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Istituto Nazionale di Fisica Nucleare

INTERVIEW

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ALICE, EYES FOCUSED ON THE PRIMORDIAL UNIVERSE

Interview with Federico Antinori, an INFN researcher and spokesperson of the experiment ALICE (A Large Ion Collider Experiment) at CERN.

In mid-May Quark Matter 2018 was held in Lido di Venezia, the 27th International Conference on ultra relativistic nucleus-nucleus collisions, which brought together hundreds of physicists from all over the world to discuss new developments in high-energy heavy ion physics. The conference focused on the fundamental understanding of matter in conditions of extreme high temperature and density. In such conditions, which were a feature of the very early universe, matter appears as a plasma of quarks and gluons, with quarks and gluons not confined within protons and neutrons of the atomic nucleus.
In Lido di Venezia, we met one of the leading scientists in this field, Federico Antinori, INFN researcher and spokesperson of ALICE (A Large Ion Collider Experiment), which is an international collaboration involving over 1500 people, counting physicists, engineers and technicians, from 37 countries around the world, and one of the four main experiments at the Large Hadron Collider (LHC) of CERN, dedicated in particular to studying quark gluon plasma. Federico Antinori has been part of this collaboration since the very beginning and he has covered a number of managerial positions over the years. In 2012, he was appointed coordinator of the physics of ALICE and while he was in charge the experiment produced several of its most important results. Since January 2017 he has been the head of the experiment, an appointment he will hold until December 2019.

ALICE is a unique experiment, its objectives are very different from the other LHC detectors, ATLAS, CMS and LHCb. These two experiments have been designed to study high energy proton-proton collisions, and to detect and study the Higgs boson, what are ALICE's main objectives? What was the experiment designed for?

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Yes, ALICE is rather different from the other Large Hadron Collider experiments, it is indeed designed with the specific aim of using heavy nuclei accelerated in the LHC in order to recreate in the laboratory an extreme state of matter, which we call the Quark Gluon Plasma (QGP). We think that QGP was present in the very first microseconds of life of the universe. So the experiment was designed with the specific aim of studying heavy nuclei collisions, which are very different from proton-proton collisions, there are many more particles that are produced and also we are interested in detecting as many as possible of these particles, so down to very low energies. Whereas, the other experiments have typically a minimal energy of a particle that they can detect, which is larger than for ALICE.

What do we know, so far, about the QGP, the extreme state of matter that characterised the very early universe, when there where extreme temperature and pressure conditions?
The quark gluon plasma is an extreme state of matter. The quarks and the gluons that in standard matter are always trapped, confined, inside other particles, such as protons and neutrons, become liberated. So we think this was actually the state in the very first microseconds of life of the universe. So, we have been able to measure very precise, specific and practical properties of the system. We know that QGP behaves very much like an almost perfect liquid: a liquid with very low viscosity. We have been able to measure how such a system is opaque to the passage of high energy particles and how it responds collectively to fluctuations in the initial geometry. We have also made a whole series of measurements on how ordinary particles, the particles that we measure every day in the laboratories, emerge from these quarks and gluons that form this primordial state.

ALICE has given precious insights on the similarities and differences between matter and anti-matter. What did you observe?
With collisions of heavy nuclei we can also go beyond just the study of the properties of the quark gluon plasma. We can use the QGP itself as a source of particles: as the quark gluon plasma expands and cools down, it can generate a very large range of masses of particles and we can use it to study the properties, for instance, of anti-nuclei or anti-hyper-nuclei, exotic nuclear states. For instance, we have measured the properties of the deuteron and of the anti-deuteron, a heavy isotope of hydrogen which has in its nucleus a proton and a neutron, and we have been able to use this source of particles to measure their masses to a level that was unprecedented in precision.

How do you evaluate your first year as ALICE spokesperson? What will the experiment be

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focussing on in the near future?

We are now very active both on the experimental and on the analysis floors. We are still collecting new data and, at the same time, we are analysing a large amount of data already taken. But we are also preparing for the future. On the medium term, we have a very important data taking coming up for the rest of this year, where we will collect our largest data set, our largest statistics sample of collision events ever. And for the coming years, we are preparing a very substantial upgrade of the apparatus of the experiment. We are going to change the inner part of the detector, the area that is closer to the collision; we are going to make the experiment much faster, in terms of the amount of data that it can collect and we are going to the high-luminosity era, that will allow us essentially to collect hundred times more statistics than what we have now. So we will be able to go to a really much more precise detail in the measurement of the properties of the quark gluon plasma. This is what we call the high-precision era in the study of the QGP.

