UNIVERSITÀ degli STUDI di NAPOLI «Federico II»

DOTTORATO di RICERCA in FISICA – PhD program in Physics

- Physics PhD course catalog –

38th cycle, and till active cycles

(last updated on June, 2022)

n.b. SUPRA courses are those ones offered (on-line) in the frame of the *Southern Universities Physics Research Agreement*, involving the University of Naples "Federico II", University of Campania "L. Vanvitelli" - Caserta, University of Bari, University of Salento - Lecce

1. Theoretical Physics of Fundamental Interactions

1.1. Advanced topics in Theoretical Physics (F. Lizzi)

1.2. Fundamental interactions: QCD and BSM (SUPRA)
- **Perturbative QCD** (F. De Fazio - UniBa)
- **Teoria di Regge** (C. Corianò - UniSalento)
- **BSM** (F. De Fazio - UniBa)

1.3. Phenomenology of particle interactions
- **Introduction to Neutrino physics** (G. Ricciardi)
- **Heavy Flavour Physics** (P. Santorelli)
- **Effective Theories and Flavour Physics** (G. D'Ambrosio)

1.4. Advanced theoretical/mathematical physics
- **Supersymmetry, String and Branes** (F. Pezzella – R. Marotta)
- **Topics on Non-Perturbative Quantum Field Theory** (L. Rosa)
- **Geometric and Topological methods in Theoretical Physics** (P. Vitale)

2. Astrophysics, Astroparticle and Cosmology

2.1. Di Girolamo Multi-messenger and particle astrophysics of compact objects (SUPRA)
- **Compact objects** (F. De Paolis - UniSalento)
- **Neutrino Oscillations** (D. Montanino - UniSalento)
- **Supernova Neutrinos** (A. Mirizzi - UniBa)
- **Gravitation, Relativity and Black Holes** (M. De Laurentis)
- **Physics and evolution of supermassive Black Holes** (M. Paolillo)
- **Gravitational Waves and Gamma-Ray Bursts** (T. Di Girolamo)

2.2. Experimental High-Energy Astroparticle Physics (SUPRA)
- **Experimental Techniques in Astroparticle Physics** (G. Marsella - UniPa)
- **HE and VHE Observations from Extragalatic Sources** (L. Perrone – UniSalento)
- **HE Transients and the Multimessenger Context** (E. Bissaldi – UniBa)
- **Indirect Dark Matter Searches** (F. Loparco – UniBa)

2.3. Extended theories of Gravity and the problem of Dark Energy and Dark Matter (S. Capozziello)

3. Nuclear and Particle Physics

3.1. Particle Detectors, Trigger and DAQ (SUPRA)
- Particle detectors (M. Primavera - UniSalento)
- Photo-detection (E. Bissaldi - UniBa)
- Trigger and DAQ for Particle Physics (M. Della Pietra)
- Detection methods for nuclear astrophysics and applications (R. Buompane – UniCampania
- Nuclear Physics in low-background conditions (A. Best)

3.2. Signals formation and treatment in particle detectors (SUPRA)
- Signal formation (M. Abbrescia - UniBa)
- Signals treatment (A. Aloisio)

3.3. Unified theory of nuclear reactions (G. La Rana)

4. Physics of Matter

4.1. Advanced topics in experimental physics of matter
- Advanced Spectroscopies in strongly correlated systems (G. De Luca)
- Electrodynamic properties of novel materials and devices (A. Andreone)
- Organic conductors (A. Cassinese)
- Ultrafast processes and femtosecond laser pulses (A. Rubano)
- Physics and applications of Superconducting and Spintronic Devices (G.P. Pepe)

4.2. A general overview of the Physics of Surfaces and Interfaces (R. Di Capua)

4.3. Statistical Physics for Complex Systems (SUPRA)
- Active Matter and Complex Fluids (G. Gonnella – A. Lamura - UniBa)
- Statistical Mechanics of Complex Systems (A. De Candia)
- Stochastic Processes and Analysis of Correlations (E. Lippiello - UniCampania)

5. Artificial Intelligence and Computing

5.1. Artificial Intelligence and Machine Learning (SUPRA)
- Machine Learning: basics and applications (G. De Nunzio, G. Palma – UniBa)
- Approximate reasoning and evolutionary computation (G. Acampora – F. Di Martino – A. Vitiello)
- Causality analysis of time series (S. Stramaglia – UniBa)
- Data Modelling (N. Amoroso - UniBa)

5.2. Quantum Computing and Artificial Intelligence (G. Acampora)

5.3. Evolutionary Computation and Applications (A. Vitiello)

6. Biomedical Physics

6.1. Biophysics for Health and Environment (SUPRA)
- Biophysical mechanisms and therapeutic implications of human exposure to ionising radiation (L. Manti)
- Bio-photonics for clinics and environment (M. Lepore - UniCampania)
- Numerical Methods for Data Analysis in Optical Spectroscopy (M. Lepore – UniCampania, et al.)

