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Event - by - event studies of the discriminative features of the LDF of charged EAS particles: observable correlations and non -parametric analyses of multivariate distributions

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Using the reconstruction of the charged particle density for KASCADE-Grande, based on different LDF parameterizations, extensive studies have been done to explore features for energy estimation and mass discrimination around 10^{17} eV. Taking into account the response of the Grande detectors, results from CORSIKA simulated showers for H, C, and Fe primaries in 8 energy intervals, (10^{16} eV - 10^{18} eV), give the charge particle density S^{500}/S^{600} or $N_{ch}^{400-600}$, with similar energy dependence for all primaries, indicating such observables are suitable as energy identifier. The correlations of the reconstructed particle density S^{100}/S^{200}, or $N_{ch}^{100-200}$, with a muon number N_{μ}^{40-700} present features for mass discrimination.

1. Data basis

Using the Monte Carlo program CORSIKA (version 6.023) [1], including the QGSJET [2] model for the description of high energy hadronic interactions, a set of showers of randomly distributed angles of incidence has been performed for H, C and Fe primaries in eight energy ranges: $1.0 \cdot 10^{16}$ eV to $1.0 \cdot 10^{18}$ eV, with a statistics decreasing from 300 to 20 showers.
In order to reconstruct the particle numbers corresponding to the individual KASCADE-Grande detector stations [3], the energy deposit per charged particle (muons and electrons) from CORSIKA simulated showers has been evaluated with the GEANT [4] code. Using the SHOWREC program [5], the charged particle dis-

tributions have been fitted with the Linsley LDF [6] and Lagutin LDF [7]. Fig.1. shows the distributions of integrated numbers of charged particles in the range 100 m - 200 m as obtained by a Linsley-fit to the densities in the range of 40 m to 700 m core distance.

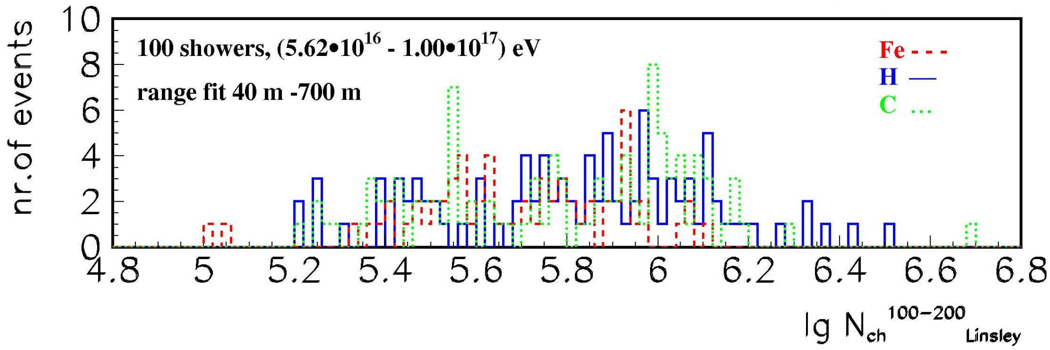

Figure 1. The distributions of lg $N_{ch}^{100-200}$ using Linsley fit for H, C and Fe primaries with energies ($5.62{\cdot}10^{16}$ eV-$1.00{\cdot}10^{17}$ eV)

2. Energy estimation

Following previous investigations [9, 10] and based on the present studies the charged particle densities S^{500}, S^{600} as well as the integrated charged particle number $N_{ch}^{400-600}$ are suitable as energy identifier with a similar energy dependence for all primaries, see Fig.2-left. A fit with a straight line at this log-log-plot was performed for the observable $N_{ch}^{400-600}$, giving almost identical slopes for both primaries and both Linsley and Lagutin LDF descriptions.

$$\langle \lg N_{H}^{400-600}\rangle = -4.96 + 1.27 \lg E_0$$
$$\langle \lg N_{Fe}^{400-600}\rangle = -4.98 + 1.27 \lg E_0$$

3. Correlations of relevance and mass discrimination

The charged particle density at lower distances, 100m - 200m, where the electron-gamma component is dominating, has features for mass discrimination. The observables S^{100}, S^{200} or $N_{ch}^{100-200}$ could play in the Grande array a similar role as the electron size N_e at the KASCADE array [11]. In the KASCADE-Grande experiment the density of muons cannot be detected in small radial ranges like for the electromagnetic component, so we have to introduce another observable of interest, N_{μ}^{40-700}, the integrated number of muons in the range of 40 m - 700 m. Our results indicate a N_{μ}^{40-700}- $N_{ch}^{100-200}$ correlation as the possible correlation for mass discrimination in KASCADE-Grande observations, being analogue to N_{μ}^{tr}-N_e correlation for the KASCADE experiment [8].
Fig.2, the right panel, compares the N_{μ}^{40-700} - $N_{ch}^{100-200}$ correlation for restricted energy ranges, selected energy ranges of the CORSIKA simulations.

