Calculation of Atmospheric Neutrino Flux in HKKM

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Overview

- Primary cosmic ray flux
- Interaction model

- Calculation scheme (include rigidity cutoff)
- Atmosphere model

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

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

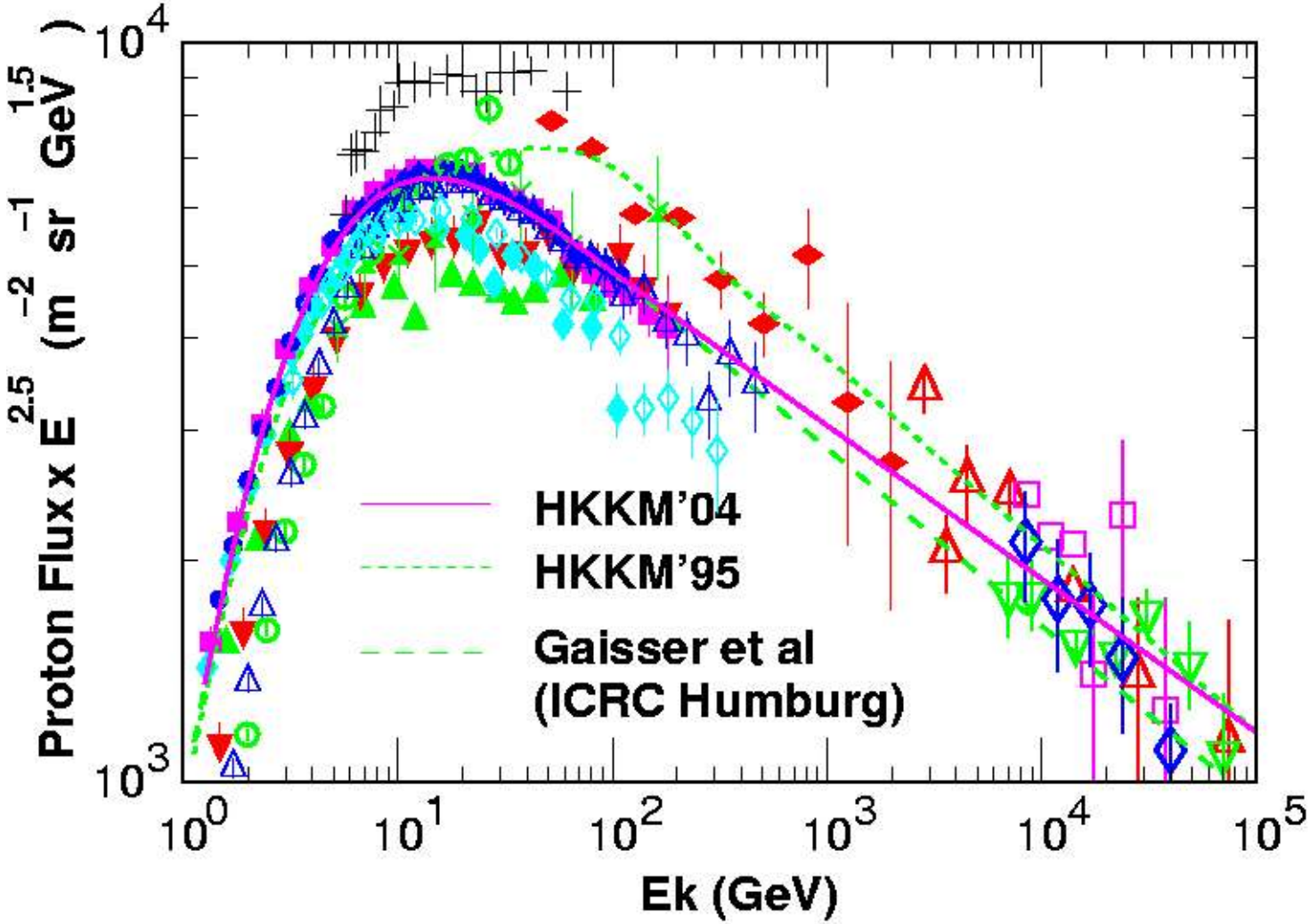
$$\phi_\mu = \phi_{primary} \otimes R^*(B_\oplus) \otimes Yield(N \to \mu)$$

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

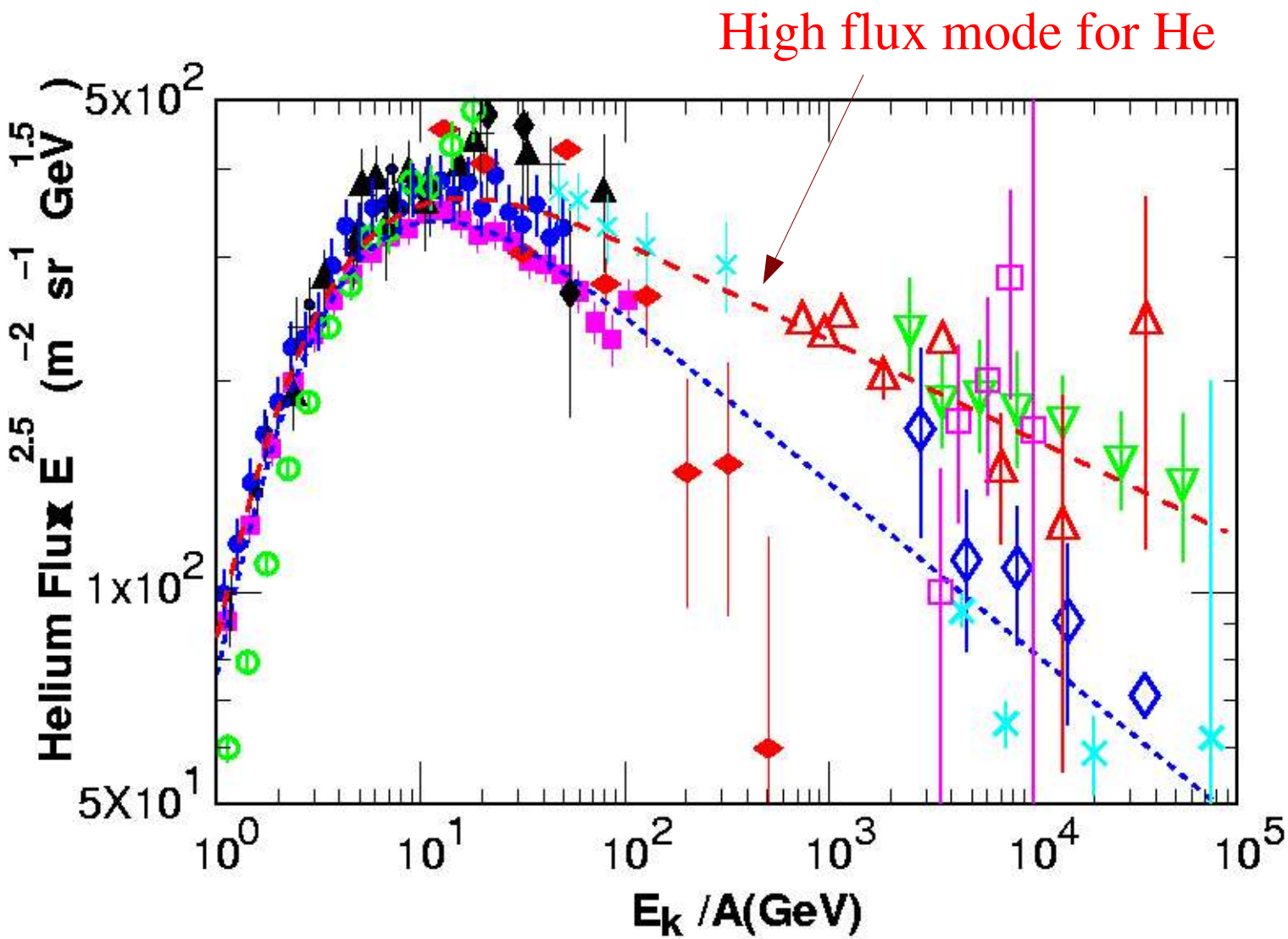
2) Primary spectrum

3) Muons 4) Yields

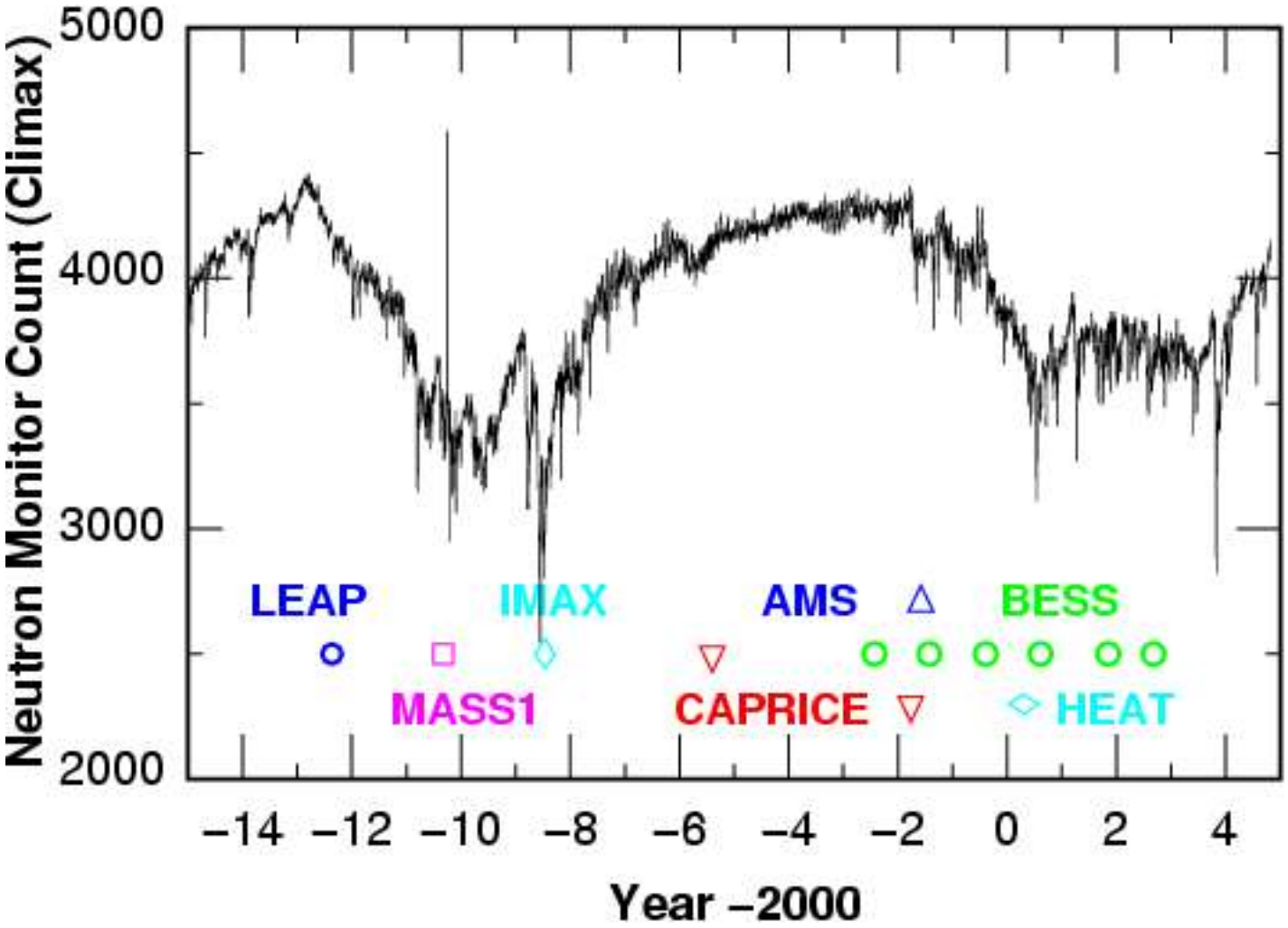
Primary Proton Flux Model



Primary He flux model



Modulation by the Solar Activity



Spectra Modulation Formula

$$F_{p,He}(E_k, N) = F_{mod}(N, r) \cdot F^0_{p,He}(E_k)$$

and

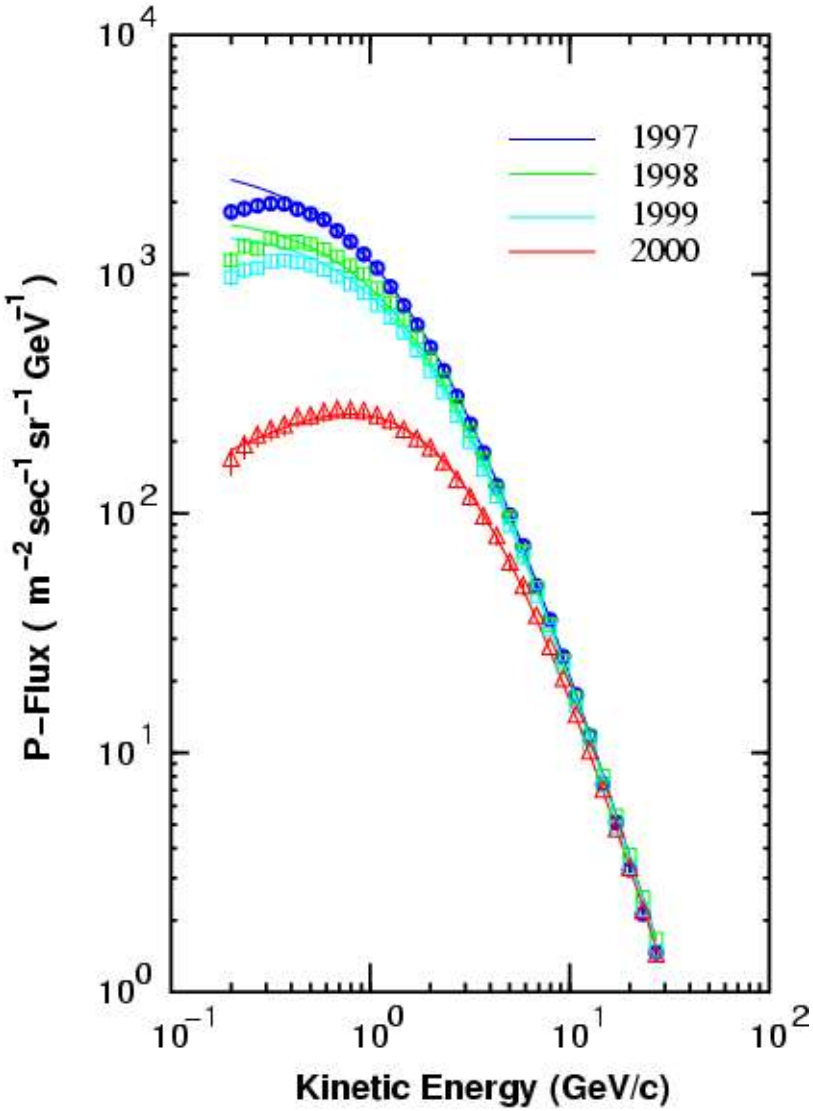
$$F_{mod}(N, r) = \exp\left(\frac{A + B \cdot N}{C + D \cdot N + r^e}\right),$$

