Exotic hadron searches in photoproduction

GHP2021

Astrid N. Hiller Blin

ahblin@jlab.org

JPAC Jefferson Lab Thomas Jefferson National Accelerator Facility

Phys. Rev. D100 (2019) 034010

1907.09393 [hep-ph]

Phys. Rev. D102 (2020) 114010

2008.01001 [hep-ph]

April 16, 2021

The family of exotics

- Since 2003:
  discovery of **many new unexpected resonance candidates** in hadron colliders

- E.g. **mesons** whose J^{PC} cannot be matched by $q\bar{q}$ content (π_1)

- XYZ states
  Guo et al., 1912.07030
  Brambilla et al., 1907.07583
  Hosaka et al., 1603.09229

- **Baryons** with exotic flavor content, e.g. positive strangeness or negative charm

- Pentaquarks, di-baryons, gluonium, quark-gluon hybrids, …

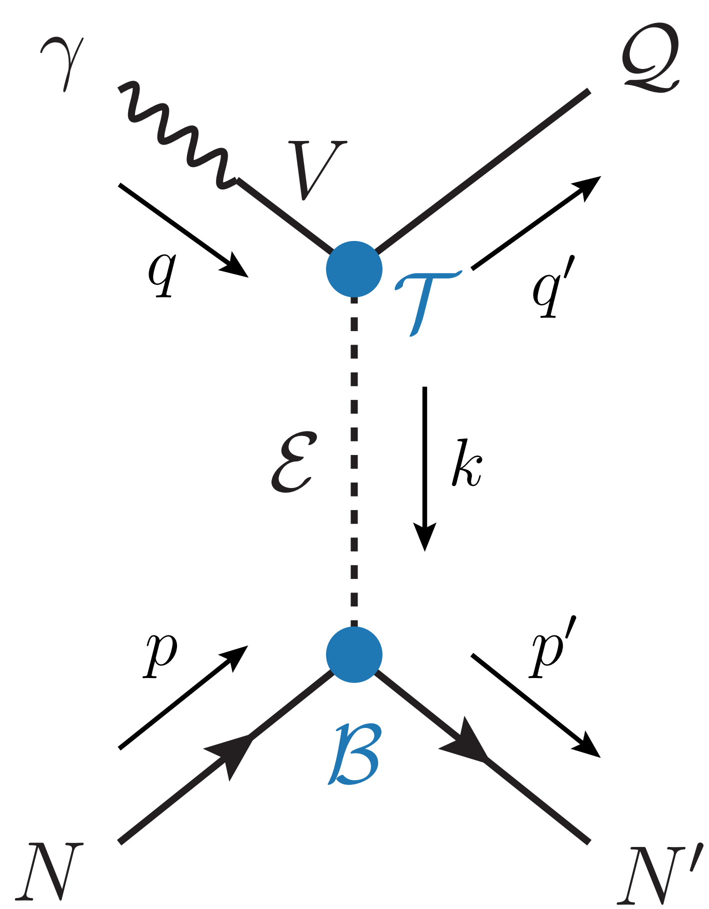
- Lepton beams provide efficient probes of the hadron spectrum,
  due to their point-like nature, free of kinematical effects from 3-body dynamics

- Independent confirmation

- Limited statistics so far at COMPASS and JLab (not yet seen in photoproduction):
  promising for searches with higher-luminosity in electron-ion colliders!

XYZ photoproduction dynamics

- t-channel exchanges assumed to give leading contributions
- **Fixed spin** near threshold:
  full s dependence, but asymptotically s^j (exceeds unitarity bound)
- **Reggeization** at high energies: tower of particles with increasing spin
- Couplings determined from known experimental branching fractions
- VMD assumed for determination of top couplings

