LHC

and

COSMIC RAY Science

- Cosmic Rays and Hadronic Interactions
- MonteCarlo codes for Cosmic Rays
- Possibilities for LHC/CR working Group

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Relativistic Particles with energies as large as $E_{lab} \approx 10^{20}$ eV reach the Earth from outer Space.

The Study of their Origin is an old field of research, at present is in a new phase of exciting developments.

- Gamma Ray Astronomy is observing some sites of acceleration for relativistic particles.

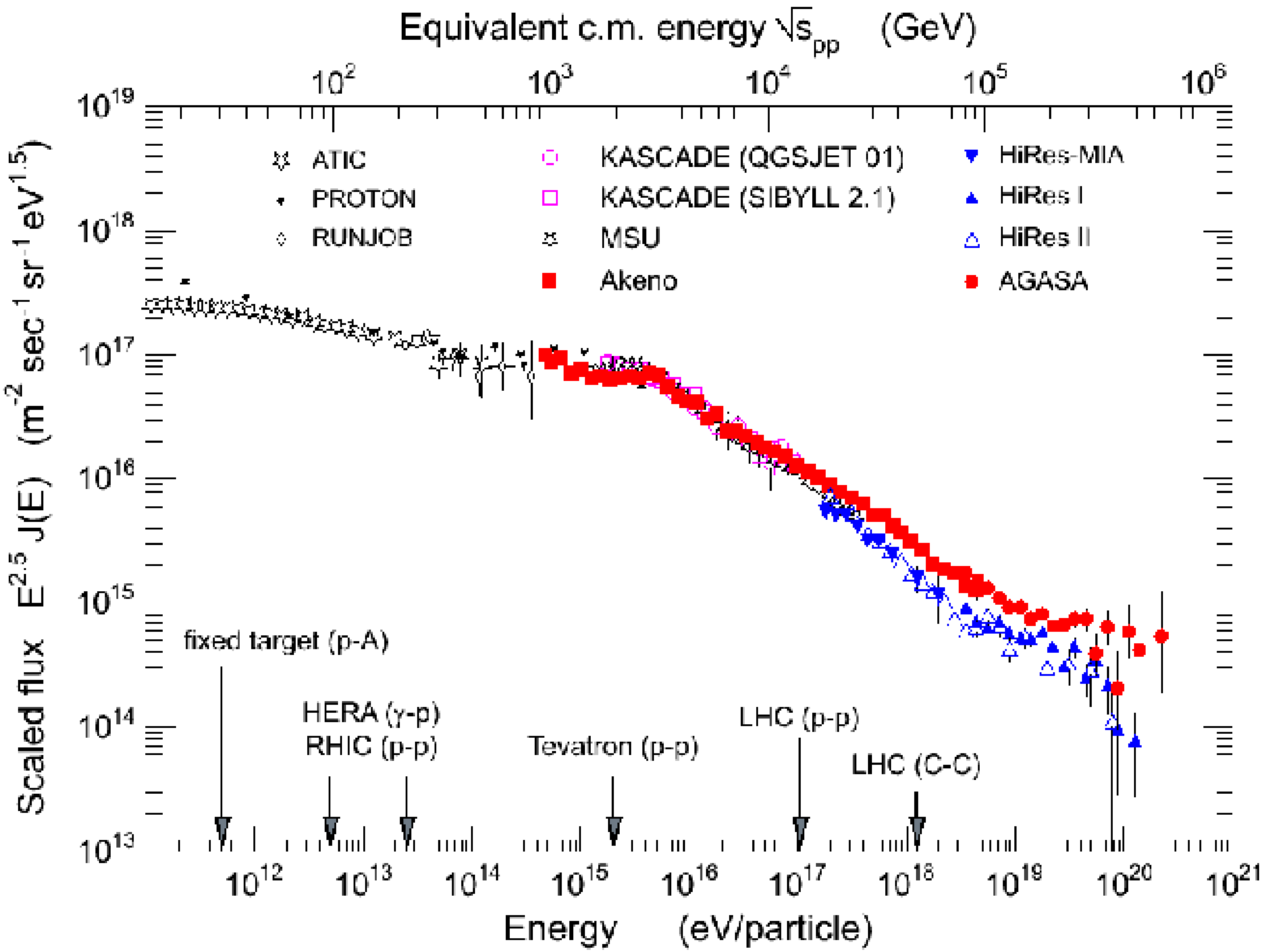
- One Major Detector (3000 Km^2): the Pierre Auger Observatory is just starting observations at the highest energies with a significantly larger acceptance.

$$E_{\rm lab} = 10^{20}\ {\rm eV}$$

$$(\sqrt{s})_{pp} \simeq 433\ {\rm TeV}$$

$$(\sqrt{s})_{pp} = 14\ {\rm TeV}$$

$$E_{\rm lab} \simeq 1.05 \times 10^{17}\ {\rm eV}$$



Equivalent c.m. energy $\sqrt{s}_{pp}$ (GeV)
10^2
10^3
10^4
10^5
10^6
Scaled flux $E^{2.5}$ J(E) (m^{-2} sec^{-1} sr^{-1} $eV^{1.5}$)
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
MSU
Akeno
HiRes-MIA
HiRes I
HiRes II
AGASA
fixed target (p-A)
HERA (γ-p)
RHIC (p-p)
Tevatron (p-p)
LHC (p-p)
LHC (C-C)
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)

Origin of Cosmic Rays:

Accelerated in "Astrophysical Accelerators"

SuperNova Remnants
Gamma Ray Bursts
Active Galactic Nuclei
....

Lower Energy : Galactic Origin
Higher Energy : Extra Galactic

Speculations ("Top-Down" Models):
The Highest Energy Particles could be produced
in the decay of Supermassive Objects [$M_{GUT} \approx 10^{25}$ eV]
Relic from the Verty Early Universe.

“High Energy Astrophysics”

[the study of high energy source in the Universe]

is a field of great importance for
the Particle Physics Community

It is “strategically” very important for INFN
to energetically pursue this line of research.

The LHC is a unique source of
essential information needed for the
interpretation of existing and future
data on Cosmic Rays.

Direct Measurements

(Detectors on High Altitude Balloons or Satellites)

Indirect Measurements

(Observations of the Showers produced in the Atmosphere).

Surface Arrays

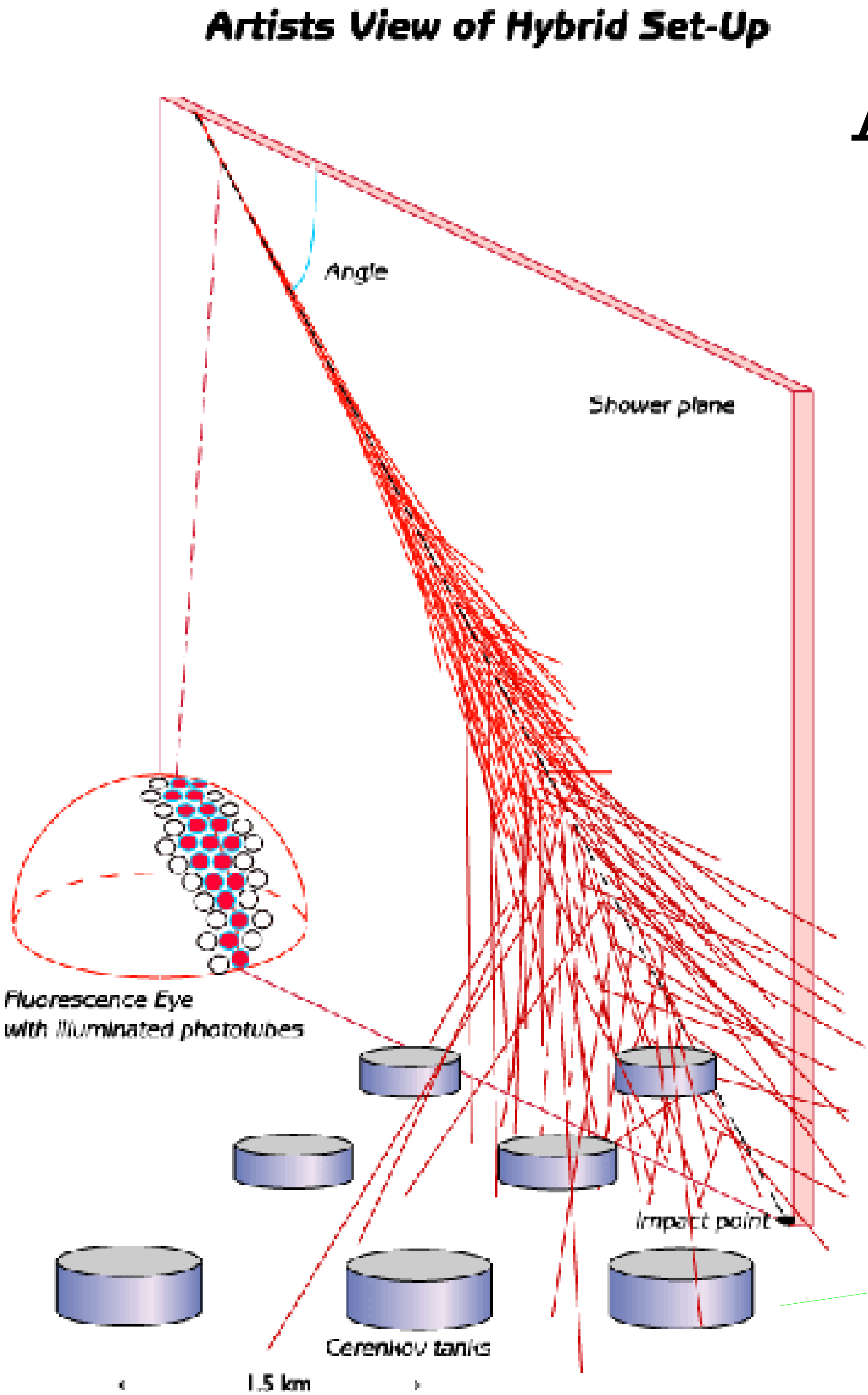
Measure one (or more) components { [eg], [m], …} of the shower at the surface

Fluorescence Detectors

Measure the Longitudinal Development of the Shower

The interpretation of these observations requires an accurate modeling of hadronic interactions

