

Resonances of the Systems $\pi^- \eta$ and $\pi^- \eta'$ in the reaction $\pi^- p \rightarrow \pi^- \eta^{(\prime)} p_{\text{slow}}$ at COMPASS

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COMPASS
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Grundlagenforschung



On the Final States $\eta\pi$ and $\eta'\pi$

Exotic Waves! Exotic Resonances?

- ▶ Quantum Numbers of the P -Wave in the $\eta\pi^0$ -system are $J^{PC} = 1^{-+}$
- ▶ i.e. a P -wave resonance in $\eta\pi$ (or $\eta'\pi$) cannot be assigned a quark-model state

Exotic $\eta\pi$ state in $\bar{p}d$ annihilation at rest into $\pi^- \pi^0 \eta$ $P_{\text{spectator}}$

Exotic meson with non- $q\bar{q}$ quantum numbers produced in $N\bar{N}$ annihilation

Study of the $\eta\pi$ and $\eta'\pi$ spectra and interpretation of possible exotic $J^{PC} = 1^{-+}$ mesons

...ITIES IN THE PARTIAL WAVE ANALYSIS OF $K^- p \rightarrow \eta \pi^0 n$ REACTION 1^{-+} exotic meson

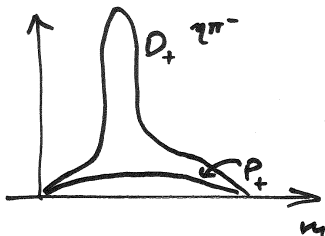
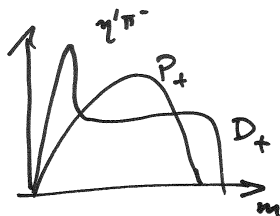
Study of the $\eta\pi^0$ spectrum and search for

- ▶ several experiments observed P -wave states that were interpreted as resonances ($\eta\pi$: $\pi_1(1400)$, $\eta'\pi$: $\pi_1(1600)$)
- ▶ yet, the interpretation is still questionable and questioned

Difficulties in Interpretation

In a production experiment such as COMPASS

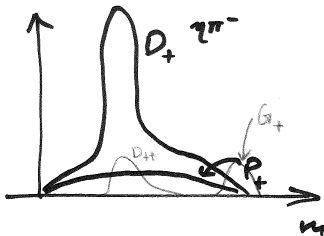
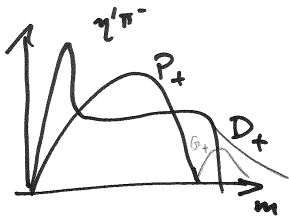
- ▶ phases can only be measured relative to other waves
- ▶ the only wave with significant overlap with the P -wave is the D -wave (2^{++} , known resonance $a_2(1320)$)
- ▶ resonant interpretation of the P -wave requires understanding of the D -wave
- ▶ structure of the D -wave is not understood



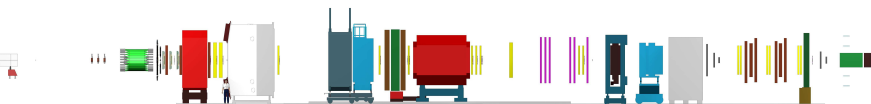
Input from COMPASS

What is novel about COMPASS data?

- ▶ higher reach in invariant masses
- ▶ higher statistics
- ▶ additional waves: D_{++} (2^{++} with $M = 2$), G_+ (spin 4, $M = 1$)
- ▶ transfer of knowledge $\eta\pi \leftrightarrow \eta'\pi$



The COMPASS Experiment



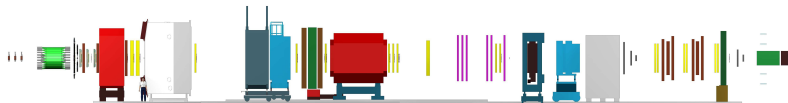
The COMPASS experiment at CERN

- ▶ high-resolution magnetic spectrometer
- ▶ particle ID with RICH detector, calorimeters, μ id
- ▶ different beams (muon, hadron, +, -)
- ▶ various targets (polarized, unpolarized)

Covers a wide range of physics

- ▶ Muon beam programme: GPDs, transversity, DVCS, ...
- ▶ Hadron beam programme: Primakoff effect, hadron spectroscopy, polarized Drell-Yann, ...

