Understanding the Atmospheric Neutrino Data

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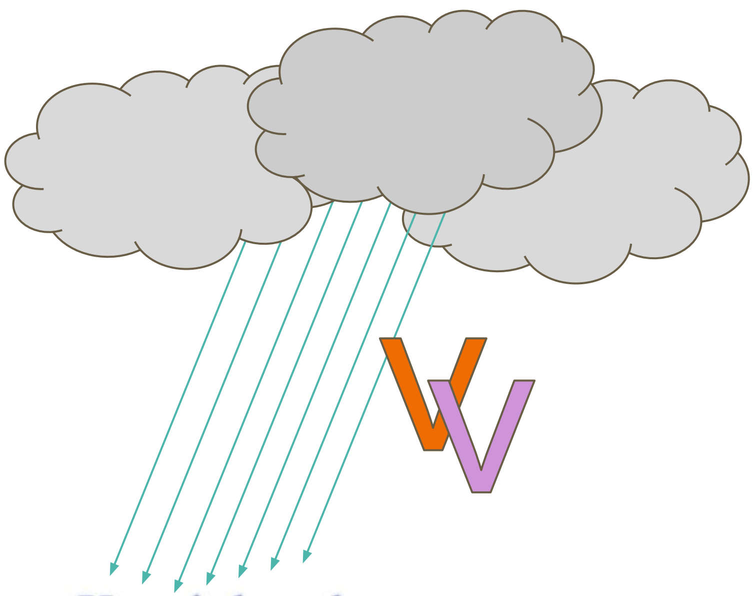
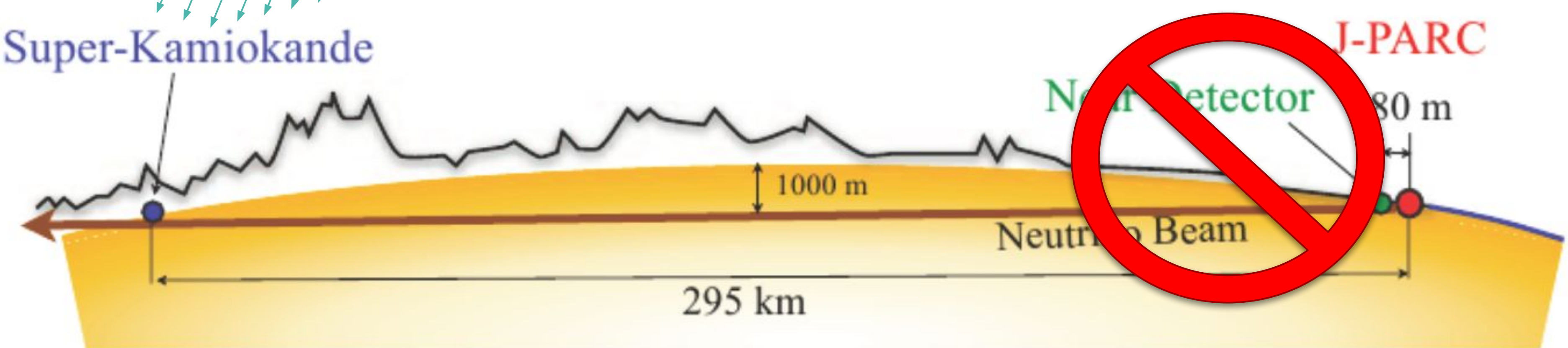
Super-Kamiokande



Detector Technology:
Water Cherenkov

Fiducial Volume:
22.5 kT

Under a big mountain:
2,700 m water equivalent



Task: Data Analysis (Part 1 and 2)

