PHYSICS 56500 − Spring 2025
Introduction to Elementary Particle Physics II

Course Information

- PHY 56500 "Introduction to Elementary Particle Physics II"
- CRN 28437
- 3 Course credit hours
- Prerequisites: Quantum Mechanics, Physics 56400

Instructor Contact Information

Lecturer: **Prof. Norbert Neumeister**
Office: Room 372 Physics Building
Phone: 49-45198
E-mail: neumeist@purdue.edu
Office hours: Tuesday 2:00 – 3:00 PM (or by appointment)

Course Description

This is the second part of a two-semester course sequence to give an introduction to Particle Physics. Focus is given to the experimental features, with phenomenological and theoretical considerations and the interplay between theory and experiment. This is not intended to be a formal course in particle theory. Most students will be concurrently taking a course in field theory (PHYS 66200/66300) which will serve as a more formal complement to the treatment given in this class.

After a review of Quantum Electrodynamics and Weak Interactions the Standard Model of particles and interactions is described. We will study the current experimental status of the Standard Model of particles and forces, possible theoretical extensions beyond the Standard Model, and related experimental searches. The efforts to construct a theory which unifies all interactions, including gravity, is discussed. The topics covered include CP violation, neutrino physics, QCD, hadron collider physics and data analysis techniques.

The goal of the course is to prepare graduate students for research in particle physics and related areas. The emphasis is on the understanding of the basic concepts and on doing simple calculations. The principles behind modern analytic methods will be illustrated, and explored more deeply in exercises, through simple Monte Carlo simulations.

This course will cover the analytic techniques commonly used today in particle physics experiments. A deeper understanding of the Standard Model will be obtained by studying how these techniques are applied. Most examples will be drawn from experiments at the

LHC, but the Tevatron and LEP experiments will also be emphasized, when appropriate.

Learning Outcomes

The goal of the course is to prepare graduate students for research in particle physics and related areas. The emphasis is on the understanding of the basic concepts and on doing simple calculations.

Class

Lectures:
ARMS 1021, Electrical Engineering Building
Tuesday and Thursday 9:00 – 10:15 AM

Learning Resources, Technology & Texts

- **Textbook:** *Modern Particle Physics*, M. Thomson, 2nd ed., Cambridge University Press, 2013, ISBN: 978-1107034266.
- **Besides our textbook, the following are useful references:**
  1. D. Griffiths, *Introduction to Elementary Particles*, 2nd ed., Wiley-VCH, 2008, ISBN: 978-3527406012.
  2. A. Bettini, *Introduction to Elementary Particle Physics*, 2nd ed., Cambridge University Press, 2014, ISBN: 978-1107050402.
  3. F. Halzen and A.D. Martin, *Quarks & Leptons: An Introductory Course in Modern Particle Physics*, John Wiley & Sons, 1984, ISBN: 978-0471887416.
  4. D.H. Perkins, *Introduction to High Energy Physics*, 4th ed., Cambridge University Press, 2000, ISBN: 978-0521621960.
  5. B.R. Martin and G. Shaw, *Particle Physics*, 3rd ed., John Wiley & Sons, ISBN: 978-0470032947.
  6. A. Seiden, *Particle Physics: A Comprehensive Introduction,* Addison-Wesley, 2004, ISBN: 978-0805387360.
  7. V.D. Barger and R.J.N. Phillips, *Collider Physics*, Addison-Wesley, 1996, ISBN: 978-0201149456.
  8. W.R. Leo, *Techniques for Nuclear and Particle Physics Experiments,* 2nd ed., Springer, 1994 ISBN: 978-3540572800.
  9. C. Grupen and B. Shwartz, *Particle Detectors*, 2nd ed., Cambridge University Press, 2011, ISBN: 978-0521187954.
  10. J. Iliopoulos and T.N. Tomaras, *Elementary Particle Physics: The Standard Theory*, Oxford University Press, 2022, ISBN: 978-0192844217.
  11. M.E. Peskin, *Concepts of Elementary Particle Physics*, Oxford University Press, 2019, ISBN: 978-0198812180.
  12. G. Cowan, *Statistical Data Analysis*, Oxford Science Publications, 1998, ISBN: 978-0198501558.

