Test of high-energy hadronic interaction models using the KASCADE-Grande data.

2020 MEETING OF THE COSMIC RAY DIVISION OF THE MEXICAN PHYSICAL SOCIETY

David Rivera Rangel. IFM-UMSNH

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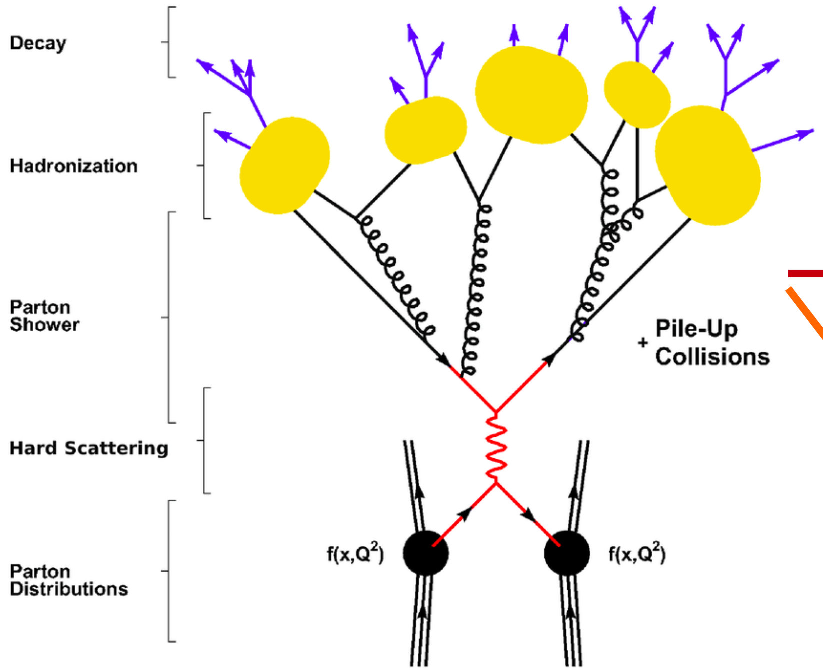
Motivation



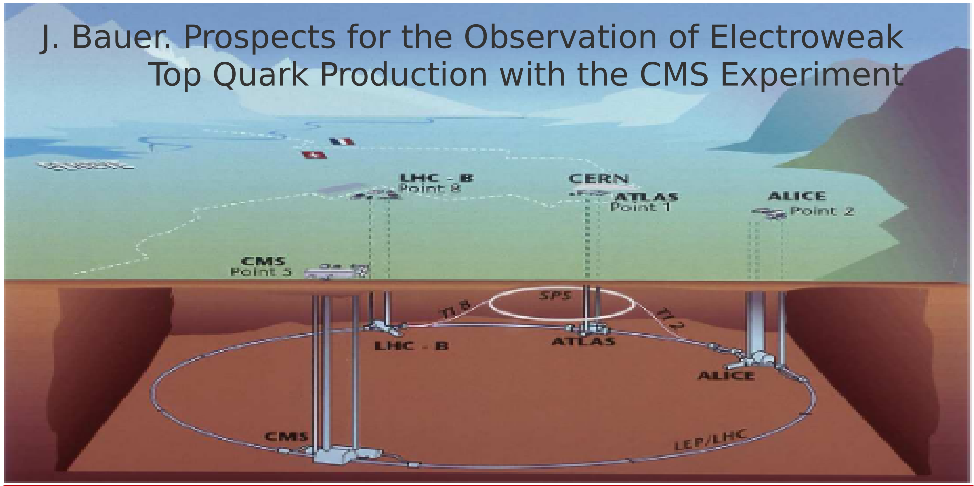
J. Bauer. Prospects for the Observation of Electroweak Top Quark Production with the CMS Experiment

Soft Region

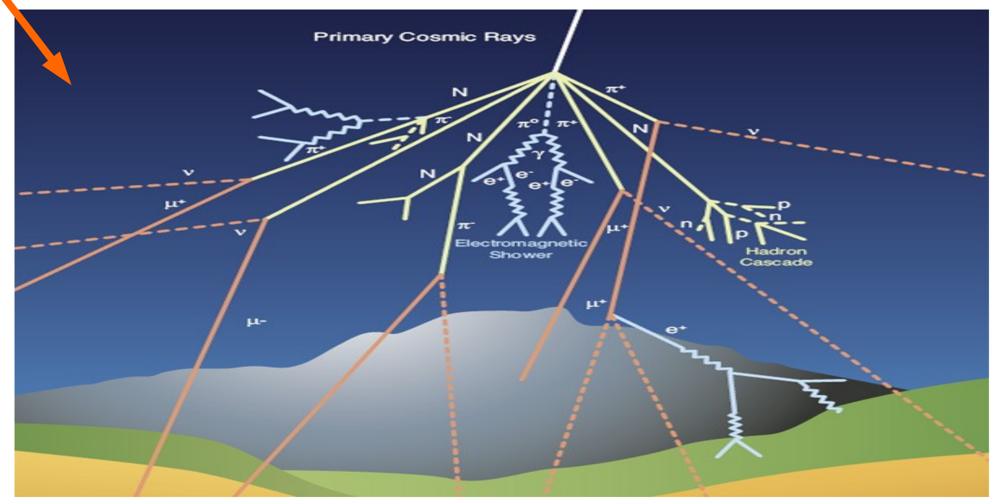
$$|q^2| \sim p_t^2 < Q_0^2, \ Q_0^2 \sim 1\,\mathrm{GeV}^2$$

Hard Region

$$|q^2| \gg Q_0^2$$



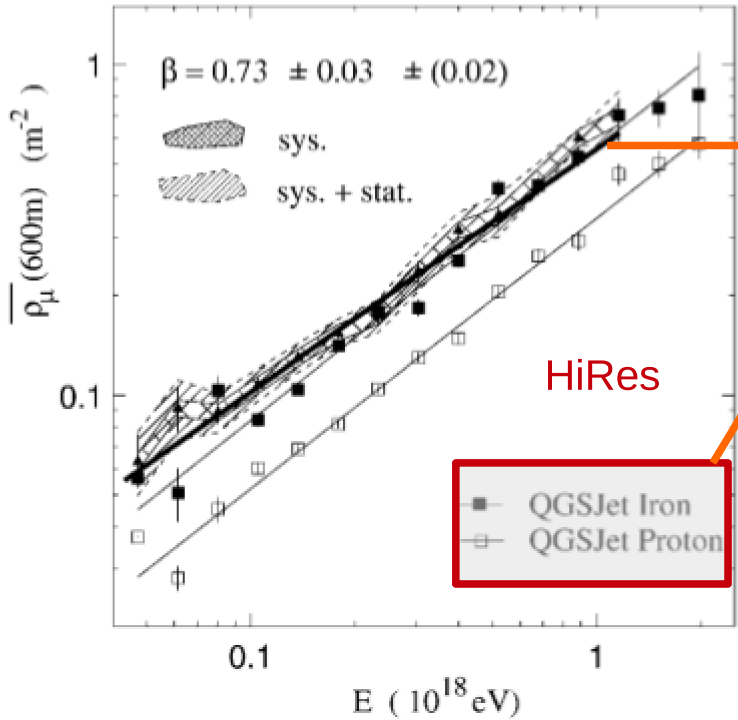
Development of the Extended Air Showers and the interactions of the particles with atmosphere are described by fenomenological models which are based on colliders data.



