



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

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**Abstract:** For the experimental conditions of the KASCADE-Grande experiment, the density of charged particles of large air showers (EAS) at the distance of about 500 m from the shower core S(500) has been shown by detailed simulation studies to be an approximate energy estimator, being nearly independent of the mass of the primary particle. This report presents some first experimentally observed features of the S(500) observable of EAS registered with the KASCADE-Grande array installed at the Forschungszentrum Karlsruhe, Germany. The measured energy deposits of particles in the 37 scintillation detector stations have been used to reconstruct the lateral charged particle distributions which are described by a Linsley LDF. With adjusting the charged particle density distribution and applying various cuts, the S(500) distribution of the data has been evaluated. Among other features, the S(500) dependence from the EAS angle of incidence has been studied.

## Introduction

It has been first shown by Hillas et al. [1] that the lateral charged particle density at a particular distance from the EAS core, dependent on the specific layout of the considered array, proves to be nearly independent of primary mass and maps only the primary energy. An estimate of the primary energy on this basis has been applied for various arrays [2]. KASCADE-Grande [3] consists as main

component of an array of 37 detector stations of 10 m<sup>2</sup> scintillation counters, that covers a total area of ~0.5 km<sup>2</sup>. Dedicated simulation studies [4] have shown for the particular case of the layout of the KASCADE-Grande array that the charged particle density at the distance of around 500 m from shower centre appears most appropriate for the energy estimate.

## Reconstruction of S(500)

In context of the present studies, a software tool has been developed [5] and was used for analyzing the lateral particle density distributions event by event. The energy deposits of particles in detectors are converted into particle numbers [6] using appropriate lateral energy correction functions, dependent of the angle of incidence. Furthermore, the reconstructed particle numbers are converted into particle densities in the detectors. The next step of the analysis approximates the shape of the lateral particle density distribution by a Linsley LDF [7]. The Linsley LDF depends on three parameters, defining the total size and the lateral shape, which are determined by fitting the data. The results are used to deduce the value of the lateral particle density at 500 m from shower core, a quantity we refer as S(500). In order to explore the influence of the considered radial range of the data, the Linsley LDF has been adjusted in different radial ranges of the registered charged particle lateral distribution (0-1000 m, 40-700 m, 200-400 m, 300-700 m). The fit in different radial ranges shows that the LDF is pushed to the limits of a good reproduction of the data when trying to describe larger radial ranges, covering the very steep decrease close to shower core and the very shallow slope at large distances. This indicates that the Linsley LDF, though found quite appropriate in the simulation studies [3], is not perfect. As expected, the quality of the fit improves when fitting the lateral distribution in restricted radial ranges (inside which the slope of the distribution does not change strongly). For the observable S(500) investigated here, the best quality of the fits is achieved for the use of the 300 - 700 m radial range. The relation of S(500) to the primary energy, resulting from simulations is shown in Fig.1 (simulations use the QGSJET II model as high energy interaction model embedded in CORSIKA; in this case, S(500) is evaluated for each shower with the same reconstruction procedure as for the experimental data). We apply this energy estimator to the measured data in the primary energy range of about  $10^{16}$ -  $10^{18}$  eV. Fig. 2 shows a preliminary plot of the electron shower size ( $N_e$ ) dependence with the S(500) for the given shower sample. The electron shower size is obtained using the standard reconstruction technique

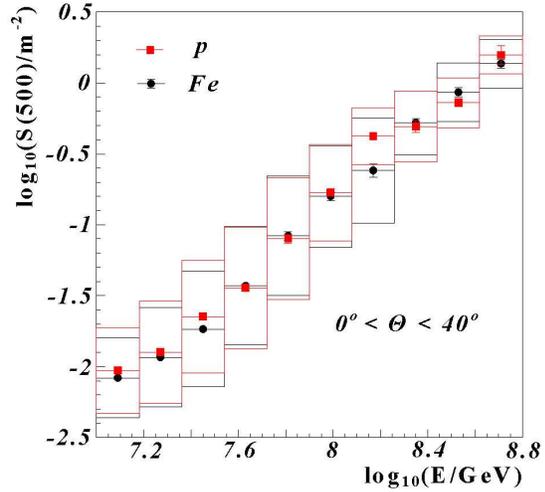


Figure 1: The relation of the mean values of S(500) to the primary energy E resulting from simulation studies for proton (squares) and Fe (dots) induced EAS:  $\log S(500)$  vs.  $\log E$ . In addition to the error of the mean (in many cases smaller than the dot size) the dispersion (standard deviation) is indicated by the error boxes.

