Distribution of multiplicity in inelastic coherent collisions of protons with nuclei in the energy interval 20-200 GeV

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We present and discuss the multiplicity distributions of charged particles in diffraction-coherent proton-nuclear interactions in a wide energy interval. A comparison is made with the data on the diffraction dissociation in pp collisions.

The distribution of the multiplicity n in diffraction processes and the energy dependence of this distribution are very important questions, particularly in connection with two-component and multicomponent models of multiple generation.[1] However, it is difficult to obtain these data in hadron-hadron collisions because of the uncertainties in the selection at large values of the system mass.[2]

We present here the n-distributions from p-nucleus coherent collisions at $p_0 = 21$, 50, 67, and 200 GeV/c. In addition to being of obvious independent interest, they can be related by means of a model with the corresponding distributions obtained in diffraction by nucleons. It is important that the selection of the coherent reactions can be carried out under much better background conditions.

We have carried out, in unified fashion, a selection of the diffraction reactions

$$p + A \to (N + k\pi^{\pm} + l\pi^{0}) + A \tag{1}$$

(A is the number of nucleons in the nucleus, k, $l = 0, 1, \ldots; k + l \geq 1$; $n = k$ if N is a neutron or $k + l$ if N is a proton) from among the inelastic events obtained in four emulsion stacks exposed to protons of the indicated energy from the accelerators of CERN, of the Serpukhov High-energy Physics Institute, and of NAL. Information on the experimental details is contained in[3-6], and some data are given in Table I.

It is well known that the inequality $q_{\parallel} \lesssim R_A^{-1}$ ($q_{\parallel}$ is the longitudinal momentum transfer and R_A is the radius of the nucleus) leads to angular collimation of the secondary particles from (1), which is much stronger than in the "background" quasinucleon cases. Therefore, comparing the distributions of the quasicoherent (i.e., without symptons of excitation or disintegration of the nucleus) and the background events with respect to the parameter $\sum \equiv \sum_{i=1}^{n} \sin\theta_i$ (θ_i is the charged-particle emission angle), which constitutes a rough estimate of $q_{\parallel}$, we can determine the number of reactions (1) independently of the mass of the diffraction cluster (an example is shown in Fig. 1a). Indeed, it is easy to find the true number of the reactions (1) by normalizing the distributions at $\sum > \sum^{\max}$ ($\sum^{\max}$ is a parameter that is varied from zero to the maximum values) in accordance with the height of the "plateau" reached by the function $N_{\text{coh}}(\sum^{\max})$. Figure 1b shows by way of example this procedure for $n = 3$, 5, and 7 at 200 GeV/c.

TABLE I. Topological cross sections

Characteristics	21 GeV/c	50 GeV/c	67 GeV/c	200 GeV/c
Track length, km	2,6	2,6	3,1	5,3
Number of stars, thousands	7.3	7.2	8.2	15.0
$\sigma_{cob}^{(1)}$, mb/nucleus	(3,9 ± 2.0)*	4.0 ± 1.1	6.2 ± 1.6	8.7 ± 1.6
$\sigma_{cob}^{(3)}$, mb/nucleus	3.9 ± 0.7	5.4 ± 0.8	6.9 ± 1.0	9.6 ± 0.8
$\sigma_{cob}^{(5)}$, mb/nucleus	0.3 ± 0.2	0.8 ± 0.3	0.8 ± 0.3	3.2 ± 0.5
$\sigma_{cob}^{(7)}$, mb/nucleus	~ 0	~ 0	~ 0	0.6 ± 0.2
$\sigma_{cob}^{tot} = \sum_n \sigma_{cob}^{(n)}$	8.1 ± 2.3	10.3 ± 1.7	14.0 ± 1.9	22.1 ± 2.0
$\sigma_{p\pi^+\pi^-}$ mb/nucleus	3.1 ± 0.6	2.6 ± 0.6	3.0 ± 1.0	—

*Estimate (see the text) from the data of[7].