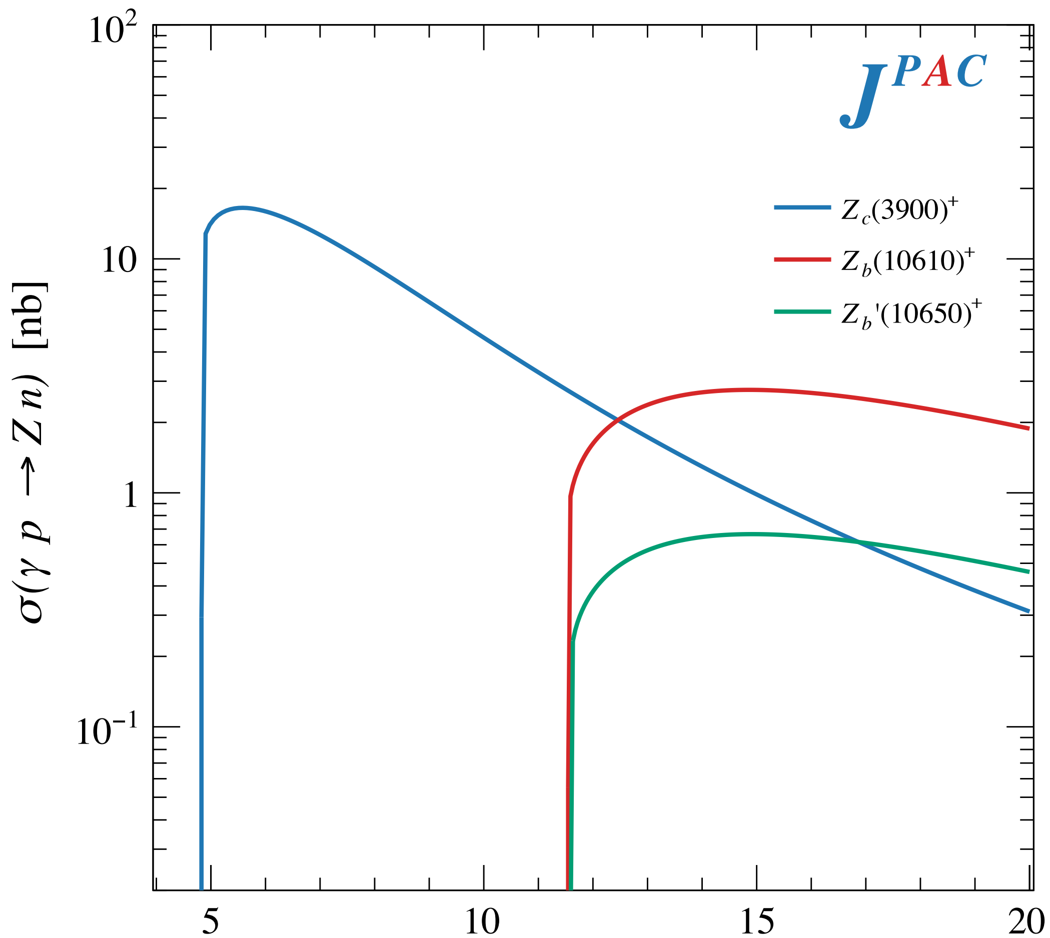


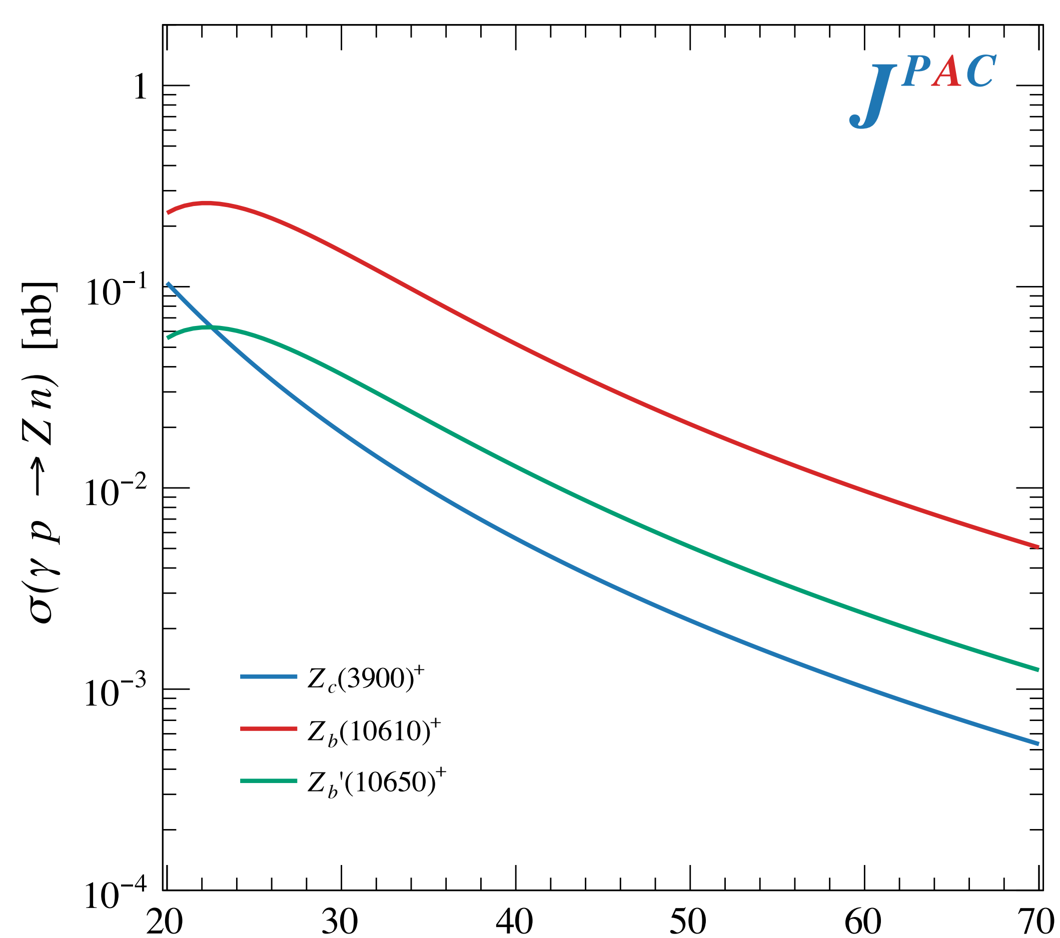
$$< \lambda_{\mathbb{Q}} \lambda'_N | T | \lambda_\gamma \lambda_N > = \sum_{V,\mathscr{E}} \frac{e f_V}{m_V} \mathscr{T}^{\alpha_1 \cdots \alpha_j}_{\lambda_V = \lambda_\gamma, \lambda_{\mathbb{Q}}} \mathscr{P}_{\alpha_1 \cdots \alpha_j; \beta_1 \cdots \beta_j} \mathscr{B}^{\beta_1 \cdots \beta_j}_{\lambda_N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

$$\left(\frac{4\, p(t)\, q(t)}{s_0} \right)^{j-M} \mathscr{N}^j_{\mu\mu'} \frac{d^j_{\mu\mu'}(\theta_t)}{\xi^{(t)}_{\mu\mu'}(s,t)} \frac{1}{t - m^2_{\mathscr{E}}} \longrightarrow -\alpha' \, \Gamma\big(j - \alpha(t)\big) \left[\frac{1 + \tau\, e^{-i\pi\alpha(t)}}{2} \right] \left(\frac{s}{s_0} \right)^{\alpha(t)-M}$$

