Atmospheric muon flux at various locations

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Outline

1. Data and possible source of systematic error
   1. Near top of the Atmosphere

      5 - 30 g/cm^2
   2. Inside the Atmosphere

      5 - 800 g/cm^2
   3. On the ground

      800 - 1000 g/cm^2

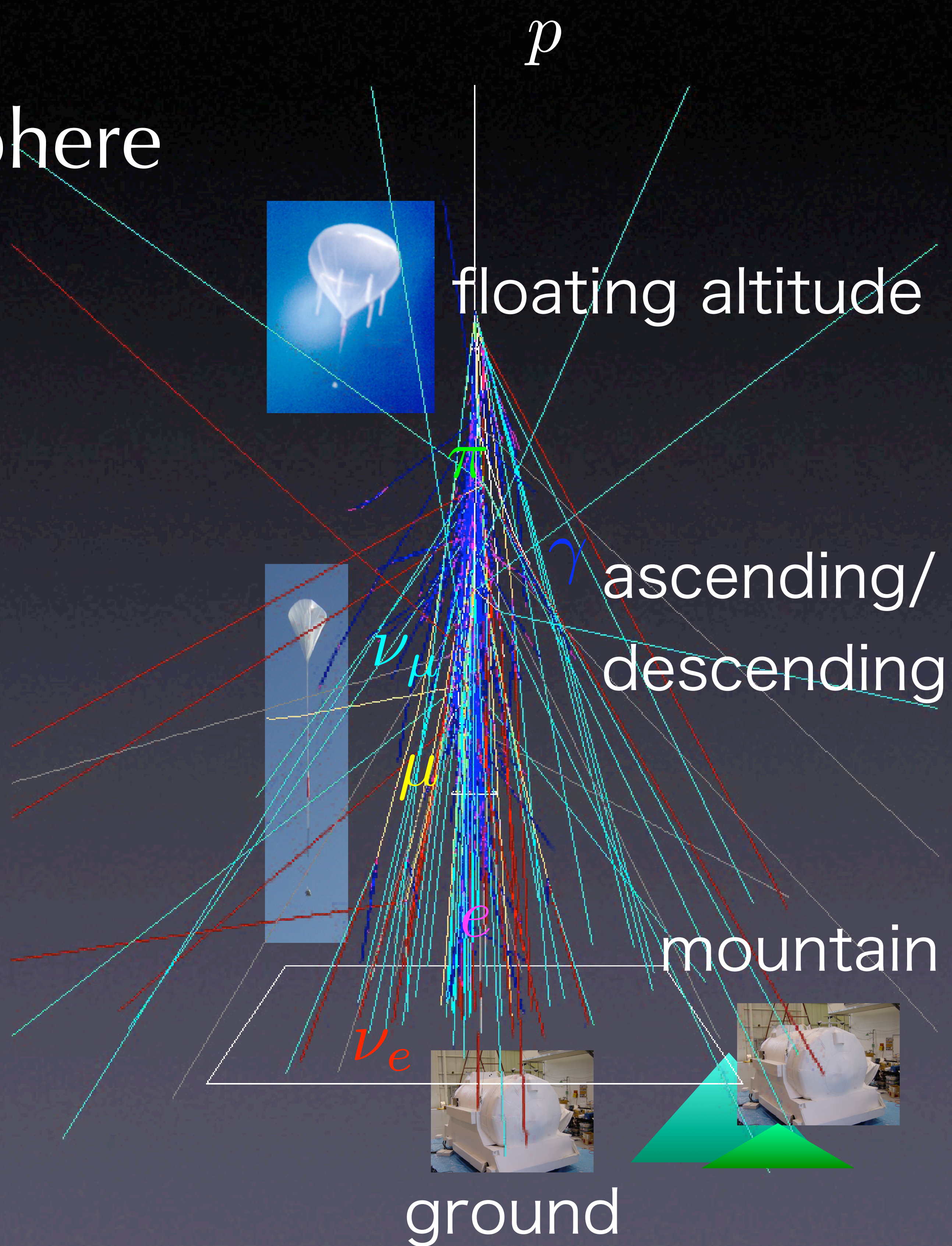
2. Observed and calculated muon spectra

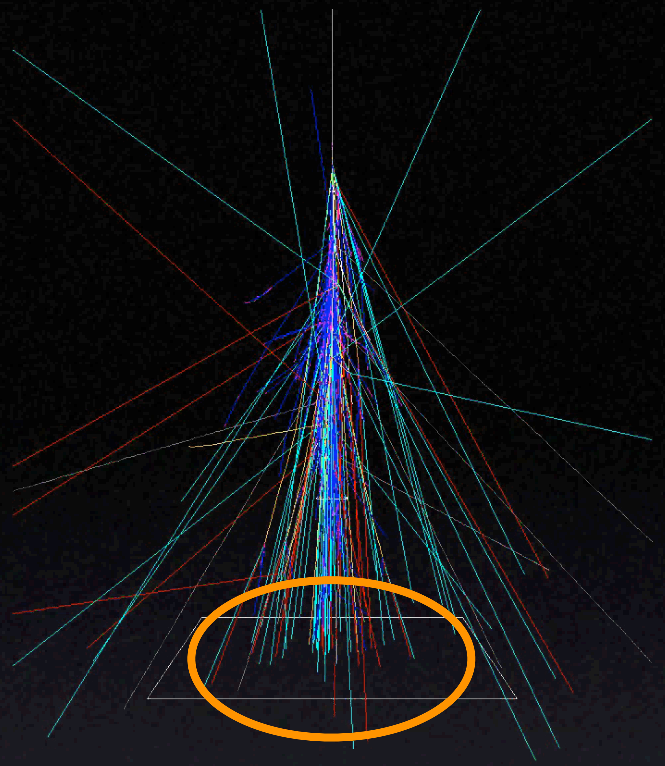
Atm. muon & neutrino

1. Near top of the Atmosphere
   5 - 30 g/cm^2
   balloon floating altitude

2. Inside the Atmosphere
   5 - 800 g/cm^2
   balloon as(des)cending

3. On the ground
   800 - 1000 g/cm^2
   ground/mountain





On the ground

800 - 1000 g/cm^2

On the ground

✓ high statistics

- infinite data taking time
- infinite batteries

calibrating atm. ν calculation (M.C. simulation)

On the ground

- Various measurement
- Two types of measurement

  a. Normalized

  b. NOT Normalized (Absolute)

