Phys 3717 Syllabus (Fall, 2019): Introduction to Particle Physics

1 Introduction

1.1 Elementary Particles: A Historical Account

1.2 General Description of Particles

1.3 High Energy Physics

1.4 The Natural Units and Dimensional Analysis

2 Overview of Relativistic Quantum Mechanics

2.1 Groups and Symmetry

2.2 Rotational Invariance

Angular momentum

2.3 Lorentz Transformation

The boost

2.4 Mass and Spin

Casimirs of the Poincaré group

2.5 Klein-Gordon Equation

Spin-0 and 1

2.6 Dirac Equation

a. Anti-particle solution

b. Dirac algebra

3 High Energy Physics Processes

3.1 Reaction Rate and Fermi's Golden Rule

3.2 Relativistic Phase Space and Particle Kinematics

Kinematics for one-body, two-body and three-body final states

3.3 Feynman Diagram Approach

a. Free particles: wave-function and propagators of spin-0, 1/2, 1

b. Interactions: vertices

c. Vacuum fluctuations: perturbation and loop diagrams

d. Calculational examples: scattering and decays

e. Calculational tools and packages

4 From hadrons to Quarks

4.1 Group Representations

4.2 The Eightfold Way: mesons and baryons

4.3 The Quark Model

a. Three-quark scheme: iso-spin and the "strangeness"

b. The potential model: no "free quarks"

4.4 Heavy Quarks

a. The R-value and $e^+e^- \to$ hadrons

b. charm quark and its discovery

c. beauty (bottom) quark and its discovery

d. truth (top) quark and its discovery

5 The Weak Interaction

5.1 Fermi's four-fermion theory

a. The β-decay and the neutrino

b. The Cabibbo angle and quark mixing

5.2 $V - A$ Interactions

Parity and Parity violation

5.3 Charge conjugate and CP violation

a. Heavy meson decays

b. Kobayashi-Maskawa matrix and CP violation

5.4 Time reversal and CPT theorem

6 High Energy Collider Experiments

6.1 Accelerators

a. The "Nature's accelerator": cosmic rays

b. Linear accelerators (Linac)

c. Cyclic accelerators (cyclotrons and synchrotron)

d. Colliders

6.2 Particle Detectors

a. Particle interactions with matter

b. Tracking chambers

c. Calorimeters

d. Triggering and data acquisition

6.3 Monte Carlo Simulations

a. Monte Carlo integration

b. Experimental simulations

c. Event generators

6.4 Statistical Treatment of Data

a. Statistical distributions and errors

b. Statistical significance and discovery

6.5 Physics at colliders: A few samples

a. $e^+e^- \to Z^0$

b. Deeply inelastic scattering in ep collisions

c. Drell-Yan signals: $\gamma^*, W^\pm, Z^0 \to$ a pair of leptons

d. Quark and gluon jets

e. "Missing energy"

f. The Higgs boson signals

7 Electroweak Unification: The Standard Model

a. The particle zoo and their interactions in the SM

b. The Higgs mechanism and mass generation of elementary particles

c. Confronting the SM at the high-energy frontier

8 Open Questions in HEP

- What is the Higgs boson? Who gave the mass to the Higgs boson?
- Neutrino masses: Dirac or Majorana?
- What is "dark matter"?
- Where is "anti-matter"?

- Unification of forces?
- Larger (largest) symmetry: Supersymmetry?
- Extra space-time dimensions and string theory?
- ... ...