Course unit English denomination	**3D printed materials and their functional properties**
SS	**ING-IND/22**
Teacher in charge (if defined)	Fabrizio BARBERIS
Teaching Hours	12
Number of ECTS credits allocated	4
Course period	TBD
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	Principal targets in 3D printing: technical vs commercial - Introduction to Additive Manufacturing technologies - Intro to 3D metal printing Microstructure of 3D printed metals and the industrial experience - 3D printing with polymers – the medical experience in tailored medicine with external and internal temporary scaffolds. – Main materials advantages and problems arising by 3D printing - Hands-on Experience via an application case study – the GeAM Project.
Learning goals	In the last 25 years Additive Manufacturing - AM matured as a technology able to deposit molded materials in a layer-by-layer process by following Project instruction provided by a virtual solid model. AM was originally born as a substitute of Rapid Prototyping techniques when the target was mainly to obtain a solid shape of the discussed project. To date the situation is different and AM is adopted to create functional parts not only in general industrial applications but also in sensitive tasks like energy, transports, aerospace and also medicine. Different names are used, Direct Manufacturing as well as Advanced Manufacturing, to generally indicate the AM process but the adopted technologies are quite different and therefore also the possible benefits. The main attractive item of AM is the chance to rebuild the Project by applying this new technology but a serious limit exists in the final microstructure of the printed materials and therefore in the overall mechanical and functional properties. The Course will evaluate the main technologies available on the market to print polymers and metals, highlighting the main features and differences in terms of the material microstructure and the overall mechanical and functional properties. Analysis of the main features of 3D printed materials

	as well as problems related to these technologies will be discussed with the students, commenting several examples coming from the industry as well as from medical applications. GeAM - Genova Additive Manufacturing facilities will be introduced and shown to the students in order to enhance the overall Course experience.
Teaching methods	Mixed Modality (physical + virtual)
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☐ Yes ☒ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	-
Suggested readings	Lecture notes and video tutorials provided by the teacher
Additional information	https://www.imeg-dottorato.it/training-activities-1

Course unit English denomination	**Adaptive Optics for Astronomy**
SS	**FIS/05**
Teacher in charge (if defined)	Carmelo Arcidiacono
Teaching Hours	12
Number of ECTS credits allocated	1,5
Course period	Mid-April 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	Adaptive optics (AO) is an advanced technology used to improve the quality of images obtained from astronomical telescopes by correcting distortions caused by the Earth's atmosphere in real time. Without AO, the scintillation and flicker effect caused by atmospheric turbulence blurs images, significantly limiting the ability to resolve fine details of astronomical objects. AO has revolutionised modern astronomy, enabling observations impossible with conventional telescopes. The PhD course 'Astronomical Observations with Adaptive Optics' will provide an in-depth understanding of how AO works and its applications in astronomy. Students will explore the fundamental concepts and mechanisms behind these technologies and will be introduced to the tools used to measure and correct atmospheric wavefront distortions.
Learning goals	Students will gain a solid understanding of the mechanisms by which adaptive optics corrects atmospheric distortions in real time, improving the quality of astronomical images. - Designing and implementing simple adaptive optics systems. At the end of the course, students will be able to design basic AO systems, understanding how to select and configure the necessary components, such as deformable mirrors and wavefront sensors. - Using adaptive optics systems to conduct astronomical observations Students will be able to apply AO principles to improve the quality of astronomical observations, exploiting technology to overcome limitations imposed by the Earth's atmosphere.

	- Interpret and analyse data obtained with AO systems. Skills will be provided to understand and reduce data acquired through AO observations, enabling students to analyse high-resolution astronomical images and draw valid scientific conclusions. - Knowing the practical applications of AO in modern astronomy
Teaching methods	-
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	-
Suggested readings	Study materials is provided by the Professor
Additional information	-

Course unit English denomination	**Adaptive optics for astronomy**
SS	**FIS/05**
Teacher in charge (if defined)	Kalyan Kumar Radhakrishnan Santhakumari
Teaching Hours	16
Number of ECTS credits allocated	2
Course period	April 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	- Atmospheric turbulence and its effects - How to remove the effects of turbulence: Classical Adaptive Optics o Wavefront sensors ▪ Tip-Tilt Sensors ▪ Shack-Hartmann ▪ Pyramid ▪ WFS curvatures o Deformable mirrors - Limitations of Classical Adaptive Optics - Laser stars as references for wavefront sensors - Multi-conjugate adaptive optics o 'Star-Oriented' systems o 'Layer-Oriented' systems - Wavefront reconstruction o Interaction matrix o Zonal reconstruction o Modal reconstruction
Learning goals	Adaptive optics is an interdisciplinary subject that embraces contributions that ranging from real-time computing to astronomy to engineering and more. This course introduces adaptive optics in astronomy to graduate students.
Teaching methods	Lectures

Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	oral exam/discussion
Suggested readings	1. ADAPTIVE OPTICS for ASTRONOMICAL TELESCOPES - JOHN W. HARDY - Oxford University Press 1998 2. Adaptive Optics for Astronomy : Principles, Performance, and Applications – Jacques M. Beckers – ANNUAL REVIEW OF ASTRONOMY AND ASTROPHYSICS Volume 31, 1993
Additional information	the student should contact the lecturer by email if he/she wishes to attend the lectures/exam

Course unit English denomination	**Advanced FPGA design and design management techniques**
SS	**ING-INF/01**
Teacher in charge (if defined)	Enrico Calore, Nicolò Vladi Biesuz
Teaching Hours	20
Number of ECTS credits allocated	2,5
Course period	The course will be held in the next Academic Year (2026/27)
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	PROGRAM: - Advanced design techniques: introduction to HLS and application examples based on AMD/Xilinx FPGA and the Vitis HLS tool of the Vivado development suite; - Versioning and maintenance tool for FPGA designs; - Introductory course on TCL scripting; - Source code versioning using git and introduction to the concept of continuous integration; - Firmware and git: peculiarities and properties
Learning goals	The course covers advanced topics on FPGA design, introducing also the students to high-leve syntehsis design methodology
Teaching methods	Lectures covering theoretical aspects and discussions of practical case studies
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	The student should be familiar with basic-to-indermediate firmware developments concepts and/or passed successfully the basic course.

Examination methods (if applicable)	Oral presentation on a topic agreed with the teacher.
Suggested readings	Slides prepared by the teachers
Additional information	-

Course unit English denomination	**Advanced numerical modeling for systems engineering theory and applications**
SS	**ING-IND/05**
Teacher in charge (if defined)	Dalla Vedova Matteo Davide Lorenzo
Teaching Hours	20
Number of ECTS credits allocated	2,5
Course period	The course will be held in the next Academic Year (2026/27)
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	1. Introduction of the course Technical-scientific framework of the problem: Systems engineering Onboard systems Numerical modelling Historical overview regarding the development of survey techniques in engineering applications Why Matlab- Simulink? Multidomain Numerical Simulation Environment Simulink for System Modeling and Simulation Introduction to the use of Matlab-Simulink 2. Numerical modelling techniques Critical analysis of the different methodologies: advantages/disadvantages and limits of use Selection strategy (use destination, level of detail, accuracy, computational costs) 3. Lumped parameters umerical modelling Introductory notes Physicalmathematical models Physical-functional diagrams (graphical representations and references to the Bond Graphs) Basic notions of block diagrams: Proposed examples Comparison with Simulink graphical programming language 3.1. Some applicative examples (from the aerospace field) 4. Simplified numerical models Models detail levels and their use High Fidelity (HF) and Low Fidelity (LF) models Some model simplification techniques 4.1. Some applicative examples (referring to the cases seen in 3.1) 5. Monitoring, diagnostics and prognostics of systems Generalities, classification and specific characteristics Diagnostic and prognostic algorithms 5.1. Some applicative examples 5.2. Final test assignment 6. Final Evaluation Sharing of the students' proposals Critical analysis of the different solutions

Learning goals	The use of lumped parameters numerical modelling tools, designed to simulate the dynamic response of a given system, is now a consolidated practice in the engineering environment, and today it is a fundamental and essential tool in many phases of the definition and development process of a project. Especially in complex dynamic systems (composite and strongly interconnected architectures, marked interdisciplinary connotations, strongly non-linear dynamics), this approach allows to support the different phases of the project, providing a versatile tool, easily reconfigurable and able to integrate easily with the usual development methodologies (analytical and / or empirical models, experimental data). In particular, these methodologies are now widely used in the systems engineering field (e.g. aerospace, mechanics, mechatronics, automation, etc.) during the preliminary design, the detailed modeling of components or subsystems, the development of dedicated control logics and the conception of simplified numerical models able to perform different functions (monitoring, diagnostics, prognostics, optimization algorithms). As regards the onboard systems, these algorithms are often implemented in the resident management software of the aircraft: therefore it was necessary to define appropriate certification and software development strategies aimed to guarantee suitable levels of safety and reliability. This approach aims to provide students with the technical-scientific bases and skills (theoretical and practical) necessary to begin to effectively understand and autonomously develop the numerical modelling of a complex system and/or simple diagnostic algorithms. In addition to focusing on the various fundamental conceptual aspects, several application examples (deriving from selected case studies) will be discussed during the lectures to encourage the students developing the critical approach and the "sensitivity" necessary to operate in this field.
Teaching methods	The course will be structured according to an “active” educational approach, proposing an alternation between classical lectures, computerbased group experiences and individual activities.
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	A multidisciplinary approach to engineering and (at least) basic knowledge of Matlab-Simulink can allow an easier and more profitable elaboration of the proposed topics.
Examination methods (if applicable)	-
Suggested readings	-
Additional information	-

