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Shower size spectrum reconstructed with KASCADE-Grande

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Abstract: The Grande array as main part of the KASCADE-Grande experiment consists of 37×10 m^2 scintillation detectors spread over an area of 700×700 m^2. Grande enables triggers and reconstruction of primary cosmic rays in the energy range of $\sim 3 \cdot 10^{15}$eV to 10^{18}eV. The detectors and the shower size (i.e.: total number of charged particles) reconstruction accuracies are discussed. The KASCADE-Grande set-up allows, for a subsample of the registered showers, detailed comparisons of the data with measurements of the original KASCADE array on an event-by-event basis. The lateral distributions of charged particles and the resulting preliminary shower size spectrum for vertical showers are presented.

Introduction

The KASCADE-Grande experiment [1, 2] located at Forschungszentrum Karlsruhe, extends the energy range covered by KASCADE [3] up to 10^{18} eV by means of the Grande array which increases the acceptance area up to 0.5 km^2. Grande, obtained reassembling the EAS-TOP detectors [4], measures the lateral distribution of charged particles up to 700 m from the core and the KASCADE muon detectors allow to reconstruct the muon lateral distribution up to the same distances [5].

The Grande Array

The Grande array consists of 37 stations with an average spacing of 137 m over a 700 x 700 m^2 area. Every detector station consists of 10 m^2 of plastic scintillator (NE102A) organized in 16 units (80 x 80 x 4 cm^3). Each unit is equipped with a high gain (HG) photomultiplier (Philips XP3462B, $\approx 1.6pC/m.i.p.$) and the 4 central units are additionally equipped with a low gain (LG) photomultiplier ($\approx 0.08pC/m.i.p.$). The signals from the PMTs are added up through passive mixers, one for the HG and one for the LG PMTs. The output signals are preamplified and shaped by Shaping Amplifier (8 μs rising time) into 3 analog signals, digitized by 3 Peak-ADCs (CAEN V785), covering the dynamic ranges 0.3 - 8, 2 - 80, 20 - 800 $particles/m^2$ respectively. The overlapping ranges between the scales are used for cross-calibration. Each detector is continuously monitored and calibrated by means of single muon spectra. The systematic uncertainty on the measured particle density by each detector is less than 15% and the statistical uncertainties are dominated by the poissonian fluctuations. The individual detector calibration is checked by comparing the 37 integral particle spectra and the spread (RMS) of the particle densities measured at fixed fluxes is 15%. For 3 Grande stations, co-located with the KASCADE array, the energy deposits in the Grande and in the 4 sorrounding KASCADE detectors are compared on an event-by-event basis. The measured energy deposits are compared to full shower and detectors simulations (fig. 1) and the result is that the difference between the mean energy deposits in the Grande detectors for data and simulations is less than 10% [6]. The array is divided in 18 trigger clusters of 7 modules each (6 modules in an hexagon and a central one). A whole cluster at the same time fired (7/7 modules) provides a trigger with a rate of 0.5 Hz and becomes fully efficient for all primaries at $\approx 3 \times 10^{16} eV$ [7]. In the following analysis additional cuts have been applied: all 37 stations working, all 18 clusters active (290 days of data taking), more than 19 stations fired, *shower age (s)* in the range 0.4-1.4 and *shower size* greater than $10^{6.3}$.

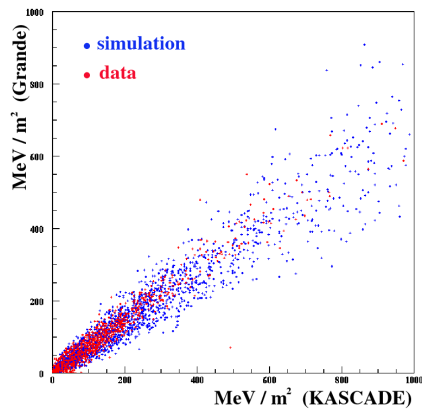

Figure 1: Energy deposits in Grande and KASCADE detectors for data and simulations.

Reconstruction accuracies

Beside the evaluation of the accuracies on the reconstructed EAS parameters by means of shower and detector simulations [7], it is possible to infer the Grande reconstruction accuracies by means of the comparison with the KASCADE reconstruction. The subsample is obtained accordingly to the following additional selection criteria: maximum in the central station of the hexagon overlapping with KASCADE, core position within a circle of 90 m radius from KASCADE center, zenith angle less than 42^o. Using KASCADE reconstruction as reference the Grande accuracies result to be:

- core position (fig. 2): 6.4 m;
- shower size (fig. 3): systematic -5%, single event fluctuation 13%;
- arrival direction (fig. 4): 0.6^o.

