Sessions HE 1.6, HE 3.x

Some highlights and thoughts

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Outline

Understanding of cosmic ray interactions (Standard Model physics)

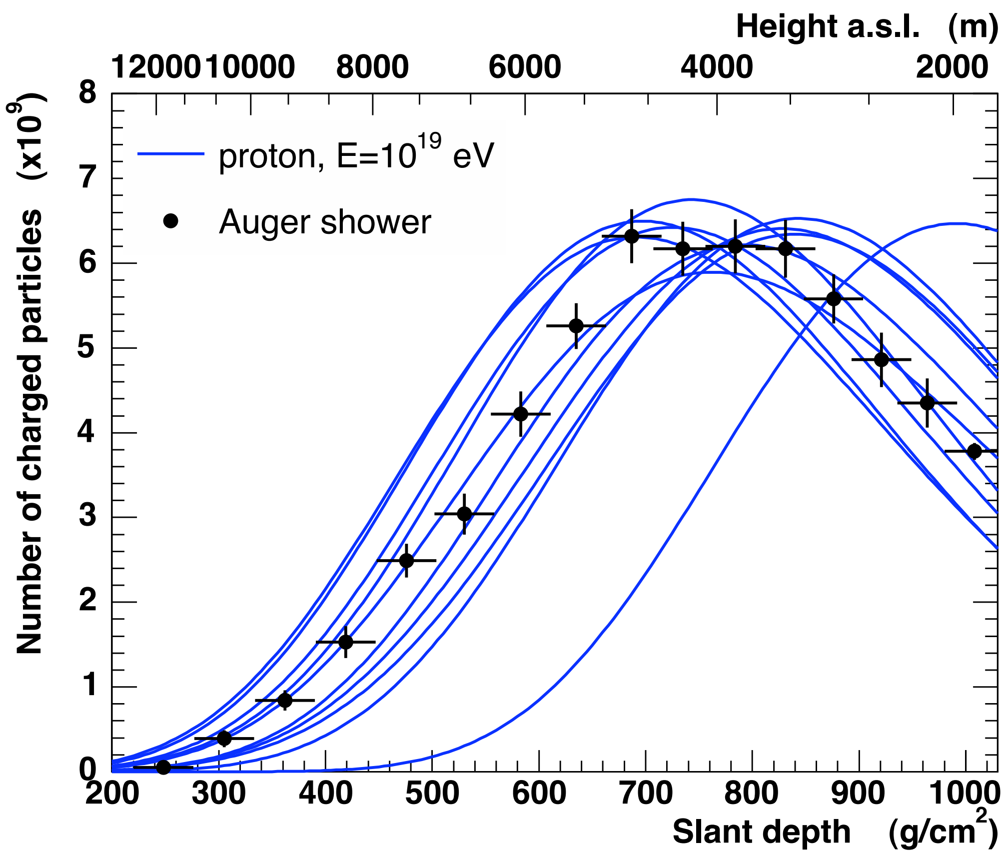
- Reliability of interpretation of air shower data
- Cross section measurements
- Simulation tools and related questions
- Accelerator data

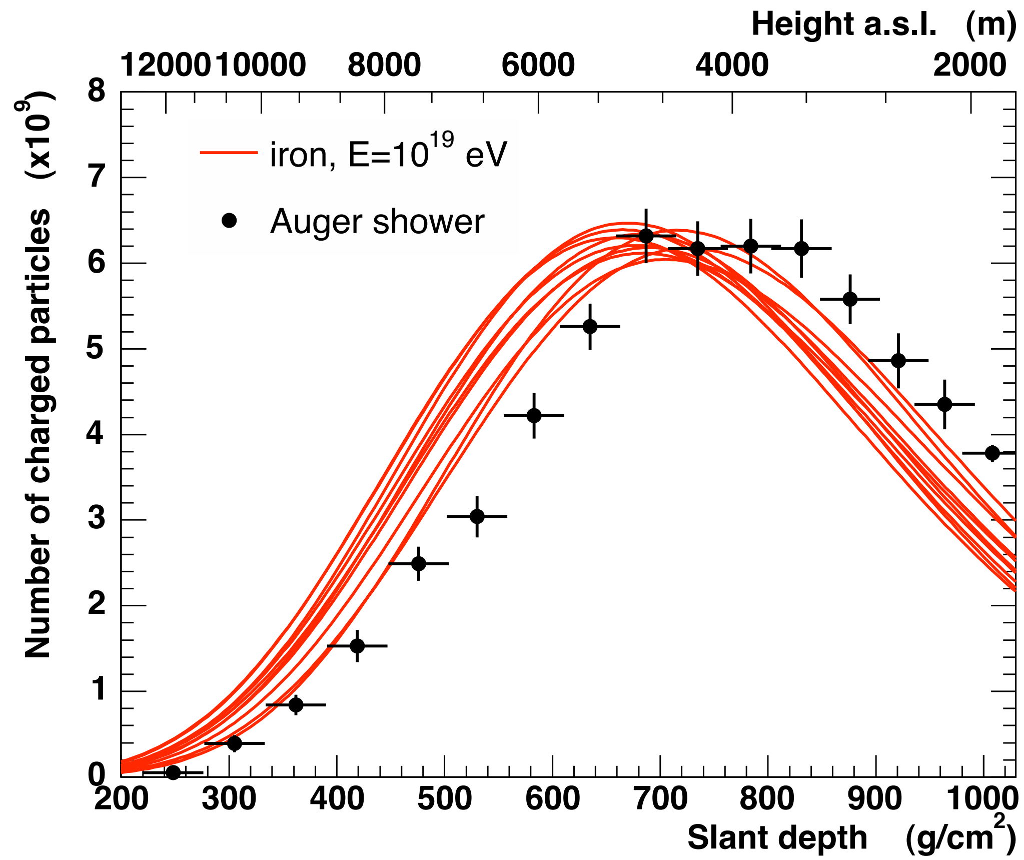
Searching for phenomena beyond the Standard Model

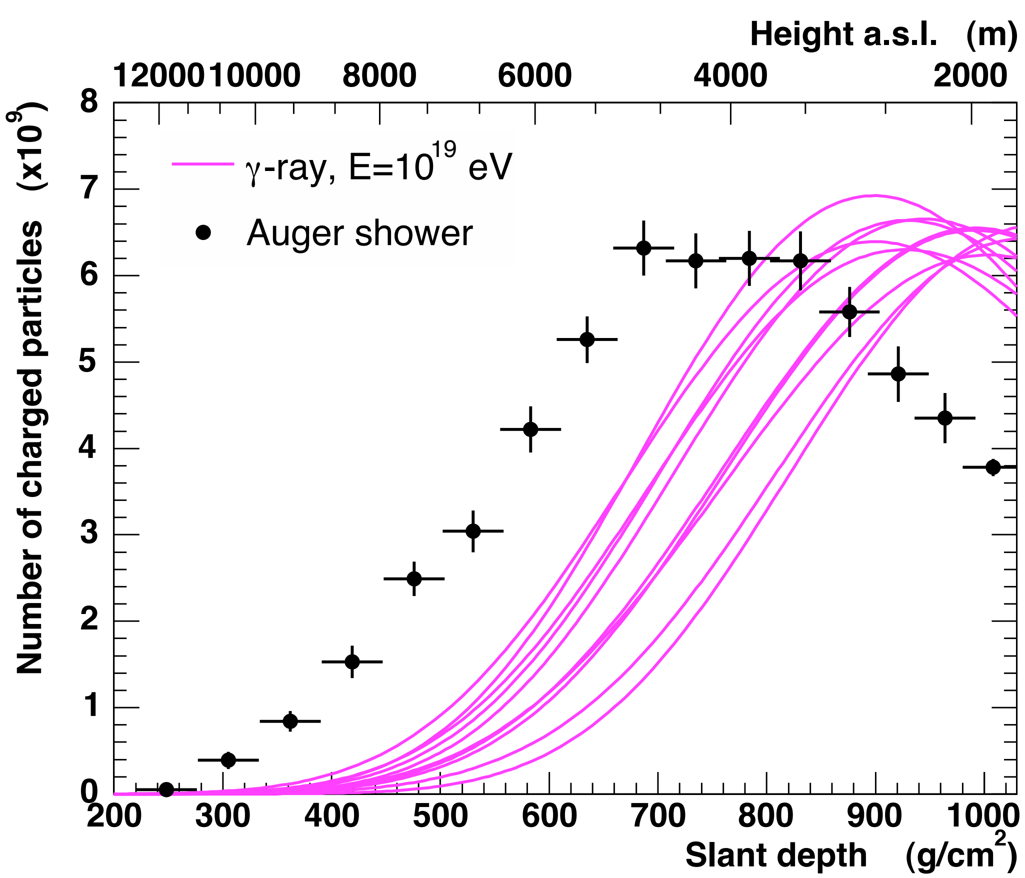
- Dark matter and anti-matter
- Monopoles, exotic particles
- Gravitational waves

Reliability of the interpretation of air shower data

Longitudinal shower profile







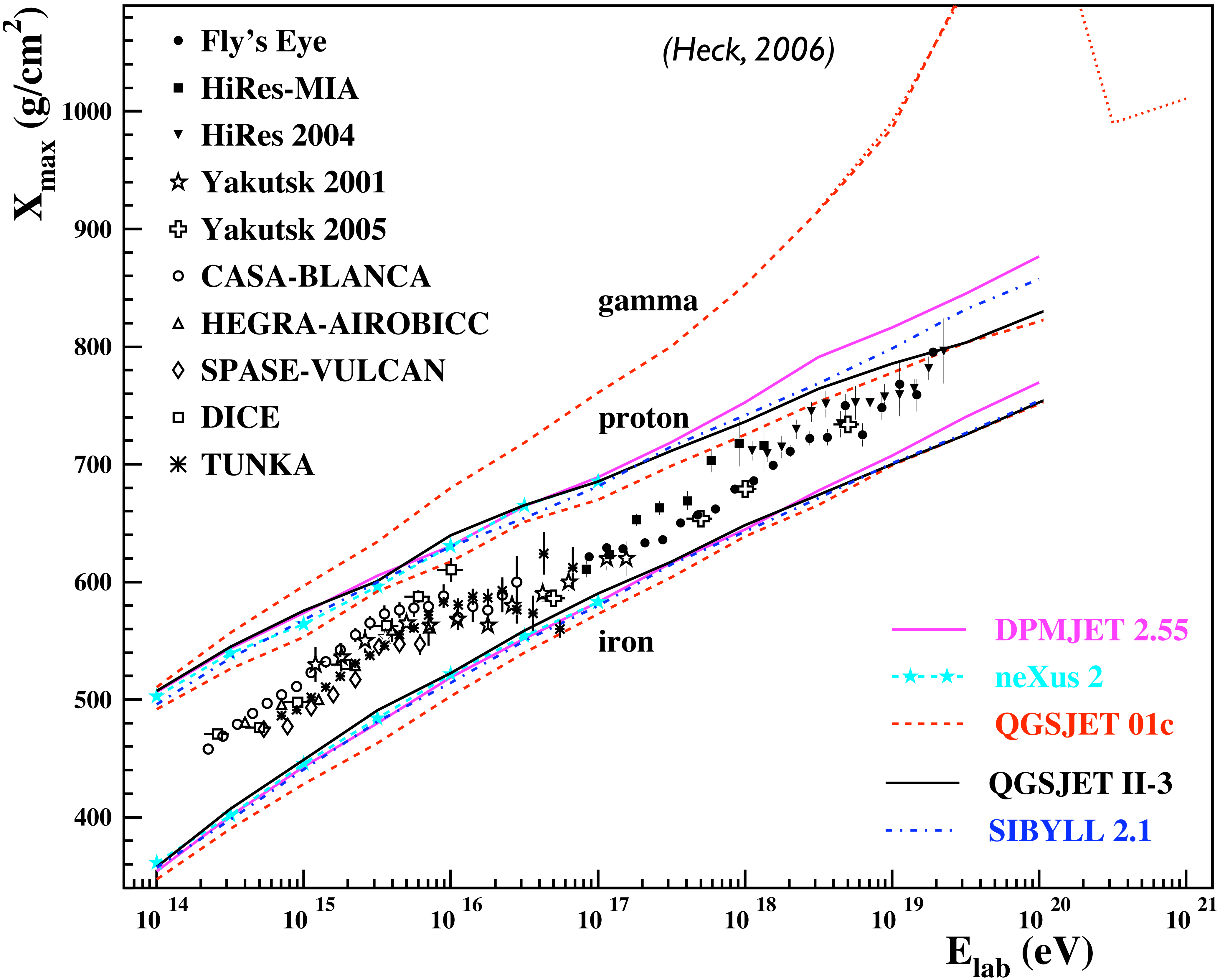
$$N_{\max} = E_0/E_c$$

$$X_{\max} \sim D_{\mathrm{e}} \ln(E_0/E_c)$$

Elongation rate

$$X_{\max}^{A} \sim D_e \ln(E_0/AE_c)$$

Shower maximum: current situation



Elongation rate theorem

X_0 = 37 g/cm²

$$D_e^{\text{had}} = X_0(1 - B_n - B_\lambda)$$

(Linsley, Watson PRL46, 1981)

$$B_n = \frac{d\ln n_{\text{tot}}}{d\ln E}$$

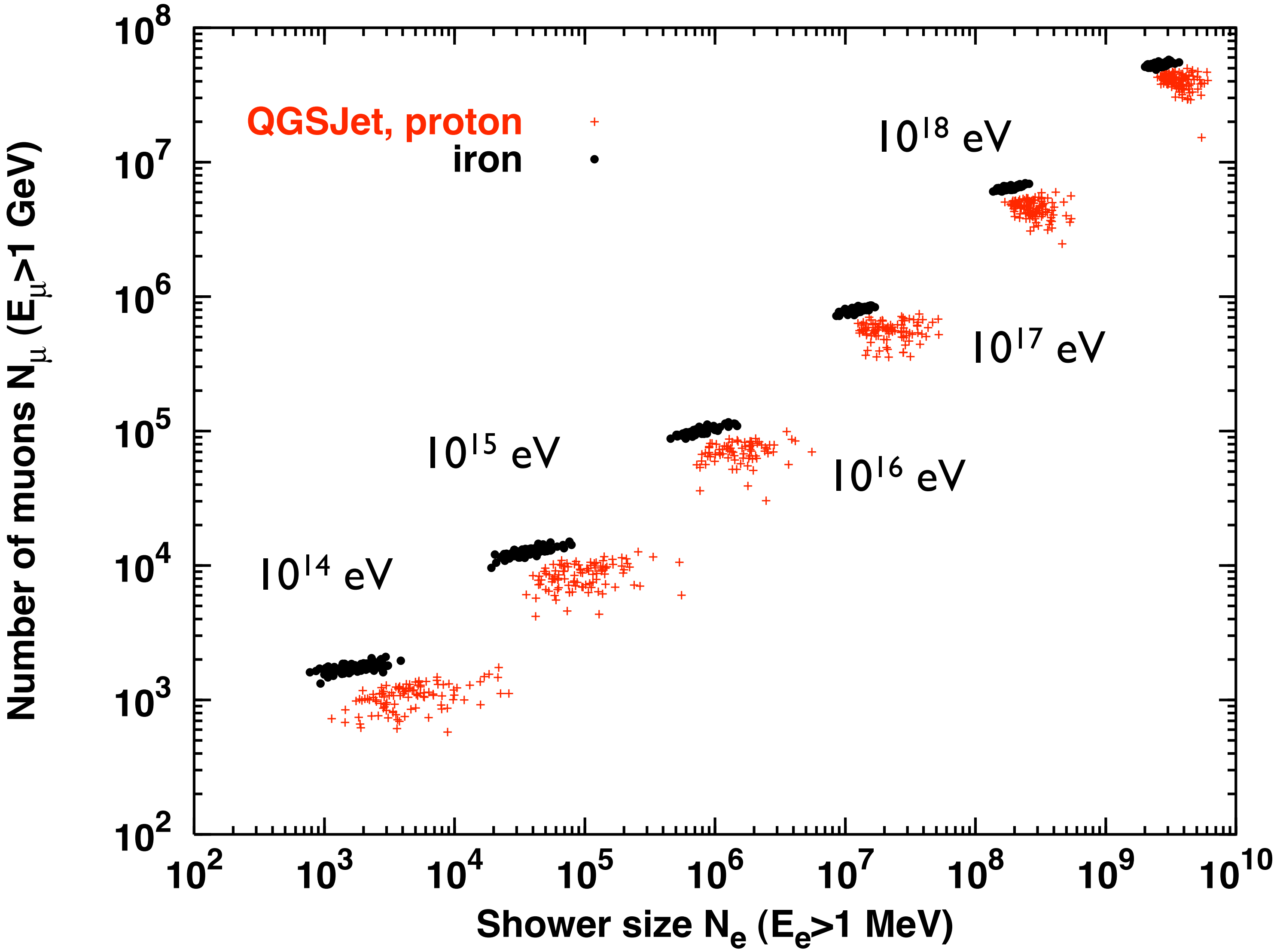
Large if multiplicity of high energy particles rises very fast, **zero in case of scaling**

$$B_\lambda = -\frac{1}{X_0}\frac{d\lambda_{\text{int}}}{d\ln E}$$

Large if cross section rises rapidly with energy

Note: $D_{10} = \log(10) D_e$

Electron-muon number correlation



$$N_\mu = \left(\frac{E_0}{E_{\rm dec}}\right)^\alpha$$

$$\alpha = \frac{\ln(n_{\rm ch})}{\ln(n_{\rm tot})} \approx 0.9$$

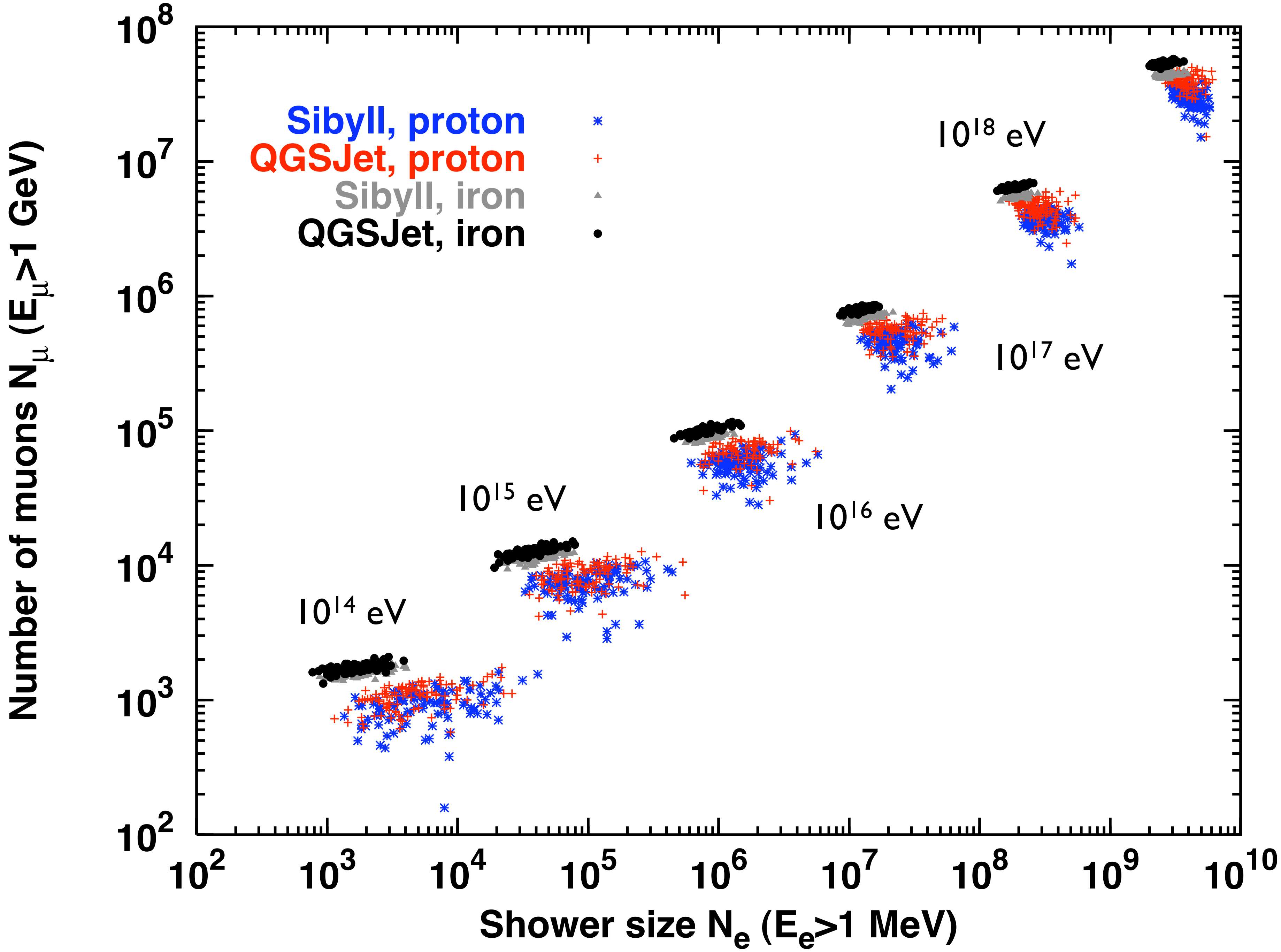
Superposition model

$$N_\mu^A = A\left(\frac{E_0}{AE_{\rm dec}}\right)^\alpha = A^{1-\alpha} N_\mu$$

Iron: factor ~1.4

(Matthews, Astropart.Phys. 22, 2005)

Models differ in their predictions



Example:
QGSJET 01
SIBYLL 2.1

Muons: current situation (very high energy)

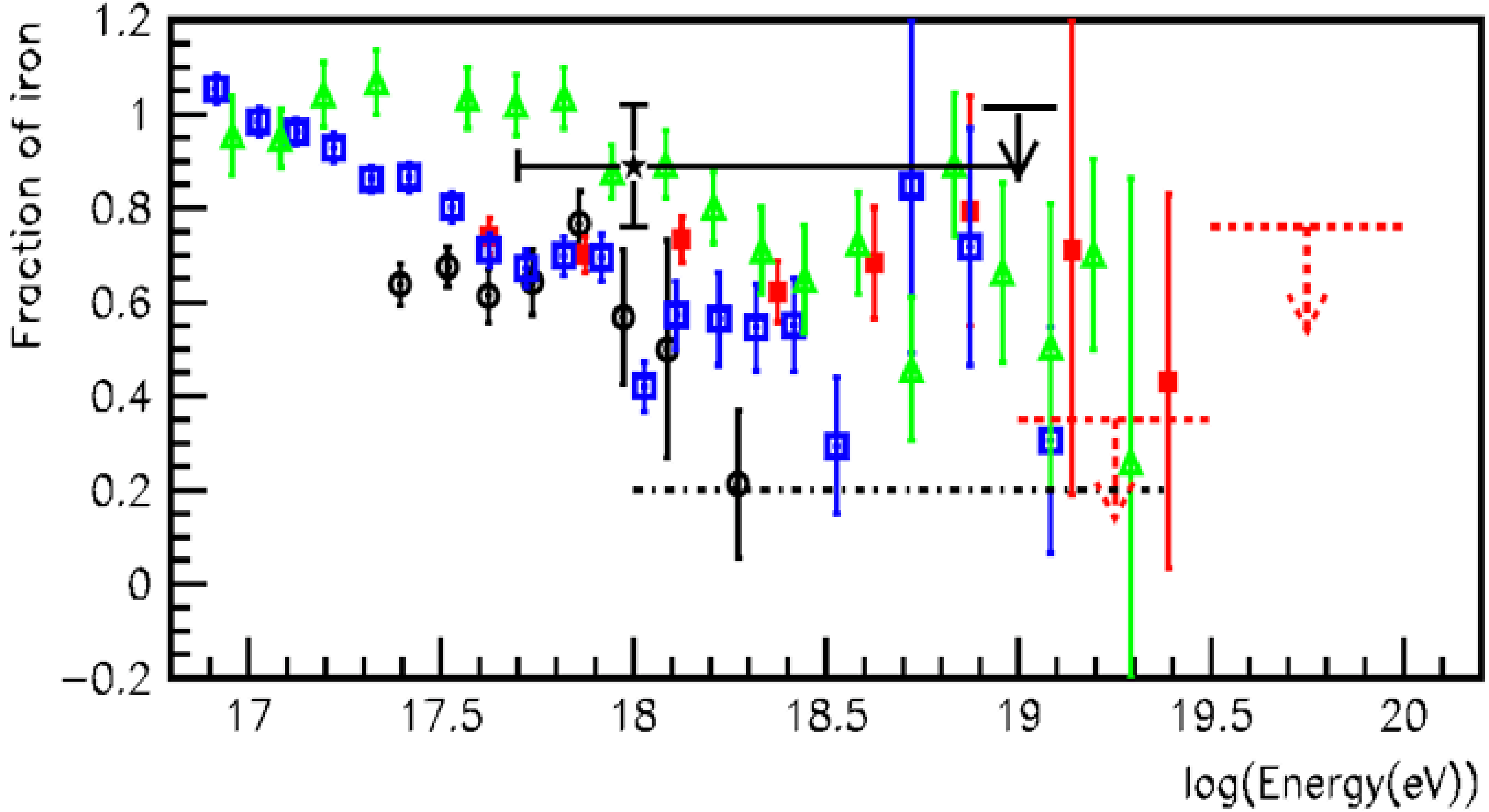
Fly's Eye
AGASA A100
AGASA A1

SIBYLL 1.6

QGSJET 98

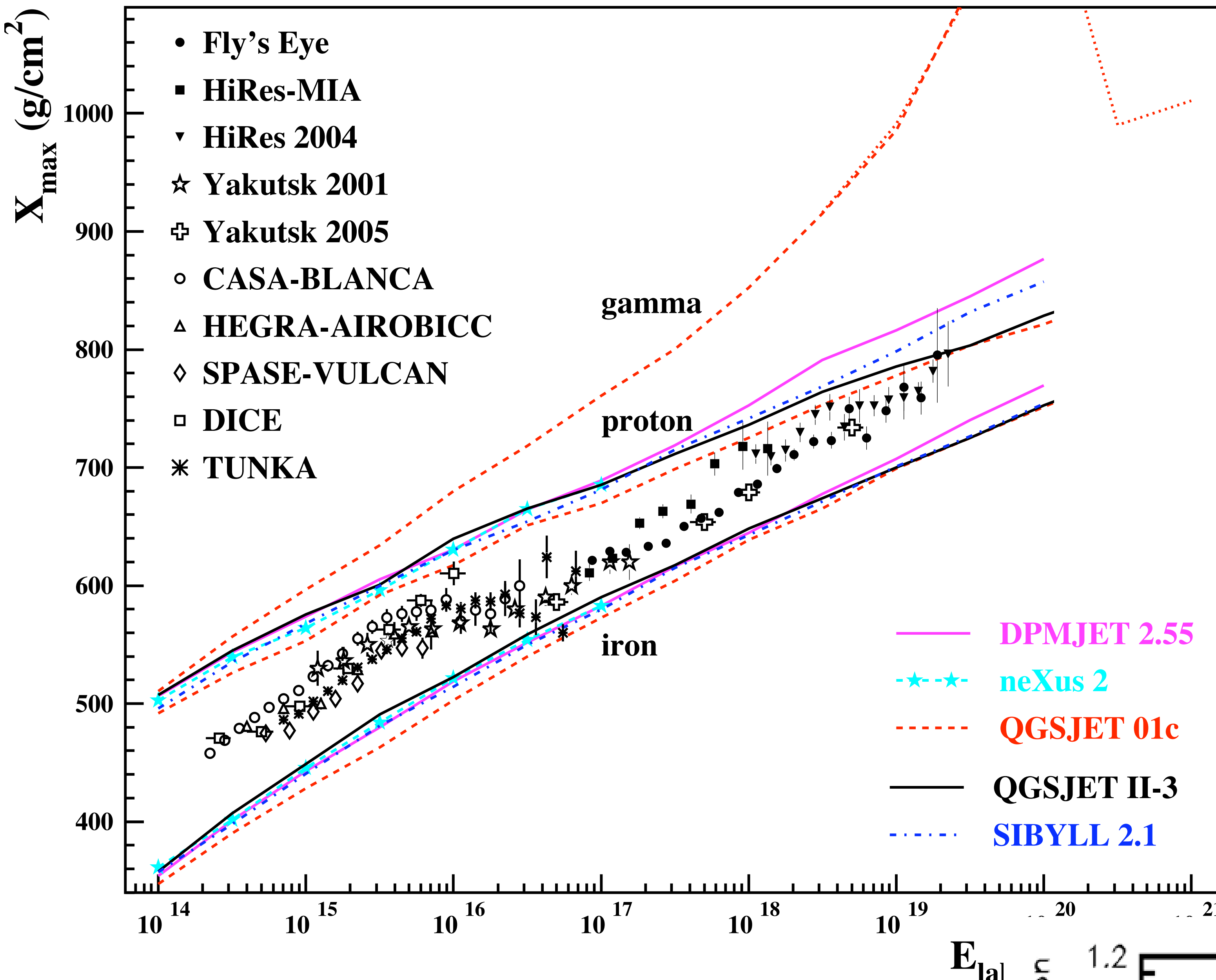
Haverah Park
AGASA

HiRes



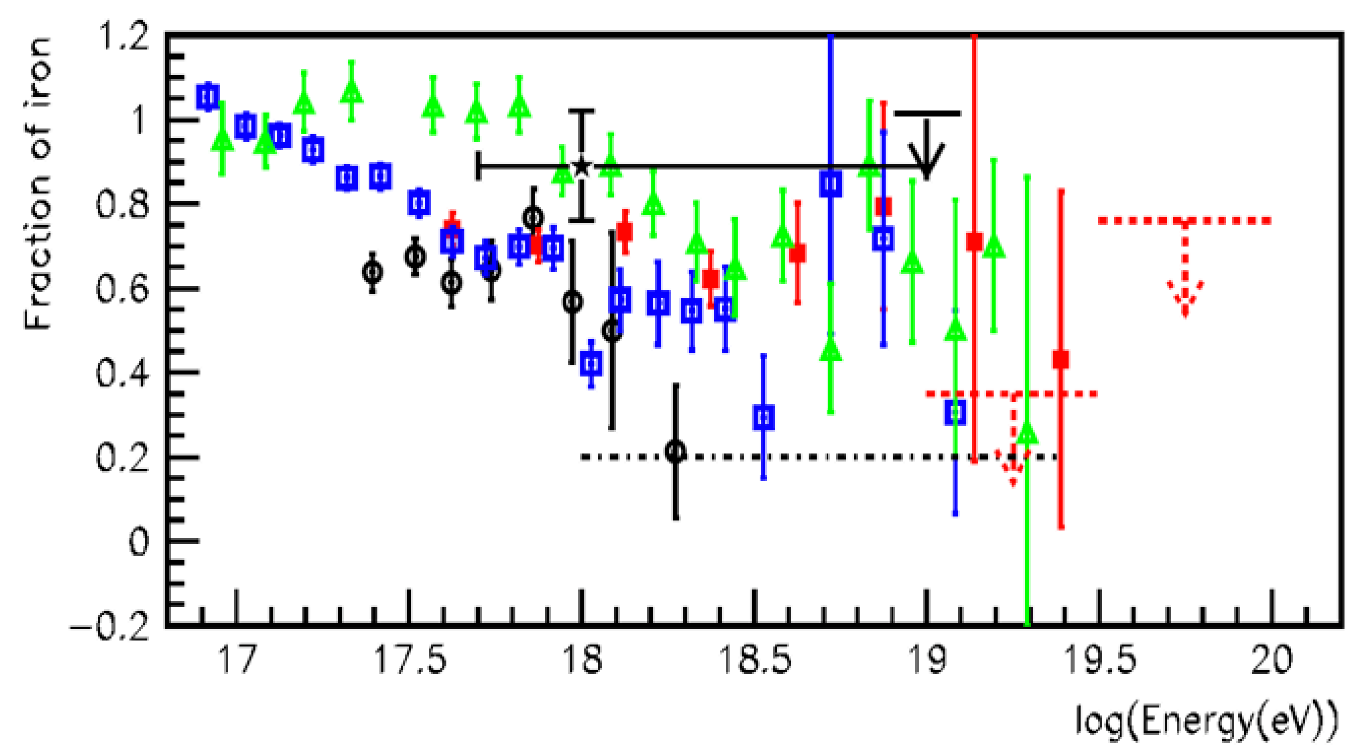
(Anchordoqui et al., 2004)

(Heck, 2006)



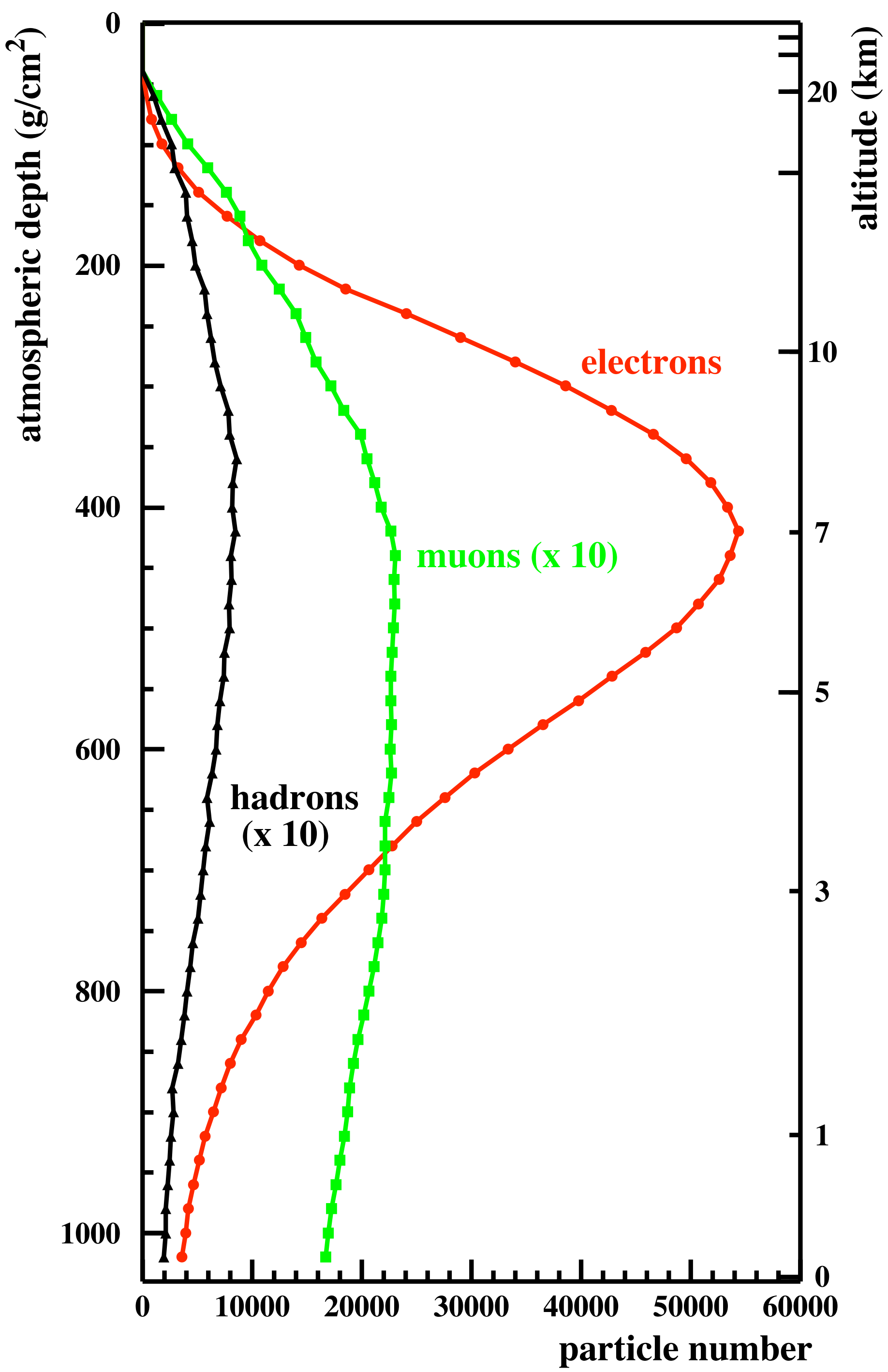
Are composition results consistent?