Z^+ photoproduction: 1^{+-}

- Focus on the 3 narrow states with large branching fractions into pion and vector
- Exotic minimum quark content: $Q\bar{Q}q_1\bar{q}_2$
- Pion exchange and VMD
- Sizeable cross sections especially at low energies

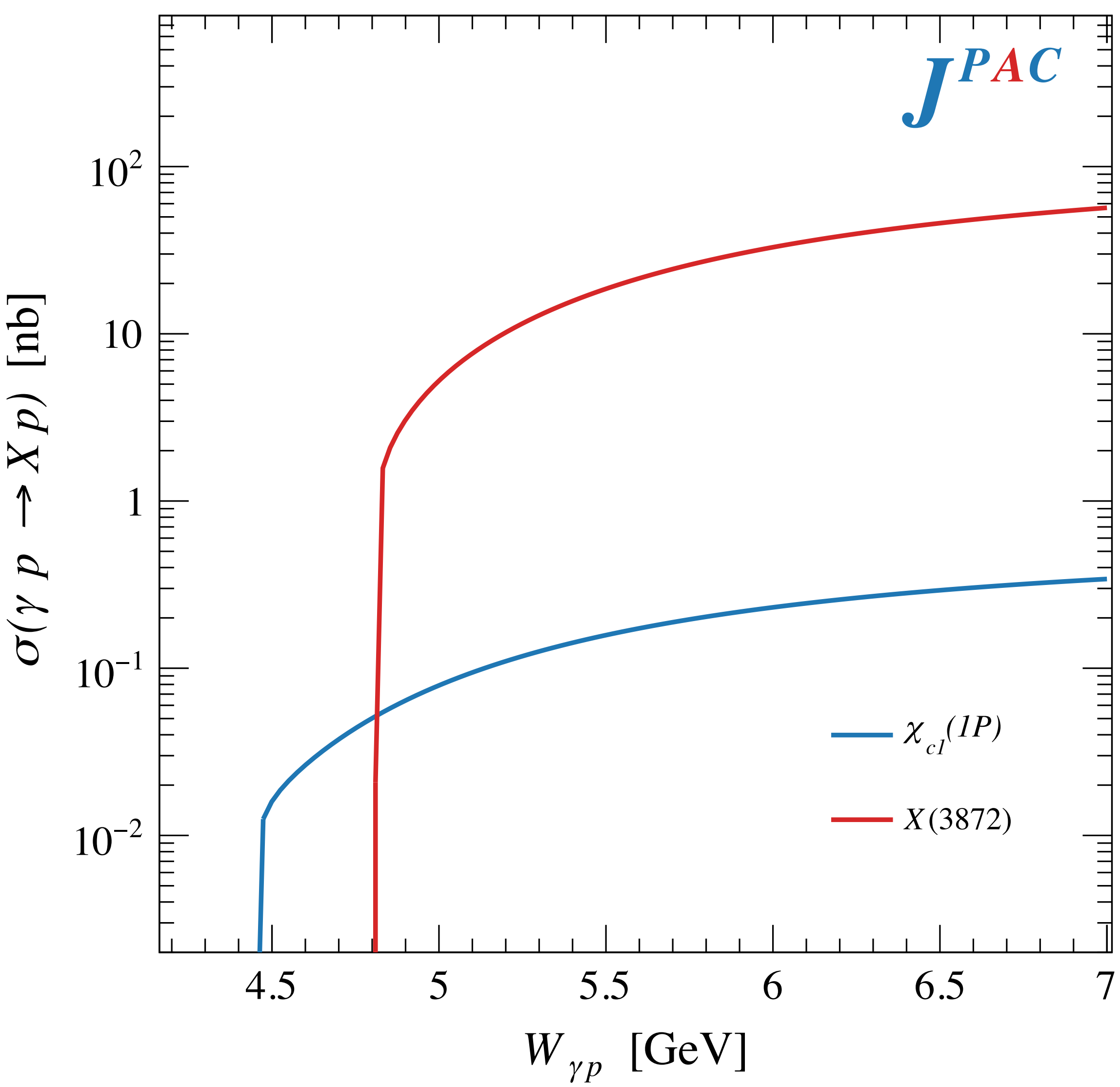


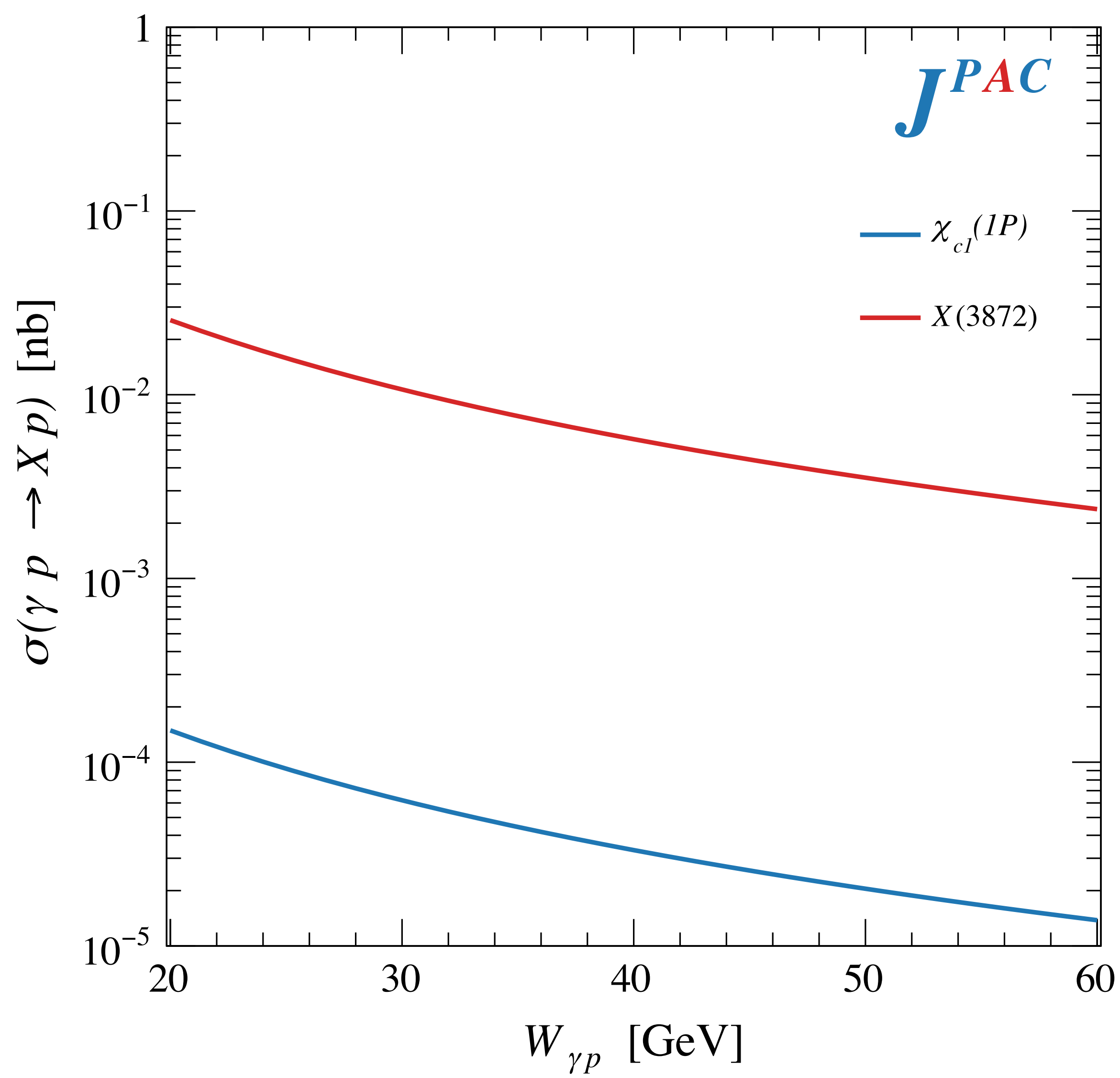


https://github.com/dwinney/jpacPhoto
Albaladejo et al., 2008.01001 [hep-ph]

X and axial vector photoproduction

- Focus on the famous X(3872), **largely isospin violating**, and similar non-exotic χ_{c1}
