The INCA Project
III. New Method for Separation of Electromagnetic and Hadron Cascades in Detection of Primary Electrons and Gamma-Rays

The INCA Collaboration

Abstract

A new method for separation of primary electrons and protons is proposed on the basis of underground cosmic-ray experimental measurements and Monte Carlo simulation to investigate the primary electron spectrum at energies $E_e \gtrsim 1$ TeV. The method is based on the difference in evaporated-neutron yield in cascades initiated by electrons and protons. It provides a total rejection factor of $\sim 10^{-5} - 10^{-6}$ that is several orders of magnitude better as compared with other methods.

1 Introduction

One of the major goals of the INCA Project (INCA Collaboration I, 1999) is to study the spectrum of primary cosmic-ray (PCR) electrons at $E_e \gtrsim 1$ TeV. The available data are rather poor, mainly due to difficulties in separation of cascades initiated by electrons in chambers against the background produced by protons because the proton flux exceeds by a factor of about 1000 the electron flux. Until now, no adequate technique has been used to solve this problem. On the other hand, the further extension of the measurements beyond the few-TeV region could bring rather dramatic new conclusions on acceleration and propagation of primary electrons.

Another astrophysical goal is studying the cosmic γ-radiation in the energy interval $30 - 1000$ GeV, which is covered neither by balloon/satellite nor by EAS-array experiments.

We propose to solve both these problems, i.e., to measure the electron spectrum at $E_e \sim 1 - 10$ TeV and spectra of primary diffusion γ-radiation as well as that from known γ-ray sources.

The INCA's capability of separating electrons/γ-rays from protons in mixed particle beams results from the fact that the evaporated-neutron yield in electromagnetic cascades is only (5-10)% as large as that in hadron- induced cascades (Bezrukov et al. 1973). We consider results of Monte Carlo simulation carried out to estimate a possibility to reject electron-like proton-initiated cascades in the INCA and to separate electron-initiated cascades, which confirm this conclusion.

2 Simulation

We simulate processes in an INCA with a periodic structure, so that each layer contains lead and light substance (polyethylene) with a thickness of 10 and 20 g/cm^2, respectively. The lead provides the neutron generation and the light substance provides the necessary cascade development.

A modified version of the MC0 code by Fedorova and Mukhamedshin (1994) was used, which additionally accounts for (a) approximation B for electron- photon cascades; (b) neutron evaporation by nuclei due to inelastic interactions of hadrons and γ-rays, and giant resonance processes.

Only the neutron generation was considered but not the posterior neutron thermalization and diffusion, which will be analyzed with using the SHIELD code by Dement'ev and Sobolevskii (1993). We believe that the results given in this paper will not be subjected to a qualitative change.

The energy dependence of multiplicity of evaporated neutrons, $\langle n_{neut} \rangle$, per one simulated inelastic hadron/photon interaction with lead nucleus is very weak at $E \gtrsim 2$ GeV ($\langle n_{neut} \rangle \approx 26$). This permits to use the neutron signal for energy measurements of primary high-energy particles (INCA Collaboration IV, 1999). Hadron interactions give the predominant contribution into the neutron yield ($\gtrsim 60\%$) even at the initial stage ($\lesssim$ 100 g/cm^2) of proton-initiated cascades at energies under consideration, and this value arises with energy, while this fraction in electron-initiated cascades is only $\sim$ 5%.