(Anchordoqui et al., 2004)



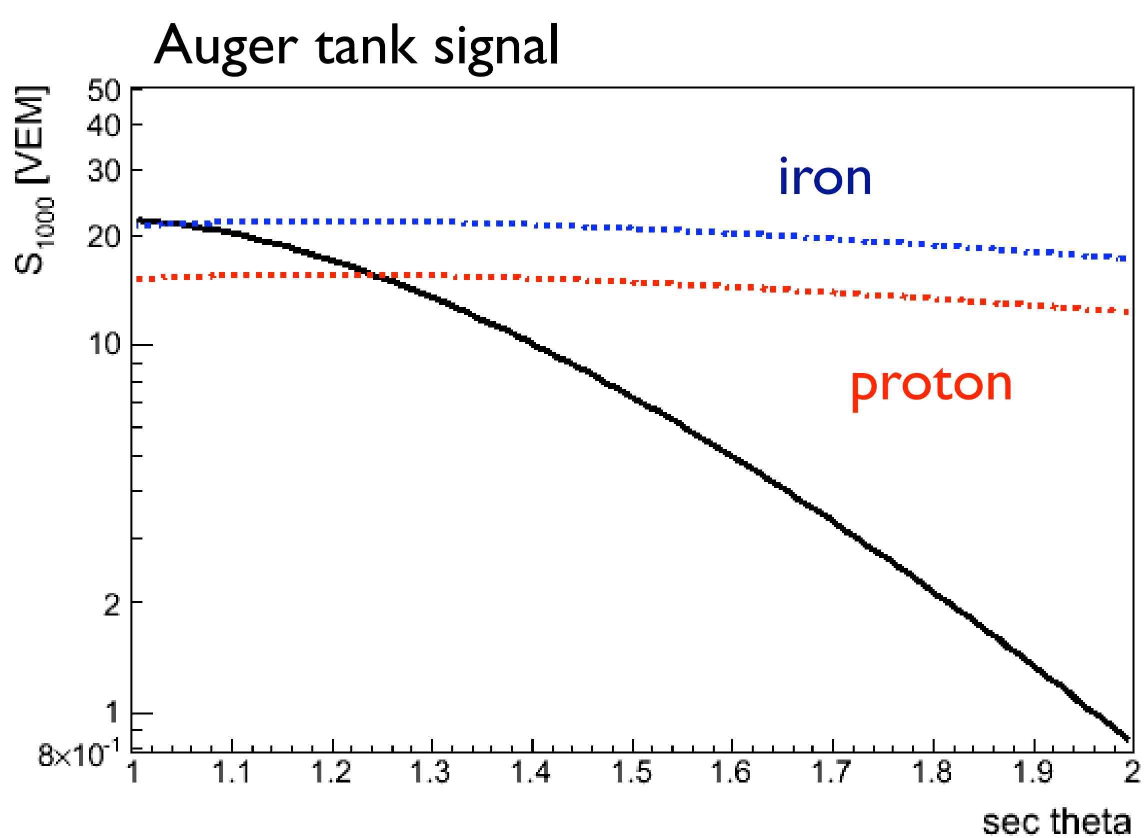
Good general agreement

Auger: test of interaction models



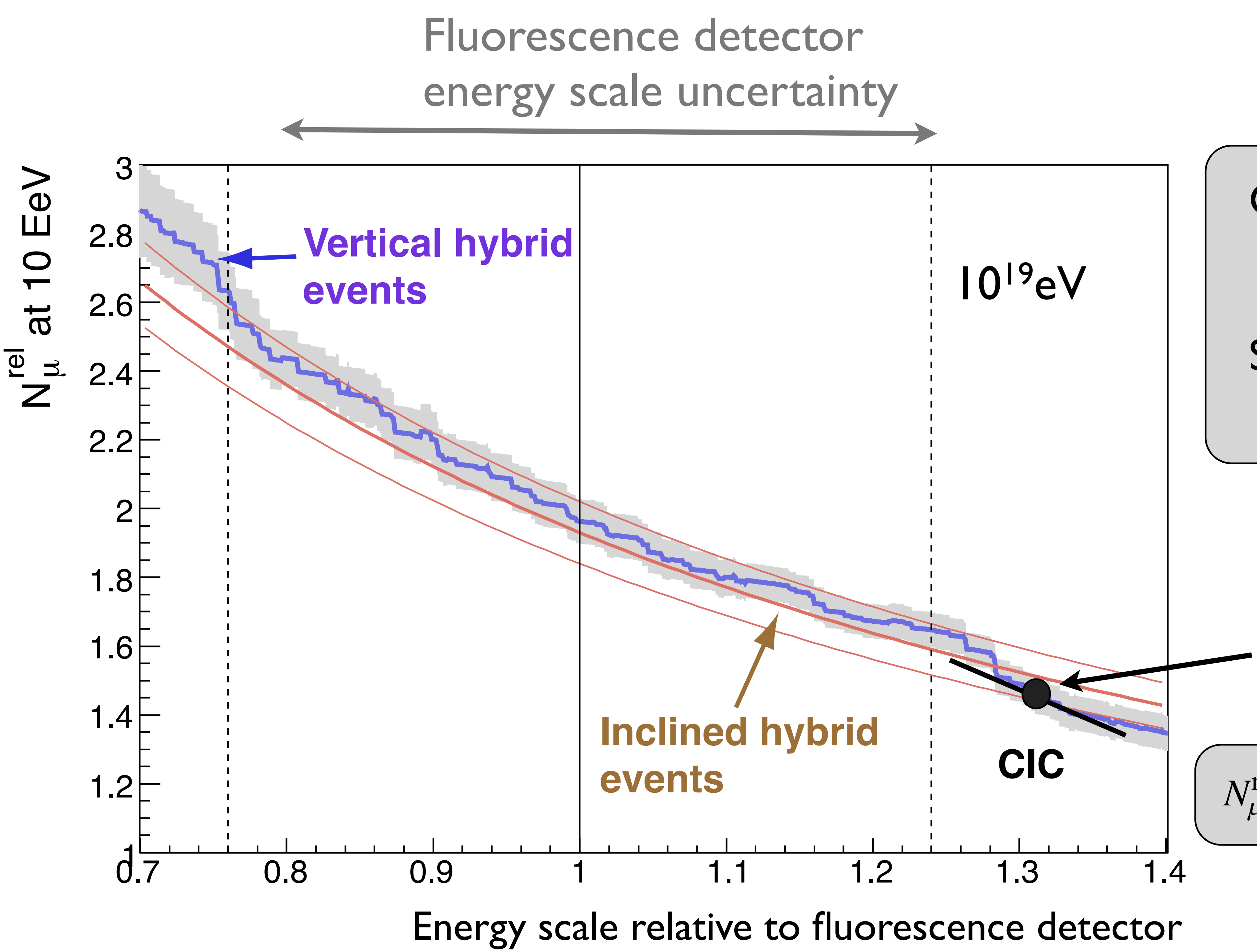
Different methods:

- constant intensity cut (independent of energy scale of experiment)
- golden hybrid events
- inclined shower (almost only muons)



(F. Schmidt et al.)

Auger: test of interaction models



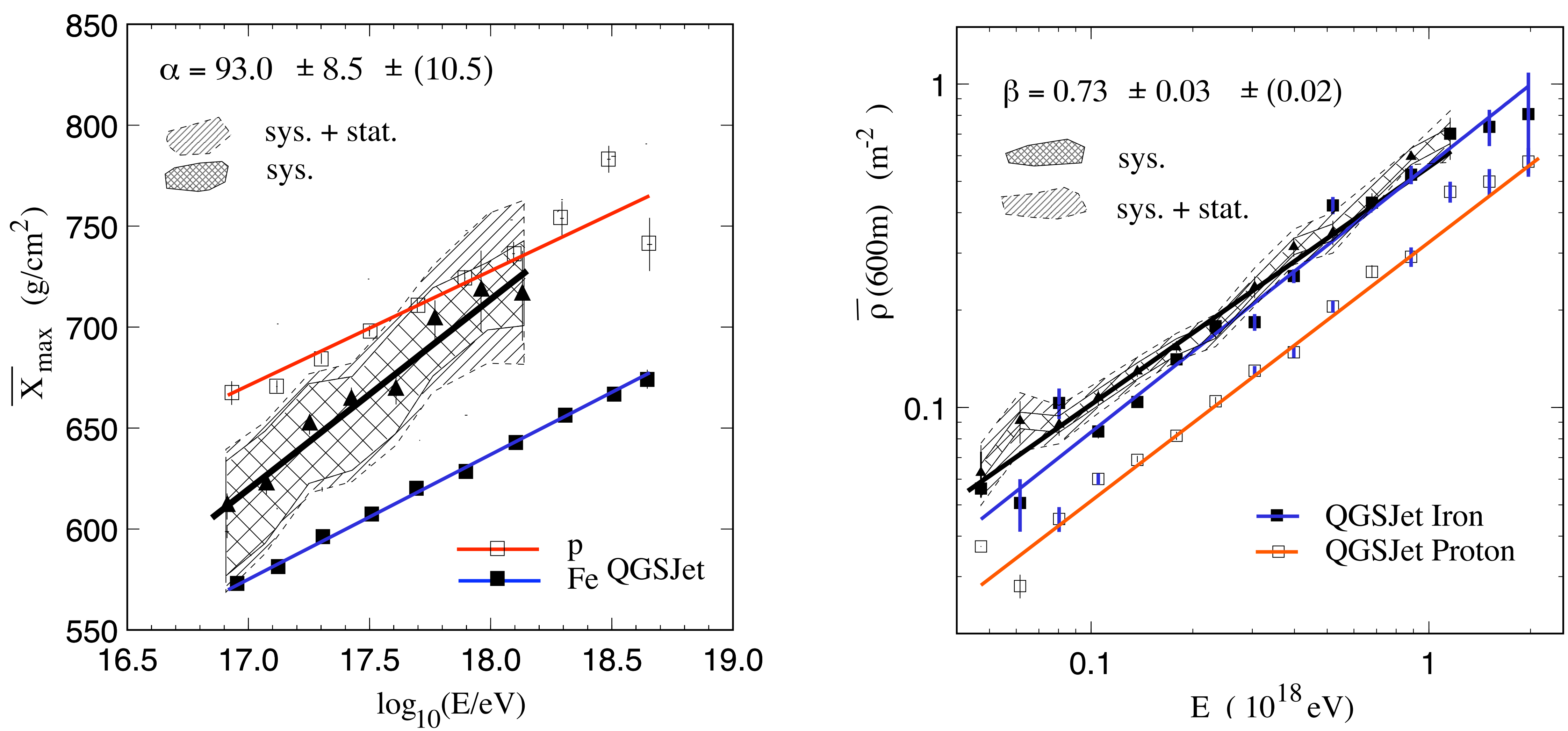
QGSJET II (p) = 1.0
(Fe) = 1.39

SIBYLL 2.1(p) = 0.87
(Fe) = 1.27

$$N_\mu^{\rm rel}(10^{19}\,{\rm eV}) = 1.45 \pm 0.11^{+0.11}_{-0.09}$$

(Auger Collab.)

HiRes-MIA hybrid measurement



Analysis with QGSJET98 (very similar to QGSJET01)

HiRes Fly's Eye and MIA Collabs., Phys. Rev. Lett. 84 (2000) 4276

Sensitivity to physics of first interaction

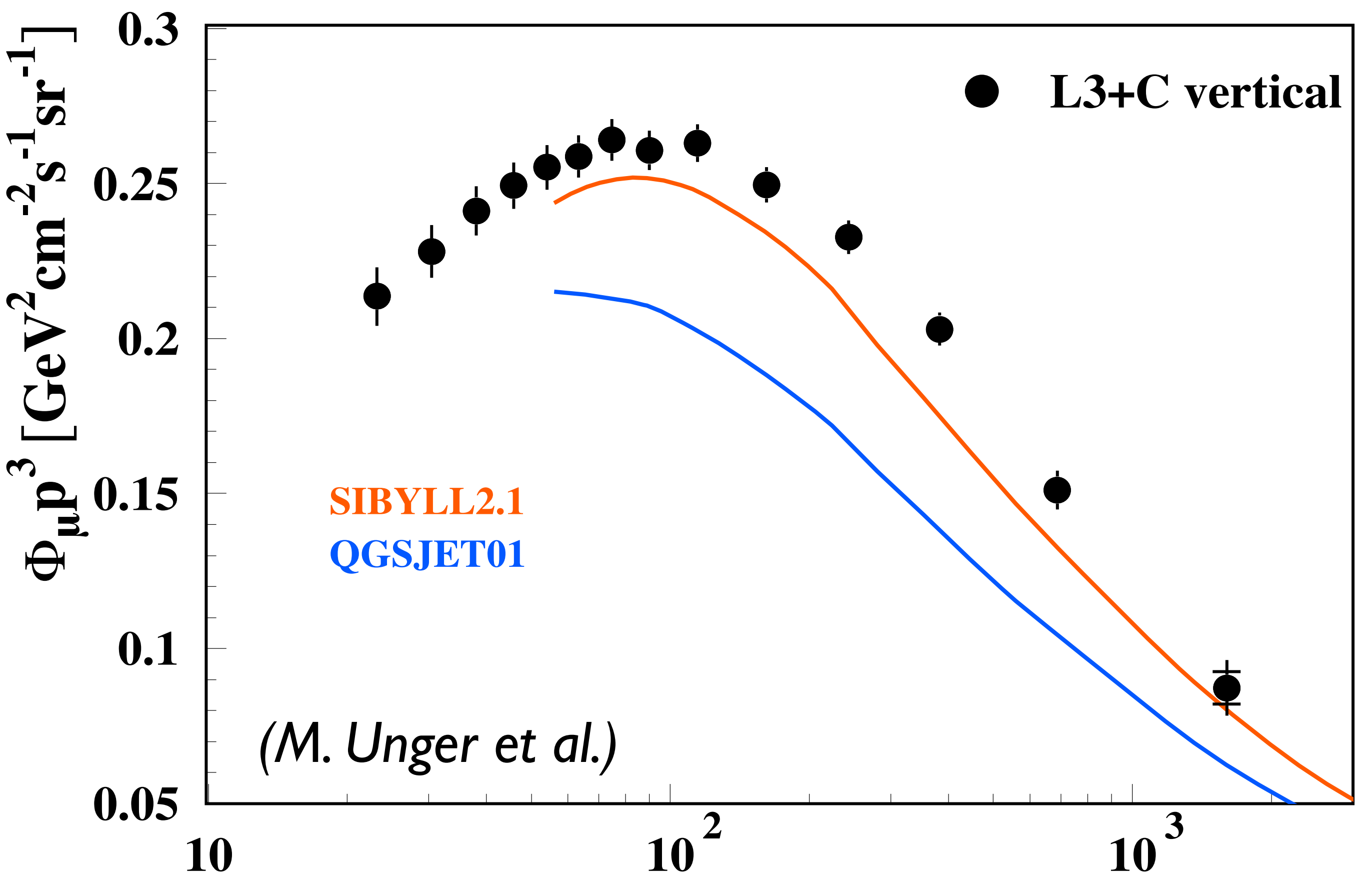
Muon production:
$$N_\mu = \left(\frac{E_0}{E_{\rm dec}}\right)^\alpha \qquad \alpha = \frac{\ln(n_{\rm ch})}{\ln(n_{\rm tot})} \approx 0.9$$

$$N_\mu = n_{\rm ch}^{(\rm first)} \left(\frac{E_0}{n_{\rm tot}^{(\rm first)} E_{\rm dec}}\right)^\alpha = k^{1-\alpha} \left(\frac{E_0}{E_{\rm dec}}\right)^\alpha$$

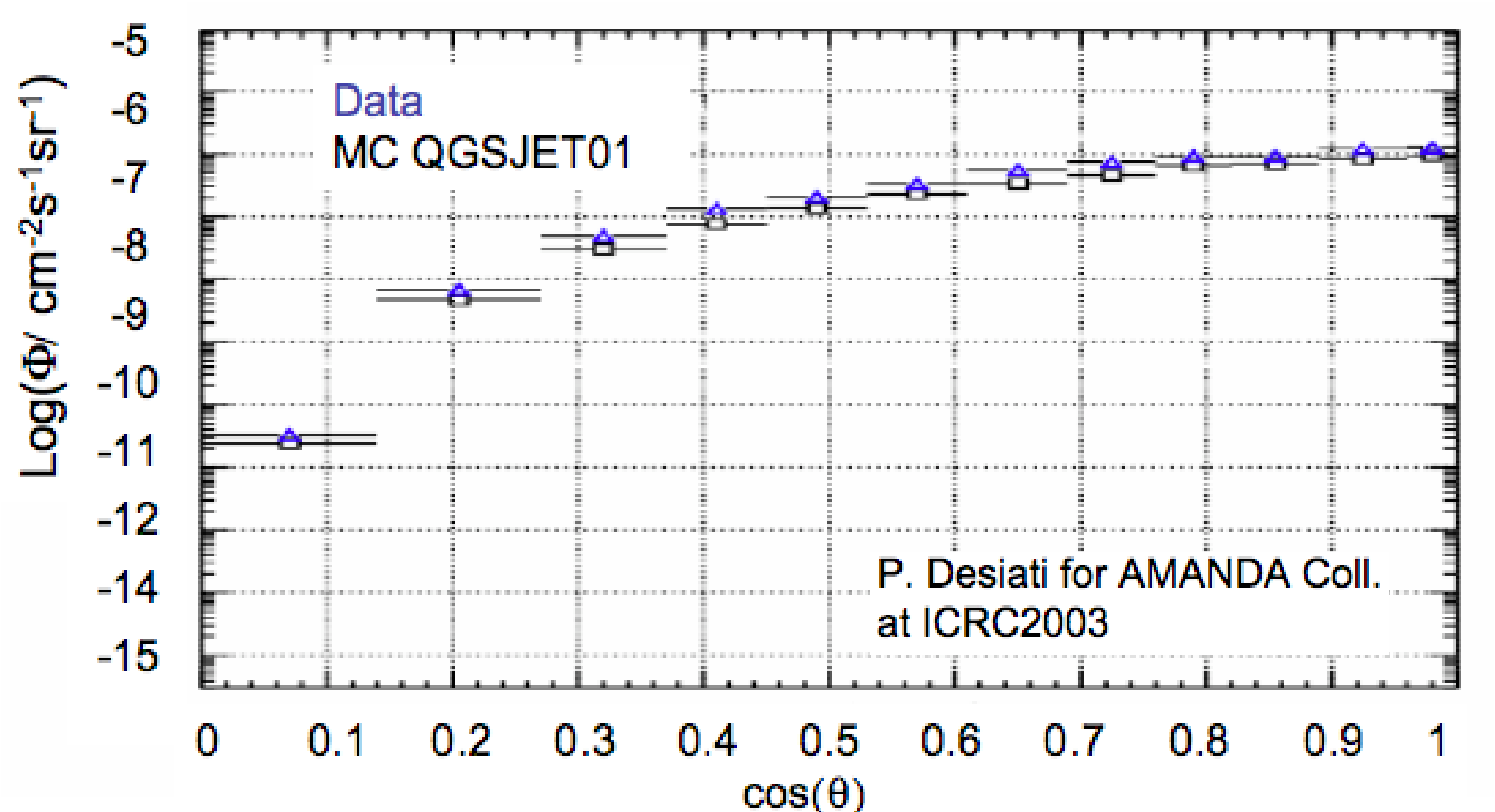
Multiplicity increase by
factor of 2: 5 -7% more muons,
factor of 10: 25% more muons

Muon number insensitive to changes of high-energy interactions

Inclusive muon flux



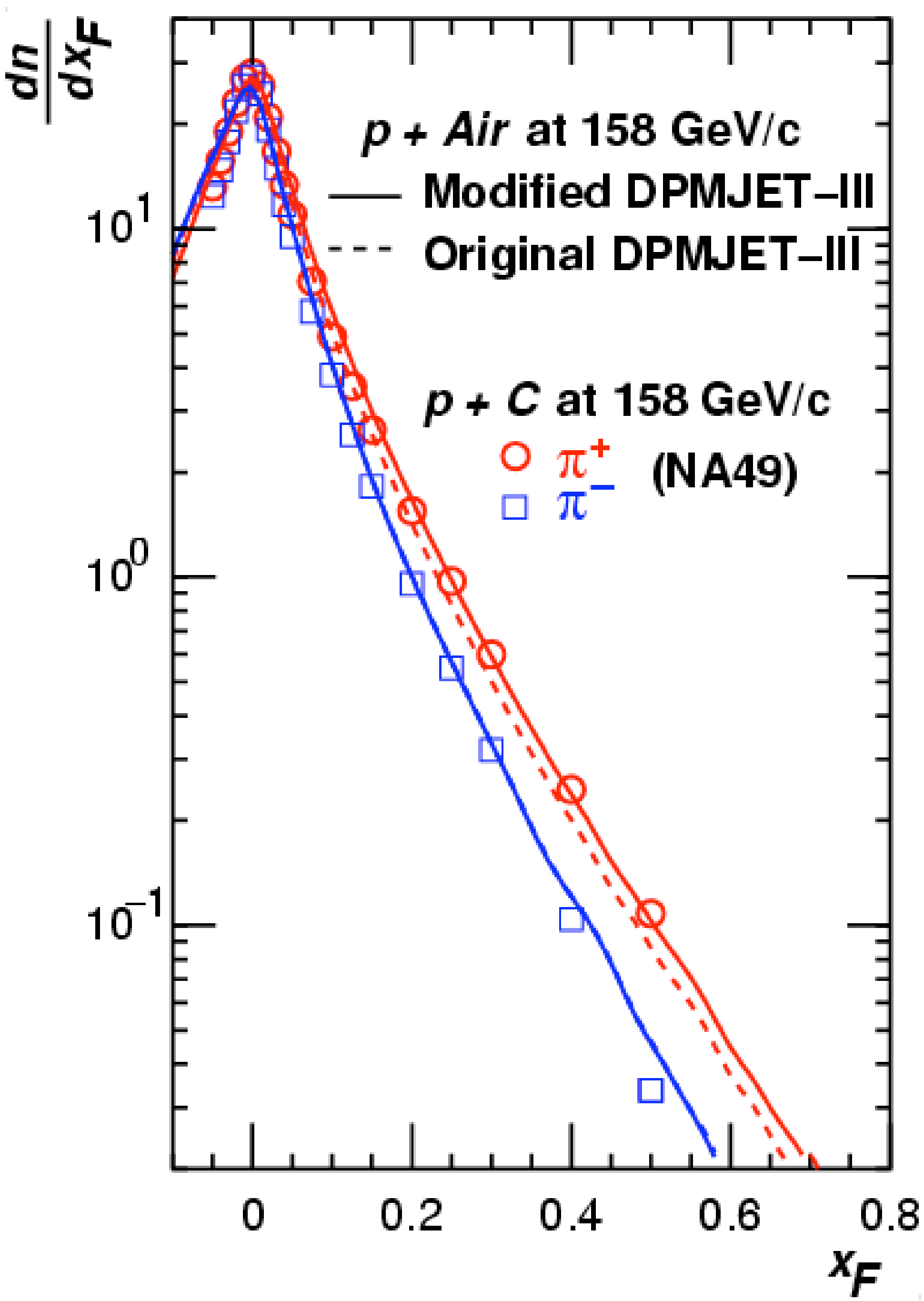
L3+Cosmics:
SIBYLL almost OK,
QGSJET 30% too low



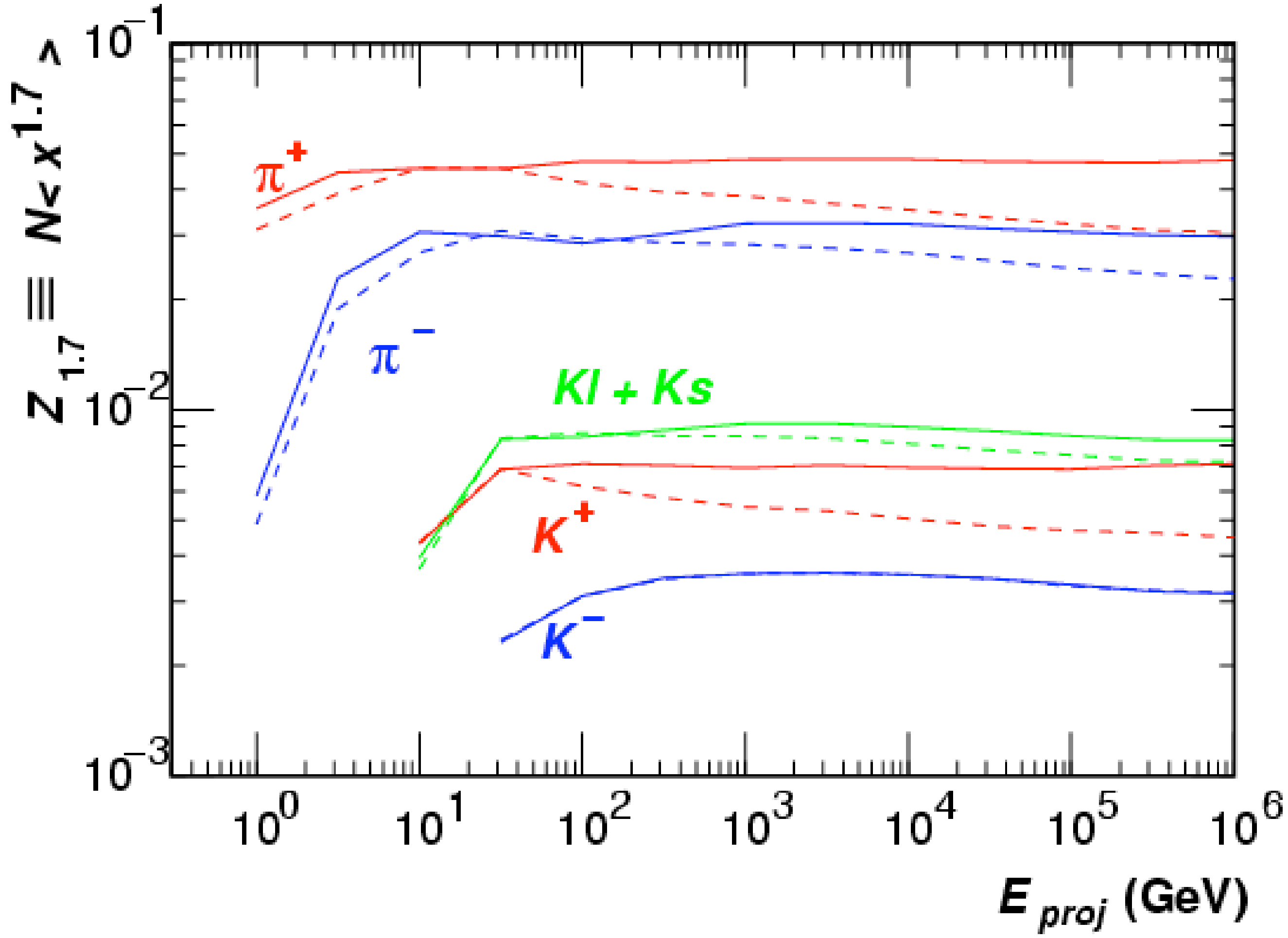
AMANDA II data:
QGSJET 30% too low

Possible fix for better inclusive flux predictions

Comparison with Accelerator experiment



Z-factors



Model changed to scaling!

(M. Honda et al.)

Was the overall agreement
just a coincidence?

EPOS: a new multi-purpose interaction model

Hadronic Models in CORSIKA and CONEX

(HDPM)

Old generation : QGSJET01 SIBYLL2.1 DPMJET2.55 VENUS

All Glauber based

But differences in hard, remnants, diffraction …

hard

soft

NEXUS

Attempt to get everything describe in a consistent way

New generation : QGSJET II-3

EPOS 1.6

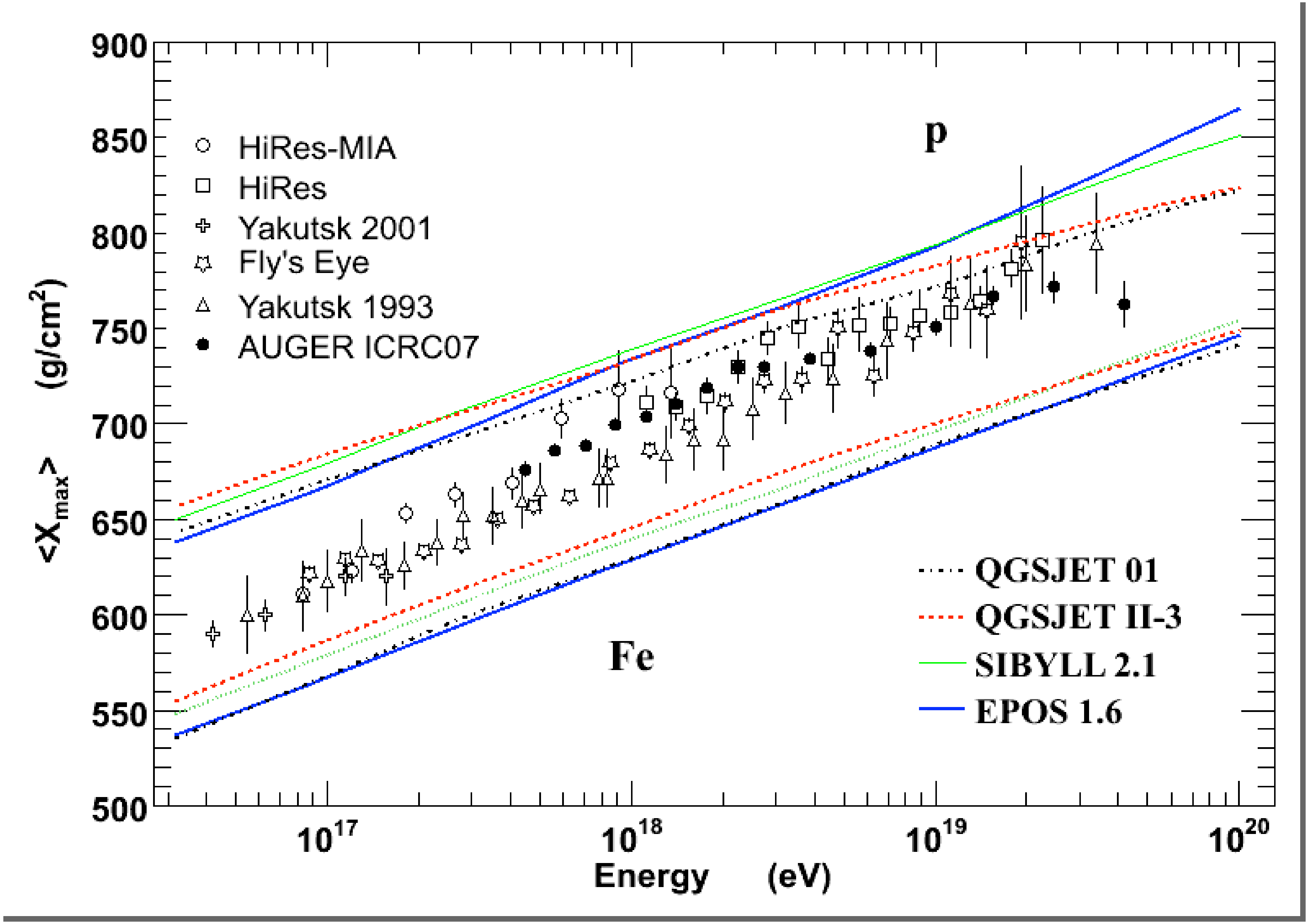
Theory ++ :

- no energy conservation at amplitude level
- Fan diagrams
- diffraction

Phenomenology ++ :

- energy conservation at amplitude level
- effective treatment of higher orders
- Nuclear effect
- High density effect (QGP)

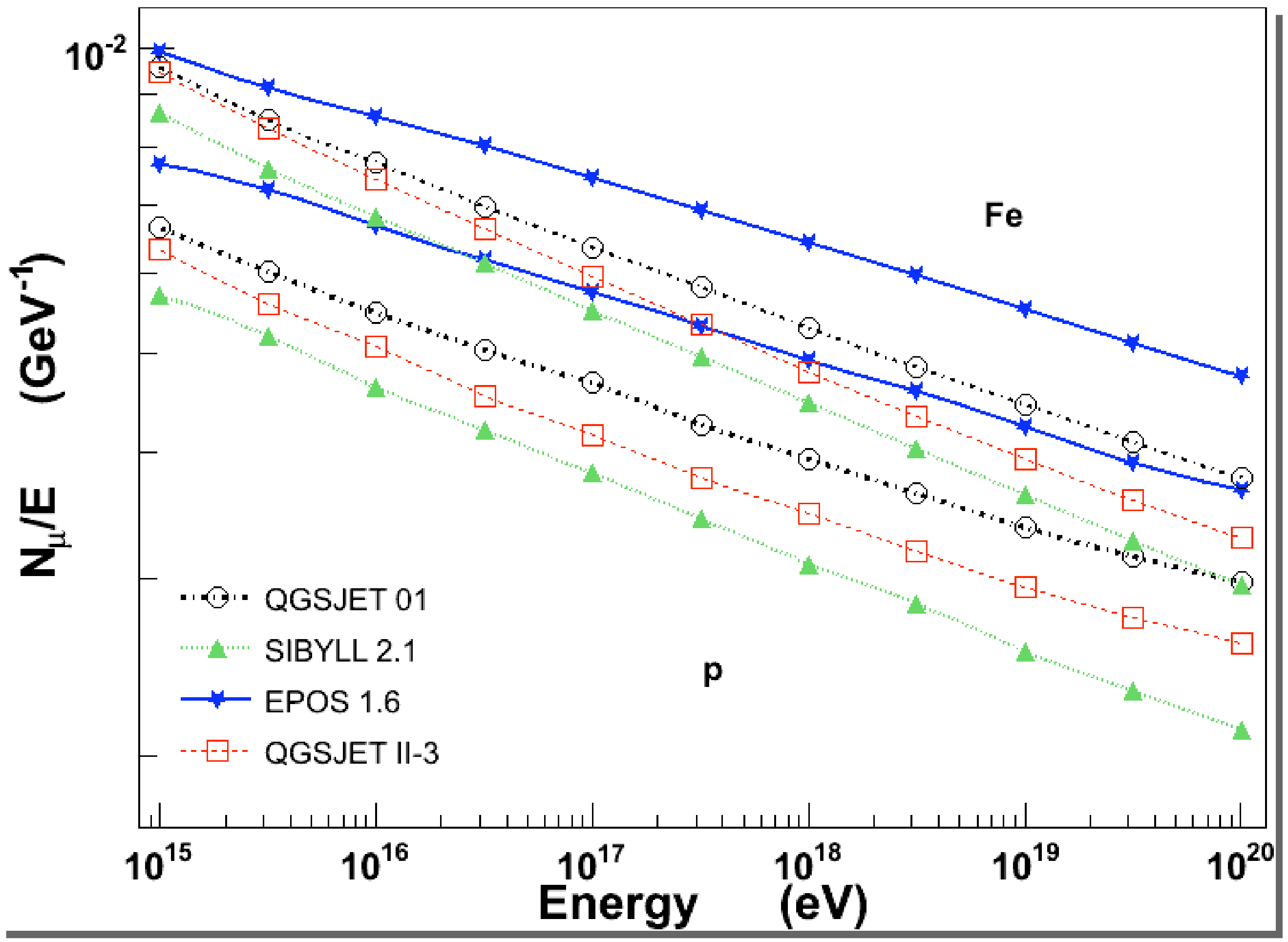
Elongation Rate



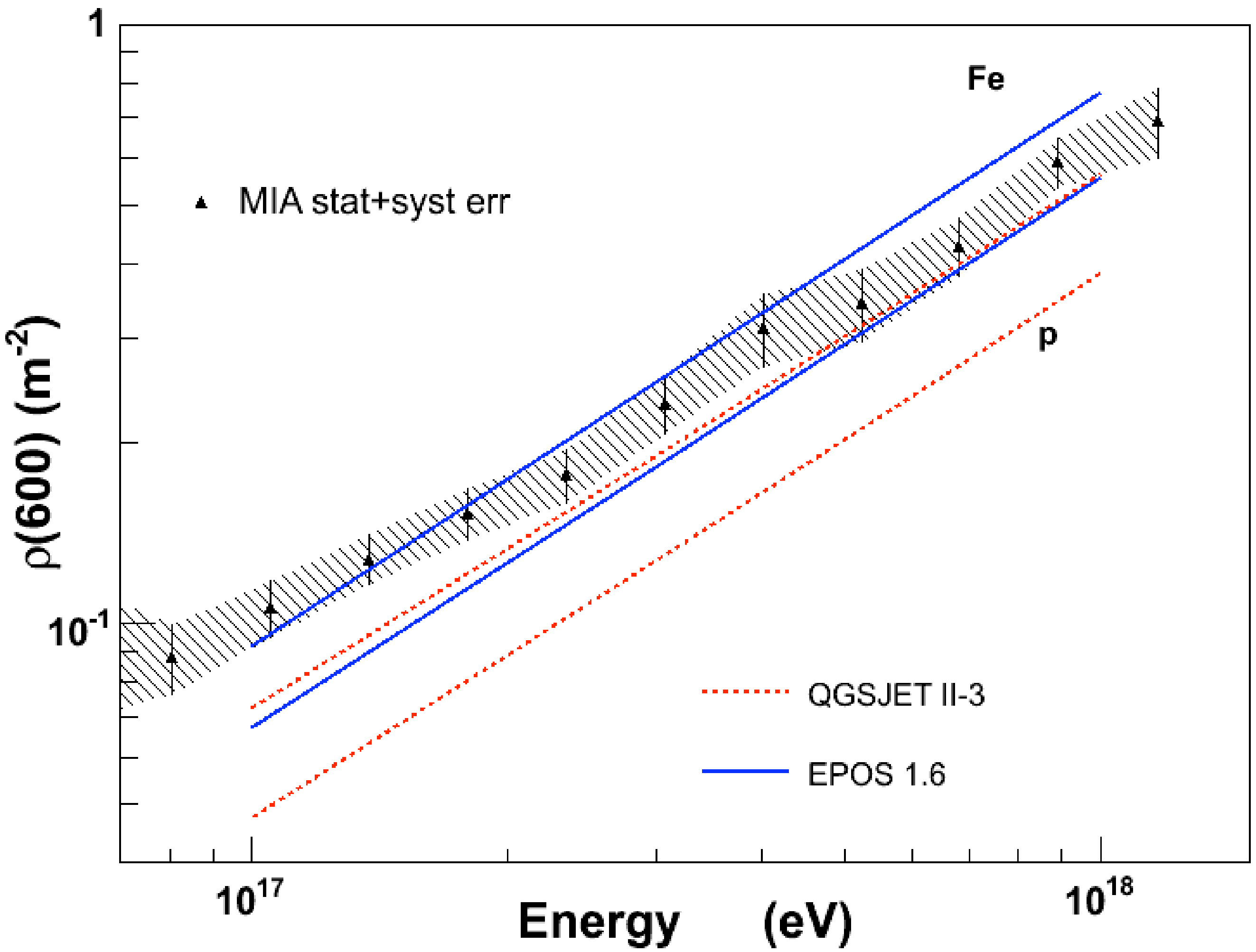
Results for EAS : N_μ

EPOS has a different slope for N_μ (~0.935, SIBYLL ~0.9)

AND a different scale : QGSJET01 +25 % or SIBYLL +50% at 10^{19}eV



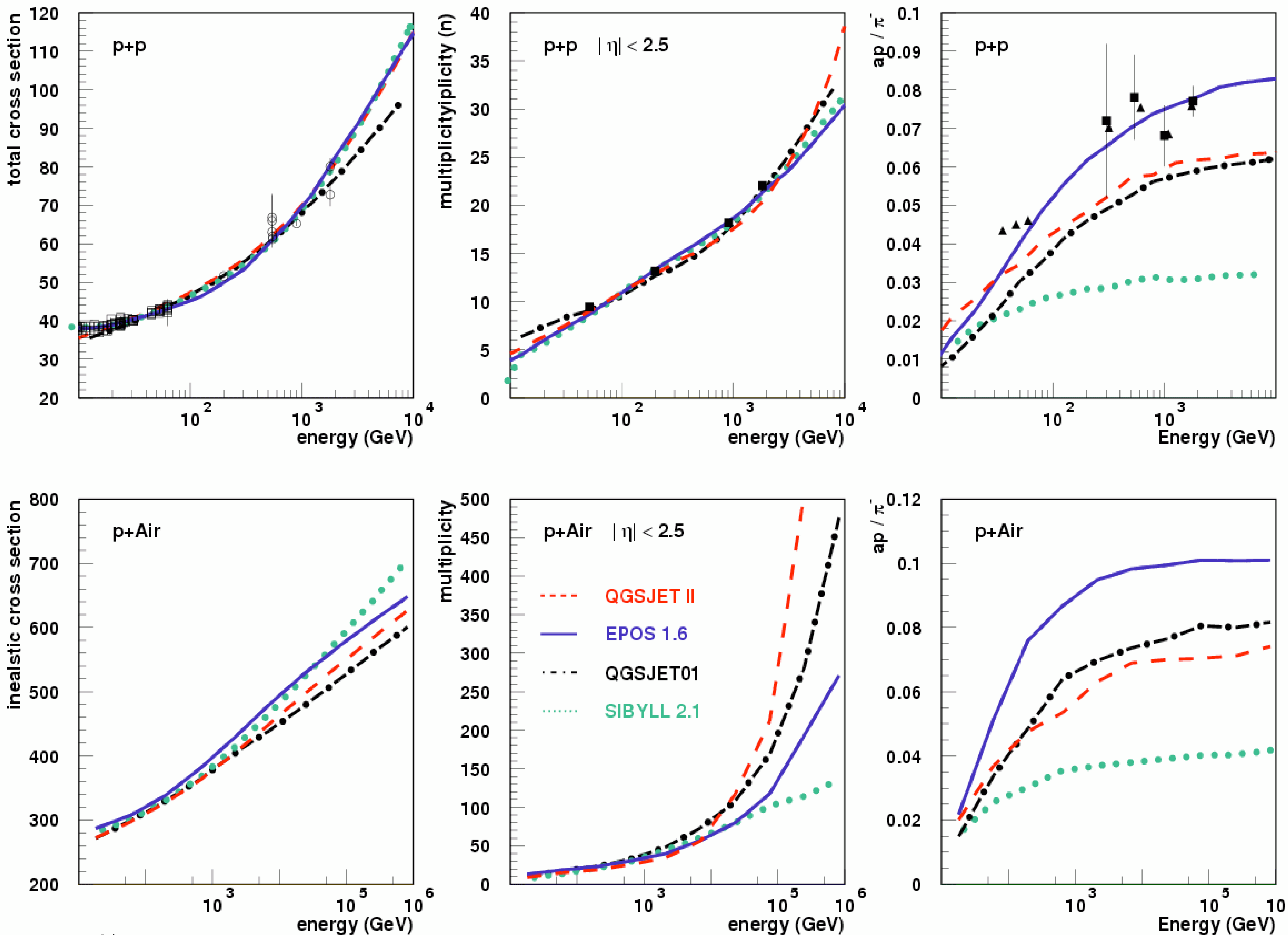
Clear discrepancy due to antibaryon number and difference in R ...