- $\boldsymbol{\omega}$ and $\boldsymbol{\rho}$ exchanges give main contributions
- Extremely suppressed cross sections at high energies: threshold most promising





Y (hybrid?) and vector-meson photoproduction

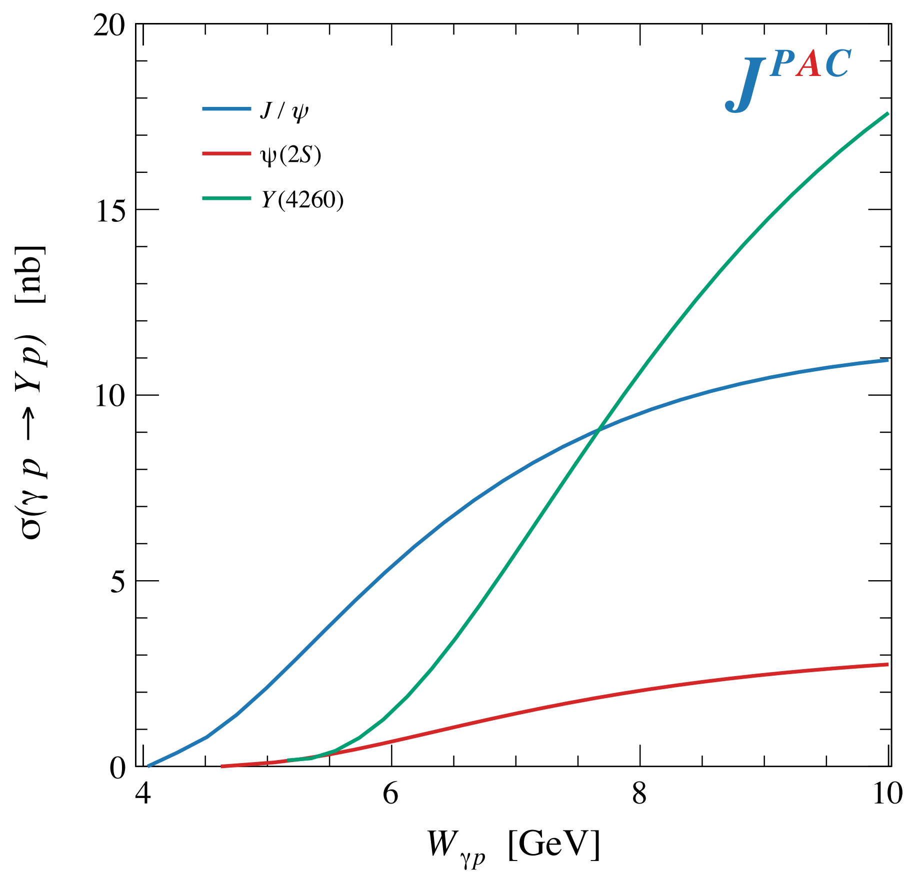
- Known to be well described by Pomeron exchange:
  we use fits from our previous works to LE (GlueX/SLAC) and HE (HERA/ZEUS);
  parameters assumed intrinsic to Pomeron   ANHB et al., Phys. Rev. D 94 (2016) 034002
  Winney et al., Phys. Rev. D 100 (2019) 034019

