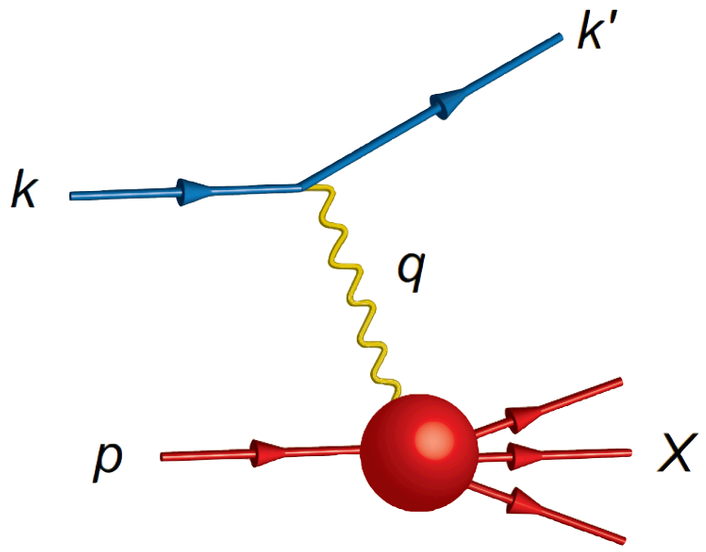
Photoproduction at the EIC

Justin Stevens

William & Mary
CHARTERED 1693

U.S. DEPARTMENT OF ENERGY | Office of Science

Photoproduction

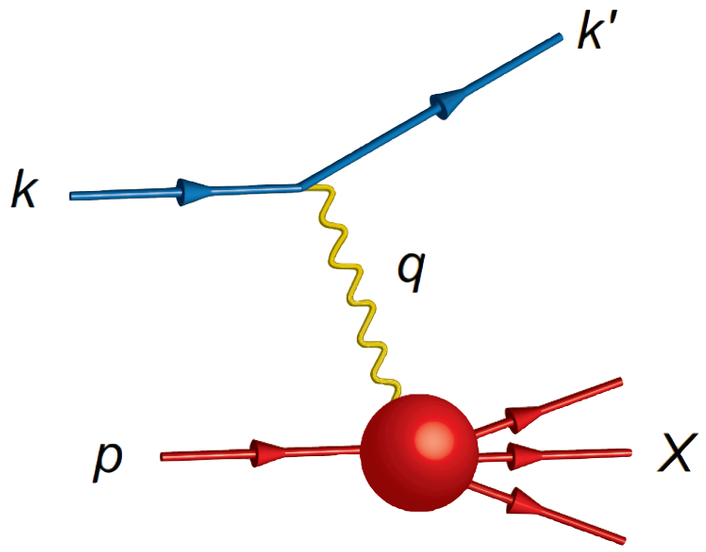


Quasi-real photons: $Q^2 < 1$ GeV^2
Real photons: $Q^2 = 0$

No hard scale in production

- What are some questions we can address with photoproduction?

Photoproduction



Quasi-real photons: $Q^2 < 1$ GeV^2
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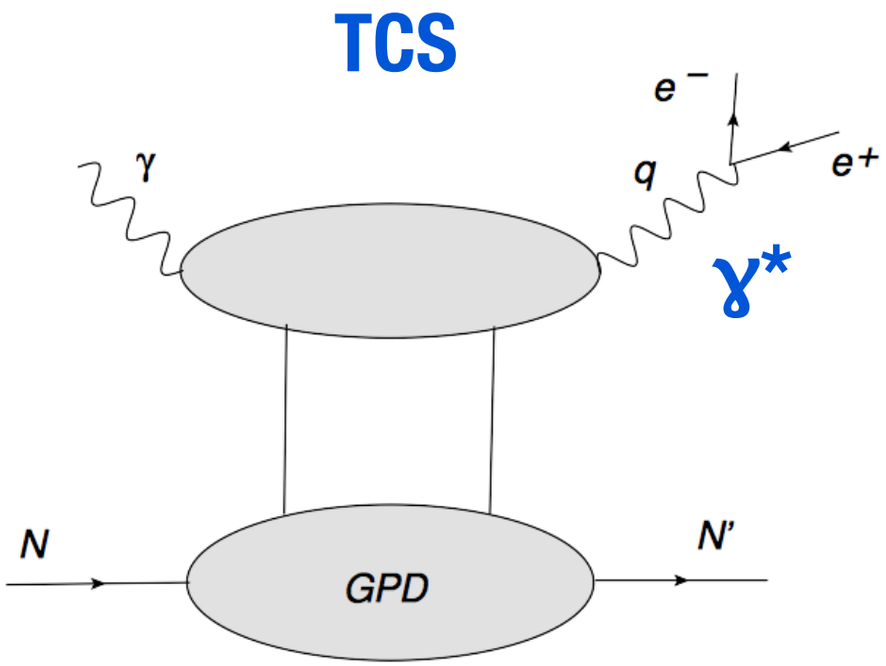
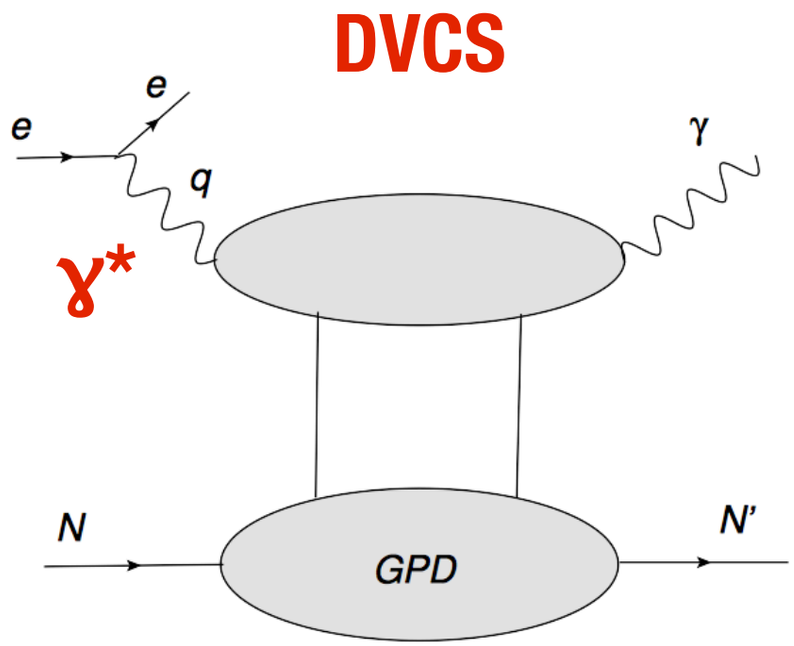
No hard scale in production

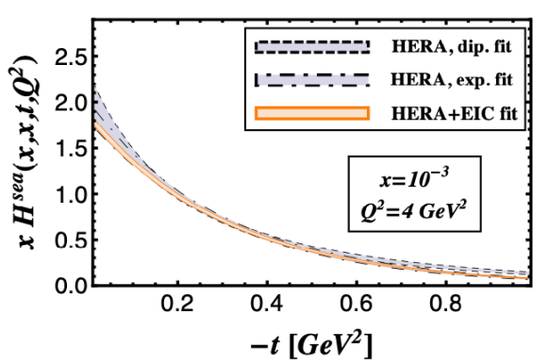
- What are some questions we can address with photoproduction?
  - **Nucleon structure (GPDs): Timelike Compton Scattering**
  - **Gluon distributions in nucleons and nuclei: Exclusive VM production**
  - **Hadron spectroscopy: XYZ, pentaquarks, gluonic hybrids, etc.**
- This talk: some biased examples (not an exhaustive list)

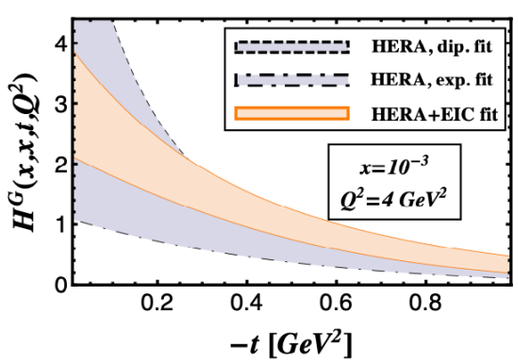
Nucleon structure (GPDs)

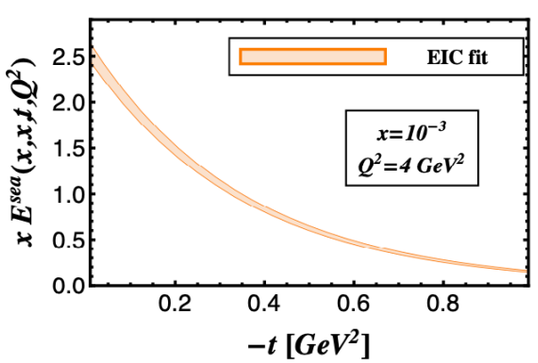




- **Timelike Compton Scattering**: perturbative hard scale set by outgoing di-lepton pair, rather than scattered electron
- Complementary to **DVCS**: universality of GPDs, different access to Compton Form Factors (H, E), systematics, etc.





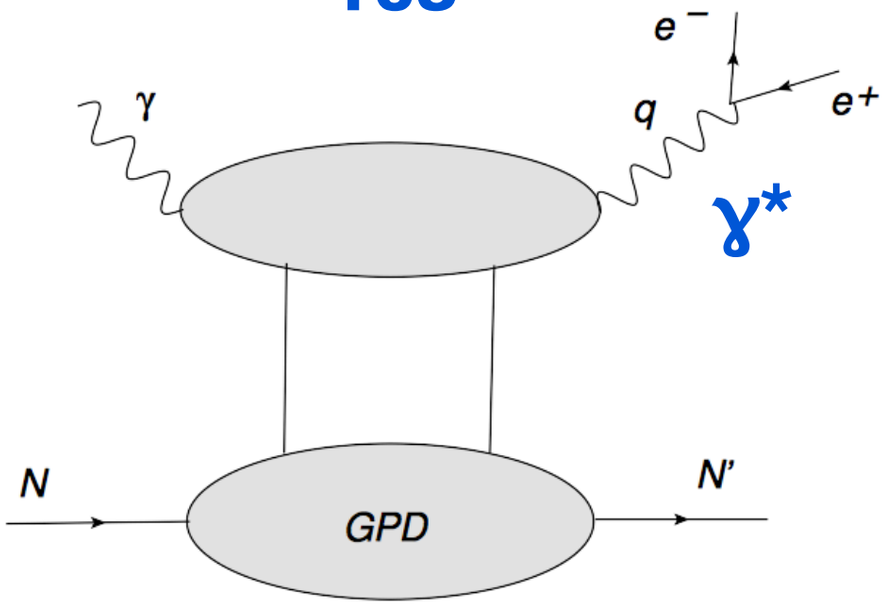


Impact studies of EIC DVCS data

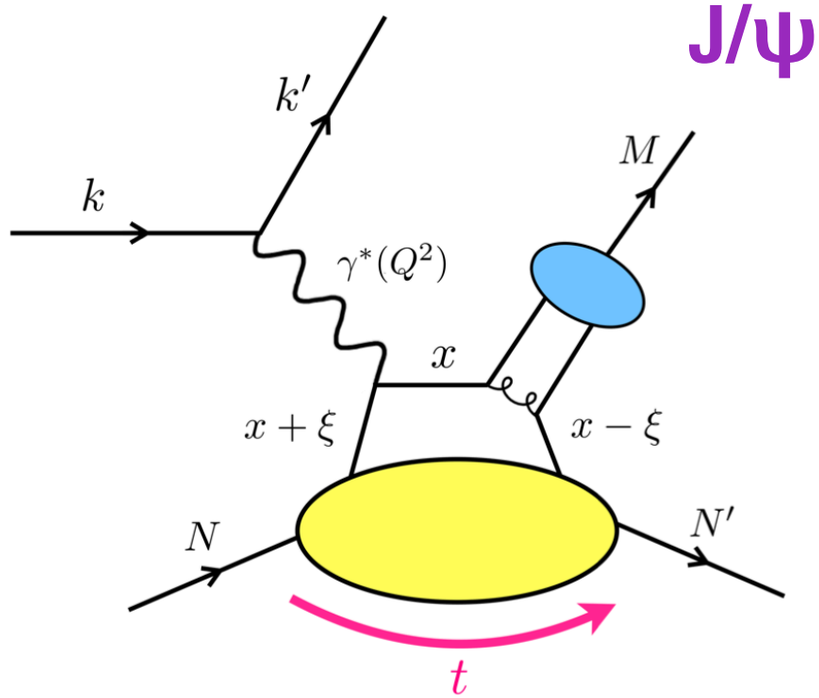
JHEP 9, 93 (2013)