ICRC'07 – Merida – July 5th 2007

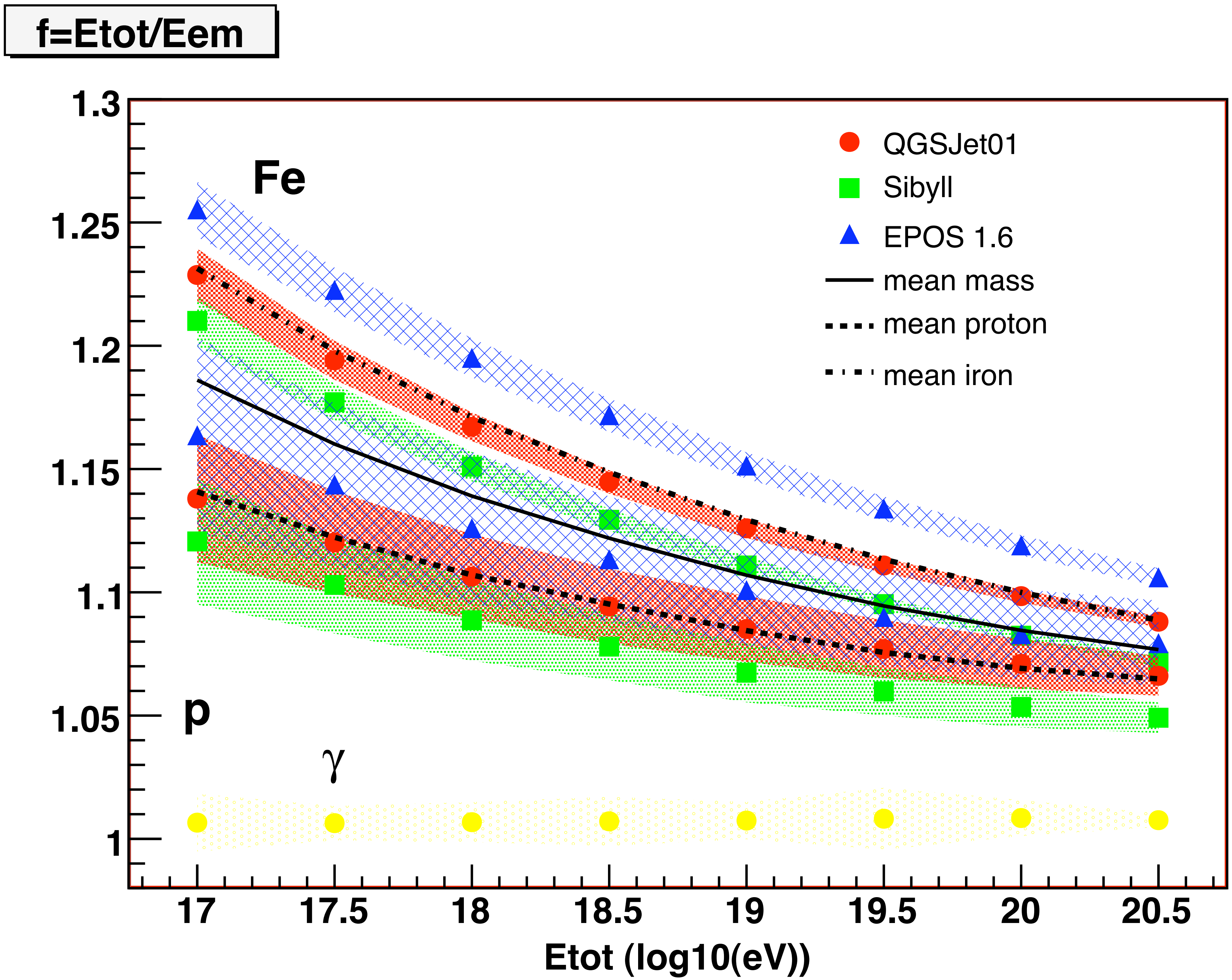
(T. Pierog et al.)

Model comparison (EPOS, QGSJET, SIBYLL)



(T. Pierog et al.)

Energy correction for fluorescence detectors



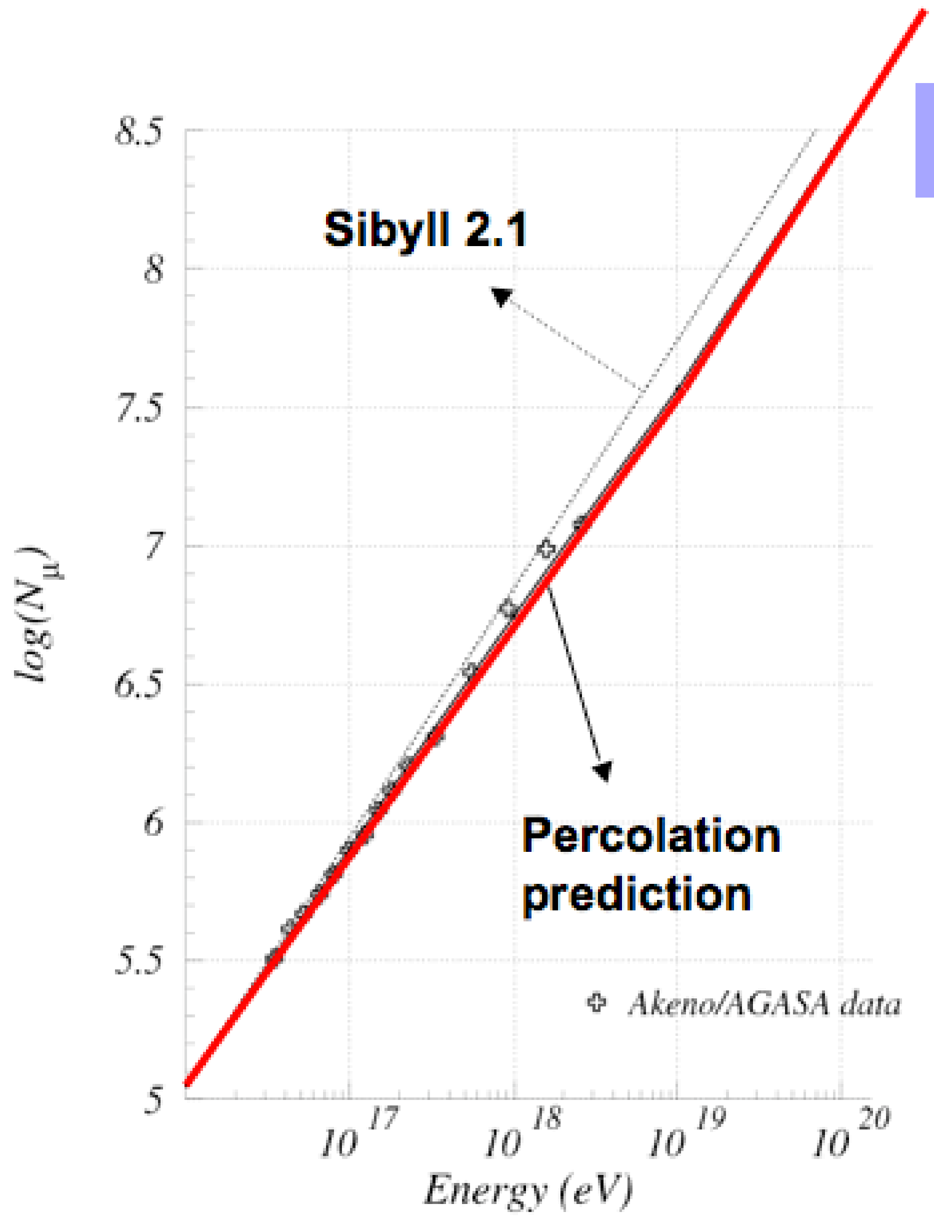
Increased muon production directly linked to missing energy correction

Overall model dependence small

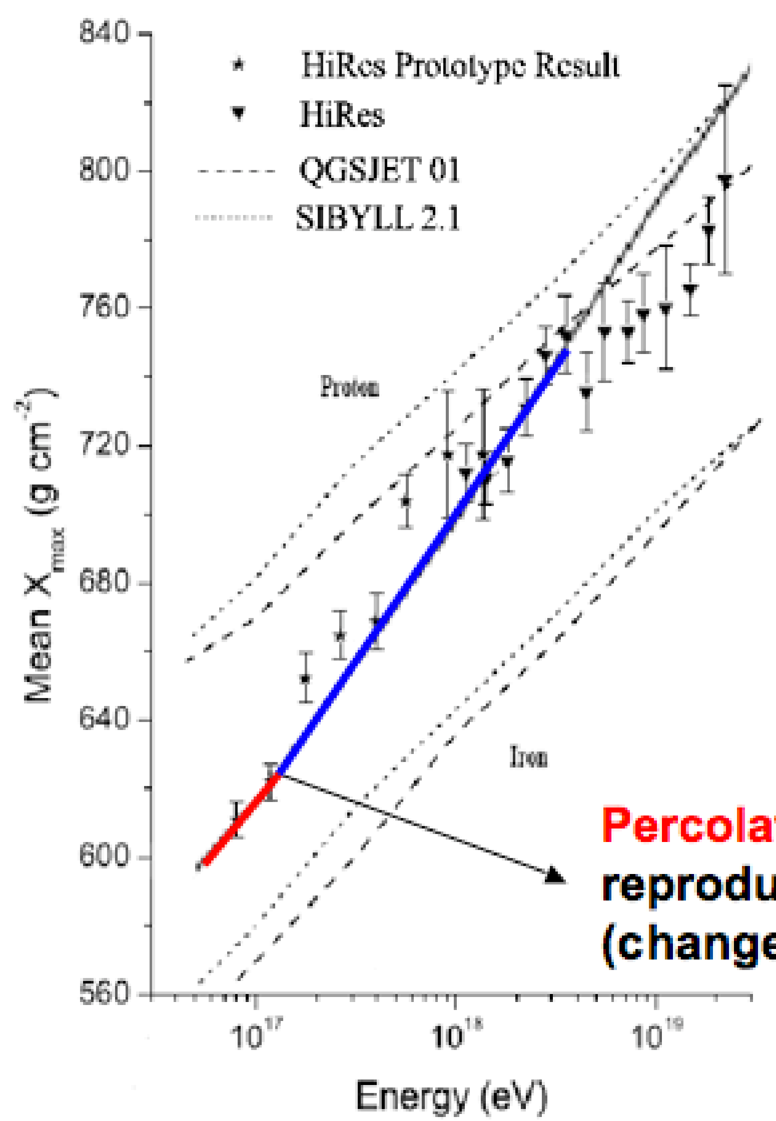
(T. Pierog et al.)

Does the composition change (10^{17} - $10^{18.5}$ eV)?

Results on N_μ vs E_{shower}



Results on <X_{max}> vs E



J. Alvarez-Muñiz et al. ICRC 2007, Mérida (México)

Percolation reproduces the right tendency of X_{max} vs E (the change of slope at ~ 10^{17} eV) without the need a change in composition.

Overshooting tendency E > 3 x 10^{18} e

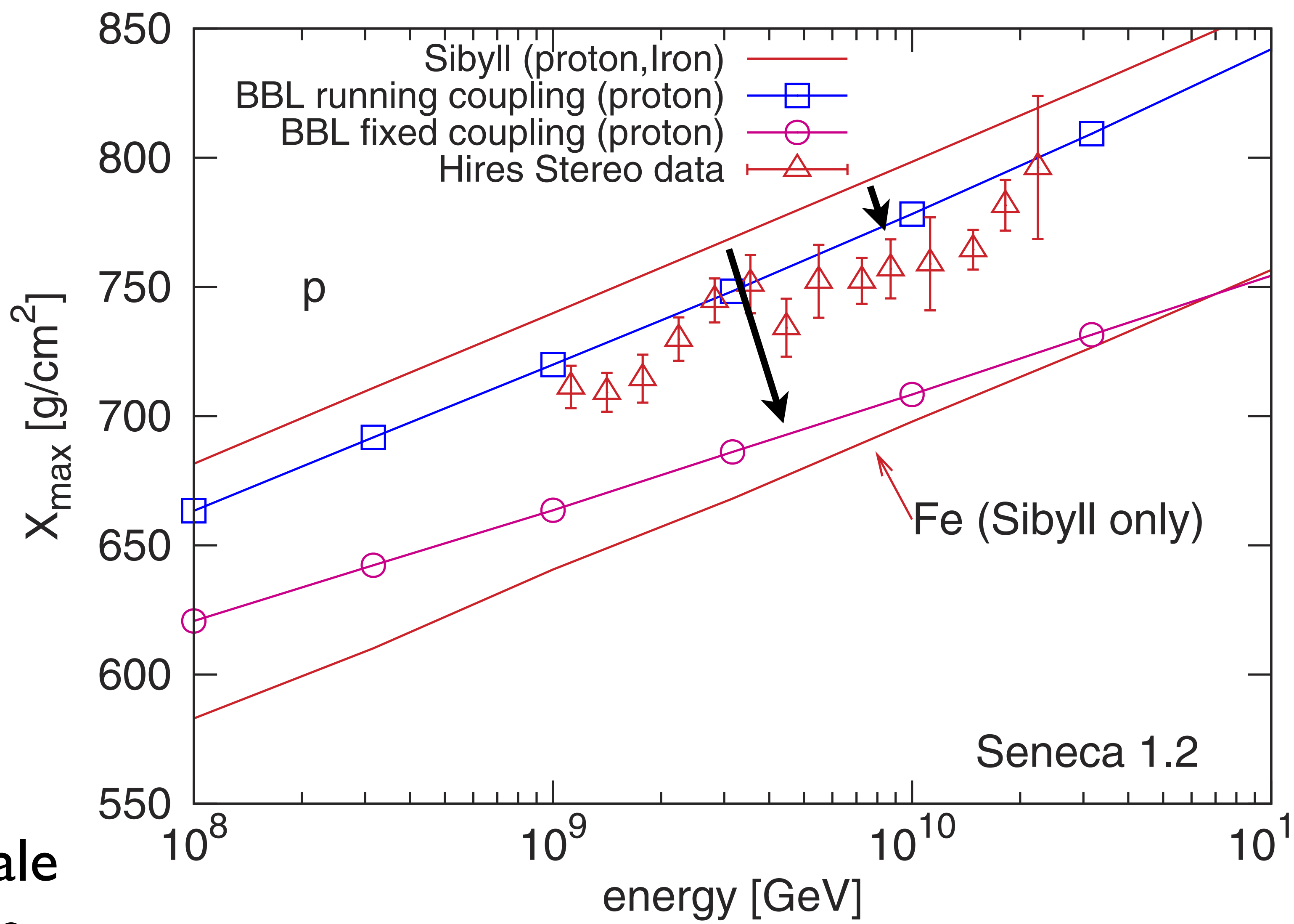
(Results obtained for proton primaries and scaled to <A> ~ 20)

Percolation model prediction reproduces the right tendency (change of slope of X_{max} at ~ 10^{17} eV)

(J.Alvarez.Muniz et al.)

Black disk scenario of high energy scattering

(Drescher et al. PRL 94, 2005)

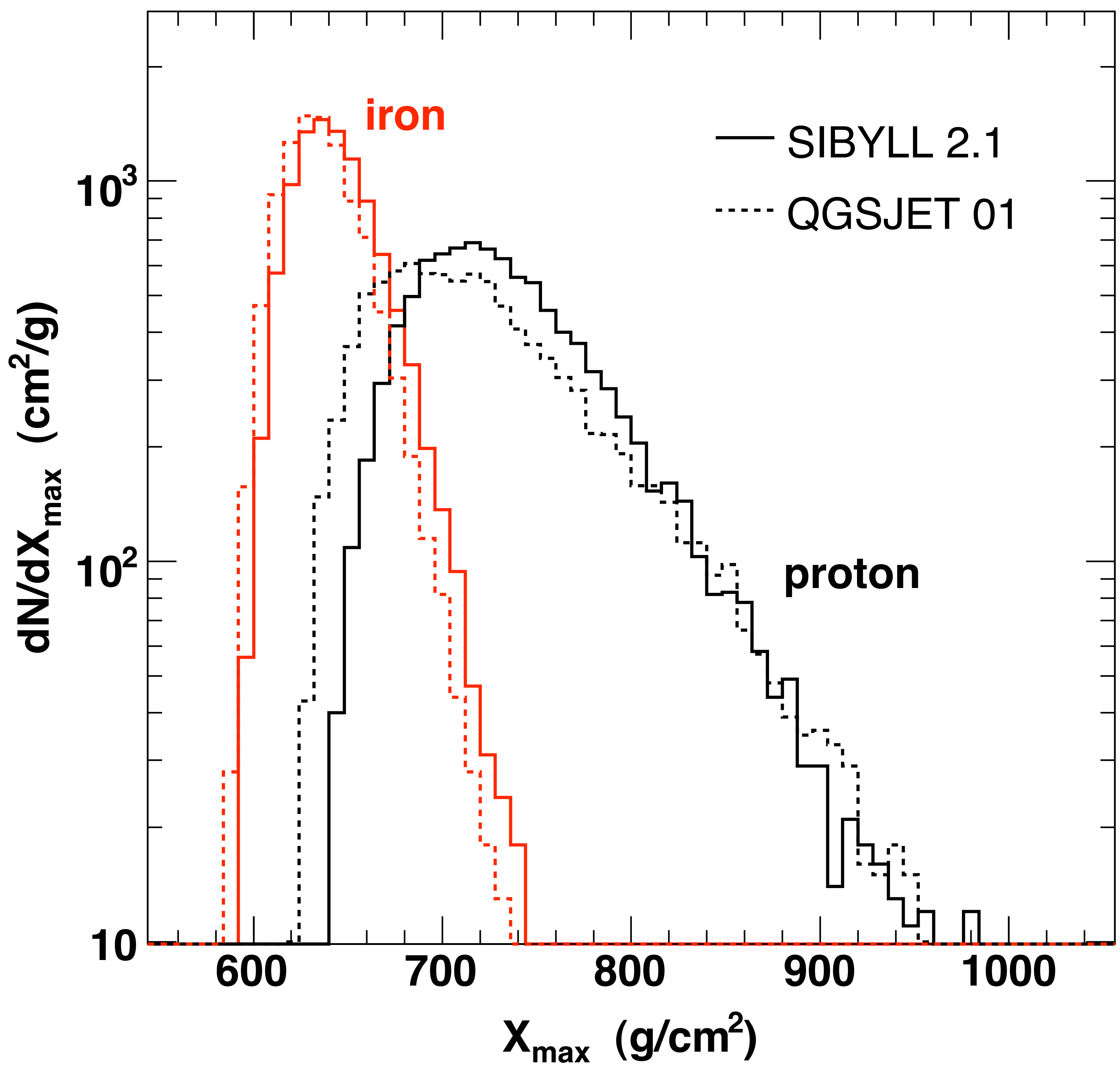


Black Disk Model

- large number of minijets
- high perturbative saturation scale
- disintegration of leading particle

Depth of shower maximum very sensitive to high energy interaction characteristics

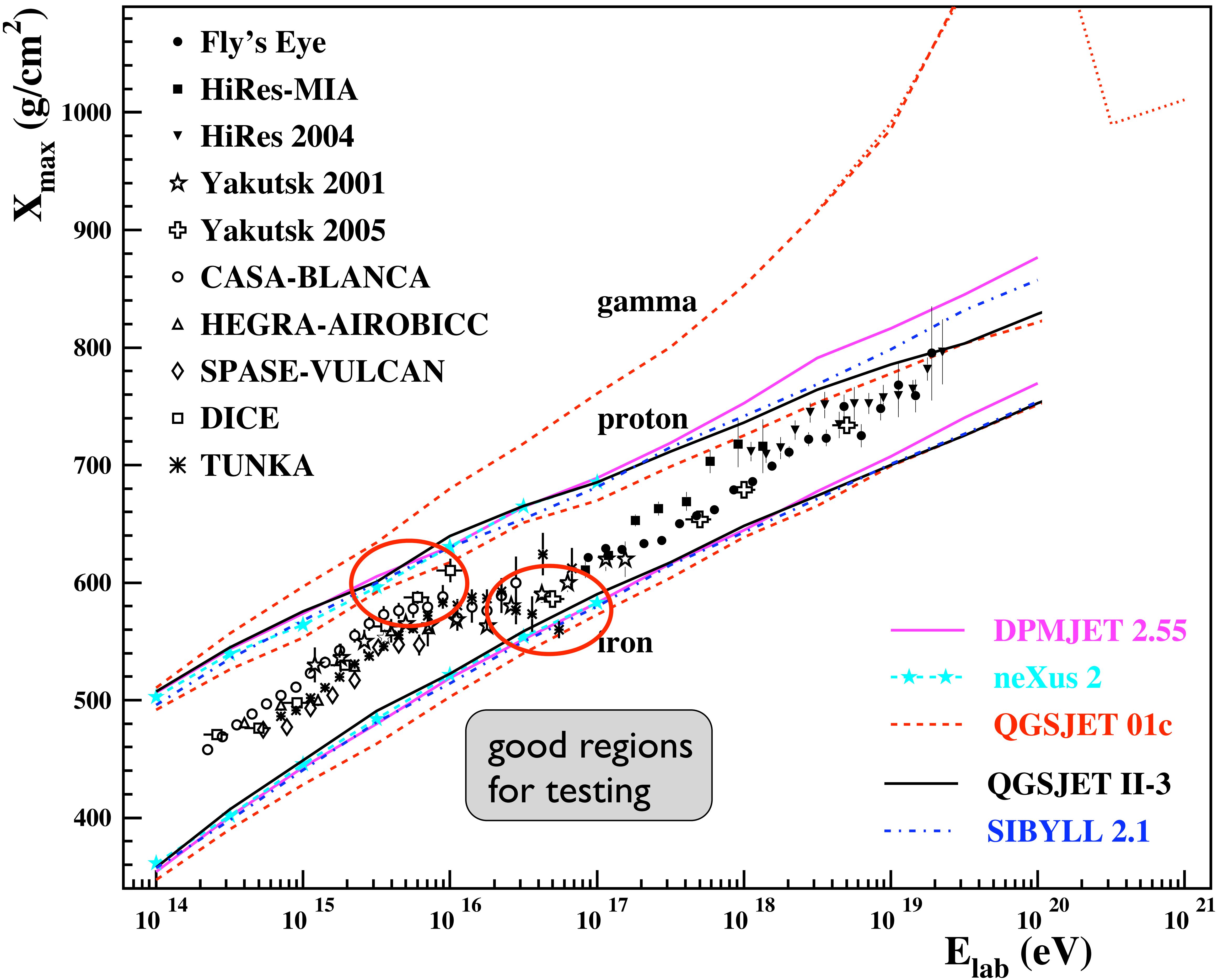
Fluctuations of X_{max} to discriminate?



Only very restrictive if composition is very heavy

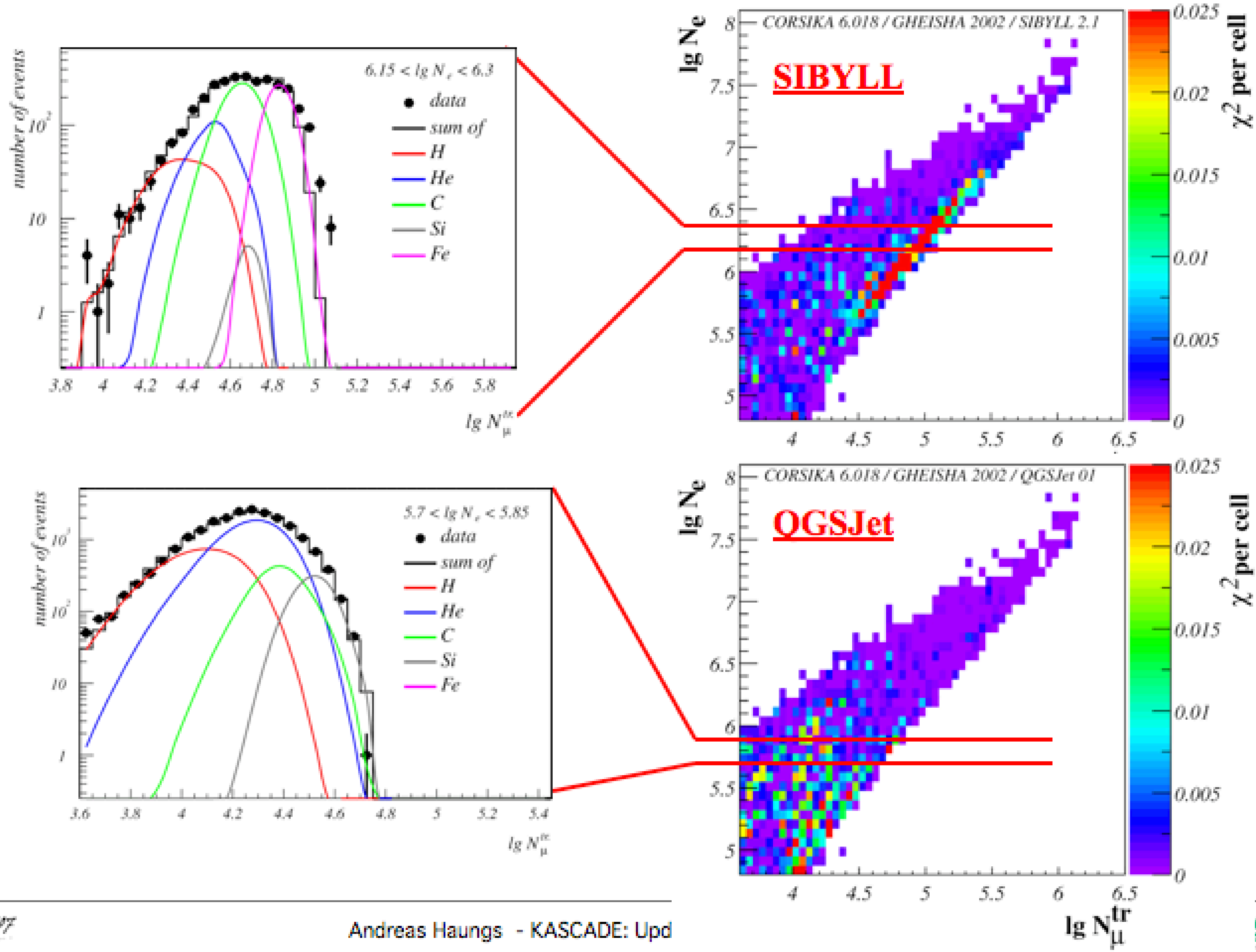
The knee energy range as model challenge

(Heck, 2006)



X_{max} (g/cm^2)
1000
900
800
700
600
500
400
Fly's Eye
HiRes-MIA
HiRes 2004
Yakutsk 2001
Yakutsk 2005
CASA-BLANCA
HEGRA-AIROBICC
SPASE-VULCAN
DICE
TUNKA
gamma
proton
iron
DPMJET 2.55
neXus 2
QGSJET 01c
QGSJET II-3
SIBYLL 2.1
good regions
for testing
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
E_{lab} (eV)

KASCADE: sensitivity to hadronic interaction models



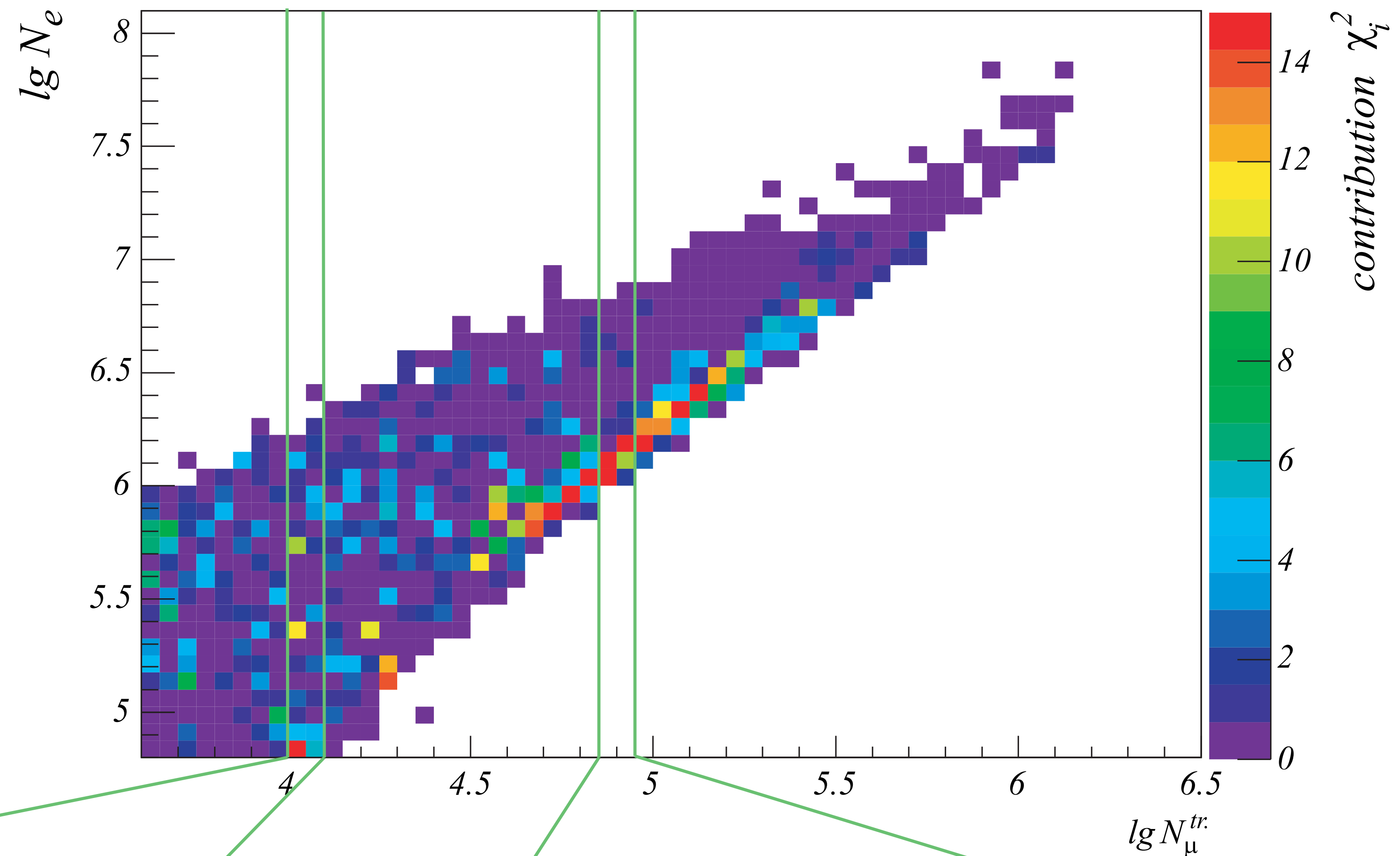
QGSJet II - result

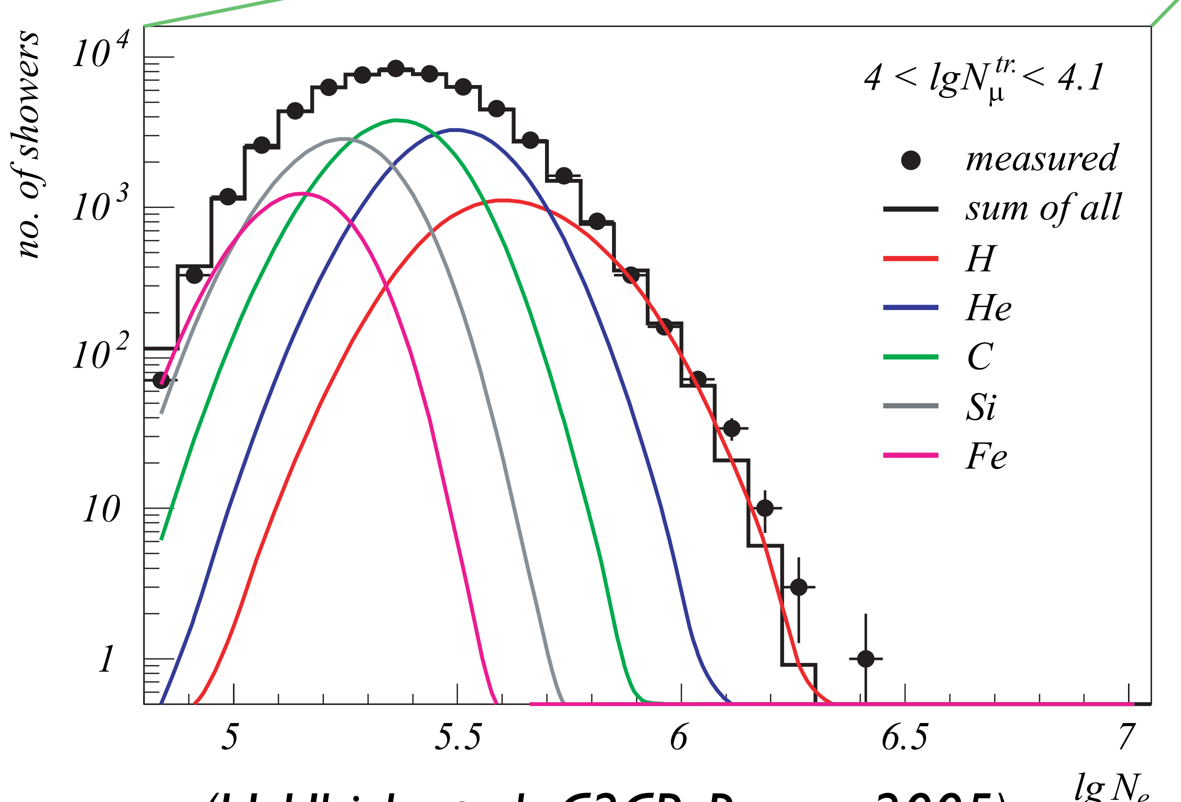
Description of data

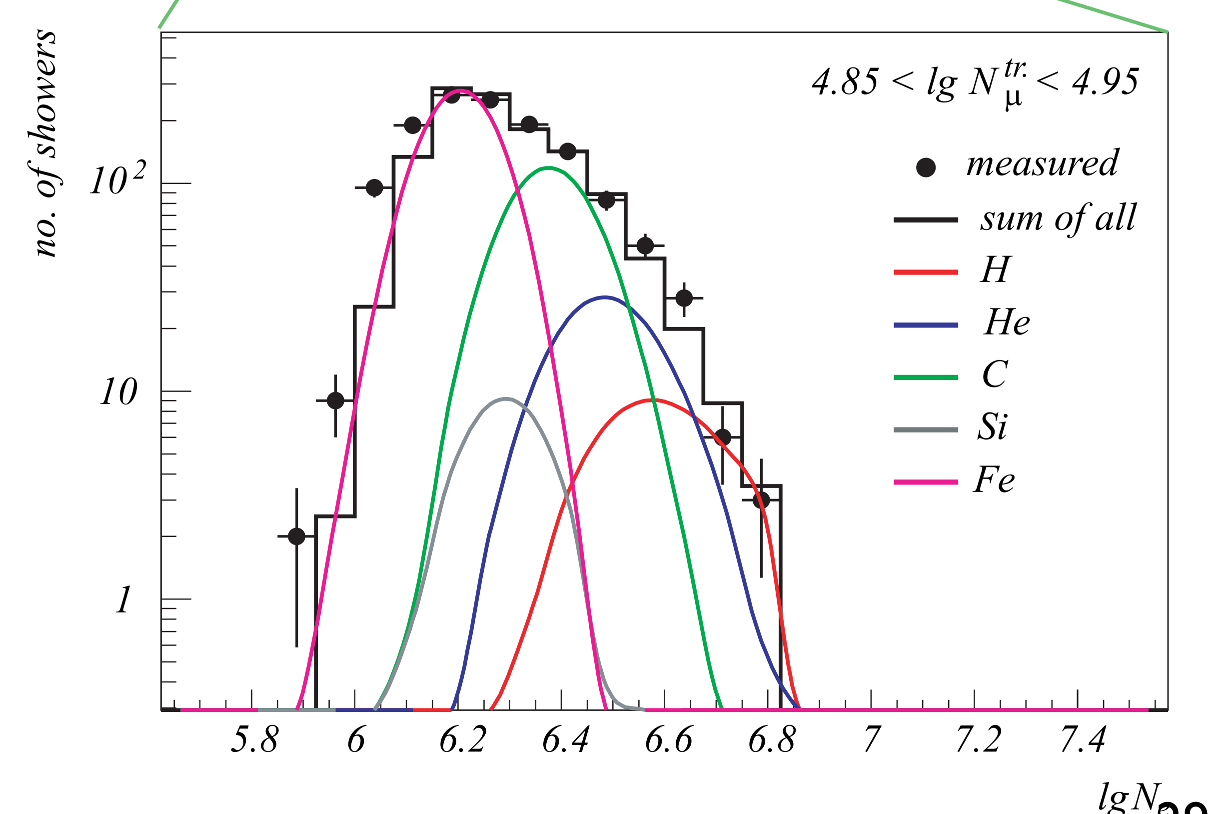
Beta version QGSJET II.02
(unpublished)

