

# Photoproduction of Charmonium

## The **GLUEX** Experience

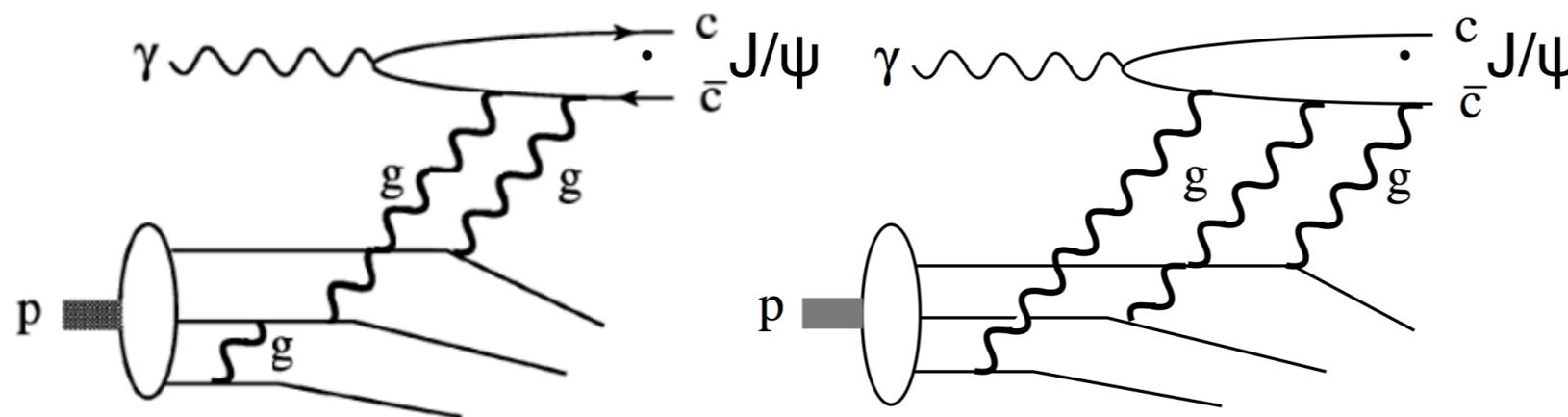
**Sean Dobbs**  
Florida State U.

The spectroscopy program at EIC and future accelerators  
ECT\*, Trento, Italy  
December 20, 2018