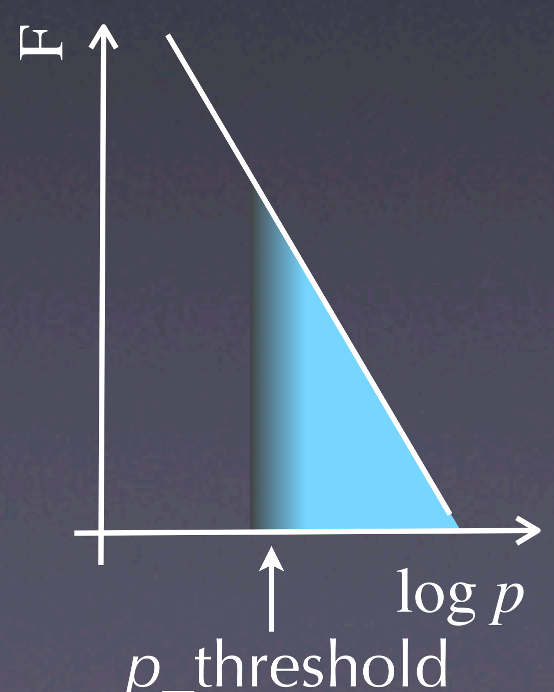
Normalized Flux

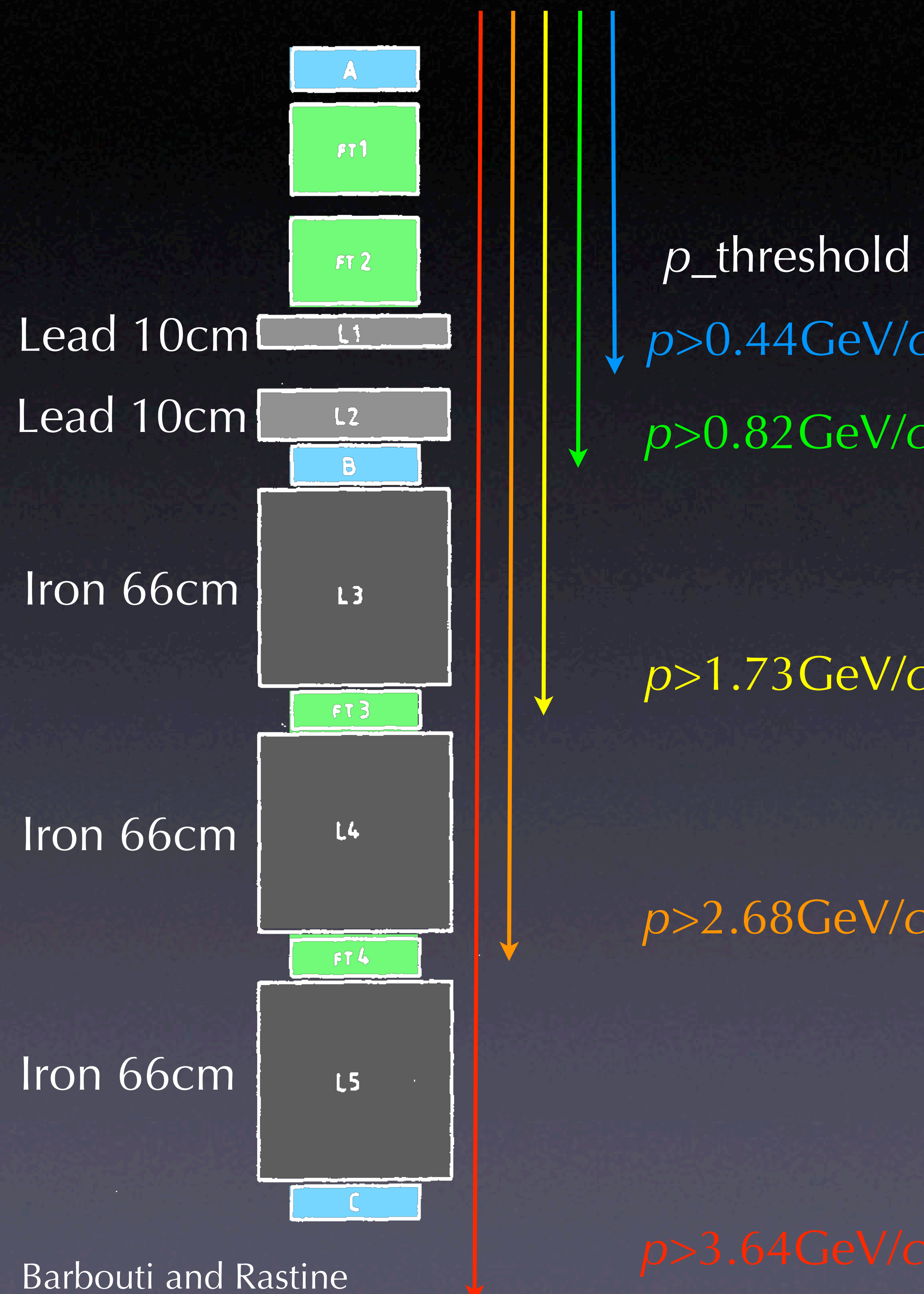
1. Measure spectrum shape (not absolute intensity)
2. Calculate integrated flux above some momentum
3. Normalize the measured spectrum to a "standard" integral intensity

“Standard” Flux

Range Counter

- Not measure momentum event by event
- Poor momentum resolution
- Mult. scatt. etc.