Have unreleased results been presented during the conference?

The vast majority of the results that were presented at Quark Matter 2018 were new. The field of ultrarelativistic nuclear collisions is mainly dedicated to understanding how matter behaves in the extreme conditions of heating and compression that are reached in collisions of heavy nuclei accelerated at the high collider energies.

We know significantly more than two weeks ago on the production from the quark gluon plasma of all kinds of particle species, from photons to nuclei and hypernuclei. We have also made crucial progress in understanding how QGP effects depend on the size of the colliding system. In addition, major advances were reported on the theoretical front. We can certainly say that QM2018 has represented a notable jump for our field.

Going back to your personal experience, what does it mean to lead a collaboration of 1500 physicists coming from all over the world?

Leading such a large collaboration is certainly something for which university does not prepare us: this is not what we study when we study physics, but it is something very enriching. What you understand is how important diversity is, how crucial it is to have different people, from different cultures, different viewpoints and different approach to work. One revelation is how this is crucial to the success of the international collaborations. People are always challenged by a different point of view, so you can never relax into you own, you have always to be ready and able to explain things to other people and to incorporate other view points in the way you work. I think that if there were one

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aspect of our job that I would put forward, it would be this one: I believe this is a key aspect for the success of this experiment.

Once again, an Italian researcher has been appointed as spokesperson of one of the main LHC experiments. What does it mean according to you?

Well, I think that having once again an Italian nominated as responsible of one of the LHC experiments gives a clear message on the quality of the whole Italian high energy physics community. There is a lot of tradition in Italy, this is an area where we have very good schools and we continue to produce very good young scientists. And I think that this, in the end, is a recognition by the whole international community of our past, our present, and the perspective that we hold for the future of Italian physics research. ■

RESEARCH

CERN NEUTRINOS TO GRAN SASSO: OPERA ANNOUNCES ITS FINAL RESULTS ON OSCILLATIONS

The international programme of the OPERA (Oscillation Project with Emulsion-tRacking Apparatus) experiment announced its final results on 22 May, during a seminar at the INFN National Laboratories of Gran Sasso (LNGS) and in an article published in the scientific magazine Physical Review Letters, as a result of 5 years of observations of the beam of muon-neutrinos produced with the CERN Neutrinos to Gran Sasso (CNGS) project. CNGS was set up to verify the transformation phenomenon of muon-neutrinos and measure the appearance of tau-neutrinos with the OPERA detector, after their 2.4-millisecond journey through the 730 km of the earth's crust separating CERN from the underground Laboratories of Gran Sasso.

The OPERA detector - 4.000 tonnes of mass, made from 150,000 bricks of lead plates and nuclear emulsion sheets to photograph the interactions - observed its first oscillation event of a muon-neutrino into a tau in 2010, followed by four more events detected between 2012 and 2015, when it announced the discovery of the tau-neutrino, having achieved for the first time the required statistical significance.

Now, thanks to the application of a new analysis strategy of the entire sample of data, collected between 2008 and 2012 when OPERA was in operation in the Gran Sasso Laboratories, a total of 10 candidate events have been identified, to further improve the level of statistical significance of the discovery: a result that directly and unequivocally demonstrates that muon-neutrinos oscillate into tau-neutrinos.

The OPERA programme has made its data public by means of the CERN Open Data Portal. This means that researchers who do not take part in the OPERA programme can also use the data to carry out new research. ■

RESEARCH

XENON1T ANNOUNCES ITS NEW RESULTS

The XENON1T experiment, for direct research of dark matter at the INFN National Laboratories of Gran Sasso, announced its latest results on 28 May. The data observed by the experiment agree with the forecasts of the small expected background, in other words, those events similar to an interaction of WIMPs, the candidate class of particles of dark matter that XENON1T is looking for, but caused by particles of a known nature. This result therefore means that new, stricter limits can be applied to WIMPs for possible interactions with ordinary matter. The result is based on a quantity of data equal to 1 tonne per annum, an exposure that has never previously been achieved: XENON1T has therefore achieved sensitivity of around four size levels better than that obtained with XENON10, the XENON project's first detector, in operation at the Laboratories of Gran Sasso since 2005. By increasing the target mass from the original 5 kg to the current 1300 kg, while at the same time reducing the background by a factor of 5000, the XENON joint operation has confirmed its status at the frontier of the direct search for dark matter. ■

SPACE

MARS: THE INSIGHT MISSION HAS TAKEN OFF, WITH THE ITALIAN LARRI SYSTEM ON BOARD

On 5 May, at 04:05 California time (13:05 in Italy), the Martian lander, InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport), was successfully launched from the Vandenberg base in America, to start its NASA mission to Mars. Equipment on board the lander included LaRRI (Laser Retro-Reflector for InSight), a laser microreflector developed by INFN with the support of the Italian Space Agency (ASI).

