The Calculation of Atmospheric Neutrino Flux

M. Honda at noon 2003, Feb 12, 2003

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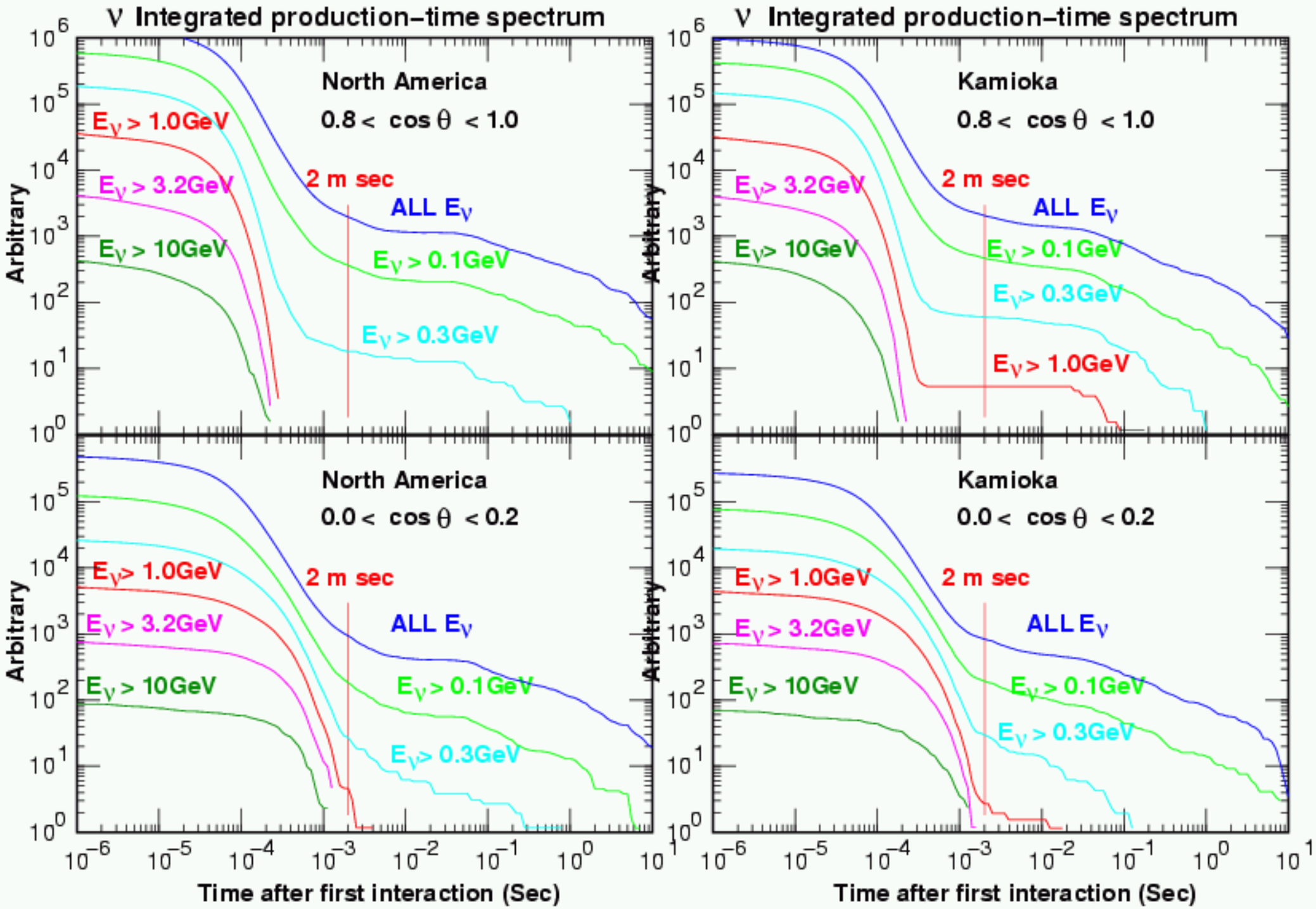
This work is based on the review work with T.K. Gaisser, and works with T. Kajita, K. Kasahara S. and Midorikawa.

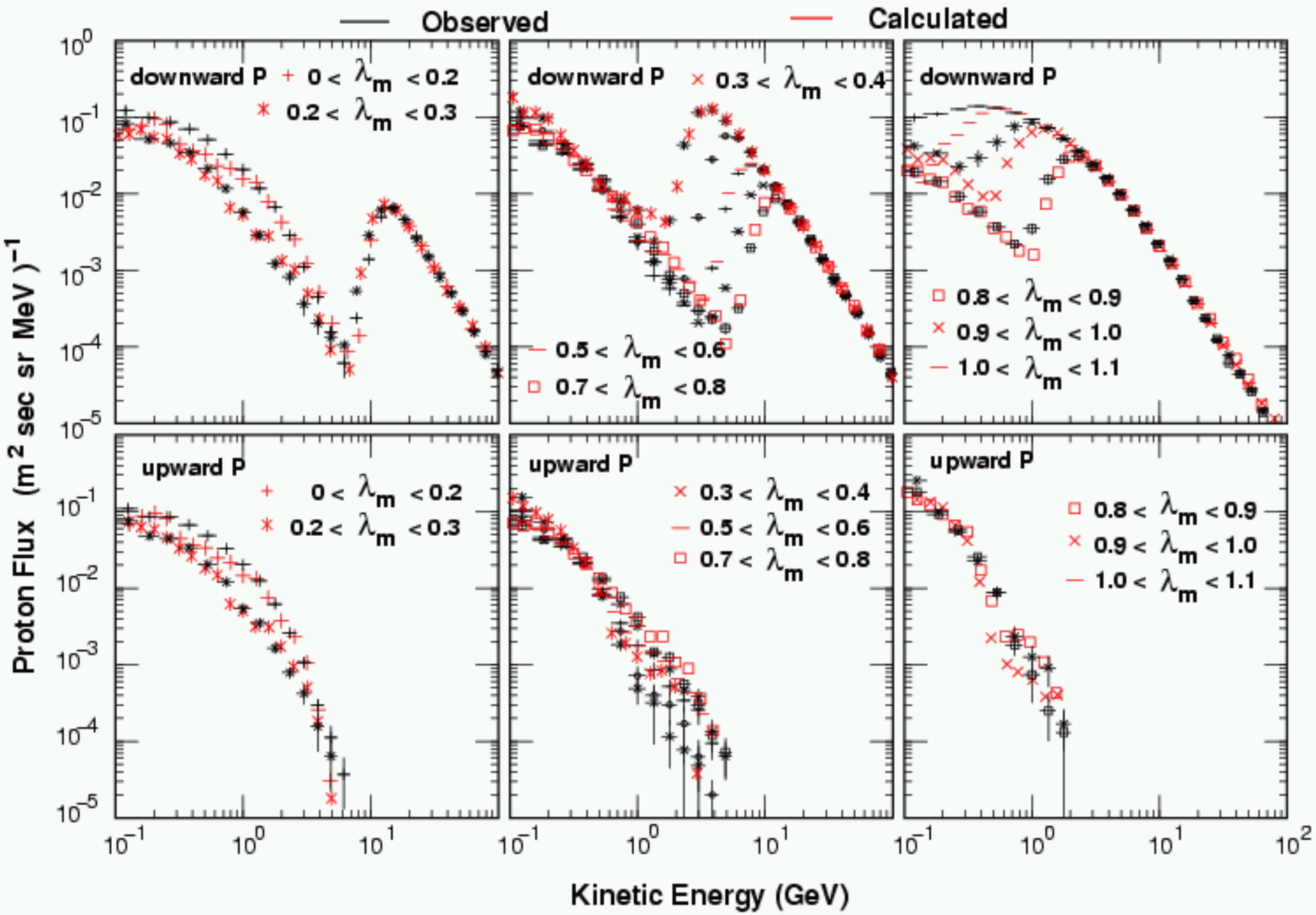
Many thanks to T. Sanuki, K. Abe and BESS collaboration, also to C. Saji, A. Okada and SK collaboration.

Neutrino prodaction time after the FIRST interaction.



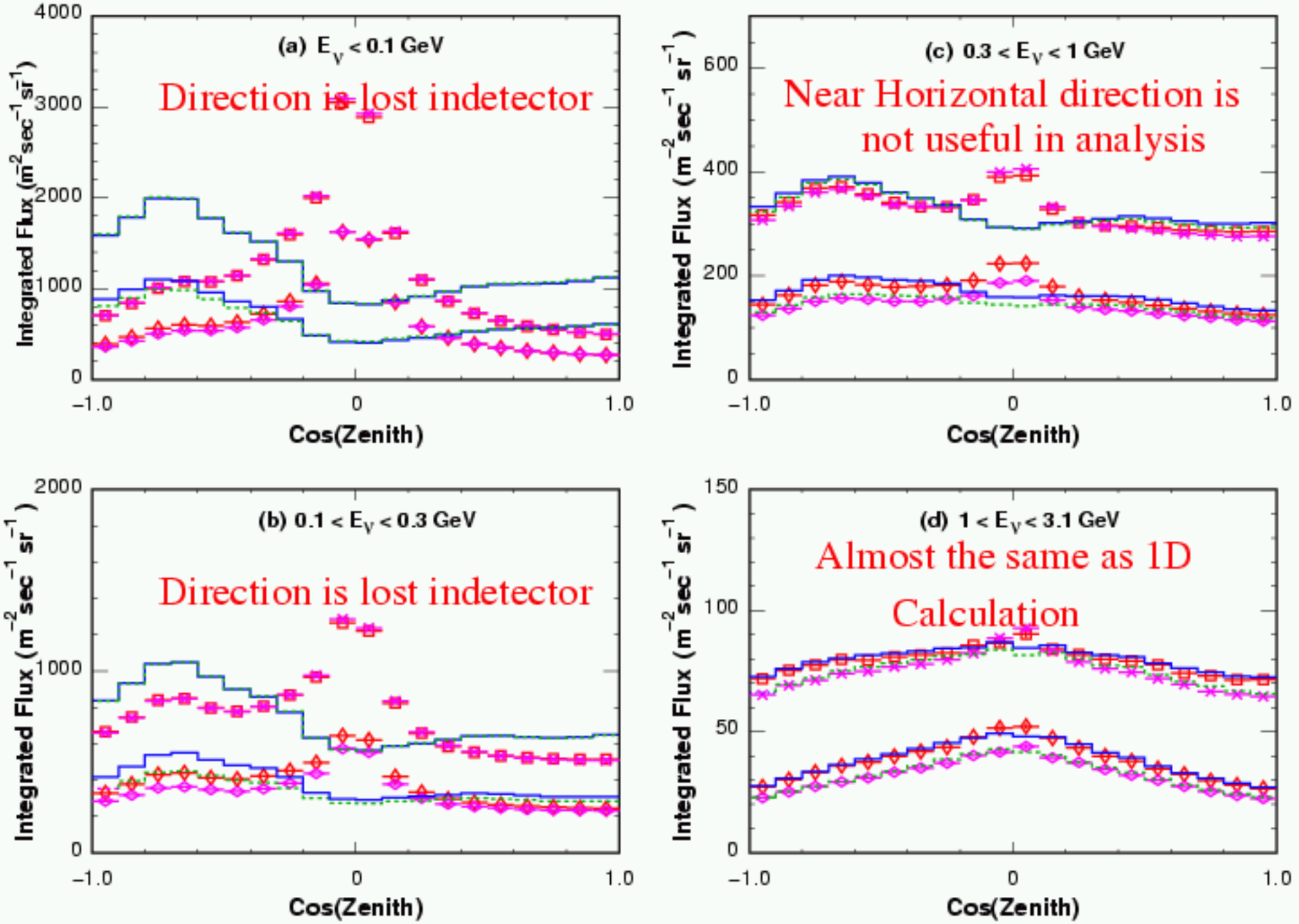
The neutrino contributed by 2nd spectra is less than 1%.

