UNIVERSITÀ degli STUDI di NAPOLI «Federico II»

DOTTORATO di RICERCA in FISICA – PhD program in Physics

- Physics PhD course catalog –

36th cycle, and till active cycles

(last updated on February 17th, 2021)

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- **Flavour Physics** *(Giulia Ricciardi)*
- **Fundamental interaction: QCD and BSM**

- **Perturbative QCD** *(Francesco Tramontano)*
- **Teoria di Regge** *(Giovanni Chirilli)*
- **BSM** *(Fulvia De Fazio)*

- **Fuzzy models and approximate reasoning in data** *(Ferdinando Di Martino)*
- **Gamma-Ray Astrophysics** *(Carla Aramo)*
- **Gamma Ray Bursts** *(Tristano Di Girolamo, Gianfranca De Rosa, Fabio Garufi, Maurizio Paolillo, Ester Piedipalumbo, Pietro Santorelli)*
- **Geometric and Topological methods in Theoretical Physics** *(Patrizia Vitale)*
- **Heavy Meson Physics** *(Pietro Santorelli)*
- **How to boost your PhD** *(Antigone Marino)*
- **Introduction to Inverse Problems** *(Antonio Emolo)*
- **Introduction to Neutrino Physics** *(Giulia Ricciardi)*
- **Introduction to QCD** *(Francesco Tramontano)*
- **Introduction to Ultra-high energy cosmic rays** *(Fausto Guarino)*
- **Mathematical aspects of gauge theories** *(Patrizia Vitale)*
- **Nuclear Physics for Astrophysics** *(Andreas Best, Gianluca Imbriani, Antonino Di Leva)*
- **Ordered phases of Condensed Matter** *(Arturo Tagliacozzo)*
- **Organic conductors** *(Antonio Cassinese)*
- **Particle Detectors – Trigger DAQ**
  - **Particle detectors** *(Margherita Primavera)*
  - **Photodetection** *(Elisabetta Bissaldi)*
  - **Trigger and DAQ for Particle Physics** *(Massimo Della Pietra)*
- **Physics and applications of Superconducting and Spintronic Devices** *(Giampiero Pepe)*
- **Physics of Plasmas and Particle Beams in Laboratory and Space** *(Renato Fedele)*
- **Quantum Communication** *(Alberto Porzio)*
- **Quantum Computing and Artificial Intelligence** *(Giovanni Acampora)*
- **Quantum Information, Quantum Computation and Quantum Imaging**
  - **Physical Coherence and Correlation Functions** *(Saverio Pascazio)*
  - **Introduction to Quantum Computation** *(Luigi Martina)*
  - **Quantum imaging** *(Milena D'Angelo)*
- **Quantum Technologies: Principles and Engineering** *(Francesco Tafuri)*
- **Radiation biophysics of charged particle exposure** *(Lorenzo Manti)*
- **Scientific writing** *(Paolo Russo)*
- **Signals formation and treatment in particle detectors**
  - **Signal formation** *(Massimo Abbrescia)*
  - **Signals treatment** *(Alberto Aloisio)*
- **Statistical Mechanics of Complex Systems** *(Antonio De Candia)*
- **Statistical Methods for Data Analysis** *(Alberto Orso Maria Iorio)*
- **String Theory** *(Wolfgang Mueck)*
- **Strings and branes** *(Franco Pezzella)*
- **Strong interactions** *(Giulia Ricciardi)*
- **Supersymmetries and dualities in various dimensions** *(Raffaele Marotta)*

- **Theoretical Astroparticle Physics** *(Ofelia Pisanti)*
- **Theory of Nuclear Matter** *(Luigi Coraggio)*
- **Topics in Non-Perturbative Quantum Field Theory (from two to four dimensions)** *(Luigi Rosa)*
- **Topics in Non-Perturbative Quantum Field Theory (Gauge Theories)** *(Luigi Rosa)*
- **Trigger and Data Acquisition for High Energy Physics Experiments** *(Massimo Della Pietra)*
- **Ultrafast processes and femtosecond laser pulses** *(Andrea Rubano)*
- **Waves and Interactions in Nonlinear Media** *(Renato Fedele)*

Important note: normally, each listed course will be actually "activated" in a given year only if at least two graduate students, even of different classes or different PhD programs, choose to attend it. If only one student is interested, then the course can be often transformed into a "supervised reading" option (see the PhD educational program for details about this option).

Advanced Spectroscopies in strongly correlated systems	
Lecturer	**Dr. Gabriella Maria De Luca** (gabriellamaria.deluca@unina.it)
Credits (planned):	4/5
Planned hours:	24 12 lectures, 2 hours each
Planned schedule:	October / November 2021
Prerequisites:	None. One or two lessons (depending on the students background) will be dedicated to the few needed concepts of solid state physics.
Description:	The aim of this course is to give an outline of the characteristic of the most important spectroscopy's techniques and to provide to the PhD student the necessary basis to plan or to develop its own spectroscopy experiment using synchrotron light and/or scanning probe microscopy. Advanced spectroscopies are the most powerful experimental tools to investigate the electronic and magnetic properties of complex materials. These techniques are based on the study of the interaction of the matter with radiation, being typically X-rays or electrons. Modern X-rays spectroscopy's takes advantages from the high brilliance third generation synchrotron sources. These techniques can achieve high momentum and energy resolution, but are typically unable to get spatially resolved information. Scanning tunneling microscopy's/Spectroscopy's are on the other hand based on the extremely high spatial resolution achieved by probing the tunneling electronic current coming from a tip in close proximity with a sample. These combined techniques can probably offer the largest possible number of information about the electronic properties of the solids. Examples of application of these techniques to different undisclosed issues in condensed matter physics will be given during the course, like the microscopic mechanism of superconductivity in the High Critical Temperature Superconductors and Novel oxides Interfaces, Proximity effect in Ferromagnetic/Superconducting heterostructures and Multiferroicity (coexistence of more of two ferroic orders). The detailed program will include: 1) Introduction to the Physics of complex, strongly correlated materials 2) Electrons and X-rays as probes of the electronic density of states 3) Introduction to the synchrotron light a. X-ray Absorption and X-ray Photoemission Spectroscopies b. Examples: HTS and other metal transition oxides c. Resonant Inelastic X-ray Scattering d. Angle resolved Photoemission Spectroscopy

Advanced Topics in Theoretical Physics	
Lecturer	**Prof. Fedele Lizzi** (fedele.lizzi@unina.it)
Credits (planned)	4-6 (to be agreed with the students)
Planned hours	24-36
Planned schedule	Tbd in a period between January – July 2021
Prerequisites	usual courses of a physics's master degree
Description	The course will be a must for theoretical physics students, but can be also useful for the other students. Its main aim is to cover important topics, which should be in the baggage of every theoretical physicist, but are not necessarily covered in the usual core study. Some lectures may be held by other researchers to offer a broader perspective. In case only some students require covering some parts, a portion of the course can be individual study. The topics to be covered will be discussed and agreed with the participants, an indicative list is the following: Topological solitons: Kinks, defects, monopoles, Skyrmions …) Nonlinear evolution equations and dynamical solitons (Sine Gordon, solutions of the Burger, Sine-Gorgon, Kortweg de Vires equations…) Caotic Systems: (logistic equation, Lorenz equation, strange attractors). Renormalization The theory of groups and Lie algebras (including quantum groups) Advanced method in quantum field theory (heath kernel expansion, spacetime approach to qft…) Phase transitions in quantum field theory. Quantum mechanics and measurement (Bell's Theorem…) Approaches to quantum spacetime (noncommutative geometry…)

A general overview of the Physics of Surfaces and Interfaces	
Lecturer	**Dr. Roberto Di Capua** roberto.dicapua@unina.it
Credits (planned)	6
Planned hours	36 hours (18 lectures, 2 hours each)
Planned schedule	the detailed schedule can be arranged with students (it can be organized in order to meet the specific demands) March – July 2021
Prerequisites	Basic knowledge of classical general physics and quantum mechanics. One or two lectures will be devoted to the few needed basic concepts of solid-state physics.
Description	The course aims to provide the foundation of physics of surfaces and interfaces. It is conceived to be of potential interest not only for Ph.D. students working in the physics of matter, but also for those involved in other fields, due to the development of fundamental issues and methodologies of wide application. The lectures are intended as an ideal prosecution of the general concepts provided by the master degree in physics on quantum mechanics, atomic-scale and many-bodies physics, structure of matter, interaction between matter and radiation: such concepts will be developed and applied to the study of solid surfaces and interfaces, a subject which is gaining more and more importance in Physics and in many other fields. One or two lectures, depending on the background of the students, will be devoted to the introduction of the few basic concepts of solid-state physics needed for the understanding of some arguments. Then, the main body of the course will be organized along the following three lines. 1) Illustration of basic phenomenological and theoretical aspects of the physics of surfaces: electronic states, charge distribution at surfaces and interfaces, the importance of strain and defects, thermodynamic aspects of the equilibrium, role of collective excitations and related states and interactions. 2) Interface phenomena: arising of new functionalities and properties at interfaces between different materials, interplay between electronic, magnetic and crystal properties, applications and perspectives of nanotechnology and engineering at atomic-scale, illustration of some current research results in this field. 3) Description of the main experimental techniques, and underlying physics, for probing and measuring the properties of surfaces and interfaces: atomic force microscopy and related techniques, scanning tunnelling microscopy and spectroscopy, diffraction analysis, photoemission spectroscopy techniques, synchrotron-based techniques.

