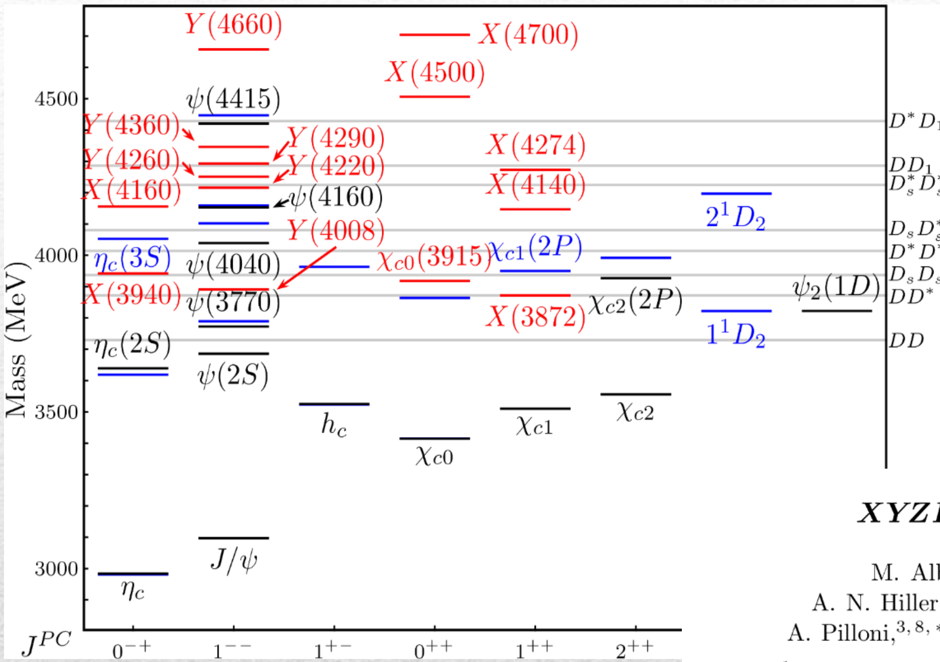
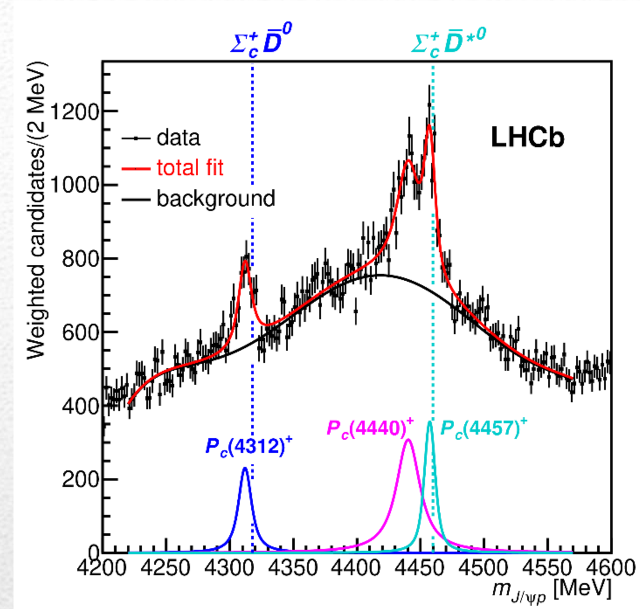
XYZP spectroscopy at a charm photoproduction factory

Alessandro Pilloni

Snowmass, RF Townhall meeting, October 2nd, 2020

Exotic landscape





XYZP spectroscopy at a charm photoproduction factory

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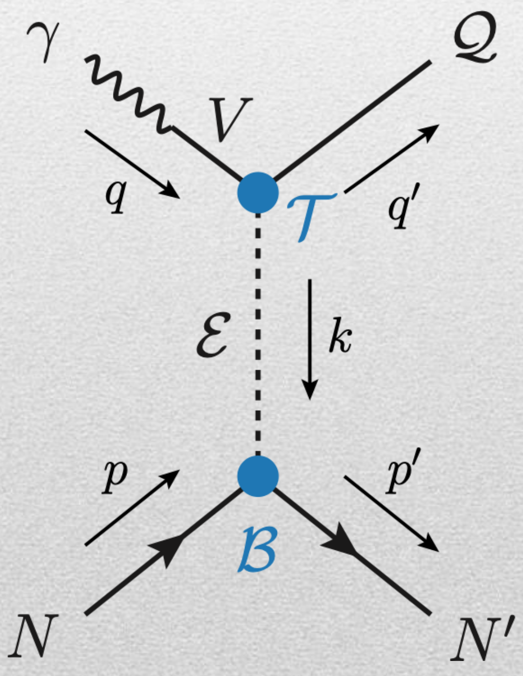
Estimates in
M. Albaladejo et al. [JPAC],
2008.01001

LoI RF7_RF0_120

Exclusive photoproduction

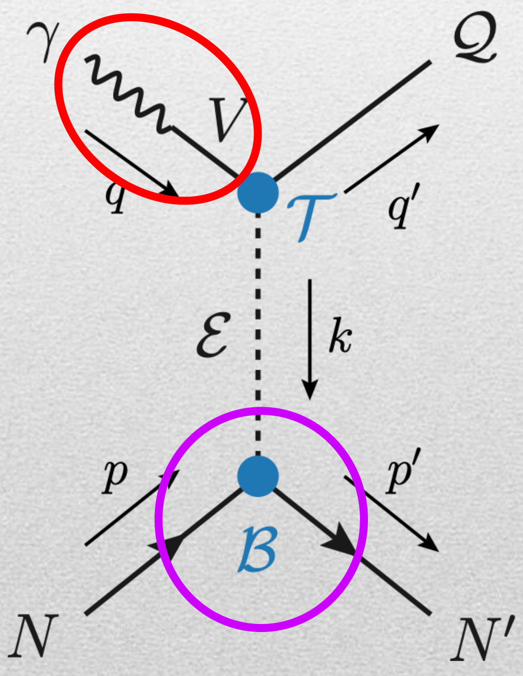
- XYZ have so far not been seen in photoproduction: independent confirmation
- Not affected by 3-body dynamics: determination of resonant nature
- Polarized photon and nucleon give further information on the exchanges



