Prediction for several narrow $N^*$ and $\Lambda^*$ resonances with hidden charm around 4 GeV

Jiajun Wu
R. Molina  E. Oset  B. S. Zou
Outline

- Introduction
- Theory for the new bound states
- Width and Coupling constant of these states
- The prediction for PANDA
- Summary
Introduction

- The Chiral Unitary Approach has been a very fruitful scheme to study the nature of many hadron resonances. The poles showed by the analysis of meson baryon scattering amplitudes are identified with existing baryon resonances.

- In the many resonances, such as N*(1535), Λ*(1405), it suggests that there are large strange quark components.

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The Chiral Unitary Approach has been a very fruitful scheme to study the nature of many hadron resonances. The poles showed by the analysis of meson baryon scattering amplitudes are identified with existing baryon resonances.

In the many resonances, such as $N^*(1535)$, $\Lambda^*(1405)$, it suggests that there are large strange quark components.

Put the **Charm** quarks in the resonances.

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Theory for the Potential V

\[ L_{VVV} = ig \langle V^\mu [V^v, \partial_\mu V_v] \rangle \]
\[ L_{PPV} = -ig \langle V^\mu [P, \partial_v P] \rangle \]
\[ L_{BBV} = g \langle \bar{B} \gamma_\mu [V^\mu, B] \rangle + g \langle \bar{B} \gamma_\mu B \rangle \langle V^\mu \rangle \]


\[ \begin{aligned}
V_1 & : \pi, K, \eta, \eta' \\
V_2 & : \rho, K^*, \omega, \phi \\
B_1 & : n, p, \Sigma, \Xi \\
B_2 & : n, p, \Sigma, \Xi \\
V^* & : \rho, K^*, \omega, \phi
\end{aligned} \]

SU(3)

\[ \begin{aligned}
\bar{D}, & D^-, D^-_s \\
\bar{D}^*, & D^{*-}, D^{*-}_s
\end{aligned} \]

SU(4)

\[ \begin{aligned}
\Lambda_c, & \Sigma_c, \Xi_c, \Xi_c', \Omega_c \\
\rho, & K^*, \omega, \phi
\end{aligned} \]

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Theory for the Potential $V$

From the Lagrangians, we can get the potential:

\[
V_{ab}(P_1B_1 \rightarrow P_2B_2) = \frac{C_{ab}}{4f^2}(E_{P_1} + E_{P_1})
\]

\[
V_{ab}(V_1B_1 \rightarrow V_2B_2) = \frac{C_{ab}}{4f^2}(E_{V_1} + E_{V_2})
\]

Here $f=93\text{MeV}$ is the pion decay constant.

$C_{ab}$ are calculated by the SU(4) Clebsch Gordan Coefficients.

E. M. Haacke, J. W. Moffat and P. Savaria

Theory for the G function

\[ G_{(mB)} = i2M_B \int \frac{1}{(P-p_m)^2 - M_B^2 + i\epsilon} \frac{1}{P_m^2 - M_m^2 + i\epsilon (2\pi)^4} d^4p_m \]

\[ G_{1_{(m,B)}} = \int_0^\Lambda \frac{p^2 dp}{4\pi^2} \frac{2M_B(w_m + w_B)}{w_m w_B(P^2 - (w_m + w_B)^2 + i\epsilon)} \]

\[ G_{2_{(m,B)}} = \frac{2M_B}{16\pi^2} \left\{ a_\mu + \ln \frac{M_B^2}{\mu^2} + \frac{M_m^2 - M_B^2}{2s} \ln \frac{M_m^2}{M_B^2} + \frac{q}{\sqrt{s}} \left[ \ln[s - (M_m^2 - M_B^2) + 2q\sqrt{s}] + \ln[s + (M_m^2 - M_B^2) + 2q\sqrt{s}] \right] - \ln[-s - (M_m^2 - M_B^2) + 2q\sqrt{s}] - \ln[-s + (M_m^2 - M_B^2) + 2q\sqrt{s}] \right\} \]

Free Parameter, Around the mass of \( \rho(770) \).

