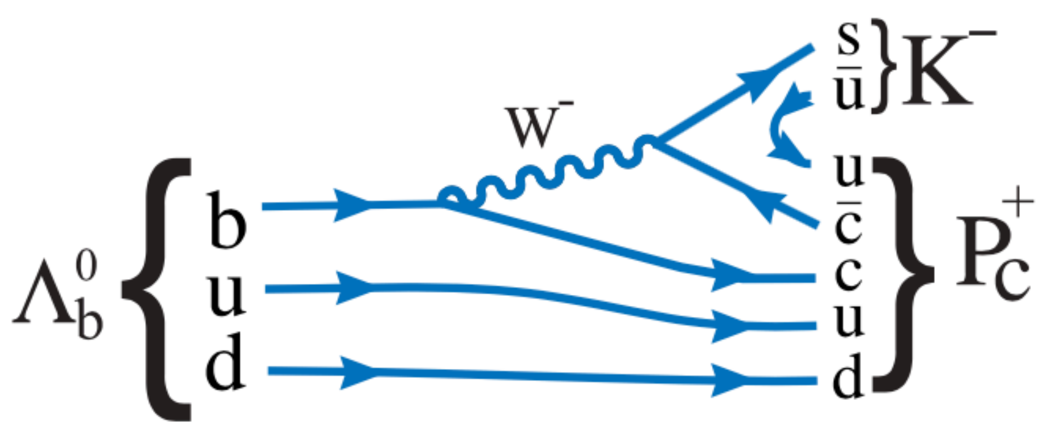
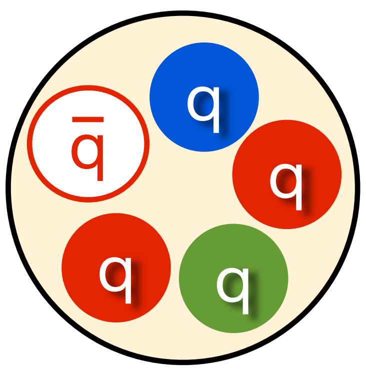
Spectroscopy with Jefferson Lab at 22 GeV

Justin Stevens

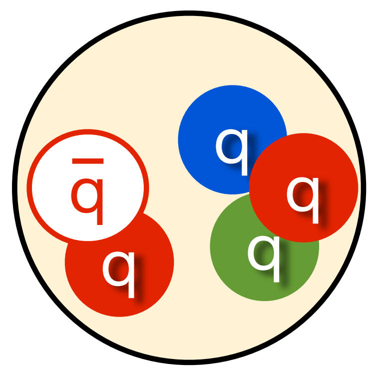
WILLIAM & MARY
CHARTERED 1693

Probing exotic charmonium at JLab



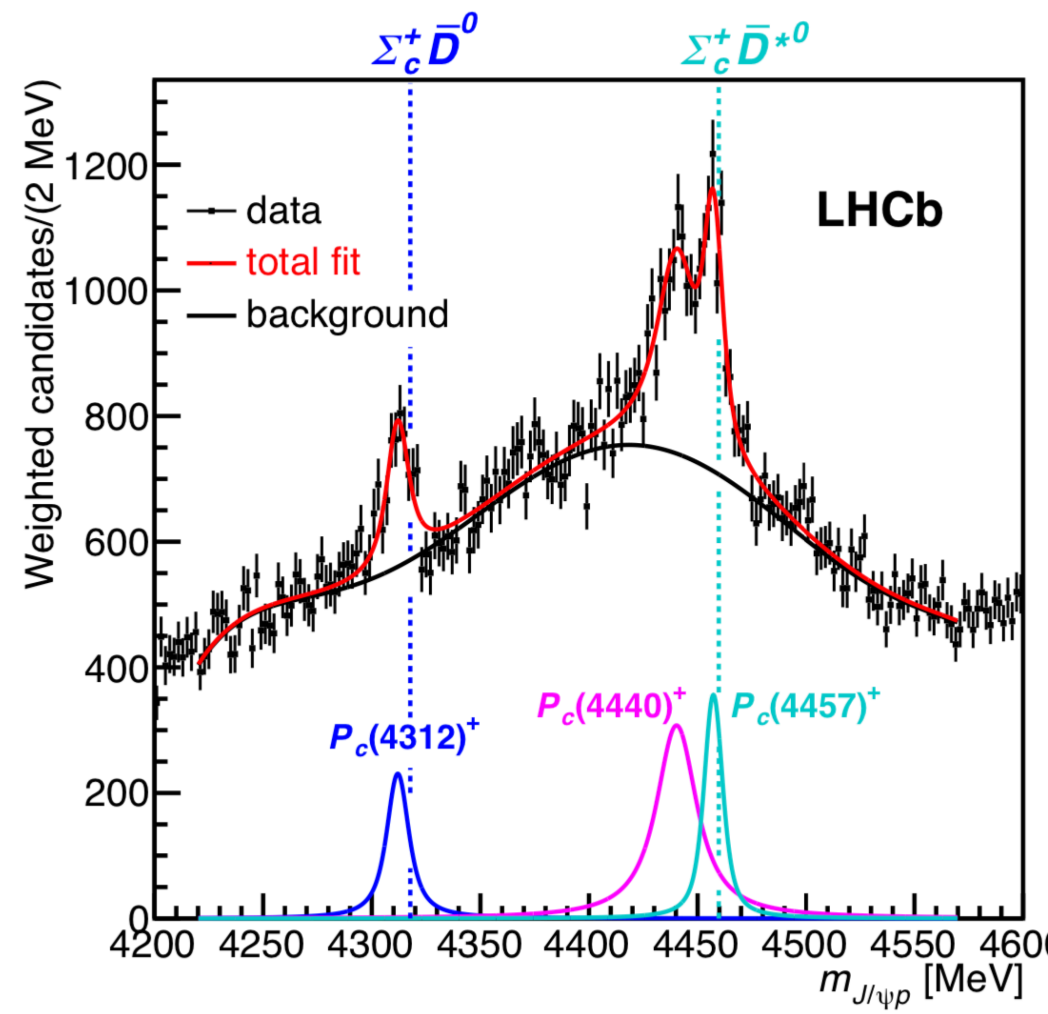


pentaquark

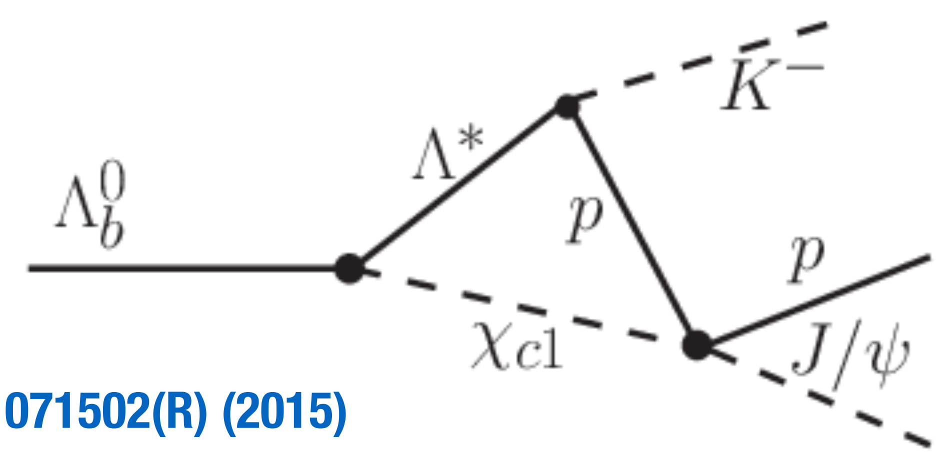


molecular

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



PRL 122, 222001 (2019)



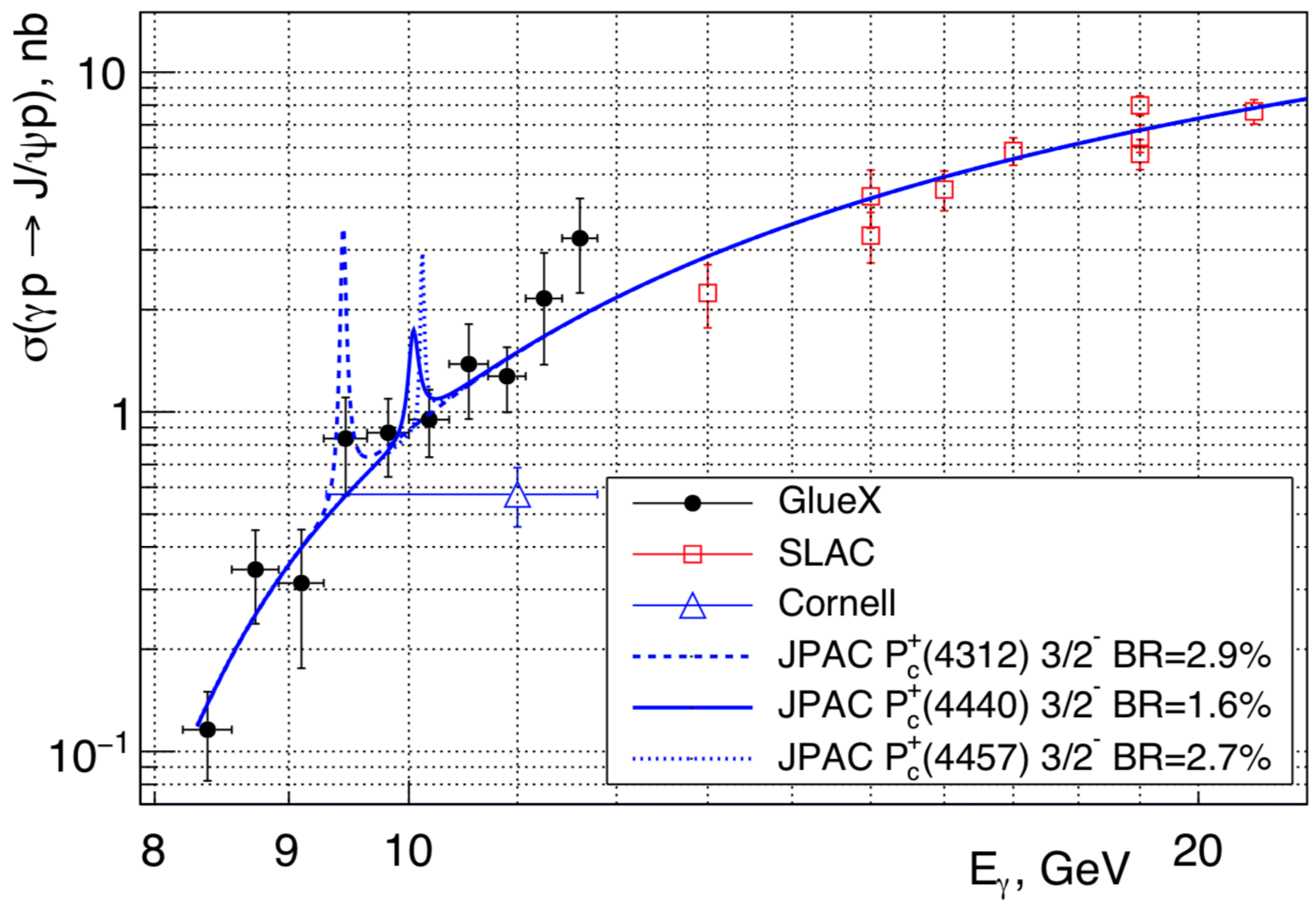
e.g. PRD 92, 071502(R) (2015)

rescattering (triangle singularity)

