The exotic $\eta'\pi^-$ Wave in 190 GeV $\pi^- p \to \pi^-\eta' p$ at COMPASS

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A sample of 35 000 events of the type $\pi^- p \to \eta'\pi^- p_{\text{slow}}$ ($\eta' \to \eta\pi^-\pi^+$, $\eta \to \gamma\gamma$) with $-t > 0.1\,\text{GeV}^2/c^2$ was selected from COMPASS 2008 data for a partial-wave analysis. We study the broad P_+ structure known from previous experiments at lower energies, in particular its phase motion relative to the D_+-wave near the $a_2(1320)$ mass and relative to a broad D_+-wave structure at higher mass. We also find the $a_4(2040)$. We compare kinematic plots for the $\eta'\pi^-$ and $\eta\pi^-$ final states.

1 Introduction

The existence of strongly-bound, resonant states with quantum numbers not allowed for a fermion-antifermion system has long been expected. In the light-quark sector isospin symmetry also disallows such a state for charged $u\bar{d}$, $d\bar{u}$ mesons. On the other hand, a system decaying into the two pseudo-scalar mesons π, η (π, η') with orbital angular momentum $L = 1$ has quantum numbers $J^{PG} = 1^{-+}$, and thus any resonant contribution to such a system would have to be identified with a non-$q\bar{q}$ resonance.

Indeed, several collaborations claimed the observation of such a resonance in the $\eta\pi$ system at $m(\eta\pi) \approx 1.4\,\text{GeV}/c^2$ [1–3]. Likewise a very strong P-wave contribution was observed in the $\eta'\pi^-$ system [1,4] at $m(\eta'\pi) \approx 1.6\,\text{GeV}/c^2$, but the resonant character of the structure observed in both systems has been questioned [5].

We report on the current status of the analysis of the $\eta'\pi^-$ and $\eta\pi^-$ final states as observed in the data from the 2008 run of the COMPASS experiment at CERN and compare our results to the above-quoted publications. The COMPASS experimental setup [6, 7] is a two-stage magnetic spectrometer attached to the SPS accelerator facility at CERN. During the bulk of the 2008/09 campaigns the experiment's goal was the study of the light meson spectrum. A 190 GeV/c secondary pion beam impinged on a liquid hydrogen target. The main trigger components were a beam definition trigger together with a recoil proton detector (RPD). The RPD ensured an unscathed proton emitted at large angles with momentum corresponding to momentum transfer $-t \gtrsim 0.1\,\text{GeV}^2$. A veto counter near the spectrometer

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entry further suppressed events with particles emitted at large angles, especially from target fragmentation [8,9]. An additional veto suppressed events where the beam particle passed through the target undeflected. Both stages of the spectrometer are equipped with tracking detectors and particle identification and neutral detection by means of electromagnetic and hadronic calorimetry. In addition, the first spectrometer stage is equipped with a Ring-Imaging Cherenkov detector, allowing for particle identifcation.

2 Data Selection

Besides trigger requirements, the events considered were selected by the following topological criteria: a well-defined primary interaction vertex inside the target with three outgoing tracks (assumed to be pions) attached and two clusters in the electromagnetic calorimeters. In order to select the intended $\pi^-\eta'$ and $\pi^-\eta$ final states, the invariant mass obtained by attaching the pair of calorimeter clusters to the primary vertex was required to fall into the range of the η or π^0 mass, respectively. The so-identified neutral particle was then — after a 1C kinematic fit — combined with both possible $\pi^-\pi^+$ pairs. If the invariant mass of either combination was found to match the $\eta' \to \pi^-\pi^+\eta$ or, respectively, $\eta \to \pi^-\pi^+\pi^0$ hypothesis, the event was accepted after additional cuts on the total momentum. The procedure yielded 35 000 events for the $\pi^-\eta'$ final state and 110 000 events for the $\pi^-\eta$ final state. The intermediate steps are illustrated in Fig. 1 for the selection of the $\eta'\pi^-$ final state. The $\eta\pi^-$ selection is similar.

