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E1-81-470

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1981

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# OBSERVATION OF $\pi^-$-MESON CORRELATED EMISSION IN C-Ta INTERACTIONS AT $P_0$ = 4.2 GeV/c PER NUCLEON

*Submitted to "Physics Letters"*

1. During the last few years interest has grown in the study of relativistic nucleus-nucleus interactions. It is anticipated that collective-type [1,2] processes may be revealed while investigating characteristics of multiple pion production in these collisions.

In this paper we present a study of correlated $\pi^-$-meson production in the interactions of relativistic carbon nuclei with tantalum. The previous analysis of the $\pi^-\pi^-$ interference phenomenon in nucleus-nucleus interactions [3,4] has given an estimate of the size of the $\pi^-$-emission region. Many-particle correlations in like particle systems were studied earlier in hadron-hadron and hadron-nucleus interactions in terms of the R and C functions [5,6], as well as in terms of $\Delta q_{ij}$ [7] - four-momenta differences for particle pairs. It was found [8,9] that groups of several like mesons tend to be emitted, as a rule, in a more narrow cone than that for unlike ones. This was attributed [7] to the Boze-effects in many-meson systems. So in [5,8,9] $3\pi^-$ and $4\pi^-$ correlations were considered to be implied by the well-studied two-particle correlations.

2. The data for this analysis have been obtained from an experiment with the LHE JINR 2-m propane bubble chamber having three 1 mm thick tantalum (A=181) plates inside the chamber volume [10]. It was exposed to the beam of $^{12}C$ nuclei at an incident momentum of 4.2 GeV/c per nucleon. The sample comprised 1228 inelastic C-Ta interactions. The average $\pi^-$ multiplicity in these events was $\langle n_- \rangle = 3.2 \pm 0.1$, while the dispersion was $D_-^2 = 8.4 \pm 0.4$ [11]. In 675 events two or more $\pi^-$ were produced.

All negative particles, except identified electrons, were considered as $\pi^-$ mesons. The misidentified electron contamination did not exceed 5% [12]. The average momentum beyond which $\pi^-$ mesons were reliably identified was $P_{min} = 80$ MeV/c.

We have analyzed the $M_{n\pi}$ effective-mass spectra of $n\pi^-$ ($n = 2$, 3, 4) systems. It is obvious that small effective masses correspond to small values of the momenta differences of the particles involved, hence our method is a modification of the $\Delta q_{ij}$ -analysis [7] of many-particle correlations.

We would like to note that in our experiment the average magnitude of the momenta difference for all possible pairs of $\pi^-$ mesons $|\Delta \vec{P}_{ij}| = |\vec{P}_i - \vec{P}_j|$ does not exceed 200 MeV/c in the range of small values of $M_{n\pi}$, where, as described below, we have observed the correlation phenomena.

The bin width of the $M_{n\pi}$ distribution was chosen equal to the average value of the experimental resolution ($\Delta M_{n\pi}$) for the masses of $n\pi^-$ meson systems in the range of $M_{n\pi} \lesssim \langle M_{n\pi} \rangle$.

To determine the value of $\Delta M_{n\pi}$ we obtained the distribution of the deviations of the simulated $M_{n\pi}$ values from the experimental ones. The momenta and angles of the particles involved were repeatedly simulated within their experimental errors according to the Gaussian distribution. The obtained resolution was $\Delta M_{n\pi}$=(20, 40 and 60) MeV for n =2, 3 and 4, respectively.

The background $M_{n\pi}$ distributions were obtained by combining $\pi^-$ mesons taken randomly from different events. It is important to take into consideration that angular and momentum distributions of $\pi^-$ mesons depend on the number of $\pi^-$ mesons produced. For instance, in the events with $n_- \leq 3$ the average momentum is $\langle P_{\pi^-} \rangle = (570 \pm 20)$ MeV/c, while for $n_- \geq 6$, $\langle P_{\pi^-} \rangle = (430 \pm 10)$ MeV/c, i.e., the momentum spectrum appreciably softens. With this respect the random selection was made in a special way. The background distribution was made up as a sum of contributions from every group of events with a certain $n_-$.

Each contribution contained 50000 combinations weighted proportionally to the contribution of the events of this group to the experimental $M_{n\pi}$ distribution. Let us denote this procedure "the respect of $\pi^-$ topology". Finally the background distributions were normalized in such a way that beyond some boundary value of mass ($M^b_{n\pi}$) the integrals of the background and the experimental distributions should be equal. The $M^b_{n\pi}$ was chosen so that its further increasing did not alter the signal to the background ratio.

