# Pentaquark Photoproduction

## PWA12/ATHOS7

**Astrid N. Hiller Blin**

ahblin@jlab.org



**Phys. Rev. D94 (2016) 034002**

1606.08912 [hep-ph]

**Phys. Rev. D100 (2019) 034010**

1907.09393 [hep-ph]

September 6, 2021

# Spectroscopy of exotic states

- Since 2003, a plethora of "**exotic**" resonance candidates has been measured: new challenges for quark model.

Choi et al., PRL 91 (2003) 262001
Ablikim et al., PRL 110 (2013) 252001

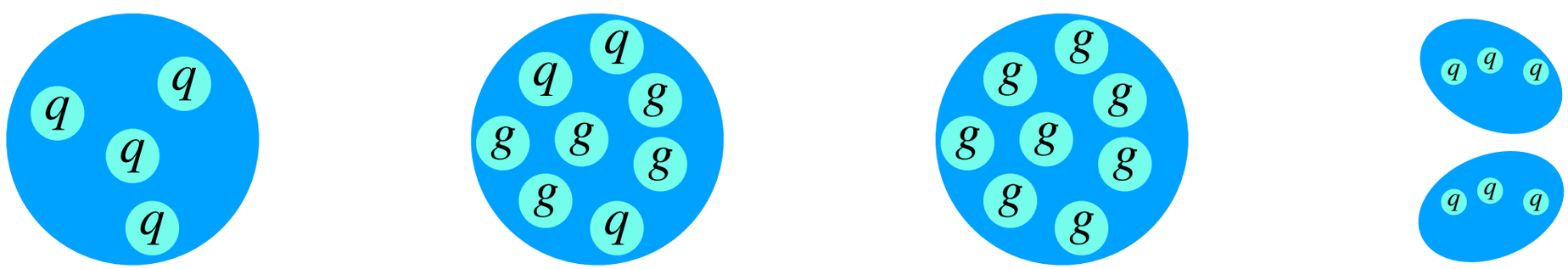
Adolph et al., PLB 740 (2015) 303
Aaij et al., PRL 115 (2015) 072001

Ablikim et al., PRL 118 (2017) 092001
Aaij et al., PRL 122 (2019) 222001

- Many such candidates found in the **meson sector.**

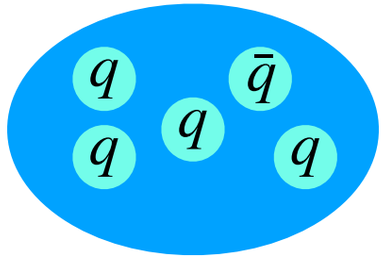
- Mesons whose $J^{PC}$ **cannot be matched by** $q\bar{q}$ **content**: hybrid smoking guns such as $\pi_1$ in $\eta(')\pi$ system, charged quarkonium Z, …

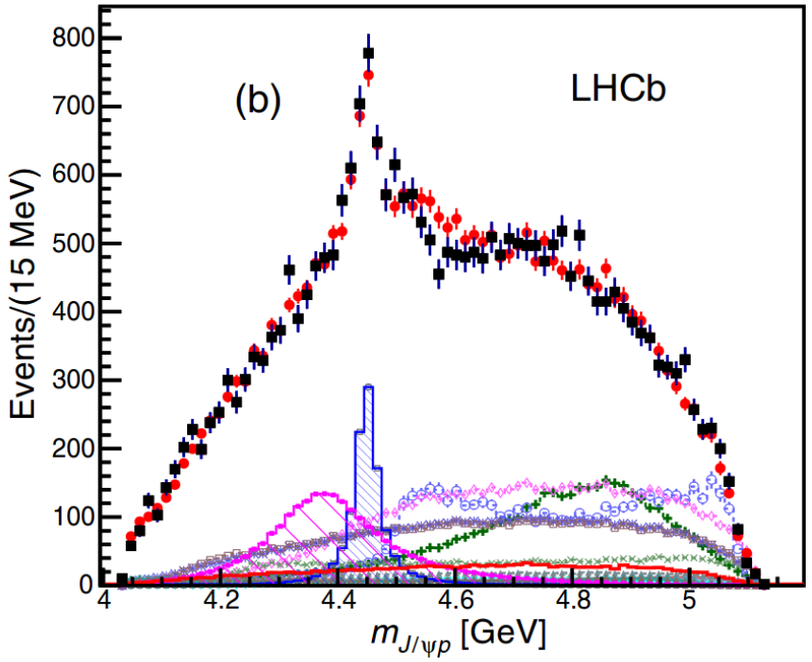
- **Exotic charmonium/bottomonium** - X and Y (vector) states: tetraquarks, hybrids, gluonium, di-baryons, …



