

Density-scaling of lateral distributions of electrons and muons in EAS

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References:

- R K Dey et al., *Astropart. Phys.* **44** 68 (2013).
- R K Dey et al., *Euro. Phys. J. P* **131** 402 (2016).

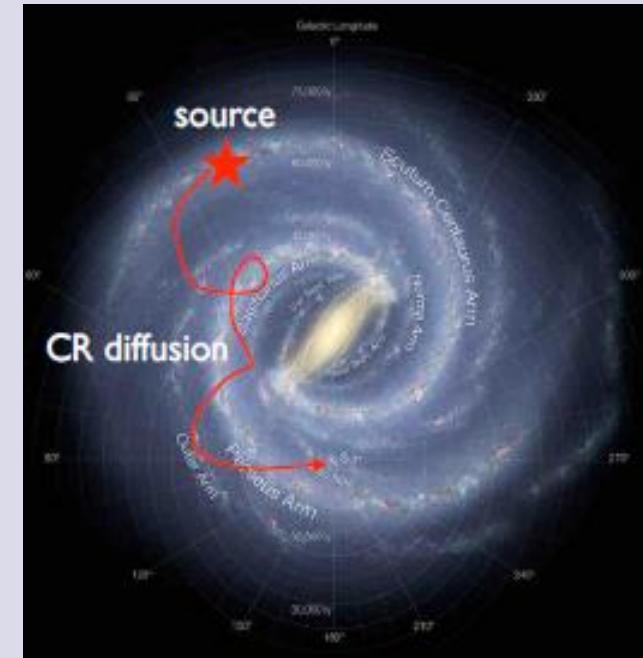
- S Dam and R K Dey, ‘Density-scaling of lateral distributions of electrons and muons in EAS’ (to be submitted).

Outline

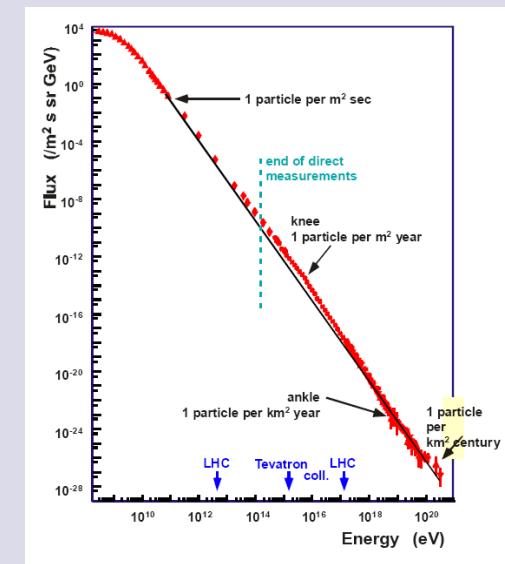
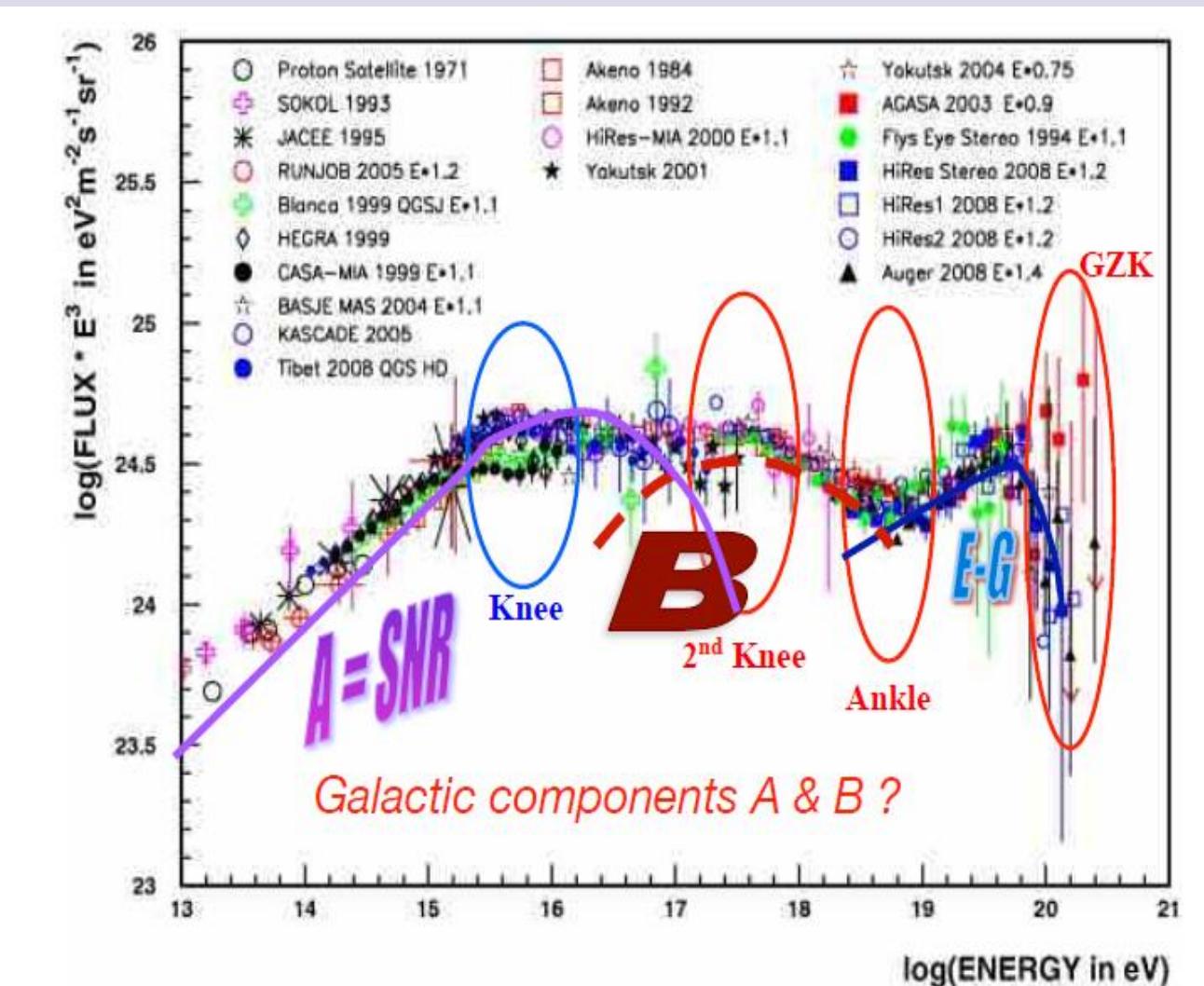
- **Galactic Cosmic Rays.**
- **The Energy Spectrum of Galactic Cosmic Rays.**
- **Detection of Cosmic Rays at Ground.**
- **Elemental Composition in the Knee Energy Region. KASCADE-Grande/Akeno data**
- **Summary.**

Galactic Cosmic Rays.

