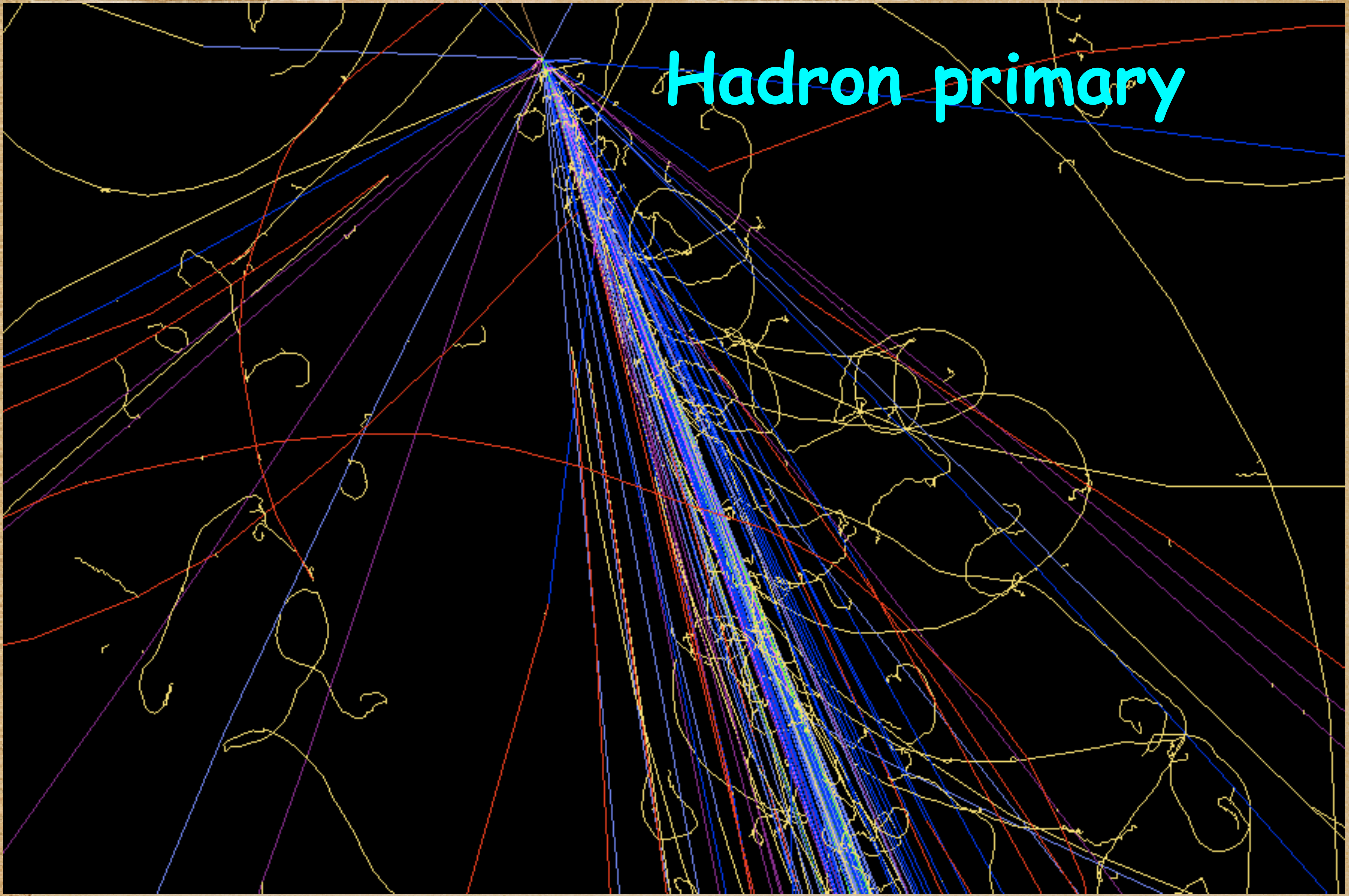

Hadron primary

Interaction models

Model	Energy(GeV)	Remarks
dpmjet3	<5<	charm. @UHE ?
qgsjetII-03	>80	
qgsjetII-04	>80	LHC-tuned
EPOS1.99	>80	
EPOS-LHC-3400	>80	LHC-tuned
EPOS-LHC-3700	>80	LHC-tuned, A>26 ok
Sibyll2.1	>80	only p, Air target
JAM	<RHIC	No heavy fragm. Pt seems small
PHITS	<2	JAEA code: neutron
Sofia	$> m\pi$	photo-hadron prod.
Fritiof1.6	<2000	
Nucrin	<5	
Gheisha	<100 ?	

- Sibyll2.3c   Sibill2.3d are now available
- New JAM   upto 10^20   CGC

How to specify the models:

IntModel = ‘“phits”   2 “ dpmjet3” 1e6 “epos” 1e8 “qgsjet”’

Why we can estimate E_0?

Property of air: $X_0 \sim \lambda_n$

Cf. Pb, W: $\lambda_n/X_0 \sim 30$

BGO: 20

- Propagation

$$\sigma_{in} \qquad f(x) = \frac{1}{\sigma_{in}}\frac{d\sigma}{dx} \qquad x \equiv E_s/E_0$$

- Spectrum Observation **Inclusive:** $\mu, \gamma, e, p, \nu, n$

$$\int \delta(E_\pi - xE_0) f(x) dx E_0^{-\gamma} dE_0 \longrightarrow x^{\gamma-1} f(x) dx$$

$$x_{eff} = \frac{< x^\gamma >}{< x^{\gamma-1} >} \sim 0.2$$

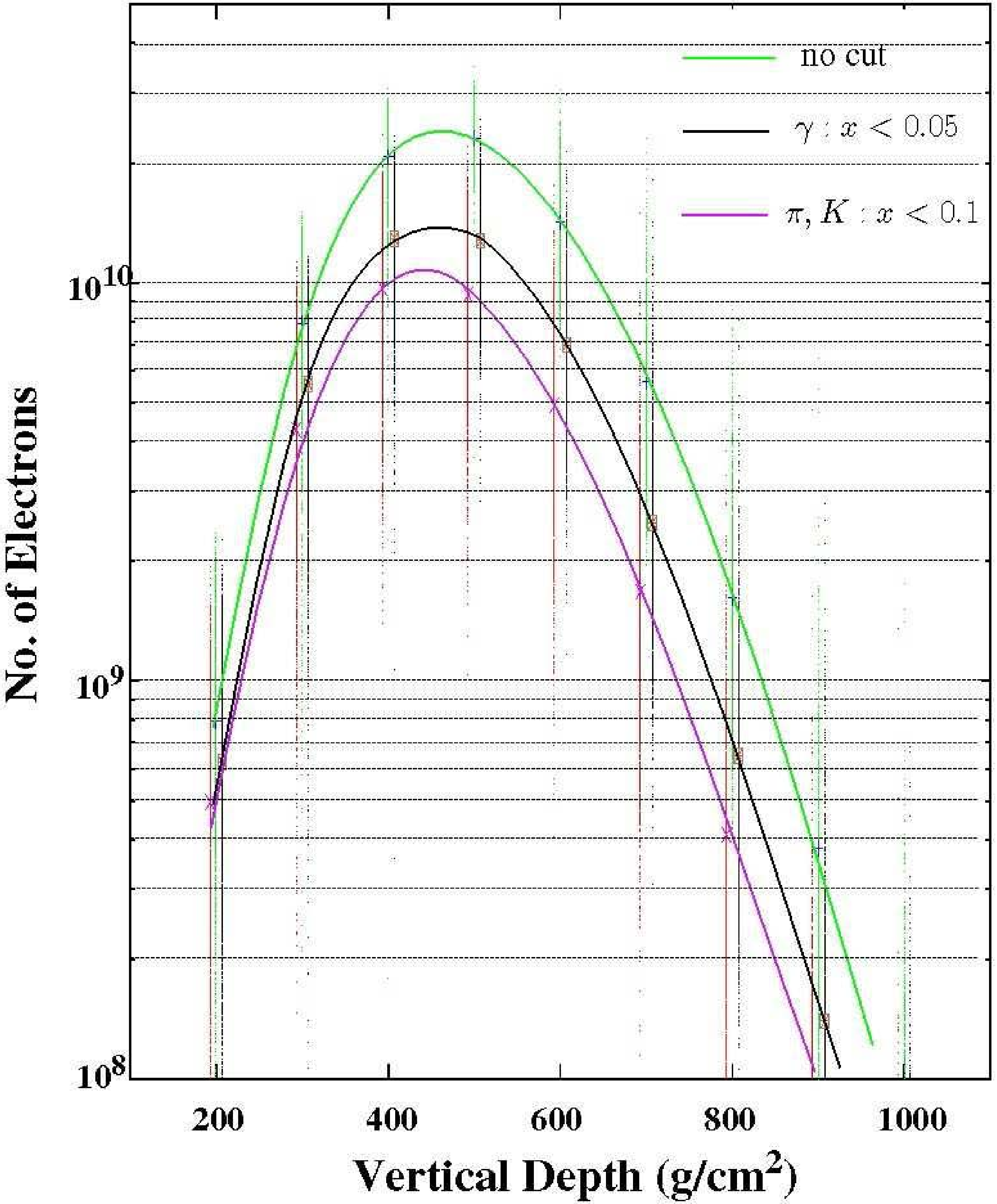
- AS Observation → N_e → N_μ

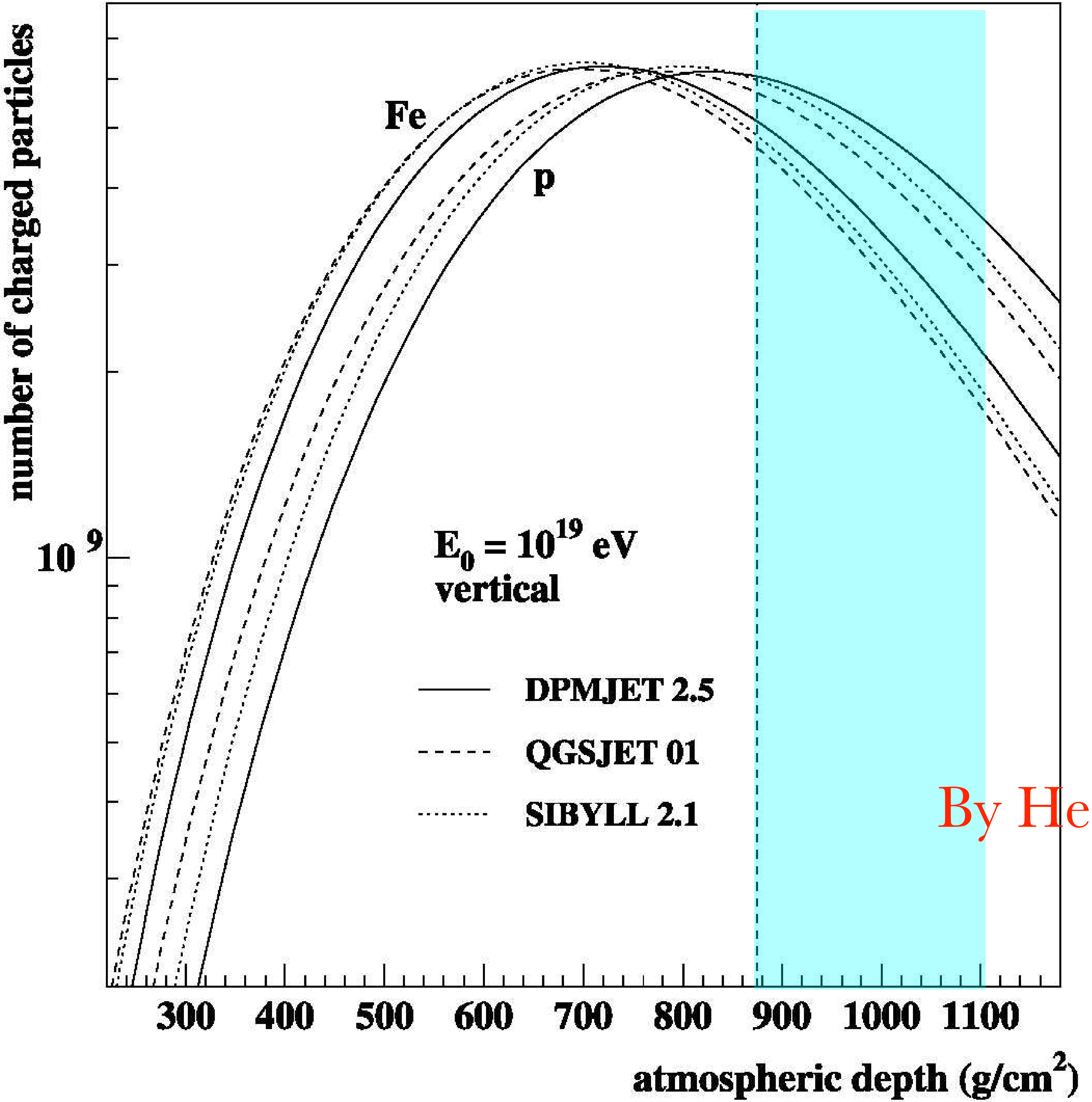
$$\int_{0.05} x f(x) dx \sim 50\%$$

- AS + Burst (or gamma ray family) (Tibet)

$5\text{x}10^{19}$ eV proton initiated showers

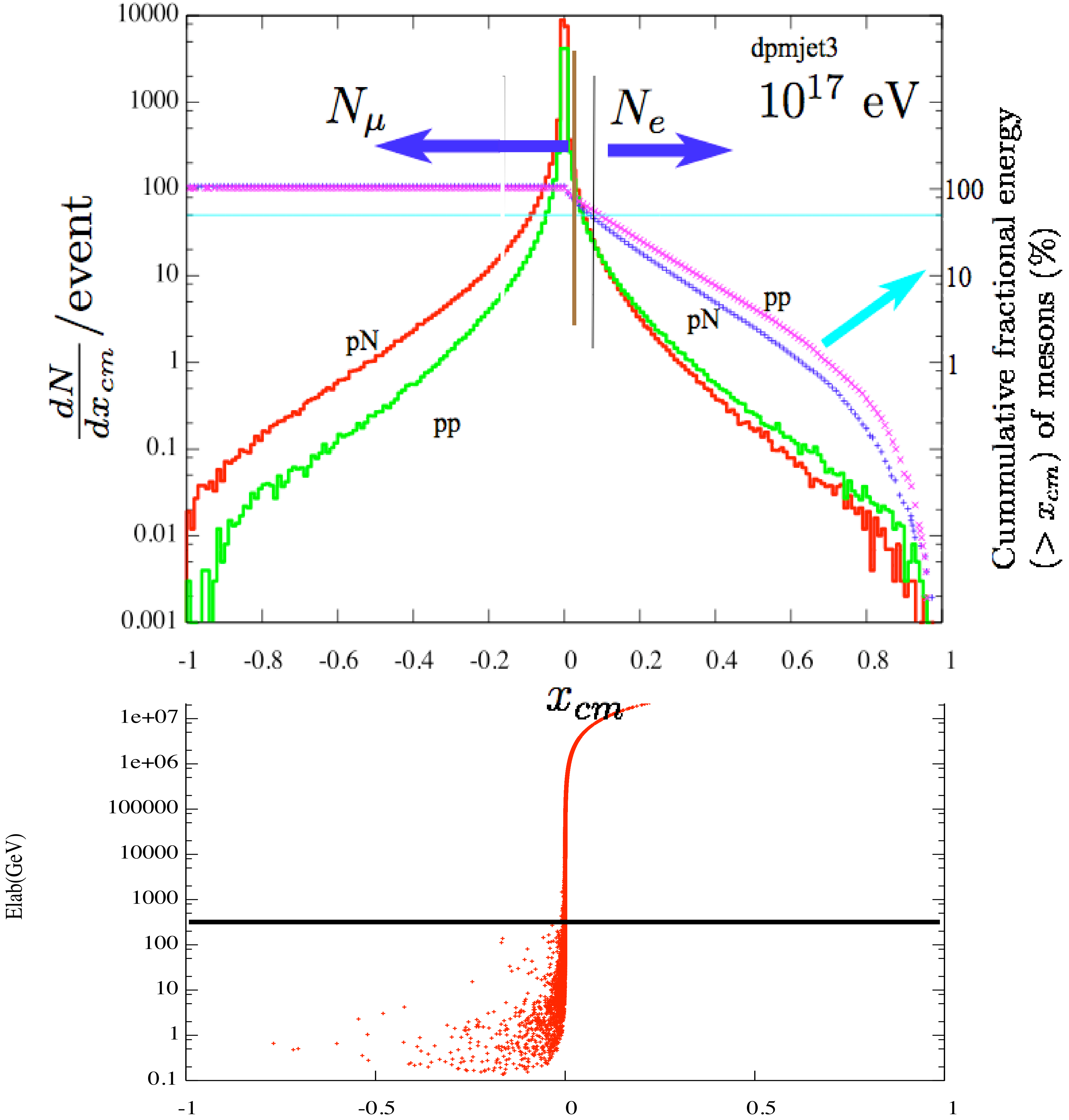
Zenith angle 60 deg.




number of charged particles
10^9
Fe
p
$E_0 = 10^{19}$ eV
vertical
DPMJET 2.5
QGSJET 01
SIBYLL 2.1
300
400
500
600
700
800
900
1000
1100
atmospheric depth (g/cm^2)

