Analysis of inclined air showers with the KASCADE-Grande experiment

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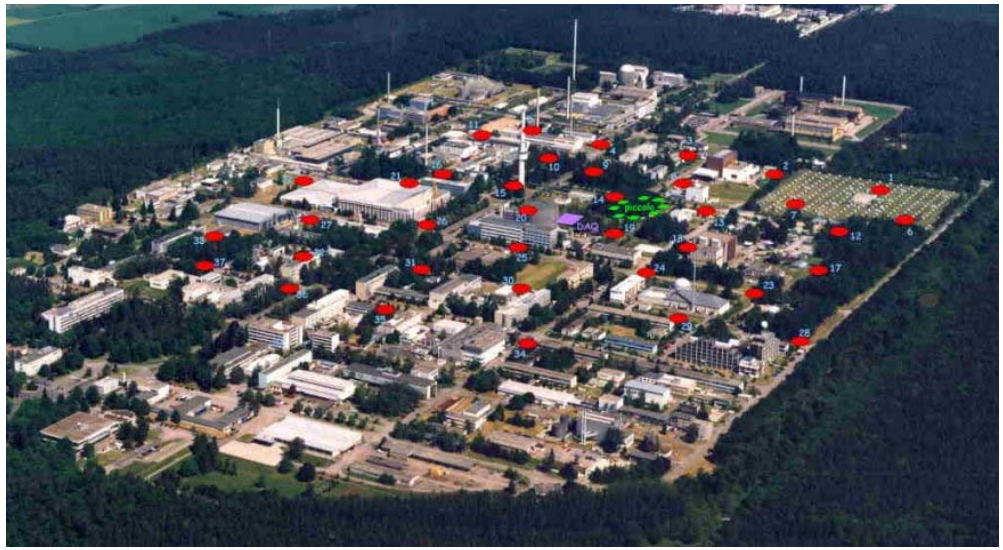


Analysis of inclined air showers with the KASCADE-Grande experiment

Outline

1) Cosmic rays between the knee and the ankle.

2) What we have learnt from the KASCADE experiment.

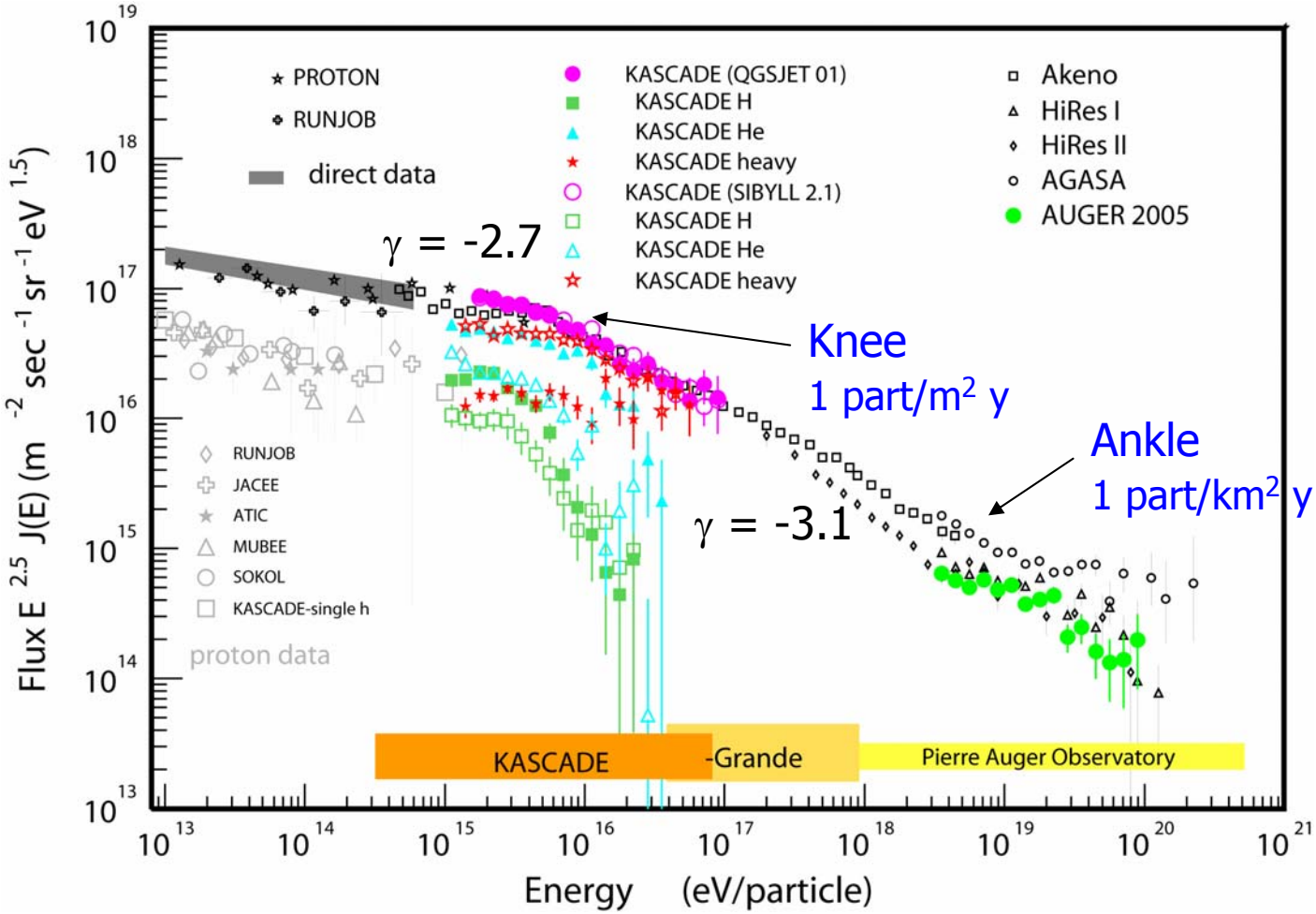
3) A step beyond: The KASCADE-Grande experiment.

