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NUCLEAR CASCADES IN ELECTROMAGNETIC SHOWERS PRODUCED BY PRIMARY GAMMA-QUANTA IN THE ATMOSPHERE.

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Distributions have been calculated for the number of electrons N_e, number of muons with the energy above 5 GeV N_μ and the energy of hadron component E_h in electromagnetic showers, produced by primary gamma-quanta with energies 10^{13} - 10^{16} eV, incident on the atmosphere at zenith angles $\theta \leq 30°$ and observed at the mountain level 700 g/cm^2. The mean number of nuclear interactions of photons with the energy above 5 GeV is about 0.3 per each TeV of the primary energy and nuclear cascades take out in average about 2% of the total shower energy. The mean number of 5 GeV muons for the electromagnetic shower is (2-5)% from the number of muons in EAS with the same number of electrons at the observation level. Similar value for the total energy of hadron component is also (2-5)%. N_μ and N_e values as well as E_h and N_e don't correlate at the fixed primary energy E_γ^o. Between N_μ and E_h there is a positive correlation at the given E_γ^o.

Simulation of nuclear cascades arising when the electromagnetic shower propagates through the atmosphere has been undertaken in connection with the works on high energy gamma-astronomy carried out at the Tien-Shan EAS array /1/. Similar study is planned at ANI array /2/. The difference between the present set of calculations and that carried out in pioneer works of Wdowczyk /3/ is in their orientation onto Tien-Shan and ANI arrays, i.e. the observation of showers at the mountain level 700 g/cm^2, higher muon threshold energy - 5 GeV and the usage of hadron component as an additional criterium for the selection of pure electromagnetic showers.

Electromagnetic showers were simulated for primary gamma-quanta with energies 10^{13}, 10^{14}, 10^{15} and 10^{16} eV, incident on the atmosphere isotropically in the zenith angle interval $\theta \leq 30°$. The total number of electrons at the level 700 g/cm^2 was determined after the sampling of the first interaction point and of the value $\cos\theta$ by means of approximation formulae of Greisen /4/ or Klimakov-Pavlov /5/. Then the development of the electromagnetic shower in the atmosphere was followed by steps $\Delta z=10$ g/cm^2. The probability for photons $\Gamma(E^o_\gamma, >5$ GeV, $z)$ to have photonuclear interaction in ide the step was estimated according to formulae of the Approximation A of the cascade theory: $W=1-\exp(-\Gamma(E^o_\gamma, >5\ \mathrm{GeV}, z/\cos\theta)\cdot \sigma_{\gamma A}\cdot \Delta z/\cos\theta)$. If this probability exceeded 0.1, then the step Δz was reduced by 2, and the procedure repeated. The cross-section of the photonuclear interaction with air atoms $\sigma_{\gamma A}$ was taken constant and equal to 2 mb. When such a photonuclear interaction occured, then the energy of the photon giving rise to the nuclear cascade was sampled within the photon spectrum at the depth z, calculated also by means of Approximation A formulae. The number of 5 GeV muons and the energy of the hadron component in that nuclear cascade, reaching the observation level 700 g/cm^2, were calculated on the base of simulation results, obtained for the "tails" of nuclear cascades with the help of the routine for small EAS simulation /5/. The result obtained for all partial nuclear subcascades in one and the same electromagnetic shower were summarized. For 10^{13}, 10^{14} and 10^{15} eV primary energy 1000 showers were simulated, for 10^{16}-100.

