Experimental Comparison between On- and Off-Mass-Shell Inelasticities in $\pi^- p$ Scattering. II*

EUGENE COLTON
Lawrence Radiation Laboratory, University of California, Berkeley, California 94720

AND

PETER E. SCHLEIN†
Physics Department, University of California, Los Angeles, California 90024

AND

Z. MING MA AND GERALD A. SMITH
Physics Department, Michigan State University, East Lansing, Michigan 48823

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It is shown that the experimental cross-section ratio of the reactions $pp \to \Delta^{++}$ (neutrals) and $pp \to \Delta^{++}(\pi^- p)$ (at 6.6 GeV/c) for low momentum transfer to the $\Delta^{++}(|t|<0.2\ \mathrm{GeV}^2)$ is approximately the same as the cross-section ratio $\sigma(\pi^- p \to \text{neutrals})/\sigma(\pi^- p \to \pi^- p)$ for $\pi^- p$ effective mass less than 1.56 GeV. The disagreement observed between the ratios for masses greater than 1.56 GeV can be explained by increased values of $t_{\min}$ and non-Δ^{++} background in the pp reactions. These results imply that pion exchange dominates $pp \to \Delta^{++}$ (neutrals) for low momentum transfer to the Δ^{++}.

IN a recent analysis of the reactions

$$pp \to \Delta^{++}(\pi^- p) \tag{1a}$$
$$\to \Delta^{++}(\pi^- \pi^+ n) \tag{1b}$$
$$\to \Delta^{++}(\pi^- \pi^0 p) \tag{1c}$$

at 6.6 GeV/c,[1] we showed that the relative yields of the bracketed systems at low momentum transfer ($|t_{p\Delta}|<0.2\ \mathrm{GeV}^2$) as a function of effective mass of that system are very nearly the same as the relative cross sections of the three on-mass-shell $\pi^- p$ reactions

$$\pi^- p \to \pi^- p \tag{2a}$$
$$\to \pi^- \pi^+ n \tag{2b}$$
$$\to \pi^- \pi^0 p. \tag{2c}$$

This agreement suggests that the bracketed systems in reactions (1a)–(1c) result from the scattering of an incident proton on a virtual pion from the other proton when it is in the virtual state $p \to \Delta^{++}\pi^-$. It furthermore suggests that the off-mass-shell corrections to the pole-equation descriptions of the three reactions (1a)–(1c) are very similar. Otherwise the physical-region comparison of the three reactions could not agree so well.

In a subsequent analysis of the reactions[2]

$$pp \to n(\pi^+ p) \tag{3a}$$
$$\to n(\pi^+ p \pi^+ \pi^-) \tag{3b}$$

we compared the relative yields of the bracketed systems in reactions (3a) and (3b) and the relative cross sections for

$$\pi^+ p \to \pi^+ p \tag{4a}$$
$$\to \pi^+ p \pi^+ \pi^-. \tag{4b}$$

In this case the comparison showed that the experimental ratios [of (3b) to (3a)] systematically exceeded the $\pi^+ p$ on-shell cross-section ratios by $\sim$25–40%. However, the difference can be explained solely by a $\Delta^-(1238)$ background contribution to reaction (3b).

We present in this note a further comparison (also at 6.6 GeV/c) which is a followup to the analysis of Ref. 1. The relative yields of the low-momentum-transfer components ($|t|<0.2\ \mathrm{GeV}^2$) of the reactions

$$pp \to \Delta^{++}(\text{neutrals}) \tag{5a}$$
$$\to \Delta^{++}(\pi^- p) \tag{5b}$$

are compared to the relative cross sections for

$$\pi^- p \to \text{neutrals} \tag{6a}$$
$$\to \pi^- p. \tag{6b}$$

The data of reaction (5a) consist of a 2.34-μb/event sample of 4026 unfitted two-prong events with $M_{p\pi^+}<1.5$ GeV and forward neutrals in the c.m. system. For these events the ionization confidence level is required to favor a $p\pi^+$ interpretation instead of pp for the two outgoing charged tracks. The data for reaction (5b), as before,[1] consist of a 0.36-μb/event sample of 7514 $pp \to pp\pi^+\pi^-$ events. The data for reactions (5a) and

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† John Simon Guggenheim fellow, on leave at CERN (1969–70).
[1] Eugene Colton, Peter E. Schlein, Eugene Gellert, and Gerald A. Smith, Phys. Rev. Letters 21, 1548 (1968). See also the detailed analysis of reaction (1a) by Eugene Colton, Peter E. Schlein, Eugene Gellert, and Gerald A. Smith, UCLA Report No. UCLA-1036 (unpublished).
[2] Eugene Colton and Peter E. Schlein, Phys. Rev. D 1, 373 (1970).

(5b) are obtained by applying the simultaneous cuts[3]

$$1.14<M_{p\pi^+}<1.30 \text{ GeV},$$
$$|t_{p\Delta}|<0.2 \text{ GeV}^2. \quad (7)$$

We take $|t_{p\Delta}|$ to be the lower of the squares of the two possible momentum transfers from the beam or target proton to the Δ^{++} and restrict the discussion henceforth to the events passing the cuts (7).

