Università di Pisa
Corso di Laurea Magistrale in Fisica

Interazioni Fondamentali (9 CFU)

Docente titolare: Prof. Francesco Forti
A.A. 2021-2022

Course goals and organization

Basic quantitative knowledge of the the physics of elementary particles and of their interactions, from the phenomenological and experimental point of view.
Ability to estimate quantitatively processes and experiments.
Knowledge of the time development of the main discoveries.
The course is organized with classroom lessons and exercise sessions.
Attendance to the lectures is recommended.
The final exam consists of a written test and an oral examination.

Prerequisites

Advanced electromagnetism, non relativistic quantum mechanics and special relativity. Calculus, linear algebra, matrix calculation, complex plan analysis.
This course assumes the completion of the bachelor degree, and with particular regard of the Physics 3 and Quantum mechanics courses.
The course uses many tools developed in the course of Theoretical Physics 1, whose simultaneous attendance is strongly advised.

Course program

Module 1: Historical and phenomenological introduction (6)

- Experimental methods in particle physics. Sources: cosmic rays, reactors and isotopes, accelerators. Extracted beams and colliders
- Reminder of radiation detection techniques and detectors.
- Brief history of the discovery of elementary particles and construction of the Standard Model. [Experiments: Conversi, Pancini, Piccioni; Powell; Cowen Reines, Andersen]
- Photon, mesons, antiparticles, baryons, leptons, strange particles, quarks and gluons, intermediate vector bosons, Higgs bosons.
- Main characteristics of the fundamental interactions and Standard Model phenomenology.
- Forbidden and allowed diagrams in the SM.

Module 2: Basic methodology (10)

- Reminder of relativistic kinematics. Notation for 4-vectors. Mandelstam relativistic invariants. Natural units
- Scattering and decay. Mean life, width, cross section. Lorentz-invariant phase space. Transition matrix. Fermi golden rule.
- Relativistic equations: Klein-Gordon and Dirac. Classification of elementary particles: spin, fermions and bosons. Particles and anti-particles.
- Concept of Feynman diagrams and calculation methods

Module 3: Symmetries and conservation laws. (6)

- Symmetries, invariance, conservation laws, symmetry breaking.
- Discrete symmetries, C, P e T. Statement of CPT theorem.
- Intrinsic parity of particles (P). Parity of the pion. [Chinowsky and Steinberger experiment(1954) on slow pion capture on deuteron]
- Intrinsic charge conjugation (C). C for photon and π^0.
- Continuous symmetries and conservation laws. Statement of Noether theorem.
- Use of group theory and their representation. Angular momentum and composition rules.
- Isospin symmetry. Doublets (nucleon) and triplets (pion). Flavor SU(2) symmetry. G-Parity
- Baryons and mesons from ud quarks: n,p,π,Δ,ρ,ω

Module 4: Electrodynamics (8)

- Feynman rules: identical particles in final state; sum on final states; average on initial states. Interaction as exchange of mediator particle.
- Charge conservation and gauge symmetry.
- QED Feynman diagrams.
- e+e- annihilation in a muon pair.
- Reminder of hydrogen levels, fine and hyperfine structure, Lamb shift.
- Positronium, level structure, decay channels. Parapositronium and ortopositronium
- Alpha QED evolution with energy.

Module 5: Hadrons and strong interactions (12)

- Hadronic resonances. The 3/2+ Δ baryons.
- Associated production of K – Λ and strangeness discovery. S=-1, -2, -3 baryons
- Dalitz plot in three-body phase space. Angular momentum and parity of final states of two or three neutral or charged pions.
- Pseudo-scalar mesons. Strange mesons K. The theta-tau puzzle. η, η'.
- Vector bosons: ρ,ω, φ. ρ decay in two charged and neutral pions.
- Approximate flavor SU(3) symmetry. Group derivation of quark model. Baryonic number. Organization in octets and decuplets.
- Pointlike nature of quarks in Deep Inelastic Scattering
- Hadronic production at e+e- colliders. Ratio R of hadronic production to muon pairs. Experimental evidence of quark colour.
- Discovery of the J/psi (charm) and of its excited states. [Richter and Ting experiments and the november revolution]
- Angular distribution of jets and quark spin. Events with tre hadronic jets and evidence of gluon.
- The third family and the completion of the quark model [Lederman experiment]
- Quarkonium. Measurement of α_s and energy dependance. OZI selection rule.
- Feynman diagrams for hadronic processes.

Module 6: Weak interactions (12)

- Charged and neutral current interactions. Muon decay. Fermi constant and 4-fermion process.

- Neutron beta decay. Pion decay and helicity suppression.
- Neutrinos and conservation of leptonic flavor. Dirac and Majorana neutrino. Neutrinoless double beta decay [Experiment on muon neutrino flavor]
- Limits on neutrino masses. [Measurement with tritium]
- Parity violation in weak interactions. [Wu experiment]
- Helicity and chirality. V-A weak currents. Pion decay.
- Helicity of the neutrino. [Goldhaber experiment]
- Weak charged currents in quarks and the Cabibbo angle.
- Charm and GIM mechanism. Absence of Flavor Changing Neutral Currents (FCNC)
- CKM matrix and quark mixing. Particle-antiparticle conjugation violation (CP)
- Feynman diagrams for weak processes.

Bibliography

Complete textbooks:
A. Bettini - Introduction to Elementary Particle Physics - Cambridge U.P. (2012),
D. Griffiths - Introduction to elementary particles - Wiley (2008),
D.H. Perkins - Introduction to High Energy Physics -- Cambridge U.P. (2000),
D. Thomson, Modern Particle Physics, Cambridge U.P. (2013).
M. E. Peskin, Concepts of Elementary Particle Phsyics, Oxford U.P. (2018)

Further reading:
H.J. Lipkin, Lie Groups for Pedestrians, Dover (2002)
Cahn, Goldhaber - The experimental foundations of Particle Physics - Cambridge U.P. (2009).
M.S. Sozzi - Discrete symmetries and CP Violation - Oxford G.T. (2008).
Povh, Rith, Scholz, Zetsche - Particles and nuclei - Springer 6-th Ed. (2008).
Hagedorn, Relativistic Kinematics

On the interactions of the radiation with matter and particle detectors:
D. Green - The physics of particle detectors - Cambridge U.P. (2000),
C. Grupen - Particle detectors - Cambridge U.P. (1996),
W.R. Leo -Techniques for nuclear and particle physics experiments - Springer-Verlag (1994).
J.D. Jackson - Classical Electrodynamics - Wiley (1998),
T. Ferbel (ed.) - Experimental techniques in HEP - Addison Wesley (1987),
K. Kleinknecht - Detectors for particle radiation - Cambridge U.P. (1998).

Essential general reference: Particle Data Group - Review of particle physics – pdg.lbl.gov

At the link: https://elearning.df.unipi.it/course/view.php?id=312 interested students will find texts and solutions of the previous years written tests and various additional scientific and historical papers and references.

Office: studio 141 Edif. C 1st floor (request appointment)
Tel 050.2214341 Email: Francesco.Forti@unipi.it