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THE SPATIAL AND TIME EVIDENCE FOR THE EXCESS OF MULTIHADRON EVENTS IN THE DIRECTION OF CYGNUS X-3

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ՏԱՐԱԾԱԿԱՆ ԵՎ ԺԱՄԱՆԱԿԱՅԻՆ ՎԿԱՅՈՒԹՅՈՒՆՆԵՐ ԿԱՐԱՊ X-3 ԱՂԲՅՈՒՐԻ ՈՒՂՂՈՒԹՅԱՄԲ ԲԱԶՄԱՀԱԴՐՈՆԱՅԻՆ ԴԵՊՔԵՐԻ ԱՎԵԼՑՈՒԿԻ ՎԵՐԱԲԵՐՅԱԼ

Աշխատանքում բերվում են 1985թ. փետրվար–օգոստոս ժամանակամիջոցում ԳԻՈՆ գիտափորձի միջոցով Կարապ X-3 աղբյուրի ուղղությամբ հադրոնային խմբերի ավելցուկի որոնման արդյունքները: Կարապ X-3 ուղղությանը համակենտրոն բջջի չափերի, որի ներսում գրանցվում են հադրոնային խմբերը, և խմբի կազմում գրանցված հադրոնների թվի աճի հետ նկատվում է դիտվող ավելցուկի վիճակագրական նշանակալիության աճ: Ավելցուկի վիճակագրական նշանակալիությունը իր մաքսիմում արժեքին $\sim 7\sigma$ է հասնում $30^\circ \times 30^\circ$ չափեր ունեցող բջջի ներսում $n \geqslant 6$ հադրոններ պարունակող խմբերի համար: $n \geqslant 6$ հադրոնային խմբերի համար ֆազային տարալուծումը 0,3–0,4 ֆազային ինտերվալում բացահայտեց գագաթի առկայություն: $n \leqslant 5$ թվով բազմահադրոնային դեպքերի համար $P_0 = 4{,}8$ պարբերությամբ ճառագայթման պարբերական բաղադրիչ չի հայտնաբերվել: Կարապ X-3 ուղղությամբ գրանցված բազմահադրոնային դեպքերի հոսքերը համատեղելի են ստորգետնյա Soudan I և NUSEX գիտափորձերում գրանցված բարձր էներգիայով մյուոնների հոսքերի հետ:

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THE SPATIAL AND TIME EVIDENCE FOR THE EXCESS OF MULTIHADRON EVENTS IN THE DIRECTION OF CYGNUS X-3

The results of the search for the signal of hadron groups correlated with Cygnus X-3 using data of the PION experiment from February ~~until~~ To August 1985 have been reported. It has been revealed the enhancement in the statistical significance of the observed excess with increasing both the size of the cell centred in the direction of Cyg X-3 and the number of hadrons in the group. The statistical significance of the excess achieves a maximum value ($\sim 7\sigma$) in a $30^{\circ}\times 30^{\circ}$ cell for groups with the number of hadrons $n > 6$. The phase analysis with the 4.8-h orbital period revealed the presence of a peak in the phase interval 0.3-0.4 for hadron groups with $n > 6$. The fluxes of multihadron events in the direction of Cygnus X-3 are comparable to the fluxes of high-energy muons detected in the two underground experiments, Soudan-1 and NUSEX.

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Препринт ЕФИ-II36(I3)-89

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ПРОСТРАНСТВЕННЫЕ И ВРЕМЕННЫЕ СВИДЕТЕЛЬСТВА ОБ ИЗБЫТКЕ МНОГОАДРОННЫХ СОБЫТИЙ В НАПРАВЛЕНИИ ИСТОЧНИКА Cyg X-3

Приводятся результаты поиска избытка адронных групп в направлении источника Cyg X-3 установкой ПИОН в период наблюдений февраль-август I985 г. Выявлено увеличение статистической значимости наблюдаемого избытка с увеличением размера ячейки, центрированной на направление Cyg X-3 и числа адронов в группе. Статистическая значимость избытка достигает максимального значения ($\sim 7\sigma$) в ячейке с размерами 30^0 x 30^0 для групп с числом адронов $n \geqslant 6$. Фазовый анализ выявил наличие пика в фазовом интервале 0,3-0,4 для адронных групп с $n \geqslant 6$. Для многоадронных событий с числом адронов в группе $n \leqslant 5$ не был обнаружен периодичный компонент излучения с периодом $P_0 = 4{,}8$ ч. Потоки многоадронных событий в направлении Cyg X-3 сравнимы с потоками мюонов высоких энергий, обнаруженными в подземных экспериментах Соудан-I и Нюсекс.

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1. Introduction

The compact X-ray source Cygnus X-3 remains the focus of attention of both physicists and astrophysicists during the last few years. This source, being an X-ray binary, in many respects is unique and stands out against a background of other galactic sources from this class by its puzzling and non-standard properties revealed at various electromagnetic wavelengths (see, e.g. [1,2]). Furthermore, many physicists call in question the electromagnetic origin of the ultrahigh energy radiation of this source. Such a radical assumption is caused by unavoidable and insuperable difficulties encountered in the interpretation (in the framework of the existing theories of particle physics; see, e.g. [3-5]) of the set of experimental data on atmospheric showers (high content of muons revealed in Kiell and CYGNUS experiments, as well as proton-like characteristics of Čerenkov light images observed by Whipple 10 m gamma-ray telescope) and underground muon events observed in Soudan-1 and NUSEX experiments. At the same time it should be noted a discrepancy in the data of various experiments obtained in particular in the underground muon detectors [6,7] . In such situation, taking into account a paramount importance of the emerged problem, it seems necessary to carry out new explorations on search for anisotropy and periodicity of radiation in the direction of this source.

An attempt to search for excess of multihadron events (MHE) in the direction of Cygnus X-3 using the data of PION experiment, obtained during 1984-1985, was undertaken in Ref.[8] . To our surprise, according to data of 1985 we revealed a statistically significant signal of MHE in a relatively wide region of the celestial sphere ($30^\circ \times 30^\circ$) which covered the Cygnus X-3 coordinates.

In the present work we present a more detailed time and directional analysis of data reported in Ref. [8] , and discuss some model-independent constraints on properties of the primary radiation from Cygnus X-3 initiating MHE in the PION experiment.

