UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

Dipartimento di Scienze Fisiche, Informatiche e Matematiche

Master’s Degree Programme in Physics · Curriculum Theoretical and Computational Physics

Theoretical Physics of Fundamental Interactions

OVERVIEW OF THE STUDY PLAN

The theoretical physics of fundamental interactions focuses on the study of various relativistic field theories, such as those that compose the Standard Model of particle physics, General Relativity and String Theory. These theories have provided astonishingly precise predictions of many elementary particle phenomena and gravitational/cosmological phenomena, and have contributed a great deal of technological progress. Moreover, they have recently yielded new efficient approaches to tackle the physics of several strongly-coupled systems, hence opening new very promising avenues of research; for example, in the field of condensed matter, they have recently played an important role in the characterization of new innovative materials.

The present study plan is devised to provide students with the most modern approaches to fundamental interactions. Students will become acquainted with the elegant and efficient formalism that characterizes the various relativistic field theories, and learn how to employ it to (analytically and/or numerically) compute relevant physical quantities, such as particle scattering amplitudes and effective actions, that enter in the evaluation of particle cross-sections, decay rates and other physical observables. However, most of the methodology they will acquire is of broader use and can also be employed in more general physical theories, such as those that model condensed matter systems and other strongly-coupled systems.

This study plan is connected to ongoing research activities carried out by our scientists in collaboration with several research centres in the world, among which Istituto Nazionale di Fisica Nucleare (Bologna), University of California (Davis, USA), King’s College (London, UK), University of Michigan Ann Arbor (USA) and Keio University (Japan). The thesis project will be carried out within the group of theoretical physics of fundamental interactions of the FIM department and/or in the national and international collaborating research groups, some of which are listed above.

FIRST YEAR

Advanced Quantum Mechanics

Advanced Quantum Mechanics A self-contained course reviewing under various, mathematically rigorous, points of view the fundamentals of the theory, studying problems at the basis of modern physics, such as the quantization of the electromagnetic field and its interaction with matter, and the relativistic wave equations with their interpretative issues.

Quantum Field Theory

A first course on Relativistic Quantum Field Theory to give students the philosophy behind such discipline, providing students the tools to compute scattering amplitudes, cross sections and decay rates for scalar and spinor particles.

Quantum Many-Body Theory

A course covering concepts and physical pictures behind various phenomena that appear in vast assemblies of interacting quantum particles. The most widely used many-body methods are presented (many-body perturbation theory, large-scale diagonalization methods, Feynman diagram, and Green’s function approaches) and applied to selected physical systems.

Statistical Mechanics and Phase Transitions

An advanced course in classical and quantum statistical mechanics, from the theoretical foundations to phase transitions and critical phenomena, to quantum condensates (BEC, superfluidity, superconductivity). Attendees will be introduced to modern theoretical methods, from mean-field approaches to statistical field theory and renormalization group theory.

Quantum Information Processing

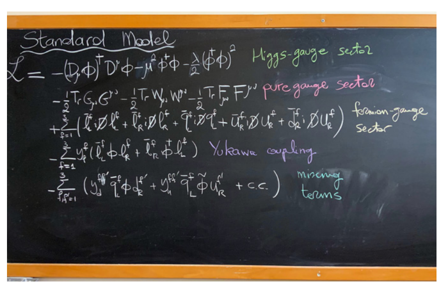
This course will give a graduate-level introduction to the theory behind quantum computers and quantum information processing (QIP) in general. The topics will range from basic QIP primitives e.g., teleportation, to quantum error correction passing through fundamental quantum computing algorithms e.g, Shor’s factoring.

Physics of Semiconductors

A course dealing with functional concepts of modern optical and electronic devices, from carrier and defect engineering, transport and carrier recombination dynamics, nanostructured semiconductors, up to their applications to transistors, laser, LEDs and solar cells.

Monte Carlo Methods in Physics

A random walk in the fields of Statistical and Quantum Mechanics



The Lagrangian of the standard model

introducing the Monte Carlo numerical approach, Markov processes, and Brownian motion, with "in silico" modeling of phase transitions and calculation of quantum properties of simple microscopic models.

Computational topology

A course to familiarize with tools, algorithms, and computational issues in topology for Data Science ensuing from the observation that "data has shape and shape matters", with an eye to problems arising in shape analysis, topological inference, and manifold learning.

Magnetism and spintronic

A course devoted to quantum and statistical description of magnetic phenomena, from atomic level to collective effects, experimental techniques for magnetic characterization, and advanced applications in spintronics, magnetic recording, molecular magnetism, quantum technologies.

SECOND YEAR

Gauge Theories

A follow-up course on Relativistic Quantum Field Theory introducing quantization of theories based on local (gauge) symmetry, the main ingredients of the Standard Model, describing with amazing precision the interactions of elementary particles.

Elementary particles

A course introducing the elementary constituents of matter and their interactions, as well as the role of symmetries and their violation, up to the most recent discoveries in the field (neutrino masses, Higgs boson, multi- quark states).

SUGGESTED FREE CHOICE COURSES

Relativity

In this course students learn the elegant mathematical framework of Special Relativity and General Relativity (GR), applying it to fascinating physical problems, including GR effects on planetary motion, light bending, black hole physics, and cosmology.

Laboratory of Computational Quantum Mechanics

A course with hands-on tutorial sessions dealing with electronic structure computational techniques as applied to condensed matter systems, with special emphasis on Density Functional Theory, the state-of-the-art parameter-free, atomistic and predictive description of materials.

PROFESSIONALIZING COURSES

Good Practices in Research

A practical introduction to soft skills needed in industrial and academic research. How to present your results at a conference, or in a paper, and get it published. How to keep your data, when you need to worry about intellectual property. How to build a path that suites your aspirations, write your CV and apply for a high-tech job. All this is also put into context: the structure of research organization and funding in Italy and Europe, with its risks, challenges, and opportunities.

Research Integrity in Sciences

A course starting from the study of recent cases of scientific misconduct, such as falsification, fabrication, plagiarism, to discuss actual aspects and concepts of research integrity, which is increasingly considered an essential aspect of research.

NOTES

Students willing to deepen their formal training may want to choose courses from the Master program in mathematics, such as *Equazioni alle Derivate Parziali or Metodi Matematici della Meccanica Quantistica* (in Italian). Students willing to see mathematical methods at work in applicative field may also enroll in *Medical Physics, Numerical Algorithm for Signal and Images, or Deep Learning and Machine Learning*. Ask the Master coordinator for the full list of available courses.

Where: Modena, Scientific Campus
Duration: 2 years
ECTS credits: 120

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