Kaonic final states in $\pi^- p$ at COMPASS

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Overview

- Overview of the COMPASS experiment
- Kaonic final states?
- Status of Analyses
Physics Goals – Overview

COMPASS, the “COnmon Muon and Proton Apparatus for Spectroscopy”, pursues two programmes, one with $\mu$ beam, one with hadron beam. Overarching goals:

- $\mu$ programme: learn about the spin structure of the nucleus
- hadron programme: meson spectroscopy, properties of mesons

In 2008, 2009 we used 190 GeV/$c$ hadron beams

- negative hadron beam (96% $\pi^-$, 3.5% $K^-$, 0.5% $\bar{p}$)
- positive hadron beam (70% $p$, 25% $\pi^+$, 5% $K^+$)

impinging on a LH$_2$ target. (Also short period with Pb target.)
Physics Goals – Meson Spectroscopy

Study by means of partial wave analysis (PWA) mesons produced in diffractive and central production processes mediated by Reggeon exchange.

Needs:
- inert target
- exclusive measurement of final state
- full angular coverage
The COMPASS experiment (Hadron setup)

- two-stage spectrometer with tracking and calorimetry in both stages, $O(100\,000)$ readout channels
- with large acceptance,
- designed for combined $\mu$ and hadron programmes
The COMPASS experiment (Hadron setup)

- 40 cm LH$_2$ target
- surrounded by recoil proton detector, and
- vertex detectors along the beam direction
The COMPASS experiment (Hadron setup)

- Large Angle Spectrometer
  - bending magnet,
  - tracking,
  - PID via RICH and calorimeters
The COMPASS experiment (Hadron setup)

Small Angle Spectrometer

- strong bending magnet for high-momentum tracks,
- tracking,
- calorimetry
The COMPASS experiment (Hadron setup)

Not pictured:

- Muon detection system (downstream)
- Beam particle identification (upstream)
The RICH – Particle Identification

COMPASS's RICH detector allows separating Kaons from Pions up to some 30–40 GeV via measurement of particle velocity. Used here to identify final-state charged Kaons.
The CEDARs – Beam Particle Identification

Two CEDARs (ChErenkov Differential counter with Achromatic Focus) allow beam particle identification. We use them as a Kaon veto ($\approx 3\%$ kaons in the negative beam).
Intro to Kaonic final states

Goals:

- find states with exotic quantum numbers $J^{PC}$
  → Accessible with $\pi K \bar{K}$.
- closely analyse glueball candidate states
  → Glueball favours decay into $K \bar{K}$ according to some theories
- expand knowledge of kaonic spectrum
  → only possible with kaons

Inside the collaboration the following processes are currently being investigated:

- $\pi^- p \rightarrow \pi^- K^+ K^- p$
- $\pi^- p \rightarrow \pi^- K_S^0 K_S^0 p$
- $K^- p \rightarrow K^- \pi^- \pi^+ p$ (not discussed in this presentation)
- $\pi^- p \rightarrow \pi^- K_S^0 K_L^0 p$ (not discussed)
- same with positive beam (not discussed)
Good:

- allowed quantum numbers are different for different combinations of kaons, namely the neutrals pick out subsets:

<table>
<thead>
<tr>
<th>state</th>
<th>allowed $J^{PC}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_S^0 K_S^0$</td>
<td>$0^{++}$ 2$^{++}$ 4$^{++}$</td>
</tr>
<tr>
<td>$K_S^0 K_L^0$</td>
<td>1$^{--}$ 3$^{--}$</td>
</tr>
<tr>
<td>$K^+ K^-$</td>
<td>$0^{++}$ 1$^{--}$ 2$^{++}$ 3$^{--}$ 4$^{++}$</td>
</tr>
</tbody>
</table>

- high mass threshold suppresses low mass intermediate states

Bad:

- charged channel needs particle identification which cuts into acceptance (no problem for $K_S^0$s)
Selection

$K^0_S K^0_S$ final state:
- reconstructed primary vertex
- one negative track in spectrometer
- exactly two displaced vertices which fit $K^0_S$ hypothesis
- exclusivity (momentum conservation)

$K^+ K^-$ final state:
- reconstructed primary vertex
- exactly three charged tracks (+ − −) in spectrometer
- one negative track < 30 GeV identified by RICH as kaon
- exclusivity (momentum conservation)
Mass spectra I