Indico.cern.ch/D.Gora

Motivation

T. Abu-Zayyad et al. (MIA, HiRes), Phys. Rev. Lett. 84, 4276 (2000)



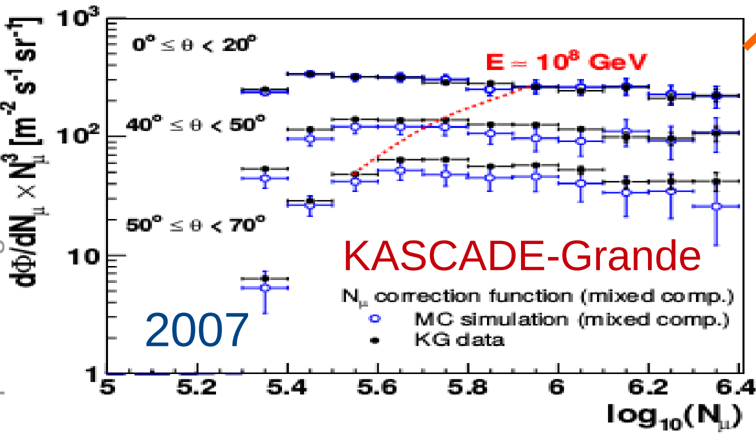
Year 2000

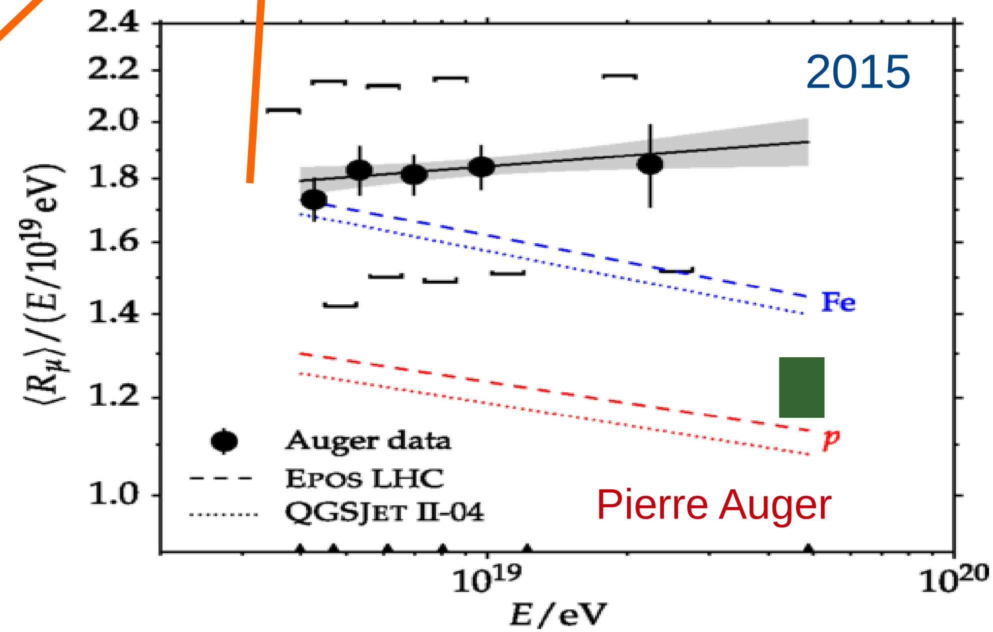
HiRes data fit line.

Simulation made with hadronic interactions models.

Experiments show a bigger abundance of muons than the model predictions.

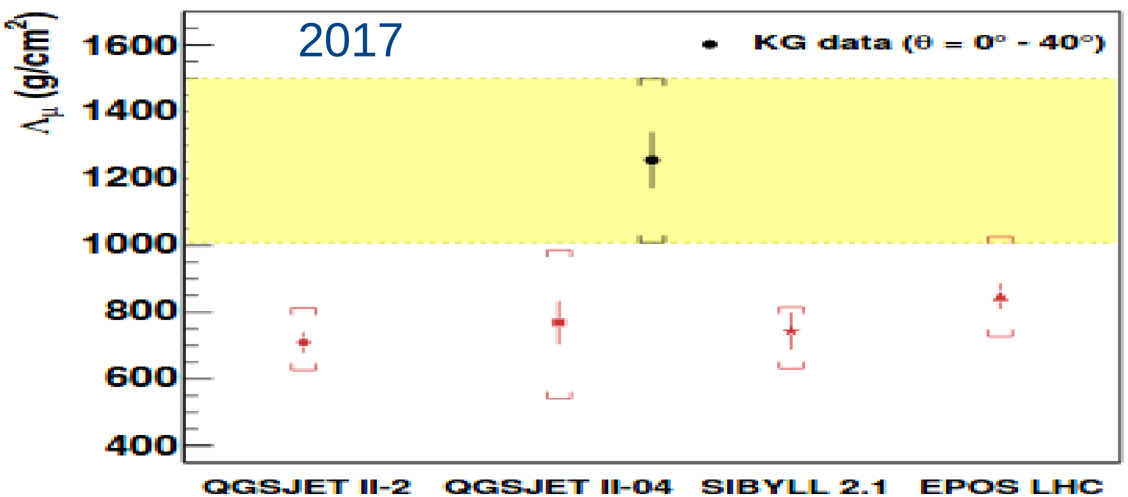
J.C. Arteaga, W.D. Apeñ et. al., ICRC 2007 proceedings.





Auger Coll., Phys. Rev. D 91, 032002 (2015)

Motivation

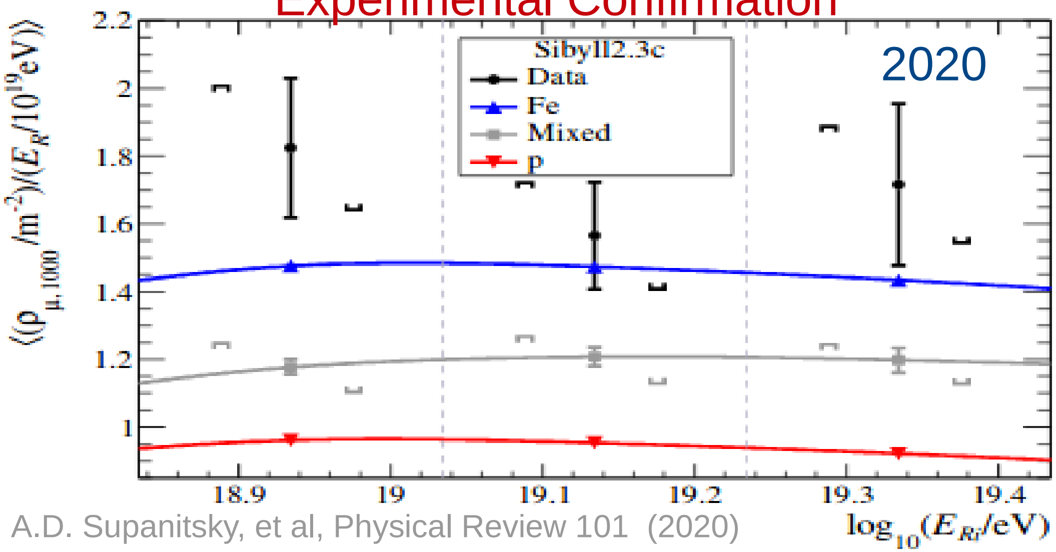


J.C. Arteaga-Velazquez, et al., Astropart. Phys. 95 (2017) 25.

KASCADE-Grande

- Discrepancies between hadronic models and experimental data on the muon densities and muon attenuation length.
- Study using muon densities, number of muons and reconstructed energy.

Experimental Confirmation



A.D. Supanitsky, et al, Physical Review 101 (2020)