on

comparison between calculated and measured data: χ^2

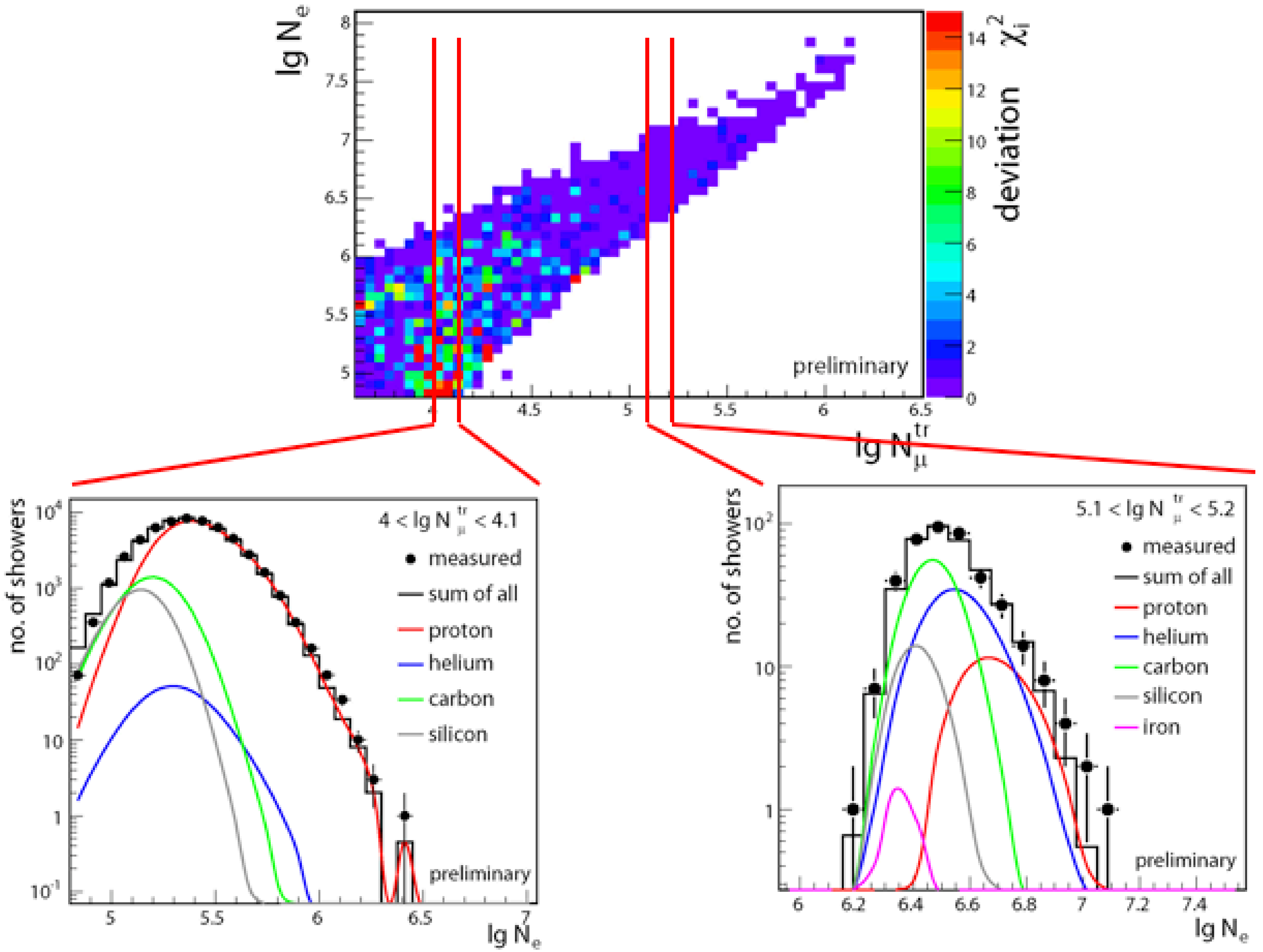




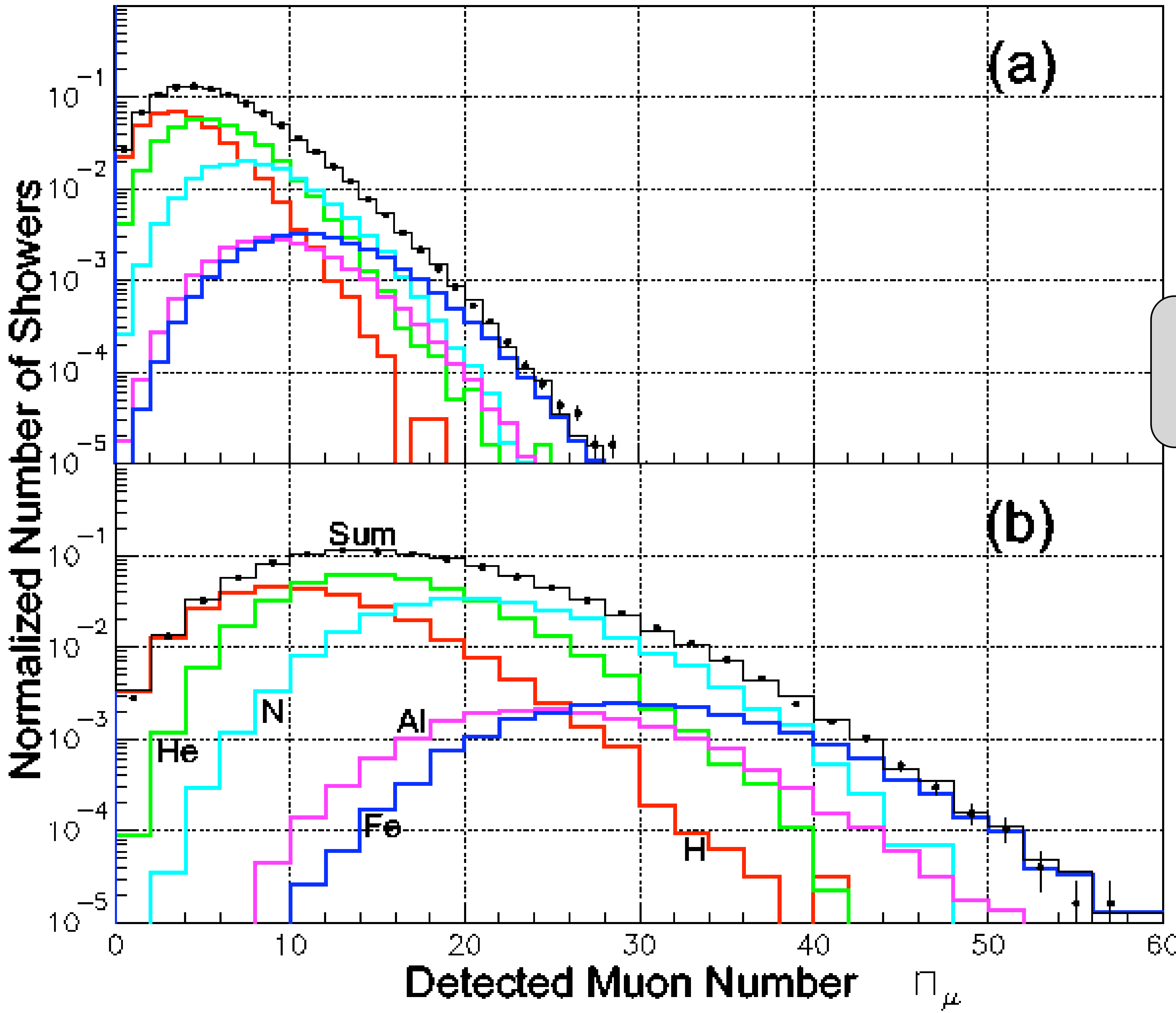


(H. Ulrich et al., C2CR, Prague 2005)

KASCADE result: EPOS in detail



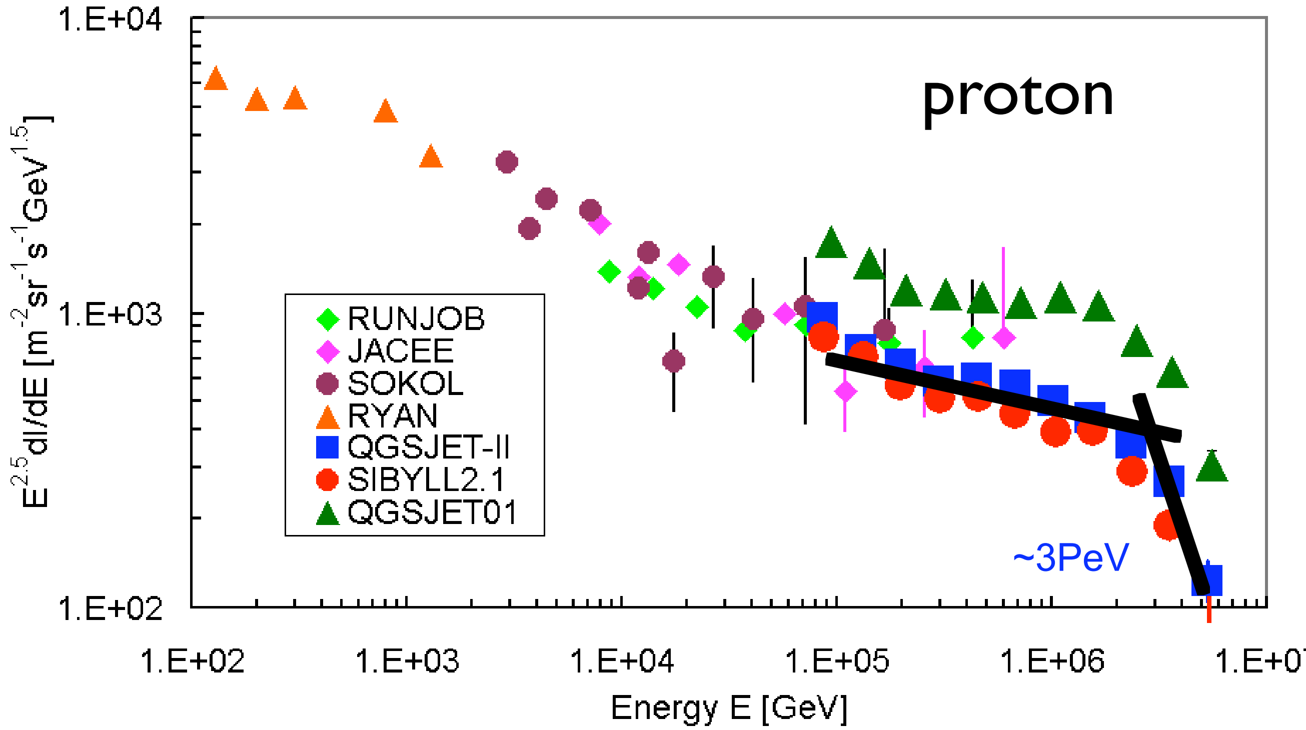
GRAPES-3



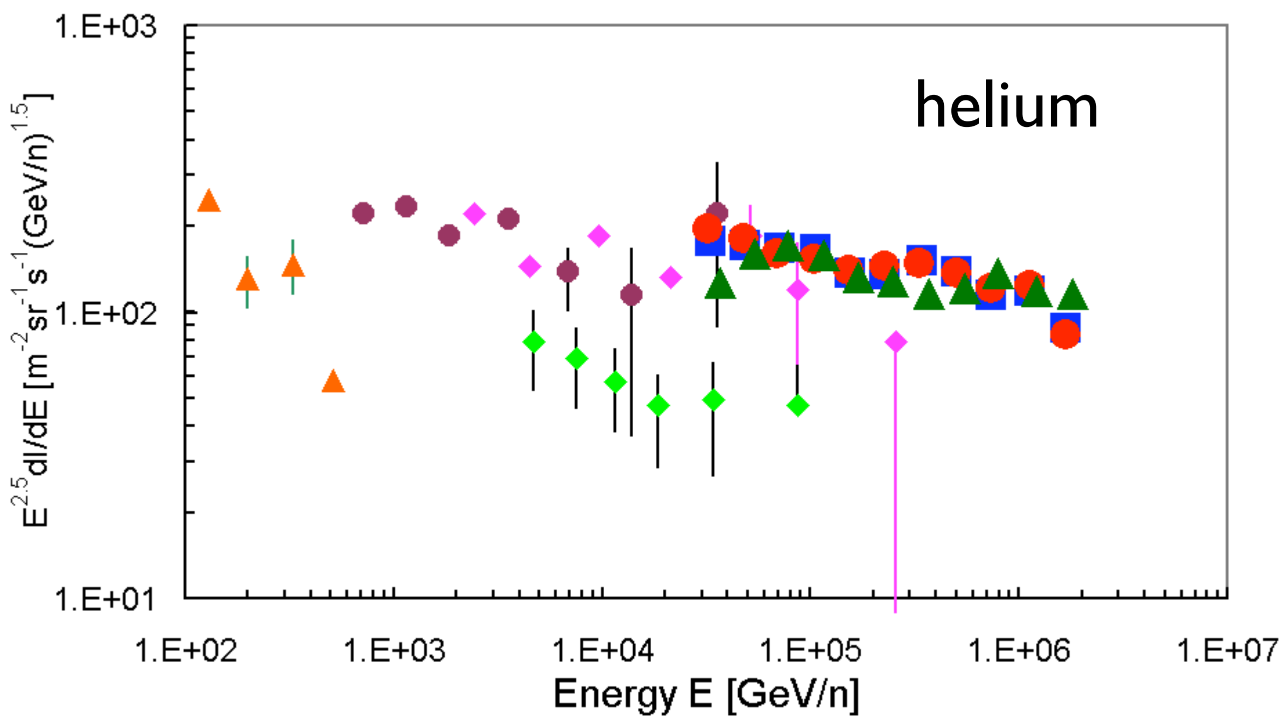
Independent test possible

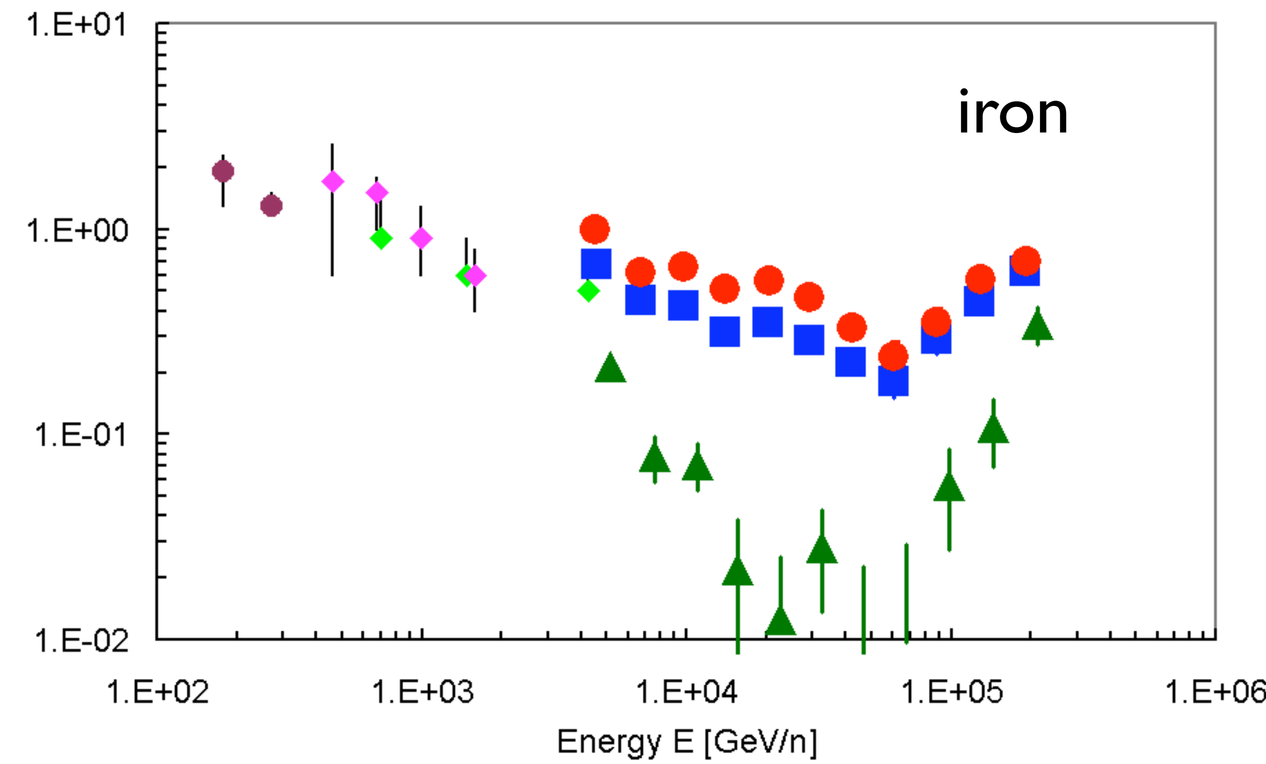
(H.Tanaka et al. S.Tonwar et al.)

GRAPES-3: element fluxes



Assessment of models by relation to direct measurements

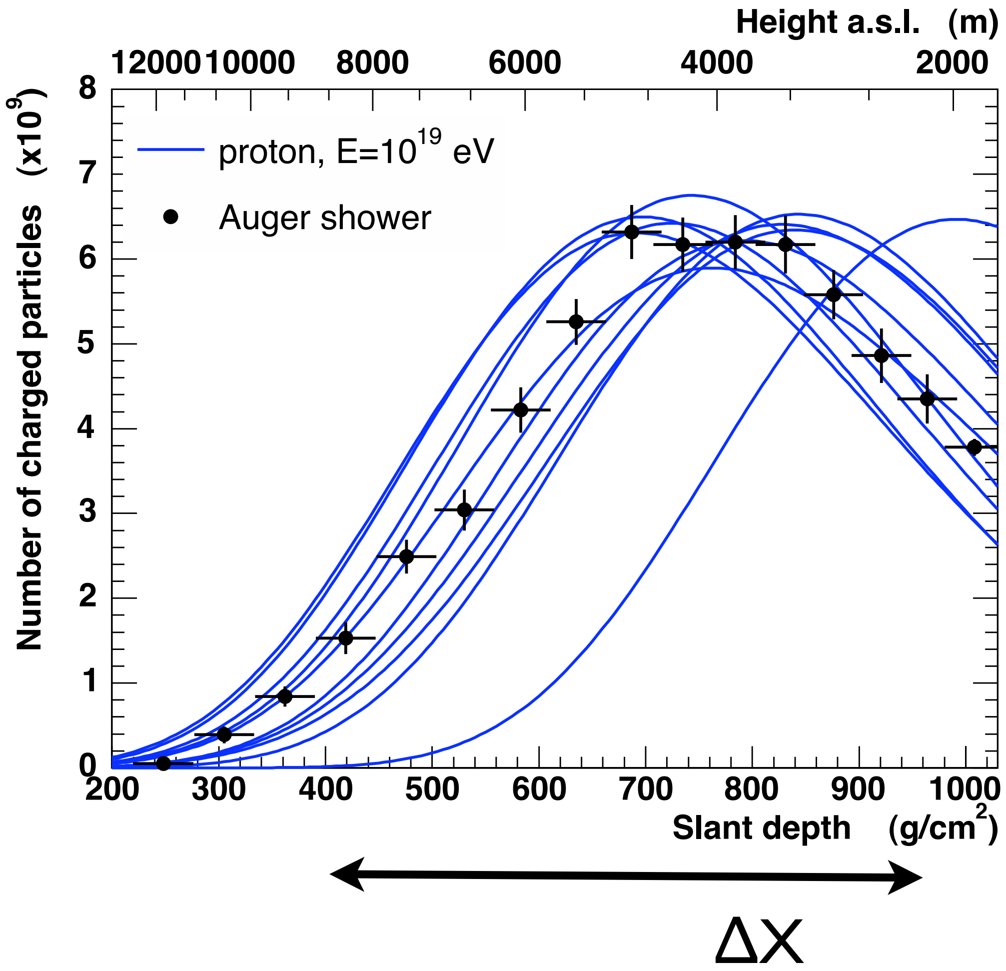




(H.Tanaka et al., S.Tonwar et al.)

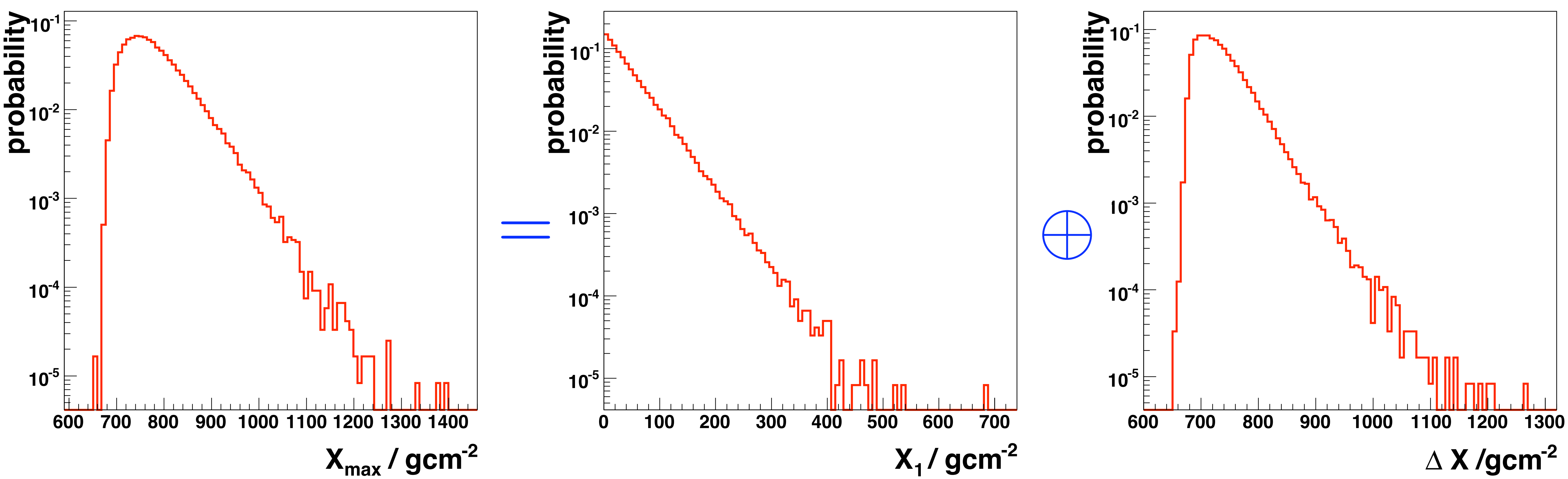
Cross section measurements

HiRes cross section measurement



$$X_{\max} = X_1 + \Delta X$$

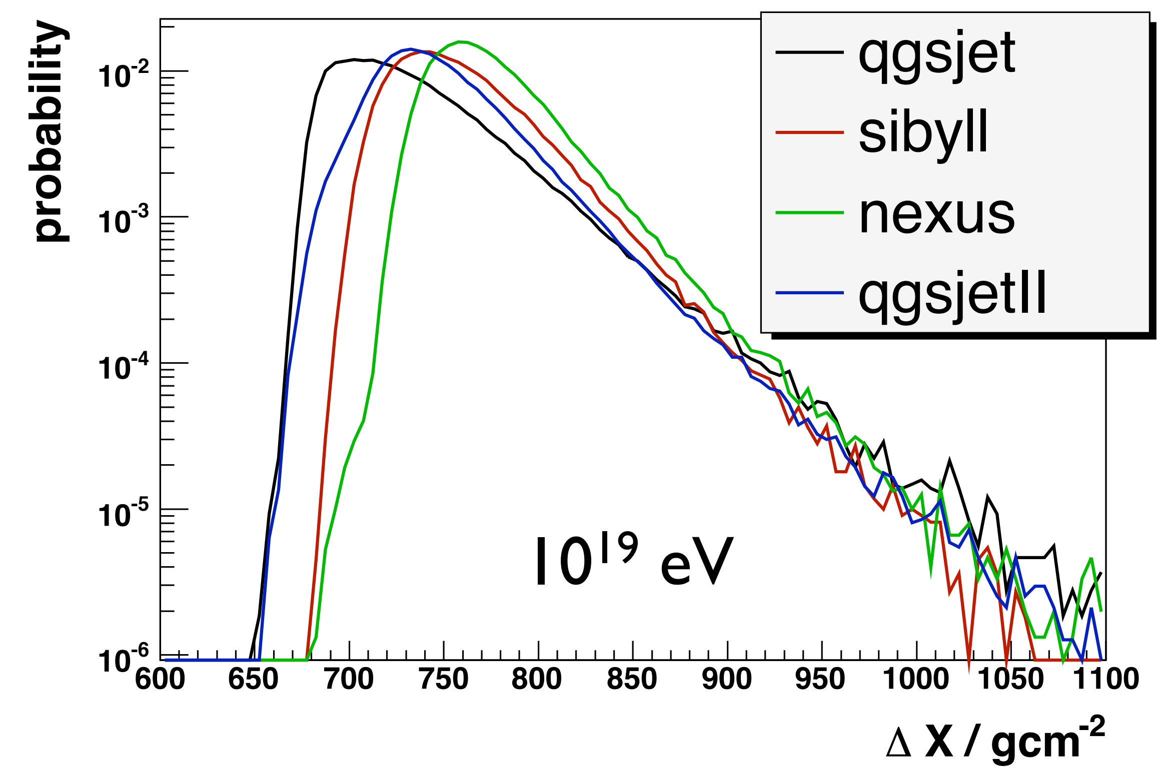
depth of shower max. | first interaction point | shower fluctuations

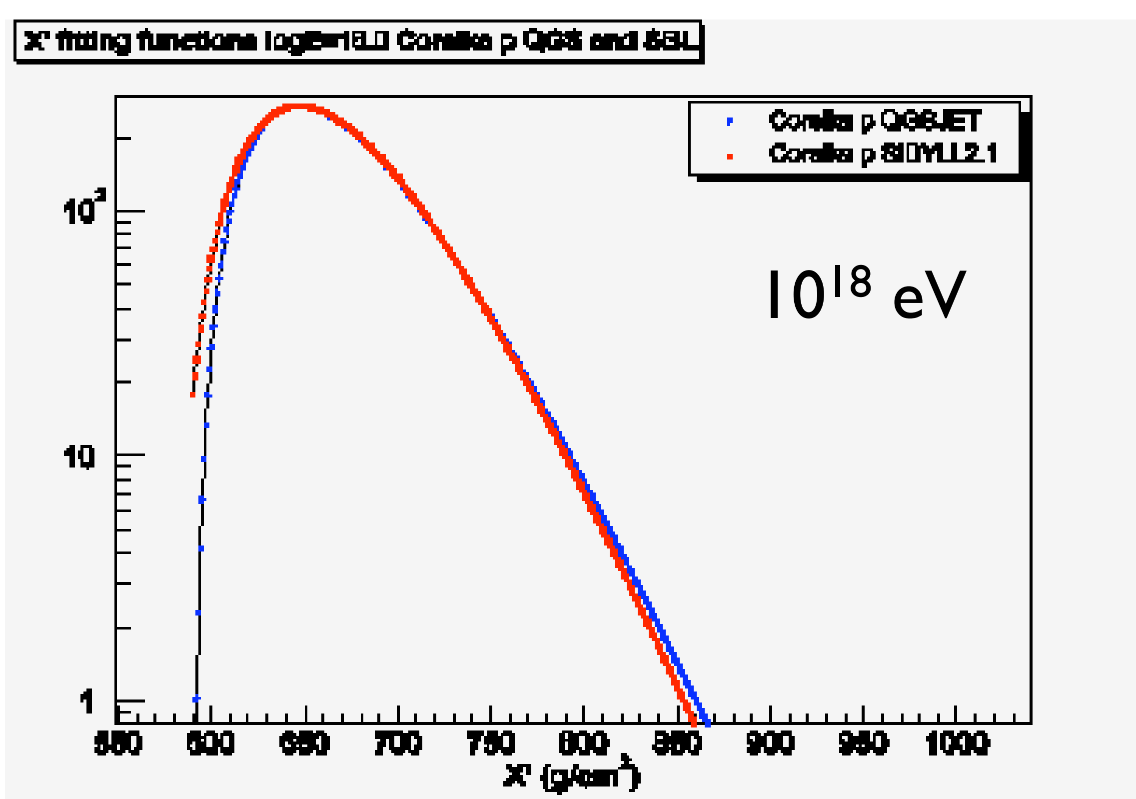


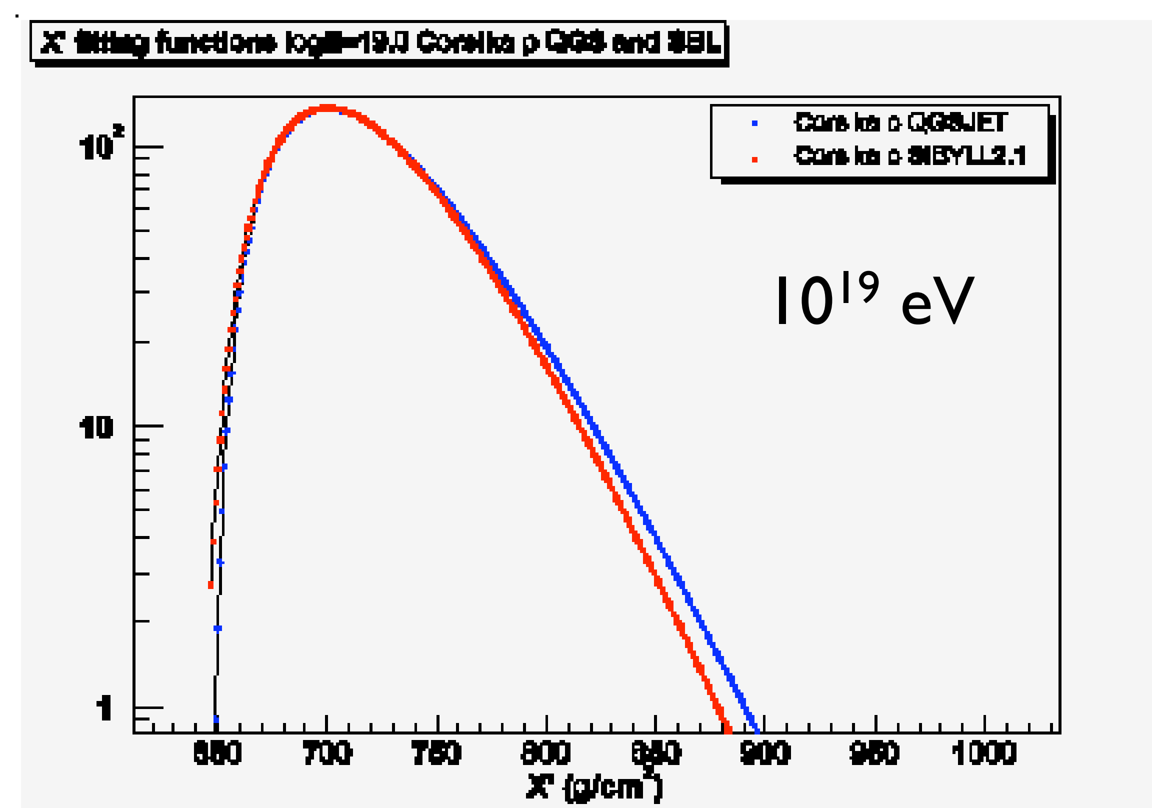
Model dependence of shower fluctuations

Different definitions of X1:

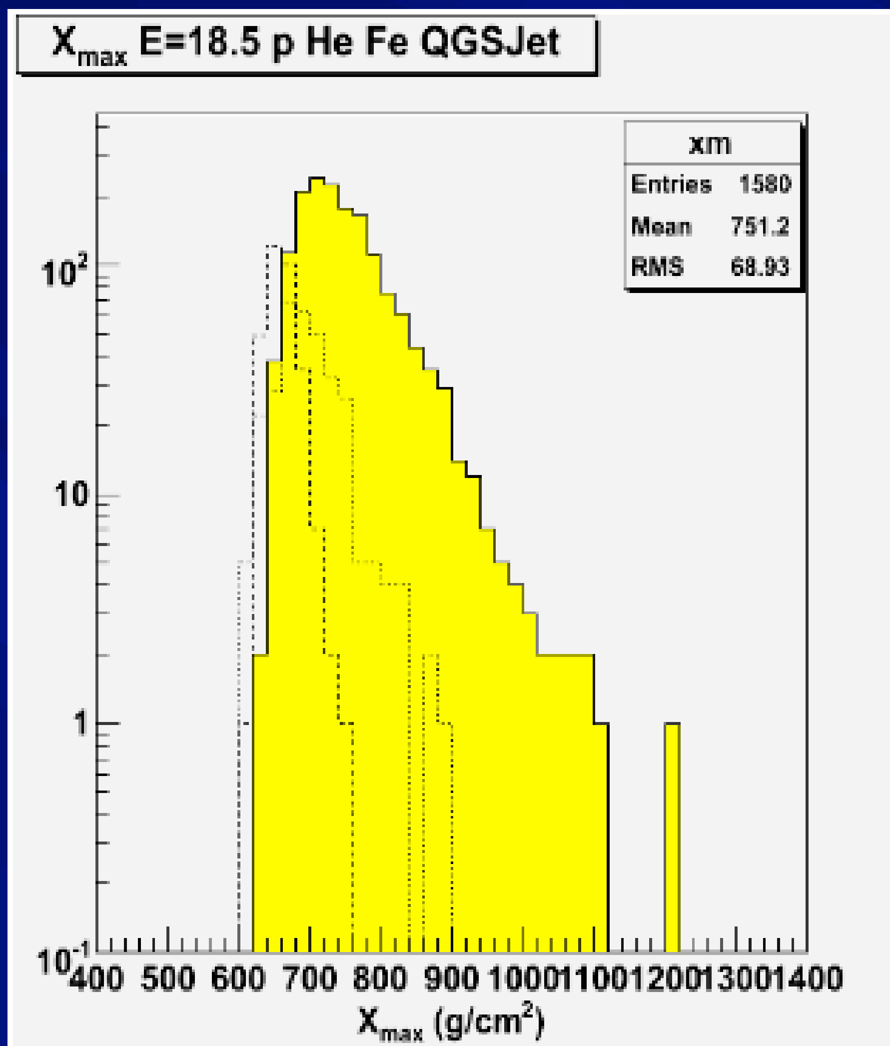
Ulrich et al.: theoretical value
HiRes (Belov et al.): effective starting point of shower

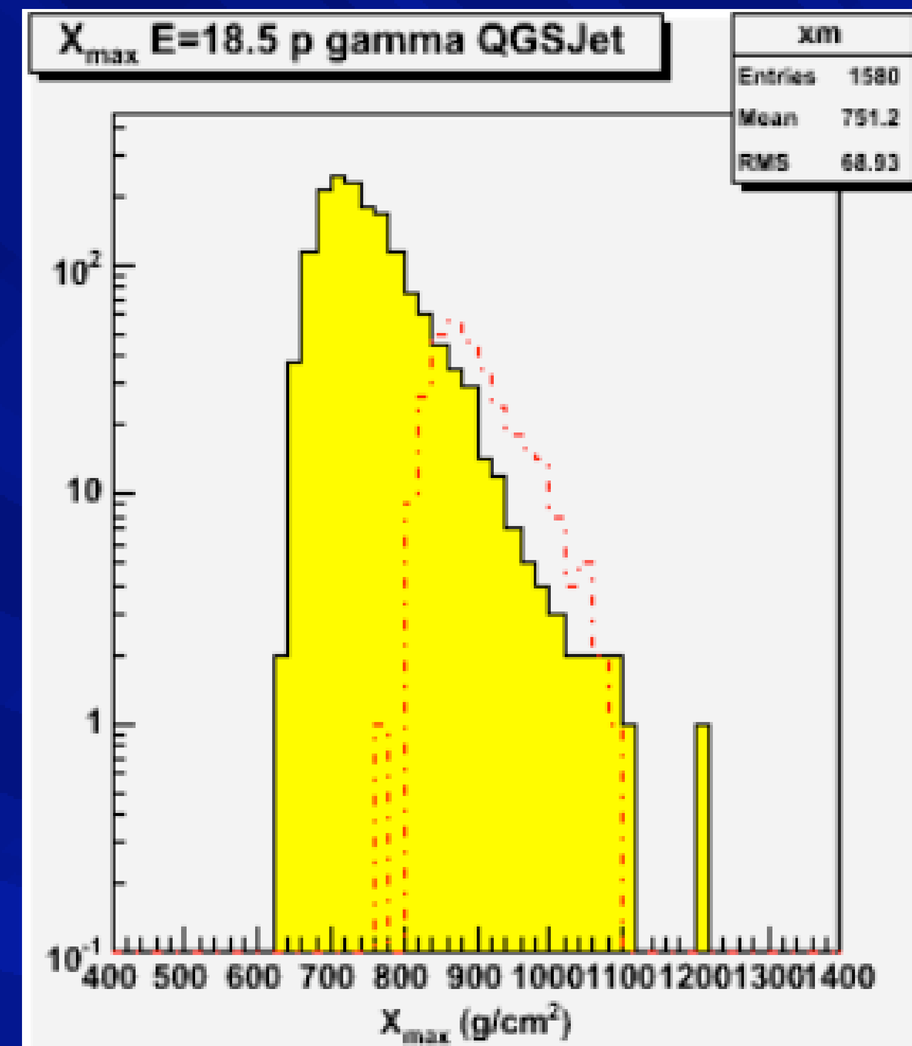


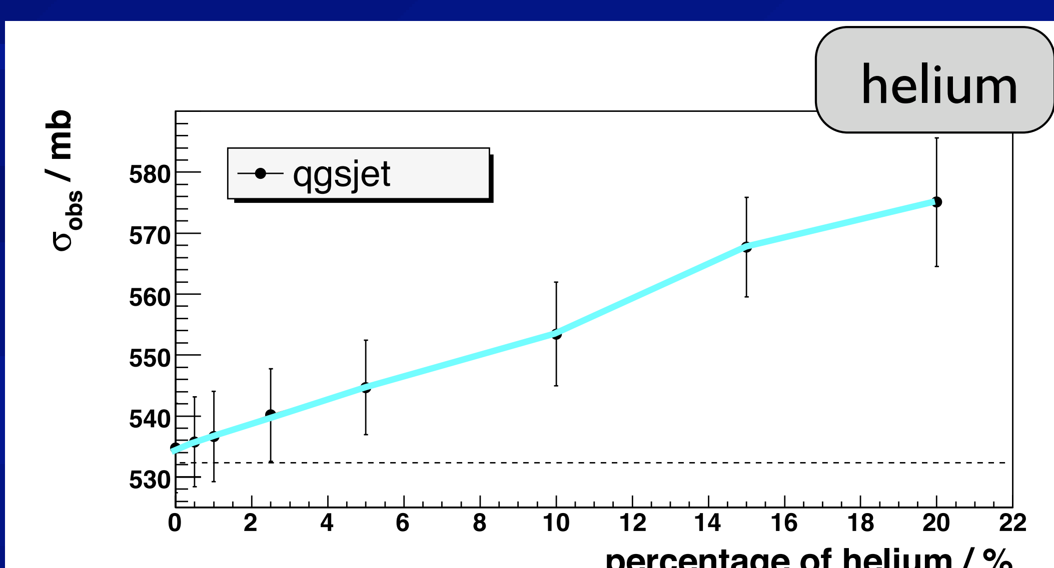




Heavier and lighter component influence.



