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A Calibration of Energy Estimates of Giant Air Showers with Help of the Cherenkov Radiation

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The energy estimates for the vertical showers used at the Yakutsk array to interpret data exploits the calorimetric method to measure various kinds of energy losses. Simulations of the Cherenkov radiation which carries nearly 80% of the energy of the primary particle have been carried out in terms of the quark-gluon string model. The suggested 5-level schemes have been used to make simulations possible. The standard codes CORSIKA have been also used. Results of simulations are compared with the parameters of the basic formula used at the Yakutsk array. Besides calibration of energy estimates signals of Cherenkov detectors are also used for testing of some parameters of the quark-gluon string model.

1. Introduction.

It is known that simulations of giant air showers (GAS) with energies above 10^{19}eV requires extreme long times. The 5-level scheme [1, 2] has been suggested to overcome the problems. Using previously generated low-energy showers goal may be gained. If the distributions of particles in low-energy (E < 10 GeV) showers and source functions of such particles (as a solution of transport equations for hadrons, electrons and gammas of higher energies) in high-energy showers we are known we can calculate particle distributions for high-energy showers. So the main goal of this work was to create a data base for Cherenkov photon distributions for vertical low-energy showers.

2. Modification of CORSIKA output file

For simulations we have used code CORSIKA 6.201 [3], with some modifications in to fit our demands. Main changes were to CORSIKA in polar coordinates. Changing a coordinate system is quite a logical step – since particle distribution for vertical showers without magnetic field has axial symmetry. Also with a square detector very few particles or even none fall on cells located far from the shower axis, and for small numbers of particles we have relative high mistakes errors. In cylindrical coordinates in detector plane cell size grows with distance from the axis. So for far cells we will collect more particles in each cell lowering relative mistake.

Due to the structure of the code we decided to recalculate coordinates of each photon in some subroutine ("cerenk") just before parameters of photon are sent to subroutine "output2", then knowing parameters of the "round" detector (azimuth step, radial step and radius of the detector) loaded from an additional configuration file we determined the cell where the photon hit detector, and increased the number of particles in that cell. Then we calculated densities and exported them into a new file.

Since the goal was to achieve more accurate results in data base for particles with lowest energies bunch size 1 was set, e.g. program traced each photon as a single independent particle. Wavelengths of photons counted were changed 300 nm (this is less that can get through the atmosphere) up to 700 nm (maximum wavelength allowed by the program, according to CORSIKA manual). CORSIKA detector was set as a single square flat surface detector of 5x5 km (as it had to be larger than the desired round detector with 2 km radius with step 25 m, azimuth step 360 degrees with step of 10º (e.g. 25m width rings). We generated 10^5 showers at each energy and starting depth.

3. Results

Some examples of distributions are shown below. From figures 1, 2, 3 and 4 it is clear that photon density as a function of starting depth, energy of particle and the distance from the shower axis is smooth enough to be interpolated as it is required for numerical interpolation.

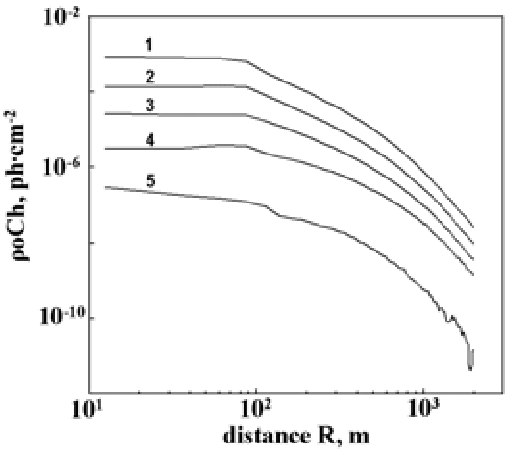

Figure1. Lateral distributions of the Cerenkov photons for the γ-induced showers from the depth of 500 g/cm^2: 1 – 10 GeV, 2 – 2.51 GeV, 3 – 0.63 GeV, 4 – 0.16 GeV, 5 – 0.04 GeV.

