HOW TO INFER THE MASS COMPOSITION FROM EAS OBSERVATIONS DEMONSTRATED WITH KASCADE DATA

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ABSTRACT

The KASCADE experiment detecting many observables of extensive air showers provides the possibility to handle data on event-by-event basis and to investigate details of the energy dependence of the primary cosmic ray flux in the energy range of 10^{14} - 10^{16} eV. We use Bayesian decision making and neural net approaches for data classification into multiple categories. A first attempt, approaching the spectra for the different elemental components of the primary flux is presented and discussed under methodical aspects.

INTRODUCTION

The ambiguities occurring in interpretations of cosmic ray experiments arise from insufficient knowledge about the characteristics of hadron-nuclear interactions above accelerator energies. Furthermore uncertainties in the primary cosmic ray composition, aggravated by strong fluctuations of all shower parameters observed in indirect experiments. In order to perform more detailed conclusions on the type of primary we develop a consistent theory of statistical inference, based on nonparametric models, in which various nonparametric procedures (density estimation, Bayesian decision making, error rate estimation, feature extraction, sample control during handling, neural net models, etc...) are implemented (Chilingarian et al.,1990; 1991).

All statistical decisions and procedures are correct within the prechosen model. Thus a realistic simulation is the key problem of any physical inference in indirect experiments. Extensive air shower (EAS) investigations are a classical example of such a situation. An adequate consideration of detector response and an identical reconstruction of experimental and simulated data are necessary.

The first simulation data base of the KASCADE experiment (Klages et al., 1997) fulfilling the above requirements is available since recently, and we use specific EAS parameters, like the truncated numbers of electrons/photons ($N_{e(truncated)}$) and muons ($N_{\mu(truncated)}$) and the age (Age_{30}) parameter (Weber et al.,1997) as input for our analysis. The physical meaning of these variables will not be discussed, we only mention that the procedures of their use are identical for experimental data and simulations. It is also very important to say that hypotheses about lateral distributions of muons and electrons at very small and large distances are not of influence.

SELECTION OF THE BEST VARIABLE SUBSET

To select signatures sensitive to the primary cosmic ray (PCR) composition, various characteristics of EAS initiated by different primaries (divided into five groups) were examined.

A comparison of selected features for Proton - Helium and Proton - Iron pairs are presented in Table 1 , where P-quantiles of Student, Kolmogorov-Smirnov and Mann-Whitney pairwise statistical tests are given. From the relative values of this quantiles one can estimate the possibility of primary discrimination by the chosen EAS parameters.

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Table 1: Student t, Kolmogorov-Smirnov D_n and Mann-Whitney MW Test for p, He and Fe Primaries

primaries		t	D_n	MW
$p\ Fe$	$N_{e_{(truncated)}}$	13.62	6.79	9.23
$p\ Fe$	$N_{\mu_{(truncated)}}$	3.28	1.67	5.76
$p\ Fe$	Age_{30}	21.13	8.71	16.54
$p\ Fe$	N_{μ}^{CD}	0.17	3.37	6.69
$p\ He$	$N_{e_{(truncated)}}$	3.33	4.13	7.84
$p\ He$	$N_{\mu_{(truncated)}}$	0.03	1.27	1.87
$p\ He$	Age_{30}	5.86	2.93	6.3
$p\ He$	N_{μ}^{CD}	1.95	1.46	2.64

The three variables used provide the opportunity to distinguish with rather high accuracy between iron and protons, but, as expected, the proton - helium discrimination is uncertain. In the present analysis we restrict ourselves to the three types of primaries: light, medium and heavy.

MASS DISCRIMINATION OF PRIMARIES

In this paper the information from the KASCADE array is used, though hadron and high energy muon N_{μ}^{CD} (Table 1) information from the central detector is also valuable for discrimination purposes (large values correspond to a good separation). At present the statistics of events hitting the central detector os still too low for use of the methods described in this paper. Our standard procedure uses alternatives of statistical decision on particle type. These techniques are multivariate and are based on a priori information from simulation trials with fixed primary mass and energy. CORSIKA (Capdevielle et al., 1992) simulation results were used like in a corresponding paper on energy estimation (Chilingarian et al., 1997). The Bayesian decision rules with nonparametric energy estimation, as well as neural classification (Chilingarian, 1994; 1995) and estimation modes prove to give very close results.This is shown in Figure 1, where true classification and misclassification rates are presented.