6.2. Advanced computational tools in Medical Physics (G. Mettivier)

6.3. Biosensors (B. Della Ventura and R. Velotta)

7. General Formation

Advanced computational tools in Medical Physics	
Lecturer	**Prof. Giovanni Mettivier** (giovanni.mettivier@unina.it)
Credits (planned)	2
Planned hours	12
Planned schedule	
Prerequisites:	Medical Physics background, Programming skills (C, python, Matlab)
Description:	The lectures introduce to some basic aspects and concepts of the use of Monte Carlo simulations procedures and Artificial Imaging tools for their application in the Medical Physics field. The use of simulation code, like Geant4, allows to students to implement and study dosimetric and radiation-matter interaction problems related to medical apparatus or medical procedure (Virtual Clinical Trials). The study of AI algorithms (Machine Learning and Deep Learning) and autonomy models are the basis for understand the basic of automatic learning and reasoning. In this course, the students will have opportunity to design and develop such systems as part practical lessons.

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 they 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	
Prerequisites	usual courses of a physics 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, though 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
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 from 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.

Artificial Intelligence and Machine Learning

First module	Machine Learning: basics and applications
Lecturers	**Giorgio De Nunzio** giorgio.denunzio@unisalento.it **Giuseppe Palma**
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** (giovanni.acampora@unina.it) **Ferdinando Di Martino** (fdimarti@unina.it) **Autilia Vitiello** (autilia.vitiello@unina.it)
Credits (planned)	tbd
Planned hours	10 (5 lessons, 2 hrs each)
Planned schedule	
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.ssa 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**
Lecturer	**Sebastiano Stramaglia** (sebastiano.stramaglia@uniba.it)
Credits (planned)	tbd
Planned hours	10 (5 lessons, 2 hrs each)
Planned schedule	
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.

Fourth module	**Data modelling**
Lecturer	**Nicola Amoroso** (nicola.amoroso@uniba.it)
Credits (planned)	tbd
Planned hours	10 (5 lessons, 2 hrs each)
Planned schedule	
Prerequisites	
Description	Introduction: graph theory. Different graph models. Nodal and edge characterization. Local and global properties. Community detection. Learning: basic definitions, bias, variance and cross-validation. Supervised models. Deep Learning. Unsupervised models: clustering

Biophysics for Health and Environment

First module	Biophysical mechanisms and therapeutic implications of human exposure to ionising radiation
Lecturer	**Lorenzo Manti** (lorenzo.manti@unina.it)
Credits (planned)	3
Planned hours	20 (10 lessons, 2 hrs each)
Planned schedule	
Prerequisites	Fundamentals of radiation-matter interaction
Description	The aim of the course is to provide an overview of the unique biological action exerted by ionizing radiation (/IR). The ensuing effects at cellular and tissue level are governed by the spatio-temporal mode with which energy deposition occurs at the nanometer level (i.e., at the scale of the DNA) and are influenced by a cascade of complex biomolecular responses. The course will therefore illustrate the main biophysical principles on which modern radiotherapy (RTR) relies. New approaches will be also discussed such as the use of accelerated particle beams (hadrontherapy) and the exploitation of nuclear fusion reactions where physics can give an essential contribution to IR-based cancer therapy.

Second module	Biophotonics for clinics and environment
Lecturer	**Maria Lepore** (maria.lepore@unicampania.it)
Credits (planned)	4
Planned hours	24
Planned schedule	
Prerequisites	Basic concepts of optical techniques
Description	The course will deal with the application of optical techniques to the development of new diagnostic strategies and environment monitoring tools. Vibrational and fluorescence spectroscopies will be used for investigating biofluids, human tissues, radioexposed cells and enzymes in order to monitor biological processes and to develop sensor devices.

