

STUDY OF THE LATERAL DISTRIBUTION OF PARTICLES IN THE EXTENSIVE AIR SHOWER FRONT

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Abstract. To obtain information about the influence of the primary particle (mass and energy) on the shape of the lateral distribution of detected shower particles, a study of simulated Extensive Air Showers (EAS) has been done. A number of showers have been simulated using CORSIKA simulation program for different primary particles (p, C, Fe) and different energies ($5.62 \cdot 10^{16}$ and 10^{17} eV). The simulated lateral density distribution has been approximated with a parametric Lateral Density Function (LDF). The interaction of the shower particles with the detectors has been simulated and the energy deposited in the detectors has been evaluated. This was used for obtaining the reconstructed (equivalent to the experimental) lateral density distribution, afterwards approximated with the same LDF. To check the quality of the fit and to investigate the sensitivity to fitting conditions, the study was done for three radial ranges, 40-200 m, 350-650 m, 0-1000 m. The total number of particles in the shower front and the truncated number of particles (in the fitting range) have been reconstructed to be compared with the real number of particles from CORSIKA simulations and in order to investigate the potential use of these parameters in a multiparametric study of extensive air showers.

Key words: extensive air showers, lateral distributions

INTRODUCTION

The primary cosmic radiation is composed of high energy particles that bombard the Earth constantly, generating particle avalanches in the atmosphere. Such avalanches are commonly called **Extensive Air Showers (EAS)**. The birth and development of an EAS is always greatly influenced by the characteristics of the primary particle (its mass and energy) and also by the characteristics of the first interaction. So, when asking questions about the nature of the primary particle, we may find the answers in the characteristics of the EAS, observables that describe the structure and development of the EAS. Such observables may be studied by means of simulation, experiment or theory. In the case of this paper, the chosen observable is the lateral density distribution of the particles in the EAS front. The distribution has been parametrised and studied for simulated events.

PARAMETRISATION

The study has been performed for a radial range that extends from 20 m to 1000 m distance from the shower axis. The 0m-20m radius interval is excluded from the analysis as the particle density in that region is too high (also the hadronic component of the EAS is

too intense in this region) and is not possible to obtain information concerning just the muonic and electronic components of the EAS. In order to express the variation of the lateral density of particles, a generalization of the NKG function has been used[1]:

$$\Delta = \frac{N}{R_0^2} \cdot C(\alpha, \eta) \left(\frac{R}{R_0} \right)^{-\alpha} \left(1 + \frac{R}{R_0} \right)^{\eta-\alpha} \quad (1)$$

where

$$C = \Gamma(\eta - \alpha) [2\pi \cdot \Gamma(2 - \alpha) \cdot \Gamma(\eta - 2)]^{-1}$$

and

Δ - the particle density at a distance R from the shower axis

N - the shower size (in our case the total number of electrons and muons)

R_0 - Moliere radius; R_0 has been given a value of 92m for this study

R - radius

α, η - two parameters.

A suitably chosen set of parameters α and η is expected to describe rather accurately the lateral density distribution from distances of a few meters to several kilometers from the shower axis.

RESULTS

For the following study, the lateral distribution of particles in the shower front is obtained by CORSIKA simulations. In the beginning, a number of 150 showers have been simulated. The simulated showers have the following characteristics:

- three different primaries have been used for generating the showers: p, C, Fe(50 showers were generated for each primary);
- all are vertical showers ($\theta_{sh}=0^\circ$);
- all have been initiated by primaries with the same energy ($E_{pr}=5.62 \cdot 10^{16}$ eV).

Later, other 20 vertical showers have been simulated for primary particles p and Fe with energies of 10^{17} eV, in order to compare results obtained for different energies.

It is expected that one of the two fit parameters is sensitive to the mass of the primary particle. Indeed, the η parameter shows promising sensitivity to the mass of the primary, while the α parameter shows no relevant sensitivity. The histograms below represent the distributions for α and η for 50 showers initiated by each kind of primaries.

