Università degli Studi di Padova

PHYSICS

Course unit English denomination	**Advanced instrumentation for the study of nuclear structure and reaction dynamics**
SS	FIS/01 , FIS/04
Teacher in charge (if defined)	Daniele Mengoni, Francesco Recchia, Kseniia Rezynkina
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	02/2027 06/2027
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (50 % minimum of presence) ☐ No
Course unit contents	**Radiation interaction with matter:** · Detectors for charged particles. Use of semiconductors to build spectrometers, spectrum characterization, and effects on energy resolution; · Neutron detection; shielding based on energy spectrum. Production of neutron beams and their use in experimental physics; · Detection of gamma and X rays. Use of hyperpure germanium, efficiency, resolution, resolving power; · Measurement systems for complete spectroscopy. Recoil decay correlation method. **Advanced measurement systems for studying nuclear systems:** · Possible configurations for hyperpure germanium detectors. Position sensitive germanium detectors. Discussion of Doppler correction capability. Segmented germanium detectors: pulse shape analysis, gamma tracking, and performance. · Detectors for light charged particles: TPC, solenoids, and highly segmented silicon detectors. Description of properties and discussion of sensitivity of different approaches and possible combined use.

	· Detectors and optical technique (laser spectroscopy) for studying properties of ground and isomeric nuclear states. Possible extension to molecules and physics BSM. **Exploration of nuclide chart for the study of nuclear structure**: · Ion sources and types of accelerators, from electrostatic machi nes to synchrotrons; · Production of radioactive beams with ISOL techniques and ex perimental setups; · Production of radioactive beams through fragmentation and ex perimental setups.
Learning goals	In depth understanding of the physical principles behind the opera tion of radiation detectors used in nuclear physics experiments. Un derstanding the performance and use of these detectors. Ability to choose the type of detector and configuration for the design of nu clear physics experiments.
Teaching methods	Lectures with possible adjustments to the program and the depth of the different topics based on the participants' interests and student feedback
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Physics laboratory courses commonly offered in master's degree programs in physics.
Examination methods (if applicable)	In depth study of one of the course topics using scientific literature that illustrates the state of the art in the field. Discussion of the chosen topic within the broader context of all the topics covered in the course.
Suggested readings	Scientific articles and material provided by the instructor. Radiation Detection and Measurement, Glenn F. Knoll, Wiley edi tions; fourth edition (August 16, 2010).
Additional information	—-

Course unit English denomination	**Advanced particle detection techniques and methods: from physics requirements to detector design**
SS	PHYS-01/A
Teacher in charge (if defined)	• Garfagnini Alberto (Dipartimento di Fisica e Astronomia, Università di Padova) • Mattiazzo Serena (Dipartimento di Fisica e Astronomia, Università di Padova)
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	Febbraio/Maggio 2027
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	Inglese
Mandatory attendance	☒ Yes (50% minimum of presence) ☐ No

Course unit contents	The course will present and review the current and innovative detection technologies used in the design of complex detector concepts for colliders. Examples of running detectors will be given, and several R&D cases for the next generation of detectors will be presented. In addition, a specific discussion of the various experimental conditions and detector requirements from physics in the case of different colliding particles and energies (pp, heavy ions, e+e-, muons) will be discussed using concrete examples of running experiments or ongoing projects (CMS, ALICE, LHCb, BELLE2, and more). In addition, a section of the course will be devoted to detectors and techniques for the detection of neutrinos of different origin (accelerators, cosmic, reactors).
	
	Part 1: Detectors and techniques for physics at colliders (16h)
	
	• Tracking and particle identification (8h)
	    o Vertex detectors
	    o Tracking detectors
	    o Detectors for particle identification

	○ Muon detectors ● Calorimetry, timing and global considerations (8h) ○ Electromagnetic Calorimeters ○ Hadronic Calorimeters ○ Timing detectors ○ Trigger and data acquisition ○ Physics requirements for detectors at different colliders (ee vs pp vs mumu) **Part 2: Detectors and techniques applied to neutrino physics (8h)** ● Neutrino Oscillation detectors: ○ Large Cherenkov Detectors (photo sensors and particle identification techniques). Threshold counters. Ring Imaging detectors. Askaryan radiation. ○ Large Cryogenic liquids detectors (LAr and LXe): properties and techniques. ● Double beta decay ○ material selections for high radiopurity detectors ○ active techniques for background suppression (PSD e active veto systems)
Learning goals	At the end of the course, students will learn the operating principles of some of the most used particle detectors. They will also have acquired knowledge of the physical quantities that can be obtained from these. Students will learn how the physical working principles of detectors might fit the needs of specific and varied experimental contexts of collider and neutrino physics. Finally, they would also learn to deal with the balance between physics needs and practical constraints that drive the ultimate design choices of real experiments
Teaching methods	Frontal teaching, case studies (example from running experiments or ongoing projects)
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	This course might be taken by students already having some preliminary knowledge of detector technology from their Master
Examination methods (if applicable)	The exam will consist of an in-depth study on a topic chosen from those presented in the course (and agreed with the teachers beforehand), in the form of an oral presentation of about 20 minutes (slides) and its discussion, followed by an additional interrogation to verify the acquisition of the knowledge of the rest of the course content.
Suggested readings	Material suggested by the teachers
Additional information	

