Odd and Even Partial Waves of $\eta\pi^-$ and $\eta'\pi^-$ in 191 GeV/c $\pi^- p$

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In the year 2008 COMPASS recorded diffractive events of the signature $\pi^- (191\text{ GeV}) p \rightarrow X_{\text{fast}} p$. We present results of the analysis of the subsystems $X = \eta(\eta')\pi^-$. Besides the known resonances $a_2(1320)$, $a_4(2040)$, we study the properties of the spin-exotic $P_{+}$ wave, and all other natural-exchange partial waves up to spin $J = 6$. We find a striking difference between the two final states: whereas the even partial waves 2, 4, 6 in the two systems are related by phase-space factors, the odd partial waves are relatively suppressed in the $\eta\pi^-$ system. The relative phases between the even waves appear identical whereas the phase between the $D$ and $P$ waves behave quite differently, suggesting different resonant and non-resonant contributions in the two odd-angular-momentum systems. Branching ratios and parameters of the well-known resonances $a_2$ and $a_4$ are measured. We find

$$m(a_2) = 1315 \pm 12\text{ MeV}, \quad \Gamma(a_2) = 119 \pm 14\text{ MeV},$$

and

$$m(a_4) = 1900^{+80}_{-50}\text{ MeV}, \quad \Gamma(a_4) = 300^{+80}_{-100}\text{ MeV}.$$ (consistent with COMPASS’s 3π analyses.) For the relative branchings we measure

$$\frac{BR(a_2 \rightarrow \eta'\pi)}{BR(a_2 \rightarrow \eta\pi)} = (5 \pm 2)\%, \quad \frac{BR(a_4 \rightarrow \eta'\pi)}{BR(a_4 \rightarrow \eta\pi)} = (23 \pm 7)\%.$$ 

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1. Introduction

The systems \( \eta \pi \) and \( \eta' \pi \) are attractive laboratories for strong-interaction physics because of their simplicity and clear experimental signature. Besides the well-known resonances \( a_2(1320) \) and \( a_4(2040) \), resonance-like behavior was observed in the \( P \)-wave, whose neutral isospin member carries the exotic quantum numbers \( J^{PC} = 1^{-+} \) (see e.g. Ref. [1]). In this contribution, we discuss an analysis of the \( \eta \pi^- \) and \( \eta' \pi^- \) systems, diffractively produced off a proton target during the 2008 run of the COMPASS experiment. Previous work on this analysis was discussed in Refs. [2, 3]. A journal publication is in progress.

The COMPASS experiment is a fixed-target experiment installed at the CERN SPS. Its two-stage spectrometer allows for high-resolution particle detection and reconstruction over a wide range in angles and momenta, both for charged and neutral particles [4]. The data recorded for the analysis under discussion was produced by having a 191GeV \( \pi^- \) beam impinge on a LH2 target. The target was surrounded by a recoil proton detector which together with a veto detector surrounding the spectrometer entry formed a trigger ensuring a clean sample of diffractive excitation reactions with momentum transfer \(|t| \gtrsim 0.08 \text{GeV}^2 \) [5]. Samples of approximately \( 35 \times 10^3 \) exclusive \( \pi^- \eta' \) and \( 110 \times 10^3 \) exclusive \( \pi^- \eta \) events with invariant masses from threshold up to several GeV is obtained in the reaction \( \pi^- p \rightarrow \pi^- \pi^+ \gamma \gamma p \), where the two photons result from the decay of an intermediate \( \eta \) (\( \pi^0 \)) in the \( \eta' \) (\( \eta \)) decay. Acceptances for the two reactions as function of mass and polar angle (Gottfried-Jackson system) are shown in Fig. 1.

![Figure 1: Acceptance evaluated from Monte Carlo. An azimuthal distribution \( \propto \sin^2 \phi \) (i.e. natural exchange, \( M = 1 \)) and the experimental \( t' \) distribution were used for these pictures.](image)

In the flavor basis, \( \eta - \eta' \) mixing is described by an angle \( \phi \approx 39^\circ \) [6]. One expects in particular for branching ratios of the \( a_2 \) and \( a_4 \) resonance decays to pseudoscalars

\[
\text{BR}(a_J \rightarrow \pi \eta')/\text{BR}(a_J \rightarrow \pi \eta) = F(J, q'(m), q(m)) \tan^2 \phi,
\]

where \( J \) is angular momentum, and \( q^{(i)}(m) \) are the breakup momenta at invariant mass \( m \). For \( q^{(i)} \rightarrow 0 \) the behavior of each cross-section has to follow \( (q^{(i)})^{2J+1} \) from analyticity of the partial-wave series. Therefore, the simplest form of dynamical term, which we use in the following, is

\[
F(J, q', q) = (q'/q)^{2J+1}.
\] (1.1)
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2. Partial-wave Analysis Procedure

The data were subjected to partial-wave analysis. Here, an acceptance-corrected partial-wave model was fit to the data in 40 MeV wide bins of $m(\eta(1)\pi^-)$ from threshold up to 3 GeV, separately for the two final states. The formalism used was an extended log-likelihood fit where partial waves were parametrized in the reflectivity basis. Natural-exchange partial waves with $M = 1$ for angular momenta up to $J = 6$ were included. For $J = 2$ in $\eta\pi$, an $M = 2$ partial wave was also included in the analysis. It was found to contribute 3% of the $a_2$ intensity. The complete four-body information was used to distinguish the three-body $\eta(2)$ peak from background reactions which were modeled by a partial wave isotropic in four-body phase space. The partial wave model consisted of three incoherent contributions: natural-exchange waves, unnatural-exchange waves and the flat four-body background. Consistent with the expectation of a dominant Pomeron contribution, unnatural parity exchange is found to be suppressed. In Fig. 2 we illustrate the procedure by overlaying the data and the fit results for the $\eta\pi^-$ data in the vicinity of the $a_2(1320)$ resonance. For details see Ref. [3]. Physical hypotheses are then tested by fitting mass-dependent (resonance) models to the partial-wave intensities and phases extracted in the mass-binned fit. The Breit-Wigner fit results for the known resonances are given in the abstract.

