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Multiplicity distribution in *pn* interaction at 400 GeV/*c* and its empirical regularity

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Multiplicity distributions in *pn* interactions derived from 400-GeV/*c* *pd* data are presented along with other available *pn* data at and above 100 GeV/*c*. Charged multiplicities are seen to be negative-binomially distributed. Moments of distribution and different parameters of fit are evaluated and compared. The rise of the single-diffractive component in *pn* interactions from 100 to 400 GeV is observed to be compatible with that in *pp* interactions in the same energy range.

I. INTRODUCTION

Interest on the shape of hadronic multiplicity distribution and of its scaling over a wide range of energy and initial state has been growing because of their implications on the models of multiparticle production at high energy. It has been observed that scaling has set in at energies much lower than asymptotic predictions. The semi-inclusive scaling hypothesis[1] and Mueller-Regge hypothesis[2] provided contrasting asymptotic predictions about the energy dependence of the multiplicity distributions. Recently it has been observed that Feynman scaling, which served as an ingredient to semi-inclusive scaling, is also violated. The problem has been further widened by the observed scaling violations as one moves from the CERN ISR region to $\bar{p}p$ collider energy.[3] A number of models[3] have been suggested to understand the mechanism of multiparticle production with or without scaling violations. The shape of the multiplicity distribution, with scaling violation, has been observed to be described fairly well by a negative-binomial distribution[4] which fits *pp* and $\bar{p}p$ data.

The above studies were made with data from experiments with doubly charged or neutral initial states, leaving enough scope for analysis of data from experiments with a singly charged initial state. In this context, it has become desirable to study the nature and properties of multiplicity distribution vis-à-vis any deviation from scaling of multiplicity distribution in *pn* interactions.

In this paper we report on the results of fit of our *pn* data at 400 GeV and other energies. We have generated a negative-binomial *pn* distribution and compared it with experimental multiplicity distribution. The parameters of fit and of resulting multiplicity distribution are evaluated and analyzed for scaling of data. The rise of the single-diffractive component in *pn* interactions in the energy range of the data is also studied.

II. DATA

Data for this experiment have been obtained from scanning at our laboratory of about 30 000 triads of frames from the 30-in. deuterium bubble-chamber experiment at 400-GeV/*c* incident proton momentum performed at Fermilab. The extraction of *pn* and *pp* multiplicity distribution from *pd* data was effected through a semiempirical model.[5] The number of events considered in this paper has been increased by a factor of more than 2 from that reported in our earlier publication. Our extracted *pn* and *pp* data are shown in Table I, from which we have used *pn* data for the present work.

We used *pn* data extracted from *pd* interactions at other energies at and above 100 GeV (Ref. 6) as reported by other authors.

TABLE I. Multiplicity distributions of *pn* and *pp* interactions derived from deuterium bubble-chamber data at 400 GeV.

n	*pn*	*pp*
1	283±37	
2		527±62
3	749±68	
4		751±72
5	947±92	
6		959±89
7	945±104	
8		1110±90
9	860±93	
10		897±85
11	627±69	
12		741±72
13	430±47	
14		516±50
15	292±34	
16		259±37
17	171±37	
18		176±23
19	85±14	
20		106±14
21	42±12	
22		43±9
23	23±5	
24		16±8
25	9±2	
26		4±1
27	9±8	
28		2±2

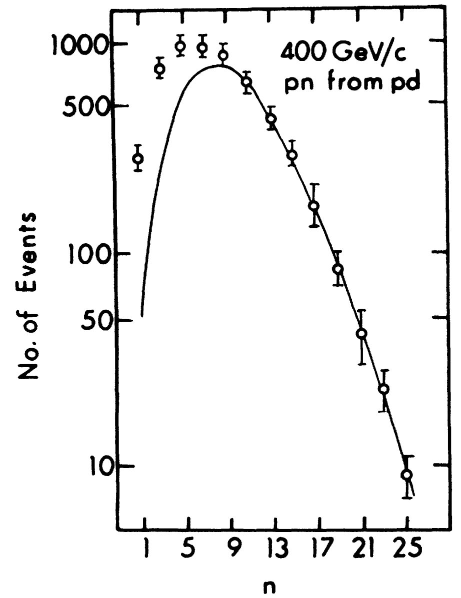

FIG. 1. Multiplicity distribution in 400-GeV *pn* interactions. The solid curve shows the result of the fit of this set of data in the range $11 \leq n \leq 23$.