Course unit English denomination	**Advanced topics in quantum sciences**
SS	PHYS-04/A
Teacher in charge (if defined)	Simone Montangero, Di Liberto Marco
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	02/2026 – 06/2027
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (50% minimum of presence) ☒ No
Course unit contents	This course introduces advanced topics in quantum many-body physics within the broader framework of quantum information science and quantum technologies. Motivated by Feynman's proposal to use quantum hardware to tackle the complexity of many-body quantum systems, the field has rapidly evolved into a highly interdisciplinary area connecting condensed matter physics, quantum optics, information theory, and high-energy physics. The course explores how quantum simulators and quantum computers provide new approaches to studying complex quantum phenomena that are difficult or impossible to access with classical methods. Selected examples include strongly correlated systems, topological phases of matter and topological order, critical systems, quantum chemistry, and lattice gauge theories, where classical numerical techniques are often limited by computational complexity or the sign problem. The course will highlight current challenges and prospective applications across physics and related disciplines.
Learning goals	Students will learn advanced concepts concerning phases of matter and quantum systems including the role of entanglement and the relevance to current quantum simulation and computation developments. They will learn how to characterize many-body quantum states and compute their relevant quantities using analytical and computational techniques and methodologies. With these abilities the student will be able to comprehend concepts present in the current literature and will understand the importance.

Teaching methods	Lectures
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Quantum mechanics and many-body theory
Examination methods (if applicable)	Oral examination (presentation of a topic of choice)
Suggested readings	T. Felser, S. Montangero, Introduction to Tensor Network Methods (2026), Springer M. Di Liberto, Lecture notes on Topological phases of matter D. Tong, Lectures on the Quantum Hall Effect (2016)
Additional information	None

Course unit English denomination	**Bosonization in Condensed Matter Physics**
SS	PHYS-04/A
Teacher in charge (if defined)	Luca Dell'Anna
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	October 2026 - January 2027
Course delivery method	X In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	X Yes (50% minimum of presence) ☐ No
Course unit contents	The course is devoted to the technique of bosonization in one-dimensional systems. We will derive in detail how to go from a fermionic model to a bosonic one, and study several relevant applications of this method in condensed matter physics. The main topics of the course are the following: 1) Fermi surface and spectrum of low energy excitations of free spinless fermions, 2) Green's functions of left and right moving Fermi fields, 3) Normal ordering and Tomonaga Hamiltonian, 4) Kac-Moody algebra as a spectrum generating algebra for Tomonaga Hamiltonian, 5) Application to an interacting fermionic system: the Luttinger liquid, 6) Application to a quantum spin chain: bosonization of the Heisenberg model, 5) Spinful fermions: spin-charge separation and application to Fermi-Hubbard model..
Learning goals	The objectives are: i) acquiring the knowledge of the method and ii) developing the skills necessary to apply this knowledge for the solution of one-dimensional quantum problems.
Teaching methods	Lessons on the blackboard

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: presentation of an application of the method)
Suggested readings	Notes will be delivered with references therein.
Additional information	None

Cosmology	**Cosmology**
SS	PHYS-05/A Astrofisica, cosmologia e scienza dello spazio
Teacher in charge (if defined)	Nicola Bartolo Daniele Bertacca Angelo Ricciardone
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	March 2027
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (50 % minimum of presence) ☐ No
Course unit contents	According to the audience, as mentioned also below, we can calibrate the course either starting from basic concepts of cosmology, and/or delving with new frontiers of Modern Cosmology - Standard cosmology: Fundamentals of General Relativity for cosmology; Cosmological models; Friedmann-Robertson-Walker metric - Thermodynamics of the Universe: elements of kinetic theory in the expanding Universe; evolution of the entropy and of the main thermodynamical quantities; photon and neutrino decoupling; relic particles - Inflation: problems of the standard cosmological model; kinematics and dynamics of inflation models; generation of primordial erturbations and of primordial gravitational waves. Models beyond the simplest one and their observational imprints on different cosmological scales. - Cosmic Microwave Background temperature anisotropies and polarization: main effects and their physical origin, dependence on cosmological

