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» INTERVIEW

REMEMBERING NICOLA CABIBBO 10 YEARS AFTER HIS DEATH

Interview with Luciano Maiani, Professor Emeritus of Theoretical Physics at the Sapienza University of Rome, national member of the Accademia dei Lincei.

On 16 August 2010, Nicola Cabibbo passed away at 75 years old. Cabibbo was a leading figure of one of the most exciting and prolific periods in the history of particle physics: the period between the post-WWI years and the end of last century. These were the years in which the Standard Model took shape: the great theory that is still today the reference for studying the ultimate constituents of matter. The Standard Model is the result of joining and summarising hypotheses aimed at describing the behaviour of three of the four fundamental interactions existing in nature (electromagnetic, nuclear, and weak forces) and of the particles associated with these. In 1963, Cabibbo inextricably linked his name to the Standard Model when he provided a universal explanation for the weak decay of particles, with and without strangeness (strange particles contain a strange quark). He hypothesised that the weak decays of all particles are determined by the transition of a single quark, which is the overlap of the down and strange quarks, determined by a new universal constant, later named "Cabibbo angle". Cabibbo's theory satisfyingly explained the data then available, an agreement that, with the improvements in data accuracy, has become increasingly precise.

Right from its publication, Cabibbo's theory was seen as a crucial development in particle physics. Abraham Pais, in his book "Inward Bound", cites Cabibbo's theory as one of the most important developments in particle physics since the war. In "History of CERN", John Iliopoulos writes: "With this work (Cabibbo) consolidated his position as one of the main theorists in the area of weak interactions".

Cabibbo's mixing idea was then applied to neutrinos by Bruno Pontecorvo, who hypothesised a new phenomenon, neutrino oscillation.

Cabibbo's happy intuition allowed scientists in the following years to first hypothesise and then prove the existence of other types of quarks (charm, top and bottom) and to develop a flavour theory that could include the new particles. Several Nobel Prizes were awarded to those involved in developing the Standard Model, with the exclusion of Cabibbo in 2008; his death in 2010 made this exclusion definitive.

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This is still a living disappointment for Italian physics.
10 years after his death, on 15 December, the INFN Frascati National Laboratories, the place where this giant of physics started his career, paid homage to Nicola Cabibbo with a symposium dedicated to his memory. Apart from his indisputable scientific merits, Cabibbo's successes in his role as science manager were also re-traced during the event. He held this role, alongside his commitment to training new generations of physicists, as president of INFN (from 1983 until 1992) and of ENEA (from 1993 to 1998). Thus, he became a reference figure for planning Italian strategic research activities. The testimonies that followed one another in the course of the symposium included that of Luciano Maiani, who was a friend and colleague of Cabibbo, as well as his successor in leading INFN.

Professor, can you share one of your personal memories of Nicola Cabibbo with us?
It would be impossible to choose just one. Having worked with Nicola for so many years, the memories I accumulated are practically infinite. Of course, the best ones relate to the beginning of our collaboration, when he was already a very famous figure within the physics community, while I was a young researcher who had only graduated a few years before. In particular, I remember that, in 1965, I, and many other young Italian researchers, went to Brandeis University, near Boston, where Cabibbo was running his course on Weak Interactions. He was one of the school's stars. Finding a colleague of our own country there as a teacher, one who was only a little older than we were but already famous, was very exciting. It was then that, in the course of some private chats with Nicola and his wife Paola, we developed a great liking for each other, based on many shared points of view. The relationship then continued and turned into a genuine friendship. In 1967, Nicola moved definitively to Rome, where we began to collaborate, to participate in conferences together and to see each other with our respective families outside of work. It was a sincere friendship that, over the years, was never interrupted, despite the fact that, at a certain point in our lives, science management began to overlap with physics. The former first brought Nicola and then, immediately afterwards, myself to hold the role of President of INFN, which I left shortly before the end of my mandate to assume the role of director of CERN. In this period too, however, our relationship was uninterrupted, even if Cabibbo's research interests shifted towards ambitious national research projects in fields other than my own research.

What were the most important results that Nicola Cabibbo achieved in physics?
Of all the research that Nicola conducted, that which led him to hypothesise the so-called "Cabibbo angle" obviously stands out. This result allowed him to resolve a question that Feynman had pointed out to him as one of physics' crucial problems. It's worth remembering, however, that in his youth Cabibbo

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was also occupied with other questions, beginning with his work on storage rings that he undertook with Raul Gatto. They were the first to grasp the enormous potential of this technology for studying fundamental particles. In addition, Nicola was certainly one of the most important figures in constructing the Standard Model. In the 1970s, the group of Roman physicists that he led, and of which I was a part along with Guido Altarelli, Massimo Testa, Giorgio Parisi, and others, was one of the best theoretical physics schools at a European and international level. We explored the phenomenological consequences of the theory in all its aspects. The work translated into important contributions. Another great merit for which Nicola deserves to be recognised is that of having been among the first to support the idea for CERN's proton-antiproton collider. This step proved to be essential for discovering the bosons that mediate the electroweak force, thanks to Carlo Rubbia and his group.