AGASA

KASCADE-Grande experiment

Karlsruher Institut für Technologie

December 2003-November 2012

$E=10^{14}$-10^{17} eV

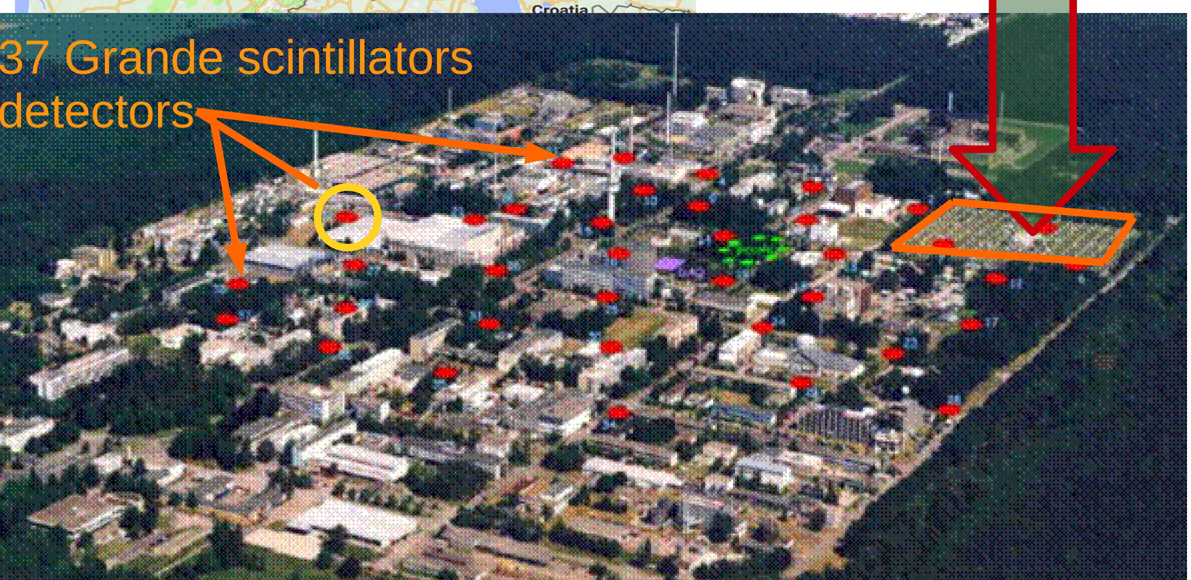
200x200 m²

KASCADE

700x700 m²

Grande

+



= KASCADE-Grande

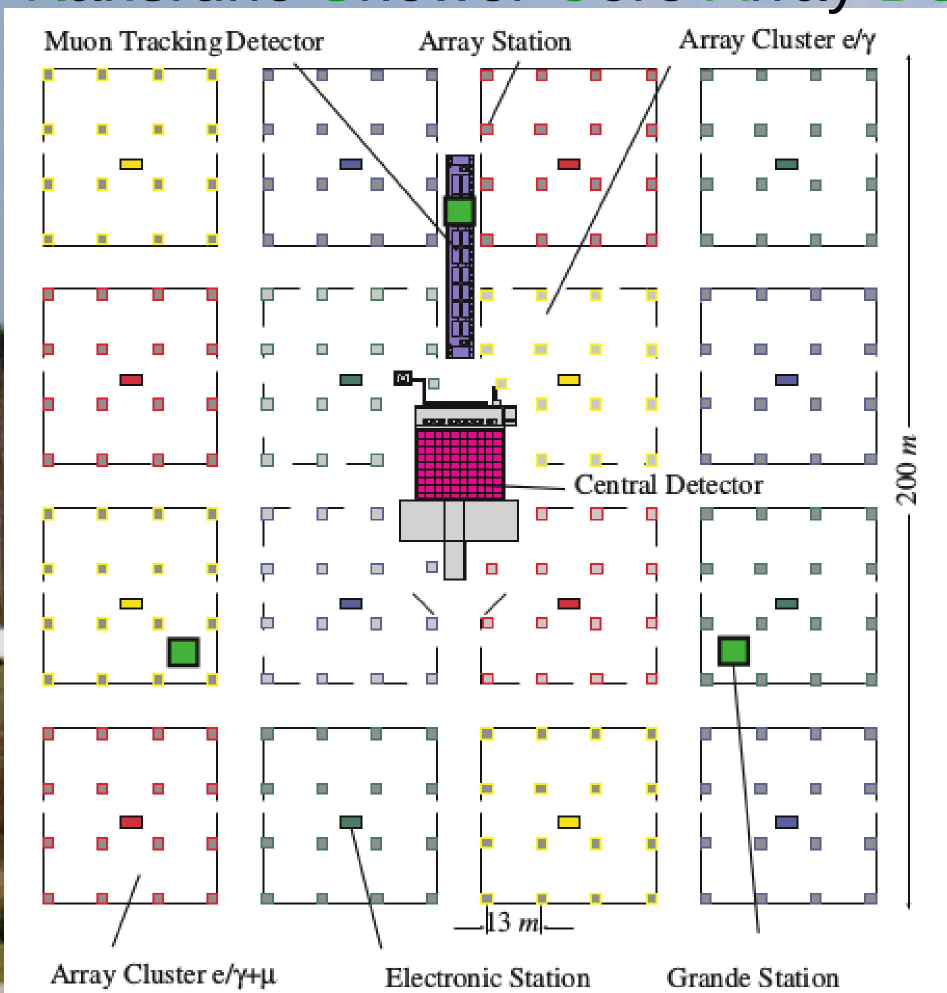
$E=10^{15}$-10^{18} eV

Observables:

- N_e
- N_μ
- N_{ch}
- N_h

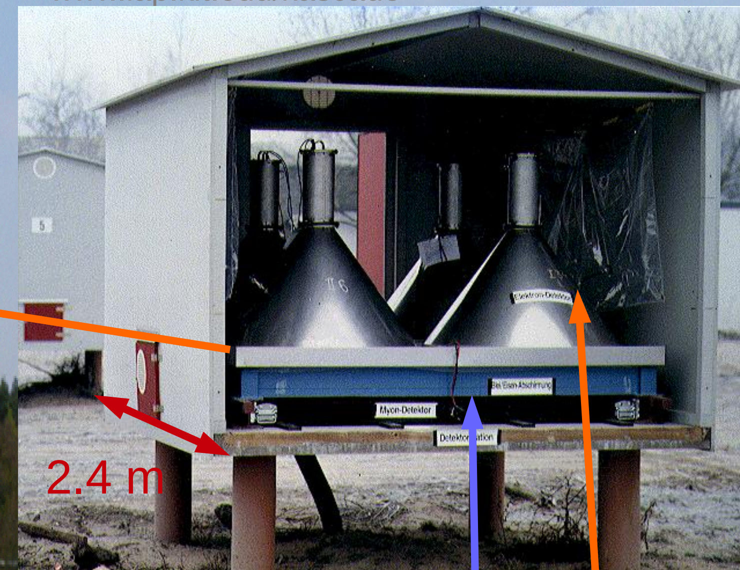
KASCADE Experiment

Karlsruhe Shower Core Array Detector



W.D. Apel, et al., Nuclear instruments in physics Research. 2010.

www.iap.kit.edu/kascade



Area: 200x200 m²

- 252 e/γ detectors (scintillator)
- 192 detectors μ (Shielded).
- Central Detector.
- Calorimeter.
- Muon Tracking detector.

Observables:

- N_e, N_μ, $N_{hadrones}$

$E=10^{14}$-10^{17} eV

Grande Array

www.iap.kit.edu/kascade

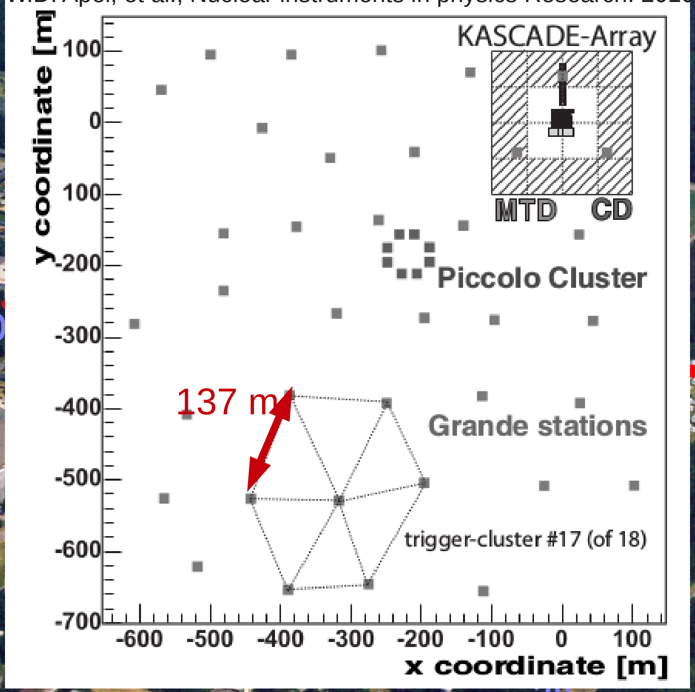
GRANDE

- Area: 0.5 km²
- $A_{detector}$: 10 m²
- 37 detector stations
- Separation: 137 m
- Increase the energy rank of the cosmic rays to the EeV.
- Clusters of 7 detectors.
- Plastic Scintillators.

