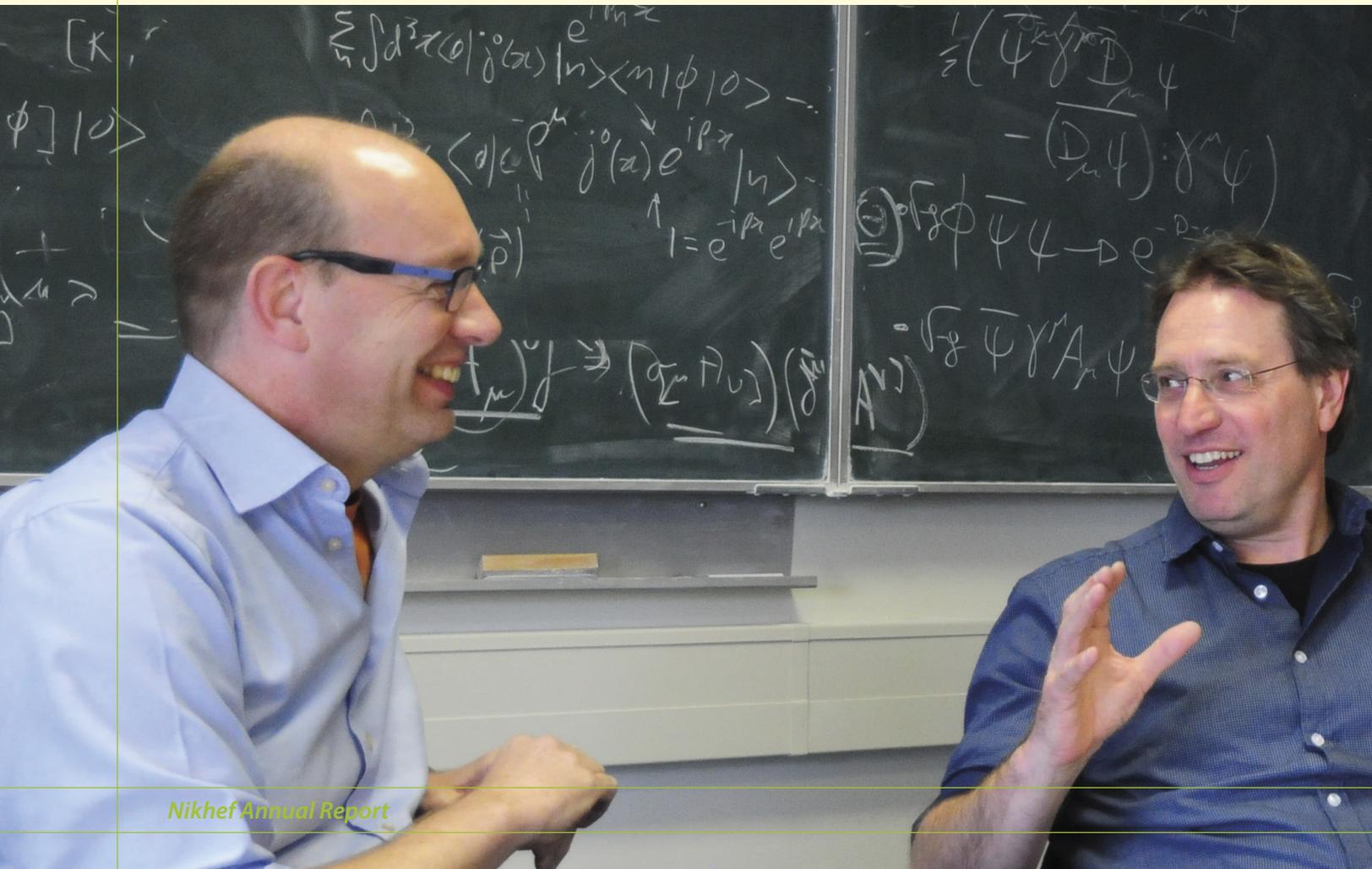
Towards groundbreaking physics

Thanks to CERN's improved particle accelerator and a brand new Dark Matter experiment the race towards new physics will shift up a gear in the coming year. Nikhef researchers look back at 2015 and look ahead to the year in which the search for new physics will finally take shape.

By George van Hal

Translation by Dave Thomas

Eric Laenen (left), Marcel Merk (middle) and Patrick Decowski (right) discussing the state of affairs in (astro)particle physics.



In 2012 a milestone was reached. At the European particle physics institute CERN, physicists discovered the clinching evidence in their data that the long-sought Higgs particle really did exist.

The discovery formed the closing piece for the Standard Model, which describes all particles and the interactions between these in a single mathematical description. It was one of the biggest success stories from modern science.

The Higgs particle confirmed that the Standard Model, which particle physicists had devised on paper, was actually correct and that the model makes valid predictions. It was a breakthrough which physicists, even more than 3.5 years later, still look back at with considerable satisfaction. "The discovery of the Higgs boson really was unprecedented. The theory had predicted it and it later emerged in the results," says Eric Laenen, head of the theoretical group at Nikhef.



Not 'finished'

But beware: the confirmation of the Standard Model certainly does not mean that particle physics is now 'finished', just like writing down Newton's laws did not form the final chapter of the history of physics. After Newton, people like Einstein and Schrödinger turned physics upside down with their revolutionary insights. And nowadays there are still more than enough major, open questions that are crying out for an answer.

"The probability that the Standard Model covers everything is definitely zero," says Patrick Decowski who leads the Dark Matter group at Nikhef. "The question is merely when we will measure something."

Physicists have already encountered the first highly promising results in the data from CERN's Large Hadron Collider (LHC). These measurements sometimes prompt some physics bookkeeping. This is rigorous work that is vitally important for correct physics. However just as often these form a possible entry point to what physicists refer to as 'physics beyond the Standard Model'. In other words: descriptions of particles, interactions and processes that are completely unknown at present.

Physicists often know what they are looking for. "Theoretical physicists have developed a vast number of ideas in recent years," says Laenen. "At present, however, experiments must lead the way. At CERN, theories can now be thoroughly tested and answers provided." At the same time theoretical physicists keep coming up with a plentiful supply of new ideas. "And some of those ideas could very well challenge all current insights."

At Nikhef the theoretical group is currently interpreting the measurements from experiments like the LHC and is placing these in an increasingly complete theoretical framework. For example, in 2015 the group spent a lot of time describing the behaviour of the Higgs particle in greater detail. "One of our highlights was the third order correction to the collision cross-section of the Higgs particle," says Laenen. "And in 2016, gaining a better understanding of the behaviour of that particle is at the top of our agenda."

Antimatter

One thing is certain though, we are still a long way off from answering all questions. For example, nobody understands the matter/antimatter problem yet. Whoever describes the universe on the basis of the Standard Model would naïvely expect that the universe contains as much matter as antimatter. But that is very clearly not the case. Everybody you know, every object you can hold, every planet, star and nebula in our universe, literally everything consists of 'normal' matter. Antimatter appears only very sporadically and when it does appear, it often disappears again just as quickly. It can only exist for slightly longer under highly controlled conditions in laboratories.

| | | Fermions | |
|---------|--|--|--|
| Quarks | u up | c charm | |
| | d down | s strange | |
| Leptons | ν_e electron neutrino | ν_μ muon neutrino | |
| | e electron | μ muon | |

The Standard Model of Physics. The graviton is still a hypothetical elementary particle that mediates the force of gravitation in the framework of quantum field theory.

| | Bosons |
|--|--------------------------------------|
| t top | γ photon |
| b bottom | Z Z boson |
| ν_{τ} tau neutrino | W W boson |
| τ tau | g gluon |
| G^* graviton | H higgs boson |

Force carriers

There are many theoretical ideas as to why there is such an excess of matter but the real pioneering work takes place at the LHC. There the LHCb experiment is searching for unexpected effects during particle collisions. These might contain clues that could throw new light on the issue.

"Analyses of the data collected by the LHC between 2010 and 2012 reveal that everything is neatly in line with the Standard Model," says physicist Marcel Merk who leads the LHCb group at Nikhef. "That outcome is perplexing because we know for sure that there is more than the Standard Model."

Whoever wants to explain antimatter therefore needs to tinker with the model here and there. And Merk hopes to find those anomalies in 2016. Now that the LHC allows particles to collide with each other at higher energies, the chances of discovering more exotic phenomena is also greater than before. "We will take a very good look at that," says Merk. "We will test the Standard Model in different ways and we want to discover whether the particles really always behave in the same manner."

And independent of the antimatter issue, the data collected by LHCb at lower energy levels were already particularly interesting. "With LHCb we are also looking for particles beyond the Standard Model," says Merk. Last year the experiment found indications for the existence of one of those particles, the so-called 'Z-prime' particle. Furthermore, Merk and his colleagues found even more indications that something is out of line in the Standard Model. "We can see that something does not quite make sense," says Merk, "even though these measurements are not yet statistically strong enough to be able to talk about a real discovery."

If these results do not melt like snow under the statistical sun then Merk thinks he knows roughly what has been discovered. "We hope that these are indications for a lepton flavour violation," he says. This is a term that physicists use to describe a certain type of particle behaviour that cannot occur according to the Standard Model. However, it does seem to happen during the particle collisions at CERN. "We will therefore take a good look at this in 2016."

Dark Matter

Measuring the lepton flavour violation is not the only breakthrough beckoning beyond the horizon of 2015. Last year the finishing touches were made to the XENON1T experiment, the most accurate Dark Matter detector in the world. With that experiment, for which physicists from Nikhef have developed several essential components, physicists hope to discover where 85% of the mass of the universe is hiding – a fundamental question to which nobody has an answer, and perhaps even the biggest question in modern physics.

Although nobody knows exactly what it is, scientists have given it a name: Dark Matter. Astronomers came across this mysterious matter years ago when they discovered that 85% of all mass in the universe is Dark Matter; it only gives away

its presence indirectly by exerting a gravitational force on other matter. This discovery immediately downgraded the known and observable universe to merely a supporting role on the cosmic stage, because if you add up all of the masses of everything you can see, you arrive at just 15% of the total. The rest is unknown. The Nikhef employees who are working on the XENON1T experiment hope to change that soon. "We expect to collect the first scientific data in March 2016," says Decowski. Although XENON1T is not fully operational yet, it is already more than ten times stronger than the most powerful experiment searching for Dark Matter to date. And as soon as it is fully operational, XENON1T will be fifty times more powerful.

The experiment is located behind enormous steel doors, deep inside a mountain, so that harmful radiation from the cosmos that could drown out the signal of Dark Matter cannot reach the experiment. XENON1T is looking for so-called WIMPs (Weakly Interacting Massive Particles). These are elusive particles that have some weight but scarcely interact with other particles.

Laenen calls the quest of Decowski and his colleagues 'highly promising', even though the WIMPs that XENON1T is searching for are not the only option, and the experiment is not alone in its search for Dark Matter. "My dream scenario is that we are not the only ones who will soon measure a signal," says Decowski. "Hopefully the LHC will also find something and astronomers will measure a Dark Matter signal in space. We all have our own approach and measurement methods. We therefore complement each other well."

Merk agrees with Decowski. According to him the focus within science is not on the competition between different experiments. "Before I die I simply want to know the truth. That is what drives us scientists. We are less concerned about who makes the discovery."

Decowski suspects in any case that it will prove to be more complex than simply a single particle that explains all Dark Matter. "I think that a single particle is an oversimplification of reality. But I do have two favourite options. WIMPs is the one and Axions (other theoretical particles beyond the Standard Model) the other."

Exciting peak

That physics beyond the Standard Model has attracted a lot of attention became clear at the end of 2015 when the ATLAS and CMS experiments, the two largest experiments at the LHC, announced that they had found something unusual. "There was excitement about a peak in the data," says Decowski. The experiments found a small peak, which indicated that a signal was measured from a particle that decayed into two photons. In the reports on Internet and in the newspapers and magazines people speculated about the possible discovery of the 'big brother' of the Higgs particle, even though everybody immediately stated that the measurement was not yet statistically strong enough to be certain that the peak was something more than an interesting coincidence. "If the results are indeed substantiated then this discovery will not fit in any of our existing models," says Decowski.

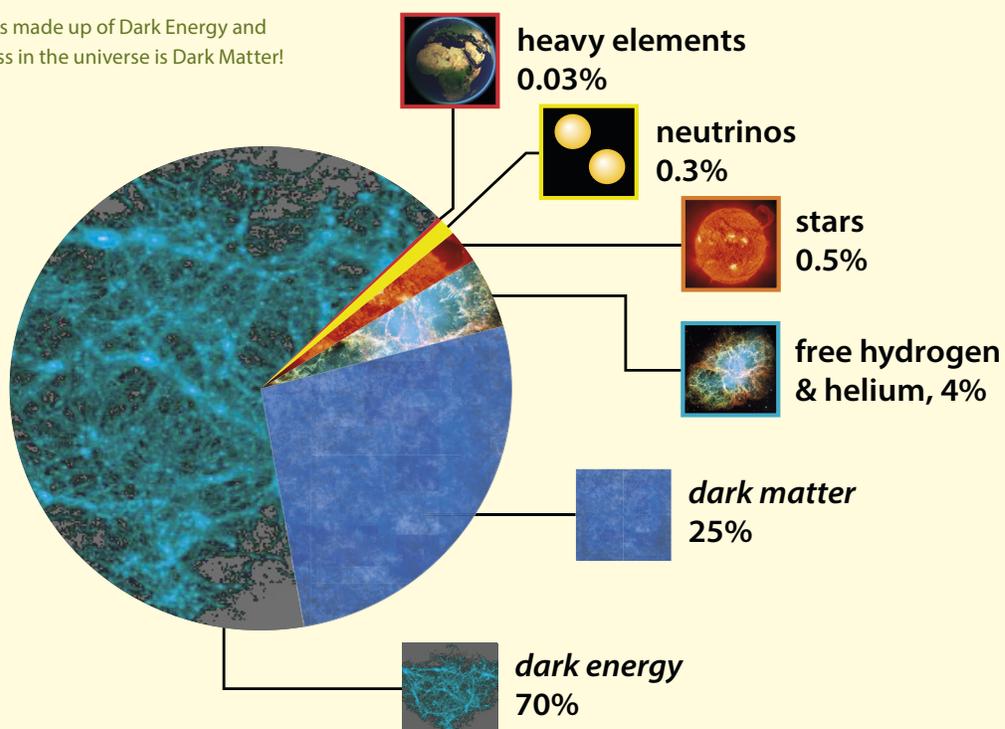
According to Laenen it is quite amazing just how much interest there is in this result. "More than 100 theoretical publications have already appeared about it. That is incredibly fast," he says. Merk, on the other hand, understands all the commotion. "If this result had already been statistically confirmed then it would be something enormous." Merk is therefore not surprised by all of the enthusiasm. Laenen, on the other hand, takes a more down-to-earth view. "I think we can better prepare ourselves for the possibility that it is nothing. Yet that could simply be my very Dutch attitude," he says. "But of course theoreticians also prefer to have a *'what on earth is going on here ...'* experience. Therefore I hope that the signal proves to be something."

From all of this it is clear that Nikhef researchers are not just professional scientists but also die-hard enthusiasts. "Interesting things are happening in so many areas of physics at the moment," says Merk. "I also try to stay informed about developments outside of my own area of expertise. I read about those after work," he says.

One area that has the interest of all three physicists is the research into gravitational waves. (At the time of the interview the first measurement of gravitational waves by the LIGO detectors had not yet been announced – *ed.*) These ripples in space-time predicted by the theory of relativity had never previously been observed and would confirm this theory. "Rumours predict that a result is in the pipeline. It would mean a confirmation of Einstein's theory and the culmination of many years of hard work," says Merk. The gravitational wave detector LIGO has now achieved a greater sensitivity for gravitational waves and the analyses are currently being performed together with the Virgo collaboration. "It is an incredibly interesting quest and an honour that we are allowed to participate in it."

According to Laenen we live in an exciting time, one in which we are coming increasingly closer to answering the biggest questions we can pose. "It is great that we can work together here at Nikhef, chat together during the coffee breaks, and keep abreast of the latest developments in all of these disciplines," he says. "That is what makes an institute like this so wonderful."

About 95% of the universe is made up of Dark Energy and Dark Matter; 85% of the mass in the universe is Dark Matter!



ATLAS in 2015

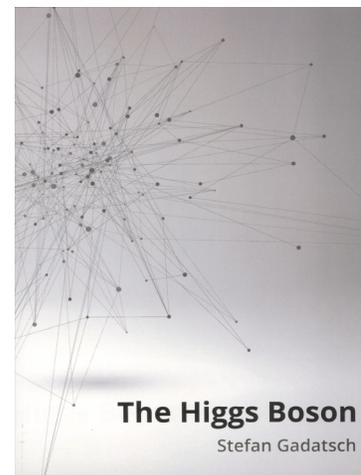
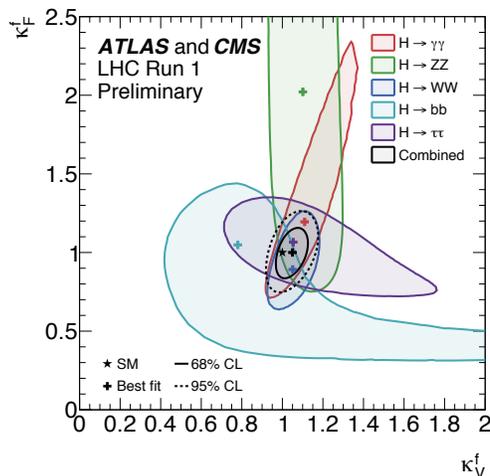
goodbye run 1, hello run 2

The year 2015 was one of transition for ATLAS. We were still very busy bringing in the last part of the rich physics harvest of run 2, while at the same time preparing the detector for the start of run 2 after a two-year shut-down, later on commissioning and operating the detector at a new energy frontier. It was also a good year for data-taking, with 4 fb^{-1} of collisions recording at an energy of 13 TeV.



2015 ended on a high note when the Dutch ATLAS group was awarded the Snellius Medal for its contribution to the discovery of the Higgs boson in 2012 by the Dutch Society for the Advancement of Science, Medicine and Surgery. The Snellius Medal is awarded for cutting-edge research in the field of physics, mathematics or computing science. The medal was established in 1951 and is awarded once every ten years. Nikhef director Stan Bentvelsen received the medal on behalf of the group and gave a presentation on the long road to discovery at the Lustrum Symposium of the society.

Figure 1. A highlight of 2015 : the final combination of the measurements of the couplings of the Higgs boson by the ATLAS and CMS experiments. The paper has a major Nikhef contribution, both in the RooFit software tools that were used for the combination which were developed by a.o. Wouter Verkerke as in the actual combination where also PhD student Stefan Gadatsch played an important role.



Stefan Gadatsch
26 June 2015



Management
prof.dr. N. de Groot
dr. W. Verkerke

Throughout the year ATLAS has maintained an impressive production of physics analyses. In 2015 ATLAS submitted 122 new papers and passed the milestone of its 500th paper. Some of the remarkable papers on run 1 data from this year were the searches for lepton flavour violation in which Nikhef played a leading role. New, improved, limits were set on the decay of the tau lepton into three muons and of the Z boson into a muon-tau pair. In the area of Higgs property measurements four papers with major Nikhef contributions were published: the assessment of the spin/CP hypothesis of the Higgs boson, measurement of the Higgs coupling structure, the interpretation of these couplings in various extensions of the Standard Model, and the final measurement of the Higgs signal strength in the decay mode $H \rightarrow WW$, the most precisely measured channel to date.

The ATLAS publication machine was led by Nikhef physicist Paul de Jong. Other coordinating positions in ATLAS were held by Pamela Ferrari ($H \rightarrow WW$ group), Olya Igonkina (Express stream), David

Salek (luminosity group), Jochen Meyer (muon software), Pierfrancesco Butti (alignment), David Berge (astroparticle physics forum), Noam Tal Hod (lepton+X exotics) and Wouter Verkerke (Higgs combination and statistics forum).

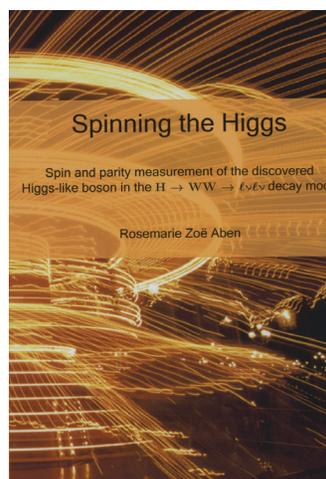
For run 2, the Insertable B-Layer (IBL), a new 4th pixel layer, close to the beam pipe has been integrated into ATLAS. Nikhef has contributed to the cooling system, the design front-end electronics and to the alignment and performance studies. The IBL has been operating smoothly in 2015 and has already shown to improve the impact parameter resolution by a factor two. Other Nikhef hardware contributions for run 2 are the firmware upgrade to the muon read-out drivers, which allows for an increased data rate in the detector and contributions to the trigger system where we built electronics to include the muon trigger information in a new topology trigger and the design of a much improved trigger for events with missing transverse energy. Run 2 started slowly, with a strong emphasis on commissioning the LHC, but in the second half the luminosity increased and the combination of the data set of over

4 fb⁻¹ together with the increased energy allowed ATLAS to improve limits in a number of searches. The 2015 data taking was concluded with a short heavy-ion run.

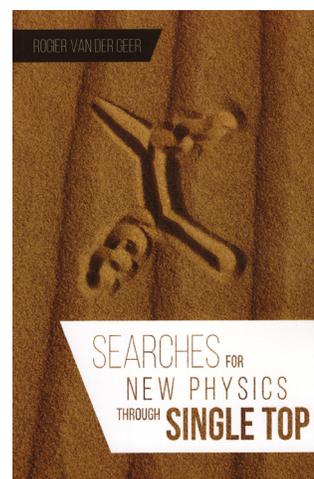
ATLAS' first 13 TeV results were presented at the EPS-HEP conference, only two months after Stable Beams were declared. On 15 December, the ATLAS collaboration presented its end-of-year results at a joint session with the CMS experiment. A total of 28 results were presented using the 2015 full data sample, with four of these results already submitted for publication. With the many ATLAS analyses, several modest deviations from the expectations of the Standard Model were observed as one would expect. These include excesses with a significance of about two sigma in the search for a hypothetical new resonance that decays into a pair of photons, and in the search for supersymmetry in the channel with jets, a Z-boson and missing energy. While tantalising, the two sigma significance is far short of that needed for a discovery, but strongly motivates ATLAS to be ready for 2016 data-taking.



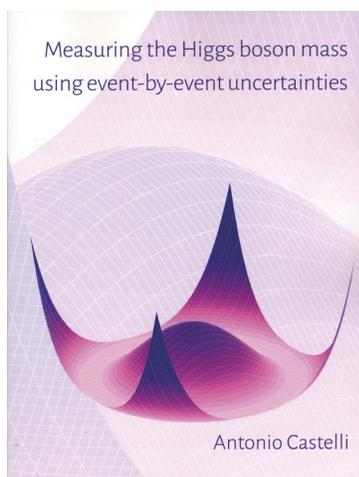
Geert Jan Besjes
19 March 2015



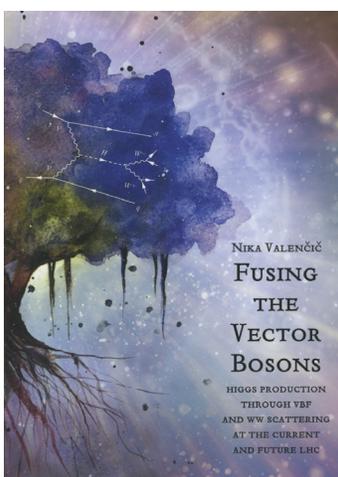
Rosemarie Zoë Aben
17 June 2015



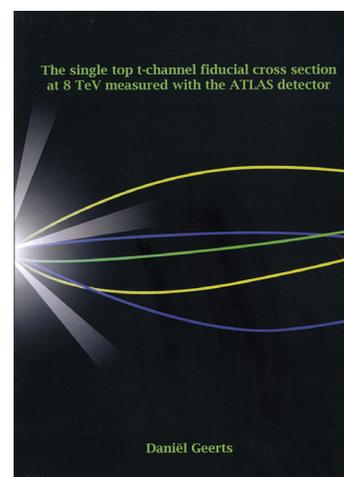
Rogier van der Geer
1 September 2015



Antonio Castelli
25 September 2015



Nika Valenčič
10 November 2015



Daniël Geerts
1 December 2015



Lucie de Nooij
Nikhef alumna,
PhD 15 May 2014

**In praise of wonder, curiosity,
and an open mind: contributing
to children's television**

By Laetis Kuipers

Of all the possible fields in which our PhD graduates may continue their careers after leaving Nikhef, children's television would seem to be a relatively unlikely candidate. But is it? It is a field where Lucie de Nooij feels completely at home working as a science and technology editor for the iconic Klokhuis series. "All things considered," she says, "my relationship with physics and Nikhef spans just over two decades, going back to when my primary school class paid an educational visit to the Institute. I vividly remember my sense of wonder and the thrill of it all, but couldn't possibly know that I would return one day."

In 2014, within the framework of CERN's ATLAS experiment, Lucie completed her dissertation on a particle that is produced during proton-proton collisions and a few other simultaneous processes. She explains: "It was the culmination of the journey I embarked on when I started my physics studies and later joined CERN's Summer School. This unique environment showed me what it means to work in a multidisciplinary and multicultural international team of people on a joint mission. My work has taught me many wise lessons that continue to stand me in good stead today: not only content-wise, but also in terms of team management, giving and receiving constructive feedback, looking at things from many different angles, and communicating scientific knowledge."

"My travels in the world of physics paired with Nikhef's unconditional support, especially when times were hard, have made me who I am today. I have always had the opportunity to raise and study fundamental questions, to explore different perspectives and to satisfy my curiosity. What more could anyone want? It gave me the courage and the confidence to apply for my current job. My move was actually inspired by my own daughter. She's very young, and I kept asking myself how she, unbiased and with the kind of open curiosity that's so typical of children, would view the world into which she was born. I wondered what kind of questions she would ask, and what conclusions she herself would draw on the basis of what she would see and hear. This has enabled me to contribute to Klokhuis' programmes for today's young viewers – and their parents, too. Working for the series requires a well-developed sense of wonder, innate curiosity, and an open mind: precisely those characteristics that typify successful scientists, whether they work at CERN or for Klokhuis."

