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$\pi\pi$ PHASE SHIFTS IN THE ENERGY REGION 0.6 to 1.42 GeV

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ABSTRACT

We present results on $\pi\pi$ scattering via the reaction $\pi^+n \rightarrow \pi^+\pi^-p$ at 6 GeV/c. Using a one-pion exchange model modified by absorption and $l=2$ phase shifts from other experiments we have extracted S, P, and D wave $\pi\pi$ phase shifts under certain energy dependent assumptions. The data sample consists of approximately 13000 events in the energy region 0.6 to 1.42 GeV.

We present results of a $\pi\pi$ phase shift analysis in the region $0.6 \text{ GeV} \leq M(\pi\pi) < 1.42 \text{ GeV}$. Using the reaction $\pi^+d \rightarrow \pi^+\pi^-pp$, our experiment is a 910,000 picture exposure of the ANL deuterium filled 30" bubble chamber to a 6 GeV/c separated π^- beam. The analysis is based on approximately 75% of the total available data. After cutting the spectator momentum at 250 MeV/c, $|M|^2 \leq .06 \text{ GeV}^2$, and $P(\chi^2) \geq .01$, our total sample for the reaction $\pi^+n \rightarrow \pi^+\pi^-p$ consists of 13,024 events. For the phase shift analysis we use only events with four-momentum transfer between the outgoing dipion system and the incident π^+ less than $0.3 (\text{GeV}/c)^2$, and we are left with 9500 events.

We have used a one pion exchange model modified by absorption, as described by Oh¹ et al. The total amplitude is given by 2 parts: the first is the regular one pion exchange amplitude and the second is a "Nuclear Pole Term". The total amplitude is

$$\langle \mu \lambda' | T | \lambda \rangle = \langle \mu \lambda' | T_{\pi \text{ ex.}} | \lambda \rangle + \langle \lambda | T_{NPT} | \lambda \rangle$$

where λ, λ' are the helicities of the incident and outgoing nucleon and μ is the helicity of the dipion system. The Nuclear Pole Term as parameterized by Oh et al.¹ yields a strongly peaked forward cross section for the diffraction dissociation process. The π exchange term is given by the following form:

$$\begin{aligned} \langle \mu \lambda' | T_{\pi \text{ ex.}} | \lambda \rangle = & \sum_{L, I} \frac{m_{\pi\pi}}{K} C'' C^I [\eta_L^I \exp(2i\delta_L^I) - 1] \\ & \times f_{\mu\lambda\lambda'}(t) d_{\mu 0}^L(-\psi) Y_L^\mu(\theta, \phi) \end{aligned}$$

where: L, I indicate the partial wave and I spin of the $\pi\pi$ system,

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C^N, C^I are the Clebsch-Gordan I-spin coefficients for the nucleon and $\pi\pi$ vertices, respectively. K is the π momentum in the dipion system; η_L^I, δ_L^I are the inelasticities and phase shifts of the dipion system; $f_{\mu\lambda\lambda}$ contains the specific t dependence of the various amplitudes, corrected for absorption as given by Durr and Pilkuhn²; ψ is the rotation angle from the helicity frame to the Jackson frame, and (θ, ϕ) are the scattering angles of one π in the Jackson frame.

To account for the Pauli exclusion principle, we have assumed total spin flip at the nucleon vertex and corrected the predicted differential cross section accordingly. A maximum likelihood fit to the data with up to 4 partial waves was used to determine the η_L^I, δ_L^I in 40 MeV intervals of the $\pi\pi$ mass. The $I=2$ phase shifts and inelasticities were interpolated from other publications³.

