STUDY OF $\pi^+\pi^-\pi^-$ INTERACTIONS AT 18 GeV/c

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A partial wave analysis (PWA) of the $\pi^+\pi^-\pi^-$ system produced in the exclusive reaction $\pi^- p \to \pi^+\pi^-\pi^- p$ for masses up to 2 GeV/c^2 has been carried out, and we present the results of the mass-independent fits. Our objective was to search for the J^{PC}-exotic wave in the vicinity of the $a_2(1320)$ meson, which was reported by the VES collaboration in Protvino, Russia.

1 Introduction

While there is now considerable evidence that mesons exist beyond the constituent quark model, observation of a state with exotic quantum numbers, for example $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$, would irrefutably identify such states, since they cannot couple to $q\bar{q}$. Several experiments have reported evidence of a $J^{PC} = 1^{-+}$ isovector state decaying to various final states- $\eta\pi$ [1,2], $f_1(1285)\pi$ [3], and $\rho\pi$ [4]. In the KEK and VES experiments the exotic meson was produced only in natural parity exchange, which is likely to be dominated by ρ exchange. With this as an indication that a $J^{PC} = 1^{-+}$ hybrid may have a significant coupling to $\rho\pi$, we have performed a full partial wave analysis of data taken in $\pi^- p$ interactions at 18.3 GeV/c producing the exclusive final state $\pi^+\pi^-\pi^- p$.

2 Experimental Arrangement

This experiment, Brookhaven National Laboratory (BNL) experiment E-852, was performed at the Multi-Particle Spectrometer (MPS) facility. The detector is shown schematically in Figure 2. The spectrometer was augmented with a 3000 element lead glass hodoscope (LGD) to detect neutral particles, described in a previous publication [5]. In this particular analysis the LGD was used to veto events with neutral energy.

In addition, a lead-scintillator veto counter (DEA) was used to veto events with γ's that missed the LGD. Also, the target region was surrounded with 192 blocks of thallium-doped cesium iodide crystals (CSI), 4 radiation lengths

[a] The E852 Collaboration authors are listed in the contribution to this conference by N. M. Cason et al, titled "Study of the $\eta\pi^-$, $\eta\pi^0$ and $\eta\eta$ systems in $\pi^- p$ interactions at 18 GeV/c"

deep, to veto events with slow γ's in the target region [6]. In total, γ veto coverage was nearly 4π.

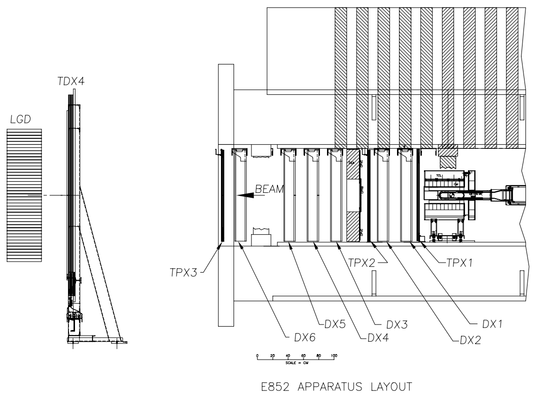

Figure 1: Diagram of apparatus

The MPS magnet region was filled with 6 drift chamber modules (DX1-6), each consisting of 7 planes. The resolution in these chambers was 330 μ. Three proportional wire chambers, TPX1, TPX2, and TPX3, were also in the magnet gap, and were used for track reconstruction and charged multiplicity triggering.

Behind the MPS magnet directly in front of the LGD was a two-plane x-measuring (horizontal) drift chamber module (TDX4) with a resolution of 140 μ, which provided good momentum resolution and position resolution at the LGD for fast tracks.

Surrounding the 30 cm liquid hydrogen target was a cylindrical drift chamber array (TCYL) consisting of four cylinders with axial wires, with a resolution of 400 μ, and charge-division readout for the longitudinal measurement, with a resolution of 8 mm. This detector was used for triggering and tracking the recoil proton.

Our 1994 run yielded a sample of 2.3 million events with three tracks in the downstream drift chambers, a recoil track in TCYL, and no neutral energy in any of the γ veto detectors (DEA, CSI, and LGD). The three downstream tracks were assumed to be pions, and events were selected consistent with a proton recoil, i.e., a missing mass squared between 0 and 2 GeV^2. The missing mass squared spectrum is shown in Figure 3.

