Physics 612: Theoretical Particle Physics, Spring, 2015

Prof. R. Shrock, office: 6-111, tel. 632-7986, email: robert.shrock@stonybrook.edu

Prerequisites: PHY 557 and PHY 610 or the equivalent

The grade for the course will be based on homework, an oral presentation, a final exam, and class participation.

Class time/place: Mon. Wed. 4-5:20 pm, Rm.: TBA; office hour: after class or by contacting me at the above email and/or tel. no.

The textbook is Paul Langacker, *The Standard Model and Beyond* (2010). The books Matthew D. Schwartz, *Quantum Field Theory and the Standard Model* (2014) and Chris Quigg, *Gauge Theories of the Strong, Electromagnetic, and Weak Interactions* (2013) will also be useful for reference. In addition, we will use recent reviews and conference presentations available from the arXiv and other websites.

This course will cover modern particle physics theory, as described by the standard $\mathrm{SU}(3)_c \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$ model (SM) and its extension to account for neutrino masses and mixing. Topics will be chosen from those listed below:

- Brief review of quantum field theory, symmetries, effective low-energy field theory methods.
- Concept of gauge invariance, gauge interactions; abelian (QED) and non-abelian (Yang-Mills).
- Construction of a unified electroweak $\mathrm{SU}(2) \times \mathrm{U}(1)_Y$ gauge theory; earlier V-A current $\times$ current theory as a low-energy effective field theory, role of spontaneous symmetry breaking; vector boson masses and couplings; Higgs mechanism.
- Fermion couplings and masses; Cabibbo-Kobayashi-Maskawa quark mixing matrix; Glashow-Iliopoulos-Maiani mechanism; $K^0 - \bar{K}^0$ mixing, $B^0 - \bar{B}^0$, and $D^0 - \bar{D}^0$ mixing, $K_L \to \mu^+\mu^-$; unitarity triangle.
- Tests of the electroweak sector, including weak decays and reactions, muon $g - 2$.
- SM Higgs boson: properties and observation at LHC.
- Models to explain quark masses and relate them to quark mixing, relating small angles in CKM matrix to generational hierarchies in quark masses.
- Quantum chromodynamics, including early indications of color, deep inelastic scattering and asymptotic freedom, quarkonium, heavy quarks c, b, t; Zweig rule; confinement, chiral symmetry breaking, and hadron spectrum; ω-ϕ system; hadronic strings and Regge recurrences; use of lattice gauge theory to understand confinement and calculate hadron masses; anomaly cancellation in SM.
- Neutrino masses and lepton mixing as evidence of physics beyond the SM; types of neutrino mass terms, models of neutrino masses, searches for neutrino masses in nuclear and particle decays, neutrinoless double beta decay, theory and experiments on solar and atmospheric neutrinos, accelerator neutrino experiments, reactor antineutrino experiments.
- Problems/mysteries in SM, including explanation for gauge group and values of gauge couplings, charge quantization, origin and values of fermion masses, three fermion generations, QCD versus electroweak scale, electroweak versus GUT and quantum-gravity scales, hierarchy problem in Higgs sector, strong CP problem, dark matter, etc.
- Ideas for physics beyond the SM, including grand unified theories and searches for baryon number violation; question of origin of electroweak symmetry breaking; supersymmetry and searches for supersymmetric partners.

The university requires us to list expected learning outcomes for all courses; these are given on the second page.

The expected learning outcomes for PHY 612 are that the students

- should gain a comprehensive working knowledge of the Standard Model of particle properties and interactions at an advanced level;
- should understand quantitatively the extensions of the original Standard Model to explain nonzero neutrino masses and lepton mixing, including experimental results and theoretical implications; and
- should understand the questions that the Standard Model does not answer or explain, current ideas on possible physics beyond the Standard Model that attempt to address these questions, and constraints from searches for new physics.