μ

N_{ch}

W.D. Apel, et al., Nuclear instruments in physics Research. 2010



Charged particles and Muons

The number of muons has to be estimated

The total number of muons N_μ in the shower disk is derived from a maximum likelihood estimation Assuming the locally muons detected by KASCADE To fluctuate according to a Poisson distribution.

$$N_\mu^{rec} = \sum_{i=1}^{k} n_i / \sum_{i=1}^{k} (f(r_i) A_i \cdot \cos(\theta))$$

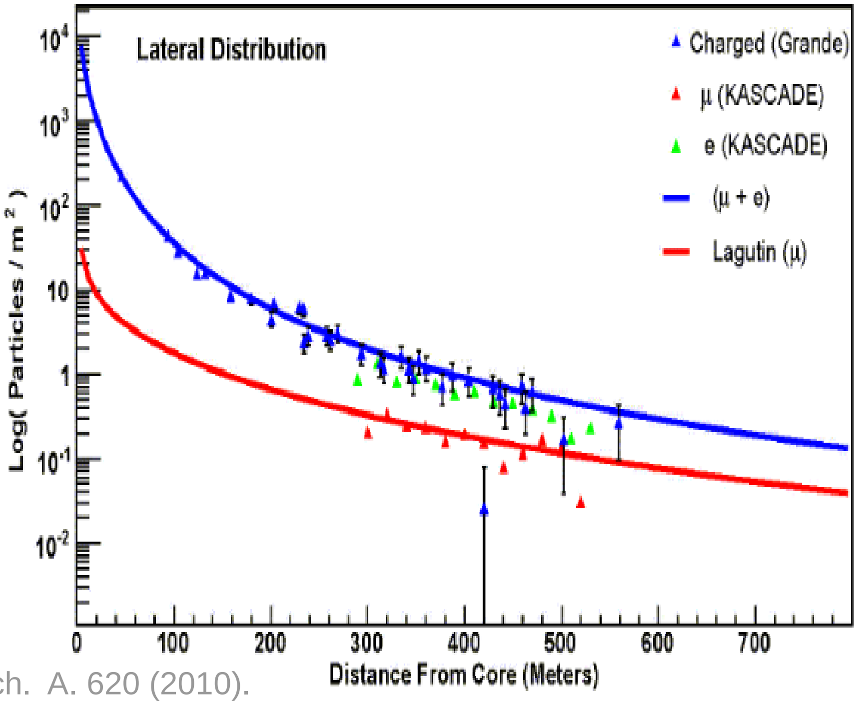
- n_i is the number of particles measured in one muon detector.
- r_i is the core distance.
- A_i is the Sensitive area of the detector.
- f(r) is a lateral distribution function based on the Proposed by **Lagutin**.

$$f(r) = \frac{0.28}{r_0^2} \left(\frac{r}{r_0}\right)^{p_1} \left(1 + \frac{r}{r_0}\right)^{p_2} \left(1 + \left(\frac{r}{10 \cdot r_0}\right)^2\right)^{p_3}$$

The parameters: p_1=-0.69, p_2=-2.39, p_3=-1.0 r_0=320 m were based on CORSIKA simulations

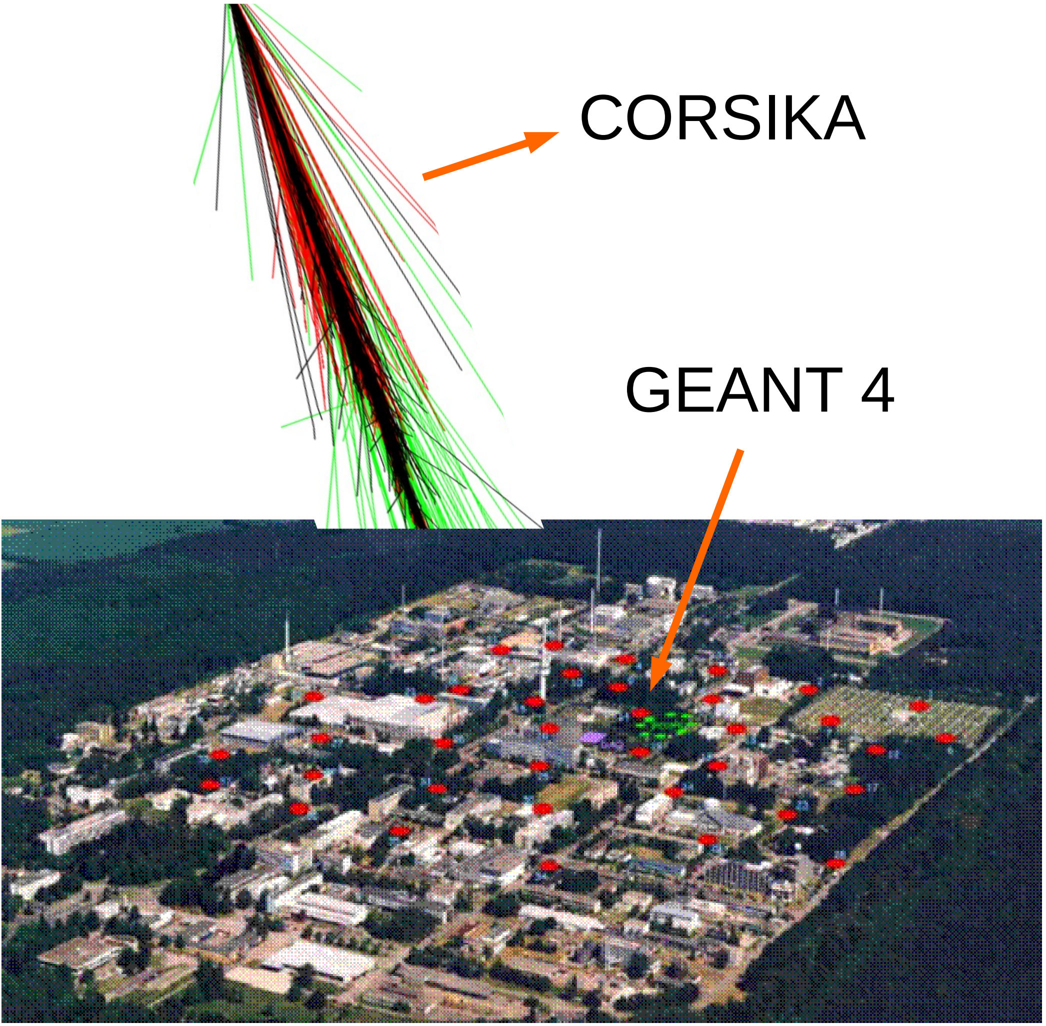
Lateral distribution

$$\rho_\mu(r) = N_\mu f(r)$$



W.D. Apel, et al., Nuclear instruments in physics Research. A. 620 (2010).

Quality Cuts



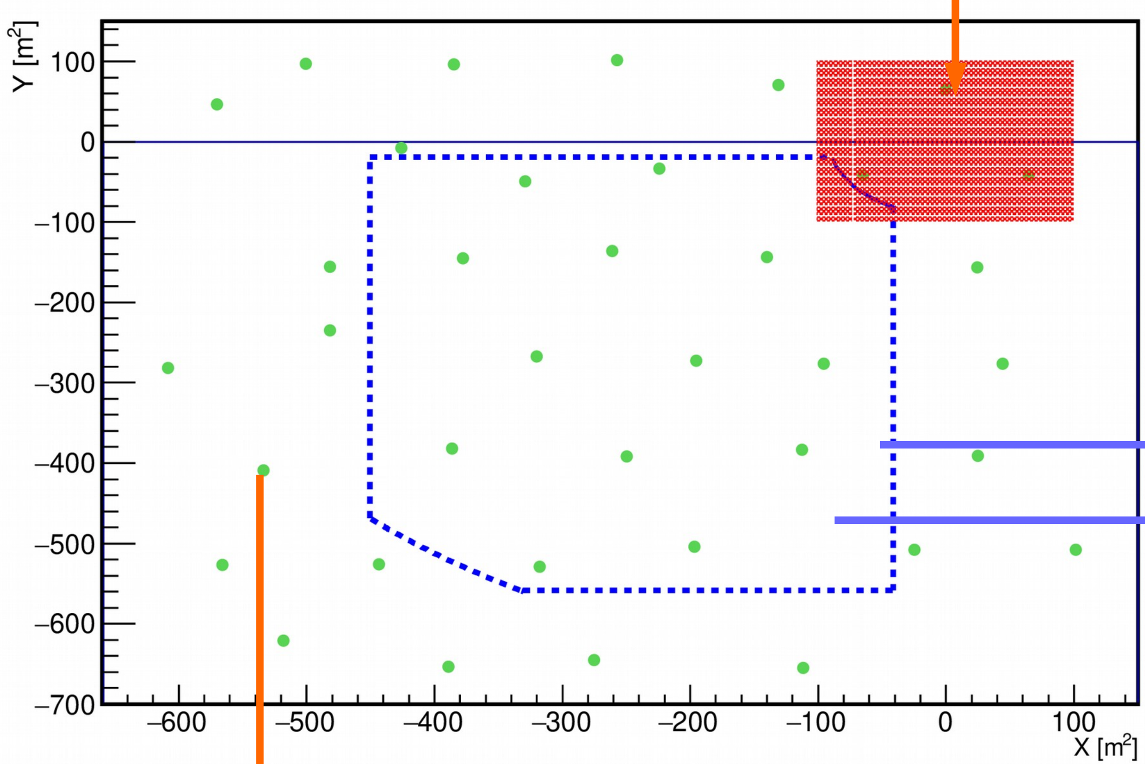
- Fiducial Area
- Cuts on the direction of arrival angle (Compare similar data sets)
  - **Acceptance** 656.902 m^2*sr
  - **Exposure** 8.1389 m^2*sr*s
    - Angle division into three intervals of equal acceptance.
    - [0°,21.78°]
    - [21.78°, 31.66°]
    - [31.66°, 40°]
- Cuts over the number of charged particles:
  - It is reconstructed from the number of charged particles
  - The charged particle range is subdivided depending on the zenith angle
- Cuts over the trigger.
  - All the stations in the cluster detects particles.
- Maximum detector efficiency.

