Studying the $\rho(770)$ Resonance with COMPASS $\pi^-\pi^+\pi^-$ Data Using the Freed-Isobar Method

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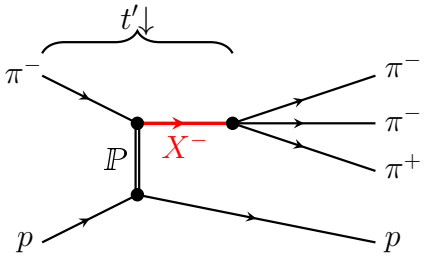
Diffractive $\pi^-\pi^+\pi^-$ Production at COMPASS

General Information

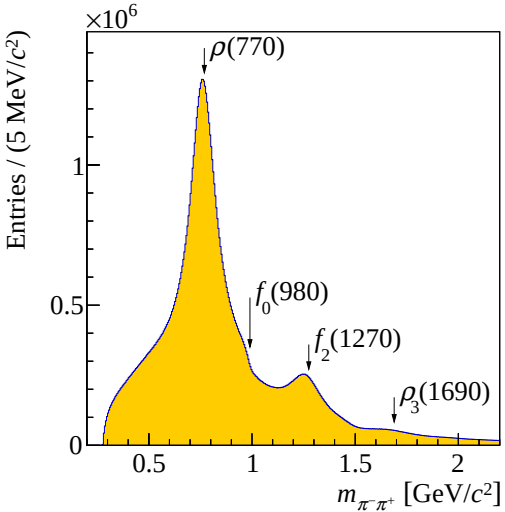
- 190 GeV/c π^- beam
- Inelastic scattering off proton target $\Rightarrow$ π^- excited to higher state X^-
- Decay via strong interaction to $\pi^-\pi^-\pi^+$ final state
- World's largest data sample: 163×10^6 exclusive events
- So far, focus on 3π resonances
  - Most detailed partial-wave analysis



Isobar Model & Partial Waves

Isobar Model

- X^- decays into ξ and π^-
- Intermediate isobar state ξ decays further in $\pi^-\pi^+$



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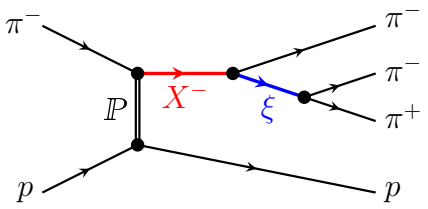

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- X^- decays into ξ and π^-
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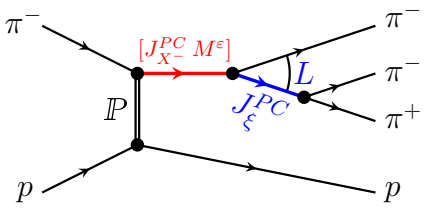
Definition of Partial Waves *i*

- Unique combination of quantum numbers for X^- : $J^{PC}_{X^-} M^{\epsilon}$ and $\pi^-\pi^+$ isobars ξ : J^{PC}_{ξ}



Isobar Model & Partial Waves

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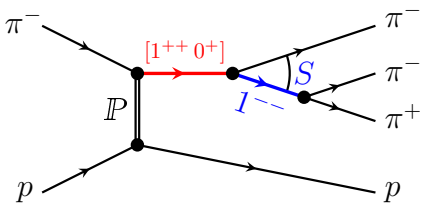
Definition of Partial Waves *i*

- Unique combination of quantum numbers for $X^- : J^{PC}_{X^-} M^{\epsilon}$ and $\pi^-\pi^+$ isobars $\xi : J^{PC}_{\xi}$
- Short Notation:
  $\Rightarrow 1^{++}0^+[\pi\pi]_{1^{--}}\pi S$

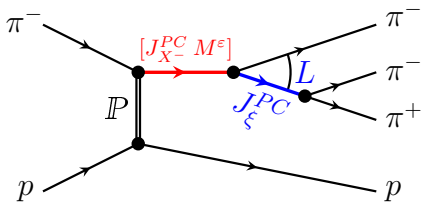


Conventional Partial-Wave Analysis (PWA)