Barbouti and Rastine
J. Phys. G 9(1983) 1577

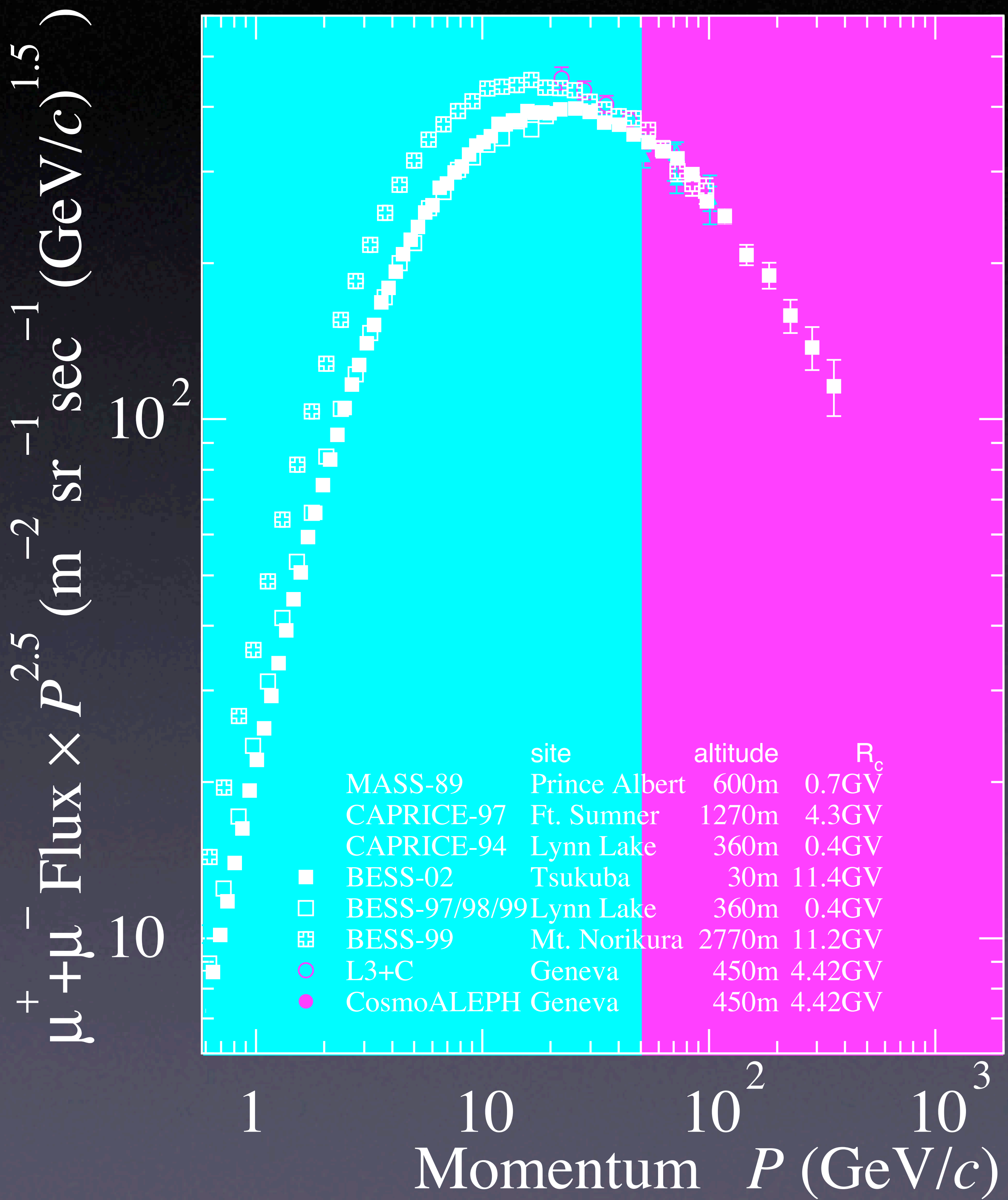
Normalized Flux

1. Poor statistics in higher momentum region
2. Same systematic error.

Absolute Flux Measurement is important

$$F(p) = \frac{N(p \sim p+\Delta p)}{\varepsilon(p) \cdot S\Omega(p) t \cdot \Delta p}$$

Absolute Flux



Primary CR Spectra

+ Hadronic Interaction

+ Decay

Production height
Altitude
Zenith angle

Different experimental condition

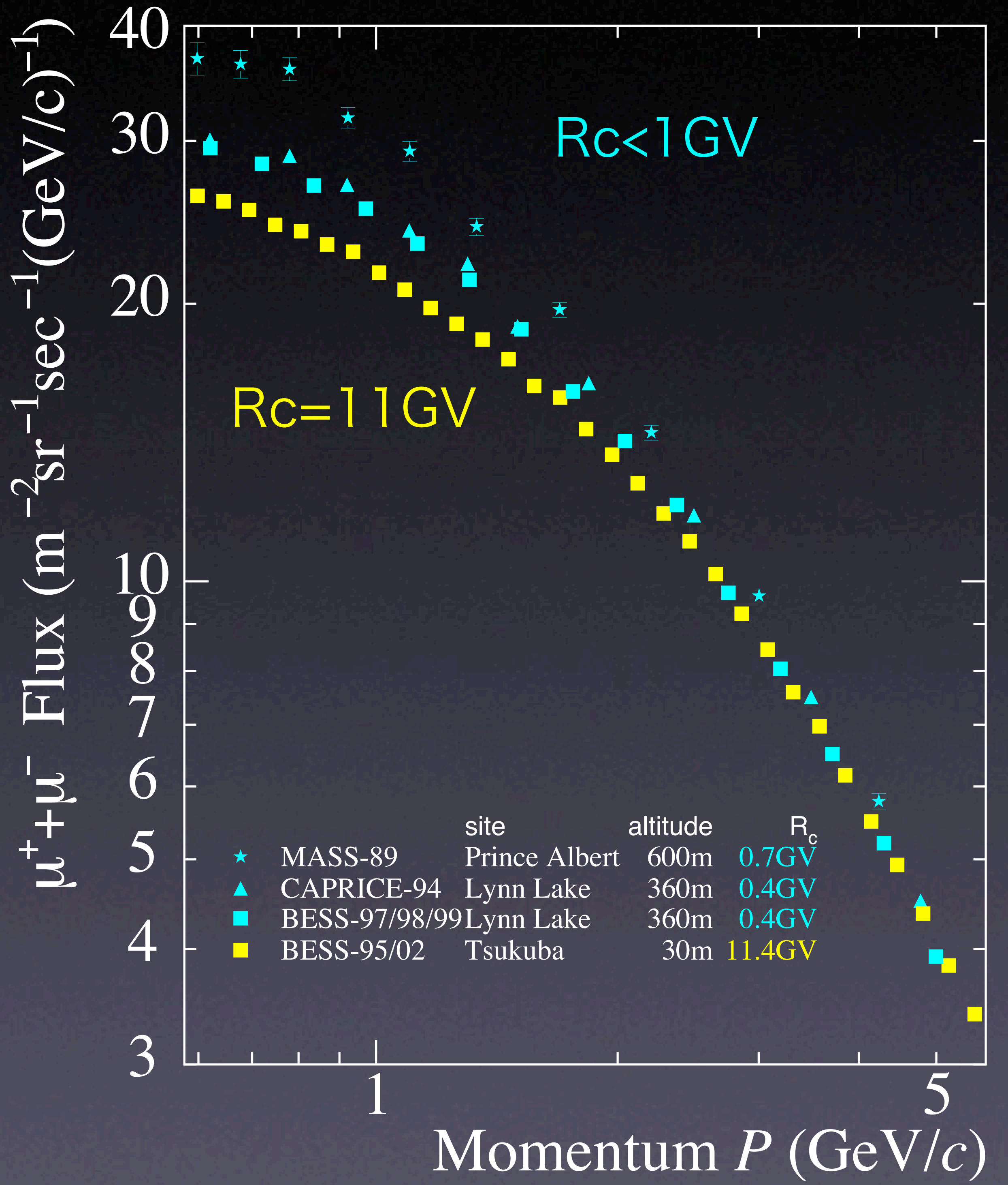
Different Condition

- Altitude
- Atmospheric Structure; $\rho(h)$
- Zenith Angle
- Geomagnetic Cutoff Rigidity
- (Solar Modulation)

BESS Data summary

site	cutoff Rigidity	atm. pressure	date
Tsukuba Japan	11.4 GV	1030 g/cm^2	Dec. 95
			May. 97
			Nov. 97
			Oct. 02
Mt. Norikura	11.2 GV	740 g/cm^2	Sep. 99
Ft. Sumner NM, USA	4.3 GV	890 g/cm^2	Sep. 01
		800 to 5 g/cm^2	Sep. 01
		5 to 30 g/cm^2	
Lynn Lake MB, Canada	0.4 GV	1000 g/cm^2	Jul. 97
			Jul. 98
			Jul. 99
			Jul. 00
		800 to 5 g/cm^2	Aug. 99
			Aug. 00