Less important things: Contribution of proton secondary spectra

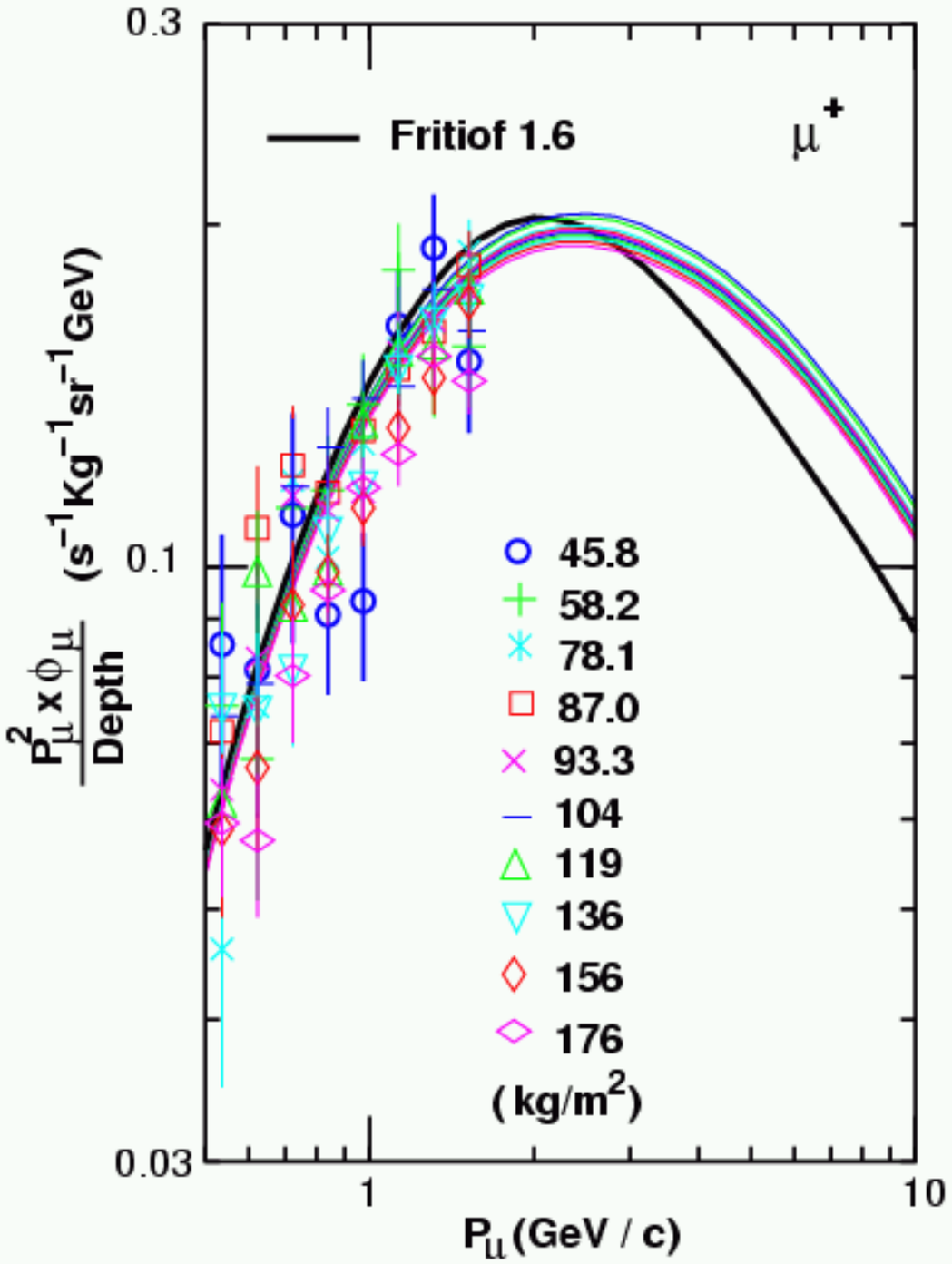


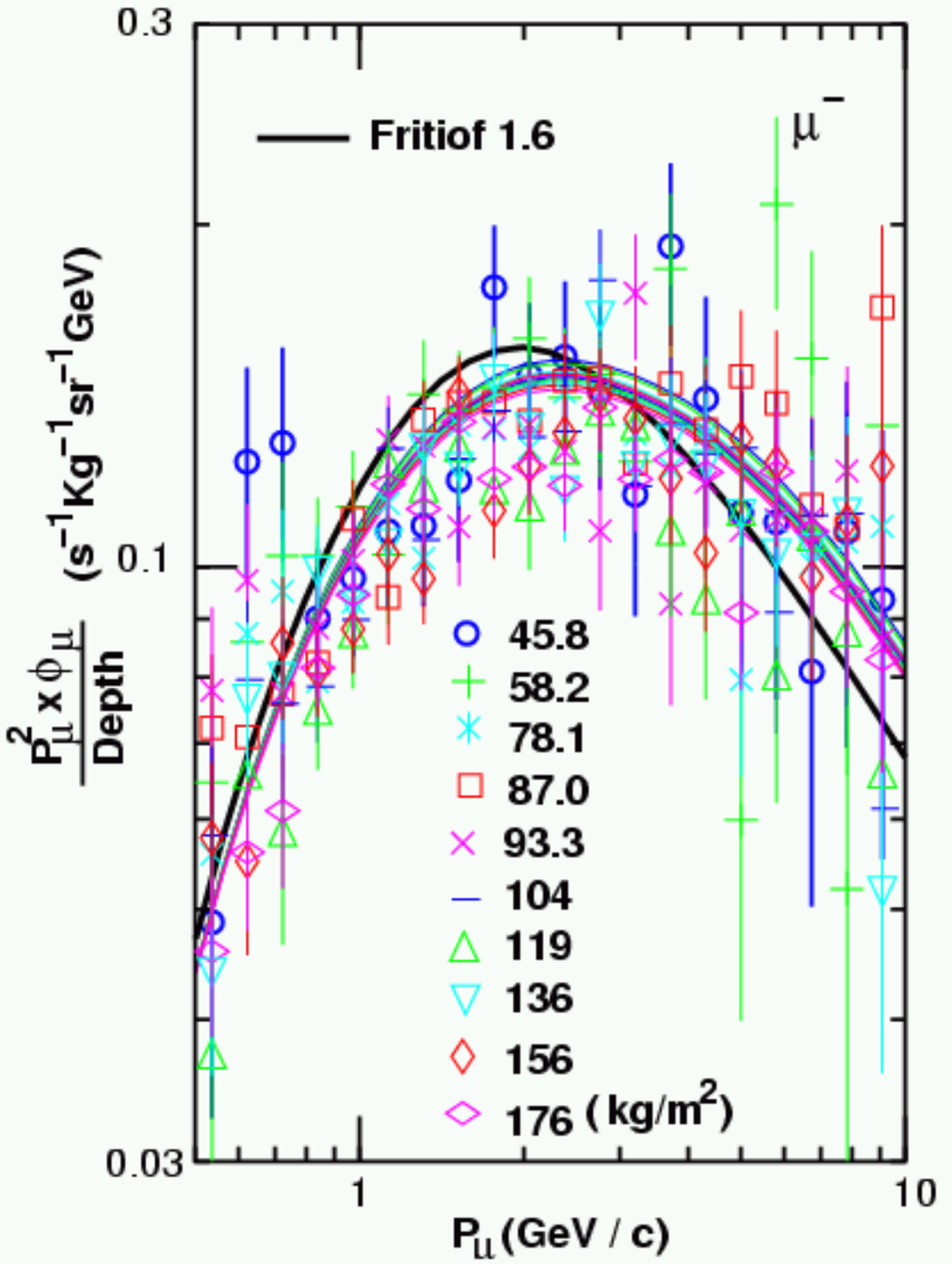
The particle produced by the cosmic rays and air nuclei interactions then go out of the atmosphere again.

