

NEWSLETTER 39

Istituto Nazionale di Fisica Nucleare

INTERVIEW



AN EYE FOCUSED ON ANTIMATTER

Interview with Giovanni Passaleva, INFN researcher, since July spokesperson of the LHCb international collaboration at CERN, p. 2

NEWS

RESEARCH

LIGO-VIRGO: A NEW ERA FOR GRAVITATIONAL WAVE SCIENCE, p. 6

INTERNATIONAL COLLABORATIONS

EUROPEAN XFEL INAUGURATED, p. 7

EVENTS

10 YEARS OF BOREXINO, p. 8

RESEARCH

CASSIOPEIA A IS NOT THE COSMIC SUPER ACCELERATOR IT WAS THOUGHT TO BE, p. 9

OUTREACH

ITALY AND INTERNATIONAL SCHOOL PROGRAMS, p. 10

FOCUS



MESSENGERS FROM DISTANT GALAXIES, p. 11

» INTERVIEW



AN EYE FOCUSED ON ANTIMATTER

Interview with Giovanni Passaleva, INFN researcher, since July spokesperson of the LHCb international collaboration at CERN.

Designed to measure the behavioural differences between matter and antimatter at LHC energy levels, the LHCb experiment at CERN records the decay of B mesons, unstable particles containing a b antiquark and a quark of another type (up, down, strange or charm), produced in large quantities in high energy collisions between LHC beam protons. In particular, LHCb investigates the reasons for the absence of antimatter particles in the current universe that are thought to have been very abundant shortly after the Big Bang. Physicists believe in fact that by studying and comparing the decays of B mesons and of the corresponding B anti-mesons, it is possible to obtain important information on the differences between matter and antimatter.

Among the challenges taken up by the international head of the experiment, Giovanni Passaleva, is also the one of taking LHCb to its next upgrade, a performance improvement of the detector, starting in 2019, which will allow phenomena that could pave the way for new discoveries to be explored with even more extreme precision.

LHCb was created with a defined objective, even though the scope of the experiment is very broad. A fascinating and difficult objective: reveal the mystery of the current asymmetry between matter and antimatter. What are the hypotheses underlying the LHCb research program?

According to what we know today about the elementary particles and the forces with which they interact with one another, we can say that in the first moments of the life of the universe after the Big Bang, there was perfect symmetry between matter and antimatter. This symmetry disappeared during the evolution of the universe, so much so that today it consists almost exclusively of matter, while antimatter is produced only for brief moments in nuclear reactions or particle collisions in accelerators or in cosmic

» INTERVIEW

rays.

In the 1960s, it was discovered that nature is not perfectly symmetrical between matter and antimatter, but there is a very small difference that manifests itself in certain weak force driven decays. Violation of the matter-antimatter symmetry goes by the name of "CP symmetry violation", CP being a mathematical operation ("symmetry") that transforms a particle into its corresponding antiparticle. "CP violation" is now a well-known and well-studied phenomenon but, based on cosmological considerations, we know that the CP violation effects we observe are not sufficient to explain the level of matter-antimatter asymmetry in the current universe. There must therefore be other sources of asymmetry related to physical phenomena which are currently unknown which, once identified, could tell us many things about the big issues still open in modern physics. LHCb was designed precisely to search for these phenomena and ultimately explain why the universe has evolved as we know it today.

To date, what pieces have you been able to put in the puzzle to explain the absence of antimatter in our universe?

Matter-antimatter asymmetry has been observed and studied in many different particle decays such as those of K mesons or B mesons, and the theory of elementary particles, the Standard Model, is able to accurately explain, in a coherent theoretical context, all the experimental observations. Nevertheless, as I explained earlier, this is not sufficient to explain the current structure of the universe. LHCb is seeking in many different ways to highlight possible new sources of asymmetry, for example by comparing many different decays or looking for CP violation in phenomena where it is not predicted by the theory, such as in the decay of the charm quark.

The search for "new physics", for phenomena that are not described by the current elementary particle theory, the Standard Model, is among the goal of all LHC experiments. How is it going?

