ACADEMY OF SCIENCES OF THE USSR

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DIFFRACTION GENERATION OF PARTICLES IN COHERENT PION-NUCLEUS INTERACTIONS AT 200 GEV/C.

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ABSTRACT

The total and topological cross-sections in reactions of coherent diffractive dissociation of 200 Gev/c π^--mesons off photoemulsion nuclei have been measured and cross-sections for the channels $\pi^- \xrightarrow{A} 3\pi^\pm$, $\pi^- \xrightarrow{A} 5\pi^\pm$ were estimated. The energy dependence of cross-sections for various channels of inelastic coherent diffraction off nuclei and invariant mass distribution of produced $3\pi^\pm$ system have been investigated. The topological cross-sections increase in the range from 40 to 200 Gev/c. This growth is the most noticeable for multiprong topologies. The cross-section of the exclusive channel $\pi^- \to 2\pi^- + \pi^+$ does not depend on incident particle momentum in the range 40 - 200 Gev/c. The topological cross-sections of coherent reactions increase with the energy due to the openning channels with larger numbers of neutral particles. Mass spectrum of $3\pi^\pm$ system in the coherent reaction $\pi^- \xrightarrow{A} 2\pi^- + \pi^+$ weakly depends on the energy.

1. INTRODUCTION

There is the indubitable interest in a study of diffractive coherent dissociation of hadrons off nuclei due to the increasing role of inelastic diffractive processes with a growth of incident energy. In this paper the experimental data of coherent pion-nucleus interactions at 200 Gev/c are presented and discussed including topological cross-sections, multiplicity distribution of charged secondaries, mass spectrum of diffractively produced systems and so on. The preliminary results on cross-sections of such reactions based on a part of experimental material were published earlier /1/.

2. EXPERIMENTAL SELECTION of COHERENT REACTIONS

This experiment was carried out in nuclear emulsions exposed to 200 Gev/c negative pions at the Fermilab accelerator. By systematic "along the track" scanning on the effective length of 3.37 km 1659 inelastic events have been recorded and measured. All this events satisfy to the necessary criteria of interactions with the free and quasifree nucleons in an emulsion (a) there is not more then one heavily ionising track of a proton with kinetic energy $T > 25$ Mev and angle of emission in the laboratory sistem $\theta < \frac{\pi}{2}$; (b) the absence of recoil nucleus at any (n) number of charged secondaries and of β-electrons at the even n; (c) the lower limit of the target mass $M_t^{min} < m_N$, where m_N is the mass of a nucleon).

The reactions of coherent dissociation of pions

$$\pi^- \xrightarrow{A} \pi^- + n_o\pi^\circ, \qquad (1)$$

$$\pi^- \xrightarrow{A} 2\pi^- + \pi^+, \qquad (2)$$

$$\pi^- \xrightarrow{A} 2\pi^- + \pi^+ + n_o\pi^\circ, \qquad (2')$$

$$\pi^- \xrightarrow{A} 3\pi^- + 2\pi^+ + n_o\pi^\circ, \qquad (3)$$

$$\pi^- \xrightarrow{A} 3\pi^- + 2\pi^- + n_o\pi^\circ, \qquad (3')$$

$$\pi^- \xrightarrow{A} 4\pi^- + 3\pi^+ + n_o\pi^\circ \qquad (4)$$

and so on (n_o= 2 ,4 ,...; A - nucleus having A nucleons) have been selected among the odd-prong (n = 1, 3,...) events of type 0 + 0 + n without any symptoms of excitation or desintegration of the target, following the method developed in the reference/ 2 /, that, for instance, was used in a number of works on coherent production of particles by protons at Serpukhov and Batavia energies/ 3 /.