$$< \lambda_Q \lambda'_N | T | \lambda_\gamma \lambda_N >= \sum_{V,\mathcal{E}} \frac{e f_V}{m_V} \mathcal{T}^{\alpha_1 \cdots \alpha_j}_{\lambda_V = \lambda_\gamma, \lambda_Q} \mathcal{P}_{\alpha_1 \cdots \alpha_j; \beta_1 \cdots \beta_j} \mathcal{B}^{\beta_1 \cdots \beta_j}_{\lambda_N \lambda'_N}$$

Exclusive photoproduction

- XYZ have so far not been seen in photoproduction: independent confirmation
- Not affected by 3-body dynamics: determination of resonant nature
- Experiments with high luminosity in the appropriate energy range are promising



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

$$< \lambda_Q \lambda_N' | T | \lambda_\gamma \lambda_N > = \sum_{V,\mathcal{E}} \frac{e f_V}{m_V} \mathcal{T}^{\alpha_1 \cdots \alpha_j}_{\lambda_V = \lambda_\gamma, \lambda_Q} \mathcal{P}_{\alpha_1 \cdots \alpha_j ; \beta_1 \cdots \beta_j} \mathcal{B}^{\beta_1 \cdots \beta_j}_{\lambda_N \lambda_N'}$$

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

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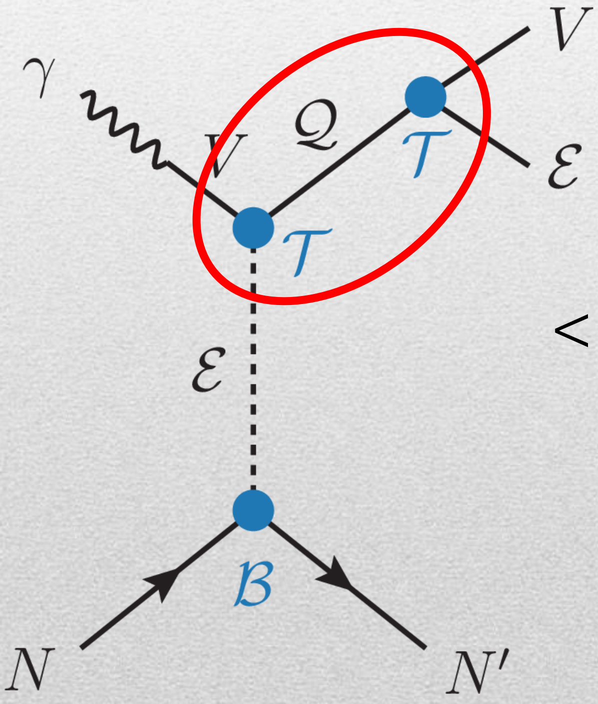
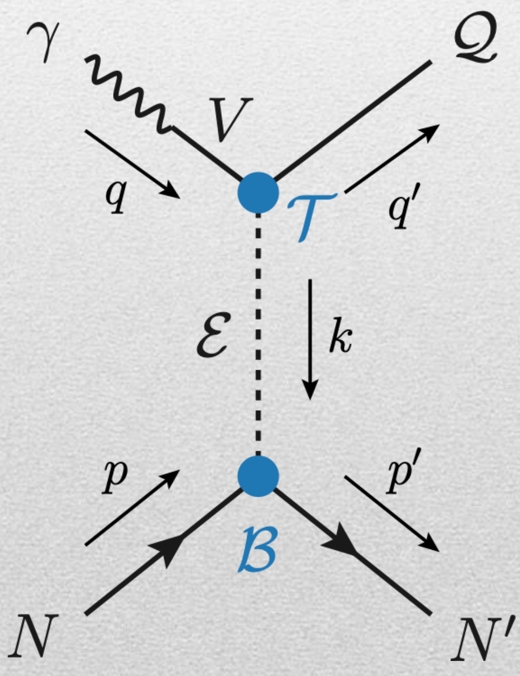


$$< \lambda_{\mathcal{Q}} \lambda'_N | T | \lambda_\gamma \lambda_N >= \sum_{V,\mathcal{E}} \frac{e f_V}{m_V} \mathcal{T}^{\alpha_1 \cdots \alpha_j}_{\lambda_V = \lambda_\gamma, \lambda_{\mathcal{Q}}} \mathcal{P}_{\alpha_1 \cdots \alpha_j ; \beta_1 \cdots \beta_j} \mathcal{B}^{\beta_1 \cdots \beta_j}_{\lambda_N \lambda'_N}$$