Course unit English denomination	**Advanced scientific programming in Matlab**
SS	**ING-INF/01**
Teacher in charge (if defined)	Paolo Bardella, Stefano Scialò
Teaching Hours	30
Number of ECTS credits allocated	6
Course period	January-February 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	1.5h: introduction to MATLAB, with particular attention on the improvements introduced in the latest versions 1.0h: source Control systems integrated in MATLAB (git) 1.5h: MATLAB internals: data structures, JIT, numerical libraries 3.0h: object oriented programming in MATLAB 3.0h: optimization of MATLAB code, use of the Code Profiler 3.0h: MEX files for the execution of C/C++ and Fortran code in MATLAB. MATLAB C code generator 3.0h parallel computing in MATLAB: introduction to parallel computing, commands parfor, spmd, advantages and limitations. 3.0h: GPUs in MATLAB: introduction to GPUs and gpuarray command 3.0h: optimization of I/O in MATLAB, control of hardware 3.0h: fundamentals of machine learning in MATLAB; Big data and tall arrays 1.0h: alternatives to MATLAB: python, Arrayfire, Gnu Scientific library, Octave, Scilab 4.0h: projects' presentation
Learning goals	The course aims to provide advanced skills in scientific programming, and to teach sound methodologies for the development of reliable, optimized and maintainable codes. During this course, many common methods used in Scientific Computing will be presented, with particular attention to the most recent programming techniques in MATLAB. At the end of the course, the student will have expanded his/her knowledge of MATLAB and will be able to choose the best approach for the solution of numerical problem he/she will face.

Teaching methods	Lectures
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge of MATLAB language
Examination methods (if applicable)	Presentation of group activity on the optimization of existing MATLAB code proposed by the students.
Suggested readings	Slides provided by the teachers, video recordings of the lessons, suggested texts on specific topics.
Additional information	-

Course unit English denomination	**Analysis and Modelling of the Additive Manufacturing**
SS	**ING-IND/26**
Teacher in charge (if defined)	Daniele Tammaro
Teaching Hours	12
Number of ECTS credits allocated	2
Course period	March-April 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	In the last years, additive manufacturing has been revolutionizing the way to manufacture structures, offering unparalleled flexibility in achieving controlled composition, geometric shape, function, and complexity over traditional manufacturing methods. Additive manufacturing is an emerging technology for the fast production of high-performance multifunctional materials used in advanced engineered systems such as aerospace and nautical structures, energy accumulators, biomedical implants, functional buildings, static coolers, mixers, columns and chemical reactors. The trialand- error approach for the process optimization is time and money consuming. The modelling of transport phenomena (i.e., momentum, energy and mass transport) is fundamental to understand, control and optimize additive manufacturing processes, such as Fused Deposition Modelling. In these processes, the miniaturization of all the parts (e.g., nozzle, heater, fan cooler) is more and more advanced in order to obtain higher resolution part. This course explains how to design those processes, i.e., melting, pumping and cooling, combining theory and practice. The deposition strategy is an important parameter to obtain good quality parts. In this course, the theoretical lessons will be followed by practical exercises to simulate the polymer flow inside microchannels.
Learning goals	The course aims at providing the principles of modelling and simulation of additive manufacturing or 3D printing. The course presents the basics of simulating momentum and heat transport in Fused Deposition Modelling and includes practical examples for its applications. At the end of the course, the student will be able to: I) design Fused Deposition Modelling processes and II) run simulation of FDM.

Teaching methods	-
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	Final test
Suggested readings	-
Additional information	https://www.dicmapi.unina.it/dottorato/dottorato/formazione/

Course unit English denomination	**Applied Superconductivity: Quantum Phenomena and Quantum Systems**
SS	**ING-INF/07**
Teacher in charge (if defined)	Enrico Silva
Teaching Hours	15
Number of ECTS credits allocated	2
Course period	The course will be held in the next Academic Year (2026/27)
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	Fundamentals: Introduction to superconductivity. Basics of microscopic theory. Superconducting materials. Thermodynamics of superconductors. Ginzburg-Landau theory. Phenomenology of the mixed state. Fluxons, fluxonic motion. Josephson effect. Advanced topics: Unconventional superconductivity. RF I superconductivity: superconductors for resonant cavities, for devices. RF Superconductivity II: presence of high dc magnetic fields, superconductors for experiments and infrastructure for fundamental physics (Haloscopes, FCC). Superconductivity in power applications (e.g. cables, magnets, FCL). Quantum metrology. Josephson devices. Qubit.
Learning goals	Superconductivity is a macroscopic quantum phenomenon with very different applications. The course aims at introducing the main roles of superconductivity in the fields of power applications, radiofrequency applications, metrology and quantum computing (from macroscopic to microscopic). The course presents first a short introduction to superconductivity and superconducting materials, and then a selection of the applications of superconductivity in the fields mentioned.
Teaching methods	Traditional teaching (slides, blackboard, possible problem assignment), with possible distance learning.

Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Electromagnetism (bachelor university level). Preferably basic training in solid-state physics.
Examination methods (if applicable)	Seminar at the end of the course.
Suggested readings	Provided during the course (slides, articles, book chapters).
Additional information	Delivered if taken at the PhD Course in Applied Electronics, University of Roma Tre. The course is adapted, where possible, to the PhD students' preparation and research projects. The dual mode is activated at the motivated request of the doctoral students.

Course unit English denomination	**Cabling and shielding for low noise applications**
SS	**FIS/01**
Teacher in charge (if defined)	Alberto Aloisio
Teaching Hours	10
Number of ECTS credits allocated	1,5
Course period	March 2026
Course delivery method	☐ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (70% minimum of presence) ☐ No
Course unit contents	Characteristics of the most commonly used cabling techniques (coax, twistedpairs, triax, ...) Analysis of capacitive and inductive coupling phenomena Analysis of the performance achievable with different interconnection schemes Ground loops Moderation of unwanted electromagnetic emissions Grounding non-ideality and effects on sensor read-out Analysis of differential connections
Learning goals	evaluate the source and characteristics of the aggressor signals choose the most appropriate wiring scheme for the specific application evaluate the impact of different grounding schemes know and apply differential interconnection schemes
Teaching methods	Frontal teaching
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-

Examination methods (if applicable)	Oral test
Suggested readings	Textbooks and slides
Additional information	-

Course unit English denomination	**Cloud Computing & Big Data Lab**
SS	**ING-INF/05**
Teacher in charge (if defined)	Tommaso Cucinotta
Teaching Hours	30
Number of ECTS credits allocated	4
Course period	April – May 2026
Course delivery method	☐ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	This is a practical and applied course that follows the Cloud Computing & Big Data course. In this course, students will put into practice the theoretical/abstract concepts acquired in the general course on Cloud Computing & Big Data. During practical sessions, we will delve into concepts such as: machine virtualisation and operating system-level virtualisation on Linux; network virtualisation on Linux;programming abstractions for cloud and distributed computing; elasticity in practice; programming frameworks for big data; command-line interface for major public cloud services; and popular open-source cloud platforms.
Learning goals	Students will gain a unique insight into the world of cloud computing and big data related technologies, and will be able to master the key tools for their use. This constitutes a fundamental element in the background of a software engineer or computer scientist who will deal with modern distributed software systems, both in industry and academia, ranging from high-performance systems to the cloud and even (increasingly connected) embedded systems.
Teaching methods	Slides and digital blackboard
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No

Prerequisites (not mandatory)	Students must have attended the general Cloud Computing & Big Data course and must have a good command of shell programming and scripting on Linux.
Examination methods (if applicable)	Programming project and oral examination
Suggested readings	slides from the lectures, manual pages and other on-line technical documentation
Additional information	tommaso.cucinotta@santannapisa.it