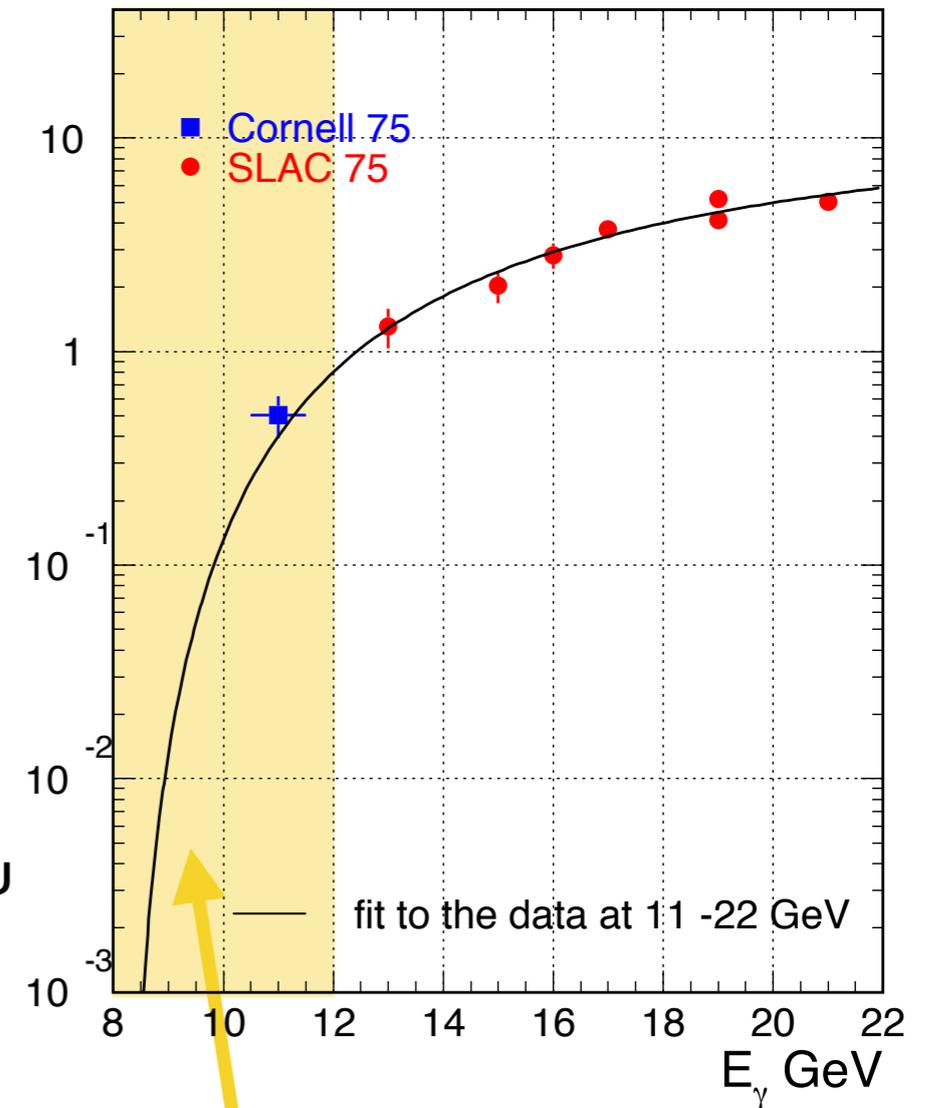
# J/ψ Photoproduction Near Threshold

- Threshold production is experimentally clean, ideal for studying J/ψ+N interaction
  - Probes gluon distributions in proton, trace anomaly  
[Kharzeev et al., NPA 661, 568 (1999)]
  - Also multiquark correlations  
[Brodsky et al., PLB 498, 23 (2001)]



leading-twist

higher-twist

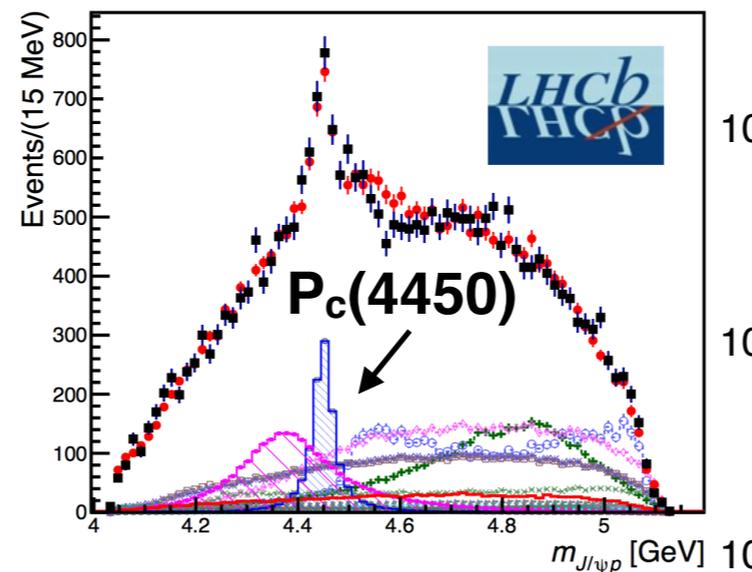
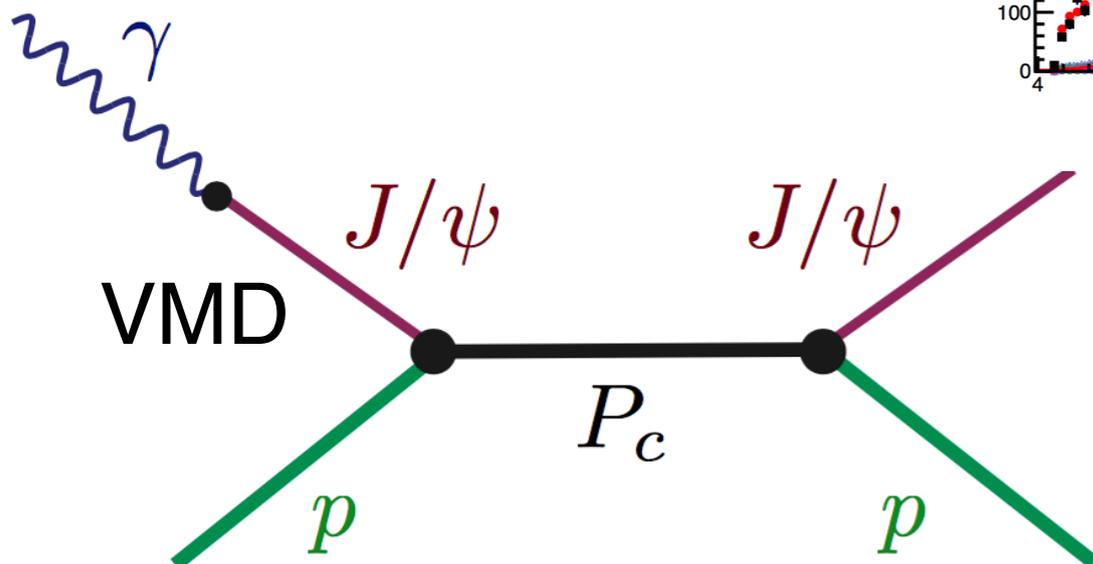


