Photoproduction of $X(3872)$ in the near-threshold region

Feng-Kun Guo

Institute of Theoretical Physics, Chinese Academy of Sciences

Xiong-Hui Cao, Meng-Lin Du, FKG, arXiv:2401.16112
J/ψ-nucleon scattering and photoproduction

- OZI suppressed scattering
  - Relatively suppressed by $O(1/N_c)$
  - General mechanisms (take $J/\psi - N$ as an example)
    - Gluon exchanges
      - Coupled-channel: $J/\psi N - \Lambda_c \bar{D}(\ast)/\Sigma_c^{\ast}(\ast) \bar{D}(\ast) - J/\psi N$

- General mechanisms (take $J/\psi - N$ as an example)
  - Gluonic exchanges
    - Coupled-channel: $J/\psi N - \Lambda_c \bar{D}(\ast)/\Sigma_c^{\ast}(\ast) \bar{D}(\ast) - J/\psi N$

Gluonic matrix elements
- $\langle J/\psi |GG|J/\psi \rangle$ ~ Chromopolarizabilities
- $\langle N|GG|N \rangle$: trace anomaly contribution to the nucleon mass
**J/ψ-nucleon scattering and photoproduction**

- The $J/\psi$ photoproduction probes the gluonic contribution to the nucleon mass
  - if the mechanism of gluon exchanges is dominant

- if the $J/\psi$ photoproduction can be modeled by vector-meson dominance

\[
\frac{d\sigma_{\gamma NN\rightarrow\psi N}}{dt}(s, t = 0) = \frac{3\Gamma(\psi \rightarrow e^+e^-)}{\alpha m_\psi}\left(\frac{k_\psi}{k_{\gamma N}}\right)^2 \\
\times \frac{d\sigma_{\psi NN\rightarrow\psi N}}{dt}(s, t = 0)
\]

- Scattering length from VMD and photoproduction: $3 - 25$ am
  - $21.3 \pm 8.2$ am

- Nucleon gluonic gravitational form factor, mass radius measured with this assumption


  [L. Pentchev, I. Strakovsky, EPJA 57 (2021) 56]

  [GlueX, PRC 108 (2023) 025201]

- For the search for hidden-charm $P_c$ pentaquarks

  [Duran et al. [J/ψ-007], Nature 615 (2023) 813]

---

$J/\psi$ in the VMD model would be highly off-shell, but the scattering length and cross section are defined for real $J/\psi$. 

3
**J/ψ photoproduction**

- Coupled-channel mechanism
  - Consider $\Lambda_c \overline{D}(*)$ channels: M.-L. Du et al., EPJC 80 (2020) 1053
  
  ![Diagram of coupled-channel mechanism](image)

  \[
  \begin{align*}
  \Lambda_c + D^- : & \quad 2286 \pm 1863 = 4151 \text{ MeV} \\
  \bar{J}/ψ + p : & \quad 3097 \pm 938 = 4035 \text{ MeV}
  \end{align*}
  \]

- Unique feature: threshold cusps

  With phenomenological couplings, not a fit.
  Data: GlueX, PRL 123 (2019) 072001
J/ψ photoproduction

- Coupled-channel mechanism
  - Hint of threshold cusps in the latest data, but still not conclusive

See also JPAC analysis in D. Winney et al., PRD 108 (2023) 054018
Search for at COMPASS, but not seen

- Evidence of $\bar{X}(3872)$ in $\gamma^* N \rightarrow X^0 \pi^\pm N'$ with 4.1$\sigma$

$$\sqrt{s_{\gamma N}} \in [8, 18] \text{ GeV}$$

- The $\pi\pi$ invariant mass suggests $C(\bar{X}) = -1$

- Cross sections at $\sqrt{s_{\gamma N}} = 13.7$ GeV:

$$\sigma(\gamma N \rightarrow \bar{X} \pi N') \times B(\bar{X} \rightarrow J/\psi \pi^+ \pi^-) = (71 \pm 28 \pm 39) \text{ pb}$$

$$\sigma(\gamma N \rightarrow X(3872)N') \times B(X(3872) \rightarrow J/\psi \pi^+ \pi^-) < 2.9 \text{ pb (CL = 90\%)}$$

