Physics 3717, Fall 2019
Course Title: Particle Physics

Room 103 Allen Hall, MW 9:30−10:45am

by Prof. Tao Han, than(at)pitt.edu, 420B Allen Hall

Prerequisites: E&M 2555; Quantum Mechanics 2565, 2566.
The course is designed to be self-contained and no need for previous knowledge of particle physics.

Text book:
• Andrew J. Larkoski: "Elementary Particle Physics: An Intuitive Introduction" Cambridge University Press 2019.
I will largely use my own lecture notes that may deviate from the text book somewhat in ordering and in treatments. I will post the notes at CourseWeb after the lectures.

References:
• David Griffiths: "Introduction to Elementary Particles", Wiley-VCH 2010, second revised edition.
• Peskin and Schroeder: "An Introduction to Quantum Field Theory", Addison-Wesley 1995.
• Review of Particle Physics, Particle Data Group, Phys. Rev. D 98, 030001 (2018) and 2019 update.

Course Description:

This course is an introduction to elementary particle physics, the description of Nature at the shortest distance scales. This class will emphasize the theoretical underpinnings of the Standard Model (SM) of particle physics and its experimental verification.
• After a historical account for particle physics thus far, we give an introduction to the necessary theoretical tools: special relativity and quantum mechanics, Fermi's Golden Rule for quantum transitions, elementary statistics, and Feynman diagrams.
• We then present some basic knowledge for experimental methods for measuring elementary particle interactions at collider experiments and their simulation with modern Monte Carlo tools. In connecting theory and experiments, we show some historically important physical processes and experimental discoveries at colliders.
• We root our presentations on the two fundamental forces that dominate physics at the shortest accessible length scales: the electroweak force and the strong force, which form the foundation for the successful theoretical framework, the Standard Model.
• We will end the course with an outlook for physics beyond the SM, indicating the exciting future for the field of high energy physics.

We emphasize the overall conceptual understanding of the underlying physics, and try to avoid technicalities in the due course.

Grade: The grade will be based on:

a. 60% homework performance (bi-weekly)

b. 20% oral presentation (about 20−30 min.) on a topic related to the course materials or your research interests

c. 20% participation of discussions during the lectures and after class

The tentative table of contents follows.

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?
- ... ...