PERFORMANCES OF THE KASCADE-Grande EXPERIMENT

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The KASCADE-Grande experiment, located at Forschungszentrum Karlsruhe, is a multicomponent extensive air shower detector to study cosmic rays in the energy range from 10^{16} to 10^{18} eV. Do to its multicomponent charactheristics, namely the former KASCADE experiment enriched by a large acceptance (0.5 km^2) scintillator detector (Grande) KASCADE-Grande is a suitable array to provide refined measurement in the 10^{16} to 10^{18} eV region. In this paper we will briefly discuss the relevance of performing high precision measurements in this energy range and the consequences expected both at higher (transition from galactic to extragalactic radiation) and lower (details about the knee) energies. The resolutions obtained with the KASCADE-Grande experiment are presented.

1 Introduction

The cosmic rays spectrum at energies above 10^{14} eV must be studied by ground based experiments detecting the secondary particles produced in the Extensive Air Showers (EAS) generated in atmosphere by the interaction of a primary cosmic ray.

A recent review of experimental results [1] is shown in Figure 1 (for the single experiments see referecences therein). It can be seen that the energies from 10^{16} to 10^{18} eV are the less widely covered, the few available results are those of the Akeno [2] and MSU [3] experiments. In the

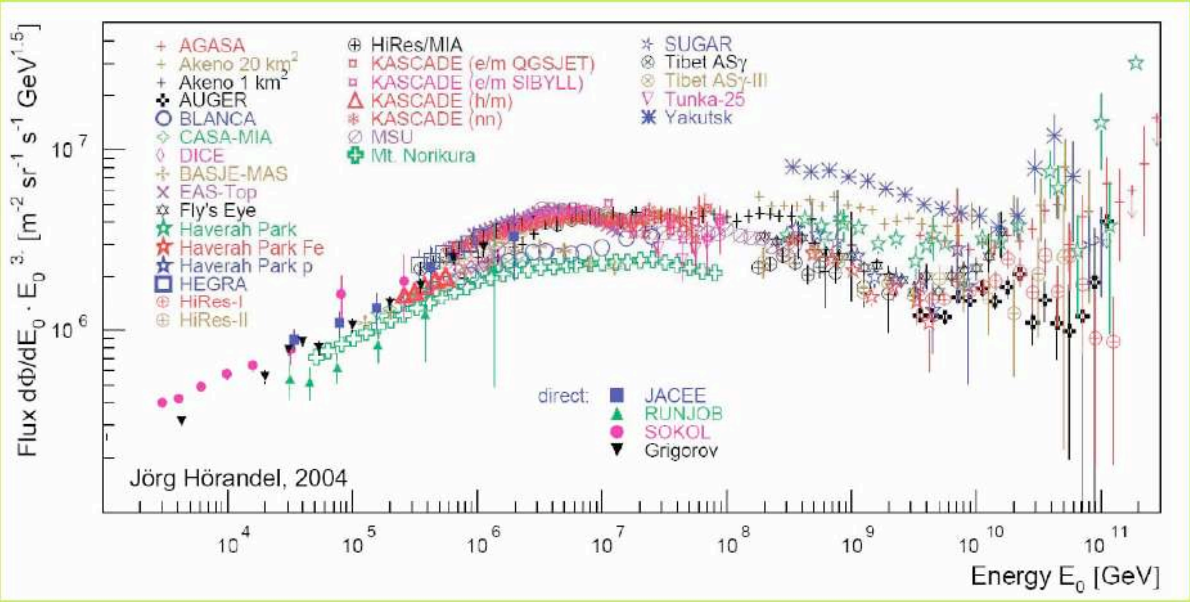

Figure 1: Review of measurements of the primary cosmic rays spectrum.

last decade no arrays have explored this energy range, hence the interest in new measurements performed with high resolution detectors.

