



# Study Plan Guide

## Master's Degree in Physics

### A.Y. 2026/2027

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Choosing the exams for the Master's Degree (LM) in Physics represents a first step towards the disciplinary field in which you will conduct your research or pursue your career. The purpose of this guide is to clarify the possible options offered by the Physics Degree Program and the steps required to implement your choice.

## 1 Glossary and formal steps

As a first step, when enrolling in the Master's Degree (LM) program, you will be required to formally choose — via the Alice portal — one out of five broad research areas, referred to hereafter as “curricula,” or alternatively a general curriculum. This choice provides an initial selection of the exams required to obtain the LM degree. However, the precise exam schedule will later be determined by the **Individual Study Plan (PdSI)**, which is usually selected at a later stage, once you are more familiar with the courses and all the educational opportunities offered by the program.<sup>1</sup>

**How to create your PdSI.** The educational offer is organized into a set of recommended Study Plans (PdS), which guide you in the creation of your PdSI. These help not only in following the formal requirements for a Master's Degree in Physics, but also in building a coherent and culturally rich path in the subject area you wish to explore.

Each recommended PdS includes “mandatory” courses and often several “recommended” courses, selected for their thematic consistency with the PdS. Every course is associated with a label: PHYS-XX/Y. The first three letters indicate the scientific discipline—PHYS for physics—while the numbers denote the subfield, with the following associations:

- PHYS-01/A - Experimental physics of fundamental interactions
- PHYS-02/A - Theoretical physics of fundamental interactions;
- PHYS-03/A - Experimental physics of matter;
- PHYS-04/A - Theoretical physics of matter;
- PHYS-05/A - Astronomy and astrophysics;
- PHYS-05/B - Earth physics;
- PHYS-06/A - Applied physics;
- PHYS-06/B - Didactics and history of physics.

Some of the proposed exams may not belong to any PHYS scientific sector, but rather to other sectors such as Information Science (INF) or Mathematics (MATH).

**Elective courses.** In the study plan, 12 ECTS credits (CFU) may be freely chosen not only within the Physics Degree Program, but also among those offered by other degree programs, or by the Scuola Normale Superiore or the Scuola Sant'Anna. Elective credits must in any case be coherent with your Individual Study Plan (PdSI), thus it is strongly recommended to first consult the list of “Recommended Elective Courses”. Note that the Physics Degree Program also includes general courses that are not tied to a specific Study Plan; a short list of these can be found in Section [3](#).

**Final recommendation.** Once your study plan has been chosen, it must be submitted for approval through the CAPS portal (Assisted Compilation of Study Plans) at [caps.df.unipi.it](https://caps.df.unipi.it). The PdSI can be submitted or modified at any time during the year, but only the most recently approved version will be considered valid. If none of the recommended Study Plans meets your educational needs or interests, you may submit a “custom” PdSI for evaluation. However, it must comply with the minimum requirements listed in the relevant section and must be carefully justified in CAPS. Approval of a PdSI is neither automatic nor guaranteed — particularly in the case of a custom PdSI — so it is important to submit your plan via CAPS before beginning to take the exams.

<sup>1</sup> If you are receiving a scholarship that depends on the number of mandatory exams to be taken, it is strongly recommended that you contact the academic office to verify which exams are required for your scholarship to be confirmed.



## 2 List of the Recommended Study Plans

The list is arranged in alphabetical order, with the custom (free) PdSI appearing at the end. At the end of each brief description of the Study Plan, the corresponding curriculum is indicated.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b><u>Astronomy and Astrophysics</u></b> The study plan addresses investigative methods related to astrophysical and space-related topics, and explores the links between fundamental physics and observational evidence in astrophysics. (Curriculum Astronomia e Astrofisica)                                                                                                                                                                      |
| <b><u>Complex Systems</u></b> An interdisciplinary program providing skills to study complex systems—those composed of many interacting components, often exhibiting unpredictable and emergent behavior. (Curriculum Generale)                                                                                                                                                                                                                      |
| <b><u>Data Analysis in Experimental Physics</u></b> An educational program focused on advanced data analysis techniques, with applications to experimental physics. (Curriculum Generale)                                                                                                                                                                                                                                                            |
| <b><u>Fundamental interactions</u></b> The study plan provides knowledge in nuclear and subnuclear particle physics, gravitational waves, and cosmic-origin particles. (Curriculum Interazioni Fondamentali)                                                                                                                                                                                                                                         |
| <b><u>Medical Physics</u></b> The study plan focuses on the application of physical principles and methods to the prevention, diagnosis, and treatment of human diseases. (Curriculum Fisica Medica)                                                                                                                                                                                                                                                 |
| <b><u>Phenomenology of Fundamental Interactions</u></b> The study plan covers both theoretical and experimental aspects of fundamental interactions in physics, positioned between theoretical physics and experimental particle physics. (Curriculum Generale)                                                                                                                                                                                      |
| <b><u>Physics for Cultural Heritage</u></b> This study plan aims to train physicists capable of effectively collaborating with art historians, restorers, and archaeologists to address complex issues through the use of tools and methods typical of physical research, within a multidisciplinary context. (Curriculum Generale)                                                                                                                  |
| <b><u>Physics of Biosystems</u></b> A program that explores the intersection between condensed matter physics, complex systems, and life sciences. (Curriculum Fisica della Materia)                                                                                                                                                                                                                                                                 |
| <b><u>Geophysical fluid dynamics and Solid Earth Physics</u></b> The plan provides theoretical and applied foundations for studying key processes in geophysical fluids and the solid Earth, with applications in seismology, volcanology, and environmental physics. (Curriculum Generale)                                                                                                                                                          |
| <b><u>Physics of Matter</u></b> Focused on the theoretical and experimental study of states of matter, both classical and quantum, and their interactions with electromagnetic fields. (Curriculum Fisica della Materia)                                                                                                                                                                                                                             |
| <b><u>Physics of the Universe</u></b> The program equips students to study cosmic phenomena using an interdisciplinary theoretical and experimental approach, including the observation of gravitational waves, electromagnetic radiation, and astroparticles. The program benefits from proximity to the European Gravitational Observatory (EGO) and research conducted with the Advanced VIRGO gravitational wave detector. (Curriculum generale) |
| <b><u>Plasma Physics</u></b> The program covers the fundamentals and basic physical processes in plasmas, with further study of space plasmas and nuclear fusion. (Curriculum Fisica della Materia)                                                                                                                                                                                                                                                  |
| <b><u>Quantum Computing and Technologies</u></b> The study plan provides both theoretical and experimental training in the field of quantum computing and related technologies. (Curriculum Generale)                                                                                                                                                                                                                                                |
| <b><u>Theoretical Physics</u></b> The study plan covers a wide range of topics in theoretical physics, including quantum field theory, the phenomenology of fundamental interactions, gravitation theory, statistical and condensed matter physics, and nuclear interactions. (Curriculum Fisica Teorica)                                                                                                                                            |
| <b><u>Theory of Quantum Materials</u></b> The program focuses on theoretical and computational methods for the study of novel materials. (Curriculum Generale)                                                                                                                                                                                                                                                                                       |
| <b>Piano di Studi Libero</b> In cases where educational needs are not met by any of the recommended study plans, students may build a fully individualized study plan that does not fall under any of the categories above.                                                                                                                                                                                                                          |

### 3 Elective courses not specific to any particular Study Plan

|    |                                                                                |     |        |
|----|--------------------------------------------------------------------------------|-----|--------|
| S1 | <a href="#">[408BB] PHYSICS OF SOUND</a>                                       | FIS | 06 CFU |
| S1 | <a href="#">[407BB] CURRENT TRENDS IN QUANTUM MATTER</a>                       | FIS | 03 CFU |
| S1 | <a href="#">[092BB] PHYSICS OF SURFACES AND INTERFACES</a>                     | FIS | 03 CFU |
| S1 | <a href="#">[0039B] THE PHYSICS OF EVERY DAY LIFE</a>                          | FIS | 06 CFU |
| S2 | <a href="#">[357BB] LASER-PLASMA ACCELERATORS</a>                              | FIS | 06 CFU |
| S2 | <a href="#">[428BB] NUCLEAR WEAPONS, DISARMAMENT AND NUCLEAR PROLIFERATION</a> | FIS | 06 CFU |

### 4 Details of the Recommended Study Plans

Please note that newly activated courses may not yet have working links on the Course Catalogue. To address this, temporary course descriptions have been created to briefly outline the content of such courses, pending their official inclusion in the catalogues. In all the recommended Study Plans listed below, please pay close attention to the following aspects:

- **Prerequisites.** When selecting the exams that will form your Individual Study Plan (PdSI), it is recommended that you consult the syllabi and prerequisite information for each course on the program website, using the links provided.
- **Courses also offered in the Bachelor's program.** Some courses are also offered at the undergraduate level. To include them in your PdSI, you must attach a transcript of records or, if applicable, declare that you come from another university. The courses subject to this rule are:
  - ⇒ [368BB] ASTROFISICA GENERALE,
  - ⇒ [0024B] FLUIDODINAMICA
- **Course with non-standard semesters.** Courses shared with or borrowed from the PhD program, as well as courses from the Scuola Normale Superiore (SNS), may be held outside the regular first and second semester schedule. It is advised to contact the instructors for more information. Be aware of the timing of these courses, as they often do not fall neatly into either semester. UniPi courses with this characteristic include:
  - ⇒ [404BB] NONPERTURBATIVE APPROACHES TO QUANTUM FIELD THEORIES S,
  - ⇒ [358BB] NONPERTURBATIVE APPROACHES TO QUANTUM FIELD THEORIES,
  - ⇒ [0041B] STATISTICAL ANALYSIS LABORATORY
- **Non-FIS courses.** In most Study Plans this is not a major issue, but it is never permitted to include more than 24 ECTS of courses from scientific areas other than FIS/xx. In the Study Plans where this limit is relevant, the rule will be explicitly stated.
- **Now many credits.** Each PdSI must include at least 75 ECTS credits of coursework. Together with the 45 credits from the final thesis, this brings the total to the required 120 ECTS for graduation. Study Plans that significantly exceed 120 ECTS will be discouraged and, if accepted, all listed courses must be completed.
- **Suggested paths.** Given the variety of available courses, many course sheets include examples of effective study paths, typically based on past student submissions, to guide your selection.
- **Modifying your PdSI.** Although you may update your PdSI at any time, it is strongly recommended to finalize your direction as early as possible. It is expected that you will pass all the exams listed in your most recently approved PdSI.

Details of the recommended Study Plans can be found in the following pages. For any doubts, difficulties in using this guide, or to report missing information (please note that it is normal for some syllabi to be unavailable or incomplete until around the end of August), do not hesitate to contact the Teaching Office ([segr.dida@unipi.it](mailto:segr.dida@unipi.it)) or the Course Coordinator ([stefano.rodaro@unipi.it](mailto:stefano.rodaro@unipi.it)).

**Attention.** While most course programs do not change from one AY to the next, AY2026/27 programs will only be available about the end of summer. This guide will thus for now only report the links to the catalogue AY2025/26. Given that during this AY there will be the shift from the FIS to the PHYS sectors, also this modification will be complete once the new course pages will be available. Only in the case of new teachings, info sheets will be created, as a substitute of the final course info that will become available on the catalogue later on.