4) Description of the present work.

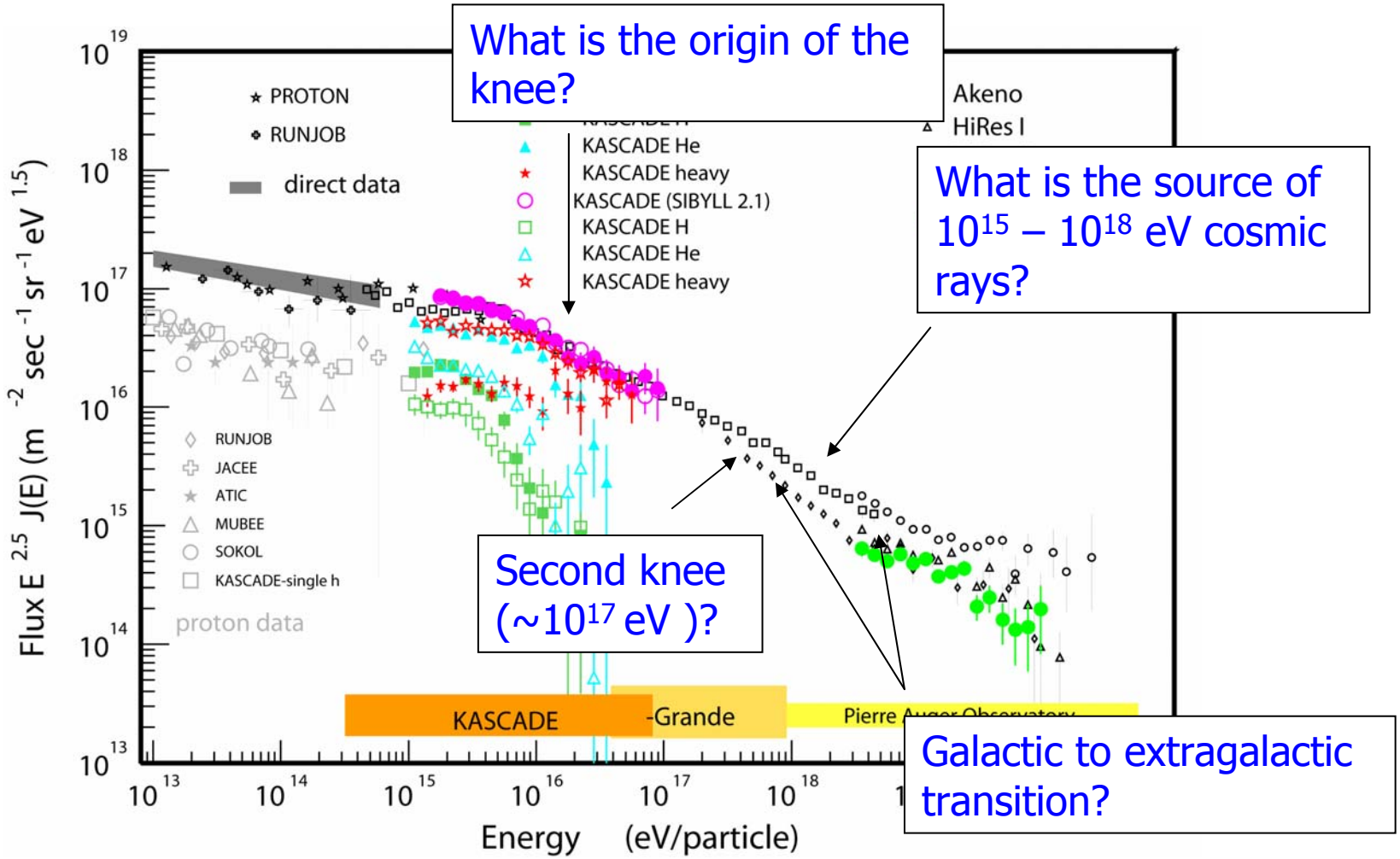
   - Arrival direction and
   - μ number reconstruction of inclined showers ($\vartheta > 40^{o}$).

5) Summary.

Cosmic rays between the knee and the ankle



Cosmic rays between the knee and the ankle



Cosmic rays between the knee and the ankle

- Astrophysical models distinguished by:
  - Distinct $E_{max} \rightarrow$ knee position of individual elements (Z or A dependence),
  - Different distributions for the arrival directions of cosmic rays.
- To discard models and solve these questions is important:
  - Determine composition (or at least, separate primaries in light and heavy groups) and measure their respective energy spectra from 10^{15} to 10^{18} eV.
  - Look for anisotropies in the arrival directions of cosmic rays.