An introduction to the Physics of Nanostructures: phenomenology, applications and theoretical aspects

Lecturer	**Dr. Giovanni Cantele** (CNR-SPIN, giovanni.cantele@spin.cnr.it)
Credits (planned):	4
Planned hours:	24
Planned schedule:	June – July 2021
Prerequisites:	Basic knowledge of quantum mechanics. One or two lessons (depending on the students background) will be dedicated to the few needed basic concepts of solid-state physics.
Description:	This course aims to give an overview of the basic properties and applications of nanostructured materials. The course can be schematically divided into two parts. The first part focuses on the most recent achievements of nanotechnology and related phenomenology. The main observed phenomena occurring at the nanoscale (electronic, optical and transport properties) are described, with a focus on applications (optoelectronics, single electron transistors, self-powered devices, nanomedicine and many others). Also, a short history of nanotechnology and its development is presented. The second part is focused on the interpretation and understanding of the observed properties in terms of basic concepts, such as electron and hole quantum confinement, effects induced by the system size and dimensionality, and so on. The main theoretical models needed to describe the optical, electronic and transport properties in nanostructured materials will be analysed. The starting point will be recent seminal experiments showing the ability of controlling and tuning the materials structure and electronic properties with atomic resolution (truly onedimensional metallic wires, two-dimensional systems and graphene, single-electron transport, etc.). **Course outline** Introduction • nanotechnology and its connection with microelectronics • synthesis techniques (very short overview) • new instruments and spectroscopies: STM and AFM • applications (special topics: nanopiezotronics, nanomedicine, nanoplasmonics) Nanostructures: from zero- to two-dimensional systems • atomic nanoclusters: physical and structural properties • quantum dots or nanocrystals: electronic properties and devices (quantum dot lasers, single-electron transistor) • nanostructured carbon: nanotubes, fullerenes, graphene Optical and electronic properties • nanocrystals, nanowires, quantum wells • elementary excitations in solids • the quantum confinement and its effects on the optical properties • transport in nanostructures The students can give indication for topics of their interest that could be part of the program of the course. Please refer to the course web page for more information: http://people.na.infn.it/~cantele/index.php?n=Teach.Nano

Artificial Intelligence and Machine Learning	
First module	**Machine Learning: basics and applications**
Lecturers	**Giorgio De Nunzio** and **Giuseppe Palma** (Università del Salento)
Credits (planned)	tbd
Planned hours	10
Planned schedule	5 lessons / 2 hrs lesson
Prerequisites	
Description	- ML taxonomy: supervised, reinforcement, unsupervised; - Regression: linear regression, GLM - Classification: scores (confusion matrix and related measures; ROC curve; calibration; cross entropy, Brier score), class imbalance; - Bias-Variance tradeoff: underfitting, overfitting. - Perceptrons and Shallow Feed-Forward Neural Networks - Regression and Classification in Matlab+Toolboxes - Applications of regression and classification: case studies in Physics and Medicine with synthetic and public access data (Matlab) - Applications of regression and classification: case studies in Physics and Medicine with synthetic and public access data (Matlab)

Second module	**Approximate reasoning and evolutionary computation**
Lecturers	**Giovanni Acampora** **Ferdinando Di Martino** **Autilia Vitiello** (Università di Napoli)
Credits (planned)	tbd
Planned hours	10
Planned schedule	5 lessons
Prerequisites	

Description	• **Introduction** (1 hour) Prof. Giovanni Acampora • **Approximate reasoning** (5 hours) Prof. Ferdinando Di Martino Lecture 1 Fuzzy sets and fuzzy relations. Fuzzy operators: t-norm, s-norm, residuum. Fuzzy membership functions and fuzzy numbers. The extension principle. Fuzzy partitions and Linguistic variables. Lecture 2 Fuzzy inference systems: fuzzy rule set inference systems. Mamdani fuzzy inference model. Tagaki-Sugeno- Fuzzy inference model. Type2 fuzzy sets: intervsl type2 fuzzy sets. Interval type2 fuzzy systems. • **Evolutionary computation** (4 hours) Prof. Autilia Vitiello Lecture 1: Introduction to the Evolutionary Computation and its motivations. The main scheme of an Evolutionary algorithm. Lecture 2: Different evolutionary algorithms: Genetic Algorithms, Differential Evolution and Particle Swarm Optimization. Design issues for evolutionary algorithms: parameter tuning and performance measures.

Third module	**Causality analysis of time series data**
Lecturers	**Sebastiano Stramaglia** (Università di Bari)
Credits (planned)	tbd
Planned hours	10
Planned schedule	5 lessons
Prerequisites	
Description	Lecture 1: Complex Networks. Small world networks: Watts-Strogatz model. Scale free networks: Albert-Barabasi model. Communities in complex networks. Applications. Lecture 2: The problem of inference of Complex Networks from multivariate time series data. Time Series. Stationarity. Linear correlations and the power spectrum. Cross-correlation and coherence between time series. Prediction. Applications.

	Lecture 3: Introduction to Information Theory. Shannon's Entropy. Mutual Information. Maximum Entropy methods. Transfer Entropy. Applications. Lecture 4: Vector autoregressive models. Granger causality and its relation with transfer entropy. Applications. Lecture 5: Decomposition of Granger causality in frequency and time. Higher order dynamical networks. Synergy and redundancy. Applications.

Astroinformatics	
Lecturer	**Dr. Massimo Brescia** (Oss. Astronomico di Capodimonte) (brescia@na.astro.it)
Credits (planned)	8
Planned hours	64
Planned schedule	**6 hours/week Febr – March – April 2021** ***course offered in the frame of the Master's programme***
Prerequisites	
Description	The Course aims at providing the fundamental concepts at the base of the theory of data mining, data warehousing and machine learning (neural networks, fuzzy logic, genetic algorithms, soft computing), approached by the point of view of Astrophysics and Information Communication Technology. During the course some practical experiences with students are foreseen: from data handling, to software design and development, statistical analysis, investigation on diagrams and tables (trend analysis, plotting, data quality). In specific cases students are allowed and invited to investigate in-depth topics and to discuss during lectures.

Black Holes	
Lecturers	**Proff. Mariafelicia De Laurentis** (mariafelicia.delaurentis@na.infn.it) **Tristano Di Girolamo** (tristano.digirolamo@unina.it) **Maurizio Paolillo** (maurizio.paolillo@unina.it)
Credits (planned)	3
Planned hours	12 lectures, 2 hours each
Planned schedule	tbd
Prerequisites	
Description	This class is intended to offer to the students a boad view of Black Holess, from the theoretical aspects of gravitational physics, through the observational evidences of their properties, all the way to their astrophysical and cosmological manifestations. **Part I**: Gravitation, Relativity and Black Holes *(Mariafelicia De Laurentis)* Rotating black holes: Kerr black holes, Kerr black hole in Boyerè Lindquist coordinates, Uniqueness of the Kerr solution, Global Properties of the Kerr metric, On the conformal structure of the Kerr solution. The four laws of black hole evolution, Surface gravity and angular velocity of the horizon, First law of black hole dynamics, Rotational Energy of Astrophysical Black Holes, Time-Evolution of black holes Quasi-stationary evolution of accreting black holes, Merging of black holes, The first “image” of a Black Hole with the Event Horizon Telescope **Part II**: Gravitational Waves and Gamma Ray Bursts *(Tristano di Girolamo)* Gravitational waves (GWs). Black holes as sources of GWs. Detection of GWs. Observations of GWs from black holes. Gamma Ray Bursts (GRBs): observations and theoretical interpretation. GRB progenitors. Black holes as centrale engines and final products of GRBs. **Part III**: Physics and evolution of supermassive Black Holes in the Universe *(Maurizio Paolillo)* The Discovery of Active Galactic Nuclei; Taxonomy of AGNs; clues to the interpretation: variability, luminosity and efficiency; steps toward unification: Eddington luminosity, Eddington mass and accretion rate; accretion efficiency. The Unified Model; AGN physical scales; broadband emission in AGNs; accretion disk spectrum; X-ray corona and other components. Observational evidence of the Unified Model: Quasar host galaxies;dynamical mass measurements; circumnuclear disks, dusty nuclear disks; reverberation mapping mass measurements; evidence of hidden BLR in Sy2; relativistic distortion in Fe lines; the Milky Way nuclear BH. AGN evolution from multi-wavelength studies of AGN populations optical, X-ray and infrared; luminosity function and number counts; AGN activity and number density evolution; resolving the Cosmic X-ray Background; Soltan argument: how to derive the current Black Hole mass density of the Universe; The link between Supermassive Black Holes and galaxy evolution; Evidences of AGN feedback in galaxies.