On the other hand, what, do you think, is the legacy of Nicola Cabibbo, science manager and president of INFN?

Nicola was a great president because he succeeded in his intention to maintain the prestige and good reputation of INFN, which was already, at the time recognised and highly regarded at an international level thanks to the work of physicists like Edoardo Amaldi, Giorgio Salvini, Antonino Zichichi, the latter being the direct predecessor of Cabibbo as leader of the institute, under whose presidency the process for the realization of the National Laboratories of Gran Sasso began. As well as having known how to manage the organisation well, taking care of recruitment and staying away from favouritism and friendships, the most important contributions that Cabibbo made as INFN president were, in my opinion, two. The first concerns his commitment in the field of neutrino research. Thanks to his overall scientific vision, the Gran Sasso National Laboratories became, in fact, the meeting point for researchers - both Italian and international - such as Till Kirsten, one of the most important figures in the laboratories' creation, Ettore Fiorini, Puccio Bellotti, Gian Paolo Bellini, and others. One of the first results was the Gallex experiment observation of the neutrinos produced by the proton-proton cycle in the sun and the proof of their oscillation. The result was announced at an INFN meeting by Cabibbo himself, who was very proud of this success, just a few months before I took over. The second contribution that I'd like to recall relates, on the other hand, to the interest that Cabibbo had regarding gravitational waves. This interest led him to work hard for the INFN approval of the construction of the VIRGO observatory. The attempt, unfortunately, didn't succeed during his mandate. In any case, Nicola conveyed the necessary enthusiasm to me to take up the project again - this time with a positive outcome. The decision laid the foundations for VIRGO's construction in collaboration with the French CNRS, with the results that we have all witnessed in recent years. Italy, with VIRGO, is at the forefront in research on gravitational waves, one of the most promising frontiers in

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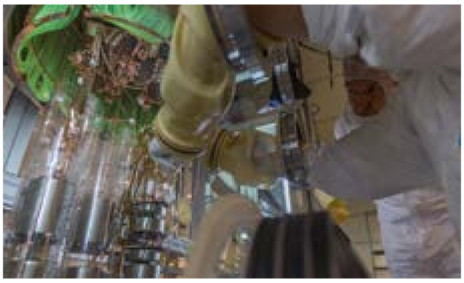
physics today.

Nicola Cabibbo was also one of the first to understand the importance of computing for the future of science. Can you tell us something about this?
The creation of the ambitious APE Array Processor Experiment is owed to Nicola Cabibbo. The project proposed to provide INFN with the computing resources necessary to physics research thanks to the creation of a supercomputer. Together with Giorgio Parisi, Nicola was the promoter of this big project, which paved the way for supercomputing from a perspective that didn't involve buying machine time from organisations like CINECA, but directly producing the hardware suitable for INFN's computing needs. It was a completely exceptional undertaking for Italy, made possible by the enlightened scientific leadership of Nicola and Giorgio and by an organisational base, that of INFN, that, on that occasion too, demonstrated its capacity to complete complex projects on time. Italy, unfortunately, hasn't developed the necessary resources to completely support the development of a similar project. In addition, at the time, Europe also hadn't understood the potentials of super computing, believing it to be a sector that was the exclusive privilege of the U.S. This attitude conditioned the future of APE, which couldn't find the necessary funding outside of Italy, and it still makes it difficult, even today, for Europe to keep up in this sector. ■



RESEARCH

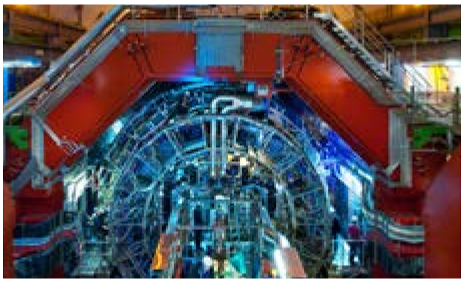
NEUTRINOS: THE PURITY OF GERDA OPENS THE WAY TO THE EXPERIMENT LEGEND AT THE INFN GRAN SASSO NATIONAL LABORATORIES

