New possibilities for primary cosmic ray investigation at Chacaltaya(*)

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Summary. — The characteristics of EAS with energies of 10^4–10^6 GeV are calculated with help the of the CORSIKA 5.62 code for the observation level 536 g cm^{-2}. The new shower selection parameter $\alpha_e(r_0)$ was defined by taking into account the detector displacement described in the recent HECRE proposal for Chacaltaya. As proven before, the EAS selection with $\alpha_e(r_0) = \text{const}$ gives the possibility to select constant efficiency showers with given energies not dependent on the atomic number of the initiating primary particle. Similar results could be obtained by selecting showers with a constant value of the Čerenkov light flux at distances of ~ 200 m from the axis $\rho_Q(200 \text{ m}) = \text{const}$. This way it is possible to obtain unbiased information about the mass composition and energy spectrum of the primary cosmic radiation at energies of 10^4–10^6 GeV by selecting EAS with $\alpha_e(49 \text{ m}) = \text{const}$ and applying extended complex analysis of the electron and muon components and Čerenkov light flux at the Chacaltaya observation level. The experimental reception "noise" was taken into account in the performed analysis.

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1. – Introduction

The mass composition and energy spectrum of the primary cosmic flux at energies of 10^4–10^6 GeV are for more than 30 years now the main topic of the investigations carried out in the field of cosmic ray physics. Independent of the obtained experimental and modelling results many problems need careful study based on the new experimental and methodological level. The most direct and clear questions are connected with the calibration of the direct and indirect methods for primary cosmic flux studies, the constant

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efficiency selection of EAS at the given observation level and the influence of the development and registration noise to the searched physical information. In the present paper we studied all these problems on the basis of the HECRE proposal [1] for Chacaltaya using the CORSIKA 5.62 code [2] for the observation level 536 g cm^{-2}and energy interval 10^4–10^6 GeV in an attempt to check and propose some new possibilities for primary cosmic ray investigation.

2. – Method

The characteristics of the electron component and Čerenkov light flux in EAS with energies of 10^4–10^6 GeV were calculated with the help of the CORSIKA 5.62 code using VENUS [3] and GHEISHA [4]. Additionally, the characteristics of the muon flux with $E_\mu > 0.5$ GeV were obtained. According to the results of our previous works [5-7] we tried to develop methods for selection of EAS with energies of 10^4–10^6 GeV with a constant efficiency

$$\varepsilon_x(A) = \left(\frac{\langle E_{op} \rangle}{\langle E_{oA} \rangle} \right)^{-\gamma_E}_{x=\text{const}} ,$$

which allows the connection from the given size fluxes of EAS generated by cosmic primaries with different masses A to the fixed incoming energy fluxes

$$\left(\frac{f_P\,(E_o)\,\mathrm{d}E_0}{f_A\,(E_o)\,\mathrm{d}E_0} \right) = \varepsilon_x(A) \left[\frac{F_P\,(X)\,\mathrm{d}X}{F_A\,(X)\,\mathrm{d}X} \right] .$$

At the same time because of the quite different development of EAS initiated by the primaries with different masses A, the selection efficiencies of EAS $\varepsilon_x(A)$ for a given observation level with $X_i = \text{const}\,(X_i = N_e, N_\mu, Q_{cer}...)$ are quite different. As it was pointed out the optimal conditions for primary cosmic ray investigations will be realized when $\varepsilon_x(A) \approx 1$. In this case it was shown that these conditions could be achieved by selecting EAS according to a specially defined directly measured shower parameter $\alpha_e\,(r)$.

3. – Results

Taking into account the electron flux detector displacement described in the HECRE proposal [1] and constructed as a detector grid with spacing of 10×10 m and a covered area of 100 m $\times$ 100 m and the calculation results obtained with CORSIKA 5.62 code for the observation level 536 g cm^{-2}, we defined the selection parameter $\alpha_e\,(r)$ as

$$\alpha_e(r_0) = \frac{r_0^2 . \rho e(r_0)}{\sqrt{f_{\text{NKG}}(r_3, s(_{r_1, r2}))}} ,$$

where $r_0 = 49$ m, $r_1 = 37$ m, $r_2 = 66$ m, $r_3 = 3$ m. As shown in fig. 1 using the selection $\alpha_e(49 \text{ m}) = \text{const}$ we could satisfy the condition $\varepsilon_e(A) = 1$ for a whole interval $A = 1$–56.