AUGER detector



3000 Km^2

Hybrid system

1600 detector stations

1.5 km spacing

3000 km²

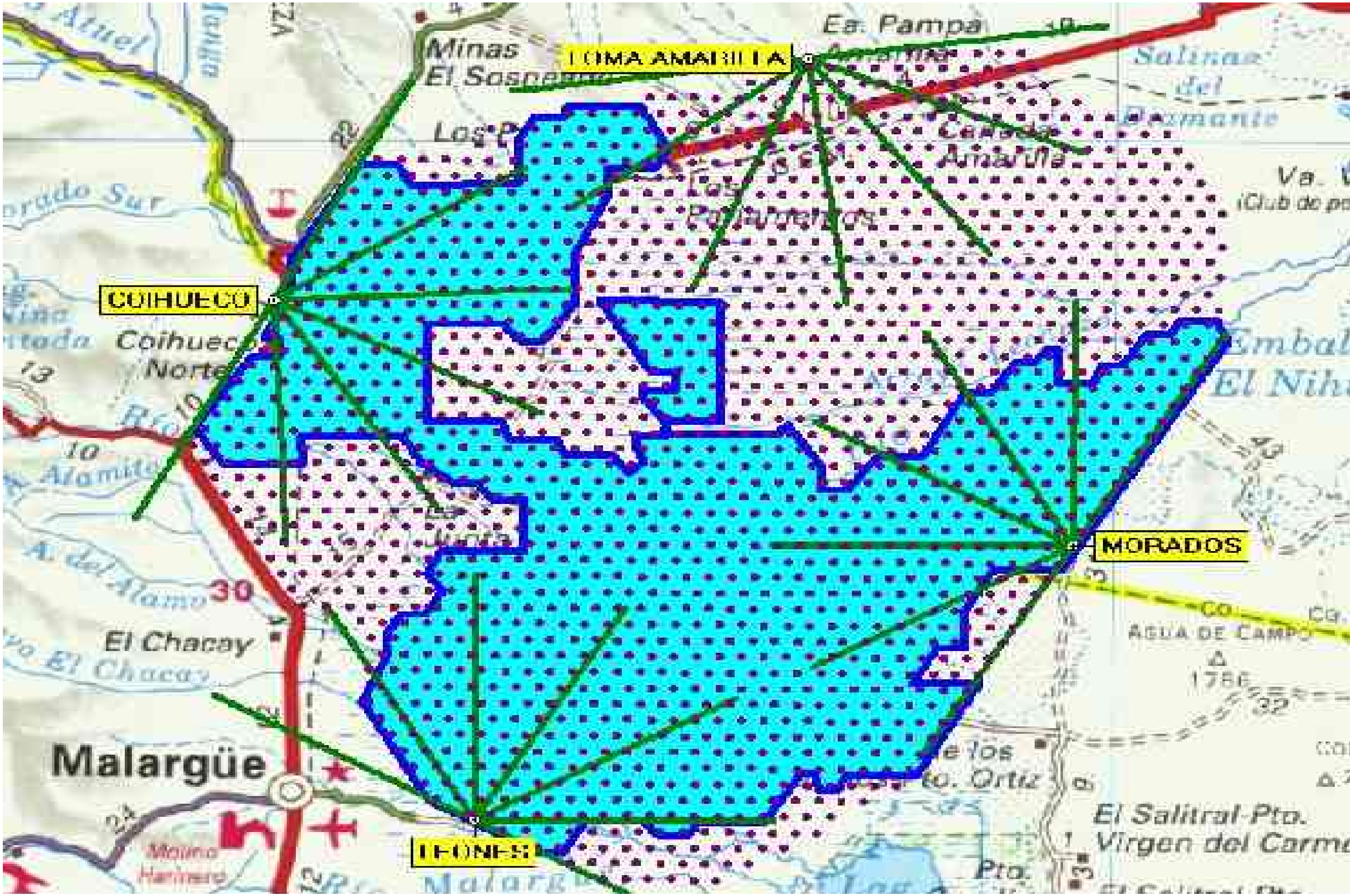
4 Telescope enclosures

6 Telescopes per enclosure

24 Telescopes total

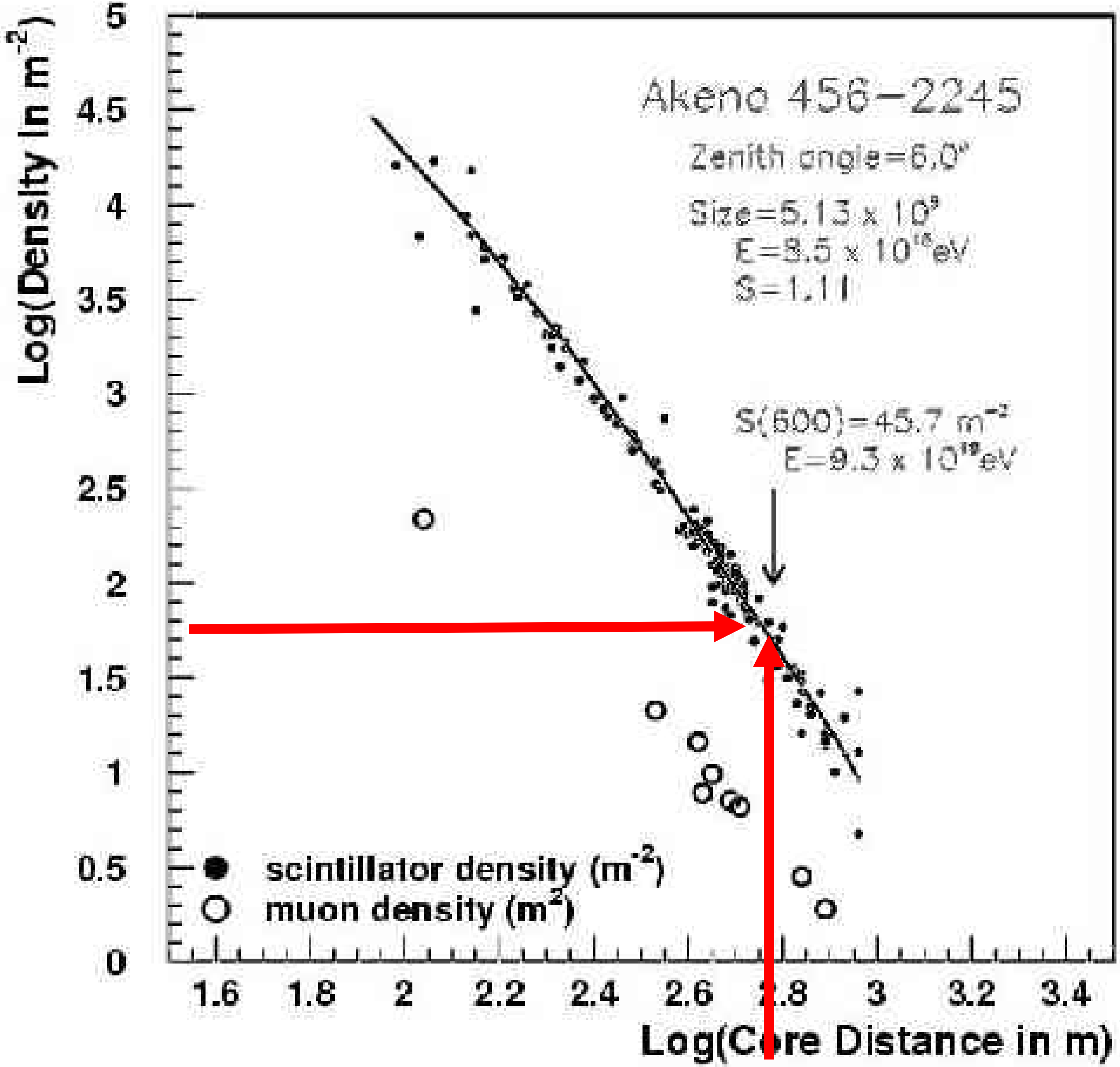
> 1000 detector stations deployed

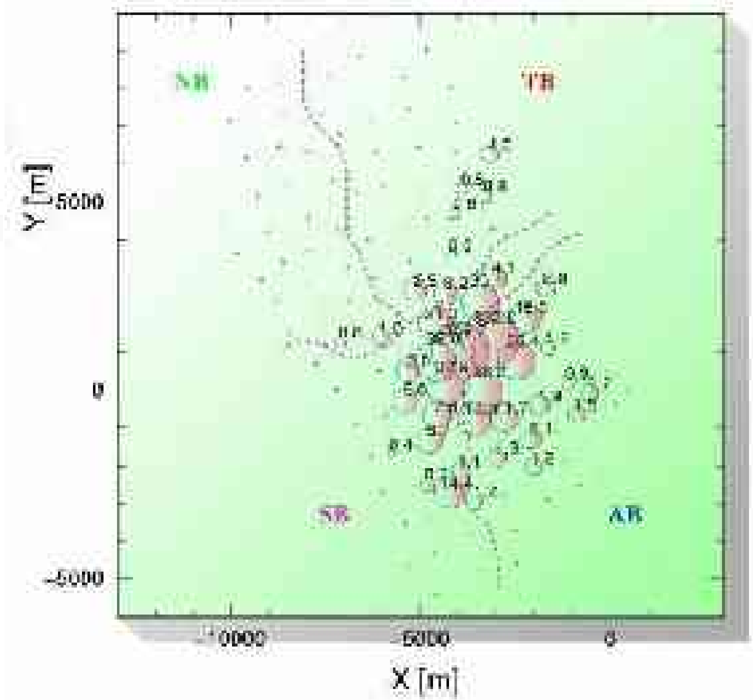
3 fluorescence building complete
each with 6 telescopes