N_e-distributions for simulated showers are shown in the fig.1a. Arrows indicate mean values in these distributions. It is necessary to notice that approximation formulae /4/ give higher values of N_e compared with /5/, which differ by 1.35 at 10^{13} eV and by 1.07 at 10^{16} eV. In the fig.1a results are given, obtained by formulae /4/. It is interesting to note the change of the distribution shape, when E^o_γ increases. It is due to the shower maximum, approaching the observation level at $E^o_\gamma=10^{16}$eV and to the different impact of deep penetrations of primary gamma-quantum on N_e, when the shower in the mean is either after the maximum

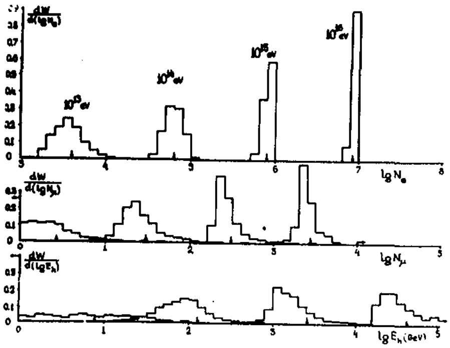

Fig.1.

or in the maximum of its development.

The simulation showed that the number of photonuclear interactions with energies above 5 GeV is proportional to the primary energy E^o_γ with a good accuracy. The proportionality coefficient is o.358 TeV^{-1} at 10^{13} eV and 0.247 TeV^{-1} at 10^{16} eV,i.e. it is equal to about 0.3 interactions per each TeV of the primary energy. The same concerns the fraction of the total energy, carried out by photons, initiating nuclear cascades in the shower. It is 0.015 at 10^{13}eV and 0.027 at 10^{16} eV,i.e. about 2% of the primary energy in the average.

In figures 1b and 1c distributions are shown for the number of 5 GeV muons and the energy of the hadron component reaching the observation level 700 g/cm^2. Arrows indicate again mean values of $\bar{N}_\mu$ and $\bar{E}_h$ in the distributions. It is seen that the muon number fluctuates less than the energy of the hadron component. In the figure 2 distributions of the muon number and of the hadron energy in the electromagnetic shower with $E^o_\gamma=10^{15}$ eV are shown in comparison with similar distributions for ordinary nuclear EAS with the same N_e. The latter distributions were obtained in the paper /6/. It is seen that N_μ and E_h distributions for electromagnetic and nuclear EAS are principally rather well separated from each other. Ratios of their mean values,shown in the fig.3, vary from 2.0% at 10^{13} eV up to 4.5% at 10^{16} eV for N_μ and from 1.4% at 10^{13} eV up to 5.0% at 10^{16} eV for E_h,i.e. are about (2-5)% for both values. However since

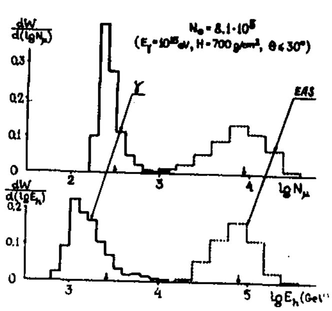

Fig.2.

the absolute number of muons with the energy above 5 GeV in electromagnetic showers is relatively small (~ 300) for $E_\gamma^o = 10^{15}$ eV and they are widely spread over the area, then it is usually difficult to identify electromagnetic showers by muons. It is possible to make this only at arrays with good resolution in the region of muon-poor showers, that is by means of large area of muon detectors about several hundreds of m^2. The identification of electromagnetic shower by the energy of the hadron component is more reliable, since this energy is considerably more concentrated around the shower core. The calorimeter area about several tens of m^2 is enough for such identification.

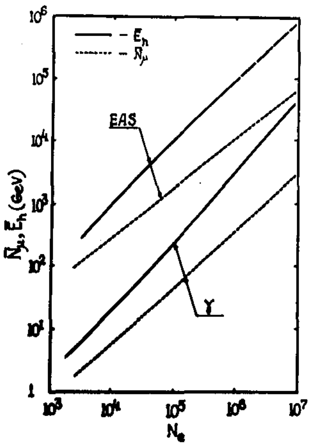

Fig.3

The simulation showed also that N_μ and N_e values, as well as E_h and N_e don't correlate with each other at the fixed value of E_γ^o. At the same time there is a strong positive correlation between N_μ and E_h at the fixed E_γ^o.

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