3 Analysis

The $\pi^+\pi^-\pi^-$ system was described as a superposition of states characterized by spin, parity, and C-parity (J^{PC}), the absolute value of projection of spin on the quantization axis (M), the isobar of the decay, the orbital angular momentum between the two decay products (L), and the reflectivity (η), which is defined to correspond to the naturality of the exchanged particle. We have applied the parametrization of Chung and Trueman [7], which ensures that the conditions of positivity and parity conservation in the production process are satisfied with the minimum number of parameters.

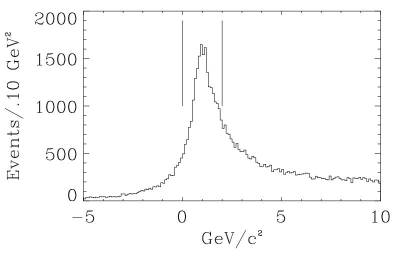

Figure 2: The missing mass^2 distribution. The vertical lines indicate the event selection cut used in the analysis.

We have assumed that the three-pion system is produced via a 2 step process with an intermediate isobar. For the isovector $\pi^+\pi^-$ system the isobar may be the ρ or $f_2(1270)$ mesons, whose Breit-Wigner parameters are taken from the Particle Data Group (PDG) [9]. The $\pi^+\pi^-$ isoscalar parametrization is more complex. Several different methods were used– the results presented here use results from the Crystal Barrel Collaboration (CB) extracted from $\pi^0\pi^0\pi^0$ data [10]. The CB results parameterize the $\pi^0\pi^0$ system with three K-matrix poles [b] corresponding to the $f_0(975)$, the $f_0(1300)$, and the $f_0(1500)$. We use only the $f_0(975)$ and the $f_0(1300)$, as attempts to include the $f_0(1500)$ did not significantly change the likelihood. We shall refer to these two $\pi^+\pi^-$ isoscalar waves collectively as $\sigma_{1,2}$. The full set of partial waves used in our fit is listed in Table 1. All other waves, when added to the fit – particularly negative naturality waves – were small. In addition to the listed waves, a non-interfering, isotropic background wave was included.

J^{PC}	*isobar*	L	M	η	J^{PC}	*isobar*	L	M	η
0^{-+}	$\sigma_{1,2}$	S	0	+	2^{-+}	$f_2(1270)$	S	0	+
0^{-+}	ρ	P	0	+	2^{-+}	ρ	P	0	+
0^{-+}	$f_2(1270)$	D	0	+	2^{-+}	$\sigma_{1,2}$	D	0	+
1^{-+}	ρ	P	1	+	2^{-+}	$f_2(1270)$	D	0	+
1^{++}	ρ	S	0	+	2^{-+}	ρ	F	0	+
1^{++}	$\sigma_{1,2}$	P	0	+	2^{-+}	$f_2(1270)$	S	1	+
1^{++}	$f_2(1270)$	P	0	+	2^{-+}	ρ	P	1	+
1^{++}	ρ	D	0	+	2^{++}	ρ	D	1	+
1^{++}	ρ	S	1	+					

Table 1: Partial Waves used in the fit

[b] The analysis is done P-vector approach according to Aitchison [8].

The intensity distribution is described by:

$$I(\tau) = \sum_{\alpha} \rho_{\alpha\alpha'} A_\alpha(\tau) A^*_{\alpha'}(\tau) \tag{1}$$

where

$$\alpha = J^{PG} M \eta(isobar) \tag{2}$$

The spin-density matrix is given by:

$$\rho_{\alpha\alpha'} = \sum_{k} V_{\alpha k} V^*_{\alpha' k} \tag{3}$$

where $V_{\alpha k}$ are complex parameters obtained in the fit and are proportional to the production amplitudes. k (= 1,2) allows for spin-flip and spin non-flip of the nucleon.

The analysis was done using 515576 events in the mass range 1 to 2 GeV/c^2 in 20 Mev/c^2 mass bins and 3 t bins, $-t < .15$ (GeV/c)^2, $.15 < -t < .30$ (GeV/c)^2, and $.30 < -t < .60$ (GeV/c)^2.

Figure 3 shows the raw $\pi^+\pi^-\pi^-$ mass spectrum as well as the raw $\pi^+\pi^-$