3. Partial-wave Results

We show the intensities of the main waves of the $\eta\pi^-$ data in Fig. 3. The $J = 1$ $P$-wave shows a broad bump and vanishing intensity above 1.8 GeV. The $J = 2$ wave is dominated by the well-
and a factor taking into account the final-state branching fractions.

Figure 4: Main waves of the $\eta'(\to \pi^+\pi^-\gamma\gamma)\pi^-$ data. In red: the $\eta\pi^-$ data multiplied by the mass-dependent phase-space factor from Eq. 1.1, taking into account final-state branching fractions.

known $a_2(1320)$ resonance with a shoulder at high mass. Besides leakage from the dominant $J = 2$ wave, the $J = 4$ wave exhibits a clear $a_4(2040)$ signal, followed by a broad structure at high mass.

The same partial waves are depicted for the $\eta'\pi^-$ data in Fig. 4. Again, we see a broad structure in the $J = 1$ $P$-wave, this time vanishing near 2 GeV with some intensity reappearing at higher masses. In the $J = 2$ wave, the relative height of the high-mass shoulder compared to the peak is enhanced compared to the $\eta\pi$. Similarly, the peak in the $J = 4$ wave stands out less in the $\eta'\pi^-$ data. Overlaid on the $\eta'\pi^-$ data are the $\eta\pi^-$ data from Fig. 3, where the content of each bin has been multiplied with the factor from Eq. 1.1 and a factor taking into account the final-state decays $\eta' \to \pi^-\pi^+\gamma\gamma$ [6]. We find a surprising difference between different partial waves: whereas the even waves with $J = 2,4$ show very similar behavior, the odd $J = 1$ wave is relatively enhanced in the $\eta'\pi^-$ data. These properties extend also to the waves with spins $J = 3, 5, 6$ (not shown): odd waves are relatively enhanced in $\eta'\pi^-$, even waves largely agree after phase-space multiplication.

For the phases similar behavior is observed, shown in Fig. 5: the phases between the even-spin waves $J = 2$ and $J = 4$ agree between the two channels. The phases between the $J = 1$ and $J = 2$ partial waves disagree in the region of the $J = 1$ intensity peaks. A particularly intriguing feature is the agreement of this $(J = 1) - (J = 2)$ phase near the $\eta'\pi^-$ threshold.

The difference in even/odd behavior is detailed in Tab. 1, where we show the relative intensities of the various partial waves and the ratios of their integrals after phase-space scaling.
Table 1: Relative intensities of the $J = 1$ to $6$ and $J = 2$, $M = 2$ partial waves resulting from the PWA fits integrated over the mass range up to 3GeV. Experimental acceptance is taken into account. The total $\eta'\pi^-$ to $\eta\pi^-$ intensity ratio in this mass range amounts to $0.19 \pm 0.02$. $R_{\text{corr}}$, given in the third row, is the ratio of the integral of the red histogram to the integral of the black histogram.

| J   | 1  | 2   | 3   | 4   | 5   | 6   |
|-----|----|-----|-----|-----|-----|-----|
| $I_1(\eta\pi^-)/I_{\text{total}}(\eta\pi)$ [%] | 4.4 | 81.9 | 0.3 | 6.9 | 0.1 | 0.7 |
| $I_1(\eta'\pi^-)/I_{\text{total}}(\eta'\pi)$ [%] | 41.7 | 42.3 | 3.7 | 8.4 | 0.9 | 1.2 |
| $R_{\text{corr}}$ | $0.17 \pm 0.01$ | $0.94 \pm 0.02$ | $0.16 \pm 0.05$ | $0.83 \pm 0.07$ | $0.15 \pm 0.12$ | $0.68 \pm 0.15$ |

References

[1] E. Klempt, A. Zaitsev, Glueballs, Hybrids, Multiquarks. Experimental facts versus QCD inspired concepts, Phys. Rept., 454:1–202, 2007, arXiv:0708.4016 [hep-ph]

[2] T. Schlüter, et al., Resonances of the systems $\pi^- \eta$ and $\pi^- \eta'$ in the reactions $\pi^- p \rightarrow \pi^- \eta p$ and $\pi^- p \rightarrow \pi^- \eta' p$ at COMPASS, in proceedings of QNP 2012 PoS(QNP2012)074, arXiv:1207:1076 [hep-ex].

[3] T. Schlüter, The $\pi^- \eta$ and $\pi^- \eta'$ Systems in Exclusive 190 GeV $\pi^- p$ Reactions at COMPASS (CERN), PhD thesis, Ludwig-Maximilians-Universität, München, 2012.

[4] P. Abbon, et al., The COMPASS Experiment at CERN, Nucl. Instrum. Meth., A577:455–518, 2007, [hep-ex/0703049]; M.G. Alekseev et al., The COMPASS 2008 Spectrometer, to be submitted, 2014.

[5] T. Schlüter, et al., Large-Area Sandwich Veto Detector with WLS Fibre Readout for Hadron Spectroscopy at COMPASS, Nucl. Instrum. Meth., A654:219-224, 2011, arXiv:1108.4587 [physics.ins-det].

[6] J. Beringer et al., Review of Particle Physics, Phys.Rev., D86:010001, 2012.