Pentaquark photoproduction limits

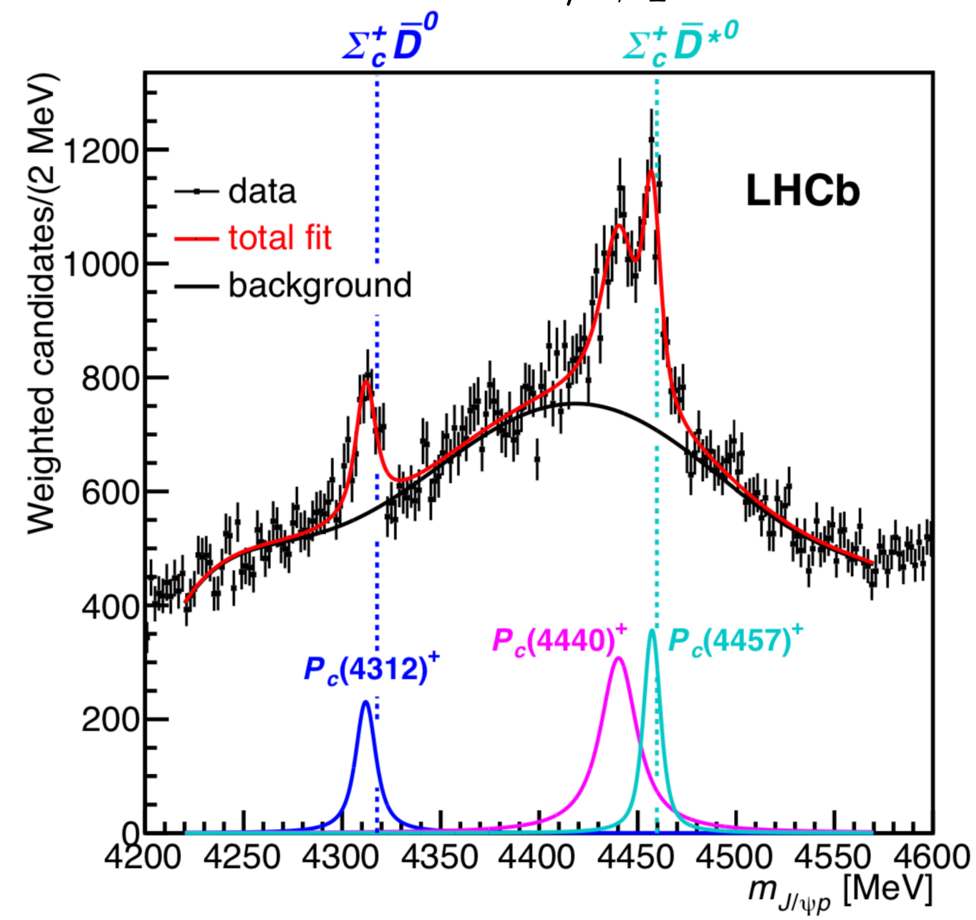
$\gamma p \to J/\psi p$

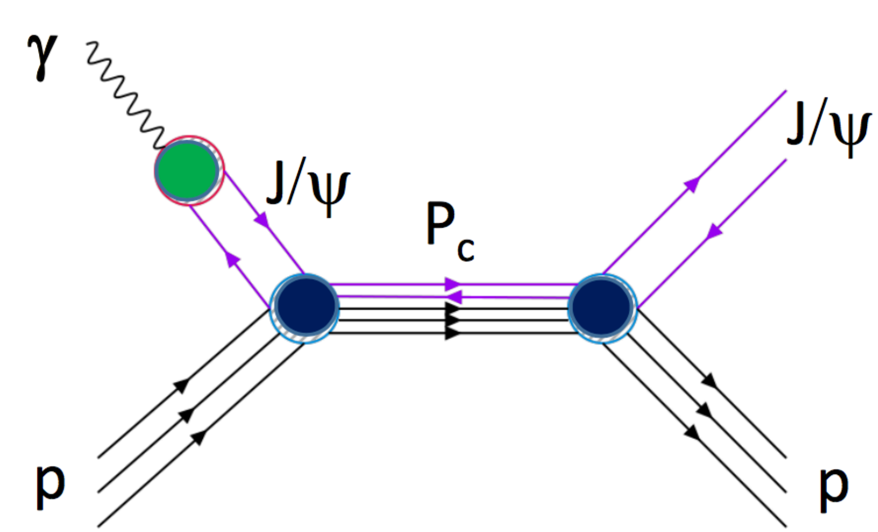
GlueX **PRL 123, 072001 (2019)**



Model-dependent limits on
$BR(P_c \to J/\psi p)$ **< 2-4%**

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



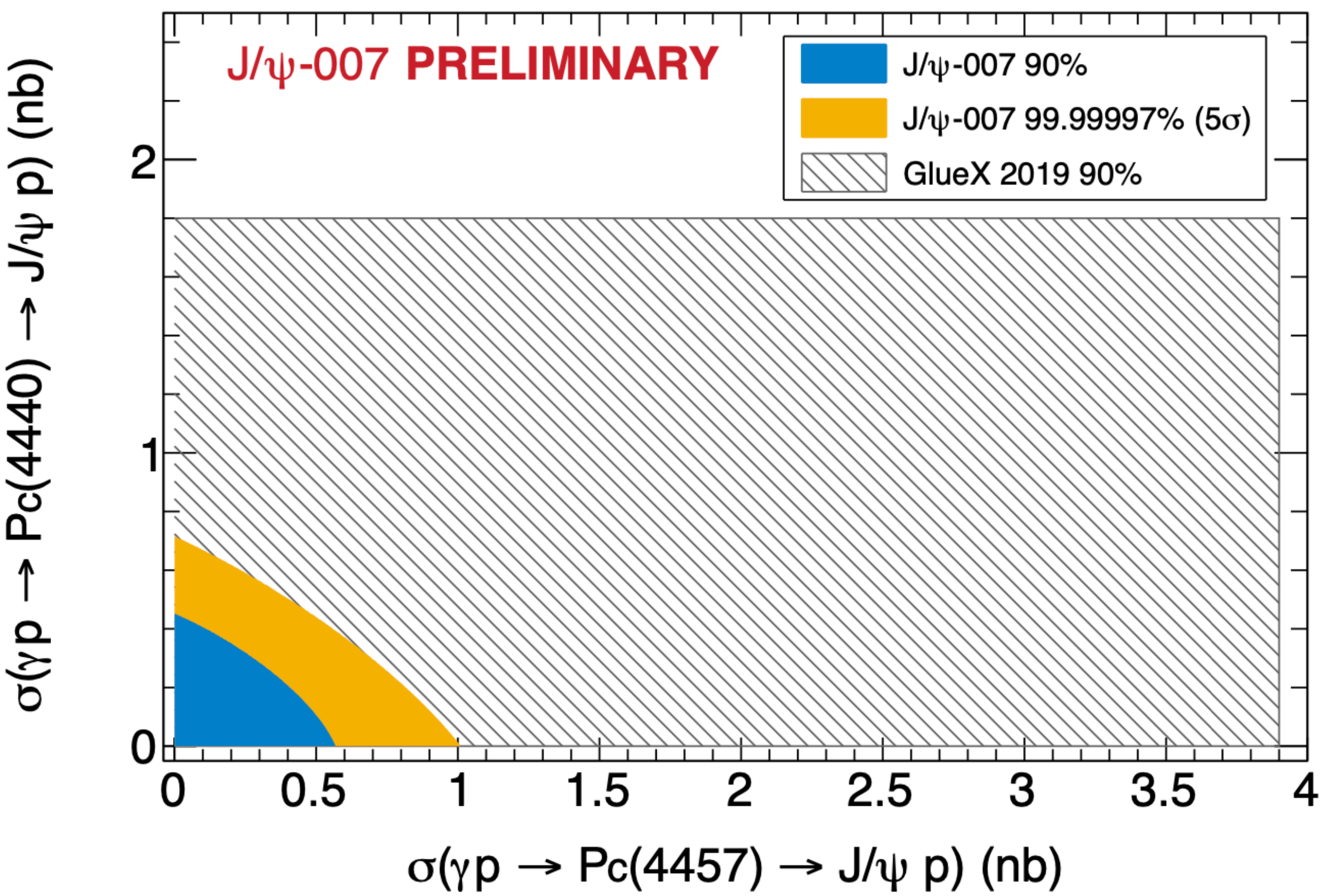


Proportional to $BR(P_c \to J/\psi p)^2$

Pentaquark photoproduction limits

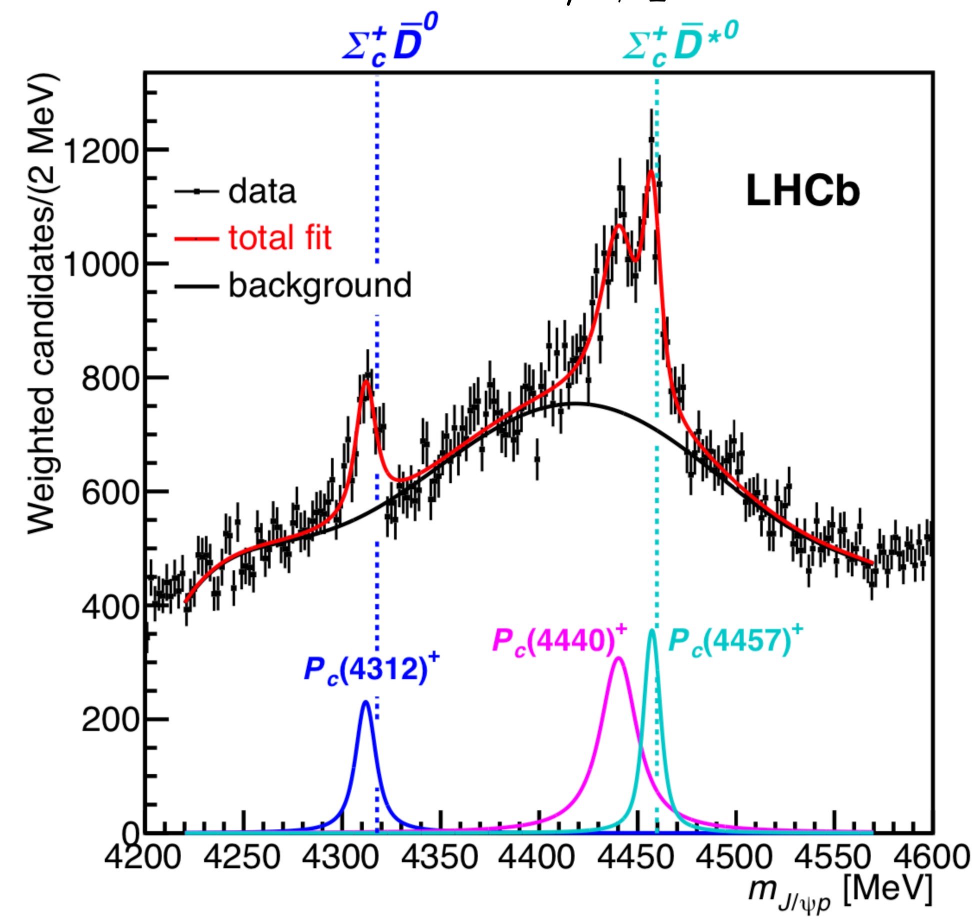
$$\gamma p \to J/\psi p$$

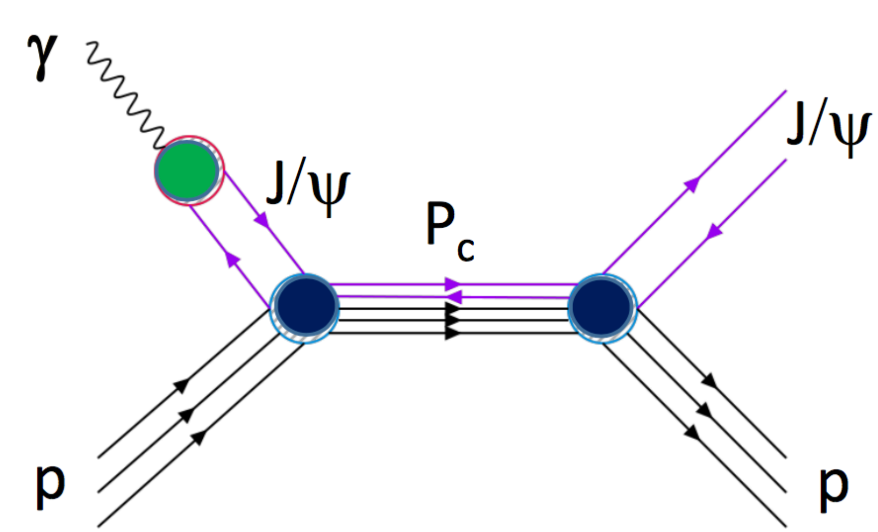
Hall C: J/ψ-007 experiment



Even stricter limits on P_c production taking into account differential cross section $d\sigma/dt$

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

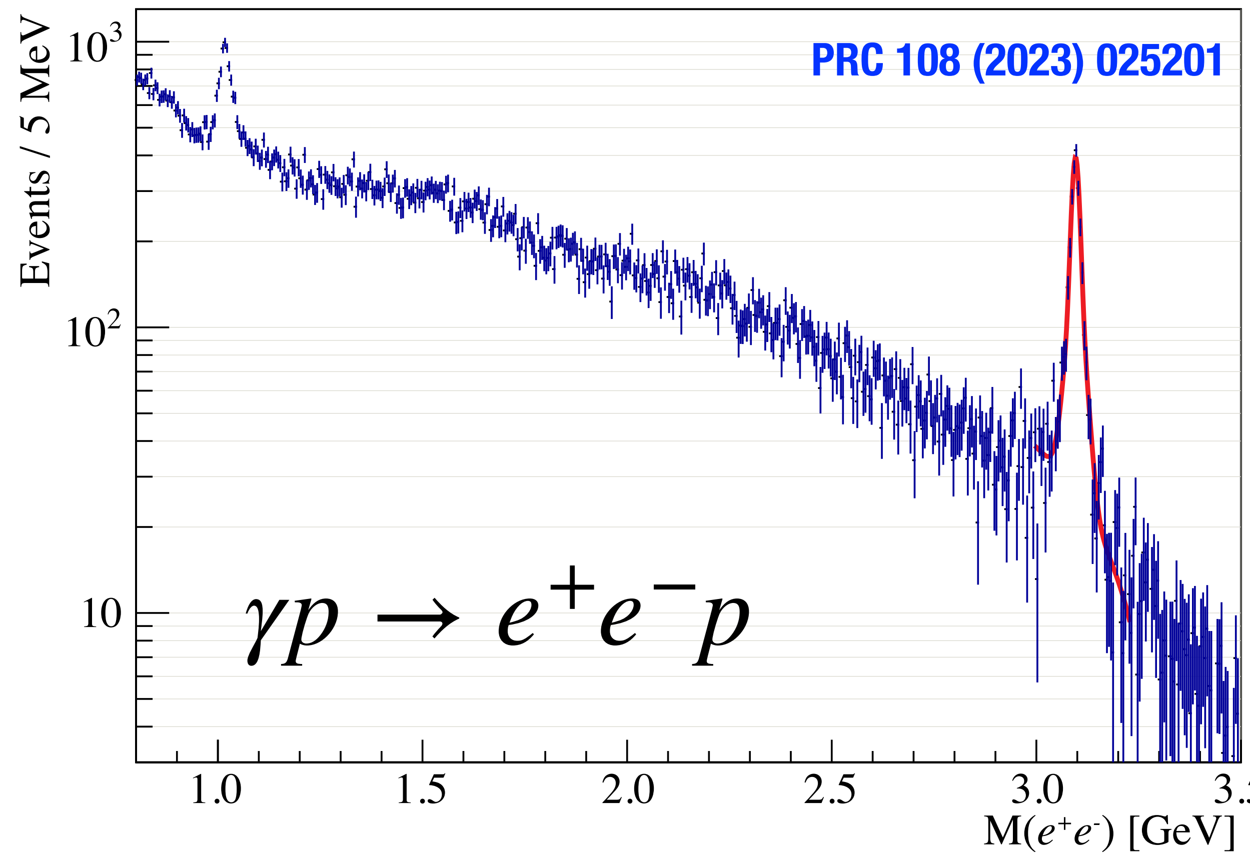




Proportional to BR($P_c \to J/\psi p$)^2

J/ψ photoproduction at GlueX

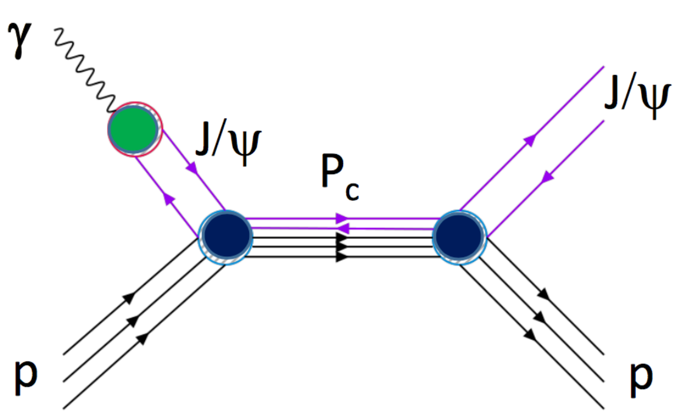
- Experimentally clean and rare probe with ~2.2k J/ψ observed in GlueX-I
- Broad physics program driven by different production mechanisms

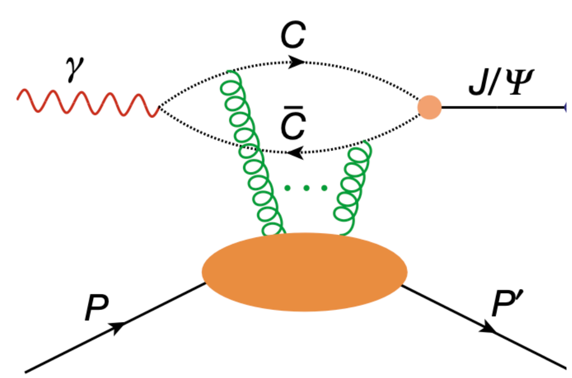


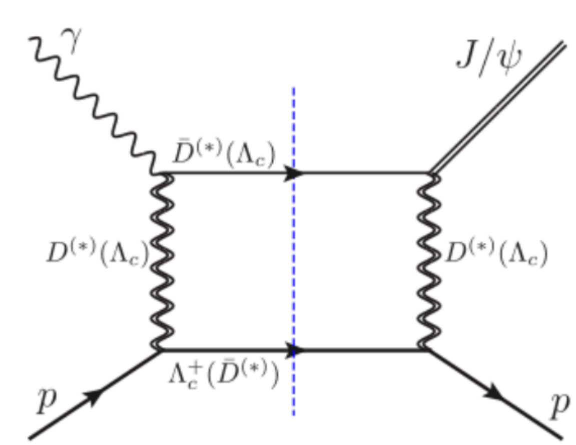
s-channel: pentaquarks

t-channel: gluon GPDs, mass radius

open charm

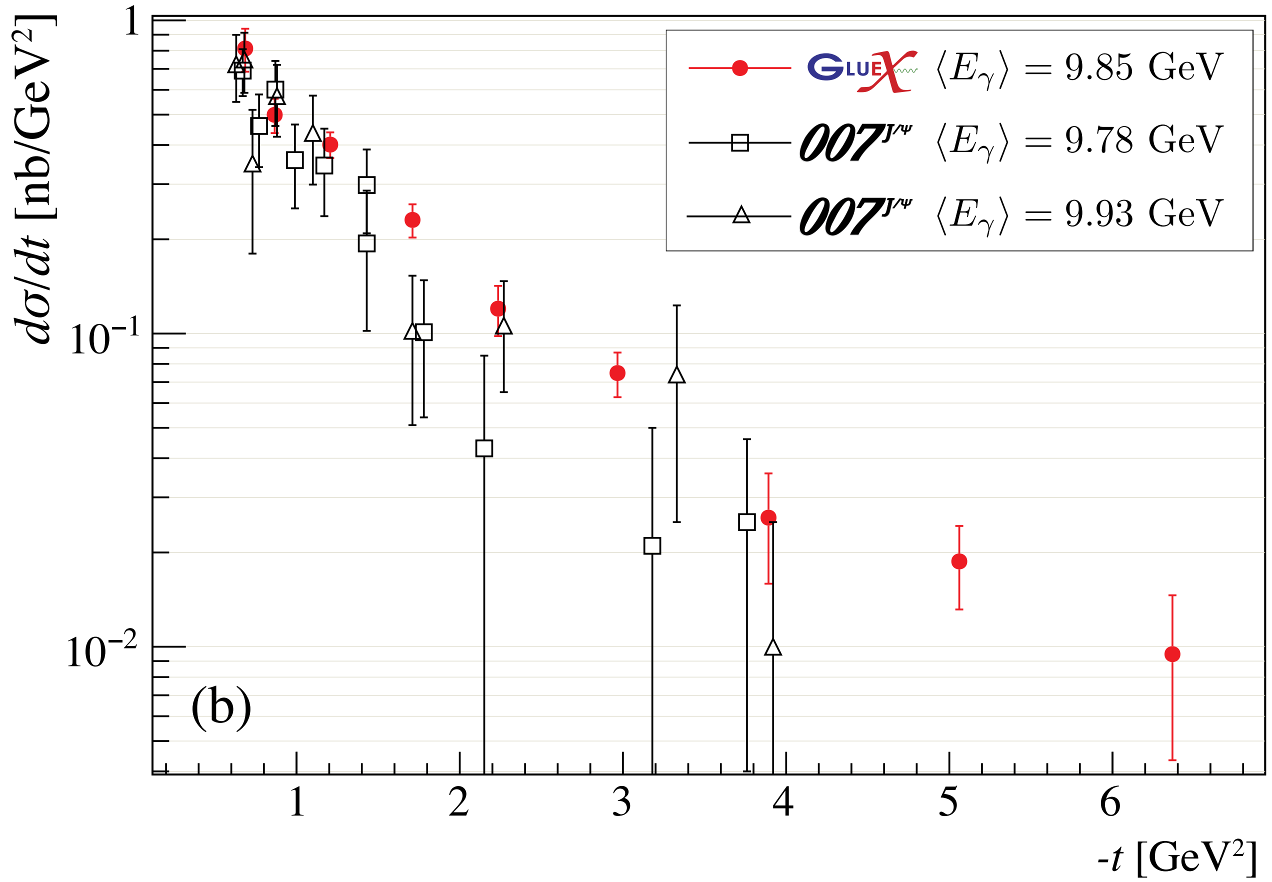


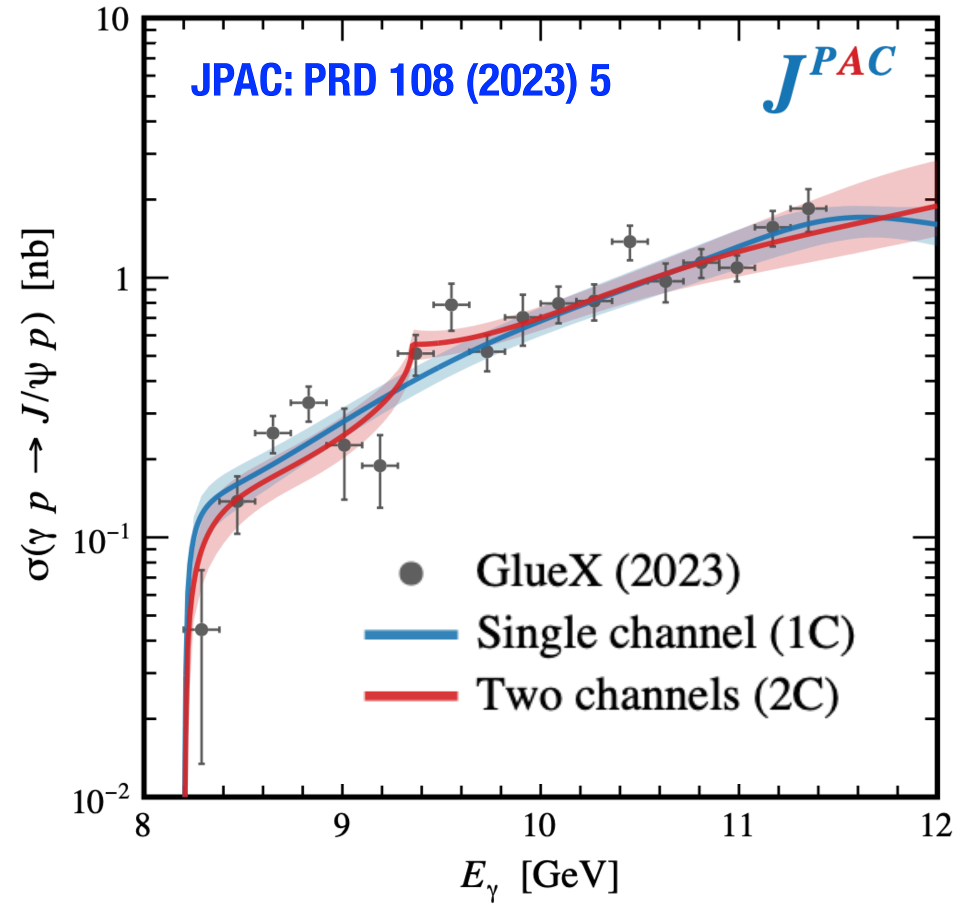




Interpretation of J/ψ results

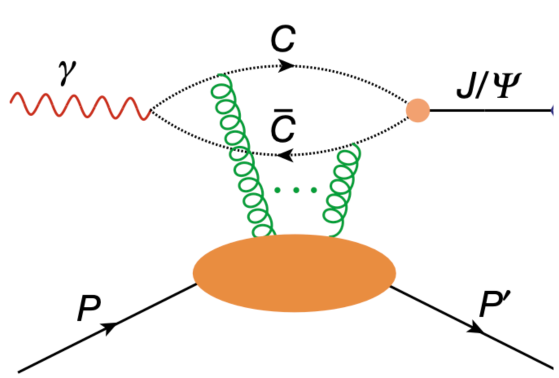
PRC 108 (2023) 025201

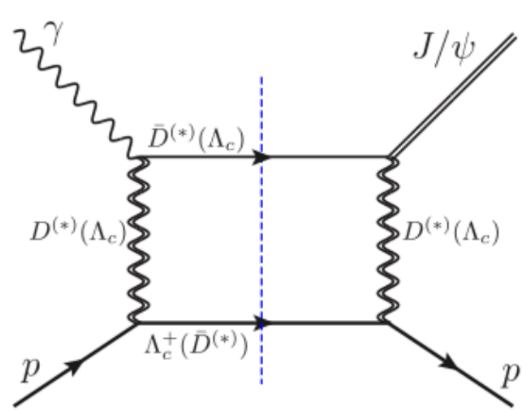




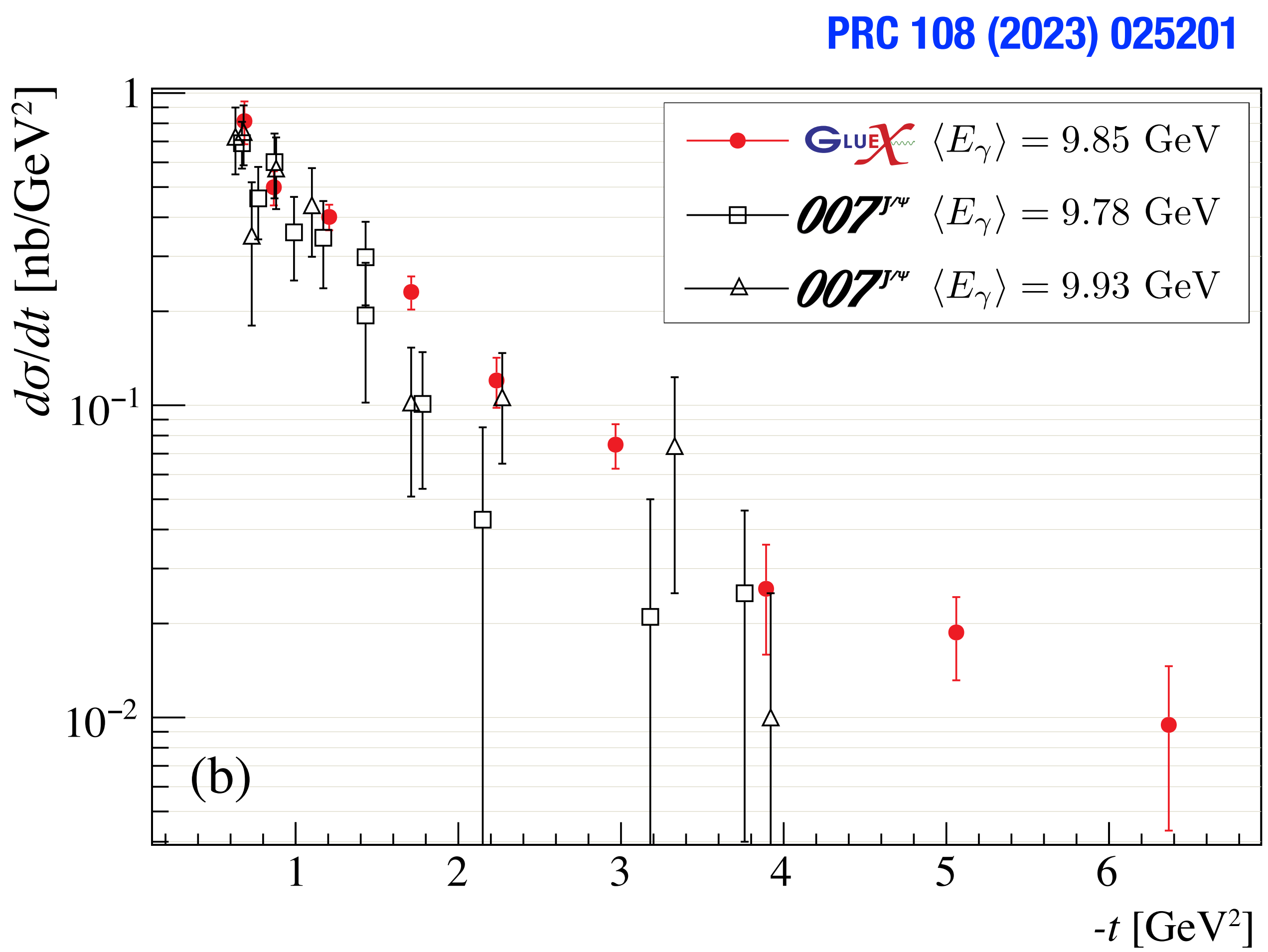
- Differential cross section $d\sigma/dt$ consistent between $J/\psi - 007$ (Hall C) and GlueX — sensitive to gluon GPDs, mass radius, etc. under certain assumptions