	parameters, connection to inflationary perturbations, in particular to primordial gravitational waves. - Gravitational Instability: linear (and non-linear) evolution of cosmological perturbations in various scenarios for dark matter candidates; analysis of how motion of matter in the universe and the paths of light rays by which we observe it are determined by spacetime curvature. - Statistics of cosmological perturbations: power-spectrum; transfer function; filter functions; higher-order statistics and primordial non-Gaussianity - Dark Energy and modified gravity: models.. A LIST OF POSSIBLE ADVANCED TOPICS: - Other techniques for computing primordial non-Gaussianity - Open quantum systems in cosmology - Non-linear and general relativistic cosmological perturbations (including classes of spatially inhomogeneous cosmologies) - Theoretical and observational characterization of the Stochastic Gravitational Wave Background
Learning goals	The "Cosmology" course aims first of all at providing a concise introduction to the current research in this field, both in the direction of Early Universe physics and Inflation and in the context of the late Universe (large-scale structure formation, evolution and statistical analysis) as well as at the phenomenological characterization of dark matter and dark energy and primordial gravitational waves. Emphasis will be given to some of the most up-to-date issues nowadays in cosmology. According to the audience, the course can be structured starting from basic concepts of modern cosmology, and/or it can be developed around the new frontiers of the field. Also, a selected list of advanced topics can be presented, tuned to the interests of the students. During the course students will be encouraged to read at least one or two papers on some topics of particular interest and to report them with a brief interactive discussion with all classmates. At the end of the course, the PhD students will be familiar with the most important concepts of cosmology, and their main implications (in terms of both modeling and observational constraints). The tools the students will acquire will allow them to solve problems related to the specific subject of the course but they will allow the students also to acquire a knowledge to

	face more general issues, e.g. those which might resemble the same complexity and approximation schemes learned during the course.
Teaching methods	Lectures will be given at the blackboard with the help of some slides. According to the audience, a selected list of advanced topics can be presented, tuned to the interests of the students. During the course students will be encouraged to read at least one or two papers on some topics of particular interest and to report them with a brief interactive discussion with all classmates. Therefore we will also • promote critical reflection in the classroom • conduct discussions in working groups in the classroom • use group work in the classroom
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Minimal knowledge of general relativity, but not mandatory, the course is self- contained
Examination methods (if applicable)	The students will be asked to prepare a short presentation (30 minutes approximately) with slides, on a topic proposed by the students that should be in connection with what has been explained during the course. The presentation will be based on the reading and study of one or more specific papers.
Suggested readings	- S. Dodelson, 2003. Modern Cosmology, Academic Press. - E.W. Kolb and M.S. Turner, 1990. The Early Universe, Addison-Wesley - A.R. Liddle and D.H. Lyth, 2000. Cosmological Inflation and Large-Scale Structure, Cambridge University Press. - S. Weinberg 2008, Cosmology, Oxford Univ. Press.

	- George F. R. Ellis , Roy Maartens , Malcolm A. H. MacCallum 2012. Relativistic Cosmology, Cambridge University Press - P. Peter and J. P.Uzan 2013. Primordial Cosmology, Oxford University Press
Additional information	—-

Course unit English denomination	**Elements of X-ray Physics**
SS	PHYS-03/A
Teacher in charge (if defined)	Sun, Peihao Monaco, Giulio
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	02/2027 – 06/2027
Course delivery method	☐ In presence ☐ Remotely ☒ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (50% minimum of presence) ☒ No
Course unit contents	This course will cover theoretical and practical aspects of modern X-ray sources and their current use in the study of materials. The course is divided into three parts: 1. Sources: synchrotron radiation, undulator, coherent sources. 2. Scattering theory: theory of X-ray – matter interaction, diffraction from amorphous materials, diffraction from crystals (kinematic and dynamical theory), refraction and reflection. 3. Applications: X-ray optics, imaging, absorption, inelastic scattering, XPCS, etc.
Learning goals	The aim of this course is to provide students with a comprehensive understanding of X-ray physics, starting from fundamental principles. Students will have a chance to: 1. Understand the principles current synchrotron light sources. 2. Develop a solid grasp of the interaction between X-rays and matter. 3. Gain in-depth knowledge of various X-ray techniques and their applications in materials science. 4. Understand the principles needed to design and perform X-ray experiments. 5. Learn to critically analyze and evaluate X-ray data. By the end of the course, students will be equipped with both theoretical knowledge and practical insights, enabling them to effectively utilize X-ray techniques in their future research and professional endeavors.

