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# The KASCADE-Grande Experiment

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**Abstract:** KASCADE-Grande is an extensive air shower experiment at Forschungszentrum Karlsruhe, Germany. Main parts of the experiment are the Grande array spread over an area of $700 \times 700\text{m}^2$, the original KASCADE array covering $200 \times 200\text{m}^2$ with unshielded and shielded detectors, and additional muon tracking devices. This multi-detector system allows to investigate the energy spectrum, composition, and anisotropies of cosmic rays in the energy range up to 1 EeV. An overview on the performance of the apparatus, shower reconstruction methods, and first results will be given.

## Introduction

The major goal of KASCADE-Grande (covering a primary energy range of $10^{14} - 10^{18}$ eV) is the observation of the 'iron-knee' in the cosmic-ray spectrum at around 100 PeV, which is expected following KASCADE observations where the positions of the knees of individual mass groups suggest a rigidity dependence [1, 2]. The capability of KASCADE-Grande will allow to reconstruct the energy spectra of various mass groups similar to KASCADE, which will give the possibility to distinguish between astrophysical models for the transition region from cosmic rays of galactic to extragalactic origin; i.e. between models of the type claimed by Berezinsky [3] (prediction of pure extragalactic proton composition already at energies around $10^{18}$ eV) and models which have an extension of the galactic component up to the ankle and therefore a mixed composition in the energy range of KASCADE-Grande (e.g. [4, 5]). Additionally, the validity of hadronic interaction models used in CORSIKA Monte Carlo simulations of ultra-high energy air showers will be tested with KASCADE-Grande. Investigations of the radio emission in air showers are continued at the site of KASCADE-Grande with promising results paving the way for this new detection technique [6].

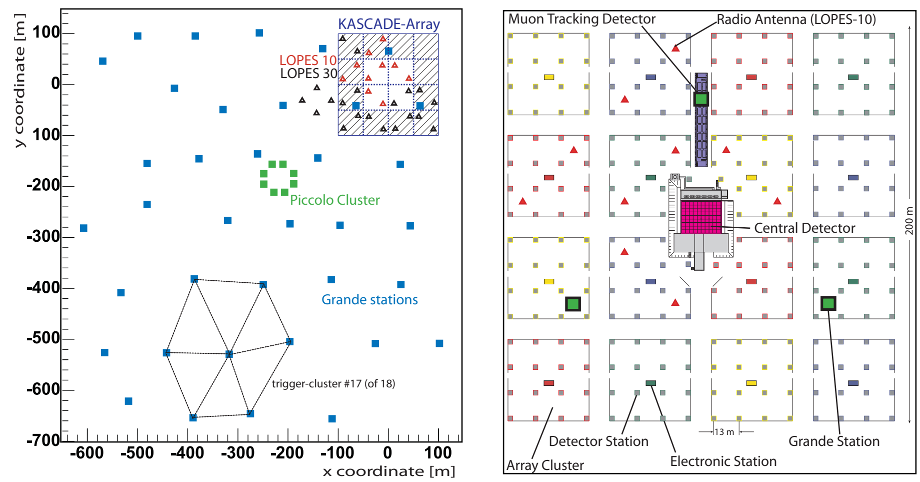


Figure 1: Layout of the KASCADE-Grande experiment: The KASCADE array, the distribution of the 37 stations of the Grande array, and the small Piccolo cluster for fast trigger purposes are shown. The location of the 30 LOPES radio antennas is also displayed. The right part zooms into the KASCADE array where the muon tracking and the central detector are located. The outer 12 clusters of the KASCADE array consists of $\mu$- and $e/\gamma$-detectors, the inner 4 clusters of $e/\gamma$-detectors, only.