Concerning the energies just below 10^{16} eV we are dealing with the well known structure in primary cosmic ray spectrum known as the knee, this feature has been widely investigated in the last decade and relevant experimental results have been obtained.

The change of slope has been observed in the spectra of all EAS components (electromagnetic [4] [5] [6], muonic [7] [8] and hadronic [9]) and at different stages of the shower development, thus demonstrating that the knee is a feature of the primary cosmic ray spectrum and it is not due to a change in the interaction mechanism.

Moreover the charactheristics of the observed change of slopes, namely the integral fluxes above the knee and the number of electrons and muons at the knee, agree with the expectations of shower development in atmosphere [7].

The EAS-TOP [7] and CASA-MIA [10] experiments have measured, through the correlation of the mean values of electrons and muons detected in the shower, that primary chemical composition becomes heavier for increasing energies.

More refined analysis performed mainly by the KASCADE experiment show that: the knee is due to the light component of cosmic rays [8] and that the spectra of single components (grouped in five groups) show knees at energies increasing with the primary atomic number [11] (a similar result has been obtained by the EAS-TOP collaboration [7]). The resolutions reached (by both experiments) do not allow to discriminate between a Z or A dependence.

All these analysis concerning the primary chemical composition heavily depends (at least for the quantitative aspects) on a complete EAS simulation, and thus suffer from the unknoledge of the primary interactions at the energies under investigation. Moreover at colliders the forward region of the interactions (the one relevant for the EAS development) is not studied.

We can conclude that the favoured scenario to explain the knee deals with astrophysical mechanism: either the acceleration or the propagation of galactic cosmic rays. In both scenarios a change of the slope of the spectra of single elements is expected at an energy scaling with Z, thus we expect the iron knee at an energy equal to $ZE_{knee} \sim 10^{17}$ eV. This energy is above the range covered by recent experiments and it is thus important to study it with detectors allowing a separation between different elements or at least between the light and heavy components.

Concerning energies above10^{18} eV the interest is connected with the transition from galactic to extragalactic cosmic rays.

In the so called "dip model" (Berezinsky et al. [12]) the fluxes of galactic and extragalactic cosmic rays become equal at $E \sim 5x10^{15}$ eV, i.e. the energy of the faint spectral feature known as the second knee. The spectral shape observed (i.e. the ankle) is reproduced in the model by pair production of protons interacting with photons of cosmic microwave background. At energies above $\sim 10^{18}$ eV the authors predict a chemical composition dominated by protons (the fraction of heavier elements expected is lower than 15%).

In the model of Allard et al.[13] the ankle is due to the transition from galactic to extragalactic primaries and the chemical composition is assumed to be similar to the one observed at lower energies, thus a mixed composition is predicted. The transition to extragalactic radiation is supposed to happen at energies $\sim 3x10^{18}$ eV.

It is thus of main importance to perform accurate measurements of the primary chemical composition in the whole energy range from 10^{16} to 10^{18} eV.

Chemical composition measurements in this energy range can be mainly performed using the N_e, N_{mu} ratio. The precision required was not yet reached by past experiments and we can expect relevant informations in the next years.

Besides the KASCADE-Grande experiment, that will be fully described in the following section, the $10^{16} - 10^{18}$ eV energy range will be covered, in the near future, by the ICE-TOP [14], TUNKA-133 [15] experiments and by the low energy extenions of the Pierre Auger Observatory [16] and of the Telescope Array [17].

2 The KASCADE-Grande experiment

The KASCADE-Grande experiment [18] is a multi-detector setup consisting of the KASCADE [19] experiment, the trigger array Piccolo and the scintillator detector array Grande (the experimental layout is shown in Figure 2). Additionally, KASCADE-Grande includes an array of digital read-out dipole antennas (LOPES) to study the radio emission in air showers at $E > 10^{16}$ eV [20]. Most important for the analysis presented here are the two scintillator arrays: KASCADE and Grande. The KASCADE experiment is itself a multiple detector setup and its major parts are an array of 252 scintillator detector stations, a streamer tube muon detector ($E_\mu > 800$ MeV) [21], and a multiwire proportional chamber muon detector ($E_\mu > 2.4$ GeV).