3. In fig. 1 and table 1 we present the values of the ratio of the experimental to the background distributions $R_n = M^{exper.}_{n\pi} / M^{backgr.}_{n\pi}$ for $n\pi^-$ meson systems versus $M_{n\pi}$. Tests of three versions of background are presented. The first one ("1+1+..."), "the respect of $\pi^-$ topology" applied, contains combinations made up of $\pi^-$ mesons all being taken randomly from different events. The second version of background ("(n-1)+1") differs from the first one in the way that only one of $n\pi^-$ mesons is taken from another event (for n =3 and 4). In the third case (see table 1) $\pi^-$ mesons are taken from different events without "the respect of $\pi^-$ topology". In all the three cases the experimental distributions exceed the background in the range of small effective masses. The effect is more pronounced for higher n. It is also seen that when the background is accounted for the softening of the momentum distributions with growing

## Table 1

Ratio of the experimental to the background distributions $\left( R_n = M_{n\pi}^{exper.} / M_{n\pi}^{backgr.} \right)$ for different versions of background. The value of the experimental effective mass resolution is taken as a bin width (20, 40 and 60 MeV for n =2, 3, 4). The errors $R_n$ are purely statistical which are calculated according to the number of combinations per interval in the experimental distribution.

| Back-ground | "1+1+..." | | | "(n-1)+1" | | Without the "$\pi^-$-topology" | | |
|---|---|---|---|---|---|---|---|---|
| Inter-val | 2 | 3 | 4 | 3 | 4 | 2 | 3 | 4 |
| I | I,23±0,06 | 2,I8±0,20 | 3,35±0,53 | I,47±0,I3 | I,93±0,30 | I,39±0,07 | 2,56±0,23 | 4,89±0,77 |
| 2 | I,09+0,05 | I,46+0,07 | I,57+0,09 | I,25+0,06 | I,49+0,08 | I,I9+0,05 | I,8I+0,09 | 6,53+0,37 |
| 3 | I,00±0,04 | I,23±0,04 | I,I4±0,04 | I,I9±0,04 | I,30±0,05 | I,I8±0,05 | I,48±0,05 | 4,45±0,I6 |
| 4 | I,05±0,04 | I,0I±0,03 | 0,93±0,03 | 0,99±0,03 | I,I4±0,03 | I,I8±0,05 | I,22±0,04 | 2,39±0,07 |
| 5 | 0,92±0,04 | I,07±0,03 | 0,89±0,02 | I,07±0,03 | I,07±0,02 | 0,99±0,04 | I,24±0,03 | 2,I2±0,05 |
| 6 | 0,95±0,04 | I,08±0,03 | I,00±0,02 | I,07±0,03 | I,I5±0,02 | I,05±0,04 | I,20±0,03 | I,97±0,04 |
| 7 | 0,96±0,04 | I,08±0,03 | 0,98±0,02 | I,06±0,03 | I,II±0,02 | I,0I±0,04 | I,I7±0,08 | I,72±0,03 |
| 8 | I,08±0,05 | I,II±0,03 | I,0I±0,02 | I,II±0,03 | I,09±0,02 | I,I5±0,04 | I,I9±0,03 | I,48±0,03 |
| 9 | I,02±0,05 | I,06±0,03 | I,05±0,02 | I,06±0,03 | I,08±0,05 | I,08±0,05 | I,08±0,03 | I,35±0,03 |
| I0 | I,0I±0,05 | I,00±0,03 | I,06±0,02 | 0,99±0,03 | I,07±0,02 | I,07±0,05 | I,00±0,03 | I,I9±0,03 |

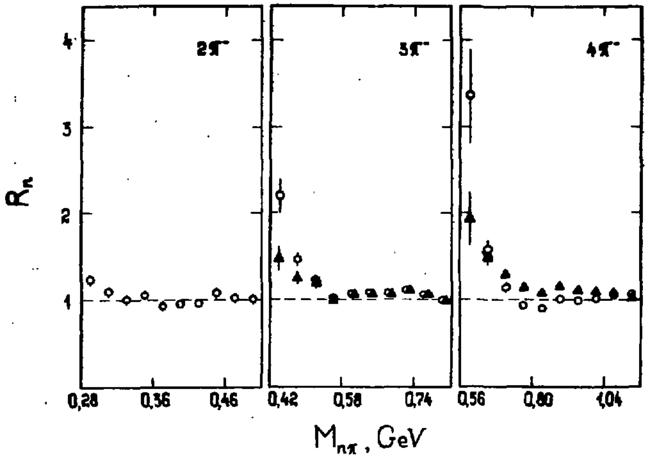


Fig. 1. Ratio of the experimental to the background distributions $R_n = M_{n\pi}^{exper.}/M_{n\pi}^{backgr.}$ for 2-, 3- and 4-$\pi^-$ meson systems for two versions of background (O - for background "1+1 ..." when all $n\pi^-$ mesons of the system are taken from different events, ▲ - for background "(n -1)+1" when ( n-1)$\pi^-$ mesons are taken from one event and one $\pi^-$ meson from another. In both cases "$\pi^-$-topology" is taken into account.

n_ using the above described procedure, the relative magnitude of the effect becomes smaller.

