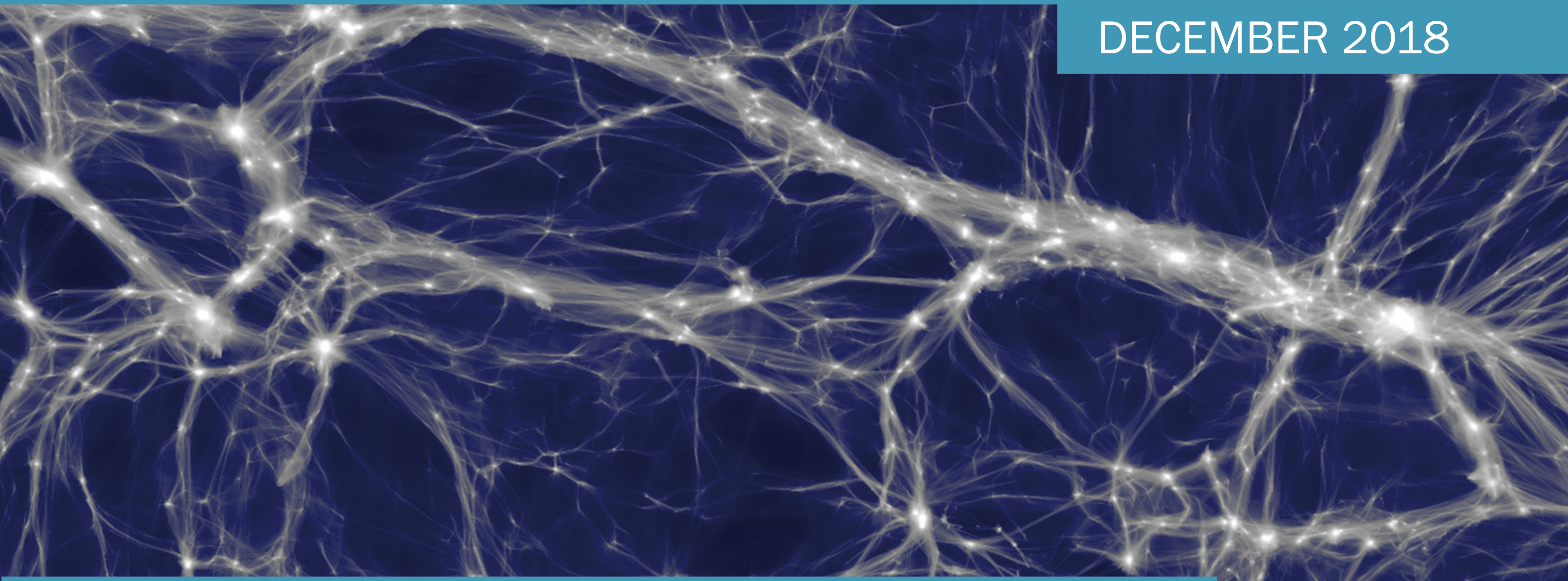

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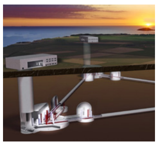

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COSINUS GETS READY TO HUNT FOR DARK MATTER

Interview with Karoline Schäffner, assistant professor at Gran Sasso Science Institute (GSSI) and INFN researcher, winner of a Max-Planck Research Grant (MPRG) with the COSINUS project for dark matter research.

Thanks to a Max-Planck Research Grant (MPRG) of 3,115,000 euros, Karoline Schäffner, assistant professor at Gran Sasso Science Institute (GSSI) and INFN researcher, will lead a research group for the next five years on dark matter at the INFN Gran Sasso National Laboratories. The Max-Planck Research Grant will allow the scientist to implement COSINUS, the experiment led by her and dedicated to the direct detection of dark matter particles.

Karoline Schäffner, experimental physicist, has focused her research on astroparticles, in particular on the physics of rare events and on the development of advanced cryogenic detection techniques for a new generation of experiments to detect dark matter. Born in Germany and a graduate from the Munich University of Applied Science, Schäffner received her PhD from the Max-Planck Institute for Physics in Munich and carried out a post-doc at the INFN Gran Sasso National Laboratories and GSSI. With the MPRG, she will continue a program started in 2016 with a grant financed by INFN that allowed her to implement the COSINUS project installed at the Gran Sasso National Laboratories. We asked the scientist to tell us about the genesis of her project and its development expectations after receiving the award from the prestigious German institute.

The hunt for dark matter is today one of the most promising frontiers in the research on the structure of our universe, and at the same time one of the most insidious and difficult to explore. What led you to investigate in this difficult direction?