**ASTRONOMY AND ASTROPHYSICS**

(Curriculum ASTRONOMY AND ASTROPHYSICS)

**Constraints of the PdS**

minimum

57 CFU

**Compulsory group***(all of the following)*

|    |                                                    |     |        |
|----|----------------------------------------------------|-----|--------|
| S1 | [226BB] ASTROPHYSICAL PROCESSES                    | FIS | 09 CFU |
| S2 | [369BB] EXTRAGALACTIC ASTROPHYSICS AND COSMOLOGY   | FIS | 09 CFU |
| S2 | [211BB] STELLAR PHYSICS                            | FIS | 09 CFU |
| A  | [0010B] ASTROPHYSICS AND MULTIMESSENGER LABORATORY | FIS | 12 CFU |

**Theoretical physics group***(at least one of the following)*

|    |                              |     |        |
|----|------------------------------|-----|--------|
| S1 | [228BB] GENERAL RELATIVITY   | FIS | 09 CFU |
| S1 | [213BB] QUANTUM FIELD THEORY | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS  | FIS | 09 CFU |

**Microphysics group***(at least one of the following)*

|    |                         |     |        |
|----|-------------------------|-----|--------|
| S1 | [206BB] NUCLEAR PHYSICS | FIS | 09 CFU |
| S1 | [353BB] PLASMA PHYSICS  | FIS | 09 CFU |

**Recommended Elective Courses**

maximum

18 CFU

*(at least 6 CFU from the following or from the unselected mandatory courses)*

|    |                                                                                               |     |        |
|----|-----------------------------------------------------------------------------------------------|-----|--------|
| S1 | [0013B] ADVANCED TECHNOLOGIES FOR GROUND-BASED ASTROPHYSICS: FROM MICROWAVES TO VISIBLE LIGHT | FIS | 06 CFU |
| S1 | [306BB] EXPERIMENTAL METHODS FOR ASTROPARTICLE PHYSICS                                        | FIS | 09 CFU |
| S1 | [307BB] EXPERIMENTAL METHODS FOR ASTROPARTICLE PHYSICS S                                      | FIS | 06 CFU |
| S1 | [0024B] FLUID DYNAMICS                                                                        | FIS | 06 CFU |
| S1 | [0011B] MULTIMESSENGER AND HIGH-ENERGY ASTROPHYSICS                                           | FIS | 06 CFU |
| S1 | [0012B] PHYSICS OF STAR FORMATION                                                             | FIS | 06 CFU |
| S1 | [353BB] PLASMA PHYSICS                                                                        | FIS | 09 CFU |
| S2 | [214BB] ADVANCED QUANTUM FIELD THEORY                                                         | FIS | 09 CFU |
| S2 | [192BB] ASTROPARTICLE PHYSICS                                                                 | FIS | 09 CFU |
| S2 | [063BB] ASTROPARTICLE PHYSICS S                                                               | FIS | 06 CFU |
| S2 | [274BB] COSMOLOGY OF THE EARLY UNIVERSE                                                       | FIS | 09 CFU |
| S2 | [275BB] COSMOLOGY OF THE EARLY UNIVERSE S                                                     | FIS | 06 CFU |
| S2 | [0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE                                               | FIS | 09 CFU |
| S2 | [251BB] GRAVITATION THEORY                                                                    | FIS | 09 CFU |
| S2 | [140BB] GRAVITATION THEORY S                                                                  | FIS | 06 CFU |
| S2 | [0046B] PHYSICS AND DETECTORS OF GRAVITATIONAL WAVES                                          | FIS | 09 CFU |
| S2 | [0047B] PHYSICS AND DETECTORS OF GRAVITATIONAL WAVES S                                        | FIS | 06 CFU |
| S2 | [0016B] THEORY OF NUCLEAR INTERACTION S                                                       | FIS | 06 CFU |
| A  | [326BB] COMPUTATIONAL PHYSICS LABORATORY                                                      | FIS | 09 CFU |

**Additional notes**

Within some possible thematic paths in Astrophysics, the following elective courses are suggested:

**Path STELLAR PHYSICS:**

- [0012B] Physics of star formation (6 CFU)
- [353BB] Plasma Physics (9 CFU) oppure [206BB] Nuclear Physics (9 CFU)

**Path GALACTIC ASTROPHYSICS E COSMOLOGY:**

- [257BB] Cosmology of the early universe S (6 CFU)
- [228BB] General relativity (9 CFU)

**Path GRAVITATIONAL WAVES:**

- [256BB] Physics of gravitational waves S (6 CFU)
- [228BB] General relativity (9 CFU)

**Path OBSERVATIONAL ASTRONOMY:**

- [0013B] Advanced technologies for ground-based astrophysics (6 CFU)
- [0011B] Multimessenger and high-energy astrophysics (6 CFU)

**COMPLEX SYSTEMS**

(Curriculum GENERAL)

**Constraints of the PdS**

minimum

33 CFU

**Compulsory group***(all of the following)*

|    |                             |     |        |
|----|-----------------------------|-----|--------|
| S1 | [230BB] COMPLEX SYSTEMS     | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS | FIS | 09 CFU |

**Experimental physics***(at least one of the following)*

|    |                                                                      |     |        |
|----|----------------------------------------------------------------------|-----|--------|
| S1 | [193BB] STATISTICAL DATA ANALYSIS                                    | FIS | 09 CFU |
| A  | [326BB] COMPUTATIONAL PHYSICS LABORATORY                             | FIS | 09 CFU |
| A  | [360BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS | FIS | 09 CFU |

**Astrophysics group***(at least one of the following)*

|    |                           |     |        |
|----|---------------------------|-----|--------|
| S1 | [353BB] PLASMA PHYSICS    | FIS | 09 CFU |
| S2 | [368BB] ASTROPHYSICS      | FIS | 06 CFU |
| S2 | [211BB] STELLAR PHYSICS   | FIS | 09 CFU |
| S2 | [098BB] STELLAR PHYSICS S | FIS | 06 CFU |

**Recommended Elective Courses**

maximum

42 CFU

*(includes unselected Constraints and those that follow)*

|    |                                                                    |            |        |
|----|--------------------------------------------------------------------|------------|--------|
| S1 | [178EE] BIOINFORMATICS                                             | INF/01     | 03 CFU |
| S1 | [420AA] DATA MINING                                                | INF/01     | 12 CFU |
| S1 | [878II] DATA MINING AND MACHINE LEARNING                           | ING-INF/05 | 12 CFU |
| S1 | [676AA] DATA MINING: FUNDAMENTALS                                  | INF/01     | 06 CFU |
| S1 | [309BB] DISORDERED SYSTEMS OUT OF EQUILIBRIUM                      | FIS        | 09 CFU |
| S1 | [0024B] FLUID DYNAMICS                                             | FIS        | 06 CFU |
| S1 | [783AA] GEOSPATIAL ANALYTICS                                       | INF/01     | 06 CFU |
| S1 | [389BB] INTRODUCTION TO MOLECULAR BIOPHYSICS                       | FIS        | 06 CFU |
| S1 | [654AA] MACHINE LEARNING                                           | INF/01     | 09 CFU |
| S1 | [387BB] PHYSICS OF BIOSYSTEMS                                      | FIS        | 09 CFU |
| S1 | [376BB] QUANTUM COMPUTING AND TECHNOLOGIES                         | FIS        | 09 CFU |
| S1 | [213BB] QUANTUM FIELD THEORY                                       | FIS        | 09 CFU |
| S2 | [0005B] 3D AND 4D NANOMATERIALS AND DEVICES                        | FIS        | 09 CFU |
| S2 | [214BB] ADVANCED QUANTUM FIELD THEORY                              | FIS        | 09 CFU |
| S2 | [279BB] COMPLEX SYSTEMS - NEURAL DYNAMICS                          | FIS        | 09 CFU |
| S2 | [513LL] COMPUTATIONAL LINGUISTICS II                               | L-LIN/01   | 06 CFU |
| S2 | [674AA] COMPUTATIONAL NEUROSCIENCE                                 | INF/01     | 06 CFU |
| S2 | [699AA] DATA ANALYSIS                                              | MAT/06     | 06 CFU |
| S2 | [0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE                    | FIS        | 09 CFU |
| S2 | [288DD] EARTHQUAKE SEISMOLOGY                                      | FIS        | 06 CFU |
| S2 | [211AA] GAME THEORY                                                | MAT/09     | 06 CFU |
| S2 | [375BB] LARGE SCALE PHYSICAL OCEANOGRAPHY                          | FIS        | 09 CFU |
| S2 | [0021B] MICROBIOROBOTICS                                           | FIS        | 06 CFU |
| S2 | [0020B] NEUROENGINEERING                                           | FIS        | 06 CFU |
| S2 | [322BB] NONLINEAR DYNAMICS                                         | FIS        | 09 CFU |
| S2 | [0028B] PHYSICS OF THE ATMOSPHERE AND PRINCIPLES OF METEOROLOGY    | FIS        | 06 CFU |
| S2 | [0019B] QUANTUM MACHINE LEARNING                                   | FIS        | 03 CFU |
| S2 | [425BB] QUANTUM THERMODYNAMICS                                     | FIS        | 06 CFU |
| S2 | [668AA] SOCIAL NETWORK ANALYSIS                                    | INF/01     | 06 CFU |
| S2 | [628PP] STATISTICS FOR DATA SCIENCE                                | SECS-S/01  | 09 CFU |
| A  | [SNS-MMQF] MATHEMATICAL MODELS FOR QUANTITATIVE FINANCE            | FIS        | 06 CFU |
| A  | [SNS-QF] QUANTITATIVE FINANCE                                      | FIS        | 06 CFU |
| A  | [SNS-SMLM] STATISTICAL AND MACHINE LEARNING MODELS FOR TIME SERIES | FIS        | 09 CFU |

**Additional notes**

- At least 18 ECTS out of the 42 elective ECTS must be in the FIS scientific sectors
- The course [878II] DATA MINING AND MACHINE LEARNING overlaps in program content with [676AA] DATA MINING: FUNDAMENTALS and [420AA] DATA MINING. Therefore, an individual study plan must be submitted to agree on how many ECTS will be counted if you intend to take the exam for more than one of these courses;
- Specifically, the course [676AA] DATA MINING: FUNDAMENTALS is the first part of [420AA] DATA MINING, so both cannot be chosen;
- The course [676AA] DATA MINING: FUNDAMENTALS is offered in a Master's Degree program with restricted access (numero programmato): the possibility of attending is subject to the availability of free places and must be agreed upon with the instructor at the beginning of the course;
- In the "Experimental Physics" group, it is possible to choose "Computing methods for experimental physics and data analysis S" (6 CFU) + "Metodi numerici per la fisica S" (6 CFU) to complete the mandatory credits (both exams must be taken).