$M_{\bar{X}} = (3860.4 \pm 10.0) \text{ MeV}$

COMPASS, PLB783(2018)334
Existing estimate for the X(3872) photoproduction

- Vector-meson-dominance (VMD) model: $\gamma^* \rightarrow J/\psi$
- Low energy: $\rho, \omega$ exchanges, $\mathcal{O}(10 \text{ nb})$
- High energy: Regge exchange
X(3872) photoproduction with coupled channels

- Coupled-channel mechanism for the X(3872) photoproduction in the near-threshold region
  - X(3872) couples strongly to $D\bar{D}^*$
  - Nearby open-charm thresholds:
    \[
    \begin{align*}
    D^0\Lambda_c(2940)^+ : 4804^{+2}_{-1} \text{ MeV} \\
    D^*\Sigma_c(2800)^+ : 4799^{+14}_{-5} \text{ MeV} \\
    D^*\Sigma_c(2800)^{++} : 4811^{+4}_{-6} \text{ MeV} \\
    D^0\Lambda_c(2860)^+ : 4863^{+2}_{-6} \text{ MeV} \\
    D^0\Lambda_c(2940)^+ : 4946^{+1}_{-5} \text{ MeV}.
    \end{align*}
    \]

- $\Lambda_c(2860) [3/2^+]$
- $\Lambda_c(2940) [3/2^-]$
- $\Sigma_c(2800) : \frac{1}{2}^-$ from the analysis of $\Lambda_b \to \pi^- p D^0$

Coupling constants
- Measured widths
- Heavy quark spin symmetry
- $XDD\bar{D}^*$ coupling consistent with hadronic molecular picture

S. Sakai, FKG, B. Kubis, PLB 808 (2020) 135623
X(3872) photoproduction with coupled channels

- Evaluate the box diagrams with a dispersive approach:

\[
\mathcal{A}_{\ell S;\ell S}(\gamma p\to \chi_{c1} p)(s) = \sum_{\ell',S'} \frac{1}{\pi} \int d s' s_{\text{cut}} \frac{\mathcal{A}_{\ell' S';\ell' S}^J(\gamma p\to D^* \Sigma_c/\Lambda_c)(s') \rho(s') \mathcal{A}_{\ell' S';\ell S}(\chi_{c1} p\to D^* \Sigma_c/\Lambda_c)(s')}{s' - s}
\]

consider S-wave for open-charm channels, S-, P- and D-waves for \(\gamma p, Xp\)

- Only limited channels, hard cutoff: 
  \[s_{\text{cut}} = \sqrt{q_{\text{max}}^2 + m_{\Sigma_c/\Lambda_c}^2} + \sqrt{q_{\text{max}}^2 + m_{D^*}^2} \text{ with } q_{\text{max}} = 1 \text{ GeV}\]

- Monopole form factor for exchanged particles with \(\Lambda = m_{\text{ex}} + \eta \Lambda_{\text{QCD}}\)
  \[F(t) = \frac{\Lambda^2 - m_{\text{ex}}^2}{\Lambda^2 - t}\]
X(3872) photoproduction with coupled channels

- Triangle singularity: subleading Landau singularity of the box diagram

- Total cross section

Here $g_{+-}$ is the ratio of the $\Lambda(2860)D^{(*)}p$ and $\Lambda(2940)D^{(*)}p$ coupling constants constrained by the measured widths

For review on TS: FKG, X.-H. Liu, S. Sakai, PPNP 112 (2020) 103757
X(3872) photoproduction with coupled channels

• Triangle singularity induced structure may be used to measure the X(3872) binding energy ($\delta$)

FKG, PRL 122 (2019) 202002

• However, here the sensitivity is smeared out by the $\Lambda(2940)$ width ($\sim 20$ MeV)
Nontrivial structures in the energy dependence of the total cross section: probe of the mechanism of the near-threshold production of hidden-charm mesons

- \( \sigma(\gamma p \rightarrow X(3872)p) = \mathcal{O}(30 \text{ nb}) \) at \( \sqrt{s}_{\gamma p} \sim 5 \text{ GeV} \) \( \Rightarrow \mathcal{O}(0.3 \text{ nb}) \) for electroproduction

- Plenty of \( X(3872) \) events will be collected with 50 fb\(^{-1}\) for EicC, 300 fb\(^{-1}\) for EIC

Summary

Thank you for your attention!

http://fb23.ihep.ac.cn