Charged Particle Accelerators	
Lecturer	**Dr. Luigi Campajola** (luigi.campajola@unina.it) Physics Department, University of Naples *Federico II*
Credits (planned)	5
Course objectives	The course provides an introduction to the physical principles used to accelerate charged particles and on the various techniques used in accelerator physics. This course also provides information on the main applications in fundamental physics and applied physics. Some experiments will be carried out in the laboratory with ion beams.
Tentative schedule	February – April 2021
Planned hours	Frontal lectures: 16 h total, 2h/lecture, to be held at the Physics Department at MSA. Laboratory: 10 h
Contents and topics	1. Fundamental principles of particle acceleration 2. Ion sources: operating principles and applications 3. Principles of operation of the accelerators: linear and circular, pulsed and continuous 4. Elements of beam dynamics and magnetic optics: emittance and brightness 5. Applications in the field of innovative technologies: • Ion beam analysis: Rutherford Backscattering (RBS), Particle Induced X-ray Emission (PIXE) • Accelerator Mass Spectrometry (AMS) • Ion implantation • Radioisotopes production
Final evaluation	The students will be required to make an oral presentation on a selected subject.

Cognitive Robotics and Artificial Intelligence	
Lecturer	**Mariacarla Staffa** mariacarla.staffa@unina.it
Credits (planned)	3
Planned hours	18
Planned schedule	Between June – September 2021 (preferably June)
Prerequisites	Foundations of Computer Science and Programming
Description	The course addresses the emerging field of autonomous systems possessing artificial cognitive skills (autonomous navigation, automatic learning and reasoning, behaviour adaptation etc.). Successfully-applied algorithms and autonomy models form the basis for study, and provide students an opportunity to design such a system as part of practical lessons. Theory and application are linked through discussion of real systems such as the Pepper and NAO humanoid robot, pioneer3DX and turtlebot mobile robots, etc..

Di GirolamoMulti-messenger and particle astrophysics of compact objects

Module 1	Compact objects
Lecturer	Francesco De Paolis (Università del Salento)
Planned hour	6 h
Planned schedule	Spring-Fall 2021
Prerequisites	Basic Astrophysics
Description	• Last stages of stellar evolution and formation of the compact objects • Phenomenological properties of neutron stars and pulsars Selected recent topics on the physics of the compact objects
Recommended texts	• Slides of the lecturer and texts suggested during the lectures
Assessment methods	Short essay on one of the topics developed during the lectures

Module 2	Neutrino Oscillations
Lecturer	Daniele Montanino (Università del Salento)
Planned hour	6-8h
Planned schedule	Spring-Fall 2021
Prerequisites	Particle physics
Description	• Introduction to the neutrino masses, mixing and oscillations in vacuum and matter • Phenomenology of neutrino oscillations from terrestrial experiments and astrophysical sources, in particular solar neutrinos
Recommended texts	• Giunti, Kim, “Fundamentals of neutrino Physics and Astrophysics” (Oxford University Press, 2007) • Slides of the lecturer
Assessment methods	Short essay on one of the topics developed during the lectures

Module 3	Supernova neutrinos
Lecturer	Alessandro Mirizzi (Università di Bari)
Planned hour	6
Planned schedule	Spring-Fall 2021
Prerequisites	Particle physics
Description	• Supernova (SN) explosion mechanism • SN 1987A neutrino observation • Future SN neutrino observations • Neutrino oscillations in dense SN medium
Recommended texts	• G. Raffelt, “Stars as Laboratories for Fundamental Physics” (University of Chicago Press, 1996) • Slides of the lectures
Assessment methods	Short essay on one of the topics developed during the lectures

Module 4	Gravitation, Relativity and Black Holes
Lecturer	Mariafelicia De Laurentis (Università di Napoli)
Planned hour	6-8
Planned schedule	Spring-Fall 2021
Prerequisites	analytical mechanics, general relativity
Description	Rotating black holes: Kerr Spacetime and its global properties. Kerr black hole in Boyer-Lindquist coordinates. Zero-mass limit. Kerr-Schild form of the Kerr solution. Ergosphere and Horizon (Infinite redshift surface, Surface gravity, Surface geometry of horizon and ergo surface) Particle and Light

	Motion in Equatorial Plane. Matter accretion and black hole parameters change. Evolution in the black hole parameter space. Geodesics in Kerr Spacetime: General Case. Light Propagation. Black hole shadow. Generic properties of the rotating black hole shadows (Asymmetry, Flattening etc..). Image of Black Holes with the Event Horizon Telescope.
Recommended texts	Slides of the lectures
Assessment methods	Short essay on one of the topics developed during the lectures

Module 5	**Physics and evolution of supermassive Black Holes**
Lecturer	Maurizio Paolillo (Università di Napoli)
Planned hour	6-8
Planned schedule	Spring-Fall 2021
Prerequisites	Basic classical physics and gravitation. Useful but not required: Module “**Gravitation, Relativity and Black Holes**”, Introductory astrophysics, Physics of Galaxies
Description	The Discovery of Active Galactic Nuclei; Taxonomy of AGNs; clues to the interpretation: variability, luminosity and efficiency; steps toward unification: Eddington luminosity, Eddington mass and accretion rate; accretion efficiency. The Unified Model; AGN physical scales; broadband emission in AGNs; accretion disk spectrum; X-ray corona and other components. Observational evidence of the Unified Model: Quasar host galaxies; dynamical and reverberation mapping mass measurements; evidence of hidden BLR in Sy2; relativistic distortion in Fe lines; the Milky Way nuclear BH. AGN evolution from multi-wavelength studies of AGN populations optical, X-ray and infrared; luminosity function and number counts; AGN activity and number density evolution; resolving the Cosmic X-ray Background; Soltan argument: how to derive the current Black Hole mass density of the Universe; The link between Supermassive Black Holes and galaxy evolution; Evidences of AGN feedback in galaxies.
Recommended texts	Lecture slides; “Exploring the X-ray Universe”, Seward & Charles,2010)
Assessment methods	Short essay on one of the topics developed during the lectures

Module 6	**Gravitational waves and Gamma-Ray Bursts**
Lecturer	Tristano Di Girolamo (Università di Napoli)
Planned hour	6-8
Planned schedule	Spring-Fall 2021
Prerequisites	Basic astrophysics and particle physics
Description	Generation of Gravitational Waves (GWs). Binary Black Holes (BBHs) as sources of GWs. Detection of GWs. Observations of GWs from BBHs. Gamma Ray Bursts (GRBs): observations and theoretical models. GRB progenitors. Black holes as central engines and final products of GRBs.
Recommended texts	Shapiro & Teukolsky, “Black Holes, White Dwarfs and Neutron Stars”
Assessment methods	Short essay on one of the topics developed during the lectures

Effective theories and flavour physics	
Lecturer	**Dr. Giancarlo D'Ambrosio** gdambros@na.infn.it
Credits (planned)	5
Planned hours	24
Planned schedule	March 2021
Prerequisites	
Description	Cross sections, decay widths, calculation of Feynman diagrams Quantum electrodynamics, precision tests: Lamb shift and g-2 Gauge theories, Yang Mills Fermi theory, beta decay, muon decay, universality of weak interactions, parity violation in weak interactions, V-A structures, effective theories Phenomenology of strong interactions, Goldstone theorem, pion as Goldstone mode spontaneous and explicit symmetry breaking Higgs mechanism Standard model of particle physics Flavour theory, quark and meson mixing, Cabibbo Kobayashi Maskawa matrix and determination of matrix elements, absence of flavor changing neutral currents, GIM mechanism and minimal flavor violation (MFV) Effective field theories, chiral perturbation theory

Electrodynamic properties of novel materials and devices	
Lecturers	**Prof. Antonello Andreone** (antonello.andreone@unina.it)
Affiliation	Physics Department, University of Naples *Federico II*
Course objectives	This is an introductory course to the electromagnetic properties of special materials, like superconductors, magnetic and dielectric materials, and artificial materials (photonic crystals and metamaterials) for operation in a wide frequency range, from microwaves up to the optical region. Applications include: telecommunication systems, microwave photonics, imaging, sensing and security
Tentative schedule	Autumn/Winter 2021
General information	8 lectures, 2 hours each, to be held at the Department of Physics, Engineering Faculty, Piazzale Tecchio 80
Contents and topics	- Electrodynamics of metals, superconductors and dielectric media: basic principles - A short introduction to artificial materials: metamaterials and photonic band gap crystals and quasicrystals - Transformation optics: a new approach to defining the light geometry using metamaterials - Cutting edge THz technology - Plasmonics and plasmonic structures - Some exemplary applications of "natural" and "artificial" materials: from microwave systems to optical devices and sensors, cloaking, solar cells
Evaluation	All participants are required to make an oral presentation or write an essay on a selected subject after the course. The participants may suggest a topic related to their own research subject.
Course weight	**4 FCs**