What we have learnt from the KASCADE experiment

KASCADE (Karlsruhe Shower Core and array detector)

Elements:

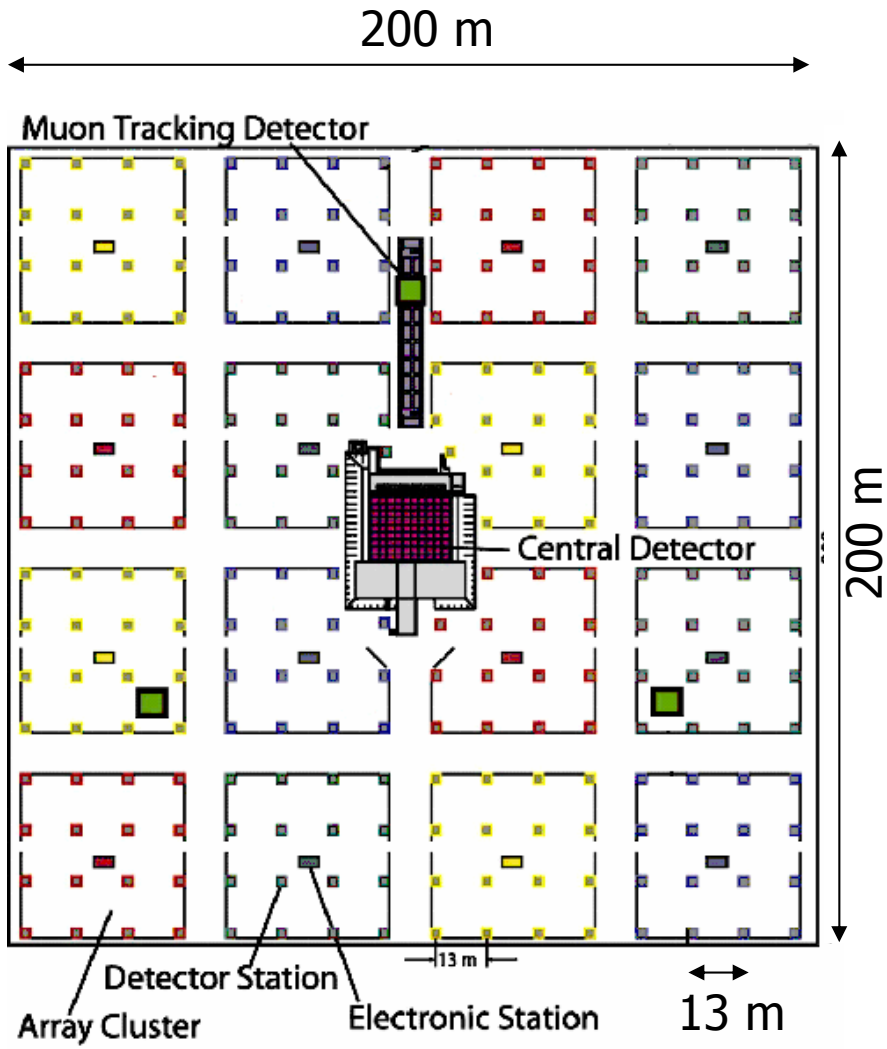
- Ground array of 252 e/γ and μ scintillator detectors.
- Central Detector (Calorimeter, muon devices).
- Muon tracking detector.

Observables:

- Electron, muon and hadron components of the EAS.

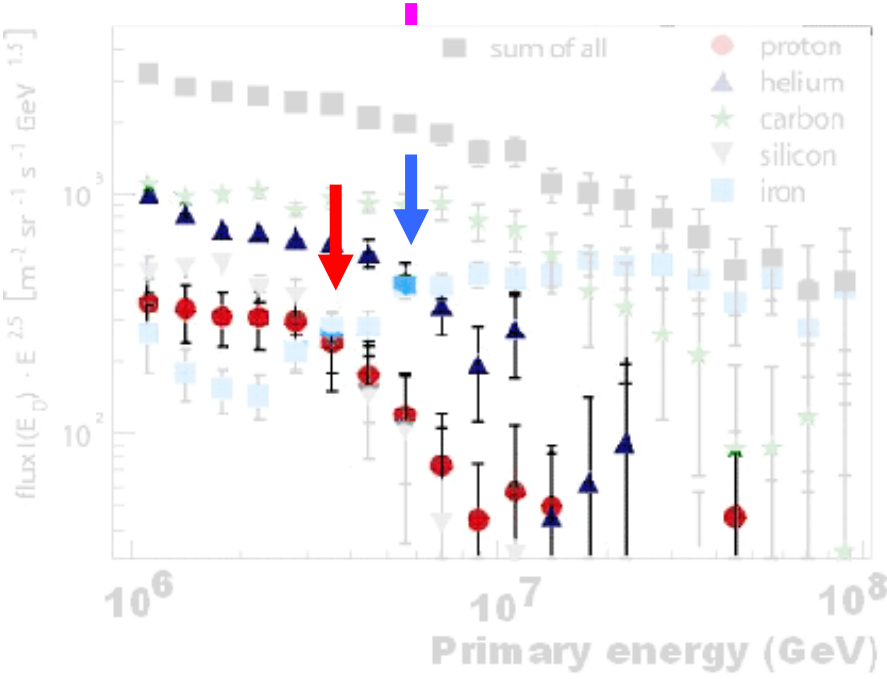
Energy region:

10^{14}-10^{17} eV.



What we have learnt from the KASCADE experiment

Main results from KASCADE:



- Isotropy in arrival directions at energies around the knee.
- Knee feature in the all particle spectrum at ~ 4 PeV.
- This feature is caused by decrease in flux of light component.
- Light primaries show an individual knee which varies with composition.

