WILLIAM & MARY
CHARTERED 1693

PHYS 772 – The Standard Model of Particle Physics

Term: Spring 2025

Credit Hours: 3

Time: Tue/Thu 9:30 am – 10:50 am

Location: Small Hall, Room 122

Webpage: https://ajackura.github.io/courses/phys772_spring_2025.html

Contact Information

Instructor: Prof. Andrew W. Jackura (he/his/him)

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Office: Small Hall, Room 326B

Office Hours: Tue/Thu 2:00 pm – 3:00 pm, or by arrangement

Course Information

Prerequisite: PHYS 721 - Quantum Field Theory I or equivalent. This course assumes comfort with tree-level calculations of cross sections in QED and decay rates in theories of scalars and fermions. Concurrent enrollment in PHYS 722 - Quantum Field Theory II is *strongly* recommended, but not required.

Overview: This course is a technical introduction to the Standard Model of Particle Physics. It will provide the necessary background needed to carry out research in modern particle and nuclear physics. We will review aspects of gauge theories and their use in the description of electroweak and strong interactions, and construct the Standard Model from the observed fundamental symmetries of nature. Goals include understanding the Standard Model theory, calculating elementary observables, and comparing theoretical results to experimental measurements.

Outcomes: After successfully completing this course, the student should be able to:

- Understand the role of discrete and continuous symmetries in the construction of the Standard Model.
- Understand the underlying principles and structure of the Standard Model of particle physics, in particular its formulation in terms of quantum gauge theories spontaneously broken via the Higgs mechanism.
- Understand predictions of the Standard Model and comparisons with experimental data, in particular the calculation of scattering and decay rates for elementary processes and referencing the *Review of Particle Physics*.
- Understand key open questions in modern particle physics and the motivation for searches for physics beyond the Standard Model.

Text: There is no required textbook for the course. One text is recommended, and suggestions for additional texts to consult can be found in the detailed bibliography. Familiarity with the *Review of Particle Physics* by the Particle Data Group (PDG) is required, see `https://pdg.lbl.gov`.

Recommended:

- *Introduction to the Standard Model and Beyond* | 1st ed.,
  by Stuart Raby, Cambridge University Press, ISBN: 978-1-108494-19-9

Lectures: I plan to focus primarily on the theoretical construction of the Standard Model of Particle Physics. A prerequisite for this course is PHYS 721 - Quantum Field Theory I. This course assumes comfort with tree-level calculations of cross-sections in Quantum Electrodynamics. I will avoid many details and proofs usually found in a field theory course, and focus only on relevant information needed to build the Standard Model and study elementary processes. However, quantum field theory is a cornerstone of the Standard Model. Therefore, it is *strongly* encouraged you enroll in PHYS 722 - Quantum Field Theory II concurrently, if you have not taken it already. This course is meant to complement the phenomenological presentation of the subject given in PHYS 638 - Nuclear and Particle Physics, offered on regular rotation by the Department of Physics at William & Mary.

The lectures will focus on three primary topics: **Symmetries**, **Gauge Theories**, and **Phenomenology** of the Standard Model. We will review aspects of quantum field theory and Quantum Electrodynamics. Starting from the fundamental symmetries observed in nature, we will construct the gauge field theories of the Standard Model – Quantum Chromodynamics and Electroweak theory. We illustrate the success of the Standard Model by computing various elementary processes and comparing the results with experimental measurements. Consult the tentative schedule for a detailed list of topics to be covered throughout the course.

Lecture Notes: Lecture notes will be posted on the course website, which will sometimes contain a bit more information than we cover during lecture time. *Please let me know of any errors you spot in the notes.*

Important Dates: See the University registrar for the complete academic calendar (link). Please note the following dates:

Add/Drop Deadline	Fri, Jan 31
Spring Break	Tue, Mar 11 (**no class**)
Spring Break	Thu, Mar 13 (**no class**)
Withdrawal Deadline	Mon, Mar 24
Last Day of Classes	Fri, May 02
Final Exam	Tue, May 06

Tentative Schedule: Here is a tentative outline of the subjects that we will cover throughout the course. *Schedule is subject to change.*