Vector meson production

TCS



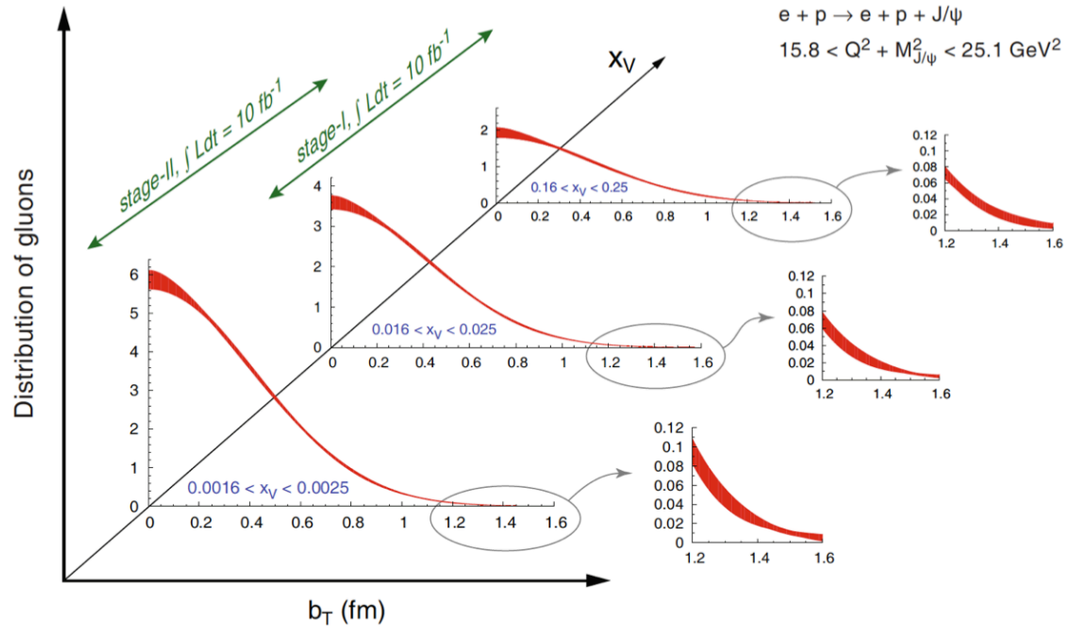
J/ψ, ϒ

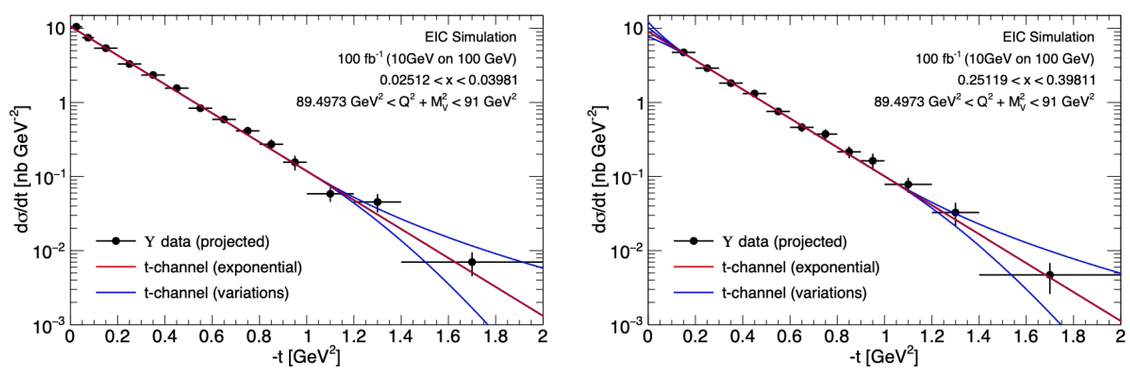


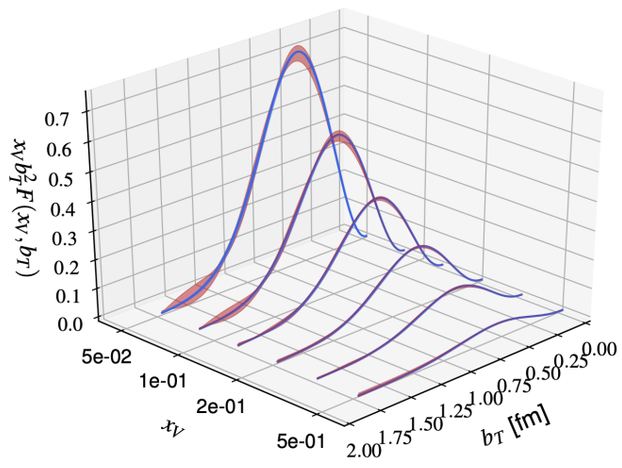
- **Timelike Compton Scattering**: perturbative hard scale set by outgoing di-lepton pair, rather than scattered electron
- **Heavy VM photoproduction:** gluon distribution in nucleons and nuclei beyond measurements at HERA, LHC, and RHIC
  - Ongoing UPC AA or pA at RHIC and LHC: eA is a cleaner probe
  - Similar requirements as TCS for forward proton and di-leptons

Vector meson production

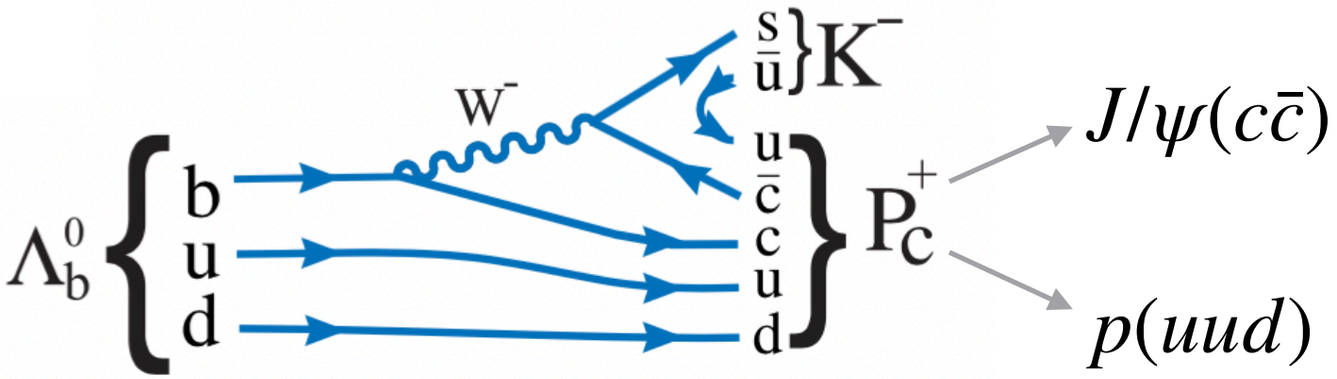
- Impact Parameter Distributions (IPD): $f(x, b_T)$ obtained from FT of dσ/dt for J/ψ with 10 fb^{-1}
- Recent work on heavier ϒ shows complimentary performance with higher luminosity of 100 fb^{-1}
- Threshold photoproduction of VMs
  - Trace Anomaly, origin of proton mass (recent workshop)
  - Exotic hadron production?



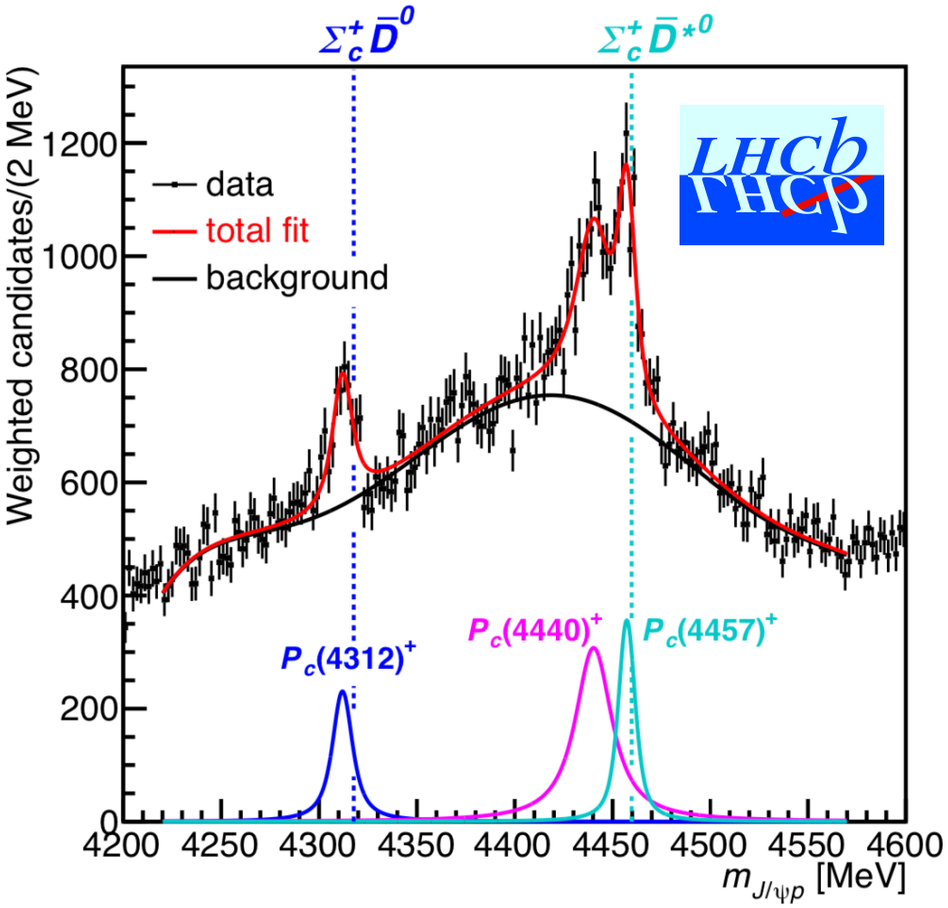


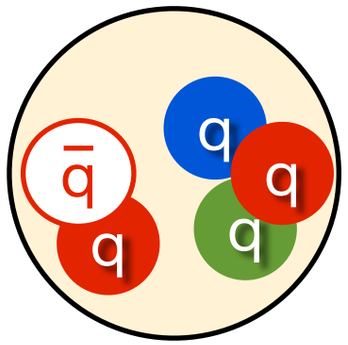


Threshold VM production and P_c^+

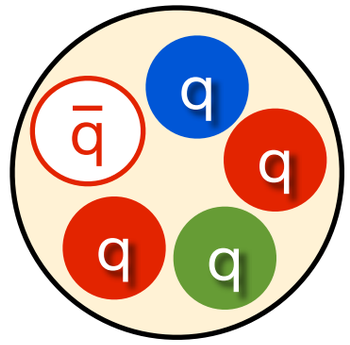


$$\Lambda_b \to J/\psi p K^-$$

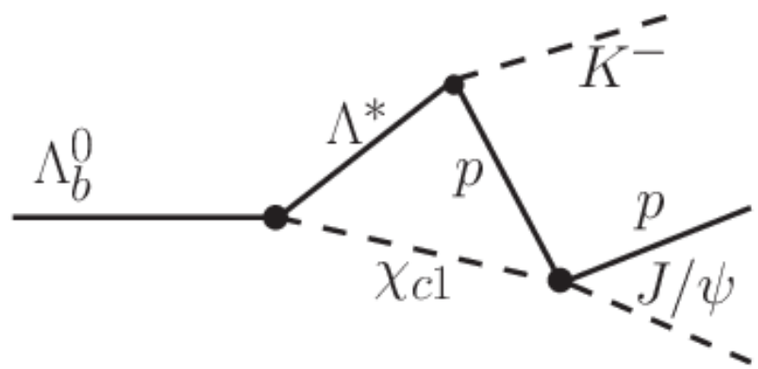




hadron molecule?

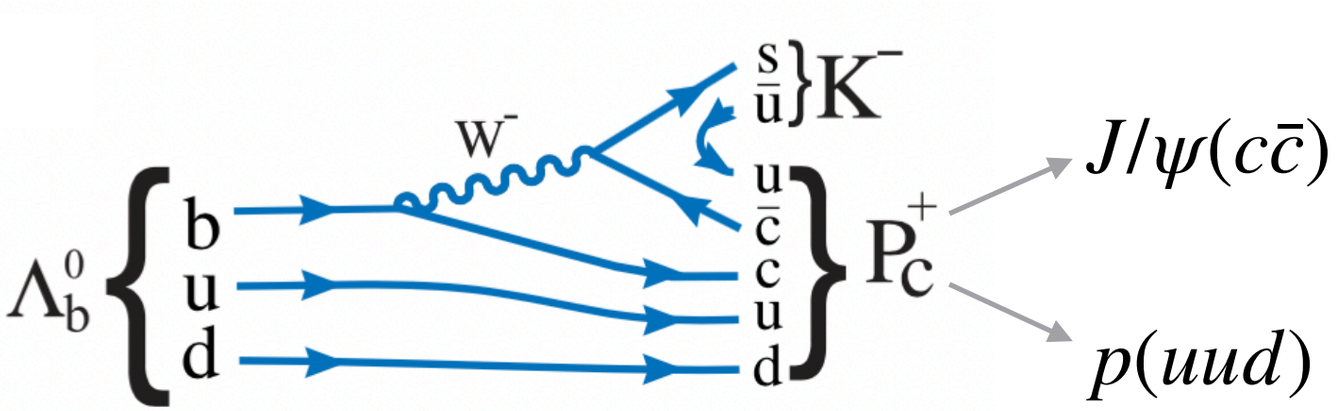


pentaquark candidate?

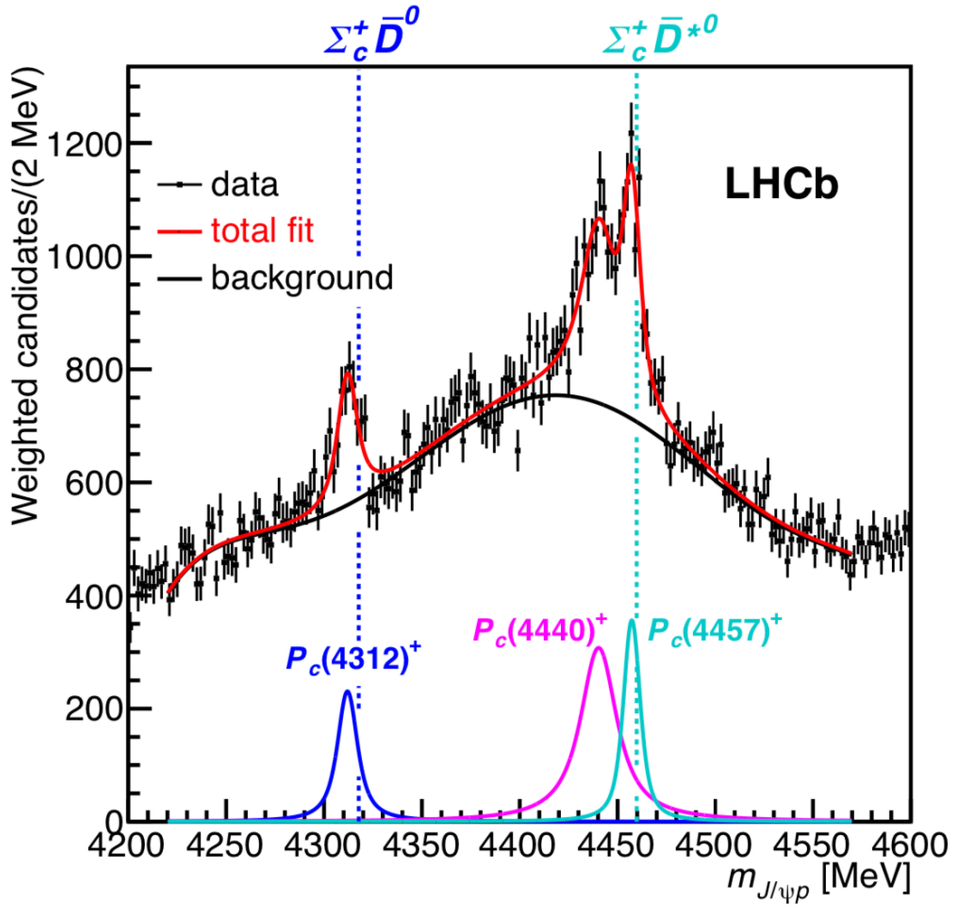


Re-scattering (triangle singularity)?

