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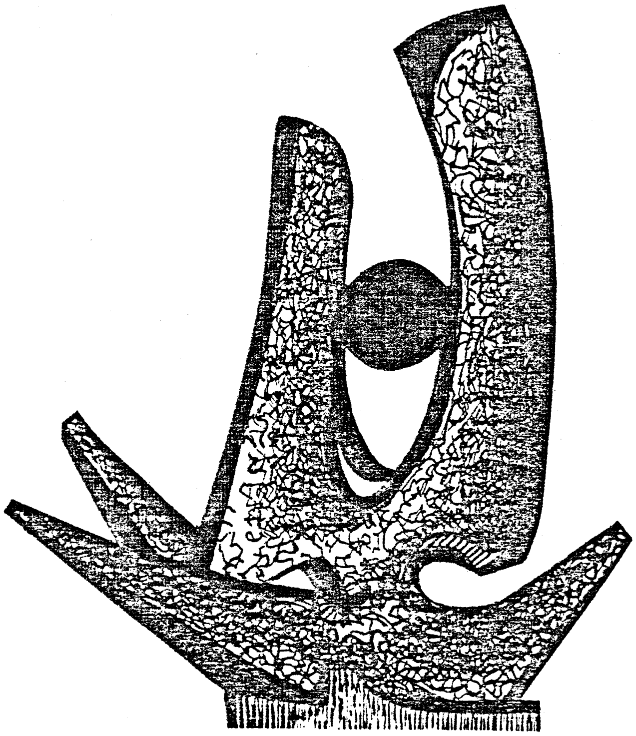

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Isospin dependence of pion absorption by nucleon pairs

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ABSTRACT

We calculate the relative absorption ratio of a pion by nucleon pairs measured recently by Ashery, et al. Standard theory based on Δ-isobar intermediate excitations agrees with the experimental observation that pion absorption by a $T = 1$ nucleon pair is strongly suppressed.

Very recently Ashery et al. performed (π^+,pp) and (π^-,pn) experiments on ^3He and ^4He at $T_\pi = 165$ MeV using the Los Alamos Meson Physics Facility.[1] They were surprised to find that the ratios $d\sigma(\pi^+,pp)/d\sigma(\pi^-,pn)$ come out to be very large; i.e. of the order of ~ 100. Arguing from isospin considerations alone,[2] they expected the ratio an order of magnitude smaller. The ratio in terms of the initial isospin is $R \equiv \sigma(T=0)/\sigma(T=1) \sim 50$.

In this short note, we would like to demonstrate that our current understanding of the pion nucleon interaction and the isobar formation provides a natural explanation for the largeness of this ratio.

In recent years there have been a number of theoretical studies of pion absorption, deriving the pion optical potential parameters from the pion-nucleon many body theory.[3-10] In particular, the imaginary part of the two body optical potential parameters has a direct relationship to the two nucleon process discussed above. The S wave pion absorption B_0 was calculated by Hachenberg and Pirner,[3] Bertsch and Riska[4] and Chai and Riska.[5] These calculations show that the S wave rescattering mechanism is able to account for the imaginary part of B_0 fairly well.[4] The further 10-20% refinement might be caused by the medium correction on the rescattering pion[11] and by the use of the better off-shell $\pi\pi NN$ amplitude.[12]

The P-wave absorption C_0, which has a direct connection to the pion induced pair nucleon emission at high energy was calcuated by several authors.[5-10] These authors recognized the important role of the Δ-isobar intermediate excitation even at the threshold. The Δ isobar-hole picture alone results in $\mathrm{Im}C_0 \sim (0.06 - 0.08) m_\pi^{-6}$ at threshold; unfortunately experimental determination for this value from the pionic atoms and pion scattering data seems ambiguous.[13] As the pion energy increases, the Δ isobar-hole mechanism should be by far the dominant mechanism for two body pion absorption.

