Nanosystems Proff. Garlatti e Chiesa (UNIPR)

The course presents an introduction to molecular nanomagnets and their applications in the field of quantum information processing. It provides the key notions of theoretical tools, experimental techniques and technological applications involving magnetic molecules. The Spin Hamiltonian model for the description of the coherent behaviour of molecular nanomagnets will be introduced as well as Rate Master Equations describing their irreversible relaxation dynamics. The most important experimental techniques will also be illustrated, focusing on inelastic neutron scattering and nuclear magnetic resonance. Then, we will focus on the two most important applications, namely the implementation of elementary units for a quantum processor and the realization of high-density data-storage devices embedding a bit of information within a single molecule. In this respect, an introduction to the basic principles of quantum computing and to the main issues related to its physical implementation will be provided, together with the most important advantages offered by molecular nanomagnets.

Nanosystems II Prof. Ripanti (UNIPG)

The aim of these lessons is the approach to the fundamentals of optical spectroscopy, in particular of conventional and surface Raman spectroscopy, through a semi-classical and a quantum description. Examples of traditional and modern applications will be shown, with particular attention to biomolecular and biophysical applications. At the end, the principles of time-resolved spectroscopy will be proposed.

Nanosystems III Dott.ssa Pedio (CNR)

The huge interest in novel nanostructured materials arises from the remarkable variations in fundamental electrical, optical and magnetic properties that deviate from those of isolated components as single crystals or gas phase. In the course will be provided an overview on the potential of electron and absorption X-ray spectroscopies to characterize nanomaterials. The theoretical basis including interaction of radiation with matter will be discussed together with the experimental know-how required to apply such methods to specific research problems. The course will focus on X-ray absorption and photoemission methods used both in campus and Large-Scale facilities, with the objective to familiarize the students with the principles, practices and applications of Spectroscopies. In particular, we will discuss in campus and by Synchrotron Radiation complementary multi-techniques approach for materials analysis. Case systems of nano and advanced materials will be discussed, including the optimization of the LHC walls, interfaces, photovoltaic systems, nanotubes.

Spintronics Prof. Manzin (INRIM)

Phenomenology of ferromagnetic media - Magnetic materials and Maxwell's equation - Hysteresis cycle and its characteristics - Exchange interaction and spontaneous magnetization - Magnetostatic dipole-dipole interactions and magnetic domains - Anisotropy - Introduction to Spin-Transfer-Torque effects. 2 - Micromagnetic free energy and magnetization dynamics - Micromagnetic free energy - Brown's equations, micromagnetic Equilibria - Nucleation and stability of equilibria (concept of ground state) - Stoner-Wohlfarth model - Landau-Lifshitz and Landau-Lifshit-Gilbert equations 3 - Micromagnetic dynamics in uniformly magnetized bodies - Switching of magnetization - Linear and nonlinear ferromagnetic resonance - Spin-Transfer-Torque driven magnetization dynamics - Magnetization self-oscillations - Elements of chaotic magnetization dynamics 4 - Micromagnetic dynamics with spatially nonuniform configurations - Linear spin-waves - Spin-waves at large microwave excitations. - Topologically non-trivial configurations: vortex, skyrmions - Thiele equation for domain wall and vortex motion. - Spin-transfer-torque driven vortex oscillators

Multimessanger - ET/Gravity Dott. Punturo (INFN)

The Multimessenger astrophysics course introduces the student to the gravitational wave research and to its impact on the fundamental physics and on the astrophysics, always keeping an experimentalist point of view. The course starts from the Newtonian description of the gravitation and quickly arrives to the key elements of the Einstein General Relativity theory of the gravitation. It introduces the tidal force concept. The gravitational waves are described as effect of the weak field linearization of the field equation of the General Relativity. Effect of the passage of the gravitational wave on a mass distribution, and then on a detector. Elements of an interferometric gravitational wave detector. Michelson Interferometer and Fabry-Perot resonant cavities. Noise in a gravitational wave detector. LIGO and Virgo. Gravitational wave sources, compact binary systems and their coalescence, black holes, neutron stars, periodic and transient gravitational wave sources. The discovery of gravitational waves in LIGO and Virgo; black hole physics. Multimessenger astronomy with gravitational waves. Future perspectives on gravitational wave research with Einstein Telescope and LISA.

Multimessanger - Gamma Proff. Germani e Tosti (UNIPG)

The module is organised in two submodules dedicated to gamma ray and neutrino astrophysics. The gamma ray astrophysics part will introduce space based detection with the Fermi mission and ground based observations with Imaging Atmospheric Cherenkov Telescopes. After the description of the emission mechanisms for high energy and very high energy photons, the two main class of sources related to multimessenger astrophysics will be presented: Active Galactic Nuclei (AGN) and Gamma Ray Burst (GRB). The AGN classification and unified model will be introduced. The GRB prompt and afterglow emissions will be described together with the fireball model and the collapsar and compact objects merger progenitors. The neutrino astrophysics part will introduce the main characteristics of the neutrino interactions and neutrino oscillations. A short history of neutrino astrophysics is presented together with significant example of neutrino experiment: - the solar neutrino problem and the radiochemical experiments - the discovery of neutrino oscillations and the SuperKamiokande and SNO experiments - SN1987A and neutrinos from cor collapse supernovas - Ice Cube and the multi messenger event IC170922A IceCube detection technique, results and possible emitting sources will be discussed in detail. Future projects and possible evolutions of the experimental techniques will be introduced.

