Accelerator Data and High Energy Cosmic Rays

Paolo Lipari
ISVHECRI 2010
Fermilab 28th June 2010

1. Introduction

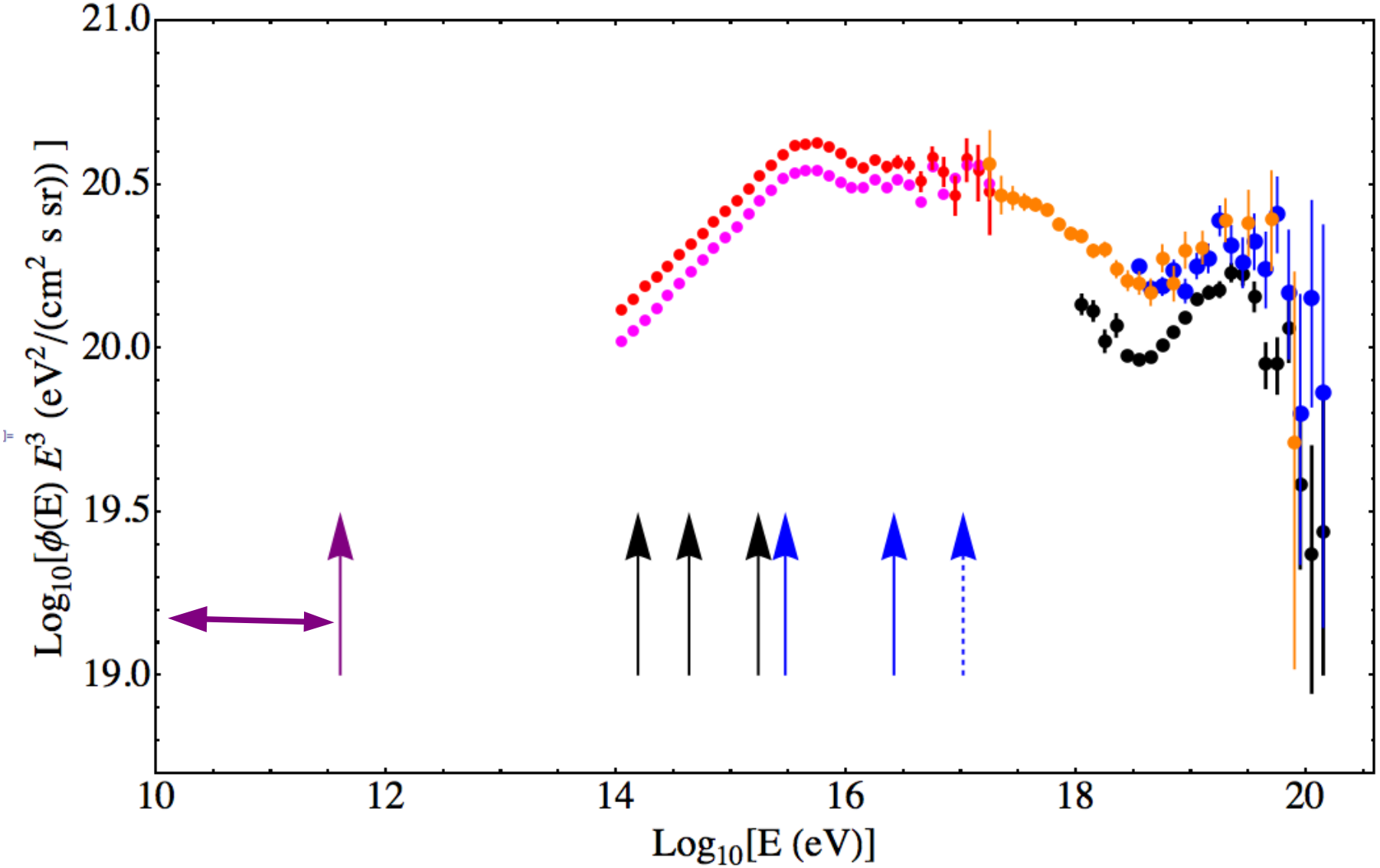
2. Phenomenology of Ultra High Energy Cosmic Rays

3. The total and elastic pp cross section

4. Properties of particle production

5. Learn about hadronic interactions with Cosmic Rays ?

6. Conclusions

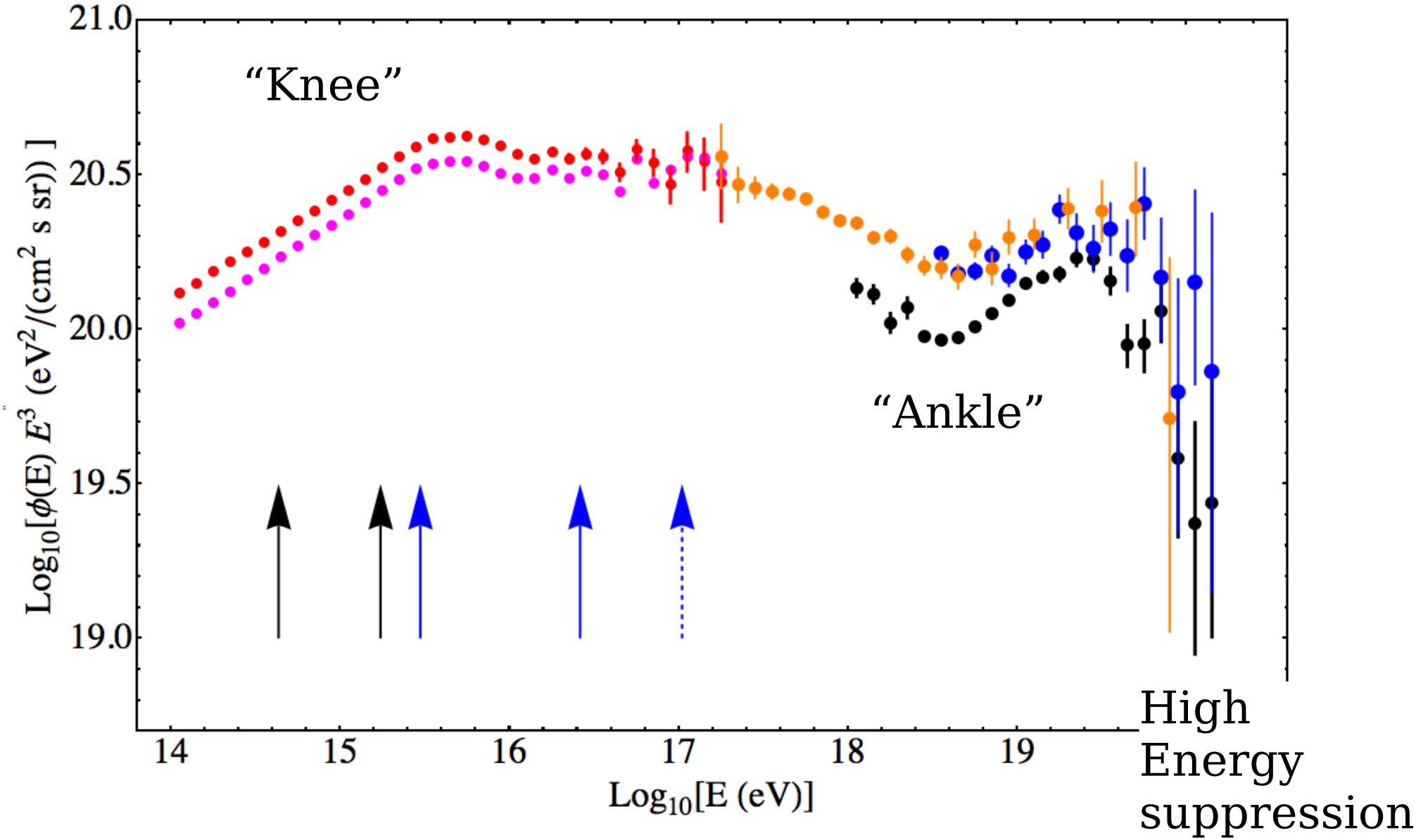


Fixed Target

Cern Tevatron

LHC

Structure in the energy spectrum



Importance of a mass composition measurement.

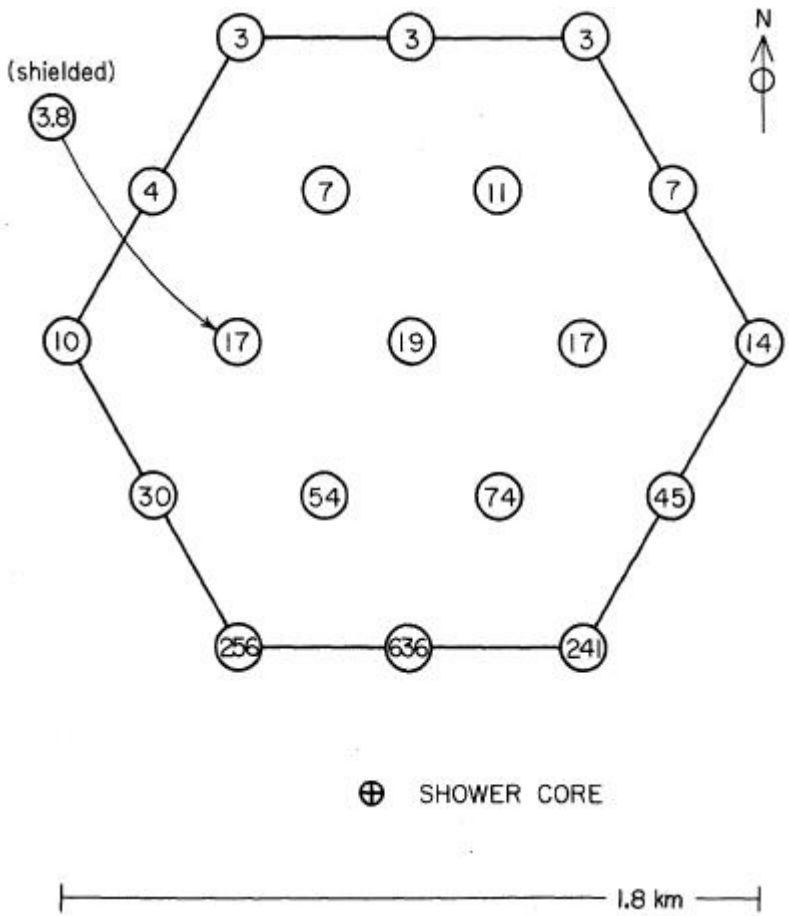
PHYSICAL REVIEW LETTERS

~50 years of UHECR

EXTREMELY ENERGETIC COSMIC-RAY EVENT*

John Linsley, Livio Scarsi,† and Bruno Rossi
Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received April 12, 1961)

Energy



it follows on any reasonable shower model that the energy of the primary particle was about 10^{19} ev. Taking the usual estimate 3×10^{-6} gauss for the galactic magnetic field, one finds the radius of curvature of the path of a proton of such energy to be about 10^4 light years. Since, according to current estimates, the radius of the galactic halo is only about five times this value, while the thickness of the galactic disk is about five or ten times smaller, it seems certain that the primary particle acquired its energy outside our galaxy.

An important question is whether the primary particle was a proton or a heavier nucleus.

Mass A

Hadronic interaction Modeling

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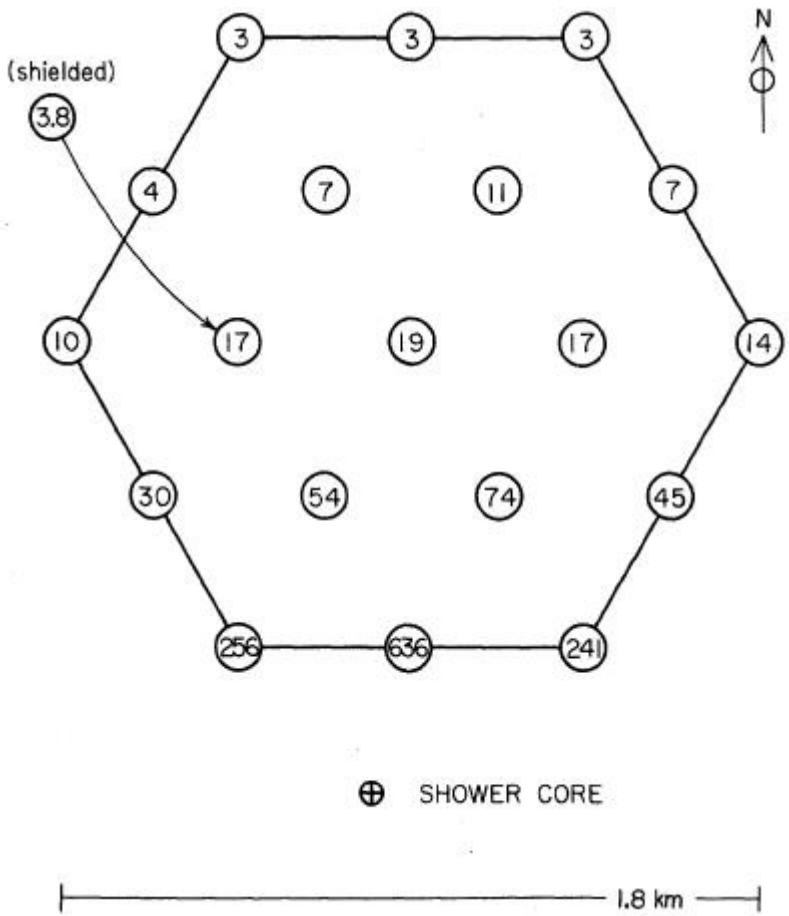

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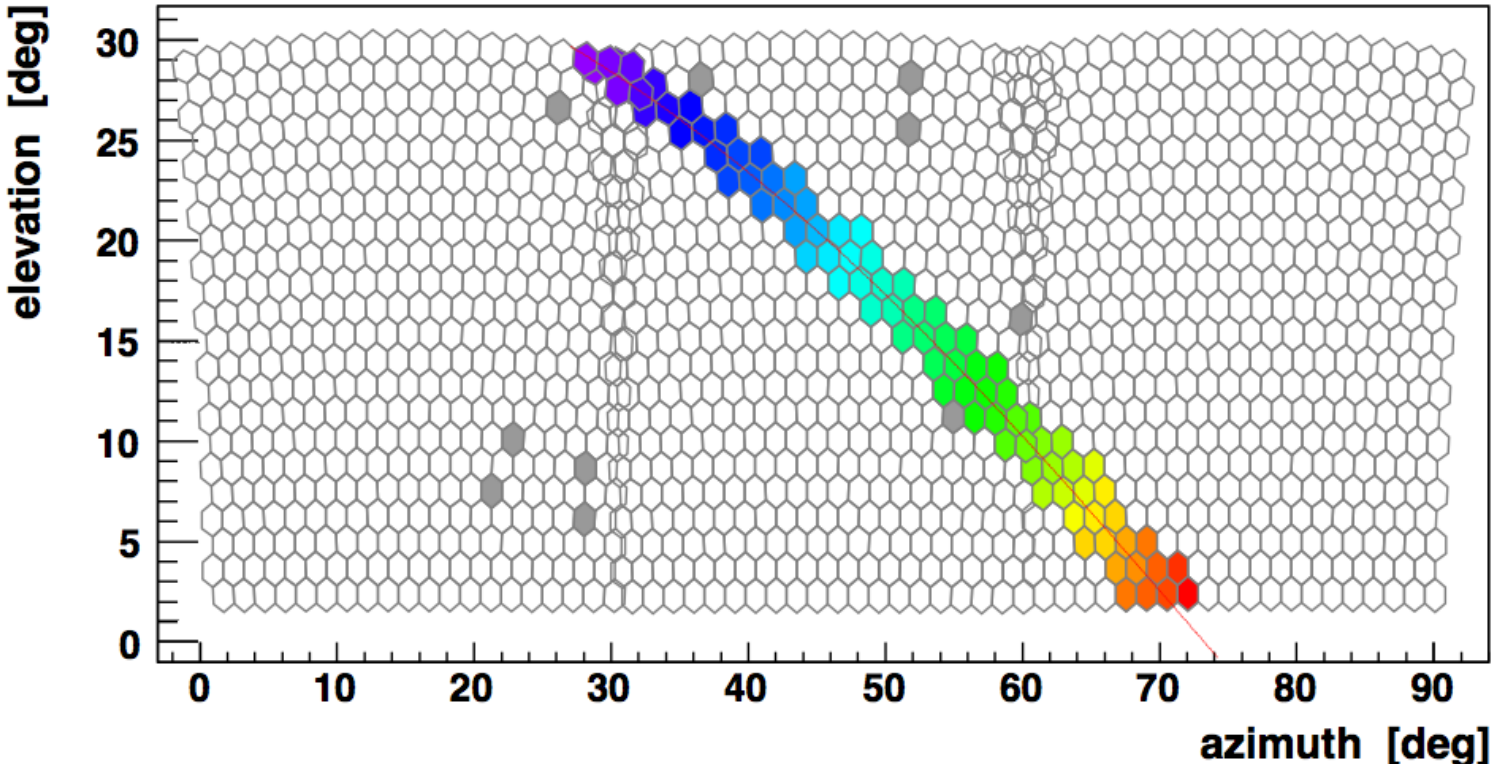
Mass A

Hadronic interaction Modeling

MUONS

Measure a single slice of the shower at the ground

Energy measurement problem “solved”: “Fly's Eye”

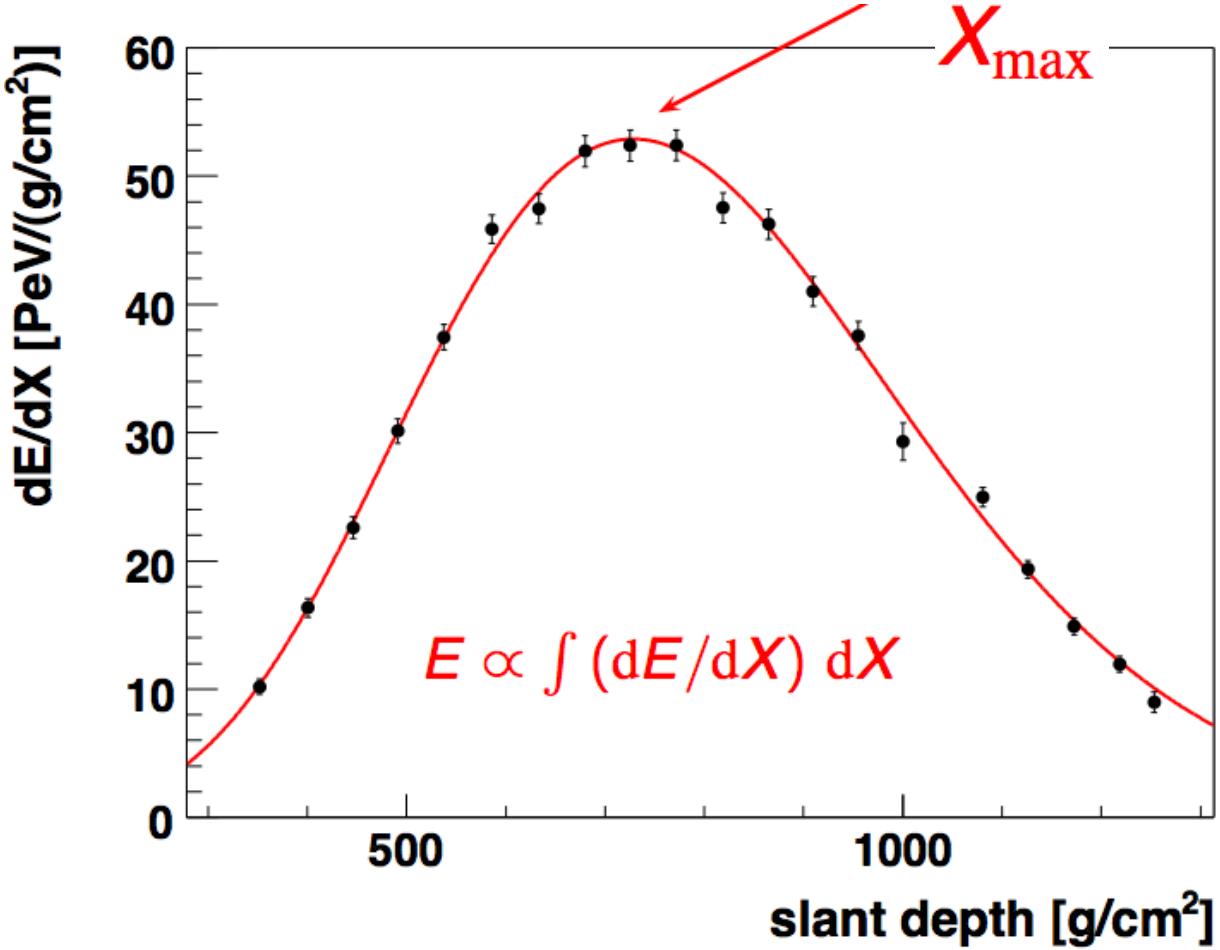


$$L(\Omega) \rightarrow F_\gamma(X) \rightarrow N_{e^\pm}(X)$$

Observed Light → Emitted Photons → Shower Size

Geometry
Atmospheric
Absorption

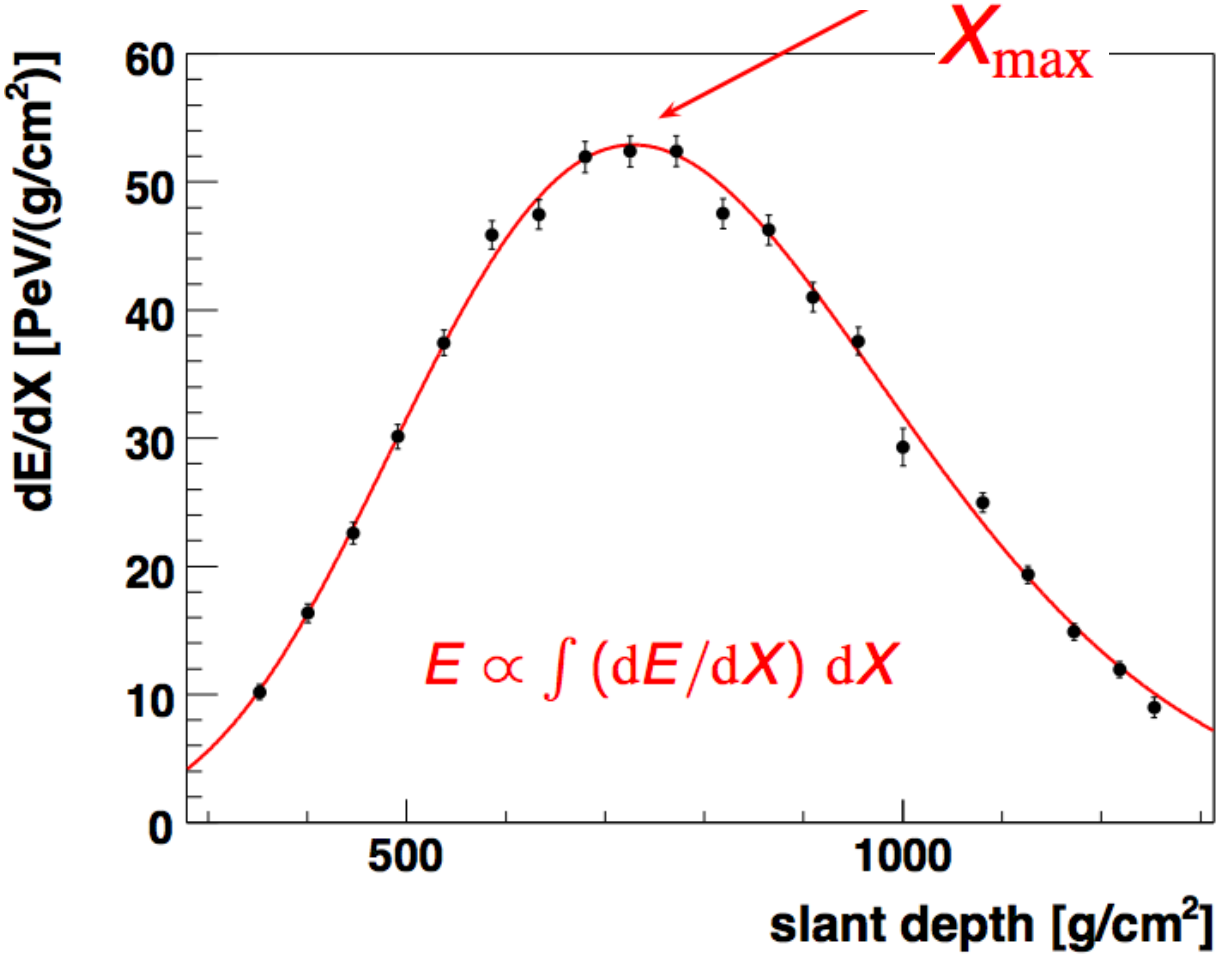
Fluorescence
Yields



$$E_{\text{ionization}} = \int dX\; N_e(X) \left\langle -\frac{dE}{dX} \right\rangle$$

Small Model dependence

$$E_{\text{tot}} = E_{\text{ionization}} + E_\nu + E_\mu + E_{\text{ground}}$$

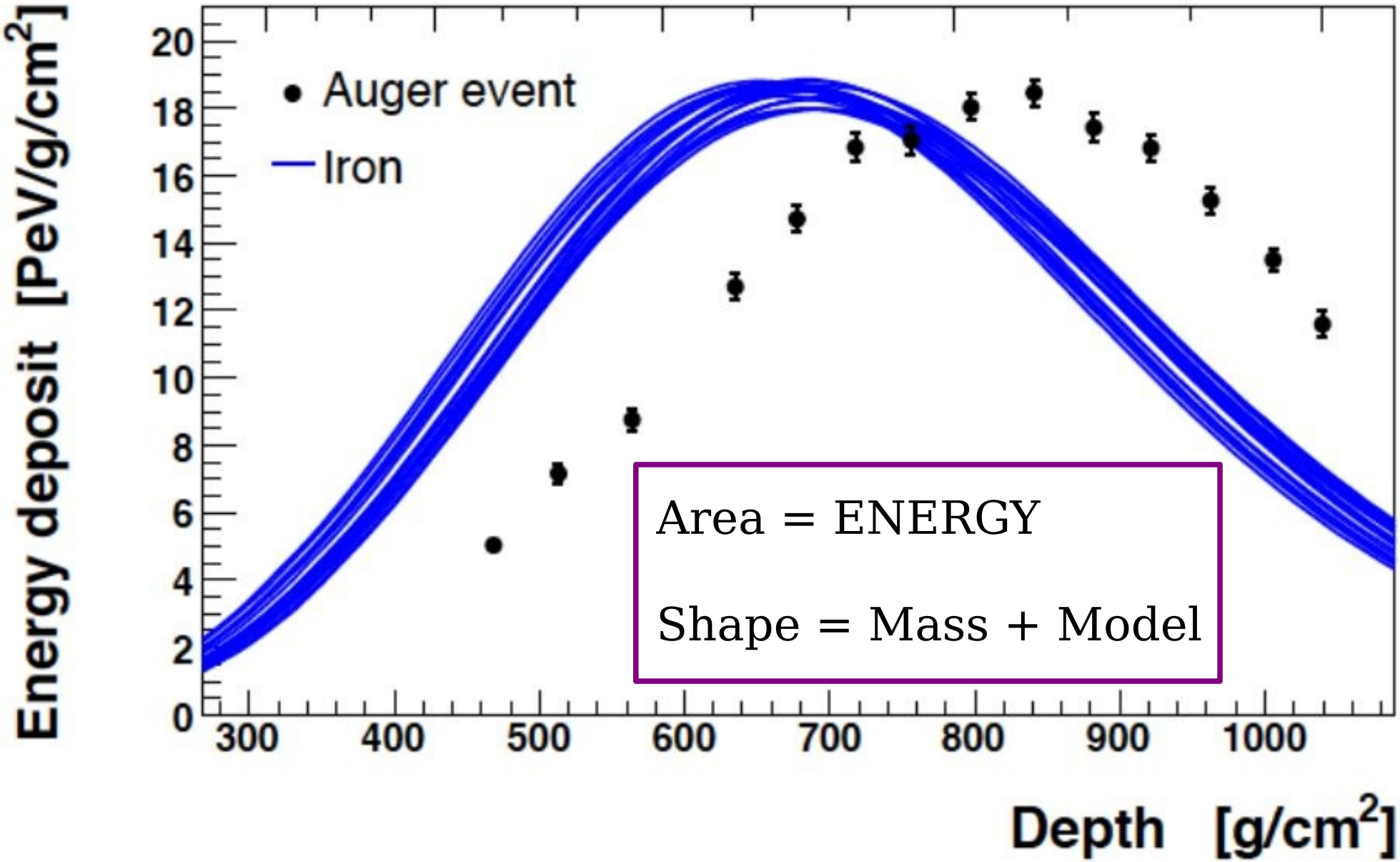


Area $\propto$ Energy

Shape depends on :

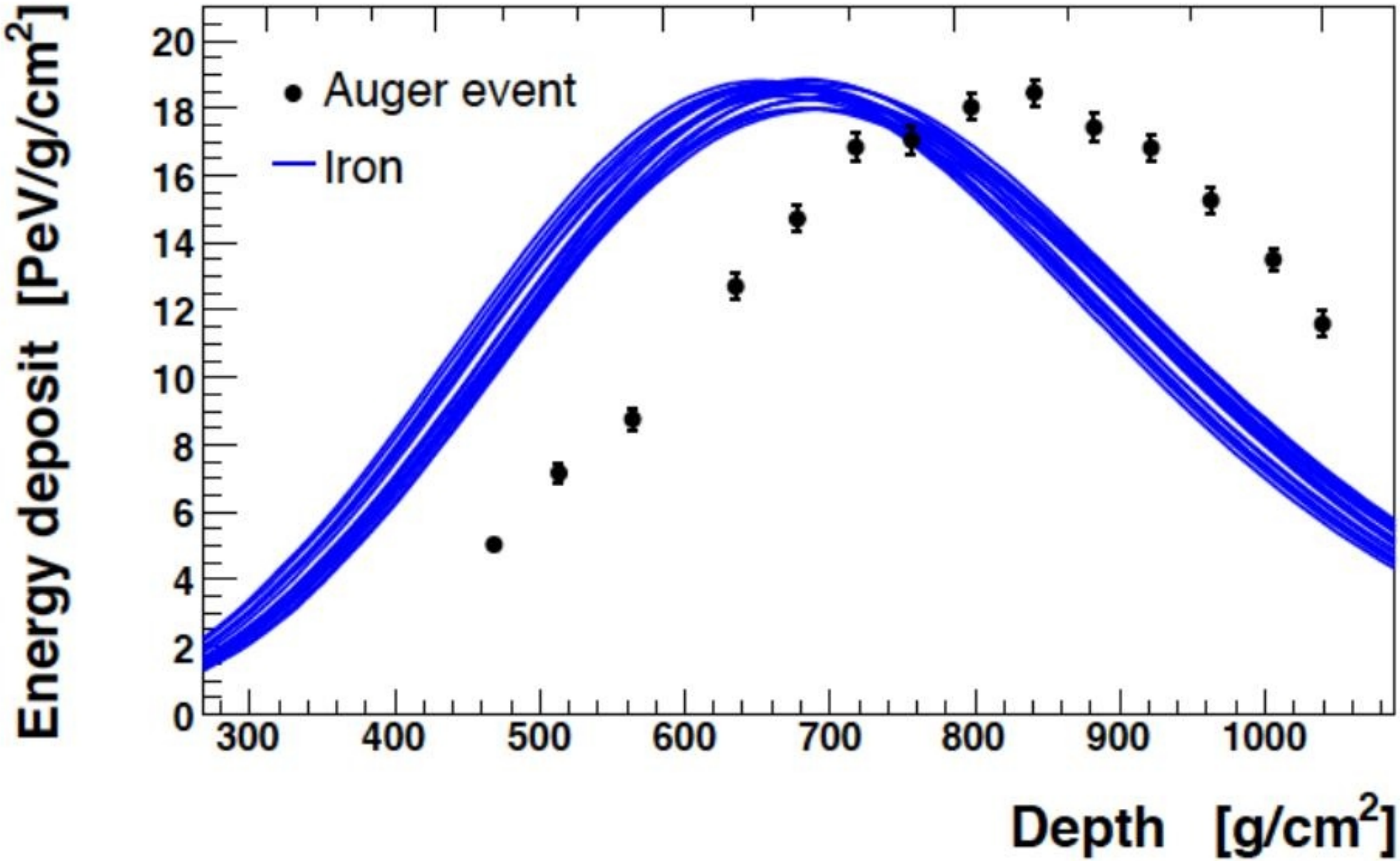
- Primary Identity
- Interaction Model

“Calorimetric” energy measurement



Area = ENERGY

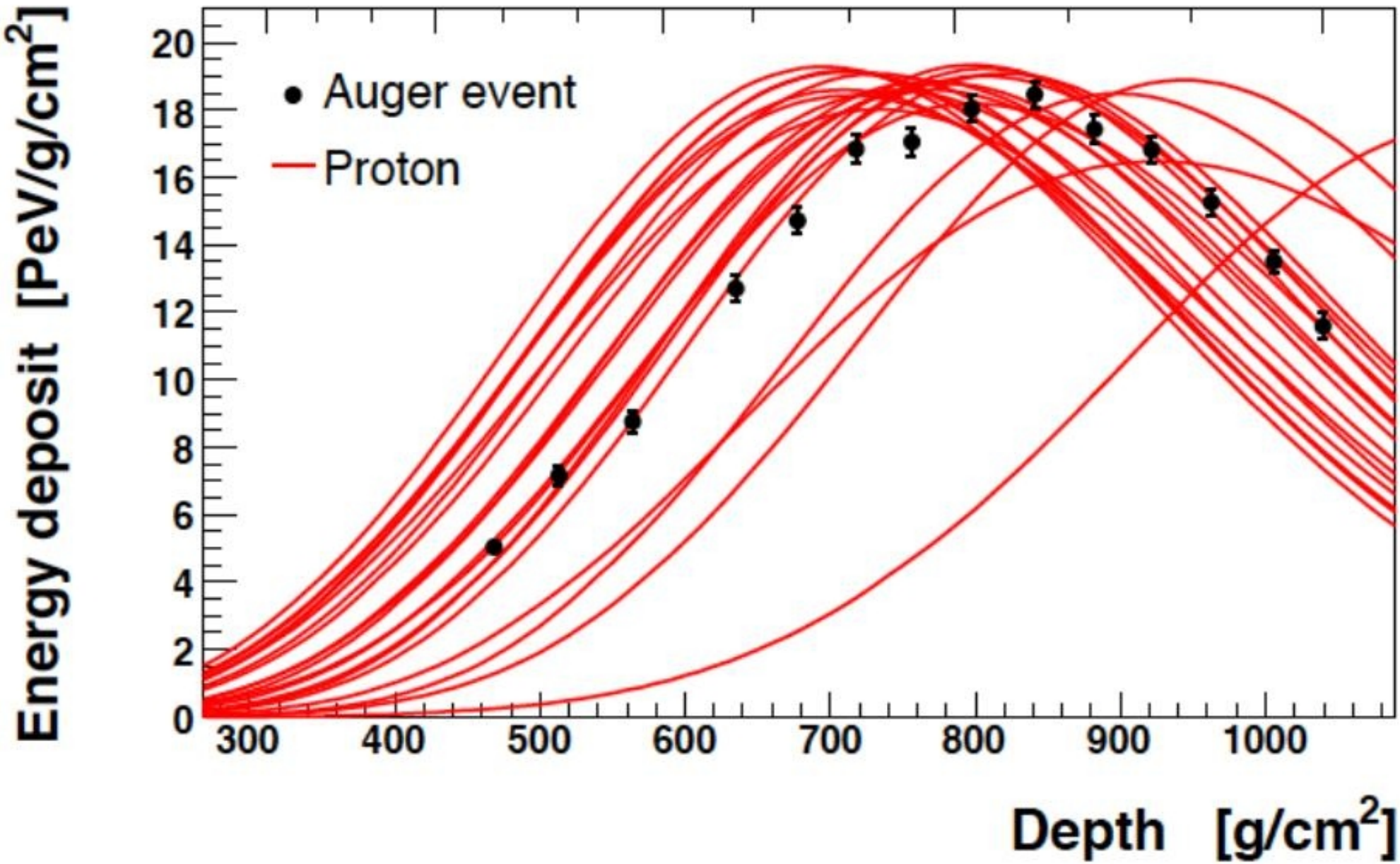
Shape = Mass + Model

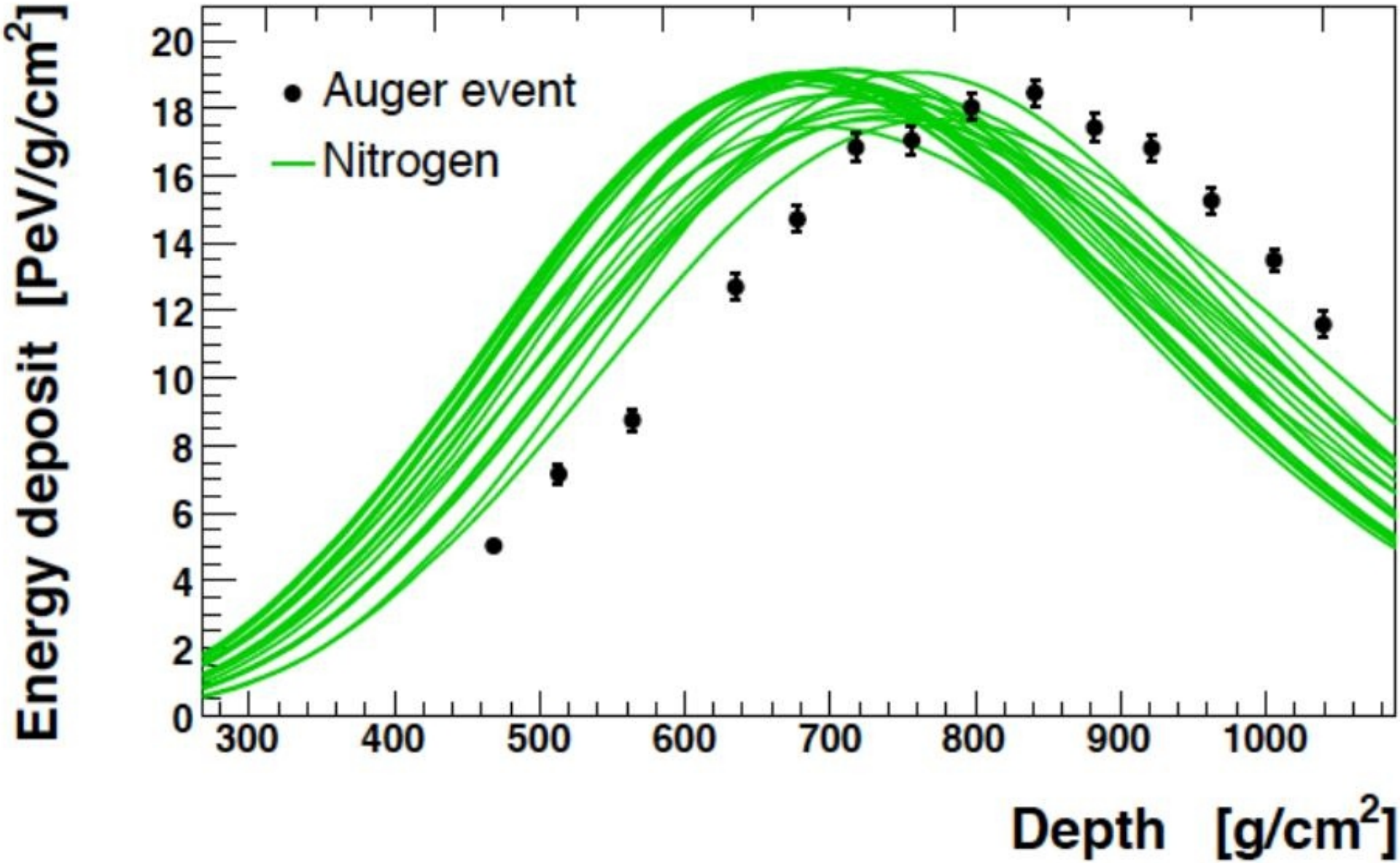


$E \simeq 10^{20}$ eV

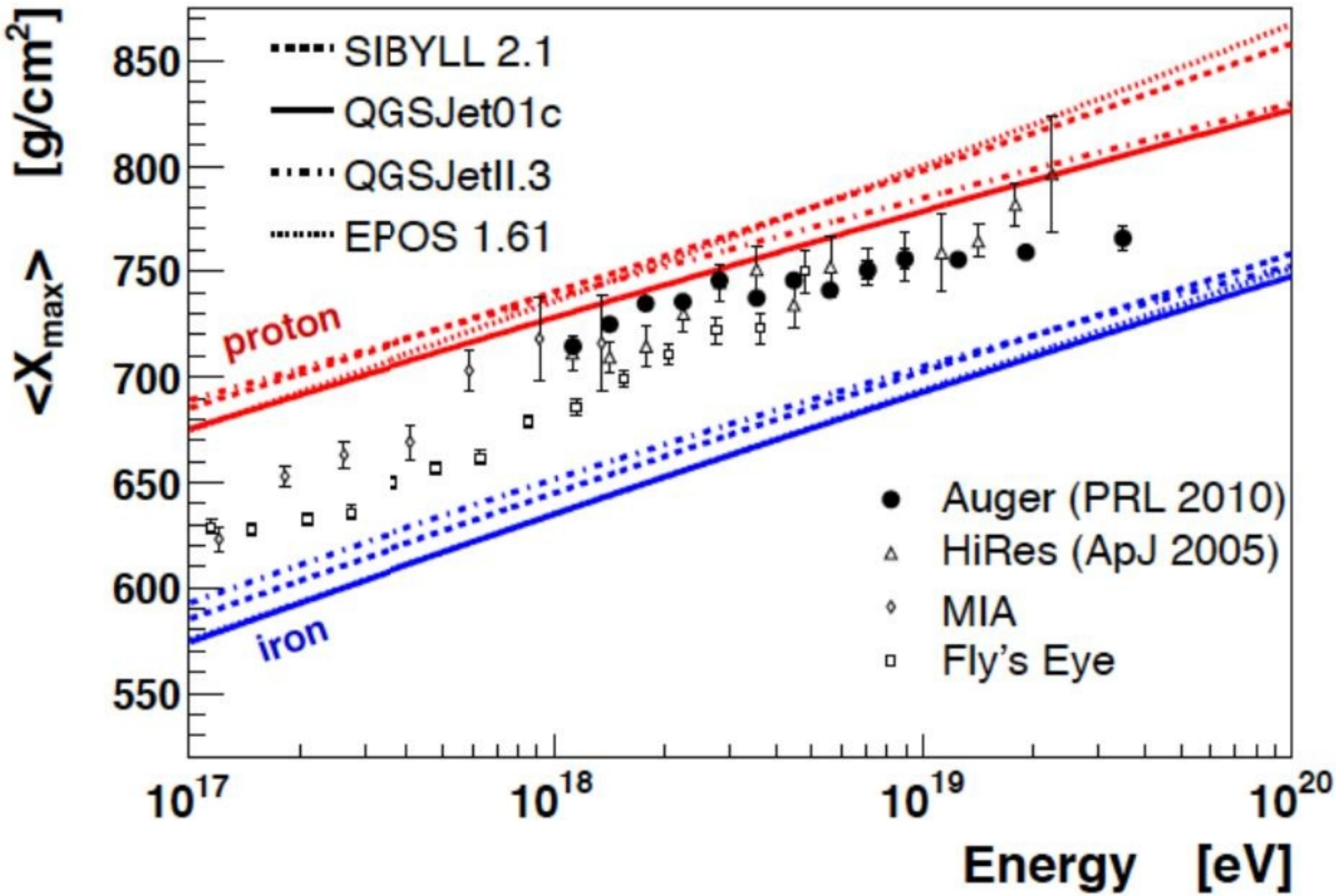
NOT an IRON nucleus
IF model is approximately correct

