# The KASCADE-Grande experiment: an overview

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*Abstract* – **The KASCADE-Grande experiment, located at Forschungszentrum Karlsruhe (Germany), is a multi-component extensive air-shower experiment to study cosmic rays and their interactions at primary energies $10^{14}$-$10^{18}$ eV. After detailed investigations of the knee in the spectrum with KASCADE and EAS-TOP experiments, the main goal of KASCADE-Grande is to provide conclusive results on the knee region by detecting the expected iron knee in the spectrum at around $10^{17}$ eV, and measuring the composition in the possible transition region between galactic and extragalactic components. Due to its multicomponent characteristics, basically the former KASCADE experiment enriched by two new arrays of scintillator detectors (Grande and Piccolo), with the aim of providing a large acceptance area (0.5 km$^2$) and prompt trigger signal, KASCADE-Grande is a suitable array to provide refined measurements in the $10^{16}$-$10^{18}$ eV region. In the following, we briefly report on the characteristics of the detector and describe its performances.**

## 1. INTRODUCTION

The scientific motivations of KASCADE-Grande reflect the observations conducted independently by the EAS-TOP and KASCADE experiments. Both experiments observed the knee in the spectra of all secondary components that have been investigated: electromagnetic [1][2], muonic [3][4] and hadronic [5]. The knee appears in all angular bins and the Ne (total number of electrons at observation level) and N$\mu$ (total number of muons at observation level) integral fluxes above the knee are consistent within the experimental errors. These results do not depend on the simulation of the EAS development and give a clear indication that the knee is a peculiarity of the primary spectrum, disfavoring a hypothesis based on changes of the interaction characteristics of the primaries with air nuclei. Moreover, these experiments indicate that the knee is due to the bending of the lightest elements, independently of the hadronic model used to simulate the EAS cascade in the atmosphere [6] and of the muon kinetic energy (GeV or TeV muons) [7].

The anisotropy study [8][9], a key parameter in interpreting the knee feature as a result of leakage from the galaxy, has set upper limits that exclude an energy dependence of the amplitude stronger than $A \propto E_0^{0.3}$.

In summary, based on EAS-TOP and KASCADE results obtained in the knee region, a definitive proof of the rigidity dependence of the knee would come from the observation of the iron knee expected around $10^{17}$eV. Moreover, the KASCADE analysis showed also the limitation of the present high-energy interaction models to describe consistently the measured data [6].

Detailed anisotropy study together with mass composition analysis, in the $10^{16}$-$10^{18}$ eV energy range, are thus very useful to discriminate astrophysical models in the explanation of the

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second knee and ankle dip (e.g. [10][11]).

All these open questions are the main physics motivations of the KASCADE-Grande experiment. Finally, the possibility of moving the EAS-TOP detector to the KASCADE site offers the unique possibility of making cross-check calibrations of the two detectors. This is very important from a technical point of view because it allows a better understanding of the systematic uncertainties of the EAS measurements technique.

## 2. EXPERIMENTAL SETUP

The KASCADE-Grande experiment [12] is a multi-detector setup consisting of the KASCADE [13] experiment, the trigger array Piccolo and the scintillator detector array Grande. Additionally, KASCADE-Grande includes an array of digital read-out dipole antennas (LOPES) to study the radio emission in air showers at $E>10^{16}$ eV [14]. Most important for the analysis presented here are the two scintillator arrays: KASCADE and Grande.

The KASCADE experiment is itself a multiple detector setup and its major parts are an array of 252 scintillator detector stations, a streamer tube muon detector ($E\mu>800$ MeV) [15], and a multiwire proportional chamber muon detector ($E\mu>2.4$ GeV).