Ko and Riska[6] and Chai and Riska[5] worked out this mechanism in detail for the pion optical potential up to the (3,3) resonance region. We shall therefore follow their derivation for two body P wave pion absorption. At high energy, the dominant mechanisms are the ones shown in Fig. 1. The wavy lines denote the spin-isospin dependent interaction which might be described by the pion and rho meson exchanges. The denominators of these diagrams for the Δ isobar (Δ isobar propagator) are

$$G_D^{-1} = m_\Delta - m + P_\Delta^2/2m_\Delta - \omega - \frac{1}{2} i\Gamma \qquad (1)$$

$$G_C^{-1} = m_\Delta - m + P_\Delta^2/2m_\Delta + \omega$$

where G_D is for the direct graph (Fig. 1a) and G_C for the crossed one (Fig. 1b), respectively. We take $\vec{P}_\Delta = \vec{k}$, the incoming pion momentum, for G_D. For G_C, this quantity is $\vec{P}_\Delta = \vec{P}_f - \vec{k}$ and $P_\Delta^2 \simeq m\omega$ due to the energy and momentum conservations. For the width of the Δ isobar, we take the empirical relation[14]

$$\Gamma = \frac{0.47}{1 + 0.6(q/m_\pi)^2} \cdot \frac{q^3}{m_\pi^2} \qquad (2)$$

The Δ isobar, nucleon and pion masses are denoted by m_Δ, m and m_π, and ω the incoming pion energy.

$\vec{q}$ in Eq. (2) is the pion-nucleon center-of-mass momentum and related with the incoming pion momentum as $\vec{q} = m/\sqrt{s}\ \vec{k}$ with s being invariant variable.

The T-matrix for the π and ρ meson rescattering processes is worked out using the Feynman graph technique and all the details for two body pion absorption are found in Secs. 3, 4 and 5 of Ref. 6.

In principle many partial waves for the incoming pion contribute to the absorption cross sections. However, at low energy the P-wave dominates[6] and therefore the ratio

$$R = \frac{\sigma(T=0)}{\sigma(T=1)} = \left|\frac{G_D}{G_C}\right|^2 . \qquad (3)$$

is simply given by the Δ-isobar propagators G_D and G_C of Eq. (1).

The calculated ratio using Eq. (3) is shown in Fig. 2. Because of the resonant behavior in the direct channel, the ratio shows peak at $k \sim 2m_\pi$ ($T_\pi \simeq 180$ MeV). At the experimental energy $T_\pi = 165$ MeV[1] this ratio is ∿200 which agrees more or less with the magnitude of the data. Note that this ratio does not depend on any details of the model. This behavior may be undertstood as follows. While the pion absorption by a $T = 0$ nucleon pair is allowed by the direct absorption mechanism, Fig. 1a, this mechanism is forbidden for that by a $T = 1$ nucleon pair. For the latter process, the initial state should have $T = 1$, $S = 0$ and $L = 0$ and absorption of a P-wave pion leads to $T = 1$, $J^\pi = 1^+$ intermediate states. This should be the quantum number of the final state but the Pauli effect between the two final nucleons does not allow this quantum number.

As the pion energy increases, higher partial waves might start to contribute to pion absorption. For example, the $\ell_\pi = 2$ pion wave (D wave) would allow the pion absorption by a $T = 1$ nucleon pair in the direct process (Fig. 1 a). Therefore, we compute explicitly higher multipole pion wave contributions. We calculate the T-matrix at the angle which corresponds to the relative momentum of an outgoing nucleon pair being perpendicular to the incoming pion momentum. The results with the pion exchange with form factor $\Lambda_\pi = 0.8$ GeV, which corresponds to the standard choice for the πNN and ρNN cutoff mass; $\Lambda_\pi = 1.2$ GeV and $\Lambda_\rho = 2.0$ GeV,[5,6] are shown in Table I. We find the $\ell_\pi = 2$ partial wave contribution stays small even up to the resonance region. Note that the explicit distinction of the direct and crossed Δ propagators G_D and G_C, which has been neglected by Ko and Riska,[6] is important to keep the $\ell_\pi = 2$ contributions small. The higher partial waves ($\ell_\pi \geq 3$) are further smaller by two order of magnitude. Though small, it is interesting to compare the two cases for the initial isospin $T = 1$. The $\ell_\pi = 2$ case is negligibly small at small pion momenta but increases very rapidly with k and becomes comparable or bigger than the $\ell_\pi = 1$ case around the resonance region. The summed values for the $T = 1$ initial state are then used to derive the ratios as a function of the pion momentum, which are depicted by the solid line in Fig. 2. The ratio now comes down to the range of 50, which agrees with experiment.