The Jan Kluiver Prize

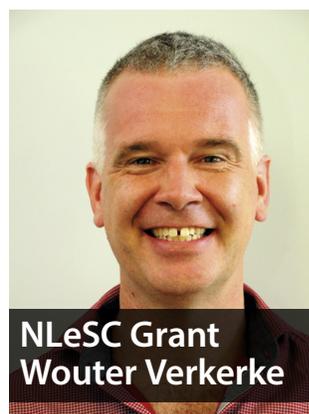
One of the highlights of 2015 and even of run 1 of the LHC has been the final combination of the measurements of the couplings of the Higgs boson by the ATLAS and CMS experiments. This paper had a major Nikhef contribution, both in the RooFit software tools that were used for the combination which were developed by *a.o.* Wouter Verkerke, as in the actual combination where also PhD student **Stefan Gadatsch** played an important part. His monumental thesis, appropriately named “the Higgs Boson”, had led to a “*cum laude*” defence and has been awarded the Jan Kluiver prize.



Presenting the Jan Kluiver prize. Left is Stefan Gadatsch, on the right is prof.dr. J. Gaemers.

Two Nikhef ATLAS initiatives among new NLeSC projects

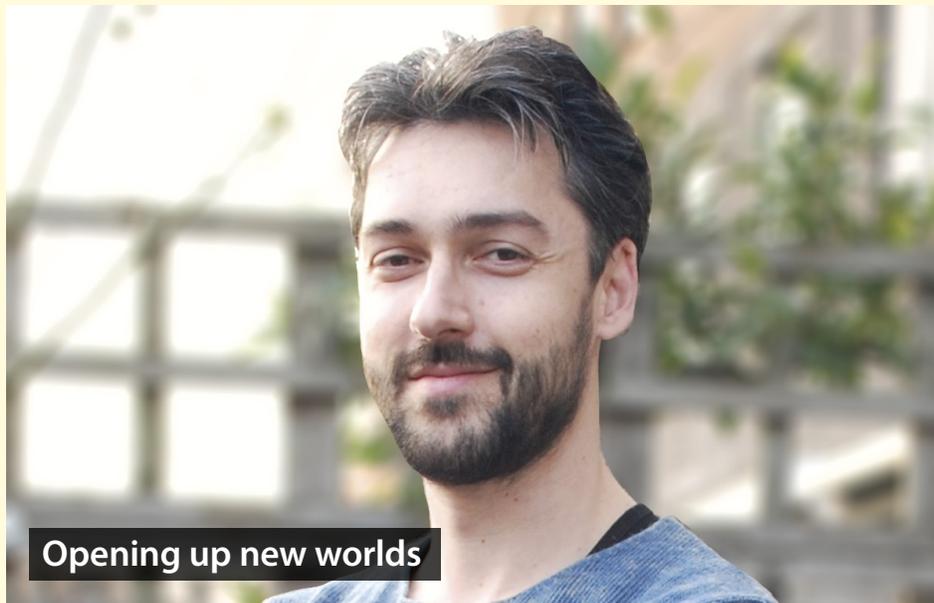
Wouter Verkerke and **Sascha Caron** have both been awarded an NLeSC grant within the framework of the ASDI (Accelerating Scientific Discovery) call. They will each be supported with 500 k€ (combined cash and in kind provision of eScience research engineers). Their projects “*Automated Parallel Calculation of Collaborative Statistical Models*” and “*iDark: The intelligent Dark Matter Survey*” are scheduled to start in 2016. The purpose of the ASDI call is to enable domain scientists, working for example in application fields of Physics & Beyond, to address compute-intensive and/or data-driven problems within their research.



Olga Igonkina appointed professor

Olga Igonkina was appointed extraordinary professor at the Faculty of Science of the Radboud University in Nijmegen with effect from 1 January 2015. Her teaching assignment is “*The study of proton-proton interactions at the Large Hadron Collider at CERN*”. Igonkina is researcher in the ATLAS group at Nikhef.





Opening up new worlds

Zdenko van Kesteren
 Nikhef alumnus,
 PhD 12 March 2010

By Laetis Kuipers

When Zdenko van Kesteren participated in CERN's ATLAS project, he couldn't know that his ensuing career steps would lead him to the Netherlands Cancer Institute (NKI) and the Amsterdam Medical Centre (AMC), where he currently operates as a medical physicist. "When my PhD project neared its completion, I found myself at a crossroads," he says, "where I had to make a decision either to continue in my field of expertise and venture abroad or to stay in Amsterdam and move into a different discipline. Making this choice wasn't easy, as my decision would obviously affect the rest of my professional career, but then I realised that my physics background and the skills I had acquired during my Nikhef years would actually stand me in good stead in a great many areas."

"You see," Zdenko explains, "my tasks at CERN involved the commissioning of muon detectors that had been built at Nikhef, and they included the final testing of the detector systems before their installation. I also developed reconstruction software for the identification of muons in the ATLAS detector, validated with the help of modelled data and real data from cosmic muons. I imagined that my skills in detection, data modelling and data analysis, paired with a thorough knowledge of statistics, would make me suitable for positions in realms that would appear to be miles apart, such as defence and security or

actuarial sciences and the share trade, for instance, or clinical physics and radiotherapy. I opted for the latter and accepted a post-doc position at the NKI, where I concentrated on the implementation of new treatment planning techniques, bridging research and application."

"In 2011, I moved to the AMC," says Zdenko, "to work as a medical physicist. Here, I continued to enjoy the best of two worlds: being involved in research as well as its application for the benefit of cancer patients. It is precisely the applied nature of my tasks and the patient care involved that makes my work so appealing, inspirational and rewarding. I am fortunate to be able to make a fundamental contribution to improvements in the treatment of cancer, and thus to make a true difference for patients. My background in physics has been instrumental to my development, and being part of CERN's multicultural and highly focused international team has proven to be an excellent preparation for working in the strongly motivated multidisciplinary group that I am part of today. There's a great deal of mutual inspiration, learning and synergy, with everyone involved pulling their weight in the design of new treatment options."

LHCb

excitement in the physics of quarks

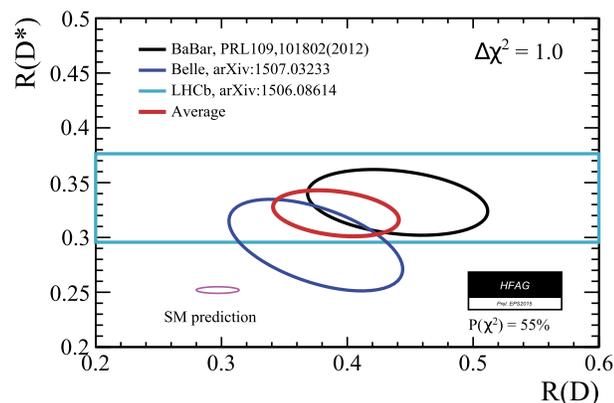
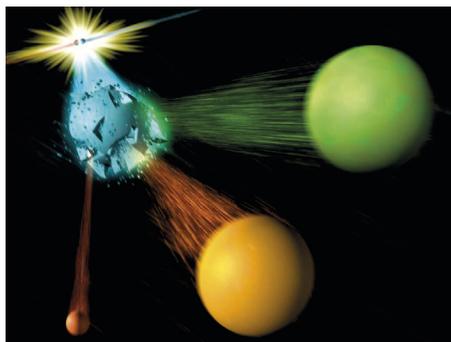
In the year 2015 the LHCb experiment welcomed back the LHC beams, this time with proton-proton collisions at a world record energy of 13 TeV. After a two-year break the experiment was in excellent shape and collected its data with a remarkably high efficiency. At the same time as the new data was being collected, the analyses of data from run 1 (2011–2012) was finalized and intriguing observations were made, resulting in a number of press releases during the year.

Rare decays under inspection

The highlight is without doubt the observation of decays of B-mesons to two muons, leading to a publication in Nature together with the CMS experiment. The work was partly done by a PhD student of Nikhef, Siim Tolk, with supervision from a former Nikhef postdoc. The decay concerns a very rare quantum process, in jargon a very rare decay process, in which a b-quark and an s-quark annihilate each other. For B_s^0 mesons, this process is seen to occur with a rate of about 3 times in a billion! The main excitement, however, was that in the same analysis also evidence for the annihilation of a b-quark and a d-quark annihilation was seen. This mirror process, of B_d^0 mesons, is expected to be even a factor 10 more rare, and since evidence for its existence arrived earlier than expected, theorists speculated about quantum effects due to new, yet undiscovered, particles such as a Z-prime.

Left: Artist's view of a $B \rightarrow D^* \tau \nu$ decay process.

Right: Measurements of Babar, Belle and LHCb of the $R(D^*)$ quantity in comparison with the Standard Model prediction.



Management
prof.dr. M. Merk

Such speculations had already appeared earlier to explain an observation in another, less rare, process: the decay of a B-meson into a kaon particle (carrying a strange quark) together with two muons. The physics of this process is a variant of the transition of a b-quark to an s-quark. Here, there are two puzzling aspects observed. The first one is that the angles under which the particles are produced in the detector are not distributed as they were predicted from calculations. The second is referred to as 'the R_k -puzzle': various decays resulting from the 'b-to-s' transition process (referred to as 'Penguins') seem to occur at a lower rate together with two muons than when they are produced with two electrons. Again, a possible quantum effect of a Z-prime particle was debated.

An anomaly in beauty to charm decays

Another unresolved issue, now called 'the R_D puzzle', is related to an earlier observation of the BaBar experiment, involving so-called semi-leptonic decays of B-mesons to charmed D-mesons and leptons. In particular the decay $B \rightarrow D^* \tau \nu$ was observed to have a different decay rate as the mirror decay $B \rightarrow D^* \mu \nu$, where the only difference is the type of lepton (τ or μ) in the final state. The so-called concept of lepton universality predicts that decay rates should be equal. Such decays, with a tau-particle and a neutrino in the final state were long considered to be one step too far for the dense environment of LHC collisions. However, Nikhef postdoc Greg Ciezarek showed that a very careful analysis made this measurement possible. He obtained a result was in agreement with the earlier measurement of the BaBar experiment, also hinting at a deviation from the Standard Model. Including finally a recent measurement of the Belle experiment results in a measurement that deviates by 3.9 sigma from the Standard Model. A comparison of the results of the three experiments and their average with the expected value is shown in above, together with an artist view of the decay process. In this case speculations are made, among others, on a possible existence of charged Higgs particles.

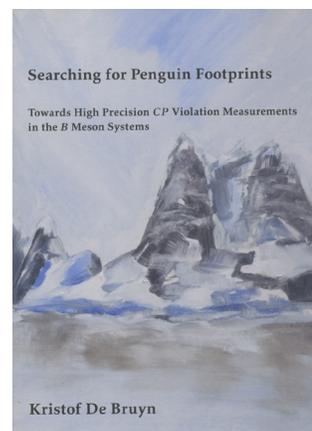
Five quarks for Muster Mark...

That LHCb not only studies weak interactions of quark decays, but also strong interactions between quarks became evident by the announcement of the discovery of the pentaquark. While investigating a specific B-particle decay process, that of B-baryons to a proton, a charmed J/ψ -meson and a kaon, LHCb researchers noticed a so-called resonance behaviour in the $J/\psi + \text{proton}$ production. A temporary state of matter of five quarks is formed, consisting of up, up, down, charm and anti-charm quarks!

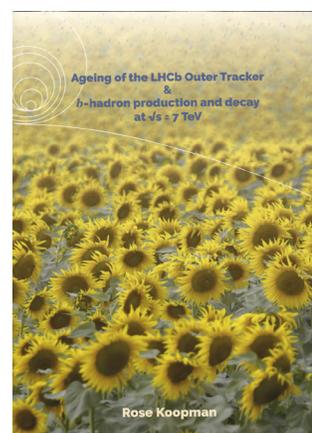
The existence of such a state of matter has been discussed several times before in history, but the LHCb observation finally settles it. In fact, two states are observed: the so-called $P_c^+(4450)$ and the $P_c^+(4380)$; both with a very large statistical significance. Whether these quarks are internally tightly bound by the strong interaction or rather resemble more a sort of 'quark-molecule system' remains to be seen.

Excitement in heavy ion collisions

The studies for the strong interactions are taken further. Since the LHCb experiment has a unique coverage to detect particles of LHC collisions at small angles relative to the beam-pipe, physicists became interested to study small angle particle production in ion-ion collisions. Although the LHCb detector is not designed to take data under these very high multiplicity collisions, the detector was carefully switched on to record these collisions. After the trigger processes were adapted, a valuable dataset of events was obtained in a very smooth data taking period towards the end of the year. Analysis of these events is currently in progress. A typical heavy ion collision event is displayed below.



Kristof De Bruyn
8 October 2015

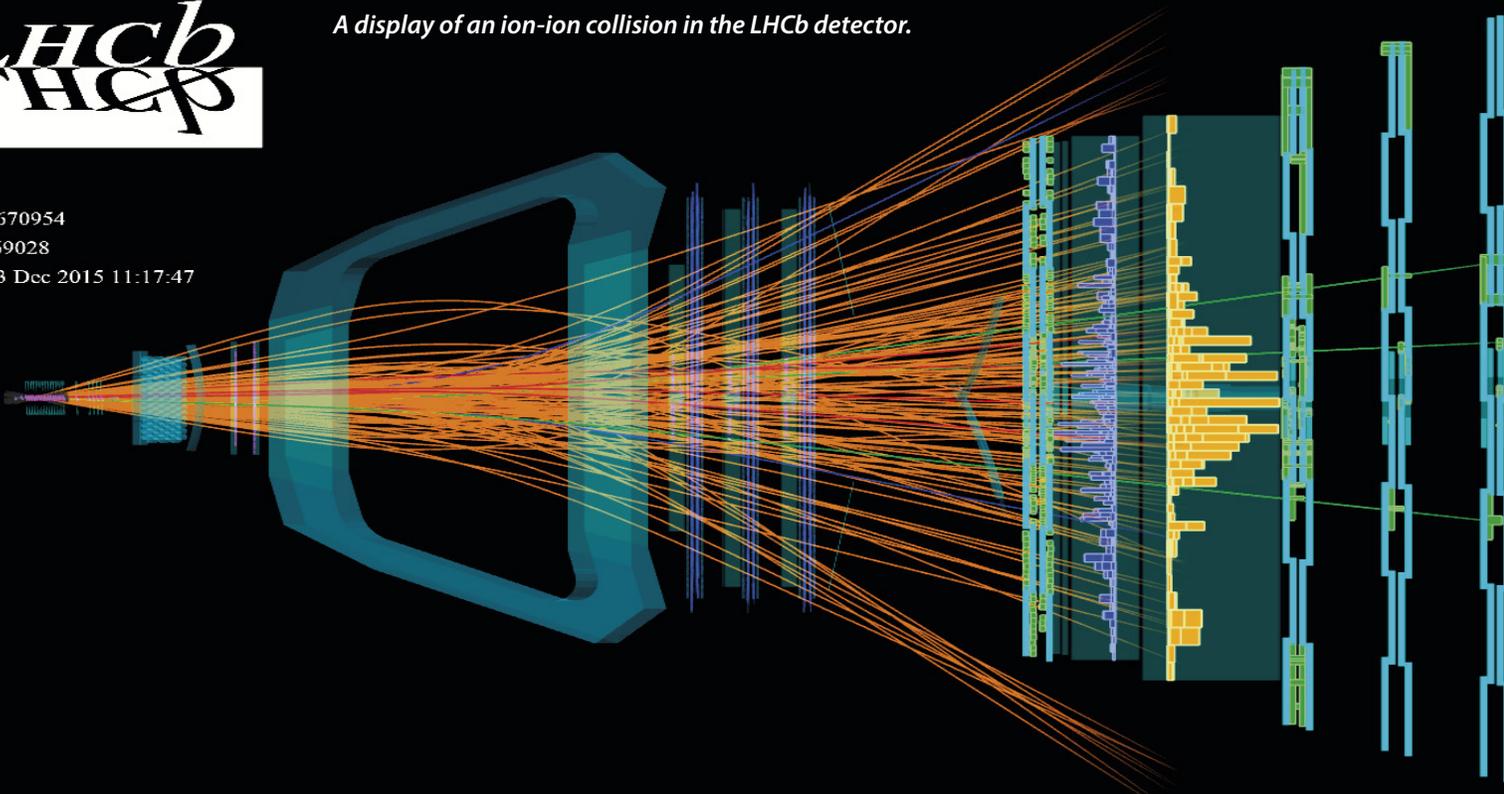


Rose Koopman
3 November 2015



A display of an ion-ion collision in the LHCb detector.

Event 670954
Run 169028
Thu, 03 Dec 2015 11:17:47





Serena Oggero
Nikhef alumna,
PhD 3 October 2013

By Laetis Kuipers

As an innovator at TNO, Serena Oggero continues the search for 'beauty in data' that started at Nikhef when she prepared her dissertation entitled *"Beauty in the Crowd"*. With its publication in 2013, Serena presented first-time evidence of the disintegration of a B_s particle into two muons, something which was hailed as a very convenient way to probe New Physics models. Serena describes herself as a physicist with a drive for science, visual communication and a strong interest in diverse cultures. "While I was completing my thesis on data from the LHCb experiment," she says, "I found that my interests had become much broader than just particle physics, and that I also wanted to explore other fields in science. My time at Nikhef definitely helped me discover who I am and what I wanted to do: communicating scientific research to lead to a better society."

"I then learned about TNO's two-year trainee programme aimed at newly graduated Master's and PhD students," Serena continues, "and I decided to apply. This programme gave me the opportunity to span a number of TNO's departments and explore career options in the field of business development, strategy, consultancy and the valorization of innovations. And this made me aware that it's perfectly okay not to be exclusively focused on pure research, but that I could also produce highly valuable work

when I concentrated on tasks involving communication and strategic thinking. To give you some examples, I worked in the Nano Instrumentation Department, where I contributed to B2B projects on contamination (nanoparticles) control for the semiconductor market. I also participated in the Climate, Air and Sustainability Group, where I worked on European projects on sustainable cities. My contribution involved data modelling activities for resource flow analysis and stakeholders management. Finally, I joined the Intelligent Imaging Group, where I focused on the development of applications in the field of visual pattern recognition and behaviour detection."

"All these beautiful new paths have led me to where I am today, in the Data Science department, collaborating with machine learning and computer vision experts to valorize their research in applications for society. I absolutely love working in multidisciplinary projects and discussing innovations with clients. My days at CERN and Nikhef, where an open environment and strong team work facilitated the exchange of perspectives from a wide range of cultures, have certainly prepared me for my current interdisciplinary tasks."

ALICE

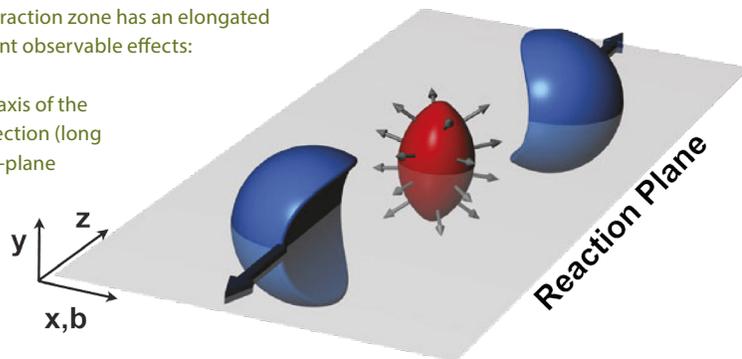
quarks, gluons and the Quark-Gluon Plasma

Detector tests for ALICE upgrades

The Inner Tracking System of ALICE will be replaced during the second long shutdown of the LHC in 2019–2020 to improve the precision and data taking capabilities of the detector. Nikhef takes part in various aspects of the upgrade including the characterization of the prototypes of the silicon sensors. The photo shows a test setup consisting of seven ALPIDE sensor chips. Each ALPIDE (prototype) chip is wire bonded to a carrier card. The carrier card is connected to a DAQ board, which can be read out via a USB connection by a PC (black connectors at the top of the photo), making the setup really easy to use. For the test beam measurements a self-consistent telescope of seven ALPIDE sensors is used where each chip is read out in the same fashion. The ALPIDE prototypes show excellent performance and fulfill the very strict requirements of the upgrade in terms of detection efficiency, position resolution and noise occupancy.

Figure 1. In non-central collisions of lead nuclei, the interaction zone has an elongated shape in the transverse (xy) plane. This has two important observable effects:

- The pressure gradient in the in-plane direction (short axis of the interaction zone) is larger than in the out-of-plane direction (long axis). This leads to larger expansion velocities in the in-plane direction, and hence more particles with a higher momentum.
- Produced particles that leave the interaction zone in the in-plane direction typically traverse a smaller amount of hot dense Quark-Gluon-Plasma and lose less energy by interactions, than particles that propagate in the out-of-plane direction.



Both effects lead to azimuthal asymmetries of the produced particles yields. The former effect (pressure gradients) is expected to be more important at low transverse momentum (p_T) while the latter effect (the path length dependence of parton energy loss) is more important at large transverse momentum.



Management
prof.dr. R. Snellings

The ALICE group at Nikhef studies the strong interaction, which binds together quarks inside protons and neutrons, which are the constituents of the atomic nucleus. The strong interaction is quite different from the more familiar interactions like gravity and the electrostatic force. Maybe the most important difference is that the strong interaction has an effective range that is limited to about the size of a proton. Moreover, there is no simple formula for the dependence of the strong force on the distance, like the $1/r$ dependence for the electrostatic and gravitational forces, due to non-linear effects. The unusual properties of the strong interaction make it a very intriguing topic to study. The ALICE group studies the strong interaction in high-energy collisions of nuclei at the Large Hadron Collider (LHC). In such collisions, a very high density and a very high temperature (of order 10^{12} K) are reached and a so-called Quark-Gluon Plasma is formed in which quarks can travel over much larger volumes than the typical size of a nucleon.

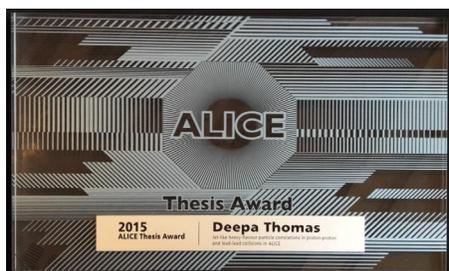
In 2015, the ALICE group focused on completing a number of studies using

the data collected in run 1 of the LHC, which took place from 2010 to 2013, after which LHC was shut down for almost two years for maintenance and upgrades. Several studies were completed, including measurements of azimuthal anisotropies with identified particles, which are indicative of the pressure that builds up inside the Quark-Gluon-Plasma and allow us to determine fundamental properties of the Quark-Gluon Plasma like the viscosity. A related topic is the azimuthal anisotropy of jet production (see Fig. 2), in which high-energy quarks and gluons, which fragment into jets, are used to probe the Quark-Gluon Plasma. The measured anisotropy in this case is related to the different path lengths for emission in different directions (see Fig. 1) and the resulting difference in energy loss due to interactions with the medium.

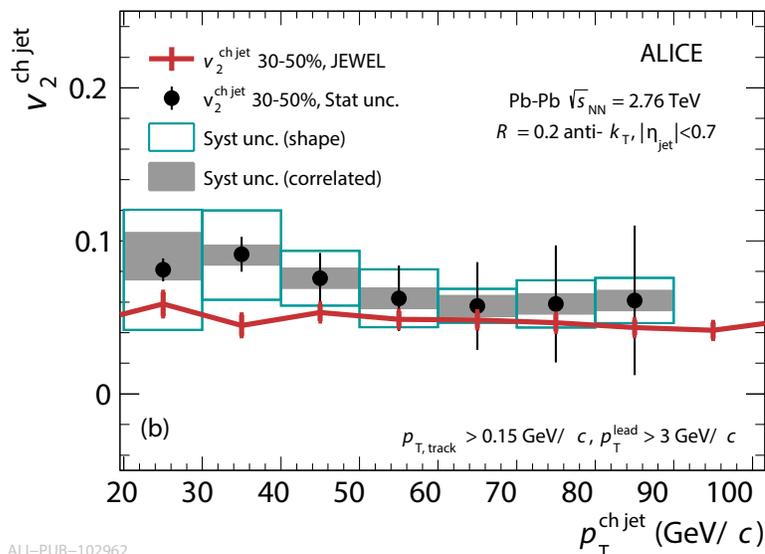
The ALICE group is also strongly involved in the study of heavy quarks, which are good probes of the Quark-Gluon Plasma, since they are produced at early times in the collision and are sensitive to the medium density and expansion velocity via interactions with the plasma.

The group was closely involved in a total of five papers on various topics regarding heavy quark production in proton-proton, proton-lead and lead-lead collisions in 2015. One of the PhD students (Deepa Thomas) received the 2015 ALICE Thesis Award for work in this area.

In 2015, the LHC accelerator was restarted after a break for maintenance and upgrades of almost two years (2013-2014). In November and December, the LHC provided collisions of lead nuclei at a new energy of 5.02 TeV per nucleon pair, almost twice the energy of the collisions that we have studied so far (2.76 TeV per nucleon pair). The first analyses of the new data sample with the higher energy have started, and new results will soon be published; it will be very interesting to see whether predictions based on the lower energy collisions will turn out to be accurate.

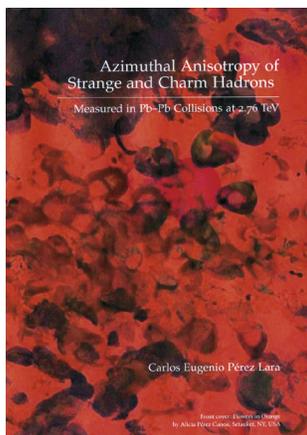


The 2015 ALICE Thesis Award went to Deepa Thomas.