# Exotic baryon candidates

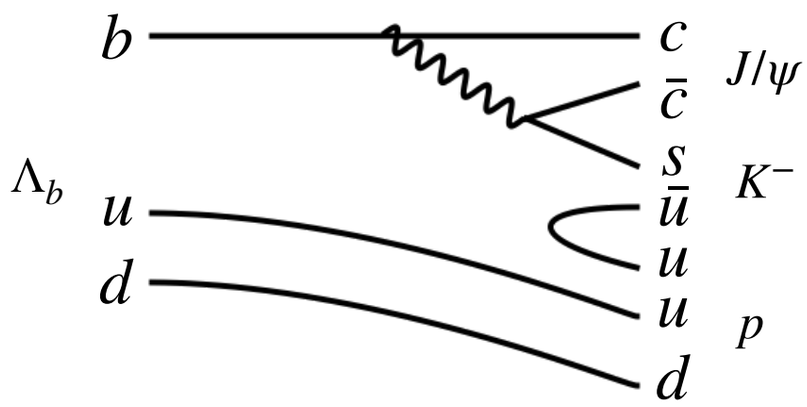
- Baryons with **exotic flavor** (positive strangeness, negative charm, …).
- Hidden-charm(beauty) **pentaquarks**, meson-baryon molecules (just below threshold and with sizable spatial extension), …




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

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




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

# Resonances? Or other nature?

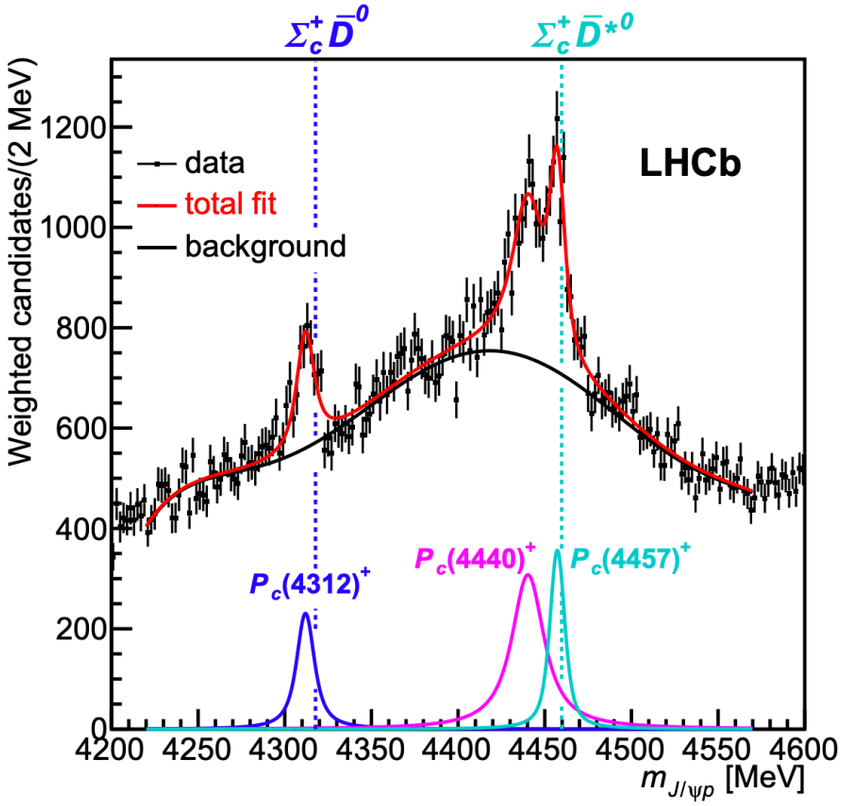
- **Resonances** arise due to poles of non-perturbative **dynamical nature** (interaction strength between quarks and gluons and among hadrons).
- **Kinematical singularities** determined by masses, energies of reaction particles: **triangle singularities** are close to pertinent thresholds and might be misidentified.