The task of the InSight mission is to explore the depths of the Red Planet, to understand how rocky planets, such as the Earth, are formed. The instruments on board include a seismometer to detect Martian earthquakes, a probe for monitoring the heat flow from inside the planet and, of course, the LaRRI microreflector, which is an instrument designed and constructed by the SCF_Lab research group from the INFN Frascati National Laboratories, in a joint programme with ASI-Matera, dedicated to geodetic measurement.

Using new satellites in orbit around Mars, the Italian laser micro reflectors will provide the precise position of the landers and rovers during their exploration, forming a network of Martian geodetic reference points, a test of Einstein’s general relativity complementing the lunar one carried out with the Apollo reflectors (measured by ASI-Matera) and a definitely better definition of the 0 Meridian of Mars (a kind of “Mars Greenwich”). ■

INFRASTRUCTURES

IN SICILY TO STUDY THE UNDERSEA FAULT LINES WITH FIBRE OPTICS

There is an idea for making use of optical fibers to identify small movements caused by fault lines on the sea bed off the coast of Sicily, involving the undersea infrastructure of the INFN National Laboratories of the South, which is currently under construction (the Idmar Project, realized thanks to funds by the Region of Sicily). This is the idea of the French scientist Marc-André Gutscher (CNRS-University of Brest) in which the European Research Council (ERC) has decided to invest by assigning an Advanced Grant to the FOCUS project, amounting to 3.5 million Euros over 5 years. FOCUS will validate a new technology, by testing the technique of laser reflectometry, which is commonly used for monitoring engineering structures, to detect small seismic movements of the undersea fault lines of Mount Alfeo, to the East of the coast of Catania, jointly with INFN and the National Institute of Geophysics and Volcanology (INGV). The project is a demonstration of how investments in infrastructures that were originally intended for basic research aims can then offer chances to carry out multidisciplinary studies. FOCUS will use a 28 km undersea optical-fibers power cable, crossing the Mount Alfeo fault line, which was mapped recently. Once Sicily has been tested and calibrated, the aim is to extend to other existing optical-fiber cable networks the technique for monitoring fault lines, thus making further additions to the number of international scientific users joining the INFN undersea infrastructures in Sicily. ■

INTERNATIONAL COLLABORATIONS

ITALY-CHINA: IN MAY THE BILATERAL MEETING BETWEEN INFN AND IHEP

The bilateral meeting between INFN and its main scientific and technological partner in China, the Institute of High Energy Physics (IHEP), which was held from 9 to 10 May in Rome in the offices of the INFN Presidency, provided an opportunity to highlight and strengthen the productive cooperation between Italy and China in the area of scientific research in particle physics and more, as well as looking at the new frontiers of physics together.

The meeting focused on discussion of joint projects. In particular, two major experiments carried out by China: JUNO (Jiangmen Underground Neutrino Observatory) and HERD (High Energy Cosmic Radiation Detection). The former involves construction of an enormous underground neutrino detector, which will exploit analogous technology to that used for the Borexino experiment at the INFN National Laboratories of Gran Sasso; the latter involves building a powerful new space telescope to detect dark matter particles, study the composition of cosmic rays and observe high-energy gamma rays from the future Chinese Space Station. Then accelerators came under discussion, with the BESIII experiment at the BEPCII accelerator and the CEPC project for a future electron-positron collider. Space physics was also discussed: not only HERD, but also the DAMPE (DArk Matter Particle Explorer) project, which has been in orbit since 2015, for dark matter research. Both the projects were developed jointly with ASI.

The meeting also provided the opportunity to renew an important agreement between INFN and IHEP for high level education, under which IHEP supports projects of shared interest through PhDs. This agreement enhances the education of future researchers and facilitates mobility between the two countries, also allowing young Chinese researchers to come to Italy to gain experience in the INFN Laboratories. ■

OUTREACH

GRAN SASSO VIDEOGAME

The first videogame set in the biggest underground astroparticle physics laboratories in the world, the INFN National Laboratories of Gran Sasso, was launched on may 27th on the occasion of the lab's Open Day.

