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Lateral particle density reconstruction from the energy deposits of particles in the KASCADE-Grande detector stations

G. TOMA[1], O. SIMA[2], I. M. BRANCUS[1], H. REBEL[3], A. HAUNGS[3], B. MITRICA[1]

[1]*Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania, gtoma@muon1.nipne.ro*
[2]University of Bucharest, Department of Atomic and Nuclear Physics, Bucharest, Romania, *osima@olimp.fiz.infim.ro*
[3]*Institute fuer Kernphysik, Forschungszentrum Karlsruhe, Germany, rebel@ik.fzk.de*

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Abstract. In the much larger framework effort of inferring data on the mass and energy of the primaries from EAS observables, the present study aims at delivering a versatile method and software tool that will be used to reconstruct lateral particle densities from the energy deposits of particles in the KASCADE-Grande detector stations.
Key words: cosmic rays, air showers, reconstruction

Lateral particle density reconstruction from the energy deposits

1. Introduction

The study of cosmic radiation aims at finding answers to questions related to ultra-high energy cosmic rays sources, cosmic acceleration mechanisms, interaction mechanisms. All these questions cannot be answered today by means of accelerator techniques as the ultra-high energy of cosmic rays is not yet accesible to accelerator devices. Thus the great interest in the study of cosmic radiation and the related phenomena. Fig. 1 shows the primary cosmic radiation spectrum integrated on all particle species.

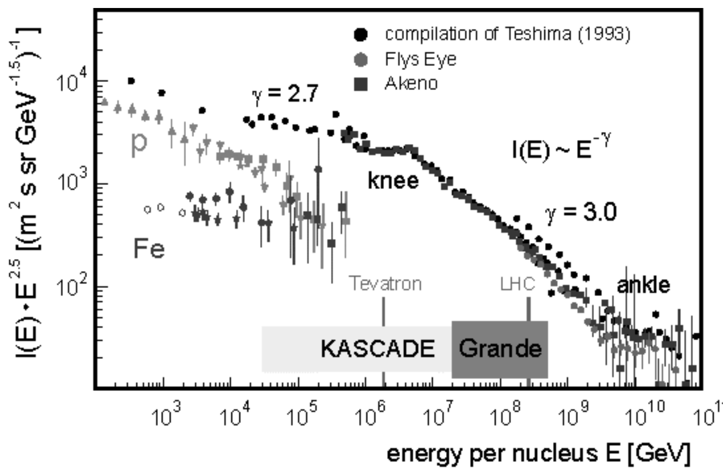


Fig. 1 - The energy spectrum of primary cosmic rays integrated on all particle species

Two features of this spectrum are obvious immediately. First is the steep exponential decrease of particle flux with the increase of energy up to energies ~10^{20} eV. Second is the sudden change in the steepness of the spectrum at several energy thresholds, most notable around 10^{16}eV. This change, although experimentally recorded, is not yet fully understood. A number of theories describe possible reasons for this characteristic, but a final answer to the question of its origin is yet to be found. Ufortunatelly, due to the low number of particles at very high energies (km^{-2}century^{-1}), the direct study of primary cosmic rays becomes unable of giving statistically reliable results.

A solution to this problem is the study of **E**xtensive **A**ir **S**howers (**EAS**), avalanches of particles generated in the Earth's atmosphere by the high energy primary cosmic radiation. Compared to a single high energy particle, an EAS is much easier to detect due to its size (~10^4m^2). The birth and development of the EAS is a complex event and is always related to the nature of the primary particle: the height of the first interaction, the particle composition of the EAS, the geometrical development are all related to the mass and energy of the primary particle. Thus a study on EAS observables might give indications on the nature of the primary.

2. The KASCADE-Grande detector array

The extensive air showers can be detected by a number of detector arrangements, a widely spread solution being the detector array. Such an array is the KASCADE-Grande array, situated at Forschungszentrum Karlsruhe, Germany (110m a.s.l.) (Fig. 2) [1].