The KASCADE array is structured in 16 clusters. Each detector station houses two separate detectors for the electromagnetic (unshielded liquid scintillators) and muonic components (shielded plastic scintillators, $E_\mu > 230$ MeV). 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 m^2 each (divided into 16 individual scintillators) spread on a 0.5 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 digitized by peak sensing ADCs. The dynamic range of the detectors is $0.3 - 8000$ particles $/10m^2$. 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 5 Hz). A stricter implemented mode, that is required for triggering the KASCADE array, is the 7/7 trigger mode, requiring all stations in a hexagon being fired (0.5 Hz).

Figure 3 show the detection and reconstruction efficiency, inside an internal fiducial area of ~ 0.3 km^2, as a function of the shower size. Full efficiency is reached at $\sim 10^6$ shower size, i.e.

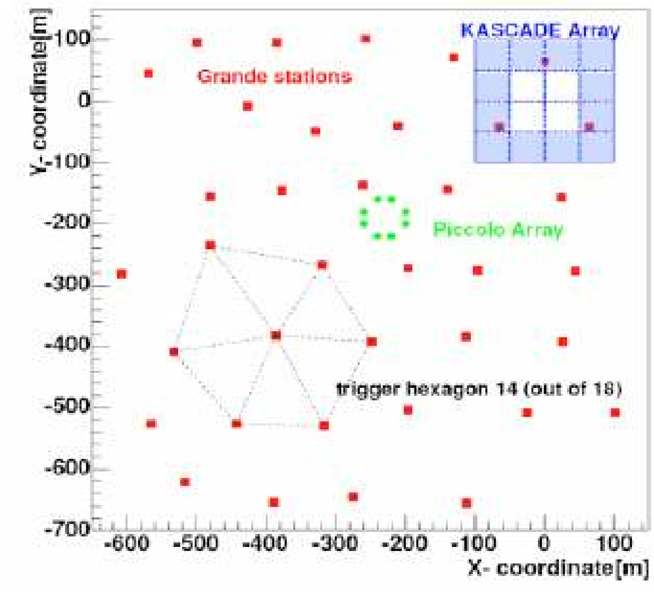

Figure 2: Layout of the KASCADE-Grande experiment.

a primary energy of $\sim 10^{16}$ eV.

2.1 Reconstruction Accuracy

The main shower parameters that are measured for each event are: the arrival direction, the total number of muons (N_{μ}) and the total number of charged particles (N_{ch}) in the shower.

The arrival direction of the events is determined fitting the arrival time of the particles in the Grande detectors to a curved shower front [22]. The core position, the shower age and the shower size (N_{ch}) are obtained fitting the particles densities measured by the Grande stations with a NKG like function [22].

The total number of muons is calculated using the core position determined by the Grande array and the muon densities measured by the KASCADE muon detectors [23].

The precisions obtained in the reconstruction of the shower parameters are evaluated exploiting the unique feature of the KASCADE-Grande experiment of having two independent samplings of the same event by the KASCADE and the Grande arrays. Selecting showers with core located in a region that is internal for both arrays (i.e. a ring around one of the Grande station located inside the KASCADE array) we have a set of events that are independently reconstructed by both arrays. We can thus compare the Grande results to those obtained by the KASCADE array that, having a better and known resolution, is used as reference (the distance between two KASCADE detectors is just 13 m). Dividing events in bins of shower size (N_{ch}^{KA} determined by KASCADE) we construct the distributions of the difference of the arrival directions $\Delta\Phi$ and of the core positions Δr. Fitting these distributions with a Rayleigh function we determine the Grande resolution as a function of the shower size. Figure 4 shows that the angular resolution is better than 1° (the increase of the errors for shower size greater than 10^7 is due to a lack of statistics). Figure 5 shows that the error on the determination of the core position is clearly lower than 10 m. The same procedure is followed for the shower size, the distributions of $\Delta N_{ch} = (N_{ch}^{KA} - N_{ch}^{Gr})/N_{ch}^{KA}$ that are fitted with a gaussian distribution. The mean value (full squares in Figure 6) represent the systematic difference in the shower size obtained by KASCADE (N_{ch}^{KA}) and by Grande (N_{ch}^{Gr}); while the RMS gives the precision of the Grande array (open squares in Figure 6). We can see that the systematic difference between