Course unit English denomination	**Cloud Computing & Big Data**
SS	**ING-INF/05**
Teacher in charge (if defined)	Tommaso Cucinotta
Teaching Hours	30
Number of ECTS credits allocated	4
Course period	Mid-November 2025
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	This course provides an overview of the challenges to be faced and the technical solutions to be adopted in building real-time, distributed, replicated, largescale and fault-tolerant cloud services. These systems must be able to handle millions or billions of requests per second with industrial-grade reliability, availability and performance, and are composed of thousands of components distributed on millions of machines worldwide. The course focuses on the design, development and operations of scalable software systems, including the processing and analysis of big data, which are increasingly used for the intensive computations required to train large machine learning and artificial intelligence models, where the huge volume of data to be handled requires the use of highly distributed algorithms. The course also covers basic concepts on network architectures for cloud computing infrastructures and data centres.
Learning goals	related to big data, and will be able to master the key concepts that characterise them. This constitutes a fundamental element in the background of a software engineer or computer scientist who will deal with modern distributed softwaren systems, both in industry and academia, ranging from high-performance systems to the cloud and even (increasingly connected) embedded systems.
Teaching methods	Slides and digital blackboard
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Students should have a basic knowledge of software, computer architectures, distributed systems and communication protocols
Examination methods (if applicable)	Oral exam
Suggested readings	slides from the lectures, book chapters and other on-line material
Additional information	tommaso.cucinotta@santannapisa.it

Course unit English denomination	**Collective effects in circular accelerators**
SS	**FIS/07**
Teacher in charge (if defined)	Mauro Migliorati
Teaching Hours	30
Number of ECTS credits allocated	3
Course period	March-June 2026
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	Wakefield: Longitudinal and transverse wakefields, Definitions, Short and long range wakefields, Expansion in cylindrical symmetry, Coupling impedances, Example of RLC, Example of wakefield calculation and energy loss, Uniform boundary conditions, Resistive wall, Green's function method, Non-uniform boundary conditions, Example of using an electromagnetic code (CST), Broadband impedance models. Longitudinal instabilities in storage rings: Synchrotron oscillations, momentum compaction, Oscillations in energy, Finite and differential equation for a single particle and a macroparticle with wakefield, Longitudinal oscillations, Robinson instabilities in the fundamental mode, Fokker-Plank equation and stationary solution, Haissinski equation and potential pit distortion, Phase shift and incoherent frequency, Perturbative methods and coherent modes of oscillation, Instability by mode coupling, Macroparticle model, Instability produced by high Q resonators. Transverse instabilities: Vlasov's equation, Perturbative theory, Head-tail instability, Transverse mode coupling instability (TMCI) => From impedance but also from space charge, Beam-beam and electyron cloudi, Transverse instabilities of coupled modes, Instability of high-Q resonators, Resistive wall instability, Landau damping: Introduction and physical origin, Loss of Landau damping.
Learning goals	The aim of the course is to provide the student with an overview of collective effects and instabilities in circular accelerator machines.
Teaching methods	Lectures

Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	Assessment test and student presentation on one of the topics covered
Suggested readings	slides and handouts from the lecturer
Additional information	-

Course unit English denomination	**Computing Methods for Experimental Physics and Data Analysis**
SS	**FIS/01**
Teacher in charge (if defined)	Andrea Rizzi, Alessandra Retico
Teaching Hours	40
Number of ECTS credits allocated	5
Course period	November – December 2025
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	Lectures for PhD students focus on the design of neural networks for the analysis of scientific data; the development of analysis projects in the context of particle physics or medical physics. 3 modules: Fundamentals (python, git, ...) Advanced (Parallelism, Machine Learning) Specific module: High Energy Physics/C++/Root Medical Physics/Image Processing/Matlab
Learning goals	By the end of the course, the student will be familiar with the following tools for scientific calculation and data analysis: - advanced unix shell commands for automating operations - python language and main system modules - python libraries for scientific calculation - tools for software management and documentation - tools for machine learning and neural network development - specific tools for applications in particle physics and/or medical physics
Teaching methods	lectures (theory) and exercises/hands-on
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	A minimum knowledge of how a computer works is necessary. It would also be advisable to have knowledge, even rudimentary, of programming in high languages (e.g. C, or python).
Examination methods (if applicable)	verification of acquired knowledge through specific questions in the oral examination on the basis of a scientific calculation project realised and presented by the students
Suggested readings	Slides and articles/books provided by lecturers
Additional information	andrea.rizzi@unipi.it, alessandra.retico@pi.infn.it

Course unit English denomination	**Cosmic radiation and radiation hardness assurance**
SS	**FIS/04**
Teacher in charge (if defined)	Pierluigi Casolaro
Teaching Hours	15
Number of ECTS credits allocated	2
Course period	December 2025
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	The course focuses on the study of radiation effects on materials and electronic components used in space missions. It begins with a description of the space environment, highlighting the main sources of radiation, such as particles trapped in the Van Allen belts, galactic cosmic rays, and particles from the Sun. Then, the interaction of radiation with matter and dosimetry are discussed. This is followed by a study of the main types of radiation damage: Total Ionizing Dose (TID), Displacement Damage Dose (DDD), and Single Event Effects (SEE). In addition to the damage to material and electronics, biological effects of radiation are discussed with a focus on the safety of space crew, providing basic concepts of radiation protection. Finally, the course discusses the characteristics of the facilities and laboratories, as well as the protocols for performing Radiation Hardness Assurance tests.
Learning goals	The course aims to provide the basic tools for performing Radiation Hardness Assurance tests. To this end, the goal is to acquire or consolidate knowledge of the interaction between radiation and matter, as well as dosimetry, which are necessary for understanding the main effects of radiation on electronics and humans (radiation protection in space environments and in laboratories for radiation testing).
Teaching methods	The lectures will be conducted in person and supported by slides prepared by the lecturer. Practical exercises will be carried out using the simulation software "Space Environment, Effects, and Education System" (SPENVIS).

Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	The final examination will include a discussion on the topics covered during the course, optionally starting from a specific topic chosen by the student related to his/her PhD project
Suggested readings	Lectures will be supported by the projection of slides prepared by the lecturer. For the study of the interaction of radiation with matter and dosimetry, the following texts will be used as a reference: • C. Leroy and P.-G. Rancoita, Principles of Radiation Interaction in Matter and Detection (World Scientific, Singapore, 2011) • P. Mayles, A. Nahum, and J.-C. Rosenwald, Handbook of Radiotherapy Physics: Theory and Practice (CRC Press, Boca Raton, 2007)
Additional information	-

Course unit English denomination	**Coupled electrical-thermal-structural Finite Element Analyses**
SS	**ING-IND/14**
Teacher in charge (if defined)	Giovanni Meneghetti, Mattia Manzolaro, Michele Ballan
Teaching Hours	10
Number of ECTS credits allocated	2
Course period	June 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	Course overview and introduction. General aspects of Finite Element analyses related to the structural, thermal and electrical fields. Structural analyses with plane and solid elements. Thermal analyses with plane and solid elements, implementing thermal conduction, thermal convection and thermal radiation. Coupled field thermal-structural analyses. Coupled field electrical-thermal analyses. Coupled field electrical-thermalstructural analyses. Presentation of a complex test case implementing all the aforementioned physical fields with a specific focus on complex geometry import.
Learning goals	The course is aimed at providing the fundamental know-how for the performance of Multiphysics Finite Element analyses related to the structural, thermal and electrical fields. ANSYS® will be the adopted engineering simulation software.
Teaching methods	Frontal lesson and tutorial
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-

Examination methods (if applicable)	Report on a project developed by the PhD student
Suggested readings	- M. Manzolaro, G. Meneghetti, A. Andrighetto, Thermal–electric numerical simulation of a surface ion source for the production of radioactive ion beams, Nucl. Instrum. Methods Phys. Res., Sect. A 623 (2010) 1061–1069. - G. Meneghetti, M. Manzolaro, A. Andrighetto, Thermal–electric numerical simulation of a target for the production of radioactive ion beams, Finite Elem. Anal. Des. 47 (2011) 559–570. - M. Manzolaro, G. Meneghetti, INTRODUCTION TO THE THERMAL ANALYSIS WITH ANSYS® NUMERICAL CODE, edizioni LIBRERIA PROGETTO, 2014, Padova, ITALY. - G. Meneghetti, M. Manzolaro, M. Quaresimin, INTRODUCTION TO THE STRUCTURAL ANALYSIS WITH ANSYS® NUMERICAL CODE, edizioni LIBRERIA PROGETTO, 2014, Padova, ITALY.
Additional information	-

Course unit English denomination	**Cryogenic sensors for astroparticle physics**
SS	**FIS/04**
Teacher in charge (if defined)	Andrei Puiu
Teaching Hours	12
Number of ECTS credits allocated	2
Course period	Mid-April 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	- Low Temperature Matter Behavior - Thermal Sensors and Their Operation - Semiconductor Thermistors - Transition Edge Sensors - Kinetic Inductance Detectors - Metallic Magnetic Calorimeters - Applications in Astroparticle Physics
Learning goals	- Understanding the working principle and characteristics of different thermal sensors - Understanding the different applications of thermal sensors in the field of rare event research
Teaching methods	Lectures with slides
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Radiation-matter interaction basics Particle physics basics

Examination methods (if applicable)	Oral
Suggested readings	Slides; bibliography referenced in the slides
Additional information	-