- We will loosely follow the textbook: Mark Thomson, "*Modern Particle Physics*". I also recommend David Griffiths, "*Introduction to Elementary Particles*", 2nd edition (Wiley, 2008) and Alessandro Bettini, "*Introduction to Elementary Particle Physics*" (Cambridge University Press, 2nd edition), which is more experimentally oriented, while the textbook by Griffiths has more theoretical details. It is not required to have a book so decide for yourself if you want to purchase one. Much of the material covered in this course is difficult to find in a single textbook or review article. Therefore, we will draw from lecture notes made available by various authors on arXiv.

- **Brightspace learning management system (LMS)**
  Access the course via Purdue's Brightspace learning management system. Begin with the Start Here tab, which offers further insight to the course and how you can be successful in it. It is strongly suggested that you explore and become familiar not only with the site navigation, but also with content and resources available for this course. See the Student Services widget on the campus homepage for resources such as Technology Help, Academic Help, Campus Resources, and Protect Purdue.

- **Additional Resources:**
  Particle Data Group
  The Particle Adventure
  The Particle Detector Briefbook

Lectures

The lectures will be used to introduce new concepts. Read the assigned text in advance of the lecture and then again afterwards for optimal comprehension. Your active participation during lectures with questions and comments is strongly encouraged. Please do not hesitate to, or be shy about, asking questions.

Prerequisites

This course is a continuation of PHYS 56400. Therefore, PHYS 56400 or an equivalent background in particle physics is assumed. It is expected that you are familiar with particle detection techniques and with Quantum Electrodynamics. Understanding of quantum mechanics at the PHYS 36000/PHYS 55000 or PHYS 46000/PHYS 46100 level is required. These courses may be taken simultaneously.

Assignments

Specific reading assignments will be given supplementing the lecture material covered in class. A tentative reading and homework assignment schedule is posted on the course website. You should read the assigned sections before attending lecture. You can always find an up-to-date version on the course website.

Problem solving is an essential as well as an integral part of this course. There will be 5 homework assignments and problem sets will be assigned on Tuesday. The homework is due and has to be brought to the lecture on Thursday of the following week. Homework grades will count 40% towards your course grade. Students may discuss the problems with each other in a general way but should **not** do the homework as a group effort. No carbon copy homework sets are acceptable. Assignments will be posted on the course web page. Further, the problem solutions should be clearly and neatly written on one side only of standard size paper. Your fellow students should be able to read, follow and understand the solutions. The quality of the presentation counts towards the grade. The problem sets will be written in a format that has your name, PHYS 565, and the due date in the upper right-hand corner of the first page and your name and PHYS 565 on each following page. The question should first be written out and then followed by the solution. Assignments will be posted on the course web page.

1. Use 8½ by 11" paper.
2. Write only on one side of the page.
3. Number the pages.
4. Write clearly and neatly.
5. Solutions should be complete, comprehensive and clearly presented.
6. Stable pages together for hand in.
7. Remember to put your name on the front of the first page in hand in.
8. Homework is due in class on the day indicated on the problem set.
9. Please contact your instructor prior to the due date if you need an extension.

Exams

Instead of the usual final exam, a research paper is required. To demonstrate the understanding of the theoretical concepts and the experimental techniques each student is required to perform a physics analysis using LHC data and write a research paper. Starting literature will be provided and students will be expected to find additional resources. The written reports are due on May 1.

Grading

In this class, grades reflect the sum of your achievement of learning outcomes throughout the semester. You will accumulate points, and your course grade will be based on homework, exam scores and the final term paper, with the approximate weights:

Homework	40%
Final term paper	60%

At the end of the semester, final grades will be calculated by adding the total points earned and translating those numbers into letter grades. We will use plus-minus letter grades in the final grading of this course. **The exact cut-offs for letter grades will not be determined until the end of the semester.**

Attendance Policy

University policies (see Academic Regulations: Attendance and Office of the Dean of Students: Class Absences posted in Brightspace under "University Policies and Statements.") states that students are expected to be present for every meeting of the classes in which they are enrolled.