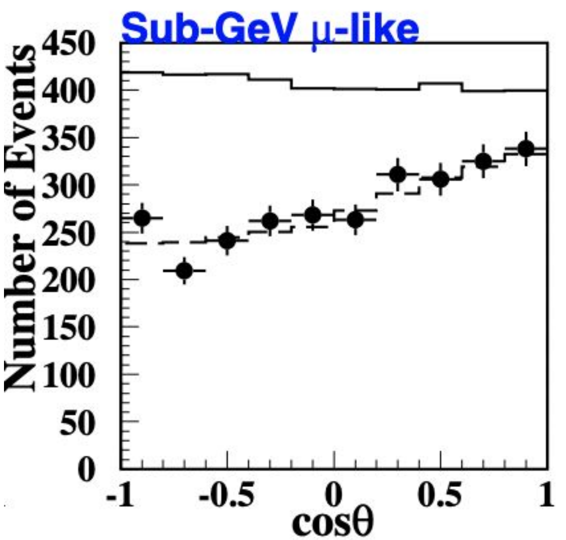
Using data obtained from T. Toshito, hep-ex/0105023

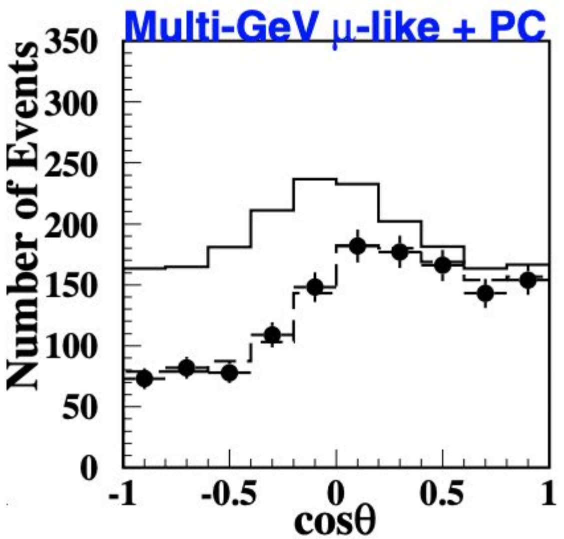
- **Plot disappearance probability...**
- **Weigh the un-oscillated prediction...**
- **Assess Data/MC agreement...**

...for $\theta = \pi/4$ and $\Delta m^2 = 2.5 \times 10^{-2}, \times 10^{-3}, \times 10^{-4}\ eV^2$

Note: Define "Sub-GeV" and "Multi-GeV" as 0.2 GeV and 2 GeV, respectively

⇒ our neutrinos are monochromatic 😳





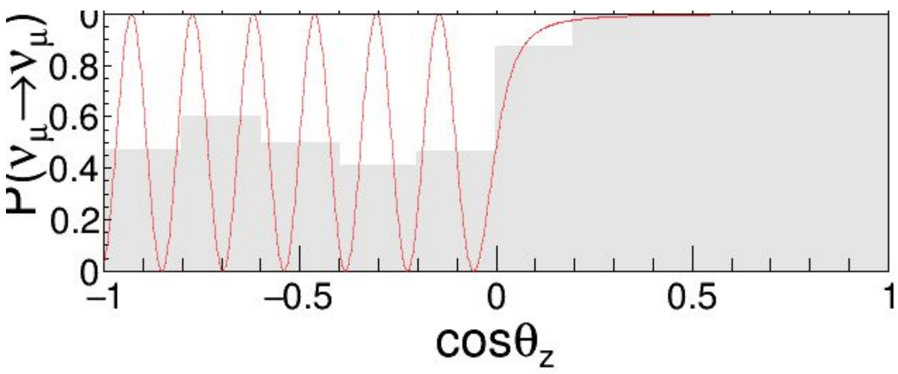
Plot Disappearance Probability

EZ part:

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2(2\theta)\sin\left(1.27\frac{\Delta m^2 L}{E}\right)$$

Less obvious part:

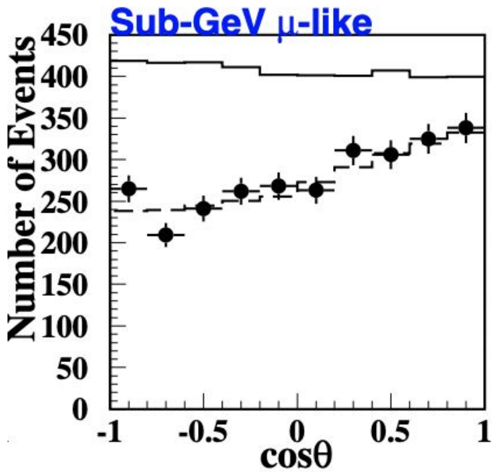
Integrate probability over $\Delta\cos\theta_z$

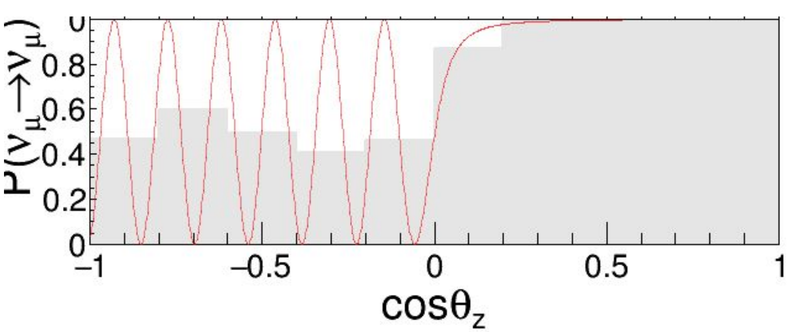


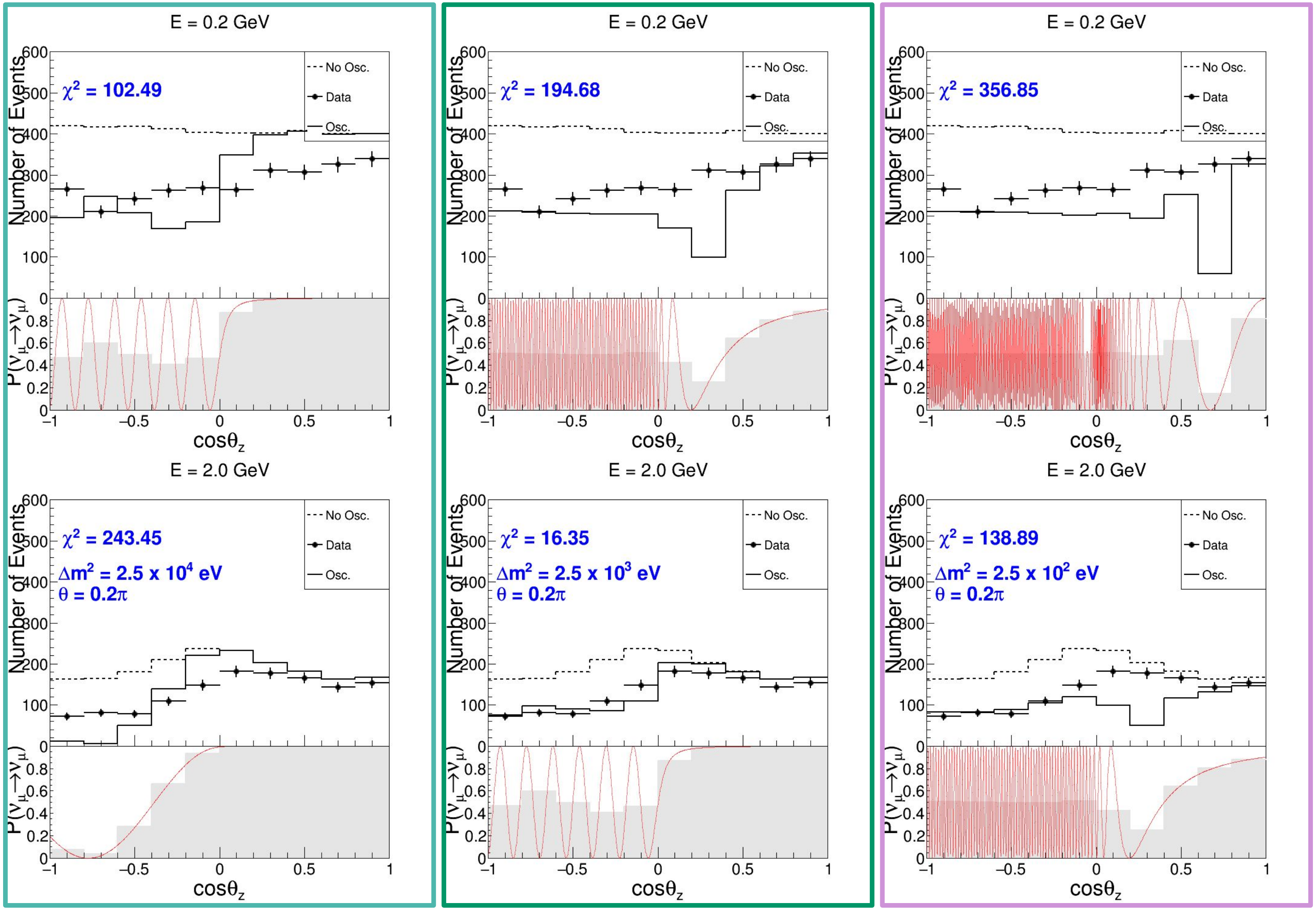
Predict

Make a prediction:

Oscillation-probability-weighted un-oscillated prediction







$$\chi^2 \equiv -2\log\mathcal{L}(\vec{\theta}) = 