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E1-82-352

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CORRELATION EFFECTS IN MULTIPLE PARTICLE PRODUCTION ON NUCLEI IN THE CUMULATIVE REGION

Submitted to the XXI International Conference on High Energy Physics (Paris, July 1982)

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1982

The studies of inelastic $\pi^{-}\,{}^{12}C$ interactions at P_{π^-}= = 40 GeV/c performed by means of the 2 m propane bubble chamber (High Energy Laboratory, JINR) enabled a large amount of experimental data to be obtained. The published results concerned a general picture of multiple processes, resonance production, correlations of like particles and so on. First results of the analysis of hard processes accompanied by the emission of cumulative particles are presented in this paper*. The experimental study of such processes on pictures from the propane bubble chamber became possible due to a large enough statistics of the investigated $\pi^{-}\,{}^{12}C$ interactions (~20 000 events). As is known, available experimental data on inclusive spectra of cumulative particles [3] including our $\pi^{-}\,{}^{12}C$ interactions at 40 GeV/c [4] allowed a number of universal properties of this interesting phenomenon to be obserbed. Of particular attention are scale invariance, universality of the dependence of production cross sections of different particles and a very weak dependence of cross sections on the flavours of cumulative particles. These properties find a natural explanation in the theory of hard collisions and represent a manifestation of the quark nuclear degrees of freedom. Their further study is of interest from the point of view of constructing the hard collision theory on the basis of quantum chromodynamics.

Chamber technique enables one to investigate processes accompanying cumulative particle production under " 4π-geometry" conditions, i.e., to study correlation phenomena. The cumulative effect is practically not studied in such a formulation. The goal of this paper is to study these correlation phenomena.

1. STATEMENT OF THE PROBLEM, DESIGNATIONS

In accordance with the aim indicated, different characteristics of $\pi^{-}\,{}^{12}C$ interactions have been analysed at P_{π^-} = = 400 GeV/c versus the largest value of cumulative number (n_c^{max}) among all the values of n_c^i for secondary $\pi^{\pm}$-mesons in each

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*More complete data are in JINR communications [1,2].

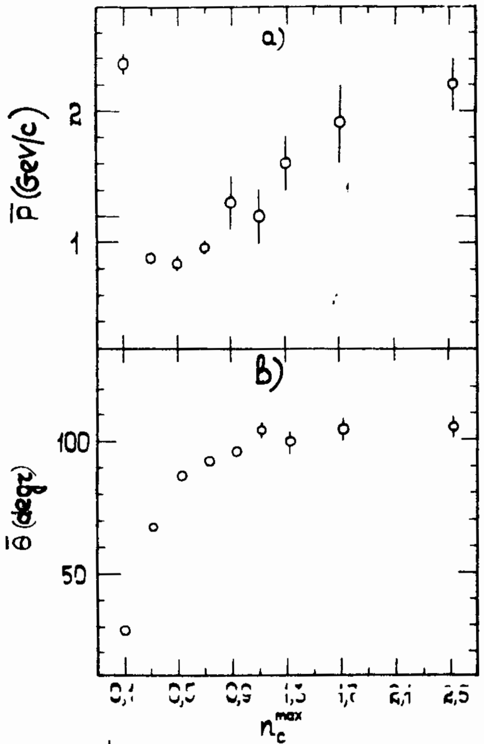


Fig.1. Dependence of the average momenta (a) and average emission angles (b) of π_c - mesons on n_c^{max} (see the text).

tonously and those of $\bar{\theta}$ go to the plateau (region II). The decrease of $\bar{P}$ and the increase of $\bar{\theta}$ in the region I are also observed for $\pi^{\pm}$-mesons ("accompanying" mesons) (fig.2a,c). The region I is also characterized by a significant increase of $\bar{n}$ with increasing n_c^{max} and a sharp shift of average rapidities $\bar{y}^*$ to the fragmentation of the target nucleus (fig.3,2b).

In the region II ($n_c^{max} \geq 0.6$) the values of $\bar{P}$, $\bar{\theta}$, $\bar{y}^*$ and $\bar{n}$ turn out to be independent of n_c^{max} (figs.2a-c,3). In this case the properties of π_a^+-mesons coincide with those of π_a^--mesons which, generally speaking, cannot be said about the region I. The difference in the average multiplicities of π_a^+- and π_a^--mesons is an exception to this. The latter is most likely due to the method of selection of the $\pi^- {}^{12}C$ interactions studied /6/.

