Possible
Errors of Atmospheric Neutrino Flux
in HKKM

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Overview of error sources

- Primary cosmic ray flux
- Interaction model

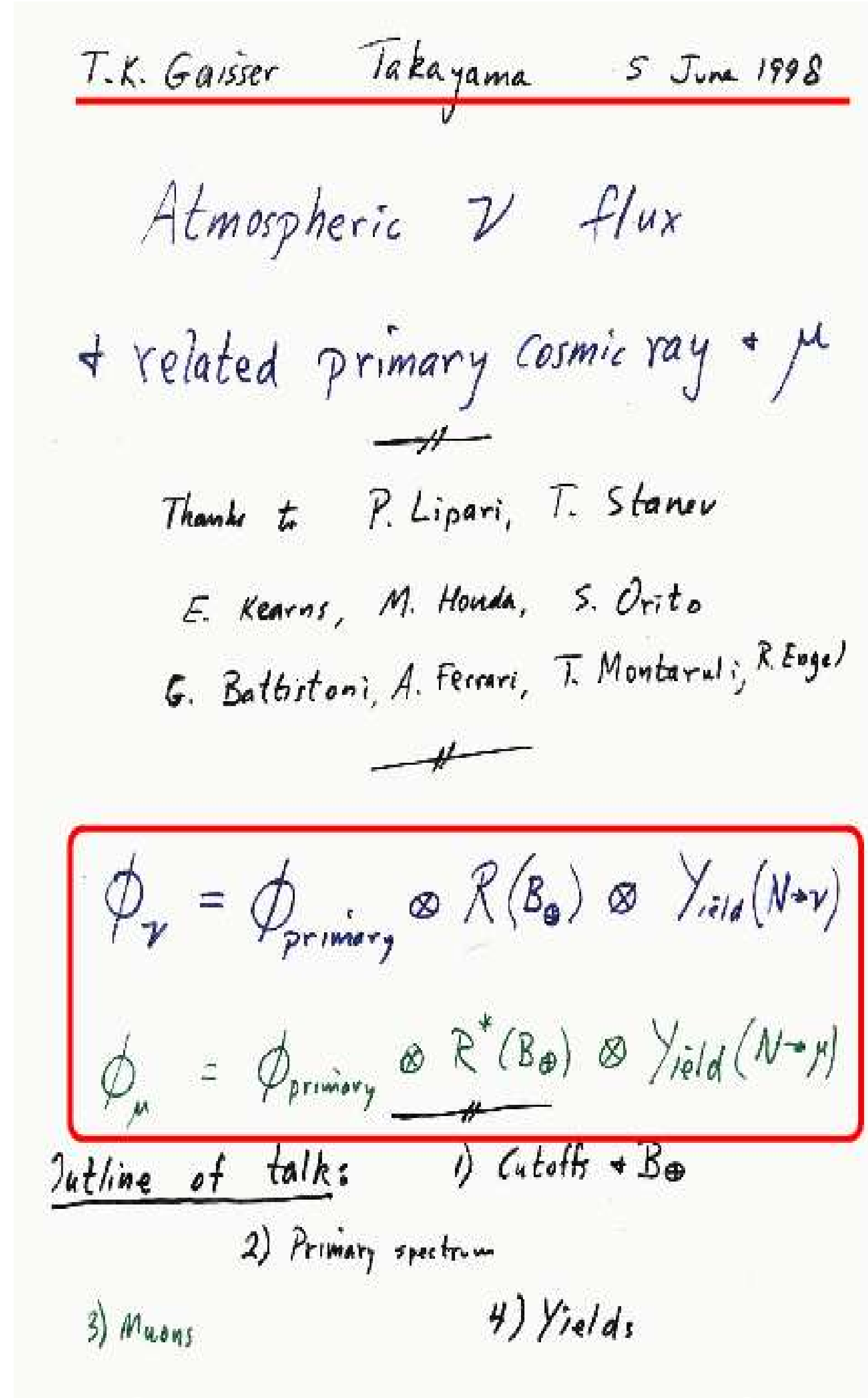
Only uncertain data available

➤ First kind uncertainty

- Calculation scheme
  (include rigidity cutoff)
- Atmosphere model

Well known but difficult to include or have large variation.

➤ Second kind uncertainty



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 + $B_\oplus$

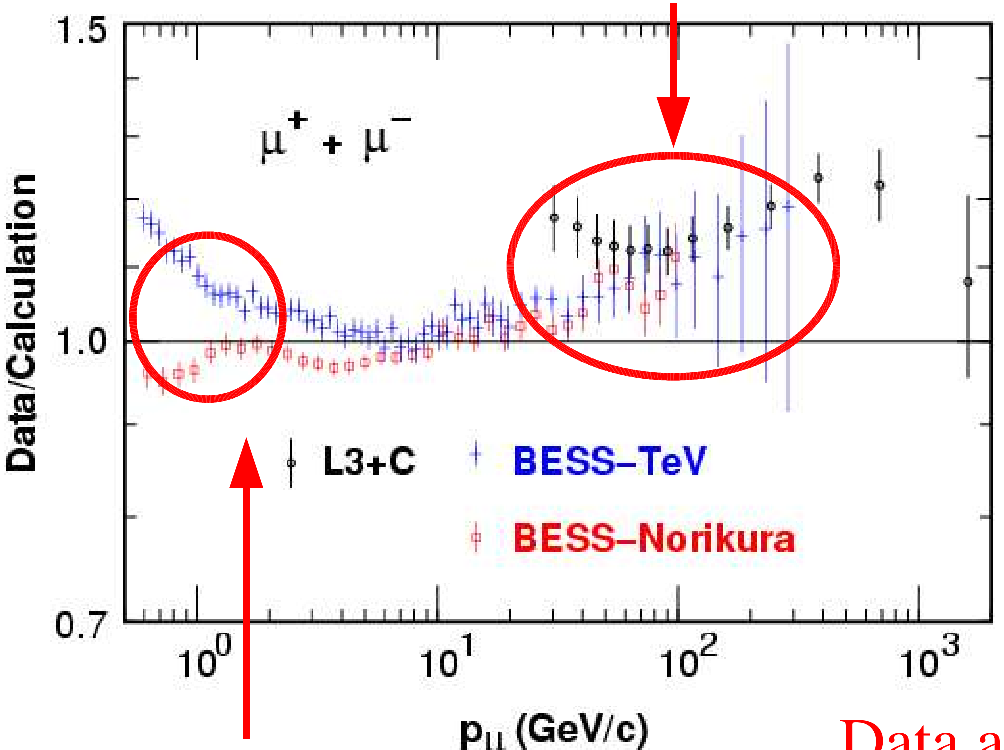
2) Primary spectrum

3) Muons

4) Yields

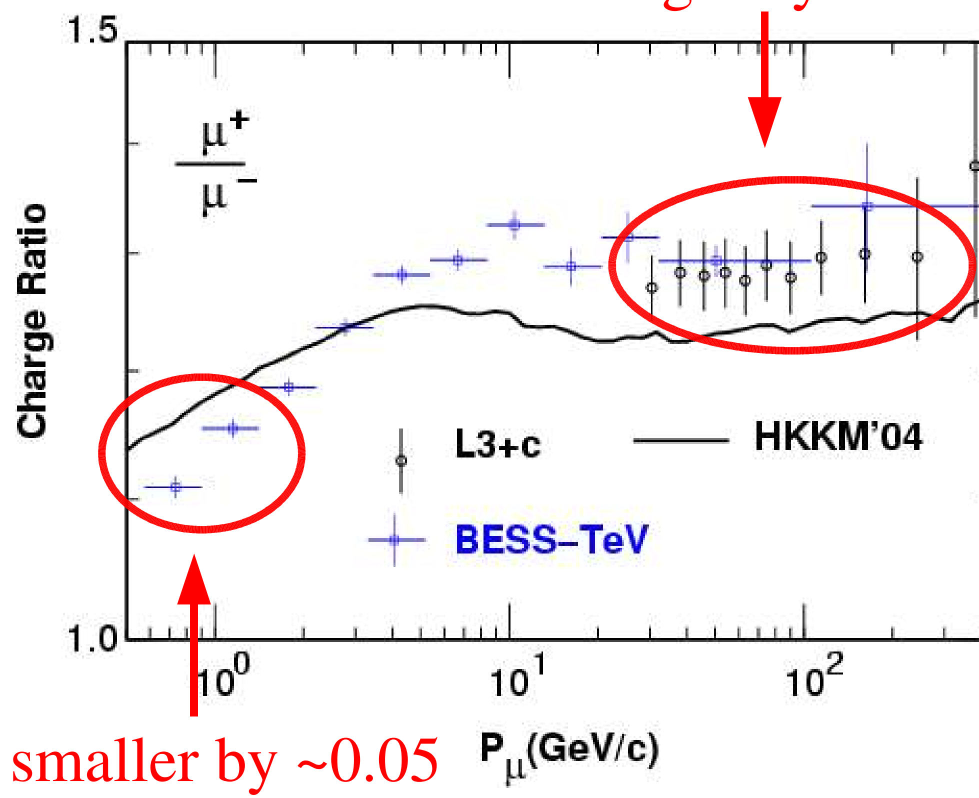
Comparison with high precision muon observations

Data are larger by ~15%



~15% scatter ?

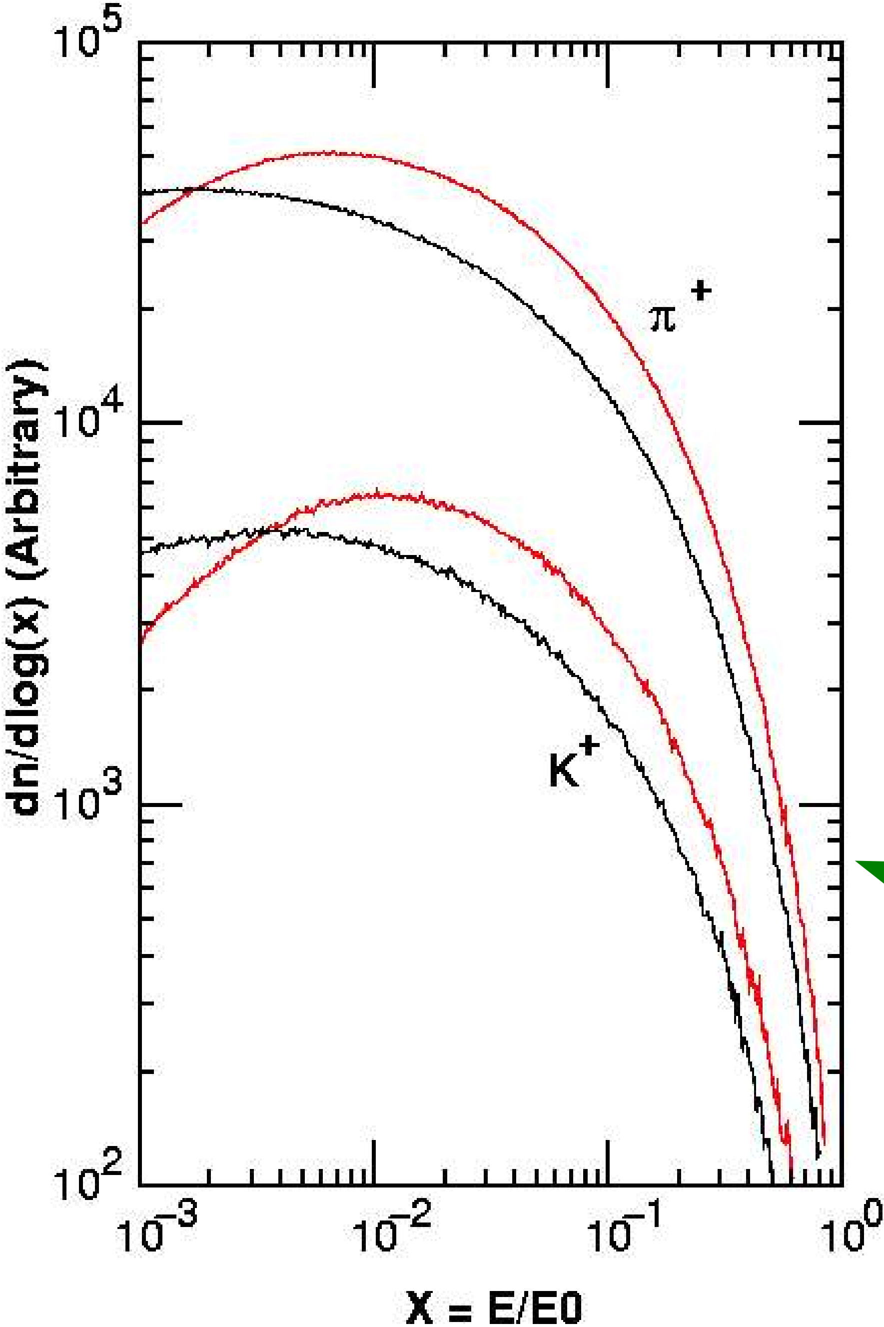
Data are larger by ~0.05



Data are smaller by ~0.05

DPMJET-III Should be Modified

Modification of DPMJET-III



- Tune the x-distribution the inter-action model, so that muon data are reproduced well.