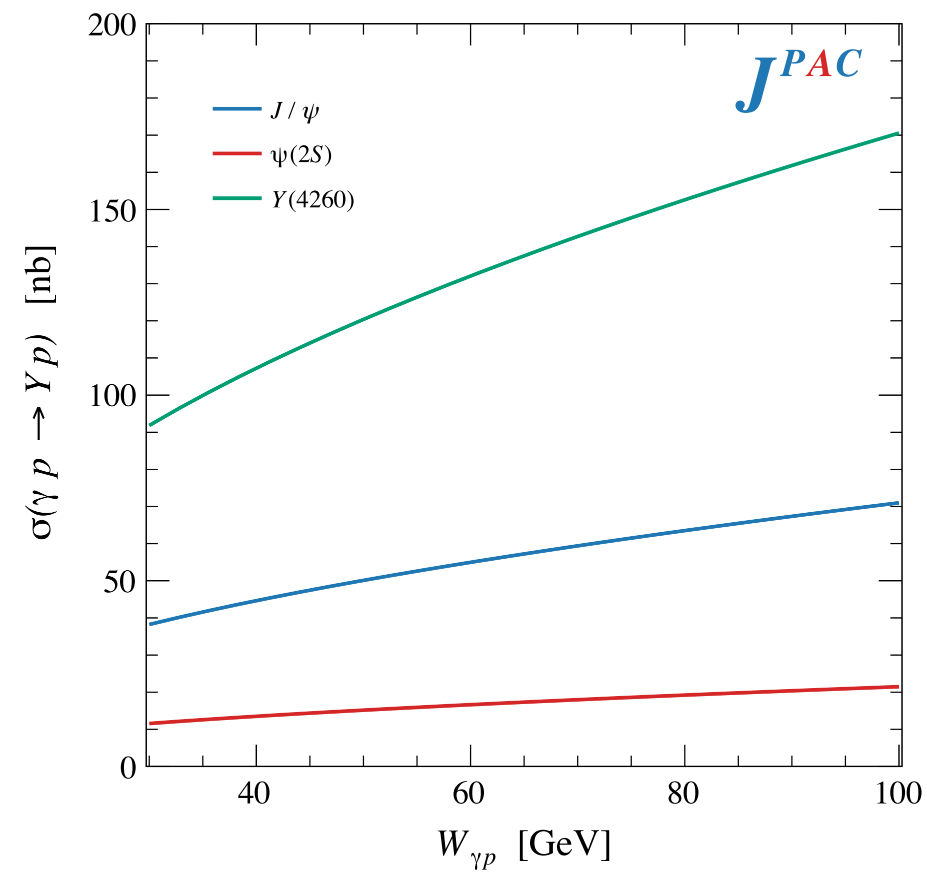
- Coupling ratio to usual J/ψ estimated from decay ratios into ggγ:

  $R_{\psi'} \approx 0.55$ (compatible with HERA/ZEUS $\sqrt{\sigma_{\psi'}/\sigma_{\psi}} \sim 0.39$)

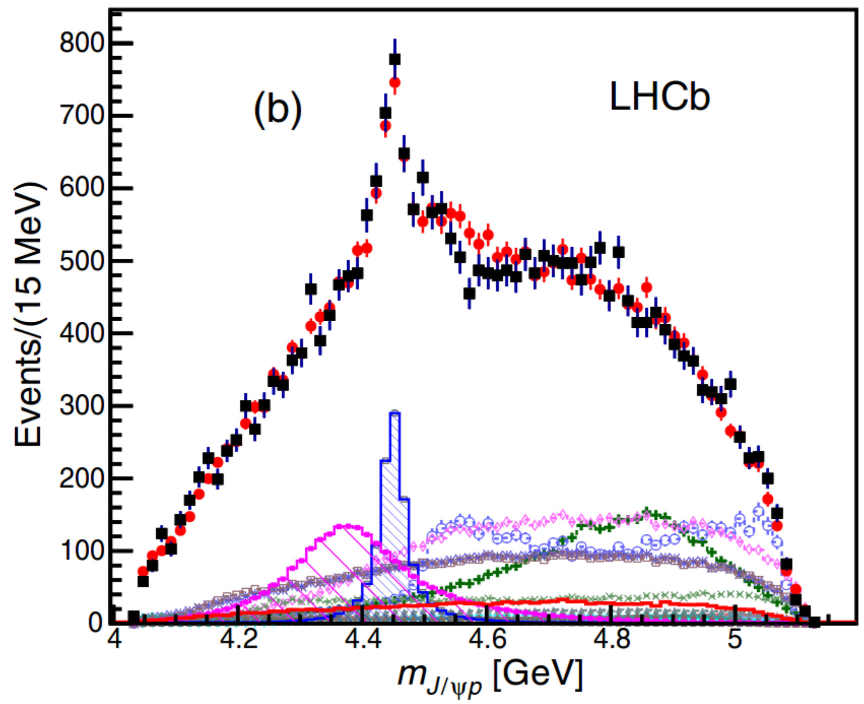
  $R_Y \approx 1.5$ (suggests affinity to gluons as expected for a hybrid Y)

