MULTIPLICITY DISTRIBUTIONS IN π^+d AND pd COLLISIONS AT 100 GeV/c

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From an exposure of the 30-inch deuterium bubble chamber at Fermilab we examine 7600 events with three or more charged prongs. Multiplicity distributions for π^+n, pn, π^+d and pd collisions are presented and are in general agreement with those expected based on knowledge of π^-p, π^+p, and pp collisions at the same energy. We find that double scattering in the deuteron, which occurs in about 14% of events, causes at most small effects on the multiplicity distributions.

We report one of the first measurements of charged particle multiplicities in hadron-deuterium interactions in the hundred GeV region. (Sheng et al., [1] have reported on multiplicities in pd interactions at 300 GeV/c). Our data come from the analysis of about 25000 pictures of the Fermilab 30-inch deuterium-filled bubble chamber in a secondary beam of 100 GeV/c positive particles. The beam composition was approximately 57% proton, 39% π^+, 2% μ^+ and 2% K^+, as determined by a Cerenkov counter in the beam. This counter, along with three sets of proportional wire chambers, formed a tagging system which allowed the determination of the mass of each beam track and its location in the bubble chamber [2]. Only 6% of the identified interactions had to be rejected because of tagging system inefficiency or unresolvable ambiguities between very close beam tracks.

The film was double scanned for all interactions with three or more outgoing prongs. Odd-prong events, in which there is presumably an unobservably short spectator proton or deuteron track, constituted 29% of the events. Prong count discrepancies between the two scans were resolved by a physicist or a third scanner. Small corrections to the multiplicity distribution were made for unobserved Dalitz pairs, and for the 2.5% of events that were uncountable. The correction for close V decays is negligible.

Multiplicity-dependent scanning biases have been investigated. The scanning efficiency of the double scan was found to be (99 ± 1)% independent of multiplicity. In addition, a loss of short forward spectator protons which increases with mutliplicity was suspected Such a bias would tend to increase the number of high-multiplicity odd-prongs reported by the scanners. The magnitude of the effect was measured by examining the deviation from isotropy of the azimuth about the beam track for the forward spectator protons in a sample of 2200 measured events with identified protons. We found no significant bias against forward spectators in high multiplicity events. Lastly, the ratio of the number of events with an observed backward

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Table 1

Corrected numbers of events, with means $\langle N \rangle$ and dispersion D calculated for $N \geq 3$ ($\pi^{\pm}$p and pp data from refs. [3–5]).

Odd prongs N	π^+d	pd	Even and odd prongs N	π^+d	pd
3	140 ± 12	304 ± 18	4	535 ± 24	1243 ± 37
5	164 ± 13	396 ± 21	6	581 ± 25	1377 ± 39
7	155 ± 13	326 ± 19	8	538 ± 25	1150 ± 36
9	99 ± 11	241 ± 17	10	317 ± 20	754 ± 30
11	73 ± 10	119 ± 13	12	207 ± 16	415 ± 23
13	36 ± 7	73 ± 10	14	98 ± 12	218 ± 17
15	17 ± 5	29 ± 7	16	42 ± 8	118 ± 13
17	3 ± 2	9 ± 4	18	12 ± 5	24 ± 6
19	1 ± 1	1 ± 1	20	4 ± 3	4 ± 3
21	1 ± 1	1 ± 1	22	2 ± 2	1 ± 2
23	0	1 ± 1	24	1 ± 1	1 ± 1
Totla	689	1500		2337	5298
$\langle N \rangle$	7.01 ± 0.14	6.83 ± 0.09	$\langle N \rangle$	7.70 ± 0.08	7.62 ± 0.05
D	3.30 ± 0.10	3.19 ± 0.08	D	3.20 ± 0.07	3.16 ± 0.04

	π^+p, 100 GeV/c	π^-p, 100 GeV/c	pp, 100 GeV/c	pp, 102 GeV/c
$\langle N \rangle$	7.50 ± 0.08	7.29 ± 0.04	7.23 ± 0.06	7.02 ± 0.05
D	2.94 ± 0.07	2.89 ± 0.03	2.94 ± 0.06	2.79 ± 0.04

spectator proton to the number of events with an unobserved spectator (odd-prongs) is consistent with being independent of multiplicity, after correcting for proton recoils from p-p interactions which have been thrown backward in the laboratory by the Fermi motion of the target proton, and correcting for the change in average multiplicity with effective center-of-mass energy of the beam neutron collision.

