

# Recent Charm(onium)

## Results and Prospects

**Sean Dobbs**

Florida State U.

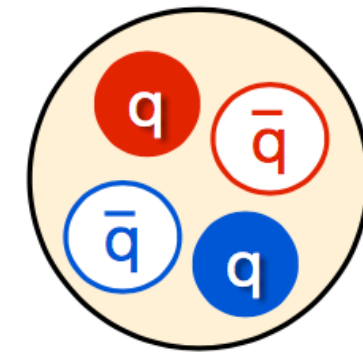
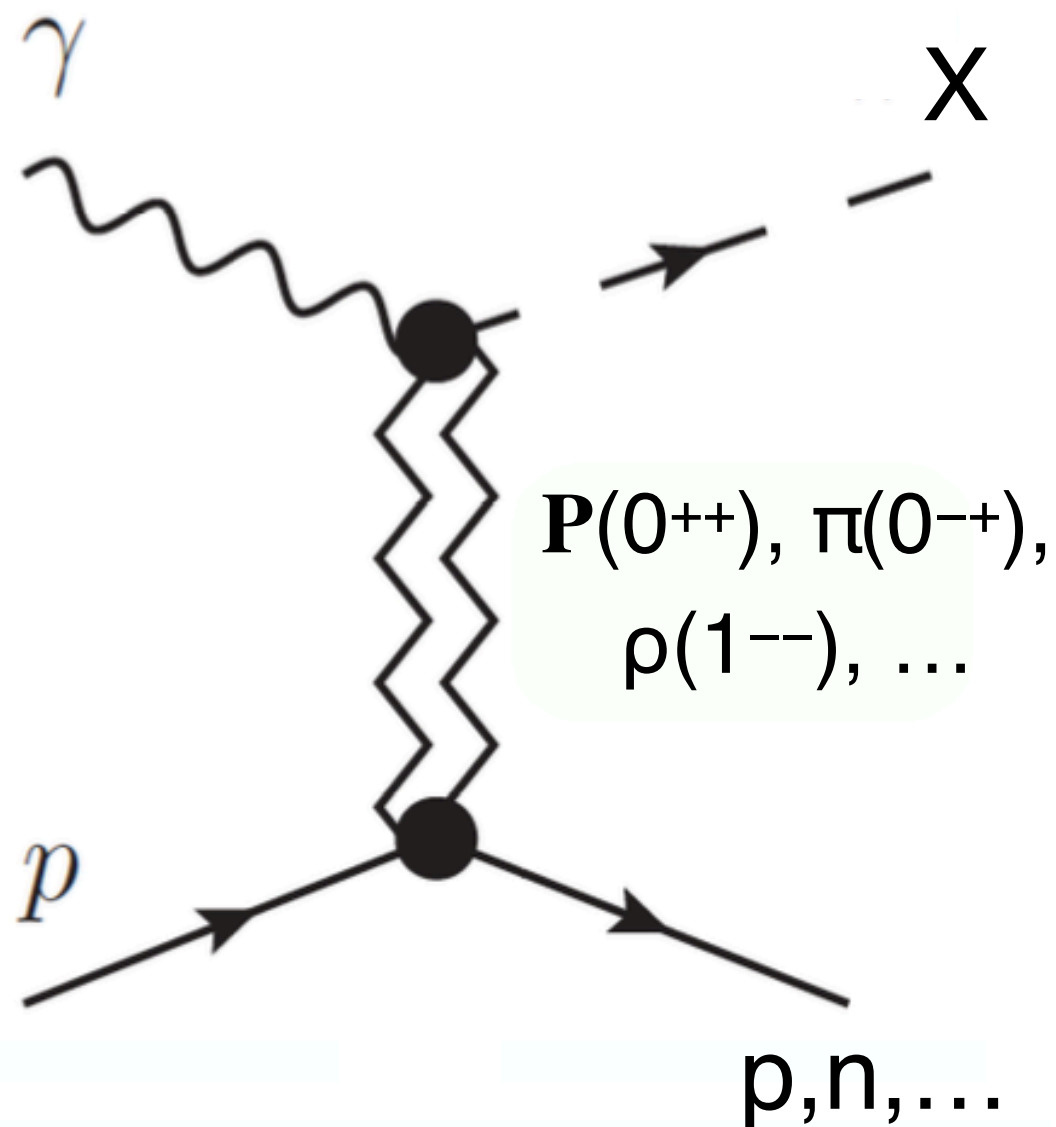
(for the GlueX Collaboration)

CHARM2020 — 10th International Workshop on Charm Physics  
May 31, 2021

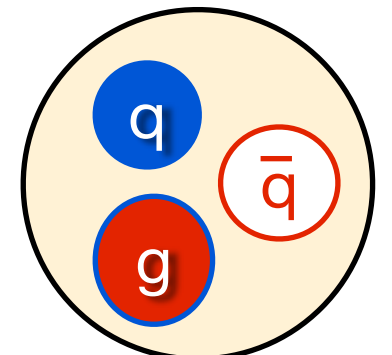


# Hadron Spectroscopy and Photoproduction

- Photoproduction is an interesting process to study normal hadrons and to search for exotic hadrons



**tetraquark**

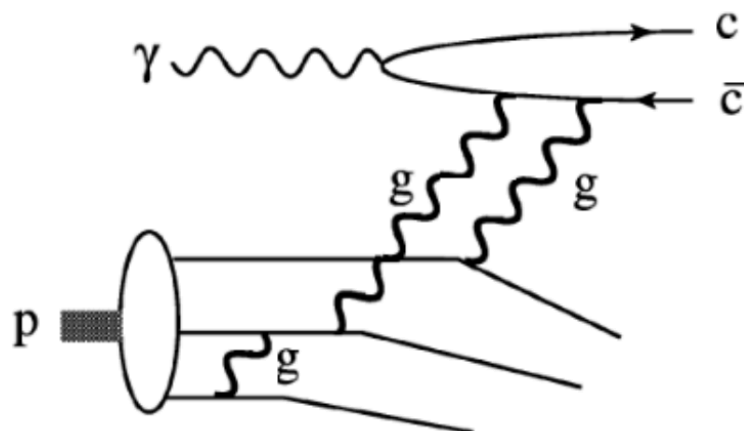
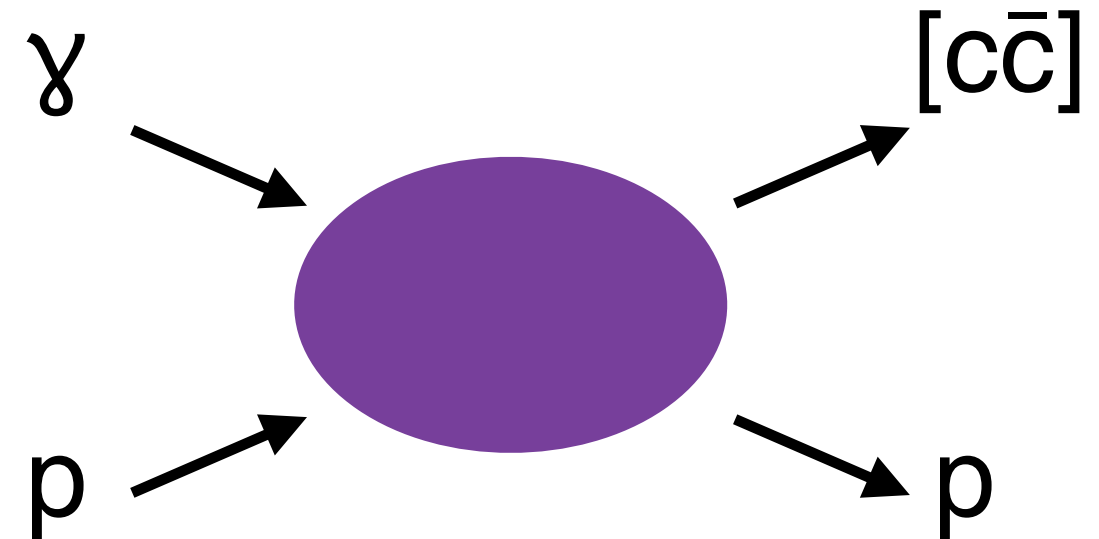


**hybrid meson**

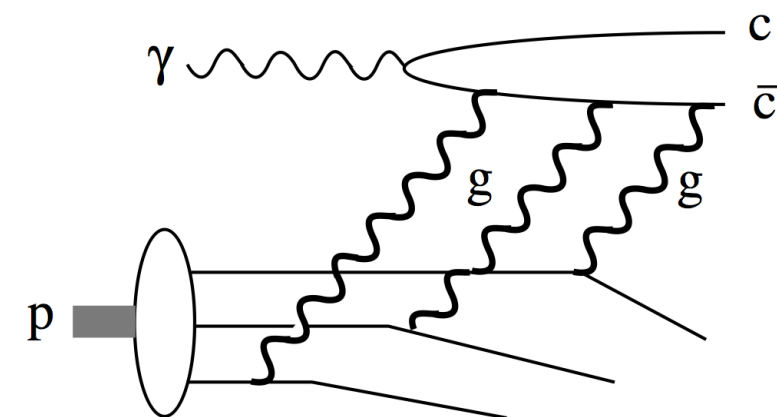
- Photons couple to proton through exchanged QNs, can produce mesons of any  $J^{PC}$
- Photon **polarization** provides constraints on production processes, probe of hadron properties

# Charmonium Photoproduction Near Threshold

- Near-threshold production is ideal for studying the  $c\bar{c}+N$  interaction
  - Probes the distribution of gluons in the proton and the nature of the proton mass
  - Insight into the nature of confinement in QCD



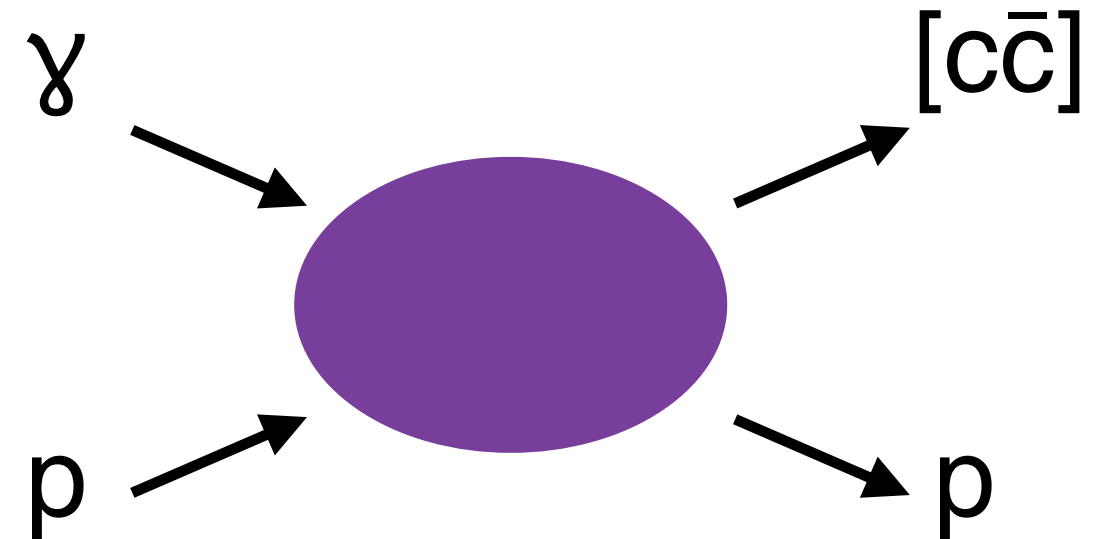
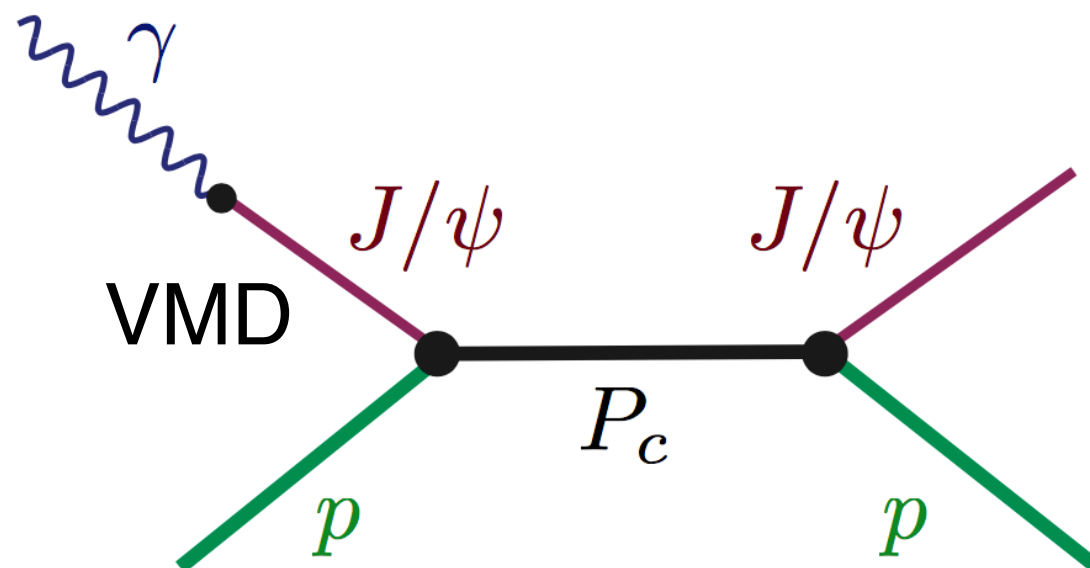
leading-twist