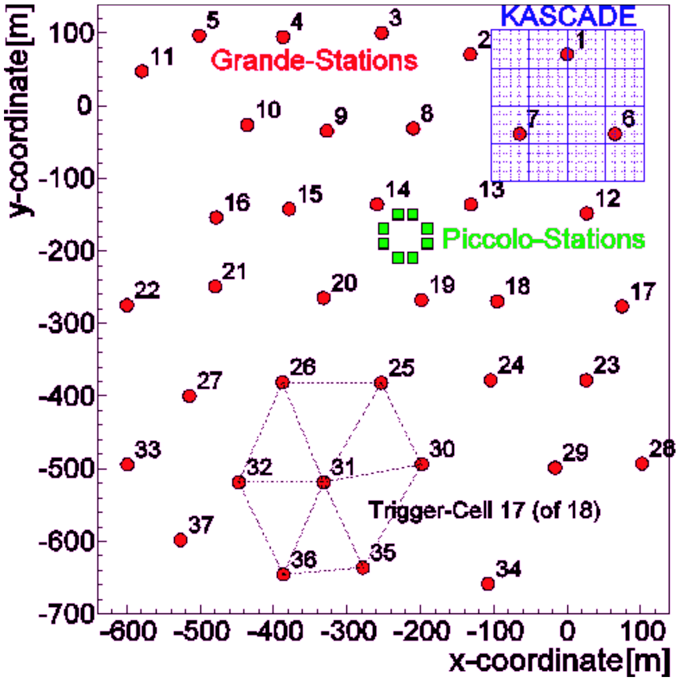

*Figure 1. Layout of the KASCADE-Grande experiment.*

The KASCADE array is structured in 16 clusters. Each detector station houses two separate detectors for the electromagnetic (unshielded liquid scintillators) and muonic components (shielded plastic scintillators, $E\mu>230$ MeV). Muon detectors are housed only in 12 clusters (or 192 stations). This enables to reconstruct the lateral distributions of muons and electrons separately on an event-by-event basis.

The Grande array is formed by 37 stations of plastic scintillator detectors, 10 m$^2$ each (divided into 16 individual scintillators) spread on a 0.5 km$^2$ surface, with an average grid size of 137 m. All 16 scintillators are viewed by a high gain photomultiplier (for timing and low particle density measurements), the four central ones are additionally viewed by a low gain one (for high particle densities). The signals are amplified and shaped inside the Grande stations, and, after transmission to a central DAQ station, they are digitized by peak sensing ADCs. The dynamic range of the detectors is 0.3 - 8000 particles/10 m$^2$.

Grande is arranged in 18 hexagonal clusters formed by six external detectors and a central one. The minimum triggering requirement is the coincidence of the central and three neighboring stations in one hexagon (4/7, rate 5 Hz). A stricter implemented mode, that is required for triggering the KASCADE array, is the 7/7 trigger mode, requiring all stations in a hexagon being fired ( 0.5 Hz).

Full detection efficiency, inside an internal fiducial area of ~0.3 km$^2$, is reached at ~$10^6$ shower size, i.e. a primary energy of ~$10^{16}$ eV.

| Detectors | Detected EAS particles | Area | Energy threshold |
|---|---|---|---|
| **KASCADE Array:** | | | |
| Liquid scintillators | Charged particles, photons | 490 m$^2$ | 5 MeV |
| Plastic scintillators | Muons | 622 m$^2$ | 230 MeV |
| **Grande Array:** | | | |
| Plastic scintillators | Charged particles, photons | 37 × 10 m$^2$ | 5 MeV |
| PICCOLO | Charged particles, photons | 80 m$^2$ | 5 MeV |
| **Central Detector:** | | | |
| Ionization chambers | Hadrons | 9×304 m$^2$ | 50 GeV |
| Plastic scintillators | Muons | 208 m$^2$ | 490 MeV |
| Streamer tubes | Muons | 247.5 m$^2$ | 2.4 GeV |
| Multiwire proportional chambers | Muons | 2×129 m$^2$ | 2.4 GeV |
| Plastic scintillators | Electrons | 23 m$^2$ | 5 MeV |
| **Muon Tracking Detector:** | | | |
| Limited Streamer tubes | Muons | 4×128 m$^2$ | 800 MeV |

*Table 1: Components of the KASCADE-Grande Experiment*

## 2. Reconstruction Accuracy

The main shower parameters that are measured for each event are: the arrival direction, the total number of muons and the total number of electrons in the shower.