- Standard paradigm: Galactic Cosmic Rays are accelerated in SNRs?
- Cosmic Rays below 10^{17} eV are Galactic.
- Accelerated via diffusive shock acceleration and follow a power-law?
- CRs of galactic origin are scrambled by galactic magnetic field – isotropy in most.
- Galactic to Extra-galactic transitions of CRs occurs beyond 10^{17} eV .



All-particle primary cosmic ray energy spectrum.



What is the
origin of the
'knee'?
Inconclusive

The ‘Knee’ Mystery consists of (at least) following Interrelated Challenges.

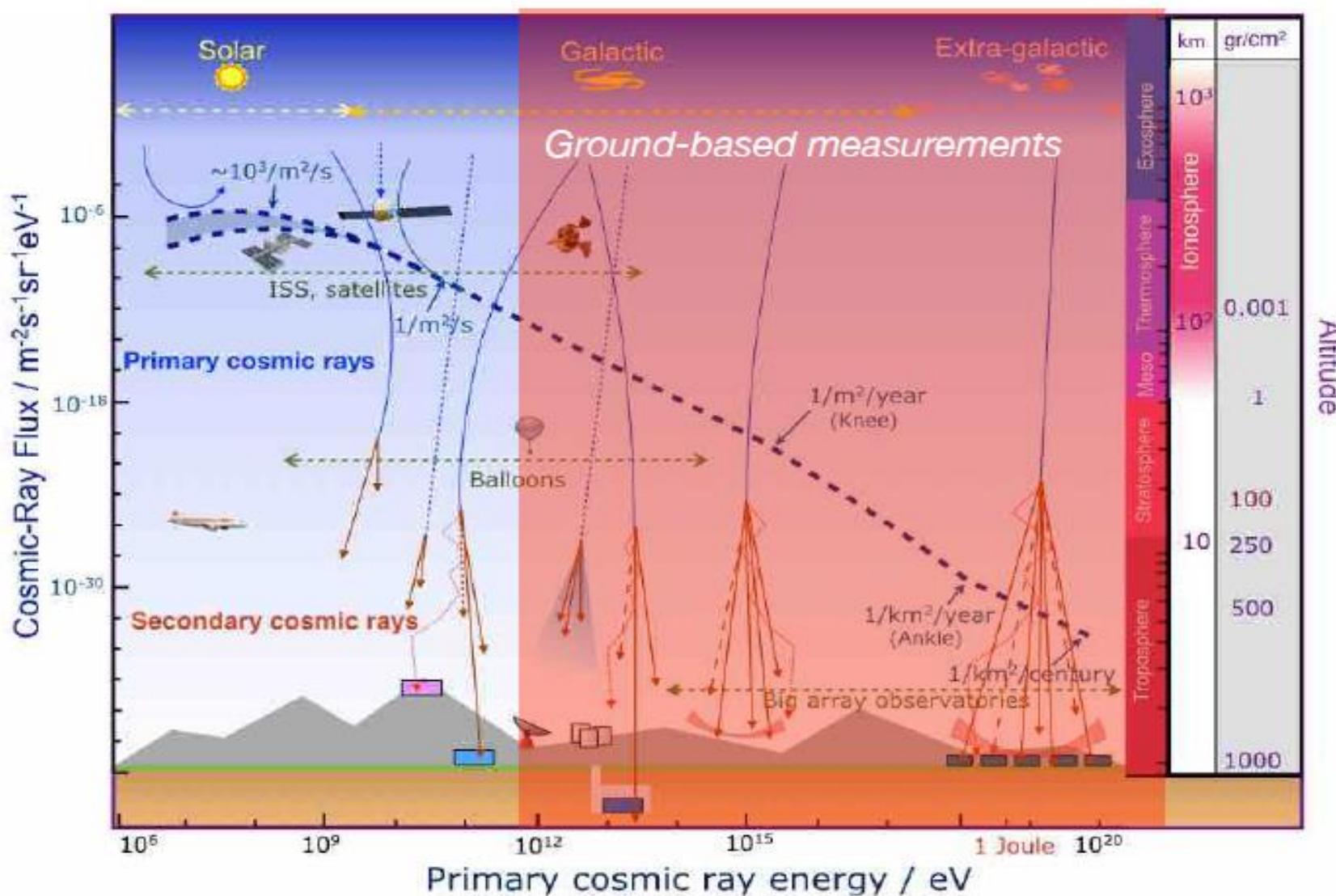
- 1. Changing of the cosmic ray sources?
(Source, Acceleration, Composition)**
- 2. Effect of Transport Mechanism?
(Leaking from Galaxy)**
- 3. Effect of Interaction of Cosmic Ray Particles in the Atmosphere?**
- 4. Effect of Observation Techniques and Observables?**

Motivation.

- The discontinuity at the source region around the knee is believed to be linked with a Z-dependent variation in the contributions of the various elements/nuclei to the CR energy spectrum .
- Measurement of the composition (and also the energy) of CRs around the knee are very important for proper understanding of the origin of this spectral feature.

The main objective of this work is to search some reliable CR composition sensitive air shower observables, by exploiting different characteristics of EASs initiated by primary particles around the knee region, from a detailed Monte Carlo simulation and interpretation of data.