- Keep the multiplicity as it is.

An example of such modification.
(P + Air at 10 TeV)

Quark Model Oriented Parametrization

Quark assignments for partilces

$$p = (u, u, d) \qquad \pi^{+} = (u, \bar{d}) \qquad K^{+} = (u, \bar{s})$$

$$n = (u, d, d) \qquad \pi^{-} = (\bar{u}, d) \qquad K^{-} = (\bar{d}, s)$$

$$\pi^{0} = \{(u, \bar{u}) + (d, \bar{d})\}/2 \qquad K^{0} = (d, \bar{s}) \leftrightarrow \bar{K}^{0} = (\bar{d}, s)$$

oscillations

1. The variation is proportinal to the number of u or d quarks in a particle. (valence quark in nucleon)

2. Neutron projectile case can be constructed from the proton projectile case with u ◄► d exchange.

Parametrization Formula

For the parameters (u, d)

$$< E^{\pi+} > / < E^{\pi+}_{orig} > = 1 + u \times \log_{10}(E_{proj})$$

$$< E^{\pi 0} > / < E^{\pi 0}_{orig} > = 1 + \frac{u}{2} \times \log_{10}(E_{proj})$$

$$< E^{K+} > / < E^{K+}_{orig} > = 1 + u \times \log_{10}(E_{proj})$$

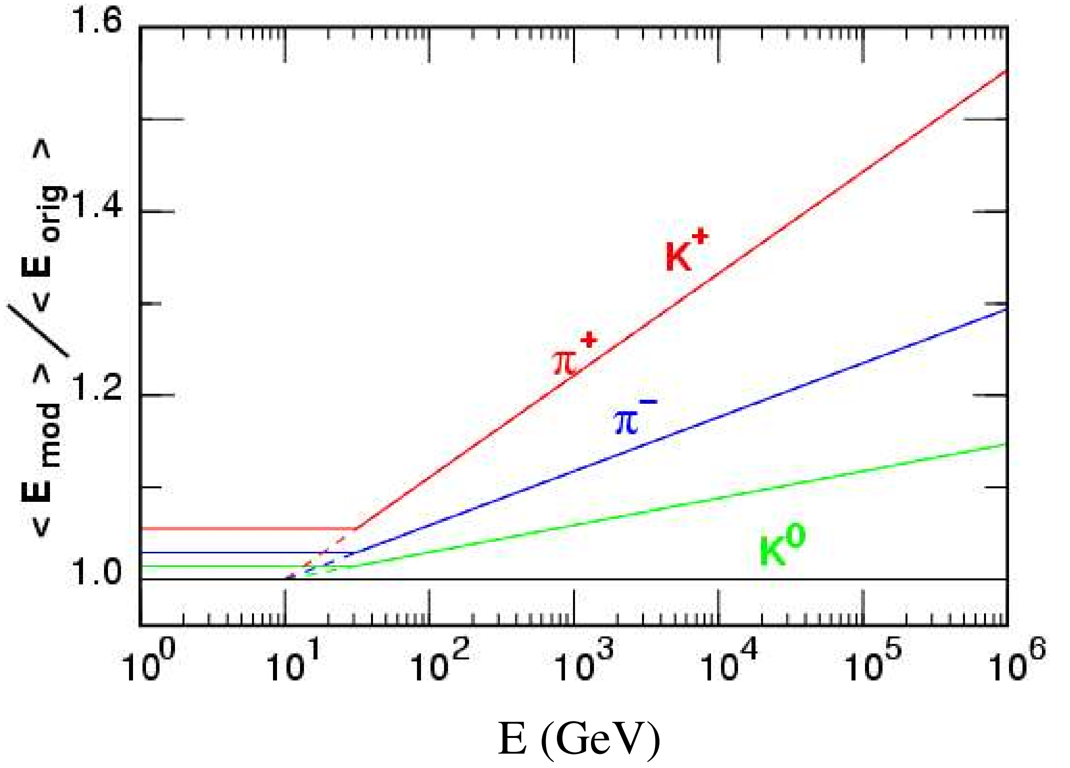
$$< E^{\pi-} > / < E^{\pi-}_{orig} > = 1 + d \times \log_{10}(E_{proj})$$

$$< E^{K0} > / < E^{K0}_{orig} > = 1 + \frac{d}{2} \times \log_{10}(E_{proj})$$

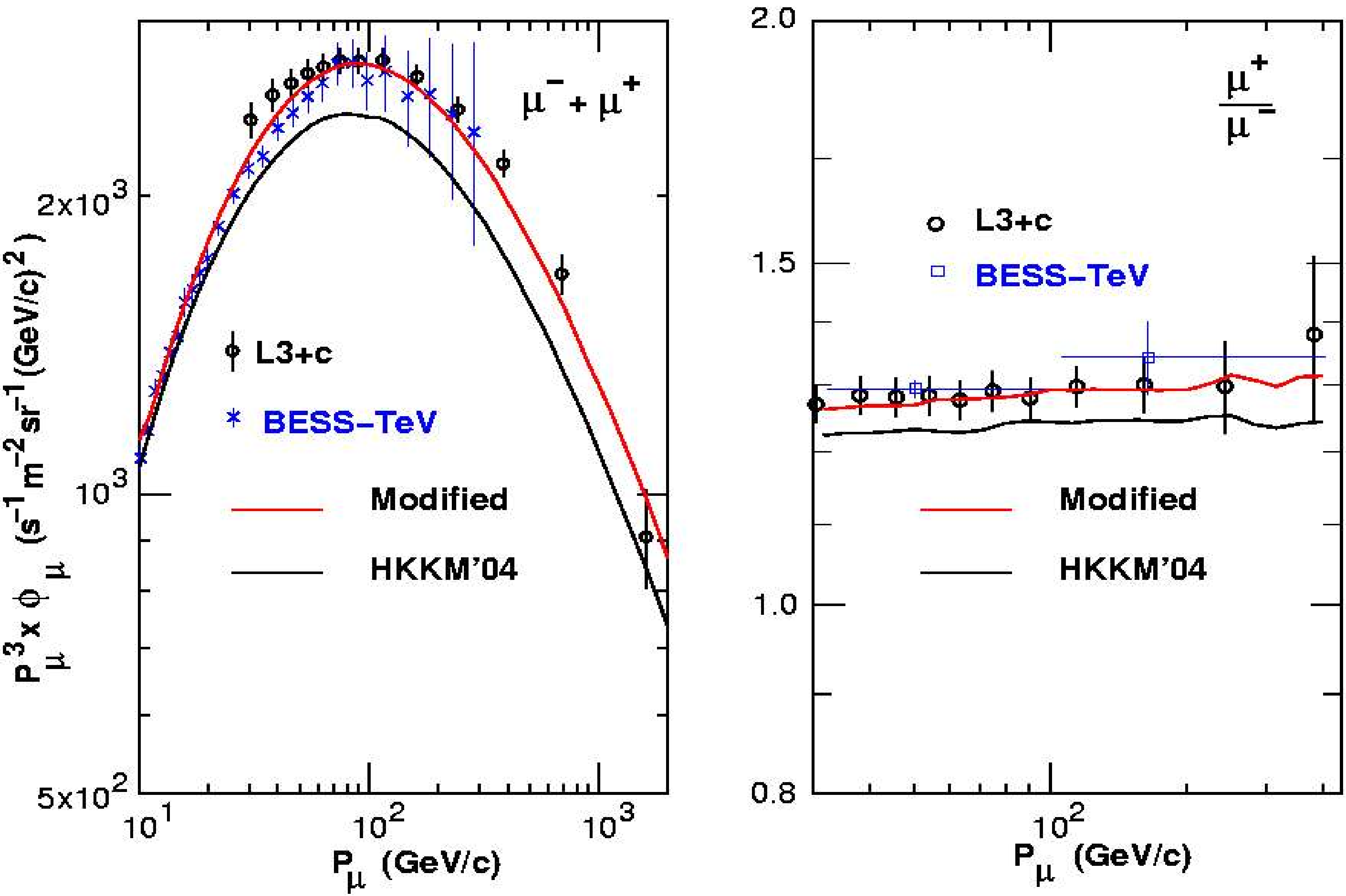
Note

1. $K_0 = (K_s + K_l) = (K^0 + \bar{K}^0)$
2. K^- is not modified in this parametrization.

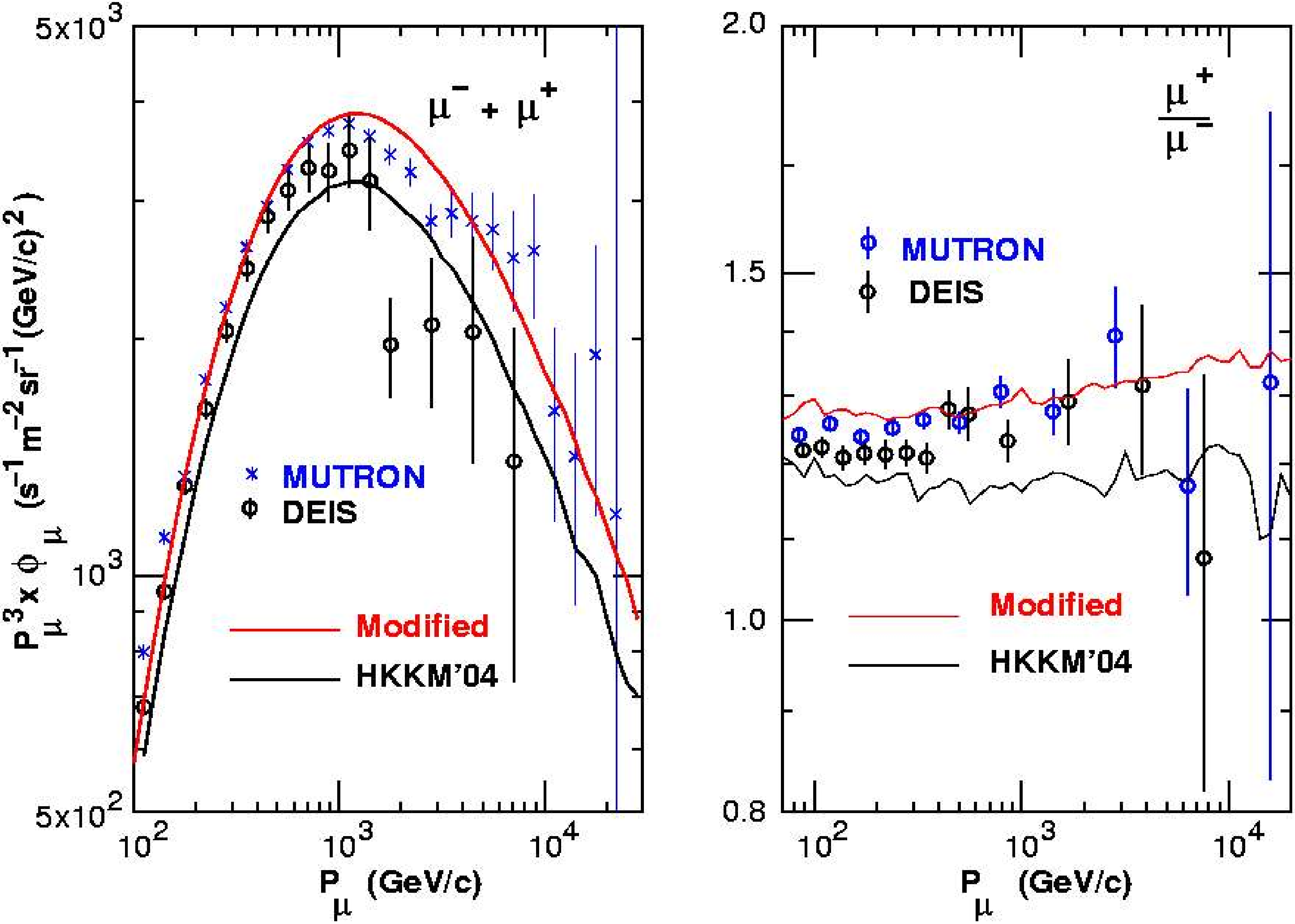
An example.