Less important things: 3D-effects

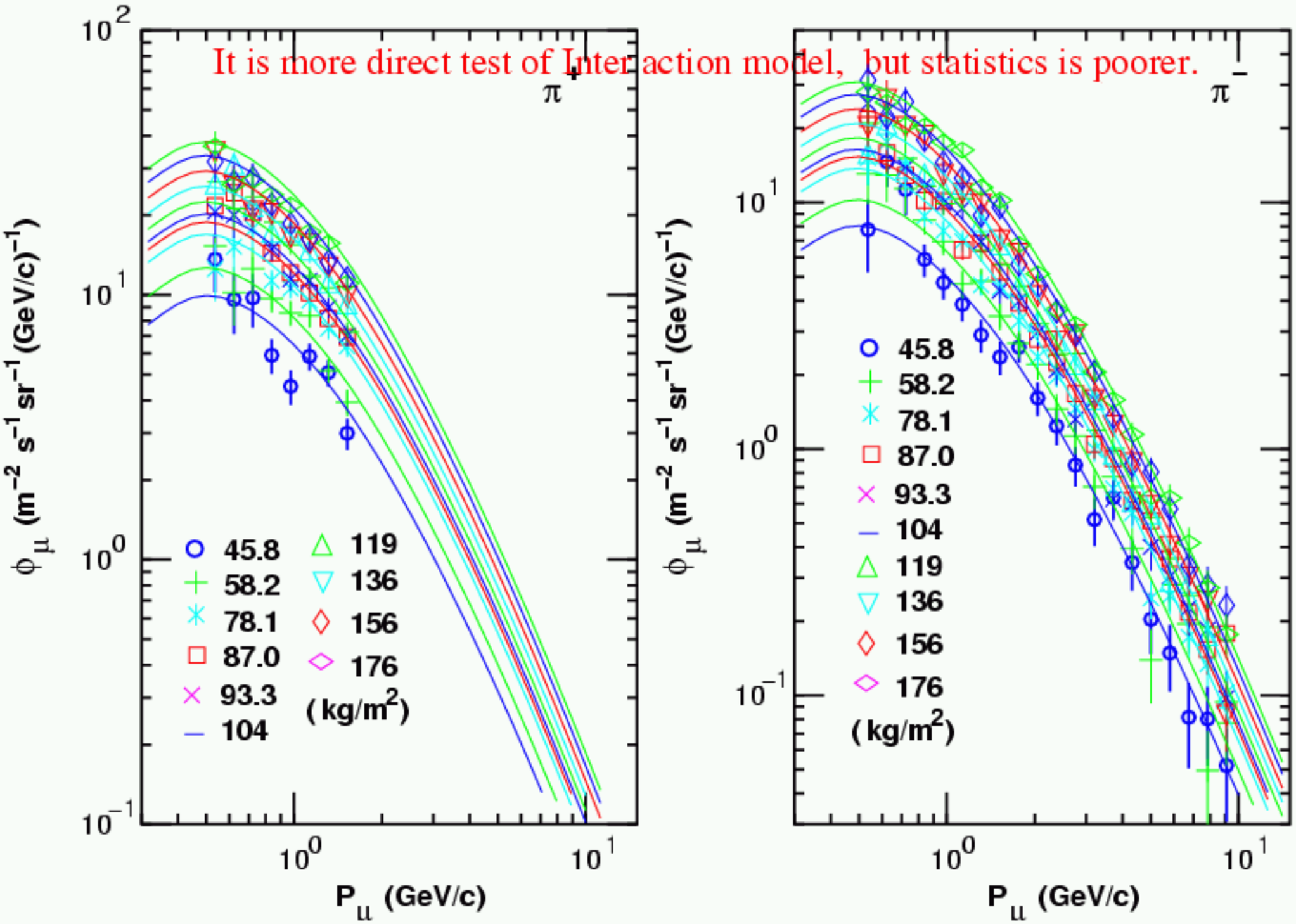


Improvement of interaction model using muons: Balloon altitude

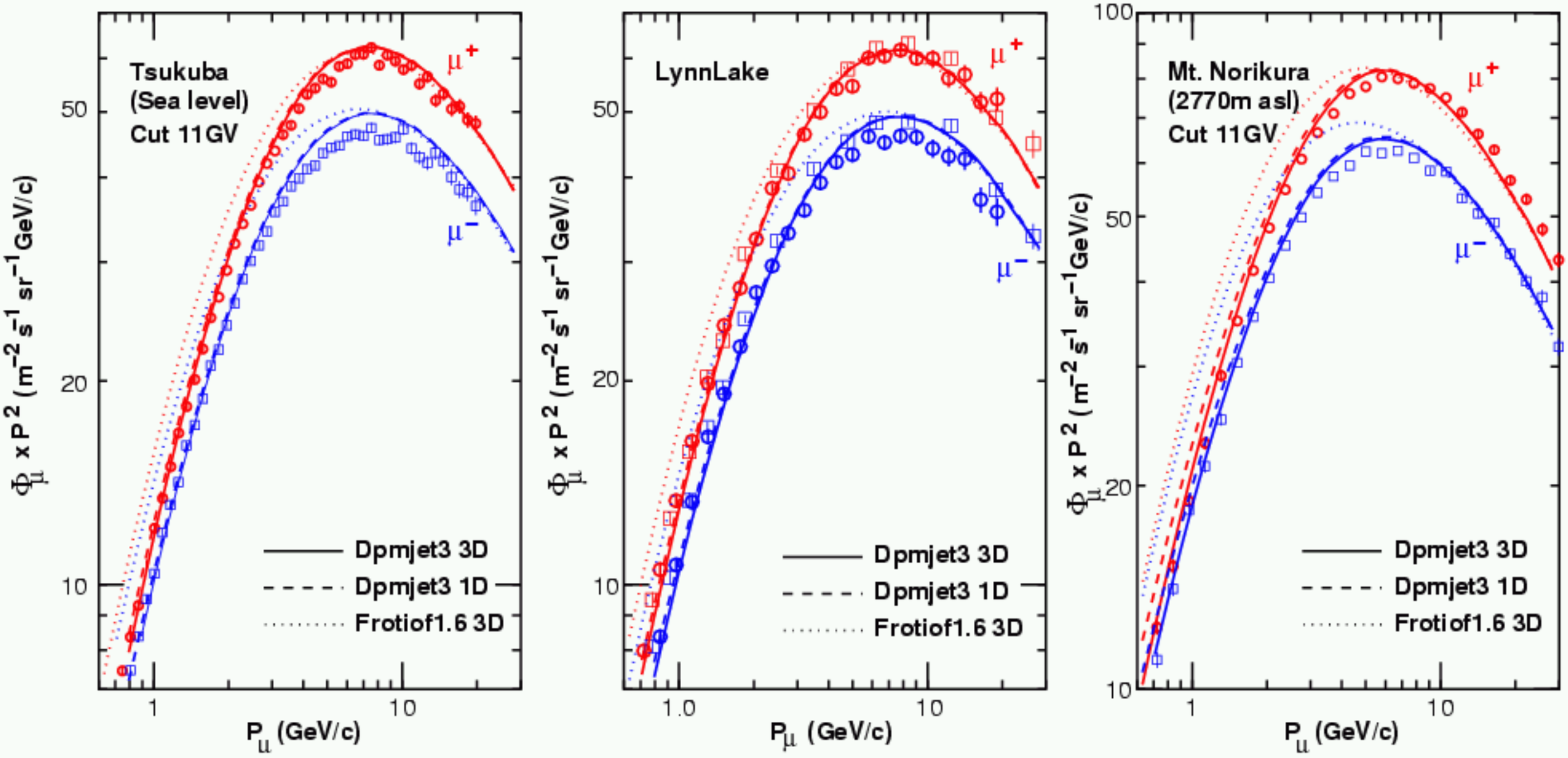




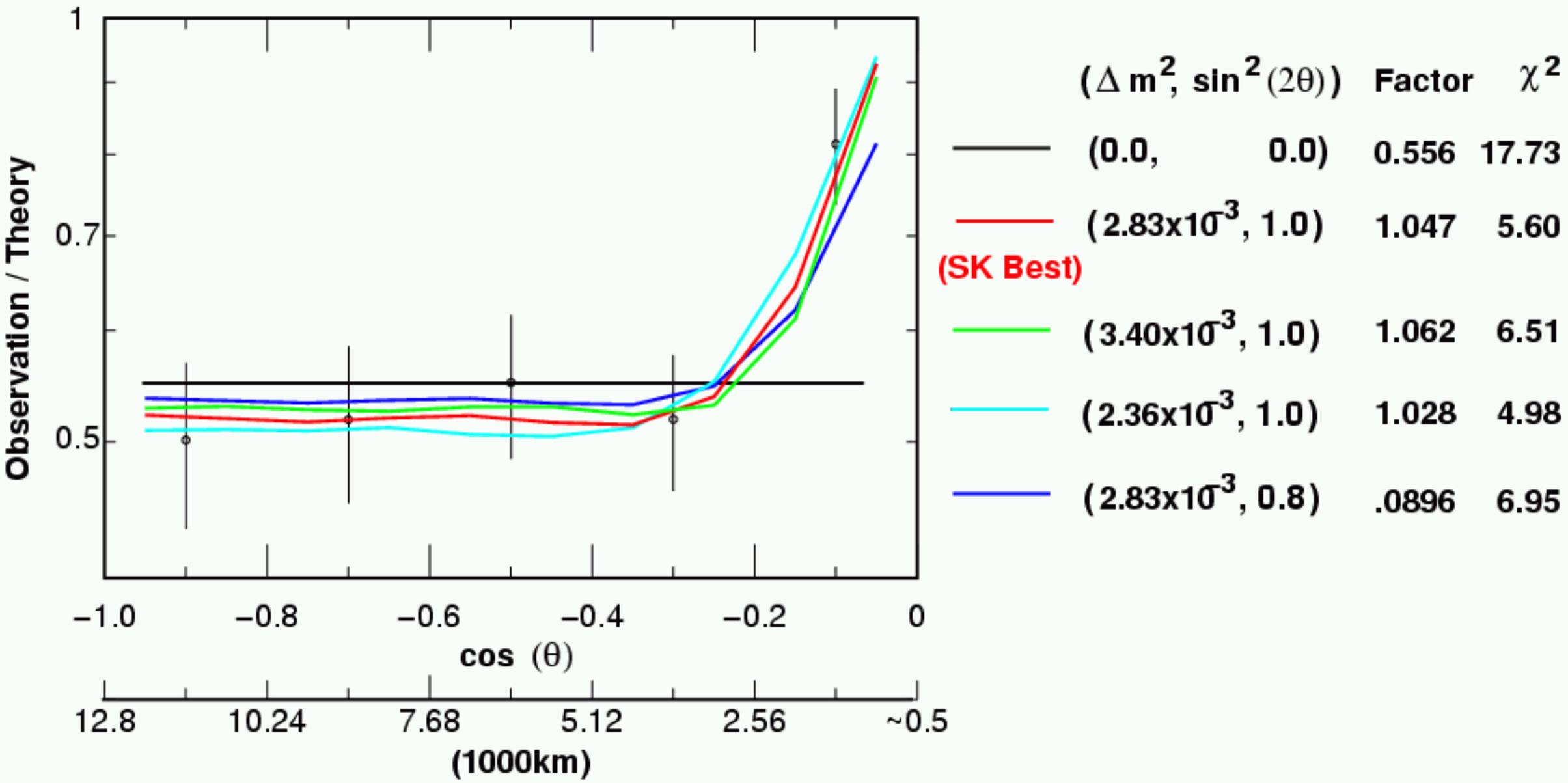
Improvement: comparison with muon observation: Baloon altitude



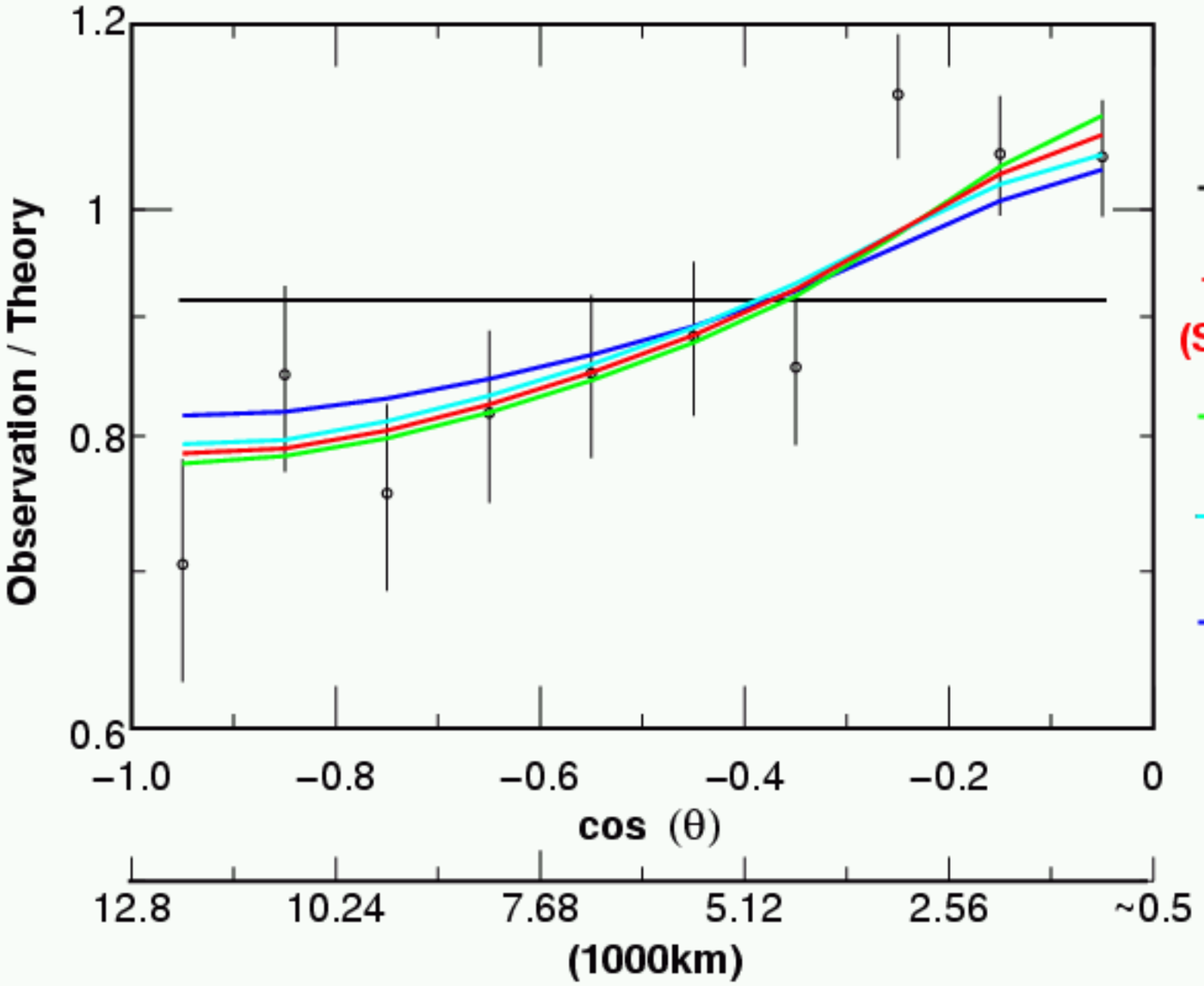
Improvement: comparison with muon observation: Graound level