When determining the number $N_{\text{coh}}^{(1)}$ of the one-prong reactions (1), the described procedure was used in the region $\theta > \theta_{\text{el}}$ (θ_{el} is the angle that has cut off the elastic events for each p_0). Corrections were next introduced for the following: 1) loss during scanning, assuming azimuthal isotropy of the ensemble of one-prong stars, and 2) omission of reactions (1) with $\theta < \theta_{\text{el}}$, assuming similarity of the angular distributions in the reactions (1) with $n = 1$ and 3.[4] Each of them amounted to ~15 - 20% of $N_{\text{coh}}^{(1)}$. The cross section $\sigma_{\text{coh}}^{(1)}$ at $p_0 = 21$ GeV/c (at this value of p_0 no single-pronged stars were

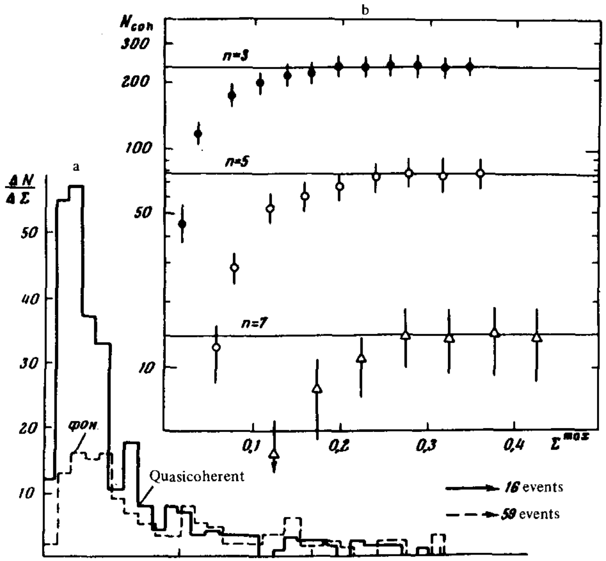

FIG. 1. Example of separation of the reactions (1) ($p_0 = 200$ GeV/c): a) $\sum$-distributions for quasicoherent and background three-pronged stars; b) determination of N_{coh} from the function $N_{\text{coh}}(\sum^{\max})$.

TABLE II. Moments of n-distribution.

	p_0, GeV/c	$\langle n \rangle$	$\langle n(n-1) \rangle$	$(\langle n^2\rangle - \langle n\rangle^2)^{1/2}$	f_2
All tracks	21	2.11 ± 0.12	3.60 ± 0.45	1.12 ± 0.26	-0.86 ± 0.67
	50	2.38 ± 0.11	4.75 ± 0.47	1.21 ± 0.24	-0.89 ± 0.69
	67	2.21 ± 0.08	4.10 ± 0.34	1.19 ± 0.18	-0.80 ± 0.50
	200	2.61 ± 0.07	6.61 ± 0.37	1.56 ± 0.14	-0.18 ± 0.51
Negative	21	0.56 ± 0.06	0.07 ± 0.04	0.56 ± 0.09	-0.24 ± 0.08
	50	0.69 ± 0.05	0.16 ± 0.05	0.61 ± 0.09	-0.32 ± 0.09
	67	0.61 ± 0.04	0.12 ± 0.03	0.60 ± 0.07	-0.25 ± 0.06
	200	0.80 ± 0.03	0.45 ± 0.05	0.78 ± 0.05	-0.20 ± 0.07

registered) was estimated from data on the reaction $nA \to p\pi^- A$,[7] using the statistical isospin model.[8]

The results[1)] are presented in Tables I and II and in Figs. 2 and 3. They lead to the following conclusions:

a) The total and topological cross sections of the reactions (1) increase in the region $p_0 = 20-200$ GeV/c most rapidly–for the multiprong channels.