The absence of clear evidence of new particles in the numerous analyses carried out by the ATLAS and CMS experiments makes the search for new physics difficult but, at the same time, increasingly fascinating. We know that there must be something new and unexpected, since the Standard Model cannot explain very significant phenomena such as dark matter or matter-antimatter asymmetry, but we do not have a clear reference theoretical framework. This opens up a phase of great scientific creativity where new technologies, new experimental techniques and increasingly refined data analysis methods are combined with new theoretical models. Compared to the recent past in which theory drove experiments, leading, for example, to the discovery of Z and W particles or the Higgs boson, now the situation is reversed and large experiments are exploring a wide spectrum of possible signs of new

» INTERVIEW

physics.

LHCb, for its part, is contributing to this "creative phase" by studying decays and extremely rare processes with ever greater accuracy, in search of some small clues revealing the presence of something new and unexpected.

What are the main differences between LHCb and the other LHC experiments?

The first obvious difference is the structure of the detector. While ATLAS and CMS are large cylinders consisting of subsequent layers of detectors coaxial with the LHC beam, LHCb has the typical structure of a "fixed target" experiment, with the detectors positioned perpendicularly and very close to the proton beam. This particular geometry is due to the fact that the particles containing b and c quarks, the main study subjects of LHCb, are produced in collisions between protons at an angle, on average, very small in relation to the beam direction.

The second significant difference is that, while ATLAS and CMS attempt to observe new particles directly, LHCb studies the effect they may have on physical quantities such as decay ratios or the matter-antimatter asymmetries in particularly rare B meson decays. This indirect research method exploits the fact that, in accordance with quantum mechanics, in the decay of a B meson particles even heavier than the meson itself can be created and re-absorbed in very short time ("virtual" particles) these particles, although not directly visible, affect the value of the physical quantities related to the decays we are studying. When the measured value and the theoretical value of one or more of these quantities differ significantly, there is clear evidence of the presence of new particles. The indirect method provides sensitivity to the presence of new particles with a mass even higher than that accessible to direct observation.

At the beginning of July, the discovery of X_{icc}^{++} , a particle known but never observed before, was announced. Does it open any new perspectives?

Observation of the new X_{icc}^{++} particle has had significant resonance not only in the media but also, and above all, in the scientific community. Particles in which two or more "heavy" (b or c) quarks bind together allow very accurate theoretical predictions of properties such as their mass or average life. The main instrument for these predictions is the study of strong interactions which link quarks together, for example in protons and neutrons, and which are therefore the basis of the building blocks constituting atomic nuclei and hence the world as we know it on a daily basis. The various theoretical models that describe how quarks and gluons are bound together to form so-called hadrons (such as, for example, neutrons and protons) can be tested very accurately by comparing the predictions of the characteristics

» INTERVIEW

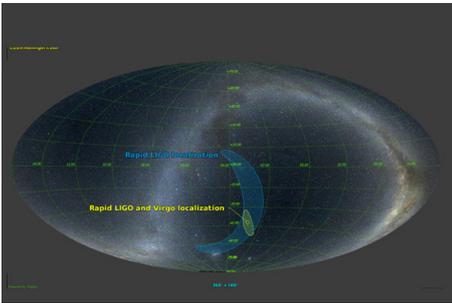
of particles such as the Xicc++ with experimental observations.

The observation of a particle like the Xicc++ paves the way for an entire research area in which many other "sister" particles of the Xicc++, or other similar particles that contain a b quark, can be observed and studied, allowing a very strict comparison with the theoretical models, confirming some and confuting others.

Simplifying somewhat, we can say that the Xicc++ and other similar particles will constitute an exceptional laboratory for studying strong interactions.

What does the role of head of a broad and culturally diverse international collaboration such as that of LHC experiments require?