In conclusion, we have demonstrated that our knowledge of the pion-nucleon and -Δ isobar interactions gives a natural explanation for the large ratio of the pion induced two nucleon emission cross sections for $T = 0$ and $T = 1$ initial pairs at the (3,3) resonance region. The ratio $R = \frac{\sigma(T=0)}{\sigma(T=1)}$ should show the resonance behavior. It would be interesting to measure this ratio at several pion energies to verify this resonant behavior and therefore the isobar-hole model.

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Table I

$k[m_\pi]$			0.5	1.0	1.5	2.0	2.5
Initial		Final					
$T=0$ $S=1$ $L=0$	$\xrightarrow{\ell_\pi=1}$	$T'=1$ $S'=0$ $L'=2$	1^*	6.7	33	89	55
$T=1$ $S=0$ $L=0$	$\xrightarrow{\ell_\pi=1}$	$T'=0$ $S'=1$ $L'=2$	0.076	0.23	0.37	0.45	0.47
$T=1$ $S=0$ $L=0$	$\xrightarrow{\ell_\pi=2}$	$T'=1$ $S'=1$ $L'=3$	2×10^{-3}	0.039	0.29	0.89	0.60

Squared T-matrices for two nucleon emission after pion absorption in the dominant channels are compared. These numbers are normalized to the $T=0$ to $T=1$ transition at $k=0.5\ m_\pi$ as indicated by *.

Figure Captions

Fig. 1 P-wave pion absorption mechanism with Δ isobar intermediate excitation.

Fig. 2 The pion absorption ratio $R = \frac{\sigma(T=0)}{\sigma(T=1)}$ as a function of the incoming pion momentum. The dashed line is obtained by the P wave only (Eq. (3)). The solid line includes the higher-partial wave contributions.

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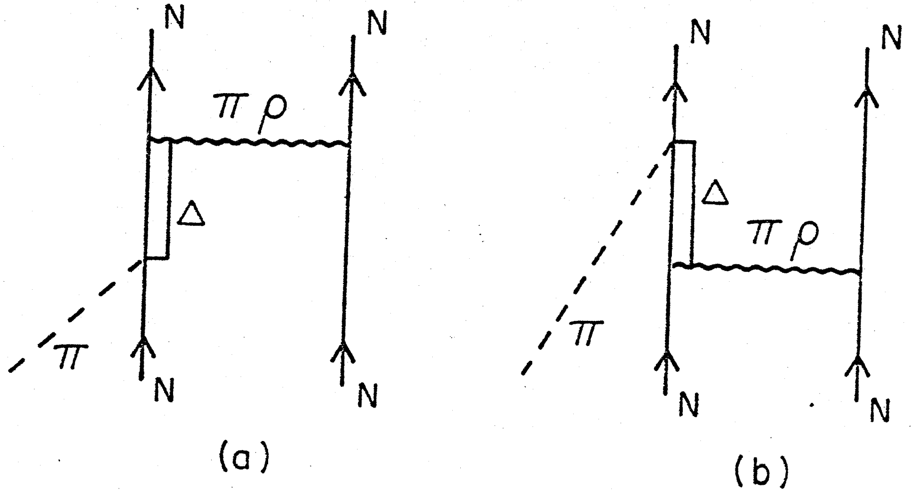