At high energies ($p_o, p_i \gg \mu$, $\cos\theta_i \approx 1$) the longitudinal momentum q_l transferred to a target in reactions (1) - (4) with high accurasy could be expressed by the simple function of the emission angles of secondary particles

$$q_l \simeq \frac{1}{2}\sum_{i=1}^{n+n_o}\left(P_{t_i} + \mu^2/P_{t_i}\right)\sin\theta_i \approx C_1 \sum_{i=1}^{n+n_o}\sin\theta_i \qquad (5)$$

where n_o is the number of neutral secondaries (recoil nucleus is not included in this number), μ is the mass of a pion, p_t is the transverse momentum of i-th particle. $C_1 = [\langle p_t\rangle + \pi\mu^2/(2\langle p_t\rangle)]/2$ if the inclusive p_t-distribution in diffractive dissociation has a form $p_t \exp(-\alpha p_t^2)$. If the summation in eq.(5) is taken over the charged particles only and $n_o > 0$, the formula (5) gives the lower limit of q_l.

Fig. 1a. shows, as the examples, distributions of the quantity

$\Sigma \equiv \sum_{i=1}^{n} \sin\theta_i$ for the "clean" and background 3-prong events. The latter group consists of 3-prong πn-reactions with the evident β-electron at the top of a star and the "artificial" events of type 0 + 0 + 3 obtained from 4-prong stars by ignoring the prong with the maximum emission angle. To subtract these distributions we have normalized the Σ-distributions for both groups in the range $\Sigma > \Sigma^{max}$, where Σ^{max} is the conditional upper limit considered as a parameter of Σ-distribution for reactions (2'), and then one can define the true number $N_{coh}^{(3)}$ of three-prong reactions (2) and (2') in accordance with the height of the plateu reached by the function $N_{coh}(\Sigma^{max})$. The same procedure was used for other n ; the dependences of $N_{coh}^{(n)}$ on Σ^{max} for n = 3, 5 and 7 are plotted in Fig. 1b.

The numbers of coherent reactions (2), (2') and (3), (3') defined in such a way equal to $N_{coh}^{(3)} = 220 \pm 30$ and $N_{coh}^{(5)} = 34 \pm 9$ respectively. The result for n = 7, $N_{coh}^{(7)} = 9 \pm 5$, should be considered only as an indication of the channel with 7 charged particles in the final state; at n = 9 there are no any indications of the coherent reactions.

There is no the significant difference between emission angles of secondary particles in the "clean" and background events of the type 0 + 0 + 1; following the paper /3/ we have estimated the lower limit of $N_{coh}^{(1)}$ for the reaction (1) from the multiplicity distribution (Fig.2). Introducing further corrections on the loss of one-prong events at the scanning(by using the azimutal isotropy of one-prong events) and on the coherent events in the "elastic" region $\theta \leq 2$ mrad (by asuming the singularity of angular distributions of secondaries in reactions (1) and

(2)), one can obtain the estimation of the number of one-prong coherent events $N^{(1)}_{coh} \approx 85$ with the statistical errow about 30%.

The data on the numbers of coherent events, corresponding to the topological channels of dissociation $\pi^- \xrightarrow{A} n$ prongs, the mean free paths $\lambda^{(n)}_{coh}$ in emulsion and the average cross-sections $\sigma^{(n)}_{coh}$ (on the conditional average nucleus of emulsion with $A = 47$) are presented in the Table 1.

The estimation of cross-sections for the reactions (2), (3) without neutral pions in the final state can be obtained from analysis of the azimutal asymmetry in 3-prong and 5-prong quasicoherent events. In fact, the restriction $q_\perp \lesssim \mu$ ($q_\perp$ is the transverse momentum transferred to the target) in the coherent reactions may be rewritten in the form

$$q_\perp = \Big[\Big(\sum_{i=1}^{n+n_0} P_{t_i} \sin\varphi_i\Big)^2 + \Big(\sum_{i=1}^{n+n_0} P_{t_i} \cos\varphi_i\Big)^2\Big]^{\frac{1}{2}} \simeq \langle P_t \rangle \big[n + n(n-1)\langle \cos\mathcal{E} \rangle\big]^{\frac{1}{2}} \lesssim \mu \quad (6)$$

where φ_i is the azimutal angle of i-th particle, $\mathcal{E}_{ij} = \varphi_i - \varphi_j$ ($i \neq j$), $\langle \cos\mathcal{E} \rangle$ - the average value of $\cos\mathcal{E}_{ij}$ in an event.