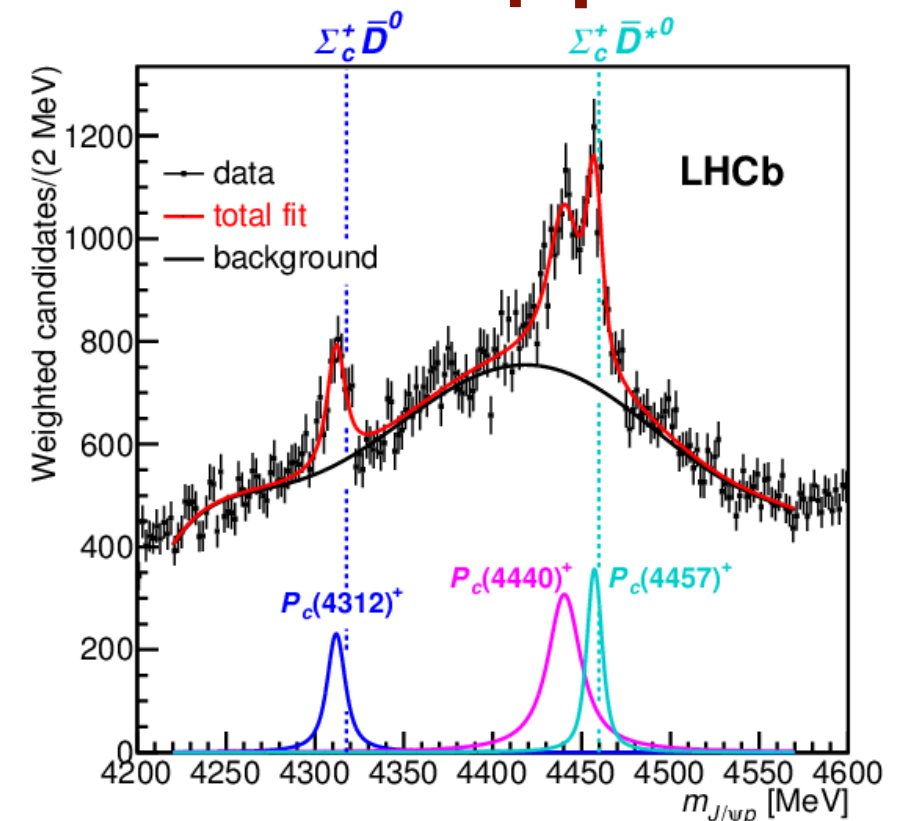
higher-twist

# Charmonium Photoproduction Near Threshold

- Near-threshold production is ideal for studying the  $c\bar{c}+N$  interaction
  - Can look for s-channel production of resonant states, extend understanding of 5-quark interaction

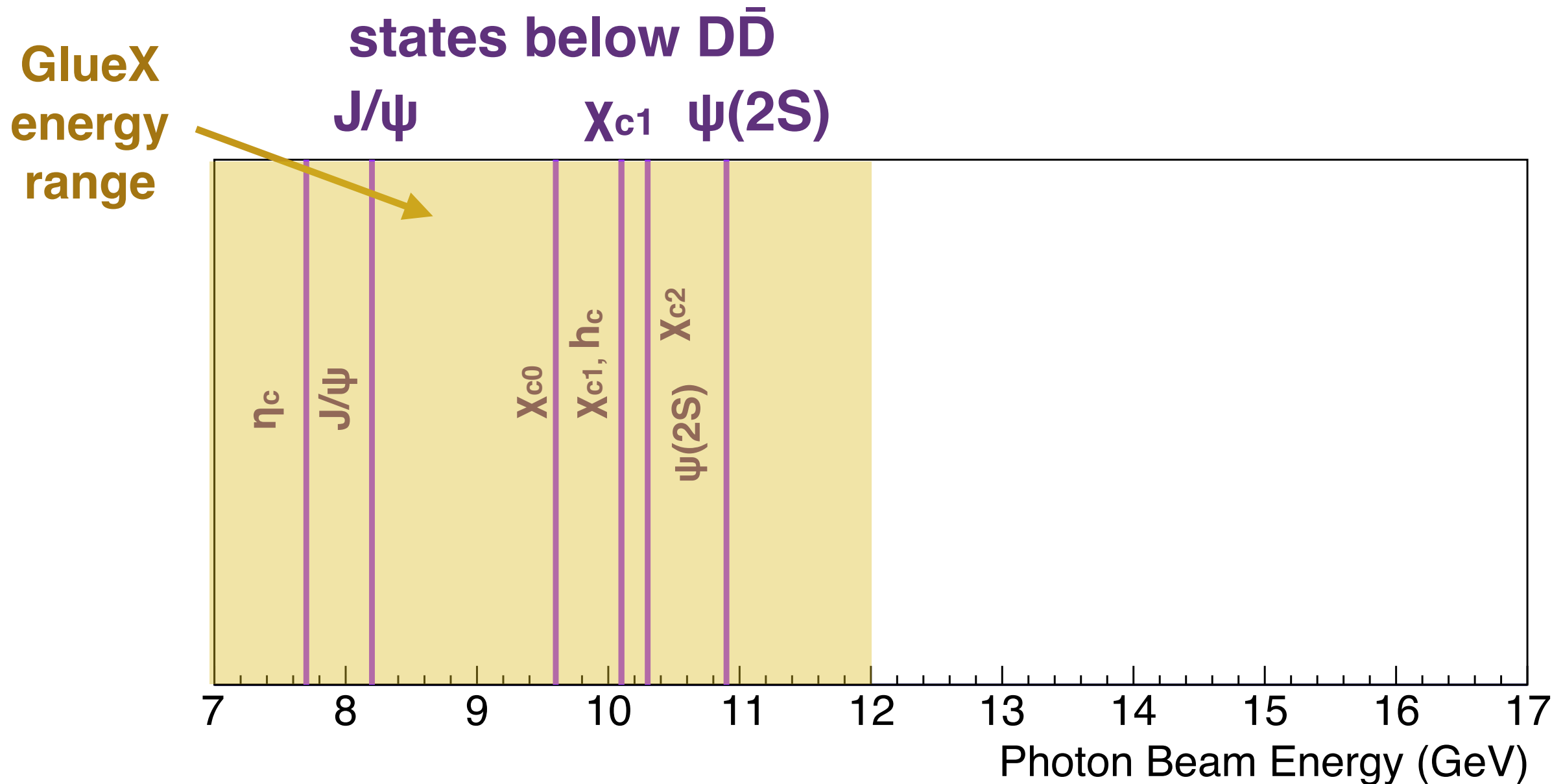


$\Lambda_b \rightarrow J/\psi \, p \, K^-$



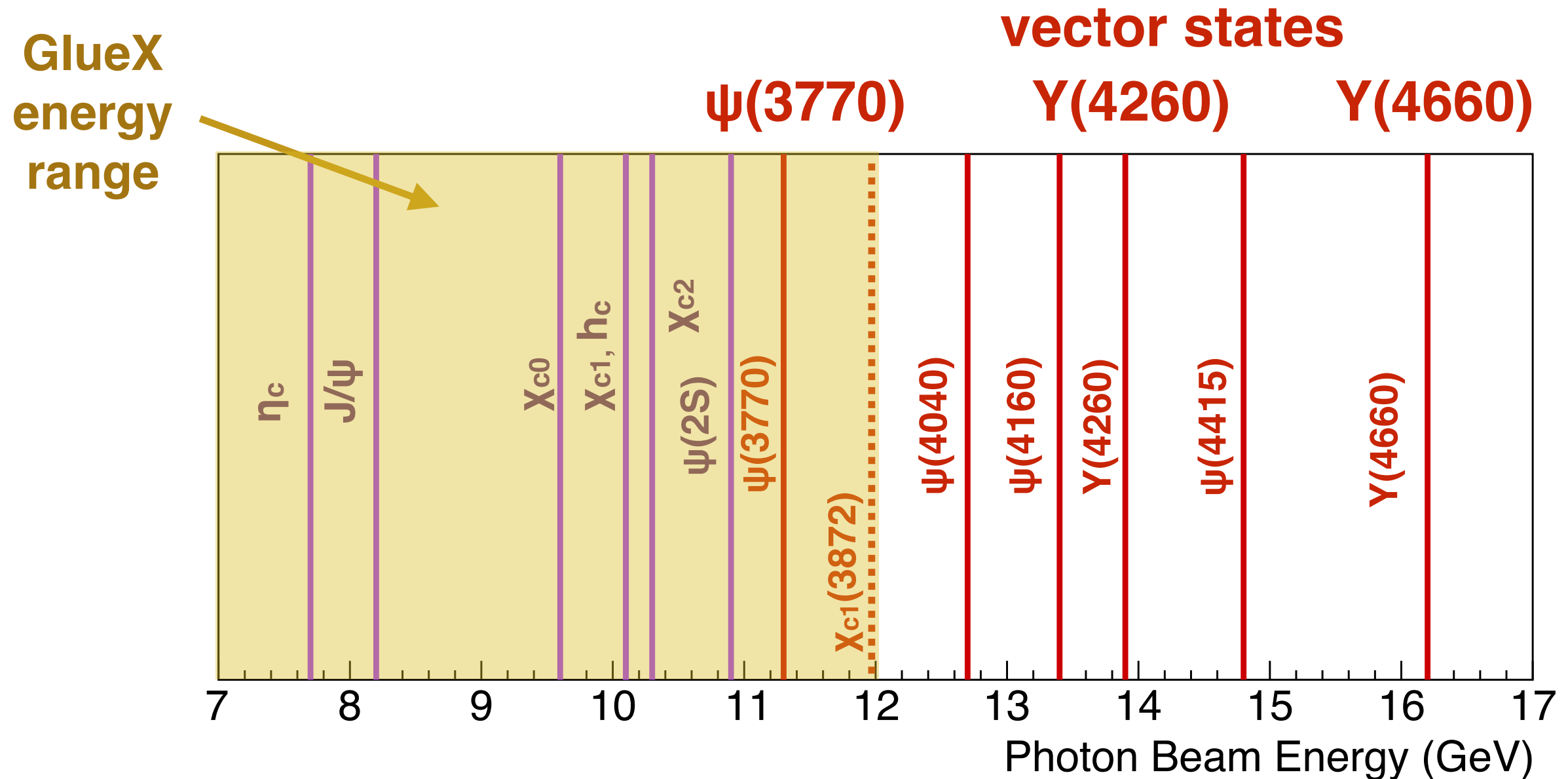
LHCb, PRL 122, 222001 (2019)

# Charmonium Photoproduction Near Threshold



- GlueX energy range:  $E_\gamma < 12 \text{ GeV}$
- Large hadronic background, focus on decays containing  $J/\psi \rightarrow e^+e^-$

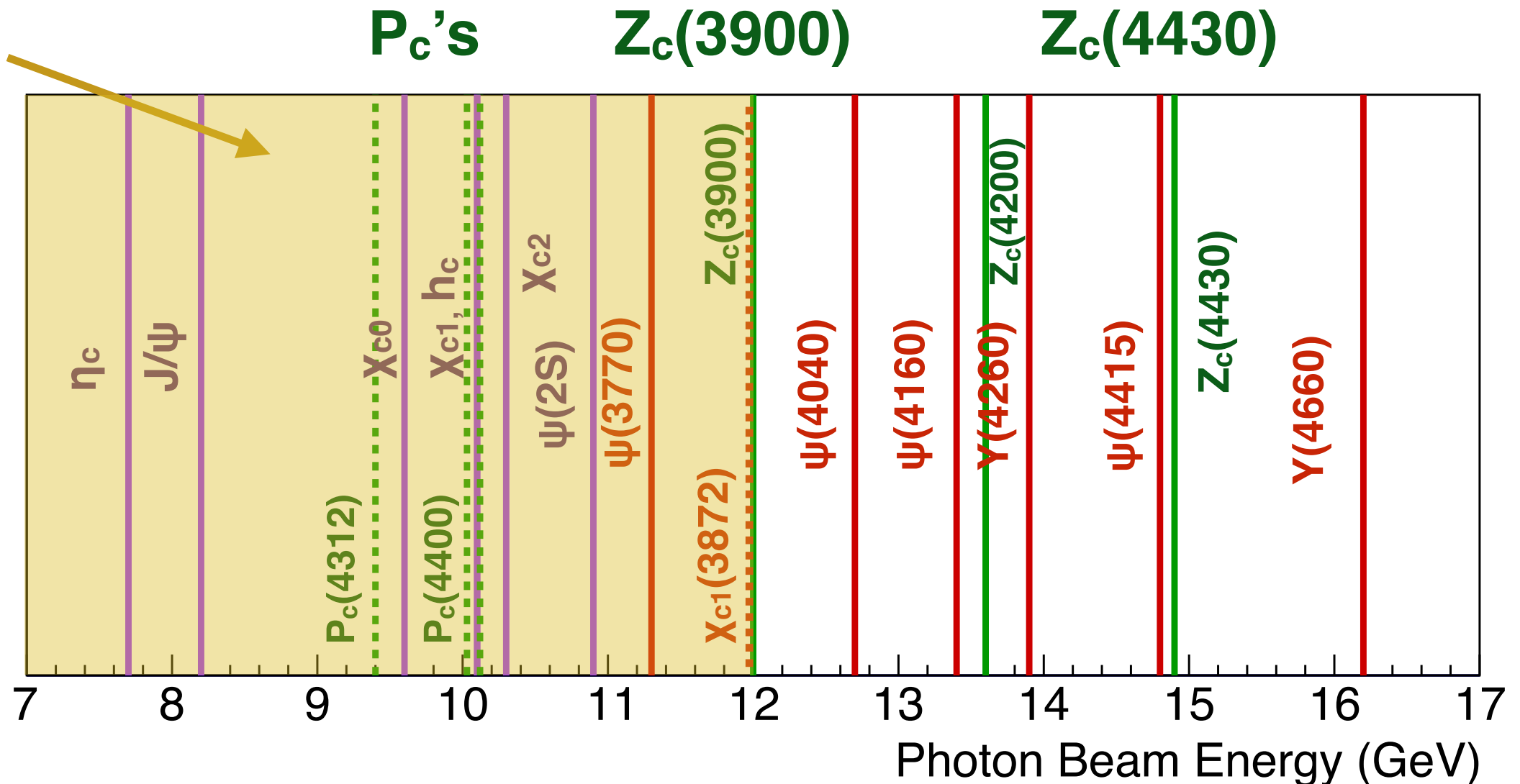
# Charmonium Photoproduction Near Threshold



- Thresholds for states above the  $D\bar{D}$  threshold extend to higher energies