For leading π-mesons no dependence of $\bar{P}$, $\bar{n}$ and $\bar{\theta}$ on n_c^{max} is obserbed over all the interval of the considered values of n_c^{max} (fig.4a-c). This is also true for the data on $\bar{P}$ and $\bar{n}$ for protons (figs.2a and 3).

3. RESULTS FOR EVENTS WITH π_b-MESONS

Two regions of the variable $n_c(4)$ are also observed at the analysis of $\pi^- {}^{12}C$ interactions in the version V2 (see Section 1) both for $\pi_a^{\pm}$ ("accompanying" mesons) and for $\pi_b^{\pm}$. The results for the dependence of $\bar{P}$, $\bar{\theta}$ and $\bar{n}$ on n_c for $\pi_b^{\pm}$-mesons are presented in fig.5 individually for events with $N_{\pi_b}=1$ and $N_{\pi_b} \geq 2$. As is seen from the figures, the value of $\bar{\theta}$ increases with increasing n_c in the region $n_c \lesssim 0.6$ (region I).

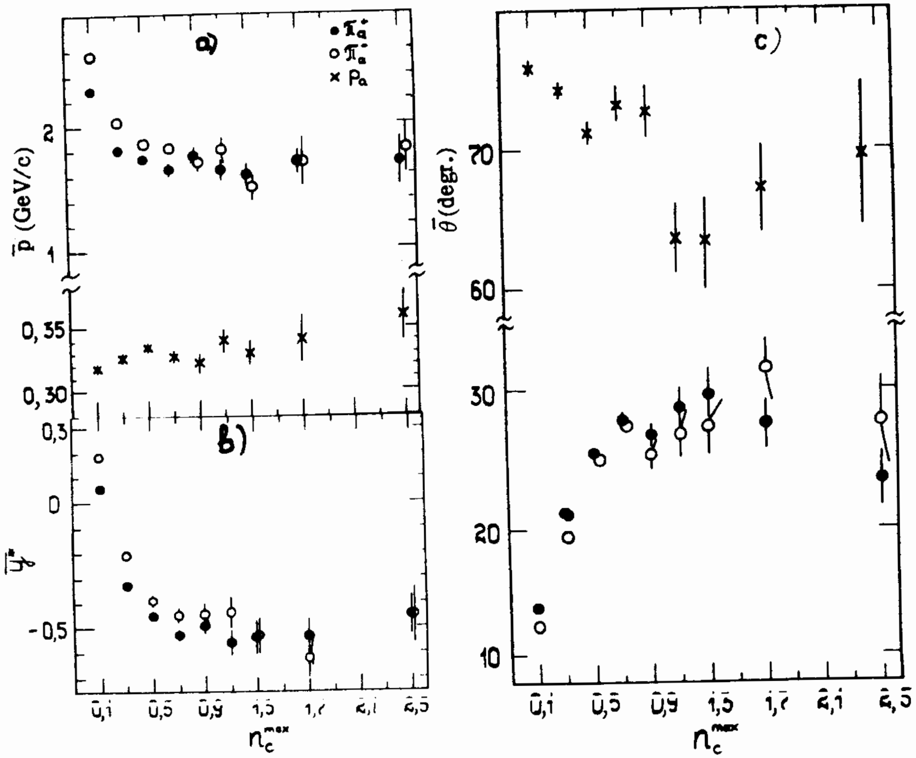


Fig.2. Values of $\bar{P}$ and $\bar{\theta}$ for $\pi^{\pm}$-mesons and protons vs n_c^{max} (values of $\bar{y}^*$ only for $\pi^{\pm}$).

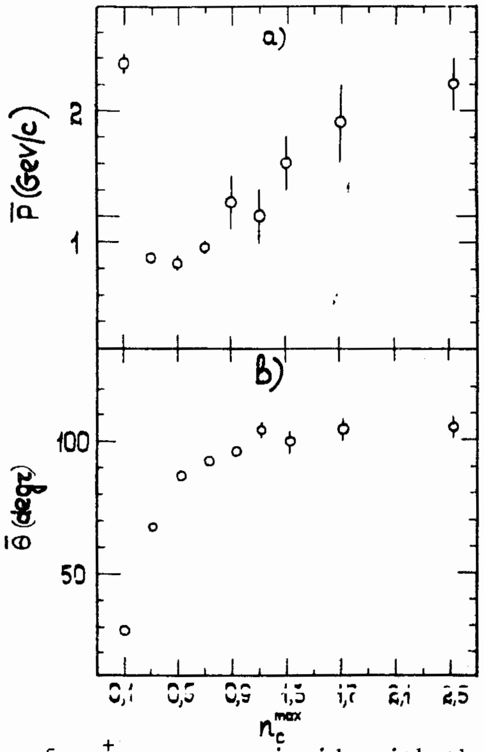
At a further increase of n_c , $\bar{\theta} \simeq$ const for the considered interactions (region II). In this region