Having just started, I still have many things to learn. Nevertheless, I believe that there are at least two fundamental things to keep in mind when leading a large international collaboration. First of all, the word "collaboration" indicates a work method that requires shared intentions and the desire to work together to achieve important results. Those who lead a scientific collaboration have the responsibility to maintain this spirit and to harmonise the work of all colleagues, taking into account the peculiarities of each. The other responsibility I believe to be fundamental, especially in the scientific sphere, is that of promoting and facilitating the development of new ideas as much as possible: this means having utmost respect for all collaborators and promoting a climate in which even the slightest form of discrimination based on gender, age, cultural or ethnic background, etc. is banned. I believe that the ability to listen to people and to understand and enhance the peculiarities and expectations of each, especially of the younger ones, are the main requirements for those who lead a large collaboration like LHCb. ■



RESEARCH

LIGO-VIRGO:

A NEW ERA FOR GRAVITATIONAL WAVE SCIENCE

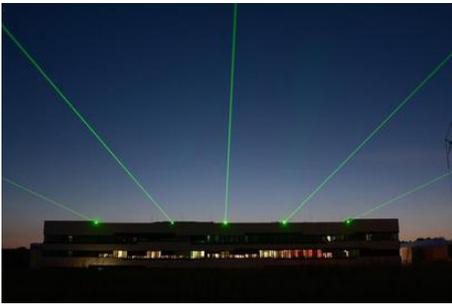
The VIRGO collaboration and the LIGO Scientific Collaboration reported on September the 27th, during the G7 Science and Technology Summit in Torino, the first three-detector observation of gravitational

waves. This result highlights the scientific potential of a global network of gravitational wave detectors, by delivering a better localization of the source and access to polarizations of gravitational waves.

The two Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors, located in the United States, Livingston Louisiana and in Hanford Washington and the VIRGO detector, located at the European Gravitational Observatory (EGO) in Cascina, near Pisa, Italy, detected a transient gravitational-wave signal produced by the coalescence of two stellar mass black holes.

The three-detector observation was made on August 14, 2017 at 10:30:43 UTC. The detected gravitational waves – ripples in space and time – were emitted during the final moments of the merging of two black holes with masses around 31 and 25 times higher than the mass of the Sun and located about 1.8 billion light-years away. The newly produced spinning black hole has about 53 times the mass of our Sun. This means that about 3 solar masses were converted into gravitational-wave energy during the coalescence.

This is the fourth detection of a binary black hole system. While this new event is of astrophysical relevance, its detection comes with an additional asset: this is the first significant gravitational wave signal recorded by the VIRGO detector, which has recently completed its upgrade to Advanced VIRGO. The article about the discovery has been accepted to be published on Physical Review Letters (<https://dcc.ligo.org/P170814> e <https://tds.virgo-gw.eu/GW170814>) and is published on arXiv since September the 28th. ■



INTERNATIONAL COLLABORATIONS

EUROPEAN XFEL INAUGURATED

On September 1 in Hamburg the European XFEL, the European super microscope implemented also thanks to the Italian contribution with INFN, was inaugurated. This is a free electron laser that will allow the structure of macromolecules in action to be observed. Unlike traditional techniques for determining the structure of a macromolecule through X-rays, the European XFEL can also analyse non-crystallised macromolecules. This is a significant advantage since, in addition to allowing macromolecular structures that are difficult to crystallise to be observed, it allows to take photographs of macromolecules at different moments in their lives. And by collecting many different photos of the same molecule (an enzyme, a virus or a catalyst), a video of the motion of the macromolecule in activity can be taken. The laser is 2.1 km long. It generates X-rays by accelerating free electrons along a 1.7 km tunnel and curving the path of these electrons through a series of magnets. The radiation emitted is very intense, the affected specimens emit many photons that allow the atomic structure of the macromolecule analysed to be identified. The radiation is so intense that the specimens are then destroyed. INFN has made a fundamental contribution to the implementation of the electron accelerator by developing some of the key elements at LASA laboratory in Milan, such as the photoemissive source of cold and intense electrons, the superconductive acceleration modules and the third harmonic system for the linearisation of the beam. The European XFEL had a total cost of 1.2 billion euros and Italy contributed to the project with a funding of approximately 40 million euros, allocated by MIUR and mediated by INFN. The first experiments of the European free electron laser will start in Autumn 2017. ■