Figure 1

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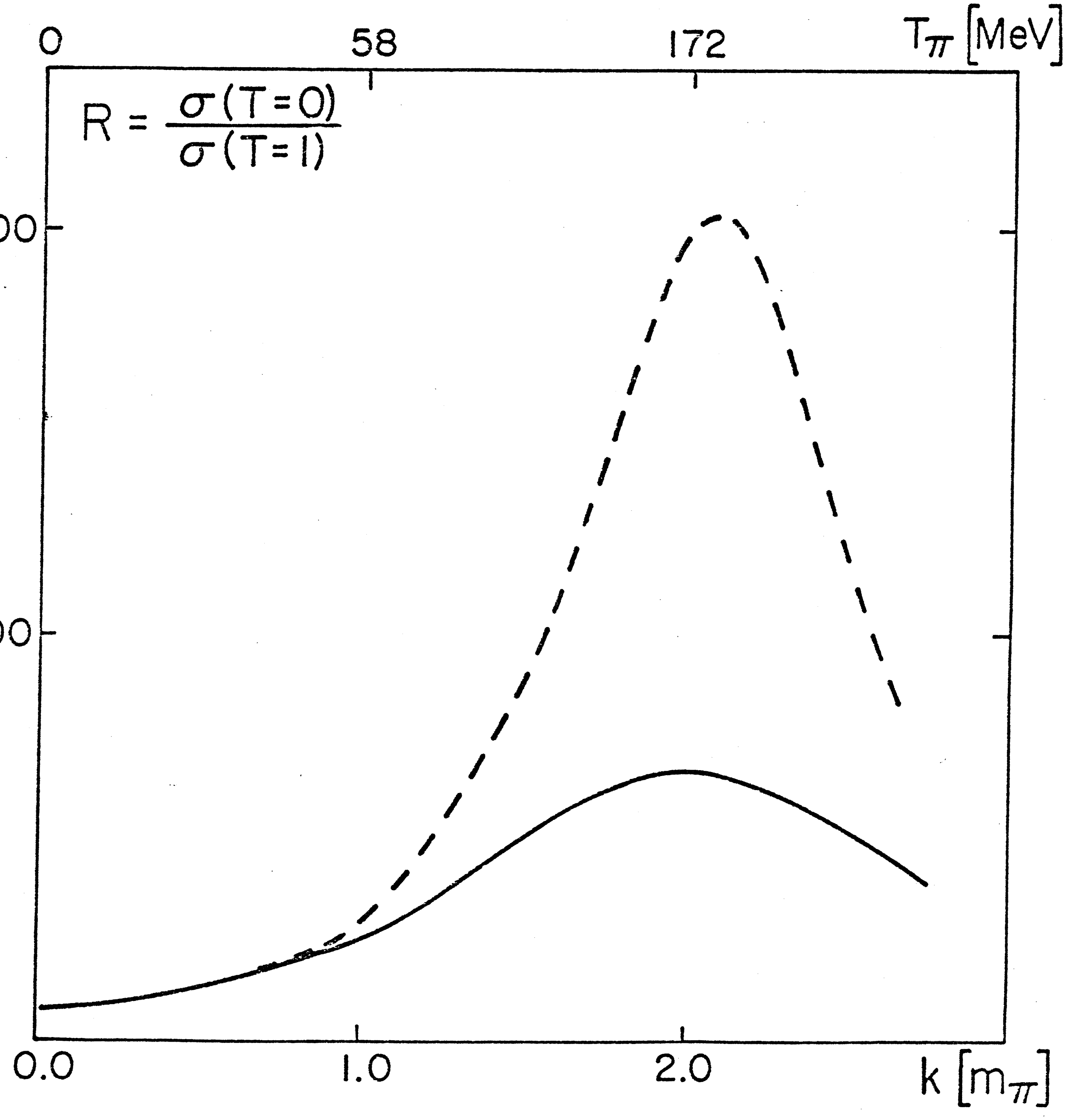

Figure 2