ROLE OF QUARK-INTERCHANGE IN NN $\rightarrow$ NNπ REACTIONS

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We have developed a general formalism of pion production via NN scattering, i.e. N + N $\rightarrow$ N + N + π, assuming that pion emission takes place effectively at the quark level and that quark-quark interactions are described to a sufficiently good approximation by one-gluon exchange plus effective one-pion exchange [Figs. 1a-1c]. Consequently, the various reaction mechanisms can be grouped into four distinct categories, viz.: (i) one-nucleon-mechanism [ONM] or the nucleon-only impulse approximation [NOIA] where a pion is emitted from one of the two nucleon clusters [Fig. 2a]; (ii) two-nucleon-mechanisms [TNM] where pion emission takes place while the two nucleon clusters exchange a pion, and here we include isobar[Δ] currents [Fig. 2b], ρ-π currents [Fig. 2d], and pair currents [Fig. 2c]; (iii) pion production with quark interchange but without boson exchange [Fig. 3d]; and (iv) pion production with quark interchange in addition to one-gluon or one-pion exchange [Figs. 3a-3c]. Using a π-d optical potential which best fits the π-d elastic scattering data [except in the ONM or NOIA contributions in order to avoid double counting with contributions from isobar currents], we are able to carry out an almost parameter-free calculation for p + p $\rightarrow$ d + π^+. Assuming that the quark inside a hadron can be described approximately by the wave

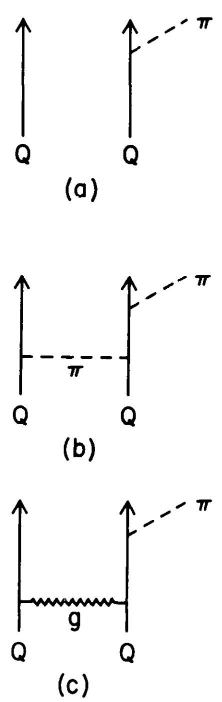

Figure 1. Pion production mechanisms at the quark level: One-body mechanism (a) and two body mechanisms (b)-(c) with respectively one-gluon exchange and one-pion exchange between quarks.

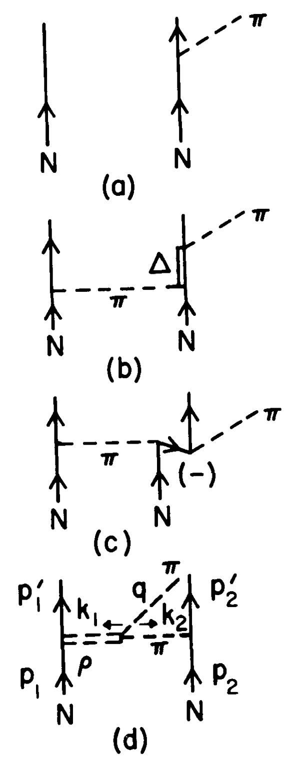

Figure 2. Intercluster reaction mechanisms, including pion production arising from nucleon only impulse approximation [NOIA; (a)], isobar currents [2(b)], pair current [2(c)], and $\rho\pi$-exchange current [2(d)].