GlueX energy range

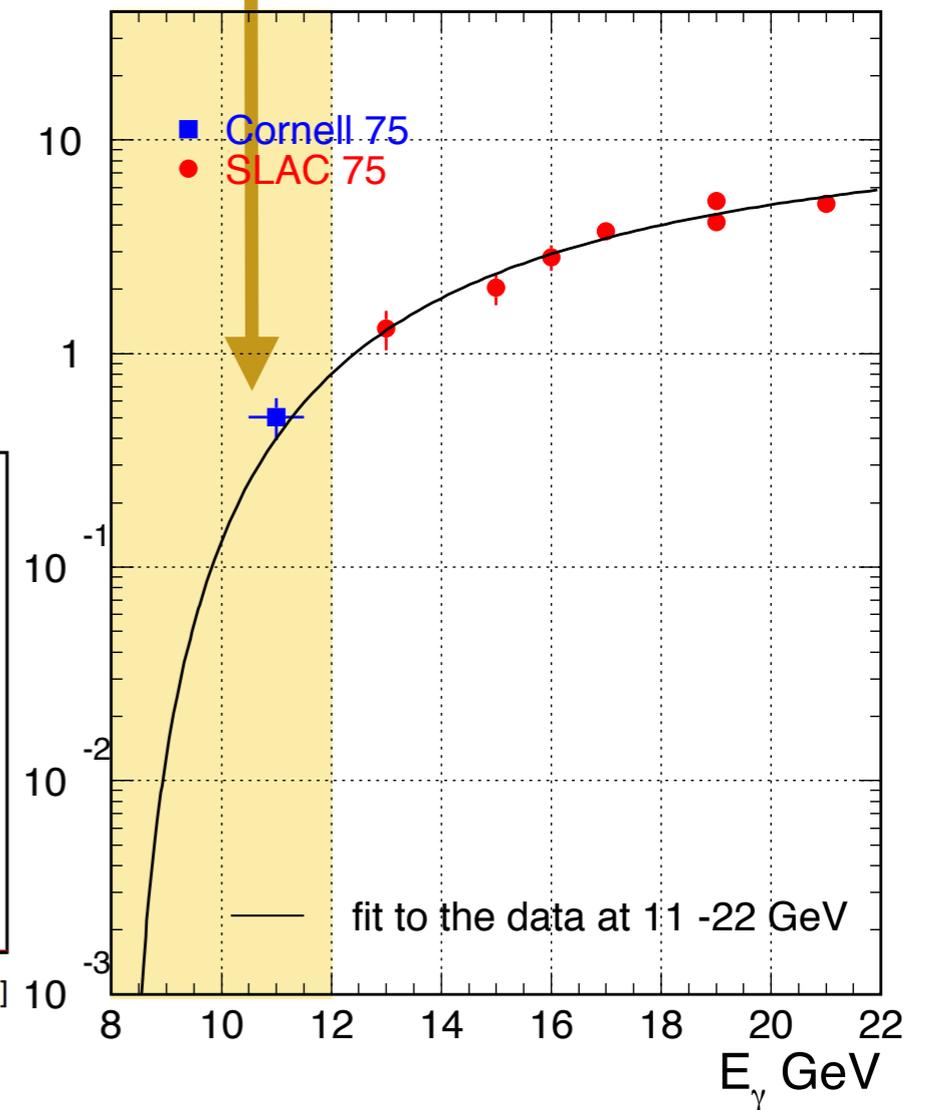
# J/ψ Photoproduction Near Threshold

- Threshold production is experimentally clean, ideal for studying J/ψ+N interaction
- Can also study coupling of resonant J/ψ+p states to photon