Because of the large number of parameters involved, and because of somewhat different assumptions used in the fitting at different $\pi\pi$ masses, we have divided the dipion mass distribution into 3 regions which were fitted separately. [a region (.6-.9) GeV; intermediate region (.9-1.08) GeV, f region (1.08-1.42) GeV]. The assumptions for the three regions are given in Table 1. The $I=1$ resonances ρ , g and the $I=0$ f^0 resonance are parametrized with a Breit-Wigner form; the phase shifts are a function of the central value m_0 and width Γ_0 of the resonances allowing us to have a smaller number of parameters to determine throughout the fit. We found that the N.P.T. as well as the correction for the Pauli exclusion principle have little effect on the phase shifts and inelasticities. In Fig. 1 the phase shifts and inelasticities of the $I=0$ partial waves as obtained from the fit are plotted as a function of the dipion mass. Only the central value and width of the ρ were fitted; for the f^0 and g^0 a few central values and widths were tried. We find that results for

TABLE 1

Partial wave	a Region	Intermediate Region	f Region
$I = 0, S$	Elastic $\rightarrow \eta_0^0 = 1$ δ_0^0 variable	δ_0^0 variable η_0^0 variable	δ_0^0 variable η_0^0 variable
$I = 1, P$	Elastic $\rightarrow \eta_1^1 = 1$ $\delta_1^1 = \arctg [m_0 f(s)/(m_0^2 - s)]$	η_1^1 variable δ_1^1 as in a region	η_1^1 variable δ_1^1 as in a region
$I = 0, D$		η_2^0 variable $\delta_2^0 = \arctg [m_0 f(s)/(m_0^2 - s)]$	$m_0 = 1.27$ GeV $\Gamma_0 = .20$ GeV
$I = 1, F$		η_3^1 variable $\delta_3^1 = \arctg [m_0 f(s)/(m_0^2 - s)]$	$m_0 = 1.68$ GeV $\Gamma_0 = .13$ GeV

$$f(s) = \frac{2 n_0}{n_0 + \sqrt{s}} \left[\frac{K}{K_0} \right]^{2L+1} \frac{D_L(K_0)}{D_L(K)} \cdot r_0, \quad f'(s) = \frac{n_0}{\sqrt{s}} \left[\frac{K}{K_0} \right]^7 \cdot r_0 \quad \text{where: } s = \text{square of dipion mass, } L = \text{spin}$$

of the resonance, K, K_0 are momenta of the π in rest frame of dipion mass $\sqrt{s}, n_0$, respectively, $D_L(K)$ correction factor for diffractive interaction radii.

$n_0^0 = n_0$ for the ρ were fitted only in the a region

the $I=0$ partial wave inelasticities and $\delta_0^0(m_{\pi\pi})$ are not very sensitive to the exact parameters of the f and g mesons; the values used are listed in Table 1. For the ρ we find: $m_\rho = (.772 \pm .004)$ GeV, $\Gamma_\rho = (.154 \pm .015)$ GeV. In general our results for the inelasticities agree with those published by the Berkeley group.⁴ Up to $m_{\pi\pi} = 1.04$ GeV our δ_0^0 agrees with the values they have published, but above 1.04 GeV δ_0^0 continues to rise and agrees with results published by a CERN group.⁵ We note that our preferred solution for δ_0^0 below 900 MeV corresponds to the "Down" solution. We also find the "Up" solution; it is 3.8 standard deviation less likely than the "Down" solution.

In Fig. 2 the differential cross section, the $\cos\theta$ - and Trieman-Yang angle distributions for the ρ and f regions are compared with the model predictions. In the ρ region the absolute predictions of the model differ only by 3% from the observed while in the f region the shapes agree but there is a discrepancy of about 20% in absolute normalization. The dipion mass distribution (not shown) also shows this normalization discrepancy in the f region. This effect is not well understood.

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FIGURE CAPTIONS

Fig. 1. δ_0^0 , η_0^0 , and η_2^0 as a function of dipion mass.

Fig. 2. $d\sigma/dt$, $\cos\theta$, and Trieman-Yang angle distributions for ρ^0 and f^0 .

Figure 1

Figure 2