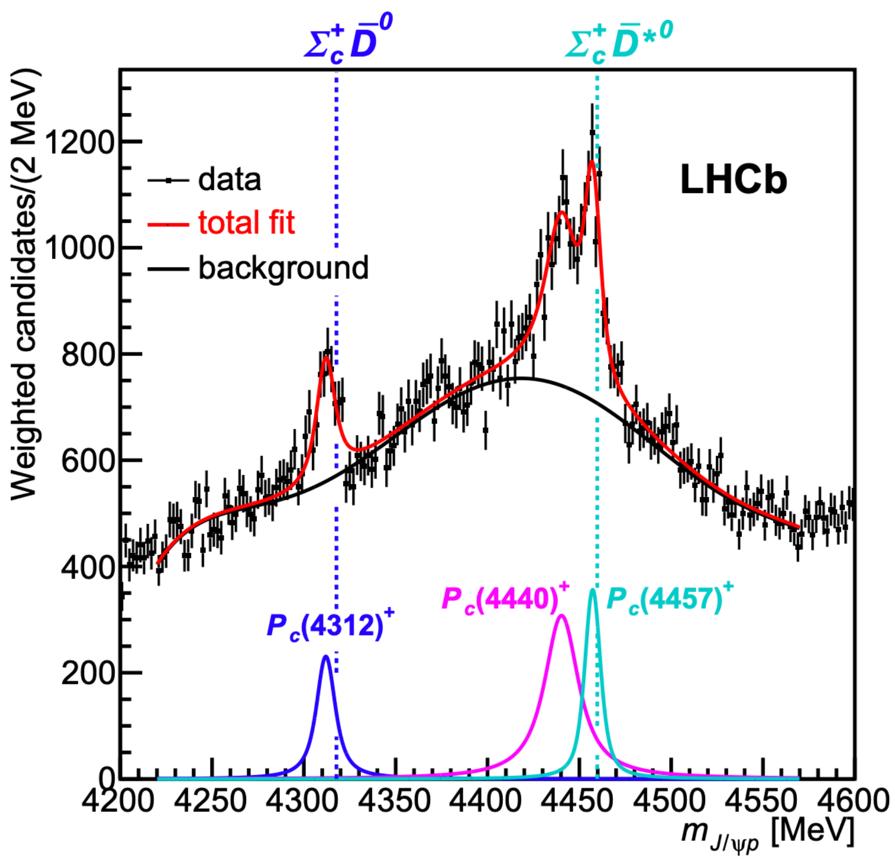
- Good candidates for EIC: diffractive production increases with energy!