It follows from the eq.(6) that in coherent reactions (2), (3) without neutral pions the coefficient of azimutal asymmetry $\langle \cos\mathcal{E} \rangle = \sum_{i \neq j} \cos\mathcal{E}_{ij} / [n(n-1)]$ must be small.

$$\langle \cos\mathcal{E} \rangle \leqslant \left(\mu^2 / \langle P_t \rangle^2 - n\right) / [n(n-1)] , \quad (7)$$

wheras at $n_0 \neq 0$ the quantity $\langle \cos\mathcal{E} \rangle$ becomes spread-out over the whole kinematically acceptable interval from $-1/(n-1)$ (the case of symmetrical emission, when the azimutal angles between neighbouring particles equal to $2\pi/n$) up to 1 (the case of asymmetrical emission when all $\mathcal{E}_{ij} = 0$). It should be noted, however, that the inequality (7) has only the approximate character and is sensible to the measurements biases, significant especially for the narrow stars.

Fig.3. exemplifies $\langle \cos\mathcal{E} \rangle$-distributions for the "clean" and background 3-prong events having $\sum_{i=1}^{3} \sin\theta_i < 0.06$. It is seen that there is the noticeable maximum at the left-hand end of $\langle \cos\mathcal{E} \rangle$-distribution for the former group of events.We have simulated by the Monte Carlo method the reactions (2),(2') and the relevant quasinucleon interactions (the curve in the Fig.3. represents the results of simulation for the last reactions) and thus the number of coherent reactions (2) was estimated to be 105 ± 25. The similar analysis of azimutal asymmetry in 5-prong coherent events gives the number of events,corresponding to the reaction (3),equal to 25 ± 9. The data on reactions (2) and (3) are presented in the Table 1 as well.

3.DISCUSSION OF EXPERIMENTAL RESULTS

The data on topological cross-sections of the reactions $\pi^- \xrightarrow{A}$ n prongs allow to obtain information on the multiplicity distribution in inelastic diffraction of hadrons. This information is interesting, in particular, in connection with the so called two-component models of multiple production. It should be noted that that the obtaining of experimental data on diffraction component in hadron-hadron collisions meets difficulties, especially in the region of large masses of produced systems. On another hand, multiplicity distribution in coherent reactions can be connected by means of a model (the Glauber model, for instance) with that in inelastic dissociation on nucleons.

Fig.4. shows multiplicity distributions of charged particles in diffractive coherent interactions of pions and protons with emulsion nuclei at the same momentum $p_{\circ}$ = 200 Gev/c(the proton data obtained in exactly the same manner were taken from the paper /3/), and the Table 2 presents some parameters of these distributions. One can see that multiplicity distributions in proton and pion induced dissociation have somewhat different widths. n-distribution in the case of π^--meson induced reactions is narrower than in pA coherent reactions (the probability of the agreement of distributions in Fig.4. is $\lesssim 0.02$). This difference if it will be supported by more precize experiments, may be explained by the phase-space arguments with the account of G-parity conservation with the reactions $\pi^- \rightarrow n\pi^{\pm} + n_0\pi^0$, that means the total multiplicity of secondary particles $(n + n_0)$ can grow only across two units. Distributions in Fig.4. are narrower than the Poisson distribution ($f_2 < 0$); for proton induced coherent reactions this fact as well as the consistence with the KNO scaling hypothesis in the range 20 - 200 Gev was pointed out in the paper /4/.

