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Istituto Nazionale di Fisica Nucleare

INTERVIEW

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"Art and science are not separate universes": this is how Fernando Ferroni, INFN president, describes "The mistery of the origin. Myths, transfigurations and science", a virtual and immersive installation produced by Foundation Carla Fendi in collaboration with INFN and CERN for Spoleto 61 Festival of 2Worlds. The installation offered, from July 1 to 15, a trip throughout the history of our universe: from the Big Bang to the formation of galaxies, black holes, stars, planets, all the way down to our solar system. It gave the visitors a chance to discover some of the instruments employed today to explore the universe, from space telescopes, to neutrino and dark matter detectors of INFN Gran Sasso National Laboratories and to the major experiments at CERN Large Hadron Collider.
Foundation Carla Fendi, which for the first time this year has hightlighted science in Spoleto Festival of 2Worlds, awarded the "2018 Carla Fendi Prize" to Peter Higgs and François Englert, 2013 Nobel Prize in physics winners for the prediction of the mechanism that gives mass to elementary particles, and to Fabiola Gianotti, CERN Director General, for her important role and her contributions in the field of experimental particle physics. The Prize has to be devolved to activities that encourage and support science dissemination. During the Prize Award Ceremony, that took place on July 15 in Spoleto, we met Peter Higgs and Fabiola Gianotti.

Fabiola Gianotti, you are leading the largest particle physics laboratory in the world, CERN, what does it mean to lead such an important laboratory, which is trying to push beyond the frontiers of our knowledge every day?
It is a great privilege, a wonderful and extremely enriching experience. The scientific programme is exciting; from the LHC, which allows us to explore the so-called "energy frontier", to the injection

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projects, such as the Antiproton Decelerator, the only structure in the world dedicated to the study of antimatter, and ISOLDE for the production of radio-isotopes. It is also a privilege to be able to work on a daily basis with scientists from all over the world. I think CERN is not just a school of physics, but also a school of life. At least for me, it has been a school of physics and life since the first day I arrived here as an undergraduate student.

How do you define an effective strategy for a laboratory like CERN, which has to continue to produce revolutionary results, such as the discovery of the Higgs Boson?

I think the best scientific strategy today lies in the diversity of projects. There are still a lot of complex questions open in fundamental physics and there is no single instrument that can guarantee to answer them all. The best we can do is to use the whole set of experimental approaches that particle and astroparticle physics have developed over the years, also thanks to the significant progress in technology. CERN is specialised in the construction and operation of accelerators, which over time have been and continue to be among the most effective instruments for exploration in fundamental physics. LHC allows us to explore the highest energies directly, and the numerous injection projects exploit lower energy beams, but with high intensity, to deal with open questions in a way that is complementary to LHC. It really is crucial to keep as wide a programme as possible, because we don't know where the new physics is, in terms of energy scale, pairing with known particles. We therefore have to look in all possible directions. Obviously, it is fundamental to follow other approaches as well, such as projects for exploring the cosmos and experiments in underground laboratories like the INFN Gran Sasso National Laboratories, which make it possible, for example, to look for and study dark matter jointly with the accelerators.

How far are we, up to now, in our understanding of particle physics? And what is CERN aiming at?

We have taken enormous steps forward. With the discovery of the Higgs Boson, we have completed the Standard Model and, over the decades, experiments at CERN and other laboratories all over the world have allowed us to verify this theory with the utmost precision. But we also know that the Standard Model is not the final theory of elementary particles, because it does not explain open questions such as the nature of dark matter or the origin of the asymmetry between matter and antimatter in the universe. So the current challenge for CERN and other laboratories in our field is to find new physics.

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CERN is also focussing on a major upgrade of the Large hadron Collider. What is HiLumi LHC? How does it differ from the current LHC?

HiLumi LHC is an upgrade of LHC which will allow us to increase the instantaneous luminosity of the beams by a factor of around three compared to current luminosity (therefore reaching a value of 5-7 x 10^{34} $cm^{-2}s^{-1}$) and will enable ATLAS and CMS to record an amount of data around ten times greater than that of LHC. HiLumi LHC will start up in 2027 and will terminate in 2037. This unprecedented amount of data will allow us, amongst other things, to make more precise measurements of the properties of the Higgs boson, including its pairing with second generation fermions, through the decay into two muons, and to extend the potential for discovery in the new physics of around 20-30%, in terms of mass of new particles.

What advice would you give to a young physicist willing to make a significant contribution in a major scientific collaboration? What attitude should he or she adopt?

My first thought would go, above all, to what is the best strategy for enabling a young person to undertake a brilliant career in our field. My advice would be to work on more than one aspect of the experiment, from construction and/or operation of the detector to data analysis, so as to acquire a varied skillset and grow “allround”.