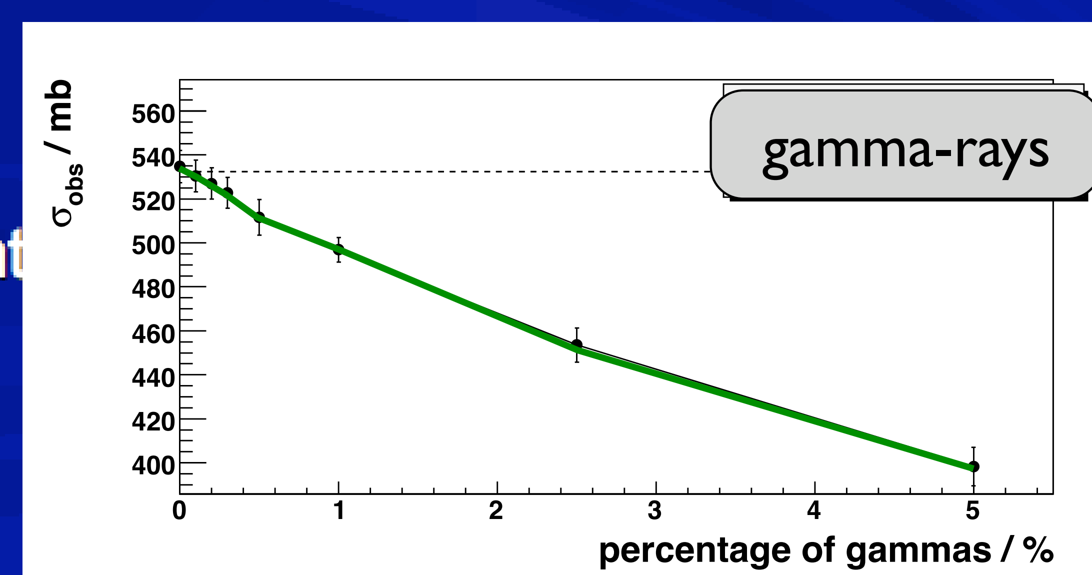




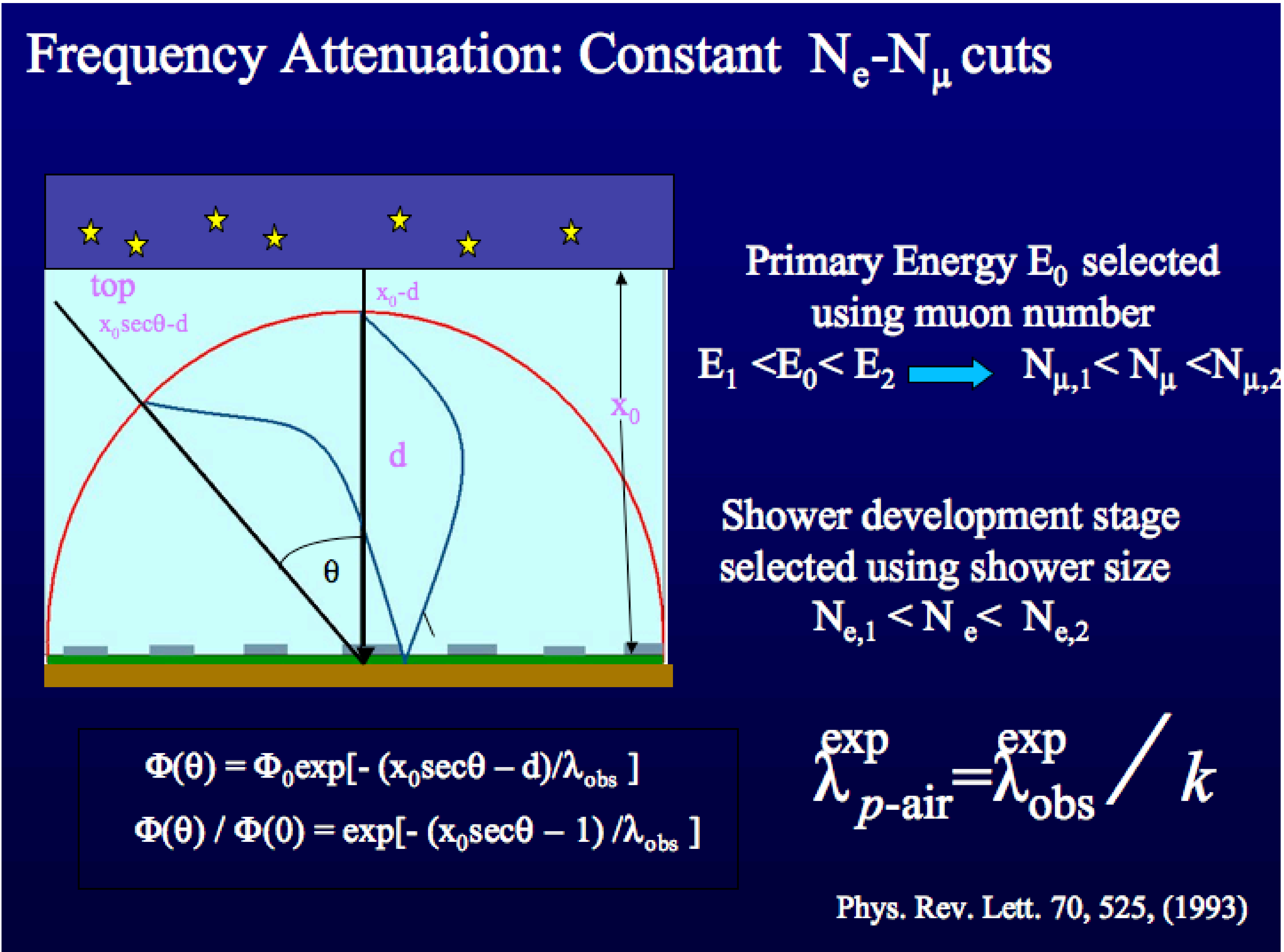
deeper portion of

taken into account

K. Belov ICRC 2007



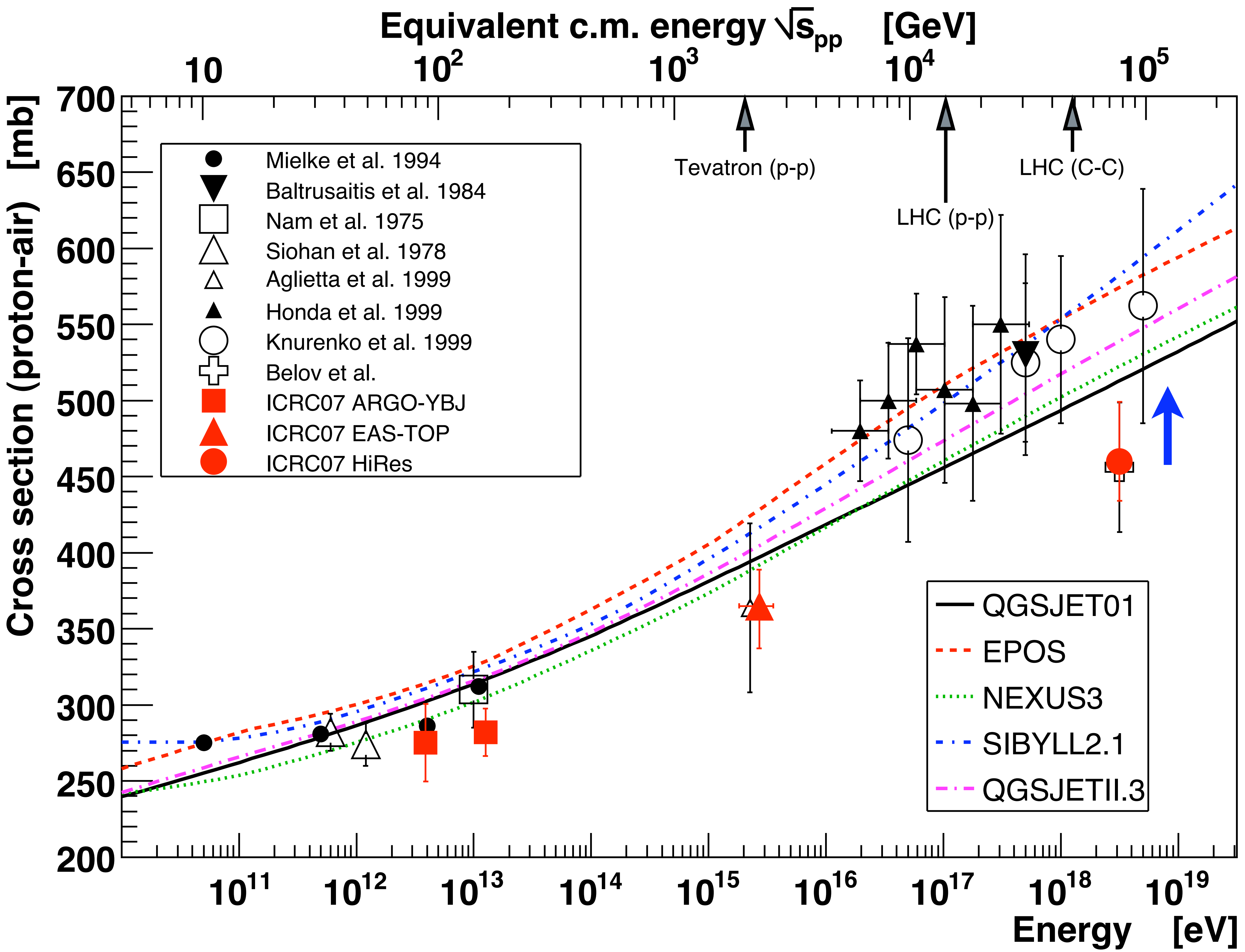
EAS-TOP and ARGO-YBJ measurements



Correction for fluctuations and invisible cross section part

(G.Trinchero et al. I. De Mirti et al.)

Summary of new cross section data

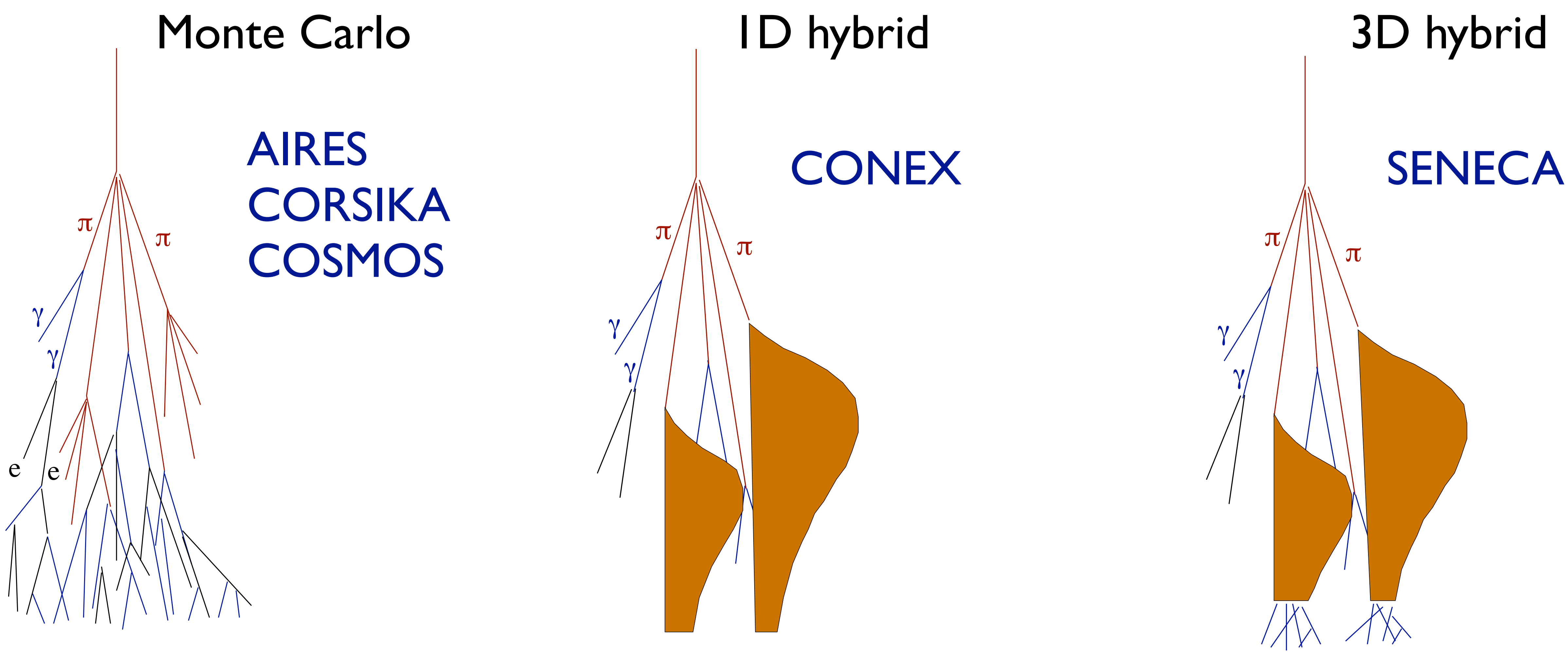


Estimated invisible cross section contribution

(R. Ulrich)

Simulation tools and related questions

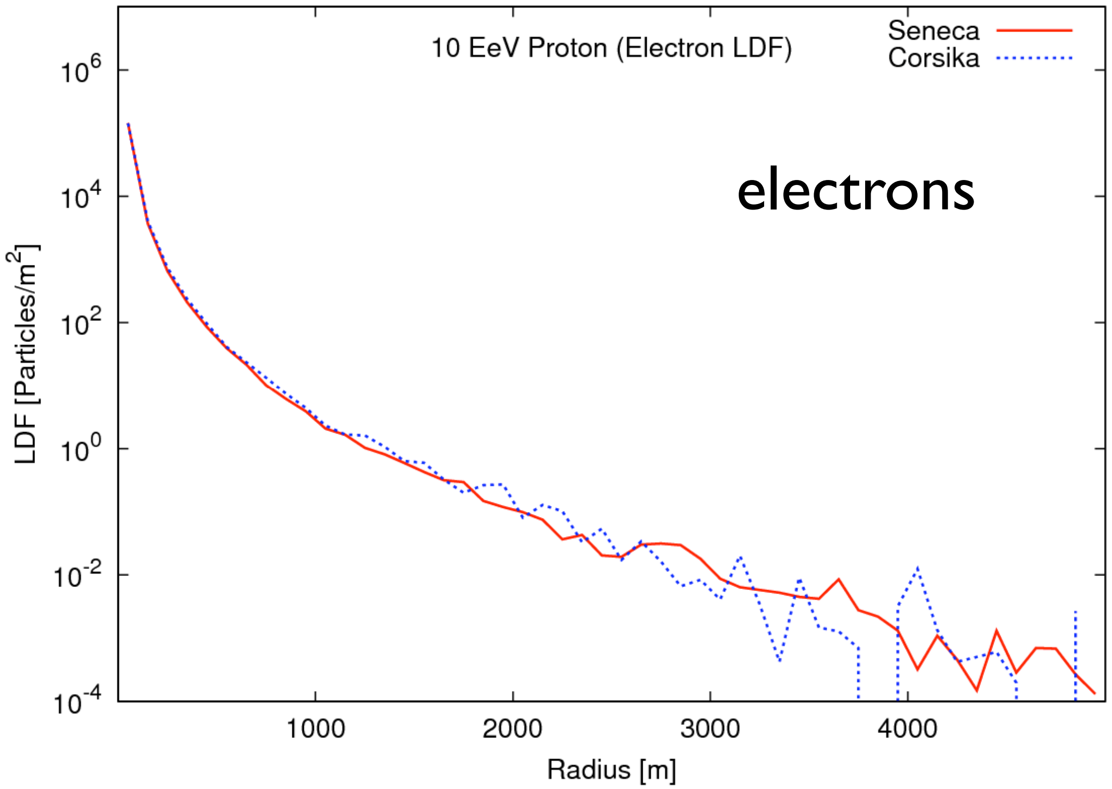
Giant air shower simulation



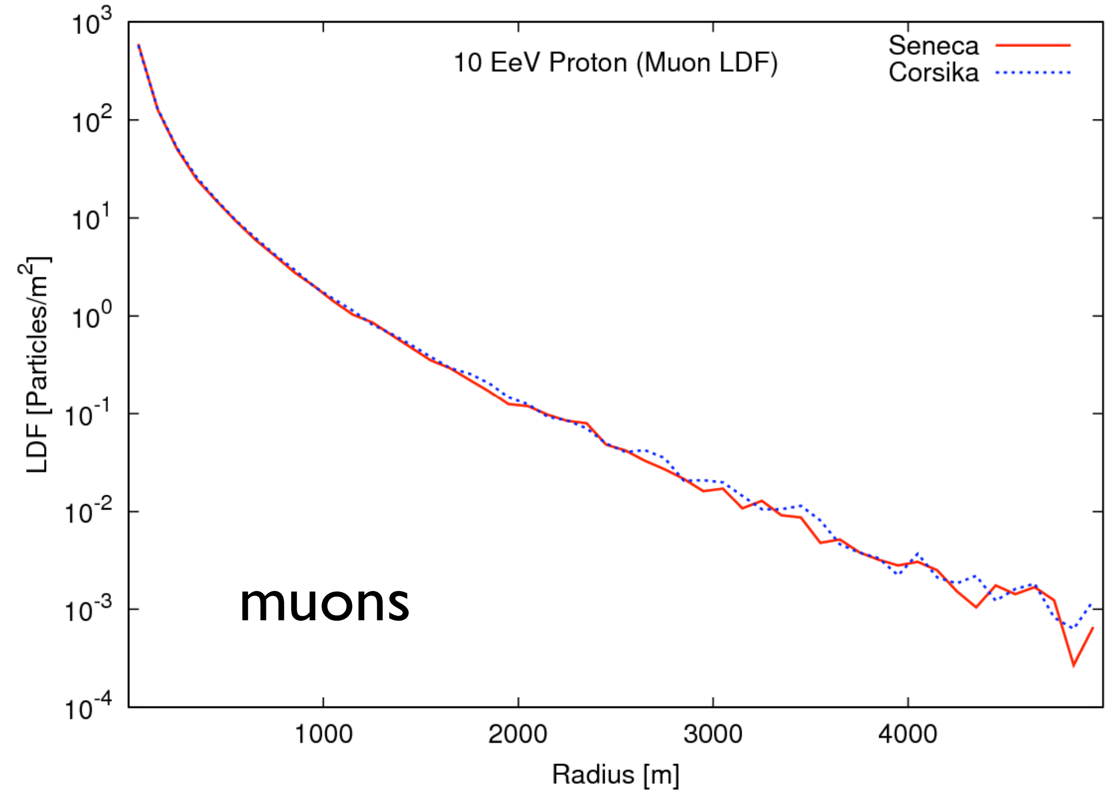
- thin sampling *(Rubtsov et al.)*
- fully simulated showers *(Rubtsov et al.)* (1 yr CPU for $10^{18.5}$ eV)
- parallel computing *(Kasahara et al.)*

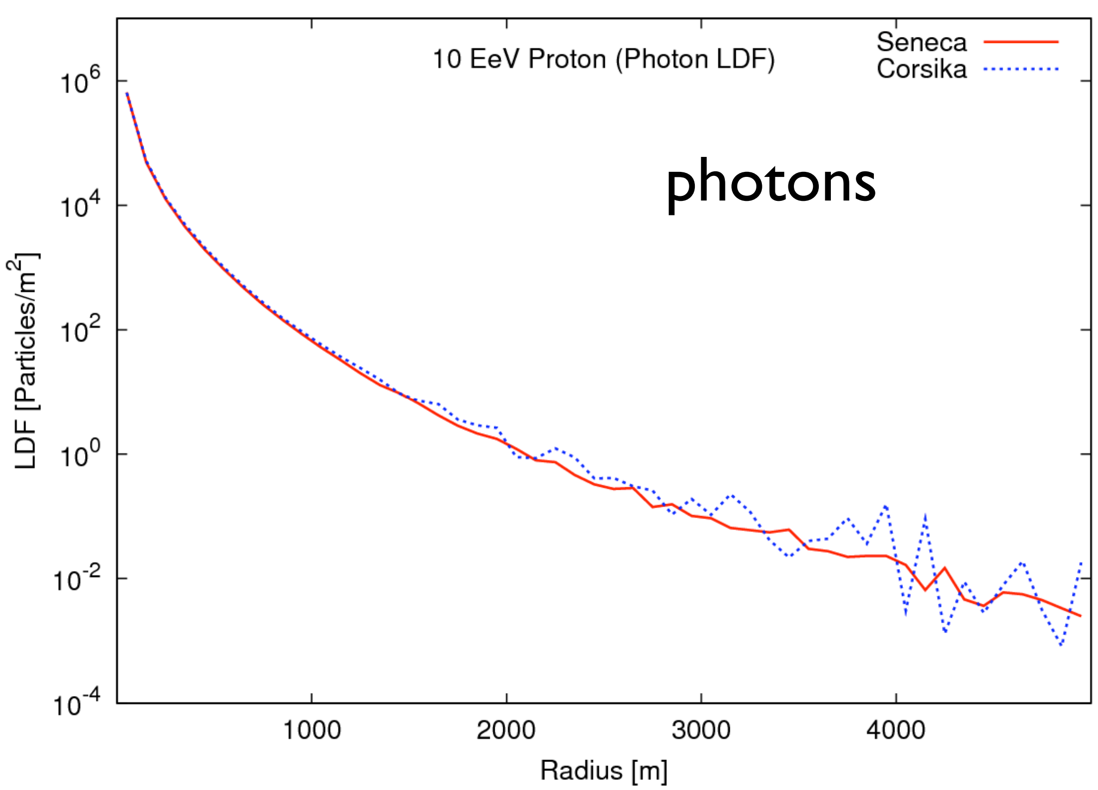
Hybrid programs are mature and checked against CORSIKA

Example: SENECA-CORSIKA comparison



(J. Allen et al.)

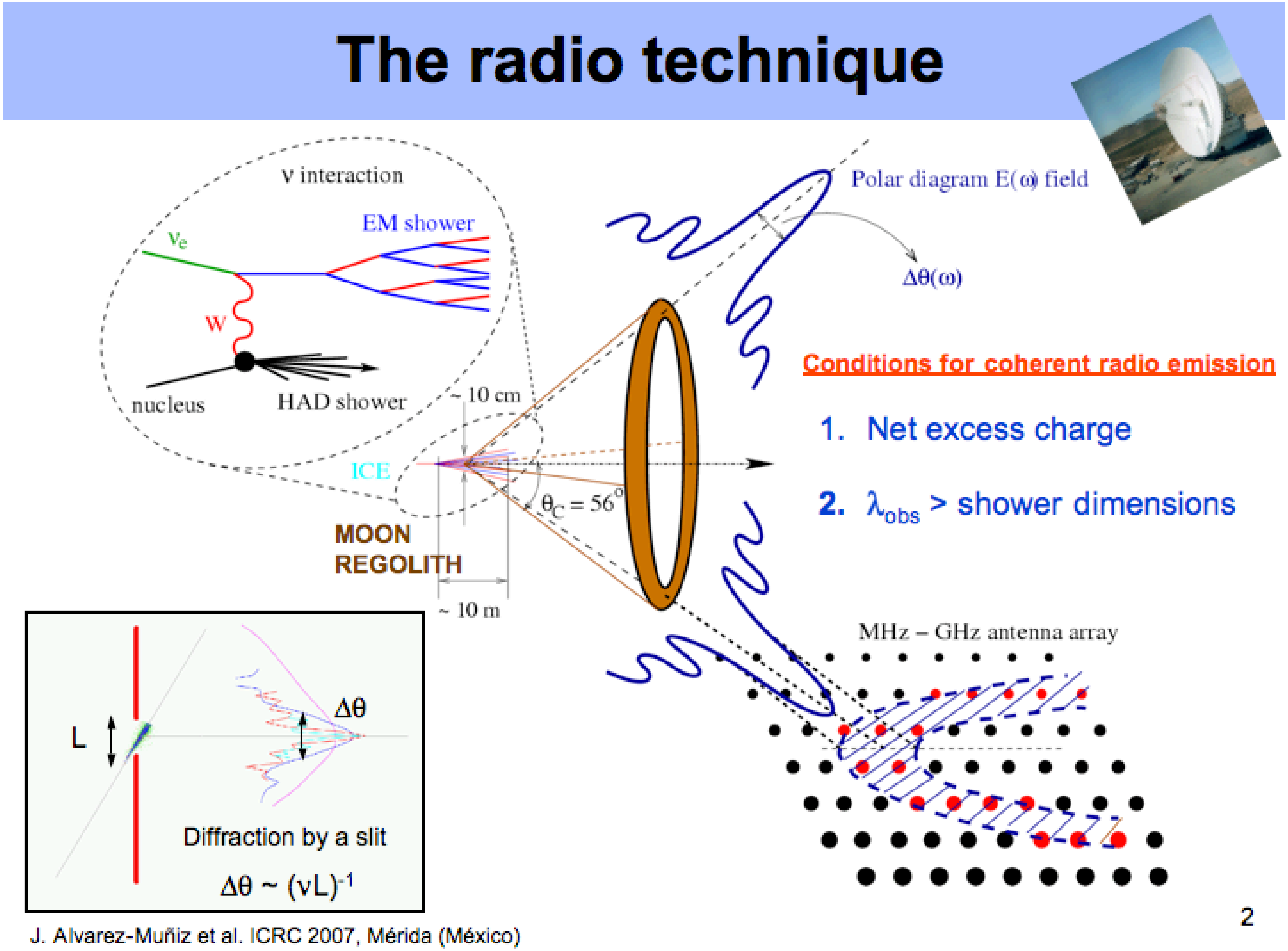




More comparisons of this type are needed (AIRES-CORSIKA, COSMOS-CORSIKA)

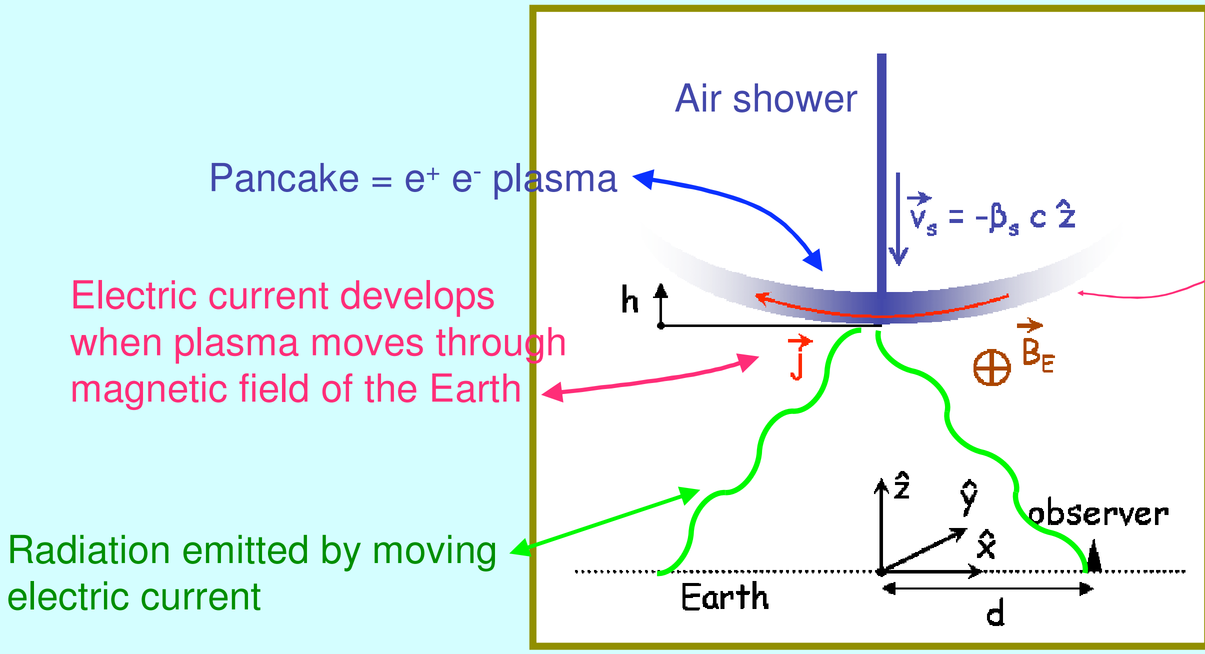
(CONEX-CORSIKA: see Astropart. Phys. 26, 2007)

Calculation of radio emission in dense media



Calculation of radio emission from air showers

(O. Scholten & K.Werner)

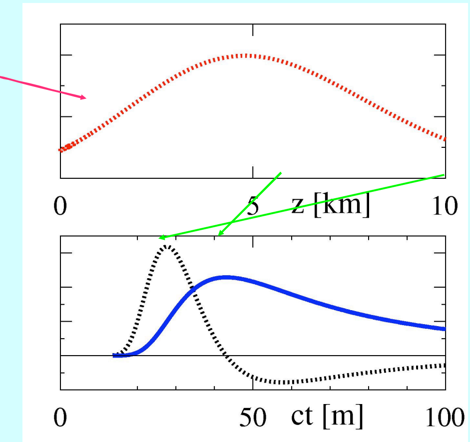


$$j_x(z) = J_0 \rho_e(z)$$

$$z \approx -d^2/2ct$$

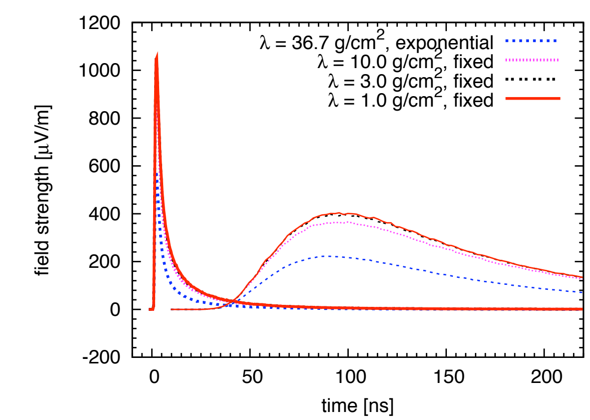
$$A^x(t,d) = \frac{j_x(z)}{\mathcal{D}}\Big|_{\text{ret}}$$

$$E^x(t,d) = \frac{d}{dt}A^x(t,d)$$

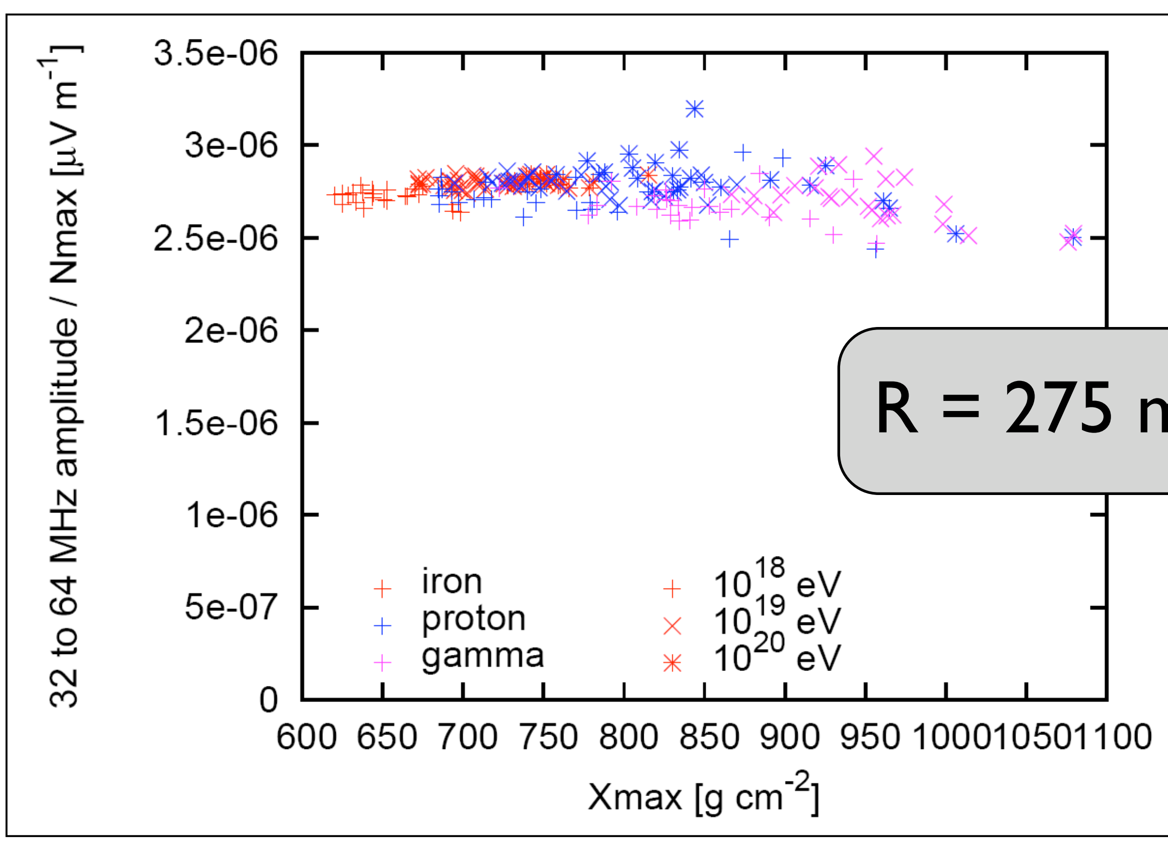


Pulse sensitive to shower development prior to maximum

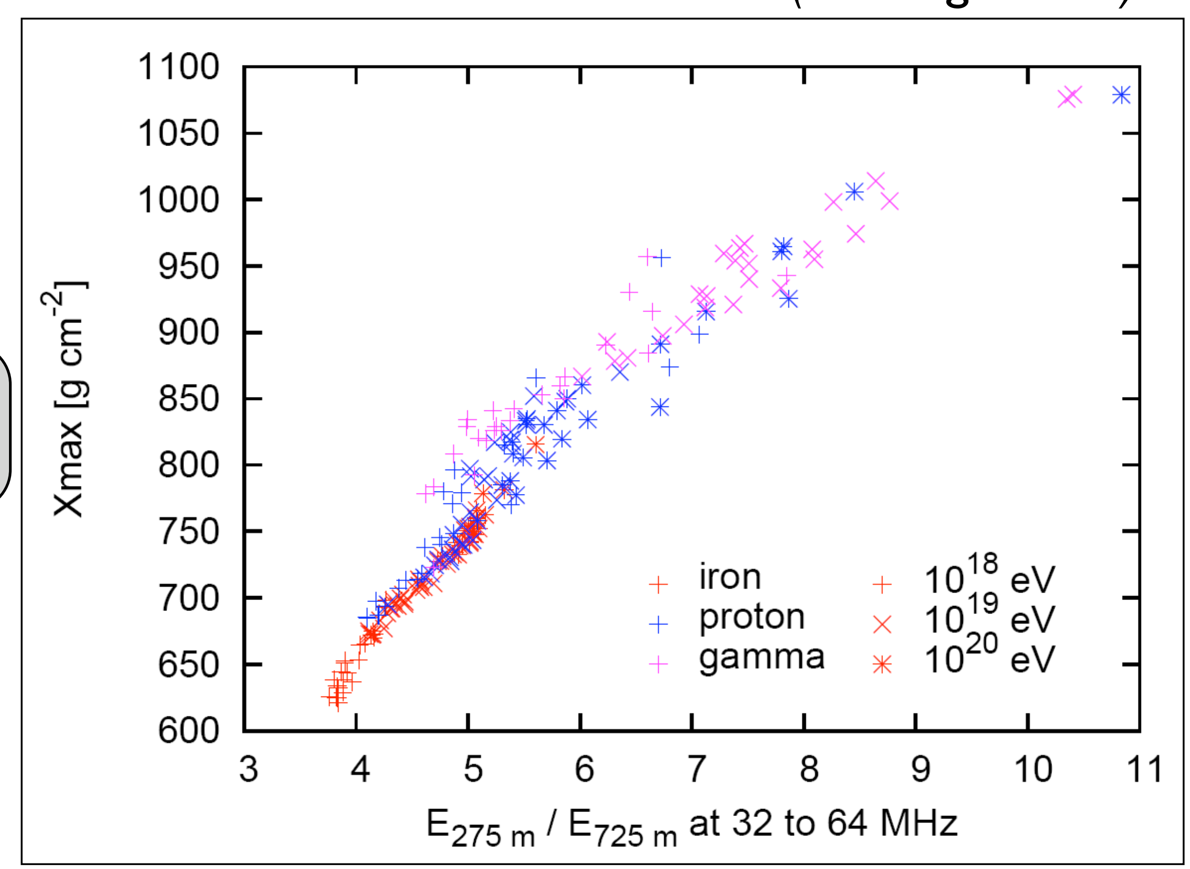
Different from calculation in dense media



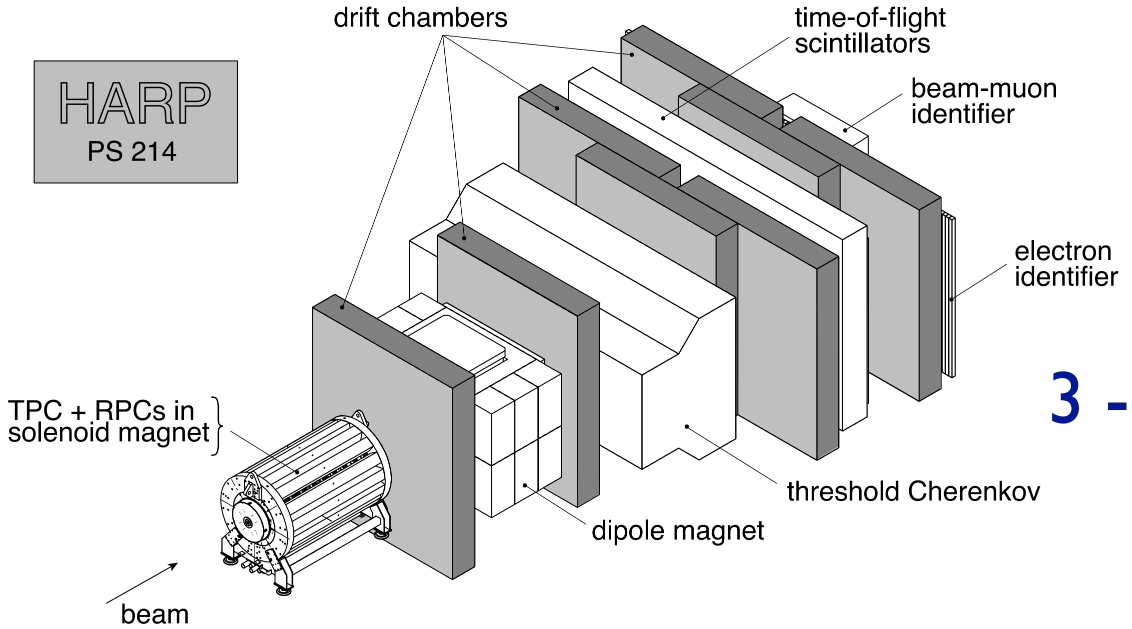
(T. Huege et al.)



