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MULTIPLICITY DISTRIBUTIONS AND DOUBLE SCATTERING EFFECTS IN $\pi^- d$ INTERACTIONS AT 205 GeV*

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ABSTRACT

Multiplicity distributions of charged secondaries, $\sigma_N(\pi^- d)$ are obtained. The effective multiplicities $\sigma_N(\pi^- n)$ and $\sigma_N(\pi^- p)$ are extracted using the measured spectator momentum. The probability of double scattering P_N is found to be independent of multiplicity.

Results are presented on the multiplicity distribution of charged particles produced in $\pi^- d$ interactions at 205 GeV using the FNAL 30-in. HBC. The $\pi^- n$ interactions are extracted and compared to $\pi^- p$ and $\pi^+ p$ data. We present evidence that there are large double scattering effects and obtain the dependence of double scattering on the multiplicity of charged secondaries. Approximately 70,000 pictures were taken and scanned twice for all beam interactions in a fiducial region 36.7 cm long. A total of 13337 primary interactions with three or more charged secondaries ($N_{ch} \geq 3$) were recorded.[1] The number of beam tracks and all electron pairs and neutral strange particle decays were recorded. Discrepancies between the two scans were resolved by a third scan. The efficiency for detecting interactions with $N_{ch} \geq 3$ is essentially 100%.

The total cross section[2] observed for $N_{ch} \geq 3$ is 35.4 mb, which corresponds to 2.6 μb/evt. This has been corrected for 2.6 ± 0.5% muon contamination determined by Bogert, et al.[3] They have also found that the K^- and $\bar{p}$ contamination compensate and no corrections (0 ± 0.2%) to the measured cross-sections are necessary.

The topological distribution of events with $N_{ch} \geq 3$ is given in Table I, where corrections have been made for Dalitz pairs, neutral strange particles decaying near the vertex, and electron pairs materializing near the vertex. Errors on the corrected multiplicity reflect both the errors in the corrections and statistical errors. From the $N_{ch} \geq 3$ distribution we find the average number of negative particles produced in $\pi^- d$ collisions at 205 GeV to be $\langle N^{Pr}_{-\pi^- d} \rangle = 3.46 \pm 0.02$, with dispersion $D^{Pr}_{\pi^- d}(-) = 1.91 \pm 0.04$. These values are both larger than those observed in $\pi^- p$ interactions at 205 GeV:[3] $\langle N^{Pr}_{-\pi^- p} \rangle = 3.26 \pm 0.03$ and

$D^{Pr}_{\pi^- p}(-) = 1.79 \pm 0.05$. However, the ratio $< N^{Pr}_{-} >/D^{Pr}(-)$ is the same for $\pi^- p$ and $\pi^- d$ collisions.

We observe in Table I considerably more events with an even number of charged particles than with an odd number of charged particles. The same effect has been found in pd interactions at 300 GeV[4] and $\pi^+ d$ and pd interactions at 100 GeV.[5] The odd-prong events mainly result from $\pi^- n$ interactions in which the momentum of the spectator proton is too small to give a visible track in the bubble chamber ($P_s \lesssim 80$ MeV/c).[6] The even-prong events have contributions from three types of interactions: (i) $\pi^- p$ interactions (ii) $\pi^- n$ interactions with a detectable spectator proton (iii) $\pi^- n$ and $\pi^- p$ interactions which have rescattered on the spectator. Thus, $\pi^- n$ interactions are to be found in even-prong as well as odd-prong events.

Since protons in the backward hemisphere in the laboratory are unambiguous spectators, the <u>effective</u> $\pi^- n$ and $\pi^- p$ multiplicity distributions can be extracted easily. The number of even-prong events of multiplicity N observed with a backward spectator are multiplied by 2.18 to account for forward spectators,[7] subtracted from the even-prong sample, and reassigned to the odd-prong sample with multiplicity N-1. The resulting cross sections are given in Table I and Fig. 1. We stress that the effective $\pi^- n$ multiplicity distribution σ_N("$\pi^- n$") only contains contributions from $\pi^- n$ interactions while the effective $\pi^- p$ distribution σ_N("$\pi^- p$") has contributions from $\pi^- n$ and $\pi^- p$ interactions which have rescattered as well as "true" $\pi^- p$ interactions.[8]

The difference between the "$\pi^- n$" and "$\pi^- p$" distribution can be understood as a result of rescattering in the deuteron. A $\pi^- n$ (odd

multiplicity) interaction which rescatters gives an even multiplicity and feeds the "$\pi^- p$" distribution, while a $\pi^- p$ (even multiplicity) which rescatters remains even and, except for elastic rescattering, shifts the event to a higher multiplicity. In Fig. 2, the ratio of our extracted σ_N("$\pi^- p$") to the $\sigma_N(\pi^- p)$ obtained by Bogert, et al.[3] shows a definite increase with N, which confirms that we observe rescattering.