Vertical muon data and calculations



Horizontal muon data and calculations



Used muon data in analysis

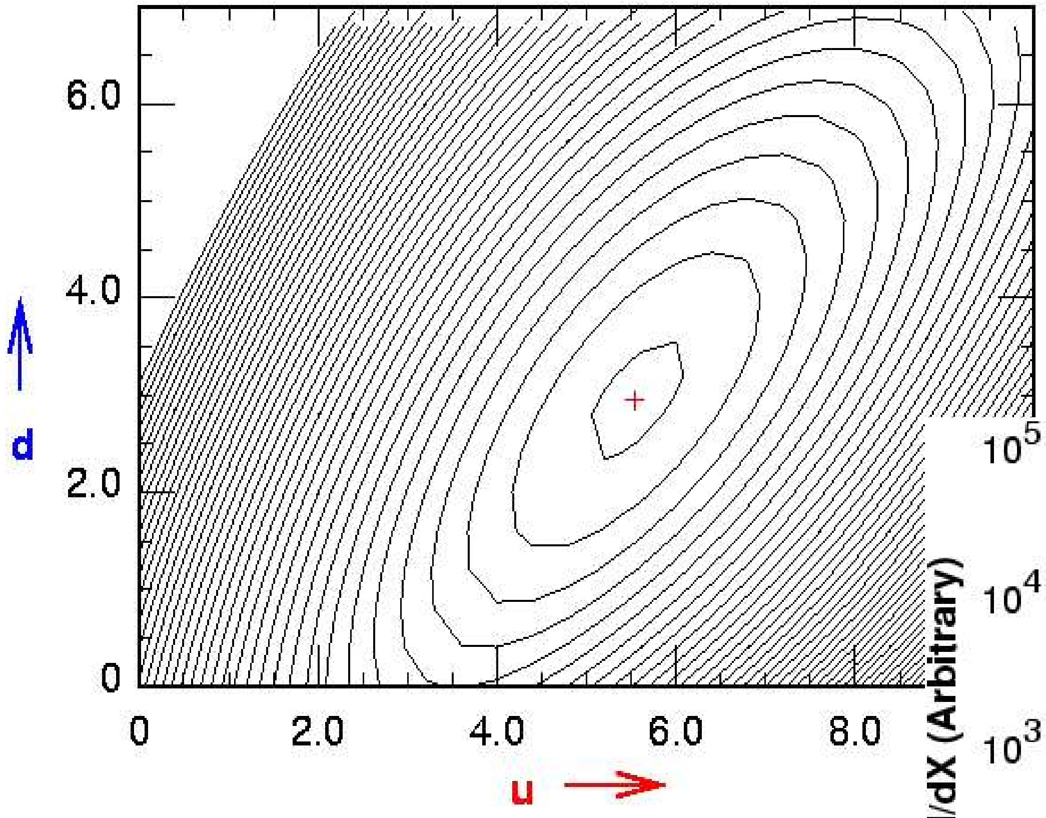
For vertical direction

1. BESS at balloon altitude (0.5~10 GeV/c)
2. BESS ground level (0.5~300 GeV/c)
3. L3+C (60 GeV/c~1.5 TeV/c)

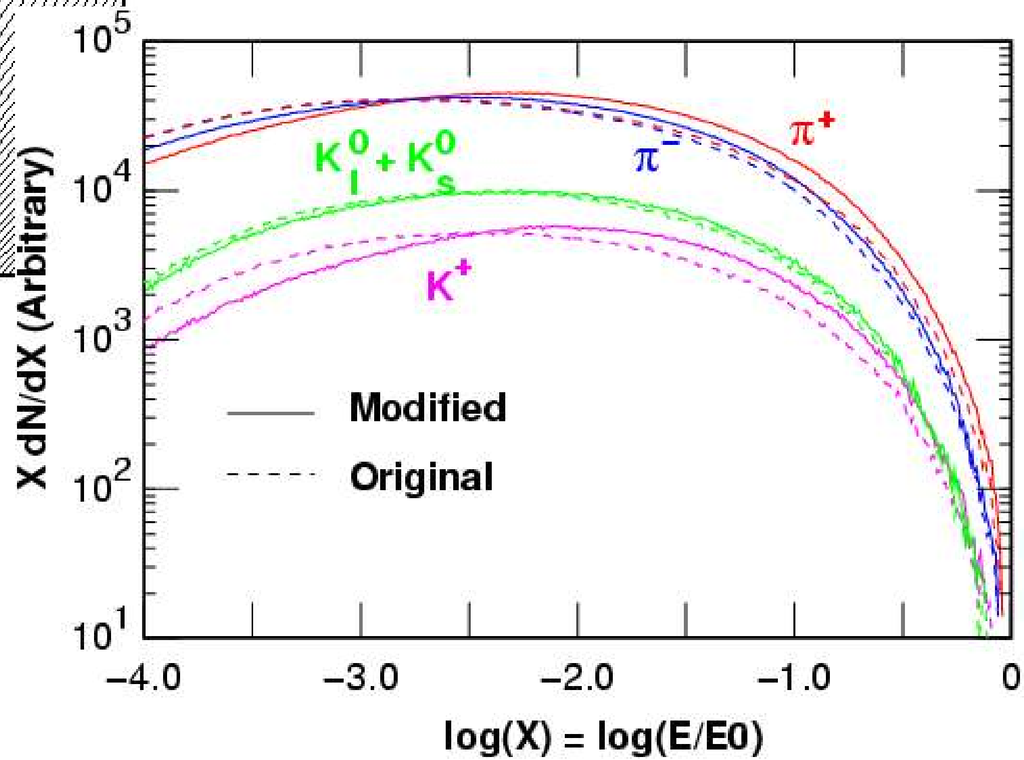
For horizontal direction

1. MUTRON at ground level (300 GeV/c~20 TeV/c)

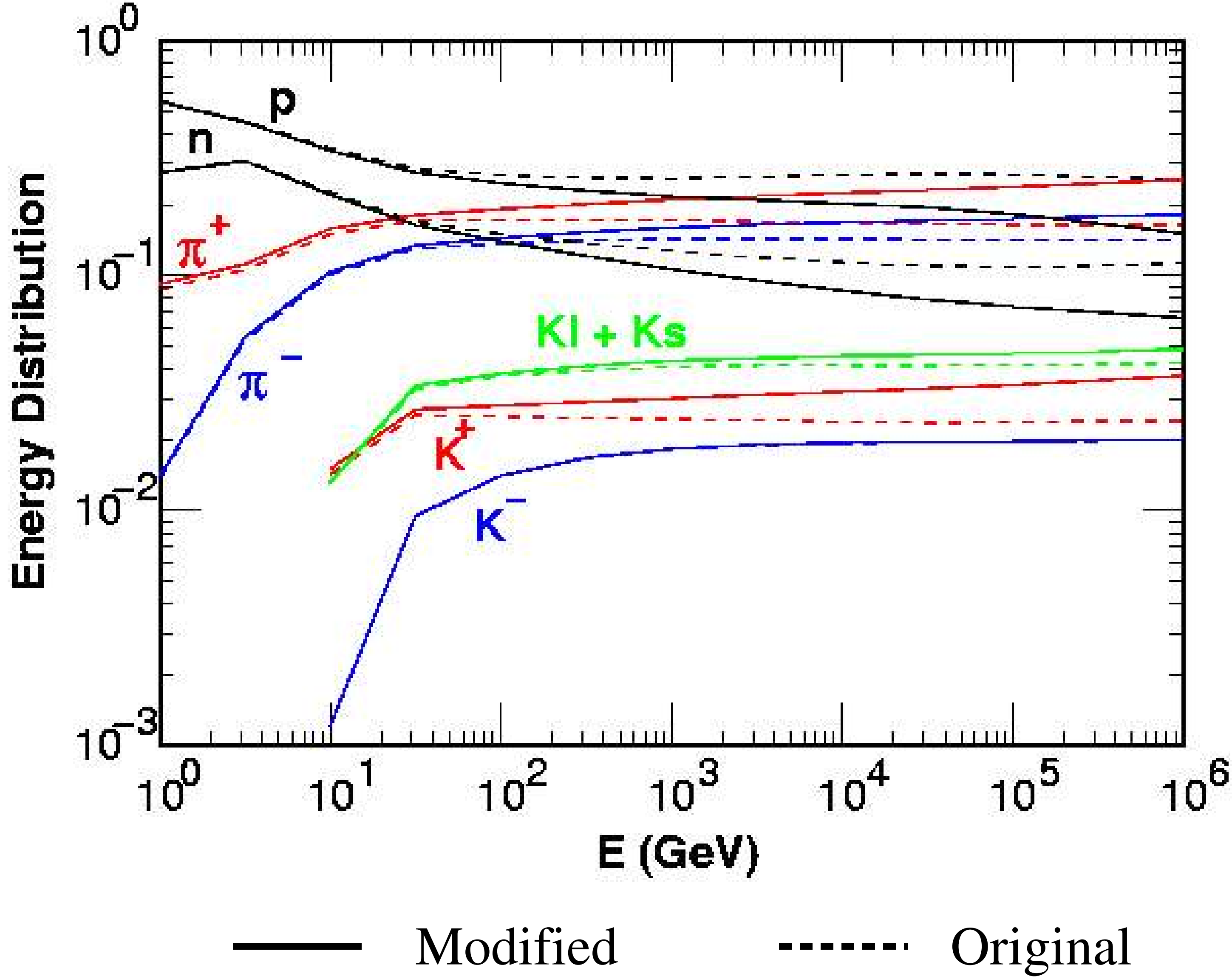
Results of the χ^2 analysis



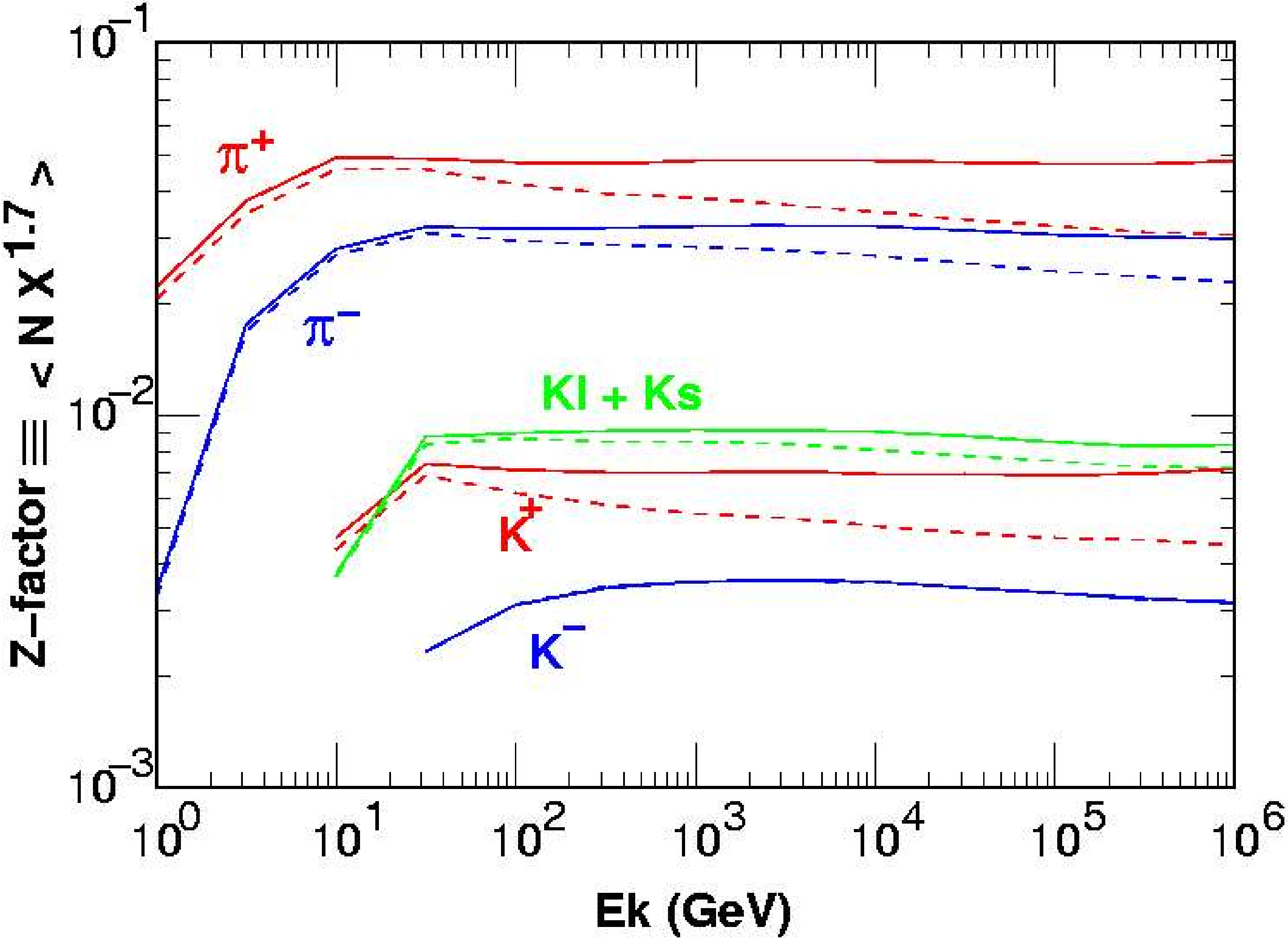
Example of x-distribution
P+Air at 10 TeV