Gaining access to a major project may seem difficult, but during my long experience in one of the LHC experiments, ATLAS, where I started to work as a young post-doc, I have seen hundreds of young people establish themselves brilliantly. Ideas (for example on how to develop a new analysis or how to solve a technical problem with a detector), determination and the desire to learn are the greatest assets and they are noticed and acknowledged in major joint projects.

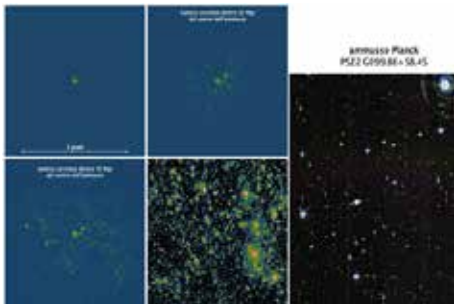
Peter Higgs, after almost 50 years from the formulation of the theory of the mechanism that gives mass to elementary particles, you have witnessed its experimental confirmation. What would you say to a young theoretical physicist who’s willing to reach such an ambitious goal? What should his attitude be like?

My recommendation to a young theoretical physicist is always to keep his/her view of the various aspects of theoretical physics broad. In my personal experience, the work, which I was involved in, was producing a theory inspired by something that had been successful in an apparently quite different area. It was essentially just a version of a successful theory of superconductivity, that’s the phenomenon where at low temperatures certain materials lose their resistance to the flow

of electricity. And somewhat ironically the successful experiments at CERN involving LHC were dependent on their ability to use superconducting magnetic materials in the magnets. So, my advice to the theorists is to keep their view of the subject broad because what has been successful in one area of physics might transfer to another area. And that is what happened to me.

On 4 July 2012, the ATLAS and CMS experiments at CERN announced the discovery of the Boson that you theorised in the 1960s. What were the feelings associated with the announcement of the discovery? How did you feel?

For years I had been aware that the "boson" would have been detected once the Large Hadron Collider (LHC) at CERN, the machine built with the discovery in mind, was turned on. I had to face up to the fact that what I had done in 1964 was going to change my life. So, it was a rather difficult experience to go through it and I think it showed on the film that was taken at the time. The film is "Particle Fever" and it includes the footage of the announcement at CERN and, it shows very clearly the emotions involved at the time of the announcement. ■



RESEARCH

ONE OF THE DENSEST COSMIC CLUMPS IN THE UNIVERSE OBSERVED

An international research group, including scientists from INFN, the Italian National Institute for Astrophysics (INAF) and the University of Bologna, has succeeded in locating one of the densest cosmic clumps in the known universe. It is the cosmic environment around the galaxy cluster known as PSZ2 G099.86+58.45. The system has a density of matter around six times greater than the average one of other observed clusters. The researchers measured the distribution of mass around the cluster up to a distance of 30 megaparsecs, in other words 6000 billion times the average distance between the Earth and the Sun. Studying this "cosmic web" is particularly complicated because there are fundamental components of the universe, dark matter and dark energy, whose properties we know nothing about. The researchers succeeded in detecting the high density of matter in the cluster because of an effect known as a "gravitational lensing", linked to the capacity of gravity to bend light and so to create distortions in the image of celestial objects that we observe. In this case, the light generated by the galaxies that lie behind the studied cluster is bent and amplified by its gravitational field. By analysing the shape of more than 150,000 galaxies, the research group managed to calculate the large concentration of matter around the cluster itself. A large number of numerical simulations led to interpreting the observational analysis of the formation of cosmic structures, which allowed us to quantify that less than 1% of galaxy clusters have such a dense cosmic web. The results of the study have been published in Nature Astronomy. ■

TECHNOLOGY TRANSFER

THE R2I NETWORK FOR ITALY WAS SET UP

Making use of technology developed by INFN and CERN is now a concrete opportunity for many hi-tech Italian companies, spin-offs and small businesses, that are willing to back and invest on innovation. Agreements have now actually been signed between INFN and the first Business Innovation Centres (BIC), which are the businesses' incubators and accelerators that applied to participate and were selected to take part in the Network R2I, Research to Innovation.