KASCADE collaboration, Astrop. Phys. 24 (2005) 1-25, astro-ph/0505413

A step beyond: The KASCADE-Grande experiment

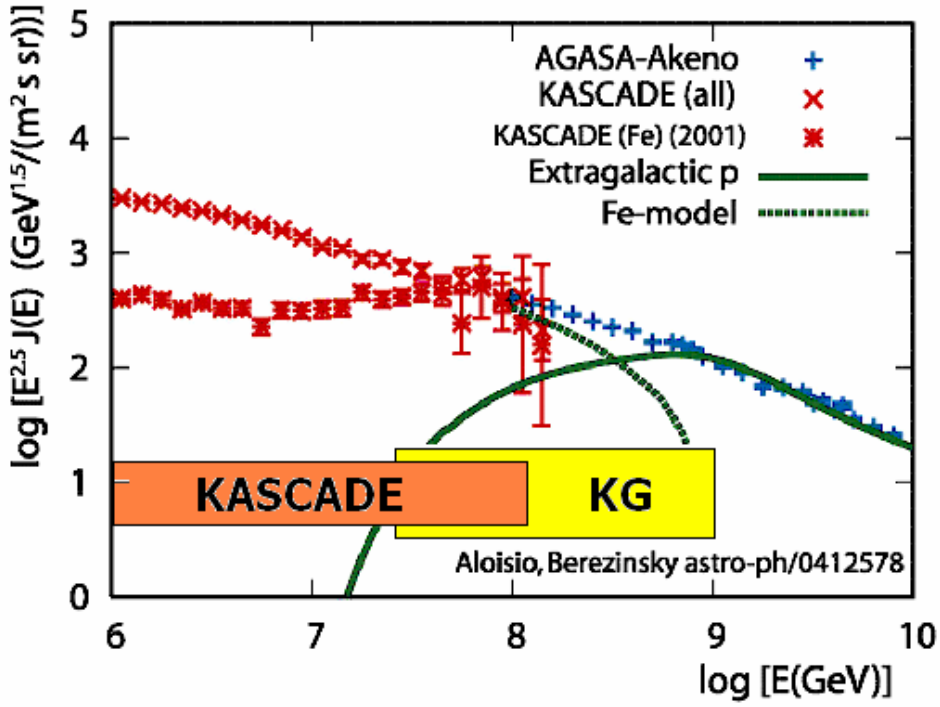
KG is an extension of the original KASCADE array experiment:

Goals:

1) Study spectrum and composition of 10^{16}-10^{18} eV cosmic rays.
2) Investigate possible existence of the iron knee.
3) Change in composition due to galactic to extragalactic transition.

Additionally:

4) Anisotropy studies.
5) Test hadronic interaction models.



The KASCADE-Grande experiment

The KASCADE-Grande experiment

Grande array:

Area: 0.5 km^2.

Stations: 37 x 10m^2 plastic scintillator detectors.

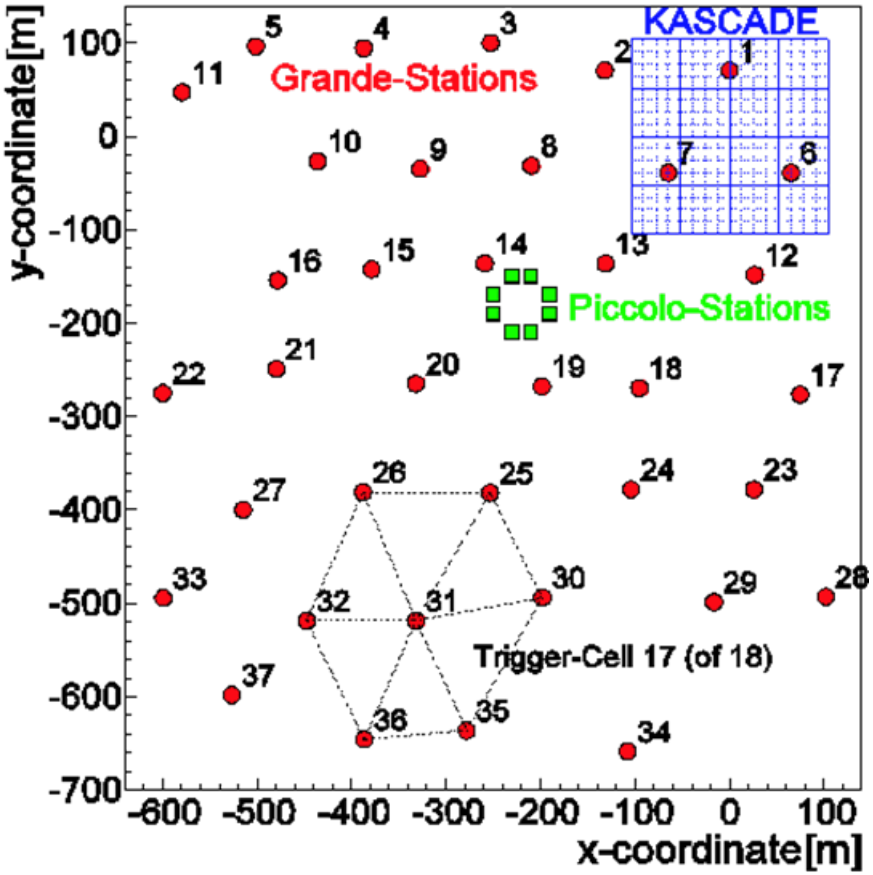
Average distance: 140 m.