2\sum_{i=1}^{N}\left[\mu_i(\vec{\theta}) - n_i + n_i \log\frac{n_i}{\mu_i(\vec{\theta})}\right]$$

Meh... Can we do better?

Big Data/MC discrepancy in the low energy bin

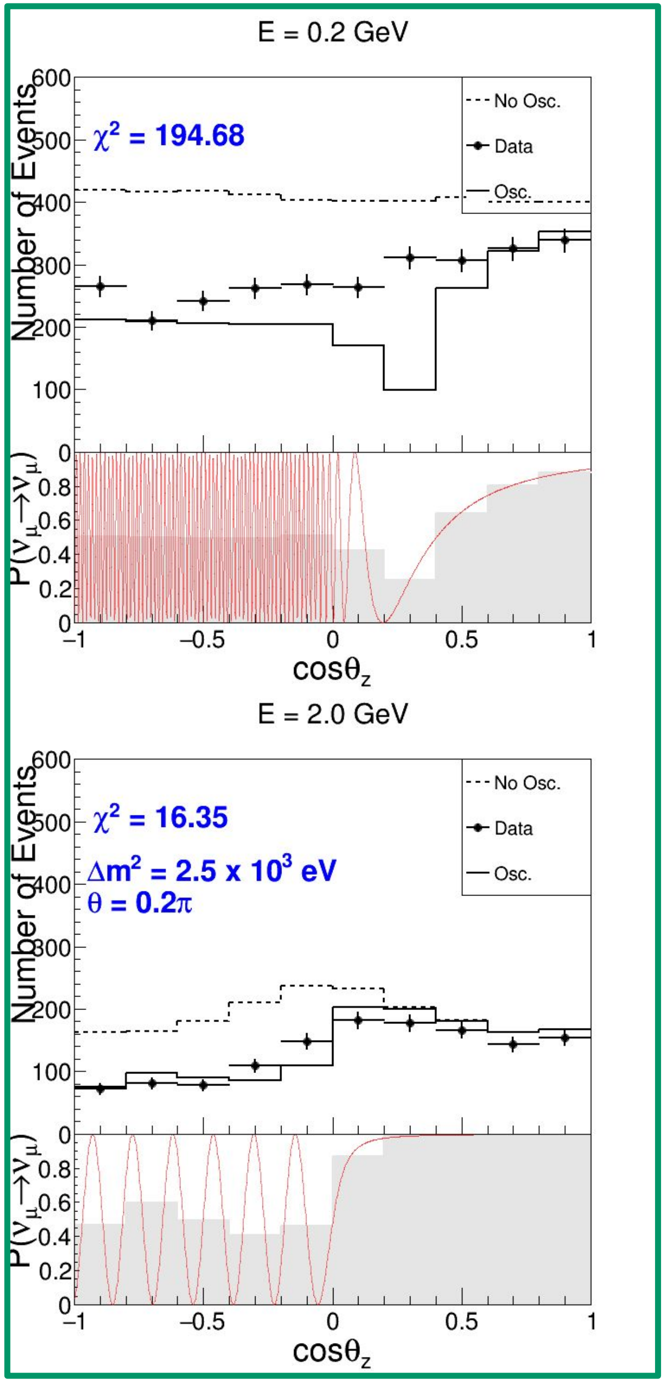
According to Toshito, their "Sub-GeV" energy regime is all E_ν < 1.3 GeV, but we assumed monochromatic neutrinos at 0.2 GeV.

