A Method to Reconstruct the Energy and Mass of Individual Primary Cosmic Ray Particles

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Abstract

A procedure to reconstruct the energy and the mass of primary cosmic ray particles with correlation analysis of size and age of individual extensive air shower, are proposed. Simulations have been performed with the corsika program.

1. Introduction

The sensitivity of majority of extensive air shower (EAS) methods to the mass of the primary cosmic ray particles is in general rather weak due primarily to large fluctuations of the showers' developments in the atmosphere which may be larger than mean differences between primary cosmic proton and iron nuclei [1]. Moreover, due these fluctuations, even a reconstruction of the energy of individual primary cosmic particles is difficult task. Of course, statistically the energy value is reconstructed enough correctly using, for example, a power dependence between primary particle energy, E_0 and shower size, N_e:

$$N_e = \alpha E_0^{\beta} \tag{1}$$

where constants α and β depend on the altitude of measurements and primary cosmic ray mass composition. But errors of the primary particle energy reconstruction for some individual EAS can reach tens and even hundreds of percents.

Here a method, which allows considerably to suppress the influence of fluctuations in EAS development on an estimation of the energy and mass of primary cosmic ray particles and therefore correctly to reconstruct the energy and the mass of individual primary cosmic particle, is presented.

EAS events for theoretical calculations were simulated by the CORSIKA program with the QGSJET/GHEISHA option [2].

2. Primary particle energy reconstruction

The energy reconstruction method is based on correlation dependence between shower age, B, and $Log(N_e)$ which corresponds for a fixed energy, E_0, and mass, A, to specific BL-curves.

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As it is seen from Figs. 1 a behaviour of BL-curves very slightly (as compared with cascade curves) depends on fluctuations in EAS development and the mass of primary cosmic particles.

