PROCEEDINGS OF SCIENCE

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

Tobias Schlüter[*][†]
Ludwig-Maximilians-Universität München, Germany
E-mail: tobias.schlueter@physik.uni-muenchen.de
on behalf of the COMPASS collaboration

In the year 2008 COMPASS recorded diffractive events of the signature $\pi^-(191\,\mathrm{GeV})p \to X_{\mathrm{fast}}p$. We present results of the analysis of the subsystems $X = \eta^{(\prime)}\pi^-$. Besides the known resonances $a_2(1320)$, $a_4(2040)$, we study the properties of the spin-exotic P_+ wave, and all other natural-parity 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

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

and

$$m(a_4) = 1900^{+80}_{-20}\,\mathrm{MeV}, \quad \Gamma(a_4) = 300^{+80}_{-100}\,\mathrm{MeV}.$$

(consistent with COMPASS's 3π analyses.) The relative branchings we measure are

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

PACS: 14.40.Be,14.40.Rt,13.85.Hd,12.39.Mk,12.38.Qk

XV International Conference on Hadron Spectroscopy-Hadron 2013
4-8 November 2013
Nara, Japan

[*]Speaker.

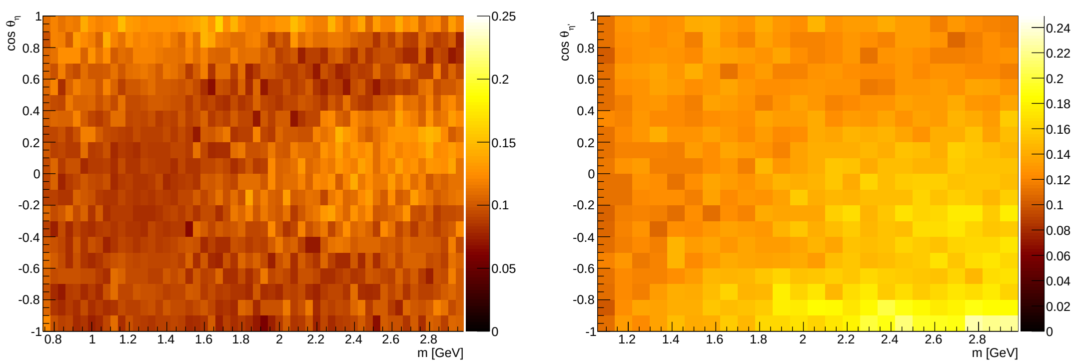
[†]The author acknowledges financial support by the Maier-Leibniz-Laboratorium der LMU und TU München, by the German Bundesministerium für Bildung und Forschung (BMBF), and by the DFG cluster of excellence "Origin and Structure of the Universe."

PoS(Hadron 2013)085

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 191 GeV π^- beam impinging 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 $|t| \gtrsim 0.08\,\mathrm{GeV}^2$ [5]. Samples of approximately 35×10^3 exclusive $\pi^-\eta'$ and 110×10^3 exclusive $\pi^-\eta$ events with invariant masses from threshold up to several GeV is obtained in the reaction $\pi^- p \to \pi^-\eta^{(\prime)} \to \pi^-\pi^-\pi^+\gamma\gamma p$, where the two photons result from the decay of an intermediate η (π^0) in the η' (η) decay. Acceptances for the two reactions as a function of mass and polar angle (Gottfried-Jackson system) are shown in Fig. 1.



(a) $\eta\pi^-$ Acceptance (b) $\eta'\pi^-$ Acceptance

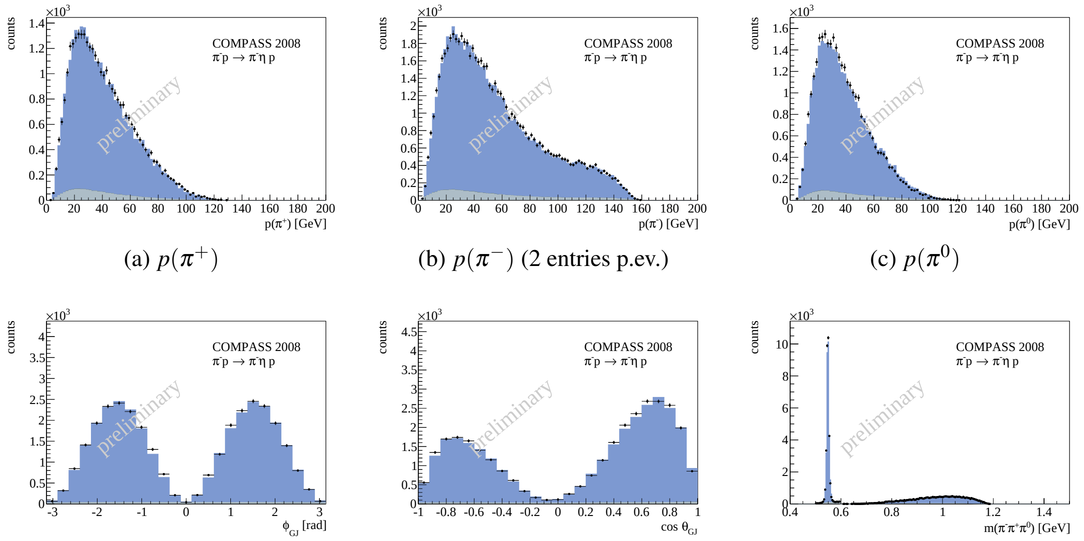
Figure 1: Acceptance evaluated from Monte Carlo simulation. An azimuthal distribution $\propto \sin^2\phi$ (i.e. natural-parity exchange, $M = 1$) and the experimental t' distribution were used.

