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Istituto Nazionale di Fisica Nucleare

INTERVIEW

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THE PARTICLE PHYSICS SCIENTIFIC COMMUNITY APPROVES THE NEW EUROPEAN RESEARCH STRATEGY IN THIS FIELD

Interview with Roberto Tenchini, President of the INFN Particle Physics National Scientific Committee

On 19 June, the new ESPPU (European Strategy Particle Physics Update) document, which sets out the scientific objectives and new challenges that will shape the future of research in this field in the short and long term, was officially approved at an open session of the CERN Council. This event marked the conclusion of a process, started in 2017, coordinated by the European Strategy Group (ESG), a working group of experts that discussed with the entire international scientific community in order to identify priorities and outline recommendations to strengthen the scientific, technological, economic and human capital of major research infrastructures. On this issue, we spoke with Roberto Tenchini, President of the INFN National Scientific Committee 1, who directs and coordinates the research activities of the Institute in this field.

What objectives inspired the new strategy?

The update of the European Particle Physics Strategy was obviously inspired and guided by science. As a first step in the process, priority scientific objectives were identified and on the basis of these, projects to achieve them were defined and will now have to undergo studies to verify their feasibility. The recommendations in the strategy document indicate, as primary scientific objectives, precision measurement of the properties of the Higgs boson and exploration of high energy frontiers as routes to enter the unexplored territory of the new physics beyond the standard model.

And what milestones does it outline?

The first milestone in the short term is the completion of the high luminosity phase of the Large Hadron Collider (LHC), the High-Luminosity LHC (HL-LHC) project already underway at CERN.

In the medium and long term, on the other hand, the aspiration and the challenge is to be able to build first a "Higgs factory", such as a Higgs boson factory capable of producing these particles in great abundance, based on electron-positron (e+e-) collisions. In this first phase, the objective is to investigate the Z, W and, precisely, the Higgs bosons in detail, substantially increasing the knowledge of what is called "electroweak physics".

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This project should also serve to lay the foundations for a future proton collider that will allow previously unexplored energies to be achieved, reaching 100 TeV in the centre of mass. This can be achieved through the construction of an infrastructure that can firstly accommodate an electron and positron accelerator and subsequently a new generation proton machine. The scientific milestones clearly imply technological challenges: the accelerators of the future will, in fact, require the development of highly innovative technologies, such as the construction of large magnets based on high temperature superconductivity.

How does the new European strategy fit into the global context of research in this field?
Europe is currently the world leader in the high-energy frontier of particle physics. This strategy, if implemented, will allow this leadership to be maintained and consolidated, with repercussions on scientific and technological research that will go well beyond particle physics. Furthermore, Europe maintaining a "frontier" vision for particle physics is also an important opportunity for non-European countries to access new facilities in an open science environment and develop complementary and diversified programmes.

What should the relationship between particle physics and other related research areas, such as astroparticle physics and nuclear physics, be according to the new strategy?
The documents produced for the ESPP update recall that particle physics has close scientific and historical links with the study of the universe and with fundamental physics not based on particle accelerators. A clear example concerns the search for dark matter, an area in which studies at accelerators and those with experiments based on other techniques are complementary. Also, nuclear physics has strong links with high energy physics, suffice it to mention the LHC programme, a machine that accelerates not only protons but also ions, allowing nuclear physics studies: the detailed study of quark and gluon plasma is an important component of the global strategy. In this context of research collaboration and complementarity, the document underlines the importance of CERN continuing to act as a hub for certain experiments in complementary disciplines. The new strategy therefore underlines the importance of exploiting synergies between the various sectors of fundamental physics, whose activities are also based on the use of technologies that can be applied in more than one of these sectors.

