

# Physics 612: Theoretical Particle Physics      Spring, 2014

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Prerequisites: PHY 557 and PHY 610 or the equivalent

Course requirements: homework and a paper and/or exam.

First meeting time/place: Mon. Jan. 27, 4:00 pm, Rm. ESS 177; office hr. TBA

The textbook is P. Langacker, *The Standard Model and Beyond* (2010). Two recently published (optional) books are C. Quigg, *Gauge Theories of the Strong, Electromagnetic, and Weak Interactions* (2013) and M. Thomson, *Modern Particle Physics* (2013) We will also use reviews and conference presentations available from the arXiv and other websites.

This course will cover modern particle physics theory, as described by the standard  $SU(3)_c \times SU(2)_L \times U(1)_Y$  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  $SU(2) \times U(1)_Y$  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,  $K_L \rightarrow \mu^+ \mu^-$ , CP violation in  $K_L$  decays, unitarity triangle
- Models to explain quark masses and relate them to quark mixing, relating small angles in CKM matrix to generational hierarchies in quark masses
- Tests of the electroweak sector, including weak decays and reactions, muon  $g - 2$ , loop corrections to  $W$  and  $Z$  propagators; LHC observation of particle consistent with being the SM Higgs boson
- Quantum chromodynamics, including early indications of color, deep inelastic scattering and asymptotic freedom, quarkonium, heavy quarks  $c$ ,  $b$ ,  $t$ ; jets, confinement, chiral symmetry breaking, 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: grand unified theories and searches for baryon number violation; supersymmetry; dynamical EWSB; constraints on physics beyond the SM.

The university requires us to list expected Learning Outcomes for all courses. The 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
- should know about the questions that the Standard Model does not answer or explain, current ideas on possible physics beyond the Standard Model, and current constraints from searches for new physics