where

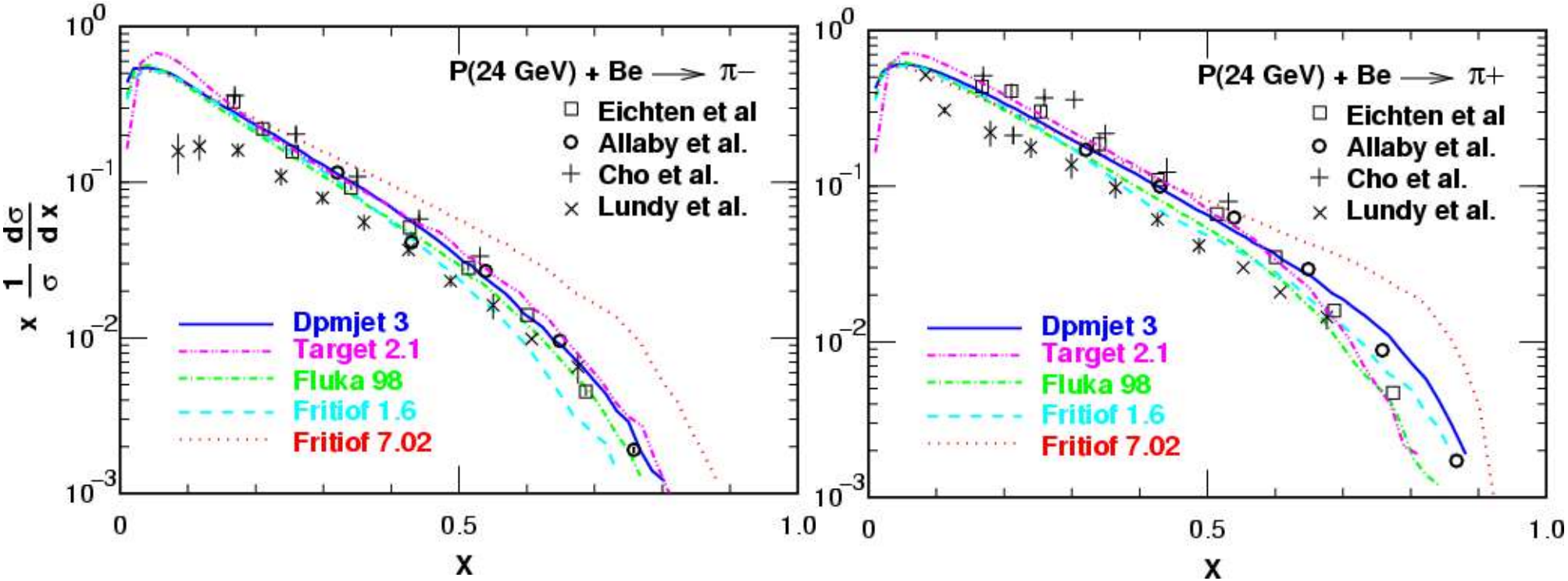
N : Neutron Monitor counts

$$r = \sqrt{(E_k + m_p)^2 - m_p^2} \quad \text{(for proton)}$$

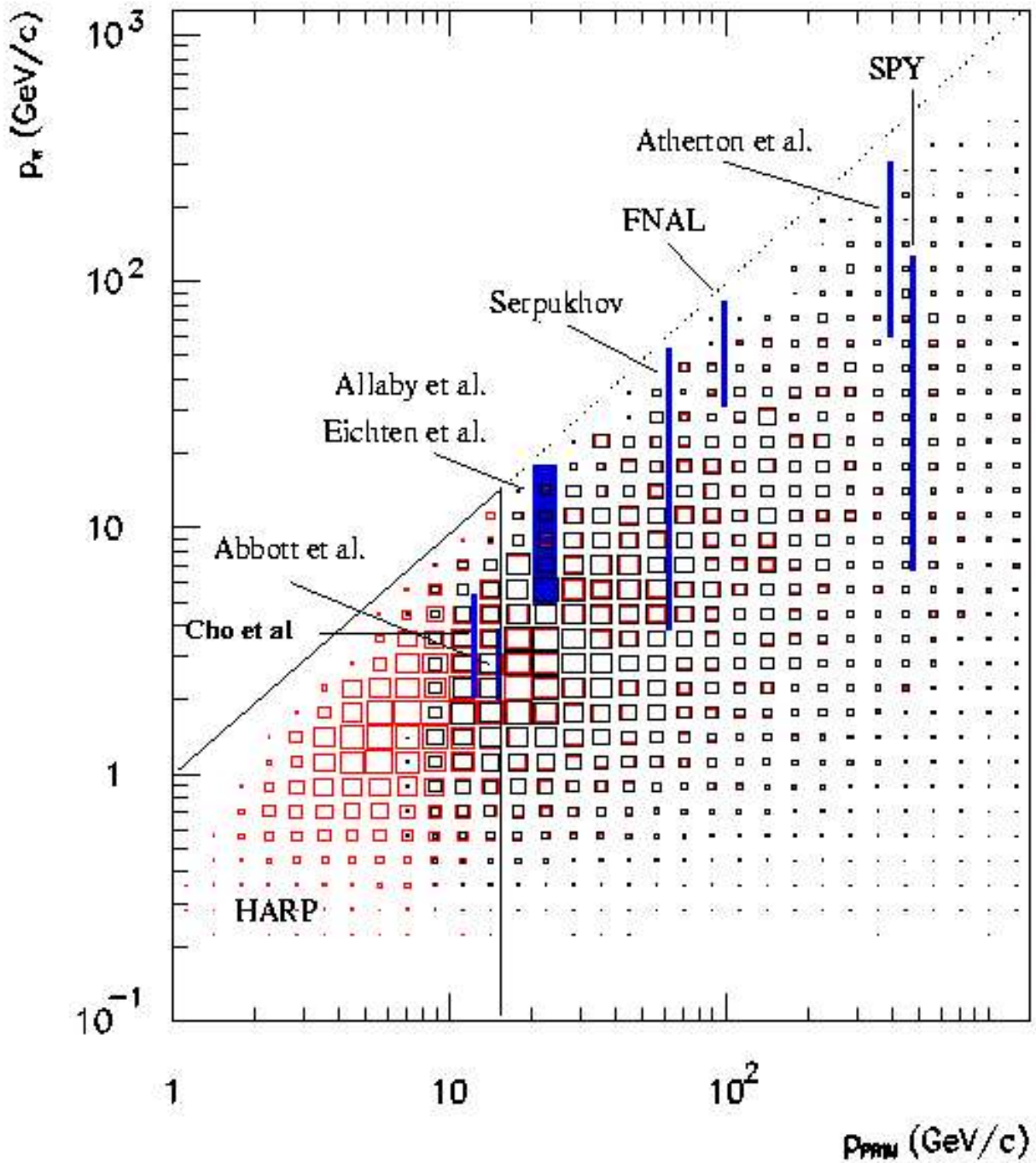
$$r = \frac{1}{2}\sqrt{(E_k + m_p)^2 - m_p^2} \quad \text{(for Helium)}$$



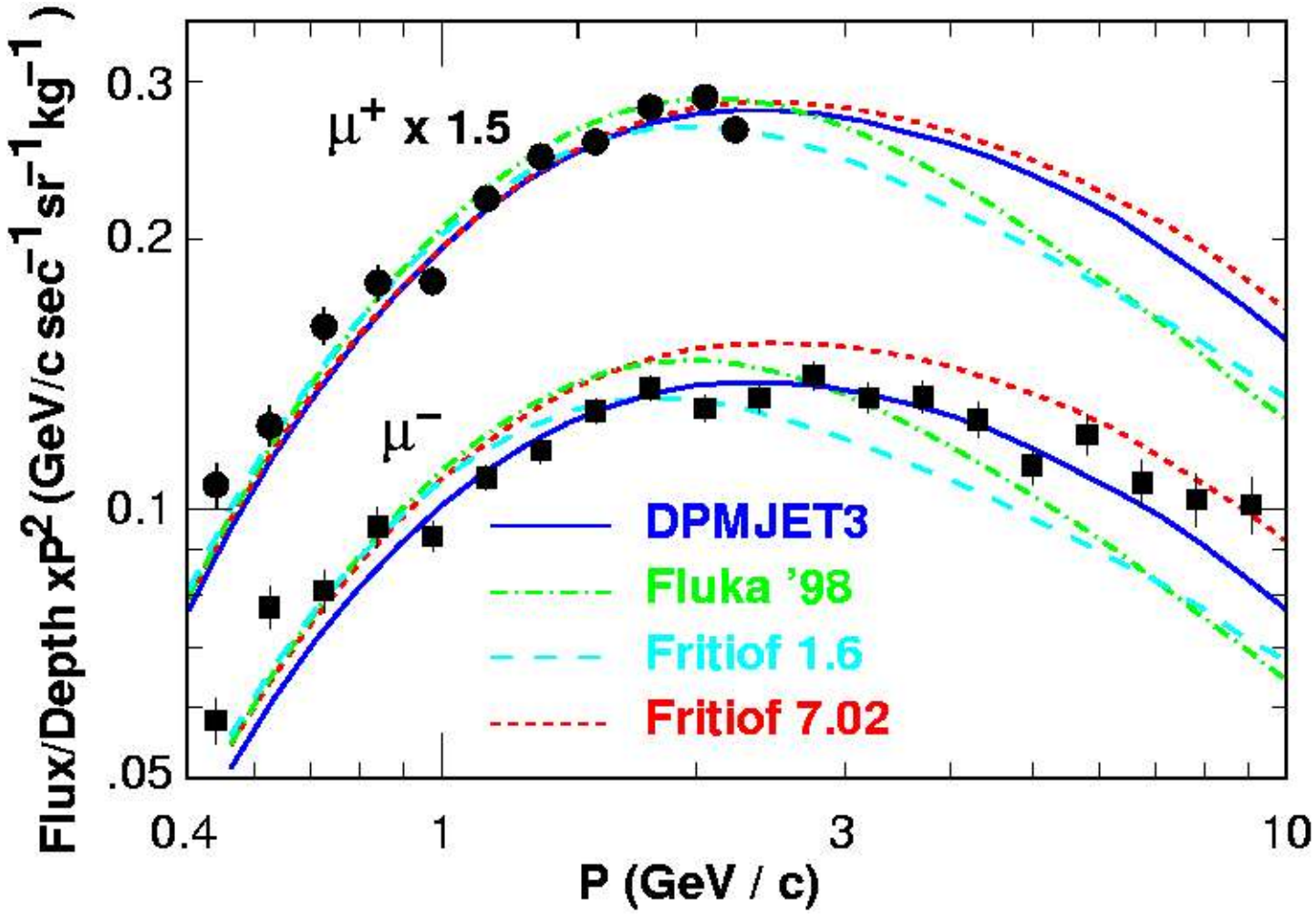
Interaction Model



Summary of available experimental data



Test with muon flux at Balloon Altiotude



Calculation Scheme

1. Primary cosmic rays are injected at injection sphere

2. Rigidity cutoff test is perfomed by the back tracing in the space between injection sphere and escape spere.

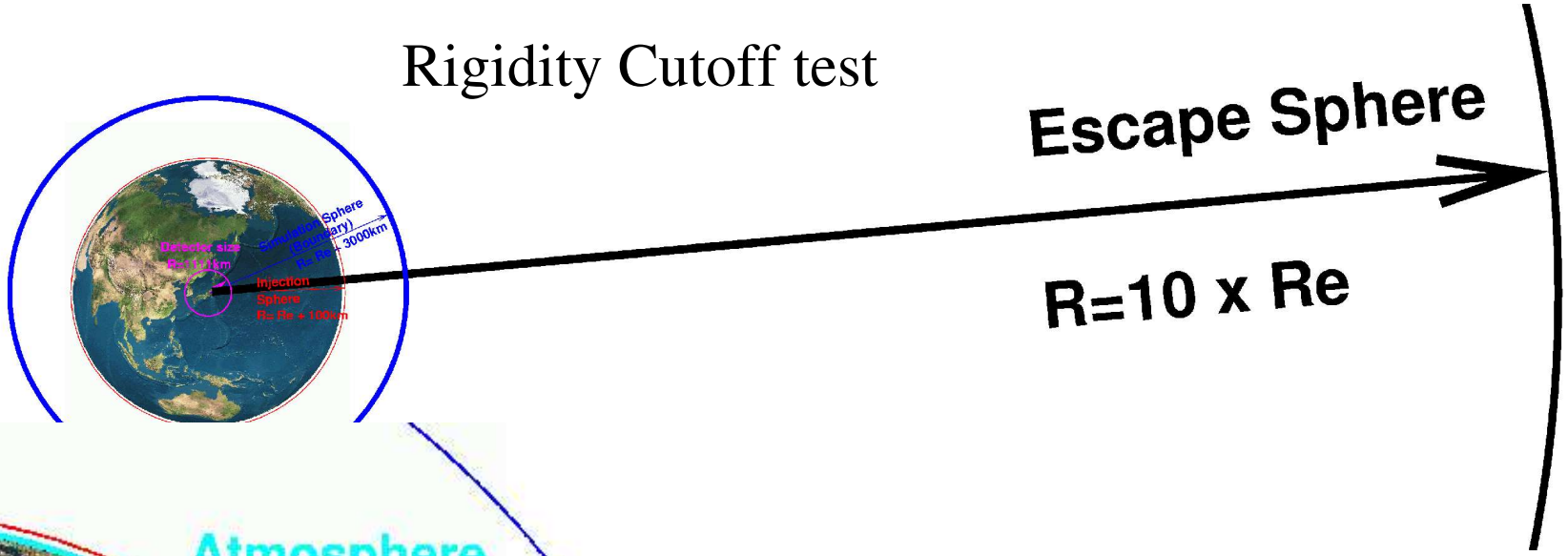
When it reaches Escape sphere without touching injection sphere again, it is fed to the simulation code in air.