Threshold VM production and P_c^+

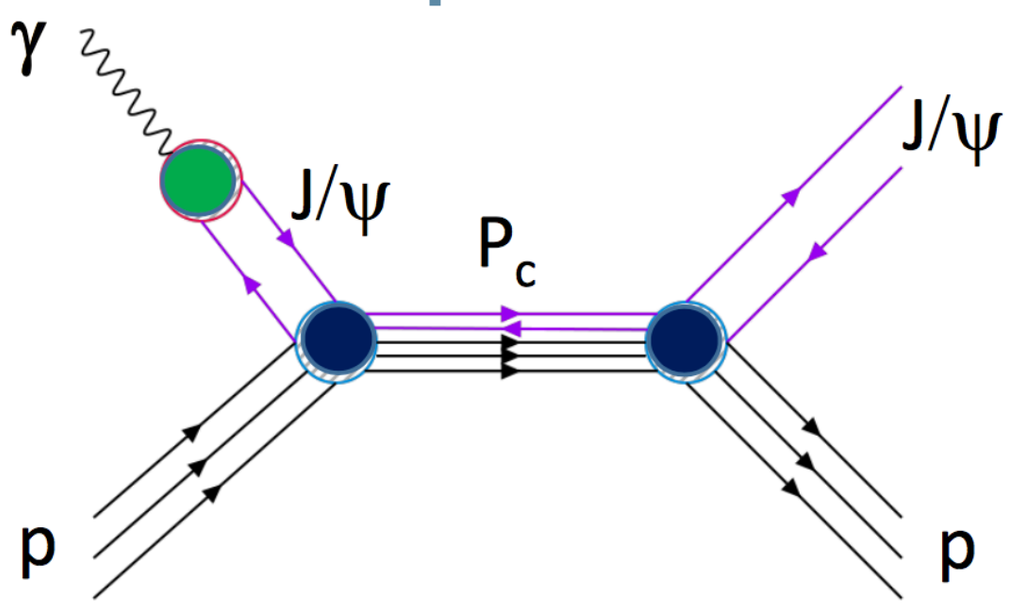


$$\Lambda_b \to J/\psi p K^-$$



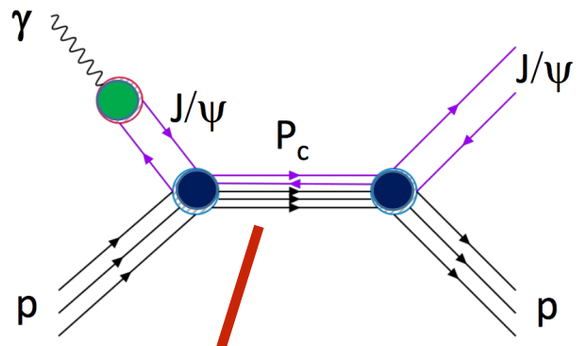
PRL 122, 222001 (2019)

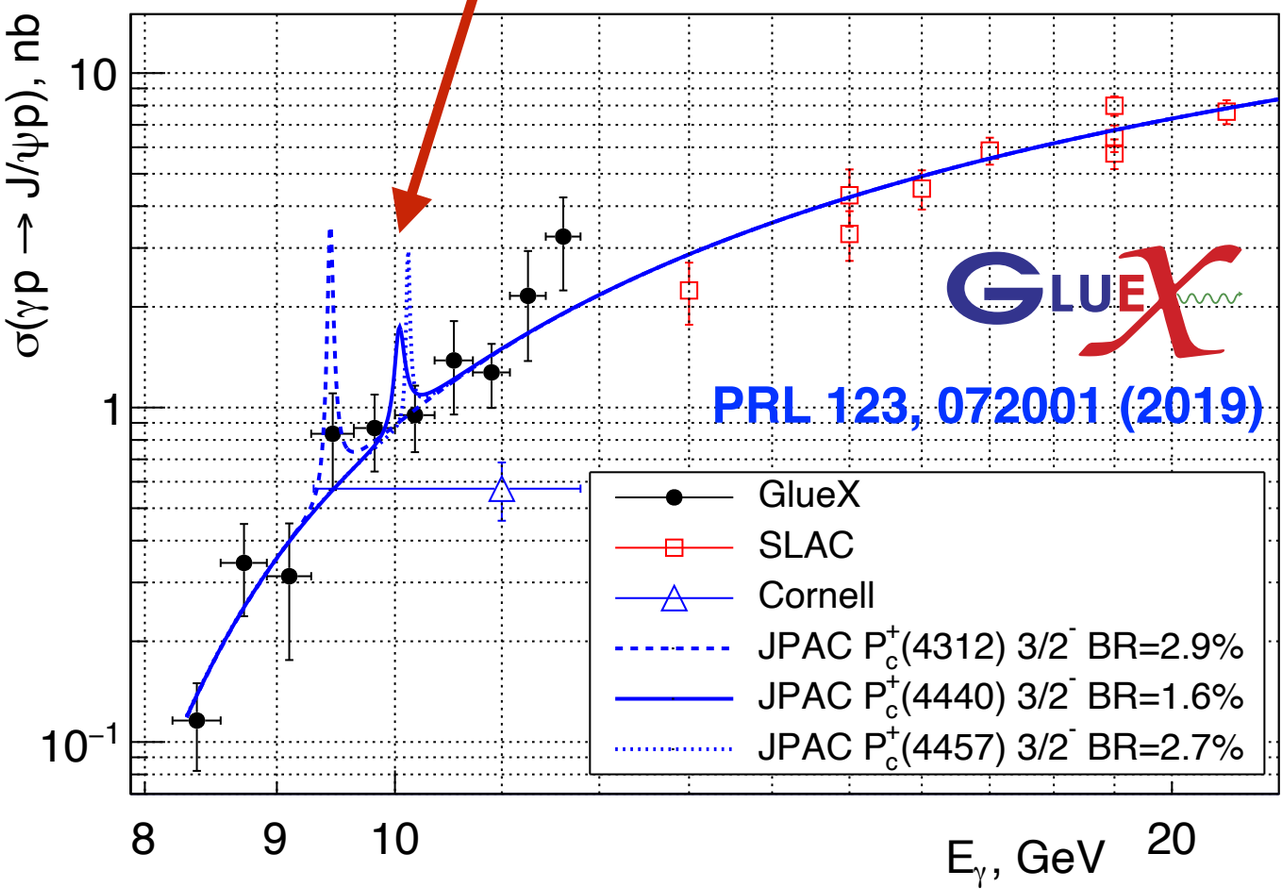
Photoproduction



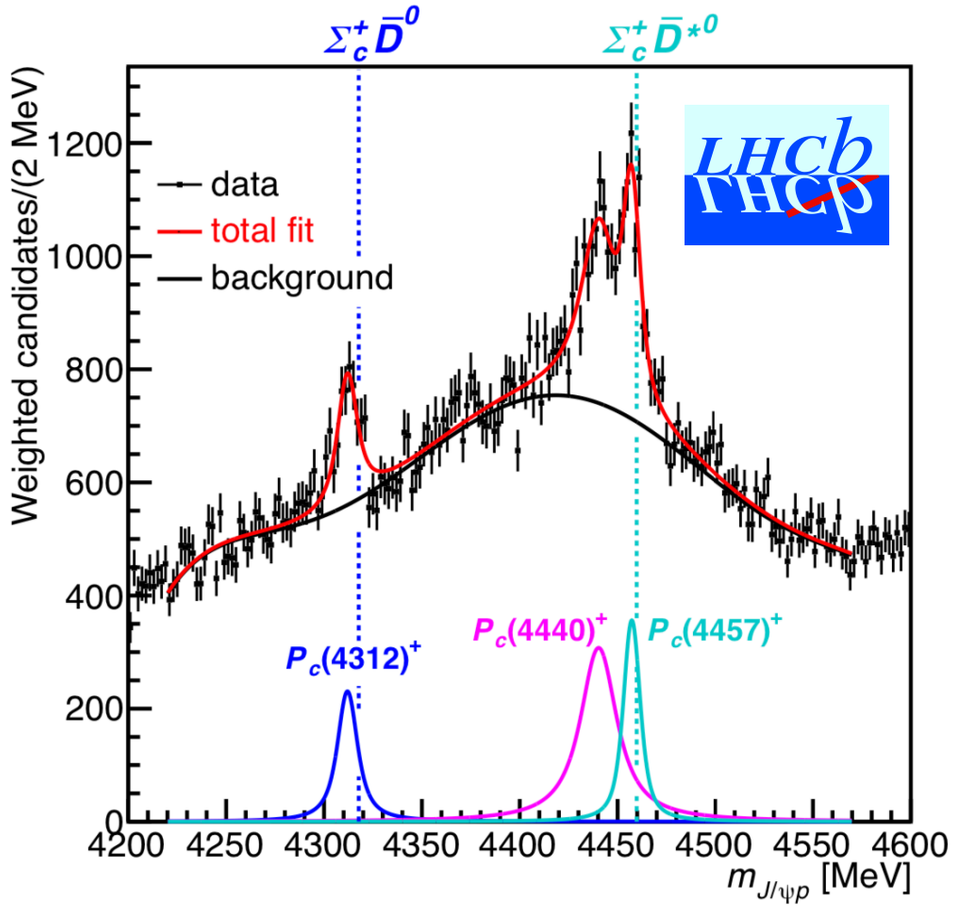
- Proportional to $BR(P_c \to J/\psi p)^2$
- Free of re-scattering effects

Threshold VM production and P_c^+





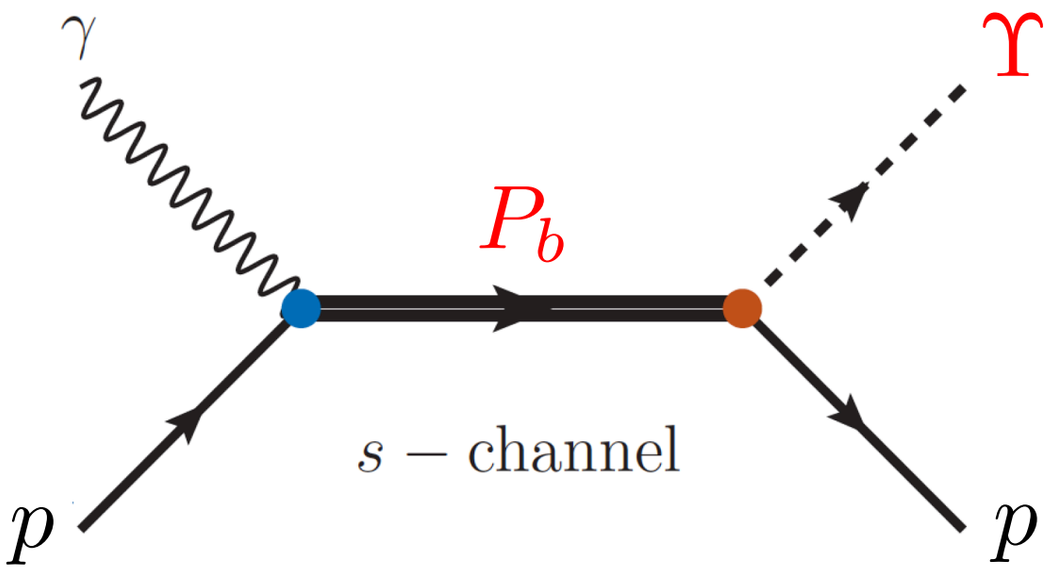
$$\Lambda_b \to J/\psi p K^-$$

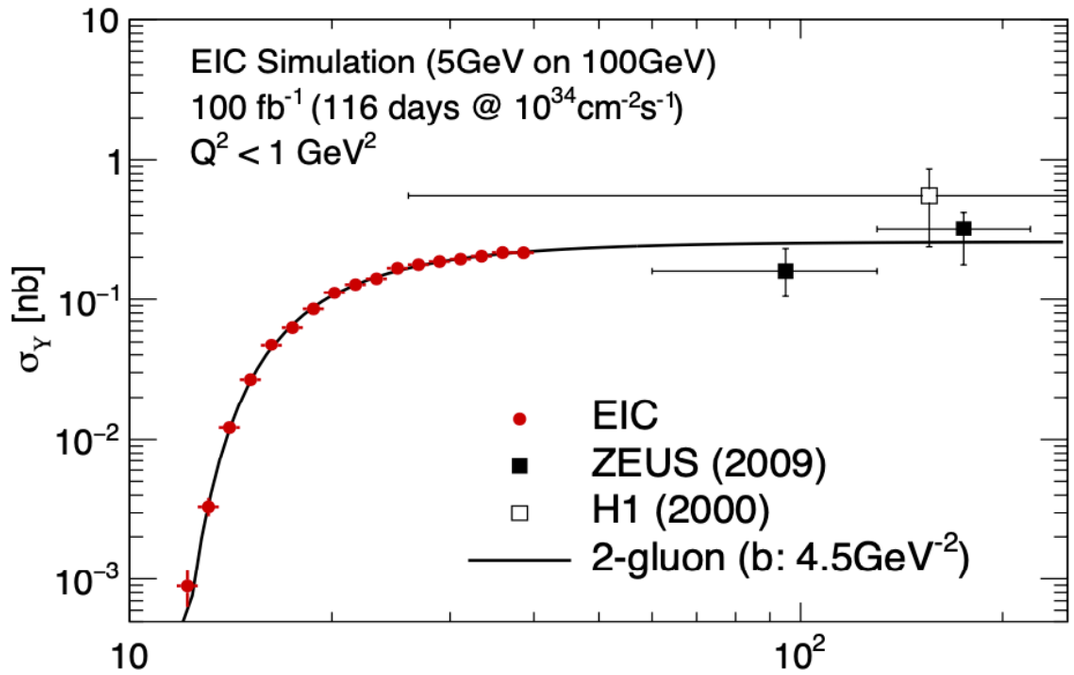


- Accessible with real photon beams at JLab up to E_γ= 12 GeV
  - Initial limits on BR($P_c \to J/\psi p$) < 2-4%, additional model constraints
  - Other experiments @ JLab: CLAS12, 007$^{J/\Psi}$ and more GlueX statistics

Threshold Υ and P_b^+ ?

