THE ELECTROMAGNETIC COMPONENT OF ALBEDO FROM SUPERHIGH ENERGY CASCADES IN DENSE MEDIA

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Albedo from cascades induced in iron by high-energy gamma-quanta were Monte-Carlo simulated. Thereafter the albedo electromagnetic component from proton-induced cascades were calculated analytically. The calculations showed that the albedo electromagnetic component increases more rapidly than the nuclear-active component and will dominate at sufficiently high energies.

1. Introduction. When a calorimetric installation is used to detect high energy particles essential methodical difficulties are caused by albedo from absorber. Experiment shows that at energies of several TeV the nuclear-active component contributes the most into the albedo effect, and the dependence of albedo on primary energy is rather weak, i.e. logarithmic. Calculations of the albedo from electron-photon cascades so far performed to energies of 100 GeV show that the albedo electromagnetic component increases more rapidly, according to a power law. It indicates that further rapid increase being present, the electromagnetic component will dominate and provide a rapid increase with energy of the overall albedo flux.

A semi-analytical Monte-Carlo method described in /1/ allowed calculations of albedo from the electron-photon showers to highest energies of interest now. In /2/, the results for lead have been reported. We present here the results on the albedo from iron. The results obtained were used to calculate the electromagnetic component of albedo from a primary proton-induced cascade. Since, according to the calculations, the albedo electron flux is 2-3 orders less than the gamma-quantum flux, results on the gamma-quantum albedo only are presented.

2. Results for primary gamma-quantum. Fig.1 shows the energy dependence of the albedo gamma-quantum flux for three angles of incidence of a primary gamma-quantum. One can see that this dependence is, with a high accuracy, a pure power law $N_{\bar{\gamma}} \sim E^{\delta}$

Fig.2 presents the albedo gamma-quantum flux versus cascade production depth. The results are for two primary energies and two incidences(production depth is measured along the normal to the entrance plane). It can be noted that i) the exponent $N_{\bar{\gamma}}(t) \sim e^{-\mu t}$ provides a good description; ii) the rate of albedo attenuation somewhat increases with energy, e.g. μ (3 GeV)=.92, μ (10^3 GeV)=.71. iii) the results for various incidence angles demonstrate a very high similarity. In Fig.3 the dependence of the mean energy of albedo gamma-quanta on the primary gamma-quantum energy is shown for three incidence angles. The mean energy can be seen to somewhat increase with primary energy.

In Fig.4, the energy spectrum of albedo gamma-quanta is presented for a primary energy of 10^3 GeV and a normal incidence. It can be noted that about 90% of the photons are confined within the energy interval to 1 MeV.

Fig.5 shows the rms radius versus primary energy. We present the results for a normal incidence and two production depths t=0 and t=2. With an increase of primary energy the area of albedo emission first apparently broadens, but at higher energies one could suppose some narrowing. In Fig.6, the albedo gamma-quanta radial distribution is shown for energy 3 GeV and a normal incidence.

The angular distribution of albedo gamma-quanta is practically izotropic in the angular range from 30° to 70°, the mean cosine being equal to $\overline{\cos\theta}=.7$ and independent of both energy and shower incidence angle.

3. <u>Discussion of results for primary gamma-quantum</u>. We make here an attempt to obtain the general features of the albedo behaviour by constructing a rather simple model of its production and applying the results of cascade theory. It proved to be feasible to deduce a simple formula which represents a good reflection of the dependence of albedo on energy and incidence angle $N_\gamma(E,t,\cos\theta)\sim\left(\frac{E}{\beta}\right)^s e^{-\mu t}/-\lambda_1(s)$

where β is the critical energy, $\lambda_1(s)$ being the known cascade theory function, and s is found from the equation $\lambda_1(s)=\mu\cos\theta$.

This formula can be thought to be approximating over E, t, and $\cos\theta$, i.e. the values of N and μ being once taken from calculations for one energy, the albedo values can be found for all energies and incidences. The agreement with calculations is demonstrated by the following comparison: if the value of μ at E=3 GeV is taken, $N\sim E^{.47}$/calculations yield $E^{.48}$/ is obtained for a normal incidence and $N\sim E^{.62}$ /calculated value is $E^{.63}$/ for the incidence angle $\cos\theta=.6$.