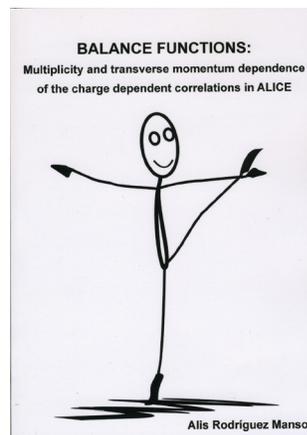


ALI-PUB-102962

Figure 2. Azimuthal anisotropy coefficient v_2 for jet production in Pb+Pb collisions at the LHC as measured by ALICE. Different energy loss mechanisms have been proposed for energetic partons (quarks and gluons) that traverse the Quark Gluon Plasma, with different characteristic dependence on the path length through the plasma: linear for elastic energy loss, quadratic for radiative loss, and cubic for strong-interaction energy loss. The measured anisotropy v_2 is the (relative) difference between in-plane yield and the out-of-plane (see Fig 1) yield, which probes the path length dependence of the energy loss in the Quark-Gluon Plasma. The measurement shown here is the first measurement of jet v_2 for jets with relatively low $p_T < 50$ GeV, which are most sensitive to interactions with the Quark-Gluon Plasma. The experimental challenge is to distinguish the azimuthal anisotropy of jet production from the anisotropy in the underlying event; a new background subtraction technique has been developed to separate the two effects. The positive value of $v_2 \approx 0.1$ indicates that the high-energy quarks and gluons lose more energy when their path through the Quark-Gluon Plasma is longer. The red line shows the prediction of the JEWEL event generator, which includes a parton energy loss model and a realistic geometry of the collision zone. The measured effect is in agreement with the prediction, confirming that the energy is mostly radiative in nature, and has a quadratic path length dependence, due to quantum-mechanical interference effects. The current experimental uncertainties are still sizeable, and ALICE is upgrading its readout systems to collect larger data samples, which will significantly improve the uncertainties on the measurement, and provide more insight in the nature of energy loss in a Quark Gluon Plasma.

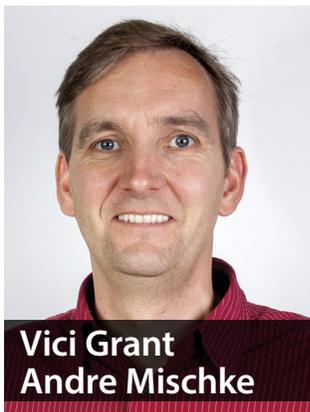


Carlos Eugenio Perez Lara
27 August 2015



Alis Rodriguez Manso
25 November 2015

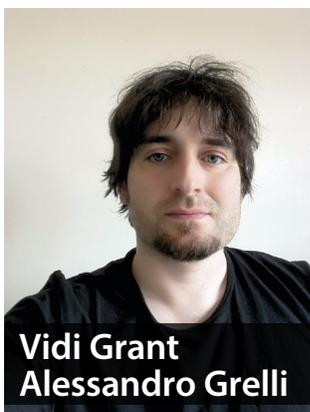
Grants



Vici Grant
Andre Mischke

NWO granted **Andre Mischke** a Vici grant for his proposal *"Tomography of the Quark-Gluon Plasma - beauty quarks as a key probe"*. This form of grant is for senior researchers who have shown that they have the ability to successfully develop their own innovative lines of research and to act as coaches for young researchers.

"After the Big Bang the young, evolving universe was in a quark-gluon plasma state. This research focuses on the study of the dynamics of this fundamental matter, that also – but just for a very short moment- occurs when laboratory atomic nuclei collide at very high energies."



Vidi Grant
Alessandro Grelli

Alessandro Grelli was awarded a Vidi grant for his proposal *"The hottest place in the Universe"*. The Vidi grants are aimed at young excellent researchers with several years of successful postdoctoral research experience to start their own research groups.

"Atoms are accelerated up to almost the speed of light and then they collide. The heat developed during such collision is so intense that ordinary matter melts. As a consequence the same state of matter present in our Universe, a few fractions of a second after the Big Bang, is created. In the study its properties will be investigated by using heavy-quarks as a probe."



FOM Projectruimte
Thomas Peitzmann

Thomas Peitzmann received a FOM 'projectruimte' grant for his proposal *"Solving the direct photon puzzle in heavy-ion reactions with direct photon interferometry"*.

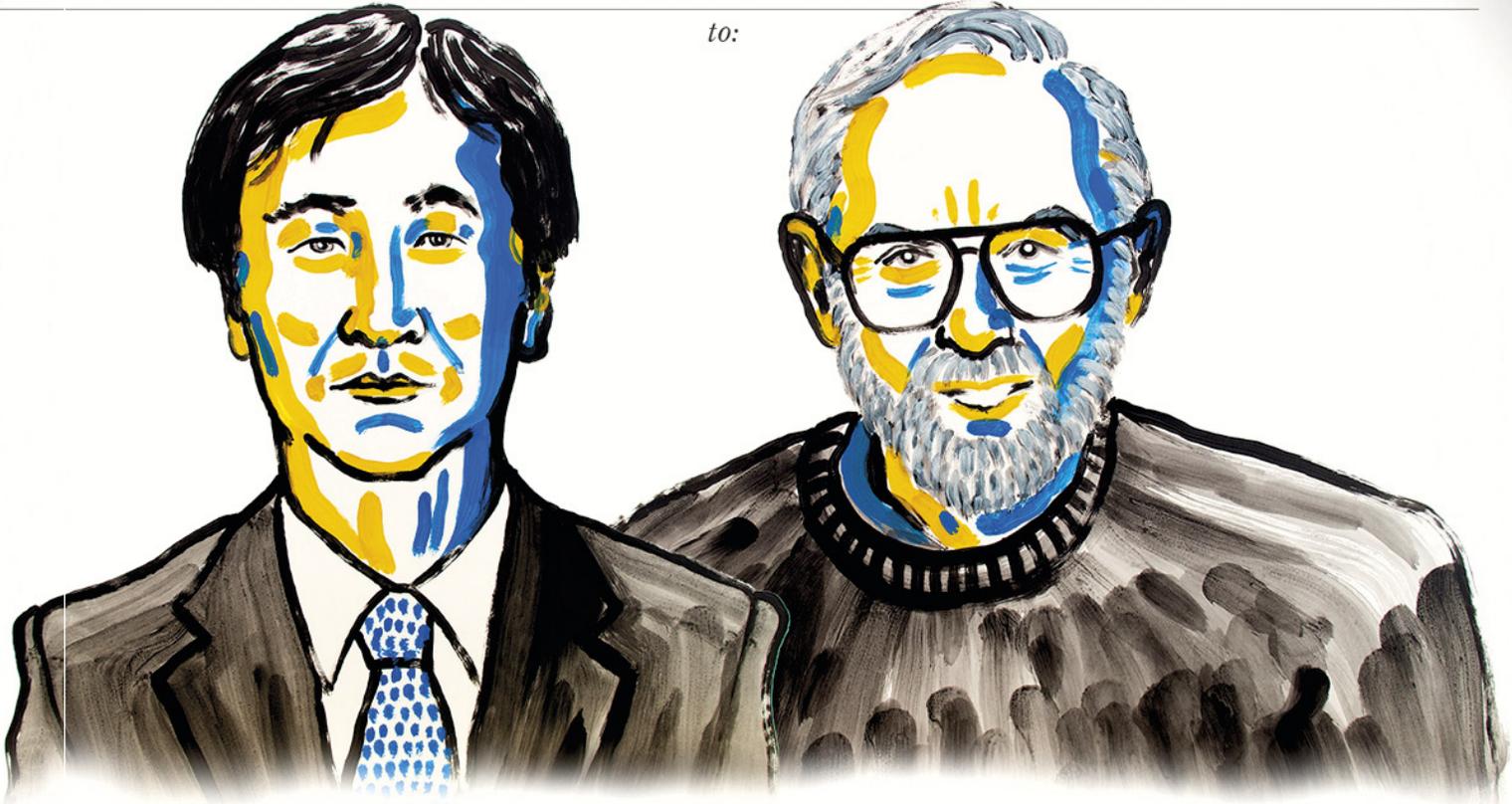
"The measurement of the spectrum of thermal photon radiation is considered to be one of the 'holy grails' of heavy-ion physics. From this spectrum one expects to obtain the best estimates for the initial temperature of the hot quark-gluon plasma state studied in heavy-ion collisions at the LHC. Measurements at the RHIC accelerator reveal a very high temperature (exceeding 10^{12} K), however, the results are not fully understood theoretically – this situation is commonly referred to as the 'direct photon puzzle'. While there is thus considerable theoretical interest in these measurements, they are extremely challenging. The ALICE experiment has also performed similar measurements at the LHC, where the temperature is expected to be still higher, however the significance of the results is limited. In this project we will apply a new, very different method using the intensity interference of photons to measure the thermal photon spectrum and significantly reduce the current uncertainty."



The Royal Swedish Academy of Sciences has decided to award the

2015 NOBEL PRIZE IN PHYSICS

to:



Takaaki Kajita and Arthur B. McDonald

“for the discovery of neutrino oscillations, which shows that neutrinos have mass”

Future of Neutrino Oscillations

by Patrick Decowski & Aart Heijboer

The Nobel prize for physics in 2015 went to Takaaki Kajita and Art McDonald for the discovery of the phenomenon of neutrino oscillations. This discovery was made using the Super-Kamiokande and SNO detectors, deep underground, sensitive to neutrinos from the Earth's atmosphere and from the Sun. The observation of neutrino oscillations implies that neutrinos are massive particles, contrary to the assumption in the Standard Model. These measurements formed the first evidence that the Standard Model is incomplete. The result is a textbook example of how particles from the cosmos can be used to study fundamental physics. In the near future, Nikhef will partake in the next chapter of this story, which will further exploit atmospheric neutrino oscillations to study their masses using the deep underwater KM3NeT detector.

Figure 1: (left) Neutrinos are produced isotropically in Earth's atmosphere by incoming cosmic rays. (right) The Super-Kamiokande detector is a 50 kton water-Cherenkov detector sensitive to both ν_e and ν_μ interactions. These interactions can be distinguished by the width and 'fuzziness' of the Cherenkov-ring.

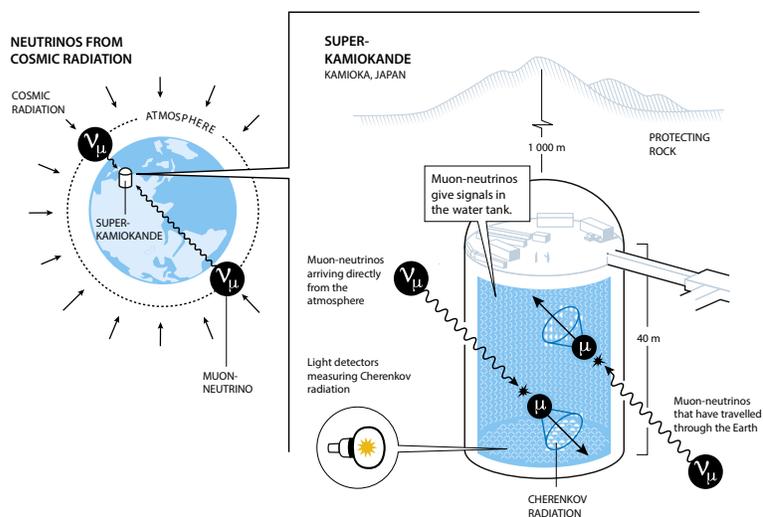


Illustration: © Johan Jarnestad/The Royal Swedish Academy of Sciences

Neutrinos from the Earth's Atmosphere

The Earth's atmosphere is constantly bombarded with high energy cosmic particles, such as protons and other nuclei. When interacting with the upper atmosphere, pions and other mesons are produced which subsequently interact and produce showers of particles. Some of the pions will decay to produce neutrinos: $\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$. As a result, the atmosphere itself provides a free, steady flux of muon-neutrinos from all directions. (There is also a contribution from electron-neutrinos originating from the muon decay.)

The Super-Kamiokande detector was the first to measure atmospheric neutrinos in detail. It consists of a huge tank of purified water, surrounded by over 11.000 photomultiplier tubes to detect the faint Cherenkov light that is produced when a neutrino interacts in the water volume. As the cosmic rays come from all directions, and neutrinos are hardly influenced by the matter in the Earth, the expectation was to observe an equal amount of muon-neutrinos from all (see Fig. 1). At the 1998 Neutrino conference, Takaaki Kajita, showed the angular direction distribution of neutrinos measured in the Super-Kamiokande detector. The observed ν_μ showed a strange pattern. Down-going ν_μ behaved as expected, but there was a clear deficit of upward-going ν_μ . The explanation is that these neutrinos have changed their identity while traveling ~ 13.000 km through the Earth from the atmosphere to the detector. As the ν_e behave as expected, the implication is that the ν_μ must have transformed into ν_τ .

Neutrinos from the Sun

Besides providing the energy required for all life on Earth, the nuclear fusion processes in the Sun provide copious amounts of neutrinos. Even on Earth, the flux is 6×10^{10} neutrinos per cm^2 per sec. The process of interest is the decay of Boron: ${}^8\text{B} \rightarrow {}^8\text{B} + e^+ + \nu_e$ which produces neutrinos of up to 15 MeV. This relatively high energy makes neutrinos from this process the 'easiest' to study, even though they make up less than 1% of the total flux. Since the 1960's, experiments sensitive to detecting

electron-neutrinos from the Sun had observed these neutrinos, but the number detected was only one third of the prediction from the Standard Solar Model (SSM) of the Solar interior. It was not clear if the fault was in the SSM or elsewhere.

The Sudbury Neutrino Observatory (SNO) was built in the 1990 by Art McDonald and his collaborators in an active nickel mine in Ontario, Canada. SNO contained 1 kton of heavy water (D_2O) as a detection medium that was borrowed from the Canadian government (see Fig. 2). The advantage of D_2O , over regular water, is that multiple types of neutrino interactions can be detected, which allowed the researchers to measure the fluxes of each of the neutrino flavours separately. The charged-current interaction, $\nu_e + D \rightarrow e^- + p + p$, is only sensitive to electron neutrino interactions, whereas the neutral-current interaction, $\nu_x + D \rightarrow \nu_x + p + n$, can proceed with each of the three neutrino flavours. Importantly, the two reactions can be distinguished experimentally. There is a third reaction, $\nu_x + e^- \rightarrow \nu_x + e^-$, which is six times more sensitive to ν_e than to ν_μ and ν_τ and is used as a cross-check. The charged-current interaction confirmed the earlier results: only a third of the solar neutrinos were detected in this channel. However, the unique capability of SNO to also detect all neutrino flavours via the other two interactions, showed that the sum of the flux of all neutrino flavours matched the SSM predictions. The conclusion was inescapable: two thirds of the ν_e produced in the Sun changed into ν_μ and ν_τ on their way to Earth. This showed conclusively that the SSM was correct, and proved that neutrinos are massive particles.

Matter Matters

Since the discovery of neutrino oscillations, experiments have measured most properties of neutrinos. All the mixing angles (see inset) have been measured. Importantly, the Daya Bay experiment showed in 2012 that the last unknown mixing angle θ_{13} has a sizable value. This opens up the possibility of CP violation in the neutrino sector. Combined with the prospect that neutrinos may have heavy partners, this provides a scenario, known as leptogenesis, where neutrinos may have caused the matter-anti-matter asymmetry in the universe.

The next big question in neutrino physics is to determine the precise pattern of neutrino masses. From the atmospheric oscillations measured by Super-Kamiokande, we know the size of Δm_{23}^2 , but not the sign. Paradoxically, the atmospheric oscillations, which happen inside the Earth, are dominated by vacuum oscillations, whereas the solar neutrino oscillations are dominated by matter effects in the Sun, and the 150 million km of travel through vacuum that follows has almost no effect.

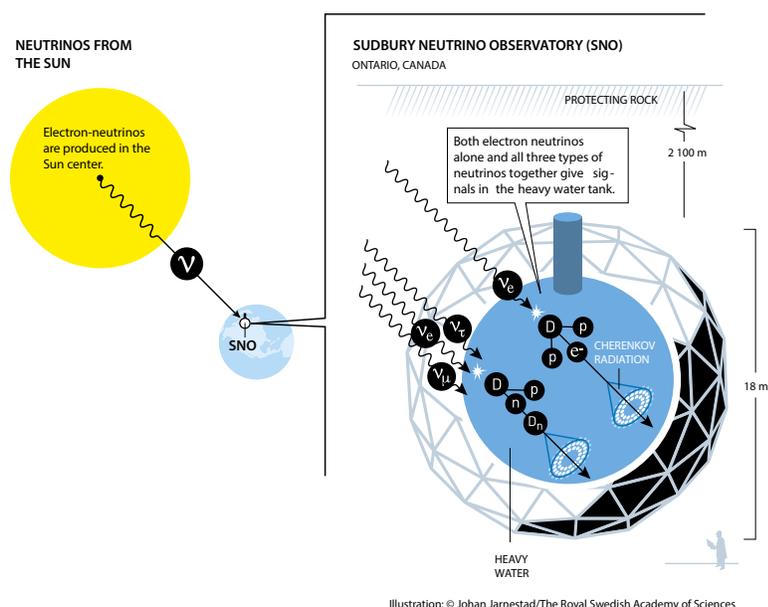


Figure 2: (left) The nuclear fusion processes in the Sun's center produce a flux of more than 65 billion $\nu_e / (cm^2s)$. (right) The SNO experiment used more than 1 kton of heavy water (D_2O) to study the ν_e flux and the sum of ν_e, ν_μ and ν_τ .

Interestingly, we do know the sign of the Δm_{21}^2 , which governs the solar neutrino oscillations. The reason is precisely that these oscillations are dominated by the effect of matter in the Sun. In vacuum, the three mass eigenstates propagate freely, and the oscillation is unaffected by interchanging the masses of two mass eigenstates. In matter, this symmetry is broken because matter contains electrons, but no μ or τ particles. As a consequence, the ν_e component feels an extra potential, which is reflected in the oscillation pattern. This is known as the Mikheyev-Smirnov-Wolfenstein (MSW) effect. For the solar neutrinos this effect is dominant, which has allowed establishing the relative ordering of the two mass eigenstates involved.

The Next Chapter

To determine the complete pattern of neutrino masses, we need to study matter effects in the oscillations involving ν_3 , which were first discovered by Super-Kamiokande. This will be done by planned experiments using neutrino beams from Fermilab, USA and J-PARC, Japan using the DUNE and Hyper-Kamiokande detectors, respectively. Neutrino telescopes such as IceCube and KM3NeT have the potential to collect huge samples of atmospheric neutrinos that can be used to determine the mass hierarchy, without the (costly and time-consuming) construction of a neutrino beamline. In the footsteps of Super-Kamiokande and SNO, these instruments could use cosmic particles to take the next big step in neutrino physics.

Nikhef is heavily involved in the KM3NeT neutrino telescope, which will be the next-generation instrument to study cosmic neutrinos with energies ranging up to several PeV. The mass hierarchy measurement requires optimal detection sensitivity to neutrinos of all flavours in the 5–10 GeV-range. The collaboration has decided to optimize part of the detector for this energy range, which means that the water-volume will be more densely instrumented. Known as ORCA, this branch of the KM3NeT infrastructure will be located in France, close to the ANTARES detector which has already observed atmospheric neutrino oscillations. It is an integral part of the next phase of the project, KM3NeT 2.0, which has been included in the 2016 ESFRI Roadmap. The technology for the ORCA lines is identical to the rest of KM3NeT, the only difference being the spacing between the optical modules and the detection lines (see Fig. 3). A limited number of ORCA detector lines is already funded, the first of which will be deployed summer 2016. The equivalent initiative for Antarctica, named PINGU, may be part of a future upgrade of IceCube.

The detector will have an instrumented volume of 3.7 Mton of highly transparent sea water; for comparison: the Super-Kamiokande detector has a volume of 50 kton. By making high-statistics studies on both ν_e appearance and ν_μ disappearance, the detector can distinguish between the two currently allowed mass hierarchy patterns on a time-scale that is very competitive with other initiatives. As such, KM3NeT-ORCA can provide timely input to future studies of CP-violation and neutrino-less double beta decay. In addition, precise measurements of the mass-squared-difference and mixing angles will be made.

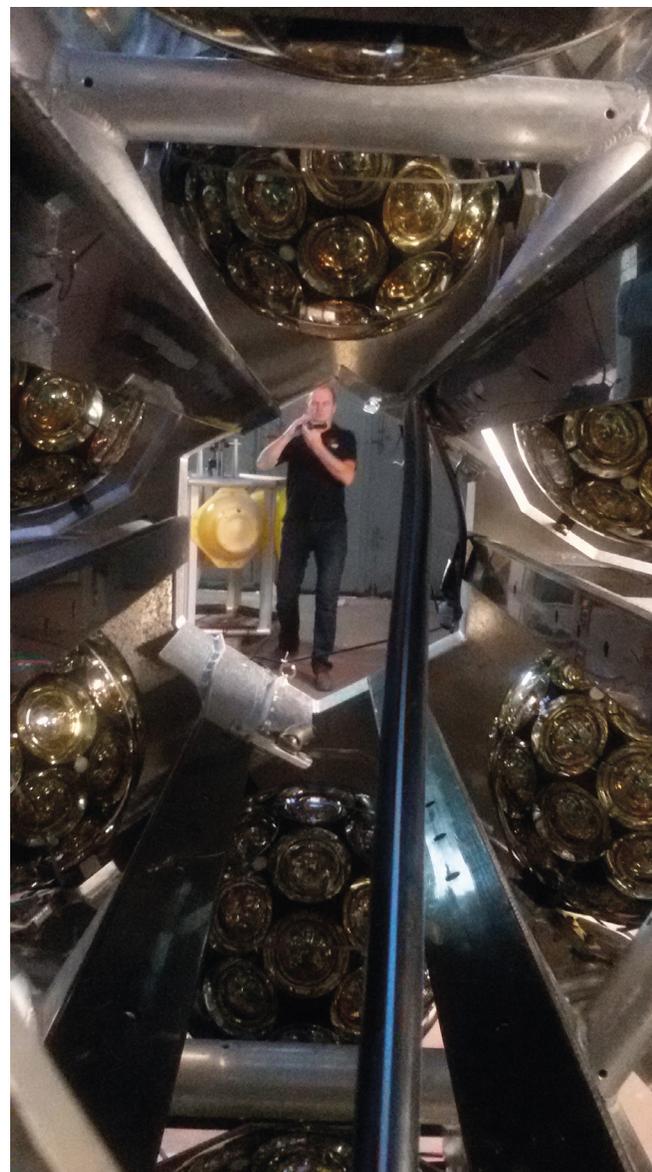


Figure 3: A KM3NeT detection line wound on the special Launcher vehicle developed by NIOZ and Nikhef. Several Multi-PMT optical modules are visible. In the background is KM3NeT's chief engineer Edward Berbee (Nikhef).

The Nikhef KM3NeT group has a leading role in the high-level likelihood-ratio-based analysis for ascertaining the sensitivity in the presence of statistical and systematic uncertainties. Over the past years, the estimates have become more solid and realistic. Depending on the as-of-yet unknown mixing angles, the mass hierarchy can be determined at three sigma significance with 1–3 years of data taking with the full detector (see Fig. 4).

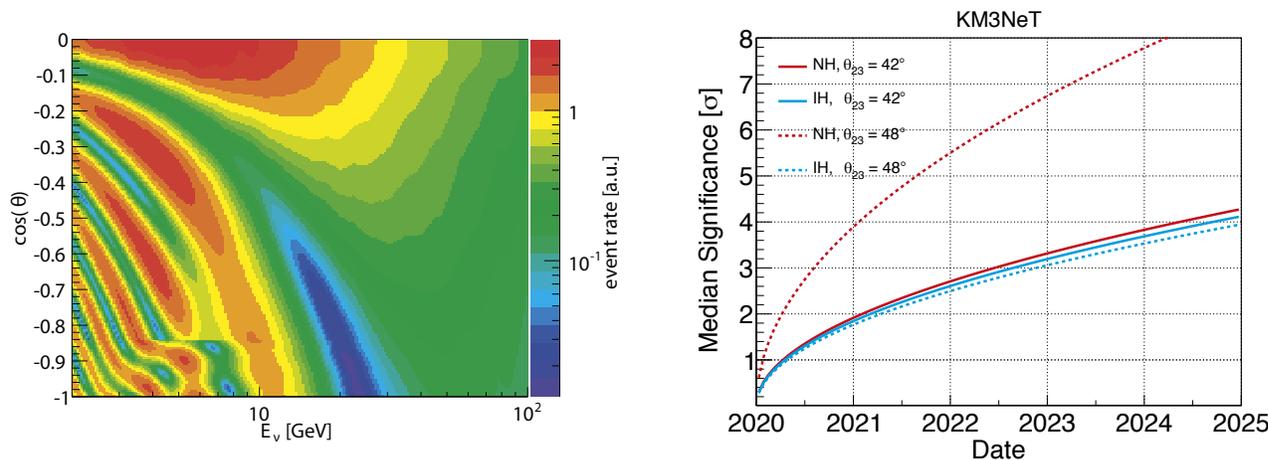


Figure 4: Left: The predicted atmospheric ν_μ event rate after oscillations as a function of energy and zenith angle. Subtle details in this oscillation pattern encode the neutrino mass hierarchy. Right: Significance as a function of time for the determination of the neutrino mass hierarchy. The different lines denote expectations for different combinations of hierarchy and atmospheric mixing angle.

neutrino mass eigenstates

In 1967 Bruno Pontecorvo suggested that the three neutrinos that are detected through the weak interaction, ν_e, ν_μ and ν_τ are perhaps not mass eigenstates. It is now certain he was correct. The mass

$$|\nu_l\rangle = \sum_{i=1}^3 U_{li} |\nu_i\rangle; \quad l = e, \mu, \tau$$

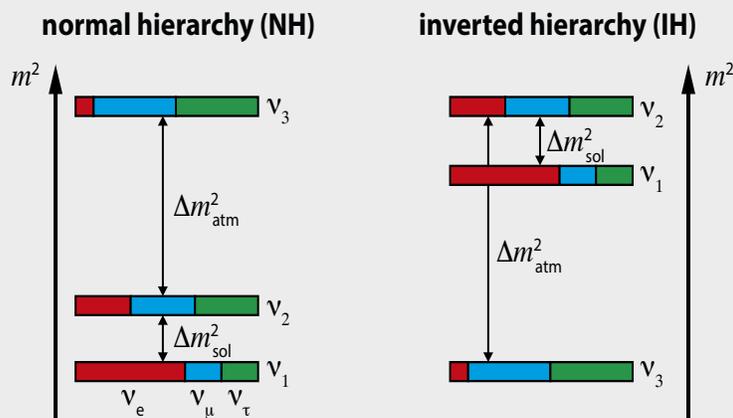
eigenstates, called ν_1, ν_2 and ν_3 , are linear superpositions of the flavour eigenstates:

Where U is the neutrino mixing matrix (*a.k.a.* Pontecorvo–Maki–Nakagawa–Sakata matrix). U can be characterised by three mixing angles and a complex phase. All three mixing angles have been measured by a series of reactor, accelerator and astroparticle experiments. If we consider only two flavours, then U can be characterized by a single mixing angle θ and the probability to change flavour when traveling a distance L is given by:

$$P(\nu_l \rightarrow \nu_{l' \neq l}) = \sin^2 2\theta_{12} \sin^2 \left(\frac{\Delta m_{21}^2 L}{4E} \right)$$

where Δm_{21}^2 is the absolute difference of the squares of the masses of the two eigenstates and E is the energy. The current situation is depicted in the figure to the right. The flavour content of each of the mass hierarchy (*i.e.* the matrix U) is fairly well determined. The relative ordering of ν_1 and ν_2 is known from solar neutrinos, but it is not known if these two are lighter or heavier than the third mass eigenstate ν_3 . This leads to the two patterns, known as ‘normal’ and ‘inverted’ hierarchy. Determining the pattern is the next step in neutrino physics. The longer-term goal is measuring the complex, CP-violating, phase of U in a long-baseline neutrino experiment such as DUNE.