- What about a bottomonium pentaquark? **arXiv:1508.01496**



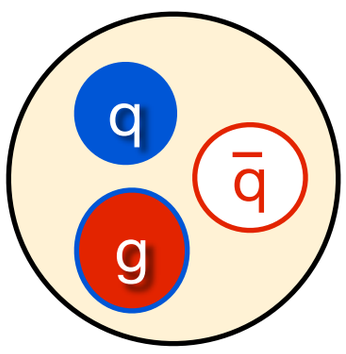


arXiv:1802.02616

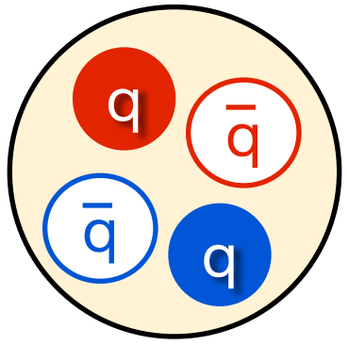
- Mass (~11 GeV) not accessible at JLab fixed target
- Is this threshold regime accessible in UPC at LHC, and if so, what is expected precision?

Hadron Spectroscopy at EIC

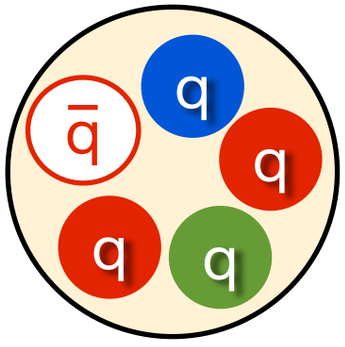
- Recent discovery of many new “exotic” states whose quark content contains both charm-anticharm and light quarks
- Where to look for them?
  - **e^+e^-**: CLEO, BESIII, BaBar, Belle II ($J^{PC} = 1^{--}$)
  - pp : LHCb, etc.
  - $p\bar{p}$: PANDA@GSI
- **Photoproduction:** GlueX, CLAS12, ... **EIC!**



hybrid meson



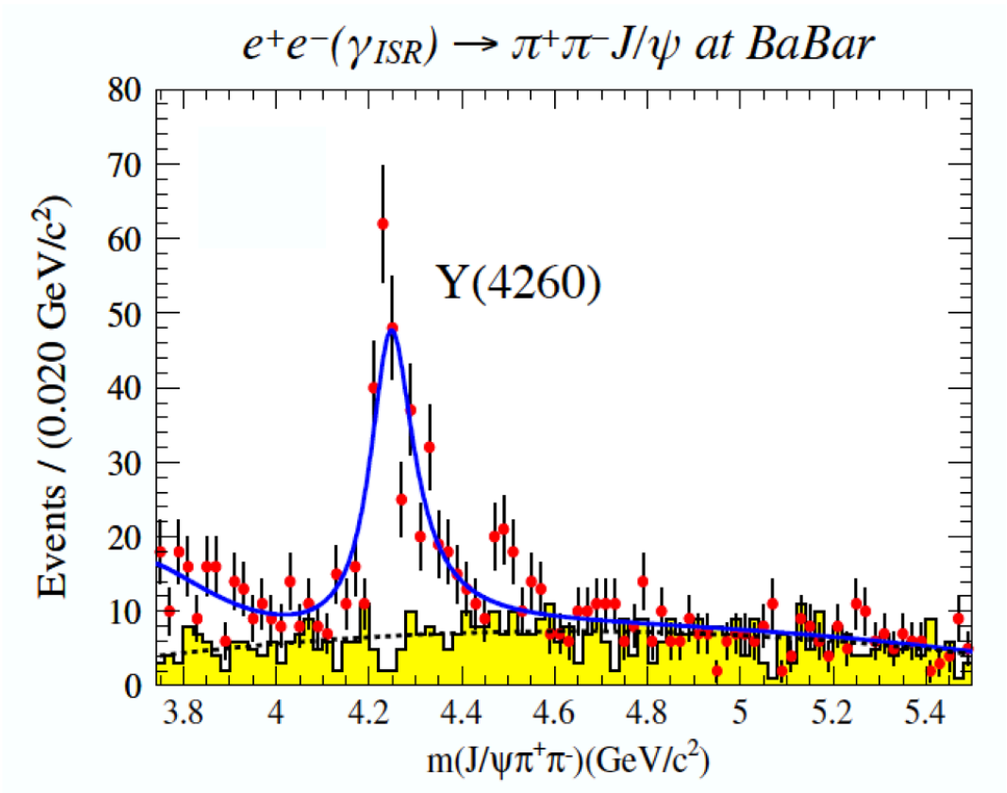
tetraquark

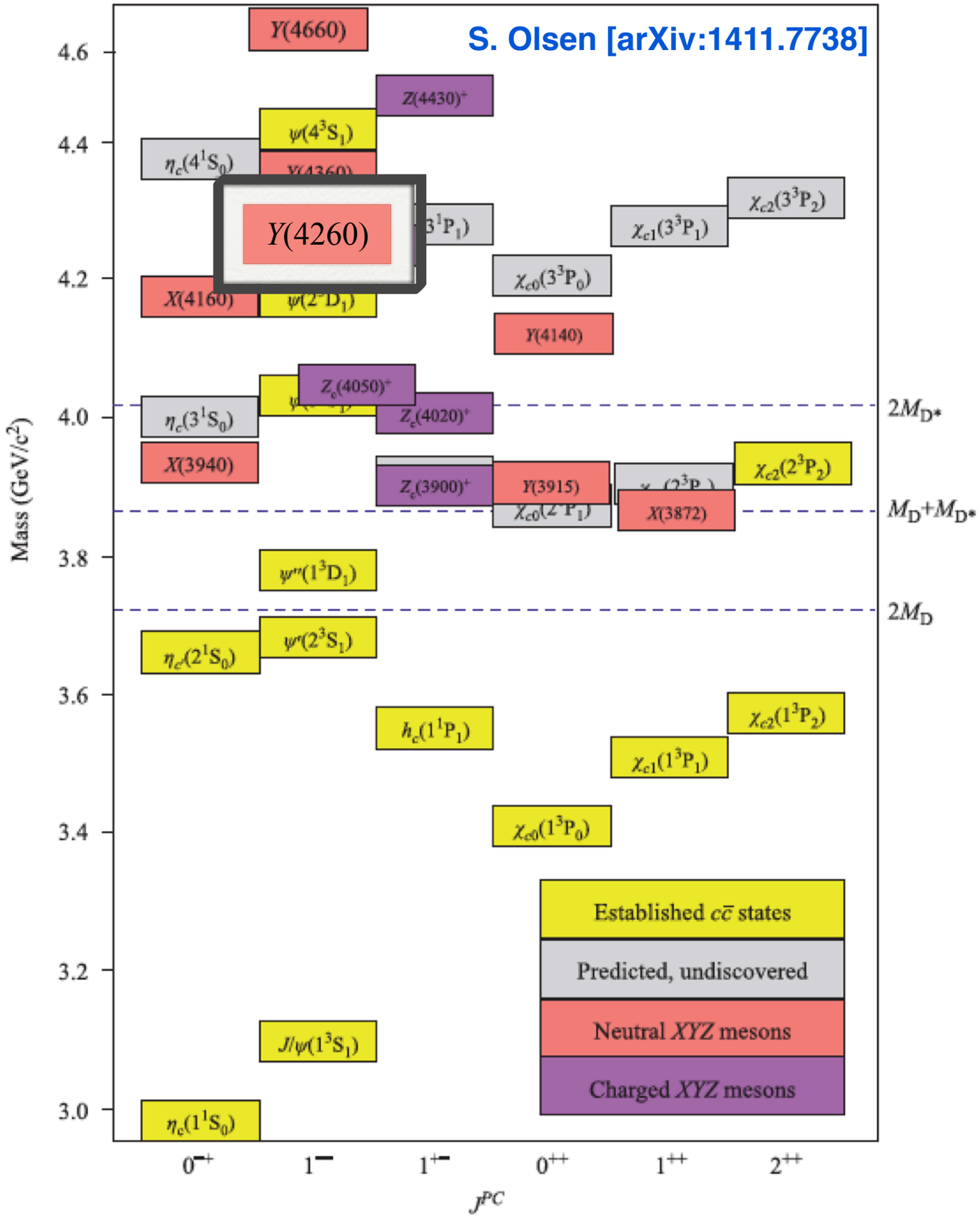


pentaquark

XYZ states

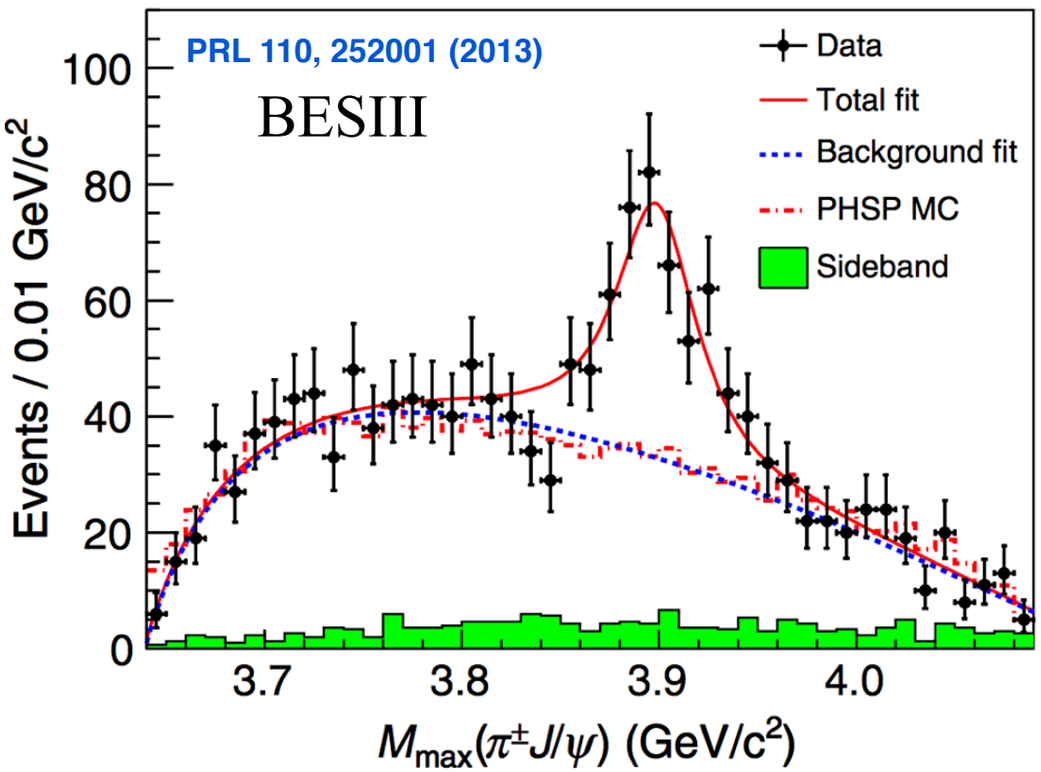
- Many new states observed in the last few years
- Not predicted by the standard charmonium models
- Many models for interpretation: resonant states, meson molecules, re-scattering effects, etc.