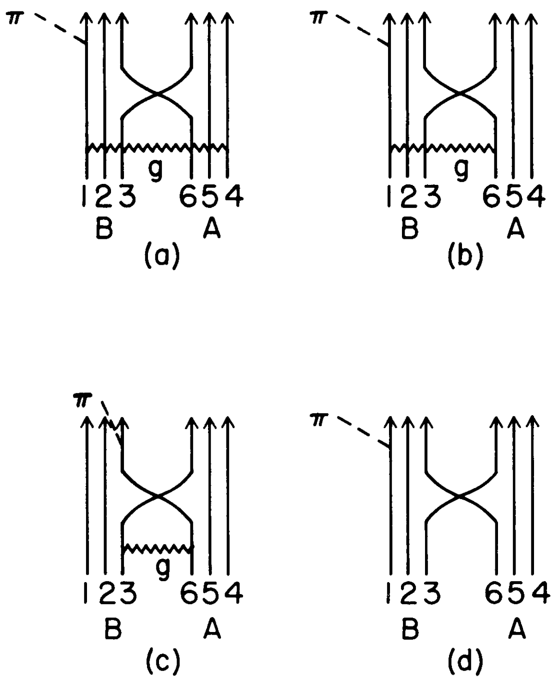

Figure 3. Typical examples for pion production involving quark interchange. Pion emission with quark interchange but without boson exchange is also shown [3(d)].

function for a Dirac particle moving in a central confining potential, we have been able to simplify a number of essentially 14-dimensional integrals associated with percolated reaction mechanisms into 5-dimensional ones, which are evaluated via a Quasi Monte-Carlo method.[1] Numerical predictions on the differential cross section and analyzing power are then made for the reactions $p + p \to d + \pi^+$ and $n + p \to p + p + \pi^-$.

In Figs. 4a and 4b, the calculated cross section for the pion-absorption reaction $\pi^+ + d \to p + p$ and the analyzing power A_y for the reaction $\vec{p} + p \to d + \pi^+$ at T_p = 180 MeV are shown respectively as a function of η [$= q_\pi/m_\pi$] and as a function of the pion scattering angle θ_{cm} [in the CM frame]. In both figures, we compare the prediction calculated with quark-interchange [Q.I.] reaction mechanisms with that calculated without Q.I. [NO Q.I.]. The p-p partial waves included in this calculation are $^3P_1$, $^1S_0$, and $^1D_2$. Although importance of Q.I. varies with the kinematic region, these two figures alone already confirm the observation made by Miller and Kisslinger[2] that effects caused by short-distance quark-interchange mechanisms need to be considered even near the threshold.

In Figs. 5a and 5b, the predicted double differential cross section $d^2\sigma/dE_\pi d\Omega_\pi$ and the analyzing power A_y for the reaction $n + p \to p + p + \pi^-$ at the p-p excitation energy E_x = 4 MeV and the pion emission angle θ_π = 30° are both shown as the initial proton energy T_p^{cm}. [Note that a neutron beam will likely be used in this experiment.] Specifically, we have included the following channels in this calculations: $^3P_0 \to {}^1S_0$, $^1S_0 \to {}^3P_0$, $^3S_1 + {}^3D_1 \to {}^3P_1$, $^3D_2 \to {}^3P_2$ [all for S-wave pions], and $^3S_1 + {}^3D_1 \to {}^1S_0$, $^3P_1 \to {}^3P_0$, $^3P_J \to {}^3P_1$, $^3P_J \to {}^3P_2$ [all for P-wave pions] for ONM (or NOIA) and TNM; $^3P_0 \to {}^1S_0$ and $^3S_1 + {}^3D_1 \to {}^1S_0$ for the various quark-interchange [Q.I.] reaction mechanisms. Once again, we see that effects due to quark-interchange reaction mechanisms may become of numerical importance and should be included even near the threshold.

In making these predictions, we have chosen to use the following input parameters:

$f = -\ 0.996$ [pseudovector πNN coupling],

$g_\Delta = 1.909$ [for isobar currents],

$g_{\rho NN} = 2.325$, $f_{\rho\pi\pi} = -\ 0.646$

[for $(\rho\pi)$-current];

[The above parameters are from ref. 3.]