# Charmonium Photoproduction Near Threshold

GlueX  
energy  
range



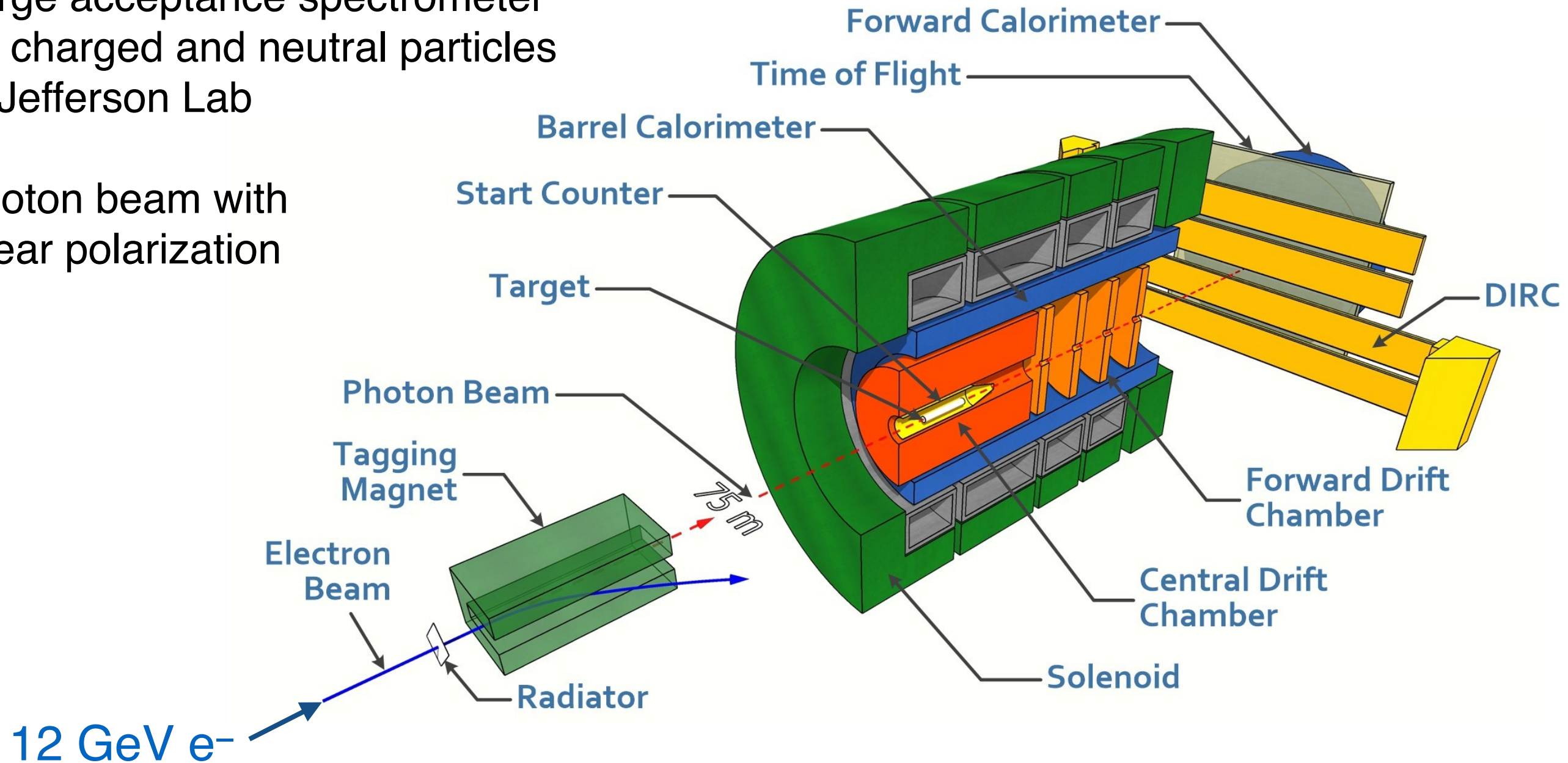
- Also have access to production of  $P_c$ 's



# The GlueX Experiment

Large acceptance spectrometer  
for charged and neutral particles  
at Jefferson Lab

Photon beam with  
linear polarization



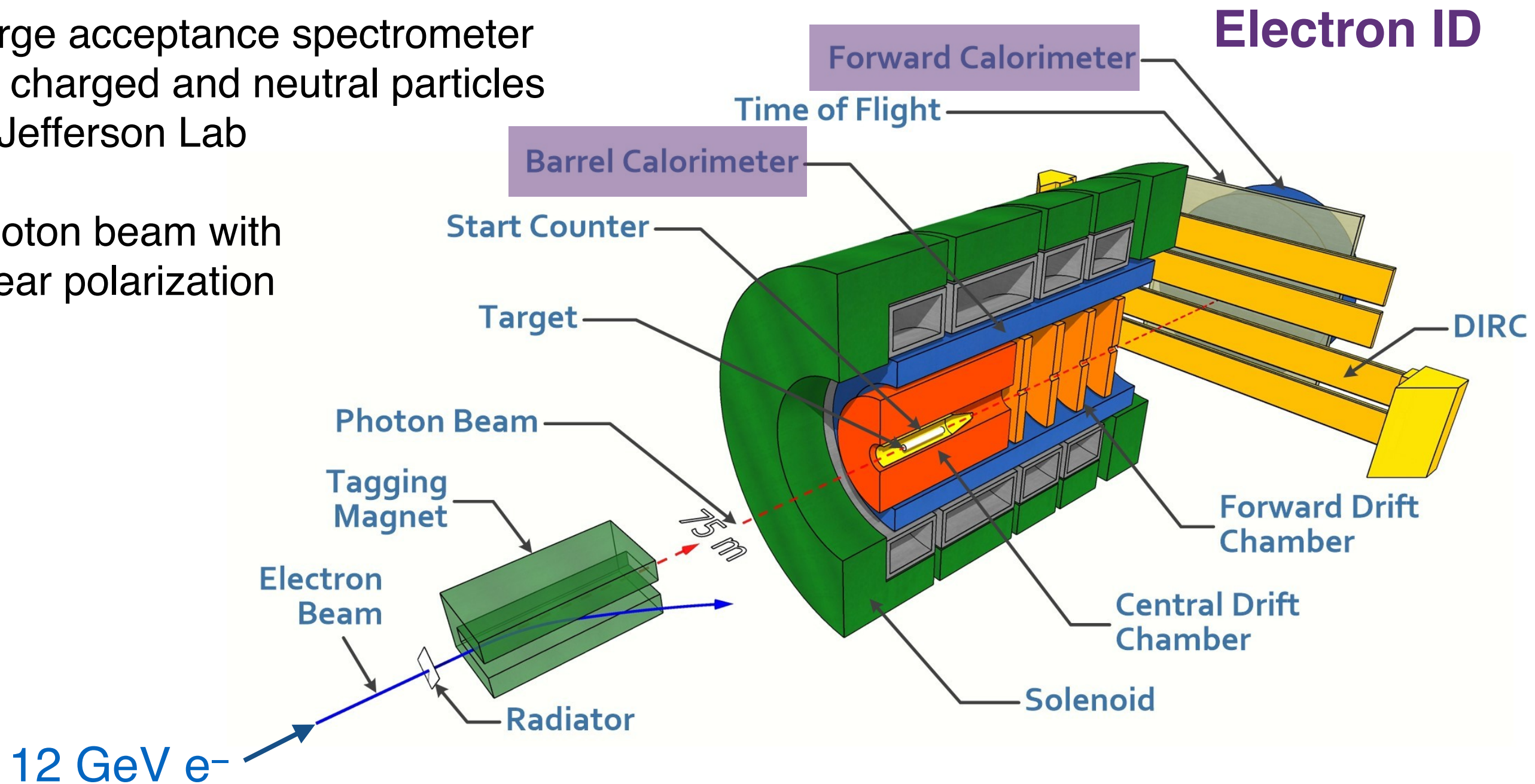
- **GlueX-I (2017–2018):**  $E_\gamma > 8$  GeV,  $L = 330$  pb $^{-1}$
- **GlueX-II (2020–):** expect 3-4x GlueX-I



# The GlueX Experiment

Large acceptance spectrometer  
for charged and neutral particles  
at Jefferson Lab

Photon beam with  
linear polarization



- **GlueX-I (2017–2018):**  $E_\gamma > 8$  GeV,  $L = 330$  pb $^{-1}$
- **GlueX-II (2020–):** expect 3-4x GlueX-I

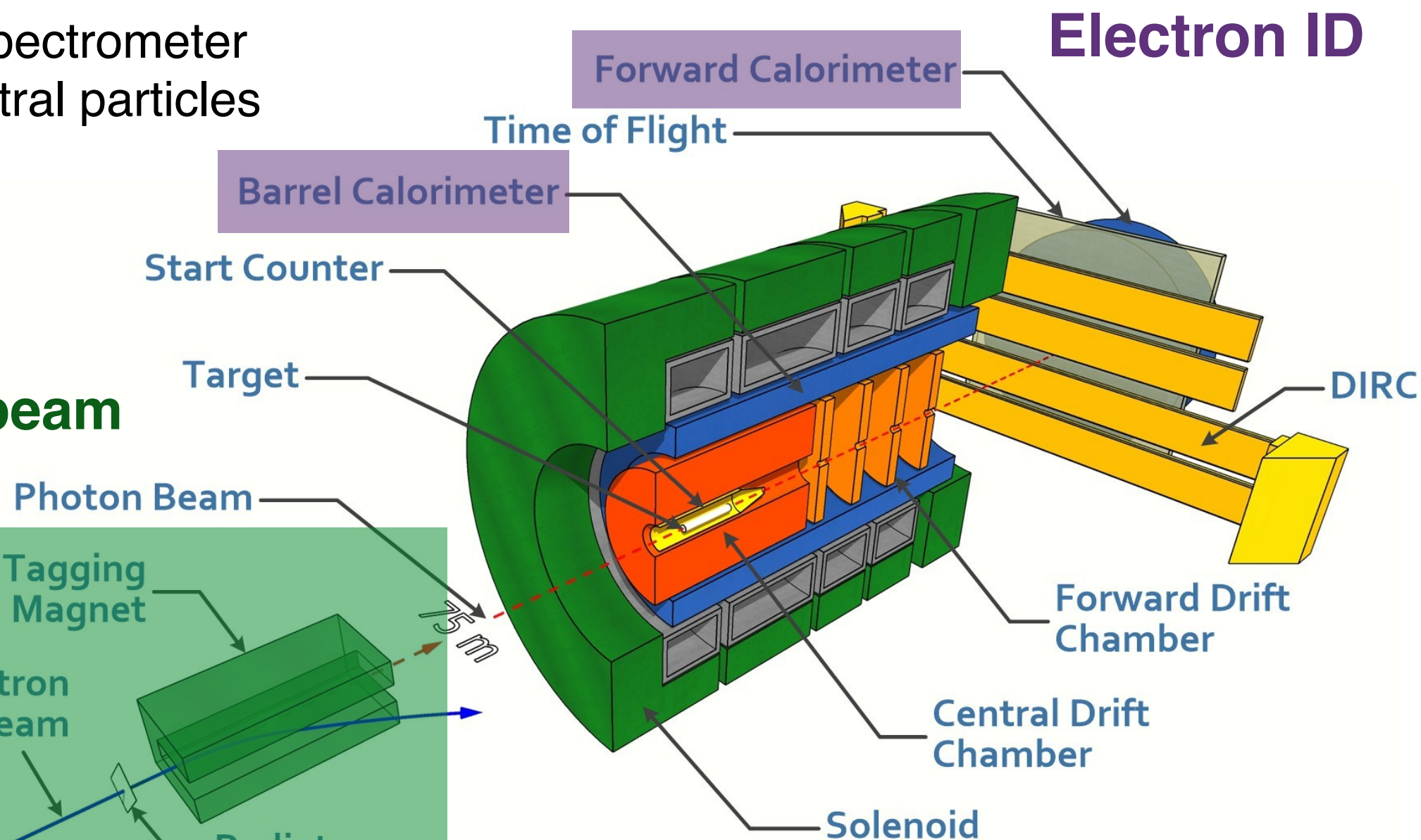
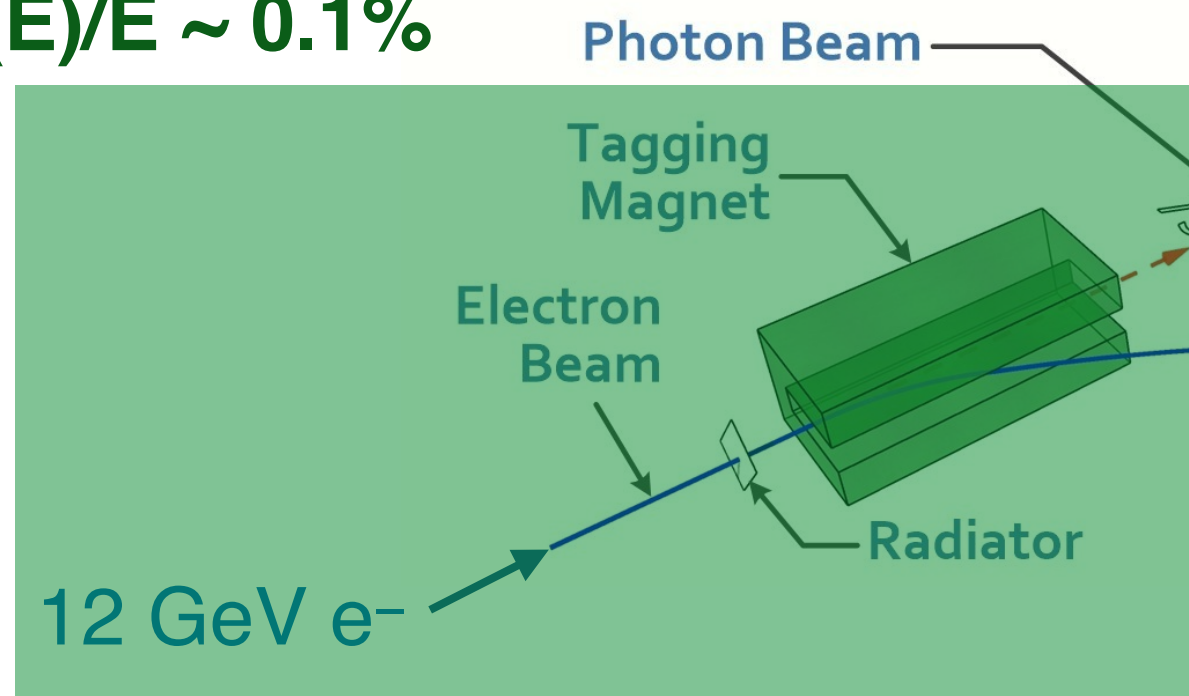
# The GlueX Experiment

Large acceptance spectrometer  
for charged and neutral particles  
at Jefferson Lab