Proton showers: Deeper, larger fluctuations



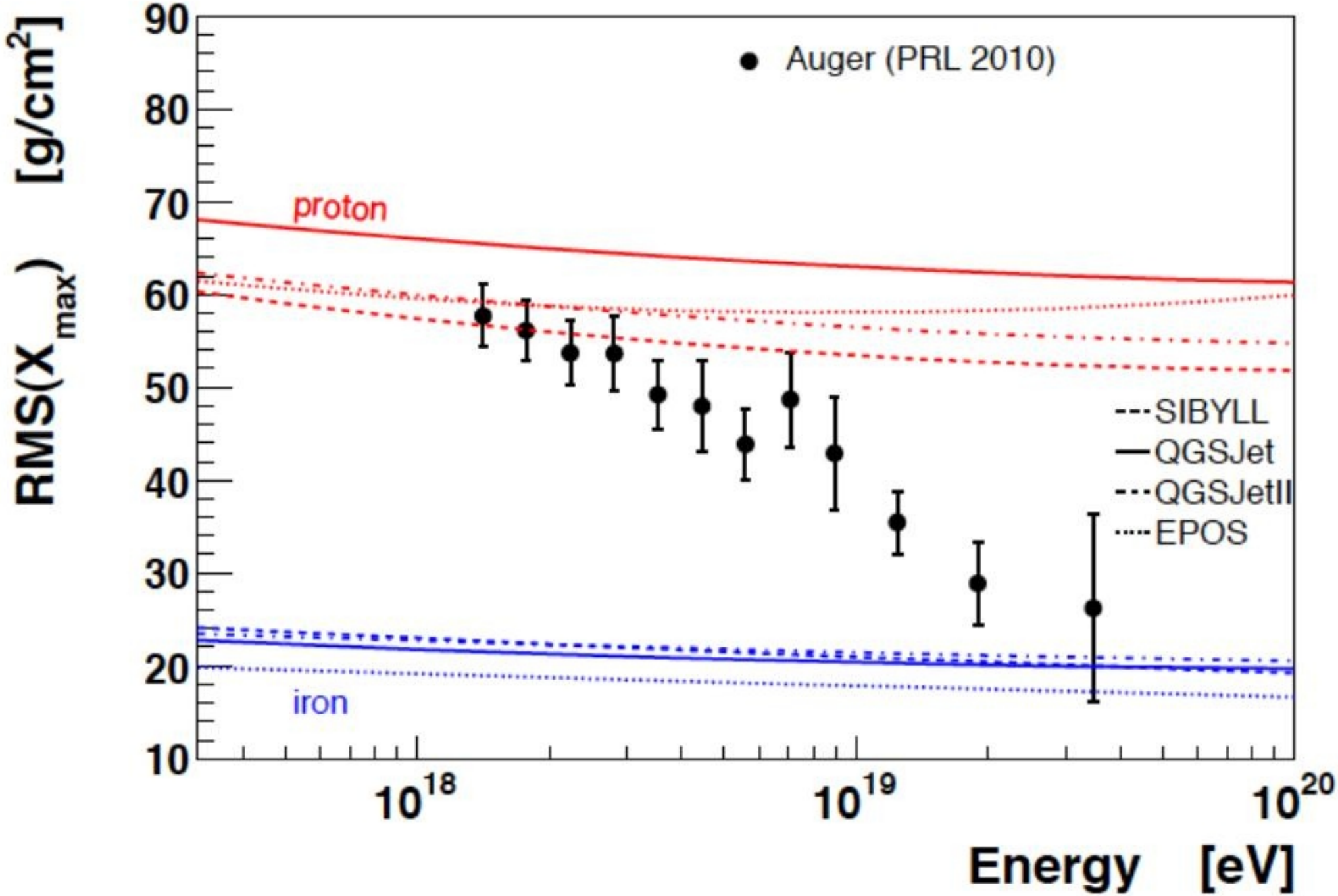

Auger event
Nitrogen
Energy deposit [PeV/g/cm^2]
Depth [g/cm^2]
0
2
4
6
8
10
12
14
16
18
20
300
400
500
600
700
800
900
1000

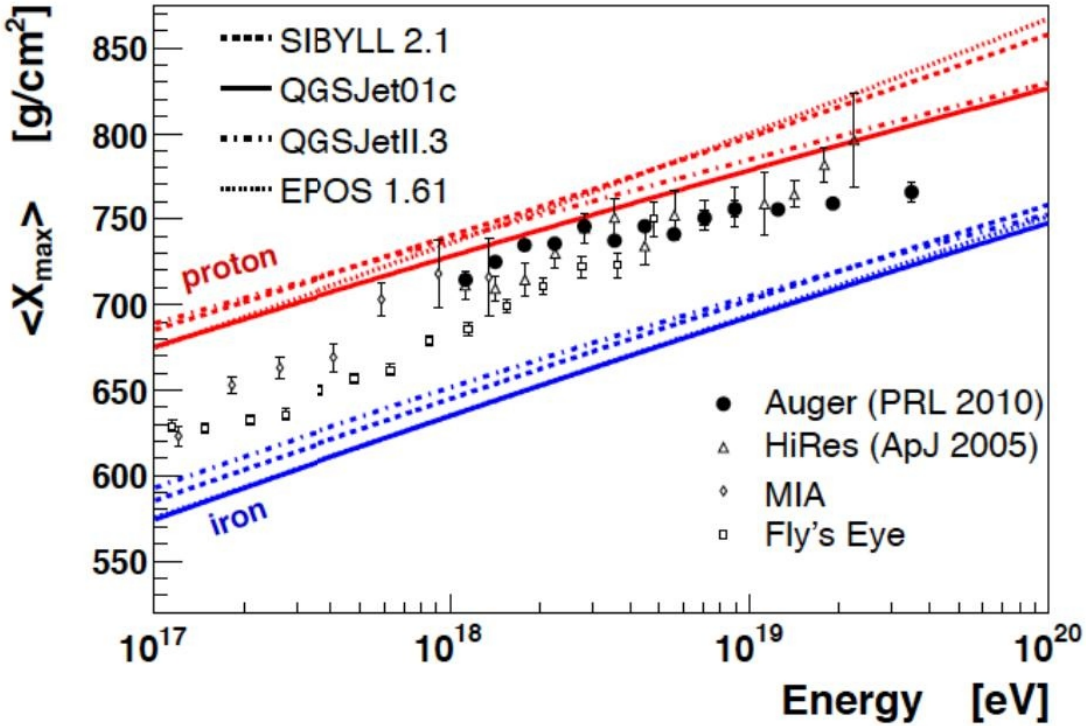
AUGER


SIBYLL 2.1
QGSJet01c
QGSJetII.3
EPOS 1.61
proton
iron
Auger (PRL 2010)
HiRes (ApJ 2005)
MIA
Fly's Eye
<Xmax> [g/cm2]
850
800
750
700
650
600
550
10^17
10^18
10^19
10^20
Energy [eV]

AUGER

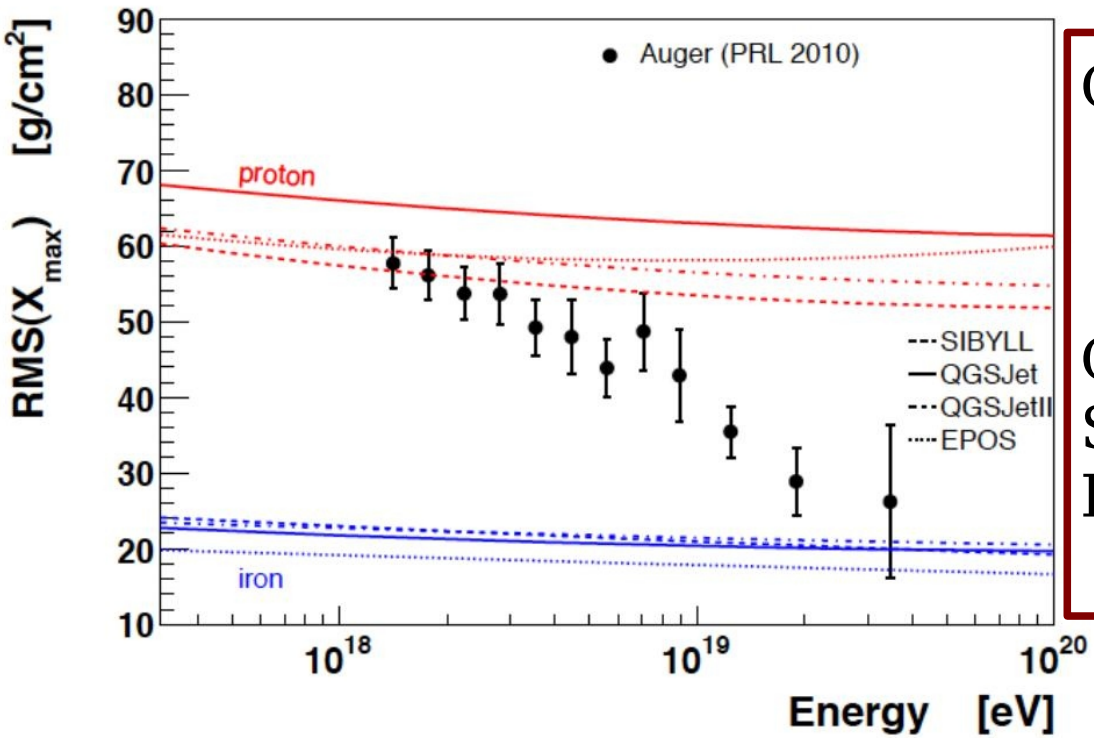
Shower fluctuations





Mass Composition
becoming heavy ?
at very high energy ?

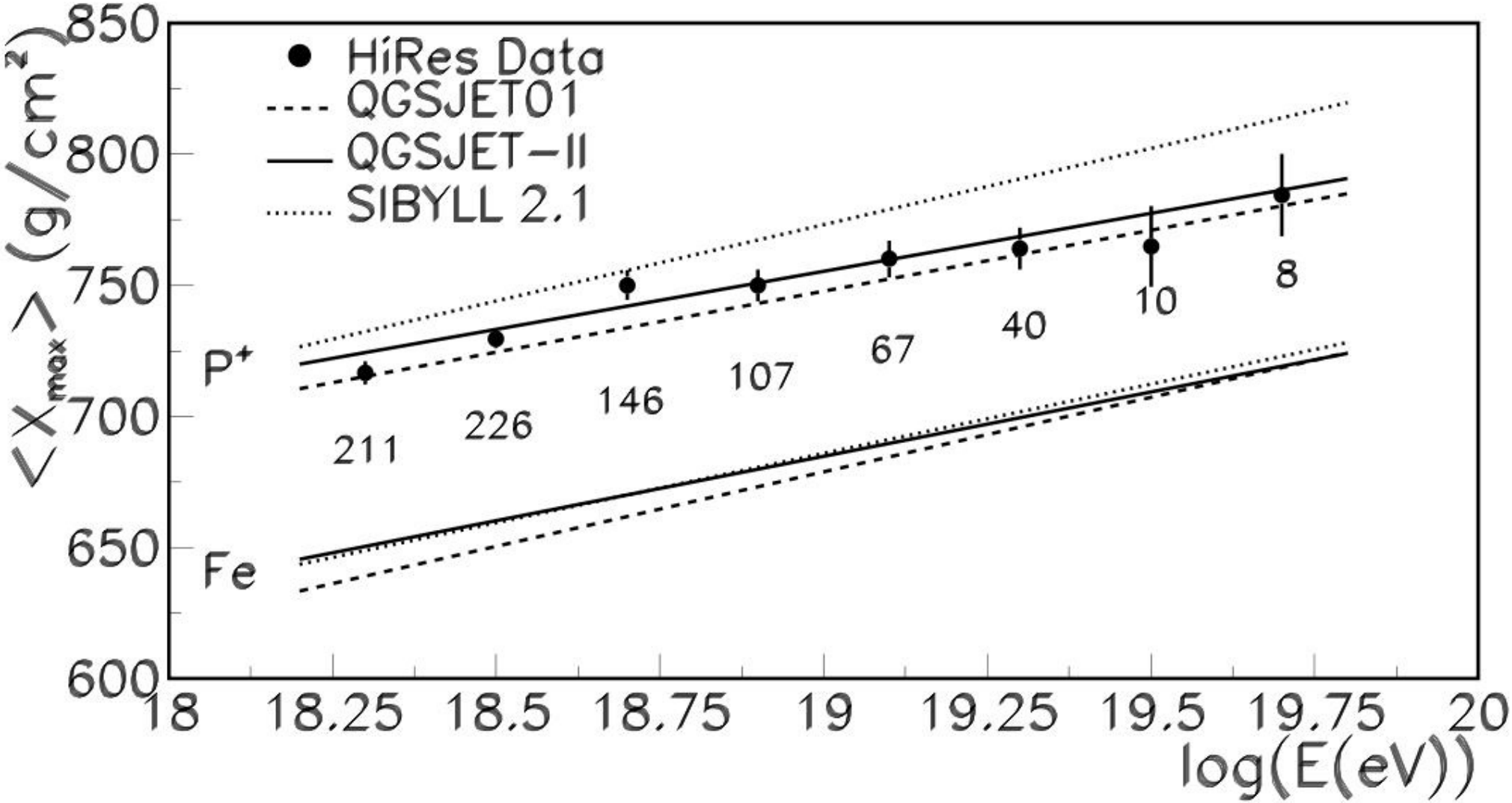
Significance would be
very important !
Constraints on the
structure and properties
of the astrophysical sources.



Observational controversy
NON confirmation
of HiRes

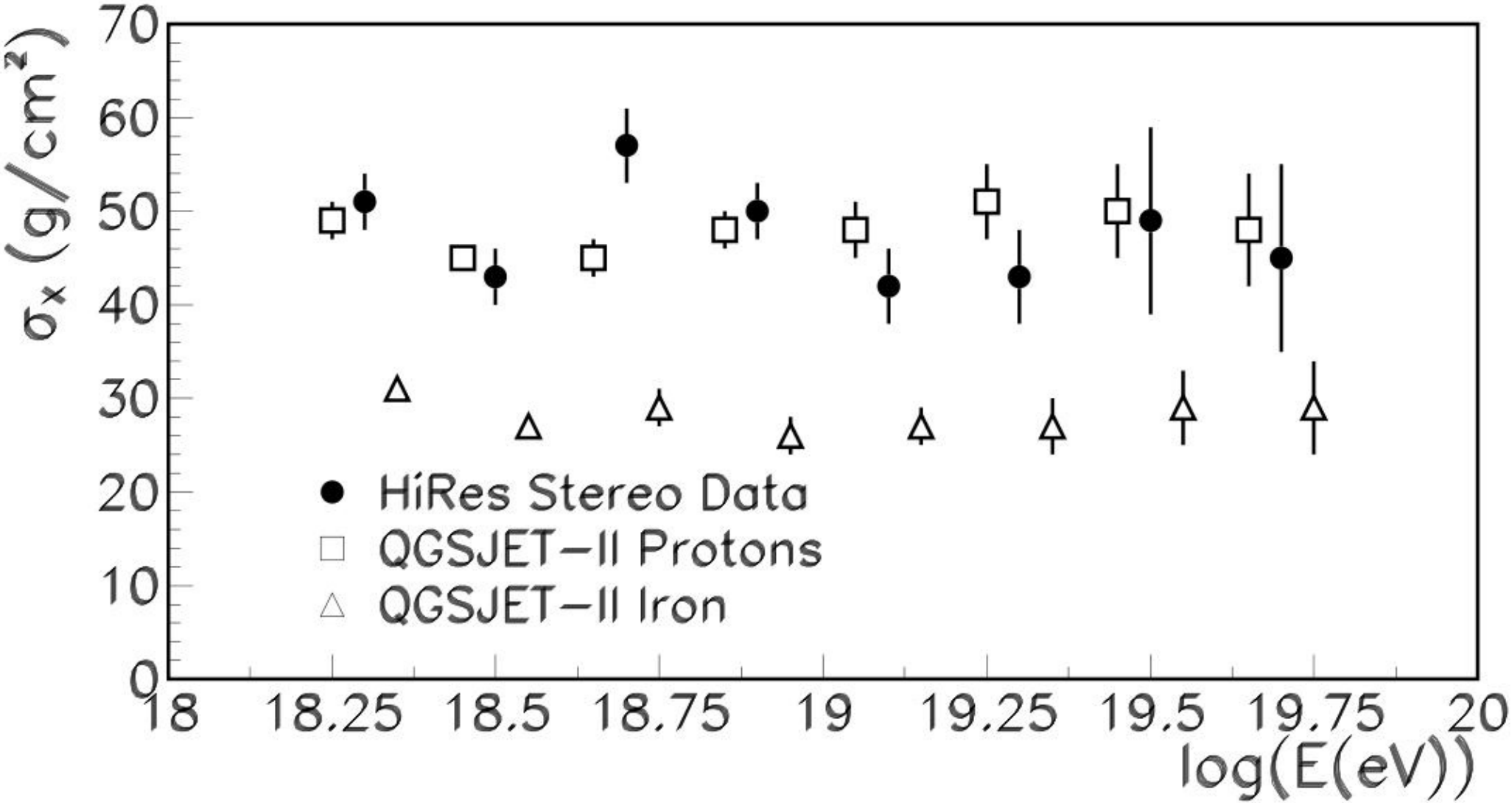
Correlation with sources
Small deviation in magnetic
Fields (Z < 3 ?)

HiRes 2009


HiRes Data
QGSJET01
QGSJET−II
SIBYLL 2.1
P+
Fe
211
226
146
107
67
40
10
8
850
800
750
700
650
600
18
18.25
18.5
18.75
19
19.25
19.5
19.75
20
log(E(eV))
<Xmax> (g/cm²)

HIRES 2009

Fluctuations on X_{max}



Overall comparison of Xmax data with QGSJET02 p and FE

HIRES

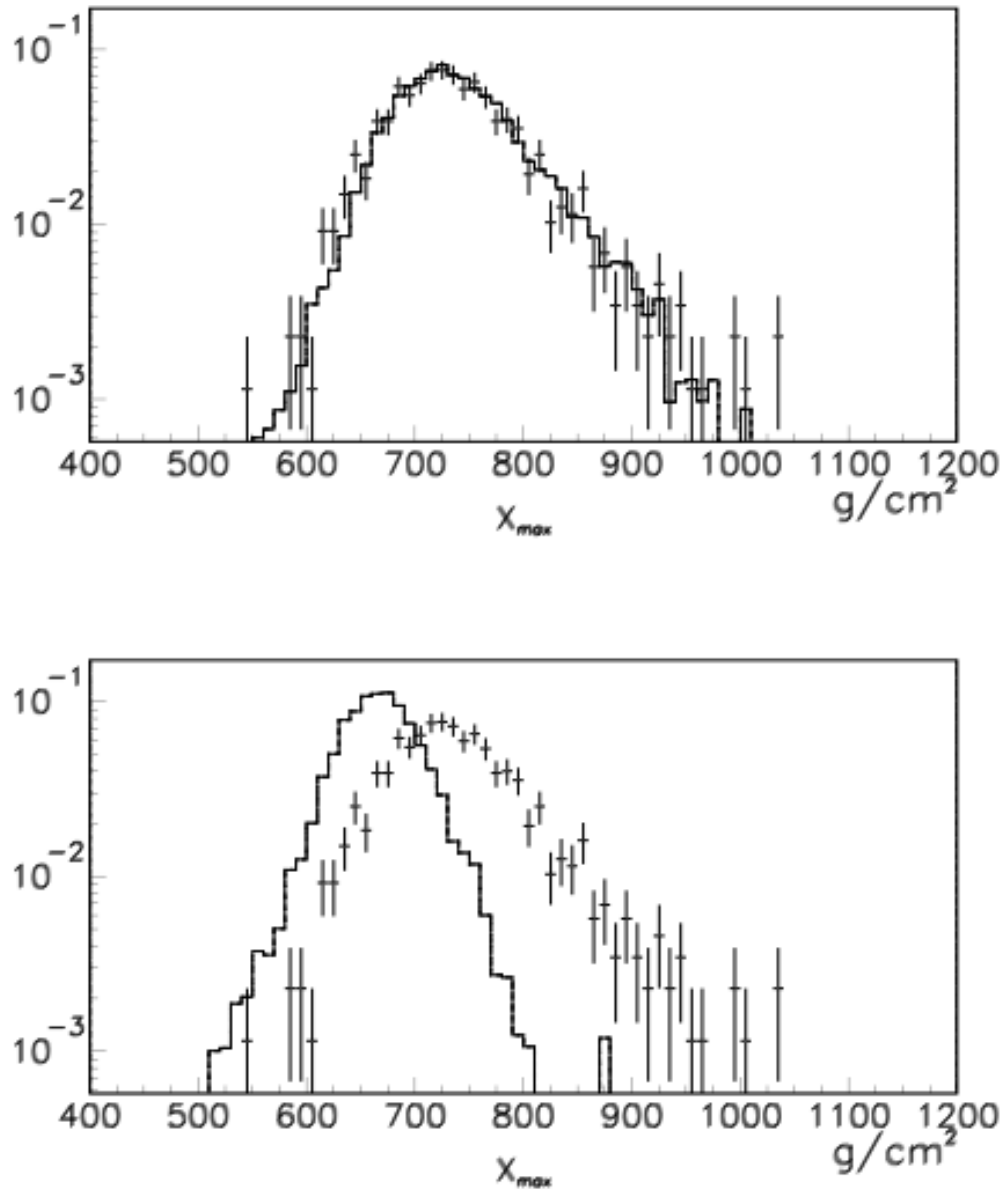
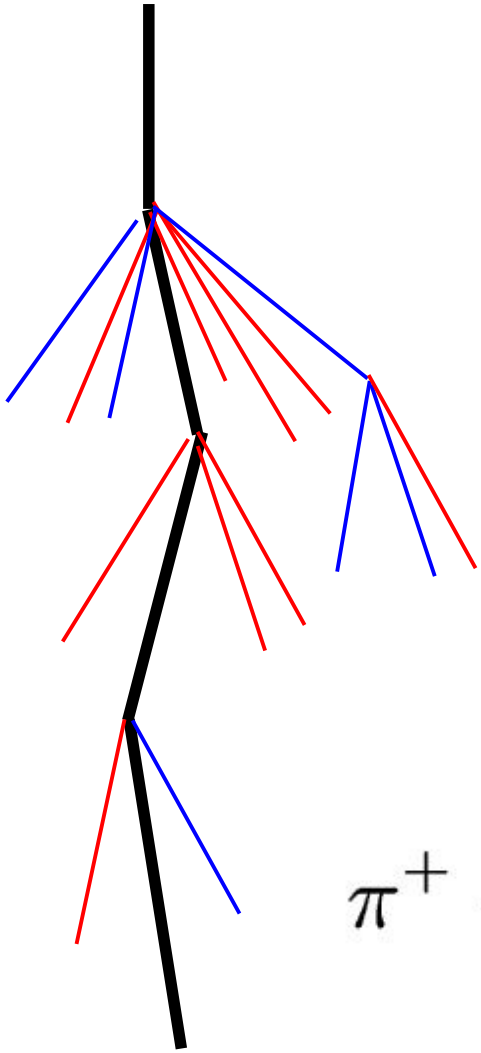


Fig. 11.— *Top:* X_{max} overlay of HiRes data (points) with QGSJET02 proton Monte Carlo airshowers after full detector simulation. *Bottom:* X_{max} overlay of HiRes data (points) with QGSJET02 iron Monte Carlo airshowers after full detector simulation.

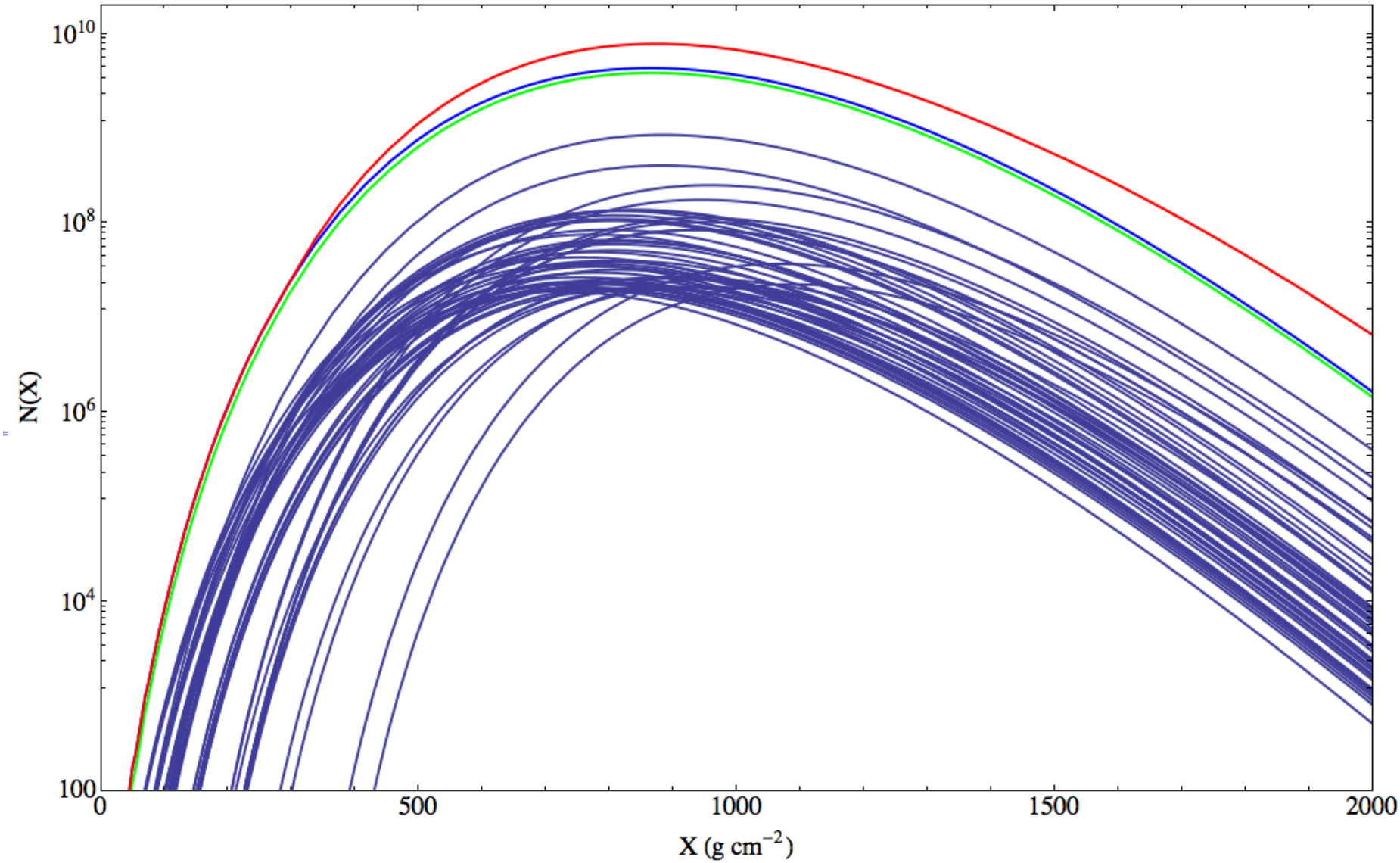
Proton Shower



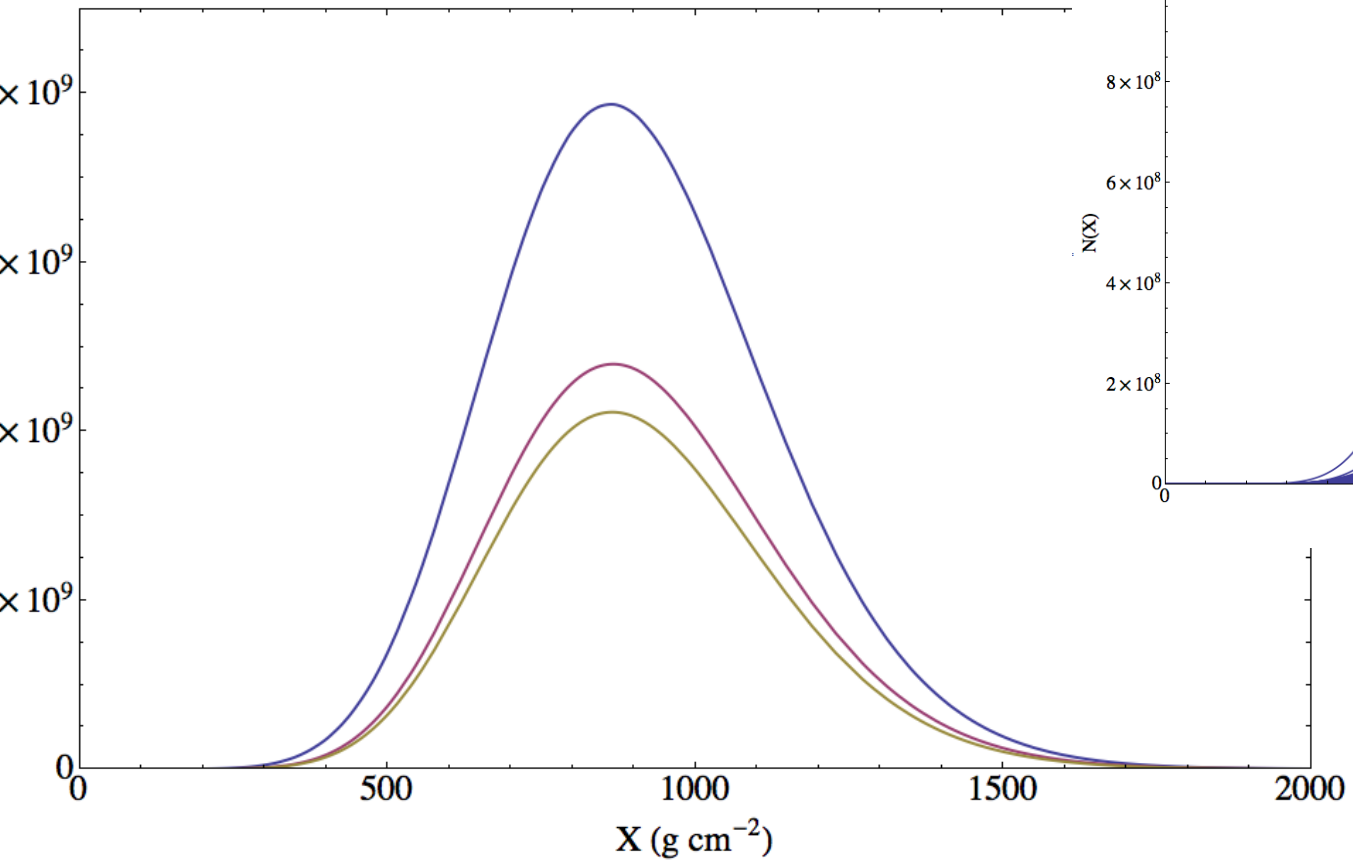
$$\pi^0 \rightarrow \gamma\gamma$$

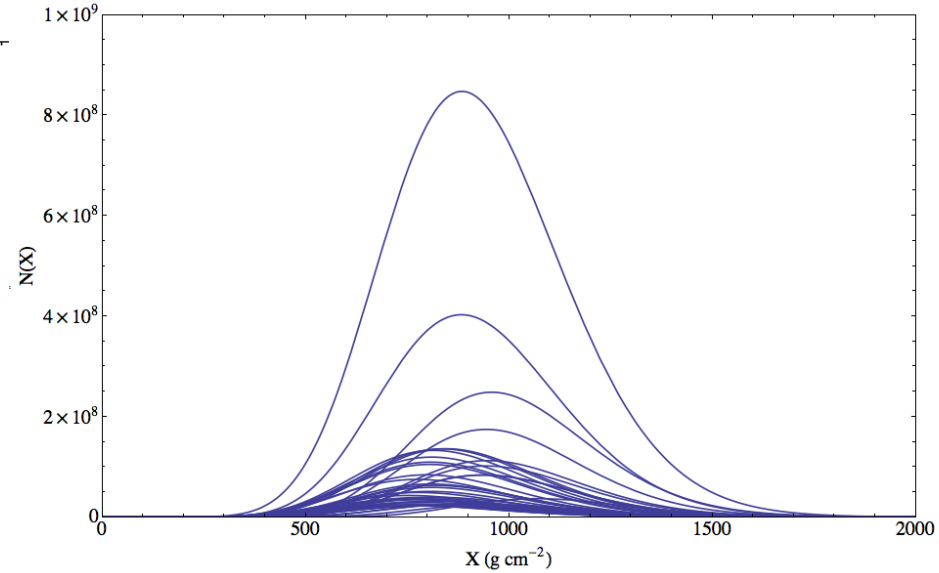
$$\pi^+ \rightarrow \mu^+\nu_\mu$$

One proton Shower: $E_0 = 10^{19}$ eV



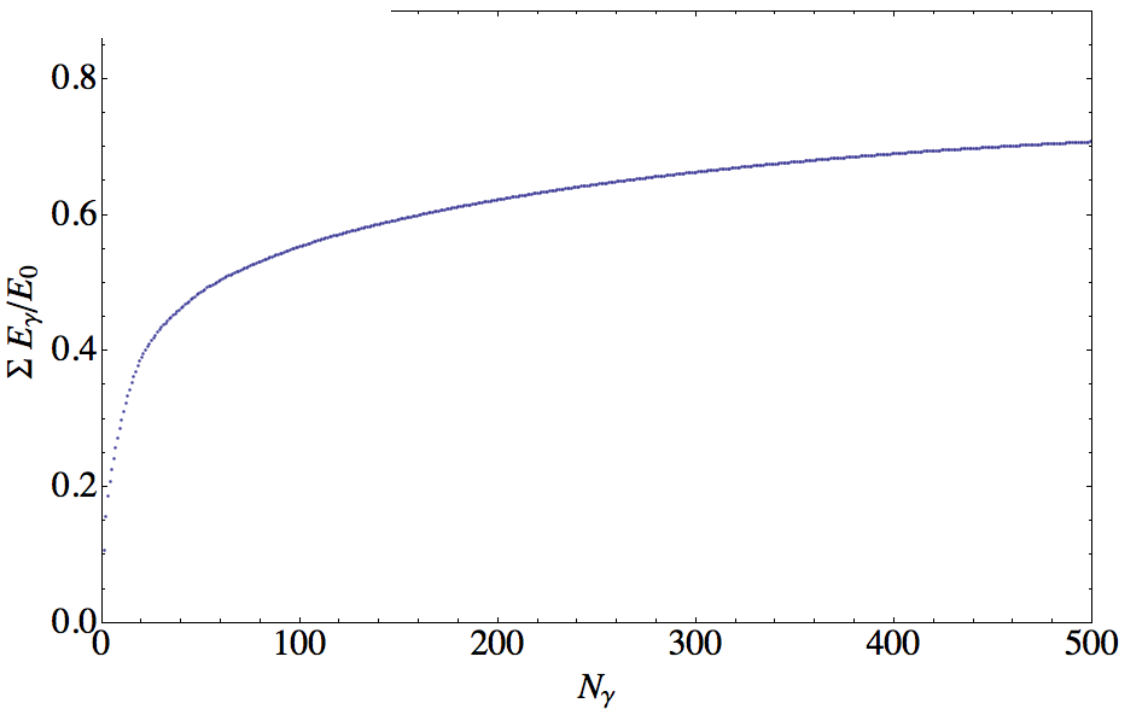
50 highest energy individual sub-showers





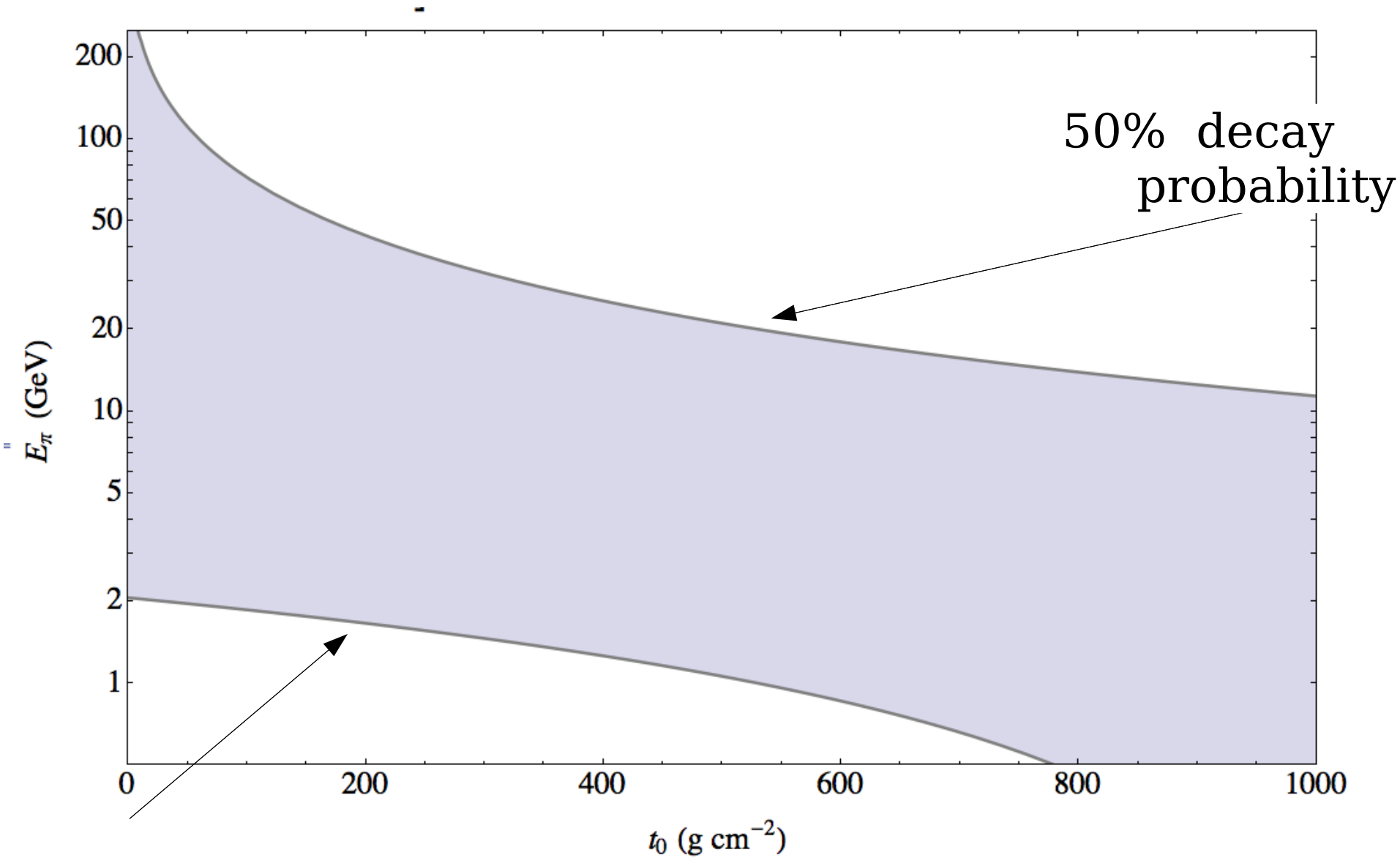
100 photons ~50% of energy
1000 photons ~70% of energy

Approximately 100 photons
In 30-40 interaction vertices
Control the structure of the
Shower: x ~ 0.1



