Shower Reconstruction Performance of KASCADE-Grande

R. Glasstetter[7], T. Antoni[1], W.D. Apel[2], F. Badea[1,a], K. Bekk[2], A. Bercuci[2,a], M. Bertaina[3], H. Blümer[1,2], H. Bozdog[2], I.M. Brancus[4], M. Brüggemann[5], P. Buchholz[5], C. Büttner[1], A. Chiavassa[3], P. Doll[2], R. Engel[2], J. Engler[2], F. Feßler[2], P.L. Ghia[6], H.J. Gils[2], A. Haungs[2], D. Heck[2], J.R. Hörandel[1], A. Iwan[8], K-H. Kampert[7], H.O. Klages[2], Y. Kolotaev[5], G. Maier[2], H.J. Mathes[2], H.J. Mayer[2], J. Milke[2], C. Morello[6], M. Müller[2], G. Navarra[3], R. Obenland[2], J. Oehlschläger[2], S. Ostapchenko[1,c], M. Petcu[4], S. Plewnia[2], H. Rebel[2], M. Roth[1], H. Schieler[2], J. Scholz[2], T. Thouw[2], G.C. Trinchero[6], H. Ulrich[2], S. Valchierotti[3], J. van Buren[2], W. Walkowiak[5], A. Weindl[2], J. Wochele[2], J. Zabierowski[8], S. Zagromski[2]

(1) Institut für Exp. Kernphysik, Universität Karlsruhe, 76021 Karlsruhe, Germany
(2) Institut für Kernphysik, Forschungszentrum Karlsruhe, 76021 Karlsruhe, Germany
(3) Dipartimento di Fisica Generale dell'Università, 10125 Torino, Italy
(4) National Institute of Physics and Nuclear Engineering, 7690 Bucharest, Romania
(5) Fachbereich Physik, Universität Siegen, 57068 Siegen, Germany
(6) Instituto di Fisica dello Spazio Interplanetario, CNR, 10133 Torino, Italy
(7) Fachbereich Physik, Universität Wuppertal, 42097 Wuppertal, Germany
(8) Soltan Institute for Nuclear Studies, 90950 Lodz, Poland
[a] *on leave of absence from (4)*
[b] *on leave of absence from Moscow State University, 119899 Moscow, Russia*

Abstract

KASCADE-Grande extends the former KASCADE experiment by a large area scintillator array (0.5 km^2) for the detection of the charged component of extensive air showers. Its goal is to reconstruct the primary energy and composition of cosmic rays up to energies of 10^{18} eV thereby allowing a detailed investigation of the expected iron-knee. Knowing the shower core and size as well as its direction from the Grande array the KASCADE detectors allow the determination of the muon number above different energy thresholds. We present the accuracy of the shower reconstruction methods based on CORSIKA simulations. Implications to the discrimination power of the obtained parameters with respect to the nature of the primary particles will be considered.

1. Introduction

The measurement of the particles of extensive air showers (EAS) requires a surface detector spread over a large area because of the decreasing primary particle flux and a large dynamic range for the detection of the enormous density ranges of the secondary particles. Both requirements are not fulfilled with the former KASCADE experiment at the site of the Forschungzentrum Karlsruhe [2] if the primary energy exceeds ≈100 PeV. An increasing amount of the array