¡Reducing the systematic error!

Quality Cuts

KASCADE

Scheme of KASCADE-Grande

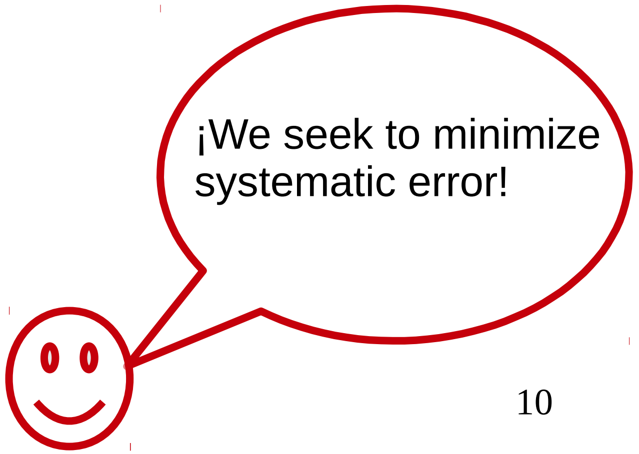


Grande scintillators detectors

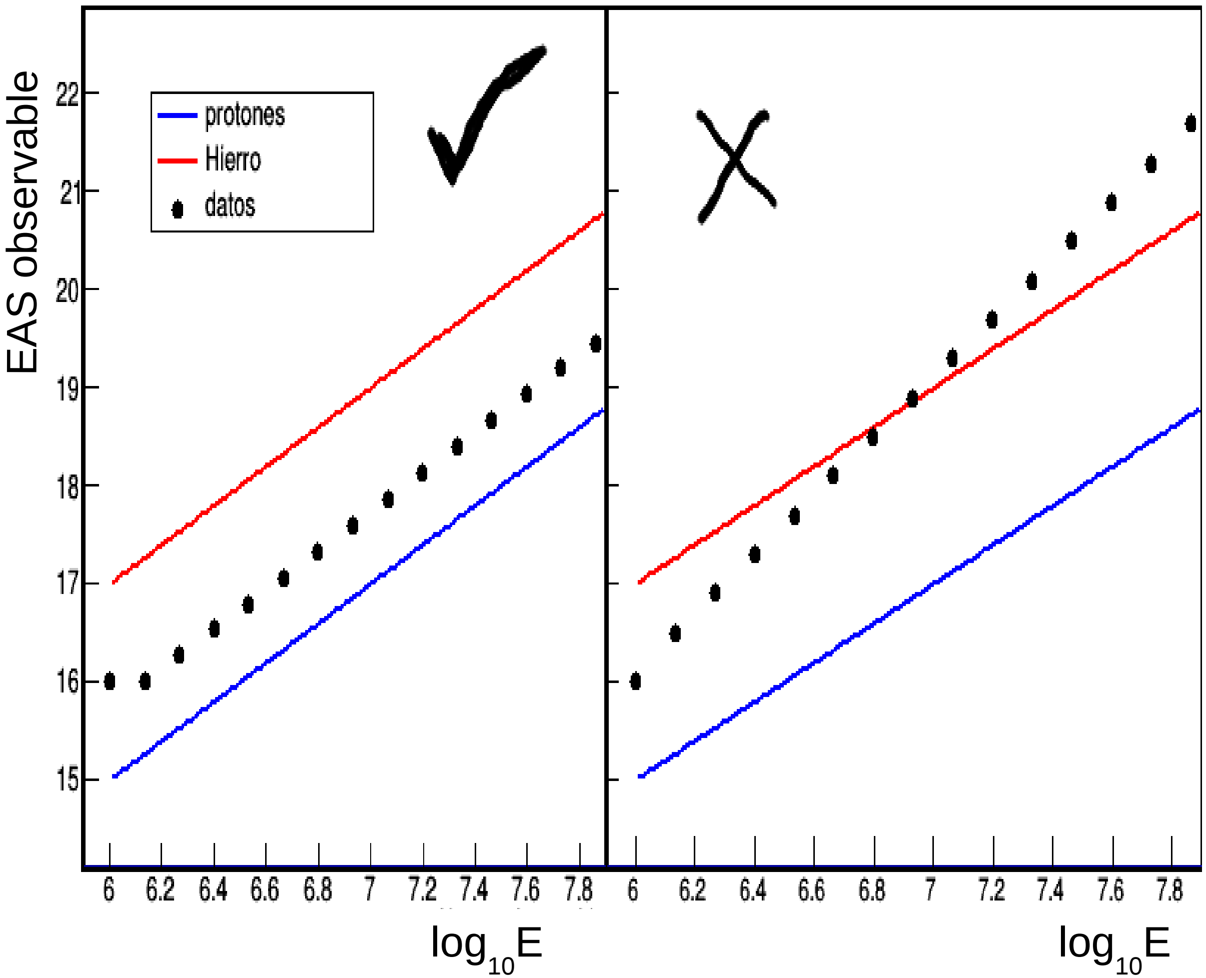
- **Fiducial Area** (Avoid edge effects, under and over estimation due to punch-through effect.)
  - Migration effects.
- $x \in [-430, -40]$
- $y \in [-560, 25]$
- $r \in [150, 650]$

Required Area.

Area = 2.252e+05 m².



Hadronic interaction models tests



- The experimental results are compared with the predictions of the models for H and Fe primaries.

Hadronic interaction models tests

CORSIKA v770

GEANT 4

FLUKA

Threshold: 230 MeV

Spectrum index: -3

Isotropic and homogeneous core distribution

POST-LHC

QGSJET-II-04

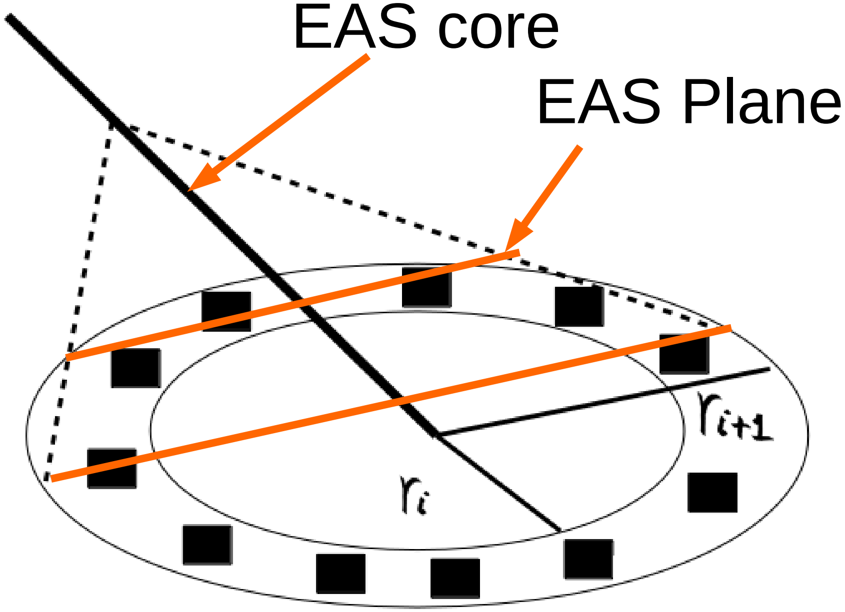
EPOS LHC

SIBYLL 2.3

SIBYLL 2.3c

- Calibrated with LHC data.
- A bigger number of muons than the prediction of QGSJET-II-02 is generated.
- No lineal and nuclear effects are considered.