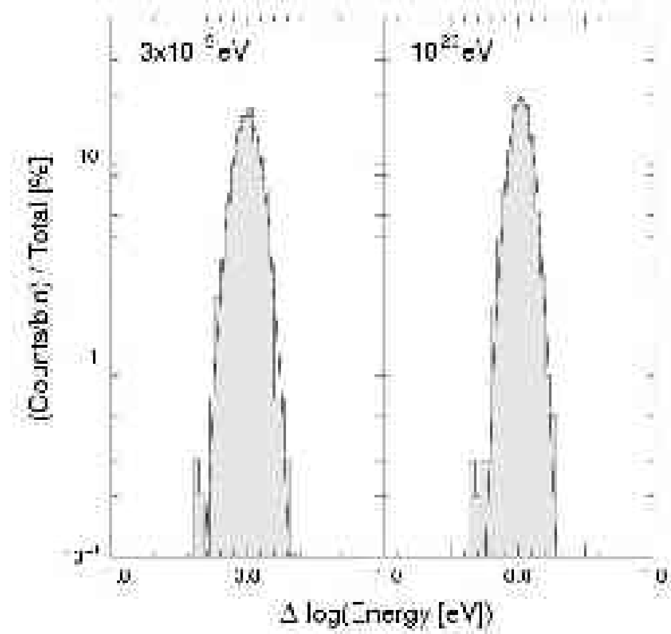


AGASA Energy determination

$$E = 2.03 \times 10^{17} \cdot S_0(600) \quad \text{eV}$$

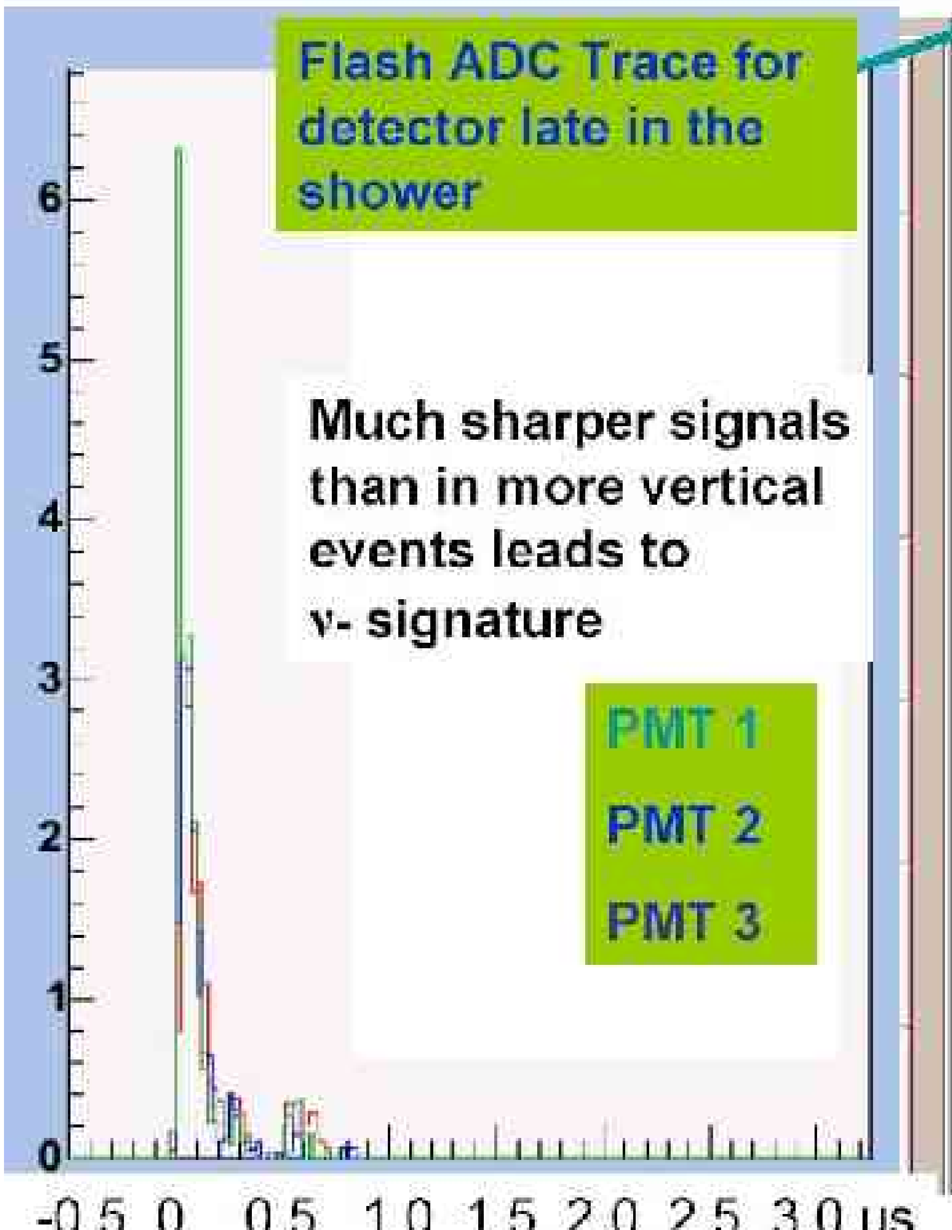


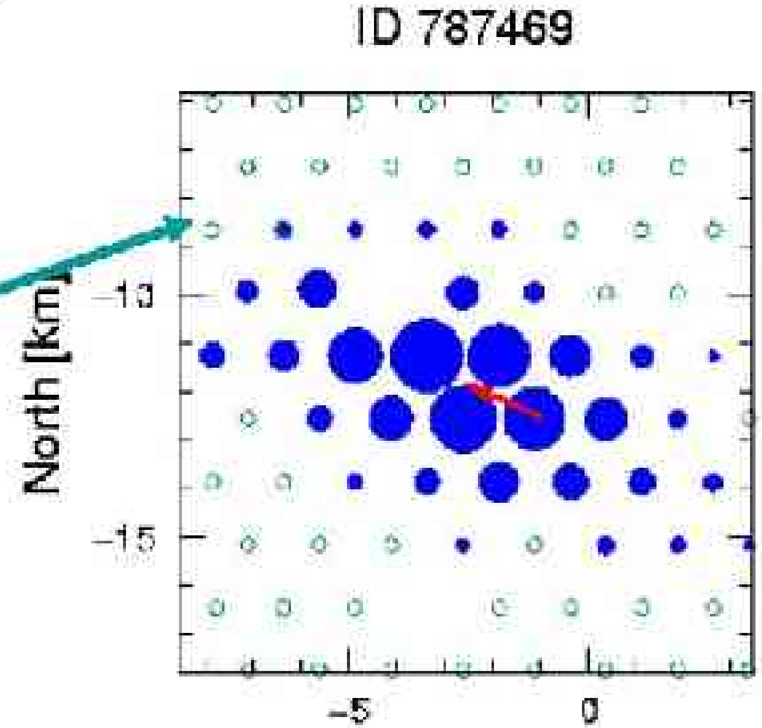


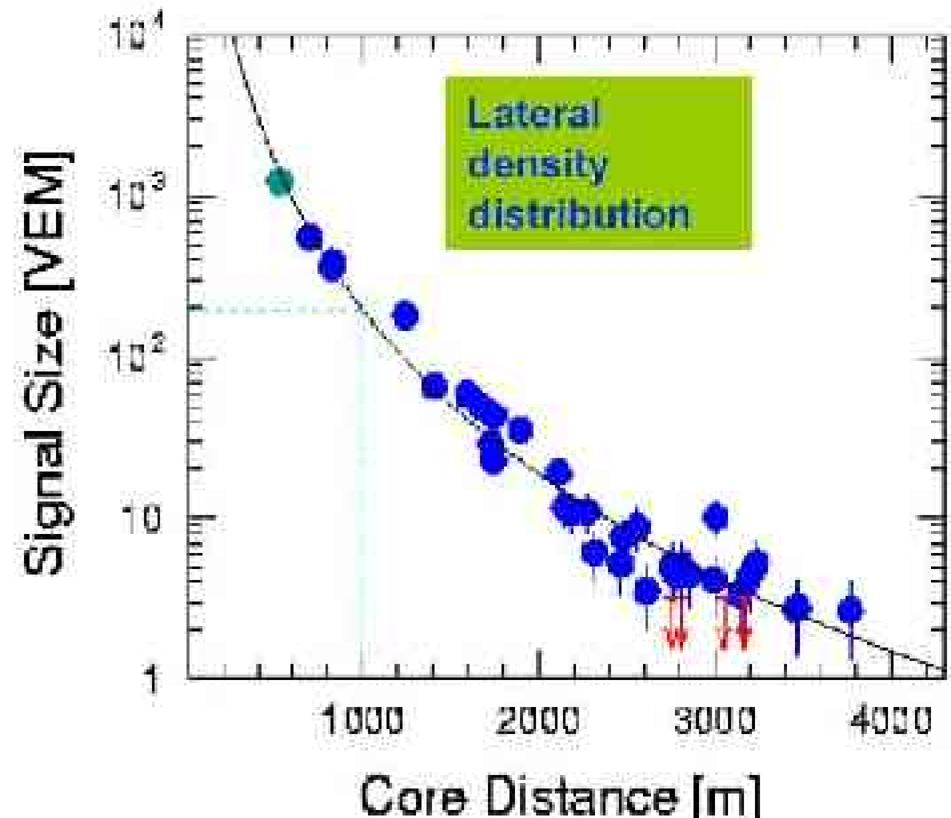


θ~ 60°, ~ 86 EeV

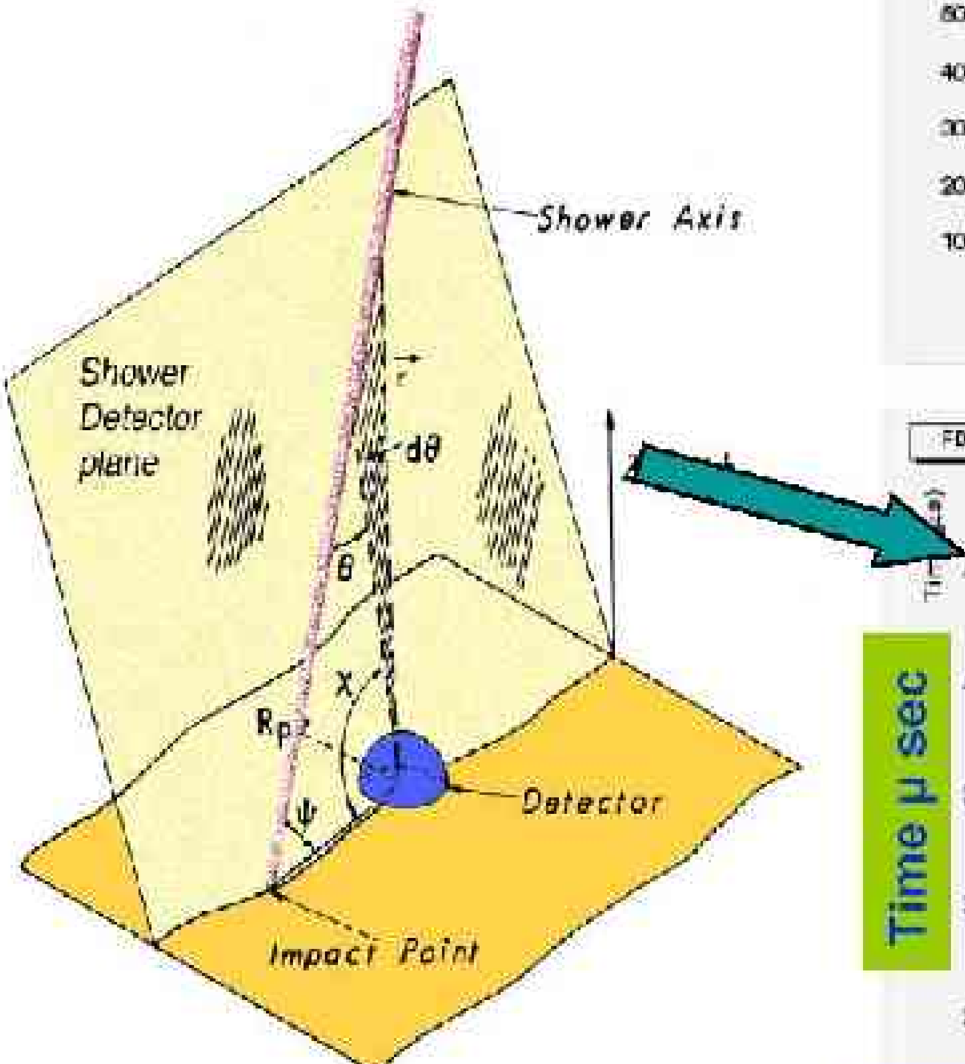
35 detectors triggered

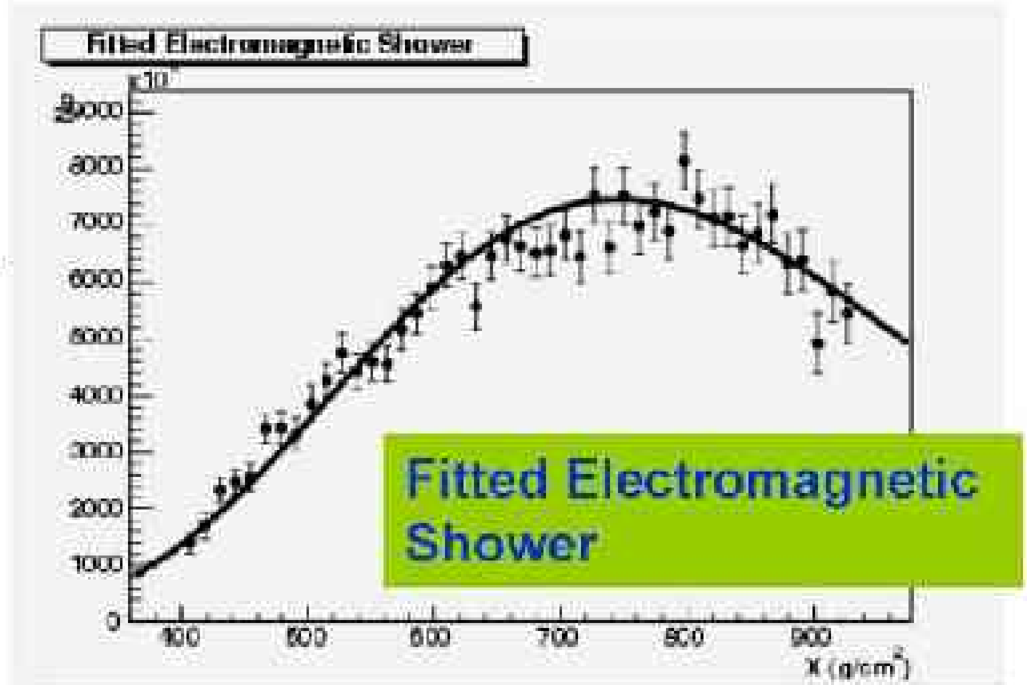