2. Experimental Data

The PION installation consists of an ionization calorimeter and XTR detectors. It is located at the high-mountain Aragats station, at an elevation of 3250 m (40.18° N latitude and 44.5° E longitude). The PION installation having been in operation since 1978 is intended for studying a composition and properties of the cosmic-ray hadron component at mountain altitudes as well as for determining major characteristics of interaction of pions, protons and neutrons with different nuclei. The total amount of matter in the calorimeter consisting of iron and lead is ~ 900 g/cm^2. The calorimeter effective area is ~ 10 m^2, the accuracy for determining an arrival direction of particle is $\sim 2^{\circ}$, energy resolution in the range 0.5 - 50 TeV is about 15-20 % . A detailed description of the PION installation can be found in Ref.[9].

Below, under MHE we shall imply a simultaneous detection of several parallel (with an accuracy to $\sim 2^{\circ}$) hadrons traversing at least 4 layers of the calorimeter. The hadron group in the calorimeter is identified on the basis of a restored trajectory of each hadron in projections using a set of energy liberations in the successive calorimeter layers. The technique of identification of hadron groups in the PION ionization calorimeter is described in detail in Ref.[10] .

It should be noted that above the ionization calorimeter in the PION installation the XTR-detectors are used to separate hadrons of different masses, namely nucleons and pions. However practically in all MHE cases the XTR-detectors were in the state of saturation, presumably due to the EAS electromagnetic component accompanying the hadrons. Therefore we cannot identify a sort of hadrons in the group. At the same time we can claim that the detected MHE are produced in the atmosphere rather than in the calorimeter.

A preliminary analysis of events registered by the PION during 1984-1985 revealed a statistically significant excess of MHE for data of 1985 in the direction of the Cygnus constellation from the region with angular sizes $30^{\circ} \times 30^{\circ}$ [8]

Here we carry out a more detailed analysis concerning the temporal and spatial distributions of MHE, detected in 1985 only. We have selected only MHE with the number of hadrons in the group $n \geqslant 4$ and with total energy release in the calorimeter $\Sigma E_h \geqslant 1$ TeV.

In 1985 the installation was working during the period February-August (effective time $T \overset{6}{\sim} 10^6$ s), and 251 MHE have been detected. For each event the values of right ascension α and declination δ were calculated using measured values of a zenith and azimuth angles of direction and local time of detection. The analysis of MHE distribution in δ (for arbitrary α) points out the presence of a distribution maximum for $\delta \sim 40^o$, which reflects the dependence of the installation sensitivity to the zenith angle. This is due to the location of the PION ($\Phi \sim 40.18^o$ N), since the hadrons incident at small zenith angles are detected most effectively by the calorimeter [8] . From this point of view, the location of the PION is ideal for the observation of Cygnus X-3 ($\alpha = 20.5$ h, and $\delta = 40.8^o$). At the same time, in order to avoid a misinterpretation of the event distribution maximum in the direction of Cygnus X-3 as a real signal, arguments are needed that would exclude the priority of events by another coordinate of this source, namely by α . Such a situation can, in principle, incidentally arise due to discontinuous operation of the installation. However the analysis of distribution of the installation operation durations versus the local sidereal time shows that all directions were scanned practically uniformly by α . At least in the time_interval

19.5 h - 21.5 h of local sidereal time which includes the transit time of Cygnus X-3 (LST = 20.5 h) the installation operation time was at a mean value level [8] .

In the further analysis of obtained data we carried out a purposeful search for a time-modulated signal in the direction of Cygnus X-3 with the known orbital period of 4.8 h of this source.

2.1. MHE Directional Distribution

Fig. 1 shows distributions of MHE with $n > 4$ in for 4 values of intervals in δ : a) $\Delta\delta = 10^\circ$ $(35.5^\circ < \delta < 45.5^\circ)$; b) $\Delta\delta = 15^\circ$ $(33^\circ < \delta < 48^\circ)$; c) $\Delta\delta = 20^\circ$ $(30.5^\circ < \delta < 50.5^\circ)$; d) $\Delta\delta = 30^\circ$ $(25^\circ < \delta < 55^\circ)$. Note that all these intervals are approximately centred around the relevant coordinate of Cygnus X-3 ($\delta = 40.8^\circ$). For each α distribution the size of $\Delta\alpha$ is chosen equal to $\Delta\delta$. In other words, the $10^\circ \times 10^\circ$; $15^\circ \times 15^\circ$; $20^\circ \times 20^\circ$ and $30^\circ \times 30^\circ$ cells in the celestial sphere were analyzed.

For each distribution the background mean value was estimated without regard for the number of events in the chosen cell in the direction of Cygnus X-3: $B = \sum_{\substack{i=1 \\ i \neq j}}^{K-1} N_i/(K-1)$, where N_i is the number of events in the i-th cell, K is the number of cells, and j is the chosen cell number towards the Cygnus X-3. In this case the background error in the j-th cell is $\sigma_j = [B + B/(K-1)]^{1/2}$. In Fig. 1 to the left of the axis of ordinates (Y-axis) the number of events is shown, an to the right of it the statistical significance S/σ_j is marked, where the signal S is the number of events above the background ($S \equiv N_j - B$).

A noticeable correlation between the values of the signal-to-noise ratio and the cell size comes out quite unexpectedly from the comparison of distributions shown in Fig. 1. Regardless of our expectations, an apparent growth in the value of S/σ_j with increasing cell size is observed. The statistical significance of the effect reaches a maximum value ($\sim 4.4\sigma_j$) for the cell size 30° x 30° and further drastically falls off as the cell size decreases. Fig. 2 shows a dependence of S/σ_j on the value of the solid angle centred in the direction of Cygnus X-3. Experimental points for groups with $n \geqslant 4$ can be approximated in the form:

$$S/\sigma_j \simeq 13(\Omega/0{,}16)^{1{,}35} \exp\left[-(\Omega/0{,}16)^{1{,}35}\right]. \qquad (1)$$

According to this approximation, a maximum of the signal-to-noise ratio is achieved for $\Omega \sim 0.2$, which corresponds to the angular size of the region $\sim 30^\circ$. Recall that the angular resolution of the PION is $\sim 2^\circ$; therefore the observed correlation cannot be caused by the apparatus effects.

For the point-like source the signal-to-noise ratio apparently must be inversely proportional to the cell angular size, since

$$S/\sqrt{B} = (A \cdot t/\Delta\Omega)^{1/2} F_S/\sqrt{F_B} \propto \Delta\Omega^{-1/2} \propto \varphi^{-1}, \qquad (2)$$

where F_S is the signal flux (cm^{-2} s^{-1}) from the point source,

F_B is the background intensity (cm^{-2} s^{-1} ster^{-1}), A is the effective detection area, t is the time of observation.

