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THE GLOBAL EFFORT TO STUDY ARTIFICIAL NEUTRINOS RESTARTS IN THE USA

Interview with Sergio Bertolucci, from 2008 to 2015 director of research at CERN, today INFN coordinator of DUNE (Deep Underground Neutrino Experiment)

Following the closure of the SLAC (Stanford Linear Accelerator) PEP-II and Chicago Fermilab (Fermi National Accelerator Laboratory) Tevatron accelerators - resulting in the confluence of many American physicists towards the LHC accelerator at CERN - the US has redefined its particle physics research strategy. The research programme, scheduled until 2024, is included in the P5 (Particle Physics Project Prioritization Panel) Report and envisages the assignment of high priority to neutrino physics and re-launch of the Fermilab in Chicago, home of the most intense neutrino beam in the world.
With the Sanford Underground Research Facility, in South Dakota, Fermilab is one of the two infrastructures on which the LNBF (Long Baseline Neutrino Facility)/DUNE project is based and whose overall character is well represented by the number of countries, 27, involved in its design. The giant underground LNBF laboratory will be built to house DUNE, the world's largest experiment with international governance to study the properties of neutrinos. Presented for the first time in January 2014 to the Fermilab Committee by the then director of research at CERN, Sergio Bertolucci, LNBF/DUNE envisages laying the foundation stone by 2017 and the start of experimentation in 2024. In 2015 Italy, represented by INFN, through the Ministry of Education, Universities and Research, signed a technical cooperation agreement with the DOE for research at Fermilab. Bertolucci is currently coordinating the Italian physicists, belonging to INFN, engaged with DUNE in neutrino research.

What is the basis for this ambitious global neutrino programme?
The main point of contact between the American P5 Report and the global strategy for particle physics is the recognition that particle physics is the most globalised field of science currently in existence. The global strategy in this research area is in fact based on two considerations which represent the current situation: no geographical region in the world can imagine doing particle

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physics research without contemplating collaboration with other regions; it is also necessary that each region focuses on a flagship project with international involvement.

CERN has played a key role in the genesis of the LNBF/DUNE project.
The great innovation introduced by the LNBF/DUNE programme is that, for the first time, the US has adopted a modus operandi, which is typical of CERN. CERN has always acted as a host laboratory and collaborated with other European and worldwide research institutions, basically providing the infrastructure, but the experiments are independent entities whose governance does not depend on CERN. For the first time in the history of American research, the US has agreed to make available the infrastructure for an experiment with international governance in which the DOE is taking part but is not the main leader. CERN, on its part, has decided to cooperate and support Fermilab in the implementation of the infrastructure part, providing, for example, the giant cryostats for the underground laboratory, for the design and construction of which it has a European patent. Two years ago, CERN also launched a prototype engineering platform, the neutrino platform, which will be a point of reference for the European community engaged in neutrino research, for all the detector prototype construction and testing activities. The project has led to the creation of a gigantic experimental area: here the cryogenic technology and the detector prototypes (single-phase and two-phase), which will constitute the four DUNE detectors, will be tested.

Is it currently worthwhile focussing on neutrino research? Is it a field that can compete with the high-energy physics?
We have still understood very little about neutrinos. Until a few years ago, for example, we thought that they had no mass, then we discovered that they oscillate and, therefore, must have mass. We still do not understand precisely their nature: they could be Majorana neutrinos, coinciding with their antiparticle, or Dirac particles, distinct from their antimatter counterpart. And neutrinos could in fact be the origin of the asymmetry between matter and antimatter in the universe. Studying the mixing mechanisms of neutrino masses is also essential to complete our knowledge of particles. For example, we know in all probability that it is not the Higgs Boson that gives mass to neutrinos. One of the fields in which the Standard Model, the current theory of particles and their interactions, has been put to the test and presents critical issues is precisely neutrino physics, a complementary aspect, therefore, to the physics that we study with the LHC accelerator.

What are the scientific objectives of LNBF/DUNE? How can its results open a path on new physics?
The programme basically envisages two main goals: measuring the neutrino mass hierarchy and measuring the violation of symmetry between matter and antimatter (CP violation). As regards the mass of neutrinos, we only know that the second stage of neutrinos is heavier than the first. But

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we do not know if the third is the lightest or the heaviest of the three (normal or inverted hierarchy). This has many implications and can give important indications on the scale of CP violation, on the neutrino mixing mechanism.
Measuring CP violation, on the other hand, helps us to understand how the original matter-antimatter asymmetry was produced. As in the case of quarks with the CKM (Cabibbo-Kobaiashi-Mascawa) matrix, mixing of neutrinos is described by the PNMS (Pontecorvo–Maki–Nakagawa–Sakata) matrix, an equivalent which provides the transformation probability density. In the terms of both these matrices there are terms that indicate a CP violation and while in the case of quarks the violation is too small to justify the asymmetry between matter and antimatter, in the case of neutrinos, if this violation is large enough, it could account for the asymmetry. Calculation of the parameters of this matrix, moreover, could reveal information on new physics, on the existence of new particles, such as sterile neutrinos.

In the last 7 years you played the strategic role of director of research and computing at CERN. What benefits can the largest particle physics laboratory in the world derive from the collaboration in neutrino research?
First of all, the advantage is cultural. A mistake not to made in fundamental research is to believe that the road you are following is the right one. It is not possible to determine a priori which is the right road and it is always necessary to keep several paths alive.
There are at least two other reasons of interest. One is to maintain, within the community, a high ability to study different things. The other is a matter of research policy: if we were not to help the American researchers, we would force the United States to focus solely on their line of research and we would no longer be able to rely on the US contribution to the LHC. In general, it is very dangerous to concentrate all research in one place; only in turn supporting the American programme can we achieve a fruitful balance.

With INFN and the experiments at the Gran Sasso National Laboratories, Italy has a long tradition of experimental research on neutrinos. Among the big detectors playing a role in this field is ICARUS, a instrument that will be soon installed at Fermilab. Is it still a cutting edge technology today?
What we are exporting with ICARUS is liquid argon technology, the same that will be used for DUNE, but with much larger detectors. DUNE will in fact be hosted in a former gold mine with more than 550 km of tunnels, up to 2500 m deep. The laboratory will be built at a depth of 1550 m and will consist of 5 large rooms, one of which dedicated to hosting the service infrastructures, while the other 4 will each host a 10,000 active ton liquid argon detector, equivalent to 17,000 actual tons. ICARUS is smaller: it's a 600 ton detector, now being updated at CERN, before being sent to Fermilab. Here, meanwhile implementing the LNBF laboratory and the DUNE detectors, ICARUS will

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be used for a short baseline experiment with a neutrino beam produced by the Fermilab booster ring: an experiment entirely contained in the laboratory to verify the anomaly observer by the Liquid Scintillator Neutrino Detector experiment, at Los Alamos (LSND anomay). The phenomenon, not yet been explained, may be attributable to experimental errors or to the existence of sterile neutrinos. Thanks to ICARUS, the experiment will be repeated in order to remove any possible systematic errors. Experimentation with ICARUS at Fermilab will also be a training ground for young physicists and for development of the software of the new experimental technologies useful for the construction and management of DUNE. ■