The R2I Network is an idea proposed by INFN and CERN with the aim of supporting initiatives in technology transfer in Italy, by promoting development of innovative products and services, starting from frontier technology developed in the field of basic research in particle physics. The BIC network managed by INFN itself is the hub of the project, which has already taken in the incubators of I3P, of the Politecnico di Torino, the BioIndustry Park of Colleretto Giacosa (Turin), and Cubact of the Università di Sassari, which will now have to run a process of assessment and selection to identify the start-ups interested in INFN and CERN technologies and commit to providing support, by financing infrastructures and consultancy for 40,000 euros. The next important date for R2I will be in September, when the Technology Transfer websites of INFN and of the BICs belonging to the network will publish the first call for tenders open to companies interested in joining the project. ■

TECHNOLOGY TRANSFER

PHYSICS AND CULTURAL HERITAGE: CHNET WAS LAUNCHED IN JULY

On July 9th the launching event of CHNet (Cultural Heritage Network) the INFN special network focused on cultural heritage, took place in Rome. The event, organised in collaboration with the Ministry for Cultural Heritage and Activities (MiBAC), provided an opportunity to take stock of the experiences, technology and skills developed over more than thirty years in the multi-disciplinary field of physics applied to cultural heritage, where joint operations between research and the safeguarding activities, of the MiBAC structures, have always played a strategic role. The congress was organised into four presentation sections entitled Analysis, Research, Training and Sustainability (ARTS), which correspond to the lines of development of the CHNet network. CHNet focuses on several topics: leading-edge analyses available for museums, supervisory boards, archives and sites of public and private culture; multi-disciplinary and frontier research; higher education; and public engagement activities for all ages. The objectives are gaining international visibility and competitivity not only for the beauties of our heritage, but also for the technology and innovation employed to preserve, safeguard, and enhance them, and responding to the ever-growing demand for cross-cutting skills. The day was rounded off by dealing with the issue of sustainability of the CHNet network activity, which is carried on jointly with the sector stakeholders and in a national and international context. In this frame, a fundamental feature is the collaboration between INFN and the Grant Office of the Ministry, which is the support office for attracting public and private investments in activities associated with the cultural heritage and artistic production. ■

INTERNATIONAL COLLABORATION

DUBNA: NEW AMBASSADOR OF ITALY VISITED JINR

On 17 July, Ambassador Extraordinary and Plenipotentiary of the Italian Republic in the Russian Federation Pasquale Terracciano paid his first official visit to the Joint Institute for Nuclear Research. The Ambassador was accompanied by the First Counselor of the Department of the promotion of Italian culture, science and language and coordination of the consular network Walter Ferrara and Scientific Attaché Aldo Spallone. Moreover, leaders of the Italian National Institute for Nuclear Physics, namely INFN President Fernando Ferroni and INFN Vice-President Antonio Masiero, also arrived at Dubna.

Pasquale Terracciano was appointed as official representative of the Italian Republic in the Russian Federation at the beginning of 2018. The main goal of the Ambassador's visit to Dubna was acquaintance with JINR and its fields of scientific activities, which is realized with a very strong connection with Italy. That's a historical connection due to Bruno Pontecorvo and the inspirational work that he conducted in this research centre, but there's also a very long tradition of cooperation in scientific fields, in particular in physics. In fact, an important agreement was signed in 1996 between the Italian research institutions and the Dubna centre. And last year, during the visit of President of the Italian Republic Sergio Mattarella, a more ambitious agreement was signed in the Italian Embassy in Moscow.

INFN has been cooperating with JINR for many years, by doing experiments together, hosting JINR researchers in Turin, and then people from Turin used to go to Dubna. Moreover, INFN and JINR researchers have been working together in CERN, in Geneva, for a long time. The cooperation is now particularly significant as JINR is at the phase of intense development with the ambitious scientific project of the accelerator NICA (Nuclotron-based Ion Collider fAcility). As an example, among other outputs of this proficient collaboration, the heart of the MPD (Multi Purpose Detector) experiment at NICA is made in Italy, in Genoa, with the contribution of INFN. ■

APPOINTMENTS

GIUSEPPE BATTISTONI APPOINTED DIRECTOR OF THE TIFPA

Giuseppe Battistoni is to become the new director of the TIFPA (the Trento Institute for Fundamental Physics and Applications), the INFN's National Centre dedicated to particle physics research and the development of cutting-edge technologies in sensoristics, space research, supercomputing and biomedicine. Battistoni, who will take up his post this coming 2 September, to replace Marco Durante, has dedicated the last fifteen years of his career applying nuclear physics and particle physics to medicine, focusing especially on hadrontherapy. This field deals with both developing Montecarlo simulations and experimenting nuclear processes relevant to therapy, as well as taking part in developments of techniques for live monitoring of treatments.