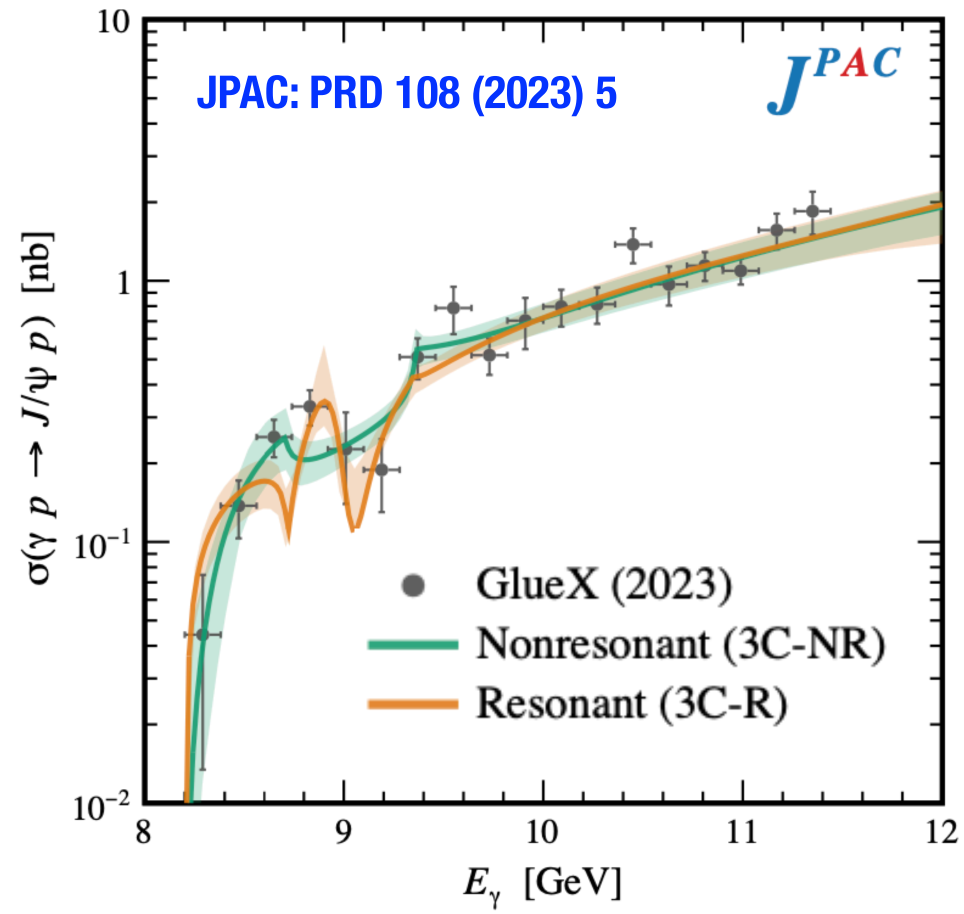
Single channel **+ Open charm = Two channel**





Interpretation of J/ψ results

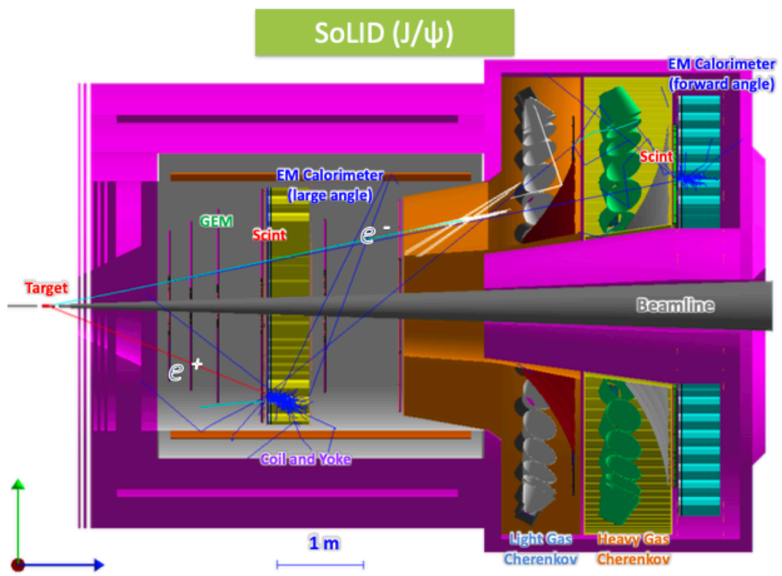


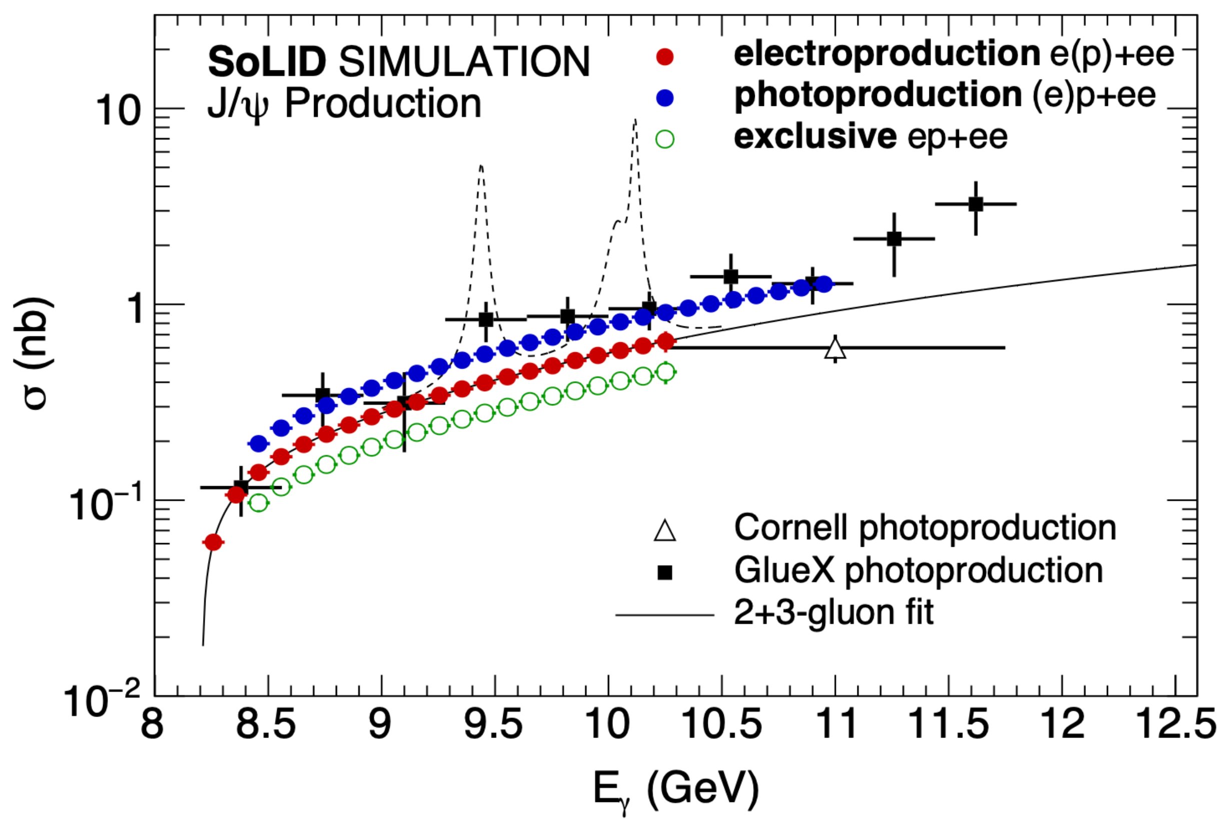


- Differential cross section $d\sigma/dt$ consistent between $J/\psi - 007$ (Hall C) and GlueX — sensitive to gluon GPDs, mass radius, etc. under certain assumptions

- Total cross section sensitive to “cusps” near open charm thresholds — models with both resonant pentaquark and purely non-resonant effects can adequately describe the data

Interpretation of J/ψ results



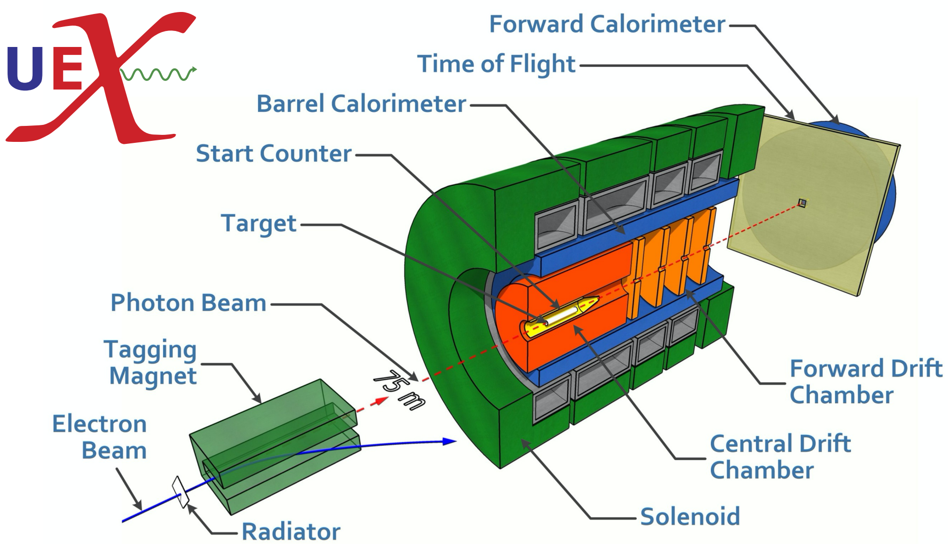


- Differential cross section $d\sigma/dt$ consistent between $J/\psi-007$ (Hall C) and GlueX — sensitive to gluon GPDs, mass radius, etc. under certain assumptions
- Total cross section sensitive to “cusps” near open charm thresholds — models with both resonant pentaquark and purely non-resonant effects can adequately describe the data
- Improved precision required to differentiate production mechanisms and spectroscopy interpretation: GlueX-III, SOLID, etc.

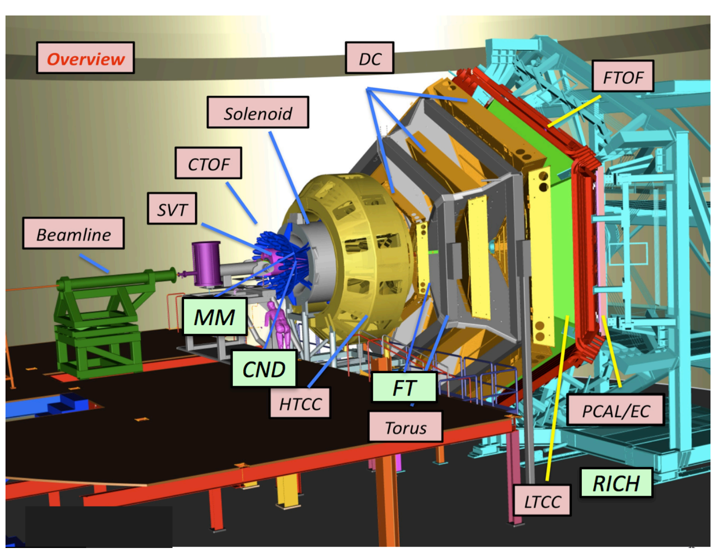
Jefferson Lab

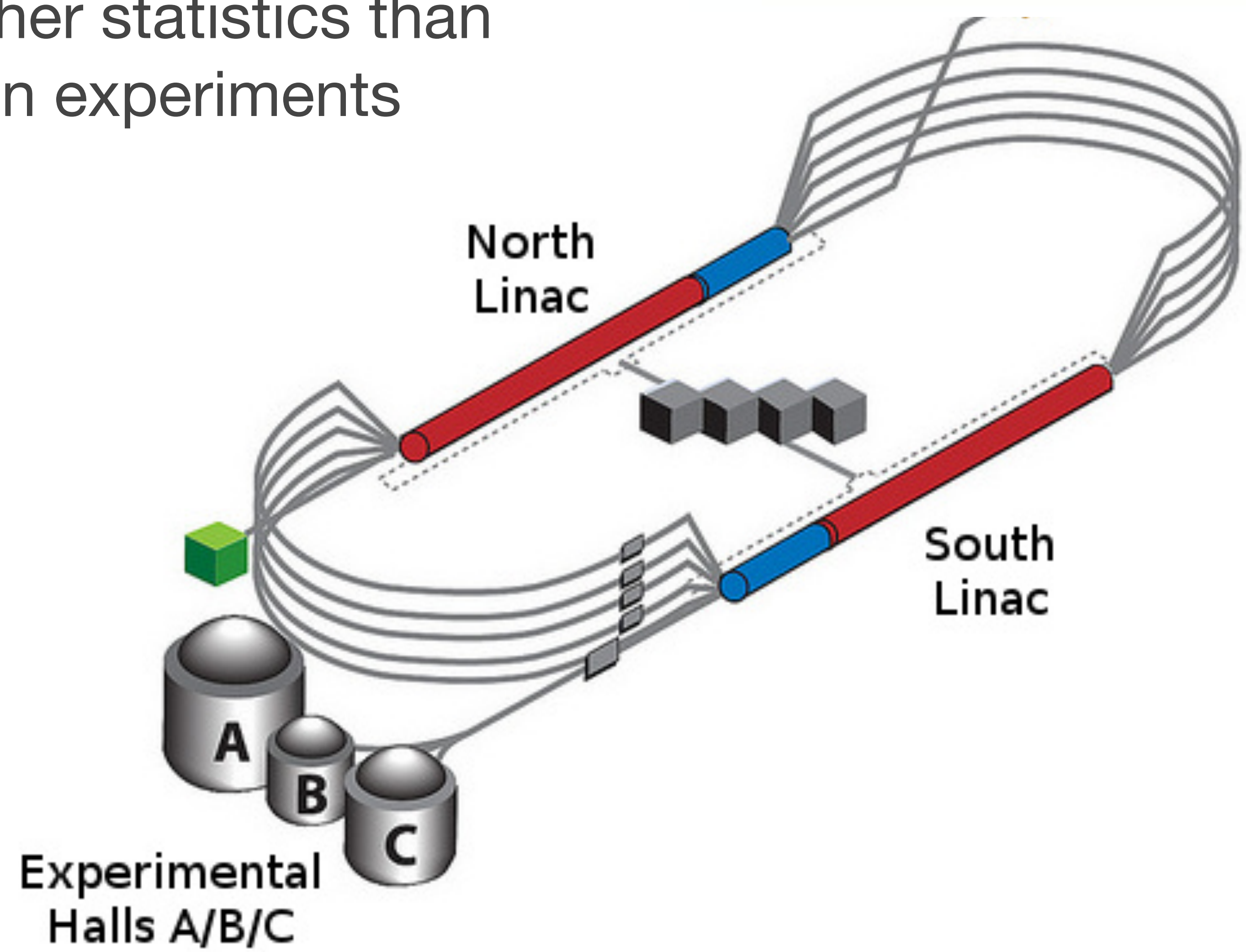
- JLab 12 GeV running since 2017: programs in hadron spectroscopy, nucleon and nuclear structure, etc.
- Photoproduction process provides access to many proposed exotic decay channels
- Orders of magnitude higher statistics than previous photoproduction experiments

GlueX



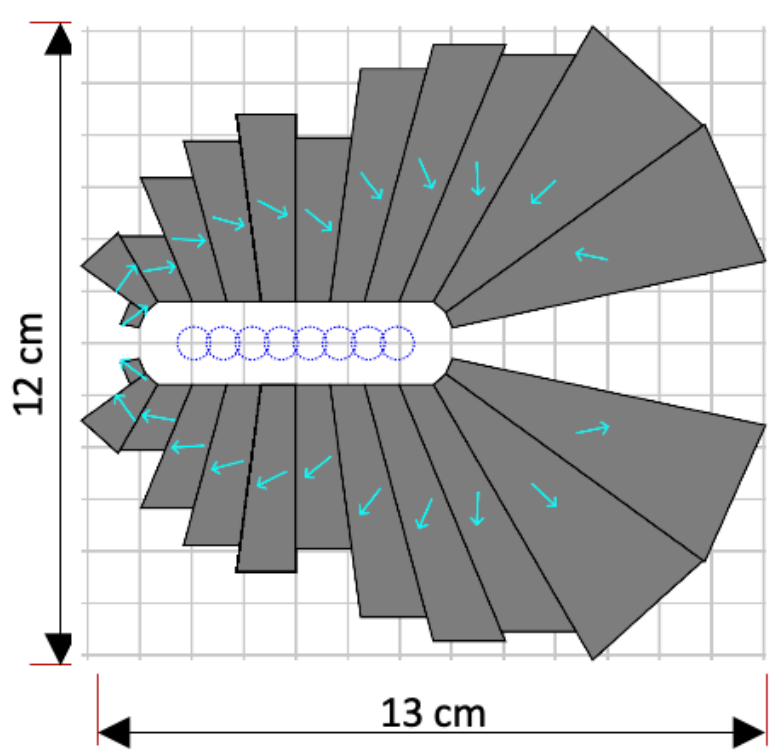
clas
CEBAF Large Acceptance Spectrometer