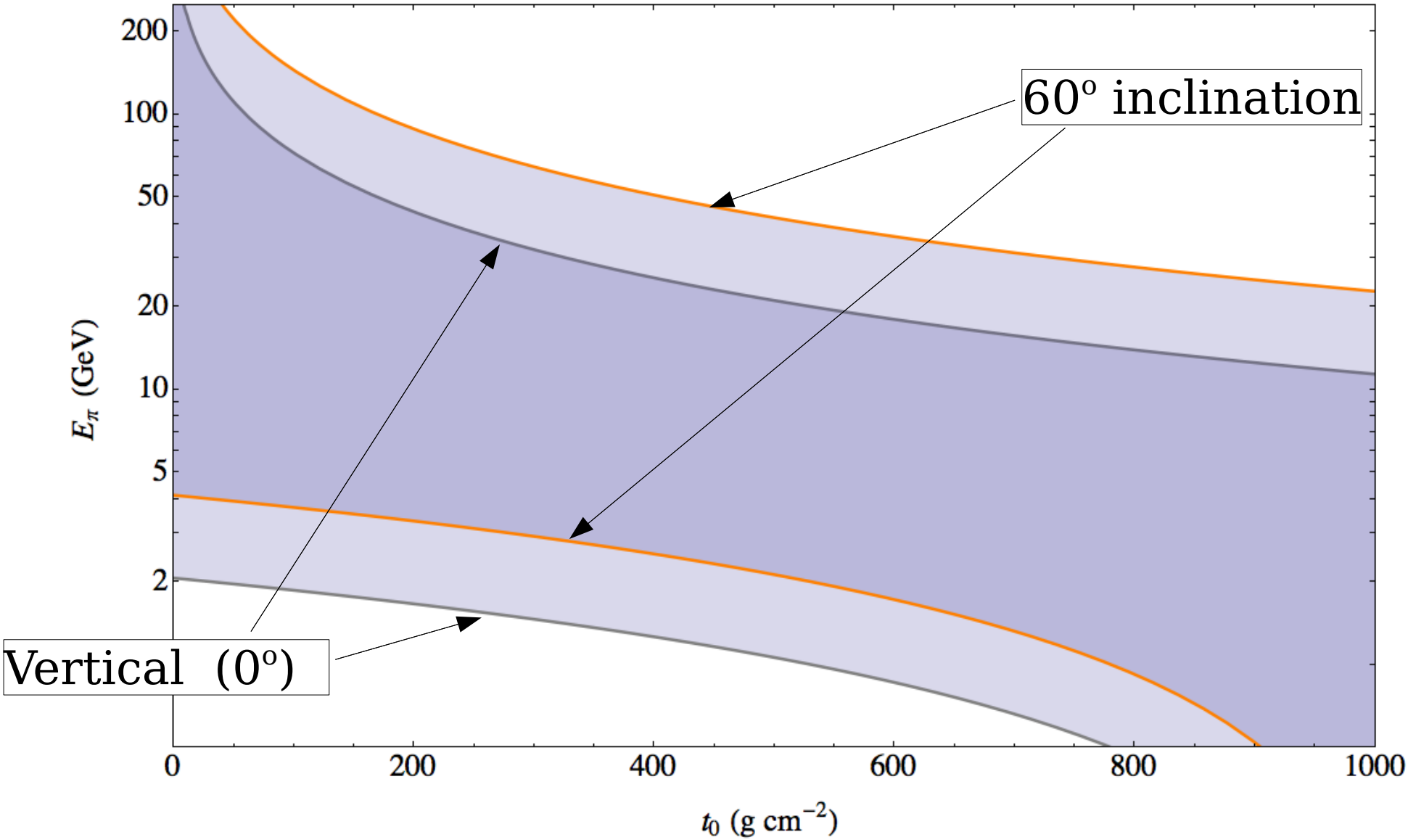
MUONS Source

Pion decay
Vertical direction

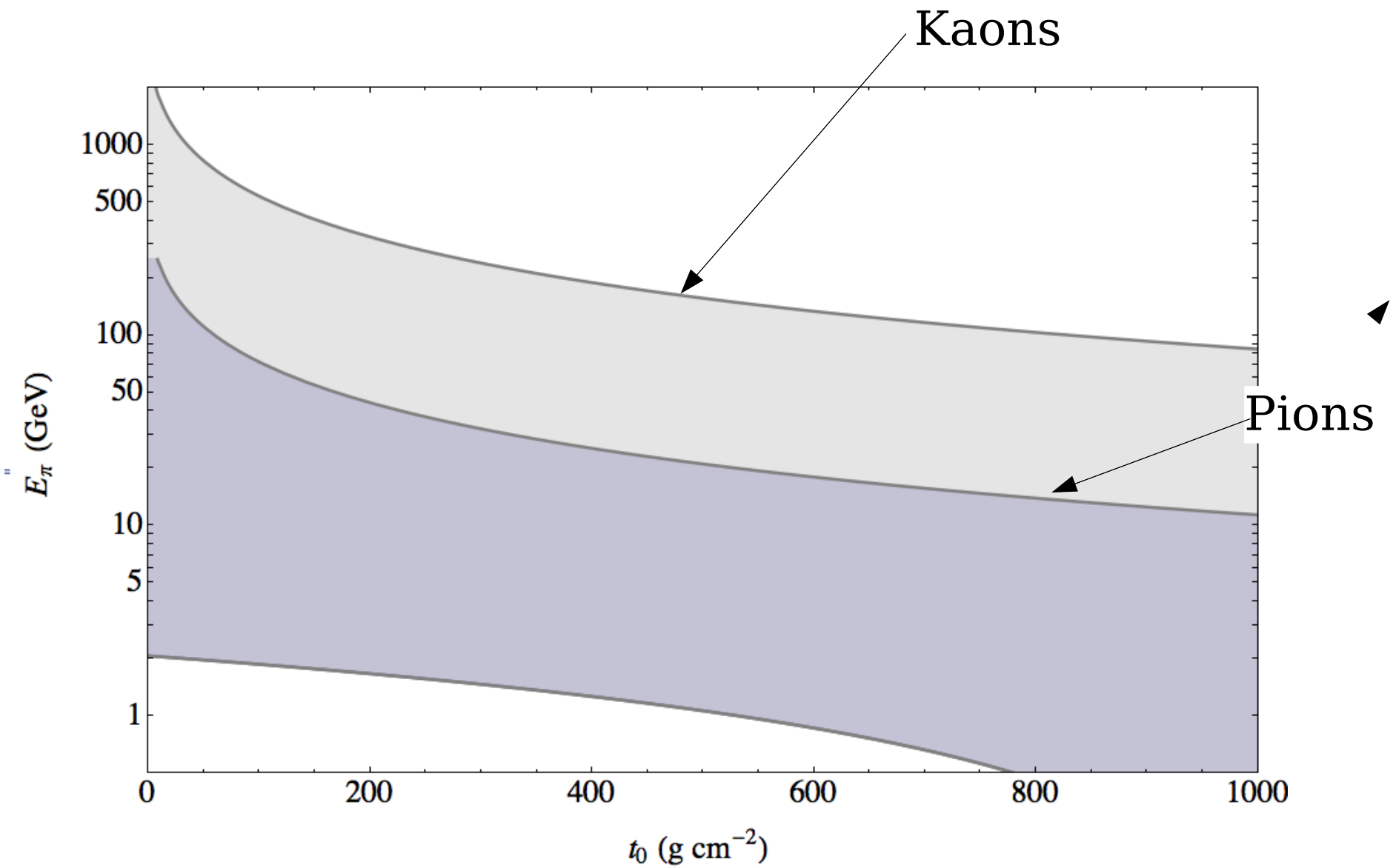


Muons do not reach the ground

Pions that generate muons

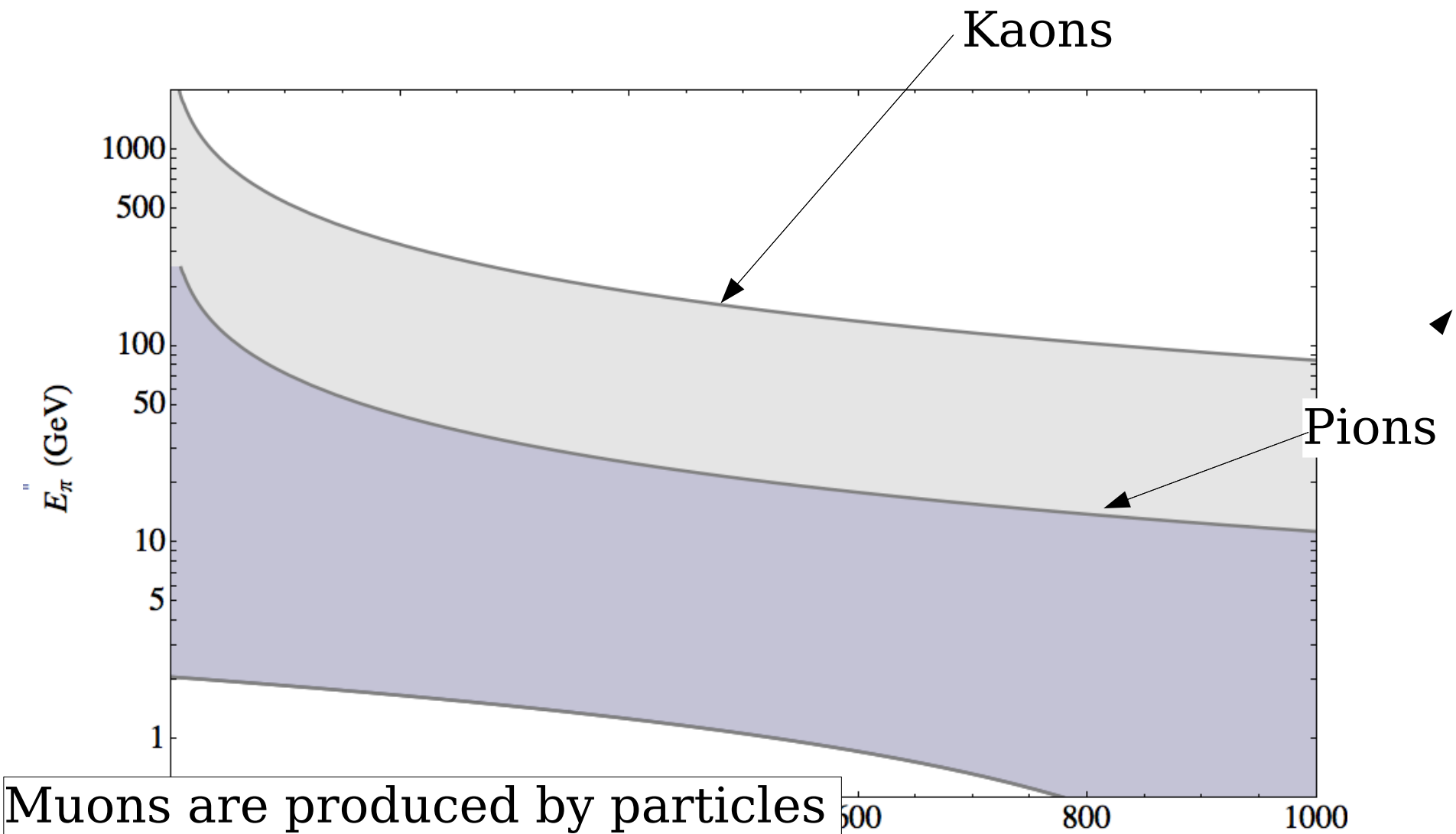


Source of Muons



Vertical direction

Source of Muons



Muons are produced by particles of few – to few hundred GeV.
Much softer in the shower.
Precise calculation is difficult.

Vertical direction

Toy Model

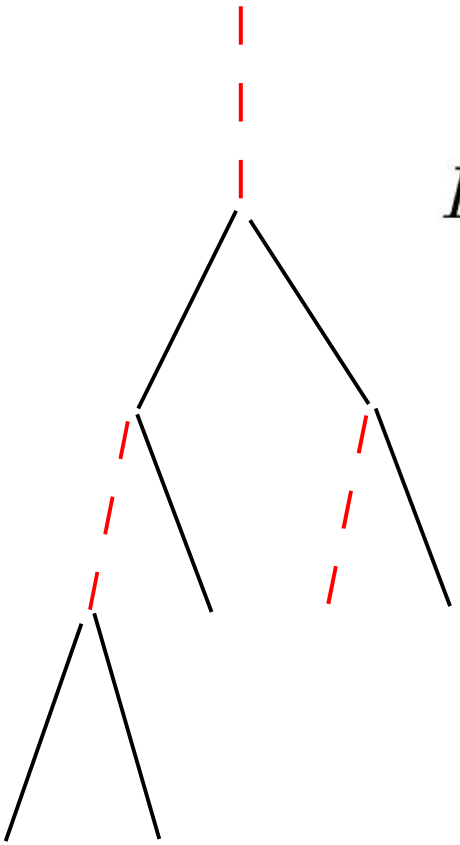
$$p + \text{air} \rightarrow \left(\frac{n}{2}\right) \pi^{\circ} \rightarrow n\,\gamma$$

Energy equally divided among n photons.

$$E_{\gamma} \simeq \frac{E_0}{n}$$

$$\frac{dN_{\gamma}}{dz} = \sum_{n} P_n\, \delta\left[z - \frac{1}{n}\right]$$

Electromagnetic Showers



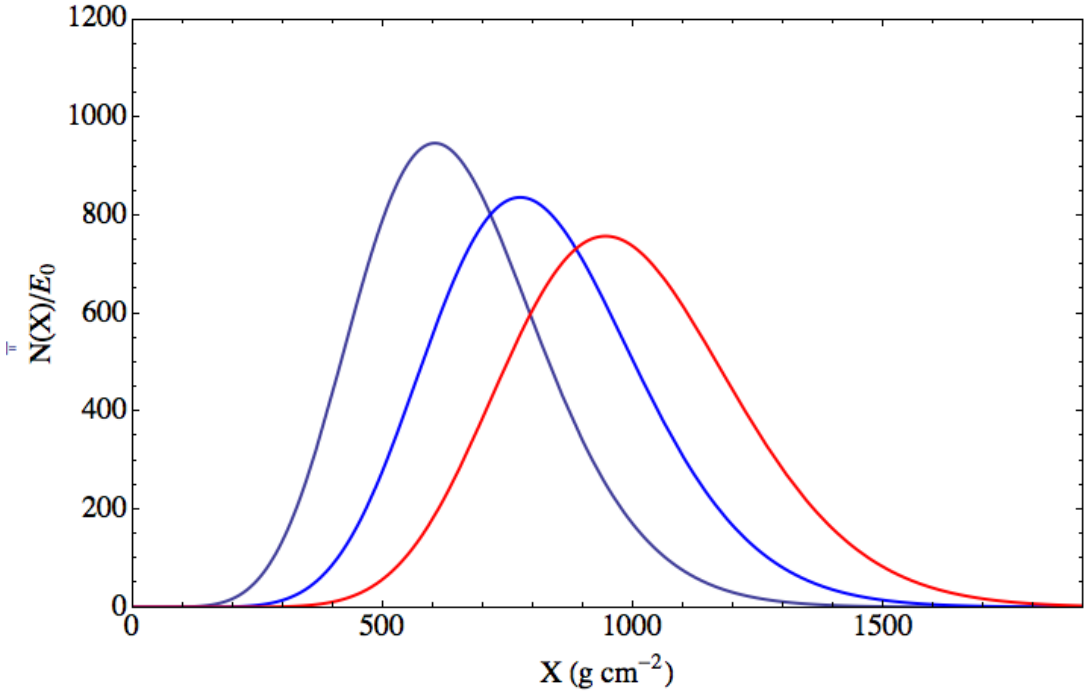
$$E_{e^+} = E_\gamma \, u \qquad \psi(u)$$

$$E_\gamma = E_e \, v \qquad \varphi(v)$$

Radiation Length
(Energy independent)

Vertices :
theoretically understood
(and scaling)

Average longitudinal development of a photon shower well understood



$$X_{\max}(E) \simeq \lambda_{\text{rad}} \ln\left(\frac{E}{\varepsilon}\right)$$

$$N_{\max}(E) \simeq \frac{E}{\varepsilon} \frac{1}{\sqrt{\ln(E/\varepsilon)}}$$

Elongation Rate

85 (g/cm^2)/decade

Photon Shower:

$$\langle X_{\rm max}^{(\gamma)} \rangle \simeq X_{\rm rad} \ \log \left[\frac{E_\gamma}{\varepsilon} \right]$$

$$\langle X_{\rm max}^{(p)} \rangle = \langle X_{\rm 1st} \rangle + X_{\rm rad} \ \left\langle \log \left(\frac{E_0}{n_\gamma \ \varepsilon} \right) \right\rangle$$

$$\langle X_{\rm max}^{(p)} \rangle = \lambda_p + X_{\rm rad} \ \log \left[\frac{E_0}{\varepsilon} \right] - X_{\rm rad} \ \langle \log n_\gamma \rangle$$

$$\frac{d\langle X_{\rm max}^{(p)}(E) \rangle}{d \log E} = X_{\rm rad} + \frac{d\lambda_p(E)}{d \log E} - X_{\rm rad} \ \frac{d\langle \log n_\gamma(E) \rangle}{d \log E}$$

$$\langle X_{\max}^{(p)} \rangle = \lambda_p + X_{\mathrm{rad}} \ \log \left[\frac{E_0}{\varepsilon} \right] - X_{\mathrm{rad}} \ \langle \log n_\gamma \rangle$$

Interaction length

“Softness”

$$\langle X_{\max}^{(p)} \rangle = \lambda_p + X_{\rm rad} \ \log \left[\frac{E_0}{\varepsilon} \right] - X_{\rm rad} \ \langle \log n_\gamma \rangle$$

Interaction length

"Softness"

$$\frac{d\langle X_{\max}^{(p)}(E) \rangle}{d \log E} = X_{\rm rad} + \frac{d\lambda_p(E)}{d \log E} - X_{\rm rad} \ \frac{d\langle \log n_\gamma(E) \rangle}{d \log E}$$

Evolution with Energy of the Interaction length

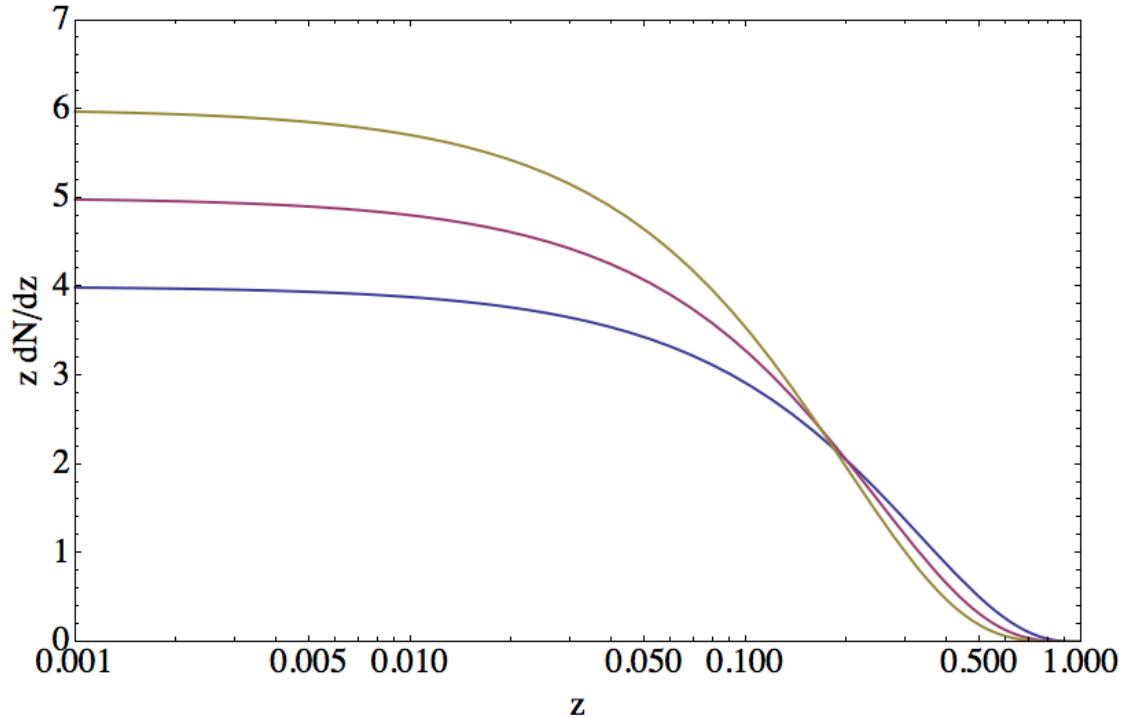
Evolution with energy of the "softness" of the spectrum

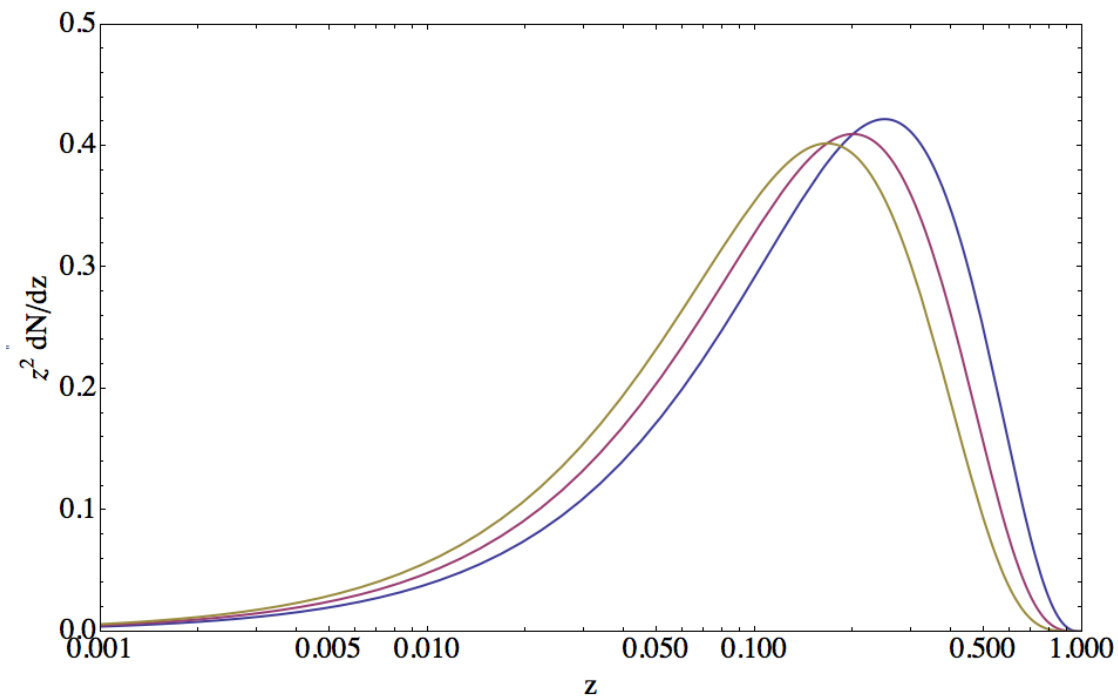
“softness”

Inclusive Pion
Energy spectrum.

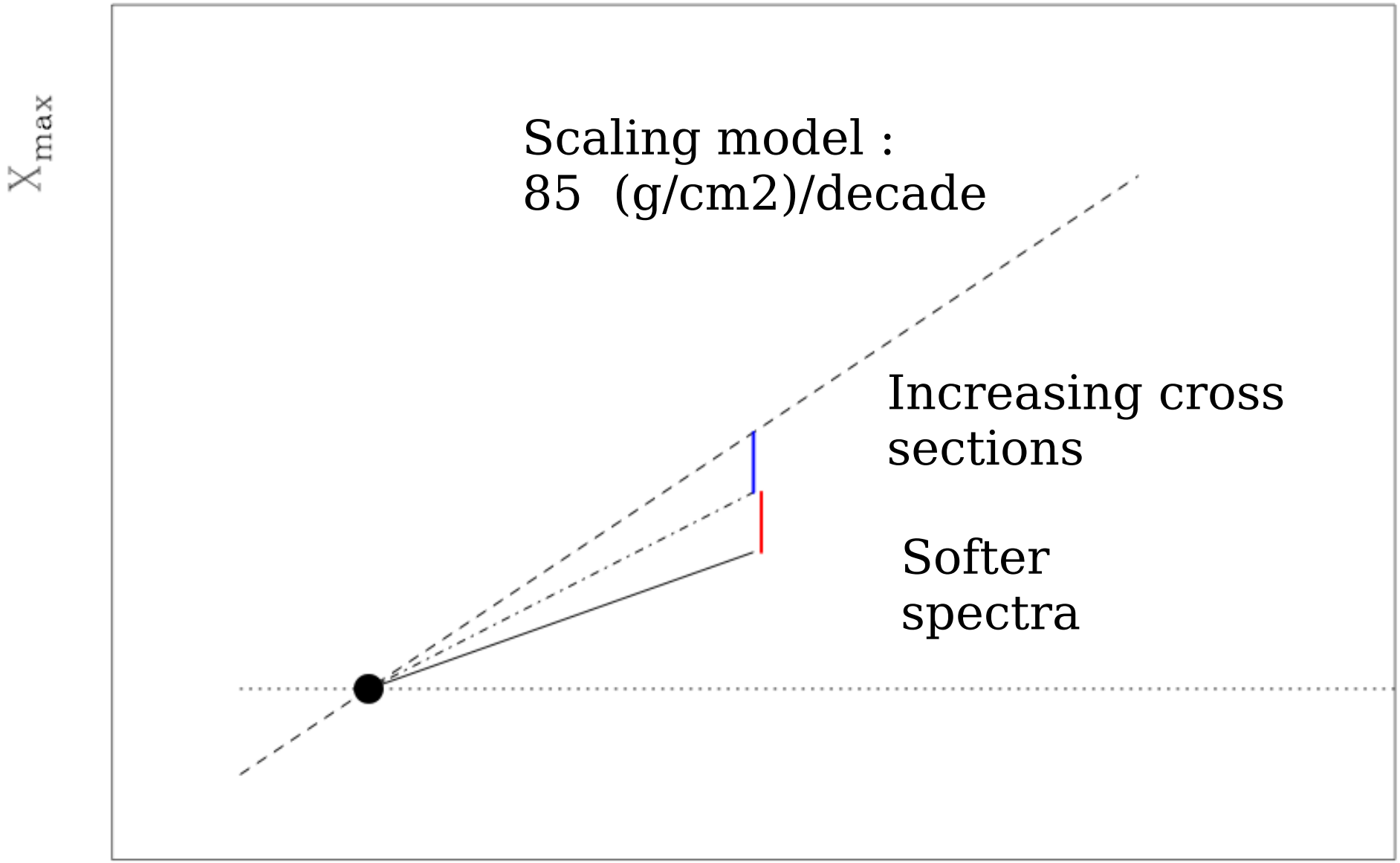
1st order approximation

$$\frac{dN_\pi}{dz} \propto \frac{(1-z)^p}{z}$$





Position of peak
1/(p+1)



Elongation Rate
For protons

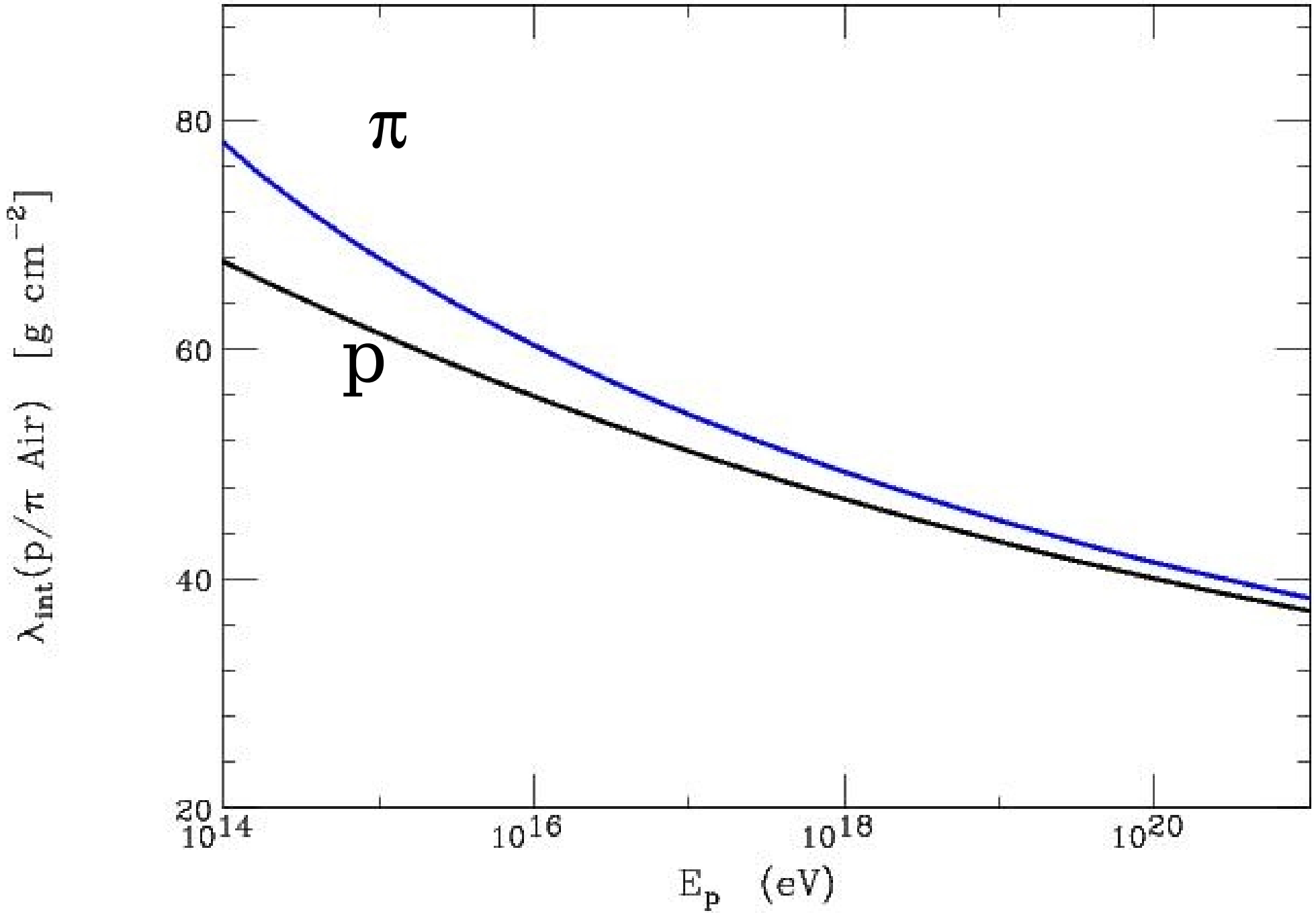
Elongation Rate for protons.

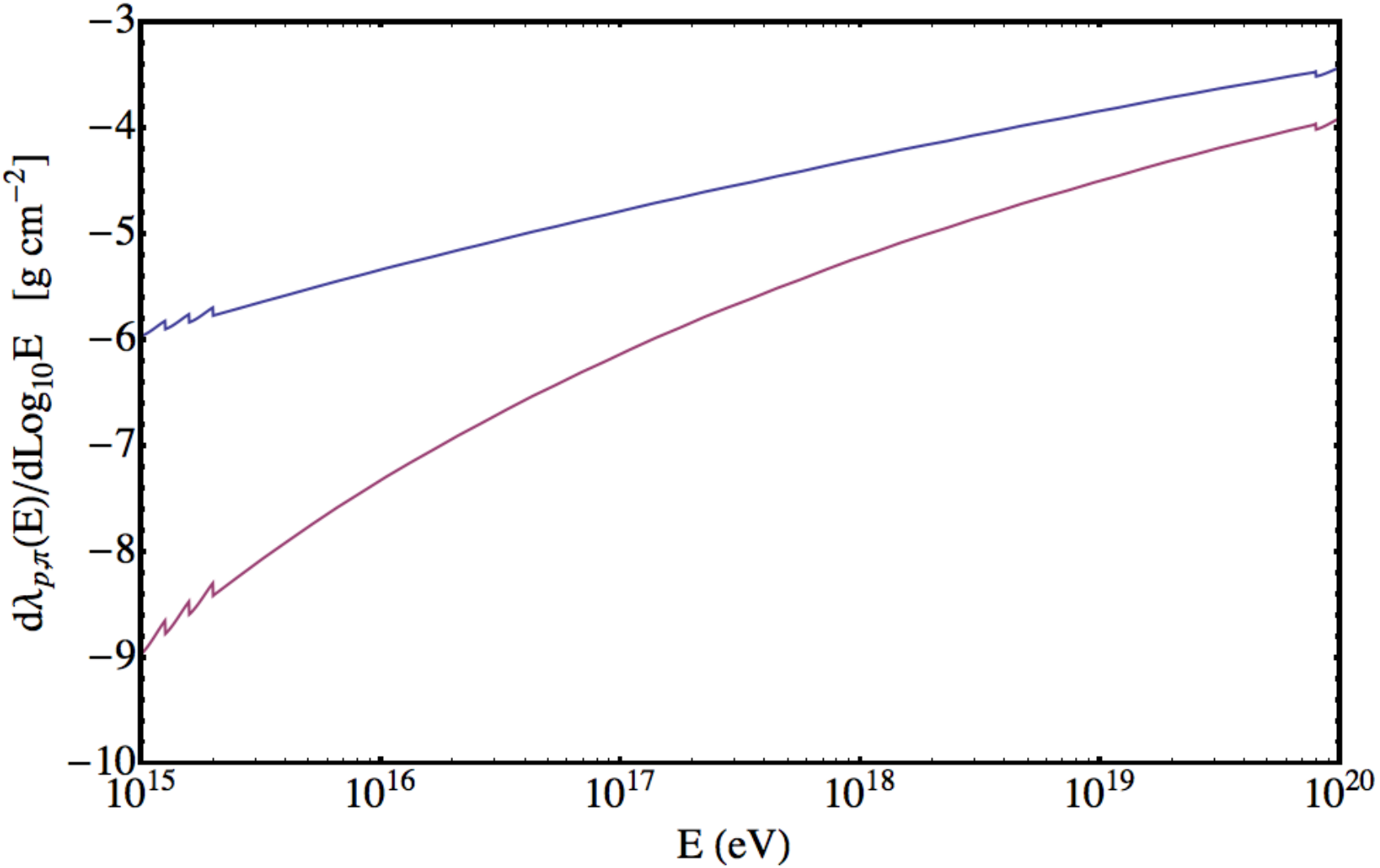
$$\frac{d\langle X_{\max}^{(p)}(E)\rangle}{d\log E} = X_{\rm rad} + f_1\,\frac{d\lambda_p(E)}{d\log E} - f_2\;X_{\rm rad}\,\frac{\log[1+p(E)]}{d\log E}$$

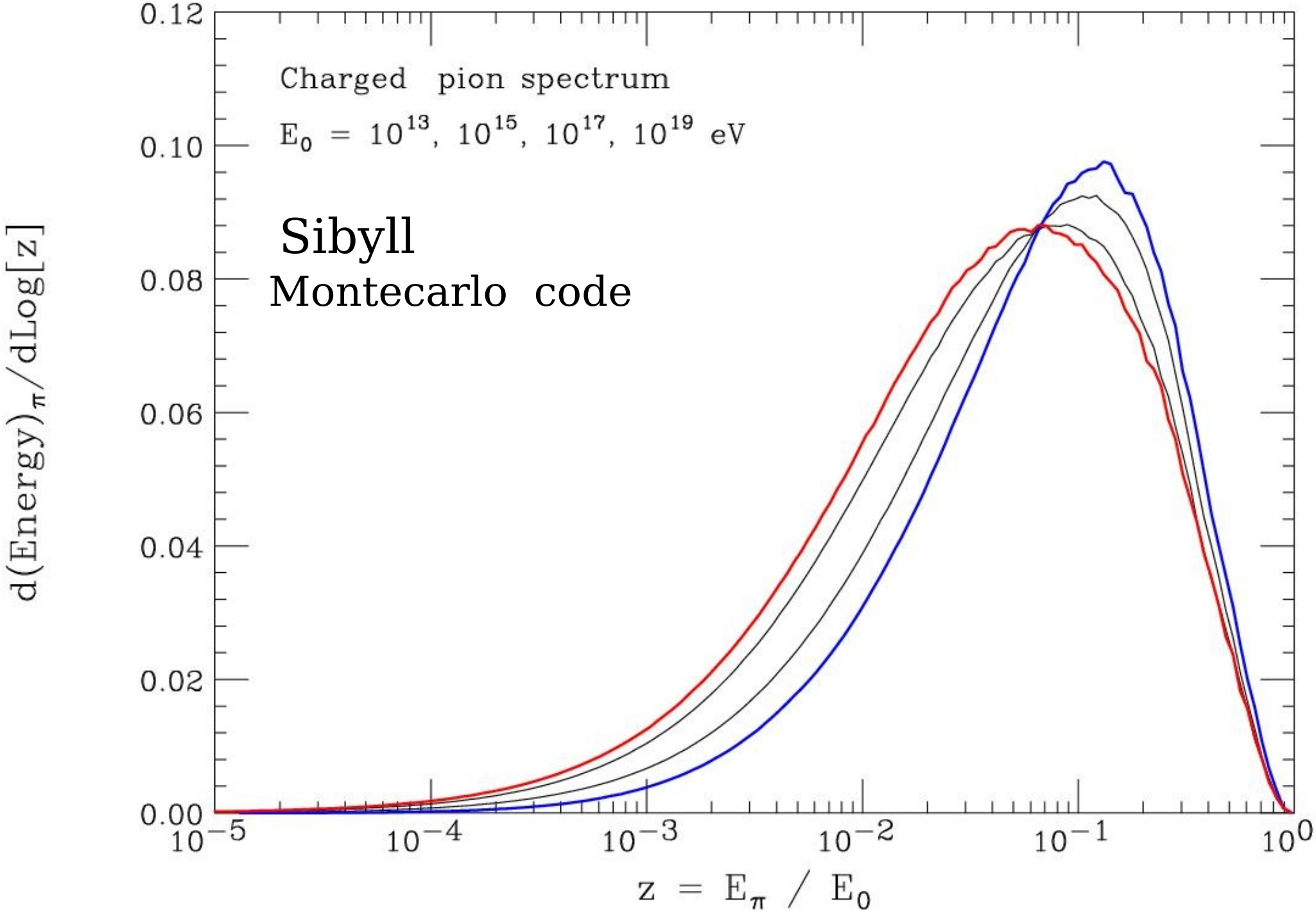
$$+g_1\,\frac{d\lambda_\pi(E)}{d\log E} - g_2\;X_{\rm rad}\,\frac{\log[1+p_\pi(E)]}{d\log E}$$

$$f_1, f_2, g_1, g_2 \sim 1$$

Significance of Pion Cross section
And particle production properties.