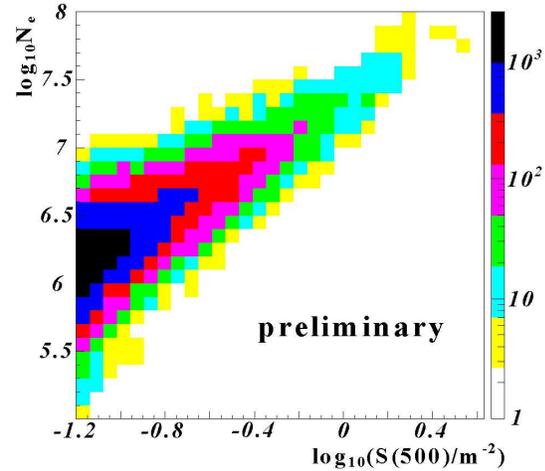


Figure 2: The dependence between electron shower size ( $N_e$ ) and the S(500) for the given shower sample - a minimum of 20 triggered stations, showers inclined up to  $45^\circ$  degrees and shower cores reconstructed inside the array.

[8], while the S(500) is obtained with the described technique. The origin of the visible fluctuations is

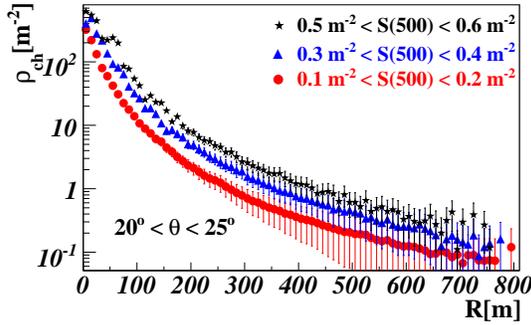


Figure 3: The measured charged particle lateral distributions for different  $S(500)$  ranges.

subject of further investigations. Fig. 3 shows for some  $S(500)$  ranges the measured charged particle distributions.

### Dependence of $S(500)$ on the angle of EAS incidence

A sample of the events detected by KASCADE-Grande has been studied in order to reconstruct the lateral distributions of charged particles and to determine  $S(500)$  distributions for EAS with different angles of incidence. In order to ensure a good quality of the shower sample, some restrictions have been applied with following requirements: (i) showers for which a minimum of 20 detector stations have been triggered, (ii) showers for which the reconstructed shower core falls inside the array and (iii) for which the Linsley LDF provided a good quality fit (as reported by MINUIT). Furthermore, only the showers for which the reconstructed zenith angle does not exceed  $45^\circ$  are considered. For values of  $S(500) > 0.6 \text{ m}^{-2}$ , the trigger threshold for all angular ranges is exceeded. Fig. 4 shows the distributions for all the showers and also specified for showers from different angles of EAS incidence in the full efficiency range of the KASCADE-Grande array. It is obvious from Fig.4 that in the range of the full detection efficiency, the  $S(500)$  distribution exhibits a power law behavior. This important feature maps the primary energy spectrum. In addition, the influence of attenuation in the Earth's atmosphere (reducing the value of  $S(500)$  for same number of events with in-

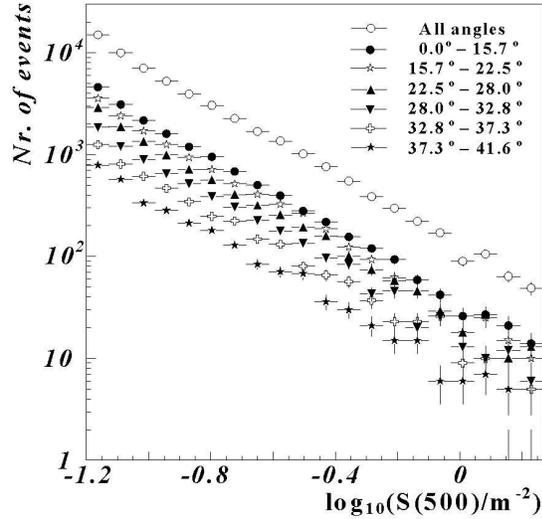


Figure 4: Differential spectra of the reconstructed  $S(500)$  observable for different EAS zenith angles opening equal solid angles and for the total shower sample (LDF adjustment performed in the radial range of 300 m-700 m).