Esposito et al., PR 668 (2017) 1
Brambilla et al., PR 873(2020) 1
Hosaka et al., PTEP 2016 (2016) 062C01

Brambilla et al., EPJC 71 (2011) 1534
Guo et al., PPNP 112 (2020) 103757

- In electro- and photoproduction, we have **beams of point-like particles**: efficient, **complementary** measurements of the hadron spectrum and structure.
- Limited statistics so far: need for confirmation and independent studies.
  **Promising for high-luminosity searches at JLab and electron-ion colliders!**

# LHCb pentaquark discovery

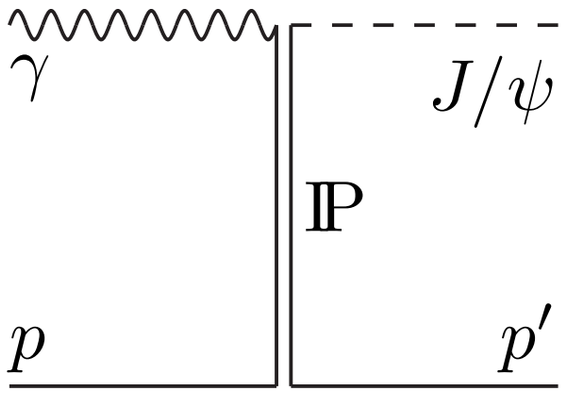


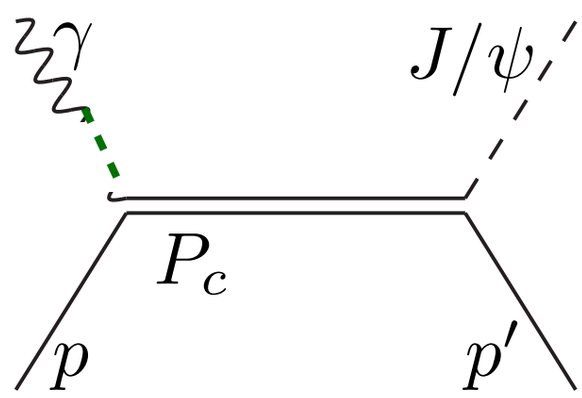

- Updated to three confirmed narrow peaks: $P_c(4312)$, $P_c(4440)$, and $P_c(4457)$.
- Two of them overlap.
- Not yet known spin-parity assignments.

- Possible interpretations: **compact** 5-quark state;
- Weakly-bound $\bar{D}^*\Sigma_c^{(*)}$;
- Or possibly just **kinematic effects**.

