UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Theory and Phenomenology of Fundamental Interations

2122-1-F1701Q128

Aims

Provide the fundamental bases of the Standard Model, in the electroweak and strong sector, the tools for cross-section and decay-rate calculations. Deepen the knowledge of the phenomenology of the fundamental particles.

Contents

Introduction to the Standard Model of the electroweak and strong interactions: the SU(2)xU(1)xSU(3) model. The spontaneous symmetry breaking, the Higgs boson, and the phenomenology of the strong and electroweak interactions.

Detailed program

1. **Mathematical tools**
   - The ? and ? functions. Angular volume in *d* dimensions
   - Feynman parametrization and one-loop integrals in dimensional regularization
   - Passarino-Veltman tensor reduction
2. **Kinematics**
   - Phase space
   - Cross sections
   - Decay widths
3. **The Standard Model Lagrangian**
   - Review of the SU(N) algebra. Considerations on SU(2) and SU(3)
   - Abelian gauge theories

- Non-Abelian gauge theories
- **The electroweak sector of the Standard Model**
  - Spontaneous symmetry breaking, the Higgs potential, vector-boson masses (W^\pm and Z)
  - Fermion masses: Yukawa potential, Cabibbo-Kobayashi-Maskawa (CKM) matrix, CP violation
  - Lepton masses, Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix, Dirac and Majorana fermions
  - The electroweak vertices of the Standard Model
- **Quantum Chromo Dynamics (QCD)**
  - The color algebra
  - The QCD vertices
  - Computation of the QCD vertices from gauge invariance: studies on q \bar{q} \to \gamma\gamma and q \bar{q} \to gg
  - Sum over polarizations

4. **Computation of several cross sections and decay widths. Comparison with the experimental values**
   - Decay widths of the Z,\, W^\pm,\, H bosons
   - e^+ e^- \to \mu^+ \mu^- . The pole of the Z boson mass
   - e^- \nu_\mu \to \mu^- \nu_e in the four-fermions theory by Fermi and in the Standard Model
5. **The optic theorem**
   - Relation between the decay width and the imaginary part of the self energy corrections
   - Unitarity bounds
6. **Deep-Inelastic Scattering (DIS)**
   - Introduction the "naive" parton model
   - The need for color: \Delta^{++}$ and e^+e^- into hadrons
7. **Review of the renormalization procedure**
   - The renormalization of the electromagnetic and of the strong coupling constant
   - The renormalization scale and the ?-function in QED and QCD
   - The asymptotic freedom in QCD
   - The renormalization group equations
8. **Electron-positron annihilation into hadrons at Next-to-Leading Order (NLO)**
   - Virtual corrections in dimensional regularization
   - Real corrections
   - Phase space
   - Total cross section and cancellation of the divergences
9. **Final-state soft and collinear singularities**
   - Eikonal approximation
   - Infrared-safe quantities, the shape variables
   - The Sterman-Weinberg jets
   - The subtraction methods
10. **Initial-state soft and collinear singularities**
    - Hadronic differential cross sections and parton distribution functions
    - The Altarelli-Parisi splitting functions
    - The factorization scale
    - The Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) evolution equations

Prerequisites

Basics knowledge of Quantum Field Theory

Teaching form

Frontal lectures.

Textbook and teaching resource

- Notes and lectures can be found at the web page: https://virgilio.mib.infn.it/~oleari
- Further readings:

    1. *An introduction to Quantum Field Theory*, M. Peskin, D.V. Schroeder
    2. *The Quantum Theory of Fields*, S. Weinberg
    3. *Foundations of Quantum Chromodynamics*, T. Muta
    4. *Handbook of perturbative QCD*, G. Sterman
       http://www.physics.smu.edu/scalise/cteq/#Handbook
    5. *QCD and Collider Physics*, K. Ellis, J. Stirling, B. Webber
    6. *Applications of Perturbative QCD*, R. D. Field

- Lectures on the Standard Model and QCD given by several teachers at CERN (Academic Training lectures), at the CTEQ school, TASI

Semester

Second semester.

Assessment method

The exam consists of two written tests. The evaluation is expressed with a grade in thirtieths.

- **The first written test**
  The first written test consists in the resolution of problems concerning the course topics.
  In this way, the real understanding of the course subjects and the ability to apply the acquired knowledge are assessed.
  Students are strongly encouraged to solve previous tests, and also older ones, before coming to the examination.
  The teacher is always available for any clarifications and suggestions for their resolution.

- **The second written test**
  During the second written test the exposition skills and the knowledge of the topics covered in the course are evaluated through the discussion of broad arguments.

During the year at least five exam sessions are provided, typically in the following periods: January, February, June, July, September, October. Further exam sessions can be agreed by contacting me directly

Office hours

By appointment.