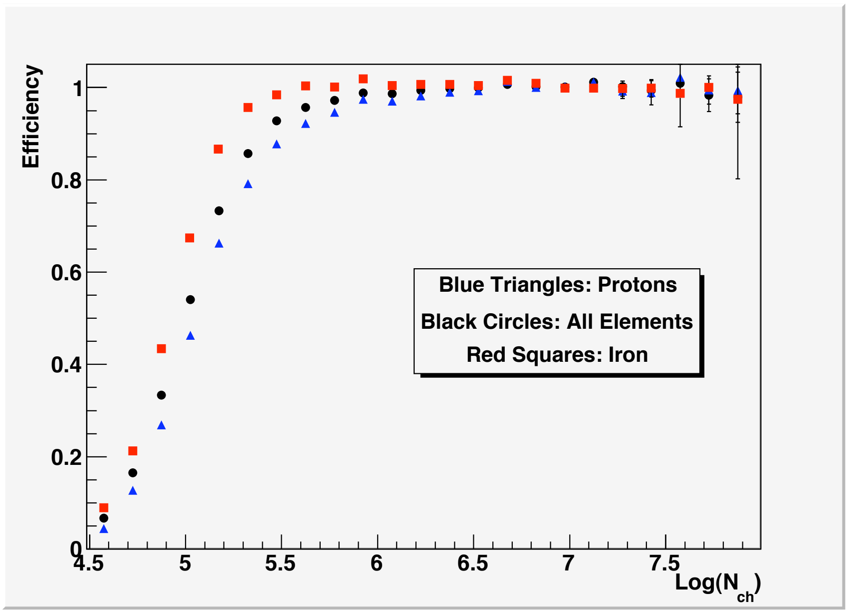

Figure 3: Detection and reconstruction efficiency as a function of the total number of charged particles of the KASCADE-Grande experiment.

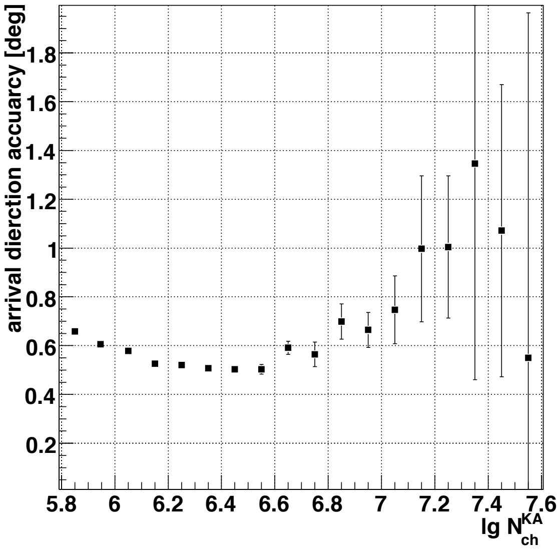

Figure 4: Grande array angular resolution measured comparing the arrival direction with the one obtained by the KASCADE array.

