NUCLEAR PHYSICS

The experimental research of the group in the field of nuclear structure is mainly conducted through the study of the gamma decay of nuclei excited in different types of reactions: Coulomb and nuclear inelastic scattering, fragmentation reactions, transfer or fusion-evaporation reactions. The experiments are carried out within large international collaborations in national (Laboratori Nazionali di Legnaro and del Sud) or in foreign laboratories such as GSI (Germany) and RIKEN (Japan)through the use of advanced detector arrays like AGATA , based on HPGe detectors with tracking capabilities, or with new generation scintillators like LaBr3:Ce.

The physical problems presently under analysis reflect the data-taking carried out during several experiments. They mainly concern isospin mixing at zero and finite temperature or isospin-dependent entrance effects (dynamic dipole), the study of the collective properties (rotations and vibrations) of the nucleus, and effects induced by the nuclear deformation. Very recently data have been acquired on the gamma decay of the collective giant dipole and quadrupole resonance state in various isotopes from Zr to Pb. The collective states have been excited through inelastic scattering reactions allowing the direct measurement of their wave function and identification of the isoscalar and isovector nature of the observed states. In the very next future such states (in particular the Pygmy Dipole Resonance of astrophysical interest) will be studied using Coulomb excitation with relativistic radioactive exotic beams. The experimental data will allow the study of the structure of exotic neutron-rich nuclei and the measurements of their 'neutron skin' providing additional important information concerning the isospin dependence of the nuclear equation of state.

Detectors and instrumentations are a key factor in such experimental research activity. A very active line of research focuses on the development of new instrumentation and experimental techniques based on pulse shape analysis for the imaging of the gamma source. Related topics range from the development of electronics (analog and digital) and algorithms for segmented HPGe tracking detectors and highly performing scintillators detectors (LaBr3:Ce) to gamma imaging. Furthermore, the group pursues R&D activity focused on silicon based detectors for the measurement of x-rays and charged particles together with the development of dedicated and optimized electronics.

The Milano nuclear physics group is also active in the LUNA (Laboratory for Underground Nuclear Astrophysics) experiment. This experiment makes use of an electrostatic accelerator, placed at the Gran Sasso Underground Laboratory, and delivering intense beams of protons and alpha particles. The accelerator, coupled to gas or solid targets and to particle or photon detection apparata, allows to reproduce in the laboratory the thermonuclear fusion reactions powering stars. These reactions are characterized by extremely low cross sections at astrophysically relevant energies, and their measurement is only possible due to the extremely high reduction of the cosmic background provided by the Gran Sasso underground laboratory. So far LUNA has measured a few key reactions belonging to the hydrogen burning cycle, which transforms 4 protons into an alpha particle with a net energy release. The Milano group is highly involved in this experimental activity and can offer exciting Ph.D theses, aiming at the preparation of new measurements and data taking to be performed at Gran Sasso, or dealing with data analysis which can also be carried out in Milano. Click here for further details about LUNA.

Another activity concerns the Aegis experiment, currently in the commissioning phase at Cern at the Antiproton Decelerator. The experiment aims at testing fundamental laws such as the Weak Equivalence Principle (WEP) and the CPT symmetry. In the first phase of Aegis, a beam of antihydrogen will be formed whose fall in the gravitational field is measured in a MoirÃ¨ deflectometer; this will constitute the first test of the WEP with antimatter. The activity of the Milano group focuses on the laser system for positronium excitation, the positronium production and spectroscopy and the antiproton beam monitoring.

There is also a substantial theoretical activity concerning the structure of atomic nuclei and the application of nuclear techniques to other many-body systems. The properties of collective states of different nature - density, spin and isospin modes of excitation - are calculated with state-of-the-art effective interactions, at the mean field level and beyond. The group has a long tradition in the study of the interplay between single-particle and collective degrees of freedom, and played a key role in the development of nuclear field theory. Recent progress has concerned the treatment of ultraviolet divergences associated with calculations beyond mean field using zero-range effective interactions, a better treatment of the continuum and the consequences of particle-vibration coupling on the low-energy spectra as well as on superfluid properties in open shell nuclei. Different aspects of the structure of exotic nuclei - light as well as heavy - are actively studied, in connection with experimental activity carried out with radioactive beams. Recently, a systematic analysis of two-nucleon transfer reactions has been carried out, leading to a calculation of the absolute cross sections which turns out to be in good agreement with experimental findings. The implications of nuclear structure on neutron stars - concerning the equations of state as well as the superfluid character of the inner crust and the microscopic structure of vortices induced by the rotation of the star - are also actively studied.

