Possible excess of hadron groups in the Cygnus X-3 direction observed at the PION installation

V. V. Avakyan, A. T. Avundzhyan, F. A. Agaronyan, G. V. Karagezyan, É. A. Mamidzhanyan, G. S. Martirosyan, G. G. Ovsepyan, G. Zh. Oganyan, and S. V. Ter-Antonyan
Erevan Physics Institute

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The results of a search for an excess of hadron groups in the Cygnus X-3 direction in the data from the PION installation collected between 1984 and 1985 are reported. The 1985 data indicate a statistically significant excess in a $30\times 30°$ cell around the coordinates of Cygnus X-3. The observed effect intensifies with increasing number of hadrons in the group.

Interest in the x-ray source Cygnus X-3 has increased particularly in recent years because of some insurmountable difficulties which have arisen in attempts to interpret the set of experimental data on extensive air showers and underground muons (Refs. 1, for example). There are contradictions among the data from different experiments, in particular, the data from underground muon detectors (Ref. 2, for example). Under these conditions, and in view of the foremost importance of the problem which has arisen, it seemed necessary to carry out some new studies to seek an anisotropy and a periodicity in the emission in the direction of this source.

In the present letter we report the results of a search for an excess of groups of high-energy hadrons in the direction of Cygnus X-3 in the data from the PION ionization calorimeter which has been in operation since 1978 at the Aragats high-altitude station (at a height of 3250 m). The effective area of the calorimeter is ~ 10 m^2; the error in the determination of the particle arrival direction is $\sim 2°$; and the energy resolution in the working energy range (~ 0.5–50 TeV) is about 15–20%. The PION installation is described in detail in Ref. 3. In 1984, the addition of a unit which detects the arrival time of each event made it possible to undertake a search for a directional anisotropy of the emission.

In the calorimeter, the hadron groups are identified by reconstructing the path traced out by each hadron in projections of the calorimeter on the basis of the set of energy releases.[4] We will use the phrase "hadron groups" to mean the simultaneous detection of several hadrons which have passed through at least four layers of the calorimeter and which were parallel, within the angular resolution of the apparatus (i.e., $\sim 2°$). For the present analysis we selected exclusively the groups which had $n\geqslant 4$ hadrons and a total energy release $\gtrsim$ 1 TeV in the calorimeter and which were detected in 1984–1985 (476 events over the "clean" operating time $\sim 10^7$ s of the installation in 1984 and 251 events over an operating time $\sim 6\times 10^6$ s in 1985).

Figure 1 shows the declination distribution of events (for arbitrary values of the right ascension α). The distribution is seen to have a maximum at $\delta\sim 40°$. This maxi-

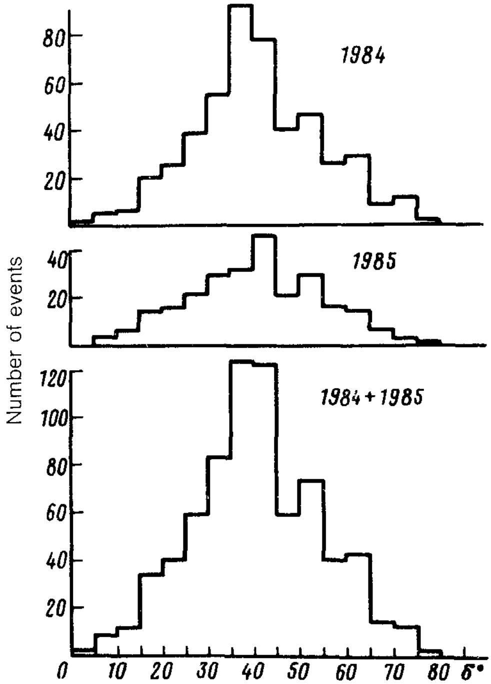

FIG. 1. Distribution of multihadron groups in the declination δ for arbitrary values of the right ascension α.

mum is a consequence of the geographical position of the PION apparatus ($\phi = 40.18°$, $\lambda = 44.5°E$), since the apparatus is most efficient at detecting hadrons incident vertically. In order to eliminate possible effects of a detection along some preferred α direction (because of, for example, interruptions in the operation of the installation), we analyzed the distribution of the operating time of the installation in the sidereal time. The results (Fig. 2) show that all the α directions were scanned uniformly in time by the installation.

Figure 3 shows the distributions of events in α in the declination interval

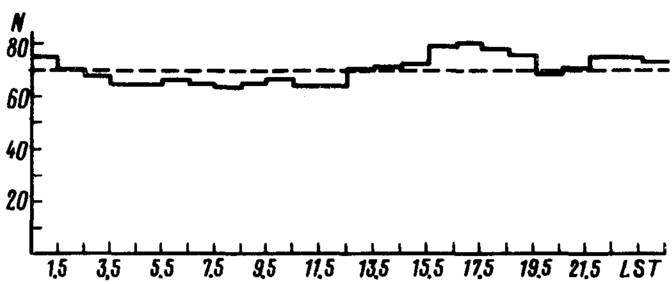

FIG. 2. Distribution of the operating time of the installation over 1985 in the sidereal time. Here N is the number of hours the installation operated in the given direction.

