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E.G.Boos, A.I.Borisenko*, A.N.Kazanskaya*, A.V.Kholmetskaya, P.V.Morozova*, N.P.Pavlova

Institute for High Energy Physics of the Kazakh Academy of Sciences, Alma-Ata.

F.G.Lepekhin and B.B.Simonov

Leningrad Institute of Nuclear Physics of Academy of Sciences of the USSR, Gatchina.

M.I.Adamovich, M.M.Chernyavskij, S.P.Kharlamov, V.G.Larionova, N.V.Maslennikova, G.I.Orlova, N.A.Salmanova, M.I.Tretyakova and F.R.Yagudina

P.N.Lebedev Physical Institute of Academy of Sciences of the USSR, Moscow.

Sh.Abdushamilov, S.A.Azimov, L.P.Chernova, G.M.Chernov, S.I. Gadzhieva, K.G.Gulamov, N.S.Kasymova, V.I.Petrov, N.S.Scripnik and T.P.Trofimova

S.V.Starodubtsev Physical Technical Institute of the Uzbek Academy of Sciences, Tashkent.

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* Also at the S.M.Kirov Kazakh State University, Alma-Ata.

ABSTRACT

Data on coherent diffractive dissociation of 400 GeV/c protons on emulsion nuclei are presented. The measurements were made of total and topological cross sections as well as cross sections of exclusive channels $p \to p\pi^+\pi^-$ and $p \to p2\pi^+2\pi^-$. The energy dependence of some basic characteristics (cross sections, multiplicity of the diffractively excited system) of such reactions in the range of 20–400 GeV/c is discussed and it is observed that these dependences are the same qualitatively for both the diffractive and nondiffractive components of multiparticle production.

This paper is part of systematical investigation of hadron-nucleus interactions in nuclear emulsions performed by our collaboration during the last few years. Its purpose is the measurement of total and topological cross sections as well as those of the exclusive channels $pA \to A + p\pi^+\pi^-$ and $pA \to A + p\ 2\pi^+2\pi^-$ in inelastic coherent reactions of protons on emulsion nuclei at the maximal energy of 400 Gev available at the present accelerators and an analysis of the energy dependence of some basic experimental characteristics of such processes. Earlier the diffractive dissociation was discussed in our papers for incident proton and pion beams at 67 [1], 200 [2] and 60 [3], 200 Gev/c [4], respectively.

Stacks of GOSNIIHIMFOTOPROECT BR-600 nuclear emulsions were exposed to 400 Gev/c proton beam at the Fermilab accelerator. On the length of 2405 m of primary track scanned by along the track method all the recorded events have been measured which satisfy the necessary criteria [1–4] for selection of inelastic proton-nucleon (pN) interactions in an emulsion - in all 1322 events. The elastic scatterings and events of electromagnetic origin (production of e^+e^- pairs and δ-electrons) were not included in this number. Multiplicity distrubition of charged secondaries in measured pN interactions plotted in Figure 1 demonstrated the prominent peaks at odd values of multiplicity $n = 1,3,5$ and indicates the presence of considerable amount of coherent reactions in low multiplicity events.

A selection of the diffractive coherent reactions

$$p + A \rightarrow A + N + k\pi^{\pm} + m\pi^{0}, \qquad (2)$$

where $k, m = 0,1,2,\ldots$ and a number of charged secondaries n is equal to k if N is a neutron or $k+1$ if N is proton, has been carried out as usualy [1-5] by using the statistical method of comparative analysis [6] of distributions of angular estimates of longitudinal and transverse momenta transferred to a target in quasicoherent and background groups of events. The first group contains "clean" odd-prong events of type 0+0+n without any simptoms of excitation or disintegration of the target nucleus and the second one - proton-neutron (pn) interactions with a β-electron at the top of a star together with (n+1)-prong proton-proton (pp) collisions in which we have ignored a prong associated with a target proton or a prong with the maximal emission angle θ .