However, the proposed electron flux detector displacement of the 1 m^2 scintillators with 10 m $\times$ 10 m spacing becomes not convenient for EAS with energies of 10^4 GeV (fig. 1B) because of the rapid increase of the relative error by parameter $\alpha_e\,(r_0)$ estimation in very small EAS. At the same time, parallel to the scintillator detector matrix is

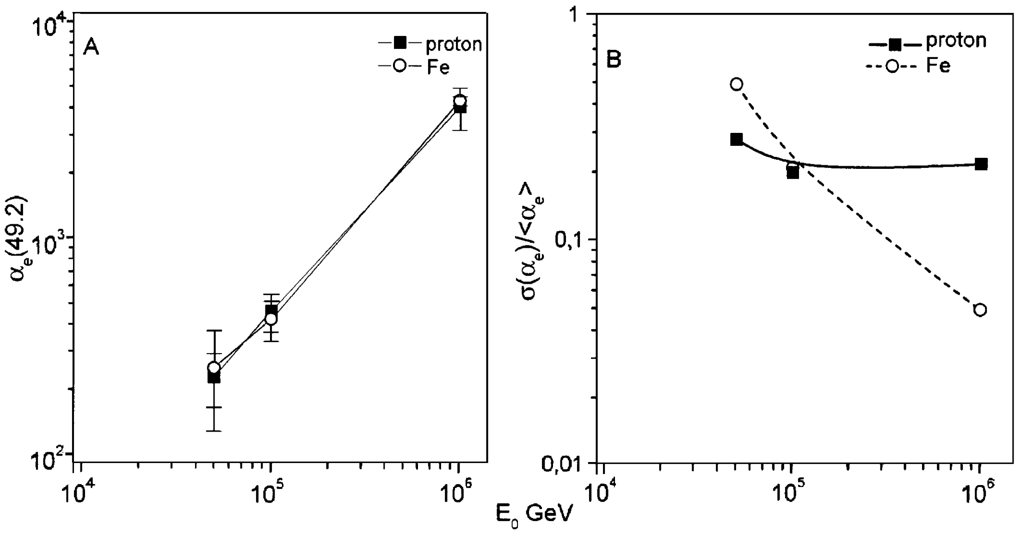

Fig. 1. – $\alpha_e(49.2\text{ m})$ for protons and Fe.

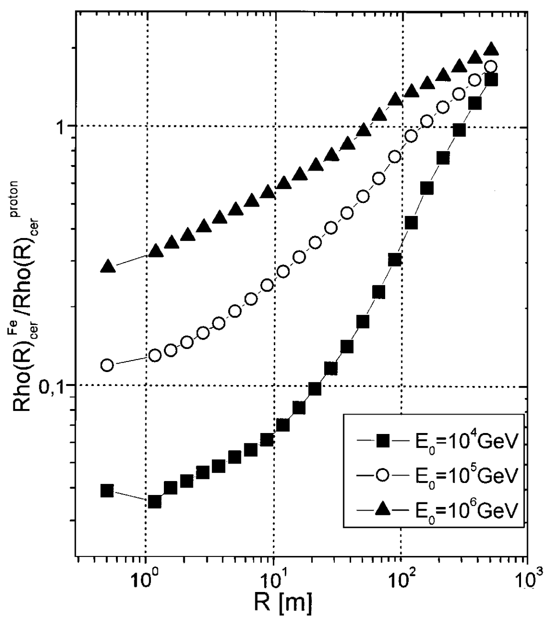

Fig. 2. – Ratio between lateral distribution function of Čerenkov light for Fe and protons.