Emergence of complexity in plankton communities	
Lecturers	**Dr. Annalisa Fierro**[1] (annalisa.fierro@spin.cnr.it) **Dr. Daniele Iudicone**[2] (iudicone@szn.it) **Dr. Antonella Liccardo**[3] (liccardo@na.infn.it) **Prof. Maurizio Ribera d'Alcalà**[2] (maurizio@szn.it) **Dr. Bruno Hay Mele**[4] (bruno.haymele@unicampania.it)
Affiliation	[1]CNR-SPIN [2]Stazione Zoologica A. Dohrn [3]Physics Department, University of Naples Federico II [4] Dip Sci e Tecn Ambientali, Univ. della Campania L. Vanvitelli
Credits (planned)	3
Planned hours	18 h (9 lectures of 2 h)
Planned schedule	to be fixed together with the students, Jan. / Febr 2021
Prerequisites	None
Description	The dynamics of complex systems, i.e., the dynamics of multi-agent systems with multiple and non linear interactions, is still a frontier topic in science. Post-graduate courses dealing with the topic are often structured to provide an overview of the theoretical framework and demonstrate how it works for various typical case studies. In this course we propose to follow an alternative approach focusing on one specific case study. That is, we intend to describe the patterns, known interactions and processes acting in a crucial natural complex system: the plankton community. Building on this background, we formulate the key questions yet to be tackled within the framework of the theory and dynamics of complex systems. Plankton is the ensemble of organisms, mostly microscopic, which make the largest part of the biomass in the ocean. Even though some may have the ability to swim, the corresponding swimming velocity is much lower than the velocity of oceanic currents, therefore making plankton exposed to water motion. The role of plankton is crucial in several biogeochemical cycles including the carbon cycle, They are abundant, though in a size dependent manner, with the very small ones (order of 10^-6 m) found in concentration of 10^6 m^-3 and the larger ones reaching concentrations of 10^3 m^-3. In a cubic meter of marine water, which can be considered to a large extent homogeneous, live millions of 'agents' displaying also a high specific diversity. All these interact quite frequently and generate resilient food webs despite the dispersion due to fluid motion at small scale and the displacement by the currents at large scales. Recent studies have shown that composition of species in plankton communities varies over space across the oceans while displaying repetitive patterns over time in the same regions. These studies also shed light on a multiplicity of interactions among the 'agents' spanning the whole suite of biotic interactions and feeding behaviors.

	Plankton community is therefore a very challenging system to analyze and is characterized as multi agent systems with complex dynamics and emergent properties. This course is thus an opportunity to understand and use the typical tools of complex system dynamics in the context of Plankton dynamics. The course will devote a first part to describe the key processes in plankton communities and the methods to characterize them. We'll then provide an overview of the most important aspects of fluid motion that affect plankton ecology, from micro-turbulence to the large scale currents, as well as the mechanisms by which plankton access to their resources, from chemical diffusion to stochastic or directed encounter rates. Basic mechanistic models to reconstruct the processes above will also be described. The last part of the course will be devoted to the development of an integrated approach on a real, though simplified system, with a continuous feedback between theoretical modeling and experiments in the experimental setup. References [1] Souissi, S., Ginot, V., Seuront, L., & Uye, S. I. (2004). Using multi-agent systems to develop individual based models for copepods: consequences of individual behaviour and spatial heterogeneity on the emerging properties at the population scale. *Handbook of scaling methods in aquatic ecology: measurement, analysis, simulation. CRC Press, Boca Raton*, 527-546. [2] Medvinsky, Alexander B., Tikhonov, Dmitry A., Enderlein, Jorg, Malchow, Horst (2000) Fish and Plankton Interplay Determines Both Plankton Spatio-Temporal Pattern Formation and Fish School Walks: A Theoretical Study. Nonlinear Dynamics, Psychology, and Life Sciences, 4: 135–152. [3] Parrish, J. K., & Edelstein-Keshet, L. (1999). Complexity, pattern, and evolutionary trade-offs in animal aggregation. *Science*, *284*(5411), 99-101. [4] Benincà, E., Huisman, J., Heerkloss, R., Jöhnk, K. D., Branco, P., Van Nes, E. H., ... & Ellner, S. P. (2008). Chaos in a long-term experiment with a plankton community. *Nature*, *451*(7180), 822-825. [5] Roques, L., & Chekroun, M. D. (2011). Probing chaos and biodiversity in a simple competition model. *Ecological Complexity*, *8*(1), 98-104. [6] Jumars, P. A. (1993). *Concepts in biological oceanography*. Oxford University Press. [7] Kiørboe, T. (2008). *A mechanistic approach to plankton ecology*. Princeton University Press.

Evolutionary Computation and Applications	
Lecturer	**Autilia Vitiello** autilia.vitiello@unina.it
Credits (planned)	3/4
Planned hours	20 hours (10 lectures of 2h)
Planned schedule	September 2021
Prerequisites	Basic concepts of computer science
Description	Evolutionary computation is a subfield of the computational intelligence which includes a group of problem-solving techniques whose basic principles rely on the theory of biological evolution. Evolutionary computation methods are characterized by high performance in a wide range of problem settings. The goal of the course is to give an overview of the best known evolutionary algorithms and show practical application examples in the scientific and engineering fields.

Extended theories of Gravity and the problem of Dark Energy and Dark Matter	
Lecturer:	**Prof. Salvatore Capozziello** (University of Naples, capozziello@na.infn.it)
Credits (planned):	2
Planned hours:	12
Planned schedule:	April / May 2021
Prerequisites:	General Relativity, Cosmology, Quantum Field Theory
Description:	**Abstract:** Extended theories of gravity can be related to several unification approaches and fundamental theories of interactions. They have recently attracted a lot of interest as alternative candidates to explain the observed cosmic acceleration, the flatness of the rotation curves of spiral galaxies, the gravitational potential of galaxy clusters, and other relevant astrophysical phenomena. Very likely, what we call "dark matter" and "dark energy" are nothing else but signals of the breakdown of General Relativity at large scales. Furthermore, PPN-parameters deduced from Solar System experiments do not exclude, a priori, the possibility that such theories could give small observable effects also at these scales. I review these results giving the basic ingredients of such an approach. **Topics:** 1. Observational cosmology: an overview 2. Dark Energy and dark Matter from the observations 3. Physical and Mathematical Foundations of Extended Theories of Gravity 4. Dark Energy and Dark Matter as Curvature Effects 5. Probing Extended Theories of Gravity at Fundamental Level 6. Advanced issues: GRBs to discriminate among Cosmological Models **References:** S. Capozziello, V. Faraoni "*Beyond Einstein Gravity*" Fundamental Theories of Physics, Springer, Dordrecht 2010

Flavour Physics	
Lecturer	**Prof.ssa Giulia Ricciardi** (University of Napoli Federico II, giulia.ricciardi2@unina.it)
Credits (planned)	4-6
Planned hours	24-36
Planned schedule	Autumn / Winter 2021
Prerequisites	basics of particle physics
Description	Flavour physics, in contrast to 'gauge physics', addresses questions such as why there are so many different species (flavours) of quarks and leptons, why they come in groups (families), why they have their masses, what their couplings are, etc. Recently, the dedicated study of b-flavoured hadrons has developed into one of the most active and promising areas of high-energy physics. Neutrino physics and oscillations are also discussed, in their theoretical aspects and in connection with recent experimental advances. <u>Topics</u>: 1. Introduction to flavour physics. The standard Model and the CKM matrix 2. What are and how to reveal discrete symmetries: C, P, T 3. CP violation in neutral meson systems 4. The Standard analysis of the Unitarity triangle(s) 5. Effective field theories and related theoretical tools 6. Heavy Quark Effective Theory: a short exposition 7. Applications to B systems, present status of the field 8. Physics beyond the Standard Model 9. Neutrino physics and oscillations

Fundamental interaction: QCD and BSM

Module 1	**Perturbative QCD**
Lecturer	Francesco Tramontano (Università di Napoli)
Planned hours	12
Planned schedule	tbd 2 lectures per week two hours each
Prerequisites	Particle physics background
Description	The lectures introduce to some basic aspects and concepts of perturbative QCD: running coupling and asymptotic freedom, the parton model, infrared divergences and the factorization theorem, parton densities and parton evolution, colour coherence. Applications to e+e-annihilation, deep inelastic lepton-nucleon scattering and hadron-hadron collisions are discussed.

Module 2	**Teoria di Regge**
Lecturer	Giovanni Chirilli (Regensburg) ref. Claudio Corianò
Credits (planned)	xxx
Planned hours	10
Planned schedule	tbd
Prerequisites	Particle physics background
Description	Regge Theory; High parton density; small x evolution equations and Wilson lines formalism; Background field method; High-energy Operator Product Expansion; High-energy factorization for scattering amplitudes;

Module 3	**BSM**
Lecturer	Fulvia De Fazio (Università di Bari)
Planned hours	16
Planned schedule	Spring 2020
Prerequisites	Particle physics background
Description	Physics beyond the Standard Model - Reasons to go beyond the Standard Model - Models based on extended gauge groups - Models introducing extra dimensions - Aspects of supersymmetry - Extension of the effective hamiltonians in New Physics Models

