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

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June 16, 2011

$\pi\eta'$ in diffractive scattering

Possible quantum numbers for the $\pi\eta'$ system:

L	S-wave	P-wave	D-wave	F-wave	G-wave	$\cdots$
J^{PC}	0^{++}	1^{-+}	2^{++}	3^{-+}	4^{++}	$\cdots$

Hence: P-wave resonant $\rightarrow$ exotic meson.

This system has been studied by the following experiments:

experiment	beam momentum	reaction	year published
VES	$37\,\mathrm{GeV/c}$	$\pi^- N \rightarrow \eta'\pi^- N$	1993, 2005
E852	$18\,\mathrm{GeV/c}$	$\pi^- p \rightarrow \eta'\pi^- p$	2001

They all see a very strong P-wave.

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COMPASS	$190\,\mathrm{GeV/c}$	$\pi^- p \rightarrow \eta'\pi^- p$	2012 (?)

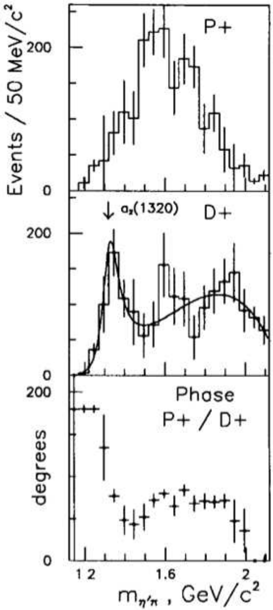
They all see a very strong P-wave.

Previous $\pi\eta'$ results – VES

Results from VES (Be target, 37 GeV):

- VES sees the $a_2(1320)$ (peak in D_+-wave)
- VES says: "there may be an $a_2(1700)$" explaining the broad structure in the D_+-wave
- VES says: "there may be an exotic $\pi_1(1600)$"

Note the jump in the relative $P_+ - D_+$ phase near 2 GeV

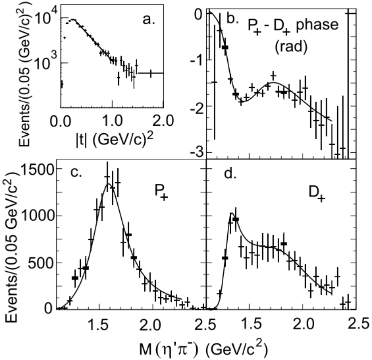


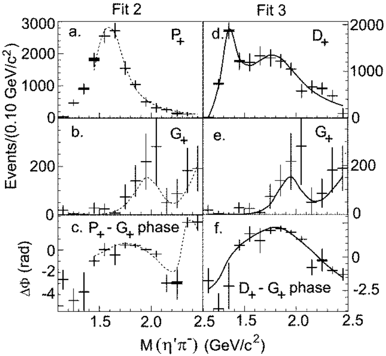
Previous $\pi\eta'$ results – BNL E852

Results from BNL E852 (proton target, 18 GeV):

- they see the $a_2(1320)$ (peak in D_+-wave)
- they add a G_+-wave to the fit, gives: $a_4(2040)$
- they explain the broad D_+-wave with an $a_2(1700)$ and the P_+-wave with an exotic resonance $\pi_1(1600)$
- they find an unusual t-slope

Note the various jumps at 2 GeV





Remarks on PWA formalism

For a given mass, two-body states in the reflectivity basis (ϵ, ℓ, m) have the form (θ, ϕ Gottfried-Jackson angles)

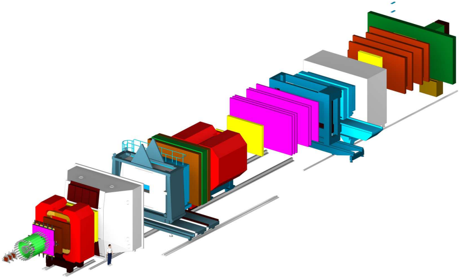
$$A_{\epsilon lm} \propto Y_\ell^m(\theta, 0) \begin{cases} \sin(m\phi) & \epsilon = +1 \quad (m > 0) \\ \cos(m\phi) & \epsilon = -1 \quad (m \geq 0) \end{cases}$$

The observed intensity is then proportional to

$$I(\theta, \phi) = \left| \sum_{lm} T_{+1,\ell m} A_{+1,\ell m}(\theta, \phi) \right|^2 + \left| \sum_{\ell m} T_{-1,\ell m} A_{-1,\ell m}(\theta, \phi) \right|^2$$

where the production amplitudes $T_{\epsilon \ell m}$ were introduced.
Important observations: only negative reflectivity (= unnatural exchange) contributes to intensity at $\phi = 0$; all positive reflectivity waves with $m = 1$ have the same ϕ dependency. Negative reflectivity compatible with zero in VES, BNL, COMPASS analyses.

