KASCADE-Grande Energy Reconstruction Based on the Lateral Density Distribution Using the QGSJet-II.04 Interaction Model

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Abstract. The charged particle densities obtained from CORSIKA simulated EAS, using the QGSJet-II.04 hadronic interaction model are used for primary energy reconstruction. Simulated data are reconstructed by using Lateral Energy Correction Functions computed with a new realistic model of the Grande stations implemented in Geant4.10.

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THE KASCADE-GRANDE EXPERIMENT

The KASCADE-Grande Experiment [1] (KArlsruhe Shower Core Array DEtector - Grande) is an extensive air shower (EAS) detector array designed to study cosmic rays in the 10^{16}-10^{18} eV energy range. KASCADE-Grande was built as an extension of the KASCADE experiment - by means of the Grande array. The KASCADE array offers information on the electromagnetic and muonic components of the EAS and the Grande array can detect charged particles that reach the ground, without the possibility of distinguishing between their types.

Meanwhile, the KASCADE-Grande experiment is no longer operational, but a large amount of data is available to be analyzed.

The analysis of CORSIKA [2] simulations has shown that the lateral density of charged particles can be used to estimate the energy of the primary particle, using the charged particle density at 500 m distance from the shower core (S(500) observable [3]).

The Grande detectors contain 16 scintillator modules, adding up to a sensitive surface of ~10 m^2. Because they contain only a single layer of scintillators, we cannot distinguish between the signal produced in the detector by a photon or a charged particle. The electrical signal produced by the PMT at the passing of secondary particles from the EAS trough the scintillator is converted in the total energy deposit measured by a particular station. In order to determine the density of charged particles using the total energy deposit, the Lateral Energy Correction Function (LECF) is used. The LECF represents the average energy deposit per charged particle as function of the azimuthal angle and distance to shower core.

COMPUTING THE NEW LECF

A new Lateral Energy Correction Function was computed using a realistic geometry of the Grande station implemented in the Geant4 simulation toolkit. For this, a set of 360 CORSIKA simulated EAS was used, half of them induced by protons and half by iron nuclei, with primary energies in the range of $10^{16} – 2\times10^{17}$. The zenithal angle of the EAS's was set in the 18^{O}-22^{O} interval to correspond to the natural maximum. The data set was computed by using the QGSJet-II.04 and FLUKA hadronic interaction models.

All the particles from the EAS are passed through an artificial array of Grande detectors simulated using the Geant4 toolkit[4], containing a total of 25600 detection stations. The total energy deposit (produced by all species of particles) in a station is determined and then divided by the number of charged particles detected in that station in order to obtain the LECF (**FIGURE 1**.).

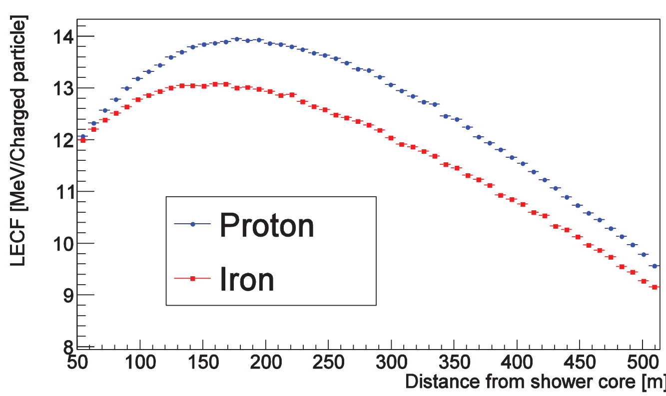

FIGURE 1. The average Lateral Energy Correction Function for proton and iron induced EAS

CORSIKA SIMULATED S(500) AND S(200)

In order to check the functionality of the new LECF, for each EAS from the set mentioned earlier, the energy deposits in the Grande array were simulated and then transformed into charged particle densities. The comparison between the original and reconstructed averages of the charged particle density is shown in **FIGURE 2**.