π
p
80
60
40
20
10^{14}
10^{16}
10^{18}
10^{20}
E_p (eV)
$\lambda_{int}(p/\pi$ Air) [g cm^{-2}]


−3
−4
−5
−6
−7
−8
−9
−10
$d\lambda_{p,\pi}(E)/dLog_{10}E$ [g cm^{-2}]
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
E (eV)


Charged pion spectrum
$E_0 = 10^{13}, 10^{15}, 10^{17}, 10^{19}$ eV
Sibyll
Montecarlo code
0.12
0.10
0.08
0.06
0.04
0.02
0.00
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
$d(Energy)_\pi / dLog[z]$
$z = E_\pi / E_0$

FLUCTUATIONS on $X_{\max}$

$$X_{\max} = X_{1\mathrm{st}} + Y_{\max}$$

$$\sigma^2_{X_{\max}} = \sigma^2_{X_{1\mathrm{st}}} + \sigma^2_{Y_{\max}}$$

$$\left(\sigma^{\mathrm{proton}}_{\langle X_{\max}\rangle}\right)^2 \simeq \lambda_p^2 + \sigma^2_{Y_{\max}}$$

Toy model

$$\left(\sigma^{\mathrm{proton}}_{\langle X_{\max}\rangle}\right)^2 \simeq \lambda_p^2 + X^2_{\mathrm{rad}} \left[\left\langle (\ln n_\gamma)^2 \right\rangle - \langle \ln n_\gamma \rangle^2\right]$$

$$\left(\sigma^{\text{proton}}_{\langle X_{\max}\rangle}\right)^2 \simeq \lambda_p^2 + \sigma^2_{Y_{\max}}$$

$$\left(\sigma^{A}_{\langle X_{\max}\rangle}\right)^2 \simeq \boxed{f(A)}\,\lambda_p^2 + \frac{\sigma^2_{Y_{\max}}}{A}$$

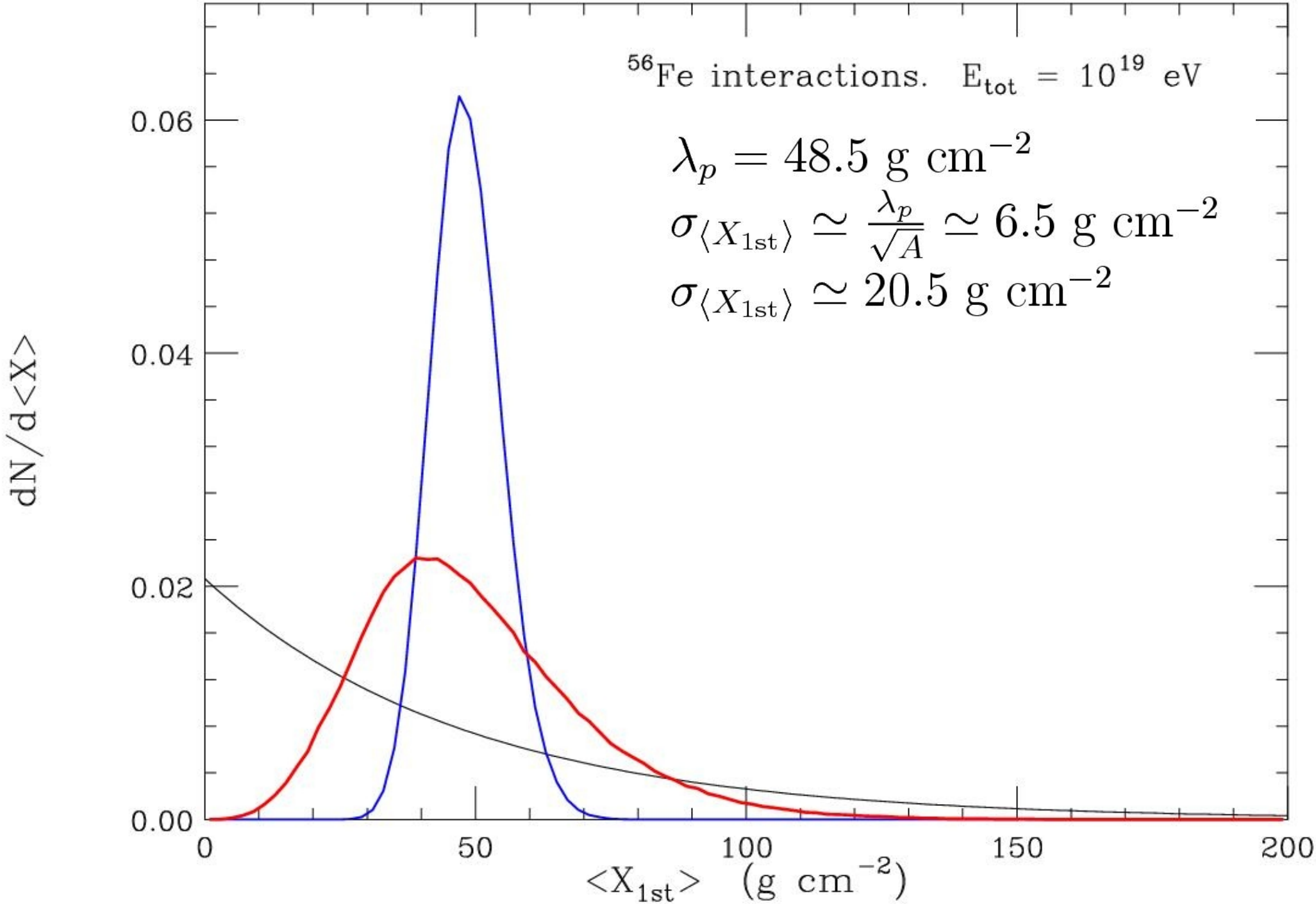
$$f(A) > \frac{1}{A}$$

$$A = 56$$

$$\frac{1}{\sqrt{A}} = 0.13$$

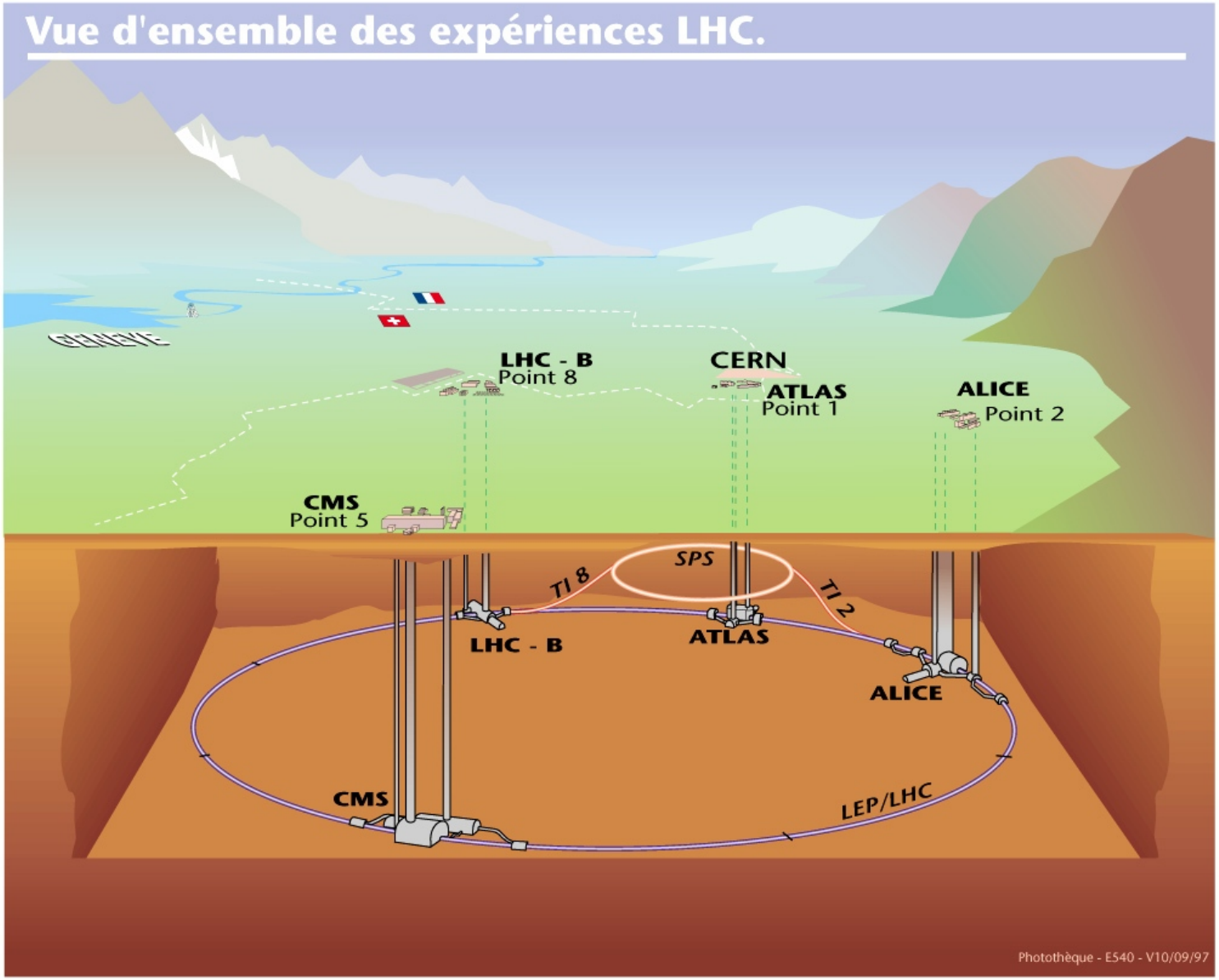
$$\sqrt{f(A)} \simeq 0.4$$

Nuclear interaction.
Several Nucleons
Interact at same point.

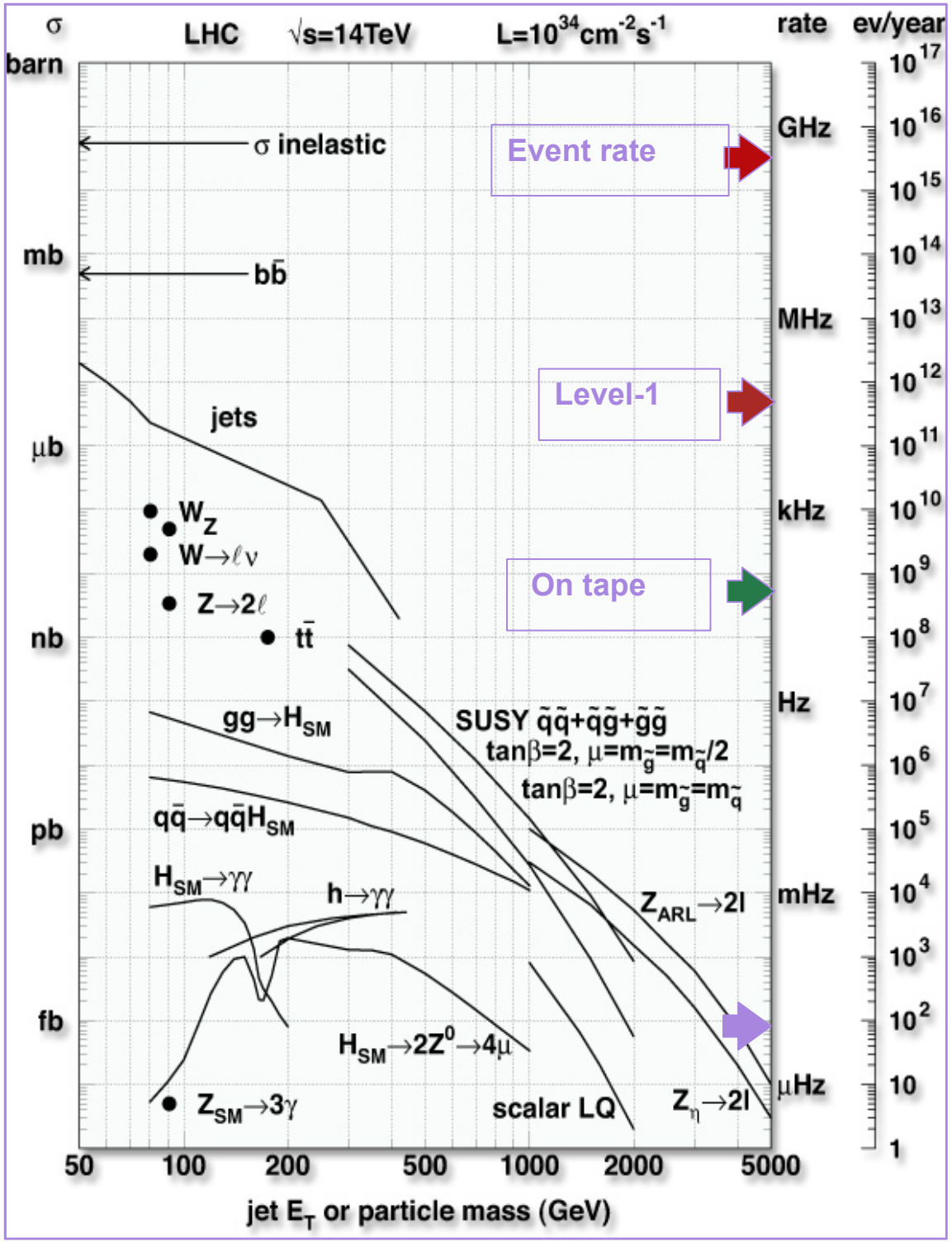

^{56}Fe interactions. $E_{tot} = 10^{19}$ eV
$\lambda_p = 48.5$ g cm^{-2}
$\sigma_{\langle X_{1st} \rangle} \simeq \frac{\lambda_p}{\sqrt{A}} \simeq 6.5$ g cm^{-2}
$\sigma_{\langle X_{1st} \rangle} \simeq 20.5$ g cm^{-2}
dN/d<X>
0.00
0.02
0.04
0.06
0
50
100
150
200
<X$_{1st}$> (g cm^{-2})

LEARNING from ACCELERATORS

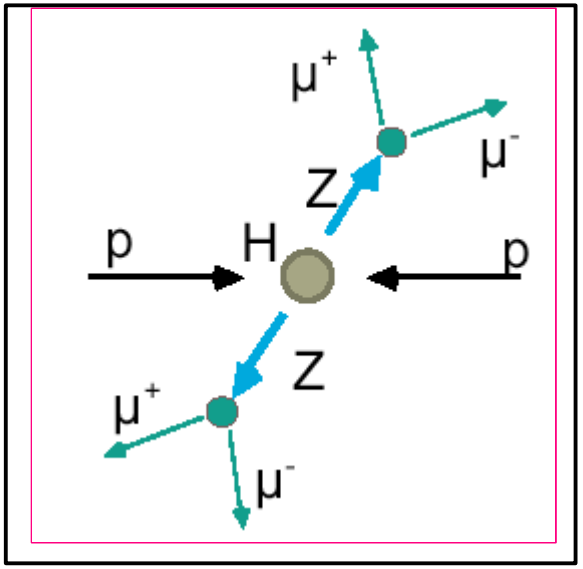
Important potential of LHC



7 + 7 TeV
PP collider



Higgs discovery golden channel



$$\sigma_{\mathrm{tot}} \qquad \sigma_{\mathrm{el}} \qquad \frac{d\sigma_{\mathrm{el}}}{dt}$$

$$\frac{dN_{\mathrm{ch}}}{dy} \qquad \frac{dN_{\mathrm{ch}}}{d\eta} \qquad \frac{dN_{\mathrm{ch}}}{dp_{\perp}\, dy}$$

$$\sigma_{\text{diffractive}}$$

$$\sigma_{\text{FD}} \qquad \sigma_{\text{BD}} \qquad \sigma_{\text{DD}}$$

$$\frac{d^2\sigma_{\text{diff}}}{dt\, dM_X^2}$$

Total, Elastic, Diffractive Cross Sections:

Cross section Measurements

Tevatron:

E710:

1.8 TeV: $\sigma_{tot} = 72.8 \pm 3.1$ mb

E811:

1.8 TeV: $\sigma_{tot} = 71.42 \pm 2.41$ mb

CDF:

546 GeV: $\sigma_{tot} = 61.26 \pm 0.93$ mb

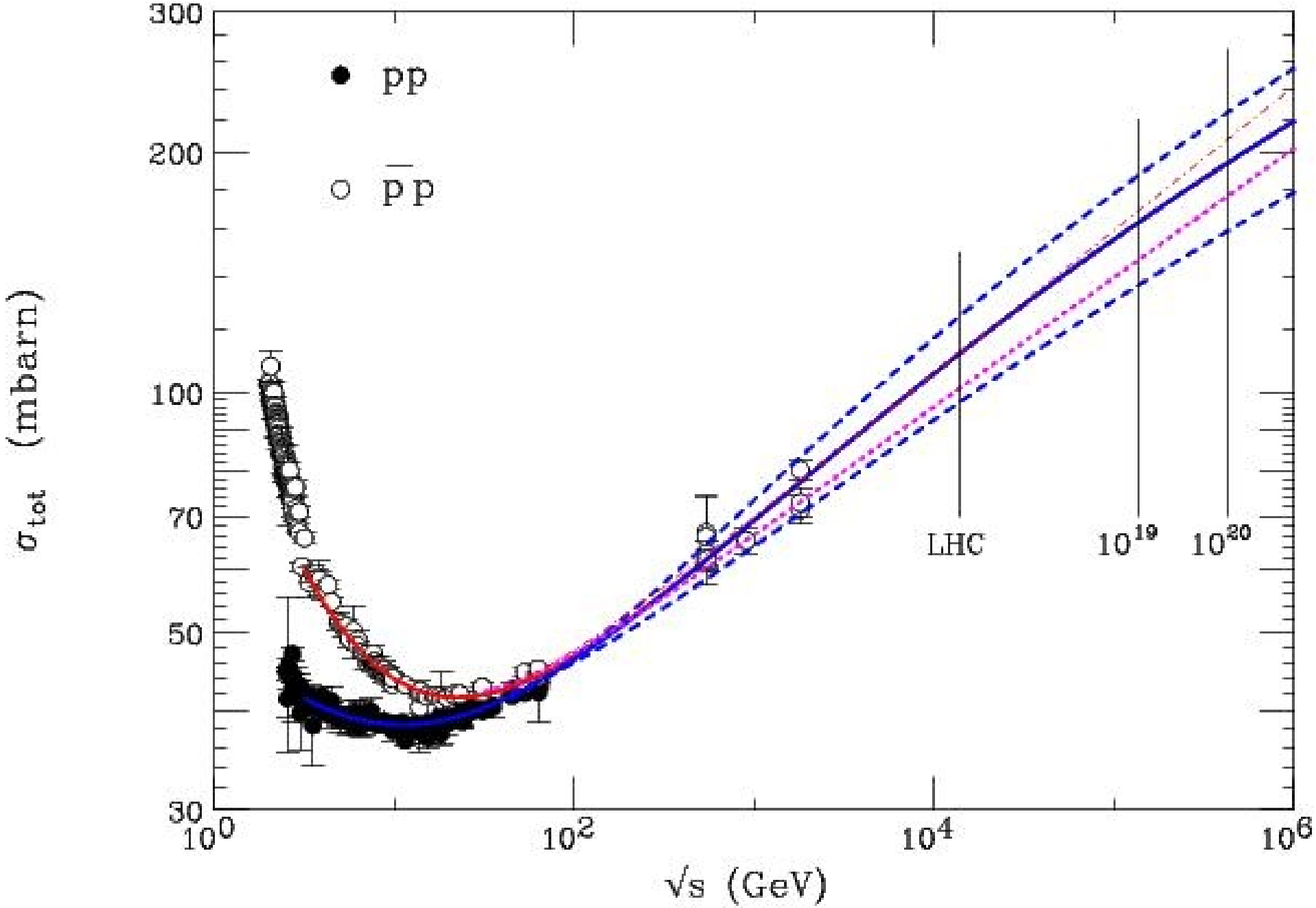
(agrees with UA4)

1.8 TeV: $\sigma_{tot} = 80.03 \pm 2.24$ mb

$$\sigma_{tot} = 111.5 \pm 1.2 \; {}^{+4.1}_{-2.1} \text{ mb}$$

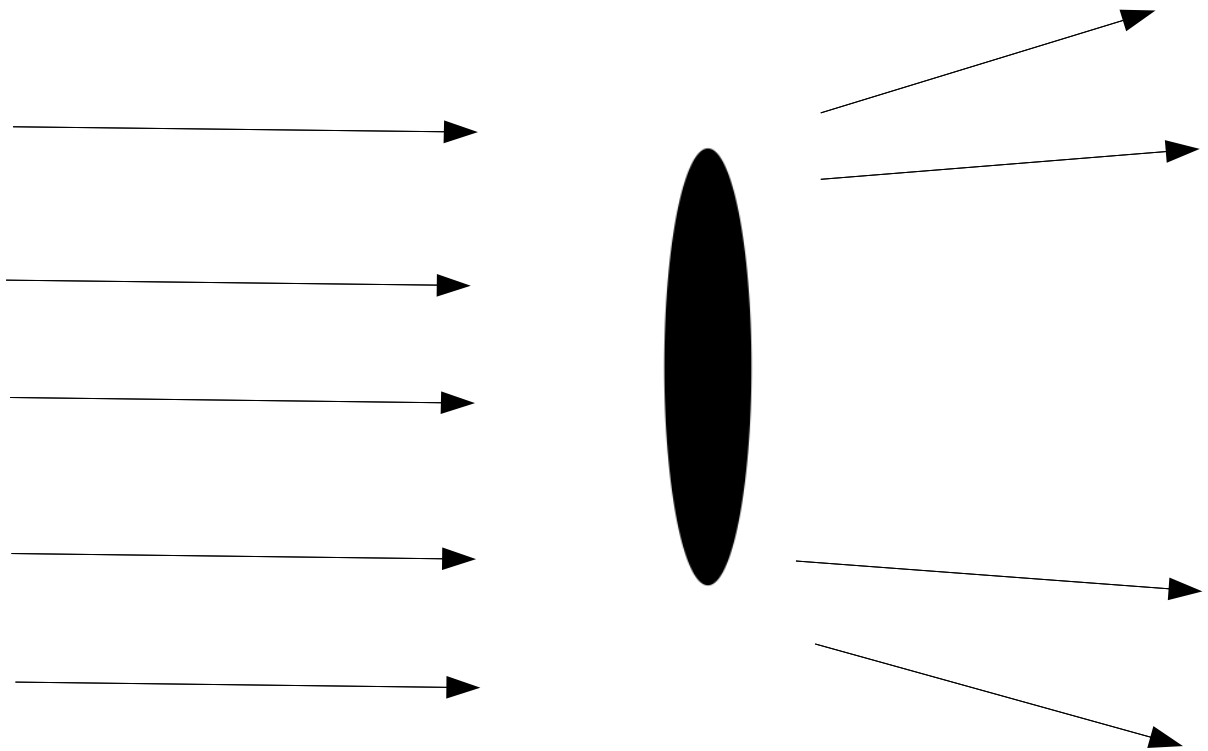
[PRL 89 201801 (2002)]

Prediction for LHC at sqrt[s] = 14 TeV

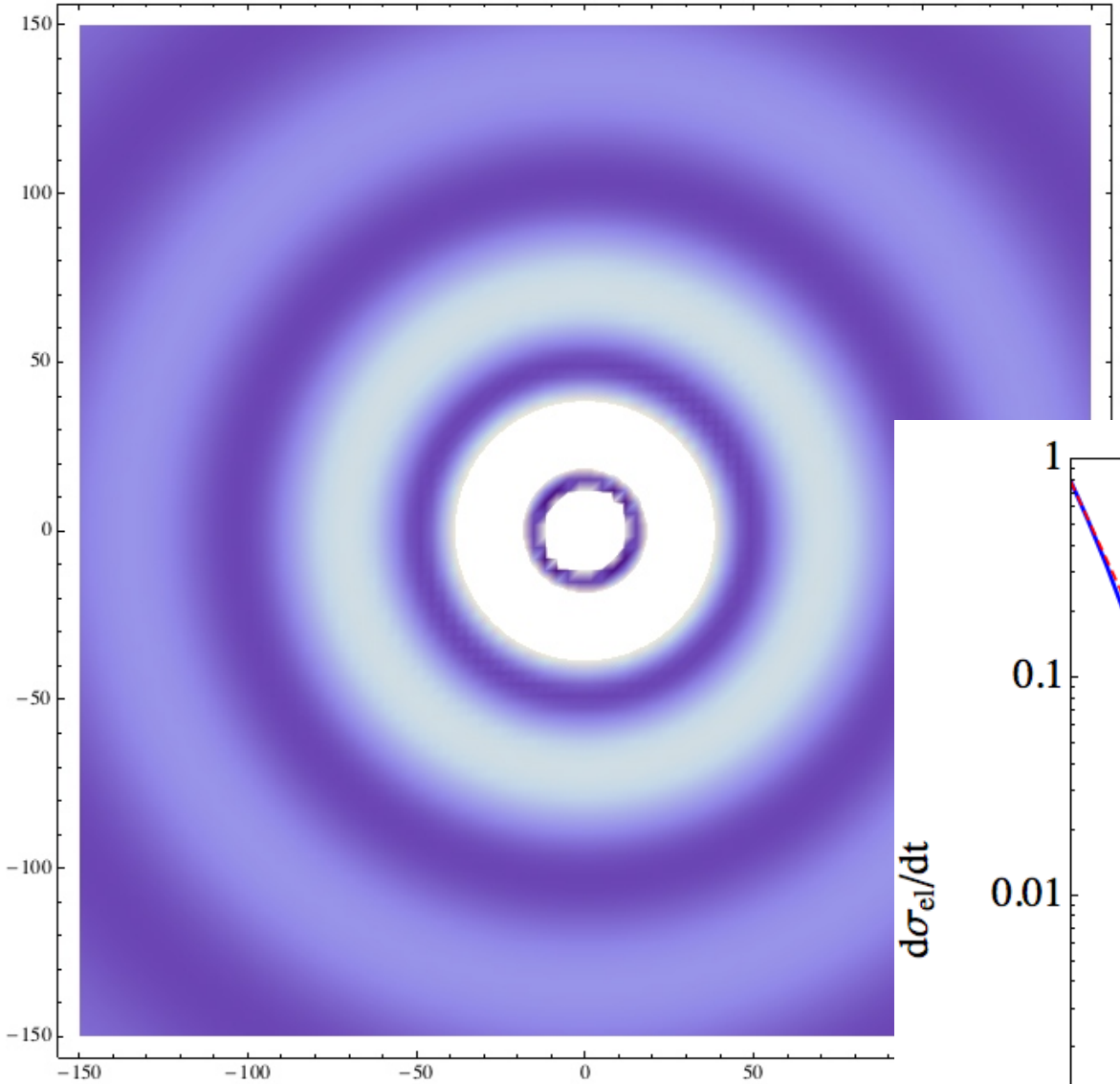

pp
p̄p
LHC
10^{19}
10^{20}
σ_{tot} (mbarn)
$\sqrt{s}$ (GeV)
300
200
100
70
50
30
10^0
10^2
10^4
10^6

Total, Elastic, Diffractive Cross Sections:

1 minute of "19th century physics":
The OPTICAL ANALOGY.

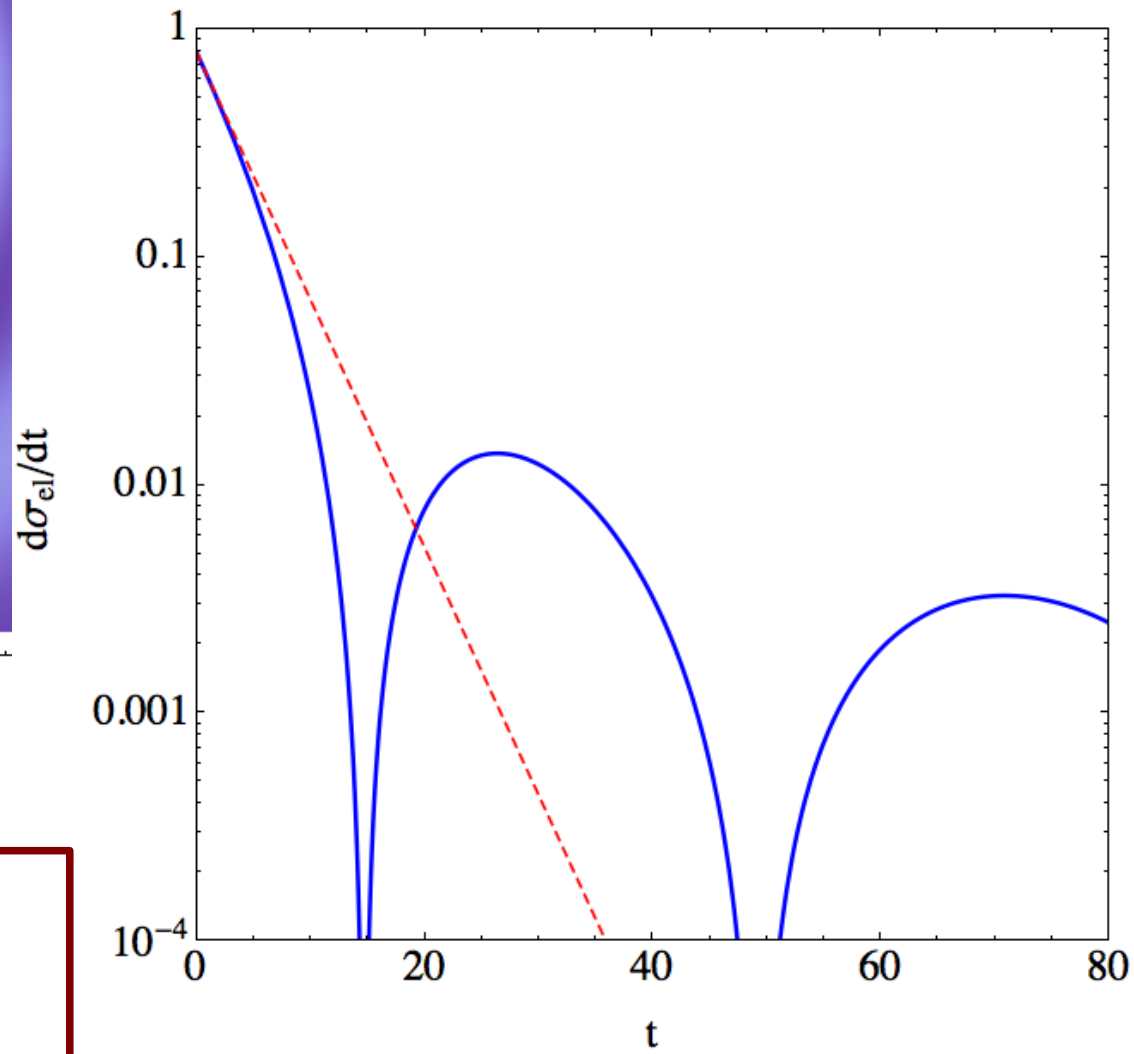


Absorption
and
Scattering
of light
from an
Opaque screen



Black Disk
Of radius R.

Diffraction Pattern



$$\sigma_{\rm el} = \sigma_{\rm abs} = \pi\, R^2$$

$$\sigma_{\text{abs}} = \int d^2b \; P_{\text{abs}}(\vec{b})$$

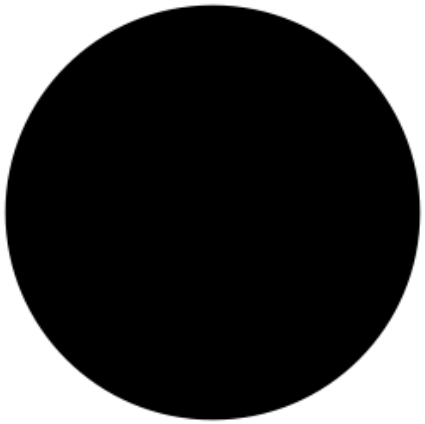
$$P_{\text{abs}}(\vec{b}) = 1 - e^{2\,\chi(\vec{b})}$$

$$0 \leq P_{\text{abs}} \leq 1$$

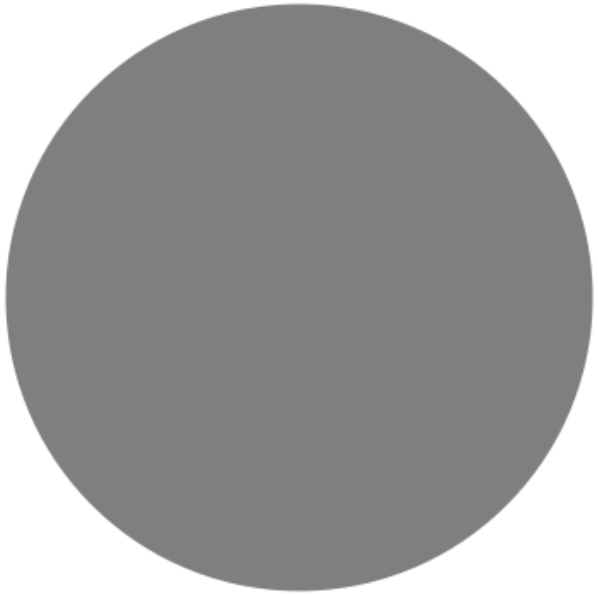
$$A_{\rm tra}(\vec{b}) = \sqrt{1 - P_{\rm abs}(\vec{b})}$$

$$1 - A_{\rm tra}(\vec{b}) \equiv \Gamma(b) = 1 - e^{\chi(\vec{b})}$$

$$\boxed{\begin{aligned} \frac{d\sigma_{\rm el}}{dt} &= \pi \left| i \int d^2b \; e^{i\,\vec{q}\cdot\vec{b}} \left[1 - A_{\rm tra}(\vec{b})\right] \right|^2 \\ \sigma_{\rm el} &= \int dt \; \frac{d\sigma_{\rm el}}{dt} = \int d^2b \; \left|1 - e^{-\chi(\vec{b})}\right|^2 \end{aligned}}$$

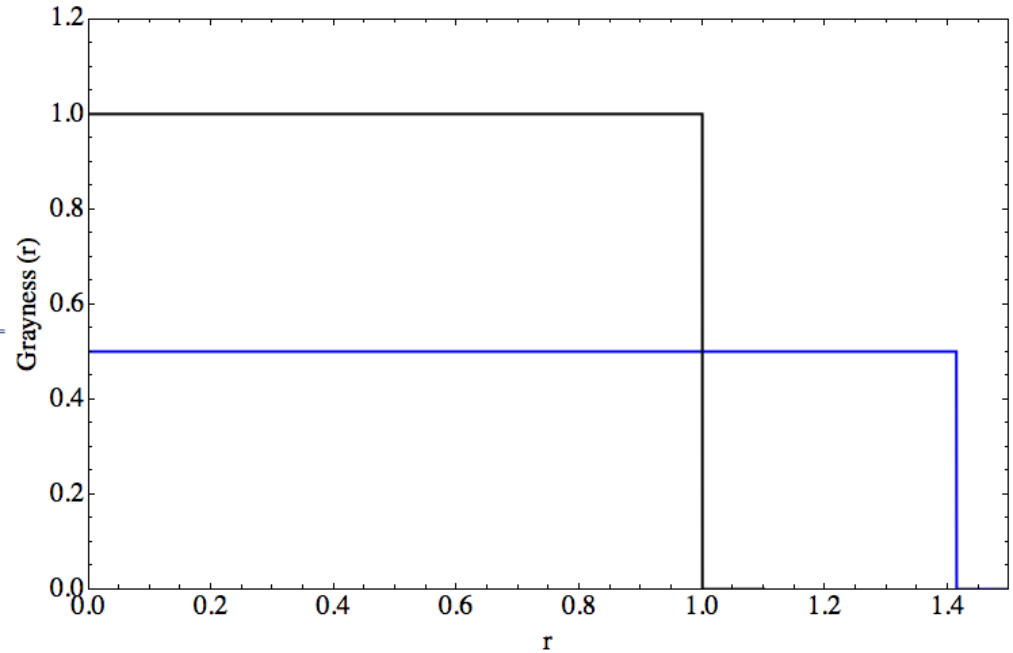


Black Disk



Gray Disk [Opacity 0.5]

Identical absorption

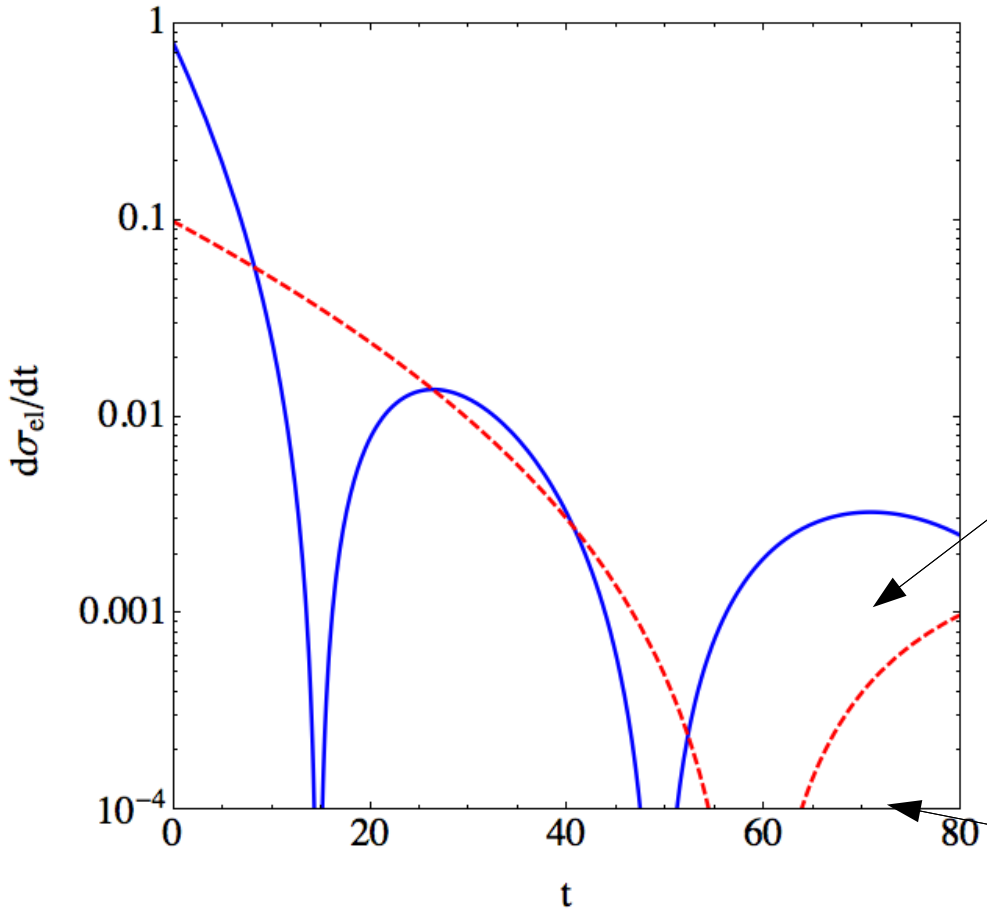


$g \leq 1$ opacity

$$\sigma_{\text{abs}} = g\ \pi\ R^2$$

$$\sigma_{\text{el}} = g^2\ \pi\ R^2$$

Elastic scattering distributions



Larger
Gray Disk

smaller
Black Disk

$$\sigma_{el} = \frac{\sigma_{tot}^2(1+\rho^2)}{16\pi B_{el}}$$

$$B_{\mathrm{el}}(s) = \left[\left(\frac{d\sigma_{\mathrm{el}}}{dt}\right)^{-1} \frac{d}{dt}\left(\frac{d\sigma_{\mathrm{el}}}{dt}\right)\right]_{t=0}$$

$$B_{\mathrm{el}}(s) = \left\{\int d^2b \frac{b^2}{2} \Gamma_{\mathrm{el}}(b, s)\right\} \times \left\{\int d^2b \Gamma_{\mathrm{el}}(b, s)\right\}^{-1}$$

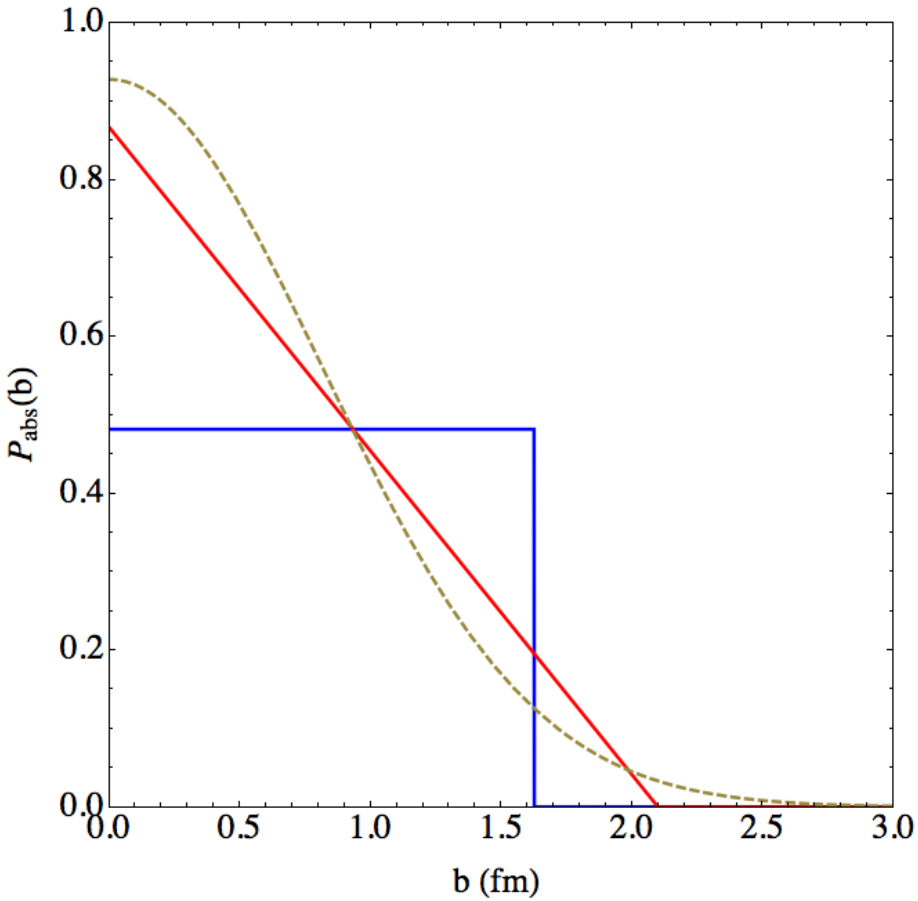
$$= \frac{\langle b^2 \rangle}{2}$$

Elastic Cross section has essentially no
Phenomenological significance for the development
Of Cosmic Ray Showers.