Teaching methods	Frontal lectures with exercises
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge in electrodynamics, special relativity, quantum physics, and solid-state physics
Examination methods (if applicable)	Oral presentation on a topic of interest to the student and relevant to the course
Suggested readings	Elements of Modern X-ray Physics (Jens Als-Nielsen & Des McMorrow) X-ray Diffraction (B. E. Warren) Lecture notes to be distributed during the course
Additional information	

Course unit English denomination	**Modern topics in Statistical Physics**
SS	PHYS-04
Teacher in charge (if defined)	Gianmaria Falasco
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	Second semester
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☐ Yes (50% minimum of presence) ☒ No
Course unit contents	The course aims to provide an overview of the recent developments in the nonequilibrium statistical mechanics and thermodynamics of (mainly classical) dissipative systems, namely, open systems weakly coupled to multiple (thermal, chemical, etc.) reservoirs An introduction to the following topics will be given, with varying emphasis depending on the background and interests of the participants: -Review of the mathematical background useful to the description of open systems: Langevin, Fokker- Planck and Master equations; path integrals and functional methods. Associated numerical methods (integration of SDEs, kinetic Monte Carlo, path sampling). -Stochastic thermodynamics: time-reversal breaking and fluctuation theorems; principles of energy transduction and far-from-equilibrium efficiency. -Linear and nonlinear response theory: generalizations of the fluctuation-dissipation relation; Kawasaki formula and Zubarev-MacLennan ensamble; negative (differential) response. -Constraints on dissipative processes: Landauer's bound; thermodynamic uncertainty relations and speed limits; bounds on population inversion.

	-Thermodynamic limit and metastability in dissipative systems: Large deviations theory; Freidlin-Wentzell quasi-potential; out-of-equilibrium generalization of Kramers-Arrhenius rate law; dynamical phase transitions. Examples will be given in the context of soft/active matter physics, biochemistry and population dynamics, electronic systems.
Learning goals	By the end of the course, students should be able to: -Explain the fundamental principles governing the dynamics and thermodynamics of systems driven far from thermodynamic equilibrium. -Compare and relate non-equilibrium phenomena to concepts from equilibrium statistical mechanics and thermostatics. -Identify and describe key dissipative processes, including population inversion, energy transduction, and non-equilibrium phase transitions. -Apply appropriate theoretical tools to analyze multi-scale stochastic models, such as those arising in population dynamics. -Independently evaluate non-equilibrium systems using analytical reasoning and modeling techniques.
Teaching methods	Lectures and application sections
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Statistical mechanics
Examination methods (if applicable)	Oral, presentation of a paper related to the topics of the course
Suggested readings	Instructor's notes, the link to which will be distributed to the participants. References: Stochastic Thermodynamics, Luca Peliti and Simone Pigolotti, Princeton University Press (2021); Alex Kamenev, An Introduction to Field Theory of Non-Equilibrium Systems, Cambridge University Press (2023); Statistical Mechanics and Stochastic Thermodynamics, David T. Limmer, Oxford University Press (2024)
Additional information	

Course unit English denomination	**Observational Multimessenger Astrophysics**
SS	PHYS01; PHYS05
Teacher in charge (if defined)	Elisa Prandini Elisa Bernardini Livia Conti Chiara Sirignano
Teaching Hours	24 hours
Number of ECTS credits allocated	3 credits
Course period	March-June
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (50% minimum of presence) ☐ No
Course unit contents	The course aims to provide solid knowledge of the main open questions driving current experimental research in astroparticle and gravitational wave physics, using an original, transversal approach: the multimessenger view. It explores interconnected topics, with a common focus on the experimental aspects of current research in the field. The course introduces key concepts, including the sources and properties of cosmic particles and of gravitational waves, as well as the properties of dark matter and dark energy. The challenge of detecting cosmic messengers forms the core of this course, offering a broad overview of the complex experimental techniques employed by the current and future generation of instruments, such as MAGIC, CTAO, IceCube, Baikal, KM3NeT, LIGO, Virgo, KAGRA, Einstein Telescope, LISA, Euclid, DESI, and Roman Space telescopes. Recent experimental results on cosmic messengers (gamma-rays, neutrinos, gravitational waves), as well as dark matter and dark energy surveys, are reviewed in detail, with special emphasis on the experimental aspects and constraints. Finally, future experimental perspectives are outlined and contextualized in terms of the expected advancements in our understanding of the multimessenger universe.
Learning goals	• Evaluate different astrophysical environments as sources of astroparticles • Explain the main mechanisms of production and propagation of gamma rays, neutrinos, gravitational waves, and possible dark matter candidates

