S-Wave π-π Scattering Phase Shifts*

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(Received 30 November 1970)

Using an absorptive one-pion exchange mechanism for the reaction $\pi^- p \to \pi^+\pi^- n$, 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 $\pi^- p \to \pi^+\pi^- n$ 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

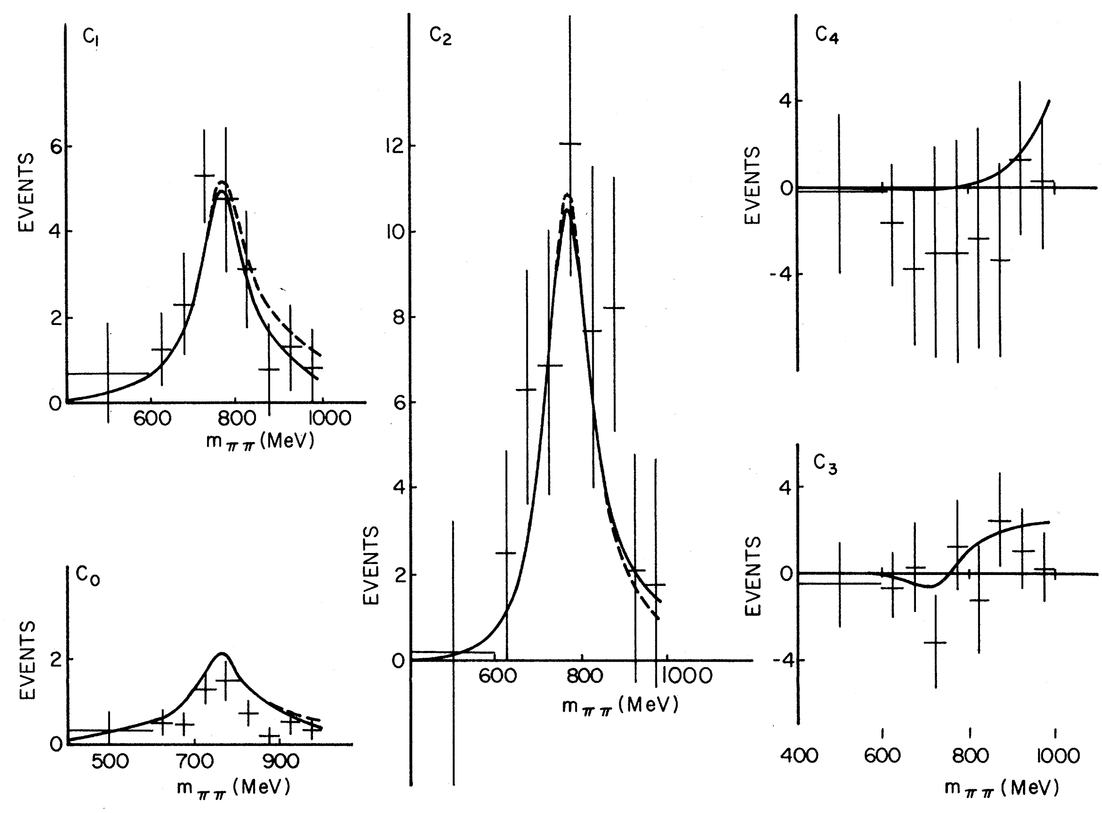

FIG. 1. Coefficients C_i of Eq. (2) against $m_{\pi\pi}$: solid line, with D wave; dashed line, without D wave. (Normalized to total number of events.)

