The KASCADE-Grande Experiment

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Abstract. KASCADE-Grande is an extensive air shower array co-located with the original KASCADE air shower experiment at Forschungszentrum Karlsruhe, Germany. The multi-detector system allows to investigate the energy spectrum, composition, and anisotropies of cosmic rays in the energy range extended up to 10^{18} eV. An overview on the performance of the apparatus and first results are presented.

Introduction. The major goal of KASCADE-Grande (covering a primary energy range of $10^{14} - 10^{18}$ eV) is the observation of the so-called 'iron-knee' in the cosmic-ray spectrum, which is expected at around 10^{17} eV following previous KASCADE results, whereby the energy positions of the knees of individual mass or charge groups suggest a rigidity dependence. 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. Examples are models of the type claimed by Berezinsky [1] predicting a 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 [2]
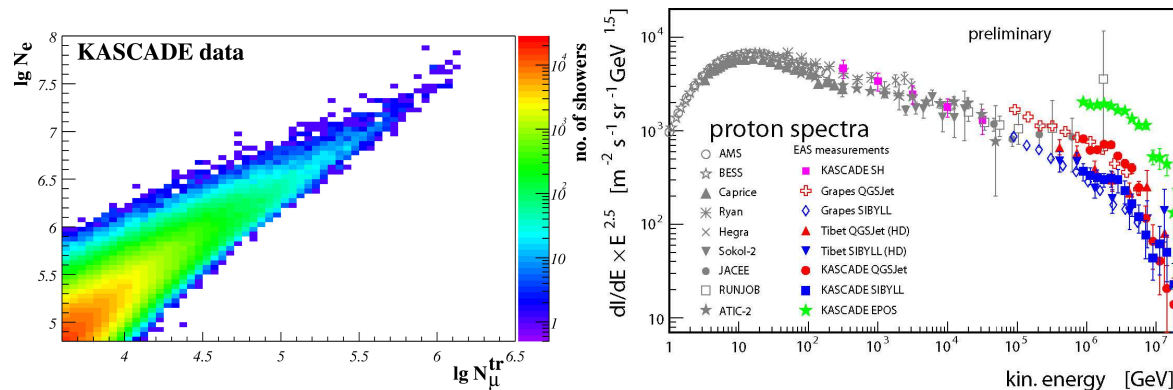
Figure 1. Left: correlation of electron and muon numbers measured with KASCADE. Right: proton spectra unfolded from the data presented in the left panel, based on different hadronic interaction models. The results are compared to direct measurements.

or assuming a mixed composition of the extragalatic flux [3]. In the two latter cases one expects a mixed composition in the energy range of KASCADE-Grande.

Unfolding procedures have been applied to the shower size data correlating the electron and muon numbers observed with KASCADE (Figure 1, left panel). The resulting energy spectra for different primary mass groups exhibit knee-like features, most clearly in the all-particle spectrum as well as for proton and helium primaries [4]. As an example, proton spectra are shown using the hadronic interaction models SIBYLL [6], QGSJet [7] and EPOS [8]. EPOS is not in agreement with results from direct measurements [9]. Improvements to the hadronic interaction models underlying the analysis are required as well as measurements extending to higher energies, in particular to energies where the iron-knee is expected.

KASCADE-Grande. KASCADE is located at 49.1°n, 8.4°e, 110 m a.s.l.. It is taking data since 1996, [10] with an effective area of 0.04 km^2. It was extended to KASCADE-Grande [11] in 2003 by installing a large array of 37 scintillation detectors at an average spacing of 137 m. Each station has a scintillation detector of 10 m^2 area read out by 16 photomultipliers. The dynamic range is $1 : 10^5$ from 1/3 to 30000 charged particles per station for the measurement of particle densities and arrival times. KASCADE-Grande provides an area of 0.5 km^2 and operates jointly with the KASCADE detectors. While the Grande detectors are sensitive to all charged particles, the KASCADE detectors measure the electromagnetic component and the muonic components separately. Muon tracking detectors allow to investigate the muon production height in the atmosphere at three different threshold energies.

