Some Features of N-P Charge Exchange Scattering

Between 60 and 300 GeV/c*

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ABSTRACT

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We examine the dependence of the N-P charge exchange cross-section on the four-momentum transfer squared and on the incident momentum, and include some comparisons with data from lower energies. Implications for the difference between N-P and P-P total cross-sections are presented.

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In the previous letter we presented the results of a new measurement of the N-P charge exchange differential cross-section covering incident momenta from 60 to 300 GeV/c and four momentum transfers squared (t) from .002 to .8 (GeV/c)². We present here an analysis of the data in which we examine the energy dependence of this reaction, and use the $t=0$ differential cross-section points to set bounds on the difference of the N-P and P-P total cross-sections.

All N-P charge exchange cross-sections above 3 GeV/c^{1,2,3,4,5} may be fit acceptably for $|t|$ less than .07 (GeV/c)² by the form

$$\frac{d\sigma}{dt} = A \left[\frac{m_{\pi}^4}{(|t| + m_{\pi}^2)^2} \right] + B \quad (1)$$

The phenomenological expression is motivated by models incorporating pion exchange with absorption⁶ and is useful in displaying the energy dependence of the size of the "pion" peak relative to the background. At $t=0$, the differential cross-section is the sum of the "pion" contribution whose coefficient is A and the sum of all other contributions given by B. The ratio A/B is a measure of the relative size of the forward peak independent of normalization. We have fit our data and that of others to expression (1) over a range of $|t|$ in the forward direction. The fits appear to be stable within errors for starting points ranging from .002 to .008 (GeV/c)² and end points from .05 to .07 (GeV/c)². In Figure 1 are plotted the results of fits to our data for the region .002 $\leq |t| \leq$ (GeV/c)², and in Table I we summarize our data as well as those of others.

It is evident that the ratio A/B fluctuates considerably between different energy bins and that there are large discrepancies between the data of some of the experiments. For instance, the experiments of Bohmer, et al and Babaev, et al⁵, display systematically larger forward peaks than ours measured at higher energies and also larger ones than those of Kreisler et al³ measured at lower and overlapping energies. The differential cross-section depends directly on correctly weighting detected events by the probability of their detection.

These weights include the efficiencies of the neutron counters, the probability of the neutron escaping from the target and the subtraction of inelastic backgrounds beneath the elastic peaks. Although we estimate the systematic effects resulting from a poor understanding of the above corrections are no more than 20% in our data, it is only fair to surmise that the systematic discrepancies observed among the several experiments may represent the true level of uncertainty involving these corrections. In order to avoid these difficulties and yet be able to study the energy dependence of the forward peak with some confidence, we choose to compare our data with that of Miller et al², an experiment in which the neutron counter geometry was similar and the corrections were applied in the same manner. We note that the ratio A/B has shrunk approximately a factor of two in going from 3-12 GeV/c to our present measurement, but that the pion peak is still statistically significant up to our highest energies.

We next examine the energy dependence of the differential cross-

section by fitting the data to a Regge form:

$$\frac{d\sigma}{dt} = n(t)S^{2\alpha(t)-2} \quad (2)$$

where S is the square of the center of mass energy. In Figure 2 we plot the resulting $\alpha(t)$ for our data and in Figure 3 we show the relative dependence of data from the cited experiments spanning the incident neutron momentum range from 3 to 300 GeV/c. For $|t|$ less than $.25 \text{ (GeV/c)}^2$ the value of $\alpha(t)$ is approximately .5 for incident momenta 60 to 300 GeV/c. This value should be compared with $\alpha \approx 0$ for 3 to 11 GeV/c, $\alpha \approx .1$ for 9 to 27 GeV/c and $\alpha \approx .25$ for 23 to 62 GeV/c. It is evident both from the increasing value of $\alpha(t)$ and from a cursory examination of Figure 3 that the momentum dependence of the data is monotonically decreasing with increasing momentum. Simple theoretical models predict that the pion exchange contribution falls with $\alpha(0) = 0$, and that $\rho - A_2$ exchange falls as $\alpha(0) = 0.5$. Within the context of these simple models, it is difficult to reconcile a value for α compatible with $\rho - A_2$ exchange with the persistence of the forward peak mentioned previously.

It is worth noting that the differential cross-section at higher momentum transfers shows a shoulder developing at $|t| \approx .1 \text{ (GeV/c)}^2$ as the incident momentum is increased, while beyond a $|t|$ of .25 the fall-off appears to be exponential. As indicated by the decreasing values of $\alpha(t)$, there is some evidence for shrinkage in this exponential region.

Using the $|t| = 0$ cross-section derived from formula (1), bounds on the total cross-section difference may be estimated from the optical theorem and assuming charge symmetry

$$\left(4 \sqrt{\pi} \hbar \sqrt{A+B} \right) \geq |\sigma_{PP} - \sigma_{NP}| \quad (3)$$

These limits are presented in Table II, together with limits from the separate measurements of the total cross-sections.^{8,9}

It is evident the limits from this experiment at the highest energies are comparable to those found from subtraction of the total cross-sections. If one wishes to bound possible differences at the two or three standard deviation level, the limits derived from this experiment are superior, as the error of the cross-section difference is a small fraction of the bound on the difference.