Since my time at university I was interested in experimental physics, in particular in low-temperature physics and cryogenic detectors for particle physics applications. I was very fascinated that with man-made machines, the dilution refrigerators, we can reach temperatures very close to the absolute zero (0 K on the Kelvin temperature scale, corresponding to -273.15 °C), and these temperatures are actually colder than the average temperature of the universe (about 2.7 K). On top of being able to reach

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temperatures lower than 0.01K (273.14 °C), in the 1980s cryogenic detectors started to be developed, which actually can detect particle interactions with unprecedented high sensitivity.
It did not take long until the idea came up to use large cryogenic detectors for the search of rare events such as neutrinoless double-beta decay and electron decay (proposed by E. Fiorini and T. O. Niinikoski in 1983). Nowadays, cryogenic calorimeters are widespread in the field of rare event searches, in particular they are also used in direct dark matter detection.
In the universe there is five times more dark matter than ordinary matter. This is by itself motivating as it demonstrates how little we actually know still today and how much we still have to start to understand. The elementary particles constituting ordinary matter are summarized in our so-called Standard Model of particle physics. The last of its 17 elements was only recently discovered: the Higgs boson, detected in 2012 at the LHC.
However, the Standard Model of particle physics does not contain a particle that could be dark matter. Consequently, the existence of dark matter requires physics beyond the Standard Model, making this specific field very attractive in astroparticle physics and explaining the huge interest and effort taken in the particle physics community to resolve this long-standing mystery.
Thus, for me there is a perfect fit. We can build this fantastic low-temperature detectors and then search with this advanced technology for dark matter, one of the biggest puzzle in today's physics. It is simply great to be part of it!

What is the peculiarity of the COSINUS experiment compared to other experiments in progress for the dark matter search?
The majority of experiments in the field of direct detection have not found any hints of dark matter yet. But there is one exception, the DAMA/LIBRA experiments located at LNGS observe since about 20 years an annual modulation signal which matches the expected signal from dark matter particles in our galaxy. Other experiments cannot confirm this result, but different experiments use diverse target materials and a direct comparison of their results is difficult and would require to take into account certain assumptions, in particular on the interaction mechanism between dark matter and ordinary matter. The only way of providing a fully model-independent clarification of the DAMA/LIBRA claim is to use the same target material, but in a different experiment. And it is right here where COSINUS starts.
In COSINUS we are using the same target material as DAMA/LIBRA: the scintillating crystals of sodium iodide (NaI). Different from all other NaI-based experiments that are currently under way to test the DAMA/LIBRA signal, COSINUS will not operate the NaI crystals as pure scintillation detectors which only acquire the scintillation light signal created by a particle interaction. Instead, COSINUS operates for

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the first time NaI crystals as cryogenic scintillating detectors at milliKelvin temperatures, very close to absolute zero. This technology was initially developed within the CRESST (Cryogenic Rare Event Search using Superconducting Thermometers) dark matter search (using $CaWO_4$ crystals, a material called scheelite), the project where I did my PhD thesis.
In such a cryogenic detector we measure two independent signals from a particle interaction: the heat signal which gives a precise measurement of the energy deposit of the particle and the simultaneously emitted scintillation light. This dual channel detection has two important advantages: first, a lower energy threshold, in particular for nuclear recoils, as conventional scintillation detectors. Second, since the amount of produced scintillation light depends on the type of particle, we can discriminate possible signal events, e.g. dark matter interactions can be distinguished from common background events (beta, gamma, alpha events). Particle identification is a completely new and unique feature for NaI based searches. Thus, in case of positive evidence COSINUS can also tell what kind of interaction the possible dark matter particles are having with the NaI crystal to finally solve the long lasting mystery.

With the funding assigned to you, you will manage a team. Who is going to be part of your team and how do you plan to use the funds that have been allocated to you?
The idea for the COSINUS project was initially born within INFN. In summer 2015 I applied for a grant on “New detection techniques for future experiments for direct detection of dark matter” awarded by the INFN Fifth National Scientific Committee.
When the proposal was positively approved the adventure could finally start. The INFN grant (2016-2018) was the precondition for us to produce the first prototype detector of COSINUS. In the beginning it was mainly Dr. Florian Reindl, that time Post-doc at INFN Roma 1 and now spokesperson of COSINUS, and myself who worked on getting started with the project. Since then we grew to about 15-20 scientists and Phd students working on COSINUS. Our collaborators come from INFN LNGS, universitites and INFN divisions of Milano and Milano Bicocca, HEPHY and TU Wien in Austria, SICCAS company as well as from the Max-Planck Institute in Munich, Germany and the CRESST group. Furthermore, we received excellent and constant support from services at LNGS, such as the mechanical workshop, the chemistry department, the low-radioactivity lab and the administration. Without their strong contribution we could not have arrived at a final working prototype, which was the pre-condition for all the next steps.
After the successful demonstration that NaI crystals can be operated as cryogenic detectors in 2017, I applied for the well-known Max-Planck Research group. This grant seemed to be the perfect fit in order to move on from a pure R&D project to a real physics experiment. The financial possibilities which come with the Max-Planck grant will allow us to set up a highly radiopure cryogenic facility at LNGS which is