Homework sets are due on the dates indicated on the class calendar. Your work is due on time, with the exception of reasonable documented excuses. If you are going to miss an exam, you must notify the instructor **in advance** (preferably one week) so alternative arrangements can be made. Unexcused absences from any exam will be assigned a zero grade; Excused grades will be given only for reasons excused by University regulations: (1) grief/bereavement, military service, jury duty, parenting leave or emergent medical care, (2) relative, weather conditions that make it impossible to get to the university); and (3) required attendance at an official Purdue activity (e.g. athletics). You **must** contact your lecturer as soon as possible but **before** the exam and discuss your problem. Appropriate documents may be needed to judge the merit of the excuse.

A student can contact the Office of the Dean of Students (ODOS) to request that a notice of the leave be sent to instructors when a situation involving **hospitalization, emergency department or urgent care visits emerges**. The student can then provide documentation of hospitalization, emergency department or urgent care as proof of legitimate absence to the ODOS as soon as these documents are available.
For more information read the **Excused Absence Policies**.

Accessibility

Purdue University strives to make learning experiences as accessible as possible. If you anticipate or experience physical or academic barriers based on disability, you are welcome to let me know so that we can discuss options. You are also encouraged to contact the Disability Resource Center at: drc@purdue.edu or by phone: 765-494-1247. More details are available on our course Brightspace under Accessibility Information.

Mental Health Statement

If you find yourself beginning to feel some stress, anxiety and/or feeling slightly overwhelmed, try WellTrack. Sign in and find information and tools at your fingertips, available to you at any time.

If you need support and information about options and resources, please contact or see the Office of the Dean of Students. Call 765-494-1747. Hours of operation are M-F, 8 am – 5 pm.

If you find yourself struggling to find a healthy balance between academics, social life, stress, etc. sign up for free one-on-one virtual or in-person sessions with a Purdue Wellness Coach at RecWell. Student coaches can help you navigate through barriers and challenges toward your goals throughout the semester. Sign up is completely free and can be done on

BoilerConnect. If you have any questions, please contact Purdue Wellness at evans240@purdue.edu.

If you're struggling and need mental health services: Purdue University is committed to advancing the mental health and well-being of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of mental health support, services are available. For help, such individuals should contact Counseling and Psychological Services (CAPS) at 765-494-6995 during and after hours, on weekends and holidays, or by going to the CAPS office of the second floor of the Purdue University Student Health Center (PUSH) during business hours.

Basic Needs Security

Any student who faces challenges securing their food or housing and believes this may affect their performance in the course is urged to contact the Dean of Students for support. There is no appointment needed and Student Support Services is available to serve students 8 am – 5 pm Monday through Friday.

Academic Integrity

Academic integrity encompasses the core values and basic principles of honesty and responsibility that govern our practices as scholars, researchers, and creative artists at Purdue. *Purdue prohibits dishonesty in connection with any University activity.* Acts of cheating, lying, and deceit in any of their diverse forms (such as the use of substitutes for taking examinations, the use of illegal cribs, plagiarism, and copying during examinations) is dishonest and is not tolerated. Moreover, knowingly to aid and abet, directly or indirectly, other parties in committing dishonest acts is in itself dishonest.

Do not let the anonymity of a large class lull you into a false confidence that cheating is acceptable. Cheating compromises yourself, your classmates, and the University, and instances will be handled sternly. If you are aware of someone who is cheating do not hesitate to let me know. Be discrete but confident that it is the right thing to do. Alternatively, individuals may alert university officials to potential breeches of this value by either emailing integrity@purdue.edu or by calling 765-494-8778. While information may be submitted anonymously, the more information that is submitted provides the greatest opportunity for the university to investigate the concern.

Purdue's Honor Pledge: "As a boilermaker pursuing academic excellence, I pledge to be honest and true in all that I do. Accountable together - we are Purdue."