What impact does the community expect outside the field of fundamental research?
The technological repercussions of a robust fundamental physics programme are evident, as history teaches us: there are many examples that demonstrate that basic research acts as a stimulus for technological innovation and is therefore able to generate significant benefits for our society and the economy of countries that invest in this research. For example, high priority is given in the strategy documents to the

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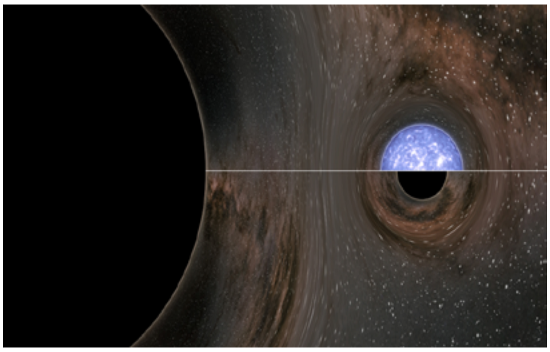
development of magnets based on high temperature superconductivity, a key technology for developing next generation accelerators and which at the same time is expected to have a significant impact on many civil applications, such as public transport. It goes without saying that maintaining world leadership in particle physics research in Europe also means achieving leadership in significant and very promising technological areas for the future. Basic research is the driver of progress because it enables us to make those leaps forward in both scientific and technological knowledge that trigger veritable paradigm shifts for societies. Fundamental research is the cornerstone on which we build and sustain our ability to effectively address the big challenges of the future.

What does approval of the strategy paper mean for the particle physics scientific community?
It is a milestone for particle physicists because it provides a common vision and an indication of a shared direction, both in the short and medium to long term. Completion of the LHC programme, preparation of Technical Design Reports (TDR) for future accelerators, research and development (R&D) on new detectors and new accelerator techniques will be the primary activities of our scientific community in Europe in the coming years. ■



RESEARCH

VIRGO AND LIGO OBSERVE A MYSTERIOUS OBJECT MERGING WITH A BLACK HOLE

For a long time the lack of observations of compact objects with masses ranging from 2.5 to 5 solar masses has left astrophysicists perplexed. This "grey area" is called mass gap: it is a range of masses apparently too light for a black hole and too heavy for a neutron star. Now, the scientific collaborations of the Virgo and LIGO gravitational wave interferometers have announced the first observation of an object that, having a mass of approximately 2.6 solar masses, is in the mass gap, thus questioning it. The nature of the object remains unknown, because observations with gravitational waves alone do not make it possible to distinguish whether it is a black hole or a neutron star. This object was swallowed, 800 million years ago, by a black hole of 23 solar masses, generating a final black hole with a mass of approximately 25 times greater than the mass of the Sun and emitting an intense gravitational wave. Another peculiarity of this event is the relationship, hitherto never observed, between the masses of the two astrophysical objects: one is approximately 9 times heavier than the other. The detection of these new classes of events also pushes theoretical models and analysis tools to their limits. The signal associated with this unusual fusion was detected by Virgo and the two LIGO instruments on 14 August 2019 - that's why it was called GW190814 - and, thanks to the delay between the arrival times of the signal on the different detectors, it was possible to locate its source within an area of approximately 19 square degrees. The astronomical community was immediately alerted: many terrestrial and space telescopes searched for electromagnetic waves, but no one picked up any signals. The study of the event was published on 23 June in The Astrophysical Journal Letters. ■

