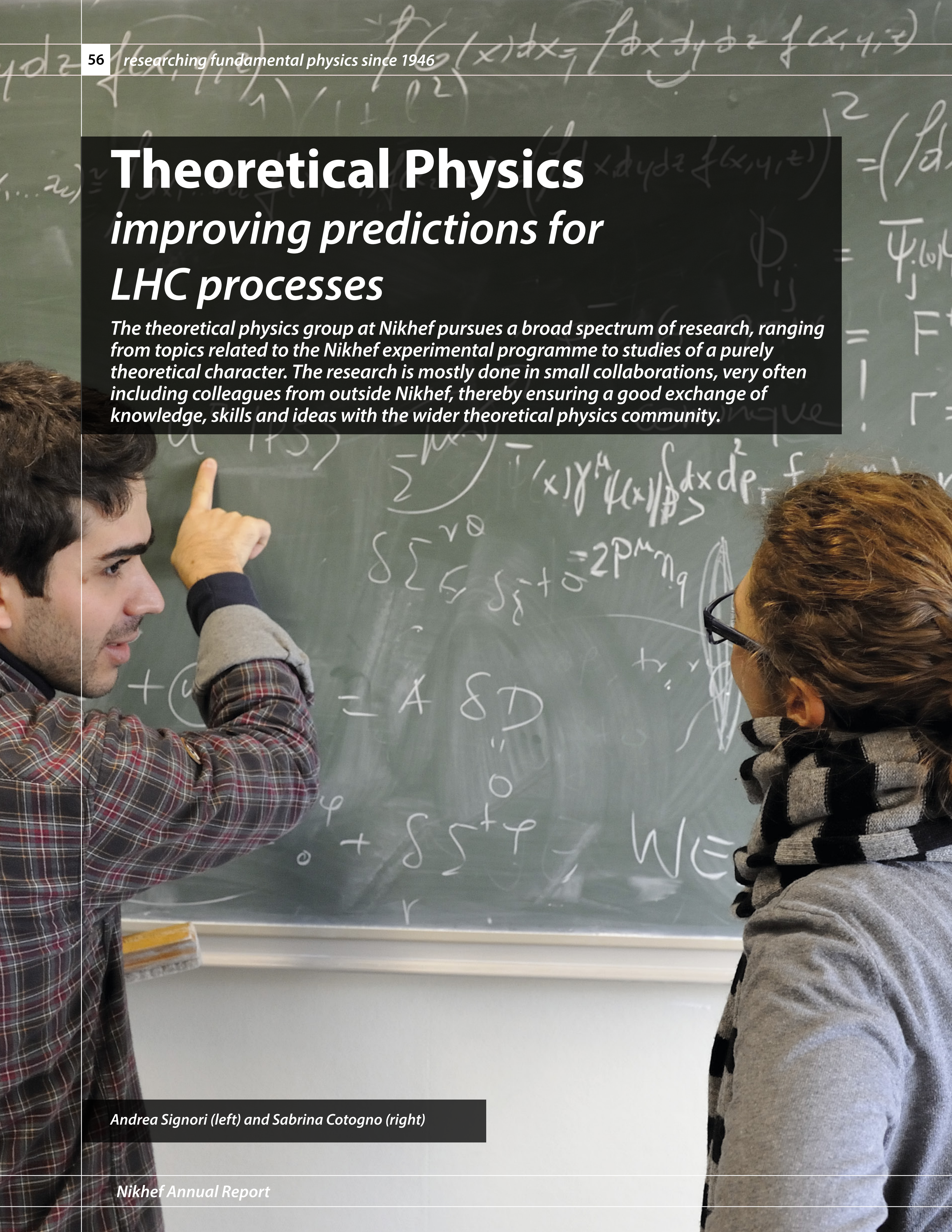
Theoretical Physics

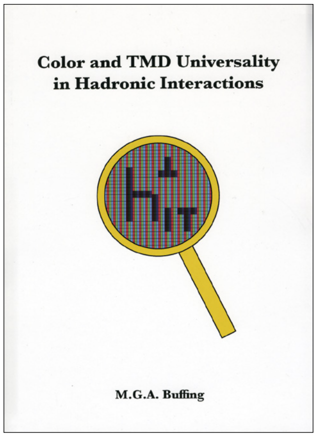
improving predictions for LHC processes

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.

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.

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.

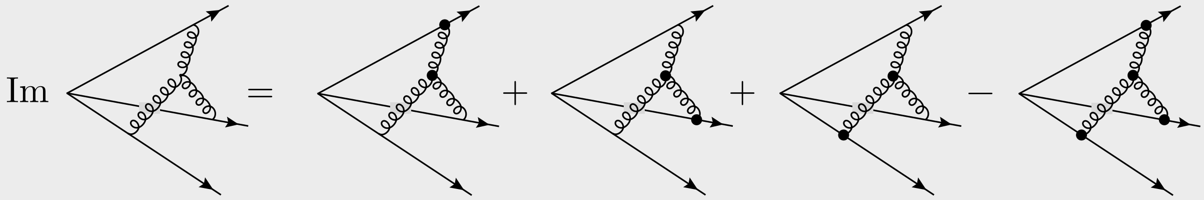
What is our universe made of? What is Dark Matter? The Large Hadron Collider will answer these questions by searching for new physics. This is only possible through realistic and accurate theoretical predictions for new physics processes. They are the objectives of the project.

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.

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.

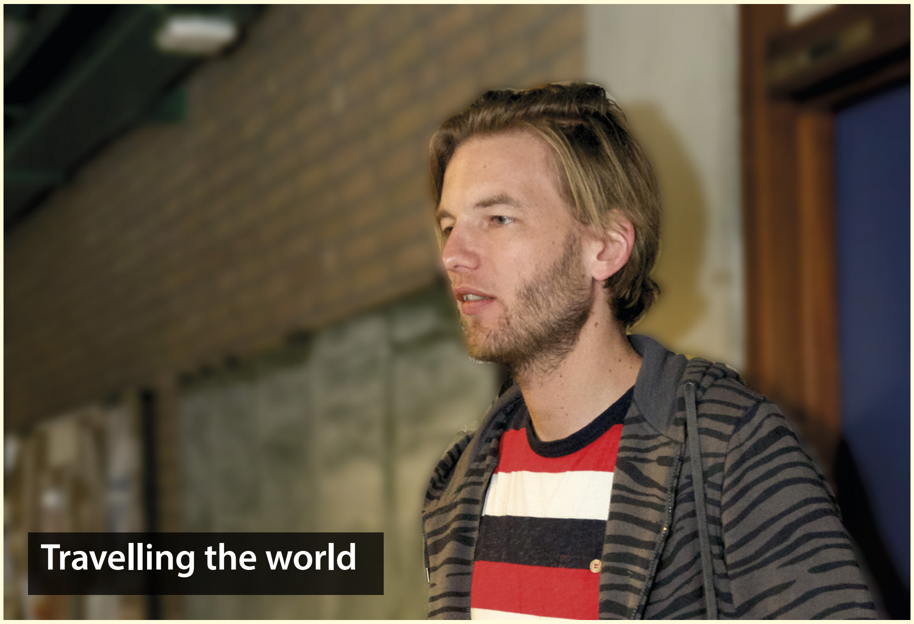
Efficient calculation method for particle collisions

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.



Travelling the world

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 spoilt 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 quantumchromodynamics, 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.

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.

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.

Colleagues and friends gathered for the JosFest

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"*.