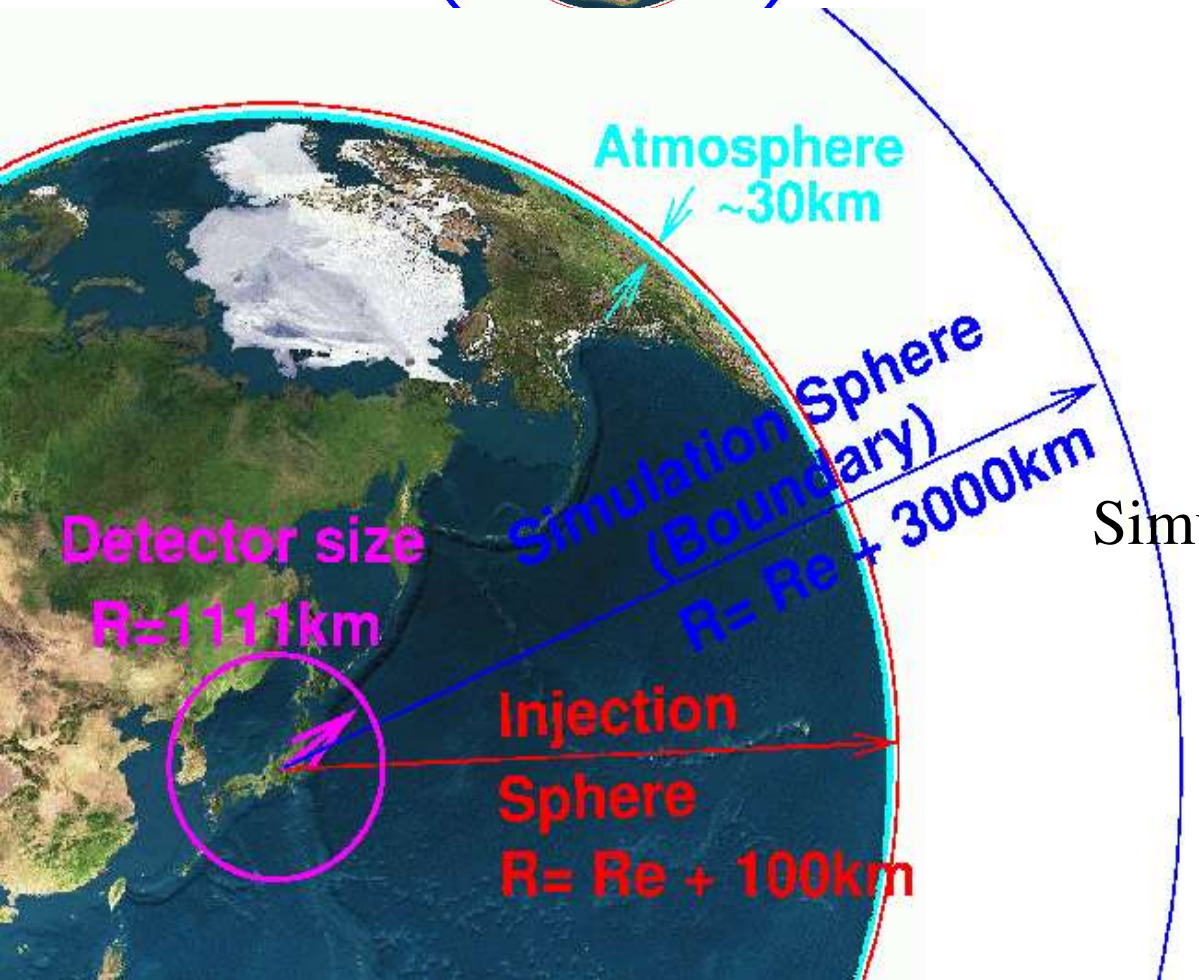
3. The simularion in air continues all the particles reach the ground or simulation sphere, or there energy is less than a minimum energy.

4. All the neutrino pass through the "detector" is recorded

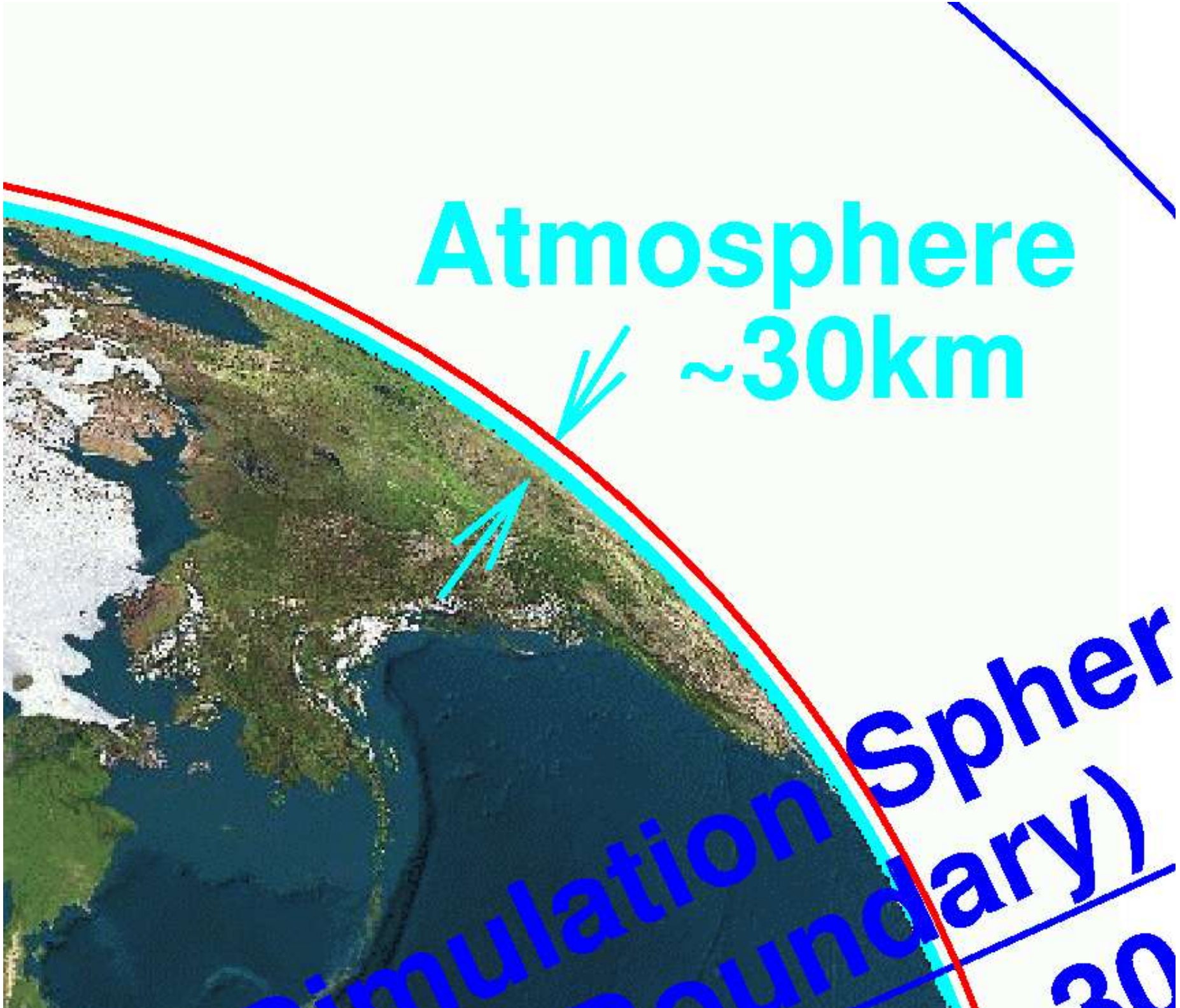
Schematic View (Re = 6378km)

