Understanding Atmospheric Neutrino Data

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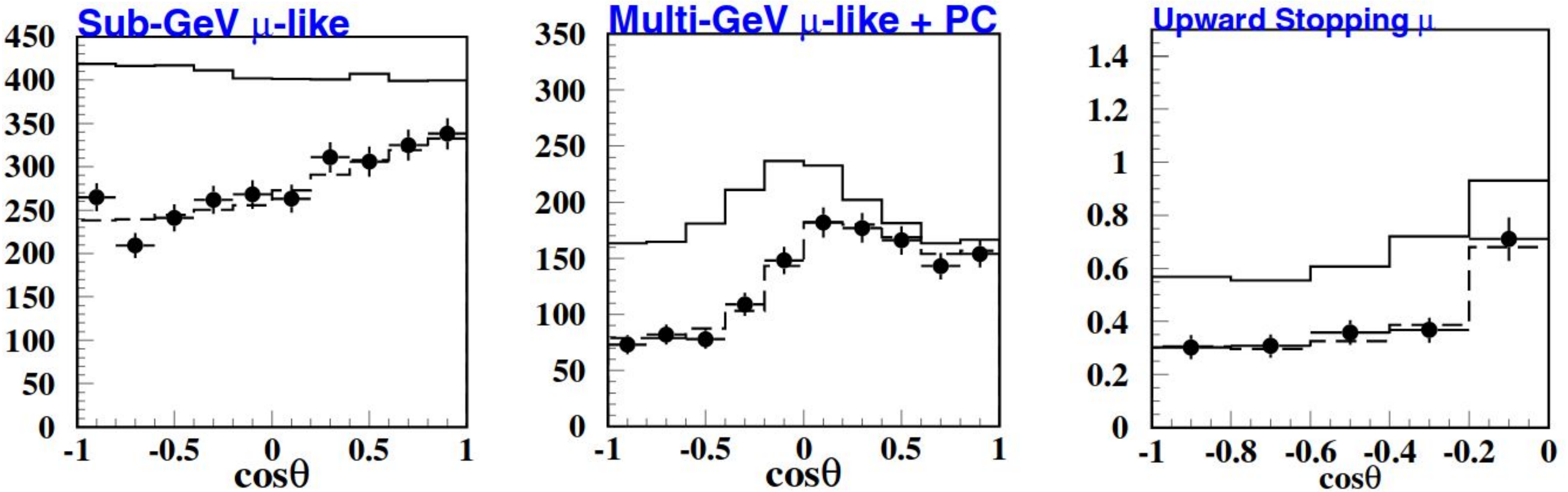
Super Kamiokande Atmospheric Samples (2001)

