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SEPARATION OF ISOTOPIC-SPIN 1/2 AND 3/2 πN SYSTEMS IN $pp \rightarrow N\pi N$ REACTIONS AT 6.6 GeV/c

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Separation of Isotopic-Spin 1/2 and 3/2 πN Systems in pp → NπN Reactions at 6.6 GeV/c

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Abstract

Data for the reactions $pp \rightarrow p\pi^+n$ and $pp \rightarrow pp\pi^0$ at 6.6 GeV/c are used to obtain the cross sections for the production of isotopic spin 1/2 and 3/2 πN systems as well as their mutual interference term. Invariant mass and momentum transfer projections are presented. Comparisons are made with previous results at 6.92 and 19 GeV/c.

In this paper we calculate the cross-sections for the production of isotopic spin 1/2 and 3/2 πN systems in single-pion production in proton-proton collisions utilizing charge independence. Isospin separations have been previously reported for π^+p interactions at 5,[1] and 8 and 16 GeV/c,[2] and for pp interactions at 6.92,[3] and 19 GeV/c.[4,5] The data for this analysis were obtained using the Lawrence Berkeley

Laboratory 72-in. hydrogen bubble chamber exposed to an external proton beam of 6.6 GeV/c incident momentum. We utilize 6424 events of the type $pp \rightarrow p\pi^{+}n$ and 2539 events of the type $pp \rightarrow pp\pi^{o}$. The production cross sections for the two reactions are 5.73 ± 0.35 and 2.54 ± 0.16 mb , respectively.

In order to perform an isotopic-spin separation in $pp \rightarrow N\pi N$ reactions the outgoing pi meson must be associated with one of the outgoing nucleons. Following earlier analyses[3,4] we assign the π to a nucleon which is referred to as N_1, such that $N_1\pi$ has the minimum invariant mass (MIM), i.e., $M(N_1\pi) < M(N_2\pi)$. The use of this criterion for separation yields [for $\sigma(pp \rightarrow N_1\pi N_2)$]

$$\begin{aligned}
\sigma_1 &\equiv (pp \rightarrow p\pi^{+}n) = 2.94 \pm 0.19 \text{ mb} \\
\sigma_2 &\equiv (pp \rightarrow n\pi^{+}p) = 2.79 \pm 0.18 \text{ mb} \qquad (1) \\
\sigma_3 &\equiv (pp \rightarrow p\pi^{o}p) = 2.54 \pm 0.16 \text{ mb}
\end{aligned}$$

In order to separate the different isotopic-spin contributions to reactions (1) we define $|A_{2I}|^2$ to be the integrated cross section for producing the $N_1\pi$ system with isotopic-spin I. Then from charge independence and Bøggild et al,[4] we have

$$\begin{aligned}
|A_3|^2 &\equiv (4/3)\sigma_1 = 3.92 \pm 0.25 \text{ mb} \\
|A_1|^2 &\equiv \sigma_3 + \sigma_2 - (1/3)\sigma_1 = 4.35 \pm 0.38 \text{ mb} \qquad (2) \\
\mathrm{Re}(A_1^* A_3) &\equiv (1/\sqrt{2})[2\sigma_3 - \sigma_2 - (1/3)\sigma_1] = 0.92 \pm 0.23 \text{ mb} .
\end{aligned}$$

The average phase angle between the two isotopic-spin amplitudes, integrated over all variables is given by

$$\cos\phi_{13} = \frac{\mathrm{Re}(A_1^*A_3)}{|A_1||A_3|} = 0.22 \pm 0.06 \quad . \qquad (3)$$

For the purpose of comparison we list in Table I the above quantities and those determined at 19 GeV/c,[4] and at 6.92 GeV/c by Rushbrooke.[6] The I = 3/2 cross sections decrease more rapidly with increasing beam momentum than do the I = 1/2 cross sections: whereas the ratio $|A_1|/|A_3|$ is consistent with 1.0 slightly below 7 GeV/c, it has risen to 1.8 at 19 GeV/c. The phase angle cosine [defined by eq. (3)] shows little change with increasing beam momentum, however.