The arrival direction of the events is determined fitting the arrival time of the particles in the Grande detectors to a curved shower front [16]. The core position, the shower age and the shower size (total number of charged particles at observation level) are obtained fitting the particles densities measured by the Grande stations with a NKG like function [16].

The total number of muons is calculated using the core position determined by the Grande array and the muon densities measured by the KASCADE muon detectors[17]. The lateral distribution of a single event is shown in figure 2. The particle densities measured by Grande detectors are those sampled by each single station, while for the KASCADE array the mean densities calculated in 20 m intervals of the core distance are shown.

The precisions obtained in the reconstruction of the shower parameters are evaluated exploiting the unique feature of the KASCADE-Grande experiment of having two independent samplings of the same event by the KASCADE and the Grande arrays.

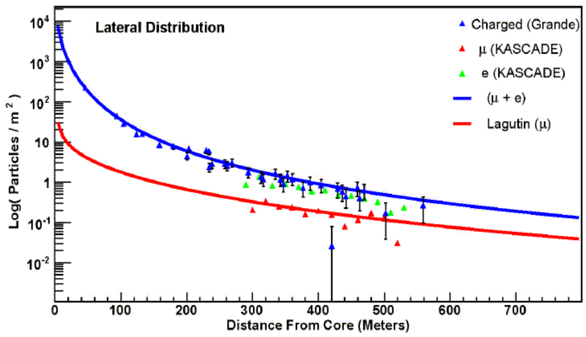

*Figure 2. Example of the lateral distribution measured for a single event by the KASCADE-Grande experiment.*

Selecting showers with core located in a region that is internal for both arrays (i.e. a ring around Grande station number 7, see figure 1) we have a set of events that are independently reconstructed by both arrays. We can thus compare the Grande results to those obtained by the KASCADE array that is used as reference (the distance between two KASCADE detectors is just 13 m).

Dividing events in bins of shower size (again determined by KASCADE) we construct the distributions of the difference of the arrival directions $\Delta\Phi$ and of the core positions $\Delta r$. Fitting these distributions with a Rayleigh function we determine the Grande resolution as a function of the shower size.

Figure 3 shows that the angular resolution is better than 1° (the increase of the errors for shower size greater than $10^7$ is probably due to a lack of statistics). Figure 4 shows that the error on the determination of the core position is clearly lower than 10 m.

The same procedure is followed for the shower size, plotting the distributions of $\Delta N=(N_{KAS}-N_{Gra})/N_{KAS}$ that are then fitted with a gaussian distribution. The mean value (Figure 5) is the systematic difference in the shower size obtained by KASCADE ($N_{KAS}$) and by Grande ($N_{Gra}$); while the RMS is the precision of the Grande array (Figure 6). We can see that the systematic difference between Grande and KASCADE is lower than 5% and that the error in the determination of the shower size is lower than 20%.

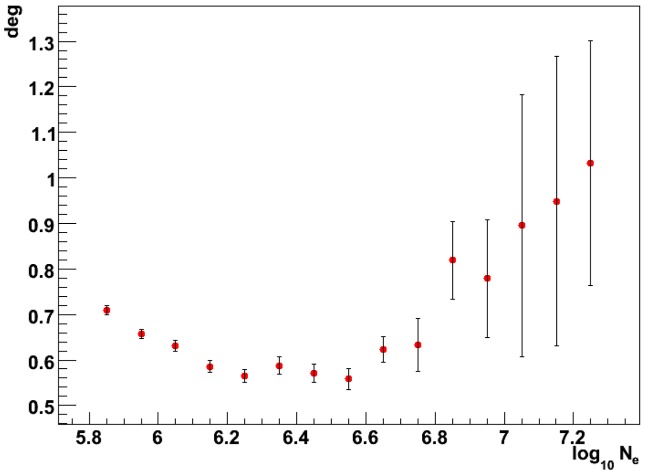

*Figure 3. Grande array angular resolution measured comparing the arrival direction with the one obtained by the KASCADE array.*

