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The properties of electron-photon component of cosmic rays at 10 g/cm^2 atmosphere depth.

RUNJOB collaboration

Abstract

We report gamma-quanta spectrum obtained at 10 g/cm^2 atmosphere depth by the second RUNJOB-campaign performed in the summer of 1996. The energy region of the presented spectrum covers 1-20 TeV. The slope and the absolute intensity are not in contradiction with proton and helium spectra results obtained by RUNJOB and JACEE experiments. The complete simulation of real experimental procedure of gamma selection and measurement in emulsion chamber was carried out with GEANT program.

1 Introduction

The study of the energy spectrum and angular distribution of secondary photon flux at 10 g/cm^2 in the atmosphere is interesting by two reasons: 1. Practically we detect photons originated from the first primary protons and alpha particles interactions and only a little bit distorted by photons originated in nuclei interactions due to different energy per nucleons and besides electromagnetic cascading in atmosphere is negligible at this level. Slow increase of proton cross sections and possible increase of inelasticity do not result in changes of photon energy spectrum slope in comparison with primary proton spectrum (Beresovskaya V.A. *et al.*, 1997). So photon spectrum gives us additional and independent information taking into account also that the energy determination in this case is more established than in the case of protons. 2. From the observation of the differences between proton and photon spectra one can get the indication about possible sharp changes in the multiple production mechanism (Nikolsky S.I., 1995) or the serious problem of misidentification of cascades induced by protons and photons in our experiment. The last item is important from methodical point of view, due to large contribution of gamma initiated cascades (about 40%) among all cascades detected in chamber. When selecting experimental events by energy transferred into the electromagnetic component, $\sum E_\gamma$, the efficiency of $\gamma-$ray detection is many times larger than for protons, because protons transfer only a part of their energy, $\sum E_\gamma = k_\gamma E_p$, while $\gamma-$ray energy is measured completely.

2 Description of Monte-Carlo codes

In RUNJOB experiment for proton and nuclei energy determination we mainly use the methods based on secondaries emission angles measurements (Apanasenko A.V. *et al.*, 1997a). But for gamma-initiated cascades it is possible to apply only developed earlier (Okamoto M., Shibata T., 1987) and widely used photometric method (by fitting the D(t) in X-ray films of lower calorimeter layers). Because of thin calorimeter in RUNJOB 96 chamber it is impossible to catch a shower maximum for high energy events. So for the correct interpretation of γ-ray flux we carried out a detailed simulation of the process of passage of high energy photons through a chamber including the procedure of converting the local shower electron density in different calorimeter layers to the local darkness in X-ray films.

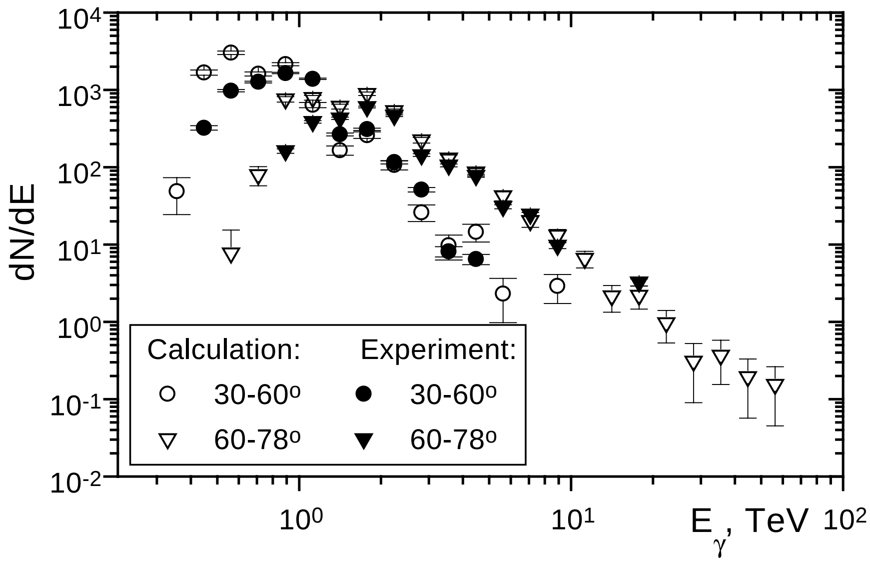

Fig. 1. Measured and calculated γ-spectra for main angle intervals.