Fuzzy models and approximate reasoning in data analysis	
Lecturer	**Dr. Ferdinando DI MARTINO** ferdinando.dimartino@unina.it
Credits (planned)	6
Planned hours	42
Planned schedule	March - July 2021 Modules: - Fuzzy sets and extension principle. Characteristic functions. Type of fuzzy sets. Fuzzy numbers. Examples. - Fuzzy relations. Triangular norm operators. Projections and Cylindrifications. Examples. - Fuzzy relation equations. Fuzzy relation equation systems Examples in physics. - Direct and Inverse Fuzzy transform Examples. - Fuzzy clustering concepts Fuzzy partitional clustering. Fuzzy C-means and its variations. Examples. - Approximate reasoning concepts. Linguistic variables and fuzzy rules. Fuzzification and defuzzification models. Generating fuzzy rules from numerical and categorical data. The Wang & Mendel model. Examples. - Fuzzy systems. Inference process. Mamdani and Takagi-Sugeno models. Examples - Type-2 fuzzy sets. The e footprint of uncertainty. Interval Type-2 fuzzy sets and their implementation. IT2 Fuzzy Systems. Type-reduction process. Examples.
Prerequisites	Set theory, Boolean logic, statistical treatment of observational data
Description	The course will deal with fuzzy set theory, fuzzy transform, approximate reasoning, fuzzy systems and its applications in physics. In physics it is often necessary to deal with vague or imprecise information for the analysis of experimental data. One type of imprecision is that managed in the statistics of experimental data through statistical inference approaches and uncertainties estimation. These approaches, however, have a not negligible computational complexity and are unsuitable for managing sets of vague and imprecise information which, on the other hand, constitute the knowledge base of human reasoning processes. Fuzzy set theory allows us to manage qualitative and fuzzy information in a formal and rigorous way in order to create models for data analysis and data mining and approximate reasoning frameworks through the use of inferential rules that translate and model human reasoning. This course initially introduces fuzzy set theory and then explores fuzzy-based methods and models of data analysis, data mining and approximate reasoning. Finally, the type-2 fuzzy sets and their implementation in the construction of intelligent systems will be treated. During the course various examples of fuzzy-based methods and techniques of data analysis applied to fields of physics will be made.

Gamma-ray Astrophysics	
Lecturer	**Dr. Carla Aramo** aramo@na.infn.it
Credits (planned)	2-3
Planned hours	14-16
Planned schedule	end of Febr. / March 2021
Prerequisites	None
Description	Following the discovery of the cosmic rays by Victor Hess in 1912, more than 70 years and numerous technological developments were needed before an unambiguous detection of the first very-high-energy gamma-ray source in 1989 was made. Since this discovery the field on very-high-energy gamma-ray astronomy experienced a true revolution: A second, then a third generation of instruments were built, observing the atmospheric cascades from the ground, either through the atmospheric Cherenkov light they comprise, or via the direct detection of the charged particles they carry. Present arrays, 100 times more sensitive than the pioneering experiments, have detected a large number of astrophysical sources of various types, thus opening a new window on the non-thermal Universe. New, even more sensitive instruments, are currently being built; these will allow us to explore further this fascinating domain. In this course will be described the detection techniques, the history of the field and the prospects for the future of ground-based very-high-energy gamma-ray astrophysics.

Gamma Ray Bursts	
Lecturers	**Dr. Tristano Di Girolamo** (tristano.digirolamo@na.infn.it), **Prof. Gianfranca De Rosa, Prof. Fabio Garufi, Prof. Maurizio Paolillo, Dr. Ester Piedipalumbo, Prof. Pietro Santorelli**
Credits (planned)	4
Planned hours	24
Planned schedule	March 2021
Prerequisites	Basic astrophysics and particle physics
Description	Gamma Ray Bursts (GRBs) are sudden, intense flashes of gamma-rays, detected mainly at keV-MeV energies. When they occur, for a few seconds they completely overwhelm any other gamma-ray source in the sky, including the Sun. The origin and mechanism of GRBs are of great interest. They appear to be connected with supernova explosions from massive stars or with mergers of compact objects (as in the case of GRB 170817A), and their huge brightness makes them temporarily detectable out to the largest distances yet explored in the Universe. After pioneering breakthroughs from space and ground experiments, the study of GRBs entered a new phase with observations from the Fermi satellite, as well as with the detection or upper limits from gravitational wave interferometers and neutrino telescopes. The interplay between such observations and theoretical models for GRBs is illustrated, together with their connections to supernovae, cosmology, gravitational radiation and astroparticle physics. Summary: ❖ Introduction ❖ The prompt gamma-ray emission ❖ The afterglow emission ❖ Fireball model and progenitors ❖ Gravitational waves from GRBs ❖ High energy neutrinos from GRBs ❖ Cosmology with GRBs

Geometric and topological methods in Theoretical Physics	
Lecturer	**Prof.ssa Patrizia Vitale** (patrizia.vitale@unina.it)
Credits (planned)	3
Planned hours	20
Planned schedule	Spring 2021
Prerequisites	Background in theoretical/mathematical physics
Description	Differential calculus on manifolds Topological invariants (homology, cohomology and homotopy groups) Lie groups and Lie algebras Riemannian geometry Fiber bundles

Heavy Meson Physics	
Lecturer:	**Prof. Pietro Santorelli** (Università di Napoli *Federico II*, pietro.santorelli@unina.it)
Credits (planned):	2-3
Planned hours:	14-16
Planned schedule:	half of June 2021 – December 2021
Prerequisites:	Basic concepts of Quantum Field Theory. Suitable for theorists and experimentalists
Description:	This course will provide an introduction to effective field theory of the QuantumChromoDynamics for heavy quarks and its application to weak decays of heavy mesons. The following arguments will be discussed: 1. A very short review of the Standard Model 2. Integrating out heavy particles, scale separation, radiative corrections 3. Heavy Quark Effective Theory 4. Semileptonic and rare decays of B mesons 5. Non-leptonic two body decays of B and D mesons 6. CP Violation

How to boost your PhD	
Lecturer	**Dr. Antigone Marino** (CNR–ISASI, antigone.marino@unina.it)
Credits (planned)	2
Planned hours	12
Planned schedule	January – February 2021
Prerequisites	none
Description	Nowadays, the scientific researcher profession requires a plurality of skills, on which we rarely stop to think about. Which ones are they? Above all, how to acquire them to turbo boost your PhD? The course is focused on this aspect of the scientific carriers. • Soft Skills - The technical skills of a person are the first ingredients for a successful career, but often the competition with others is played on other skills, which are more related to the character of the person. This does not mean owning them or not. A good training action will widen the spectrum of these skills as well as technical ones. • Scientific Communication – A large amount of researcher's work is now devoted to communication. Mostly through posters, slides, papers and reports. We will see what are the channels of communication and how to treat them properly. • Digital Reputation - Once upon a time, there was a file in every scientist's computer called curriculum dot something. Nowadays, this file is not enough to promote your career. Society is collecting all the information in the biggest database we have ever had, internet. The care of our digital records can be a fundamental key for our work. The digital reputation of a scientist is defined by his/her behaviour in the online environment and by the content he/she posts about him/her self and others. Tips to analyse and control your digital presence will be given. • Outreach - Political institutions are now asking us to bring our work to the attention of journalists, citizens and stakeholders. That is why outreach is playing an important role in scientific careers. Organizing a good outreach event needs a little bit of experience and a well-defined project. We will see which the conditions that make the outreach event effective are.

Introduction to Inverse Problems	
Lecturer	**Prof. Antonio Emolo** antonio.emolo@unina.it
Credits (planned)	2
Planned hours	12
Planned schedule	January – February 2021
Prerequisites	Familiarity with linear algebra, differential equations, probability and statistics, and calculus.
Description	The course aims at providing fundamental understanding of parameter estimation and inverse problem philosophy and methodology, specifically regarding such key issues as uncertainty, ill–posedness, regularization, bias, and resolution. Theoretical come with illustrative examples implemented numerically. Main topics covered in the course are: inverse problems characterization, L_2 and L_1 linear regression, Singular Value Decomposition, Tikhonov regularization, numerical optimization techniques.

Introduction to Neutrino Physics	
Lecturer	**Prof.ssa Giulia Ricciardi** (University of Napoli Federico II, giulia.ricciardi2@unina.it)
Credits (planned)	4-6
Planned hours	24-36
Planned schedule	Autumn / Winter 2021
Prerequisites	basics of particle physics
Description	This course aims at providing the basics of the theory of neutrino physics and their oscillations. Some recent experimental results are also discussed. It can be extended to include the basics of leptogenesis.

Introduction to QCD	
Lecturer	**Prof. Francesco Tramontano** (francesco.tramontano@na.infn.it)
Credits (planned)	2
Planned hours	12
Planned schedule	January 2021 2 lectures per week, 1.5 hours each
Prerequisites	Particle physics background
Description	The lectures introduce to some basic aspects and concepts of perturbative QCD: running coupling and asymptotic freedom, the parton model, infrared divergences and the factorization theorem, parton densities and parton evolution, colour coherence. Applications to e+e-annihilation, deep inelastic lepton-nucleon scattering and hadron-hadron collisions are discussed.