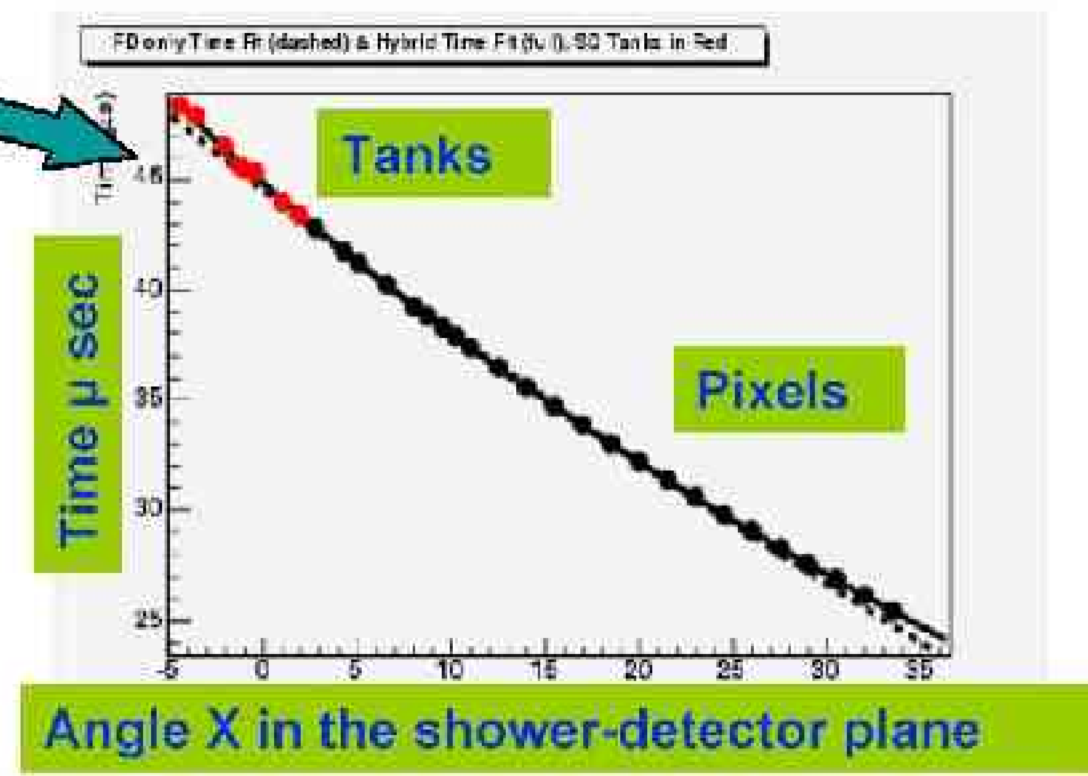




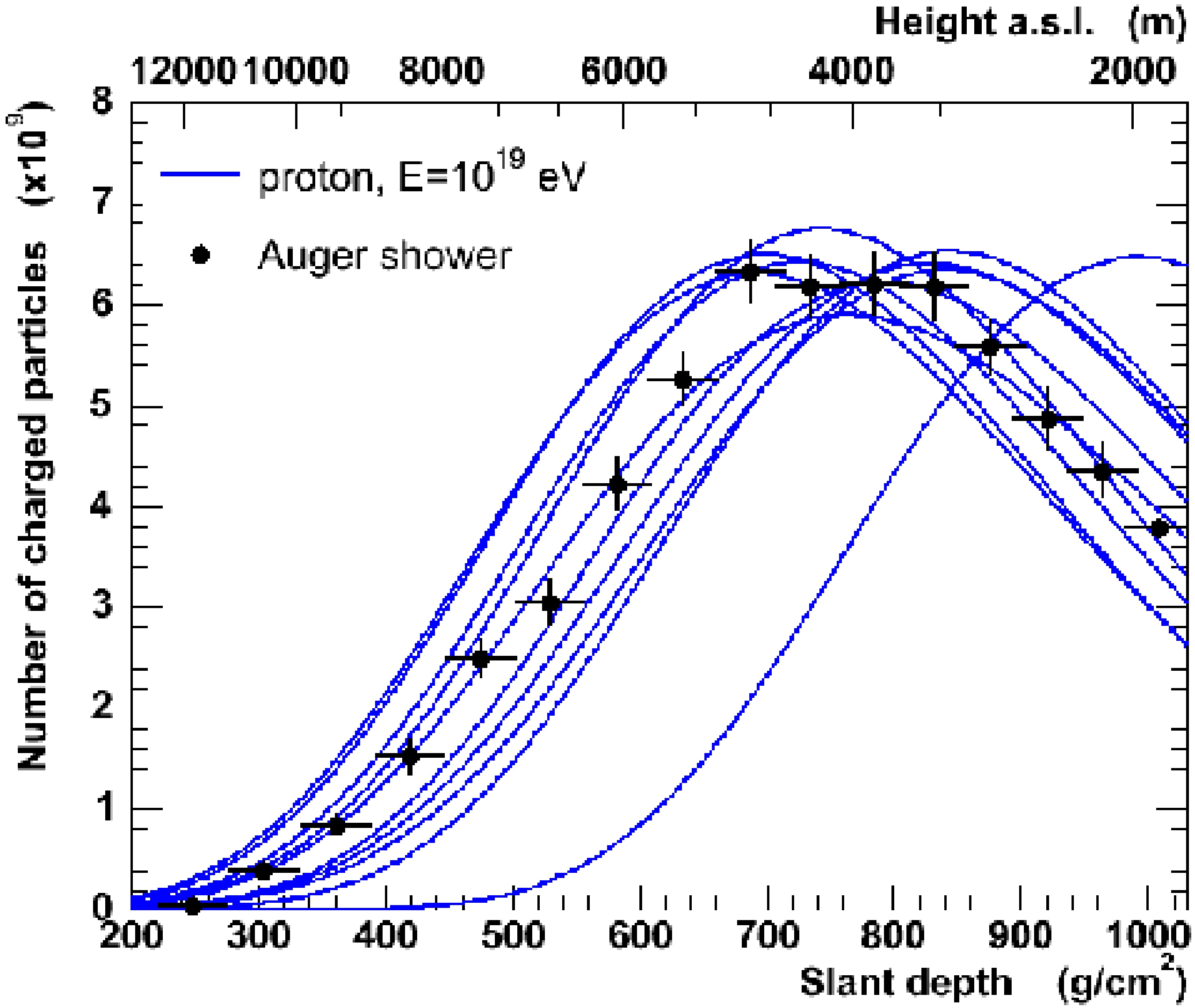
Hybrid Event
θ~ 30º, ~ 8 EeV







Fluorescence Light Measurements



Longitudinal Development of the Shower

Area $\propto$ Energy

Shape depends on :

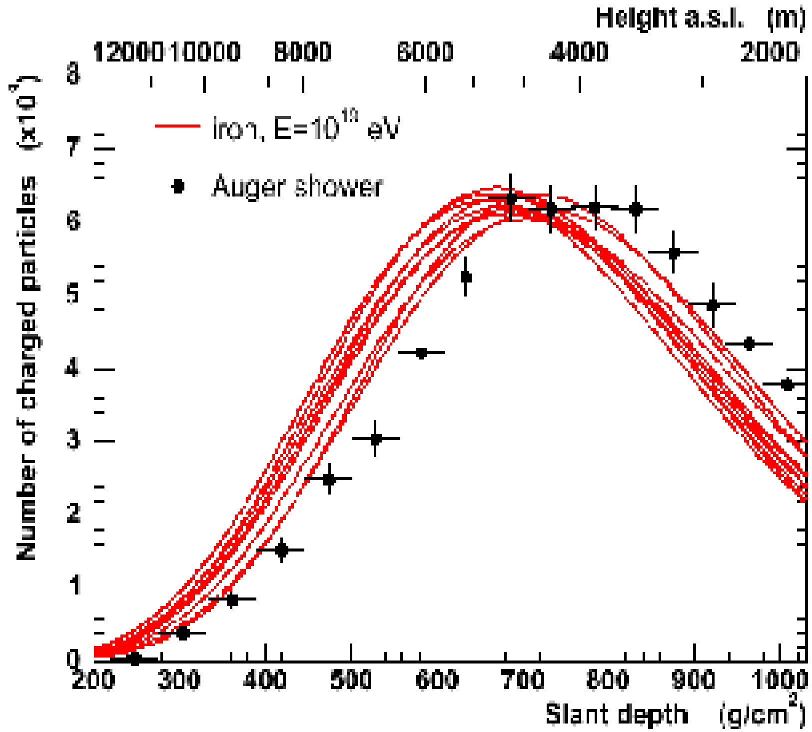
- Primary Identity
- Interaction Model

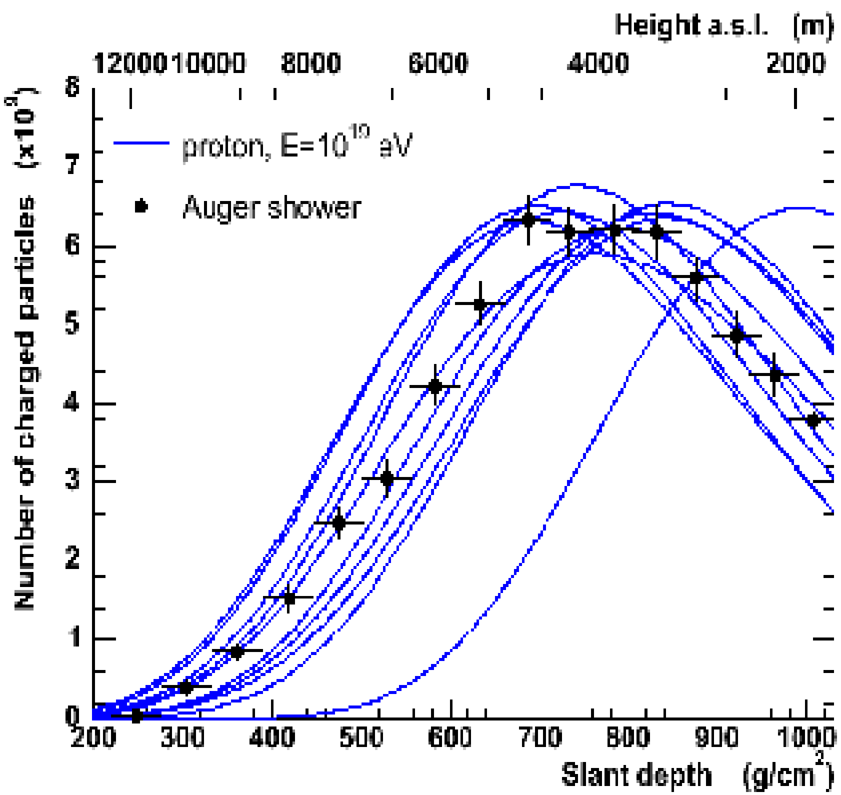
MC simulation: 10 showers
zenith angle 35°, QGSJET

