Distributions of the Zenith Angle of Hadrons Registered in the Pamir Experiment

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Abstract

We present differential zenith angle distributions of hadrons and of gamma quanta registered in the Pamir experiment. The data registered in two types of emulsion chambers, slightly different in construction, are presented and compared.

1 Introduction

The aims of this paper are the analysis and the presentation of zenith angle distributions of particles registered in carbon emulsion chambers of the Pamir experiment (4370 m a.s.l. - 600 g/cm^2). Special attention is paid to the comparison of the data of zenith angle distribution for different particle components (hadrons and gamma quanta) measured in slightly different chambers and to the comparison of the experimental results with the calculations.

The traces of the hadron initiated cascades (in H block) or gamma quanta and electrons (in Γ block), which (the cascades) were registered in X-ray films, have been measured with the use of a photometer with diaphragms of a constant radius r, where r = 48, 84 or 140 μm. Optical densities measured in the experiment have been standarized and corrected following the procedures described in (Pamir Collaboration 1984).

Apart from the optical densities, zenith and azimuth angles and the coordinates of the registered particles are measured.

2 Experimental data

The experimental data from chambers C141, C200 and C201, each of 24 m^2 area, have been measured totally or partly and used in the analysis.

The carbon emulsion chamber C141 has a typical construction, i.e. Γ block: 6 cm Pb, H block: 60 cm C (with density ρ=1.55 g/cm^3) and 5 cm of Pb below. The main registration layers are below 5 cm of Pb in Γ-block and below 4 cm of Pb in H block.

The chambers C200 and C201 have an additional layer of carbon (thickness 5 cm) above the Γ block. Table 1 presents information about the analysed chamber data.

Table 1
Basic information about the experimental data

Component	Chamber	S [m^2]	Year exp.	Time exp. [year]	N (for D>0.2)	N registered
hadrons	C141	24	85/86	0.978	1179	2858
γ quanta	C141	12	85/86	0.978	882	1447
hadrons	C200+C201	24+12	88/89	1.014/0.981	1196	4278
γ quanta	C200	8.5	88/89	1.014	1343	1758

The condition $D_{r=140} > 0.2$ corresponds to the energy of hadrons $E_h > 18.6$ TeV (i.e. $E_h^{(\gamma)} > 7.7$ TeV).

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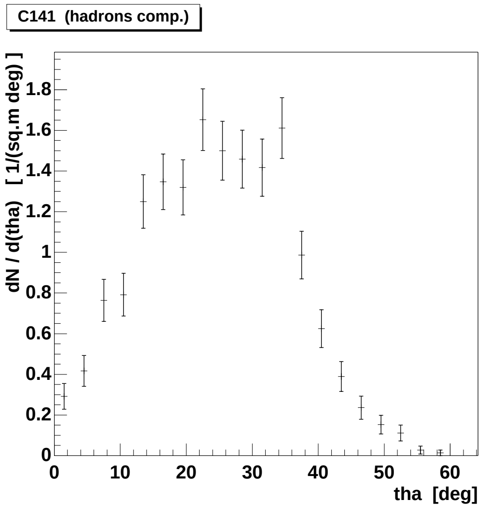

Figure 1a: Distributions of zenith angles of hadrons.

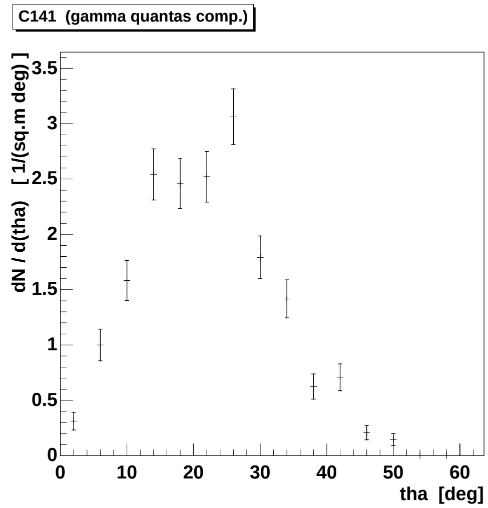

Figure 1b: Distributions of zenith angles of γ quanta.

In all presented distributions each bin of a histogram represents the multiplicity of a given component per area unit and per zenith angle unit measured in degrees. Differential zenith angle distributions of the hadrons and gamma quanta registered in the experiment have been depicted in Figures 1a and 1b respectively. These distributions agree with expectations within the statistical error limits. The comparison of the experimental with preliminary reconstructed data has been published in (Bialobrzeska et al. 1999). The simulation was made with the CORSIKA v.5.6 program (Heck et al. 1998) using Venus and QGSJET models. A similar form of the θ-distributions and a good agreement with experimental data has been noticed.

The differential zenith angle distributions of hadrons registered in C200 and C201 chambers have been shown in figure 2a. These chambers are different from the standard ones due to the presence of the additional layer of carbon above the Γ block.

An additional peak can be seen for $\theta \in$(5 - 15) deg in this distribution with maximum at about $\theta \approx 8^o$. The number of the hadrons which created the peak is about 15% of the whole number of hadrons in the distribution. This effect is not observed in C141 chamber (Figure 1a).