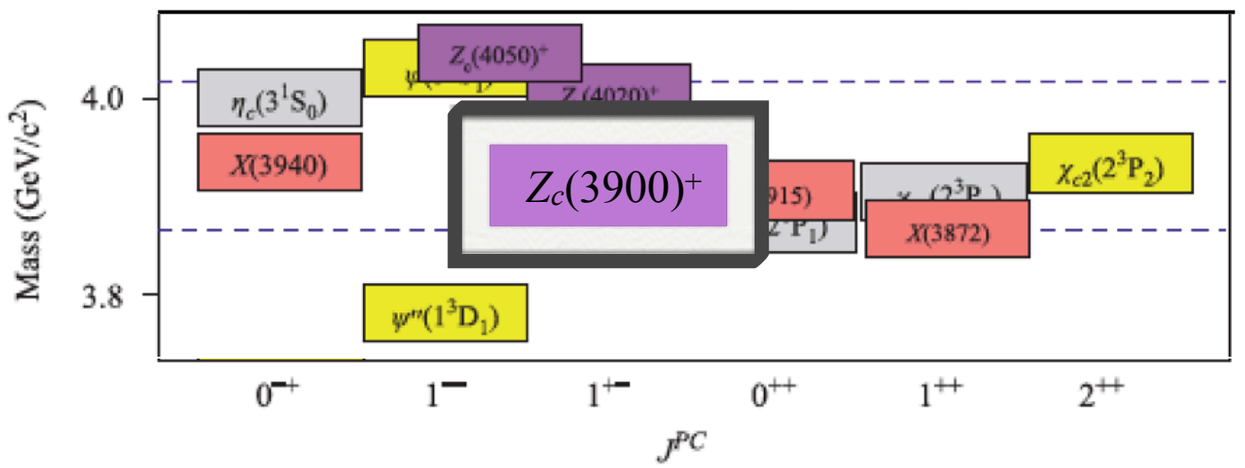


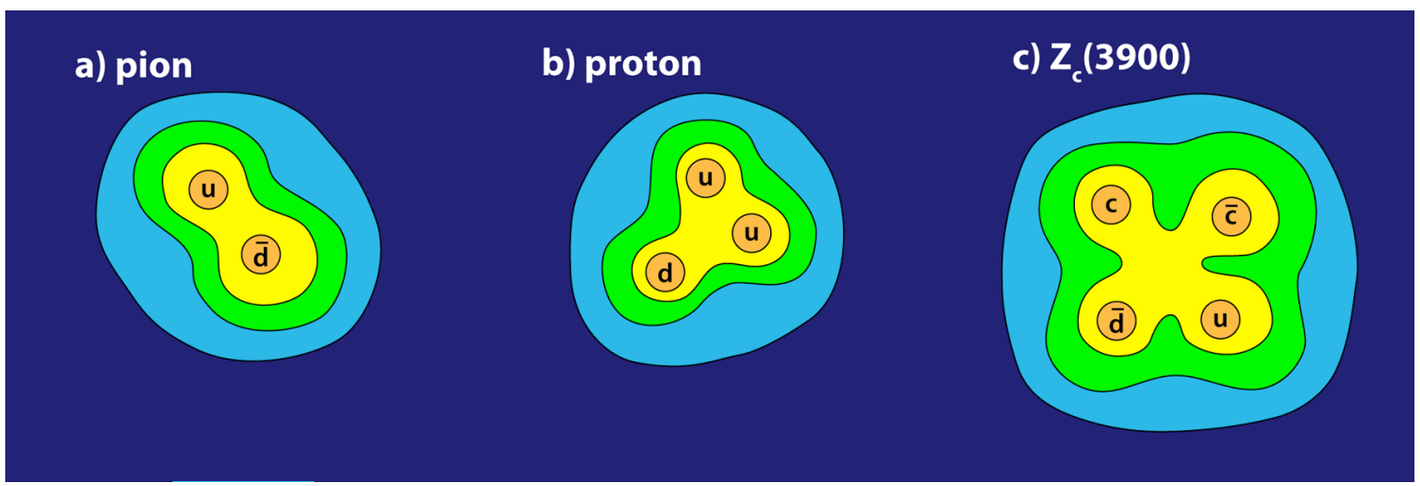
Charged charmonium states

$e^+e^- \to \pi^+\pi^- J/\psi$ (4260 MeV)



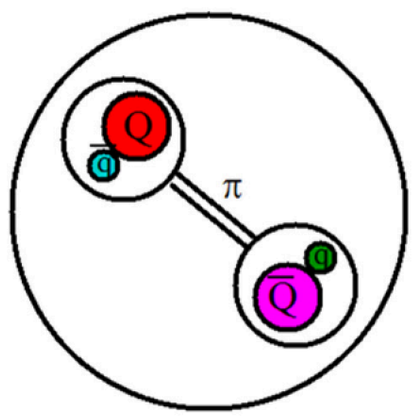
4-quark content ($c\bar{c}u\bar{d}$)



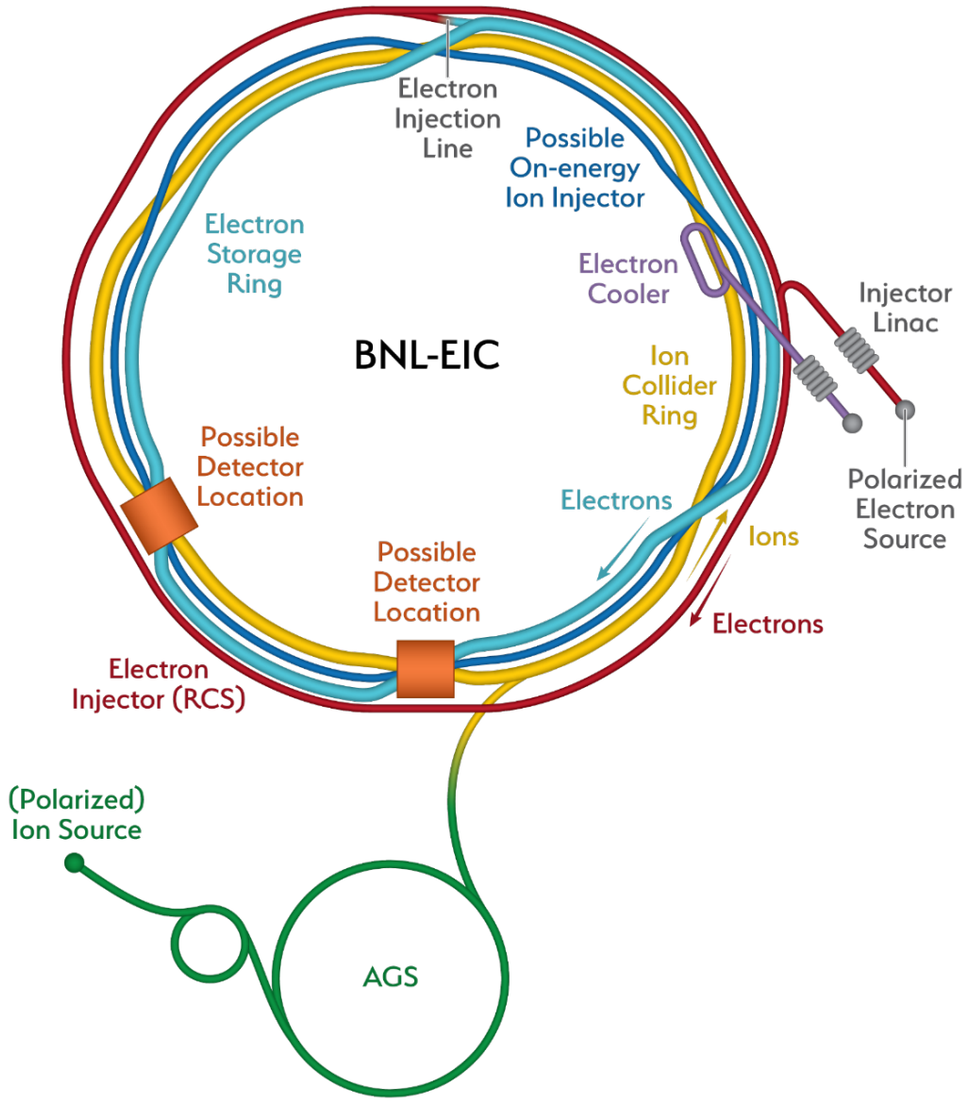


Physics Viewpoint 6, 69 (2013)

Meson Molecule?



What does EIC have to offer?



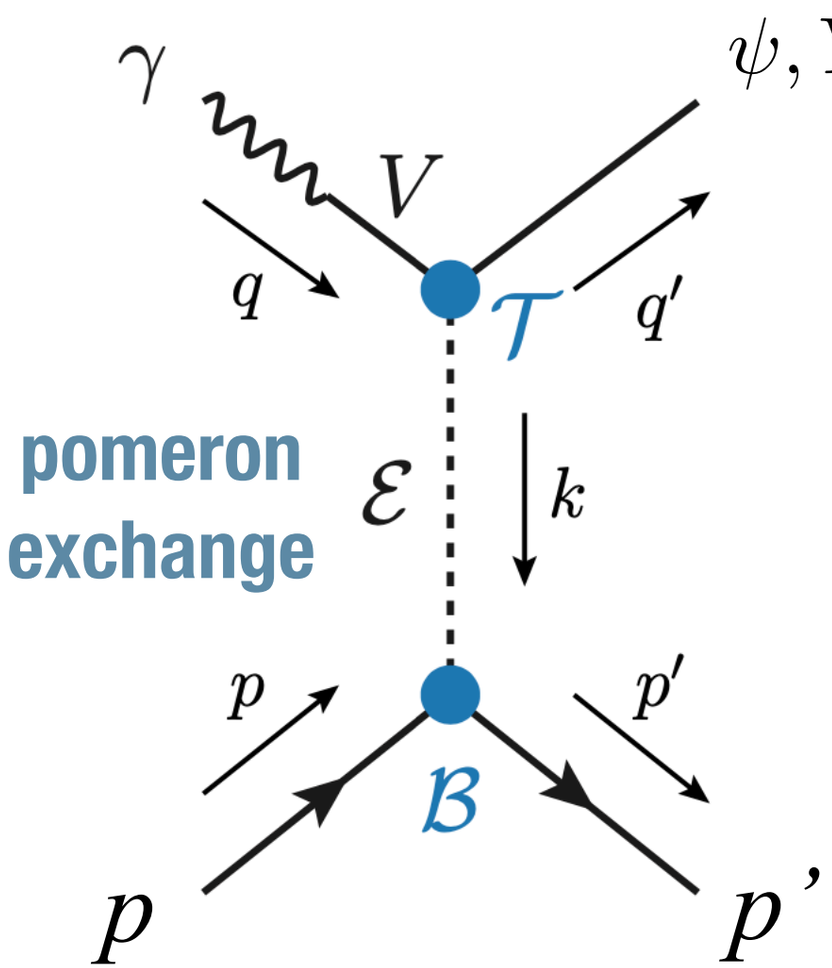
$$\sqrt{s} = 20 - 141 \text{ GeV}$$

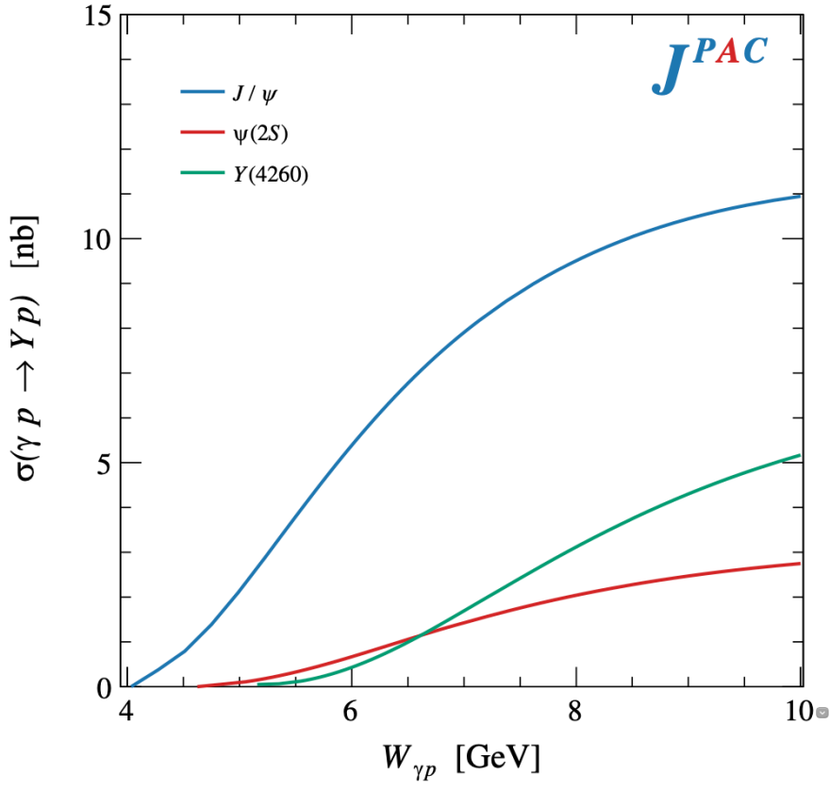
$$\mathcal{L} = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$$

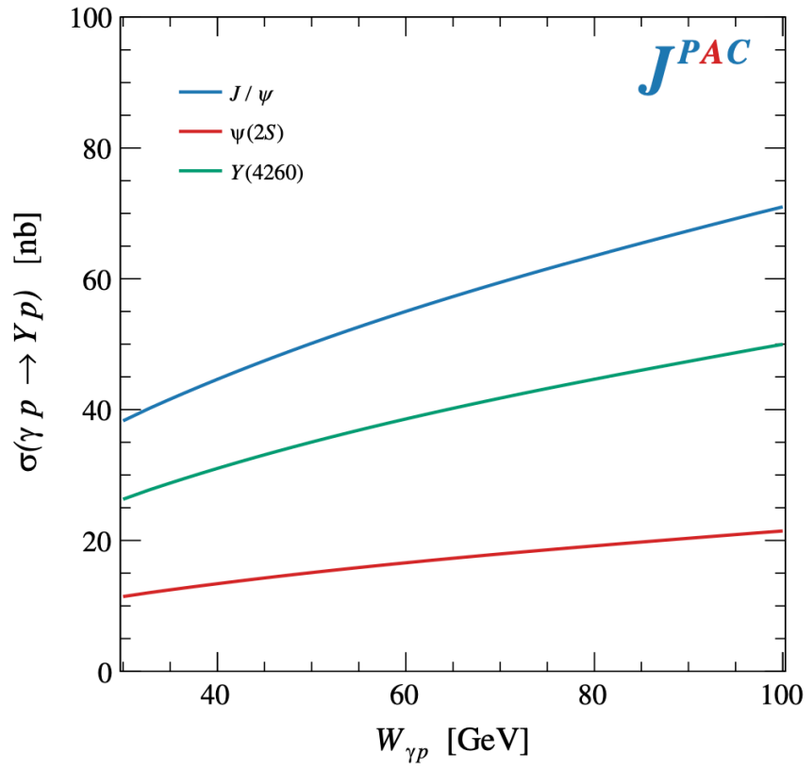
- Alternative production mechanism for XYZs: **photoproduction**
  - Polarized beams provide additional handle on production
- High luminosity, exclusive detection, and “clean" environment, relative to HL-LHC
- Very active development of detector conceptual designs with potential for optimization (EIC Yellow Report)