The data from Table 1 allow to check some relations between the cross-sections of different channels of diffractive dissociation of pions, following from the assumption that all the projections of isospin in the intermediate state have equal probabilities (the statistical isospin model). For instance, the ratio of cross-sections of the reactions (1) and (2) equal to 0.8 ± 0.3 agrees satisfactorily with the prediction of this model: $\sigma(\pi^- \rightarrow \pi^- + 2\pi^0)/\sigma(\pi^- \rightarrow 3\pi^{\pm}) = 0.72$. The ratio of cross-sections of reactions (2') and (3) equal to 4.6 ± 2.4 does not contradict the prediction $\sigma(\pi^- \to 2\pi^- + \pi^+ + 2\pi^0)/\sigma(\pi^- \to 3\pi^- + 2\pi^+) = 2.3$, if one take into account the possible contribution of the reaction $\pi^- \to 2\pi^- + \pi^+ + 4\pi^0$ in (2') ($\sigma(\pi^- \to 2\pi^- + \pi^+ + 4\pi^0)/\sigma($[illegible]$) = 2.1$ in the model).

Topological cross-sections in the studied reactions as well as cross-sections of the exclusive reactions (2),(3) are shown in Fig.5. as function of the incident energy. The data at 17, 45 and 60 Gev were taken from /2,5/. One can see that topological cross-sections increase in the energy range from 17 to 200 Gev due to the openning channels with larger total multiplicities. The cross-section of the reaction $\pi^- \xrightarrow{A}$ 3 prongs in the range 40 - 200 Gev increases through exclusive channels with neutral pions since the cross-section of the reaction (2) is constant in this energy range. It should be noted, that analogical behavior of topological cross-sections was observed in coherent reactions induced by protons in the range 20 - 400 Gev. /6/

In conclusion let us consider the invariant masses of $3\pi^{\pm}$ system produced in the exclusive coherent reaction (2), estimated in the present work by the method suggested in the paper /7/.

There is the simple kinematical relation between the mass M_{inv} and longitudiual (q_l) and transverse (q_t) components of momentum transferred to the target

$$M_{inv}^2 \simeq 2p_0 q_l + \mu^2 - \left(1 + \frac{p_0}{M_A}\right) q_t^2 \qquad (8)$$

where M_A is the mass of target-nucleus, p_0 - momentum of the incident particle in the laboratory system. Using the estimations of q_l and q_t (eq.(5) and (6), respectively) based on angular measurements, one can obtain the estimation of M_{inv} in coherent events without neutral particles in the final state

$$M_{inv}^2 \simeq p_0 \mu \left(\frac{\langle p_t \rangle}{\mu} + \frac{\pi \mu}{2 \langle p_t \rangle} \right) \sum_{i=1}^{n} \sin \theta_i - \left(1 + \frac{p_0}{M_A}\right) \langle p_t \rangle^2 \left[\left(\sum_{i=1}^{n} \sin \varphi_i \right)^2 + \left(\sum_{i=1}^{n} \cos \varphi_i \right)^2 \right] \quad (9)$$

where θ_i, φ_i are the emission angles of secondary pions.

Fig.6. shows distribution of invariant masses of $3\pi^{\pm}$ system, obtained following the formula (9) in the exclusive coherent reaction $\pi^- \xrightarrow{A} 2\pi^- \pi^+$. For comparision we have plotted, with the relevant normalization, the data obtained in the paper /8/ for the coherent reactions $\pi^- \xrightarrow{A} 2\pi^- \pi^+$ at 16 Gev/c on a variety of nuclei.

One can see that the spectrum of M_{inv} of $3\pi^{\pm}_{2}$ system depends on the incident energy weakly, although M_{inv} increases slightly in the range 16 - 200 Gev/c. This fact is consistent with the weak energy dependence of the cross-section of the exclusive reaction $\pi^- \xrightarrow{A} 3\pi^{\pm}$,that reaches the plateau at $\sim$ 40 Gev/c

4. CONCLUSIONS

From the present study of coherent reactions we have conclude that:

1. The total and topological cross-sections of diffractive coherent production by pions on emulsion nuclei increase in the range 17 - 200 Gev/c. This growth is the most noticeable for multiprong topologies.
2. Topological cross-sections of coherent reactions increase with the energy due to the openning channels with larger total multiplicities.