RESEARCH

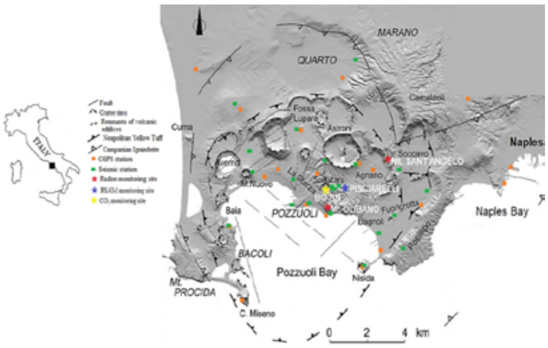
AMS: EVEN COSMIC RAYS HAVE A WEIGHT

The measurements of the AMS-02 experiment carried out on the International Space Station (ISS) have improved the knowledge of the properties of cosmic rays by detecting subtle differences between heavy and light rays, thus providing new opportunities for understanding the origins and propagation of cosmic particles. Indeed, the scientific collaboration of the AMS experiment recently published a new high-precision measurement of the abundance and shape of the primary neon, magnesium and silicon cosmic ray flux spectrum in Physical Review Letters. The analysis of the properties of this class of cosmic rays, less abundant than other lighter primaries such as helium, carbon and oxygen, provides unique information for studying their astrophysical sources in the Galaxy and for understanding the mechanisms of their propagation in the interstellar medium and detection in the Solar System. In fact, neon, magnesium and silicon cosmic rays show a similar dependence of their intensity according to energy, which is, however, different from that characteristic of lighter primary cosmic rays, thus highlighting that there are different classes of primary cosmic rays with different properties. The research, which was indicated as the Editor's suggestion by PRL, was carried out as part of an international collaboration in which researchers from INFN, the Universities of Bologna, Milan Bicocca, Perugia, Rome Sapienza, Rome Tor Vergata and Trento and the Italian Space Agency (ASI) are participating for Italy. ■

APPLICATIONS

CARBON 14 DATING: REPORT OF THE HOLY FACE OF LUCCA PRESENTED

On 19 June, the results of the diagnostic tests on the Holy Face, an ancient and imposing wooden crucifix (247 cm) of great historical-artistic and religious importance, were presented to the press. The measurements, carried out by a team from the INFN Laboratory for Cultural Heritage and Environment (LABEC) in Florence, using the carbon 14 method, proved decisive in giving an answer to the controversial problem of when the work was carried out, which most experts believe dates back to the second half of the 12th century. The results indicate, however, that the crucifix can be dated between the last decades of the 8th and the beginning of the 9th century: it would therefore be the oldest wooden sculpture in the Western world. The analyses were conducted within the scope of INFN CHNet (Cultural Heritage Network) thanks to the LABEC particle accelerator using the AMS (Accelerator Mass Spectrometry) technique, which dates organic materials (such as wood, tissue or bone) through the analysis of a carbon isotope: carbon 14, also called radiocarbon. ■



MULTIDISCIPLINARY RESEARCH

FROM RADON MONITORING NEW RESULTS ON THE ACTIVITY OF THE PHLEGRAEAN FIELDS

With a study that lasted seven years, from 2011 to 2017, a group of researchers from the L. Vanvitelli University of Campania, INGV National Institute of Geophysics and Volcanology and INFN monitored the radon emitted in two sites of the Phlegraean Fields caldera. The results were recently published in the Scientific Reports of Nature journal. Two radon measurement stations designed and built by INFN researchers were used for the radon measurement. As part of a collaboration with the INGV, the two prototypes were installed at the Phlegraean Fields in two sites 1 to 4 km from the Solfatara and Pisciarelli areas, where the current phenomenology is more evident. The instruments acquired data automatically, providing a unique set of radon data and environmental parameters, which show variations over time well correlated with the most classic geophysical and geochemical parameters regularly monitored at the Phlegraean Fields. These results represent an absolute innovation in the study of the Phlegraean caldera and mark a significant step forward in the use and interpretation of the radon signal, indicating that extensive time series, properly filtered by the effects of environmental parameters, are an excellent additional tool in monitoring volcanic activity. ■