Photon beam with  
linear polarization

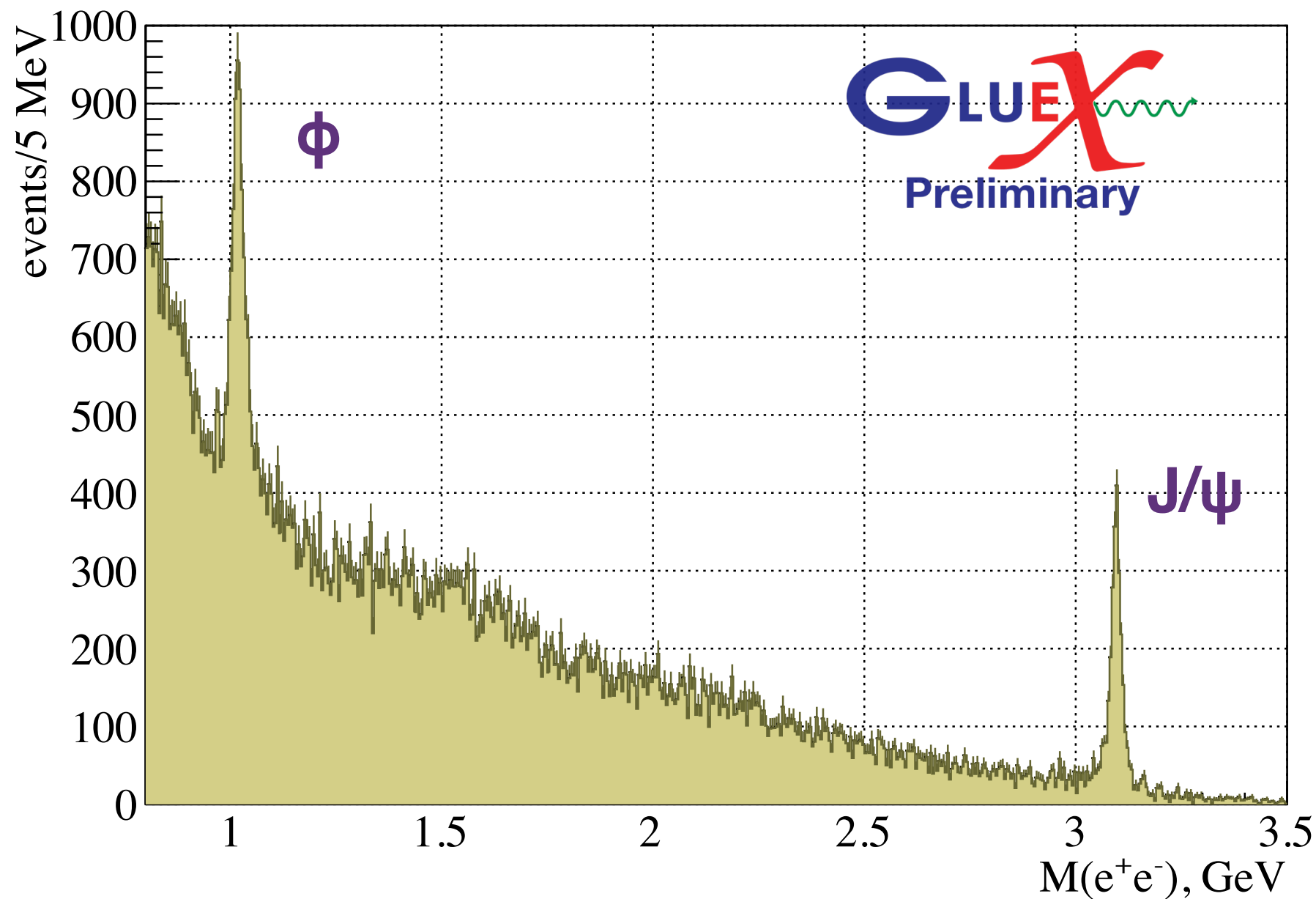
**Tagged Photon beam**

$\sigma(E)/E \sim 0.1\%$



- **GlueX-I (2017–2018):**  $E_\gamma > 8 \text{ GeV}$ ,  $L = 330 \text{ pb}^{-1}$
- **GlueX-II (2020–):** expect 3-4x GlueX-I

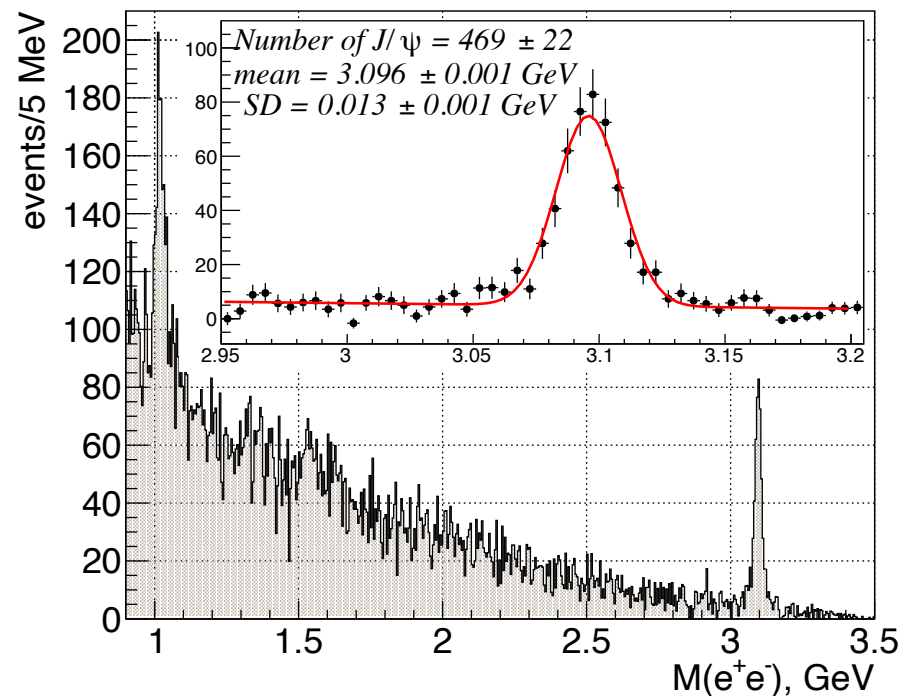
# J/ψ Photoproduction at GlueX: Mass Spectrum



- Reconstruct  $p \gamma \rightarrow p + J/\psi, J/\psi \rightarrow e^+e^-$
- Calculate J/ψ cross sections normalized by non-resonant  $e^+e^-$

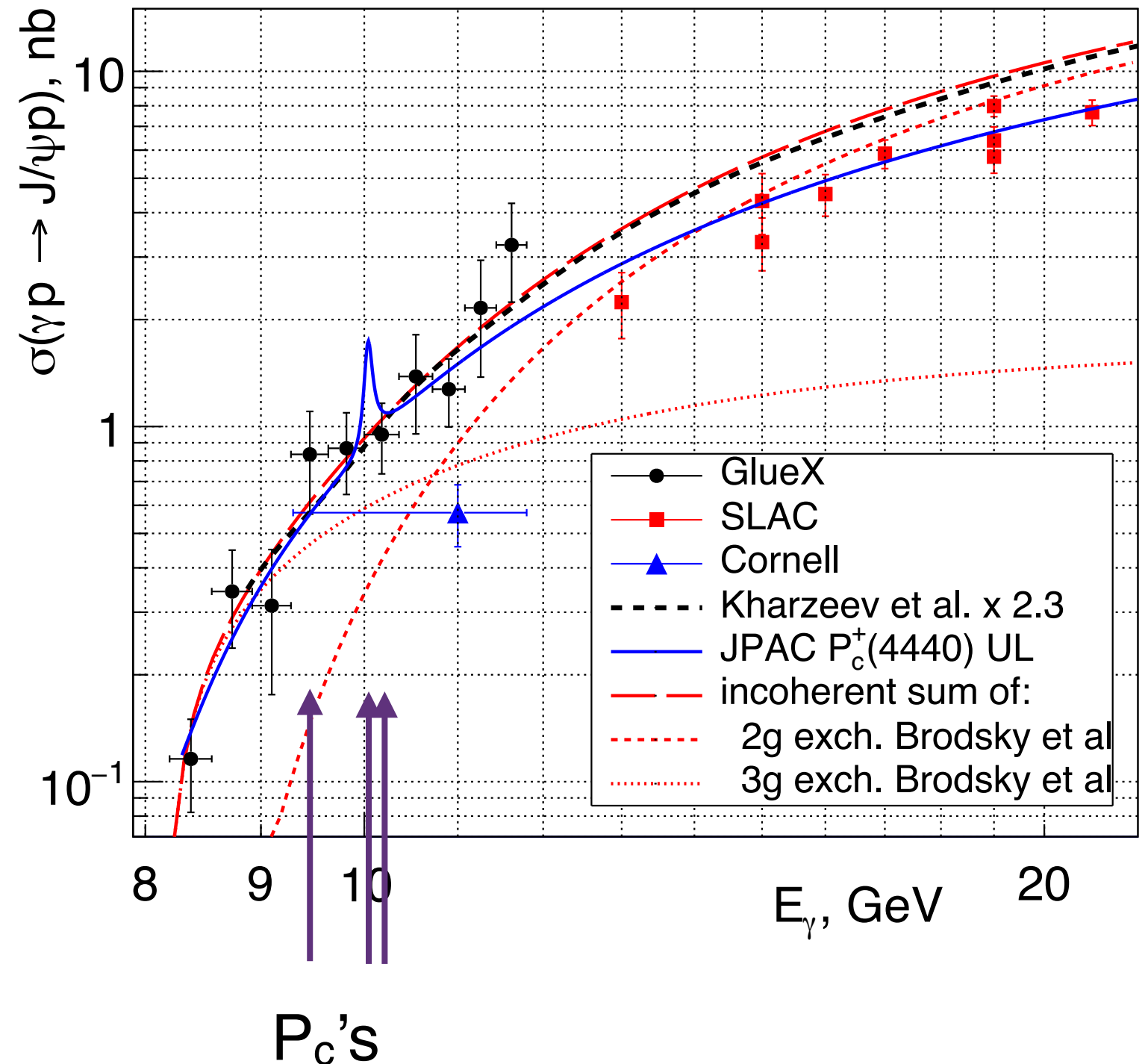


# Published GlueX $J/\psi$ Photoproduction Results



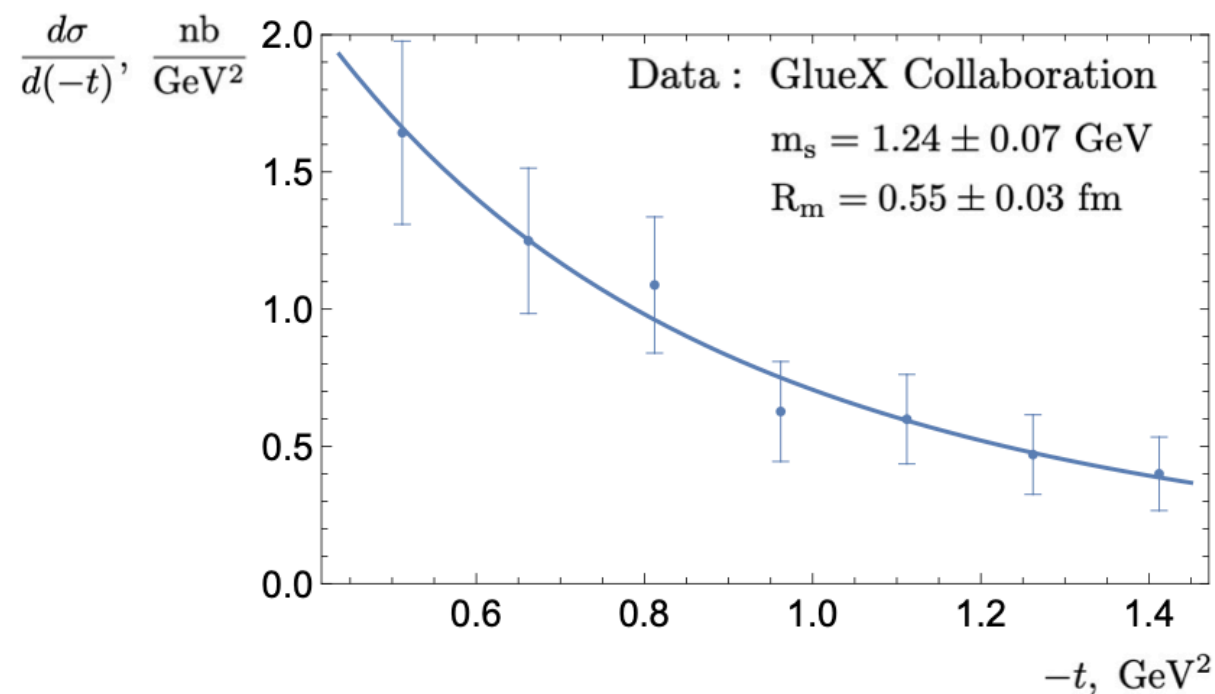
- Used portion of GlueX-I data [469  $J/\psi$ ] to measure cross sections
- 27% normalization uncertainty
- Model-dependent limits set on  $P_c$  production

GlueX: PRL 123, 072001 (2019)



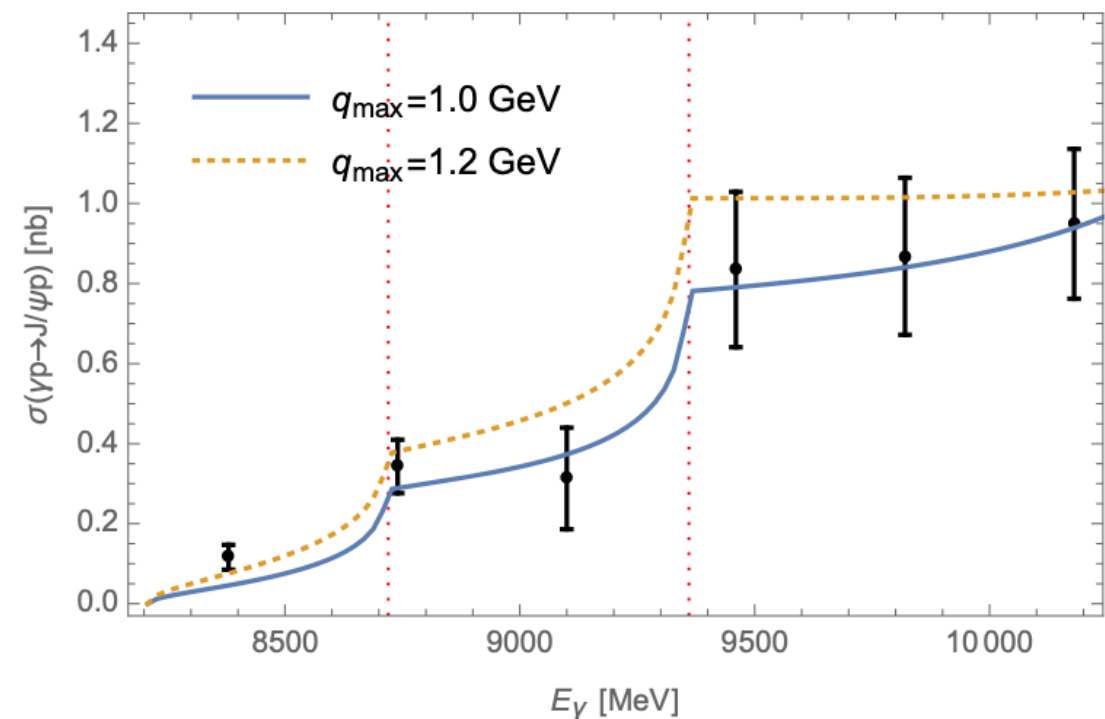
# Interpretations of GlueX J/ψ Photoproduction Results