Modified energy distribution

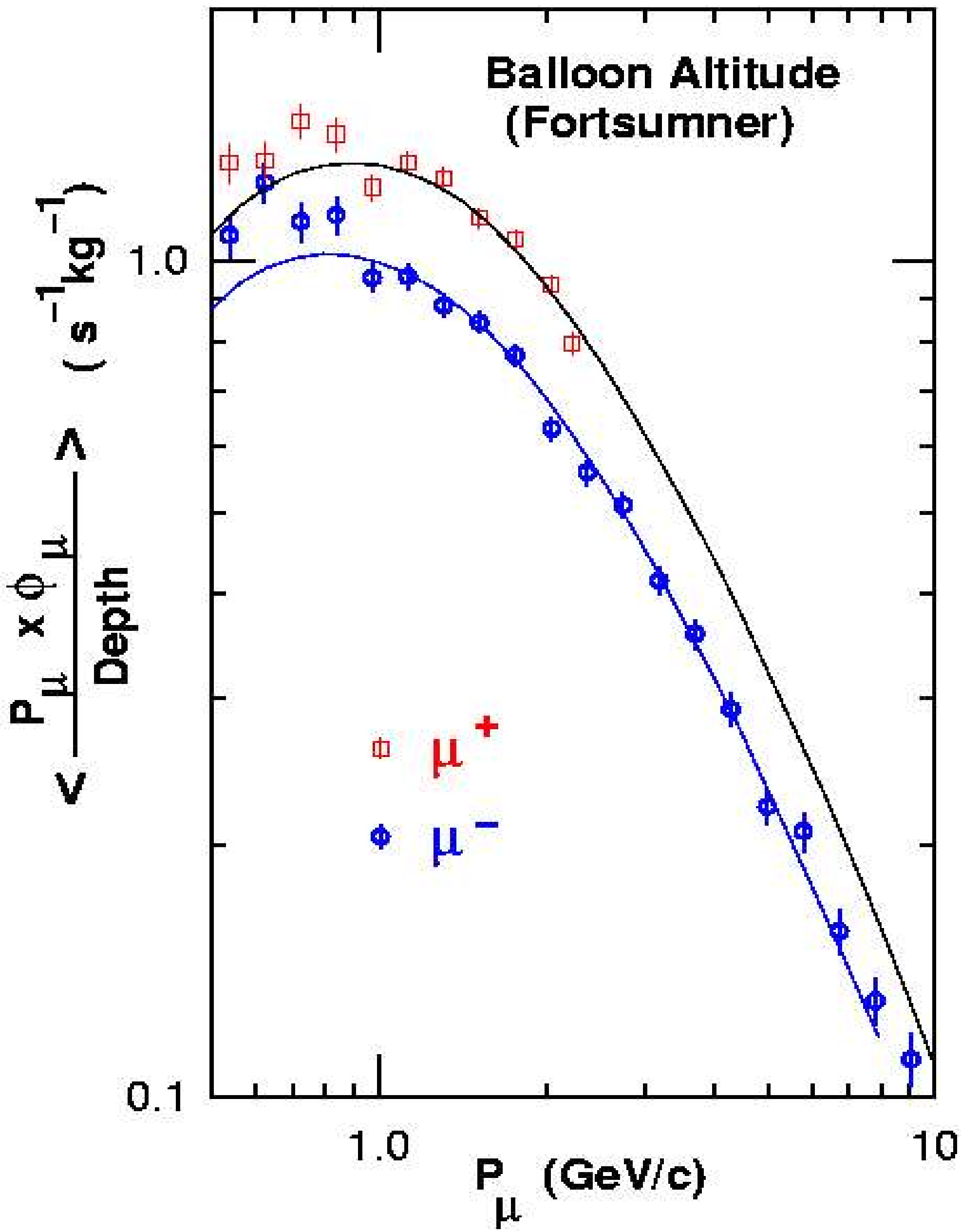


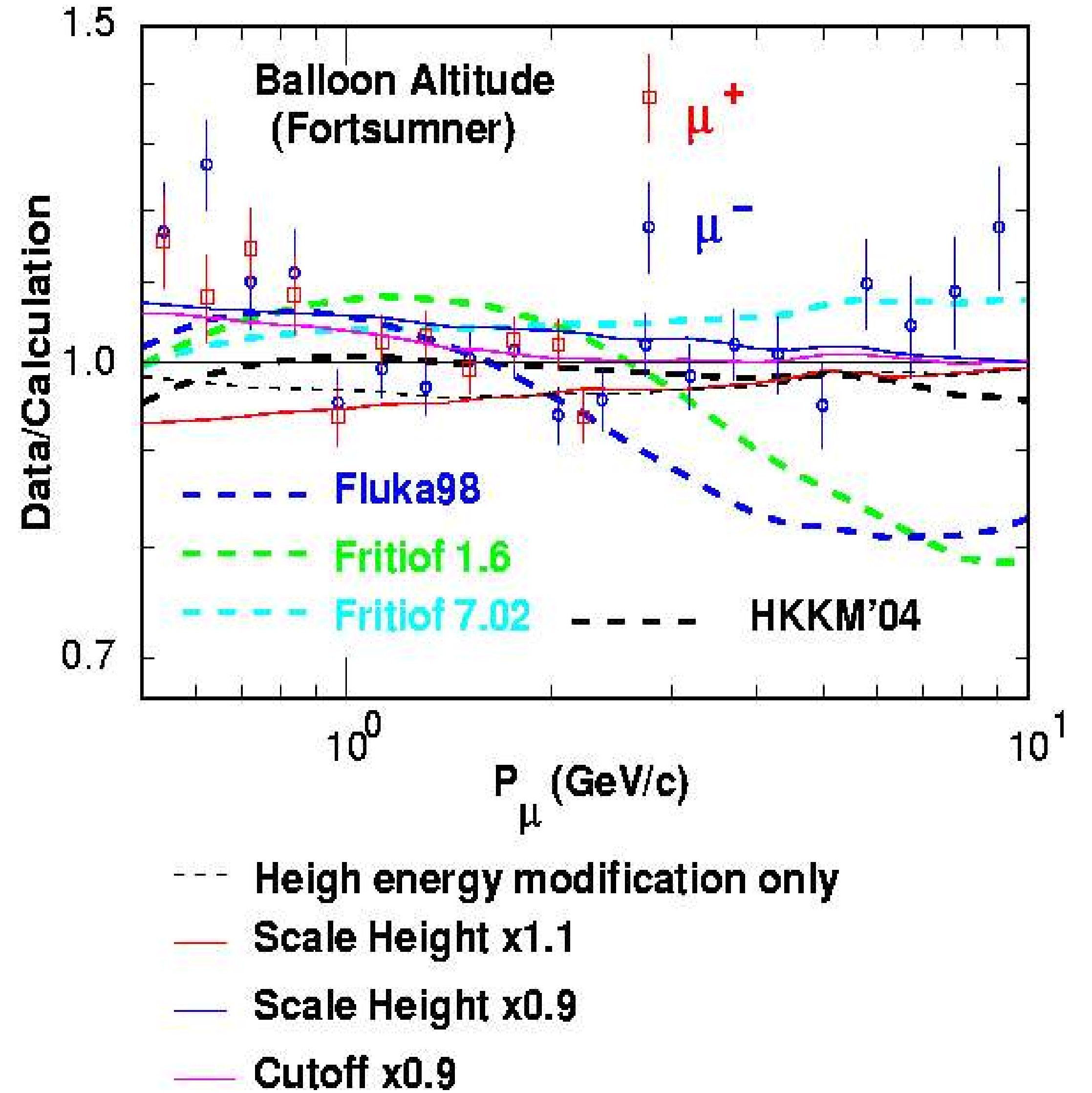
Modification z-factors



Original Modified

Test of modified DPMJET-III at balloon altitude





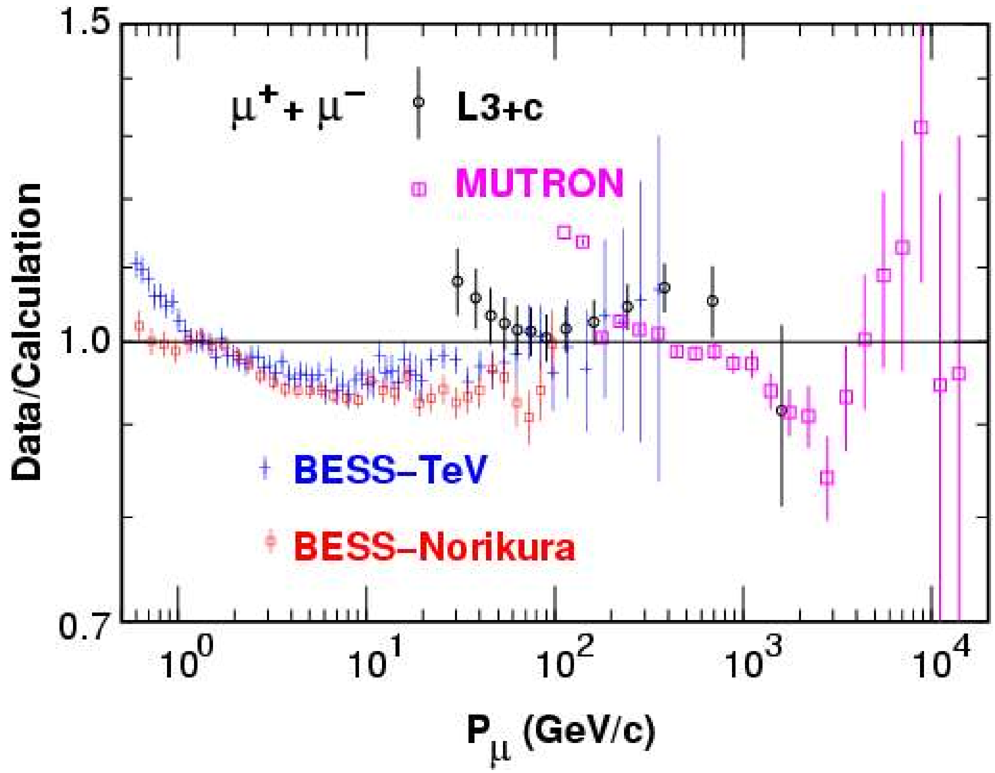
Modified calculation of muon fluxes

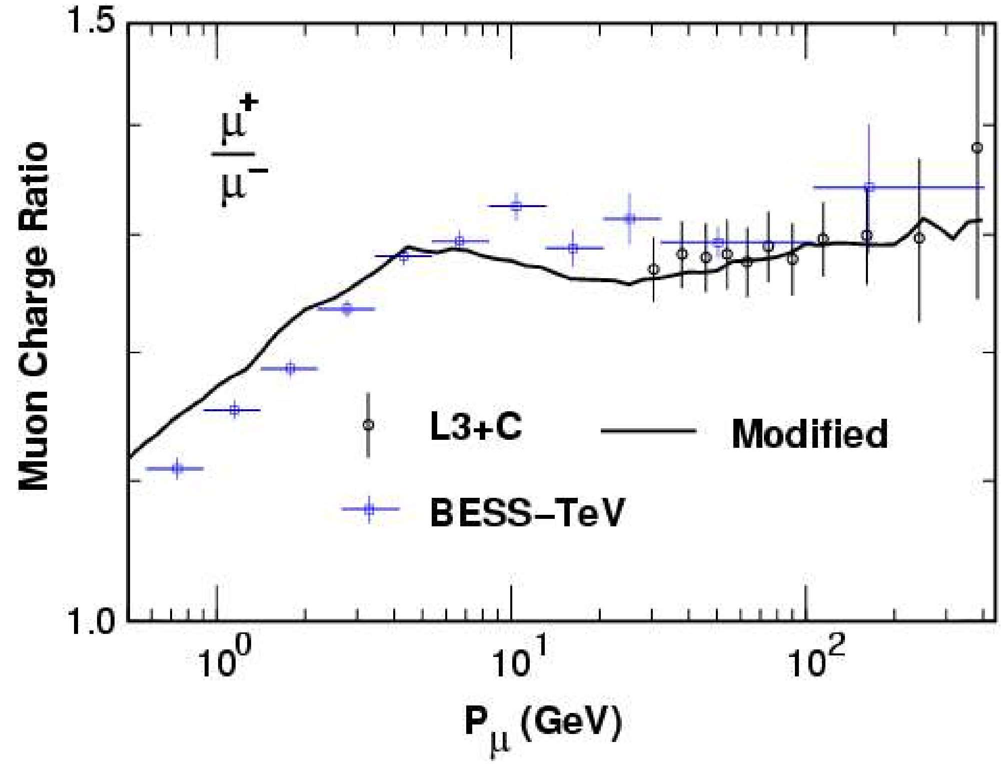
- Primary flux model is the same as before.
- Use the modified DPMJET-III.