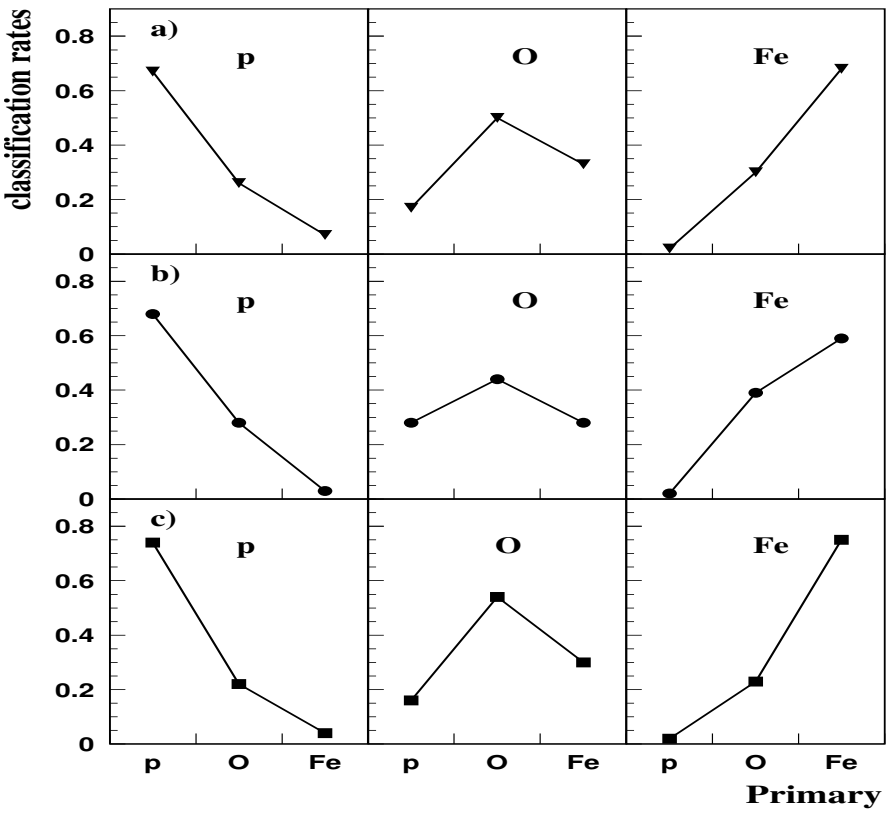

Fig. 1: The classification rates for three groups of primary nuclei using a) estimation by neural net b) classification by neural net c) Bayes classification .

After the training of neural networks with simulation data for three types of primaries, the

obtained relatively low misclassification rates allow to perform the neural classification of a part of KASCADE experimental data. 120,000 events have been used.

