Freed-isobar Partial-Wave Analysis of the Spin-Exotic $J^{PC} = 1^{-+}$ Wave at COMPASS

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Plan of the talk

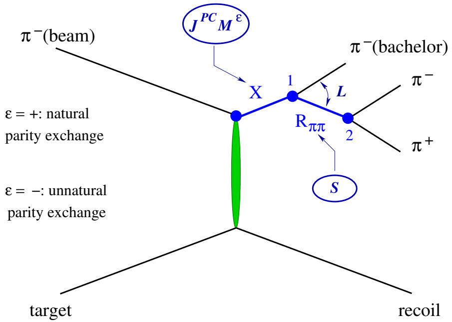
- Conventional PWA for 3π final states
- PWA with model-independent (free) parametrization of $\pi^-\pi^+$ isobars
  - Formulation of the technics
  - Continuous ambiguities in 3-body amplitudes - Zero Modes
  - Approaches for resolving the ambiguities and extracting physics information from the experimental data
- Results for free-isobarred analysis of $J^{PC} = 1^{-+}$ amplitude in COMPASS $\pi^-\pi^+\pi^-$ system

This Meeting: $\pi^-\pi^+\pi^-$ COMPASS results
HK1 Boris Grube, SYCC Bernhard Ketzer, HK30 Fabian Krinner

"Resonance production and $\pi\pi$ S-wave in $\pi^- p \to \pi^-\pi^-\pi^+ p_{recoil}$ at 190 GeV/c"
Phys. Rev. D95(2017) no.3, 032004, COMPASS collaboration

arXiv:1710.09849 [hep-ph]
"Ambiguities in model-independent partial-wave analysis"(F. Krinner et al.)

The reaction



- Reggeon exchange, naturality $\eta = P_R(-1)^J{}_R$
- Gottfried-Jackson frame: SCM of X: $Z_{GJ} \| \vec{p}^{*}_{beam}$, $Y_{GJ} = [\vec{p}^{*}_{recoil} \times \vec{p}^{*}_{beam}]$
- Reflectivity basis for system of mesons: $|JM\epsilon> = |JM> - \varepsilon P(-1)^{J-M}|J-M>$
- At high beam energies: reflectivity ε equal to naturality η
- unpolarised target: $\varepsilon = \pm 1$ states do not interfere

PWA with fixed shapes of isobars vs. freed isobares

PWA with established isobars:

Partial waves are labelled as $J^{PC}M^{\epsilon}\xi\pi L$

The mass-independent PWA events density:

$\mathcal{I}(\tau) = \sum_{\epsilon}\sum_{r}\left|\sum_{i} T^{\varepsilon}_{ir}\psi^{\varepsilon}_{i}(\tau)\right|^{2}$

The decay amplitude $\psi^{\varepsilon}_{i}(\tau)$ contains angular part and $\pi^{-}\pi^{+}$ isobar Breit-Wigner function and is bose-symmetrized by (1) $\leftrightarrow$ (3) of $\pi^{-}_{(1)}\pi^{+}_{(2)}\pi^{-}_{(3)}$ system:

$\psi^{\varepsilon}_{i}(\tau) = A(\Omega_{12},\Omega^{*}_{1})BW(m_{12}) + A(\Omega_{32},\Omega^{*}_{3})BW(m_{32})$

PWA with free isobars:

The fixed amplitude of $\pi^{-}\pi^{+}$ isobar is replaced by sum of step-like functions with complex coefficients: $BW(m)^{a} \to \sum_{\beta}\omega^{a}_{\beta}\Pi_{\beta}(m)$

The full free-isobarred amplitude for $J^{PC}M^{\epsilon}$ sector:

$\sum_{a}\sum_{\beta}\omega^{a}_{\beta}(A^{a}_{12}\Pi_{\beta}(m_{12}) + A^{a}_{32}\Pi_{\beta}(m_{32}))$

Switch off bose-symmetrization $\to$ components of freed amplitude will be orthogonal for each different indeces a and β

Bose-symmetrization breaks orthogonality in 2-fold way:

a) Step-like functions with different β - intersect on the Dalitz plot

b) Different angular functions are cross non-orthogonal

Analysis with freed isobars - Zero Modes

We have found sets of linear dependences between "free"-components inside same $J^{PC}M^{\epsilon}$, they are always real-valued functions z^a_β so that
$\omega^a_\beta \to \omega^a_\beta + C_z z^a_\beta$ will not change the whole amplitude.