The GERDA (GERmanium Detector Array) experiment at the INFN Gran Sasso National Laboratories (LNGS) is investigating the extremely rare process called neutrinoless double beta decay, using a technology based on germanium crystals enriched with ^{76}Ge isotope. This process, if observed, would allow to affirm that the neutrino is a Majorana particle, i.e. coinciding with its antiparticle, thus allowing the determination of the neutrino mass, which has never been measured by any other experiment. The detection of the phenomenon would also constitute an important contribution to the explanation of the abundance of matter in the universe, compared with antimatter. The experiment published in Physical Review Letters, on December the 17th, the tighter *limit* on the half-life of this rare decay, setting it at $1{,}8{\cdot}10^{26}$ years, more than a million billion times the life of the universe. This exceptional result was achieved thanks to the very limited number of background events in the signal region, $5{,}2{\cdot}10^{-4}$ counts / (keV · kg · year): the lowest level ever achieved in the world in similar experiments. GERDA thus confirms the achievement of all its objectives, also demonstrating the opportunity for a new generation of experiments with even higher sensitivity. The future LEGEND experiment has precisely the purpose of increasing the sensitivity on the half-life of the double decay neutrino-free beta decay up to 10^{28} years (one hundred times more than the result of GERDA). ■

RESEARCH INFRUSTRUCTURES

HI-LUMI LHC: THE FIRST MADE IN ITALY PROTOTYPES FOR FUTURE SUPERCONDUCTING MAGNETS SUCCESSFULLY TESTED

It will be the successor of LHC, at the end of its scientific programme; it will be the biggest particle physics project of the next few years. For its implementation, the INFN scientific community has already been at work for some time with Italian industry. The project is High Luminosity LHC and will strengthen the CERN superaccelerator so as to increase its luminosity - one of the main performance indicators for a particle accelerator. The challenge for its implementation is to develop cutting-edge technology, not yet available “on the market”. The first Made in Italy results come from the INFN Genoa Division with ASG Superconductor, a leading company internationally for superconducting magnets, and from the INFN LASA Laboratory - Laboratory for Accelerators and Applied Superconductivity - and the University of Milan, with SAES RIAL Vacuum di Parma, a very innovative company in vacuum systems and cryogenics used in accelerators and research. Over the last few months, tests for checking the operation of one of the superconducting magnets, which will be part of the LHC upgrade for Hi-Lumi, were successfully conducted at CERN. The magnet concerned is a prototype with reduced length of so-called D2 magnets that, generating a magnetic field of 4.5 Tesla in an opening of 105 mm, have the function of directing beams to the collision points and then separating them. Again, in the context of the Hi-Lumi LHC upgrade, the LASA Laboratory is looking after the production and testing of 54 corrector magnets, divided into five families of 4, 6, 8, 10 and 12 magnetic poles. The magnets are being manufactured at Saes Rial Vacuum in Parma according to INFN’s design. The first magnet in sequence, a ten-pole magnet, has easily passed the acceptance tests at LASA. ■



RESEARCH

A NEW MEASURING SYSTEM FOR THE INTERACTION BETWEEN ORDINARY AND STRANGE MATTER

The international collaboration of the ALICE experiment at CERN's LHC accelerator, to which INFN makes a significant contribution, has developed and applied a new technique for measuring the strong interaction that regulates the interaction between hadrons. Called femtoscopy, because it concentrates on sizes in the order of the femtometre (10^{-15} metres), the technique is based on the quantum principle that links the impulse difference of particles that are not very far apart to their interaction. Its application to LHC collisions has enabled the collaboration to measure, for the first time, the attraction owing to the strong interaction existing between a proton and the heaviest of the hyperons, the Ω particle: a "strange" particle consisting of three strange quarks. The work was published in the Nature issue of 9 December. In the future, using the LHC as a particle "factory", the methodology will be adopted in studying the interaction dynamics of any pair of hadrons. In addition, another interesting application concerns the understanding of the state of matter that composes the nucleus of neutron stars. Because of the high pressure that characterises these stars, it is hypothesised, in fact, that inside them hyperons can also be produced, since, in these conditions, it is energetically favourable for matter to be in the strange quark form, as in well as the up and down quark form, which constitute ordinary matter. The future measurements of interactions between ordinary matter (protons) and strange matter (hyperons) using femtoscopy could, therefore, be an essential piece for developing equations on the state of neutron star matter and in determining their evolution over time. ■