The core position can be reconstructed within ≈ 15 m and a direction resolution of $\approx 0.5°$ is reached. KASCADE-Grande is fully efficient at energies above $3 \cdot 10^{16}$ eV, thus providing a large overlap with the KASCADE energy range. The total muon number in showers is obtained from KASCADE detectors, which is a particular asset of KASCADE-Grande compared to other experiments in the energy range of the expected iron-knee. Figure 2 shows the data quality of KASCADE-Grande for a single event and a similar correlation matrix as Figure 1. It was recently demonstrated that the muon number can be reconstructed for showers with inclination angles up to 70° with sufficient accuracy [12]. Hence, additional sensitivity to composition and hadronic interactions is derived from muon density measurements, muon tracking at different muon energy thresholds, and from an extended range in zenith angle. In addition, a large data set has been analysed in terms of searches for anisotropies. The bottom panel of figure 2 shows the Rayleigh amplitude using two different methods [13].
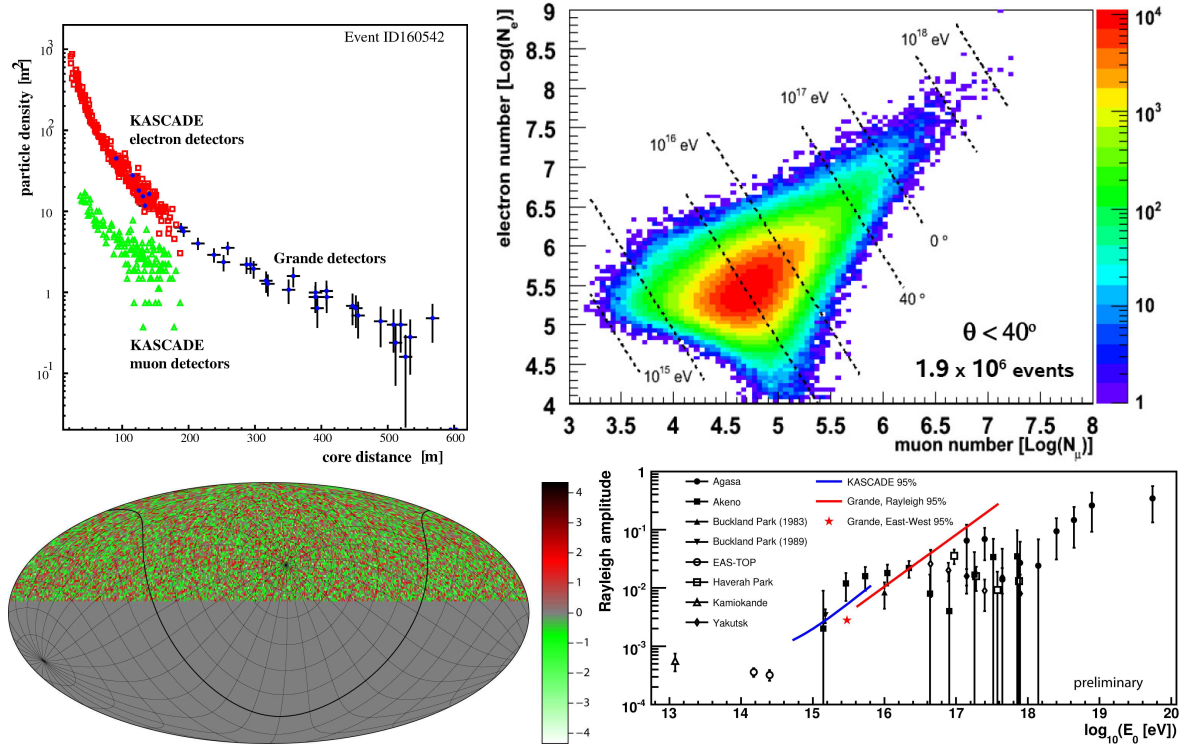
Figure 2. Top-left: lateral distribution of an event measured with KASCADE-Grande. Top-right: correlation between inferred electron and muon numbers in showers measured with KASCADE-Grande, similarly to the left panel of Figure 1. Bottom-left: Significance map of local excesses of particle arrival directions; the distribution is Gaussian and exhibits no significant excess. Bottom-right: Rayleigh amplitude of the harmonic analyses of KASCADE-Grande data compared with results of other experiments.

Conclusion. We have illustrated the capabilities of KASCADE-Grande to perform studies of air showers up to energies of 10^{18} eV, including inferences on the nature of the primary particles, energy spectra for mass groups, tests of hadronic interaction models and anisotropy analyses.

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