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necessary in order to perform a dark matter experiment – a dream which now really becomes true. The underground facility will consist of a large water tank to shield against the natural radioactive background and a dilution cryostat, a machine that allows us to produce the low-temperatures necessary to make our NaI cryogenic detectors work.
Furthermore, within the grant I have the possibility to build up my own small group at the Max-Planck-Institute in Munich consisting of a Post-doc and PhD students as well as a technician to support the experimental works.

The Max-Planck Research Grant is of great importance in terms of both the amount of the funding and the institution that awarded it. What are the ingredients of a successful research program, if any?
This is a difficult question and I think I have neither a satisfying answer to it nor a recipe.
I would say from the personal side the most important thing is to like your job. This can help you to keep on track and go on also through difficult periods where things do not work out and/or where the workload is getting very high.
It is definitely also very helpful if you have the instinct and conviction to never give up and always try again, at least from my experience this already often turned out to be the best strategy to finally arrive at a new and good result and results are always the basis no matter what is the next step to move forward. Furthermore, in science to bring things forward you have to be able to motivate yourself as there will be nobody doing this for you. And last but not least creativity and curiosity are important driving factors for a good experimentalist. Most of this I learned already during my time as a PhD student in the CRESST group at the Max-Planck Institute for Physics in Munich, at that time led by Franz Pröbst (the CRESST group at MPP is now led by Federica Petricca). Looking back, this was really a very intense and invaluable time for acquiring experience and learning what scientific work and methodology is about.
From the professional side working at an Institute or University which has a stimulating and motivating environment is definitely worthwhile and I was lucky being at LNGS and GSSI, two institutions which supported my ideas and helped me to move on during my time as a Post-doc. Furthermore, it is very important to have strong collaborators and colleagues which share their experience and work on the big vision with enthusiasm and constancy.
Personally I think having the possibility to work in science is really a privilege and I am very thankful that I can go on contributing to this exciting field of direct dark matter detection.

Why did you choose Italy to start and then consolidate your research career?
During my time as a PhD student I had the possibility to come to LNGS for shifts and onsite work for the

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CRESST dark matter search. I was very fascinated by all the exciting and great research which is done at the underground labs. There is a long history of physics in Italy and one feels this in many occasions as students are very well prepared and you can find Italian physicists in every physics institution you visit in the world.

During my visits to LNGS I also got in contact with colleagues working permanently at LNGS, in particular with Dr. Stefano Pirro who explained to me that low-temperature detectors are also excellent devices to search for neutrino-less double beta-decay, a very rare decay which may help us to learn about the last open questions of neutrinos. I was motivated to broaden my mind in this direction of physics, but always staying with low-temperature detectors. LNGS hosts, with GerDA, CUORE and CUPID-0, some of the world-leading experiments in this field. Stefano Pirro encouraged me to apply for a INFN scholarship for foreign students and this worked out. I then started to work on Lucifer (Low-background Underground Cryogenic Installation For Elusive Rates), an ERC Grant won by the present president of INFN, Fernando Ferroni, and later renamed to CUPID-0: this work was a lot of fun and I profited from the experience and expertise of people involved in this field.

Later I moved on to GSSI as Post-doc and RTD-A and it was during my time there that the idea for COSINUS came up, followed by the INFN grant and so forth. ■

RESEARCH GRANT

TWO ERC CONSOLIDATOR GRANTS TO ELISABETTA BARACCHINI AND MASSIMILIANO FIORINI

The European Research Council (ERC) has awarded to Elisabetta Baracchini, assistant professor at the GSSI Gran Sasso Science Institute and researcher at INFN, and Massimiliano Fiorini, researcher at INFN and tenure track associate professor at the University of Ferrara, two Consolidator Grants of € 1,995,719 and € 1,975,000, respectively.

The project proposed by Elisabetta Baracchini, INITIUM (an Innovative Negative Ion Time Projection Chamber for Underground dark Matter searches), aims to implement an innovative detector for the direct search for dark matter, based on the development and implementation of a gas Time Projection Chamber (TPC), able to reconstruct the traces of detected events in high precision 3D. The 5-year project envisages the installation of INITIUM at the INFN Gran Sasso National Laboratories.