The two possible spectra of the neutrino mass eigenstates allowed by the current measurements. The colour coding represents the contribution of each of the flavour eigenstates to the mass eigenstate.



National Research Agenda: Route 5

Until 1 May 2015, everybody in the Netherlands could submit his or her questions for research via a dedicated website. In total, individuals and parties from science, the business community and civil society organizations submitted 11,700 questions.

The questions were assessed for usefulness and, in consultation with the parties involved, were brought together into themes or routes. The agenda was then launched in November 2015. One of the many themes is Route 5: **Building blocks of matter and fundamentals of space and time.**

Route 5 is driven by the curiosity-based research in the field of space, time and matter, with topics that can count on great interest and fascination of society. Research that cannot do without advanced, innovative technology and of which developments in this area in turn can lead to surprising technological innovations and new applications. Three sub-questions have been formulated:

What are the elementary particles and forces and what is the dynamics of space and time?

Obvious stakeholders in this section are the high-energy physics, and philosophy, mathematical physics, astronomy and pure mathematics communities. Central are the search for new elementary particles, including Dark Matter, the study of gravitational waves, black holes and the development of a theory of quantum gravity. Of great importance in this context are also the (international) experimental infrastructures, with their proven impact on technological innovation and spin-offs.

What is the content, evolution and origin of the universe?

Here cosmology, astroparticle physics, astrochemistry and astronomy overlap. All aforementioned stakeholders play a role. In particular, in the detection of gravitational waves, in the search for Dark Matter and for the development and testing of models of the origin of the universe the high-energy physics, astrophysics and cosmology communities have common interest. Again, the existence and development of frontier (international) observational facilities is a key factor for technological innovation and spin-off.

nationale
wetenschaps
agenda



How does interaction between building blocks of matter lead to new and unexpected properties and behaviour?

The collective behaviour of large numbers of components (from quarks to molecules) can be rich and unpredictable and depends on their complex mutual interactions, the geometry and symmetry. The emergent behaviour transcends the properties of individual building blocks alone. This theme connects various disciplines such as physics and chemistry, but also information theory. Important examples are the phase transition to the quark-gluon plasma, the study of topological systems, emergent gravity, self-organization and non-equilibrium processes.

All involved parties should identify, within the framework, new links and partnerships in the broadest sense of the word, including the social and economic sector. The cooperation with education should be sought, a centralized and professional outreach programme developed, and new relationships with (innovative) businesses established.

New APPEC Chair

Frank Linde, the new chair of the Astroparticle Physics European Consortium

By Eleni Chatzichristou, APPEC Communications Office

Given the latest results from Planck, AMS, Ice Cube, and the upcoming second run of LHC, it is exciting times for astroparticle physics and cosmology.

For me astroparticle physics addresses incredibly tantalizing and fundamental scientific questions such as: What is the nature of Dark Matter & Dark Energy? What is the true nature of the neutrino? Can we, in addition to the cosmic microwave background, observe other signals from our infant universe e.g. primordial gravitational waves and/or neutrinos? Moreover, astroparticle physics promises to open entirely new windows on our universe complementing 'traditional' electromagnetic dominated astronomy, by measurements of high-energy cosmic-rays and neutrinos, photons and gravitational waves. Examples of hot issues for me are: the indirect observation, albeit disputed, of primordial gravitational waves by BICEP2 and the high-energy (PeV) neutrinos observed by ICECUBE. More excitement I expect from the imminent release of the full Planck dataset; the eagerly expected first direct observation of gravitational waves by LIGO/Virgo; and the forthcoming results of next generation direct Dark Matter searches such as XENON1T as well as the results of LHC data-taking at 13–14 TeV. And on a slightly longer time schedule I look forward to the numerous facilities addressing neutrino properties. So: indeed astroparticle physics finds itself in very exciting times!

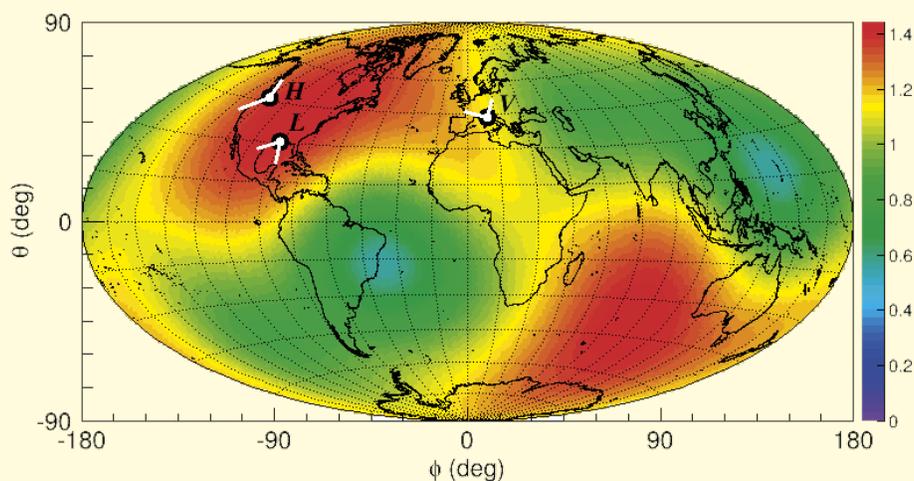
What are the top priorities for APPEC in the near future and how do you expect to influence national and European policies in this direction?

A constant future challenge will be the development of ever more creative and performant detection technologies which can, where appropriate, be scaled-up to the required quantities at affordable costs. A top priority for me will be to get the large observatories in particular for multi-messenger studies really on



On 9 January 2015 the General Assembly of the Astroparticle Physics European Consortium, APPEC, elected Frank Linde (director of Nikhef from 2004 to 2014) as its new Chair. He is taking over from Stavros Katsanevas (director of APC), who was chairing APPEC since November 2012. Linde's appointment will be effective for the coming two years.

Nikhef participates in the Advanced Virgo project and together with LIGO, this LIGO Virgo Consortium (LVC) pursues the first direct detection gravitational waves by developing a worldwide network of second generation laser interferometric GW detectors. In colour is shown the relative angular sensitivity of the present LVC detector network: Virgo (V), Livingston (L) and Hanford (H).



track *i.e.* funded with a realistic spending profile taking into account exploitation costs. This will require in-depth project scrutiny notably in view of possible cost reductions and possibly some re-alignment of the ambitions of some projects in order to maintain the overall scope of the research field. Of course intense negotiations with the various funding agencies will be a sine-qua-non. I am convinced that with realistic proposals with an appealing discovery potential and by delivering upon our promises we will gain the support of our funding agencies.

During the past couple of years APPEC has seen great achievements, continuing what ASPERA started: building the feeling of a European community in astroparticle physics. How do you think this can be strengthened in the future?

Like many of today's astroparticle physicists, also my own background is in accelerator-based particle physics. It is also a well-known secret that I am a proponent of an expansion of CERN's involvement in astroparticle physics. This not only because of its huge discovery potential and the many synergies between both fields but also because I deem it crucial that CERN continuous to 'serve' its home base *i.e.* the physicists at institutes and universities in Europe of which many have already a decade ago fully embraced astroparticle physics as a mature and important endeavour. From APPEC's perspective we would benefit from a stronger CERN involvement by tapping into CERN's very professional project review mechanisms as well as by hopefully attracting some of CERN's resources to astroparticle physics. A difficulty will of course be that CERN itself has already more ambitions than it can presently fund. The best strategy to address all of this is by cooperation and I conclude with a quote from the latest release of the European Strategy for Particle Physics (2013) which I plan to take up from APPEC's side: *-In the coming years, CERN should seek a closer collaboration with APPEC on detector R&D with a view to maintaining the community's capability for unique projects in this field.*"

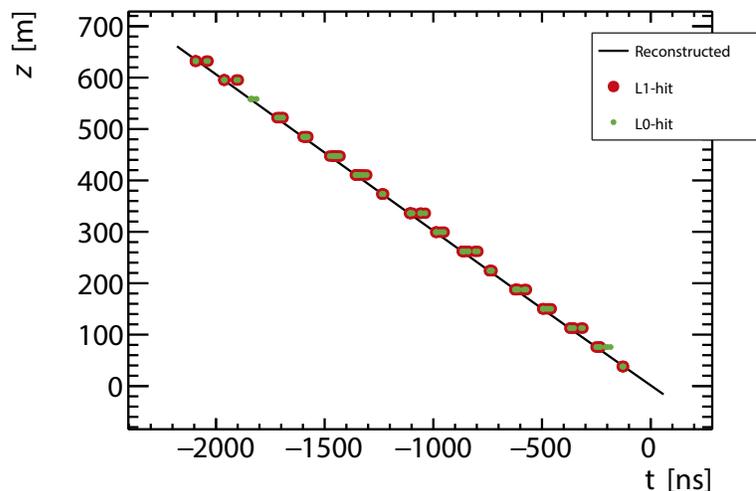


Neutrino telescopes *launch of KM3NeT's first detection line*



After years of preparations the first KM3NeT detector line was successfully launched in 2015, 100 km off the Sicilian coast. The 780 m long line detector, tightly rolled on a special frame developed by NIOZ, was gently placed on the seabed at a depth of 3,500 m. The detector was then connected by an unmanned submarine to the existing underwater network and via a 100 km fiber cable to the control room in Porto Palo di Capo Passero in Sicily. The next step was the rollout of the line, until it came to stand upright in the water.

Figure 1. Event display of an atmospheric muon detected on the first deployed KM3NeT detection line. The plot shows the height of the sensors along the detection line vs. the time of the detected Cherenkov light. The line is a fit of a muon moving downwards along the detection line with the speed of light.



Management
dr. A. Heijboer

Nikhef is heavily involved in the construction of the next generation neutrino telescope in the Mediterranean Sea: KM3NeT. We have led the development of the chosen technology at both the conceptual and technical level. This cost effective technology is a major asset of the project. An example is the Multi-PMT optical module, which offers more information per detected Cherenkov photon, and a better price per unit sensor area compared to earlier options. A novel deployment mechanism developed by NIOZ and Nikhef allows for multiple lines to be deployed safely in a single sea campaign, which is essential for deploying the hundreds of lines that will make up KM3NeT. We are also involved in optical module production, mechanics and optical-network efforts, and we provide the spokesperson.

The collaboration has recently published a letter of intent, which details the science reach of the next phase of the project, KM3NeT 2.0, comprising 345 detection lines in France and Italy. On 10 March 2016 it was officially announced that KM3NeT 2.0 will appear on the renewed version of the European ESFRI roadmap for large-scale infrastructures.

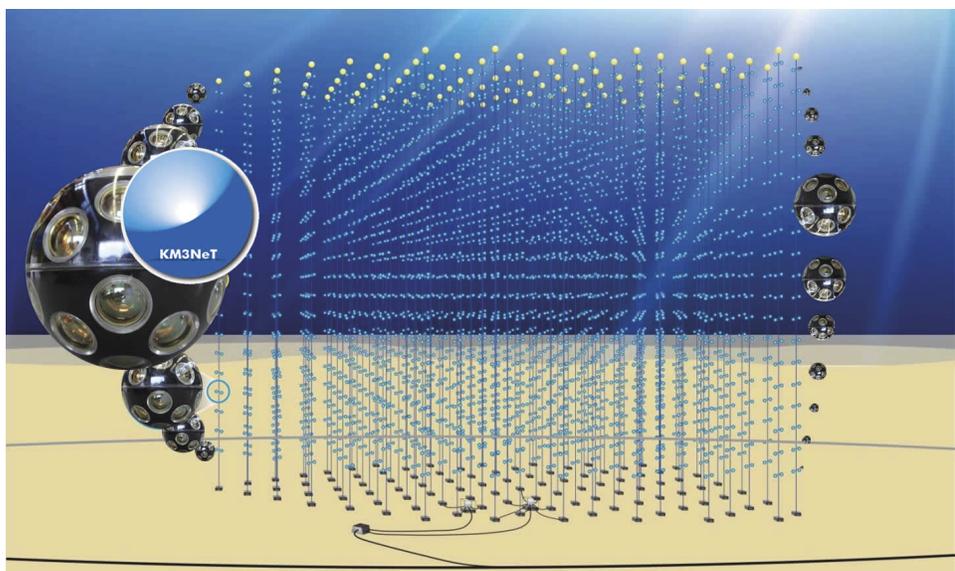
First detection line

The first detection lines of the KM3NeT detector have been constructed in the Nikhef workshop. In December 2015, the first line has been deployed at 3.5 km depth, and connected via a pre-installed 100 km long electro-optical cable to the shore station in Porto Palo, Sicily. Hours after deployment, the line was powered up and data immediately began flowing from each of the 18 optical modules. PhD students Martijn Jongen en Karel Melis have been analysing this data since the first hours. Using the signals that will eventually become the background to cosmic neutrinos, like ^{40}K decays and atmospheric muons (see Fig. 1), they were able to verify the nanosecond timing accuracy of the detector and to measure the photomultiplier sensor efficiencies. The timing accuracy, which is key for the accurate reconstruction of neutrinos, has further been verified with optical flashers. All these measurements are consistent with the internal timing system based on White Rabbit-technology, another technical Nikhef contribution.

As the moment of writing, every one of the 558 sensors in the line is functional and producing high-quality data with nanosecond timing accuracy. The next string will be deployed in May 2016; this will allow for the identification and reconstruction of the first neutrinos.

Neutrino Oscillation Physics

The Nobel prize for Physics in 2015 was awarded for the discovery of neutrino oscillations. The experiments involved detected neutrinos from the atmosphere and the Sun to show that neutrinos change flavour along the way. For the solar neutrinos, the presence of matter in the Sun allows a determination of the absolute ordering of the two mass eigenstates involved. For the atmospheric neutrinos, this has not yet been possible. Hence, it is presently unknown what the ordering, or hierarchy, of neutrino masses is. This is the next big question in neutrino research, with large implications for future efforts to detect CP-violation in neutrinos and neutrinoless double beta decay. It turns out that large volume neutrino telescopes have the ability to answer this question. By measuring, with unprecedented accuracy, the oscillation of atmospheric neutrinos with energies in the few-GeV-range, these detectors are sensitive to the hierarchy-dependent effect of matter in the Earth. KM3NeT has decided to optimize part of the detector for this goal. The resulting setup (called ORCA) will be able to determine the neutrino mass hierarchy within three years of data taking, in addition to provide precise measurements of the mixing angles, making it very competitive with other (accelerator- based) efforts which are planned on longer timescales.

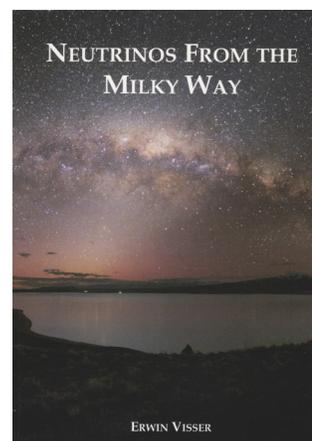


Artist's impression of the KM3NeT detector with strings anchored to the sea bottom.

All-flavour neutrino detection

With the discovery of cosmic neutrinos by IceCube, it has become very clear that neutrino astronomy not only requires the ability to detect muon-neutrinos. The capability to accurately measure the other two types, electron- and tau-neutrinos, is a crucial asset. The ability to identify the sources of neutrinos depends strongly on the pointing capabilities for each neutrino type. Due to neutrino oscillations, all flavours will be present, but the precise abundances carry information on the astrophysics of the source, and on the particle-physics of the neutrino themselves. Exotic scenarios like decaying neutrinos could lead to very clear signatures in the neutrino flavour ratios.

Members of the Nikhef group have developed methods to reconstruct the experimental signatures produced by electron- and tau neutrinos. We have shown KM3NeT will achieve degree-level pointing accuracy for



Erwin Lourens Visser
12 May 2016

these events: an order of magnitude better than the current accuracy of IceCube. This is made possible by the clarity of the Mediterranean sea water, combined with the multi-PMT design. This capability, which came as a surprise to many of our colleagues, now underpins a large part of the planned science programme as described in the recent Letter of Intent.

In synergy with the KM3NeT effort, we have also implemented a method to reconstruct electron- and tau-neutrinos with the ANTARES detector, which has been taking data for eight years now. The ability to detect these signatures has been used to significantly enhance the search for cosmic neutrino sources (see Fig. 2). These results, which are the topic of Tino Michael's PhD thesis, represent the most sensitive exploration of the Southern neutrino sky, including the Galactic Centre, to date. While Nikhef's activity on ANTARES data analysis is decreasing, the tools to use all flavours of neutrinos, will be used by the collaboration to enhance many other analyses in the next few years. The ability to detect all flavours, and to accurately distinguish between them also underpins the measurement of the neutrino mass hierarchy with ORCA.

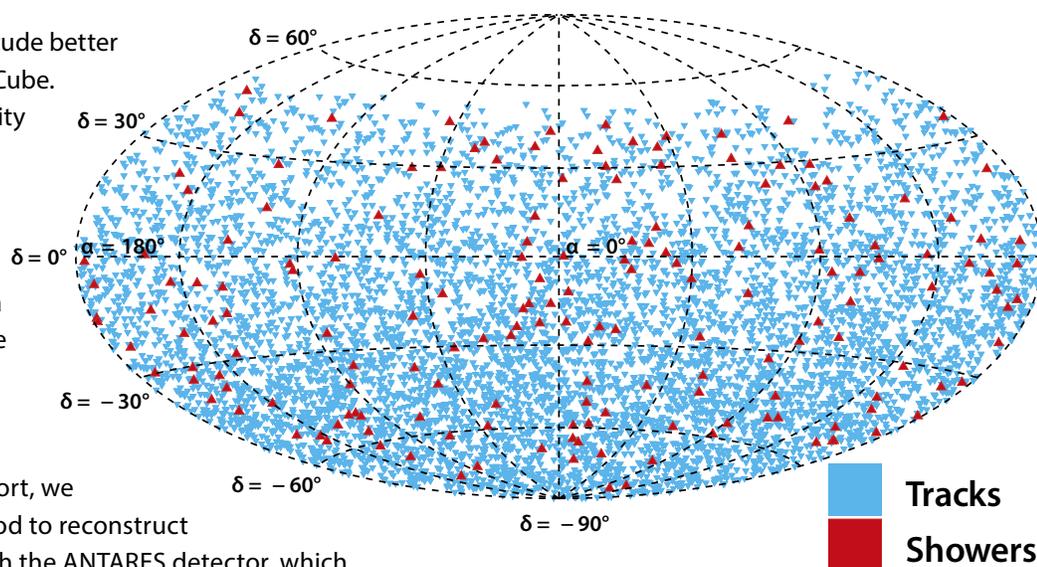


Figure 2. A sky map of neutrino candidates detected in ANTARES from the most recent cosmic source search. The blue dots represent muon-neutrino candidates (most of which are real atmospheric muon neutrinos), whereas the red dots are electron- or tau-neutrino candidates, which have a significantly reduced background. The angular resolution of these events is roughly the size of the dots. The corresponding analysis is the world-first search of cosmic neutrino point sources using all neutrino flavours.

NLeSC Grant
Dorothea
Samtleben



NLeSC Grant
Ronald
Bruijn



NLeSC Path-finding grants

The Netherlands eScience Center (NLeSC) approved the Nikhef proposal "Real-time detection of neutrinos from the distant Universe" by **Dorothea Samtleben** together with **Ronald Bruijn** for a so-called Path-finding project. NLeSC funds these projects by in kind provision of eScience research engineers. The Path-finding grants are intended to develop new lines of eScience research that may develop into bigger programs and projects.

Gravitational Waves

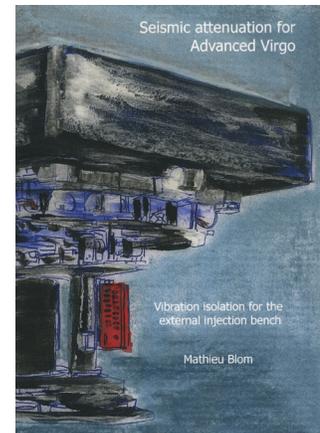
listening to a chirp in the universe

MultiSAS systems have been assembled and tested at Nikhef, and were subsequently installed at the Virgo site and pre-commissioned. All ground vibrations are attenuated by at least a million times.

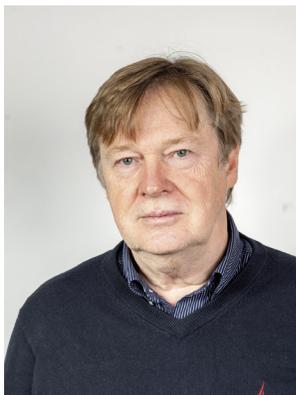


FOM projectruimte
Chris Van Den Broeck

Chris Van Den Broeck received a FOM 'projectruimte' grant for his proposal "*The discovery of gravitational waves with Advanced Virgo and LIGO*": "Systems that include a black hole, have exceedingly complex gravitational-wave signal waveforms. I will develop a method that will boost detection efficiency by searching with the most advanced waveform models, that will deliver fast information to astronomers and will enable the full scientific exploitation of the signals."



Matheus Ronaldus Blom
9 December 2015



Management
prof.dr. J.F.J. van den Brand

Albert Einstein predicted the existence of gravitational waves in 1916, the year after the final formulation of the field equations of general relativity. He showed that the linearised weak-field equations had wave solutions: transverse waves of spatial strain that travel at the speed of light, generated by time variations of the mass quadrupole moment of the source. In 1974 Hulse and Taylor discovered the binary pulsar system PSR B1913+16, and the observed energy loss was in agreement with predictions from the quadrupole formula. Subsequent analysis led to the recognition that direct observations of the amplitude and phase of gravitational waves (GW) would enable studies of additional relativistic systems. This will provide new tests of general relativity, especially in the dynamic strong-field regime. Nikhef participates in the Advanced Virgo project and together with LIGO, this LIGO Virgo Consortium (LVC) pursues the first direct detection gravitational waves by developing a worldwide network of second generation laser interferometric GW detectors. These instruments will have ten times enhanced sensitivity with respect to initial LIGO and Virgo instruments, and thus a 1000 times larger accessible volume of the universe. The detectors are undergoing a commissioning phase in 2015 with first LVC data taking with both Advanced LIGO interferometers scheduled to start in September 2016. Joint data taking with Advanced Virgo is planned for the second half of 2016.

Instrumentation for Advanced Virgo

Advanced Virgo is a major upgrade, with the goal of increasing the sensitivity by about one order of magnitude with respect to initial Virgo in the whole detection band. Nikhef contributes to Advanced Virgo by providing cryogenic vacuum links in the interferometer arms. Vacuum pressures below 10^{-9} mbar are required to suppress frequency noise introduced by scattering the laser beam from fluctuating residual gas atoms in the interferometer arms. Four cryogenic systems to achieve such ultra-high vacuum pressures have been designed at Nikhef. These so-called cryolinks were installed and commissioned in 2015, and are now fully operational in Advanced Virgo. Also the linear alignment system that is used for the angular alignment of Virgo's core optical components, has been upgraded. Sensing can now be accomplished at



Figure 1. Ultra-high vacuum cryolinks, designed at Nikhef, were installed and commissioned in 2015.

DC and can accommodate modulation frequencies as high as 131 MHz. Demodulation is carried out with digital techniques. Also novel vacuum compatible low power galvoscanners have been installed. These scanners are needed for the automatic beam centering on the RF quadrant photodiodes used for differential wavefront sensing.

Nikhef leads the Suspended Benches project subsystem, and has improved the external benches for the injection and detection optical tables, as well as for the optical tables at the end of the interferometer arms. All ground vibrations are attenuated by at least a million times. In this manner Virgo's sensing elements are now under

stable conditions. This ensures that the seismic motion of the angular alignment sensors (and related pick-off telescopes) placed on the suspended benches will not couple to the output of the detector through scattered light. All five so-called MultiSAS have been assembled and tested at Nikhef, and were subsequently installed at the Virgo site and pre-commissioned; full commissioning is foreseen before summer 2016.

In addition, Nikhef has responsibility for the input mode cleaner (IMC). The IMC is a high finesse triangular cavity with 145 m length which is used to clean the injected laser beam from unwanted optical modes. Moreover, the IMC is part of Virgo's elaborate frequency stabilization scheme. Fig. 2 shows the dihedron that is installed on the new injection bench. Finally, Nikhef is responsible for the development and commissioning of three new phase cameras. These instruments can provide accurate images of the spatial distribution of amplitude and phase of the various circulating laser fields (both the carrier and sidebands are imaged). These instruments are of paramount importance for the active compensation of the aberrations of the transmissive optics of the interferometer, which otherwise could compromise the detector stability and would limit the usable optical power. Installation of the first unit took place in 2015, while the remaining systems will be installed in early 2016.

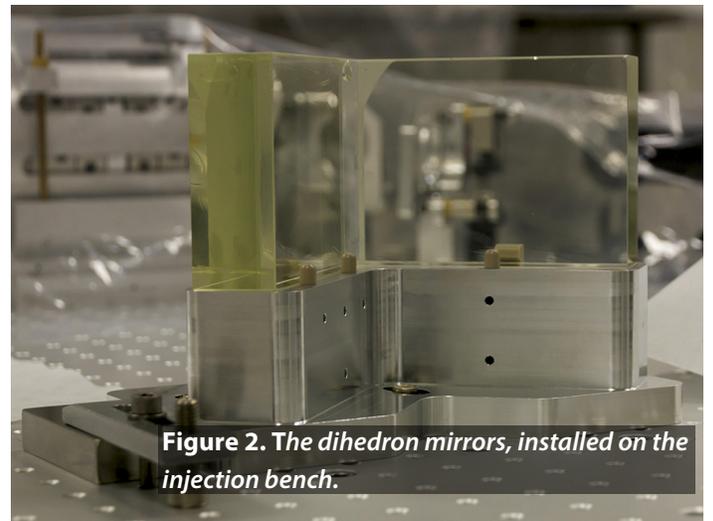


Figure 2. The dihedron mirrors, installed on the injection bench.