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



$$s^j \longrightarrow s^{\alpha_0 + \alpha' t}$$

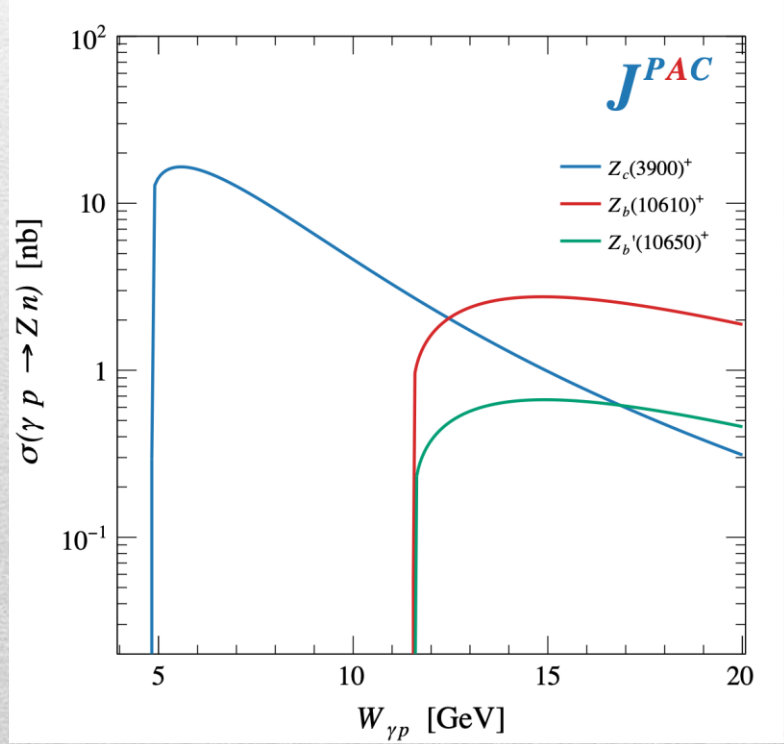
Holds at low energy, fixed spin

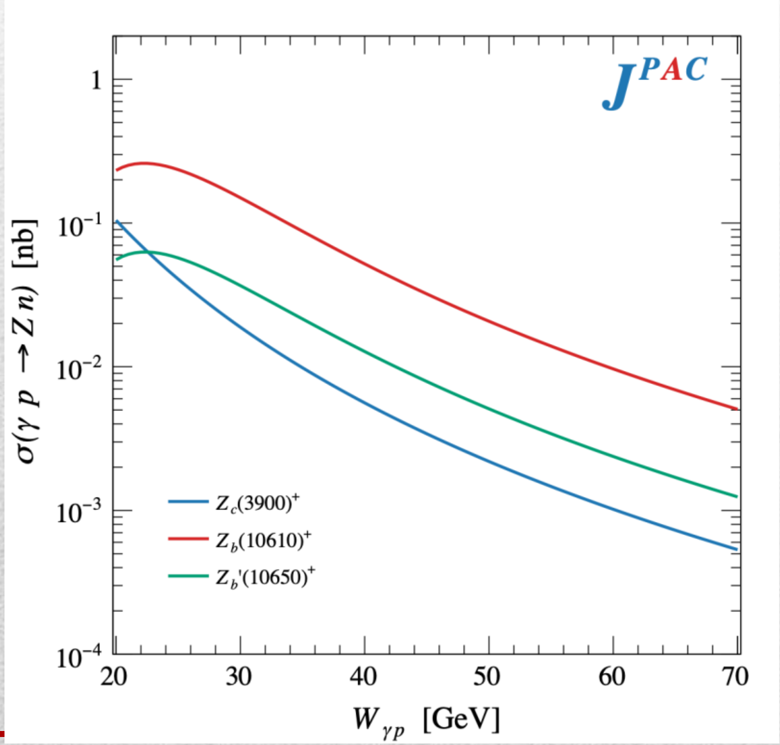
Holds at high energy, resummation of leading s power

- If $\varepsilon \neq \mathbb{P}$, $\alpha_0 < 1$, $d\sigma/dt$ decreases with energy
- Exchange of heavy particles further suppressed

Z photoproduction

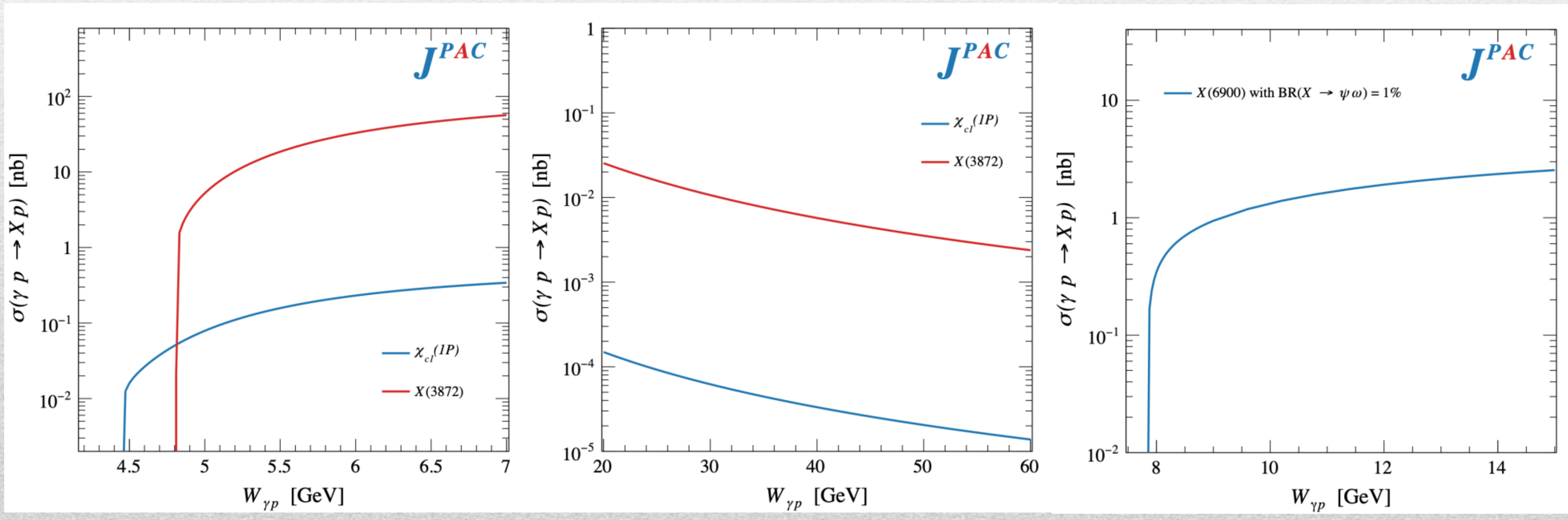
- The Zs are charged charmoniumlike 1^{+-} states close to open flavor thresholds
- Focus on $Z_c(3900)^+ \to J/\psi\, \pi^+, Z_b(10610)^+, Z_b'(10650)^+ \to \Upsilon(nS)\, \pi^+$
- The pion is exchanged in the t-channel
- Sizeable cross sections especially at LE