Week	Date	Topic	PSets
1	Thu, Jan 23	**Class Cancelled due to Weather**	
2	Tue, Jan 28	Introduction & Overview of the Standard Model	
	Thu, Jan 30	Aspects of QFT – Scalar fields, S-matrix and cross-sections	
3	Tue, Feb 04	Aspects of QFT – Spinor fields, chiral fermions	PS1 due
	Thu, Feb 06	Symmetry I – Lie Groups and Lie Algebras	
4	Tue, Feb 11	Symmetry I – Basic Properties of U(1) and SU(2)	PS2 due
	Thu, Feb 13	Symmetry I – Discrete Symmetries: C, P, & T	
5	Tue, Feb 18	Gauge Theory I – Local U(1) invariance & Electromagnetism	PS3 due
	Thu, Feb 20	Gauge Theory I – Quantum Electrodynamics	
6	Tue, Feb 25	Phenomenology I – e^-e^+ annihilation in QED	PS4 due
	Thu, Feb 27	Phenomenology II – Lepton $g-2$, Atomic level shifting	
7	Tue, Mar 04	Symmetry II – Basic Properties of SU(3)	PS5 due
	Thu, Mar 06	Symmetry II – Hadrons & the Quark Model	
8	Tue, Mar 11	**Spring Break (no class)**	
	Thu, Mar 13	**Spring Break (no class)**	
9	Tue, Mar 18	Gauge Theory II – Non-Abelian SU(N) gauge theory	PS6 due
	Thu, Mar 20	Gauge Theory II – Quantum Chromodynamics	
10	Tue, Mar 25	Phenomenology II – QCD, Running Coupling, and Hadrons	PS7 due
	Thu, Mar 27	Phenomenology II – Deep Inelastic Scattering, Parton Model	
11	Tue, Apr 01	Phenomenology II – Chiral Symmetry in QCD	PS8 due
	Thu, Apr 03	Symmetry III – Spontaneous Symmetry Breaking	
12	Tue, Apr 08	Symmetry III – Higgs Mechanism	PS9 due
	Thu, Apr 10	Gauge Theory III – the Electroweak Model of Leptons	
13	Tue, Apr 15	Gauge Theory III – the Standard Model	PS10 due
	Thu, Apr 17	Phenomenology III - Leptonic Weak Decays	
14	Tue, Apr 22	Phenomenology III – $K^0\bar{K}^0$ Oscillations, Z-boson	PS11 due
	Thu, Apr 24	Symmetry IV – Anomalies, Neutral Pion decay	
15	Tue, Apr 29	Beyond the Standard Model – Neutrinos Oscillations	PS12 due
	Thu, May 01	Beyond the Standard Model – Neutrinos Masses	
16	Tue, May 06	**Final Exam Due: 9:00 a.m. - 12:00 p.m**	

Assessment

Problem Sets: There will be weekly exercises assigned on Tuesdays, and due the following week. All problem sets are to be turned into the instructor by the due date. In case of holidays, breaks, or conferences, the deadline may be adjusted accordingly. All problem sets are individual assignments, where you will turn in your own solution to the prescribed problems. I *strongly* encourage you to discuss the problems with your fellow students. However, mindless copying of solutions will not be tolerated. Assignments can be submitted either typeset or handwritten, however please ensure your submissions are well-structured and legible. *Show your work & clearly indicate your final answer. Late assignments will not be accepted unless prearranged under extreme circumstances.*

Exams: There will be one take-home final exam. The take-home final exam will be due at the time of the final exam, **Tuesday May 06, 12:00 pm**. In contrast to the problem sets, you are expected to solve the exam individually.

Evaluations: Final grades will be calculated from the weekly problem sets, and the take-home final exam. Their contributions to the total grade is:

Problem Sets	70%
Final Exam	30%

Final letter grades will be determined from the numerical grades using:

Grade	Percentage	Grade	Percentage	Grade	Percentage
		A	92 – 100	A-	88 – 92
B+	84 – 88	B	80 – 84	B-	86 – 80
C+	72 – 76	C	68 – 72	C-	64 – 68
D+	60 – 64	D	55 – 60	D-	50 – 55
F	< 50				

Policies

Attendance: Attendance does not form part of the grade for this class and thus is not mandatory. However, you are responsible for your own understanding of the course material. Attending class will significantly improve your enjoyment of the course and will likely improve your satisfaction with both your own understanding and your grade.

Rescheduling: On occasion, there may be need to reschedule a lecture. The class will be polled to decide on when the make-up lecture will take place.

Auditing: Students are welcome to audit this course (i.e., participate not for credit). Since one only learns by doing, students who audit this course are expected to hand in exercises as well as the final take-home exam. Although you will not be graded on them, you are expected to make a good faith effort as you would for other courses.

Electronic Devices: You are welcome to bring laptops and mobile devices to class and are responsible for their appropriate use. Please be considerate of others in the class and avoid disrupting the lecture.

Code of Conduct: You will be expected to follow the William & Mary Honor Code as well as the Code of Student Conduct. "As a member of the William & Mary community, I pledge on my honor not to lie, cheat, or steal, either in my academic or personal life. I understand that such acts violate the Honor Code and undermine the community of trust, of which we are all stewards." To read the Honor Code, please see https://www.wm.edu/honor.

Accommodations: William & Mary accommodates students with disabilities in accordance with federal laws and university policy. Any student who feels they may need an accommodation based on the impact of a learning, psychiatric, physical, or chronic health diagnosis should contact Student Accessibility Services staff at 757-221-2512 or at sas@wm.edu to determine if accommodations are warranted and to obtain an official letter of accommodation. For more information, please see https://www.wm.edu/sas.

Mental and Physical Well-Being: William & Mary recognizes that students juggle different responsibilities and can face challenges that make learning difficult. There are many resources available at W&M to help students navigate emotional/psychological, physical/medical, material/accessibility concerns, including:

- The W&M Counseling Center at 757-221-3620. Services are free and confidential.
- The W&M Health Center at 757-221-4386.
- To seek assistance for interpersonal, academic, and wellness challenges, please contact Care Support Services at wm.edu/care (care@wm.edu).
- For a list of other resources available to students, see https://www.wm.edu/offices/wellness/resources/