Based on the study paths previously chosen by students who decided to follow a specific educational path within the field of complex systems, the courses typically included in their respective study plans are indicated here:

## Path FINANCE:

- [SNS-MTT] Markets, trading and technologies
- [SNS-MMQF] Mathematical models for quantitative finance: market microstructure, networks, and systemic risk
- [SNS-QF] Quantitative finance
- [SNS-SMLM] Statistical and machine learning models for time series analysis
- [668A] Social network analysis

## Path NEURONS and BRAIN:

- [279BB] Complex systems - neural dynamics
- [674AA] Computational neuroscience
- [326BB] Computational physics laboratory (inclusando modulo Metodi della fisica non lineare e delle neuroscienze)
- [0020B] Neuroengineering
- [322BB] Nonlinear dynamics
- [420AA] Data mining

## Path ACTIVE MATTER:

- [309BB] Disordered systems out of equilibrium
- [0021B] Microbiorobotics
- [273BB] Biophysical modelling of complex systems
- [0024B] Fluid dynamics
- [389BB] Introduction to molecular biophysics
- [375BB] Large scale physical oceanography
- [387BB] Physics of biosystems

## Path EARTH SYSTEM:

- [0024B] Fluid dynamics
- [375BB] Large scale physical oceanography
- [0028B] Physics of the atmosphere and principles of meteorology
- [288DD] Earthquake seismology
- [353BB] Plasma physics

## Path CHAOS and DYNAMICAL SYSTEMS:

- [PHD-DCS] Dynamics of complex systems
- [326BB] Computational physics laboratory (inclusando modulo Metodi della fisica non lineare e delle neuroscienze)
- [322BB] Nonlinear dynamics
- [425BB] Quantum thermodynamics

## Path COMPLEXITY and NETWORKS:

- [420AA] Data mining
- [783AA] Geospatial analytics
- [654AA] Machine learning
- [668AA] Social network analysis

## DATA ANALYSIS IN EXPERIMENTAL PHYSICS

(Curriculum GENERAL)

### Constraints of the PdS

minimum

48 CFU

#### Compulsory group

(all of the following)

|    |                                                                      |     |        |
|----|----------------------------------------------------------------------|-----|--------|
| S1 | [193BB] STATISTICAL DATA ANALYSIS                                    | FIS | 09 CFU |
| A  | [360BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS | FIS | 09 CFU |

#### Experimental physics

(at least one of the following)

|    |                                                                  |     |        |
|----|------------------------------------------------------------------|-----|--------|
| S1 | [414BB] FUNDAMENTAL INTERACTIONS LABORATORY S                    | FIS | 09 CFU |
| S2 | [380BB] INSTRUMENTATION FOR FUNDAMENTAL INTERACTIONS PHYSICS     | FIS | 09 CFU |
| S2 | [0047B] PHYSICS AND DETECTORS OF GRAVITATIONAL WAVES S           | FIS | 06 CFU |
| S2 | [0007B] QUANTUM TECHNOLOGIES FOR FUNDAMENTAL INTERACTION PHYSICS | FIS | 09 CFU |

#### Theoretical physics group

(at least one of the following)

|    |                              |     |        |
|----|------------------------------|-----|--------|
| S1 | [228BB] GENERAL RELATIVITY   | FIS | 09 CFU |
| S1 | [213BB] QUANTUM FIELD THEORY | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS  | FIS | 09 CFU |

#### Microphysics group

(at least one of the following)

|    |                                  |     |        |
|----|----------------------------------|-----|--------|
| S1 | [305BB] FUNDAMENTAL INTERACTIONS | FIS | 09 CFU |
| S1 | [206BB] NUCLEAR PHYSICS          | FIS | 09 CFU |
| S1 | [353BB] PLASMA PHYSICS           | FIS | 09 CFU |
| S1 | [204BB] SOLID STATE PHYSICS      | FIS | 09 CFU |
| S2 | [217BB] ACCELERATOR PHYSICS      | FIS | 09 CFU |

#### Astrophysics group

(at least one of the following)

|    |                                                  |     |        |
|----|--------------------------------------------------|-----|--------|
| S2 | [063BB] ASTROPARTICLE PHYSICS S                  | FIS | 06 CFU |
| S2 | [368BB] ASTROPHYSICS                             | FIS | 06 CFU |
| S2 | [274BB] COSMOLOGY OF THE EARLY UNIVERSE          | FIS | 09 CFU |
| S2 | [369BB] EXTRAGALACTIC ASTROPHYSICS AND COSMOLOGY | FIS | 09 CFU |
| S2 | [098BB] STELLAR PHYSICS S                        | FIS | 06 CFU |

### Recommended Elective Courses

maximum

27 CFU

(at least 9 CFU from the following or from the unselected mandatory courses)

|    |                                                    |            |        |
|----|----------------------------------------------------|------------|--------|
| S1 | [878II] DATA MINING AND MACHINE LEARNING           | ING-INF/05 | 12 CFU |
| S1 | [676AA] DATA MINING: FUNDAMENTALS                  | INF/01     | 06 CFU |
| S1 | [654AA] MACHINE LEARNING                           | INF/01     | 09 CFU |
| S1 | [376BB] QUANTUM COMPUTING AND TECHNOLOGIES         | FIS        | 09 CFU |
| S1 | [338BB] SIGNAL PROCESSING FOR PHYSICS              | FIS        | 06 CFU |
| S2 | [699AA] DATA ANALYSIS                              | MAT/06     | 06 CFU |
| S2 | [185BB] MONTECARLO METHODS IN EXPERIMENTAL PHYSICS | FIS        | 06 CFU |
| S2 | [668AA] SOCIAL NETWORK ANALYSIS                    | INF/01     | 06 CFU |
| A  | [326BB] COMPUTATIONAL PHYSICS LABORATORY           | FIS        | 09 CFU |
| A  | [420AA] DATA MINING                                | INF/01     | 12 CFU |

### Additional notes

- The course [878II] DATA MINING AND MACHINE LEARNING overlaps in program content with [676AA] DATA MINING: FUNDAMENTALS and [420AA] DATA MINING. Therefore, an individual study plan must be submitted to agree on how many ECTS will be counted if you intend to take the exam for more than one of these courses;
- Specifically, the course [676AA] DATA MINING: FUNDAMENTALS is the first part of [420AA] DATA MINING, so both cannot be chosen;
- The course [676AA] DATA MINING: FUNDAMENTALS is offered in a Master's Degree program with restricted access (numero programmato): the possibility of attending is subject to the availability of free places and must be agreed upon with the instructor at the beginning of the course.

**FUNDAMENTAL INTERACTIONS**

(Curriculum FONDAMENTAL INTERACTIONS)

**Constraints of the PdS**

minimum

54 CFU

**Compulsory group***(all of the following)*

|    |                                                             |     |        |
|----|-------------------------------------------------------------|-----|--------|
| S1 | <a href="#">[305BB] FUNDAMENTAL INTERACTIONS</a>            | FIS | 09 CFU |
| S1 | <a href="#">[413BB] FUNDAMENTAL INTERACTIONS LABORATORY</a> | FIS | 15 CFU |

**Experimental nuclear and subnuclear group 1***(at least one of the following)*

|    |                                                                                  |     |        |
|----|----------------------------------------------------------------------------------|-----|--------|
| S2 | <a href="#">[373BB] PARTICLE PHYSICS S</a>                                       | FIS | 06 CFU |
| S2 | <a href="#">[0047B] PHYSICS AND DETECTORS OF GRAVITATIONAL WAVES S</a>           | FIS | 06 CFU |
| S2 | <a href="#">[0007B] QUANTUM TECHNOLOGIES FOR FUNDAMENTAL INTERACTION PHYSICS</a> | FIS | 09 CFU |

**Experimental nuclear and subnuclear group 2***(at least one of the following)*

|    |                                                                                      |     |        |
|----|--------------------------------------------------------------------------------------|-----|--------|
| S1 | <a href="#">[193BB] STATISTICAL DATA ANALYSIS</a>                                    | FIS | 09 CFU |
| S2 | <a href="#">[217BB] ACCELERATOR PHYSICS</a>                                          | FIS | 09 CFU |
| S2 | <a href="#">[380BB] INSTRUMENTATION FOR FUNDAMENTAL INTERACTIONS PHYSICS</a>         | FIS | 09 CFU |
| A  | <a href="#">[360BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS</a> | FIS | 09 CFU |

**Theoretical physics group***(at least one of the following)*

|    |                                              |     |        |
|----|----------------------------------------------|-----|--------|
| S1 | <a href="#">[228BB] GENERAL RELATIVITY</a>   | FIS | 09 CFU |
| S1 | <a href="#">[213BB] QUANTUM FIELD THEORY</a> | FIS | 09 CFU |

**Astrophysics group***(at least one of the following)*

|    |                                                           |     |        |
|----|-----------------------------------------------------------|-----|--------|
| S2 | <a href="#">[063BB] ASTROPARTICLE PHYSICS S</a>           | FIS | 06 CFU |
| S2 | <a href="#">[368BB] ASTROPHYSICS</a>                      | FIS | 06 CFU |
| S2 | <a href="#">[275BB] COSMOLOGY OF THE EARLY UNIVERSE S</a> | FIS | 06 CFU |

**Recommended Elective Courses**

maximum

21 CFU

*(at least 9 CFU from the following or from the unselected mandatory courses)*

|    |                                                                           |            |        |
|----|---------------------------------------------------------------------------|------------|--------|
| S1 | <a href="#">[306BB] EXPERIMENTAL METHODS FOR ASTROPARTICLE PHYSICS</a>    | FIS        | 09 CFU |
| S1 | <a href="#">[304BB] FUNDAMENTALS OF LIGHT MATTER INTERACTION</a>          | FIS        | 09 CFU |
| S1 | <a href="#">[385BB] INTRODUCTION TO NEUTRINO PHYSICS</a>                  | FIS        | 03 CFU |
| S1 | <a href="#">[206BB] NUCLEAR PHYSICS</a>                                   | FIS        | 09 CFU |
| S1 | <a href="#">[427BB] PARTICLE DARK MATTER</a>                              | FIS        | 06 CFU |
| S1 | <a href="#">[1095I] RADIATION PROTECTION</a>                              | ING-IND/20 | 06 CFU |
| S1 | <a href="#">[338BB] SIGNAL PROCESSING FOR PHYSICS</a>                     | FIS        | 06 CFU |
| S1 | <a href="#">[204BB] SOLID STATE PHYSICS</a>                               | FIS        | 09 CFU |
| S1 | <a href="#">[207BB] STATISTICAL PHYSICS</a>                               | FIS        | 09 CFU |
| S2 | <a href="#">[214BB] ADVANCED QUANTUM FIELD THEORY</a>                     | FIS        | 09 CFU |
| S2 | <a href="#">[0008B] BIOPHYSICS FOR EFLASH THERAPY</a>                     | FIS        | 09 CFU |
| S2 | <a href="#">[0035B] DESIGN OF DIGITAL SYSTEMS FOR RADIATION DETECTION</a> | FIS        | 06 CFU |
| S2 | <a href="#">[0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE</a>           | FIS        | 09 CFU |
| S2 | <a href="#">[308BB] DISCRETE SYMMETRIES</a>                               | FIS        | 06 CFU |
| S2 | <a href="#">[198BB] DOSIMETRY</a>                                         | FIS        | 06 CFU |
| S2 | <a href="#">[080BB] ELECTRONICS AND SENSORS</a>                           | FIS        | 06 CFU |
| S2 | <a href="#">[0004B] FLEXIBLE AND NANO-ELECTRONICS</a>                     | FIS        | 09 CFU |
| S2 | <a href="#">[201BB] HADRON COLLIDER PHYSICS</a>                           | FIS        | 09 CFU |
| S2 | <a href="#">[371BB] HADRON COLLIDER PHYSICS S</a>                         | FIS        | 06 CFU |
| S2 | <a href="#">[185BB] MONTECARLO METHODS IN EXPERIMENTAL PHYSICS</a>        | FIS        | 06 CFU |
| S2 | <a href="#">[302BB] PARTICLE PHYSICS</a>                                  | FIS        | 09 CFU |
| S2 | <a href="#">[0046B] PHYSICS AND DETECTORS OF GRAVITATIONAL WAVES</a>      | FIS        | 09 CFU |
| S2 | <a href="#">[0060B] STANDARD MODEL S</a>                                  | FIS        | 06 CFU |
| A  | <a href="#">[SNS-SMB] STANDARD MODEL AND BEYOND</a>                       | FIS        | 06 CFU |