It is well known that the inequality $q_l \leqslant R_A^{-1}$ (q_l is the longitudinal momentum transfer and R_A is the radius of a nucleus) leads to angular collimation of the secondary particles from (1), which is much stronger than in background quasinucleon cases. Therefore, comparing the distributions of the quasicoherent and background events with respect to the parameter $\Sigma_n = \sum_{i=1}^{n} \sin\theta_i$, which constitutes a rough estimate of q_l, one can determine the number of reactions (1) with fixed n independently of the mass of the diffractively excited cluster (examples are shown in Figure 2 for $n = 3,5$). Indeed, it is easy to find the true number of the

coherent events (1) $N_{coh}^{(n)}$ by normalyzing the distributions at $\Sigma_n > \Sigma_n^{max}$, Σ_n^{max} being a parameter that is varied from zero to the maximum values, in accordance with the height of the "plateau" reached by the function $N_{coh}^{(n)}(\Sigma_n^{max})$.

This procedure has been used for all the odd multiplicities n and the results of such a selection are shown in Figure 3. It should be noted that at 400 Gev we have firstly observed the nine-prong channel of coherent dissociation (see Figure 3). Of course, there is no difference between angular collimation of secondaries in two groups of events considered for $n \geqslant 11$ that indicates the absence of reactions (1) in such topologies. The same was true for $n \geqslant 9$ at $p_0 \leqslant 200$ Gev/c and for $n \geqslant 7$ at $p_0 \leqslant 70$ Gev/c [1-4].

When determining the number of the one-prong reactions (1) the described procedure gives however only the lower limit of $N_{coh}^{(1)}$. Therefore, corrections were next introduced for the following: 1) the possible loss of one-prong events with $\theta > \theta_{el}$ during scanning ($\theta_{el} \cong 1$ mrad is the angle that has cut off the elastic events), assumihg azimuthal isotropy of the ensemble of one-prong stars, and 2) omission of reactions (1) with $\theta < \theta_{el}$, assuming similarity of the angular distributions in the reactions with $n = 1$ and 3. These corrections amounted to $\sim 15\,\%$ of $N_{coh}^{(1)}$.

Table 1 presents the results obtained on the numbers of coherent reactions $p \rightarrow n$ prongs, the mean free paths in an

emulsion $\lambda^{(n)}_{coh}$ and topological cross sections $\sigma^{(n)}_{coh}$ which were calculated for some conventional "average" emulsion nucleus having $A = 47$*). Contribution of coherent reactions in the total multiplicity distribution of pN events in emulsion are shown in Figure 1, and Figure 4 shows the energy dependence of total and topological cross sections of these reactions in the range 20–400 GeV/c. The data plotted in the range 20–200 GeV/c are taken from the review [7] and they are based on the same selection criteria as discussed above.

It is seen from Figure 4 that total and topological cross sections of coherent reactions (1) increase with p_0 rapidly in the region $p_0 = 20$–200 GeV/c ; this growth weakens noticeably in the range 200 - 400 GeV/c for topological channels with $n = 3$ and, maybe, 5 as well as for the total cross section, while the cross section for $n = 1$ $\sigma^{(1)}_{coh}$ in this range even seems to be falling. Besides, one can conclude from this figure that the behaviour of topological cross sections with energy in coherent reactions looks like a usual picture of topological cross sections in inelastic hadron-hadron interactions at moderate energies.

We noted earlier [1–4] that the growth of topological cross sections with p_0 in coherent reactions mostly is due to

*) Although the low-energy data offer evidence that the heavy nuclei of emulsion (Ag,Br) play a predominant role in reaction (1), this is immaterial for our present purposes.

opening of new exclusive channels of dissociation contributing into interactions with fixed n. In order to clarify the effects of summation of exclusive cross sections in semi-inclusive topological ones we made an attempt to estimate cross sections for the exclusive dissociation channels on emulsion nuclei $p \to p\pi^+\pi^-$ and $p \to p\, 2\pi^+ 2\pi^-$ at 400 GeV/c.

It is known [4] that the restriction $q_t \lesssim m_\pi$ (q_t is the transverse momentum transfer) in coherent interactions may be rewritten in the form

$$q_t = \left[\left(\sum_{i=1}^{n+m} P_{ti} \sin\varphi_i\right)^2 + \left(\sum_{i=1}^{n+m} P_{ti} \cos\varphi_i\right)^2\right]^{1/2} \simeq$$

$$\simeq \langle P_t\rangle \left[n + n(n-1)\langle\cos\varepsilon\rangle\right]^{1/2} \lesssim m_\pi, \qquad (2)$$