Assuming that $\sum_{N\geq 3} \sigma_N$ is the same for $\pi^- p$ and $\pi^- n$ interactions,[9] the average rescattering per $\pi^- d$ interaction can be estimated from the ratio $f = \sum_{N\geq 3} [\sigma_N(\text{"}\pi^- p\text{"}) - \sigma_N(\text{"}\pi^- n\text{"})] / \sum_{N\geq 3} \sigma_N(\pi^- d) = 0.14 \pm 0.01$. A similar result has been obtained by Dado, et al.[5] for $\pi^+ d$ interactions at 100 GeV. Even if $\sum_{N\geq 3} \sigma_N$ on free protons and free neutrons are equal, this ratio would be a slight overestimate because the 1 and 2 prong events can rescatter and contribute to the $N \geq 3$ events, and they are not included. Assuming that <u>all</u> the $N \leq 2$ prongs which rescatter inelastically go to $N \geq 4$, we can use the $\sigma_{TOT}(\pi^- d)$ measured by Carroll, et al.[10] and our $\sum_{N\geq 3} \sigma_N(\pi^- d)$ and the above 14% to obtain a lower limit for f. We thus conclude that $0.10 \leq f \leq 0.15$.

The mechanism of reinteraction in nuclei has received considerable attention recently. Several models have been advanced. The Cascade models[11] attempt to explain the rescattering by assuming that each of the produced particles independently reinteracts on the secondary nucleon. Other models[12] assume that the space-time structure of strong interactions is such that hadronic matter immediately after being produced interacts more like a single particle rather than N particles. The

dependence of charged particle multiplicity with A (for $A \geq 12$) observed in π nucleus interactions[13] agrees with this space-time development picture.

A crucial, yet simple, test of these models is the dependence of the rescattering probability on multiplicity. Cascade models will give a probability that increases with multiplicity, while the other models give a rescattering probability which is essentially independent of multiplicity. Assuming that $\sigma_N(\pi^+p) = \sigma_N(\pi^-n)$ and using the π^+p data of Ref. 9, we can obtain the probability of rescattering at each multiplicity from the ratio $P_N \equiv [\sigma(\pi^+p)-\sigma(\text{"}\pi^-n\text{"})]/\sigma(\pi^+p)$. Since π^+p interactions give even multiplicities and π^-n give odd multiplicities, there is a question of how the comparison should be made. We have done this in two ways. In Fig. 3a we give the result where we have interpolated the "π^-n" data by averaging $\sigma_N(\text{"}\pi^-n\text{"})$ and $\sigma_{N+2}(\text{"}\pi^-n\text{"})$ and compare with $\sigma_{N+1}(\pi^+p)$. In Fig. 3b we give the result when we compare $\sigma_{N+1}(\pi^+p)$ and $\sigma_N(\text{"}\pi^-n\text{"})$. In either case, we conclude that the reinteraction probability (P_N) does not increase with multiplicity. The curves in Figs. 3a,b are linear fits to the distributions.[14]

Our data argue against a Cascade model. If we choose a particular and simple Cascade model where ε is the probability of rescattering per charged secondary, then for small ε we can write $\sigma_N(\text{"}\pi^-n\text{"}) = A\,\sigma_N(\pi^+p)[1-\varepsilon N]$, where A is a normalization constant. Since $dP_N/dN = A\varepsilon$, our <u>data give</u> $\varepsilon \not\approx 0$, which contradicts the Cascade assumption.[15] Note, this result does not depend on uncertainties in normalization.

We conclude by direct measurement that the rescattering probability within a few fermi of the interaction does not depend on multiplicity. This confirms the space-time development picture of strong interactions discussed above. Deuterium is a particularly attractive target for studying the time development of hadronic matter since the backward spectator "tags" single interaction events.

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REFERENCES

1) We have neglected the 1 and 2 prong events because $\pi^- d$ coherent and $\pi^- n$ elastic interactions make it difficult to correct for scanning inefficiencies.

2) We have used $\rho_d = 0.137$ gm/cm^3.

3) D. Bogert, et al., Phys. Rev. Lett. 31, 1271 (1973) and "$\pi^- p$ at 205 GeV/c: Charged and Neutral Multiplicities; Characteristics of Neutral Production." To be published.