Nondiscrimination Statement

Purdue University is committed to maintaining a community which recognizes and values the inherent worth and dignity of every person; fosters tolerance, sensitivity, understanding, and mutual respect among its members; and encourages each individual to strive to reach his or her own potential. In pursuit of its goal of academic excellence, the University seeks to develop and nurture diversity. The University believes that diversity

among its many members strengthens the institution, stimulates creativity, promotes the exchange of ideas, and enriches campus life. A hyperlink to Purdue's full Nondiscrimination Policy Statement is included in our course Brightspace under University Policies and Statements.

Emergency Preparation

In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances beyond the instructor's control. Relevant changes to this course will be posted onto the course website or can be obtained by contacting the instructors or TAs via email or phone. You are expected to read your @purdue.edu email on a frequent basis.

Here are ways to get information about changes in this course:

- Course web site: https://purdue.brightspace.com/d2l/home/1225564
- E-mail: neumeist@purdue.edu (use subject PHYS 565)
- Phone: 494-5198

A link to Purdue's Information on Emergency Preparation and Planning is located on our Brightspace under "University Policies and Statements." This website covers topics such as Severe Weather Guidance, Emergency Plans, and a place to sign up for the Emergency Warning Notification System. I encourage you to download and review the Emergency Preparedness for Classrooms document (PDF) or (Word).

Copyright

See the University Policies and Statements section of Brightspace for guidance on Use of Copyrighted Materials. Effective learning environments provide opportunities for students to reflect, explore new ideas, post opinions openly, and have the freedom to change those opinions over time. Students and instructors are the authors of the works they create in the learning environment. As authors, they own the copyright in their works subject only to the university's right to use those works for educational purposes Students may not copy, reproduce, or post to any other outlet (e.g., YouTube, Facebook, or other open media sources or websites) any work in which they are not the sole or joint author or have not obtained the permission of the author(s).

Disclaimer

Course requirements, deadlines and grading percentages are subject to changes that may be necessitated in the event of major campus emergency or other circumstances. You can get information about changes in this course in Brightspace.

Course Schedule

	Date		Lecture Topics	Deadline

Week 1	Jan 14	Lecture 1	Introduction, Basics	
	Jan 16	Lecture 2	Review of QED	
Week 2	Jan 21	Lecture 3	Review of QED	
	Jan 23	Lecture 4	Weak Interactions	
Week 3	Jan 28	Lecture 5	Weak Interactions	
	Jan 30	Lecture 6	Electroweak Symmetry Breaking	
Week 4	Feb 4	Lecture 7	Electroweak Symmetry Breaking	
	Feb 6	Lecture 8	Standard Model	HW 1
Week 5	Feb 11	*no class*		
	Feb 13	*no class*		
Week 6	Feb 18	Lecture 9	CP Violation	
	Feb 20	Lecture 10	CP Violation	
Week 7	Feb 25	Lecture 11	Neutrinos	
	Feb 27	Lecture 12	Neutrinos	HW 2
Week 8	Mar 4	*no class*		
	Mar 6	*no class*		
Week 9	Mar 11	Lecture 13	QCD	
	Mar 13	Lecture 14	QCD	HW 3
Week 10	Mar 18	*Spring break (no class)*		
	Mar 20	*Spring break (no class)*		
Week 11	Mar 25	Lecture 15	BSM Physics	
	Mar 27	Lecture 16	BSM Physics	
Week 12	Apr 1	Lecture 17	LHC Physics	
	Apr 3	Lecture 18	LHC Physics	HW 4
Week 13	Apr 8	Lecture 19	Statistics	
	Apr 10	Lecture 20	Statistics	
Week 14	Apr 15	Lecture 21	Statistics	
	Apr 17	Lecture 22	Statistics	HW 5
Week 15	Apr 22	Lecture 23	Analysis Techniques	
	Apr 24	Lecture 24	Analysis Techniques	
Week 16	Apr 29	Lecture 25	Analysis Techniques	
	May 1	Lecture 26	Analysis Techniques	Paper
Week 17	May 6	Finals week		
	May 8	Finals week		