Introduction to Ultra-high energy cosmic rays	
Lecturer	**Prof. Fausto Guarino** (fausto.guarino@unina.it)
Credits (planned)	4-6
Planned hours	24-36
Planned schedule	Autumn 2021
Prerequisites	None
Description	The course is designed for students performing doctoral studies in experimental astroparticle physics or experimental particle physics. The focus is on the Ultra-high energy component of cosmic ray radiation and will address 1. Introduction on Cosmic Rays 2. Ultra-high energy Cosmic Rays: status of present knowledge and open questions 3. Experimental techniques 4. Spectral features (ankle, cutoff) 5. Composition 6. Anisotropy 7. Possible sources and propagation scenarios

Mathematical aspects of gauge theories	
Lecturer	**Prof.ssa Patrizia Vitale** (patrizia.vitale@unina.it)
Credits (planned)	3
Planned hours	20
Planned schedule	Spring 2021
Prerequisites	background in theoretical/mathematical physics
Description	• Principal G-bundles and associated vector bundles • Gauge connections • Abelian and non-Abelian gauge theories as theories of connections on fiber bundles

Nuclear physics for astrophysics (an experimental approach)

Lecturers	**Prof. Gianluca Imbriani** (g.imbriani@unina.it) **Prof. Antonino Di Leva** (antonino.dileva@unina.it) **Dr. Andreas Best** (andreas.best@na.infn.it)
Credits (planned)	3 – 4
	18 – 24
Planned schedule	Autumn / Winter 2021
Prerequisites	Basic knowledge of nuclear and/or astrophysics
Description	The theories of nucleosynthesis have identified the most important sites of element formation and also the diverse nuclear processes involved in their production. The detailed understanding of the origin of the chemical elements combines astrophysics and nuclear physics, and forms what is called nuclear astrophysics. Nuclear fusion reactions are at the heart of nuclear astrophysics: they influence sensitively the nucleosynthesis of the elements in the earliest stages of the universe and in all the objects formed thereafter, and control the associated energy generation, neutrino luminosity, and evolution of stars. A good knowledge of the rates of these reactions is thus essential for understanding the broad picture outlined above. In the astrophysical environments the energy available to nuclear species is usually much lower than the Coulomb barrier, i.e. the nuclear reactions happen via the tunnel effect and therefore the probability decreases exponentially with energy. The aim of experimental nuclear astrophysics is to determine such extremely low reaction rates at the relevant astrophysical energies. The problems posed by the experimental determination of the reaction cross section are really challenging, and they require the development of peculiar detection techniques. The detailed program will include: 1. Aspects of Astrophysics a. Big bang nucleosynthesis b. Star formation and evolution c. Quiescent and explosive stellar burnings 2. Stellar nucleosynthesis: a. Definitions and general characteristics of thermonuclear reactions b. Hydrogen burning c. Helium burning d. Advanced burnings e. r and s processes 3. Measure of nuclear processes of astrophysical interest a. Experimental techniques b. Some examples

Ordered phases of Condensed Matter	
Lecturer	**Prof. Arturo Tagliacozzo** (arturo.tagliacozzo@unina.it)
Credits (planned)	5 (about = no. hours 30 / 6) or according to students request
Planned hours	30
Planned schedule	end of May – June – July 2021 four hours, twice a week
Prerequisites	Phenomenology of Condensed Matter, Quantum Mechanics
Description	It is a theoretical overview on • broken symmetry in Superconductivity and Magnetism in various space dimensions, • Quantum Hall effect, Topological Insulators. • Mesoscopic devices Tools are: functional integration of Fermions and coherent spin states, non-linear sigma model and XY model, Berezinskii-Kosterlitz-Thouless transition, Berry phase

Organic conductors	
Lecturer	**Antonio Cassinese** antonio.cassinese@unina.it
Credits (planned)	3
Planned hours	8 - 10 lectures, 2 hours each
Planned schedule	tbd
Prerequisites	Introductory course to organic compounds with different functionalities (like semiconductors, conductors, ferroelectrics, superconductors) of interest for electronic and optoelectronic application. Both fundamental aspects and practical application will be described.
Description	- Organic semiconductors, working principles and applications: - Injection and Electrical conductivity in organic semiconductors and I/O hybrids. P-type and n-type semiconductors - Experimental techniques for the realization of organic and I/O hybrid films and single crystal and devices. - Organic compounds with different functionalities (conductors, ferroelectric, electrical bistable and superconductors - Electro –optical techniques for the characterization of organic and I/O hybrid materials. - Organic Field effect transistor (OFET) basic issues and practical application - Organic/Inorganic and Organic/Organic interface - Emerging Routes in Organic Electronics

Particle Detectors–Trigger/DAQ

Module 1	**Particle Detectors**
Lecturer	Margherita Primavera (INFN Lecce)
Planned hours	22
Planned schedule	Spring 2021
Prerequisites	Charged particles interactions with matter
Description	Generalities on gaseous detectors. Ionization and transport phenomena in gases. Amplification in gases. Gaseous detectors: ionization chambers, proportional counters, MultiWire Proportional Chambers, Drift chambers, TPC, Geiger counters, streamer tubes, Resistive Plate Counters. Calorimetry. Electromagnetic and hadronic calorimeters. Calorimeter calibration and monitoring. Cherenkov detectors: DISC, RICH, DIRC. Transition radiation detectors. Micropattern detectors, dual readout calorimeters.

Module 2	**Photodetection**
Lecturer	Elisabetta Bissaldi (Politecnico di Bari)
Planned hours	16
Planned schedule	Apr/May/June 2021 (TBD) 1 lecture per week two hours each
Prerequisites	Experimental particle physics background
Description	This course aims to provide the student with advanced knowledge of radiation measurements and detection techniques, from classic scintillation detectors to Silicon Photomultiplier devices. It requires an elementary background in radiation measurements, radiation matter interactions and basic electronics. The program includes Photon-matter interactions; Organic and Inorganic scintillators; Optical coupling; Solid-state photodetectors; SiPM technologies, properties and Applications. Part of the course will be devoted to laboratory sessions.

Module 3	**Trigger and DAQ for Particle Physics**
Lecturer	Massimo Della Pietra (Univ. Federico II Napoli)
Planned hours	10
Planned schedule	Spring 2021
Prerequisites	Experimental particle physics background
Description	Introduction to trigger and data acquisition system for experimental physics. Basic elements and definitions: trigger latency and trigger rate. Connection between trigger e data acquisition: dead time and busy status. Multilevel trigger systems, trigger for High Energy Physics at colliders. Integration of Trigger - DAQ and related systems Event building, Run Control, Online data quality. Description of most relevant trigger system for collider HEP: the trigger system of the LHC experiments. Trigger systems for fixed target experiments and for test-beam setup. Triggerless DAQ systems for particle and astroparticle physics. The impact of the trigger system efficiency on a physical measurement.

Physics and applications of Superconducting and Spintronic Devices	
Lecturer	**Prof. G.P. Pepe** (giovannipiero.pepe@unina.it)
Credits (planned):	4 /5
Planned hours:	about 30 (2-3 hours/week)
Planned schedule:	Autumn / Winter 2021
Prerequisites:	basic knowledge of solid state physics and electronics
Description:	The aim of the course is to furnish competences on both fundamental and applied aspects related to the superconducting electronics mainly in nanosized regime, including deposition techniques, nano-patterning, cryogenics, diagnostic tools for advanced microscopy (AFM, MFM, SQUID-based microscopy) and time resolved spectrometry, superconducting detectors and nonequilibrum physics. Moreover, the recent achievements in spintronics (mainly containing superconducting structures) will be also presented and discussed. A brief overiew of the program is the following: The physics of superconductivity: linear electrodynamics, The Ginzburg-Landau theory, weak superconductivity, the Josephson effect, some non-equilibrium effects in superconductors, superconducting quantum devices, superconductivity in low dimension systems. Nanotechnologies: thin films deposition and characterization, top-bottom nano-litography, the self-assembling processes in nanotechnology, advanced imaging on the nano-scale (AFM, STM, advanced microscopy). Cryogenic techniques. Materials and devices for spintronics: magnetism and nanostructures, magneto-resistance and magneto-optics mainly in superconducting based systems. Students will be asked to present seminars on topics related to the above program, producing final reports using general templates as proposed by international scientific journals.

Physics of Plasmas and Particle beams in Laboratory and Space	
Lecturer	**Prof. Renato Fedele** (University, renato.fedele@unina.it)
Credits (planned):	5
Planned hours:	32
Planned schedule	Spring 2021
Prerequisites:	General Physics, Fundamentals of Quantum Mechanics
Description:	This course provides an introduction to the physics of both plasmas and charged particle beams in the presence of collective effects. The course contains a short preparatory part on kinetic theory and statistical mechanics, then develops the subject matter on the basis on the kinetic and fluid theories within the contexts of both classical and quantum physics, with emphasis on the relevant applications t plasma-based particle accelerators, condensed matter physics and astrophysics. In particular, the course includes the following topics: - nonlinear stability and confinement theorems; - collective waves and instabilities in laboratory and space physics; - coherent electromagnetic radiation generation by free electron lasers; - nonlinear processes and particle acceleration in astrophysical environments; - nonlinear processes related to compact plasma-based accelerator concepts.

Quantum Communication	
Lecturer	**Dr. Alberto Porzio** (alberto.porzio@spin.cnr.it)
Credits (planned)	4/6
Planned hours	20 to 24
Planned schedule	Spring 2021
Prerequisites	Quantum mechanics; Quantum Optics (basic)
Description	The program overviews: a) basic principles of quantum information (entanglement, Bell inequalities, no-cloning theorem, measurement theory in QM, coherence and de-coherence); b) the concepts of fidelity and state reconstruction (with experimental aspects); c) q-bit and Continuous Variable QI (with examples of physical implementations); d) simple quantum protocols (quantum cryptography and teleportation); e) intrinsic and technological limits of QI.