where $\langle P_t\rangle$ is the mean transverse momentum of secondary particles, φ is the asimuthal angle, $\varepsilon_{ij} = \varphi_i - \varphi_j$ $(i \neq j)$ and $\langle\cos\varepsilon\rangle$ is the average value of $\cos\varepsilon_{ij}$ in an event. It follows from (2) that in coherent reactions without neutral particles in the final state ($m = 0$ in (1)) the coefficient of asimuthal asymmetry must be small and

$$\langle\cos\varepsilon\rangle \lesssim \left[\left(m_\pi^2/\langle P_t\rangle^2\right) - n\right]/n(n-1), \qquad (3)$$

whereas at $m = 0$, $\langle\cos\varepsilon\rangle$ becomes spread out over the whole kinematically allowed interval from $-1/(n-1)$ (the case of symmetrical emission, when the azimuthal angles between neighbouring particles are equal to $2\pi/n$) up to 1 (the case of

asymmetrical emission when all $\varepsilon_{ij} = 0$).

We have plotted in Figure 5 $\langle \cos \varepsilon \rangle$ - distributions for clean and background three prong events with $\Sigma_n < 0.1$ (the first group is composed mostly of coherent reactions and only some 10 % of these events is due to incoherent interactions). One can observe a maximum for the first group of events around the value $\langle \cos \varepsilon \rangle \simeq -0.4$ which is caused, as shown, for instance, in [4], by three prong events without additional neutral particles in the final state, except the recoil nucleus . Assuming that this maximum belongs just to the exclusive coherent reactions $p \to p\pi^+\pi^-$ on nuclei, it is easy to find the number of such events following the subtraction procedure similar to that used for analysis of Σ_n - distributions. The same method has been applied for selection of $p \to p\, 2\pi^+ 2\pi^-$ reactions from five-prong clean events. The results obtained are presented in Table 1 and the energy dependence of exclusive channels cross sections is plotted in Figure 6 (again, the data at lower energies are taken from [7]).

As seen from Figure 6 the cross section of the reaction $p \to p\pi^+\pi^-$ approximately does not depend on the energy in the range 20-400 GeV and cross section of the channel $p \to p\, 2\pi^+ 2\pi^-$, although is larger at $p_0 > 100$ GeV/c than that at $p_0 < 100$ GeV/c, increases much slower than $\sigma^{(5)}_{coh}$ (Figure 4). This data confirm the assumption that a growth of total and topological cross sections is due to the opening of new exclusive channels. The change in the energy dependence of cross sections of low multiplicity reactions and σ^{tot}_{coh} is related evidently with the phase space effects, namely with the fact that with increasing p_0 channels with larger total multiplicity become kinematically allowed, whereas the comparative contribution of exclusive channels with small number of neutral pions in semi-inclusive reactions with small n decreases.

The growth of the mass of coherently produced system with p_0 may be illustrated by the energy dependence of the average multiplicity of charged secondaries in reactions (1) (Figure 7). It is seen that $\langle n \rangle_{coh}$ as a function of E_0 does not contradict the logarithmic law, which, as known, quite satisfactorily describes multiplicity in hadron-hadron and incoherent hadron-nucleus interactions.

Thus, we can conclude, that the data demonstrate the qualitative similarity of the energy dependence of the basic experimental characteristics in the diffractive and non-diffractive components of multiparticle production.

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Table 1. Characteristics of coherent production by protons on emulsion nuclei at 400 GeV/c.

	$N_{coh}^{(n)}$	$\lambda_{coh}^{(n)}$, m	$\sigma_{coh}^{(n)}$, mbn/nucleus
p → 1 prong	77 ± 23	31^{+14}_{-7}	6.6 ± 2.0
3 prongs	120 ± 13	$20.0^{+2.5}_{-1.9}$	10.3 ± 1.1
5 prongs	50 ± 10	48^{+12}_{-8}	4.3 ± 0.9
7 prongs	10 ± 5	240^{+240}_{-80}	0.9 ± 0.4
9 prongs	9 ± 4	267^{+213}_{-82}	0.8 ± 0.4
n prongs (total)	266 ± 30	$9.0^{+1.2}_{-0.9}$	22.9 ± 2.6
$p \to p + \pi^+ + \pi^-$	32 ± 8	75^{+25}_{-15}	2.8 ± 0.7
$p \to p + 2\pi^+ + 2\pi^-$	18 ± 6	134^{+66}_{-34}	1.6 ± 0.5