The experimental data from C200 chamber have been measured by two persons independently to eliminate mistakes while the measurements in C201 and C141 chambers have been made by a third person.
In our opinion, the observed effect cannot have been caused by zenith angle measurement errors. We estimate this error as $\Delta\theta \simeq 6^o$ for hadrons and $\Delta\theta \simeq 3^o$ for gamma quanta.
A different type of emulsion has been put in some of the standard construction chambers since 1989. The zenith angle distributions of gamma quanta for this type chambers (data from chamber C207 have been analysed) are similar in shape to those for C141 chamber (in Figure 1b). That is why we can say that this effect does not depend on the type of emulsion.

The presence of the effect in the angular distribution does not depend on the procedure of the analysis. An additional peak in the distribution can be always observed, no matter what part of the chamber the data was taken from. In the H block data the particles which entered the chamber from aside were omitted. The contribution of families is not important and omitting them does not change the distribution. The azimuth angle distributions of the analysed data do not show any anomalies.

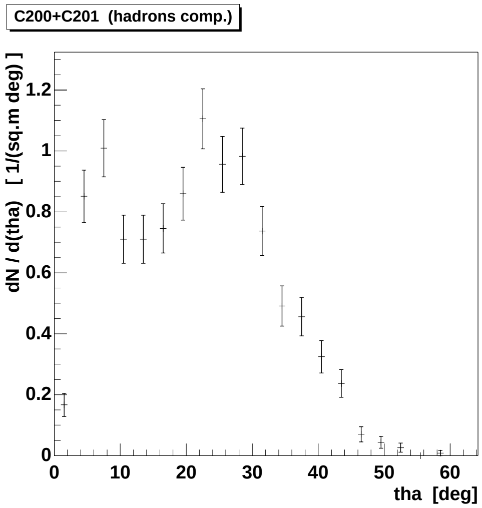

Figure 2a: Distributions of zenith angles of hadrons.

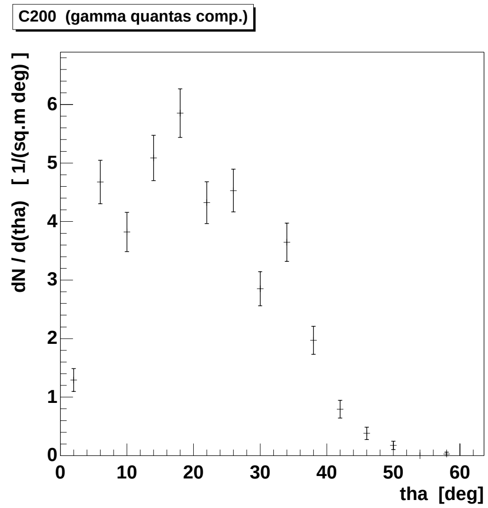

Figure 2b: Distributions of zenith angles of γ quanta.

3 Discussion of the results

No similar anomalies have been observed so far. It should be stressed that such a large statistics of hadrons have not been gathered by anyone before.

The question whether a similar shape in the θ distributions is also observed in a Γ block is very interesting. The zenith angle distributions of gamma quanta in the Γ block are presented in Figure 2b. Contrary to the θ distribution for γ quanta from C141 chamber, a similar peak as for hadrons can be observed for the γ quanta data from C200 chamber.

The number of hadrons which interacted in Γ block and left a visible track in the plate of a standard construction carbon chamber is estimated as smaller than 5% (Pamir Collaboration 1984). The observed peak in θ distribution of γ quanta can be a result of the increased interaction probability of hadrons in the additional layer above the Γ block.

It is not possible to distinguish the types of separate hadrons in the experiment. It can be concluded from the simulations that the shapes of zenith angle distributions are different for different hadrons.

In Table 2 the values of the exponents of distributions $f(\theta) = A\ \cos^m(\theta)$ for the particles of different types are presented at the 600 g/cm^2 level in the atmosphere. These data have been received from the Monte Carlo simulations by CORSIKA v.5.6 with the Venus model.

Table 2
The exponents of zenith angle distributions for particles at the 600 g/cm^2 level

type of particles	m
all hadrons	5.71 ± 0.06
n, p	6.23 ± 0.17
$\pi^\pm$	5.59 ± 0.10
$K^\pm$	5.47 ± 0.24
K_s^o, Λ	11.5 ± 1.9

Mesons $\pi^\pm$ and $K^\pm$ have similar angular distributions within error limits while those of n and p are a little steeper. However, K_s^o and Λ particles have the angular distributions of strongly different shape, with the maximum moved towards 0 with respect to the p and π distributions.

4 Conclusions

For the chambers with an additional 5 cm carbon layer above the Γ block the anomalies in zenith angle distributions of hadrons and gamma quanta have been observed. An additional local maximum exists for small angles (0^o - 15^o).
The number of hadrons which created the peak is about 15% of the whole number of the hadrons in the distribution.

Such a maximum is not observed in the standard carbon emulsion chambers.

It was checked that the effect does not depend on:

a) a person making the measurements;

b) the type of the microscope used for the measurements of θ and their accuracy;

c) the type of X-ray film;

d) the year in which the chambers were exposed.

As a similar, but not so clear, effect has been observed for these chambers in the Γ block, it is supposed that the local maximum for $\theta \approx 8^o$ is a result of interactions of hadrons in the additional layer of carbon.

The slopes of the angular distributions as shown in Table 2 suggest that hadrons whith a relatively short lifetime could be responsible for the observed effect. These hadrons could be K^o_s and Λ; however, the peak observed in the experiment is definitely larger than it would follow from the observed numbers of K^o_s and Λ particles above the observation level.

To give a clear explanation of the discussed problems additional calculations are required on the penetration of particles through the chambers and their registration.

References

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