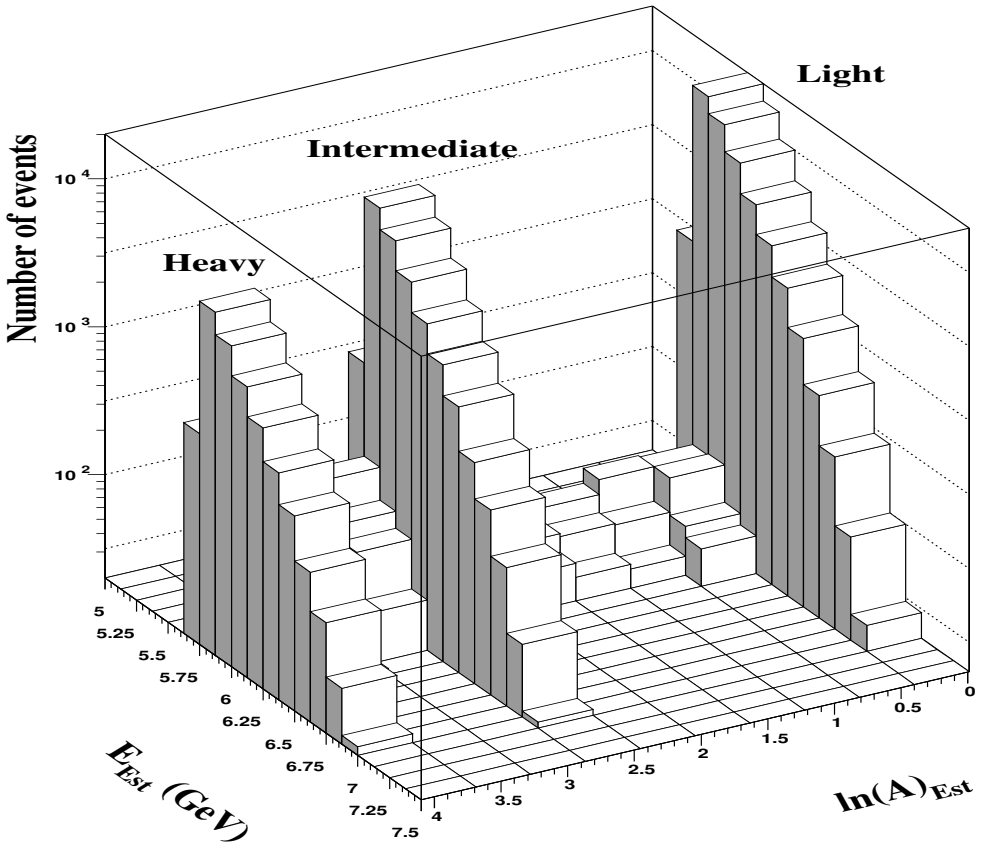

Fig. 2: The energy spectrum of light, medium and heavy CR flux components.

Details of the event selection are described in the corresponding paper (Chilingarian et al., 1997). Neural estimation and classification methods were used for determination of the type of primary. Results of both procedures are compatible with Bayesian classification. The details of statistical procedures will be presented elsewhere. We emphasize the advantage of neural algorithms due to their speed in application phase. For all 120,000 experimental events only several seconds CPU time of a workstation are required. Remembering the high trigger rate of KASCADE of $\approx 1/sec$, this advantage may be crucial in selecting between neural and a more time consuming Bayesian procedure. The presented

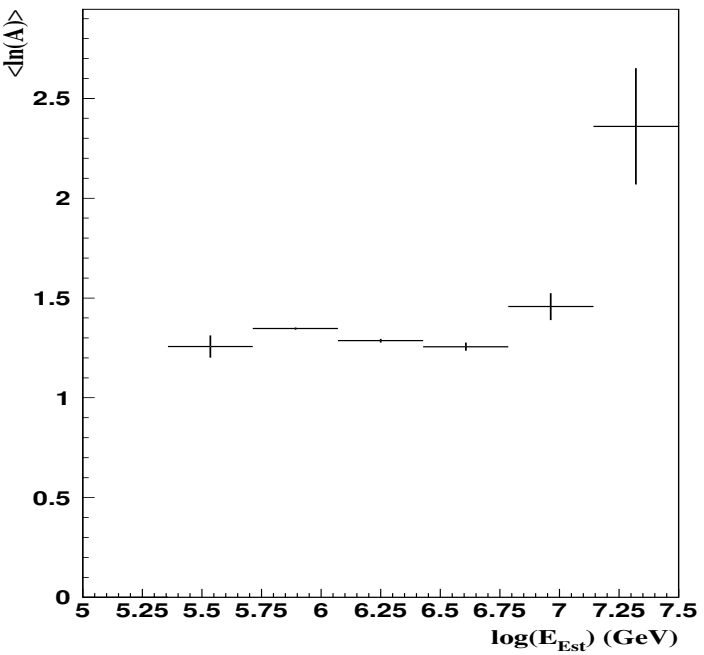

Fig. 3: The energy dependence of average primary mass.

data on the energy spectra of PCR flux, of course, are very preliminary and prove only the principal possibility of KASCADE to measure energy spectra of different species. Figure 2 shows the distribution of experimental data on three major components. The quality of primary mass estimation is practically energy independent. The dependence of average primary mass on energy is shown in Figure 3. A tendency towards heavier composition beyond the knee is indicated. This result has to be confirmed by further simulations, especially for high energies and by analysing a larger number of observables and a larger sample of experimental data in particular including measurements of the KASCADE central detector.

CONCLUSIONS

The presented results on the energy dependence of elemental composition are of preliminary character. The major feature of the observed energy region (the abrupt change of the spectral index and composition) seems to be reproduced by our analysis. Large samples of experimental data and cross checks of simulation models, for sea level and mountain altitudes (experiment ANI, 3200 m a.s.l.) are expected to provide a good opportunity for a reliable inference on elemental composition from the KASCADE data.

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