- The calculation scheme is the same as before.
- < 30 ~ 100 GeV is calculated in 3D
- > 30 ~ 100 GeV is calculated in 1D
  (Note, 30 ~ 100 is overlup region)

The atmosphere model is constructed by the data from meteorological office up to ~30 km asl and MSISE90 above that altitude.

Modified calculation results

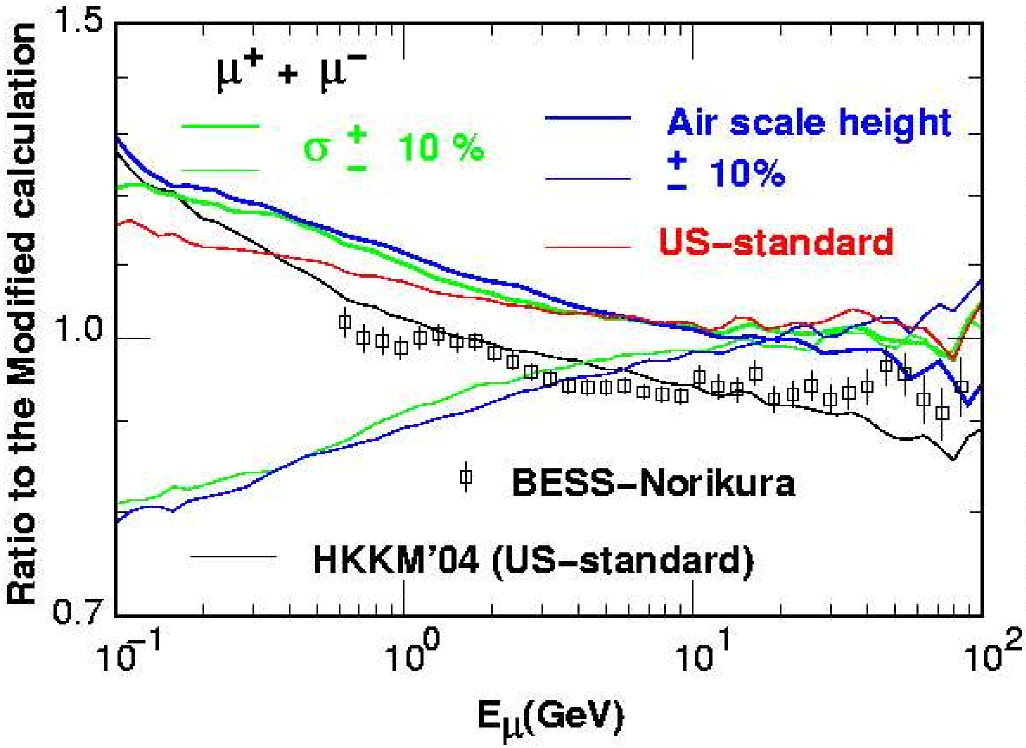


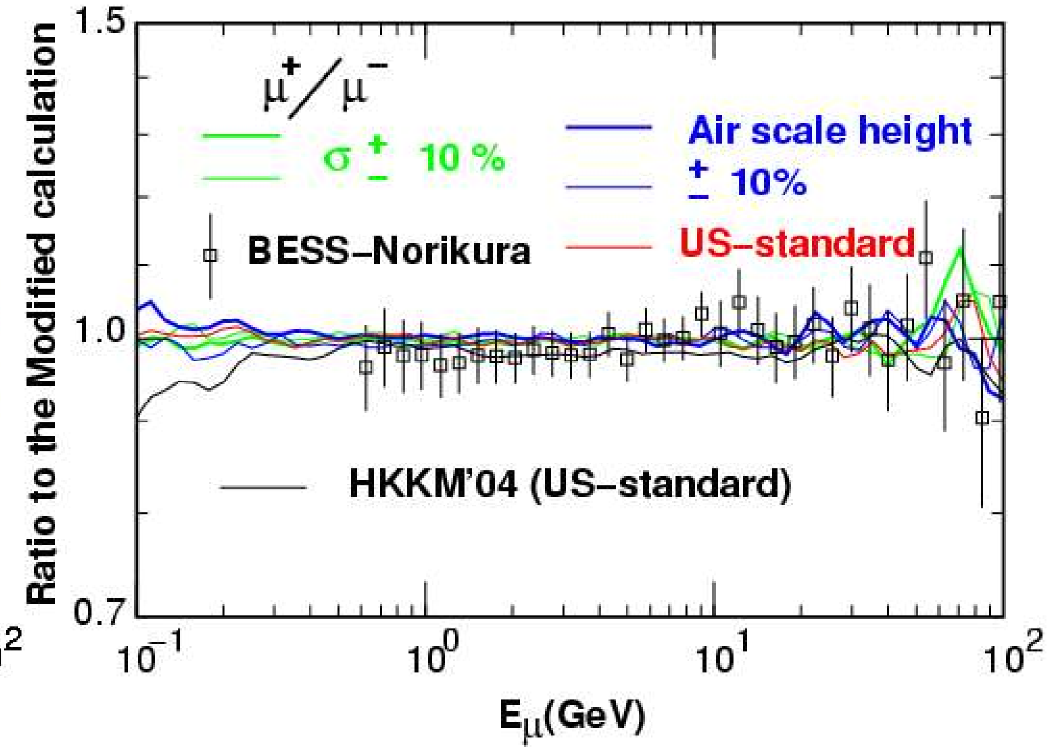


The calculation and data agrees well within 10 % in
1 GeV/c ~1 TeV/c.

Scatters at low energies are reduced with precise atmosphere model.

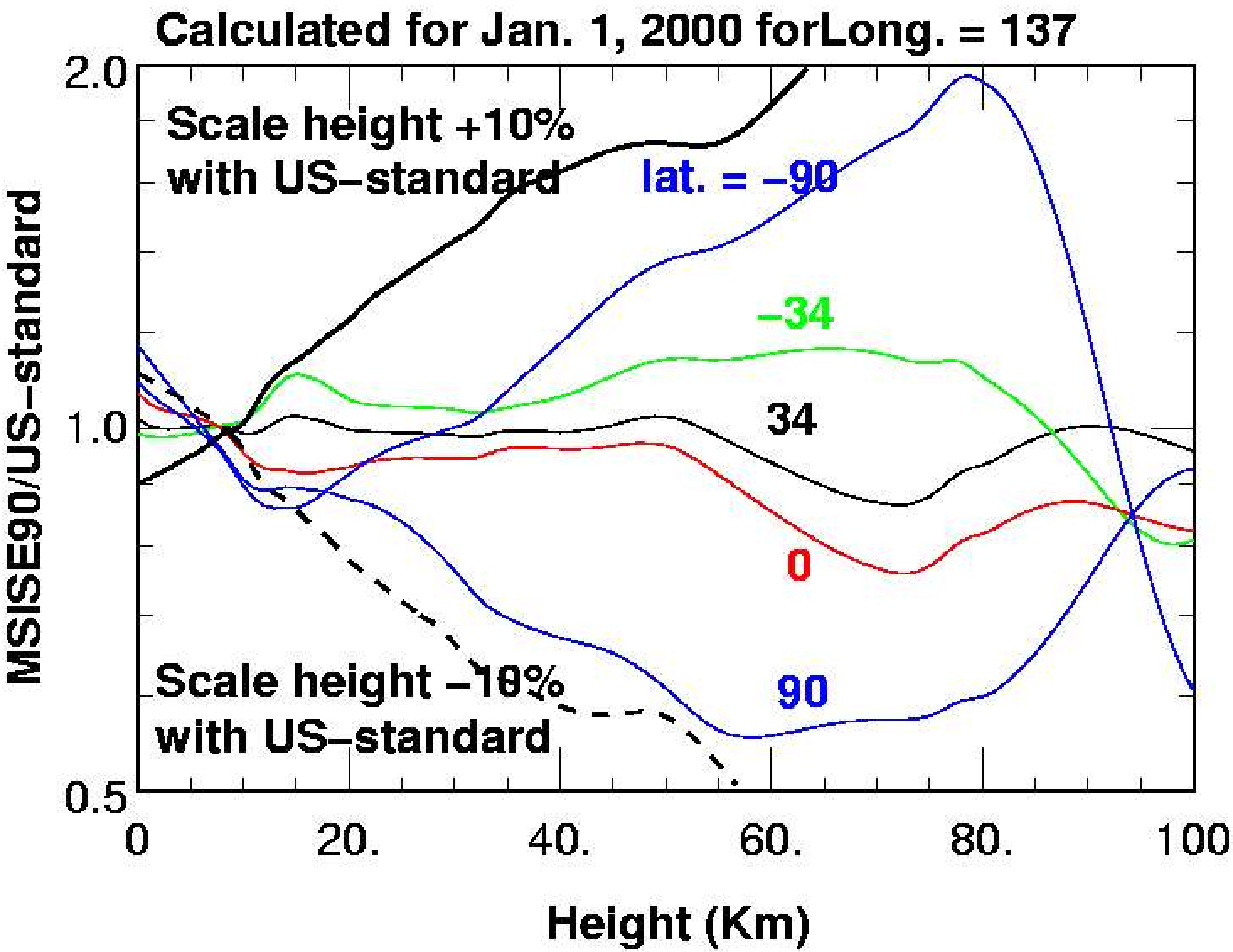
Muon flux and calculation conditions (3D)





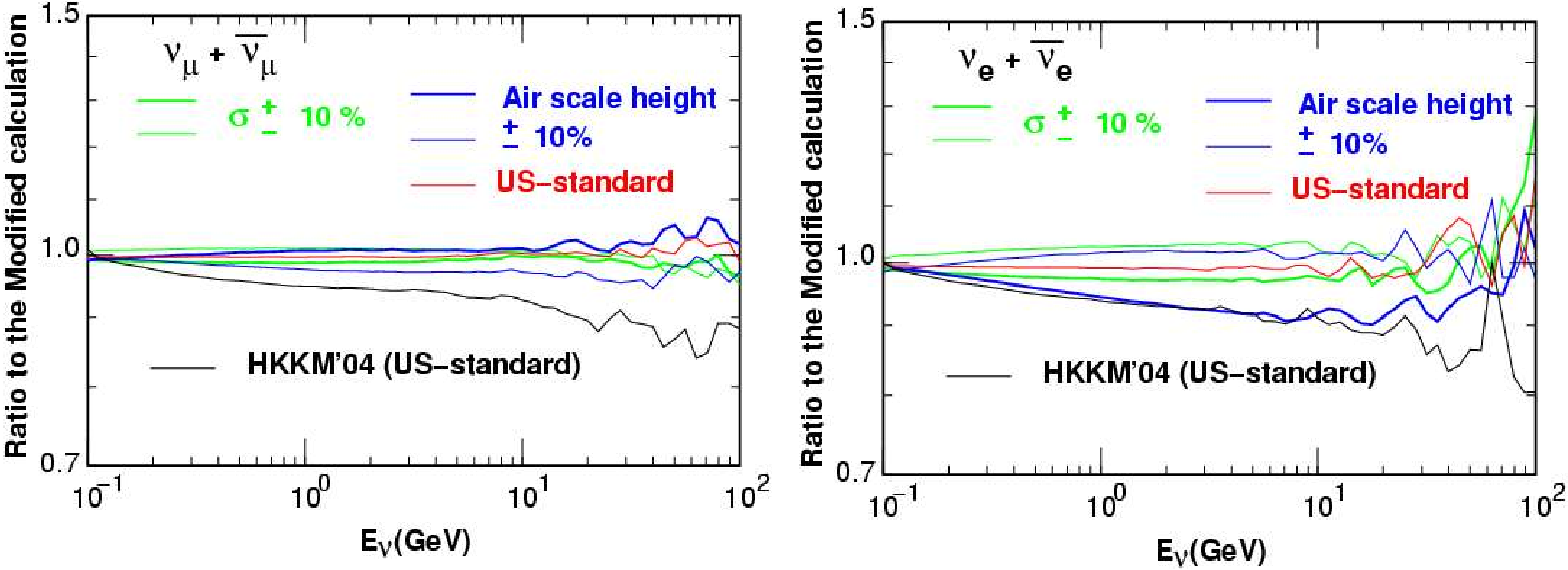
The variation of the calculation condition can be applied to the study of the systematic error of the atmospheric neutrino fluxes !