b) This growth is due to the opening of new diffraction channels with larger total multiplicities (cf. e.g., $\sigma^{(3)}_{\text{coh}}$ and $\sigma_{p\pi^+\pi^-}$).

c) The form of the n-distribution does not change noticeably with increasing p_0; the n_--distribution agrees poorly with a Poisson distribution (Fig. 2a), although the latter cannot be excluded, owing to the existing uncertainty (~20–30%) of $\sigma^{(1)}_{\text{coh}}$.

d) The n-distributions in the reactions (1) do not contradict the KNO scaling,[9] and are described by the same universal functions[10] as the pp collisions (we do not concern ourselves here with more subtle questions connected with violation of KNO scaling in pp collisions and the degree of the approach to this violation). This indicates that the scaling properties of the diffraction and nondiffraction components in hadron-hadron collisions are identical.

e) $\langle n \rangle$ in the reaction (1) increases slowly with p_0 (Fig. 3). A good fit is given by

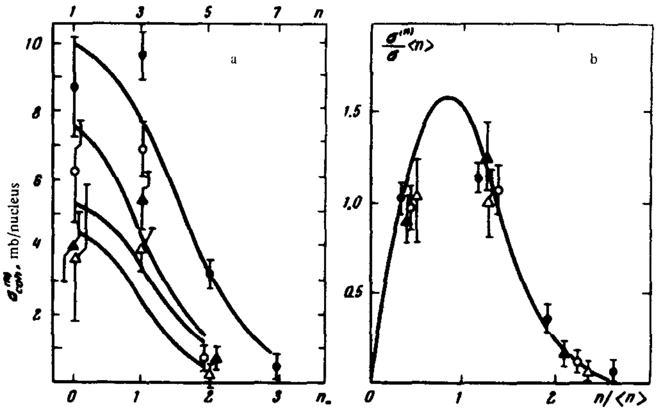

FIG. 2. n-distributions in the reactions (1): a) Poisson distributions, Δ—21 GeV/c, ▲—50 GeV/c, ○—67 GeV/c, ●—200 GeV/c; b) Slattery function.[10]

$$\langle n_- \rangle = 0.1 \ln p_0 + 0.26. \qquad (2)$$

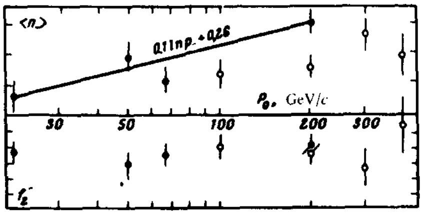

FIG. 3. Energy dependence of $\langle n_- \rangle$ and of f_2^- for the reaction (1) (dark circles) and for pp collisions (light circles).

Comparing with the NAL data on the multiplicites of the fragmentation of beam protons by protons, and bearing in mind that they represent the lower limits, due to the uncertainties in the selection,[2] we arrive at the important conclusion that the n-distribution has no dependence (or a weak dependence) on the target mass. This is the so-called factorization in pomeron exchange, but it is of interest that in our case (where the target is a nucleon or a compound nucleus) an approximate equality of the masses of the produced systems is observed at significantly different distributions of the momentum transfers (for nuclei we have $d\sigma/dt \sim \exp(-R_A^2 t/4)$).

f) The values of the correlation parameters $f_2 = \langle n(n-1)\rangle - \langle n \rangle^2$ also agree for the p-nucleus and pp collisions, and do not depend on p_0 (Fig. 3). Their values agree with those expected for diffraction.

The foregoing data offer evidence of universality of the mechanism of the diffraction dissociation of hadrons, particularly the weak dependence of its dynamic properties on the nature and energy of the primary particles.

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[1)] The presented topological cross sections are referred to an arbitrary emulsion nucleus ($\langle A \rangle = 47$). Although the low-energy data offer evidence that the heavy nuclei (Ag, Br) play a predominant role in reactions of type (1), this is immaterial for our present purposes.

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