3 Results

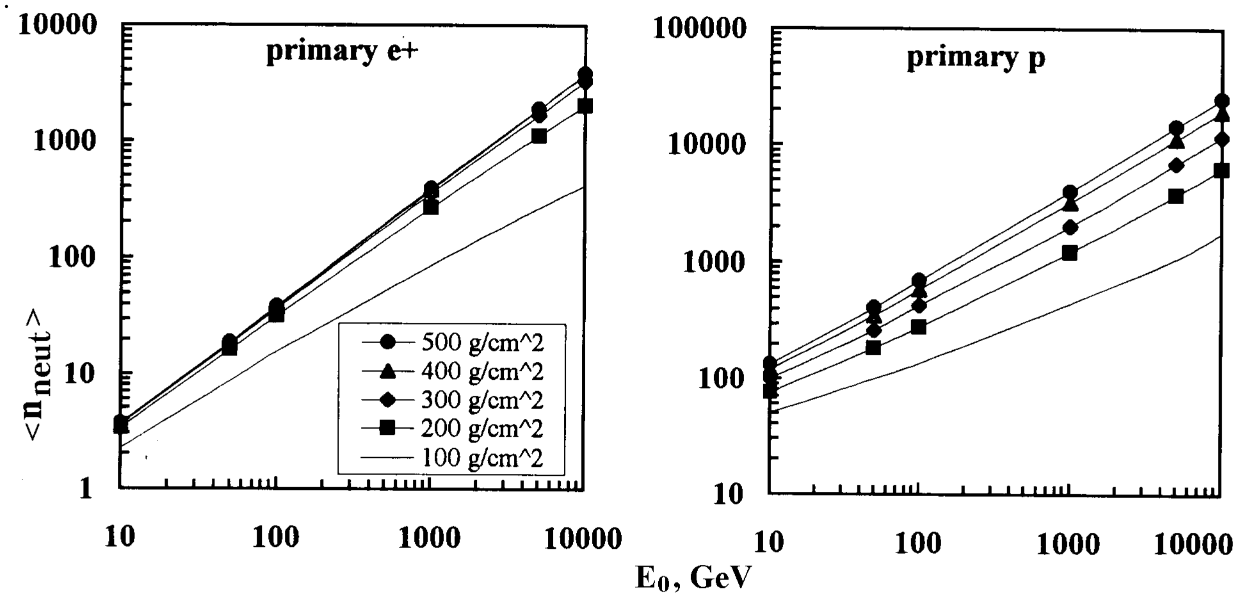

Figure 1: Energy dependence of the total evaporated-neutron number $\langle n_{neut} \rangle$ at various INCA's thickness in cascades initiated by primary electrons and protons.

Generally, procedures applied to separate electrons against the predominant proton background can be characterized by two rejection factors K_1 and K_2 as follows:

(i) When fixing the cascade starting point within the first lead layer with a thickness of $\Delta x \sim 1$ cm, protons can be discriminated with $K_1 = \Delta x / \lambda_{int}^{p-Pb} \simeq 1/20$.

(ii) If the energy released into the electromagnetic component is E_γ, the average proton energy is $\langle E_p \rangle \approx E_\gamma / K_\gamma \approx 5E_\gamma$. Since the integral proton spectrum decreases as $E_p^{-1.7}$, the effective flux of protons (releasing the same energy E_γ as electrons) must be decreased by $K_2 \simeq 0.2^{1.7} \simeq 1/15$.

The use of these factors permits to consider only proton-initiated cascades which start within the top 10-g/cm^2 lead layer and release the energy $E_\gamma \sim E_e$, namely, $E_\gamma = (0.8 - 1.2)E_e$.

We suggest a new powerful rejection factor associated with the neutron detection.

As is seen from Fig. 1, the energy dependence of the total cascade evaporated-neutron number $\langle n_{neut} \rangle$ integrated over various values of the INCA thickness initiated by electrons and protons is linear in the doubly logarithmic scale. The difference for cascades of different origin is significant. Obviously, the actual separation is possible only in the case of small corresponding dispersions.

Figure 2 demonstrates an example of the distribution of neutron total multiplicity in cascades generated by 1000-GeV electrons and in proton-initiated cascades with $E_\gamma = 800 - 1200$ GeV i.e., $E_\gamma \sim E_e$) within the top 10-g/cm^2 lead layer in an INCA with an effective thickness of 300 g/cm^2. The narrow distribution for electron- initiated cascades does not actually overlap the broad distribution for proton-initiated cascades. The INCA concept uses this feature of neutron signal to reject electron-like proton-initiated cascades, additionally to the criteria K_1 and K_2. Quantitatively, this idea can be described by the rejection factor K_3 which depends on both absorber thickness and the efficiency δ of primary-electron detection (Fig. 3). Here δ is the fraction of electron-initiated events considered after cutting off their distribution's right wing, which could overlap the distribution of proton-initiated

