Particle Physics Phenomenology II

FS 11, Series 9

Due date: 25.04.2011, 1 pm

Exercise 1 Consider neutrinos traveling through a medium of constant matter density ρ .

i) Write down the Feynman diagrams of electron neutrinos scattering off electrons. Which diagram is responsible for neutrino oscillations?

ii) The matter oscillation may be described by adding an additional term to the Hamiltonian in the flavor basis, such that

$$\mathcal{H}_F = U\text{diag}(0, \Delta m^2_{21}/2E, \Delta m^2_{31}/2E)U^\dagger + \text{diag}(V_{CC}, 0, 0)$$

where $V_{CC} = \pm\sqrt{2}G_F N_e$ (plus for neutrinos, minus for antineutrinos) is the *matter potential* with $N_e \simeq Y_e\rho/m_N$ the electron density in matter, Y_e the number of electrons per nucleon with mass m_N. In the two flavor case show that this Hamiltonian leads to an effective mixing angle satisfying

$$\tan 2\theta_m = \frac{\sin 2\theta_{12}}{\cos 2\theta_{12} - \frac{2EV_{CC}}{\Delta m^2_{21}}}.$$

Hint: Ignore third components. Multiply out $\mathcal{H}_F$ and subtract a suitable diagonal term, (why can you always do this?) which brings $\mathcal{H}_F$ into a form such that $\mathcal{H}_{11} = -\mathcal{H}_{22}$ as in the vacuum case. Read of the modified $\cos 2\theta$.

iii) Compute the Energy of the neutrino which leads to maximal mixing in the sun, where $\theta_{12} = 33.9°$, $\Delta m^2_{21} = 8 \cdot 10^5 \text{eV}^2$ and $\rho = 150\text{gcm}^{-3}$.

iv) Is the sign of Δm^2_{21} important?

v) The parameters Δm^2_{21} and θ_{12} extracted from solar oscillations can also be obtained in laboratory experiments, namely accelerator and reactor experiments (with typical energies: 1 GeV for accelerator ν's and 4 MeV for reactor ν's). What is the optimal distance between neutrino source and detector for these two types of experiments to confirm the solar parameters?