$$\Gamma_\Delta = (0.35/6)\cdot(q^{*3}/m_\pi^2)\cdot[(M^* + M)^2 - m_\pi^2] \cdot M^{*-2},$$

$$\text{with } q^* = q_\pi \cdot \left(1 - \frac{E_\pi}{2(M+E_\pi)}\right);$$

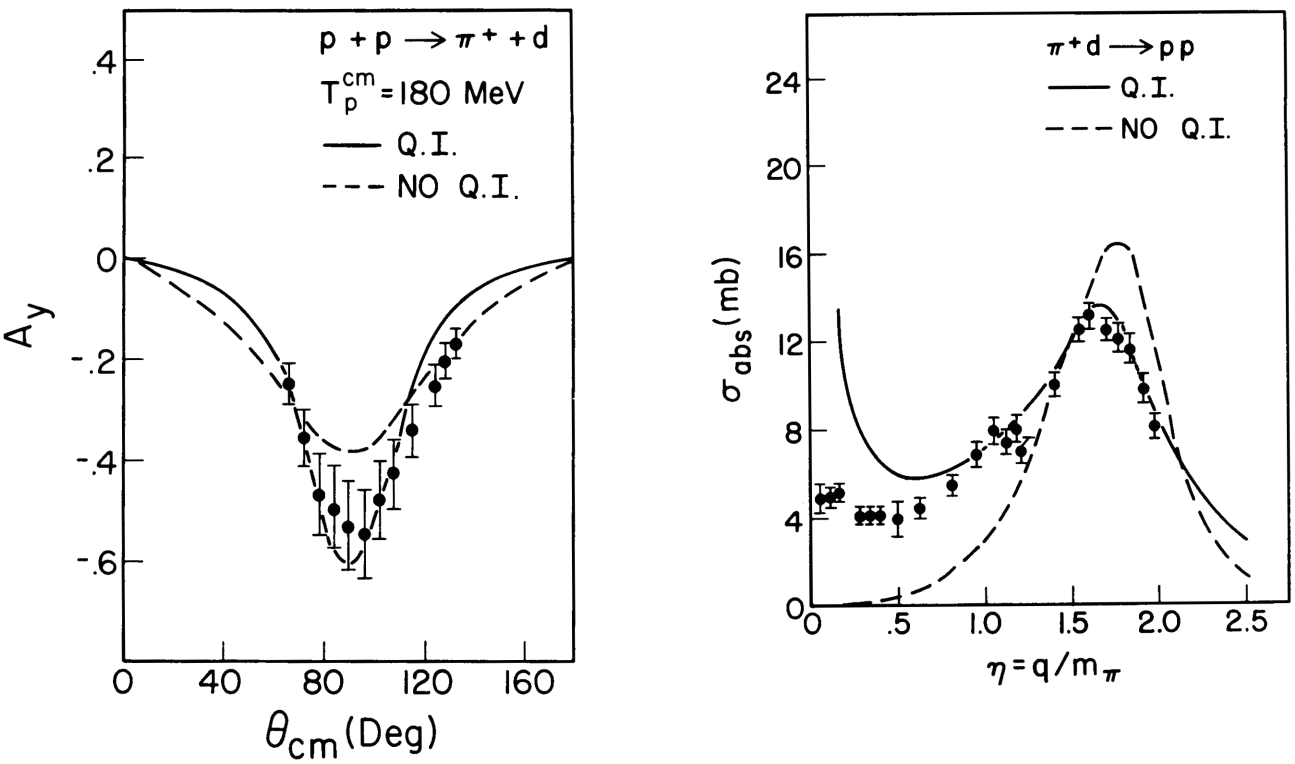

Figure 4(a) and 4(b). The calculated cross section for the pion-absorption reaction $\pi^+ + d \rightarrow p + p$ and the analyzing power A_y for the reaction $p + p \rightarrow d + \pi^+$ at T_p = 180 MeV, respectively, as a function of $\eta[=q_\pi/m_\pi]$ and as a function of the pion scattering angle θ_{cm}.