---

pp. 781–784

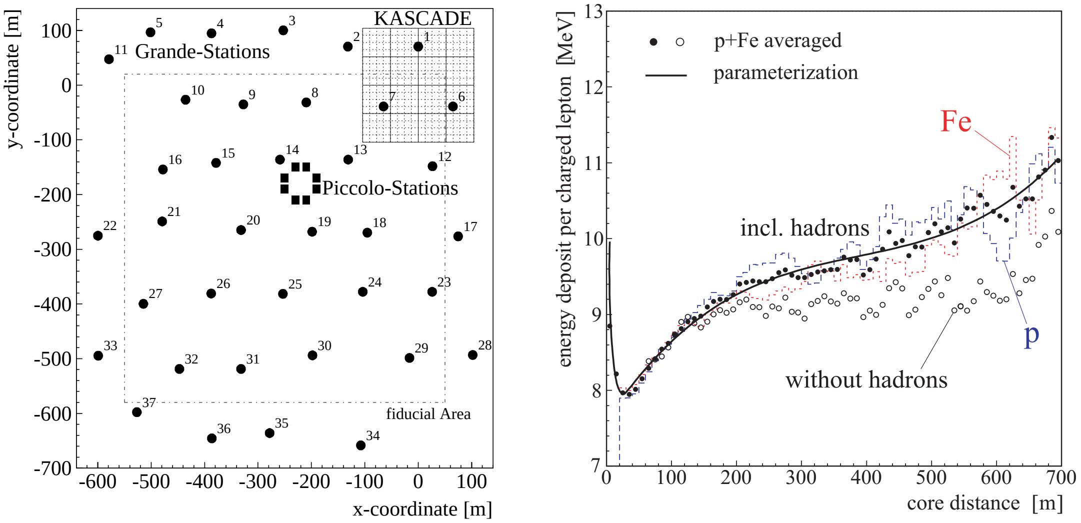

Fig. 1. Layout of the KASCADE-Grande experiment (left) and average energy deposit of an extensive air shower per Grande station (right, p+Fe, 100 PeV, 22°).

detectors shows ADC overflows which reduces the reconstruction accuracy and only a few hundred showers have been measured so far by KASCADE.

To overcome these limitations KASCADE has been extended by 37 new stations equipped with the former EAS-Top [1] scintillation detectors (Fig. 1, left). Each detector station contains a segmented 4 cm thick scintillator with a total detection area of 10 m^2. The stations are distributed over an area of 700×700 m^2 in a hexagonal grid with an average distance of 137 m (see [4, 5] for details).

2. Shower Reconstruction

The energy deposit of shower particles in a scintillation detector is dominated by ionization losses of shower electrons and muons. Therefore with a single Grande array detector it is only possible to reconstruct the combined number of these charged leptons. However, within EASs an additional contribution stems from the conversion of the shower gamma component as well as from hadrons.

To take these effects into account a so-called *Lateral Energy Correction Function* (LECF) is used which gives the average energy deposit per charged lepton at a given core distance. Such a curve has been derived from detailed GEANT3 [3] detector simulations and is plotted in Fig. 1 (right) for 100 PeV proton and iron showers with 22° zenith angle. The showers were generated with the Monte Carlo (MC) code CORSIKA (V6.014) using the QGSJET model [6]. The difference between the two primary particle types p and Fe is not significant and therefore a suitable parameterization is fitted to the average deposits.

After applying this correction to the calibrated detector signals the density distribution of the charged leptons is described by an appropriate lateral distribution function (LDF) to get the core position and a first guess for the shower size. Since the NKG function used in the KASCADE reconstruction is not sufficient to describe the densities for KASCADE-Grande distances, a polynomial approximation with a scaling radius r_0 was chosen:

$$\varrho(r) = C \cdot \frac{N_{tot}}{2\pi r_0^2} \cdot 10^{c_1 x + c_2 x^2 + c_3 x^3} \text{ with } x = \lg \frac{r}{r_0} \tag{1}$$

The normalization parameter C and the form parameters c_i have been adjusted to average CORSIKA lateral distributions for the different particle types ($\sigma < 1\%$). Since these parameters are not independent from r_0 one has to fix the scaling radius in this step. For the charged lepton, electron, and muon LDFs the values 90 m, 70 m, and 310 m respectively are chosen in correspondence to the RMS radius of these distributions.

After the adjustment of the functional form the LDFs are fitted to single shower measurements just by varying r_0 and N_{tot} as well as the core position in a log-likelihood approach assuming Poissonian fluctuations for the particle numbers.

To deduce the shower direction the average arrival time probabilities $P_e(t)$ and $P_\mu(t)$ from CORSIKA are used to get the correct dependence of the arrival time t of the first of n particles on the total detected particle number n. This probability $P_1(t)$ can be described by:

$$P_1(t) = n \cdot P(t) \left[\int_t^\infty P(\tau) d\tau \right]^{n-1} \text{ with } P(t) = \frac{\varrho_e P_e(t) + \varrho_\mu P_\mu(t)}{\varrho_e + \varrho_\mu} \tag{2}$$

Because shower muons arrive earlier at the observation level than the electrons, this formalism offers the advantage to get an additional information on the mass of the primary particles from the arrival times. The probability density $P_1(t)$ is used directly in a log-likelihood minimization to get the shower direction. Because of its strong correlation with the detected number of particles it can even be combined with the LDF minimization which depends on the angle anyway.