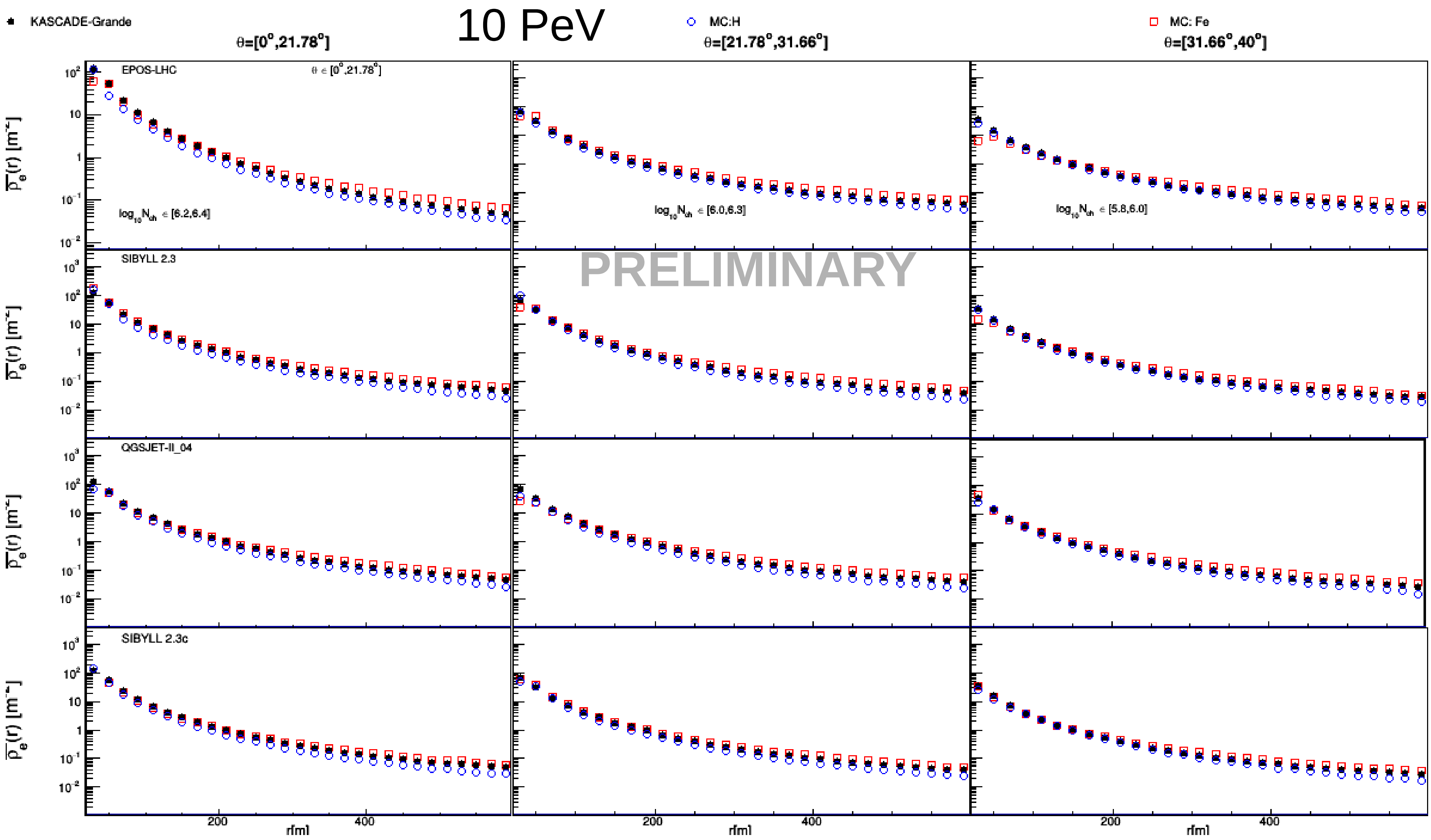
Density tests



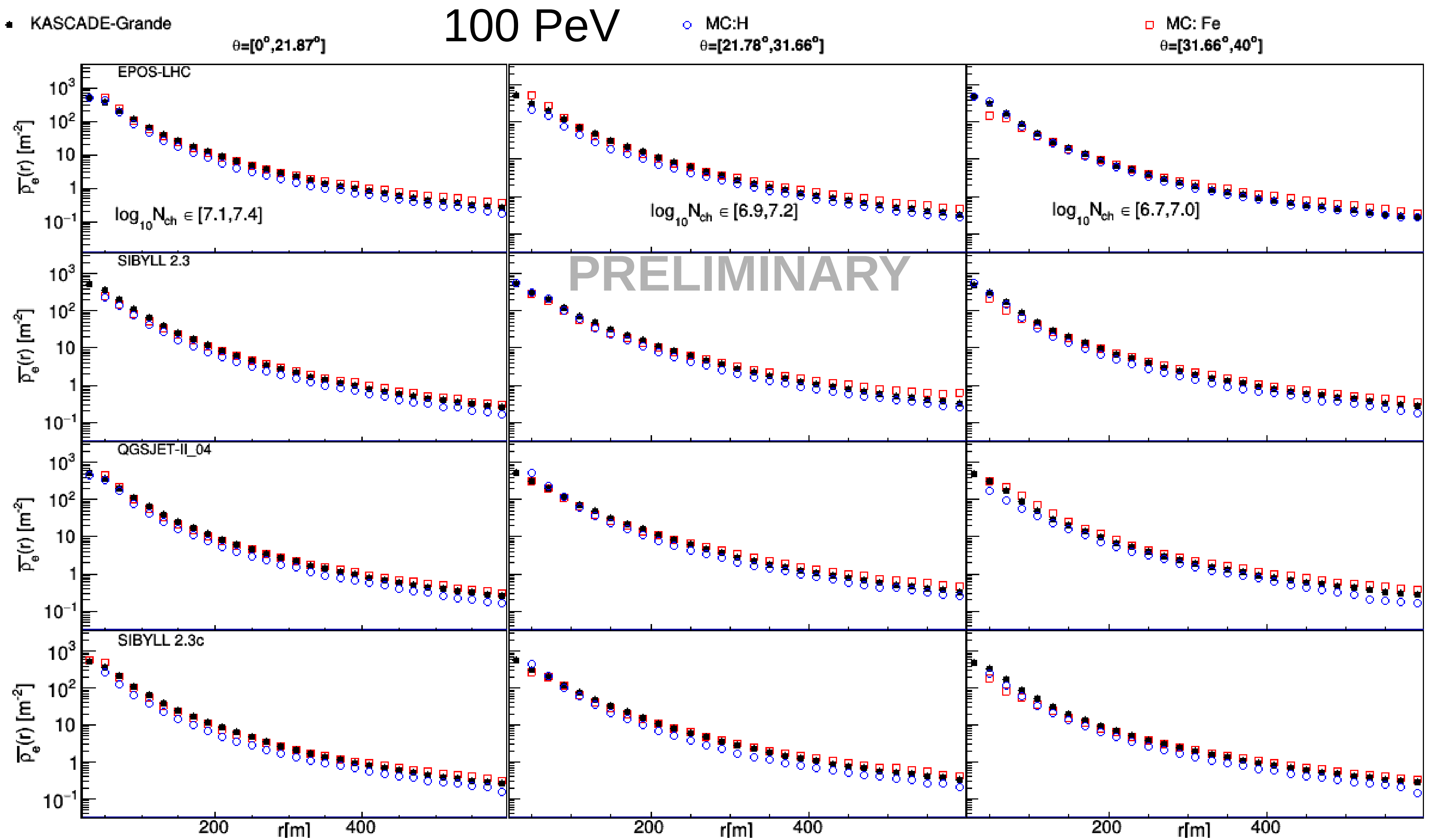
$$\bar{\rho} = \frac{\sum_{i}^{k} n_{ippb}}{\sum_{i}^{k} A_b}$$

- n_i is the number of particles measured in one muon detector.
- A_i is the Sensitive area of the detector.
- r_i is the core distance.