Scale height change by $\pm 10\,\%$



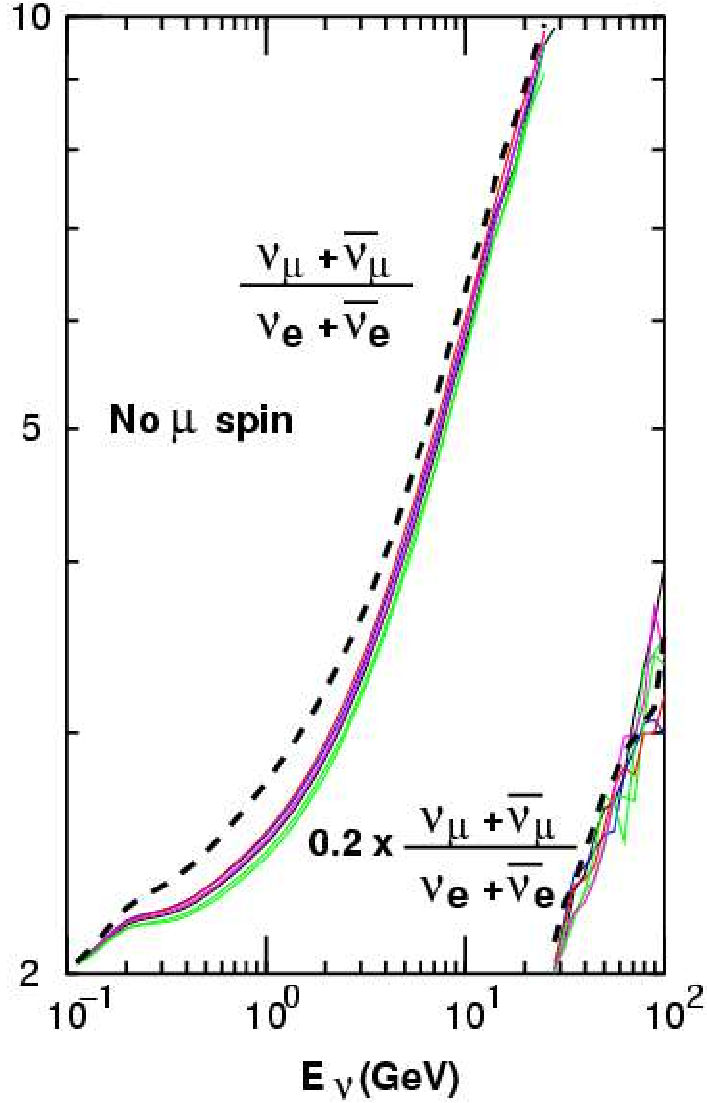
Larger than most of atmosphere variations

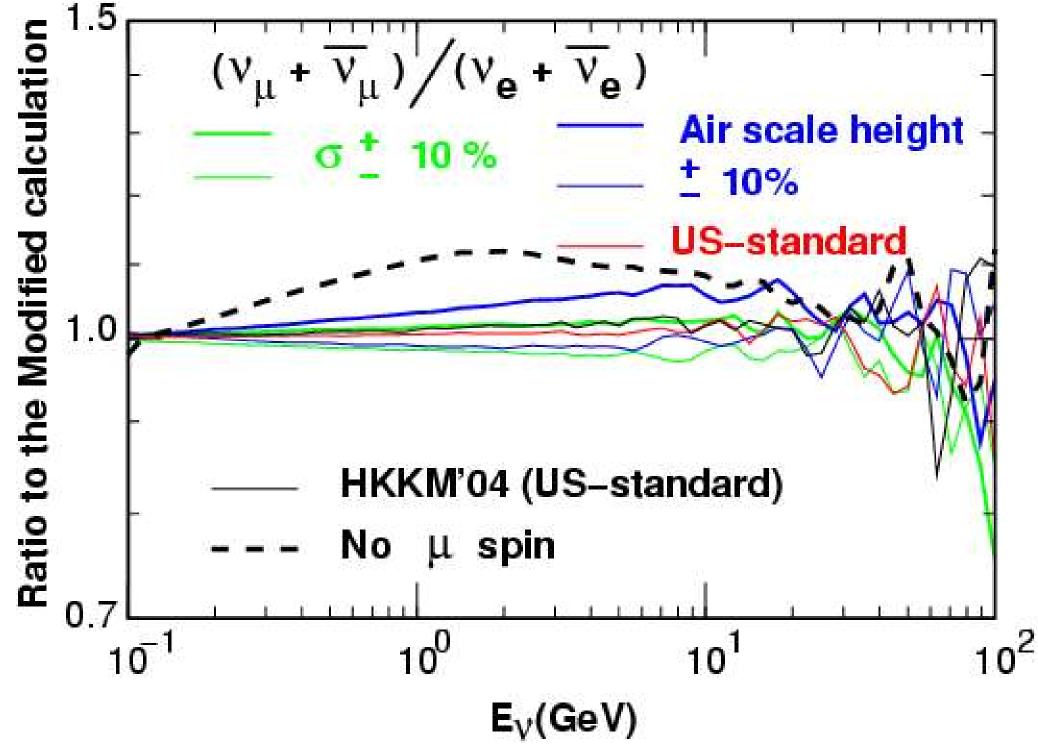
Neutrino flux and calculation conditions (3D)



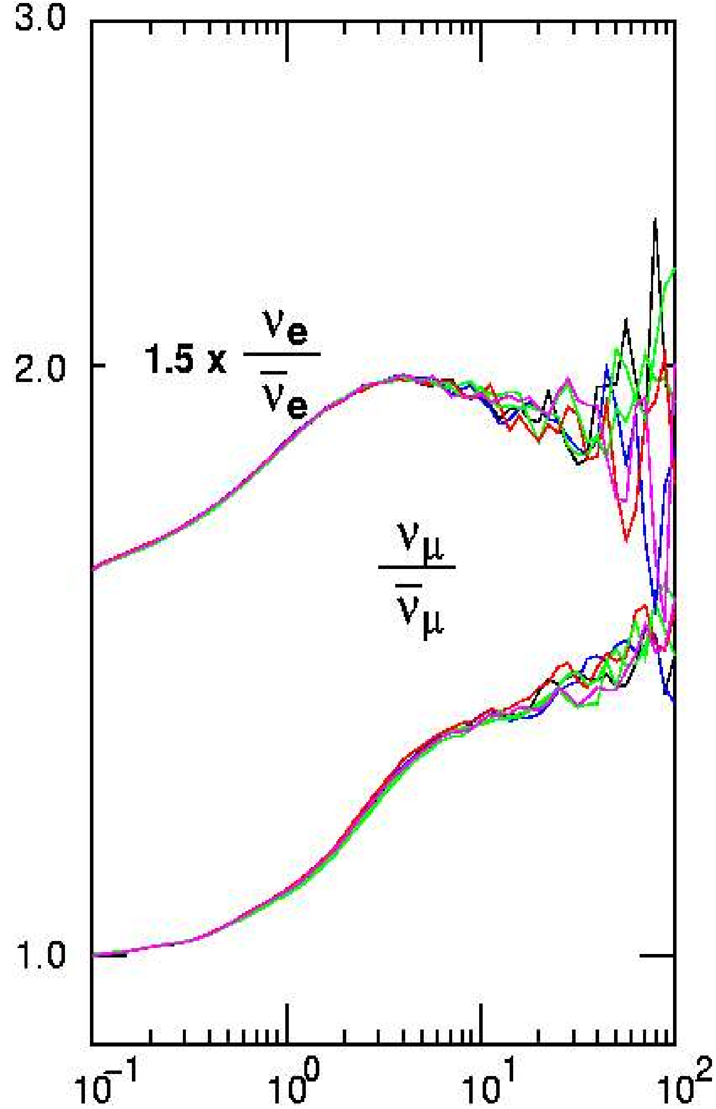
Interaction model before modification gives the largest difference. However, the atmosphere movel variation also give the similarly large difference for ν_e.