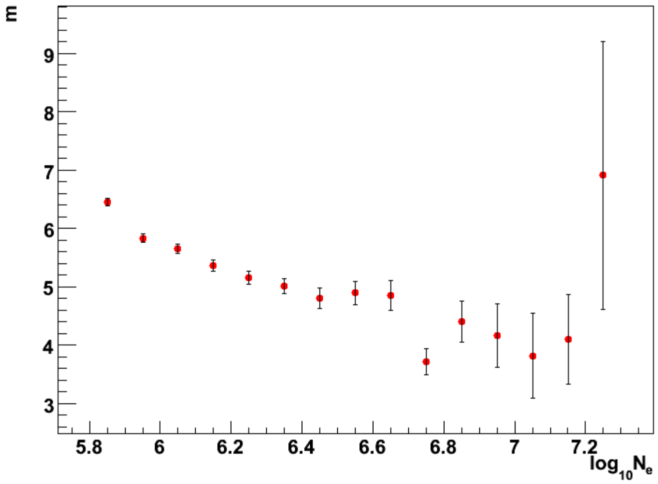

*Figure 4. Grande array core position resolution obtained by the comparison with the KASCADE array.*

The errors on the shower parameters that have been obtained, and shown in this work, are those foreseen in the project of the KASCADE-Grande experiment.

The KASCADE-Grande experiment is in continuous data taking since January 2004, a conclusive evaluation of systematic effects and the whole data processing are currently in progress.

## 3.EXPERIMENTAL PERSPECTIVES

The experiment will measure the cosmic ray primary spectrum using different approaches, thus having the possibility of cross checking its results.

One technique is based on the well known constant intensity cut method applied both to the muon and charged particle size spectra. Preliminary studies show that the resolution that can be reached is about 22% at $E_0 \sim 10^{17}$ eV.

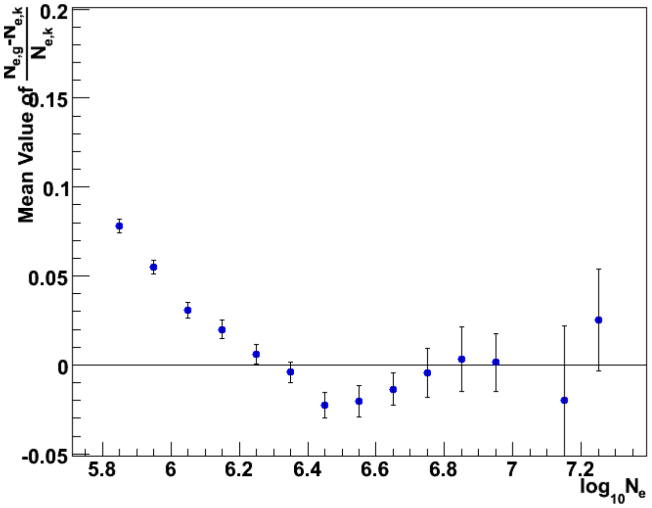

*Figure 5. Systematic difference on the Shower Size obtained by the Grande and the KASCADE arrays. The latter one is considered as reference.*

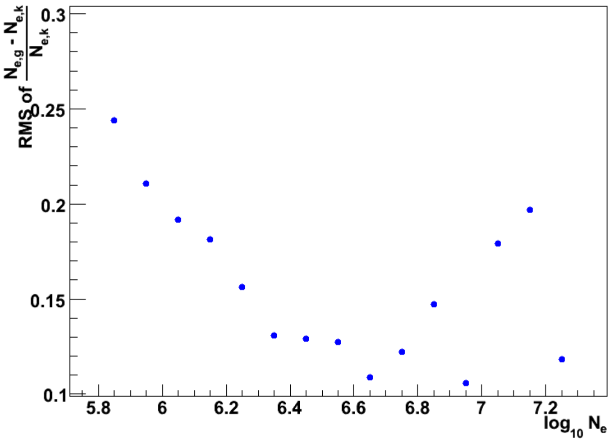

*Figure 6. Grande array precision in the determination of the shower size. This value is obtained from the comparison with the shower size obtained for the same events by the KASCADE array.*

In a different approach we try to measure the primary energy for single events using the shower size weighted with the Nμ/Ne ratio. The systematic errors and the accuracy of this procedure are currently under investigation.