COMPASS talks



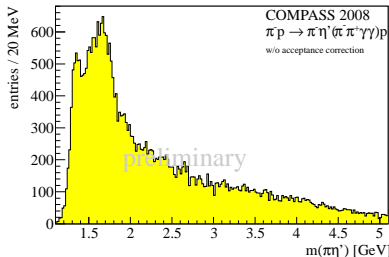
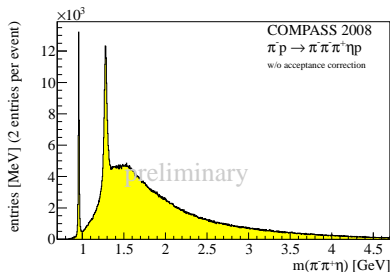
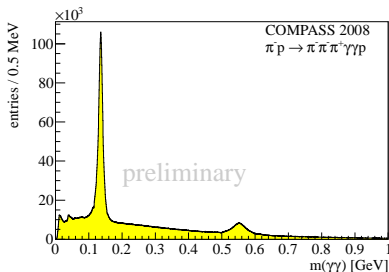
COMPASS talks at this conference:

- ▶ Right now (session A): G. Sbrizzai: Transverse spin and momentum distributions, K. Schmidt: Exclusive ρ^0 muoproduction on transversely polarized p and d
- ▶ Tuesday (session D): S. Grabmüller on χ PT tests in Primakoff scattering (π^- beam, Pb target)
- ▶ poster session: A. Austregesilo, PWA of centrally produced $\pi^- \pi^+$ data (p beam, LH2 target)
- ▶ plenary: B. Ketzer on Hybrid Mesons (overview, but will show more from COMPASS)
- ▶ this talk: PWA of data from 190 GeV π^- beam on a LH2 target

Data Selection for $\pi^- p \rightarrow \pi^- \eta^{(\prime)} p$

Selected final state: slow recoil proton, three charged tracks
($- - +$), two photons.

Illustrated for the final state $\eta' \pi^-$

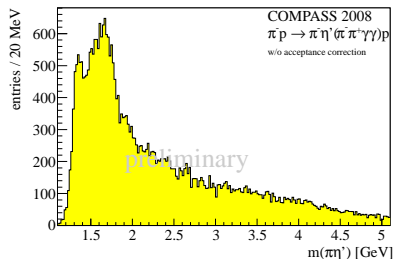


Results in (case $\eta' \pi^-$):

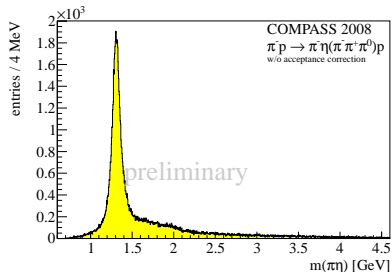
- ▶ 18 000 events with $m(\eta' \pi^-) < 2$ GeV, 35 000 in toto
- ▶ inv. masses way above 2 GeV

The Data

Invariant mass of $\eta'\pi^-$



Invariant mass of $\eta\pi^-$

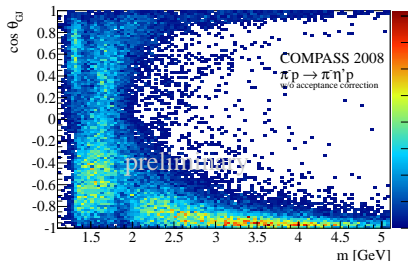


- ▶ $\eta\pi^-$ dominated by $a_2(1320)$, also visible in $\eta'\pi^-$
- ▶ a_2 close to $\eta'\pi^-$ threshold
- ▶ broad structure around 1700 MeV dominates the $\eta'\pi^-$ spectrum (PWA \rightarrow P -wave)

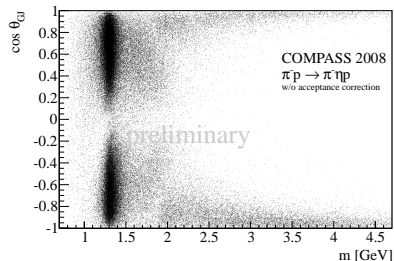
The Data

Now in 2D!

$m(\eta'\pi^-)$ vs. $\cos\theta_{\text{GJ}}(\eta')$

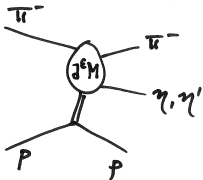


$m(\eta\pi^-)$ vs. $\cos\theta_{\text{GJ}}(\eta)$



- ▶ horizontal: inv. mass, vertical: $\cos\theta_{\eta^{(\prime)}}$ in the Gottfried-Jackson frame (vulgo: “= 1 means η along beam direction”)
- ▶ $a_2(1320)$ clearly visible, hints of $a_4(2040)$
- ▶ P -wave visible (asymmetry!)
- ▶ high masses: forward-backward peaking