Rigidity Cutoff test

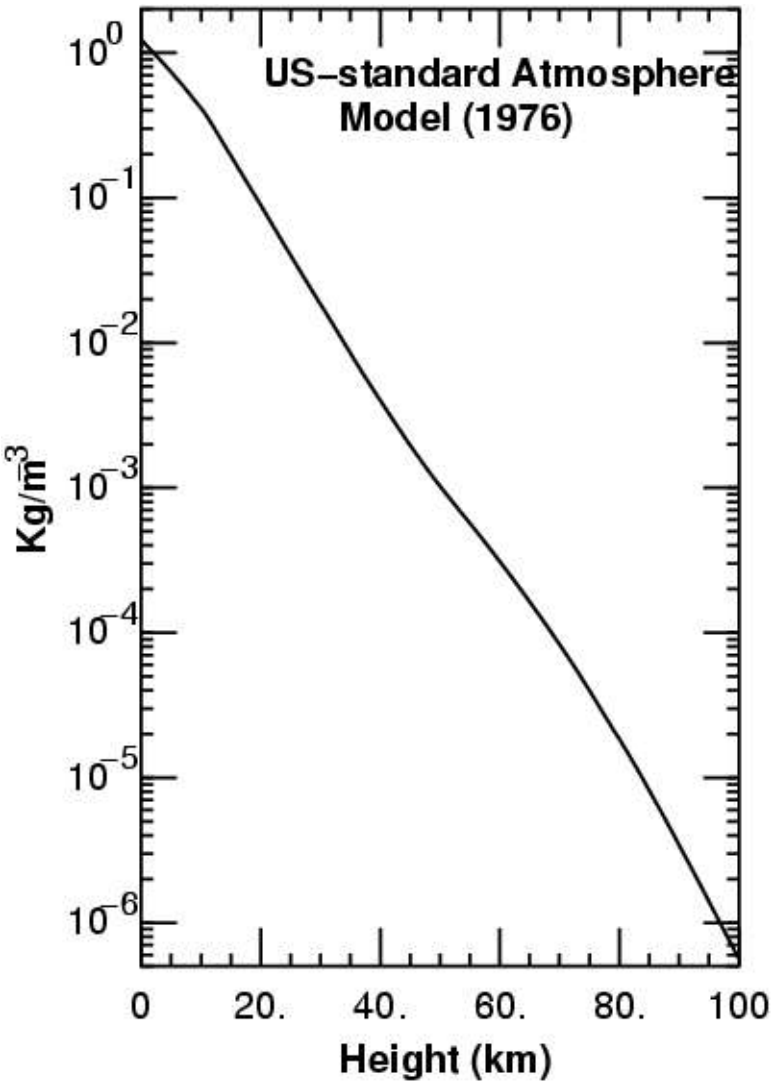




Simulation in Atmosphere

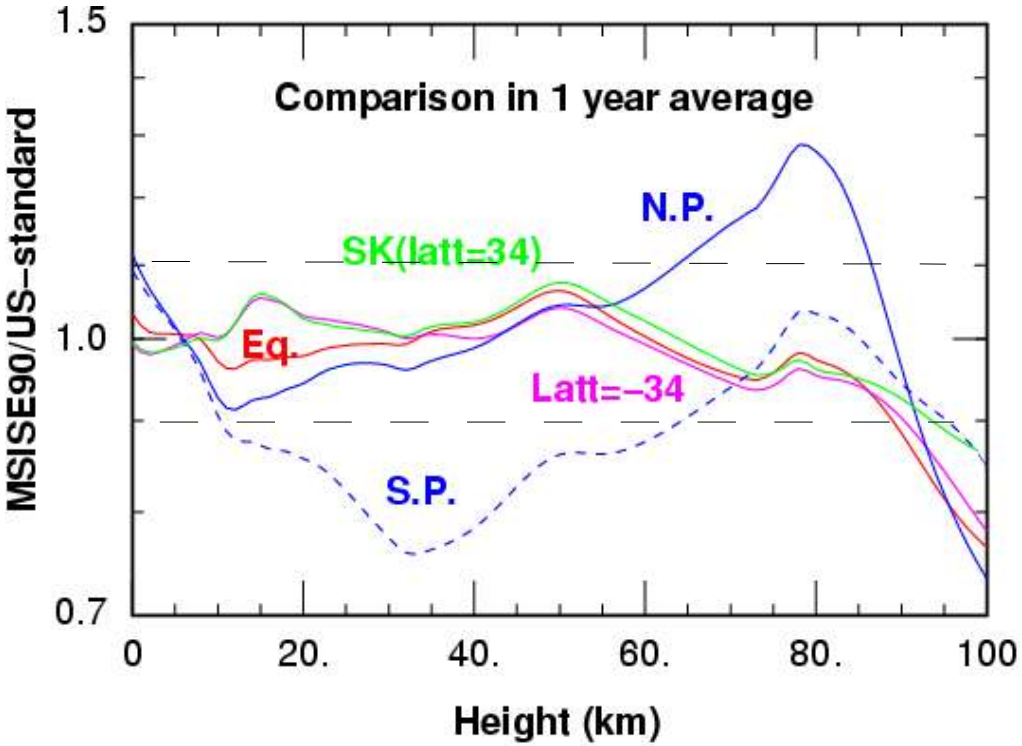

Atmosphere
~30km
Simulation Spher
Boundary)
30

Model for Atmosphere



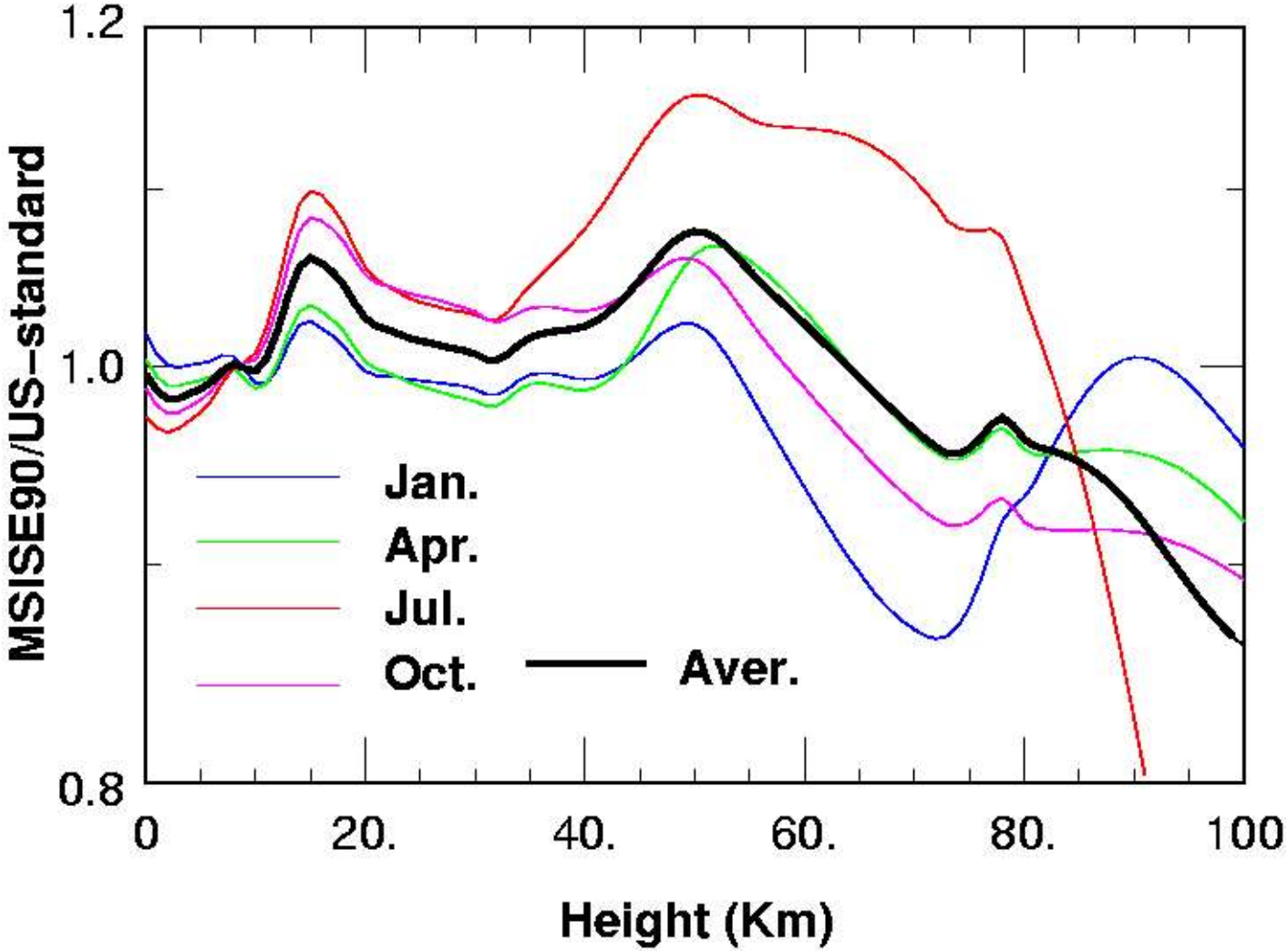
But, there are new atmosphere models.

Air density comparison with MSISE90



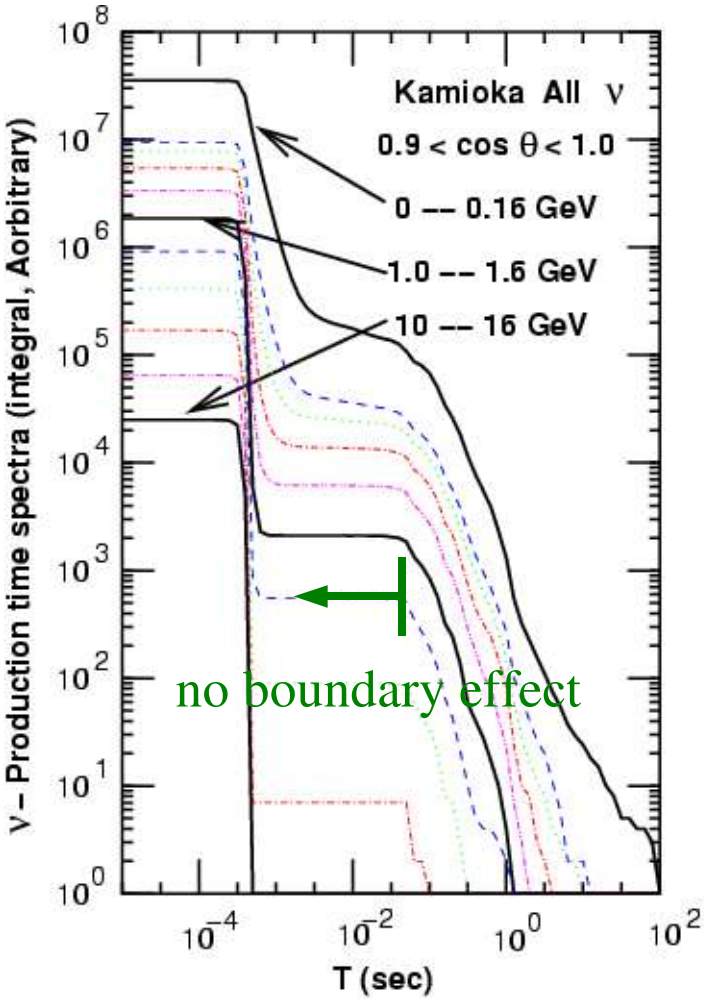
US-starndard may be used as the global approximation of the atmosphere