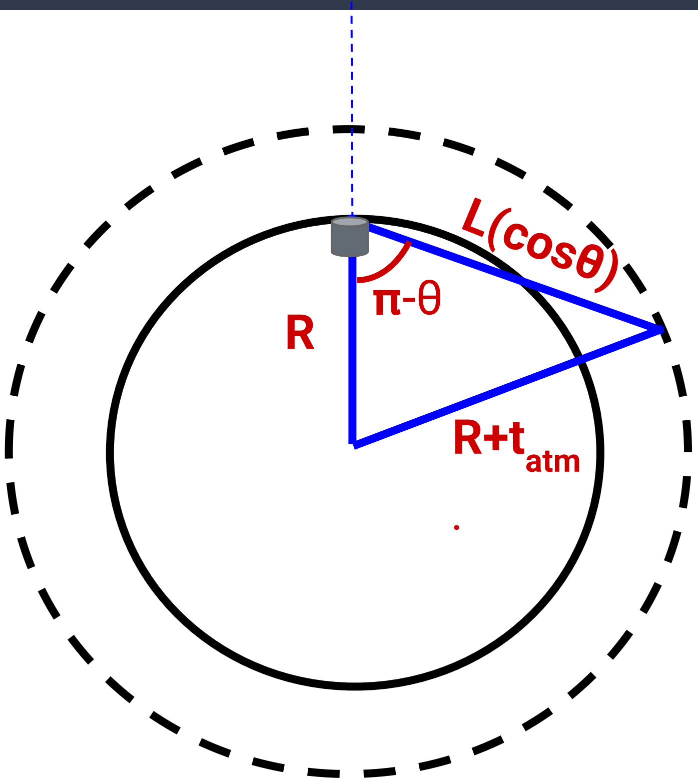
arXiv:hep-ex/0105023



Baseline Angular Dependence

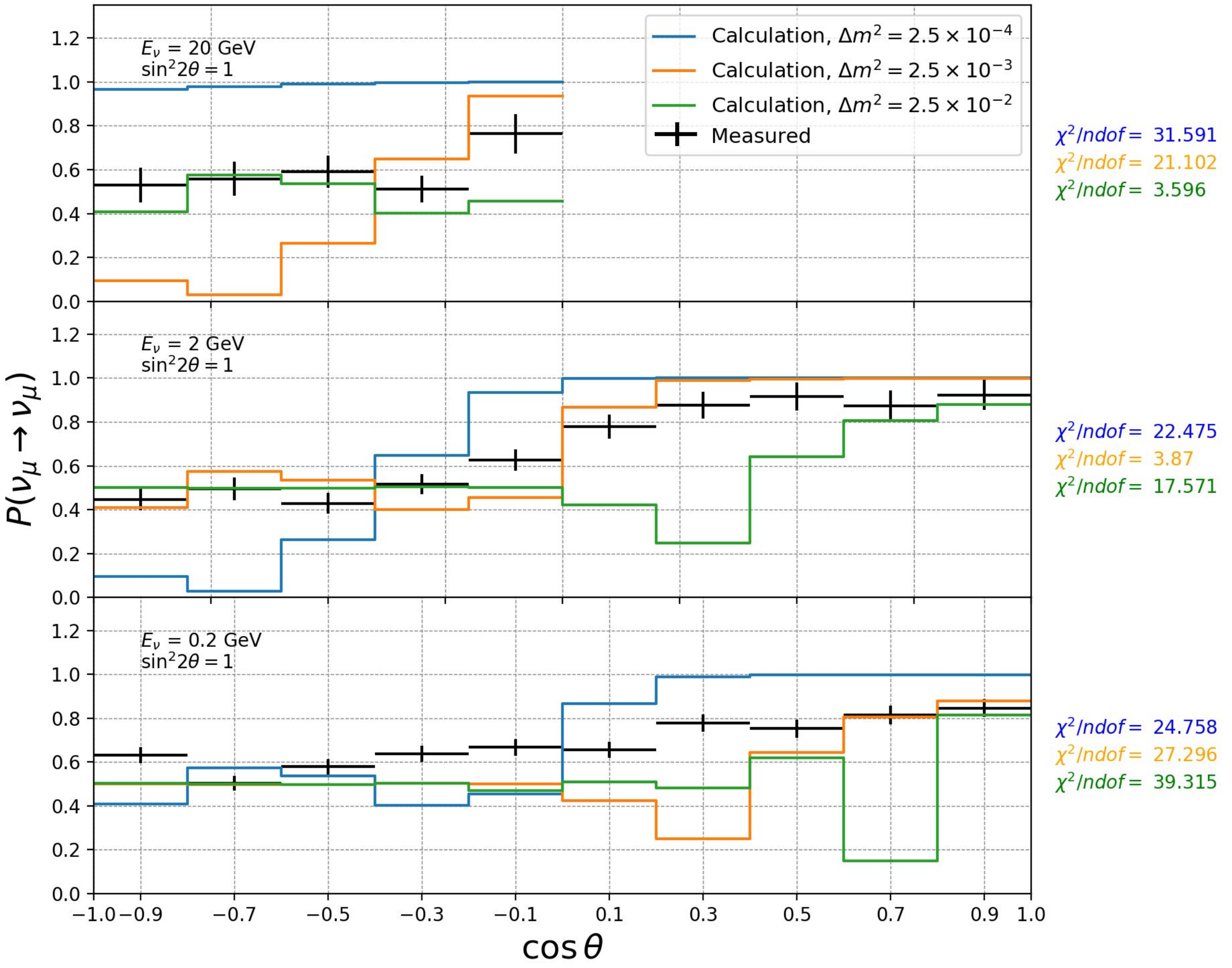
$$(R + t_{atm})^2 = L^2 + R^2 + 2LRcos\theta$$