Comparing these results to the KASCADE accuracies [3] we can conclude that despite the 2 arrays are rather different (the KASCADE array is composed of 252 detectors over an area of 200 $\times$ 200 m^2 with a spacing of 13 m) the Grande shower reconstruction has a good accuracy with respect to KASCADE and adequate for its aims.

Mean lateral distributions

In fig. 5 the experimental mean lateral distributions for vertical showers ($0^o - 18^o$) and for different shower sizes in the range $6.3 < Log_{10} N_{ch} < 8.1$ are shown. The line represents a fit with a slightly modified NKG function, optimized by means of shower simulations [8]:

$$\rho_{ch} = N_{ch} \cdot C(s) \cdot \left(\frac{r}{r_0}\right)^{s-\alpha} \left(1 + \frac{r}{r_0}\right)^{s-\beta} \quad (1)$$

with the normalization factor:
$C(s)$=$\Gamma(\beta{-}s)/(2\pi r_0^2 \Gamma(s{-}\alpha{+}2)\Gamma(\alpha{+}\beta{-}2s{-}2))$, the shower size N_{ch}, age parameter s and α=1.5 , β=3.6 and r_0=40 m. The lateral distributions measured by the Grande array extend up to more

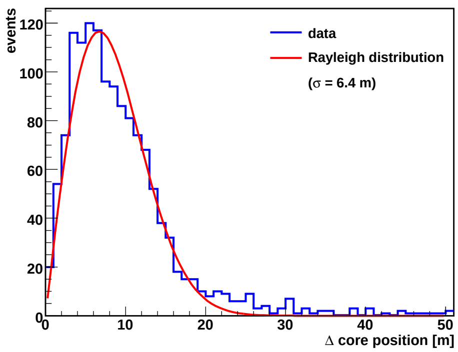

Figure 2: Core position accuracy: difference in reconstructed core position by KASCADE and Grande.

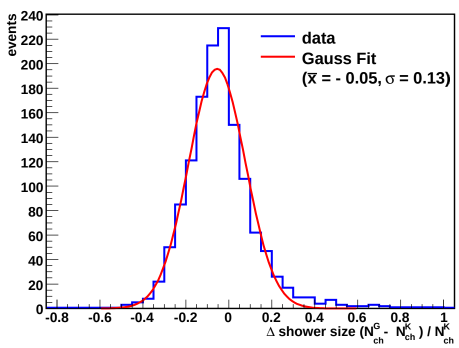

Figure 3: Shower size accuracy: difference in reconstructed shower size by KASCADE and Grande.

than 700 m and the used lateral distribution function well represents data over the whole range. An effect due to the saturation of the detectors starts to be evident only very close to the core (r $<$ 75 m) and for the highest energies. The *"shower age (s)"* has been studied as a function of the shower size (N_{ch}) for different angular bins of equal acceptance. Fig. 6 shows that the s (*age*) value, as expected, increases with increasing zenith angle and decreases with increasing shower size.

The experimental lateral distributions are compared to simulated ones, obtained for proton and iron primaries in the energy range $10^{16} - 10^{18}$ eV with QGSjet-II interaction model (fig. 7). The measured particle densities by each detector are normalized to the total number of particles. The

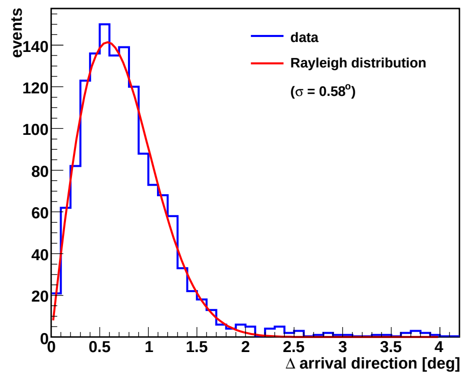

Figure 4: Arrival direction accuracy: difference between the arrival direction reconstructed by KASCADE and by Grande.