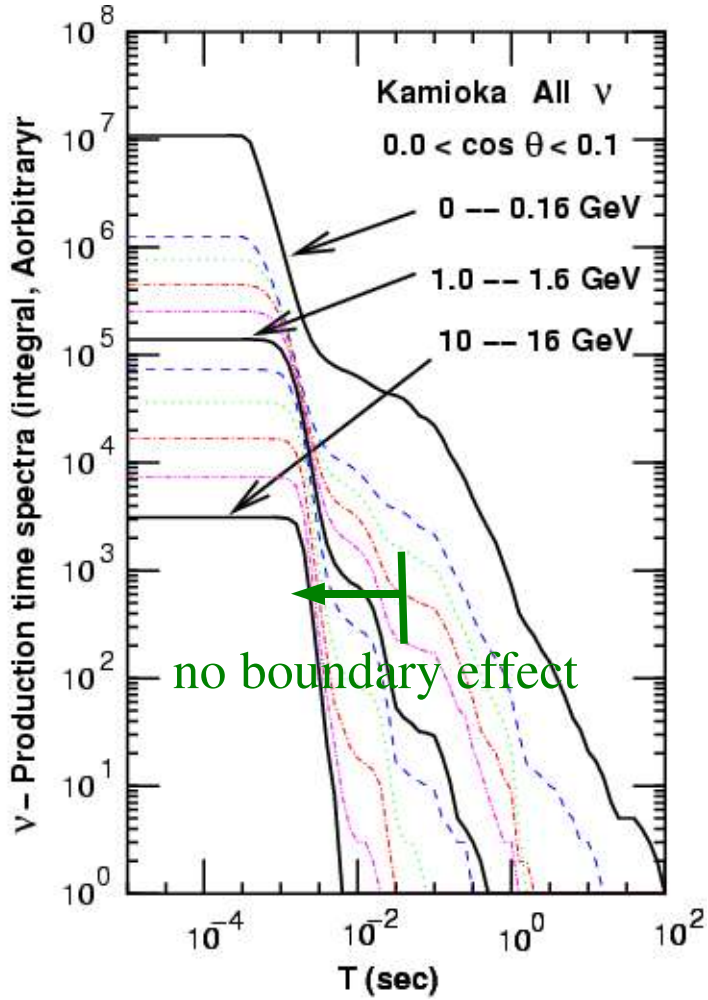
Atmosphere : Seasonal variation



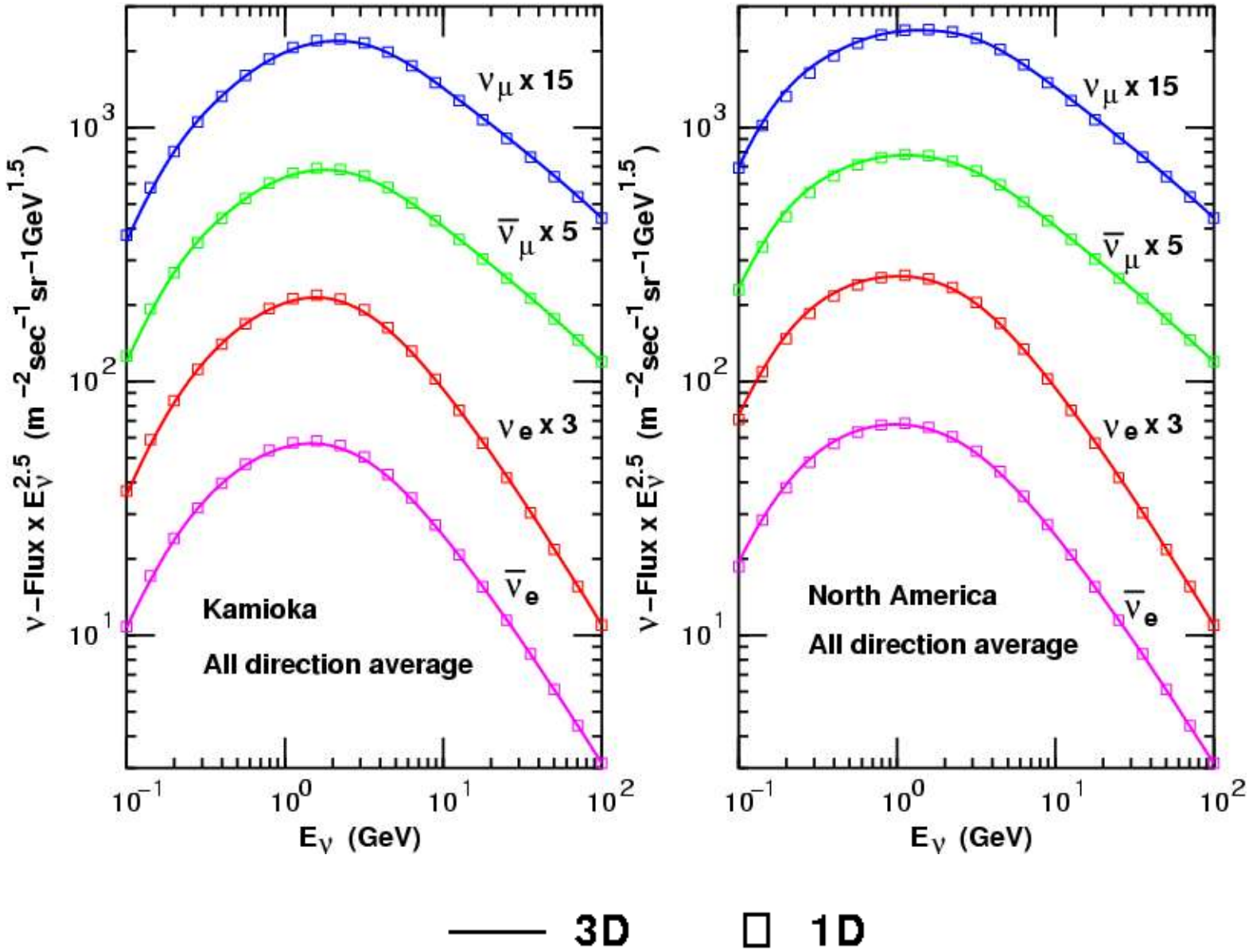
Production time of neutrinos

The particle produced within 0.02 sec is free from the boundary at Re + 3000km

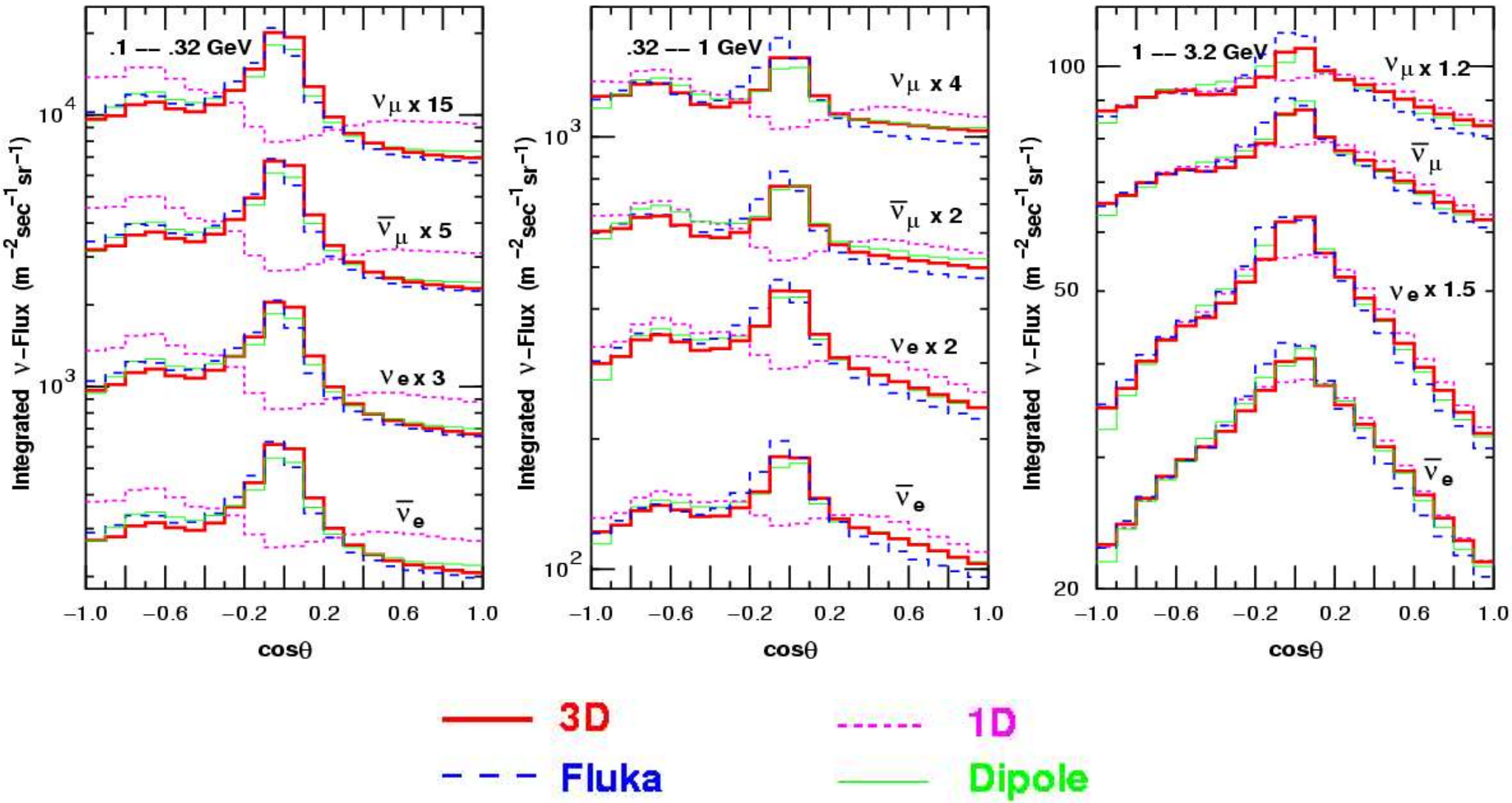




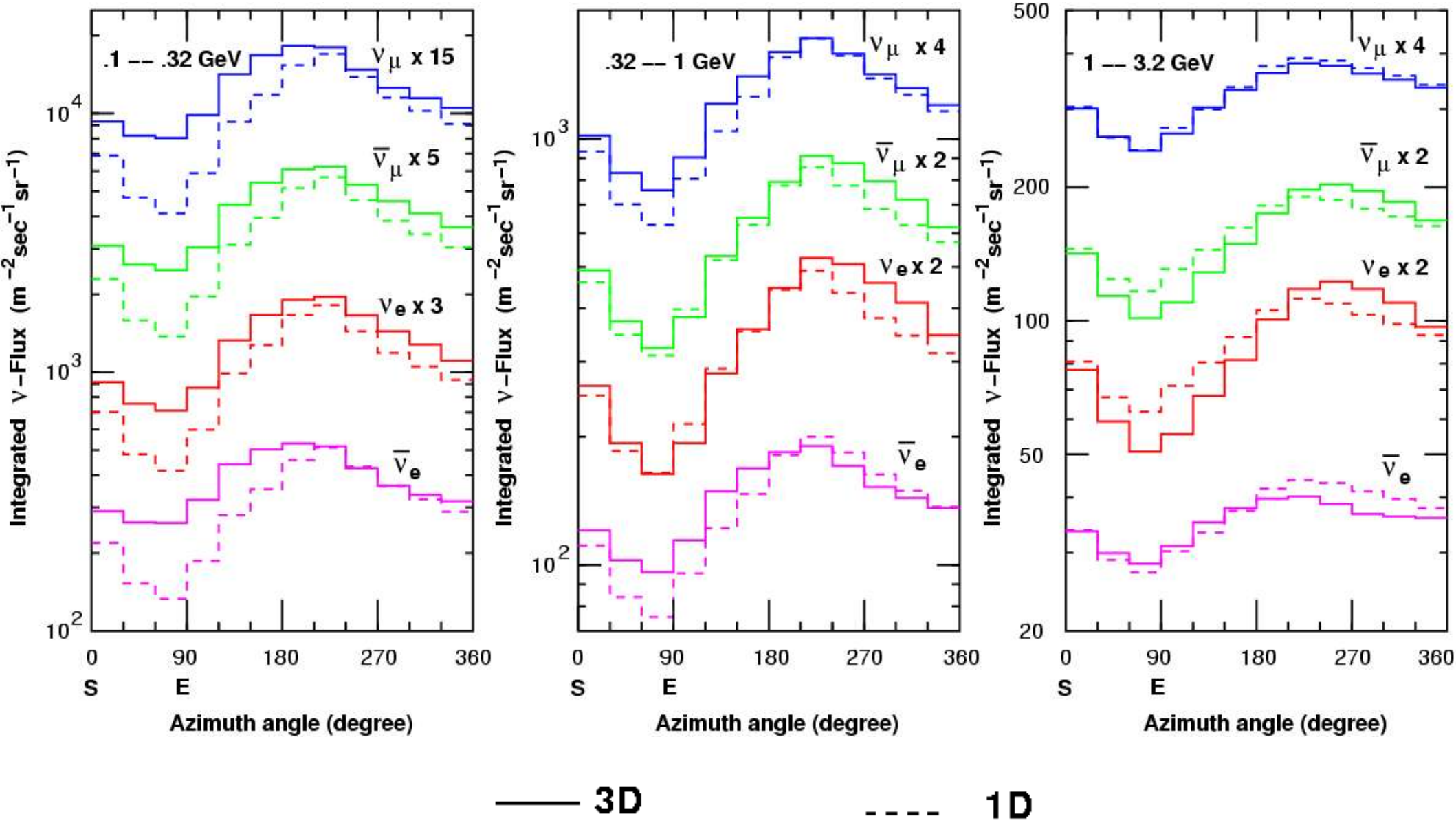
Neutrino fluxes : Alldirection average



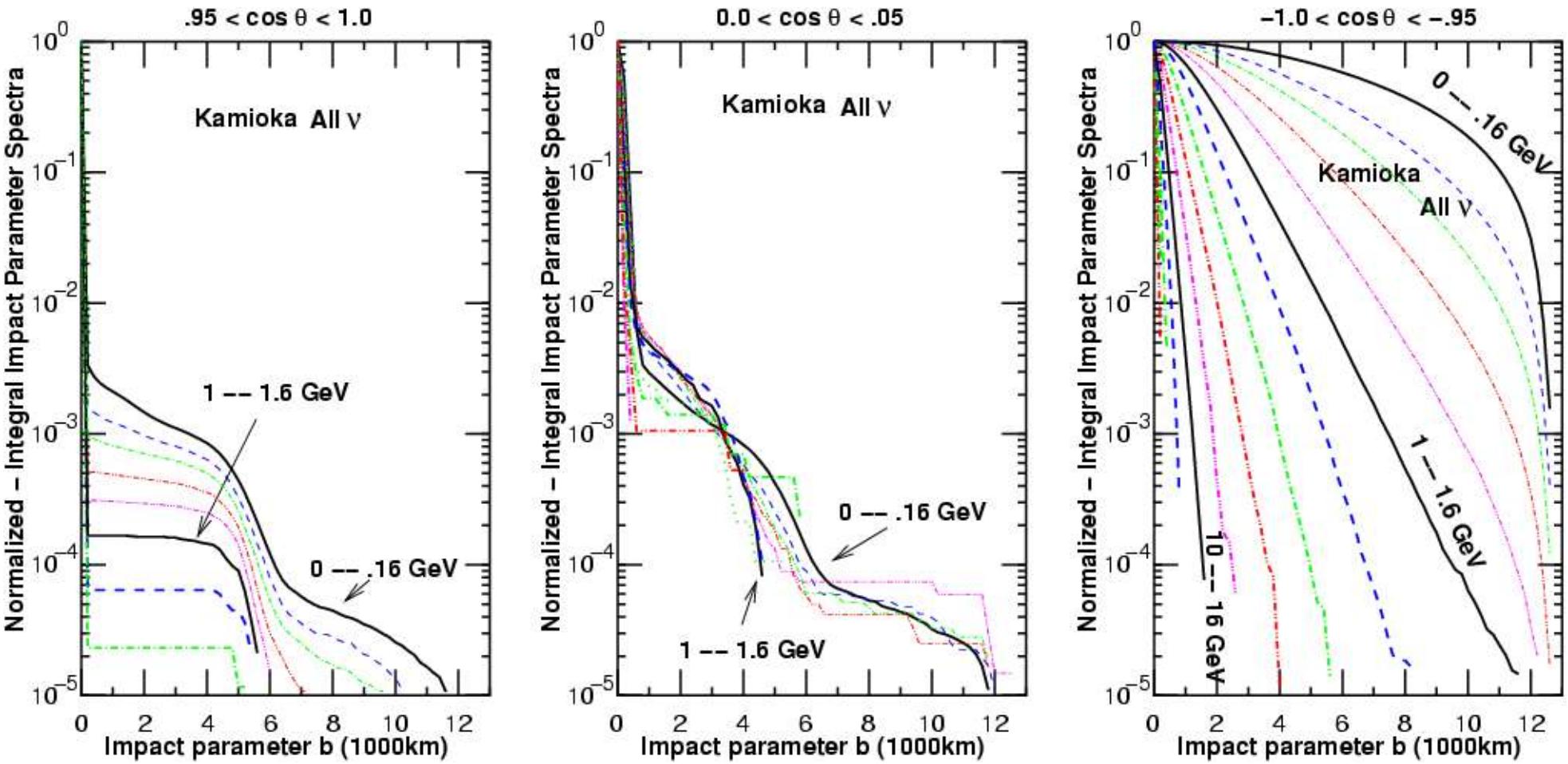
Zenith angle dependence



Azimuth angle dependence

