New determination of the lightest hybrid meson

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Topical Group on Hadronic Physics
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This work: Motivation

- In this talk: Recent analysis on spectroscopy
- Ordinary hadrons $\rightarrow$ first part of the talk
- Not so ordinary
- Hybrid
This work: Motivation

- Only one hybrid expected.
- $J^{PC} = 1^{-+} \rightarrow$ lightest hybrid candidate.
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Data: COMPASS experiment

- \( E_{\text{Beam}} = 190\text{GeV} \Rightarrow \) Peripheral production
- Dominated by \( J^{PC} = 2^{++} \Rightarrow \) Ordinary meson.

- Asymmetry \( \rightarrow \) odd (exotic) waves.
- Dominated by \( J^{PC} = 1^{-+} \Rightarrow \) non \( q\bar{q} \) quantum numbers.
Status

- Clear $a_2(1320)$ decaying into $\eta \pi$ and $\eta' \pi$?

- Is there a clear $a'_2(1700)$? What are its parameters?
## PDG status

<table>
<thead>
<tr>
<th>$\pi_1(1400)$</th>
<th>$I^G(J^{PC}) = 1^-(1^{-+})$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode</strong></td>
<td><strong>Fraction ($\Gamma_i / \Gamma$)</strong></td>
</tr>
<tr>
<td>$\gamma_1$</td>
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<tr>
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<td>$\eta \pi^-$</td>
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<td>$\gamma_2$</td>
<td>$\rho^0 \pi^-$</td>
</tr>
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<td>$\gamma_3$</td>
<td>$f_2(1270) \pi^-$</td>
</tr>
<tr>
<td>$\gamma_4$</td>
<td>$b_1(1225) \pi$</td>
</tr>
<tr>
<td>$\gamma_5$</td>
<td>$\eta'(958) \pi^-$</td>
</tr>
<tr>
<td>$\gamma_6$</td>
<td>$f_0(1285) \pi$</td>
</tr>
</tbody>
</table>

- PDG reports 2 different resonances
- $\pi_1(1400)$ decaying into $\eta \pi$? $\pi_1(1600)$ decaying into $\eta' \pi$?
Partial waves

- Coupling to $\eta\pi$ much smaller than $\eta'\pi \Rightarrow$ Hybrid nature?
- Data looks suspicious above 2 GeV.
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Lightest Hybrid Meson
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Method


- Peripheral production ⇒ factorization of the pomeron ⇒
  \[ \text{Ima}(s) = \rho(s)t^*(s)a(s). \]

- Amplitude built around
  \[ t(s) = \frac{N(s)}{D(s)} \]
  method ⇒
  \[ a(s) = p^2 q \frac{n(s)}{D(s)}. \]

- Smooth polynomials
  \[ n(s) = \sum_j a_j w^j(s) \]
Method

- $N(s)$ and $n(s)$ are process dependent, they have only left hand cuts.
- $D(s)$ has a right hand cut, altogether $t(s)$ has the correct analytic structure.

- By adding this discontinuity over the RHC one could go to the direct continuous Riemann sheet.
Single channel

- A. Jackura et al. (JPAC & COMPASS), PLB779, 464-472

\[ \text{Im} t(s) = \rho(s)|t(s)|^2 \Rightarrow \text{Im} D(s) = -\rho(s)N(s), \text{so that} \]

\[
D(s) = D_0(s) - \frac{s}{\pi} \int_{s_{th}}^{\infty} ds' \frac{\rho(s')N(s')}{s'(s' - s)},
\]

where \( D_0(s) = c_0 - c_1 s - \frac{c_2}{c_3 - s} \rightarrow \text{CDD poles} \).

- And \( \rho(s)N(s) = g \frac{\lambda^{(2l+1)/2}(s,m_\eta^2,m_\pi^2)}{(s+s_R)^{2l+3}} \).

