
1. From the numbers given in Table 1, calculate $R$-values yourself and discuss possible interpretations.

2. Figure 1 shows the zenith angle distribution of the $e$-like and $\mu$-like data both for sub-GeV and multi-GeV. The dashed histogram shows the Monte Carlo prediction with $\nu_\mu \rightarrow \nu_\tau$ oscillation with $\Delta m^2 = 2.2 \times 10^{-3}$ eV$^2$ and $\sin^2 2\theta = 1$, which gives a good fit to the data. Answer the following questions on $\mu$-like data based on the interpretation that there is neutrino oscillation with the above parameters.
   (a) Explain why there is about a factor-of-two depletion for $\cos \Theta < 0$ both for sub-GeV and multi-GeV data. (b) Explain why there is basically no depletion for $\cos \Theta > 0.2$ in multi-GeV data, but there is some depletion in sub-GeV data. (c) Figure 6 gives the $\Delta m^2$, $\sin^2 2\theta$ region preferred by their data. Discuss why the data prefers $\Delta m^2 \approx 10^{-3} - 10^{-2}$ eV$^2$ and a large $\sin^2 2\theta$ using an order-of-magnitude argument.

3. One of the pressing questions is if the $\nu_\mu$ oscillates into $\nu_\tau$ or $\nu_s$ (an exotic particle which does not interact at all in the detector). They can address this question by studying neutral-current induced $\pi^0$ in the data. Make a rough estimate on how much depletion in $\pi^0$ events you would expect if the oscillation is $\nu_\mu$ to $\nu_s$, and discuss how it compares to the data discussed in Section 3. Assume that neutrinos responsible for producing $\pi^0$ are mostly multi-GeV neutrinos.

4. MINOS experiment attempts to study the neutrino oscillation $\nu_\mu \rightarrow \nu_\tau$ by looking for the appearance of $\tau$ from $\nu_\mu$ beam motivated by this atmospheric neutrino anomaly. Using a neutrino beam of $E_\nu \sim 30$ GeV, how long baseline do they need to study the relevant $\Delta m^2$ range? Given their baseline of about 700 km (Illinois to Minnesota), what energy would be optimal for the purpose?

5. Despite the anomaly, the Super-Kamiokande data confirms that the cosmic ray particles produce neutrinos in the atmosphere which penetrate all the way through the Earth. Using the number of sub-GeV $e$-like events they have seen, estimate the neutrino flux (# particles per unit time per unit area). The CC cross section of neutrino at this energy range is roughly 5 fb.

6. Point out systematic issues in Super-Kamiokande data you can think of. (Then I can write a paper with you! :-) )