Elementary Particle Physics
(Physics 125)

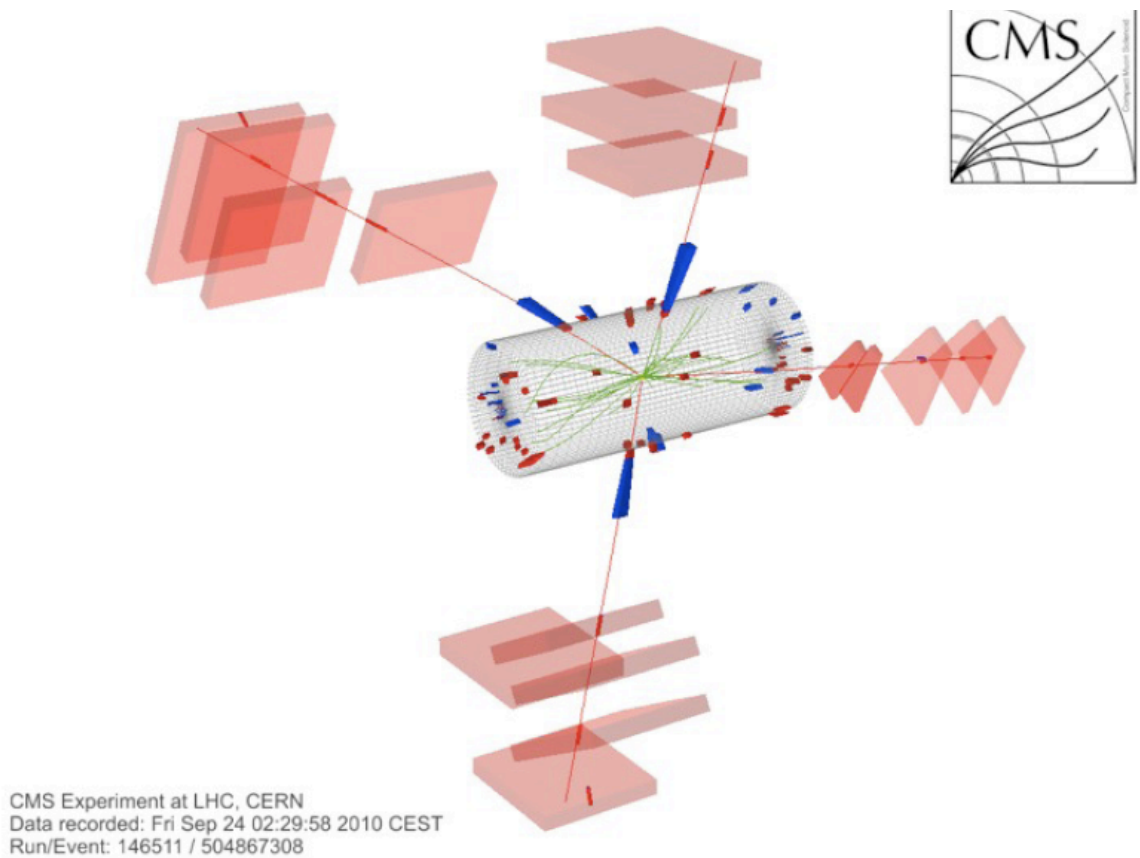
Syllabus, Spring 2012

Professor Jeffrey D. Richman

Broida Hall 5111, 893-8408
richman@charm.physics.ucsb.edu
http://hep.ucsb.edu/people/richman/richman.html

Graduate teaching assistant: Jason Gran
jgran@physics.ucsb.edu

April 2, 2012



Goals of Physics 125

Particle physics addresses fundamental and challenging questions. What are the fundamental constituents of matter? How do they interact? What are the laws of physics that governed the behavior of matter in the early evolution of the universe?

The smallest objects observed so far—quarks, leptons, and gauge bosons—behave in a manner that we can now describe in great detail. Yet, in spite of tremendous progress in this field, many deep mysteries remain. What is the origin of mass? Why do neutrinos have very tiny masses? Why is there a three-fold replication of a basic set of particles (the generation puzzle)? Are quarks truly elementary particles? Why are some conservation laws violated by a narrow class of processes? Why is there much more matter than antimatter in the universe, whereas in most processes, matter and anti-matter are transformed ("created" or "destroyed") in equal amounts? Is there, as theorists predict, an undiscovered ``supersymmetric'' partner for every known type of elementary particle? Do supersymmetric particles account for the dark matter inferred from astrophysical observations, or is the true explanation something completely different ? Are there additional undiscovered dimensions of space?