Geomagnetic Field

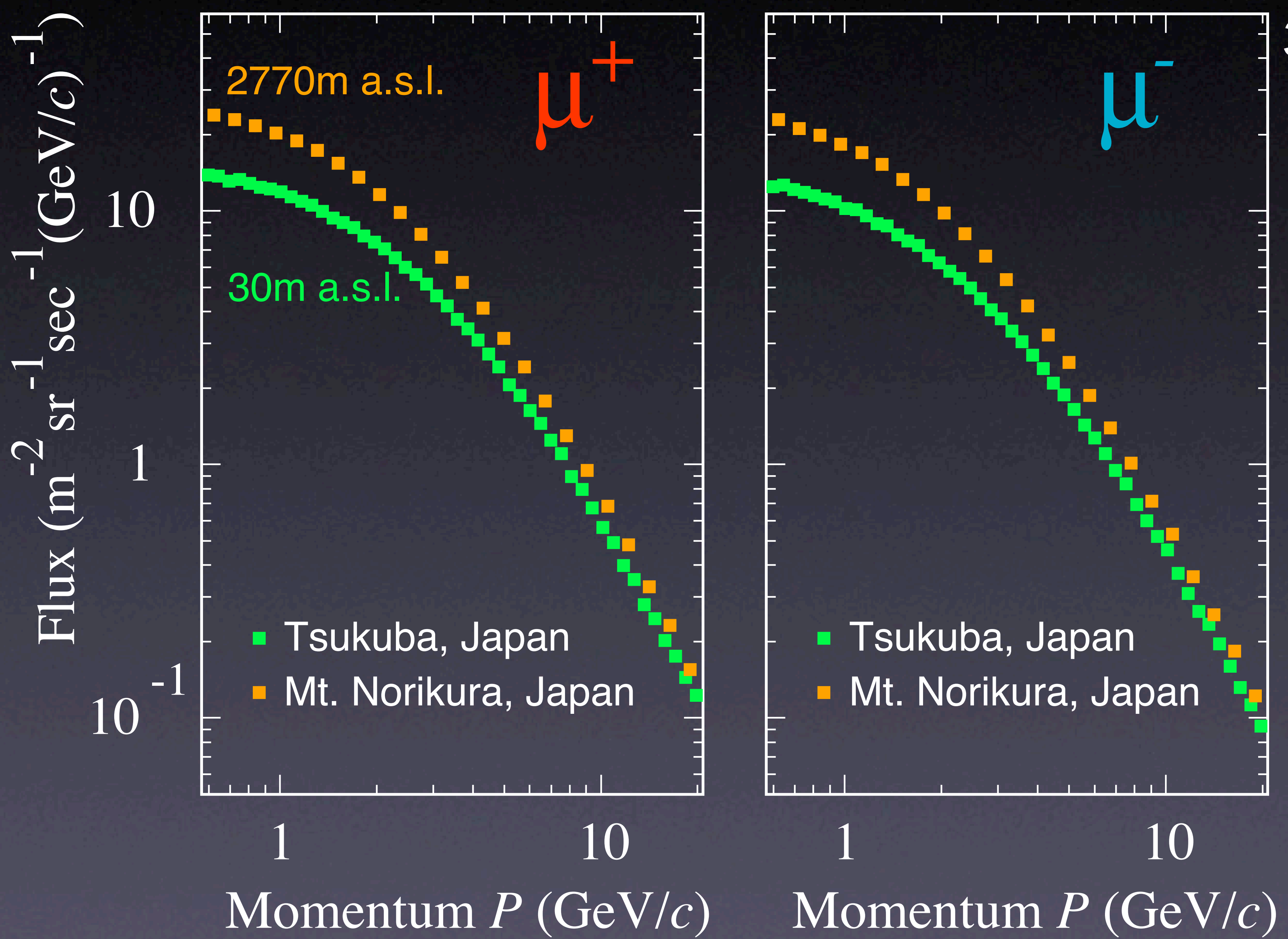


10% effect
@1GeV/c

Altitude correction is important, but...

Altitude

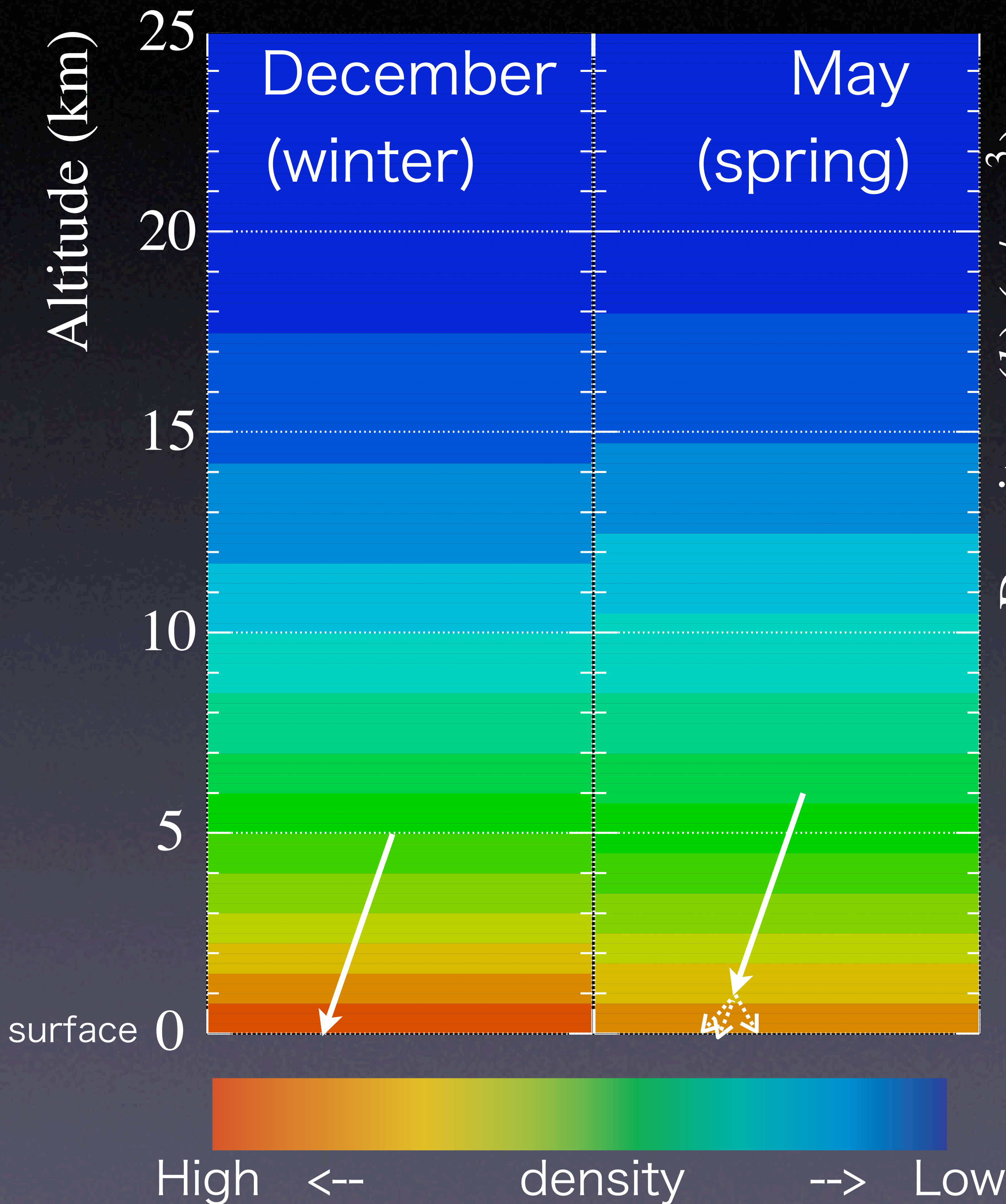
ex) BESS; Almost same condition except for altitude