E range: 10^{16}-10^{18} eV.

Trigger: 18 clusters of hexagonal shape.

Rate: 0.5 Hz.

EAS e/γ and μ components together.



The KASCADE-Grande experiment

EAS reconstruction:

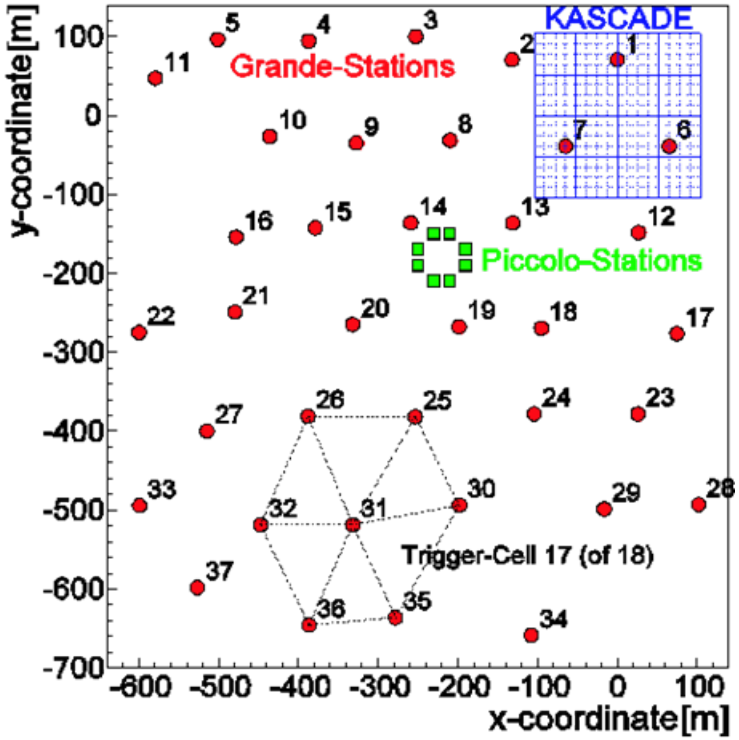
Relevant EAS parameters obtained from combined LL-Chi^2 fit to energy deposits and arrival times.

1) Core position, arrival direction use Grande array data

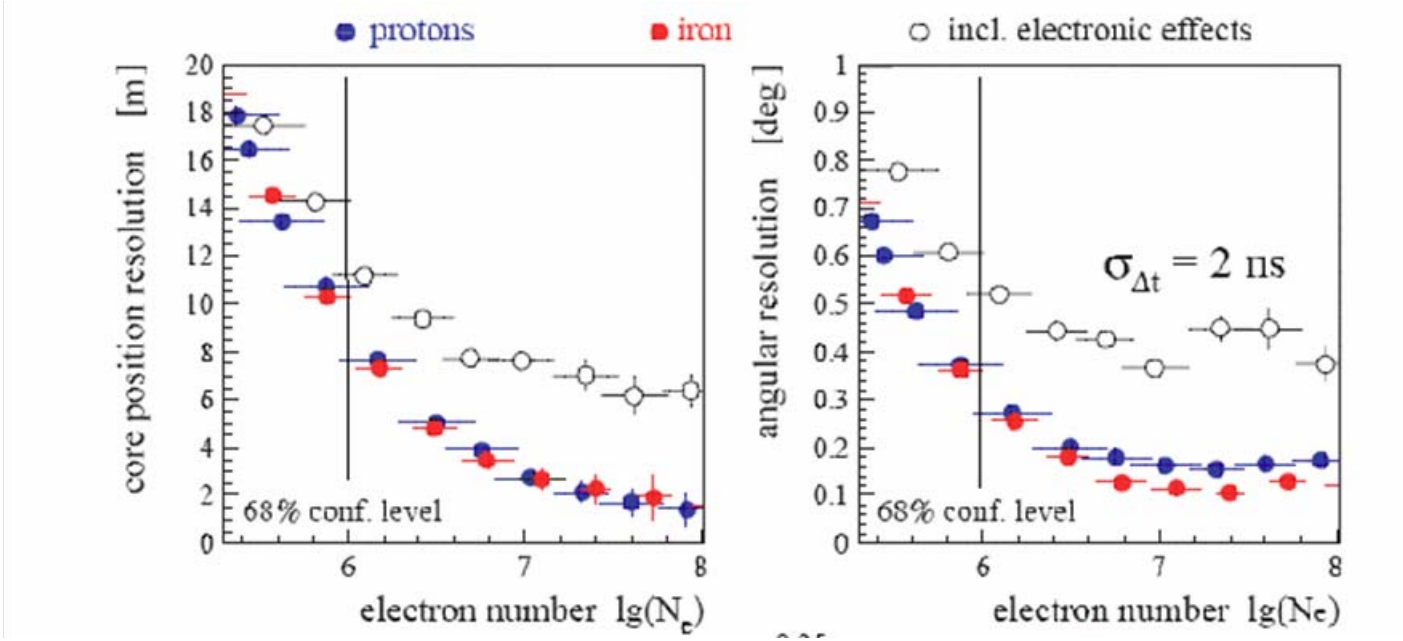
2) Number of charged particles from Grande array data

3) Muon number obtained with KASCADE μ detectors

4) Electron number extracted from Grande and KASCADE μ detectors information.