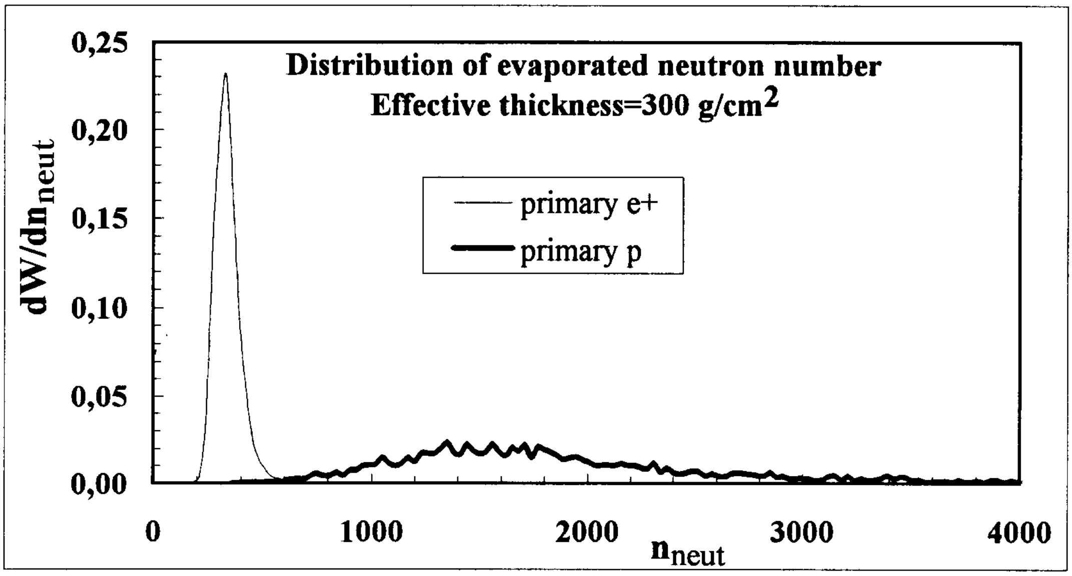

Figure 2: Distribution of the neutron total multiplicity $\langle n_{neut} \rangle$ in cascades generated by 1000-GeV electrons and in the case of $800 - 1200$-GeV energy release into the electromagnetic component in cascades initiated by primary cosmic-ray protons in the top 10-g/cm^2 lead layer in an INCA with an effective thickness of 300 g/cm^2.

events. Even for a thin (100 g/cm^2) setup, $K_3 \approx 10^{-2}$ at $\delta = 0.8$. For a thickness of 300 g/cm^2, $K_3 \approx 10^{-3} - 10^{-4}$ at $\delta = 0.9$. Calculations show that K_3 weakly depends on E_e up to 10 TeV. Figure 4 illustrates the energy dependence of the threshold neutron signal required to separate electron cascades at varying δ. As is seen, the neutron number corresponding to $E_e = 1$ TeV and $\delta = 0.9$ exceeds 10^2. Thus, we can realize this criterion even in the case of the neutron detection efficiency of about $10 - 20\%$. At the same time, a high level of the neutron threshold signal suppresses the influence of background PCR neutrons.

Let us note that corresponding selection criteria, proposed recently by various authors and based on cascade lateral and longitudinal characteristics provide an additional rejection factor only of about 0.1. Moreover, the efficiency of these criteria decreases with increasing energy.

The criterion based on the neutron signal is more efficient by two or three orders of magnitude as compared to other methods. It is simple in realization and keeps its high efficiency at all energies. **The total INCA's e/p rejection factor ($K = K_1 \cdot K_2 \cdot K_3$) can attain $10^{-6} - 10^{-7}$ at the electron detection efficiency $\delta = 0.8 - 0.9$ up to $E_e \gtrsim$ 10 TeV.**

We assume to provide the separation of electrons from γ-rays at a level of 10^{-3} by a particle charge detector.

