Amplitude analysis for diffractive resonance production

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Bad Honnef, March 13th – 17th, 2017
Outline

- Theoretical tools for amplitude analysis
- JPAC work on $\eta\pi$ at COMPASS
  - $D$-wave resonances
Joint Physics Analysis Center (JPAC)

- JPAC is a collaboration between theorists, phenomenologists, and experimentalists to provide phenomenological and data analysis tools for hadron physics
- [http://www.indiana.edu/~jpac/](http://www.indiana.edu/~jpac/)

JPAC talks
- A. Szczepaniak - Tuesday 9:45 - 10:30
- A. Hiller Blin - Tuesday 18:00-18:30
- V. Mathieu - Thursday 16:30-17:00
- A. Pilloni - Thursday 17:30 - 18:00
- M. Mikhasenko - Thursday 17:30-18:00
- J. Nyes - Friday 11:30-12:00

Upcoming Workshop
- Summer Workshop on Reaction Theory (June 2017)
- [http://www.indiana.edu/~ssrt/](http://www.indiana.edu/~ssrt/)
Hadron Spectroscopy

**Mass [GeV]**

- $\pi$
- $\sigma$
- $f_0$
- $\omega$
- $\phi$
- $a_0$
- $\eta'$

**$J^{PC}$**

- $0^+$
- $1^-$
- $1^+$
- $2^+$

### Experiment

GlueX - Hall D, JLab

### Lattice

Dudek *et al.*, PRD 87, 034505

### GlueX - Hall D, JLab

**Amplitude Analysis for Resonances**

PWA/ATHOS - 03/13/2017
**S-Matrix Principles**

\[ A(s, t) \]

\[ m \rightarrow M \]

\[ s - \text{channel} \quad \text{decay channel} \]

**Crossing**

\[ A(s + i\epsilon, t) - A(s - i\epsilon, t) \neq 0 \]

**Unitarity**

\[ A(s, t) = \int \frac{ds'}{\pi} \frac{\text{Im} A(s', t')}{s' - s} \]

- Amplitudes must satisfy these constraints, but the constraints do not fix the dynamics
- Resonance content comes from quark models, LQCD, experiment, ...
Resonances

- Resonances are associated with poles of the scattering amplitude in the complex energy plane.
- Understanding of amplitude model important when continuing to complex energies.
- Causality $\implies$ poles lie on unphysical sheets.
- Breit-Wigner:

\[
 t(s) = \frac{g^2}{m^2 - s - im\Gamma\rho(s)}
\]
COMPASS and JPAC are working together on diffractive resonance production in the $3\pi$ and $\eta^{(i)}\pi$ channels

$$\pi^- N \rightarrow \pi^- \pi^- \pi^+ N \quad \text{and} \quad \pi^- N \rightarrow \eta^{(i)} \pi^- N$$

[See M. Mikhasenko’s talk on $3\pi$, Thursday 17:30]

- The $\eta\pi$ system is one of the golden modes for hunting hybrid mesons
- Focus on $J^{PC} = 2^{++}$ first to test methodology
- High-energy behavior, $s \rightarrow \infty$ (190 GeV/c $\pi^-$ beam at COMPASS)
  $\implies$ Exchange process dominated by pomeron
Hadron Spectroscopy

\[ \pi^- p \rightarrow \eta \pi p \] at COMPASS

- COMPASS presents \( t' \)-integrated intensities
- Expect \( a_2(1320) \) (Large peak) to be narrow resonance, from quark models and LQCD expect excited \( a_2 \).
- The coupled channel analysis to extract the parameters of the exotic \( P \)-wave is ongoing

\[ \pi^- p \rightarrow \eta \pi p \] in \( D \)-wave

Formalism

- $\pi p \rightarrow \eta \pi p$ is high-energy peripheral process $\Rightarrow$ pomeron dominated exchange
- Factorize pomeron-nuclear vertex
- Expand amplitude into partial waves, separates spectrum into $J^{PC}$ sectors. Unitarity constrains partial wave amplitude

$$\Delta_s a_{\ell m\ell}(s) = 2i \rho_{\ell}(s) t_{\ell}^*(s) a_{\ell m\ell}(s)$$
Formalism

- Model for $a_{\ell m_{\ell}}$

$$a_{\ell m_{\ell}} = f_{\ell m_{\ell}}(s) t_{\ell}(s)$$

where $f_{\ell m_{\ell}}(s)$ is flexible model for production mechanism, given by

$$f_{\ell m_{\ell}}(s) = \sum_{n=0}^{\infty} \alpha_n T_n(\omega(s)), \quad \text{with } \omega(s) = s/(s + \Lambda)$$

- Parameterize $t_{\ell}(s)$ by $N/D$, $\implies t_{\ell}(s) = N(s)/D(s)$, where

$$D(s) = D^0(s) - \frac{s}{\pi} \int_{s_{th}}^\infty ds' \frac{\rho(s')N(s')}{s'(s' - s)}$$

and the model for left-hand cuts is a pole approximation

$$\rho(s)N(s) = g \chi^{\ell + 1/2}(s, m_\eta^2, m_\pi^2)/(s + \Lambda_R)^{2\ell + 3}, \quad \ell = 2$$
Avoiding First Sheet Poles

- Causality ensures resonance poles lie on unphysical sheets
  \[\Rightarrow\] Must parameterize amplitude to satisfy requirements
- For \( s = x - iy \), where \( x > s_{th} \) and \( y > 0 \), find \( \text{Im} \, D^0(s) > 0 \).
  And acceptable parameterization is
  \[ D^0(s) = a - bs - \sum_r \frac{c_r}{s_r - s}, \quad \text{provided} \ b, c_r > 0. \]
  This guarantees, along with \( l(s) \), NO poles on the first sheet
  \[\Rightarrow\] these are CDD poles
- Coupled channel systems involve more complicated constraints
Results of Fit

\[ D\text{-wave } \pi^- p \rightarrow \eta \pi p \]

- Model fit to COMPASS \( D\)-wave intensity
- Tested stability of fit by changing number of parameters, etc.

AJ et al., in preparation
Results of Fit

- Find two $a_2$ poles, and one additional pole on second sheet
- Test pole origin by seeing how poles move in complex plane as the phase space coupling vanishes
Pole Movement

AJ et al., in preparation
Two poles were found in the $2^{++}$ sector

- $M(1320) = 1.308(2)$ GeV, $\Gamma(1320) = 0.113(1)$ GeV
- $M(1700) = 1.71(6)$ GeV, $\Gamma(1700) = 0.30(6)$ GeV
Coupled Channel Analysis

$\eta\pi$ in $D$-wave

$\rho\pi$ in $D$-wave

- The $a_2$ resonance decays predominantly to $\rho\pi$
- Find the addition of the $\rho\pi$ channel does not change the pole position of $a_2$, but some shifting in the $a_2'$
  - $M(1320) = 1.31$ GeV, $\Gamma(1320) = 0.11$ GeV
  - $M(1700) = 1.72$ GeV, $\Gamma(1700) = 0.27$ GeV
Summary

- Have constructed analytic amplitude for the fitting of partial wave intensities and the extraction of resonance pole positions for the $D$-wave $\eta\pi$ system at COMPASS.
- Have performed systematic studies on model to understand stability and nature of poles found.
- Full coupled channel studies are on-going, including the exotic $\eta\pi$ $P$-wave.