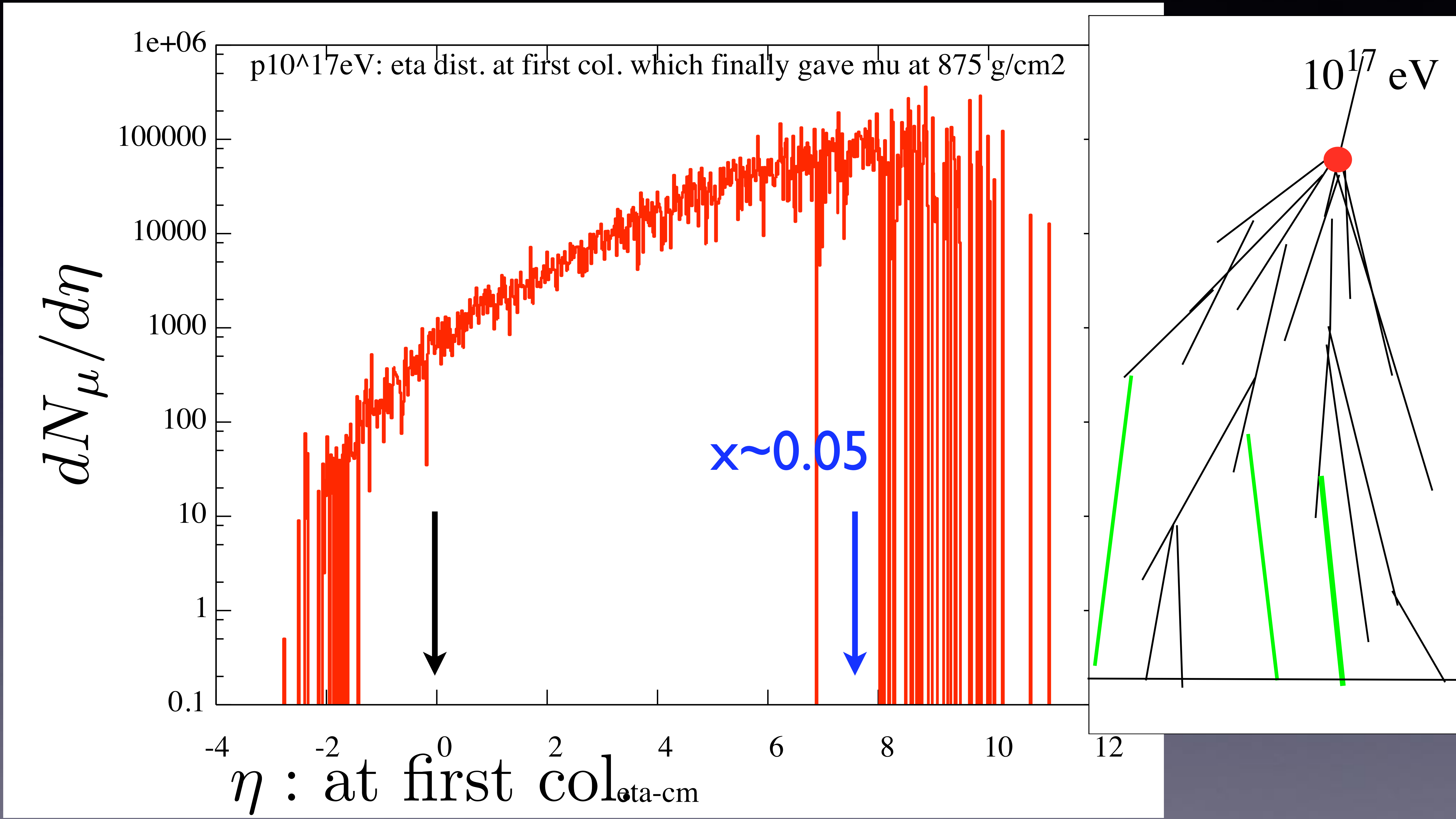
By Heck etal

Meson x

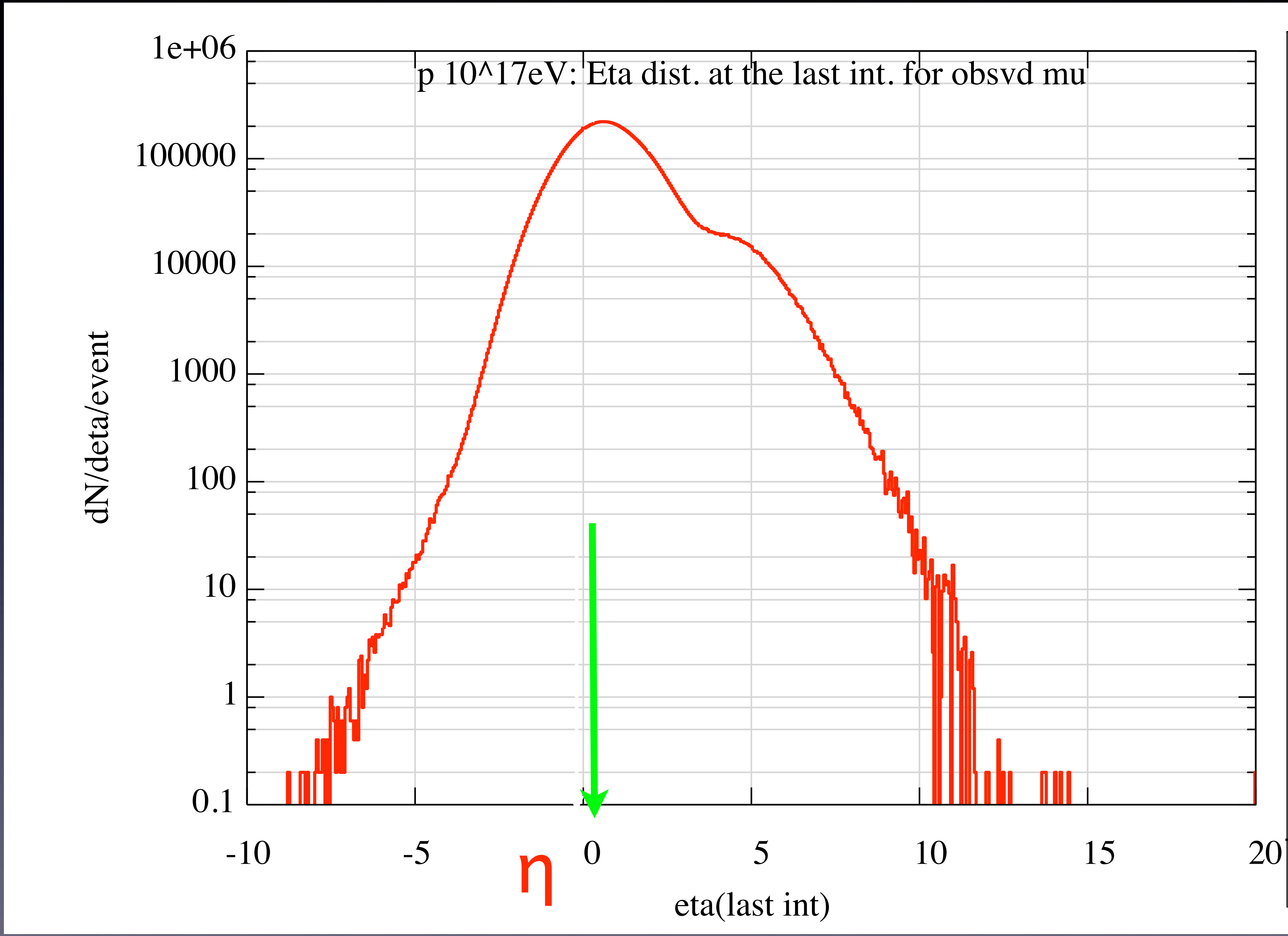

10000
1000
100
10
1
0.1
0.01
0.001
$\frac{dN}{dx_{cm}}$ /event
dpmjet3
10^{17} eV
N_μ
N_e
pN
pp
pN
pp
100
10
1
Cummulative fractional energy
($> x_{cm}$) of mesons (%)
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
x_{cm}
1e+07
1e+06
100000
10000
1000
100
10
1
0.1
Elab(GeV)
-1
-0.5
0
0.5
1

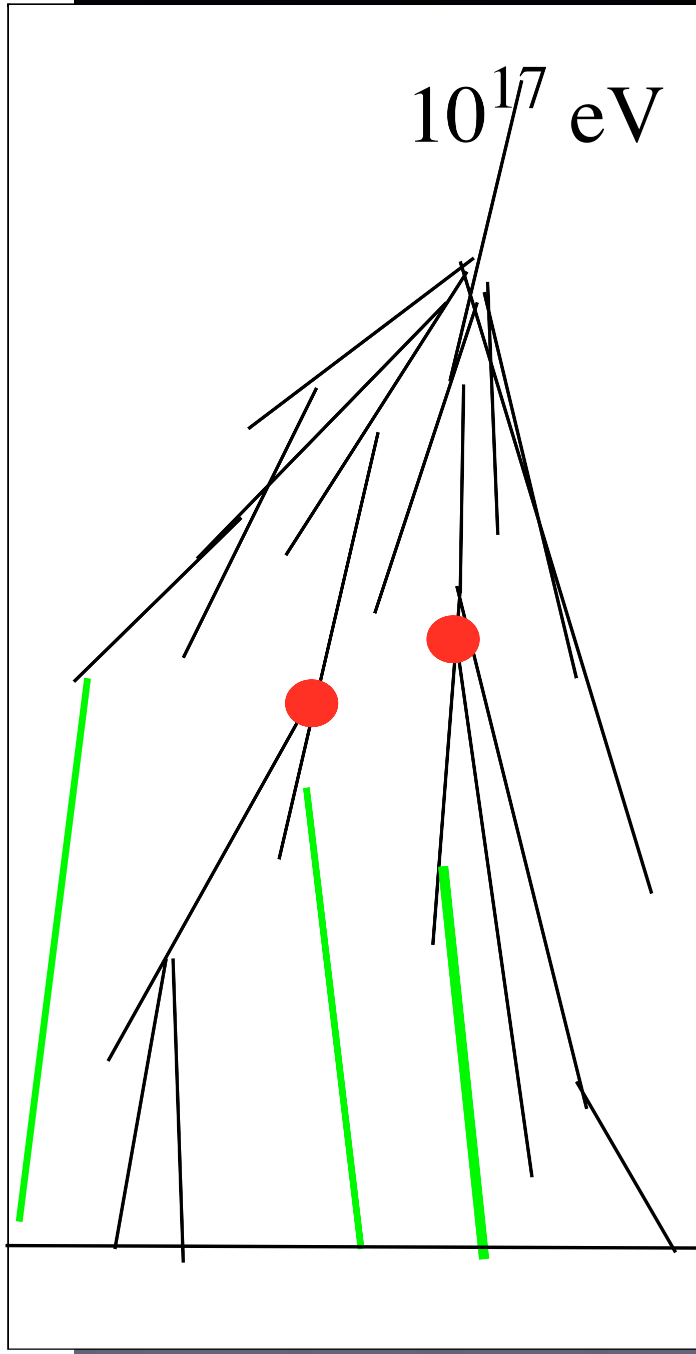
Muons

Number of muons produced from descendent of first interaction: p 10^{17}eV

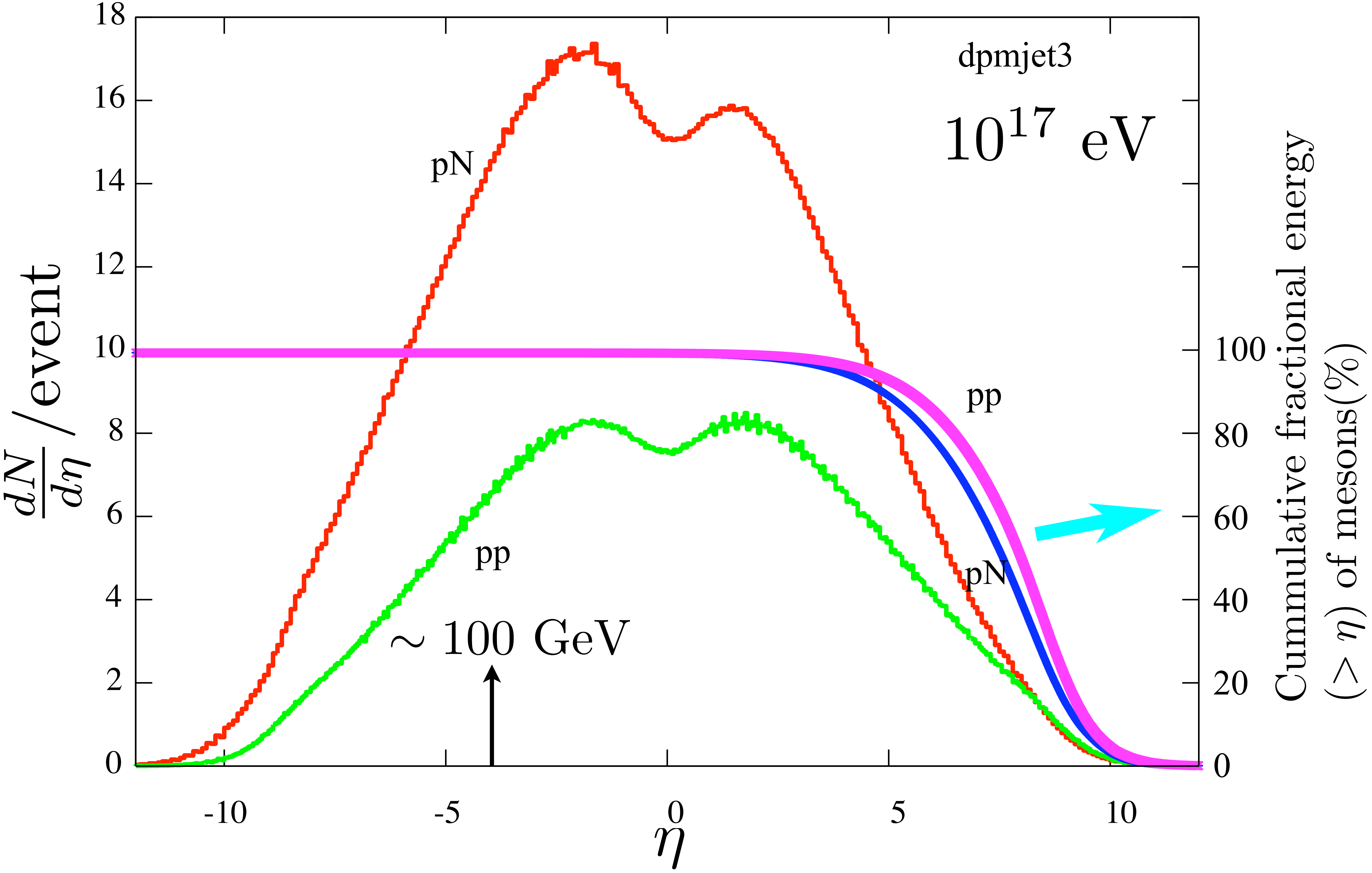


Eta dist. of last interaction which produced muons:





Meson pseudo rapidity



Low Energy

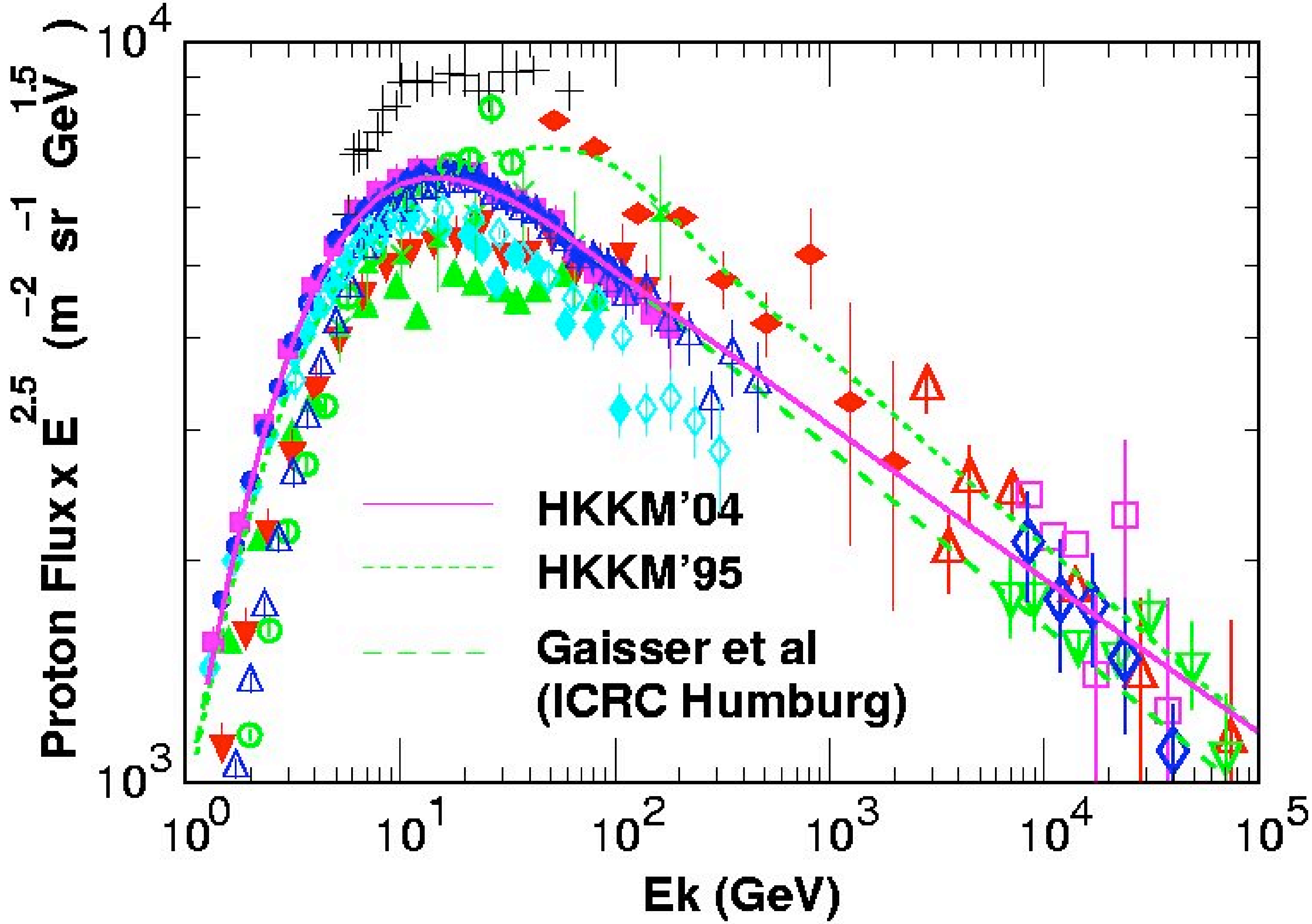
Atmospheric Neutrino
(muons and protons: mainly by M.Honda)

We have to select “GOOD” data !

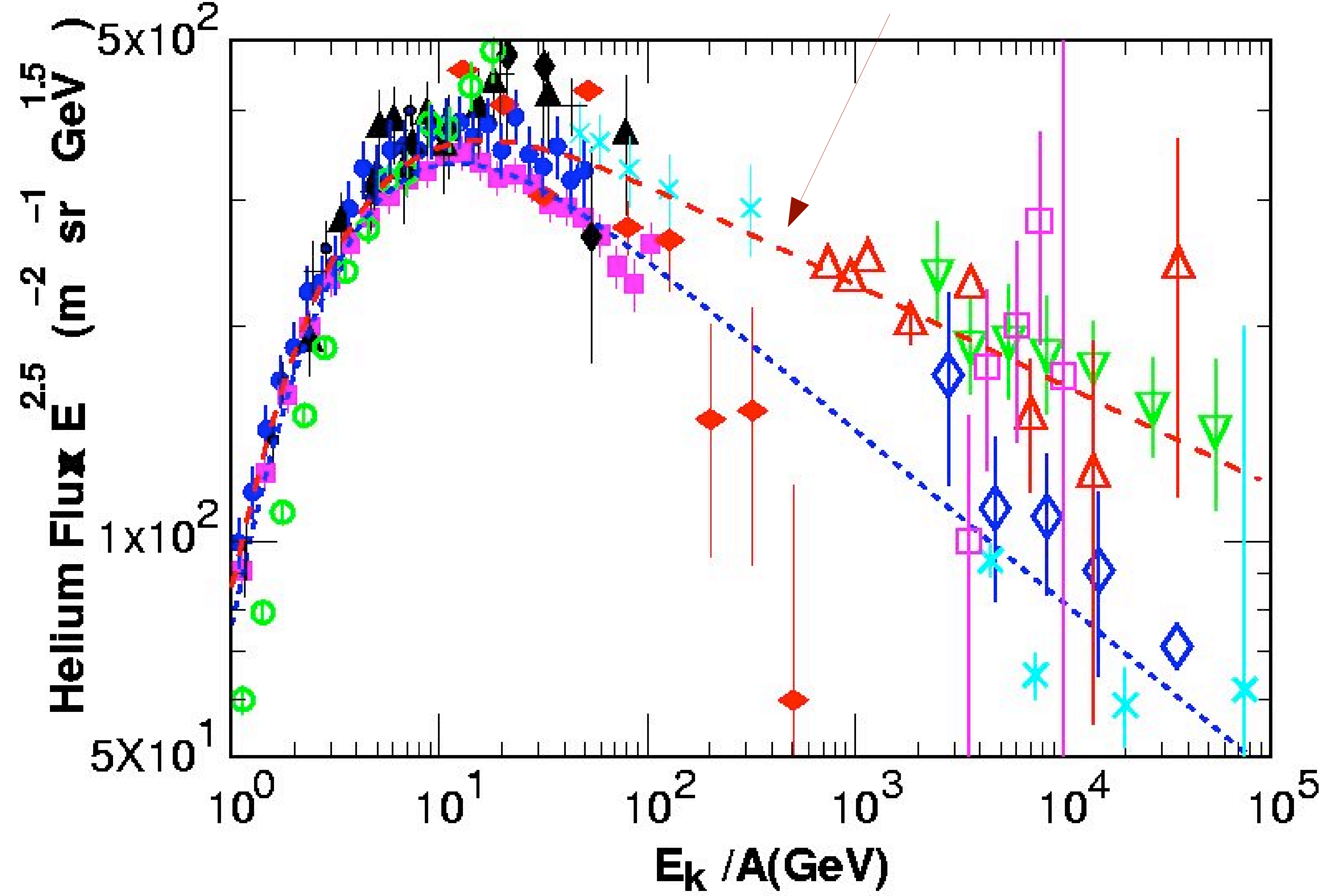
BESS 1ry: AMS 1ry
muon observation
gamma ray observation
proton observation

