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Investigation of the S(500) distribution for large air showers detected with the KASCADE-Grande array

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Previous EAS investigations have shown that the charged particle density becomes independent of the primary mass at certain distances from the shower core and can be used as an estimator for the primary energy. In the context of the KASCADE-Grande experiment, the particular distance to shower core at which t his effect takes place is around 500 m, hence the study at this particular distance and the notation $S(500)$ for the charged particle density. It has been shown that $S(500)$ maps the primary energy. We present results of further investigations in this direction. An attenuation correction function can be derived from the $S(500)$ attenuation with the EAS angle of incidence, allowing us to build an all event $S(500)$ spectrum. In view of a future conversion of the recorded $S(500)$ spectrum to the primary energy, based on simulations a calibration of the observed S(500) values with the primary energies has been worked out (in the energy range accessible to the KASCADE-Grande array, 10^{16}-10^{18} eV).

1. Introduction

It has been shown by Hillas [1] that the particle density at a certain distance (dependent on the EAS detection array) from shower core becomes independent of the primary mass and can be used as a primary energy estimator. Different reconstruction techniques have relied on this property of the particle density in the case of different detector arrays [2]. Detailed simulations [3] have shown that for the particular case of the KASCADE-Grande array [4] (110 m a.s.l., at Forschungszentrum Karlsruhe, Germany), the

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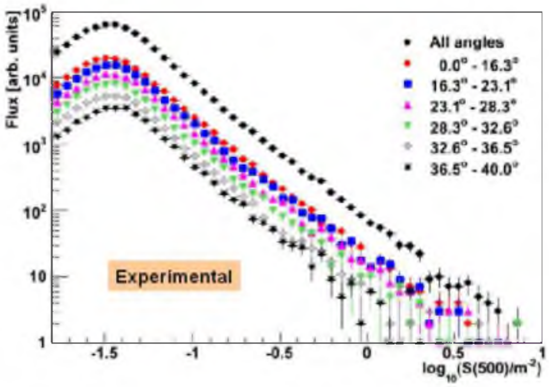

Figure 1. $S(500)$ differential spectra for different zenith angular intervals; the angular intervals are chosen so that they subtend equal solid angles.

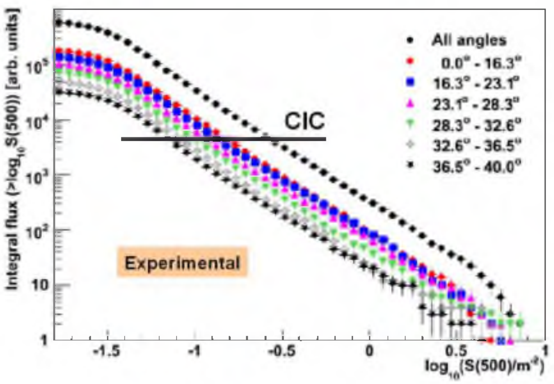

Figure 2. S(500) integral spectra.

particular distance to the shower core for which the particle density can be efficiently used as a primary energy estimator is 500 m. This has prompted us to study in detail the significance of the charged particle density at this distance. In what follows, the notation used for charged particle density in this particular case will be $S(500)$.

2. S(500) reconstruction

In the frame of this study, both simulated and experimental EAS data are processed with the same reconstruction tool [5] so the same steps are followed in the reconstruction of both cases. The reconstruction chain uses for input the energy deposits of particles in the detectors and the arrival time information. The energy deposits are converted into particle numbers [6] by using appropriate lateral energy correction functions that are zenith angle dependent, accounting for effects induced by inclined showers. Particle numbers in the stations are next converted into particle densities. A Linsley function [7] is employed in order to parameterize the resulting lateral particle density distribution from which the density at 500 m distance from the shower core is obtained. In order to avoid the very high particle densities close to the shower core (station overflow) and to ensure optimum reconstruction quality also for small showers, the radial range used for parameterization of the particle density distribution ranges from 40 m to the maxiumum available radial range with recorded data (around 1000 m).

3. Attenuation correction

For the reconstructed $S(500)$ values, one has to consider that, for a given primary mass and energy, the shower development in the atmosphere is greatly influenced by its inclination. Thus an inclined shower passes a longer path length through the atmosphere and reaches the detector level at a later development stage than a vertical one. This means that the inclined shower will get more attenuated. When compared to the vertical event, the inclined shower has a reduced value of S(500) though being initiated by an identical primary. The experimental $S(500)$ spectra in Fig. 1 show this effect. The spectra, though similar in shape, get more and more attenuated with increasing zenith angle. In order to build an all particle spectrum, we need firstly to correct for this attenuation. The correction technique is called the Constant Intensity Cut (CIC) method for reasons that will be explained in the

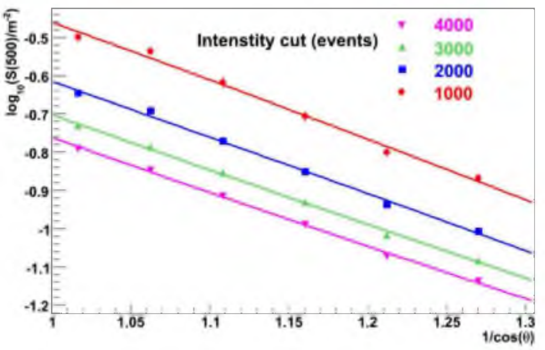

Figure 3. Attenuation of $S(500)$ with the zenith angle for different intensity cuts; the continuous lines correspond to second-degree polynomial fits.