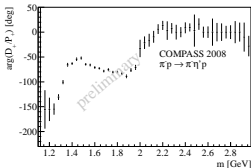
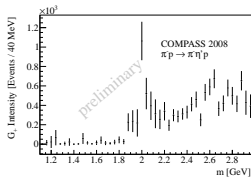
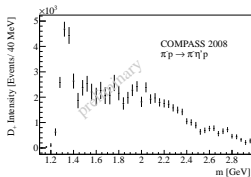
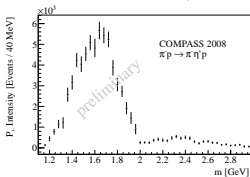
Partial Wave Analysis in Mass Bins



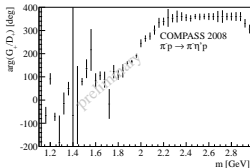
Procedure:

- ▶ bin data in mass (40 MeV)
- ▶ independent fit of bins to an acceptance corrected partial-wave model given in the reflectivity basis

Results for $\eta'\pi^-$:



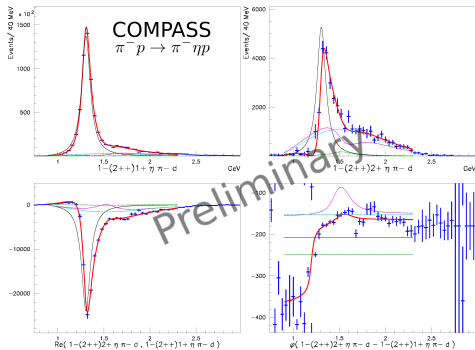
First Line:
Intensity P_+ , D_+ , G_+
Second Line:
Relative phases
 $D_+ - P_+$ $G_+ - D_+$



Modelling Physics

Mass-dependent PWA of $\eta\pi^-$

Fit of the data to a model, e.g. $\pi^- \eta$



Colors: fit in mass bins, model fit,
others: components

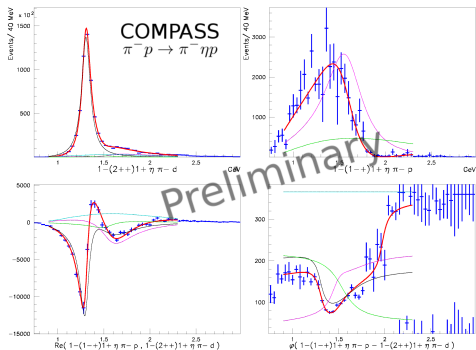
Model:

- ▶ depicted are D_+ , D_{++} waves
- ▶ two BW resonances (dynamical width BW for $a_2(1320)$)
- ▶ coherent exponential BG with phase-space factor
- ▶ for these waves same components but different admixtures

Modelling Physics

Mass-dependent PWA of $\eta\pi^-$

Other Waves Wellen: D_+ , P_+ :



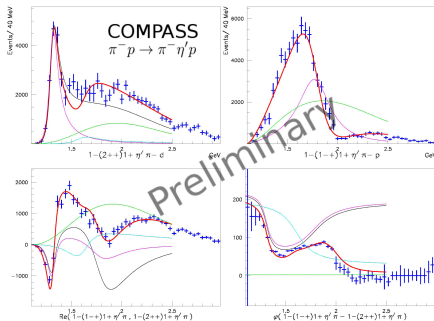
- ▶ P_+ wave: single Breit-Wigner, exponential BG as before
- ▶ description possible, BW mass higher than for $\pi_1(1400)$

Colors: fit in mass bins, model fit,
others: components

Modelling Physics

Mass-dependent PWA of $\eta' \pi^-$

For comparison D_+ , P_+ in $\eta' \pi^-$



Farben: fit in mass bins, model fit,
others: components

- ▶ D_+ -wave: as before, but second BW is fixed at $m = 1600$ MeV
- ▶ P_+ -wave: single BW, exponential BG as before
- ▶ description possible, but huge amount of non-BW BG in P_+ -wave

Improvement desirable!

Similarity of $\eta\pi^-$, $\eta'\pi^-$

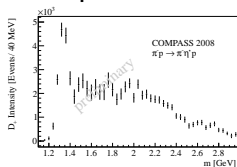
We looked for similarities between these two final states and found the following:

- ▶ scale the results of the $\pi^-\eta$ PWA according to ($q =$ break-up momentum):

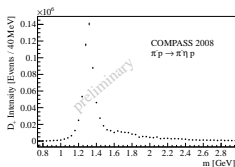
$$\text{Amplitude}(\text{Spin } J) \mapsto \left(\frac{q_{m \rightarrow \pi\eta'}}{q_{m \rightarrow \pi\eta}} \right)^{J+1/2} \times \text{Amplitude}(\text{Spin } J)$$