In order to illustrate the invariant mass and four-momentum transfer dependence of the amplitudes defined in Eqs. (2) we show first in Figs. 1(a)—1(c) the $d\sigma/dM(N_1\pi)$ projections of $|A_3|^2$, $|A_1|^2$, and $\mathrm{Re}(A_1^*A_3)$, respectively, as a function of $M(N_1\pi)$ in 40 MeV bins. Figure 1(a) indicates copious production of the $J^P = \frac{3}{2}^+$ $\Delta^{++}(1238)$ resonance with little or no significant structure at higher mass values. The I = 1/2 mass distribution [Fig. 1(b)] displays an enhanced region from threshold to 1.75 GeV: Discernable peaks are seen near 1.45 and 1.65 GeV. We have reported on these I = 1/2 resonances in an earlier publication.[7] Below 1.4 GeV the structure is similar to the I = 1/2 invariant mass distributions observed by the ABBCC collaboration[2] in their study of π^+p interactions at 8 and 16 GeV/c: The data show an excess near 1.3 GeV, which is well below the central mass value of the first I = 1/2 πN resonance [$J^P = 1/2^+$ N(1470)]. The interference term [$Re(A_1^* A_3)$] plotted in Fig 1(c) is consistent with zero from 1.12 to 1.28 GeV and is positive elsewhere. This observation is opposite to that reported at 6.92 GeV/c;[3] however, this discrepancy may be due in part to the values used for σ_3 in Eq. (2): 2.54 mb at 6.6 GeV/c and 2.0 mb at 6.92 GeV/c. In any case, structure does exist in Fig. 1(c) but clearly more accurate data are required for serious studies.

The $d\sigma/dt$ projections of $|A_3|^2$ and $|A_1|^2$ are given in Figs. 2(a)-2(d). The data are plotted vs. both t_1 and t_2 where $-t_i$ is the four-momentum transfer squared from the appropriate incoming proton to the outgoing N_i.[8] The $d\sigma/dt_1$ projections of $|A_3|^2$ and $|A_1|^2$ (Figs. 2(a) and 2(c), respectively) are markedly different. Figure 2(a) exhibits different behavior in three clearly defined regions of t_1, where each behavior is mainly due to a different $M(p\pi^+)$ region.[9] Figure 2(a) is similar to the corresponding distribution observed at 19 GeV/c[5] in that a break is seen near 0.7 GeV/c, however the break appears as a dip at 0.8 GeV^2 at the higher beam momentum. The data in Fig. 2(c) decrease smoothly with t_1 to 2.0 GeV^2, then fall off more rapidly. The $d\sigma/dt_2$ projections of $|A_3|^2$ and $|A_1|^2$ (Figs. 2(b) and 2(d), respectively) both display a smooth drop-off with t_2. The data in Figs. 2(b)-2(d) have been fit, using the least-squares method, to the function

$$\frac{d\sigma}{dt} = Ae^{xt} + Be^{yt} \quad . \tag{4}$$

The resulting confidence levels, as well as the best fit values of the parameters are listed in Table II. The small t behavior of each distribution in Figs. 2(b)-2(d) appears to be different, as evidenced by the differing values of the slope parameter x. The y slope parameters are similar in each case, however. This behavior was also observed at 19 GeV/c.[5]

Turning now to the question of the dominant exchange responsible for the $|A_3|^2$ and $|A_1|^2$ cross section, we have shown[10] that one-pion-exchange (OPE) is dominant in the reaction $pp \to \Delta^{++}(1238)n$. In work in progress we have verified[11] that significant OPE contributions exist also at higher $M(p\pi^+)$ values. Thus we conclude that the $|A_3|^2$ cross section is dominantly due to OPE, in agreement with Bøggild et al.[5] In the case of the $|A_1|^2$, it was shown earlier,[4] by means of energy independence arguments, that Pomeron exchange appears to be dominant at 19 GeV/c. If the I=1/2 cross section is due mainly to Pomeron exchange at both 6.6 and 19 GeV/c, then the ratio of these cross sections should closely approximate the square of the ratio of the pp total cross sections,[12] ~~(by the optical theorem)~~ which is roughly $(41/39)^2 = 1.11$. From Table I we have $|A_1|^2_{6.6}/|A_1|^2_{19} = 4.35/2.3 = 1.89 \pm 0.30$. The two ratios differ by roughly 2.5 standard deviations, indicating energy non-independence of $|A_1|^2$ in going from 6.6 to 19 GeV/c. Therefore Pomeron exchange is not dominant in producing $I = 1/2$ $N\pi$ systems at 6.6 GeV/c. In fact, Rushbrooke[6] has shown, using the pp and pd data at 6.92 GeV/c, that the Pomeron-exchange contribution amounts to $(36^{+7}_{-11})\%$ of the total reaction amplitude.[13] A similar calculation using our pp data (at 6.6 GeV/c) together with the 6.92 GeV/c pd data[6] indicates a 33% contribution.