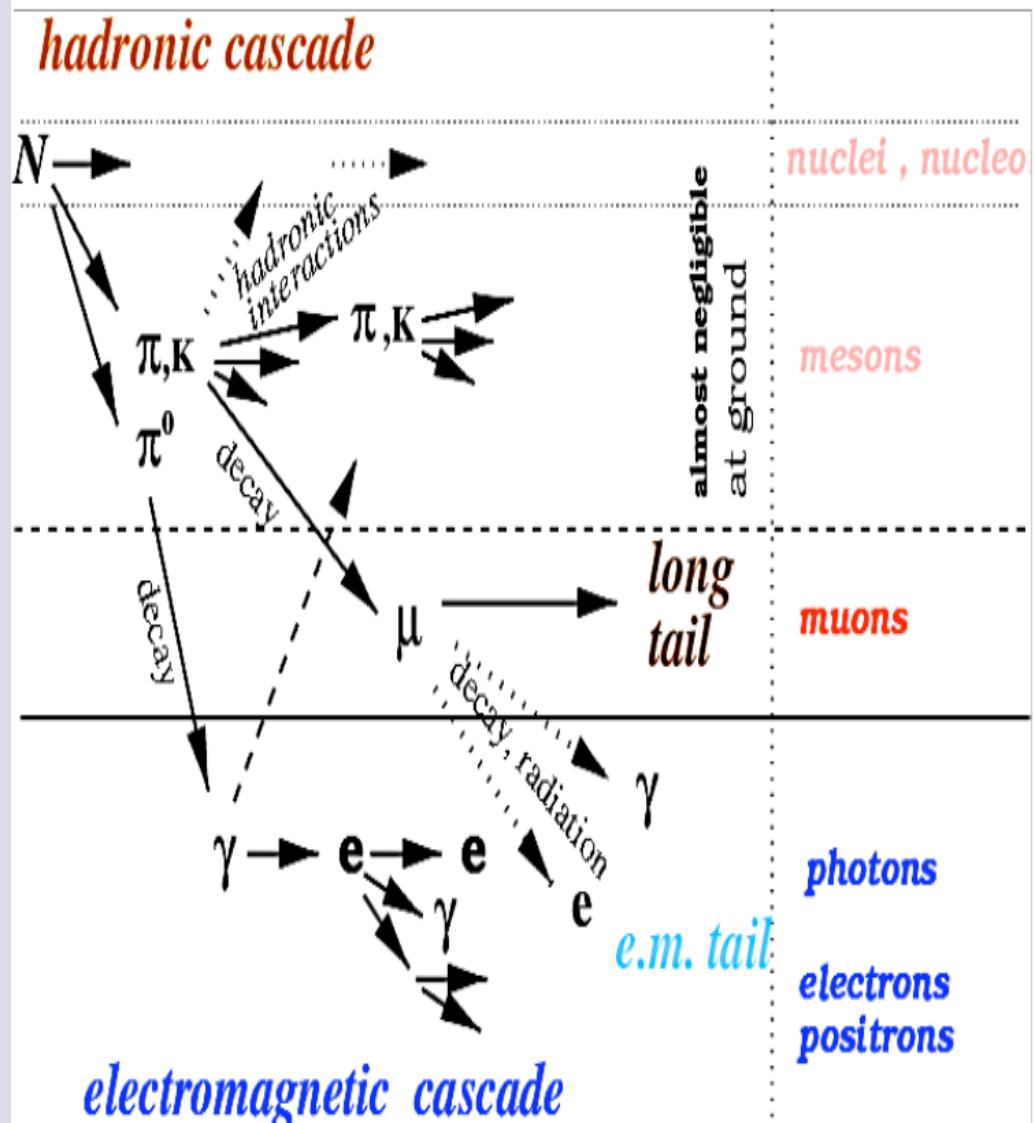
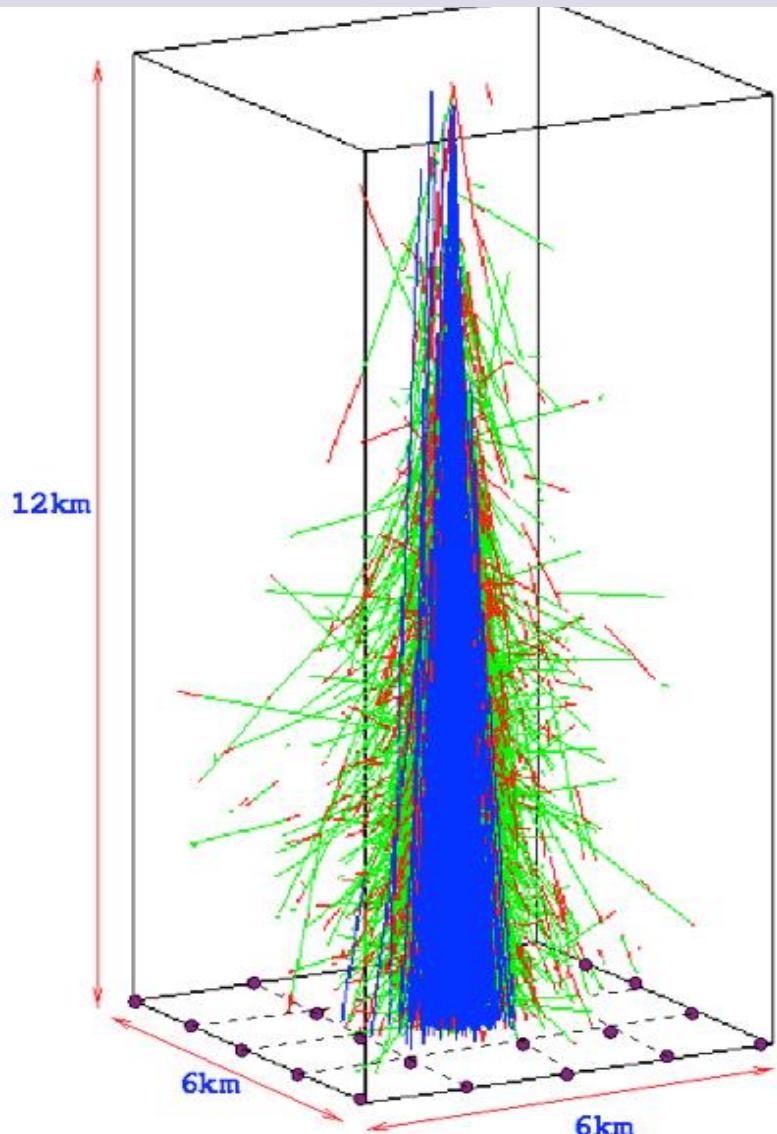
Cosmic Ray Detection.



CR Composition Sensitive Observables in EAS.

- 1. Number of charged particles or electrons - N_e**
- 2. Number of muons - N_μ**
- 3. Deflection angles of muons or their production heights - h_μ**
- 4. Slope (β) or shower age (s) from lateral distributions of electrons/muons. More than one observable is needed for unfolding composition.**
- 5. Cherenkov photons – intensities and density.**
- 6. Fluctuations of electrons, muons and X_{max} .**
- 7. Arrival times of particles and Cherenkov photons etc...**

Extensive Air Showers.



Way of the EAS data analysis.

We explored a possibility of using shower age/slope parameter of the lateral density distribution of EAS electrons and muons (a reliable and unambiguous estimation method is needed) for composition study.

Particle detectors - electron component and its lateral density distribution.

Muon detectors - muons.