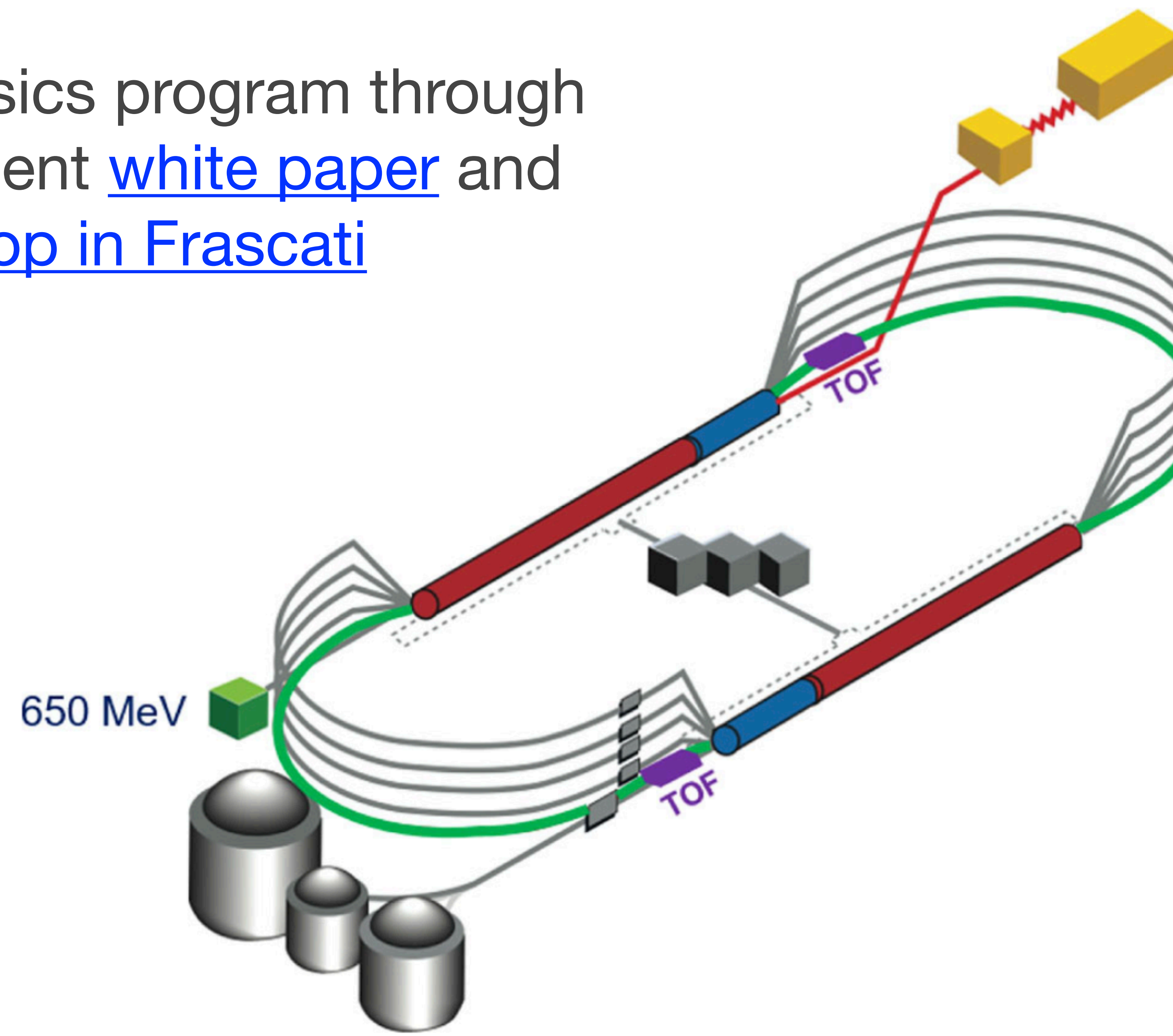




Jefferson Lab at 22 GeV

- Add 6 additional "passes" with Fixed Field alternating gradient Accelerator (FFA) magnets
- Steady progress on physics program through series of workshops: recent [white paper]() and [December 2024 workshop in Frascati]()





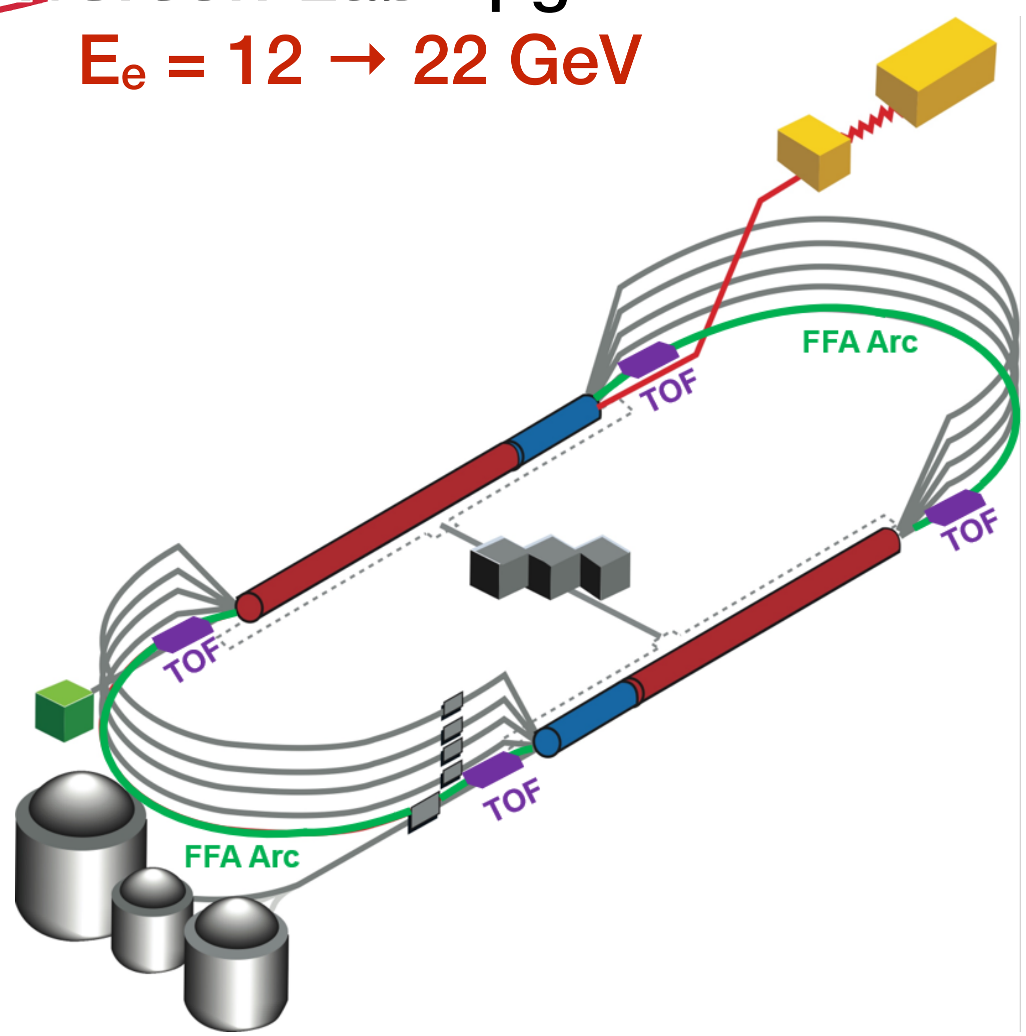
White Paper: EPJA 60 (2024) 9, 173

Photoproduction of XYZ states

Complementary access to charmonium photoproduction with higher energy facilities

Jefferson Lab upgrade:

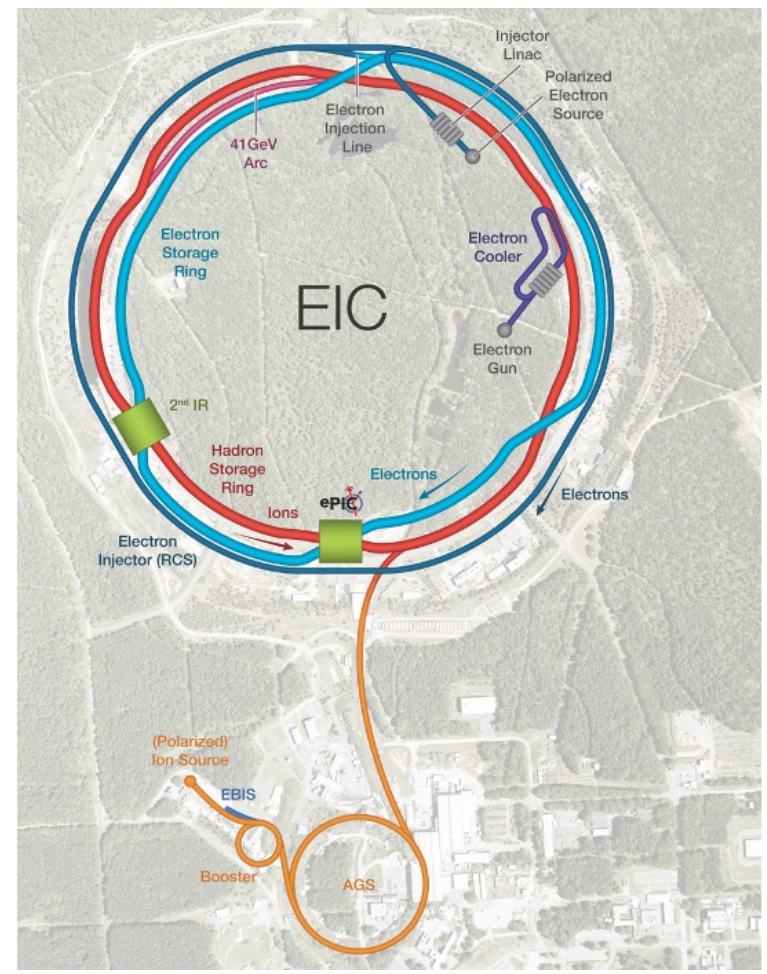
$E_e = 12 \rightarrow 22$ GeV



$$\sqrt{s}_{\gamma p} = 1.5 \ - \ 6.5 \text{ GeV}$$

$$\boxed{\mathscr{L}_{ep} = 10^{35} - 10^{37} \ cm^{-2}s^{-1}}$$

Electron Ion Collider (EIC)



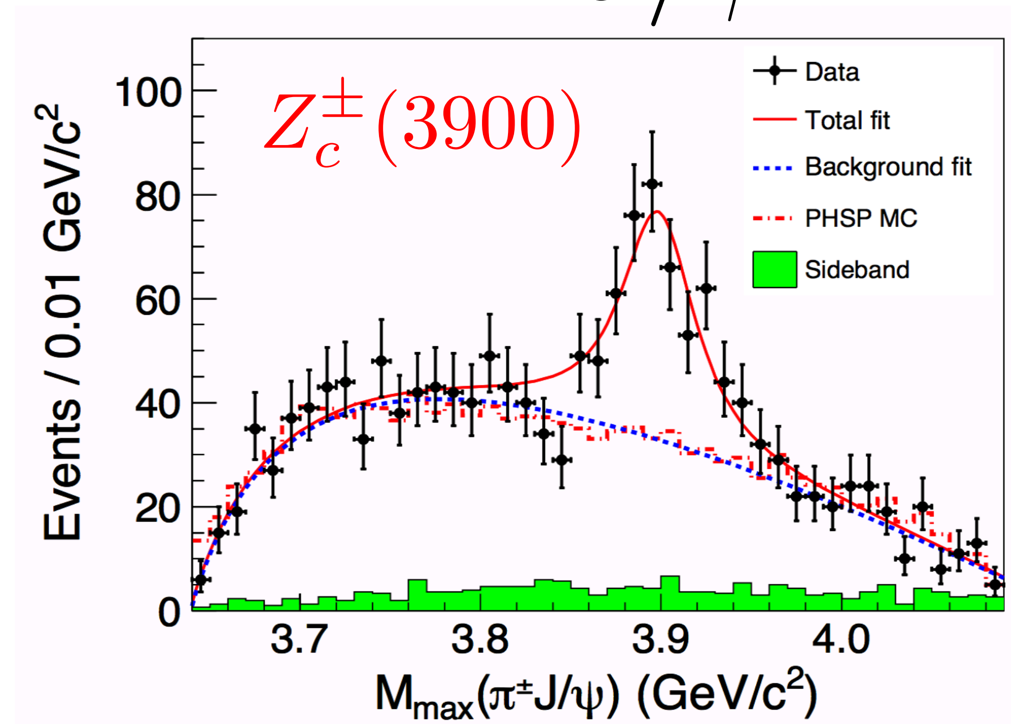
$$\boxed{\sqrt{s}_{\gamma p} = 5 \ - \ 141 \text{ GeV}}$$

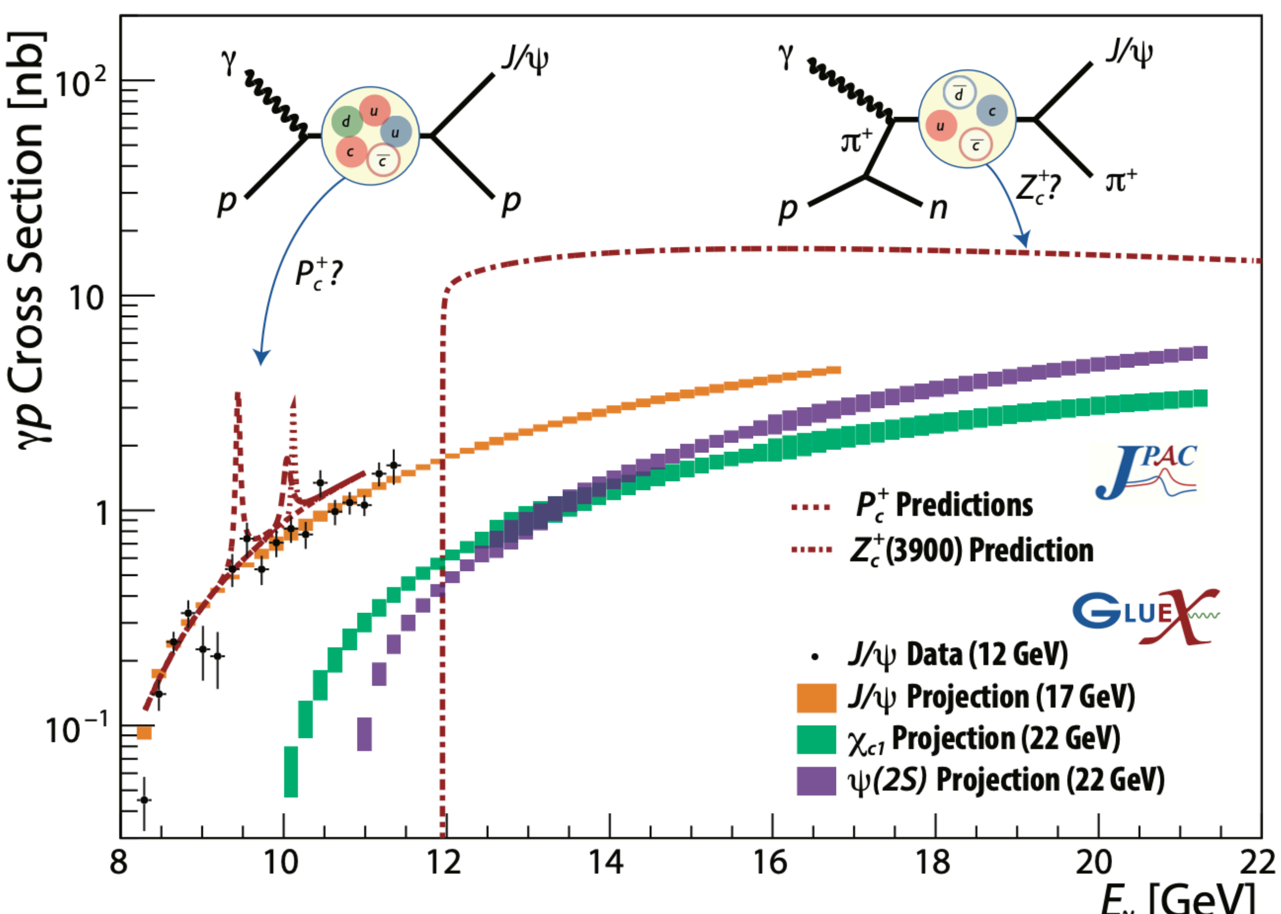
$$\mathscr{L}_{ep} = 10^{34} \ cm^{-2}s^{-1}$$

Exotic states with $c\bar{c}$

- Thresholds for XYZ states open just above 12 GeV
- For example, Z_c enhanced in 22 GeV region, consistent with COMPASS upper limit

$$e^+e^- \to J/\psi\pi^+\pi^-$$





White Paper: EPJA 60 (2024) 9, 173

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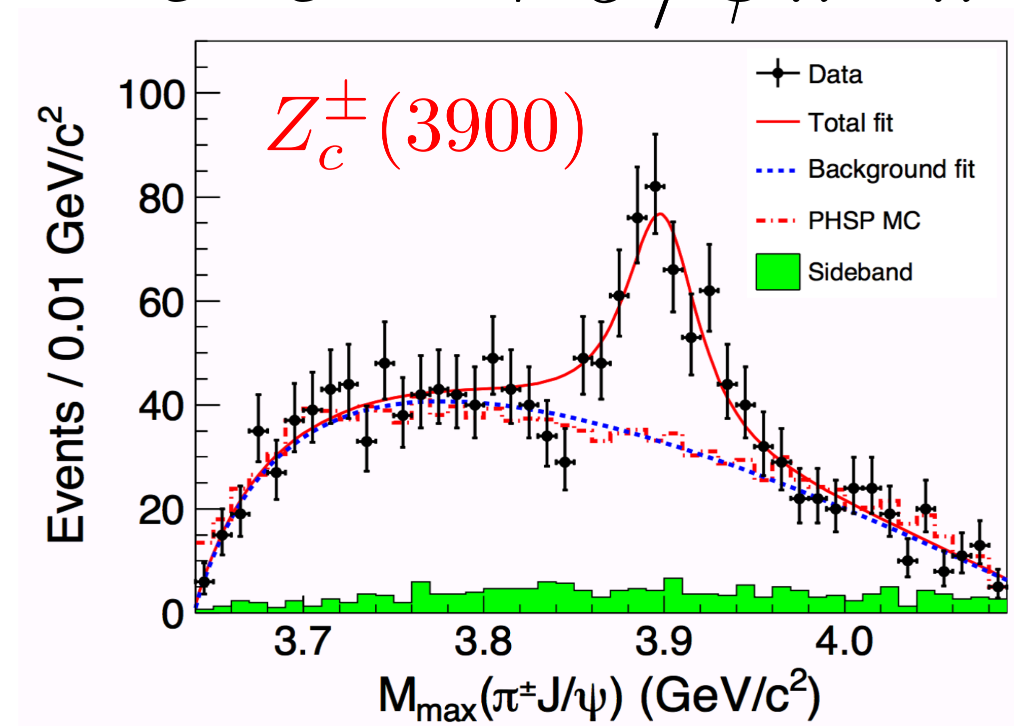

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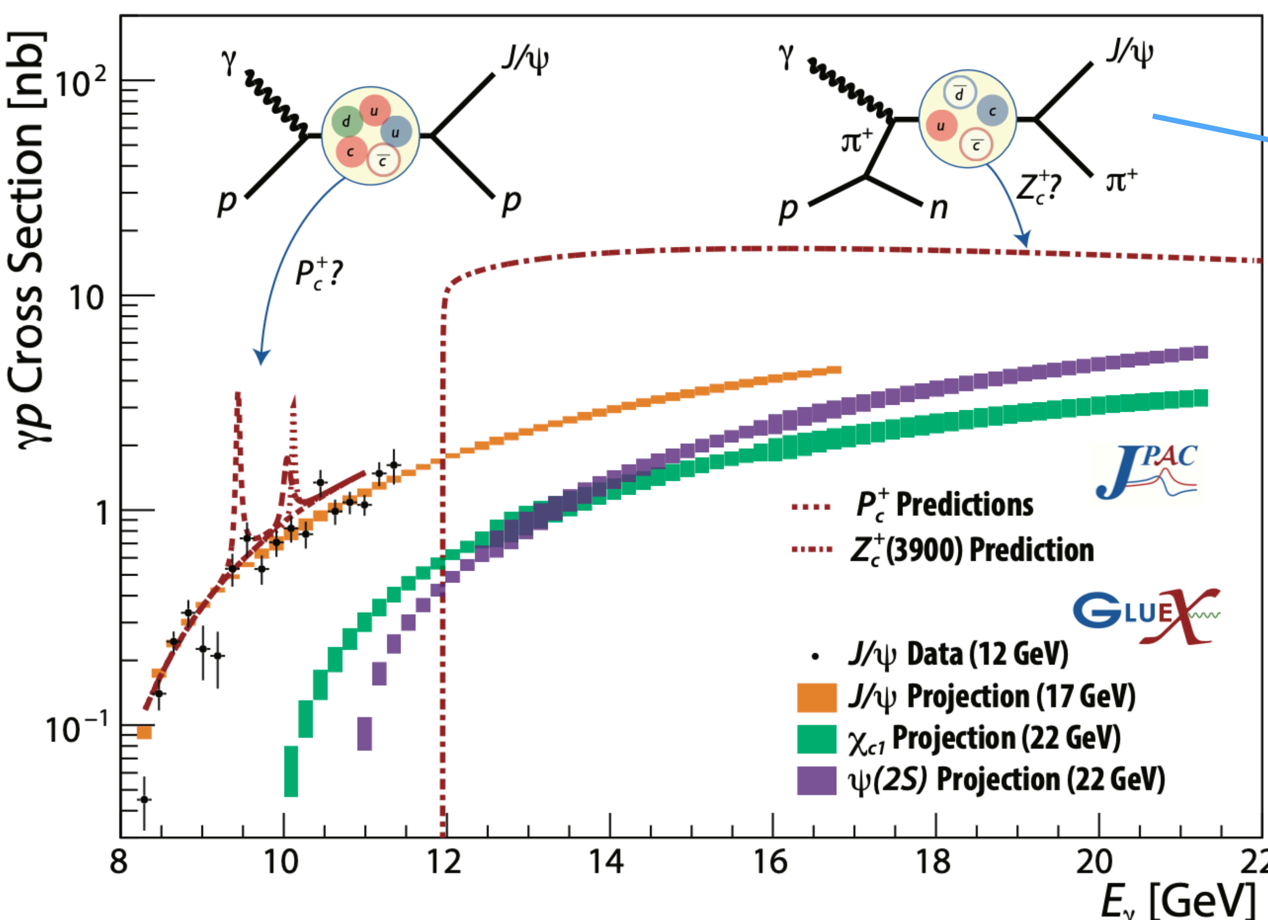