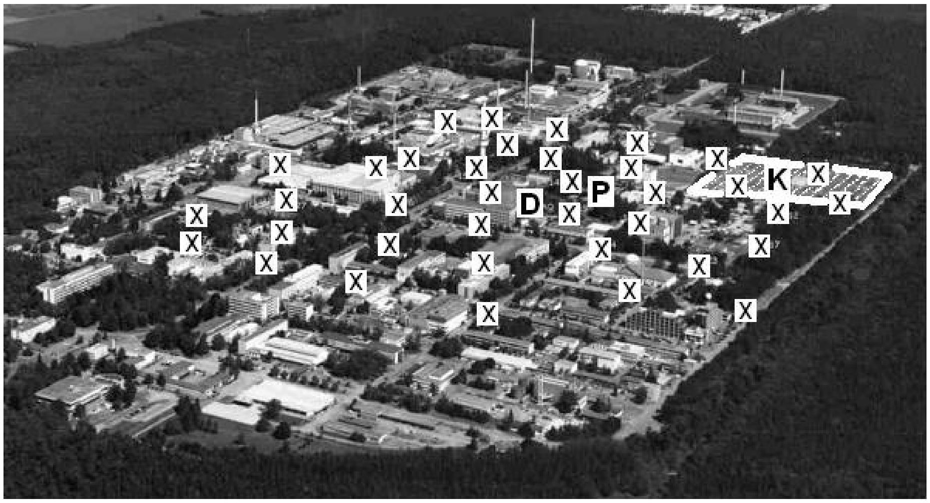


Fig. 2 - The KASCADE-Grande detector array with its components: the KASCADE array (K - the upper right rectangular area), the Digital Acquisition Station (D), the Grande stations (X), the Piccollo trigger array (P).

The KASCADE-Grande array is an extension of the previously built KASCADE array. The KASCADE array was able to detect different EAS components (electrons, gamma, muons, hadrons) for air showers initiated by primaries with energies up to $2 \cdot 10^{16}$eV. In order to make possible the observation of EAS phenomena for primary energies up to 10^{18}eV, the KASCADE array has been extended by adding 37 new detector stations on a wide surface with a diameter of roughly 600m. The KASCADE-Grande array is able to detect a number of EAS observables such as: particle densities, particle arrival times, etc. With these data one can "reconstruct" the main characteristics of an air shower in the effort of finding the nature (mass, energy) of the primary.

3. The lateral particle density

This study concentrates on the study of the lateral particle density for simulated showers (with Monte-Carlo simulation code CORSIKA [2]). The lateral particle density in the EAS front (ρ) exibits a steep decrease away from the shower core[3]. This is true for all the EAS components (see Fig. 3, Fig. 4).