vs Model Calculations

Primary Proton Flux Model

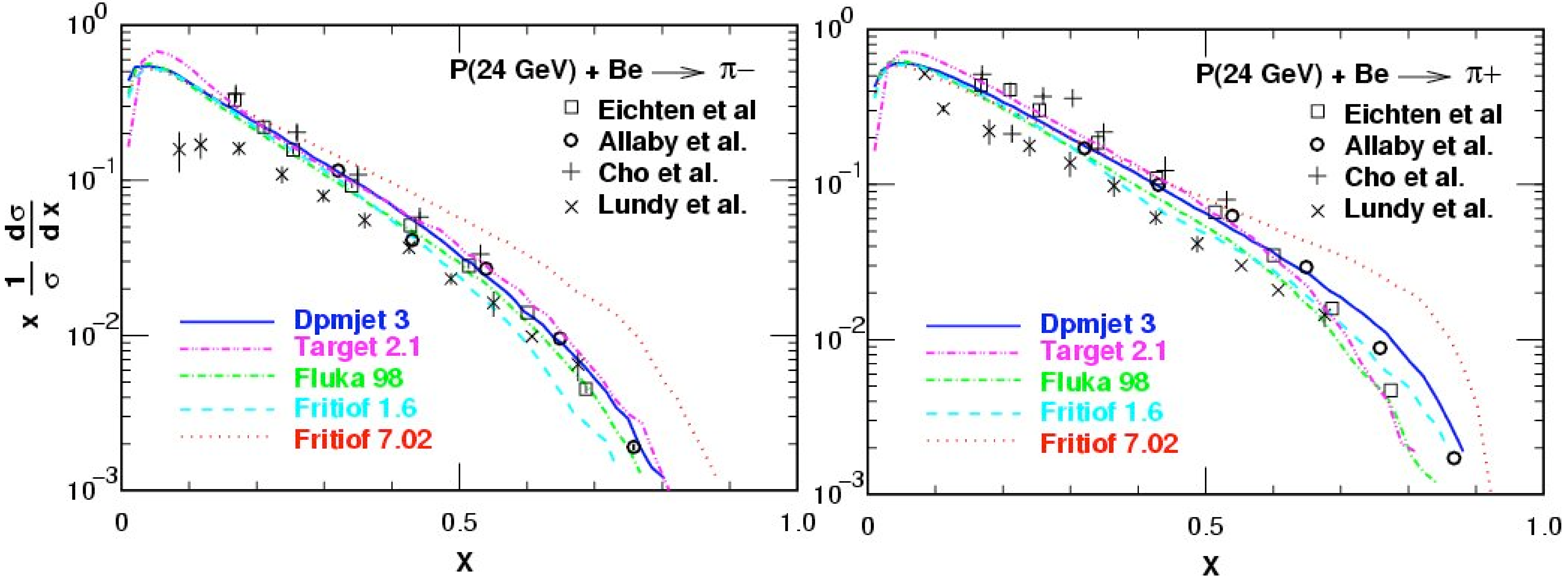


Primary He flux model

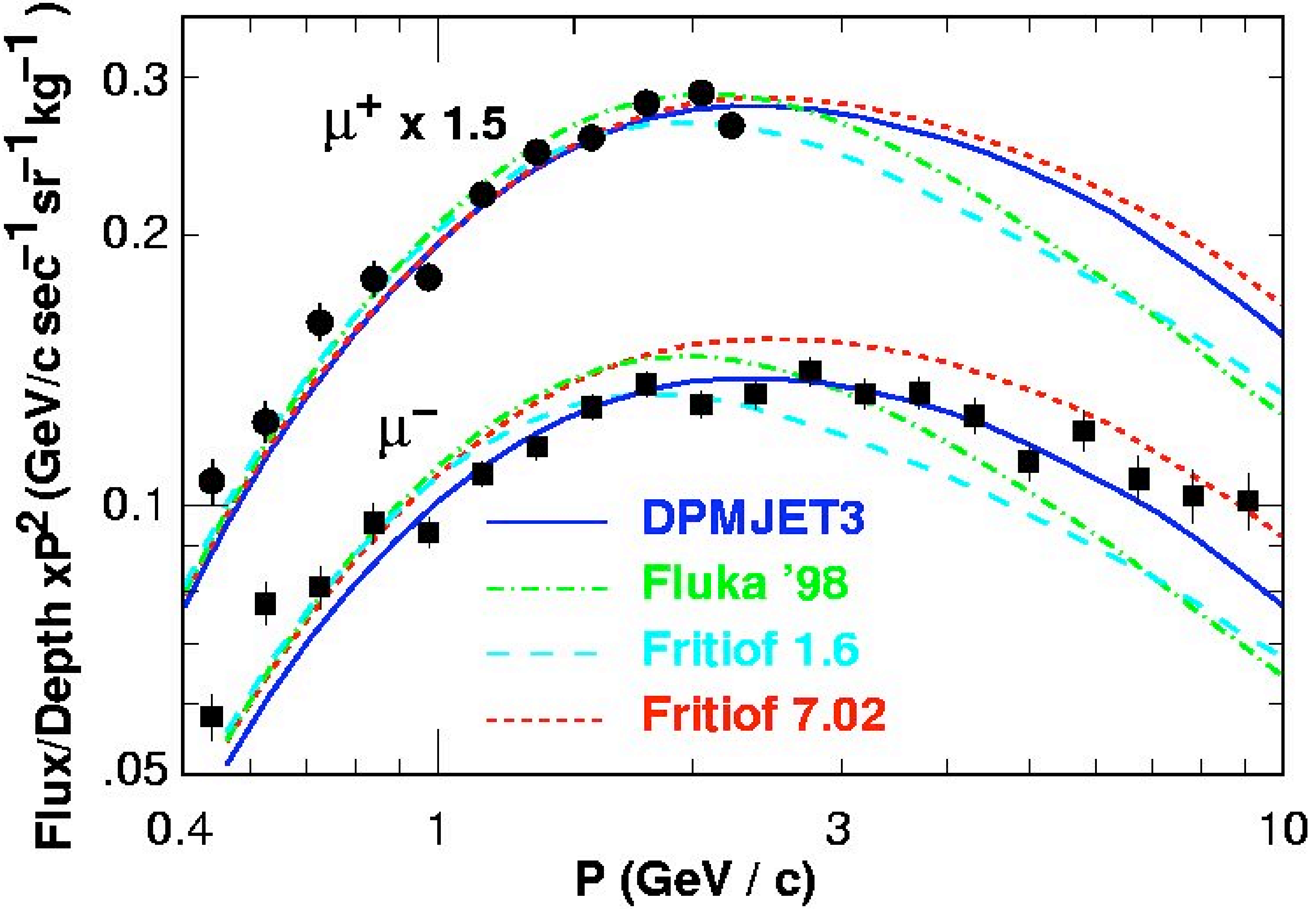


High flux mode for He

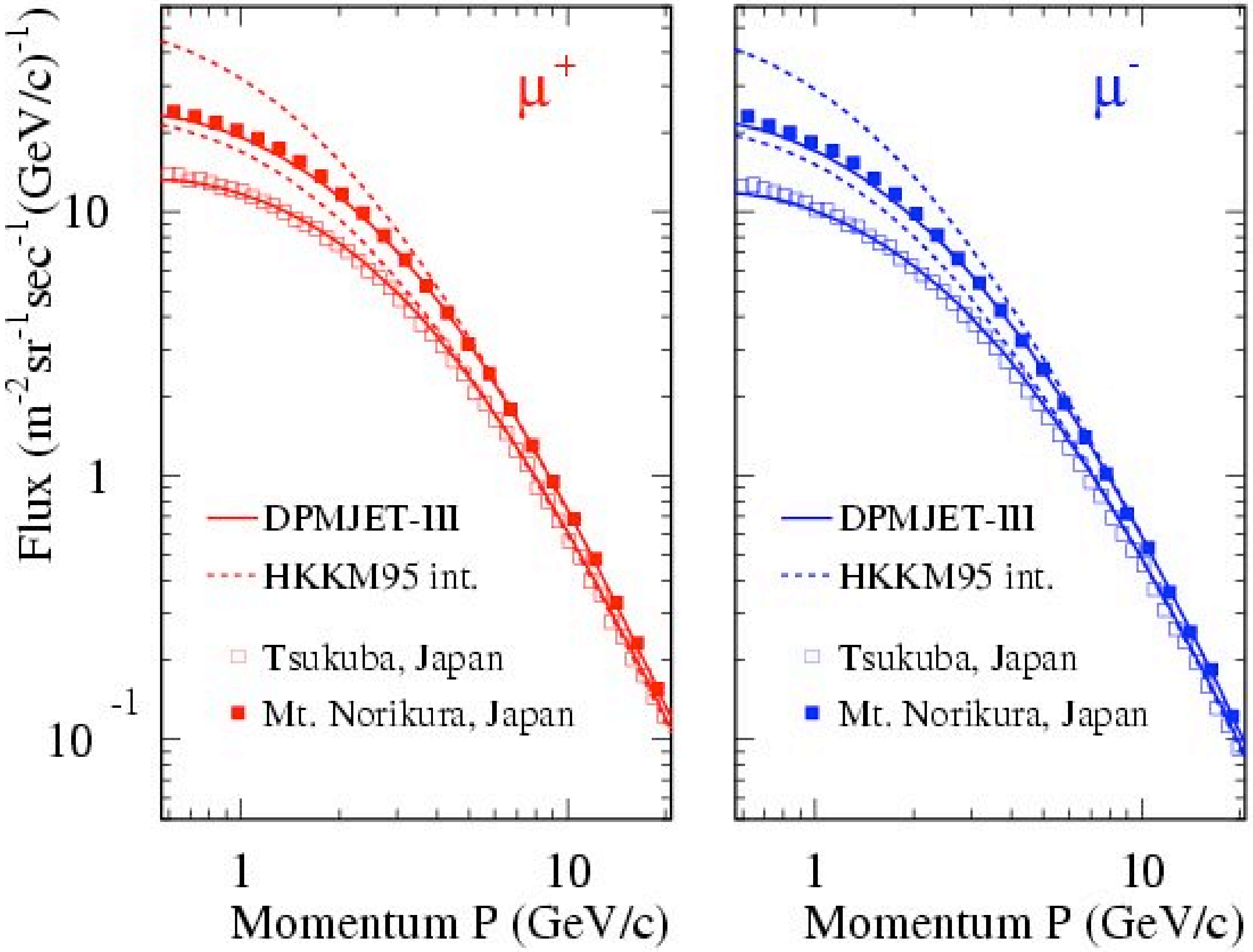
Interaction Model

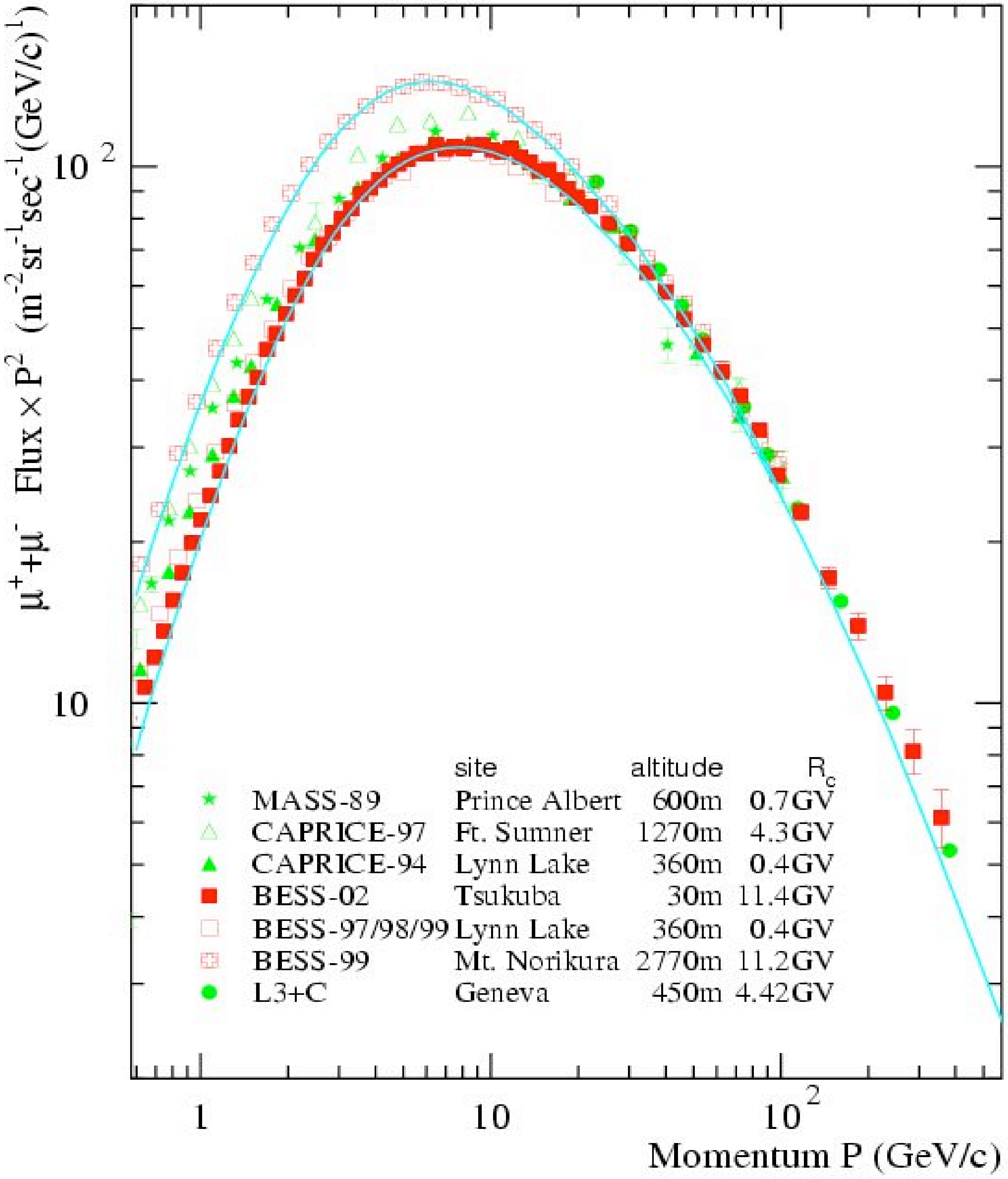


Test with muon flux at Balloon Altiotude



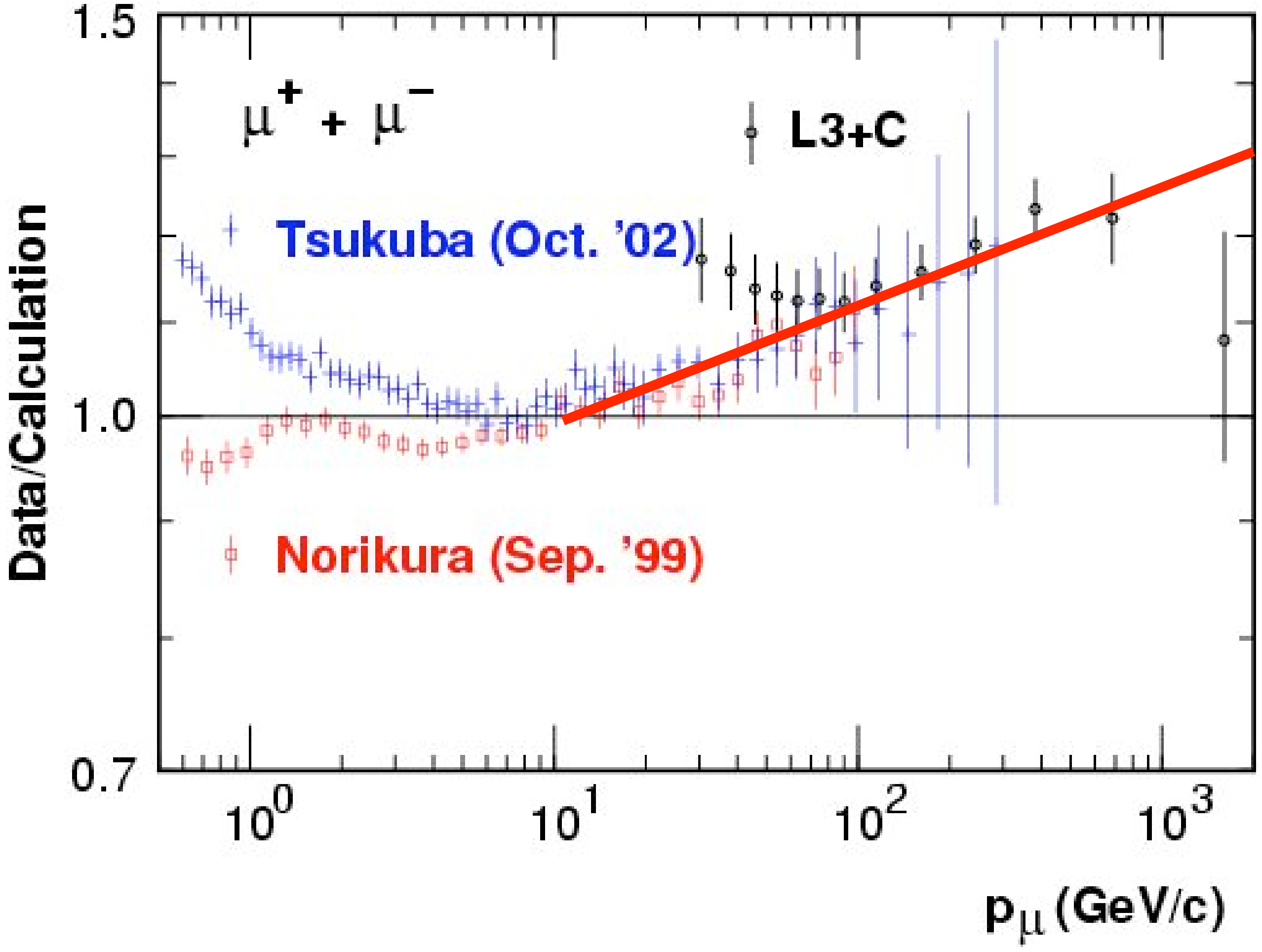
Muon Observations

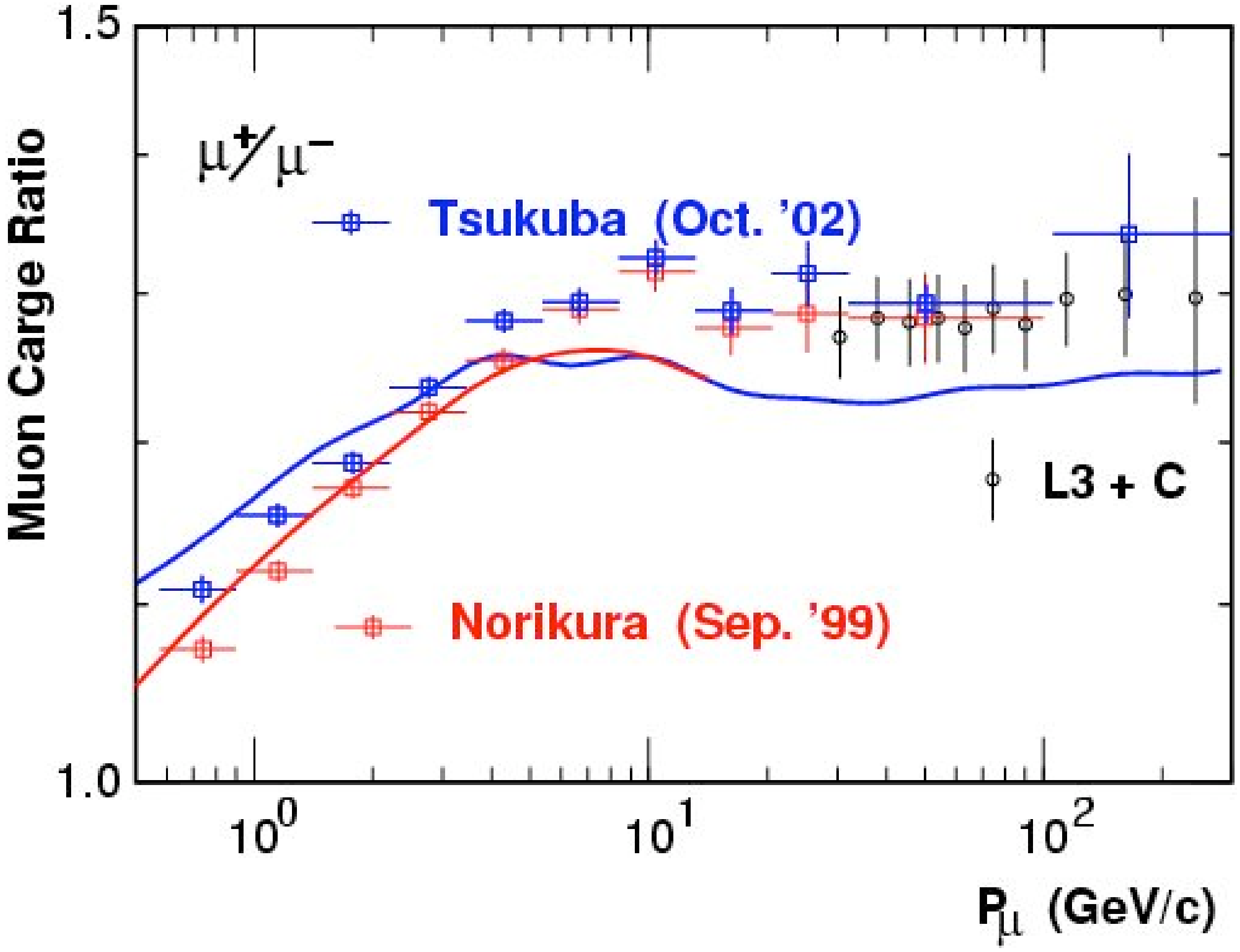




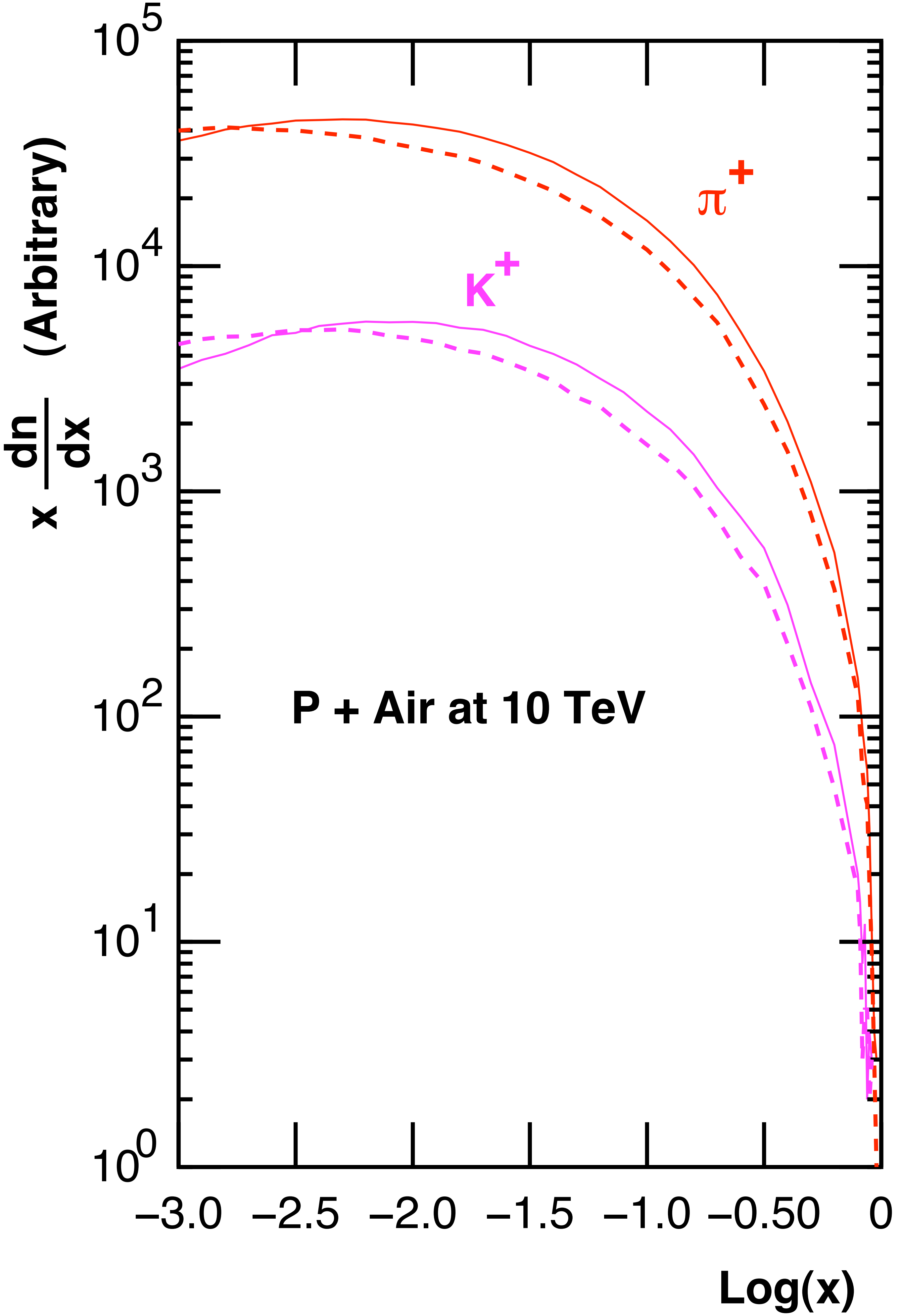
Comparison of Muon Flux Calculated in HKKM04 and Observed Data.