Stopping muons



Through up-going muons II



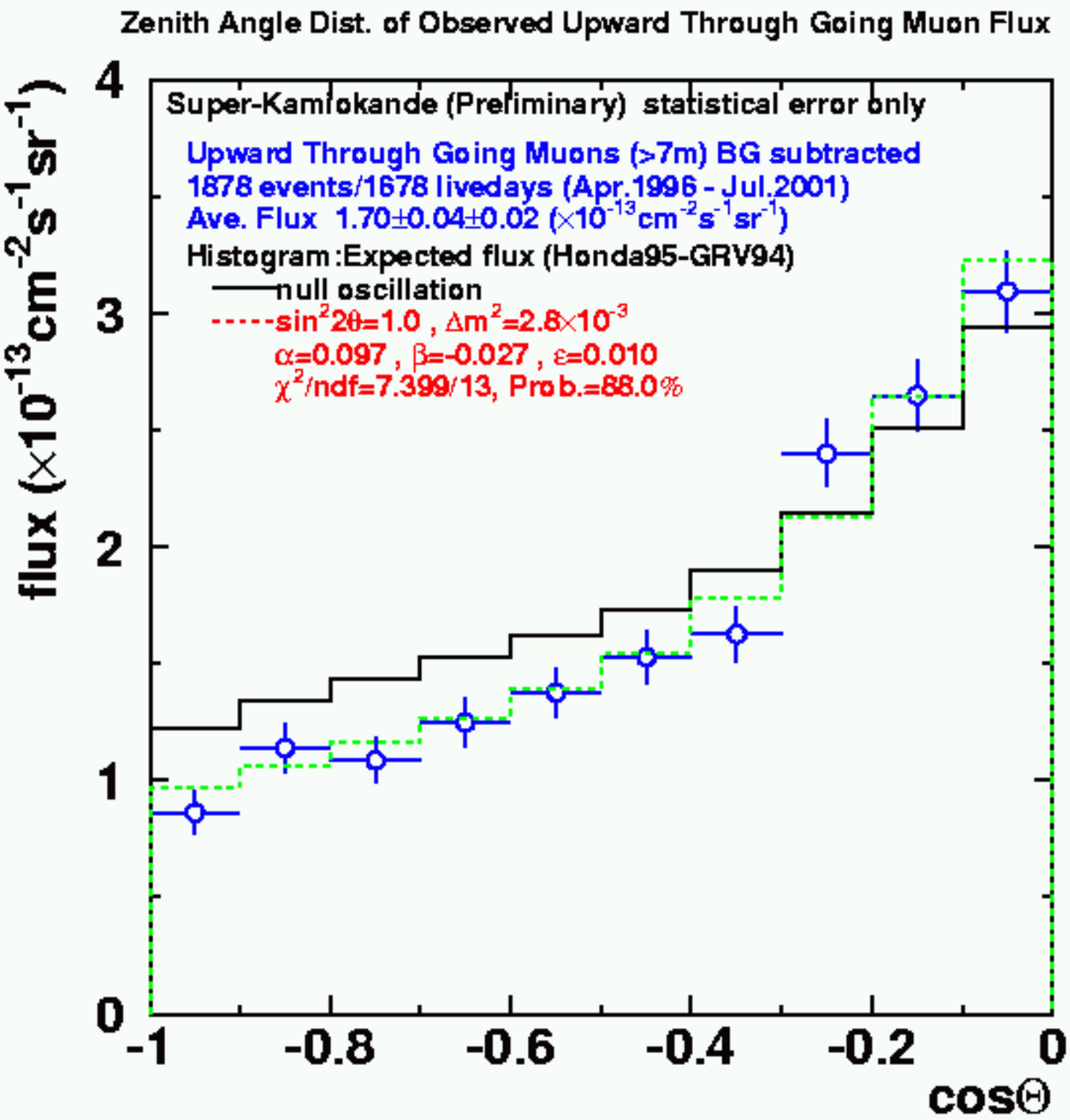
With Nomalization

	$(\Delta m^2, \sin^2(2\theta))$	Factor	χ^2
———	(0.0, 0.0)	0.907	36.61
———	(2.83×10^{-3}, 1.0)	1.084	7.92

(SK Best)

———	(3.40×10^{-3}, 1.0)	1.108	7.97
———	(2.36×10^{-3}, 1.0)	1.061	8.41
———	(2.83×10^{-3}, 0.8)	1.046	10.54

Through up-going muons



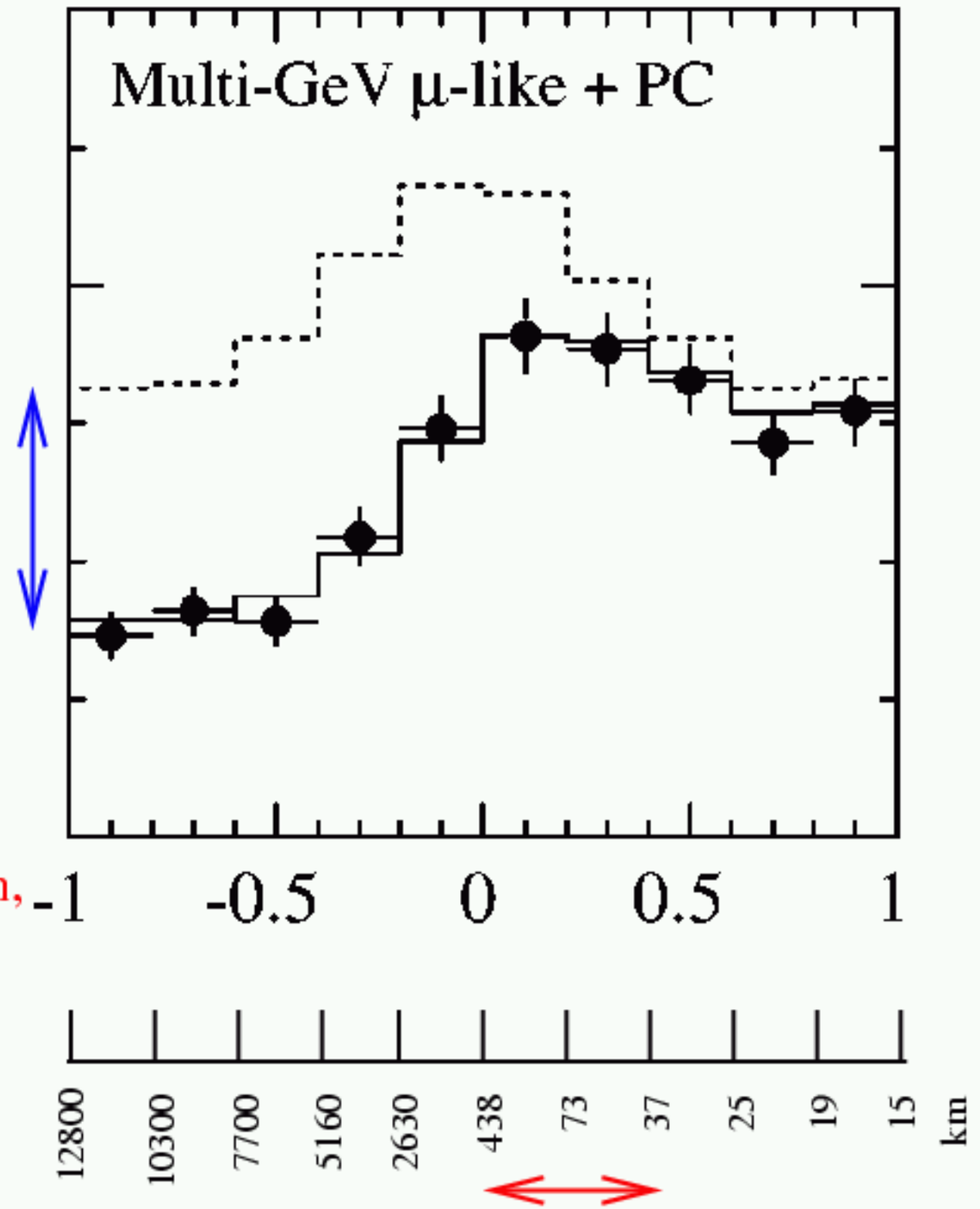
Multi-GeV events : Normalization is fixed in experiments, but ..

Expectation is almost updown symmmetry for Multi-GeV experiment

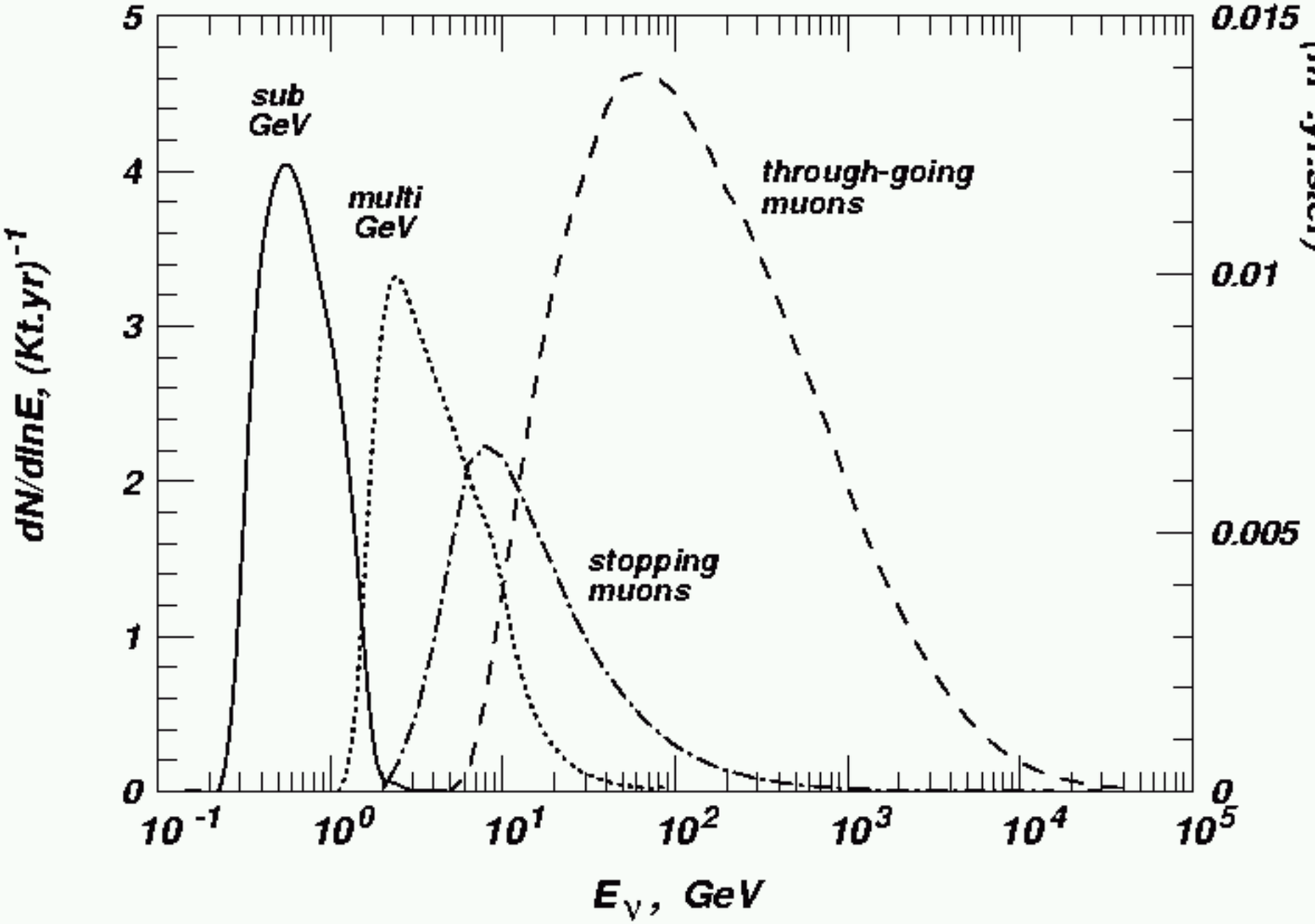
~ 1/2 $\sin^2(2\theta)$ is well determined

Due to the quick distance change at variaion reagion, it is difficult to determine the "oscillation length"