In case of extended source and when events are distributed uniformly inside the cell wherein the signal is observed, we have to expect an inverse dependence:

$$S/\sqrt{B} = (A\, t \cdot \Delta\Omega)^{1/2} F_c/\sqrt{F_B} \sim \Delta\Omega^{1/2} \sim \varphi \quad (3)$$

where F_c is the signal flux (cm^{-2} s^{-1} ster^{-1}).

It follows from the comparison between the observed (Eq.(1)) and expected (Eq.(3)) dependences that events inside the cell are distributed not quite uniformly, the density of events near the periphery being higher than in the centre of the cell. However such a statement can be done only with reserve, taking into account the poorness of statistics.

The observed excess inside the large solid angle points out that either the source of primary radiation is extended or the effect is due to the kinematics of interaction of primary particles, namely due to the emission of secondary products (hadrons) under large angles. Below we present arguments, based on the phase analysis of data, in favour of the second assumption.

Another interesting feature of data obtained in the direction of Cygnus X-3 is that the signal-to-noise ratio grows with increasing number of hadrons in the group (see Table 1). Fig. 3 shows α-distribution of MHE with $n \geqslant 5$ and $n \geqslant 6$ for three intervals of δ: a) $33^\circ \leqslant \delta \leqslant 48^\circ$; b) $30.5^\circ \leqslant \delta \leqslant 50.5^\circ$; c) $25^\circ \leqslant \delta \leqslant 55^\circ$.

Table 1 (see also Figs 1 and 3) shows that for each chosen size of the cell $\Delta\alpha \times \Delta\delta$ one observes a growth in the signal-to-noise ratio with increasing n, despite the sharply decreased statistics. In particular, for the cell dimensions $\Delta\alpha \times \Delta\delta = 30^\circ \times 30^\circ$, when the observed effect is maximal, the statistical significance of excess for hadron groups with $n \geqslant 4$, $n \geqslant 5$ and $n \geqslant 6$ is respectively $4.4\sigma_j$; $6.2\sigma_j$ and $7\sigma_j$.

Fig. 4 shows a distribution of detected MHE by the number of hadrons in the group, $I(\geqslant n)$ in the direction of Cygnus X-3 ("on" direction) and outside this direction ("off" direction) for the cell $30^\circ \times 30^\circ$. According to 1984 data no difference is practically observed between MHE distributions in "on" and "off" directions. This should have been expected, since the analysis of 1984 data did not reveal a statistically significant excess in the direction of Cygnus X-3 [8] , whereas by 1985 data substantially different dependences in "on" and "off" directions are observed. If we approximate the distribution $I(\geqslant n)$ by power-law function, then for "on" direction we have $I_{\text{"on"}}(\geqslant n) = 6 \cdot 10^3 n^{-3.69 \pm 0.54}$, while for "off" direction $I_{\text{"off"}}(\geqslant n) = 4 \cdot 10^4 n^{-5.73 \pm 0.42}$.

Fig. 4 presents essentially different dependences of distributions in "on" and "off" directions by 1985 data which clearly demonstrate the cause of the enhancement of statistical significance of the signal with the increase in the number of hadrons in the group. It is interesting that the values of $I_{\text{"on"}}(\geqslant n)$ and $I_{\text{"of"}}(\geqslant n)$ become comparable for $n \sim 3$; therefore the search for the excess of MHE with the number of hadrons $n_0 \leqslant 3$ does not lead to a positive result, though the statistics of such events is considerably higher.

It should be noted that the n distribution of MHE inside the "on" cell is determined by a superposition of contributions of the background (due to cosmic ray interactions) and the signal (due to primary particles from Cygnus X-3). Admitting the power-law dependence of the signal on n ($S \sim n^{-\alpha}$), for the signal-to-noise ratio we have

$$S/\sqrt{B} \propto n^{-\alpha+2,85} \tag{4}$$

From the comparison of obtained data with the signal-to-noise ratio for $n \geqslant 4$, $n \geqslant 5$, $n \geqslant 6$ it follows that $S/\sqrt{B} \propto n^{\beta}$, where $\beta > 1$. Therefore the signal spectral index $\alpha < 1.85$, which is at least by a factor of 3 less than the background ("on") spectral index.

The increase in the signal-to-noise ratio with increasing number of hadrons in the group is probably due to the fact that the particles responsible for the observed excess produce MHE more efficiently than the protons and nuclei of isotropic primary cosmic radiation. Another interpretation of this effect is also possible, namely that these particles have higher penetrability ($\lambda_c > 100$ g/cm^2, but obviously $\lambda_c < 700$ g/cm^2) than protons and nuclei and interact in deeper atmospheric layers. The secondary hadrons of the group have no time to disperse at large distances and hence are detected by PION more efficiently. Perhaps some other explanations for the mentioned effect are possible. Here we shall restrict ourselves only to the remark that owing namely to the introduced criterion of selecting the events by high multiplicity, it is possible to detect the excess in the direction of Cygnus X-3 using the PION installation with a relatively small effective area ($\sim 10\ m^2$). This criterion, affecting the signal far more weakly, allows to sharply suppress the background. Therefore, despite the reduced statistics, the excess significance enhances with the required number of hadrons in the group.

2.2. Phase Analysis

The modulation of radiation with the orbital period of 4.8 h is the most important criterion to relate the detected flux to Cygnus X-3. In view of this, we have done a phase analysis for those 30 events that occurred in the cell with $292.5^\circ < \alpha < 322.5^\circ$ and $25^\circ \leq \delta \leq 55^\circ$. The phase for each event was calculated by the expression:

$$\phi = (t - T_0)/[P_0 + \dot{P}(t - T_0)/2], \quad (5)$$

where T_0 = JD2442946.739, $P_0 = 0.1996851d$, $\dot{P} = 7.84 \cdot 10^{-10}$, t is universal time (UT) of event detection.

Here, following Protheroe's recommendation [11], we use Mason ephemeris, which increases the phase value by 0.07 compared to Van der Klis ephemeris.

Fig. 5 shows the phase distributions of MHE. A comparison of phase distributions for different values of the number of hadrons in the group shows that a statistically significant peak is observed at $\Delta\phi = 0.28 - 0.38$ only for MHE with $n \geq 5$.