\( \mu=1\text{GeV} \) and let \( a_\mu \) is Free Parameter

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Theory for the G function

\[ G_{(m_B)} = i 2 M_B \int \frac{1}{(P-p_m)^2 - M_B^2 + i\varepsilon} \frac{1}{p_m^2 - M_m^2 + i\varepsilon} \frac{d^4 p_m}{(2\pi)^4} \]

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Theory for the $T$ matrix

- We get the potential $V$ and the $G$ function.
- The unitary $T$ amplitudes can be obtained by solving the coupled channels Bethe-Salpeter equation:

$$T = [1 - VG]^{-1} V$$

From the $T$, we can find some poles by using different $G$ functions and parameters.
**The Pole position**

<table>
<thead>
<tr>
<th>I, S</th>
<th>Pole Position</th>
<th>Pole Position</th>
<th>Pole Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2, 0</td>
<td>4291(4273)</td>
<td>4269(4236)</td>
<td>4240(4187)</td>
</tr>
<tr>
<td>0, -1</td>
<td>4247(4120)</td>
<td>4213(4023)</td>
<td>4170(3903)</td>
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<tr>
<td></td>
<td>4422(4394)</td>
<td>4403(4357)</td>
<td>4376(4308)</td>
</tr>
</tbody>
</table>

\[ \bar{D} \Sigma_c \]
\[ \bar{D}_s \Lambda_c^+ \bar{D} \Xi_c \]
\[ \bar{D} \Xi_c' \]

**TABLE I:** Pole position from \( PB \rightarrow PB \) with the two \( G \) functions. The unit is MeV

<table>
<thead>
<tr>
<th>I, S</th>
<th>Pole Position</th>
<th>Pole Position</th>
<th>Pole Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2, 0</td>
<td>4438(4410)</td>
<td>4418(4372)</td>
<td>4391(4320)</td>
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<tr>
<td>0, -1</td>
<td>4399(4256)</td>
<td>4370(4155)</td>
<td>4330(4030)</td>
</tr>
<tr>
<td></td>
<td>4568(4532)</td>
<td>4550(4493)</td>
<td>4526(4441)</td>
</tr>
</tbody>
</table>

\[ \bar{D}^* \Sigma_c \]
\[ \bar{D}_s^* \Lambda_c^+ \bar{D}^* \Xi_c \]
\[ \bar{D}^* \Xi_c' \]

**TABLE II:** Pole position from \( VB \rightarrow VB \) with the two \( G \) functions. The unit is MeV

There are 6 bound states.

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The coupling constants

\[ T_{ab} = \lim_{\sqrt{s} \to z_R} \frac{g_ag_b}{\sqrt{S - z_R}} \]

\[ |g_a|^2 = \lim_{\sqrt{s} \to z_R} T_{aa}(\sqrt{S - z_R}) \]

\[ g_b = \lim_{\sqrt{s} \to z_R} \frac{g_a T_{ab}}{T_{aa}} \]
The width of New bound states

These bound states can decay by two types:

1. Decay to the light meson and baryon channels without charm quark.

   Such as $\pi N$, $\eta N$, $\eta' N$, $KN$

2. Decay to the $cc$ meson and baryon channels with charm quark.

   Such as $J/\psi N$, $\eta_c N$, $\eta_c N$,
### Light Meson and Baryon channel

The widths are all very narrow.