4. <u>Primary proton</u>. The above discussed features of the behaviour of albedo from a primary gamma-quantum allowed analytical going over to the albedo from a primary proton. The expression for the mean albedo value reads

$$N_\gamma^p=\left\{\frac{2}{s+1}\,\frac{f_{N\pi}(s)}{\mu\lambda_N+1-f_{NN}(s)}\left[1+\frac{2f_{\pi\pi}(s)}{\mu\lambda_\pi+1-2f_{\pi\pi}(s)}\right]\right\}N_\gamma^\gamma(E_p)$$

Here $f_{ij}(s)=\int_0^1 dx\,\frac{x^s}{\sigma_{ij}}\,\frac{d\sigma_{ij}}{dx}$

in the $h_i+A=h_j+x$-reaction, where a h_{ij} hadron is either nucleon or pion, λ_i being the nucleon or pion interaction length. The above expression shows that the contribution of the secondary interactions is about 25%, i.e. the albedo is mainly determined by the first interaction characteristics and primary proton path. Only the variation of these characteristics and μ with energy provides a weak energy dependence of the expression in the figure brackets, i.e. the albedo energy dependence maintains to be a power law with about the same exponent S. For the inclusive distributions and interaction lengths corresponding to the modern accelerator data the calculated values for the coefficient of transition from a primary gamma-quantum to a proton/expression in the figure brackets/ are the following

$$\{\ldots\}_{\cos\theta=1} = 0.16 \;, \quad \{\ldots\}_{\cos\theta=0.6} = 0.022$$

5. Conclusion. The gamma-quantum albedo indicates a rapid power law increase of $N \sim E^s$, where $s \gtrsim 0.5$, to the highest energies for which the calculation was performed. The mean energy of albedo gamma-quanta slightly increases with primary energy, the lateral distribution becomes broader, and the angular distribution maintains its shape, being close to the izotropic one. We should notice finally, our simulations do not incorporate the Landau-Pomeranchuk effect. The effect should reveal itself in Fe at energies $>10^{14}$eV, i.e. providing far deeper cascade development the albedo should sharply decrease with energy (see /2/).

References

1. Plyasheshnikov A.V., Vorobyev K.V., 1981, Proc. 17th ICRC, 5, 206.
2. Plyasheshnikov A.V., Vorobyev K.V., 1983, Proc. 18th ICRC, 11, 73.

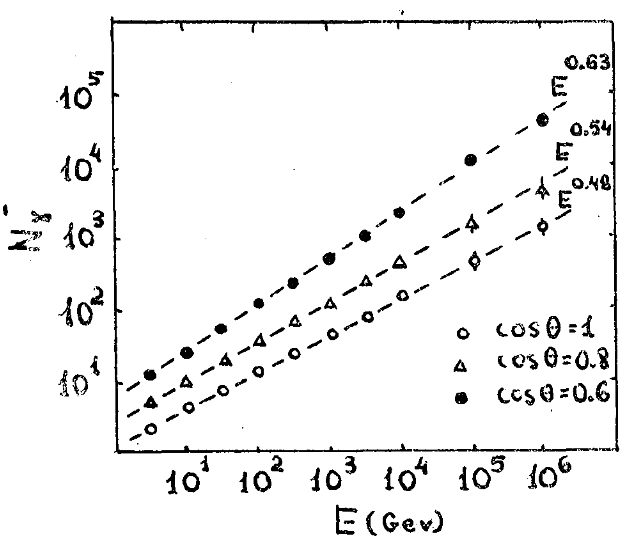

Fig.1. The dependence of the albedo flux on the energy of the primary gamma-quantum. Lines are for the power approximation.

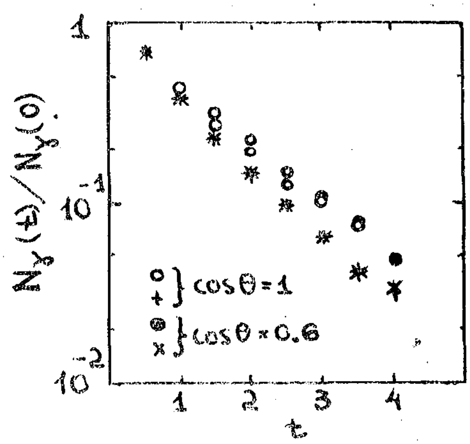

Fig.2. The albedo attenuation with the shift of the cascade generation point.

Crosses are for primary energy $E = 3$ GeV; circles – 10^3 GeV.

