XYZP spectroscopy at a charm photoproduction factory

Alessandro Pilloni

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Exotic landscape

Estimates in M. Albaladejo et al. [JPAC], 2008.01001

LoI RF7_RF0_120

A. Pilloni – XYPZ spectroscopy at a charm photoproduction factory
Exclusive photoproduction

- XYZ have so far not been seen in photoproduction: independent confirmation
- Not affected by 3-body dynamics: determination of resonant nature
- Polarized photon and nucleon give further information on the exchanges

\[
\langle \lambda_Q \lambda_{N'} | T | \lambda_Y \lambda_N \rangle = \sum_{V, \mathcal{E}} \frac{e f_V}{m_V} \mathcal{T}_{\lambda_Y=\lambda_Q} \mathcal{P}_{\alpha_1 \ldots \alpha_j} \mathcal{B}_{\beta_1 \ldots \beta_j}^{\lambda_N \lambda_{N'}}
\]
Exclusive photoproduction

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- Experiments with high luminosity in the appropriate energy range are promising

\[
\langle \lambda_Q \lambda'_N | T | \lambda_Y \lambda_N \rangle = \sum_{V, \epsilon} \frac{e f_V}{m_V} g_{\lambda_Y = \lambda_Q} \mathcal{P}_{\alpha_1 \cdots \alpha_j} \beta_{\beta_1 \cdots \beta_j} \frac{B_{\lambda_N \lambda'_N}}{\lambda_N \lambda'_N}
\]

VMD is used to couple the incoming photon to a vector quarkonium V

Bottom vertex from standard photoproduction pheno, exponential form factors to further suppress large t
Exclusive photoproduction

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\[ < \lambda_Q \lambda_N' | T | \lambda_Y \lambda_N > = \sum_{V, \mathcal{E}} \frac{e f_V}{m_V} \int_{\lambda_Y = \lambda_N, \lambda_Q} P \alpha_1 \cdots \alpha_j \beta_1 \cdots \beta_j \mathcal{B}_{\lambda_N \lambda_N'} \]

Top vertex well constrained by production and decay
Threshold vs. high energy

- Fixed-spin exchanges expected to hold in the low energy region
- $t$ channel grows as $s^j$, exceeding unitarity bound, Regge physics kicks in: Reggeized tower of particles with arbitrary spin at HE

\[ s^j \rightarrow s^{\alpha_0 + \alpha't} \]

Holds at low energy, fixed spin
Holds at high energy, resummation of leading $s$ power

- If $\varepsilon \neq 1 \ P$, $\alpha_0 < 1$, $d\sigma/dt$ decreases with energy
- Exchange of heavy particles further suppressed
\( Z \) photoproduction

- The \( Zs \) are charged charmoniumlike \( 1^{+-} \) states close to open flavor thresholds
- Focus on \( Z_c(3900)^+ \to J/\psi \pi^+ \), \( Z_b(10610)^+ \), \( Z_b'(10650)^+ \to \Upsilon(nS) \pi^+ \)
- The pion is exchanged in the \( t \)-channel
- Sizeable cross sections especially at LE

![Graphs showing cross sections](image.png)
**X photoproduction**

- Focus on the famous $1^{++} \text{X}(3872) \rightarrow J/\psi \rho, \omega$
- Studying also $\text{X}(6900) \rightarrow J/\psi J/\psi$ (assumed $0^{++}$)
- $\omega$ and $\rho$ exchanges give main contributions:
  need to assume the existence of a OZI-suppressed $\text{X}(6900) \rightarrow J/\psi \omega$
- Extremely suppressed cross sections at HE: LE most promising
An example of yield estimate

- Example with an ideal CharminGlueX detector
- $E_{\text{lab}} \sim 20$ GeV, photon flux $10^8 \, \gamma/s$
- Tipical target, $500 \, \text{pb}^{-1} \,/\text{yr}$
- Assuming efficiency 1%

<table>
<thead>
<tr>
<th>$W_{\gamma p}$ (GeV)</th>
<th>$\sigma$ (nb)</th>
<th>$\mathcal{B}(\mathcal{Q} \to \ell^+ \ell^- n\pi) \times 10^{-3}$</th>
<th>Counts</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X(3872)$</td>
<td>6</td>
<td>5.3</td>
<td>877</td>
<td>$\sim 90$ [52]</td>
</tr>
<tr>
<td>$Z_c(3900)$</td>
<td>15</td>
<td>12.5</td>
<td>994</td>
<td>$\sim 1300$ [15]</td>
</tr>
<tr>
<td>$Z_b(10610)$</td>
<td>15</td>
<td>2.8</td>
<td>36</td>
<td>$\sim 750$ [53]</td>
</tr>
<tr>
<td>$Z_b'(10650)$</td>
<td>0.66</td>
<td>2.1</td>
<td>7</td>
<td>$\sim 200$ [53]</td>
</tr>
</tbody>
</table>

$\mathcal{B}(J/\psi \to \ell^+ \ell^-)^2 \times 10^{-3}$

| $X(6900)$            | 12            | 14                                               | 133    | $\sim 800$ [32] |
Conclusions

• Photoproduction is a valuable tool to study exotic states

• Complementary information to other mechanisms

• Facilities to study photoproduction at low energies are very welcome to pursue this program

• As for writing: some overlap with the EIC Yellow Report (see LoI RF7_RF0_090 and J. Stevens’s talk), more material to be produced during the next year

Thank you!
Joint Physics Analysis Center

Exclusive reactions: 2008.01001

Inclusive reactions: in progress

Code available on https://github.com/dwinney/jpacPhoto

Contact: pillaus@jlab.org
BACKUP
Another $\tilde{\Xi}$?