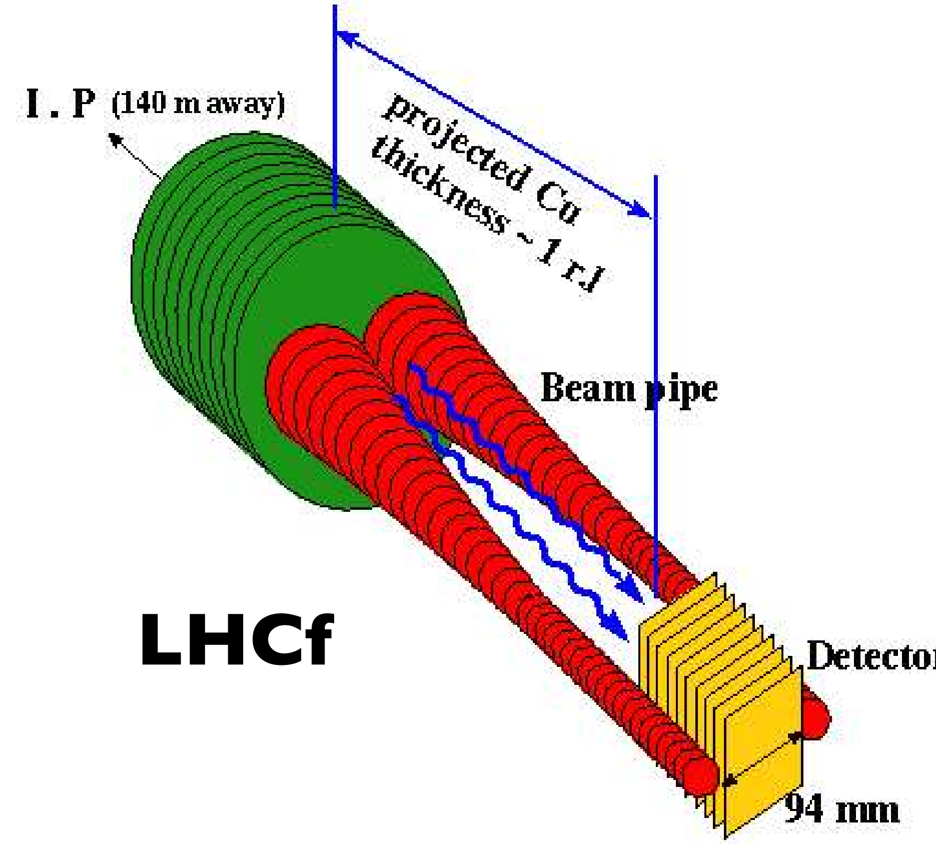
R = 275 m



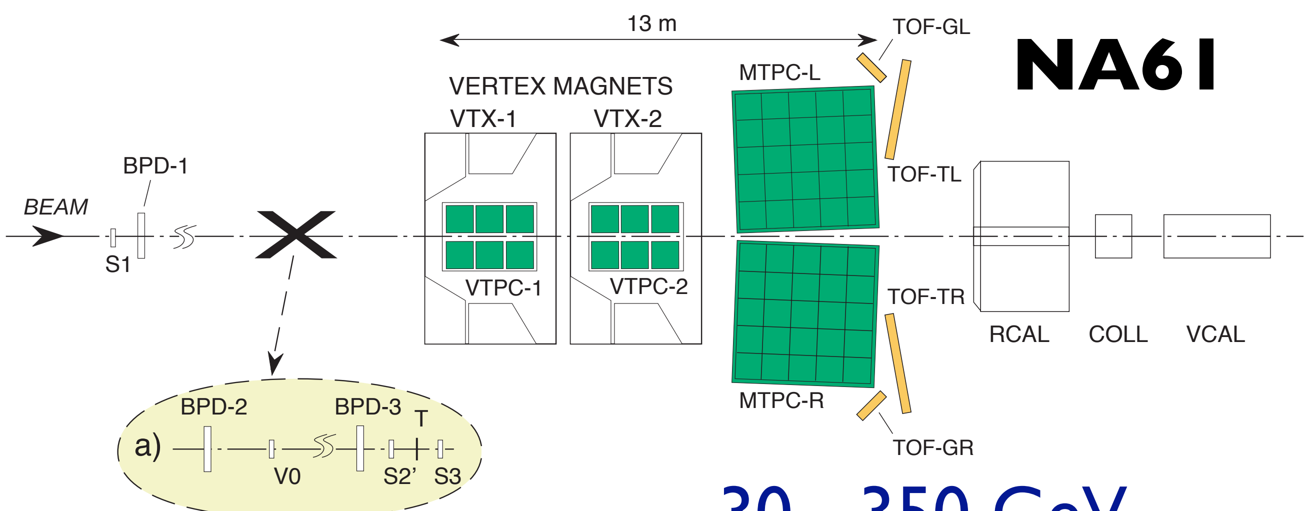
Accelerator data



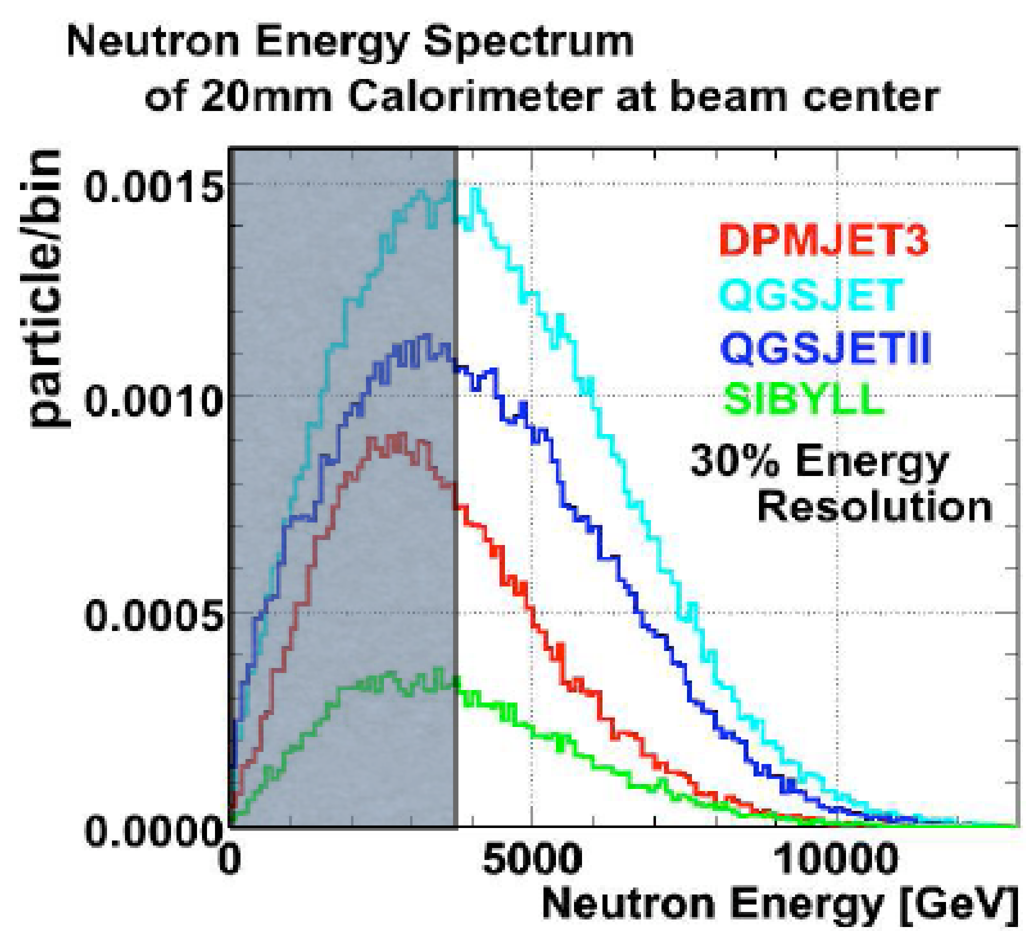
3 - 12 GeV

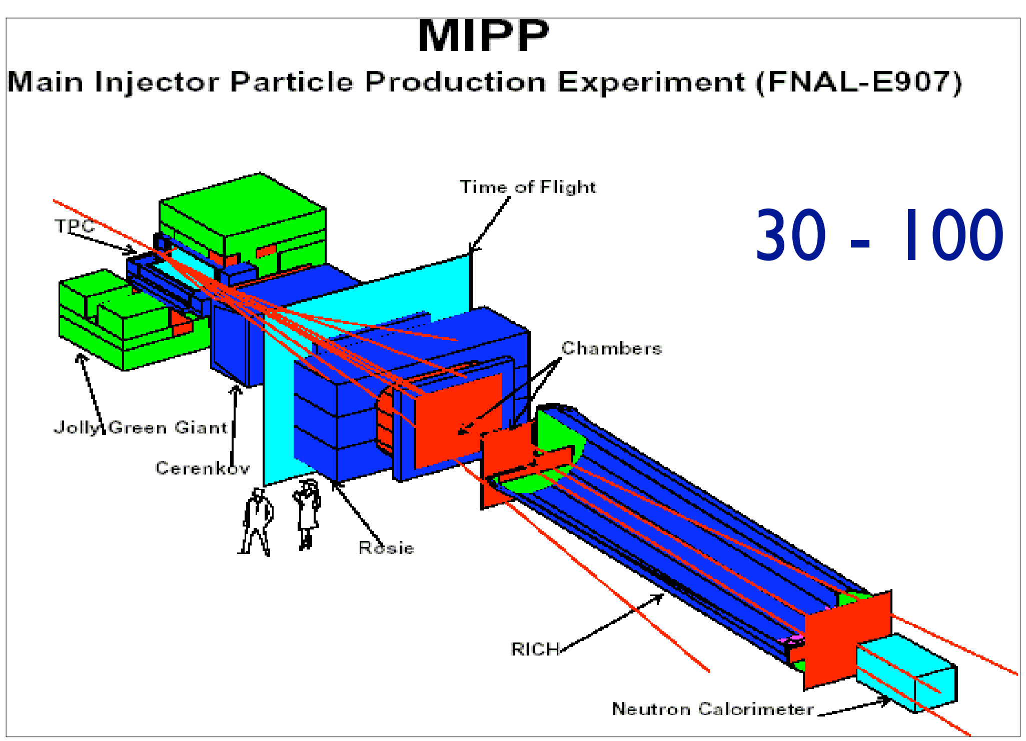


14,000 GeV (cms)



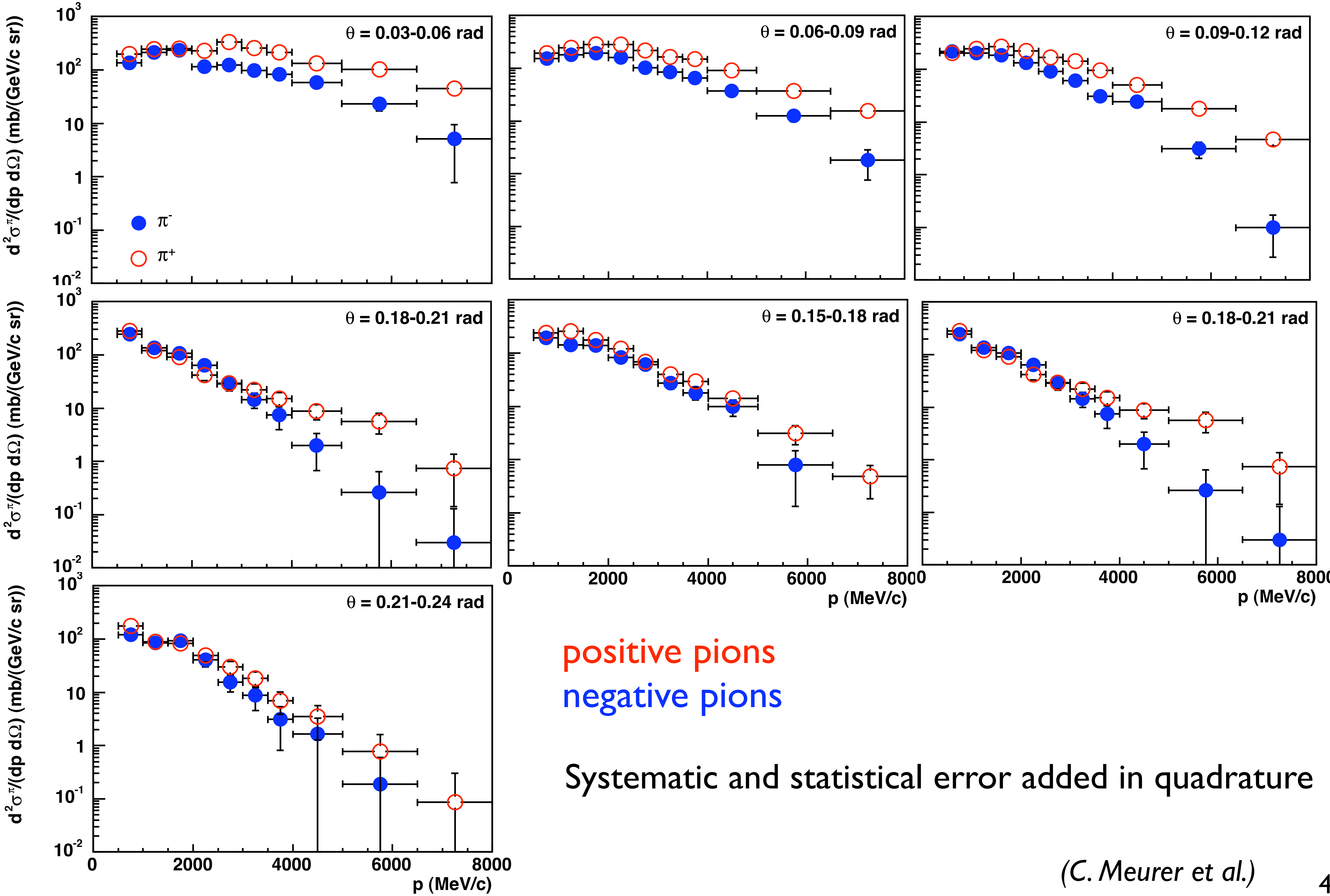
30 - 350 GeV





30 - 100 GeV

HARP: $p + C \to \pi^{\pm} + X, \quad p_{\text{lab}} = 12\text{GeV}/c$



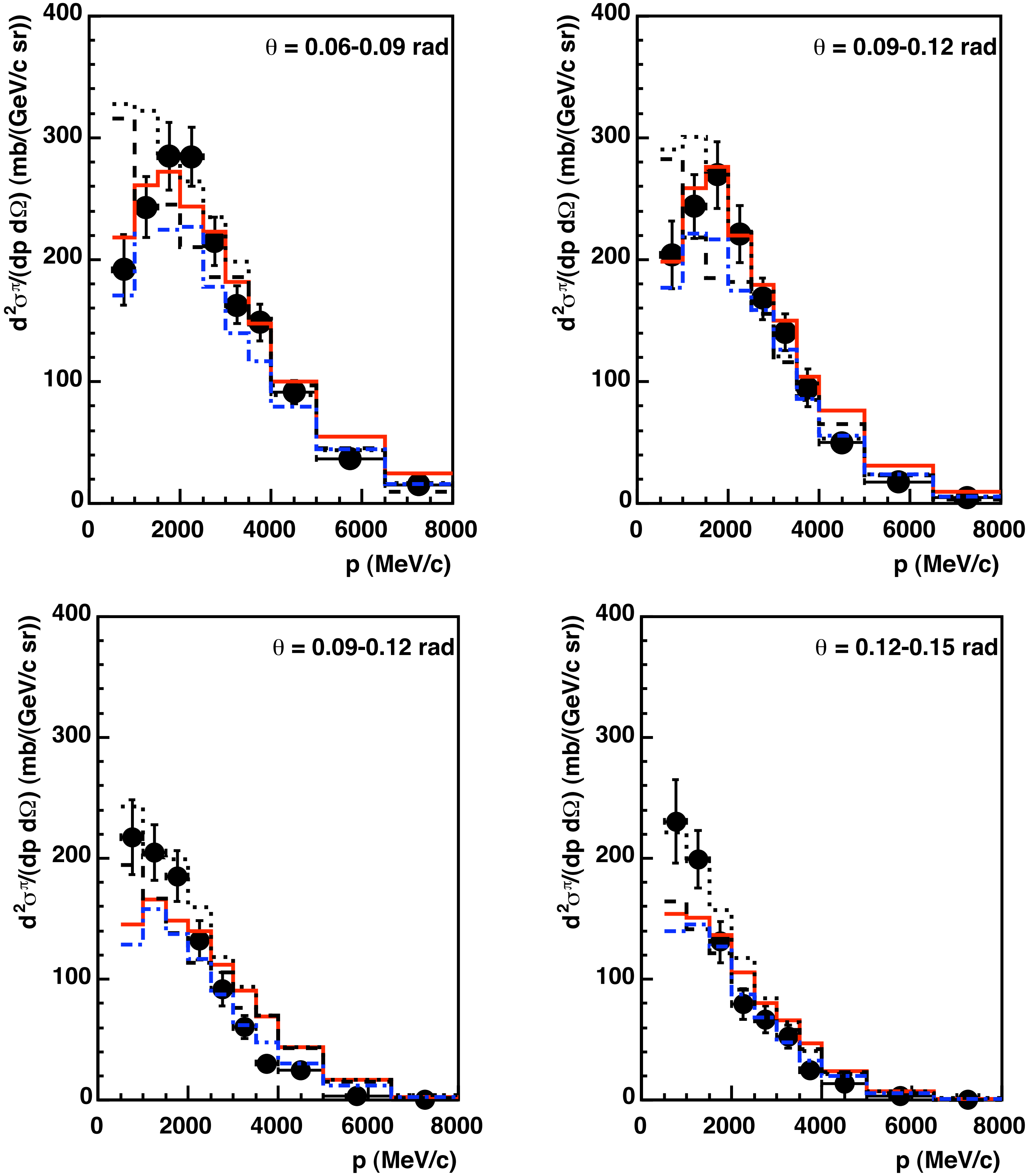
positive pions

negative pions

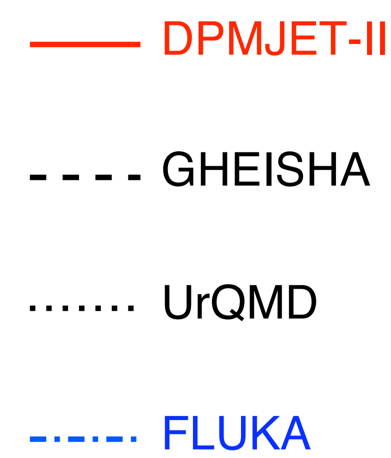
Systematic and statistical error added in quadrature

(C. Meurer et al.)

HARP: comparison with models



Positive pions



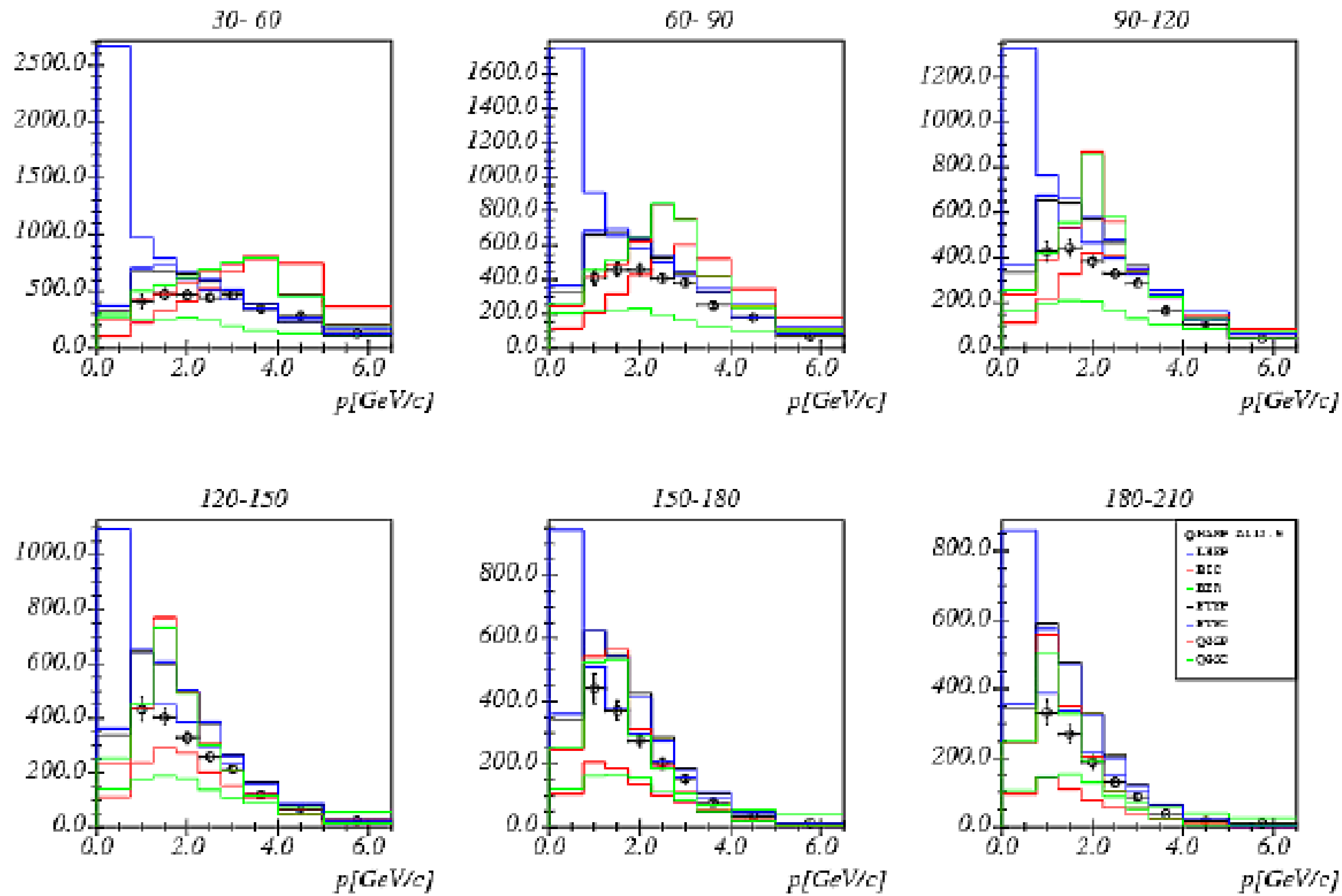
Negative pions

$$p + C \rightarrow \pi^{\pm} + X, \qquad p_{\text{lab}} = 12\text{GeV}/c$$

None of the models describes data consistently

(C. Meurer et al.)

Al 12 GeV/c : a first (raw) comparison with some geant4 hadronic generators:



- LHEP
- Binary
- Bertini
- FTFP
- FTFC
- QGSP
- QGSC

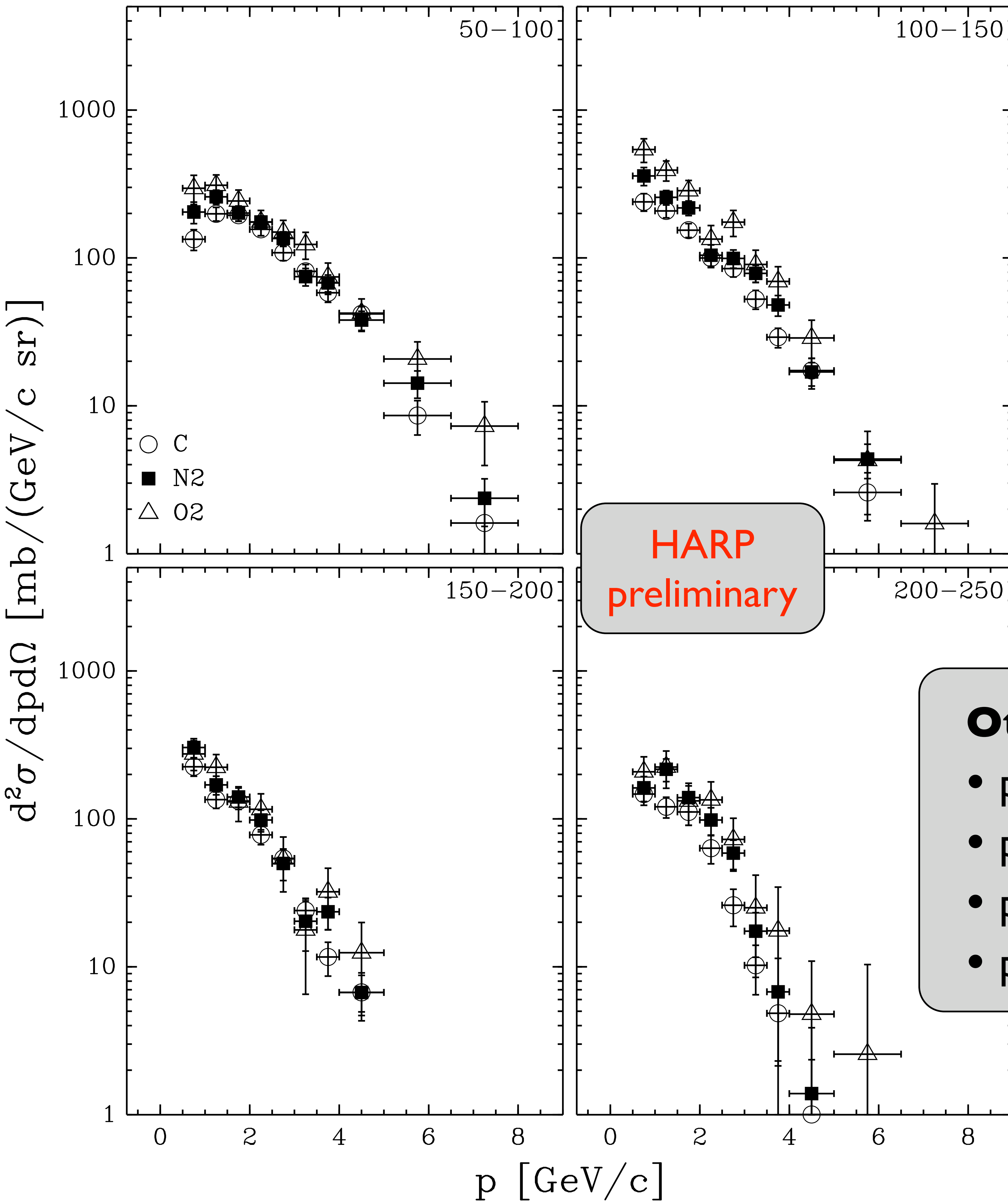
black points are HARP data

(Catanesi et al., NOW 2006)

Cryogenic target data

$$p + N/O \rightarrow \pi^- + X$$

$$p_{\mathrm{lab}} = 12\,\mathrm{GeV/c}$$



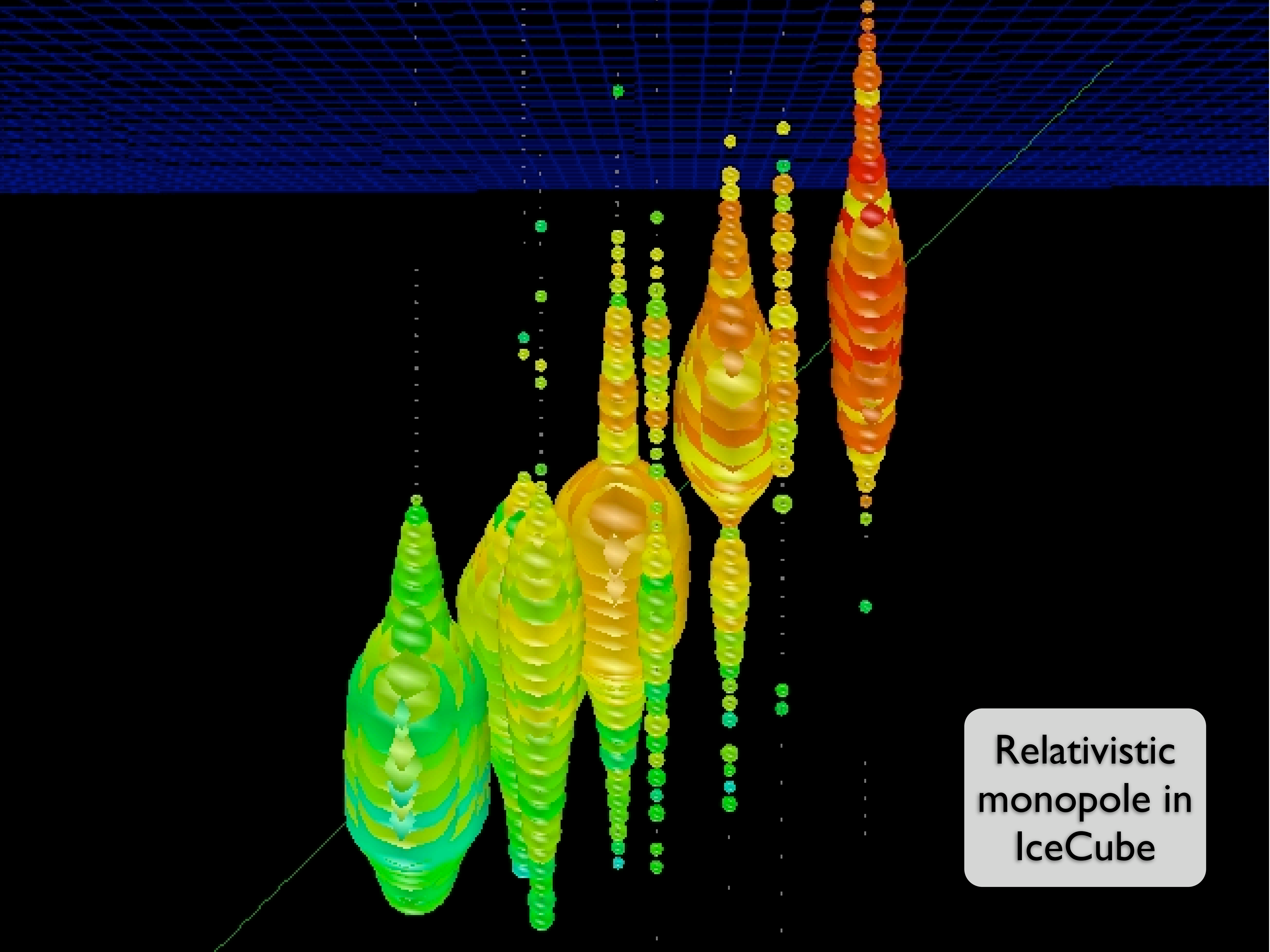
Other HARP data:

- p-Be (8.9 GeV, MiniBoone)
- p-C (3, 5, 8,12 GeV, large angles)
- p-Al (12.9 GeV)
- p-Ta (3, 5, 8, 12 GeV)

(C. Meurer et al.)

Searches for physics beyond the Standard Model

Monopoles, exotic particles
Dark Matter
Gravitational waves


Relativistic
monopole in
IceCube

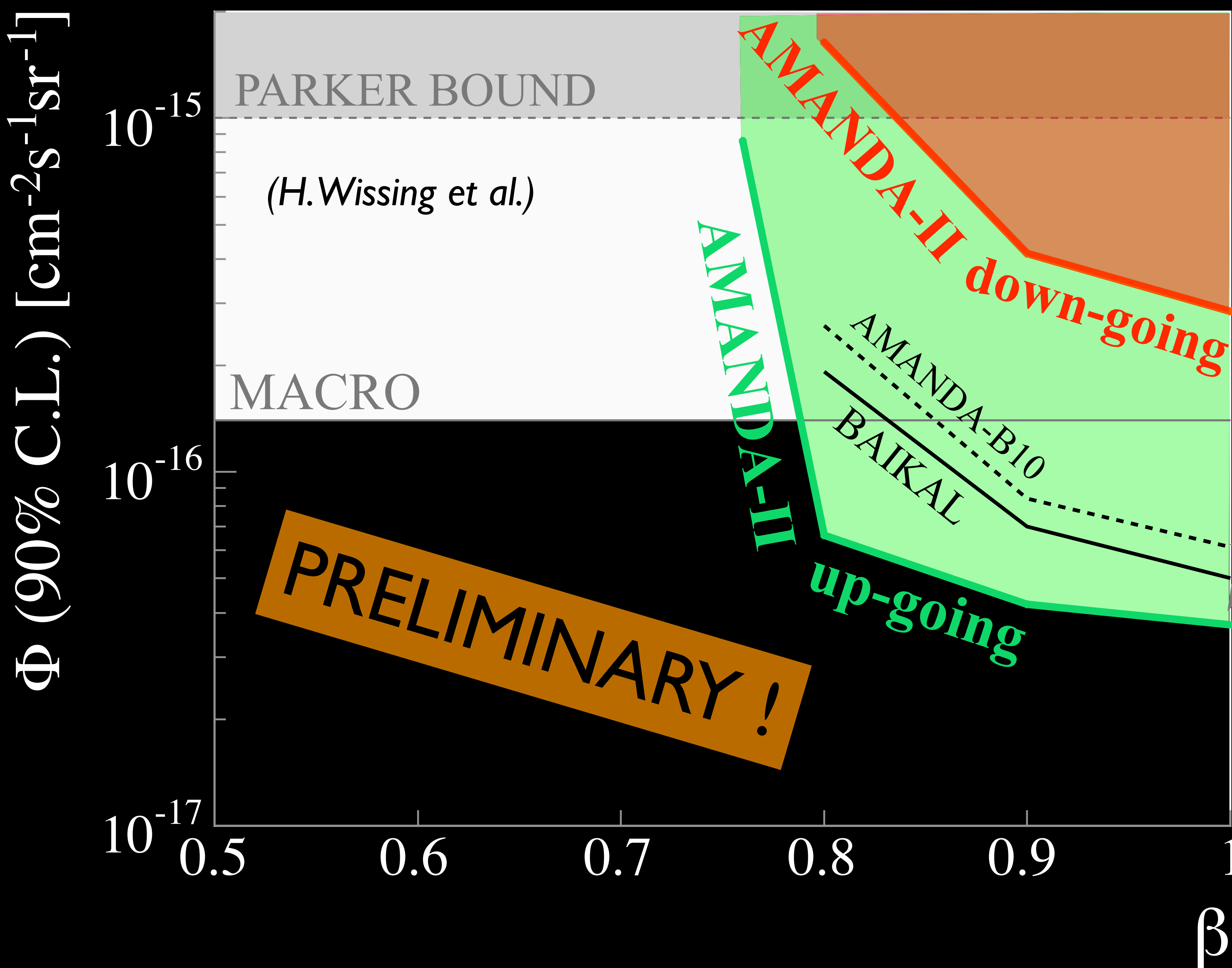
Relativistic Monopole Flux Limits

this work: AMANDA-II (1 year operation, blind analysis)

154 days livetime

up-going: m > 10^{11} GeV

down-going: m > 10^{8} GeV



MACRO
≥ 6 years operation

AMANDA-B10
179 days livetime

BAIKAL
994 days operation
Proc. 29th ICRC (2005)

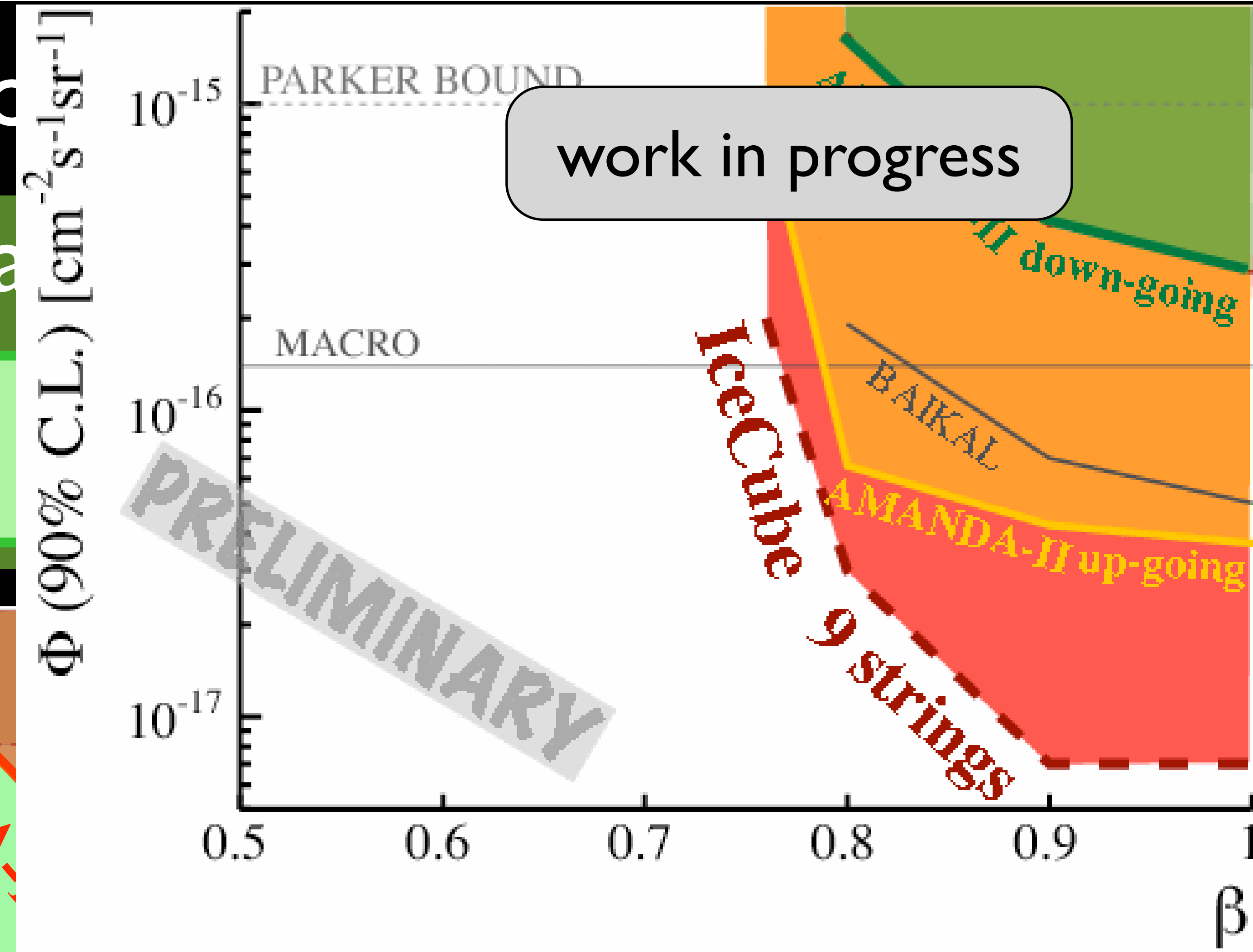
Subrelativistic monopoles:
nucleon decay catalysis,
Q-balls and nuclearites planned

