Model dependence of the \( \pi_1 (1600) \rightarrow \rho(770) \pi \) signal

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Spin-exotic states
Beyond $q\bar{q}$

- Constituent quark model: Mesons are $|q\bar{q}\rangle$ state
  \[
P = (-1)^{L+1}
  \]
  \[
  C = (-1)^{L+S}
  \]
- Forbidden combinations, e.g. $J^{PC} = 1^{-+}$
- $\rightarrow$ (a superposition) of something else

\[
|q\bar{q}\rangle = |q\bar{q}\rangle + |q\bar{q}g\rangle + |gg\rangle + |q^2\bar{q}^2\rangle + \cdots
\]
Constituent quark model: Mesons are $|q\bar{q}\rangle$ state

\[ P = (-1)^{L+1} \]

\[ C = (-1)^{L+S} \]

Forbidden combinations, e.g. $J^{PC} = 1^{-+}$

$\rightarrow$ (a superposition) of something else
**COMPASS**: Large data set for the diffractive process

\[ \pi^-_{\text{beam}} + p \rightarrow \pi^- \pi^+ \pi^- + p \]

- Squared four-momentum transfer \( t' \) by Pomeron \( \mathcal{P} \)
- \( 46 \times 10^6 \) exclusive events
Diffractive $3\pi$ production

**COMPASS**: Large data set for the diffractive process

$\pi^-_{\text{beam}} + p \rightarrow \pi^- \pi^+ \pi^- + p$

Squared four-momentum transfer $t'$ by Pomeron $P$

$46 \times 10^6$ exclusive events

Rich structure in $\pi^- \pi^+ \pi^-$ mass spectrum:

Intermediate states $X^-$

[Graph showing mass spectrum with peaks at $a_1(1260)$, $a_2(1320)$, $\pi_2(1670)$]

**COMPASS** collaboration, PR D95 (2017) 032004
Diffractive $3\pi$ production

**COMPASS:** Large data set for the diffractive process

$$\pi^-_{\text{beam}} + p \rightarrow \pi^- \pi^+ \pi^-_{\text{bachelor}} + p$$

- Squared four-momentum transfer $t'$ by Pomeron $\mathbb{P}$
- $46 \times 10^6$ exclusive events
- Rich structure in $\pi^- \pi^+ \pi^-$ mass spectrum: Intermediate states $X^-$
- Also structure in $\pi^+ \pi^-$ subsystem: Intermediate states $\xi$ (isobar)

**COMPASS collaboration, PR D95 (2017) 032004**
Spin-exotic wave

Previous results

Fig 18(b) of *Phys. Rev. D* 65 (2002) 072001

Fig. 4(a) in *Nucl. Phys. A675* (2000) 155-160

Fig. 25(a) in *Phys. Rev. D* 73 (2006) 072001

Fig. 2(d) in *Phys. Rev. Lett.* 104 (2010) 241803
Spin-exotic wave

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Fig. 2(d) in Phys. Rev. Lett. 104 (2010) 241803
Spin-exotic wave
Reasons for deviations

- Set of partial-waves too small
  - Missing $2^{-+}$ waves
  - Actually $\pi_2(1670)$

- Treatment of $t'$
  - At low $t'$: non-resonant processes
  - Resonant signal is obscured

**COMPASS**: Resolve these issues:
- Binning in $t'$
- Large set of 88 partial waves
Resonance model fit to 14 partial waves simultaneously
Extensive systematic studies

\[
m_{\pi_1(1600)} = 1600^{+110}_{-60} \text{(sys.) MeV/}c^2; \quad \Gamma_{\pi_1(1600)} = 580^{+100}_{-230} \text{(sys.) MeV/}c^2
\]
COMPASS model: largest remaining model dependence:

- Fixed parameterization of isobars

However: $1^{-+} 1^{+} \rho(770) \pi P$ still modeled

- Fixed shape of $\rho(770)$ as model assumption
- Breit-Wigner amplitude, no free parameters

Use freed-isobar approach

- Replace fixed shape by step-like functions

$$\Delta_{i}^{\text{bin}} (m_{\pi^{-}\pi^{+}}) = \begin{cases} 1, & \text{if } m_{\pi^{-}\pi^{+}} \text{ in the bin.} \\ 0, & \text{otherwise.} \end{cases}$$

- Cover kinematically allowed range
- Every step: individual partial wave
- Extract $\rho(770)$ shape from the data
Freed-isobar approach

Results

Clear $\pi_1 (1600) \rightarrow \rho(770) \pi$ without assumptions on resonance content
Summary & conclusions

$\pi_1 (1600)$
- Spin-exotic quantum numbers
- Not a $q\bar{q}$-state

$1^- + 1^+ \rho (770) \pi P$ wave
- Various, seemingly contradicting results
- Large model dependence:
  - Partial-wave set
  - Treatment of $t'$ dependence
- Resolved using COMPASS 2008 data

COMPASS
- Freed-isobar approach:
  - Isobar model valid
- $\pi_1 (1600)$ not an artifact
- Convincing evidence for $\pi_1 (1600) \rightarrow \rho (770) + \pi$

Outlook
- Further $\pi_1 (1600)$ decay channels
  $$\eta (l) \pi; \ b_1 \pi; \ f_1 \pi$$