3. Multiplicity distribution in coherent reactions $\pi^- \to$ n prongs seems to be somewhat narrower than in p $\to$ n prongs at the same energy of projectile.

4. The cross-section of the exclusive channel $\pi^- \to 2\pi^- \pi^+$ does not depend on energy in the range ~ 40 - 200 Gev.

5. Mass spectrum of $3\pi^{\pm}$ system in the reaction $\pi^- \to 2\pi^- \pi^+$ weakly depends on the energy.

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TABLE I. The summary data on the numbers of coherent events, mean free path in emulsion and the average cross-sections for the topological channels of dissociation of negative pions at 200 Gev/c.

66

Channel	$N^{(n)}_{coh}$	$\lambda^{(n)}_{coh}$, m	$\bar{\sigma}^{(n)}_{coh}$, mbn/nucleus
$\pi^- \xrightarrow{A} 1$ prong	85 ± 25	40^{+16}_{-9}	5.2 ± 1.5
$\pi^- \xrightarrow{A} 3$ prongs	220 ± 30	$15.3^{+2.4}_{-1.8}$	13.5 ± 1.8
$\pi^- \xrightarrow{A} 5$ prongs	34 ± 9	99^{+36}_{-21}	2.1 ± 0.5
$\pi^- \xrightarrow{A} 7$ prongs	9 ± 5	375	0.5 ± 0.3
$\pi^- \xrightarrow{A} n$ prongs ($n = 1 \div 7$)	348 ± 45	$9.7^{+1.4}_{-1.1}$	21.3 ± 2.8
$\pi^- \xrightarrow{A} 3\pi^\pm$	105 ± 25	32^{+10}_{-6}	6.4 ± 1.5
$\pi^- \xrightarrow{A} 5\pi^\pm$	25 ± 9	135^{+75}_{-36}	1.5 ± 0.5

TABLE II. The moments of multiplicity distributions of charged particles in reactions of diffractive dissociation of pions and protons on emulsion nuclei at 200 Gev/c.

Projectile	$\langle n \rangle$	$\langle n(n-1) \rangle$	$[\langle n^2 \rangle - \langle n \rangle^2]^{1/2}$	f_2
π	2.81 ± 0.09	6.8 ± 0.5	1.32 ± 0.15	−1.1 ± 0.6
p	2.61 ± 0.07	6.6 ± 0.4	1.56 ± 0.14	−0.2 ± 0.5