Third module	Numerical Methods for Data Analysis in Optical Spectroscopy
Lecturers	**Ines Delfino** (delfino@unitus.it) **Carlo Camerlingo** (carlo.camerlingo@spin.cnr.it) **Maria Lepore** (maria.lepore@unicampania.it)
Credits (planned)	3
Planned hours	18
Planned schedule	
Prerequisites	Basic notions of a programming language
Description	The course aims to introduce numerical methods particularly useful for the analysis of spectral data with particular attention to background subtraction, noise reduction and quantitative applications (chemometrics). Univariate and multivariate analysis (PCA, Principal Component Analysis), wavelet algorithms will be discussed and applied in the analysis of practical cases of students' interest.

Biosensors	
Lecturers	**Dr. Bartolomeo Della Ventura** (bartolomeo.dellaventura@unina.it) **Prof. Raffaele Velotta** (raffaele.velotta@unina.it)
Credits (planned)	2
Planned hours	12
Planned schedule	tbd
Prerequisites	Physics background
Description	The course aims at providing the student with the most widespread techniques currently used in realizing biosensors. Lectures will include the discussion of the physical mechanisms underlying the transduction processes and laboratory demonstrations of some devices. The following biosensors will be described. Piezoelectric biosensors: quartz-crystal microbalances. Electrochemical biosensors: volt-amperometric and impedance spectroscopy techniques. Fundamentals of plasmonics: surface plasmon resonance and localized-surface plasmon resonance. Plasmonic-based biosensors: colorimetric and fluorescence-based biosensors.

Black Holes

Lecturers	**Mariafelicia De Laurentis** **Tristano Di Girolamo** **Maurizio Paolillo**	(mariafelicia.delaurentis@na.infn.it) (tristano.digirolamo@unina.it) (maurizio.paolillo@unina.it)
Credits (planned)	4	
Planned hours	24 (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.	

Di Girolamo Multi-messenger and particle astrophysics of compact objects

Module 1	**Compact objects**
Lecturer	Francesco De Paolis (francesco.depaolis@unisalento.it)
Planned hour	6
Planned schedule	
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 (daniele.montanino@unisalento.it)
Planned hour	6-8h
Planned schedule	
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 (alessandro.mirizzi@uniba.it)
Planned hour	6
Planned schedule	
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 (mariafelicia.delaurentis@unina.it)
Planned hour	6-8
Planned schedule	
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 (maurizio.paolillo@unina.it)
Planned hour	6-8
Planned schedule	
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 (tristano.digirolamo@unina.it)
Planned hour	6-8
Planned schedule	
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	
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	
Lecturer	**Prof. Antonello Andreone** (antonello.andreone@unina.it)
Credits (planned)	4
Planned hours	24
Planned schedule	
Prerequisites	
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.

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	
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.

Experimental High-Energy Astroparticle Physics

Module 1	Experimental Techniques in Astroparticle Physics
Lecturer	Giovanni Marsella (giovanni.marsella@unipa.it)
Credits	2-3
Planned hours	16
Planned schedule	
Prerequisites	Basic particle physics, astrophysics and detectors
Description	Description of the principal experimental techniques in Astroparticle Physics. Contents: • Introduction to Cosmic Rays (CR) sources • Primary CRs, acceleration mechanism, propagation • Secondary CRs, atmospheric showers • Detection techniques in Space, Extensive Air Shower arrays and underground detectors • Presentation of the principal experiments and recent results

Module 2	Experimental and VHE Observations from Extragalactic Sources
Lecturers	Lorenzo Perrone et al. (lorenzo.perrone@unisalento.it)
Credits	1-2
Planned hours	5 - 10
Planned schedule	
Prerequisites	Basic particle physics, astrophysics and detectors
Description	The lectures intend to cover the description of the detection techniques of ultra-high energy comic rays (Pierre Auger Observatory, Telescope Array) and the current status of the art (results and perspectives) in the field. *Recommended texts: review papers and journal papers*

Module 3	HE Transients and the Multimessengers Context
Lecturer	Elisabetta Bissaldi (elisabetta.bissaldi@uniba.it)
Credits	2-3
Planned hours	16
Planned schedule	
Prerequisites	Basic astrophysics, detectors
Description	• Transient phenomena in the gamma-ray sky: Gamma-Ray Bursts (GRBs), Soft Gamma Repeaters. Terrestrial Gamma-Ray Flashes; Solar Flares. Temporal and spectral characteristics • Multi-frequency and Multi-messenger studies; LIGO/Virgo gravitational wave (GW) events and follow-up observations; The case of GRB 170817A/GW 170817; IceCube neutrino events and follow-up observations; The case of TXS 0506+056; Other recent discoveries in the field. 1. Longair, “High-energy astrophysics”

	2. De Angelis & Pimenta, "Introduction to Particle and Astroparticle Physics" 3. Recent publications *Assessment methods: lessons, final report*