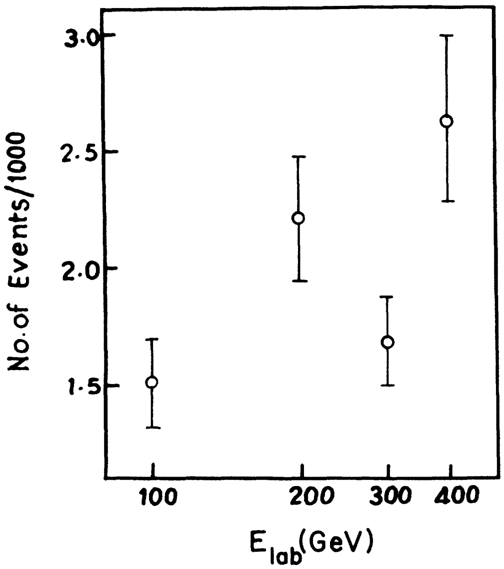

FIG. 2. Energy dependence of diffractive events (see text) in *pn* interactions derived from deuterium bubble-chamber data.

III. METHODS AND ANALYSIS OF DATA

Our experimental *pn* distribution has been compared with a negative-binomial (NB) distribution:

$$P_n = \left[\begin{matrix} n+k-1 \\ n \end{matrix} \right] \left[\frac{\bar{n}/k}{1+\bar{n}/k} \right]^n \frac{1}{(1+\bar{n}/k)^k} ,$$

where P_n is the probability of observing a charged multiplicity n, $\bar{n}$ is the average multiplicity, and k is a parameter affecting the shape of the distribution. The best fit was achieved using the minimum$-\chi^2$ method. The fitted distribution shows a clear good fit for events with multiplicities n within the interval $11 \leq n \leq 23$. (See Fig. 1.) Similar fittings with NB distribution of *pn* data at 100, 200, and 300 GeV have been made. The range of multiplicities fitted together with the fitted parameters and goodness of fit at all these energies are given in Table II.

The differences observed for lower multiplicities provided a means to study the energy variation of the single-diffractive component in the total inelastic sample of data. The topological variation of these differences normalized to a total of 10 000 inelastic events at each energy is given in Table III. We compared the variation in the number of single-diffractive events with energy in *pn* interactions with that observed in *pp* interactions. (See Fig. 2.) The increase in the total single-diffractive component in *pp* interactions from $P_{lab} = 100$ GeV/c to $P_{lab} = 400$ GeV/c is approximately twofold[7] which is found to be quite consistent with that obtained in *pn* interactions.

The feature of data shown by the above analysis favors a mechanism where scaling is not essential. However, the C_q moments which were expected to show energy independence under scaling can be deduced from the NB description without any assumption about the asymptotic nature of energy. The values of C_q moments calculated from the fitted parameters are given in Table IV. It can be seen that they maintain energy independence fairly well. This feature can be accommodated within the framework of the NB description in a manner as shown in Fig. 3. We have plotted the energy variation of the inverse parameters $\bar{n}^{-1}$ and k^{-1} in the energy range $100 \leq E_{lab} \leq 400$ GeV. The sum $(\bar{n}^{-1} + k^{-1})$ is seen to have a broad minimum at about 300 GeV. The C_q moments will similarly show this behavior as they are dedu-

TABLE II. Parameters of negative-binomial distribution fitted to the *pn* data samples and the resulting χ^2_{min} and $y = (2\chi^2_{min})^{1/2} - (2N_{DF} - 1)^{1/2}$, where N_{DF} is the number of degrees of freedom.