	• Assess qualitatively and quantitatively the various methodologies for detecting cosmic messengers • Identify the main features of next-generation detectors and their impact on the current observational landscape • Explain the main experimental techniques applied in large galaxy surveys. • Critically assess some recent experimental results
Teaching methods	The activities include classroom lectures using digital support, with the use of slides. Some lessons will be supplemented with audio-visual material.
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge of the theory of special relativity, elementary particle physics and their interactions, and nuclear physics is requested.
Examination methods (if applicable)	The final exam consists of the discussion of two articles, selected and presented by the student, covering various topics addressed during the course. The articles, agreed upon in advance with the lecturers, must explore the connections between different areas of research. The exam also includes some questions on all the topics covered throughout the course.
Suggested readings	• Thomas K. Gaisser, Ralph Engel, Elisa Resconi, Cosmic Rays and Particle Physics, Cambridge Uni. Press (2016), old book: https://galileodiscovery.unipd.it/permalink/39UPD_INST/prmo4k/alma990000040660206046 • Maurizio Spurio, Particle and Astrophysics, Springer (2015), Galileo discovery link: https://galileodiscovery.unipd.it/permalink/39UPD_INST/prmo4k/alma990024057240206046 • Felix A. Aharonian, Very high energy Cosmic Gamma Radiation (2004) https://galileodiscovery.unipd.it/permalink/39UPD_INST/prmo4k/alma990013728970206046 • De Angelis, Pimenta, An Introduction to Particle and Astroparticle Physics, Springer (2018), https://galileodiscovery.unipd.it/permalink/39UPD_INST/prmo4k/alma990031884740206046 • Scott Dodelson, Fabian Schmidt, Modern Cosmology, Elsevier (2020) https://galileodiscovery.unipd.it/permalink/39UPD_INST/prmo4k/alma990008568700206046

	• Bond, C., Brown, D., Freise, A. *et al.* Interferometer techniques for gravitational-wave detection. *Living Rev Relativ* **19**, 3 (2016). https://doi.org/10.1007/s41114-016-0002-8 • Abbott, B.P. et al., “Prospects for observing and localizing gravitational-wave transients with Advanced LIGO, Advanced Virgo and KAGRA”, Living Rev Relativ 23, 3 (2020), https://doi.org/10.1007/s41114-020-00026-9
Additional information	The course is divided into the following four modules: • The High-Energy Universe (E. Prandini) • Astrophysical Neutrinos (E. Bernardini) • Gravitational Waves (L. Conti) • Experimental Aspects of Dark Matter and Energy Surveys (C. Sirignano)

Course unit English denomination	**Quantum Physics with Atoms and Ions**
SS	PHYS-04/A
Teacher in charge (if defined)	Prof. Luca Salasnich
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	March-April-May 2027
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (50% minimum of presence) ☐ No
Course unit contents	1. Bose-Einstein condensation with ultracold alkali-metal atoms (4 h). 2. Experimental trapping techniques for atoms and ions (4 h). 3. Topological states with ultracold atoms: quantized vortices and dark solitons. Bright solitons (4 h). 4. Superfluid hydrodynamics for bosons and fermions. Macroscopic quantum tunneling and Josephson junctions (4 h). 5. Two-dimensional systems: topological phase transition of Kosterlitz-Thouless (2 h). 6. BCS theory for superconductors and fermionic atoms. Ginzburg-Landau equation (2 h). 7. BCS-BEC crossover for atoms (4 h)..
Learning goals	The student will learn the basic quantum phenomena with atoms and ions (and also superconductors) which are currently under intensive investigations: Bose-Einstein condensation, topological quantum states, macroscopic quantum tunneling and Josephson effect, and BCS-BEC crossover. The student will be able to discuss and analyze both theoretical and experimental methods and techniques in this field of research.
Teaching methods	Slides + Blackboard + Questions and Answers

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)	Seminar of the student on a specific topic of the course.
Suggested readings	R. Onofrio and L. Salasnich, Physics and Technology of Ultracold Atomic Gases (Springer, 2024).
Additional information	

Course unit English denomination	**Scientific Computing for Physics Students**
SS	PHYS-01/A, PHYS-02/A, PHYS-03/A,PHYS-04/A, PHYS-05/A, PHYS-05/B, PHYS-06/A
Teacher in charge	Alessandro Renzi
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	March - June 2027
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (50% minimum of presence) ☐ No
Course unit contents	The course provides skills in using tools for developing scientific software for physics, covering development environments, programming languages, algorithms, data structures, parallel and GPU computing, FFTs, Monte Carlo techniques, machine learning, and code optimization. Languages covered include C, C++, Fortran, Python, Julia and Mathematica.
Learning goals	Acquire knowledge and abilities in using scientific languages, managing Linux environments, implementing numerical algorithms and data structures, following software development best practices, and utilizing high-performance computing techniques.
Teaching methods	Lectures, hands-on coding exercises, case studies, group work
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge of programming and numerical computing

Examination methods (if applicable)	Final coding project with weekly handouts
Suggested readings	Suggestions for books or websites for scientific computing related to the course modules will be provided during the lectures.
Additional information	Course designed for theorists and experimentalists.