4) A. Sheng, et al. Phys. Rev. D12, 1219 (1975).

5) S. Dado, et al., "Multiplicity Distributions in $\pi^+ d$ and pd collisions at 100 GeV/c." Carnegie-Mellon University preprint.

6) We neglect the $\pi^- p$ interactions in which the momentum transferred to the proton is less than 80 MeV/c. This results in a small over estimate of the $\pi^- n$ cross section.

7) The factor 2.18 is obtained by averaging the invariant flux factor over the measured P_s momentum distribution. We have verified that this value does not depend on multiplicity.

8) The $\pi^- d$ coherent events which contribute mainly to the 3 and 4 prongs (A_1) are left in the sample. Because we can detect deuteron recoils only for $P_d \gtrsim 120$ MeV/c, the coherent events, based on an exp(40t) form factor, will give approximately equal contributions to the odd and even multiplicities.

9) J. Erwin, et al., "Multiplicity Distribution of $\pi^+ p$ and pp Interactions at 200 GeV/c", UCD-PPL-9-15-75. They have observed that $\sigma_N(\pi^+ p) = \sigma_N(\pi^- p)$ at 200 GeV. Thus, from charge symmetry this is probably a good assumption.

10) A.S. Carrol, et al., Phys. Rev. Lett. 33, 932 (1974).

11) A. Dar and J. Vary, Phys. Rev. D6, 2412 (1972); P. M. Fishbane and J. S. Trefil, Phys. Rev. Lett. 31, 734 (1973) and Phys. Rev. D8, 1467 (1973); I. Z. Artykow, et al., Nucl. Phys. B6, 11 (1968); and references therein. See also Ref. 5 for a specific application of a Cascade model to pd interactions.

12) A. Dar and J. Vary, ibid; A. Goldhaber, Phys. Rev. D7, 765 (1973); K. Gottfried, Phys. Rev. Lett. 32, 957 (1974); E. S. Lehman and G. A. Winbow, Phys. Rev. D10, 2962 (1974).

13) W. Busza, et al., Phys. Rev. Lett. 34, 836 (1975); J. R. Elliott, et al., Phys. Rev. Lett. 34, 607 (1975).

14) The same conclusion is obtained if we compare our σ_N("π^-n") to the measured $\sigma_N(\pi^-p)$ (Ref. 3) or to a $\sigma_N(\pi^-n)$ which is calculated using $\sigma_N(\pi^\pm p)$ and the assumption of isospin independence.

15) There is always the possibility that A could have an N dependence such that it compensates ε and gives $dP_N/dN \simeq 0$.

FIGURE CAPTIONS

Fig. 1 : Multiplicity distribution of $\pi^- d$ interactions at 205 GeV after correction for spectator protons, which gives the effective $\pi^- p$ and $\pi^- n$ multiplicity distribution.

Fig. 2 : Comparison of $\sigma_N(\pi^- p)$ of Ref. 3 and the effective $\sigma_N(\text{"}\pi^- p\text{"})$ from this experiment.

Fig. 3 : Dependence of rescattering probability (P_N) on multiplicity:

a) by comparing the average of $\sigma_N(\text{"}\pi^- n\text{"})$ and $\sigma_{N+2}(\text{"}\pi^- n\text{"})$ with $\sigma_{N+1}(\pi^+ p)$ of Ref. 9.

b) by comparing $\sigma_N(\text{"}\pi^- n\text{"})$ with $\sigma_{N+1}(\pi^+ p)$.

