Physics 165: Particle Physics

Instructor: Flip Tanedo (flip.tanedo@ucr.edu / PHYS 3054) **Office Hours**: by appointment; usually available Wed 4-5pm

TA: Kuntal Pal (kpal002@ucr.edu)

Course Information

Introduction to Particle Physics

4 Units, Prerequisite: Physics 156A (quantum mechanics) Tue/Thu 2:00-3:00pm PHYS 3035 (reading room) sites.google.com/ucr.edu/p165

Textbook: *Elementary Particle Physics* by Larkoski (Cambridge 2019) Course notes and supplemental material will be provided on the course website.

Elementary particle physics is the study of the fundamental constituents of matter and the forces that dictate their interactions. This course builds a theoretical understanding of the Standard Model of particle physics based on Feynman diagrams. We will cover kinematics, what it means to have a theory of particle physics, how we perform experiments in particle physics, and what the future holds.

Course format: 80 min meeting with 10 min break

- First 35 minutes may include student presentations and brief assessments
- Remainder of course is a traditional lecture; student discussion *strongly encouraged*

Learning Objectives

By the end of this quarter, students will be trained to:

- Take a theory written as Feynman rules and determine multiparticle interactions that are allowed in that theory based on kinematics and dynamics.
- Estimate the rate of basic scattering events.
- Communicate information about frontier experiments in particle physics to peers.
- Given a set of particles with specified symmetry properties, identify the allowed three- and four-Feynman rules.
- Apply for REUs and graduate programs in a range of fields including particle physics.

Assessment

Students' course grade will be determined by the following

- **5 bi-weekly homework assignments** due in class (*20 points x 5 = 100 points*)
    - 5 points per short homework (due Thursday, 2 days after it is assigned)
    - 15 points per long homework (due Tuesday, 2 weeks after it is assigned)
- **5-Minute Homework Presentation** (*20 points*) Each student presents the solution to one homework problem in front of the class.
- **In-class assessments*** (*2 points x approximately 10 = 20 points*) Quick assessments as notecards completed during class time.
- **5-Minute Research Presentation** (*20 points*) To be assigned later in the term.
- **Take-home final exam**, no collaboration (*20 points*) Details announced closer to the date; we will not be using the designated final exam slot.

Additional points for participation in discussions may be assigned at the end of the term at the discretion of the instructor. Homework may include extra credit opportunities.

Bug bounty extra credit: The first person to inform the instructor of significant errors on the homework receives extra credit. (Catching obvious typos do not count for points, but they are appreciated.)

REU Extra Credit: students who apply for a summer REU receive 10 points extra credit.

Homework Philosophy

This course uses *asymmetric assessment* (short + long homework) to give feedback to students and to the instructor about how well each topic is understood and when additional work is needed. It helps students ask informed questions in class and helps the instructor tailor subsequent lectures.

It is not only important to understand material, but to be able to *explain it* to your peers. The presentations are a critical part of your training as a physicist.

Course Philosophy

The Two Questions You Can Always Ask

> *There are no stupid questions. Only stupid students.* --Physics Proverb

Questions and discussions *during class* are strongly encouraged. Do not wait until after class, do not ask physics questions privately. Our material will force you to think differently than you do in other classes you have taken, it will be a challenge.

To help, you should *always* feel comfortable to ask the following questions. They are phrased in a way that you will never "look stupid" for asking them:

1. "*Is it obvious that ... ?*" This means: I don't understand something. Maybe I'm looking at it the wrong way, what is the best way to see why this is true?
2. "*Why are we doing this?*" I understand the details, but I do not understand what the big picture is. What is the main point of this lesson? How do I use this in my study of particle physics?

Teaching Philosophy

1. Learning is a challenge that requires work, commitment, and time.
2. It is dangerous to go alone. Collaborate (with academic integrity).
3. Instructors should never do for students what students can do for themselves.