## The Set-Up

The existing multi-detector experiment KASCADE [7] (located at 49.1°n, 8.4°e, 110 m a.s.l.), which takes data since 1996, was extended to KASCADE-Grande in 2003 by installing a large array of 37 stations consisting of 10 m$^2$ scintillation detectors each, with an average spacing of 137 m (Figure 1). The stations comprise 16 photomultipliers each providing a high dynamic range from 1/3 to 30000 charged particles per station for the reconstruction of particle densities and timing measurements. The signals are amplified and shaped inside the Grande stations, and after transmission to a central DAQ station digitized in peak sensitive ADCs. KASCADE-Grande provides an area of 0.5 km$^2$ and operates jointly with the existing KASCADE detectors. Grande is electronically subdivided in 18 trigger clusters (see Fig. 1) and read out and jointly analyzed with KASCADE for showers fulfilling at least one of these 7-fold coincidences. The joint measurements are ensured by an additional cluster (Piccolo) close to the center of KASCADE-Grande for trigger purposes. Piccolo consists of $8 \times 10\,\mathrm{m}^2$ stations equipped with plastic scintillators. While the Grande detectors are sensitive to charged particles, the KASCADE detectors measure the electromagnetic component and the muonic components separately. The 252 KASCADE stations covering an area of $200 \times 200\,\mathrm{m}^2$ consist of unshielded liquid scintillators on top of shielded plastic scintillators. The latter enables to reconstruct the lateral distributions of muons on an event-by-event basis. Further muon detector systems at a muon tracking detector (MTD) and at the Central Detector of KASCADE allow to investi-

Table 1: Compilation of the KASCADE-Grande main detector components.

| Detector / Particles | sensitive area [m$^2$] |
|---|---|
| Grande | |
| charged | 370 |
| Piccolo | |
| charged | 80 |
| KASCADE array $e/\gamma$ | |
| electrons | 490 |
| KASCADE array $\mu$ | |
| muons ($E_\mu^{\mathrm{thresh}} = 230\,\mathrm{MeV}$) | 622 |
| MTD | |
| muons ($E_\mu^{\mathrm{thresh}} = 800\,\mathrm{MeV}$) | 3×128 |
| MWPCs/LSTs | |
| muons ($E_\mu^{\mathrm{thresh}} = 2.4\,\mathrm{GeV}$) | 3×129 |
| LOPES 30 antennas | |
| radio emission | $> 5 \cdot 10^5$ |

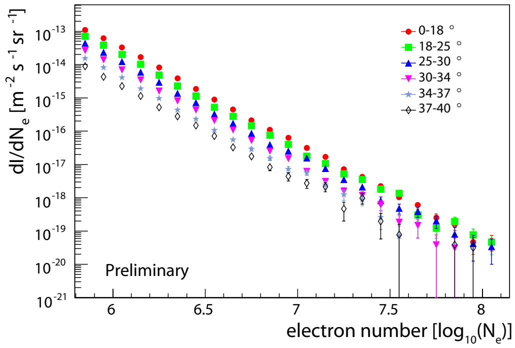


Figure 2: KASCADE-Grande shower size (total number of electrons) spectra for different zenith angular ranges.

gate the muon component of EAS at three different threshold energies.

## Capabilities

Basic shower observables like the core position, angle-of-incidence, or total number of charged particles are provided by the Grande stations. A core position resolution of $\approx 15\,\mathrm{m}$ and a direction resolution of $\approx 0.5^\circ$ is reached. The estimation of energy and mass of the primary particles is based on a combined investigation of the charged particle [8, 9], electron and muon components measured by the detector arrays of Grande and KASCADE [10, 11]. In particular the possibility to reconstruct the total muon number for Grande measured showers is the salient feature of KASCADE-Grande compared to other experiments in this energy range. A common fit to the energy deposits with the relative muon to electron ratio as additional free parameter enables a resolution of electron and muon numbers in the order of 15% and 20%, respectively, for primary energies of 100 PeV. Additional sensitivity for composition estimates and interaction model tests is provided by muon density measurements and muon tracking at different muon energy thresholds [12]. The MTD measures the incidence angles of muons in EAS. These angles provide sensitivity to the longitudinal development of the showers [13, 14]. Below the hadron calorimeter of the central detector there are three layers of position sensitive muon detectors, measuring high-energy muons also in case of Grande triggered showers. The complementary information of the showers measured by the central and the muon tracking detectors is predominantly being used for a better understanding of the features of an air-shower and for tests and improvements of the hadronic interaction models underlying the analyses.

