Analysis of Air Showers at the Trigger Threshold of KASCADE

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Abstract

The KASCADE experiment measures extensive air showers. It is 100% efficient for showers which are induced by primary particles with energies above 10^{15} eV to pursue its main goal, the examination of the knee in the flux spectrum at $\approx 5 \cdot 10^{15}$ eV. A specially adapted method to calculate two observables (N_{ch}, the number of charged particles and N_{μ}, the number of muons) by means of a maximum likelihood estimate will be presented. The estimate combines different detector systems and works already at energies around the trigger threshold of KASCADE at $\approx 10^{14}$ eV. These observables are used to reconstruct a preliminary energy flux spectrum which is compared with direct measurements and previous measurements of KASCADE at energies above 10^{15} eV. The reconstruction of energy spectrum and elemental composition around the trigger threshold of KASCADE is important for two reasons. First the estimated spectrum at higher energies has to be congruent with the results of direct measurements. Second it is a cross-check of the interaction models underlying the analysis of extended air showers.

1. Methods

KASCADE[1] is designed to measure extended air showers induced by cosmic rays around the energy region of the so-called knee at ca. $5 \cdot 10^{15}$ eV.

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Hence the standard reconstruction procedure is optimized for energies starting from $1 \cdot 10^{15}$ eV. This standard reconstruction determines two of the most important observables, the number of electrons N_e and the number of muons N_μ by fitting appropriate lateral distribution functions (NKG-functions) to the particle densities measured in each detector of the KASCADE field array. The separate handling of muons and electrons is possible due to the setup of the array stations at KASCADE, where shielded and unshielded detectors are placed one upon the other. The lateral distribution functions have two parameters, the number of particles (electrons/muons) and the slope of the function. For low particle numbers this two parameter fit does not work. However, simulations show that the slope of the distributions does not vary very much for showers near the trigger threshold at KASCADE observation level. Thus we can assume the slope parameter as being constant and determine efficiently the number of particles with a maximum likelihood estimate[5]. A sacrifice we have to make is that we can no longer differentiate between electrons and muons in the unshielded detectors. So we use as a new observable the number of charged particles N_{ch}^{est} which is the sum of the number of electrons N_e and the number of muons N_μ. The other new observable is the estimated number of muons N_μ^{est}.

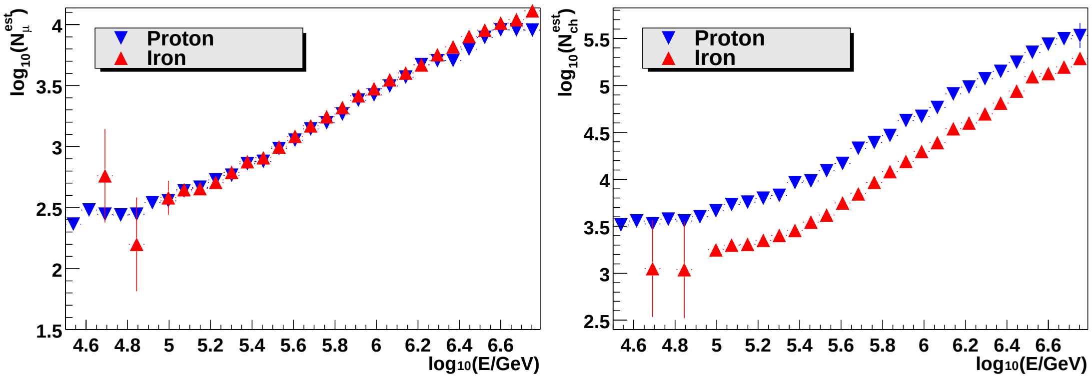

Fig. 1. Dependence of N_μ^{est} and N_{ch}^{est} on the primary energy for simulated proton and iron induced events.

The maximum likelihood estimate allows easily the combination of different detector systems. In our case, the number of charged particles is measured by the unshielded e/γ-detectors of the field array and the so called top cluster of the KASCADE Central Detector ($490\,\mathrm{m}^2$+$25\,\mathrm{m}^2$ sensitive area). The number of muons is measured by combining the shielded μ-detectors of the field array and the trigger plane of the Central Detector ($622\,\mathrm{m}^2$+$208\,\mathrm{m}^2$). As only showers are selected which have their core within a radius of 40 m around the Central Detector, the high coverage of top cluster and trigger plane can be used. This extends the energy range where full trigger and reconstruction efficiency is given down by