Course unit English denomination	**Statistical Mechanics of Disordered Systems**
SS	PHYS-04/A
Teacher in charge (if defined)	Prof. Giacomo Gradenigo
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	February 2027
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (50% minimum of presence) ☐ No
Course unit contents	Statistical mechanics of the most important mean-field models of spin-glasses: the Sherrington-Kirckpatrick model, discrete spins, and the spherical p-spin model. Self-averaging property of the free-energy in a system with quenched disorder. Replica trick for the calculation of the free energy. Overlap as global order parameter. Calculation of the free energy as a variational problem over replica matrices. Replica-symmetric ansatz for the high-temperature phase. Instability of the replica-symmetric ansatz at low temperature. Eigenvalues of the stability matrix: the replicon. One-step and full replica symmetry breaking patterns: infinite number of order parameters. Solution of the variational problem in the case of the full-replica symmetry breaking scenario: Parisi equation, order parameter of the spin-glass transition is a probability distribution, hierarchical free-energy landscape. Physical interpretation of the one-step replica symmetry breaking scenario in the p-psin system, Random First-Order Transition and connections with the phenomenology of glasses. Dynamical mean-field theory, exact equations for correlation and response function in the p-psin model.
Learning goals	Illustrate the main ideas and analytical techniques in the statistical mechanics of disordered systems. Show the statistical mechanics formalism, i.e., replica matrices, to describe ergodicity breaking transitions without spontaneous symmetry breaking, which is a generic phenomenon in system with a multi-minima complex landscape.
Teaching methods	Blackboard lectures

Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	Basic knowledge of classical statistical mechanics, i.e., the theory of statistical ensembles, mean-field theory of phase transitions, e.g., the Curie-Weiss model of magnetism.
Examination methods (if applicable)	Seminar/presentation on a topic agreed with the teacher OR standard examination method, i.e., questions on the topics presented in the lectures. The choice is free, but must be agreed upon with the teacher in advance.
Suggested readings	"Spin-glass theory for pedestrians", T. Castellani, A. Cavagna, https://arxiv.org/abs/cond-mat/0505032 "Statistical Physics of Spin Glasses and Information Processing: an introduction". H. Nishimori, Oxford (2001). Course notes that will be given by the teacher to the students
Additional information	

Course unit English denomination	**Statistical methods for physics analysis**
SS	PHYS-01/A, PHYS-02/A, PHYS-03/A, PHYS-04/A, PHYS-05/A, PHYS-05/B, PHYS-06/A
Teacher in charge (if defined)	Denis Bastieri, Tommaso Dorigo Luca Stanco
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	March - June 2027
Course delivery method	X In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	X Yes (50% minimum of presence) ☐ No
Course unit contents	The course aims at providing students with a basic understanding of fundamental issues in statistics of relevance for practical data analysis, and a knowledge of the main techniques for statistical inference in experimental science. General Introduction: - Random variables, probability density functions, the Central Limit theorem, cumulative function, properties of estimators, examples and applications. - Methods of minimum squares and maximum likelihood, covariance matrix. Applications and examples. - Error propagation: some examples and practical applications. - Probability theory, Kolmogorov axioms, theorem of Bayes, practical applications. - Lemma of Neyman-Pearson. Probability ordering. - Interval estimation, confidence intervals, hypothesis testing and p-values, goodness of fit and practical applications. Construction of the power-curve. Coverage for the confidence intervals from maximum likelihood. - The problem of the measurement of 0 or very few events. The method of Feldman-Cousins. - Technicalities in the generation of random numbers. Simulations of several functional relations. - Processes of Markov. Sketch of Markov chain. The process of Filtering