Kharzeev, arXiv:2102.00110 (2021)



mass radius:  $R_m = 0.55 \pm 0.03$  fm  
charge radius:  $R_c = 0.8409 \pm 0.0004$  fm  
More data closer to the threshold is needed

Du et al., EPJC 80, 1053 (2020)

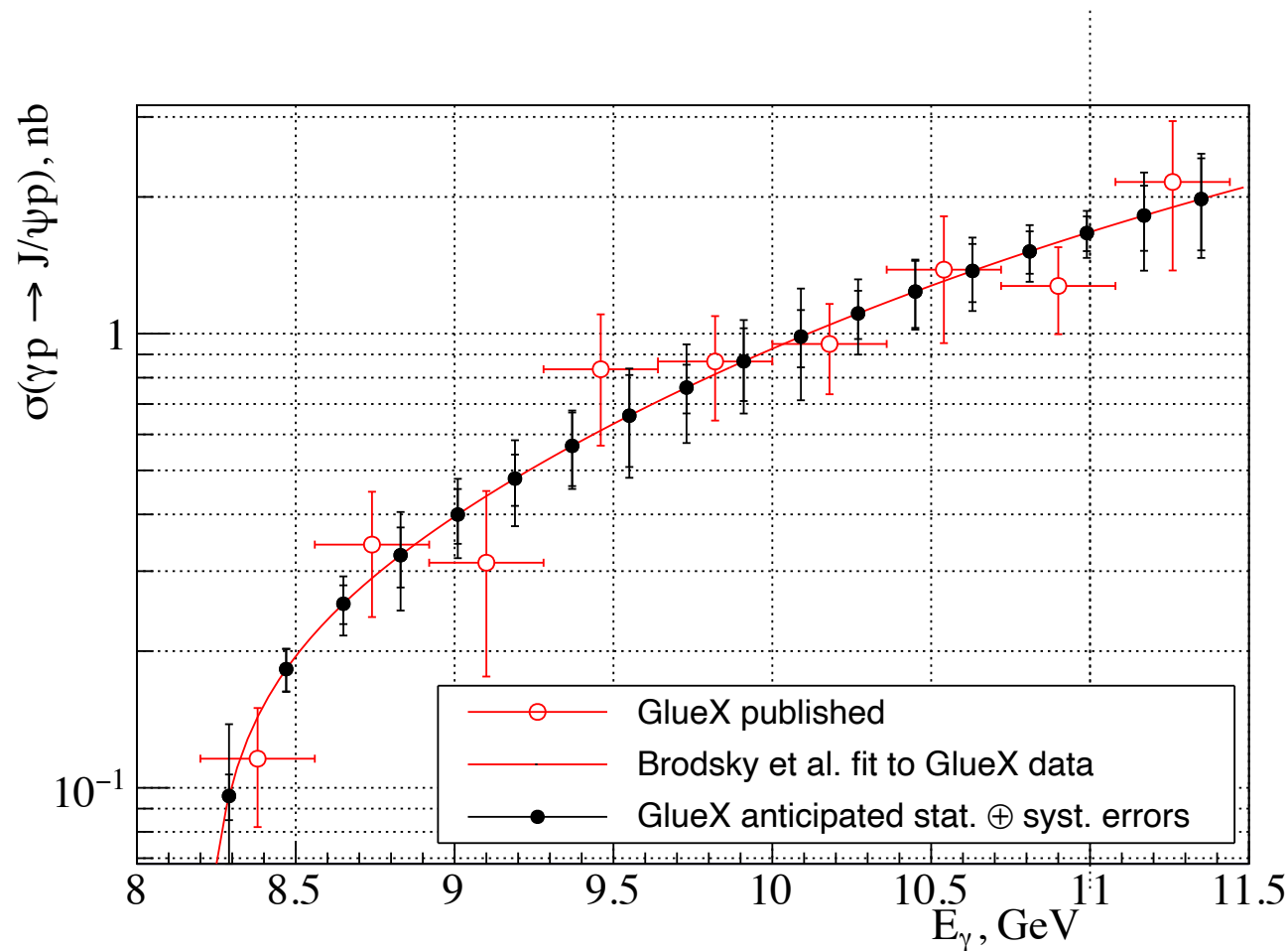


Calculated cross section energy dependence including open charm loops  
Higher precision data is needed

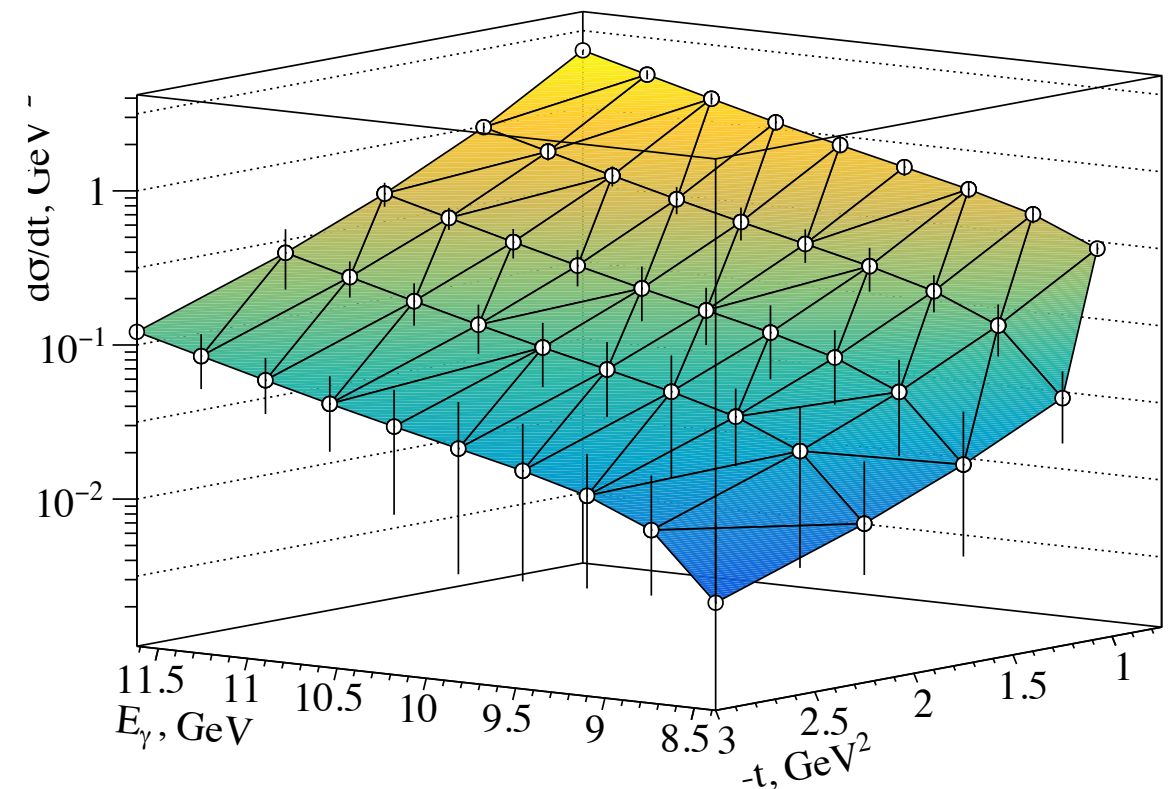
- Lots of interest in these measurements—selected results shown above

# Projected GlueX-I J/ψ Photoproduction Results

Estimated errors using full GlueX-I data



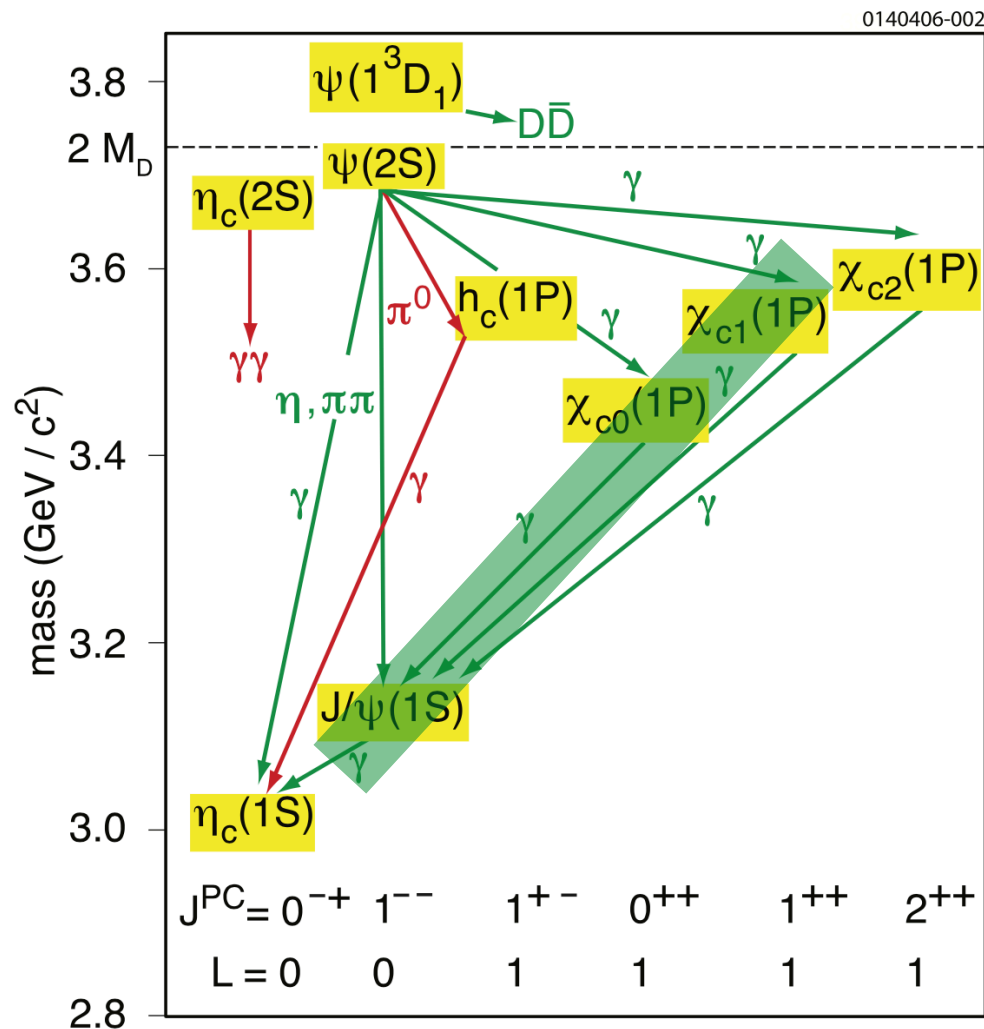
ERRORS ONLY shown for 2D differential cross-sections



Estimated errors using energy dependence from published results and dipole  $t$ -dependence

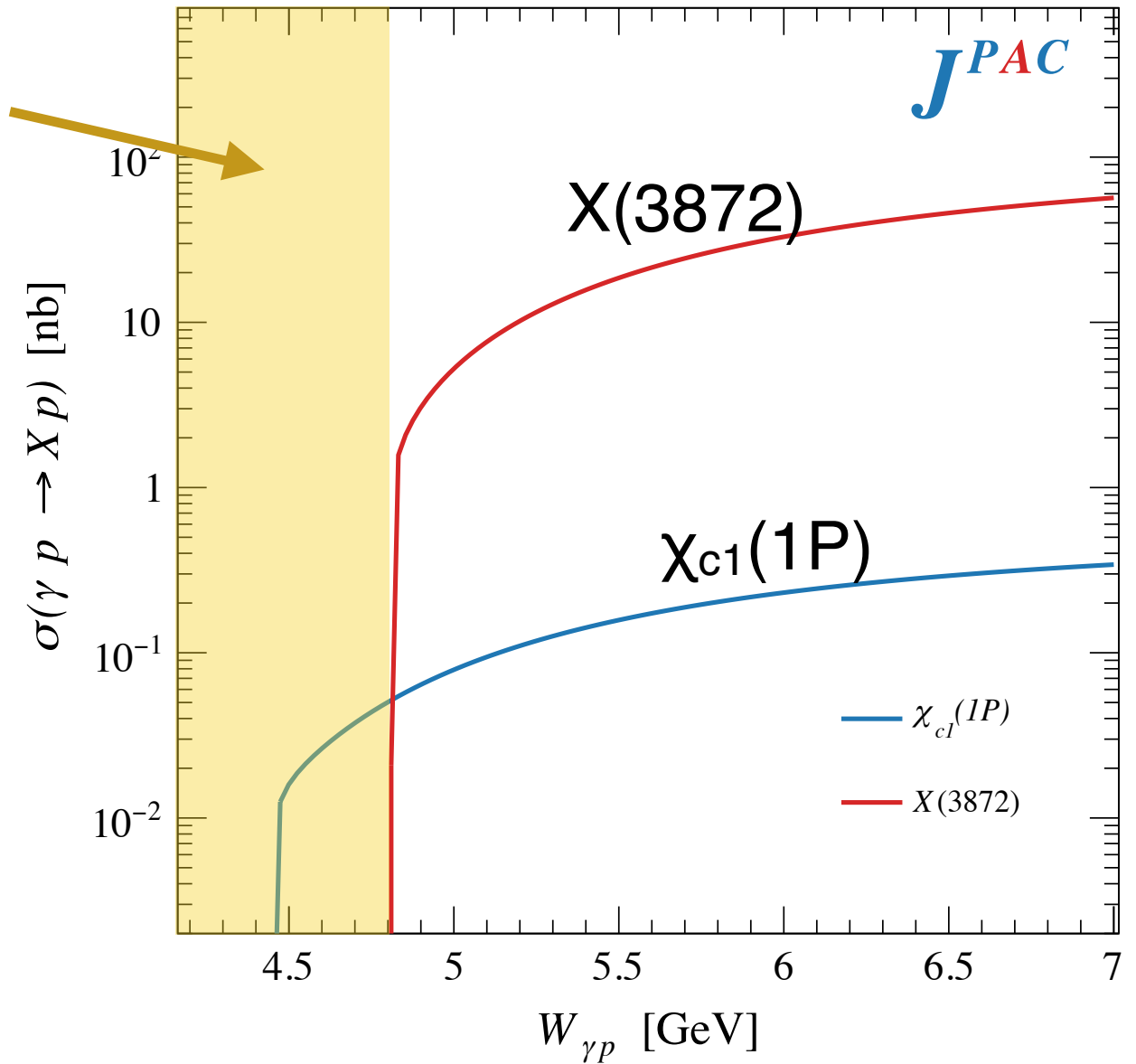
- Full GlueX-I run has **2k J/ψ**, expect updated results soon!
- Measurement of cross section  $t$ -dependence benefits from additional data