**Additional notes**

-

**MEDICAL PHYSICS**

(Curriculum MEDICAL PHYSICS)

**Constraints of the PdS**

minimum

51 CFU

**Compulsory group***(all of the following)*

|    |                                      |     |        |
|----|--------------------------------------|-----|--------|
| S1 | [205BB] MEDICAL PHYSICS              | FIS | 09 CFU |
| S2 | [0037B] MOLECULAR IMAGING            | FIS | 06 CFU |
| A  | [281BB] MEDICAL PHYSICS LABORATORY B | FIS | 15 CFU |

**Theoretical physics group***(at least one of the following)*

|    |                              |     |        |
|----|------------------------------|-----|--------|
| S1 | [228BB] GENERAL RELATIVITY   | FIS | 09 CFU |
| S1 | [213BB] QUANTUM FIELD THEORY | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS  | FIS | 09 CFU |

**Microphysics group***(at least one of the following)*

|    |                                              |     |        |
|----|----------------------------------------------|-----|--------|
| S1 | [305BB] FUNDAMENTAL INTERACTIONS             | FIS | 09 CFU |
| S1 | [389BB] INTRODUCTION TO MOLECULAR BIOPHYSICS | FIS | 06 CFU |
| S1 | [206BB] NUCLEAR PHYSICS                      | FIS | 09 CFU |
| S1 | [387BB] PHYSICS OF BIOSYSTEMS                | FIS | 09 CFU |

**Astrophysics group***(at least one of the following)*

|    |                                 |     |        |
|----|---------------------------------|-----|--------|
| S2 | [063BB] ASTROPARTICLE PHYSICS S | FIS | 06 CFU |
| S2 | [368BB] ASTROPHYSICS            | FIS | 06 CFU |
| S2 | [098BB] STELLAR PHYSICS S       | FIS | 06 CFU |

**Recommended Elective Courses**

maximum

24 CFU

*(at least 9 CFU from the following or from the unselected mandatory courses)*

|    |                                                                        |        |        |
|----|------------------------------------------------------------------------|--------|--------|
| S1 | [361BB] ACUSTICA AMBIENTALE                                            | FIS    | 06 CFU |
| S1 | [478EE] ELEMENTS OF PHYSIOLOGY, PHYSIOPATHOLOGY AND DIAGNOSTICS        | BIO/09 | 06 CFU |
| S1 | [305BB] FUNDAMENTAL INTERACTIONS                                       | FIS    | 09 CFU |
| S1 | [304BB] FUNDAMENTALS OF LIGHT MATTER INTERACTION                       | FIS    | 09 CFU |
| S1 | [389BB] INTRODUCTION TO MOLECULAR BIOPHYSICS                           | FIS    | 06 CFU |
| S1 | [206BB] NUCLEAR PHYSICS                                                | FIS    | 09 CFU |
| S1 | [387BB] PHYSICS OF BIOSYSTEMS                                          | FIS    | 09 CFU |
| S1 | [338BB] SIGNAL PROCESSING FOR PHYSICS                                  | FIS    | 06 CFU |
| S1 | [193BB] STATISTICAL DATA ANALYSIS                                      | FIS    | 09 CFU |
| S2 | [217BB] ACCELERATOR PHYSICS                                            | FIS    | 09 CFU |
| S2 | [107BB] ACCELERATOR PHYSICS S                                          | FIS    | 06 CFU |
| S2 | [164BB] ACUSTICA 2                                                     | FIS    | 06 CFU |
| S2 | [0008B] BIOPHYSICS FOR EFLASH THERAPY                                  | FIS    | 09 CFU |
| S2 | [0039E] CELL BIOPHYSICS                                                | BIO/10 | 03 CFU |
| S2 | [0035B] DESIGN OF DIGITAL SYSTEMS FOR RADIATION DETECTION              | FIS    | 06 CFU |
| S2 | [0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE                        | FIS    | 09 CFU |
| S2 | [198BB] DOSIMETRY                                                      | FIS    | 06 CFU |
| S2 | [0004B] FLEXIBLE AND NANO-ELECTRONICS                                  | FIS    | 09 CFU |
| S2 | [0021B] MICROBIOROBOTICS                                               | FIS    | 06 CFU |
| S2 | [185BB] MONTECARLO METHODS IN EXPERIMENTAL PHYSICS                     | FIS    | 06 CFU |
| S2 | [0020B] NEUROENGINEERING                                               | FIS    | 06 CFU |
| S2 | [124BB] NUCLEAR MAGNETIC RESONANCE                                     | FIS    | 06 CFU |
| S2 | [0040B] QUANTUM BIOLOGY                                                | FIS    | 09 CFU |
| A  | [326BB] COMPUTATIONAL PHYSICS LABORATORY                               | FIS    | 09 CFU |
| A  | [360BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS   | FIS    | 09 CFU |
| A  | [365BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS S | FIS    | 06 CFU |

**Additional notes**

As a further guide for selection, some possible suggested paths are listed below:

Path MEDICAL PHYSICS. Path recommended for students interested in deepening their knowledge of physical methodologies applied to medicine, also in view of a possible professional career as a specialist in medical physics.

*(from "Gruppo microfisica")*

[206BB] Nuclear physics (FIS/04) 9 CFU

*(from "Insegnamenti a scelta")*

[360BB] Computing methods for experimental physics and data analysis (FIS/01) 9 CFU

[198BB] Dosimetry (FIS/07) 6 CFU

[124BB] Nuclear magnetic resonance (FIS/07) 6 CFU.

Path FLASH RT. *Path recommended for students interested in acquiring in-depth knowledge of the physical phenomena and radiobiological mechanisms underlying FLASH radiotherapy, providing computational and experimental skills typical of research in the field.*

(from "Gruppo microfisica")

[389BB] Introduction to molecular biophysics (FIS/03) 6 CFU

(from "Insegnamenti a scelta")

[0008B] Biophysics for eflash therapy (FIS/07) 9 CFU

[360BB] Computing methods for experimental physics and data analysis (FIS/01) 9 CFU

[185BB] Montecarlo methods in experimental physics (FIS/01) 6 CFU

Path BIOMEDICAL IMAGING. *Path recommended for students interested in developing an in-depth understanding of the physical principles and technologies used in the generation and analysis of images of biological phenomena across different dimensional scales.*

(from "Gruppo microfisica")

[389BB] Introduction to molecular biophysics (FIS/03) 6 CFU

(from "Insegnamenti a scelta")

[360BB] Computing methods for experimental physics and data analysis (FIS/01) 9 CFU

[124BB] Nuclear magnetic resonance (FIS/07) 6 CFU

[387BB] Physics of biosystems (FIS/03) 9 CFU

Path INSTRUMENTATION FOR MEDICAL PHYSICS. *Path recommended for students interested in technologies for biomedical imaging and radiotherapy, with particular attention to the instrumental, computational, and physical aspects involved in the development and optimization of data acquisition, dosimetric, and imaging systems.*

(from "Gruppo microfisica")

[206BB] Nuclear Physics (FIS/04) 9 CFU

(from "Insegnamenti a scelta")

[107BB] Accelerator physics S (FIS/04) 6 CFU

[360BB] Computing methods for experimental physics and data analysis (FIS/01) 9 CFU

[0035B] Design of digital systems for radiation detection (FIS/07) 6 CFU

**PHENOMENOLOGY OF FUNDAMENTAL INTERACTIONS**

(Curriculum GENERAL)

**Constraints of the PdS**

minimum

66 CFU

**Compulsory group***(all of the following)*

|    |                                       |     |        |
|----|---------------------------------------|-----|--------|
| S1 | [305BB] FUNDAMENTAL INTERACTIONS      | FIS | 09 CFU |
| S1 | [228BB] GENERAL RELATIVITY            | FIS | 09 CFU |
| S1 | [213BB] QUANTUM FIELD THEORY          | FIS | 09 CFU |
| S2 | [214BB] ADVANCED QUANTUM FIELD THEORY | FIS | 09 CFU |
| S2 | [192BB] ASTROPARTICLE PHYSICS         | FIS | 09 CFU |

**Theoretical nuclear and subnuclear physics group***(at least one of the following)*

|    |                                             |     |        |
|----|---------------------------------------------|-----|--------|
| S1 | [206BB] NUCLEAR PHYSICS                     | FIS | 09 CFU |
| S2 | [197BB] QUANTUM CHROMODYNAMICS              | FIS | 09 CFU |
| S2 | [0060B] STANDARD MODEL S                    | FIS | 06 CFU |
| A  | [SNS-EFT] EFFECTIVE FIELD THEORIES I AND II | FIS | 06 CFU |

**Experimental nuclear and subnuclear group***(at least one of the following)*

|    |                                 |     |        |
|----|---------------------------------|-----|--------|
| S1 | [427BB] PARTICLE DARK MATTER    | FIS | 06 CFU |
| S2 | [308BB] DISCRETE SYMMETRIES     | FIS | 06 CFU |
| S2 | [201BB] HADRON COLLIDER PHYSICS | FIS | 09 CFU |
| S2 | [302BB] PARTICLE PHYSICS        | FIS | 09 CFU |

**Experimental physics***(at least one of the following)*

|    |                                                                      |     |        |
|----|----------------------------------------------------------------------|-----|--------|
| S1 | [414BB] FUNDAMENTAL INTERACTIONS LABORATORY S                        | FIS | 09 CFU |
| S1 | [193BB] STATISTICAL DATA ANALYSIS                                    | FIS | 09 CFU |
| S2 | [0007B] QUANTUM TECHNOLOGIES FOR FUNDAMENTAL INTERACTION PHYSICS     | FIS | 09 CFU |
| A  | [0010B] ASTROPHYSICS AND MULTIMESSENGER LABORATORY                   | FIS | 12 CFU |
| A  | [360BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS | FIS | 09 CFU |

**Recommended Elective Courses**

maximum

09 CFU

*(includes unselected Constraints)***Additional notes**

-

**PHYSICS FOR CULTURAL HERITAGE**

(Curriculum GENERAL)