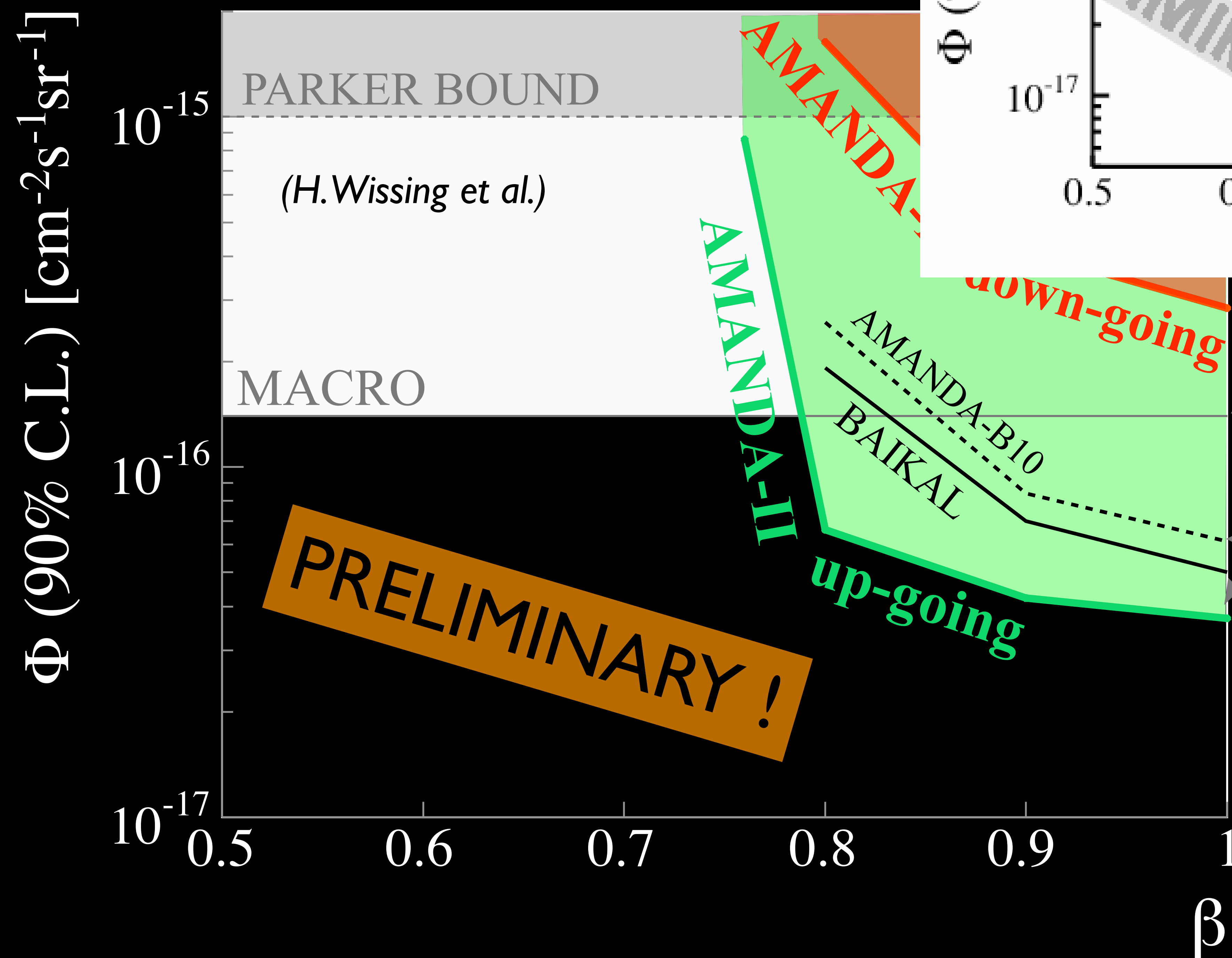
Mono…

I yea…

livetime

up-going: m >





MACRO
≥ 6 years operation

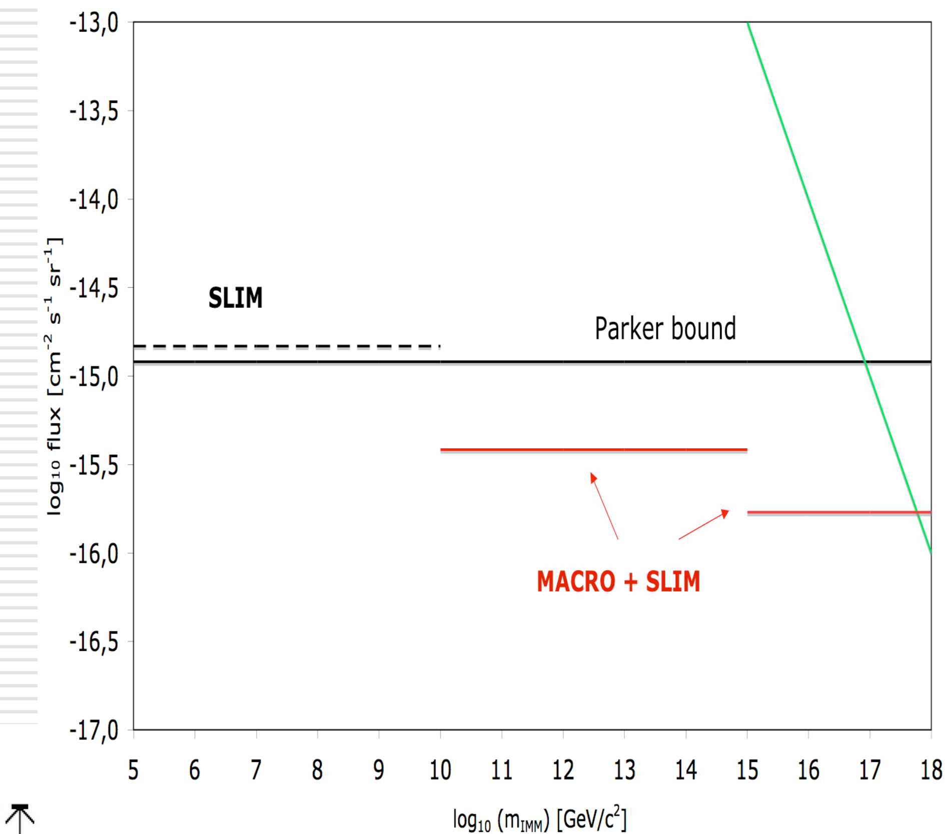
AMANDA-B10
179 days livetime

BAIKAL
994 days operation
Proc. 29th ICRC (2005)

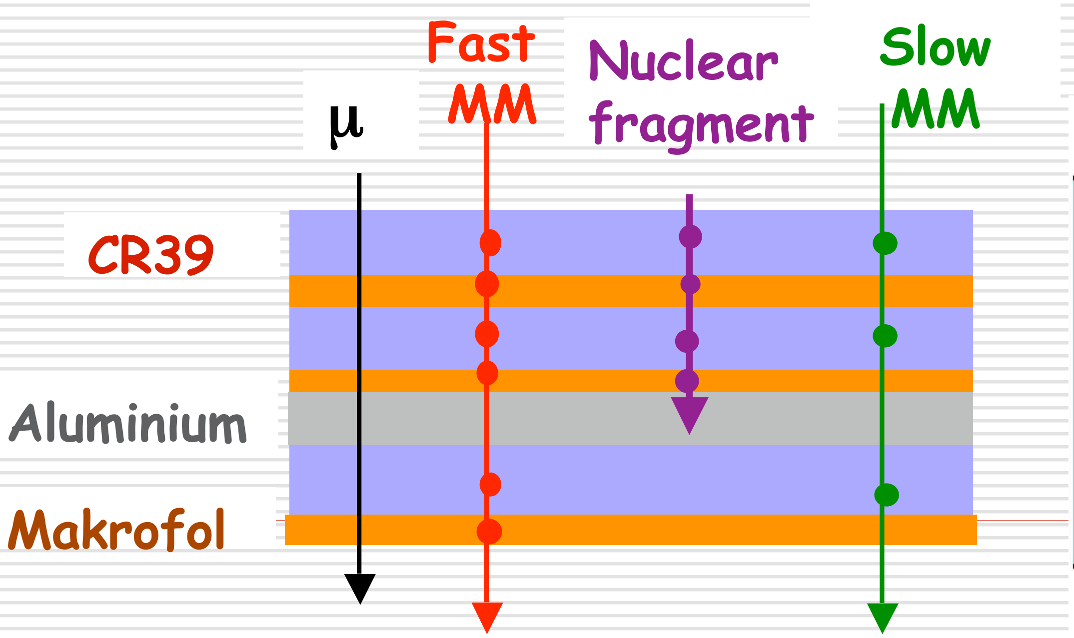
Search for Light Magnetic Monopoles

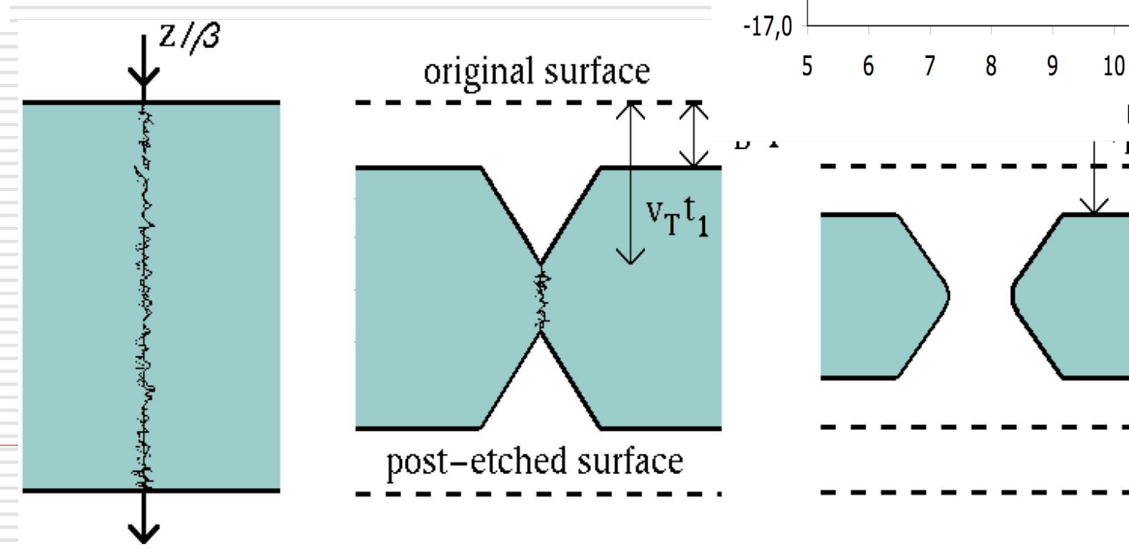
beta > 0.01

- Intermediate mass Magnetic Monopoles
- Strange Quark Matter
- Q-balls



Nuclear Track Detectors



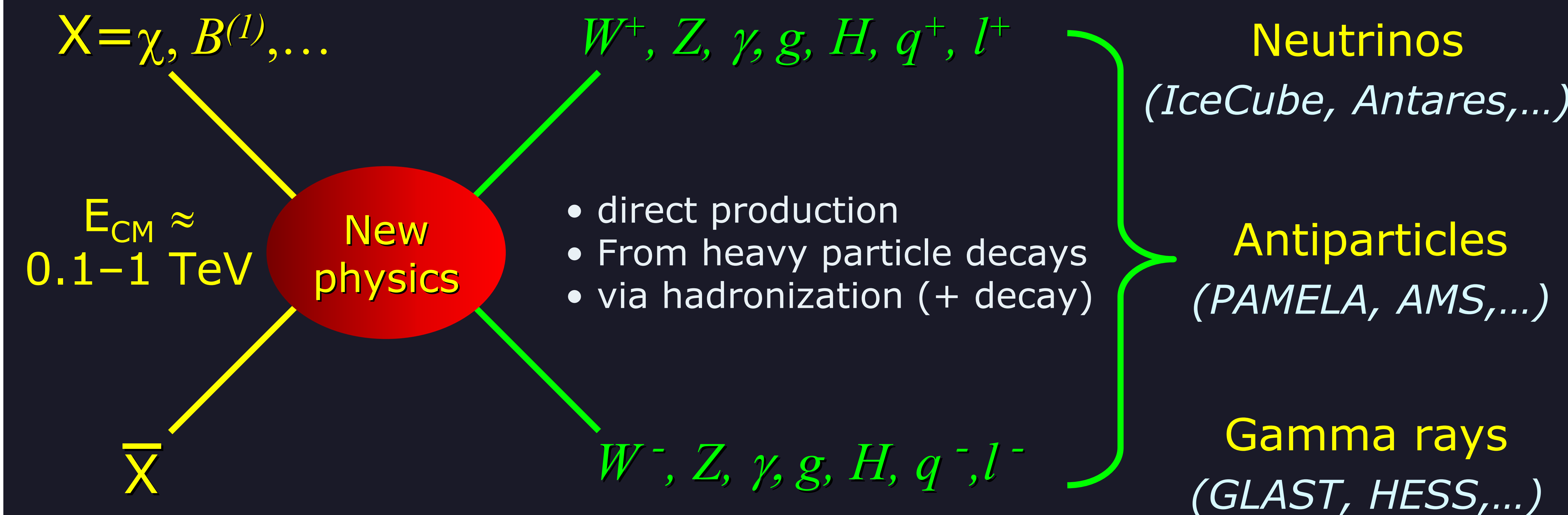


Exposure of 4 years

(S. Checchini et al.)

Dark Matter

Principle of indirect constraints on DM

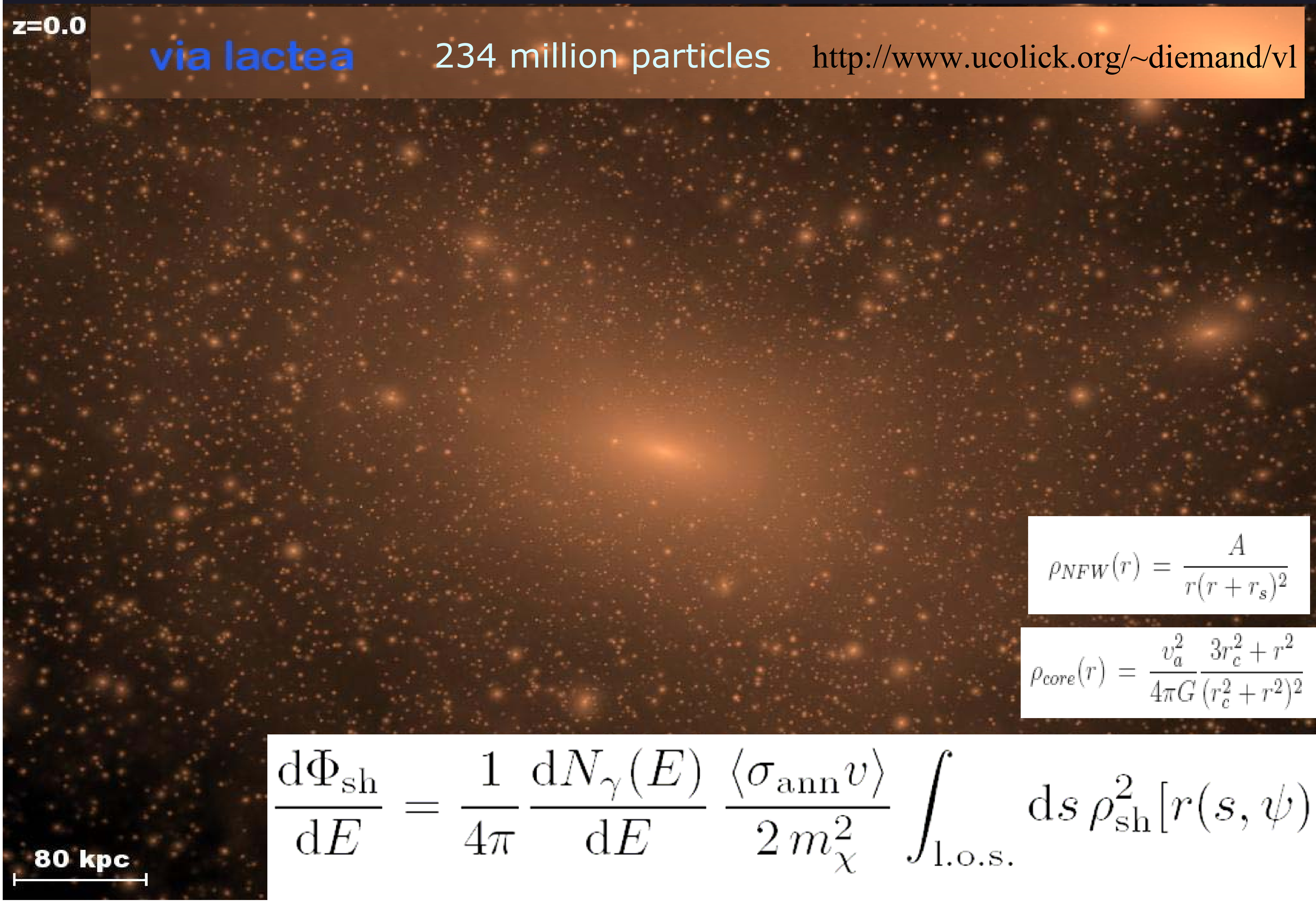


- B.r.'s depend on the model (typical bounds are model-dependent)
- Occam's razor requires only SM particles in the final state
- Since neutrinos represent the most elusive channel, ν-based bounds are the most conservative (general) ones

(P. Serpico)

J. Beacom, N. Bell, G. Mack, astro-ph/0608090

The Galactic halo DM flux



$$\rho_{NFW}(r) = \frac{A}{r(r+r_s)^2}$$

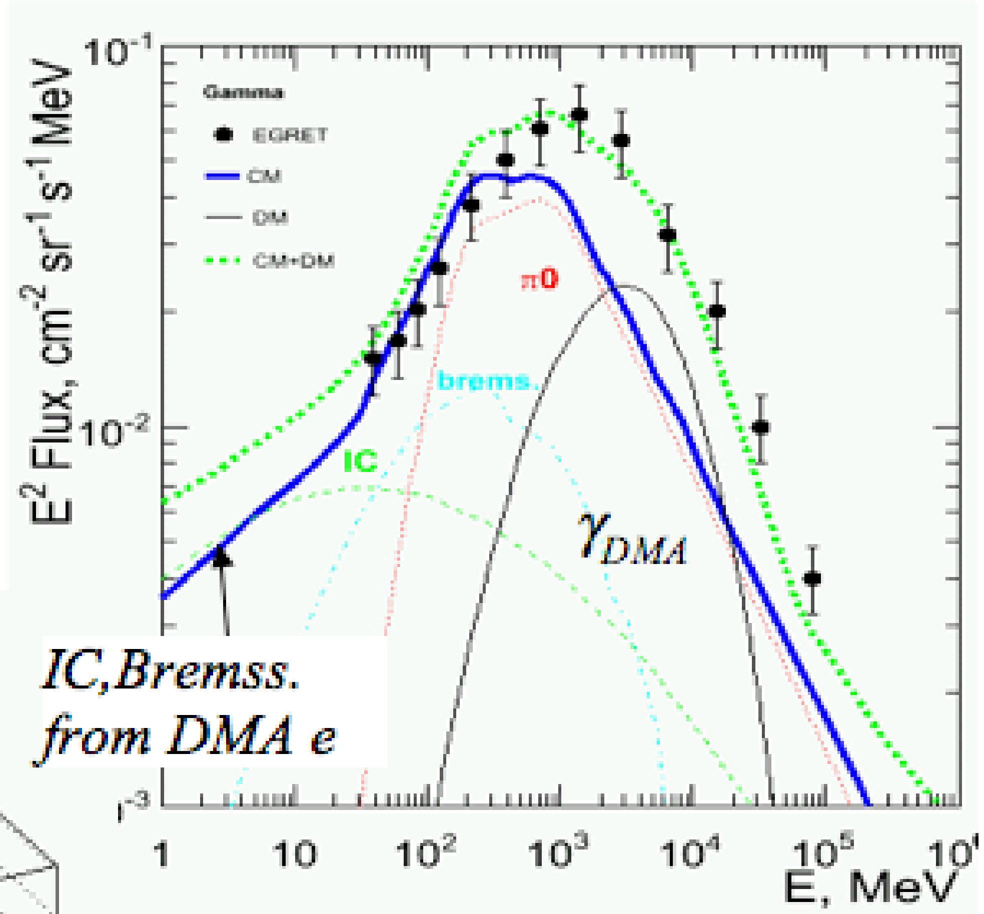
$$\rho_{core}(r) = \frac{v_a^2}{4\pi G}\frac{3r_c^2 + r^2}{(r_c^2 + r^2)^2}$$

$$\frac{\mathrm{d}\Phi_{\mathrm{sh}}}{\mathrm{d}E} = \frac{1}{4\pi}\,\frac{\mathrm{d}N_\gamma(E)}{\mathrm{d}E}\,\frac{\langle\sigma_{\mathrm{ann}} v\rangle}{2\,m_\chi^2}\int_{\mathrm{l.o.s.}} \mathrm{d}s\,\rho_{\mathrm{sh}}^2[r(s,\psi)]$$

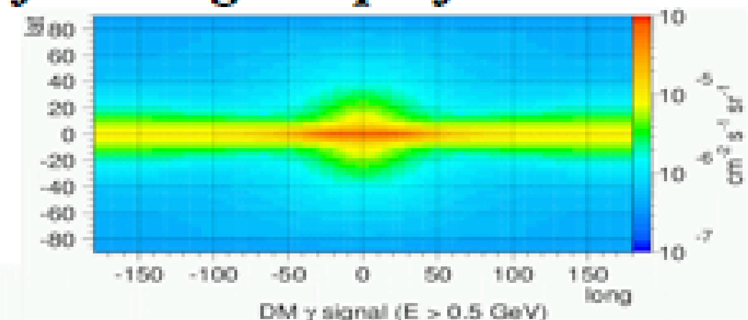
Ex: isotropic propagation model with DMA

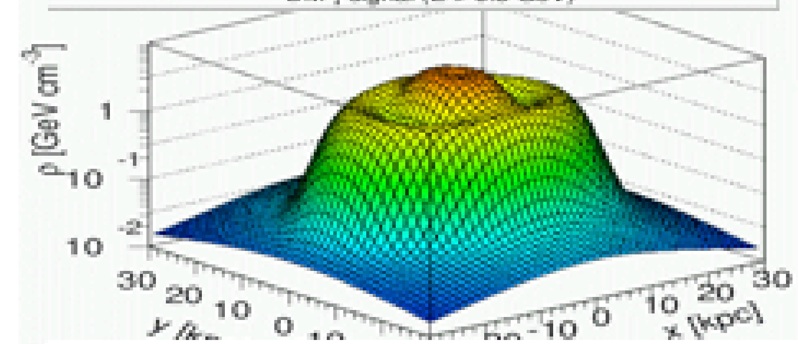
DeBoer et al 2005

EGRET excess interpreted as a DMA signal (SUSY neutralino) $m_\chi \sim 60$ GeV Boost factor ~50 -> DM clumps

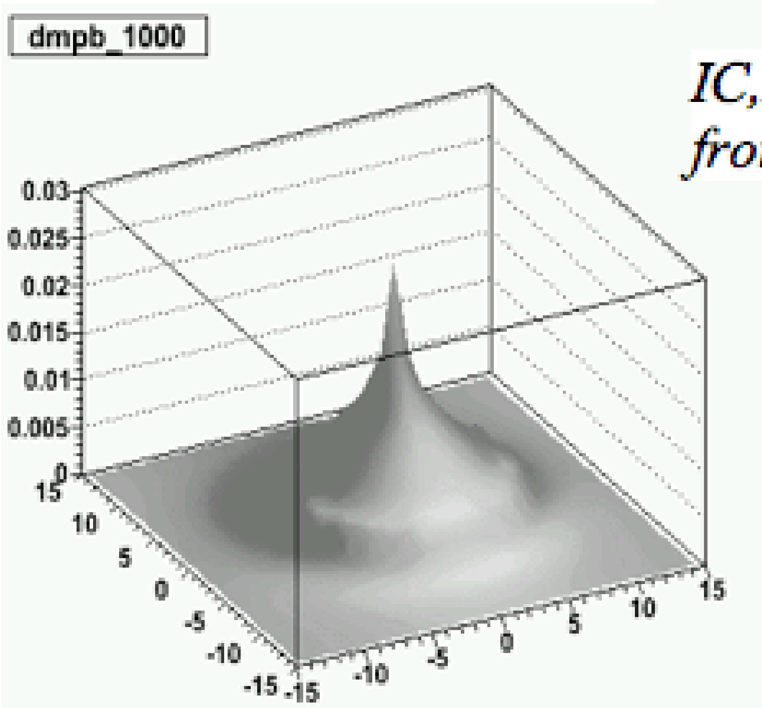


Reconstruct DMA effective profile (clumps distribution) from angular profiles



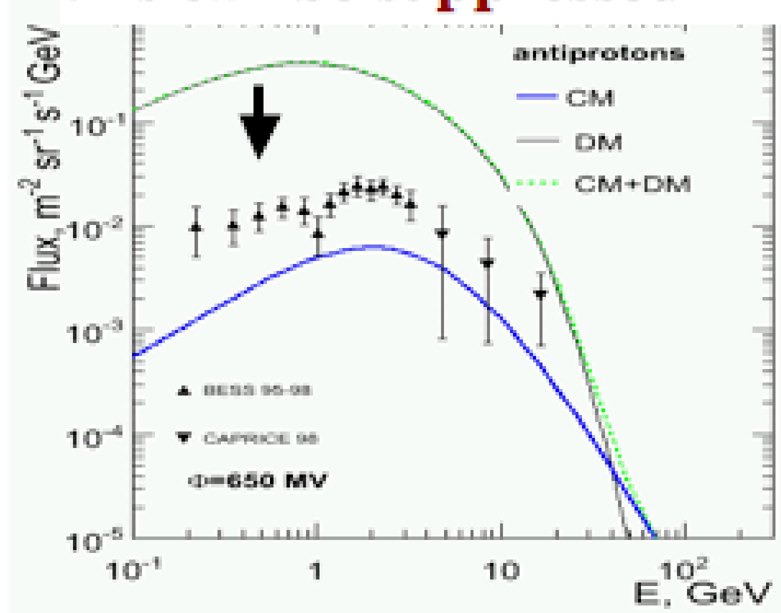


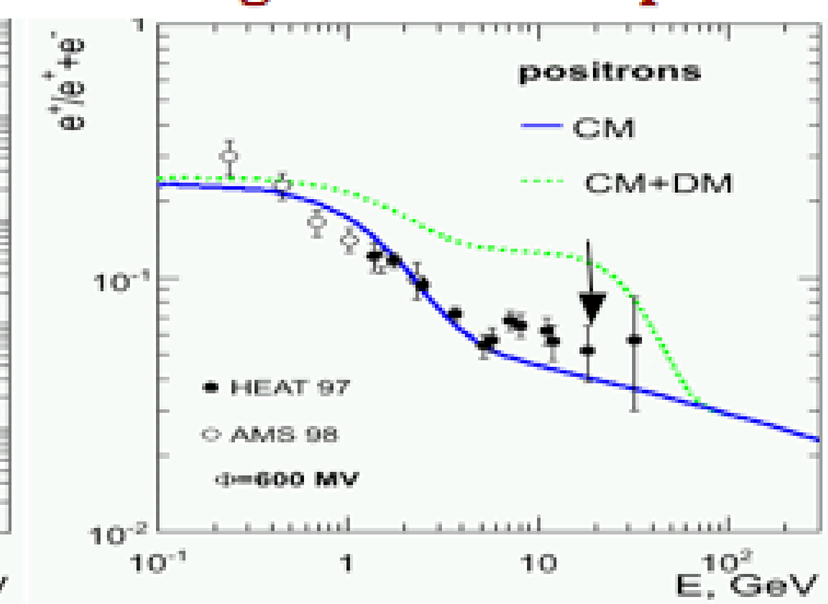
Explains rotation curve



DMA antiprotons(1GeV) in CM DM rings like structure from 'EGRET' profiles (GALPROP+DMA)

But too many p^- and e^+ from DMA in isotropic CM
this can be suppressed in confining in DM clump





Ex: DMA in model with inhomogeneous medium

Decouples locally observed CR from gamma rays

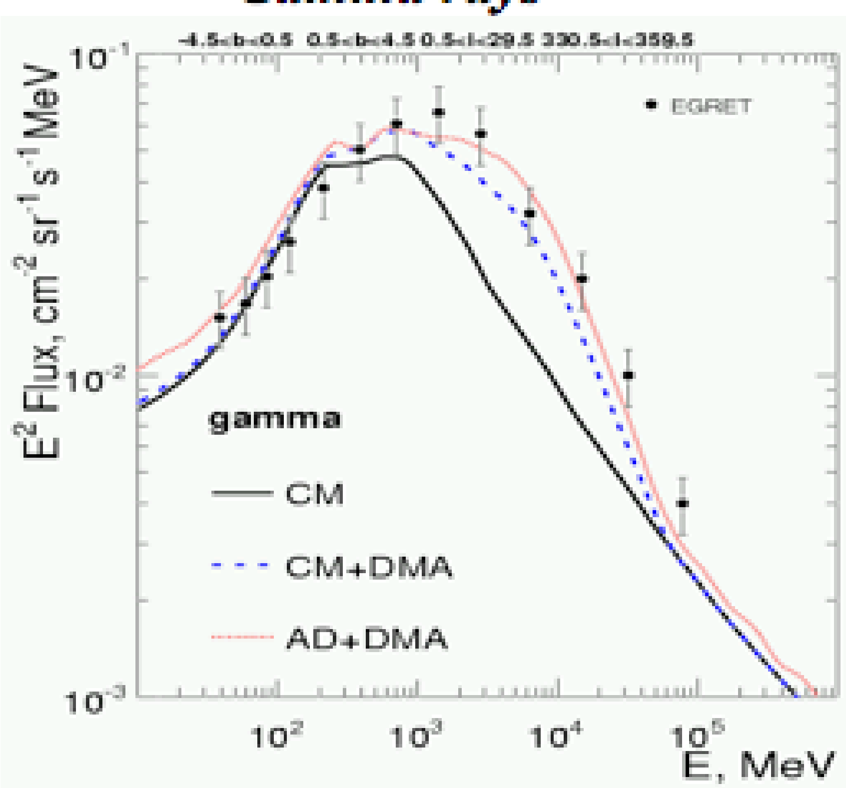
GALPROP numerical code modified with :

- ***including DMA in charged components and gamma rays***
- ***adjustable grid up to pc scales***
- ***anisotropic nonuniform propagation** (AD+DMA) dD/dx, dVc/dx*

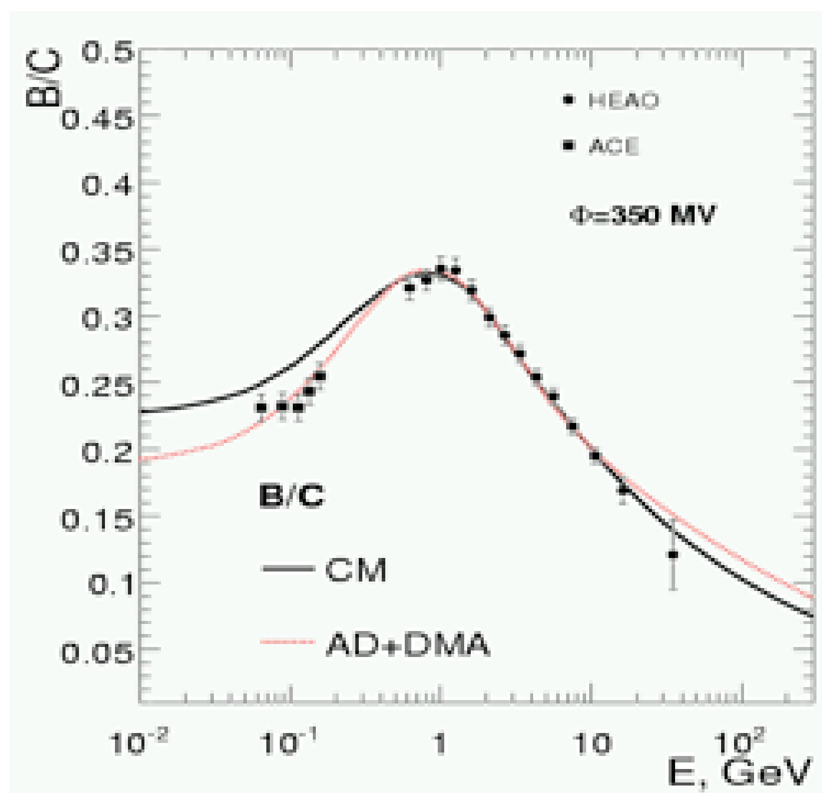
for.ex:
can build a consistent model with DMA for the EGRET excess.

Zd=200 pc D_d=10^{30} cm^2 s n(r,z), snr(r,z) (Lorimer et al)
*Zh=4 kpc D_h=10^{28} cm^2 s , Vc=z*dV/dz=20 km/s/kpc*
nH2 scaling~40, Dc ~10^{-2} Dd

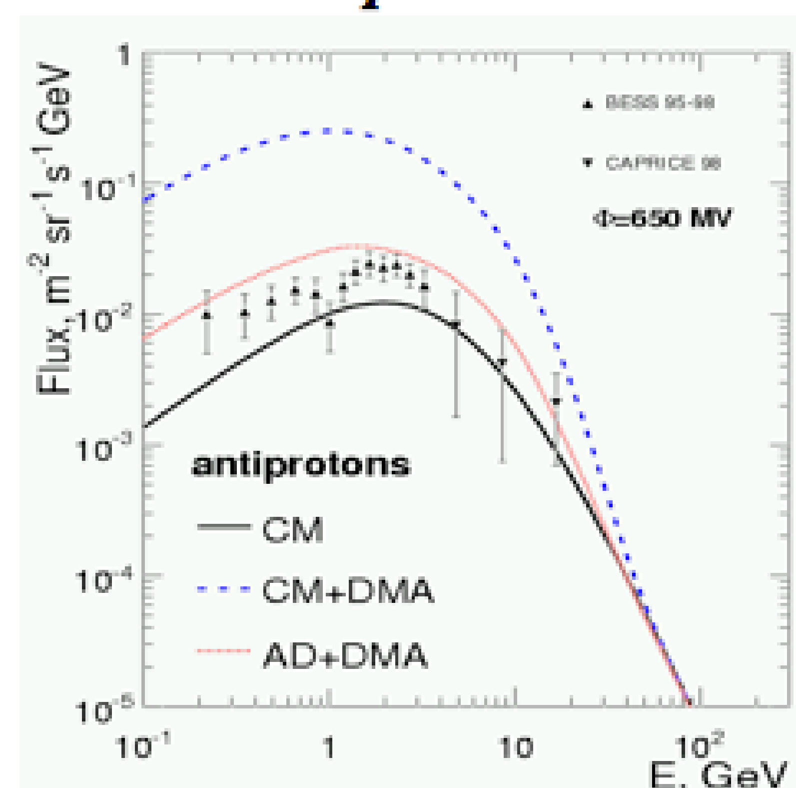
Gamma rays



B/C

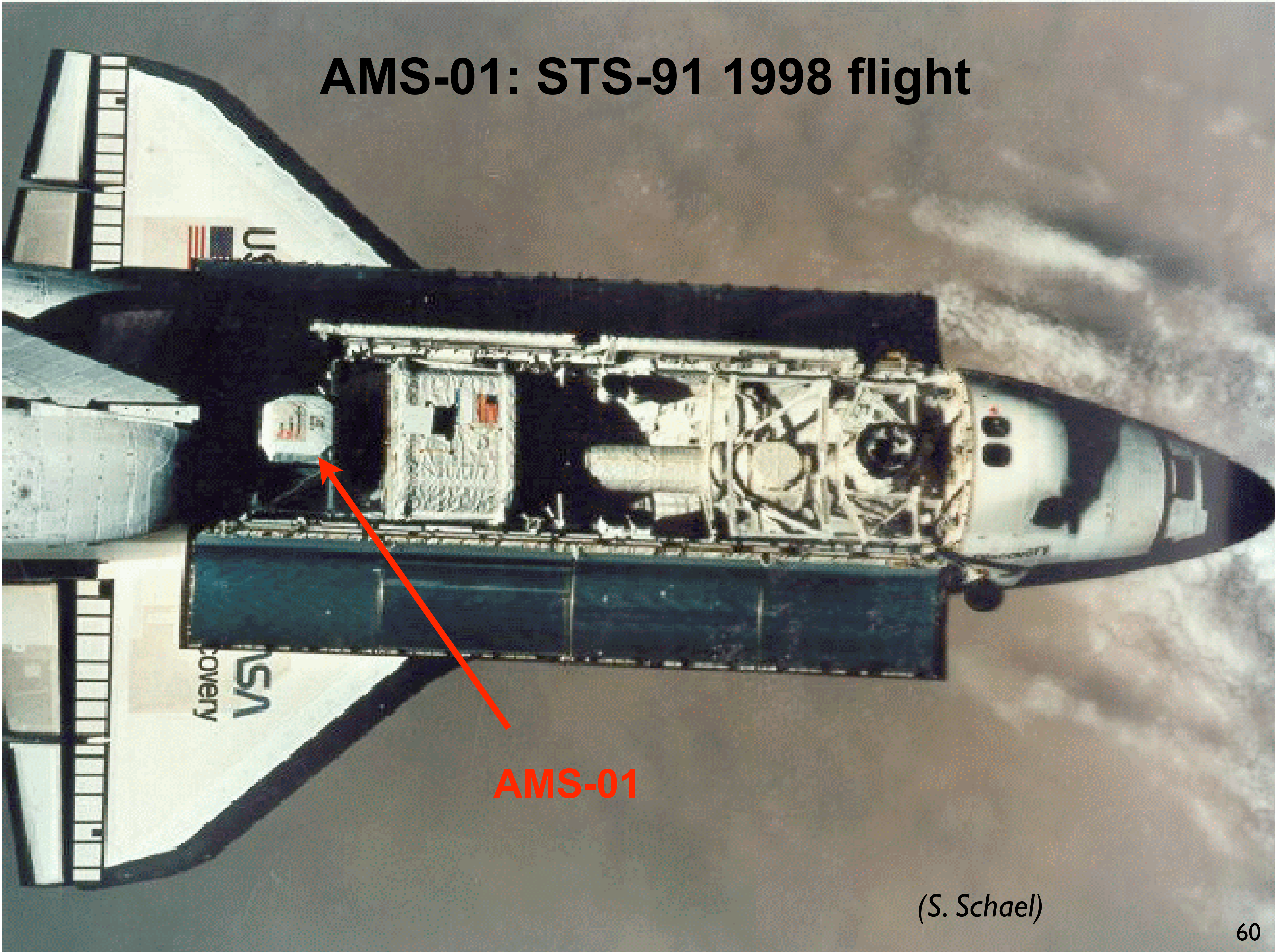


antiprotons



see discussion of EGRET calibration
Stecker et al., 0705.4311 [astro-ph]