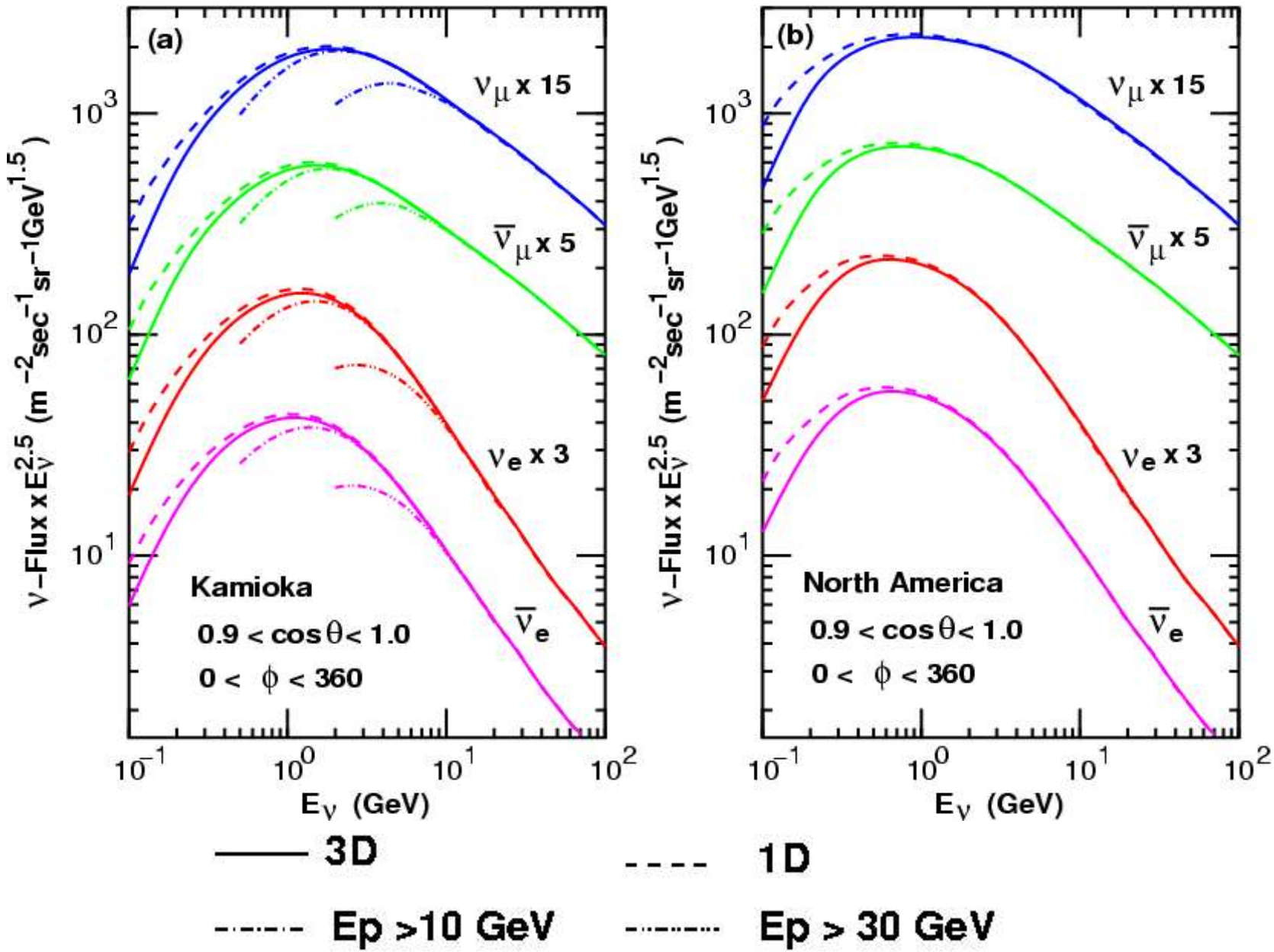


Impact parameter of primary cosmic ray



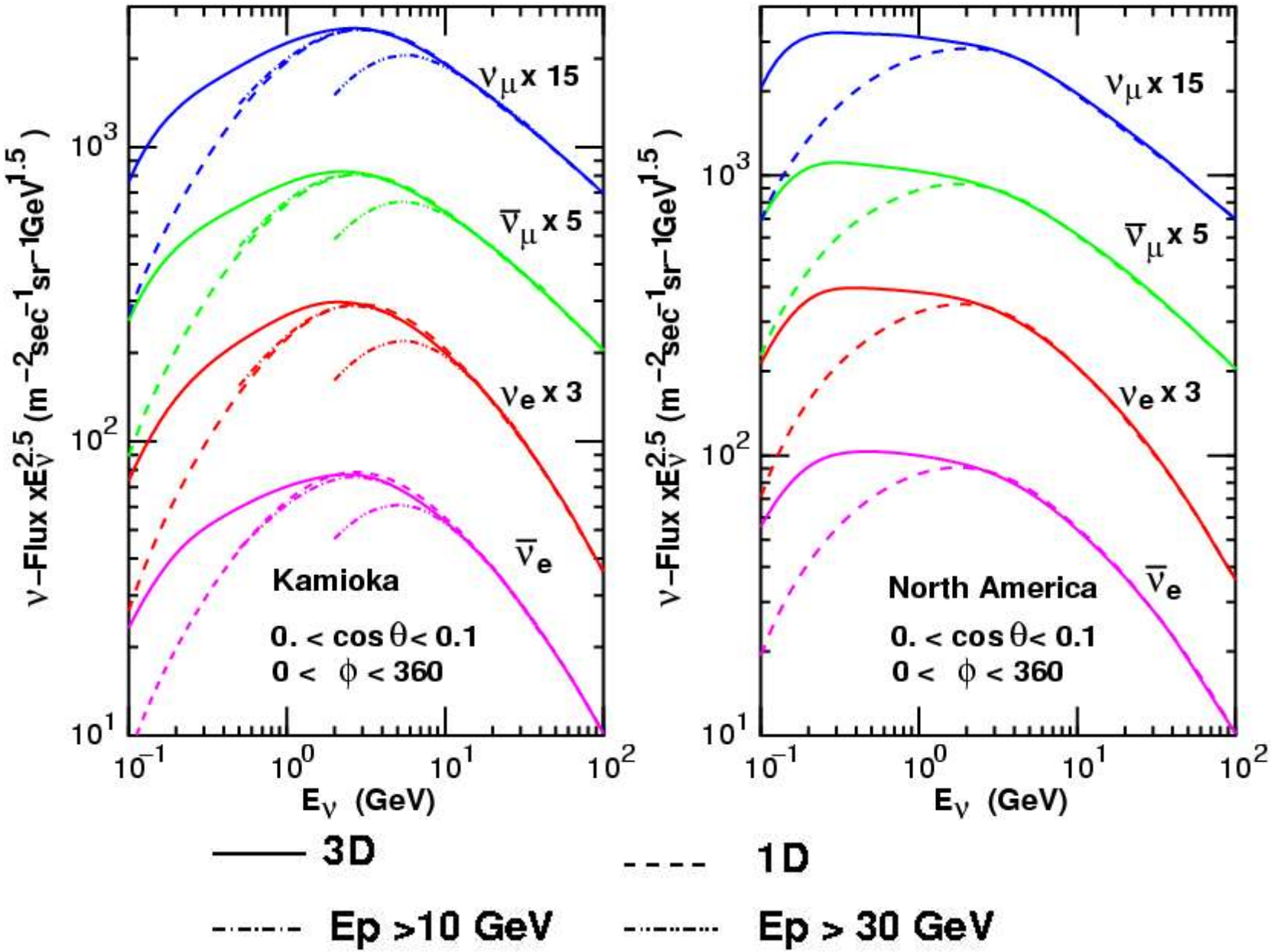
3D vs 1D: vertical direction

(averaged over azimuth directions)



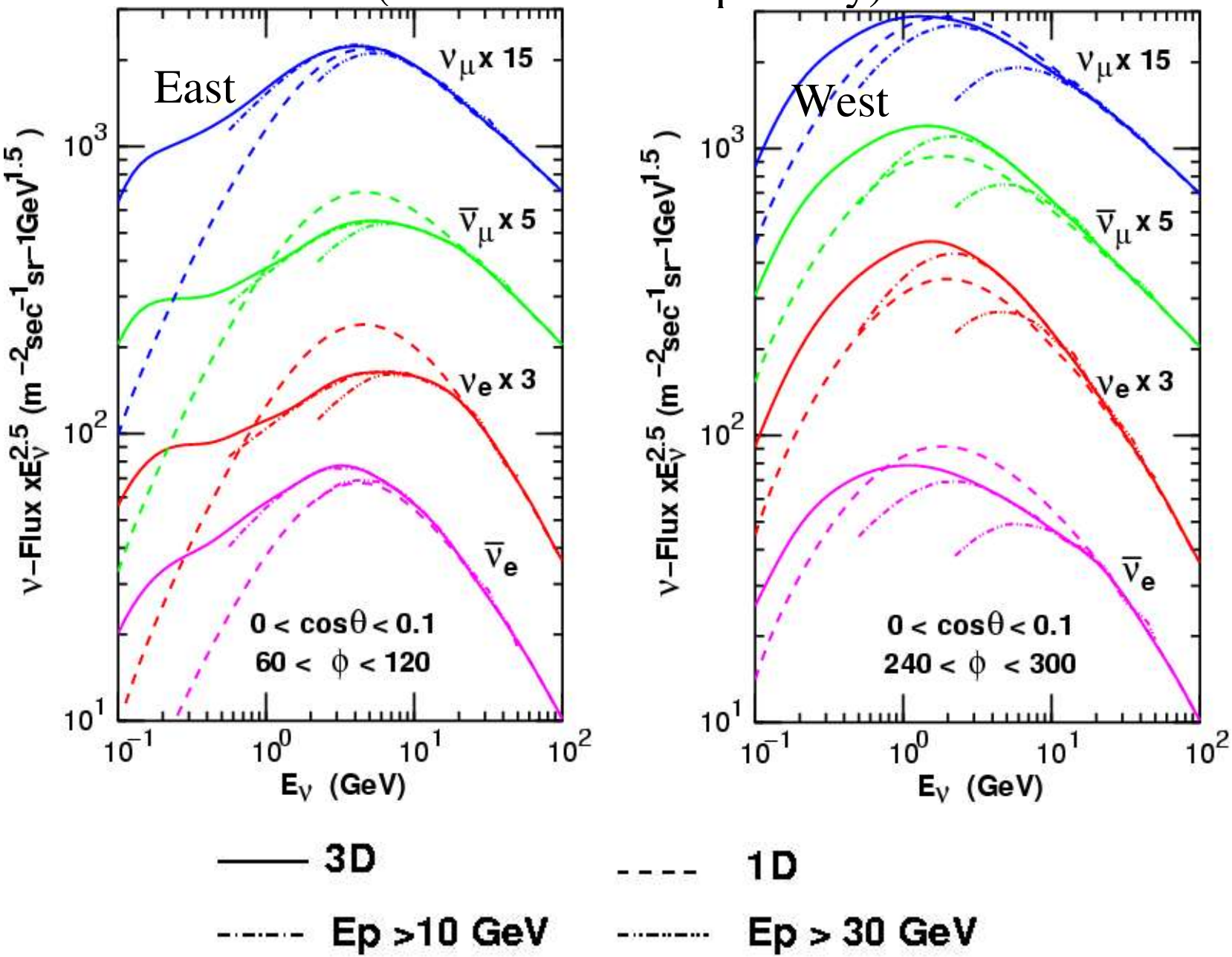
3D vs 1D: horizontal direction

(averaged over azimuth directions)

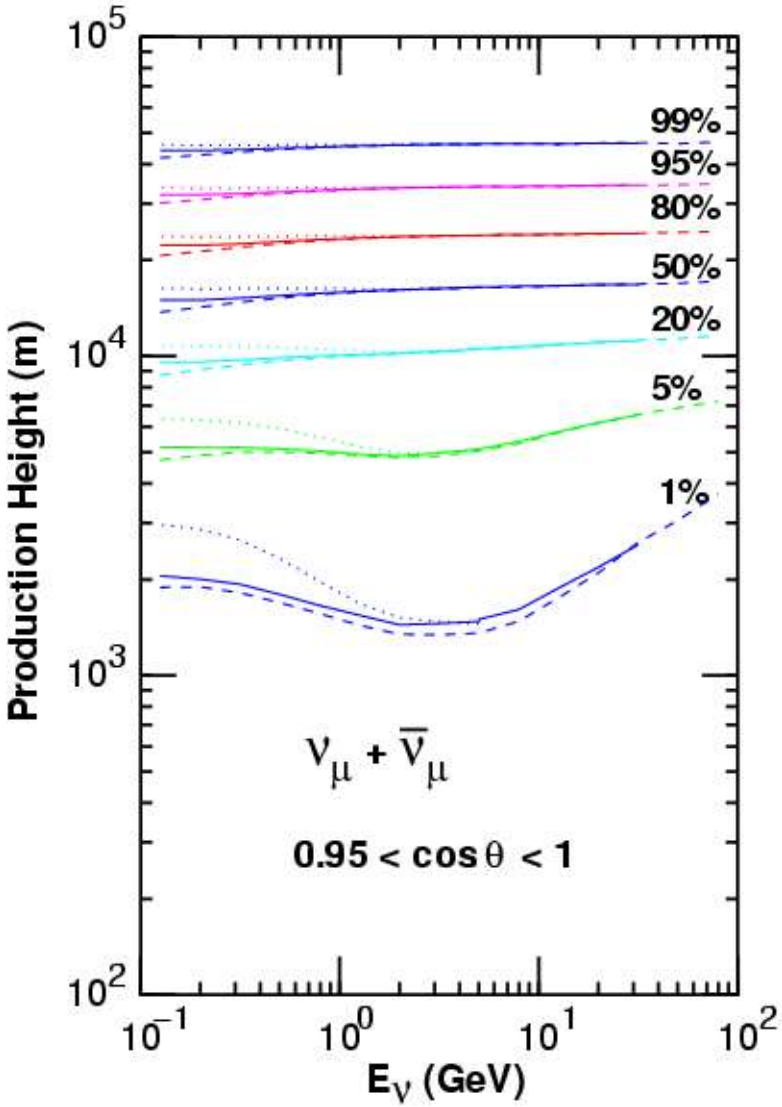


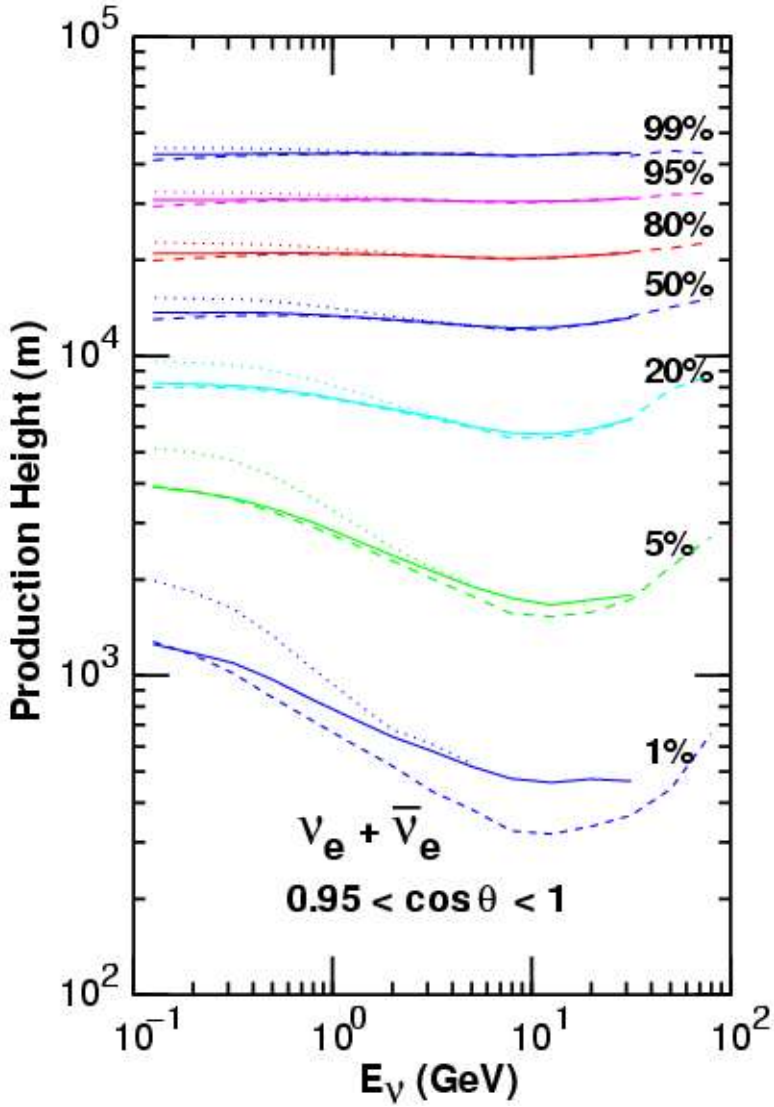
3D vs 1D: horizontal direction

(East and West separately)