EVENTS

10 YEARS OF BOREXINO

For ten years, in the bowels of the Gran Sasso mountain, the Borexino experiment has been scanning the sky above us and the heart of our planet, installed at the INFN Gran Sasso National Laboratories (LNGS). The tenth anniversary of Borexino's full operation and collection of scientific data was celebrated at LNGS and at the Gran Sasso Science Institute (GSSI) with an event that attracted the most important physicists and astrophysicists in the world, including Art McDonald, Nobel Prize winner in Physics in 2015 for his neutrino studies, Yoichiro Suzuki, Head of Super-Kamiokande, one of the world's most important neutrino experiments, Victor Matveev, Director of the JINR in Dubna, the most important Russian physics research centre, Masayuki Nakahata, one of the authors of the measurement of the latest supernova explosion detected on Earth, Alexei Smirnov, author of the MSW effect explaining neutrino oscillation, Laura Cadonati, Deputy Head of the LIGO collaboration who along with the colleagues from the VIRGO collaboration made the historic discovery of gravitational waves, Jim Cao, Vice President of IHEP, the Chinese high energy physics institute, and many others. Their host was Gianpaolo Bellini, creator of Borexino and its coordinator for 22 years.

With important results ranging from the measurement of the properties of solar neutrinos in a wide energy spectrum, of the Sun's energy at the time of its generation, to the detection of geoneutrinos and to the first observation in a vacuum of the neutrino oscillation phenomenon, Borexino has had and still has significant resonance in all major international conferences, giving fundamental contributions to our advances in physics, astrophysics and geophysics. These results were made possible thanks to the technological success of Borexino, which holds the world record for the "most radio-pure" experiment in its sector. The experiment, the result of a collaboration between European countries (Italy, Germany, France, Poland), the United States and Russia, will continue its data acquisition for a few more years, improving the accuracy of the measurements already taken as well as addressing new ones. ■

**RESEARCH****CASSIOPEIA A IS NOT THE COSMIC SUPER ACCELERATOR IT WAS THOUGHT TO BE**

For decades, scientists have thought that galactic cosmic rays were accelerated, up to the highest observed energies, in what remains after the explosion of a supernova. Today, the MAGIC (Major Atmospheric Gamma-ray Imaging Cherenkov) telescopes, in which Italy is participating with INFN and the Italian Institute for Astrophysics (INAF), studying the residue of the Cassiopeia A supernova – which had so far been considered one of the best cosmic accelerator candidates – have discovered that, in reality, it does not have the necessary energy. This result, though revealing to us that the hypotheses concerning Cassiopeia A were incorrect, is of great interest and impact for the scientific community: in fact, by eliminating one of the best cosmic accelerator candidates, it clearly indicates that we must also extend our search in other directions.

Cosmic rays are particles that fill our galaxy with a broad energy spectrum, up to energies far superior to those that manage to reach the laboratories on Earth. Cassiopeia A, a famous supernova residue, produced by a giant explosion of a massive star approximately 350 years ago, seemed to be the perfect candidate for a PeVatron, i.e. a particle accelerator up to energies in the order of the PeV (1 PeV = 1,000 TeV). However, contrary to what was expected, in Cassiopeia A, particle energy only reaches a few tens of TeV.

The study which led to this conclusion was led by scientists from the Institute for Spatial Sciences (ICE - IEEC-CSIC, CSIC), the Institute for High Energy Physics (IFAE) and the Institute of Cosmic Sciences of the University of Barcelona (ICCUB), Spain, and is based on more than 160 hours of data acquired between December 2014 and October 2016 by the MAGIC telescopes. ■



OUTREACH

ITALY AND INTERNATIONAL SCHOOL PROGRAMS

There are numerous initiatives in which the Italian Institute for Nuclear Physics (INFN) collaborates which are addressed to high school students throughout Italy, in which young students have the opportunity to become acquainted with frontier particle physics research, discussing with their peers abroad.

