Experimental Comparison between On- and Off-Mass-Shell Inelasticity in π^+p Scattering*

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(Received 8 September 1969)

Evidence is presented from a proton-proton bubble-chamber experiment at 6.6-GeV/c beam momentum that the cross-section ratio $\sigma(pp\to\pi^+p\pi^+\pi^-n)/\sigma(pp\to\pi^+pn)$ for low momentum transfer to the neutron ($t<0.2$ GeV^2) is approximately the same as the cross-section ratio $\sigma(\pi^+p\to\pi^+p\pi^+\pi^-)/\sigma(\pi^+p\to\pi^+p)$ when compared as a function of invariant mass of the non-neutron system in the pp reactions. These results imply that (a) pion exchange dominates $pp\to(\pi^+p\pi^+\pi^-)n$ for low momentum transfer to the neutron, in view of the recent results of Ma *et al.* on $pp\to(\pi^+p)n$, and (b) the off-shell corrections to the pion pole equation for $pp\to(\pi^+p\pi^+\pi^-)n$ are similar to those for $pp\to(\pi^+p)n$; the results presented here complement those presented earlier by Colton *et al.* for the reactions $pp\to(p\pi^-)\Delta^{++}$, $(p\pi^-\pi^0)\Delta^{++}$, and $(n\pi^-\pi^+)\Delta^{++}$.

IN a recent analysis with Gellert and Smith[1] of the reactions

$$pp\to\Delta^{++}(\pi^-p)\,, \tag{1a}$$

$$pp\to\Delta^{++}(\pi^-\pi^+n)\,, \tag{1b}$$

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

at 6.6 GeV/c, we demonstrated that the relative yields of the bracketed systems at low momentum transfer ($|t_{p,\Delta}|<0.2$ 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 π^-p reactions:

$$\pi^-p\to\pi^-p\,, \tag{2a}$$

$$\pi^-p\to\pi^-\pi^+n\,, \tag{2b}$$

$$\pi^-p\to\pi^-\pi^0p\,. \tag{2c}$$

This suggests strongly that the bracketed systems in reactions (1) result from the scattering of an initial 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 (1) are very similar. Otherwise, the physical region comparison of the three reactions could not agree so well.

We present in this paper a brief description of a similar comparison we have made between the reactions

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

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

in which we compare the relative yields of the bracketed quantities in these reactions and the relative cross sections for

$$\pi^+p\to\pi^+p\,, \tag{4a}$$

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

We use a sample of 6424 examples of reaction (3a) on which a pole extrapolation analysis has been reported.[2] The sample of 7302 events of reaction (3b) is identical to reaction (1b) except for the different selection criteria used. We discuss the overlap problem below.

For momentum transfer to the neutron $|t_{p,n}|<0.2$ GeV^2, we show in Fig. 1(a) the ratio of the cross sections for reactions (3) as a function of mass of the bracketed systems (x). The cross-hatched band shows the on-mass-shell ratio for reactions (4). Although the two quantities have the same general behavior, our experimental ratio is systematically larger than the π^+p on-shell cross-section ratio.

The discrepancy in Fig. 1(a) may be understood by examining the π^-n effective-mass spectrum of reaction (3b), shown in Fig. 1(b). We see significant $\Delta(1238)^-$

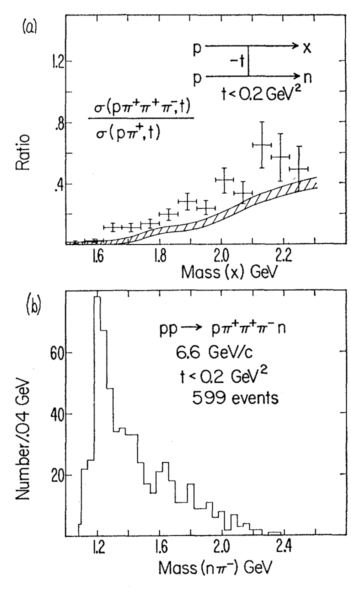

FIG. 1. (a) Cross-section ratio $[\sigma(pp\to n(\pi^+p\pi^+\pi^-)]/[\sigma(pp\to n(\pi^+p)]$ plotted versus effective mass of the non-neutron final-state system for momentum transfer $t_{p,n}<0.2$ GeV^2. The inset shows the process which we are trying to study. The cross-hatched band is the known on-shell ratio. (b) π^-n effective-mass distribution for all 599 events used in the ratio shown in (a).

* Supported in part by the U. S. Atomic Energy Commission.
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[1] E. Colton, P. E. Schlein, E. Gellert, and G. A. Smith, Phys. Rev. Letters **21**, 1548 (1968).