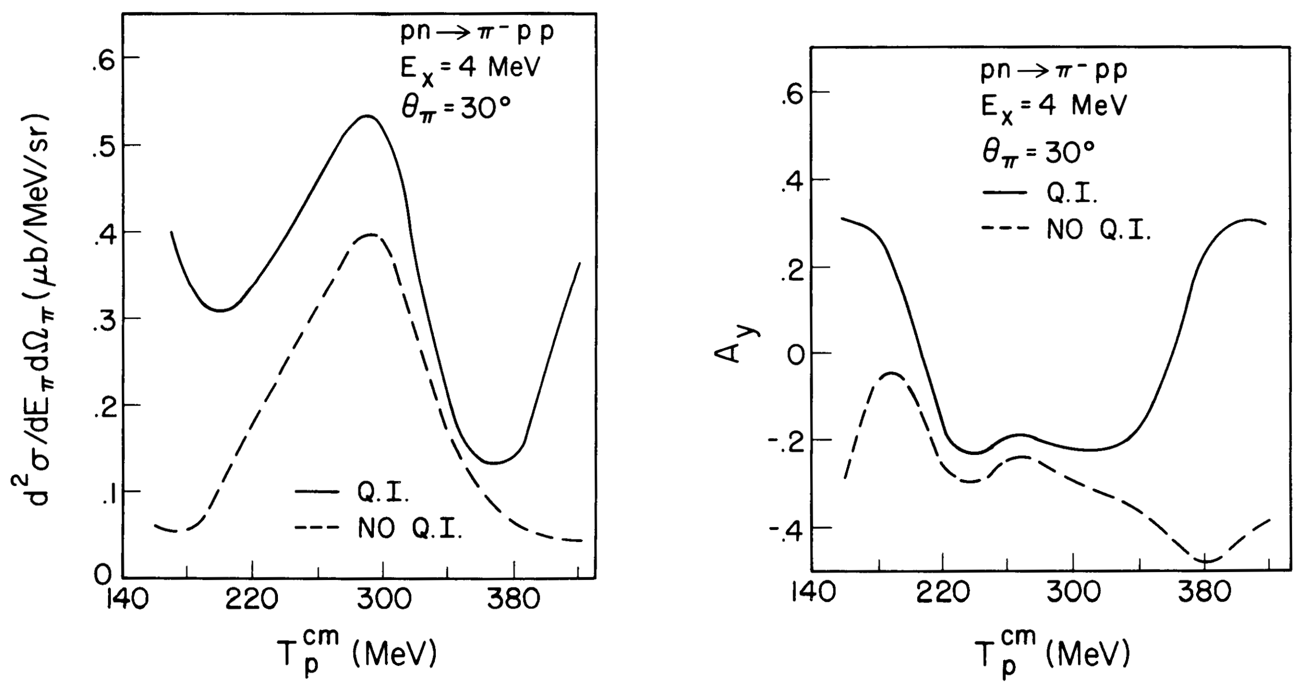

Figure 5(a) and 5(b). The predicted couble differential cross section $d^2\sigma/dE_\pi\, d\Omega_\pi$ and the analyzing power A_y for the reaction $n + p \rightarrow p + p + \pi^-$ at the p-p excitation energy E_x = 4MeV and the pion emission angle $\theta\pi$ = 30° as the function of the initial proton energy T_p^{cm}.

[for isobar currents; from Ref. 4.]

R = 0.57154 fm [corresponding to R_{MIT} = 0.8 fm],

$\alpha_S^* = 1.97$,

$\alpha_\pi^*(r = 0) = 0.31$ and $\alpha_\pi^*(r = \infty) = 3.572$.

[for quark-interchange mechanisms; from Ref. 5.].

We wish to refer an interested reader to either Cao's Ph.D. Thesis or Ref. 6 for a detailed account of the formalism as well as for additional numerical results.

1) Masaaki Sugihara and Kazuo Murota, Mathematics of Computation 39, 549 (1982).

2) G.A. Miller and L.S. Kisslinger, Phys. Rev. C 27, 1669 (1983).

3) W-Y.P. Hwang and G.E. Walker, Ann. Phys. 159, 118 (1985).

4) H. Sugawara and F. von Hippel, Phys. Rev. 172, 1764 (1968).

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