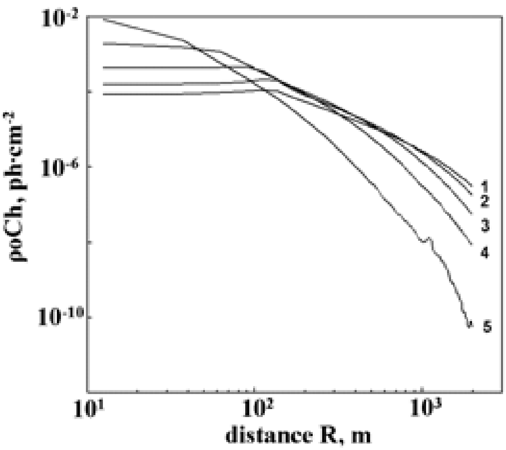

Figure 2. Lateral distributions of the Cerenkov photons for the γ-induced showers with energy of 10 GeV: 1 – 0 g/cm^2, 2 – 200 g/cm^2, 3 – 400 g/cm^2, 4 – 600 g/cm^2, 5 – 800 g/cm^2.

Figure1 shows the lateral distributions of the Cherenkov photons in gamma-induced showers generated at the starting point of 500 g·cm^{-2}. The energy of gammas changes from 0.04 GeV up to 10 GeV. It is clear that statistics is not enough for the low energy gammas. As for the lateral distribution up to nearly 100 m from the shower core there is a flat region followed by the rapid decreasing. Thus a standard picture of the lateral distribution of the Cherenkov photons is observed. Figure2 illustrated how this standard picture changes with the starting point of a cascade generated in the atmosphere by the 10 GeV photons. It is quite natural that at the starting point of 500 g·cm^{-2} (see curve 5) the lateral distribution is steep. For the rest of starting points distributions have the same character as in Figure 1.

Density of the Cherenkov photons at a distance of 400 m from the shower core is of interest ultra-high energy region. Figure 3 shows how this density depends on the depth of the starting point of a cascade in the atmosphere for the gamma induced showers with various energies. Again only at very low energies (see carves 8 and 9) some peculiarities are seen. For the most of cascade standard picture is observed. The dependence of this density at 400 m on the energy of the gamma quantum is shown in Figure 4. Again the standard picture is observed Figure 5 displays the lateral distribution of the Cherenkov photons in EAS with various energies as curves 1 – 4 (solid and dotted curves are estimated for γ =1 and γ =2 accordingly). Circles and crosses show data observed at the Yakutsk array at energies of 10^{18} eV and 10^{19} eV accordingly. It should be pointed out that simulations show more steep function than the experimental one's. This problem should be investigated. Then at higher energies simulations seems produce less the Cherenkov photons than data show. It is also should be checked.

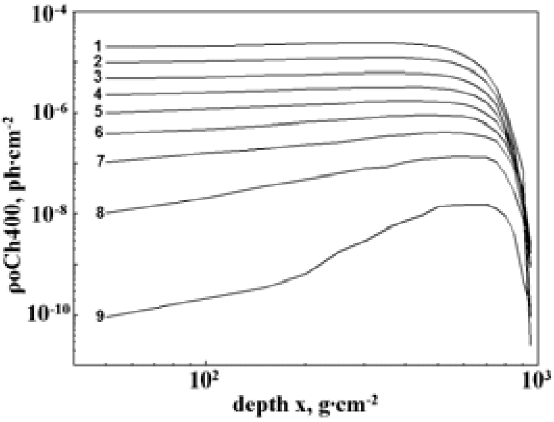

Figure 3. Dependence of the Cherenkov photon density at a distance of 400 m in the γ-induced showers from the shower core on depth x: 1 – 10 GeV, 2 – 5.01 GeV, 3 – 2.51 GeV, 4 – 1.26 GeV, 5 – 0.63 GeV, 6 – 0.32 GeV, 7 – 0.16 GeV, 8 – 0.08 GeV, 9 – 0.04 GeV.

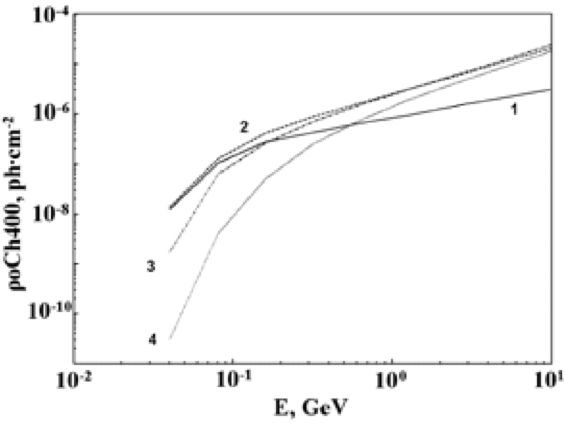

Figure 4. Dependence of the Cherenkov photon density at a distance of 400 m in the γ-induced showers from the shower core on energy E: 1 – 0 g/cm^2, 2 – 250 g/cm^2, 3 – 500 g/cm^2, 4 – 750 g/cm^2.