Modelling the Intensity Distribution

- Bin data in $(m_{3\pi}, t')$ cells
- For each cell:
  Sum over partial wave amplitudes $\mathcal{A}_i$
- Model full decay dynamics of X^-
  - Angular distribution from first principles
  - Dynamic amplitude of isobar is fixed
    $\Rightarrow$ introduces model bias

$$\mathcal{I}(\tau, m_{3\pi}, t') = \left| \sum_{i \in \text{waves}} \mathcal{A}_i(\tau, m_{3\pi}, t') \right|^2$$



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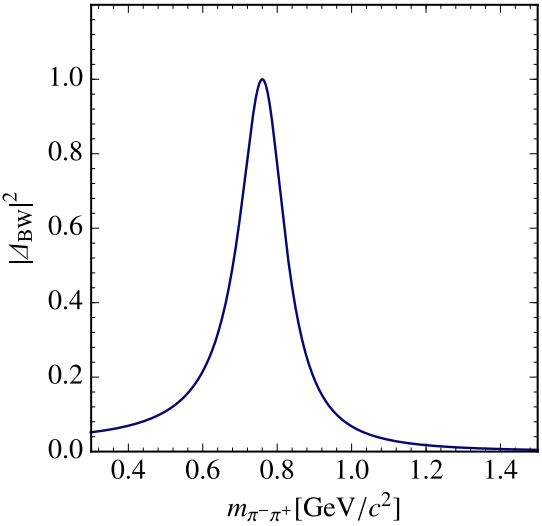
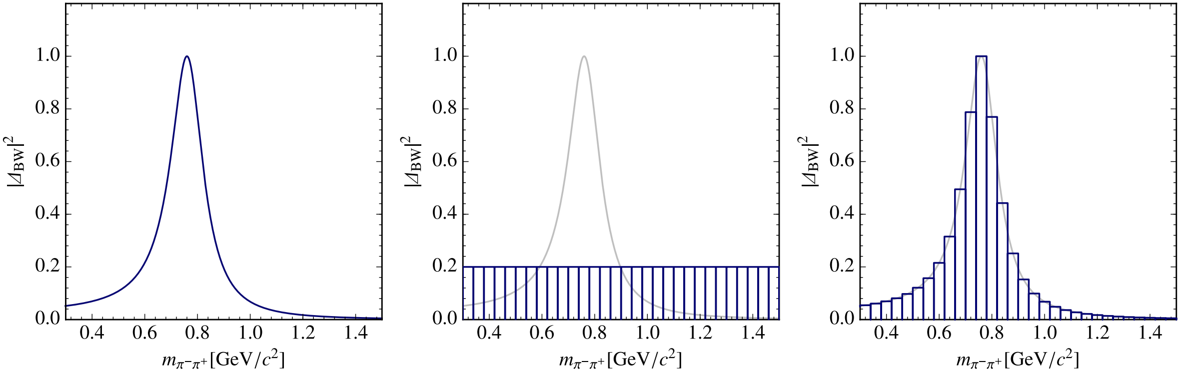


Study $\pi^-\pi^+$ Subsystems

- Our goal: Extract 2π resonance states
- But: 2π resonances states only model input in conventional PWA
  $\Rightarrow$ apply freed-isobar PWA
  - No assumptions in ”freed” dynamic isobar amplitudes
  - Fit to $\pi^-\pi^+$ amplitude possible
    $\Rightarrow$ extract 2π resonances
- This work:
  - Test assumptions of the conventional PWA model
  - First study of the $\rho(770)$ with this novel approach
    $\Rightarrow$ proof-of-principle analysis

Freed-Isobar PWA



- Replace fixed dynamic isobar amplitudes with step-like functions ("freed isobars")
- 2π binning approach, from physical amplitude (left) to freed result (right)

Study of the $\pi^-\pi^+$ subsystem with $J^{PC}_{\xi} = 1^{--}$

- Measure the same $\pi^-\pi^+$ subsystem with $J^{PC}_{\xi} = 1^{--}$ from different sources
  $\Rightarrow$ different $m_{3\pi}$ and t' in multiple 3π systems with different $J^{PC}_{X^-}$:

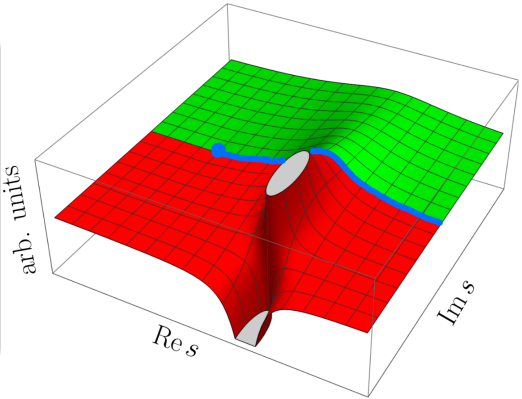
  $0^{-+}0^{+}[\pi\pi]_{1^{--}}\pi P$ $1^{++}0^{+}[\pi\pi]_{1^{--}}\pi S$ $1^{++}1^{+}[\pi\pi]_{1^{--}}\pi S$ $1^{-+}1^{+}[\pi\pi]_{1^{--}}\pi P$
  $2^{++}1^{+}[\pi\pi]_{1^{--}}\pi D$ $2^{-+}0^{+}[\pi\pi]_{1^{--}}\pi P$ $2^{-+}0^{+}[\pi\pi]_{1^{--}}\pi F$ $2^{-+}1^{+}[\pi\pi]_{1^{--}}\pi P$

  $\Rightarrow$ multiple measurements within a single analysis
- Fit $m_{2\pi}$ dependence for each source with resonance model
  $\Rightarrow$ extract $\rho(770)$ parameters
  $\Rightarrow$ study their source dependence
  $\Rightarrow$ check self-consistency with ourselves

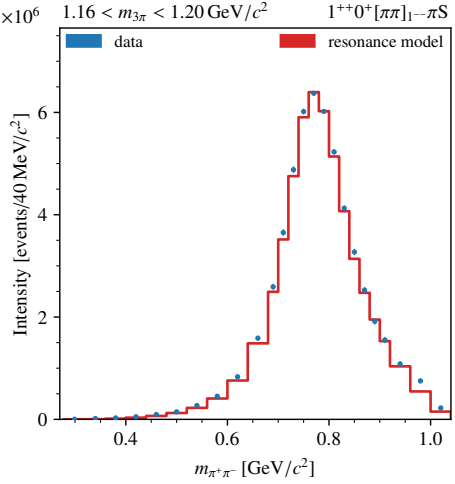
Resonance Model for the $\pi^-\pi^+$ subsystem with $J^{PC}_{\xi} = 1^{--}$

Elaborate Resonance Model

- Relativistic Breit-Wigner
  $\Rightarrow$ intrinsic limitations
- Elaborate model based on the Gounaris-Sakurai parametrization of the pion form factor
- Extracted resonance parameters less process-dependent than for Breit-Wigner



Independent Fits in $(t', m_{3\pi})$ Cells: $1^{++}0^{+}[\pi\pi]_{1^{--}}\pi S$ Wave



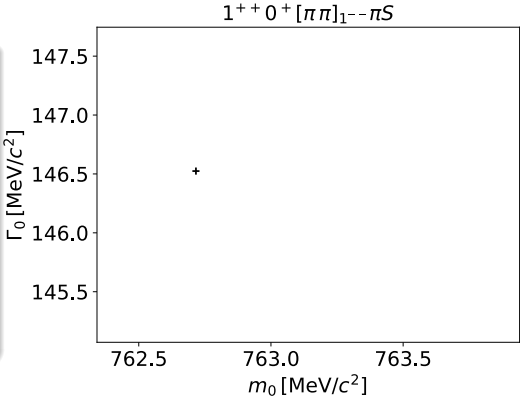
- χ^2 fit of the model to measured amplitudes for a given wave
- $\rho(770)$ parameters should be the same for each $(m_{3\pi}, t')$ cell
  $\Rightarrow$ independent fit in each cell