The observed effect indicates the existence of correlations in the emission of $2\pi^-$, $3\pi^-$ and $4\pi^-$mesons produced in C-Ta interactions at 4.2 GeV/c per nucleon.

In table 2 we present the average values of emission angle $\langle\theta_{n1}\rangle$ of $\pi^-$ meson with respect to the direction of the momentum of the whole system of $n\pi^-$mesons in the region $M_{n\pi} \leq \Delta M^*_{n\pi}$, where the effect is seen.

The fact that the effect is seen against the background of the "(n -1)+1" - type indicates that there exist nontrivial $3\pi^-$ and $4\pi^-$ meson correlations which are not a simple consequence of the known $2\pi^-$ and $2\pi^-$ meson correlations, respectively. Such a result was predicted in /17/, where it was argued that 2-particle correlations can account for only 1/2 (n -2)! part of the interference peak at $\vec{P}_1 = \vec{P}_2 = \ldots = \vec{P}_n$.

## Table 2

The average values of emission angle $\langle\theta_{ni}\rangle$ of $\pi^-$ meson with respect to the direction of the momentum of the whole system of $n\pi^-$ mesons in the region $M_{n\pi} \le M^*_{n\pi}$

| n | 2 | 3 | 4 |
|---|---|---|---|
| $\langle\theta_{ni}\rangle$, rad | 0,252±0,005 | 0,451±0,006 | 0,514±0,006 |

4. Interference effects for the like-particle systems essentially depend on the dynamics of relativistic nuclei interaction process. Many characteristics of nucleus-nucleus collisions are satisfactorily described by the models /13/ considering the collision of nuclei as a superposition of nucleon-nucleon interactions. At our energies in NN interactions the cross section for production of two and more $\pi^-$ does not exceed several per cent of the inelastic cross section /14/, the main part of which consists of the $\Delta_{33}$ production processes. The $\pi^-$ mesons from the decay of $\Delta_{33}$ should have small transverse momenta. All these facts favour the appearance of correlations in the like-particle systems.

In fig. 2 the $P_T^2$ distribution for $\pi^-$ mesons produced in C-Ta interactions at 4.2 GeV/c per nucleon is shown along with the slope parameters of the two-exponential fit.

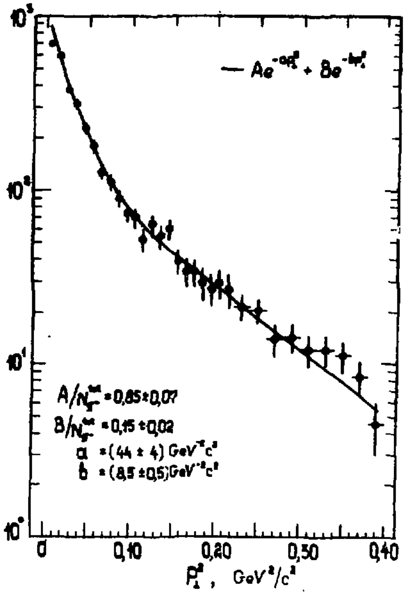


Fig.2. The $P_T^2$ distribution for $\pi^-$ mesons produced in C-Ta interactions at 4.2 GeV/c per nucleon.

Note that for $\pi^-$ mesons which contribute to the range of small masses $M_{n\pi} \le M^*_{n\pi}$ the $P_T^2$ distribution is well fitted by a single exponential with the slope parameter close to that for the first exponential in fig. 2 ($a = (4[illegible] \pm 2)\ GeV^{-2}c^2$, $(43 \pm 2)\ GeV^{-2}c^2$, $(46 \pm 4)\ GeV^{-2}c^2$ for $n = 2,3,4$ respectively).

5. Thus, in the inelastic C–Ta interactions at 4.2 GeV/c per nucleon the correlated emission of $\pi^-$ mesons is observed. The experimental distributions of $2\pi^-$, $3\pi^-$ and $4\pi^-$ meson effective masses exceed the background in the region of small masses. The effect is revealed independent of the procedure by which the background is obtained. In the region of small masses the main contribution comes from the $\pi^-$ mesons with low $P_T$.

Correlations in $3\pi^-$ and $4\pi^-$ meson systems cannot be explained by $2\pi^-$ and $3\pi^-$ meson correlations.

The authors are indebted to express their gratitude to M.I.Podgoretsky for valuable discussions.

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Received by Publishing Department
on July 10 1981.