	and Smoothing. The Kalman filter. Statistics in HEP: - Evaluation of p-values for counting experiments, with and without nuisances. - Definition and computation of significance for a signal. - Correspondence between p-value and significance in case of non-Gaussian nuisances. - Look-elsewhere effect and approximate methods for its estimation. - The CLS method and its application to the search for signals. - Profile likelihood and statistical tests. - Application to the search for the Higgs boson at LHC. - Asymptotic methods for the evaluation of sensitivity with the profile likelihood. Statistics in Astrophysics: - Applications of statistical inference and test of models: Z-score and T-score - Coefficient of correlation and related test. Bootstrapping. - Non-parametric tests: Spearman's rank. - Kolmogorov-Smirnov: test and related applications, test of Cramér-von Mises- Test of isotropy: monolope, dipole and quadrupole, statistics of Rayleigh, Watson and Bingham. - Correction of Bonferroni or trial factors. - Test of Anderson-Darling. - Statistics of Cash (Poisson) - Application of maximum likelihood: the catalogue. - Errors of type I and type II: screening and testing, technicalities, sensitivity and power of testing. - Data analysis: correlation, auto-correlation, function of angular correlation at 2 points, and applications. - Analysis of images: linear filters and applications, the Gaussian filter
Learning goals	Enable students to appropriately choose the statistical method for different use cases in data analysis tasks; teach students the importance of reasoning on the sampling distribution of their data, and on its effects on inference; stress the importance of error analysis and uncertainty quantification; make them better scientists by distributing information on what are sound analysis practices and what are incorrect or faulty techniques
Teaching methods	Frontal lectures; open discussion of software solutions; homework exercises; stimulating students to critically assess topics in open discussion
Course on transversal, interdisciplinary, transdisciplinary skills	☒ Yes ☐ No

Available for PhD students from other courses	☒ Yes ☐ No
Prerequisites (not mandatory)	
Examination methods (if applicable)	Discussion of a topic of interest of the candidate, chosen from the course; or of aspects of the statistical analysis relevant for the research carried out by the candidate
Suggested readings	Lecture notes, slides shown during lectures, software provided by the instructors; book by Glen D. Cowan “Statistical Data Analysis”, Oxford Science Publications 1997
Additional information	It is advisable to download and install the ROOT program from root.cern.ch to carry out exercises proposed during the course

Course unit English denomination	**STRUCTURED LIGHT: from principles to modern applications**
SS	PHYS-03/A, PHYS-04/A, PHYS-06/A
Teacher in charge (if defined)	Prof. Gianluca Ruffato (12 hrs), Prof. Filippo Romanato (12 hrs)
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	February-May 2027
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (50% minimum of presence) ☐ No
Course unit contents	• Review of wave optics and electromagnetism • Fourier optics: description of light beam propagation in the paraxial regime • Orbital angular momentum of light: beam families and their properties • Light polarization and its combination with structured light: from vector beams to optical skyrmions • Refractive and diffractive optical elements and metasurfaces: physical principles, design methods, and fabrication • Spatial modes in multimode optical fibers and their applications in classical and quantum telecommunications • Methods for the generation, measurement, and control of the orbital angular momentum of optical beams • Design and fabrication of optical elements for structured light generation • Nanostructuring of optical components to achieve nano-optical effects • Fundamentals of nanofabrication of nanostructured optical devices • Optical characterization and applications of metalenses and advanced optics • Applications of structured light with innovative devices: optical quantum computing and trapping, optical processing, metaguides, and quantum imaging
Learning goals	At the end of the course, the student will be able to:

	• Describe the propagation of an optical beam in free space or in optical fibers • Describe the effect of an optical element on the propagation of a light beam • Design standard optical elements (refractive or diffractive) and metasurfaces to perform specific optical operations • Understand the operating principles of optical devices used in information and communication technologies, particularly for the encoding and transmission of information in the spatial degrees of freedom of light, in both classical and quantum regimes • Apply simulation and computational methods to the design and development of nanostructured optical devices • Understand the relationship between matter nanostructuring and nanostructured light effects • Understand the steps and parameters of nanofabrication processes and protocols
Teaching methods	Lectures and case studies
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)	Seminar on a topic selected from a suggested list
Suggested readings	Slides of the lessons, books, and articles suggested by the teachers
Additional information	

Course unit English denomination	**Theoretical High Energy Physics**
SS	Phys02
Teacher in charge	Gianluca Inverso & Flavio Tonioni
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	Second semester 2027
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (50% minimum of presence) ☐ No
Course unit contents	Advanced topics and mathematical aspects underpinning modern theoretical high energy physics will be covered, from the standard model and its extensions all the way up to the quantum regime of gravity, with applications to a range of other research directions, from particle and astroparticle physics to cosmology. The program can be adapted to the background of the students.
Learning goals	The students will gain expertise on several topics relevant in current research in high-energy theoretical physics.
Teaching methods	Blackboard lectures
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☐ Yes ☒ No
Examination methods	Oral exam and/or written assignment
Suggested readings	Announced at the start of the course
Additional information	None