Usually, lateral density distributions of electrons/muons in EAS are approximated by the well known Nishimura-Kamata-Greisen (NKG)-type lateral density function:

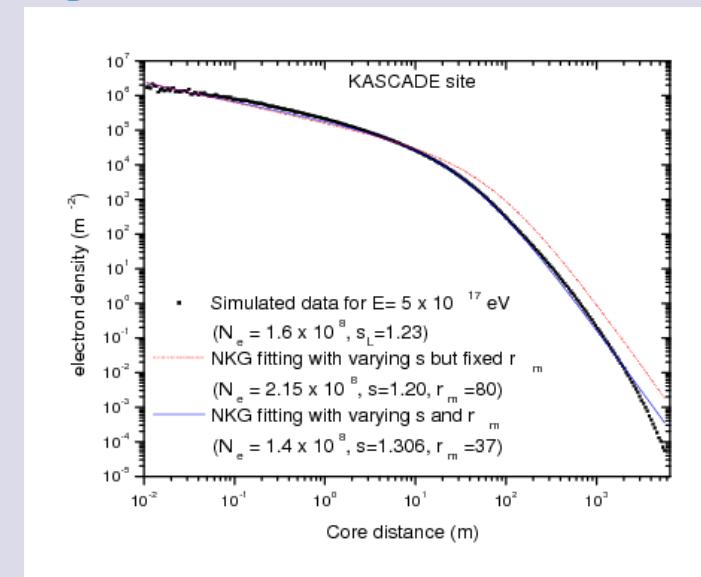
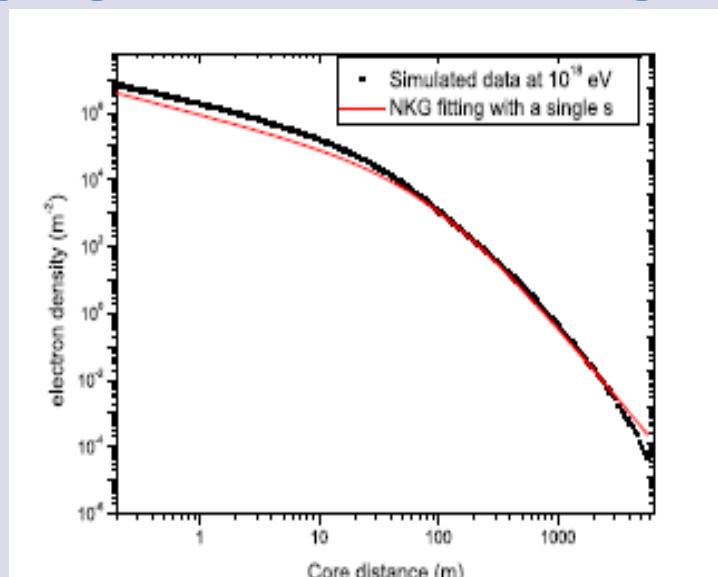
Contd..

$$f(r) = C(s_{\perp})(r/r_m)^{s_{\perp}-2}(1+r/r_m)^{s_{\perp}-4.5}, \quad (1)$$

where,

$$C(s_{\perp}) = \frac{\Gamma(4.5 - s_{\perp})}{2\pi \Gamma(s_{\perp}) \Gamma(4.5 - 2s_{\perp})}.$$

It is observed that the NKG function with a single lateral age/slope parameter is inadequate to describe the lateral distribution of EAS electrons/muons properly at all distances implying that the lateral age changes with radial distance.



Local age or segmented slope parameter.

We introduced the concept of local age parameter which is quite helpful to judge the radial variation of shape of the structure function.

For two neighbouring points, i and j , one can give a local age parameter for any distribution $f(x)$ which characterizes the best fit by a NKG-type function ($x = \frac{r}{r_m}$):

$$a(i, j) = \frac{\ln(F_{ij} X_{ij}^{\alpha_1} Y_{ij}^{\alpha_2})}{\ln(X_{ij} Y_{ij})} \quad (2)$$

$$F_{ij} = f(r_i)/f(r_j), \quad X_{ij} = r_i/r_j, \quad \text{and} \quad Y_{ij} = (x_i + 1)/(x_j + 1)$$

For the lateral density distribution of muons we have used (1) and also the Greisen function,

$$f_\mu(r) = A(r/r_G)^{-\beta}(1 + r/r_G)^{-2.5} \quad (3)$$

Estimation of local age/segmented slope.

NKG-type function - Local age: Electrons and Muons

$s_{local}(r)$ or $s(i,j)$: $\alpha_1 = 4.5, \alpha_2 = 2, r_m = 89$ or 320 m in eqn. (2)

Greisen-type function – Segmented slope: Muons

$\beta_{ss}(r)$ or $\beta(i,j)$: $\alpha_1 = 0, \alpha_2 = 2.5, r_G = 320$ or 420 m in eqn. (2)

The shape of the lateral density distribution from the fitting by NKG/Greisen function is the same for any EAS event, irrespective to the energy and type of the shower initiating particle, which implies that the structure function or lateral density distribution of electrons/muons exhibits some sort of scaling behaviour.

Simulation.

Monte Carlo code CORSIKA 7.400.

Interaction models:

**High Energy models: EPOS 1.99 and QGSJET 01
ver. 1c**

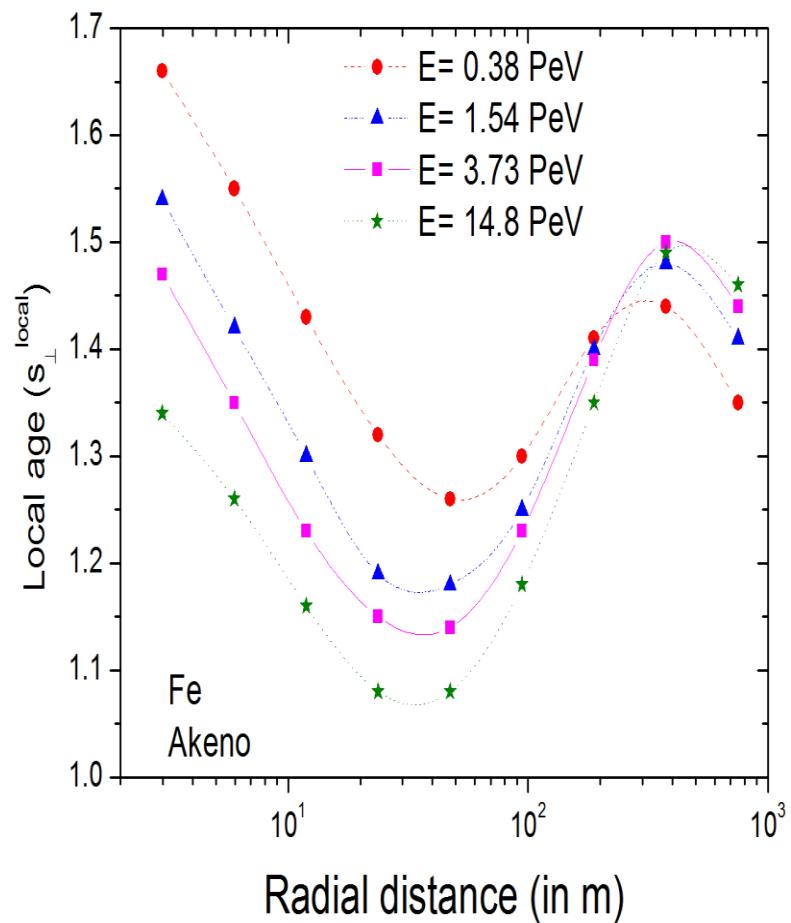
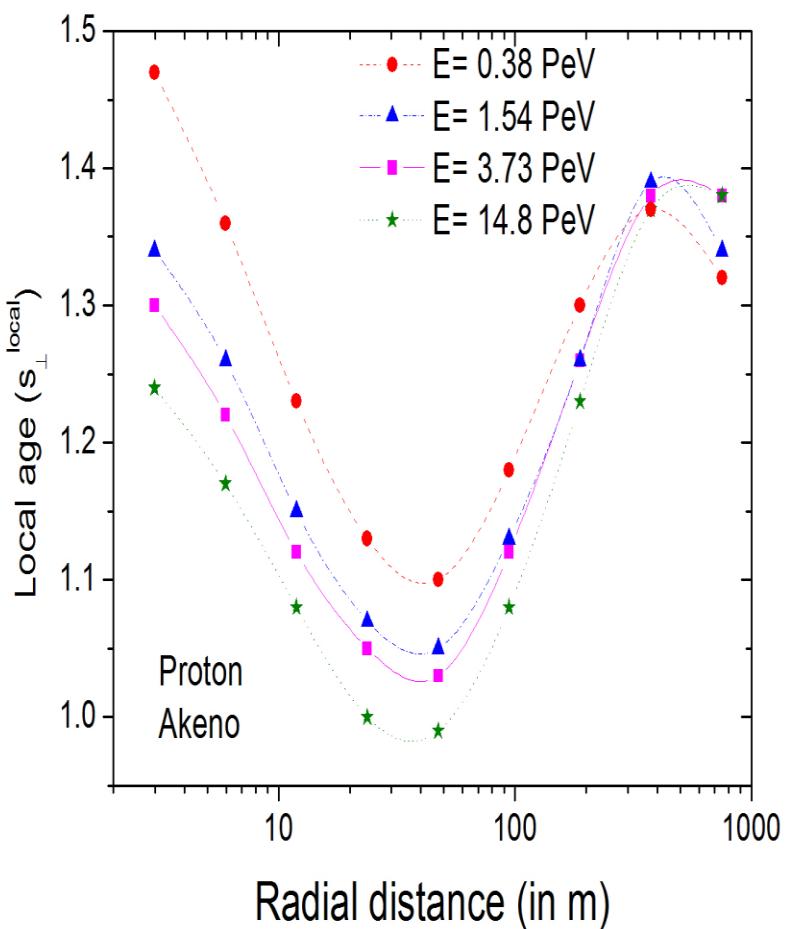
Low energy: UrQMD.