Proper treatment:

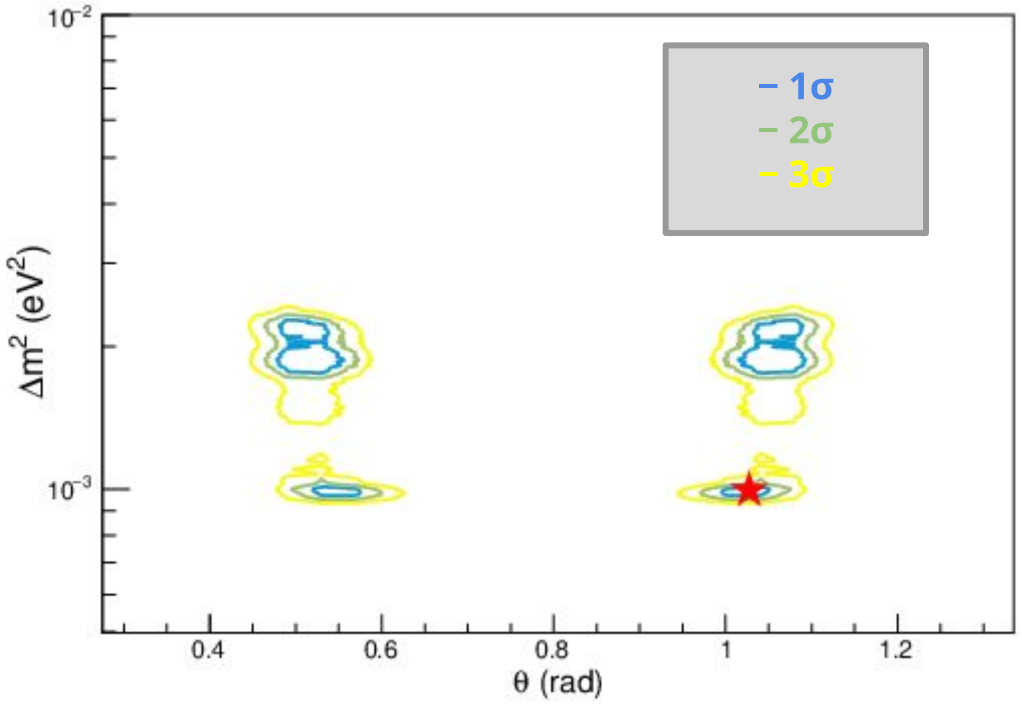
> **Expand un-oscillated prediction to 2D with**
>
> $$\Phi(\cos\theta_z, E) * \sigma_\nu(E)$$
>
> **normalize to total number of events and weigh by**
>
> $$\langle P(\nu_\mu \rightarrow \nu_\mu; \cos\theta_z, E) \rangle$$