Theory predictions for XYZ states

JPAC: PRD 102, 114010 (2020)







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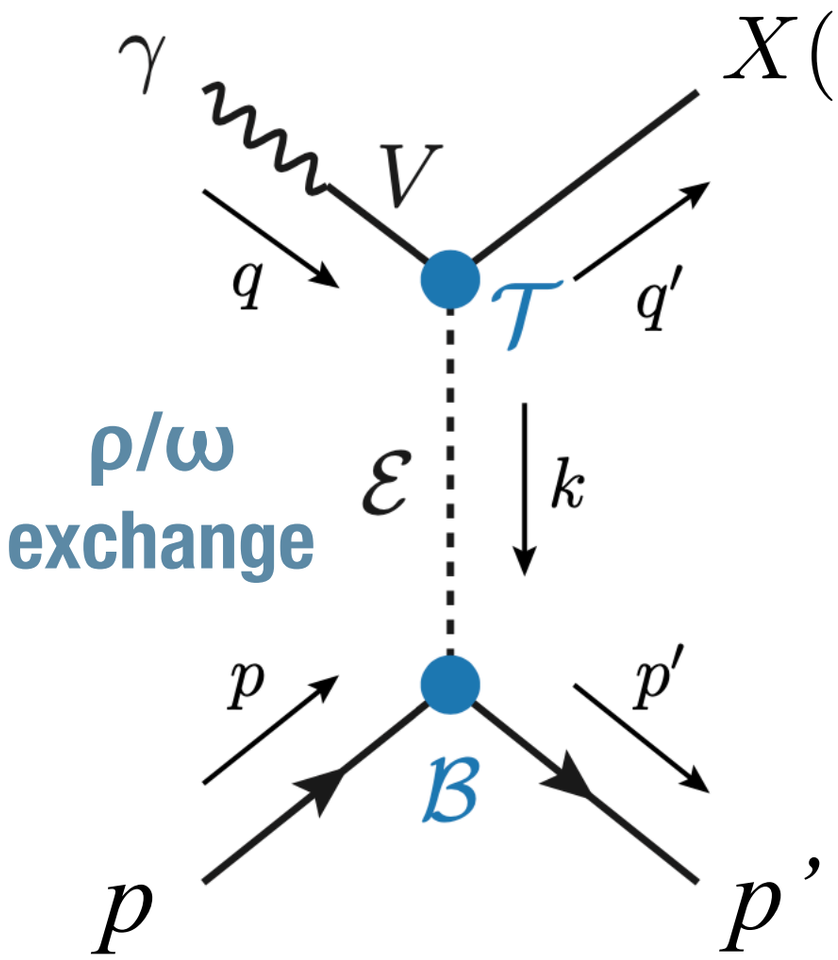

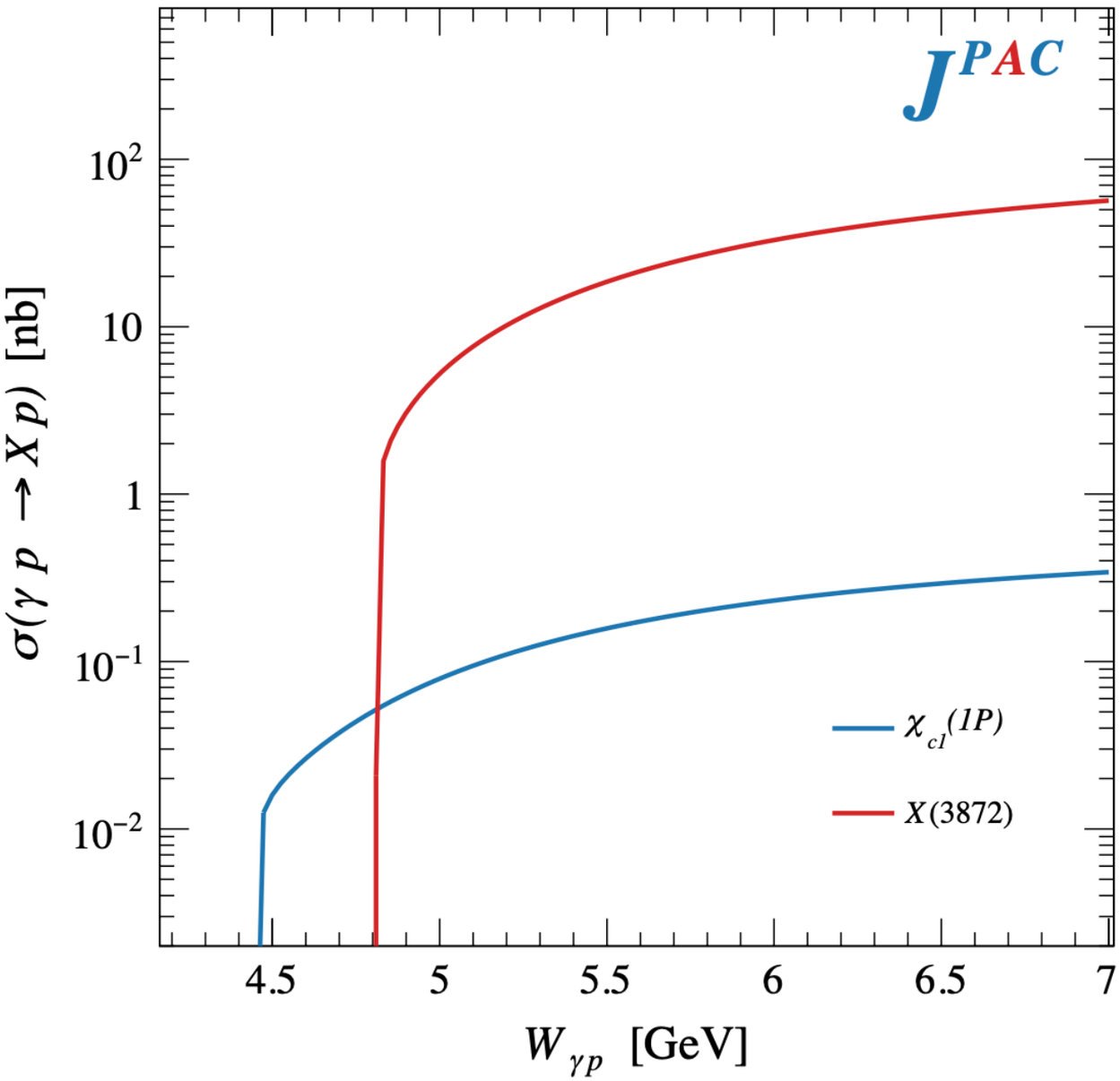

Theory predictions for XYZ states

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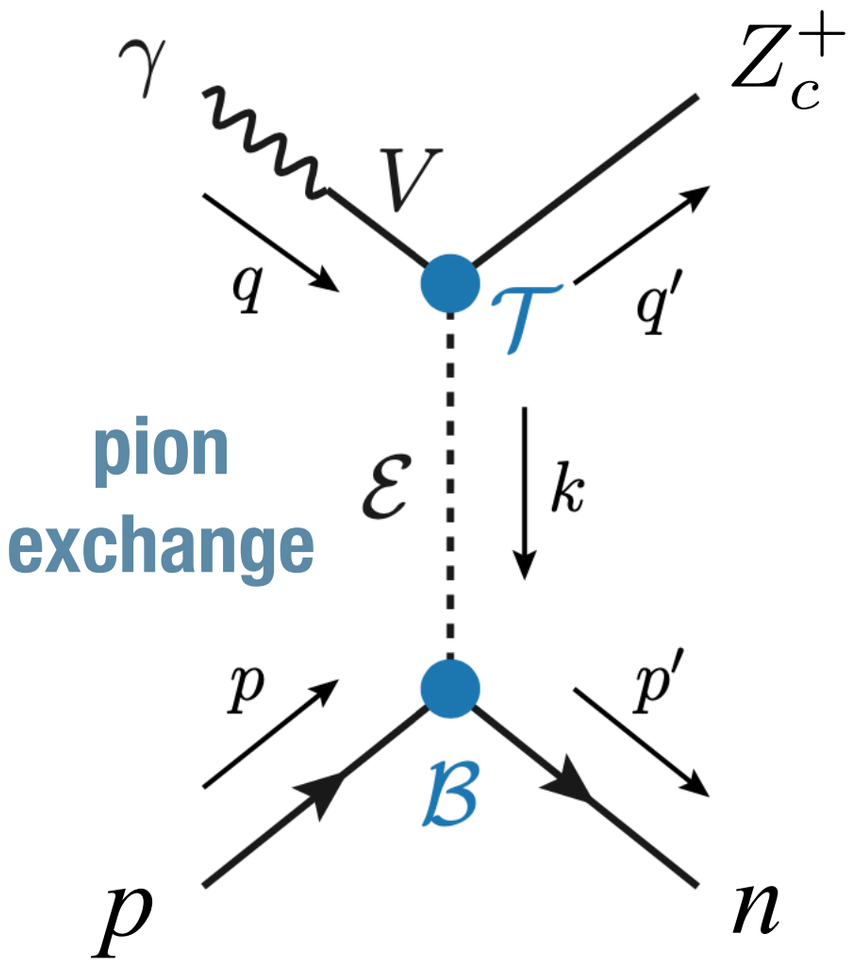
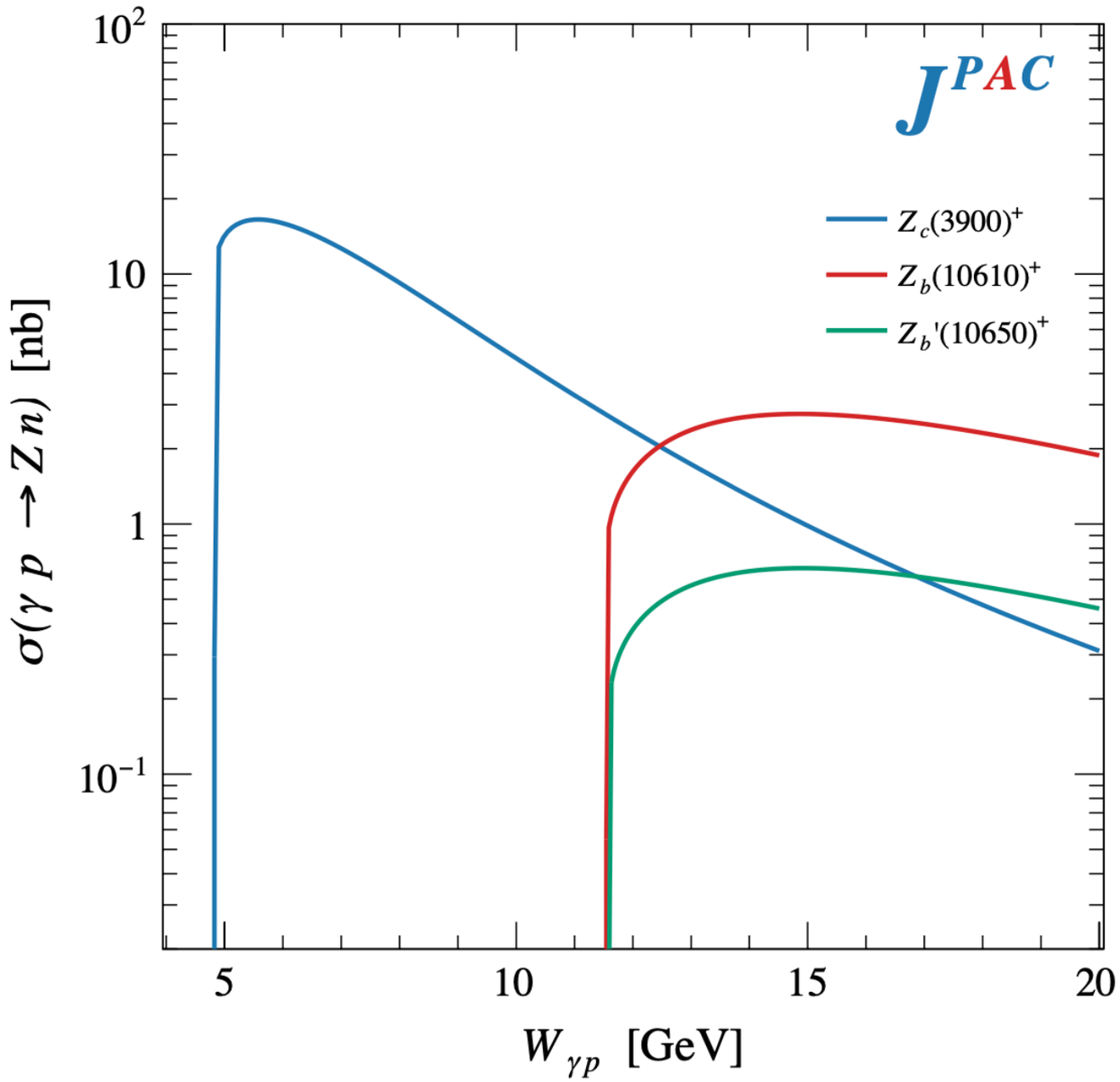
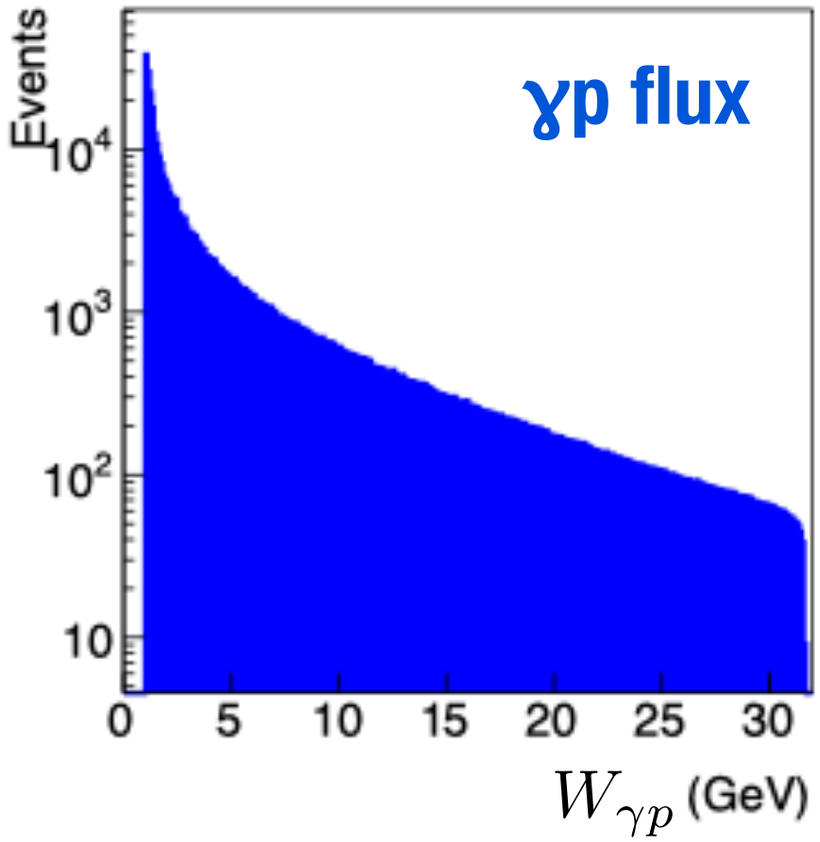
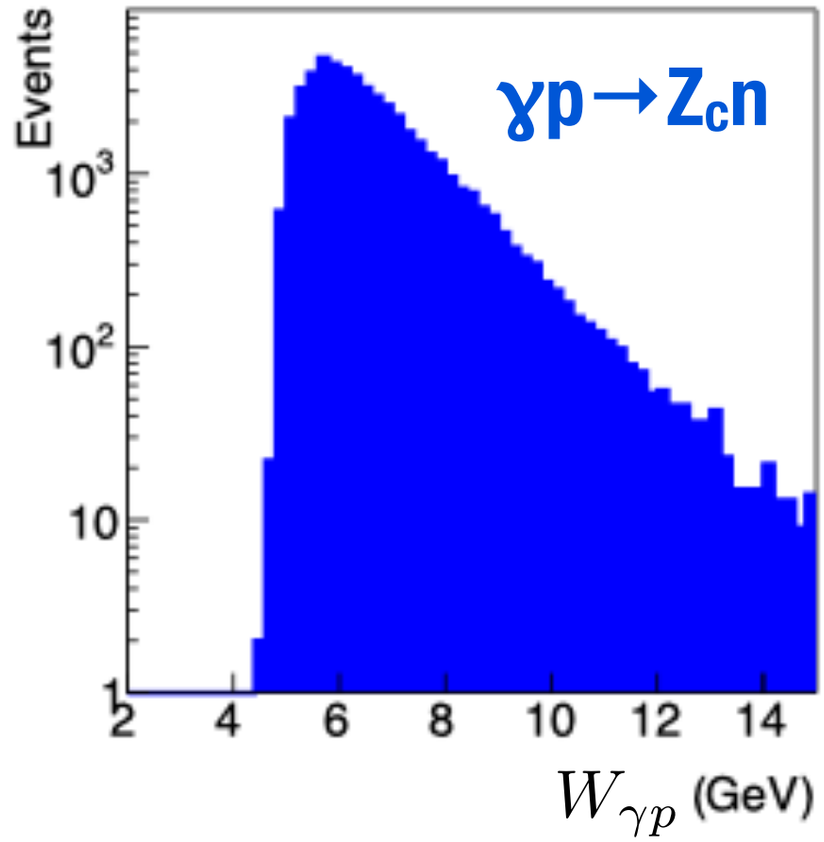