It is important here to present the amount of events with the different n falling into this phase interval: $N(\geqslant 6) = 6$; $N(\geqslant 5) = 7$ and $N(\geqslant 4) = 7$ for the total amount of events observed in the direction of Cygnus X-3, $N_{tot}(\geqslant 6)=11$; $N_{tot}(\geqslant 5)=18$ and $N_{tot}(\geqslant 4)=30$, respectively. Whence it follows that into the cited phase interval fall practically only events with $n \geqslant 6$ (only one event with $n = 5$ and none with $n = 4$). In other words, the radiation modulation with period $P_o = 4.8$ h is observed only for groups with $n \geqslant 6$ (for the latter case the value of the signal-to-noise ratio is not presented in Fig. 5, since the background is practically zero). A possible interpretation of this nontrivial result is discussed below.

3. Discussion

The main conclusions following from the spatial and time analysis of MHE detected by the PION experiment during the observations done in February-August 1985 can be summarized as follows:

1. A statistically significant excess of MHE in the direction of Cygnus X-3 is revealed. The signal-to-noise ratio grows with increasing angular size of the cell and achieves a maximum value for $\Delta\alpha \times \Delta\delta = 30^\circ - 30^\circ$. A statistical significance of the observed effect inside this cell for the MHE with the number of hadrons in the group $n \geqslant 4$ is $4.4\,\sigma_j$.

2. A noticeable growth in the signal-to-noise ratio with increasing number of hadrons in the group has been revealed. A statistical significance of the observed excess of MHE

inside the cell of $\Delta\alpha \times \Delta\delta = 30^\circ \times 30^\circ$ with $n \geqslant 4$, $n \geqslant 5$ $n \geqslant 6$ is $4.4\sigma_j$, $6.2\sigma_j$ and $7\sigma_j$, respectively.

3. As a result of the time analysis of data it has been revealed the presence of periodic component of radiation with the known orbital period of Cygnus X-3, $P_0 = 4.8$ h, for the MHE with $n \geqslant 6$. Here a peak in the phase range $\sim 0.3 - 0.4$ is observed. The phase analysis reveals no periodic component for the MHE with $n < 6$ of hadrons in the group.

Assuming that the above-cited effects are of real physical nature (in any case, no apparatus-caused arguments against this assumption have been revealed [8]), one can establish some model-independent properties of MHE-initiated primary particles from Cygnus X-3. By tradition, we call these hypothetical particles "cygnets". This term was introduced originally in connection with the serious difficulties occurred in the interpretation of EAS data and underground muon events observed in the direction of Cygnus X-3 (see, e.g. [3-5]). The analysis of these data implies that the cygnets must be neutral, (quasi)stable ($\tau_c \leqslant 10^6\,(\Gamma/10^6)^{-1}$ s, where $\Gamma \equiv E/m_c c^2$ is Lorentz factor of the cygnet) and relatively small in mass ($m_c c^2 \lesssim 0.5\,(E/10\ \text{TeV})$ GeV; see, however [12] too). In addition, they must copiously produce secondary muons.

The presented data on MHE associated with Cygnus X-3 allow one to derive a new information about properties of the cygnets.

It follows from Fig. 1 that the "source" of MHE observed in the direction of Cygnus X-3 is an extended one with the angular size of the order of 30°. It is noteworthy that the excess of multimuon events in such large cell ($30^\circ \times 30^\circ$) was reported in the first publication of the Soudan-1 group [13], and their result was obtained without implication of the phase analysis. The further publications of this as well as NUSEX groups reported only data on the excess of the underground muon events revealed after the phase analysis. However for these cases too, the angular spread of events remained large [14,15], especially for the data of the NUSEX experiment - of the order of 10^o [15].

The presence of the periodic component in the observed signal with the known orbital period of the X-ray binary Cygnus X-3 excludes a possibility of an extended source of primary radiation (cygnets). In this case the wide angular spread of the observed MHE excess may be caused either by the broadening of the cygnet beam when it travels the way from the source to the observer or by peculiarities of the kinematics of interaction of cygnet with atmosphere. The former version was discussed by Arbuzov [16,17] to interpret the angular spread of underground muon events [14,15] and the time delay of the signal from Cygnus X-3 between EAS data [18] and a maximum of the radio outburst in October 1985.

The principal idea of this model is that cygnets are free gluons produced in Cygnus X-3. As to the muon angular spread, it is caused by the broadening of ultrahigh-energy gluon beam owing to multiple scattering on a thermal (primordial) gluon gas. This model also gives rise to a qualitative understanding of angular spread of MHE, especially as the model implies that gluons because of large cross section ($\sim 10^{-23}$ cm^2) interact effectively with the atmosphere.

Another reason of the large angular spread of MHE may be connected with the peculiarities of the kinematics of the cygnet - atmospheric nuclei interaction, namely with the emission of secondary products at large angles. Such a possibility can be realized in case when the detected hadrons are the product of the decay of an intermediate short-lived heavy particle. Such idea to explain the wide angular spread of underground muon events was suggested in the phenomenological model of Ruddick [19] .

It should be noted that the very fact of detection of the MHE excess from the Cygnus X-3 at an observation level of ~ 700 g/cm^2 implies that the total cross section of the cygnet - atmosphere interaction must be larger than a few tens of mb. In case of underground muon events, it is difficult to estimate unambiguously the interaction cross section, since in this case the interaction of cygnets both in the atmosphere (~ 100 mb) and in the rock ($\geqslant 10 \mu$b) is not excluded [*)]. Therefore, in order to explain the muon events, the models assuming the interaction of cygnets both with the atmosphere [16,17,20-23] and the rock [19, 24-26] have been proposed. If the MHE are initiated by the same particles as the underground muon events are, then, obviously, the preference should be shown to those models which imply a large interaction cross

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[*)] A lower bound on the cross section of the cygnet interaction in rock is due to the absence of the effect of signal enhancement with increasing zenith angle in the NUSEX experiment [15] section of the cygnets ($\geqslant 10$ mb). However, it is not excluded that these events are initiated by a different particle; then we deal with the family of cygnets.