Using non-parametric statistical analysis, the multidimensional observable distributions are studied by associating the single observed events to different classes and comparing the observed events with the model distributions (reference pattern) without using a pre-chosen parameterization. Applying this technique based on the

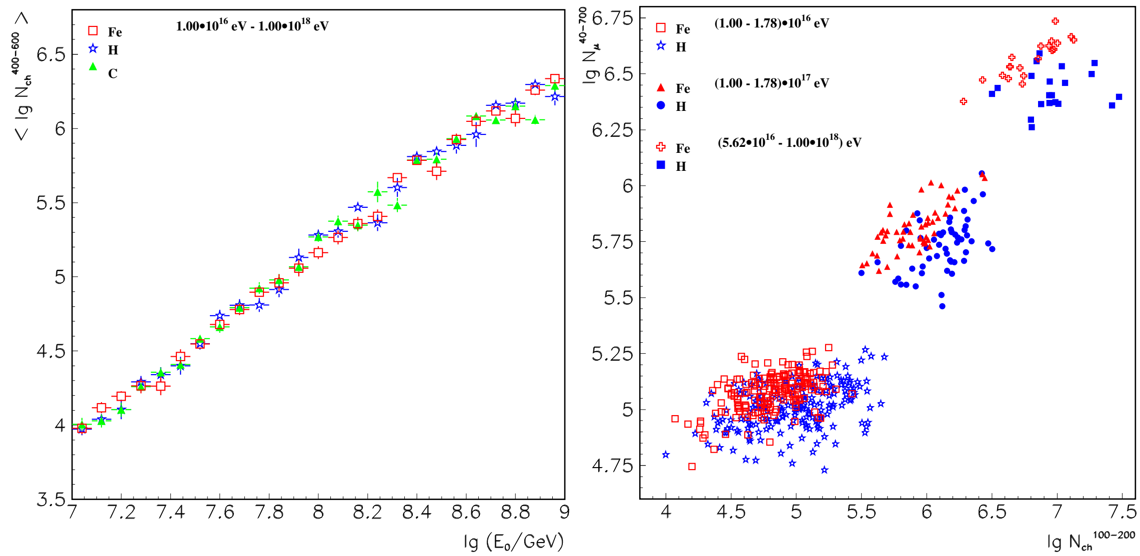

Figure 2. Left panel: The variation of average charged particle densities, $< lgN_{ch}^{400-600} >$ with lgE_0 for H, C and Fe primaries with energies ($1.00 \cdot 10^{16}$eV-$1.00 \cdot 10^{18}$ eV). Right panel: The mean values of the lgN_{μ}^{40-700} - $lgN_{ch}^{100-200}$ correlation for H, C and Fe primaries with energies ($1.00 \cdot 10^{16}$ eV-$1.00 \cdot 10^{18}$ eV) for different energy ranges.

ANI code [12] (using the one-leave-out test to characterise the quality of the classification [13]), the discrimination of 3 classes of EAS primaries, H, C and Fe is represented by the degree of separation of multidimensional distributions. The procedure takes into account the EAS fluctuations and specifies the uncertainties by estimating the true classification and misclassification probabilities, based on Bayesian decision rule. Using a set of observables based on the basic N_{μ}^{40-700}- $N_{ch}^{100-200}$ correlation, a good classification in 3 classes of primaries is obtained, being improved by adding the angle of incidence, Θ, to correct for the angular dependent attenuation of the N_{ch} parameters. Fig.3 presents the discriminative power by the classification probabilities of the N_{μ}^{40-700} - $N_{ch}^{100-200}$ - Θ correlation with higher incident energy.

4. Conclusions

The present studies are based on an event-by event analysis of EAS leading to the following concluding remarks:
i). The reconstructed charged particle density in a range of distances of 500 m and 600 m could be used as good energy identifier for EAS observed with KASCADE-Grande array, indicating that the $< lgN_{ch}^{400-600} >$ observable can be suitable for energy estimation.
ii). The reconstructed charged particle density at 100 m - 200 m exhibits features of mass discrimination in correlation with the number of muons, suggesting the N_{μ}^{40-700} - $N_{ch}^{100-200}$ correlation as the relevant correlation for mass discrimination in KASCADE-Grande observations, being analogue to N_{μ}^{tr} - N_e correlation for the KASCADE experiment.
iii). Using a non-parametric multidimensional statistical analysis with the ANI program, taking into consideration event-by-event showers, a set of three observables, N_{μ}^{40-700}- $N_{ch}^{100-200}$ - Θ, leads for both cases, Linsley

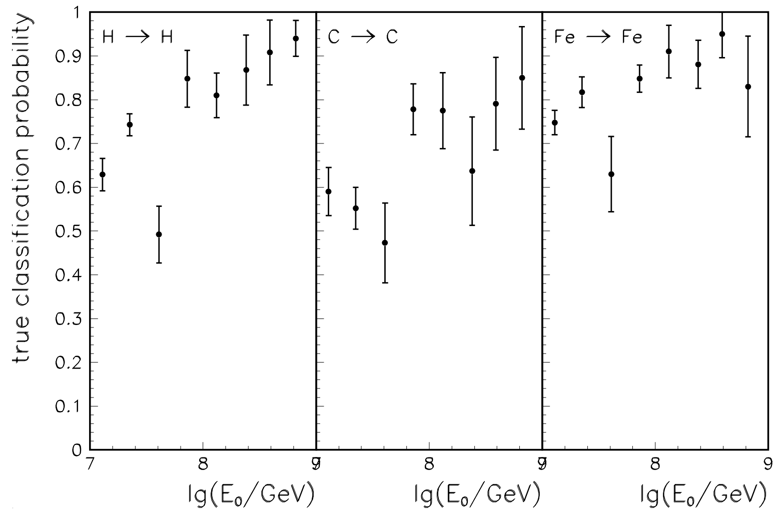

Figure 3. The energy variation of the true classification probabilities using the lgN_{μ}^{40-700}, $lgN_{ch}^{100-200}$, and Θ observables as input in the non-parametric statistical analysis. The observable $N_{ch}^{100-200}$ is obtained using fits with the Linsley lateral distribution function.

and Lagutin fit, to a good classification in three classes of primaries, H, C and Fe. The studies will be continued in the future by applying the procedures described to the experimental data of KASCADE-Grande.

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