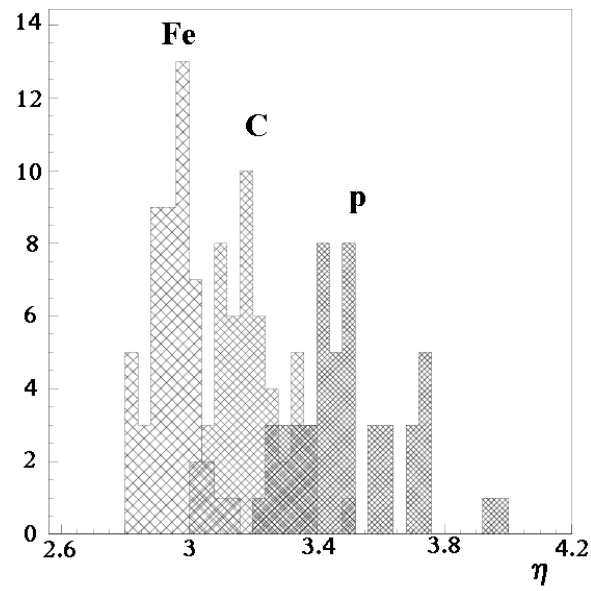


Fig.1 - The histograms show how the η parameter is sensitive to the mass of the primary particle

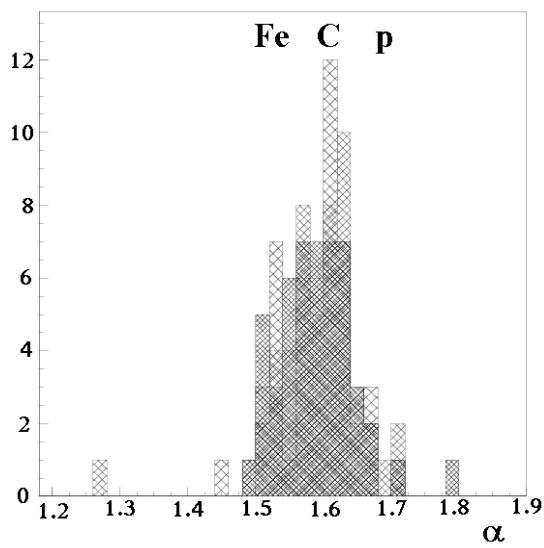


Fig. 2 - The histogram shows no relevant sensitivity of α parameter with the mass of the primary

Depending on the interaction probability of the primary particle with the atmosphere, the distributions are more or less affected by fluctuations. As iron has the largest interaction cross section (thus first interaction takes place in a more restricted range of heights) the overall statistic of an iron initiated shower is of higher quality[8]. The quality of this statistics decreases with the mass. This is why in the histogram above, the η distribution of proton initiated showers has the greatest fluctuations.

The following pictures show a comparison between ρ_{ch} and reconstructed particle density, S , for 10 added shower distributions. The study is done for iron and proton induced showers, for the energy of primary in both cases equal to $5.62 \cdot 10^{16} \text{eV}$. S has been calculated from the energy deposited by the particles in detectors. Both curves (ρ_{ch} and S) have been fitted with a modified Linsley LDF (eq. 1) and the η values for each curve are also presented in the picture.

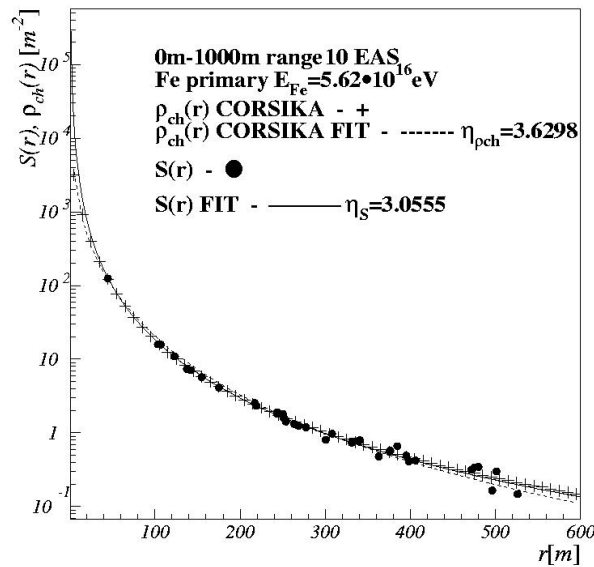


Fig. 3 - ρ_{ch} and S comparison with fits for each curve

Because of the larger energy per primary nucleon (in the case of proton primary), the proton induced showers contain more electrons than iron induced showers, this leading to an overall greater number of charged secondaries (electrons are generated mainly in electromagnetic interactions). As electrons come in much greater numbers, the greater number of muons in the iron induced shower do not make a significant contribution to the total number of charged secondaries (the iron induced shower has more muons as they are generated in hadronic interactions that are in turn related to the number of hadrons in the primary). However at larger distances from shower core, as electrons get absorbed much more than muons, the iron induced shower will have more charged particles (at about 500m from shower core there are practically no electrons in the shower front). The effect is clearly visible in the pictures.