Electromagnetic Interaction Model: EGS4

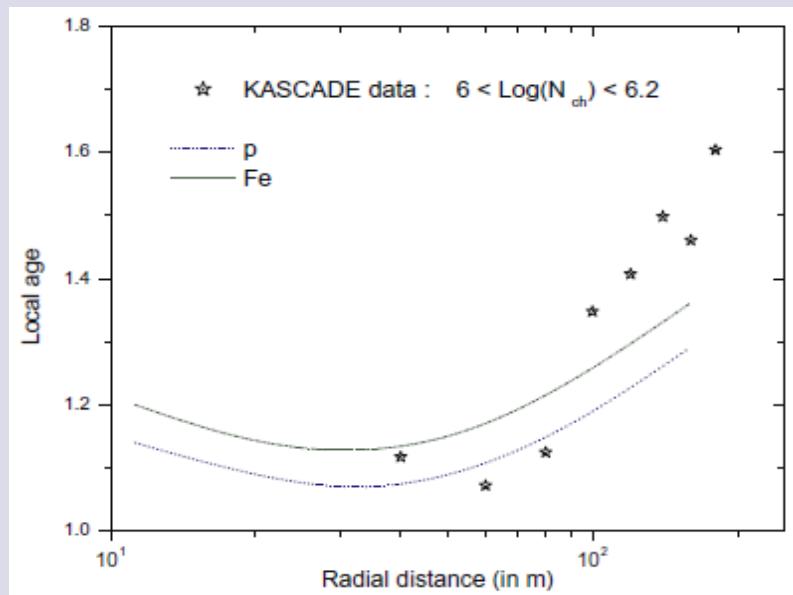
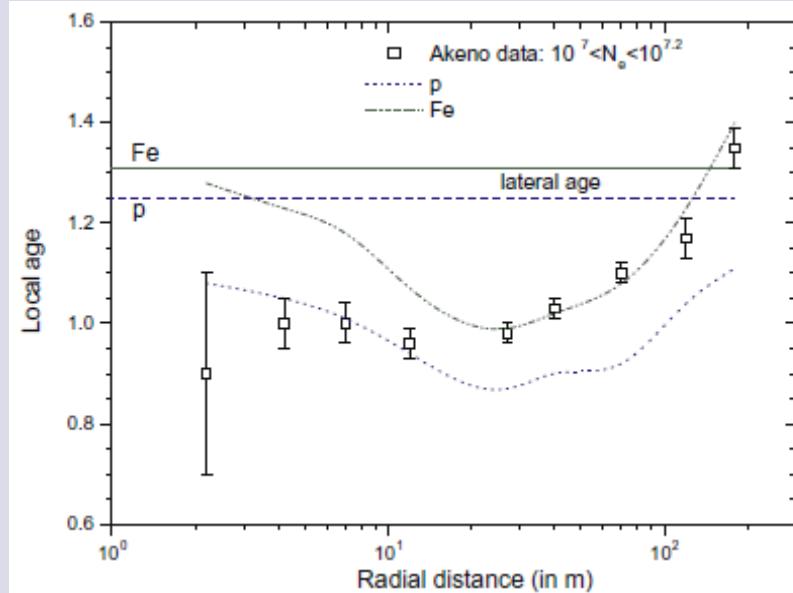
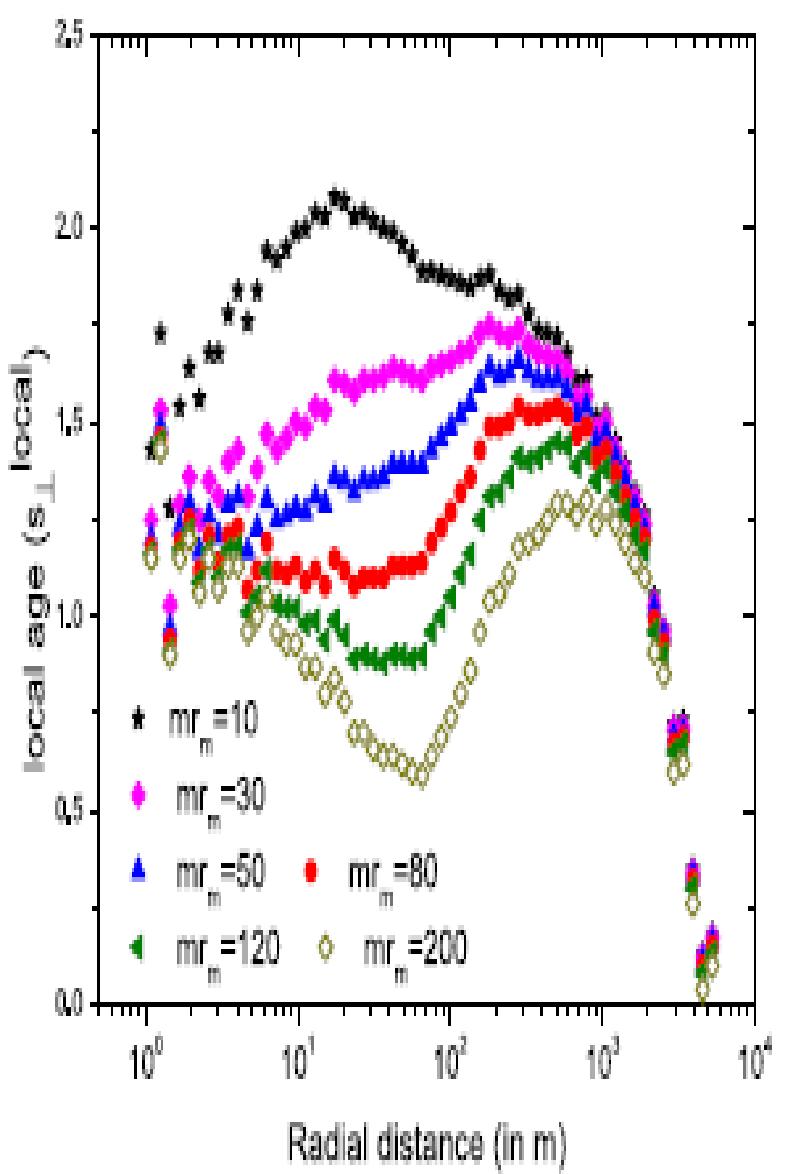
Location: KASCADE (Karlsruhe), Akeno (Osaka)

Experimental data: KCDC (KASCADE), Akeno (AGASA Coll.)

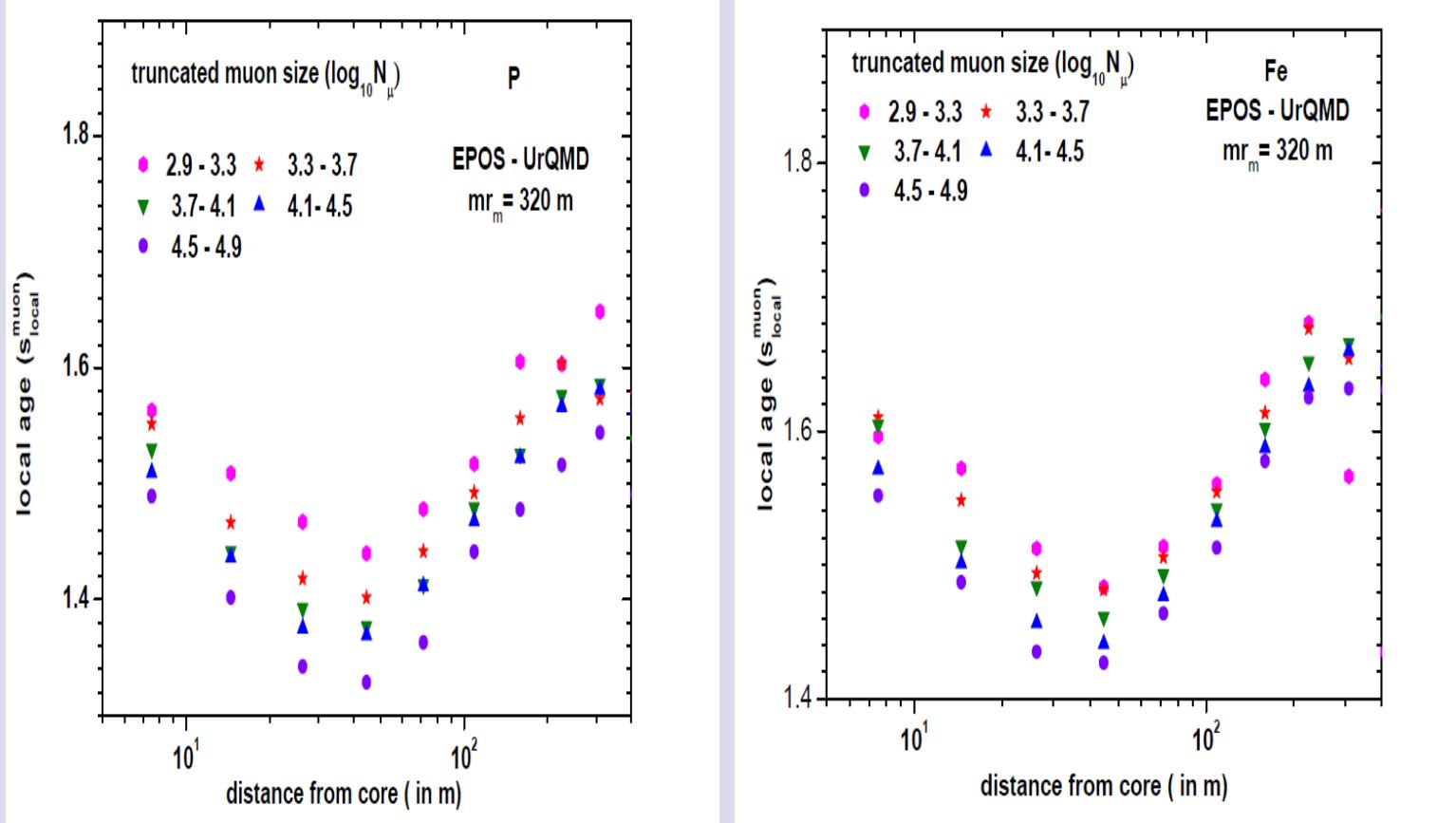
Results: $s_{\perp}^{local}(r)$ and $\beta_{ss}(r)$ - measurements.