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<table>
<thead>
<tr>
<th>I, S</th>
<th>Pole</th>
<th>real axis</th>
<th>Width</th>
<th>Decay Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position</td>
<td>Mass</td>
<td>Width</td>
<td>ΠN</td>
</tr>
<tr>
<td>1/2, 0</td>
<td>4269</td>
<td>4267</td>
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<td>3.8</td>
</tr>
<tr>
<td>0, -1</td>
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<td>4213</td>
<td>26.4</td>
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<tr>
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<td>4416</td>
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<td>3.2</td>
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<tr>
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<td>4371</td>
<td>23.3</td>
<td>13.9</td>
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<tr>
<td></td>
<td>4550</td>
<td>4549</td>
<td>23.7</td>
<td>0</td>
</tr>
</tbody>
</table>
**cc Meson and Baryon channel**

1. The potentials of VB ↔ PB are very small. When they exchange pseudo-scalar meson, the BBP vertex is very small; when they exchange vector meson, the VVP vertex is very small.

2. The bound states from the PB channels only can decay to the $\eta_c B$, and the bound states from the VB channels only can decay to the $J/\psi B$.

<table>
<thead>
<tr>
<th>I, S</th>
<th>Mass</th>
<th>Width</th>
<th>Decay Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/2, 0$</td>
<td>4261</td>
<td>56.9</td>
<td>$\eta_c N$</td>
</tr>
<tr>
<td>0, -1</td>
<td>4209</td>
<td>32.4</td>
<td>$\eta_c \Lambda$</td>
</tr>
<tr>
<td></td>
<td>4394</td>
<td>43.3</td>
<td>5.8</td>
</tr>
<tr>
<td>$1/2, 0$</td>
<td>4412</td>
<td>47.3</td>
<td>$J/\psi N$</td>
</tr>
<tr>
<td>0, -1</td>
<td>4368</td>
<td>28.0</td>
<td>$J/\psi \Lambda$</td>
</tr>
<tr>
<td></td>
<td>4544</td>
<td>36.6</td>
<td>13.8</td>
</tr>
</tbody>
</table>
The prediction for PANDA

The $\bar{p}$ beam of 15 GeV one has the invariant mass of C.M. about 5470 MeV, which allows one to observe resonances in $\bar{p}X$ production up to a mass $M=4538$ MeV.

From PB

$$\frac{d\sigma}{d\cos\theta dM^2_{N^*}} \bigg|_{\theta=0} = 0.7 - 1.9 \mu b / GeV^2$$

From VB

$$\frac{d\sigma}{d\cos\theta dM^2_{N^*}} \bigg|_{\theta=0} = 0.015 - 0.12 \mu b / GeV^2$$
The prediction for PANDA

\[ \sigma (\mu b) \]

\[ F = \frac{\Lambda_{\pi}^2 - M_{\pi}^2}{\Lambda_{\pi}^2 - p_{\pi}^2} \]

\[ F = \frac{\Lambda_{N^*}^4}{\Lambda_{N^*}^4 + (p_{N^*}^2 - M_{N^*}^2)} \]

pp \to \eta_c \quad pp \quad 0.13 - 1.3 \mu b

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The prediction for PANDA

\[ \bar{p}p \rightarrow J/\psi \bar{p}p \quad 0.002 - 0.037 \mu b \]

But the J/ψ is much easier to be detected by lepton channels than ηc.

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We find 6 bound states by using the Chiral Unitary Approach. All of these bound states have hidden charm quarks.

These states can decay to two types of channels:

1 light meson and baryon channels: about 1MeV—14MeV because of $\bar{c}c$ annihilation.

2 $\bar{c}c$ meson and baryon channels: about 20MeV because of small phase space.

These heavy states have narrow width.
The suggestion for PANDA

These new states could be looked for in the reaction $\bar{p}p \to \eta_c \, \bar{p}p$ and $\bar{p}p \to J/\psi \, \bar{p}p$.

- $\bar{p}p \to \eta_c \, \bar{p}p \quad 0.13 \text{ } - \text{ } 1.3 \text{ } \mu b$
- $\bar{p}p \to J/\psi \, \bar{p}p \quad 0.002 \text{ } - \text{ } 0.037 \mu b$

It can provide almost 110000 and 1700 events per day in PANDA by $L=10^{31} \text{ cm}^{-2}\text{s}^{-1}$.
Thank you!