SUBNUCLEAR PHYSICS

Research in subnuclear physics aims at the understanding of the elementary constituents of the Universe and of their interactions. The Milano group is engaged both in experiments in particle physics performed with the use of accelerators and in astroparticle physics.

PARTICLE PHYSICS AT ACCELERATORS

Particle physics experiments using particle accelerators study fundamental interactions of matter. At present, the best theory to describe our knowledge of subnuclear physics is the Standard Model. The aim of current research is to gain a deeper understanding of certain aspects, such as the origin of the mass of these particles. In that context, the recent discovery of the Higgs boson represents a great step forward and determining its characteristics is now a priority. Scientists are hopeful that ongoing experiments will also enable them to discover new phenomena and fill some of the gaps in the Standard Model. One such example would be the discovery of supersymmetric particles, some of which are candidates for the constituents of dark matter (we know this pervades the universe, but have so far been unable to detect or describe its nature). Other examples would be the discovery of new signals that explain the asymmetry between matter and antimatter in our universe, or proof of the existence of further space-time dimensions.

In working to broaden the scope of our knowledge, experiments in subnuclear physics explore two different and complementary frontiers of our experimental limits: the energy frontier and the high intensity frontier. On the one hand, we use ever-more powerful particle accelerators to achieve ever higher collision energies and the formation of new particles at the Large Hadron Collider at CERN. Alternatively, we search for new physics phenomena in the flavor physics sector through precision measurements, inferring the presence of high mass new particles from their effect on lower energy processes.

These kinds of search require the accumulation of large samples of data that are available at high luminosity colliders, and in some cases can exceed the values of the new particle masses that can be observed directly at the LHC. Both of these lines of research are pursued at Milano University: the ATLAS experiment at the high energy frontier and the flavor experiment BaBar, as well as the SuperB project, at the high intensity frontier.

Experiments in subnuclear physics involve the use of large, highly complex equipment based on the latest technology in the field of detectors, electronics, data acquisition and computing systems. Collaborations to build this equipment involve hundreds of physicists from institutes and laboratories around the world (thousands in the case of the LHC). These projects are significant examples of effective international cooperation, bringing together the world's best physicists and providing an opportunity for young scientists to gain experience and learn fundamental skills.

ATLASexperiment at the High Energy Frontier

ATLAS is a particle physics experiment currently taking data at the Large Hadron Collider at CERN. The ATLAS detector is searching for new discoveries in the head-on collisions of protons of extraordinarily high energy. ATLAS will learn about the basic forces that have shaped our Universe since the beginning of time and that will determine its fate. Among the possible unknowns are the origin of mass, extra dimensions of space, unification of fundamental forces, and evidence for dark matter candidates in the Universe.

The Milano group had and is having an important role in the construction, commissioning and operation of the calorimeter and of the pixel detector of the ATLAS experiment. The group is presently involved in the exciting search for the Higgs boson, as well as for supersymmetric particles, a possible solution to Dark Matter enigma. The group and the INFN Computing center have contributed in an important way to the development of GRID computing and middleware software, and Milano host a TIER2 facility for the analysis of data from LHC.

Using data collected up to June 2012 ATLAS has observed an excess of events at a mass of approximately 126 GeV with a statistical significance of more than five standard deviations above background expectations. The probability of the background alone fluctuating up by this amount or more is about one in three million. The evidence is strongest in the two final states with the best mass resolution: first the two-photon final state and second the final state with two pairs of charged leptons (electrons or muons).

ATLAS has interpreted this to be due to the production of a previously unobserved particle with a mass of around 126 GeV. The new particle observed at about 126 GeV is compatible, within the limited statistical accuracy, with being the Standard Model Higgs boson. However, more data are required to measure its properties such as decay rates in the various channels (??, ZZ, WW, bb and ??) and ultimately its spin and parity, and hence ascertain whether it is indeed the Standard Model Higgs boson or the result of new physics.

More information on the ATLAS group in Milano can be found here.

Flavor physics at the High Intensity Frontier

BABAR is a particle physics experiment designed to study some of the most fundamental questions about the universe by exploring its basic constituents - elementary particles. The BABAR Collaboration's research topics include the nature of antimatter, the properties and interactions of the particles known as quarks and leptons, and searches for new physics.