An absolute novelty will be held on November 14: the World Wide Data Day (W2D2), organised this year for the first time by the International Particle Physics Outreach Group (IPPOG), of which the INFN is a member. Students will learn from their teachers how to analyse the real data of the CERN experiments and will then connect to discuss the overall results with other student groups worldwide who have simultaneously analysed the same data, in videoconference (in English). On November 30, on the other hand, the International Cosmic Day (ICD) will be dedicated to cosmic rays. Students, who in order to participate will have to go to the INFN divisions in universities, will analyse the data of real cosmic ray "detector". The same spirit is behind CERN's "historic" Masterclass, organised in collaboration with IPPOG for more than 10 years now by INFN, inspiring all these initiatives. Students, by going to the INFN divisions, will become researchers for a day, analysing the real data of the CERN experiments. The CERN Masterclasses will take place between February 15 and March 28 2018 throughout the country. Finally, CERN has announced the new edition of the "Beamline for Schools" competition, which offers high school students from all over the world the opportunity to carry out a real experiment they have designed at the prestigious Swiss laboratory. The teams wishing to participate must register on the CERN website by March 31 2018. There will also be an all Italian selection of teams, among which INFN will choose one team to conduct its experiment in one of the Italian laboratories. ■

» **FOCUS**



**MESSENGERS
FROM DISTANT GALAXIES**

A result published in September in *Science* by the Pierre Auger Observatory situated in Argentina, in Mendoza Province, answers questions that scientists have been asking for half a century. Where do high energy cosmic rays come from? Are they produced in our galaxy or do they come from distant galaxies? Auger's recent results clearly indicate an extragalactic origin of these particles, an important first step that will be followed by many others in order to identify the sources that emitted them.

Cosmic Rays are high energy atomic particles and nuclei that, moving almost at the speed of light, hit the Earth from every direction and possess different energies. The experiment obtained this important result by observing very high energy cosmic particles (of the order of tens of exaelectron volts). At these energies, cosmic rays do not arrive uniformly from all directions in the sky. In fact, the frequency with which they arrive shows an excess in an area located about 120° from the centre of our galaxy, from a direction distant, therefore, from the galactic centre.

The Pierre Auger Observatory is the largest cosmic ray observatory ever built by man, an international collaboration with over 400 scientists from 18 countries. Situated in the heart of the Argentine Pampas, it is named after the French physicist Pierre Auger, the discoverer of extended air showers. The observatory is a hybrid system that includes surface detectors and fluorescence telescopes situated in proximity to the Andes Mountains at a height of 1400 metres. The surface detectors (approximately 1600) cover an area of 3000 km^2 , spaced 1.5 km apart, and are able to observe swarms of cosmic rays when they hit the Earth's surface. The fluorescence telescopes (27 in total), on the other hand, observe the weak light produced by the swarms while they form in the atmosphere (Cherenkov radiation). The joint activity of the two detection systems allows the energy and direction of the cosmic rays to be identified and the fundamental information on the location and type of sources to be traced. INFN has contributed to the

» FOCUS

implementation of the Pierre Auger Observatory and is actively participating in its upgrade program. About 15% of the scientists of the Auger collaboration are Italian and their participation in the research activities of the Observatory is possible thanks to the contribution of the Italian Institute for Nuclear Physics, the Italian Institute for Astrophysics and the Universities of L'Aquila, Catania, Milan, Federico II of Naples, Rome Tor Vergata, Salento and Turin, of the Politecnico of Milan and of GSSI.

Auger is part of a global multi-messenger astronomy program that sees INFN engaged in the Fermi, MAGIC, CTA, KM3NeT, DAMPE and VIRGO experiments. With the development of new detectors and experimental methods, multi-messenger astronomy, engaged in the coordinated detection of electromagnetic signals, cosmic rays, gamma rays, high energy neutrons and gravitational waves will allow us to observe the universe in its variety, integrating the results obtained in particle physics, theoretical physics and astronomy in a unitary framework. ■

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