Course unit English denomination	**Fundamentals of system engineering and project management for large scientific projects**
SS	**SSD ING-INF/05**
Teacher in charge (if defined)	Marco Xompero, Runa Briguglio
Teaching Hours	12
Number of ECTS credits allocated	1,5
Course period	Second half of February 2026
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	Today, scientific research projects are carried out by large international teams and involve a multi-disciplinary approach. In add, specific tools are requested: to organize the team-work, to meet the deadlines, to define a common language and comprehension across all the elements in the project. The system engineer and the project manager are key-figures in the organizational chart. System engineering is an approach for successful systems, focusing on the early analysis of the user needs, then proceeding with design synthesis and system validation considering the complete problem. Project management, in parallel, is related to the organizational aspects: the definition of who will be doing what and how, the creation and optimization of a project calendar, based on the activities prioritization and their conflicts, the identification and management of risks, and much more. The class is intended to provide PhD students with a basic package to understand the project's working mechanisms.
Learning goals	Project planning System management
Teaching methods	Slides and group work, analysis of use cases. The course is organized as a 2, 3 days workshop in Florence
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No

Available for PhD students from other courses	☐ Yes ☒ No
Prerequisites (not mandatory)	None
Examination methods (if applicable)	class work, organization of a custom project
Suggested readings	None. References will be given during the classes
Additional information	https://sites.google.com/inaf.it/syseng-phdnazionale/home-page

Course unit English denomination	**Gaseous Detectors for Experimental Particle Physics**
SS	**FIS/01**
Teacher in charge (if defined)	Luigi Longo, Antonio Pellecchia
Teaching Hours	16
Number of ECTS credits allocated	2
Course period	April – May 2026
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (60% minimum of presence) ☐ No
Course unit contents	● Recalls of interaction between radiation and matter; ionisation and excitations; photoelectric effect; ● charge transport, diffusion, drift in electric and magnetic fields; ● charge and avalanche multiplication, first and second T ownsend coefficient, Penning effect, avalanche statistics; ● signal formation; ● ionisation chambers, proportional counters, proportional wire chambers multiple (MWPC), Micro Strip Gas Chambers, Triple GEM, Micromegas, Micro-rwell. ● Applications in high-energy physics experiments
Learning goals	By the end of the course, the student will have: - learned the basics of the operating principle of gas-gaseous detectors - acquired skills in the characteristic parameters of detectors, such as spatial and temporal resolution spatial and temporal resolution, gain, rate capability - acquired knowledge of the use of such devices in high energy physics experiments energies - learned how to search and consult scientific articles on the subject and how to present their contents
Teaching methods	Lectures with slides
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Electromagnetism, Mathematical Analysis, Modern Physics and Statistical Methods
Examination methods (if applicable)	Oral exam
Suggested readings	Provided by the lecturers
Additional information	-

Course unit English denomination	**Generative Design for smart Additive Manufactruing**
SS	**ING-IND/15**
Teacher in charge (if defined)	Antonio Gloria
Teaching Hours	12
Number of ECTS credits allocated	3
Course period	February 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	Advanced Design for Additive Manufacturing and Generative Design in sustainable and smart product design and development. Functional Analyses, Mechanical and Thermal Measurements to support the product design and development. Generative Design: challenges and innovative design solutions. Generative Design: artificial intelligence (AI) and machine learning to transform the design process into a sophisticated engineer computer interaction. AI-driven process towards the development of design solutions. Design for Smart Additive Manufacturing of cellular structures, lattice structures, geometrically hybrid lattice structures and solid-lattice hybrid structures. Optimality Criteria and Integrated Design Methods. Bioinspired architectures for sustainable, smart and lightweight products. Examples of design and application.
Learning goals	The Course deals with the GENERATIVE DESIGN FOR SMART ADDITIVE MANUFACTURING as an advanced strategy to design and develop innovative, sustainable, smart and lightweight products with tailored morphological, mechanical and functional properties, as well as with integrated functionalities. The CREAMI and RICREAMI laboratories will be available to the students.
Teaching methods	Mixed Modality (physical + virtual)
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge of Computer-Aided Design
Examination methods (if applicable)	Written and/or Oral and/or Project discussion
Suggested readings	Course notes
Additional information	-

Course unit English denomination	**HE-5: Front-end and readout electronic systems for High Energy Astroparticle Physics**
SS	**FIS/01**
Teacher in charge (if defined)	Felicia Barbato, Adriano Di Giovanni
Teaching Hours	15
Number of ECTS credits allocated	2
Course period	Second semester 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	Waveforms and signal processing. Front End electronics. Review of electronics systems for signal conditioning. Signal charge collection in low power regimes. Data processing and decoding. Radiation hardness. Specific examples on spacebased detectors. Hands-on sessions with signal simulation tools.
Learning goals	Acquisition and processing of particle detector signals
Teaching methods	Slides and hands-on
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	Exercises and oral discussion
Suggested readings	-

Additional information -

Course unit English denomination	**High-energy particle physics detectors in space**
SS	**FIS/01**
Teacher in charge (if defined)	Serena Loporchio
Teaching Hours	16
Number of ECTS credits allocated	2
Course period	January-February 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	Basic elements of particle physics. Radiation-matter interaction Basic knowledge of astroparticle physics Detectors for space applications (scintillators, photodetectors, silicon detectors) Space qualification tests
Learning goals	Know the instruments for detecting high-energy particles used in aerospace Know the verifications and tests required for instrumentation validation
Teaching methods	Lectures with slides
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge of particle physics
Examination methods (if applicable)	Oral presentation
Suggested readings	Slides; Knoll, Radiation detection and measurements

Additional information -

Course unit English denomination	**Introduction to Neuromorphic Computing**
SS	**FIS/07**
Teacher in charge (if defined)	Andrea Duggento
Teaching Hours	12
Number of ECTS credits allocated	1,5
Course period	TBC
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	The mammalian brain is a very sophisticated, highly efficient biocomputer from which technology has begun to draw inspiration for developing artificial neural networks. However, this biologyto-technology translation is still in its infancy. Spiking neural networks based on neuromorphic architectures are emerging as a more biologically-inspired artificial minds which will likely underlie next-generation AI paradigms. This course will explore the biological – in silico correspondence at all levels, introducing key concepts of neuronal membrane potential dynamics, neuroanatomy and chemical neuromodulation, neural tissue energy demands, theory of evolution and principles of cognition. For each topic, its state-of-the-art neuromorphic engineering application counterpart will be presented. All major aspects of spiking neural network applications will be introduced, from training strategies (including principles of reinforcement learning, synaptic plasticity and multi-agent evolutionary artificial neural networks) to software and hardware implementation, e.g. including CMOS neuromorphic chips and memristor-based neuromorphic computers. Lecture 1: Introduction, membrane potential, synapses, and chemical neuromodulation Lecture 2: Spiking neural network in silico: models and simulation environments Lecture 3: Hard-wired spiking neural network: CMOS vs Memristors Lecture 4: Synaptic plasticity, neuromodulation strategies and learning. Lecture 5: Chemical-modulated reinforcement learning and evolution: from biology to engineering
Learning goals	By the end of the course, the student is expected to have acquired:

	A basic understanding of the biological mechanisms that have inspired the field of neuromorphic engineering. The ability to conceptualise biologically plausible mechanisms in a neural simulation with learning capabilities.
Teaching methods	Lectures will be blackboard-based for analytical and qualitative concepts, while slides will be used to illustrate applications
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Key concepts of Machine Learning
Examination methods (if applicable)	The student will prepare a seminar on a topic to be agreed upon
Suggested readings	- Principles of Neural Science, Sixth Edition, by Eric R. Kandel et Al., 2021 - Neuromorphic Engineering; The Scientist's, Algorithm Designer's, and Computer Architect's Perspectives on Brain-Inspired Computing, by Elishai Ezra Tsur, 2021 - Neuroscience, by D Purves et Al., 2018 - Selected articled from scientific literature.
Additional information	-

Course unit English denomination	**Laboratory of high-energy radiation measurement**
SS	**FIS/01**
Teacher in charge (if defined)	Felicia Barbato, Adriano di Giovanni
Teaching Hours	20
Number of ECTS credits allocated	5
Course period	Second semester 2026
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (60% minimum of presence) ☐ No
Course unit contents	Silicon-based light detectors. Readout and DAQ systems. Applications to space-based experiments. Tracking systems: measurement of observables and diagnostics. This is a laboratory course: lectures will be held at the Gran Sasso National Laboratory (LNGS)
Learning goals	- Understanding the working principle and characteristics of different thermal sensors - Understanding the different applications of thermal sensors in the field of rare event research
Teaching methods	Laboratory
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Radiation-matter interaction basics Particle physics basics
Examination methods (if applicable)	Seminar on an agreed topic followed by questions and a short discussion

Suggested readings	Knoll - Radiation detection and measurement, Wiley
Additional information	-