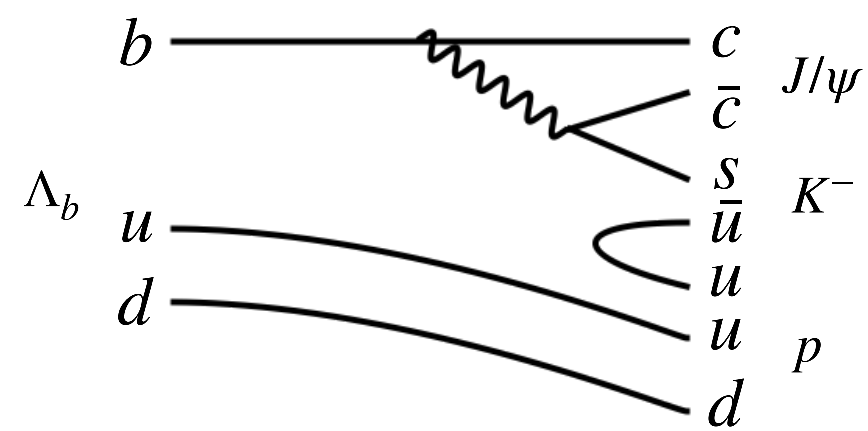
LHCb discovery





- **2015:** **exotic-like** structures in $J/\psi\, p$ channel found

LHCb collaboration, PRL 115 (2015) 072001; PRL 122 (2019) 222001

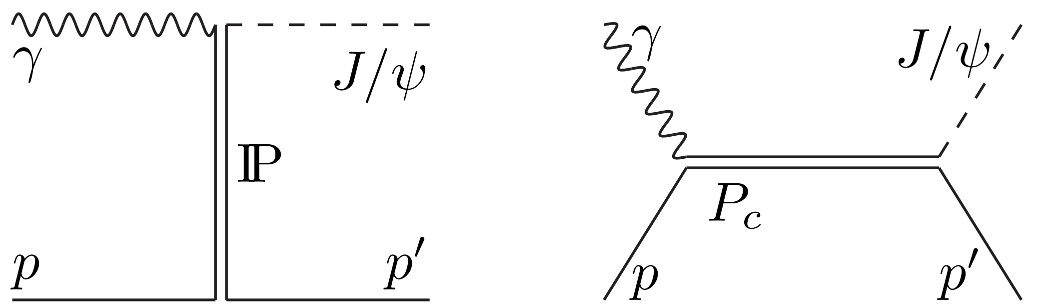


$$P_c \equiv c\bar{c}uud$$

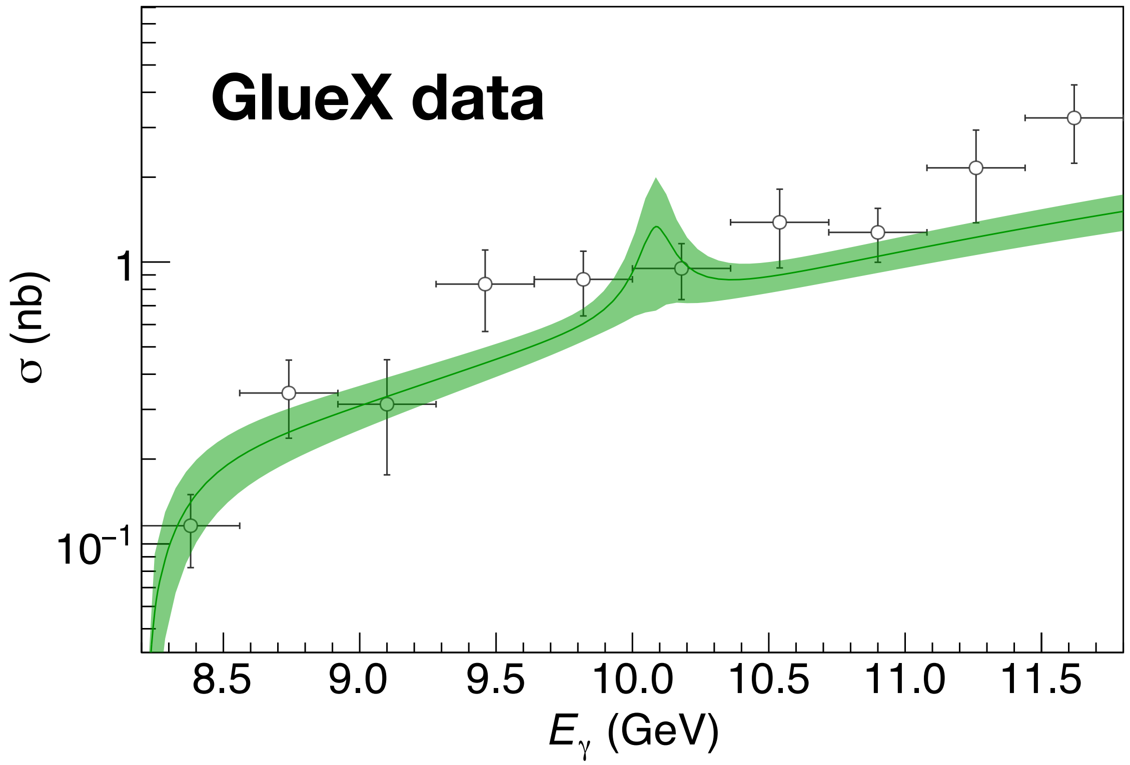
- $K^- p$ resonances (Λ: sud content) not sufficient to fit data
- Compact 5-quark state or weakly-bound $\bar{D}^*\Sigma_c^{(*)}$ interpretations possible
- Or possibly just kinematic effects

Pentaquarks in J/ψ photoproduction

- Confirmation of **resonant nature** vs kinematic effects
- Peak close to threshold: **low background**
- Non-resonant contribution — Pomeron exchange;
  Resonant amplitude — Breit-Wigner ansatz and VMD assumption



ANHB et al., Phys. Rev. D 94 (2016) 034002
Winney et al., Phys. Rev. D 100 (2019) 034019

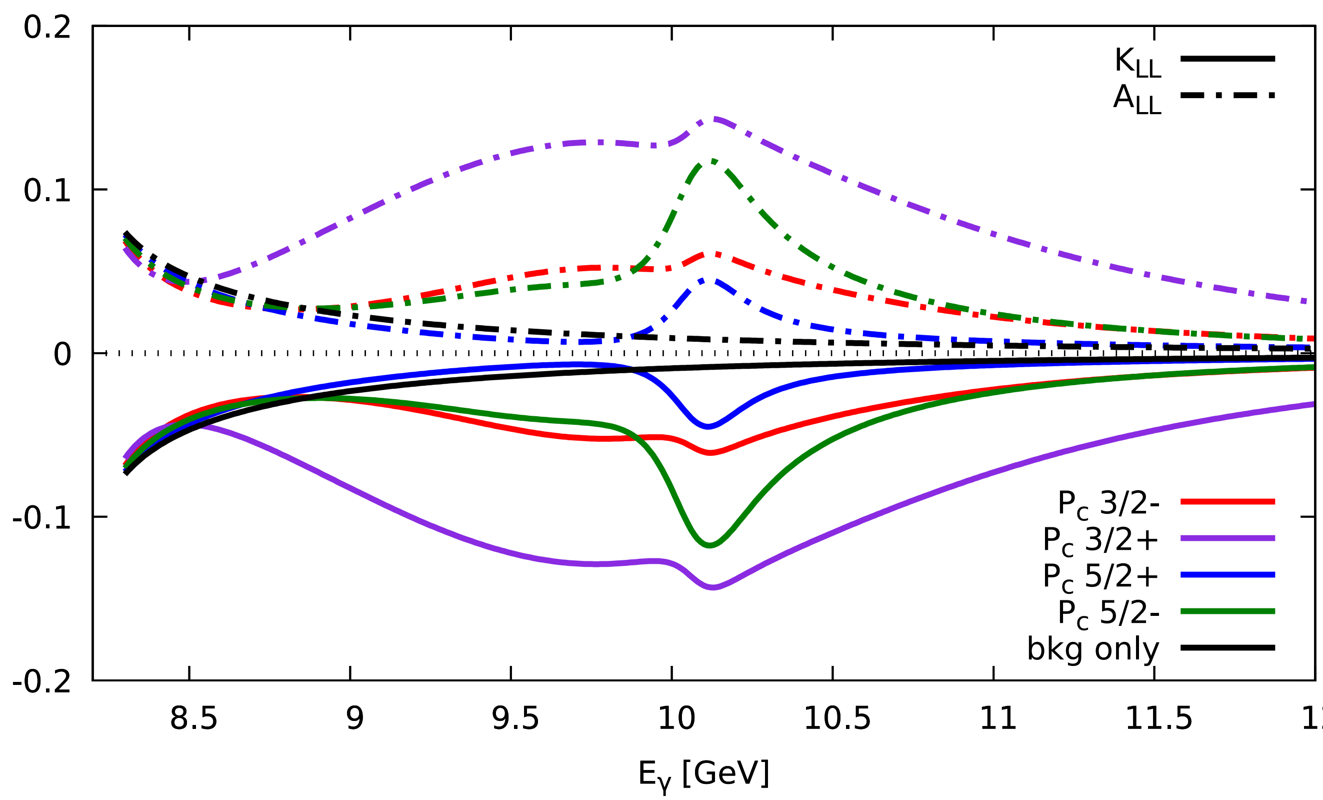


- Fits to GlueX data (no peak evidence) allowed for P_c branching fractions of 1-5%
- If photoproduction experiments fail in finding signals,
  the scenario of LHCb signals being kinematic effects in the final-state is favoured