In many studies based on the phase analysis of data of EAS and underground muon experiments the upper limit of cygnet rest mass was estimated: $m_c c^2 \leqslant 0.5$ (E_c/10 TeV) GeV. The idea is that because of the large distance to Cygnus X-3 (10 kpc) the signal time structure would not be essentially distorted only in case when cygnet mass is less than some critical one. The same statement is valid also for MHE with $n \geqslant 6$. At the same time, although for MHE with $4 \leqslant n \leqslant 6$ a statistically significant excess in the direction of Cygnus X-3 is observed, nevertheless the phase analysis reveals no periodicity for these events. If the time structure of radiation would not have been dependent on the number of hadrons in MHE, then for events with $n \leqslant 5$ in the phase range 0.3 – 0.4 one should have expected the number of events 1.5 times that with $n \geqslant 6$ (i.e. ~10, since the total number of events in the $30^\circ \times 30^\circ$ cell for $n \geqslant 5$ is 19, and for $n \geqslant 6$ it is 11).

Actually, for $n \leqslant 5$ only one event falls into the mentioned phase range (see Sect. 2.2). This means that in fact the signal time structure depends on the number of hadrons in the group. Taking into account that the number of hadrons in MHE reflects (directly or indirectly) the energy of primary particles, this statement points out that the signal time structure depends on the cygnet energy. A possible reason of such a dependence, to our opinion, may be the non-zero mass of MHE-initiating cygnets. Indeed, the presence of radiation periodicity with the phase width $\Delta\Phi = 0.1\ P_0 \sim 0.5$ h for MHE with $n > 6$ implies that the cygnet mass is to be about

$$m_c c^2 \lesssim (2\Delta\Phi c/L)^{1/2} E_c^{(>6)} \sim 0{,}6\,(E_c^{(>6)}/10\,\mathrm{TeV})\ \mathrm{GeV} \qquad (6)$$

where $E_c^{(>6)}$ is energy of the cygnet initiating MHE with $n > 6$, L is the distance to the source, c is the velocity of light.

On the other hand, taking into account the absence of the expected signal from MHE with $n < 6$ (one event instead of ten expected) in the phase range 0.3 - 0.4 and assuming that this absence is due to the violation in the signal time structure due to non-zero mass of cygnets, we arrive at the lower bound on the cygnet mass:

$$m_c c^2 \gtrsim (2\Delta\Phi \cdot c/L)^{1/2} E_c^{(<6)} \sim 0{,}6\,(E_c^{(<6)}/10\,\mathrm{TeV})\quad \mathrm{GeV} \qquad (7)$$

where $E_c^{(<6)}$ is the energy of the cygnet initiating MHE with $n < 6$.

Unfortunately, it is impossible on the basis of the measured number of hadrons in the group to estimate correctly the primary particle energy, first of all because of the lack of any information about the nature of cygnet interaction. Therefore we cannot estimate the absolute values of the limits to cygnet mass. At the same time the characteristic values of measured energy releases in the PION calorimeter for MHE should be given: ~ 10 TeV and ~ 3.5 TeV respectively for $n > 6$ and $n = 4$. The substantial difference in energy liberations apparently reflects the fact of the appreciable difference in primary energies. In this case taking into consideration that the cygnet arrival time delay (due to non-zero mass) is

$$\Delta t = \frac{L}{2c} (m_c c^2 / E_c^*)^2 , \qquad (8)$$

it turns out that under the given finite mass of the cygnet there exists a critical energy E_c^* above which the time structure of primary radiation maintains, and below that it does not. In our case this critical energy corresponds to the number of MHE hadrons $n \sim 6$. The lack of information about the exact value of E_c^* allows us to estimate the cygnet mass only by the order of magnitude: from one to ten GeV if the critical energy varies within $E_c^* \sim 10 - 100$ TeV. Note, however, that this estimate of cygnet mass should be regarded with certain caution, since the correct calculations need in an additional information about the primary energy spectrum of cygnets [12] .

Table 1 presents MHE fluxes for various sizes of the cell centred to the direction of Cygnus X-3, as well as for different values of the number of hadrons in the group. These fluxes are comparable with the fluxes of underground muon events detected in experiments of Soudan-1 [14] ($\sim 7.3 \cdot 10^{-11}$ cm^{-2}s^{-1}) and NUSEX ($\sim 5 \cdot 10^{-12}$ cm^{-2}s^{-1}) [15], and are almost by two orders of magnitude less than the sporadic muon flux detected during 2-12 October 1983 at the IMB experiment [27] . Whereas for the underground muon events it is impossible to unambiguously conclude about the site of cygnet interactions, the MHE detected by the PION obviously are connected with the interaction of cygnets with the atmosphere. Therefore it is of interest also to compare the MHE fluxes with the measured atmospheric shower fluxes in the direction of Cygnus X-3.

The decrease in the MHE flux with increasing n (see Table 1) apparently is connected with the fact that groups with high multiplicity are initiated by more energetic particles. Unfortunately, because of great uncertainty in the transition from the hadron energy to the primary particle energy and due to the absence of information about the nature of cygnet interactions we cannot estimate correctly their fluxes at different energies. Nevertheless, a most reasonable energy range for the MHE-initiating primary radiation seems to be 10 - 100 TeV. To our regret, this energy range for Cygnus X-3 is studied worse that the energy regions $E \leq 10$ TeV (using the Čerenkov telescopes) and $E \geq 100$ TeV (using the EAS arrays). From the available data we should mention the flux observed during 1980-1983 at the Plateau Rosa detector with the energy above 30 TeV : $I(\geq 30\ \mathrm{TeV}) = (4.2 \pm 1.5)\ 10^{-12}$ $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ [28] . In the energy range above 5 TeV a high radiation flux was obtained using the Čerenkov telescope by the Tien Shan group [29] : $I(\geq 5\ \mathrm{TeV}) = 1.6\ 10^{-10}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ (1977-1978). These fluxes obtained by averaging during a large period of observations should be attributed to a stationary radiation component of Cygnus X-3. As it is known, Cygnus X-3 besides the stationary component also has a sporadic component of radiation [30] . Recently this sporadic component has been confirmed by Fly's Eye installation [31] . Over one night in June 17, 1985 this installation detected a powerful outburst in the direction of Cygnus X-3; note that during 21 nights of observations (in June-August 1985) the averaged flux of sporadic radiation above 10 TeV was $I(\geqslant 10\ \mathrm{TeV}) = (1.1 \pm 0.3)\ 10^{-11}$ $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$, and above 100 TeV: $I(\geqslant 100\ \mathrm{TeV}) = (2.5 \pm 1)\ 10^{-13}$ $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ [31] . This result is interesting to us not only in view of the similar energy range of primary radiation, but also because the period of the Fly's Eye observations falls within the time interval when the MHE excess towards Cygnus X-3 is detected by the PION installation. Moreover, namely during June-July 1985 an appreciable share of MHE in the direction of Cygnus X-3 was detected. Thus, 7 MHE with $n \geqslant 6$ inside the cell $30^\circ \times 30^\circ$ were detected during 2 months (June-July 1985), whereas all the 11 MHE were detected during 7 months (February-August 1985) of the PION continuous operation.