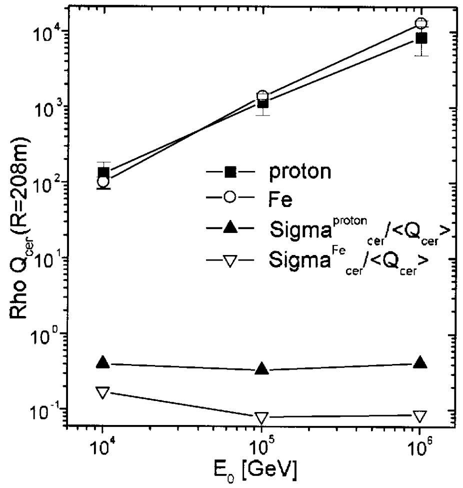

Fig. 3. – Čerenkov Rho parameter at $R = 208$ m for primary protons and Fe.

proposed similar displacement of the Čerenkov light detectors. Taking this into account we studied the possibility to realize $\varepsilon_Q(A) \approx 1$ by using the calculated characteristics of the Čerenkov light flux. Applying the CORSIKA 5.62 code we obtained the lateral distribution of Čerenkov light flux in EAS initiated by proton and iron primaries with energies of 10^4–10^6 GeV. In fig. 2 one can see the dependence of the ration $[\rho_{\rm p}(r)/\rho_{\rm Fe}(r)]_{r=\rm const}$ on the distance from the axis in EAS with energies of 10^4–10^6 GeV. This ration becomes quite constant at distances of $r \approx 200$ m from the shower axis. Figure 3 shows the primary energy dependence of the Čerenkov light flux density in EAS initiated by primary protons and iron nuclei. Because of the quite effective generation of Čerenkov light in the atmosphere in comparison with the corresponding electron flux, the fluctuations of the Čerenkov light densities remain relatively small until energies near 10^4 GeV. Taking this into account one could use the shower selection with the constant density of the Čerenkov light flux at distances of $r_0 = 200$ m for the EAS selection constant efficiency $\varepsilon_Q(A) = 1$ independent of the mass number on the initiating particle. This way measuring the EAS spectra for Čerenkov light density at distances of 200 m we could measure directly the primary energy spectrum without any suppositions about the primary mass composition. Moreover, by selecting EAS with $\rho_Q(200\ {\rm m}) = {\rm const}$ we select events with $E_0 = {\rm const}$ independent of the mass of the initiating primary particle. By comparing the behavior of the electron and muon ($E_\mu > 0.5$ GeV) flux depending on the energy of the iniating primary particle (fig. 4) mainly for the interval 10^4–$3 \cdot 10^5$ GeV one can analyze the fluctuation distributions $w\left(N_\mu/\overline{N}_\mu\right)$ and $w\left(N_e/\overline{N}_e\right)$ for $\rho_Q\,(200\ {\rm m}) = {\rm const}$, respectively; $E_0 = {\rm const}$ towards to obtain independent information about the mass composition of the primary cosmic radiation at a very interesting energy interval 10^4–10^6 GeV, where the calibration of direct and indirect methods for primary mass composition estimation is possible. As it was pointed out, the muon flux fluctuation analysis in very small EAS require extreme large muon detector areas ~ 1000 m^2 [8]. However, the present analysis shows that by using the experimental information from the Čerenkov light and electron flux detectors such an analysis on the electron flux fluctuations to obtain information about the mass composition of the primary cosmic radiation at energies 10^4–10^6 GeV is realistic.