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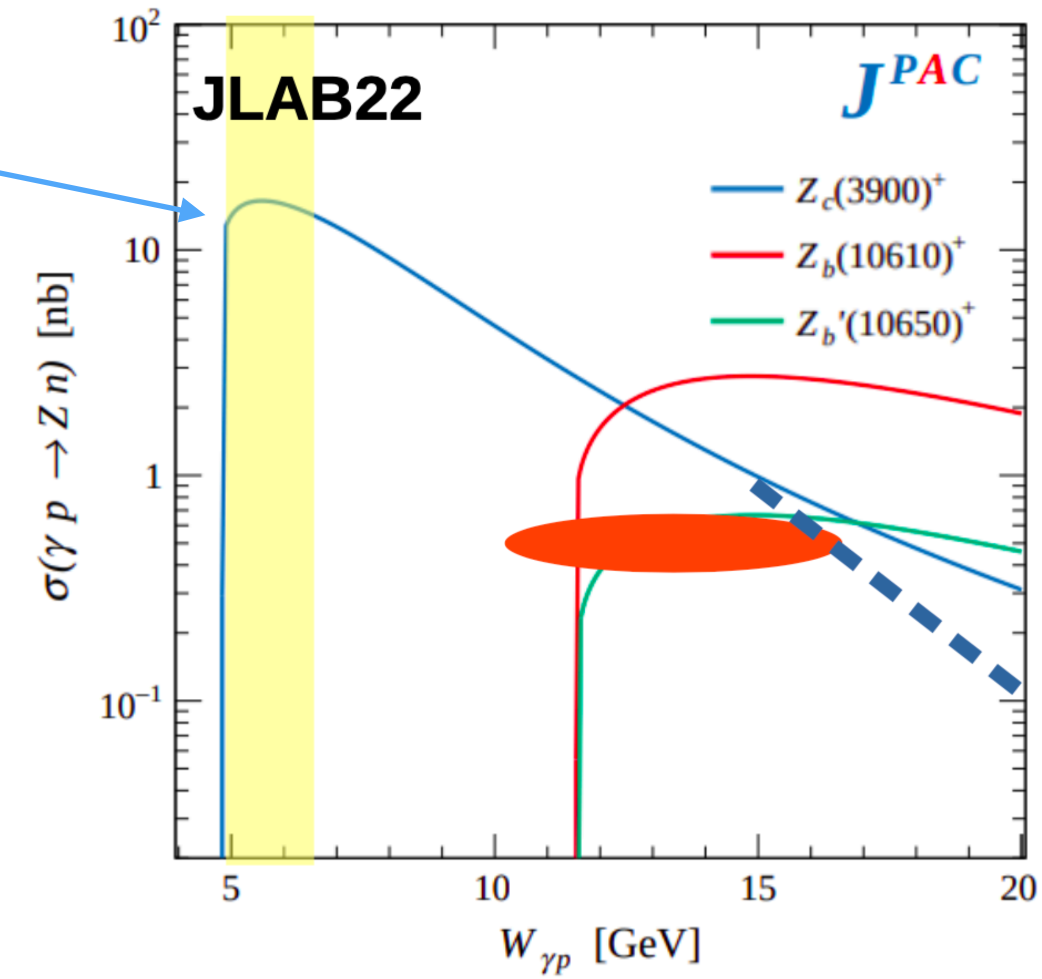

Exotic states with $c\bar{c}$

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- Keep in mind, field is still moving forward at BESIII, LHCb, etc.

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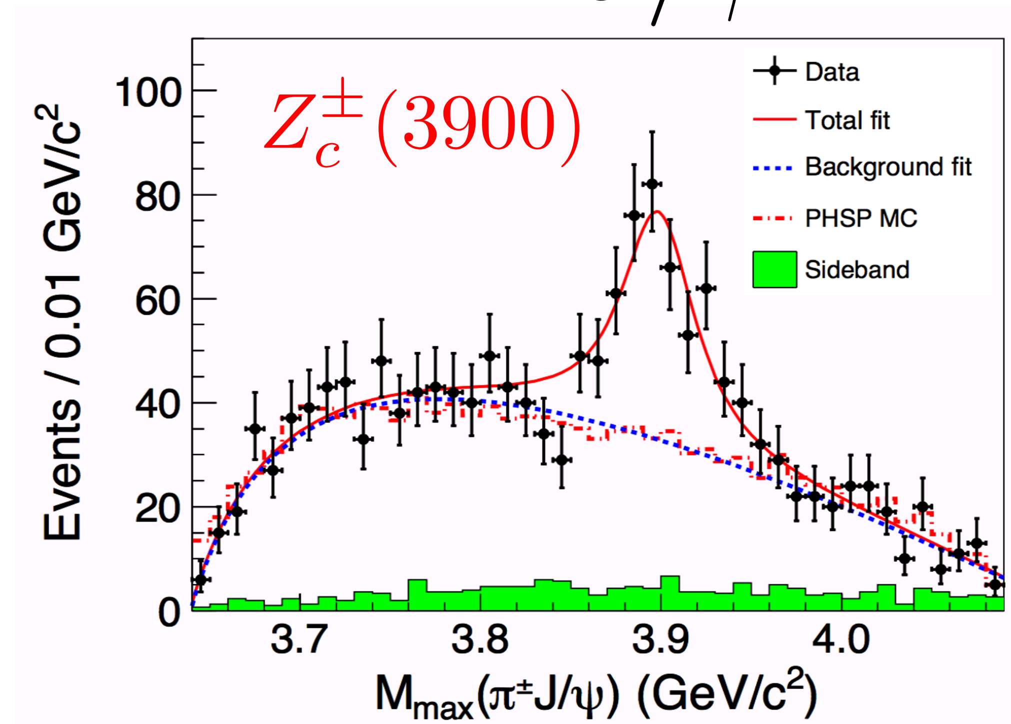
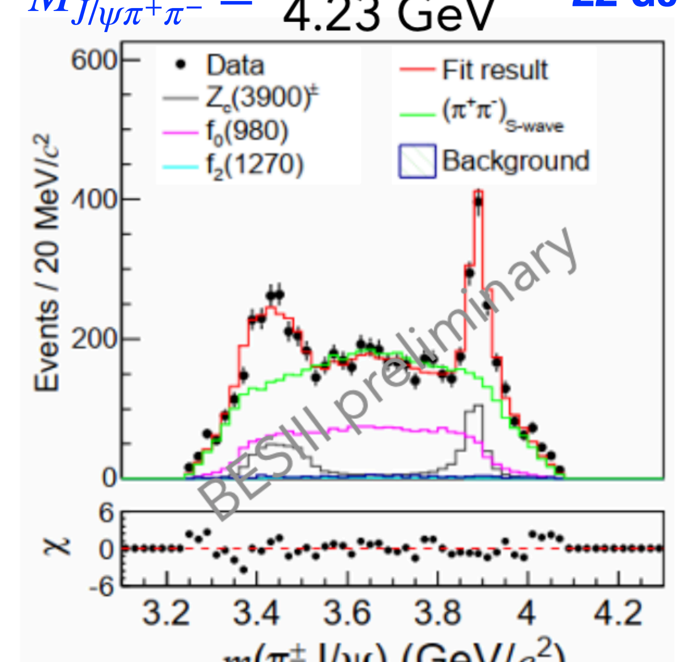


More data

Nils Hüsken (Frascati 22 GeV workshop)

$M_{J/\psi\pi^+\pi^-} =$ 4.23 GeV



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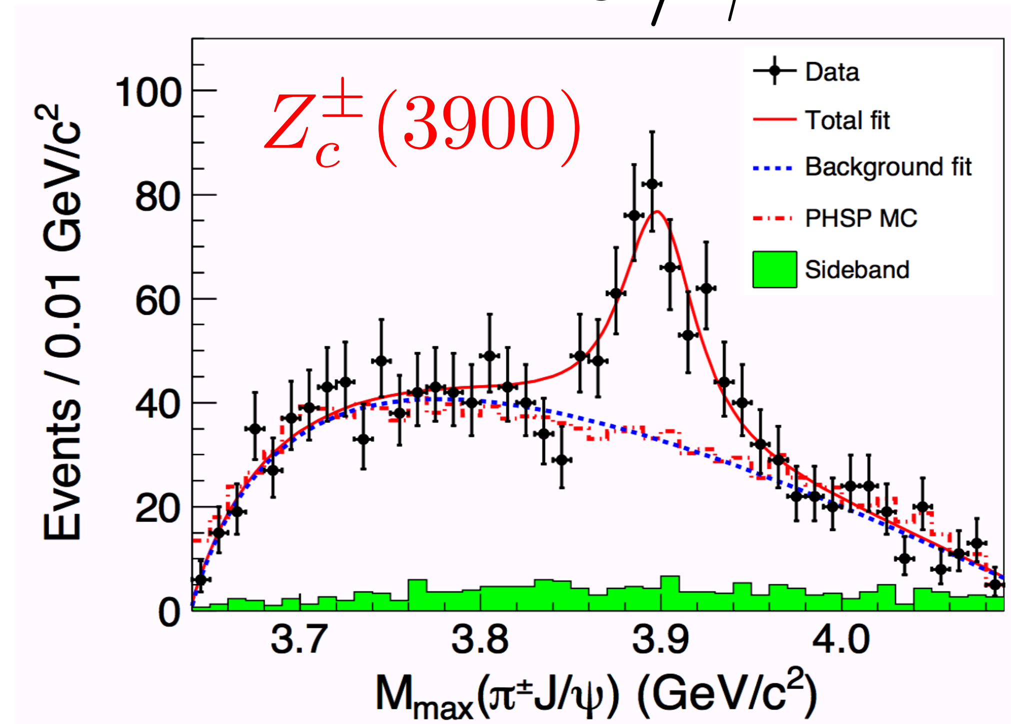

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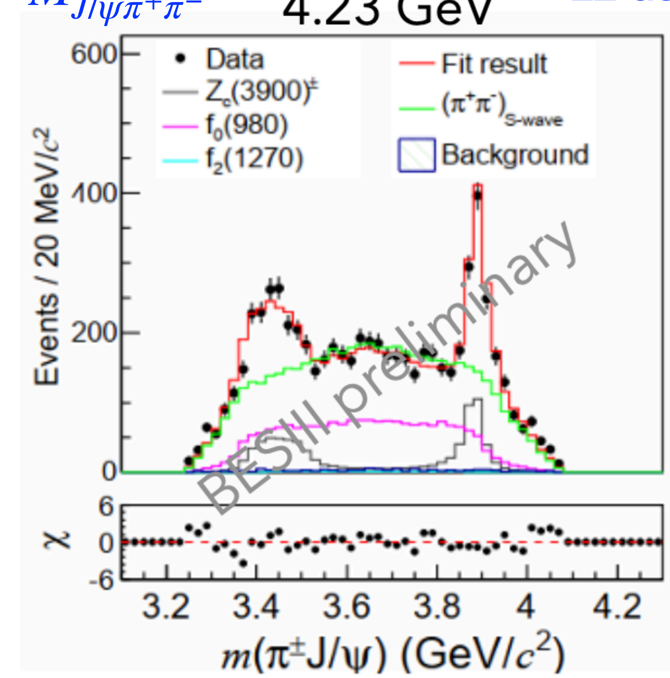
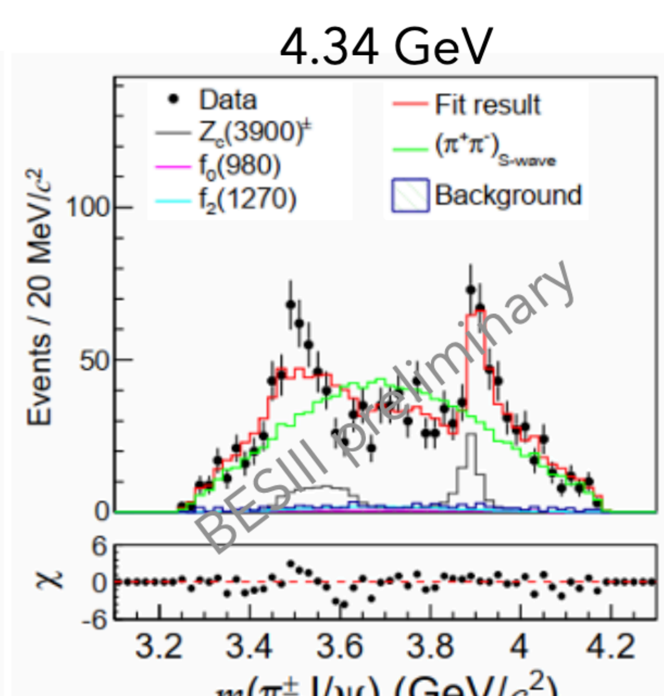
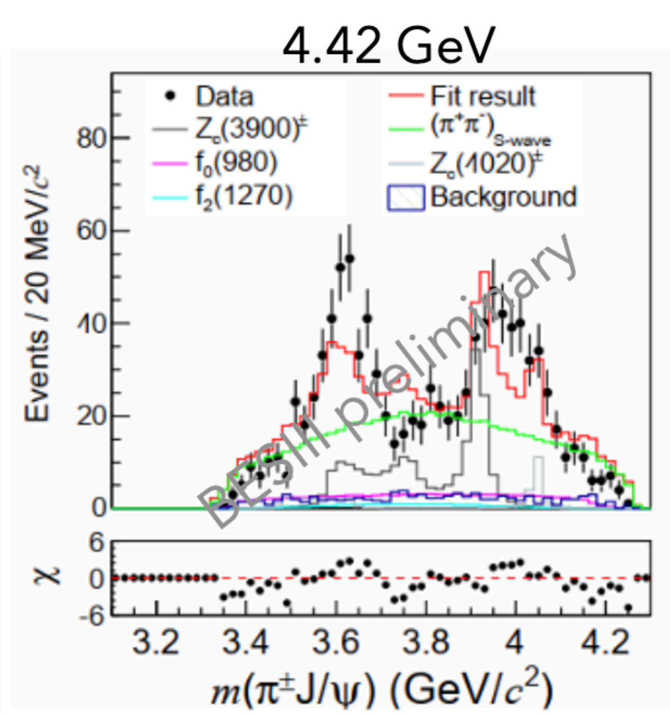


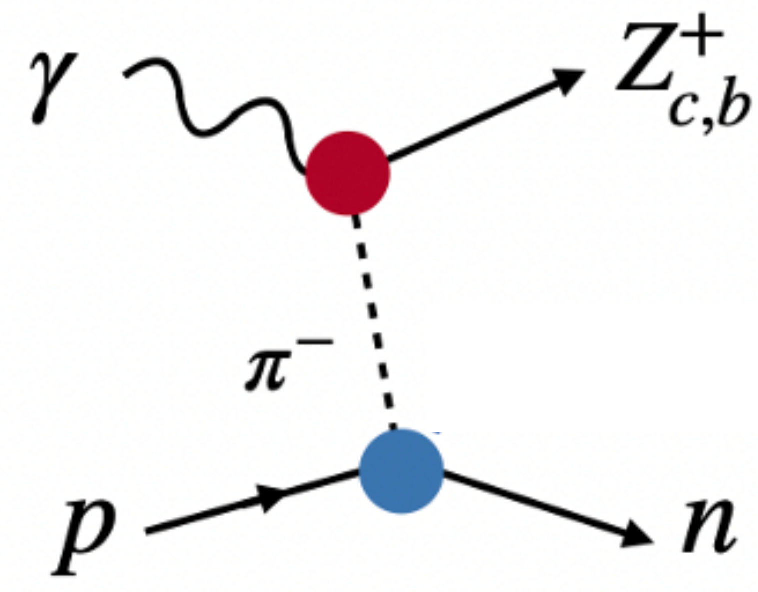
Higher energy

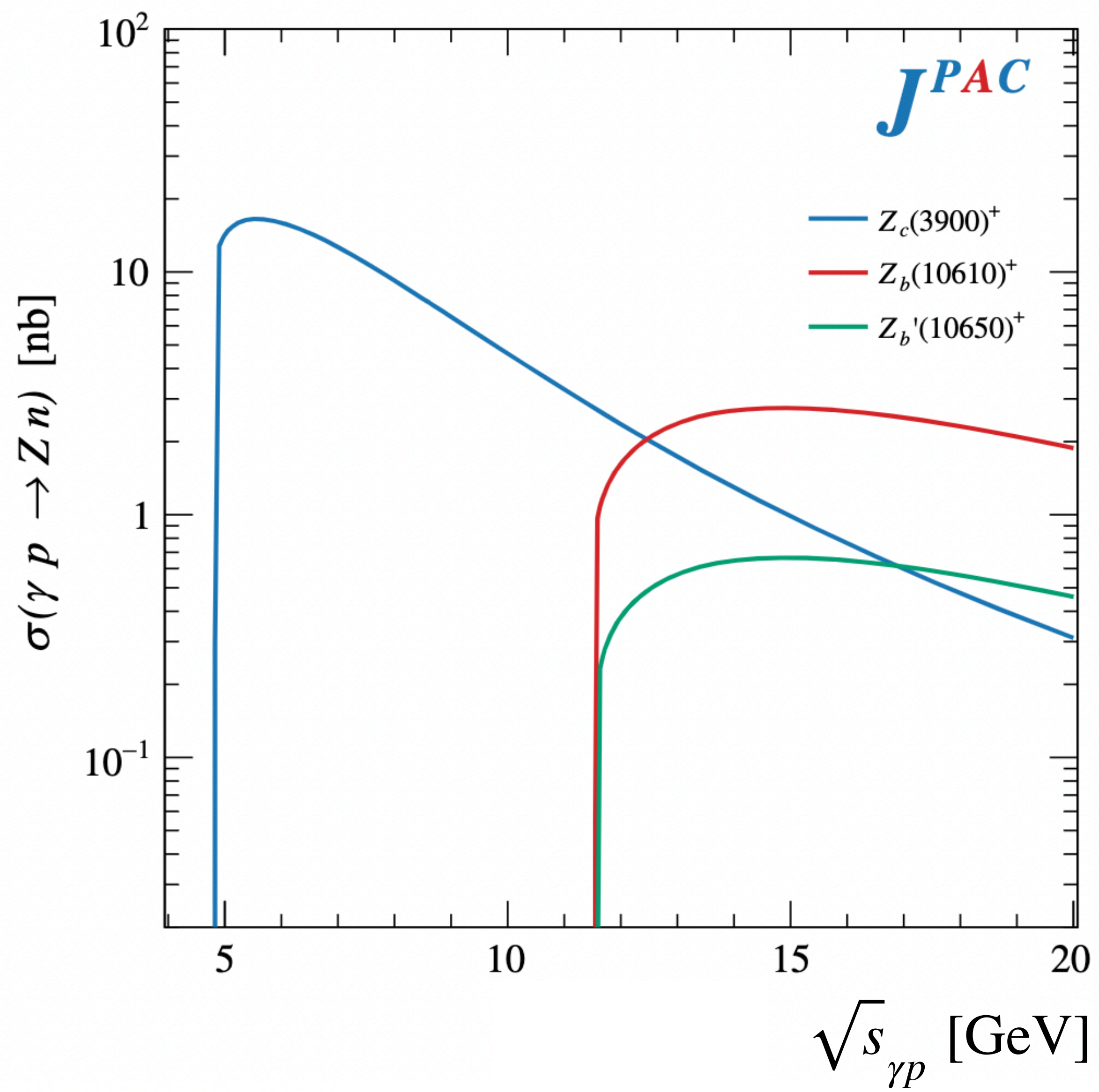




Photoproduction of $Z_c^+(3900)$

- Alternative production mechanism: free of rescattering effects and sensitive to photo couplings
- Same production mechanism near threshold (π exchange) studied with light quarks in GlueX and CLAS12