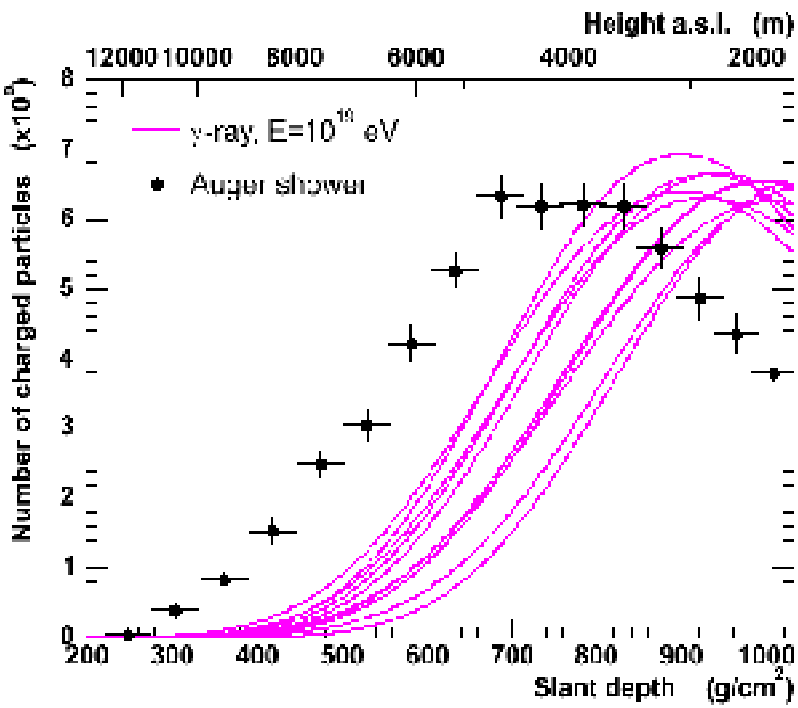
Fluorescence Light Measurements

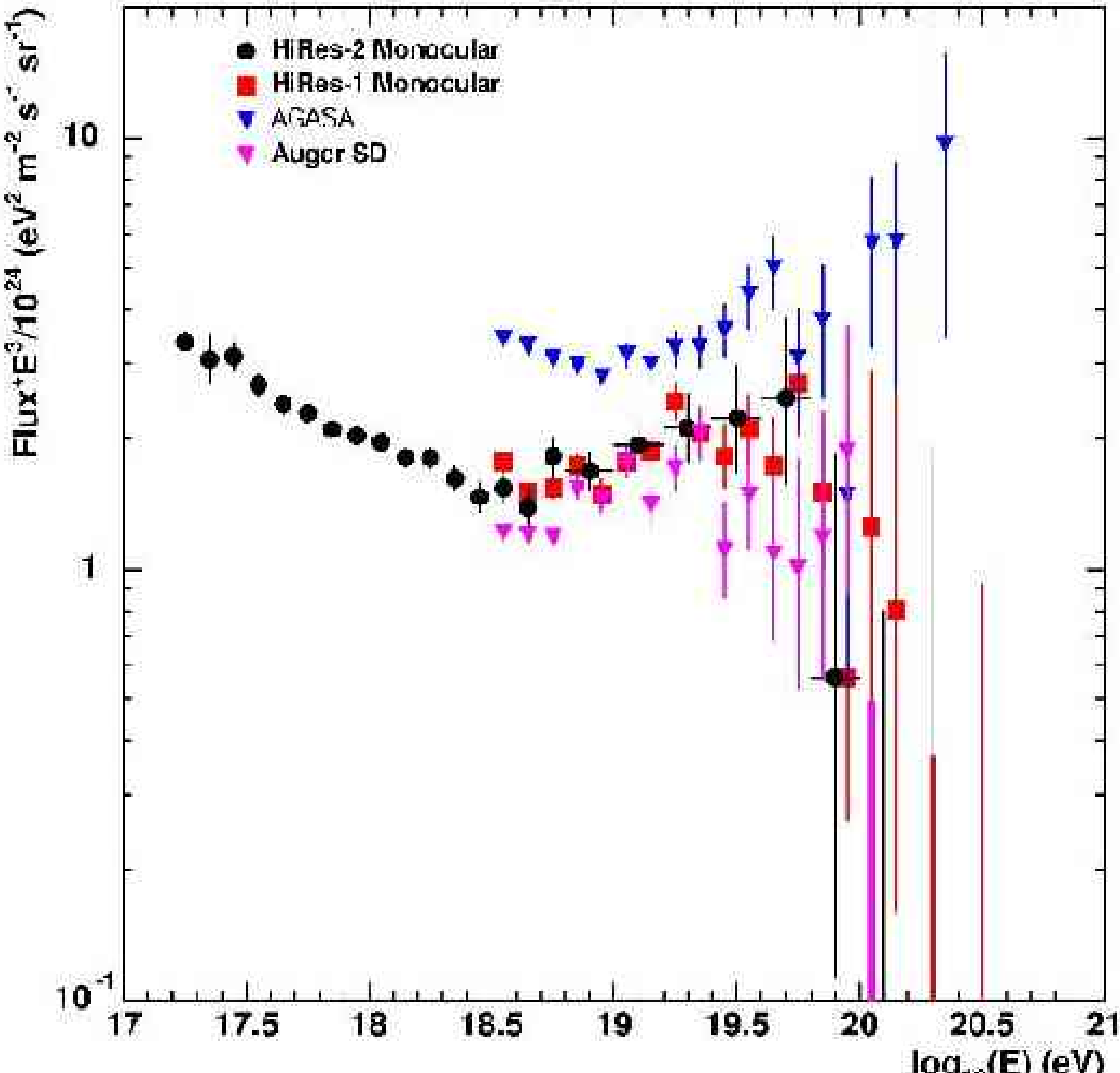
MC simulation: 10 showers
zenith angle 35°, QGSJET

Protons, Iron, Photons









Spectrum
at the
highest Energies

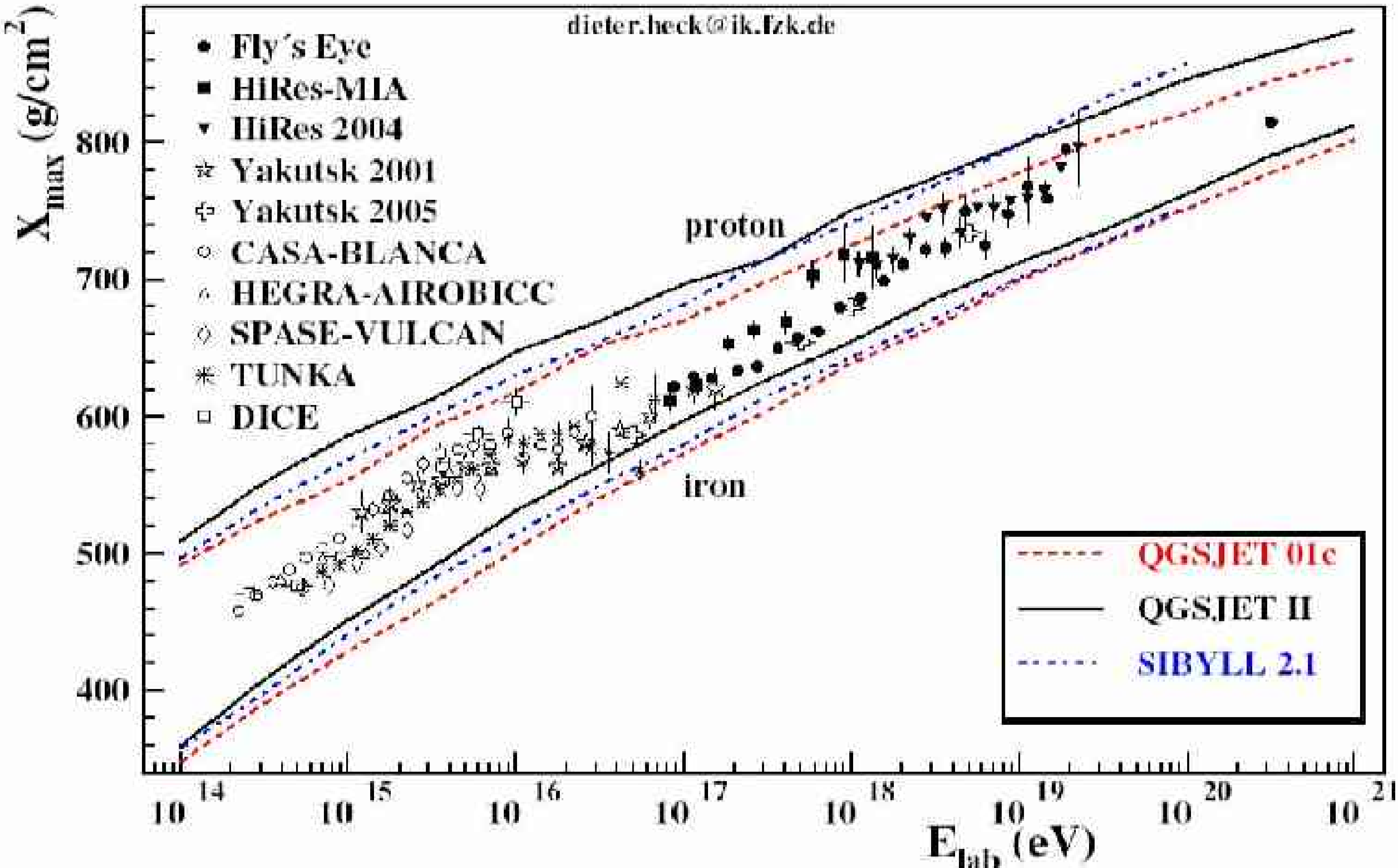
Form:

$\text{Flux} * E^3$

Discrepant
Results

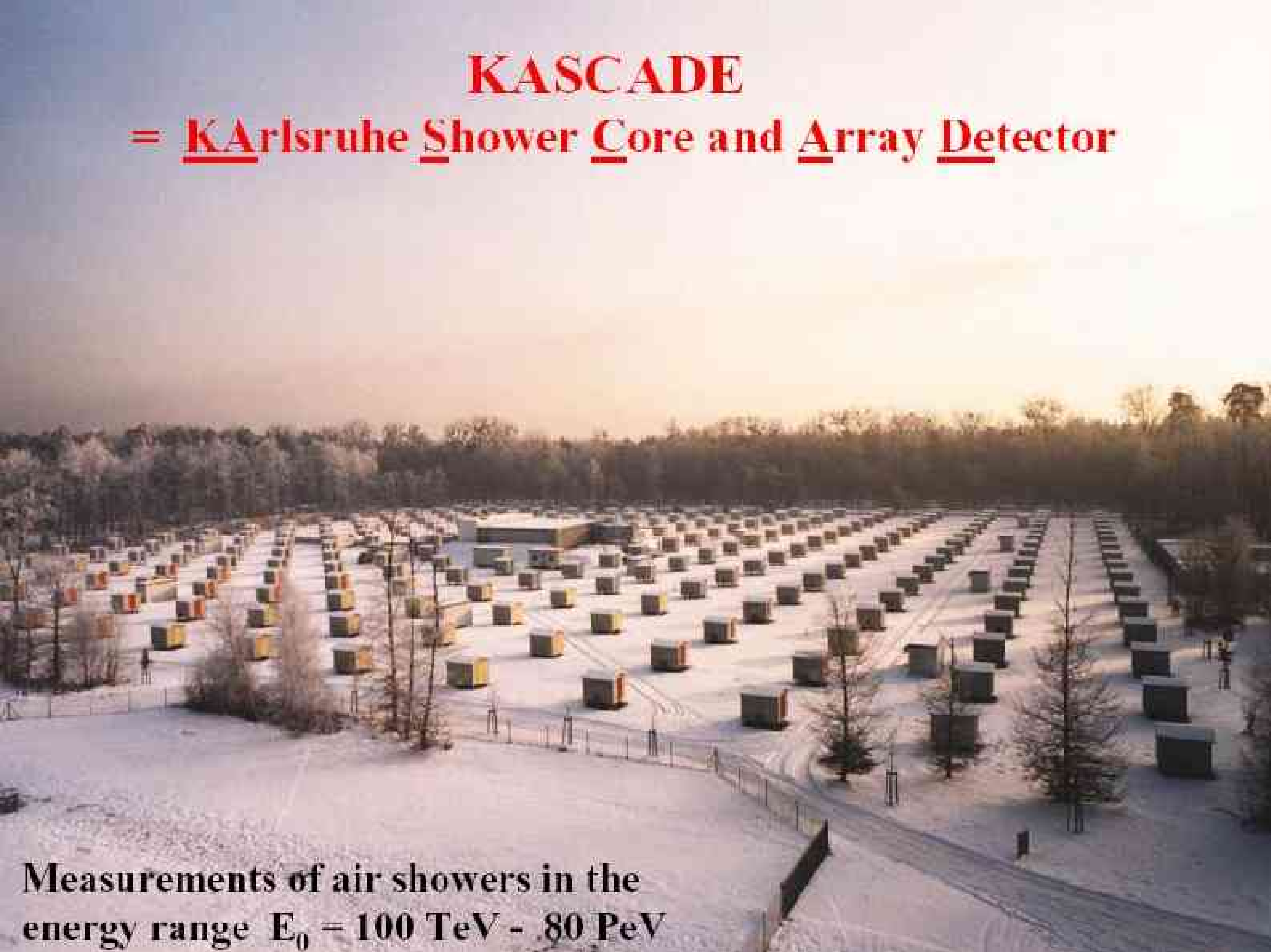
AGASA
HIRES
AUGER (1st release)