Space and cosmic rays Physics   Prof. Barao (Università di Lisbona) e Dr. Graziani (UNIPG)

Cosmic rays, mostly atomic nuclei, have their origin beyond the solar system and while crossing the universe in all directions bombard Earth continuously. The study of the cosmic radiation have been made indirectly with detector apparatus located on Earth or directly with detectors placed on stratospheric balloons and satellites. This course will focus on space-borne and balloon-borne detection of space charged particles. It is meant to introduce the fundamental concepts of cosmic ray detection and performance, near-Earth environment and the principles of radiation shielding needed to long-term travles in space.

Experimental techniques for GW detectionProf. Bawaj (UNIPG)

The course Experimental techniques for gravitational waves detection focuses on the most important experimental techniques involved in gravitational wave detectors. In the introduction we will review shortly the noise theory in measuring instruments: stochastic process, fluctuation-dissipation theorem and statistics on experimental data. Next part of the course will cover necessary aspects of signal processing: correlation, autocorrelation, linear transformation, power spectrum and signal-to-noise ratio. Finally we will discuss extraction of a signal from noisy data and the problem of linear data filtering, in particular matched filter and the SEOB waveform model. The second part of the course will focus on the existing interferometric gravitational wave detectors of the second generation and its relevant noise sources. In particular we will approach: Michelson interferometer and Fabry-Perot cavity, recycling of light inside the interferometer, opto-mechanical systems with feedback: control techniques and Pound-Drever-Hall technique as well as wide band optical detectors. The quantum limit is currently one of the most recent limit to overcome for gravitational detectors. We will approach the optical shot noise and the radiation pressure noise reduction techniques.

Physics at Collider **Prof. Gallinaro (LIP, Lisbona)**

This is intended to be a specialized course on the Physics at the Large Hadron Collider (LHC) at Cern, and its experimental research program. The course is intended for graduate students with basic training in Particle Physics. The objective of the course is to introduce the physics concepts and goals, analysis methods, and discuss the results obtained and present the challenges of the different areas of research covered by the LHC experiments. Emphasis is placed on the search for new physics. Benchmark channels in proton-proton collisions are discussed in detail, covering the identification of the objects involved, the signal and background properties, the background estimation and the signal-to-background discriminants, the evaluation of systematical errors, and the extraction and interpretation of the results.

Flavour Physics **Prof. Sozzi (UNIPI)**

This is intended to be a specialized course on the Physics at the Large Hadron Collider (LHC) at Cern, and its experimental research program. The course is intended for graduate students with basic training in Particle Physics. The objective of the course is to introduce the physics concepts and goals, analysis methods, and discuss the results obtained and present the challenges of the different areas of research covered by the LHC experiments. Emphasis is placed on the search for new physics. Benchmark channels in proton-proton collisions are discussed in detail, covering the identification of the objects involved, the signal and background properties, the background estimation and the signal-to-background discriminants, the evaluation of systematical errors, and the extraction and interpretation of the results.

Charm Physics at LHC **Prof.ssa Mariani (UNIPG)**

This is a specialized course on the charm physics at the Large Hadron Collider (LHC) at Cern. The course is intended for graduate students with basic training in Particle Physics. The objective of the course is to introduce the flavor physics, with a focus on charm, and discuss the results obtained and present the challenges of the different areas of research covered by the LHC experiments. Emphasis is place on the possible discrepancies with respect to the Standard Model and frontier measurements

Introduction to Quantum Computing **Prof. Baioletti (UNIPG)**

Basic concepts of QC (qubits, gates, circuits, etc.). Overview of existing real architectures. Challenges of current quantum computers (circuit compilation, error mitigation). The most famous quantum algorithms (Shor and Grover). The QAOA algorithm. Algorithms for Quantum Machine Learning. Other important quantum algorithms. Modes of using simulators and real quantum computers. QC and computational complexity. Introduction to quantum cryptography. Introduction to Quantum Error Correction. Quantum annealers and their usage.

Teaching and Learning Physics **Prof. Organtini (Sapienza)**

The course consists of an initial part where the use of the Arduino programming language will be introduced. Participants will then be asked to design an experiment, which will be carried out using readily available materials during laboratory sessions in the presence of the tutor. At the end of the activity, students will need to present the results of the experiment and how they were obtained.

TCAD (Technology Computer Aided Design) **Dr.ssa Morozzi (INFN)**

The course aims to provide students with methodologies and tools for conducting numerical simulations of electronic device/circuit types using technology CAD tools (TCAD - Technology Computer Aided Design). In particular, it will cover the simulation of integrated circuit fabrication processes and the simulation of their device-level operation. The Synopsys Sentaurus TCAD software will be utilized, which is currently state-of-the-art for process and device simulation. Theoretical lectures will be complemented by practical sessions.

Gaussian Mixture Models **Prof. Scrucca (UNIPG)**

The course introduces Gaussian mixture models, a widely-used family of models that have proved to be an effective and computationally convenient way to perform model-based clustering, classification, and density estimation. Topics presented during this course are maximum likelihood estimation via the EM algorithm, resampling-based inference, model selection, data simulation, Bayesian regularization, presence of noise and outliers, dimension reduction methods, variable selection for model-based clustering. All the methods are illustrated using the mclust package for the software R.

Physics of Biomaterials **Prof. Valentini (UNIPG), Prof. Paciaroni (UNIPG), Prof. Mattarelli (UNIPG), Prof. Libera (UNIPG), Prof. Luchini (UNIPG), Prof. Orecchini (UNIPG), Prof. Corezzi (UNIPG), Prof. De Michele (Sapienza), Dr. Comez (IOM-CNR)**

The course is divided into two main branches: experimental techniques and numerical methods for investigating the physical properties of biomaterials for potential therapeutic and technological applications.