Previous Lecture

- Cerenkov effect
- Its application to SuperKamiokande
- Start atmospheric neutrinos…

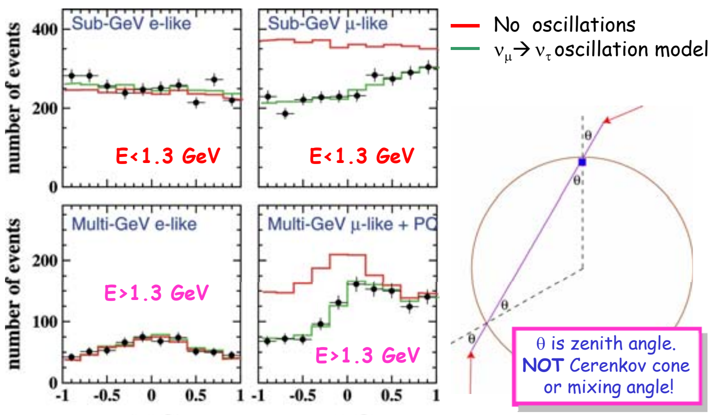
Lecture Content

- Approx. lecture content
  1. PP intro
  2. PP intro.
  3. ν props 1: strong/e.m./weak, no. neutrino generations
  4. ν props 2: lepton no., ν existence
     - Examples of decay/production
  5. Neutrino mass
     - Fermi-Kurie plot
     - Phase space kinematics/4-momentum
  6. Parity and CP violation… (why so important in lepton sector?)
     - Wu et al., ^{60}Co experiment
  7. Detection & observation
     - Liquid, solid, bubble chamber
     - "Direct" methods (DONUT)
  8. Atmospheric neutrinos
     - Cerenkov detectors
     - SuperKamiokande experiment
  9. Atmopsheric neutrino data and oscillations
     - Interpretation of atmospheric ν data
     - Two-flavour neutrino oscillation formalism
  10. Solar neutrinos and SSM
      - SNO experiment and data
      - NDBD (NEMO, etc.)
  11. Implications for cosmology
      - Open vs. closed scenarios. various m_ν regions
      - ν as DM candidate?
      - Subject outlook (JPARC, MICE, Neutrino Factory, SK, SNO, KAMLAND, CHOOZ MINOS, miniBOONE, JPARC, νF,

Today

- Atmospheric ν data and their interpretaion
- Neutrino oscillation concept
- 2 flavour neutrino flavour oscillation formalism
- Generalisation to 3 flavours: MNS (Maki-Nakagawa-Sakata) mixing

Super-Kamiokande results II



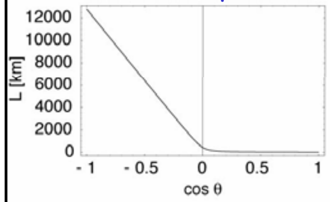
[Fig. from H.Murayama]

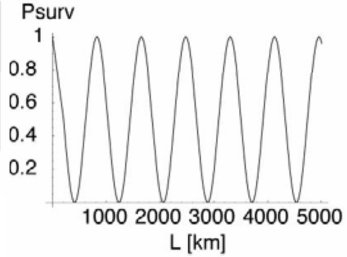
Super-Kamiokande results I

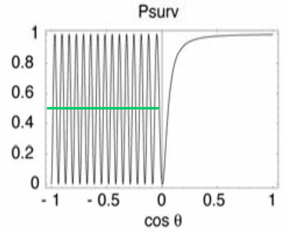
- Super-K atmospheric ν data, solid evidence for oscillations (1998)
- Predicted $N(\mu)/N(e)$ ratio $\cong 2$
  - μ from $\pi^- \to \mu^- + \bar{\nu}_\mu$ and $\mu^- \to e^- + \nu_\mu + \bar{\nu}_e$
  - e only from μ^- decay
- Measured $N(\mu)/N(e)$ /predicted $N(\mu)/N(e) = 0.64 \pm 0.05$
  - Prediction includes simulation of resolution, detector thresholds,etc.
- $N(\mu)/N(e)$ increases for higher energy μ (time dilation by Lorentz γ factor)
  - More time dilation $\Rightarrow$ fewer μ decay in atmosphere: $R = \gamma c\tau = (E/m)c\tau$
  - Remember μ from $\pi^- \to \mu^- + \bar{\nu}_\mu$ and $\mu^- \to e^- + \nu_\mu + \bar{\nu}_e$
  - e only from μ^- decay
- Clear asymmetry in upward/downward μ events
  - Shows no. of ν_μ depends on distance travelled between production (in atmosphere) and detector
  - No such effect for electons
  - Common interpretation: $\nu_\mu \to \nu_\tau$ oscillation

"Survival" Probability

Distance from production, L, as f(zenith angle), e.g. in Super-K



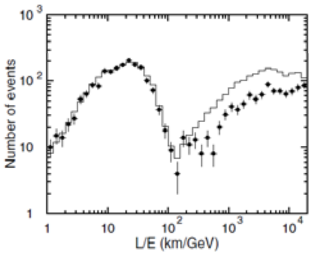


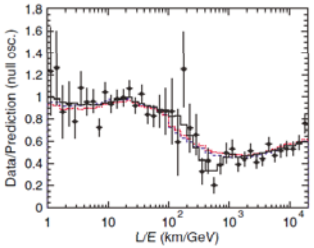


Finite angular resolution may effectively average over several oscillation cycles, net result is see $P_{surv} \sim 0.5$

[Figs. from H.Murayama]

Superkamiokande data





From Phys. Rev. Lett. 93, 101801 (2004)

- Compare (r.h.s.) best-fit expectations for
  - ν decay (dashed) – disfavoured at 3.4 σ significance
  - ν decoherence (dotted) – disfavoured 3.8 σ significance
  - ν oscillations (solid) – preferred hypothesis