$$L(cos\theta) = \sqrt{R^2(cos^2\theta - 1) + (R + t_{atm})^2} - Rcos\theta$$

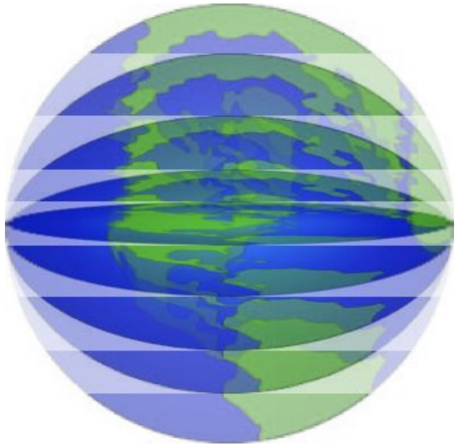


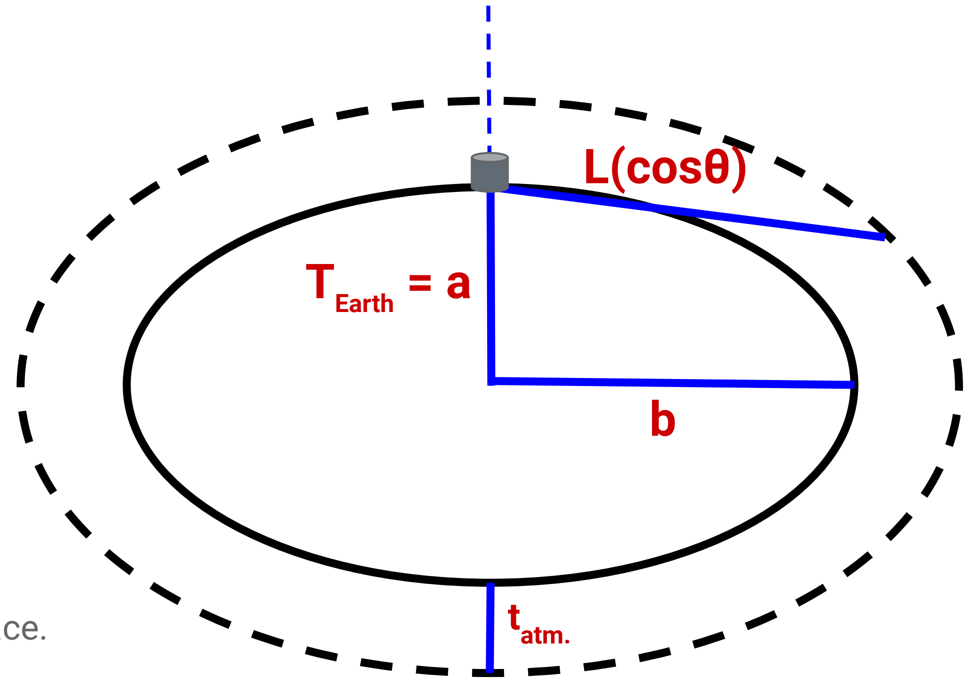
Disappearance Plots

(Assuming 2-flavor transitions)