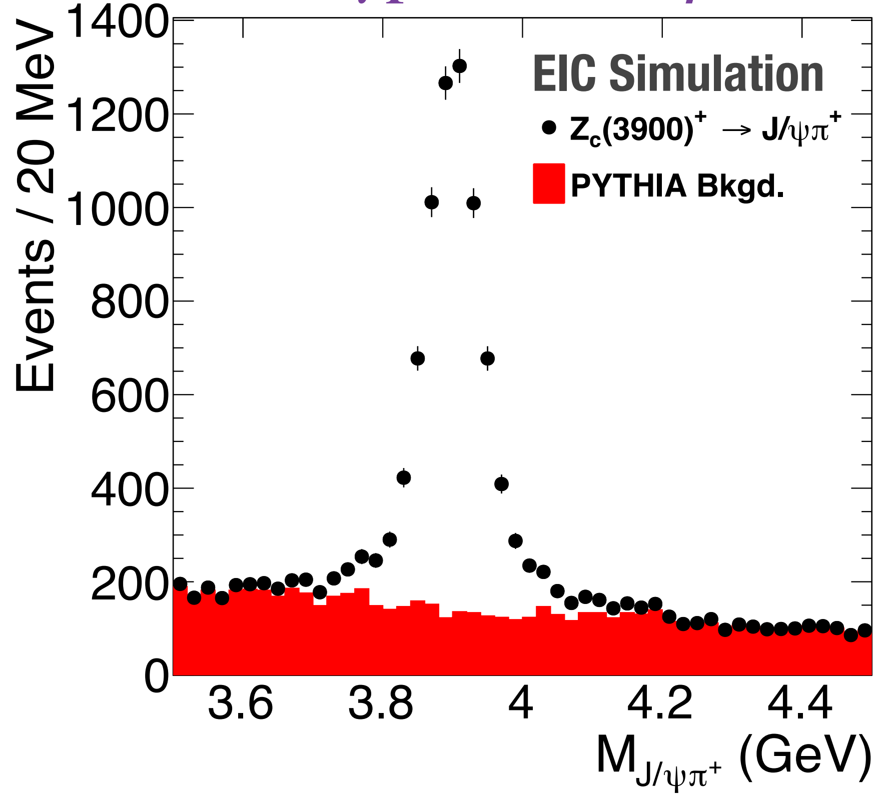




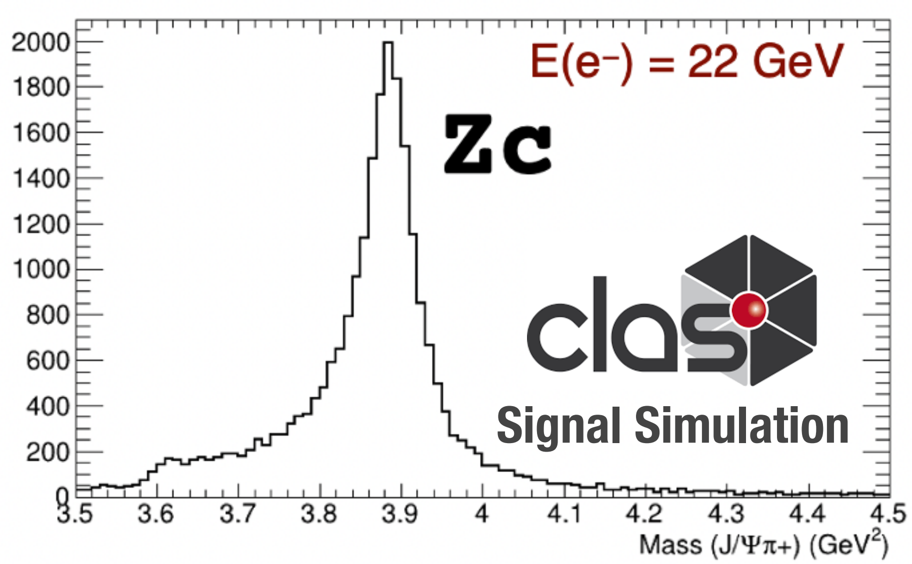
J^{PAC}: PRD 102, 114010 (2020)

Photoproduction of $Z_c^+(3900)$

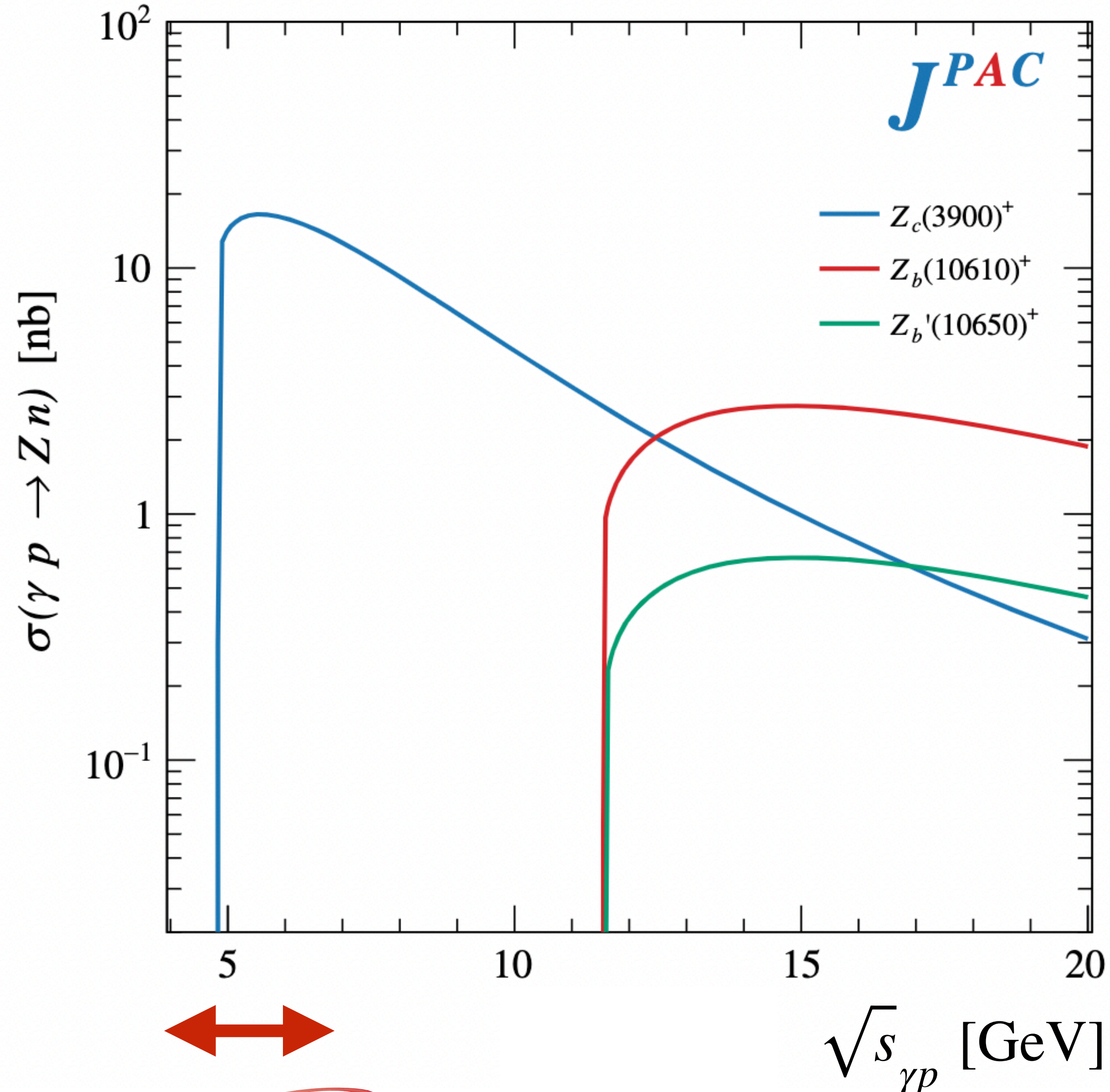
EIC: $\gamma p \to nJ/\psi\pi^+$



JLab 22 GeV: $\gamma p \to nJ/\psi\pi^+$



EIC broad energy coverage

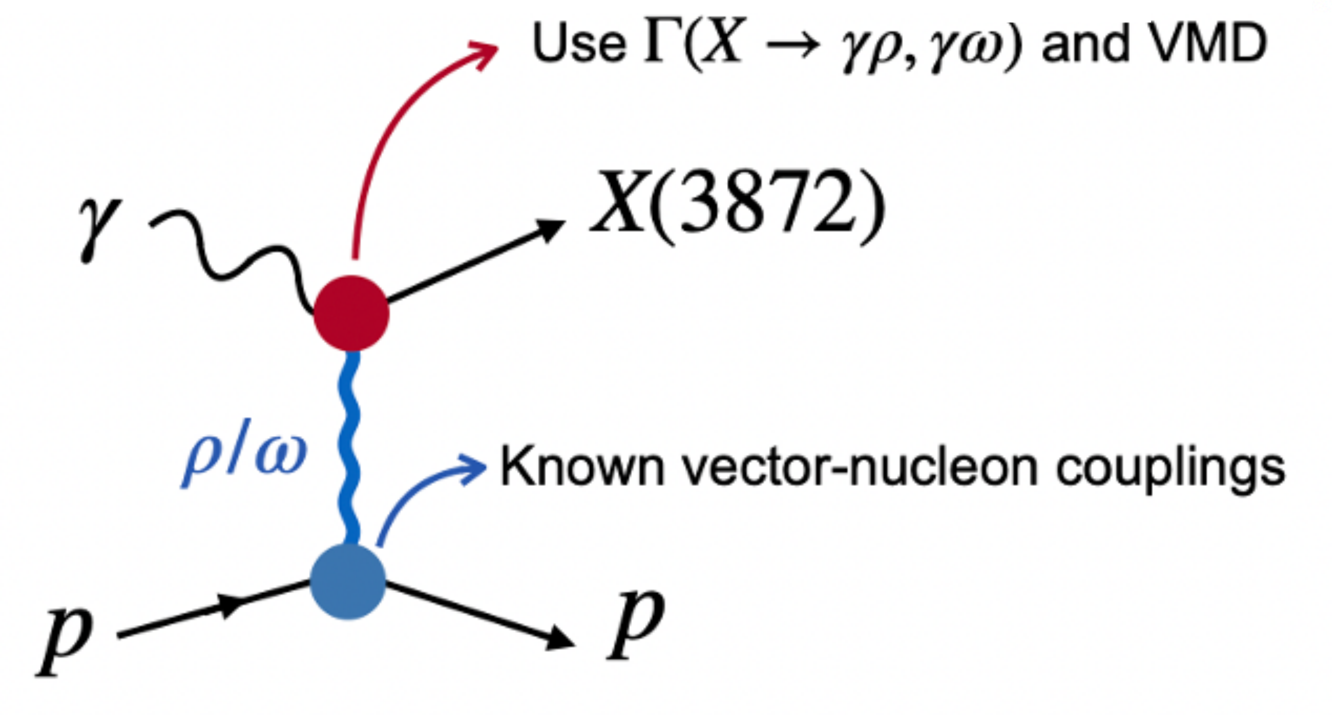


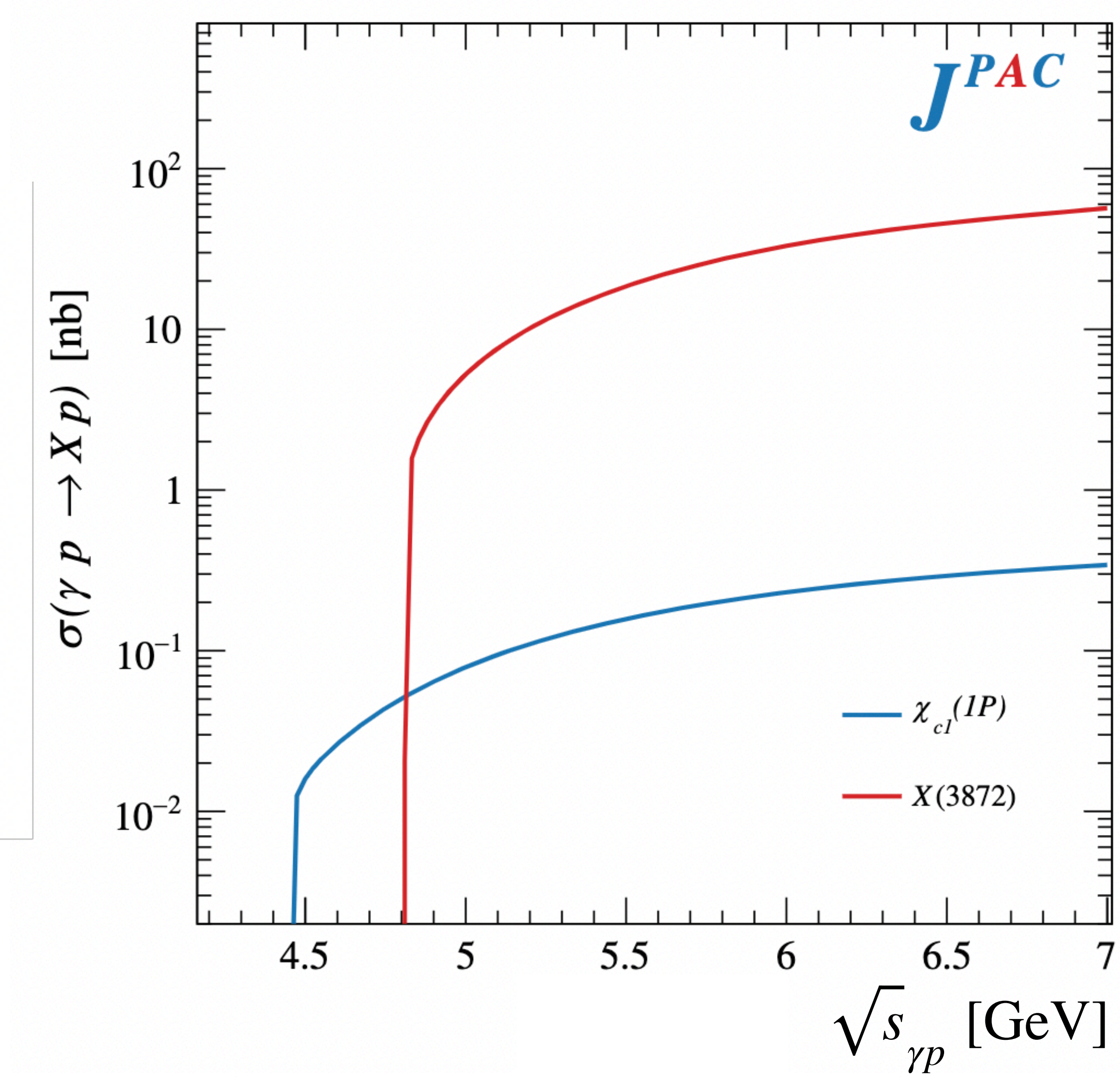
Jefferson Lab 22 GeV

High luminosity near-threshold

Photoproduction of $X(3872)$

JPAC: PRD 102, 114010 (2020)





Jefferson Lab 22 GeV

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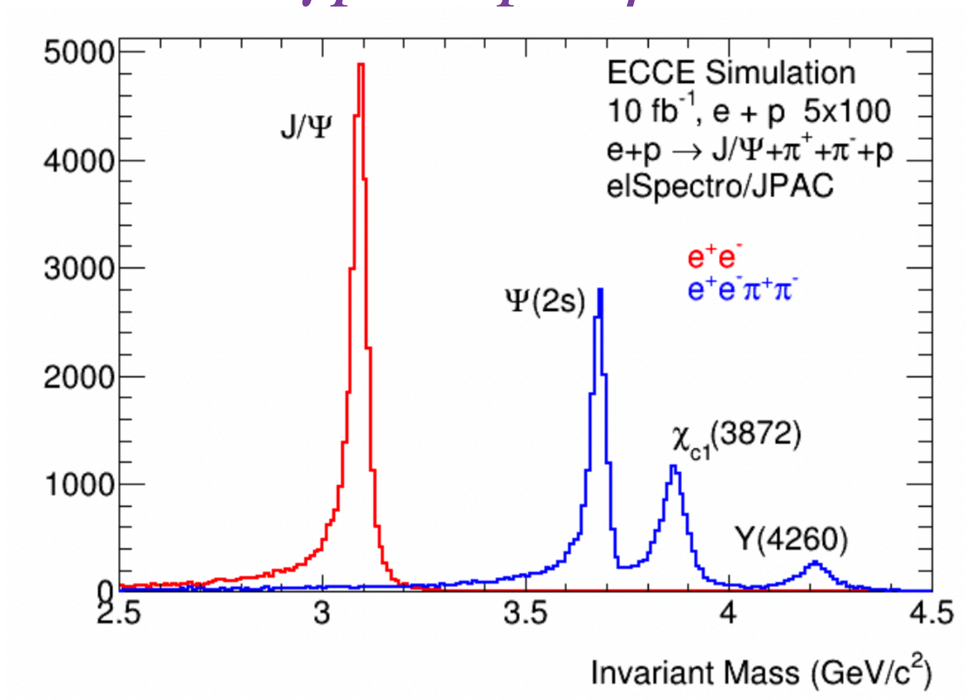
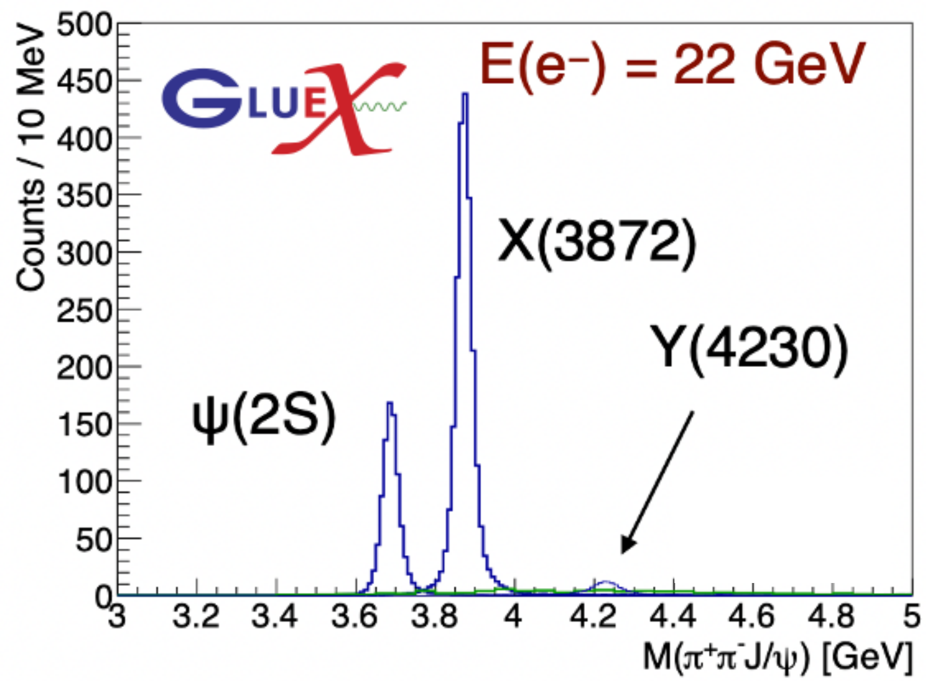
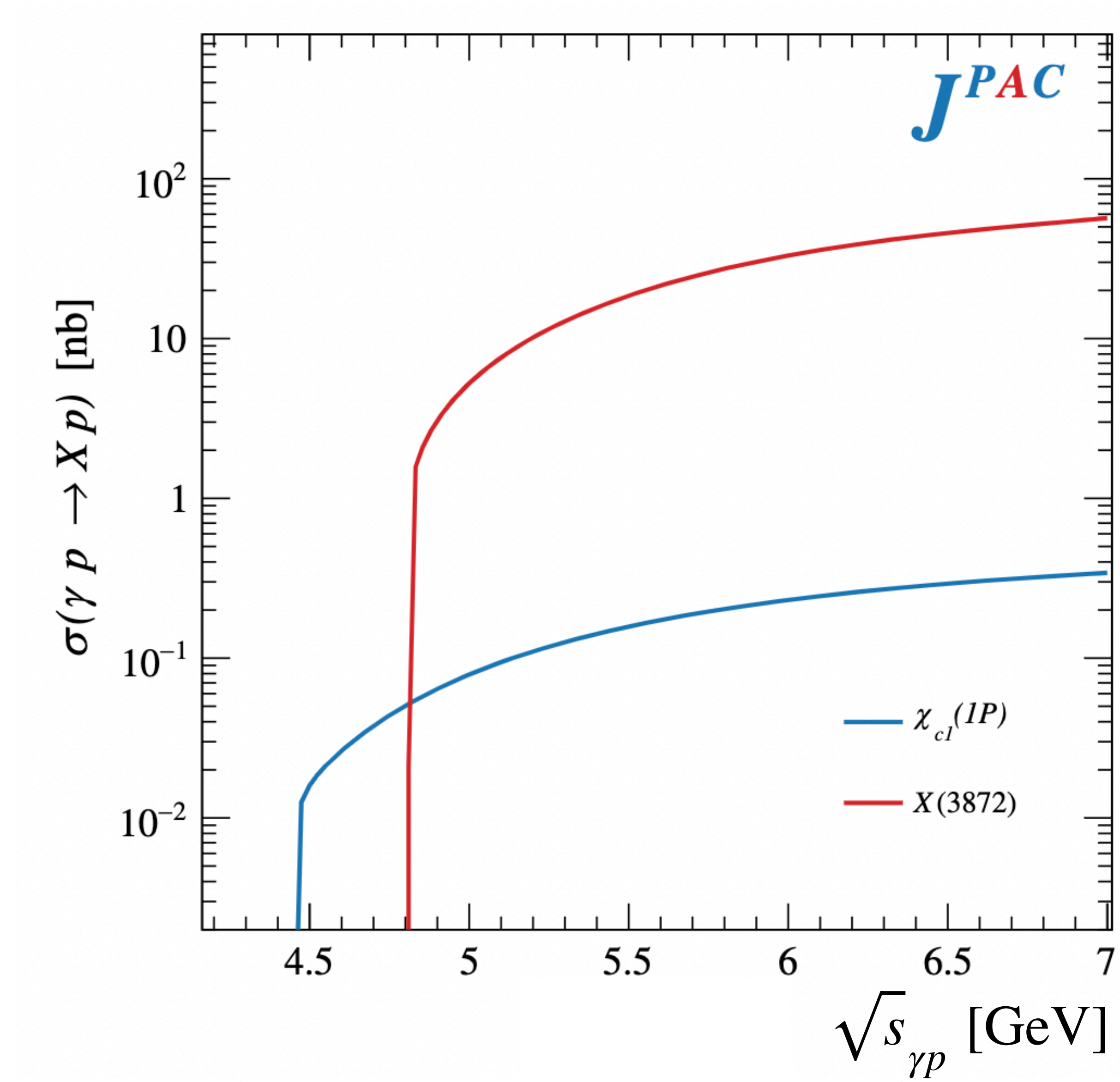
Photoproduction of $X(3872)$