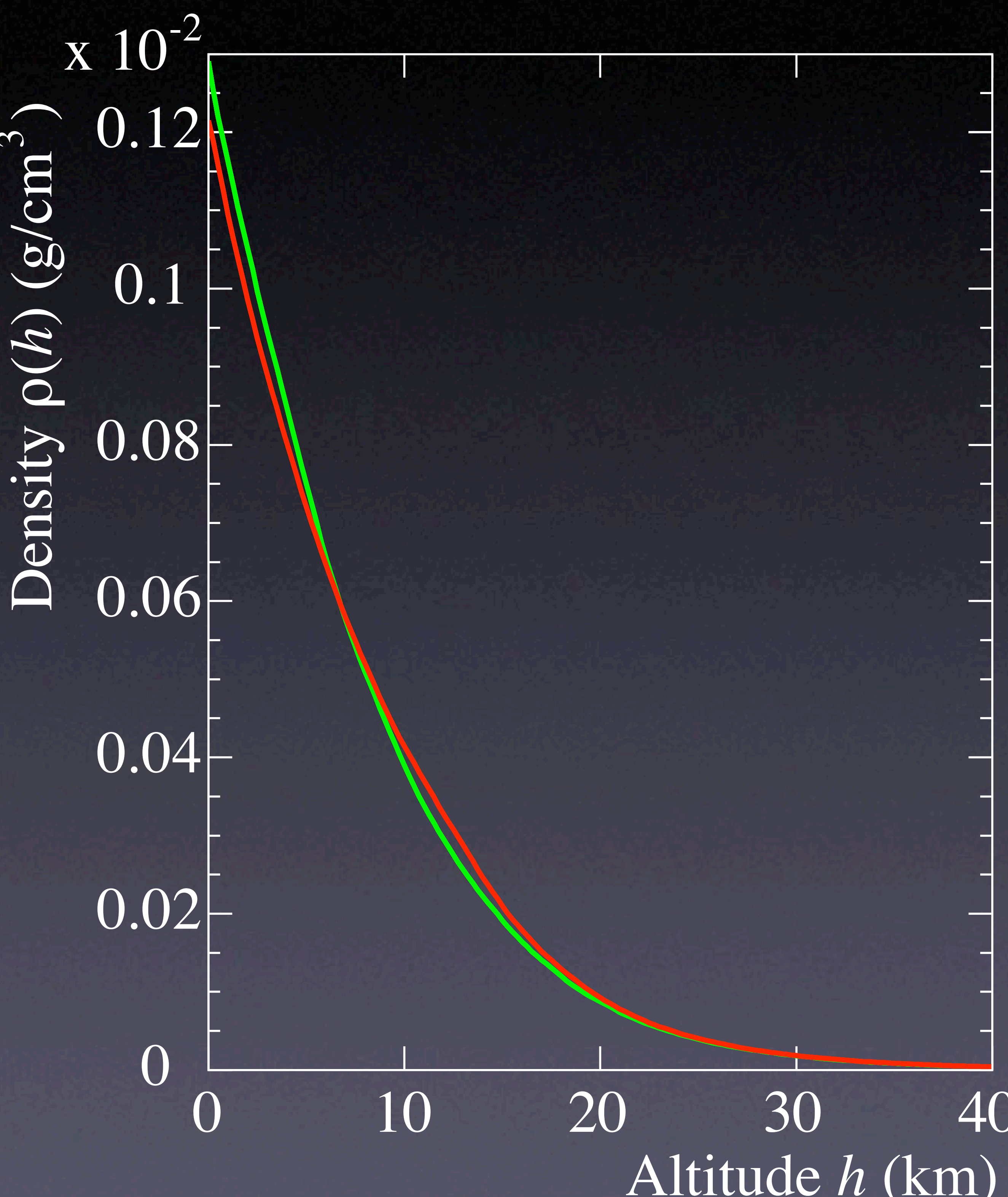


30~40% effect @1GeV/c

Huge effect on flux in low momentum region

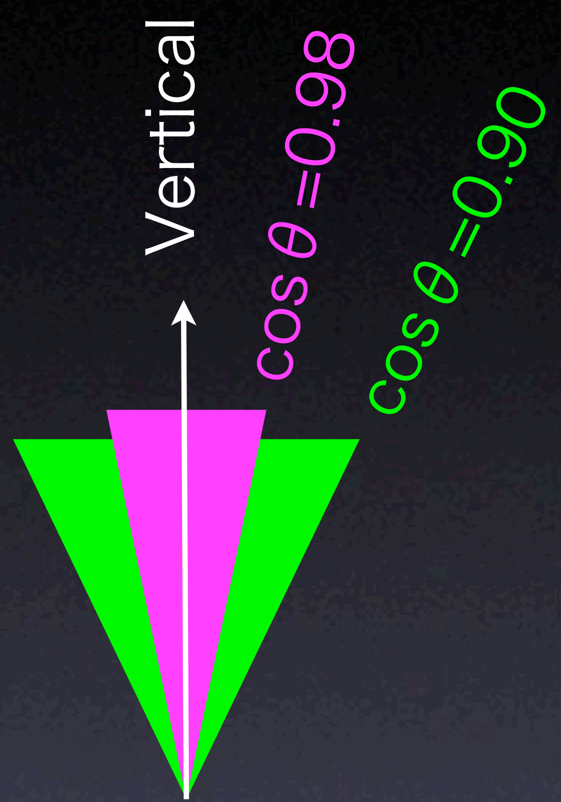
Seasonal variation in muon

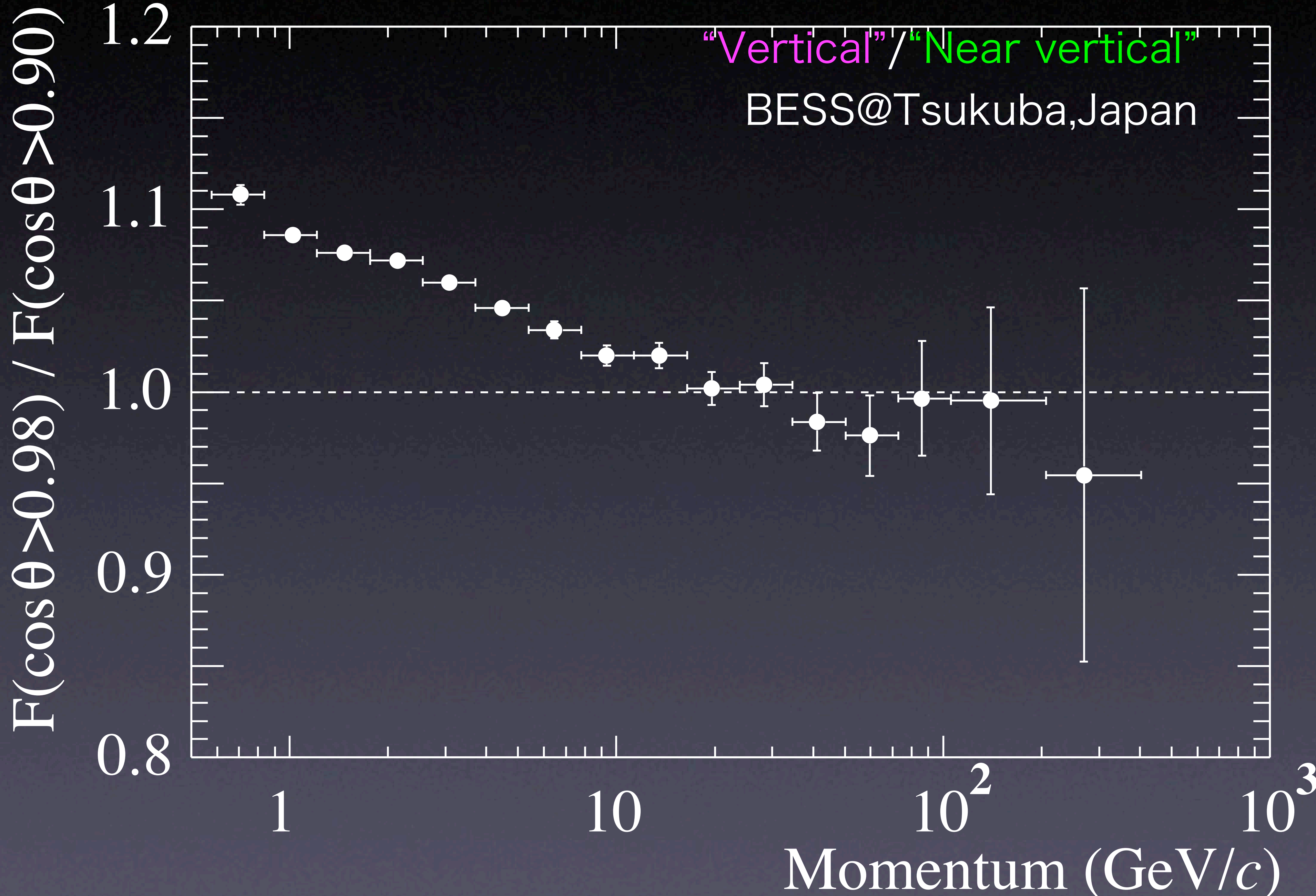




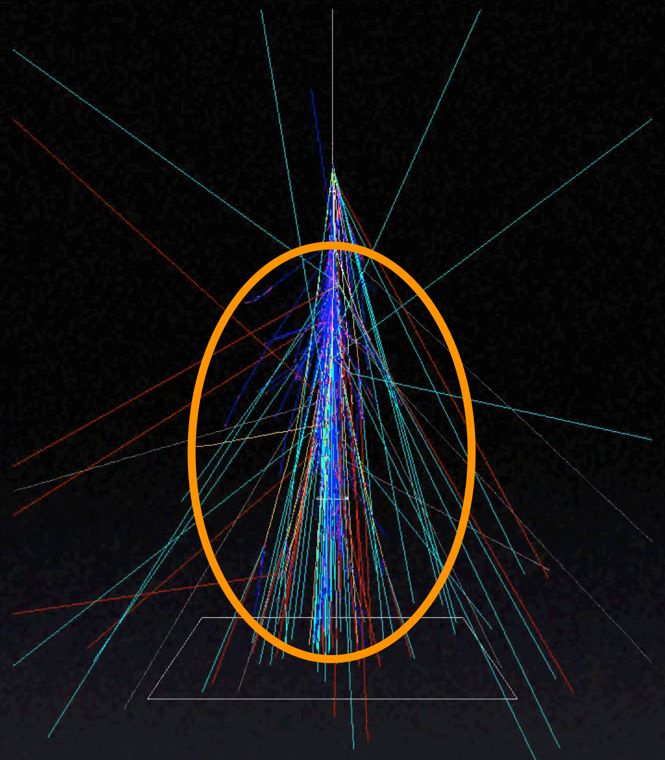
Zenith Angle

ex) BESS; Same condition except for zenith angle





Experimental/Analysis condition should be considered