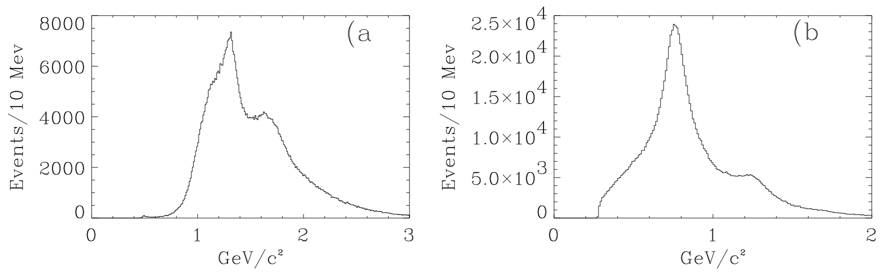

Figure 3: a) Uncorrected $\pi^+\pi^-\pi^-$ effective mass b) Uncorrected $\pi^+\pi^-$ effective mass

mass spectrum. The $a_2(1320)$, and $\pi_2(1670)$ are clearly seen in the uncorrected spectrum, while the broad $a_1(1160)$ is also evident. The $\pi^+\pi^-$ mass spectrum is dominated by ρ and $f_2(1270)$. The results of the partial wave analysis are shown in Figures 4, 5, and 6 for each of the respective t bins.

In $J^{PC} = 0^{-+}$ the broad $\pi(1300)$ is seen in each t bin, and decays to $\rho\pi$, $f_2(1270)\pi$, and $\sigma_{1,2}\pi$. The $\pi(1800)$, previously reported by VES [11], is seen in the lowest t bin, and decays primarily to $\sigma_{1,2}\pi$. Figure 7 (a) shows

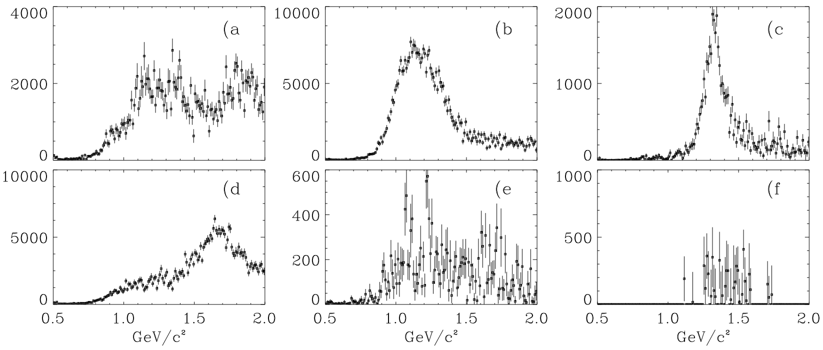

Figure 4: Wave intensities for $-t < .15(GeV/c)^2$ for J^{PC} a) 0^{-+} b) 1^{++} c) 2^{++} d) 2^{-+} e) 1^{-+} f) background

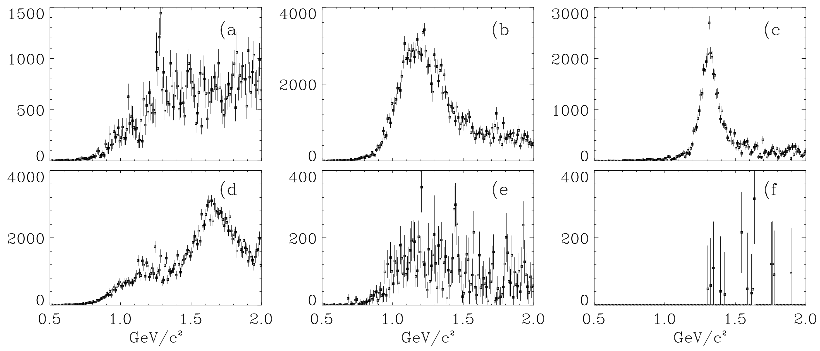

Figure 5: Wave intensities for $.15 < -t < .30(GeV/c)^2$ for J^{PC} a) 0^{-+} b) 1^{++} c) 2^{++} d) 2^{-+} e) 1^{-+} f) background

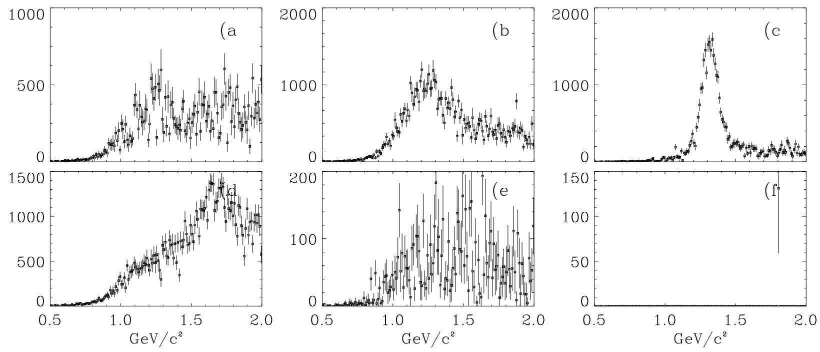

Figure 6: Wave intensities for $.30 < -t < .60(GeV/c)^2$ for J^{PC} a) 0^{-+} b) 1^{++} c) 2^{++} d) 2^{-+} e) 1^{-+} f) background