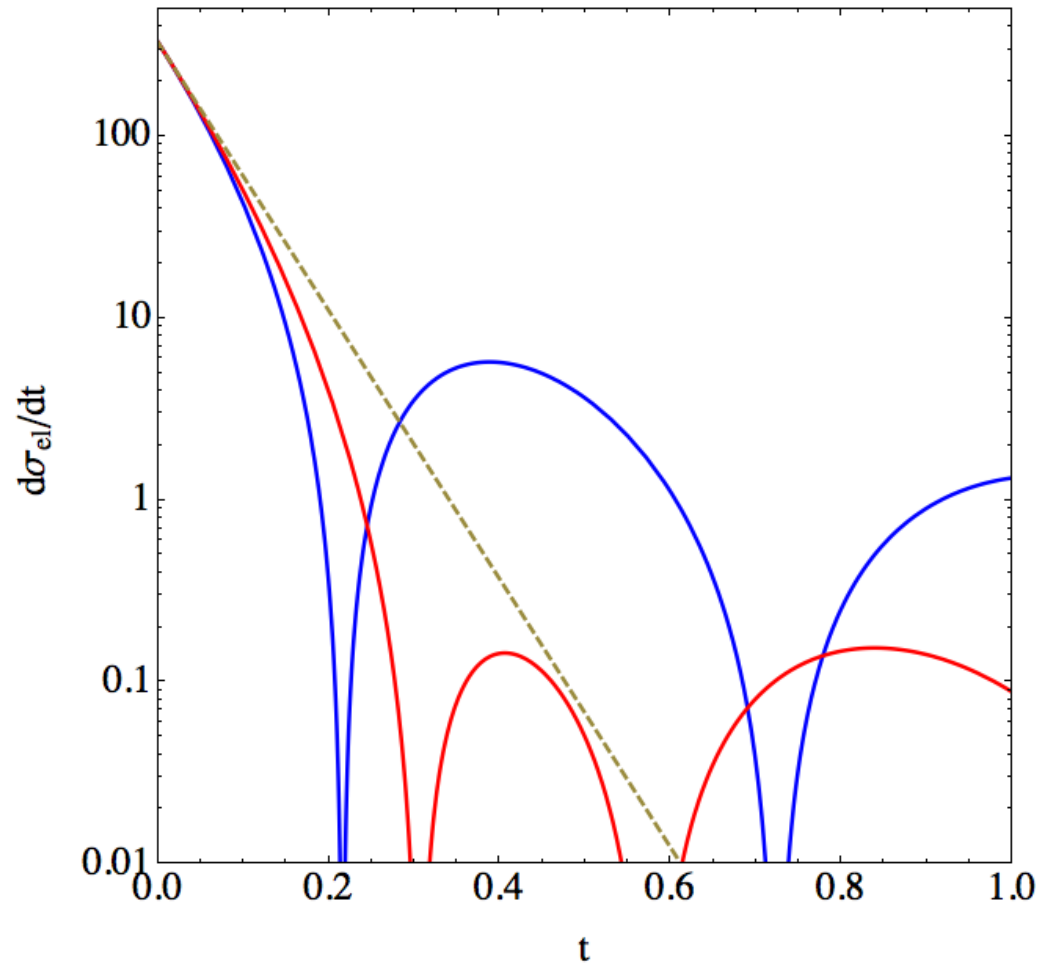
[Very small angle scattering]

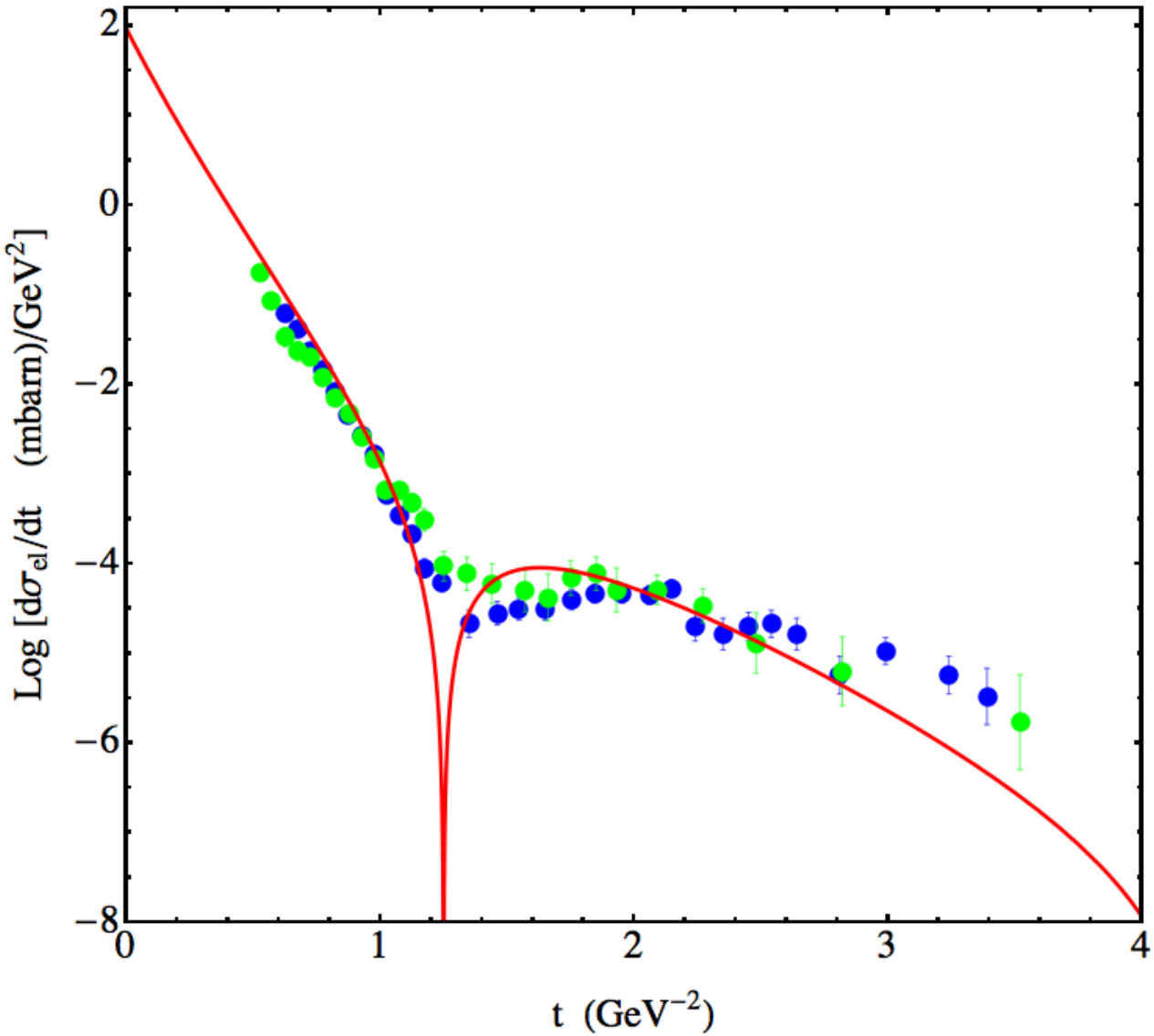
But conceptually it is of great importance
Because it can lead to a deeper understanding
Of the dynamics of the hadron-hadron interaction.

Absorption profiles

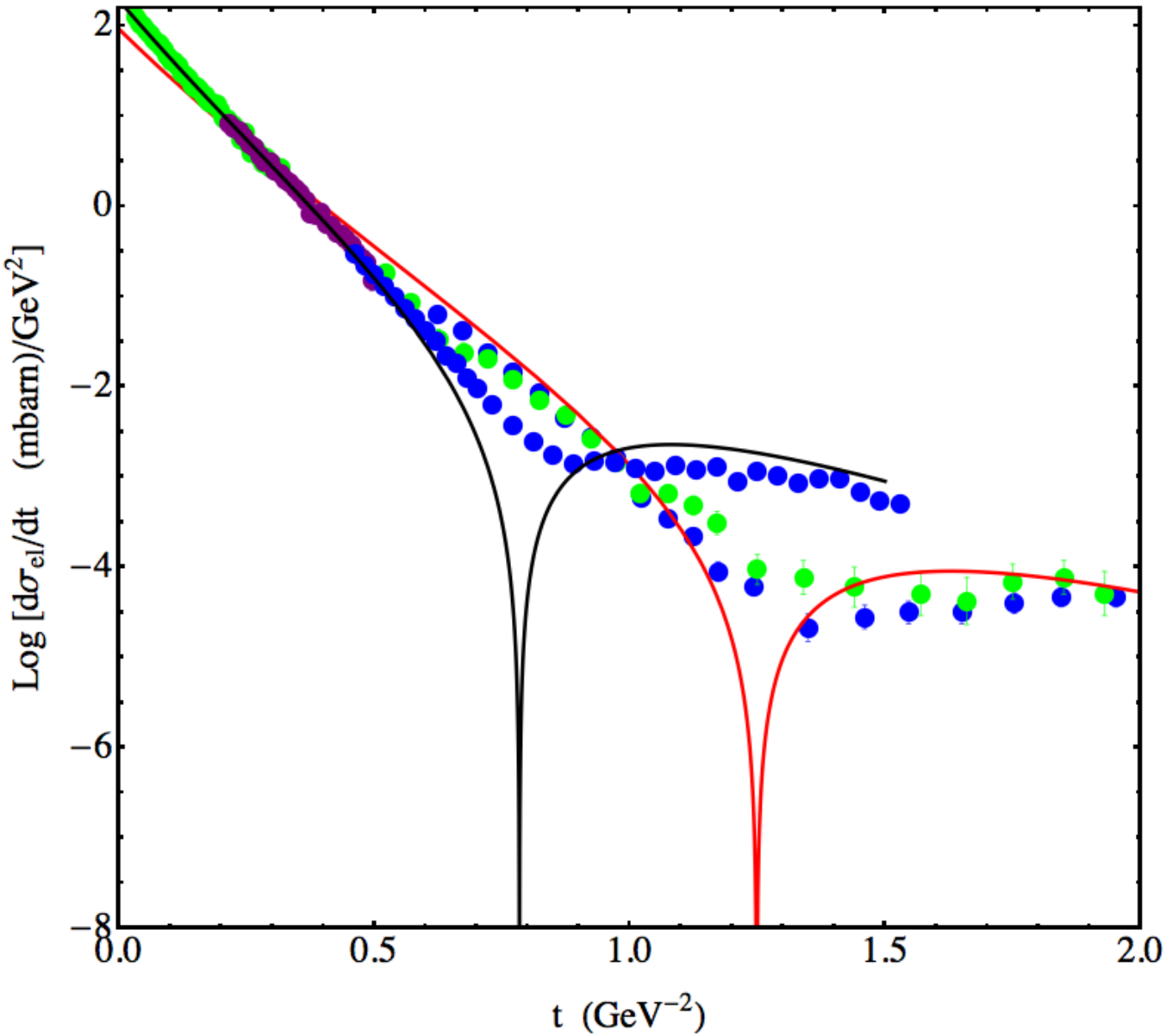


Elastic scattering




2
0
−2
−4
−6
−8
0
1
2
3
4
Log [dσel/dt (mbarn)/GeV2]
t (GeV−2)

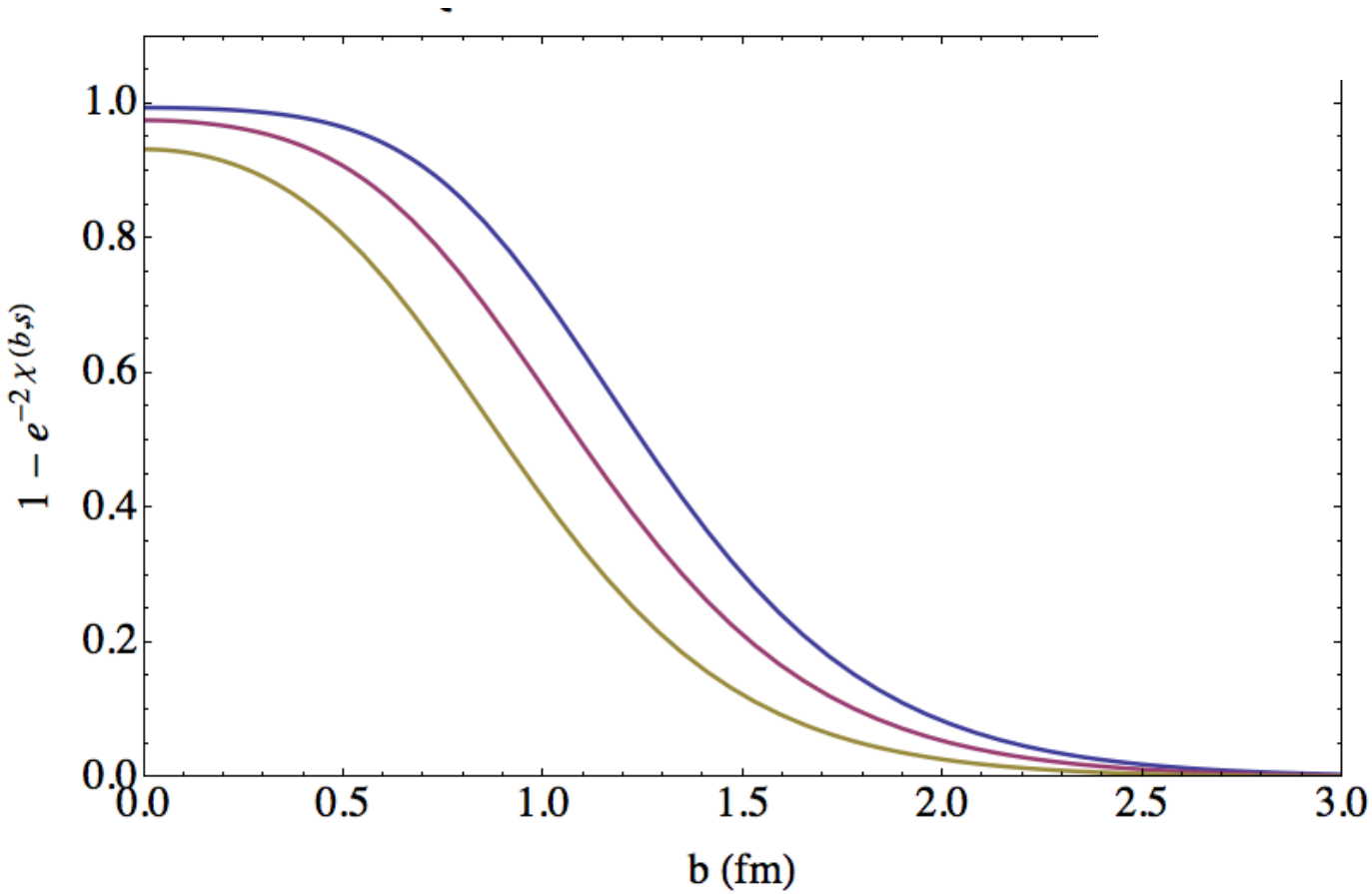
ISR 62.3 GeV
CERN UA4 546 GeV



“Absorption profile”
Obtained from the elastic scattering of pp

ISR
CERN SpS (UA4)
CDF

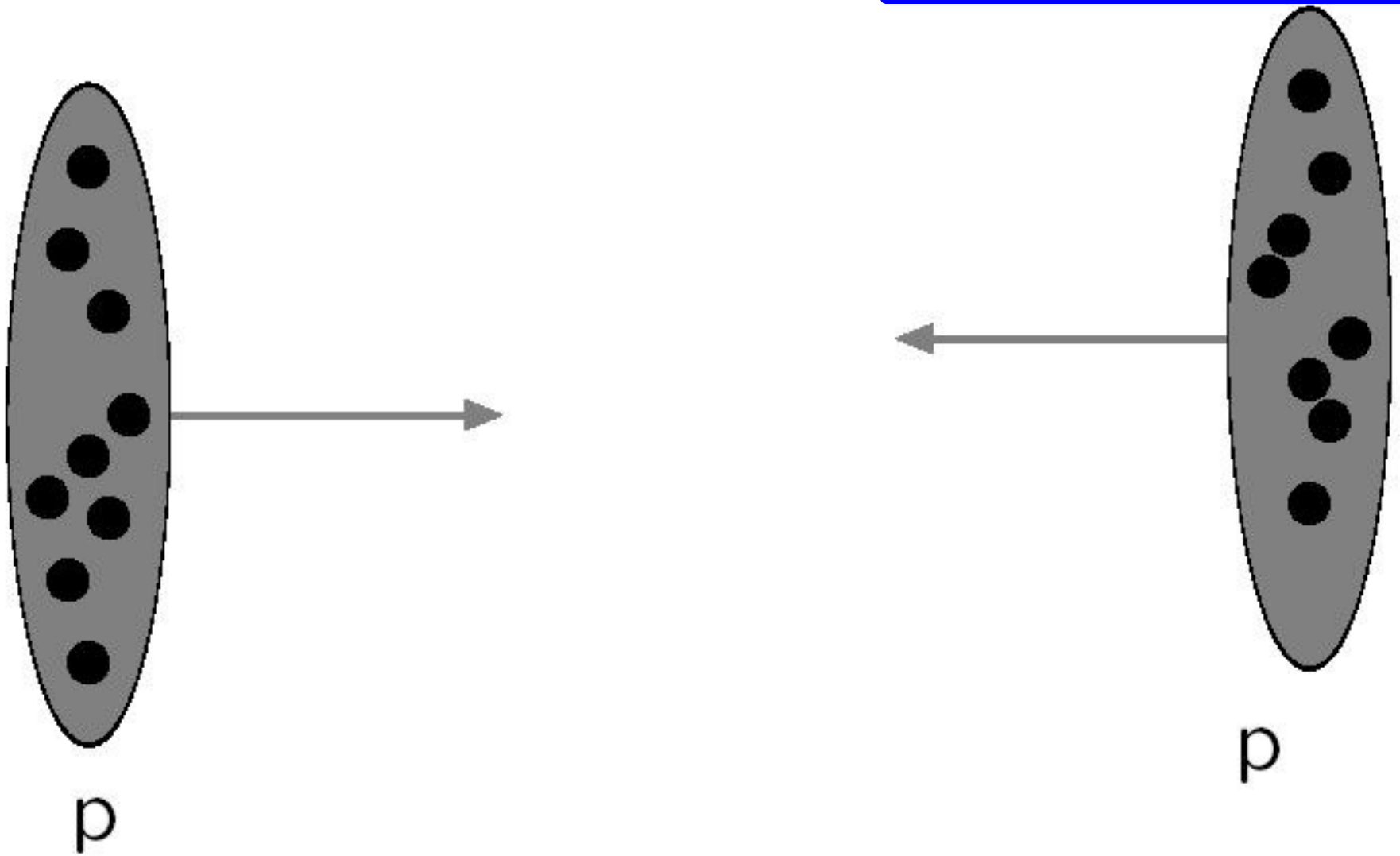
$$\chi(b, s)$$

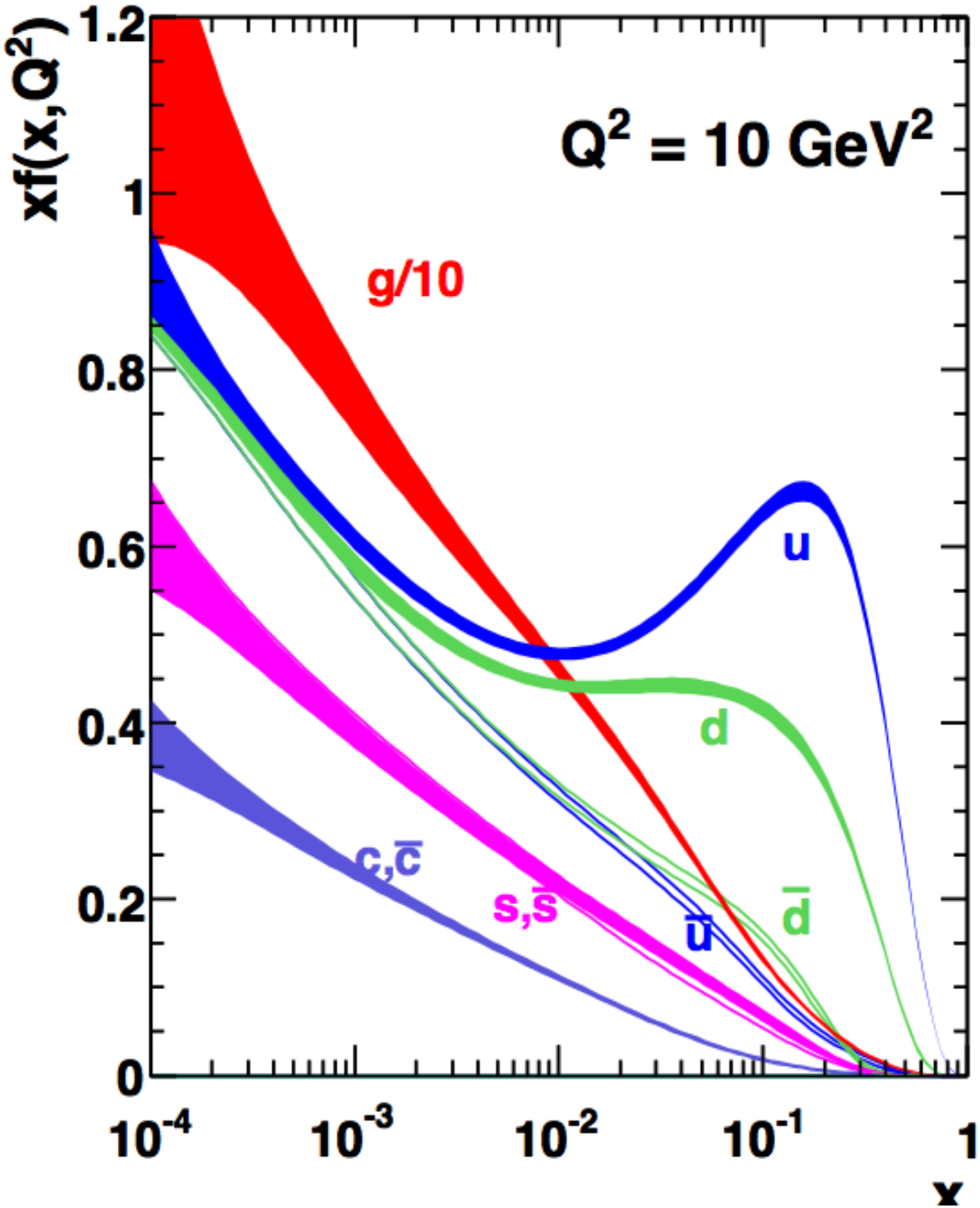


Hadronic Interactions

Composite (complex) Objects
Multiple interaction structure

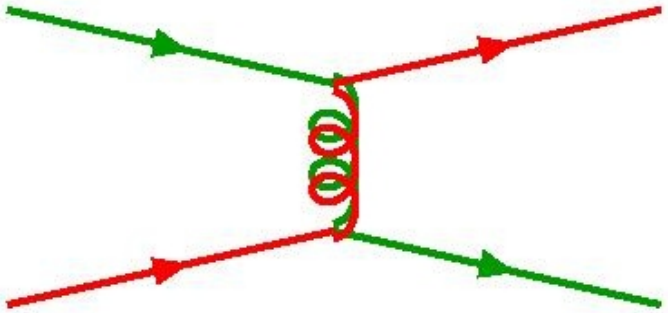
QCD



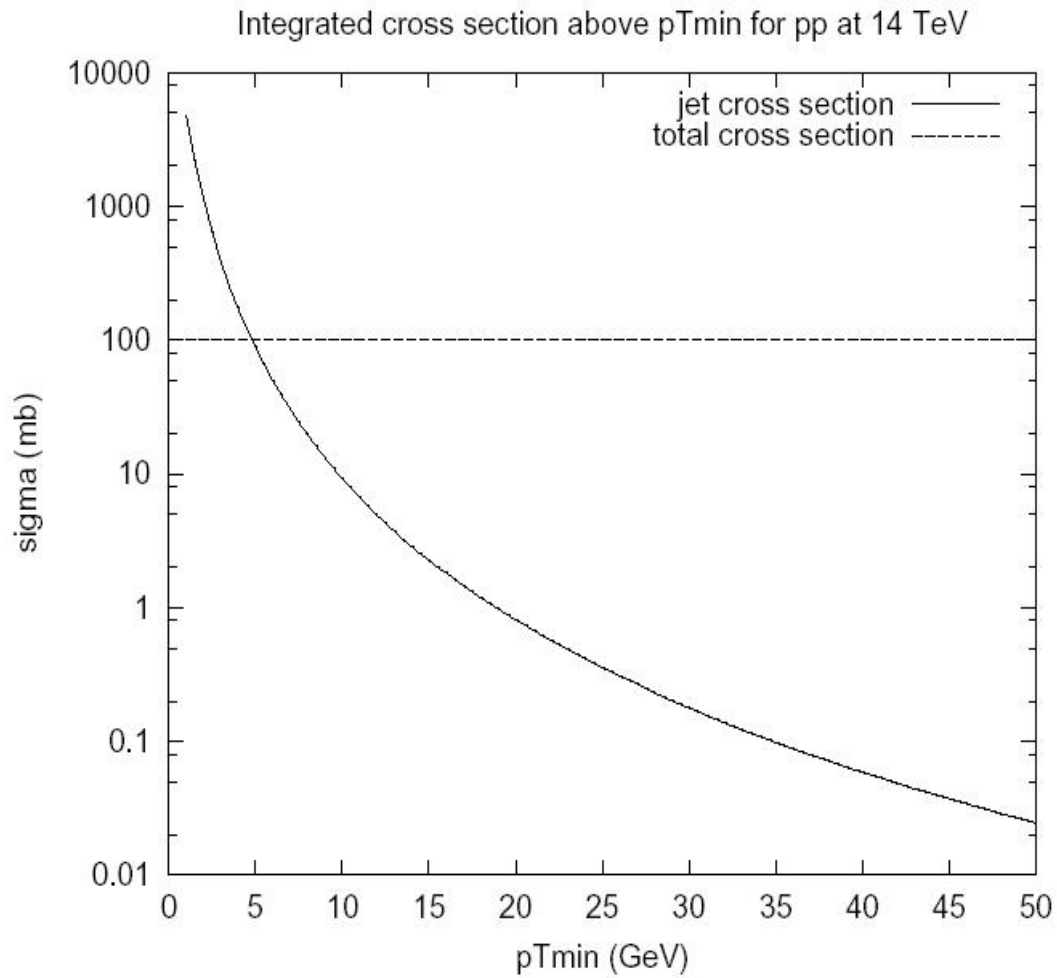


Parton Distribution Function

QCD $2 \to 2$



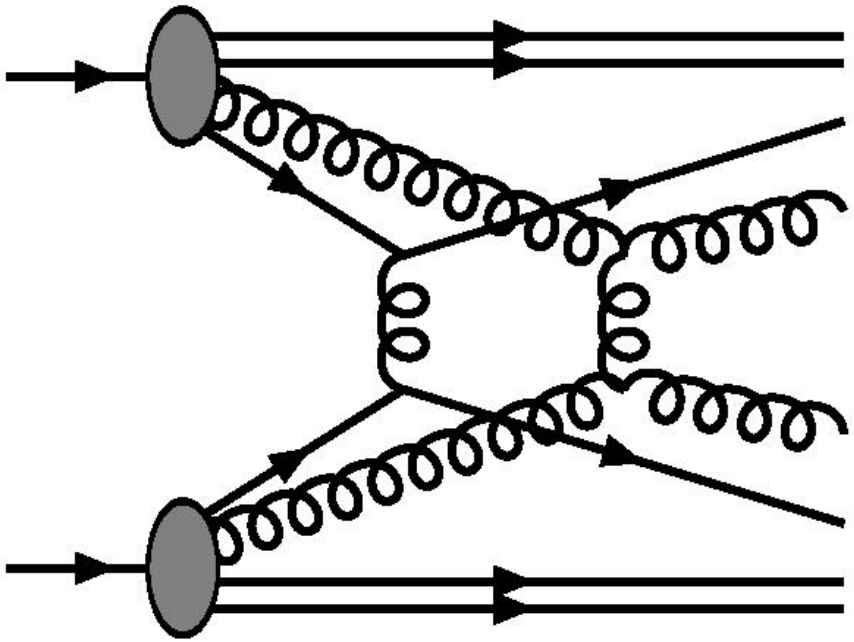
$$qq' \to qq'$$
$$q\bar{q} \to q'\bar{q}'$$
$$q\bar{q} \to gg$$
$$qg \to qg$$
$$gg \to gg$$
$$gg \to q\bar{q}$$



$$d\sigma/dp_\perp^2 \approx 1/p_\perp^4 \text{ for } p_\perp \to 0.$$

Typically 2 – 3 interactions/event at the Tevatron, 4 – 5 at the LHC, but may be more in "interesting" high-$p_\perp$ ones.

Pythia MC



Most particles in Fragmentation Regions Described by the "beam remnants strings"

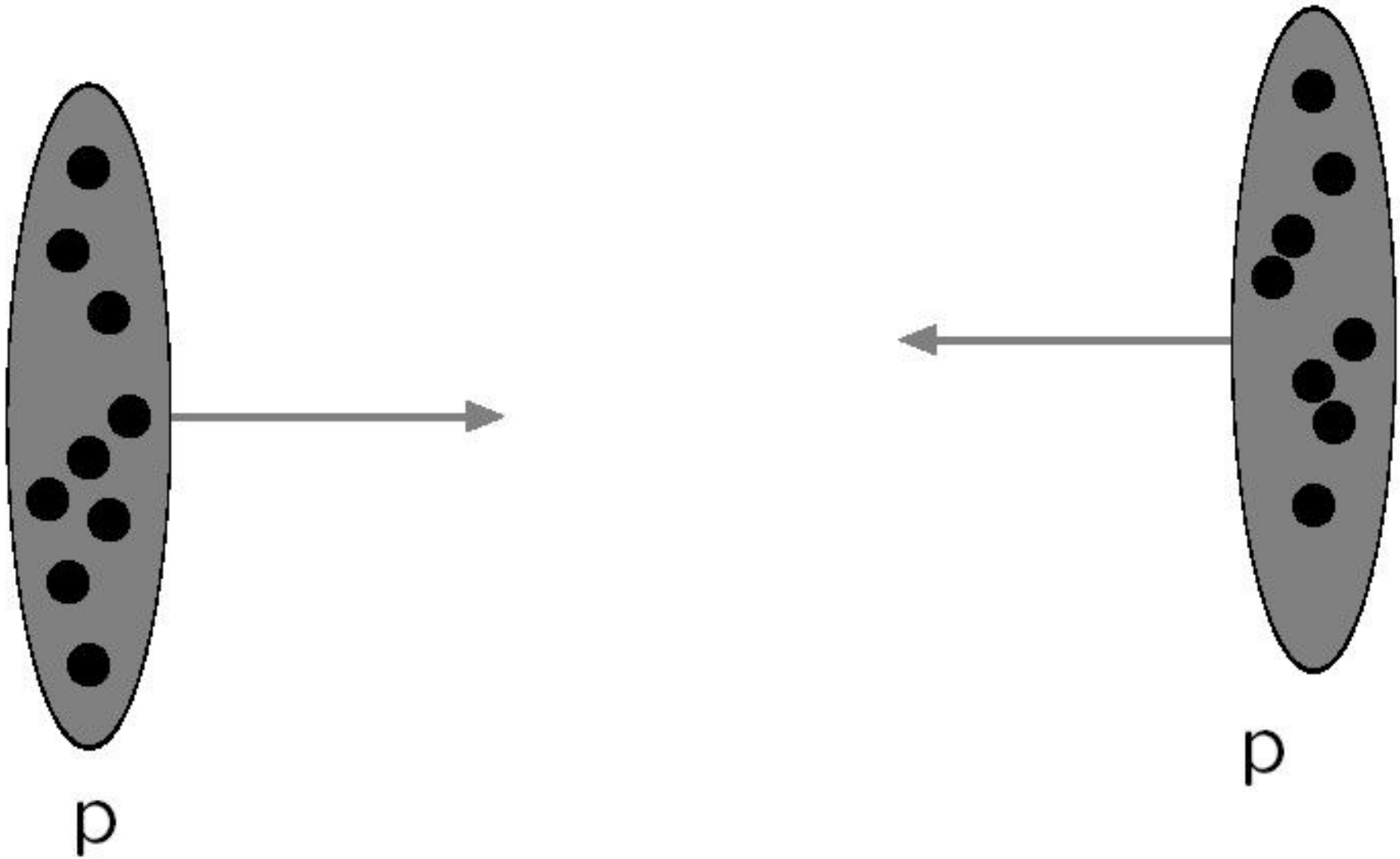
MULTIPLE INTERACTIONS

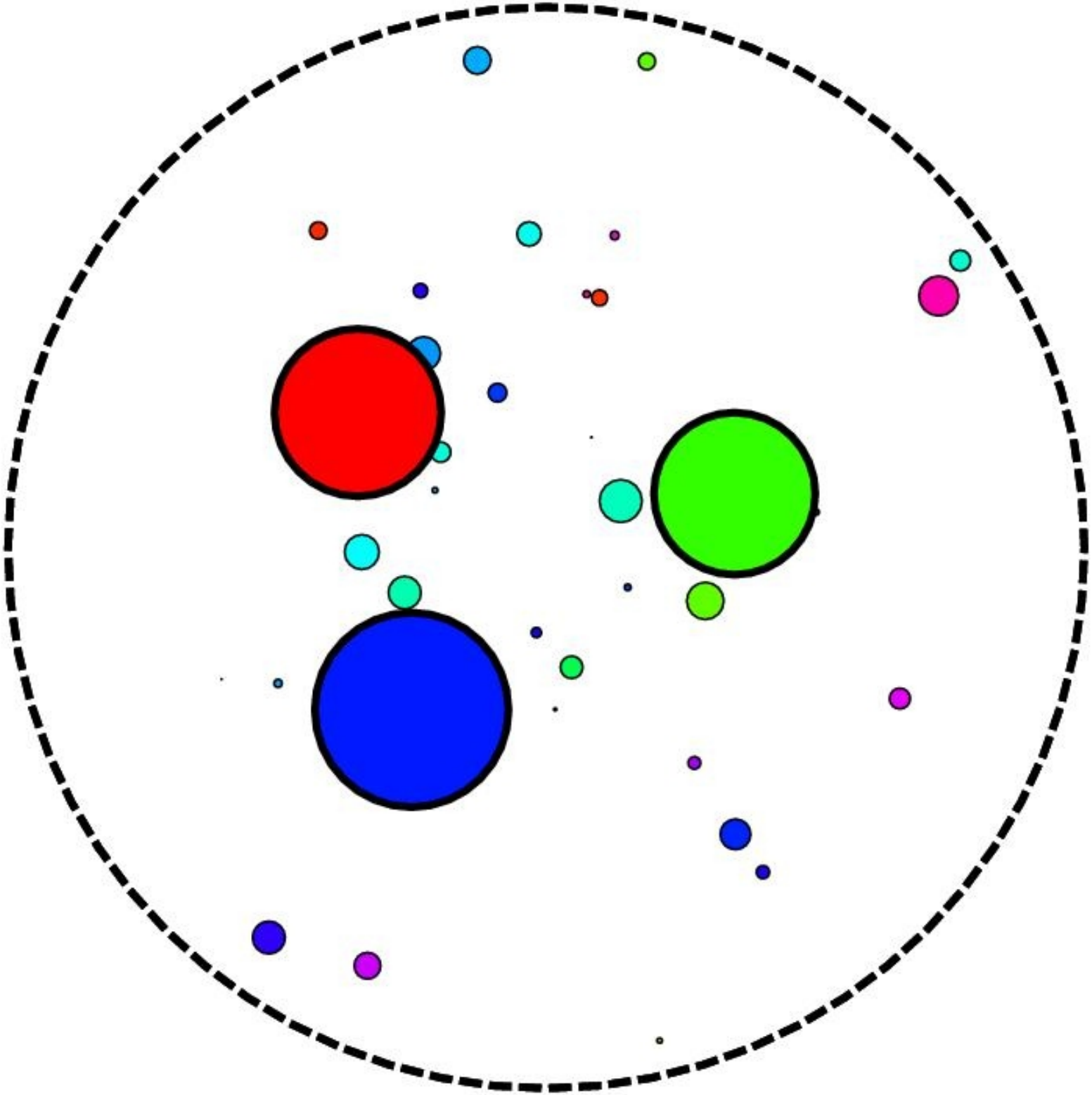
- Estimate of the average number of Elementary interactions per pp scattering
- "Spatial Distribution" [proton spin]
  (Transverse coordinates)
  of the partonic constituents.
- Fluctuations of the
  "parton configuration" of an interactig hadron.

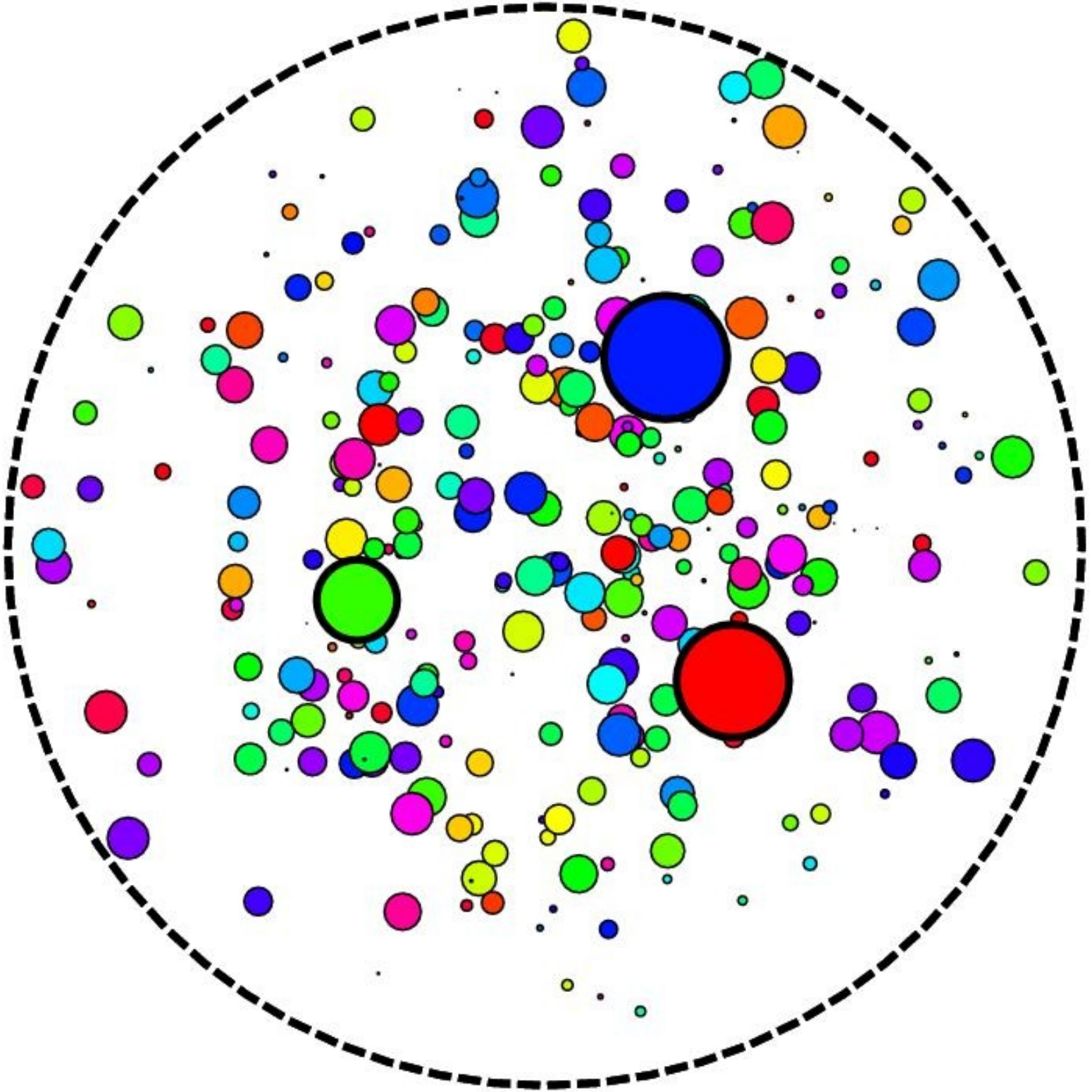
Beyond PDF's
Parton Distribution Functions

Hadrons crossing time short

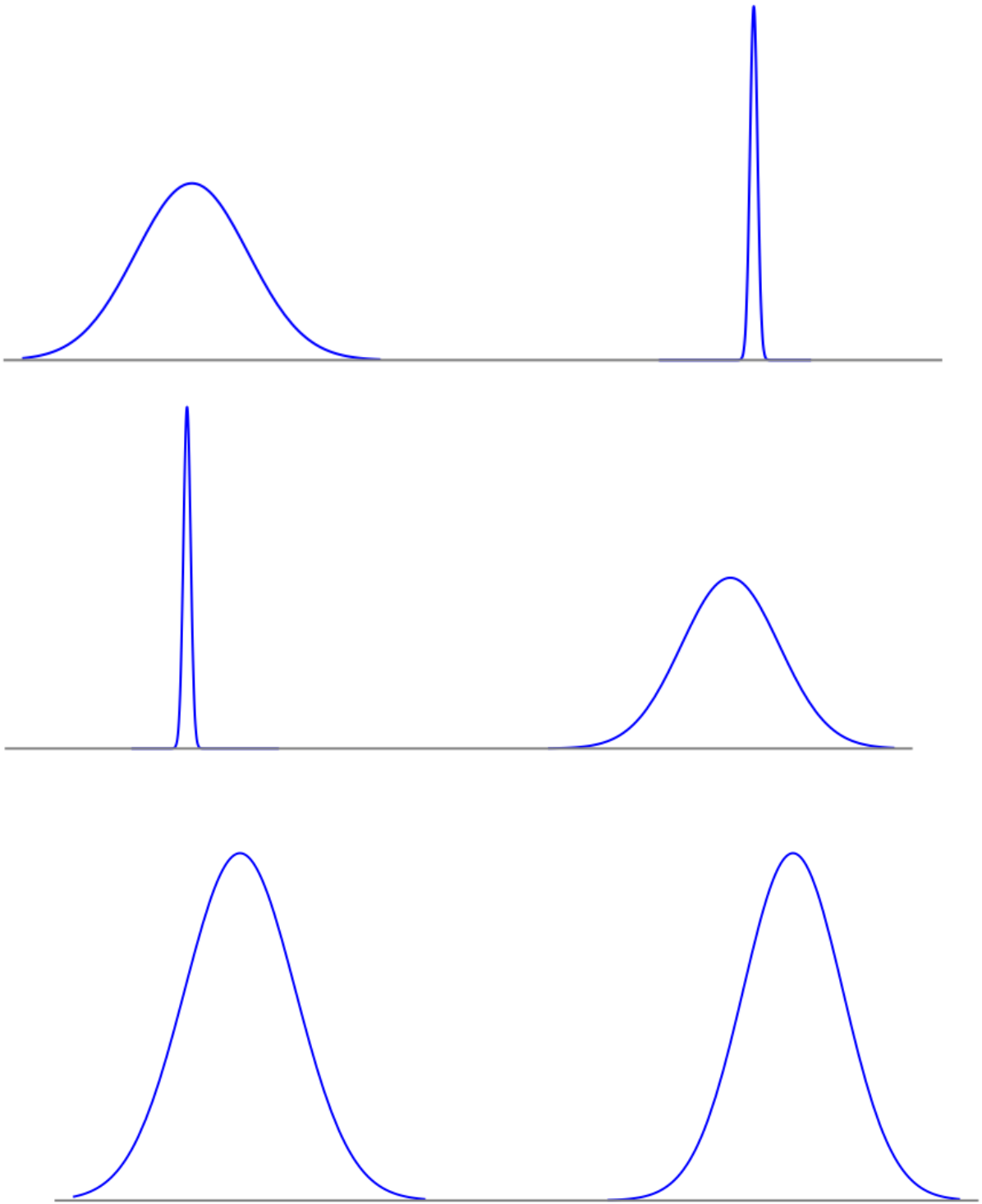
“Snapshot” of the Parton Configuration.