The project proposed by Massimiliano Fiorini is called 4DPHOTON (Beyond Light Imaging: High-Rate Single-Photon Detection in Four Dimensions) and envisages the development of an innovative tool able to detect single photons in time and space (in 4 dimensions) with combined resolutions hitherto never obtained. The project, which will be developed over 5 years, will have a great impact in various disciplines, from high energy physics to biology, and will be implemented by scientists from INFN Ferrara division, the University of Ferrara and CERN in Geneva. ■

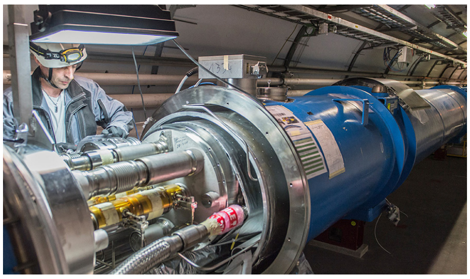
RESEARCH

THE FIRST CATALOGUE OF GRAVITATIONAL WAVES DETECTED BY LIGO/VIRGO WAS PUBLISHED

A total of eleven gravitational wave events have been observed by the interferometers of the LIGO/Virgo collaboration, all described in detail in their first catalogue, recently published. From the analysis of the data collected during the first two observation periods of LIGO and Virgo, four other events emerged, compared to those previously announced, all generated by the fusion of binary black holes: GW170729, the most massive and distant gravitational wave source ever observed, GW170809, GW170818 and GW170823.

During the first observation run (O1), from 12 September 2015 to 19 January 2016, three gravitational wave signals were detected from the fusion of black holes. The second observation run (O2), from 30 November 2016 to 25 August 2017, recorded gravitational waves emitted by the fusion of a binary neutron star system and a total of seven signals from the fusion of black holes. The new events also include GW170818, measured by all the three interferometers that form the global network of gravitational waves observatories, the two LIGO located in the United States in Livingston, Louisiana and Hanford, in the State of Washington, and the Virgo interferometer in Italy, in Cascina near Pisa. The position of the binary system, located 3.3 billion light years from Earth, was identified in the sky with an accuracy of 39 square degrees: the best location of a gravitational wave source, after the GW170817 neutron star fusion.

The publication of this work summarises the discoveries made so far. The restart of the LIGO/Virgo network, is scheduled for next spring, following conclusion of work to upgrade the three interferometers, which will increase their ability to observe the sky and therefore their discovery potential. ■



INFRUSTRUCTURES
IMPORTANT WORKS AT LHC STARTED

On 3 December, the operators of the CERN Control Center turned off the beams of the Large Hadron Collider (LHC). After four years of intense activity that led the proton beams to collide at an energy of 13 TeV, LHC has produced a very rich collection of data, which has allowed physicists to begin to outline a very accurate picture of the Higgs boson and, for the first time, to define many details and behaviours that are still little known of the other particles of the Standard Model.

LHC, as scheduled, has interrupted data acquisition for a long two-year break (LS2, Long Shutdown 2), during which physicists, technicians and engineers will be engaged in a substantial modernisation process of the most powerful accelerator in the world and of all its big experiments: ATLAS, CMS, ALICE and LHCb. The entire accelerator and experiment complex will be upgraded and updated for the next LHC Run, partially bringing forward the future LHC High Luminosity (Hi-Lumi or HL-LHC) project, which will see the light and start collecting data after 2025.

In particular: the injectors that produce the proton beams for the LHC will be renovated; the first linear accelerator of the acceleration chain will be replaced by the brand new Linac4, which will produce brighter beams; the second accelerator in the chain, the Proton Synchrotron Booster, will be equipped with a completely new injection and acceleration system; the Super Proton Synchrotron (SPS), the last injector before LHC, will have a new radiofrequency system; the transfer lines will be improved. During the stop, one of the protective elements of the LHC magnets will also be modified, thus increasing the magnetic field and with it the machine’s energy, reaching a new record: 7 TeV per beam, 14 TeV in the centre of the mass of collisions. At the same level, all the experiments at LHC will work to update important parts of their detectors to optimize their performances in view of the next LHC run. ■

INTERNATIONAL COLLABORATIONS

ITALY AND UNITED STATES SIGN AGREEMENT FOR THE NEW PIP-II ACCELERATOR

On 4 December at the Italian Embassy in Washington, Italy and the United States signed the international scientific and technological collaboration agreement for implementation of the PIP-II (Proton Improvement Plan-II) project at the Fermi National Laboratory (Fermilab) in Batavia, Illinois.