- P<sub>c</sub>(4450) produced at **E(γ) ~ 10.3 GeV**

s-channel photoproduction probes nature of 5-quark interaction!



P<sub>c</sub>(4450)



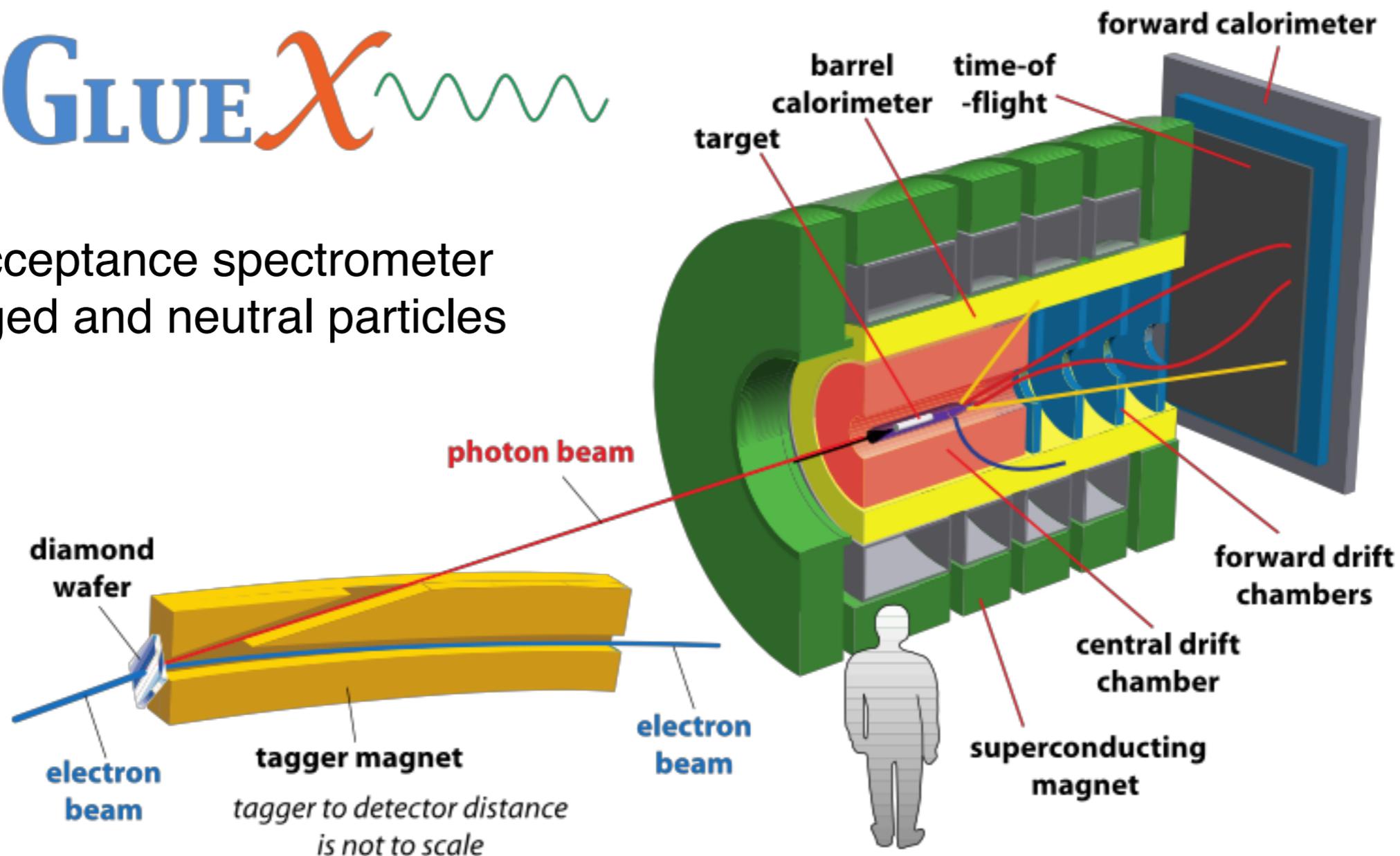
## Theory papers:

Wang, Liu, and Zhao, PRD 92, 034022 (2015).  
 Kubarovsky and Voloshin, PRD 92, 031502 (2015).  
 Karliner and Rosner, PLB 752, 329 (2016).  
 Hiller Blin et al. (**JPAC**), PRD 94, 034002 (2016).  
 and many more...

# The GlueX Experiment

GLUEX 

Large acceptance spectrometer  
for charged and neutral particles

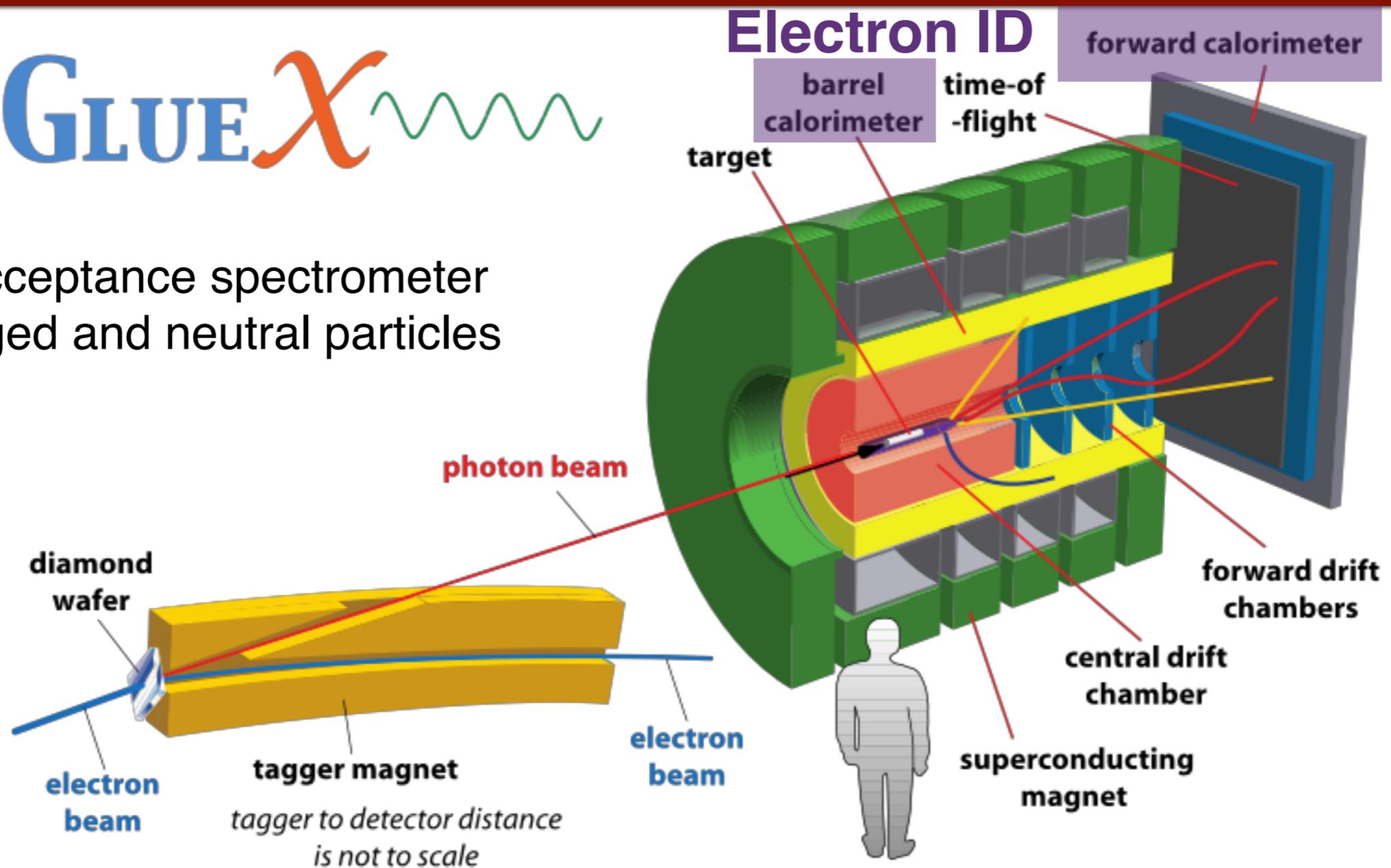


- 2016: 10 pb<sup>-1</sup>
  - 2017: 45 pb<sup>-1</sup>
  - 2018: ~150 pb<sup>-1</sup> in spring & fall, GlueX Phase-I is now finished!
- ← Data being analyzed

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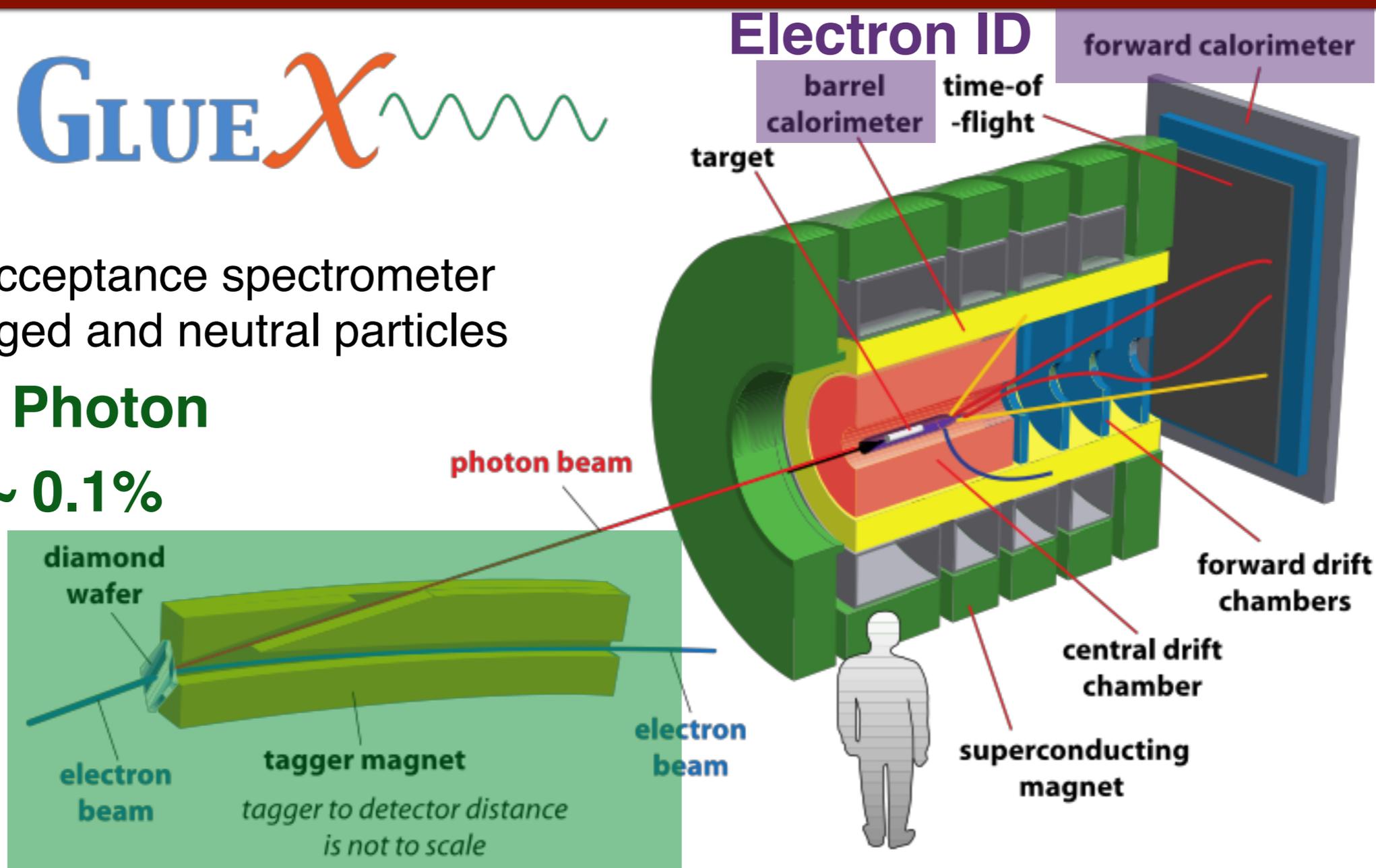
# The GlueX Experiment