The current PWA includes 12 different $J^{PC}M^{\epsilon}\xi\pi L$ free-isobarred amplitudes:

$J^{PC}M^{\epsilon}$	ξ L	ZM
$0^{-+}0^{+}$	$(\pi^+\pi^-)_S\ \pi\ S$; $(\pi^+\pi^-)_P\ \pi\ P$	+
$1^{++}0^{+}$	$(\pi^+\pi^-)_S\ \pi\ P$; $(\pi^+\pi^-)_P\ \pi\ S$	+
$1^{++}1^{+}$	$(\pi^+\pi^-)_P\ \pi\ S$	
$1^{-+}1^{+}$	$(\pi^+\pi^-)_P\ \pi\ P$	+
$2^{-+}0^{+}$	$(\pi^+\pi^-)_S\ \pi\ D$; $(\pi^+\pi^-)_P\ \pi\ P$; $(\pi^+\pi^-)_P\ \pi\ F$; $(\pi^+\pi^-)_D\ \pi\ S$	+
$2^{-+}1^{+}$	$(\pi^+\pi^-)_P\ \pi\ P$	
$2^{++}1^{+}$	$(\pi^+\pi^-)_P\ \pi\ D$	

+72 waves with fixed isobares

Strategy for resolving the ambiguity:

a) find the PWA solution for 2π amplitude $\hat{\omega}^a_\beta$
(which is ambiguous, so has huge correlations)

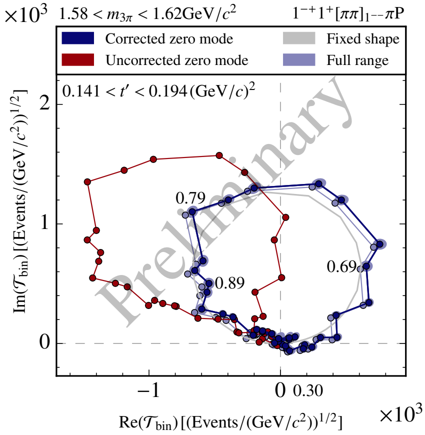
b) perform model-dependent fit to 2π amplitude:
$C_a BW^a_\beta(M_0,\Gamma_0) + \sum_z C_z z^a_\beta$ to $\hat{\omega}^a_\beta$

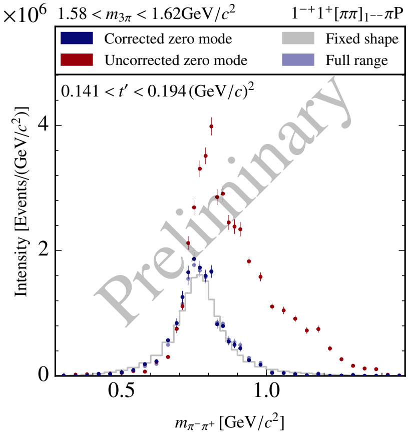
c) Substract zero mode(s) $\sum_z C_z z^a_\beta$ from $\hat{\omega}^a_\beta$

Non-relativistic (Zemach) tensor formalism used to derive the decay amplitude:

$$\psi_{1-+}(\tau)_k = [\vec{p_1} x \vec{p_2}]_k (BW(m_{12}) + z(m_{12})) + [\vec{p_3} x \vec{p_2}]_k (BW(m_{32}) + z(m_{32}))$$

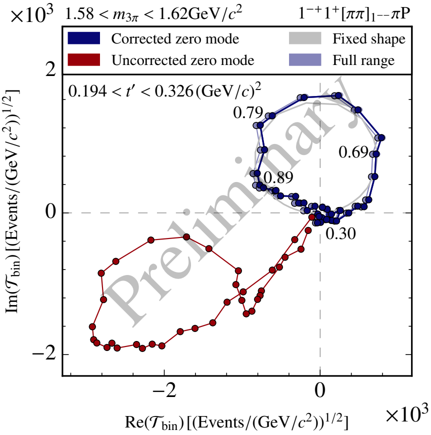
as $[\vec{p_3} x \vec{p_2}] = -[\vec{p_1} x \vec{p_2}]$
vanishing reads: $z(m_{12}) - z(m_{32}) = 0 \ \rightarrow z(m) = const.$