**Constraints of the PdS**

minimum

54 CFU

**Compulsory group***(tutti i seguenti)*

|    |                                                                      |     |        |
|----|----------------------------------------------------------------------|-----|--------|
| S1 | [304BB] FUNDAMENTALS OF LIGHT MATTER INTERACTION                     | FIS | 09 CFU |
| S1 | [418BB] PHYSICS FOR CULTURAL HERITAGE                                | FIS | 09 CFU |
| A  | [360BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS | FIS | 09 CFU |

**Thematic group***(at least one of the following methodological course from archeological/historical/artistic ambit)*

|    |                                                     |          |        |
|----|-----------------------------------------------------|----------|--------|
| S1 | [614LL] HISTORY OF ART RESTORATION                  | L-ART/04 | 06 CFU |
| S1 | [1261L] HISTORY OF ARTISTIC TECHNIQUES              | L-ART/04 | 06 CFU |
| S1 | [289LL] METHODOLOGY OF HISTORICAL-ARTISTIC RESEARCH | L-ART/04 | 06 CFU |
| S1 | [1276L] METHODS OF ARCHAEOLOGICAL RESEARCH          | L-ANT/10 | 06 CFU |
| S1 | [1407L] PALEOECOLOGIA E BIOARCHEOLOGIA              | L-ANT/10 | 06 CFU |
| S2 | [402LL] ARCHEOLOGY OF PRODUCTION                    | L-ANT/10 | 06 CFU |

**Theoretical physics group***(at least one of the following)*

|    |                              |     |        |
|----|------------------------------|-----|--------|
| S1 | [213BB] QUANTUM FIELD THEORY | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS  | FIS | 09 CFU |

**Microphysics group***(at least one of the following)*

|    |                                 |     |        |
|----|---------------------------------|-----|--------|
| S1 | [206BB] NUCLEAR PHYSICS         | FIS | 09 CFU |
| S1 | [0043B] PHOTONICS AND MATERIALS | FIS | 06 CFU |

**Astrophysics group***(at least one of the following)*

|    |                               |     |        |
|----|-------------------------------|-----|--------|
| S1 | [353BB] PLASMA PHYSICS        | FIS | 09 CFU |
| S2 | [192BB] ASTROPARTICLE PHYSICS | FIS | 09 CFU |
| S2 | [368BB] ASTROPHYSICS          | FIS | 06 CFU |
| S2 | [098BB] STELLAR PHYSICS S     | FIS | 06 CFU |

**Recommended Elective Courses**

maximum

21 CFU

*(includes unselected Constraints and further courses from archeological/historical/artistic ambit)*

|    |                                                           |            |        |
|----|-----------------------------------------------------------|------------|--------|
| S1 | [244CC] CHEMICAL PHYSICS OF MOLECULES                     | CHIM/02    | 09 CFU |
| S1 | [1403L] COMPETENZE DIGITALI PER I BENI CULTURALI          | L-ANT/10   | 06 CFU |
| S1 | [230BB] COMPLEX SYSTEMS                                   | FIS        | 09 CFU |
| S1 | [1237L] DIAGNOSTICS FOR THE STUDY OF WORKS OF ART         | L-ART/04   | 06 CFU |
| S1 | [309BB] DISORDERED SYSTEMS OUT OF EQUILIBRIUM             | FIS        | 09 CFU |
| S1 | [0024B] FLUID DYNAMICS                                    | FIS        | 06 CFU |
| S1 | [305BB] FUNDAMENTAL INTERACTIONS                          | FIS        | 09 CFU |
| S1 | [414BB] FUNDAMENTAL INTERACTIONS LABORATORY S             | FIS        | 09 CFU |
| S1 | [387BB] PHYSICS OF BIOSYSTEMS                             | FIS        | 09 CFU |
| S1 | [412BB] PHYSICS OF MATTER AND NANOTECHNOLOGY LABORATORY S | FIS        | 09 CFU |
| S1 | [1095I] RADIATION PROTECTION                              | ING-IND/20 | 06 CFU |
| S1 | [338BB] SIGNAL PROCESSING FOR PHYSICS                     | FIS        | 06 CFU |
| S2 | [217BB] ACCELERATOR PHYSICS                               | FIS        | 09 CFU |
| S2 | [221BB] ATOM OPTICS                                       | FIS        | 09 CFU |
| S2 | [0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE           | FIS        | 09 CFU |
| S2 | [198BB] DOSIMETRY                                         | FIS        | 06 CFU |
| S2 | [080BB] ELECTRONICS AND SENSORS                           | FIS        | 06 CFU |
| S2 | [124BB] NUCLEAR MAGNETIC RESONANCE                        | FIS        | 06 CFU |
| S2 | [203BB] PHYSICS OF PHOTONIC DEVICES                       | FIS        | 09 CFU |
| S2 | [354BB] QUANTUM OPTICS AND PLASMA PHYSICS                 | FIS        | 09 CFU |
| A  | [326BB] COMPUTATIONAL PHYSICS LABORATORY                  | FIS        | 09 CFU |
| A  | [281BB] MEDICAL PHYSICS LABORATORY B                      | FIS        | 15 CFU |

**Additional notes**

- The "Medical Imaging" module must be included among the modules of the course [360BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS.

**PHYSICS OF BIOSYSTEMS**

(Curriculum PHYSICS OF MATTER)

**Constraints of the PdS**

minimum

54 CFU

**Compulsory group***(all of the following)*

|    |                                                         |     |        |
|----|---------------------------------------------------------|-----|--------|
| S1 | [304BB] FUNDAMENTALS OF LIGHT MATTER INTERACTION        | FIS | 09 CFU |
| S1 | [387BB] PHYSICS OF BIOSYSTEMS                           | FIS | 09 CFU |
| A  | [411BB] PHYSICS OF MATTER AND NANOTECHNOLOGY LABORATORY | FIS | 15 CFU |

**Physics of matter group***(at least one of the following)*

|    |                                               |     |        |
|----|-----------------------------------------------|-----|--------|
| S1 | [309BB] DISORDERED SYSTEMS OUT OF EQUILIBRIUM | FIS | 09 CFU |
| S1 | [389BB] INTRODUCTION TO MOLECULAR BIOPHYSICS  | FIS | 06 CFU |

**Theoretical physics group***(at least one of the following)*

|    |                              |     |        |
|----|------------------------------|-----|--------|
| S1 | [213BB] QUANTUM FIELD THEORY | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS  | FIS | 09 CFU |

**Astrophysics group***(at least one of the following)*

|    |                           |     |        |
|----|---------------------------|-----|--------|
| S2 | [368BB] ASTROPHYSICS      | FIS | 06 CFU |
| S2 | [098BB] STELLAR PHYSICS S | FIS | 06 CFU |

**Recommended Elective Courses**

maximum

21 CFU

*(includes unselected Constraints and those that follow)*

|    |                                                                                 |            |        |
|----|---------------------------------------------------------------------------------|------------|--------|
| S1 | [1054I] BIOFLUIDS AND MATERIALS INTERACTIONS                                    | ING-IND/22 | 03 CFU |
| S1 | [178EE] BIOINFORMATICS                                                          | INF/01     | 03 CFU |
| S1 | [244CC] CHEMICAL PHYSICS OF MOLECULES                                           | CHIM/02    | 09 CFU |
| S1 | [230BB] COMPLEX SYSTEMS                                                         | FIS        | 09 CFU |
| S1 | [389BB] INTRODUCTION TO MOLECULAR BIOPHYSICS                                    | FIS        | 06 CFU |
| S1 | [1057I] MANUFACTURING OF POLYMERS AND NANOCOMPOSITES FOR BIOMEDICAL APPLICATION | ING-IND/22 | 03 CFU |
| S1 | [205BB] MEDICAL PHYSICS                                                         | FIS        | 09 CFU |
| S1 | [1053I] NANOMEDICINE AND REGENERATIVE MEDICINE                                  | ING-IND/22 | 06 CFU |
| S1 | [0043B] PHOTONICS AND MATERIALS                                                 | FIS        | 06 CFU |
| S1 | [204BB] SOLID STATE PHYSICS                                                     | FIS        | 09 CFU |
| S2 | [0005B] 3D AND 4D NANOMATERIALS AND DEVICES                                     | FIS        | 09 CFU |
| S2 | [728II] BIOMATERIALS                                                            | ING-IND/22 | 06 CFU |
| S2 | [0008B] BIOPHYSICS FOR EFLASH THERAPY                                           | FIS        | 09 CFU |
| S2 | [0039E] CELL BIOPHYSICS                                                         | BIO/10     | 03 CFU |
| S2 | [0042B] GRAPHICS AND ANIMATION WITH PYTHON                                      | FIS        | 03 CFU |
| S2 | [0021B] MICROBIOROBOTICS                                                        | FIS        | 06 CFU |
| S2 | [0037B] MOLECULAR IMAGING                                                       | FIS        | 06 CFU |
| S2 | [0020B] NEUROENGINEERING                                                        | FIS        | 06 CFU |
| S2 | [0040B] QUANTUM BIOLOGY                                                         | FIS        | 09 CFU |
| S2 | [383BB] SPECTROSCOPY AND MICROSCOPY OF NANOMATERIALS                            | FIS        | 06 CFU |
| A  | [374BB] COMPUTATIONAL PHYSICS LABORATORY S                                      | FIS        | 06 CFU |
| A  | [365BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS S          | FIS        | 06 CFU |
| A  | [1056I] FUNDAMENTALS OF BIOPHYSICS AT THE NANOSCALE                             | ING-IND/22 | 06 CFU |
| A  | [SNS-PLC] PHYSICS OF THE LIVING CELL                                            | FIS        | 06 CFU |

**Additional notes**

Please note that it is possible to replace **[411BB]** LABORATORIO DI FISICA DELLA MATERIA E NANOTECNOLOGIE (15 CFU) with the "short" version **[412BB]** (9 CFU), combined with 6 CFU of **[326BB]** METODI NUMERICI PER LA FISICA (modules "Calcoli da principi primi" and "Dinamica molecolare classica").

Within some possible thematic paths in Physics of Biosystems, the following courses are suggested:

**Path BIOPHYSICS:** a path that deepens the processes and techniques involved in cellular and molecular biophysics.

- [403BB] Bio-systems lab (15 CFU)
- [0039E] Cell biophysics (3 CFU)
- [309BB] Disordered systems out of equilibrium (9 CFU)
- [389BB] Introduction to molecular biophysics (6 CFU)

**Path ACTIVE MATTER:** a path that provides the physical basis characterizing the complexity of the mechanisms underlying "bio-inspired" materials.

- [230BB] Complex systems (9 CFU)
- [309BB] Disordered systems out of equilibrium (9 CFU)
- [0021B] Microbiorobotics (6 CFU)



[411BB] Physics of matter and nanotechnology laboratory (15 CFU)

Path BIOPHYSICS FOR FLASH (experimental): a path that provides the basic physical skills on biophysical mechanisms and experimental techniques oriented to the study of effects induced by Flash radiotherapy.

[0008B] Biophysics for eflash therapy (9 CFU)

[389BB] Introduction to molecular biophysics (6 CFU)

[205BB] Medical physics (9 CFU)

[0042B] Graphics and animation with python (3 CFU)

Path BIOPHYSICS FOR FLASH (computational): a path that provides the basic physical skills on biophysical mechanisms and computational techniques for the study of effects induced by Flash radiotherapy.