Policies

- **Course load policy**: By UCR Senate Regulation 760, one unit corresponds to 3 hours of course work per week (including time in class). This is a 4 unit class, the expectation is that you spend *9 hours outside of lecture* per week on reading, assignments, and engagement with the material. If you find that you are spending significantly more than this time on the course, please contact the instructor.
- **Equity and Inclusion policy**: we are committed to creating an inclusive learning space where we respect one another regardless of race/ethnicity, gender identities, gender expressions, sexual orientation, socioeconomic status, age, disabilities, religion, regional background, veteran status, citizenship status, nationality and other diverse identities that we each bring to class.
- **"I'm stuck on the homework" policy**: the suggested course of action is:
    1. Discuss with your classmates and/or ask a question during class (not before class, not after class).
    2. If you and your colleagues are confused, contact the TA.
    3. If you are all confused (or there's potentially an error on the homework), contact the instructor.
- **Attendance policy**: Attendance is strongly suggested, most of the narrative of the course will be crafted in lectures not in the textbooks.
    - You are responsible for all material presented in class and for any in-class assessments. There are no make ups for assessments.
    - It is understood that life happens: the penalty for missing only a few classes is negligible.
    - You're not required to notify me if you will be absent, but it is appreciated.
- **Email policy**: I will do my best to respond to emails on Tuesdays and Thursdays.
- **Academic integrity**: conduct.ucr.edu/policies/academic-integrity-policies-and-procedures All students are expected to abide by the highest standards of academic integrity. Academic misconduct (cheating) will be reported to the UCR Student Conduct & Academic Integrity Programs and will be penalized to the fullest amount. A brief summary:
    - You are encouraged to collaborate with others on homework and presentations. You are expected to write your solutions based on your own understanding.
    - You are allowed you use any references outside of the assigned course materials. You are expected to *cite* these sources in your submitted work or presentations.
    - You are *not* allowed to collaborate with any human being on the final exam. This includes asking questions to people outside of this class or posting questions on any internet forum or platform.
    - When in doubt, ask.

Student Support Services

- **Disability Accommodations**: if you have a disability may affects your ability to participate in this course, please make arrangements with the Student Disability Resource Center (SDRC) within the first week of class, sdrc.ucr.edu/.
- **Counseling**: this is a challenging course in a challenging major. If you are concerned that you feel overwhelmed, depressed, or in need of someone to talk to during your time at UCR, you are encouraged to contact Counseling & Psychological Services (CAPS), counseling.ucr.edu/. CAPS is confidential and is a resource that many in academia have turned to at one point or another.
- **Concerns about the course**: You are strongly encouraged to speak directly to the instructor early in the quarter if there are concerns about the course. If you have concerns regarding severe problems with the course or instructor that you do not feel comfortable bringing to the instructors attention, you may reach out to the ombudsperson, help.ucr.edu/office-ombuds. encouraged to speak to the instructor first.

Other useful information

Via registrar.ucr.edu/calendar (subject to my ability copy the dates correctly)

- **Last day to drop this course**: January 17, 2020
- **Last day to withdraw** (no fee, appears on transcript): January 24, 2020
- **Last day to change grading basis** (no fee): January 24, 2020

All material in this syllabus is subject to changes by the instructor.

Weekly Course Plan

1. Introduction:
    - Feynman: QED
    - Theory: special relativity and kinematics
2. Quantum
    - Feynman: QED variants
    - Theory: quantum mechanics, amplitudes,
3. Putting it all together, experiments in particle physics
    - Feynman: Weak force
    - Theory: Cross sections
4. Symmetry, tensors, and indices
    - Feynman: Flavor physics
    - Theory: symmetries and indices
5. Unified electroweak theory
    - Feynman: the electroweak sector
    - Theory: a hint of broken symmetries

6. Quarks, gluons, and why we never see them
    - Feynman: QCD
    - Theory: SU(3)
7. The Higgs
    - Feynman: helicity arrows
    - Theory: order parameters for symmetry breaking
8. Relativistic wave equations
9. The Standard Model
10. Beyond the Standard Model