The three km long north pipe of Virgo.



Data analysis

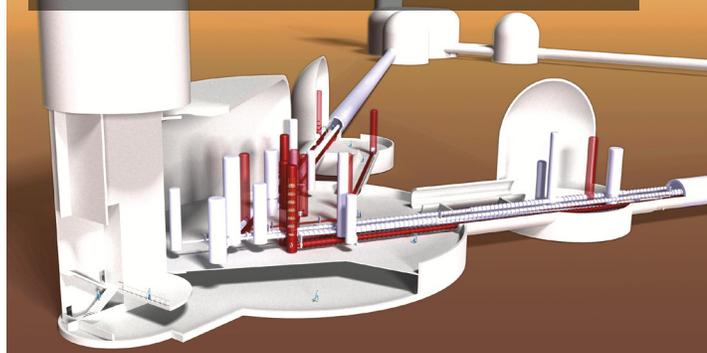
Nikhef has made leading contributions to the LIGO–Virgo analysis effort, and at present Chris van den Broeck is Data Analysis Coordinator for the Virgo Collaboration. Software has been developed that allows extracting fundamental physics information from the signal of merging compact binaries. This includes individual component masses and spins, the sky location and orientation of the binary, and the distance to the source. Coalescence of compact binaries that are composed of neutron stars (NS) and black holes (BH), is considered one of the most probable sources for the first direct detection of GW events. The so-called TIGER (Test Infrastructure for GEneral Relativity) pipeline has been developed, to test the genuinely strong-field dynamics of general relativity in a model-independent way up to seventh order in a post-Newtonian expansion of the GW phase.

Significant effort has been devoted to characterise the equation of state (EOS) of neutron stars by using future data from NS–NS coalescences. Note that the NS EOS represents one of the most unknown observables in astrophysics. In addition, the Nikhef Virgo group has developed a dedicated data analysis pipeline called Polynomial Search. This pipeline is used in the search for continuous gravitational waves from fast-spinning neutron stars in binary systems.

Einstein Telescope

Einstein Telescope (see Fig. 3) is a new infrastructure project that will bring Europe to the forefront of the most promising new development in our quest to fully understand the origin and evolution of the universe, the emergence of the field of Gravitational Wave Astronomy. Gravitation is the least understood fundamental force of nature. Challenges include discovery and exploitation of various sources of gravitational waves, experimental constraints on the corresponding quantum (graviton) and the development of an observation-based field of research on quantum gravity. We propose that Einstein Telescope is realized in the Netherlands and will be an underground international facility containing cryogenic interferometers with 10 km arms. We have submitted proposals to both KNAW (Royal Netherlands Academy of Arts and Sciences) and NWO (Netherlands Science Organization) and propose a phased approach where Phase I will allow qualification of sites in the Netherlands. After successful site selection, next phases will involve construction, followed by exploitation.

Figure 3. Artist's impression of the Einstein Telescope.



Dark Matter Experiments

inauguration of XENON1T

Construction of the XENON1T Dark Matter detector in Hall B of the Gran Sasso laboratory (LNGS) in Italy was completed near the end of 2015. The Nikhef Dark Matter group played a leading role in the design and construction of several of its subsystems. The experiment is now moving into the commissioning phase, with first science data expected to arrive in early 2016 and our group is preparing for the analysis of this data. While the XENON1T construction was ongoing, the XENON collaboration also maintained the operation and data analysis of the XENON100 detector, resulting in a number of important publications. More locally, the Nikhef group has also commissioned XAMS, the dual-phase liquid xenon detector operating in Nikhef's cryo-lab. The analysis of the XAMS data has already given us insights into analyses improvements of the larger XENON detectors.

The XENON1T Dark Matter experiment is being commissioned in the underground Gran Sasso Laboratory in Italy. XENON1T, with a total xenon mass of 3.500 kg, is the third XENON experiment. It all began 10 years ago with a detector of just 15 kg mass. XENON1T is the follow-up of XENON100, the world's most sensitive Dark Matter detector until 2013.

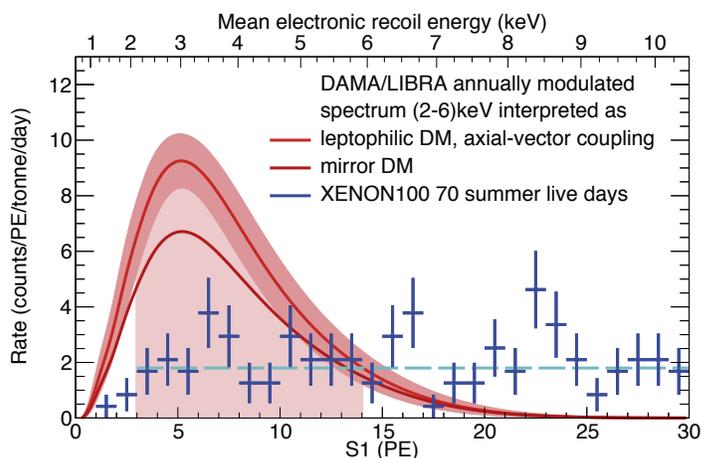


Figure 1. Contrasting XENON100 data with the claimed DAMA Dark Matter detection signal. The DAMA modulated spectrum, interpreted as WIMPs coupling to electrons through axial-vector interactions, is excluded at a 4.4σ confidence level. A separate analysis searching for an annual modulation in XENON100 data, excludes the DAMA signal at 4.8σ .



Management
prof.dr. M.P. Decowski

Effective 1 March 2015, **Patrick Decowski** was appointed professor of experimental astroparticle physics at the Faculty of Science of the University of Amsterdam.

The main priority of the XENON collaboration in the past year was completing the construction of the XENON1T experiment. Nevertheless, the smaller XENON100 experiment continues to take data and results are being analysed. This resulted in the publication, one of which in the journal *Science*, of two important analyses related to a Dark Matter detection claim by the DAMA collaboration. This claim is based on the observation of an annual modulation in the DAMA data. Since about a dozen Dark Matter experiments have excluded this signal as being due to WIMP-nucleus scattering, only an interpretation as WIMP-electron scattering was still viable. The XENON100 data has now excluded the observed DAMA modulation signal as being induced by WIMP-electron interactions, see Fig. 1. This result was further strengthened by an annual modulation analysis of XENON100 data, which included a generic search for modulation periods down to the week scale.

The Nikhef group also continues to be heavily involved in XENON100 data analysis. Our group led, and recently completed, the analysis of low-mass WIMP signals and we are also leading the analysis of the ^{88}YBe neutron source data. This latter analysis can provide essential information on the response of xenon detectors at very low nuclear recoil energies. Separately, our group is developing and testing various new algorithms on XENON100 data that will be used for XENON1T analyses. The collaboration is testing a number of novel calibration methods using the XENON100 detector that will also allow us to improve XENON1T data analysis.

Ready for data in 2016

The major event of the year was the completion of the XENON1T construction. This was celebrated with an inauguration event on 11 November. With all components installed, the collaboration is gearing up for a few months of detector commissioning before science data taking starts.

The Nikhef team is responsible for the trigger and event builder as part of the data acquisition group. Most of our on-site focus this year was the installation of the

DAQ system. This included a week-long testing phase on the running XENON100 experiment to identify any problems and exercise the full system. With the help of the Nikhef CT-group, we also installed and commissioned the 12 km-long underground-to-outside fiber network system and made Nikhef one of the best connected outside institutes to LNGS. All of this will ensure that we will be able to analyse data quickly once detector operation starts.

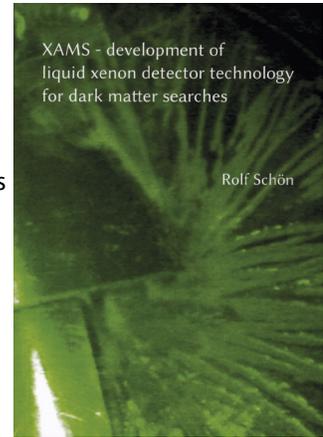
Another focus-area for our group has been the XENON data processing software, named *PAX*. Nikhef has initiated and led the development of *PAX*, and it has become the official XENON data processing software. *PAX* takes care of taking the raw PMT signals, applying all signal conditioning and processing steps, performing event position reconstruction etc. to finally provide ROOT-based output files to analysers. While the data processor was written for XENON1T, it is fully configurable and is able to also analyse XENON100 data and data from smaller setups, such as XAMS. The Nikhef team has also recently organized workshops in both the US and Europe to prepare collaborators for XENON1T data analysis with *PAX*.

Our Dark Matter group activities positioned us well to have a leading role in the first XENON1T Dark Matter analysis and indeed one of our postdocs (Christopher Tunnell) has become one of two XENON1T analysis coordinators. His task will be to organize and lead the publication of the first XENON1T Dark Matter data analysis.

XAMS R&D at Nikhef

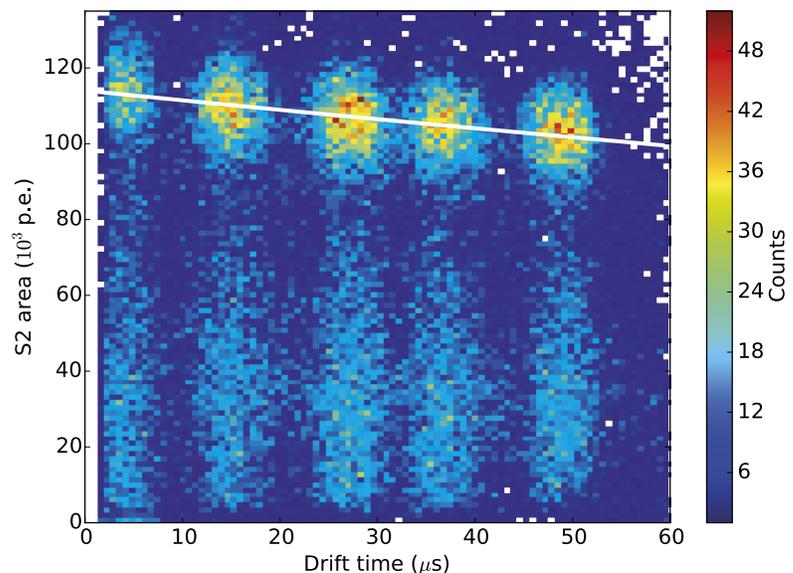
Over the past few years, we designed, built and operated XAMS, a small dual-phase xenon TPC at Nikhef. We improved several items this year, such as a better functioning xenon level-meter and a tagged ^{22}Na radioactive source. Data from this detector have already been used to benchmark our *PAX* data processing software, see Fig. 2. Based on XAMS data we have also developed a new PMT gain calibration procedure and will submit a paper describing this procedure shortly. We plan to apply this method to XENON1T data. This will allow us to have an alternative gain calibration and stability procedure for XENON1T, in addition to the standard LED-based gain calibration. Finally, after receiving the necessary permits, we are in the process of procuring a neutron source. The neutrons will allow us to see nuclear recoils in XAMS, the same signal as is expected from WIMP collisions and complements our γ -sources.

The Nikhef Dark Matter group is extremely dynamic with all group members participating in our three main experimental activities.



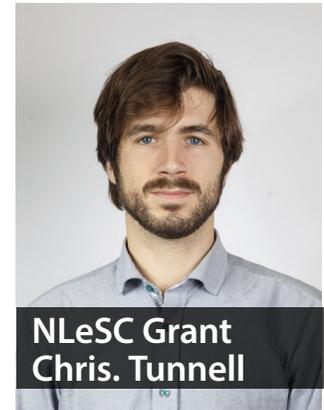
Rolf Schön
1 July 2015

Figure 2. Data taken with a collimated ^{22}Na γ -source pointing at five different positions in the XAMS TPC. The density plot shows the S2-signal for the five different z-positions, corresponding to different drift times. The thick white line is a fit to the photo-peak. The decreasing S2-signal with increasing drift time is due to electron loss as they drift through the xenon liquid and corresponds to an electron life-time of $(429 \pm 29 \mu\text{s})$.



Christopher Tunnell receives NLeSC Path-finding grant

Christopher Tunnell received a Path-finding grant from the Netherlands eScience Center (NLeSC) for his proposal *"Giving pandas a ROOT to chew on: Modern Big Data front and backends in the hunt for Dark Matter"*. The project will involve collaborating with one of their eScience engineers for one year. The Path-finding grants are intended to develop new lines of eScience research that may develop into bigger programs and projects.



The completed XENON1T Time Projection Chamber (TPC) just before it was moved underground for installation in the cryostat.

Cosmic Rays

Pierre Auger Observatory



After ten years of successful running, the decision for a major upgrade of the Auger experiment on the Argentine Pampas has been made. The key element of the upgrade is the installation of a plastic scintillator on top of each existing surface detector station. It will provide a complementary measurement of the showers allowing the reconstruction of muons and electromagnetic particles. The surface scintillator detector stations (SSD) will be deployed over the full 3,000-km² area of the overall surface detector.

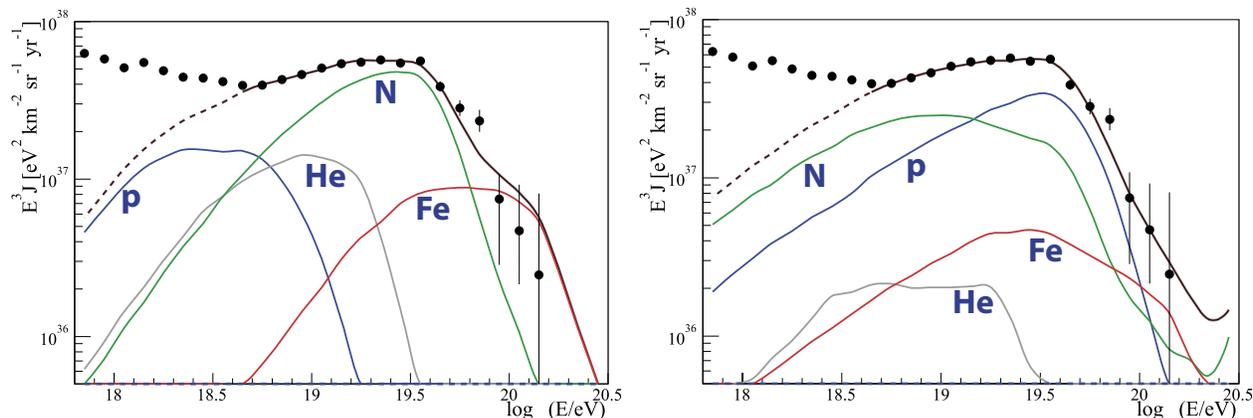


Figure 1. Fits of the cosmic ray flux at the highest energy for the maximum energy (left) and GZK (right) scenarios.



Management
prof.dr. S.J. de Jong

Ultra-high-energy cosmic rays are the most energetic particles we know, exceeding the LHC energy by many orders of magnitude. Yet we neither know their sources, the physics that is needed to generate them, nor the physics that governs their interactions with the air in our atmosphere. The Pierre Auger Observatory was built to resolve these mysteries. It is the world's largest cosmic ray observatory located on 3,000 km² near Malargüe in the province of Mendoza in Argentina.

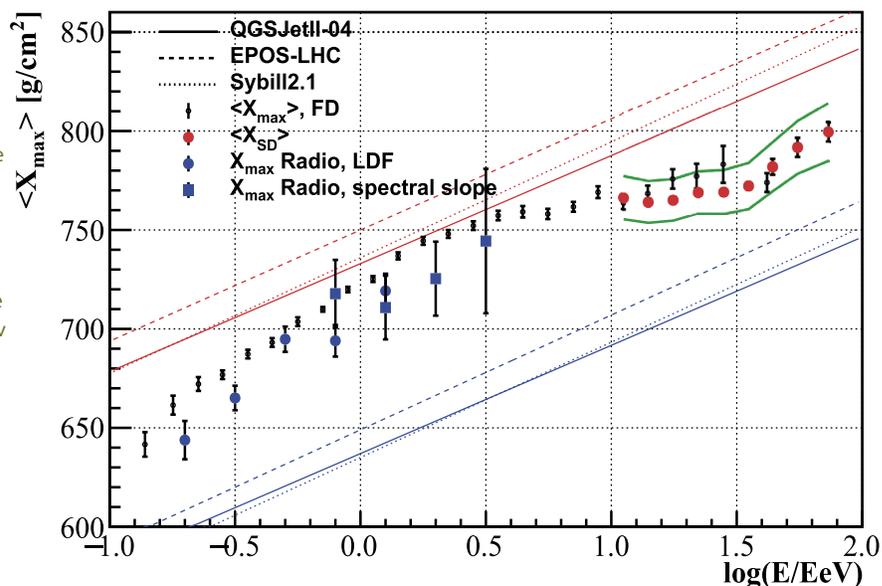
The origin of ultra-high-energy cosmic rays

The Pierre Auger Collaboration had already definitively shown that the energy spectrum of cosmic rays exhibits a sharp drop around 10²⁰ eV. This drop is compatible with the Greisen-Zatsepin-Kuz'min (GZK) cut-off, above which ultra-high-energy cosmic rays interact with photons of the 2.7 K cosmic microwave background and will lose their energy when traveling over inter-galactic distances.

However, recent measurements by the Pierre Auger Collaboration have cast doubt on this to be the only explanation. Where for the GZK cut-off explanation the highest energy cosmic rays are thought to consist mostly of protons, extrapolation from energies just below this regime seems to indicate domination by heavier elements. This is illustrated by fits of the particle spectrum at the highest energy using the two models mentioned in Fig. 1, which both describe the data quite well, despite the completely different particle type composition.

The crux of the answer lies in knowing the particle composition of cosmic rays at the highest energy. The current technique in Auger that was explicitly designed to determine this composition by fluorescence detection of air showers can only be used in pitch dark nights, which is only 10% of the day on average. The Nikhef group pioneers both the use of the already existing Auger surface detector and the use of the entirely new radio detection technique in determining the cosmic ray composition, ultimately on an event-by-event basis.

Figure 2. Cosmic ray average penetration depth in grammage, X_{\max} , as a function of energy. The small black points are published data from the Auger fluorescence detector. The full red dots are the preliminary measurement using the Auger surface detector. The green band around them is the systematic uncertainty on these points. The blue square points are the preliminary pulse length measurements of the radio detection. The blue dots are from the radio detection Cherenkov ring radius measurements. The estimation of the systematic uncertainty on these points is ongoing research. The lines are prediction from various air shower simulation models: full lines from QGSJetII-04, dashed lines from EPOS with LHC tuning and dotted lines from Sybill2.1



Cosmic ray composition from the Auger surface detector

The Auger Surface Detector consists of about 1,660 water Cherenkov tanks of 12 ton water each. These tanks are spaced by 1.5 km to cover a surface of 3,000 km² in total. When high-energy particles at the end of the air showers pass through the water they make Cherenkov radiation that is observed by three photomultipliers that look down in the water of the tank. For ultra-high-energy cosmic rays, many tanks are hit. The particle flux in a collection of tanks is fit as a lateral density profile and its normalisation renders the energy of the incoming cosmic ray. Depending on the direction of the incoming cosmic ray, the water tanks are hit at different times by the air shower front. From timing reconstruction the arrival direction of the incoming cosmic ray can be determined.

At the same energy light and heavy cosmic ray particles have different interactions with the atmosphere. Light particles, *in extremum* the proton, have a smaller cross section with air molecules than heavy elements, such as nitrogen or even iron nuclei. Therefore, light cosmic rays have the development of their shower deeper into the atmosphere than heavier nuclei. Moreover, the interactions with heavier cosmic rays invoke a more rapid shower development than with lighter ones. And in addition, heavier elements tend to produce significantly more muons, especially also at the early stage of the shower, than light cosmic rays.

The penetration depth of the shower in the atmosphere can be assessed by carefully studying the shower front when it arrives at ground. The front is an hyperbolic surface, where the focal area points back to the points on the shower axis where the particles in the shower were produced. This *curvature* can be measured using the timing of the tanks that are hit. The shower thickness is produced by the different arrival times of particles that are produced relatively early in the shower that arrive early and particles formed at the end of the shower that arrive later. Using the *rise-time* of the signal in the tanks is a measure of the ratio of early particles, mostly muons and late particles mostly electrons, positrons and photons.

Combining the curvature and rise-time, promising first preliminary results have been produced on the already available Auger surface detector data of the past decade. A resolution of better than twice that of the fluorescence detector can be attained for a factor of nearly ten more data. A publication is in preparation in which this is used to provide data points on composition at significantly higher energy than any such measurement previously. The preliminary measurement is shown in Fig. 2.

Surface detector upgrade

To improve significantly on the composition determination by the surface detector it will be upgraded with electronics with a better timing resolution and a new detection layer will be installed. Together with the Cherenkov tank the new detection layer will allow the muon flux to be distinguished from the flux of electromagnetic particles. These improvements will lead to a composition resolution of the surface detectors that is similar to that of the existing fluorescence detector, but with a 24 hours per day duty cycle.

Nikhef is involved in the design of the new detection layer, which is called the scintillator surface detector (SSD). It consists of a 1 cm thin plane of nearly 4 m² of scintillator, read out with wave length shifting fibers that collect the signal onto a single photomultiplier (see Fig. 3). The readout of the photomultiplier is integrated in the new surface detector electronics.



Figure 3. The scintillator surface detector (SSD) as seen on top of the Cherenkov tank. It consists of a 1 cm thin plane of nearly 4 m² of scintillator, read out by a single photomultiplier.

The new electronics and the SSD will be installed in 2017 and 2018, at which time the Auger Observatory smoothly rolls into the new mode of operation without stopping data taking and with negligible efficiency loss.

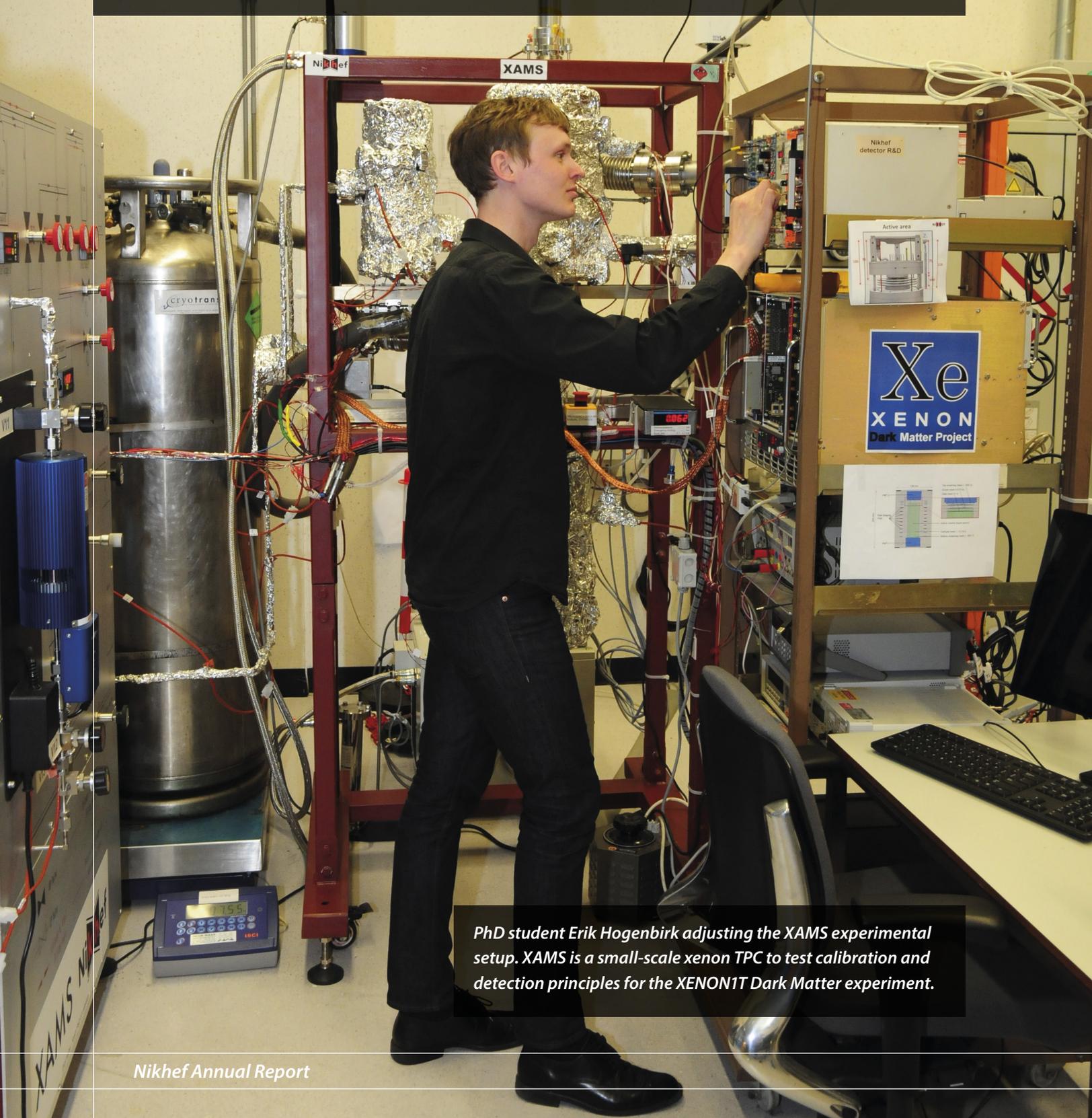
Cosmic ray composition from radio detection

The position in the atmosphere where the radio wave signal from extensive air showers is created is one-to-one correlated to the penetration depth of the shower in the atmosphere. This fact can be used in at least three different ways to determine the incoming cosmic ray mass composition. A curved shower front can be reconstructed, with a focal area that corresponds to the penetration depth of the air shower. The radio pulse duration for an observer is a measure for the distance and the projection angle of the emission area of the air shower. This duration, in the form of a spectral slope, can be used together with the knowledge of the distance of the observer from the air shower axis to estimate the penetration depth of the air shower. In a third method, it is used that the radio wave emission peaks in a Cherenkov cone around the air shower axis. By measuring the radius of this Cherenkov cone the emission region and thereby the penetration depth of the air shower can be estimated.