Finally, formula (3) neglects both the real part of the amplitude, and the double flip zero net helicity flip amplitude. Thus, any theoretical model which estimates these large contributions should be able to establish significantly stronger bounds on the cross-section difference than those presented in this paper.

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FIGURE CAPTIONS

- Figure 1 Fits to the highest energy data using pion exchange plus background. The data are from reference (1), the solid curve is the best least squares fit of formula (1).
- Figure 2 The best least squares fit of $\alpha(t)$ from formula (2) to the data of reference (1). Please note that the zero has been suppressed.
- Figure 3 Data from several experiments are presented within three fixed bins in momentum transfer. Though the normalization from the experiments is not always compatible, there is a strong indication the energy dependence decreases as the energy increases.
- Table I The ratio of pion peak to background (A/B) is shown as a function of incident neutron momentum for five different experiments. The errors shown are generally those given by least squares, but have been increased when necessary to cover dependence of (A/B) on the range of momentum transfers used in the fitting.
- Table II $|\sigma_{PP} - \sigma_{NP}|$ derived from differences of total cross-sections and inferred from the NP charge exchange cross-section extrapolated to zero degrees.

FIGURE I

FIGURE II

FIGURE III

P (GeV/c)	(A/B)	Authors
60-90	0.85 ± 0.23	Barton, et al (1)
90-120	0.70 ± 0.22	
120-160	0.92 ± 0.21	
160-200	1.13 ± 0.23	
200-240	0.98 ± 0.22	
240-300	0.52 ± 0.19	
4	1.50 ± 0.13	Miller, et al (2)
5	1.56 ± 0.13	
6	1.82 ± 0.15	
7	1.51 ± 0.20	
8	1.68 ± 0.24	
9	1.78 ± 0.16	
10	1.81 ± 0.15	
11	1.86 ± 0.20	
11.75	3.03 ± 0.35	
8-11	1.39 ± 0.39	Kreisler, et al (3)
11-14	2.29 ± 0.42	
14-16	2.10 ± 0.47	
16-18	1.56 ± 0.41	
18-20	2.99 ± 0.54	
20-22	2.06 ± 0.42	
22-24	1.31 ± 0.32	
24-26	1.76 ± 0.39	
26-29	1.28 ± 0.32	
9-12	2.31 ± 0.20	" Bohmer, et al (4)
12-15	2.68 ± 0.29	
15-17	3.03 ± 0.45	
17-19	3.04 ± 0.42	
19-21	2.92 ± 0.32	
21-23	3.23 ± 0.39	
23.5	1.33 ± 0.69	Babaev, et al (5)
27.5	3.27 ± 0.42	
32.5	3.98 ± 0.51	
37.5	3.17 ± 0.37	
42.5	4.12 ± 0.57	
47.5	5.00 ± 0.59	
52.5	3.66 ± 0.41	
57.5	2.99 ± 0.34	
62.5	2.36 ± 0.28	

TABLE I

P (Average)	(a)	(b)	From Total Cross Section Differences		Bound From Charge Exchange (Formula 3)
	σ_{PN}	σ_{PP}	σ_{PP}	σ_{NP} (c)	
75 GeV/c	$38.63 \pm .40$ mb	$38.26 \pm .06$ mb	$.37 \pm .40$ mb		$.66 \pm .06$
105	$38.95 \pm .26$	$38.43 \pm .06$	$.52 \pm .27$		$.54 \pm .06$
140	$39.28 \pm .19$	$38.61 \pm .06$	$.67 \pm .20$		$.49 \pm .05$
180	$39.61 \pm .20$	$38.79 \pm .06$	$.82 \pm .21$		$.44 \pm .05$
220	$39.90 \pm .24$	$38.95 \pm (?)$	$.95 \pm (?)$		$.39 \pm .04$
265	$40.19 \pm .24$	$39.11 \pm (?)$	$1.08 \pm (?)$		$.34 \pm .04$

(a) Taken from the fit $\sigma = 38.4 + .085 \left[\ln (S/95) \right]^{1.47}$

given in reference 7. The errors are interpolated from neighboring data points.

(b) The data from reference 8 are fit to the similar form

$$\sigma = 38.14 + 0.46 \left[\ln (S/95) \right]^{1.47}$$

Errors are not stated above the 200 GeV/c end point of the data.

(c) We could have used the NP cross-sections derived from the proton-deuteron cross sections of reference 8, but would have incurred an error of ± 0.6 mb. For example, the point at 180 GeV would have been 0.33 ± 0.6 mb. Thus, we preferred to use the directly measured NP cross-section given in reference 7.

TABLE II