Status
KASCADE-Grande
Cosmic Rays around the knee(s)

Astrophysical questions for this energy range:

- **(1st) knee**
  - Knee position
  - Composition at the knee
  - Anisotropy around the knee
  - Structure of spectrum
    (below, around, and above the knee)

- **2nd knee (dip, ankle) ?**
  - Transition to extragalactic CR?
  - The iron knee?
  - Anisotropies, Point Sources?
Experiment: KASCADE-Grande
= KArlsruhe Shower Core and Array DEtector + Grande and LOPES

Measurements of air showers in the energy range $E_0 = 100$ TeV - 1 EeV
KASCADE: multi-parameter measurements

- energy range 100 TeV – 80 PeV
- up to 2003: $4 \times 10^7$ EAS triggers
- large number of observables:
  - electrons
  - muons (@ 4 threshold energies)
  - hadrons
Suggestion A. Watson
(Summary ISVHECRI 2006):
basic observable analysis first

KASCADE: Astroparticle Physics 16 373 2002

- KNEE CAUSED BY DECREASING FLUX OF LIGHT ELEMENTS
- Do we need hadronic interaction models?
  ➔ yes, for normalization of absolute energy and mass scale!!
KASCADE : energy spectra of single mass groups

Measurement:
- KASCADE array data
- 900 days
- 0-18° zenith angle
- 0-91m core distance
- $\lg N_e > 4.8$
- $\lg N_\mu^{\text{tr}} > 3.6$
- $685868$ events

Searched:
- $E$ and $A$ of the Cosmic Ray Particles

Given:
- $N_e$ and $N_\mu$ for each single event

$\Rightarrow$ solve the inverse problem

$$g(y) = \int K(y, x)p(x)dx$$

with $y = (N_e, N_\mu^{\text{tr}})$ and $x = (E, A)$
KASCADE results

- same unfolding but based on two different interaction models:
  - SIBYLL 2.1 and QGSJET01 (both with GHEISHA 2002) all embedded in CORSIKA

KASCADE results: confirmation

- same unfolding but based on two different low energy interaction models and different zenith angle ranges:
- GHEISHA 2002 and FLUKA (both with QGSJET01)
- 0-18°, 18-25.9°, 25.9-32.3° (all with QGSJET01/FLUKA)

- Less dependence for unfolding based on different low energy hadronic interaction models
- Weak dependence on zenith angular binning (not significant)

H.Ulrich, XIV ISVHECRI, Weihai, China 2006
KASCADE result: sensitivity to hadronic interaction models

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

KASCADE analysis: muon production height

Sensitivity to composition & models!

Good angular resolution allows to determine the relative angles between muons and shower axis.
KASCADE result: analyses of anisotropies
large scale, point sources, photon limit

- no large scale anisotropy observed
- no positive signal from point sources
- no positive gamma signal observed
  best limits for the diffuse flux

KASCADE collaboration
Summary KASCADE Results (first knee):

- Analysis: Correlation studies are required (multiparameter measurements needed)
  (Analyzing mean values of data and simulations appears inadequate)

- Knee is due to decrease in flux in light primaries! (model independent; most experiments)

- How precise are the models? (no new physics needed, compare proton spectrum)

- Distinguishing between astrophysical models (Investigation of Anisotropy for different primaries)

- Knee position dependence: \( \propto Z \) or \( \propto A \)?
Motivation for measurements 100 – 1000 PeV

- Iron knee?
- Second knee??
- Transition galactic-extragalactic CR??
Motivation for KASCADE-Grande

Fe-knee $\sim 10^{17}$ eV
gal-eg transition $\sim 10^{17.7}$ eV
Ankle = eg characteristics

Cannonball modell:
Fe-knee $\sim 2 \times 10^{17}$ eV
All is galactic
(knee = elastic scattering)

Various theories on energy range $10^{17}$-10$^{19}$ eV:

- e.g. Berezinsky et al

- e.g. Wibig et al

- e.g. de Rujula

Grande E$_0$-range

Fe-knee $\sim 10^{18}$ eV
gal-eg transition $\sim 10^{19}$ eV
Ankle = eg characteristics
KASCADE-Grande:
multi-parameter measurements