$\tilde{\Xi}(3872)$ as a new state

$\tilde{\Xi}(3872) = (3860.0\pm10.4)\,\text{MeV}/c^2$

$\Gamma_{\tilde{\Xi}(3872)} < 51\,\text{MeV}/c^2$ (CL=90%)

Significance (including systematics) is $4.1\sigma$

$\mathcal{C}=-1$ (?)

COMPASS claimed the existence of a state degenerate with the $X(3872)$, but with $\mathcal{C} = 1$

Large photoproduction cross section

At COMPASS conditions:

$\sigma_{\mu N} \approx \sigma_{\gamma N} / 300$

**EIC**

$L=10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$

$e^- N \rightarrow e^- \tilde{\Xi}(3872)\pi^\pm N' \rightarrow$

$\rightarrow e^- J/\psi \pi^+ \pi^- \pi^\pm N' \rightarrow e^- \mu^+ \mu^- \pi^+ \pi^- \pi^\pm N'$

$\sim 10$ events per day
Exclusive $P_c$ photoproduction

At Jlab12 measurements of direct $P_c$ production are being performed

Using VMD, $\text{BR}(P_c \rightarrow J/\psi p) \sim 1\%$
Polarized $P_c$ photoproduction

- $s$ channel resonances significant at low energies:
  - $u$ channel dominates at high energies
- Main background from $N(\ast)$ trajectories
- Estimated $P_c$ coupling upper bound of same order of magnitude as $N(\ast)$ coupling
- Reggeization suppresses $P_c$ due to larger mass (smaller trajectory intercept)
- We estimate that the $P_c$ trajectories will hardly be visible at the EIC
- $P_b$ searches still possible: $s$ channel at higher energies!

Y (vector) photoproduction

- Focus on the $1^{--} Y(4260) \rightarrow J/\psi \pi^+\pi^-$, check with $\psi' \rightarrow J/\psi \pi^+\pi^-$
- Diffractive production, dominated by Pomeron (2-gluon) exchange
- Good candidates for EIC: diffractive production increases with energy!
- We have $\gamma\psi$-pomeron coupling from our analyses 1606.08912, 1907.09393

How to rescale from $J/\psi$ to $\psi'$?

$$R_{\psi'} = \sqrt{\frac{g^2(\psi' \rightarrow \gamma gg)}{g^2(\psi \rightarrow \gamma gg)}} \sim 0.55$$

$$g^2(\psi \rightarrow \gamma gg) = \frac{6m_\psi B(\psi \rightarrow \gamma gg)\Gamma_\psi}{PS(\psi \rightarrow \gamma gg)}$$
**Y (vector) photoproduction**

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**How to rescale from $J/\psi$ to $Y(4260)$?**

We assume VMD and $g^2(Y \to \psi\pi\pi) = g^2(Y \to \psi gg) \times g^2(gg \to \pi\pi)$ (Novikov & Shifman)

$$R_Y = \frac{ef_{\psi}}{m_{\psi}} \sqrt{\frac{g^2(Y \to \psi\pi\pi) \ g^2(\psi' \to \psi gg)}{g^2(\psi \to \gamma gg) \ g^2(\psi' \to \psi\pi\pi)}}$$

Caveat: $BR(Y \to \psi\pi\pi)$ only known times the leptonic width $\Gamma_{ee}^Y$
**Y (vector) photoproduction**

Existing data allow to put a 95% upper limit on the ratio of $\psi'/Y(4260)$ yields

Assuming previous formula, one gets:

$\Gamma_{ee}^Y = 930 \text{ eV}$

(cfr. hep-ex/0603024, 2002.05641)

$BR(Y \to J/\psi \pi \pi) = 0.96\%$

$R_Y = 0.84$

Data from H1

hep-ex/971112
Using measurement of $\Gamma(X \rightarrow \gamma\gamma^*)$ from Belle, one can get predictions for Primakoff.

Makes use of the ion beam, enhancement of cross sections as $Z^2$. 

Primakoff X photoproduction

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Diffractive semi-inclusive $Z_c$ ph.

If the target fragments are separated from the beam ones, one can invoke Regge factorization.

Quark-Regge duality allows to replace the intermediate hadrons with Pomeron, prediction reliable for $x_B \sim 1, t \ll W_{\gamma p}^2$.
Semi-inclusive $X$ production

For large $Q^2$ one can invoke NRQCD factorization to describe quarkonium(-like) production

$$d\sigma(e^- + p \rightarrow H + X) = \sum_n d\sigma(e^- + p \rightarrow Q\bar{Q}(n) + X)\langle O^H(n) \rangle$$

Perturbative partonic matrix element, calculable

Nonperturbative transition matrix element $Q\bar{Q} \rightarrow H$ fitted from data

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Semi-inclusive $X$ production

One can assume the same NRQCD factorization for exotics, independent of their internal structure.

$$\sigma[X(3872)] = \sum_n \hat{\sigma}[c\bar{c}_n] \langle O^X_n \rangle,$$

$$\text{Br}[X \rightarrow J/\psi \pi^+ \pi^-] (\langle O^X_8(3S_1) \rangle + 0.159 \langle O^X_8(1S_0) \rangle + 0.085 \langle O^X_1(1S_0) \rangle$$
$$+ 0.00024 \langle O^X_1(3S_1) \rangle) = (2.7 \pm 0.6) \times 10^{-4} \text{ GeV}^3$$

Artoisenet and Braaten, PRD81, 114018 from Tevatron data

If one consider the first term only, it leads to

$$\text{Br}[X \rightarrow J/\psi \pi^+ \pi^-] \sigma(X(3872), Q^2 > 1 \text{ GeV}) \approx 2.6 \text{ pb} \quad \sqrt{s} = 100 \text{ GeV}$$

X. Yao