# $\chi_{c1}(1^3P_1)$ Photoproduction at GlueX



GlueX  
energy  
range

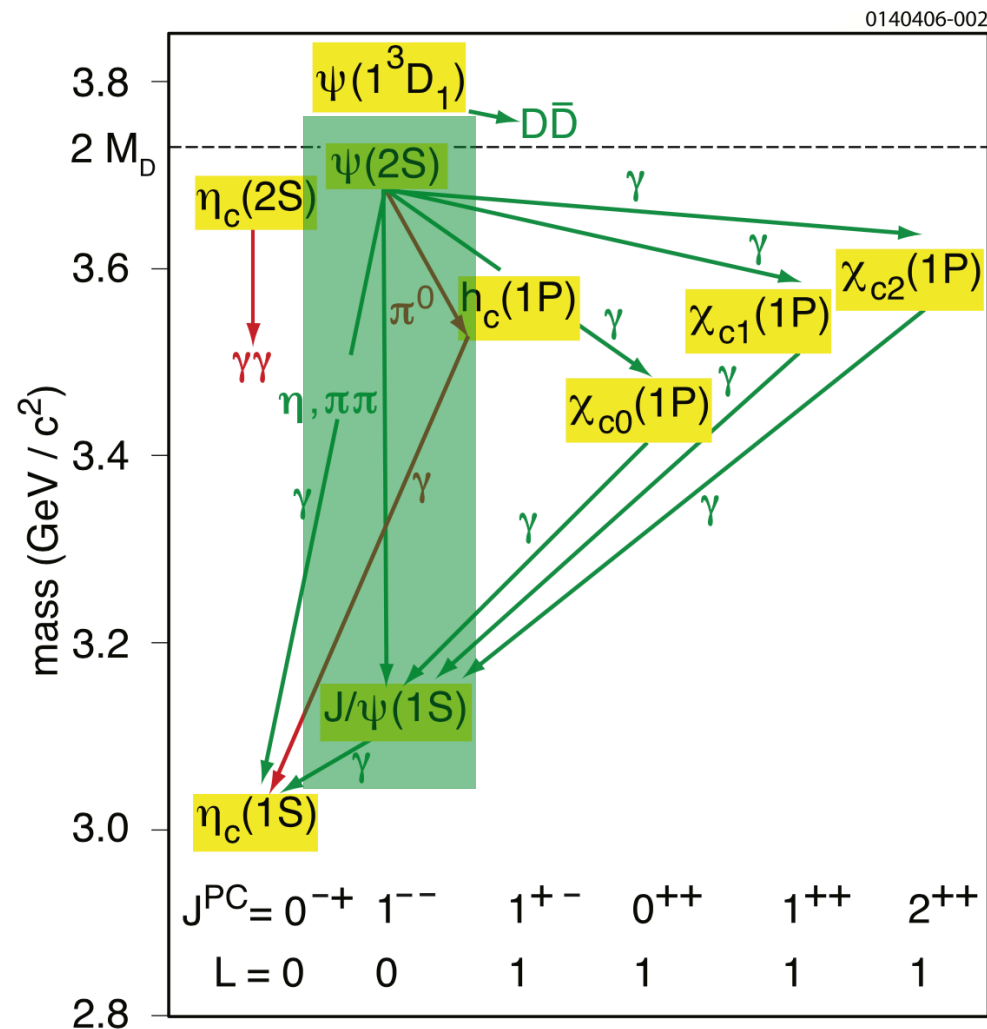
JPAC: PRD 102, 114010 (2020)



- $\chi_{c1}(1^{++})$  photoproduction: probe of different parity,  $P_c$  search
- JPAC model estimate using known  $\chi_{c1} \rightarrow \gamma(\rho, \omega, \phi, J/\psi)$  couplings
- GlueX-I expectation:  $N(\chi_{c1} \rightarrow \gamma J/\psi, J/\psi \rightarrow e^+e^-) = O(50)$

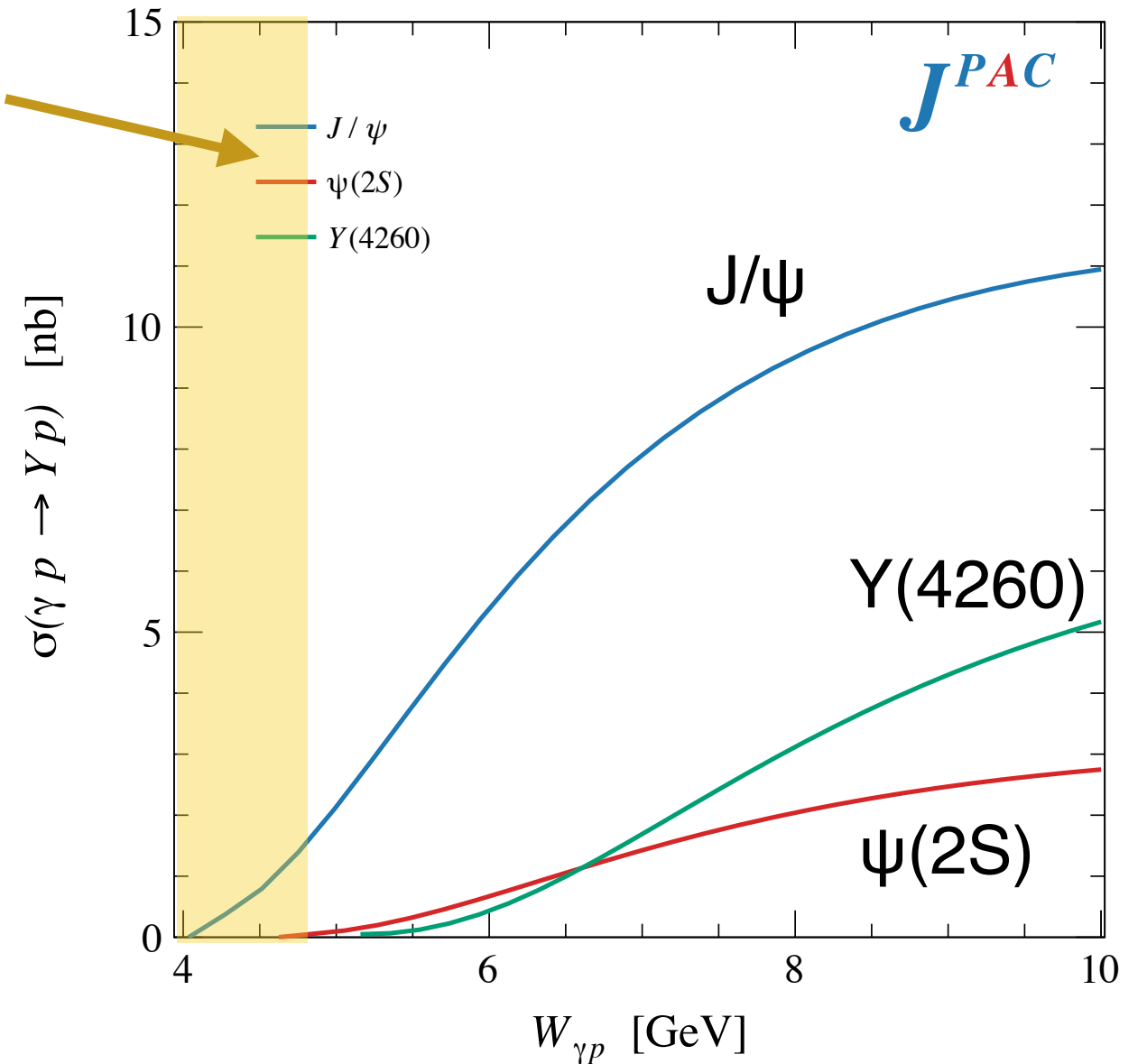


# $\psi(2^3S_1)$ Photoproduction at GlueX



GlueX  
energy  
range

JPAC: PRD 102, 114010 (2020)



- $\psi(2S)$  photoproduction: probe of wave function dependence
- JPAC model estimates using known  $\Gamma_{\gamma gg}(\psi(2S)) / \Gamma_{\gamma gg}(J/\psi)$
- GlueX-I expectation:  $N(\psi(2S) \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow e^+e^-) < 10$

# Open Charm Production Near Threshold

**PRL 51, 156 (1983)**

$$\gamma p \rightarrow p D^0 \bar{D}^0 \text{ neutral(s)} \\ \begin{cases} \rightarrow + - \text{ neutral(s)} \\ \rightarrow \pi^+ K^- \end{cases}$$

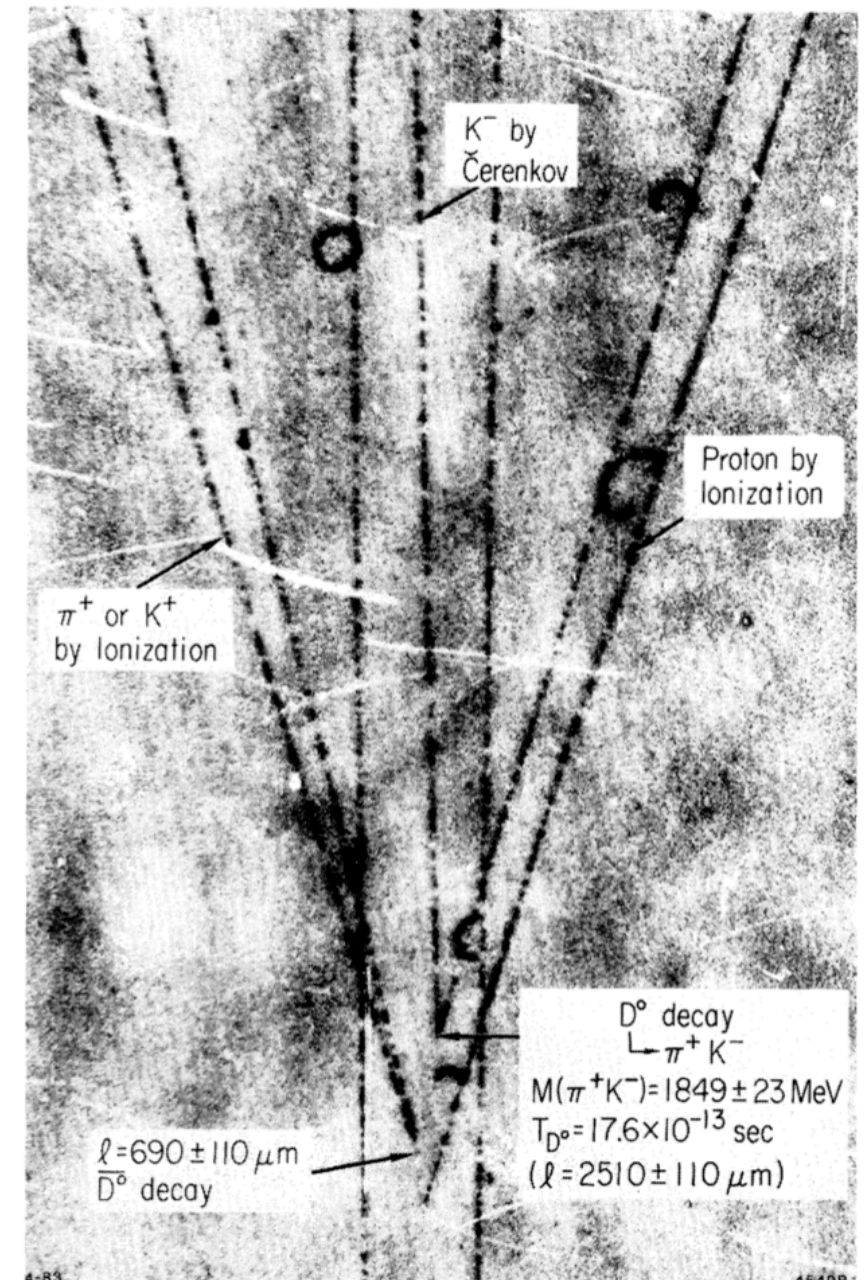


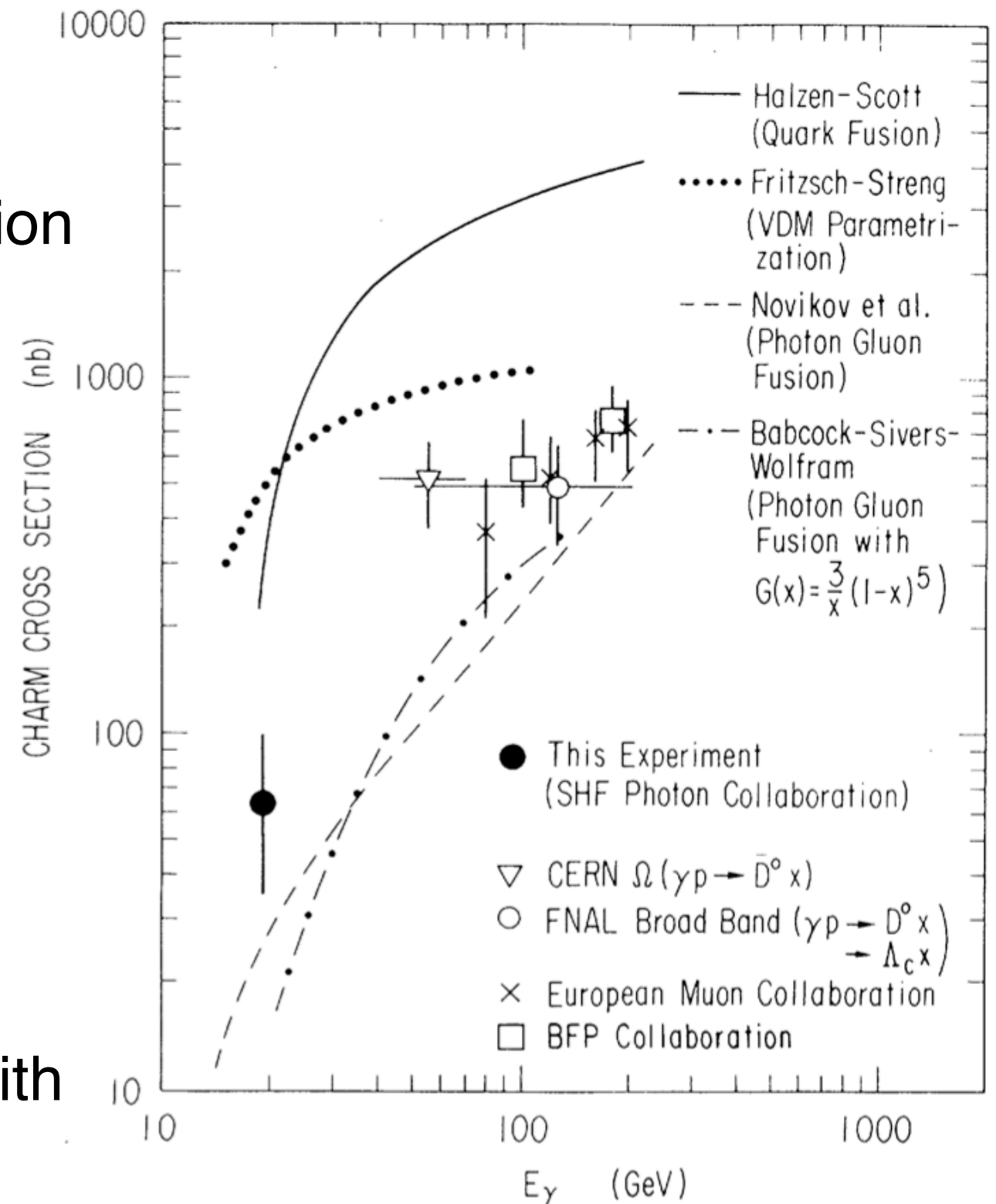
FIG. 2. An example of a charm event.