The effective-mass spectra of the bracketed systems of reactions (5a) and (5b) are presented in Figs. 1(a) and 1(b), respectively. The smooth curve drawn in Fig. 1(a) represents an estimate of the background due to the reaction $pp \to p\pi^+n$. The intercept at 1166 MeV is the point above which no $pp \to p\pi^+n$ constrained fits are observed. In Fig. 2 we show the ratio of the cross sections of reactions (5a) to (5b) as a function of mass of the bracketed systems (M_X). The ratios have been corrected for $pp \to p\pi^+n$ background in reaction (5a) for $M_X<1.166$ GeV. The cross-hatched band shows the known on-mass-shell ratio of reactions (6a) to (6b).[4] The experimental and on-mass-shell ratios agree quite well below 1560 MeV except for the first point from 1080 to 1120 MeV (which may just be due to poor statistics or an overestimate in $p\pi^+n$ background). Above 1560 MeV the experimental ratios exceed the on-shell ratios by a factor of 2 or 3.[5] This disagreement at large M_X may just be due to the use of events with generally larger values of $|t|$ (because $t_{\min}$ increases with M_X) or simply non-Δ^{++} background in the peripheral data of reaction (5a).

We have looked at the $p\pi^+$ mass spectra in reactions (5a) and (5b) for several regions of the mass of the bracketed systems (X) in order to see if the difference in ratios for large M_X is due to non-Δ^{++} background in the data of reaction (5a). For $M_X<1500$ MeV the non-Δ^{++} background appears to be small. However, the phase space available to the $p\pi^+$ mass for large M_X is so small (max $M_{p\pi^+}<1.4$ GeV) that one cannot judge the percentage of non-Δ^{++} events in this sample. Assuming that non-Δ^{++} background, if present, is weakest in the central region of the Δ^{++}, we here again calculated the

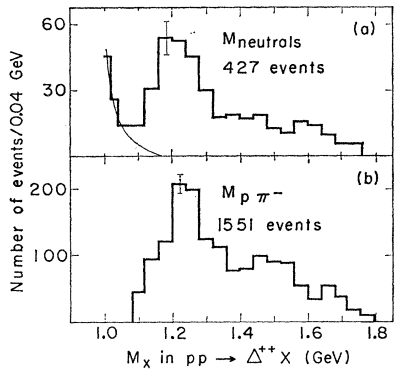

FIG. 1. Effective-mass distributions of X in $pp \to \Delta^{++}X$ for $|t|<0.2$ GeV^2 at 6.6 GeV/c. The Δ^{++} selection is 1.14–1.30 GeV. (a) X=neutrals; (b) $X=p\pi^-$.

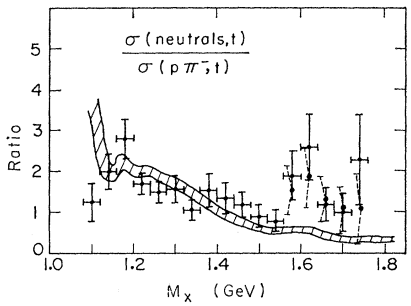

FIG. 2. Cross-section ratio $\sigma(pp \to \Delta^{++}(\text{neutrals}))/\sigma(pp \to \Delta^{++}(p\pi^-))$ plotted as a function of the mass of the non-Δ^{++} final-state system, for momentum transfer to the Δ^{++} $|t|<0.2$ GeV^2. The dashed points in the uppermost five mass bins represent the ratios calculated using $1.18<M_{p\pi^+}<1.26$ GeV for the Δ^{++} selection. The cross-hatched band is the known (Ref. 4) on-shell ratio $\sigma(\pi^-p \to \text{neutrals})/\sigma(\pi^-p \to \pi^-p)$.

experimental cross-section ratios of reactions (5a) to (5b) using peripheral ($|t|<0.2$ GeV^2) data with a narrower Δ^{++} cut ($1.18<M_{p\pi^+}<1.26$ GeV). These ratios are identical to those displayed in Fig. 2 for $M_X<1.56$ GeV, except for the larger errors (fewer events are utilized in this case). The ratios for the five M_X bins with $M_X>1.56$ GeV are represented by the points with dashed errors in Fig. 2. For $M_X>1.56$ GeV, the ratios calculated using a narrow Δ^{++} cut are in better agreement with the on-shell ratios than those experimental ratios obtained with data satisfying both restrictions of Eq. (7).

Experimental determinations of on-shell inelastic cross sections ($X\pi \to Y$, $Y \neq X\pi$) in processes of the type $Xp \to Yn$ or $Xp \to Y\Delta^{++}$ can be obtained by extrapolation of the appropriate Chew-Low distribution to the pion-exchange pole. Our results show, as before,[1,2] that the form of the extrapolation function used should have approximately the same form used for elastic $X\pi$ scattering.

[3] In the case of the $pp\pi^+\pi^-$ events, if both $M_{p\pi^+}$ combinations fall within the Δ^{++} band and both have $|t|<0.2$ GeV^2 we use that combination with the smallest $|t|$. This procedure tends to distort the $M_{p\pi^-}$ distribution slightly by depleting combinations at intermediate and high $p\pi^-$ masses and correspondingly adding the other low-t combinations to the low end of the $M_{p\pi^-}$ spectrum.

[4] The π^-p elastic cross sections were constructed from the CERN phase shifts; see, e.g., A. Donnachie, R. G. Kirsopp, and C. Lovelace, CERN Report No. CERN-TH 838, Addendum, 1967 (unpublished). For a summary of cross sections for $\pi^-p \to$ neutrals see, e.g., C. B. Chiu, R. D. Eandi, A. C. Helmholz, R. W. Kenney, B. J. Moyer, J. A. Poirier, W. B. Richards, R. J. Cence, V. Z. Peterson, N. K. Sehgal, and V. J. Stenger, Phys. Rev. 156, 1415 (1967).

[5] W. E. Ellis, R. R. Kinsey, T. W. Morris, and R. S. Panvini, BNL Report No. 14426, 1970 (unpublished). These authors also report that their experimental ratios exceed the on-mass-shell ratios by roughly a factor of 2 [see their Fig. 5(a)].