Even if a final study of systematic effects is not yet completed the experiment is nevertheless already able to give preliminary, but relevant results. Using one third of the currently available statistics limits about the cosmic ray anisotropy in the knee region have been obtained.

The result is shown in figure 7, showing that the limits obtained with KASCADE-Grande are already relevant at the knee energies and can already give informations about the increase of the amplitude of the anisotropy measured at energies below the knee [18].

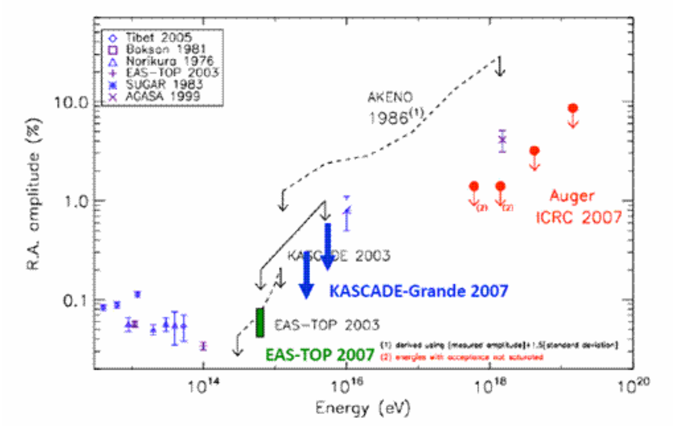

*Figure 7. Limits on the amplitude of the cosmic ray anisotropy obtained by the KASCADE-Grande experiment [19] compared to the results of other experiments.*

## *4.CONCLUSIONS*

In this paper the actual status of the KASCADE-Grande experiment has been discussed.

The resolutions obtained in the measurement of the showers parameters have been shown using the KASCADE array as a reference: <1° on the arrival direction, <10 m on the core location and <20% on the shower size. The experiment will thus study primary cosmic rays in the range $10^{16}$-$10^{18}$ eV with a previously unreached precision.

## ACKNOWLEDGMENTS

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## REFERENCES

[1] M. Aglietta et al., Aastropart. Phys., 10 (1999) 1.
[2] T. Antoni et al., Astrop. Phys., 19 (2003) 703.
[3] M. Aglietta et al., Astrop. Phys., 21 (2004) 583.
[4] T. Antoni et al. Astrop. Phys., 16 (2002) 373.
[5] J. Hőrandel et al., in: Proceedings of the 26th ICRC, 1999, vol. 1, 337.

[6] T. Antoni et al., Astrop. Phys., 24 (2005) 1.
[7] M. Aglietta et al., Astrop. Phys., 20 (2004) 641.
[8] M. Aglietta et al., Astrophys. J., 470 (1996) 501.
[9] T. Antoni et al., Astrophys. J., 604 (2004) 687.
[10] V. Berezinsky et al., Phys. Rev. D 74 (2006) 43005.
[11] D. Allard et al., in: Proceedings of the 30th ICRC, Merida 3-11 July 2007
[12] G. Navarra et al., Nucl. Instr. and Meth. A, 518 (2004) 207.
[13] T. Antoni et al., Nucl. Instr. and Meth., A 513 (2003) 429.
[14] H. Falcke et al., Nature 435 (2005) 313.
[15] P. Doll et al., Nucl. Instr. and Meth. A 488 (2002) 517.
[16] R. Glasstetter et al., Proc. of the 29th ICRC, Pune (India), 6 (2005) 293.
[17] J. Van Buren et al., Proc. of the 29th ICRC, Pune (India), 6 (2005) 301.
[18] M. Aglietta et al., Ap. J. 470 (1996) 501.
[19] S. Over et al. Proc. of the 30th ICRC Merida (Mexico), (2007)