Course unit English denomination	**Laboratory of low-energy radiation measurement**
SS	**FIS/04**
Teacher in charge (if defined)	Andrei Puiu, Lorenzo Pagnanini
Teaching Hours	20
Number of ECTS credits allocated	5
Course period	May-June 2026
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (60% minimum of presence) ☐ No
Course unit contents	Measurement of low-energy radioactivity with High Purity Germanium detectors and low temperature scintillators (from 20 to 300 K). This is a Laboratory course that includes the detector installation and operation at LNGS external laboratories, as well as data taking and analysis.
Learning goals	- Understanding the working principle and characteristics of different thermal sensors - Understanding the different applications of thermal sensors in the field of rare event research
Teaching methods	Laboratory
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Radiation-matter interaction basics Particle physics basics
Examination methods (if applicable)	Seminar on an agreed topic followed by questions and a short discussion

Suggested readings	Knoll - Radiation detection and measurement, Wiley
Additional information	-

Course unit English denomination	**Lattice Structures via Additive Manufacturing for Multifunctional Aerospace Components**
SS	**ING-IND/05**
Teacher in charge (if defined)	Carlo Giovanni Ferro
Teaching Hours	15
Number of ECTS credits allocated	2
Course period	January/February 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	Week 1 • Introduction to Lattice Structures and Aerospace Applications • Overview of Additive Manufacturing Technologies • Fluid Dynamics in Aerospace & Heat Exchangers Week 2 • Structural Analysis of Lattice Structures • Manufacturability Constraints in Additive Manufacturing • Sensors and Smart Materials: Introduction to FBG Sensors Week 3 • Design and Analysis Tools for Multidisciplinary Optimization • Case Studies: Real-world Aerospace Applications • FBG Sensors in Aerospace: Methods and Challenges Week 4 • Research Methodologies: From Hypothesis to Experimentation • Workshop: Developing Your Research Proposal Week 5 • Final Presentations and Peer Review
Learning goals	This advanced PhD course aims to delve into the multifaceted realm of lattice structures manufactured through additive manufacturing (AM) techniques, particularly focused on their applications in aerospace engineering. Through a multidisciplinary lens, this course will tackle the challenges and potentials in optimizing various functions such as heat exchange, structural integrity, and manufacturability. The course also aims to introduce also embedding of Fiber Bragg Grating (FBG) sensors for realizing smart components. It will conclude with an individual research project and peerreviewed presentations.
Teaching methods	-

Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☐ Yes ☒ No
Prerequisites (not mandatory)	- Basics of Additive Manufacturing - Introduction to Aerospace Engineering - Fundamentals of Fluid Dynamics and Structural Analysis - Research Methodologies in Engineering
Examination methods (if applicable)	-
Suggested readings	-
Additional information	https://didattica.polito.it/pls/portal30/gap.pkg_guide.viewGap?p_cod_ins=01HVVIW&p_a_acc

Course unit English denomination	**Machine Learning for Physics**
SS	**FIS/01**
Teacher in charge (if defined)	Pierluigi Bortignon
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	March-June 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	Regression. Classification. Supervised learning. Unsupervised learning. Reinforcement learning. Function approximation, Model, Hyperparameters, Generalization, Regularization. Decision trees (bagging, boosting, random forest), Artificial neural network, the Multi LayerPerceptron, Gradient descent techniques. Deep networks. Convolutional networks. Recursive networks. Autoencoders. Transfer learning. Keras toolset.
Learning goals	The course has the objective to introduce the theoretical concept of Machine Learning. It creates abilities and competences on how to use the most common machine learning architectures used in physics.
Teaching methods	The course will have half of the lectures as frontal lectures on theoretical aspects of the machine learning and half of the lectures as hands-on session where the most common architecture will be used with simple dataset together in class.
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic understanding of statistics and programming

Examination methods (if applicable)	The evaluation will be based on a data analisys project on a dataset agreed with the teacher that uses one or more of the machine learning techniques studies in class.
Suggested readings	Introduction to Statistical Learning. G. James. Springer edition Hands-on Machine Learning with Scikit-Learn, Keras & TensorFlow - Aurelien Gerontoiatrie - O'Reilly (2nd edition)
Additional information	-

Course unit English denomination	**Maximum-entropy methods for complex systems I**
SS	**FIS/03**
Teacher in charge (if defined)	Diego Garlaschelli
Teaching Hours	20
Number of ECTS credits allocated	2,5
Course period	January 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	This interdisciplinary course aims to introduce rigorous tools from statistical physics, information theory and probability theory to investigate the complex real-world systems that emerge in different fields of research. Initially, some key aspects of complexity encountered in physical, biological, social, economic and technological systems will be examined. Subsequently, the focus will be on the construction of theoretical models based on the concept of constrained randomness, i.e. entropy maximisation subject to appropriate constraints. This will lead to the introduction of maximum entropy models, which serve as mathematical references for the properties of highly heterogeneous complex systems. Cases of special interest include statistical sets of complex networks and multivariate time series with given properties. Comparisons between model results and empirical properties will be systematically presented. Comprehensive mathematical derivations of the models will be provided, as well as statistical inference methods, model selection and computer codes for parameter estimation on empirical data.
Learning goals	-
Teaching methods	Slides and digital blackboard
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Solid mathematical training, scientific curiosity, interest in multidisciplinarity, passion for theory
Examination methods (if applicable)	Oral exam
Suggested readings	TBD
Additional information	diego.garlaschelli@imtlucca.it; phd@imtlucca.it

Course unit English denomination	**Maximum-entropy methods for complex systems II**
SS	**FIS/03**
Teacher in charge (if defined)	Tiziano Squartini
Teaching Hours	20
Number of ECTS credits allocated	2,5
Course period	April 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	The second part of the Advanced Methods for Complex Systems course focuses on advanced practical applications of the concepts introduced in the first part. In particular, emphasis will be placed on the successful areas of pattern detection and reconstruction of networks from partial information. Pattern detection in networks consists of identifying robust empirical patterns (such as scale invariance, clustering, assortativity, reciprocity, recurring patterns, etc.) that are widespread in real-world networks and that systematically deviate from certain null hypotheses formalised in terms of an appropriate random graph model. The models introduced in Part I will therefore be used here for pattern detection purposes. The problem of community detection will also be addressed, with an emphasis on the differences between finding communities in network data and in correlation matrices constructed from time series databases (e.g. financial or neural series). The problem of reconstructing networks from partial topological information will be addressed by focusing on reconstructing financial and interbank networks from specific node properties, with the aim of improving stress tests and estimates of systemic risk in real markets and providing better tools for policy makers. The statistical physics methods that central banks have recently identified as the best reconstruction techniques will be examined in detail.
Learning goals	-
Teaching methods	Slides and digital blackboard

Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Solid mathematical training, scientific curiosity, interest in multidisciplinarity, successful completion of the Advanced Methods for Complex Systems I course.
Examination methods (if applicable)	Oral exam
Suggested readings	-
Additional information	tiziano.squartini@imtlucca.it; phd@imtlucca.it

Course unit English denomination	**Metal Additive Manufacturing**
SS	**ING-IND/14**
Teacher in charge (if defined)	Pietro Rebesan
Teaching Hours	16
Number of ECTS credits allocated	4
Course period	TBC
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (75% minimum of presence) ☐ No
Course unit contents	The course provides students with the basic knowledge and skills for metal Additive Manufacturing (AM) including AM processes and their capabilities, raw materials production chain, designing AM parts according to design for additive manufacturing (DfAM) rules, AM software introduction, case study on materials production and characterization, main defects on additively manufactured metals components, simulation, and post-processing. Practical experience will be gained through individual projects and laboratory hands-on experience.
Learning goals	Understand the fundamental principles of metal additive manufacturing (AM). Identify AM processes and their capabilities. Analyze the raw materials production chain. Apply the principles of Design for Additive Manufacturing (DfAM). Use software for additive manufacturing. Evaluate case studies on AM materials production and characterization. Recognize common defects and post-processing phase in components produced via AM. Develop practical skills through individual or group projects.
Teaching methods	Lectures and exercises
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No

Prerequisites (not mandatory)	None
Examination methods (if applicable)	Discussion/Report of a case study within the individual or group project
Suggested readings	Courses slides and papers recommended during the course
Additional information	-

Course unit English denomination	**Metodologies and techniques for the analysis of experimental data**
SS	**FIS/01**
Teacher in charge (if defined)	Alexis Pompili
Teaching Hours	16
Number of ECTS credits allocated	2
Course period	TBC
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	Theory of Probability Probability Density Functions of random variables Distribution functions and Central Limit Theorem Hypothesis testing Parameter estimation and Goodness-of-fit Likelihood ratio and Local statistical significance of a signal. Classical confidence intervals; Global statistical significance of a new signal and Upper Limits.
Learning goals	Learners are expected to achieve, by the end of the course, a good knowledge of advanced statistics concepts and methodologies widely used in the field of Subnuclear and Nuclear Physics. Moreover, they are expected to have acquired a critical approach to handle observations and measurements while being aware of the statistical and systematic uncertainties and the correlations involved.
Teaching methods	Theoretical concepts are always complemented by practical applications and examples in order to establish a clear link between concepts on one hand and methodologies and application contexts on the other. Applications and examples are borrowed from the High Energy Physics field and are executed in the framework of a (PyROOT) Jupyter notebook.
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge of Python and ROOT.
Examination methods (if applicable)	-
Suggested readings	-
Additional information	-

