Physics 612: Advanced Particle Physics Spring, 2013

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Prerequisites: PHY 557 and PHY 610 or the equivalent

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

Meeting times: Mon. 4:00-6:45 pm, Rm. P119 (time chosen to avoid schedule conflicts with other courses); first meeting: Jan. 28

Recommended books include:

C. Burgess and G. Moore, *The Standard Model: a Primer* (2007)
P. Langacker, *The Standard Model and Beyond* (2010)
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. An approximate course outline is as follows:

- 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, $B^0 - \bar{B}^0$ mixing, CP violation, unitarity triangle
- Quantum chromodynamics, including early indications of color, deep inelastic scattering and asymptotic freedom, quarkonium, jets, confinement, chiral symmetry breaking, instantons, hadron mass spectrum, use of lattice gauge theory to understand confinement and calculate hadron masses and matrix elements; anomaly cancellation in SM
- Tests of the electroweak sector, including weak decays and reactions; W and Z masses and couplings, lepton $g-2$ values; observation of Higgs-like boson at LHC and current results on its properties
- 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.
- Models to explain quark masses and relate them to quark mixing
- 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
- Grand unified theories; searches for baryon number violation
- Ideas to address the hierarchy problem in the SM: supersymmetry, dynamical electroweak symmetry breaking, extra dimensions; current status after Tevatron era and LHC 7 TeV and 8 TeV runs