Study plan in

Theoretical physics of fundamental interactions

UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA
Dipartimento di Scienze Fisiche, Informatiche e Matematiche

M.Sc. program in Physics – Curriculum Theoretical and Computational physics

Overview

The theoretical physics of fundamental interactions focuses on the study of **particles, fields and strings**, which are the ingredients of theories such as the **Standard Model** of particle physics, **General Relativity** and **String Theory**. They provide astonishingly precise predictions of many phenomena, ranging from the microscopic to the cosmological scales of the Universe. Moreover, this area of research has recently yielded new approaches to tackle **strongly-coupled systems**, opening new, very promising avenues of research, for example in **nuclear** and **condensed matter physics**.

Goal

This study plan provides students with the most **modern approaches to fundamental interactions**. Students will become acquainted with the elegant and efficient formalism of **quantum field theory**, and will learn how to employ it to compute (analytically and/or numerically) relevant physical quantities, such as scattering amplitudes, effective actions, correlation functions, spacetime geometries, and so on. Most of these methodologies are of broader use and are also employed in other physical theories, such as those modeling condensed matter and other strongly-coupled systems.

More info and suggestions from

Study plan coordinator
Prof. Olindo Corradini

Program director
Prof. Paolo Bordone

Program website
`www.fim.unimore.it/LM/FIS`

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Fist year

Advanced quantum mechanics (M) – M Gibertini

A self-contained course addressing several aspects of quantum mechanics relevant to modern developments of physics, from condensed-matter theory to particle physics and their fundamental interactions. Emphasis will be given to the concept of Berry phase, the path integral formulation, and scattering theory.

Quantum field theory (M) – D Trancanelli, E Bertuzzo

An introductory course on QFT providing the quantization of scalar, spinor and vector fields, and covering the computation of scattering processes and decay rates in 4, Yukawa and QED theory. The course also provides a first discussion of radiative correction and renormalization.

Statistical mechanics and phase transitions (M) – G Goldoni

An advanced course in statistical mechanics, from theoretical foundations to phase transitions and critical phenomena, including quantum condensates (BEC, superfluids, superconductors). Attendees are introduced to modern theoretical methods, from the Ginzburg-Landau theory to the statistical field theory and the renormalization group approach.

Quantum physics of matter (M) – R Magri

An advanced course on matter-light and matter-electron interactions, using quantum linear response theory to discuss elementary excitations of material systems and their spectral features: electronic and phonon excitations, excitons, plasmons, polaritons.

Elementary particles (D) – A Bizzeti

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.

Quantum many-body theory (D) – A Ferretti

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.

Solid state physics (D) – G Goldoni, F Grasselli

A course on the quantum theory of solid matter which is behind modern material science and semiconductor technology which shape the technological world. From electronic properties and transport phenomena to interaction with radiation, topological properties and advanced phenomena like superconductivity.

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Fields of specialization

- Quantum Field Theory
- General Relativity
- Particle and Astroparticle physics
- String Theory

Opportunities

This study plan is connected to ongoing research activities carried out by our scientists in collaboration with several research centers worldwide, including the Istituto Nazionale di Fisica Nucleare (Italy), DESY Hamburg (Germany), Univ. of California (USA), King's College London (UK), Univ. 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 at the FIM department and/or in the national and international collaborating research groups. Students may also opt for the **Double Degree program** and spend the 2^{nd} year on a research project at the Radboud University (NL).

Employment

The skills developed will allow the student to pursue a PhD (both in the **Graduate School in Physics and Nanoscience** in Modena or in other institutions) or to work in public or private institutions (for instance in modelling for industry or in the financial sector).

Notes

Ask the Master coordinator for further suggestions on other available courses to tailor the program to your interests.

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Advanced quantum field theory (R) – O Corradini

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, the theory that describes with amazing precision the interactions of elementary particles. More advanced topics, including Supersymmetry and/or BRST-BV formalism, will be covered.

Relativity (R) – D Trancanelli

Learn the elegant mathematical framework behind Special and General Relativity and apply it to fascinating physical problems, including GR effects on planetary motion, the physics of black holes, gravitational waves and cosmology. The course also provides a first discussion of quantum gravity.

Theoretical astroparticle physics (R) – E Bertuzzo

What is the universe made of? We will learn how particle physics and cosmology get together to provide a comprehensive framework. After a recap of the Standard Model of Particle Physics, we will describe the concordance model of Cosmology and its successes. We will then turn our attention to dark matter, presenting knowns and unknowns about this fascinating component of the universe.

Second year

Synchrotron radiation: basics and applications (D) – S D'Addato

A course on the working principles of synchrotrons and the use of emitted radiation, from description of single ultra-relativistic particles sources to essentials of storage rings, bending magnets, wigglers and undulators, free electron lasers, beam lines. Examples of ensuing popular techniques, as X-ray diffraction, scattering, absorption and X-ray microscopy, are discussed and a visit to to ELETTRA labs in Trieste ends the course.

Astrophysics (F) – M Gaspari

A course exploring key modern topics in astrophysics, with focus on the complex universe of multi-scale black holes and their profound influence on galaxies throughout the cosmic evolution. It blends theoretical, numerical, and observational approaches. Students delve into the fascinating areas of extragalactic astrophysics, from the basics to the cutting-edge concepts and recent discoveries, such as gravitational waves and weather-like feedback mechanisms.

Quantum information processing (F) – P Bordone

An introduction to the theory behind quantum computers and QIP in general. Topics range from the basic concepts of QIP such as quantum entanglement and generalized quantum dynamics, to fundamental QIP algorithms, such as Shor's factoring, and quantum cryptography.

Legend: (M) mandatory course for this curriculum; (D) chosen within distinctive (*caratterizzanti*) courses; (R) chosen within related (*affini*) courses; (F) selected as a free choice course

This study plan is a suggested set of courses, chosen within the curriculum, to ensure an in-depth professional training combined with the broad spectrum of skills required to modern scientists. Mandatory, distinctive and related courses provide the natural background of this study plan. However, the study plan can also be tailored to the students' scientific interests. Ask the study plan coordinator for further indications.