Inside the Atmosphere

5 - 800 g/cm^2

Balloon ascending period

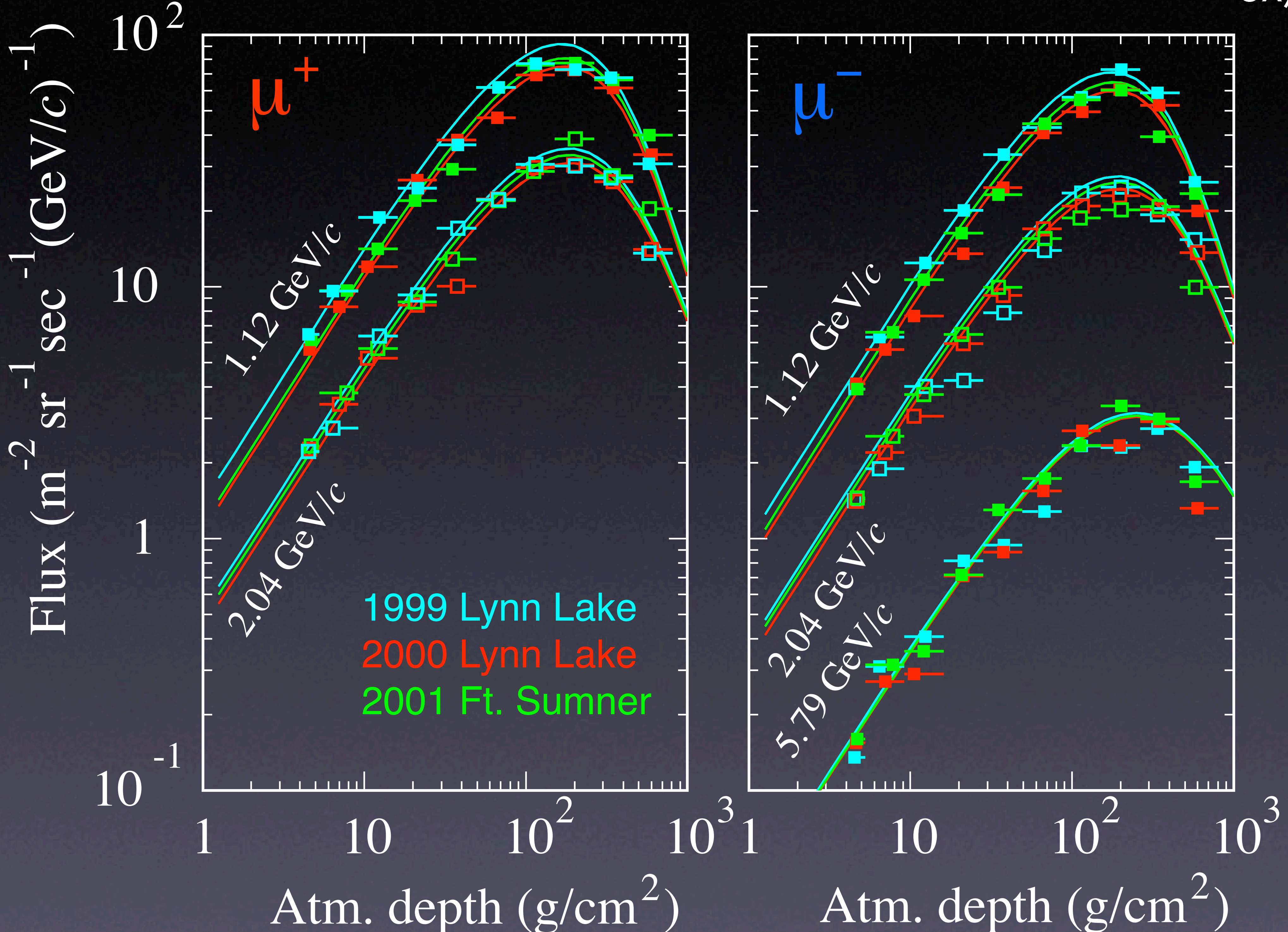
- ✓ Flux vs Residual Atmospheric depth
- ✓ growth curve ~5 - 800 g/cm^2

$$
\begin{aligned}
p + A &\longrightarrow \pi + \pi + \cdots \\
\pi &\longrightarrow \mu + \nu_\mu \\
\mu &\longrightarrow e + \nu_e + \nu_\mu
\end{aligned}
$$