EIC: $\gamma p \to pJ/\psi\pi^+\pi^-$



JLab 22 GeV: $\gamma p \to pJ/\psi\pi^+\pi^-$





Jefferson Lab 22 GeV

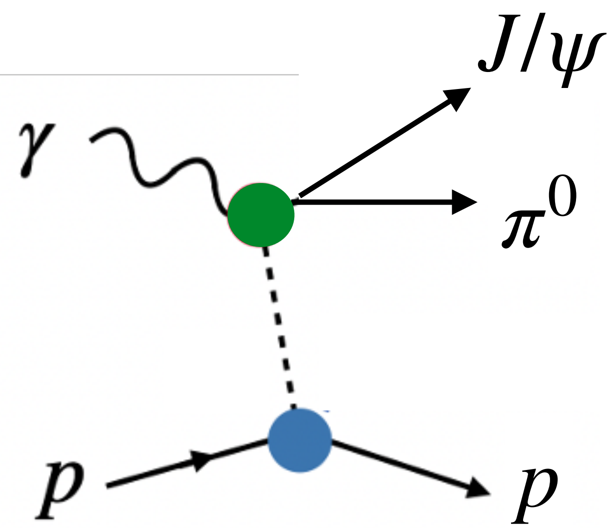
Challenges and Next Steps

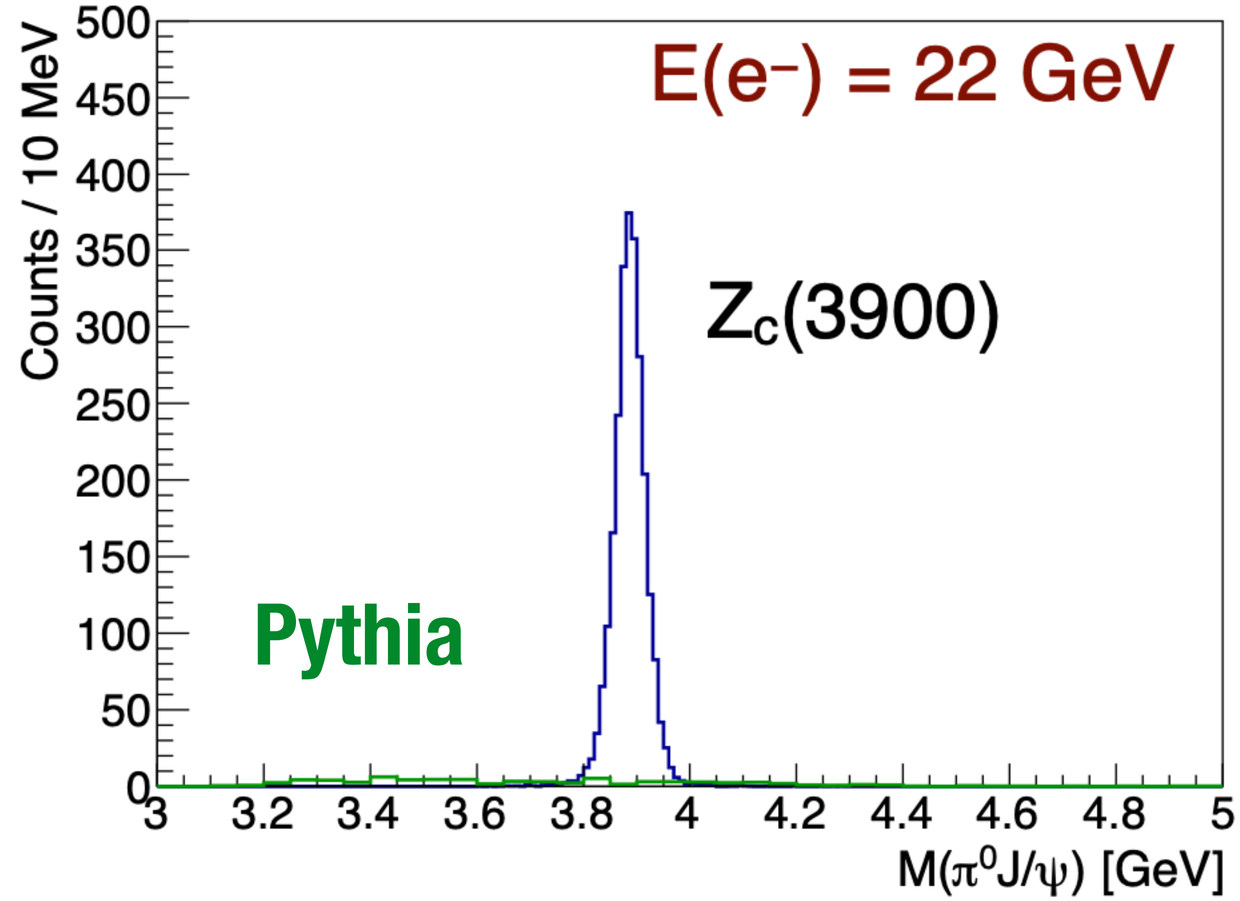
- JLab at 22 GeV and EIC are complementary
- Common challenges
  - Non-resonant production
  - Interpretation…
  - Final states with open charm

Next steps: non-resonant background

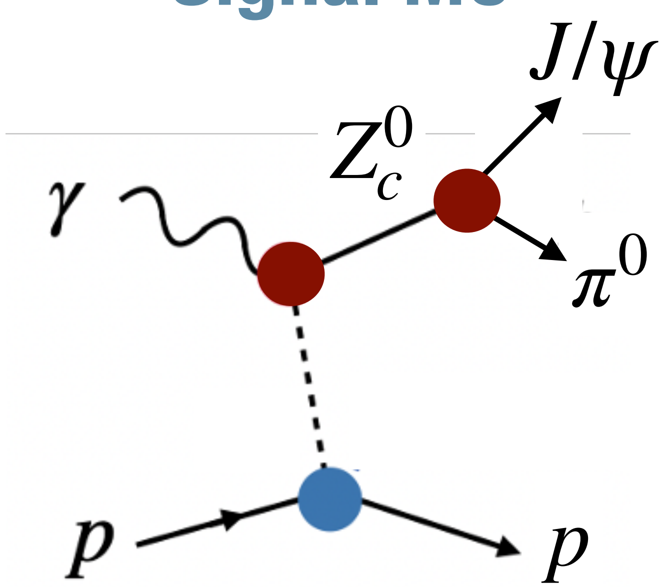
$$\gamma p \to J/\psi \pi^0 p, \;\; J/\psi \to e^+ e^-$$

Non-resonant





Signal MC



- Exclusive reconstruction of signal MC show clear structure with limited particle mis-ID backgrounds
- However, need estimates for non-resonant background: can learn from ULs at COMPASS UL and/or existing data from GlueX

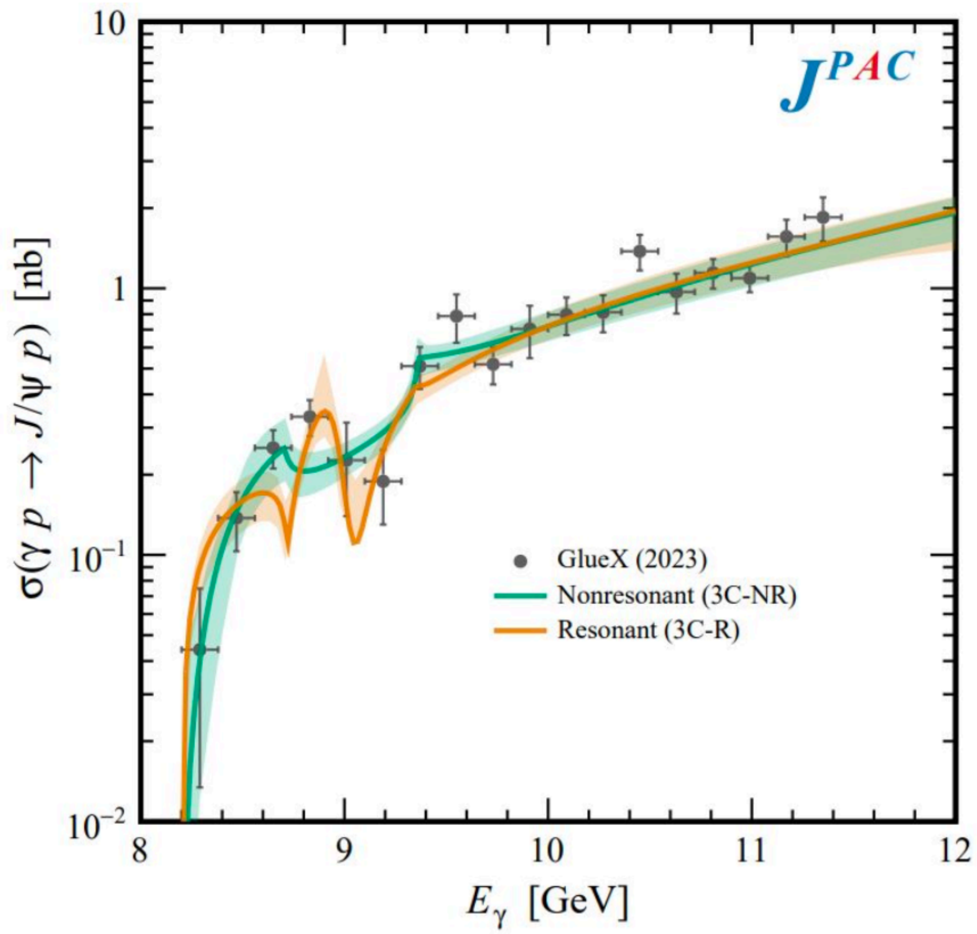
Next steps: quantifying interpretation

- Any observation would be a critical confirmation of the resonance picture, but what about non-observation?

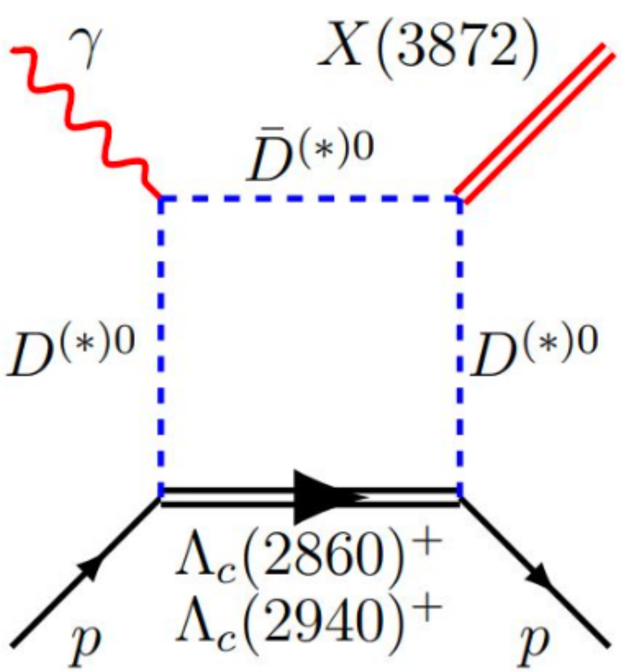
- Current 12 GeV data on J/ψ is consistent with weak resonant (P_c) and non-resonant interpretation, limiting models for nature of P_c

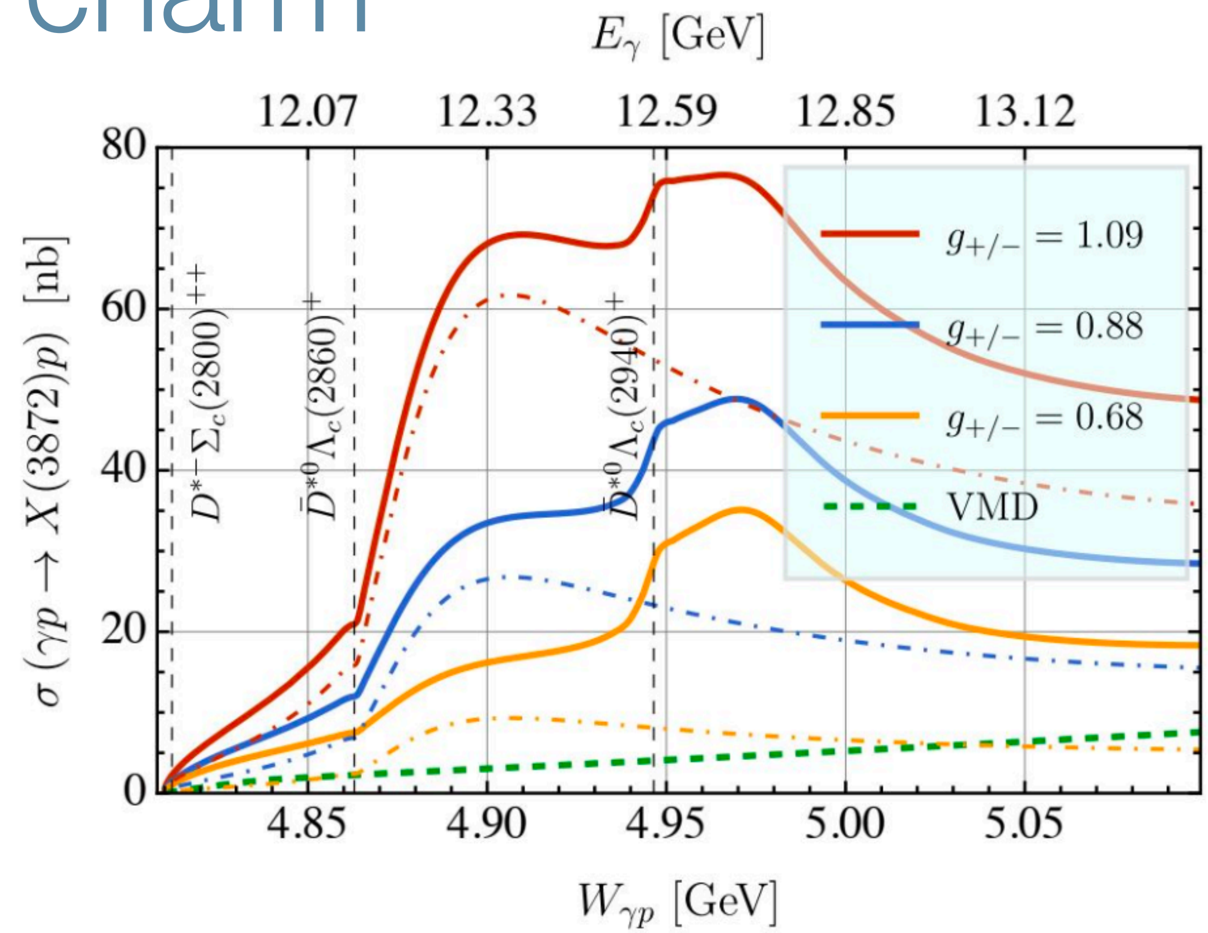
- For EIC and 22 GeV we need quantitative interpretation of photocouplings for models of Z_c microscopic structure?

  - How to connect this with Lattice QCD or QCD-inspired models?



Next steps: open charm





- Open charm continues to play important role interpretation of existing observations and can produce non-trivial structure

- What can we learn from 12 GeV? Studies with existing GlueX data to at least set an upper limit on ground state $\gamma p \to \Lambda_c D$

- Are detectors capable of a robust open charm program?