Although the MHE fluxes listed in Table 1 are somewhat higher than follows from the conventional representations on the Cygnus X-3 fluxes, nevertheless, taking into account a sporadic nature of radiation of this source and the uncertainty in the energy range of primary radiation there is no obvious contradiction between the MHE and air shower data. Besides, it seems to us not quite correct to compare the MHE data and the air shower data, since the latters have been obtained under assumption that the shower excess towards Cygnus X-3 is due to ultrahigh energy photons. As to the MHE, they cannot be accounted for by photons under any reasonable assumptions on interactions of the latters with matter.

In conclusion we wish to note that the data on MHE discussed above and the following radical conclusions concerning the existence of new particles even more aggravate a sufficiently intricate situation with a puzzling source - Cygnus X-3. Nevertheless, we consider it necessary to publish these data.

Finally, we would like to express our gratitude to V.V. Avakian, A.T. Avundjian, E.A. Mamidjanian, G.V. Karageuzian, G.G. Ovssepian, H.Zh. Ohanian, and S.V. Ter-Antonian for presenting us the PION primary data on multihadron groups and for the useful discussions.

Table 1

Characteristics of multihadron events detected in the direction of Cygnus X-3 by the PION installation (February - August, 1985)

$\Delta\alpha \times \Delta\delta$	$\geqslant n$	N_{tot}	B	S	S/σ_j	I
15^ox15^o	4	9	4.09	4.91	2.4	$4.9\ 10^{-11}$
	5	5	1.52	3.48	3.2	$3.5\ 10^{-11}$
	6	3	0.54	2.46	3.3	$2.5\ 10^{-11}$
20^ox20^o	4	17	6.41	10.59	4.1	$1.1\ 10^{-10}$
	5	9	2.35	6.65	4.2	$6.7\ 10^{-11}$
	6	5	0.88	4.12	4.3	$4.1\ 10^{-11}$
30^ox30^o	4	30	13.18	16.82	4.4	$1.7\ 10^{-10}$
	5	18	4.45	13.55	6.2	$1.4\ 10^{-10}$
	6	11	1.64	9.36	7.0	$9.4\ 10^{-11}$

$\Delta\alpha \times \Delta\delta$ - size of the cell centred to Cygnus X-3;

n - number of hadrons in the group;

N_{tot} - total number of events in the given cell;

B - the value of background;

S - the value of the signal (of the excess): $S = N_{tot} - B$;

σ_j - background error in the given cell;

S/σ_j - signal-to-noise ratio;

I - the flux of MHE corresponding to the given value of a signal ($cm^{-2}\ s^{-1}$).

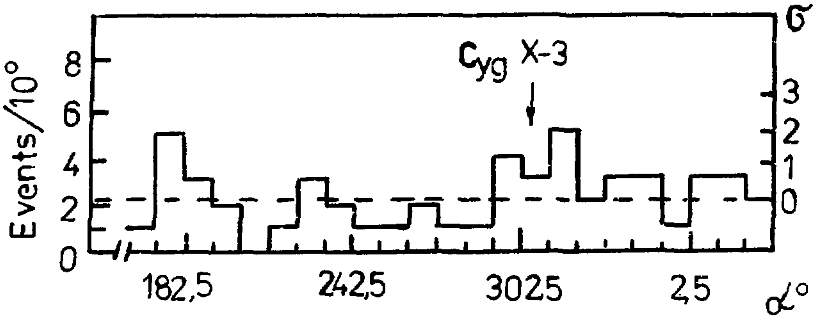

Events/10°
0
2
4
6
8
σ
0
1
2
3
Cyg X-3
182,5
242,5
302,5
2,5
α°

Fig.1a

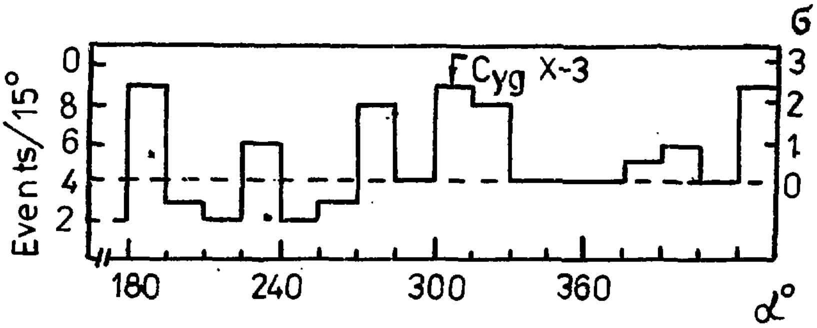
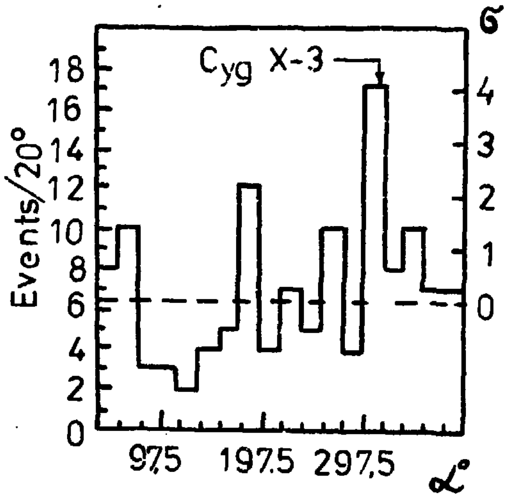
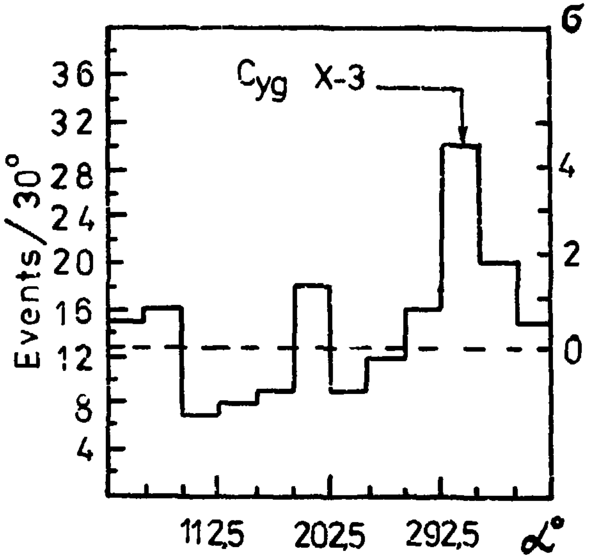