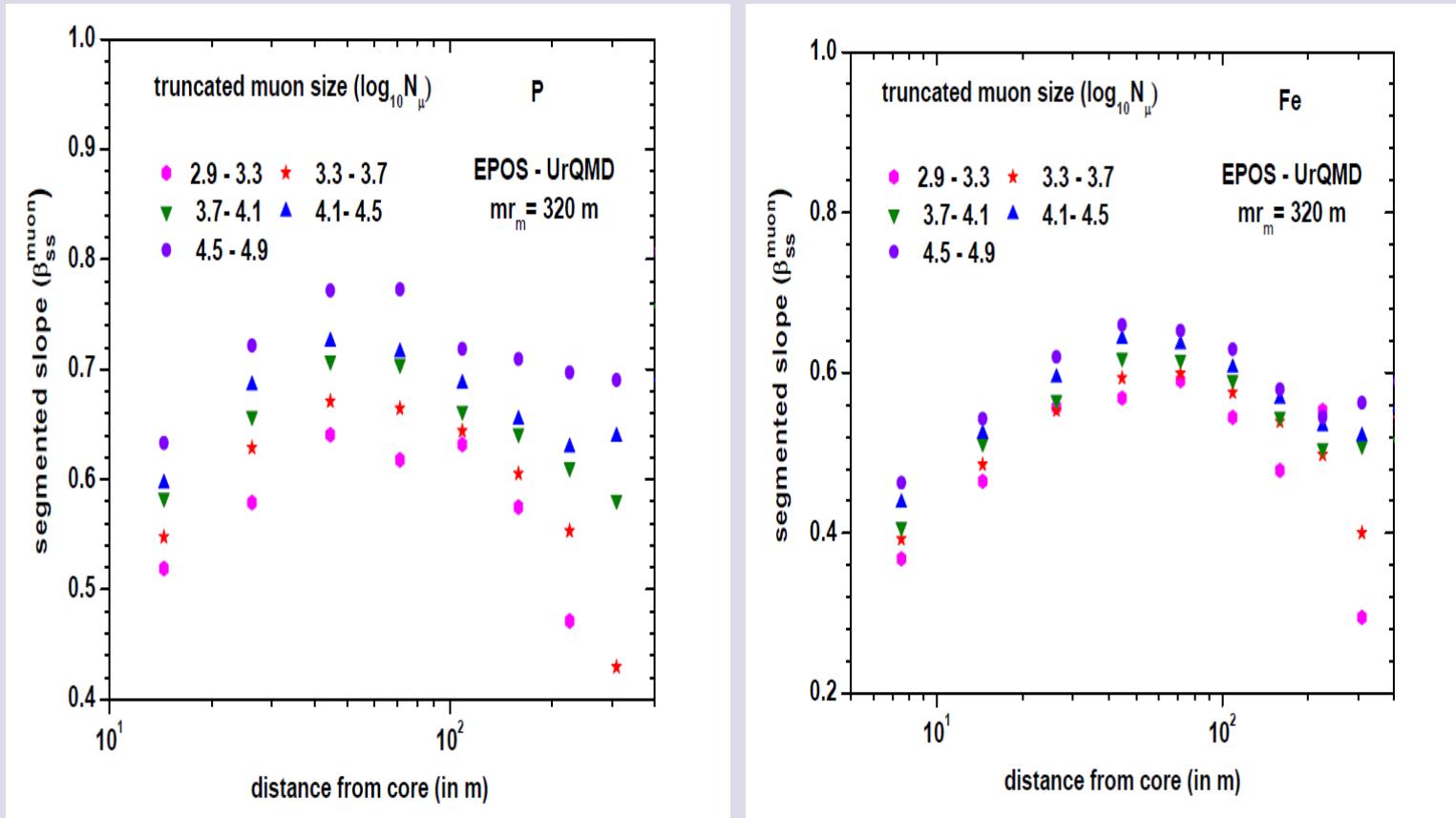
Local age parameter (obtained from simulated electron density data) as a function of radial distance for different primary energies.