X photoproduction

- Focus on the famous 1^{++} $X(3872) \to J/\psi\,\rho, \omega$
- Studying also $X(6900) \to J/\psi\,J/\psi$ (assumed 0^{++})
- **ω** and **ρ** exchanges give main contributions:
  need to assume the existence of a OZI-suppressed $X(6900) \to J/\psi\,\omega$
- 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 $10^8\ \gamma/\text{s}$
- Tipical target, 500 pb^{-1} /yr
- Assuming efficiency 1%

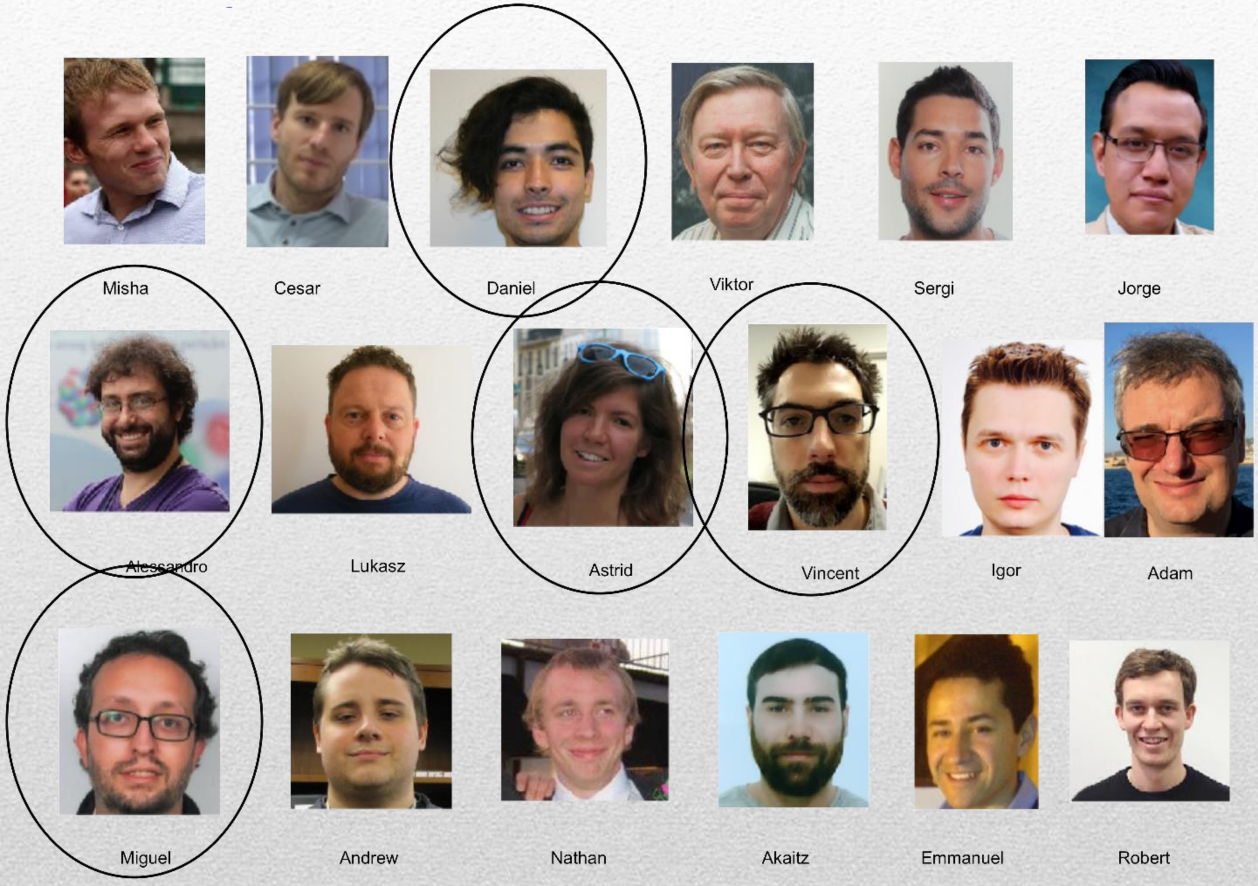
	$W_{\gamma p}$ (GeV)	σ (nb)	$\mathcal{B}(\mathcal{Q} \to \ell^+\ell^-\ n\pi)$ $(\times 10^{-3})$	Counts	Comparison
$X(3872)$	6	33.1	5.3	877	~ 90 [52]
$Z_c(3900)^+$		15.9	12.5	994	~ 1300 [15]
$Z_b(10610)^+$	15	2.8	2.6	36	~ 750 [53]
$Z_b'(10650)^+$		0.66	2.1	7	~ 200 [53]
			$\mathcal{B}(J/\psi \to \ell^+\ell^-)^2$ $(\times 10^{-3})$		
$X(6900)$	12	1.9	14	133	~ 800 [32]

Conclusions

- Photoproduction is a valuable tool to study exotic states
- Complementary infomation 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