A step beyond: The KASCADE-Grande experiment



Resolution at 100% efficiency ($N_e > 10^6$) and $\vartheta = 0^o - 18^o$:

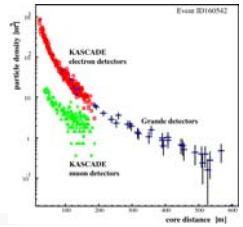
$\Delta r < 12$ m,

$\Delta\vartheta < 0.6^o$.

Studied with MC simulations (shower development and detector).

Description of the present work

Reconstruction of inclined air showers ($\vartheta \geq 40$ º)

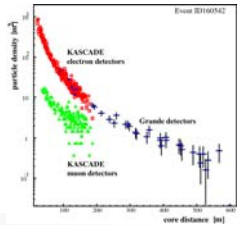


Motivations

- Increase data sample on cosmic rays for physical studies.
- Analysis of MC data and real data to identify problems in reconstruction:
  - ➢ Arrival direction of primary:
    - Increasing errors in arrival direction for $\vartheta \geq 40$ º.
    - Improve standard reconstruction.
  - ➢ Total number of μ´s in the shower:
    - Check if MC models work for high zenith angles,
    - Study development of air shower,
    - look for azimuthal asymmetries.

Description of the present work

Arrival direction of primary.



- Arrival direction of primary from χ^2 minimization to measured arrival times:

$$\chi 2 = \sum_i (T_i^{data} - T_i^{model} - \Delta T_i)^2 / \sigma_i^2$$

Where:

$$T_i^{model} = \mathbf{r_i} \cdot \mathbf{n}/c$$

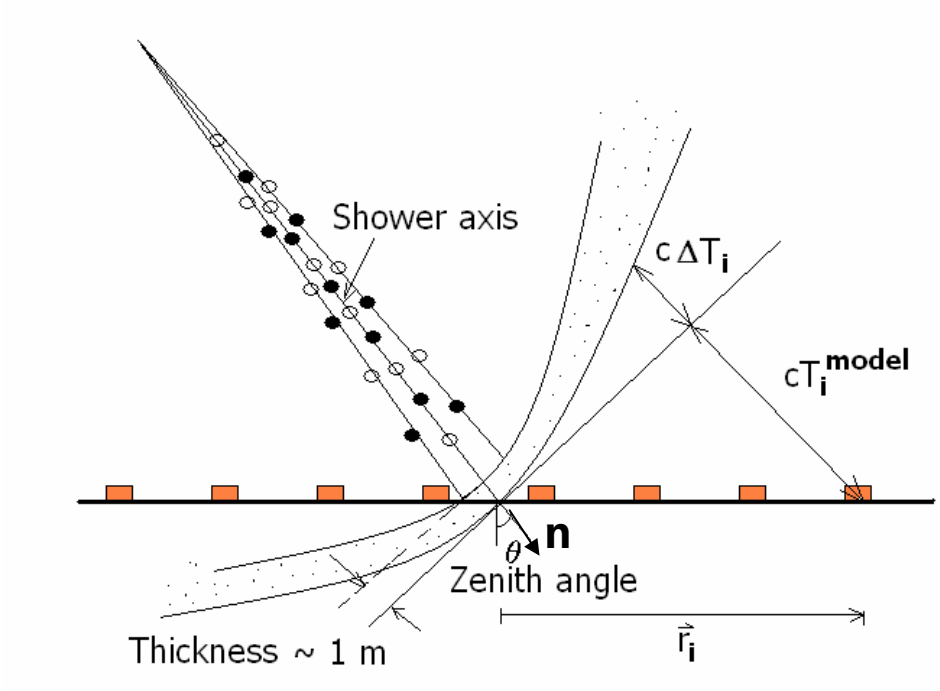
$$= [x_i \cos a + y_i \cos b + z_i \cos c]/c$$

with:

$\cos a = \sin \vartheta \cos \varphi$

$\cos b = \sin \vartheta \sin \varphi$

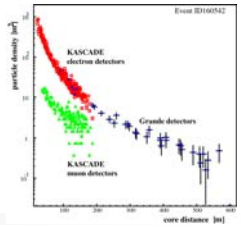
$\cos c = [1 - \cos^2 a - \cos^2 b]^{1/2}$



σ_i: Minimum time uncertainty (~ 2 ns) and fluctuations of ΔTi.

Description of the present work

Arrival direction of primary.