Local age estimated from electron density data

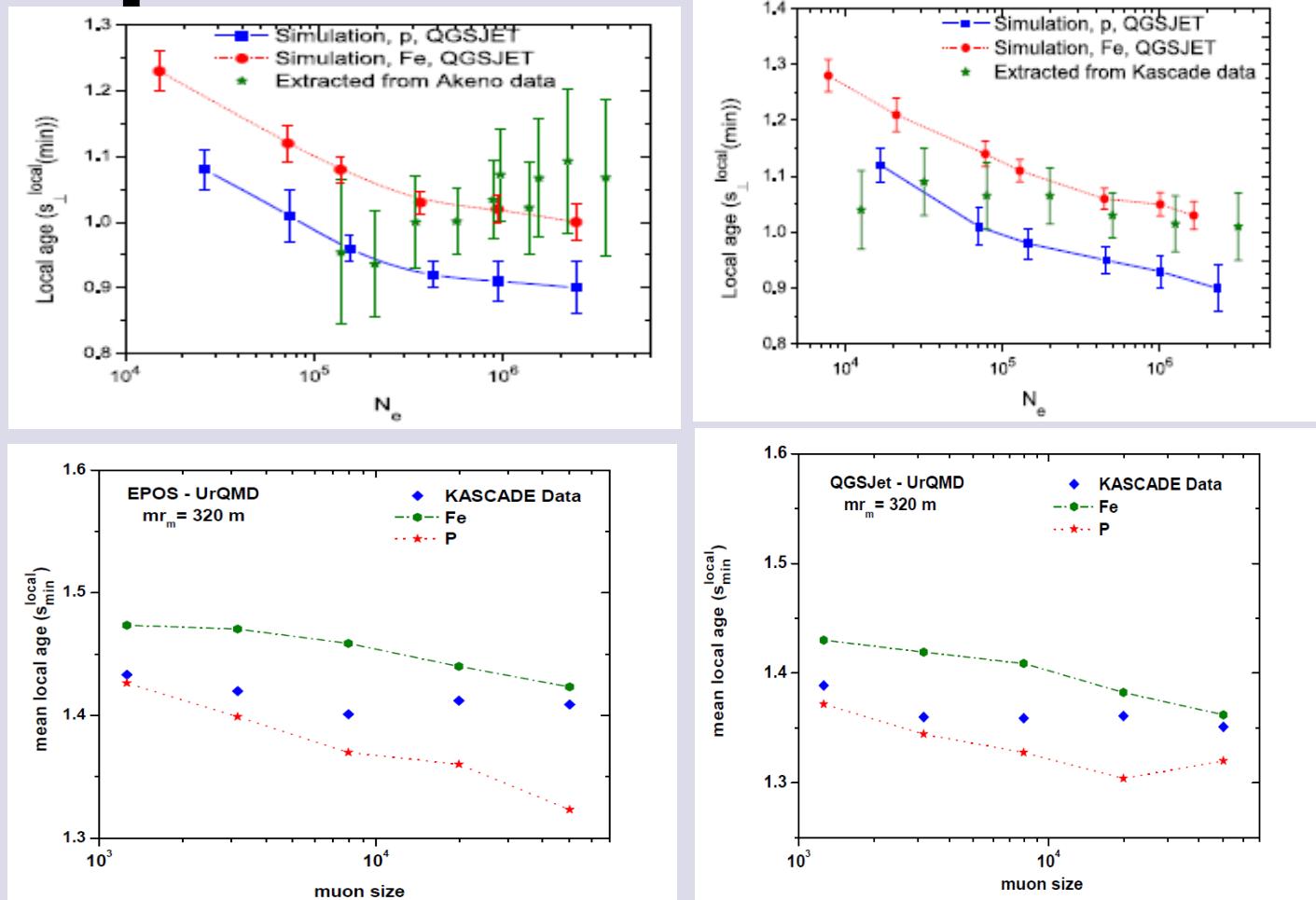


Local age estimated from muon density data.



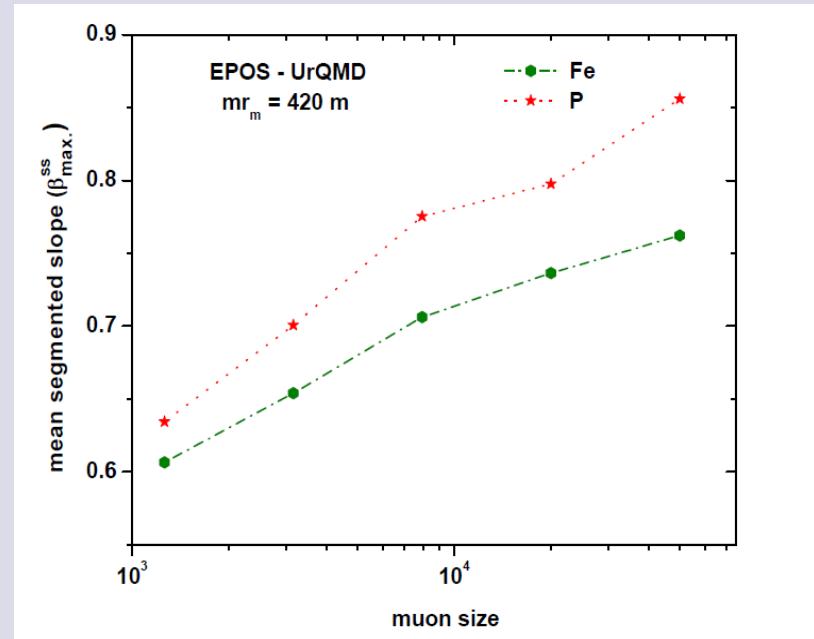
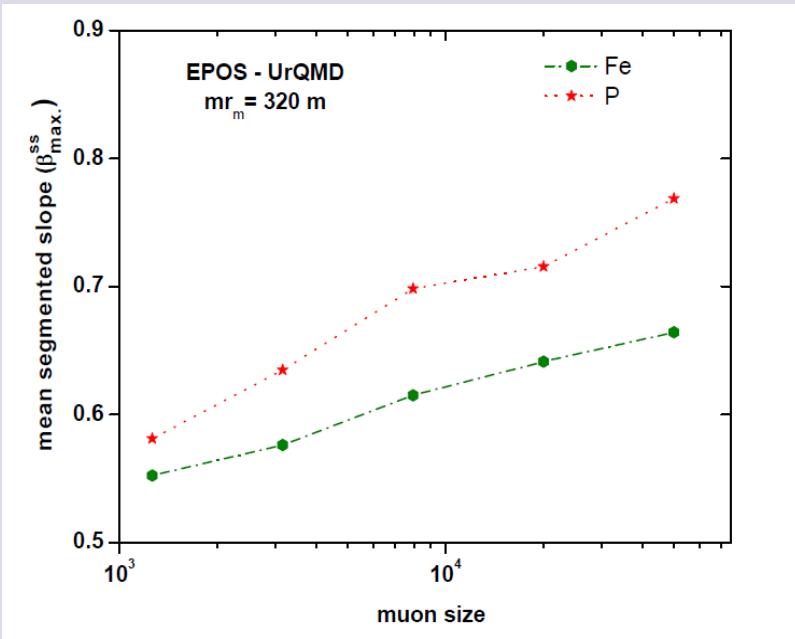
Segmented slope estimated from muon density data.

Minimum local shower age: Estimation of CR composition.



Minimum local age estimated from local age. Above – electron density data; Bottom – muon density data.

Maximum segmented slope: Estimation of CR composition.



Maximum segmented slope estimated from segmented slope. Two high-energy hadronic interaction models. Experimental data with Greisen fitting is unavailable in KCDC.

Summary.

- **Understanding the origin of the knee is necessary for developing an actual theory of the origin of CRs in the 0.1-100 PeV region.**
- **Estimation of CR composition around the knee is crucial to understand the range of the galactic CRs in the energy spectrum.**

- **The local age/segmented slope offers a good solution towards an unambiguous estimation of the shower age/slope parameter.**
- **Lateral distribution of electrons/muons in EAS exhibits scaling behaviour in terms of local age/segmented slope.**
- **The local age at a particular distance (~ 40 m, where it takes the minimum value) exhibits sensitivity to the CR composition. The maximum value of the segmented slope is also found composition sensitive.**