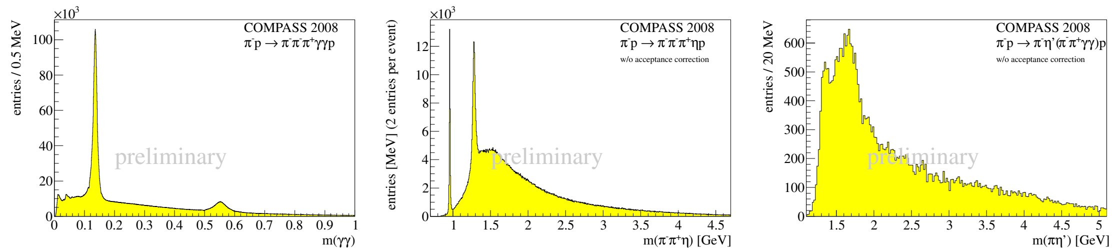

Figure 1: Data selection. Left: $\gamma\gamma$ mass spectrum for events with three charged tracks. The $\pi^0(135)$ and $\eta(548)$ peaks are clearly visible. Center: $\pi^-\pi^+\eta$ mass spectrum for kinematically complete events. Two peaks corresponding to $\eta'(958)$ and $f_1(1285)$ stand out. Right: Final $\pi^-\eta'$ mass spectrum. The peak of the $a_2(1320)$ is visible near threshold.

3 Final-State Kinematics

The data are expected to be dominated by natural parity exchange waves with $M = 1$, both from the favored pomeron exchange and from the results of previous analyses. This is easily verified by plotting the angle ϕ between decay and production plane in the

mass bin [GeV/c^2]	fit with $A\exp(-B\|t\|)$	fit with $A\|t\|\exp(-B\|t\|)$
$m < 1.5$	5.5	8.2
$1.5 < m < 1.9$	5.1	7.5
$1.9 < m < 2.2$	4.8	7.1
$2.2 < m < 3$	4.6	6.9

Table 1: Fit to the slope parameter B in units of GeV^{-2} for momentum transfer as function of mass. E852 found the much broader $B = 2.93\,\mathrm{GeV}^{-2}$ when fitting with a single exponential.

Gottfried-Jackson frame [10] where the $\sin^2\phi$ contribution dominates (not shown). The remainder of the kinematical information is contained in the momentum transfer t, the polar angle of the η or η' meson in the GJ frame $\cos\theta_{\mathrm{GJ}}$, and the invariant mass m of the two-body system under consideration. In Fig. 2 the distribution of $\cos\theta_{\mathrm{GJ}}$ as function of m is shown for both the $\eta\pi^-$ and $\eta'\pi^-$ systems. Outstanding features are the occurence of the $a_2(1320)$ meson, a structure near $2\,\mathrm{GeV}/c^2$ corresponding to the $a_4(2040)$ meson, whose intereference with a spin-2 background can be made out in the $\eta\pi^-$ data, and a strong forward-backward peaking for masses above $2\,\mathrm{GeV}/c^2$, pointing towards non-resonant contributions. Especially in the $\eta'\pi^-$ data a strong forward backward asymmetry is observed in the data, with a fast turnover around the $a_2(1320)$ mass range, corresponding to relative phase motion of the odd (P_+) and even (D_+) contributions.

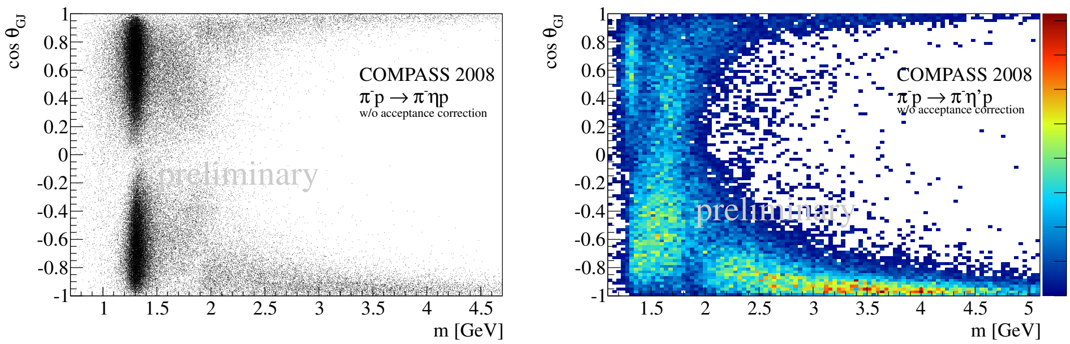

Figure 2: Kinematics. The distribution in $\cos\theta_{\mathrm{GJ}}$ as function of invariant mass m (not acceptance corrected). Left for the $\eta\pi^-$ system, right for the $\eta'\pi^-$ system.