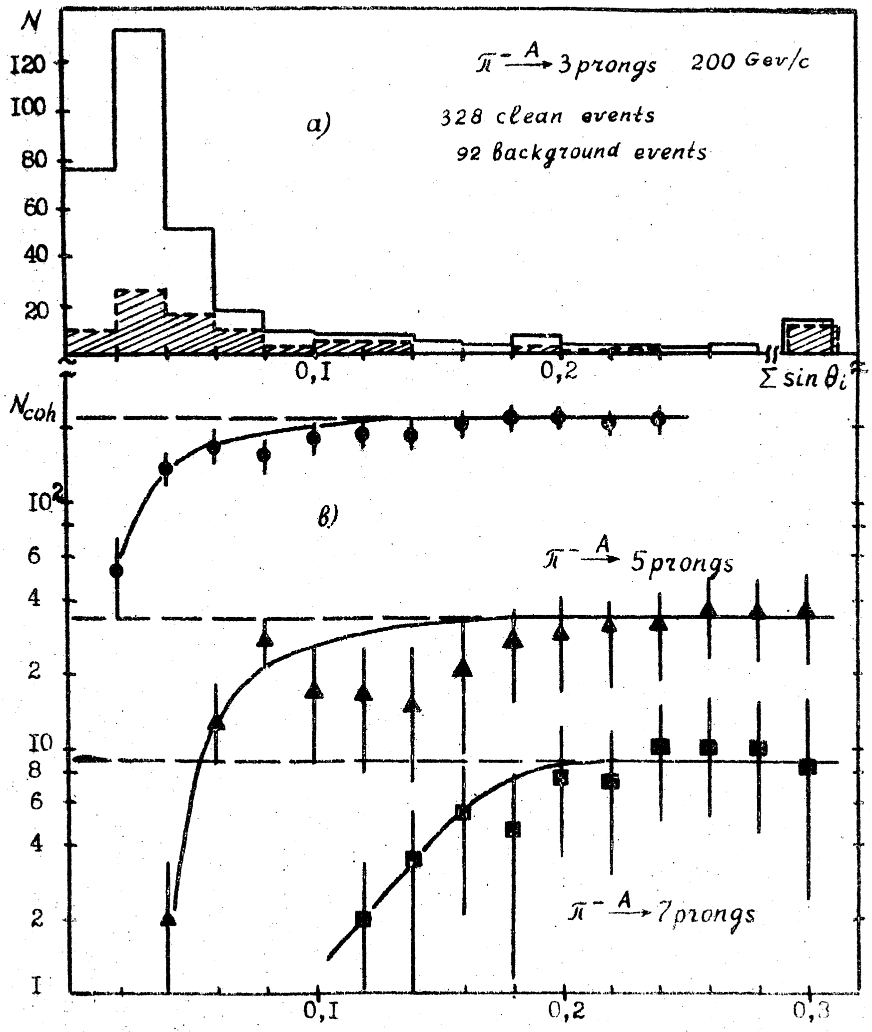

N
120
100
80
60
40
20
a)
π⁻ —A→ 3 prongs 200 Gev/c
328 clean events
92 background events
0,1
0,2
Σ sin θᵢ
N_coh
10²
6
4
2
10
8
6
4
2
1
в)
π⁻ —A→ 5 prongs
π⁻ —A→ 7 prongs
0,1
0,2
0,3

Fig.1.

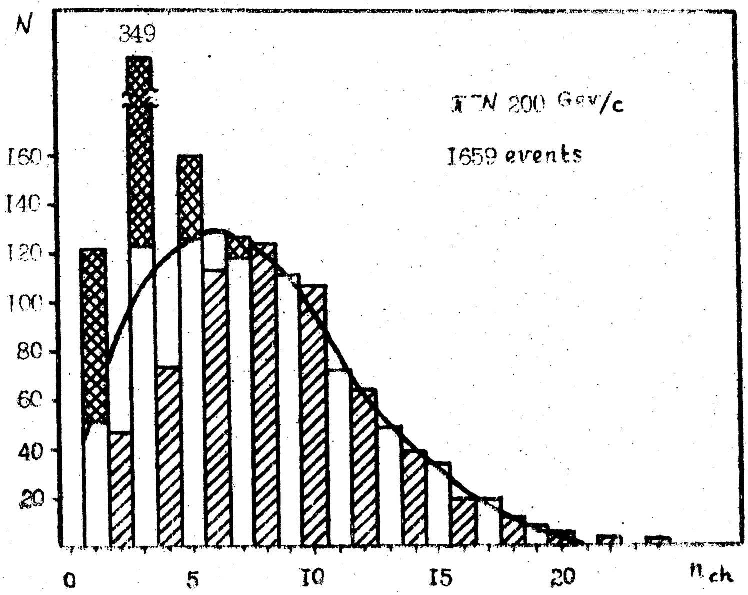

N
349
π⁻N 200 GeV/c
1659 events
160
140
120
100
80
60
40
20
0
5
10
15
20
n_ch

Fig.2.