References

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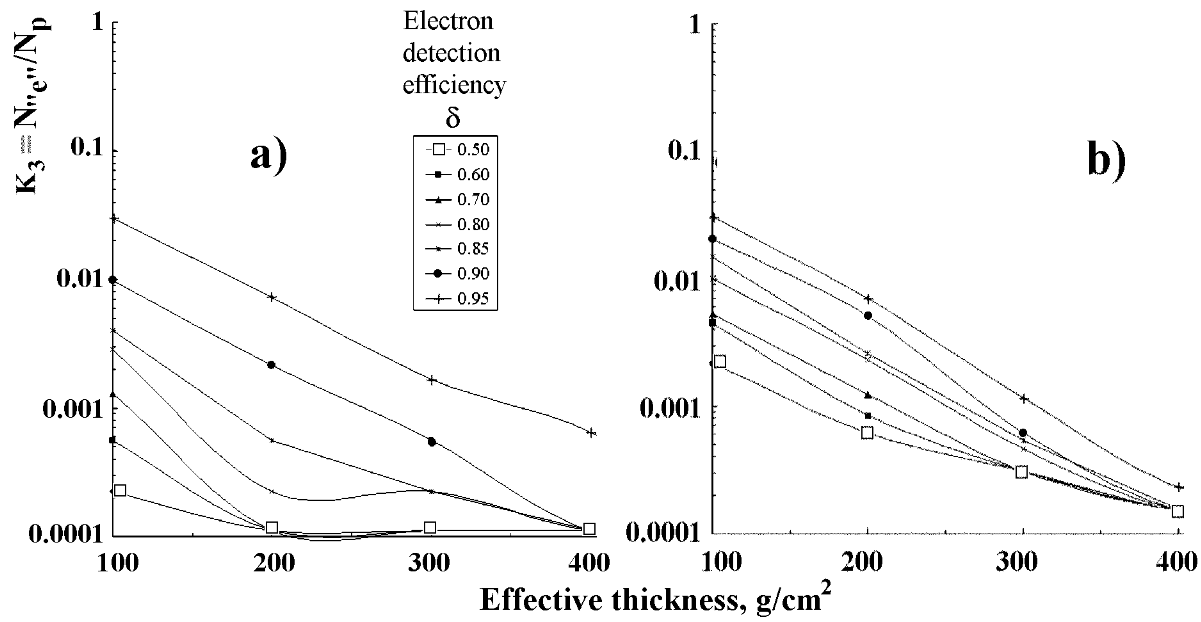

Figure 3: Rejection factor K_3 for electron-like proton-initiated cascades vs. INCA's thickness for various electron detection efficiency δ at (a) $E_e = 100$ and (b) $E_e = 1000$ GeV.

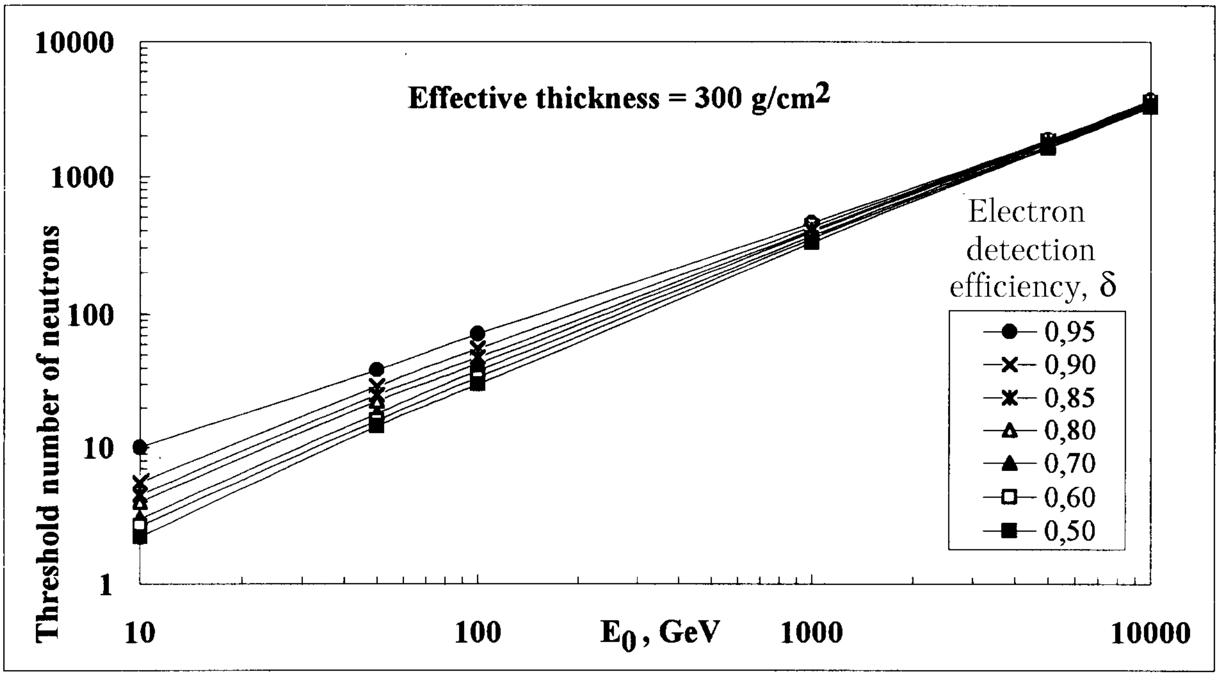

Figure 4: Threshold number of neutrons used to separate electron cascades from proton cascades at various electron detection efficiency δ.