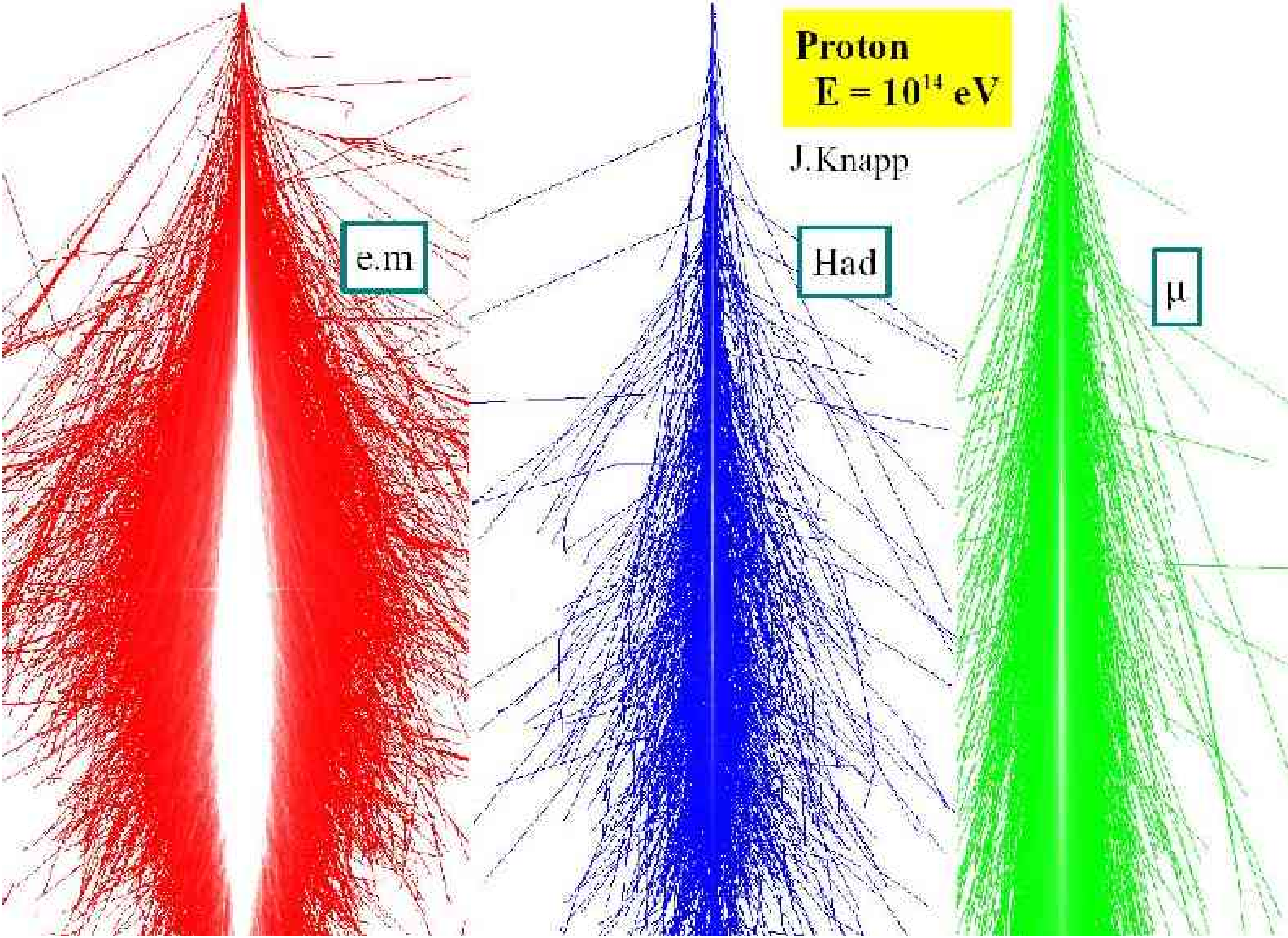
X_{max} vs. Energy for different models compared with data



Heck and Ostapchenko: ICRC 2005

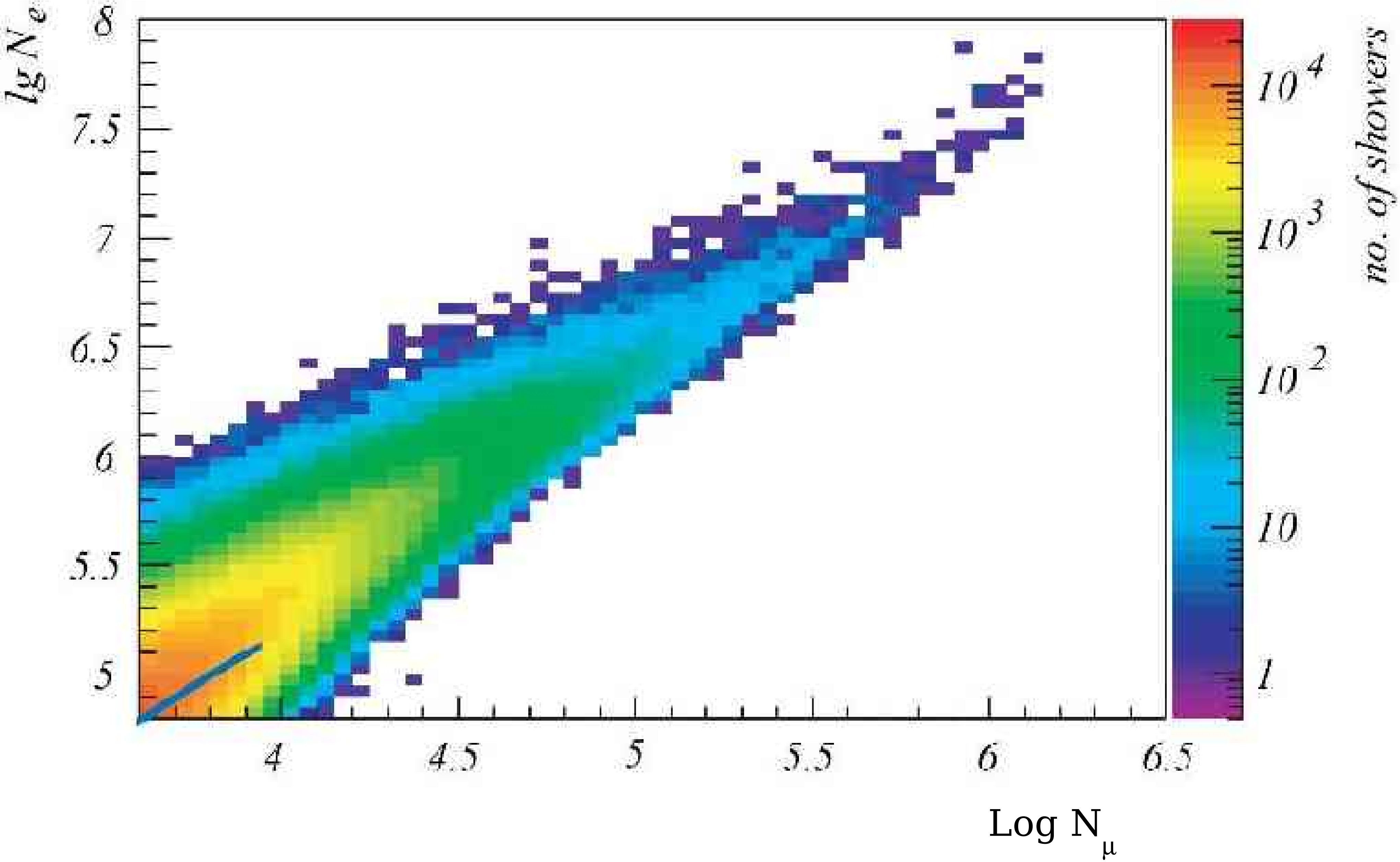
Significant Increase in MASS

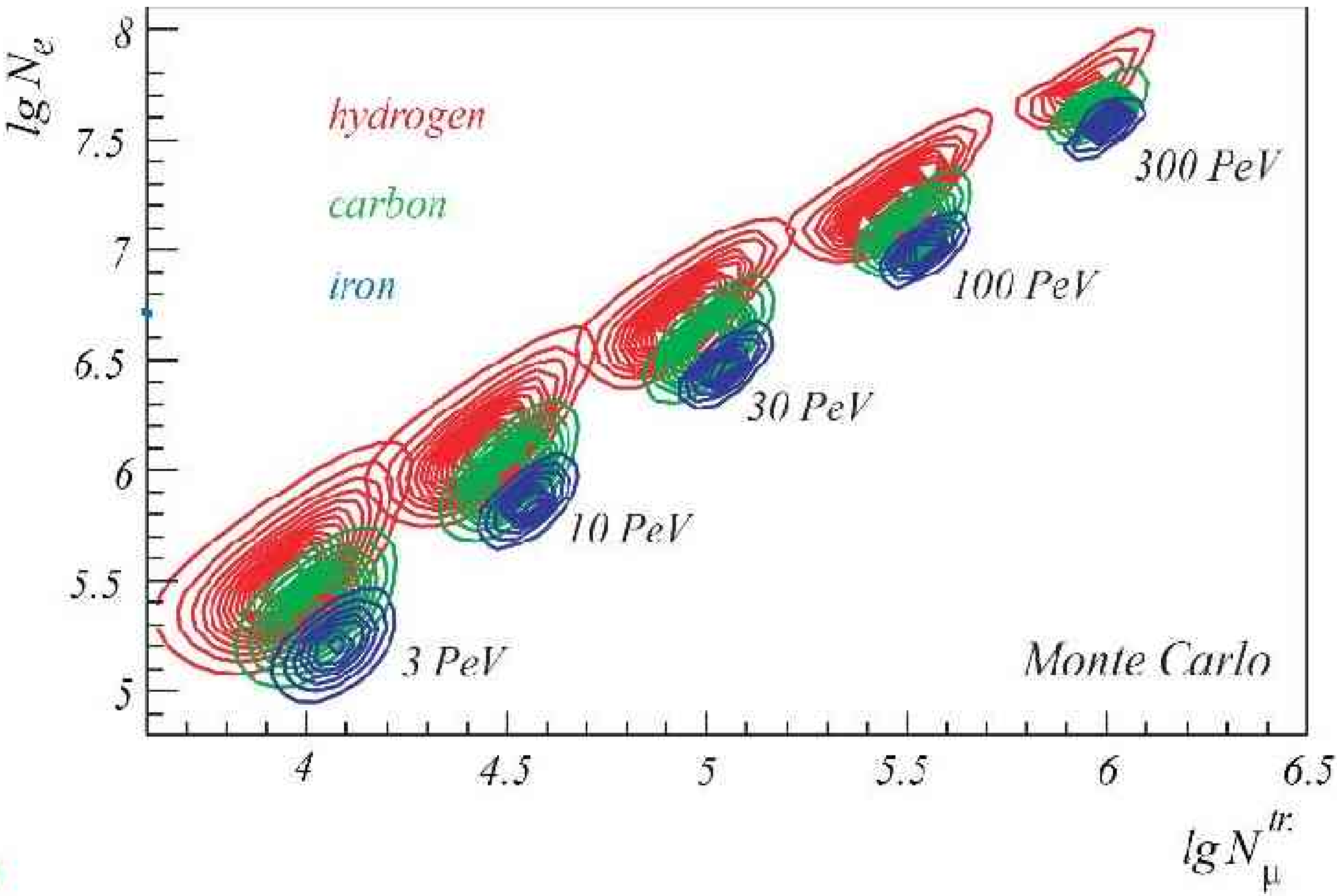

KASCADE
= KArlsruhe Shower Core and Array Detector
Measurements of air showers in the
energy range E_0 = 100 TeV - 80 PeV



