Y2 Neutrino Physics: 2009-10   Dr. N.K.Watson

Course Summary

This is a non-exclusive summary of the material covered during the course. Please do not take this to mean it is *all* that you need to know – reading around the subject in textbooks (or on reliable web pages) is always encouraged and advantageous. "Reliable" here means either in a "peer-reviewed" scientific journal, or in major scientific conference. Please refer to handouts and information distributed as part of the course, in addition to notes taken during lectures. Information placed on the web after each lecture will replace that from the previous year on a rolling basis.

1. Basics of particle physics
   a. Generation structure of quarks, leptons
   b. Mesons, baryons, and their quark flavour content
   c. Gauge bosons
      i. Range of forces, relative strengths
      ii. Colour degree of freedom in QCD
   d. Conservation laws (charge, lepton/baryon number, energy)
   e. Symmetry and conserved quantities
      i. Parity and its violation in weak decays
   f. Relativistic kinematics and natural units ($E^2=p^2+m^2$, invariant mass of a system of particles by adding four-momenta)
2. Neutrino properties and experimental evidence
   a. Existence
      i. Continuous vs. discrete e^- energy spectrum in nuclear β decay
   b. Number of generations
      i. LEP ("direct" from $e^+e^- \to (\nu\nu)\gamma$)
      ii. LEP ("lineshape")
   c. Mass (direct measurement)
      i. Phase space, Kurie plot
      ii. Electron end point (effect of finite m_ν on form of spectrum)
   d. Helicity ("handedness") of leptons
      i. From Wu et al ^{60}Co experiment
3. Detection
   a. Inverse β decay as primary tool
   b. Bubble chambers (see background reading material of handouts)
   c. Radio-chemical detectors (e.g. R. Davis's HOMESTAKE)
4. Atmospheric neutrinos
   a. $\pi^\pm$ shower production from incident cosmic rays, relative e and μ neutrino fluxes expected and observed
   b. Super-Kamiokande
      i. General description and technology
      ii. Water Čerenkov detectors
   c. Deficit of muon neutrinos cf. expectation
      i. Up/down asymmetry

        ii. Energy dependence (sub-GeV, multi-GeV), Lorentz factor
    d. $\nu_\mu \rightarrow \nu_\tau$ as possible explanation of data in terms of oscillation
5. Solar neutrinos
    a. SNO detector
    b. Processes used for neutrino detection (NC/CC/ES), incl. Feynam diagrams (benefit of adding NaCl to water, to enhance cross-section for NC process)
    c. Standard Solar Model
        i. pp, CNO processes – only summary of pp reqd. – fraction of solar energy in neutrinos
        ii. typical energy ranges of neutrinos produced (^{8}B and pp)
        iii. statement of the "solar neutrino problem"
    d. implications of SNO data, possible interpretation for oscillations
6. Neutrino mixing and oscillations
    a. Concept of mixing, weak eigenstates as superposition of mass eigenstates
    b. Formalism for two-flavour mixing (but *not* derivation of oscillation formula itself)
    c. Formula for survival probability for (b)
    d. Three flavour mixing and hierarchies
7. Dark Matter – rotation curves as a motivation for "missing mass"
    a. Classification of matter into hot/cold/baryonic/non-baryonic
    b. Possible dark matter candidates
8. Neutrinoless double beta decay (NDBD) and Majorana vs Dirac neutrinos
9. Experimental design, contrast between
    a. "appearance" experiments: explicitly detect production of a given ν flavour, giving clear result:: knowledge of absolute initial flux much less important but need to be sensitive to produced ν flavour(s)).
    b. "disappearance" experiments, such as Super-Kamiokande: detect a deficit in absolute flux of initial ν flavour - easier to design, but interpretation more difficult as need to understand absolute initial flux itself, and more difficult to interpret as not known what missing ν have changed into.
10. Future directions
    a. Follow on from existing long baseline neutrino experiments (e.g. MINOS, etc.): CNGS, neutrino factory, CHOOZ, Daya Bay, DUSEL, SNOLAB, Project-X, …
    b. $0\nu2\beta$ (a.k.a. NDBD), e.g. SuperNemo, direct ν mass measurements, …