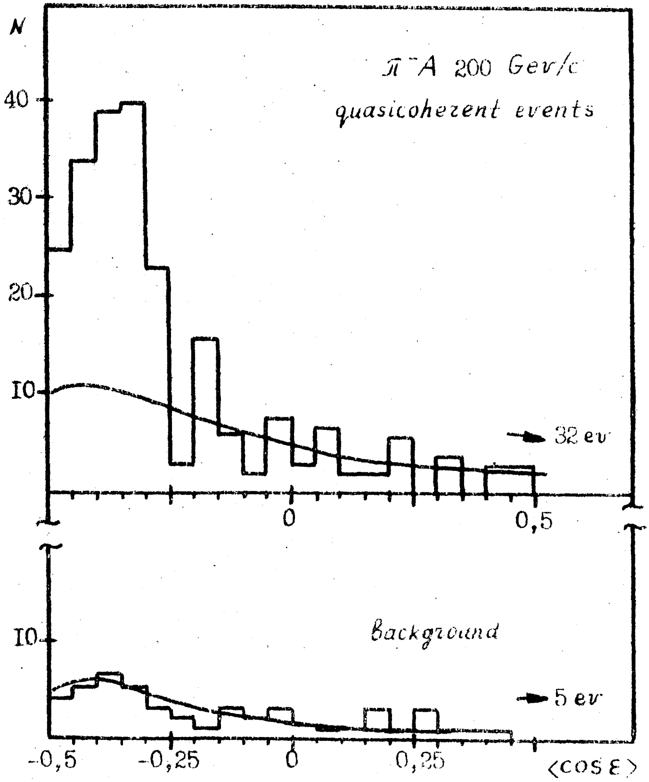
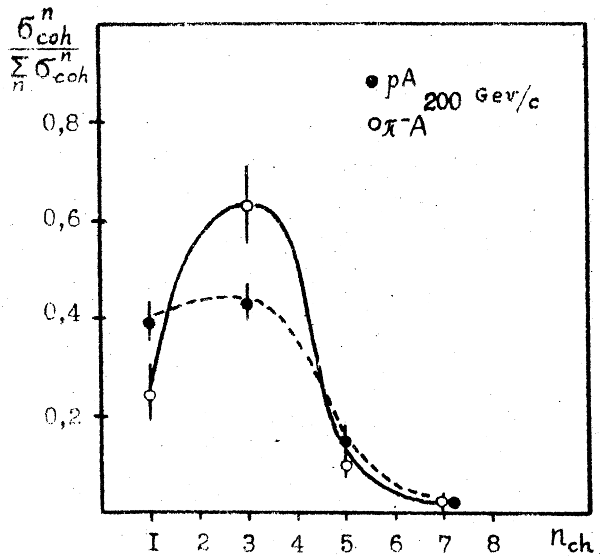

N
40
30
20
10
π^-A 200 Gev/c
quasicoherent events
32 ev
0
0,5
10
Background
5 ev
-0,5
-0,25
0
0,25
<cos ε>

Fig.3.



$\frac{\sigma^n_{coh}}{\sum_n \sigma^n_{coh}}$
0,8
0,6
0,4
0,2
● pA
200 Gev/c
○ π⁻A
I
2
3
4
5
6
7
8
n_{ch}

Fig.4.

