

SYMMETRIES IN THE SUBATOMIC WORLD

Symmetries play a fundamental role in elementary particle physics. The Standard Model describing electromagnetic, weak and strong interactions, is based on a gauge symmetry which is the source of all its mathematical coherence. Electroweak spontaneous symmetry breaking is the central pillar of the model, generating gauge bosons and fermions masses and creating Higgs boson, the research of which is the major purpose of LHC collider at CERN. Since LHC start, the progress made on Higgs boson research is considerable, and a definitive answer to the question of the existence of Higgs boson such as predicted by the Standard Model is expected with 2012 LHC data. This result will be of a crucial importance and will determine future projects, such as the construction of a electron-positron linear accelerator, or various possibilities of further LHC exploitation. In addition to the Higgs boson research, precision measurements on parameters relative to electroweak interactions or to quantum chromodynamics allow decisive tests of the Standard Model and better understanding of elementary components of the matter. With this knowledge, the research for new phenomena predicted by theories beyond the Standard Model, such as a supersymmetry with its procession of new particles, or models of additional dimensions of space-time, becomes possible.

The difference between matter and antimatter, the most evident demonstration of which is the prevalence of matter in our Universe, is one of the fundamental questions of current physics. At the elementary level, it manifests itself in terms of symmetry violation between quarks and anti-quarks, or in the neutrinos sector. Finally, study of antihydrogen atom is yet another way to study the difference between matter and antimatter. Accurate measurements of symmetry violation effects of beauty type quarks is at the heart of one of LHC experiments program, LHCb. To study further this approach, some physicists are also interested in a new project, a beauty quarks “super factory”, recently approved in Italy.

Measurements of neutrino oscillation parameters, which has been demonstrated in the late 90s, will give access to the only free parameter, the angle θ_{13} . First indications of T2K and Double Chooz experiences point to a rather large value of this angle, which would allow the observation of a symmetry violation in the neutrino sector. In addition, R&D activities are on-going to study other properties of this particle: the measurement of its mass by double beta decay without neutrinos or by cosmological constraints, its Dirac or Majorana nature, the mass hierarchy between the three neutrinos families or sterile neutrinos research.

These experimental activities are accompanied by theoretical work, for results interpretation as well as for development of new models or by the provision of new tools, which is possible only through continuous exchange between the communities of theorists and experimentalists.

DARK ENERGY AND MATTER

The Universe history and the evolution of its big structures, is a very hot research topic at the international level, as well as in P2IO's laboratories. Indeed, cosmological observations show a remarkable composition of the energy content of our universe: matter that we know only represents 4% of the total, while the remaining 96% are allocated for 22% to dark matter, and for the remaining 74% to a mysterious dark energy associated with the Universe expansion acceleration, a discovery that led to the 2011 Nobel Prize in Physics.

The identification of these enigmatic dark components of the universe is one of the major challenges of contemporary physics, on the border of cosmology, astrophysics and astroparticle physics. It requires many programs of observation, simulation and phenomenological analysis, such as the direct detection of dark matter in the form of WIMPS, or its research in the form of supersymmetric particles at LHC.

The observation of cosmological radiation and of galaxies and clusters distribution aims at measuring dark energy influence on cosmological parameters.

Contributions of P2IO's teams in the resolution of this scientific enigma are multiple and concern in particular:

- A strong involvement in LHC program, both in ATLAS and CMS experiments as well as in data analysis.
- The direct detection of dark matter, where three P2IO laboratories take part in the EDELWEISS experiment. These laboratories also insure the coordination of EURECA European project, whose objective is to obtain one ton of cryogenic detectors.
- the measurement of cosmological parameters and the characterization of dark energy and of dark matter distribution via a strong involvement in the European Space Agency's major space missions, such as Planck and Euclid. Large ground surveys such SNLS, BOSS or LSST will also be very useful tools.
- Computer simulations of the Universe evolution including its big structures until galaxies.
- Indirect detection of dark matter, with significant participations in HESS-2 gamma astronomy experiment, and to its successor CTA (Cerenkov Telescope Array), as well as to FERMI space experiment.