Course unit English denomination	**Theoretical Physics of the Universe**
SS	Phys02
Teacher in charge (if defined)	Philip Soerensen and Gabriele Franciolini
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	Second semester 2027
Course delivery method	X In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	X Yes (50% minimum of presence) ☐ No
Course unit contents	This course investigates the deep connections between particle physics, gravitational physics, astroparticle physics and cosmology, aiming to provide comprehensive theoretical description of the universe. We cover advanced topics ranging from phenomenological aspects to more mathematical ones, exploring old and new phenomena and giving an overview of recent formal developments. The syllabus will be adjusted according to the background of the students...
Learning goals	The students will gain expertise on the topics of particle physics, gravitational physics, astroparticle physics and cosmology.
Teaching methods	Blackboard 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 and/or written assignment
Suggested readings	Announced at the start of the course
Additional information	None

Course unit English denomination	**Theoretical Physics of the Fundamental Interactions**
SS	PHYS-02/A
Teacher in charge	Claudia Cornella and Arsenii Titov
Teaching Hours	24
Number of ECTS credits allocated	3
Course period	Second semester of academic year 2026–2027
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (50% minimum of presence) ☐ No
Course unit contents	This course explores the theoretical foundations of the four fundamental forces through the lens of modern particle physics tools. We delve into advanced topics in a wide range of phenomena in the Standard Model and beyond, including flavor and electroweak physics, and aspects of astroparticle physics and cosmology. A special focus is on mathematical frameworks such as quantum field theories, effective field theories, symmetries, scattering amplitudes, and their phenomenological implications.
Learning goals	Students will develop a solid working knowledge of modern theoretical particle physics tools and learn to apply them to various Standard Model (SM) and beyond SM phenomena.
Teaching methods	Blackboard lectures
Course on transversal, interdisciplinary, transdisciplinary skills	☐ Yes ☒ No
Available for PhD students from other courses	☐ Yes ☒ No
Examination methods	Oral exam and/or written assignment
Suggested readings	Announced at the start of the course

Additional information None

Course unit English denomination	**INFORMATION LITERACY & OPEN SCIENCE FOR PHYSICS AND ASTRONOMY PHD STUDENTS**
SS	
Teacher in charge (if defined)	Barbara Serino
Teaching Hours	12
Number of ECTS credits allocated	3
Course period	First semester
Course delivery method	☒ In presence ☐ Remotely ☐ Blended
Language of instruction	English
Mandatory attendance	☒ Yes (80% minimum of presence) ☐ No
Course unit contents	**Module 1: Research in the library** ● Learn research strategies to get the best results ● Use GalileoDiscovery, the Library system discovery service to search for books, articles, journals and many other resources ● Learn the search techniques implemented by databases, to access relevant academic articles ● Browse the web to find academic content **Module 2: Mindful citation: understanding copyright in Academia** ● Foundations of intellectual property law ● Citations and plagiarism ● Non-Textual elements: ethical use of images, tables and graphs ● Reuse in various contexts (scientific publications, conferences, educational settings) **Module 3: Scholarly communication** ● Scholarly communication and publication cycle ● Types of publication ● The functions of scientific journals ● How to choose the journal (journal/article-level metrics, researcher metrics, CC licenses, OA colours: green, gold & hybrid, diamond) ● Publication process (article versions, peer review) ● How to identify a predatory publisher

	Module 4: Open Science and institutional repositories at the University of Padova ● Open access mandates to scientific publications and research data ● Repositories; UniPd institutional archive of the scientific production: Padua Research Archive (IRIS) ● The management of research data (DMP, FAIR principles, Research Data Unipd) ● Facilitations for authors (read & publish agreements) ● UniPd Library System services for authors
Learning goals	- Develop advanced research skills using library resources, databases, and web-based academic content. - Understand intellectual property law, citation practices, and ethical use of content in academic contexts. - Comprehend the scholarly communication cycle, including publication types, journal selection, and the peer review process. - Gain knowledge of Open Access models, Creative Commons licenses, and strategies to identify predatory publishers. - Learn about Open Science principles, including Open Access mandates and FAIR data management practices. - Master the use of institutional repositories and discover University of Padova's specific tools and services for researchers. - Develop skills in research data management, including creating Data Management Plans and applying FAIR principles. - Discover author facilitations and services provided by the University of Padova Library System.
Teaching methods	The course employs a blend of traditional and interactive teaching approaches. Lectures provide traditional classroom instruction to deliver core content and concepts. Interactive sessions utilize digital tools like Wooclap to enhance student engagement and real-time participation.
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	Aczel, Balazs, et al. “The present and future of peer review: Ideas, interventions, and evidence”, Proceedings of the National Academy of Sciences 122.5 (2025): e2401232121. https://doi.org/10.1073/pnas.2401232121

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Additional information