Research topics of interest of the Milano group are the searches for new physics in charm e B meson decays. By analyzing the large data sample available in BABAR, we are looking for signatures that cannot be explained in the Standard Model of particle physics, and would require an alternative explanation.

The SuperB project has been included in the Italian Ministry National research plan in 2010, and in June 2011 the accelerator site has been chosen to be in the University of Tor Vergata campus, in Rome. The SuperB project consists of an e+e- collider with a general purpose detector dedicated to the study of precision flavor physics. This will be built at the Cabibbo Laboratory and commence taking data later this decade. SuperB is expected to accumulate: a data sample more than 100 times the BABAR data sample. If new physics phenomena will be directly observed at the LHC, we will need data from very sensitive heavy flavor experiments to understand them in detail. On the other hand, if such signatures of new physics are not observed at the LHC, then the excellent sensitivity provided at the luminosity frontier by a next generation super B-factory provides another avenue to observing new physics at mass scales that, depending on couplings, can extend up to 10 TeV or more.

The Milano group research activity is focused on the design and construction of the silicon vertex detector of SuperB, and on the simulation of its response. In particular, the Milano group has leading a role in the design and construction of the vertex detector readout electronics, and in the simulation of the vertex detector performance.

ASTROPARTICLE PHYSICS

The particle and nuclear astrophysics program addresses questions of fundamental physics in astrophysical systems. Current research topics include Solar Neutrinos, Neutrino Oscillations, WIMP Dark Matter searches, Neutrino-less Double Beta Decay, and detection of Ultra-High Energy Cosmic Rays.

Solar Neutrinos: Milano has a major role in the Borexino Solar Neutrino Experiment at the Gran Sasso Laboratory. The detector consists of 1300 tons of ultra-pure liquid scintillator, and it made the first direct-counting measurement of low-energy neutrinos from the Sun (7Be and pep neutrinos). The measurement has allowed to verify some fundamental features of neutrinos oscillations. It serves also as a fundamental test for the theory of the complex physics of the Sun and of stellar evolution.

Neutrino Oscillations: The Borexino detector is perfectly suited to host a short baseline neutrino oscillation experiment able to shed light on the several intriguing experimental hints accumulated so far pointing to the possible existence of a sterile neutrino at the few eV mass scale. The experiment will be carried out by using a 51Cr neutrino source placed close to the detector and in a second phase by deploying a 144Ce-144Pr anti-neutrino source inside the detector. The search for sterile neutrinos is also addressed by the Icarus collaboration, that is preparing a dedicated experiment with two liquid argon detectors complemented by magnetic spectrometers to be operated on a new short base line facility at CERN. Meanwhile, the analysis of data collected with the CNGS neutrino beam will provide results on neutrino interactions and neutrino oscillations. There are still many questions to be answered about neutrinos, questions that can point to new phyisics beyond the standard model. Some of these questions, like sterile neutrinos, the mass hierarchy and the existence of a CP-violating phases, can be aswered by accelerator neutrino beams coupled with massive Liquid Argon detectors, of which Icarus is the first successful prototype. Icarus is a pioneering detector, that can open the way to future experiments on proton decay and CP violation in the neutrino sector.

WIMP Dark Matter Searches: There is an overwhelming evidence that some 30% of the universe is in the form of cold dark matter, but the nature of this matter remains a mystery. The most attractive theory is that it is Weakly Interacting Massive Particles (WIMPs) that froze out of the early universe. A powerful way of detecting WIMPs directly in the local galactic halo is to look for the nuclear recoils produced when they collide with ordinary matter in a sensitive detector. DarkSide is an innovative experiment for the direct detection of dark-matter particles at Gran Sasso Laboratory. The design concept involves a two-phase, liquid-argon time-projection chamber (LAr-TPC) in which the energy released in WIMP-induced nuclear recoils can produce both scintillation and ionization.

Ultra High Energy Cosmic rays: The Pierre Auger Observatory (PAO) is an international cosmic ray observatory designed to detect ultra high energy cosmic rays. These are sub-atomic particles (protons or other nuclei) with energies beyond 10^20 eV. These high energy particles have an estimated arrival rate of 1 per square kilometer per century, therefore, in order to record a large number of these events, the Auger Observatory has created a detection area the size of 3000 square km The PAO is the largest ultra-high energy cosmic ray detector in the world and it is located on the vast plain of Pampa Amarilla in Argentina. The PAO is the first experiment that combines both ground and fluorescence detectors at the same site thus allowing cross-calibration and reduction of systematic effects that may be peculiar to each technique.