Course unit English denomination	**Microelectronics for radiation detectors II**
SS	**FIS/01**
Teacher in charge (if defined)	Giovanni Mazza
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	May 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	The scope of the course is to provide a more in depth treatment of integrated electronics for radiation sensors, with emphasis on electronics for single photon, X-ray and charged particles detectors. The course outlines the key issues about radiation damage in integrated circuits, with particular emphasis on applications with particle accelerators and aerospace. The implications of radiation tolerant in the design of key building blocks in radiation detection system such as time-to-digital converters, phaselocked loops, ADCs and memories is discussed.
Learning goals	Understanding the details of design of critical building blocks, such as ADC, TDC and PLL that have to operate in harsh environmental conditions
Teaching methods	Lectures covering theoretical aspects and discussions of practical case studies
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☐ Yes ☒ No
Prerequisites (not mandatory)	Basic knowledge in circuit theory and CMOS technology

Examination methods (if applicable)	Oral presentation on a topic agreed with the teacher
Suggested readings	Slides prepared by the teacher and key papers with a detailed list given at the beginning of the course
Additional information	Course borrowed from the Doctorate in Electrical, Electronic and Communications Engineering of the Polytechnic University of Turin

Course unit English denomination	**New technologies for Cherenkov telescopes**
SS	**FIS/01**
Teacher in charge (if defined)	Serena Loporchio
Teaching Hours	16
Number of ECTS credits allocated	2
Course period	January-February 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	Development of Extensive Air Shower Operating Principles of Cherenkov Telescopes Detection Techniques and Instruments (PMT, SiPM) Readout Electronics Image reconstruction
Learning goals	Advanced knowledge of technologies currently used in Cherenkov telescopes and future technologies under development
Teaching methods	Lectures with slide support
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge of high-energy astrophysics and detector physics
Examination methods (if applicable)	Oral presentation
Suggested readings	Slides

	De Angelis and Pimienta, Introduction to Particle and Astroparticle Physics. ISBN 978-3-319-78180-8. Springer International Publishing AG Spurio, Probes of Multimessenger Astrophysics. ISBN 978-3-319-96853-7. Springer Nature Switzerland AG, 2018 Knoll, Radiation detection and measurement, New York, John Wiley and Sons, Inc.
Additional information	-

Course unit English denomination	**Novel detectors for future experiments at collider**
SS	**FIS/01**
Teacher in charge (if defined)	Domenico Colella
Teaching Hours	16
Number of ECTS credits allocated	2
Course period	January – March 2026
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (50% minimum of presence) ☐ No
Course unit contents	-) Introduction to future collider and to the european strategy for the R&D activities to develop new detectors specifically designed for experiments at future colliders (2h) -) New technologies in gas detectors: muon system, inner and central tracking, photon detector, time-of-flight, rare-decays (3h) -) New technologies in solid state detectors: MAPS, CMOS planar/3D/passive, LGAD (6h) -) New technologies in PID and photon detectors: RICH, DIRC, TOF, TPC, TRD, MCP-PMT, PMT, MaPMT , HPD, MPGD, SiPM, SNSPD, TES, MKID (3h) -) New technologies in calorimetry: based on silicon, liquid noble gas, gas (1h) -) Quantum and emerging for particle detectors (1h)
Learning goals	The course aim to provide to the students the fundamental characteristics of the technologies under development for experiment to be designed to work in future colliders. Focus will be paid to the relevant aspects that are guiding the development of these technologies: radiation hardness, material budget, channel multiplicity and readout electronics bandwidth.
Teaching methods	Seminars will be given guided by educational material to be projected (slides), encouraging students interaction during the comprehension of different arguments.
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Knowledge of radiation-material interaction Knowledge of basic principle of particle radiation
Examination methods (if applicable)	Seminar on selected detector realization, possibly related to the student research, focusing on relevant aspects for the technology choice.
Suggested readings	Educational material (slides) used during lectures. Selected articled concerning specific arguments.
Additional information	-

Course unit English denomination	**Physics of High Brightness Accelerators**
SS	**FIS/01**
Teacher in charge (if defined)	Massimo Ferrario
Teaching Hours	60
Number of ECTS credits allocated	6
Course period	Mid-March – End of June 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	Course description - Light sources based on high-gain free-electron lasers or future high-energy linear colliders require the production, acceleration and transport to the point of interaction of low divergence, high charge density, short electron beams (high-brightness beams). Many effects generally contribute to the degradation of the final beam quality, including colour effects, wake fields, coherent radiation emission,accelerator misalignments, etc. In particular, space charge effects and mismatch with focusing and acceleration devices contribute to the degradation of the emittance of high charge-density beams, so the control of beam transport and acceleration is at the forefront of producing high quality beams. In these lectures, we introduce from basic principles the main concepts of beam focusing and transport in modern accelerators using the beam envelope equation as a convenient mathematical tool, suitable for any type of charged particle accelerator. Matching conditions that preserve beam quality are derived from the model for significant beam dynamics regimes. An extension of the model to the plasma accelerator case is also introduced. An understanding of the similarities and differences to conventional accelerators is emphasised. Course Details - The main topics covered during the lectures will include: - Overview of advanced accelerator techniques and their applications - The concepts of emittance, luminance and luminosity - Summary of relativistic dynamics - Phase space and Liouville's theorem - Beam thermodynamics - Longitudinal and transverse envelope equations - Space charge effects

	- Beam manipulation and emittance compensation - Wake fields and instability - Physics of free-electron lasers - Introduction to plasma accelerator physics - The EuPRAXIA project at LNF Dedicated seminars will be given by experts in specific fields of interest related to this course. A detailed visit to the current SPARC_LAB high luminosity facility at LNF will conclude the course.
Learning goals	Students will gain an understanding of new acceleration techniques, as well as advanced topics such as beam quality control, phase space dynamics, energy efficiency and collective instabilities.
Teaching methods	Lectures
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Electromagnetism, Special Relativity
Examination methods (if applicable)	In-depth presentation of a topic of your choice from those discussed during the course and follow-up questions
Suggested readings	slides and lecturer's handouts
Additional information	[1] J. B. Rosenzweig, “Fundamentals of beam physics”, Oxford University Press, New York, 2003 [2] M. Reiser, “Theory and Design of Charged Particle Beams” , Wiley, New York, 1994 [3] L. Serafini, J. B. Rosenzweig, Phys. Rev. E 55 (1997) 7565 [4] M. Ferrario et al., Phys. Rev. Let. 99, 234801 (2007) [5] Beam dynamics newsletter, n. 38 wwwbd.fnal.gov/icfabd/Newsletter38.pdf [6] M. Ferrario et al., Phys. Rev. Let. 104, 054801 (2010) [7] T. Wangler, “Principles of RF linear accelerators”, Wiley, New York, 1998

Course unit English denomination	**Physics with High Energy particle detectors from photographic plates to the LHC experiments**
SS	**ING-INF/04**
Teacher in charge (if defined)	Simone Paoletti, Antonio Cassese (and/or Rudy Ceccarelli)
Teaching Hours	18
Number of ECTS credits allocated	2
Course period	February-June 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	In the first part of the course, we will retrace the main experiments that have contributed to the knowledge of the electroweak physics. While following the steps made to solve the main puzzles that have engaged the particle physicists from the 20th century, we will take the chance of exploring the ideas underlying the design and development of detectors. In the second part of the course we focus on the scientific goals of the LHC accelerator, how LHC works, the interaction process in proton-proton high energy collisions, specific details of the ATLAS and CMS detectors and their design differences, a brief overview of the Higgs physics at LHC and of the detector upgrades being prepared for High Luminosity LHC (HL-LHC).
Learning goals	We expect the students to learn the basic concept behind the high energy physics experiments and detectors
Teaching methods	Slides
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-

Examination methods (if applicable)	-
Suggested readings	slides
Additional information	-

Course unit English denomination	**Physics, Technology and Applications of Linear Accelerators**
SS	**FIS/07**
Teacher in charge (if defined)	David Alesini
Teaching Hours	30
Number of ECTS credits allocated	3
Course period	The course will be held in the next Academic Year (2026-27)
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (60% minimum of presence) ☐ No
Course unit contents	1) Introduction to the course and basics of LINAC acceleration structures 2) Normal and superconducting structures 3) Power coupling, scattering parameters, linac technology 4) High-power RF sources for particle accelerators 5) Longitudinal and transverse beam dynamics, bunching, capture sections, envelope equation 6) Magnet design: basic design principles and parameters: POISSON 7) Pumping system and linac vacuum basics 8) Timing and synchronisation systems 9) Diagnostic devices 10) ASTRA CODE for beam dynamics simulations: introduction and example of photoinjector design 11) Electronic thermionic cannons 12) Application of proton linacs for cancer therapy 13) Applications of electronic linacs: injectors, industrial applications, FEL, tomography
Learning goals	The main objective of the course is to provide an overview of physics (longitudinal and transverse dynamics), technology (radio-frequency cavities and systems, magnets, ultra-high vacuum systems) and the main applications of linear accelerators with particular reference to electron accelerators
Teaching methods	lectures

Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	The examination will consist of questions related to the course topic
Suggested readings	Slides Other material will be indicated during the course
Additional information	-

Course unit English denomination	**Programmable System on Chip (SoC) for data acquisition and processing**
SS	**ING-INF/01**
Teacher in charge (if defined)	Andrea Fabbri
Teaching Hours	20
Number of ECTS credits allocated	4
Course period	The course will be held in the next Academic year (2026-27)
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	The course will introduce the latest generation programmable devices (FPGA and ACAP) describing their characteristics and main modules (DDR management, integrated processors, DSP, AI engine...) and their interaction. Use cases will then be presented and a classroom project will be carried out aimed at learning the methodologies for using these complex systems in the field of data acquisition systems (DAQ) for physics and astrophysics equipment.
Learning goals	The main objective is to give the student a vision of the tools currently available on the market that can be used in the context of complex data acquisition systems. The student will be provided with the methodologies for the architectural design of such systems through the use of such platforms and hints on the relative programming methods.
Teaching methods	The course includes an introductory part in which the basic concepts related to the needed functionality of an acquisition systems. Moreover, the components integrated within a modern FPGA will be discussed and recalled. Two case studies will then be viewed in the classroom as an example of complex acquisition systems based on programmable devices.
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	Oral interview (By appointment)
Suggested readings	handouts provided by the teacher
Additional information	-

Course unit English denomination	**Quantum Artificial Intelligence**
SS	**FIS/03**
Teacher in charge (if defined)	Filippo Caruso
Teaching Hours	10
Number of ECTS credits allocated	1
Course period	TBC
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	Quantum Artificial Intelligence (Quantum AI) is a very young but rapidly evolving field of research, combining AI with the enormous power of quantum computers, now available via the cloud and even on the market. This intensive short course sheds light on this new Quantum AI framework by presenting an overview of the basic elements of quantum computing and quantum machine learning, where supervised and unsupervised learning algorithms, reinforcement learning and generative AI models can be generalised to the quantum world by running them on real and very powerful quantum processing units.
Learning goals	Knowledge of the basic elements of quantum computing and quantum machine learning, understanding the differences and advantages over classical machine learning
Teaching methods	Slides and digital blackboards
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge of mathematical analysis and linear algebra

Examination methods (if applicable)	project and oral interview
Suggested readings	Machine Learning With Quantum Computers, M. Schuld and F. Petruccione, Springer Nature 2021
Additional information	Available only if activated for the AI Health PhD program

Course unit English denomination	**Radiation Matter Interaction**
SS	**FIS/01**
Teacher in charge (if defined)	Piet Verwilligen
Teaching Hours	16
Number of ECTS credits allocated	2
Course period	End of September – early December 2026
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	- Ionizing radiations source - Heavy charged particles interaction - Electrons interaction - Gamma/X rays interaction, photoelectric and Compton effects, pair production - Neutron interaction - Radiation and dose exposure - Methods for measuring dose - Effects on materials and detectors
Learning goals	The educational objectives of the course are: - to acquire the foundational principles of physical theories that describe the interaction of radiation with matter and its propagation; - to develop the ability to connect concepts and theories to the experimental practice of detecting ionizing radiation.
Teaching methods	Lectures supplemented by slides
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No

Prerequisites (not mandatory)	Calculus, Mechanics, Electromagnetism, Elements of Quantum Mechanics, Statistical methods
Examination methods (if applicable)	Interview/final report
Suggested readings	Slides and reference book “Techniques for Nuclear and Particle Physics Experiments” [Williams R. Leo]
Additional information	-

Course unit English denomination	**Radio and optical interferometry**
SS	**FIS/05**
Teacher in charge (if defined)	Fabrizio Massi, Luca Olmi
Teaching Hours	12
Number of ECTS credits allocated	2
Course period	April – May 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	After reviewing the basic principles of interferometry, the course will deal with the astronomical applications of interferometry at optical and radio wavelengths. Observational methods, and technical and practical issues will be discussed, as well as the main differences between radio and optical astronomical interferometry. An overview of available and future observational facilities will conclude the course.
Learning goals	The main aim of the course is to provide the students with the basic knowledge needed to interpret interferometric observations and to plan their own interferometric observation
Teaching methods	Small seminars (slides), references to texts and webpages
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	None

Examination methods (if applicable)	The student is asked to discuss an interferometric science case found in the literature.
Suggested readings	The student will be provided with a copy of the slides and further notes
Additional information	-

Course unit English denomination	**Random Excitation and response of structures**
SS	**ING-IND/04**
Teacher in charge (if defined)	Francesco Franco, Giuseppe Petrone
Teaching Hours	12
Number of ECTS credits allocated	3
Course period	September 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	-
Learning goals	-
Teaching methods	Mixed Modality (physical + virtual)
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	-
Suggested readings	-
Additional information	http://www.dii.unina.it/page.php?tabella=livello3&id_livello=456&flag=pagina&livello1=7&livello2=131&livello3=0

Course unit English denomination	**Rare event search with Noble Liquids**
SS	**FIS/01**
Teacher in charge (if defined)	Paolo Agnes
Teaching Hours	12
Number of ECTS credits allocated	2
Course period	March-May 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	Working principles of single and double phase experiments for dark matter searches and neutrino physics: 1.Physics of signals creation and detection, focus on recent developments of the scintillation light detection technology; 2. Challenges to calibrate detectors, identify and suppress backgrounds; 3. Review the rich physics program
Learning goals	Understanding the working principle, characteristics and limitations of different noble liquid detectors
Teaching methods	Lectures with slides, one hands-on session on real data analysis
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Radiation-matter interaction basics Particle physics basics
Examination methods (if applicable)	Seminar on an agreed topic followed by questions and a short discussion

Suggested readings	Slides of the course Knoll - Radiation detection and measurement, Wiley
Additional information	-

Course unit English denomination	**Scintillators and Silicon Photomultipliers**
SS	**FIS/01**
Teacher in charge (if defined)	Elisabetta Bissaldi, Serena Loporchio
Teaching Hours	16
Number of ECTS credits allocated	2
Course period	May-June 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	The program includes Photon-matter interactions; Organic and Inorganic scintillators; Optical coupling; Solid-state photodetectors: The pn junction, the Photodiode, the SPAD, the SiPM. Different SiPM technologies. SiPM properties: single photoelectron resolution, gain, signal to noise ratio, photo-detection efficiency. Temperature dependence. The equivalent circuit of a SiPM. Optimal front-end: current feedback, pole zero cancellation network. SiPM arrays. SiPM coupled to scintillators. SiPM applications. Part of the course will be devoted to laboratory sessions
Learning goals	This course aims to provide the student with advanced knowledge of radiation measurements and detection techniques, from classic scintillation detectors to modern Silicon Photomultiplier devices.
Teaching methods	Lectures and lab sessions
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	It requires an elementary background in radiation measurements, radiation matter interactions and basic electronics.

Examination methods (if applicable)	Final laboratory report
Suggested readings	1. G. Knoll – “Radiation Detection and Measurement” 2. Sedra and Smith – “Microelectronic Circuits” 3. Sze - “Physics of Semiconductor Devices” 4. Recent Publications
Additional information	It is delivered in hybrid mode (both in-person and distance) including activities in the lab.