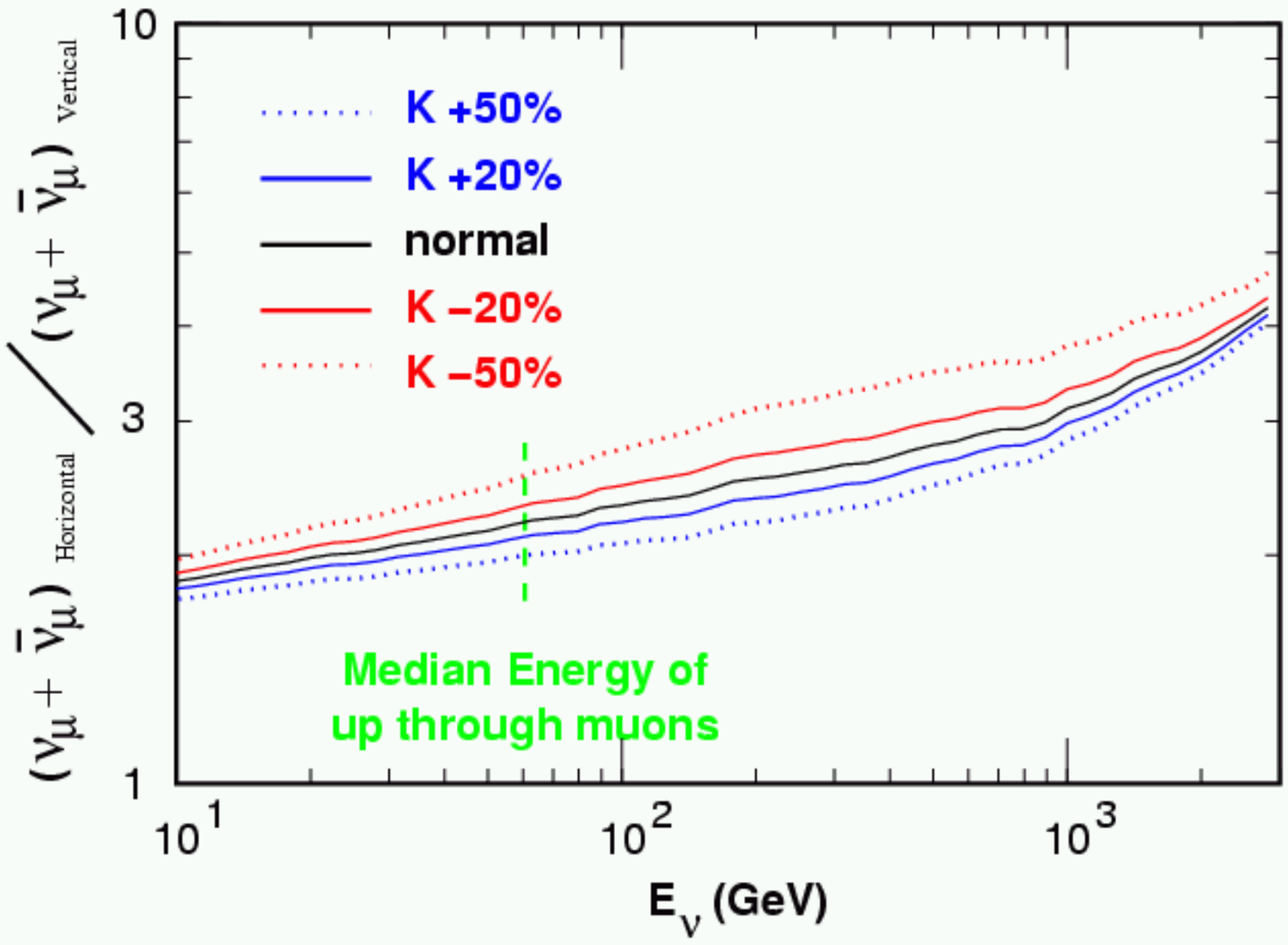
or Δm^2



Normalization problem : Cagery of experiments



Horizontal/Vertical variations due to the change of k/pi ratio



- Need more than 20% change in k/pi ratio to have a visible change.

Angular variation: The Kaon contribution to the neutrino flux

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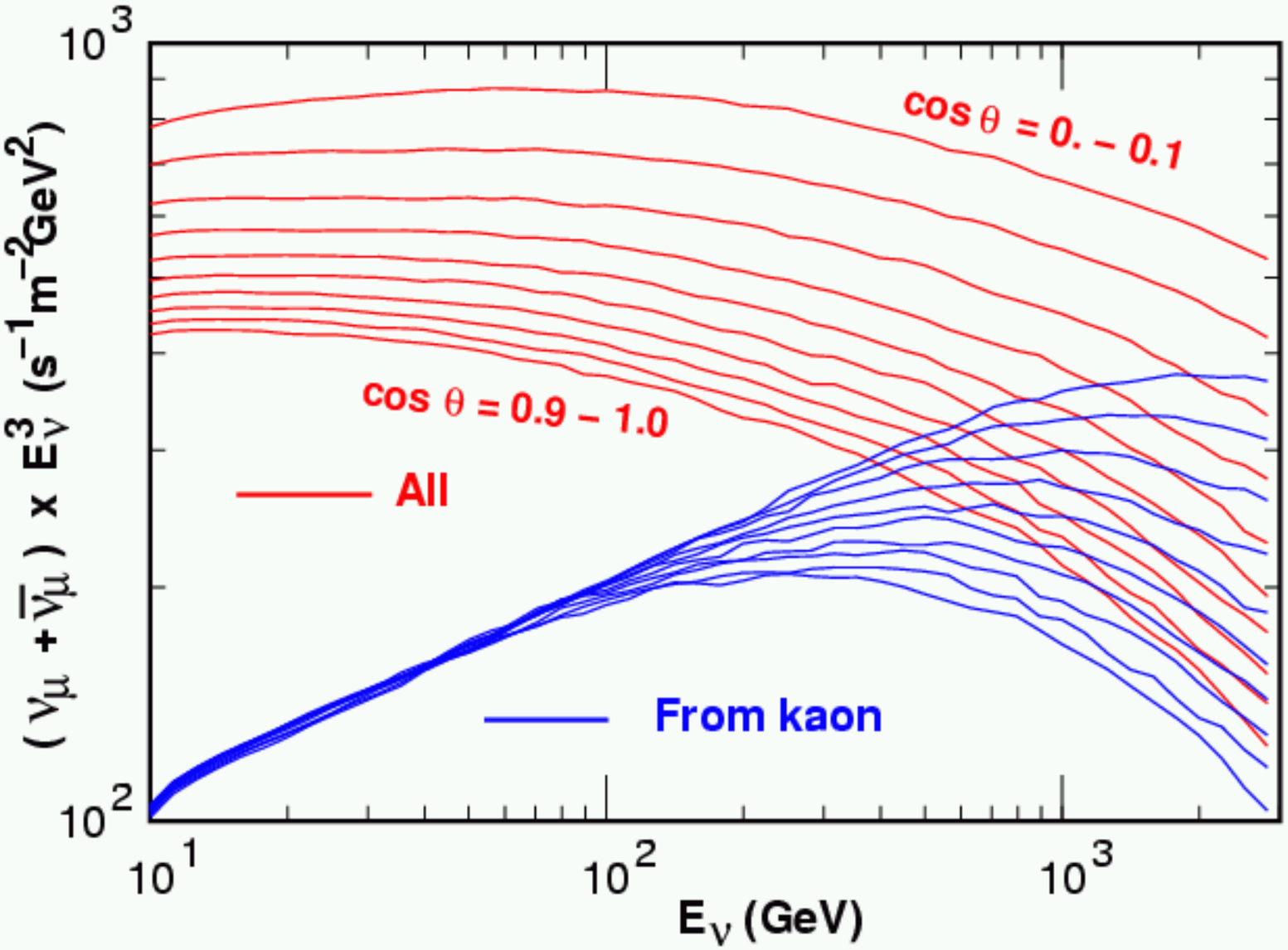
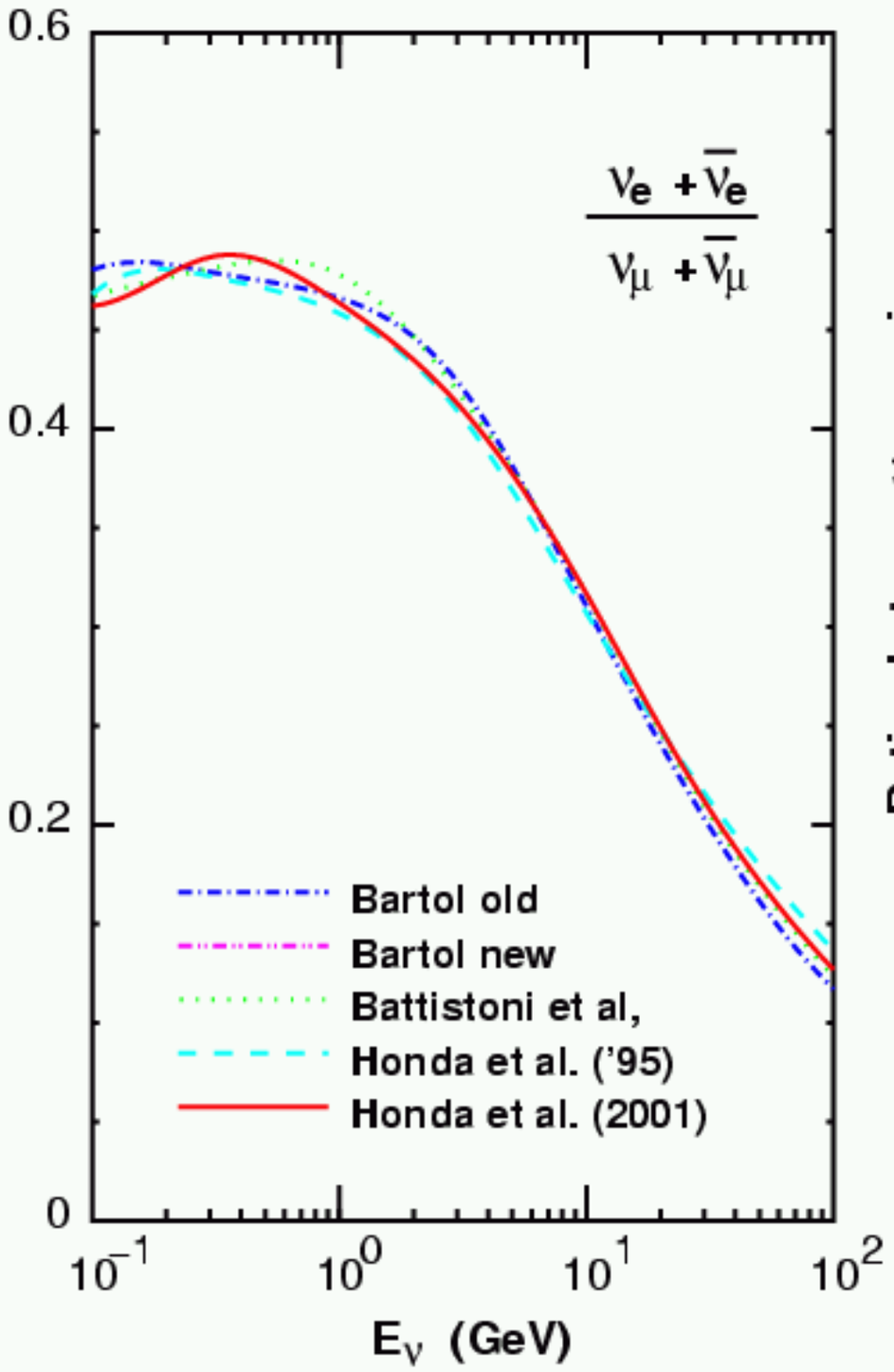
Note, main uncertainty comes from that of k/pi ratio

