Neutrino Physics: Assignment 1

(Given 01/03/2010, To be submitted 15/03/2010)

1. The mass of ν_μ can in principle be determined by measuring the momentum of muon (in the rest frame of pion) produced in the decay $\pi^+ \to \mu^+ \nu_\mu$. (forget about neutrino mixing for the moment). Calculate an expression for the ν_μ mass in terms of observable quantities in this decay. To what accuracy should the momentum of muon be measured, if $m^2_{\nu_\mu}$ is to be measured to an accuracy of 1 eV^2 ? Assume that the masses of π^+ and μ^+ are known to infinite precision.

2. In Tritium decay (end-point energy $E_0 = 18.57$ keV), the fraction of decays within 1 eV of the end point is 2×10^{-13}. (See the side shown in the class). The KATRIN experiment plans to determine the neutrino mass to within 0.2 eV. What would be the fraction of decays within 0.2 eV of the end point ? (You may have to do this numerically.)

3. A neutrino with energy E strikes a nucleus with mass M_N. Calculate the center-of-mass energy, and point out its leading dependence on E when (i) $E \ll M_N$ and (ii) $E \gg M_N$.

4. Calculate the thickness of lead shielding required to reduce the intensity of a 10 MeV neutrino beam by a factor of 2. Convert this to light years. Calculate the same quantity for a 10 TeV neutrino beam. Use the expressions given in the "cross section" tables in Class notes.

5. Consider the data (shown in class) for zenith angle dependence of atmospheric neutrinos: (i) e-like sub-GeV, (ii) e-like multi-GeV, (iii) mu-like sub-GeV, and (iv) mu-like multi-GeV. Calculate the values of χ^2/dof for the no-oscillation hypothesis with these data.

6. For atmospheric neutrinos, for ν_μ-ν_τ mixing,

   (a) Plot $P_{\mu\mu}$ as a function of the zenith angle Θ for three values of energy: $E = 0.2, 2, 20$ GeV (on the same plot). Show the numerical values on both the axes explicitly.

   (b) Plot the up-down asymmetry $(U - D)/(U + D)$ as a function of energy. The "up" events U are defined as those with $\cos\Theta < -0.2$ and the "down" events D are those with $\cos\Theta > 0.2$. You may do the integrals numerically. Assume that the neutrino flux isisotropic at all energies.

   Use the paremeter values $\Delta m^2 = 2.4 \times 10^{-3}$ eV^2 and $\theta = 45°$.