$$(\bar{\theta}_{\pi_b^+} \simeq \bar{\theta}_{\pi_b^-})_{N_{\pi_b} \geq 2} \simeq (\bar{\theta}_{\pi_b^{\pm}})_{N_{\pi_b}=1} \quad . \qquad (5)$$

It is of importance that in the region I for events with $N_{\pi_b}=1$ the difference $R_n = \bar{n}_{\pi_b^+} - \bar{n}_{\pi_b^-} \simeq 0$ and in the region II $R_n > 0$.

Two regions of n_c are also observed for R_n ($R_n \simeq 0$ and $R_n > 0$) for events with $N_{\pi_b} \geq 2$. In distinction to the event with $N_{\pi_b} = 1$, the corresponding regions along the axis n_c are shifted by $\simeq 0.40$, i.e., by the minimum value of n_c for the event with $N_{\pi_b} \geq 2$.

The value of $\bar{P}$ for the events having $N_{\pi_b}=1$ coincides with that of $\bar{P}_{tot}$ calculated for the events having $N_{\pi_b} \geq 2$



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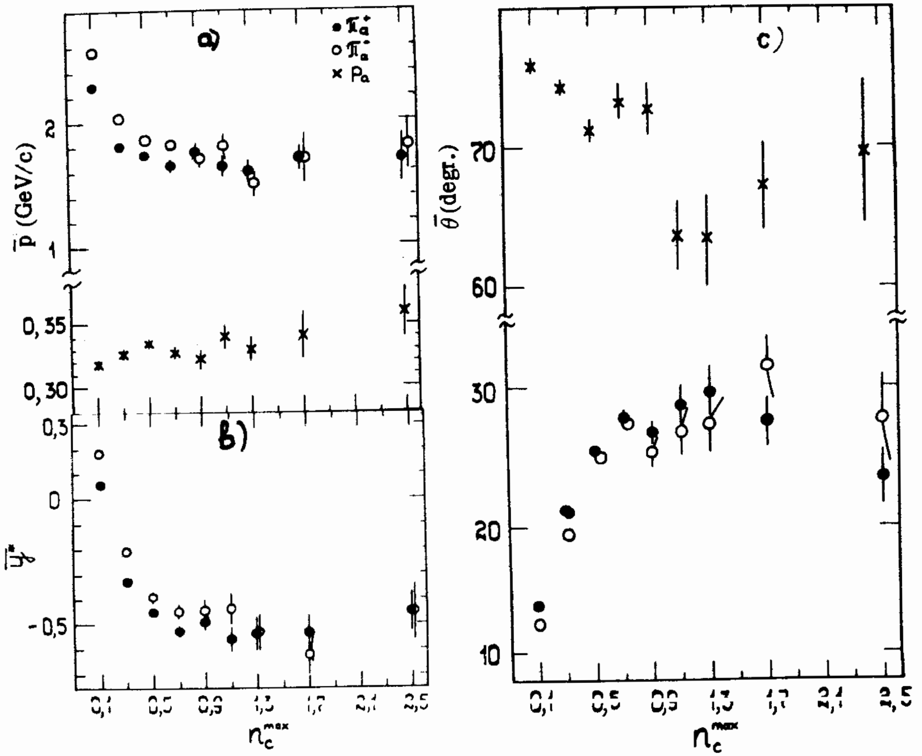