To make progress in the study of elementary particles, one needs sophisticated experimental and theoretical tools. We use accelerators of monumental size to produce particle collisions at energies that are equal to those 10^{-12} s after the big bang. We routinely collide matter with antimatter, transforming the initial particles and creating new ones. The detectors that we use to study these collisions are nearly as impressive. Here at UCSB, the high-energy physics group is very active in constructing such detectors and in analyzing the results of experiments that we perform at various laboratories.

The theoretical tools required to analyze elementary particle phenomena are also extremely interesting and challenging. Nearly all processes involve phenomena that must be described with relativistic quantum mechanics. Theories must also cope with the fact that, in high-energy collisions, matter and energy are usually transformed. In other words, we don't simply smash two watches together and observe the little pieces come flying out---entirely new pieces are created! We have come to understand that the "new" particles observed in such experiments are every bit as fundamental and important to piecing together the puzzle of matter as the particles that make up atoms. The theoretical framework for describing these processes is called quantum field theory.

In Physics 125 we will make a start towards understanding the nature of elementary particles and their interactions. We can go quite far without using the full apparatus of quantum field theory. We will, however, need to use special relativity and quantum mechanics routinely. If you are just learning quantum mechanics, many aspects of this course may be challenging. You will need to work extra hard to understand the subject, which for the most part is inherently quantum mechanical and cannot be treated with the tools and concepts of classical physics.

Finally, let me repeat a sentiment of a physicist I know. She said that doing particle physics is like climbing a mountain: the journey up can be a struggle, but the view from the top is great!

How to succeed in this course

You will face four main challenges in this course:

- Unlike upper division courses in some other subjects like electromagnetism or classical mechanics, you probably have not seen this material before in a simpler form.
- The course will make substantial use of quantum mechanics and special relativity.
- The pace will be fast. If you do not keep up with the reading, HW, and absorbing the lectures, you will get lost very quickly.

If you have not encountered quantum mechanics and special relativity before, this course is probably not a good use of your time right now. If you have had these subjects before, Physics 125 will help you understand them better by applying them to interesting situations.

Some (mostly obvious) advice:

Keep up with the reading and do the homework on time. Take careful notes when you read the textbook and bring lots of questions to class. Come to office hours to get mysterious concepts clarified. Do not wait to start the homework assignments until the night before they are due. When an assignment is handed out, read it as soon as possible. You might then notice that some of the questions are at least partially answered in the lectures, or you might realize that you need to get started especially early if some computer resources are needed.

Ask questions! Some students are too intimidated to ask questions. Questions don't need to be brilliant. Here is a perfectly good one: "Could you please explain the main point again?" Remember that your professor cannot anticipate all of the particular issues that will confuse you, so you should ask questions in class and office hours. Office hours are especially valuable in clearing up misunderstandings because there is more time.

Remember information. In this course, there will be more to remember than you are probably used to. This is because we are studying real, crucial physical systems, not just getting practice in applying laws of physics to a variety of situations. In fact, this type of learning is closer to actual research, where you have to know where the boundary is between the known and the unknown in order to identify the most important avenues of investigation. And knowing the properties of real physical systems is critical for understanding what methods can be used to make new discoveries.

Remember the main results of homework problems: you will often need to use them later. Many of the problems will address important issues and will be applied in many different contexts; they are not simply cooked-up examples. The attitude, “I can always just look it up in the book” leads to an inability to reason about new situations.

Recognize that this is a difficult (but fun) subject. You need to make a proportional level of effort to succeed. You may well want to consult additional textbooks or resources on the web. I can make many suggestions if you are interested in going deeper.

Grades, tests, and all that stuff

Immediate action item: explore in detail the web site of the Particle Data Group: http://pdg.lbl.gov/

Homework will be assigned on Wednesday and will be due on class on the following Wednesday. You may talk with other students about the problem, but copying of other people’s work is not allowed.

Graduate Teaching Assistant: Jason Gran (jgran@physics.ucsb.edu) ; Jason’s office hours will be Monday 2-4 PM and Tuesday 11 AM-noon in the Physics Study Room.