$\Leftarrow$ Intensity of model and data: Reasonably good agreement

Resonance Parameter Extraction

Elaborate Resonance Model

- Model parameters not directly resonance parameters
  $\Rightarrow$ additional steps needed for physical parameters



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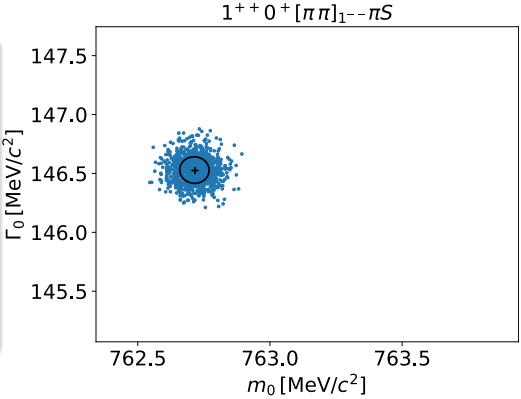
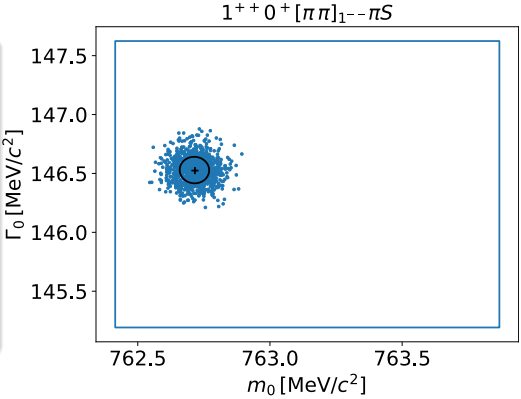
- Uncertainty propagation with Monte Carlo approach (point clouds)



Resonance Parameter Extraction

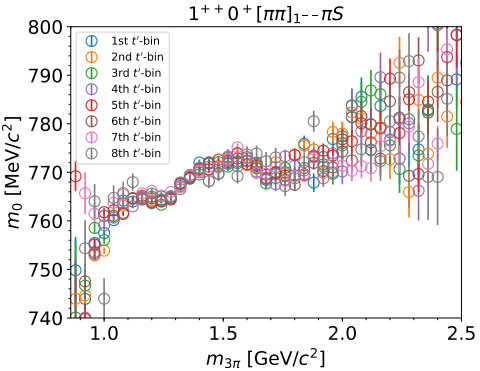
Elaborate Resonance Model

- Model parameters not directly resonance parameters
  $\Rightarrow$ additional steps needed for physical parameters
- Uncertainty propagation with Monte Carlo approach (point clouds)
- Systematic uncertainties (boxes)



Independent Fits in Individual $(t', m_{3\pi})$ Cells: $1^{++}0^{+}[\pi\pi]_{1--}\pi S$ Wave

Breit-Wigner



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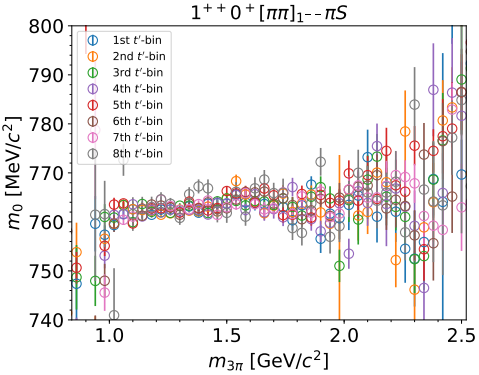
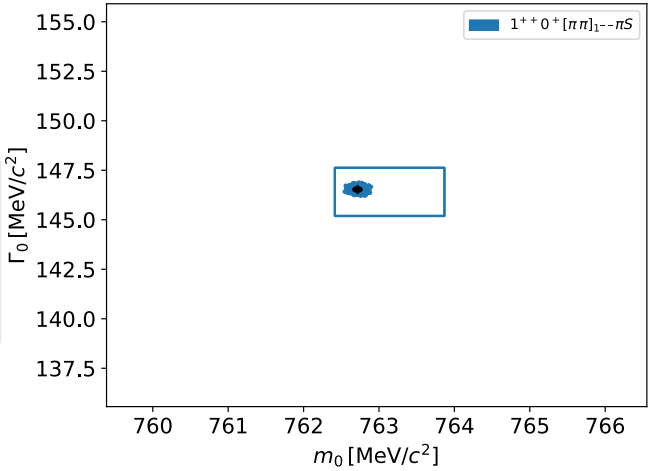