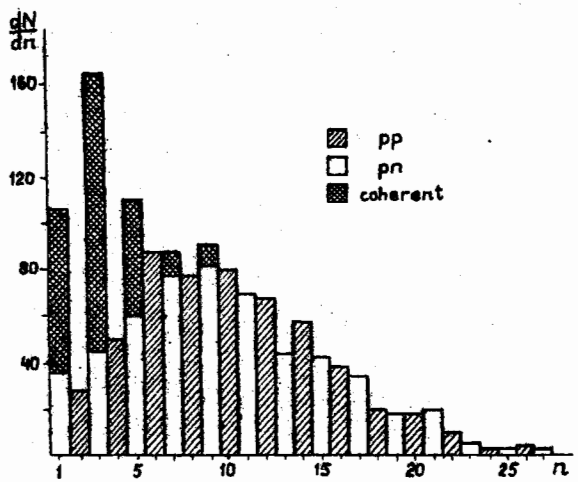

Figure 1. Multiplicity distribution of charged secondaries in inelastic quasinucleon interactions at 400 GeV/c.

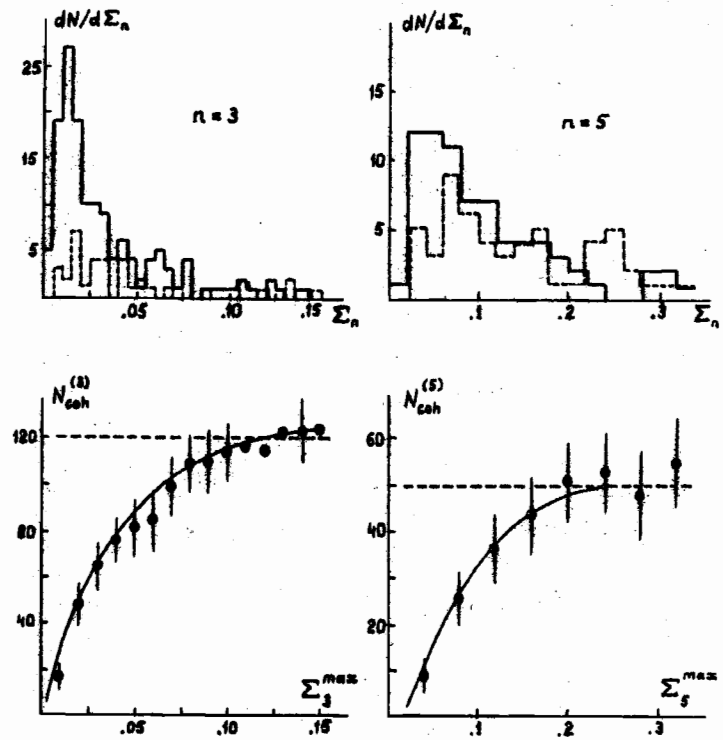

Fig.2. $\sum_n \sin\theta_i$ distributions for "clean" (the solid histogram) and background events and dependences of $N^{(n)}_{coh}$ on Σ_n^{max} for $n = 3$ (the left of figure) and $n = 5$.

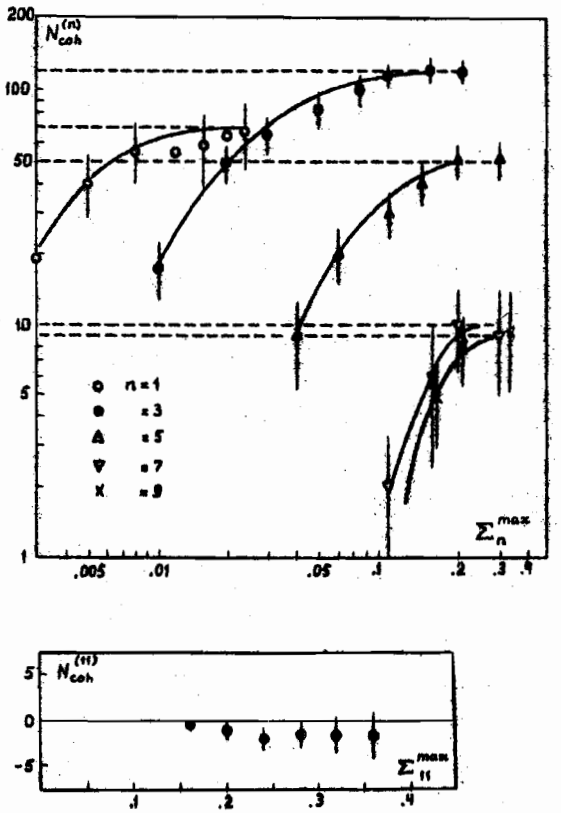

Fig.3. $N_{coh}^{(n)}$ as function of Σ_n^{max} for $n = 1,3,5,7,9$ and 11.