The agreement, signed between DOE (Department Of Energy) and MIUR (Ministry of Education, University and Research), in particular envisages the production of a number of high technology components for a new particle accelerator, which will serve to produce the world's most powerful high energy neutrinos beam for the DUNE (Deep Underground Neutrino Experiment) project.

These components will be implemented by the INFN Accelerator and Applied Superconductivity Laboratory (LASA).

The new 176 meters particle accelerator will be the heart of the Fermilab accelerator complex, and will provide the proton beam to feed a vast research program in particle physics that will develop over several decades.

In addition to Italy, other international partners are making significant contributions to PIP-II, as an example of the increasingly global nature of particle physics projects. The PIP-II accelerator complex will be made available to the international particle physics scientific community and will extend the discovery potential far beyond that achievable with the current experiments. ■

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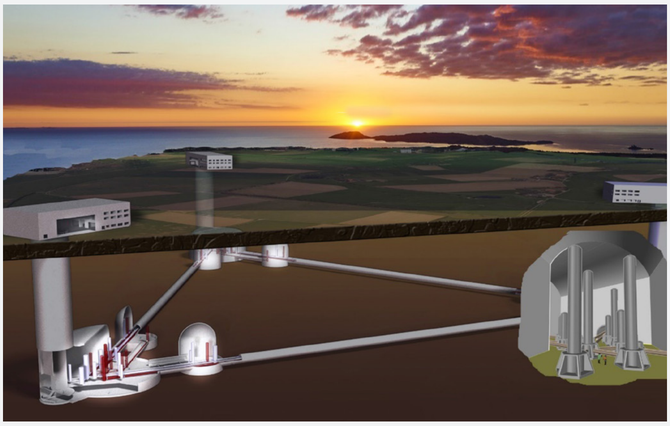

THE EINSTEIN TELESCOPE

Gravitational waves and the Einstein Telescope (ET) project for the implementation of a gigantic third generation underground interferometer in Europe were one of the topics of the conference *EU research and innovation in our daily life*, which was held in Brussels at the European Parliament in early December. The conference addressed the topic of the impact of scientific research on daily life and represented an important moment to support this project at the highest European institutional level. At the opening, Michele Punturo, INFN researcher and international coordinator of the ET project, illustrated the objective of the future research infrastructure, which could be built in Sardinia, in Lula, in the former Sos Enattos mine. For the implementation site the decision is still open. There are three candidate sites: one in Hungary, one on the border between the Netherlands, Belgium and Germany, and the Italian one. The application of the Sos Enattos mine is coordinated by INFN with the support of the Ministry of Education, University and Research (MIUR), the Sardinia Region and the University of Sassari.
Dedicated to Albert Einstein, ET is a very ambitious engineering, technological and scientific challenge and involves the implementation of a third-generation gravitational wave detector, with a triangular layout, consisting of three 10 km long arms, for a total perimeter of approximately 30 km. The detector will be placed at a depth of between 100 and 300 metres, to isolate it from seismic wave movements. It is therefore an underground infrastructure, comparable in size to LHC, with very low levels of environmental noise.
The technological leap brought by ET will improve sensitivity by a factor of 10, equal to an observable volume 1000 times greater than second generation detectors. Designed to be sensitive especially at low frequencies, ET will allow the gravitational waves produced by the coalescence of compact bodies, such as black holes and neutron stars at cosmological distances, to be observed with regularity and great detail, thus inaugurating precision gravitational astronomy. To build the Einstein telescope, the technologies developed in the high

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energy world, such as cryogenics, technologies for ultra-high-vacuum systems of gigantic dimensions, control systems, high-performance electronics, data acquisition systems and computing, will be crucial.
ET is a pan-European project costing approximately one billion euros. The countries that support it are Italy, thanks to the direct contribution of INFN, the support of Sardinian universities, above all Sassari, and the interest of the National Institute of Astrophysics (INAF); France, through the collaboration of the Center National de la Recherche Scientifique (CNRS) with INFN in the European Gravitational Observatory (EGO); the Netherlands, which with the Nikhef institute, is pushing strongly for the North-European site, together with some Belgian universities, Germany with the Max Planck Institute for Gravitational Physics (MPG) and the University of Hanover and Hungary which sponsors the local/Hungarian site through the Wigner Institute. In the United Kingdom, the Scottish and English universities of Glasgow, Birmingham and Cardiff are strongly supporting the project. ■

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Cover

Simulation of large-scale cosmic structures

Credit: Kavli Institute for particle Adtrophysics and Cosmology: Stanford/SLAC