The COMPASS spectrometer

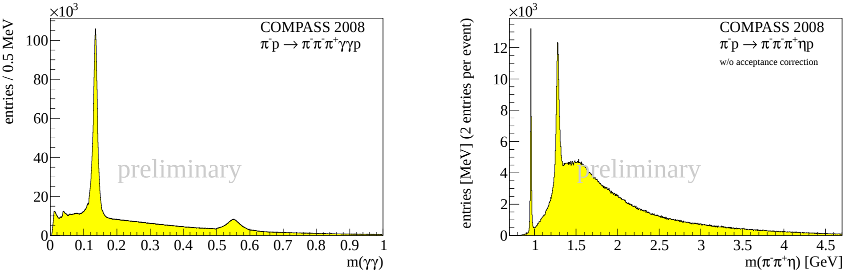


- fixed target experiment at CERN's SPS accelerator
- variety of beams available (pos/neg muon, pos/neg hadron)
- variety of targets (polarized targets, LH2, solid state)
- diverse physics program
- 2008, 2009 : hadron beam runs with various targets

In this talk: 2008 data, negative pion beam at 191 GeV, LH2 target

Data selection

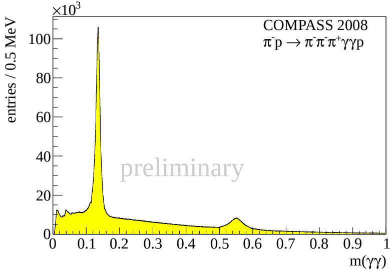
Final state selected: exclusive 3 tracks, 2 photons

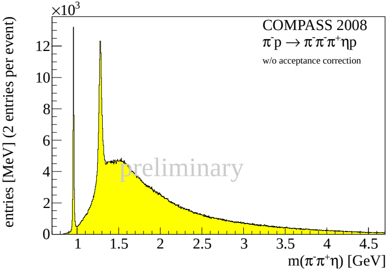


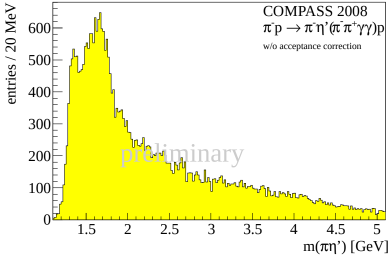
- select exclusive events with 3 tracks + recoil proton, 2 good ECAL clusters
- select $\eta \rightarrow 2\gamma$ (left)
- select $\eta' \rightarrow \pi^-\pi^+\eta$ (right)

Data selection

Final state selected: exclusive 3 tracks, 2 photons







Result:

- 18 000 events with $m(\eta'\pi) < 2\,\mathrm{GeV}/\mathrm{c}^2$, 35 000 total
- mass reach beyond $2\,\mathrm{GeV}/\mathrm{c}^2$
- additionally, about 3 000 events in $\pi\eta'$, $\eta \to 3\pi$ channel

First look at the data: t slopes

We find indication for a continuous transition between different production mechanisms, fitting the t distribution in several areas

mass bin	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

(BNL fitted with a simple exponential between $0.25 < |t| < 1.0\,\mathrm{GeV/c^2}$, they found $B = 2.93/\mathrm{GeV}^2$)

We find: higher mass $\rightarrow$ broader slope

and: clear contradicition with BNL

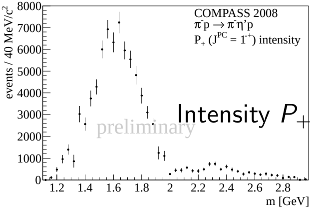
Input to the PWA

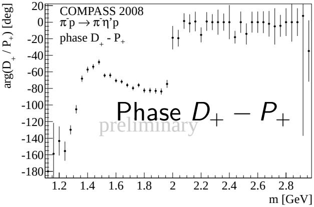
Like previous analyses, we used all waves with $\ell \leq 2$, $m \leq 1$ and additionally the $\epsilon = +1$, $\ell = 4$, $m = 1$. I.e.:

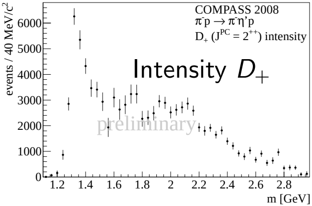
$\epsilon = +1$			P_+		D_+	G_+
$\epsilon = -1$	S_0	P_0	P_-	D_0	D_-	

As expected from Pomeron (i.e., natural) exchange, the negative reflectivity waves turn out compatible with zero (below $2\,\mathrm{GeV}$). Ambiguities are bounded by the size of the negative waves, i.e. they are not a problem.