The differences are ~5% in absolute value for 1 ~ 30 GeV/c, and ~ 5% in charge ratio for all momentums.

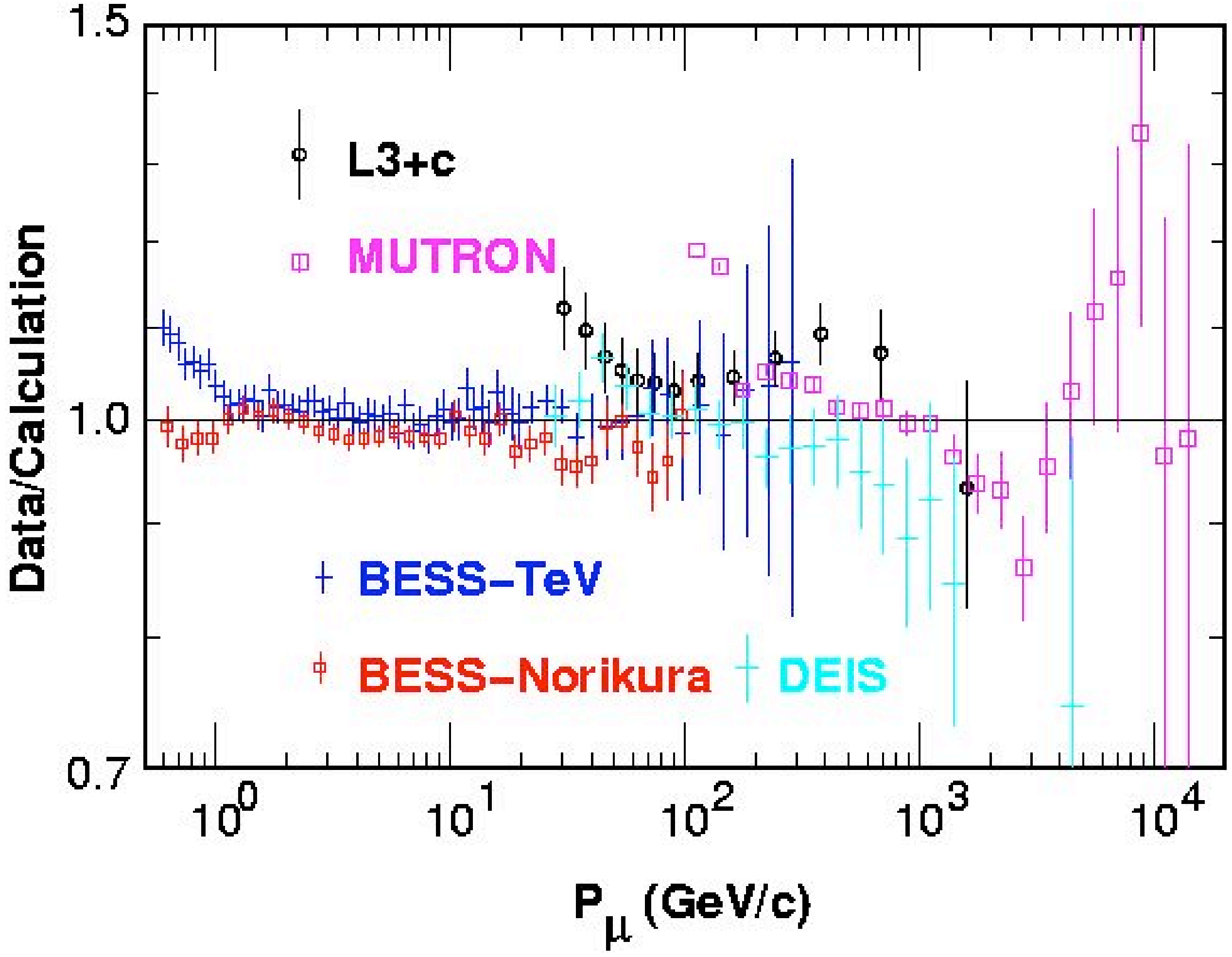


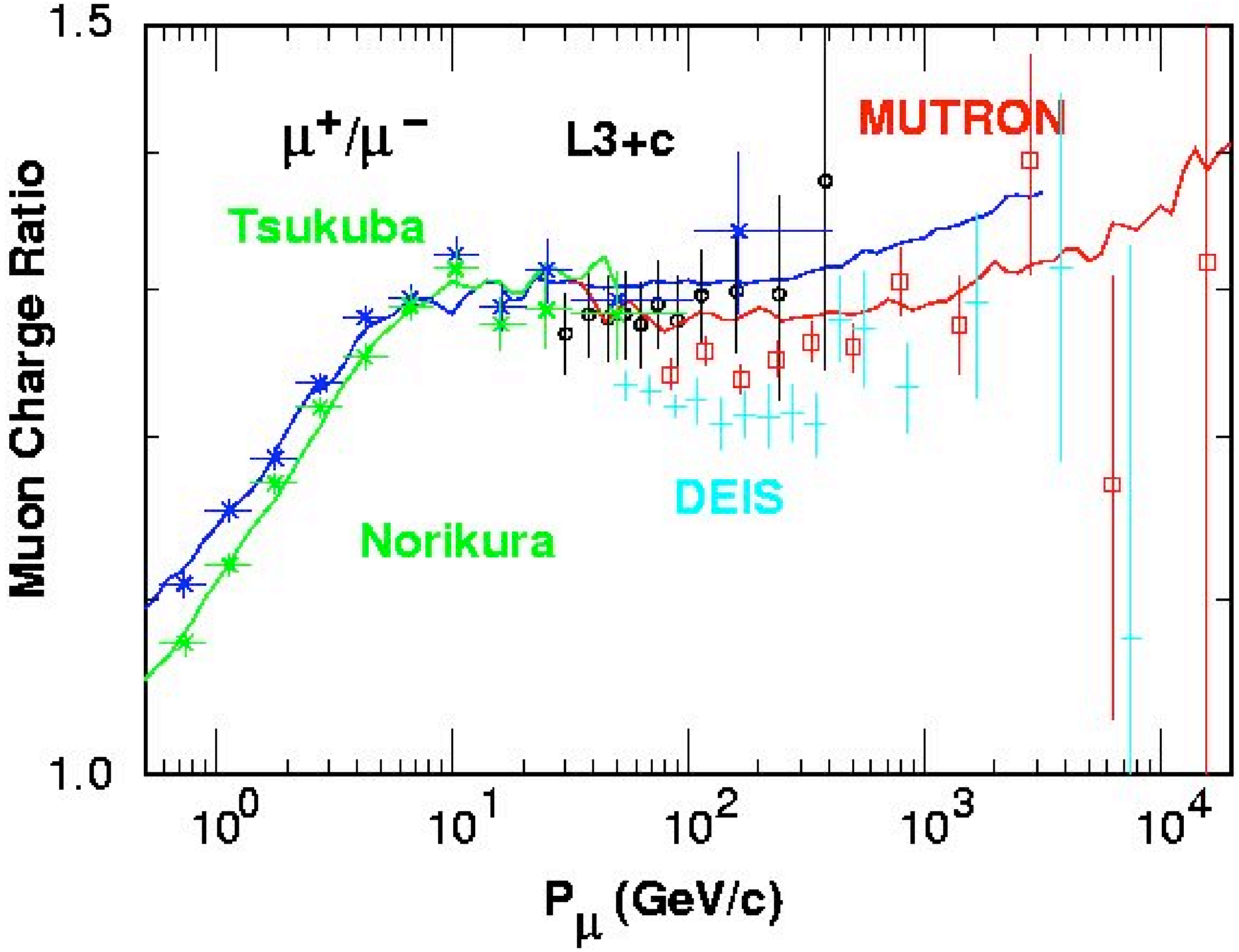


The difference of the absolute value increases at high energies, as $\sim(P/10\,GeV)^{0.05}$.


10^5
10^4
10^3
10^2
10^1
10^0
x dn/dx (Arbitrary)
π^+
K^+
P + Air at 10 TeV
−3.0
−2.5
−2.0
−1.5
−1.0
−0.50
0
Log(x)

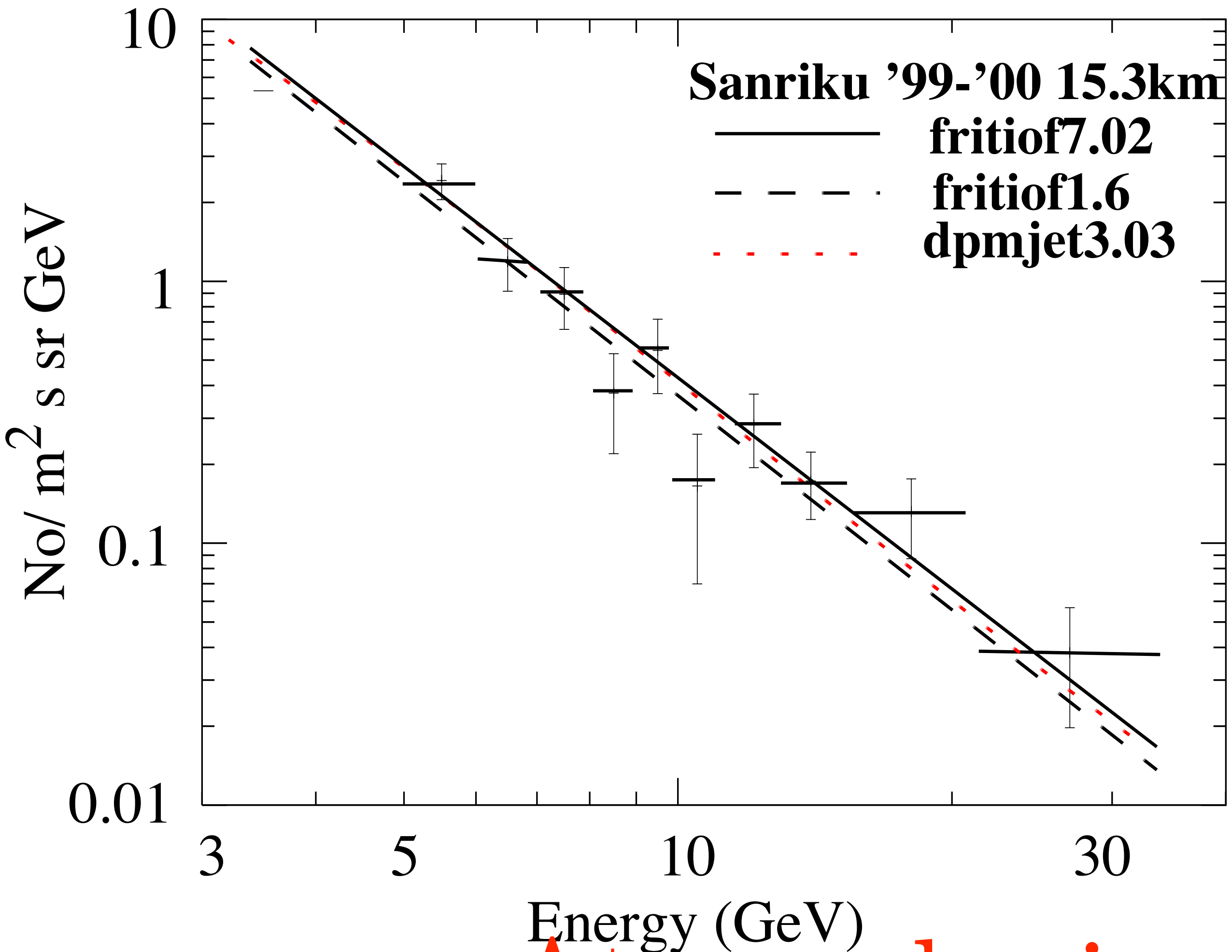
Comparison of Modified Results with the Observations

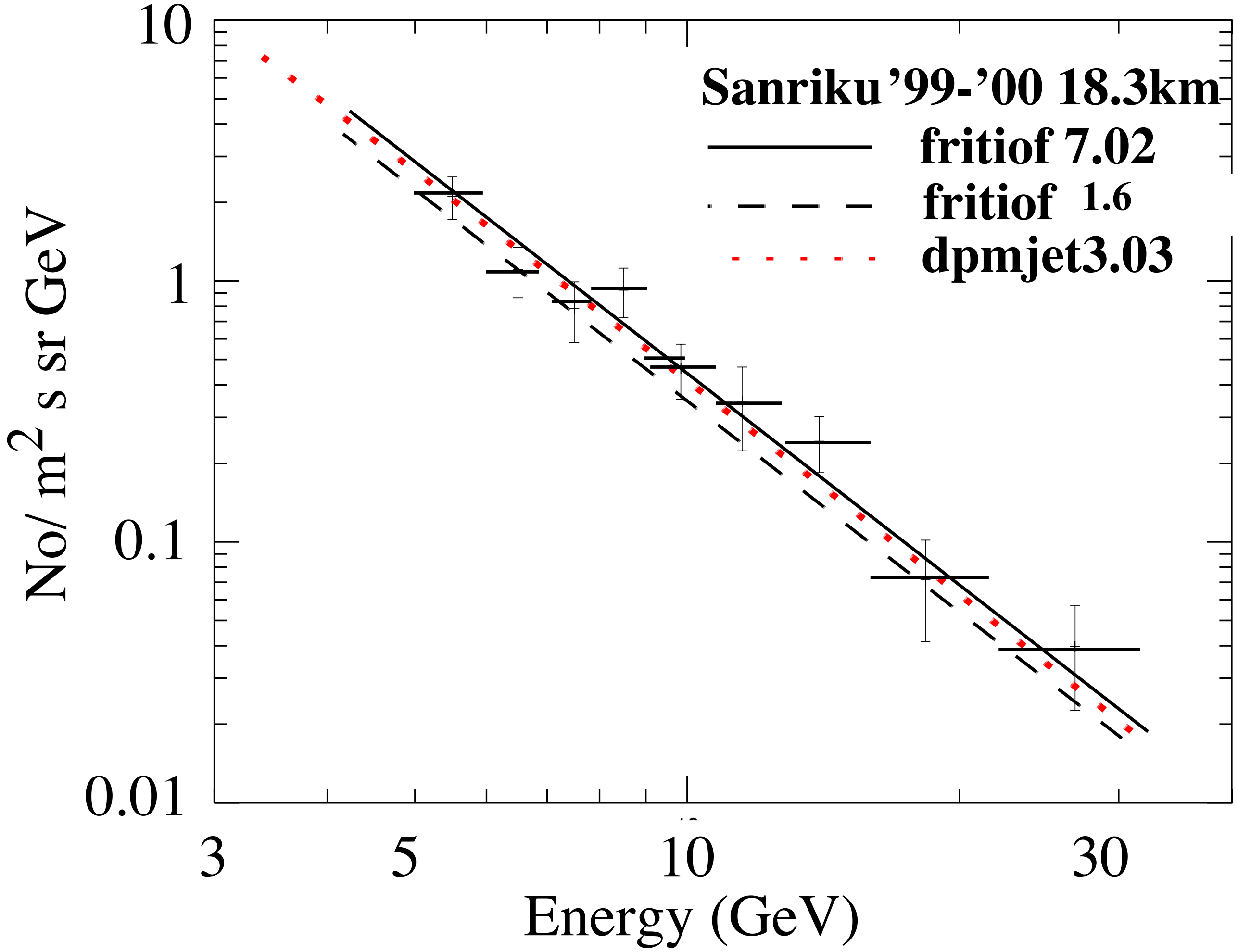


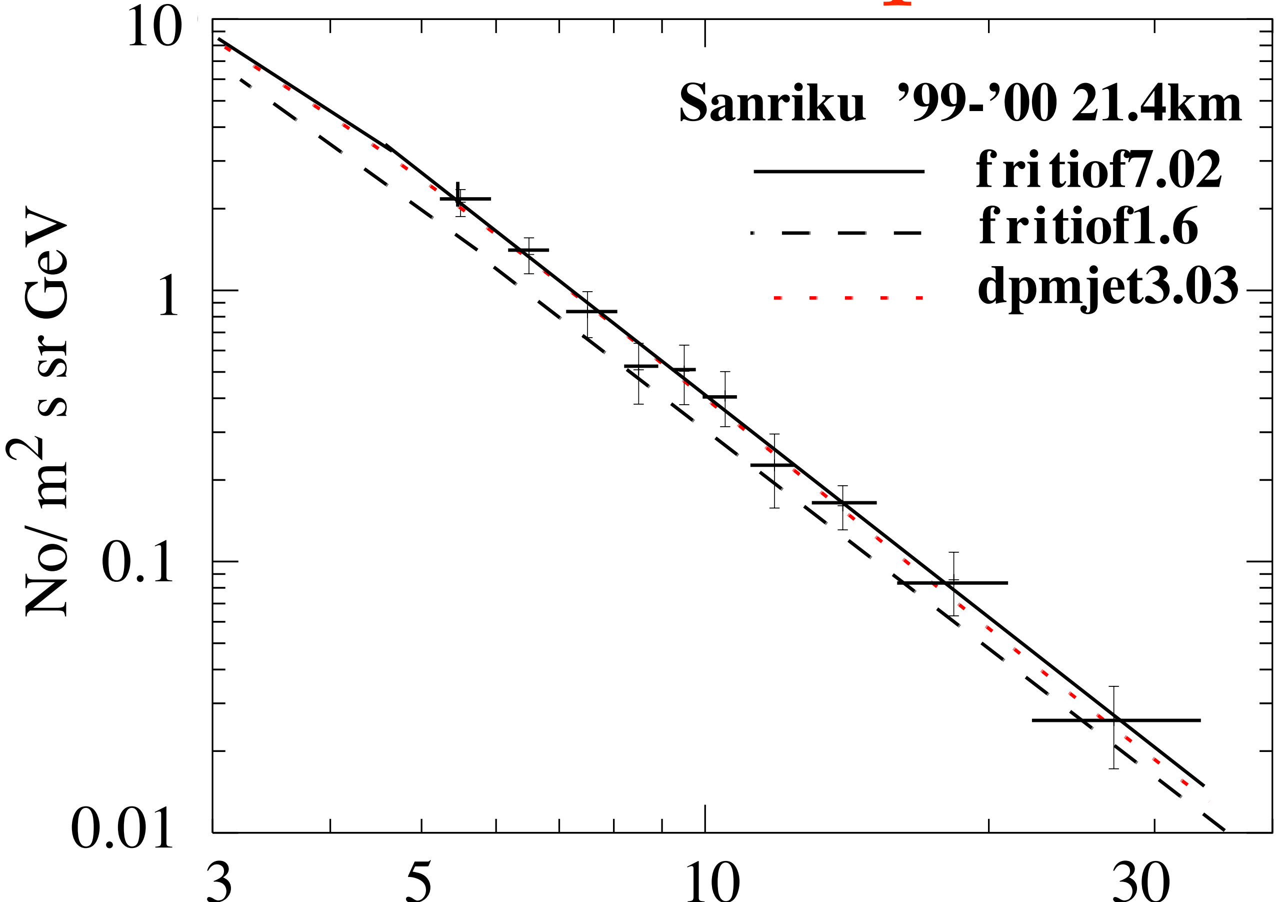


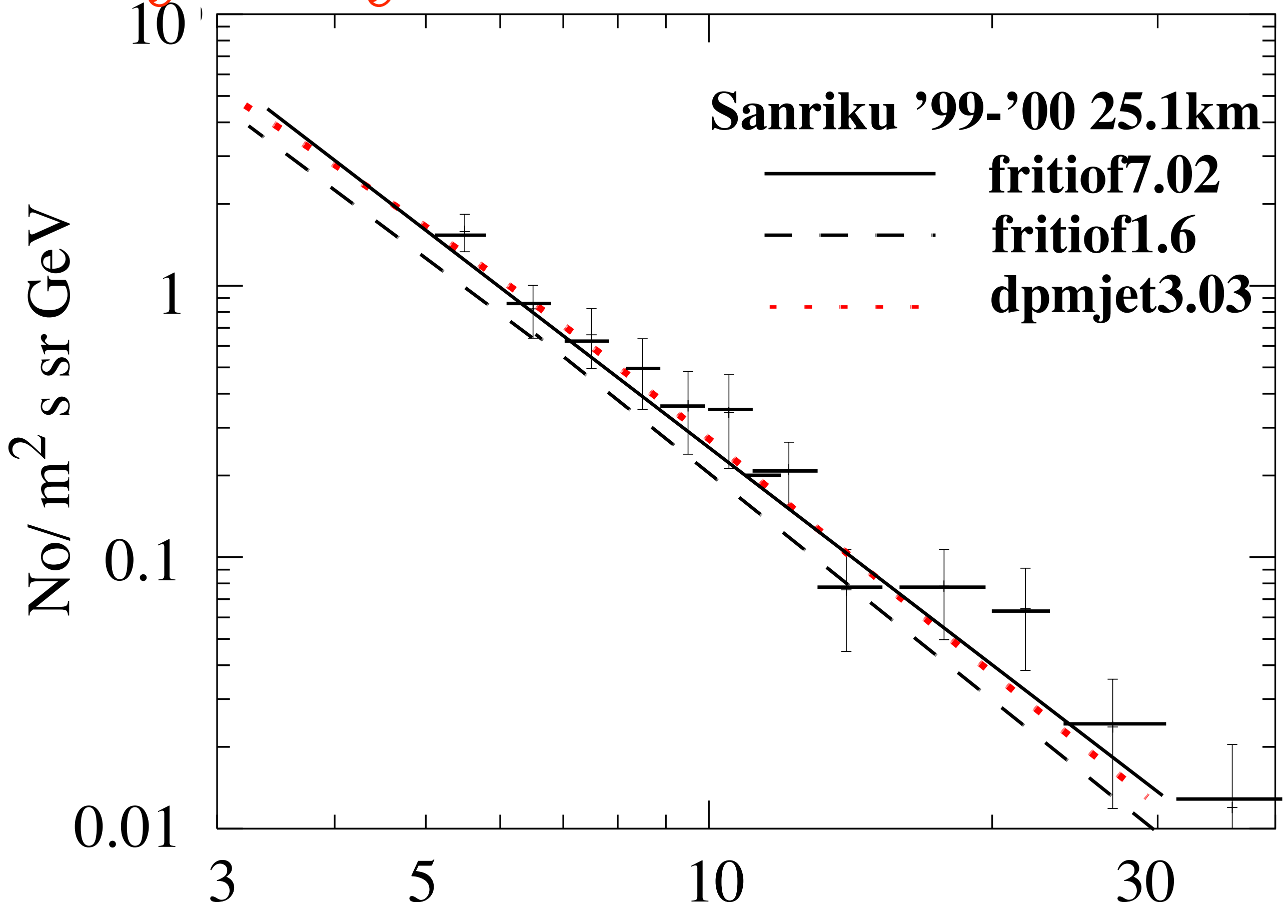
The calculation and data agree well within 10 % in 0.5 GeV/c ~1 TeV/c, and < 5% in 1~30GeV/c.