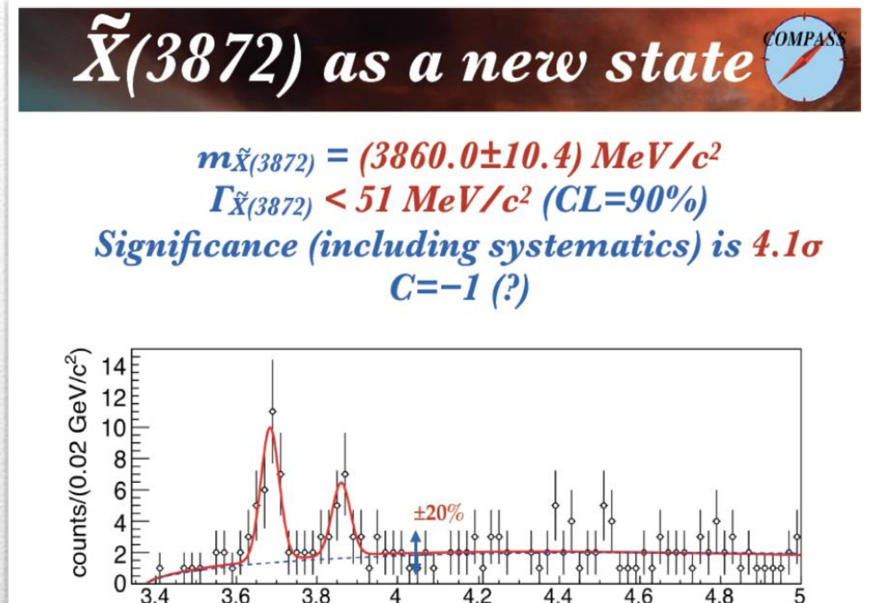
Inclusive reactions:
in progress

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

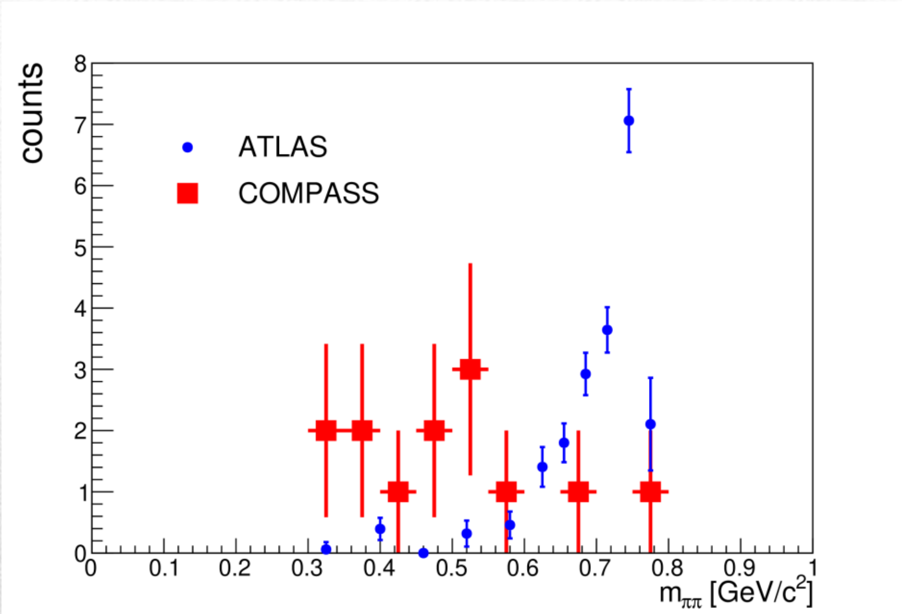
Contact : pillaus@jlab.org

BACKUP

Another $\tilde{X}$?



A. Guskov



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

Large photoproduction cross section

A. Guskov

At COMPASS conditions:

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

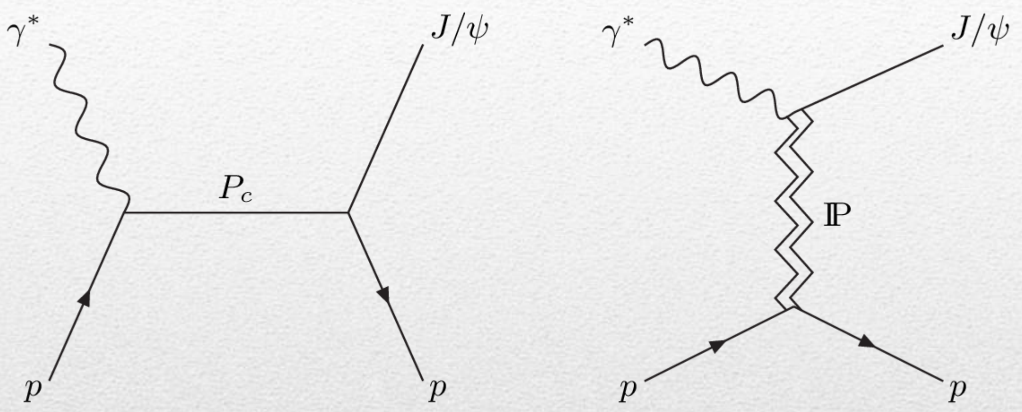
EIC L=10³⁴ cm⁻² s⁻¹

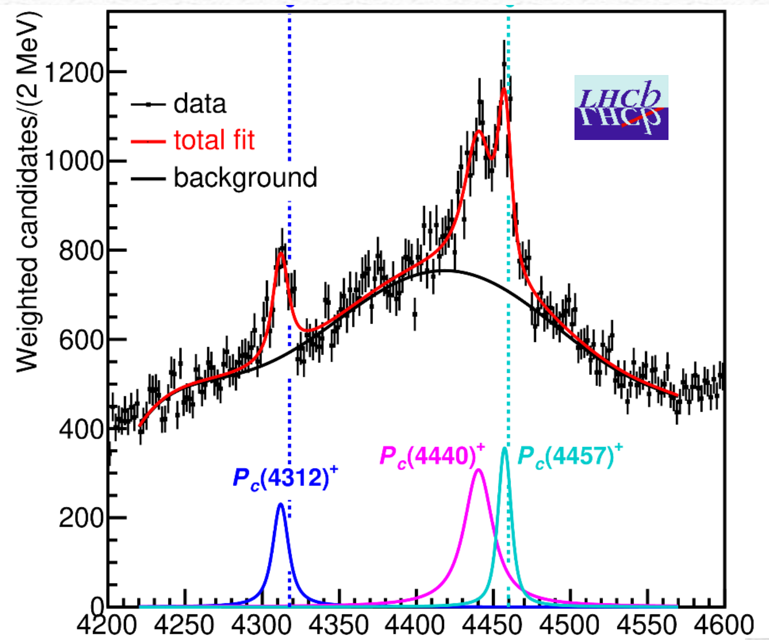
$e^- N \to e^- \widetilde{X}(3872)\pi^\pm N' \to$