[0008B] Biophysics for eflash therapy (9 CFU)

[389BB] Introduction to molecular biophysics (6 CFU)

[205BB] Medical physics (9 CFU)

[412BB] Physics of matter and nanotechnology laboratory S (9 CFU)

[374BB] Computational physics laboratory S (6 CFU)

**GEOPHYSICAL FLUIDS DYNAMICS AND SOLID EARTH PHYSICS**

(Curriculum GENERALE)

**Constraints of the PdS**

minimum

60 CFU

**Compulsory group***(all of the following, except 0024B if already given at the bachelor)*

|    |                                                                  |     |        |
|----|------------------------------------------------------------------|-----|--------|
| S1 | [0048B] EARTH SENSING AND GEOPHYSICAL MONITORING INSTRUMENTATION | FIS | 06 CFU |
| S1 | [0024B] FLUID DYNAMICS                                           | FIS | 06 CFU |
| S1 | [353BB] PLASMA PHYSICS                                           | FIS | 09 CFU |
| S1 | [346BB] ROCK PHYSICS                                             | FIS | 06 CFU |
| S1 | [207BB] STATISTICAL PHYSICS                                      | FIS | 09 CFU |
| S2 | [0022B] LABORATORY OF INSTRUMENTAL SEISMOLOGY                    | FIS | 09 CFU |
| S2 | [0023B] MECHANICS OF GEOPHYSICAL FLUIDS                          | FIS | 09 CFU |

**Thematic group***(at least one of the following)*

|    |                                           |            |        |
|----|-------------------------------------------|------------|--------|
| S1 | [230BB] COMPLEX SYSTEMS                   | FIS        | 09 CFU |
| S1 | [338BB] SIGNAL PROCESSING FOR PHYSICS     | FIS        | 06 CFU |
| S2 | [454II] COMPUTATIONAL FLUIDODYNAMICS      | ING-IND/06 | 06 CFU |
| S2 | [288DD] EARTHQUAKE SEISMOLOGY             | GEO/10     | 06 CFU |
| S2 | [375BB] LARGE SCALE PHYSICAL OCEANOGRAPHY | FIS        | 09 CFU |

**Recommended Elective Courses**

maximum

15 CFU

*(includes unselected Constraints and those that follow)*

|    |                                                        |            |        |
|----|--------------------------------------------------------|------------|--------|
| S1 | [226BB] ASTROPHYSICAL PROCESSES                        | FIS        | 09 CFU |
| S1 | [230BB] COMPLEX SYSTEMS                                | FIS        | 09 CFU |
| S1 | [309BB] DISORDERED SYSTEMS OUT OF EQUILIBRIUM          | FIS        | 09 CFU |
| S1 | [1074I] INTRODUCTION TO MACHINE LEARNING IN GEOPHYSICS | GEO/11     | 03 CFU |
| S1 | [234DD] INVERSE PROBLEMS IN GEOPHYSICS                 | GEO/11     | 06 CFU |
| S1 | [338BB] SIGNAL PROCESSING FOR PHYSICS                  | FIS        | 06 CFU |
| S1 | [193BB] STATISTICAL DATA ANALYSIS                      | FIS        | 09 CFU |
| S2 | [454II] COMPUTATIONAL FLUIDODYNAMICS                   | ING-IND/06 | 06 CFU |
| S2 | [267DD] COMPUTATIONAL GEOPHYSICS                       | GEO/11     | 06 CFU |
| S2 | [288DD] EARTHQUAKE SEISMOLOGY                          | GEO/10     | 06 CFU |
| S2 | [375BB] LARGE SCALE PHYSICAL OCEANOGRAPHY              | FIS        | 09 CFU |
| S2 | [322BB] NONLINEAR DYNAMICS                             | FIS        | 09 CFU |

**Additional notes**

-

**PHYSICS OF MATTER**

(Curriculum PHYSICS OF MATTER)

**Constraints of the PdS**

minimum

57 CFU

**Compulsory group***(all of the following)*

|    |                                                         |     |        |
|----|---------------------------------------------------------|-----|--------|
| S1 | [304BB] FUNDAMENTALS OF LIGHT MATTER INTERACTION        | FIS | 09 CFU |
| A  | [411BB] PHYSICS OF MATTER AND NANOTECHNOLOGY LABORATORY | FIS | 15 CFU |

**Physics of matter group (group 1)***(at least one of the following)*

|    |                             |     |        |
|----|-----------------------------|-----|--------|
| S1 | [353BB] PLASMA PHYSICS      | FIS | 09 CFU |
| S1 | [204BB] SOLID STATE PHYSICS | FIS | 09 CFU |

**Physics of matter group (group 2)***(at least one of the following)*

|    |                                               |     |        |
|----|-----------------------------------------------|-----|--------|
| S1 | [230BB] COMPLEX SYSTEMS                       | FIS | 09 CFU |
| S1 | [309BB] DISORDERED SYSTEMS OUT OF EQUILIBRIUM | FIS | 09 CFU |

**Theoretical physics group***(at least one of the following)*

|    |                              |     |        |
|----|------------------------------|-----|--------|
| S1 | [213BB] QUANTUM FIELD THEORY | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS  | FIS | 09 CFU |

**Astrophysics group***(at least one of the following)*

|    |                                 |     |        |
|----|---------------------------------|-----|--------|
| S1 | [353BB] PLASMA PHYSICS          | FIS | 09 CFU |
| S2 | [063BB] ASTROPARTICLE PHYSICS S | FIS | 06 CFU |
| S2 | [368BB] ASTROPHYSICS            | FIS | 06 CFU |
| S2 | [098BB] STELLAR PHYSICS S       | FIS | 06 CFU |

**Recommended Elective Courses**

maximum

18 CFU

*(includes unselected Constraints and those that follow)*

|    |                                                                  |         |        |
|----|------------------------------------------------------------------|---------|--------|
| S1 | [244CC] CHEMICAL PHYSICS OF MOLECULES                            | CHIM/02 | 09 CFU |
| S1 | [230BB] COMPLEX SYSTEMS                                          | FIS     | 09 CFU |
| S1 | [309BB] DISORDERED SYSTEMS OUT OF EQUILIBRIUM                    | FIS     | 09 CFU |
| S1 | [0024B] FLUID DYNAMICS                                           | FIS     | 06 CFU |
| S1 | [389BB] INTRODUCTION TO MOLECULAR BIOPHYSICS                     | FIS     | 06 CFU |
| S1 | [0043B] PHOTONICS AND MATERIALS                                  | FIS     | 06 CFU |
| S1 | [387BB] PHYSICS OF BIOSYSTEMS                                    | FIS     | 09 CFU |
| S1 | [353BB] PLASMA PHYSICS                                           | FIS     | 09 CFU |
| S1 | [376BB] QUANTUM COMPUTING AND TECHNOLOGIES                       | FIS     | 09 CFU |
| S1 | [0061B] QUANTUM MANY-BODY STATES OF MATTER                       | FIS     | 09 CFU |
| S1 | [204BB] SOLID STATE PHYSICS                                      | FIS     | 09 CFU |
| S1 | [0039B] THE PHYSICS OF EVERY DAY LIFE                            | FIS     | 06 CFU |
| S2 | [0005B] 3D AND 4D NANOMATERIALS AND DEVICES                      | FIS     | 09 CFU |
| S2 | [221BB] ATOM OPTICS                                              | FIS     | 09 CFU |
| S2 | [370BB] CONDENSED MATTER PHYSICS                                 | FIS     | 09 CFU |
| S2 | [0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE                  | FIS     | 09 CFU |
| S2 | [0004B] FLEXIBLE AND NANO-ELECTRONICS                            | FIS     | 09 CFU |
| S2 | [0042B] GRAPHICS AND ANIMATION WITH PYTHON                       | FIS     | 03 CFU |
| S2 | [0045B] GROUP THEORY FOR MATERIAL SCIENCE                        | FIS     | 03 CFU |
| S2 | [0034B] INTRODUCTION TO THE PHYSICS OF CONTROLLED NUCLEAR FUSION | FIS     | 06 CFU |
| S2 | [322BB] NONLINEAR DYNAMICS                                       | FIS     | 09 CFU |
| S2 | [203BB] PHYSICS OF PHOTONIC DEVICES                              | FIS     | 09 CFU |
| S2 | [0062B] QUANTUM FOUNDATIONS FOR QUANTUM TECHNOLOGY               | FIS     | 06 CFU |
| S2 | [354BB] QUANTUM OPTICS AND PLASMA PHYSICS                        | FIS     | 09 CFU |
| S2 | [0007B] QUANTUM TECHNOLOGIES FOR FUNDAMENTAL INTERACTION PHYSICS | FIS     | 09 CFU |
| S2 | [383BB] SPECTROSCOPY AND MICROSCOPY OF NANOMATERIALS             | FIS     | 06 CFU |
| S2 | [0059B] THEORY OF SUPERCONDUCTIVITY AND QUANTUM DEVICES          | FIS     | 06 CFU |
| A  | [326BB] COMPUTATIONAL PHYSICS LABORATORY                         | FIS     | 09 CFU |

**Additional notes**

- Alternatively to [411BB] PHYSICS OF MATTER AND NANOTECHNOLOGY LABORATORY (15 CFU), it is possible to take the "short" version [412BB] (9 CFU), in combination with at least two modules (for 6 CFU) of [326BB] COMPUTATIONAL PHYSICAL LABORATORY S. The modules "Calcoli da principi primi" and "Dinamica molecolare classica" are strongly suggested.