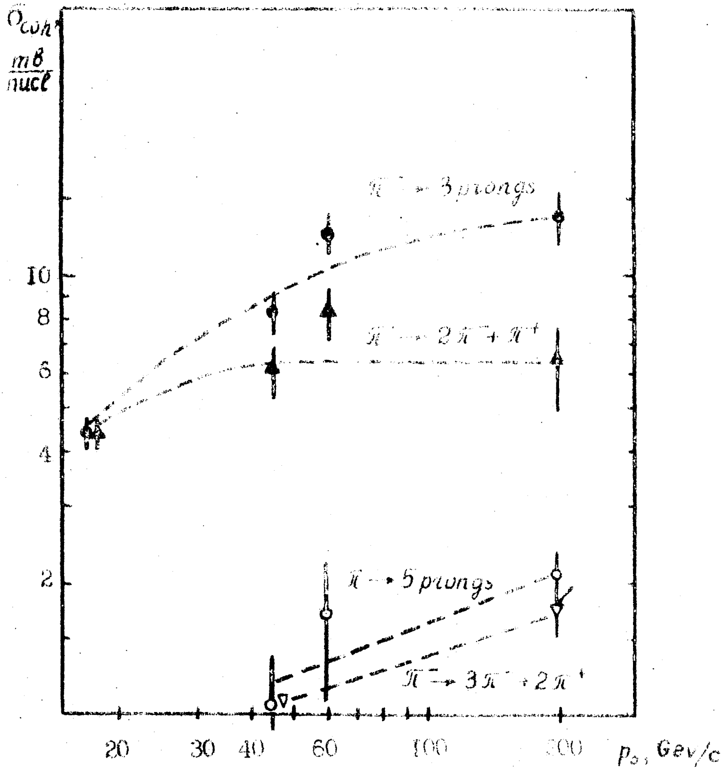

σ_coh, mb/nucl
π⁻ → 3 prongs
π⁻ → 2π⁻ + π⁺
π⁻ → 5 prongs
π⁻ → 3π⁻ + 2π⁺
10
8
6
4
2
20
30
40
60
100
200
p₀, Gev/c

Fig.5.

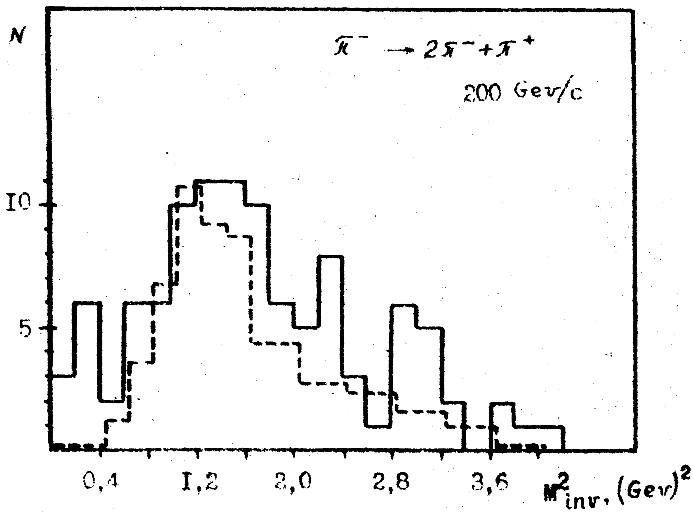


Fig.6.

FIGURE CAPTIONS

Fig.1. a) Distribution of the quantity Σ for "clean" and background 3-prong events;

b) $N_{coh}^{(n)}$ as function of Σ^{max} for 3-,5-and 7-prong reactions

Fig.2. Multiplicity distribution of charged particles in quasifree pion-nucleon and coherent pion-nucleus interactions in emulsion at 200 Gev/c. Doubly stroked areas show contribution of coherent events.

Fig.3. Distribution of the $\langle \cos \varepsilon \rangle$ for "clean" and background 3-prong events having $\Sigma < 0.06$. The curves represent the results of Monte Carlo simulation (see text).

Fig.4. Multiplicity distribution of charged particles in coherent pA- and π^-A-interactions at 200 Gev/c.

Fig.5. The energy dependences of topological cross-sections. The curves - hand drawn fits to guid the eyes.

Fig.6. Mass spectrum of the $3\pi^{\pm}$ system produced in reaction $\pi^- \xrightarrow{A} 3\pi^{\pm}$ at 200 (the solid line) and 16 Gev/c (data from /8/- the dotted histogram).

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