Events/15°
2
4
6
8
0
σ
0
1
2
3
Cyg X-3
180
240
300
360
α°

Fig.1b



Events/20°
18
16
14
12
10
8
6
4
2
0
97,5
197,5
297,5
α°
6
4
3
2
1
0
Cyg X-3

Fig.1c



Events/30°
36
32
28
24
20
16
12
8
4
112,5
202,5
292,5
α°
6
4
2
0
Cyg X-3

Fig.1d

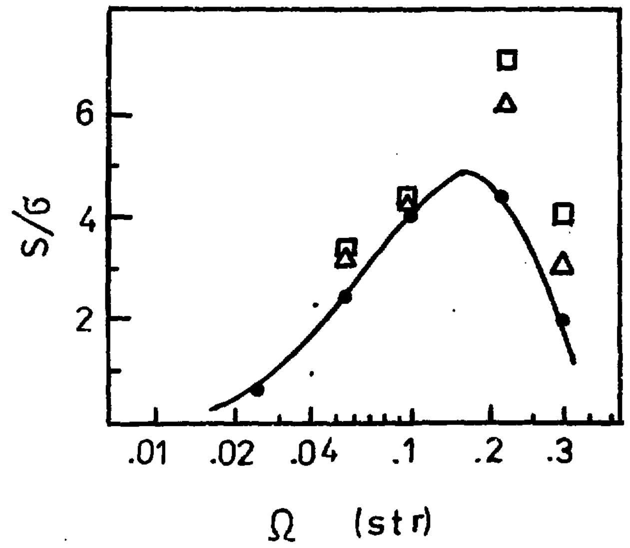

S/σ
6
4
2
.01
.02
.04
.1
.2
.3
Ω (str)

Fig.2

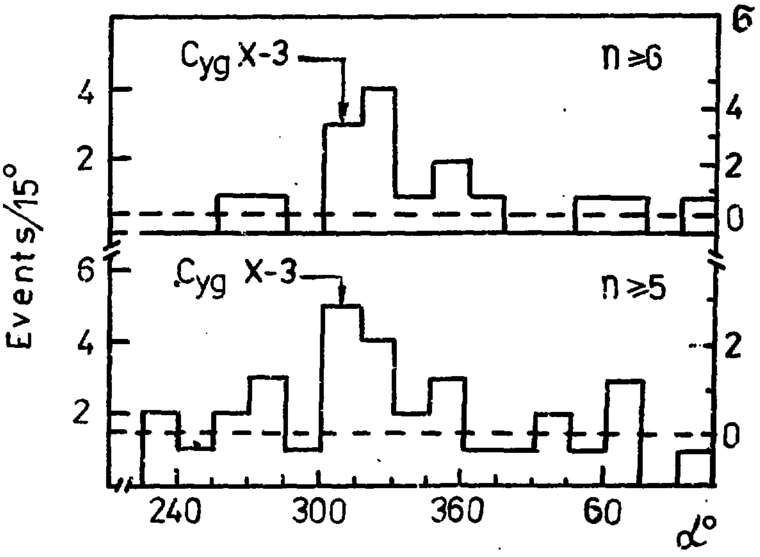

Events/15°
Cyg X-3
n ≥6
Cyg X-3
n ≥5
4
2
6
4
2
6
4
2
0
2
0
240
300
360
60
α°

Fig.3a

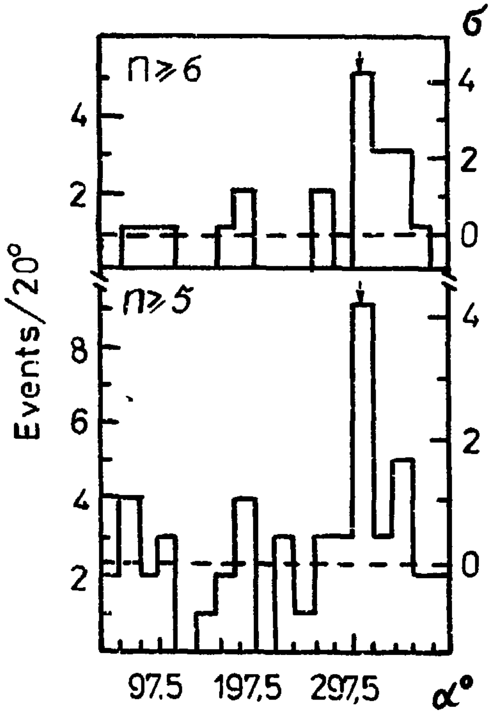

n≥6
n≥5
Events/20°
4
2
8
6
4
2
σ
4
2
0
4
2
0
97.5
197.5
297.5
α°

Fig.3b

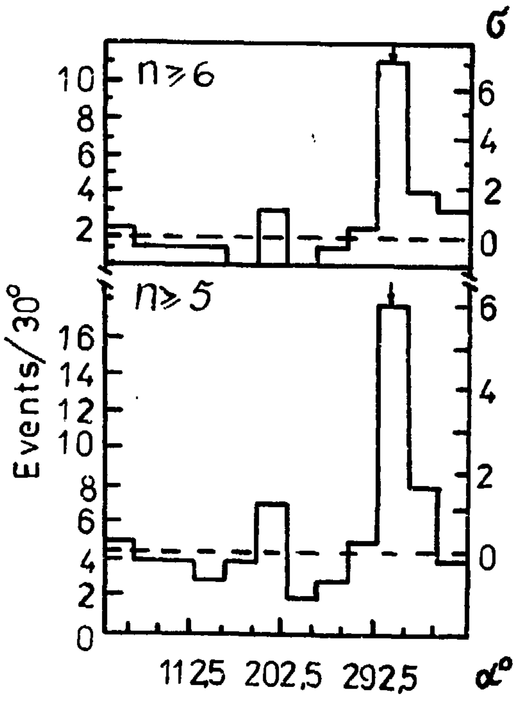

n≥6
n≥5
Events/30°
10
8
6
4
2
16
14
12
10
8
6
4
2
0
σ
6
4
2
0
6
4
2
0
112.5
202.5
292.5
α°