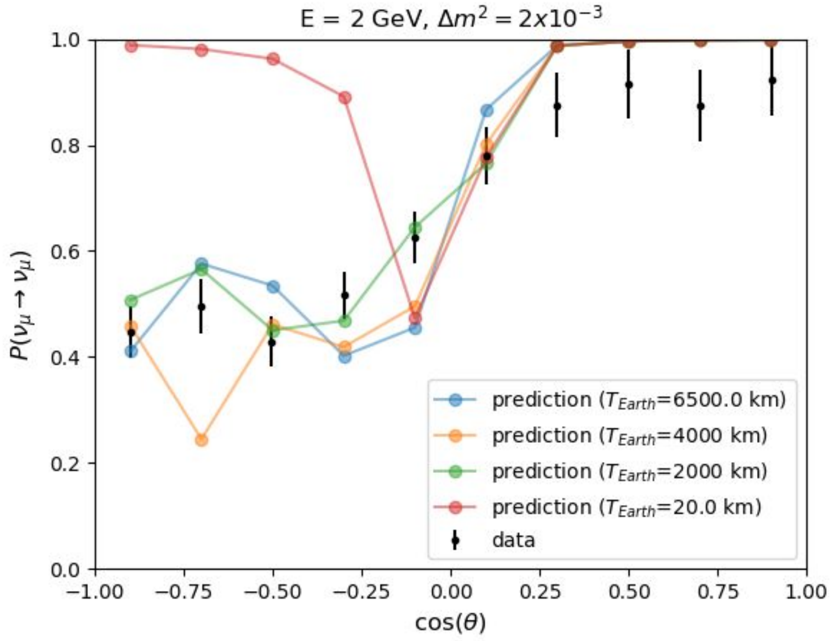
Beyond Standard (BS) Earth Model



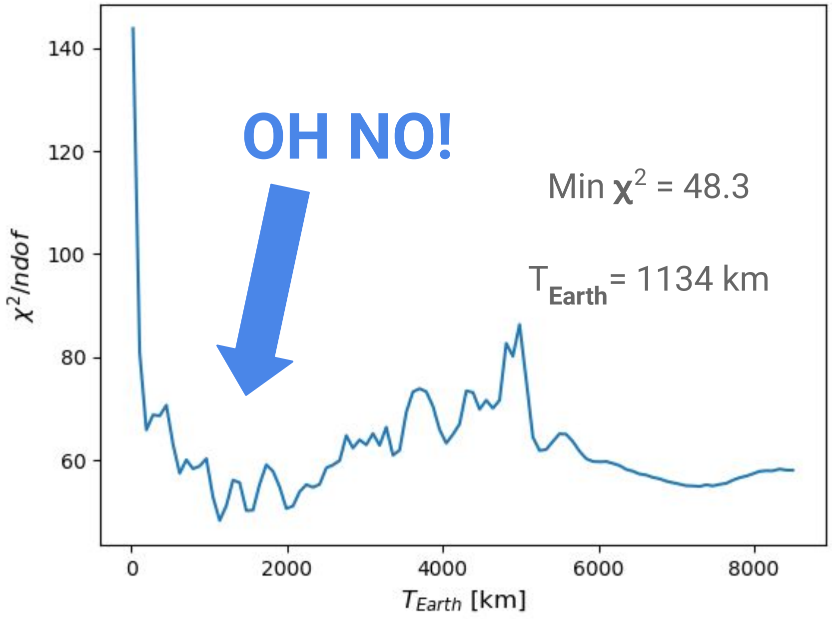


- Assume volume of Earth remains constant.
- Assume Super-K in the middle of flat Earth surface.
- Fix Δm^2 = 2.5 x 10^{-3} eV^2.

Flat Earth Plots



Add χ^2/ndof for Sub-GeV, Multi-GeV and Upward Stopping data.