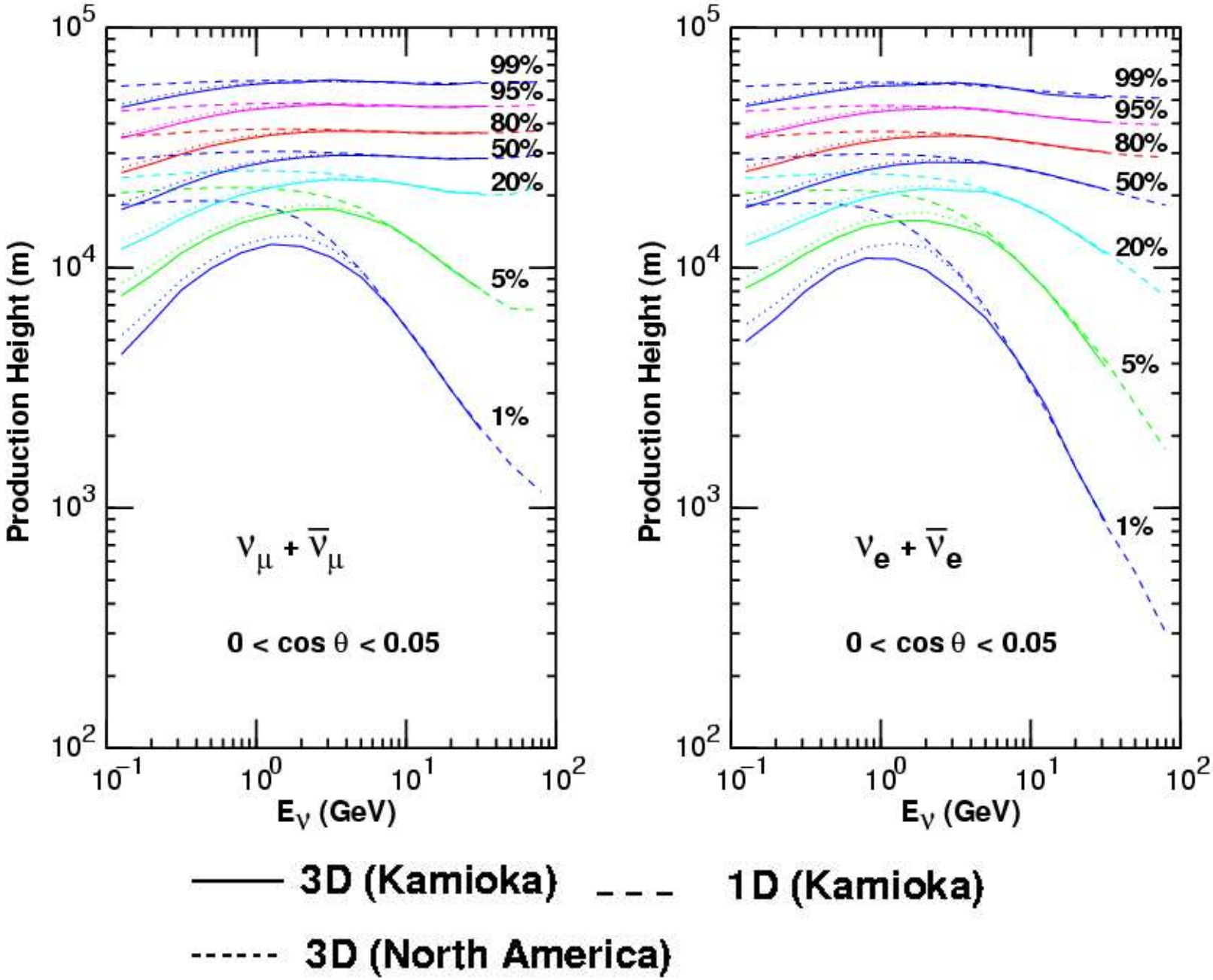


Production Height : vertical directions

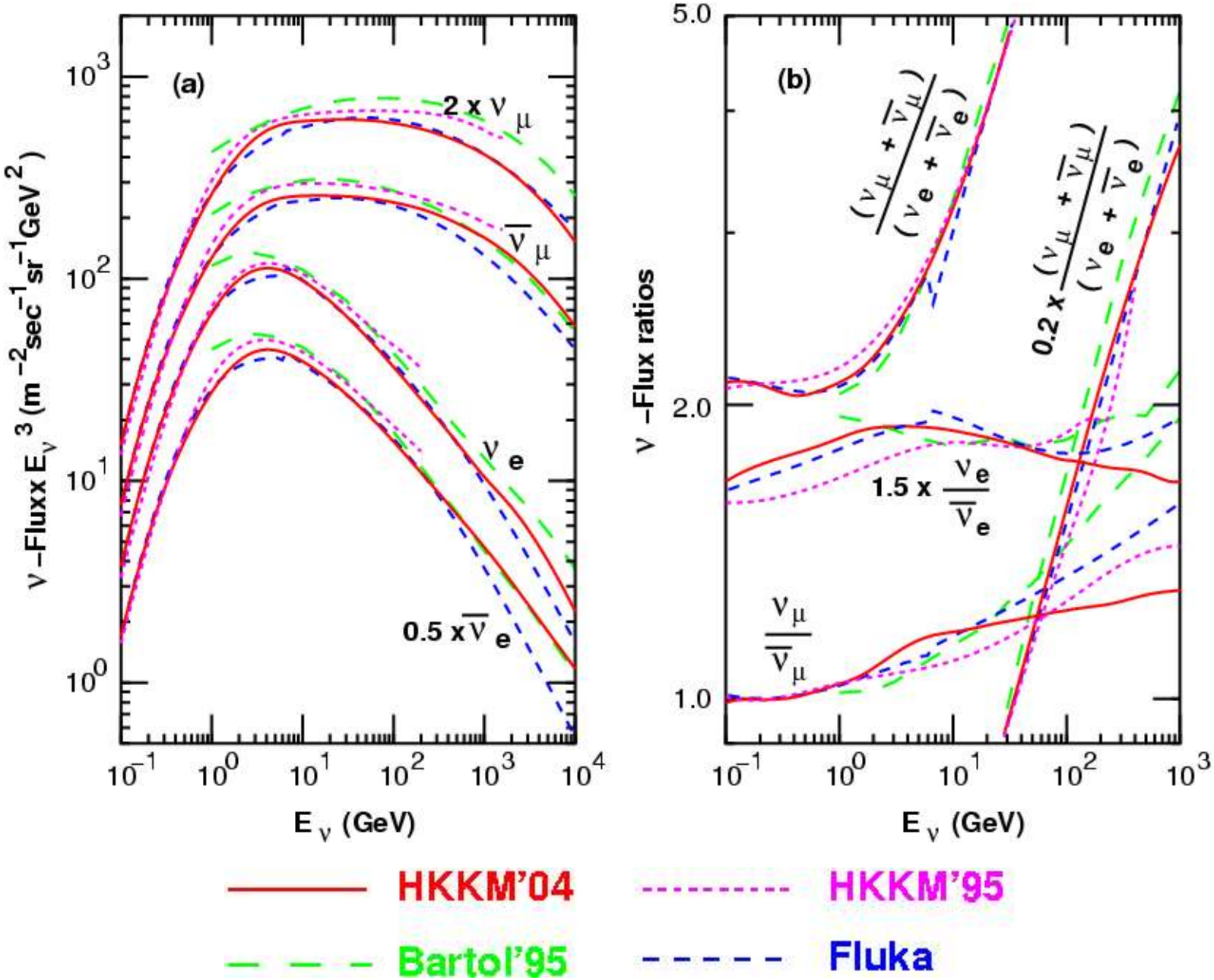




Production Height : horizontal directions



High Energy neutrino fluxes



High Energy Neutrino Flux

Study of zenith angle dependence with:

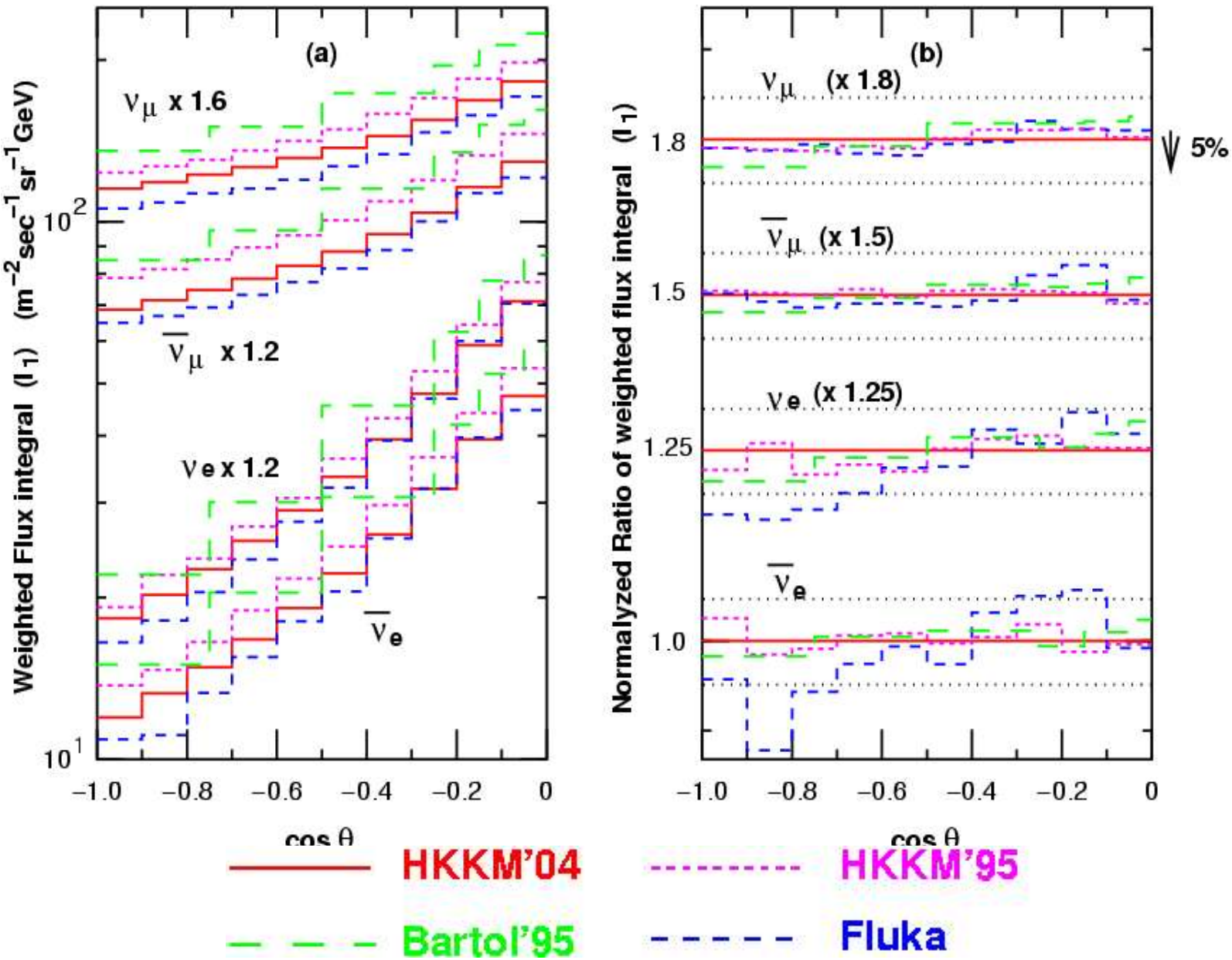
$$I_n(\cos\theta) = \int_{E1}^{E2} E_\nu^n \frac{dN_\nu}{dE_\nu}(\cos\theta)dE_\nu$$