Fig.3c

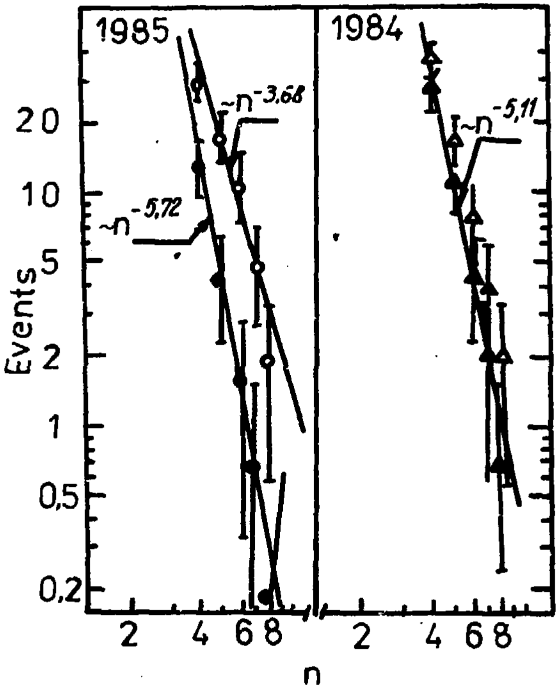

1985
1984
$\sim n^{-3.68}$
$\sim n^{-5,72}$
$\sim n^{-5,11}$
Events
20
10
5
2
1
0,5
0,2
2
4
6
8
n

Fig.4

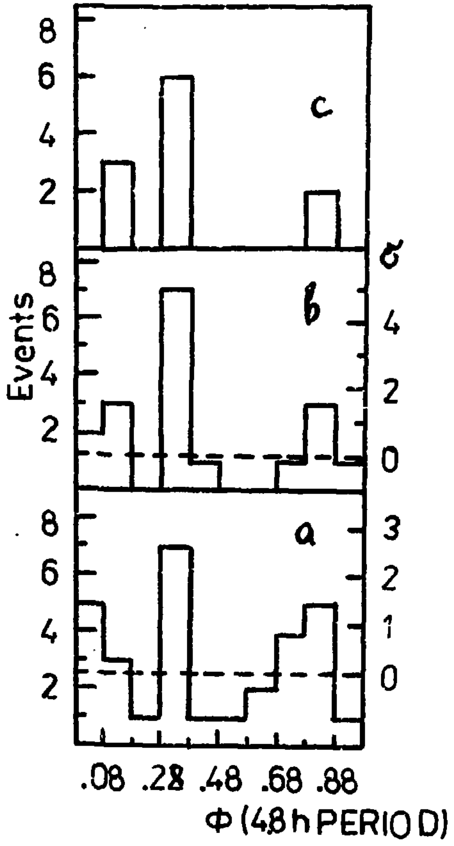

c
b
a
Events
8
6
4
2
σ
4
2
0
3
2
1
0
.08
.28
.48
.68
.88
Φ (48 h PERIOD)

Fig.5

Figure Captions

Fig.1. The right-ascension distribution of events with the number of hadrons in the group $n \geqslant 4$ for different sizes of a cell: a) $\Delta\alpha = 10^\circ$; $35.5^\circ \leqslant \delta \leqslant 45.5^\circ$; b) $\Delta\alpha = 15^\circ$; $33^\circ \leqslant \delta \leqslant 48^\circ$; c) $\Delta\alpha = 20^\circ$; $30.5^\circ \leqslant \delta \leqslant 50.5^\circ$; d) $\Delta\alpha = 30^\circ$; $25^\circ \leqslant \delta \leqslant 55^\circ$. The dotted line refers to the background level. On the right of the ordinate axis the statistical significance of the signal (S/σ_j) is marked. The arrows point to the cells centred to Cygnus X-3.

Fig.2. The value of S/σ_j as a function of the solid angle centred to Cygnus X-3. The solid line is the approximated value of S/σ_j for groups with the number of hadrons $n \geqslant 4$. Experimental values of S/σ_j : ● - $n \geqslant 4$; Δ - $n \geqslant 5$; ☐ - $n \geqslant 6$.

Fig.3. The right-ascension distribution of events with the number of hadrons in the group $n \geqslant 5$ and $n \geqslant 6$ for different sizes of the cell: a) $\Delta\alpha = 15^\circ$, $33^\circ \leqslant \delta \leqslant 48^\circ$; b) $\Delta\alpha = 20^\circ$, $30.5^\circ \leqslant \delta \leqslant 50.5^\circ$; c) $\Delta\alpha = 30^\circ$, $25^\circ \leqslant \delta \leqslant 55^\circ$. The dotted line refers to the background level. On the right of the ordinate axis the statistical significance (S/σ_j) is marked. The arrows point to the cells centred to Cygnus X-3.

Fig.4. Distribution of multihadron events by the number of hadrons in the group ($I(\geqslant n)$) in "on" and "off" directions with respect to Cygnus X-3. The cell size is $\Delta\alpha \times \Delta\delta = 30^\circ \times 30^\circ$. Experimental points: ○ - "on" direction; ● - "off" direction (the 1985 data), and △ - "on" direction, ▲ - "off" direction (the 1984 data). Solid lines refer to power-law approximation of experimental points.

Fig.5. Phase distribution of multihadron events falling into the $30^\circ \times 30^\circ$ cell centred to Cygnus X-3 for the different values of n : a) $n \geqslant 4$; b) $n \geqslant 5$; c) $n \geqslant 6$. The dotted line refers to the background level. On the right of the ordinate axis the statistical significance of the signal (S/σ_j) is marked.

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ПРОСТРАНСТВЕННЫЕ И ВРЕМЕННЫЕ СВИДЕТЕЛЬСТВА ОБ ИЗБЫТКЕ МНОГОАДРОННЫХ СОБЫТИЙ В НАПРАВЛЕНИИ ИСТОЧНИКА Cyg X-3

(на английском языке,перевод Асланян З.Н.)

Редактор Л.П.Мукаян
Технический редактор А.С.Абрамян

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ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