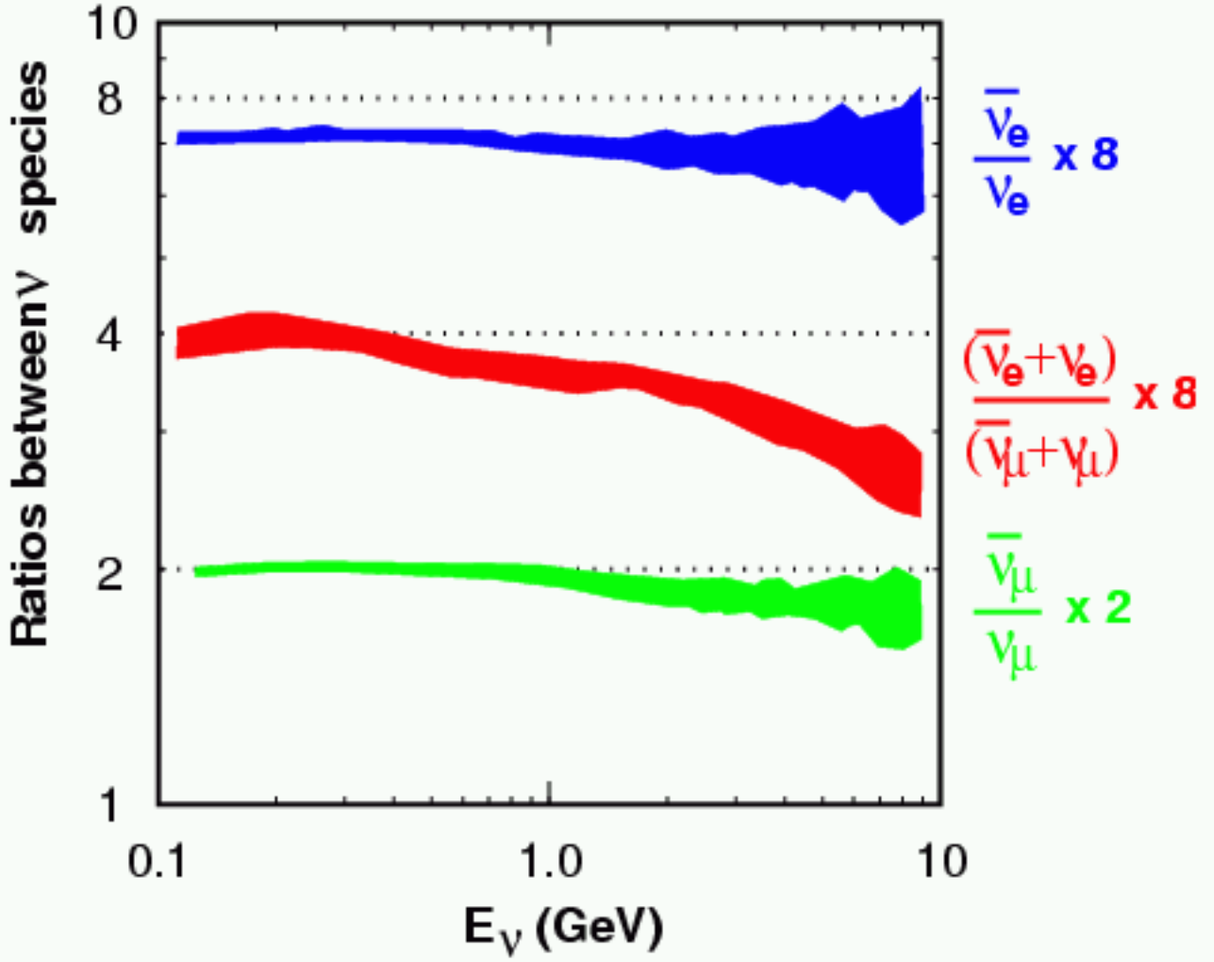


Sure Things : Ratio between neutrinos

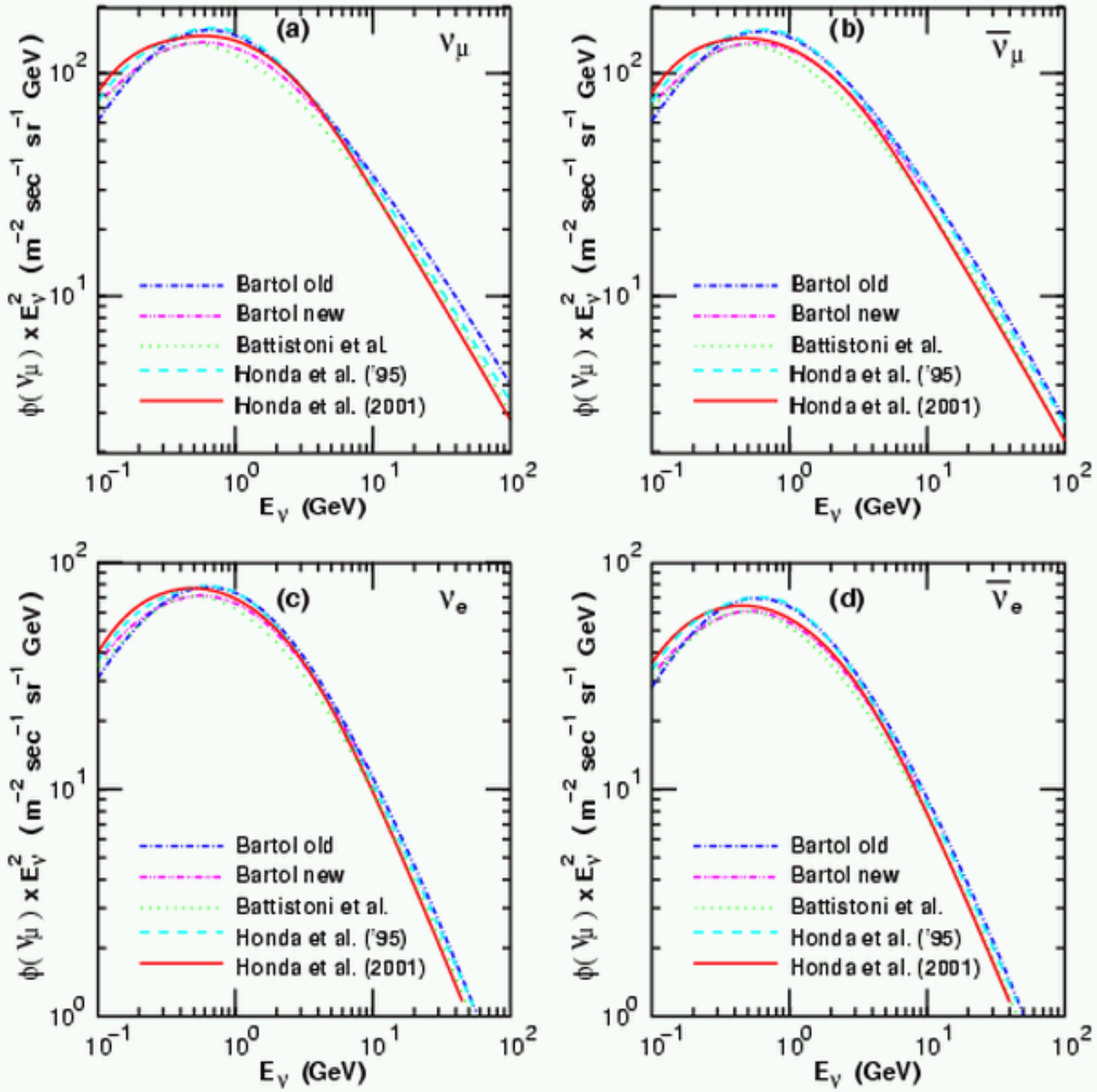
Comparison between different calculation



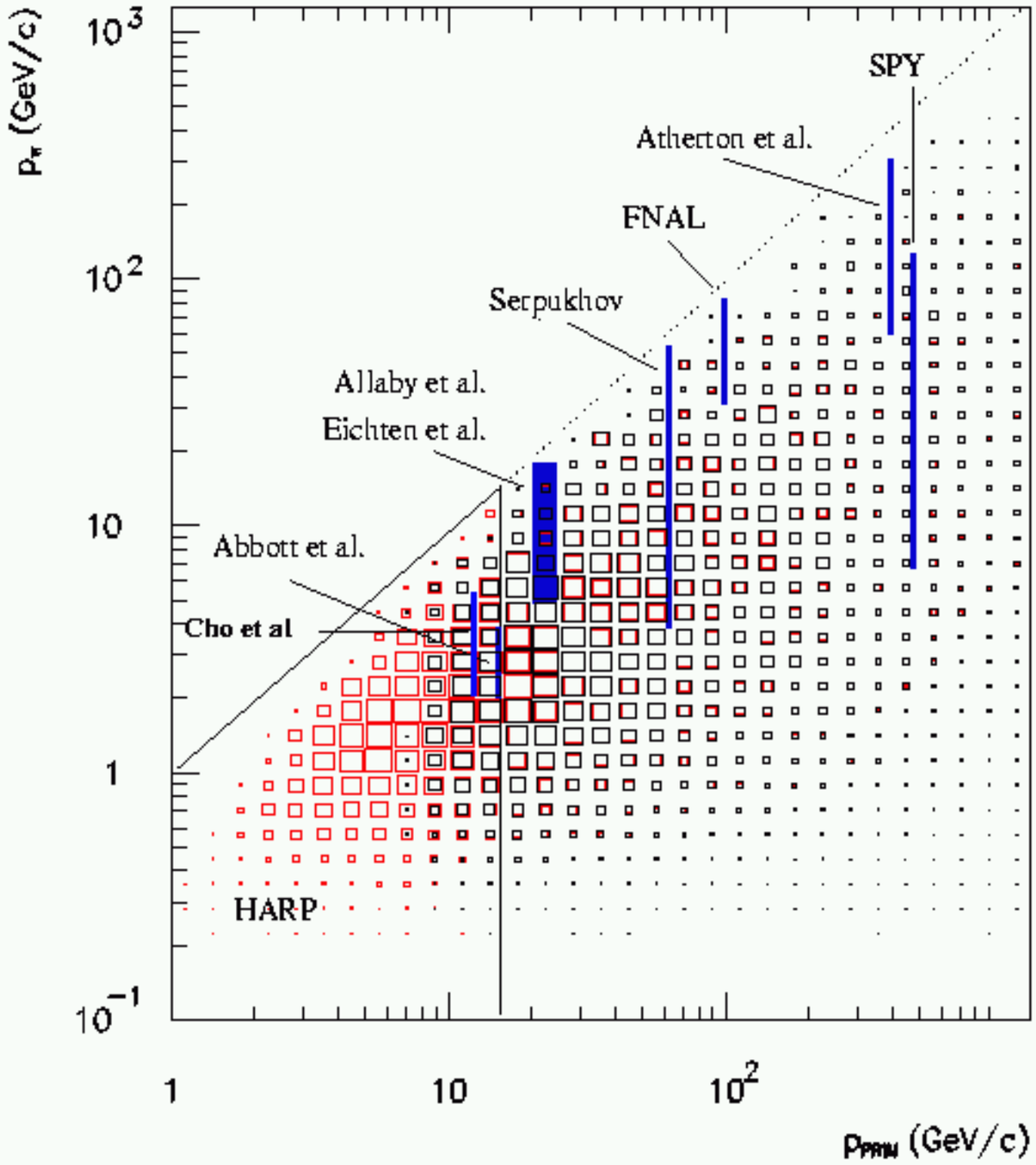
Artificial variation of interaction model
(Multiplicity, secondary spectra)



The atmospheric neutrino flux calculated by several group

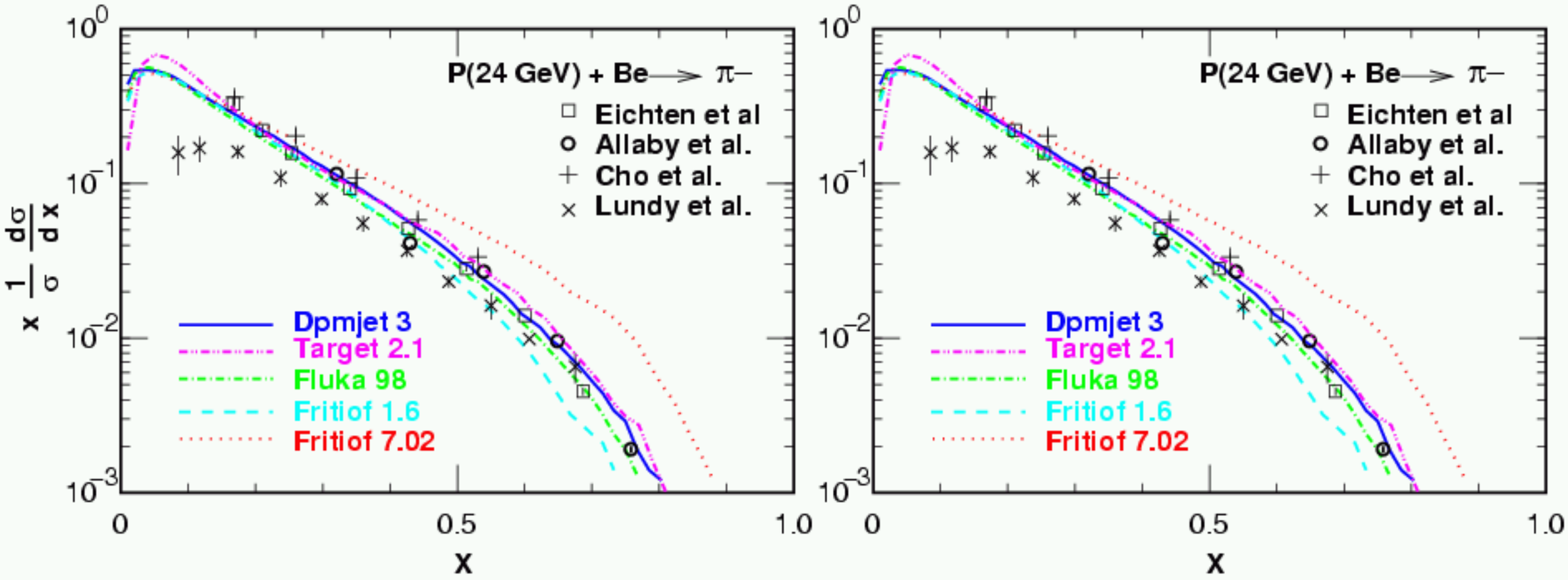


Hadronic interaction experiments so far and future



Yield : Hadronic interaction models

Some interaction models and available data.