The E852 experiment claimed an unusual momentum transfer distribution in the production of the $\eta'\pi^-$ system [4]. We cannot confirm this observation, see Tab. 1.

4 Partial-Wave Analysis of the $\eta'\pi^-$ System

In this section we present the results of a partial-wave analysis in mass bins of the $\eta'\pi^-$ data. The analysis follows the lines of the previous analyses, allowing S, P, and D waves with $M \leqslant 1$ in both natural and unnatural exchange. Additionally, the spin-4, $M = 1$ G_+-wave was allowed. The η' was separated from the $\pi^-\pi^+\eta$ background by introducing its experimental shape as a pseudo-isobar and fitting in the complete 4-body phase-space where besides the $\pi^-\eta'$ waves an additional incoherent flat, phase-space-like contribution was allowed. From these ingredients an extended log-likelihood function is constructed and maximized, taking into account the detector acceptance via normalization integrals calculated from Monte-Carlo data. The results for the intensities of the positive-reflectivity wave are shown in Fig. 3. The relative phases are shown in Fig. 4.

We confirm the presence of a broad structure in the P_+-wave of the $\eta'\pi^-$. A fit to the intensity of this structure by a single-channel relativistic Breit-Wigner shape underestimates the high-mass side of the distribution. We confirm the presence of the $a_4(2040)$ resonance in this channel previously seen by E852 [4]. This resonance is also visible in the 3π data [11]. A resonant interpretation of the P_+-wave would have to be reconciled with the relative phase-motions compared to the other waves, and the apparent onset of double-Regge production or similar processes above $\approx 2\,\text{GeV}$ whose low-mass impact is not yet understood.

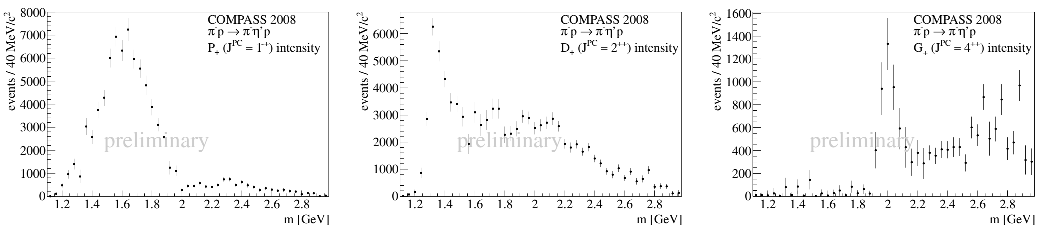

Figure 3: Intensities of the positive-reflectivity waves. From left to right: P_+, D_+, G_+.

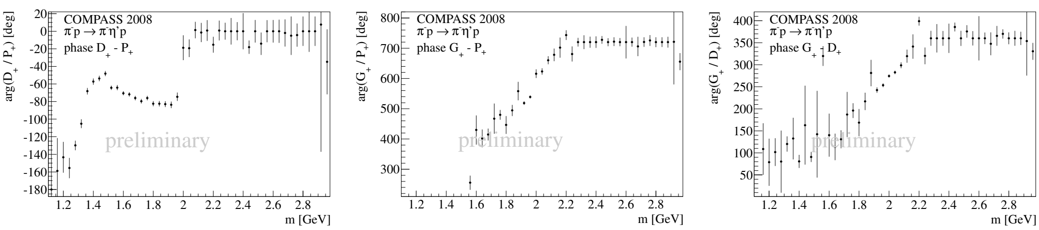

Figure 4: Relative phases of the positive-reflectivity waves. From left to right in obvious notation: $D_+ - P_+$, $G_+ - P_+$, $G_+ - D_+$.

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