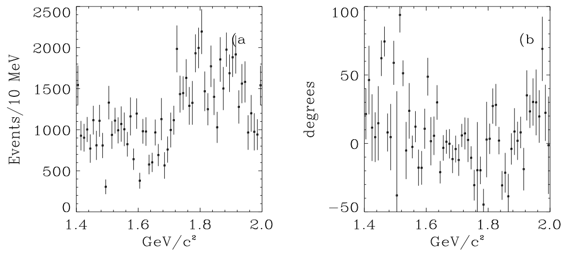

Figure 7: $0^{-+}\sigma_{1,2}$ wave a) Intensity b) Phase with respect to $2^{-+}f_2$

the $J^{PC} = 0^{-+}$ wave decaying to $\pi^+\pi^-$ isoscalar, and the phase motion with respect to the $J^{PC} = 2^{-+}$ (π_2) is shown in Figure 7(b), which suggests that the $\pi(1800)$ is resonant. In $J^{PC} = 1^{++}$, all fits show the $a_1(1160)$ with a mass of $\sim$ 1200 MeV/c^2. The $a_2(1320)$ is clearly seen in all t bins, enhanced, as expected, at larger t.

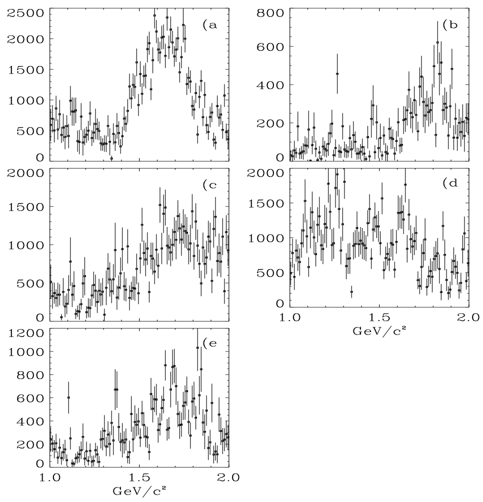

Figure 8: Decay modes of $\pi_2(1670)$ a) $f_2(1270)\pi$ S-wave b) $f_2(1270)\pi$ D-wave c) $\sigma_{1,2}\pi$ d) $\rho\pi$ P-wave e) $\rho\pi$ F-wave

The $J^{PC} = 2^{-+}$ shows the $\pi_2(1670)$. Figure 3 shows the decomposition of this wave into its various decay modes, and indicates that the $\pi_2(1670)$ decay is dominated by $f_2(1270)\pi$ S-wave.

The exotic $J^{PC} = 1^{-+}$ in natural parity exchange is small in all t bins, and is consistent with zero. The ratio of $1^{-+}/2^{++}$ is less than 1/25, in marked contradiction with VES, which report a ratio of 1/6 [4]. However, a 1^{-+} wave produced by unnatural parity exchange, although small, is not insignificant, and is currently being studied.

4 Conclusions

The partial-wave analysis of the reaction $\pi^- p \to \pi^+\pi^-\pi^- p$ has been performed on a sample of 500 thousand events taken in 1994 by E-852. All well-known states are observed, i.e., the $a_1(1160)$, $a_2(1320)$, and $\pi_2(1670)$. In addition, the $\pi(1800)$ is observed at low t. An exotic, $J^{PC} = 1^{-+}$ wave is less than 1/25 of the 2^{++} wave in natural parity exchange.

References

1. D. Alde et al, *Phys. Lett.* B **205**, 397 (1988).
2. H. Aoyagi et al, *Nuovo Cimento* **107**, 1925 (1994).
3. J. H. Lee et all, *Phys. Lett.* B **323**, 227 (1994).
4. Yu. P. Gouz et al, *Proceedings of the XXVI International Conference on High Energy Physics* 572.
5. B.B. Brabson et al, *Nucl. Instrum. Methods* **332**, 419 (1993).
6. "Design and Performance of a Cesium Iodide Detector", T. Adams et al, Nuclear Instruments and Methods (to be published).
7. S.U. Chung and T. L. Trueman, *Phys. Rev.* **D11** 633 (1975).
8. I.J.R. Aitchison, *Nucl. Phys.* A **189**, 417 (1972).
9. Particle Data Group, *Phys. Rev.* **D50** 1173 (1994).
10. C. Amsler et al, *Phys. Lett.* B **342**, 433 (1995).
11. D. V. Amelin et al, *Phys. Lett.* B **356**, 595 (1995).