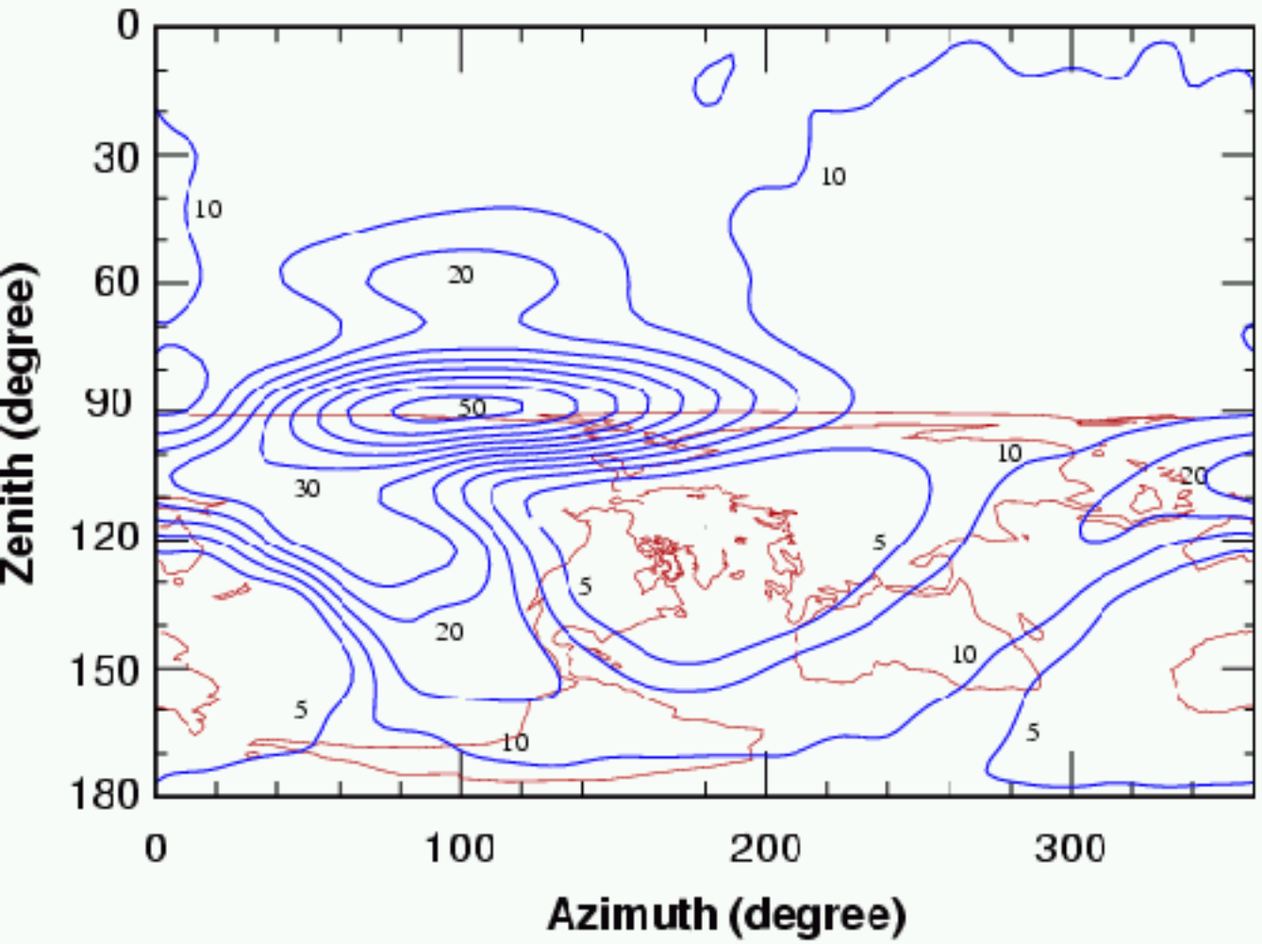


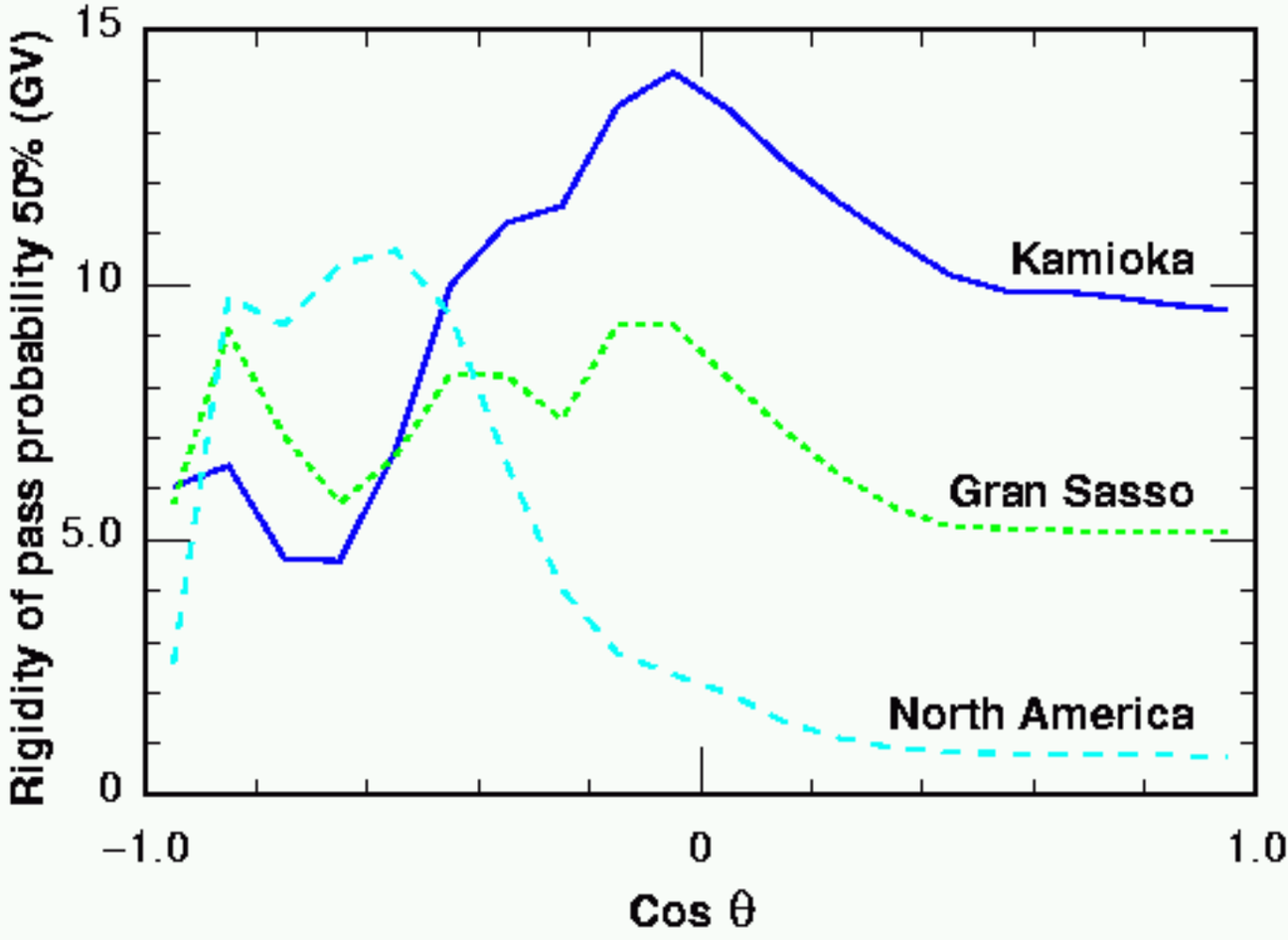
Are the Data good ?

Geomagnetic Cutoff: Back tracing test is used commonly

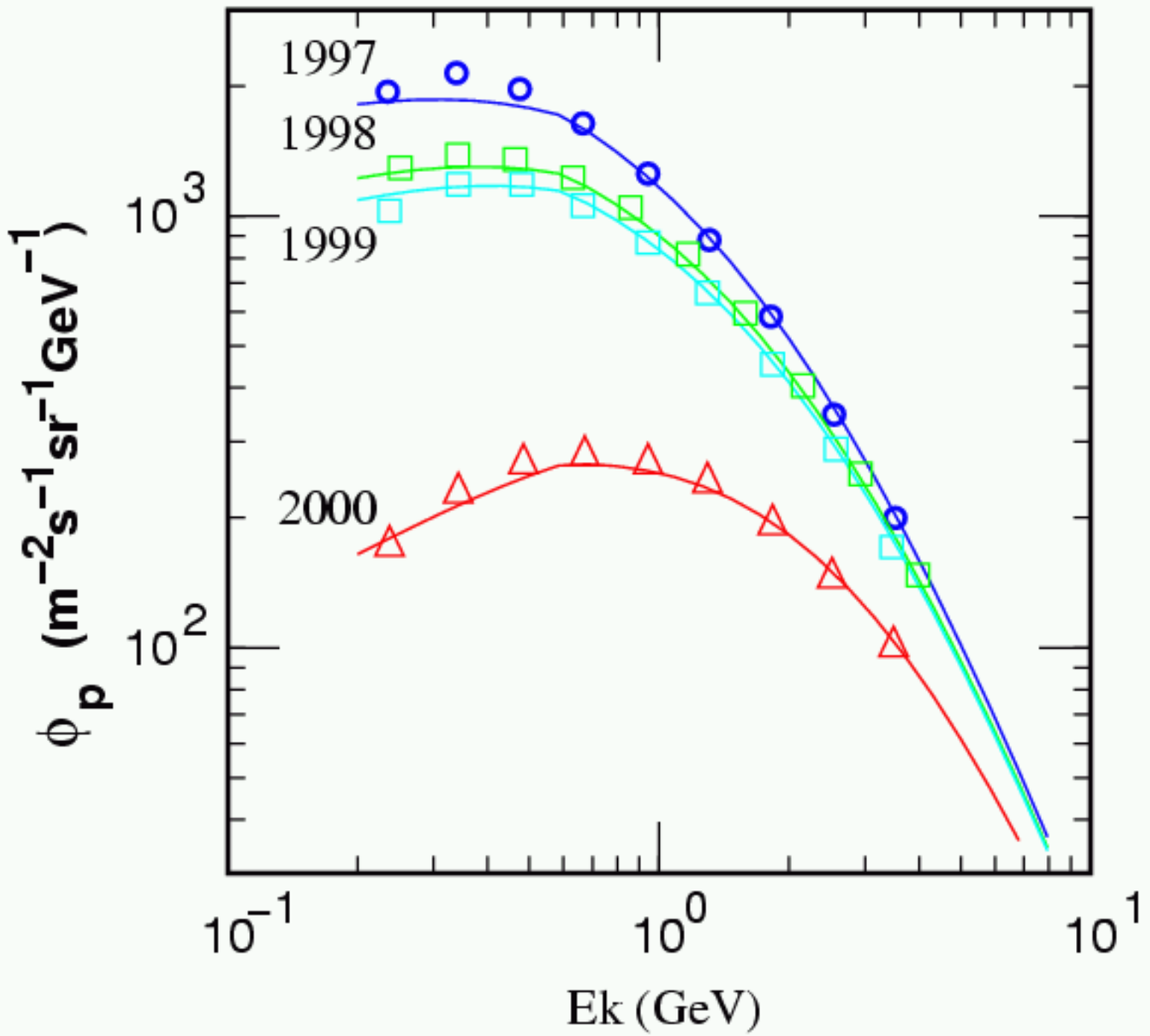
Following the particle to the backward direction, check if it reaches ~10 times Earth radius.

Yes, the particle can reach Earth from ourside of geomagnetic field.
No, the particle can not comes from the out side of geomagnetic field.