# Our goal: pentaquarks in $J/\psi$ photoproduction

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



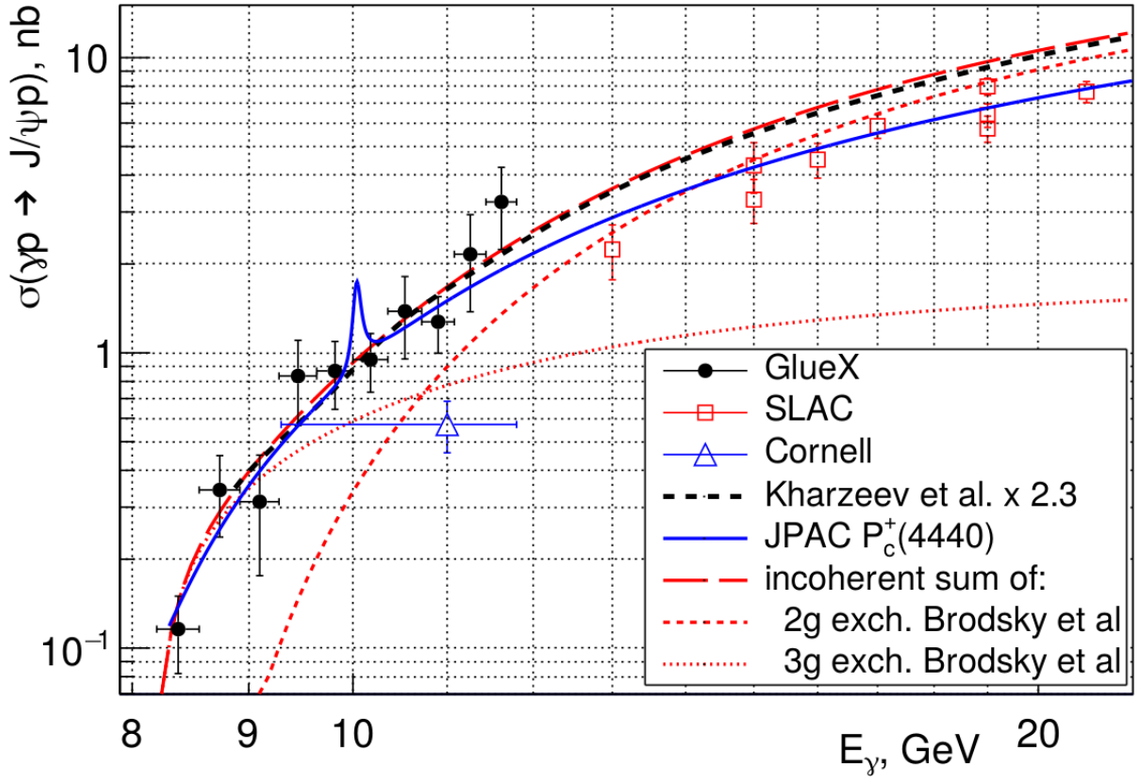




ANHB et al., Phys. Rev. D 94 (2016) 034002
Winney et al., Phys. Rev. D 100 (2019) 034019

- Hadronic couplings related to $P_c \to J/\psi\ p$ branching fractions.
- Photocouplings estimated via vector-meson dominance.
- Still leaves room for 3 independent couplings (spin-1 production): initially assumed of equal size.

# Fits to data

- Fits to (off-peak) data allow to constrain Pomeron parameters.
- Spin-parity assignment unknown, so different scenarios analyzed:
  however, in principle $6^3$ possibilities (6 $J^P$ assignments, 3 $P_c$ signals)!
- Fits to low-energy data (GlueX and SLAC) allow for branching fractions of 1-5%:
  model dependent, thus constraining validity of some predictions.
- If photoproduction experiments fail in finding signals (Hall A/C update coming soon),
  scenario of kinematic effects becomes more and more favored.