Lectures: M, W, F 12:00—12:50 in Phelps 3519

Professor Richman’s office hours: tentatively, Friday 3:00 PM- 5:00 PM or by appointment or just walk in and see if I’m here.

E-mail policy: I usually receive >100 e-mails per day. It is very difficult to keep up with all of it. For any e-mail that you send, please include a subject line “Ph 125” (not Phy 125, etc.). Please do this for Jason also.

In general, it’s better to talk to me about something in person rather than sending an e-mail.

Grading policy:

- Homework: 30%
- Midterm: 20%
- Final exam: 50%

Textbook: *Introduction to Elementary Particles,* 2nd edition, by David Griffiths

Final Exam Date: see schedule below.

Class	Date	Topics	Reading (chapters in Griffiths)
1	Mon, Apr 2	Goals of particle physics; assumptions, particle content of the standard model.	Introduction, C1
2	Weds, Apr 4	Types of particle processes and observables (I).	C2
3	Fri, Apr 6	Types of particle processes and observables (II).	C2
4	Mon, Apr 9	Fundamental vertices of the SM. Concepts of perturbation theory.	C2
5	Weds, Apr 11	Using the fundamental vertices of the SM in Feynman diagrams (I): photon-mediated (EM) interactions; crossing symmetry.	C2
6	Fri, Apr 13	The quark model & the hadron spectrum.	C5.6-C5.9, supp. notes
7	Mon, Apr 16	Using the fundamental vertices of the SM in Feynman diagrams (II): Weak interactions mediated by the W boson; Cabibbo suppression & CKM matrix.	C2, supp. notes and papers
8	Weds, Apr 18	Using the fundamental vertices of the SM in Feynman diagrams (III): Weak interactions mediated by the Z boson.	C2, supp. notes and papers
9	Fri, Apr 20	Using the fundamental vertices of the SM in Feynman diagrams (III): gluon-mediated (strong) interactions; QCD jets.	C2, supp. notes and papers
10	Mon, Apr 23	Applied special relativity (I).	C3
11	Weds, Apr 25	Applied special relativity (II).	C3
12	Fri, Apr 27	Relativistic wave equations (I): Klein-Gordon equation.	C7.1-7.2
13	Mon, Apr 30	Relativitistic wave equations (II): Dirac equation.	C7.1-7.2
14	Weds, May 2	Relativistic wave equations (III): Dirac equation.	C7.1-7.2
15	Fri, May 4	Detectors and the LHC (I): accelerators.	Notes
16	Mon, May 7	Detectors and the LHC (II): tracking and calorimetry.	Notes
17	**Weds, May 9**	**MIDTERM**	**C1—3, 7.1, 5.6-5.9 Lecs 1-12**

C

18	Fri, May 11	Detectors and the LHC (III): example measurement: searching for supersymmetric particles.	Notes
19	Mon, May 14	Applications of Feynman Rules (I) Physics of the propagator; s-and t-channel scattering; Rutherford scattering angular dependence.	C6, notes.
20	Weds, May 16	Applications of Feynman rules (II) Muon decay; origin of Fermi's constant, tau-lepton decay.	C6, notes
21	Fri, May 18	Applications of Feynman rules (III): e+e- annihilation.	C8.1-8.2
22	Mon, May 21	Global symmetries (I): definition of a symmetry operator; consequences of symmetries. Continuous symmetries.	C4, notes
23	Weds, May 23	Global symmetries (II): discrete symmetries C, P, & T; application to the hadron spectrum.	C4, notes
24	Fri, May 25	Global symmetries (III): application of P, C, T, and CP to weak decays.	C4, notes
25	**Mon, May 28**	**Memorial Day holiday**	**-**
26	Weds, May 30	Gauge symmetries – Abelian (EM) (I)	Notes, C11.1-11.4
27	Fri, Jun 1	Gauge symmetries – non-Abelian (I)	Notes, C11-11.4
-	Mon, Jun 4	Memorial Day Holiday	Notes, C11-11.4
28	Weds, June 6	Gauge symmetries – non-Abelian (II)	Notes, C11-11.4
29	Fri, June 8	Higgs boson & other puzzles of particle physics.	Notes
FINAL	**Tues, Jun 12**	**FINAL EXAM noon—3:00 PM.**	**Covers textbook, HW,lectures**