Energy E_{lab} (GeV)	Fitted multiplicity range	Parameters of fit $\bar{n}$	k	Goodness of fit χ^2_{min}/N_{DF}	y	$1/\bar{n}+1/k$
100	9–23	(6.8±0.13)	(12.4±2.06)	2.4/6	−0.8	0.228
200	9–23	(8.2±0.08)	(11.4±0.90)	2.43/6	−0.8	0.21
300	11–27	(8.9±0.08)	(11.0±0.57)	7.45/7	0.54	0.203
400	11–23	(9.6±0.09)	(9.3±0.63)	1.4/5	−0.97	0.212

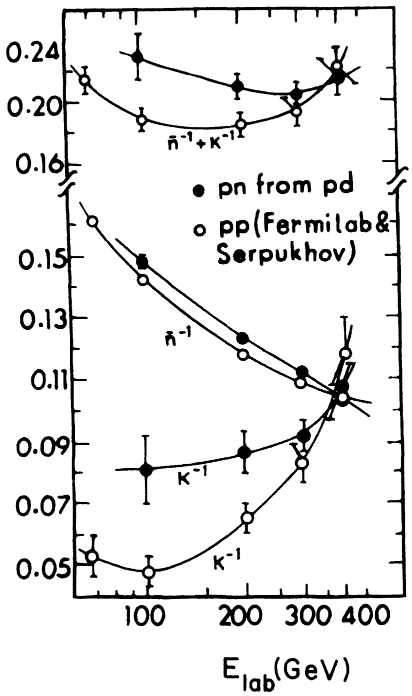

FIG. 3. Approximate scaling of *pn* multiplicity distributions compared with those of *pp* interactions in the energy range $69 \le E \le 405$ GeV within the framework of the NB description from the addition of an increasing k^{-1} and the decreasing $\bar{n}^{-1}$.

cible from these parameters. This shows that the early scaling shown by data is accidental and approximate.

The fitting of data with the negative-binomial distribution, viewed in the context of absence of asymptotic scaling and the explanation of accidental and approximate scaling, shows that the *pn* data have similar characteristics to *pp* data. This is important in the context of the suggestions of the coherence effect, e.g., pionic amplification by stimulated emission of radiation[8] and many-fold convolution of (logarithmic) multiplicity distributions for the number of particles in a "clan" (i.e., a set having a common "ancestor")[9] as well as the manifestation of a phase transition from hadrons to a quark-gluon plasma in the statistical bootstrap model.[10]

TABLE III. Normalized multiplicity distribution of diffractive events in *pn* interactions derived from deuterium bubble-chamber data (see text).

E_{lab} n	100 GeV	200 GeV	300 GeV	400 GeV
1	552±154	710±237	603±177	422±66
3	605±82	975±71	784±58	892±121
5	317±58	430±66	289±50	724±163
7	38±38	130±59		373±183
9		20±48		203±163
11				13±117
Total	1512±188	2265±267	1676±193	2627±345

IV. SUMMARY

From detailed studies on the nature and properties of multiplicity distributions in *pn* interactions from the deuterium bubble chamber and comparing these with *pp* interaction data from the hydrogen bubble chamber, we show that the negative binomial describes the multiplicity distributions in *pn* interactions over a wide range of energy. This implies that the Koba-Nielsen-Olesen scaling in this range is approximate.

This new regularity for multiplicity distributions in *pn* interactions points to some mechanism of particle production bearing a dependence on the parameters $\bar{n}$ and k.

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TABLE IV. The average multiplicity $\langle n \rangle$, and C_q moments defined by $C_q = \langle n^q \rangle / \langle n \rangle^q$, calculated from the two parameters of the fitted negative-binomial distribution.

Energy E_{lab} (GeV)	$\langle n \rangle$	$C2$	$C3$	$C4$	$C5$
100	6.8±0.13	1.23±0.01	1.75±0.05	2.83±0.15	5.08±0.41
200	8.2±0.08	1.21±0.01	1.69±0.03	2.67±0.07	4.66±0.2
300	8.9±0.08	1.20±0.005	1.67±0.02	2.61±0.05	4.51±0.13
400	9.6±0.09	1.21±0.01	1.70±0.03	2.70±0.08	4.78±0.21

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