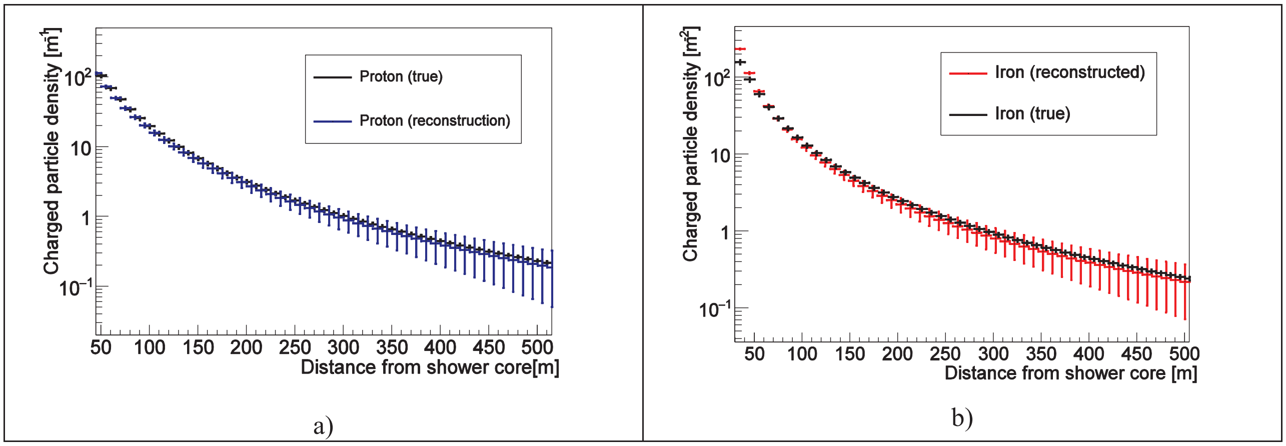

FIGURE 2. True (black, CORSIKA average) and reconstructed lateral distributions of charged particles:

a) Proton induced EAS, b) Iron induced EAS

Special attention was given to the charged particle density at 500 m from the shower axis. The aim is to check if the reconstruction procedure applied to simulated events disturbs the equality of the charged particle densities for the proton and iron induced EAS. **FIGURE 3.** illustrates the linear variation of the S(500) observable in respect to the primary particle's energy.

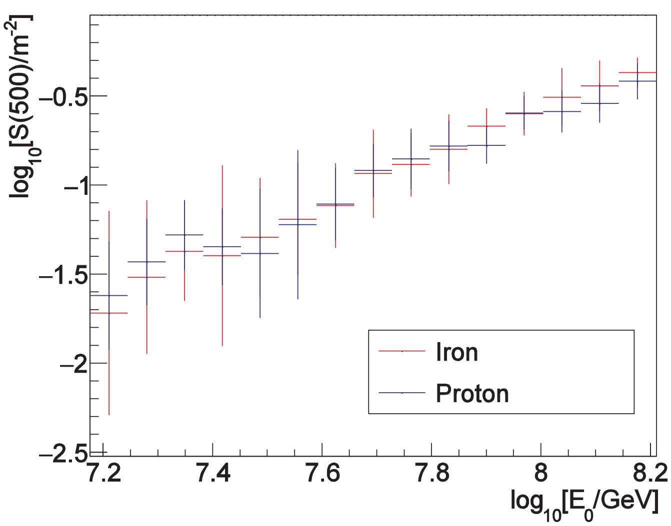

FIGURE 3. The reconstructed charged particle density at 500 m from the shower core for proton (blue markers) and iron (red markers) primaries

S(200) FOR MASS DISCRIMINATION

The charged particle density near the shower core presents a visible difference for proton and iron induced EAS. This feature of the lateral density of the charged particles can be used for mass discrimination [5,6]. For this purpose, the distance of 200 m from the shower core was chosen in order to avoid detector saturation that occurs near the shower core, where the detector is flooded with particles.

As an alternative analysis to the standard one used at KASCADE-Grande, we intend to use the S(500) observable for determining the energy of the primary particle and the S(200) observable for mass discrimination. The relation between these two observables is illustrated in **FIGURE 4.**

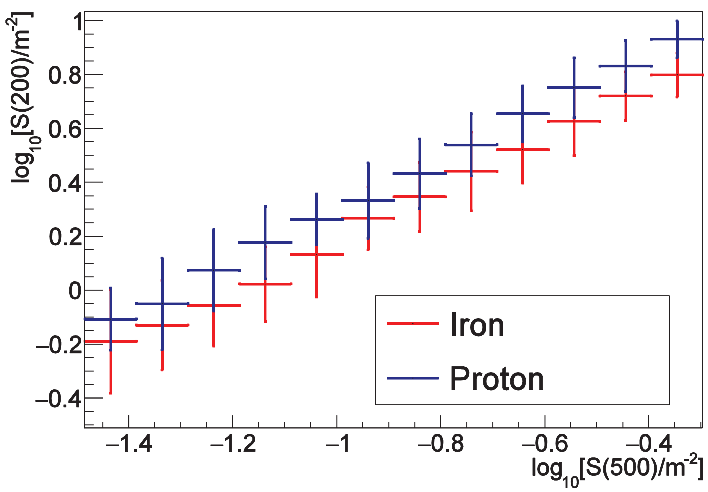

FIGURE 4. The reconstructed charged particle density at 200 m from the shower core for proton (blue markers) and iron (red markers) primaries

CONCLUSIONS AND PERSPECTIVES

A new lateral energy correction function for the KASCADE-Grande detectors was computed using the QGSJet-II.04 hadronic interaction model and a realistic geometry of the Grande stations implemented in Geant4.

The reconstructed lateral distribution of charged particles is in good agreement with the data provided by CORSIKA simulations and with previous results. The S(500) and S(200) observables have proved to be suitable for energy estimation and mass discrimination, confirming previous results obtained with the QGSJet-II.02 and EPOS 1.99 hadronic interaction models. The method presented will be used for the reconstruction of data recorded by the KASCADE-Grande experiment and compared to the results obtained with the standard analysis.

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