The corrected numbers of odd-prong events found are given in table 1, and the odd-prong probability distributions are plotted in fig. 1(a) (we consistently normalize all P_N distributions to 1.0, starting at $N = 3$ for odd prongs and $N = 4$ for even prongs). The errors include systematic errors in the corrections mentioned previously. The deuteron multiplicity distributions are also given in table 1 and fig. 1(b). This latter sample is the sum of the observed even-prong events and the odd-prong events with the unobserved spectator added to the prong count. For comparison, table 1 also gives some results from hydrogen experiments [3–5].

A subsample of about half the film was used to measure the total cross sections on deuterium for producing three or more prongs. These cross sections were found to be 33.0 ± 1.6 mb and 54.0 ± 2.0 mb for incident π^+ and protons, respectively.

We now argue that the odd-prong multiplicity distributions may be interpreted without further correction as free neutron multiplicity distributions. Odd-prong events result predominantly from beam interactions with neutrons in which the spectator proton was too short to be observed, with a negligible contamination from events with deuteron final states* which we neglect. Rescattering off the spectator proton, following a beam-neutron interaction, will nearly always render the spectator visible, thus producing an even-prong event. This rescattering could deplete the odd-prong sample in a multiplicity-dependent manner if the rescattering probability depended upon the multi plicity of the neutron interaction. We believe that such dependence is small, for the following reason. If we define the number of "free neutron" events as the

* We estimate that deuteron final states may necessitate downward corrections to both π^+d and pd odd-prong multiplicities of 11% for 3-prongs and 2.5% for 5-prongs in order to arrive at neutron multiplicities. Such corrections would change $\langle N \rangle$ to 7.12 (π^+n) and 6.93 (pn), and (see further on) would would reduce Y_{av} to 0.52 and X_{av} to 0.48.

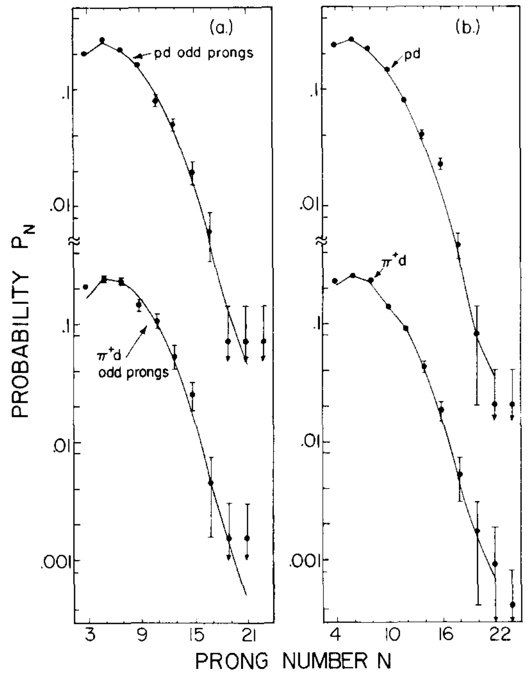

Fig. 1. (a) Odd prong multiplicity distributions; $P_N = \sigma(N$ prongs$)/\sigma($odd prongs, $N \geqslant 3)$. The lines join points calculated from pp and π^-p data respectively (see text). (b) Even plus odd prong multplicity distributions, (odd multiplicities increased by one); $P_N = \sigma(N$ prongs$)/\sigma($total, $N \geqslant 4)$. The lines join points calculated from pn plus pp data, and π^+n plus π^+p data, respectively (see text).

number of odd-prong events plus twice the number of events with backward protons, with corrections for the Moller flux factor and for Fermi-momentum smearing of proton recoils from target proton events, we find that (44 ± 1.5)% of both π^+d and pd interactions (with charged multiplicity $N \geqslant 3$) are "free neutron" events. The deficit from the 51% expected in the case of an unbound equal mix of proton and neutron targets is interpreted as resulting from rescattering following beam-neutron interactions. In a simple cascade model, we would expect the rescattering probability to be approximately proportional to the charged multiplicity N of the beam-neutron interaction. Then a correction factor of $(1 + 0.02N)$ would be required for the odd-prong distribution, to give a rescattering probability of 14% as indicated by the above percentages. However, experiments on nuclear targets [6] have shown that a simple cascade model is incorrect, and suggest a much weaker N-dependence for rescattering. Hence we conclude that any correction factor will be considerably weaker than $(1 + 0.02N)$