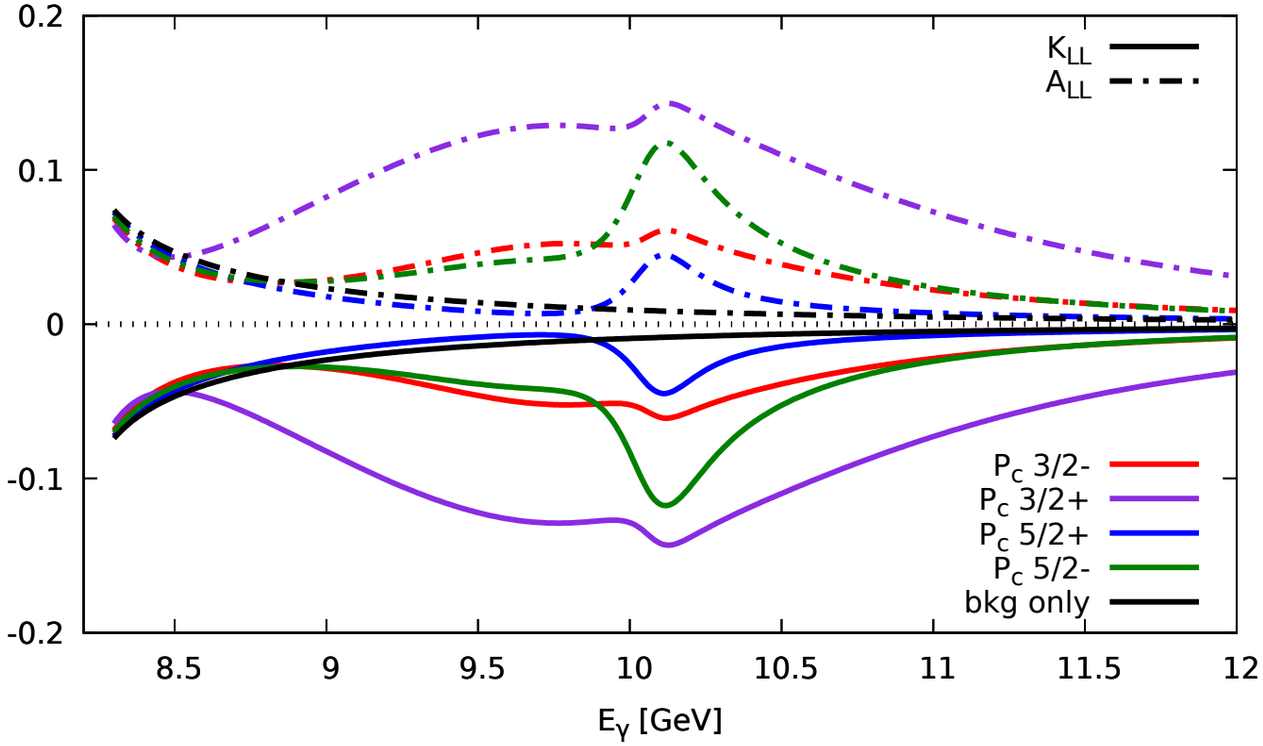
# Discriminatory power of polarization observables

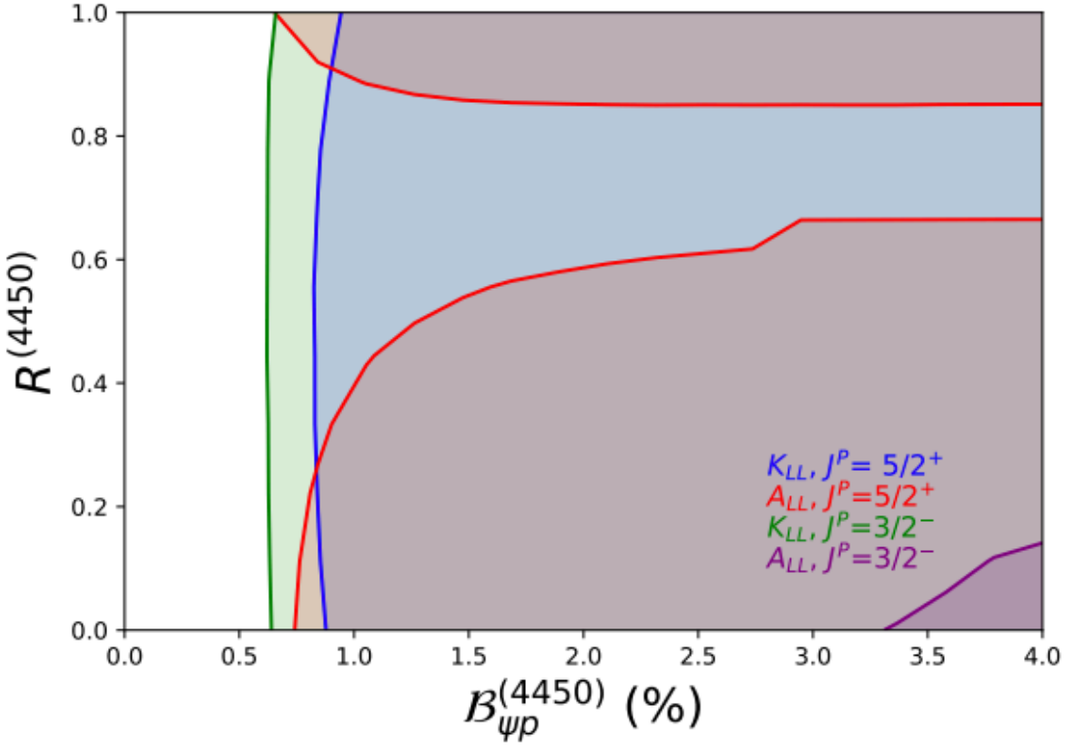
- Polarization observables more sensitive to broader or overlapping signals.
- Helpful information for determining quantum numbers.