Module 4	**Indirect Dark Matter Searches**
Lecturer	Francesco Loparco (francesco.loparco@uniba.it)
Credits	2-3
Planned hours	16
Planned schedule	
Prerequisites	Basic particle physics and detectors
Description	Dark Matter models Dark matter distribution in galaxies WIMPs as dark matter searches with gamma rays and charged particles Searches dark matter from the Sun Recent publications, some textbooks, slides from the lecturer *Assessment method: final report*

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

Fundamental interaction: QCD and BSM

Module 1	**Perturbative QCD**
Lecturer	Francesco Tramontano (francesco.tramontano@unina.it)
Credits	2
Planned hours	12 (2 lectures per week, 2 hours each)
Planned schedule	tbd
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)	2
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	
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

Geometric and topological methods in Theoretical Physics	
Lecturer	**Prof.ssa Patrizia Vitale** (patrizia.vitale@unina.it)
Credits (planned)	3
Planned hours	20
Planned schedule	
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 Flavour Physics	
Lecturer:	**Prof. Pietro Santorelli** (pietro.santorelli@unina.it)
Credits (planned)	2-3
Planned hours	14-16
Planned schedule	
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	
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	
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** (giulia.ricciardi2@unina.it)
Credits (planned)	4-6
Planned hours	24-36
Planned schedule	
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.

Mathematical aspects of gauge theories	
Lecturer	**Prof.ssa Patrizia Vitale** (patrizia.vitale@unina.it)
Credits (planned)	3
Planned hours	20
Planned schedule	
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

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 (margherita.primavera@le.infn.it)
Planned hours	22
Planned schedule	
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 (elisabetta.bissaldi@ba.infn.it)
Planned hours	16
Planned schedule	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 (massimo.dellapietra@unina.it)
Planned hours	10
Planned schedule	
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.

Module 4	**Nuclear Physics in low-background conditions**
Lecturer	**Dr. Andreas Best** (andreas.best@unina.it)
Credits (planned):	3-4
Planned hours:	16-24
Planned schedule:	To be arranged in discussion with students
Prerequisites:	Basic knowledge of nuclear physics.
Description:	This course aims to give an overview of the challenges and specific characteristics of experimental nuclear physics in low-background conditions, in particular in reference to nuclear astrophysics deep underground. We will discuss the main differences between "traditional" laboratories and underground ones; the motivations for wanting to measure in low-background environments; main sources of backgrounds and their rejection via passive and active methods; examples of currently active low-background laboratories; intrinsic backgrounds in common materials; methods to achieve similar or closely similar conditions on the surface. **Course outline** Introduction • Background sources in nuclear physics, intrinsic and extrinsic • Signal to noise in nuclear astrophysics Backgrounds and suppression thereof • Deep-underground environments • Passive shielding • Active shielding, pulse shape discrimination Real-world examples • Operational deep-underground laboratories • Low-background measurements on the surface • Possible site visit at INFN-LNGS (to be determined) The students can give indication for topics of their interest that could be part of the program of the course.

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	
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 overview 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.

Quantum Computing and Artificial Intelligence

Lecturer	**Prof. Giovanni Acampora**	giovanni.acampora@unina.it
Credits (planned)	4/6	
Planned hours	20 to 24	
Planned schedule		
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.

Scientific writing	
Lecturer	**Prof. Paolo Russo** (paolo.russo@unina.it)
Credits (planned)	5
Planned hours	30 2 (hrs per lecture, 2 lectures per week)
Planned schedule	
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 marcello.abbrescia@uniba.it
Planned hours	10
Planned schedule	5 lectures of 2 hours each
Prerequisites	Basic notions of electromagnetism and of particle detector physics
Description	- Electrostatics-Principles-Reciprocity-Induced currents-Induced voltages - 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 (alberto.aloisio@unina.it)
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	
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 Physics for Complex Systems

Module 1	Active Matter and Complex Fluids
Lecturers:	**Giuseppe Gonnella** (giuseppe.gonnella@uniba.it) **Antonio Lamura**
Credits (planned)	2-3
Planned hours	16 (8 two hrs lectures)
Planned schedule	
Prerequisites	Background in classical physics and statistical mechanics
Description	Statistical physics and biological systems. Active matter: basic particle and continuous models. The phase diagram of passive and active colloids. Topological transitions. Complex fluids: theoretical modelling. Polymers: static and dynamical properties in dilute conditions. Ternary mixtures with surfactant: self -aggregation, active and double emulsions. Basic rheological behavior of complex fluids. The yielding transitions. Simulations methods in soft and active matter. Molecular dynamics, Multi-Particle Collision Methods, lattice Boltzmann Methods

Module 2	Statistical Mechanics of Complex Systems
Lecturer:	**Prof. Antonio De Candia** (antonio.decandia@unina.it)
Credits (planned)	2-3
Planned hours	16 (8 lectures, two hrs each)
Planned schedule	
Prerequisites	basic knowledge of statistical mechanics
Description	Sherrington - Kirkpatrick model for spin-glasses. 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.