Nuclear matter strongly coupled

The behaviour of matter on the scale of the atomic nucleus and its constituents is a fascinating area of research. The strong interaction that dominates on this scale is responsible for the confinement of quarks and gluons within the hadrons (nucleons, mesons...), but also for the existence of extreme, exotic states that can exist inside certain astrophysical objects such as neutron stars.

By studying the interactions of two colliding lead (Pb) ions in experiments in progress at the LHC (CERN), physicists hope to attain in the laboratory, in a microscopic region of space-time, the extremely high energy and matter densities that are thought to have prevailed in the Universe shortly after its violent creation in the Big Bang. According to the theory of quantum chromodynamics, a plasma of quarks and gluons, whose properties one aims to probe and disentangle, will be created in such collisions. In another energy domain, the Jefferson Laboratory (situated in Virginia, USA) elucidates the dynamics of confinement by probing the quark-gluon structure of the nucleon with continuous, high-energy beams of electrons. In 2014, following an upgrade of its CEBAF accelerator, a new cycle of experiments proposed by teams from P2IO will be undertaken. At the crossroads between CEBAF and LHC physics, a project (AFTER) employing a fixed target with extracted beams from the LHC has been initiated by teams from P2IO and is currently achieving an international dimension.

In the catalogue of atomic nuclei from which normal matter is formed, one finds, alongside those whose lifetimes are longer than that of the Universe itself, certain species whose existence is so ephemeral that their creation and detection present enormous technological challenges. These « exotic » nuclei often exhibit properties very different from those of their better-known stable cousins, and this gives them a key role in testing the nuclear models crucial to our understanding of how the elements were formed in the Universe. In order to extend our knowledge and understanding of these short-lived isotopes, many facilities throughout the world (including ALTO and GANIL in France) are exploited to study their decays, break-up, masses, excited states and their possible relevance to stellar evolution and nucleosynthesis. Teams from P2IO play a major role in this work as well as in the setting up of SPIRAL 2, the large, European, exotic-beams project currently under construction in Caen.

Alongside these experimental studies we are also seeing significant theoretical advances including, for example, the development of universal nuclear models and more fundamental descriptions of light nuclei obtained through complex « lattice simulations » starting from quantum chromodynamics itself.

Formation of star systems and life emergence conditions

The thematics related to star systems formation and life emergence conditions are in full evolution. The complex chain of events leading from a molecular cloud to a star system with all its planets is being better understood with astrophysical observations, particularly those of Herschel (sub-mm observatory launched in 2009) and soon those of ALMA (interferometer in the millimeter). Ground observations (radial velocity) and in space (CoRoT, Kepler) enrich at a rapid rate statistics on exoplanetary systems, with the observed objects increasingly close to the Earth size and multiple systems increasingly complex. The next step will be exoplanets spectroscopic characterization, in particular the detection of possible atmospheres.

On-going or planned exploration missions of solar system will have a significant impact on these issues. Based on the results of Mars Express and MRO orbiters, NASA vehicle "Curiosity" that was recently successfully launched, will explore in-situ by the end of 2012 a Mars area that could have shown favorable conditions for life emergence several billion years ago, and future missions are planned for 2018-2020 (ExoMars). The comet "rendez-vous" planned mid-2014 (Rosetta,

ESA) will allow observing and analyzing the surface of a small component having survived to initial stages of the solar system formation.

Laboratory studies of meteorites, micrometeorites and sample returns scheduled to medium term (asteroids: Hayabusa 2 and Osiris-Rex) or longer term (return of Mars samples), is quite complementary to laboratory simulations of processes leading to the complexity, especially organic, in astrophysical environments, which can lead to pre-biotic chemistry on the telluric type planets' surface ...

Combination of these three approaches (astrophysical, solar system exploration, laboratory study of extraterrestrial matter and of the processes at work in astrophysical environments) will clearly revolutionize our understanding of life emergence conditions in the Universe during the next decade.