



# UNIVERSITÀ DI PISA

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## FUNDAMENTAL INTERACTIONS / INTERAZIONI FONDAMENTALI

**FRANCESCO FORTI**

Anno accademico 2021/22  
CdS FISICA  
Codice 305BB  
CFU 9

Moduli	Settore/i	Tipo	Ore	Docente/i
INTERAZIONI FONDAMENTALI	FIS/04	LEZIONI	54	FRANCESCO FORTI GIOVANNI SIGNORELLI

### Obiettivi di apprendimento

#### *Conoscenze*

Conoscenza quantitativa di base della fisica delle particelle elementari e delle loro interazioni, dal punto di vista fenomenologico e sperimentale. Conoscenza dello sviluppo temporale delle principali scoperte.

#### *Modalità di verifica delle conoscenze*

La verifica delle conoscenze acquisite avviene attraverso un colloquio di esame.

#### *Capacità*

Valutazione quantitativa di processi di scattering e decadimento di particelle elementari. Progettazione concettuale di esperimenti di fisica delle particelle

#### *Modalità di verifica delle capacità*

La verifica delle capacità acquisite avviene attraverso le discussioni degli esercizi proposti per casa e durante le esercitazioni e tramite un esame scritto che consiste nella risoluzione di alcuni esercizi.

#### *Prerequisiti (conoscenze iniziali)*

Conoscenze di elettromagnetismo avanzato, meccanica quantistica non relativistica e relatività ristretta. Competenze di calcolo differenziale, algebra lineare, calcolo con matrici, analisi nel piano complesso.

La frequenza al corso presuppone il completamento della laurea triennale, e in particolare il superamento degli esami di Fisica 3 e Meccanica Quantistica.

#### *Indicazioni metodologiche*

Il corso è organizzato con lezioni ed esercitazioni in aula con frequenza fortemente consigliata.

#### *Programma (contenuti dell'insegnamento)*

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



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- 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  $\gamma$ .
- 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,?,?,?,?

### 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

### Module 5: Hadrons and strong interactions (12)

- Hadronic resonances. The  $3/2^+$  ?
- Associated production of K – ? 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. ?, ?'.
- Vector bosons:  $\rho, \omega, \phi$ . ? 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 three hadronic jets and evidence of gluon.
- The third family and the completion of the quark model [Lederman experiment]
- Measurement of  $\alpha_s$ . OZI selection rule.
- Concept of running coupling constants for QED and  $\alpha_s$
- 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.

### Bibliografia e materiale didattico

#### Complete textbooks:

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

#### Further reading:



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- 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:

- Green - The physics of particle detectors - Cambridge U.P. (2000),
- 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),
- Ferbel (ed.) - Experimental techniques in HEP - Addison Wesley (1987),
- Kleinknecht - Detectors for particle radiation - Cambridge U.P. (1998).

Essential general reference:

- Particle Data Group - Review of particle physics – [pdg.lbl.gov](http://pdg.lbl.gov)

### Modalità d'esame

L'esame finale è strutturato con una prova scritta ed una prova orale.

### Pagina web del corso

<https://elearning.df.unipi.it/course/view.php?id=312>

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