PHYS-416 Particle Physics II Review

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## 5. Neutrinos and Neutrino Oscillations

* Neutrino Flavours
* Mass and Weak Eigenstates
  + Neutrino Oscillations in 2 Flavors
  + Neutrino Oscillations in 3 Flavors
    - CP and CPT in the Weak Interaction
      * violation of C and P in weak interactions but weak interaction is invariant under CP.
      * CP and T violation in neutrino oscillations
        + small excess of matter over dark matter
    - Neutrino mass hierarchy
    - 3-flavor oscillations neglecting CP violation
    - PNMS
* Neutrino Experiments
  + Neutrino Interaction Thresholds
  + Neutrino Detection

## 6. CP Violation and the Weak Hadronic Interactions

* 1. CP Violation in the Early Universe
  + baryon number violation
  + C and CP violation
  + Departure from thermal equilibrium
* 2. GIM Mechanism
  + Additional Quark proposal (c quark)
  + Suppression of FCNC (flavor changing neutral current) process
* 3. CKM matrix
  + Vij in the vertex factor if the adjoint spinor is u, Vij\* if d
  + Near diagonal, can be obtained from experiments
  + Off diagonal terms are relatively small
* 4. The Neutral Kaon System
  + 4.1 CP Eigenstates
    - Strong eigenstates are not the eigenstates of CP. (K0, K0bar)
    - Their linear combinations create the CP eigenstates
  + 4.2 Decay of CP Eigenstates
    - 4.2.1 Decay to Two Pions
    - 4.2.2 Decay to Three Pions
* 5. Strangeness OScillations
  + 5.1 CPLEAR Experiment
* 6. CP Violation in the Kaon System
  + 6.1 CP Violation in Semileptonic Decay
* 7. CP Violation and CKM Matrix

## 7. Determination of the CKM Matrix Elements

1. Determination from mainly the leptonic decays
2. Particle-Anti-particle Mixing
3. B-Physics
   1. Similar to kaon oscillations, oscillations in heavy mesons have been also observed
4. CP violation
   1. Using Wolfenstein parametrisation, create CKM triangle (unitary triangle)

## 8. Electroweak Unification and the W and the Z bosons

1. W boson decay
   1. In ultrarelativisitic limit, only LH particle and RH anti-particle
   2. Total W decay is independent of polarization
2. From W to Z
3. SU(2) Weak Interaction
   1. 3 gauge boson W1, W2, W3, determine ladder operators from W1, W2
   2. Weak Isospin (neutrino, electron)
   3. W3 is a mixture of photon and Z boson
4. U(1)
   1. Define new boson B for electroweak unification

## 9. Test of the Standard Model

1. Electroweak Measurement at LEP
2. Electron-Positron Annihilations in Feynman Diagrams
3. Cross Section Measurements
4. Measurements of the Z-line Shape
   1. Number of Generations
5. Forward-Backward Asymmetry
6. Determination of the mixing angle Theta\_W
7. (W+)W- production
8. W-mass and W-width
   1. No resonant like in the case of e+ e->Z
   2. W boson decay either to leptons or hadrons
9. Precision tests of the SM
10. The Top Quark
    1. Top quark does not hadronize
    2. Decay before forming a bound state

## 10. Higgs Boson

1. Higgs Mechanism
   1. Gauge symmetry works only for massless gauge boson, the Higgs mechanism solves this issue
   2. Analogy: Massless photons propagating through a plasma behave as massive particles
   3. Higgs boson is electrically neutral but carries WEAK HYPERCHARGE of ½
   4. Photons do not couple to Higgs field, thus remains massless
2. Precision tests of the standard model
   1. Prediction of mass of W boson, yet VIRTUAL LOOPs should be considered as well.
   2. Hunting the Higgs Boson at LEP
      1. H decays predominantly to heaviest particles which are energetically allwed
      2. At LEP c.o.m energy sqrt(s) is up to 207 GeV, thus, mH<207-mz which should be 116 GeV, yet H boson is around 125 GeV. Thus, LEP is not sufficient. After LHC (2012) in ATLAS and CMS experiments H is detected via two different channels. In CMS, H->gamma+gamma; whereas, in ATLAS, H->Z+Z\*

## 11. Higgs Mechanism

1. Interacting Scalar Fields
2. Symmetry breaking for a complex scalar field
   1. Derive Higgs boson mass
   2. Derive mass terms for the gauge boson
   3. Derive interactions of the Higgs boson and gauge bosons

## 12. Higgs Decay

1. Fermion Masses
2. Transformation of left doublet
   1. LH chiral fermions -SU(2) doublets, RH chiral fermions SU(2) singlet
   2. Electron Case
   3. Up-type fermions
3. Higgs Boson Decays
   1. Spin-averaged Matrix Elements (ME) proportional to mass of bottom quark and mass of Higgs
   2. H->bb\_bar mostly
   3. Decay to massless particles (photon and gluons) happen via loops