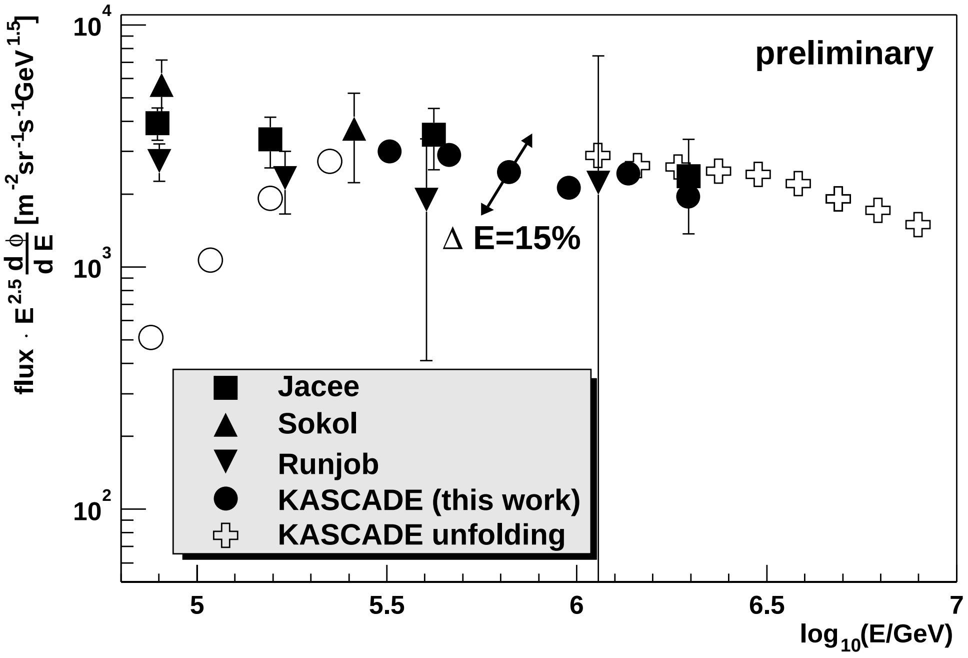

Fig. 2. The energy flux spectrum from KASCADE data. The trigger threshold is at $\log_{10}(\mathrm{E[GeV]}) = 5.5$. Data points below this threshold are marked with open circles. Results from three experiments with direct cosmic ray measurements[3] are shown. The KASCADE unfolding data are taken from [4].

more than half a decade.

With the help of detailed CORSIKA[2] simulations (QGSJET/GHEISHA including full detector simulations), the dependence of these observables on primary mass and energy is examined. As Fig. 1 shows, the relation between primary energy and estimated number of muons is a power law and independent of the primary particle. In a first step, using this dependency, we reconstruct an energy flux spectrum from measured data by taking the number of muons N_{μ}^{est} for each event and calculating the corresponding primary energy which is then histogrammed. If the simulations are correct, one should get a correct energy calibration at KASCADE for the higher energies and the flux should be compatible with that of direct measurements at lower primary energies.

In a second step, the new observables will be used together with additional hadronic and muonic observables measured by the Central Detector as input to a neural net analysis with which the energy spectrum and the elemental distribution of the measured data will be calculated.

2. Results

Simulations show that the uncertainties of the observables N_{ch}^{est} and N_{μ}^{est} are below 10% in the energy range $5 \cdot 10^{14}$ eV – $8 \cdot 10^{15}$ eV. The flux spectra for both observables follow a power law.

The dependence on mass and energy of the new observables is shown in Fig. 1: Whereas N_{μ}^{est} is a good estimator of the primary energy independent of the primary mass, N_{ch}^{est} is also dependent on the mass of the primary particle, which will be used for mass reconstruction.

Fig. 2 shows a first preliminary flux spectrum calculated by applying the described method to a small set of KASCADE data (75 hours measuring time). The flux is compatible with the direct measurements at low energies (above the threshold of $3 \cdot 10^{14}$ eV) and with KASCADE results for high energies. The statistical errors are smaller than the symbol size. Systematical errors have not been fully calculated yet. The effect of an energy uncertainty of 15% due to uncertainties of the underlying interaction model or a different chemical composition is shown for one data point as an arrow in Fig. 2.

3. Conclusions

The energy determination of KASCADE is based on simulations of extended air showers. To check this method, one has to compare the absolut flux at certain reconstructed energies with the flux of direct measurements. As these fluxes match, this is a further hint that the energy calibration at KASCADE is correct.

Together with further observables from the central detector, the new observables can also be used to determine the mass of the primary particle via a neural net at the trigger threshold of KASCADE. The result of the individual particle fluxes will then be compared to the direct measurements, too.

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