

Recent Results from KASCADE-Grande

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Outline

Motivation

Update on KASCADE results
 EAS measurements 10¹⁴ eV ÷ 8 · 10¹⁶eV

- KASCADE-Grande status
 EAS measurements 3 · 10¹⁶eV ÷ 10¹⁸eV
- Conclusion and Outlook

Origin of the Knee







3 Transition Galactic → Extragalactic



Where is the transition ? Is this the cause of the ankle?

KASCADE-Grande = KArlsruhe Shower Core and Array DEtector + Grande and LOPES

Measurements of EAS in the energy range $E_0 = 100 \text{ TeV} - 1 \text{ EeV}$



KASCADE : multi-parameter measurements



KASCADE-Grande = KArlsruhe Shower Core and Array DEtector + Grande and LOPES

Key-Parameters:

- Data Taking started in 2004
- Covered E-range: 100 TeV 1 EeV
- Instrumented area: KASCADE 0.04 km²; Grande: 0.45 km²
- Number of Stations: KASCADE: 252 á 3.8 m²; Grande: 37 á 10 m²

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• **Detected particles:** electrons (1200 m² instrumented area)

muons (1100 m² @ $E \ge 230, 490, 800, 2400 \text{ MeV}$)

muon tracking (150 m² instrumented area)

hadrons (\gtrsim 80 GeV; 320 m² instrumented area)

→ best sampling of all EAS expts. in this E-range

• Radio Antennas (LOPES) (A. Haungs, yesterday)

KASCADE : Electrons & Muons in a single event



(N_e , N_μ) \Leftrightarrow (Energy, Mass)

CORSIKA Simulations



Data

Result of Unfolding: QGSJet01





Result of Unfolding: Sibyll 2.1





More CNO & Iron with Sybill based unfolding

? E/Z or E/A ?



? E/Z or E/A ?



? E/Z or E/A ?



All-Particle Spectra

Antoni et al., APP 24 (2005) 1



Sensitivity to hadronic interaction models



Sensitivity to hadronic interaction models



Main results robust against method or model:
-) knee caused by light primaries
-) positions of knee vary with primary elemental group
-) no (interaction) model can describe the data consistently

KASCADE collaboration, Astroparticle Physics 24 (2005) 1-25, astro-ph/0505413

(N_e, N_µ) ⇔ N_h: Consistent Inconsistencies

QGSJET 01

Milke et al, ICRC 2005



(N_e, N_µ) ⇔ N_h: Consistent Inconsistencies

SIBYLL 2.1

Milke et al, ICRC 2005



Compare to µ-production height



Idea:

Use composition from Ne-N μ as input and simulate expected μ -production height and compare with data

Preliminary Result:

Showers penetrate deeper than expected at all energies



Model tests by muon density measurements



model sensitive parameters:

$$\begin{split} \mathbf{R}_{\rho}^{2.4/0.49} &= \rho_{\mu}^{2.4\text{GeV}} \ / \ \rho_{\mu}^{0.49\text{GeV}} \\ \mathbf{R}_{\rho}^{2.4/0.23} &= \rho_{\mu}^{2.4\text{GeV}} \ / \ \rho_{\mu}^{0.23\text{GeV}} \\ \mathbf{R}_{\rho}^{0.49/0.23} &= \rho_{\mu}^{0.49\text{GeV}} \ / \ \rho_{\mu}^{0.23\text{GeV}} \end{split}$$



Model tests by muon density measurements

Haungs et al, ICRC 2005



Results in terms of the muon energy spectrum in EAS: -deviation between measurements and predictions increases with energy -large deviations in the width of the distributions (shower to shower fluctuations)

Comparison with direct experiments



Systematic uncertainties in p and He spectra comparable to uncertainties of direct measurements !

Analysis of large scale anisotropy of cosmic rays



Search for point sources of cosmic rays

Point sources: not expected at these energies, but needs to be checked. Muon poor events is a sample enriched by possible gamma induced showers.

Li-Ma significances $E_0 > 10^{14.5} eV$



Search for primary photons (diffuse Gamma-ray flux)

Primary photons: point directly to the source of cosmic rays EAS are μ -poor, i.e. small ratio of μ to electron number



What did KASCADE tell us?

- Knee is caused by light primaries
- Knee marks a change from light meavy
- E/A vs E/Z cannot be sufficiently well separated
- Interaction models still unsatisfactory; 10-15 % deviations in EAS observables really matter ...!



- KASCADE provides important clues to interaction models
- LHC data in forward region will be highly welcome
- But still more data to come from KASCADE
- no global anisotropies observed
- no point sources observed
- upper limit on γ -flux deduced

Towards higher Energies: KASCADE-Grande



Is there a transition galactic - extragalactic ? If yes, where is it ?



KASCADE-Grande : multi-parameter measurements

KASCADE-Grande : multi-parameter measurements

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KASCADE + Grande

 energy range: 100 TeV – 1 EeV
 large area: 0.5 km²
 Grande: 37x10 m² scintillators
 Piccolo: trigger array

KASCADE-Grande Trigger Efficiency



Common events

 (all detector components)
 measured since December 2003

 Trigger: 7 of 7 stations in one

 of 18 hexagons



KASCADE-Grande : Single event measurement

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lateral distribution of a single event measured by KASCADE-Grande: $E_0 \approx 2 \cdot 10^{17} eV$, $\Theta = 33^{\circ}$



KASCADE-Grande : Observables

- core position and angle-of-incidence from Grande array data
- 2a) shower size (charged particles) from Grande array data
 2b) muon number from KASCADE muon detectors
 2c) muon production height
 - from KASCADE muon tracking detector
- 3) electron number from Grande by subtraction of muon content
- 4) two dimensional size spectrum for the analysis



KASCADE-Grande : Reconstruction uncertainties



KASCADE-Grande : lateral distributions

Glasstetter et al, ICRC 2005



KASCADE-Grande : first analyses

Glasstetter et al, ICRC 2005



KASCADE-Grande : all-particle energy spectrum



KASCADE-Grande: E-Spectrum from µ-number estimate and I-dim unfolding

First energy spectrum (by muon number only)



KASCADE-Grande: first analyses: Anisotropies

Large scale anisotropy? Distributions of events in galactic coordinates

Point sources? ← Angular differences between two events



KASCADE-Grande : Flash ADC system

• Flash-ADC system for the Grande array

with optical links and a ring buffer system
→ self triggering → full signal information of the detectors
→ high time resolution → intrinsic electron muon separation



High precision data from Grande array

Summary & Conclusions

- ,Revival' of research activities in knee- & ankle region
- Comparison of data and models has become more quantitative; we are discussing 10-15%-effects!
- Limitations are by EAS-simulations and by data itself
- KASCADE-Grande just about to start delivering high-quality data from the knee up to the ankle
- A true understanding of CRs requires:
 - origin of the knee (E/Z vs E/A)
 - answer question about Fe-knee
 - transition galactic-extragalactic
 - (astro)physics of the ankle
 - GZK-existence

KASCADE-Grande Collaboration

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