A computer code was developed on the basis of a well known three dimensional Monte-Carlo simulation GEANT, widely used and tested with accelerator data. We modified a part of GEANT source code responsible for nucleus-nucleus interaction simulation — we included QGSJET generator (Kalmykov N.N., Ostapchenko S.S., 1993) for high energy ($>$ 80 GeV) interactions and used the standard GEISHA code for lower energies. QGSJET code was extracted from CORSIKA simulation package (Knapp J., Heck D., Schats G., 1996) developed for EAS experiments.

Simulation of passage of about 10000 photons with energy more than 300 GeV through the RUNJOB-96 chamber was made. The photons were sampled from power law energy spectrum with power index 2.8 and angular distribution $f_\gamma(\Omega)d\Omega \sim d\Omega$. Local darkness matrix in different calorimeter layers for every event was converted into integral darkness with imitation of experimental procedure of searching the maximum density by the square diaphragm 300×300 μm. $D_i(t_i)$ selection criterium used there simply follows the one used in real experiment: measured darkness should exceed $D_{\rm cut} = 0.1$ in any two of X-ray films in calorimeter. The measured energy $E_{\rm meas}$ was ascribed by fitting the $D_i(t_i)$ with theoretical curves from (Okamoto M., Shibata T., 1987). Further, all cascades were divided into different groups by angles θ_i and for every group the distortion function $G^\theta(E_{\rm meas} = E_{\rm real}) = dN(E_{\rm real})/dN(E_{\rm meas})$ was calculated. This function reflects the efficiency of gamma cascade detection and also the influence of fluctuations in energy determination. For the wide range of angles $(30 - 60^o)$ $G(E) \sim 1$ in our energy interval 1-20 Tev. The similar distortion function was calculated also for angular distribution.

3 Experimental results

The total number of cascades detected in RUNJOB 96 chamber and identified as gamma-initiated ones is about 500, that is approximately 40% of all selected cascades. In a few cases

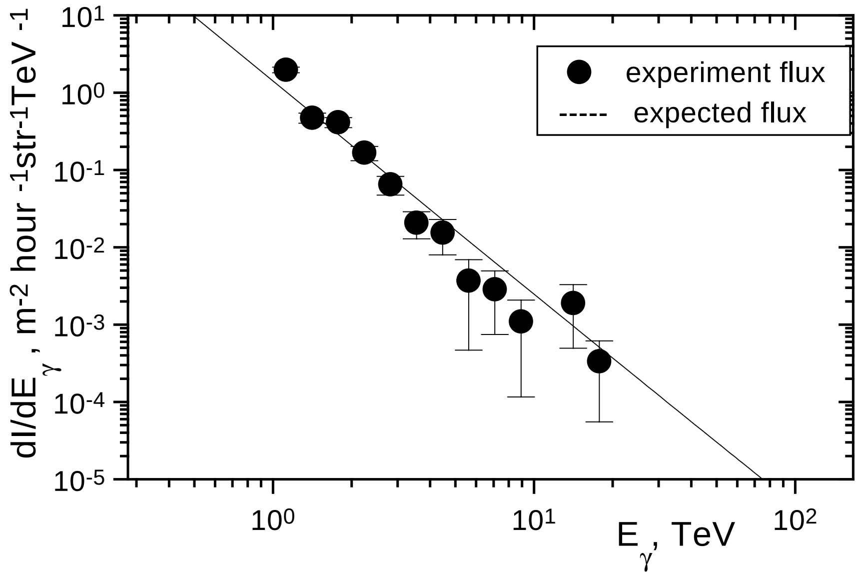

Fig. 2. Measured γ-spectrum and expected one taken from hadron spectrum.