KASCADE + Grande
- energy range: 100 TeV – 1 EeV
- large area: 0.5 km²
- Grande: 37x10 m² scintillators
- Piccolo: trigger array
KASCADE-Grande: Single event measurement

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

Event ID160542

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<th>Particle density [m$^{-2}$]</th>
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</tr>
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<td>1</td>
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<td>500</td>
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<td>600</td>
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KASCADE electron detectors
KASCADE muon detectors
Grande detectors

$N_e = 9.5 \times 10^5$
$N_\mu = 1.2 \times 10^5$
$x_e = -66$ m
$y_e = -49$ m
$\Theta = 33.1^\circ$
$\phi = 225^\circ$

deposited energy [MeV/m$^2$] arrival time [ns]
KASCADE-Grande: Efficiency

- Common events (all detector components) measured since December 2003
- Trigger: 7 of 7 stations at one of 18 hexagons

100% efficient above \(2 \times 10^{16} \text{eV}\)

600x600 m²

\(<42°\)
KASCADE-Grande :
Reconstruction

1) 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

3) electron number from Grande by subtraction of muon content

4) two dimensional size spectrum for the analysis
KASCADE-Grande: Reconstruction

Monte-Carlo studies:

- Sufficient reconstruction accuracies for
  - core
  - direction
  - shower size, and
  - muon number
  \((E_\mu > 230\text{MeV})\)
KASCADE-Grande: lateral distributions

1-year data, core inside Grande array, $E_{\text{est}} = f(N_{\mu}, N_e, \Theta)$ [Monte-Carlo based]
KASCADE-Grande: first analyses
electron size spectra

- stable data taking since 2004
- performance of array looks promising
- reconstruction gives reasonable spectra
- careful checks of systematic effects in work

KASCADE-Grande: first analyses
muon size spectra

- stable data taking since 2004
- performance of array looks promising
- reconstruction gives reasonable spectra
- careful checks of systematic effects in work

KASCADE-Grande: first analyses
muon reconstruction at inclined showers

-muon number reconstruction possible up to 70°
-investigation of attenuation of muon component
- model tests
- Increasing of KASCADE-Grande statistics

Juan Carlos Arteaga et al. – KASCADE-Grande coll., ICRC (2007)
KASCADE-Grande: first analyses
muon density investigations

- muon density reconstruction possible for different distances
- muon density reconstruction possible by direct measurement or via LDF
  ➔ composition sensitivity
  ➔ model tests

KASCADE-Grande: first analyses

Unfolding of 2-dimensional shower size spectrum possible

- energy & composition
- still improvements in systematics needed

Myon number estimate and 1-dim unfolding

First energy spectrum (by muon number only)

Jurriaan van Buren, PhD thesis (2006)
KASCADE-Grande: first analyses: point sources

Until now no hint for point source (very preliminary)

Sven Over et al. – KASCADE-Grande coll., ICRC (2007)
HE Muon Measurements at KASCADE-Grande

- Central Detector muon facility
  \[ E_\mu^{\text{thresh}} = 2400 \text{ MeV} \]

- Muon Density measurements \( \rho_\mu^{2.4\text{GeV}} \)
- Lateral distributions
- Model tests (muon energy spectrum)
  \[ R_\rho^{2.4/0.23} = \frac{\rho_\mu^{2.4\text{GeV}}}{\rho_\mu^{0.23\text{GeV}}} \]

- Muon Tracking Detector
  \[ E_\mu^{\text{thresh}} = 800 \text{ MeV} \]

- Measurement of radial and tangential angles \( \rho_\mu, \tau_\mu \)
- Muon production height
- Lateral distributions
- Model tests (pseudorapidity)
  \[ \eta_\mu = -\ln(\zeta/2) \quad \zeta = \frac{p_t}{p_\parallel} = \sqrt{\rho^2 + \tau^2} \]
KASCADE-Grande: Summary

- Knee physics needs (still) air-shower investigations
- Sophisticated experiments and analyses needed
- Knee is caused by light primary elements
- Cosmic rays are isotropic around the knee
- Consistency of data is not given if compared to Monte Carlo predictions
- Interaction models have to be further improved
- Knee physics do not need 'new' particle physics
- KASCADE-Grande will cover whole "knee" range
  ➔ Promising status and first data!
- Radio detection as new technique (LOPES)?

Still a Vital Field of Research