- n=1, E1 = 3.2 GeV roughly proportional to Stop Muon event number

- n=2, E1 = 10 GeV routghly proportional to up through going muon event numbers

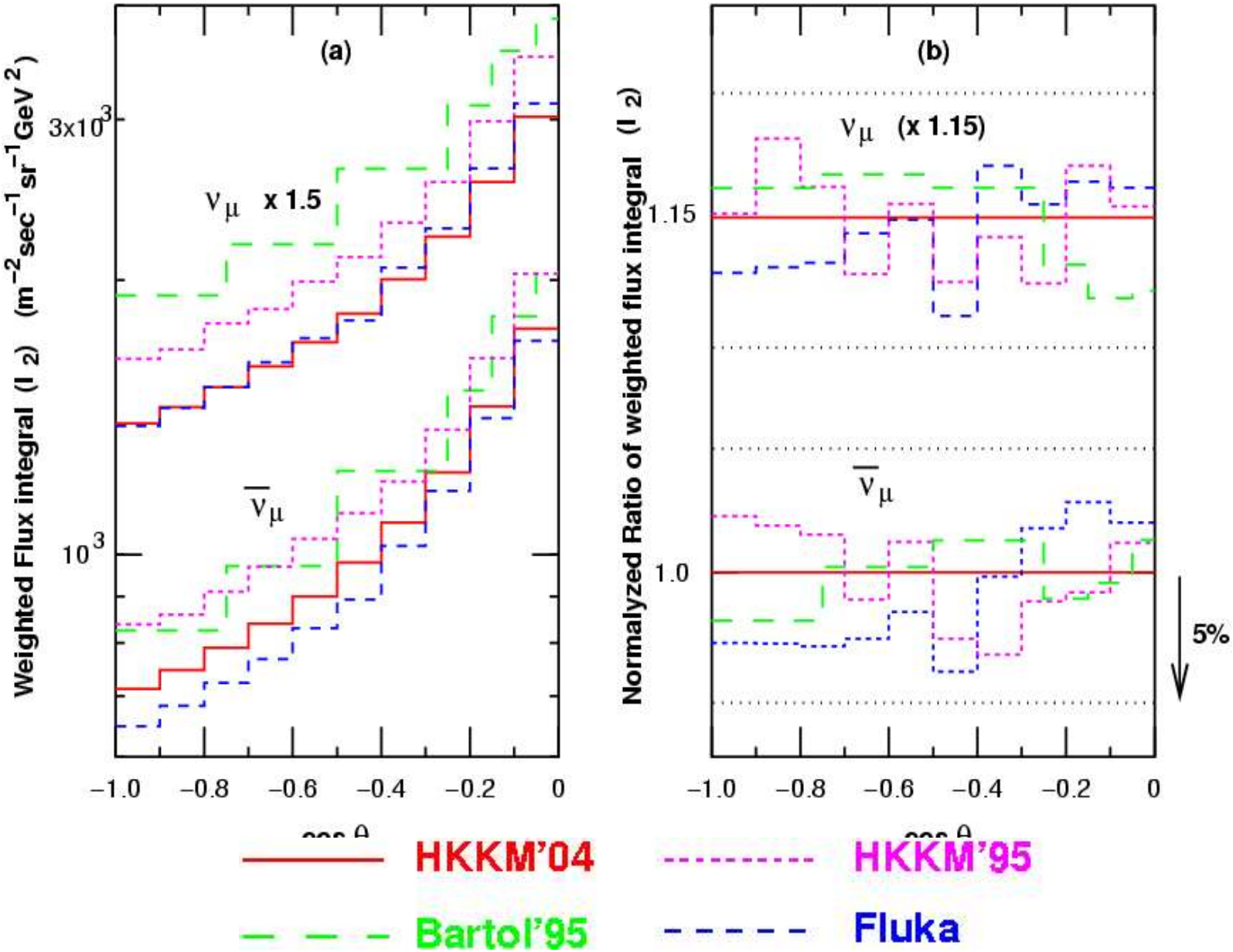
High Energy neutrino fluxes

n=1, E1 = 3.2 GeV



High Energy neutrino fluxes

n=2, E1=10 GeV

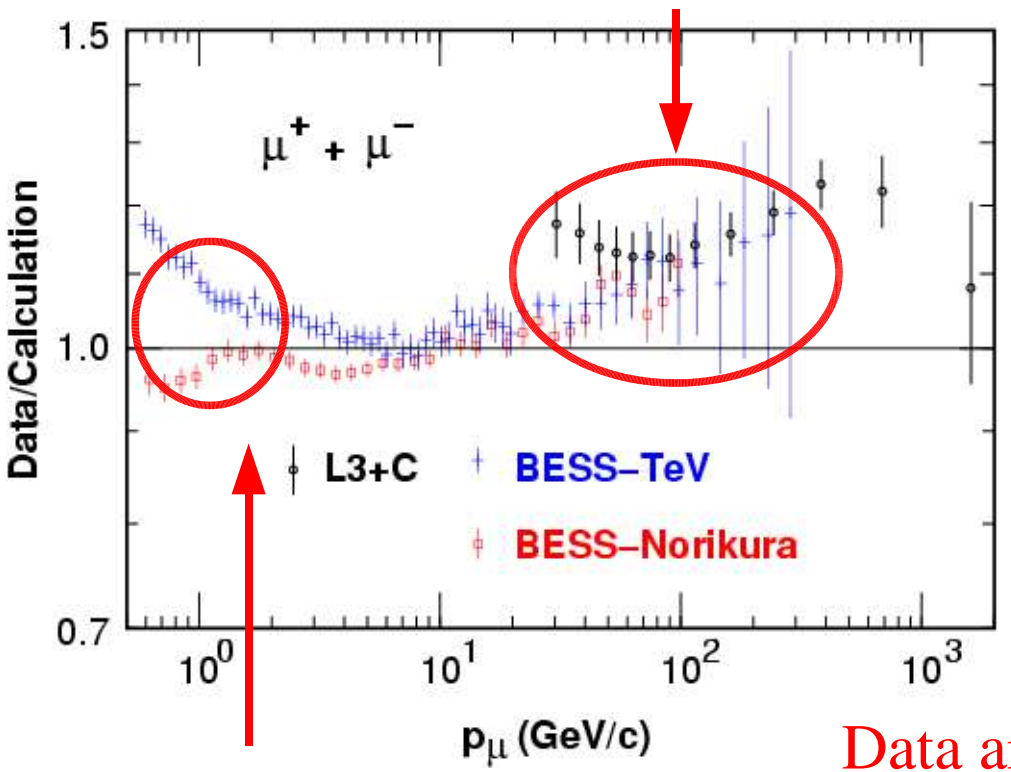


Summary

- Flux of primary cosmic ray flux is well determined for < 100GeV
- The hadronic interaction model could be studied with secondary cosmic rays
- The systematic errors due to the calculation scheme is smaller than 1%.
- The “3D effects" are well understood.
- Accordingly the accuracy of the calculated atmospheric neturino flux is improved to < 10 % in absolute values, and < 5% in flavor ratio below 10 GeV. ???

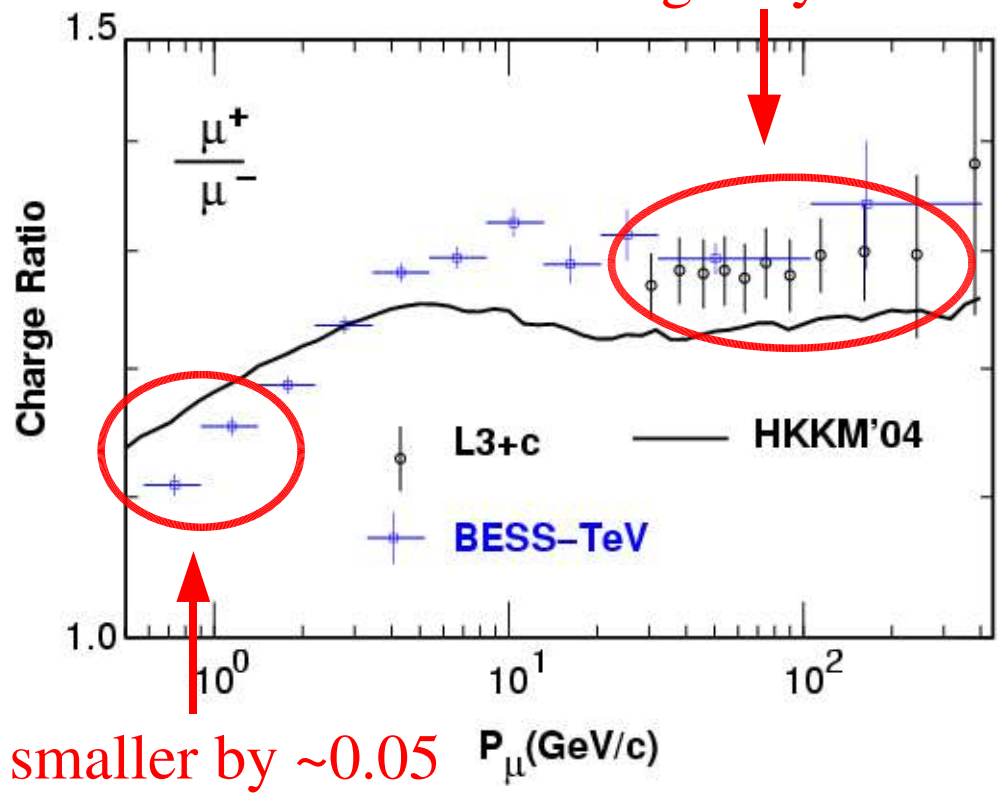
Comparison with high precision muon observations

Data are larger by ~15%



~15% scatter ?

Data are larger by ~0.05



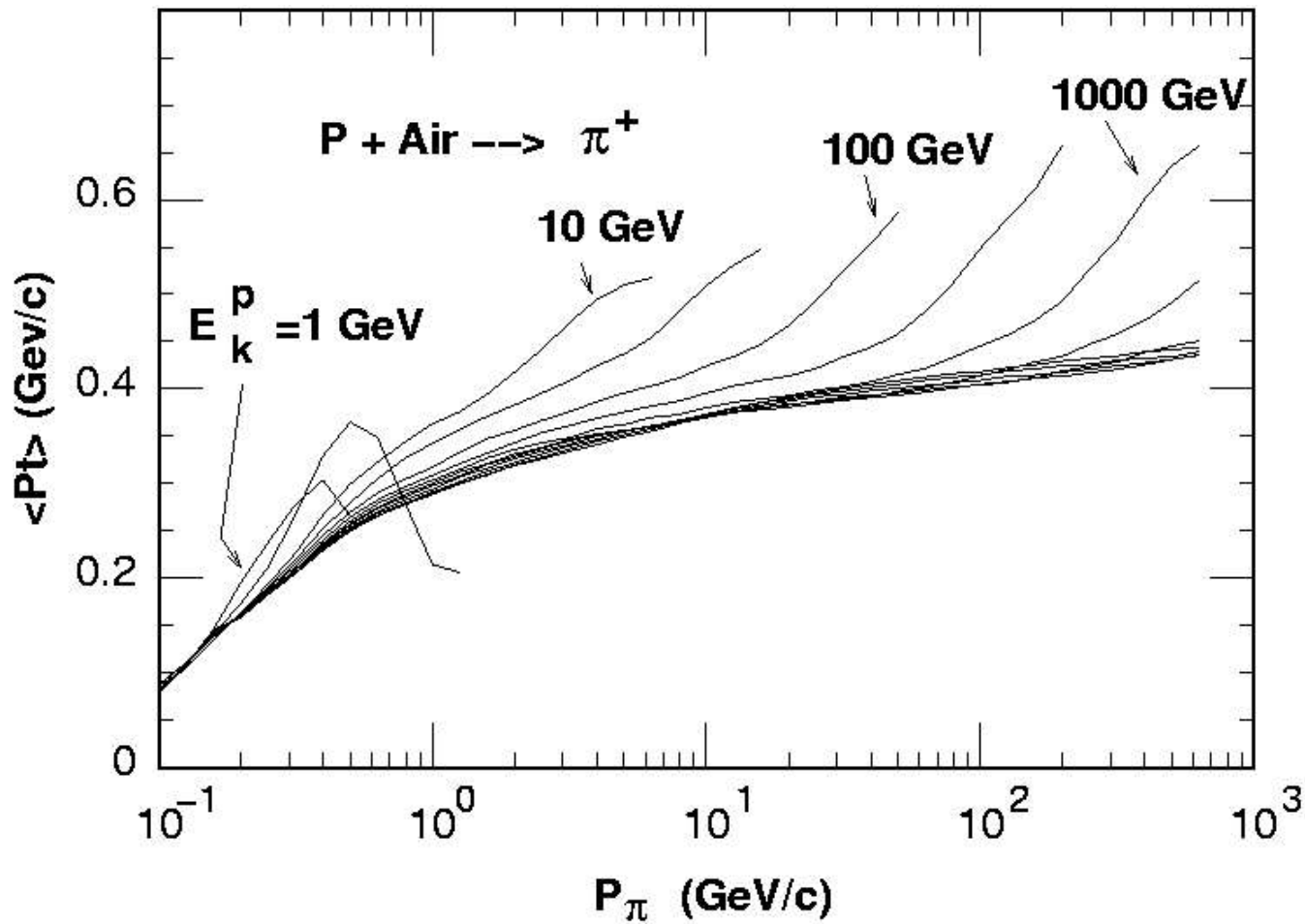
Data are smaller by ~0.05

DPMJET-III Should be Modified

Transverse Momentums

Sample a scattering angle following the probability :

$$\propto \exp(a \cdot \cos\theta) \cdot d\cos\theta$$

"a" is determined so that it reproduce the <pt> for secondary particles for various projectile energy.

<pt> calculated with DPMJET-III