INTERNATIONAL COLLABORATIONS

AN IMPORTANT STEP FORWARD TOWARDS THE FUTURE OF FERMILAB

A new fundamental step has been reached in the achievement of the objectives of the Proton Improvement Plan-II (PIP-II), the upgrade plan of Fermilab, the largest US laboratory for the study of high energy physics. The main goal of the plan, which aims to the construction of a new superconducting linear accelerator, is doubling in the near future the energy of the particle beams destinated to the next experiments. On Friday 11 December the United States Department of Energy (DoE) formally approved the aims, timing and costs of the project, in which INFN participates with an important contribution, both technological, through the construction of fundamental components for the accelerator, and scientific, contributing with its know-how to the design of one of the most important experiments that will be hosted at Fermilab, DUNE, an international collaboration devoted to the study of neutrinos. The green light of the DoE comes nine months after the start of construction work of the PIP-II accelerator, which, once operational, will represent the heart of Fermilab and will project particle physics research into the future, with particular attention for the study on neutrinos, to which DUNE is dedicated. The experiment, in which 30 countries participate, will consist of two underground detectors located 1300 kilometers apart, with the task of identifying the characteristics of the neutrinos and their transformations on their way from Fermilab, where high-energy beams of these particles will be produced using the new superconducting accelerator, to Sanford Underground Research Facilities in South Dakota. ■

AWARDS

LORENZO BIANCHINI WINS AN ERC CONSOLIDATOR GRANT FOR THE ASYMOW PROJECT

The ERC (European Research Council) has awarded Lorenzo Bianchini, researcher at the INFN Pisa Division, a Consolidator Grant for the ASYMOW project, Power to the LHC data: an ASYmptotically MOdel-independent measurement of the W boson mass, for developing a new methodology for data analysis and calibration techniques for the CMS detector of CERN's LHC accelerator. In particular, the ASYMOW project, lasting five years, aims to measure the mass of the W boson with unprecedented precision for an individual experiment, i.e. less than 10 Megaelectronvolts (MeV). This accuracy will be enough to resolve the current tension between the experimental mW measurement at the accelerators and the Standard Model's predictions. In addition, it will make it possible not only to explore more thoroughly the electroweak theory, but also to establish a milestone in measuring proton-proton interaction processes at the LHC, with implications that range beyond determining mW. All this will be made possible by a new approach to measures, which will have to be developed in detail in the course of the project and which will make it possible to maximally exploit the statistical power offered by the LHC through the CMS detector. To implement it, all the data already collected during the second cycle of activity of LHC, the so-called Run2, will be used, as well as the data produced during the next Run3, which is expected to start in 2022. ■

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MUTOMCA: A NEW PROJECT WITH MUON TOMOGRAPHY FOR NUCLEAR WASTE

Recreating in total safety a 3D map of the spent nuclear fuel produced by the nuclear power plants in Europe and stored in shielded casks, by using a technology developed from particle physics: this is the task of the MuTomCa (MUon TOmography for shielded CAsks) project. It implies the construction of a muon detector (muons are particles similar to electrons but with a mass about 200 times higher), capable of showing the interior of the shielded casks including the spent fuel assemblies in a very precise tomographic image while operating from the outside. The project is an international collaboration among the INFN, for Italy, the Jülich Research Center (FZJ) and the BGZ Company for Interim Storage, for Germany, and the European Atomic Energy Community (EURATOM).
In Europe, there are currently around 1500 casks to which this technology could be applied and the relevance of this issue will increase with phasing out nuclear energy production. Currently, no sufficiently precise method is available for a re-verification of spent fuel assemblies enclosed in thick-walled strongly shielded casks, where the inner fuel assemblies are mostly inaccessible to neutron and gamma ray detection as they are masked by the outer spent fuel assemblies. While X-rays, used in radiographs, cannot cross more than a few tens of centimeters, muons can pass through large thick layers of material, even a few kilometers. This characteristic allows the use of these particles to create three-dimensional images of large structures from the outside and in complete safety.
In the MuTomCa project context, a research team led by physicists from the Padua division of INFN, which also includes researchers from Genoa and Pavia, is working on the construction of a muon detector based on "drift tube" technology, a method often used to detect charged particles and it is used in the muon detectors of the LHC accelerator experiments at CERN, where it made a fundamental contribution, for example, to the discovery of the Higgs boson.
Once completed, the detector will consist of two modules each composed by six layers of 30 or 31 drift

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tubes filled with a particular mixture of gas. Each tube is equipped with a thin copper and beryllium wire in the centre at a voltage of 3000 V. As the cosmic muons pass, the detector is able to measure their position and direction with extreme precision: an information that makes it possible to reconstruct the internal image of the structure to be analyzed. The construction and assembly phase, in progress in Italy, will last about one year while the test phase will take place in Germany and will last about six months.
The first application of this technology dates back to the late 1960s, when it was used to study pyramids and, more recently, it was applied to the study of to volcanoes. Other applications of technologies related to cosmic muons can be found in the controls of means of transport to counteract nuclear smuggling in industrial applications to avoid accidents due to melting of radioactive sources in foundries and for the optimization of the cycle of blast furnaces. Moreover, the same technology could be used to study other types of nuclear waste stored in the past decades in concrete containers that need to be secured. ■

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