**PHYSICS OF THE UNIVERSE**

(Curriculum GENERAL)

**Constraints of the PdS**

minimum

60 CFU

**Compulsory group***(all of the following)*

|    |                                                    |     |        |
|----|----------------------------------------------------|-----|--------|
| S1 | [228BB] GENERAL RELATIVITY                         | FIS | 09 CFU |
| S1 | [213BB] QUANTUM FIELD THEORY                       | FIS | 09 CFU |
| S2 | [192BB] ASTROPARTICLE PHYSICS                      | FIS | 09 CFU |
| A  | [0010B] ASTROPHYSICS AND MULTIMESSENGER LABORATORY | FIS | 12 CFU |

**Experimental physics***(at least one of the following)*

|    |                                                                  |     |        |
|----|------------------------------------------------------------------|-----|--------|
| S1 | [193BB] STATISTICAL DATA ANALYSIS                                | FIS | 09 CFU |
| S2 | [0046B] PHYSICS AND DETECTORS OF GRAVITATIONAL WAVES             | FIS | 09 CFU |
| S2 | [0007B] QUANTUM TECHNOLOGIES FOR FUNDAMENTAL INTERACTION PHYSICS | FIS | 09 CFU |
| A  | [326BB] COMPUTATIONAL PHYSICS LABORATORY                         | FIS | 09 CFU |

**Microphysics group***(at least one of the following)*

|    |                                                  |     |        |
|----|--------------------------------------------------|-----|--------|
| S1 | [304BB] FUNDAMENTALS OF LIGHT MATTER INTERACTION | FIS | 09 CFU |
| S1 | [206BB] NUCLEAR PHYSICS                          | FIS | 09 CFU |

**Astrophysics group***(at least one of the following)*

|    |                                           |     |        |
|----|-------------------------------------------|-----|--------|
| S1 | [226BB] ASTROPHYSICAL PROCESSES           | FIS | 09 CFU |
| S2 | [368BB] ASTROPHYSICS                      | FIS | 06 CFU |
| S2 | [275BB] COSMOLOGY OF THE EARLY UNIVERSE S | FIS | 06 CFU |
| S2 | [098BB] STELLAR PHYSICS S                 | FIS | 06 CFU |

**Recommended Elective Courses**

maximum

15 CFU

*(includes unselected Constraints and those that follow)*

|    |                                                                                               |     |        |
|----|-----------------------------------------------------------------------------------------------|-----|--------|
| S1 | [0013B] ADVANCED TECHNOLOGIES FOR GROUND-BASED ASTROPHYSICS: FROM MICROWAVES TO VISIBLE LIGHT | FIS | 06 CFU |
| S1 | [306BB] EXPERIMENTAL METHODS FOR ASTROPARTICLE PHYSICS                                        | FIS | 09 CFU |
| S1 | [305BB] FUNDAMENTAL INTERACTIONS                                                              | FIS | 09 CFU |
| S1 | [414BB] FUNDAMENTAL INTERACTIONS LABORATORY S                                                 | FIS | 09 CFU |
| S1 | [385BB] INTRODUCTION TO NEUTRINO PHYSICS                                                      | FIS | 03 CFU |
| S1 | [0011B] MULTIMESSENGER AND HIGH-ENERGY ASTROPHYSICS                                           | FIS | 06 CFU |
| S1 | [427BB] PARTICLE DARK MATTER                                                                  | FIS | 06 CFU |
| S1 | [0012B] PHYSICS OF STAR FORMATION                                                             | FIS | 06 CFU |
| S1 | [353BB] PLASMA PHYSICS                                                                        | FIS | 09 CFU |
| S2 | [214BB] ADVANCED QUANTUM FIELD THEORY                                                         | FIS | 09 CFU |
| S2 | [274BB] COSMOLOGY OF THE EARLY UNIVERSE                                                       | FIS | 09 CFU |
| S2 | [0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE                                               | FIS | 09 CFU |
| S2 | [369BB] EXTRAGALACTIC ASTROPHYSICS AND COSMOLOGY                                              | FIS | 09 CFU |
| S2 | [251BB] GRAVITATION THEORY                                                                    | FIS | 09 CFU |
| S2 | [140BB] GRAVITATION THEORY S                                                                  | FIS | 06 CFU |
| S2 | [0046B] PHYSICS AND DETECTORS OF GRAVITATIONAL WAVES                                          | FIS | 09 CFU |
| S2 | [0047B] PHYSICS AND DETECTORS OF GRAVITATIONAL WAVES S                                        | FIS | 06 CFU |
| S2 | [0016B] THEORY OF NUCLEAR INTERACTION S                                                       | FIS | 06 CFU |

**Additional notes**

Within some possible thematic paths in Physics of the Universe, the following elective courses are suggested:

**Path GRAVITATIONAL WAVES:**

- [0046B] Physics and detectors of gravitational wave physics (9 CFU o versione short da 6 CFU [0047B])
- [251BB] Gravitation theory (9 CFU o versione short da 6 CFU [140BB])

**Path COSMOLOGY and DARK MATTER:**

- [274BB] Cosmology of the early universe (9 CFU)
- [369BB] Extragalactic astrophysics and cosmology (9 CFU)
- [427BB] Particle dark matter (6 CFU)

## PLASMA PHYSICS

(Curriculum PHYSICS OF MATTER)

### Constraints of the PdS

minimum

60 CFU

#### Compulsory group

(all of the following, except 0024B if already given at the bachelor)

|    |                                                           |     |        |
|----|-----------------------------------------------------------|-----|--------|
| S1 | [0024B] FLUID DYNAMICS                                    | FIS | 06 CFU |
| S1 | [304BB] FUNDAMENTALS OF LIGHT MATTER INTERACTION          | FIS | 09 CFU |
| S1 | [412BB] PHYSICS OF MATTER AND NANOTECHNOLOGY LABORATORY S | FIS | 09 CFU |
| S1 | [353BB] PLASMA PHYSICS                                    | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS                               | FIS | 09 CFU |
| A  | [374BB] COMPUTATIONAL PHYSICS LABORATORY S                | FIS | 06 CFU |

#### Astrophysics group

(at least one of the following)

|    |                           |     |        |
|----|---------------------------|-----|--------|
| S2 | [368BB] ASTROPHYSICS      | FIS | 06 CFU |
| S2 | [098BB] STELLAR PHYSICS S | FIS | 06 CFU |

### Recommended Elective Courses

maximum

15 CFU

(includes unselected Constraints and those that follow)

|    |                                                                        |            |        |
|----|------------------------------------------------------------------------|------------|--------|
| S1 | [230BB] COMPLEX SYSTEMS                                                | FIS        | 09 CFU |
| S1 | [309BB] DISORDERED SYSTEMS OUT OF EQUILIBRIUM                          | FIS        | 09 CFU |
| S1 | [389BB] INTRODUCTION TO MOLECULAR BIOPHYSICS                           | FIS        | 06 CFU |
| S1 | [654AA] MACHINE LEARNING                                               | INF/01     | 09 CFU |
| S1 | [387BB] PHYSICS OF BIOSYSTEMS                                          | FIS        | 09 CFU |
| S1 | [376BB] QUANTUM COMPUTING AND TECHNOLOGIES                             | FIS        | 09 CFU |
| S1 | [213BB] QUANTUM FIELD THEORY                                           | FIS        | 09 CFU |
| S1 | [204BB] SOLID STATE PHYSICS                                            | FIS        | 09 CFU |
| S1 | [193BB] STATISTICAL DATA ANALYSIS                                      | FIS        | 09 CFU |
| S2 | [368BB] ASTROPHYSICS                                                   | FIS        | 06 CFU |
| S2 | [221BB] ATOM OPTICS                                                    | FIS        | 09 CFU |
| S2 | [279BB] COMPLEX SYSTEMS - NEURAL DYNAMICS                              | FIS        | 09 CFU |
| S2 | [454II] COMPUTATIONAL FLUIDODYNAMICS                                   | ING-IND/06 | 06 CFU |
| S2 | [370BB] CONDENSED MATTER PHYSICS                                       | FIS        | 09 CFU |
| S2 | [0034B] INTRODUCTION TO THE PHYSICS OF CONTROLLED NUCLEAR FUSION       | FIS        | 06 CFU |
| S2 | [0022B] LABORATORY OF INSTRUMENTAL SEISMOLOGY                          | FIS        | 09 CFU |
| S2 | [375BB] LARGE SCALE PHYSICAL OCEANOGRAPHY                              | FIS        | 09 CFU |
| S2 | [0023B] MECHANICS OF GEOPHYSICAL FLUIDS                                | FIS        | 09 CFU |
| S2 | [322BB] NONLINEAR DYNAMICS                                             | FIS        | 09 CFU |
| S2 | [354BB] QUANTUM OPTICS AND PLASMA PHYSICS                              | FIS        | 09 CFU |
| S2 | [425BB] QUANTUM THERMODYNAMICS                                         | FIS        | 06 CFU |
| S2 | [098BB] STELLAR PHYSICS S                                              | FIS        | 06 CFU |
| A  | [365BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS S | FIS        | 06 CFU |
| A  | [SNS-SMLM] STATISTICAL AND MACHINE LEARNING MODELS FOR TIME SERIES     | FIS        | 09 CFU |

### Additional notes

The following exams among the elective group are strongly suggested for this PdS:

- [230BB] Complex Systems
- [454II] Computational Fluidodynamics
- [0034B] Introduction to the Physics of Controlled Nuclear Fusion
- [0023B] Mechanics of Geophysical Fluids

**QUANTUM COMPUTING AND TECHNOLOGIES**

(Curriculum GENERAL)

**Constraints of the PdS**

minimum

48 CFU

**Compulsory group***(all of the following)*

|    |                                            |     |        |
|----|--------------------------------------------|-----|--------|
| S1 | [376BB] QUANTUM COMPUTING AND TECHNOLOGIES | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS                | FIS | 09 CFU |

**Physics of matter group 1***(at least one of the following)*

|    |                                                  |     |        |
|----|--------------------------------------------------|-----|--------|
| S1 | [304BB] FUNDAMENTALS OF LIGHT MATTER INTERACTION | FIS | 09 CFU |
| S1 | [204BB] SOLID STATE PHYSICS                      | FIS | 09 CFU |

**Physics of matter group 2***(at least one of the following)*

|    |                                                    |     |        |
|----|----------------------------------------------------|-----|--------|
| S1 | [0061B] QUANTUM MANY-BODY STATES OF MATTER         | FIS | 09 CFU |
| S2 | [0062B] QUANTUM FOUNDATIONS FOR QUANTUM TECHNOLOGY | FIS | 06 CFU |

**Experimental physics***(at least one of the following)*

|    |                                                           |     |        |
|----|-----------------------------------------------------------|-----|--------|
| S1 | [412BB] PHYSICS OF MATTER AND NANOTECHNOLOGY LABORATORY S | FIS | 09 CFU |
| S1 | [193BB] STATISTICAL DATA ANALYSIS                         | FIS | 09 CFU |
| S2 | [0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE           | FIS | 09 CFU |
| A  | [326BB] COMPUTATIONAL PHYSICS LABORATORY                  | FIS | 09 CFU |

**Astrophysics group***(at least one of the following)*

|    |                        |     |        |
|----|------------------------|-----|--------|
| S1 | [353BB] PLASMA PHYSICS | FIS | 09 CFU |
| S2 | [368BB] ASTROPHYSICS   | FIS | 06 CFU |

**Recommended Elective Courses**

maximum

27 CFU

*(includes unselected Constraints and those that follow)*

|    |                                                                    |            |        |
|----|--------------------------------------------------------------------|------------|--------|
| S1 | [244CC] CHEMICAL PHYSICS OF MOLECULES                              | CHIM/02    | 09 CFU |
| S1 | [213BB] QUANTUM FIELD THEORY                                       | FIS        | 09 CFU |
| S1 | [0061B] QUANTUM MANY-BODY STATES OF MATTER                         | FIS        | 09 CFU |
| S2 | [214BB] ADVANCED QUANTUM FIELD THEORY                              | FIS        | 09 CFU |
| S2 | [221BB] ATOM OPTICS                                                | FIS        | 09 CFU |
| S2 | [370BB] CONDENSED MATTER PHYSICS                                   | FIS        | 09 CFU |
| S2 | [0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE                    | FIS        | 09 CFU |
| S2 | [827II] MATERIALS AND DEVICES FOR NANOSCALE ELECTRONICS            | ING-INF/01 | 06 CFU |
| S2 | [203BB] PHYSICS OF PHOTONIC DEVICES                                | FIS        | 09 CFU |
| S2 | [0040B] QUANTUM BIOLOGY                                            | FIS        | 09 CFU |
| S2 | [0019B] QUANTUM MACHINE LEARNING                                   | FIS        | 03 CFU |
| A  | [SNS-MQT] METHODS IN QUANTUM TECHNOLOGIES: THEORY AND APPLICATIONS | FIS        | 08 CFU |