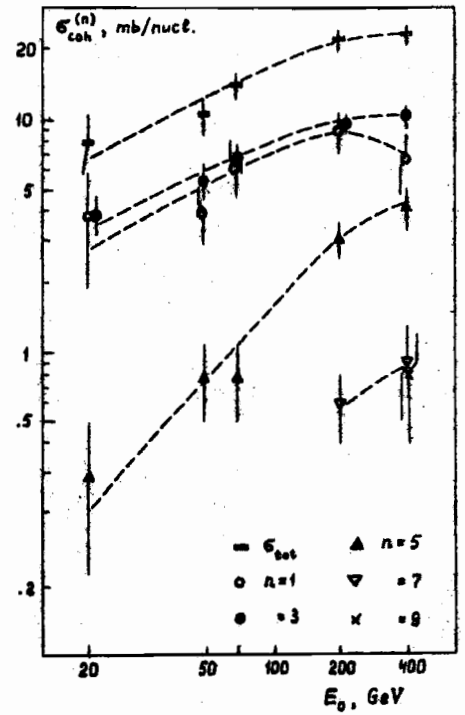

Fig.4. The energy dependence of total and topological cross sections of coherent reactions (1) on emulsion nucleus.

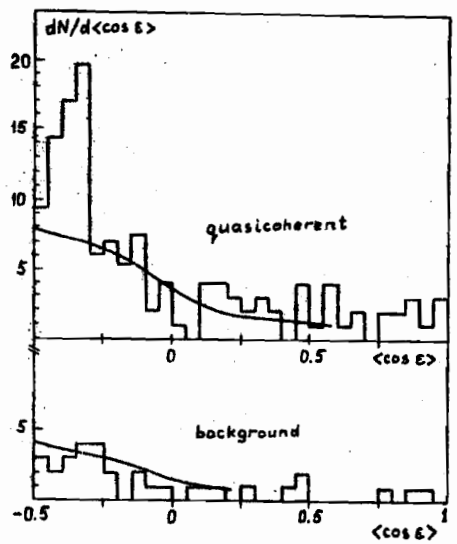

Fig.5. <cos ε> distributions for quasicoherent and background events with $\Sigma_n < 0.1$ for n = 3. The curves belong to the Monte Carlo calculation which takes into account production of additional neutral pions (see for details [4]).

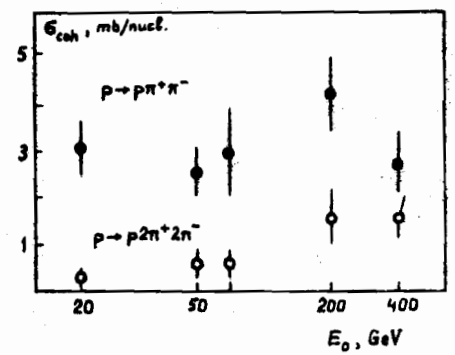

Fig.6. Cross sections of the exclusive channels of proton dissociation $p \to p\pi^+\pi^-$ and $p \to p\,2\pi^+2\pi^-$ (open circles) as functions of E_0.

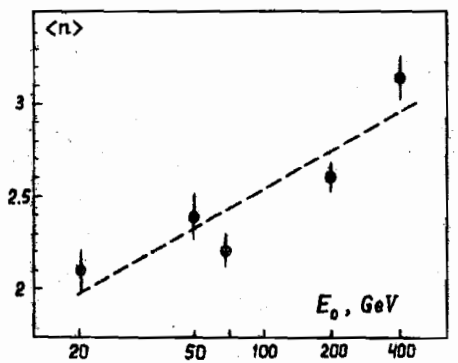

Fig.7. The average multiplicity of charged secondaries in reactions (1) as a function of incident beam momentum.