Physics 861 Nuclear and Particle Physics Fall 2014

INSTRUCTOR: Prof. John Wilkerson
238 Phillips Hall.
Phone: 962-1384
Email: jfw@unc.edu

LECTURES: Wed-Fri from 11:30 to 12:45 PM, Phillips Hall 220.
(May hold some lectures in Phillips Hall 006)

OFFICE HOURS: TBD and by appointment.

PREREQUISTE: Physics 543 (or equivalent) & Physics 721
or permission of the instructor.

SYNOPSIS: The intent of the course is to provide an overview of fundamental symmetries and neutrinos in nuclear physics. Many of the topics of interest are aimed at probing for physics beyond the standard model of fundamental interactions, often using the nucleus as a laboratory to make precision tests. The course will be enriched by selected readings from foundation papers in the published literature. These examples will prove interesting while motivating the underlying nuclear and particle physics. The plan is to on average cover a foundations related topic every week, either in class or as part of the homework.

The exact content of the course will be tailored to address the interests and experience levels of the students.

The course is not a traditional lecture course, but something of a hybrid, with about 2/3 of the time devoted to lectures and 1/3 to discussions. For the discussions you will read published research papers (some old and some new). We will discuss these papers in class as a group. To help you as you're reading each paper, I will provide a set of "guiding questions". For each assigned paper discussed in class, students will be asked to present a summary of the paper and start the discussion.

GOALS:

1. Provide an overview of fundamental symmetries and the weak interaction.
2. Explore the use of fundamental symmetry measurements to test the standard model and beyond.
3. Understand neutrino properties and their context in astro-, nuclear, and particle physics.
4. Apply your knowledge of Quantum Mechanics.

5. Strengthen ability to read/understand/interpret published literature.
6. Prepare and present an APS style talk.

COURSE TEXTBOOKS:

There is no single textbook that covers all of the topics in the syllabus. I have placed the available texts (a couple are apparently missing) on reserve in the Library. Please refer to the text and references information sheet.

LECTURE NOTES:

Slides or material shown during class will be made available on the course web page.

COURSE ASSIGNMENTS, EXAMINATIONS, GRADING:

Reading: Suggested reading assignments from text(s), handouts, or published papers will be assigned before each lecture and can be found on the course information web page. For the text assignments, if a reading from a particular author is marked in **bold**, this is an indication that I have found it to be particularly relevant to the lecture subject.

Homework: On average one problem set every two weeks. Students are expected to work independently on assignments related to foundational papers.

In Class: Participation and Discussions – You are expected to participate in the class discussions. You will also be asked to "present" a summary and help lead the discussion of one of the weekly research papers that we will be reading.

Project: An independent and original research paper on a topic of your selection. You will give an APS style 10 minute talk at the end of the semester. Details on the paper/project and a list of potential topics will be updated later in the semester.

Exams: None.

Grades:

Homework	60%
Participation	20%
Paper/Talk	20%

Physics 861 Fundamental Symmetries and Neutrinos Fall 2014 in Nuclear Physics

Syllabus

Current Revision: October 01, 2014

Nuclear Properties and Interactions (review) [1]
- Global properties
- Decay modes
- Interactions
- Symmetries of the nuclear Hamiltonian

Nuclear Models [2]
- Fermi Gas Model
- Shell Model
  - *Foundations Topic: Nuclear Shell Model*
- Collective Model
  - *Foundations Topic: Nuclear Collective Model*

Symmetries and Conservation Laws [6]
- Additive Conservation Laws
- Angular momentum and isospin
- Discrete Symmetries, Parity
  - *Foundations Topic: Parity Violation*
  - *Foundations Topic: Neutrino Helicity*
- Angular momentum and isospin
- Dynamical symmetries, Charge Conjugation
  - *Foundations Topic: The neutral Kaon*
- CP Violation
  - *Foundations Topic: CP Violation*

Interactions, Field Theories, and the Standard Model [5]
- Klein-Gordon Field
- The Dirac Field
  - *Foundations Topic: Dirac*
- Symmetry considerations
- Interacting Fields
  - *Foundations Topic: Yang-Mills Theory*
- Electroweak theory
- Spontaneous symmetry breaking – the Higgs
  - *Foundations Topic: Weinberg*

The Weak Interaction [3]
- Beta-decay
- The Current–Current Interaction
- Weak Current of Leptons
- The Weak Coupling Constant
- Weak Decays of Quarks and the CKM Matrix
- Weak Currents in Nuclear Physics

Beyond the Standard Model - Neutrinos [5]

- Neutrino Mixing and MNSP Matrix
- Neutrino Oscillations in vacuum and matter
- Majorana versus Dirac Neutrinos
- Experimental evidence that neutrinos have mass and oscillate
  - *Solar neutrinos*
  - *Atmospheric neutrinos*
  - *Reactor neutrinos*
  - *Accelerator neutrinos*
- Constraints on Neutrino Mass
- Neutrinoless Double Beta Decay – Case Study
  - Nuclear Matrix Elements
  - *(Foundations Topic: Nuclear Shell Model)*
- Sterile Neutrinos
- Future Perspectives

Beyond the Standard Model – Fundamental Symmetry tests [5]

- Baryon number violation
- Parity violation (J-Lab)
- Charged Lepton flavor violation
- EDM searches
- Muon g-2

Connections to Cosmology [2]

- Observational Cosmology
- ΛCDM model
- Evidence for Dark Matter
- Neutrinos as warm or hot dark matter
- Non-standard model particles

Beyond the Standard Model – Dark Matter and Dark Energy [2]

- Dark Matter Models and Interactions
- Spin-independent and spin dependent interactions
- WIMP, Axions
- Direct searches - Coherent scattering on nuclei
- Indirect searches
- Dark Energy and Vacuum energy