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References and Footnotes

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8. Since pp interactions are peripheral at 6.6 GeV/c, the outgoing nucleons can be associated with the appropriate initial-state protons in nearly all cases.
9. The three regions of t_1 are approximately 0.05-0.7 GeV^2, 0.7-1.8 GeV^2, and 1.8-3.0 GeV^2. The dominant effects observed in these regions are associated with data for $M(p\pi^+) < 1.4$ GeV, $1.4 < M(p\pi^+) < 1.8$ GeV and $M(p\pi^+) > 1.8$ GeV, respectively.

10. Z. Ming Ma, Gerald A. Smith, R. J. Sprafka, Eugene Colton, and Peter E. Schlein, Phys. Rev. Letters 23, 342 (1969).

11. Pole-extrapolation techniques applied to the reaction $pp \to (p\pi^+)n$, in order to determine the on-mass-shell π^+p elastic scattering cross section, have yielded correct results up to $M(p\pi^+) = 2.02$ GeV.
12. If we invoke factorization and assume that the N_2 vertices are of the same type as exist in elastic scattering, then the total cross sections can be related to the $I = 1/2$ cross sections by the optical theorem.
13. The use of reactions (1) along with data for the process $pn \to pp\pi^-$ leads to a determination of the $I = 0$ exchange amplitude in $NN \to NN\pi$. See Ref. 6.

Table I. Isotopic spin cross section for the reactions $pp \to N_1 \pi N_2$ for different beam momenta.

Momenta (GeV/c)	$\|A_1\|^2$ (mb)	$\|A_3\|^2$ (mb)	$\cos\phi_{13}$	$\|A_1\|/\|A_3\|$
6.6	4.35±0.38	3.92±0.25	0.22±0.06	1.05±0.06
6.92[a]	4.3 ±1.2	2.9 ±0.7	0.06±0.16	1.2 ±0.2
19[b]	2.3 ±0.3	0.7 ±0.1	0.4 ±0.3	1.8 ±0.3

a. Reference 6

b. Reference 4

Table II. Results of least-squares fits of the $d\sigma/dt$ distributions in Figs. 2(b)-2(d) to the form $Ae^{xt} + Be^{yt}$.

	Distribution		
Fit Quantity	$\|A_3\|^2$[Fig.2(b)]	$\|A_1\|^2$[Fig.2(c)]	$\|A_1\|^2$[Fig.2(d)]
t range (GeV^2)	0.0-3.0	0.05-1.90	0.05-3.0
confidence level (%)	2	89	6
A	18.2±1.4	5.7±0.9	16.4±1.4
B	1.6±0.3	3.3±1.0	1.8±0.4
x (GeV^{-2})	-7.2±0.6	-4.4±1.4	-5.8±0.5
y (GeV^{-2})	-1.2±0.1	-0.9±0.2	-1.1±0.1

Figure Captions

Figure 1. $d\sigma/dM(N_1\pi)$ projections for $pp \to N_1\pi N_2$ at 6.6 GeV/c where $M(N_1\pi) < M(N_2\pi)$. (a) $|A_3|^2$; (b) $|A_1|^2$; (c) $Re(A_1^*A_3)$ where these quantities have been calculated using Eqs. (2).

Figure 2. $d\sigma/dt_i$ projections for $pp \to N_1\pi N_2$ at 6.6 GeV/c where $M(N_1\pi) < M(N_2\pi)$ and $-t_i$ is the four momentum transfer squared from the appropriate incoming proton to the outgoing N_i. (a)-(b) t_1 and t_2 projections of $|A_3|^2$, respectively; (c)-(d) t_1 and t_2 projections of $|A_1|^2$, respectively. $|A_3|^2$ and $|A_1|^2$ have been calculated using Eqs. (2).