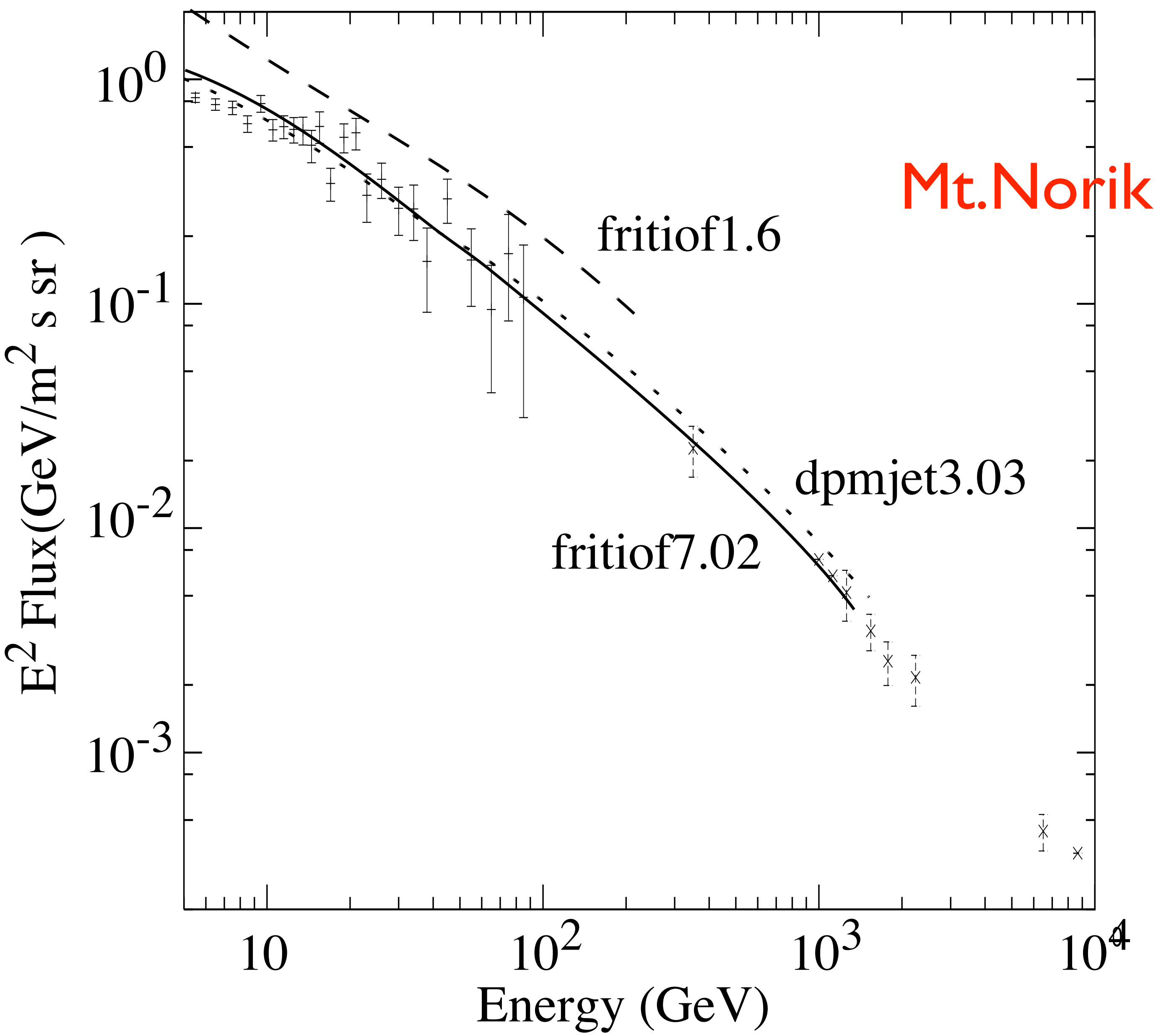
Atmospheric γ-rays by BETS










10^0
10^{-1}
10^{-2}
10^{-3}
E^2 Flux(GeV/m^2 s sr)
10
10^2
10^3
10^4
Energy (GeV)
fritiof1.6
dpmjet3.03
fritiof7.02

Mt.Norikura

Summary at low energies (<10TeV)

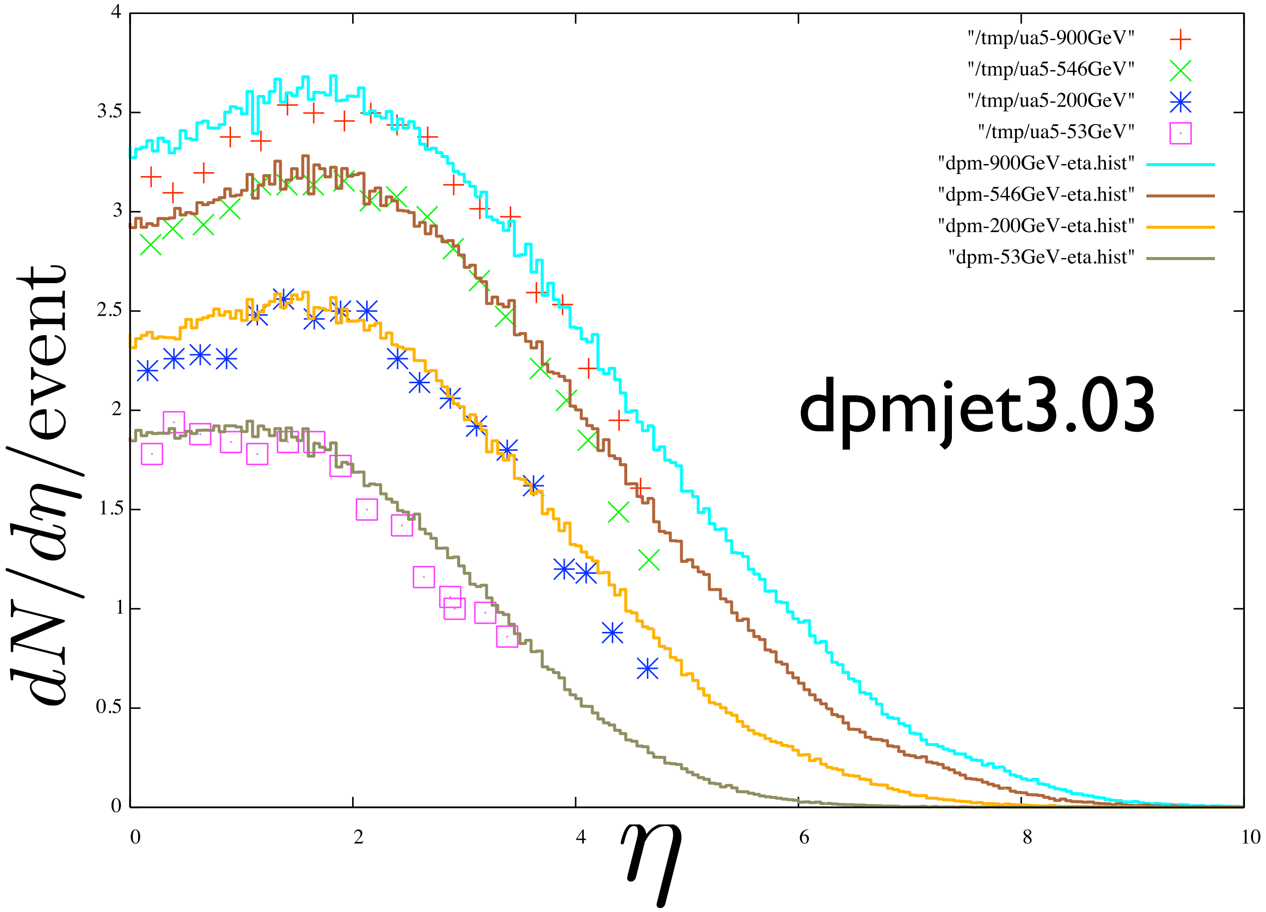
- dmpjet3 seems good: flux within ~10 %
- However, for better agreement with obsrvations: X-distribution must be enhanced.

10^{14} eV region

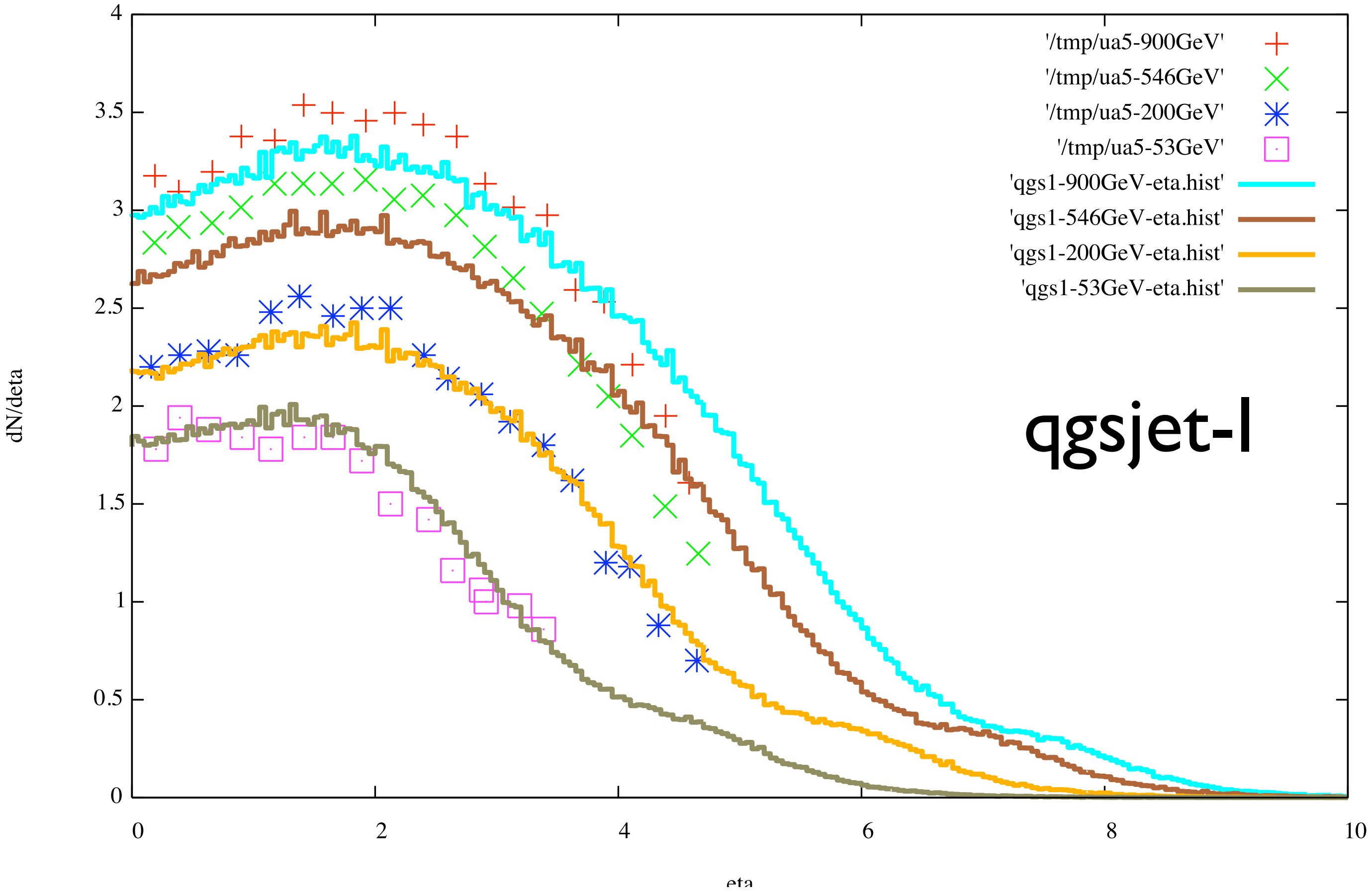
- UA5 problem
  - SPS + (ISR); pseudo rapidity distribution