Gran Sasso videogame is the result of cooperation between researchers, communicators and videogames developers, who have created a multi-platform product which can be accessed with a computer, tablet or smartphone: it is an instrument for active orientation, designed to bring students closer to the frontiers of physics and to the opportunities available through scientific careers. It is addressed to young people aged between 14 and 19, as well as to their teachers.

The videogame project is a result of the PILA (Physics In Ludic Adventure) project, financed by the Italian Ministry for Education, Research and University (MIUR), and it was conceived by joint cooperation between National Laboratories of Gran Sasso, the agency for scientific communication 'formicablu srl', the production company 'IV Productions' and with the support of INDIRE (the National Institute for Documentation Innovation and Educational Research). The videogame is available for free and students and teachers will test it in schools before the definitive version released. In this way the schools will be involved in an assessment pathway that will lead to optimising materials that can help to deal with physics in the classroom. This is a pathway that takes into consideration the need of tools that speak the language of the millennials, when creating new educational pathways and those for enhancing human capital. Within this context, Gran Sasso Videogame was selected among the 100 projects of the sustainable Italian Public. ■

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NUMEN: NUCLEI AND THE FUNDAMENTAL NATURE OF THE NEUTRINO

The May edition of the European Physical Journal, Hadrons and Nuclei has announced the first results of the NUMEN (NUclear Matrix Elements of Neutrinoless double beta decay) project, together with an updated, detailed overview of the R&D activities relating to the project and associated theoretical developments.

NUMEN is installed in the INFN Southern National Laboratories, in Catania, and brings together joint international cooperation, also including, for Italy, the INFN divisions of Catania, Turin and Genoa. The project focuses on studying the nuclear characteristics of the phenomenon of neutrinoless double beta decay, with its important implications for the physics of neutrinos and astroparticle physics, in order to study cosmic neutrinos and dark matter.

Neutrinos, which are particles with no electric charge and an extremely low mass, interact very little with matter, but play a central role in the functioning of stars, in supernovae explosions and in the formation of the elements during the Big Bang. One of the fundamental properties of neutrinos, which is the subject of study of various experimental groups, is still unknown: whether they are Majorana particles, identical to their antiparticles, or they are Dirac particles, distinguishable from their counterparts in antimatter. If neutrinos and antineutrinos were identical, we should be able to observe the phenomenon of neutrinoless double beta decay: a process that has never been experimentally observed, but which, although prohibited by the Standard Model of elementary particles, is predicted by a lot of reliable theories. In neutrinoless double beta decay, two neutrons inside a nucleus decay simultaneously into two protons and two electrons, without emitting any neutrinos. The search for neutrinoless double beta decay, is a tough battle against other much more common natural events, the so called “background processes”, which simulate the sought signal, thus contaminating it and making it difficult to detect.

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For this reason, the technique suggested by NUMEN at the Southern National Laboratories, suggests indirect study of the phenomenon through the use of appropriate Double Charge Exchange (DCE) nuclear reactions, carried out in the laboratory, to determine the probability of nuclear transition characterising neutrinoless double beta decay. Despite the fact that the two processes, neutrinoless double beta decay and DCE reactions, are triggered by different forces (the weak force and the strong nuclear force respectively) it is held that the two phenomena feature important analogies. In particular, the crucial aspect is the coincidence between the initial and the final quantum states of the nuclei involved in the double charge exchange and in the double beta decay reactions, a feature that allows quantitative information to be obtained about the process of neutrinoless double beta decay. The main experimental instruments for this project are the K800 Superconducting Cyclotron, for accelerating heavy ion beams of high resolution and low emittance, and the MAGNEX detector, a large angular and impulse acceptance magnetic spectrometer, for detecting the products of the reaction.

The first experimental results obtained from NUMEN for the reactions (^{18}O,^{18}Ne) and (^{20}Ne,^{20}O) on targets of ^{40}Ca,^{76}Ge,^{116}Cd and ^{130}Te at energies included between 270 and 300 MeV, provide an encouraging indication of the capacity of the proposed technique for giving access to significant quantitative information.

Although the technique gives good results in terms of resolution and sensitivity, NUMEN expects significant improvements in the near future in overall performance, thanks to the already planned upgrade (2019-2021) of the infrastructure of the INFN Southern National Laboratories. ■

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