$Z_c^+(3900)$ at an EIC

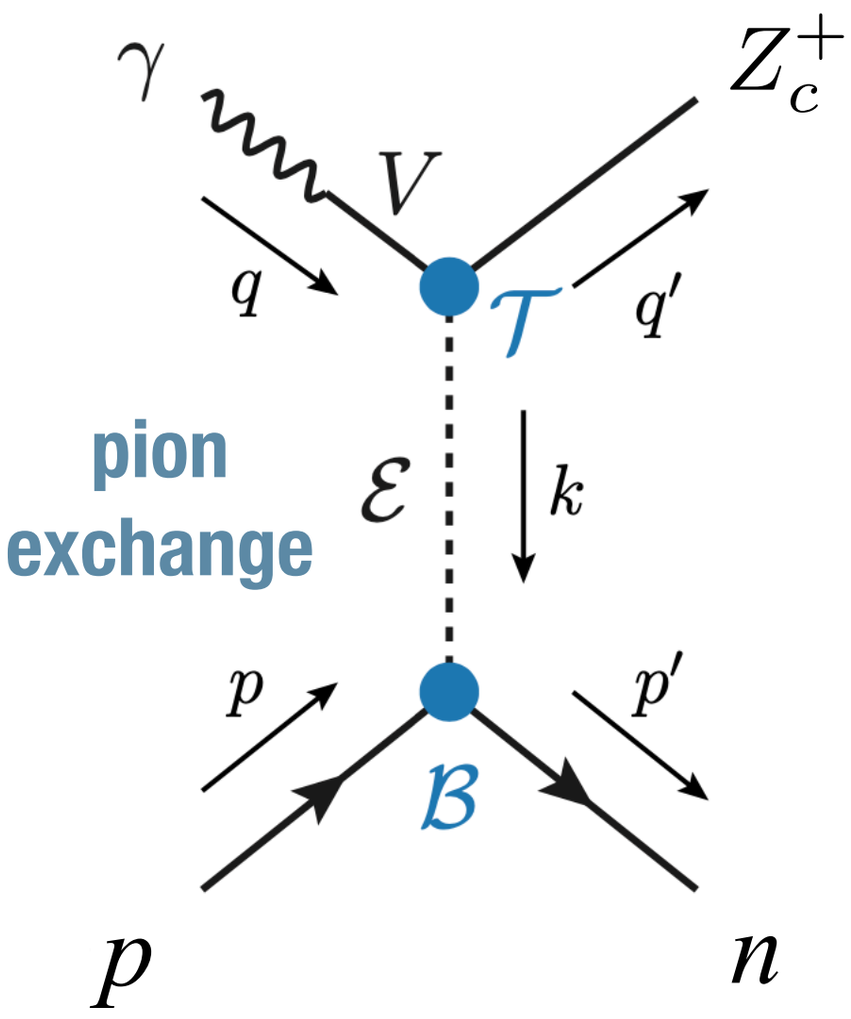


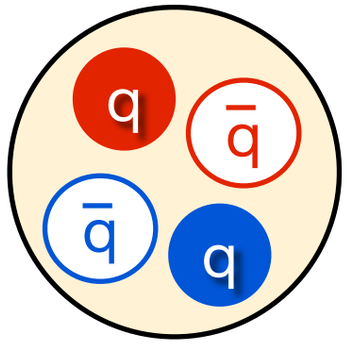


- Assume modest energy electron and proton beams: **E_p = 41 GeV** and **E_e = 5 GeV**
- Z_c and subsequent decays are boosted in proton direction
- Low-Q^2 electron and forward neutron in ZDC

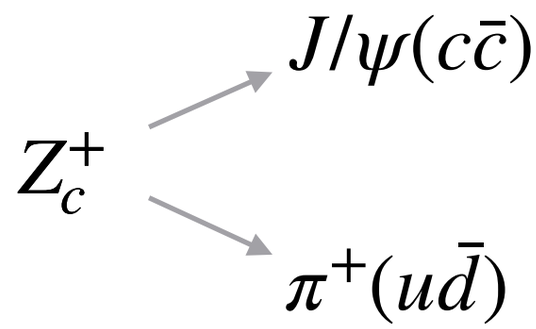
$Z_c^+(3900)$ at an EIC

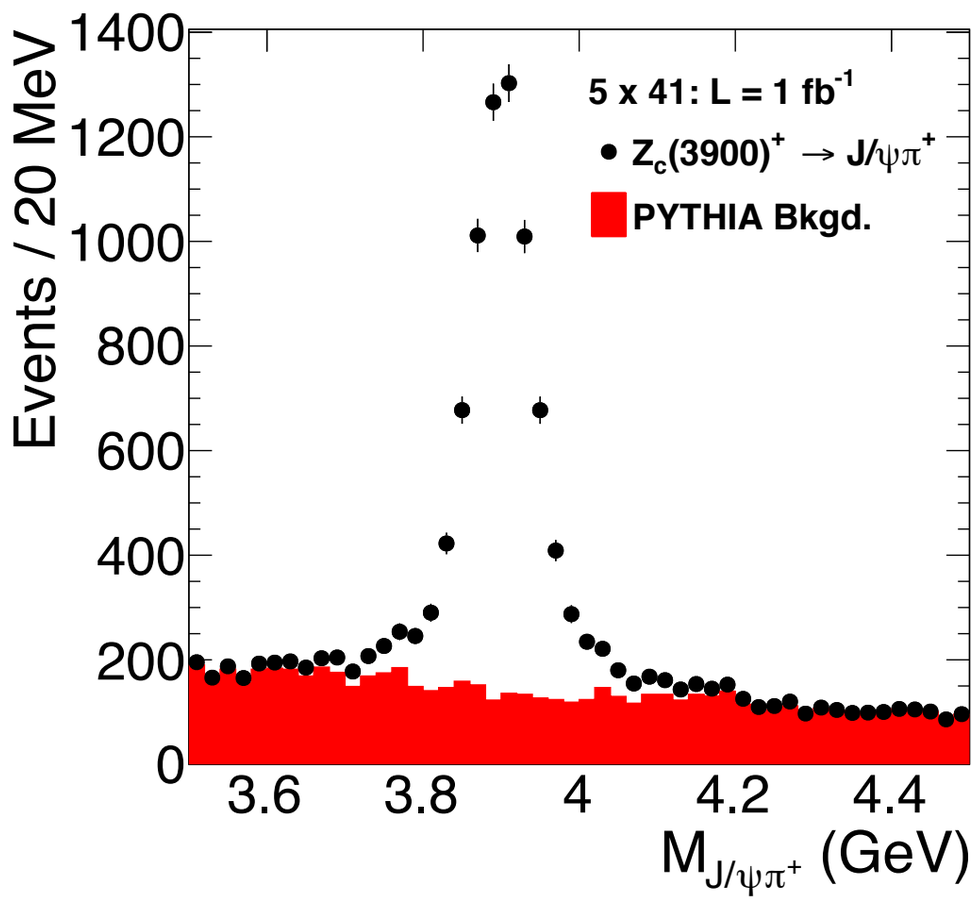
JPAC: PRD 102, 114010 (2020)