Quantum Computing and Artificial Intelligence	
Lecturer	**Prof. Giovanni Acampora** giovanni.acampora@unina.it
Credits (planned)	4/6
Planned hours	20 to 24
Planned schedule	Autumn 2021
Prerequisites	Foundations of Computer Science and Computer Programming
Description	The program overviews: a) concepts of Artificial Intelligence; b) Machine Learning; c) Implementation of Machine Learning algorithms in Python; d) Quantum Computing; e) Quantum Architectures; f) Quantum Algorithms; g) An embryonic view on Quantum Machine Learning.

Quantum Information, Quantum Computation and Quantum Imaging

Module 1	Physical Coherence and Correlation Functions
Lecturer	Saverio Pascazio (Università di Bari)
Planned hours	16
Planned schedule	Eight two-hour lectures between February and July 2021
Prerequisites	Background in quantum theory, technologies and applications
Description	Optical Fluctuations and Coherence. Classical and Quantum theory. The Radiation field. Experimental milestones. Measuring correlation functions. Equilibrium equal-time (spatial) correlation functions Equilibrium equal-position (temporal) correlation functions. Beyond equilibrium. Phase transitions and correlation functions.

Module 2	Introduction to Quantum Computation
Lecturer	Luigi Martina (Università del Salento)
Planned hours	16
Planned schedule	Eight two-hour lectures between February and July 2021
Prerequisites	Quantum Mechanics and Statistical Mechanics
Description	Since at least a couple of decades, the Physics of Information and Computation has been a recognized as an autonomous discipline. In fact, the latter fields should be linked to the study of the underlying physical processes, namely of the quantum mechanical universe. But the intrinsic probabilistic character of the quantum measurements and the non-commutative algebra of the observables induce important modifications in the central results of classical information theory, including: quantum parallelism, compression of quantum information, bounds on classical information encoded in quantum systems, bounds on quantum information sent over a noisy quantum channel, efficient quantum algorithms and quantum complexity. The course will touch the above topics.

Module 3	Quantum imaging
Lecturer	Milena D'Angelo (Università di Bari)
Planned hours	16
Planned schedule	Eight two-hour lectures between June and July 2021
Prerequisites	Background in quantum theory and optics. Attendance of either one of the two above modules is suggested.
Description	From classical to quantum imaging. Klyshko advanced wave model. Ghost imaging and diffraction, from first protocols to recent advances (differential GI, computational GI, compressive GI,..). Single-pixel imaging. Super-resolution: NOON states, and Quantum Fisher information. Sub-shot-noise imaging. Imaging by undetected photons. Imaging through turbulence and scattering media, and imaging around corners. Correlation plenoptic imaging: from principles to applications.

Quantum Technologies: Principles and Engineering
(mostly in Condensed Matter Physics)

Lecturer	**Prof. Francesco Tafuri** (francesco.tafuri@unina.it)
Credits (planned)	6
Planned hours	24
Planned schedule	May / June 2021
Prerequisites	Elementary Quantum Mechanics and Solid State Physics
Description	Quantum hardware is what transforms the novel concepts of quantum computation and communication into reality. The key challenge is to control, couple, transmit and read out the fragile stage of quantum systems with great precision, and in a technologically viable way. This course aims at illustrating some aspects of this key challenge in realizing quantum hardware and technology, focusing on solid state and superconducting hardware. Some key notions on advanced solid state physics will be introduced as a bridge to standard courses. Description by keywords: • Mesoscopic with Superconductivity (including notes on quantum interference effects in transport properties and on quantum transport) • Order and Excitations in Condensed Matter, topological defects, vortex pairs and notes on vortex matter and dynamics, topological quantum numbers in nonrelativistic physics • Macroscopic Quantum Phenomena & broken symmetry • Superconducting Devices, the Josephson effect and dissipationless conversion, Andreev reflection, Dynamical Coulomb Blockade in Josephson junctions; • Notes on dissipation in a Josephson junction, decoherence and noise, macroscopic quantum tunneling and its foundations on dynamics, correlation and response, diffusion and Langevin theory • Nanoelectronic Devices: main notions and physical principles; Nanoscale Processing for Advanced Devices • Quantum bits and essential concepts that distinguish quantum from classical, Quantum states superpositions: introduction of the Bloch sphere quantum operations, Two particles superpositions (EPR): Entanglement, Bell inequalities • Superconducting and hybrid qubits, dissipation engineering, principles of superconducting design, phase-, charge- and flux qubits, from transmon to fluxonium • Josephson bifurcation amplifier, SQUIDs and qubit read-out, entangled microwave photons, Circuit-QED architecture to readout a Josephson qubit.

Radiation biophysics of charged particle exposure	
Lecturer	**Prof. Lorenzo Manti** (lorenzo.manti@unina.it)
Credits (planned)	3
Planned hours	18
Planned schedule	*subject to arrangements with students: Sept. 2021*
Prerequisites	None
Description	The course has the objective of illustrating the basic principles underlying the biological effects ionising radiation, and particulalry of charged particles, as a result of their phyiscal properties. In particular, the consequences of radiation exposure for human health (both acute and delayed) and the radiobiological rationale for the medical use of accelerated ions for cancer treatment will be discussed.

Scientific writing	
Lecturer	**Prof. Paolo Russo** (paolo.russo@unina.it)
Credits (planned)	5
Planned hours	30
Planned schedule	March-May 2021, 2 hrs per lecture, 2 lectures per week
Prerequisites	none
Description	The course provides basic intro to the professional task of scientific publication in international journals, with reference to motivations for publishing, scientific journal selection, writing style, ethical issues, manuscript editing, revision and proofs reading, manuscript correspondence. Moreover, the following aspects will be covered: description of the basic aspects of the Editorial structure of a scientific Journal (Editor, associate editors, editorial board members, publisher, journal manager); basic aspects of the manuscript review process; methods for manuscript review; understanding and evaluation of bibliometrical indices. The course evaluation will be based on exercises assigned to attendees on selected aspects of the course material.

Signals formation and treatment in particle detectors

Module 1	Signals formation
Lecturer	Marcello Abbrescia (Università di Bari)
Planned hours	10
Planned schedule	5 lectures of 2 hours each, in April-May 2021
Prerequisites	Basic notions of electromagnetism and of particle detector physics
Description	- Electrostatics-Principles-Reciprocity-Induced currents-Inducedvoltages -Ramo-Shockley theorem -Mean value theorem - Capacitance matrix -Equivalent circuits; - Signals in: - Ionization chambers - Liquid argon calorimeters - Diamond detectors - Silicon detectors - GEMs (Gas Electron Multiplier) - Micromegas (Micromesh gas detector) - APDs (Avalanche Photo Diodes) - LGADs (Low Gain Avalanche Diodes) – SiPMs (Silicon Photo Multipliers) - Strip detectors - Pixel detectors - Wire Chambers - Liquid Argon TPCs.

Module 2	Signals treatment
Lecturer	Alberto Aloisio (Università di Napoli)
Planned hours	10
Planned schedule	
Prerequisites	
Description	Sistemi di schermatura e di guardia nella lettura di sensori e rivelatori - Cenni sul noise di componenti attivi e passivi - Uso del simulatore analogico per l'analisi di alcuni casi di studio: rumore di alcune configurazioni base degli amplificatori operazionali, effetto della capacità del rivelatore sul noise gain

Statistical Methods for Data Analysis	
Lecturer:	**Dr. Alberto Orso M. Iorio** (albertoorsomaria.iorio@unina.it)
Credits (planned):	2-3
Planned hours:	12-18
Planned schedule:	February 2021
Prerequisites:	Basic knowledge of the concept of probability. Examples and exercises will be done in C++, so basic knowledge of computer programming is recommended.
Description:	Statistical methods for data analysis: • Statistics and probability distributions • Parameter estimates and maximum likelihood (ML) and extended ML methods • The Bayes theorem: frequentistic and Bayesian approaches • Computation of upper limits • Combining measurements • Monte Carlo techniques • Fit quality with Toy Monte Carlo • Multivariate discrimination methods • Artificial Neural Networks Introduction to statistics application frameworks based on ROOT toolkit: • RooFit • TMVA

Statistical Mechanics of Complex Systems	
Lecturer:	**Prof. Antonio De Candia** (antonio.decandia@unina.it)
Credits (planned):	2-3
Planned hours:	12-18
Planned schedule:	Autumn / Winter 2021
Prerequisites:	basic knowledge of statistical mechanics
Description:	Sherrington - Kirkpatrick model. Replica - symmetric solution. The Parisi solution. The p - spin model. The cavity method. Dynamics and Mode - Coupling theory. TAP equations. The spin - glass on the Bethe lattice. Reconstruction on trees and point – to - set correlations.