Lightest Hybrid Meson

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Single channel

- 12 parameters, $\chi^2 \approx 2$.
- Good description of both peaks, the residuals of the fits follow a Gaussian distribution.
Single channel

- Various systematics
  1. Effective mass of the pomeron.
  2. Different values for N(s) scale parameters.
  3. Including $\rho\pi$ channel.

- $m(a_2) = 1307 \pm 1 \pm 6$ MeV \hspace{0.5cm} $\Gamma(a_2) = 112 \pm 1 \pm 8$ MeV
- $m(a_2') = 1720 \pm 10 \pm 60$ MeV \hspace{0.5cm} $\Gamma(a_2') = 280 \pm 10 \pm 70$ MeV
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Coupled channel

- $\eta^{(1)}\pi$ coupled channel up to 2 GeV.
- $\rho\pi$ cannot be included without including big systematic contribution (Deck).
- We use a K-matrix approach with a Chew-Mandelstam phase space.

$$D^J(s)_{ki} = (K^J(s)^{-1})_{ki} - \frac{s}{\pi} \int_{s_k}^{\infty} ds' \frac{\rho(s')N^J_{ki}(s')}{s'(s' - s - i\epsilon)},$$

$$\rho N^J_{ki}(s') = \delta_{ki} \frac{\lambda^{J+1/2}\left(s', m^2_{\eta^{(1)}}, m^2_{\pi}\right)}{(s' + s_L)^{2J+1+\alpha}},$$

$$K^J_{ki}(s) = \sum_R \frac{g^J,R_k g^J,R_i}{m^2_{R} - s} + c^J_{ki} + d^J_{ki} s.$$ 

- Just 1 K-matrix pole for the P-wave.
Coupled channel analysis

- Average of 6 parameters for each figure.
- $\chi^2 \approx 1.3$, no significant deviation for any partial wave.
- 1 K-matrix pole produces 2 different P-wave peaks.
Coupled channel analysis

- No correlation between $n^J(s)_k$ and $D^J(s)_{ki}$.

- Numerator is smooth and process dependant.
Poles

- Statistical uncertainties calculated through bootstrapping
- \( m(a_2) = 1306.0 \pm 0.8 \pm 1.3 \) MeV \( \Gamma(a_2) = 114.4 \pm 1.6 \pm 0.0 \) MeV
- \( m(a'_2) = 1722 \pm 15 \pm 67 \) MeV \( \Gamma(a'_2) = 247 \pm 17 \pm 63 \) MeV
- All systematics (different LHC masses, numerator models …) included.
Poles

- Only one, isolated pole for the P-wave.
- \( m(\pi_1) = 1564 \pm 24 \pm 86 \text{ MeV} \quad \Gamma(\pi_1) = 492 \pm 54 \pm 102 \text{ MeV} \).
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Future project: Hunting hybrids at JLab

- New GlueX/CLAS data?
- $2 \rightarrow 3$ finite energy sum rules (FESR2)
- $\pi p \rightarrow \eta(\prime) \pi p$ at JLAB kinematics.
Future project: Hunting glueballss with BESIII

- BESIII data on glueball “rich” experiments.

- Slightly different kinematics
Future project: Hunting glueballss with BESIII

- BESIII data on gluebal “rich” experiments.

- Slightly different kinematics

Lightest Hybrid Meson

\[ J/\psi \rightarrow \gamma \pi \pi (S\ wave) \]

\[ J/\psi \rightarrow \gamma K \bar{K} (S\ wave) \]

\[ \gamma \rightarrow J/\psi \pi \]

\[ \gamma \rightarrow J/\psi K \bar{K} \]
Summary

- Phenomenological analysis of COMPASS data → Analyticity and Unitarity.
- Past: JPAC and COMPASS collaboration to extract the ordinary $a_2(1320)$ and $a'_2(1700)$ resonances.
- This work: New method to analyze also the non-ordinary $\pi_1$. Just one resonance opposed to the PDG.
- Future: Gluex
- Future: BESIII $J/\psi$ radiative decays
Thank you for your attention!