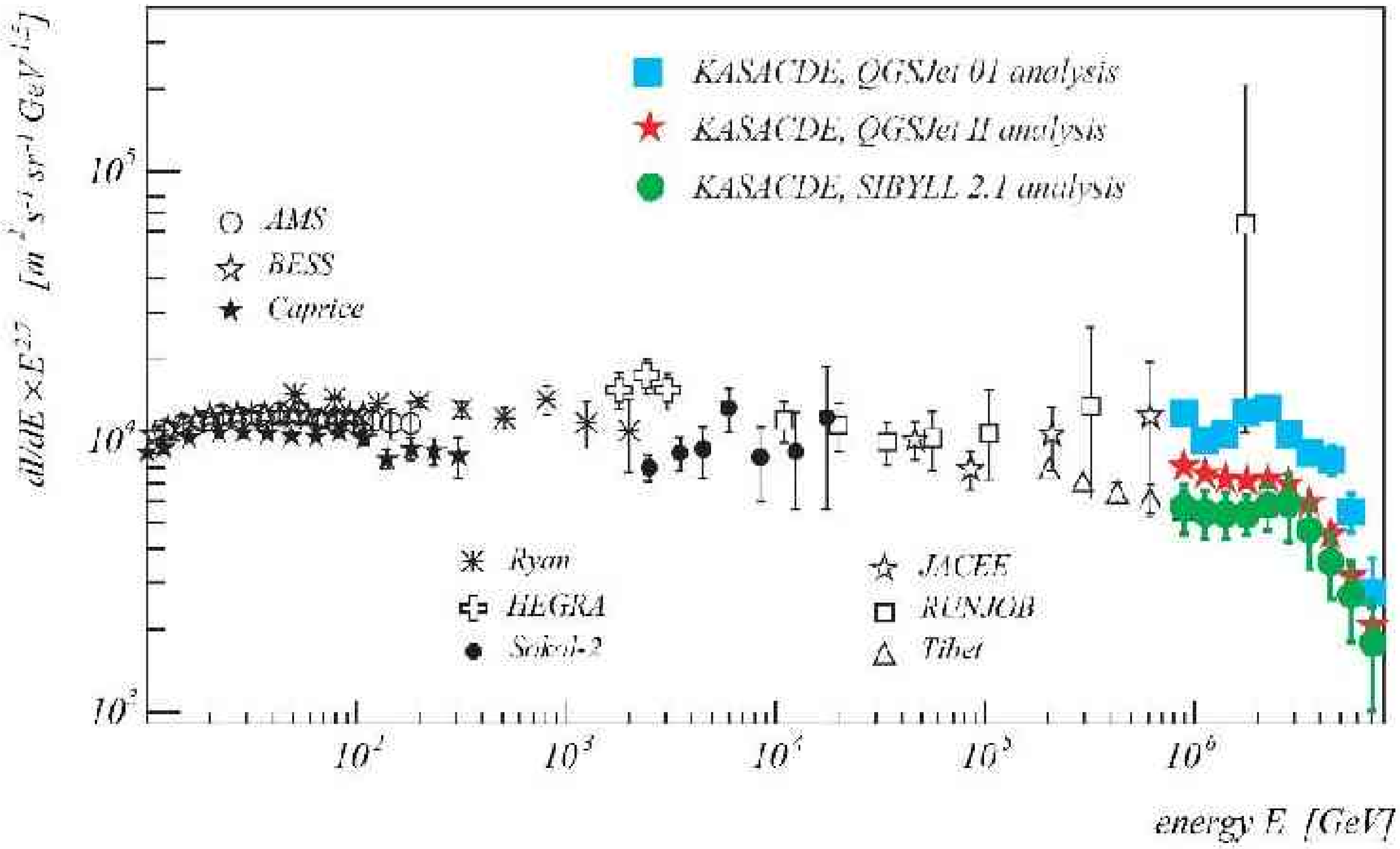
Proton
E = 10^{14} eV
J.Knapp
e.m
Had
μ

KASCADE Data : N(electrons) versus N(muons)




lg N_e
hydrogen
carbon
iron
300 PeV
100 PeV
30 PeV
10 PeV
3 PeV
Monte Carlo
8
7.5
7
6.5
6
5.5
5
4
4.5
5
5.5
6
6.5
lg $N_\mu^{tr.}$

QGSJET II : Lower Normalization heavier composition.



Hadronic Interaction Models (HE) for Cosmic ray Studies

DPMJET II.5 and III
(Ranft / Roesler, Engel & Ranft)

neXus 2.0 and 3.0
(Drescher, Hladik, Ostapchenko, Pierog & Werner)

QGSJET 98 and 01
(Kalmykov & Ostapchenko)

SIBYLL 1.7 and 2.1
(Engel , Fletcher, Gaisser, Lipari & Stanev)

Requirements for MC codes for CR studies:

- Hadron-Nucleus Capabilities (Nucleus-Nucleus)

$$p\text{–Nitrogen}, \qquad p\text{–Oxygen},$$
$$\pi^{\pm}\text{–Air},$$
$$K^{\pm}\text{–Air},$$

- Large Energy

$$\text{c.m. energy: } (\sqrt{s})_{pp} \sim 10^3 \text{ TeV}$$

- Single Initialization for
  a broad range of energies and Projectiles

- Accurate description of the highest energy
  particles in an interaction
  (Projectile Fragmentation region)

Most Important Ingredients for CR Energy Measurement and Particle Identification

- Inelastic Cross Sections
- Separation of Diffractive and Non Diffractive Events
- “Leading Baryon” Particle
- Projectile Fragmentation region : $[x_F > 0.1]$
- Nuclear Effects
  (from p-p to p-Nitrogen)

Total Cross section

$$\sigma_{pp}(\text{tot}) = \sigma(\text{elastic}) + \sigma(\text{inelastic})$$
$$= \sigma(\text{elastic}) + \sigma(\text{Non Diffractive}) + \sigma(\text{Single Diffraction}) + \sigma(\text{Double Diffraction})$$

Elastic Cross section

$$E_{f,\text{lab}} = E_{0,\text{lab}} \left[1 - \frac{|t|}{s}\right]$$

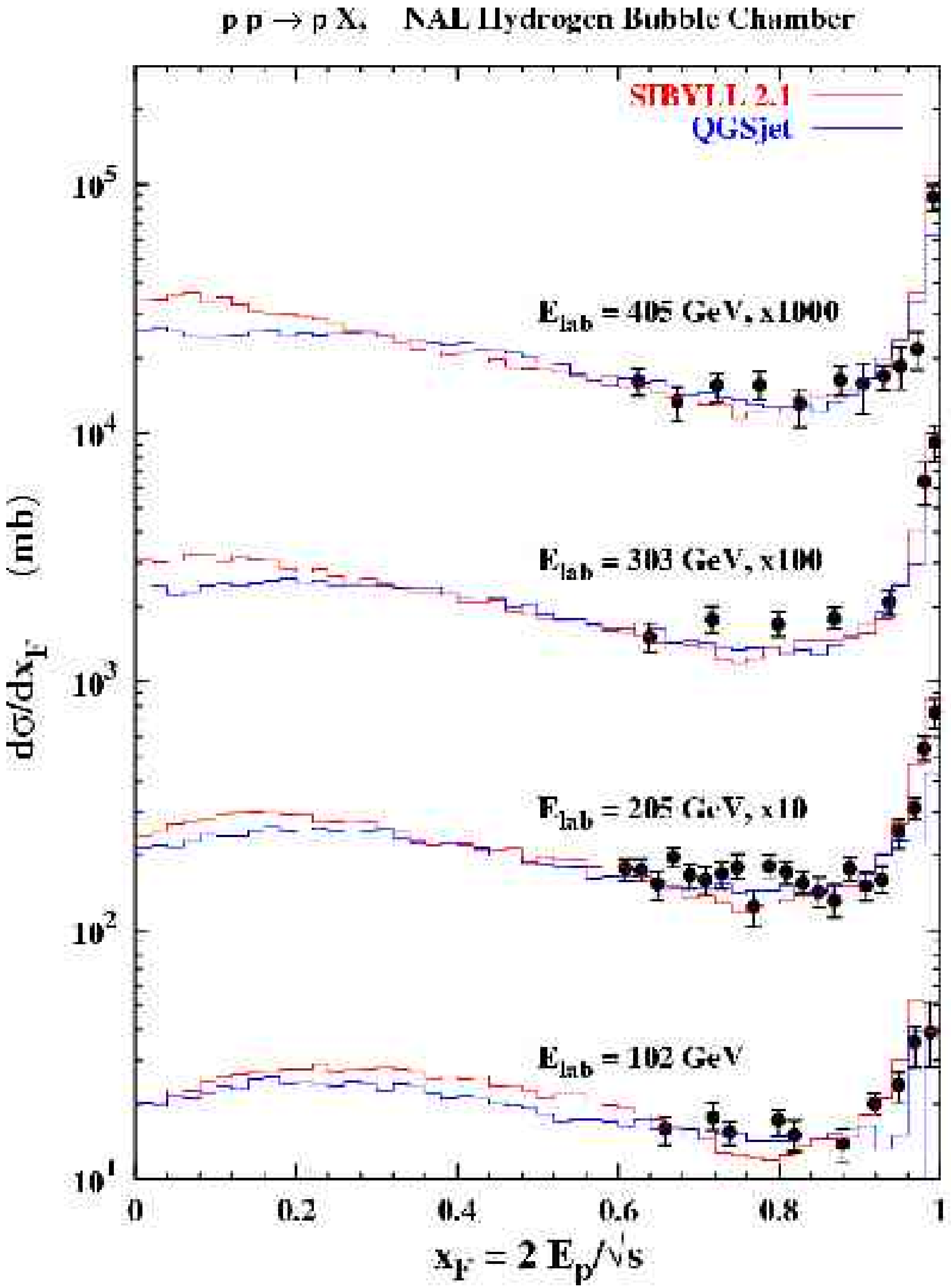
Target Diffraction Cross Section: $p + p \rightarrow p + p^*$

$$E_{f,\text{lab}} \simeq E_{0,\text{lab}} \left[1 - \frac{M_X^2 - m_p^2}{s} - \frac{|t|}{s}\right]$$

$$\sigma_{p\ \text{Nitrogen}}(\text{tot}) = \sigma(\text{elastic}) + \sigma(\text{Nuclear Fragmentation}) + \sigma(\text{Particle Production})$$