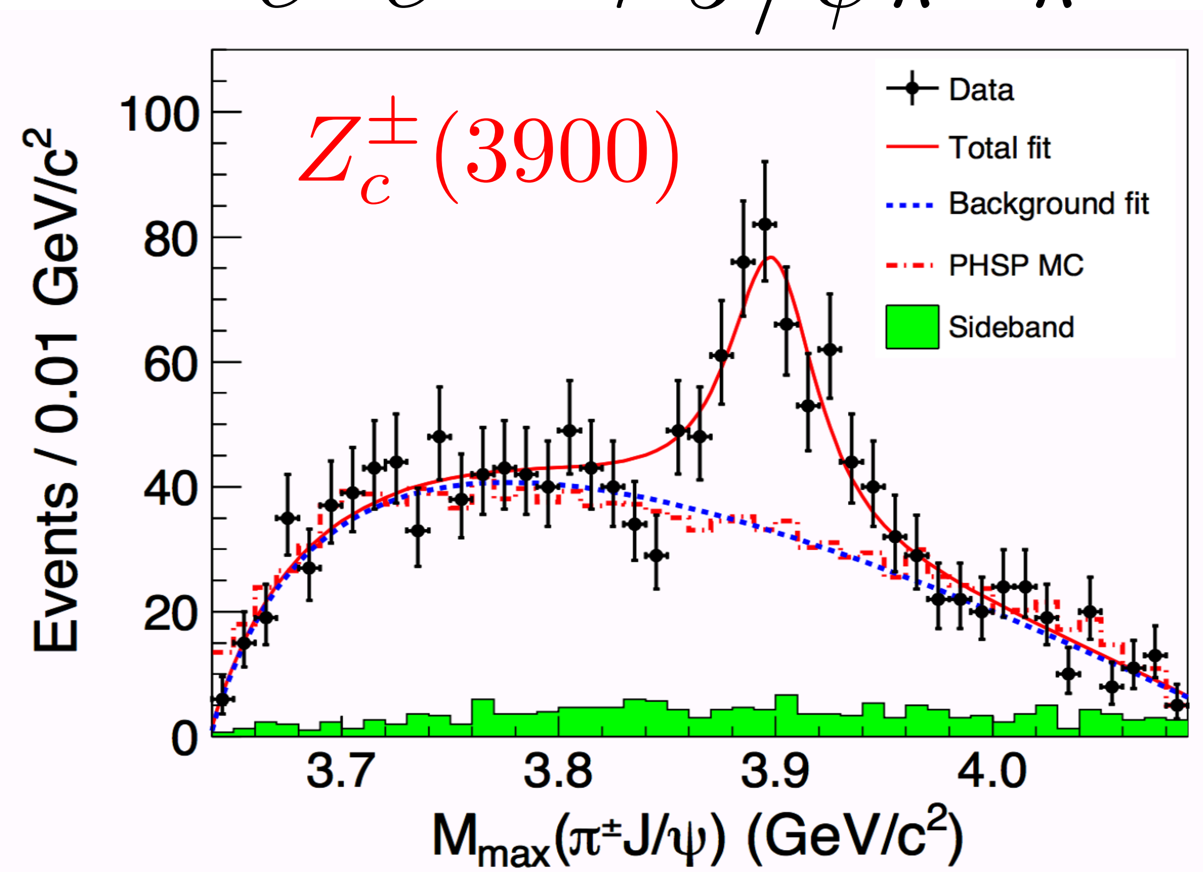
Summary

- Spectroscopy of exotic states is a clear argument for a JLab energy upgrade to cross the $c\bar{c}$ production thresholds
- The EIC and JLab 22 GeV are capable of complementary measurements to cover the relevant energies and luminosities for this exotic spectroscopy program
- There are challenges: non-resonant background, quantifying interpretation, open charm channels, etc.
- The next steps to address these challenges are clear, but will take some time and should proceed in collaboration between the EIC, 22 GeV and theory communities

Backup

Charged tetraquark candidates: Z_c

$e^+e^- \to J/\psi\pi^+\pi^-$

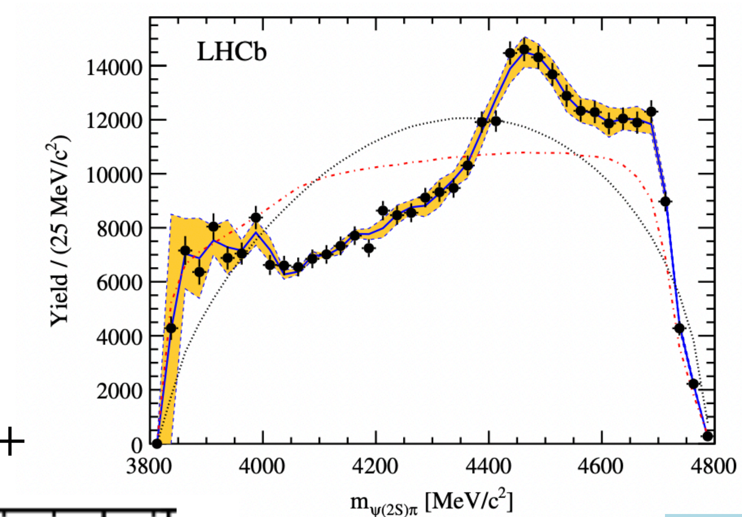


PRL 110, 252001 (2013)

PRL 110, 252002 (2013)

$Z_c^-(4430)$

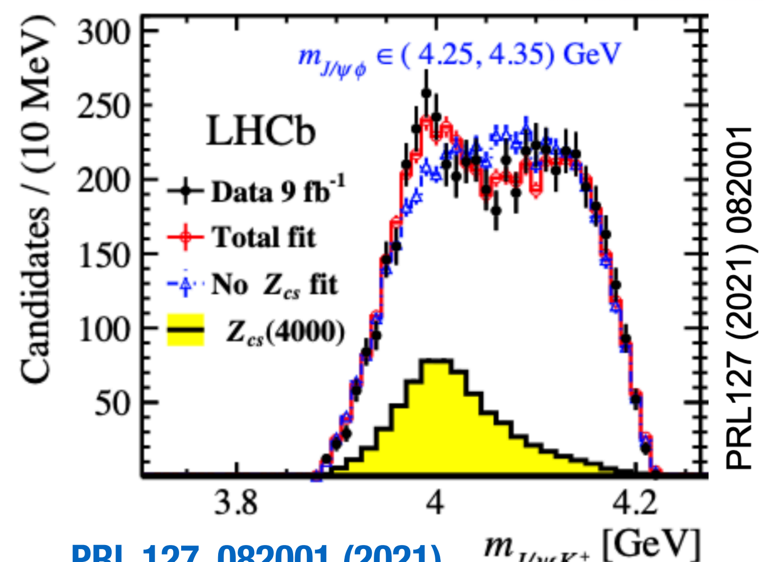
$B^0 \to \psi(2S)K^+\pi^-$



PRD 92, 112009 (2015)

$Z_{cs}^+(4000)$

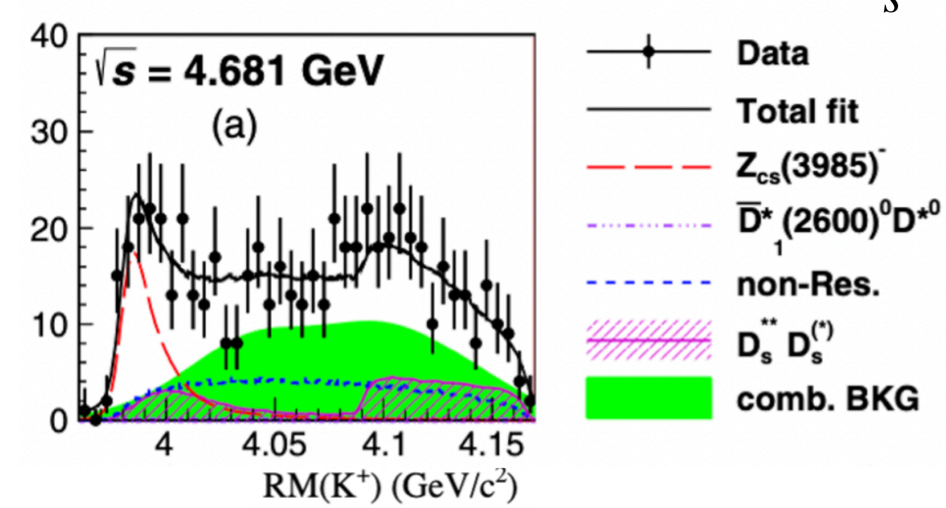
$B^+ \to J/\psi\phi K^+$



PRL 127, 082001 (2021)

$Z_{cs}^+(3985)$

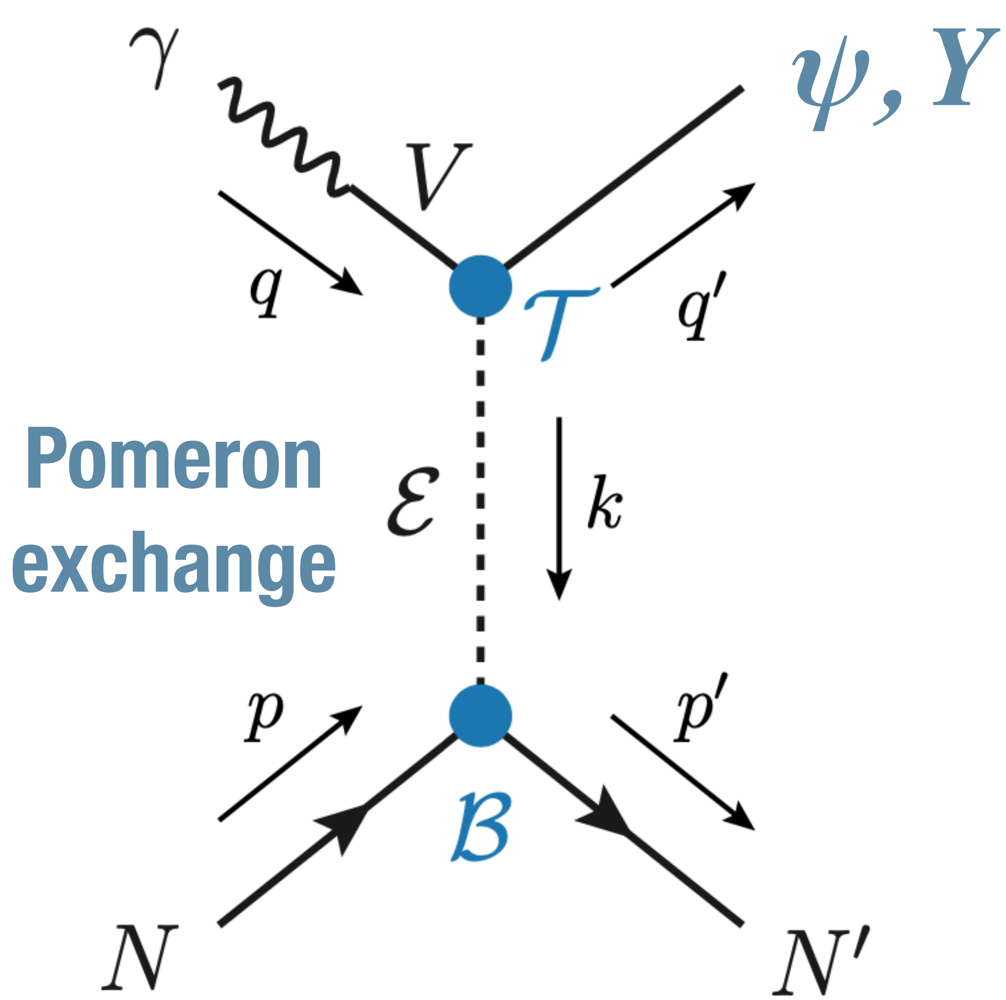
$e^+e^- \to K^+D_s^-X$

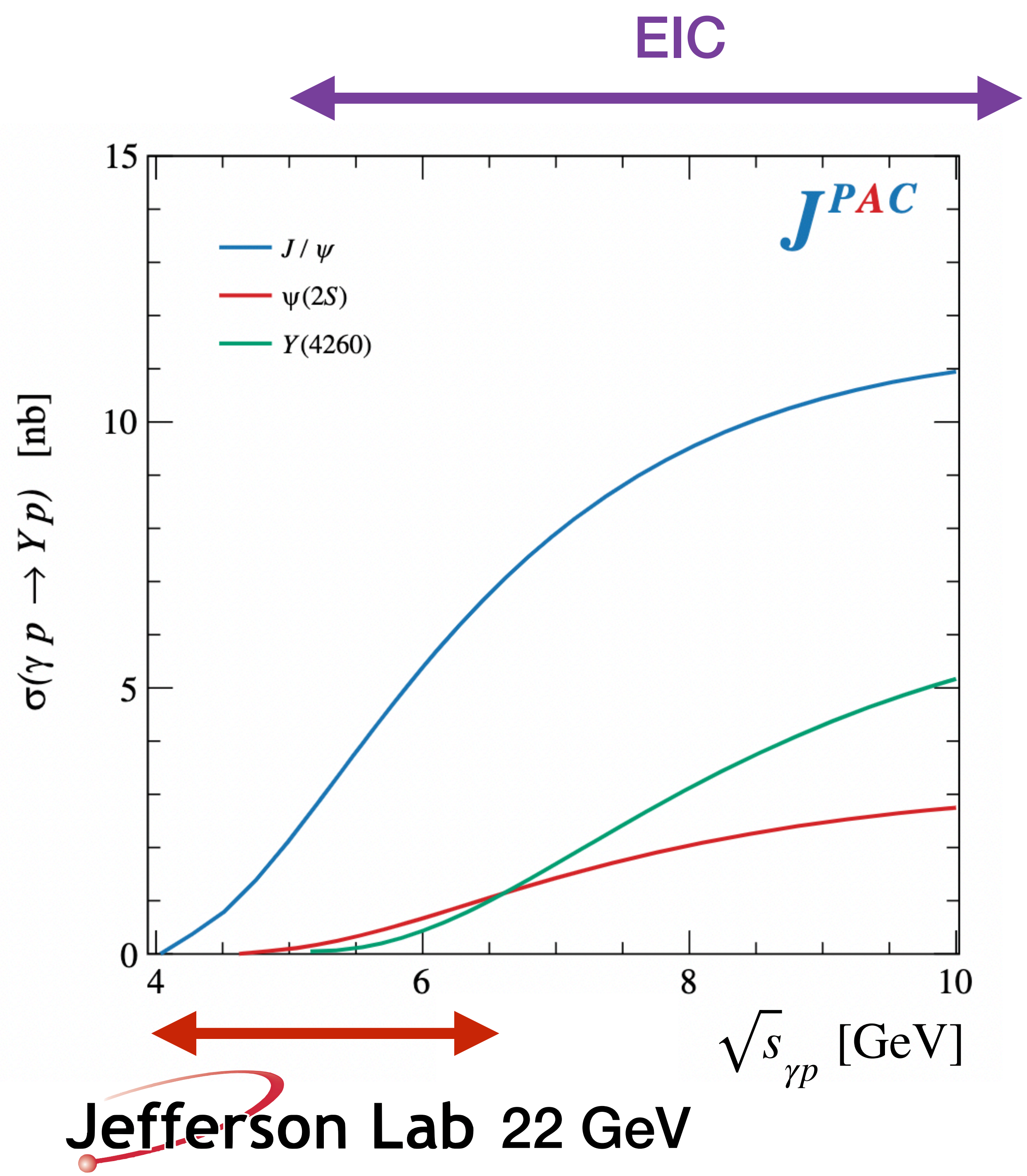


- Many observations of charged Z_c $(c\bar{c}q\bar{q})$ and Z_{cs} $(c\bar{c}s\bar{q})$
- Production mechanism dependent masses and widths (e^+e^- vs B decay)

Photoproduction of XYZ states

JPAC: PRD 102, 114010 (2020)

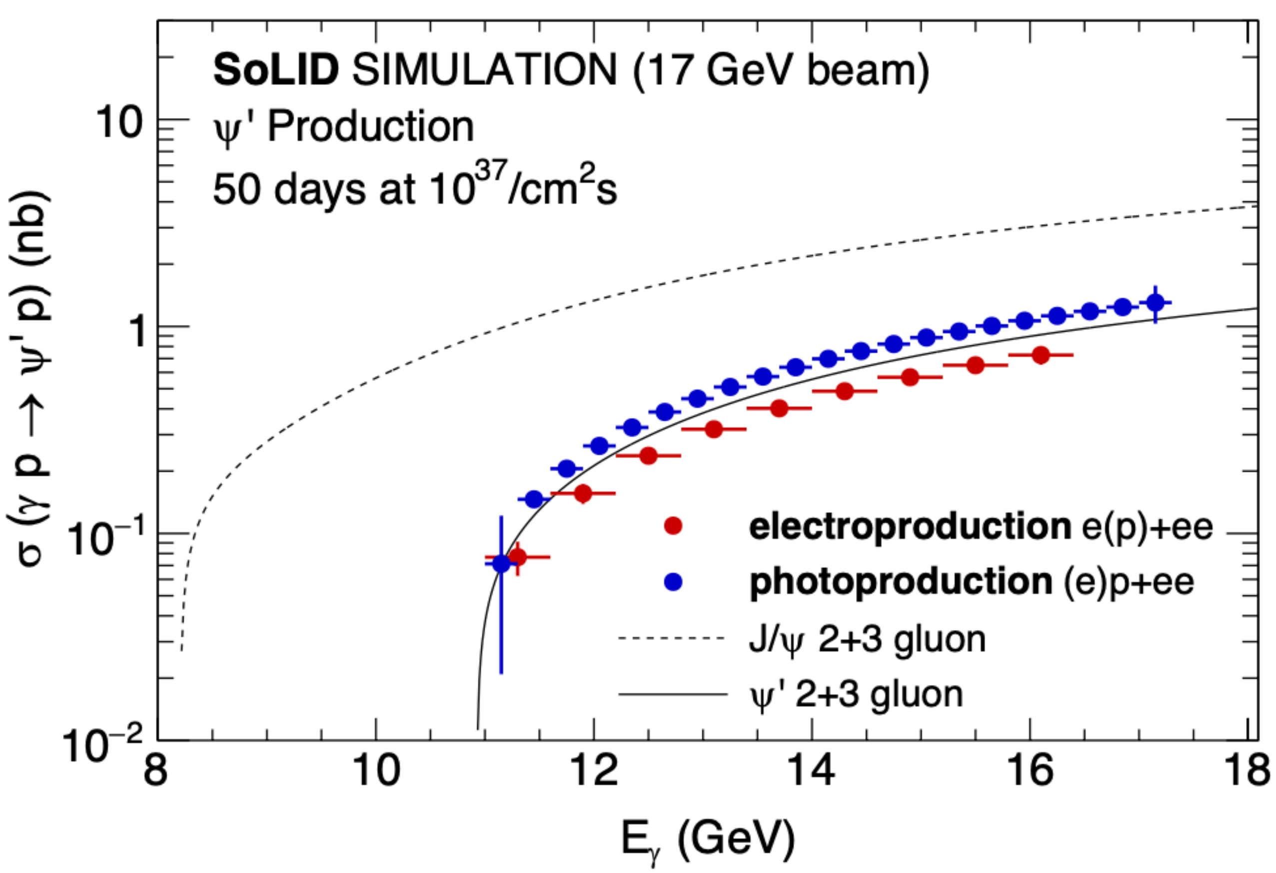


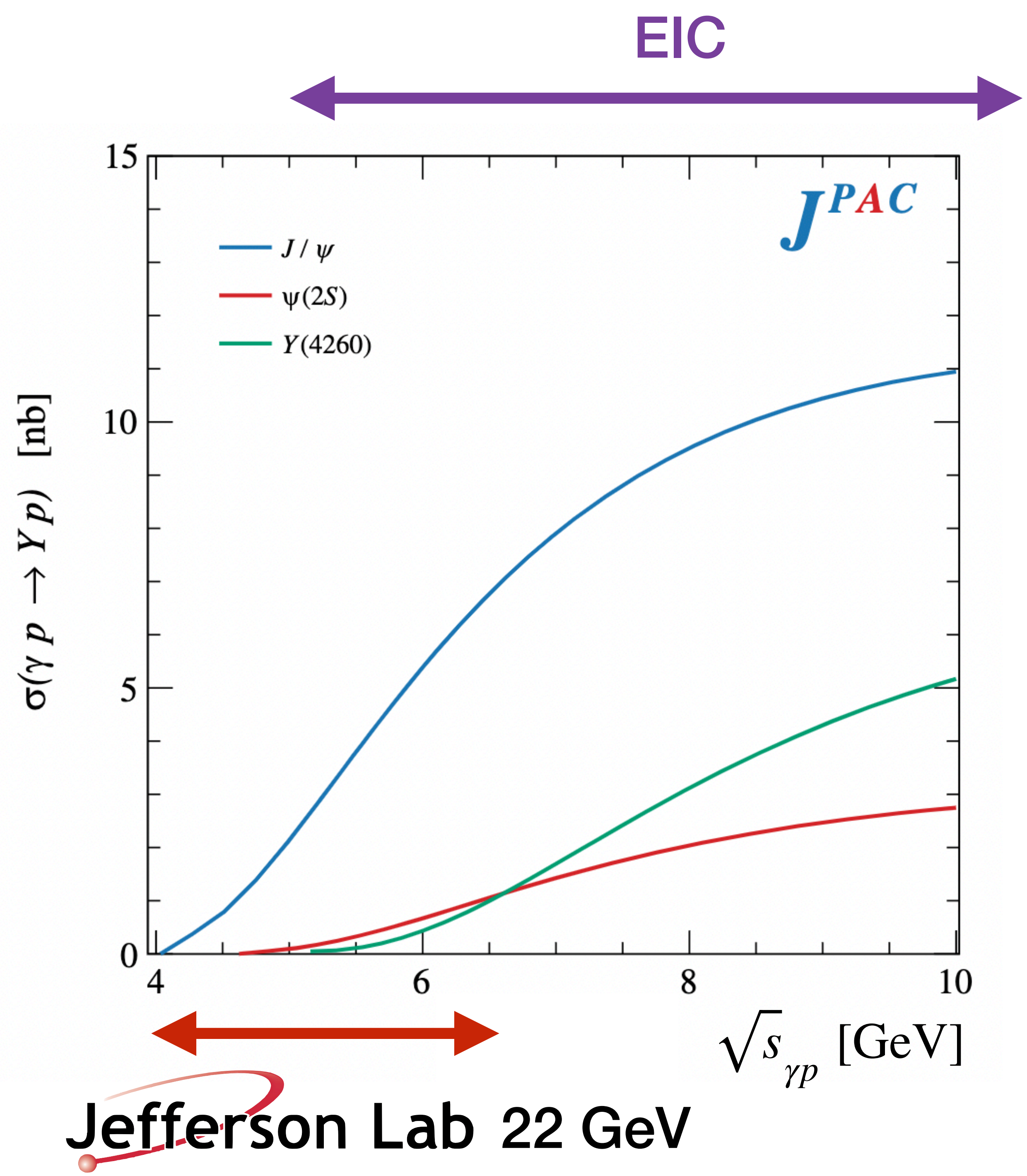


Y(4260) production increases with energy like other vectors, ideal for higher energies accessible at EIC

Photoproduction of $\psi(2S)$

SoLID example at 17 GeV





JLab 22 GeV ideal to study threshold $\psi(2S)$ production, but limited access to Y(4260) region