TABLE I

TOPOLOGICAL CROSS SECTIONS IN 205 GeV $\pi^- d$ INTERACTIONS

No. of Prongs	Events Found	Corrected Number	$\sigma_N(\pi^- d)$ mb	σ_N("$\pi^- p$") mb	σ_N("$\pi^- n$") mb
3	596	593.7 ±26.0	1.58 ±0.07		2.53 ±0.10
4	1537	1579.5 ±42.0	4.22 ±0.11	3.27 ±0.13	
5	624	632.2 ±25.4	1.69 ±0.07		2.75 ±0.10
6	1837	1868.0 ±43.9	4.99 ±0.12	3.92 ±0.14	
7	700	712.2 ±27.1	1.90 ±0.07		3.11 ±0.11
8	2003	2038.3 ±46.0	5.44 ±0.12	4.23 ±0.15	
9	638	644.4 ±25.9	1.72 ±0.07		2.59 ±0.10
10	1641	1628.5 ±41.0	4.35 ±0.11	3.48 ±0.13	
11	499	495.0 ±22.7	1.32 ±0.06		1.94 ±0.09
12	1182	1159.1 ±34.9	3.09 ±0.09	2.48 ±0.11	
13	327	309.7 ±18.2	0.83 ±0.05		1.16 ±0.07
14	706	673.7 ±26.9	1.80 ±0.07	1.46 ±0.08	
15	175	154.3 ±13.5	0.41 ±0.04		0.60 ±0.05
16	390	355.4 ±20.2	0.95 ±0.05	0.76 ±0.06	
17	79	69.7 ±13.8	0.19 ±0.04		0.26 ±0.04
18	190	170.5 ±25.5	0.46 ±0.07	0.39 ±0.07	
19	55	53.0 ± 8.5	0.14 ±0.02		0.18 ±0.03
20	77	61.3 ±19.7	0.16 ±0.05	0.13 ±0.06	
21	13	7.3 ± 7.3	0.019±0.019		0.019±0.019
22	40	37.6 ± 7.8	0.10 ±0.02	0.10 ±0.02	
23	6	6.3 ± 2.8	0.017±0.007		0.017±0.007
24	11	9.1 ± 4.0	0.024±0.010	0.024±0.010	
25	5	4.1 ± 2.8	0.011±0.007		0.011±0.007
26	3	$2.4^{+2.7}_{-1.8}$	$0.006^{+.007}_{-.005}$	$0.006^{+.007}_{-.005}$	
27	1	$1.0^{+2.6}_{-1.0}$	$0.003^{+.007}_{-.003}$		$0.003^{+.007}_{-.003}$
28	1	$1.0^{+2.6}_{-1.0}$	$0.003^{+.007}_{-.003}$	$0.003^{+.007}_{-.003}$	
29	0	$0.0^{+1.15}_{-0.0}$	$0.0^{+.003}_{-.0}$		$0.0^{+.003}_{-.0}$
30	1	$1.0^{+2.6}_{-0.0}$	$0.003^{+.007}_{-.003}$	$0.003^{+.007}_{-.003}$	
TOTAL	13337	13268 ± 123	35.43±0.33	20.25±0.33	15.17±0.25

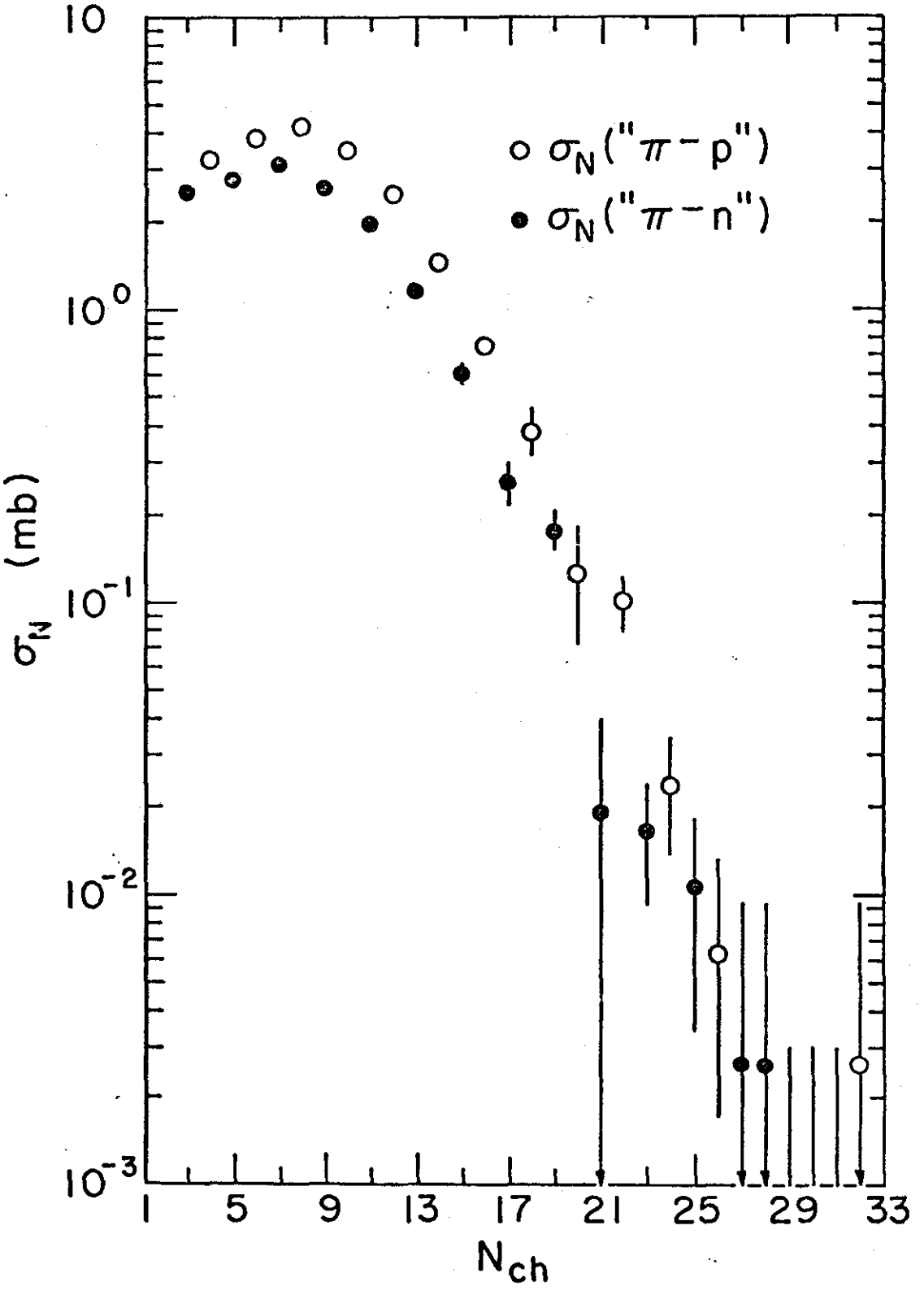
10
10^0
10^{-1}
10^{-2}
10^{-3}
σ_N (mb)
σ_N("π^-p")
σ_N("π^-n")
1
5
9
13
17
21
25
29
33
N_{ch}