Nikhef plays the leading role in the latter two techniques, the pulse length and Cherenkov radius measurements. The pulse length method is published in Stefan Jansen's PhD thesis (2016) and the Cherenkov ring radius method is published in the PhD theses of Anna Nelles (2014) and Johannes Schulz (2016).

Figure 2 shows the measurement of the average penetration depth in grammage, X_{\max} , as a function of the measured energy of the air showers. The standard Auger surface detector reconstruction is used for the energy determination. The figure shows the published Auger fluorescence detector data points, together with Nikhef preliminary measurements from the surface detector and from the two methods in radio detection pioneered by Nikhef. The theoretical predictions vary considerably in absolute value between models. However, the slope of the average X_{\max} as a function of energy is always the same and the distance between the average X_{\max} for protons and iron is also very similar in the different models.

Detector Research & Development



PhD student Erik Hogenbirk adjusting the XAMS experimental setup. XAMS is a small-scale xenon TPC to test calibration and detection principles for the XENON1T Dark Matter experiment.

Enrico Schioppa shows the 2014 Jan Kluyver price in his research lab of the Detector R&D group.



Management
dr. N.A. van Bakel

Answering the biggest mysteries in physics requires pioneering experiments. New instrumentation ideas need to be initiated and developed long before they can be implemented in Nikhef's scientific experiments. In addition, today's push for knowledge transfer to industry leads to a diverse detector R&D programme. For years, detectors developed for particle physics find applications in various fields. Two examples are presented here.

Imaging with muons

High up in the Earth's atmosphere cosmic radiation creates an avalanche of secondary particles, bombarding the Earth's surface in high numbers with nearly the speed of light. Within such an avalanche C.D. Anderson discovered the muon in 1936. The muon is basically a heavy cousin of the electron. High energetic muons can penetrate far more deeply into matter than electrons and photons. The exact penetration depth depends on the energy of each individual muon and the material properties. A cosmic muon has an average energy (4 GeV in physics unit

of energy) and will be stopped by four meter of iron or 12 meter of rock. Less energetic muons will be stopped earlier and more energetic muons penetrate deeper.

Since the energy distribution and the muon flux reaching the Earth are known with high precision, one can determine the amount of material above a muon detector by measuring the decrease in flux. The idea is to use cosmic muons in combination with a smart detector topology, to image the interior of a steel furnace during production. In practice this means that we measure the muon flux along several lines-of-sight through the furnace with pairs of muon detectors (also see *Knowledge Transfer*). This way we compare the penetrated with the expected flux to quantify the amount of iron along a line-of-sight. By measuring with high statistics we get a detailed image of the iron-coke ratio inside the steel furnace. A quantity that is not known very accurately today.

Proton therapy

The number of people that survive up to five years after the diagnosis of cancer increases rapidly. Many of these survivors

suffer from (long-term) side effects of cancer treatment in general and more specifically from treatment with (conventional) radiotherapy. In the Netherlands the future of radiotherapy will include the use of proton beams. With protons the dose release can be targeted to a volume as small as a green pea, leading to dose reduction in healthy organs, glands or nerves surrounding the tumour. By preventing such collateral damage, the quality of life can be improved considerably. For head and neck cancer this may be the difference between losing or maintaining vision, speech and the ability to swallow. In some cases of breast cancer the risk of damage to the heart can be decreased significantly.

Els Koffeman (photo right) develops techniques, experimental methods and instruments that exploit and enhance the intrinsic benefits of the proton beam precision. Her work focusses on novel and more accurate imaging techniques: spectral CT scanning and proton radiography. Present imaging techniques are adequate but not dedicated for proton therapy and this opens the opportunity to conceive a genuinely new experimental approach with 'smart' pixel detectors. The goal is to extract data on the tissue composition of a patient with a fast scan that can be used during the course of proton treatment.

Given our expertise the R&D group aims to become a serious partner on different medical imaging techniques. For mammography we work with Andre Mischke and Utrecht Medical center, for proton radiography with Sytze Brandenburg in Groningen and others.

Els Koffeman lectures advances in medical imaging at the UvA/VU master program.



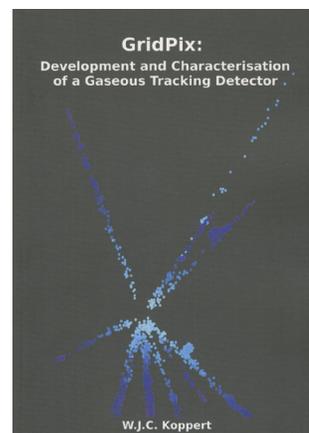
Highlights

Enrico Schioppa received the Jan Kluyver-prijs of 2014 in February 2015. Enrico did his PhD research within the Detector R&D-group and graduated in December 2014 with his thesis *"The Color of X-Rays"*. The Jan Kluyver-prijs for the best English summary of a Nikhef PhD thesis was established in 2010 by the Education Committee of the Research School for Subatomic Physics. The jury consists of the former directors of Nikhef.

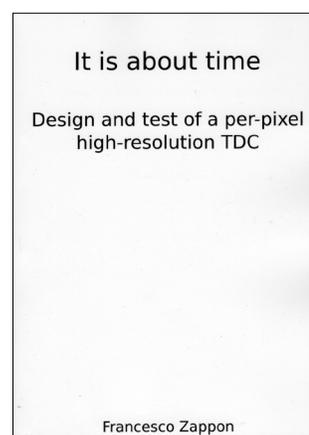
SENSEIS, Nikhef's first HTSM top-sector project together with Twente University started in 2015. Future Gravitational Wave detectors require the development of state-of-the-art seismic sensor networks for subtraction of so-called gravity gradient noise. SENSEIS will develop ultra-sensitive readout electronics for micro-electromechanical (MEMS) accelerometers in the low 1–100 Hz frequency band. The innovative integrated circuits and MEMS accelerometers will also find applications in consumer electronics and scientific instrumentation. Partners in this project are Shell, semiconductor multinational STMicroelectronics, and Nikhef's spin-off Innoseis.



Maria Bader with seismometers developed for the Virgo project.



Willem Jakobus Cornelis Koppert
13 January 2015



Francesco Zappon
5 June 2015

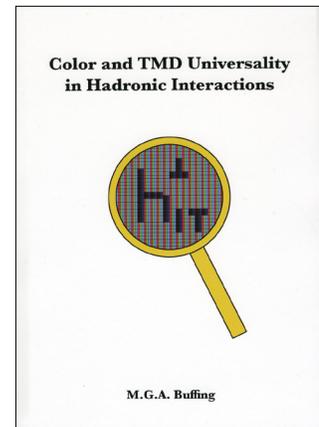
Theoretical Physics

improving predictions for LHC processes

The theoretical physics group at Nikhef pursues a broad spectrum of research, ranging from topics related to the Nikhef experimental programme to studies of a purely theoretical character. The research is mostly done in small collaborations, very often including colleagues from outside Nikhef, thereby ensuring a good exchange of knowledge, skills and ideas with the wider theoretical physics community.

Andrea Signori (left) and Sabrina Cotogno (right)

Martinus Gerardus Antonius Buffing
16 September 2015



Management
prof.dr. E. Laenen

Numerous projects completed this year can be categorized as improving predictions for LHC processes, in the sense of making them more accurate and realistic, and developing methods for this. A particular highlight this year was the calculation of the 3rd order (NNNLO) corrections to the Higgs boson production rate, by a team that included one of our postdocs (Herzog). This result, which quickly reached worldwide fame, enables more precise and therefore more meaningful comparison with LHC data. Another noteworthy result, featured on the cover of *Physical Review Letters*, is described in the insert.

In the physics of B-mesons, a joint study by Nikhef theorists and experimenters from the LHCb group explored the possibilities of high-precision analyses of CP violation in B-meson decays to D mesons, containing charm quarks, as probes of physics beyond the Standard Model. A special focus was put on the era of the Belle II e^+e^- super-B factory at KEK in Japan and the LHCb upgrade.

Another line of the research explored the intricacies related to the quantum mechanical description of gravity and of black holes. A particularly important tool here is supersymmetry, relating matter (fermions) and force (bosons). Black holes can be described using concepts from statistical physics, such as entropy. A number of projects in this area were completed in this year, including one where an alternative way to derive an expanding (so-called de Sitter) universe from string theory was shown.

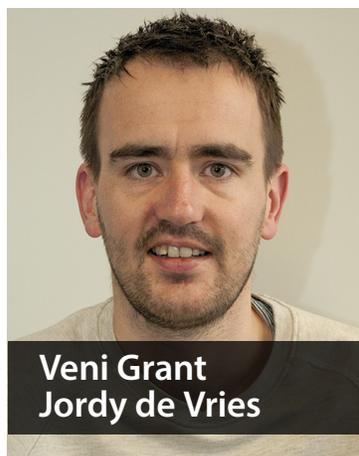
One particular theme in our cosmology research is the issue whether the Higgs boson could, in some way, have acted as the inflaton in the very early universe. Another is the nature and behaviour of Dark Matter; this year the possibility of strongly interacting Dark Matter, possibly even forming bound states, was investigated.



Vidi Grant
Kalliopi Petraki

Dark Matter is a mysterious substance that makes up most of the mass in our universe. Its gravity made it possible for galaxies to form, and host stars and planets like our own. By careful observation of galaxies, new research will try to infer what Dark Matter consists of and how it interacts.

Kalliopi Petraki was awarded a Vidi grant for her proposal *“Deciphering the Dark Matter code”*. The Vidi grants are aimed at young excellent researchers with several years of successful postdoctoral research experience to start their own research groups.



Veni Grant
Jordy de Vries

There are strong indications that our universe partly exists of Dark Matter. This research will develop novel theoretical methods to describe collisions of Dark Matter and atom nuclei. The goal is to unravel the mysterious nature of Dark Matter.



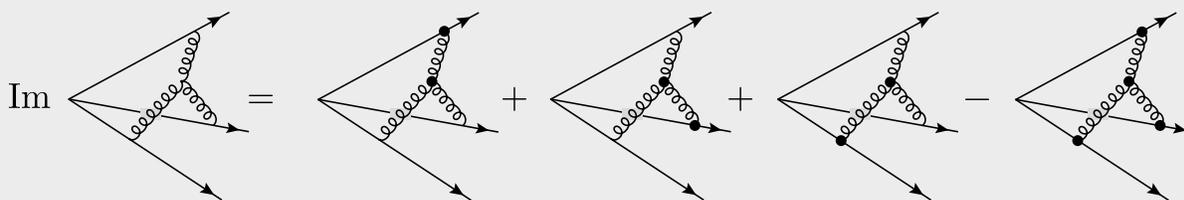
Veni Grant
Lisa Zeune

What is our universe made of? What is Dark Matter? The Large Hadron Collider will answer these questions by searching for new physics. This is only possible through realistic and accurate theoretical predictions for new physics processes. They are the objectives of the project.

Jordy de Vries and **Lisa Zeune** each received a Veni grant for the proposals *“Heart of Darkness: How to unravel the nature of Dark Matter”* and *“Towards realistic predictions for new physics searches at the LHC”* respectively. The Veni grant offers researchers who have only recently completed their doctorates the opportunity to develop their ideas during three years.

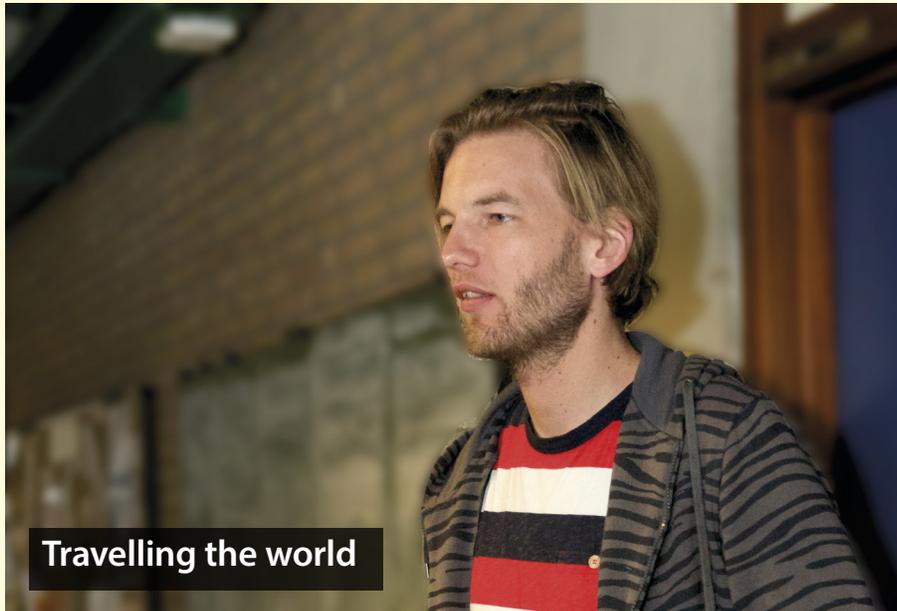
Efficient calculation method for particle collisions

Group members came up with a new method to efficiently compute relevant information about particle collisions. Collisions between elementary particles, such as those occurring at the Large Hadron Collider in Geneva, are tremendously complicated events. Predicting the outcome of such collisions accurately requires likewise highly involved calculations. To simplify their task, physicists use ‘eikonal’ Feynman diagrams. Such diagrams represent a simplified version of a collision, but still retain its essential information.



An example where the imaginary part is calculated via the new method.

The project focussed on the mathematical imaginary parts of the eikonal diagrams. These are important for phase differences in LHC collisions, as well as for a number of theoretical issues. Their method involves ‘cutting’ the diagrams into simpler pieces and subsequently extracting the relevant information from the constituents. A remarkable feature of the method is that it is very systematic, allowing it to be applied to a large variety of eikonal Feynman diagrams.



Sander Mooij
Nikhef alumnus,
PhD 24 September 2013

By Laetis Kuipers

When I completed my dissertation on effective theories in cosmology," says Sander, "I definitely wished to continue my work in this field and felt that the world lay at my feet. You see, for my research I have always been in a position to travel the globe. This is one of the many exciting opportunities that Nikhef offers to all its PhD candidates, and I had certainly jumped at it. It literally gave me the chance to broaden my horizons and expand my scope, and it gave me exactly the type of orientation that I needed to apply for an international post-doc position. And thanks to all my travels and the papers I authored or co-authored, I was able to build a considerable professional network to assist me on my quest."

"When I started to look for a new position, I decided to give it my best shot. Believe it or not, but I wrote as many as one hundred and one application letters, which resulted in firm offers from research institutions in Chile, Hong Kong and South Africa. I found myself a bit spoiled for choice, to be honest, but I opted for the Group of Cosmology and Theoretical Astrophysics at the University of Chile, a group led by a fellow physicist who had completed his post-doc studies in Leiden. I currently work on cosmological perturbation theory and on inflationary models in which the Higgs field is responsible for inflation. Chile is a fascinating

country, which is an additional benefit, and Spanish proved to be much easier to learn than Chinese ..."

"Luckily, I am still in a position to travel the world and stay in touch with my network. I do this by visiting people and pro-actively communicating my research. All of my past and present activities have increasingly enabled me to become the master of my own fate, so to speak. And I find that making subsequent moves has become easier. I still have one exciting year left in Chile, but I have already landed my next dream job in Lausanne, Switzerland. This time I only needed to write ten application letters, and I recently spent a week at the institute to learn more about its work and to meet my future colleagues. I still have a long way to go before I can get a permanent job in this field, but doing a PhD at Nikhef has certainly given me a perfect position to enter the academic job market."



We stress-test the Standard Model to find new physics, using the spin of the top quark. It combines a very accurate measurement of spin-dependent top quark decay patterns using new LHC run 2 ATLAS data with state-of-the-art theory predictions including higher order corrections due to quantum chromodynamics, to reliably identify small deviations from the Standard Model. The single-top quark production process used, provides a spin-polarised sample of top quarks. The outcome of our test, whatever it will be, will be highly interesting.

A FOM-*'projectruimte'* was granted to **Eric Laenen** together with **Marcel Vreeswijk** of the Nikhef ATLAS group for their (combined experimental and theoretical) proposal *"Top Spin"*.

The European Research Council (ERC) has awarded a prestigious Starting Grant to **Wouter Waalewijn** for his proposal *"MULTISCALE: Precision Multi-Scale Predictions for the LHC: Higgs, Jets and Supersymmetry"*. An ERC Starting Grant is a personal grant of about 1.5 million euros and provides research support to talented researchers for a period of five years.



The project's goal is to improve the theoretical description of collisions at the Large Hadron Collider (LHC). To find a faint new physics signal, precise descriptions as well as sophisticated experimental techniques are needed.

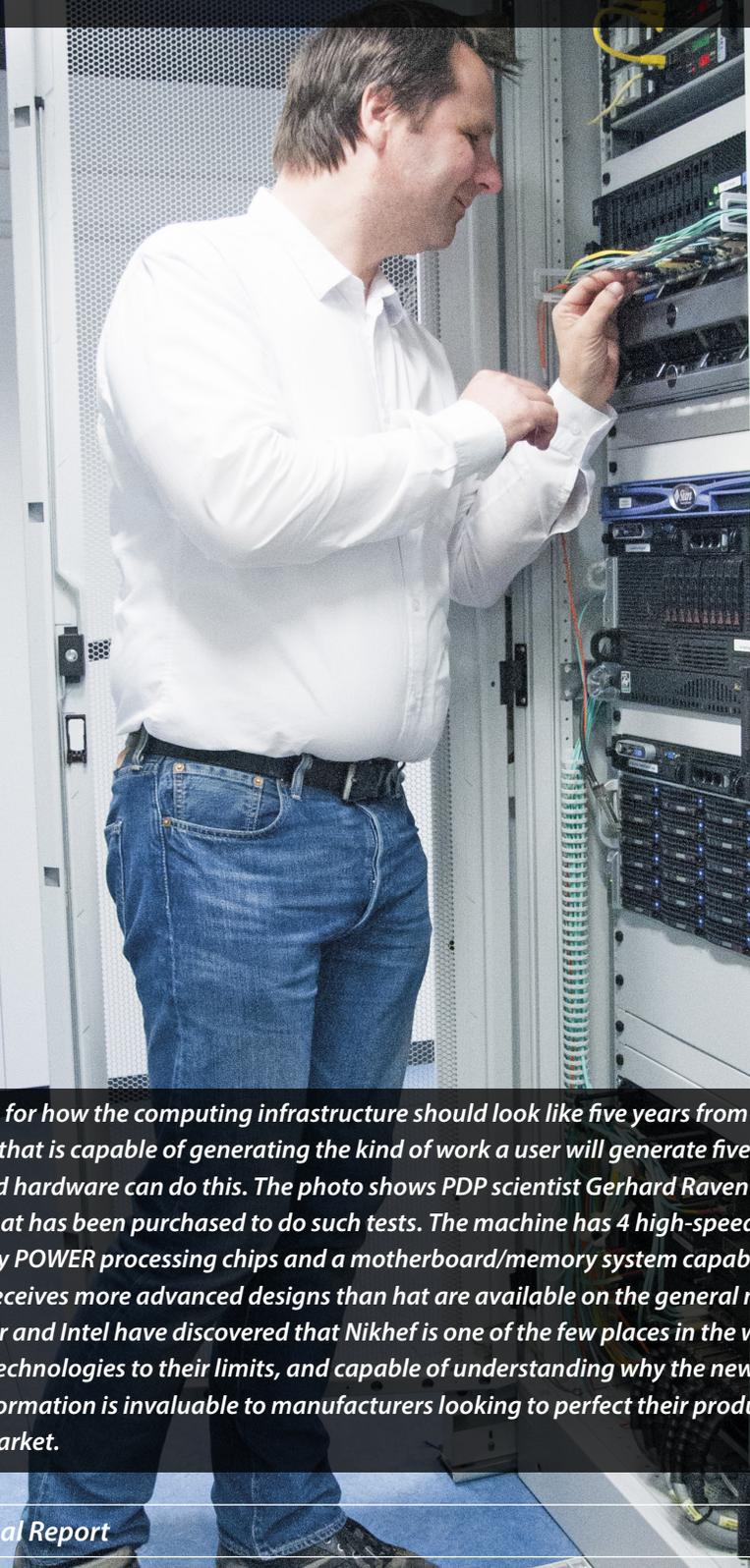


JosFest

On 3 July a conference was organized for Jos Vermaseren, the JosFest, on the occasion of his 66th birthday. Many colleagues and friends of Jos came from all over the world, some from as far as Japan. It showed their deep appreciation of and regard for Jos' achievements in physics, and of course for his world-renowned computer algebra program FORM. One participant thanked Jos *"for empowering a whole scientific community with unique tools, and pushing the boundary of complexity and feasibility"*. Jos himself was very grateful for so many of his friends and colleagues showing up, and quipped *"I could easily do this every year"*.

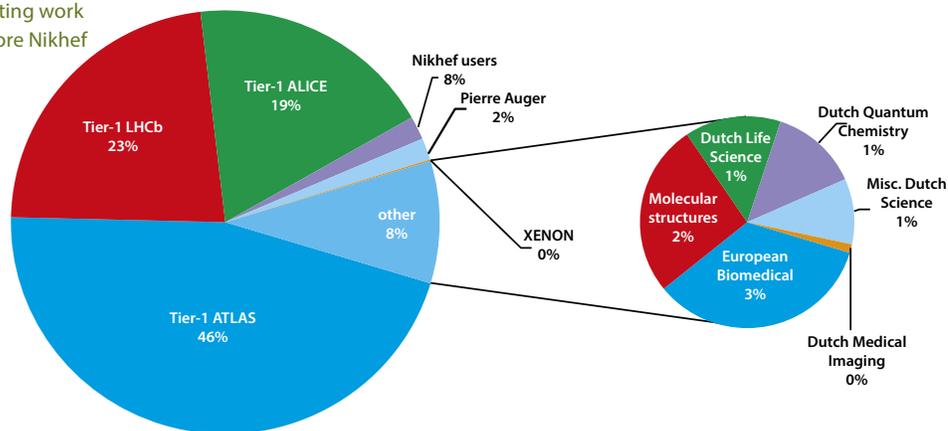
Physics Data Processing

advanced computing for physics and other sciences



To test designs for how the computing infrastructure should look like five years from now, we need test hardware that is capable of generating the kind of work a user will generate five years from now. Only the most advanced hardware can do this. The photo shows PDP scientist Gerhard Raven with a new test machine, "achtbaan", that has been purchased to do such tests. The machine has 4 high-speed network connections, each backed by POWER processing chips and a motherboard/memory system capable of high throughput. Nikhef often receives more advanced designs than hat are available on the general market; manufacturers such as Juniper and Intel have discovered that Nikhef is one of the few places in the world capable of pushing new technologies to their limits, and capable of understanding why the new technology might have failed. This information is invaluable to manufacturers looking to perfect their products before they hit the commercial market.

Figure 1. Breakdown of all computing work performed in 2015 on the 4500-core Nikhef Data Processing Facility.



Management
dr. J. Templon

For the PDP group, 2015 was a year of Research and Development. Our computing infrastructure was actively used by researchers at Nikhef, within the Netherlands, and worldwide in pursuit of a wide range of scientific goals. The Research and Development work done addressed challenges to be faced in the coming five years. These challenges stem from the large increases in data volume and complexity at the LHC and other experiments, and from changes in the technology behind large-scale scientific computing.

Computing Infrastructures

The PDP group operates two major computing infrastructures. For in-house users we operate the 'stoomboot' cluster which currently consists of about 800 cores of processing power, backed by 185 terabytes of fast storage. For the Dutch National infrastructure we operate the Nikhef Data Processing Facility (NDPF) containing about 4,500 cores of processing power and around two petabytes of fast storage, the storage and processing being connected by 300 gigabit-per-second internal network, this high bandwidth needed to

prevent cores from idling while waiting for data.

The facility runs largely unattended, thanks to a significant investment we made in monitoring and automated problem resolution several years ago. The computing cluster typically runs at 96% capacity. The major part of the NDPF is part of the Netherlands LHC Tier-1 centre provided by the Dutch National infrastructure and co-operated by Nikhef and SURFsara. As a result close to 90% of the computing work done is for the LHC experiments; the other 10% comes from a wide range of scientific activities pursued on the Dutch National infrastructure, mostly outside of high-energy physics (see Fig. 1).

R & D on large-scale computing

Run 2 of the LHC started in 2015, marking the start of a ramp-up period to new levels of data flow, storage space, and processing power needs for the LHC experiments. Run 2 will continue until 2019, after which run 3 will start in 2021. While run 2 can be seen as extending the current large-scale computing paradigms into challenging new

territory, it is not clear these paradigms will work for the computing needs generated by the run 3 data. R&D is needed for both the short- and long-term challenges.

Our group gave priority in 2015 to research on cloud technologies and next-generation networking. Cloud technologies provide increased flexibility both to the scientific user groups as well as to the teams operating and funding the infrastructures. As a simple example, cloud technologies will be used to unify our 'stoomboot' and 'NDPF' infrastructures, allowing us to easily move computing power between the two systems according to the demands and priorities. Advanced networking is needed partly in order to deal with the cloud technologies, as different parts of one cloud (stoomboot and NDPF above) will need to be in different networks. The other reason to work on

networks is purely to be able to handle the wide-area and local-area data rates needed to deal with LHC run 3 data as well as the data from other projects in which the Dutch National infrastructure is involved, like the Square Kilometer Array (SKA).

Developments on Collaboration Technologies

Most of the large-scale distributed computing frameworks are based on the use of 'certificates' similar to those used to identify web sites to web browsers (the green padlock icon in a browser address bar). Our frameworks required its users, the scientists, to also possess and use certificates. Nikhef staff work on new software and frameworks that avoid the need for user certificates, as the burden of securely managing a certificate was seen by most users as a significant barrier to using our infrastructures. The technology is similar to what is behind the button "log on with Facebook" on many web sites; for us it would be "start your data analysis on the Cloud using your Nikhef password".

The Nikhef Data Processing Facility.