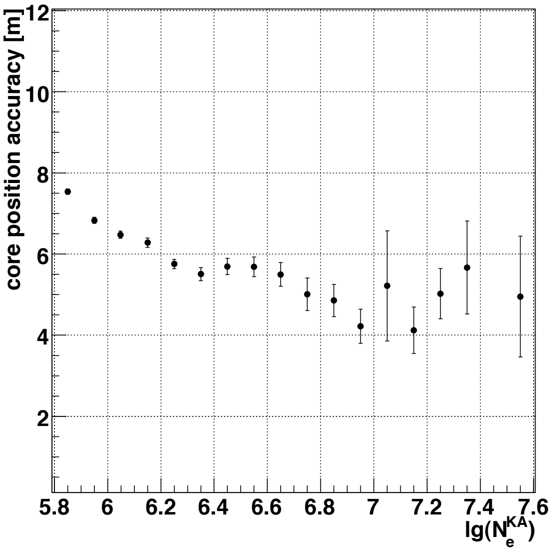

Figure 5: Grande array core position resolution obtained by the comparison with the KASCADE array.

Grande and KASCADE is lower than 5% and that the error in the determination of the shower size is lower than 20%.

The errors on the shower parameters that have been obtained are those foreseen in the proposal of the KASCADE-Grande experiment. The KASCADE-Grande experiment is in continuous data taking since January 2004, a conclusive evaluation of systematic effects and the whole data processing are currently in progress.

As an example of the KASCADE-Grande potentialities we mention the measurements of the all particle spectrum that are currently undergoing following different approaches. One technique is based on the well known constant intensity cut method applied both to the muon and to the charged particle size spectra. Preliminary studies show that the resolution that can be reached is about 22% at $E \sim 10^{17}$ eV. In a different approach we try to measure the primary energy for single events using the shower size weighted with the N_μ/N_{ch} ratio. The systematic errors and the accuracy of this procedure are currently under investigation.

3 Conclusions

We have presented the resolutions obtained by the KASCADE-Grande experiment in the measurement of the EAS parameters. These performances have been evaluated in a purely experimental way using the KASCADE array as reference. The results are those expected in the proposal of the experiment: $< 1^\circ$ on the arrival direction, < 10 m on the core location and $< 20\%$ on the shower size. Thus allowing investigations of cosmic rays in the energy range from 10^{16} to 10^{18} eV with a previously unreached precision.

Acknowledgments

The authors would like to thank the members of the engineering and techcnical staff of the KASCADE-Grande collaboration, who contributed to the success of the experiment. The KASCADE-Grande experiment is supported by the BMBF of Germany, the MIUR and INAF of Italy, the Polish Ministry of Science and Higher Education and DAAD (PPP grant for 2007-2008), and the Romanian Ministry of Education and Research (grant CEEX05-D11_79/2005).

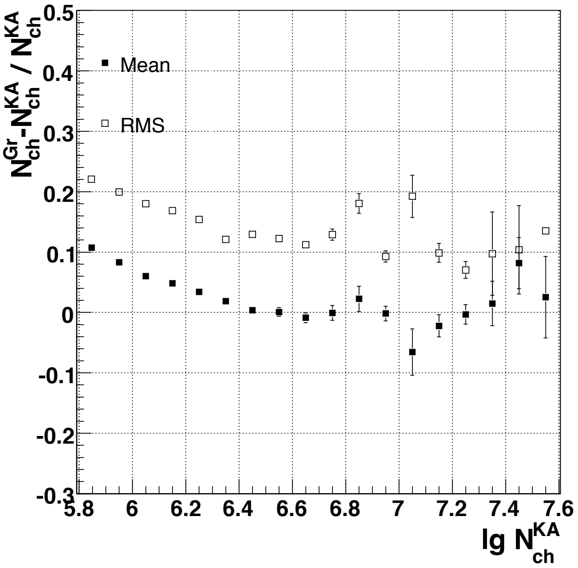

Figure 6: Grande array precision in the determination of the shower size. Full squares show the systematic difference between the Grande and the KASCADE determination of N_{ch}; open squares show the Grande precision in the single event measurement of the shower size N_{ch}^{GR}

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