SPACE

EUCLID SPACE TELESCOPE NEARS FINAL INTEGRATION

The ESA - European Space Agency's Euclid mission is about to reach another milestone on its journey to launch in 2022. Its two instruments, VIS (VISible Instrument) and NISP (Near Infrared Spectro-Photometer), implemented with a significant Italian contribution from the National Institute for Astrophysics (INAF) and INFN, coordinated by the Italian Space Agency (ASI), were completed and delivered to be integrated with the telescope and, subsequently, with the rest of the satellite. Euclid consists of a 1.2 metre mirror telescope designed to operate at both visible and near-infrared wavelengths. It will have the task of creating an extremely detailed map of the distribution and evolution of dark matter and dark energy in the universe. Integration of the on-board software of the two instruments, which was developed by INAF researchers, and validation and testing of the hot electronics of the NISP instrument and of the application software of the ICU module (Instrument Control Unit) were carried out by researchers from various INFN divisions, the main contribution came from the Bologna and Padua INFN divisions. By the end of its operational life, of approximately 6 years, Euclid will have produced images and photometric data for more than one billion galaxies and millions of galaxy spectra, data that will be of great importance for many other areas of astrophysics. ■

TECHNOLOGY

SUPERKEKB WINS NEW WORLD RECORD FOR BRIGHTNESS

The SuperKEKB accelerator, at the KEK laboratory in Japan, recently set a new world record for brightness, achieving $2{,}25\times10^{34}$ cm^{-2} s^{-1}, and thus breaking the previous record of $2{,}14\times10^{34}$ cm^{-2} s^{-1} obtained in 2018 and hitherto held by CERN's LHC accelerator. In order to achieve high brightness, SuperKEKB adopted an innovative nano-beam scheme, according to which electron and positron beams collide in long and extremely thin packets with a relatively large intersection angle. This brightness record was obtained by integrating the nano-beam pattern with crab-waist, a technique that limits the distribution in space of the phases of the particles in the interacting beams and thus stabilises the collisions. The nano-beam and crab-waist concepts were conceived and developed over ten years ago, thanks to the original approach of the physics group of the accelerators of the INFN Frascati National Laboratories (LNF), at the time led by the Italian physicist Pantaleo Raimondi. The effectiveness of these new concepts in increasing brightness and containing the noise affecting the detector was experimentally demonstrated in the years 2007-2009 on LNF's DAFNE collider, and DAFNE's nano-beam and crab-waist collision patterns were then successfully integrated with the complex apparatus of the KLOE2 experiment, to which DAFNE provided data for three years. The record achieved at SuperKEKB now confirms these techniques to be very promising for future accelerator machine development projects.

INTERNATIONAL PROJECTS

CRAB NEBULA OBSERVED BY THE FIRST TELESCOPES OF THE FUTURE CTA PROJECTS

Two successes for the new telescopes of the next generation CTA (Cherenkov Telescope Array) observatory, made possible by the technological solutions developed in particular by INFN and INAF, National Institute for Astrophysics. The pSCT telescope, a prototype of a Schwarzschild-Couder type telescope at the VERITAS (Very Energetic Radiation Imaging Telescope Array System) observatory in Arizona, USA, recorded its first gamma-ray signal from the Crab Nebula during the observation campaign conducted between January and February this year. This result is crucial for the prospects of the SCT project and for the CTA observatory in general. Another crucial result is the detection, a few days later, of the weak pulsed emission of gamma photons, again from the Crab Nebula, by LST-1, the first of four large Cherenkov telescopes (23m in diameter) which, together with a dozen or so medium-sized telescopes (12m), will comprise the array of detectors at the northern CTA site in the Canary Islands. Two results that mark the success of the technology used and demonstrate the great potential of the future observatory. ■

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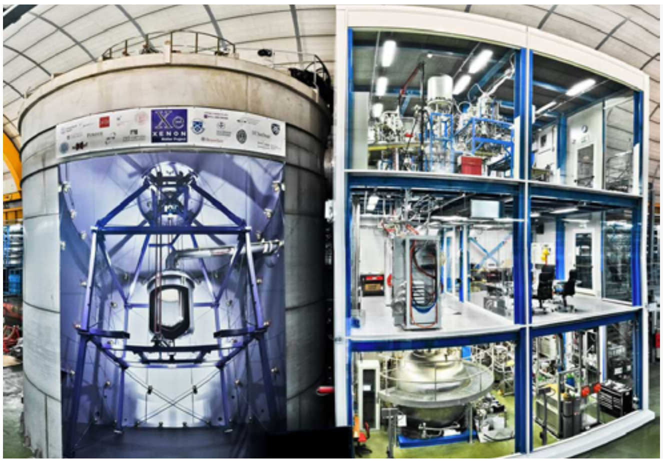

LNGS, XENON1T OBSERVES AN UNEXPECTED EXCESS OF EVENTS: TRITIUM, SOLAR AXIONS OR MAGNETIC MOMENT OF THE NEUTRINO?

