1. Physicists now believe that neutrinos oscillate between different types of flavors. If it oscillates to ν_μ, it means that ν_e is not a mass eigenstate. Denote the mass eigenstates by ν_1 and ν_2. The ν_e would be a superposition of ν_1 and ν_2. Using the fact that ν_1 and ν_2 is a mass eigenstate, i.e. $|\nu_i(t)>= e^{-iEt}|\nu_i(t=0)>$, if initially, you have an electron neutrino ν_e, what is the probability of observing a muon neutrino ν_μ after a distance L? (*Hint:* Expand the relativistic energy around zero mass, and then use $L \simeq ct$)

Questions From the Book

2. The values of mc^2 for the pion π^+ and muon μ^+ are 139.57 MeV and 105.66 MeV respectively. Find the kinetic energy of the muon in the decay $\pi^+ \to \mu^+\nu_\mu$ assuming that the neutrino is massless. For a neutrino of finite but very small mass m_ν show that, compared with the case of a massless neutrino, the muon momentum would be reduced by the fraction

$$\frac{\Delta p}{p} = -\frac{m_\nu(m_\pi^2 + m_\mu^2)}{(m_\pi^2 - m_\mu^2)^2} \simeq -\frac{4m_\nu^2}{10^4}$$

3. State which of the following reactions are allowed by the conservation laws and which are forbidden, giving the reasons:

$$\begin{aligned}
\pi^0 &\to e^+ + e^- \\
e^- + p &\to n + \nu_e \\
\mu^+ &\to e^+ + e^- + e^+ \\
K^0 + n &\to \Lambda + \pi^0 \\
\Xi^0 &\to \Lambda + \pi^0
\end{aligned}$$

4. In the following reaction in hydrogen

$$\pi^- + p \to X^- + p$$

a boson X is observed with a mass 2.4 GeV (a) If the incident pion beam momentum is 12 GeV, calculate the maximum angle of emission of the

recoil proton with respect to the beam direction, and its momentum.
(b) Calculate the angle and momentum of the proton when the 4-momentum transfer is a maximum, and compute the value of q^2_{max}