Module 3	Stochastic Processes and Analysis of Correlations
Lecturer:	**Prof. Eugenio Lippiello** (eugenio.lippiello@unicampania.it)
Credits (planned)	2-3
Planned hours	16 (8 two hrs lectures)
Planned schedule	
Prerequisites	Background in classical statistical mechanics.
Description	The purpose of these lectures is to give a simple mathematical introduction to the description of stochastic processes with innovative applications in the field of epidemiology and earthquake data time- series analysis. - Markov processes. - Master and Fokker Plank equations. - Stochastic energetics. - Branching processes. - Watson-Galton model. - Application to genetics. - Epidemic models. - Applications to epidemiology and earthquake occurrence. - Analysis of correlations in stochastic signals. - Detrended Fluctuation Analysis. - Power spectrum of a signal

Supersymmetries, Strings and branes	
Lecturers	**Dr. Franco Pezzella** (INFN, pezzella@na.infn.it) **Dr. Raffaele Marotta** (INFN, lmarotta@na.infn.it)
Credits (planned):	4
Planned hours:	24
Planned schedule	
Prerequisites	General Relativity, Quantum Field Theory
Description	1) Supersymmetry in two space-time dimensions (D=2): 2) Superstring Theories 3) N=1,2 in D=4 Supersymmetry 4) N=1 in D=6 and D= 10 Supersymmetry 5) A Brief introduction to supergravity theories 6) Aspects of duality Classical and quantum aspects of superstrings are discussed together with the properties of D-branes, string dualities and more recent developments in String Theory.

Topics in Non-Perturbative Quantum Field Theory (from two to four dimensions)	
Lecturer	**Prof. Luigi Rosa** (luigi.rosa@unina.it)
Credits (planned)	4
Planned hours	30
Planned schedule	
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: Fundamental 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 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

Ultrafast processes and femtosecond laser pulses	
Lecturer	**Dr. Andrea Rubano** (andrea.rubano@unina.it)
Credits (planned)	3
Planned hours	18
Planned schedule	
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.

Unified theory of nuclear reactions	
Lecturer	**Prof. Giovanni La Rana** (Giovanni.larana@na.infn.it)
Credits (planned):	4
Planned hours:	20 10 lectures, 2 ours each
Planned schedule:	To be agreed with students
Prerequisites:	Basic knowledge of nuclear physics and quantum mechanics.
Description:	This course aims to deepen the study of nuclear reactions induced by light and heavy ions at low energy (E / A <10 MeV / A). Starting from phenomenology and the main nuclear models, the final goal is to present and discuss the unified theory due to H. Feshbach. This theory, based on the projection operator technique, provides an important framework for understanding the physics and modelling nuclear processes, from direct mechanisms to the formation of compound nuclei. Part of the course makes use of advanced quantum mechanics concepts applied to nuclear physics, the basic elements of which will be introduced during the lectures. **Course outline** • Phenomenology of nuclear reactions at low energy (E/A < 10 MeV/A): direct and compound nucleus processes, giant resonances, fluctuations in the cross section. • Nuclear models: single particle potential model for nuclear scattering, theory of the compound nucleus in the discrete and continuum region, Statistical Model, Optical model. • Brief review of scattering and reactions theory: cross section and T matrix, Green operator, Lippmann Schwinger equation, Born development and approximate methods. • Unified Theory of nuclear reactions: prompt and time-delayed processes, the projection operator technique, general expression of the transition amplitude, resonance theory. Derivation of the generalized Optical-Model potential. Intermediate structure in nuclear reactions: 'doorway states'. References G.R. Satchler: Introduction to nuclear reactions D.F. Jackson: Nuclear Reactions P. Roman: Advanced Quantum Theory F.S. Levin/H. Feshbach: Reaction Dynamics

Waves and Interactions in Nonlinear Media	
Lecturer	**Prof. Renato Fedele** (renato.fedele@unina.it)
Credits (planned)	4
Planned hours	25
Planned schedule	
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.