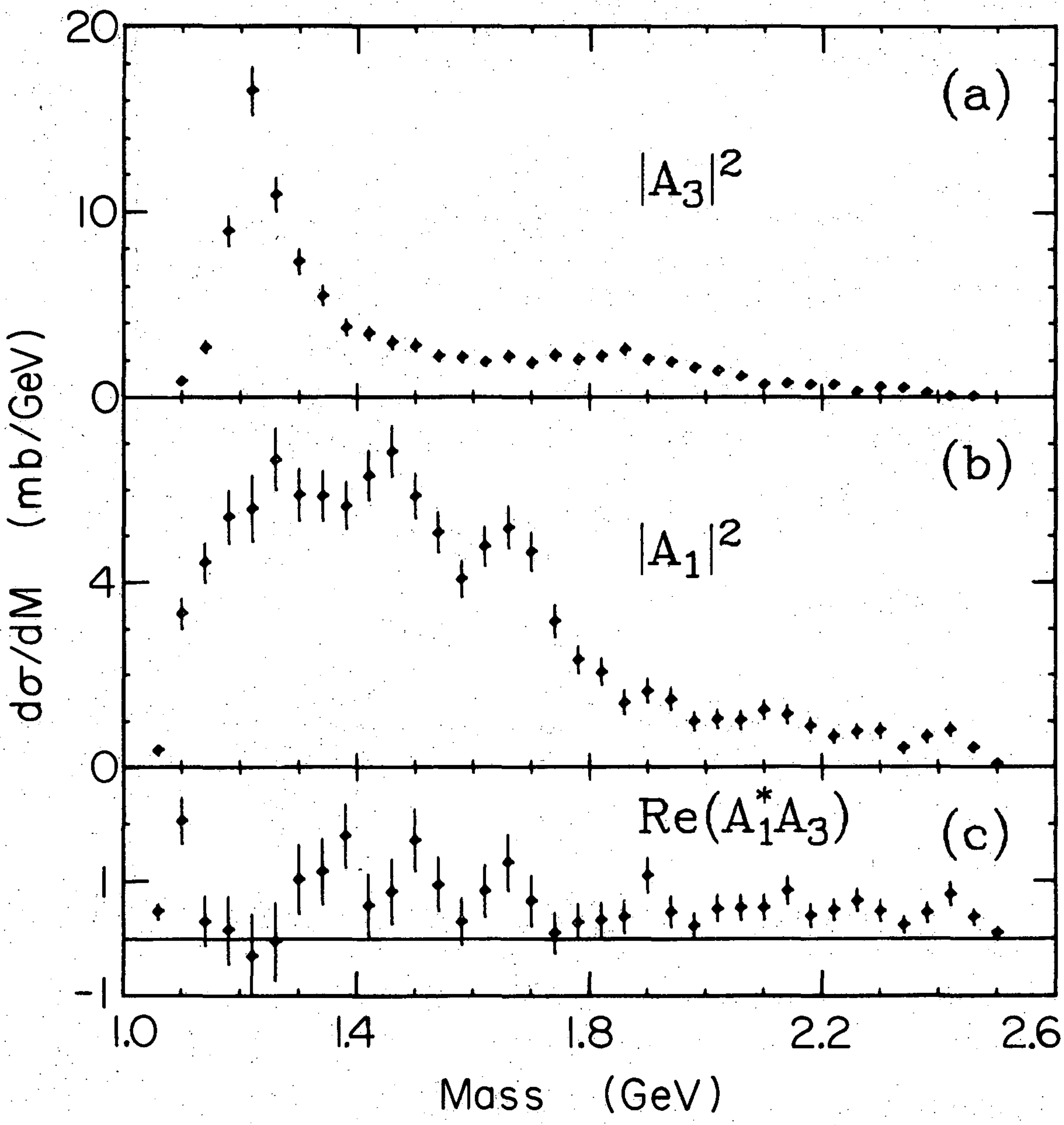

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FIGURE 1

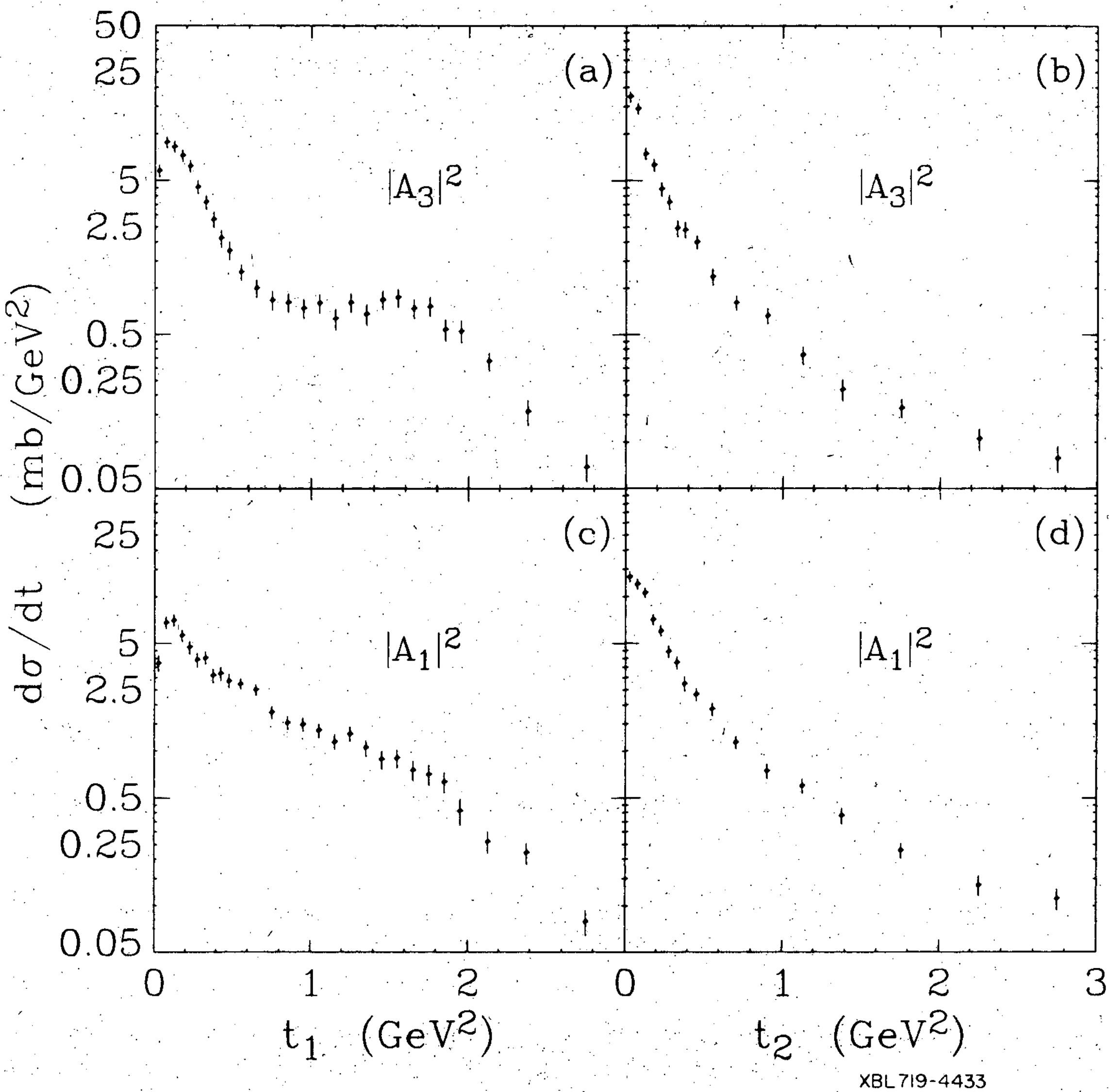
(a)
(b)
(c)
(d)
|A3|2
|A3|2
|A1|2
|A1|2
dσ/dt (mb/GeV2)
50
25
5
2.5
0.5
0.25
0.05
0
1
2
3
t1 (GeV2)
t2 (GeV2)
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FIGURE 2

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