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S-Wave π - π Scattering Phase Shifts*

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Using an absorptive one-pion exchange mechanism for the reaction $\pi^-p \rightarrow \pi^+\pi^-n$, a fit is made to experimental data at 4 GeV/c in order to extract the π - π scattering phase shifts. The analysis was carried out up to D waves in the π - π amplitude. The best results indicate a very broad $I = 0$ S -wave resonance with $M_R = 820$ MeV and $\Gamma = 600$ MeV.

The determination of low-energy π - π scattering phase shifts has been pursued over the last several years. Two recent works in this direction are those of Oh *et al.*¹ and of Chan *et al.*² We present an analysis similar to that of Ref. 1, but carried out on different experimental data. We study the data of Johnson *et al.*,³ and use a peripheral model with absorptive corrections to determine the π - π scattering parameters. These data have been previously analyzed^{3,4} and the improvement in the present analyses consists in the inclusion of an $I=0$ D -wave amplitude in π - π scattering. Though our analysis has been restricted to $m_{\pi\pi} < 900$ MeV, the tail of the f^0 resonance is seen to be important.

The process under study is the reaction $\pi^-p \rightarrow \pi^+\pi^-n$ at 4 GeV/c incident momentum. The production mechanism was assumed to be due to a one-pion exchange modified by initial- and final-state absorption. The details of this calculation are presented in a subsequent paper.⁵ A cut in t , the momentum transfer between the proton and final neutron, was made and events with $|t| < 3m_\pi^2$ were considered. It is hoped that with this assumption the peripheral hypothesis will be valid. Likewise, we feel that 4 GeV/c is a more desirable incident momentum for this kind of analysis than is 7 GeV/c, which was used in the analysis of Ref. 1. At 7 GeV/c the exchanges of the ω and A_2 Regge

FIG. 1. Coefficients C_i of Eq. (2) against $m_{\pi\pi}$: solid line, with D wave; dashed line, without D wave. (Normalized to total number of events.)

FIG. 2. Treiman-Yang distribution. (Normalized to total number of events.)

trajectories may have to be taken into account. The π - π scattering amplitude was parametrized in an energy-dependent way. The P and D waves were taken to be resonance-dominated by the ρ and f^0 mesons, respectively. The positions and widths were not varied but were set at the accepted values.⁶ In the case of the P wave, a radius of inter-

action was included and varied in the fit. For the D wave no such radius was included as we were always on the low side of the resonance. The S wave was parametrized by an effective-range expression,

$$(q/\sqrt{s})\cot\delta_{0I}(s) = a_I + b_I q^2, \quad (1)$$

FIG. 3. π - π phase shifts. The solid line is our solution; the dashed line is the solution of Ref. 1.

with q and s the relative momentum and effective mass squared of the final $\pi-\pi$ system.

Though all the distributions were fitted, the one most useful in determining the phase shifts was the $\cos\theta$ distribution, where θ is the scattering angle in the $\pi-\pi$ center-of-mass system. At each $\pi-\pi$ effective mass, the distribution was expanded in a power series in $\cos\theta$,

$$\frac{dN}{d\cos\theta} = \sum_{n=0}^4 C_n \cos^n\theta. \quad (2)$$

In Fig. 1 we show the experimental values of the expansion coefficients as well as the best fits with and without a D -wave contribution. Whereas the previous analysis of these data^{3,4} had difficulty in obtaining a good fit to the magnitude of the forward-backward asymmetry, the inclusion of the D wave reduces the discrepancy. We likewise present, in Fig. 2, the results for the fit to the distribution in the Treiman-Yang angle ϕ . Comparisons with other distributions are presented in Ref. 5.

The best fit to the data was attained with an S wave $l=0$ dominated by a broad resonance centered

at 820 MeV with a width $\Gamma=600$ MeV. This is consistent with the findings of other groups.⁶ To recapitulate, the results we obtain for the $\pi-\pi$ amplitudes are (the quantities in square brackets were not varied)

$$\begin{aligned} \frac{q}{\sqrt{s}} \cot\delta_{00}(s) &= \frac{m_s^2 - s}{m_s \Gamma_s} \frac{q_s}{m_s}, \\ q \cot\delta_{20}(s) &= -12.5\mu + 0.25q^2/\mu, \\ \frac{q^3}{\sqrt{s}} \cot\delta_{11}(s) &= \frac{m_p^2 - s}{m_p \Gamma_p} \frac{q_p^3}{m_p} \frac{1 + 0.193\mu^{-2}q^2}{1 + 0.193\mu^{-2}q_p^2}, \\ \frac{q^5}{\sqrt{s}} \cot\delta_{02}(s) &= \frac{m_D^2 - s}{m_D \Gamma_D} \frac{q_D^5}{m_D}, \end{aligned} \quad (3)$$

where μ is pion mass in MeV, $m_s=820$ MeV, $\Gamma_s=600$ MeV, $[m_p]=765$ MeV, $[\Gamma_p]=125$ MeV, $[m_D]=1264$ MeV, $[\Gamma_D]=151$ MeV, and q_l for $l=S, P, D$ is q at the resonance in l th partial wave.

A graphical presentation of these results is given in Fig. 3 together with the results of Ref. 1.

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