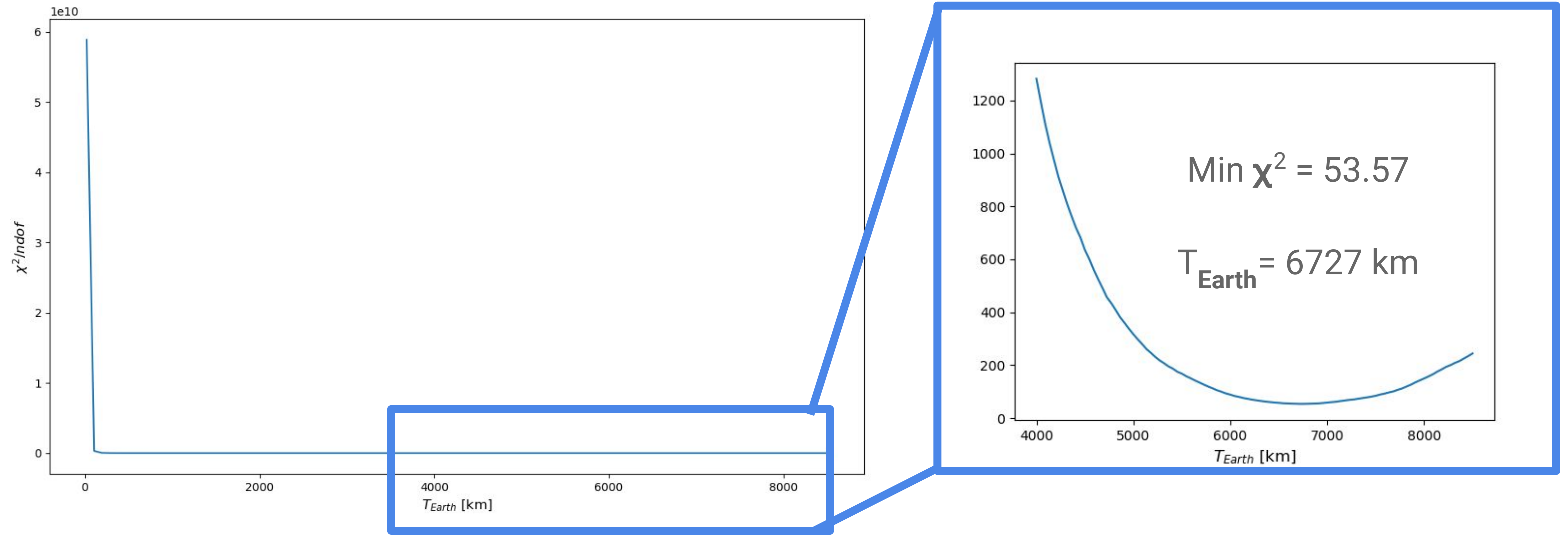
OH NO!

Min χ^2 = 48.3

T_{Earth} = 1134 km

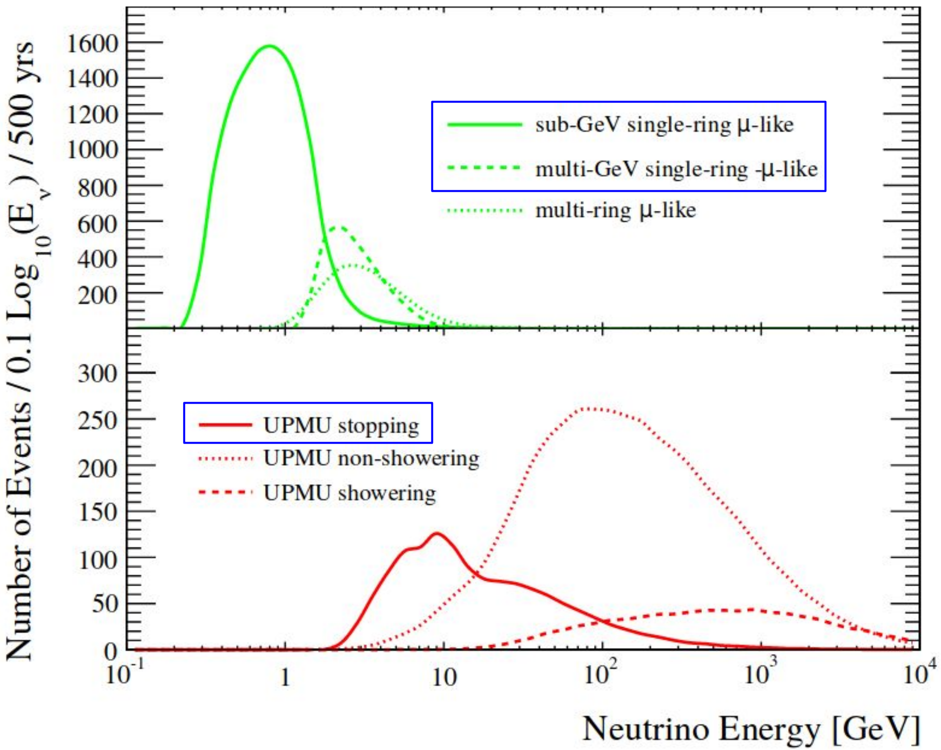
Flat Earth Plots (Flux Correction)