# GLUEX

Large acceptance spectrometer  
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## Tagged Photon

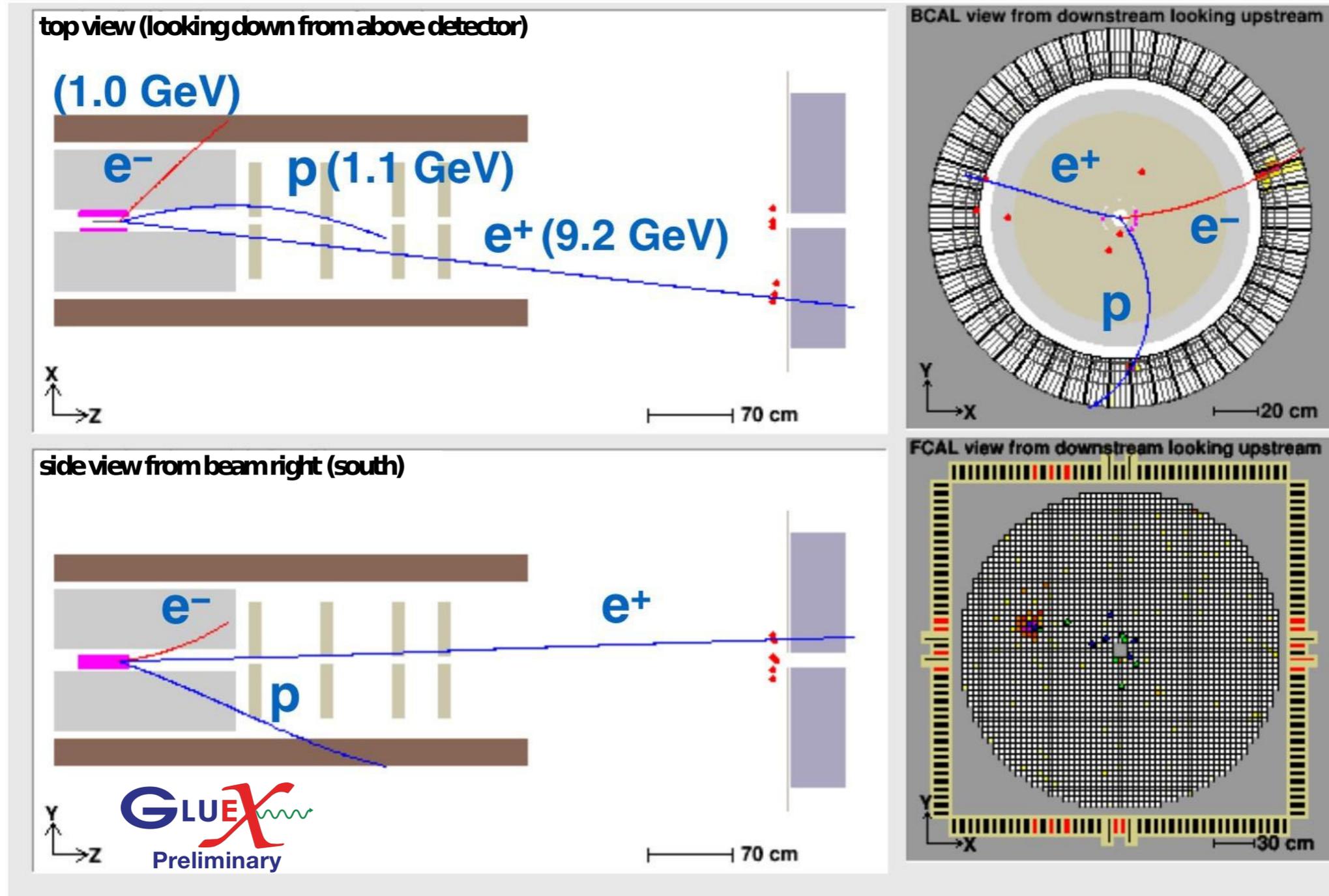