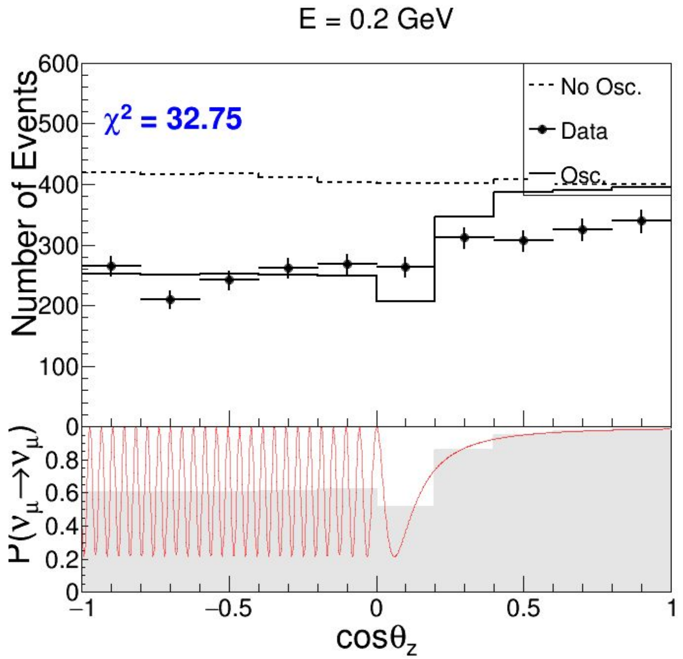
What we'll do here:

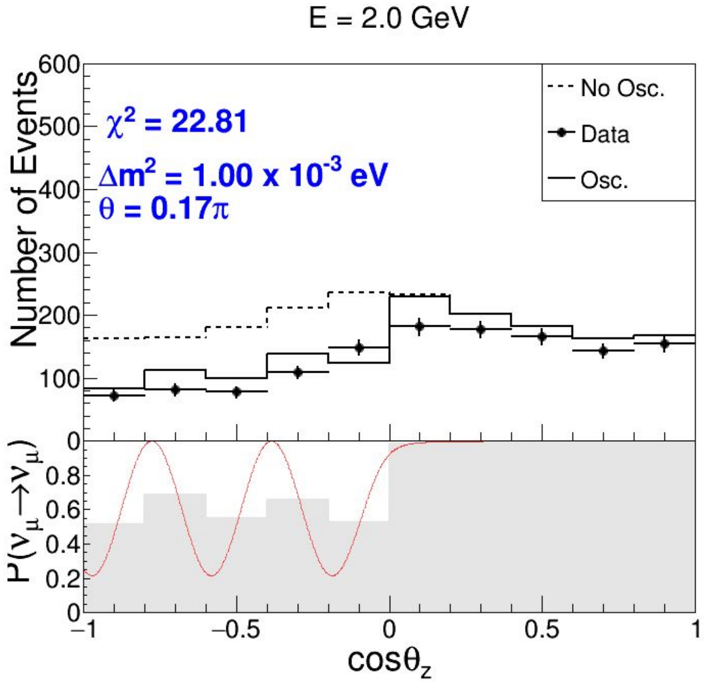
> **Perform a fit allowing θ and Δm^2 float**



Quick Fit Results (Minuit2 🤢)







Part 3: Flux Estimate for ν_e's

We want to use the number of observed Sub-GeV e-like events to infer the flux of these types of particles.

