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Section A

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KASCADE-Grande: An overview and first results

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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 multi-component 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, its performance, and first results based on 2 years of data taking.

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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 N_e and N_μ 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, the knee is due to the bending of the lightest elements, independently of the hadronic model used to simulate the EAS cascade in 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 to be 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]. An extended detector with high accuracy up to 10^{17}–10^{18} eV is, therefore, very useful to tune the simulations up to such energies. The experiments working at higher energies will benefit from a sound starting point at KASCADE-Grande energies. Detailed anisotropy studies together with mass composition analyses could be very useful to discriminate astrophysical models in the explanation of the 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 measurement technique.

2. The KASCADE-Grande experiment

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 antennas (LOPES) to study the radio emission in air showers at $E > 10^{16}$ eV [14]. The KASCADE experiment is itself a multiple detector setup and its major parts are an array of 252 scintillator detector stations, a Muon Tracking Detector (MTD) [15], and a central detector. Most important for the analysis presented here are the two scintillator arrays: KASCADE and Grande.

The KASCADE array is structured in 16 clusters. The detector stations house two separate detectors for the electromagnetic (unshielded liquid scintillators) and muonic components (shielded plastic scintillators); 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, $10\,\mathrm{m}^2$ each (divided into 16 individual scintillators) spread on a $0.5\,\mathrm{km}^2$ 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 digitalized by peak-sensing ADCs. The dynamic range of the detectors is 0.3–8000 particles/$10\,\mathrm{m}^2$. 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$\sim$5 Hz). A stricter implemented mode, also required for triggering the KASCADE array, is the 7/7 trigger mode, requiring all stations in a hexagon to be fired ($\sim$0.5 Hz). With a further condition of the muon number successfully reconstructed by KASCADE and at least 20 active Grande stations, full efficiency for proton and iron primaries is reached at $N_e = 2 \times 10^6$.

The uncertainties of the Grande detector are being evaluated by taking into account the responses of ADCs, electronics, and the PMT gains. The systematic uncertainties are always below 15% even at the highest particle densities. Such a result was confirmed independently by comparing the integral spectra of the particle densities for each station. Concerning the accuracies, we compared the reconstructed shower parameters, for the same events, by KASCADE and Grande, where the two arrays overlap. As a result, the accuracy in the core position for showers with $\mathrm{Log}_{10}(Ne_{\mathrm{KASCADE}}) > 6.3$ is 6.4 m, and 0.6° in the arrival direction. Concerning the shower size N_{ch} measured by the two arrays $((N_{ch}^{G} - N_{ch}^{K})/N_{ch}^{K})$, a very limited offset (-5%) with 13% shower-to-shower fluctuation is observed. This is also a cross-check between the former electromagnetic detector of EAS-TOP and KASCADE array, showing that no significant systematic effect occurs between the two detectors.

3. First results

In the following, some examples of the first analyses based on the present available data set of KASCADE-Grande are given. Fig. 1 shows the lateral distribution of the charged particle densities ρ_{ch} compared with

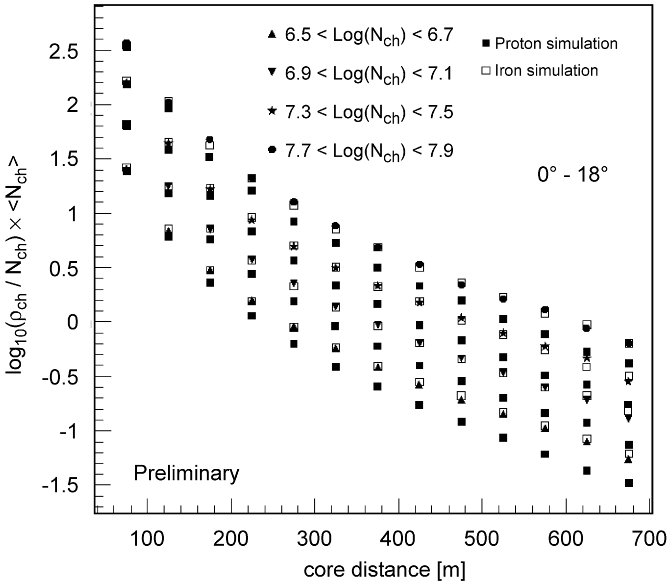

Fig. 1. Lateral distributions of N_{ch} obtained by Grande, compared with results from simulations (H–Fe, QGSJetII interaction model).

CORSIKA simulations (H and Fe), assuming the QGSJetII interaction model for vertical showers (0–18°) and for different shower sizes in the range $6.3 < \text{Log}_{10}(N_{ch}) < 8.1$. The extended array offers the opportunity to measure the lateral distributions at much further distances from the core (700–800 m) compared to the former KASCADE array [16].

For each event, the μ number is reconstructed and the μ density as a function of the distance from the shower axis is determined (see Fig. 2) [17]. Due to its sensitivity to the mass of the primary particle, the μ density is an important parameter to check changes in the elemental composition as a function of energy.