String Theory	
Lecturer	**Prof. Wolfgang Mueck** (wolfgang.mueck @unina.it)
Credits	8
Planned hours	64
Planned schedule	***course offered in the frame of the Master's programme to be held on Autumn / Winter 2021***
Prerequisites	Basic knowledge in General Relativity and Quantum Field Theory
Description	Outline: 1) Historical Introduction 2) Point particle 3) Bosonic String – canonical quantization 4) Conformal Field Theory 5) String interactions 6) BRST and path integral quantization 7) Low-energy effective actions 8) T-duality and D-branes 9) Superstrings 10) Type IIA and IIB supergravity

Strings and branes	
Lecturer	**Dr. Franco Pezzella** (INFN, pezzella@na.infn.it)
Credits (planned):	4
Planned hours:	24
Planned schedule:	October / November 2021
Prerequisites:	General Relativity, Quantum Field Theory
Description:	Classical and quantum aspects of superstrings are discussed together with the properties of D-branes, string dualities and more recent developments in String Theory.

Strong Interactions	
Lecturer	**Prof.ssa Giulia Ricciardi** (University of Napoli Federico II, giulia.ricciardi2@unina.it)
Credits (planned)	4-6
Planned hours	24-36
Planned schedule	Autumn / Winter 2021
Prerequisites	basics of particle physics
Description	The aim of the course is to provide the necessary background to fully understand and work on processes involving hadrons. Topics: - Non abelian gauge theories: QCD - Renormalization group, infrared and ultraviolet divergencies - Asymptotic freedom and confinement - Fundamental applications of perturbative QCD - Deep Inelastic Scattering; Parton Model - Structure Functions; DGLAP equations, their solution and interpretation - Effective field theories - Introduction to the lattice

Supersymmetries and dualities in various dimensions	
Lecturer	**Dr. Raffaele Marotta** (INFN, lmarotta@na.infn.it)
Credits (planned)	3-4 depending on the type of exam chosen by the students
Planned hours	20
Planned schedule	September / October 2021
Prerequisites	Quantum Field Theory
Description	• Preliminary Contents 1) Supersymmetry in two space-time dimensions (D=2): Supersting Theories 2) N=1, 2 in D=4 Supersymmetry 3) N=1 in D=6 and D= 10 Supersymmetry 4) A Brief introduction to supergravity theories. 5) Aspects of duality.

Theoretical Astroparticle Physics	
Lecturer	**Prof.ssa Ofelia Pisanti** (ofelia.pisanti@unina.it)
Credits (planned)	8
Planned hours	64
Planned schedule	1st semester academic year 2020/21
Prerequisites	Basics of Elementary Particle Physics (Standard Model)
Description	The course is borrowed from "Laurea Magistrale in Fisica" and gives the opportunity of understanding modern theories on matter constituents and their liaison with the origin of the universe. Contents: • Elements of general relativity • Standard cosmology • Termodynamics of the expanding universe • Out of equilibrium processes (Boltzmann equation) • Out of equilibrium phenomena: baryogenesis, big bang nucleosynthesis, • recombination • Dark matter and dark energy • Inflation • Cosmological perturbation theory, large scale structures and CMB • Cosmic rays

Theory of Nuclear Matter	
Lecturer	**Dr. Luigi Coraggio** - INFN (coraggio@na.infn.it)
Credits (planned)	3
Planned hours	20
Planned schedule	to be defined with the interested students
Prerequisites	none
Description	- Basic properties of the nuclear matter - The Fermi gas model - The nucleon-nucleon potential - The Brueckner theory - The reaction matrix G - The Bethe-Brandow-Petschek theorem - The Brueckner-Hartree-Fock approach - Calculation of reaction matrix with the momentum space matrix equation method - Lowest order Brueckner-Hartree-Fock theory - Microscopic derivation of the nuclear matter equation of state and neutron stars

Thin films: physics and applications	
Lecturer	**Dr.ssa Alessia Sambri** (SPIN-CNR, alessia.sambri@spin.cnr.it)
Credits (planned)	4
Planned hours	24
Planned schedule	tbd
Prerequisites	basic knowledge on Solid State Physics
Description	The course is focused on the very actual and appealing field of thin films. The fascinating properties exhibited by several compounds when combined together as thin film heterostructures and the possibility to tune, or even enhance, some bulk physical properties when the compound are engineered as thin films, are driving a broad research in solid state physics labs worldwide. Moreover, the push toward devices miniaturization is taking great advantages of the constantly improving abilities to fabricate high quality thin films and heterostructure and to optimize the microfabrication processes that shape thin films into devices. The course will give a broad overview on the physics related to thin films and interfaces, with a focus on the fabrication processes, on a number of structural, morphological and chemical characterization techniques, and on the technological issues related to the employment of thin films in the modern miniaturized devices. Beside the frontal lessons, some practical examples of thin films depositions and characterizations are planned, accordingly to the calendar of the involved labs.

Topics in Non-Perturbative Quantum Field Theory (from two to four dimensions)	
Lecturer	**Prof. Luigi Rosa** (luigi.rosa@unina.it)
Credits (planned)	3
Planned hours	20
Planned schedule	Spring 2021
Prerequisites	theoretical physics background
Description	NON-PERTURBATIVE METHODS IN TWO-DIMENSIONAL FIELD THEORY: From massless scalar field to conformal field theories. TWO-DIMENSIONAL NON-PERTURBATIVE GAUGE DYNAMICS: Foundamental aspects of gauge theories in two dimensions FROM TWO TO FOUR DIMENSIONS: Conformal invariance in four-dimensional field theories and in QCD From two-dimensional solitons to four-dimensional magnetic monopoles Instantons in QCD

Topics in Non-Perturbative Quantum Field Theory (Gauge theories)	
Lecturer	**Prof. Luigi Rosa** (luigi.rosa@unina.it)
Credits (planned)	3
Planned hours	20
Planned schedule	Spring 2021
Prerequisites	theoretical physics background
Description	GAUGE THEORIES: The gauge principle; Functional quantization of gauge theories BRST symmetry and physical states Realizations of symmetry; Ward-Takahashi identities Spontaneous symmetry breaking; Continuous global symmetry; The Goldstone's theorem; the Higgs mechanism Casimir energy and the cosmological constant problem NON ABELIAN GAUGE FIELDS: the Gribov ambiguity; path integral in QCD; Instantons; confinement and dual superconductivity; 't Hooft-Polyakov magnetic monopoles

Trigger and Data Acquisition for High Energy Physics experiments	
Lecturer	**Prof. Massimo Della Pietra** (massimo.dellapietra@unina.it)
Credits (planned)	4
Planned hours	24
Planned schedule	June – September 2021 2 lectures per week, 2 hours each
Prerequisites	Radiation - matter interactions background, basic C and C++ programming
Description	This set of lectures are dedicated to provide an overview of the basic instruments and methodologies used in high energy physics for triggering and acquiring data, spanning from small experiments in the lab to the very large LHC experiments, emphasizing the main building blocks as well as the different choices and architectures at different levels of complexity.

Ultrafast processes and femtosecond laser pulses	
Lecturer	**Dr. Andrea Rubano** (andrea.rubano@unina.it)
Credits (planned)	3
Planned hours	18
Planned schedule	Autumn / Winter 2021
Prerequisites	Basic knowledge of Solid-state Physics would be helpful. Linear Optics and basics of Quantum Physics are required.
Description	The PhD Course will introduce the students to the realm of Ultrafast Processes, with a special focus on optical pulses and their interaction with matter. The introduction will give broad overview about pulsed light, pulsed sources, and especially commercial femtosecond lasers. Theoretical and technical description about the most common ways to produce and amplify short pulses will be given in some detail. In the main part, different applications of ultrafast pulses will be described as follows: 1) Metrology: How to measure optical frequencies? Frequency Comb, optical clockwork. 2) Nonlinear Optics: New frequencies, new probes? Nonlinear light-matter interaction, principles and main applications. Sum and difference frequency generation. Frequency doubling. Extreme cases: THz and X-rays generation schemes. 3) Novel states: How to access non-equilibrium states? Scanning microscopy approaches: two-photon microscopy, stimulated emission-depletion microscopy. 4) Fs-spectroscopy: How to resolve ultrafast dynamics? Overview about the general Pump&Probe experimental scheme. Examples: coherent phonon control, isomerization and structural transitions, charge transfer and separation, hot-electron dynamics in metals. 5) Fs-photonics: How to control light with light? Spectral lenses in photonic crystals. The aim of the Course is to give a wide panorama on today's available techniques using ultrashort laser pulses and to provide technical skills and theoretical background to the student which intends to work within this field of research. The actual layout of the course can be extended in some aspects and reduced in others, depending on the student's interests and motivations.

Waves and Interactions in Nonlinear Media	
Lecturer	**Prof. Renato Fedele** (renato.fedele@unina.it)
Credits (planned):	4
Planned hours:	25
Planned schedule	Spring 2021
Prerequisites:	Classical Electrodynamics, Fundamentals of Quantum Mechanics, Fundamentals of Statistical Mechanics
Description:	The course is interdisciplinary and gives a general description of the propagation of waves in nonlinear media and their interactions (three and four waves parametric processes). Some physical examples in nonlinear optics (Kerr media, optical fibers), surface gravity waves (ocean waves), large amplitude waves in plasmas (Langmuir wave packets) and matter waves physics (Bose-Einstein condensates) are given. From these examples, a unified description modelled by suitable nonlinear Schrödinger equations is extrapolated. Such a description is then extended to phase space by means of the Wigner quasi-distribution. Particular attention is devoted to both theoretical and experimental aspects of the modulational instability and the related stabilizing role of the Landau damping for an ensemble of partially incoherent waves.