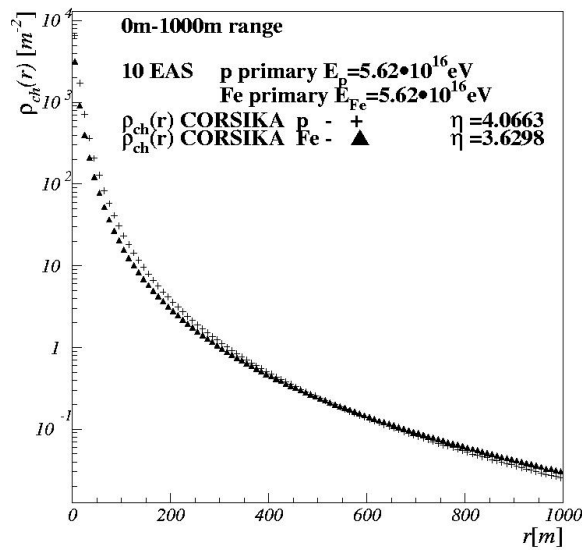


Fig. 4 - True (as given by CORSIKA simulation) lateral density distribution for two primaries

The fit curve does not describe the data very well (see Fig. 3.) on all ranges simultaneously and a test of the fit procedure on restricted ranges is presented in Fig. 5. The fit quality is improved when fitting only on a restricted range, in this case 350m-650m.

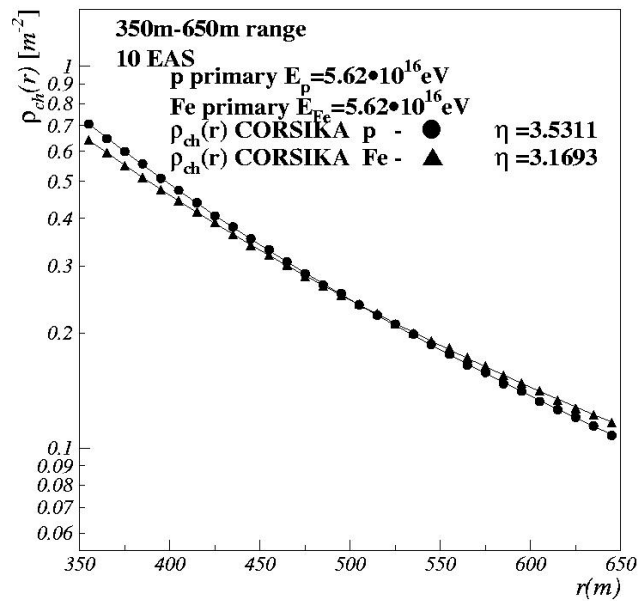


Fig. 5 - Results obtained for fit on a restricted radial range (showers initiated by p and Fe)

Although values of η parameter are likely to change when the fitting range is changed, the general tendency $\eta_{Fe} > \eta_p$ remains valid, proving that η is a good parameter, in the sense that it is primary mass dependent. As a promising feature for future studies, this behaviour remains true even for very poor statistical quality of the data. Note in these pictures the overlapping of $\rho_{ch\ Fe}$ and $\rho_{ch\ p}$ at $\sim 500m$. This characteristic of the lateral density encourages us to believe that its value could be used as an estimator for the primary energy, as it is mass independent.

The radial range close to the shower core includes the greatest overall decrease in density, testing the chosen LDF to its limits. This is why fits on restricted radial ranges give a better description for the lateral density.

The picture below (Fig. 6.) shows a comparison of reconstructed lateral density for showers initiated by different primaries (p and Fe) with an energy of 10^{17} eV. The picture also presents the reconstructed number of particles in the given radial range as it is obtained by integrating the two curves.