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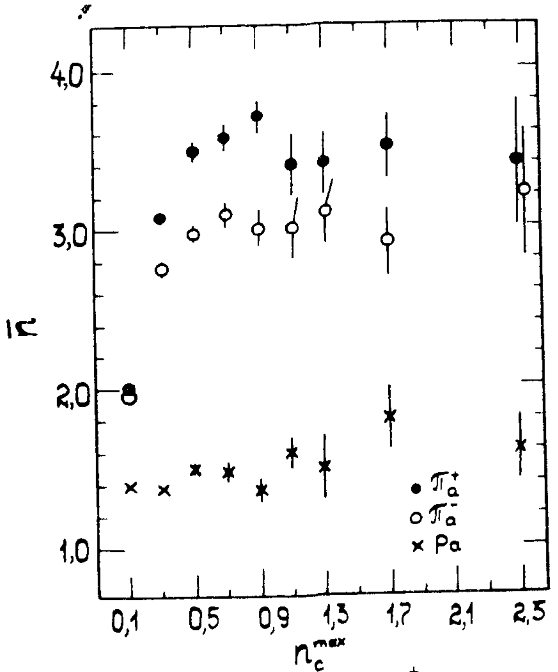

Fig.3. Average multiplicity of $\pi_a^{\pm}$-mesons and protons vs n_c^{max}.

by the formula:

$$\bar{P}_{tot} = \bar{n}_{\pi_b^+} \bar{P}_{\pi_b^+} + \bar{n}_{\pi_b^-} \bar{P}_{\pi_b^-} , \qquad (6)$$

i.e., it coincides with the momentum transferred to the group of π_b-mesons at a given value of n_c.

In the discussed version V2 of experimental data analysis the properties of leading particles turned out to be independent of n_c as in the case of the version V1.

4. ANGULAR DISTRIBUTIONS OF PROTONS

The angular distributions of protons have been investigated in the two regions of n_c^{max} (1) and n_c(4) (see above). In both cases in the angular distributions of protons from the events corresponding to the region II (n_c^{max} and n_c), the maximum is observed for $\cos\theta \simeq 0.5$. This is seen in the angular distributions of protons from the events having $\pi^{\pm}$-meson with

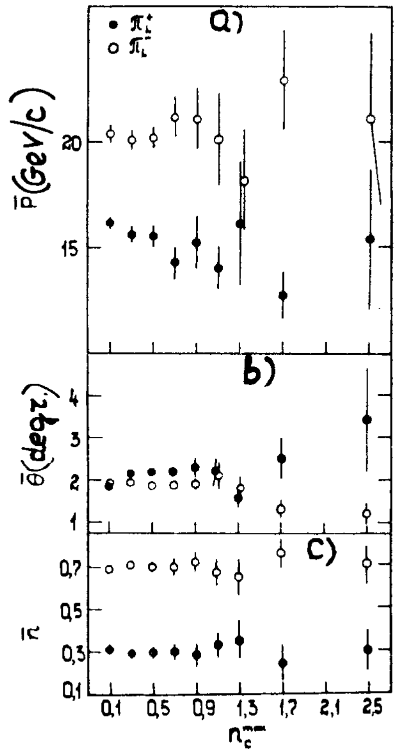

Fig.4. Properties of leading π-mesons versus n_c^{max}.

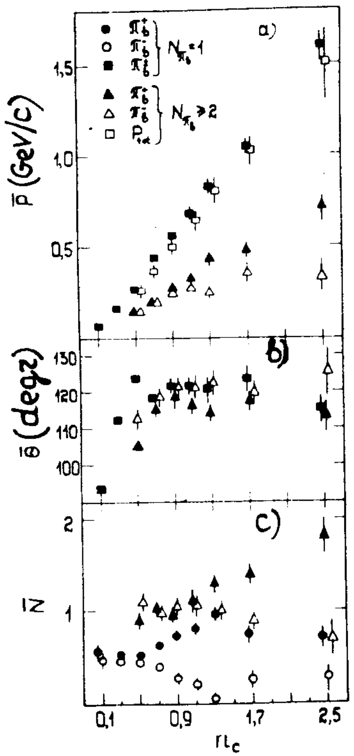

Fig.5. Properties of $\pi_b^{\pm}$-mesons versus n_c (see the text).

n_c^{max} >0.6 (fig.6b). The angular distribution of protons from the events corresponding to the region I (n_c^{max} <0.6) has no distinct anomalies (see fig.6a). As is known, the maximum in the angular distributions of protons at $\cos\theta \simeq 0.5$ has been observed in the events with complete disintegration of the carbon nucleus/7/. This can be interpreted as an evidence for the existence of multiparticle, collective phenomena which accompany the cumulative effect.