Indirect measurement of atm. ν production

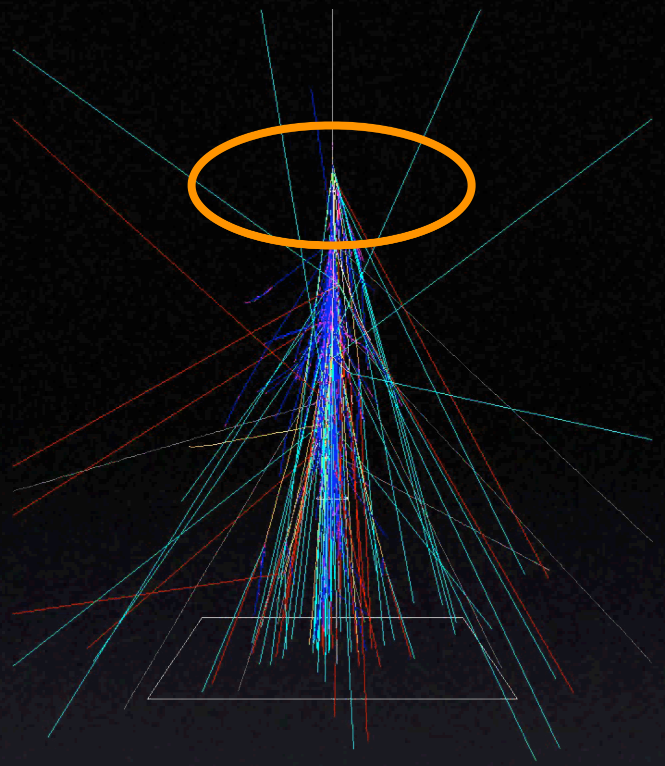
Growth curve

ex) BESS



Y. Yamamoto

Poor statistics



Near
Top of the Atmosphere

5 - 30 g/cm^2

Balloon altitude

✓ Thin target ~5 - 30 g/cm^2 < 100g/cm^2

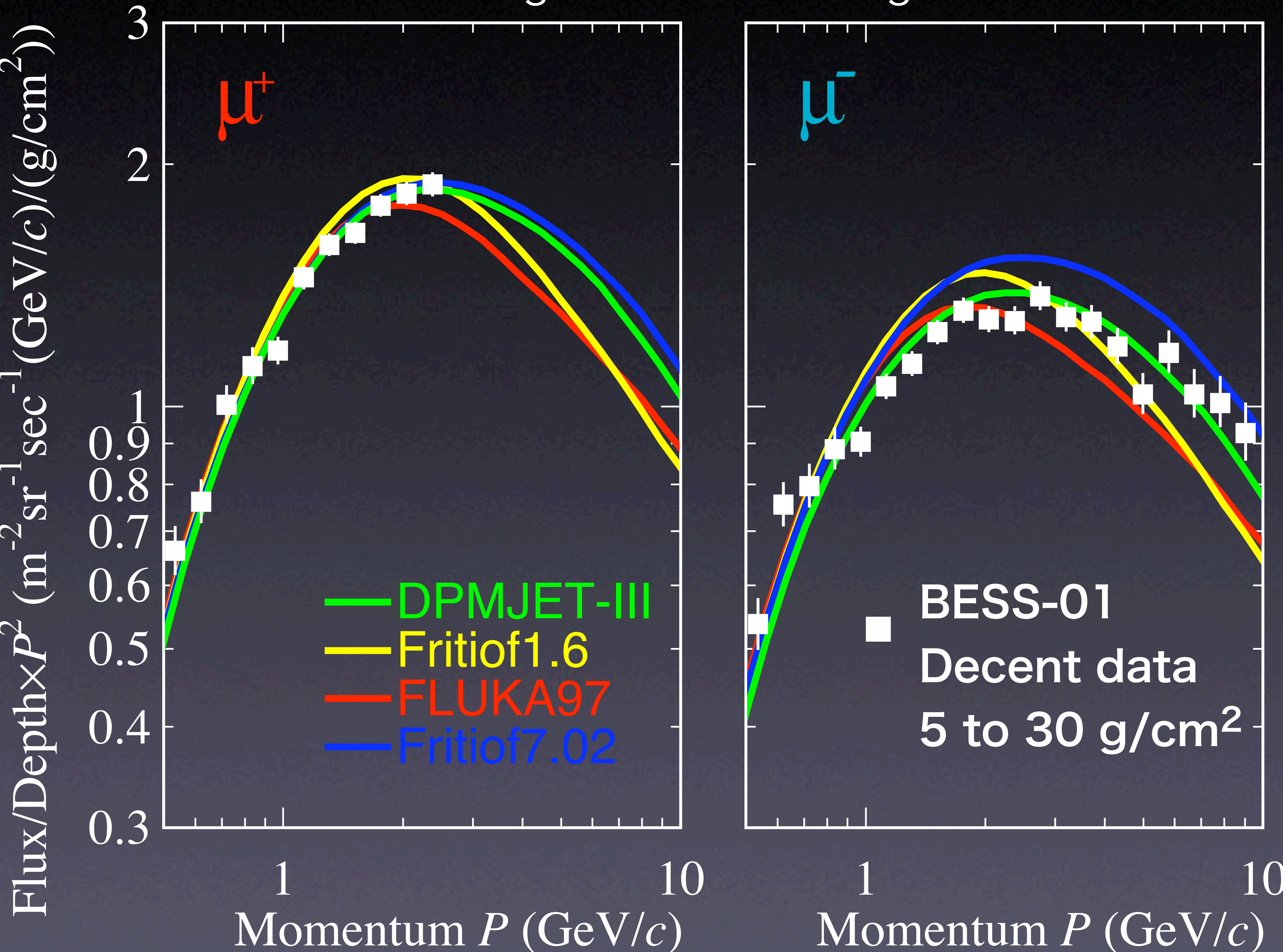
$$\begin{aligned} p + A &\rightarrow \pi + \pi + \cdots \\ \pi &\rightarrow \mu + \nu_\mu \\ \mu &\rightarrow e + \nu_e + \nu_\mu \end{aligned}$$

sensitive to <u>hadronic interaction</u> model

Balloon altitude

ex) BESS; Unique balloon flight at Ft. Sumner, NM, US.

Good statistics during slow descending.



Honda-san's talk...

Perfect MC ?

MC simulation

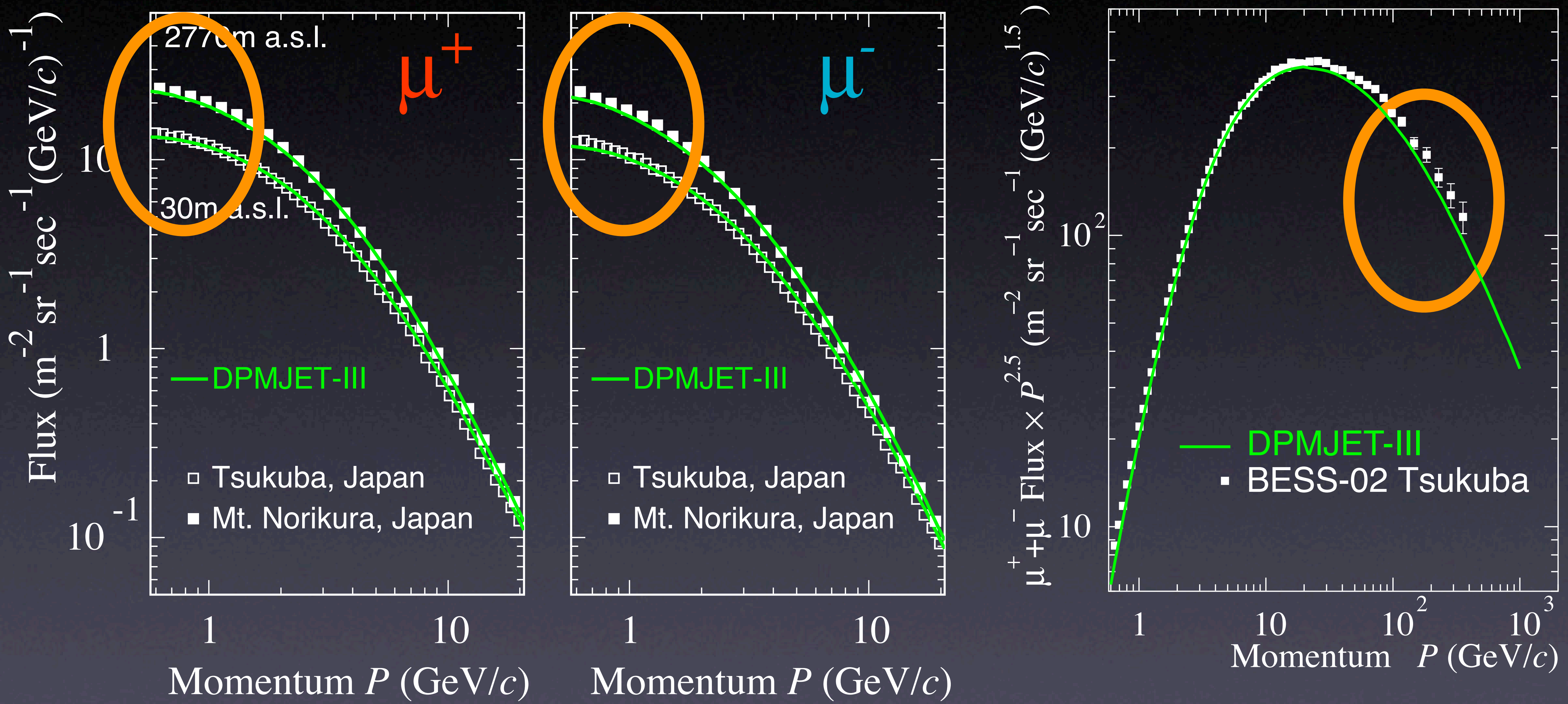
1. input spectrum
   - BESS data + power-law extrapolation
2. hadronic interaction
   - DPMJET-III - based

3. same condition as BESS observation
   - latitude and longitude (geomagnetic R_c)
   - altitude
   - date
     - observed $\rho(h)$ data + NRLMSISE-00 Model
     - solar modulation
   - zenith angle

M. Honda

http://nssdc.gsfc.nasa.gov/space/model/atmos/nrlmsise00.html

Not perfect ...



MC < DATA

Honda-san's talk...

Summary

- Many experiments at various locations
  - Site (Cutoff Rigidity, Altitude)
  - Date (Solar modulation, atm. structure)
  - Zenith angle
  - ***Huge effect on flux in low momentum region***
- Calculation under the same condition as experiment

  For controlling systematic error in neutrino calculation.