the sure separation between proton and photon cascades leads to troubles, for example in the case of low multiplicity events. We estimated the ratio of doubtful identification not more than 7% among gamma and proton initiated cascades. At Fig.1 we present the measured spectra of photons for the main angle intervals $30^o - 60^o$ and $60^o - 78^o$ together with corresponding calculated spectra in terms of $E_{\rm meas}$. We see that calculation reproduces the threshold range and changing of the measured spectra with changing of angle intervals very well. It indicates the validity of calculation. To reconstruct the total gamma flux we used the distortion function described above $I(E_{\rm meas} = E_{\rm real}) = \sum\limits_{\theta}(dN^{\theta}/dE_{\rm meas})G^{\theta}(E_{\rm meas})$. The differential spectrum of gamma quanta with taking into account not only statistical errors but also the errors of G-function is presented at Fig.2. The angular distribution of photons with energy more than 1 TeV, corrected by the efficiency of registration, is presented at Fig.3.

The expected photons flux at the level 10 g/cm^2 can be simply estimated analytically if suggesting all gamma quanta are originated in one interaction and neglecting the cascade processes in a thin layer of the atmosphere above the chamber. Our previous Monte-Carlo calculation (Beresovskaya V.A. *et al.*, 1997) showed, that the contribution of electrons in photon-electron flux at 10 g/cm^2 is not larger than 10%. We chose parameters of multiple production: interaction cross sections, inclusive distribution of secondary photons, number of wounded nucleons and others in accordance with QGSJET (Kalmykov N.N., Ostapchenko S.S., 1993) model. The absolute fluxes and power indexes of different primary components were chosen as they were obtained in our experiment (Apanasenko A.V. *et al.*, 1997b; Apanasenko A.V. *et al.*, 1997c).

We present calculated by this way energy spectrum of photons at Fig.2 and angular distribution at Fig.3. No significant divergence between measured and expected photon fluxes can be seen. The form of experimental angular distribution demonstrates the lack of events with

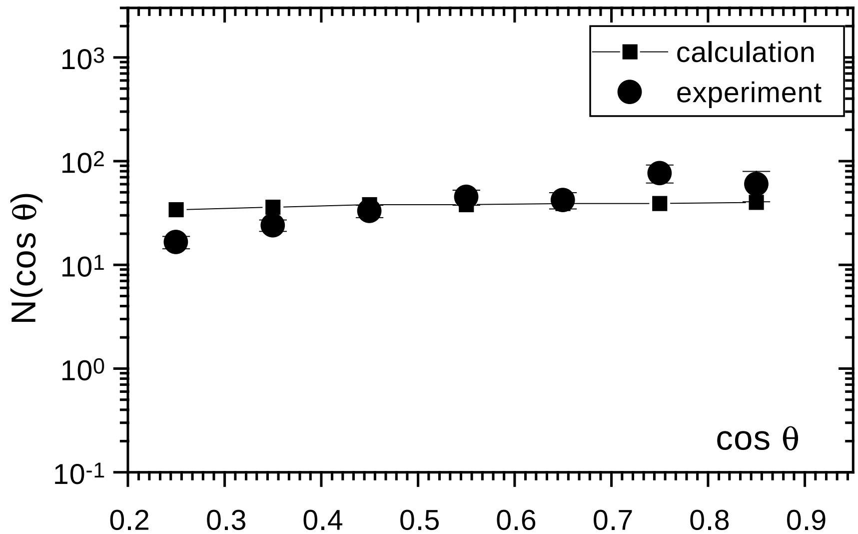

Fig. 3. Angular distribution of γ-quanta: experimental and expected one.

large angles in comparison with expected ones and possible reasons are now under study. (One should note that presented angular distribution includes the factor $\cos\theta$ caused by detector geometry.)

4 Conclusions

The photon flux measured in RUNJOB-96 campaign in energy interval 1-20 TeV confirms the proton spectrum measured directly in energy interval about an order higher. This fact proves the reliability of experimental prcocedure of gamma events separation.

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