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

- With sensitivity studies provided by JPAC, Hall A LoI submitted: measuring $A(K)_{LL}$.

$$A(K)_{LL} = \frac{\mathrm{d}\sigma(\uparrow\uparrow) - \mathrm{d}\sigma(\uparrow\downarrow)}{\mathrm{d}\sigma(\uparrow\uparrow) + \mathrm{d}\sigma(\uparrow\downarrow)}$$



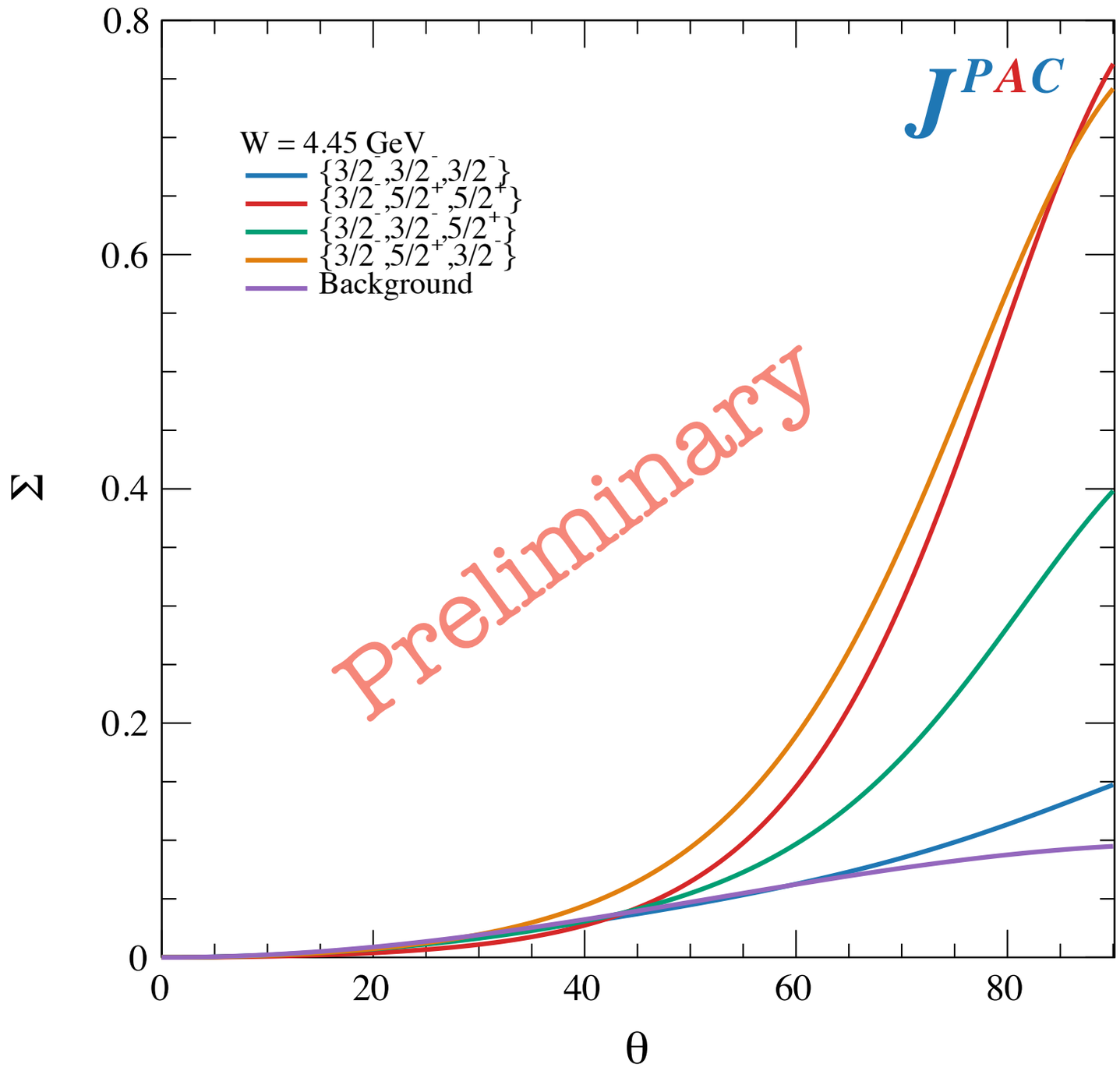




Winney et al., Phys. Rev. D 100 (2019) 034019
https://github.com/dwinney/jpacPhoto

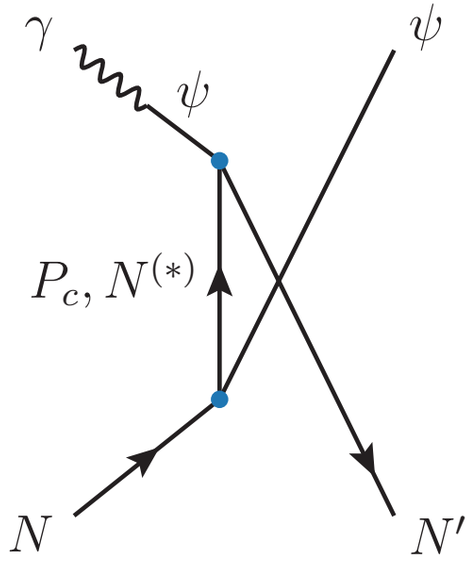
# Beam asymmetries: a complementary option

Wang et al., Phys. Rev. D 99 (2019) 114007

$$\Sigma = \frac{d\sigma_\perp - d\sigma_\parallel}{d\sigma_\perp + d\sigma_\parallel}$$



# EIC for higher luminosity?




- $s$ channel resonances significant at low energies —not in the ideal EIC range.
- $u$ channel dominates at high energies, main contributions are $N^{(*)}$ trajectories.
- $P_c$ coupling upper bound of same order of magnitude as $N$ coupling.
- Suppressed $P_c$ trajectory due to larger mass, hardly visible at EIC energies: low-energy, high-luminosity experiments called for.
- $P_b$ searches optimal at EIC in $s$ channel at higher energies!

Cao et al., Phys. Rev. D 101 (2020) 074010

# Summary and open challenges

- $P_c$ searches require higher luminosity at lower energies.
- Spin-parity assignments unknown — not many model constraints.
- Vector-meson dominance is just an approximation: how well does it work?
- Possibility: **polarization observables!**
- **Semi-inclusive** reactions:
  complicate the identification of final states, but have larger cross sections.
- **Extension to electroproduction:** better experimental feasibility.
- Structure and nature of the exotic states needs to be understood.