5. DISCUSSION AND CONCLUSIONS

The general properties have been analysed of $\pi^{\pm}$-mesons, produced in $\pi^{-}\,{}^{12}C$ interactions, which have the largest value of cumulative number (1) in each individual event ($\pi_c^{\pm}$), of $\pi^{\pm}$-mesons emitted into the backward hemisphere ($\pi_b^{\pm}$) and of "ac-

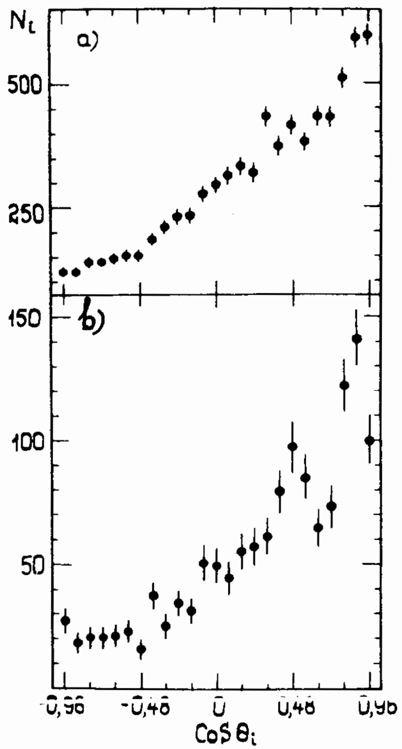

Fig.6. Angular distribution of protons in the laboratory system for $\pi^- \, ^{12}C$ interactions having $\pi^{\pm}$-meson with $n_c^{max} < 0.6$ (a) and $n_c^{max} > 0.6$ (b).

companying" $\pi^{\pm}$-mesons ($\pi_a^{\pm}$). According to all the considered parameters ($\bar{P}$, $\bar{\theta}$, $\bar{y}^*$, n), the two regions of n_c^{max} (1) and n_c (4) are observed with the boundary $n_c^{bound.} \simeq 0.6$ for n_c^{max} (or n_c): the region I with $n_c^{max}(n_c) < n_c^{bound}$. and the region II with $n_c^{max}(n_c) > n_c^{bound}$. The results obtained indicate the existence of two mechanisms at least which are responsible for the production of secondary π-mesons. The role of the mechanisms is different in the regions I and II.

As n_c^{max} (and n_c) increases, the properties of $\pi_a^{\pm}$-mesons in the region II are constant, this constancy extending to the region with $n_c^{max} > 1$. Thus, one of the main conclusions concerning the study of the particle distributions accompanying the cumulative effect is that the cumulative number $n_c = 0.6$ is the boundary on which there change the regimes of multiple particle production on nuclei. In the region with $n_c \geq 0.6$ the average multiplicities of the emission angles of secondary charged particles are larger and their average momenta are smaller than for all other events (see also /8,9/). This can be explained by the fact that in cumulative events there takes place the interaction with the target the mass of which is larger than the nucleon mass (flucton, cluster and so on). It should be noted that when passing from region I to region II, the relation between the numbers of π_b^+- and π_b^--mesons changes. If in the region I $R_n = \bar{n}_{\pi_b^+} - \bar{n}_{\pi_b^-} \simeq 0$, in the region II $R_n > 0$.

The obtained conclusion of the existence of the physically observed region of cumulative interactions justifies the problem of determining the cross sections of such processes. The Table* presents the results obtained using the criterion of n_c^{max} and n_c. The data for cumulative interactions (with n_c^{max} or $n_c > 1.0$) are shown in the same table.

*The event was assumed to be a cumulative one if it has secondary π-meson with $n_c^{max} > 0.6$ or $n_c > 0.6$ for π-mesons emitted into the backward hemisphere.

Table

Boundary for n_c^{max} (or n_c)	Number of events				Probability, %	σ(mb)
	$N_{\pi_b}=0$	$N_{\pi_b}=1$	$N_{\pi_b}\geq 2$	Sum		
0.6	362	529	319	1210	14.0±0.4	12.2±0.4
1.0	62	138	137	337	3.9±0.2	3.4±0.2

The fact itself of independence of the properties of $\pi_a^{\pm}$-mesons of n_c^{max} (or n_c) in the region II is rather amazing. Increasing the number of cumulativity, i.e., practically the number of nucleons which take part in the interaction, has no influence on the properties of all particles ($\pi_a^{\pm}$), except cumulative $\pi_c^{\pm}$ (or $\pi_b^{\pm}$). It turns out that there is a source, having strikingly equal properties independent of the number of interacting nucleons, for $\pi_a^{\pm}$-meson emission in cumulative interactions. As would be expected, the characteristics of π_a^+- and π_a^--mesons appear to be close to all the considered parameters.