$K^+\pi^- \text{ mass}$

$K_S^0\pi^- \text{ mass}$

- Different shape in part due to two combinations in $K_S^0\pi^-$. 
- $K_1^*(892)$, $K_2^*(1430)$, $K_3^*(1780)$, and (with some good will) $K_4^*(2045)$ all appear to be there in the left plot
**Mass spectra II**

\( K^+ K^- \) mass

\( K_S^0 K_S^0 \) mass

- Difference near threshold due to low momentum requirement for RICH identification (and a small \( \phi \) contribution).
- Threshold not sharp in \( K_S^0 K_S^0 \), because \( K_S^0 \)'s not yet kinematically fitted.
- Known resonances appear to be at their places.
Mass spectra III – an aside

Comparison of $K^+\pi^-$ mass distribution to data taken with the muon beam

Pion data

Muon data

COMPASS produces similar states under very different circumstances.
Mass spectra IV – decay chains

Three-body invariant mass over two-body invariant mass

\[ K^+\pi^- \text{ vs } K^-K^+\pi^- \]

\[ K_S^0\pi^- \text{ vs } K_S^0K_S^0\pi^- \]

- notice bulks at 2.2 GeV, resonance which decays via the \(K^*\)s?
- more structure near 3-body threshold in neutral channel due to crosstalk from \(KK\) states which are not affected by 30 GeV (RICH) cut near threshold
Mass spectra V – decay chains ctd

Three-body invariant mass over two-body invariant mass

\( K^+K^- \) vs \( K^-K^+\pi^- \)

\( K_S^0K_S^0 \) vs \( K_S^0K_S^0\pi^- \)

- structure looks fairly different until one realises that this is due to the 30 GeV (RICH) cut
- notice bulks near 1.8 GeV, resonance which decays via the \( K\bar{K}\)? Also bulks at 2.2 GeV.
- \( f_0(980) \) (\( a_0(980) \)) stands out quite well
Rapidity, central vs. diffractive production

- large overlap in rapidity between $\pi^-$ and $K_S^0$s
- therefore separation between central and diffractive productions doesn’t come for free
- employed various separation strategies
The $\pi(1800)$

Decision to do PWA of diffractive states in neutral channel first. Selected subsample with no rapidity gap between Kaons and Pions.

Barnes et al. (PRD 55, 4157) give the following partial widths for the $\pi(1800)$ ($J^{PC} = 0^{-+}$) interpreted as a $3S$ $n\bar{n}$ state vs. an interpretation as a hybrid state:

<table>
<thead>
<tr>
<th></th>
<th>$\rho\pi$</th>
<th>$\rho\omega$</th>
<th>$\rho(1465)\pi$</th>
<th>$f_0(1300)\pi$</th>
<th>$f_2\pi$</th>
<th>$K^*K$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n\bar{n}$</td>
<td>30</td>
<td>74</td>
<td>56</td>
<td>6</td>
<td>29</td>
<td>36</td>
<td>231</td>
</tr>
<tr>
<td>hybrid</td>
<td>30</td>
<td>0</td>
<td>30</td>
<td>170</td>
<td>6</td>
<td>5</td>
<td>$\approx 240$</td>
</tr>
</tbody>
</table>

Hence: PWA of $K\bar{K}\pi$ is important in determining whether the $\pi(1800)$ is a hybrid.
Status of neutral mode diffractive PWA

- mass-independent PWA is getting off the ground
- acceptance approximately flat, decreases near 3-body threshold
- waveset mostly reproduces data, from the looks of it a high-spin wave is still missing, probably corresponds to the state at approx. 2.2 GeV
- we see a $0^{-+}$ wave around 1.8 GeV decaying via the $K\bar{K}$ S-wave and the $K\pi$ S-wave, i.e. the $\pi(1800)$ (consistent with VES results), but I won’t dare to give branching ratios at this point
Conclusions

- kaonic final states open up lots of physics that purely pionic final states don’t
- two strong structures in $K\bar{K}\pi$ at 1.8 GeV and 2.2 GeV with prominent selective decays
- PWA of $K\bar{K}\pi$ ongoing, far from release, state at 1.8 GeV appears consistent with $J^{PC} = 0^{--}$
- lots of work to be done
Backup: data quality in $K^0_S$ channel

TL: momentum exclusivity
BL: co-planarity
TR: reconstructed $K^0_S$ masses
Backup: production regimes

Apparent presence of different production regimes.
Backup: naïve central selection

Select events where $\pi^-$ has the highest momentum