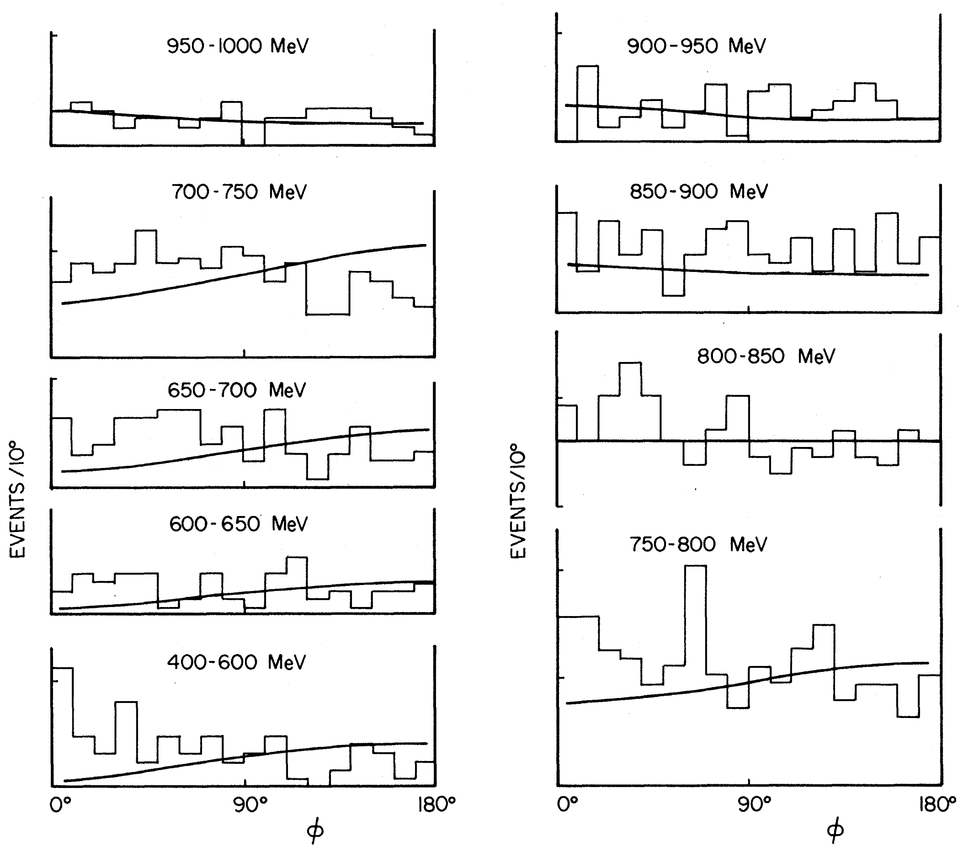

FIG. 2. Treiman-Yang distribution. (Normalized to total number of events.)

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 interaction 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,

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

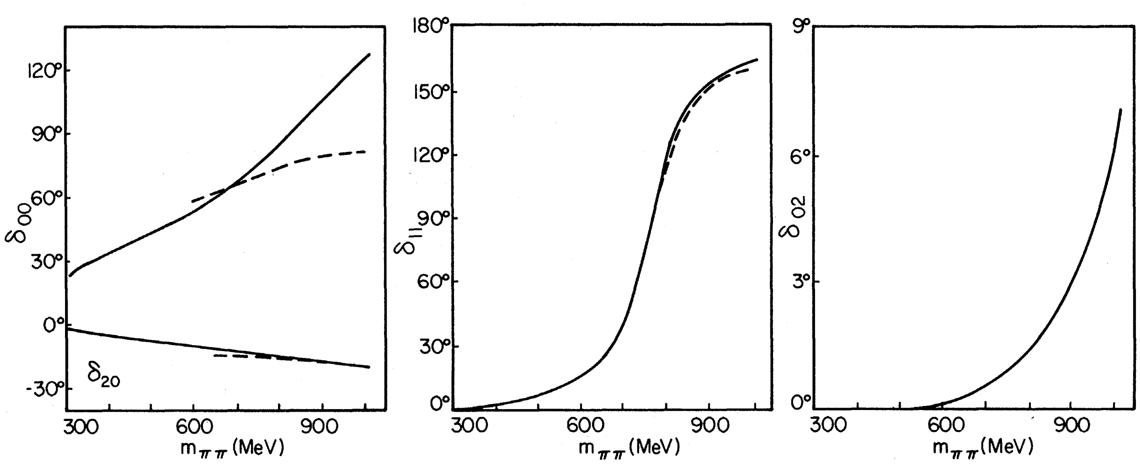

FIG. 3. π-π phase shifts. The solid line is our solution; the dashed line is the solution of Ref. 1.

with q and s the relative momentum and effective mass squared of the final π-π 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 π-π center-of-mass system. At each π-π effective mass, the distribution was expanded in a power series in $\cos\theta$,

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

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 $I=0$ 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 π-π amplitudes are (the quantities in square brackets were not varied)

$$\frac{q}{\sqrt{s}}\cot\delta_{00}(s)=\frac{m_S{}^2-s}{m_S\Gamma_S}\frac{q_S}{m_S},$$

$$q\cot\delta_{20}(s)=-12.5\mu+0.25q^2/\mu,$$

$$\frac{q^3}{\sqrt{s}}\cot\delta_{11}(s)=\frac{m_P{}^2-s}{m_P\Gamma_P}\frac{q_P{}^3}{m_P}\frac{1+0.193\mu^{-2}q^2}{1+0.193\mu^{-2}q_P{}^2}, \tag{3}$$

$$\frac{q^5}{\sqrt{s}}\cot\delta_{02}(s)=\frac{m_D{}^2-s}{m_D\Gamma_D}\frac{q_D{}^5}{m_D},$$

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 lth partial wave.

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

*Partially supported by the National Science Foundation.

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PHYSICAL REVIEW D VOLUME 4, NUMBER 1 1 JULY 1971

T, P, and *C* Symmetries in $K_{L,S}\to\gamma\gamma$

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(Received 8 February 1971)

The Bernstein-Michel analysis of $\pi^0\to\gamma\gamma$ is applied to the decays $K_{L,S}\to\gamma\gamma$. It is shown that, in contrast to the situation in $\pi^0\to\gamma\gamma$, a hypothetical violation of CP invariance in $K_{L,S}\to\gamma\gamma$ can, in principle, be detected by a measurement of the circular polarization of *one* of the two photons.

I. INTRODUCTION

In a paper entitled "T, P, and C Symmetries in $\pi^0\to\gamma\gamma$," Bernstein and Michel[1] obtained the necessary and sufficient conditions for the two-photon state created in this decay to be an eigenstate of P, T, and PT (or, equivalently, of CP, T, and CPT, since the state necessarily has $C=+1$). Their conclusions were as follows: If the polarization wave function of the photons is

$$\psi=\alpha\vec{\epsilon}\cdot\vec{\epsilon}\,'+\beta\vec{\epsilon}\times\vec{\epsilon}\,'\cdot\hat{k}, \tag{1}$$

then the two-photon state is an eigenstate