- Hadron ( $c\bar{c}$ ) molecules like to decay to open-charm final states, can we see them at GlueX?
- Also will help with  $J/\psi$  interpretation
- Open charm photoproduction cross section measured at SLAC for  $E_\gamma \approx 20 \text{ GeV}$  based on  $\sim 50$  events
- Roughly 5-10 larger than  $J/\psi$  cross section
- Exclusive reconstruction of e.g.  $D^{(*)0} \Lambda_c^+$  is a factor  $\approx 25$  lower due to b.f.s
- Likely need full GlueX-II statistics with improved  $\pi/K$  separation

# Open Charm Production Near Threshold

**PRL 51, 156 (1983)**

- Hadron ( $c\bar{c}$ ) molecules like to decay to open-charm final states, can we see them at GlueX?
- Also will help with  $J/\psi$  interpretation
- Open charm photoproduction cross section measured at SLAC for  $E_\gamma \approx 20$  GeV based on  $\sim 50$  events
- Roughly 5-10 larger than  $J/\psi$  cross section
- Exclusive reconstruction of e.g.  $D^{(*)0} \Lambda_c^+$  is a factor  $\approx 25$  lower due to b.f.s
- Likely need full GlueX-II statistics with improved  $\pi/K$  separation



# Summary and Prospects

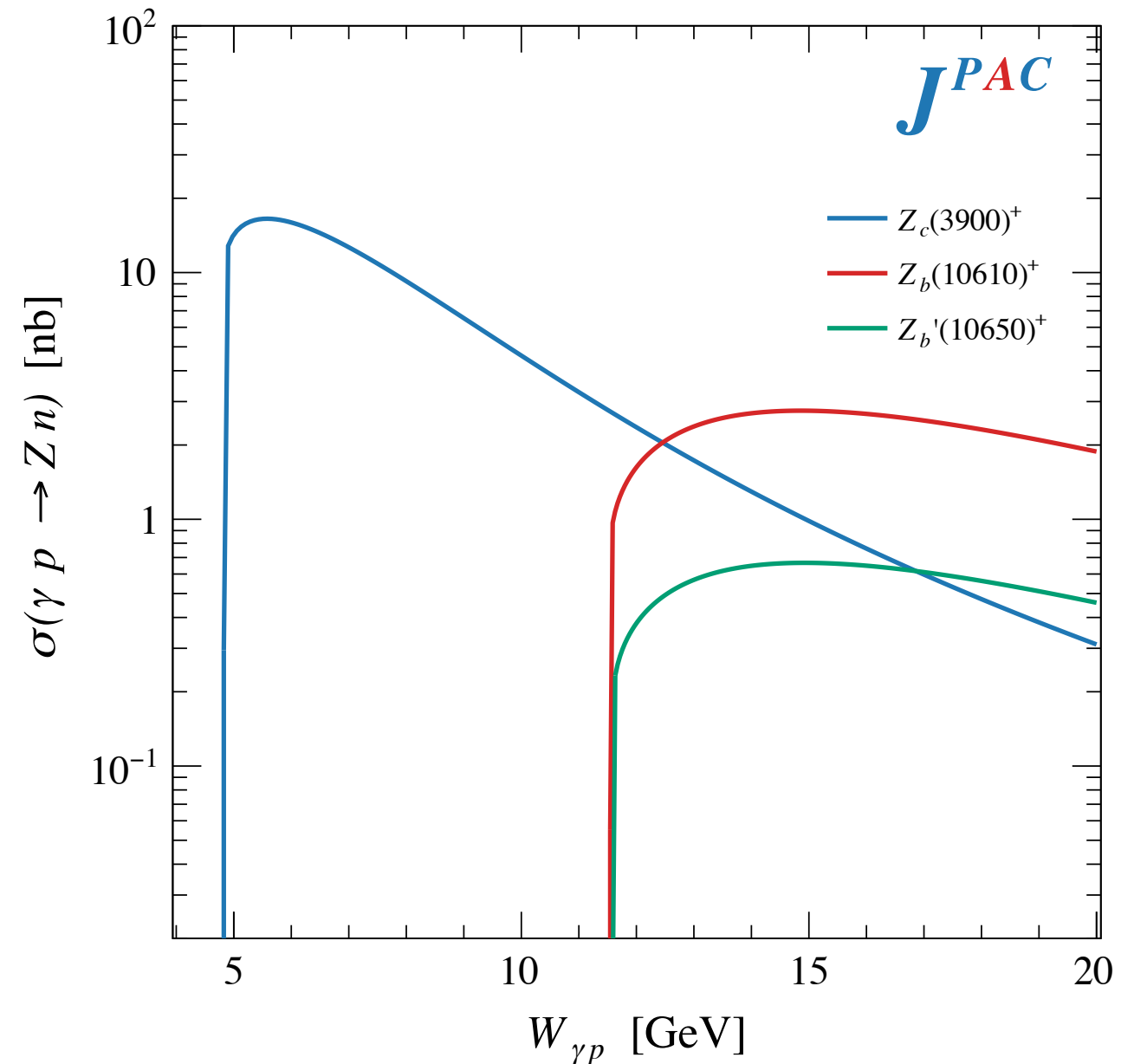
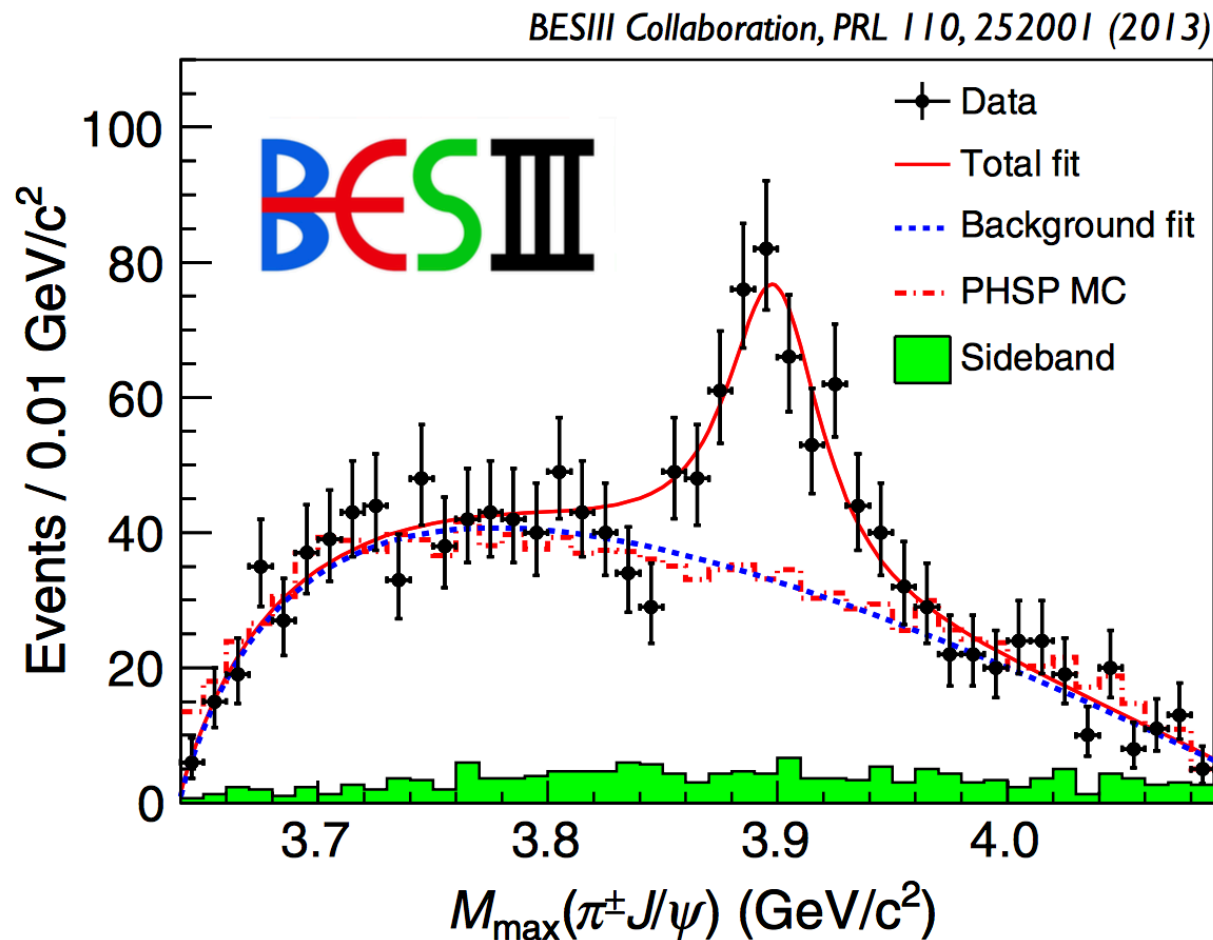
- GlueX has made the first measurement of the energy dependence of the  $J/\psi$  cross section near threshold
  - Expect an update soon with the full **2k  $J/\psi$**  from GlueX-I
  - The ongoing GlueX-II run allows us to measure  **$d\sigma / dt dE$**
- Other measurements of bound charmonia are possible with the growing GlueX data set
  - **$\chi_{c1}$**  and  **$\psi(2S)$**  appear feasible
  - **Other ideas:** production off  $\Delta$ 's, deuteron/nuclear targets, ...
  - **Open charm:** important measurement but very difficult due to small b.f.'s, large background levels, GlueX-II DIRC will help...
- Exploring near-threshold photoproduction of other charmonia requires a higher-energy machine or an EIC

# Backup Slides



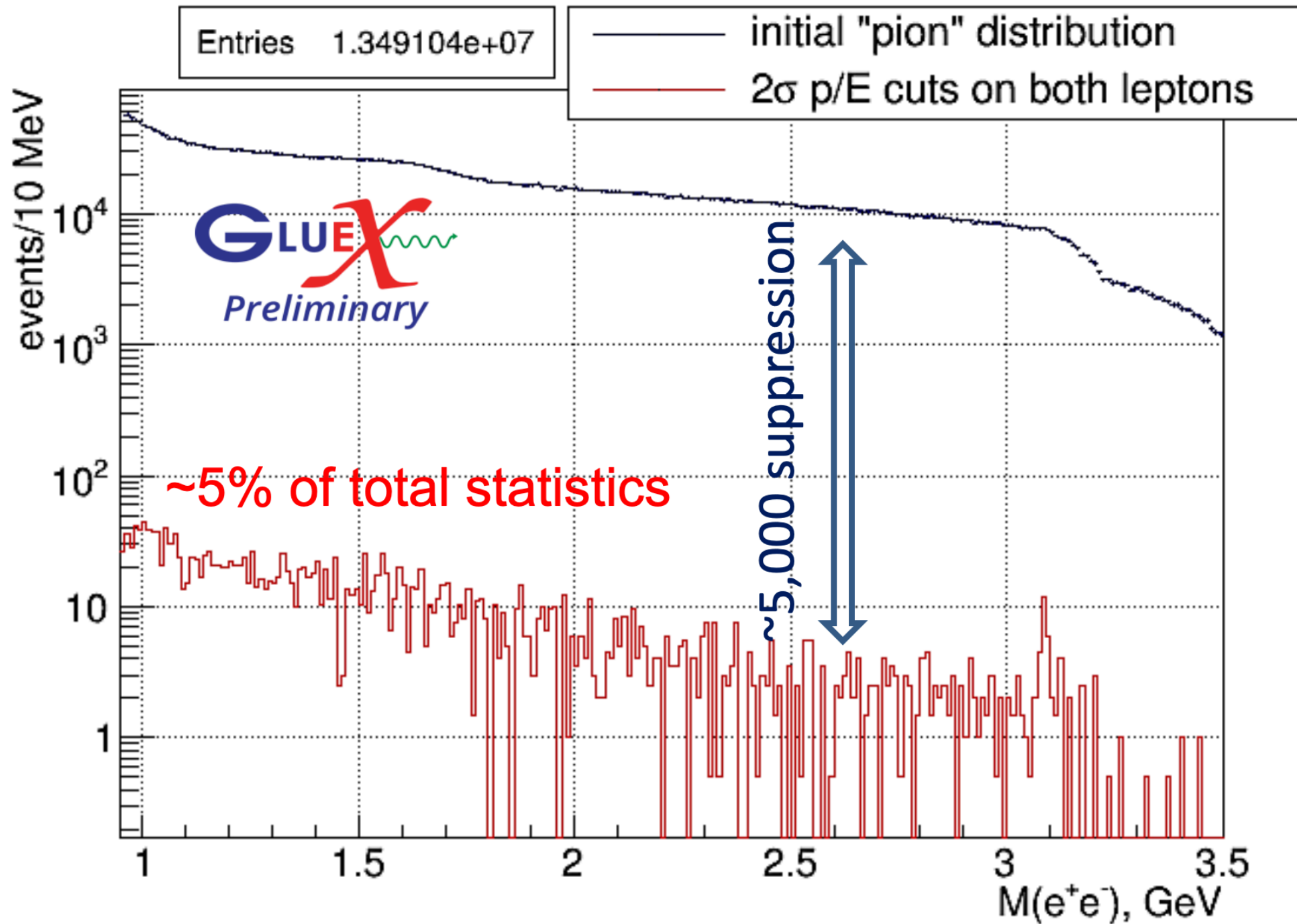
# Zc Photoproduction at GlueX

JPAC: PRD 102, 114010 (2020)