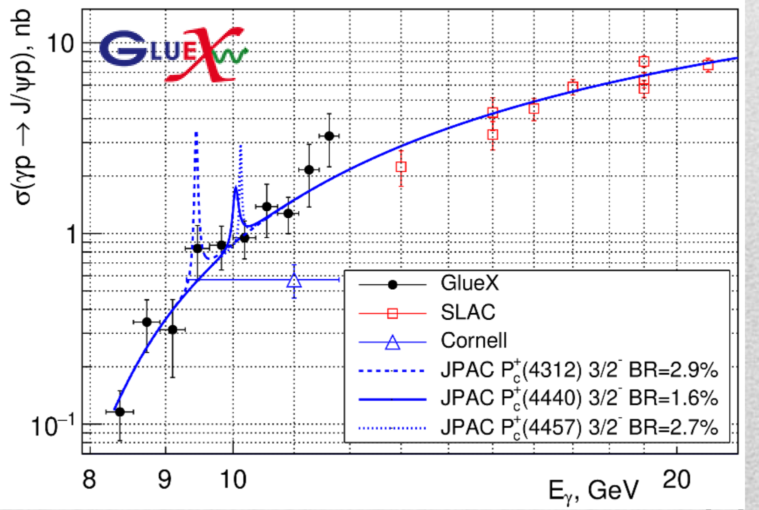
$\to e^- J/\psi \pi^+\pi^-\pi^\pm N' \to e^-\mu^+\mu^-\pi^+\pi^-\pi^\pm N'$

~10 events per day

Exclusive P_c photoproduction



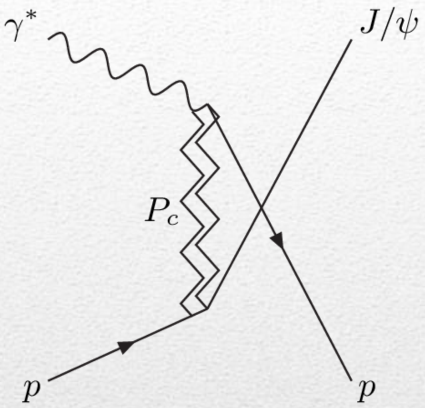


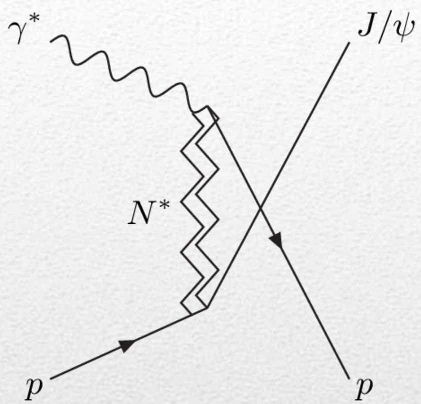


At Jlab12 measurements of direct P_c production are being performed

Using VMD, $\mathrm{BR}(P_c \to J/\psi\, p) \sim 1\%$

Polarized P_c photoproduction





$\sim s^{\alpha(u)}$

- s channel resonances significant at low energies:
  u channel dominates at high energies
- Main background from N(*) trajectories
- Estimated P_c coupling upper bound of same order of magnitude as $N^{(*)}$ 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!

Cao et al., Phys.Rev. D 101, 074010 (2020)
E. Paryev, arXiv:2007.01172 [nucl-th] (2020)

Y (vector) photoproduction

- Focus on the 1^{--} $Y(4260) \to J/\psi\, \pi^+\pi^-$, check with $\psi' \to J/\psi\, \pi^+\pi^-$
- 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/ψ to ψ' ?

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

$$g^2(\psi \to \gamma g g) = \frac{6 m_\psi \mathcal{B}(\psi \to \gamma g g)\Gamma_\psi}{\mathrm{PS}(\psi \to \gamma g g)}$$

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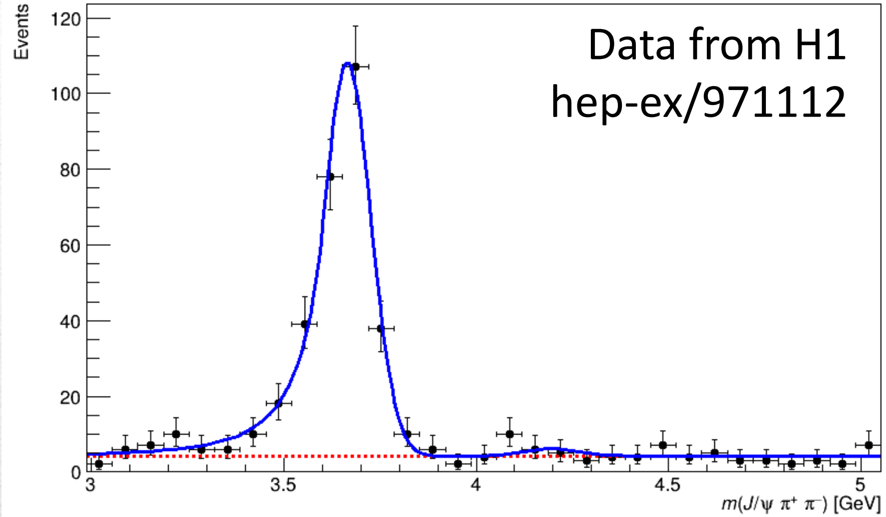
How to rescale from J/ψ to $Y(4260)$?

