Status of the KASCADE-Grande experiment

H Ulrich1, W D Apel1, J C Arteaga1, F Badea1, K Bekk1, M Bertaina2, J Blümer1,3, H Bozdog1, I M Brancus4, M Brüggemann5, P Buchholz5, A Chiavassa2, F Cossavella3, K Daumiller1, V de Souza3, F Di Pierro2, P Doll1, R Engel1, J Engler1, M Finger3, D Fuhrmann6, P L Ghia7, H J Gil1, R Glasstetter6, C Grupen5, A Haungs1, D Heck1, J R Hörandel3, T Huege1, P G Isar1, K H Kampert6, D Kickelbick5, H O Klages1, Y Kolotaev5, P Luczak5, H J Mathes1, H J Mayer1, C Meurer1, J Milke1, B Mitrica1, A Morales1, C Morello7, G Navarra2, S Nehls1, J Oehlschläger1, S Ostapchenko1, S Over5, M Petcu4, T Pierog1, S Plewnia1, H Rebel1, M Roth1, H Schieler1, O Sima9, M Stümpert3, G Toma4, G C Trinchero7, J van Buren1, W Walkowiak5, A Weindl1, J Wochele1 and J Zabierowski9

1 Institut für Kernphysik, Forschungszentrum Karlsruhe, 76021 Karlsruhe, Germany
2 Dipartimento di Fisica Generale dell’Università di Torino, 10125 Torino, Italy
3 Institut für Experimentelle Kernphysik, Universität Karlsruhe, 76021 Karlsruhe, Germany
4 National Institute of Physics and Nuclear Engineering, 76900 Bucharest, Romania
5 Fachbereich Physik, Universität Siegen, 57068 Siegen, Germany
6 Fachbereich Physik, Universität Wuppertal, 42097 Wuppertal, Germany
7 Istituto di Fisica dello Spazio Interplanetario, INAF Torino, 10133 Torino, Italy
8 Soltan Institute for Nuclear Studies, 00950 Lodz, Poland
9 Department of Physics, University of Bucharest, Bucharest-Magurele, 077125, Romania

E-mail: holger.ulrich@ik.fzk.de

Abstract. The KASCADE-Grande experiment, located on site of the Forschungszentrum Karlsruhe, Germany, measures extensive air showers in the energy range between $5 \times 10^{14}$ and $10^{18}$ eV, thus covering the first and the possible second knee of cosmic rays. Main goals of the experiment are investigations of the knee at around $4 \times 10^{15}$ eV and the verification of the existence of an expected ‘iron knee at energies around $10^{17}$ eV. Furthermore, the energy range between $10^{17}$ eV and $10^{18}$ eV is of special interest since some theories predict that the transition from galactic to extragalactic cosmic rays already begins at these energies. In this overview the apparatus, its performance, and first results are presented.

1. Introduction

Even though recent cosmic ray investigations focus on the highest energies ($10^{19}$ eV and above), the energy region around and above the knee in the cosmic ray energy spectrum (a steepening of the spectrum at around $4 \times 10^{15}$ eV) is still of considerable interest. It is widely believed, that our understanding of the physics of cosmic rays of galactic origin depends strongly on precise knowledge of the chemical and energetic composition in and beyond the knee region. Recent analyses [1, 2] find a steepening in the light element energy spectra. They explain the knee
by a superposition of “breaks” in the single-element spectra with differing positions of these knee-like features depending on the element. To clarify this dependence, it is necessary to verify a steepening in the heavy-element spectra. Especially the position of the expected iron knee would give information on a possible dependence of the individual knee energies on rigidity or mass. Furthermore, the existence and energy of the so-called second knee in the all-particle spectrum at $3-7 \times 10^{17} \text{eV}$ and its connection to the iron knee (if any) is still under debate.