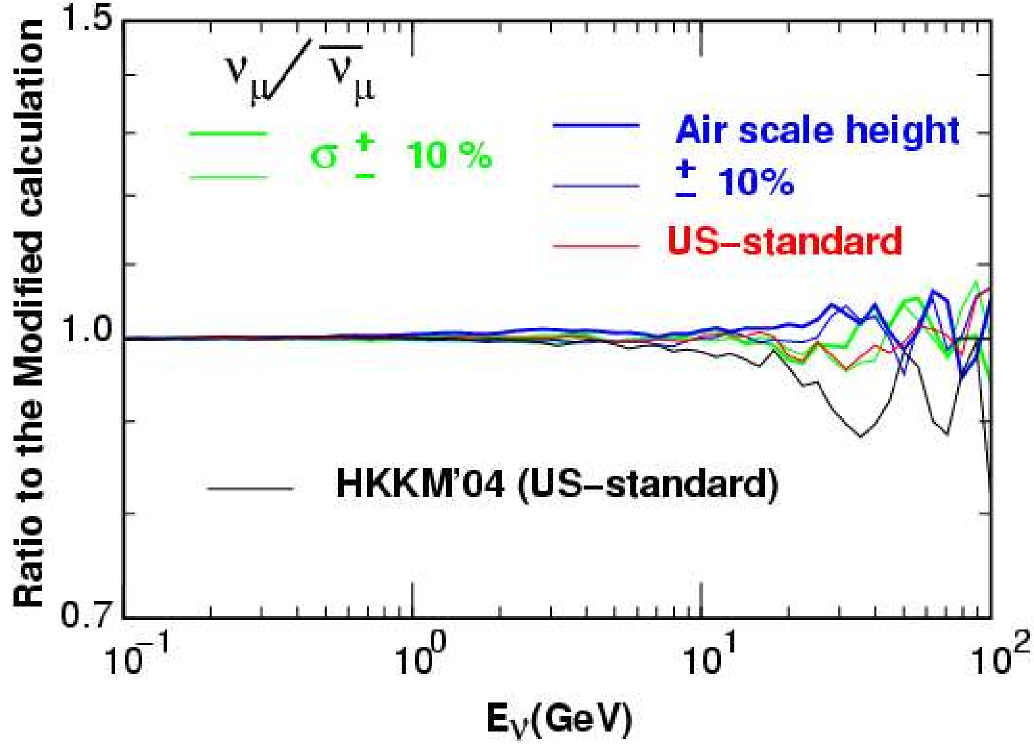
Neutrino Ratios I

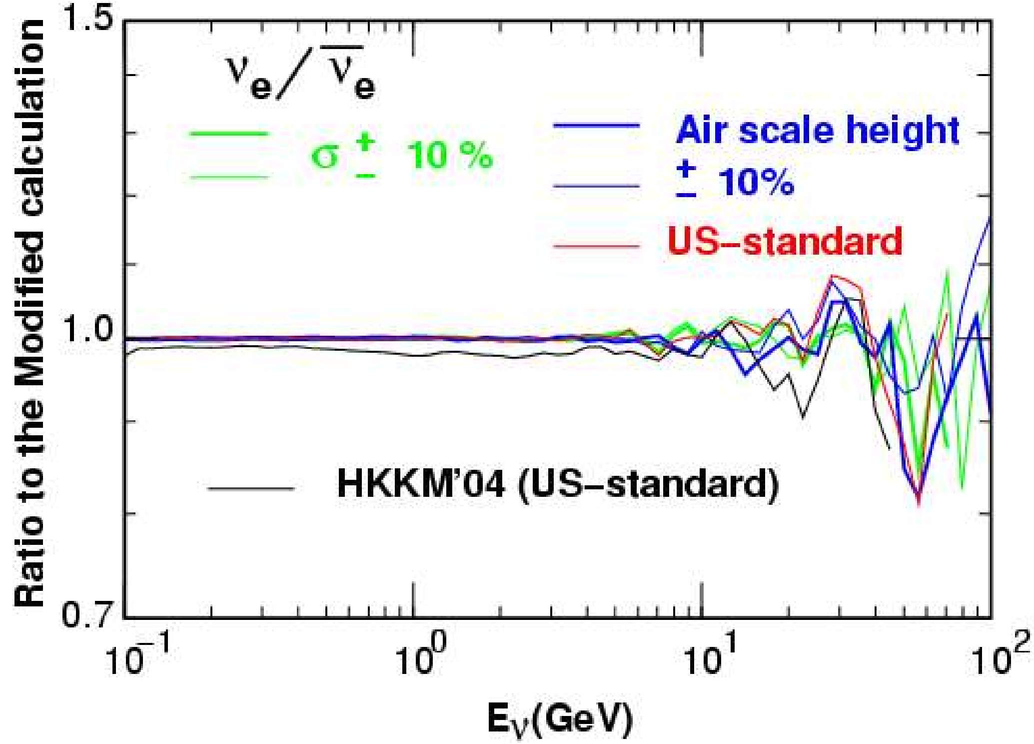




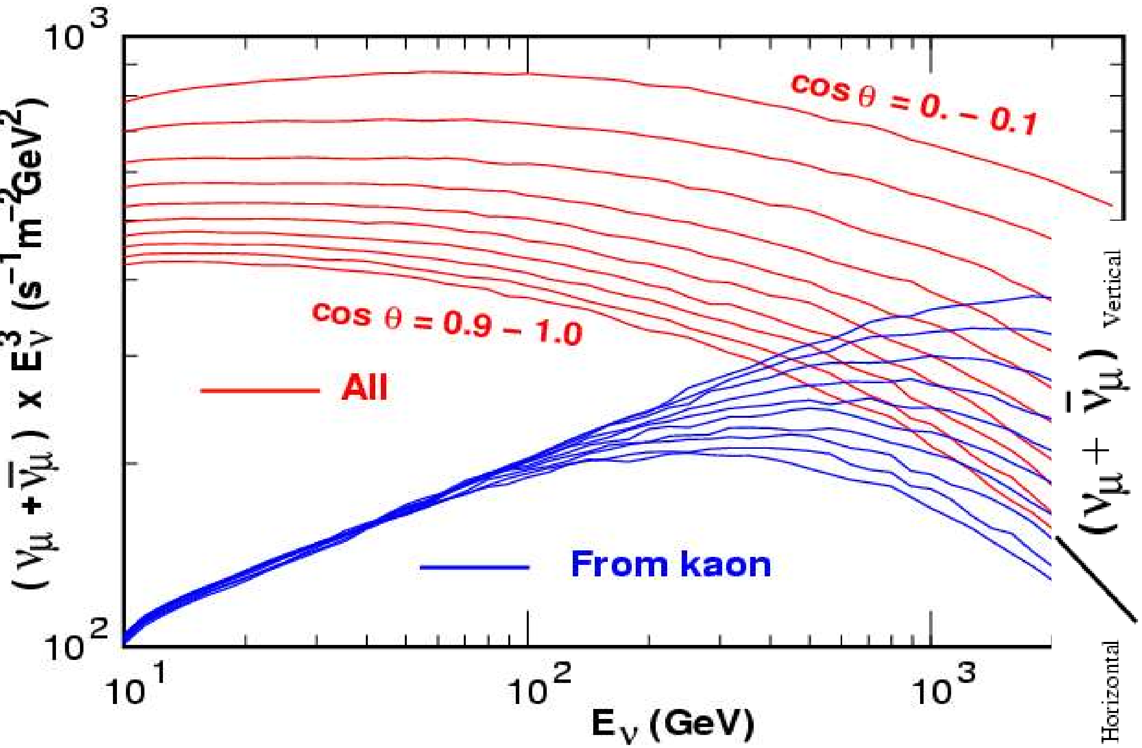
Neutrino Ratio II

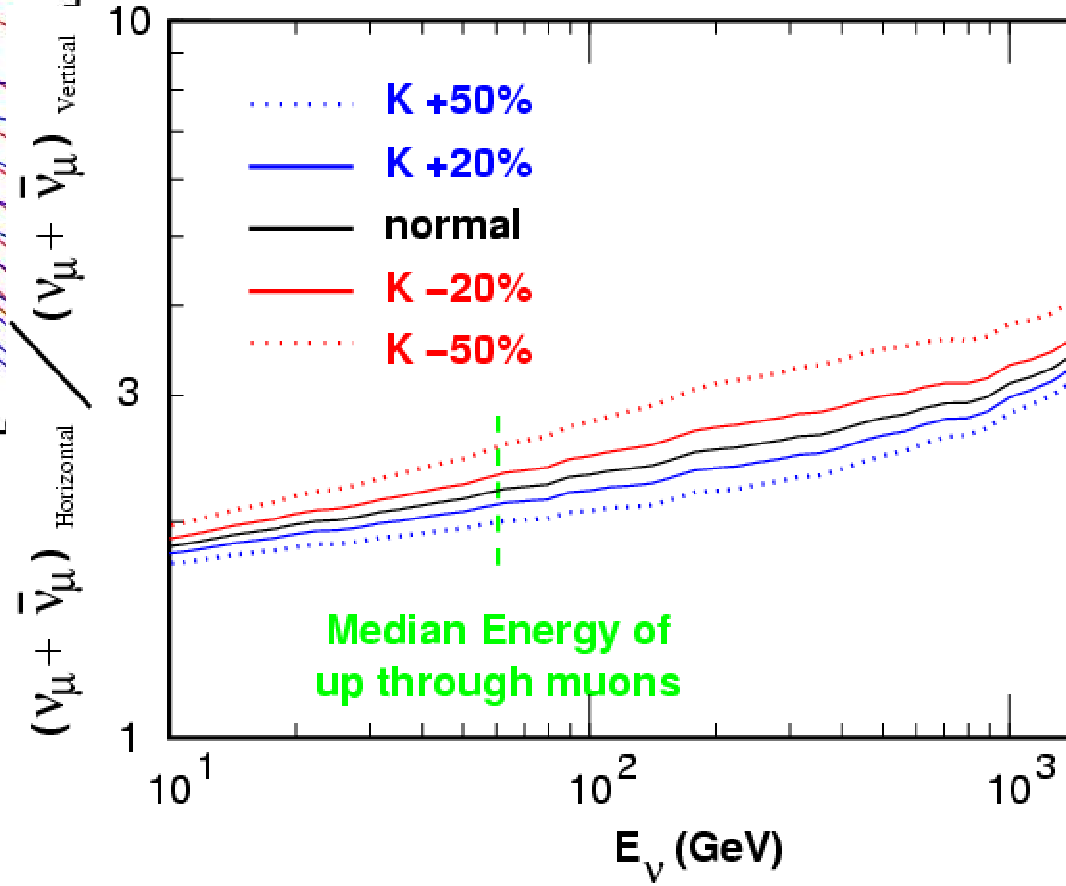






K/π ratio and zenith angle dependence of neutrino flux





Summary

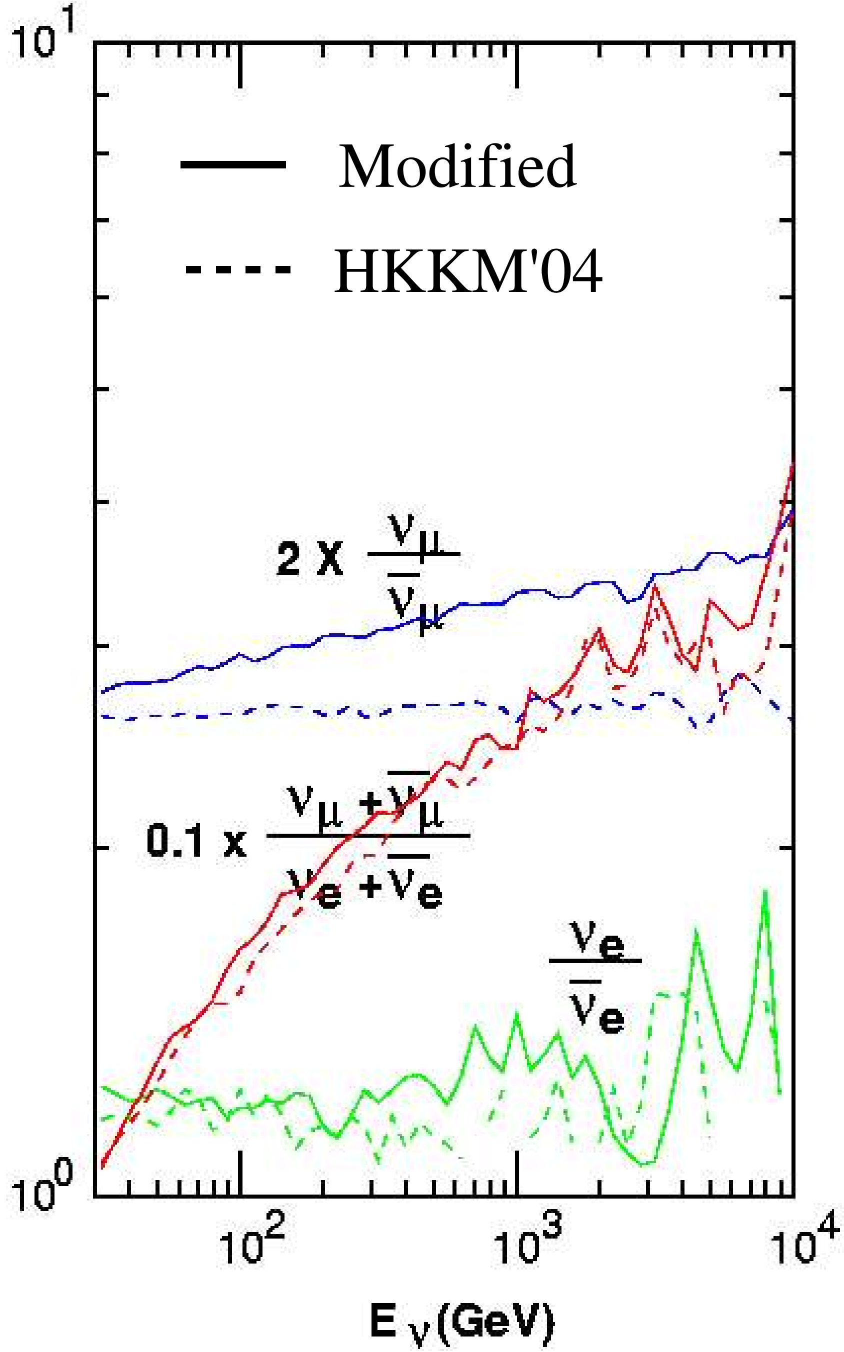
- The Modified DPMJET-III can reproduce the muon flux for a wider muon momentum range (1~1000GeV) in a good accuracy.

- However, to reproduce the muon flux in a good accuracy, it is important to use proper calculation conditions.

