General information		
Academic subject	Particle Detector Physics	
Degree course	Physics - LM17	
Academic Year	First	
European Credit Transfer and Accumulation System (ECTS)	6	
Language	English	
Academic calendar (starting and ending date)	First semester (September-December)	
Attendance	Not mandatory, but strongly recommended	

Professor/ Lecturer	
Name and Surname	Marcello Abbrescia
E-mail	marcello.abbrescia@uniba.it
Telephone	0805443143
Department and address	Interuniversity Physics Department - Bari
Virtual headquarters (Microsoft Teams code)	
Tutoring (time and day)	By appointment (made by phone or email) with the teacher

Syllabus	
Learning Objectives	The course aims at providing students with an overview of the particle detectors used for elementary particle physics, astroparticle physics and medical physics. Starting from the fundamental mechanisms of interaction of radiation with matter, gaseous, semiconductor, and scintillation detectors are illustrated, and calorimetry techniques are discussed, together with their applications for particle identification and tracking and energy measurements.
Course prerequisites	Basic knowledge of: electromagnetism, structure of matter, particles and nuclear physics, integral and differential calculus, analytical functions.
Contents	**1. Introductory concepts** The tradition of imaging detectors. First particle discovery. Cloud chambers. Units of measure. From image to electronic detectors. Spark chambers. More sophisticated electronic detectors. Design of particle detectors. Characteristics of particle detectors. Detectable particles. Basics of interaction of particles in detectors. Structure of High Energy Physics experiments. Particle detectors of astroparticle physics and medical applications. **2. Interaction of particles with matter** Basics of particle detection and identification. Possible types of interactions. Cross section. Beam attenuation in matter. Electromagnetic interactions of charged particles in matter. Ionization and excitation. Energy loss of charged particles. Bohr's calculation of dE/dx. Bethe-Bloch equation and its meaning. Dependence on A and Z. dE/dx for particle identification. Mean particle range and Bragg's peak. Fluctuations of energy loss. Energy loss for electrons. Bremsstrahlung. Energy loss for muons. Multiple scattering. Cherenov radiation. PID with threshold Cherenkov detectors. Transition radiation. Transition radiation detectors. Interactions of photons with matter. Intensity of a photon beam. Photon cross section. Photoelectric effect. Emission of photo-electrons. Relaxation mechanisms. Fluorescence yield. Compton scattering. Pair production. Material dependence of electromagnetic interactions. **3. Gaseous detectors** Schematics and working principles of gaseous detectors. Excitation and ionization in gases. Secondary ionization. Energy loss in various gases. Statistics of ion-electron production. Diffusion of electrons and ions in gases. Drift of ions/electron in gases. Drift velocity. Diffusion in electric fields. Diffusion in magnetic fields. Effects of electronegative gases. Intense electric fields. First Townsend coefficient. Korff approximation. Electron gain in gases. Avalanches. Streamers. Breakdown. Operational regimes of gaseous detectors. Geometries of gaseous detectors. Ionization chambers. Limits of ionization chambers. Proportional gaseous detectors. Avalanche development in proportional detectors. Evaluation of

