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General information		
Academic subject	***Elementary Particle Physics***	
Degree course	*Physics*	
Academic Year	*1st*	
European Credit Transfer and Accumulation System (ECTS)		6
Language	*English*	
Academic calendar (starting and ending date)	*2nd semester (March 2022 – June 2022)*	
Attendance	*Yes*	

Professor/ Lecturer	
Name and Surname	Anna Colaleo
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Department and address	Department of Physics Room 134, 1st floor
Virtual headquarters	*Teams*
Tutoring (time and day)	

Syllabus	
Learning Objectives	*The objective of the course is to introduce to modern view of particle physics with the emphasis on how theoretical concepts relate to the experimental measurements. The Standard Model will be derived basically following it development in historical order, each topics will be supported by the discussion of the main articles published at the time of the experiments. The fundamental equations required to understand those experiments will be derived.* *The student will be introduced to the notions of symmetry principles and groups, to describe the Standard Model as well as its possible extensions. The student will become familiar with the phenomenology of low- and high-energy collisions with reference to classic, current and future experiments and he/she will have some hints on the functioning of accelerators and multipurpose detectors.* *Aim: by the end of the course the student should have a good understanding of the theoretical and experimental aspects of particle physics.*
Course prerequisites	*Institutions of Nuclear and Subnuclear Physics, Special Relativity, Mathematical Methods for Physics, Particle Detector Physics, Quantum Field Theory*
Contents	***Introduction:*** *The structure of the Standard Model, Natural Units, Symmetries and Conservation Laws, Relativistic Kinematics, Particle Properties, Decays, Cross Sections, Scattering and Resonances.* ***Collider physics:*** *Accelerators, particle interactions in matter, particle detection and large detectors in modern colliders.* ***Relativistic wave equations:*** *The Klein-Gordon equation; spin and helicity; the Dirac equation and Dirac spinors.* *Antimatter, Interaction via particle exchange, Virtual particles, Feynman diagrams.* ***QED:*** *gauge invariance; e^+e^- scattering and annihilation in QED; electron-proton scattering; Drell-Yan process; Experimental tests; Running of alpha; Rutherford Scattering e Mott Scattering Elastic Scattering from a finite size proton; the role*

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<tr><td></td><td>of spin and helicity in QED.

Quark model: deep-inelastic scattering and structure functions; Bjorken scaling and the Callan-Gross relation; the proton form factor; Quark-Parton Modell; HERA e±p collider and LHC pp collider; Symmetry, Isospin, mesons and baryons.

QCD: from QED to QCD; Color and gluons; the binding of mesons, the long-range QCD potential, confinement, running couplings and asymptotic freedom; hadron production; jet production; experimental evidence for QCD, SU(3) symmetry.

Weak interactions: V-A theory and parity violation, experimental evidence for V-A, charged current interaction; connection with Fermi theory; weak leptonic interaction and deep inelastic neutrino scattering: muon decay and lepton universality, neutrino helicity, neutrino beam scattering, (anti)neutrino-(anti)quark scattering, structure functions; CDHS experiment; neutral weak current interaction.

Neutrino physics: CP and CPT in weak interactions and neutrino oscillations, mass hierarchy and PMNS matrix, neutrino experiments: long baseline, solar neutrinos, reactor experiments, atmospheric neutrinos.

Weak quark interaction: GIM mechanism and CKM matrix; the neutral kaon system and CP eigenstates; strangeness oscillations; CP violation and the CPT theorem. direct and indirect CP violation; neutral B mesons, CP violation in the B sector.

Electroweak Unification: Weak interactions; weak isospin and weak neutral currents; the W and Z bosons and the unified electroweak theory; the Higgs mechanism, spontaneous symmetry breaking, generation of vector boson masses; Tests of the electroweak theory at e^+e^- colliders.

Search for Higgs boson at Tevatron and LHC: the Higgs couplings and decay modes, production cross sections, data analysis for Higgs searches, latest results.

Beyond the Standard Model: Problems with the Standard Model and possible solutions; the problem of naturalness and fine tuning; Supersymmetry and extra dimensions; experimental signatures of supersymmetric particles, the baryon asymmetry in the universe and dark matter; future experiments, the Large Hadron Collider, the future lepton, and hadron colliders.</td></tr>
<tr><td>Books and bibliography</td><td>- F. Halzen, A.D. Martin, Quarks and Leptons: An Introductory Course in Modern Particle Physics (John Wiley & SonsParticle Physics, Martin B R and Shaw G (2nd edn Wiley 1997).
- Introduction to High Energy Physics, Perkins D H (4th edn CUP 2000).
- Introduction to Elementary Particles, Griffiths D (Harper & Row 1987)</td></tr>
<tr><td>Additional materials</td><td>Teacher’s slides and other materials on internet.</td></tr>
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Work schedule			
Total	Lectures	Hands on (Laboratory, working groups, seminars, field trips)	Out-of-class study hours/ Self-study hours