[2] Z. M. Ma, G. A. Smith, R. J. Sprafka, E. Colton, and P. E. Schlein, Phys. Letters **23**, 342 (1969).

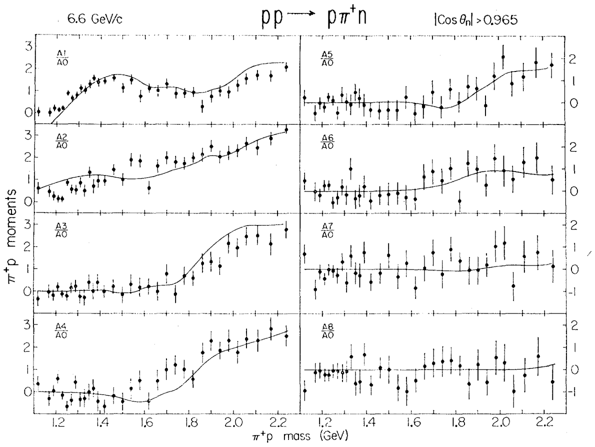

FIG. 2. Legendre coefficients of the $p\pi^+$ system in $pp\to p\pi^+n$ versus $p\pi^+$ effective mass for events with c.m. production angle $|\cos\theta_n|>0.965$. Solid curves represent the moments from real π^+p elastic scattering experiments.

production ($\sim 25\%$). Furthermore, we note that of the 599 events of reaction (3b) used in Fig. 1(a), 116 of them also contribute to the sample of reaction (1b) used in Ref. 1. We conclude that if this contributing source of background to the numerator of the ratio plotted in Fig. 1(a) is taken into account, one achieves approximate agreement between this ratio and the on-shell π^+p cross-section ratio. In view of the proximity of data points and curve in Fig. 1(a) when this correction is made, it seems pointless to pursue model-dependent corrections further at this stage.

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 suggest that the form of the extrapolation function used should have approximately the same form used for elastic $X\pi$ scattering.

Finally, to demonstrate explicitly the one-pion-exchange (OPE) character[3] of reaction (3a), we show in Fig. 2 the Legendre moments for $l\leq 8$ $[A_l/A_0=(2l+1)\langle P_l\rangle]$ evaluated in the π^+p rest frame[4] as a function of π^+p effective mass. The solid curves represent the known[5] on-shell π^+p elastic scattering data. The agreement is seen to be quite good in general, although there do exist several discrepancies which may have to do with, for example, (a) off-mass-shell effects in π^+p scattering (this affects A_1/A_0 at low mass most severely),[6] and (b) spin alignment of $\Delta(1238)$ not in agreement with the simple-minded OPE model (which predicts $\sim 1+3\cos^2\Theta$). This may be analogous to the observed "depolarization" of the ρ^0 produced in $\pi^-p\to\rho^0 n$. In this case nonzero helicity states of the ρ^0, forbidden by simple-minded OPE but explained, for example, by the absorption model, are found to occur.

[3] The pole extrapolation results from the analysis quoted in Ref. 2 provide further evidence. The t-dependent extrapolation function used is approximately the same used in all other reactions involving D^{++} production (see also Ref. 6).

[4] We used the incident proton at the π^+p vertex as seen in the π^+p rest frame as the polar axis in evaluating these moments.

[5] A. Donnachie, R. G. Kirsopp, and C. Lovelace, CERN Report No. CERN TH 838, Addendum, 1967 (unpublished).

[6] Eugene Colton and Peter E. Schlein, in Proceedings of the Conference on $\pi\pi$ and $K\pi$ Interactions, Argonne National Laboratory, 1969, edited by F. Loeffler and E. Malamud (to be published).

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Errata

Baryon Exchanges from *u*-Channel Finite-Energy Sum Rules, V. BARGER, C. MICHAEL, AND R. J. N. PHILLIPS [Phys. Rev. **185**, 1852 (1969)]. Equations (16) and (17) should have a factor of 2 on the right-hand side, since they refer to s-channel isospin eigenstates. This error originated from a misprint in the second paper of Ref. 11. The following changes should be made in the evaluations displayed in Fig. 5: The solid curve of $\int$ Disc$B$ for the Λ_γ-Λ_δ FESR should be displaced upwards by $+10$, and the Λ_α pole values for the Λ_α-Λ_β FESR should be doubled.

Regge Poles and Finite-Energy Sum Rules for Kaon-Nucleon Scattering, G. V. DASS AND C. MICHAEL [Phys. Rev. **175**, 1774 (1968)]. We wish to clarify that on p. 1782, the Born terms of Eqs. (17) and (19) are written for the contributions of conventional A (not A') and B amplitudes to K^-p elastic scattering.