- The flux seen as a function of cos(θ) is not constant as we move from a sphere to an ellipsoid.
- Apply a flux correction proportional to (Area of ellipsoid in cos(θ) bin)/(Area of sphere in cos(θ) bin).
- This changes the expected unoscillated flux and hence observed oscillation probability.



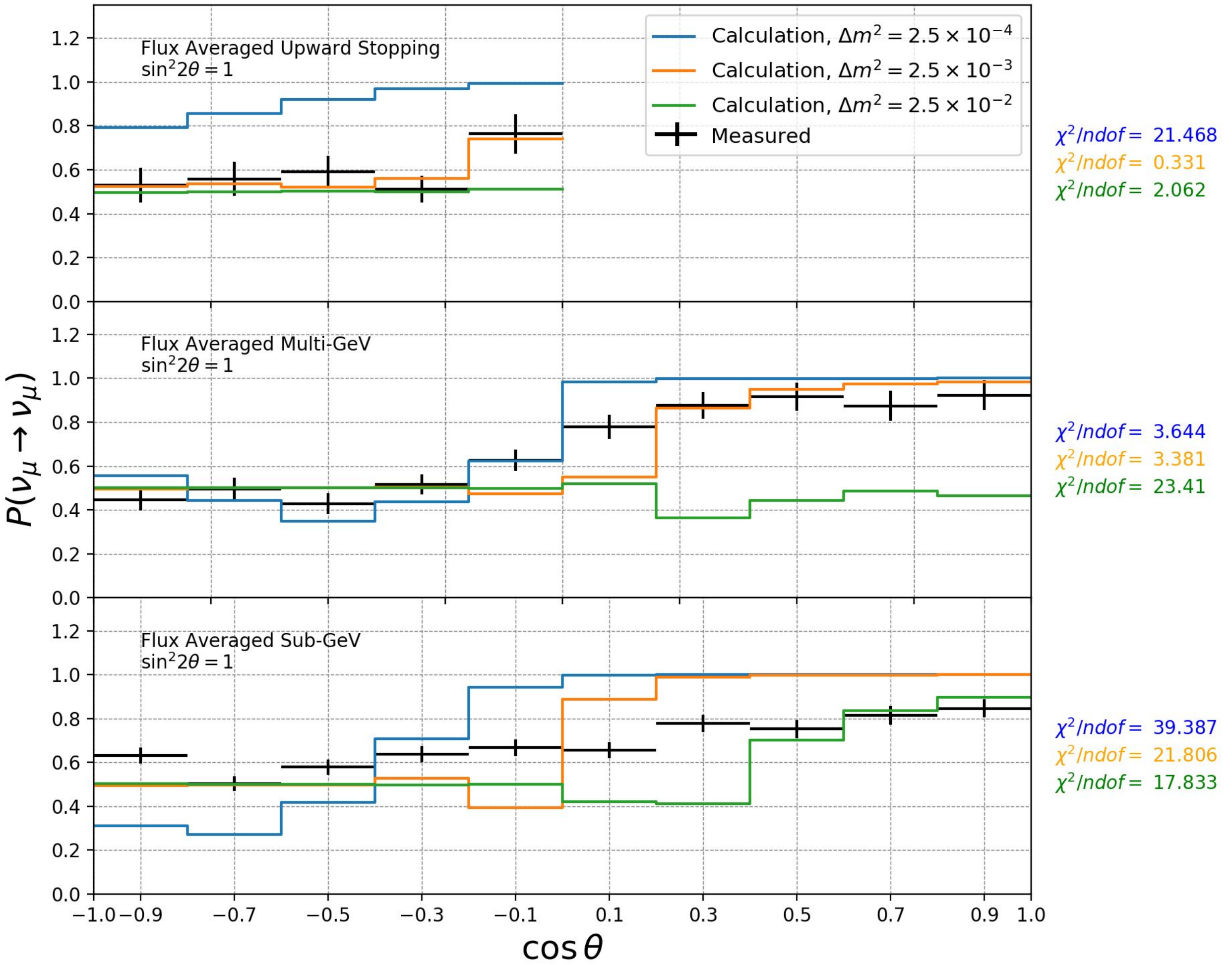
Neutrino Spectrum

arXiv:1510.08127



Flux-Averaged Disappearance Plots

(Assuming 2-flavor transitions)



Summary

- Earth is probably not flat.

Δm^2 [eV^2]	$\sum_s (\chi^2/ndof)_s$	
	Monoenergetic	Flux averaged
2.5×10^{-4}	78.8	64.5
2.5×10^{-3}	52.3	25.5
2.5×10^{-2}	60.5	43.3

Backup: Ellipsoid Distance to Detector

$\theta < \pi/2$:

$$y = \frac{\sqrt{(a+t_{atm})^2(b+t_{atm})^2 * (2at_{atm}\tan^2(\theta)) + b^2 + 2bt_{atm} + t_{atm}^2\tan^2(\theta) + t_{atm}^2} - ab^2 - 2abt_{atm} - at_{atm}^2}{a^2\tan^2\theta + 2at_{atm}\tan^2(\theta) + 2bt_{atm} + t_{atm}^2\tan^2(\theta) + t_{atm}^2}$$