## First Analyses

In the following some examples are given for first analyses based on the present available data set of KASCADE-Grande.

Figure 2 presents the differential shower size spectra for various zenith angular ranges, where the shower size here describes the number of electrons, only, corrected for the muon content in the shower [15]. Full efficiency is reached for a shower size of approximately one million corresponding to a primary energy of $\approx 3 \cdot 10^{16}$ eV.

For each event also the total muon number is reconstructed and the muon size spectra can be determined. It was found [16], that this works for showers with inclination angles up to $70^\circ$ with sufficient accuracy. In particular, inclined showers allow a cross-check of the predictions of hadronic interaction models concerning the muon content in EAS. Figure 3 compares for three zenith angular ranges the measured muon size spectra with the simulated ones (full simulations including detector response and reconstruction), where the simulations are normalized to the number of vertical showers. The increasing deviation with increasing zenith angle hints to a too less muon number predicted by the Monte Carlo simulations (QGSJET II) or an insufficient description of the muon energy spectrum in the simulations.

In addition to the total muon number KASCADE-Grande allows to reconstruct the muon density at a certain distance to the shower core, which gives a sensitivity to changes in the elemental composition [17].

Analyzing the arrival directions of the detected showers a preliminary result on limits of the large scale anisotropy in terms of the Rayleigh amplitude [18] could be obtained (Fig. 4) applying two different methods.

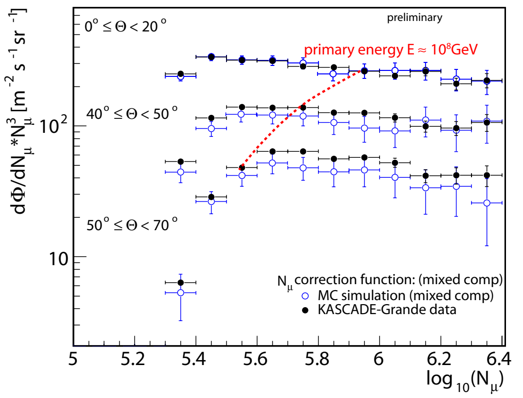


Figure 3: Muon Shower size spectra for different zenith angular ranges. The data are compared with QGSJETII simulations (including detector response and reconstruction), which are normalized to the vertical shower sample.

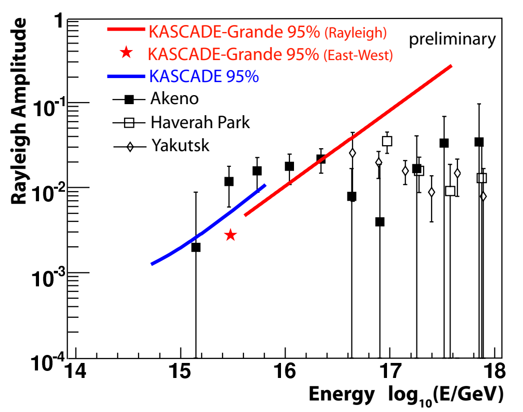


Figure 4: Rayleigh amplitude of the harmonic analyses of KASCADE-Grande data compared with results of other experiments.

## Conclusions

At the KASCADE experiment, the two-dimensional distribution shower size - number of muons played the fundamental role in reconstruction of energy spectra of single mass groups. By the first analyses shown here we illustrate the capability of KASCADE-Grande to perform an unfolding procedure like in KASCADE. KASCADE-Grande is fully efficient at energies above $3 \cdot 10^{16}$ eV, thus providing a large overlap with the KASCADE energy range. Due to the fact that also for KASCADE-Grande a wealth of information on individual showers is available, tests of the hadronic interaction models and anisotropy studies will be possible in addition to the reconstruction of energy spectrum and composition.

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