**Additional notes**

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**THEORETICAL PHYSICS**

(Curriculum THEORETICAL PHYSICS)

**Constraints of the PdS**

minimum

60 CFU

**Compulsory group***(all of the following)*

|    |                                       |     |        |
|----|---------------------------------------|-----|--------|
| S1 | [213BB] QUANTUM FIELD THEORY          | FIS | 09 CFU |
| S2 | [214BB] ADVANCED QUANTUM FIELD THEORY | FIS | 09 CFU |

**Theoretical physics group***(at least two of the following)*

|    |                                |     |        |
|----|--------------------------------|-----|--------|
| S1 | [228BB] GENERAL RELATIVITY     | FIS | 09 CFU |
| S1 | [206BB] NUCLEAR PHYSICS        | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS    | FIS | 09 CFU |
| S2 | [197BB] QUANTUM CHROMODYNAMICS | FIS | 09 CFU |

**Experimental physics***(at least one of the following)*

|    |                                                                      |     |        |
|----|----------------------------------------------------------------------|-----|--------|
| S1 | [414BB] FUNDAMENTAL INTERACTIONS LABORATORY S                        | FIS | 09 CFU |
| S1 | [412BB] PHYSICS OF MATTER AND NANOTECHNOLOGY LABORATORY S            | FIS | 09 CFU |
| S1 | [193BB] STATISTICAL DATA ANALYSIS                                    | FIS | 09 CFU |
| S2 | [0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE                      | FIS | 09 CFU |
| S2 | [0046B] PHYSICS AND DETECTORS OF GRAVITATIONAL WAVES                 | FIS | 09 CFU |
| A  | [0010B] ASTROPHYSICS AND MULTIMESSENGER LABORATORY                   | FIS | 12 CFU |
| A  | [326BB] COMPUTATIONAL PHYSICS LABORATORY                             | FIS | 09 CFU |
| A  | [360BB] COMPUTING METHODS FOR EXPERIMENTAL PHYSICS AND DATA ANALYSIS | FIS | 09 CFU |

**Microphysics group***(at least one of the following, except for 206BB is already chosen in the second group)*

|    |                                                  |     |        |
|----|--------------------------------------------------|-----|--------|
| S1 | [230BB] COMPLEX SYSTEMS                          | FIS | 09 CFU |
| S1 | [305BB] FUNDAMENTAL INTERACTIONS                 | FIS | 09 CFU |
| S1 | [304BB] FUNDAMENTALS OF LIGHT MATTER INTERACTION | FIS | 09 CFU |
| S1 | [206BB] NUCLEAR PHYSICS                          | FIS | 09 CFU |
| S1 | [376BB] QUANTUM COMPUTING AND TECHNOLOGIES       | FIS | 09 CFU |
| S1 | [204BB] SOLID STATE PHYSICS                      | FIS | 09 CFU |
| S2 | [370BB] CONDENSED MATTER PHYSICS                 | FIS | 09 CFU |

**Astrophysics group***(at least one of the following)*

|    |                                           |     |        |
|----|-------------------------------------------|-----|--------|
| S1 | [226BB] ASTROPHYSICAL PROCESSES           | FIS | 09 CFU |
| S1 | [353BB] PLASMA PHYSICS                    | FIS | 09 CFU |
| S2 | [192BB] ASTROPARTICLE PHYSICS             | FIS | 09 CFU |
| S2 | [063BB] ASTROPARTICLE PHYSICS S           | FIS | 06 CFU |
| S2 | [368BB] ASTROPHYSICS                      | FIS | 06 CFU |
| S2 | [274BB] COSMOLOGY OF THE EARLY UNIVERSE   | FIS | 09 CFU |
| S2 | [275BB] COSMOLOGY OF THE EARLY UNIVERSE S | FIS | 06 CFU |
| S2 | [211BB] STELLAR PHYSICS                   | FIS | 09 CFU |
| S2 | [098BB] STELLAR PHYSICS S                 | FIS | 06 CFU |

**Recommended Elective Courses**

maximum

15 CFU

*(includes unselected Constraints and those that follow)*

|    |                                                                |     |        |
|----|----------------------------------------------------------------|-----|--------|
| S1 | [358BB] NONPERTURBATIVE APPROACHES TO QUANTUM FIELD THEORIES   | FIS | 09 CFU |
| S1 | [404BB] NONPERTURBATIVE APPROACHES TO QUANTUM FIELD THEORIES S | FIS | 06 CFU |
| S1 | [427BB] PARTICLE DARK MATTER                                   | FIS | 06 CFU |
| S1 | [0061B] QUANTUM MANY-BODY STATES OF MATTER                     | FIS | 09 CFU |
| S2 | [274BB] COSMOLOGY OF THE EARLY UNIVERSE                        | FIS | 09 CFU |
| S2 | [275BB] COSMOLOGY OF THE EARLY UNIVERSE S                      | FIS | 06 CFU |
| S2 | [251BB] GRAVITATION THEORY                                     | FIS | 09 CFU |
| S2 | [0046B] PHYSICS AND DETECTORS OF GRAVITATIONAL WAVES           | FIS | 09 CFU |
| S2 | [0062B] QUANTUM FOUNDATIONS FOR QUANTUM TECHNOLOGIES           | FIS | 06 CFU |
| S2 | [425BB] QUANTUM THERMODYNAMICS                                 | FIS | 06 CFU |
| S2 | [0060B] STANDARD MODEL S                                       | FIS | 06 CFU |
| S2 | [0016B] THEORY OF NUCLEAR INTERACTION S                        | FIS | 06 CFU |
| S2 | [0059B] THEORY OF SUPERCONDUCTIVITY AND QUANTUM DEVICES        | FIS | 06 CFU |
| A  | [326BB] COMPUTATIONAL PHYSICS LABORATORY                       | FIS | 09 CFU |
| A  | [374BB] COMPUTATIONAL PHYSICS LABORATORY S                     | FIS | 06 CFU |
| A  | [SNS-EFT] EFFECTIVE FIELD THEORIES I AND II                    | FIS | 06 CFU |
| A  | [SNS-SMB] STANDARD MODEL AND BEYOND                            | FIS | 06 CFU |

**Additional notes**

## THEORY OF QUANTUM MATERIALS

(Curriculum GENERAL)

### Constraints of the PdS

minimum

54 CFU

#### Compulsory group

(all of the following)

|    |                                                         |     |        |
|----|---------------------------------------------------------|-----|--------|
| S1 | [213BB] QUANTUM FIELD THEORY                            | FIS | 09 CFU |
| S1 | [204BB] SOLID STATE PHYSICS                             | FIS | 09 CFU |
| S1 | [207BB] STATISTICAL PHYSICS                             | FIS | 09 CFU |
| S2 | [0059B] THEORY OF SUPERCONDUCTIVITY AND QUANTUM DEVICES | FIS | 06 CFU |
| A  | [374BB] COMPUTATIONAL PHYSICS LABORATORY S              | FIS | 06 CFU |

#### Physics of matter group

(at least one of the following)

|    |                                            |     |        |
|----|--------------------------------------------|-----|--------|
| S1 | [0061B] QUANTUM MANY-BODY STATES OF MATTER | FIS | 09 CFU |
| S2 | [370BB] CONDENSED MATTER PHYSICS           | FIS | 09 CFU |

#### Astrophysics group

(at least one of the following)

|    |                           |     |        |
|----|---------------------------|-----|--------|
| S1 | [353BB] PLASMA PHYSICS    | FIS | 09 CFU |
| S2 | [368BB] ASTROPHYSICS      | FIS | 06 CFU |
| S2 | [098BB] STELLAR PHYSICS S | FIS | 06 CFU |

### Recommended Elective Courses

maximum

21 CFU

(includes unselected Constraints and those that follow)

|    |                                                                    |     |        |
|----|--------------------------------------------------------------------|-----|--------|
| S1 | [230BB] COMPLEX SYSTEMS                                            | FIS | 09 CFU |
| S1 | [0024B] FLUID DYNAMICS                                             | FIS | 06 CFU |
| S1 | [376BB] QUANTUM COMPUTING AND TECHNOLOGIES                         | FIS | 09 CFU |
| S1 | [0061B] QUANTUM MANY-BODY STATES OF MATTER                         | FIS | 09 CFU |
| S2 | [214BB] ADVANCED QUANTUM FIELD THEORY                              | FIS | 09 CFU |
| S2 | [370BB] CONDENSED MATTER PHYSICS                                   | FIS | 09 CFU |
| S2 | [0009B] DETECTION TECHNIQUES: FROM LAB TO SPACE                    | FIS | 09 CFU |
| S2 | [0004B] FLEXIBLE AND NANO-ELECTRONICS                              | FIS | 09 CFU |
| S2 | [0062B] QUANTUM FOUNDATIONS FOR QUANTUM TECHNOLOGIES               | FIS | 06 CFU |
| S2 | [0007B] QUANTUM TECHNOLOGIES FOR FUNDAMENTAL INTERACTION PHYSICS   | FIS | 09 CFU |
| S2 | [425BB] QUANTUM THERMODYNAMICS                                     | FIS | 06 CFU |
| A  | [SNS-MQT] METHODS IN QUANTUM TECHNOLOGIES: THEORY AND APPLICATIONS | FIS | 08 CFU |

### Additional notes

- In the course [374BB] COMPUTATIONAL PHYSICS LABORATORY S, the modules "Calcoli da principi primi" and "Dinamica molecolare classica" must be completed. It is also possible to choose Metodi numerici per la fisica (9 CFU), adding an extra module to the two mandatory ones in this case.



## FREE STUDY PLAN

(Curriculum GENERALE)

According to the regulations, any Individual Study Plan (PdSI) must meet certain general requirements, including in particular:

- At least 6 ECTS credits in courses in experimental physics;
- At least 6 ECTS credits in courses in theoretical physics;
- At least 6 ECTS credits in courses in micro/nuclear physics;
- At least 6 ECTS credits in courses in astrophysics;

For a complete list of the constraints that must be satisfied — for example, the total number of ECTS credits dedicated to related and supplementary subjects — please refer to the official regulations of the Master's Degree Program. The total number of credits thus accumulated must reach 75 ECTS, which, combined with the 45 ECTS of the final examination, adds up to the required 120 ECTS.

The submission of a free-form Individual Study Plan (PdSI) must be motivated by specific educational needs and one should first verify if the intended goals can be achieved through one of the recommended study plans. The recommended approach for creating a free-form PdSI is to **start from one of the suggested plans**, and to replace some of the courses with others, in order to assemble a new plan that meets administrative requirements and forms a complete and coherent academic path. When submitting a free-form PdSI, a **motivation behind the proposed plan must be uploaded in CAPS**. Please note that comments and attachments can only be added after the PdSI has been submitted. The approval of the PdSI will be based on the adequacy of the proposed educational path, which must consist of a set of courses that not only comply with general rules but also constitute a complete and coherent program. In particular, make sure to respect course prerequisites and avoid courses with overlapping or redundant content. Be aware that the approval process for a free-form study plan is inherently slower and its outcome is uncertain.