$$\eta = -\log(\tan\frac{\theta}{2})$$

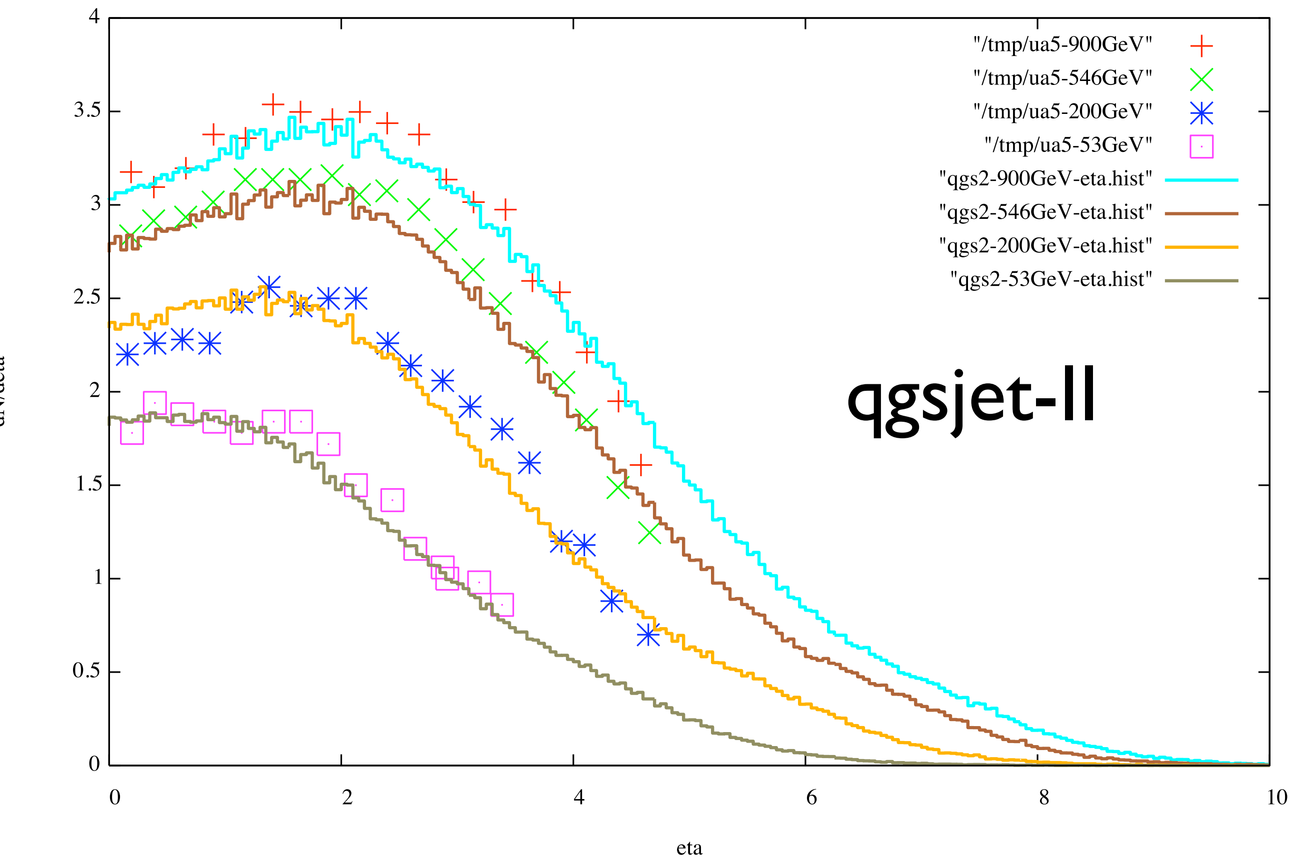
  - Contradicting to a Si data and M.C



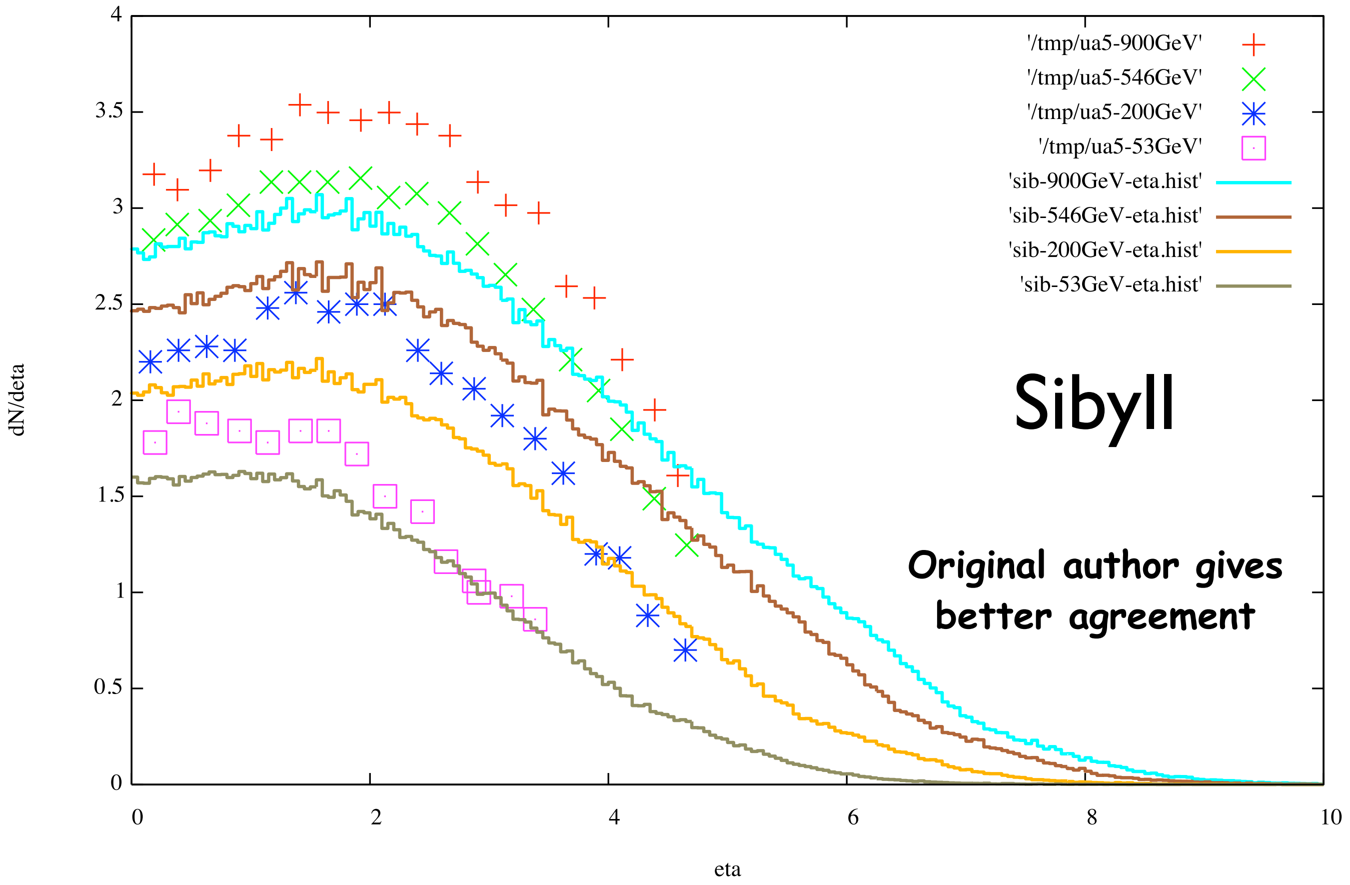
QGSJET01



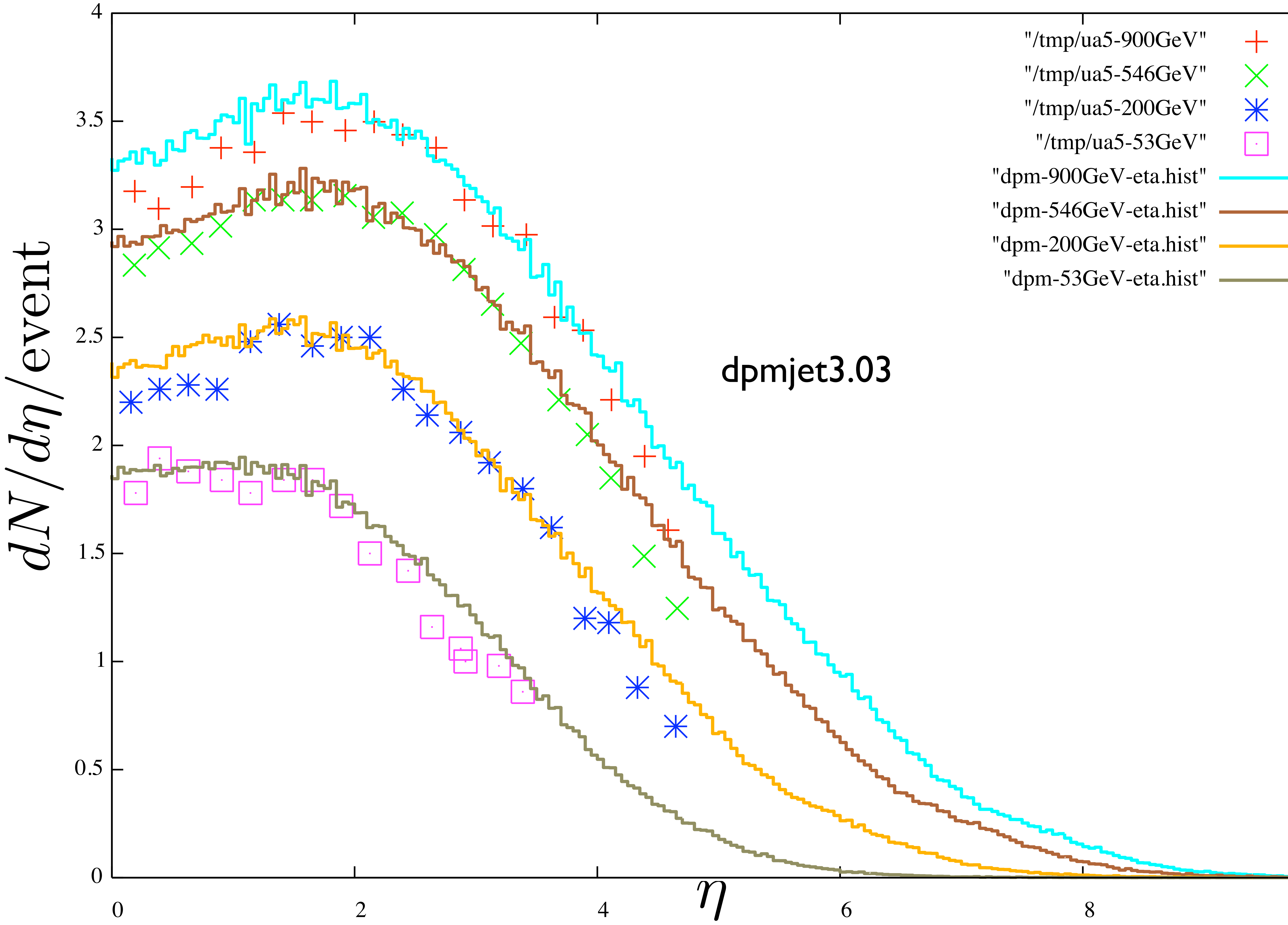
QGSJET-II



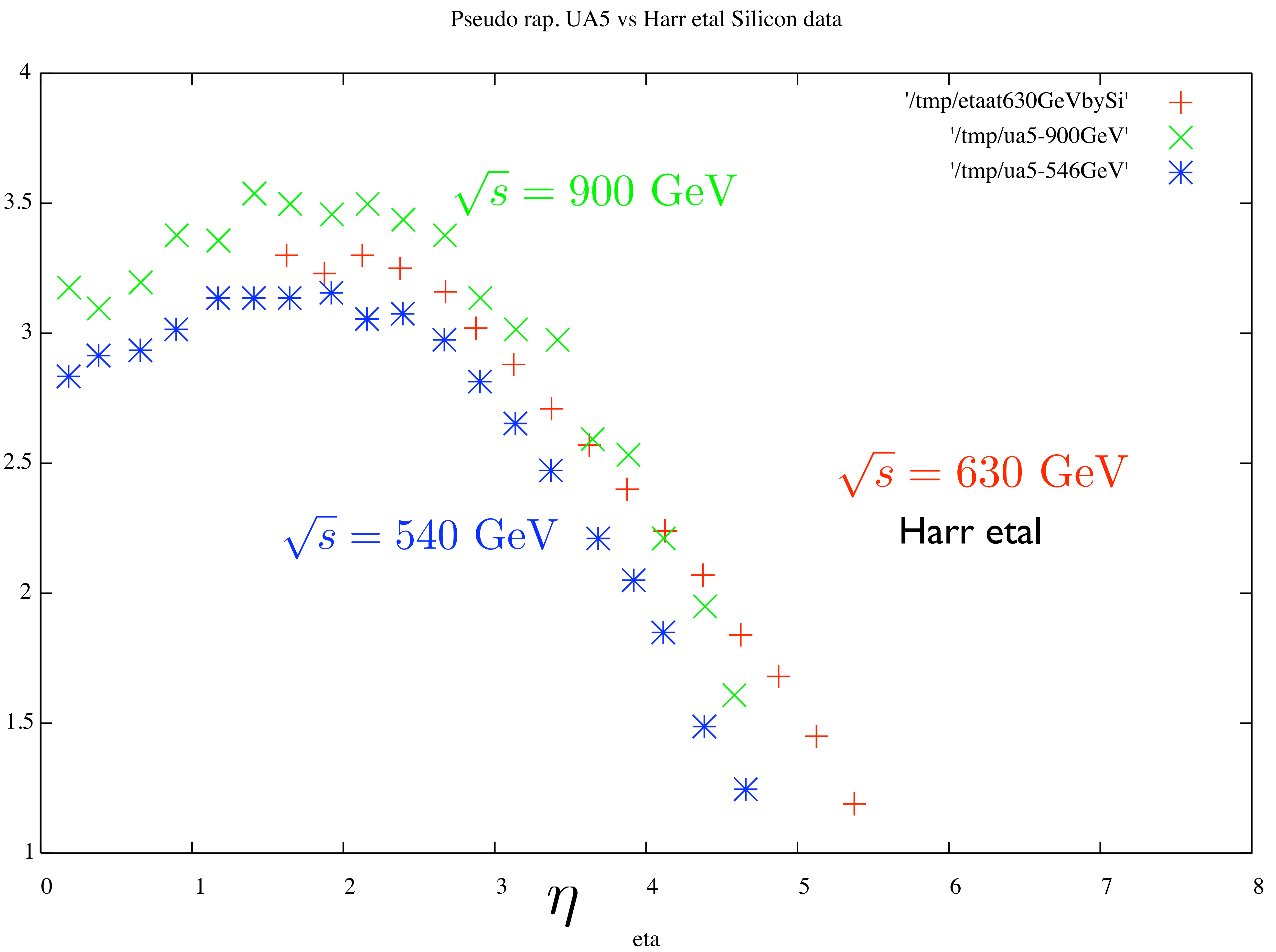
Sibyll

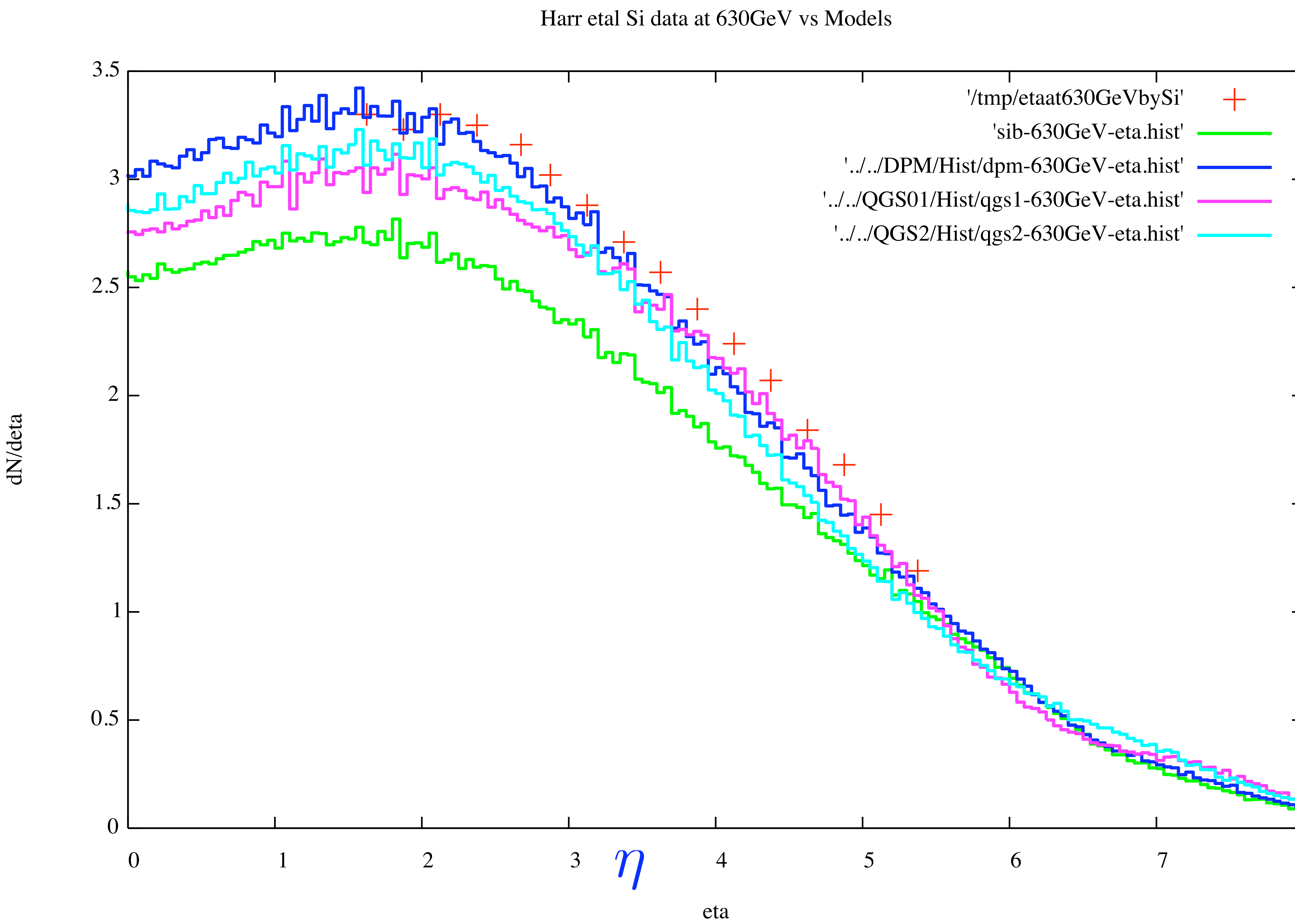


Original author gives better agreement



"/tmp/ua5-900GeV"
"/tmp/ua5-546GeV"
"/tmp/ua5-200GeV"
"/tmp/ua5-53GeV"
"dpm-900GeV-eta.hist"
"dpm-546GeV-eta.hist"
"dpm-200GeV-eta.hist"
"dpm-53GeV-eta.hist"
dpmjet3.03
$dN/d\eta/\mathrm{event}$
η
0
0.5
1
1.5
2
2.5
3
3.5
4
0
2
4
6
8


Pseudo rap. UA5 vs Harr etal Silicon data
'/tmp/etaat630GeVbySi'
'/tmp/ua5-900GeV'
'/tmp/ua5-546GeV'
$\sqrt{s} = 900$ GeV
$\sqrt{s} = 540$ GeV
$\sqrt{s} = 630$ GeV
Harr etal
4
3.5
3
2.5
2
1.5
1
0
1
2
3
4
5
6
7
8
η
eta


Harr etal Si data at 630GeV vs Models
'/tmp/etaat630GeVbySi'
'sib-630GeV-eta.hist'
'../../DPM/Hist/dpm-630GeV-eta.hist'
'../../QGS01/Hist/qgs1-630GeV-eta.hist'
'../../QGS2/Hist/qgs2-630GeV-eta.hist'
dN/deta
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
η
4
5
6
7
eta

M.C method itself:

Computation time and memory size for Full M.C ($E_{min} < 1 MeV$)

	E_0	cpt time @2GHz cpu	disk size
●	10^{17} eV	~ 1 week	10 GB
●	10^{19} eV	~ 2 years	1 TB
●	10^{20} eV	~ 20 years	10 TB

Thin sampling (a la Hillas) etc

- Usable for seeing the transition of the total number of particles
- Dangerous for seeing individual particle properties (happens that 10^5 particles at the same point with the same energy, angle, arrival time etc.)

Distributed-parallel computing

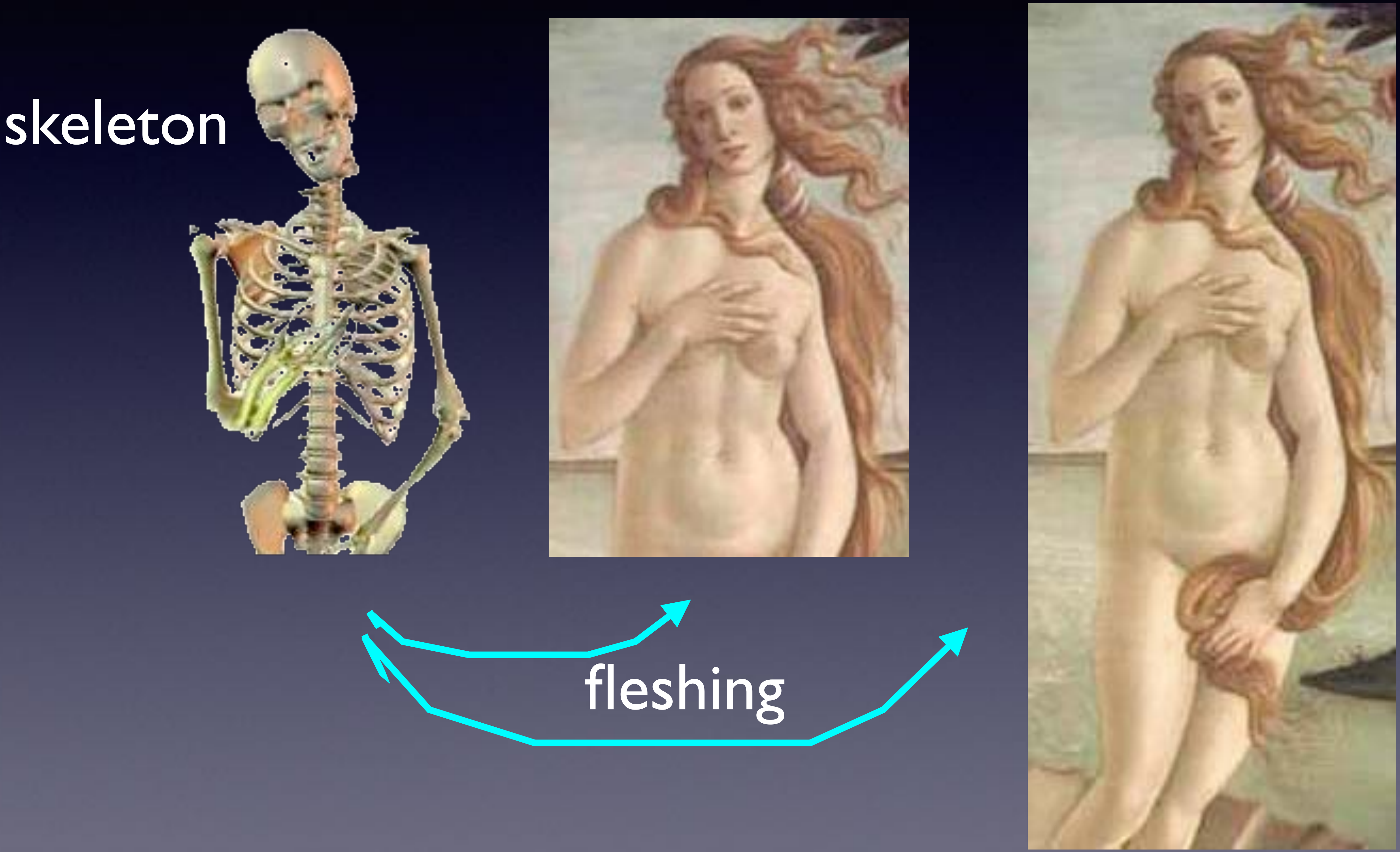
- MPI (?)
- Need complex communications among a number of cpu's (how to distribute tasks).
- Normally not efficient when the number of cpu exceeds some limit (say, 7).

New distributed-parallel computing method

Skeleton-Flesh method

- Enables Full M.C up to 10^{19} eV
- Enables virtual F.M.C at 10^{20} eV or higher energies
- *At the same time, settles the storage size problem*