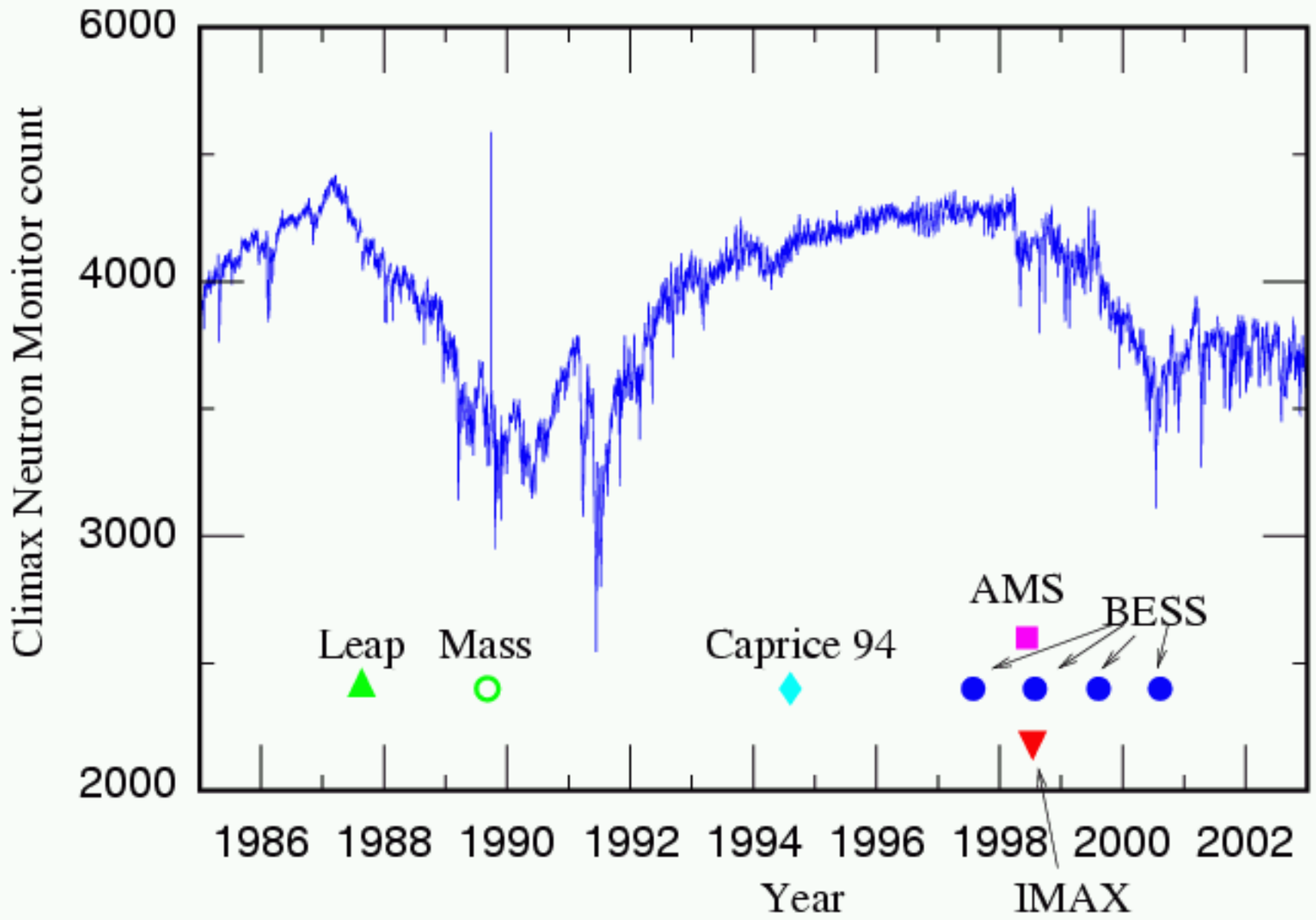
Primary Spectrua: BESS 4 Years Observation



Solar modulation

Note !
BESS observation at 4 different Solar phase are very important.

=> Over 11 year observations are desired



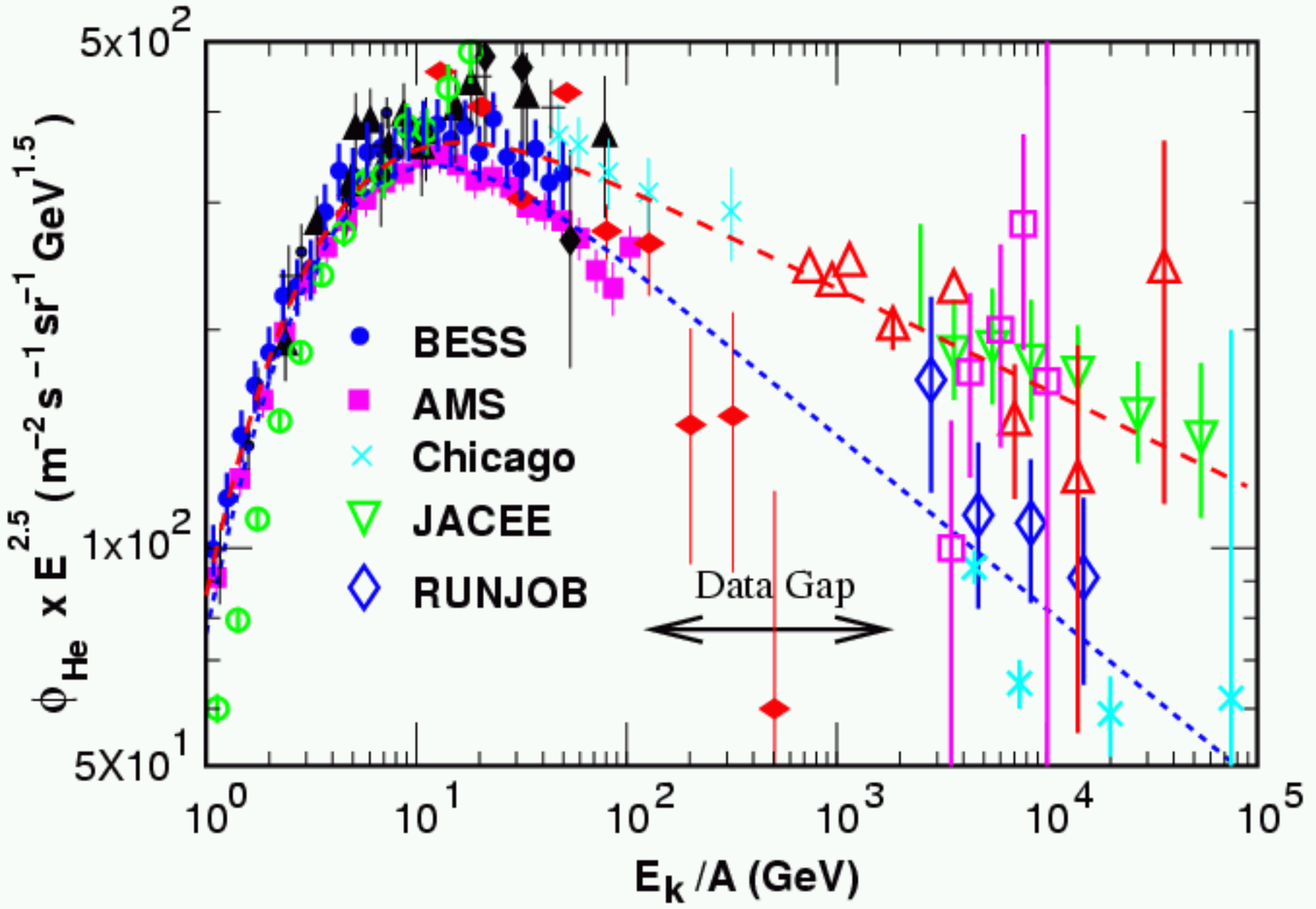
Primary Helium Spectrum

There are two data groups

BESS - Chicago - JACEE

AMS - RUNJOB

Observation at Data Gap may determine which is the case

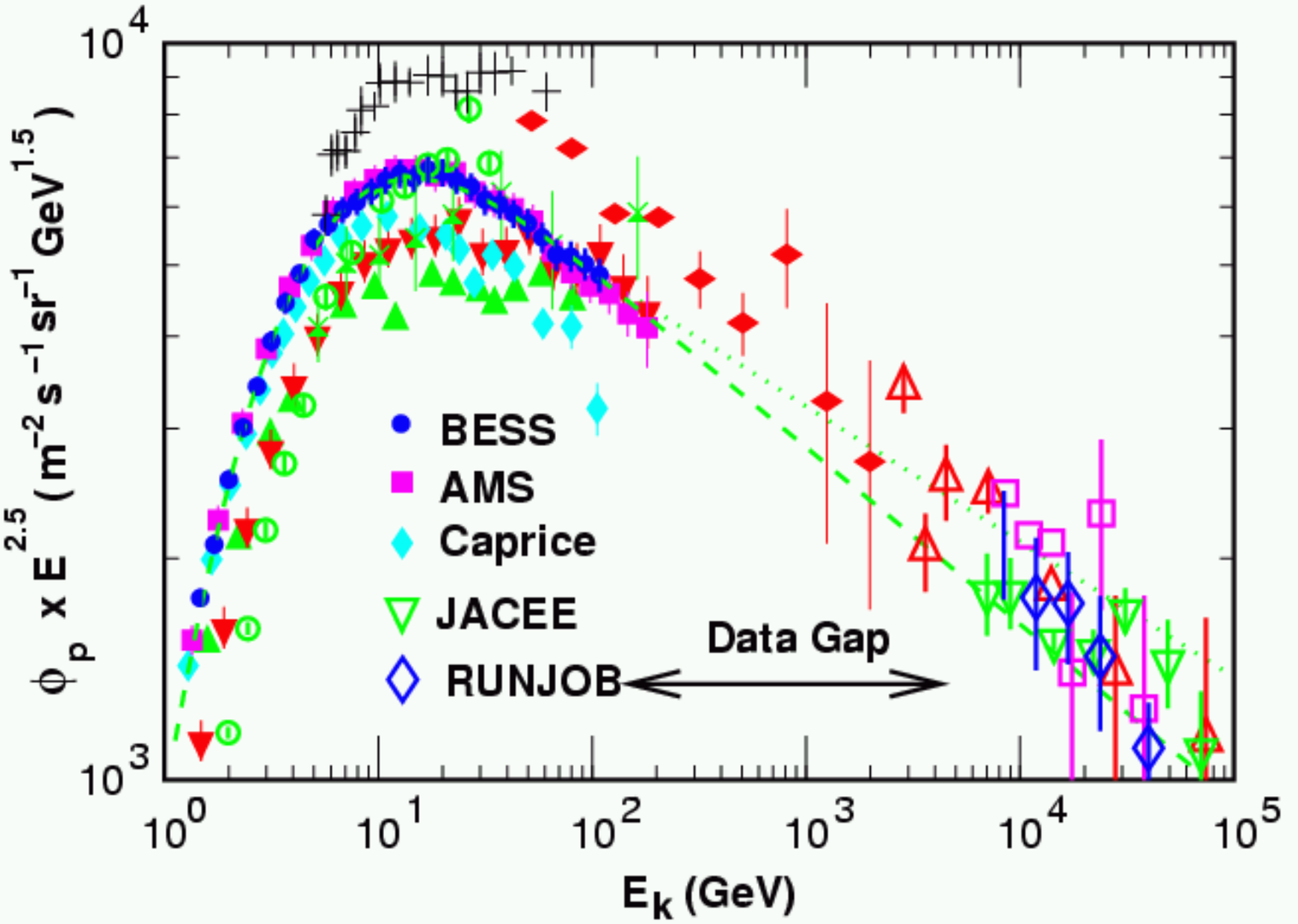


Proton primary spectrum

Below data gap, BESS and AMS determined proton flux ?

To ease 1% anxiety,
new data in data gap necessay.

Above Energy Gap, data have large errors, but are consistent within experimental errors



Overview of the atmospheric neutrino calculation

1. Primary Cosmic Ray Spectra

2. Geomagnetic Cutoff

3. Yield (hadronic interaction)

T.K. Gaisser Takayama 5 June 1998

Atmospheric ν flux

+ related primary cosmic ray + μ

Thanks to P. Lipari, T. Stanev

E. Kearns, M. Honda, S. Orito

G. Battistoni, A. Ferrari, T. Montaruli; R. Engel

$$\phi_\nu = \phi_{primary} \otimes R(B_\oplus) \otimes Yield(N \to \nu)$$

$$\phi_\mu = \phi_{primary} \otimes R^*(B_\oplus) \otimes Yield(N \to \mu)$$

Outline of talk: 1) Cutoffs + $B_\oplus$

2) Primary spectrum

3) Muons 4) Yields

Outline of This Talk

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1. Overview of atmospheric neutrino calculation

2. Sure things:
   - Neutrino ratio and angular variation

3. Uncertain things:
   - Absolute value: problems and improvements

4. Less important thins:
   - "3-D Effects", secondary P spectra

5. Summary

Summary

Flux ratio between neutrinos and angular variation are stable by the change of calculation elements.

However, the absolute flux values are not well determined.
We need accurate primary cosmic ray spectra above 100 GeV, and accurate hadronic interaction data to determine the absolute flux value.

Accurately measured muon fluxes are useful to determine the hadronic interaction model and check the calculation totally.

"3D-effects", Secondary proton spectra ... are not important.

Nothing new, but there are improvements.