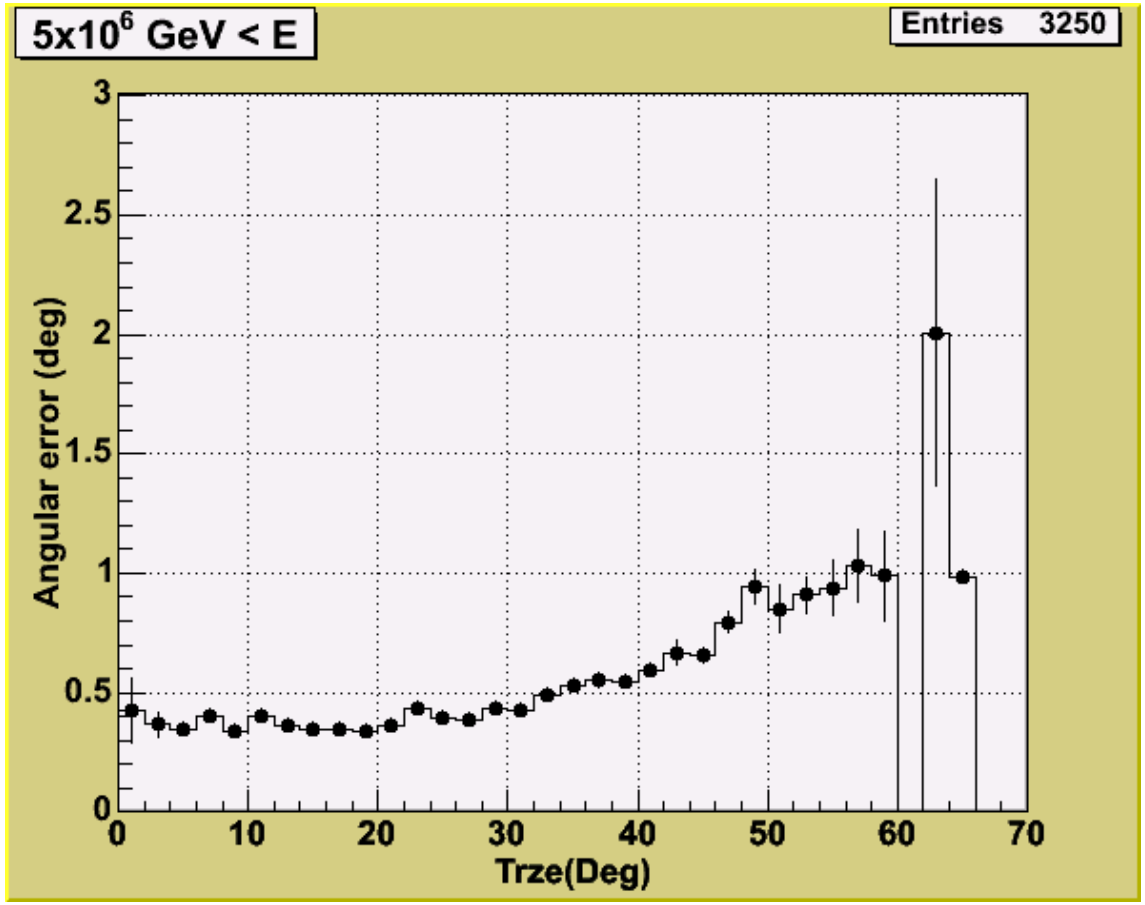


Problem:

Increasing errors in arrival direction for $\vartheta \geq 40$ º.

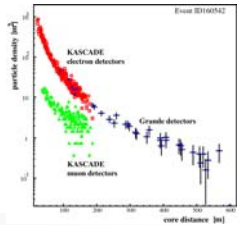
Planned work:

Improve standard reconstruction for arrival direction of the primary at $\vartheta \geq 40$º.