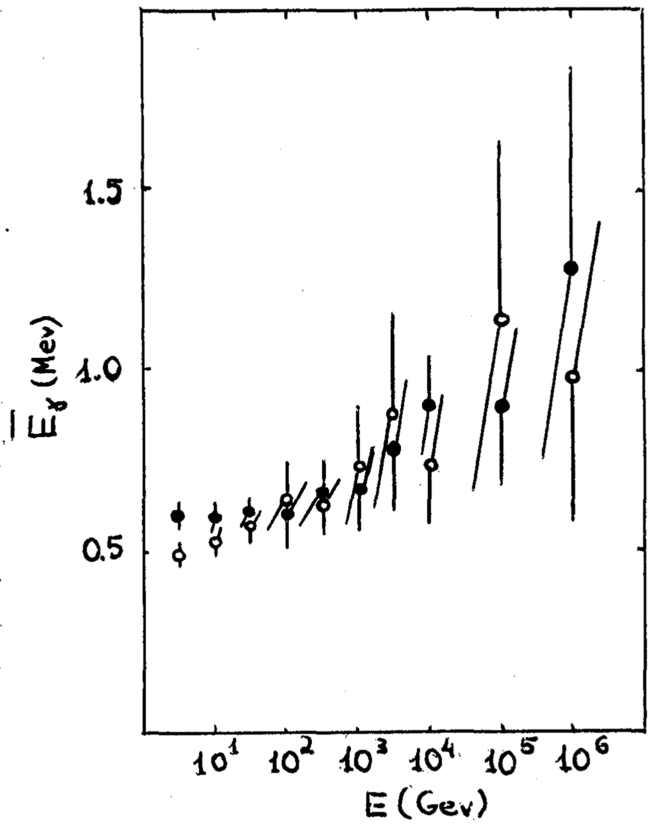

Fig.3.Mean energy of the albedo quanta versus the primaru quantum energy

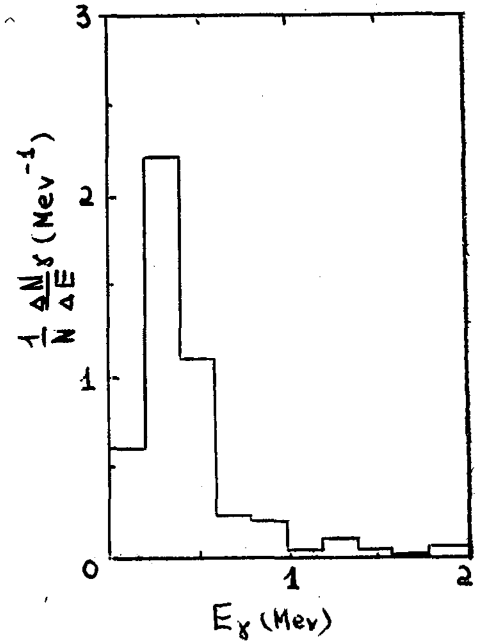

Fig.4.The energy spectra of the albedo quanta. The primary quantum energy is 10^3 GeV, normal incidence

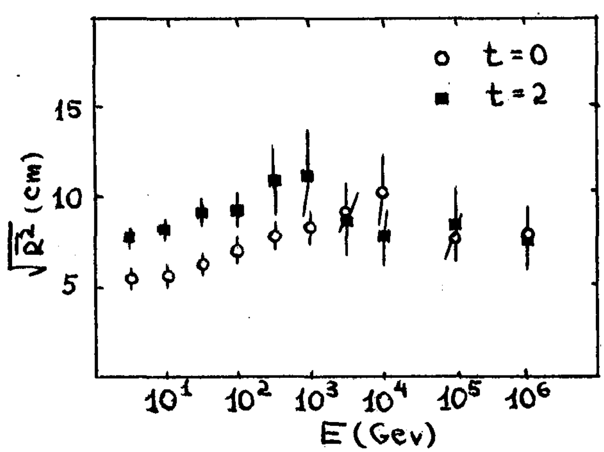

Fig.5.The albedo RMS radius vs primary energy, for two depths of the cascade generation, normal incidence

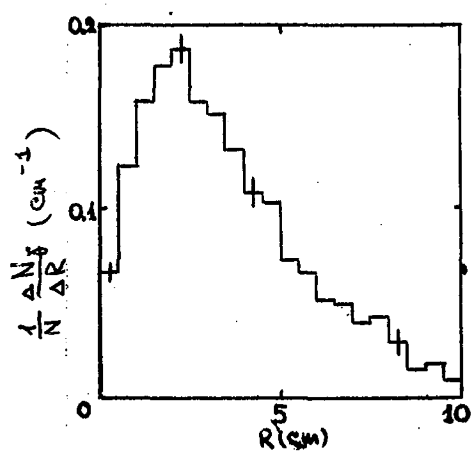

Fig.6.The albedo quanta radial distribution. Primary energy is 3 GeV, normal incidence