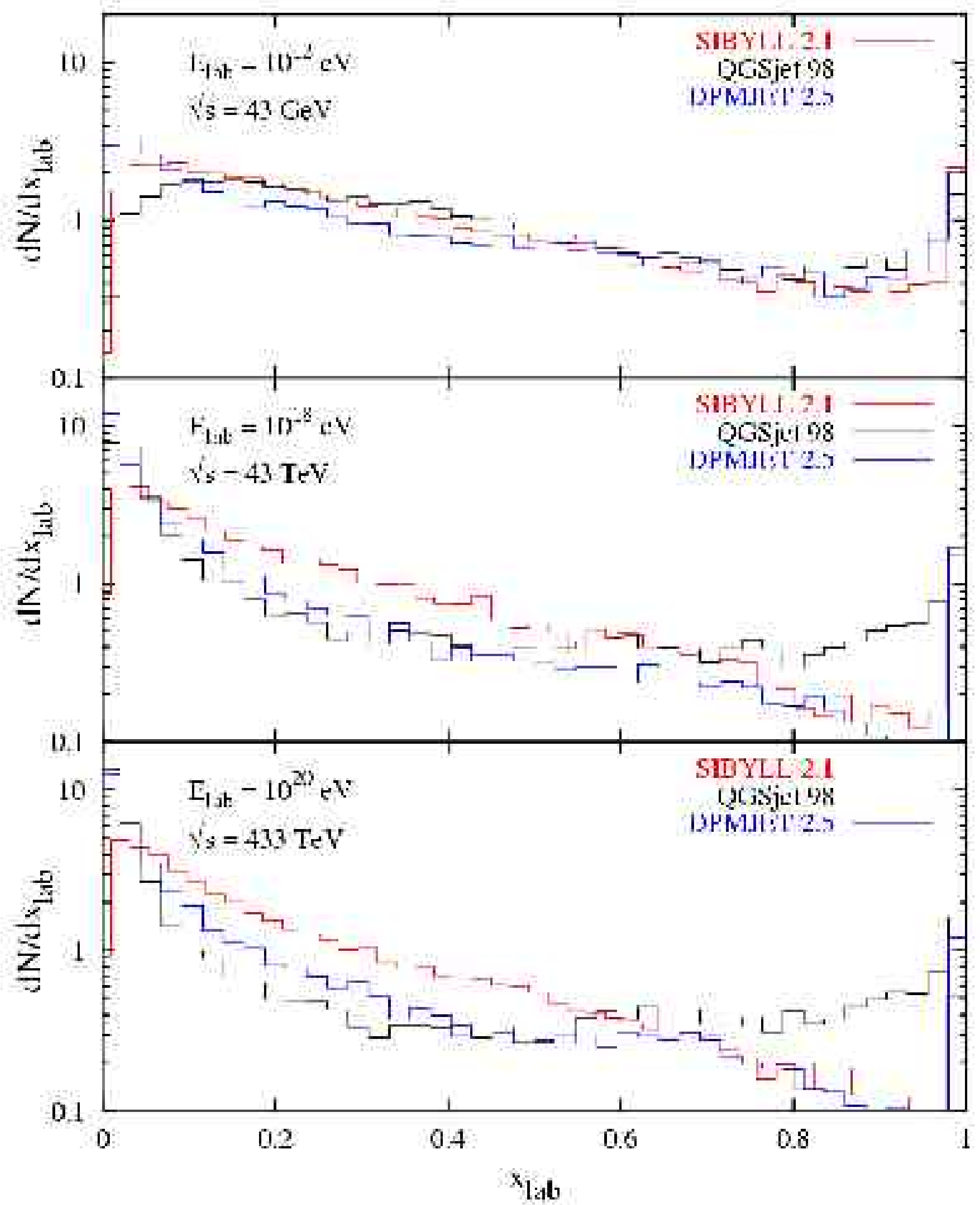
“Leading” particle production

Low Energy
(Fixed Target)
DATA



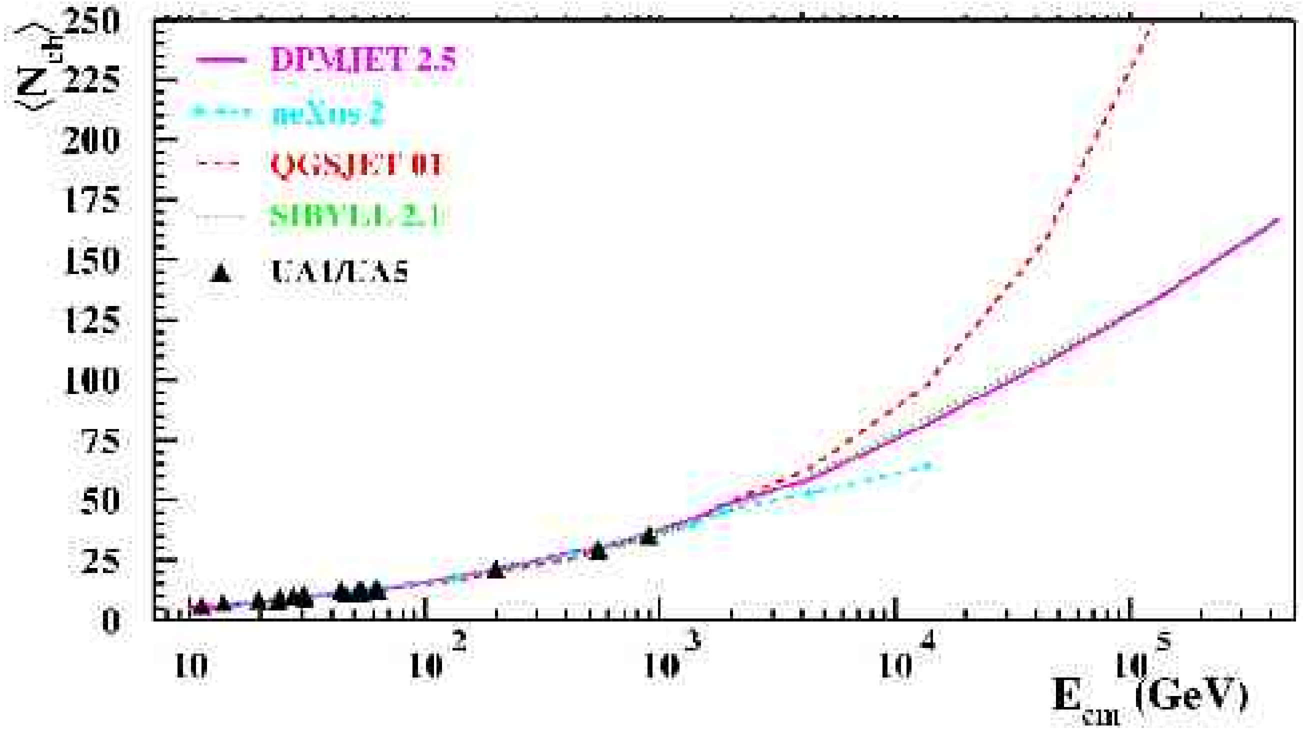
“Leading” particle production

Extrapolation to High Energy



Secondary particle multiplicity

Mean charged
particle multiplicity



Proton-antiproton
at CERN SPS & Tevatron

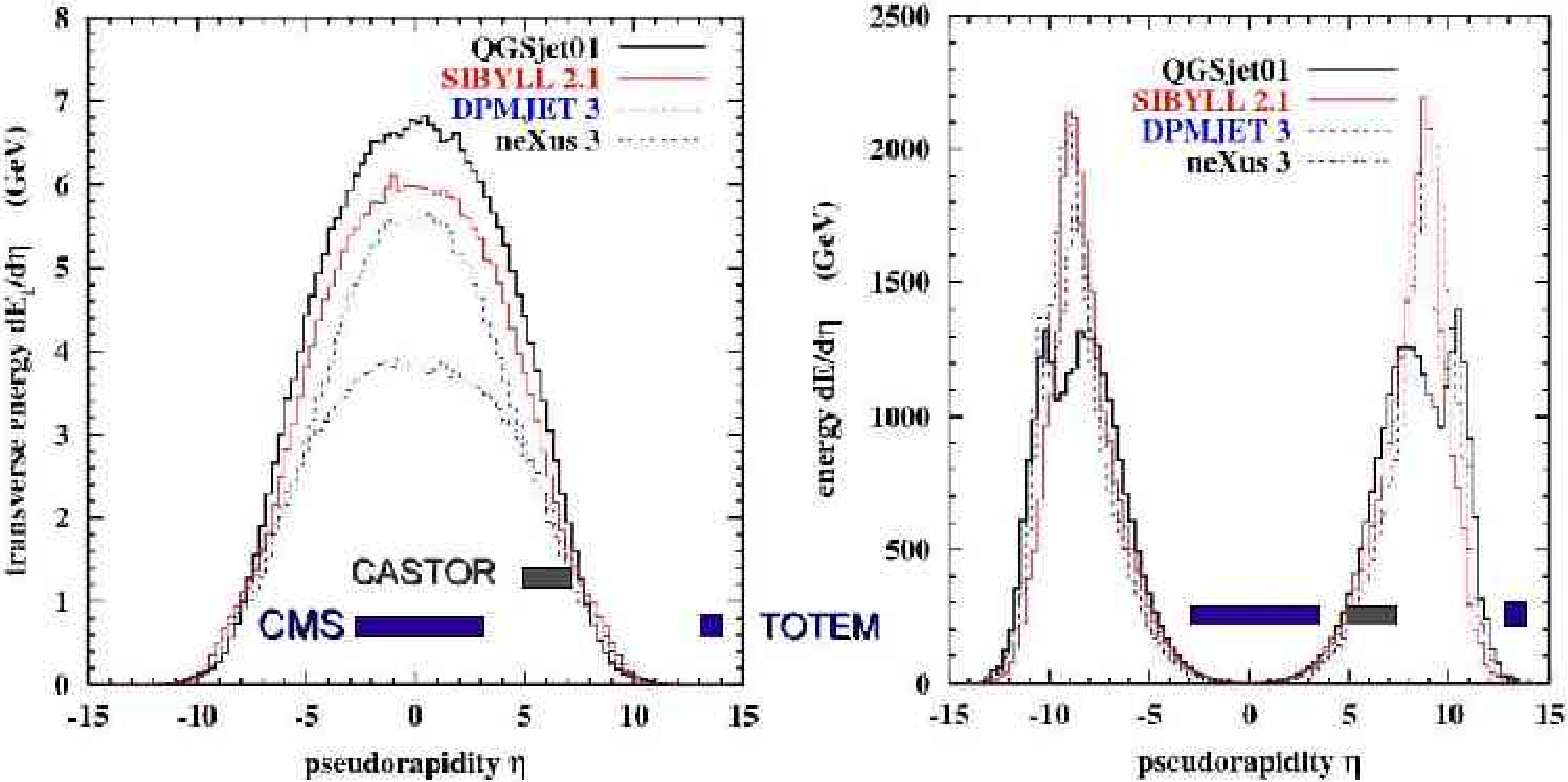
Projectile Fragmentation Region

Few Particles control the “Energy Flow”

$$\frac{dn}{dx_F} \propto \frac{(1 - |x_F|)^\alpha}{|x_F|}$$

$$|\eta| \sim \log\left[\frac{\sqrt{s}}{\langle p_\perp \rangle \, (1+\alpha)}\right]$$

Discrimination potential of LHC



- p-p collisions at LHC at $\sqrt{s}$ = 14 TeV
- major experiments consider to do CR relevant measurements (for example, CMS / CASTOR / TOTEM)

LHC is a UNIQUE possibility to obtain information on hadronic interaction properties that is crucial for Cosmic Ray studies.
This potential should be fully exploited.

- Very small integrated luminosities are in principle sufficient to obtain significant results.

- MonteCarlo codes developed to descrive Minimum bias event samples at LHC have immediate applications for CR.

- Only a part of the kinematical space important for CR studies is directly observable with the present detectors.

Testable theoretical ideas can relate the Physics in the "central region" to particle production in the "fragmentation regions".

Verify the interests for this line of research.

Organize forms of comunication and collaboration LHC/CR.

Understand rapidly the relevant information contained in the LHC data.
(Information could also flow in the opposite direction from CR → particle physics)

Develop MC algorithms/codes to describe the LHC minimum bias data possibly within a consistent and well motivated theoretical framework.

Make these MC algorithms/codes available for the simulation of CR showers.

Discuss the "fundamental (per se) significance" of detailed studies of "forward physics" for LHC

Ringraziamenti a:

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