PHYS 575 (Particle Physics I), Spring 2021

Contact Information

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Course website: `http://courses.physics.illinois.edu/phys575/sp2021`

Overview

PHYS 575, "Particle Physics I," is a quantitative introduction to the Standard Model of Particle Physics. No background in quantum field theory will be assumed, but prior exposure to the topics in PHYS 582 and/or PHYS 583 will be extremely helpful in understanding the justification and context for many of the calculations we will do. (Note that PHYS 570 is listed in the course catalogue as a prerequisite, but the material covered in that course is not actually required to understand what we will do in this course.) By the end of the course, students will be familiar with the particles, forces, and interactions of the Standard Model, and will be able to perform basic calculations which can be directly compared with experimental results to justify our understanding of the Standard Model as the correct description of elementary particle processes at energies up to 1 TeV.

The language of high-energy physics in general, and the Standard Model in particular, is mathematics. The first 4 weeks of the course will be devoted to group theory and understanding how the observed symmetries of nature impose themselves on the structure of fundamental particle interactions. As a reward for this mathematical introduction, we will be able to write down the complete Lagrangian for the Standard Model by the end of Week 4. After an interlude devoted to the experimental details of elementary particle detection, the remaining 7 weeks of the course will be devoted to pulling apart this Lagrangian, term by term, and comparing its predictions with concrete experimental results. In the final week of the course, we will take stock of the Standard Model and see where old and new experimental results might point to physics beyond the Standard Model.

Textbooks

We will primarily use the following textbooks for this course, all of which are required. All three are available for online purchase from the Illini Union bookstore. In particular, the books by Larkoski and Peskin do not require any knowledge of quantum field theory, and perform many of the same calculations as Schwartz using reasoning motivated by quantum mechanics.

Schwartz, **Quantum Field Theory and the Standard Model**
Larkoski, **Elementary Particle Physics: An Intuitive Introduction**
Peskin, **Concepts of Elementary Particle Physics**

For additional reading, you many find the following books useful. They are both available for checkout from the library; if unavailable, the instructor and/or TA will provide scans of the suggested reading.

Peskin and Schroeder, **An Introduction to Quantum Field Theory**
Chen (ed.), **Quantum Field Theory Lectures of Sidney Coleman**

Grading

Grading will be based on a combination of homework, class participation, and a take-home problem set which will serve as the final exam. Most homework will be assigned weekly, but occasional problem sets will cover multiple weeks and will be longer (and worth more points) – see schedule below. The final exam will be due on 5/13 at 5pm, via `my.physics` upload. More details on grading and point values can be found on the course webpage. **Please note: Unless a valid, verifiable excuse is given, homework sets which are submitted late will receive a 10% penalty per day (between Friday and Monday a 20% penalty applies). Homework sets which are turned in more than a week late will receive no credit.**

Your final grade for Physics 575 will be based upon your total score on all the components of the course. The total possible score is 2000 points. Homework will count for 1200 points, attendance and participation for 500 points, and the take-home final for 300 points. Letter grade cutoff values can be found on the course website.

Schedule

- **Week 1** (1/25, 1/27) – Introduction to group theory and representations of the Lorentz and Poincaré groups
- **Week 2** (2/1, 2/3) – Classification of elementary particles by mass and spin; unitary representations and relativistic Lagrangians for spin-0 particles with space-time and internal symmetries
  - HW #1 due 2/1
- **Week 3** (2/8, 2/10) – Relativistic Lagrangians for spin-1 and spin-1/2 particles; gauge invariance
  - HW #2 due 2/8
- **Week 4** (2/15) – Lagrangian for the Standard Model
  - **NO CLASS** 2/17
- **Week 5** (2/22, 2/24) – particle detectors, cross sections, and phase space; QED Lagrangian and classical spinor solutions
- **Week 6** (3/1, 3/3) – Quantum electrodynamics (QED) at e^+e^- colliders: cross sections, Feynman rules, angular dependence
  - HW #3 due 3/1
- **Week 7** (3/8, 3/10) – QED at low energies; electron and muon $g-2$, soft and collinear singularities
  - HW #4 due 3/10
- **Week 8** (3/15, 3/17) – QED with quarks: electron-proton fixed-target experiments and deep inelastic scattering, resonances in e^+e^- annihilation
  - HW #5 due 3/17
- **Week 9** (3/22) – Quantum chromodynamics (QCD) at high-energy colliders: gluons, asymptotic freedom
  - **NO CLASS** 3/24
- **Week 10** (3/29, 3/31) – Jets in QCD; discovery of the top quark
- **Week 11** (4/5, 4/7) – Chiral symmetry breaking and pions as pseudo-Goldstone bosons; intro to spontaneous gauge symmetry breaking and Abelian Higgs model
  - HW #6 due 4/5

- **Week 12** (4/12, 4/14) – The Higgs mechanism in the Standard Model; 3 generations and flavor (CKM and PMNS matrices), Feynman rules for electroweak interactions
  - HW #7 due 4/12
- **Week 13** (4/19, 4/21) – Basic electroweak processes and neutrino oscillations; Discovery of the W, Z, and Higgs
  - HW #8 due 4/19
- **Week 14** (4/26, 4/28) – P and CP violation; weak interactions at low energies: muon decay, integrating out the W, introduction to effective field theories
- **Week 15** (5/3, 5/5) – Beyond the Standard Model: SM effective field theory; introduction to dark matter
  - HW #9 due 5/3
- **Week 16** (5/10, 5/12) – **NO CLASS: Finals Week**
  - **Take-home final due 5/13 at 5pm**