Diffraction

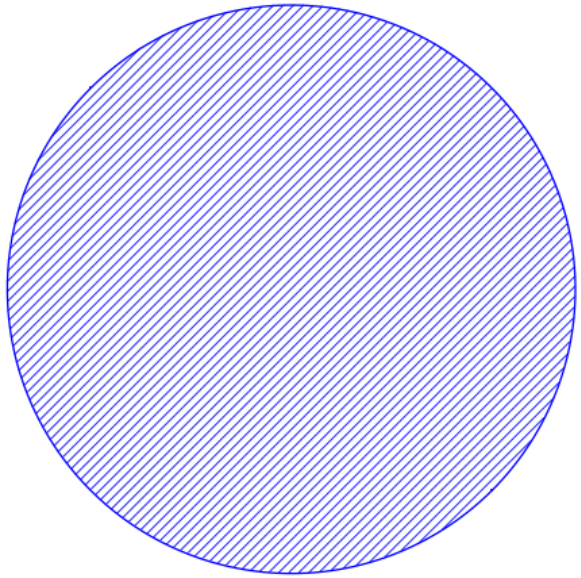


$h_1 h_2 \to h_1^* h_2$ (beam diffraction),

$h_1 h_2 \to h_1 h_2^*$ (target diffraction),

$h_1 h_2 \to h_1^* h_2^*$ (double diffraction).

“Good-Walker ansatz” for inelastic diffraction.
[Extension of the optical analogy]
Scattering of polarized light from a “polarimeter”



Incident beam: $|x\rangle$

Absorbtion of $|x'\rangle$

Out scattered light
In polarizations

$|x\rangle$ $|y\rangle$

$$|x'\rangle = \cos\varphi|x\rangle + \sin\varphi|y\rangle,$$

$$|y'\rangle = -\sin\varphi|x\rangle + \cos\varphi|y\rangle$$

Elastic scattering

“inelastic diffraction”

$$|x'\rangle = \cos\varphi|x\rangle + \sin\varphi|y\rangle,$$

$$|y'\rangle = -\sin\varphi|x\rangle + \cos\varphi|y\rangle$$

$|x\rangle$ $|y\rangle$ ..... = p, Delta, ...

$|x'\rangle$ $|y'\rangle$ ... = different
"Parton configurations"

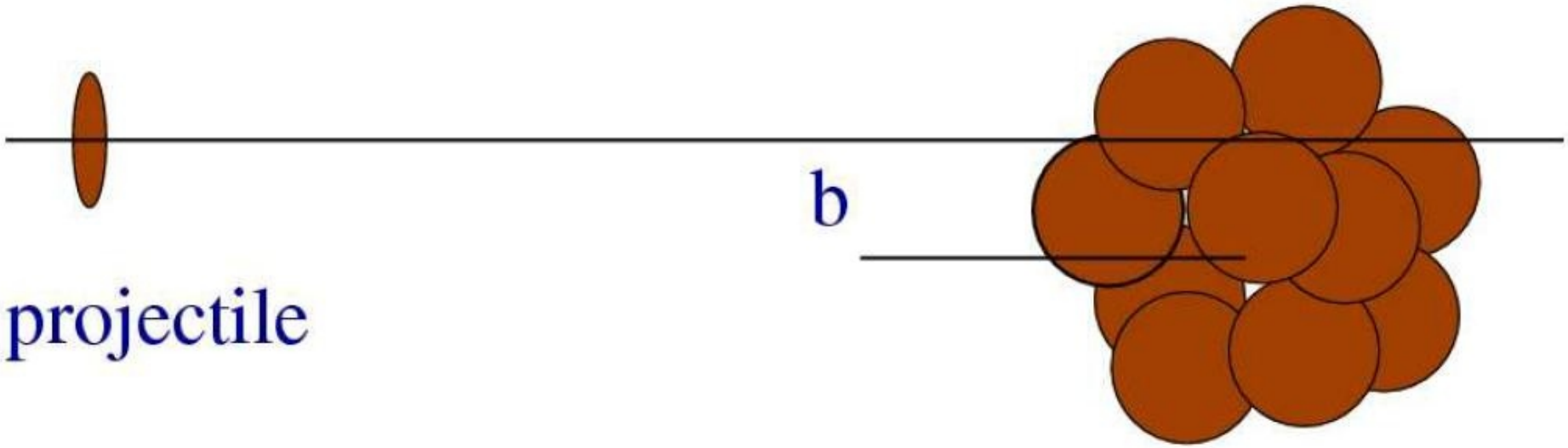
Phenomenological
Significance of Pion Cross section
In Cosmic Ray Showers.

Theoretical interest:
Range of predictions:

$$\sigma_{\pi p}(\sqrt{s}) \simeq \sigma_{pp}(\sqrt{s})$$

$$\sigma_{\pi p}(\sqrt{s}) \simeq \frac{2}{3}\,\sigma_{pp}(\sqrt{s})$$

Nuclear Effects



Possibility to study
proton-nucleus interactions at LHC

Heavy in program

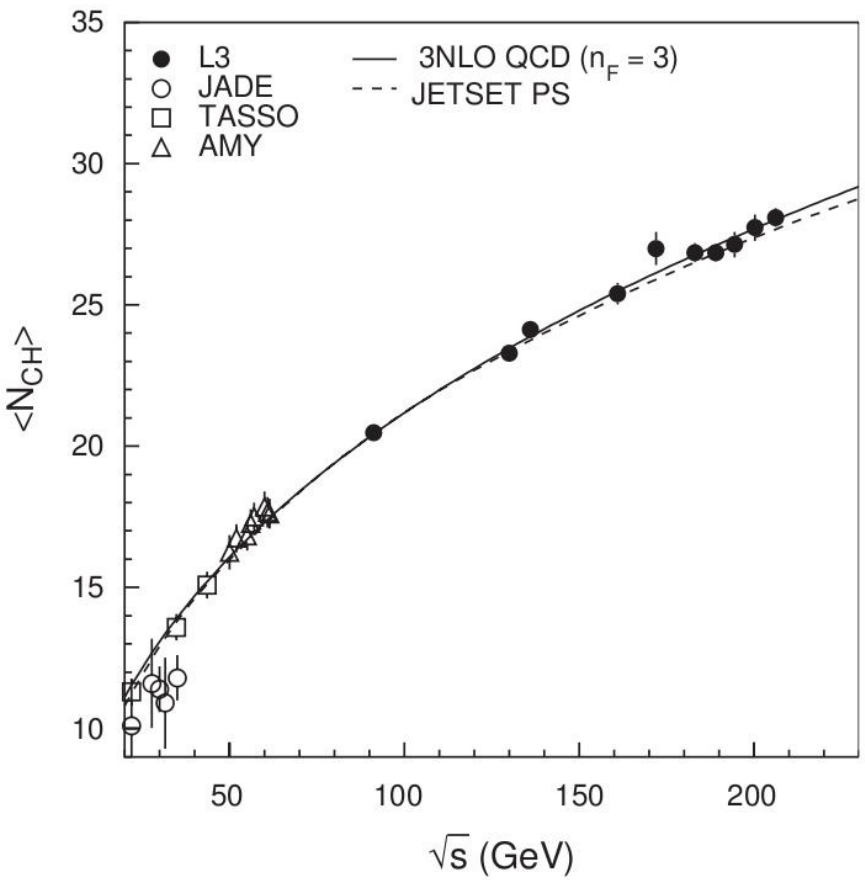
Properties of Particle Production.

From the modeling of the total cross section
To the description of particle production

Need of additional assumptions.

Electron - Positron Results

Quark-gluon structure + Hadronization. Excellent agreement



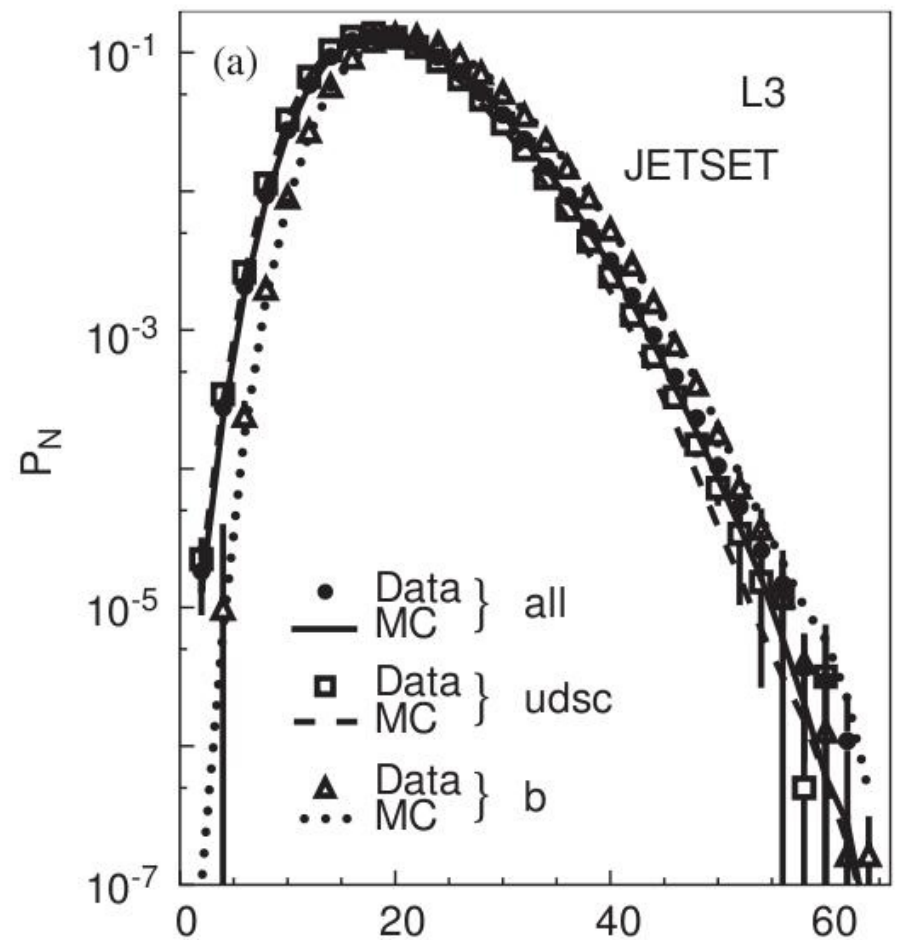
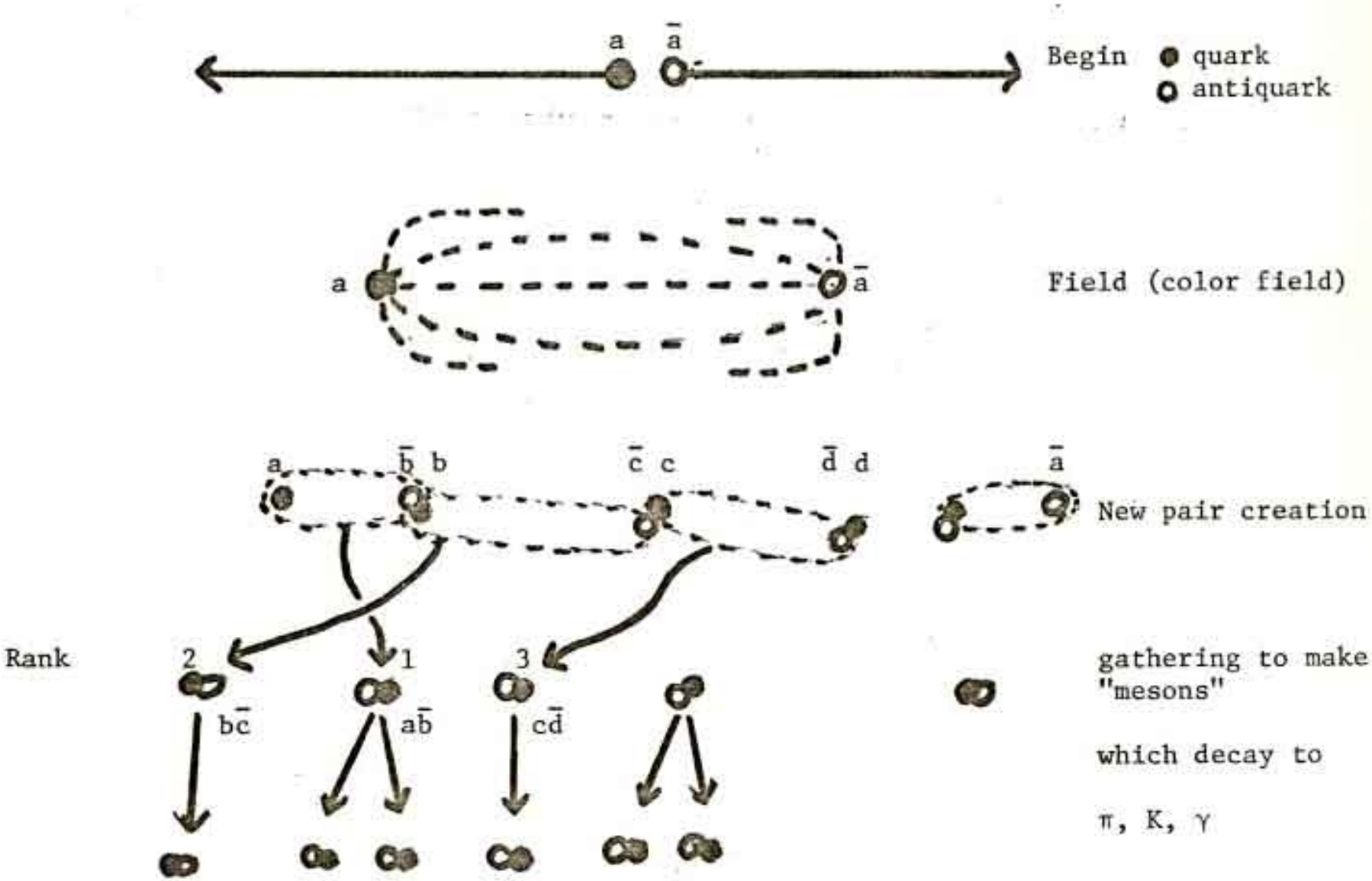
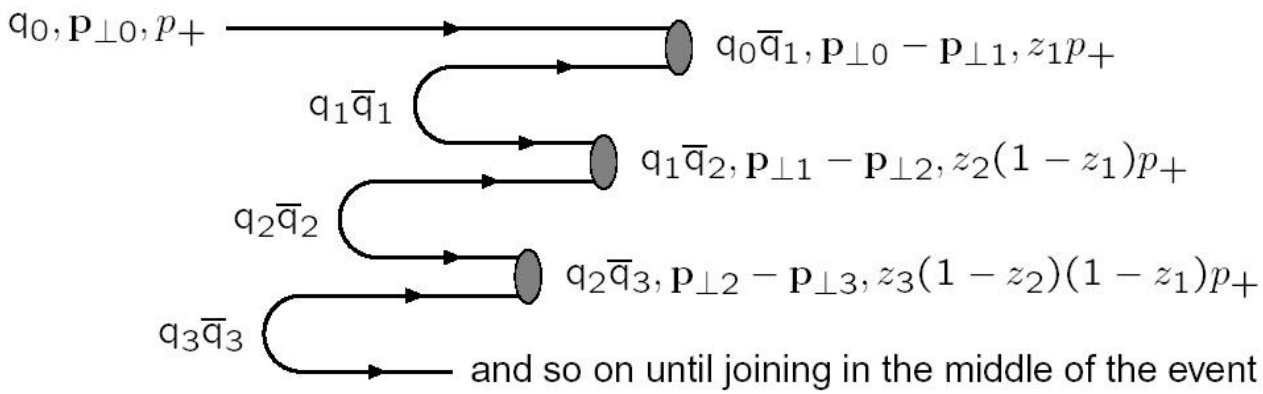


Fig. 1. An e^+e^- Annihilation

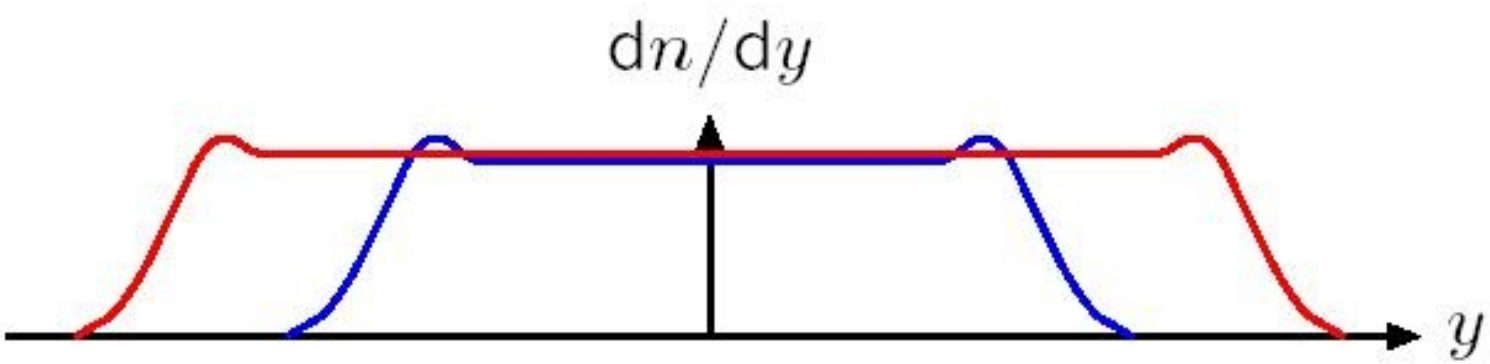


Field -Feynman : Quark - Fragmentation

The (iterative) Fragmentation of one COLOR STRING produces a SCALING SPECTRUM of HADRONS

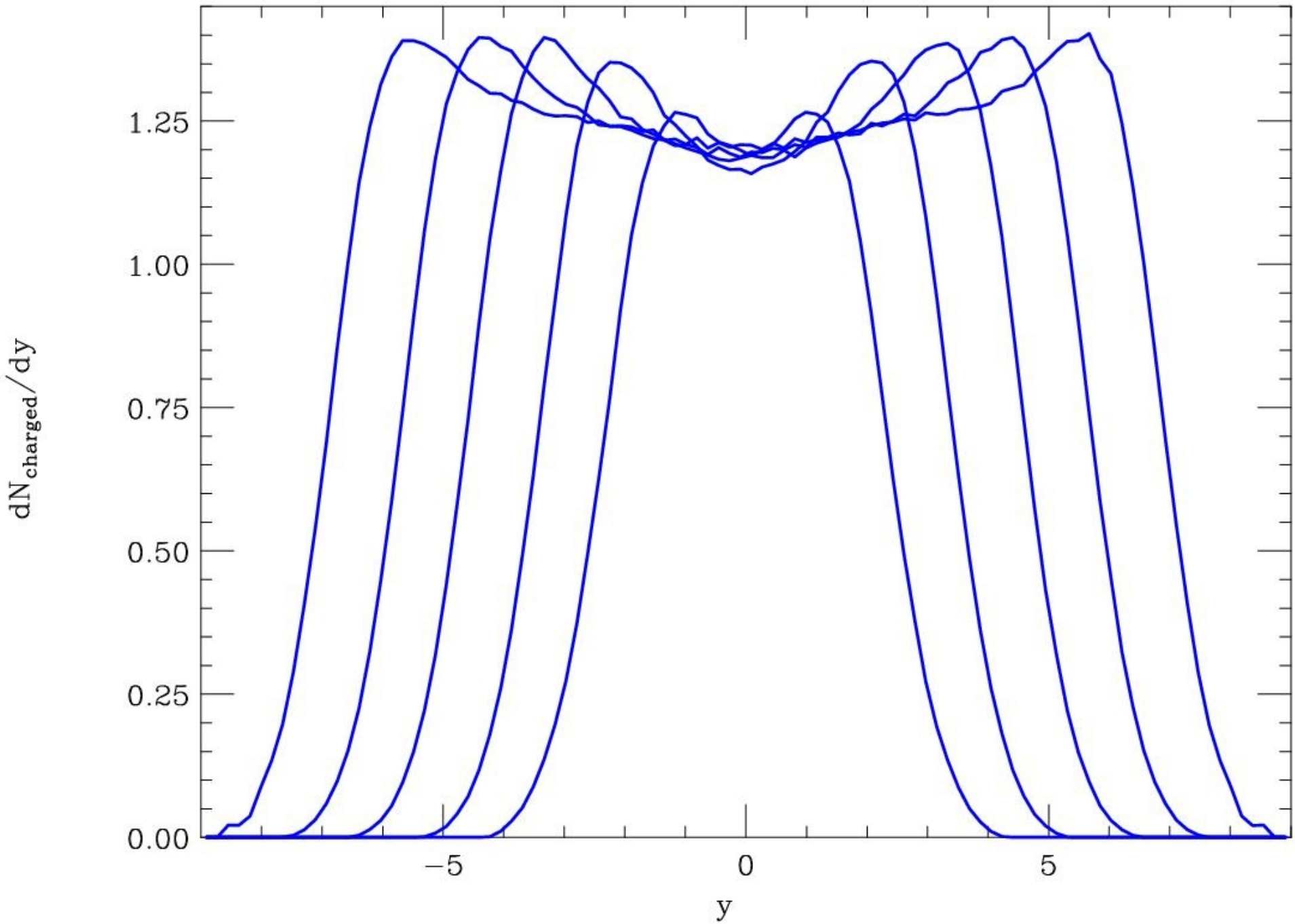


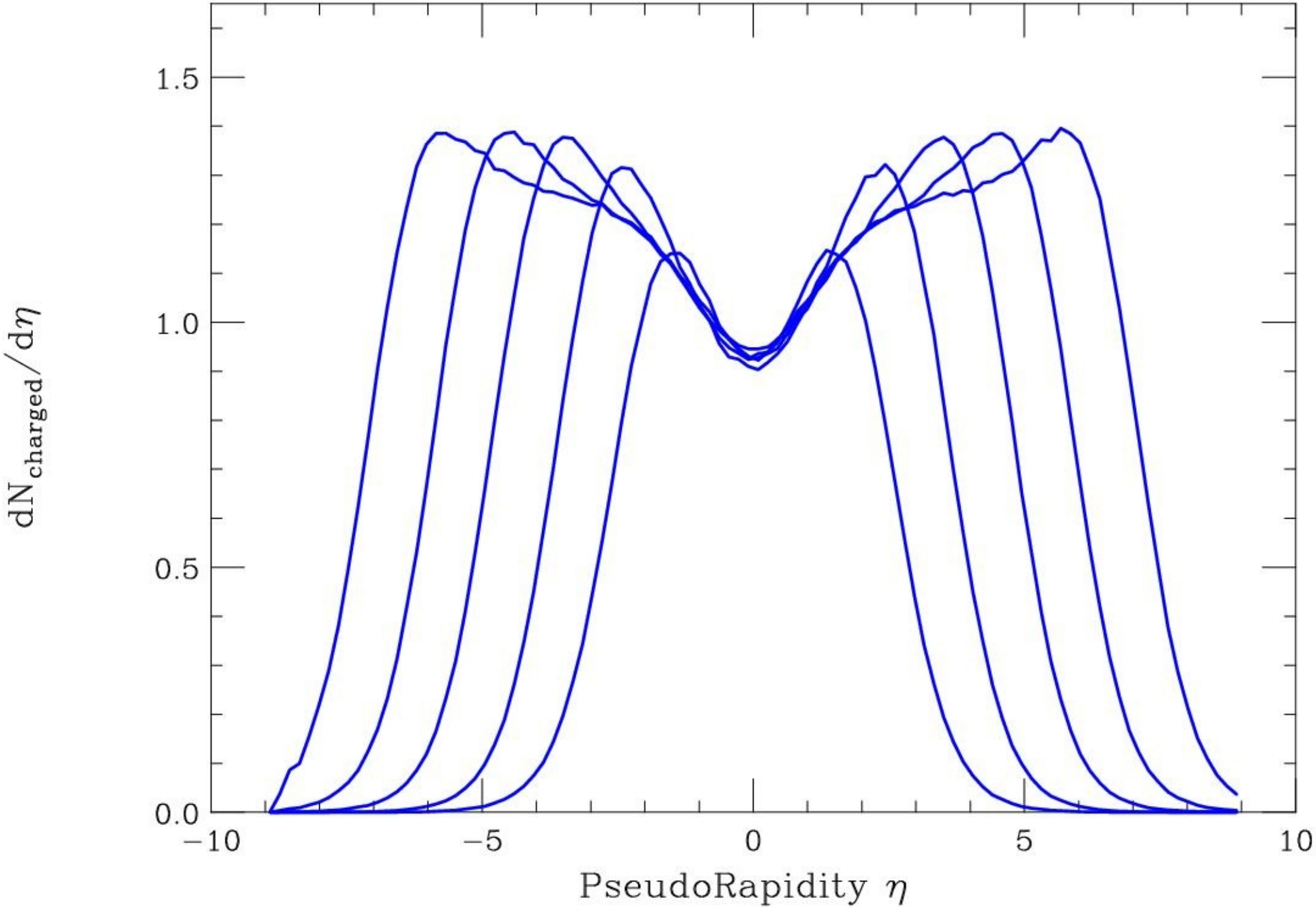
int effects:

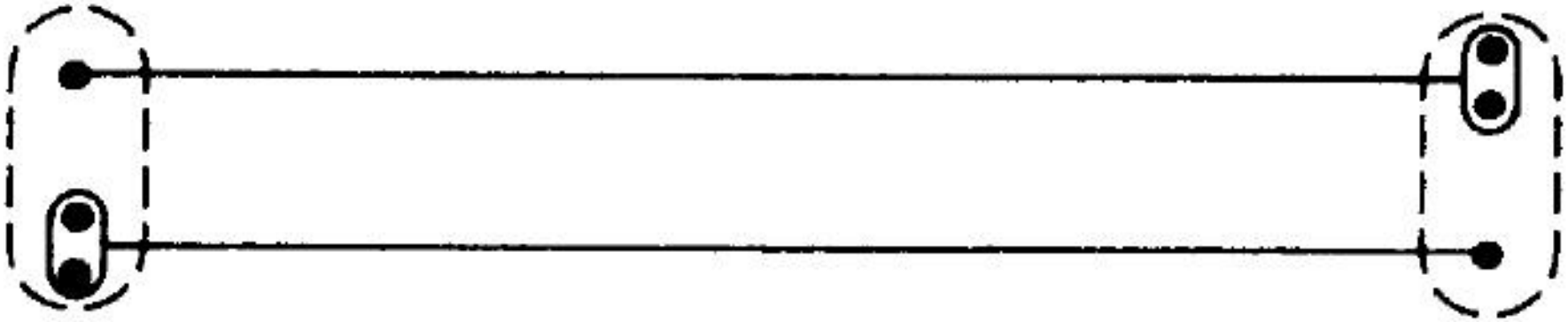


$\langle n_{\mathrm{ch}} \rangle \approx c_0 + c_1 \ln E_{\mathrm{cm}}$, $\sim$ Poissonian multiplicity distribution

Charged particle rapidity distribution : qq system




1.5
1.0
0.5
0.0
−10
−5
0
5
10
$dN_{charged}/d\eta$
PseudoRapidity η



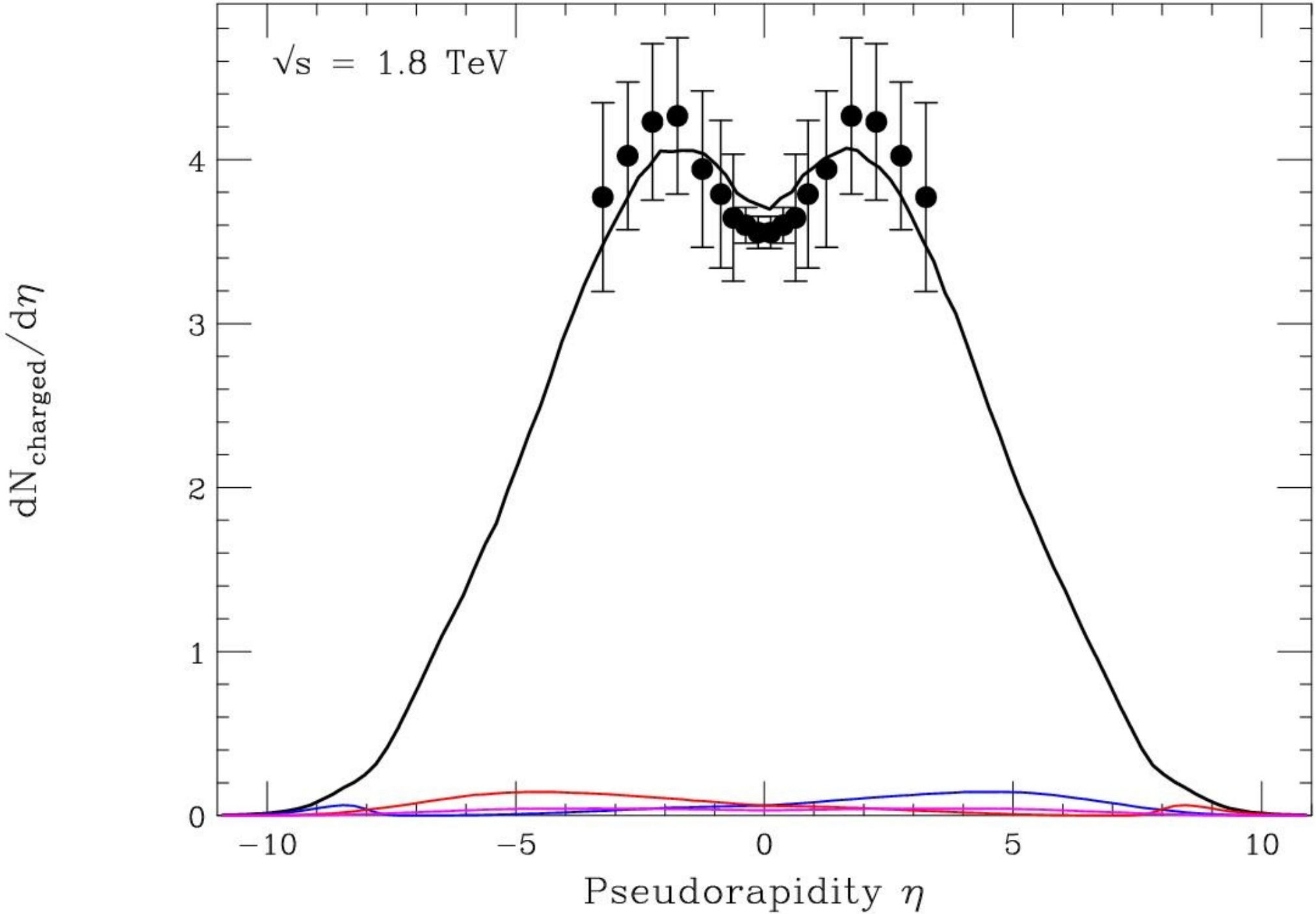
Basic Structure of
a NON diffractive PP interactions
is made of TWO STRINGS

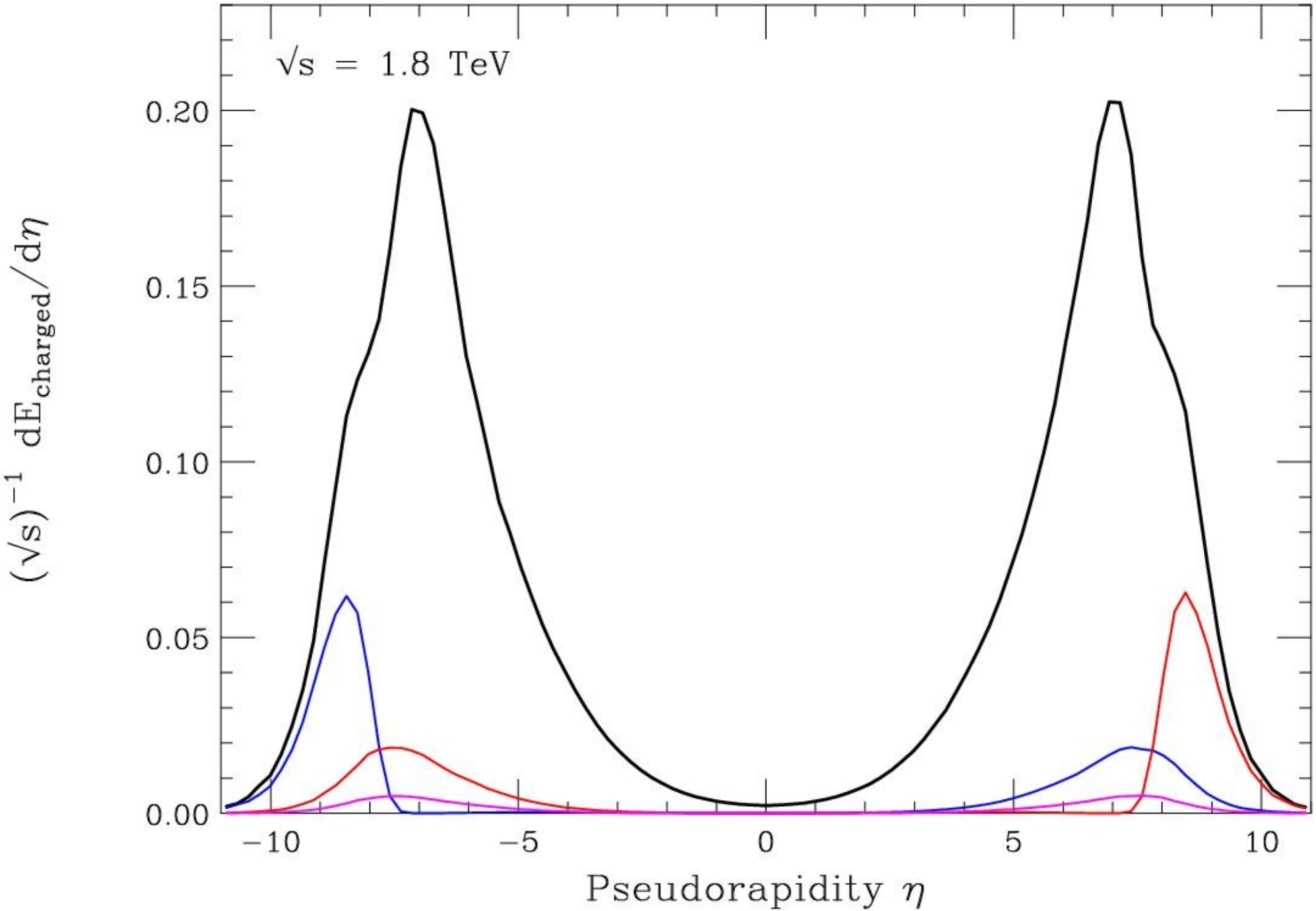
hard/semihard interactions
result in additional strings

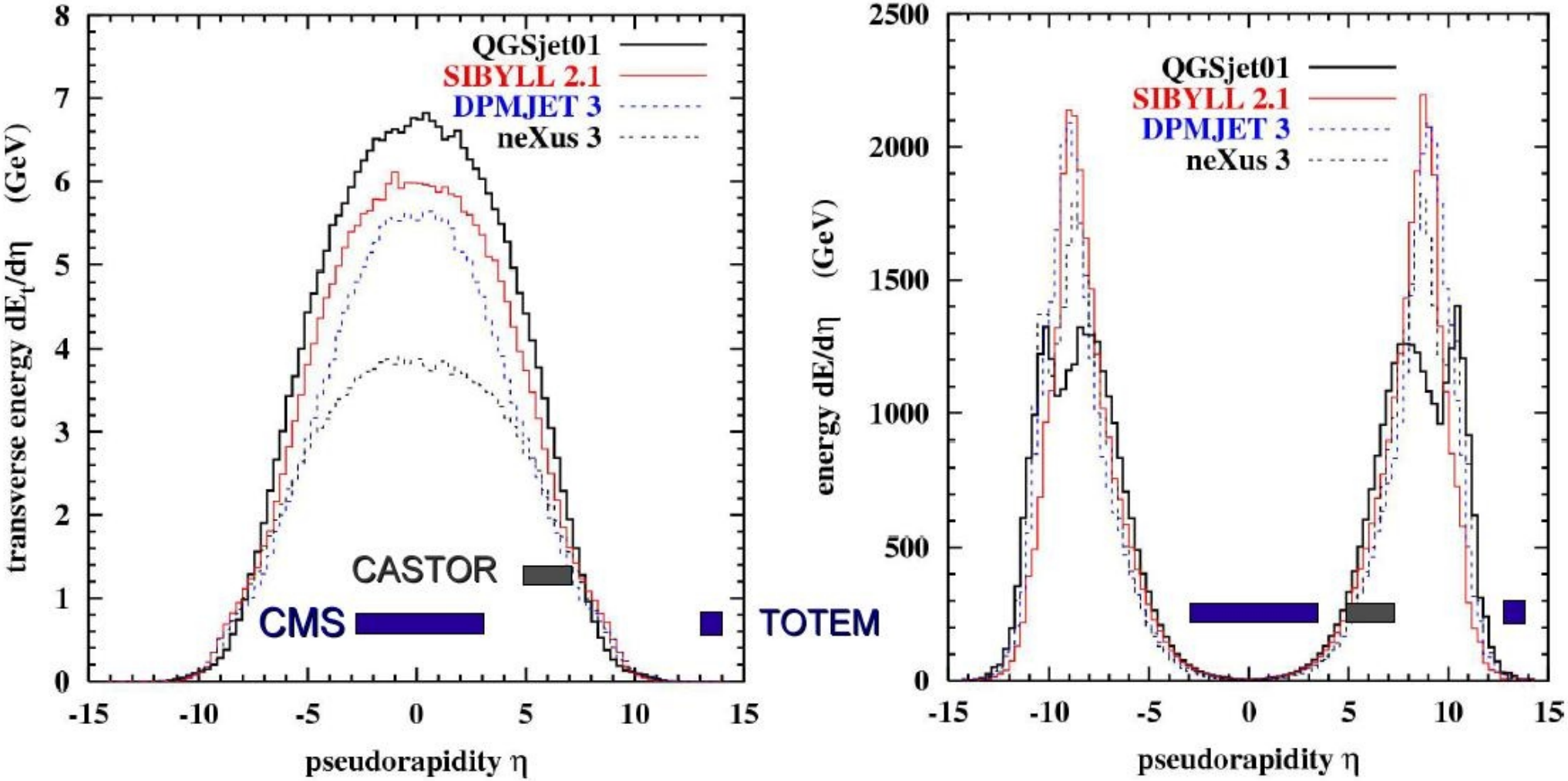
Color Structure

$$3 \otimes 3 = \overline{3} \oplus 6$$

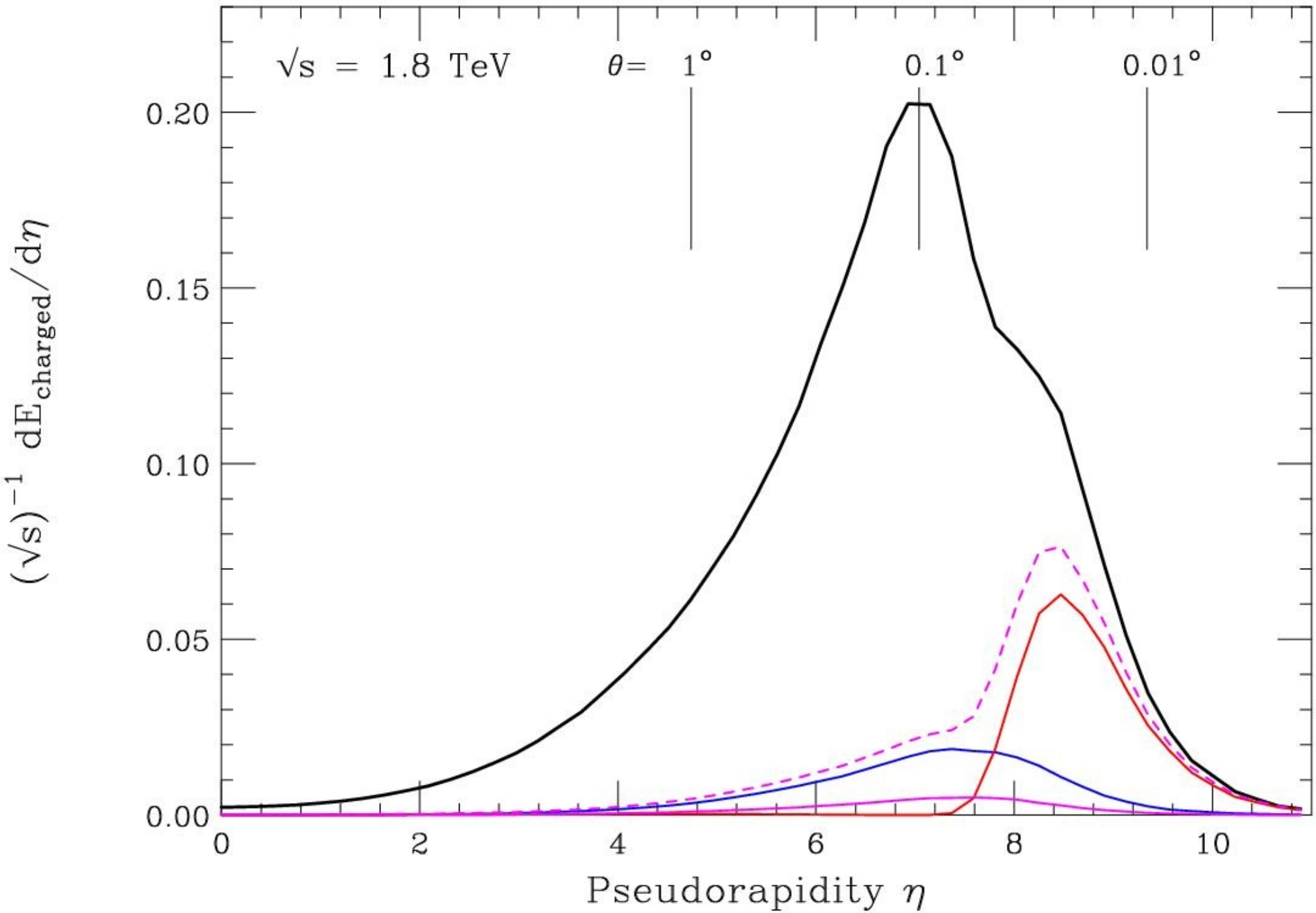
$$3 \otimes \overline{3} = 1 \oplus 8$$


√s = 1.8 TeV
dN_charged/dη
Pseudorapidity η
0
1
2
3
4
−10
−5
0
5
10


√s = 1.8 TeV
0.20
0.15
0.10
0.05
0.00
−10
−5
0
5
10
Pseudorapidity η
(√s)⁻¹ dE_charged/dη