Course unit English denomination	**Semiconductor light sources for engineers**
SS	**ING-INF/01**
Teacher in charge (if defined)	Mariangela Gioannini, Lorenzo L. Columbo
Teaching Hours	20
Number of ECTS credits allocated	2,5
Course period	June 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (…% minimum of presence) ☒ No
Course unit contents	Principles: - Spontaneous emission, stimulated emission and light amplification in semiconductors. Semiconductor optical waveguides - Semiconductor devices based on spontaneous emission and light amplification: light emitting diodes (LEDs) and superluminescent light emitting diodes (SLDs) - Semiconductor devices based on stimulated emission: laser diodes with emission in the visible and near-infrared range - Semiconductor Quantum Cascade Lasers for Mid-infrared and THz emission - Non-linear effects in multimode semiconductor lasers: four-wave mixing; generation of optical frequency combs and optical solitons Applications: - Application of SLDs: optical coherence tomography as non-invasive technology for high resolution imaging of biological tissues - Application of laser diodes: laser diode dynamics and self-mixing interferometry for measurements of distance and velocity. Laser diodes for LIDAR. - Application of QCLs: MID-IR dual-comb spectroscopy for high-resolution, high-sensitivity broadband molecular spectroscopy. THz scattering high resolution, high sensitivity broadband molecular spectroscopy. THz scattering type scanning near field microscopy (s-SNOM) for subwavelength imaging
Learning goals	The aims of course are:

	1) providing to students the basic principles of lightmatter interaction in semiconductors and the fundamentals of semiconductor device operation for light emission. The course will present the principles of light emitting diodes, superluminescent light emitting diodes and semiconductor lasers 2) present examples of applications of these devices with focus on the most emerging applicative fields other than the conventional optic communication systems The course will therefore provide basic notions and tools to PhD students that are, or may be in future, involved in the design or application of systems employing semiconductor lasers or LEDs.
Teaching methods	-
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	- Fundamentals of semiconductor physics and electromagnetism - Basic notions on semiconductor devices (diodes)
Examination methods (if applicable)	Oral presentation at the end of the course
Suggested readings	-
Additional information	The course is delivered every two years. Next course is scheduled in June 2026. It typically starts mid of June with 4 or 6 hours of lesson per week. The detailed calendar of the lessons will be presented at the beginning of the course and possibly discussed with the students to meet their requests and availability for attending the lessons. For additional information contact mariangela.gioannini@polito.it

Course unit English denomination	**SIMULATION OF OPTICAL PHOTON PROPAGATION FOR GENERIC SCINTILLATOR-BASED DETECTORS**
SS	**FIS/01**
Teacher in charge (if defined)	Davide Serini
Teaching Hours	16
Number of ECTS credits allocated	2
Course period	The course will be held in the next Academic Year (2026-27)
Course delivery method	☐ In presence ☒ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	Scintillator materials are widely used in particle physics for ionidentification and energy measurements. Next-generation space missions will employ plastic scintillator detectors (PSDs) equipped with the new Silicon Photomultipliers (SiPMs) technology to read out the scintillator light emission. Scintillator based detectors are also widely used for radiation monitoring for environmental or industrial purposes. This course aims to provide the student with knowledge of radiation measurements and detection techniques. It will also provide the student the capability to implement a dedicated MC simulation of the performances of a generic scintillator-based detector using the GEANT 4 toolkit with hands-on sessions. Part 1 (Theoretical): Absorption of radiation in scintillation materials. Light yield, organic and inorganic scintillators. Quenching effect and Birk's Law. Optical coupling. Solid state photodetectors: the Silicon Photomultiplier (SiPMs). Scintillator-based detectors application for space missions and for radiation environmental monitoring. Part 2 (Hands-on sessions): An introduction to GEANT4 simulation toolkit. Make your own optical simulation project: the geometry, the physic list and the optical processes. Sensitive detector and optical photon hit. An introduction to ROOT toolkit: how to read the simulation results. Each topic will be correlated to progressive exercises aimed to make the student able to implement a complete simulation tool.
Learning goals	Understand the base classes to implement a generic simulation using the Geant4 toolkit.

	Understand the operating principles of detectors based on scintillators and photosensors. Implement a simple simulation involving optical processes.
Teaching methods	Lectures with slides support. Progressive exercises aimed to make the student able to implement a complete simulation tool.
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☐ Yes ☒ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	-
Suggested readings	-
Additional information	-

Course unit English denomination	**Solid State Detectors**
SS	**FIS/01**
Teacher in charge (if defined)	Donato Creanza, Ilirjan Margjeka
Teaching Hours	16
Number of ECTS credits allocated	2
Course period	September 2026
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	Principles of Operation of Solid-State Detectors • Manufacturing Technologies of Solid-State Devices • Solid State Detectors for Energy and Radiation Measurement • Solid State Detectors for Position Measurement • Readout Electronics • Radiation Damage • Solid State Detectors in Big Experime
Learning goals	The course aims to illustrate the main characteristics of solid-state devices used in high-energy physics experiments
Teaching methods	Lectures supplemented by slides
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	Final Report about course topics

Suggested readings	Lecture slides Gerhard Lutz, Semiconductor Radiation Detectors, Springer Frank Hartmann, Evolution of Silicon Sensor Technology in Particle Physics, Springer
Additional information	-

Course unit English denomination	**STATISTICAL PROCESS MONITORING OF COMPLEX ENGINEERING DATA**
SS	**SECS-S/02**
Teacher in charge (if defined)	Antonio Lepore, Christian Capezza
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	February 2026
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	• Univariate and Multivariate Statistical Process Monitoring (3 CFU) • Statistical Process Monitoring of Functional Data (3 CFU)
Learning goals	Training on the application (illustrated through open-source statistical software environment R) of statistical process monitoring of complex engineering data for decision-making. Every student must choose a data analysis project gathered during the course and develop it by working in a team. In this way, students will have the opportunity to improve their ability to recognize and implement the most suitable statistical techniques for the problem at hand, as well as to communicate relevant results and the impact of their analysis also to non-statisticians
Teaching methods	-
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-

Examination methods (if applicable)	The final examination will consist of the presentation and discussion of a data set – chosen by the student – on which at least one of the method presented in the course will be applied.
Suggested readings	- Montgomery, D.C. (2012). Introduction to Statistical Quality Control. John Wiley & Sons. - Johnson, R.A. & Wichern, D.W. (2007) Applied Multivariate Statistica Analysis, Pearson. - Ramsay, J.O. & Silverman, B.W. (2005) Functional Data Analysis, Springer.
Additional information	-

Course unit English denomination	**Structural simulation techniques in the dynamic and non-linear field**
SS	**ING-IND/14**
Teacher in charge (if defined)	Martina Scapin
Teaching Hours	18
Number of ECTS credits allocated	2
Course period	Late June-Early July 2026
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	Italian
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	-
Learning goals	The course aims to describe the basic principles and main numerical techniques necessary for the understanding and application of the finite element method (FEM) with special emphasis on dynamic and transient nonlinear structural analysis. During the course, both the theoretical foundations and numerous applications in various fields will be illustrated through the discussion of numerical examples and specific case studies solved with the aid of the Ansys LS-DYNA software. The notions learned will make it possible to explore the possible applications of the methods and aspects discussed in various fields of engineering.
Teaching methods	-
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☐ Yes ☒ No
Prerequisites (not mandatory)	Knowledge of numerical calculation (approximation methods, interpolation techniques, numerical integration, scientific calculation tools for solving partial differential equations), fundamentals of structural mechanics (mechanical and strength characteristics of materials, stress and strain states in the linear

	elastic field) and mechanics of materials (elastic-plastic behaviour, plastic flow models, failure methodologies).
Examination methods (if applicable)	-
Suggested readings	-
Additional information	https://didattica.polito.it/pls/portal30/gap.pkg_guide.viewGap?p_cod_ins=

Course unit English denomination	**Thermo-fluid dynamics in 3D printed channels**
SS	**ING-IND/10**
Teacher in charge (if defined)	Simone Mancin
Teaching Hours	8
Number of ECTS credits allocated	1
Course period	February 2026
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (90% minimum of presence) ☐ No
Course unit contents	Thermo fluid dynamics of printed channels and systems
Learning goals	Learn which are the most important parameter to control to design efficient 3D printed heat exchangers
Teaching methods	Lecture
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Thermodynamics and Heat Transfer
Examination methods (if applicable)	-
Suggested readings	Notes
Additional information	-

Course unit English denomination	**Vacuum Technologies**
SS	**ING-IND/22**
Teacher in charge (if defined)	Oscar Azzolini
Teaching Hours	16 (8 lecture + 8 lab) two full days at LNL
Number of ECTS credits allocated	2
Course period	April 2026
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (100% minimum of presence) ☐ No
Course unit contents	Gas flux through channels: flux regimes; Conductance and Impedance; gas flux in viscous regime; gas flux in molecular regime; Conductance of short, long and elbow tubes; Vacuum materials: desorption, permeability, solubility, diffusion and degassing; Vacuum System Baking; Vacuum welding and brazing; Vacuum components; electrical, rotary and linear feedthroughs, Vacuuming: rotary pumps; zeolites and traps; piston pumps, membrane pumps, trochoidal pumps, scroll pumps, roots pumps, claw pumps, turbomolecular pumps, diffusion and cryogenic pumps; measuring of a vacuum chamber in low and UHV; Fundamentals of Designing – golden rules and mistakes to avoid ; Vacuum Measurement: Pirani Vacuum meters, Thermocouple Vacuum meters, Capacitance Vacuum meters, Penning Vacuum meters, Ionizing Vacuum meters, Bayard Alpert Vacuum meters, Quadrupoles Mass Analysers; real and virtual Leaks Detection. Experimental activities in Laboratory on vacuum production and leak detection.
Learning goals	Knowledge of the instruments commonly used in vacuum systems, how to solve problems that may occur, how to work towards optimal vacuums.
Teaching methods	Lectures and practical laboratory
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	-
Examination methods (if applicable)	10-min PPT presentation on a topic of the course
Suggested readings	Lectures PPT
Additional information	-