FIG. 1

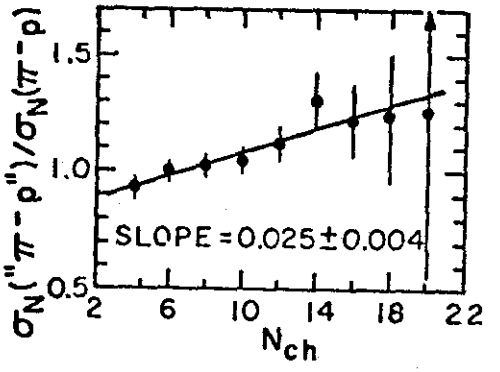
$\sigma_N(\pi^- - p)/\sigma_N(\pi^- - p)$
1.5
1.0
0.5
SLOPE = 0.025 ± 0.004
2
6
10
14
18
22
N_{ch}

FIG. 2

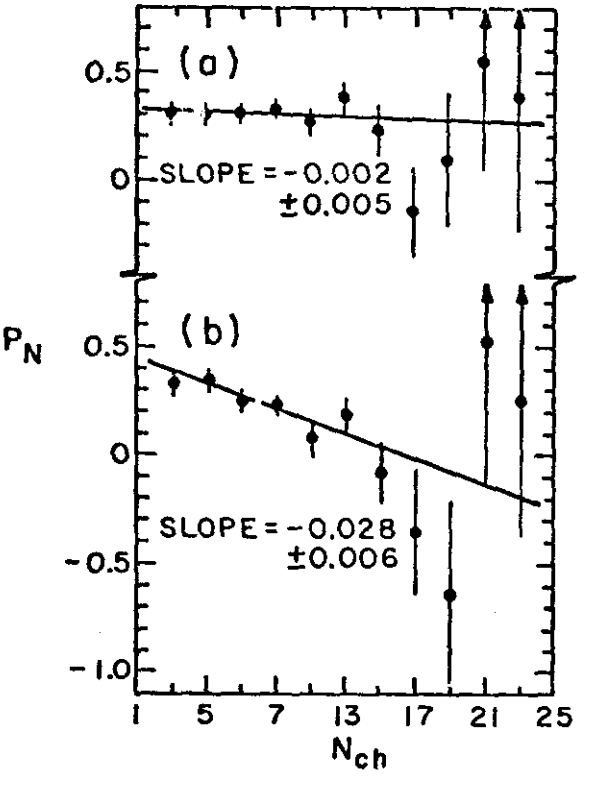
(a)
0.5
0
SLOPE = -0.002
± 0.005
(b)
P_N
0.5
0
-0.5
-1.0
SLOPE = -0.028
± 0.006
1
5
7
13
17
21
25
N_{ch}

FIG. 3