PROBLEM of PHASE SPACE COVERING


√s = 1.8 TeV
θ= 1°
0.1°
0.01°
0.20
0.15
0.10
0.05
0.00
0
2
4
6
8
10
Pseudorapidity η
(√s)⁻¹ dE_charged/dη

Kinematical Variables:

$$dy = \frac{dp_z}{E}$$

Good theoretical variable

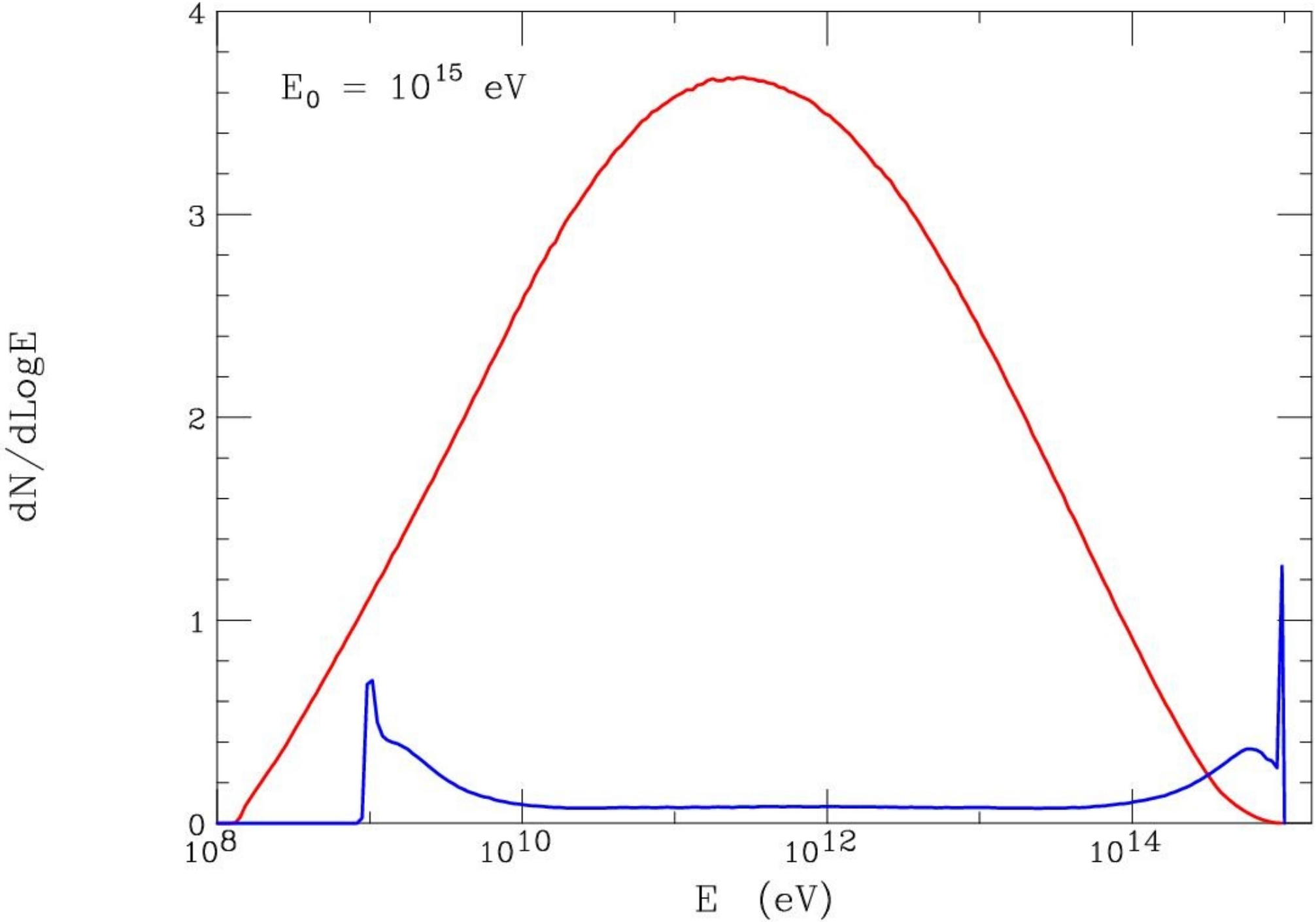
$$d\eta = \frac{dp_z}{p}$$

Experimentally easy

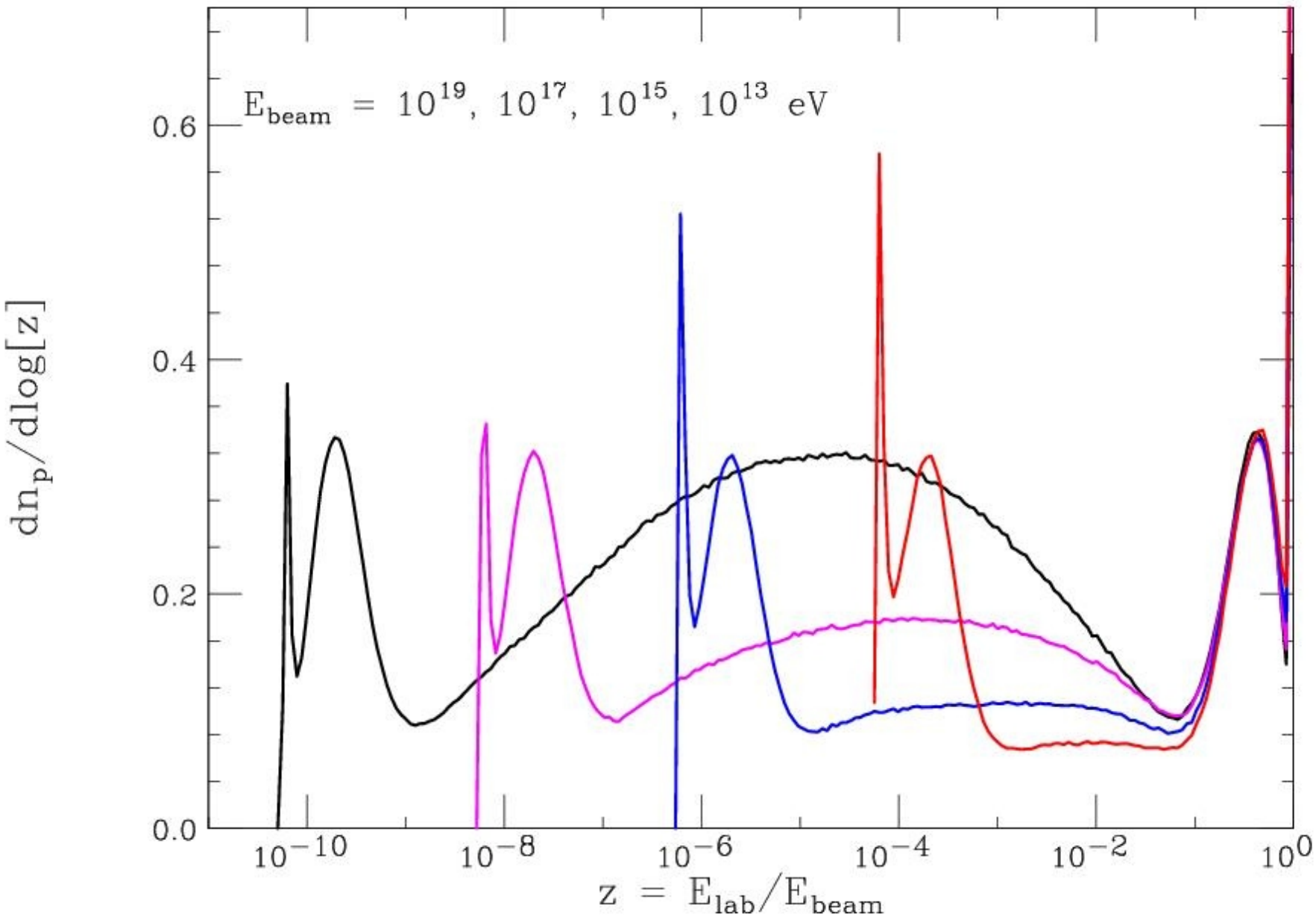
$$dE_{\rm lab} \qquad dz = \frac{dE_{\rm lab}}{E_0}$$

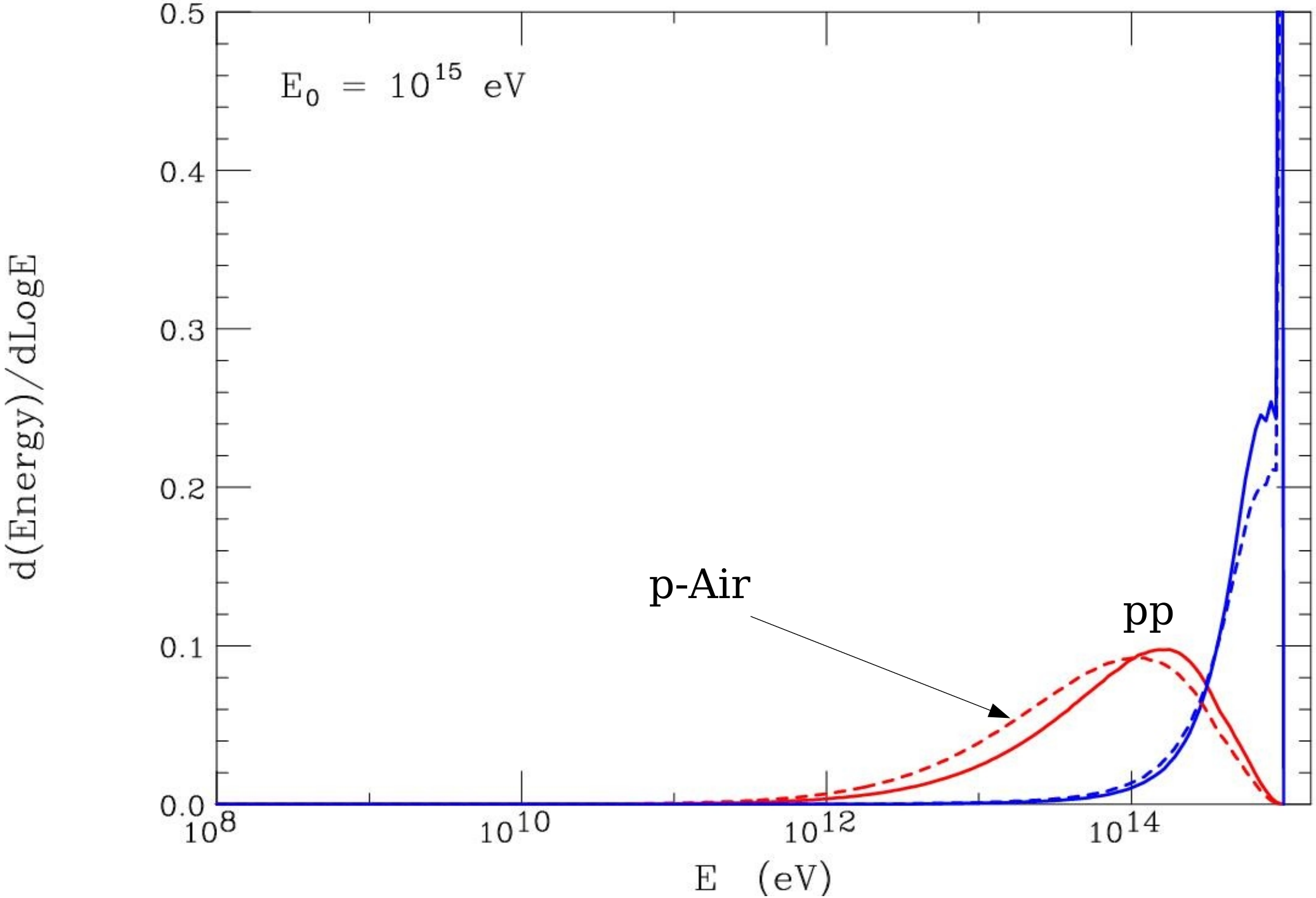
Cosmic Ray interest

$$dy \simeq d\eta \simeq d\ln E = d\ln z$$

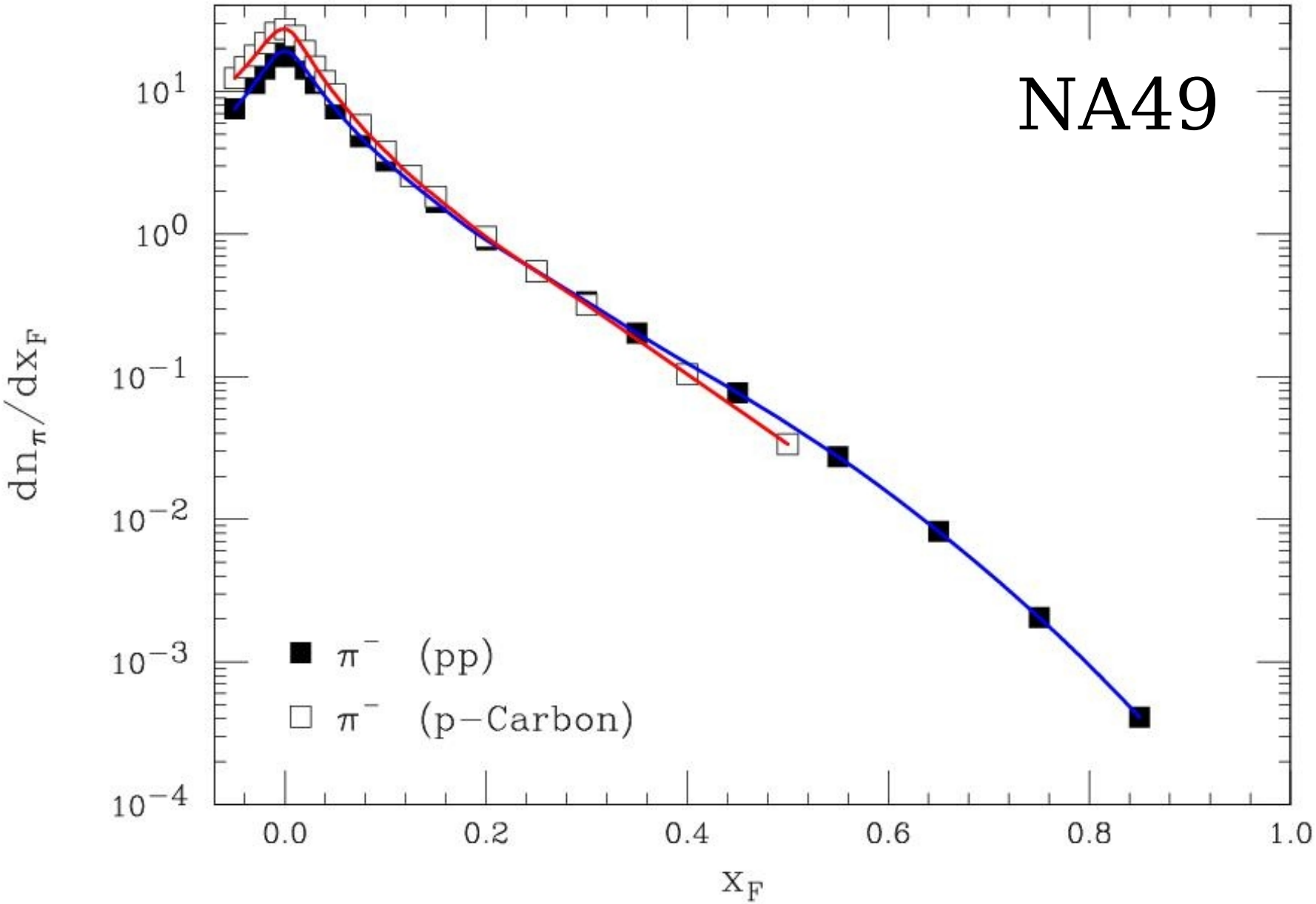

$E_0 = 10^{15}$ eV
dN/dLogE
E (eV)
0
1
2
3
4
10^8
10^{10}
10^{12}
10^{14}

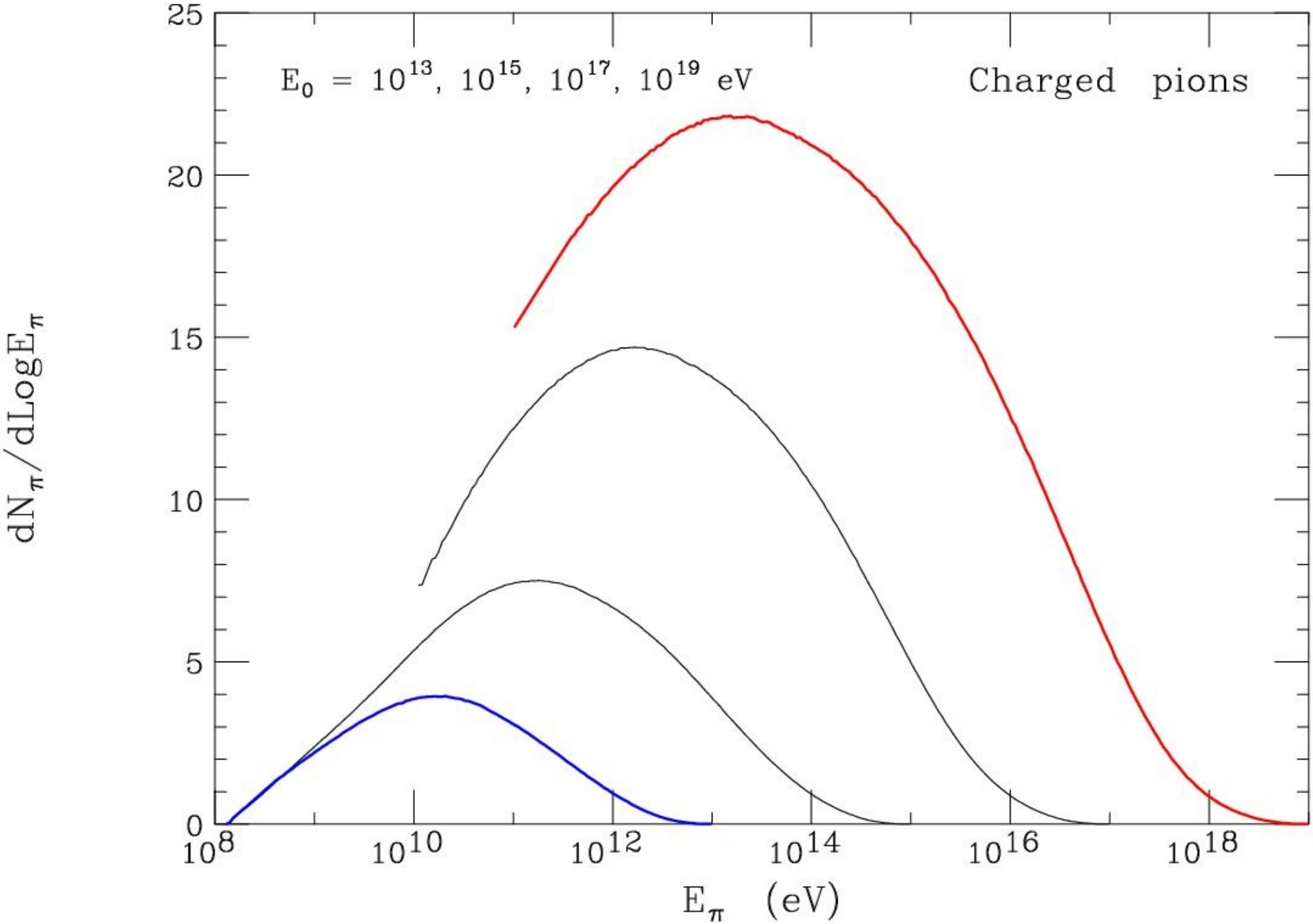
PROTON Spectra (elasticity spectra)

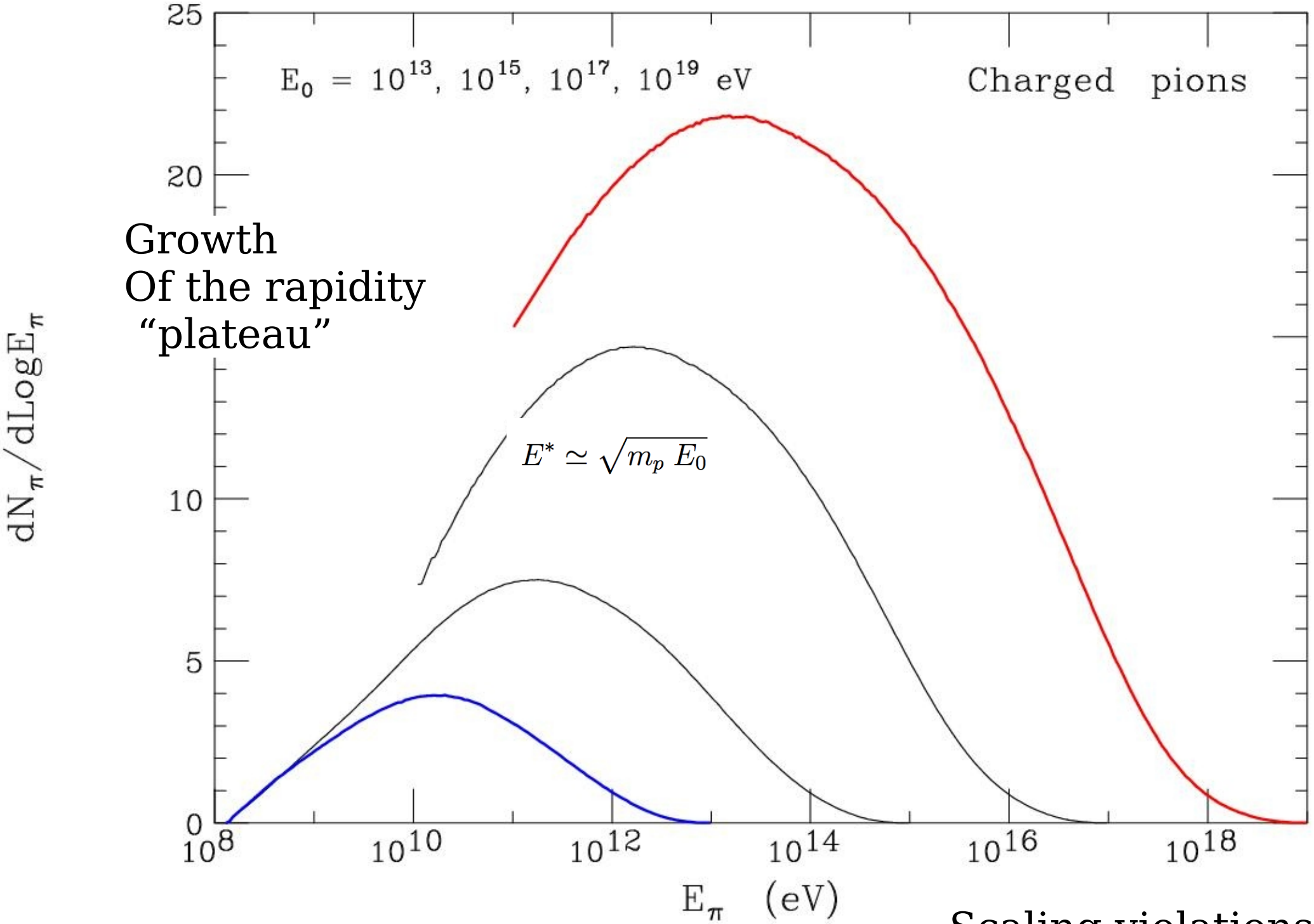



$E_0 = 10^{15}$ eV
p-Air
pp
d(Energy)/dLogE
E (eV)
0.0
0.1
0.2
0.3
0.4
0.5
10^8
10^{10}
10^{12}
10^{14}

NUCLEAR effects: pp vs p-^{12}C

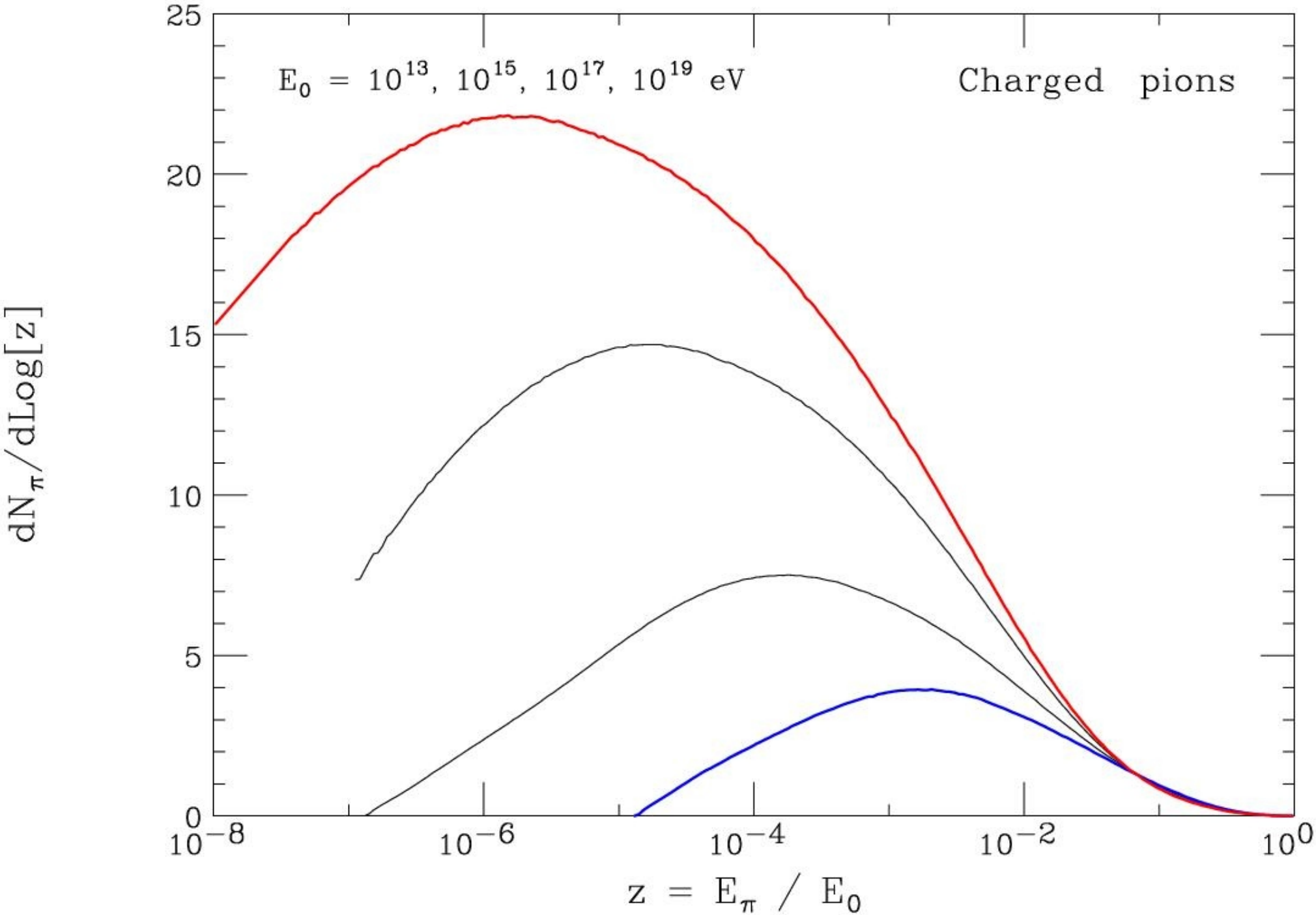


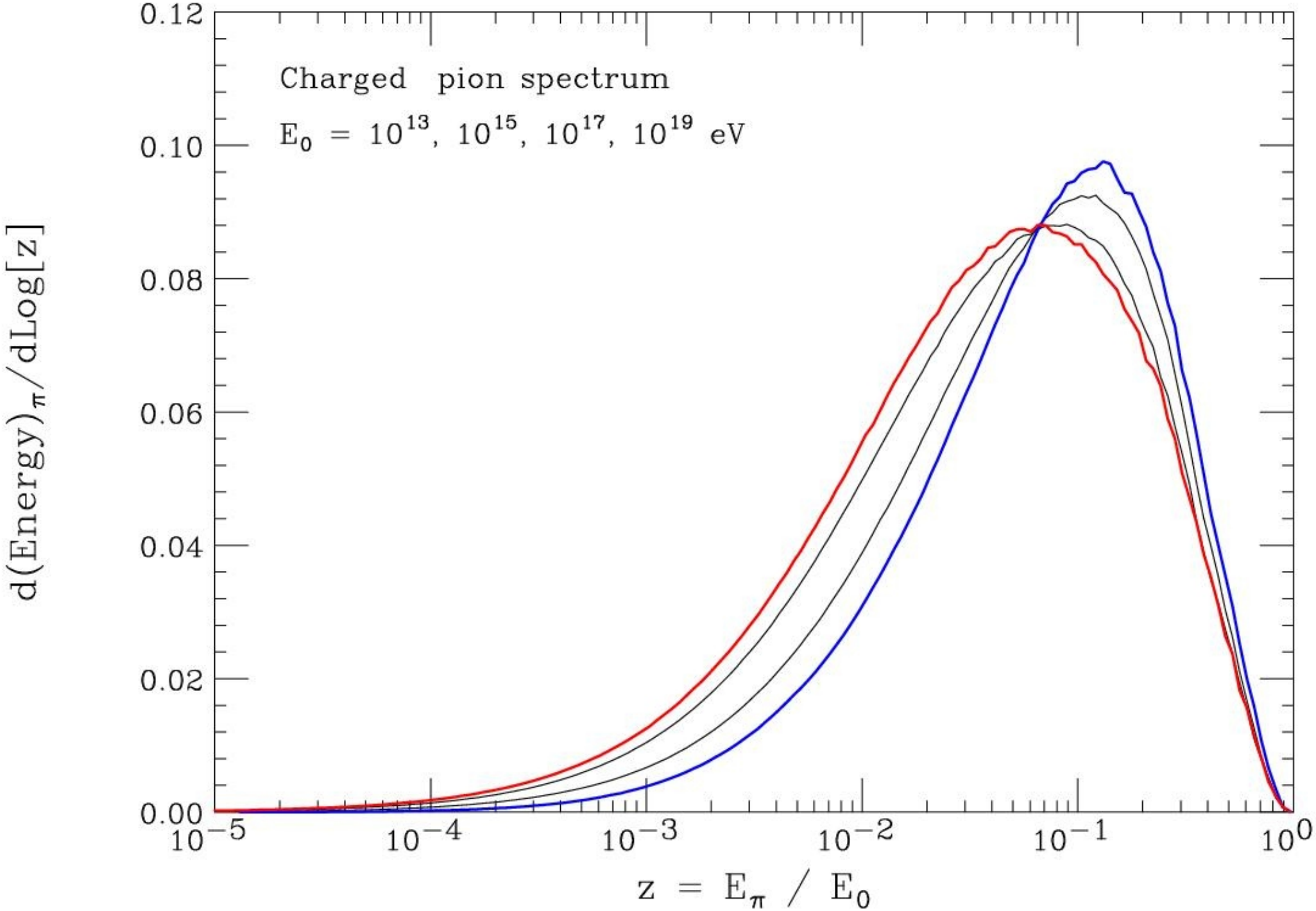

$E_0 = 10^{13}, 10^{15}, 10^{17}, 10^{19}$ eV
Charged pions
$dN_\pi / dLogE_\pi$
E_π (eV)
0
5
10
15
20
25
10^8
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}



Growth
Of the rapidity
"plateau"

Scaling violations


$E_0 = 10^{13}, 10^{15}, 10^{17}, 10^{19}$ eV
Charged pions
$dN_\pi / dLog[z]$
$z = E_\pi / E_0$
25
20
15
10
5
0
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}


Charged pion spectrum
$E_0 = 10^{13}, 10^{15}, 10^{17}, 10^{19}$ eV
0.12
0.10
0.08
0.06
0.04
0.02
0.00
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
$d(Energy)_\pi / dLog[z]$
$z = E_\pi / E_0$

“METHODOLOGY”

Can you learn about hadronic
Interactions studying High Energy Cosmic Rays ?

Problem: Poor knowledge of the beam !

X_{max} and the Composition of Cosmic Rays

Proton Showers

$$X^p_{\max}(E) = X^p_{\max}(E^*) + D_p(E^*)\ \ln\left(\frac{E}{E^*}\right)$$

Logarithmic growth of average X_{max} with energy

$$X^A_{\max}(E) \simeq X^p_{\max}\left(\frac{E}{A}\right)$$

Mass dependence

X_{max} and the Composition of Cosmic Rays

Proton Showers

$$X^p_{\max}(E) = X^p_{\max}(E^*) + D_p(E^*)\ \ln\left(\frac{E}{E^*}\right)$$

Logarithmic growth of average X_{max} with energy

$$X^A_{\max}(E) \simeq X^p_{\max}\left(\frac{E}{A}\right)$$

Mass dependence

$$\langle X_{\max}(E)\rangle \simeq X^p_{\max}(E) - D_p(E)\ \langle \ln A\rangle$$

Obtain the average mass and its variation with energy

$$\langle \ln A \rangle_E = \frac{\sum_A \phi_A(E)\ \ln A}{\sum_A \phi_A(E)}$$

$$\langle \ln A \rangle_E = \frac{\langle X_{\max}(E) \rangle - X_p(E)}{D_p}$$

$$\frac{d\langle \ln A \rangle_E}{d \ln E} = 1 - \frac{D_{\exp}}{D_p}$$

Obtain the average mass and its variation with energy

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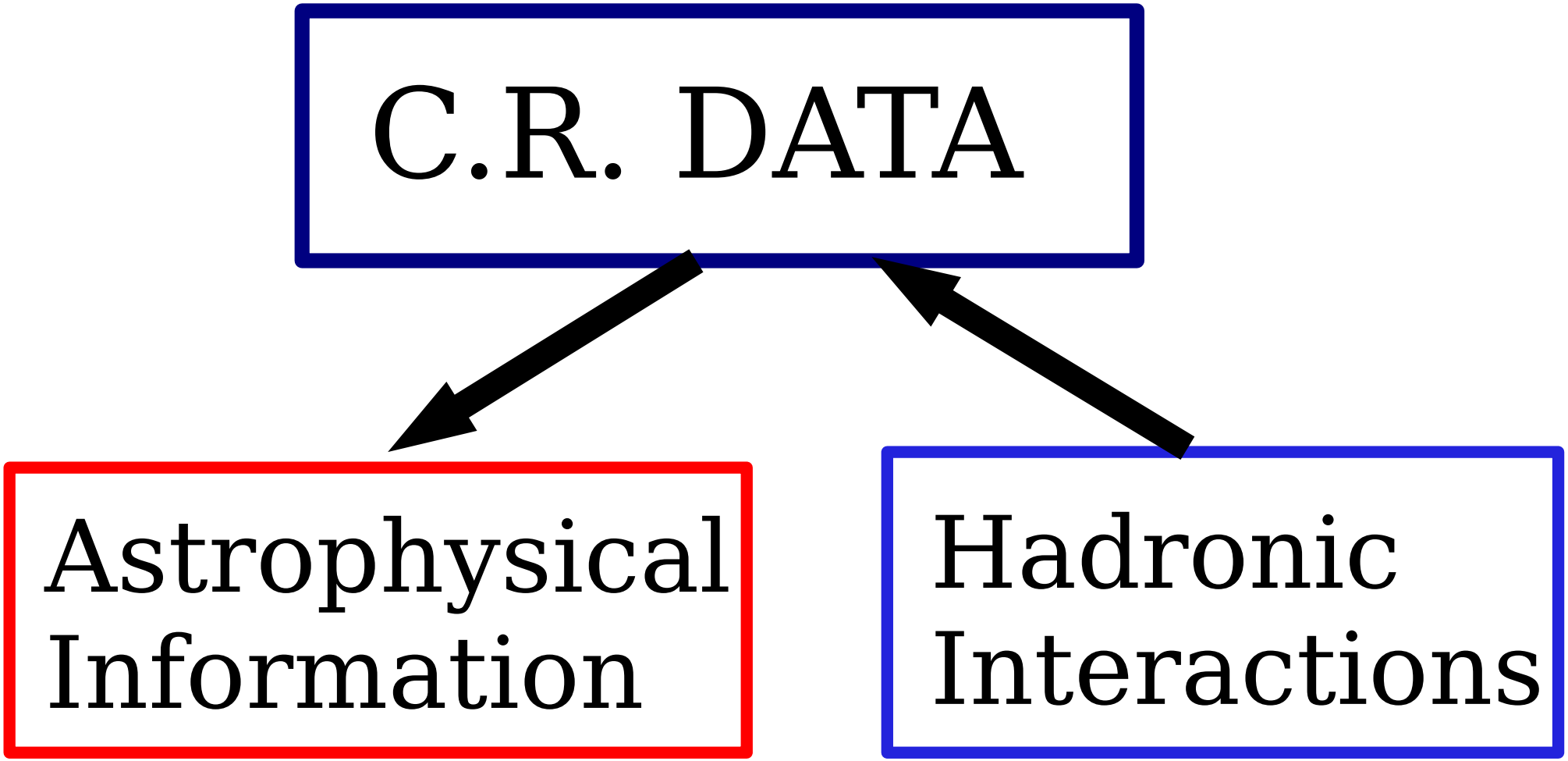
$$\frac{d\langle \ln A \rangle_E}{d \ln E} = 1 - \frac{D_{\exp}}{D_p}$$

C.R. DATA

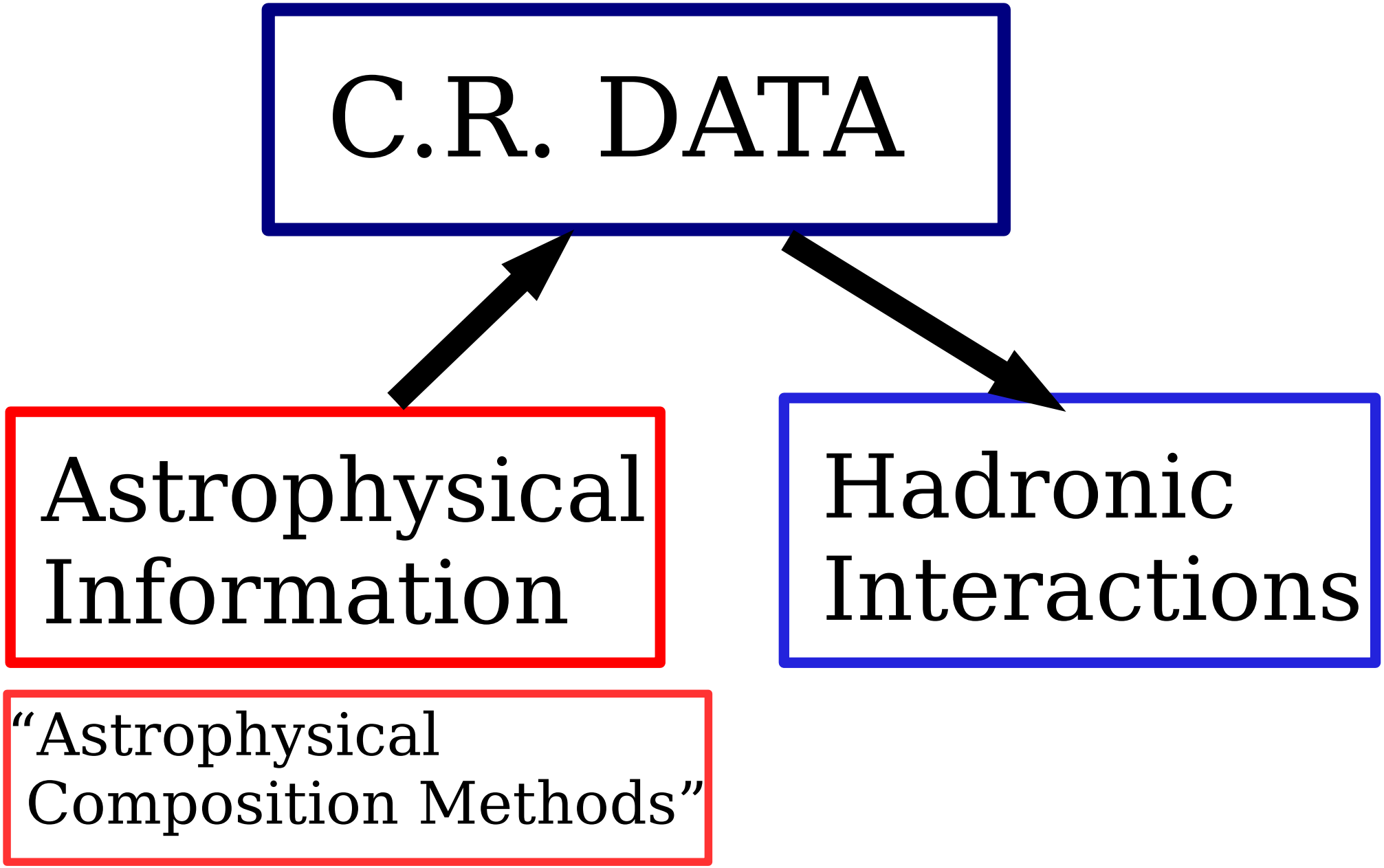
Astrophysical Information

Hadronic Interactions

From Accelerator Data + Theory → Astrophysics



From Cosmic Ray Data → Hadronic Interactions



“Astrophysical Composition Methods”

- Energy Spectrum

  “imprints” of Energy Loss

- “Cosmic Magnetic Spectrometer”

Features in the Cosmic Ray Energy Spectrum can in principle give information on the nature of the particle

Interpreted as the effect of energy loss during propagation from their extragalactic sources.