	detector gain. Diethorn formula. Choice of the gas filling. Use of quencher gases. Aging in wire detectors. Geiger-Muller counters. Multi-wire proportional chambers. Electric field and potential in a MWPC. Choice of the geometry. Spatial resolution in MWPC. Electrostatic forces. Drift chambers. Position measurements in drift chambers. Space-time relationship. Stability of operation. Geometries of drift chambers. Time Projection Chambers. Examples of TPC. The streamer regime. Streamer tubes. Visual streamer detectors. Resistive Plate Chambers. RPC: avalanche and streamer mode of operation. Examples of application of RPC in modern HEP experiments. **4. Solid state detectors** Historical developments of solid state detectors. Advantages and disadvantages of semiconductor detectors. Elemental semiconductors. Compound semiconductors. Intrinsic semiconductors. Band structure of electronic levels. Temperature dependence. Fermi energy. Intrinsic carrier concentration. Drift velocity and mobility. Resistivity. Properties of intrinsic Si and Ge. Principles of operation of a Si detector. n-type doped silicon. p-type doped silicon. Fermi level in doped semiconductors. Donor and acceptor levels in Si and AsGa. p-n junctions. Electrical characteristics of a p-n junction. Forward and reverse bias. Depletion zone. Leakage current. Detector capacitance and depletion voltage. Manufacturing techniques. Crystals and wafers. Pad detectors. DC-coupled strip detectors. AC-coupled strip detectors. Biasing methods: poly-silicon, punch through, FOXFET. Stereo modules. Double Sided Silicon Detectors. Pixel detectors. Landau distribution in thin layers. Signal to noise in silicon detectors. Noise contributions: leakage current, detector capacitance, parallel resistor and series resistor. Position resolution. Diffusion. Digital and analog readouts. Radiation damage. Point and cluster defects. Dependence on type and energy of radiation. Aging and leakage current. Annealing. Effective doping concentration. Type inversion. Charge collection efficiency. The CMS tracker detector. **5. Signal formation in particle detectors** Basics of electrostatics. Induced charged on metal electrodes. Superposition principle. Induced charge on an infinite plane. Charge moving in front of a plane. Induced charge on a strip electrode. Reciprocity theorem. Weighting potential. Induced charge in the general case. Induced current. Ramo-Shockley theorem. Signal polarity. Parallel plate geometry. TCT diamond detector signals. Signals in ionization chambers. Signals in ATLAS liquid Ar calorimeter. Signals in diamond detectors. Signals in silicon detectors. Signals in gaseous detectors. Weighting field in parallel strip geometry. Signals in wire chambers. **6. Calorimetry** Basic concepts. Types of calorimeters. Electromagnetic calorimeters. Electromagnetic cascades. Radiation length. Critical energy. Toy model for electromagnetic cascades. Longitudinal and transversal development of EM cascades. Cascade measurements. Response and linearity. Sources of non-linearity. Homogenous calorimeters. Sampling calorimeters. Energy resolution of EM calorimeters: sampling fluctuations, noise term, constant term, additional contributions. The ECAM of the CMS experiment. The FERMI-LAT calorimeter. Hadronic calorimeters. Hadronic cascades. Interaction length. Material dependence. Lateral and longitudinal development of hadronic cascades. Internal EM cascades and EM fraction. Compensating calorimeters. Calorimeters with scintillators, with liquid gases, with proportional counters, with streamer or Geiger tubes. Energy resolution of hadronic calorimeters. The HCAL of the CMS and ATLAS experiments. **6. Scintillators** General characteristics. Basic counter set-up. Inorganic scintillators: time constant and light output. Scintillation in liquid noble gases. Organic scintillators. Plastic and liquid scintillators. Wavelength shifting. Light yield and Birk's law. Photon detection. Photomultipliers, photocathodes, dynode chain. Energy resolution of photomultipliers. Micro Channel Plates. Silicon Photomultipliers. Applications: spaghetti calorimeter, CMS ECAL, ATLAS tile calorimeter, CALICE analogue HCAL,

	CALICE scintillator ECAL. **7. Particle Identification and detector systems** Tracking detectors. Magnets for 4π experiments. Tracking in a magnetic field. Momentum resolution. Particle Identification. Motivations for particle identification. Measurement of particle velocity: Time Of Flight, Cherenkov detectors, Transition radiation detectors, the TRD of ATLAS and ALICE, dE/dx. PID in space experiments: PAMELA. Detector systems: design choice. Occupancy and track density. Material budget. Event rate. Trigger and trigger levels.
Books and bibliography	- Hermann Kolanoski and Norbert Wermes, Particle Detectors: Fundamentals and Applications, Oxford University Press, 2020, ISBN-13: 9780198858362 - F. Sauli: Gaseous Radiation Detectors: Fundamentals and Applications, Cambridge University Press, July 2014, ISBN: 9781107337701 - C. Groupen and B. Swartz, Particle Detectors, Cambridge University Press, 2008 - G. Knoll, Radiation Detection and Measurement, Wiley and sons, 3rd edition - W. R. Leo, Techniques for Nuclear and Particle Physics experiments, Springer-Verlag, 1994 - Christian W. Fabjan and Herwig Schopper Editors, Particle Physics Reference Library, Volume 2: Detectors for Particles and Radiation, Springer
Additional materials	Additional material consisting of the transparencies presented during lectures.

