JPAC recent results: Determination of the lightest hybrid meson

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Excited QCD 2019, Schladming, Austria

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

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JPAC: theory, phenomenology and analysis tools in support of experimental data from JLab12 and other accelerator laboratories.

Contribute to education of new generation of practitioners in strong interactions.
Joint Physics Analysis Center

- **Single meson production**
  

- **Global analysis**
  

- **Regge Phenomenology**
  
  J. A. Silva-Castro et al. (JPAC), arXiv:1809.01954

- **Pion Photoproduction**
  
  V. Mathieu et al. (JPAC), Phys.Rev. D98 (2018) no.1, 014041

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A.Rodas

Determination of the lightest hybrid meson

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- $\tau \rightarrow 3\pi \nu$
  - M. Mikhasenko et al. [JPAC], Phys.Rev. D98 (2018) no.9, 096021

- $Z_c(3900)$

- $P_c(4450)$

- Right helicity formalism

- $3 \rightarrow 3$ interactions
This work: Motivation

- In this talk: Recent analysis on spectroscopy
- Ordinary hadrons → first part of the talk

Not so ordinary

Hybrid
This work: Motivation

- Only one hybrid expected.
- $J^{PC} = 1^{-+}$ → lightest hybrid candidate.

```
"gluonic field"
$(J^{PC})_g = 1^+$
mass \approx 1.0-1.5$ GeV
```

```
\textbf{Lightest Hybrids}
\begin{align*}
S_{qq} &= 1 & S_{qq} &= 0 \\
J^{PC} &= 0^+, 1^+, 2^+ & 1^{--}
\end{align*}
```

```
0^{--} 2^{--} \\
1^{--} 0^{--} 1^{--} 2^{--}
```

```
J. Dudek
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m = 396$ MeV
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\text{M. R. Shepherd}\
\text{Hadron 2017, Salamanca}\
\text{September 28, 2017}
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Data: COMPASS experiment

- $E_{Beam} = 190\text{GeV} \Rightarrow$ 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.
Clear $a_2(1320)$ decaying into $\eta\pi$ and $\eta'\pi$?

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

PDG reports 2 different resonances

- \( \pi_1(1400) \) decaying into \( \eta \pi \)? Different \( \pi_1(1600) \) decaying into \( \eta' \pi \)?
Partial waves

- Coupling to $\eta\pi$ much smaller than $\eta'\pi \Rightarrow$ Hybrid nature?
- Ordinary mesons have similar couplings.
- Data looks suspicious above 2 GeV.
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Method

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

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

- They are smooth polynomials
  \( n(s) = \sum_j a_jw^j(s) \), where
  \( w(s) = \frac{s}{s+s_0} \).
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, M. Mikhasenko, A.Pilloni et al. (JPAC & COMPASS), PLB779, 464-472

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

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

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

- And \( \rho(s) N(s) = g \frac{\lambda^{(2l+1)/2}(s, m_{\eta}^2, m_{\pi}^2)}{(s+s_R)^{2l+3}}. \)
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{1cm} $\Gamma(a_2) = 112 \pm 1 \pm 8$ MeV
- $m(a'_2) = 1720 \pm 10 \pm 60$ MeV \hspace{1cm} $\Gamma(a'_2) = 280 \pm 10 \pm 70$ MeV
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Coupled channel

- \( \eta^{(')} \pi \) 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.

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

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

\[
K^J_{ki}(s) = \sum_R g^J,R_k g^J,R_i \frac{1}{m^2_R - s} + c^J_{ki} + d^J_{ki} s.
\]

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

- We use an 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 peaks for the P-wave \( \rightarrow 300 \text{MeV} \) distance.
Coupled channel analysis

- There is no correlation between the numerator $n^J(s)_k$ and denominator $D^J(s)_{ki}$.

- As explained before, numerator is smooth and process dependant.
- Statistical uncertainties calculated through bootstrapping
- \( m(a_2) = 1306.0 \pm 0.8 \pm 1.3 \text{ MeV} \quad \Gamma(a_2) = 114.4 \pm 1.6 \pm 0.0 \text{ MeV} \)
- \( m(a'_2) = 1722 \pm 15 \pm 67 \text{ MeV} \quad \Gamma(a'_2) = 247 \pm 17 \pm 63 \text{ MeV} \)
- Clearly compatible with the single channel case.
- All systematics (different LHC masses, numerator models ...) included.
Poles

- Only one 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 (FESR)
- $\pi p \rightarrow \eta^{(')} \pi p$ at JLAB kinematics.
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 contrary to the PDG status.

Future: Understanding Gluex exchanges.

Future: Analytic dispersive constraints for $2 \rightarrow 3$. 
Thank you for your attention!