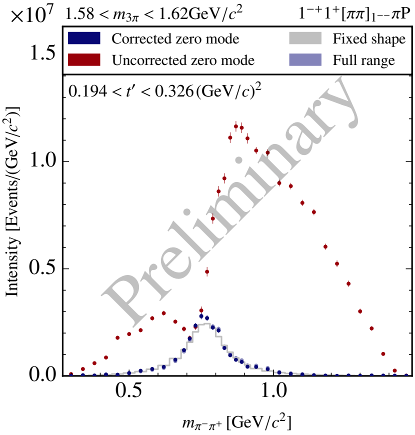




Argand diagram for $(\pi\pi)_P$-amplitude. Intensity of $(\pi\pi)_P$-amplitude.

Red -ambiguity unresolved. Blue - ambiguity resolved.





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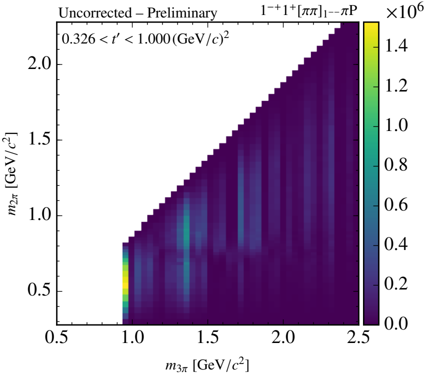
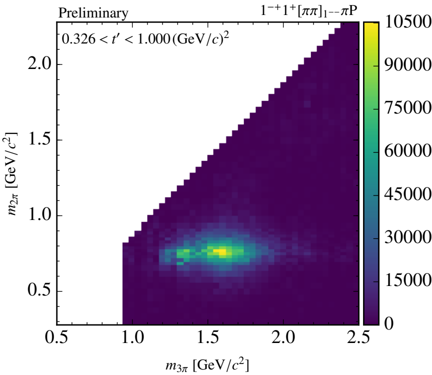
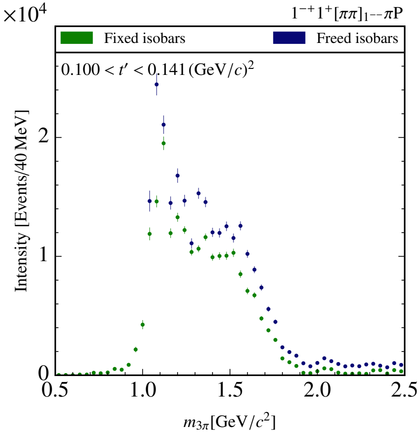
Results for COMPASS $\pi^-\pi^+\pi^-$ data



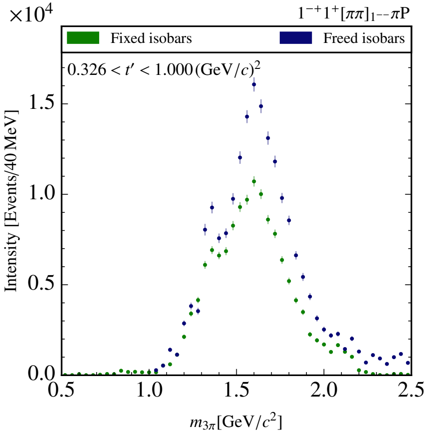
Unresolved ambiguity $\rightarrow$



Resolved ambiguity



The lowest t' interval



The highest t'-interval - peak of spin-exotic $\pi_1(1600)$ (?)

CONCLUSIONS, OUTLOOK

CONCLUSIONS:

- Analysis with freed isobars was first time performed for $J^{PC}M^{\epsilon} = 1^{-+}1^{+}(\pi\pi)_{P}\pi\ P$
- The continuous ambiguities were resolved by applying Breit-Wigner model for $(\pi\pi)_P$ freed amplitude
- The data shows clean signal of $\rho(770)$ as $(\pi\pi)_P$ isobar in 3π amplitude with $1^{-+}1^{+}$ quantum numbers for various $m(3\pi)$ and t' bins

OUTLOOK:

- Extract physical quantities: intensities and coupling phases of the model components (so called fixed-shapes) and compare with PWA results with fixed isobars
- Study other $J^{PC}M^{\epsilon}$ freed amplitudes