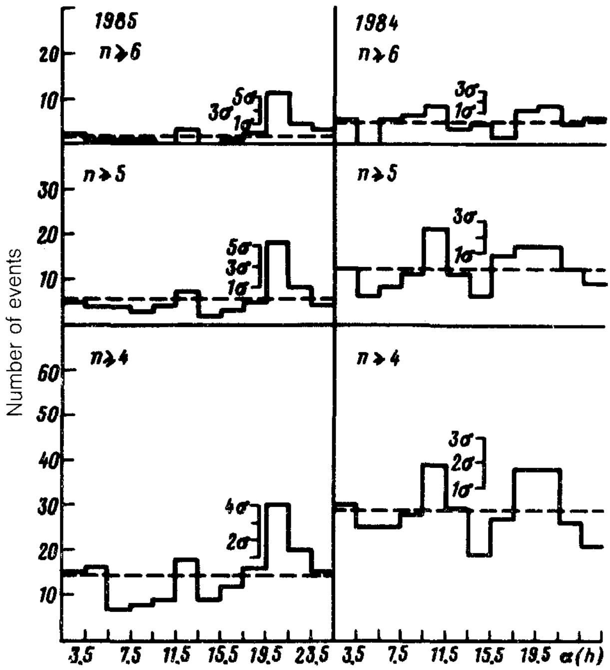

FIG. 3. Distribution of groups with $n \geqslant 4$, $n \geqslant 5$, and $n \geqslant 6$ hadrons in the right ascension α for the declination interval $25° \leqslant \delta \leqslant 55°$.

$25 \leqslant \delta \leqslant 55°$ for 1984 and 1985. It can be seen from this figure that the distribution based on the 1985 data exhibits a statistically significant excess in the interval 19.5 h$\leqslant \alpha \leqslant$21.5 h. The interval in α and δ in which the excess is observed includes the coordinates of Cygnus X-3 ($\delta = 40.8°$, $\alpha = 20.5$ h). For the 1984 data, on the other hand, no significant excess is observed in this direction.

A noteworthy feature of the distribution based on the 1985 data is an increase in the signal-to-noise ratio in the Cygnus X-3 direction with increasing hadron multiplicity in the group. The significance of the excess for $n \geqslant 4$ is about 4σ, and it increases to 5.5σ for $n \geqslant 6$, despite the fact that the statistical base falls off sharply. This result means that the particles which are responsible for the observed excess generate multihadron events more efficiently than do nuclear-active particles of the isotropic primary cosmic rays. Obviously, caution is called for in a discussion of hypothetical new particles. However, if the observed effect has a real physical basis (and we have, at any rate, found no methodological factors which would argue against this position), then there will be no way to escape a radical hypothesis regarding the nature of the primary particles which are causing the excess of hadron groups in this direction. In terms of the complexity of interpreting the data, the situation here is reminiscent of the familiar situation regarding underground muon data. Furthermore, the situation in this case is aggravated by the circumstance that the particles initiate multihadron groups which interact effectively with the atmosphere and thus have a large interaction cross section ($\gtrsim 30$ mb).

Analyzing the angular distribution of the excess emission, we arrive at some extremely strange conclusions. Our analysis shows that as the dimensions of the angular cell are reduced, the signal-to-noise ratio decreases, vanishing completely at cell dimensions less than $10\times10°$. This result could not be an instrumental effect, since the angular resolution of the apparatus is significantly better ($\sim2°$). Interestingly, a qualitatively similar picture is drawn by data from the NUSEX experiment on high-energy muons in the Cygnus X-3 direction,[5] but in that case the maximum signal-to-noise ratio is observed at cell dimensions $\sim10\times10°$. That result means that either the source of the primary particles is extended or the effect is caused by the emission of secondary products at large angles. In particular, Ruddick[6] has discussed a model in which secondary particles are produced with large transverse momenta as a result of the decay of intermediate particles with a large mass, in an effort to explain the NUSEX data. With regard to the first suggestion, we note that evidence against it comes from the results of a phase analysis of the data with the known period $P_0 = 4.8$ h of the x-ray source Cygnus X-3. Our analysis reveals a maximum at a phase of 0.20–0.25 and possibly another at 0.70–0.75. The results of this analysis will be published later.

We conclude with some estimates of the fluxes of multihadron groups in the Cygnus X-3 direction according to the 1985 data: $\sim2.6\times10^{-11}$ $cm^{-2}\cdot s^{-1}$, $\sim2.1\times10^{-11}$ $cm^{-2}\cdot s^{-1}$ and $\sim1.4\times10^{-11}$ $cm^{-2}\cdot s^{-1}$ for respectively $n\geqslant4$, $n\geqslant5$, and $n\geqslant6$ hadrons in the group. By way of comparison, the fluxes of underground muons found in the Soudan 1 experiment (at a depth of 600 meters water equivalent)[7] and the NUSEX experiment (1850 meters water equivalent)[8] are $\sim7\times10^{-11}$ $cm^{-2}\cdot s^{-1}$ and $\sim5\times10^{-11}$ $cm^{-2}\cdot s^{-1}$, respectively.

We acknowledge the ambiguity and the complexity of the interpretation of these results, which simply aggravate the already tangled situation regarding Cygnus X-3, but we believe these results need to be published.

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