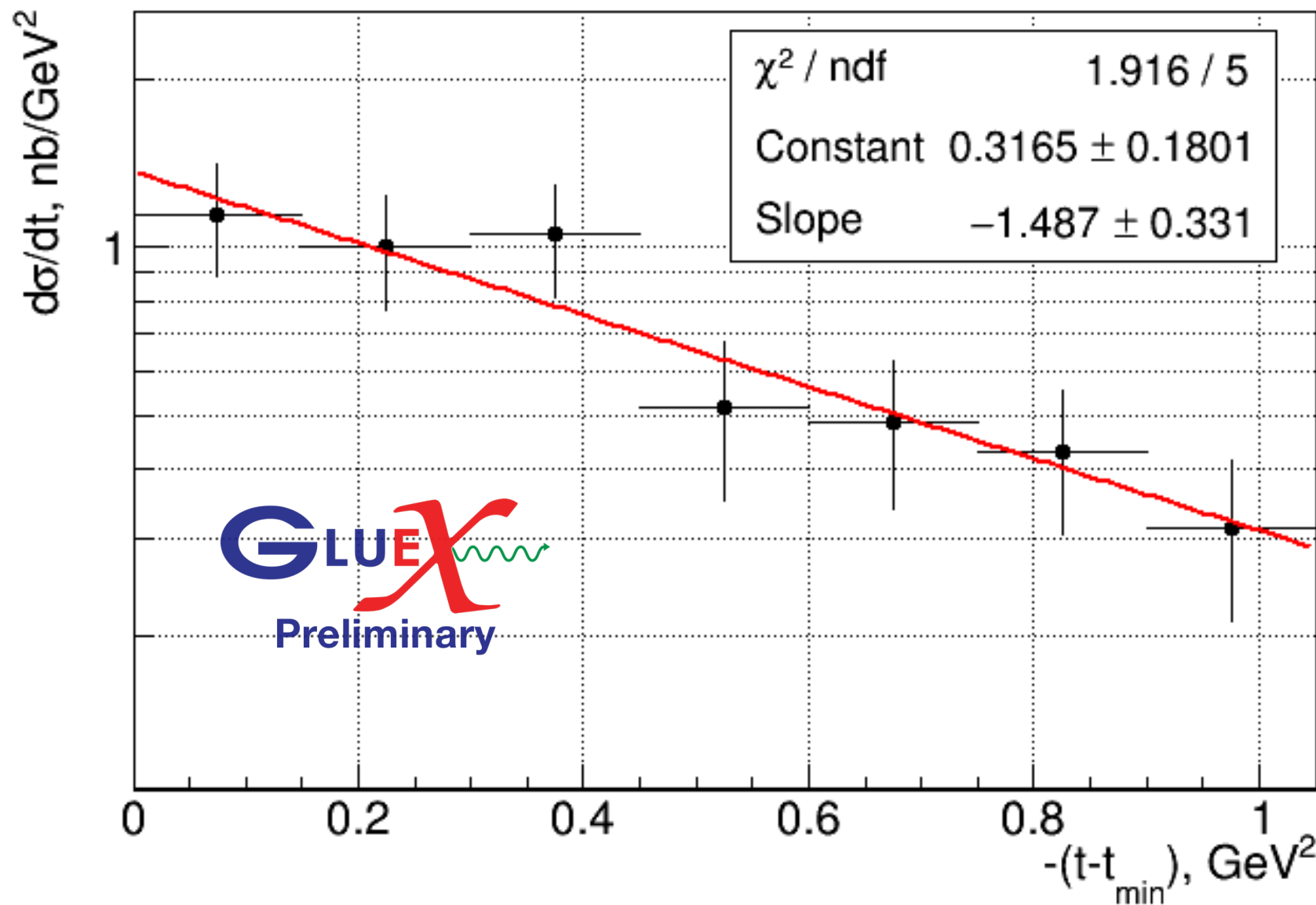
- $Z_c(3900)$  production threshold just above energies accessible at GlueX—need CEBAF energy upgrade or EIC

# J/ψ @ GlueX: Background Rejection





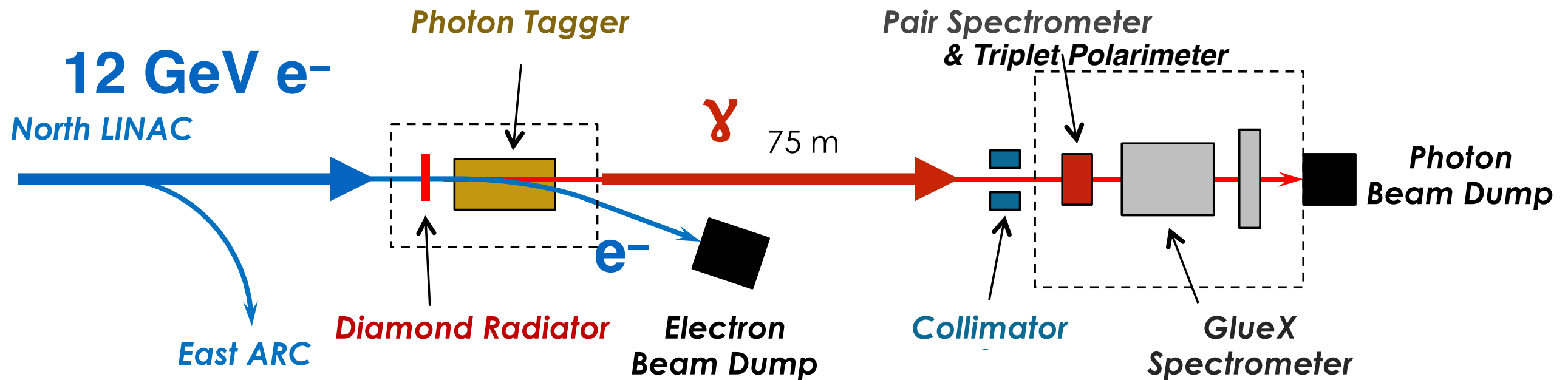
# J/ψ @ GlueX: t-slope



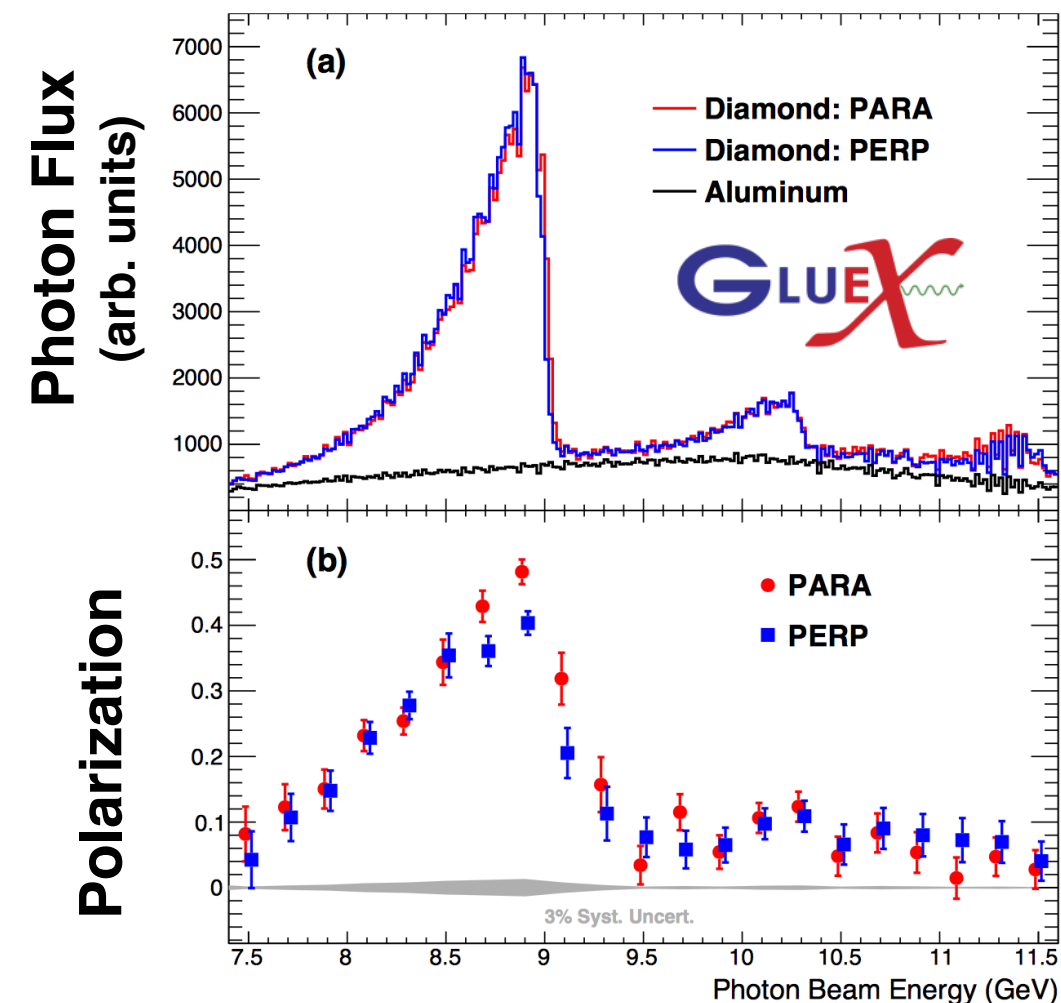
## Measurements near threshold

- Cornell at  $\sim 11$  GeV  
 $1.25 \pm 0.20 \text{ GeV}^{-2}$
- **GlueX at 10–11.8 GeV**  
 **$1.49 \pm 0.33 \text{ GeV}^{-2}$**
- SLAC at 19 GeV  
 $2.9 \pm 0.3 \text{ GeV}^{-2}$

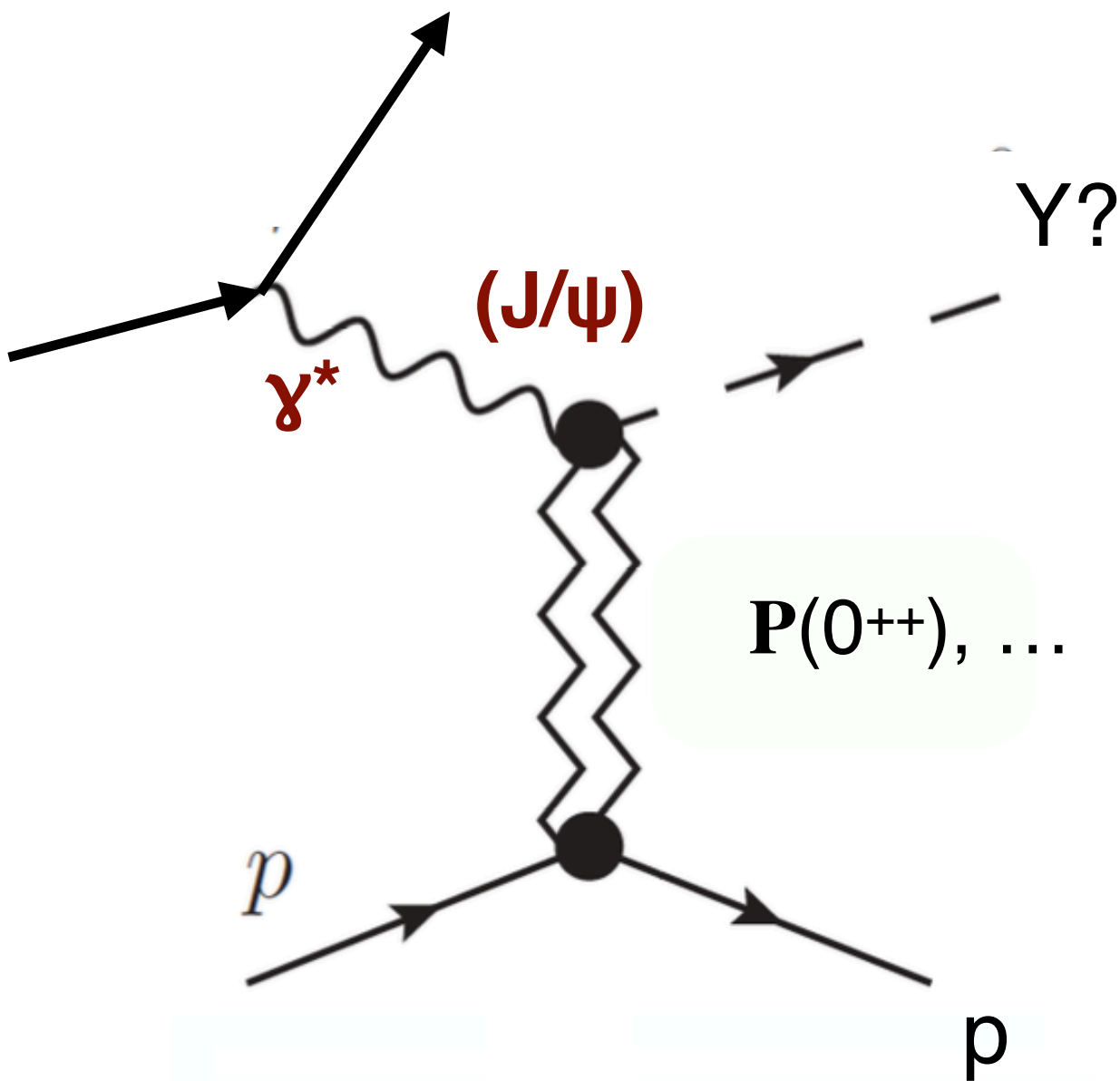
# The GlueX Experiment: Photon Beam



- Photon beam generated via coherent bremsstrahlung off thin diamond radiator
- Photon energies tagged by scattered electrons
  - Energy measurement precision  $< 25$  MeV
- Photon linear polarization  $P_\gamma \sim 40\%$  in peak
- Intensity of  $\sim 1-5 \times 10^7$   $\gamma/s$  in peak



# Searching for “Charming” Hybrids



- Hybrid mesons should have charm-quark counterparts
- Candidates exist
- (Polarized) photons give clean probe
- Vector mesons should be well produced via VMD
- Other QN mesons can be produced as well
- EIC gives required CM energy (and luminosity?) to search for these

# The GlueX Experiment in Hall D @ JLab

- The GlueX experiment is located in Hall D, newly constructed as part of the Jefferson Lab 12 GeV upgrade.
- Large acceptance solenoidal spectrometer
- Linearly polarized photon beam peaking at 9 GeV
- Detects all decay products from full hadronic photoproduction rate
- 100+ Collaborators from 26 institutions