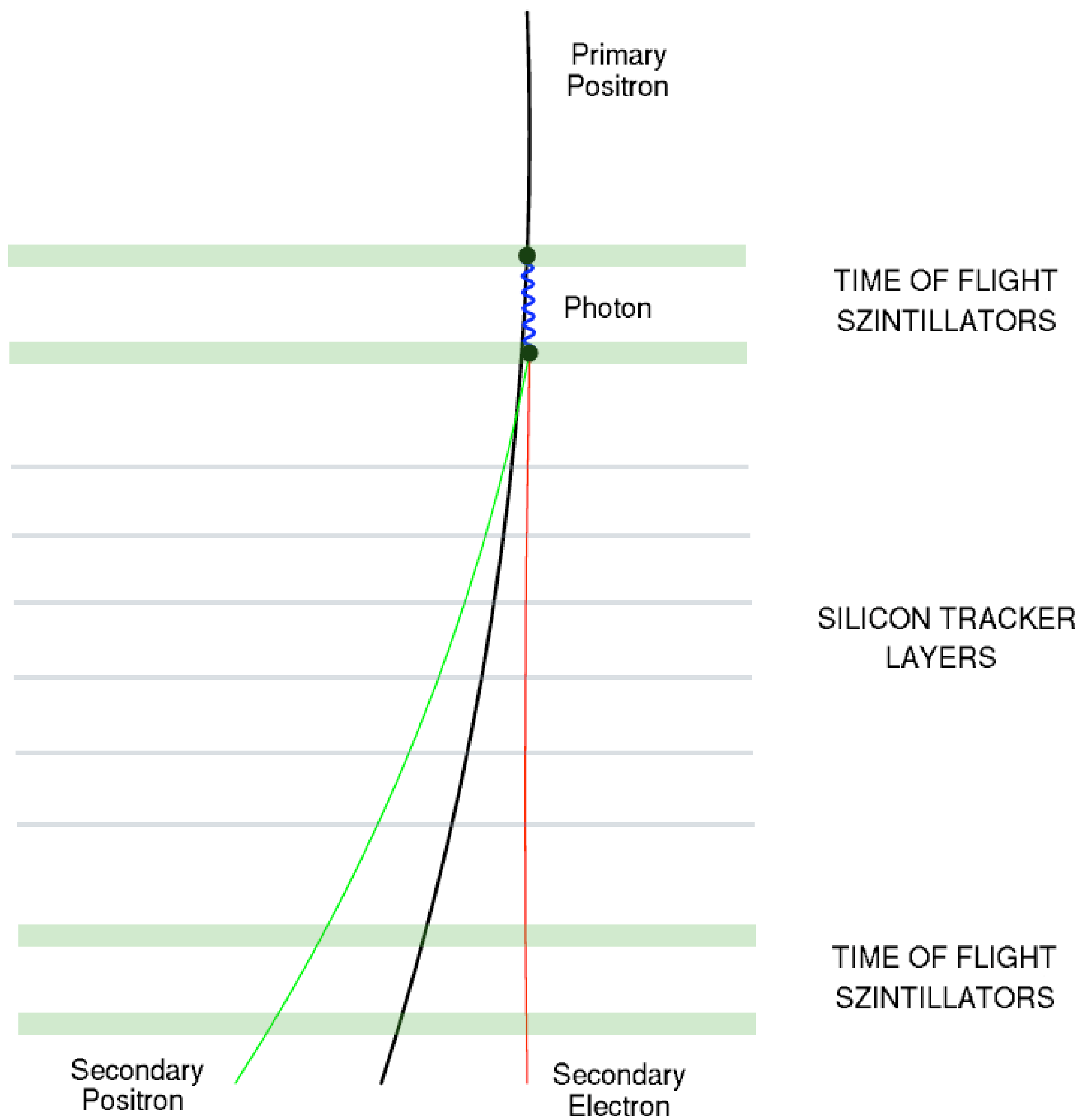
AMS-01: STS-91 1998 flight

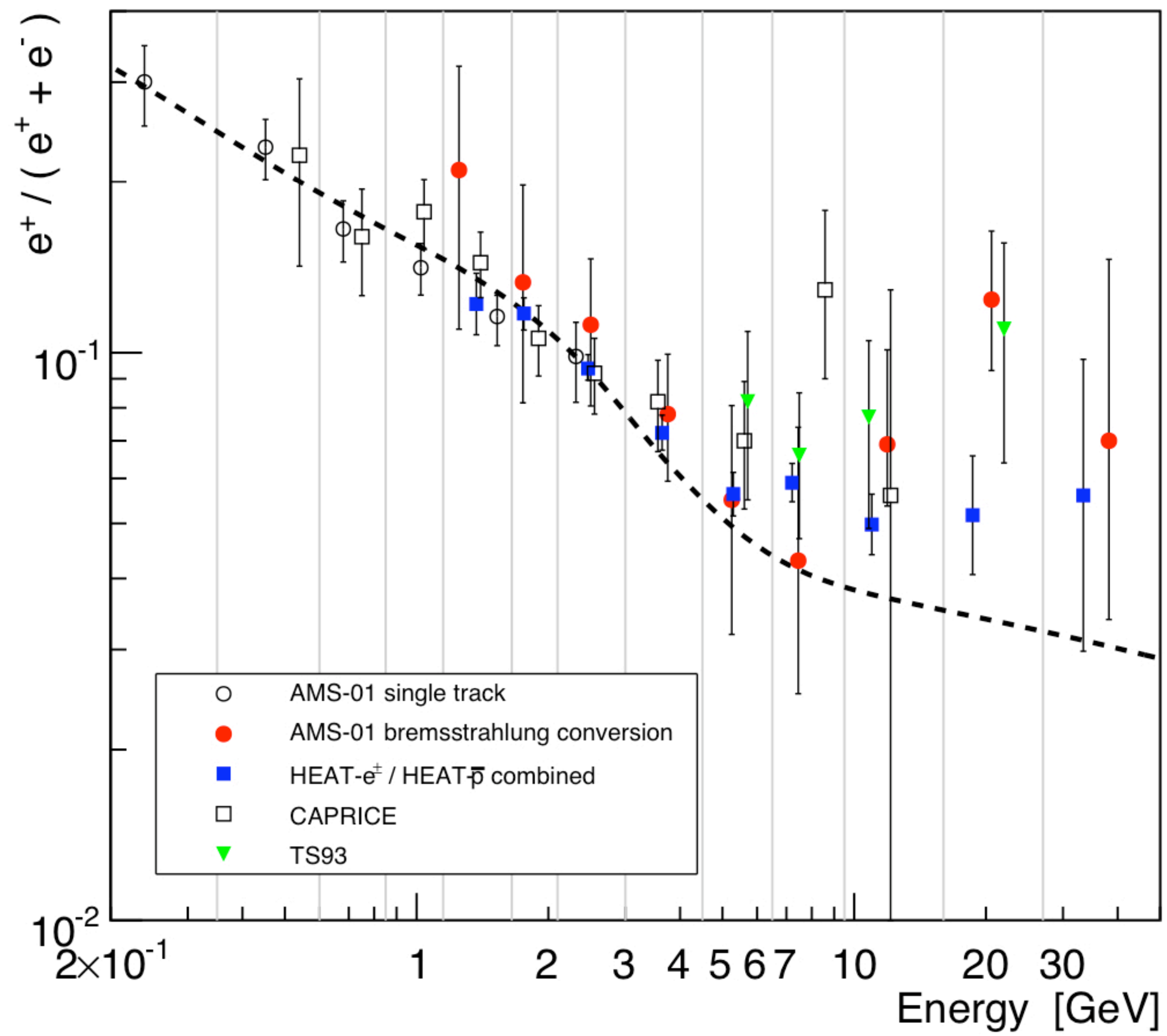


(S. Schael)

AMS-01: positron identification

Positron Identification with AMS-01





Possible positron excess supported

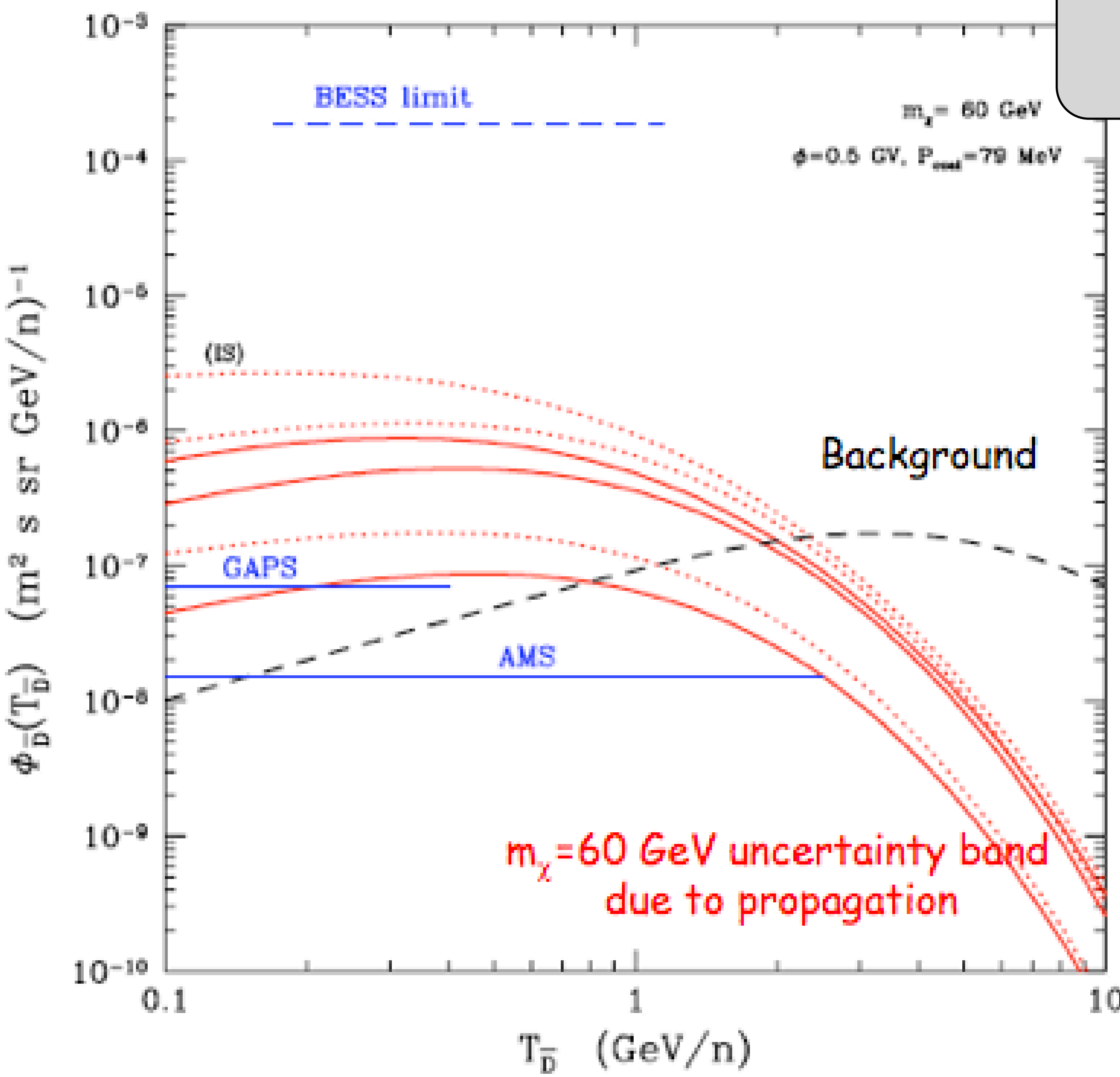
Phys. Lett. B646 (2007), 145-154

(S. Schael et al.)

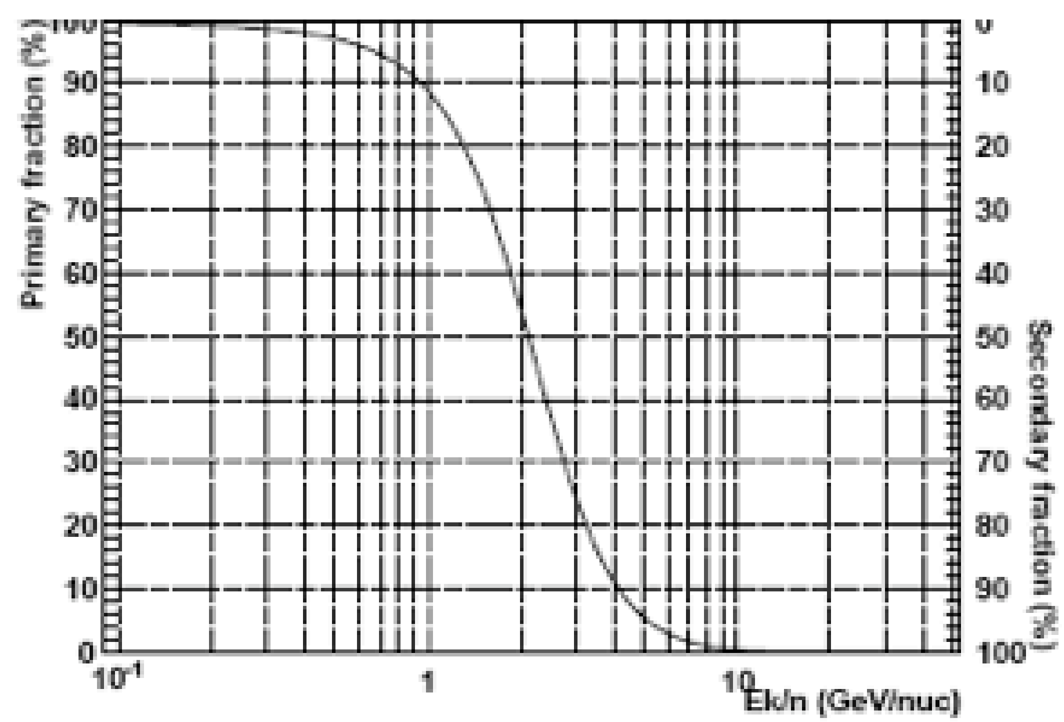
PRIMARY & SECONDARY ANTIDEUTERONS in a 2-zones diffusion model

Results for the BEST FIT (with convection & reaccelaration)

Large uncertainty due to propagation model parameters



Fraction of primary/secondary for best fit propagation & m_χ=60 GeV



(F. Donato et al.)

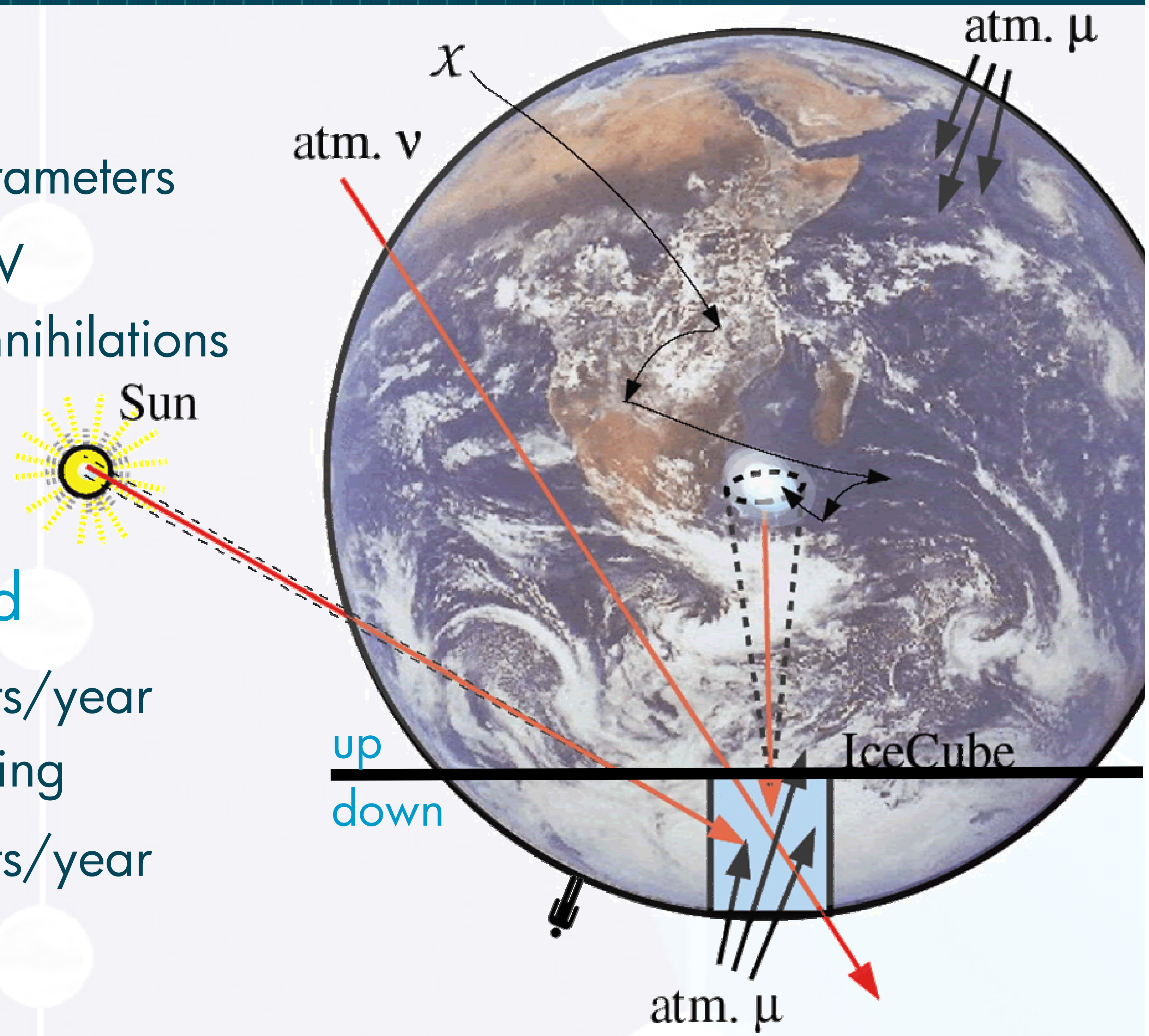
...with neutrinos

Neutralino signal

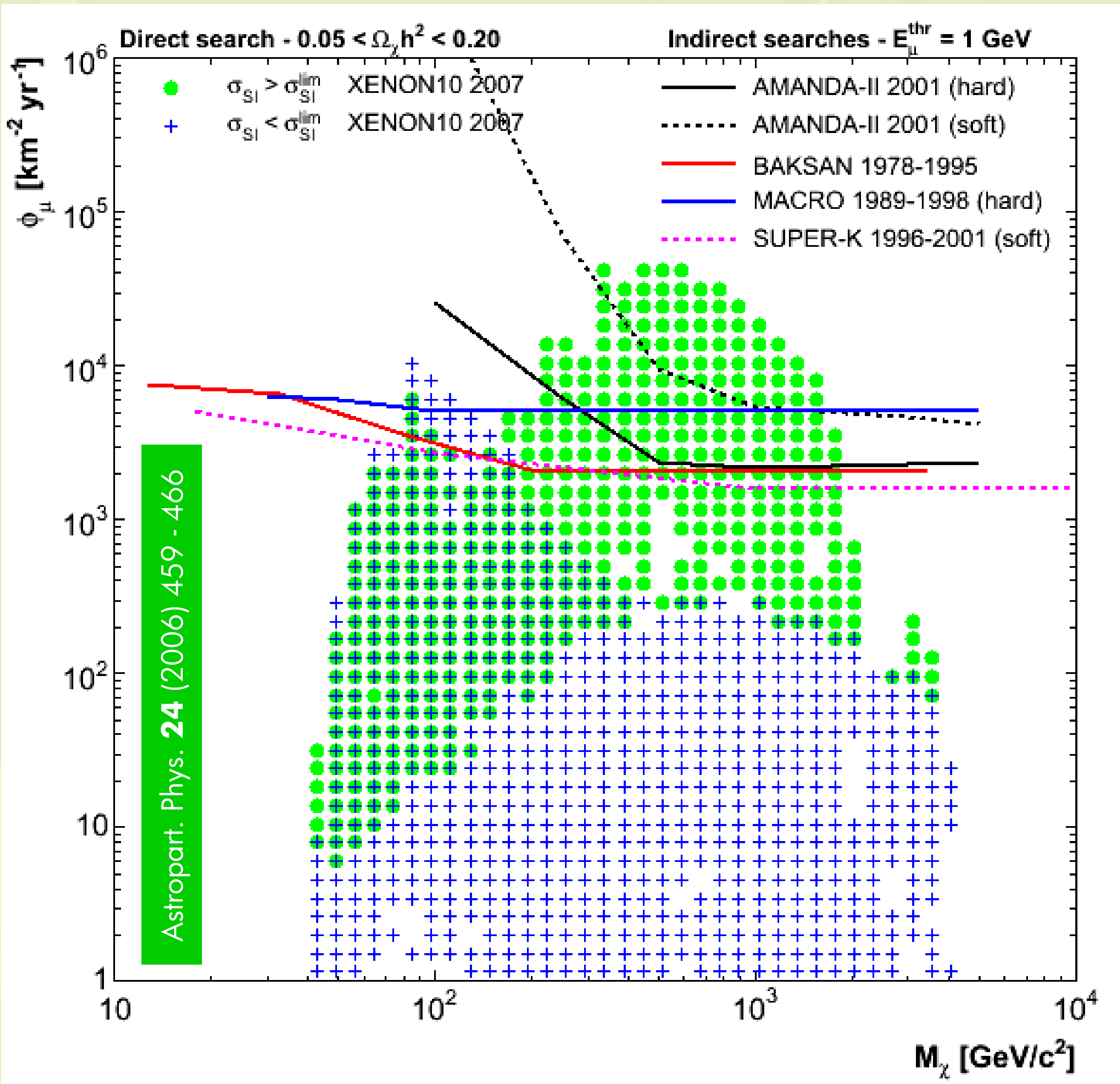
- rate depends on SUSY parameters
- 50 GeV < M_χ < 5000 GeV
  hard (W^+W^-) & soft ($b\bar{b}$) annihilations
- vertically upward (Earth)
  ~horizontal (Sun)

Atmospheric background

- muons ~O(10^9) events/year
  downward going
- neutrinos ~O(10^3) events/year
  all directions



Muon flux limit – Sun 2001



Current results

- 1st AMANDA result
- competitive with 144 days of livetime
- no string trigger

Outlook

- inclusion of low E triggers
- more statistics (2001–2003 data)
- improved analysis methods

Daan Hubert for the IceCube Collaboration
Vrije Universiteit Brussel, Belgium

THE DRACO DWARF GALAXY

ICRC 2007, Merida, Mexico

$$F(E > E_0) = \frac{N_\gamma < \sigma v >}{8\pi m_\chi^2} \frac{1}{\Delta\Omega} \int_{\Delta\Omega} B(\Omega) \mathrm{d}\Omega \times \int_{los} \rho^2 (\Omega, \Psi, s)\, \mathrm{d}s$$

J(Ψ)

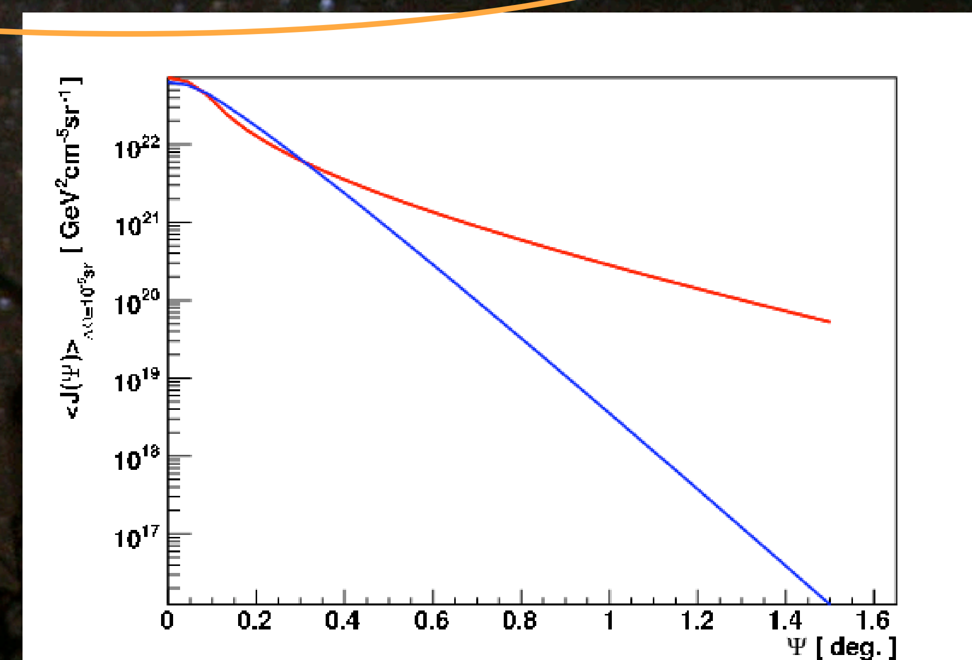
Draco:

Dwarf spheroidal galaxy, accompanying the Milky Way at a galactocentric Distance of 82 kpc, (distance to earth: 86 kpc)

M/L > 200

After L. Mayer et al. (Nature, 445, 738, 2007):

Highly DM dominated



The factor J(Ψ) for the cusp and core profile

The DM halo is modeled by a power law with an exponential cut off:

$$\rho_{\mathrm{DM}} = C r^{-\alpha} \exp\left(-\frac{r}{r_b} \right)$$

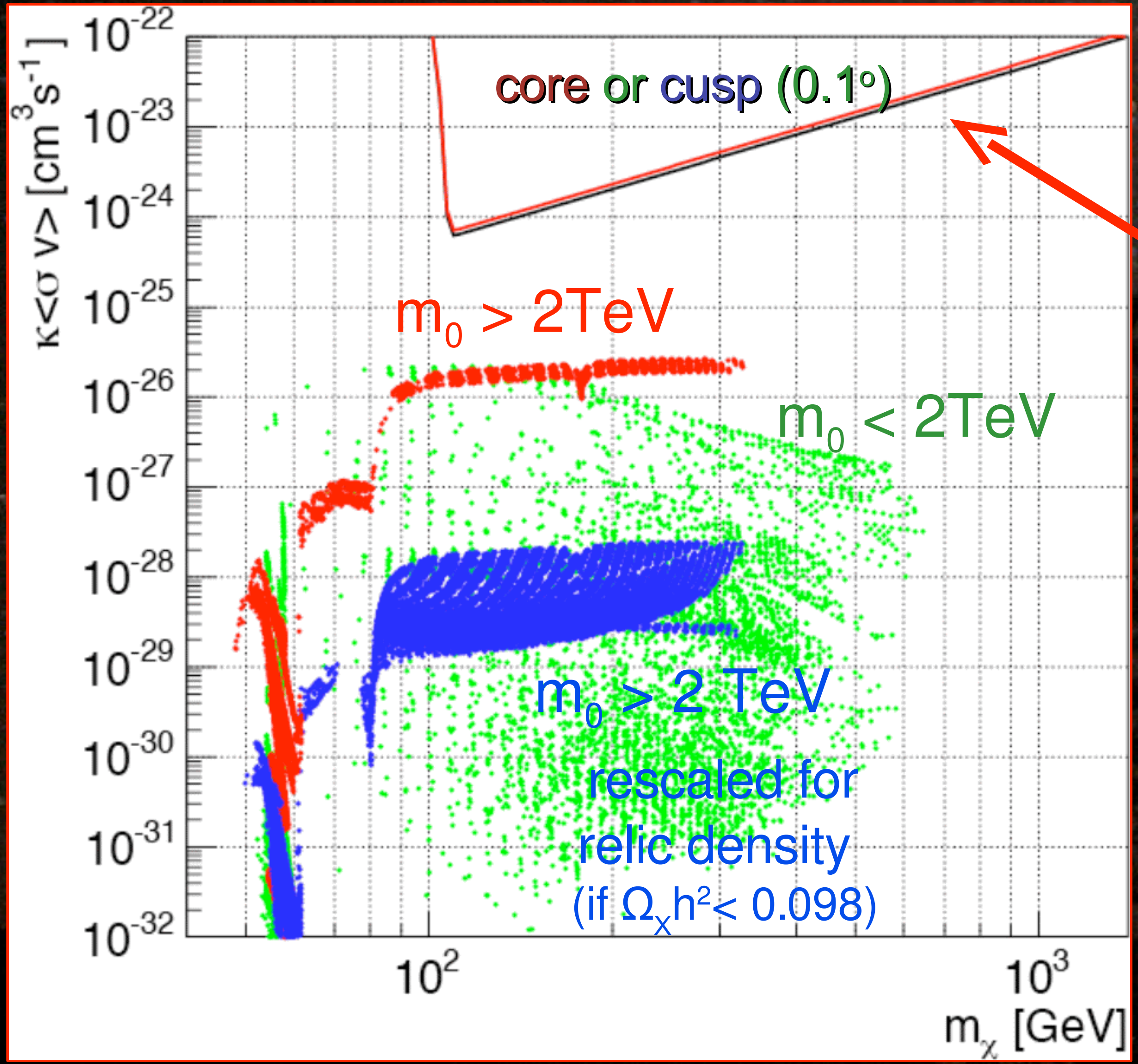
With the following values for C, α and r_b (Sanchez-Conde et al, 2007):

profile	C	r_b[kpc]	α
cusp	$3.1\times10^7 M_e\,\mathrm{kpc}^{-2}$	1.189	1
core	$3.6\times10^8 M_e\,\mathrm{kpc}^{-3}$	0.238	0

Michael Rissi, Institute for Particle Physics, ETH Zürich
for the MAGIC collaboration

FLUX FROM NEUTRALINO ANNIHILATION

$$F(E > E_0) = \frac{N_\gamma < \sigma v >}{8\pi m_\chi^2} \frac{1}{\Delta\Omega} \int_{\Delta\Omega} B(\Omega) d\Omega \times \int_{los} \rho^2(\Omega, \Psi, s)\, ds$$



predicted cross-section for parameters within the mSUGRA-framework

line: 5σ sensitivity curve for 50h of observation by MAGIC. (Tasitsiomi, 2002)

Scalar mass m_0 < 6 TeV
Gaugino mass $m_{1/2}$ < 4 TeV
Trilinear coupling -4 TeV < A_0 < 4 TeV
tanβ < 50

Gravitational waves

LIGO

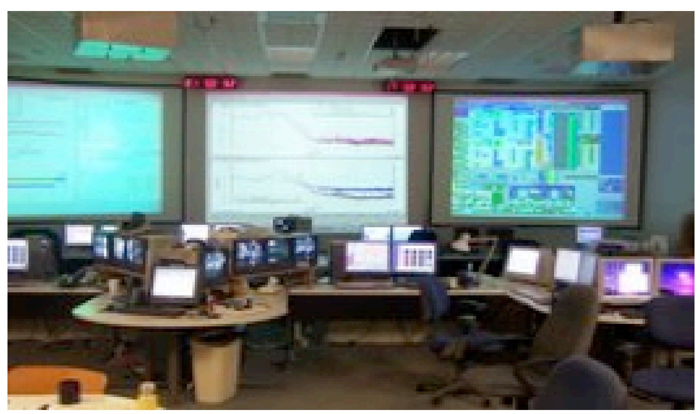
LIGO Detectors

- LIGO observatory contains 2 (H2) km and 4 km (H1) interferometers at Hanford, WA and a 4 km interferometer at Livingston, LA (L1). They are designed to detect gravitational waves from astrophysical sources.

Hanford

Livingston

Inside the LIGO control room

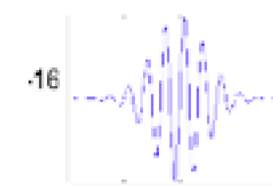


LIGO-G070415-00-Z

2

ent Sensitivity

— 70 Hz
— 153 Hz
— 235 Hz
— 554 Hz
— 849 Hz
— 1053 Hz



Efficiency Estimate :

E_{gw} @153 Hz with 50% detection probability:

~ 2×10^{-8} $M_\odot c^2$ at 10 kpc

~ 0.05 $M_\odot c^2$ at 16 Mpc

Core-collapse Supernovae : *Ott et al , PRL 96, 201102 (2006)*

11 $M_\odot$ progenitor $\Rightarrow$ reach $\approx$ 0.4 kpc
25 $M_\odot$ progenitor $\Rightarrow$ reach $\approx$ 16 kpc

Binary Black Hole mergers : *Baker et al PRD 73, 104002 (2006)*

10+10 $M_\odot$ binary $\Rightarrow$ reach $\approx$ 3 Mpc
50+50 $M_\odot$ binary $\Rightarrow$ reach $\approx$ 100 Mpc

8

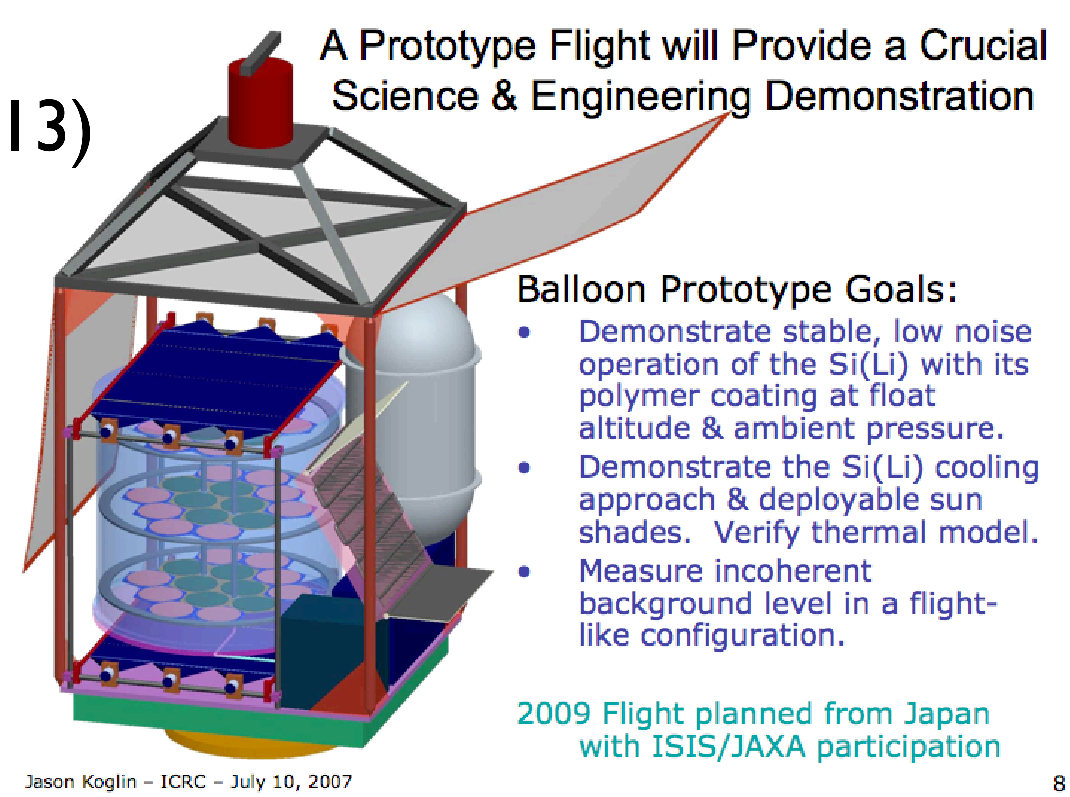
Science run 5
since Nov 2005
(End fall 2007)

(S. Desai, LIGO Collab.)

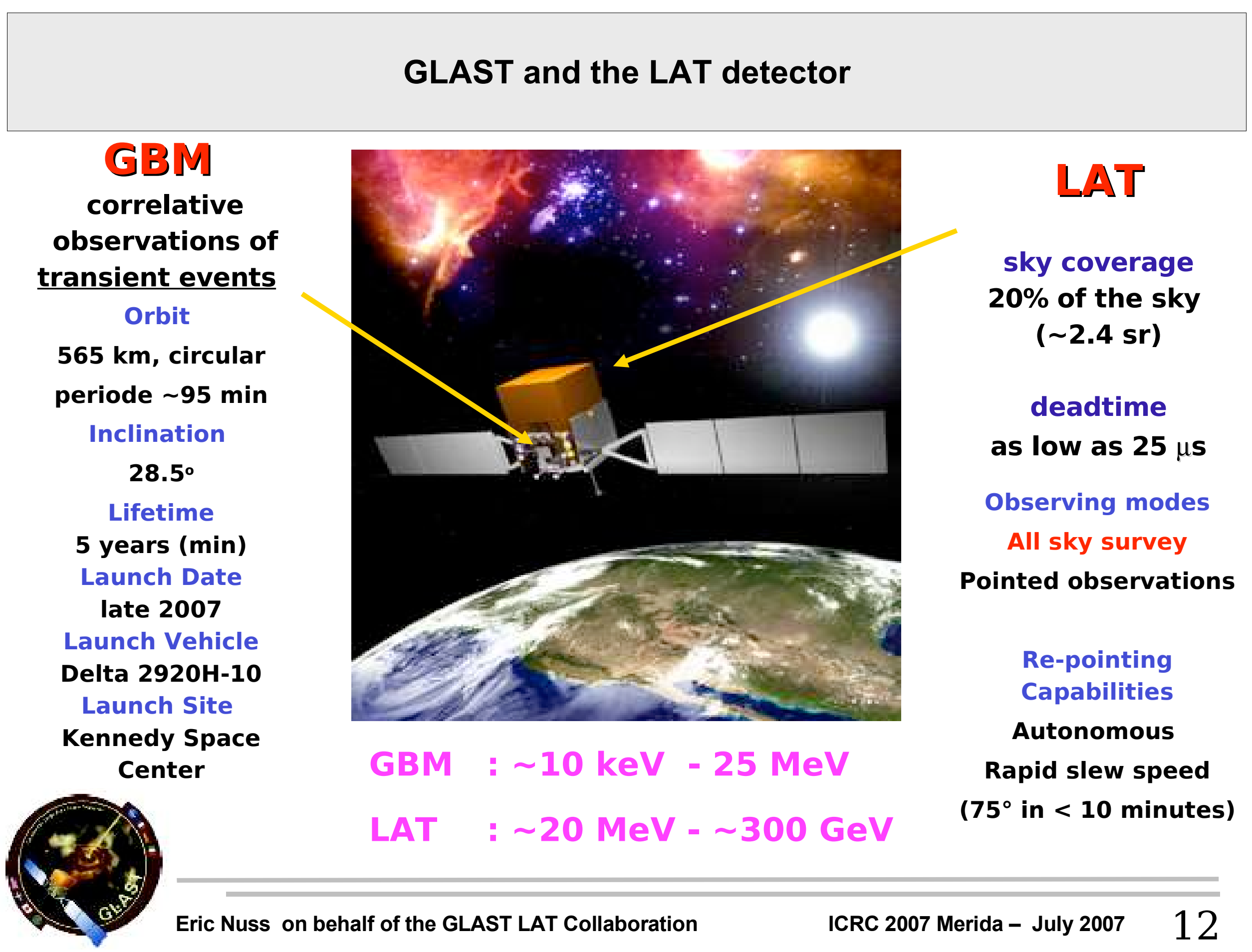
Outlook

- Neutrino telescopes
- Gamma-ray telescopes
- PAMELA, 2006

GAPS
(2009/2013)



GLAST, 2007



AMS02, 2009