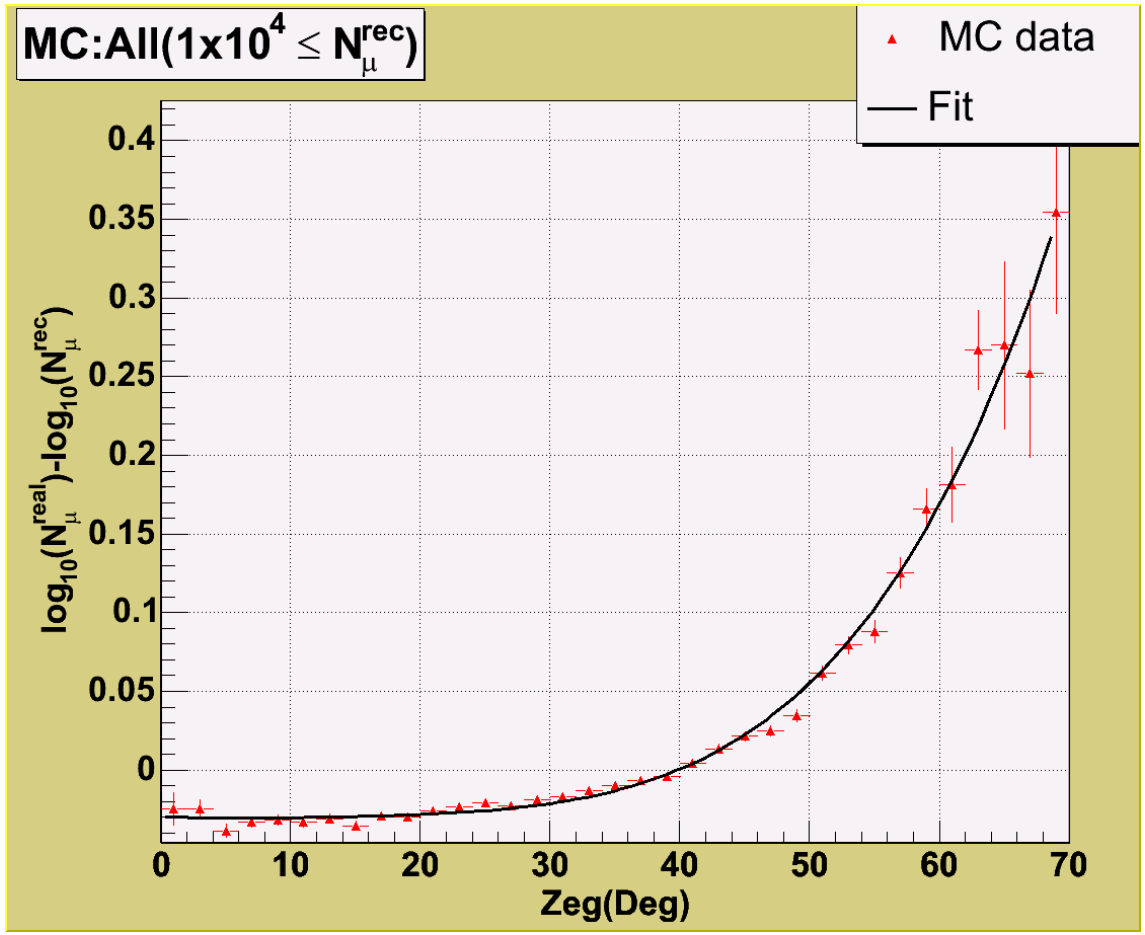
Description of the present work

Total number of muons



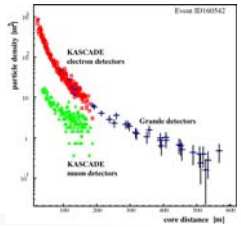
Problem:

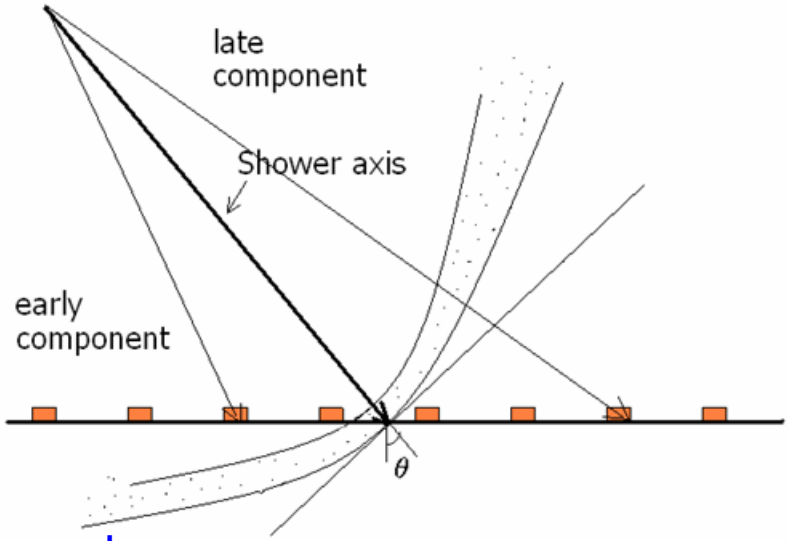
Also increasing errors in total μ number for $\vartheta \geq 40^{o}$.



Description of the present work

Total number of muons





Early and late components do not move parallel to shower axis.

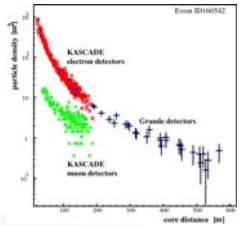
In reality, they enter with a different angle through detectors.

→

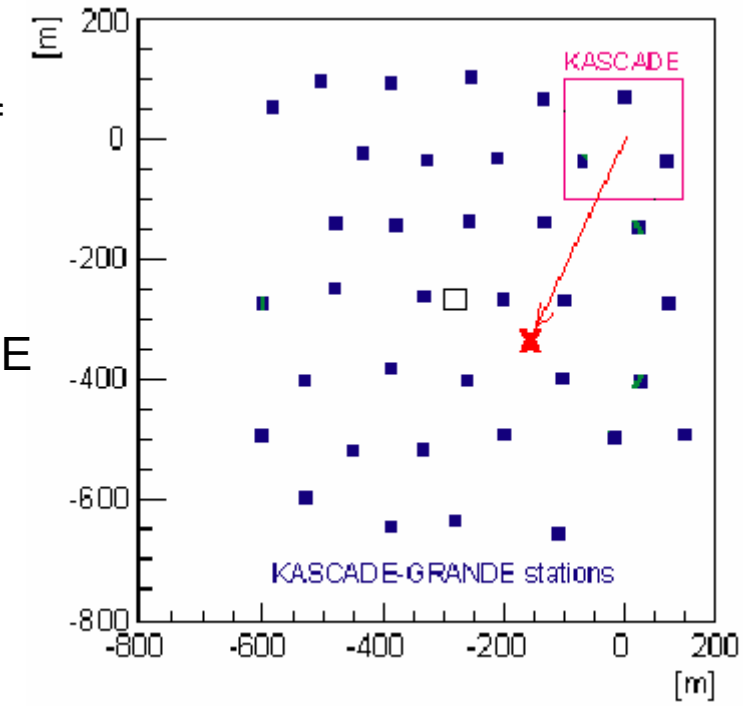
Change estimations on number of particles in each station.

Description of the present work

Total number of muons



- Any difference in reconstruction if late component hit KASCADE array instead of early one?
- Look for azimuthal asymmetries (KASCADE plane, $\vartheta \geq 40$ º).
- Work with real data.



Summary

- KASCADE showed that the knee is produced by the light primaries of the cosmic ray flux.
- KASCADE was expanded to KASCADE-Grande, which is in stable operation and taking data since 2004.
- KG will address important questions for the physics of the cosmic rays between the knee and the ankle.
- KG will look for the iron knee, predicted by different models.
- Include inclined events above $\vartheta \geq 40^{\circ}$ in analysis will require to check and improve standard reconstruction techniques.

KASCADE-Grande Collaboration

KASCADE-Grande Collaboration

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