- ▶ and superimpose the scaled $\eta\pi^-$ plots on the $\eta'\pi^-$ plots while respecting the η , η' decay branching fractions η Zerfälle

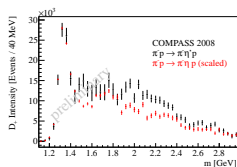
Beispiel:



D_+ -wave in $\eta'\pi^-$



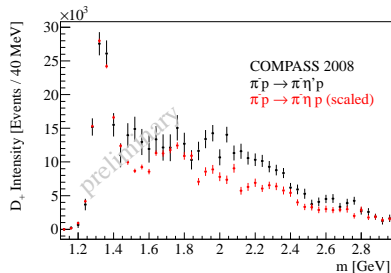
D_+ -wave in $\eta\pi^-$



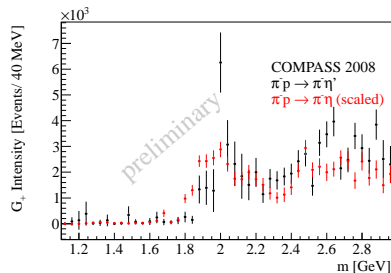
scaled comparison

Comparison of Even-Spin Waves

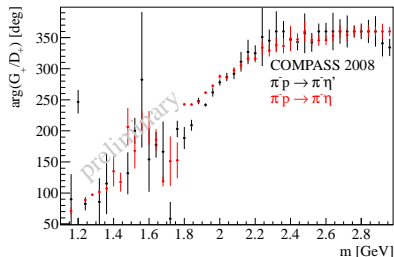
D_+ Wave



G_+ Wave

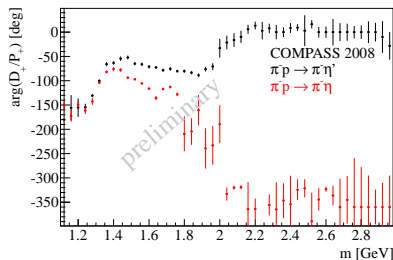
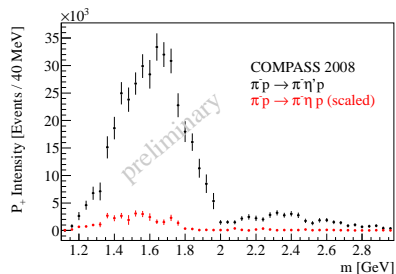
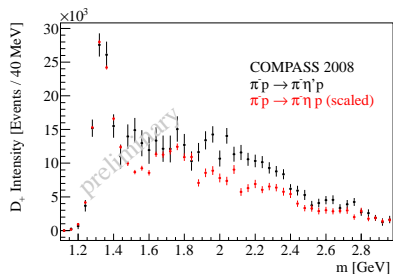


Phase $G_+ - D_+$



Very similar between $\eta\pi^-$, $\eta'\pi^-$. Expected for $n\bar{n}$ resonances (keyword: OZI), but not all of this is resonant. Maybe Deck-like a_2 exchange? (Absolute scale to be taken with a grain of salt.)

Comparison D_+ , P_+ Waves



P_+ -wave completely different.
Relative suppression predicted
for intermediate state $q\bar{q}g$
(careful: argument independent
of hybrid resonance).

Summary

To summarize:

- ▶ COMPASS shows convincing PWAs of the $\eta\pi^-$ and $\eta'\pi^-$ systems
- ▶ an interpretation in terms of resonances alone – especially of the spin-exotic P_+ -Welle – is questionable
- ▶ similarity of even waves, dissimilarity of P_+ wave

Other work, not touched upon:

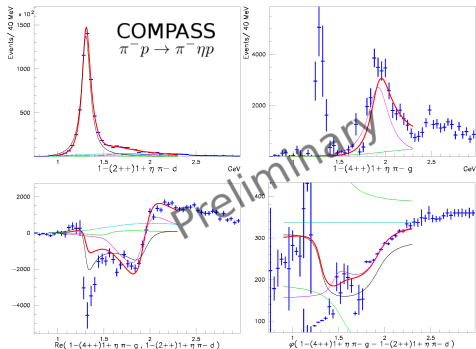
- ▶ studies of contributions from double-Pomeron exchange or Deck-like exchanges
- ▶ extraction of the branchings of the a_2 and a_4 (and thus the η - η' mixing angle)
- ▶ impact of high-spin waves which we included in more recent fits

Backup

Modelling Physics

Mass-dependent PWA of $\pi^- \eta$

Other waves: D_+ , G_+ :



- ▶ G_+ -wave: single BW, exponential BG as before wie vorhin
- ▶ G_+ -wave shows leakage from D_+ -wave, this hints towards lacking acceptance description