In the flavor basis, η-η' 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

$$\mathrm{BR}(a_J \to \pi\eta')/\mathrm{BR}(a_J \to \pi\eta) = F(J, q'(m), q(m)) \tan^2\phi,$$

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

$$F(J, q', q) = (q'/q)^{2J+1}. \tag{1.1}$$



(a) $p(\pi^+)$ (b) $p(\pi^-)$ (2 entries p.ev.) (c) $p(\pi^0)$

(d) ϕ_{GJ} (e) $\cos\theta_{\mathrm{GJ}}$ (f) $m(\pi^-\pi^+\pi^0)$ (two entries p.ev.)

Figure 2: Comparison of fit results to the data. First row: lab momenta of pions, second row: two-body angular variables and invariant three-body mass with the $\eta(548)$ peak. Black dots: data. The fit result is decomposed into the incoherent contributions as follows: Light blue: natural-parity exchange waves. Gray: non-η background. Dark blue: unnatural-parity exchange waves (negligible).

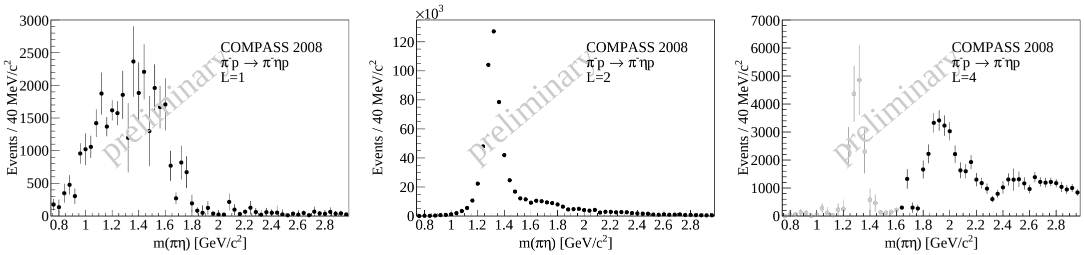
2. Partial-wave Analysis Procedure

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 $m(\eta^{(\prime)}\pi^-)$ 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-parity exchange partial waves with spin projection $M = 1$ 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 $\eta^{(\prime)}$ 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-parity exchange waves, unnatural-parity exchange waves and the four-body phase-space 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

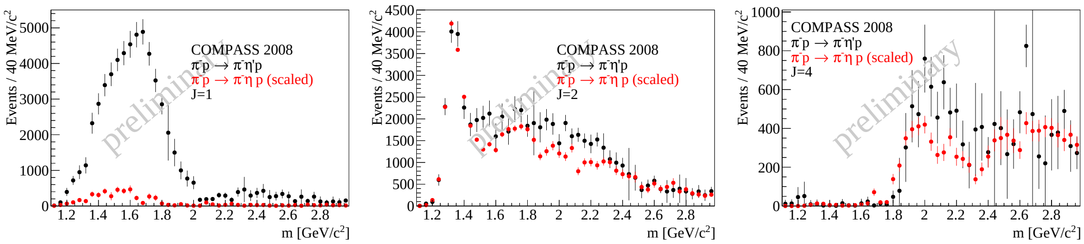
We show the intensities of the main waves of the $\eta\pi^-$ data in Fig. 3. The $J = 1$ P-wave shows a broad bump and vanishing intensity above 1.8 GeV. The $J = 2$ wave is dominated by the well-

PoS(Hadron 2013)085



(a) P-wave, $J = 1$ (b) D-wave, $J = 2$ (c) G-wave, $J = 4$

Figure 3: Main waves of the $\eta(\to \pi^-\pi^+\gamma\gamma)\pi^-$ data.



(a) P-wave, $J = 1$ (b) D-wave, $J = 2$ (c) G-wave, $J = 4$

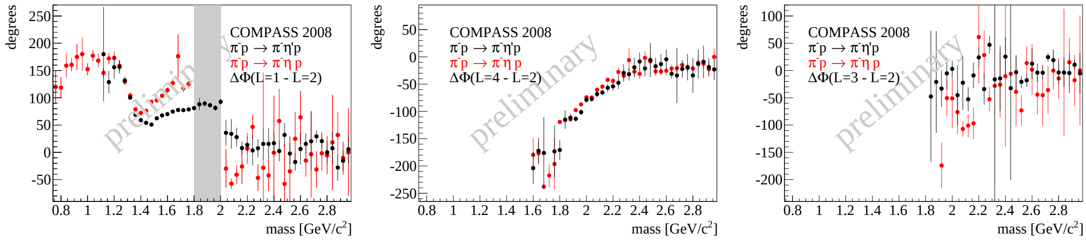
Figure 4: Main waves of the $\eta'(\to \pi^-\pi^+\gamma\gamma)\pi^-$ data. In red: the $\eta\pi^-$ data multiplied by the mass-dependent phase-space factor from Eq. 1.1, taking into account final-state branching fractions.

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 $\eta^{(\prime)} \to \pi^-\pi^+\gamma\gamma$ [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, a 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.



(a) Phase $(J=1)-(J=2)$ (b) Phase $(J=4)-(J=2)$ (c) Phase $(J=3)-(J=2)$

Figure 5: Relative phases in $\eta'\pi^-$ and $\eta\pi^-$ (red) for selected partial waves.

Table 1: Relative intensities of the $J=1$ to 6 partial waves resulting from the PWA fits integrated over the mass range up to 3 GeV. Experimental acceptance is taken into account. The total $\eta'\pi^-$ to $\eta\pi^-$ intensity ratio in this mass range is 0.19 ± 0.02. The ratio of the integrals of the red and black histograms in Fig. 4, and similar for the other waves, is given in the last row.

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