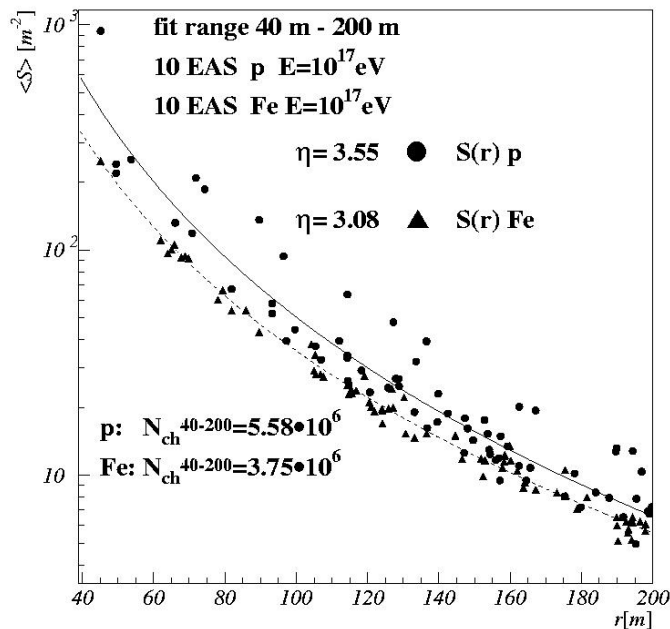


Fig. 6 - Comparison of reconstructed lateral densities for p and Fe primaries at a higher energy (10^{17} eV)

Fig. 7 shows a histogram similar to the one presented in Fig.1, but for showers initiated by primaries with energy 10^{17} eV. It is clear how the mean value of the distribution changes with the change of the primary particle.

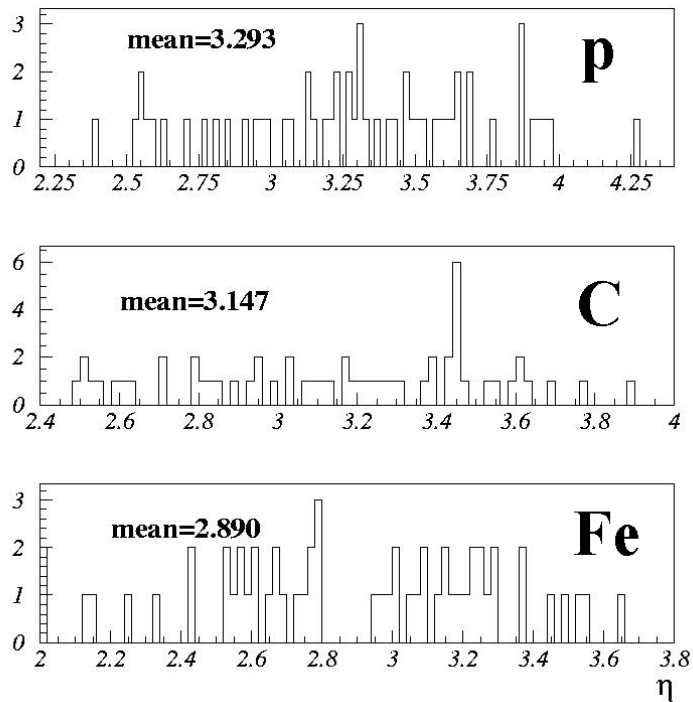


Fig. 7 - Histogram showing the sensitivity of η parameter with the primary mass (for primary energy 10^{17} eV)

CONCLUSIONS

The goal of the study was to find a reliable set of observables that are primary particle sensitive. Such observables could prove valuable in any multiparametric analysis of an experimental EAS event. The observable tested was the particle lateral density distribution. Some relevant parameters describing this distribution have been chosen in the form of the fit parameters of a Linsley function.

The study achieved its goal, proving that the distribution is primary mass sensitive. Variation characteristics of the chosen parameters with the primary mass have been studied and explained phenomenologically. The results show that they can be successfully used in multiparametric studies at KASCADE-Grande experiment as η parameter clearly indicates any change in the mass of the primary particle. While it is expected that such sensitivity of these parameters will decrease when dealing with an energy spectrum for primary (instead of single energy as it is the case of this study) or an angular interval for the angle of incidence, the multiparametric study will still be able to make good use of their values.

Future development of this study will involve test fits of lateral distributions with other promising LDF functions, finding a preferred fit range (if there is one), test of same results for different primary energies (energy spectrum) and incidence angles.

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