In term of 5-level scheme we could determine distributions of Cherenkov photons from ultrahigh energy showers

$$\rho(r) = \int_0^{1020} dx \int_{0.01}^{10} S_\gamma(E,x) ch_\gamma(E,x,r) dE + \int_0^{1020} dx \int_{0.01}^{10} S_e(E,x) ch_e(E,x,r) dE \qquad (1)$$

where $ch_{e,\gamma}(E,x,r)$ are the base, $S_{e,\gamma}(E,x)$ are source functions of gammas and electrons accordingly. For our calculations we used test source function [4]:

$$S(E,x) = K_0 e^{-\frac{(x-C)^2}{A(x-C)+2B^2}} \frac{f_0}{E^\gamma}, \qquad (2)$$

where K_0, A, B, C, f_0 are some constants, which depends on the primary energy, and a spectral factor γ ($\gamma = 1$ and γ=2 have been used). Following results were achieved.

But in common we have good correlation between theoretical expectations and experimental data of to take into account that experiment data have ~30% error.

4. Conclusion

The data base to estimate the Cherenkov radiations has been calculated. The preliminary results show reasonable argument with data observed at the Yakutsk array.

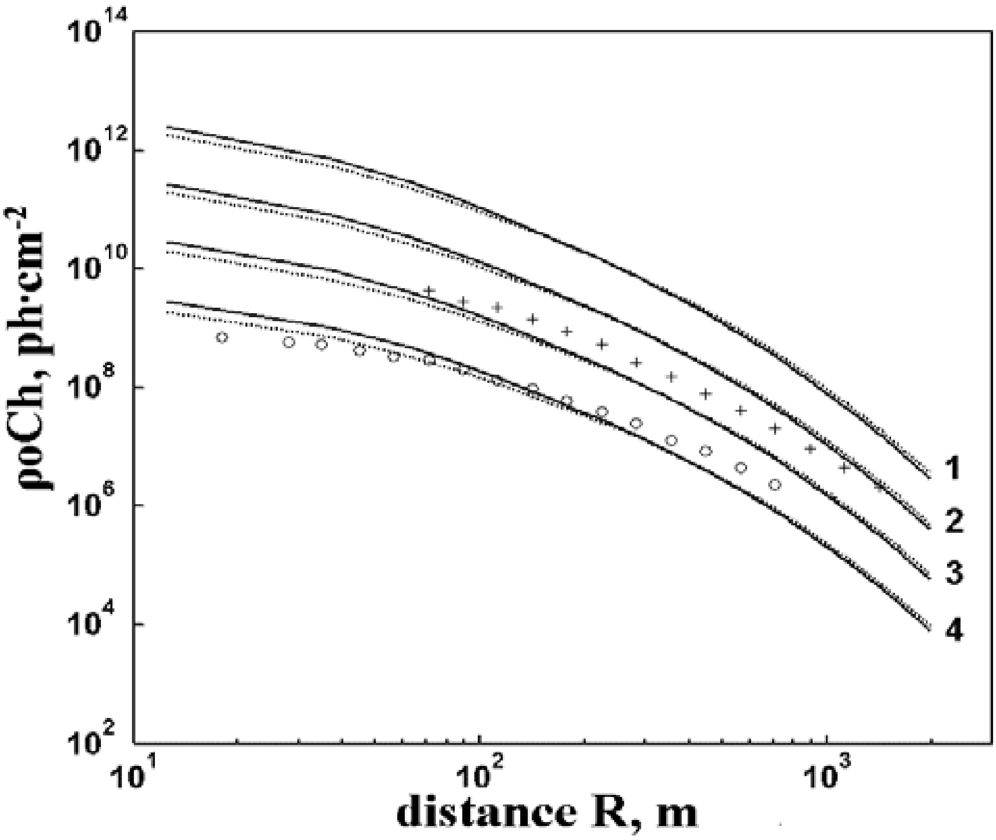

Figure 5. Lateral distribution of the Cherenkov photons in EAS. Solid and dotted curves – simulations for the test function 1 and 2 accordingly and crosses – the Yakutsk data: 1 – 10^{21} eV, 2 – 10^{20} eV, 3 – 10^{19} eV, 4 – 10^{18} eV

5. Acknowledgements

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