After the determination of core position and shower direction the muon number is derived from the KASCADE array muon detectors by fitting the appropriate muon LDF with fixed slope parameter because of the limited radial range. Taken into account this muon LDF it is possible to use again the Grande array data (now with the electron LDF) to get the shower electron number instead of the charged lepton number.

3. First Results

Fully simulated 100 PeV proton and iron showers (22°) have been scattered over the Grande area 10 times each and tracked through the detector MC (400 showers total). Because of misreconstructed core positions a fiducial area of 600×600 m^2 around the center of the Grande array was chosen and the reconstructed electron scaling radii $r_{0,e}$ were restricted to 20 m$< r_{0,e} <$200 m. The

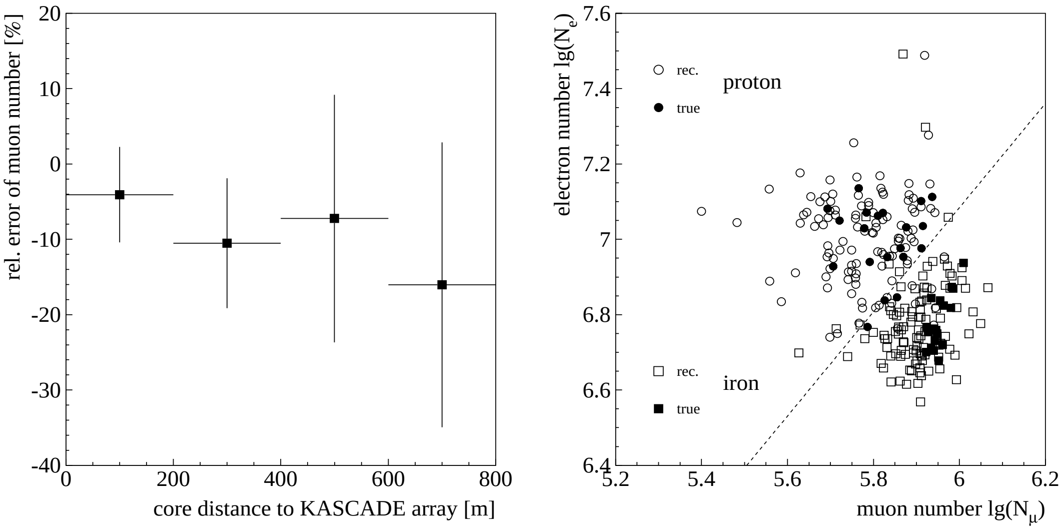

Fig. 2. Systematic (squares) and statistic (bars) errors of the muon number as function of the core distance to the KASCADE array (left) and the distribution of the reconstructed shower sizes (right) for proton resp. iron showers (100PeV, 22°).

reconstruction accuracy of the shower core position and direction has been estimated to 4 m (13 m) and 0.18° (0.32°) with 68% (95%) confidence level.

The statistical uncertainty of the shower sizes are around 15% both for the total number of electrons and muons and so in the same order of magnitude as the intrinsic shower fluctuations in that energy range. The systematic uncertainty depends strongly on the radial range of the data and the chosen LDF. Especially for the muon size both uncertainties are a function of the distance of the KASCADE array to the shower core as can be seen in Fig. 2 (left). This may be optimized by choosing either the muon number for a fixed radial range or the muon density at a fixed radius as reconstructed muon parameter.

Fig. 2 (right) shows the distribution of the reconstructed shower sizes compared to the simulated ones. It can be seen that at least the two extreme primaries proton and iron are distinguishable. The misclassification probability due to the plotted line of constant masses ($\ln A \approx \frac{\ln 56}{2}$) is below 10% for both primaries.

Acknowledgment: This work has been funded by the Ministry for Education and Research of the Federal Republic of Germany.

1. Aglietta M. et al. 1988, Nucl. Instr. & Meth., A277, 23
2. Antoni T. et al. 2003, Nucl. Instr. & Meth. A, submitted
3. Brun R. et al. 1987, CERN report DD/EE/84/1
4. Chiavassa A. et al. 2003, Proc. 28th ICRC, these proceedings
5. Haungs A. et al. 2003, Proc. 28th ICRC, these proceedings
6. Heck D. et al. 1998, Forschungszentrum Karlsruhe, Report FZKA 6019