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

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

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

Y (vector) photoproduction



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

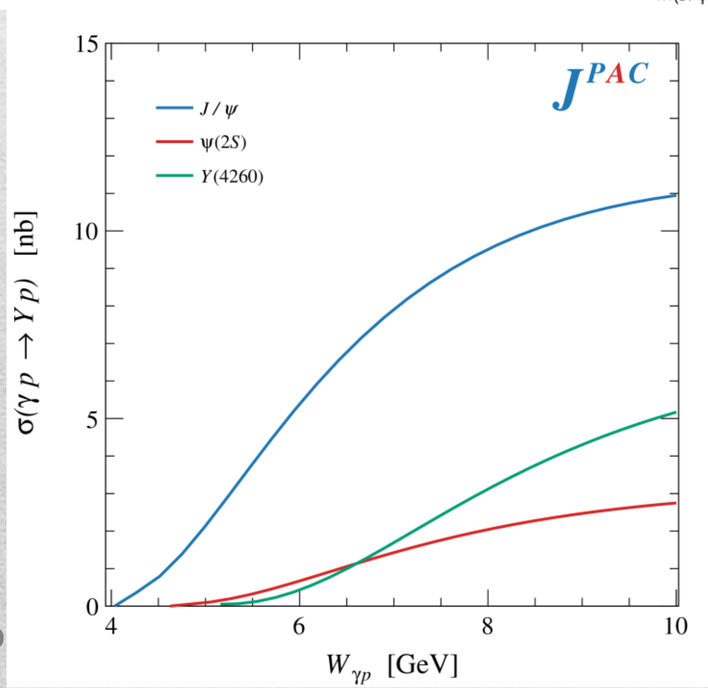
Assuming previous formula, one gets:

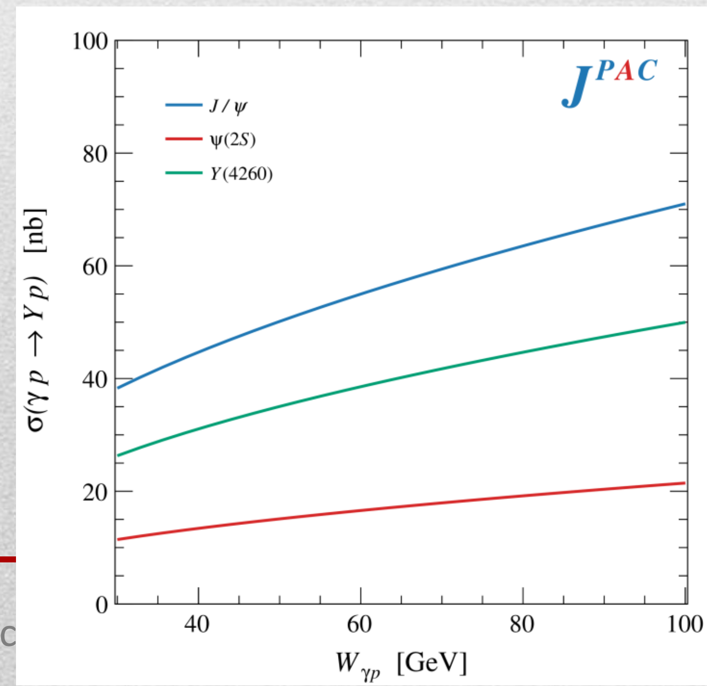
$\Gamma_{ee}^{Y} = 930\ eV$

(cfr. hep-ex/0603024, 2002.05641)