Work schedule			
Total	Lectures	Hands on (Laboratory, working groups, seminars, field trips)	Out-of-class study hours/ Self-study hours
Hours			
150	40	15	95
ECTS			
6	5	1	

Teaching strategy	
	A "blended learning" approach is used, combining classroom lectures with the use of digital technologies, and including student-led discussions on the technologies examined, and simulations for a "hands-on" approach. Classroom lessons are supported by a video projector and with the help of transparencies provided to the students. Furthermore, from time to time, digital content and seminars are provided, as well as specialized software aimed at deepening the topics covered in the course, followed by a discussion in the classroom.

Expected learning outcomes	
Knowledge and understanding on:	At the end of the course, the student will have acquired the following knowledge: 1) will know the main mechanisms of interaction of radiation with matter; 2) will be able to understand how to use the radiation-matter interaction mechanisms to obtain a measurable signal through electronic devices; 3) will know the main types of particle detectors: scintillators, semiconductor detectors, gaseous detectors; 4) will be able to understand the structure of complex experimental apparatuses such as those used in high energy physics or in the physics of neutrinos and cosmic rays.
Applying knowledge and understanding on:	At the end of the course, the student will have acquired the following skills: 1) will be able to develop a general design and optimize a detector for measuring the position and trajectory of charged particles; 2) will be able to develop a general design and optimize a detector for energy measurement of charged and neutral particles with calorimetric techniques; 3) will know how to combine the different detection techniques to determine the type of particle being measured and measure its main characteristics.
Soft skills	• **Making informed judgments and choices** At the end of the course, the student Development of the critical sense

	necessary to distinguish the significant aspects from the marginal ones in the design of a particle detector and in the evaluation of its characteristics, evaluating the correctness of the assumptions and taking into account the approximations adopted. • **Communicating knowledge and understanding** The student will acquire skills on how to present scientific concepts and experimental results concerning the physics of particle detectors in an accurate, precise and direct way. He will acquire the ability to interact with his colleagues and work as a team to achieve a shared goal. • **Capacities to continue learning** The student will develop the ability to access sources directly, and to read, applying a critical sense, an article or scientific material concerning particle detectors for high energy physics.

Assessment and feedback	
Methods of assessment	The final exam verifies the acquisition of the expected knowledge and skills by means of an oral exam. In the oral exam, which typically lasts 40-50 minutes, students are usually asked to discuss three topics covered during the course.
Evaluation criteria	• **Knowledge and understanding** The ability to master the main instrumental techniques for the detection of particles in high energy physics will be assessed, and the ability to identify and use the proper experimental technique in relation to the scientific experimental objective to be achieved in relation to the identification and the measurement of the properties of elementary particles. • **Applying knowledge and understanding** The ability to apply the knowledge acquired in the field of particle detector physics for the design of high-energy or astroparticle experiments will be evaluated. The ability to perform simple calculations and numerical simulations for the optimization of apparatuses for high energy physics will also be evaluated. • **Autonomy of judgment** The acquired ability to apply critical reasoning to select the relevant aspects in the design of detectors and experiments in the field of particle and astroparticle physics will be evaluated. The ability to identify potential problems through qualitative and quantitative observations and to propose original solutions will be evaluated. • **Communicating knowledge and understanding** The student's ability to present orally in English, with proper language and terminological rigour, scientific topics related to the physics of particle detection, briefly illustrating the motivation for the choices made and the expected results, will be assessed,. • **Communication skills** The student skill to communicate scientific concepts in proper lexicon and appropriate English language, and to effectively communicate with colleagues and teachers in order to develop strategies for problem solving will be assessed. • **Capacities to continue learning** The student ability to understand the physics of detectors, starting from physical principles and not with a simple phenomenological approach, will be evaluated. Furthermore, the ability to effectively consult the indicated bibliographic material and the supporting material, correctly selecting the useful sources in the various cases and focusing on the significant aspects will be evaluated.
Criteria for assessment and attribution of the final mark	During the oral exam, during which 100% of the final score is attributed, the ability to illustrate the topics with completeness and precision to other people, connect different parts of the program, use the scientific language introduced in the course and the mathematical formalism at appropriate to the level of the course will be evaluated.
Additional information	