Number Observed:

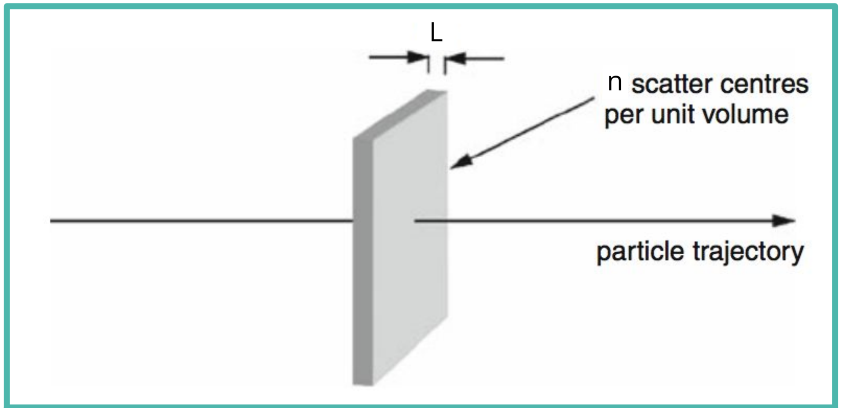
$$N_{obs} = \Phi \times P_{int} \times T \times A$$

Prob. of a single particle interacting:

$$P_{int} = nL\sigma$$

Solve for Flux:

$$\Phi = N_{obs} / (n \times L \times \sigma \times T \times A)$$

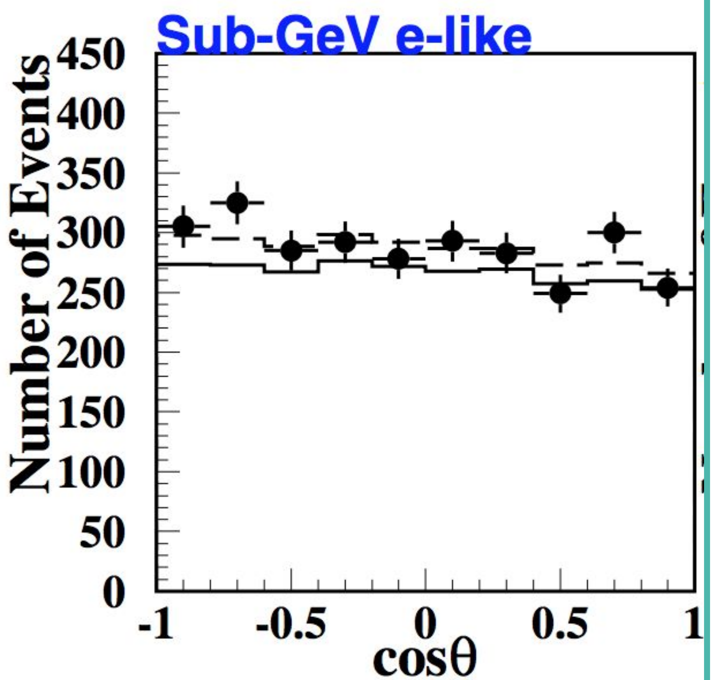


S. Tavernier, *Experimental Techniques in Nuclear and Particle Physics*

Part 3: Flux Estimate for ν_e's

Plugging in Numbers:

- **Cross Section:**
  - $\sigma \sim 5$ fb $= 5\times10^{-39}$ cm^2
- **Number Density of nuclei for water:**
  - $n = \rho N_A / A = 0.33\times10^{23}$ cm^{-3}
- **Time:**
  - $T = 1289$ days $= 1.11\times10^{8}$ s
- **Size of Super-Kamiokande:**
  - $A = \pi R^2 = \pi(40 \text{ m})^2 = 5026 \text{ m}^2$
  - $L = 40$ m
- $N_{obs} \sim 3000$



"Super-Kamiokande Atmospheric Neutrino Results" by T. Toshito, hep-ex/0105023

$$\Phi = N_{obs} / (n \times L \times \sigma \times T \times A) = 0.8 / \text{cm}^2\text{s}$$