Known target: 2.7 K CMBR radiation field

Energy Thresholds for protons :

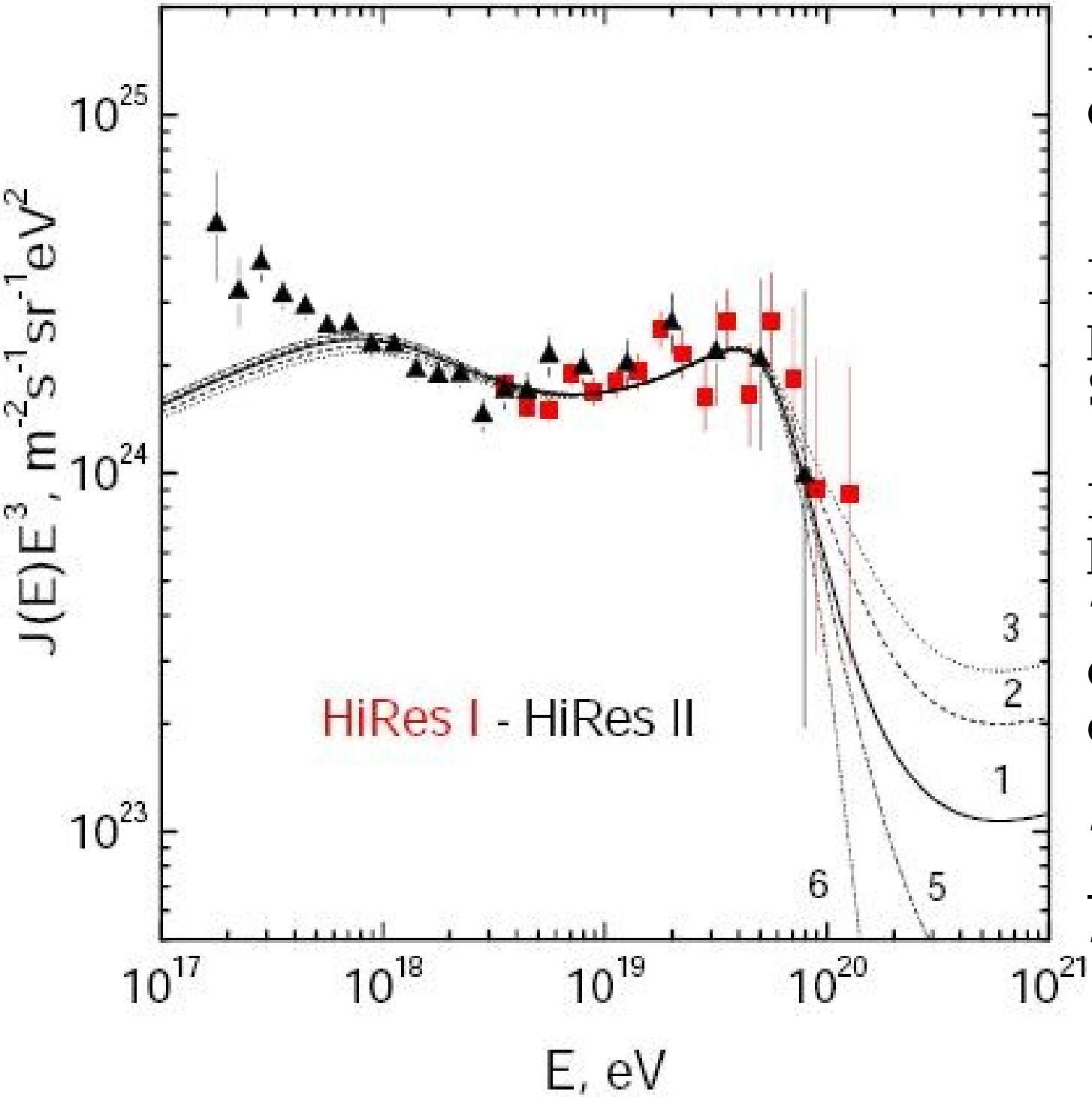
$$p\,\gamma \rightarrow p\pi^{\circ}$$

$$p\,\gamma \rightarrow n\pi^{+}$$

"GZK"

$$p\,\gamma \rightarrow p\,e^{+}e^{-}$$

Pair Production



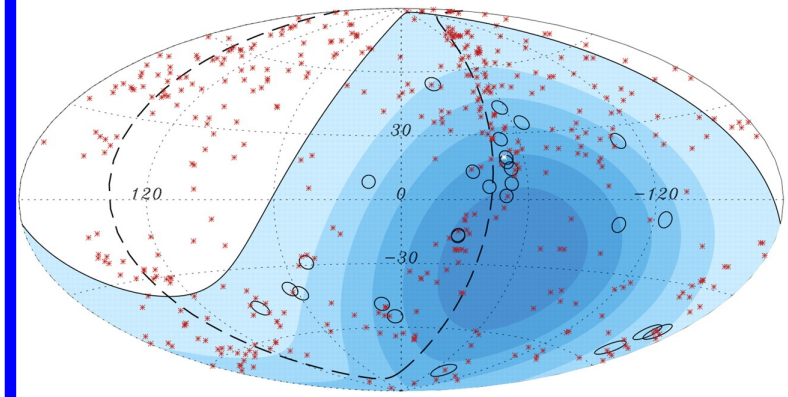
Berezinsky
et al.

Inject Smooth
power law
Spectrum.

Let propagation
leave its
“imprint”
on the shape
of the spectrum.

“ANKLE”
-->
“DIP”
e+e- production

“COSMIC MAGNETIC SPECTROMETER”



Constraint on : B, Z

AUGER RESULT

Correlations of the Highest-Energy Cosmic Rays with Nearby Extragalactic Objects (AGN)

Protons are preferred [....? ....]

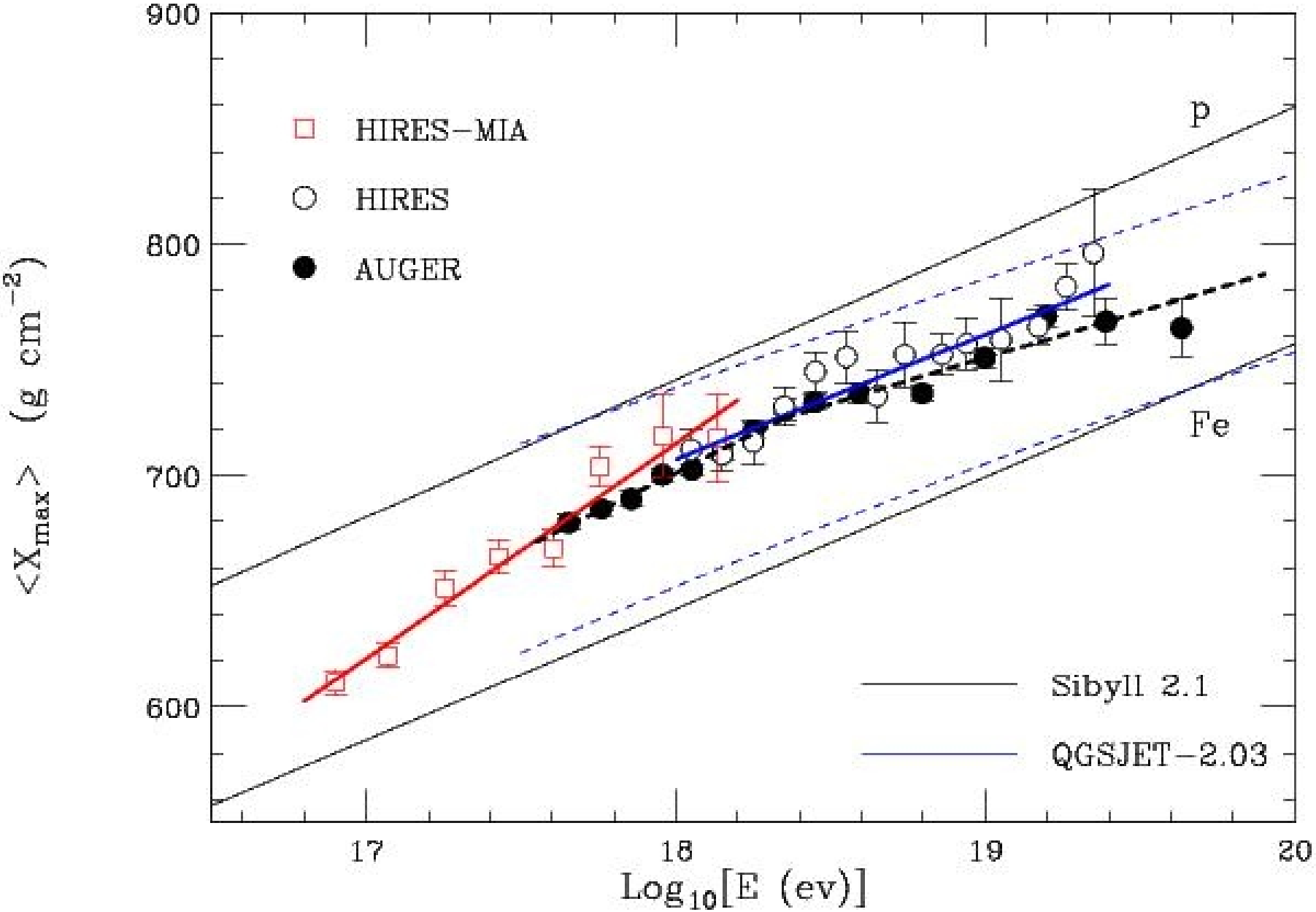
Deviation in GALACTIC Magnetic Field

$$\delta \simeq 2.7^\circ \frac{60\ \mathrm{EeV}}{E/Z} \left| \int_0^D \left(\frac{\mathrm{d}\mathbf{x}}{\mathrm{kpc}} \times \frac{\mathbf{B}}{3\ \mu\mathrm{G}} \right) \right|$$

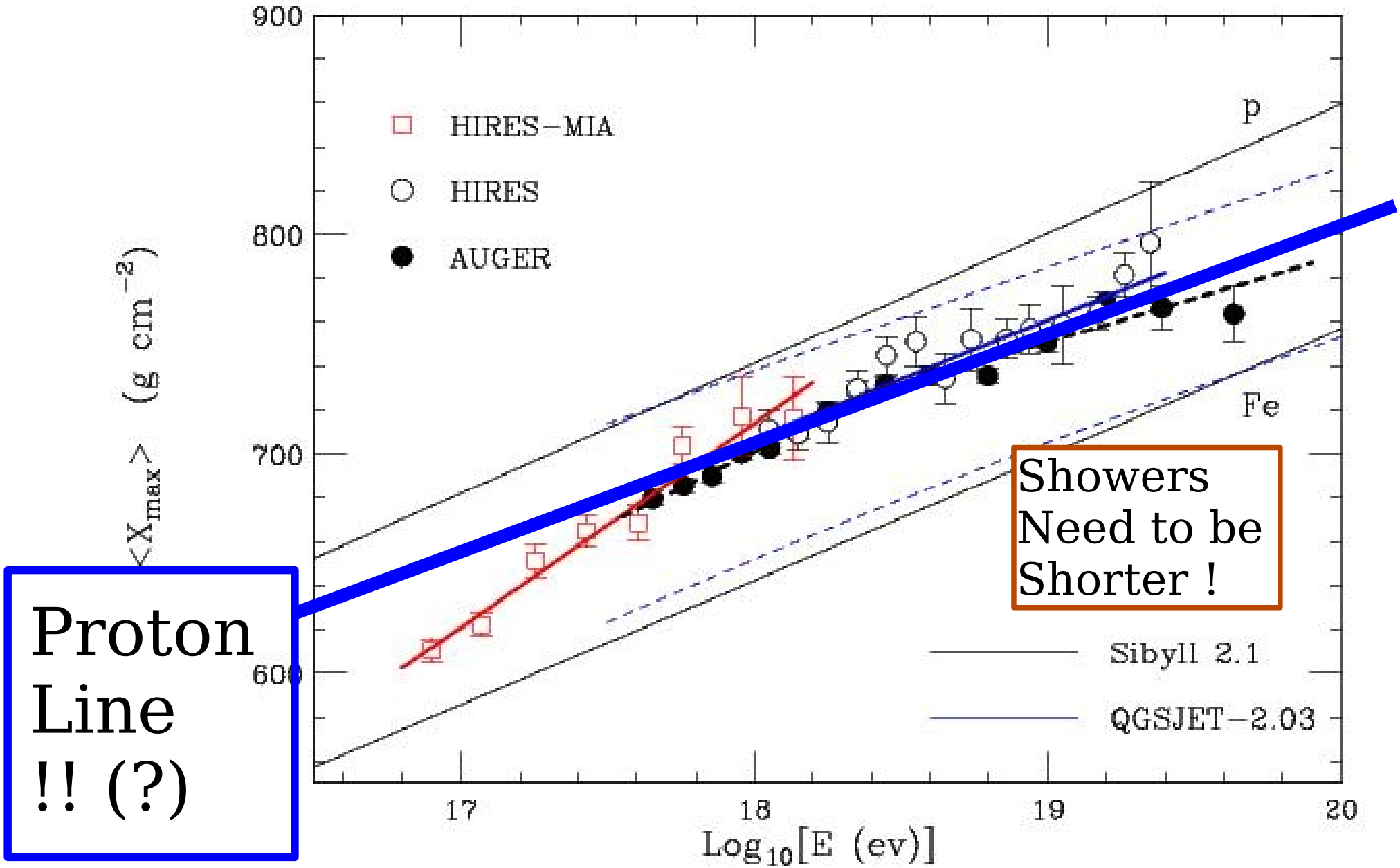
Deviation in EXTRA-GLACTIC Magnetic Field

$$\delta_{rms} \approx 4^\circ \frac{60\ \mathrm{EeV}}{E/Z} \frac{B_{rms}}{10^{-9}\mathrm{G}} \sqrt{\frac{D}{100\ \mathrm{Mpc}}} \sqrt{\frac{L_c}{1\ \mathrm{Mpc}}}$$

IF one accepts (at least for the sake of discussion) the astrophysical hints of a proton dominated composition....

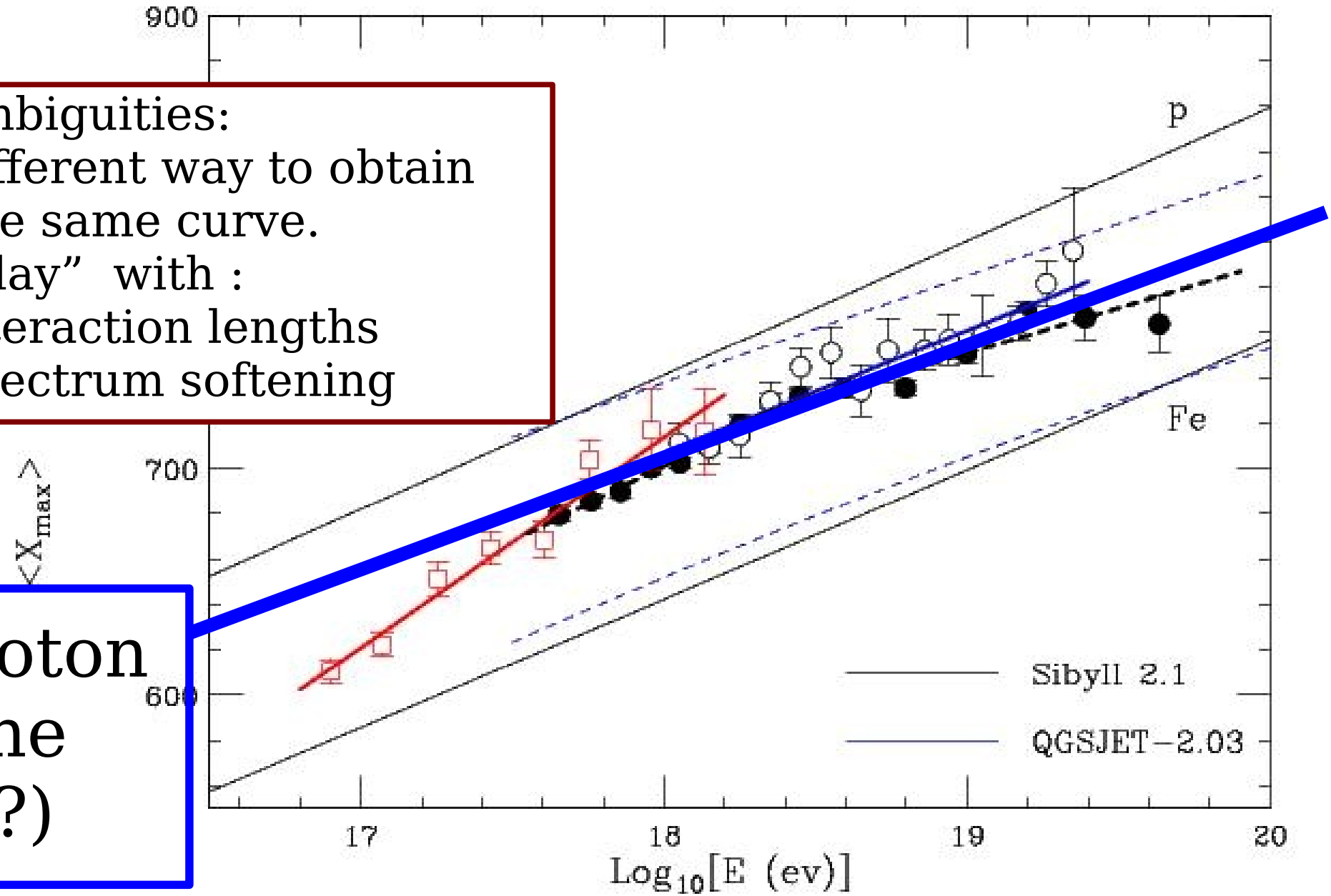


IF one assumes [for the sake of discussion]
the astrophysical hints of a proton dominated composition....

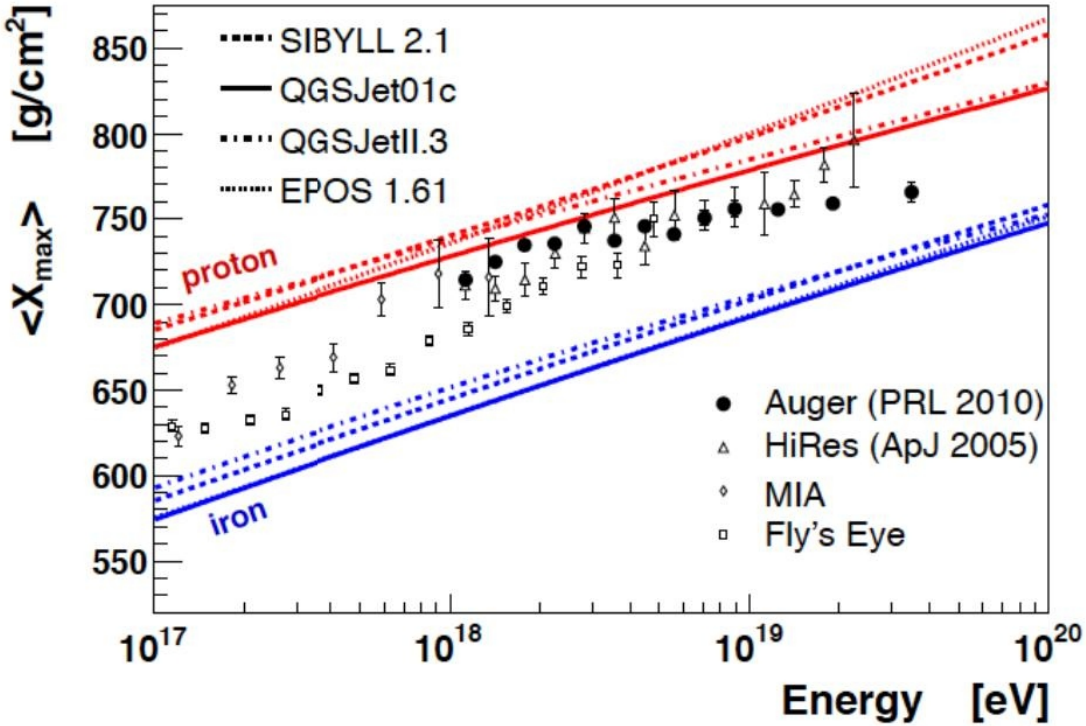


IF one assumes [for the sake of discussion]
the astrophysical hints of a proton dominated composition....

Ambiguities:
Different way to obtain
The same curve.
"Play" with :
interaction lengths
Spectrum softening

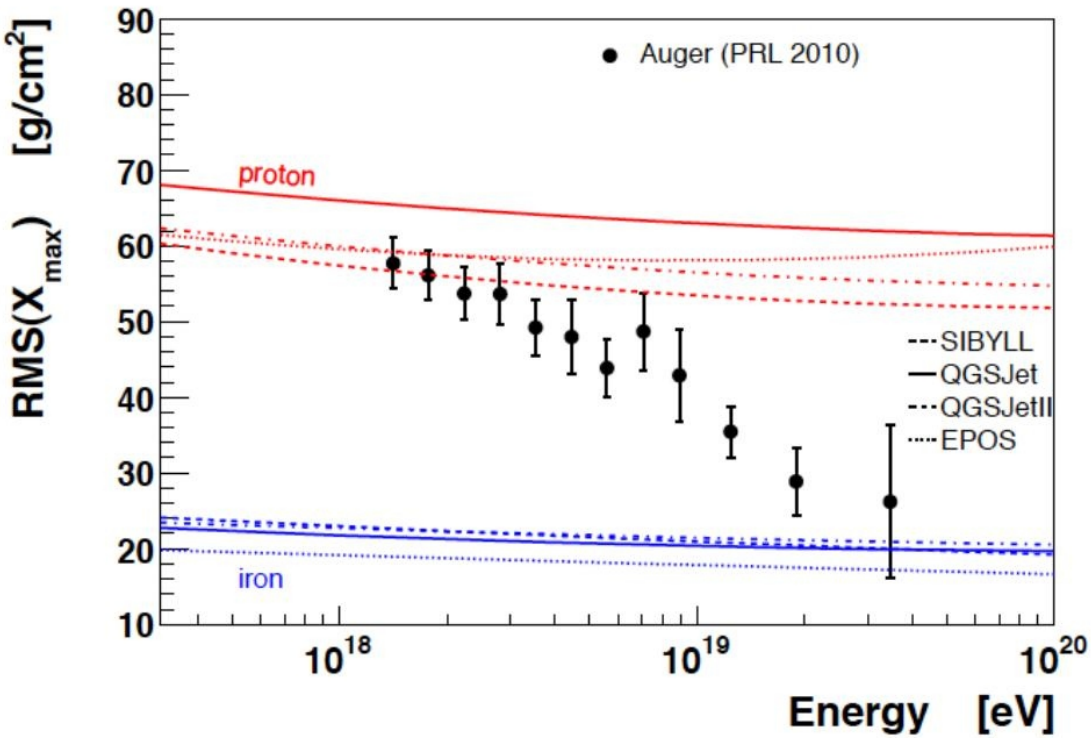


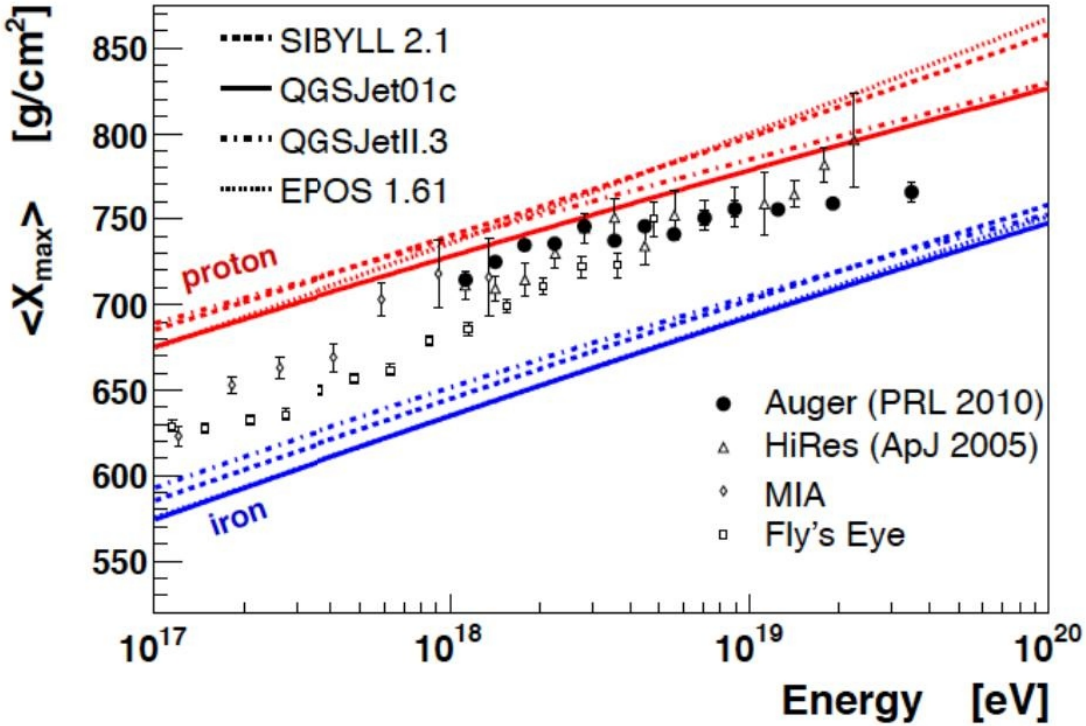
Proton
Line
(! ?)



AUGER
Fluctations result.

Sufficient
[after experimental
confirmation]
to establish
That the highest particle
Mass is close to iron ?





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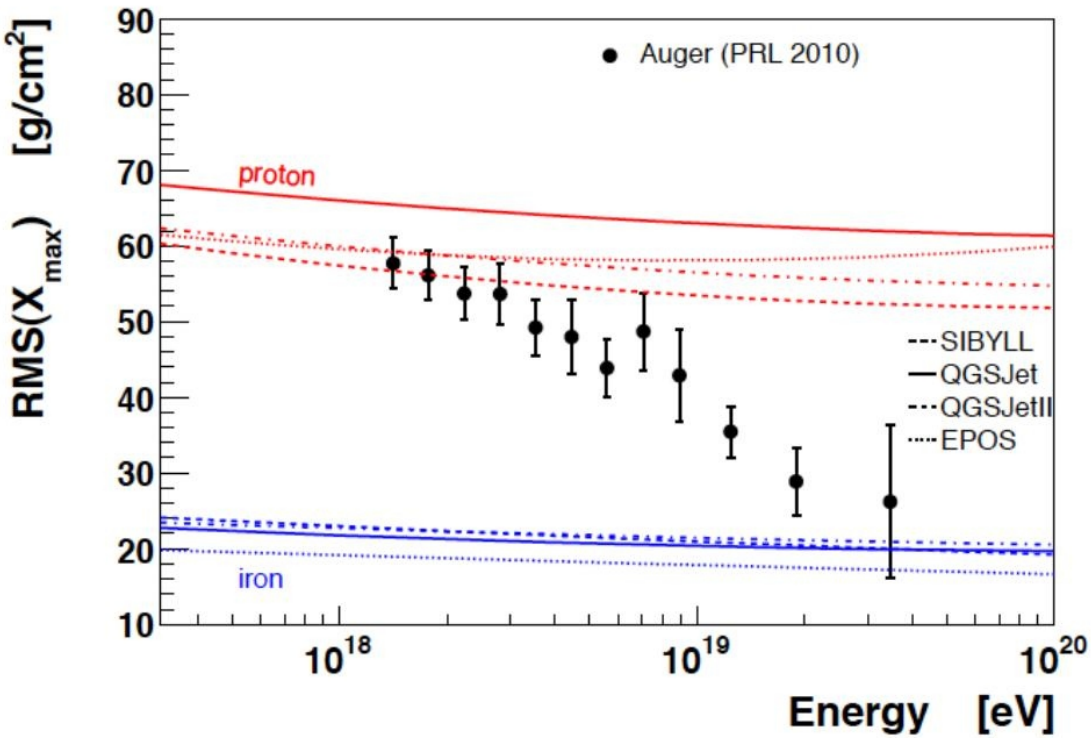
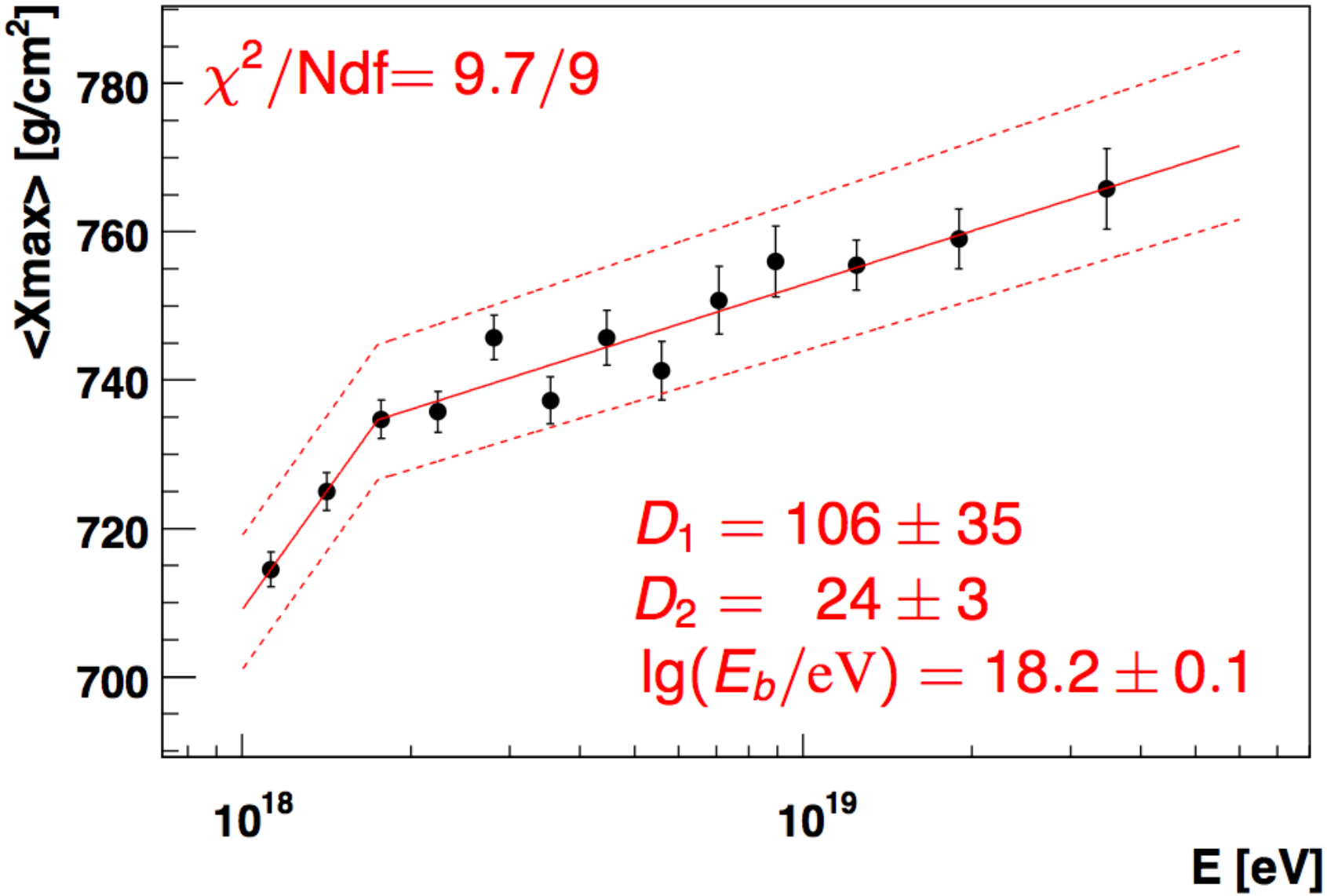


But then also in
This case one should change
the interaction model.

In the "opposite direction":
Longer showers

The importance of “CORNERS”

(when real)



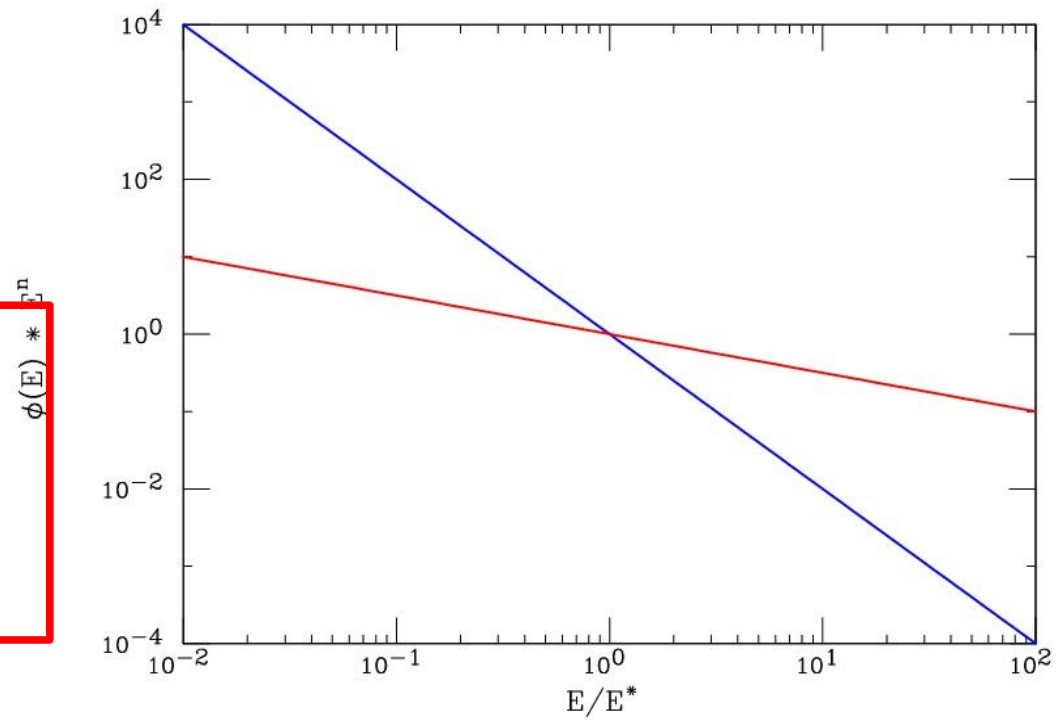
Naive 2-component model

$$\phi(E) = \phi_p(E) + \phi_{\mathrm{Fe}}(E)$$

$$\phi(E) \propto r \left(\frac{E}{E^*}\right)^{-\alpha_p} + \left(\frac{E}{E^*}\right)^{-(\alpha_p+\beta)}$$

$$E^* = 10^{19}\ \mathrm{eV}$$

Consistent picture
Of composition evolution
And spectral features



Conclusions

Conclusions

1. Many important open questions.
   [....which make life interesting....]

Conclusions

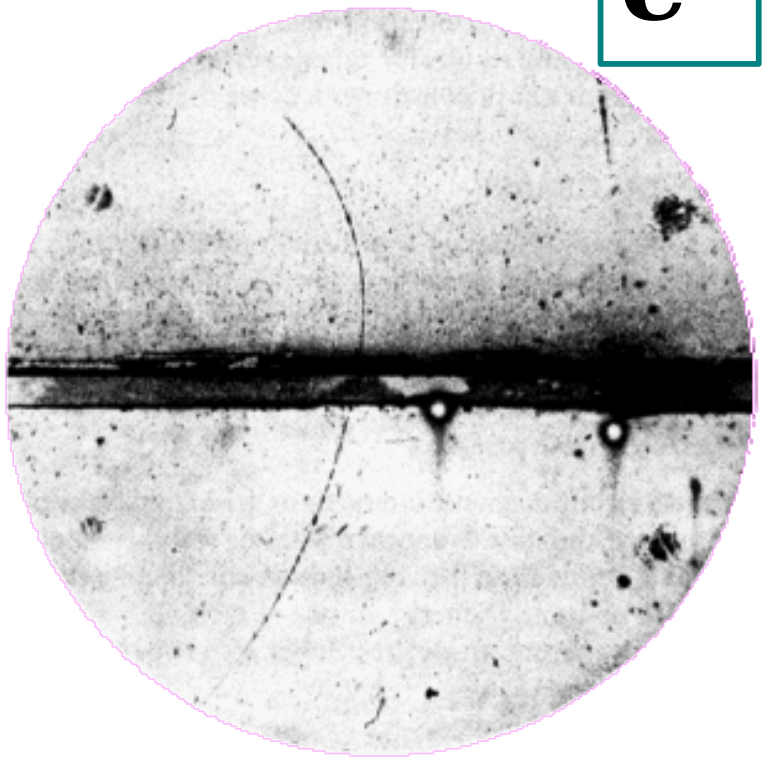
1. Many important open questions.
   [....which make life interesting....]

2.a Crucial moment for
   Particle Physics and accelerators.

2.b Very exciting moment for
   Cosmic Ray science and
   High Energy Astrophysics

3. Possibility [in fact need] for comunication

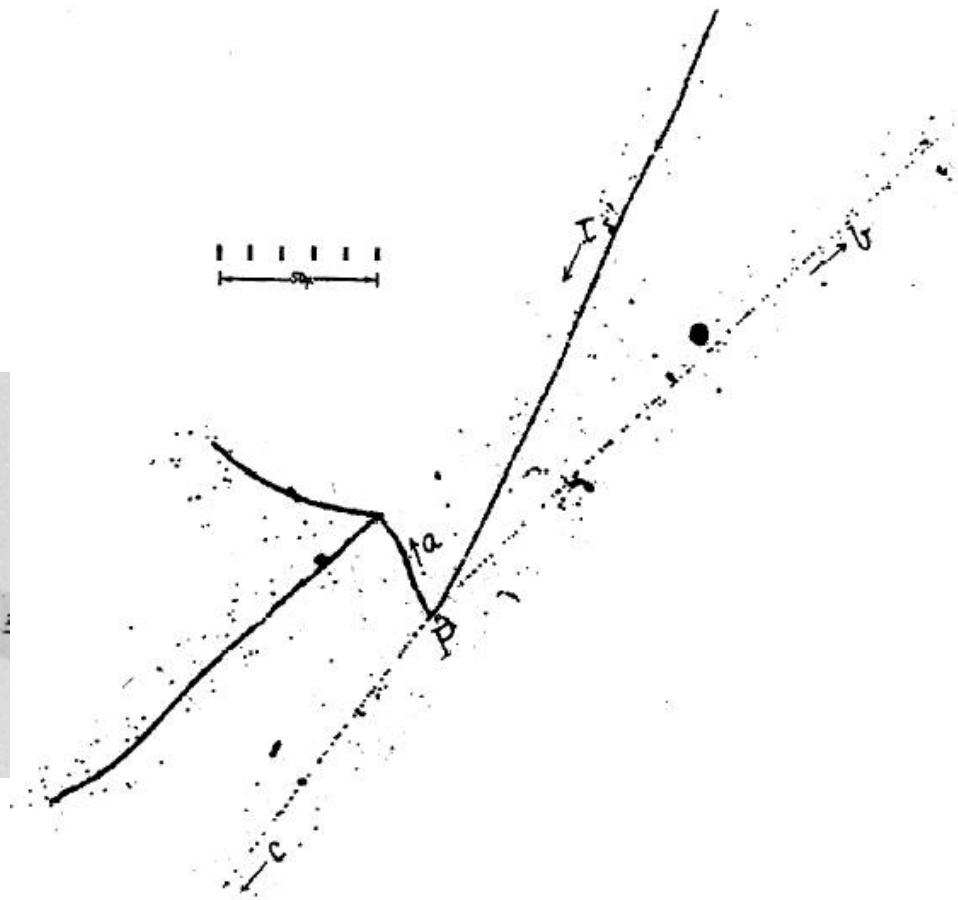
e^+

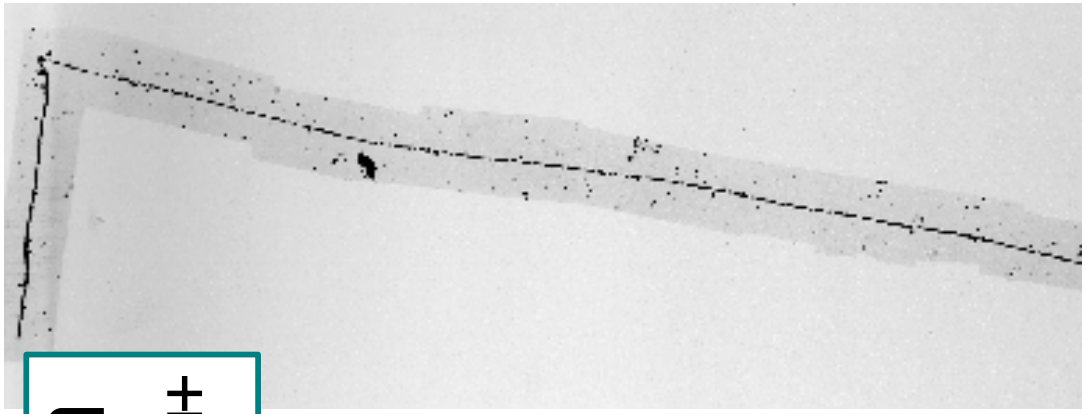


Anderson discovery of positron

Particle Physics ⇄ Cosmic Ray Physics

$K^{\pm}$





$\pi^{\pm}$

Occhialini , Powell