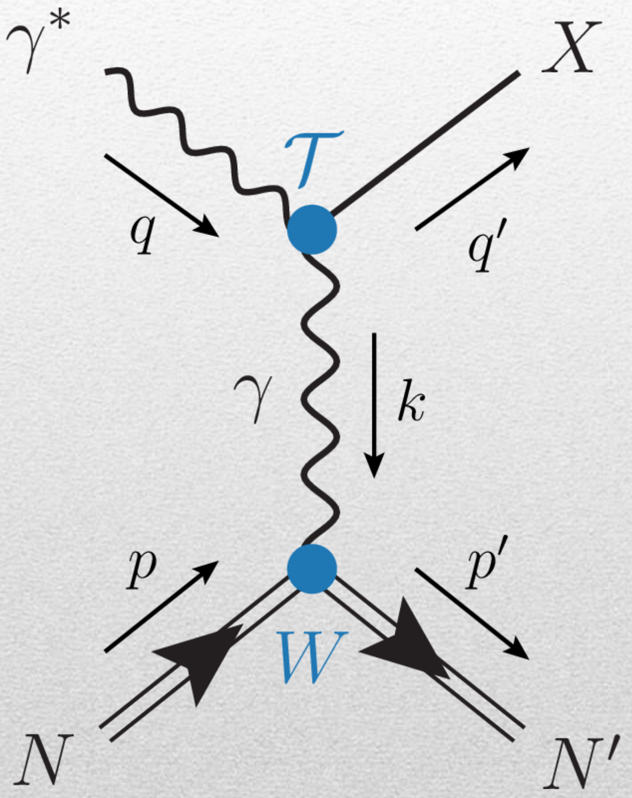
$BR(Y \to J/\psi\pi\pi) = 0.96\%$

$R_Y = 0.84$





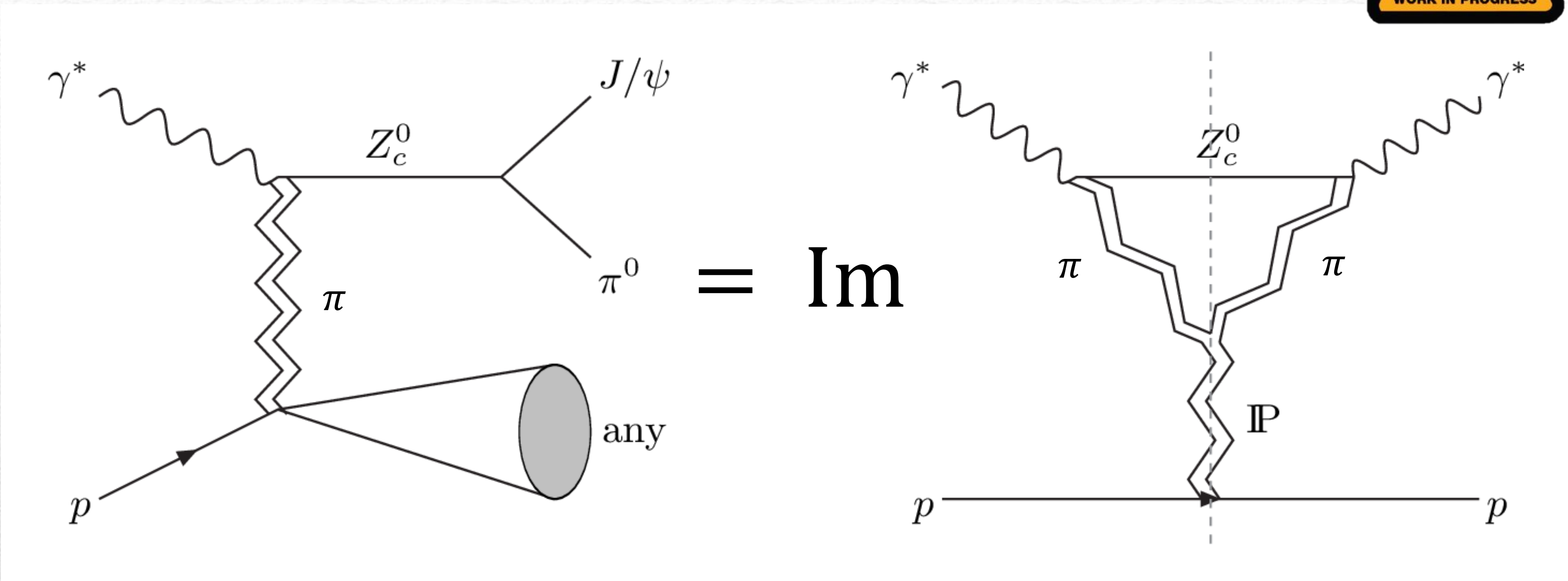
Primakoff X photoproduction



Using measurement of $\Gamma(X \to \gamma\gamma^*)$ from Belle, one can get predictions for Primakoff

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

Diffractive semi-inclusive Z_c ph.



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

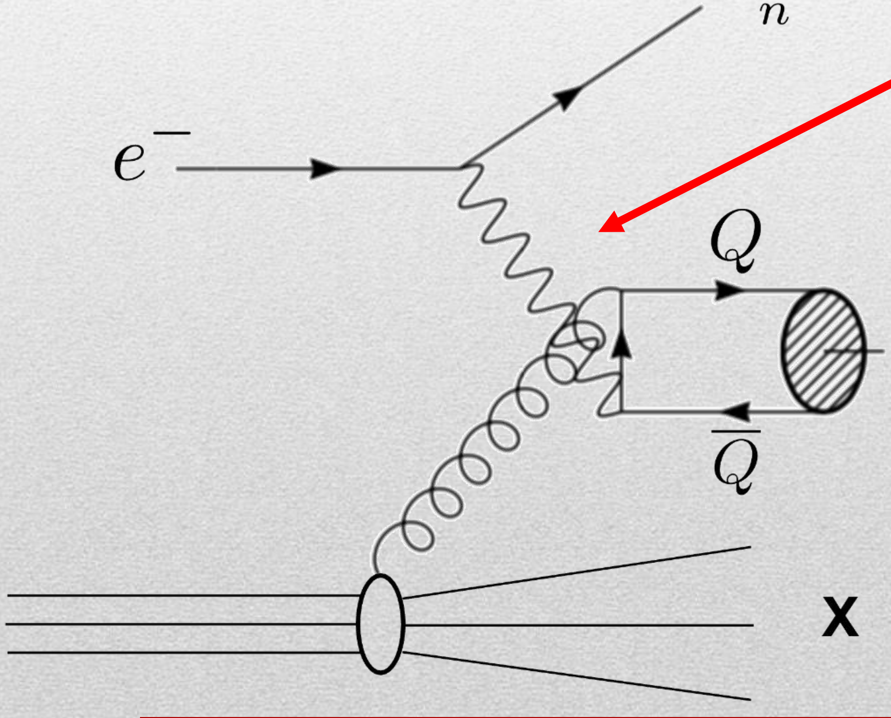
Quark-Regge duality allows to replace the intermediate hadrons with Pomeron , prediction reliable for $x_B \sim 1$, $t \ll W_{\gamma p}^2$

Semi-inclusive X production

X. Yao

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

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



Perturbative partonic
matrix element, calculable

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

Semi-inclusive X production

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

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

$$\mathrm{Br}[X \to J/\psi\pi^+\pi^-] \left(\langle \mathcal{O}_8^X(^3S_1) \rangle + 0.159\, \langle \mathcal{O}_8^X(^1S_0) \rangle + 0.085\, \langle \mathcal{O}_1^X(^1S_0) \rangle + 0.00024\, \langle \mathcal{O}_1^X(^3S_1) \rangle \right) = (2.7 \pm 0.6) \times 10^{-4}\ \mathrm{GeV}^3$$

Artoisenet and Braaten, PRD81, 114018 from Tevatron data

If one consider the first term only, it leads to

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

X. Yao