$$L = y\sqrt{1+\tan^2(\theta)}$$

$\theta > \pi/2$:

$$y = \frac{\sqrt{(a+t_{atm})^2(b+t_{atm})^2 * (2at_{atm}\tan^2(\pi-\theta)) + b^2 + 2bt_{atm} + t_{atm}^2\tan^2(\pi-\theta) + t_{atm}^2} + ab^2 + 2abt_{atm} + at_{atm}^2}{a^2\tan^2\pi - \theta + 2at_{atm}\tan^2(\pi-\theta) + 2bt_{atm} + t_{atm}^2\tan^2(\pi-\theta) + t_{atm}^2}$$

$$L = y\sqrt{1+\tan^2(\pi-\theta)}$$

Backup: Flux Correction

$$Area_{Sphere}^{[\theta_1,\theta_2]} = 2\pi(R + t_{atm})|L_{Sphere}^{\theta_1}\cos(\theta_1) - L_{Sphere}^{\theta_2}\cos(\theta_2)|$$

$$Area_{Ellipsoid}^{[\theta_1,\theta_2]} = \pi|(L_{Ellipsoid}^{\theta_1})^2 - 2t_{atm}L_{Ellipsoid}^{\theta_1}\cos(\theta_1) - (L_{Ellipsoid}^{\theta_2})^2 + 2t_{atm}L_{Ellipsoid}^{\theta_2}\cos(\theta_2)|$$

$$\Phi_{corrected}^{[\theta_1,\theta_2]}(NoOsc) = \frac{Area_{Ellipsoid}^{[\theta_1,\theta_2]}}{Area_{Sphere}^{[\theta_1,\theta_2]}}\Phi_{Original}^{[\theta_1,\theta_2]}(NoOsc)$$