tetraquark candidate

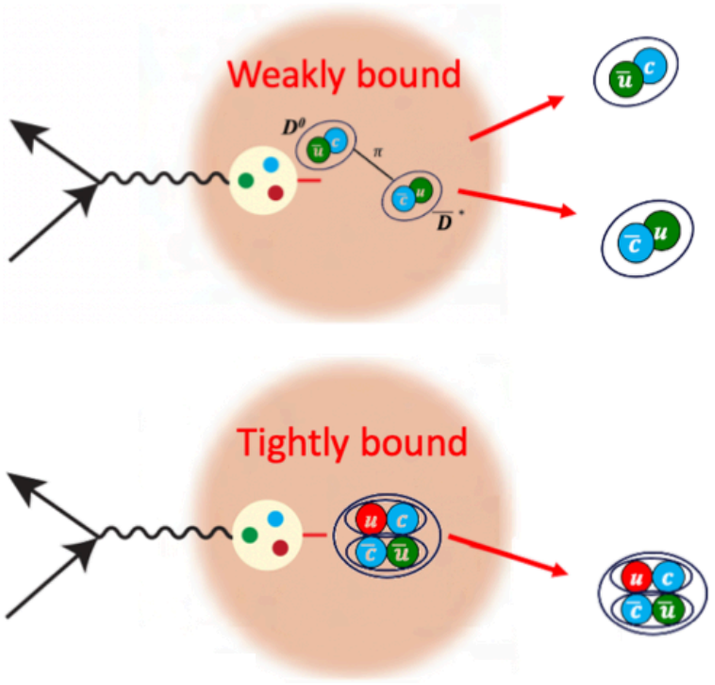


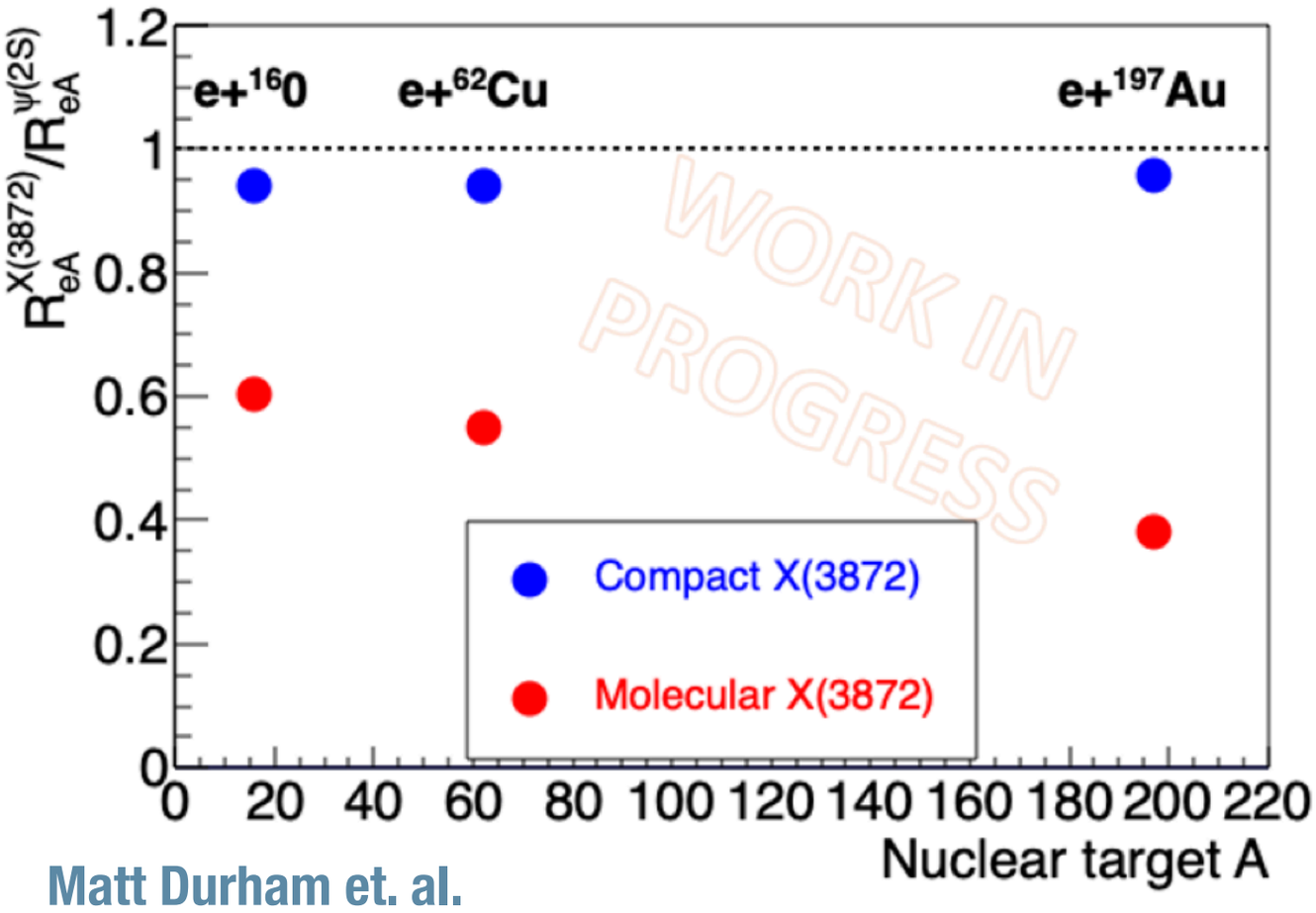


In-medium effects @ EIC

- Dependence of breakup of X(3872) in nuclei?

- Therefore, exotic structure can be studied by measuring suppression in eA collisions.





Matt Durham et. al.

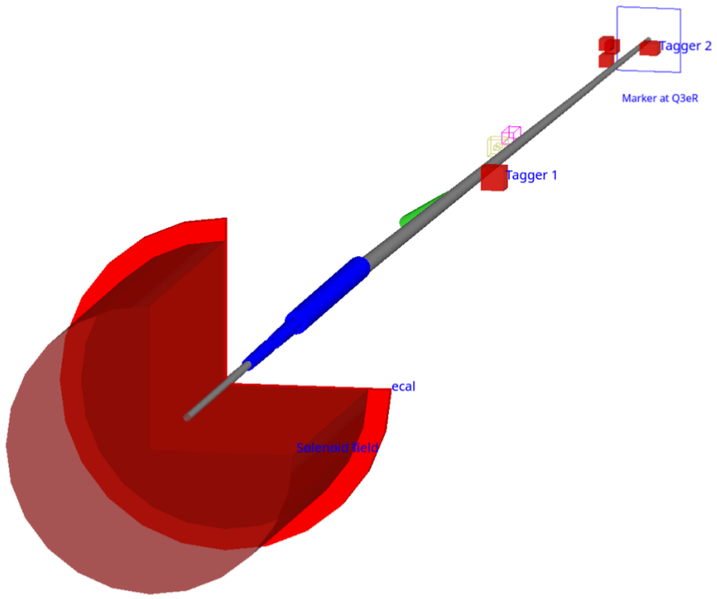
https://indico.bnl.gov/event/8231/contributions/37696/attachments/28300/43650/EIC_Pavia_JHF_Ping_Xuan_Matt_v4.pdf

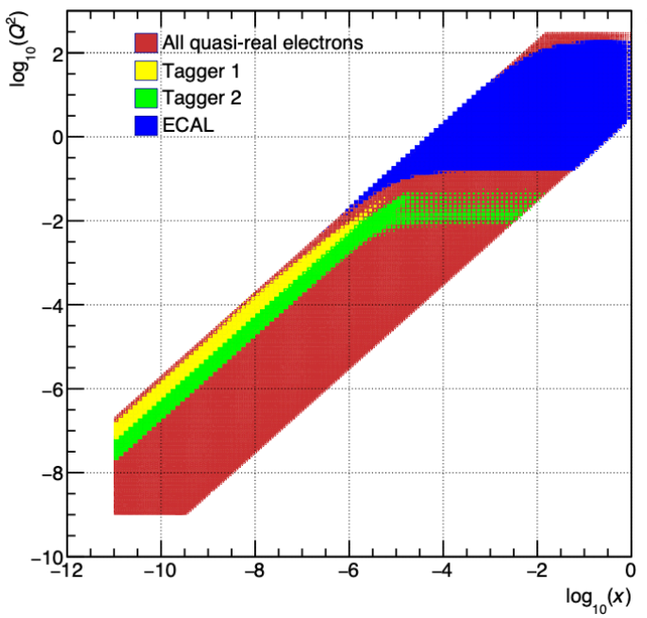
Hadron Spectroscopy @ EIC

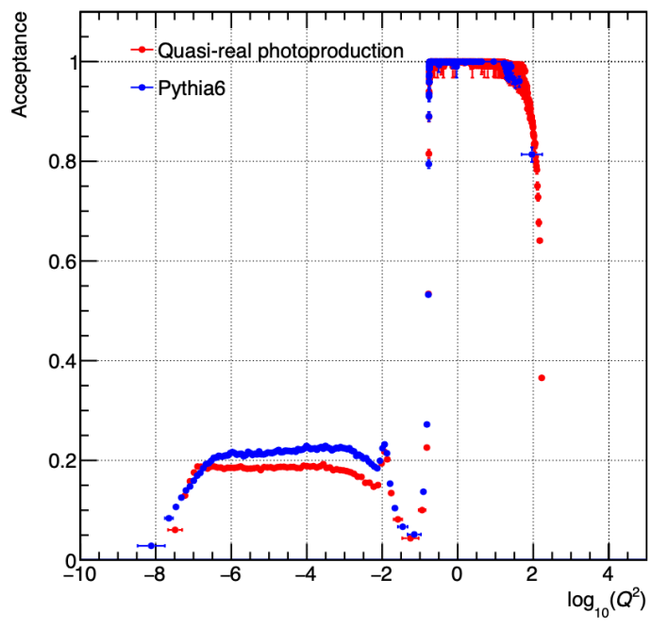
- Energy coverage provides opportunities in XYZ, P_c, etc.

- EIC Yellow Report: defining detector detector requirements for EIC, to be completed in 2020

"Far-backward": low-Q^2 tagger







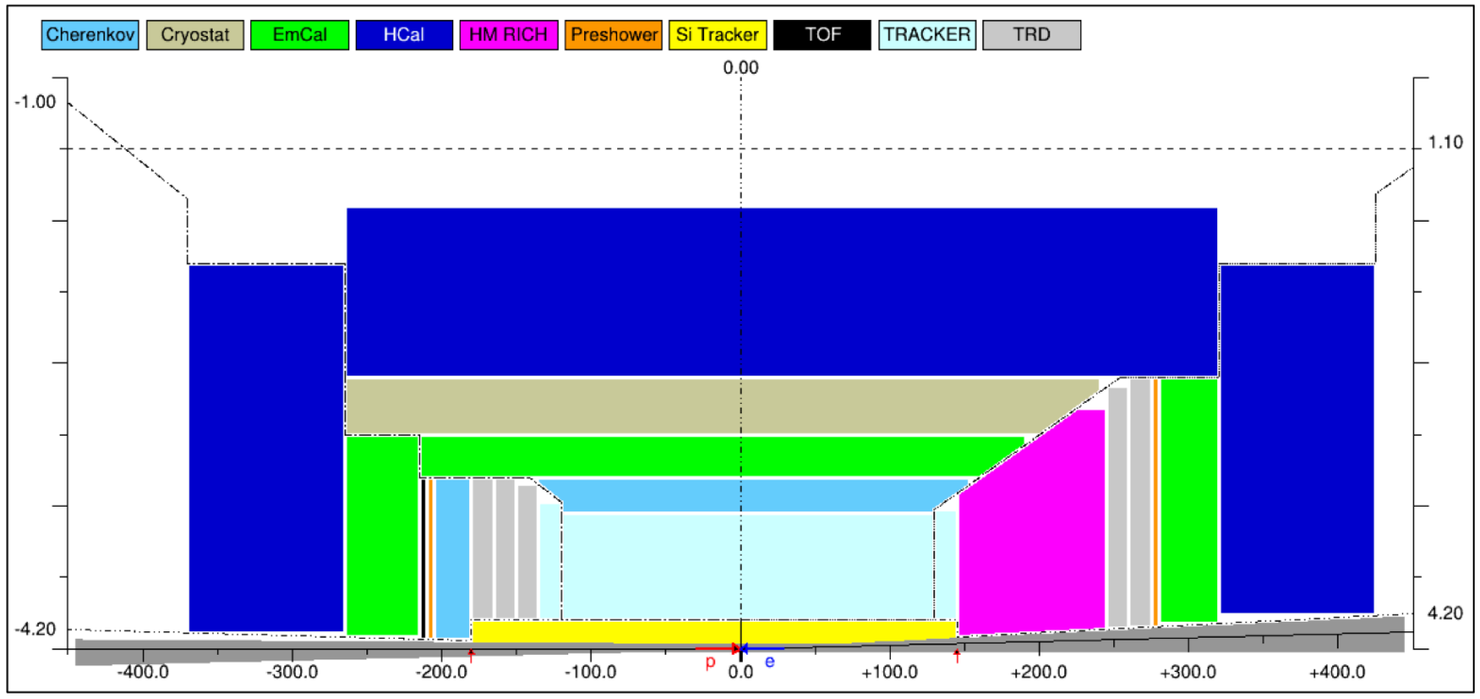
- See previous talk for more details on forward scattered nucleon detection for exclusivity

Hadron Spectroscopy @ EIC

- Energy coverage provides opportunities in XYZ, P_c, etc.

- EIC Yellow Report: defining detector detector requirements for EIC, to be completed in 2020

Asymmetric detector concepts due to asymmetric beam energies: "complete" coverage for $|\eta| < 3.5$



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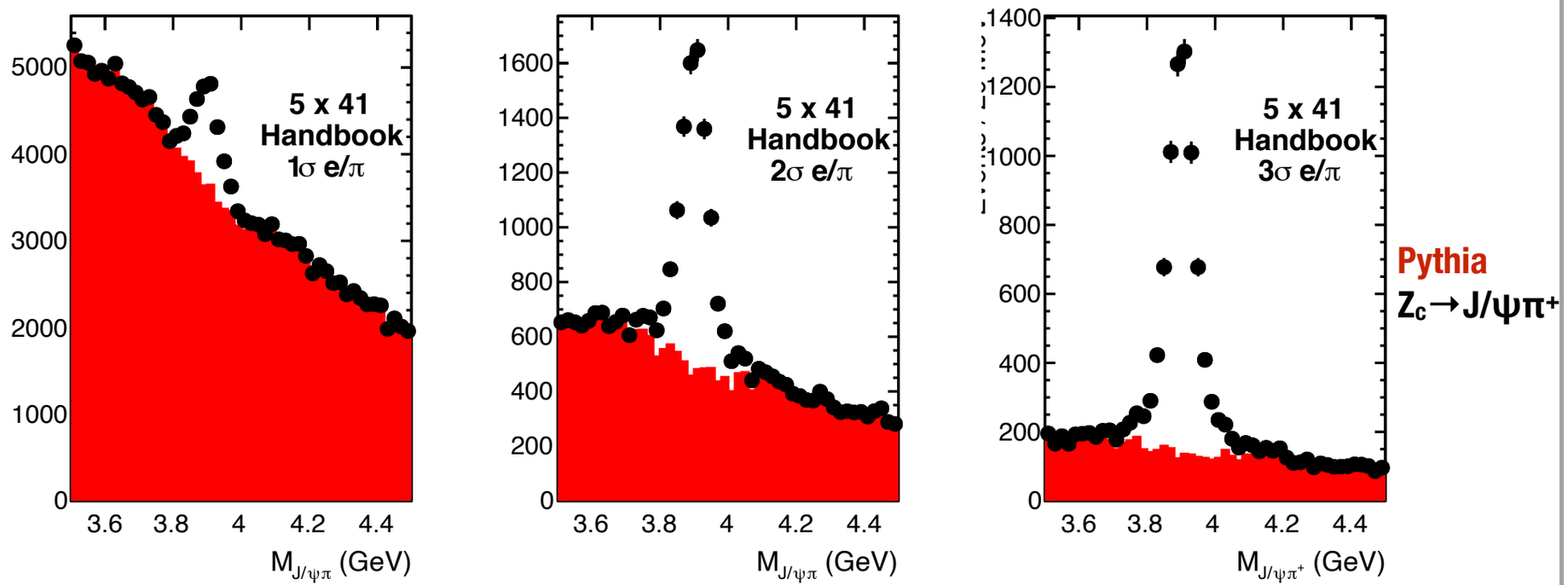
e.g. e/π separation requirements



Many groups participating: JPAC, JLab, Florida State, Indiana, W&M, Glasgow, INFN, Regina. More welcome!

Summary

- Photoproduction provides some new avenues to pursue the EIC physics program: 3D nucleon structure, gluon distributions, etc.
- Observation of “exotic” states in heavy quarkonium are challenging our understanding of the hadron spectrum and QCD
  - Plenty more data to come from BESIII, Belle II, LHC, PANDA, etc. on the timeline of the EIC
  - EIC provides an alternative production mechanism to probe exotic hadrons, with detector requirements being defined now!
- Continued theory/experiment collaboration and high statistics experiments promise to provide an exciting (exotic) future

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