- Left; Breit-Wigner model: Systematic dependence of m_ρ on $m_{3\pi}$
- Right; Elaborate model: Smaller effect $\Rightarrow$ improvement
- Both models: No systematic t' dependence

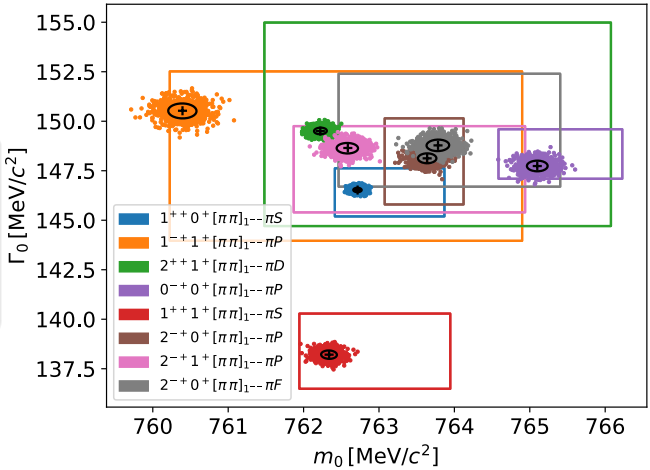
Combined Fit of All $(m_{3\pi}, t')$ Cells

- Simultaneous extraction of resonance parameters for all $(m_{3\pi}, t')$ cells



Combined Fit of All $(m_{3\pi}, t')$ Cells

- Simultaneous extraction of resonance parameters for all $(m_{3\pi}, t')$ cells
- Fit for all 8 waves
  $\Rightarrow$ most in agreement

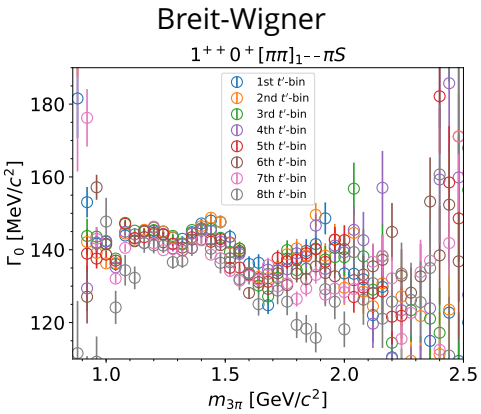


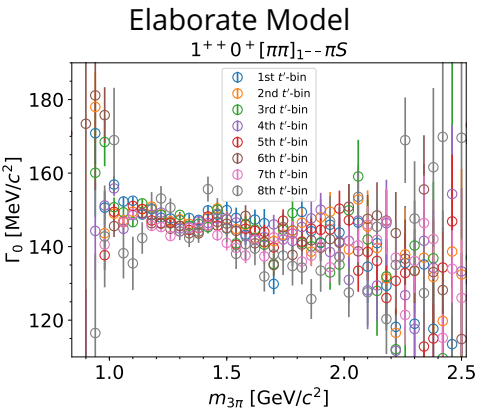
Summary

- Established framework for fitting of 2π resonance models to results of freed-isobar PWA
- Performed first analysis for ρ like isobars with $J^{PC} = 1^{--}$ from different sources in single measurement (proof-of-principle)
- $\rho(770)$ pole parameters extracted from $\pi^-\pi^+\pi^-$ final state for the first time
- Elaborate model shows less source dependence of $\rho(770)$ parameters than a Breit-Wigner model
- Most waves yield comparable $\rho(770)$ pole parameters results

Backup

Independent Fits in Individual $(t', m_{3\pi})$ Cells: $1^{++}0^{+}[\pi\pi]_{1^{--}}\pi S$ Wave





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