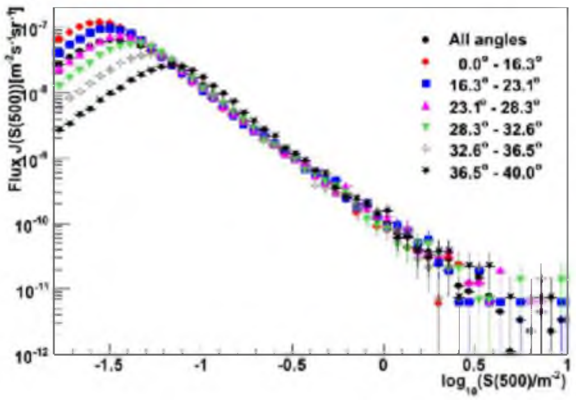

Figure 4. $S(500)$ for different zenith angles after the attenuation correction.

following. We assume, that for a given primary energy threshold we register the same number of events coming from all zenith angles. Therefore, we build the integral $S(500)$ spectra (using the differential ones in Fig. 1) and use a constant intensity cut, equivalent to a primary energy cut (in the hypothesis that a given intensity corresponds to a specific primary energy). For several considered cuts (in Fig. 2) we build the attenuation curves (see Fig. 3). A linear interpolation is used between the two neighboring points in the integral spectrum in order to convert the value of the intensity into particle density for each angular bin. From this interpolation, the uncertainties of the fit parameters are taken into account when evaluating the uncertainty of each $S(500)$ value in Fig. 3. The attenuation curves are later approximated with a simple second-degree polynomial function that is used next for correcting the $S(500)$ value of each shower to its would-be value at a reference angle. This angle is considered to be 21° for the purpose of this study, since the zenith angular distribution for the recorded EAS sample is peaked at this value. As in the case of the above-mentioned linear interpolation, also the uncertainties of the second-degree interpolation are propagated when obtaining the attenuation corrected S(500) values. The resulting $S(500)$ spectra, corrected for the attenuation, are presented in Fig. 4. In evaluating the uncertainty of this result, the systematic uncertainties induced by the CIC method have been taken into account by propagating the uncertainties of the fit parameters through the entire reconstruction chain. In particular for more inclined showers above above 35° there are systematic effects which will be studied in more detail.

4. Conversion to the energy

A calibration of $S(500)$ with the primary energy, E, is derived from the simulations. Fig. 5 shows such a calibration constructed for events close to our reference zenith angle (21° as employed with CIC). A conversion of $S(500)$ into primary energy is then possible by using this curve.

5. Conclusions

A possibility to reconstruct the primary energy spectrum from the particle densities recorded in the stations of the KASCADE-Grande array has been investigated. The particular case of charged particle densities at 500 m distance from the

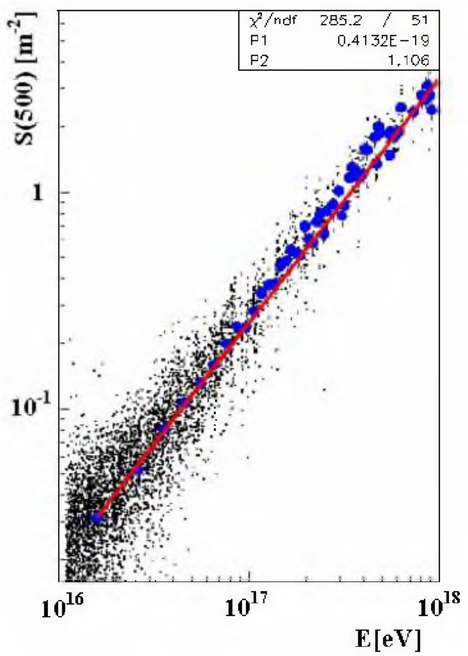

Figure 5. Simulations for the $S(500)$-E calibration curve.

shower core was shown to be insensitive to the mass of the primary. The $S(500)$ spectrum for the recorded shower sample has been investigated and the CIC method was applied in order to correct each shower for attenuation effects. Using a simulation-derived calibration curve between $S(500)$ and E, the attenuation corrected $S(500)$ spectrum can be converted into the primary energy spectrum.

In view of this goal, future simulated and experimental investigations will concentrate on increasing the quality of reconstruction as well as gaining a better understanding of the uncertainties induced by the reconstruction technique.

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