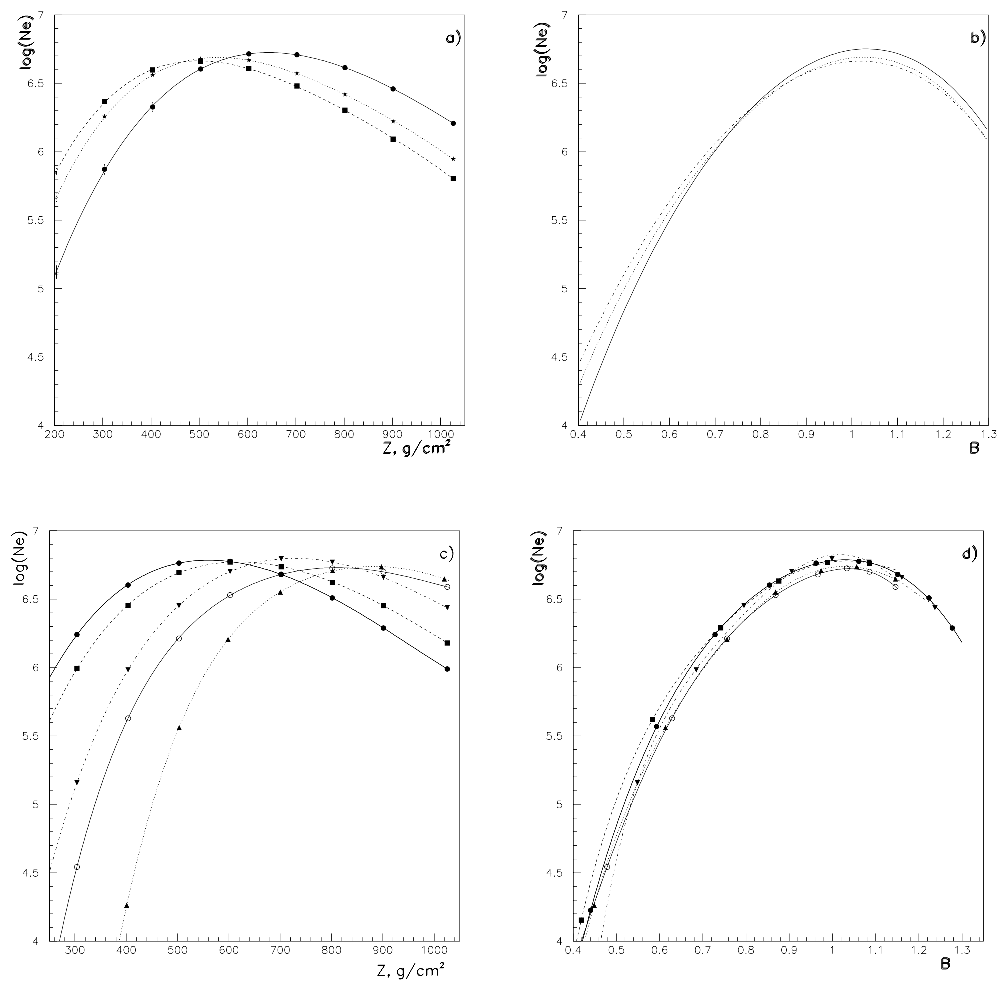

Fig. 1. a) mean cascade curves of EAS induced primary cosmic proton (solid), oxygen (dotted) and iron (broken) at primary energy of $10^{16}eV$; b) mean BL-curves for the same EAS; c) cascade curves of five individual showers induced $10^{16}eV$ primary cosmic proton; d) BL-curves for the same five showers.

Fig.2$left$ shows one of proton EAS generated at 10^{15}eV and one of iron EAS generated at 10^{16}eV. At observation level $Z = 1023g/cm^2$ the proton energy calculated with Eq.1 will be more than iron energy! With BL-curves the energy of these showers are reconstructed enough correctly (see Fig. 2$right$).

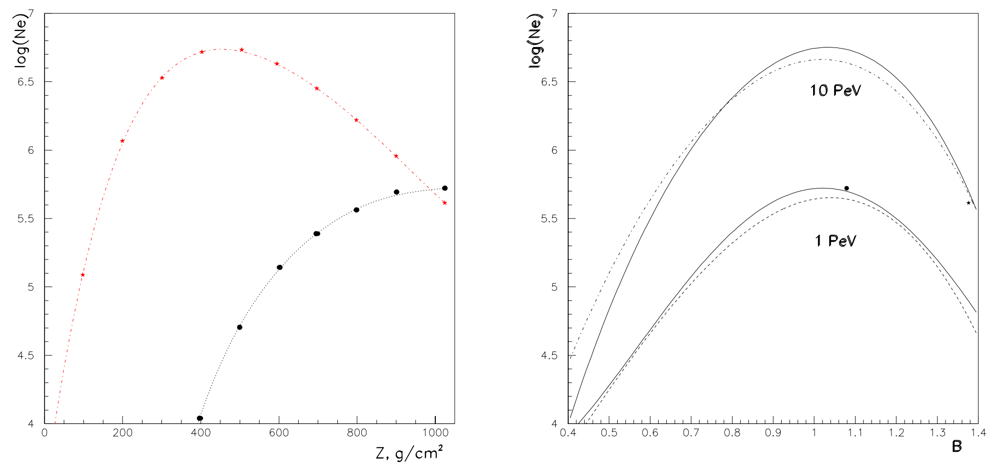

Fig. 2. Left: cascade curves for one of $10^{15}eV$ proton EAS (stars) and one of iron EAS (points) with energy of $10^{16}eV$. Right: the same iron (star) and proton (point) showers at $Z = 1023g/cm^2$. Lines are mean BL-curves for proton(solid) and iron(broken) EAS at 10^{15} and $10^{16}eV$.

2.1. Method

Since the mass is not known at this stage and the method very slightly depends on the mass, a primary mass has to be assumed. This will be iron in the following consideration. After the mass has been determined this step can be iterated.