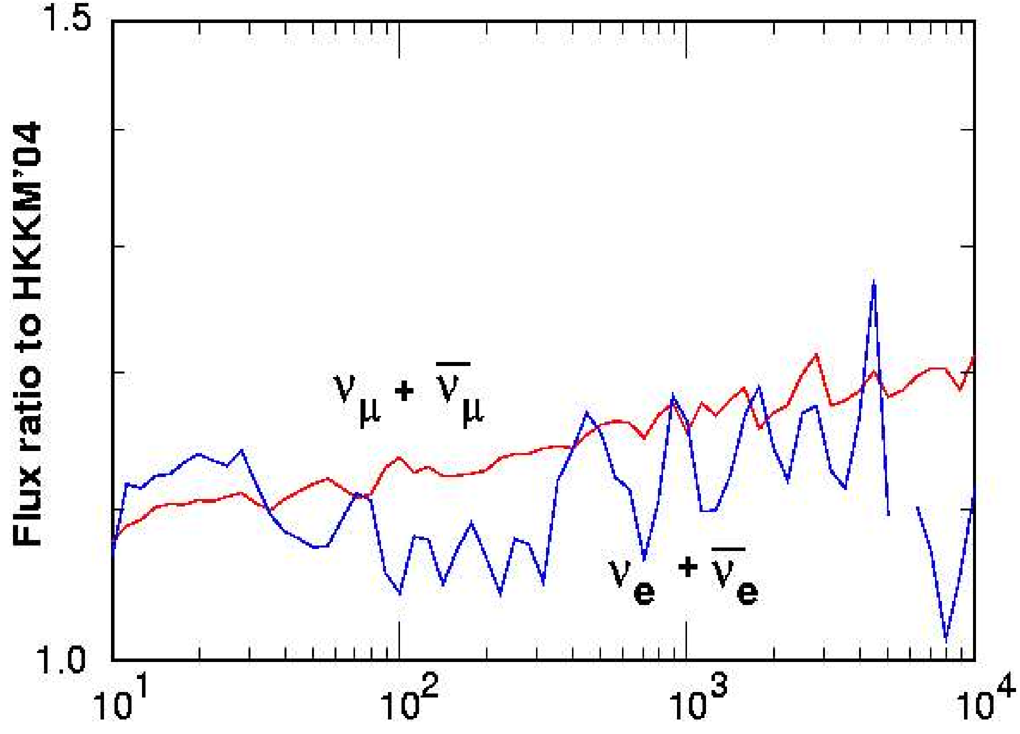
- On the other hand, the possible errors for the atmospheric neutrino flux due to ill calculation conditions is less that of atmospheric muon flux, and is estimated as 2~3 % for muon neutrinos and 3~5 % electron nuetrino absolute values. For the ratio of neutrino flavors, it is estimated much smaller.

- However, the uncertaintiy of the first kind source of systematic error introduce 5~10 % additional errors to the absolute value, and 2~3 % errors to the flavor ratios below 10 GeV. Above this energy, the errors introduced by the first kind uncertainty are much larger than these.

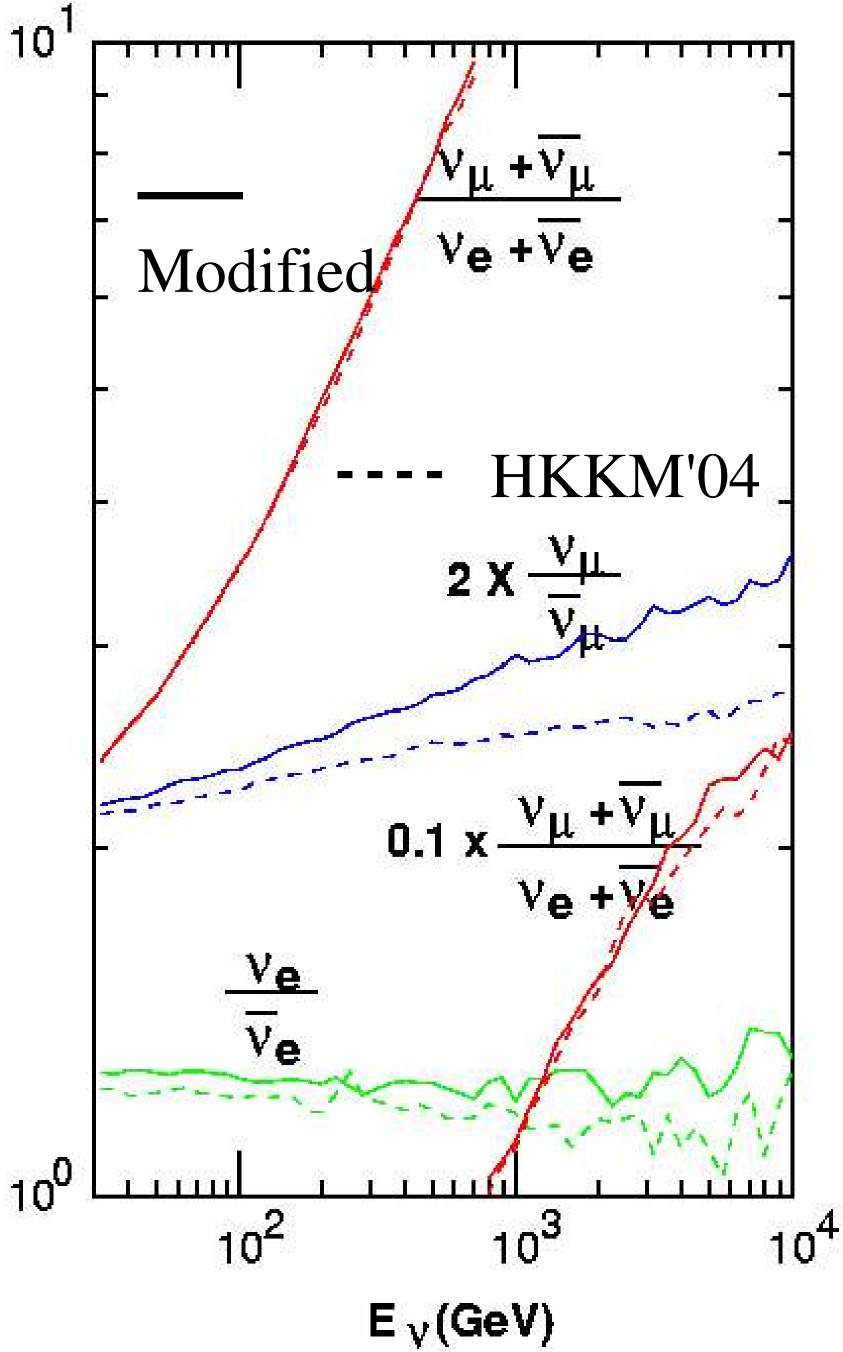
Change of High energy neutrino flux by the modification



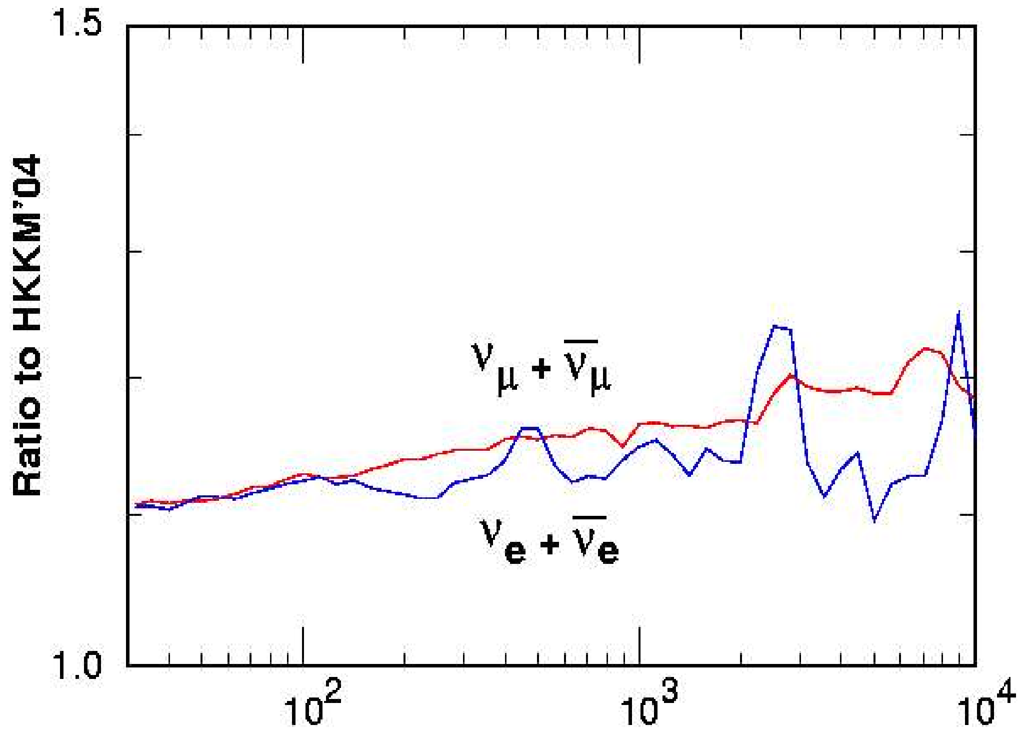
Vertical direction



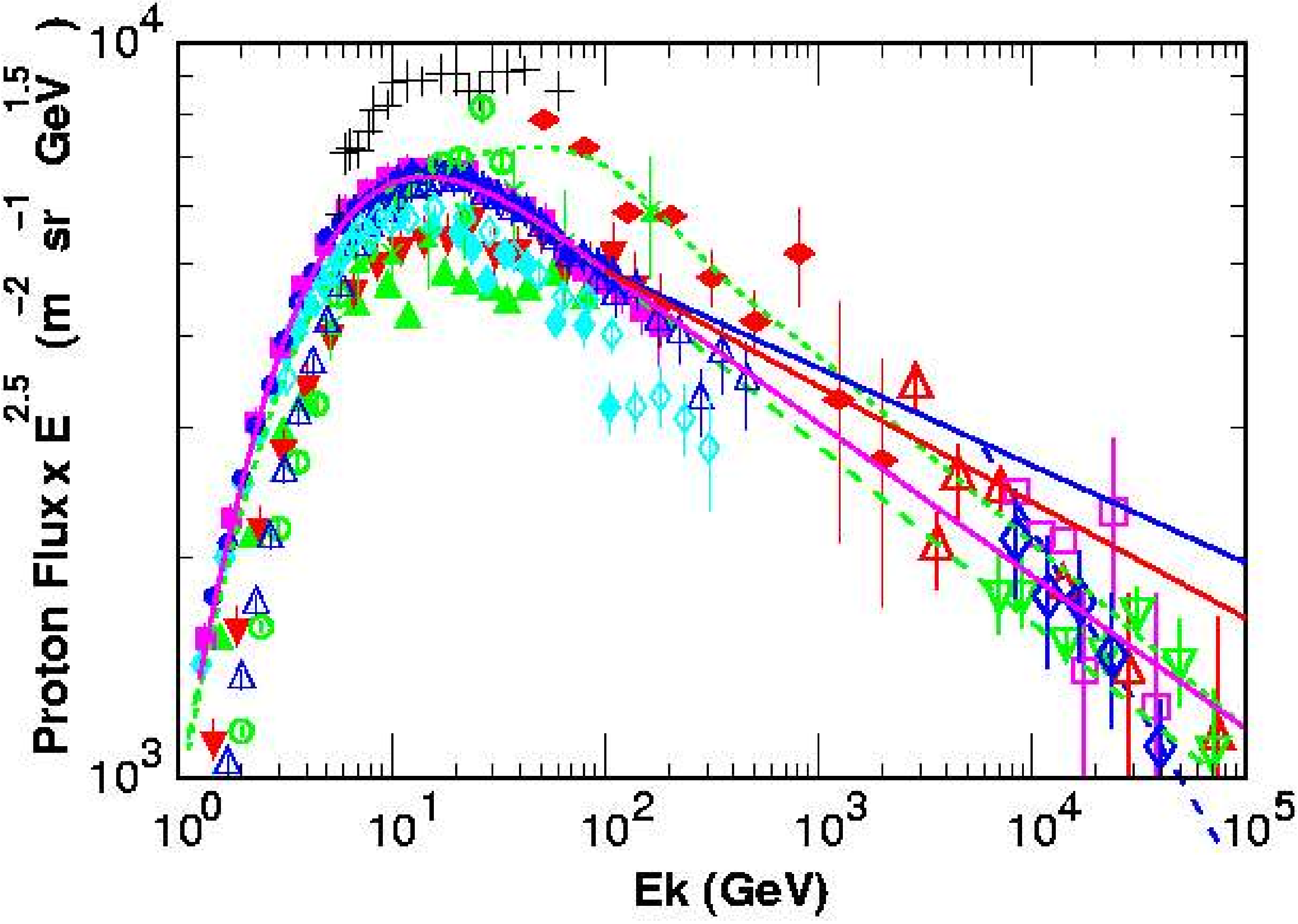
Change of High energy neutrino flux by the modification



Vertical direction



Alternative solution: modify primary flux



Anyway, hadronic interaction model should be modified, because of the muon charge ratio