Skeleton-Flesh method

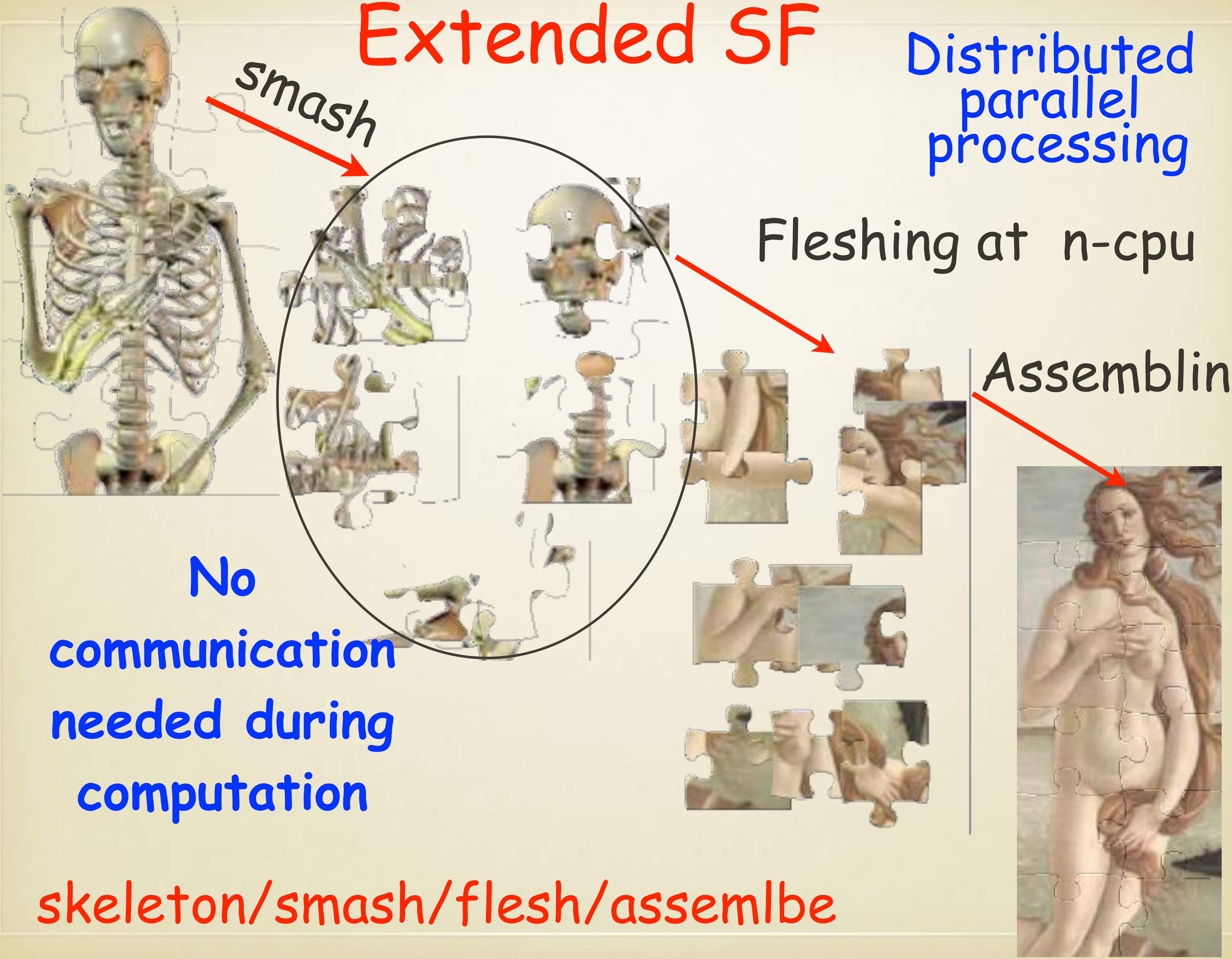


skeleton

fleshing

Extended SF

Distributed parallel processing



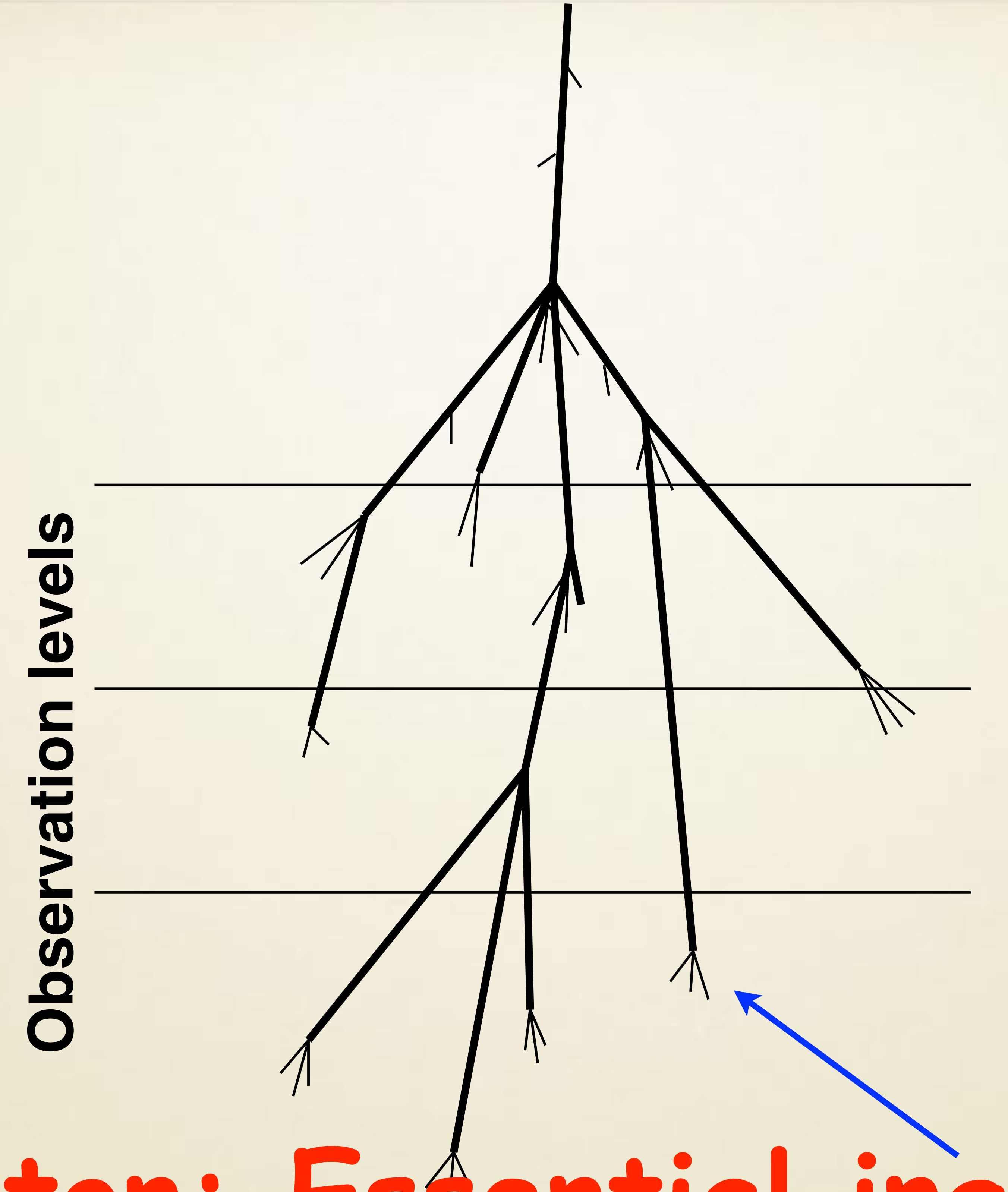
smash

Fleshing at n-cpu

Assembling

No communication needed during computation

skeleton/smash/flesh/assemlbe

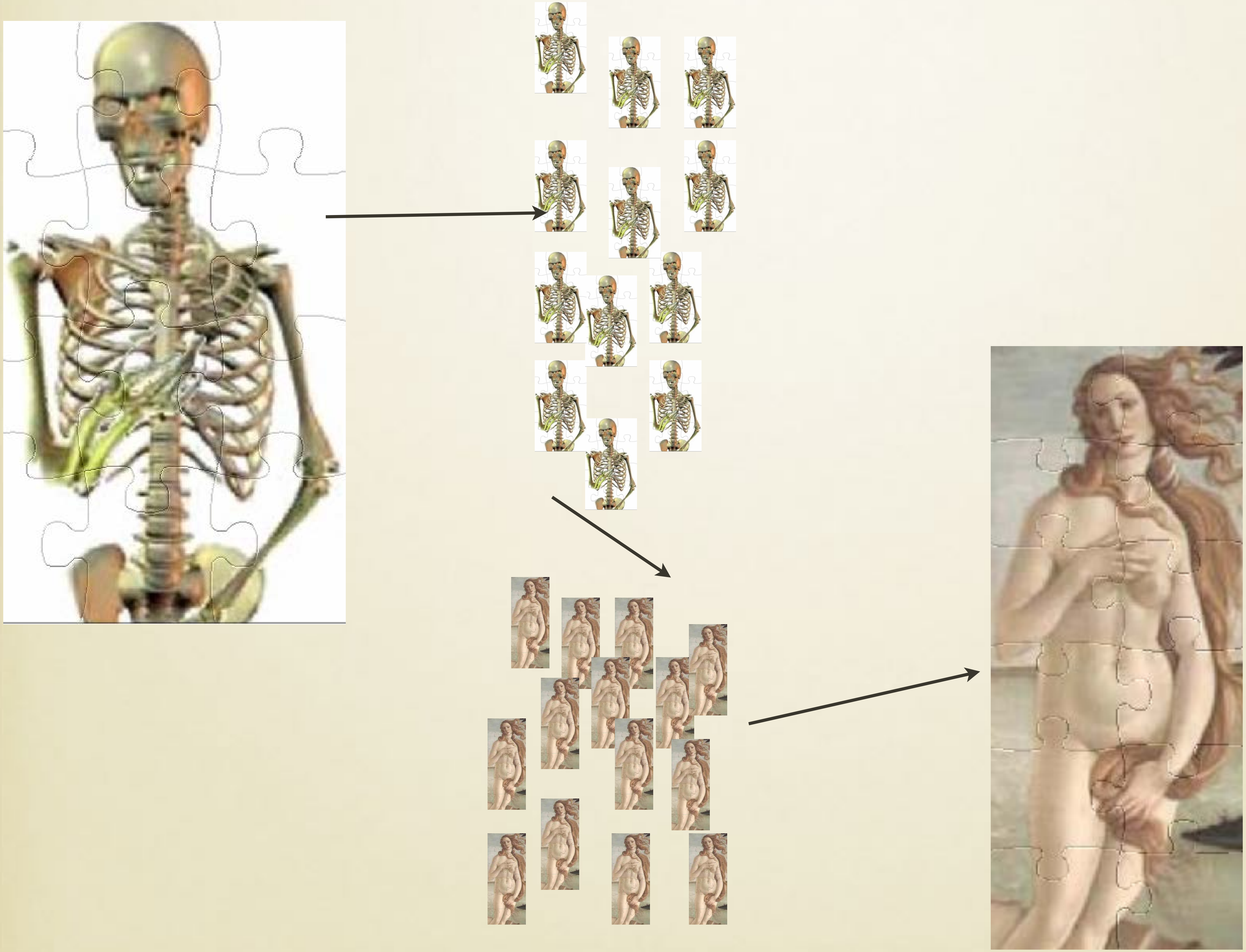


Skeleton: Essential ingredients: low energy partilcs

- If ~ 50 cpu's available
  - 10^{19} eV → 1 ~ 2 weeks
  - Storage: randomly select particles to be recorded
- How about 10^{20} eV or higher energies

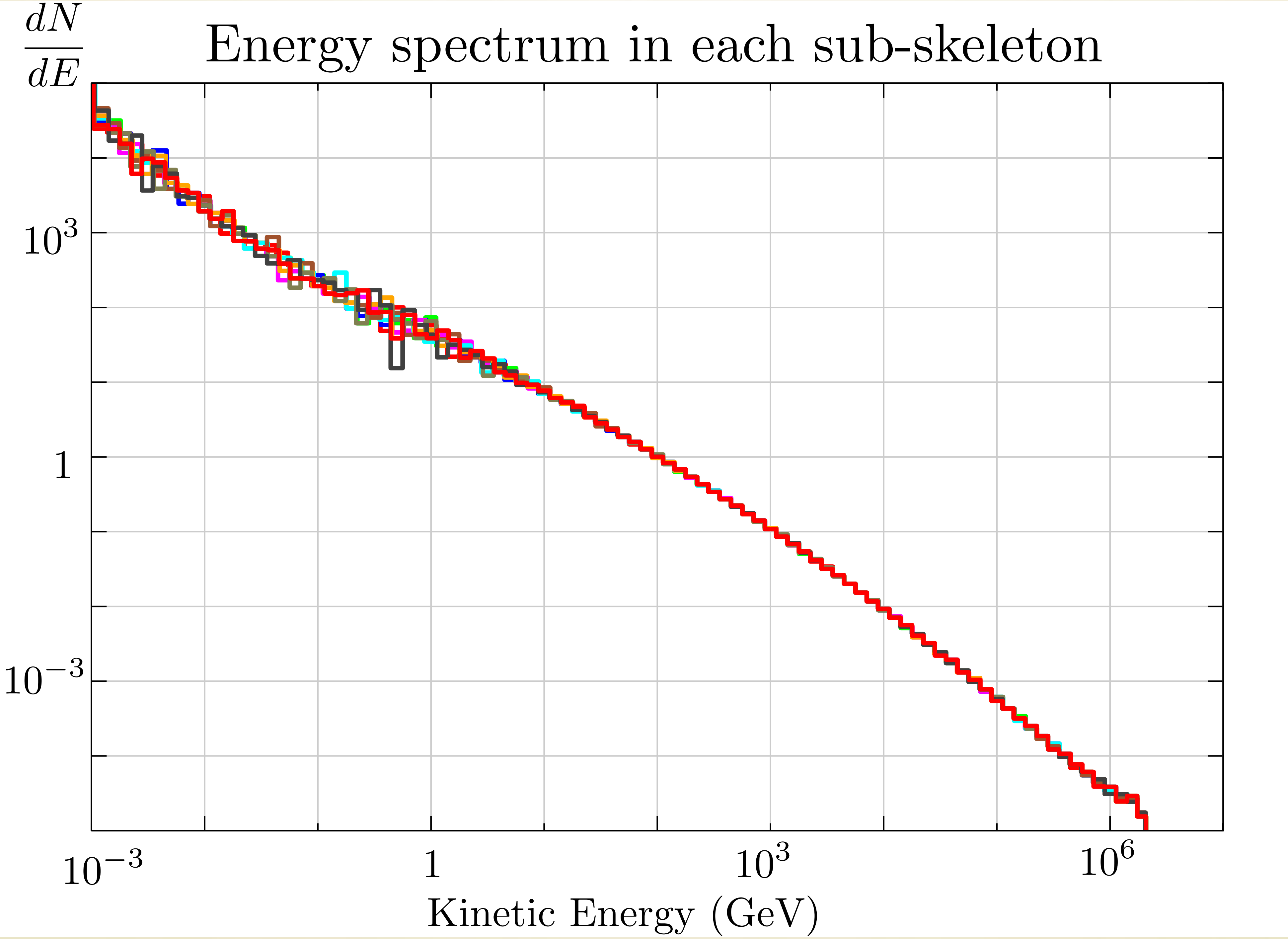
things are rather easy:

smashed skeletons are almost identical

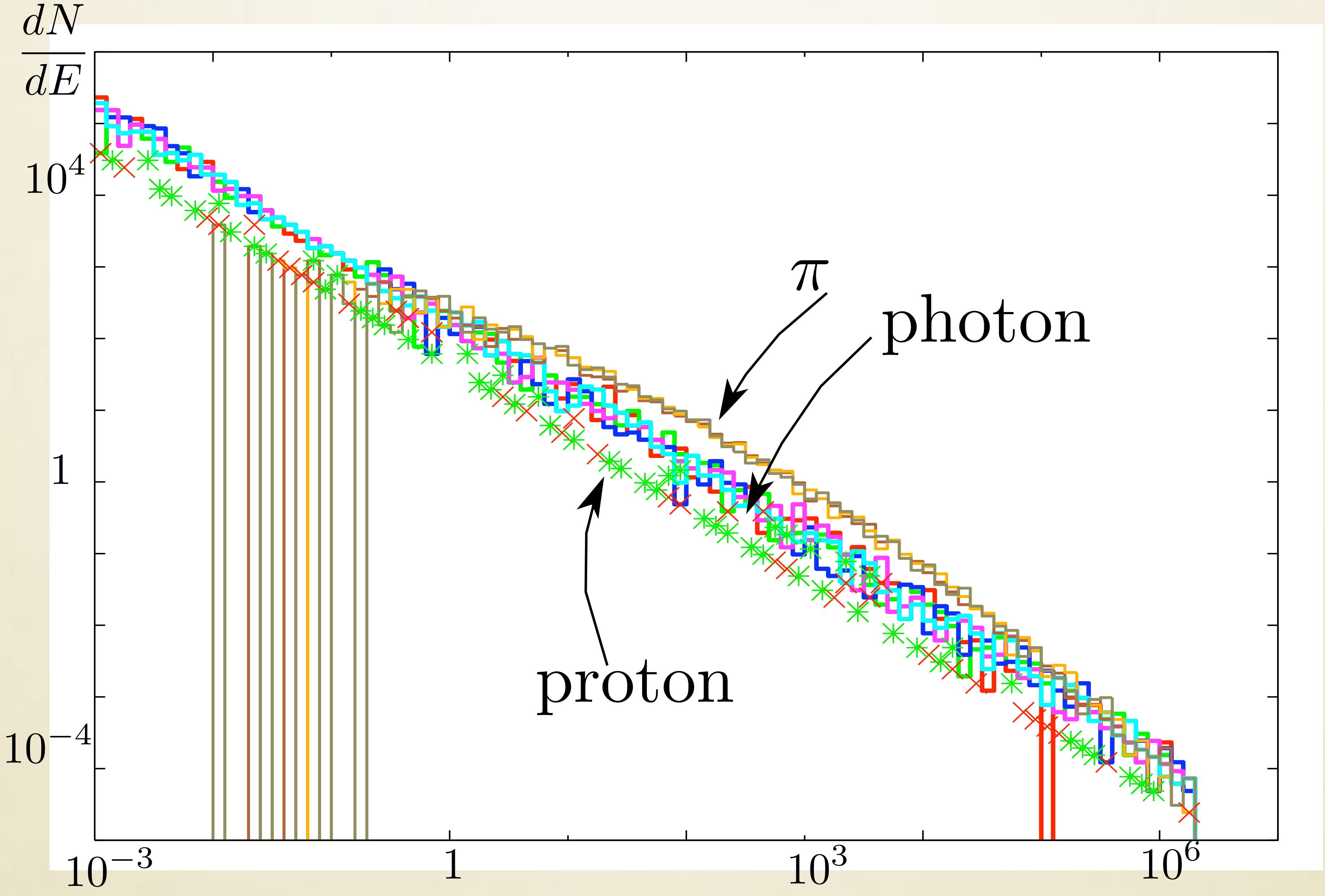


10^{20} eV $E_{min}=2\times10^{15}$ eV; 1534303 ptcls

cpu#	cpuPW	Sum E	# of ptcls
1	1.0	0.9827795E+08	1535
2	1.0	0.9827795E+08	1536
3	1.0	0.9827795E+08	1536
4	1.0	0.9827795E+08	1536
5	1.0	0.9827795E+08	1535
		...	
995	1.0	0.9827795E+08	1536
996	1.0	0.9827795E+08	1536
997	1.0	0.9827795E+08	1536
998	1.0	0.9827795E+08	1536
999	1.0	0.9827795E+08	1535

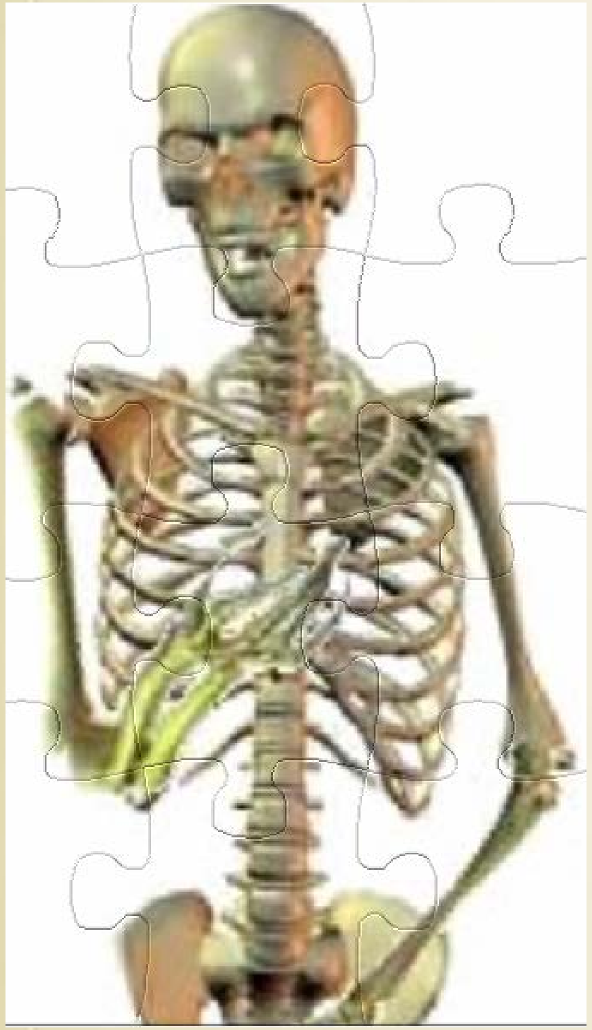


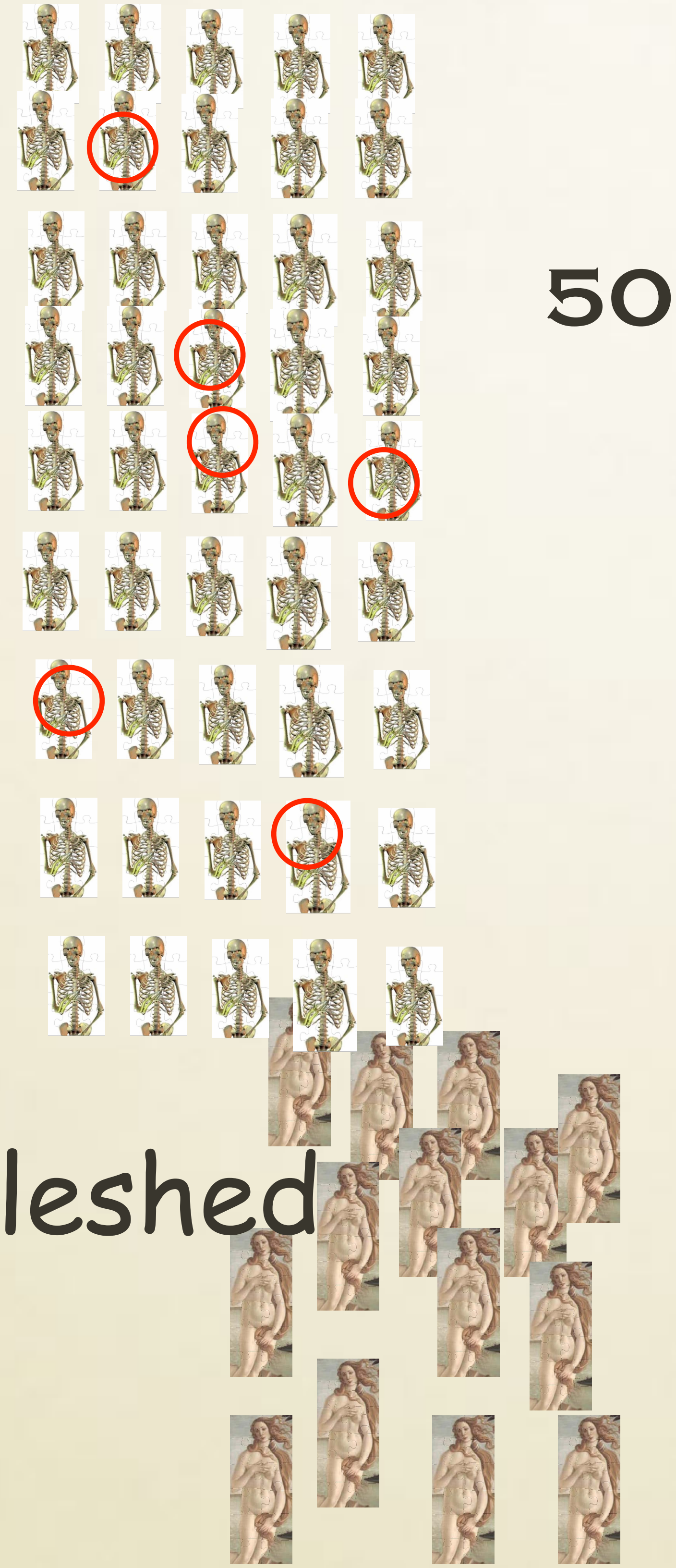
Energy spectrum in each sub-skeleton



Kinetic energy (GeV)

