# Introduction to Particle Physics

Phys 366

"Not only God knows, I know, and by the end of the semester, you will know." -*Sidney Coleman*

January 28, 2021

**Professor**: Andrew Larkoski
Office: P124
Email: larkoski@reed.edu

**Lectures**: Tuesday, Thursday 10:25-11:45 am (Eliot Chapel and online)
Lectures for this course will consist of two components. I have pre-recorded all lectures for the course and will make the next lecture video available at least two days in advance. At the assigned lecture time, I will hold a live, "flipped-classroom"–like session over Zoom to answer questions, have you work in small groups, etc., covering the lecture that you should have just watched. You can ask questions live, through Zoom chat, or send me an email before lecture to have your question presented and answered anonymously.

**Week of March 8**:
The CAPP has requested that faculty reduce the workload of their courses around the week of March 8 because of the lack of spring break. In response to this, homework 6 will be optional and I will drop your two lowest homeworks (rather than one as usual). More information about the modified schedule will be provided during the semester.

**Office Hours**: Tuesday, Thursday 2-4 pm (Zoom)
`https://reed-edu.zoom.us/j/94705413724`

**Regarding Office Hours**: You are required to virtually visit my office hours at least once in the first 3 weeks of the course. We can talk about anything you'd like, related to the course or not. I use this requirement both to lower the barrier to getting help from faculty as well as a way to get to know each of you!

**Text**: Andrew J. Larkoski, "Elementary Particle Physics: An Intuitive Introduction", Cambridge, 2019.
This book is available for purchase from the bookstore, from Cambridge directly, or anywhere you buy books. There is also an electronic version. See `https://www.cambridge.org/larkoski` for more details.

**Supplemental References**:
Mark Thomson, "Modern Particle Physics", Cambridge, 2013.
Another modern particle physics textbook for undergraduates.

David Griffiths, "Introduction to Elementary Particles", Wiley, 2008.
An elementary introduction from a more historical perspective.

Sidney Coleman, "Aspects of Symmetry", Cambridge, 1985.
Notes from the Erice summer school from Sidney Coleman. Coleman's quantum field theory class at Harvard was legendary and lectures from 1975 were recorded and are available to view online at: https://www.physics.harvard.edu/events/videos/Phys253.

Ta-Pei Cheng, Ling-Fong Li, "Gauge Theory of Elementary Particle Physics", Oxford, 1984.
Graduate-level textbook surveying many fundamental topics in particle physics.

Matthew Schwartz, "Quantum Field Theory and the Standard Model", Cambridge, 2014.
A modern graduate-level book on quantum field theory.

Anthony Zee, "Quantum Field Theory in a Nutshell", Princeton, 2003.
An approachable, readable introduction to ideas in quantum field theory.

**Course Website**: Linked to from my Reed website: `http://people.reed.edu/~larkoski/`

**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 of particle physics and its experimental verification.

This class will broadly consist of three parts. First, an introduction to the necessary theoretical tools like special relativity, Fermi's Golden Rule, elementary statistics, and Feynman diagrams, as well as introductions to experimental methods for measuring elementary particle interactions and their simulation with modern Monte Carlo tools.

With this introduction, we will then discuss the properties of the two fundamental forces that dominate physics at the shortest accessible length scales: the electroweak force and the strong force (quantum chromodynamics). In addition to the predictions and experimental validation of these theories, students will also analyze real data that has been collected by the experiments at the Large Hadron Collider.

**Learning Outcomes**: This course is an introduction to the physics of elementary particles. Weekly homeworks will introduce the subject and have students perform and test calculations to compare to experimental data in the same way that an expert practitioner does. The culture and history of particle physics will also be discussed through the instructor's experience and anecdotes to emphasize to students that fundamentally science is a human endeavor. Through a final project, students will also be able to manipulate and analyze real or simulated particle physics data that has been made public by experiments.

**Course Requirements**: There will be two graded aspects of this course: weekly homework problems and a final project. In calculating your final grade, your two lowest homework scores will be dropped.

**Homework**: Homework will consist of problems taken from the textbook, and will develop methods discussed in lecture. Homework should be written by hand (with pen/pencil and paper) or typed up and is assigned through the course website during the week of classes on that topic. Homework is due by Friday of the following week and is to be submitted to Gradescope. Late homework will not be accepted.

**Final Project**: An important part of science is the ability to efficiently communicate in writing. There will be a final project for this course in which students will study a topic relevant to particle physics in more detail. Students will then write a 5-page, *Physical Review*–style paper on the topic, with appropriate references. More details will be provided throughout the semester.

**Grading**: The amounts to which the homework, final project and participation contributes to your grade are:

| | |
|---|---|
| Homework | 70% |
| Final Project | 25% |
| Visiting Office Hours | 5% |

**Weekly Lecture Topics**: The following page shows a list of topics we'll discuss this semester during each week. This isn't a final schedule, and may possibly change as the semester goes on.

| Week: | Date: | Topic: | Textbook: |
|---|---|---|---|
| 1 | 1/26 | The Big Picture: The Standard Model | Chap. 1 |
| | 1/28 | Dimensional Analysis, Natural Units, and Relativity | Sec. 1.4, 2.1 |
| 2 | 2/2 | Review of Special Relativity I | Sec. 2.1 |
| | 2/4 | Review of Special Relativity II | Sec. 2.2 |
| 3 | 2/9 | A Little Group Theory | Sec. 3.1-3.2 |
| | 2/11 | The Quark Model | Sec. 3.3 |
| 4 | 2/16 | Fermi's Golden Rule | Sec. 4.1-4.2 |
| | 2/18 | Space-Time (Feynman) Diagrams | Sec. 4.3 |
| 5 | 2/23 | Particle Physics Detectors | Sec. 5.1-5.5 |
| | 2/25 | Statistical Analyses | Sec. 5.6 |
| 6 | 3/2 | Electron-Positron Annihilation | Sec. 6.1 |
| | 3/4 | Hadron Production in Electron-Positron Annihilation | Sec. 6.2 |
| 7 | 3/9 | The Parton Model | Sec. 7.1-7.2 |
| | 3/11 | The Gluon | Sec. 7.3 |
| 8 | 3/16 | Non-Abelian Gauge Theories | Sec. 8.1-8.2 |
| | 3/18 | Quantum Chromodynamics | Sec. 8.3 |
| 9 | 3/23 | Parton Evolution | Sec. 9.1-9.2 |
| | 3/25 | Jets in QCD | Sec. 9.3 |
| 10 | 3/30 | Parity Violation in the Weak Interaction | Sec. 10.1-10.3 |
| | 4/1 | V-A Theory Predictions | Sec. 10.4 |
| 11 | 4/6 | Spontaneous Symmetry Breaking | Sec. 11.1-11.2 |
| | 4/8 | The W and Z Bosons | Sec. 11.3 |
| | | **Spring Break** | |
| 12 | 4/20 | CP Violation | Sec. 12.1-12.2 |
| | 4/22 | Neutrinos and their Mixing | Sec. 12.3 |
| 13 | 4/27 | Discovery of the Higgs Boson | Chap. 13 |
| | 4/29 | Particle Physics at the Frontier | Chap. 14 |