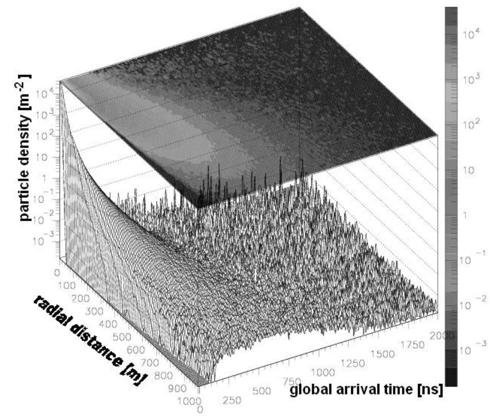


Fig. 3 - Structure of the EAS front for all EAS components

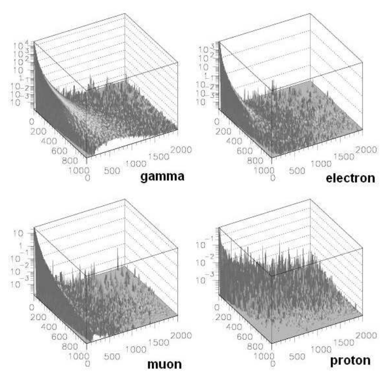
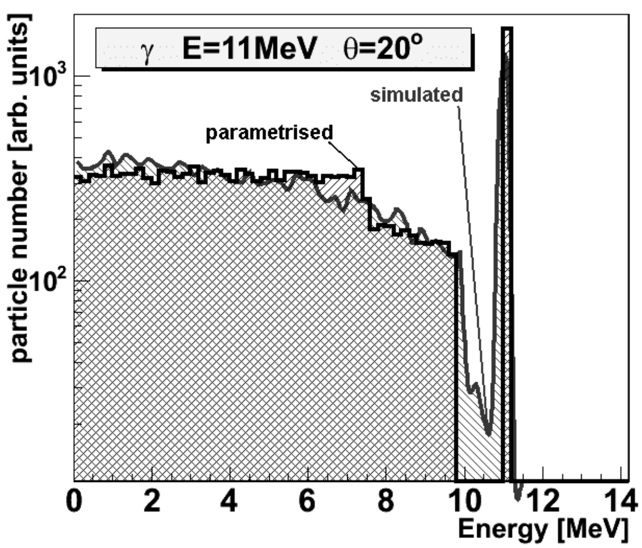


Fig. 4 - Structure of the EAS front for each component

Different EAS components have different characteristics. The electrons for example are absorbed fast in the atmosphere so at ranges greater than 600m from shower core there are practically no electrons in the shower front. In contrast, the muon component is considerably more penetrating and will dominate at large distances from shower core. Also the electrons are generated in greater numbers by a light primary (ex. H) than by a heavier primary (ex. Fe) at the same energy. Similarly, the muons are generated in greater number by a heavier primary at a given energy. The hadronic component has a very narrow spread and propagates close to the shower core. It has been shown that the charged component (electrons and muons) carries a significant amount of information related to the primary particle.

4. Lateral charged particle density reconstruction

The KASCADE-Grande stations record the energy deposits of particles in the scintillators (without being able to tell the nature of the particle that deposited that energy, as opposed to the KASCADE array). The reconstruction procedure uses these deposits to reconstruct the lateral charged particle density (ρ_{ch} – density of charged particles, electrons and muons). The study has been done so far for simulated events for different primaries (p, C, Fe) with energies in the ($1.00 \cdot 10^{16}$, $1.00 \cdot 10^{18}$ eV) interval and for different radial ranges from shower core (40-700m, 40-200m, 400-700m, 100-200m, 500-600m). For the simulated event, the particle interaction with detector stations is simulated. In the case of real events, the particles are coming on inclined trajectories, so this too is taken into account. At this point the data has the same level of consistecy as the data recorded by the detectors. A mean energy deposit is calculated for each EAS component. With these mean energy deposits, the reconstructed charged particle density *S* is obtainded. The procedure is considerably accelerated by the parametrisation of the energy deposits, so Monte – Carlo calculations using GEANT are not used repeatedly as in previous studies. As an example, a comparison between simulated energy deposits and parametrised energy deposits is presented in the figures below.



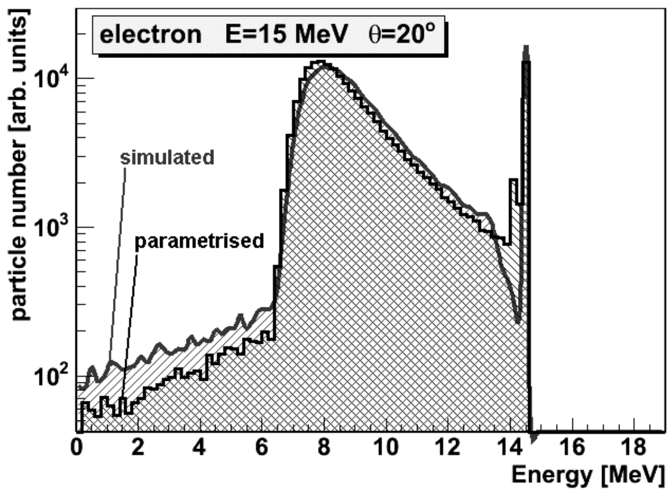


Fig. 5 - Example: comparison between simulated energy deposits and parametrised energy deposits for photons and electrons with a 20° angle of incidence