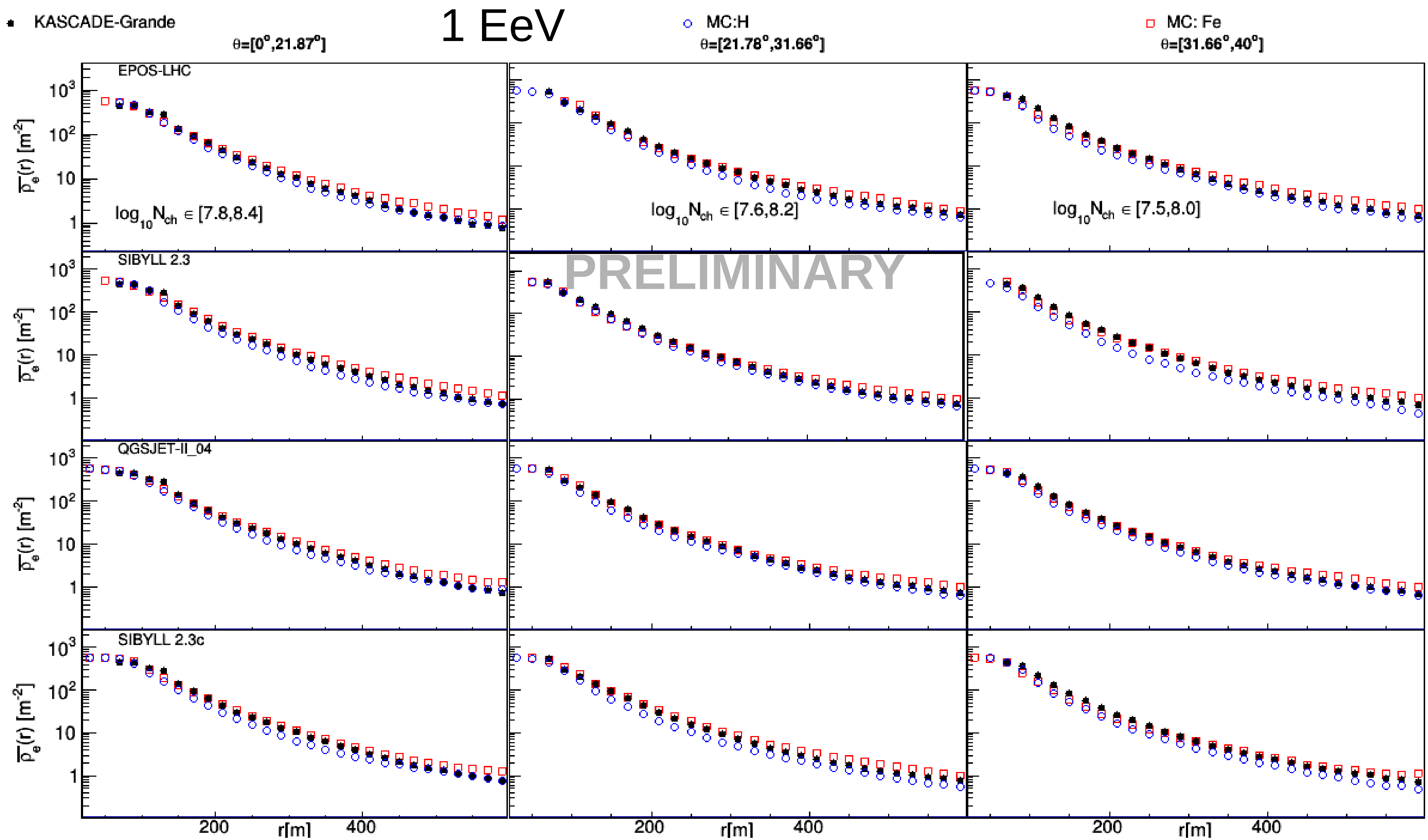
Electron density data



Electron density data

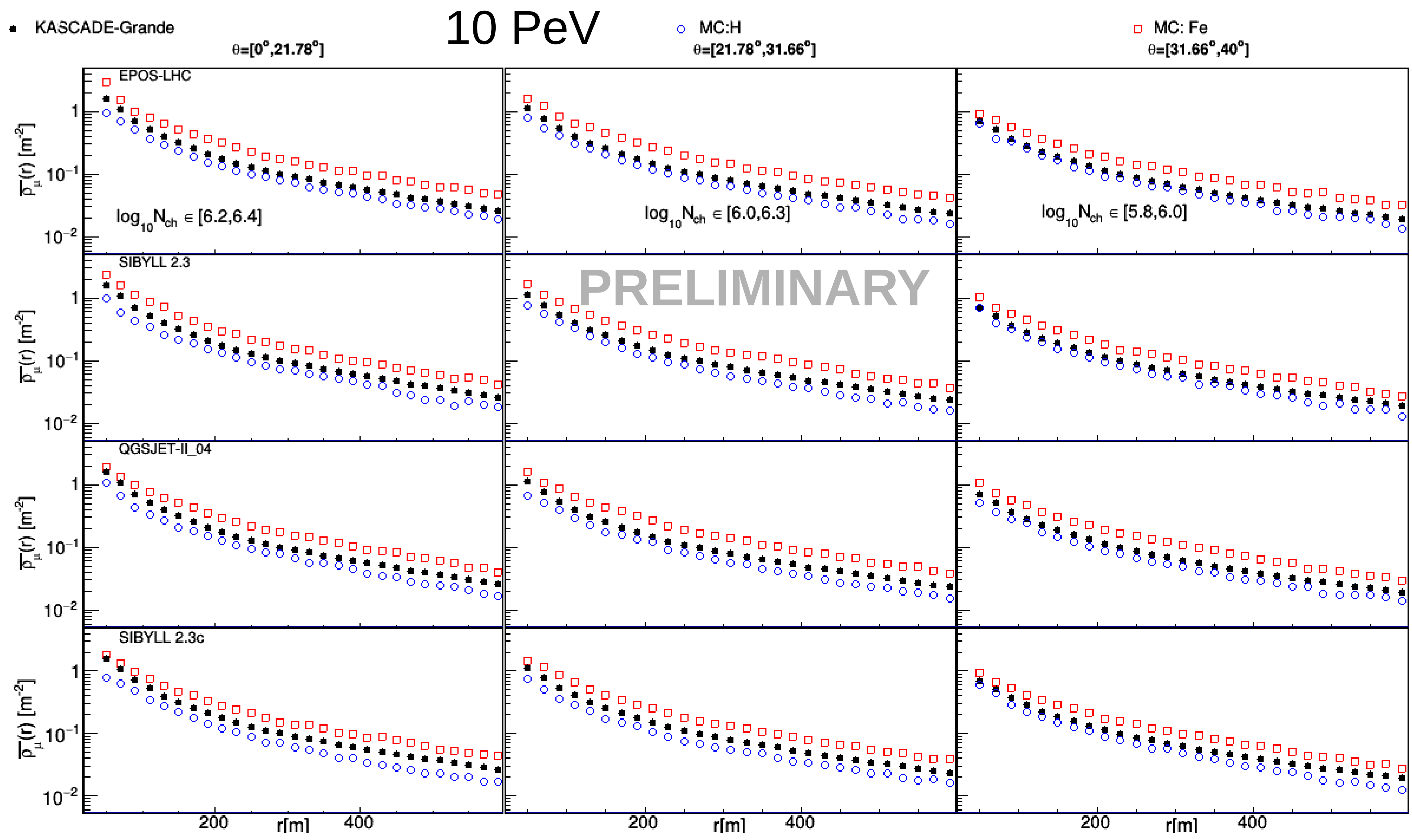


Electron density data

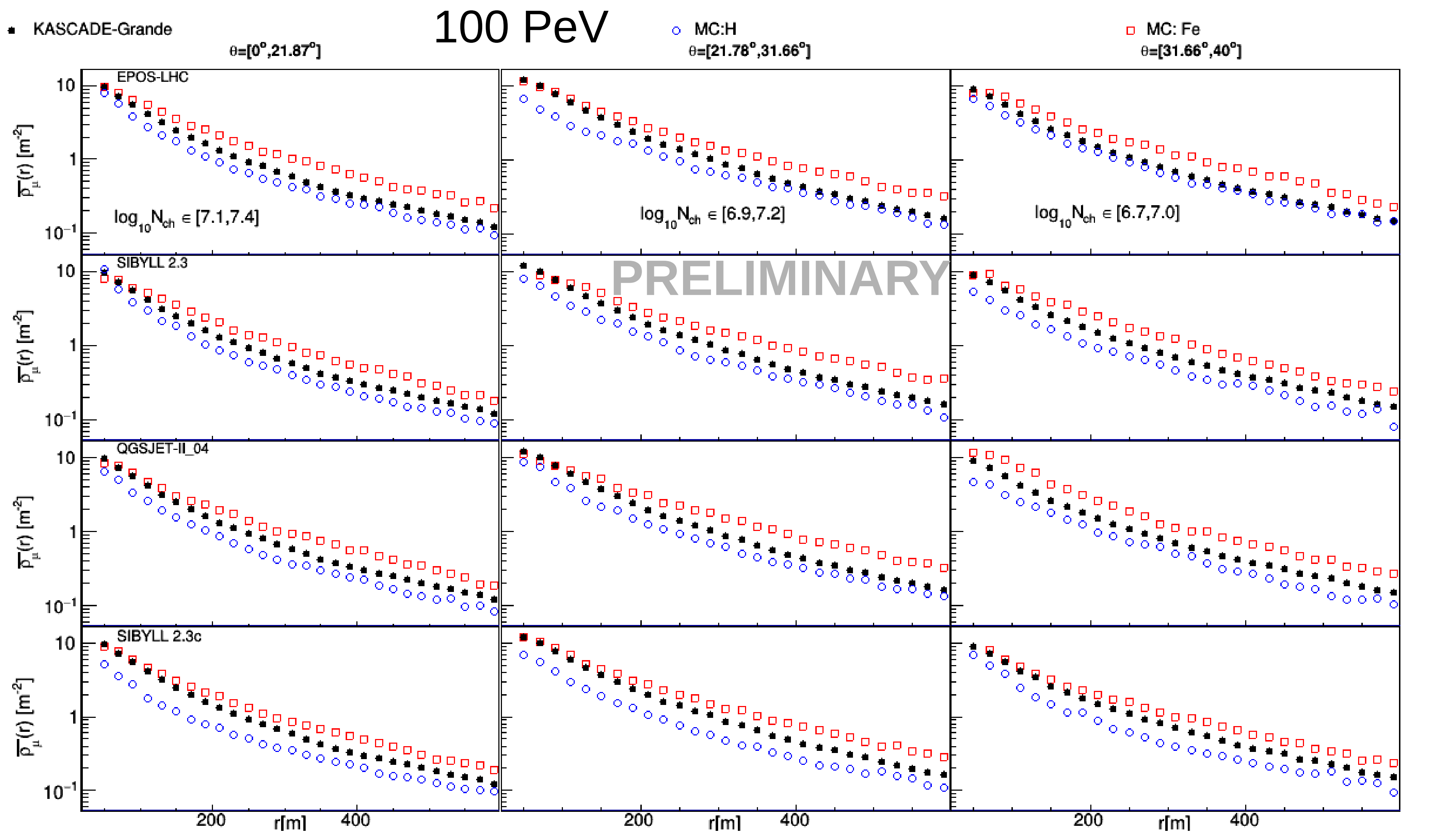


Muon density data

10 PeV

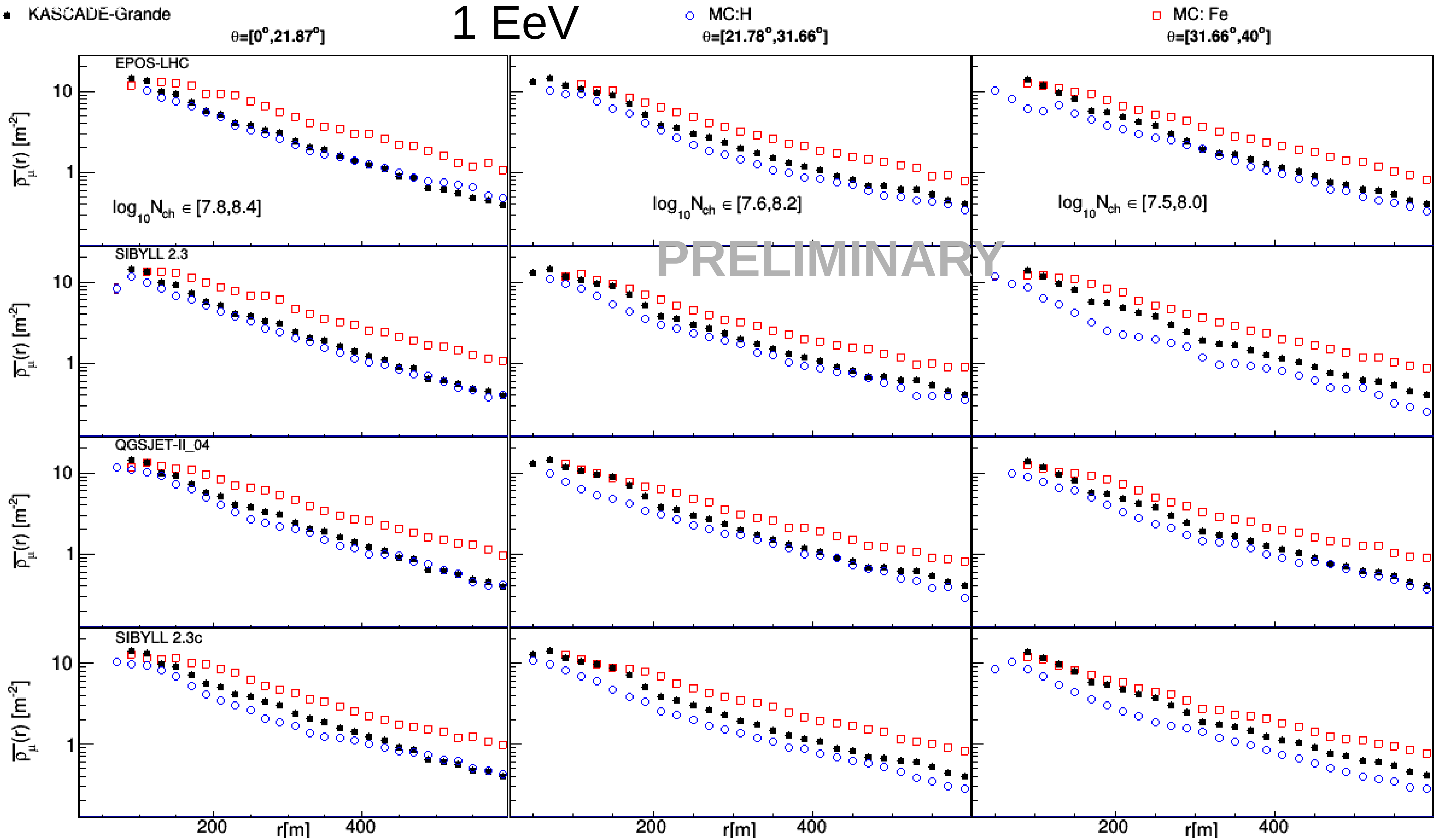


Muon density data



Muon density data

1 EeV



Conclusions and final remarks

- The electron densities seem to be well described by the hadronic models at different energies.
- The muonic component otherwise shows discrepancies between the data and the predictions.
- In the muonic sector the data shown a stepper behavior on the curve for the most energetic events.
- The EPOS-LHC model shows the most evident discrepancies in the muon sector for the EeV events. However, all the models present this behavior for EeV and vertical events.