The KASCADE-Grande experiment [3] aims at these questions. By the extension of the former KASCADE experiment [4] by the Grande array, the accessible energy range has been extended by an order of magnitude, thus allowing the measurement of extensive air showers (EAS) with primary energies from $5 \times 10^{14} \text{eV}$ up to $10^{18} \text{eV}$. In the following, the properties and performance of the extended installation together with first results will be discussed.

2. Experimental setup

In order to increase the accessible energy range, the KASCADE experiment was upgraded by 37 detector stations, the so-called Grande array. Each station consists of 16 scintillation counters ($80 \times 80 \times 4 \text{cm}^3$) with a total detection area of $10 \text{m}^2$ per station. The stations are organized in 18 hexagonal trigger cells. Each trigger cell consists of 7 stations, with an average distance of 135 m between two stations. Located between the KASCADE array and the Grande center, the Piccolo cluster was added. It consists of 8 stations of plastic scintillators and provides a fast common trigger for KASCADE and Grande. A sketch of the KASCADE-Grande installation is shown in Fig. 1.

The Grande detectors cannot discriminate between electrons and muons. Therefore, the muon information of EAS is obtained only by the KASCADE detectors. Demanding a 7 stations coincidence (one trigger hexagon), a successful reconstruction of the muon number, and at least 20 triggered stations, full efficiency is reached at a primary energy of $3 \times 10^{16} \text{eV}$ for showers with zenith angles up to $42^\circ$, as can be seen in Fig. 2.

![Figure 1](image1.png)

**Figure 1.** Layout of the KASCADE-Grande experiment with the Grande array, Piccolo, KASCADE, and a schematic trigger hexagon.

![Figure 2](image2.png)

**Figure 2.** Trigger and reconstruction efficiency of the Grande array. A minimum of 20 stations is demanded for reasons of reconstruction quality.
3. First analyses and results

From the Grande array data, the shower core position, the arrival direction, and the number of charged particles \(N_{\text{ch}}\) are retrieved. Considering the muon number \(N_{\mu}\) and the muon lateral distribution (described by a modified Lagutin function [5]) from the KASCADE array, the electron number \(N_e\) can be determined. The electron lateral distribution itself is described by a modified NKG function [6]. In Fig. 3, good agreement of these functions with first Grande data is demonstrated. Here, the fit function \(\rho_{\text{ch}} = \rho_e + \rho_\mu\) with average fit parameters is superimposed on measured data.

Analyzing the arrival directions of measured air showers, first results of investigations on large scale anisotropies have been obtained [7]. No significant deviation from isotropy is found, therefore resulting in upper limits on the Rayleigh amplitude of the first harmonic. In Fig. 4, these upper limits are presented and compared with other data, nicely pursuing the trend of the KASCADE result.

4. Summary and outlook

KASCADE-Grande, focusing at energies beyond \(5 \times 10^{16}\) eV, is continuously taking data and has already collected more showers in the overlapping energy region from \(10^{15}\) eV to \(10^{17}\) eV than KASCADE. First studies on anisotropy and the properties of measured showers (like their lateral distribution) demonstrate the capability of the experiment. With improving understanding of the data, more sophisticated analyses will be carried out, allowing the reconstruction of the energy spectrum and composition of cosmic rays around the second knee.

References

[1] Aglietta M et al 2004 Astropart. Phys. 21 583–596
[2] Antoni T et al 2005 Astropart. Phys. 24 1–25
[3] Navarra G et al 2004 Nucl. Instr. Meth. A 518 207–209
[4] Antoni T et al 2003 Nucl. Instr. Meth. A 513 490–510
[5] van Buren J et al 2005 Proc. of 29th Int. Cosmic Ray Conf. (Pune) 6 301–304
[6] Glasstetter R et al 2005 Proc. of 29th Int. Cosmic Ray Conf. (Pune) 6 293–296
[7] Over S, Stümpert M et al 2007 Proc. of 30th Int. Cosmic Ray Conf. (Merida)