On 17 June, during an online seminar hosted by the INFN Gran Sasso National Laboratories (LNGS), XENON1T, one of the leading experiments in the direct search for dark matter, operating from 2016 to 2018 at the INFN LNGS, presented the analysis of its latest data, showing an unexpected excess of events. When the data of XENON1T, which contains 3.2 tonnes of ultra-pure liquid xenon, of which 2 tonnes are enclosed in the sensitive area of the detector, were compared with the expected background, an excess of 53 events was observed compared to the 232 expected. The excess is mainly present at low energy, below 7 keV, and is due to events evenly distributed in the sensitive volume of the detector and over the data acquisition period. The nature of this excess, which could also be due to a mere statistical fluctuation, is not yet fully understood because it has characteristics that make it compatible with various hypotheses. It could, in fact, be due to a minuscule presence of tritium, an isotope of hydrogen. But it could also be a sign of something much more exciting that would take us beyond the Standard Model, such as the existence of new particles, e.g. solar axions, or, according to another interesting hypothesis, it could involve new neutrino properties.

In the first case, the excess could reside in a new background source, not initially considered in the estimate, due to a small amount of tritium. Tritium, which can be present naturally in small traces in materials, is an isotope of hydrogen that decays spontaneously, emitting an electron with energy similar to that observed. Even a few atoms of tritium out of 10^{25} atoms of xenon would suffice to explain the observed excess. At the moment there are no independent measurements to confirm or refute the presence of tritium in the detector, so a definitive answer to this explanation is not yet possible.

Another much more stimulating explanation could be the existence of a new particle. Indeed, the observed excess has an energy spectrum similar to that expected in the case of axions produced in the Sun. Axions

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are a hypothetical particle proposed to explain a particular symmetry in strong nuclear interactions, and the Sun could be a powerful source of these particles. Solar axions are not candidates for dark matter, but their discovery would mark the first observation of a class of particles well known theoretically but never observed yet, with a significant impact in the understanding of particle physics and astrophysical phenomena. If it were confirmed, this result would also have a significant impact on the search for dark matter, since the axions, produced in the primordial universe, represent a possible dark matter candidate. Alternatively, the excess could also be due to neutrinos, billions of which pass undisturbed through our bodies every second. This interpretation would imply that the magnetic moment of the neutrino - a property of elementary particles related to their spin - is larger than what expected by the Standard Model. This would be a strong indication in favour of a new physics model to explain the phenomenon.

Of the three possible explanations considered by the XENON collaboration, the observed excess is more in agreement with a sun axion signal. In statistical terms, the solar axion hypothesis has a significance of 3.5 sigma, equal to a probability of approximately 2 in 10,000 that the excess is due to a random fluctuation of the background, rather than a new signal. Although this significance is rather high, it is still not enough to conclude the definitive observation of solar axions. The significance of the tritium and magnetic moment of the neutrino hypotheses corresponds to 3.2 sigma, so they are also very much compatible with the experimental data.

The XENON1T result demonstrates the value of the technological solutions adopted and developed by the Collaboration and the extraordinary potential of the detector, which confirms to be the most sensitive in the world in the direct search for dark matter, and in general in the search for various rare events. In order to better understand the nature of this excess, the upgrade of the detector in the new phase called XENONnT will be crucial. Thanks to the aid of the LNGS staff and the XENON Collaboration personnel on site, the current health emergency has not stopped the upgrading works but only slowed them down a little: XENONnT will be in the data acquisition phase at the Gran Sasso Laboratories by the end of the year. ■

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