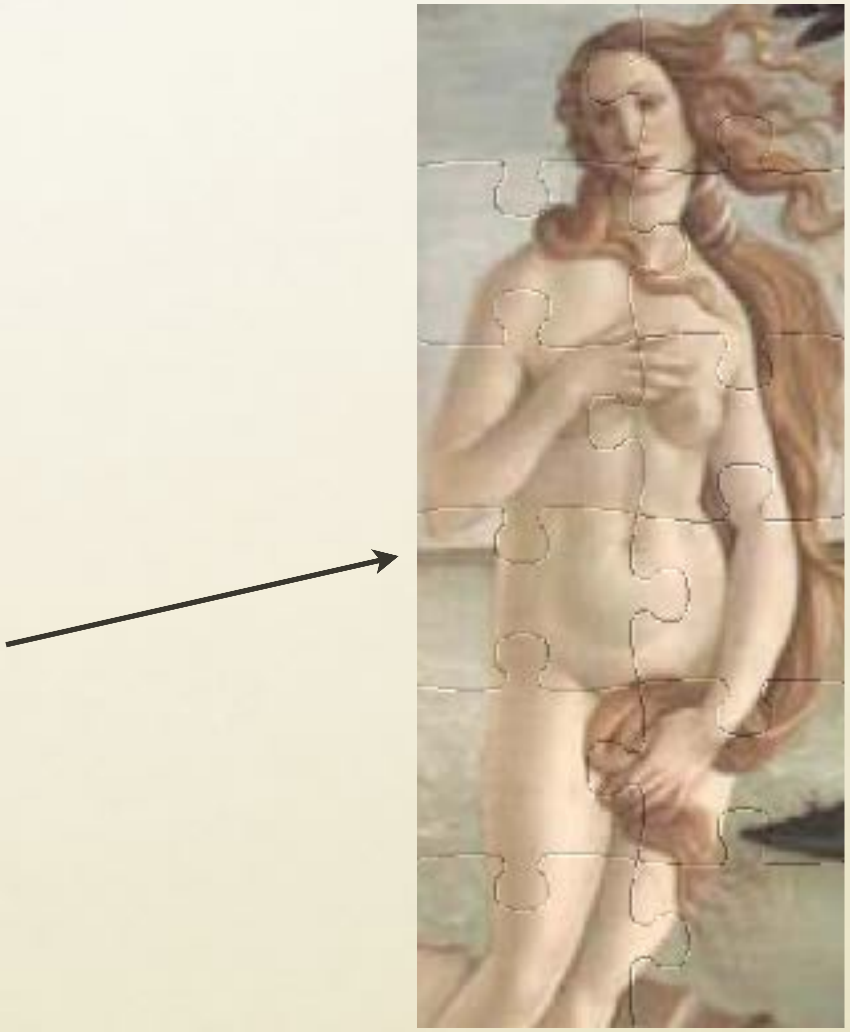
Virtual (Quasi) Full M.C at 10^{20} eV





500 skeleons

50's are fleshed



Assemble Thinning

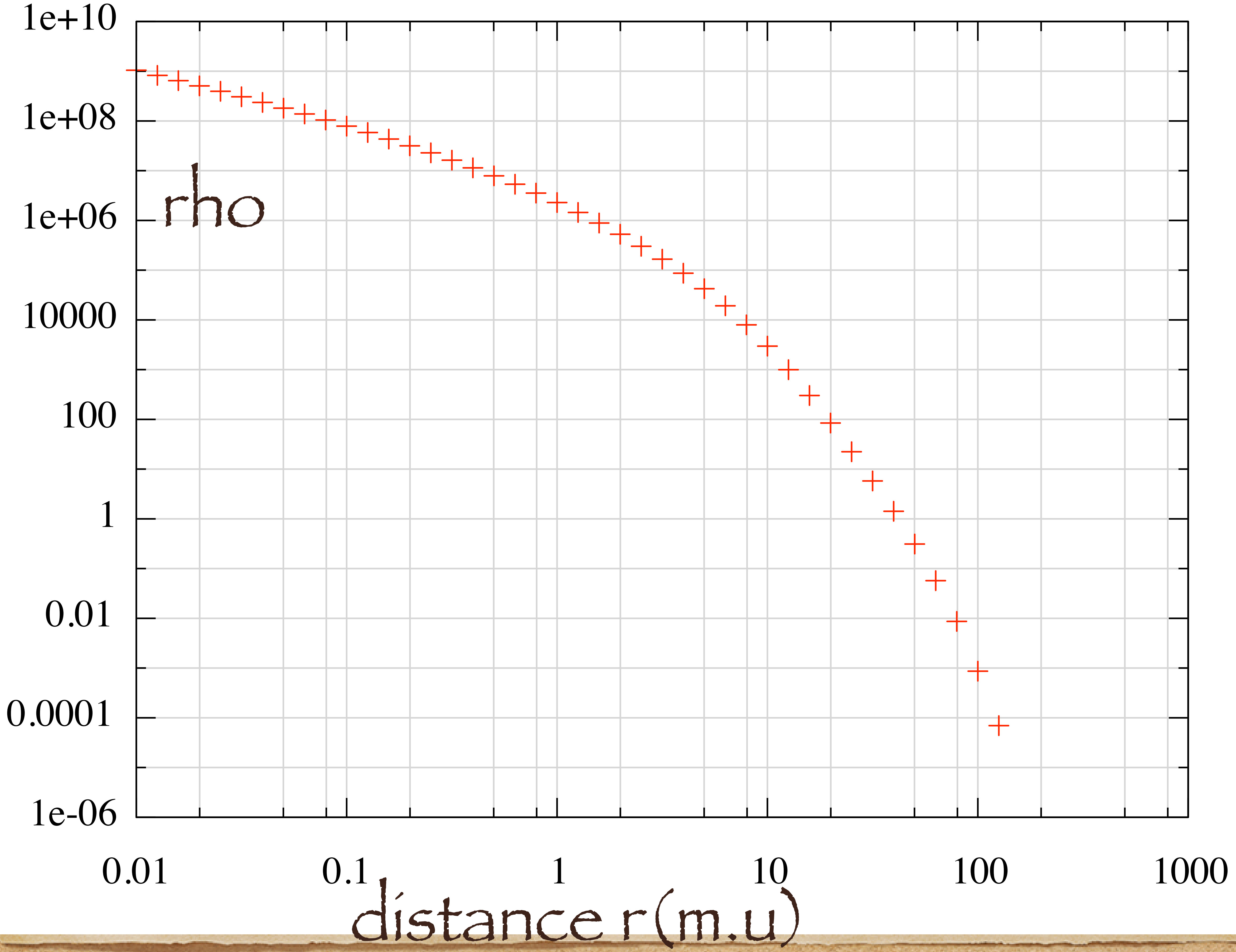
No weighted ptcl's

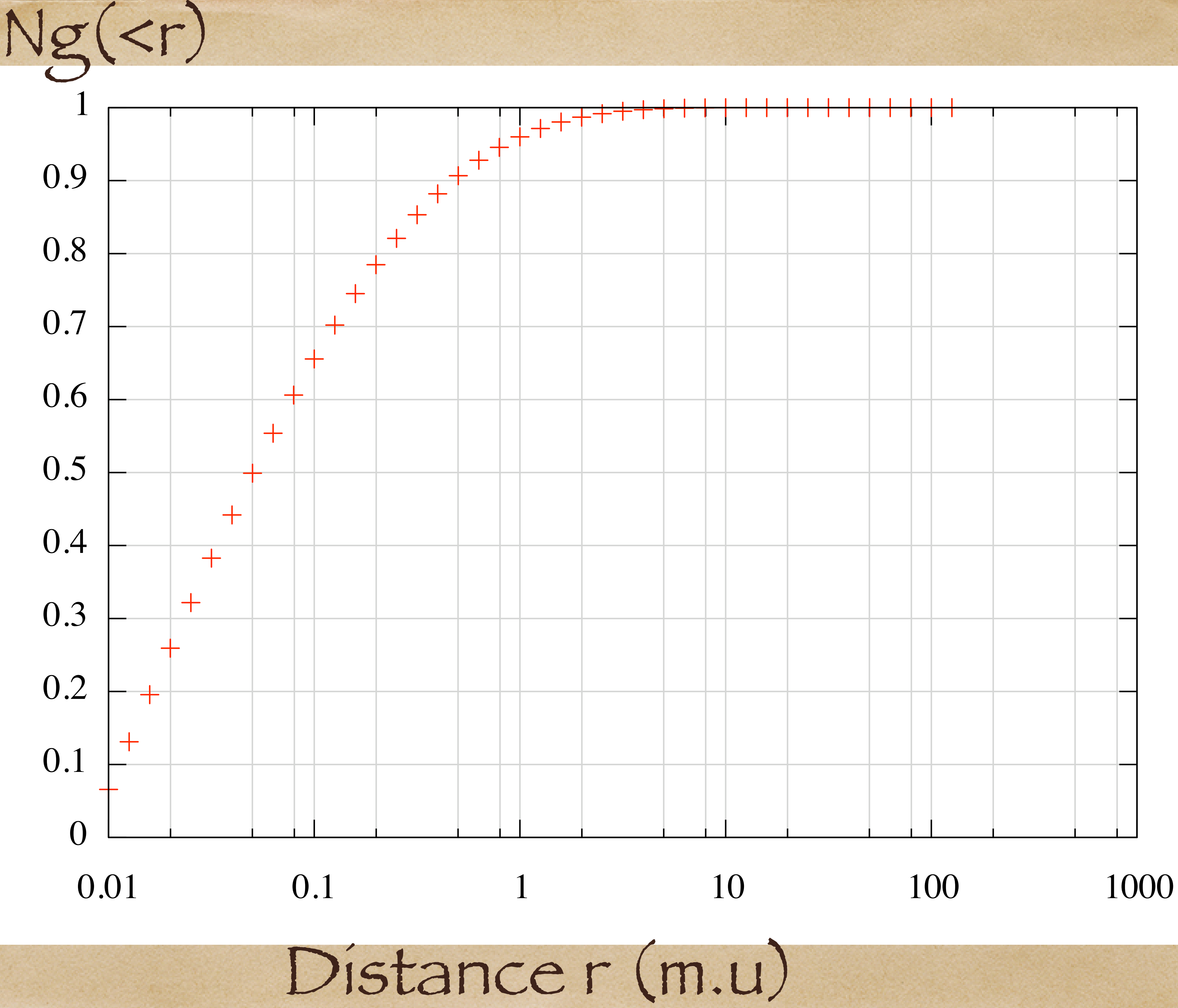
- (Virtual) Full M.C with Emin=500 keV is possible at the GZK energies.
- One or at most several showers with a given primary energy and angle
- Actually we need ~10^3 showers for a given condition

Is such a small number of showers valuable ?

yes !

- Thin sampling for transition: 10^3 showers
- Particle properties can be extracted from F.M.C results
- Model dependence: difference of particle numbers and transition


1e+10
1e+08
1e+06
10000
100
1
0.01
0.0001
1e-06
rho
0.01
0.1
1
10
100
1000
distance r(m.u)

Ng(<r)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.1
1
10
100
1000
Distance r (m.u)

Particle decay

- The concept of decay constant:

  The density of atmosphere at height, h, is roughly expressed as

  $$\rho = \rho_0 e^{-\frac{h}{h_0}}$$

  Since the atmospheric depth, z, is also roughly proportional to ρ, it is also such a function. h_0 is called the scale height of the atmosphere and can be regarded as a measure to express the thickness (height) of the atmosphere.

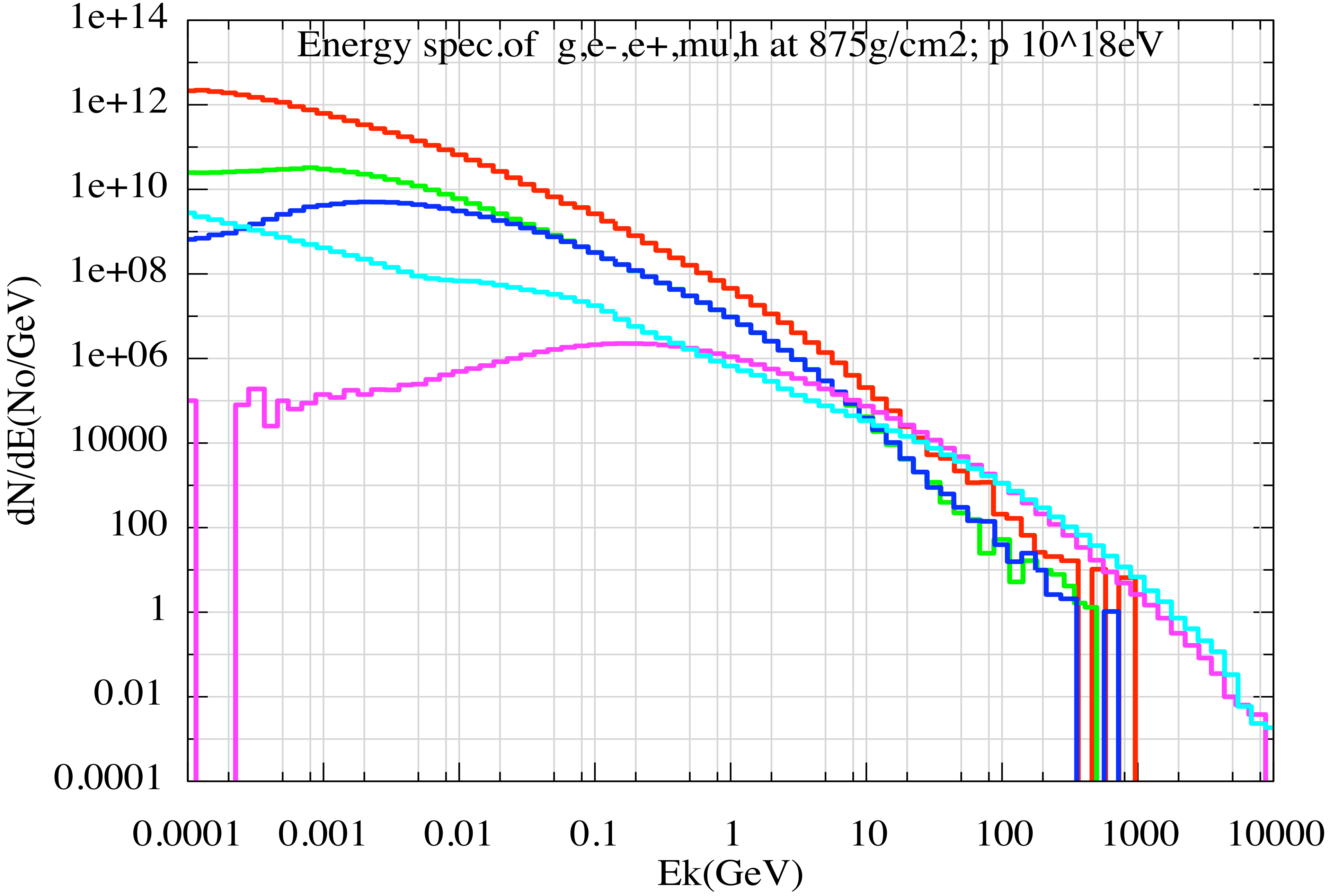
  The value of h_0 is $6.5 \sim 8.5$ km, although it should be constant for an ideal isothermal atmosphere (kT/Mg).

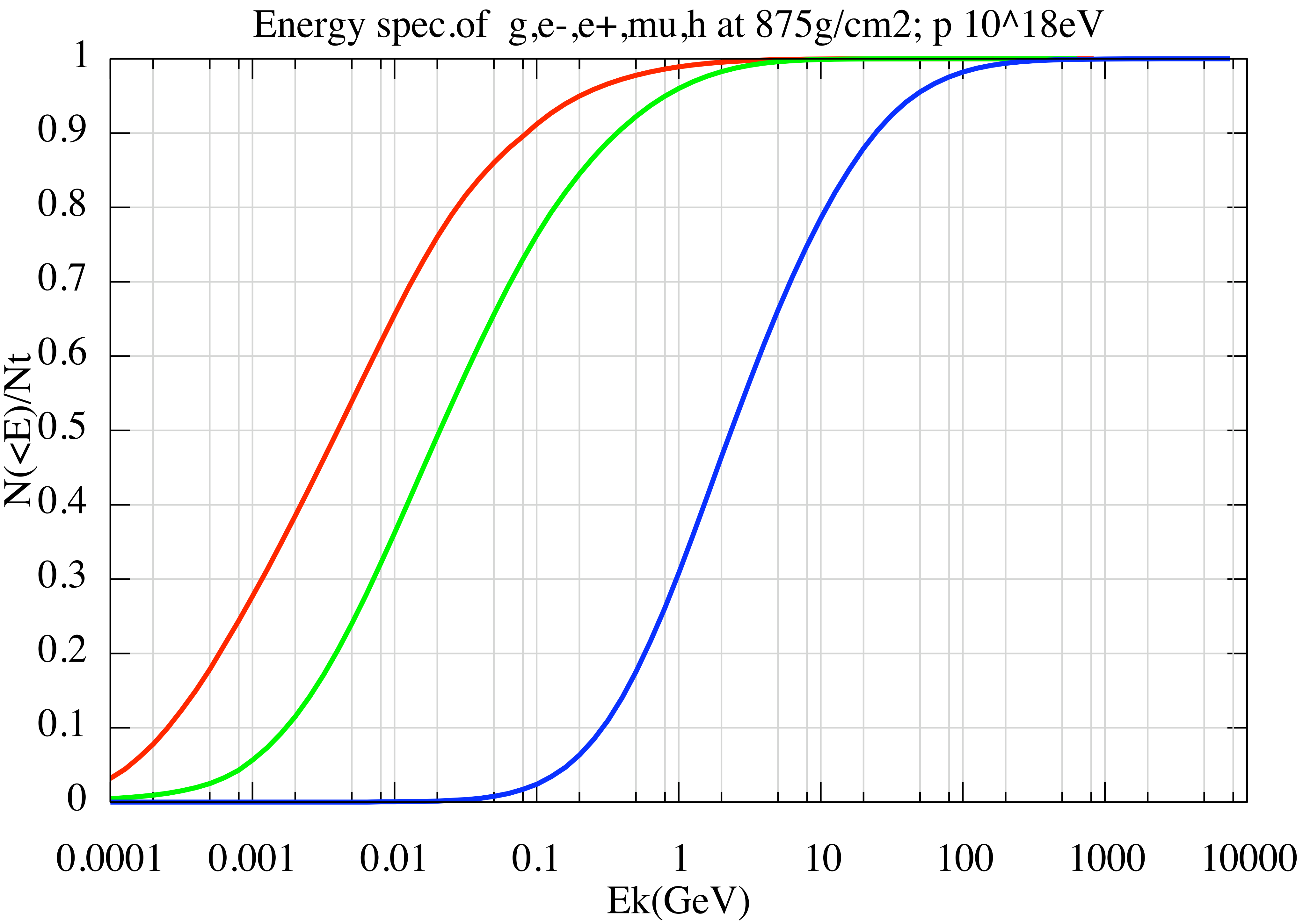
  Suppose a particle of mass m, proper decay time τ runs in the atmosphere with momentum, p (gamma factor γ and $\beta = 1 - 1/\gamma^2$). If $h_0 > c\beta\gamma\tau$, the particle will tend to decay before reaching the earth surface. While if $h_0 < c\beta\gamma\tau$, it will difficult for the particle to decay. Since $p = m\gamma\beta c$, $h_0 = c\beta\gamma\tau$ is re-written as $h_0 = p\frac{\tau}{m}$ or $p = h_0\frac{m}{\tau} \equiv b$. If $p > b$, the particle decay is less probable. b is called the decay constant. At high energies we may regard momentum as energy, and we may express it in energy. Some important rough numbers:

	mass (GeV)	$c\tau$ (m)	b (GeV)
μ	0.1	600	1.5
$\pi^{\pm}$	0.14	8	150
π^0	0.14	25×10^{-9}	5×10^{19}(eV)
K$^{\pm}$	0.5	4	500

Some conclusions from this table:

- Muon energy spectrum bends below few GeV.
- Since major muon source is π, muon spectrum tends to steepen over 150 GeV. Major source changes to K.
- At ultra high energy, even π^0 cannot decay and tends to collide with air. No source of high energy photons so that the LPM will not work efficiently in proton primary showers.


Energy spec.of g,e-,e+,mu,h at 875g/cm2; p 10^18eV
dN/dE(No/GeV)
1e+14
1e+12
1e+10
1e+08
1e+06
10000
100
1
0.01
0.0001
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
Ek(GeV)


Energy spec.of g,e-,e+,mu,h at 875g/cm2; p 10^18eV
N(<E)/Nt
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
Ek(GeV)