The shower size, N_e, is extracted from the N_{ch} information, taking into account the μ information from KASCADE. A two-dimensional size spectrum N_e–N_μ (see Fig. 3) will be used in future as a starting point for the application of an unfolding analysis that will lead to the determination of spectra of different mass groups, as done in the past for KASCADE. This plot shows also that already sufficient statistical accuracy has been reached up to $E \sim 3 \times 10^{17}$ eV and that events up to 10^{18} eV have been detected [18]. More detailed investigations of systematic uncertainties are in progress with the present data set.

The MTD allows the measurement of μ directions with an accuracy of ~0.35°. The reconstruction of the longitudinal development of the μ component by triangulation is an important tool for primary mass measurements and for the study of high-energy hadron interactions with the atmospheric nuclei. Preliminary results of this technique, applied to the KASCADE energy region, indicate that the primary composition is becoming heavier as a function of energy, in a qualitative agreement with the N_e–N_μ technique [19]. Grande will offer the opportunity to exploit the same technique at higher shower energies and at larger distances up to 700 m from the shower core.

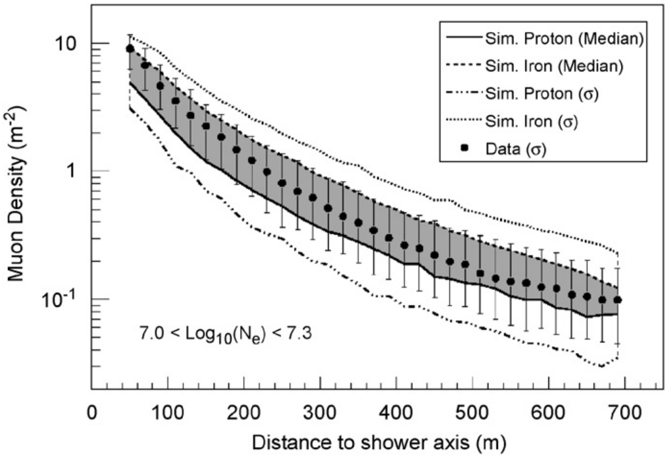

Fig. 2. Density of muons as a function of the distance from the shower axis (zenith angle below 40°). Error bars represent one sigma of the data distribution. See Ref. [17] for details.

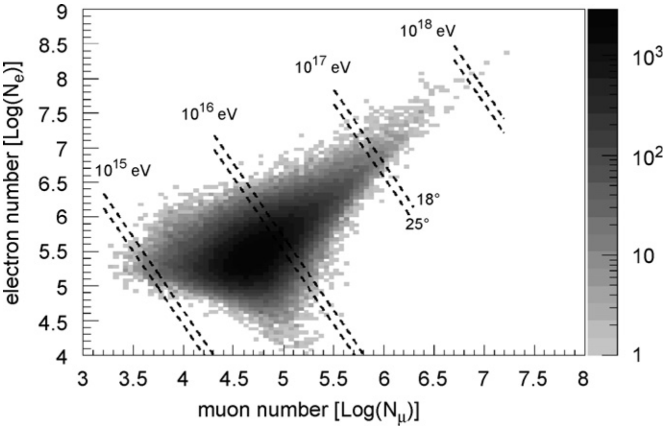

Fig. 3. Reconstructed N_e and N_μ distributions [18] (preliminary).

Analyzing the arrival direction of the detected showers, a preliminary result on upper limits of the large-scale anisotropy using two distinct techniques (Rayleigh amplitude and East–West method) [20] is obtained. The analysis of the measured right ascension distribution suggests an upper limit on the large-scale anisotropy of 3×10^{-3} at 95% CL at a primary energy of 3×10^{15} eV.

Acknowledgments

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References

[1] M. Aglietta, et al., Astropart. Phys. 10 (1999) 1.
[2] T. Antoni, et al., Astropart. Phys. 19 (2003) 703.
[3] M. Aglietta, et al., Astropart. Phys. 21 (2004) 583.
[4] T. Antoni, et al., Astropart. Phys. 16 (2002) 373.
[5] J. Hörandel, et al., in: Proceedings of the 26th ICRC, 1999, vol. 1, p. 337.
[6] T. Antoni, et al., Astropart. Phys. 24 (2005) 1.
[7] M. Aglietta, et al., Astropart. 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 Jul, 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] F. di Pierro, et al., in: Proceedings of the 30th ICRC, Merida, 3–11 Jul, 2007.
[17] V. de Souza, et al., in: Proceedings of the 30th ICRC, Merida, 3–11 Jul, 2007.
[18] F. Cossavella, et al., in: Proceedings of the 30th ICRC, Merida, 3–11 Jul, 2007.
[19] P. Doll, et al., in: Proceedings of the 30th ICRC, Merida, 3–11 Jul, 2007.
[20] S. Over, et al., in: Proceedings of the 30th ICRC, Merida, 3–11 Jul, 2007.