We next compare our π^+d and pd multiplicity distributions with those predicted by simple averages of neutron-target and proton-target multiplicity distributions. Differences between predicted and observed values would imply multiplicity-increasing effects in the deuteron, such as inelastic rescattering on a spectator nucleon. In fig. 1(b), the lines join points which are the average of $P_N(\pi^+\mathrm{p})$ and $P_{N-1}(\pi^+\mathrm{n})$, and similarly for pd. We have used our own π^+n and pn data and published [3, 4] π^+p and pp data (we use a simple average of the two pp data sets near 100 GeV/c). Errors (not shown) on the calculated points are approximately the same size as, and are correlated (via the odd prongs) with, the data point errors. The figure suggests reasonably agreement. To purdue this comparison, we avoid the point-by-point correlations and compare the average multplicities of the even-prong events alone with the predictions of appropriate sums of neutron-target and proton-target averages, taking into account the number of neutron-target events that are even prongs. For example, in the pd data there are 3798 even-prong events (see table 1), assumed here to contain 49% of 5298 or 2596, pp interactions and 1202 pn interactions. The observed even-prong average multiplicities are 7.57 ± 0.08 (π^+d) and 7.53 ± 0.05 (pd), while the predictions are 7.66 ± 0.07 (π^+d) and 7.35 ± 0.04 (pd). Hence the pd data show some slight evidence (a 3 standard deviation difference) of a multiplicity-increasing effect, whereas the π^+d data do not.

We now relate our π^+n multiplicities to properties of π^-p interactions. The following relation follows from charge symmetry:

$$\sigma(\pi^+\mathrm{n} \rightarrow N) = \sigma(\pi^-\mathrm{p} \rightarrow \mathrm{p} + N) + \sigma(\pi^-\mathrm{p} \rightarrow \mathrm{n} + N-1) \quad (1)$$

which can be rewritten as:

$$\sigma(\pi^+\mathrm{n} \rightarrow N) = Y_{N+1}\,\sigma(\pi^-\mathrm{p} \rightarrow N+1) + (1 - Y_{N-1})\,\sigma(\pi^-\mathrm{p} \rightarrow N-1) \quad (2)$$

where N, N+1, and N−1 refer to numbers of charged particles excluding those explicitly stated, and Y_N is the average number of (non-produced) protons per event in N prong π^-p interactions. No values of Y are available from π^-p experiments, so we can use our data and eq. (2) plus measured π^-p multiplicities [5] to extract these Y values. Combining all π^+n multiplicities appropriately, we obtain $Y_{av} = 0.57 \pm 0.08$, where Y_{av} is now the average number of outgoing protons in inelastic $\pi^- p$ interactions, and we have assumed $\sigma(\pi^+ n \to 1\text{-prong, inel.}) = (0.6 \pm 0.1)\, \sigma(\pi^- p \to 2\text{-prongs, inel.})$.

An equation analogous to eq. (2) can be derived relating pn and pp multiplicities if one additional assumption is made. We assume that the cross section for two ordered initial state nucleons to yield two ordered final state nucleons plus N additional charged particles depends only on how many nucleons (0, 1, or 2) have flipped charge state and on N. Again combining all pn multiplicities, we obtain $X_{av} = 0.53 \pm 0.07$ where X_{av} is one-half the average number of (non-produced) protons in inelastic pp interactions. We have used pp multiplicity data [3, 4] and have assumed $\sigma(pn \to 1\text{-prong, inel.}) = (0.6 \pm 0.1)\, \sigma(pp \to 2\text{-prongs, inel.})$. This value of X_{av} can be compared to the value of 0.54 ± 0.05 estimated directly from pp data [7] (we made a zero slope straight line extrapolation of their $d\sigma/dx$ data to $x = 0$).

The lines on fig. 1(a) join points calculated from eq. (2), and its pn analogy, with the simple assumption that Y_N or $X_N = 0.5$. We see reasonable agreement, with no significant N-dependent depletion at large N, in support of our earlier contention of no strong multiplicity-dependent rescattering.

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