PWA results – P_+ and G_+ waves

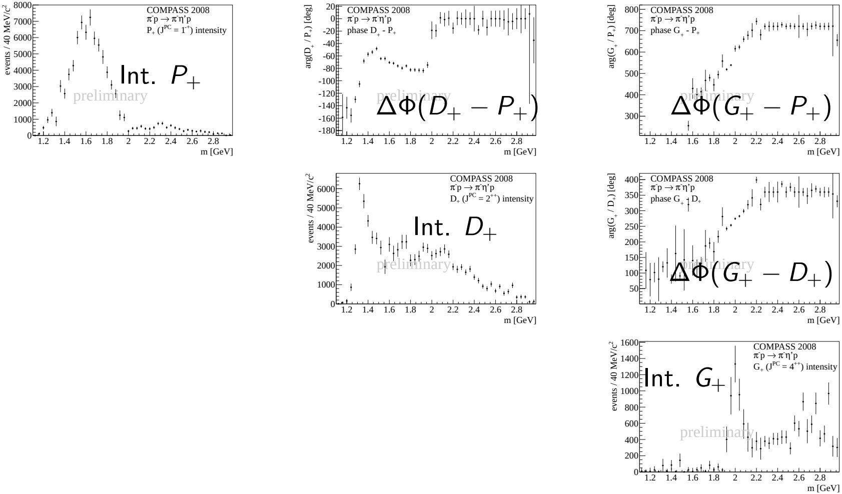






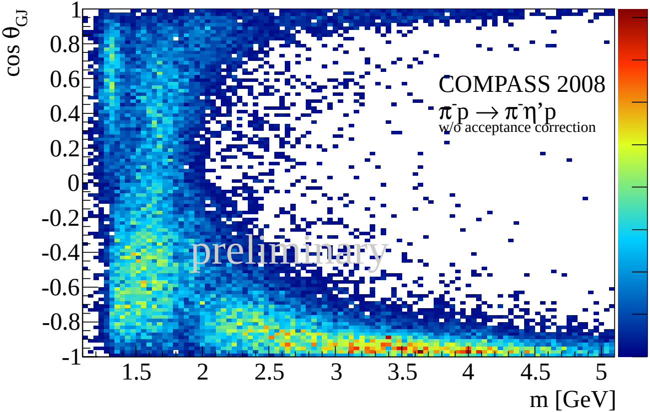
Clear phase-motion from $a_2(1320)$, jump in phase near $2\,\mathrm{GeV}$, slow phase-motion in range of P_+-wave intensity peak.

PWA results – can the G_+-wave clarify the picture?



Clear phase-motion in G_+-wave relative to D_+ wave, compatible with $a_4(2040)$. Again: jump at $2\,\mathrm{GeV}$ in phase relative to P_+ wave. But: unlike between P_+ and G_+ no rapid phase jump between D_+ and G_+ waves at $2\,\mathrm{GeV}$

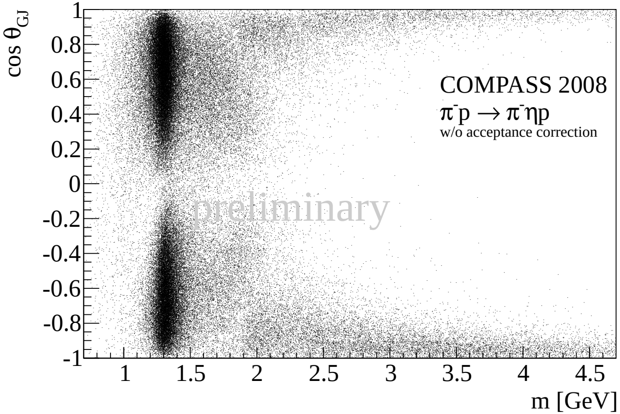
Transition between different production processes?



Depicted: $\cos\theta_{\mathrm{GJ}}$ of the η' in the $\pi^-\eta'$ GJ restframe vs. $m(\pi\eta')$.
Low masses show *P* and *D* wave interference, a_4 near $2\,\mathrm{GeV/c}^2$, above that strong forward/backward peaking indicative of central production.
Question: How does the forward/backward peaking at high masses affect the interpretation at low masses?

Comparison to $\eta\pi$

We also selected the $\eta\pi^-$ final state along the same lines. No PWA yet, for comparison, here's the same plot as on the previous slide, but for the $\pi\eta$:



Depicted: $\cos\theta_{\mathrm{GJ}}$ of the η in the $\pi^-\eta$ GJ restframe vs. $m(\pi\eta)$. Dominated by $a_2(1320)$, structures due to $a_4(2040)$ visible, again forward/backward peaking at high masses.

Conclusions

- COMPASS can confirm previous observations of a strong *P*-wave in $\eta'\pi$ and in addition finds confirming evidence for the $a_4(2040) \rightarrow \pi^-\eta'$
- the *t* distribution shows a decreasing slope with increasing $m(\eta'\pi^-)$ and the slope disagrees with the findings of E852
- resonant interpretation of the *P*-wave cannot be confirmed (at this point)

The road ahead:

- Primary Objective: clarify what happens in the transition between the regimes below and above $\approx 2\,\mathrm{GeV/c^2}$
- Secondary Objective: use this to gain clearer understanding of the nature of $\pi^-\eta'$ *P*-wave

Thank you!