The behaviour of leading π-mesons is of interest. Their properties ($\bar{P}$, $\bar{\theta}$, $\bar{n}$) appear to be independent both of n_c^{max} and of n_c, i.e., they do not "feel" the cumulative effect. Probably, it is difficult to explain this fact in the framework of the models based on the notions of central collisions in which the leading effect should be suppressed. On the other hand, it is difficult to understand this effect using the models of rescattering, of collision of incident hadron with nucleon having large fermion momentum and so on. The independence of the properties of leading mesons of n_c^{max} (n_c) is in good agreement with the fact that leading particles are produced from spectator quarks, which pass through the nucleus without interaction, and cumulative particles are the result of hard interaction of another quark of the incident pion.

The data of this paper agree with the conclusion drawn previously /7/ of anisotropy in the angular distribution of protons (maximum at an angle of $\simeq 60°$). This phenomenon is worthy of studying thoroughly as anisotropy can be due to the motion of the colour charge of this quark from the incident pion in nuclear matter which took no part in the hard collision.

The authors are grateful to the staff of the 2 m propane bubble chamber collaboration for the help in obtaining the material and discussions.

REFERENCES

1. Anoshin A.I. et al. JINR, P1-80-716, Dubna, 1980.
2. Anoshin A.I. et al. JINR, 1-81-214, Dubna, 1981.
3. Baldin A.M. Brief Comm. on Physics, 1971, No.1, p.35; Baldin A.M. ECHAYA, 1977, vol.8, 3, p.429; Stavinsky V.S. ECHAYA, 1979, vol.10, 5, p.449; Baldin A.M. et al. IV Int. Seminar on High Energy Physics Problems. JINR, D1,2-9224, Dubna, 1975.
4. Anoshin A.I. et al. JINR, P1-81-678, Dubna, 1981; YaF, 1982, vol.36.
5. Baldin A.M. JINR, E1-80-545, Dubna, 1980; Submitted to the XX Int. Conf. on High Energy Physics, Madison, USA, 1980.
6. Abdurakhimov A.U. et al. YaF, 1972, vol.16, p.989; Angelov N. et al. YaF, 1977, vol.25, p.1013.
7. Anoshin A.I. et al. YaF, 1981, vol.33, p.164.
8. Angelov N. et al. YaF, 1979, vol.29, 5, p.1227.
9. Anoshin A.I. YaF, 1980, vol.31, p.668.

Received by Publishing Department
on May 17 1982.

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Аношин А.И. и др. Корреляционные явления в множественном рождении частиц на ядрах в кумулятивной области — E1-82-352

В $\pi^-{}^{12}C$-взаимодействиях, отобранных на снимках с 2-метровой пропановой камеры, облученной π^--мезонами с P_{π^-} = = 40 ГэВ/с, изучены характеристики вторичных частиц, такие, как средние импульсы, средние углы вылета, средние быстроты, средние множественности, в зависимости от переменной, характеризующей порядок кумулятивности. Оказалось, что по всем исследуемым характеристикам четко выделяется область кумулятивных взаимодействий с границей по кумулятивному числу $n_c \simeq 0.6$. Обсуждаются замеченные особенности этих взаимодействий. Получено указание на наличие пика в угловом распределении протонов из этих событий /под углом $\theta \simeq 60°$ /, обнаруженного ранее при исследовании столкновений, сопровождающихся полным развалом ядра углерода.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1982

Anoshin A.I. et al. Correlation Effects in Multiple Particle Production on Nuclei in the Cumulative Region — E1-82-352

In $\pi^-{}^{12}C$ interactions selected on pictures from the 2 m propane bubble chamber exposed to 40 GeV/c π^--mesons, the following characteristics of secondaries have been studied: average momenta, average emission angles, average rapidities as functions of the variable which characterizes the order of cumulativity. It has been found that the region of cumulative interactions with the boundary n $\simeq 0.6$ is distinctly singled out for all the studied properties. The observed peculiarities of these interactions are discussed. An indication is obtained of a peak in the angular distribution of protons from these events (at an angle of $\theta \simeq 60°$) which has been previously obserbed in investigations of collisions accompanied by the complete disintegration of the carbon nucleus.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1982