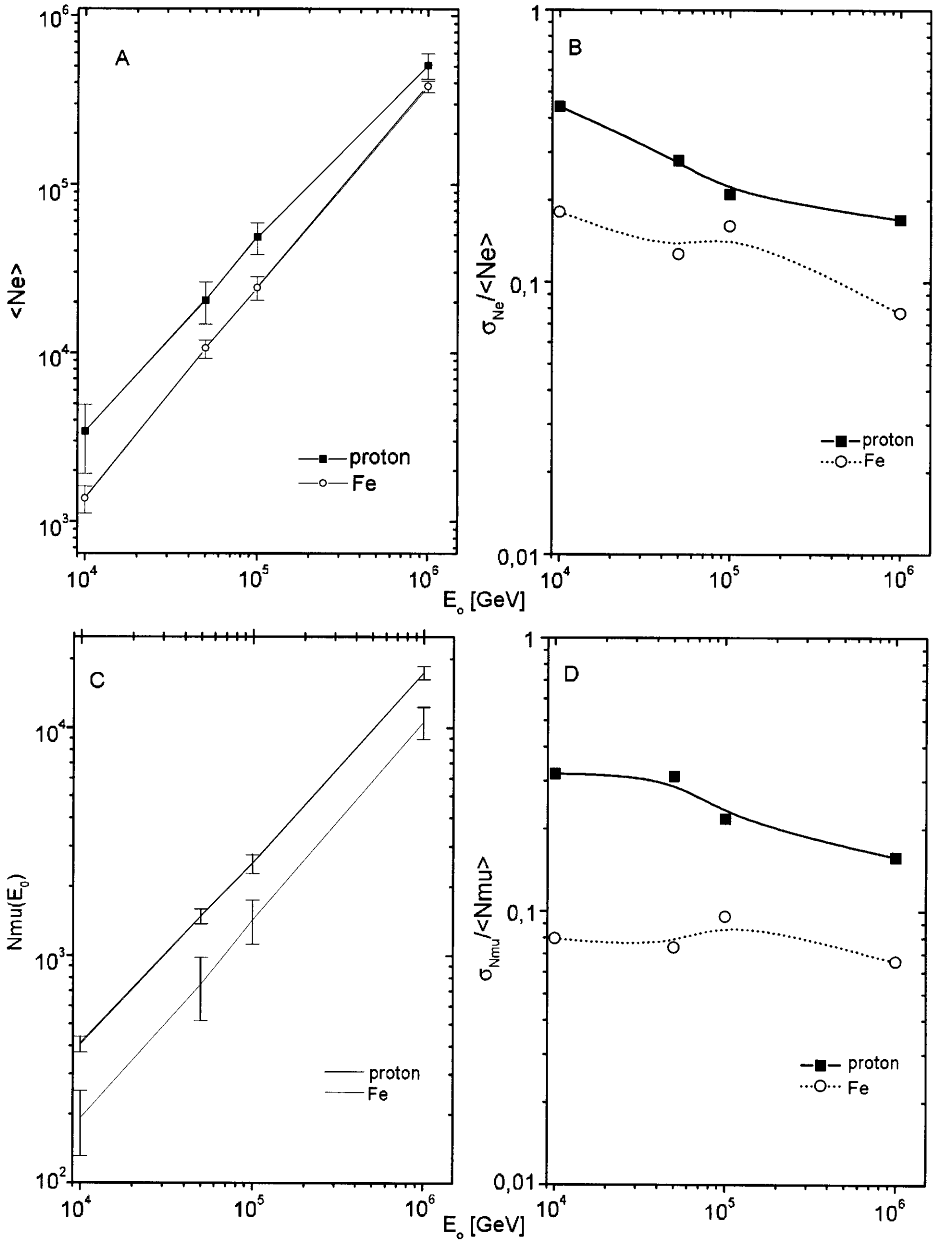

Fig. 4. – N_e and N_μ for primary protons and Fe.

4. – Conclusions

Analyzing the characteristics of the electron, muon and Čerenkov light components of EAS, calculated with the CORSIKA 5.62 code for the observation level of 536 g cm^{-2}and taking into account the detector displacement of the HECRE proposal for Chacaltaya it was shown that the EAS selection with $\alpha_e\,(49\ \mathrm{m}) = \mathrm{const}$ or $\rho_Q\,(200\ \mathrm{m}) = \mathrm{const}$ gives the real basis in an attempt to obtain exact information about the mass composition and energy spectrum of the primary cosmic ray radiation at indicated energies.

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