Technical Departments

The technical departments play an essential role in producing parts for detectors, in getting them ready for taking data, in preparing designs for future experiments and in offering good experimental conditions for the researchers at Nikhef. Below a summary is given of activities of the three technical departments in 2015.

| | Highlights | New techniques and expertise |
|-------------------------------|---|--|
| <i>Mechanical Technology</i> | <ul style="list-style-type: none"> • Start of KM3NeT line production and deployment • Virgo and Xenon both installed • VELO box milling to 0.5 mm Al completed • Organization of Forum on Tracking Detector Mechanics | <ul style="list-style-type: none"> • Transition to Siemens NX CAD software and Teamcenter PLM • 3D Measuring table for ALICE ladder production • Cleanroom preparation for LHCb SciFi production |
| <i>Electronics Technology</i> | <ul style="list-style-type: none"> • Deployment of first line KM3NeT with optical network, CLB readout and White Rabbit ns timing • Demonstration of ATLAS Felix DAQ • VELO-GWT 5.12 Gbps serializer chip design • LHCb SciFi DAQ board finished, with CERN GBT links | <ul style="list-style-type: none"> • Start with 65 nm chip technology • Chip development in cooperation with SRON • Full outsourcing of firmware: ATLAS Rasnik frame grabber • FPGA firmware for ATLAS Felix DAQ published in Open Source: bug reporting and software porting by external users as result! |
| <i>Computer Technology</i> | <ul style="list-style-type: none"> • White Rabbit demonstration in KM3NeT • Streamlining of ICT services behind the scenes | <ul style="list-style-type: none"> • 100 Gbit/s connection to SURFnet • Partnership in CAD software selection |

Forum on Tracking Detector Mechanics 2015
<http://forum2015.nikhef.nl>
15 - 17 June 2015
 Amsterdam Science Park

TOPICS

- Mechanical design, advanced materials and construction technologies
- Thermal management, cooling and bake-out
- Humidity control, monitoring and sealing
- Installation, integration, disassembly and transportation
- Stability, alignment and adjustment systems
- Quality control, failure and service management
- Radiation effects on materials and handling of irradiated structures
- Structural and vibration analyses

Organising Committee
 Frank Raphael Cadoux, Andrea Catnaccio, Massimiliano Ferro-Luzzi, Corrado Gargiulo, Claire Gibon, Sebastien Michal, Andreas Mussgiller, Antti Onnela, Paolo Petagna, Hans Postema, Burkhard Schmidt, Paola Tropea, Bart Verlaet, Georg Vrehhauser, Patrick Werneke

Local Organising Committee
 Eric Hennes, Kees Huyser, Macro Kraan, Bart Verlaet, Rob Walet, Patrick Werneke
 Secretary: Joan Berger (jberger@nikhef.nl)

Nikhef

Graphic Design: Carolina Deluca © 2015 - carolina.berberg@gmail.com

From 15 June to 17 June, the Forum on Tracking Detector Mechanics was hosted in Amsterdam by the Mechanical Technology Department. The poster was designed by ex-Nikhef postdoc Carolina Deluca.

Awards & Grants

FOM Valorisation Prize 2015 for Jo van den Brand

Jo van den Brand, programme leader of the Nikhef Gravitational Physics group, is the winner of the FOM Valorisation Prize 2015. He receives the prize for *“his efforts to valorise the very fundamental knowledge and expertise that emerges from his research within subatomic physics”*. The aim of the FOM Valorisation Prize is to encourage the utilisation of knowledge from physics research. Each year FOM awards the prize of 250 k€ to a Dutch researcher (or group of researchers) in physics who has succeeded in making the results from his or her own research useful for society.



Jet Bussemaker, Minister for Education, Culture and Science, presents Jo van den Brand the FOM Valorisation Prize 2015 at the FOM@Veldhoven conference.

IXA Proof of Concept grant for Innoseis

Nikhef spin-off company **Innoseis** received a Proof of Concept grant worth 100 k€ from IXA, the Amsterdam Innovation Exchange. Innoseis develops sensor technology to search for energy resources and plans to use this funding to demonstrate the feasibility of advanced communications protocols for its TremorNet seismic sensing system. IXA awards Proof of Concept grants to promising young technology companies to enable them to undertake technical feasibility studies for their concept, invention or idea.



**UvA Grassroot
Marcel Vreeswijk**

Marcel Vreeswijk giving a lecture with the aid of a tablet.

UvA Grassroot grant for Marcel Vreeswijk

Marcel Vreeswijk received a grant of 10 k€ in the framework of the UvA Grassroot programme. In his proposed project *“Van het Krijt naar het Tablet-tijdperk”*, a group of teachers will develop an accessible wireless and chalk-free approach for giving lectures in science education. The focus is on the completely wireless use of drawing tablets and multi-beaming technology.

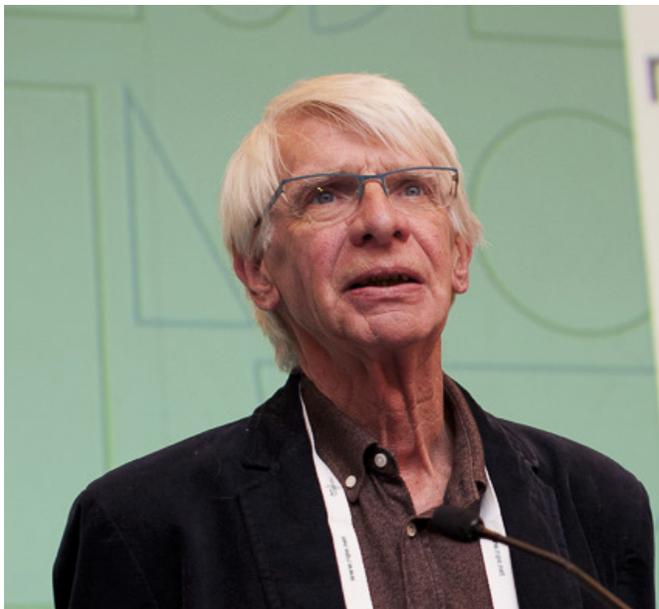
The UvA Grassroot programme funds small-scale, accessible ICT projects, from which the results immediately can be implemented in education. ‘Grassroots’ are a great example of introducing and testing new techniques in education.

Nikhef one of the nodes of new European COST Network

A new COST Network was approved under the name of *“Connecting insights in fundamental physics”*, with **Nikhef** being one of the nodes. COST (European Cooperation in Science and Technology) is the longest-running European framework supporting trans-national cooperation among researchers, engineers and scholars across Europe. This new COST Network provides a platform to exploit the latest experimental results not only from the LHC, but also from a host of new facilities, while at the same time using the insights gained to inform and guide theoretical endeavours. Nikhef scientists can get reimbursed for travel expenses via this network’s funding.

Prestigious Snellius Medal for Dutch ATLAS group

The 'Genootschap ter Bevordering van Natuur-, Genees- en Heelkunde' (Society for the Promotion of Physics, Medicine and Surgery) from the University of Amsterdam has awarded the Snellius Medal 2015 to the Dutch ATLAS group. The researchers received the medal, which is awarded only once every ten years, for their contribution to the research that led to the discovery of the Higgs particle. By this, the Society wants to give recognition specifically for the Dutch contribution which has been made by Nikhef researchers. The medal was presented on 21 November during a Symposium marking the 225th anniversary of the Society.



Rob Blokzijl, a former Nikhef physicist and computer scientist who sadly passed away in December 2015, had been awarded with the Jonathan B. Postel Service Award 2015 by the Internet Society only a few months before. Blokzijl received the prestigious award for *“his pioneering work, 25 years of leadership at Réseaux IP Européens (RIPE), and for enabling countless others to spread the Internet across Europe and beyond”*.



Knowledge Transfer

Frank Linde at a steel company, where an experiment to analyse the homogeneity of liquid-steel-filled vessels by muon radiography was carried out.

Valorisation & Spin-off Activities

This year was another exciting year for ASI and Omics2image (an ASI company) that has resulted in an even clearer focus on the company's vision, path and value to customers. In the past four years since the company was founded its imaging technology platform for the next generation radiation cameras, based on the Medipix chip and its derivatives, demonstrated an increased impact in the field of Life Sciences. The implementation in the area of Mass Spectrometry and Electron Microscopy has shown some great results that have increased the interest from around the globe and resulted in several new customers. This has resulted in a substantial growth of the top line in 2015, with an even better outlook for 2016.

Since the summer of 2015, ASI has also opened up an office and lab facilities at the Maastricht Health Campus. These facilities offer users access to ASI's advanced imaging technology implemented in mass spectrometry and electron microscopy systems.

The focus has been on expanding sales channels and opportunities beyond the scientific market. ASI has agreements in place with a number of resellers in China, Japan, Russia and India. ASI has also established strong relationships with multinational scientific equipment companies and partners that will integrate ASI's core technology in a total solution for their customers. These relationships demonstrate the added value of ASI in collaborative projects together with academic and industrial partners.

Innoseis, Nikhef's gravitational wave detection spin-off, has achieved a milestone by producing the first batch of 200 ultra low power seismic sensors, of which 100 will be delivered to Shell. Innoseis is also involved in another project: field testing seismic nodes in the realm of perimeter monitoring, involving *a.o.* the Dutch police, starting in 2016. Another highlight has been that Jo van den Brand, Nikhef staff member and one of the founders of Innoseis, has won the prestigious FOM Valorisation Prize.

The CERN-Business Incubation Center at Nikhef has received one Expression of Interest in 2015. This regarded the plans for establishing a company (working title '*Particle Toys*') for selling products serving outreach purposes in subatomic physics, such as a muon lifetime measurement setup and a 'do-it-yourself' interferometer. No company has yet been established. First the viability of the idea is now tested with selling a small series of products at exhibitions and conferences.

Furthermore, Nikhef has been involved in a project with a steel producing company, evaluating the viability of muon radiography for the analysis of the homogeneity of large vessels with (liquid) steel. A follow-up project is being negotiated. Also, Nikhef has completed a short feasibility study for another Dutch company, regarding the use of the RASNIK alignment system.

Finally, Nikhef's datacenter activities (in particular for customers of the Amsterdam Internet Exchange, AMS-IX) have further grown, reaching over 3 M€ turnover in 2015. Likewise, our position as provider in the national e-infrastructure, coordinated by SURF, has been consolidated.



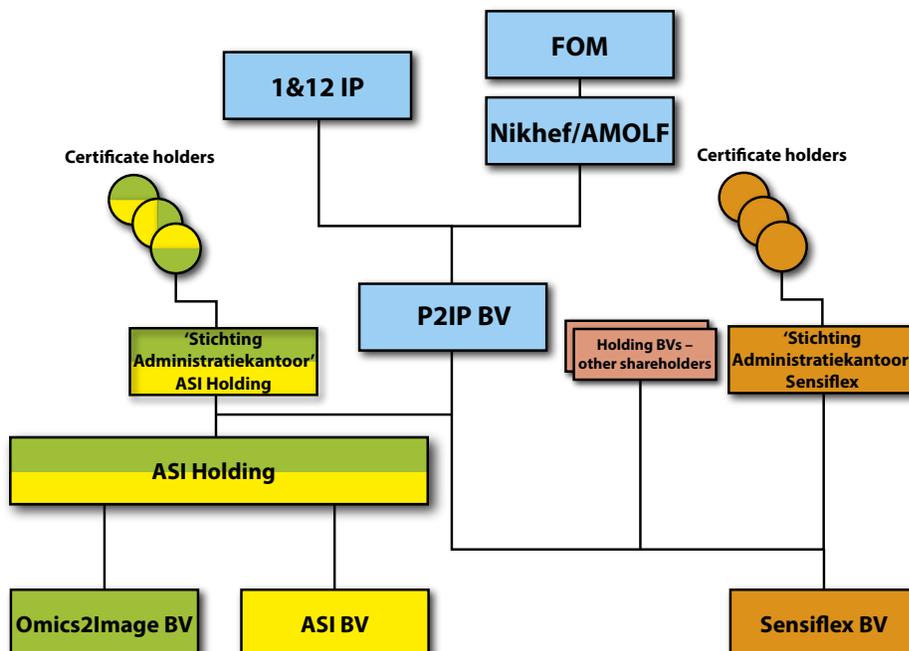
SENSIFLEX



INNOSEIS



amsix
amsterdam
internet exchange



The current legal structure of Nikhef's start-ups.

Education

Inspiring and training the next generation

The excitement of the research carried out at Nikhef can enthuse young people and help attract students into science and technology subjects. In turn, the skills acquired during physics education are highly in demand in the labour market, in particular in the high-tech and IT industry.

Nikhef recognises these unique opportunities and puts great effort into inspiring and training the next generation of young scientists. From various programmes for secondary school students and their teachers, to the education of master and PhD students, Nikhef considers these an integral part of its activities to benefit society.

Programmes for secondary school students

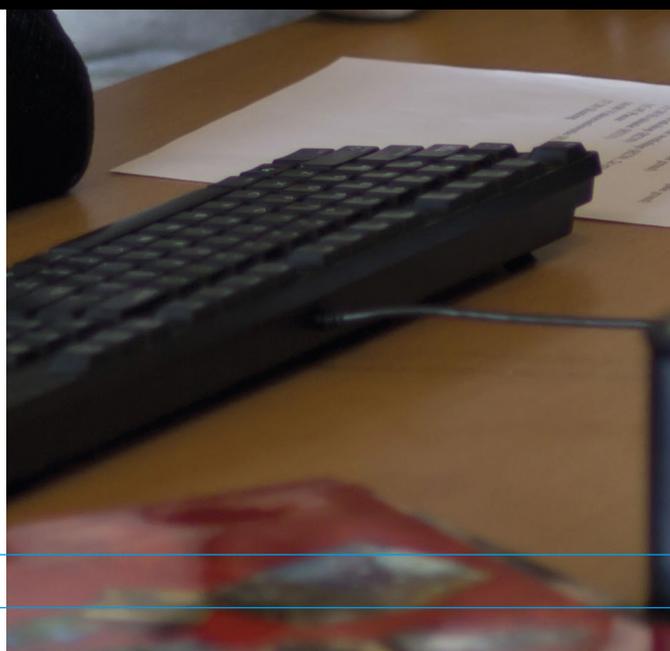
Nikhef offers secondary school students many opportunities to get introduced to particle and astroparticle physics. In 2015, again many school groups with in total about 300 students visited Nikhef for an afternoon programme of a lecture, film and guided tour. Eighteen secondary school students were helped by Nikhef scientists to carry out their '*profielwerkstuk*' (research project). The one-day



International Masterclasses on Particle Physics, held at Nikhef in Amsterdam and Nijmegen every year, attracted nearly 80 students.

Trainings for teachers

Nikhef also invites teachers to refresh and deepen their knowledge of particle and astroparticle physics. The aim of this programme is twofold. On the one hand it offers teachers the opportunity to experience state-of-the-art research themselves. On the other hand by motivating teachers their enthusiasm is passed on to their students as well. In 2015, 20 teachers got the chance to come to know CERN first hand during the annual four day Dutch CERN Teachers programme organised by CERN and Nikhef. Five teachers



participated in the teacher-in-research programme (*'Leraar in Onderzoek'*) in the academic year 2014/2015, which was made possible by FOM and Nikhef. Two additional positions were funded with contributions from the *'Sectorplan Natuur- en Scheikunde'*. Nikhef also collaborated with the Its Academy to organise a teachers course on particle physics consisting of six evenings that was attended by 32 teachers. Furthermore, a networking meeting of Its Academy's *'vaksteunpunt natuurkunde'* (section Physics) was organised at Nikhef, focussing on particle and astroparticle physics, supported by hands-on experiments.

Master's programme at Nikhef

All four partner 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 and astroparticle physics. These lectures include: a solid introduction to the Standard Model, including Higgs physics, physics beyond the Standard Model, cosmology, field theory, general relativity, CP violation, gravitational waves etc., as well

various European countries. A total of 26 students graduated in 2015.

Research School Subatomic Physics

All PhD students at Nikhef receive academic training through the Research School Subatomic Physics (*'Onderzoeksschool Subatomaire Fysica'*, OSAF). In 2015, 20 students from OSAF obtained their PhD degrees, while 12 new students started their PhD. A total of 101 students were registered with the school.

OSAF organised three topical lecture series in 2015 on *'Cosmic Rays'*, *'Kinetic Theory - Hydrodynamics and AdS/CFT to Model Heavy-Ion Collisions'*, and *'Neutrino Physics'*. The annual BND summer school (Belgium, the Netherlands, Germany) was held in Germany and was attended by 62 participants.

HiSPARC

Since 2003, the High School Project on Astrophysics Research with Cosmics (HiSPARC) offers high-school

students and teachers a chance to participate in a modern, large-scale scientific experiment. Schools take part in the project by hosting one or more cosmic-ray detection stations on the roof of their building. Their students work together in building and installing the measurement device for detecting high-energy cosmic rays. Data is collected and stored around the clock in a central

as advanced experimental methods like statistical data analysis, particle detection, detector R&D and a C++ course.

The various aspects of experimental particle physics are combined in a semester-long project, and this year a water Cherenkov detector, based on the KM3NeT multi-PMTs, was built and tested in a lake in Minnesota, USA. During their second year the students work on their own research project in one of the physics groups at Nikhef. In 2015 more than 20 new students enrolled in the first year of the Master's programme, among them students from

database at Nikhef, while access to the data for analysis is granted via a public web interface. This facilitates students to carry out their own research with data from their own or from any other station in the network. A sizable series of *'profielwerkstukken'* has been published over the years. In 2015, the HiSPARC detector network is still expanding with more than 120 stations throughout the Netherlands. Abroad, the HiSPARC network has clusters in Aarhus, Denmark and the cities of Birmingham, Durham, Bristol (and nearby villages) in the UK.



Outreach & Communications

Open Day Nikhef yet again a very popular event

On 3 October, hundreds of people attended the annual Open Day at Nikhef. Visitors enjoyed demonstrations and listened to short lectures on various interesting topics such as neutrino and Dark Matter research. Children took part in a treasure hunt for particles and constructed their own electronic gadgets or Meccano models. Nikhef researchers were happy to answer any question about their research, all in the framework of the '*Nationale Wetenschapsagenda*' (National Research Agenda), for which Nikhef had registered this event.

The Open Day is organized annually together with the other institutes, universities and companies at Amsterdam Science Park as part of the '*Weekend van de Wetenschap*' (Weekend of Science).

Nikhef researchers give lectures at many outreach events

Nikhef researchers André Mischke (ALICE), Ivo van Vulpen (ATLAS) and Aart Heijboer (KM3NeT) gave lectures at *Bessensap*. This annual event is organised by NWO and VWN (*Vereniging voor Wetenschapsjournalistiek en –communicatie Nederland*, Association of Science Journalism and Communication Netherlands). Themed "*science meets the press*", it brings together hundreds of science journalists, science communicators and researchers.



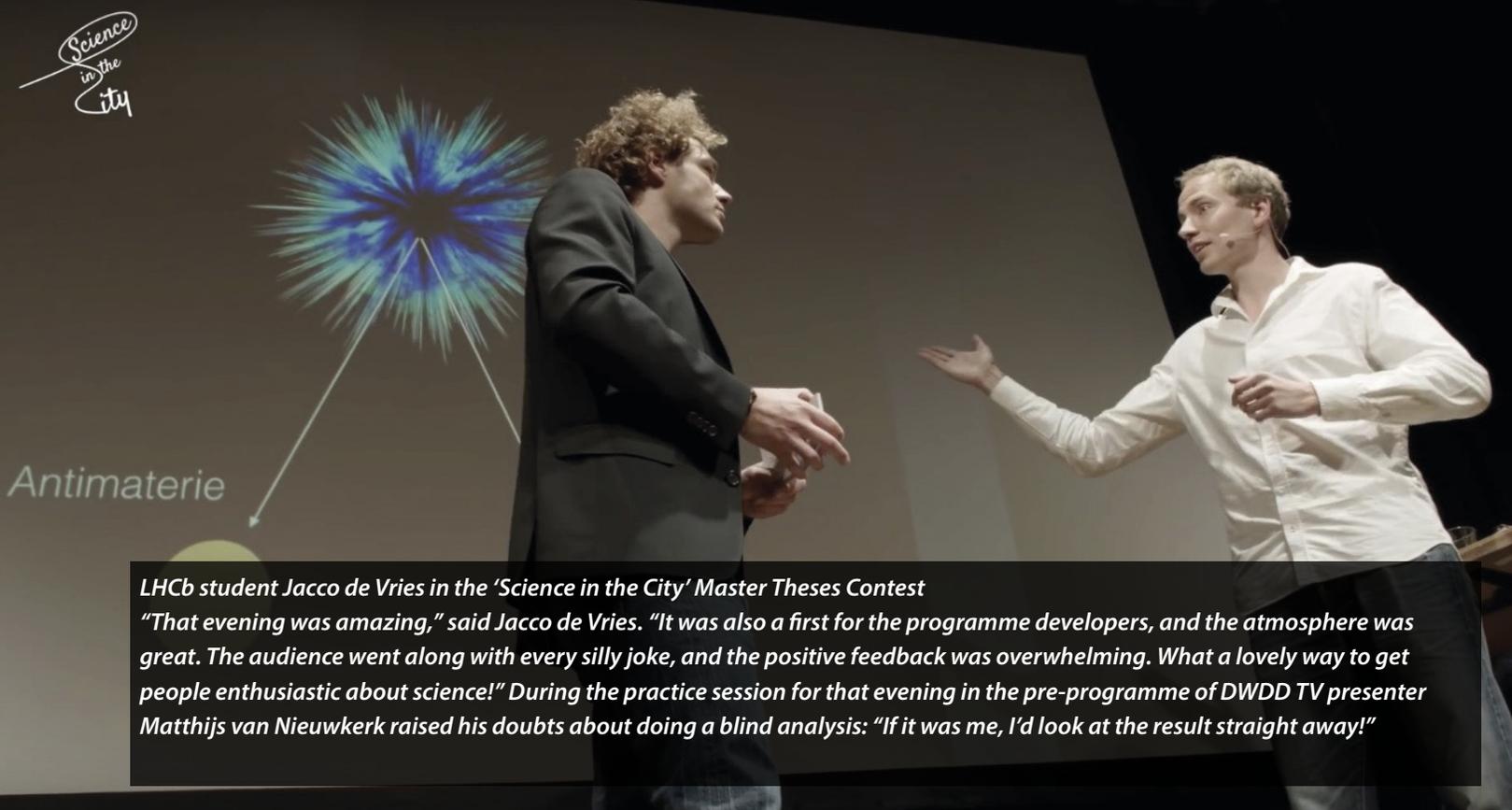
Children experimenting with the 'candy growing machine' at the Open Day.

Ivo van Vulpen spoke at the '*Gala van de Wetenschap*' (Gala of Science) in the '*Stadsschouwburg Amsterdam*' (City Theater Amsterdam). At this festive event top researchers from the Netherlands and Belgium gave insight into remarkable and promising developments in their area of research. The '*Gala van de Wetenschap*' is an initiative of magazine *New Scientist*, newspaper *Het Parool*, *Folia* and the *Stadsschouwburg Amsterdam*.

Laura van der Schaaf appeared in a *KIJK Live!* event to explain gravitational waves, and the experiments set up to detect them. In the *KIJK Live!* events, organised by the science magazine *KIJK*, speakers from the field of science and technology tell about their research in a casual setting with ample opportunity for interactions with the audience.



Laura van der Schaaf lecturing at *Kijk Live!* about gravitational waves.



LHCb student *Jacco de Vries* in the 'Science in the City' Master Theses Contest

"That evening was amazing," said Jacco de Vries. "It was also a first for the programme developers, and the atmosphere was great. The audience went along with every silly joke, and the positive feedback was overwhelming. What a lovely way to get people enthusiastic about science!" During the practice session for that evening in the pre-programme of DWDD TV presenter Matthijs van Nieuwkerk raised his doubts about doing a blind analysis: "If it was me, I'd look at the result straight away!"



Nikhef researcher Ivo van Vulpen was one of the speakers at *Bessensap*, where science journalist George van Hal tweeted "What a fine speaker is @lvovanVulpen. Now a great story about 'that crazy gravity' #bsap15".

For a full list of outreach talks please refer to the Appendix of the Annual Report on the Nikhef website.

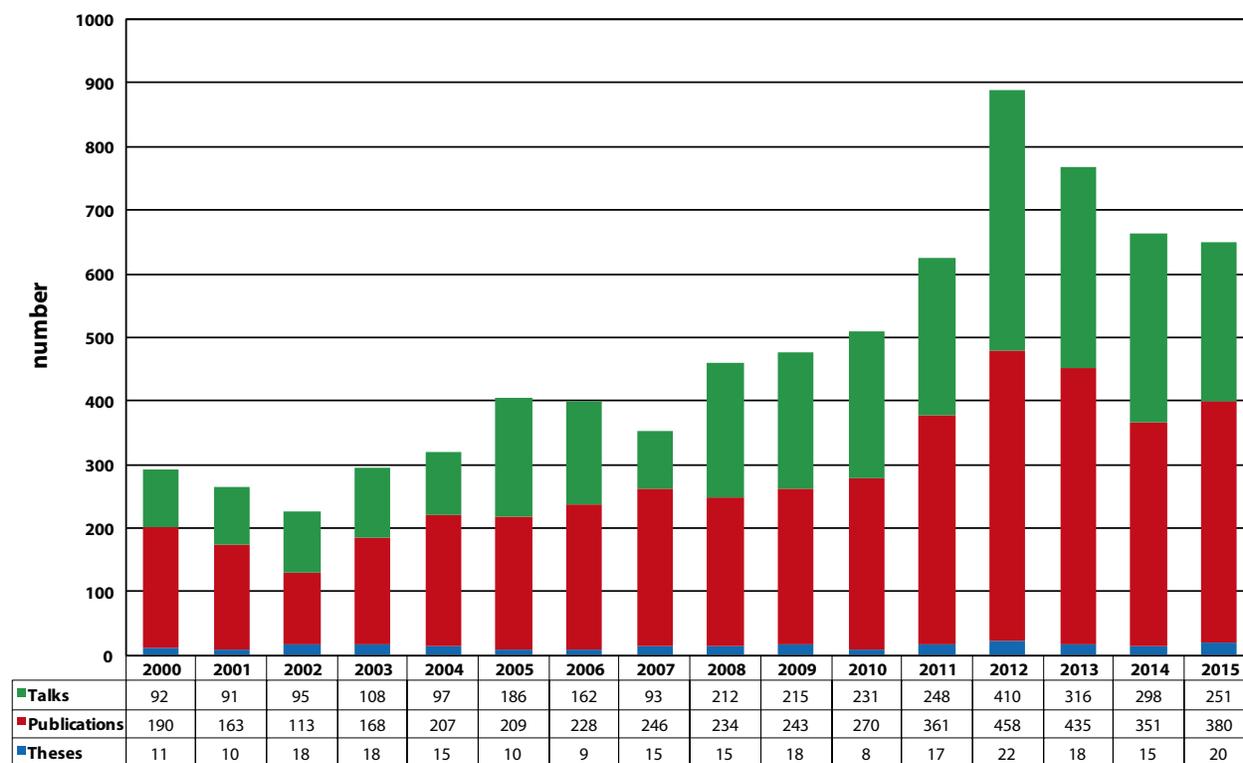
Nikhef & the media

Nikhef invests in good relations with various media. By providing the media with expert views on new research results and current developments, Nikhef strives to serve as a trusted, accurate and open source of information about particle and astroparticle physics. Nikhef informs the media by means of full press releases sent out to journalists as well as shorter news items published on the Nikhef website and distributed via social media. Where possible, Nikhef also invites journalists to visit research facilities, and organises press events in case of scientific discoveries.