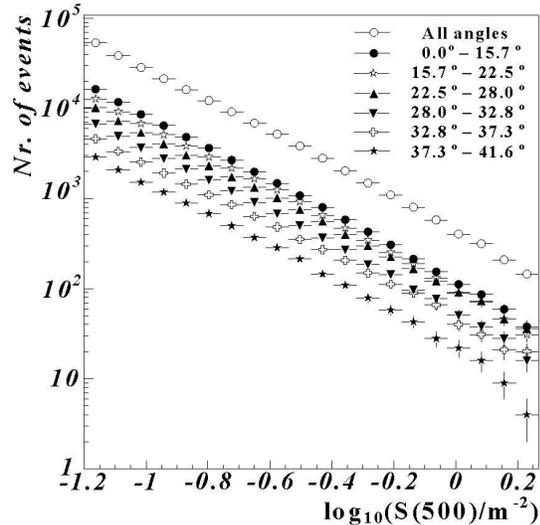


Figure 5: Integral spectra of the reconstructed  $S(500)$  observable for different zenith angles of EAS incidence as compared to that of the total shower sample.

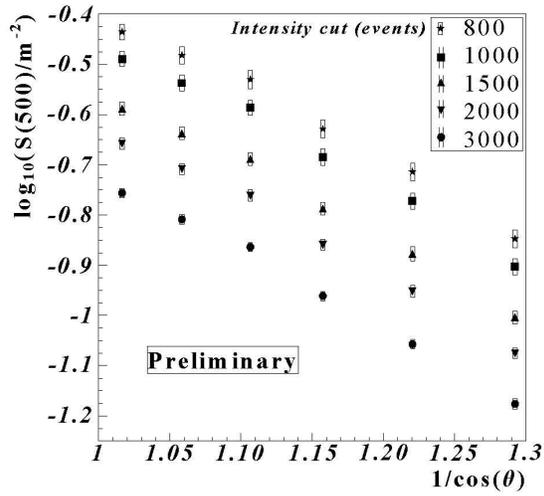


Figure 6: The  $S(500)$  dependence of the angle of incidence for various pre-chosen intensities (number of events). For a given angle of incidence, the  $\log_{10}S(500)$  value on the vertical axis is the corresponding  $\log_{10}S(500)$  in the integral spectrum for which we have an intensity equal to the one used for the constant intensity cut.

creasing angle of EAS incidence), the spectra follow approximately the same slope for all angular intervals. This is a consequence of the isotropic incidence of the primary cosmic radiation. In Fig. 5 the integral  $S(500)$  spectrum is shown as derived from the data. Fig. 6 shows the  $S(500)$  dependence on the angle of EAS incidence for different pre-chosen constant intensities in the integral spectrum. The spectra have been approximated with power-laws. After choosing different values for the intensity, the corresponding  $S(500)$  value has been calculated using the inverse function of the power-law. Since the  $1/\cos(\theta)$  value shows the atmospheric depth, the constant intensity cut provides a method for observing the  $S(500)$  attenuation with the atmospheric depth.

## Conclusions

The value of particle density at 500 m from shower core was indicated by simulation studies to be a suitable energy estimator for EAS in the range of  $10^{16}$ -  $10^{18}$  eV. With this aspect, the experimental lateral density distribution of charged particles has

been investigated for EAS events detected with the KASCADE-Grande array. The reconstructed experimental lateral density distributions have been approximated with a Linsley LDF and the values of particle density at 500 m distance from shower core  $S(500)$  are derived. The distribution of  $S(500)$ , assumed to reflect the primary energy spectrum, and the dependence of  $S(500)$  on the angle of EAS incidence have been shown.

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