TIFPA grew out of joint cooperation between INFN, the University of Trento, the Bruno Kessler Foundation and the Provincial Health Service Authority (APSS) and has become a unique project in Italy, on account of its ability to integrate basic research, technology transfer and innovation, while also involving infrastructures such as the Centre for Materials and Microsystems, the ECT centre for theoretical physics of FBK and the new accelerator for oncological protontherapy run by the APSS. ■

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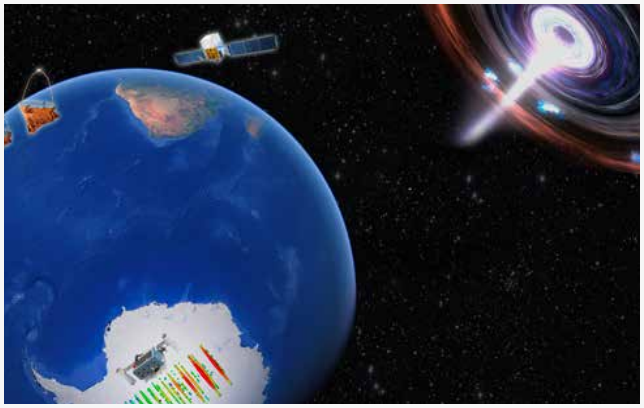

FIRST OBSERVATION OF NEUTRINOS AND PHOTONS EMITTED BY THE SAME COSMIC SOURCE

For the first time, we have been able to identify the possible source of a cosmic neutrino, thanks to its association with a gamma ray source. We are talking about a blazar, that is an active galaxy with a supermassive black hole at its centre, at a distance of 4.5 billion light-years, in the direction of the constellation of Orion. Researchers achieved this extraordinary result, published in Science, by combining the data from the IceCube neutrino detector, which operates among the glaciers of the South Pole, with 15 other experiments for detecting photons from Earth and in space. The INFN, the National Institute for Astrophysics (INAF), the Italian Space Agency (ASI) and various Italian Universities made decisive contributions by participating with their researchers in many of the experiments and observatories involved in the discovery.

On 22 September 2017 the IceCube neutrino detector observed an interesting neutrino, then named IC-170922A. This was of interest, because its extremely high energy, equal to 290 TeV (teraelectronvolts, one thousand billion electronvolts), showed that, in all probability, it originated from a very “active” remote celestial object. Since, in theory, production of cosmic neutrinos is always accompanied by gamma rays, when IceCube observed IC-170922A, it immediately sent a “neutrino alert” to all telescopes, spread around in space and on earth, in the hope that their observations might help identifying the source accurately. And that’s what happened: the Fermi satellite, designed by NASA with an important contribution from ASI, INAF and INFN, observed through its LAT telescope very high energy gamma-waves coming from the direction of the neutrino and found an emission coinciding with a source of gamma-rays in an “excited” state, the blazar TXS 0506+056, which is an active galaxy, expelling a jet of relativistic matter, particle and radiation energy flows at a speed close to that of light. Fermi-LAT immediately passed on the alert via an astronomical telegram, allowing all the other 14 experiments to aim at the source. The Italian AGILE satellite, made

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by ASI with the contribution of INAF and INFN, then confirmed the Fermi-LAT information with another Telegram. The MAGIC telescopes, desgined and run with a major contribution from INAF and INFN, on the island of La Palma in the Canaries, to study the gamma-rays from Earth through Cherenkov radiation produced by the interaction of gamma-photons from celestial sources with the Earth's atmosphere, also turned their gigantic mirrors towards the source and, after 12 hours of observation, managed to detect it, observing it at an energy one thousand times greater than that of Fermi and thereby supplying another important piece towards the completion of this discovery.

This unprecedented observation has provided a solid clue towards explaining one of the biggest as yet unresolved mysteries: the origin of ultra-high energy cosmic rays. Cosmic rays are actually composed mainly of protons, electrically charged particles which are then deviated by magnetic fields permeating space, preventing us from tracing them back to their origin. Help in clearing up this mystery, which has lasted more than 100 years, therefore comes from neutrinos, which are actually produced by high energy protons. Since they are neutral particles with a tiny mass, neutrinos are not deviated by magnetic fields and interact very little with matter, so they prove to be perfect messengers that can lead us right to their origin.

In the TXS 0506+056 blazar, the jet, fed by matter expelled from the accretion disk of the black hole it fell into, is the precise region where the observation of radio waves and gamma-rays tell us high-energy particles are accelerated. Now that we have observed a very high energy neutrino, as well as gamma-rays, we may conclude that, besides electrons (and positrons), protons are also definitely accelerated. We may also come to the conclusion that, in order to produce the observed neutrino, these protons must definitely be ultra-high energy. As well as providing clear evidence of the presence of accelerated protons, the IC-170922A neutrino therefore allows us to resolve partly the mystery represented by ultra-high energy cosmic rays. This exceptional result of the new-born multi-messenger astronomy therefore confirms the extremely close connection that exists between the various cosmic messengers. ■

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Cover

A distant astrophysical source emits neutrinos, later detected by DOM, IceCube detectors placed under ice, illustration © IceCube / Nsf