Using Monte Carlo (MC) data at different energies the BL-curves are fitted with polynomial taking E_0 as parameter, i.e. this yields a function $LogN_e(B, E_0)$.

The energy E_0 is determined from this function by varying E_0 and minimizing the difference between the measured $Log(N_e)$ value and the function $LogN_e(B, E_0)$ at the measured B.

2.2. Results

For the Monte Carlo samples of 100 events for proton, oxygen and iron generated at 10^{16} eV and tested for the iron hypothesis at observation level of $700g/cm^2$ an energy resolution $\sigma \sim 7\%$ is achieved.

For protons (assuming the iron nuclei hypothesis) the energy shows a systematic shift of $\sim 10\%$ and for oxygen of $\sim 2\%$.

The shift will be removed after the mass determination.

3. Primary particle mass estimation

At the observation level N_e and B of proton showers differ from N_e and B of iron EAS of the same energy. And so, using BL-curves for energy reconstruction allows to estimation of primary particle mass by $Log(N_e)$. As it is seen from Fig. 3$left$ only 3 EAS out 200 (100 Fe + 100 p) is determined wrong, i.e. separation accuracy of proton and iron showers achieves 98.5%. The cross region of oxygen and proton EAS (see Fig.3$right$) achieves 21 events (out 200), i.e. 10.5%, of oxygen and iron showers - 32 (out 200), i.e. 16%. And so separation accuracy of oxygen and proton is 89.5%, of oxygen and iron is 84%.

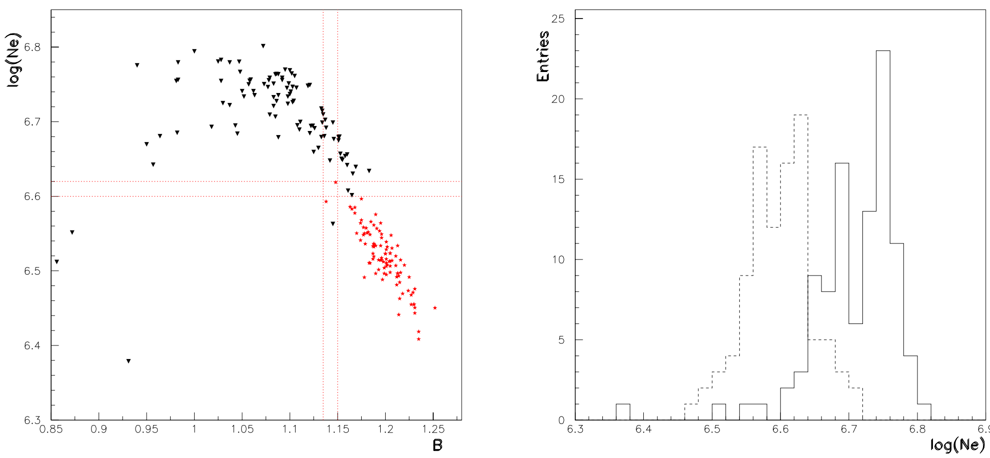

Fig. 3. Left: EAS size and age on the observation level of $700g/cm^2$ for primary cosmic protons (triangles) and iron (stars); Right: $Log(N_e)$-distribution at observation level of $700g/cm^2$ for EAS initiated $10^{16}eV$ primary cosmic proton (solid) and oxygen (dashed).

4. Conclusion

A procedure of reconstructing the energy and the mass of primary cosmic particle with BL-curves, are proposed.

Using the BL-curves allows non-statistically and rather precisly to reconstruct primary particle energy and, in consequence of that, to estimate primary particle mass. In spite of that primary particle mass is reconstructed with large errors, the method allows to separate (with enough good accuracy) light, middle and heavy primary cosmic nuclei.

1. Kampert K-H. et al. ICRC2001, 240
2. Heck D. et al. 1998, Report FSKA 6019