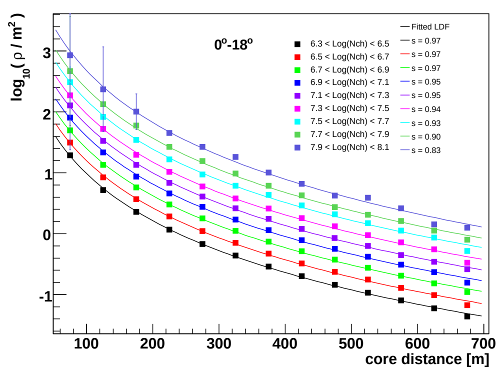

Figure 5: Experimental mean lateral distributions fitted with the LDF (eq. 1).

obtained lateral distributions are multiplied by the mean N_{ch} of the bin in order to distinguish the different graphs (for the same reason only 4 N_{ch} bins are plotted). Data, as expected, lie between iron and proton simulations and show the same shape. This result shows that the lateral distribution can be indeed an efficient composition estimator.

Shower size spectrum

A preliminary shower size spectrum, for vertical events ($0^o - 18^o$), selecting an internal area of 0.3 km^2 and 290 days of effective data taking is shown in fig. 8. Reconstruction accuracies are not de-

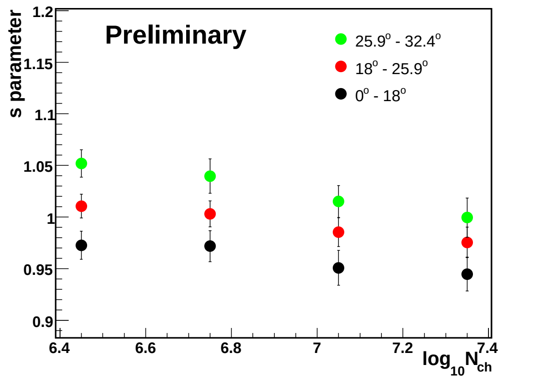

Figure 6: Age parameter values (s) as a function of shower size (N_{ch}), for different zenith angles.

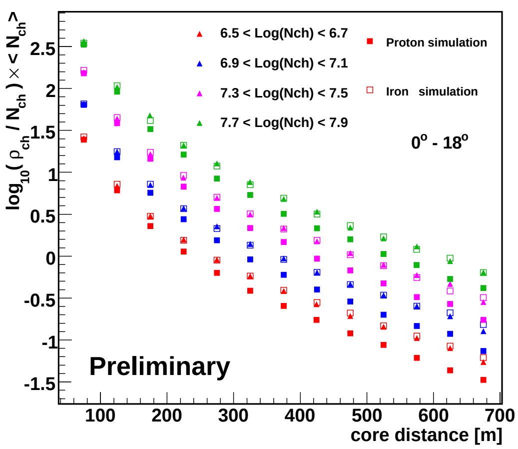

Figure 7: Comparison between experimental (dots) and simulated (open squares = iron, full squares = proton) mean lateral distributions.

convoluted. Fluxes are multiplied by N_{ch}^3. The spectrum extends from $log_{10}(N_{ch}) = 6.3$ corresponding to efficiency ≈ 1 up to $log_{10}(N_{ch}) = 8$ where still few events are collected. The limited statistics considered in this analysis does not allow conclusions for sizes larger than $log_{10}(N_{ch}) = 7$. Statistics can be increased using less restrictive selection criteria and mainly by means of the analysis of different zenith angles.

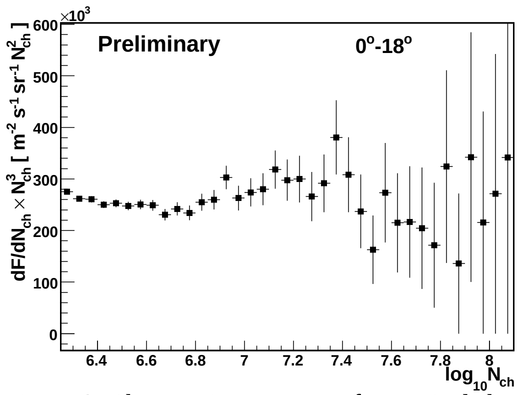

Figure 8: Shower size spectrum for vertical showers ($0^o - 18^o$), not deconvoluted for reconstruction accuracies. Fluxes are multiplied by N_{ch}^3.

Conclusions

The KASCADE-Grande reconstruction accuracies have been discussed. The charged particle lateral distribution is measured up to 700 m from the core and is well reproduced by simulations. A preliminary shower size spectrum is shown in a range corresponding to energies $3 \cdot 10^{16} - 10^{18}$eV.

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