In 2015, there was broad media coverage of the LHC restart at higher energies and of the first promising research results from the new data. A lot of attention was also given to the upgrading and opening of new astroparticle physics experiments, bringing them ever closer to the potential discovery of exciting new physics.

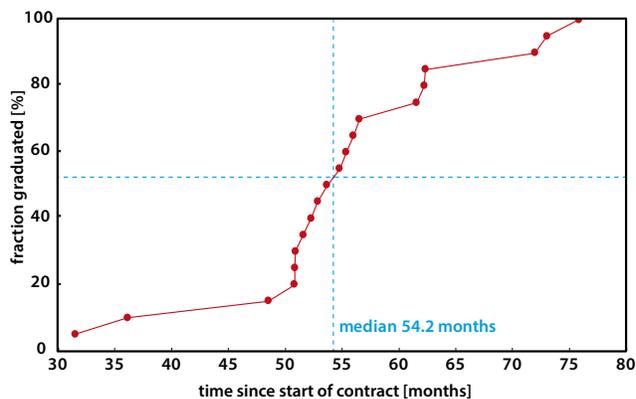
Output

The scientific output of the institute can be measured in the number of publications, talks and even more important, in the number of PhD theses. In the output we see fluctuations in time depending on whether accelerators were active and experiments took data. The Large Hadron Collider (LHC) started delivering physics data again on 3 June 2015 for the first time in 27 months. After an almost two year shutdown and several months re-commissioning, the LHC is now able to provide collisions to all of its experiments at the unprecedented energy of 13 TeV, almost double the collision energy of its first run, thereby opening new windows of discovery.

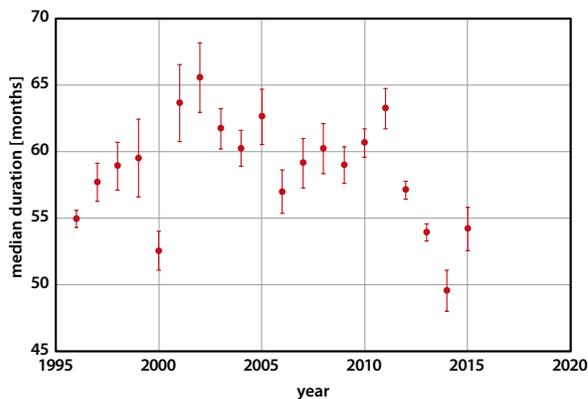


Nikhef's scientific output in the last 16 years. See also online Appendix.

Also in the PhD duration we see yearly fluctuations, depending on the above mentioned experimental conditions, but also depending on the collaborations' internal policies for analysis and publication. Outliers in the frequency distribution sometimes have to do with the difficulty of finishing a thesis when already in a new job.



Fraction of PhD students working at Nikhef that graduated in the year 2015 as a function of time since the start of their thesis contract. The median PhD duration is 54.2 months.



Median PhD duration of Nikhef PhD students since 1996 as a function of graduation year. The error bars represent the median absolute deviation (MAD)/ $\sqrt{(n-1)}$.

PhD Theses

Stef Marten Johan Janssens

Stabilisation and precision pointing quadrupole magnets in the Compact Linear Collider (CLC)

Universiteit van Amsterdam, 14 January 2015

Promotores: J.F.J. van den Brand, F. Linde, Copromotor: A. Bertolini

Willem Jakobus Cornelis Koppert

GridPix: Development and characterisation of a Gaseous Tracking Detector

Universiteit van Amsterdam, 13 January 2015

Promotores: F. Linde, N.P. Hessey, Copromotor: H. van der Graaf

Geert Jan Besjes

Pushing SUSY's boundaries; searches and prospects for strongly-produced supersymmetry at the LHC with the ATLAS detector

Radboud Universiteit Nijmegen, 19 March 2015

Promotor: N. de Groot, Copromotor: S. Caron

Veerle Anna Margeretha Heijne

Search for long-lived exotic particles at LHCb

Vrije Universiteit Amsterdam, 26 March 2015

Promotores: M.H.M. Merk, W.D. Hulsbergen

Erwin Lourens Visser

Neutrinos from the Milky Way

Universiteit Leiden, 12 May 2015

Promotor: M. de Jong, Copromotor: D.F.E Samtleben

Roel Johannes Makis Aaij

Triggering on CP violation. Real-time selection and reconstruction of $B_s \rightarrow J/\psi\phi$ decays

Vrije Universiteit Amsterdam, 7 May 2015

Promotor: H.G. Raven, Copromotor: M.H.M. Merk

Francesco Zappon

It is about time. Design and test of a per-pixel high-resolution TDC

Universiteit Amsterdam, 5 June 2015

Promotor: E.N. Koffeman, Copromotor: M.G. van Beuzekom

Stefan Gadatsch

The Higgs boson

Universiteit Amsterdam, 26 June 2015

Promotor: S.C.M. Bentvelsen, Copromotor: W. Verkerke

Rosemarie Zoe Aben

Spinning the Higgs – Spin and parity measurement of the discovered Higgs-like boson in the $H \rightarrow WW \rightarrow l\nu l\nu$ decay mode

Universiteit Amsterdam, 17 June 2015

Promotor: S.C.M. Bentvelsen, Copromotor: P.M. Kluit

Rolf Schön

XAMS – Development of liquid xenon detector technology for dark matter searches

Universiteit Amsterdam, 1 July 2015

Promotor: E.N. Koffeman, Copromotores: M. Alfonsi, N. van Bakel

Carlos Eugenio Perez Lara

Azimuthal anisotropy of strange and charm hadrons – measured in Pb-Pb collisions at 2.76 TeV

Universiteit Utrecht, 27 August 2015

Promotor: T. Peitzmann, Copromotor: P.G. Kuijer

Rogier van der Geer

Searches for new physics through single top

Universiteit van Amsterdam, 1 September 2015

Promotor: S.C.M. Bentvelsen, Copromotor: M. Vreeswijk

Martinus Gerardus Antonius Buffing

Color and TMD Universality in hadronic interactions

Vrije Universiteit Amsterdam, 16 September 2015

Promotor: P.J.G. Mulders



Angelantonio Castelli

Measuring the Higgs boson mass using event-by-event uncertainties

Universiteit van Amsterdam, 25 September 2015

Promotor: E.N. Koffeman, Copromotor: I.B. van Vulpen

Kristof Antoon Maria De Bruyn

Searching for Penguin footprints: Towards high precision CP violation measurements in the B-meson systems

Vrije Universiteit Amsterdam, 8 October 2015

Promotor: R. Fleischer, Copromotor: P. Koppenburg

Rose Footini Koopman

Ageing of the LHCb Outer Tracker & b-hadron production and decay at $\sqrt{s} = 7$ TeV

Vrije Universiteit Amsterdam, 3 November 2015

Promotor: M.H.M. Merk, Copromotor: N. Tuning

Nika Valenčič

Fusing the Vector Bosons – Higgs production through VBF and WW scattering at the current and future LHC

Universiteit van Amsterdam, 10 November 2015

Promotor: S.C.M. Bentvelsen, Copromotores: P. Ferrari, N.P. Hessey

Alis Rodriguez Manso

Balance functions: Multiplicity and transverse momentum dependence of the charge dependent correlations in ALICE

Universiteit Utrecht, 25 November 2015

Promotor: R.J.M. Snellings, Copromotor: P. Christakoglou

Daniel Alphonsus Adrianus Geerts

The single top t-channel fiducial cross section at 8 TeV measured with the ATLAS detector

Universiteit van Amsterdam, 1 December 2015

Promotor: S.C.M. Bentvelsen, Copromotor: M. Vreeswijk

Matheus Ronaldus Blom

Seismic attenuation for advanced Virgo: vibration isolation for the external injection bench

Vrije Universiteit Amsterdam, 9 December 2015

Promotor: J.F.J. van den Brand, Copromotor: A. Bertolini

New CERN Council Chair



The CERN Council has elected prof. Sijbrand de Jong as its 22nd president, with a mandate starting on 1 January 2016. He teaches High-Energy Physics at the Radboud University Nijmegen and is a Nikhef staff member.

On 24 April, Sijbrand de Jong was awarded the title Knight in the Order of the Lion of the Netherlands. He received this honour for his outstanding achievements in science, education and outreach.

CERN has generated a scientific golden age. The recent discovery of the Higgs boson in 2012 and the restart of the LHC in 2015 at an unprecedented collision energy of 13 TeV have already turned the LHC into a great success. It seems nearly impossible to trump the LHC successes of the past few years and some even say that particle physics may now be fully understood. However, this last statement is far from the truth. Within the Standard Model there are tensions with some experimental observations, including some of the tantalizing preliminary results that were shown by the ATLAS and CMS experiments at the end of last year. This clearly warrants the collection of much more data at the LHC.

A second reason that the Standard Model is not complete is that we neither know the neutrino masses, nor do we have detailed knowledge of the lepton mixing matrix. There is an interesting challenge in pulling the European neutrino physics community together for maximum efficacy. In 2015 a start was made with a new neutrino platform that supports test beams and experimental areas at CERN for the design and construction of future neutrino physics experiments.

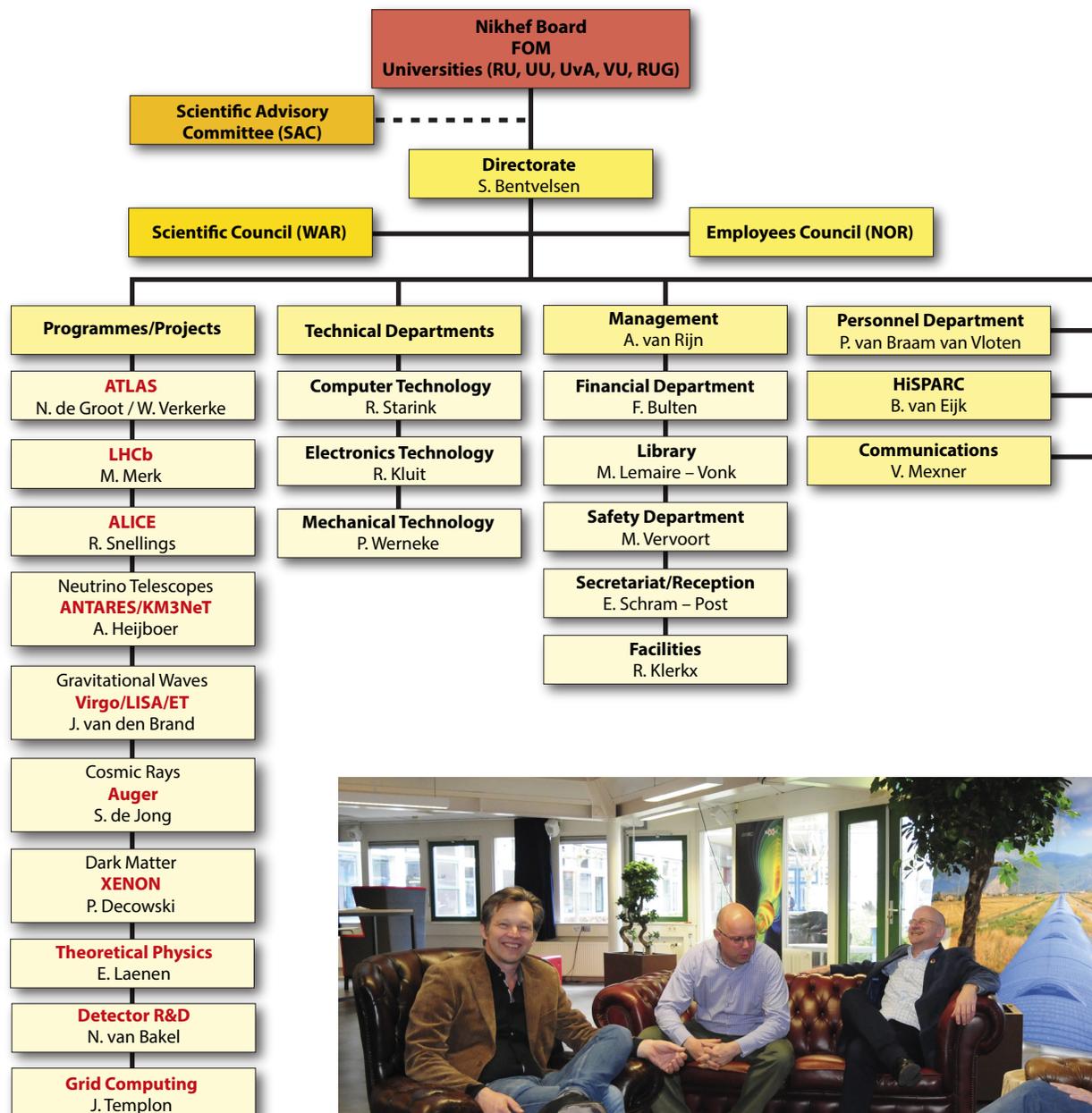
Even more challenging to the idea that the Standard Model is a complete theory of nature is that it only seems to describe about 4.5% of the content of the universe. The largest part, tentatively called Dark Matter and Dark Energy, remains to be explained. This last most important issue may be approached in different ways. Dedicated Dark Matter experiments and astroparticle physics observations may help to resolve it. However, being able to produce Dark Matter ourselves will remain the ultimate aim.

When nature is kind to us, we will see evidence of new physics at the LHC in the coming years. What CERN should be doing after the LHC or already in parallel to the LHC will depend on what we see the coming years at the LHC and elsewhere. At the same time we cannot wait with important R&D and have to be ready to take decisions knowing what can be done when the time comes.

I am honoured to chair the discussion in the CERN Council at the strategic level on this important issue and to prepare the process of a next update of the CERN strategy in about three to four years from now. It will be exciting times.

*Sijbrand de Jong,
President of CERN Council*

Organigram



The Nikhef management team; from left to right: Stan Bentvelsen, Pieter van Braam van Vloten, Arjen van Rijn and Els Koffeman.

Nikhef Organization

Nikhef Board: C. Gielen (*chair, Radboud University Nijmegen*), J. de Kleuver (*secretary, FOM*), H. Irth (*VU University Amsterdam*), N. Lopes Cardozo (*FOM*), G. van Meer (*Utrecht University*), K. Maex (*University of Amsterdam*), W. van Saarloos (*FOM*)

Management Team: S. Bentvelsen, P. van Braam van Vloten, A. van Rijn, E. Koffeman

Scientific Advisory Committee (SAC): H. Abramowicz (*University of Tel Aviv, Tel Aviv*), 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): L. Brenner, R. Hart (*secretary*), J.J. Keijser (*vice chair*), N. Rem, B. Schellekens, F. Schreuder (*vice secretary*), H. Snoek, G. Visser, J. Visser (*chair*)

CERN Contact Committee (Nikhef members only): S. Bentvelsen, S. de Jong (*chair*), N. de Groot, E. Laenen (*secretary*), M. Merk, Th. Peitzmann

Scientific Council (WAR): S. Bentvelsen, D. Boer, C. van den Broeck, S. Caron, A.P. Colijn, W. Hulsbergen, P. de Jong, M. van Leeuwen, G. Onderwater, Th. Peitzmann (*chair*), M. Postma, G. Raven, A. van Rijn (*secretary*), D. Samtleben, C. Timmermans, N. Tuning (*staff meeting*), I. van Vulpen

Programme Leader Consultation (OPL): N. van Bakel, S. Bentvelsen, P. van Braam van Vloten, J. van den Brand, P. Decowski, N. de Groot, A. Heijboer, S. de Jong, E. Koffeman, E. Laenen, M. Merk, A. van Rijn, R. Snellings, J. Templon, W. Verkerke.

Research School Subatomic Physics (OSAF)

– **Education Committee:** S. Bentvelsen (*Nikhef, UvA*), J. Berger (*secretary*), J. van den Brand (*VU*), P. van Braam van Vloten (*Personnel*), B. van Eijk (*Nikhef, UT*), R. Fleischer (*VU*), N. de Groot (*RU*), P. de Jong (*UvA*), S. de Jong (*RU*), E. Koffeman (*UvA*), M. Merk (*Nikhef, VU*), P. Mulders (*VU*), Th. Peitzmann (*UU*), A. Pellegrino (*VU*), G. Raven (*VU*), R. Snellings (*UU, chair*), A. Schellekens (*RU*)

Overview of Nikhef personnel (31-12-2015)

I - Scientific groups (fte; institute & university groups)

| | |
|----------------------------|--------------|
| Permanent Scientific staff | 66.8 |
| PhD students | 100.0 |
| Post-docs | 24.8 |
| Other scientific staff | 1.8 |
| Total I | 193.4 |

II - Management, technical/engineering and general support (fte; institute)

| | |
|------------------------------------|------------|
| <i>Management team</i> | |
| Director | 1.0 |
| Institute manager | 1.0 |
| Personnel manager | 1.0 |
| Manager Scientific Instrumentation | 0.5 |
| <i>Subtotal</i> | <i>3.5</i> |

Technical/engineering support

| | |
|------------------------|-------------|
| Electronics technology | 22.9 |
| Computer technology | 21.5 |
| Mechanical technology | 26.8 |
| <i>Subtotal</i> | <i>71.2</i> |

General support

| | |
|------------------------------|-------------|
| Financial administration | 3.8 |
| Personnel/HRM administration | 1.0 |
| Library | 0.6 |
| Facilities & Datacenter | 10.2 |
| Secretariat & reception | 3.9 |
| PR & communication | 3.1 |
| Occupational health & safety | 2.0 |
| Staff | 2.4 |
| <i>Subtotal</i> | <i>27.0</i> |

Total II **101.2**

Total I & II **295.1**

III - Other groups (persons)

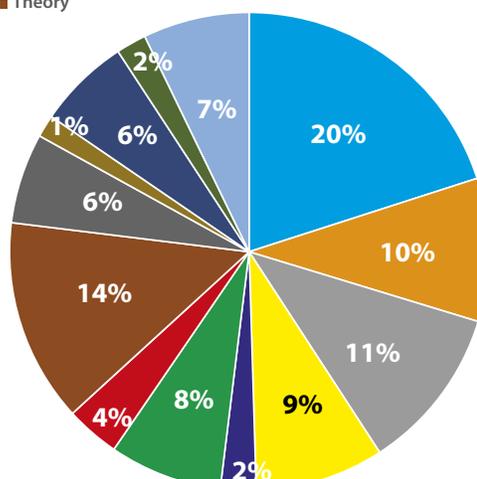
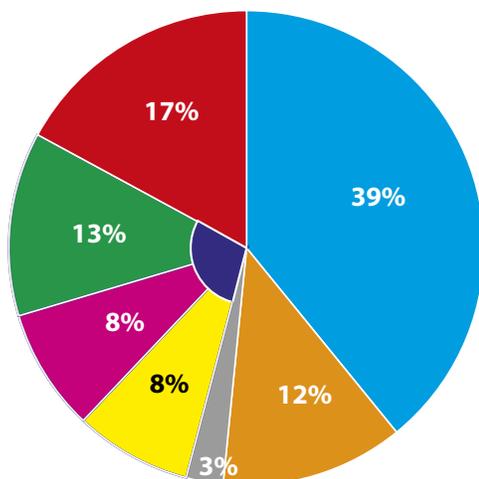
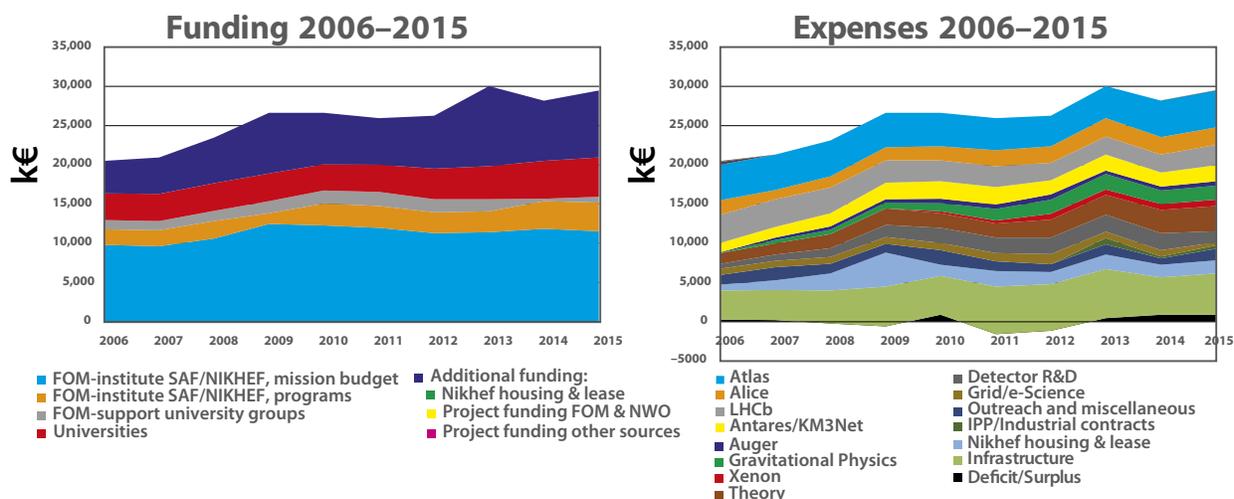
| | |
|-------------------------------------|-----|
| Guests (researchers, retired staff) | 107 |
| Master students | 42 |
| Apprentices | 11 |

Funding & Expenses

The 2015 funding level of the Nikhef collaboration is higher than last year: 29.5 M€ (versus 28.2 M€ in 2014), although still a bit lower than the all-time high in 2013 (30.1 M€). No new FOM-programmes have been acquired in 2015 (there has been no call), however, a special request to the FOM Board, backed up by the university partners involved (VU and RU) has resulted in a modest (about 1 M€) but important FOM-programme grant to the Gravitational Wave detection activities, partly at the expense of the LHC programme. After a low harvest of grants in 2014, the year 2015 has been successful again: 7 M€ has been acquired from a variety of funding channels (FOM, NWO, EU, RVO), see the online Appendix. Nikhef has now also obtained the first projects from the EU Horizon2020 programme.

The expenses for accelerator-based particle physics (ATLAS, LHCb and ALICE) have slightly increased (to 41%), due to the ramp up of instrumentation activities for the detector upgrades. The astroparticle physics activities, for which construction activities are still considerable, have consumed about 23% of direct expenses. The enabling activities (computing, detector R&D and particularly theory) comprise 22% of expenses, whilst industrial activities, outreach and lease activities make out the remainder (14%) of the direct costs.

Budget and grants labelled as investments are not included in the graph, in particular the investments in the KM3NeT detector, Advanced Virgo and the LHC detector upgrades, in 2015 together budgeted at about 4 M€.



Glossary

Accelerator

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

ALICE (A Large Ion Collider Experiment)

One of the four major experiments that uses the LHC.

AMS-IX (Amsterdam Internet Exchange)

The main place in the Netherlands for Internet Service Providers to interconnect and exchange IP traffic with each other at a national or international level.

Annihilation

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

ANTARES (Astronomy with a Neutrino Telescope and Abyss Environmental Research)

Large area water Cherenkov detector in the deep Mediterranean Sea near Toulon, optimised for the detection of muons resulting from interactions of high-energy cosmic neutrinos.

Antimatter

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

Antiproton

The antiparticle of the proton.

APPEC (Astroparticle Physics European Coordination)

The assembly of 17 funding agencies, governmental institutions and institutes from 14 European countries for coordinating efforts in astroparticle physics, created in 2012.

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. Operation stopped in 2008.

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.

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.

eLISA (evolved LISA)

ESA-only gravitational wave space mission, orbiting around the Sun as a giant equilateral triangle 1 million km on a side. Candidate for launch in 2028.

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 ($\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \dots$). 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 analogue 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.

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 several cubic kilometres at the bottom of the Mediterranean Sea, distributed over three locations offshore the coasts of France, Italy and Greece,

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 biggest accelerator, started in 2008.

LHCb (Large Hadron Collider beauty)

One of the four major experiments that uses the LHC.

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).

NNLO (Next-to-Leading Order)

Third-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

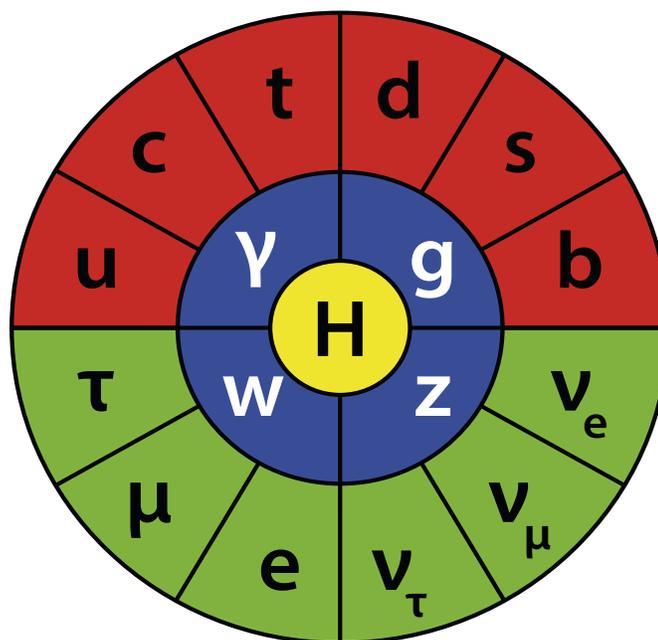
The antiparticle of the electron.

Quantum electrodynamics (QED)

The theory of the electromagnetic interaction.

Quantum chromodynamics (QCD)

The theory for the strong interaction analogous to QED.

**fermions**

 quarks

 leptons

bosons

 gauge bosons

 higgs boson

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.

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.

Sigma (σ)

In statistics, a measure of the dispersion or variation in a distribution.

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.

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 organization in the Netherlands.

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.

WLCG (Worldwide LHC Computing Grid)

The mission of the WLCG is to provide data-storage and analysis infrastructure for the entire high-energy physics community using the LHC.

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.