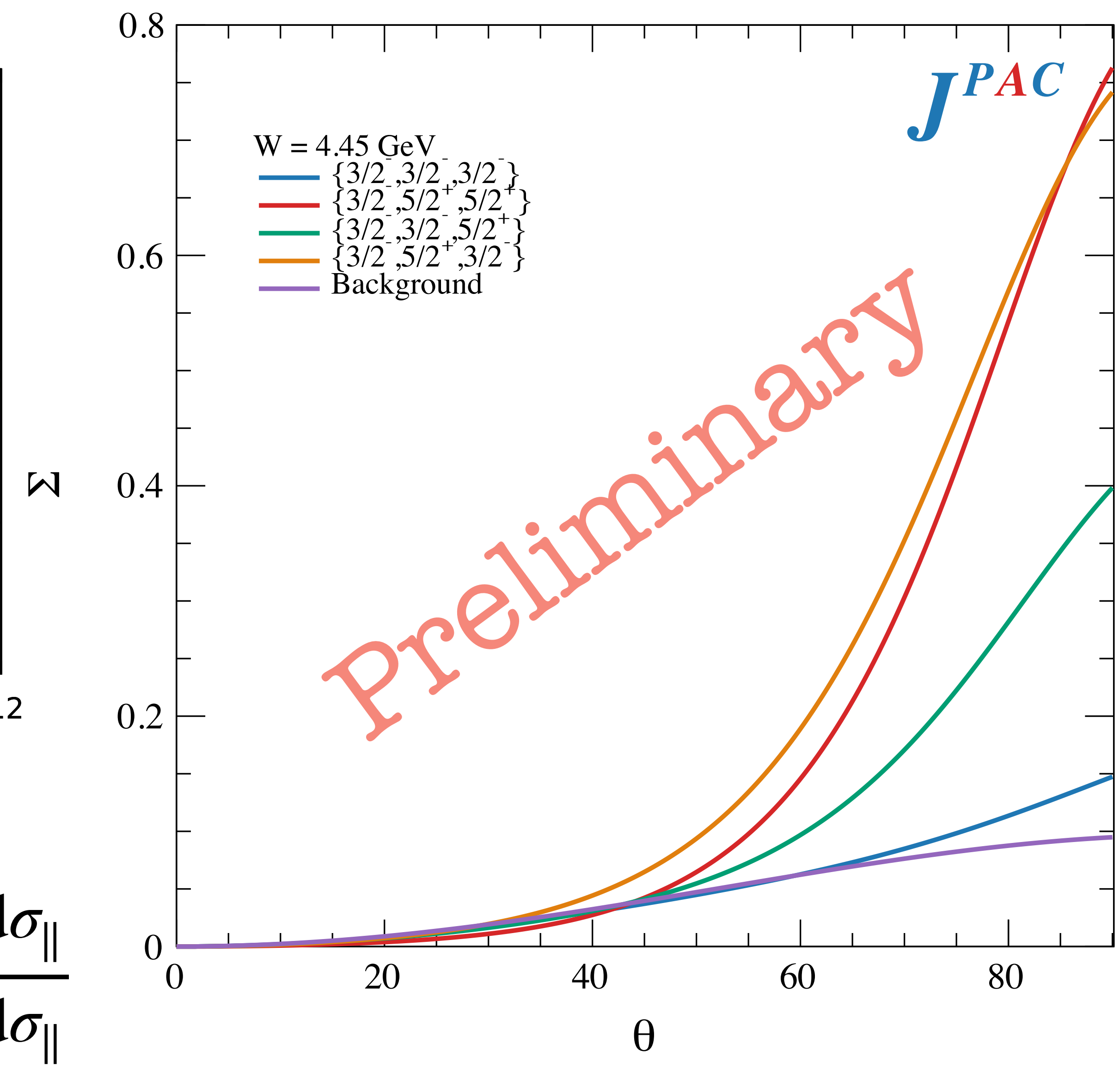
Discriminatory power of polarization observables

- Polarization observables more sensitive to broader or overlapping signals
- With sensitivity studies provided by JPAC, Hall A LoI submitted: measuring $A(K)_{LL}$

LoI12-18-001 (PAC 46)
C. Fanelli, L. Pentchev, B. Wojtsekhowski



Winney et al., Phys. Rev. D 100 (2019) 034019
https://github.com/dwinney/jpacPhoto



$$A(K)_{LL} = \frac{d\sigma(\uparrow\uparrow) - d\sigma(\uparrow\downarrow)}{d\sigma(\uparrow\uparrow) + d\sigma(\uparrow\downarrow)} \qquad \Sigma = \frac{d\sigma_\perp - d\sigma_\parallel}{d\sigma_\perp + d\sigma_\parallel}$$

- Beam asymmetries Σ can provide complementary information!

Summary

- X and Z states most promising close to threshold;
  diffractive states such as the Y are good candidates for the EIC

- P_c searches require higher luminosity at low energies:
  polarization observables!

Outlook:

Albaladejo et al., SNOWMASS21-RF7_RF0-120
Albaladejo et al., SNOWMASS21-RF7_RF0-090
Albaladejo et al., SNOWMASS21-RF7_RF0-081

- **Semi-inclusive** reactions:
  though complicating the identification of final states, they have larger cross sections

- **Electroproduction:** better experimental feasibility

- Studies trivially extended to other XYZP once information about them is available