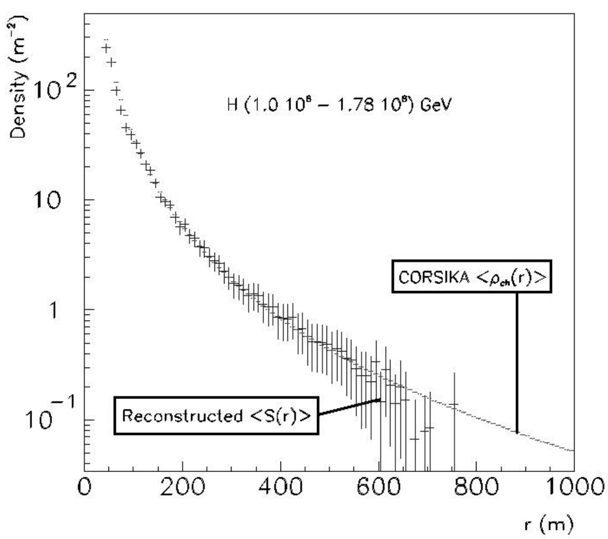


Fig. 6 - Comparison between the simulated charged particle density (ρ_{ch}) and the reconstructed particle density (S) from the energy deposits

The study advances gradually to a stage when it will be applied on real events detected by the KASCADE-Grande array.

5. Parametrisations of the lateral charged particle density

Once the lateral particle density has been reconstructed, a number of parametrisations (**L**ateral **D**istribution **F**unction **- LDF**) have been used to infer information on the nature of the primary particle. The LDFs that have been used are NKG, Linsley, Lagutin and a polynomial form[4,5]. A quality factor has been defined and calculated for each LDF in order to test the capability of each parametrisation to describe the particle density distribution (Fig. 7).

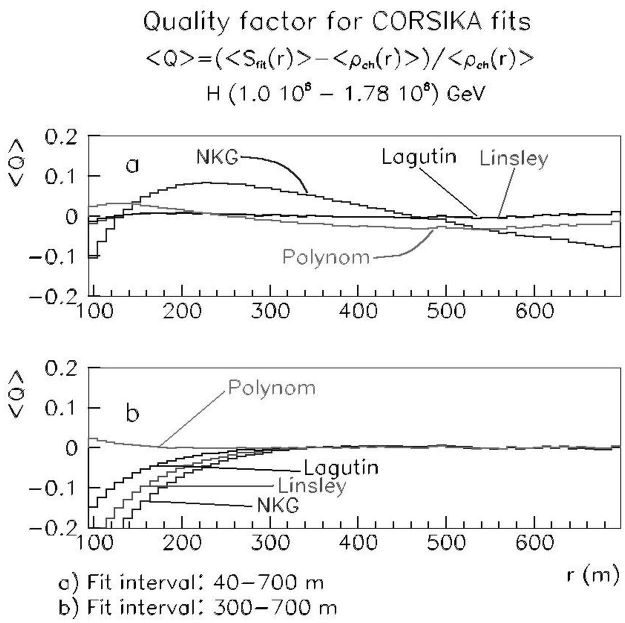


Fig. 7 - Example: Comparison of the reproduction of the average CORSIKA lateral charged particle distribution by various forms of the LDF (case : proton induced EAS of (1.0-1.78) $\cdot 10^{17}$ eV)

It was shown that different fit parameters are primary particle sensitive, recording the changes in mass and energy of the primary particle. Such parameters have been selected for future multiparametric studies[5,6].

6. Conclusions

An extensive study has been performed on simulated EAS events in order to develop a method and a software tool able to reconstruct the lateral particle density in the EAS front. The final purpose of this work is to serve the study of real events detected by the KASCADE-Grande detector array. The energy deposits of particles have been simulated and parametrised for different EAS components and for different particle angles of incidence, bringing the simulated data to the same level of consistency with the experimantal data. The reconstructed charged particle density has been parametrised using four LDFs and the posibility of inferring information on the primary from the fit parameters has been investigated. It has been demonstrated that the lateral charged particle density carries information on the nature of the primary. With the study of energy deposits for inclined particles, the study on simulated events ends and the analysis of real events can begin.

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