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Hours				
	32	*30*		*88*
ECTS				
	4	*2*		
Teaching strategy				
	Lectures will be delivered in person or in streaming via Teams. A blended learning approach will be adopted by combining traditional face-to-face class lectures with the use of digital technologies. Classroom lessons supported by video projector and with the help of networked PCs and, if needed, in streaming via Teams. Provision of digital content and seminar aimed at deepening the topics covered by the course, followed by a discussion in classroom.			
Expected learning outcomes				
Knowledge and understanding on:	*The student will acquire the tools for understanding physical phenomena and their mathematical formulation:* - *Knowledge of the theoretical framework of the Standard Model (quantum field theory and special relativity)* - *Understanding of the phenomenological aspects of elementary particle physics and the ability to put in the theoretical context the phenomenology of elementary processes.* - *Knowledge of experimental observables for physics measurements and understanding of experimental methods for implementing measurements.* - *Understanding of the limitations and open questions in the current description of fundamental interactions.* *Through the historical development of the Standard Model the student will learn how scientific theories are born, from the scientific observation of a phenomenon to the development of hypotheses through the formalism of theoretical models, to the rigorous process of hypothesis testing through experimental tests and data analysis.* *The student will acquire critical thinking, creativity, and analytical skills.*			
Applying knowledge and understanding on:	*The student will develop the ability to analyze phenomena with a critical attitude, having the theoretical and experimental tools to verify the properties and foundations of the proposed theories and models.* *The student will acquire the know-how to apply knowledge in different contexts and will be able to perceive the interdisciplinary value of the theories and experimental methodologies learned.* *The student will acquire knowledge and understanding of experimental methods and techniques to do high-level research in any field, including in an international context.*			
Soft skills	• *Making informed judgments and choices* *The student will develop the ability to analyze the phenomenology with a critical attitude, having the theoretical tools to verify the properties and foundations of the proposed theories and models. The student will learn how to analyse problems and results, and develop critical skills to get autonomously conclusions, highlighting, where possible, the approximations and assumptions and any weaknesses in the reasoning.* • *Communicating knowledge and understanding* The student will acquire skills on how to present scientific concepts and results in a precise, accurate and direct way.			

	He/she will develop an aptitude to share the opinions with colleagues and working in groups to understand problems and to infer the solutions and the research strategies through scientific discussion. • *Capacities to continue learning* *The student will learn how to consult bibliographic material, databases, and scientific literature, in order to continue her/his studies in the field of experimental, theoretical particle physics and any other discipline with an open-minded and interdisciplinary approach.*

Assessment and feedback	
Methods of assessment	*Oral examination will consist of a colloquium typically around topics explained during the course and a question on applied aspects of the topics covered in the course.*
Evaluation criteria	• Knowledge and understanding *At the end of the course the student must demonstrate to have:* - *Basic knowledge of the theoretical aspects and an understanding of the experimental aspects of the Standard Model.* - *Understanding of the phenomenological aspects of elementary particle physics and ability to put in the proper context the phenomenology of elementary processes within the theoretical model.* - *Knowledge of the experimental observables for physics measurements and understanding of experimental methods to implement measurements.* - *Understanding of the limitations and open questions in the current description of fundamental interactions.* • Applying knowledge and understanding *The student should be able to apply the acquired knowledge to solve typical problems in particle physics, such as the production and decay of elementary particles using relativistic kinematics, calculations of cross sections, description of processes using Feynman diagrams. She/he should be able to apply the rules of composition of angular moments and isospin in Quantum Mechanics and the properties of the phenomenology discussed during the course.* *The student should be familiar with the theories underlying modern experiments and should have learned the tools to apply these theories to calculate experimentally measured observables.* *The student should have acquired the skills to carry out research work in particle physics independently.* *The student should have the knowledge and understanding of experimental methods and techniques to do high-level research in any field, including in an international context.* • Autonomy of judgment *The student should have acquired the ability to identify problems by making qualitative and quantitative observations and analyzing them critically.* *She/he should be able to identify relevant measurements to verify properties and models.* *She/he should have the ability to carry out scientific research in any field and to draw conclusions independently through the analysis and interpretation of experimental data.*

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	• Communicating knowledge and understanding *The student must demonstrate the ability to express him/herself using the appropriate terminology, commonly used in high energy and elementary particle physics.* *She/he should be acquitted with the tools necessary for the presentation of the scientific data. She/he should be able to study a scientific paper, understands the results and present them.* • Communication skills *The student has the skill to communicate scientific concepts in proper lexicon and appropriate English language, to work in a group and to develop strategies for problem solving by comparing with colleagues and teachers.* *He/she can communicate with other coworkers by asking questions and listening to answers, debating in a clear and critically way.* *The student should be able to analyse an experiment in front of an audience, evaluate the experimental techniques and results and deduce possible future developments, supporting a scientific discussion using the topics learnt during the course.* • Capacities to continue learning *The student should demonstrate to have gained the skills to consult efficiently the bibliographic material, databases and material on internet. The student should be able to study independently, by selecting properly the sources, texts, scientific literature and web resources, with an open-minded and interdisciplinary approach. In order to expand the knowledge she/he should be able to select interesting topics, address and solve new problems, and acquire new tools.*
Criteria for assessment and attribution of the final mark	*Oral examination consisting of a colloquium typically around topics explained during the course. The final mark is given in thirtieths. The examination is considered passed when the mark is greater than or equal to 18.* *The following aspects will be assessed:* - *Acquisition of knowledge and understanding of concepts. Maximum score can be achieved if a very broad, complete, and in-depth knowledge of the contents is demonstrated.* - *Ability to relate the concepts and their implications and ability to apply the contents. Maximum score can be achieved if excellent ability to analyse, synthesize and make interdisciplinary connections is demonstrated.* - *Use of appropriate language and terminology* - *Expository skills and mastery of exposition*
Additional information	