$\sigma(E)/E \sim 0.1\%$



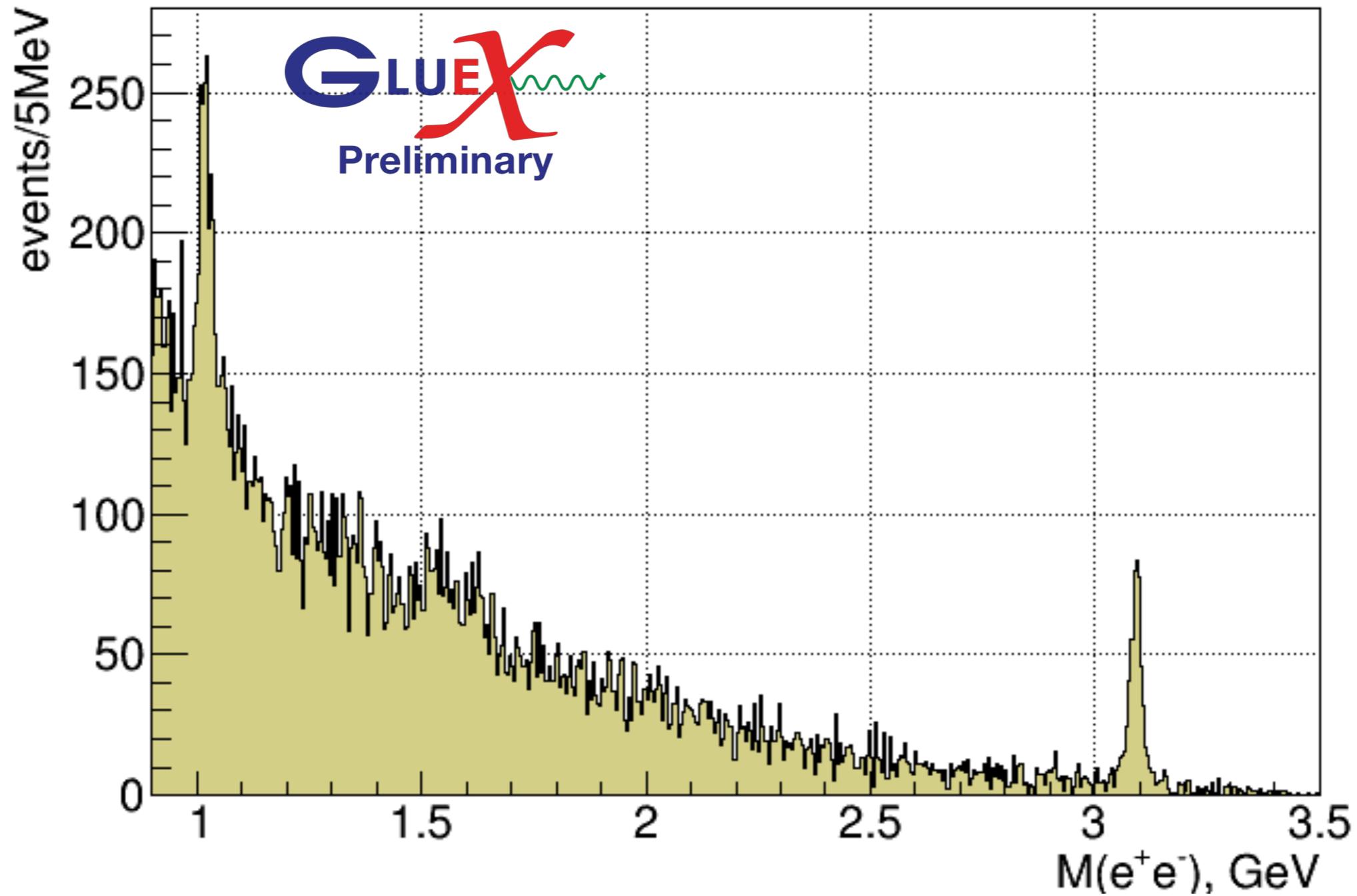
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# J/ψ Photoproduction at GlueX

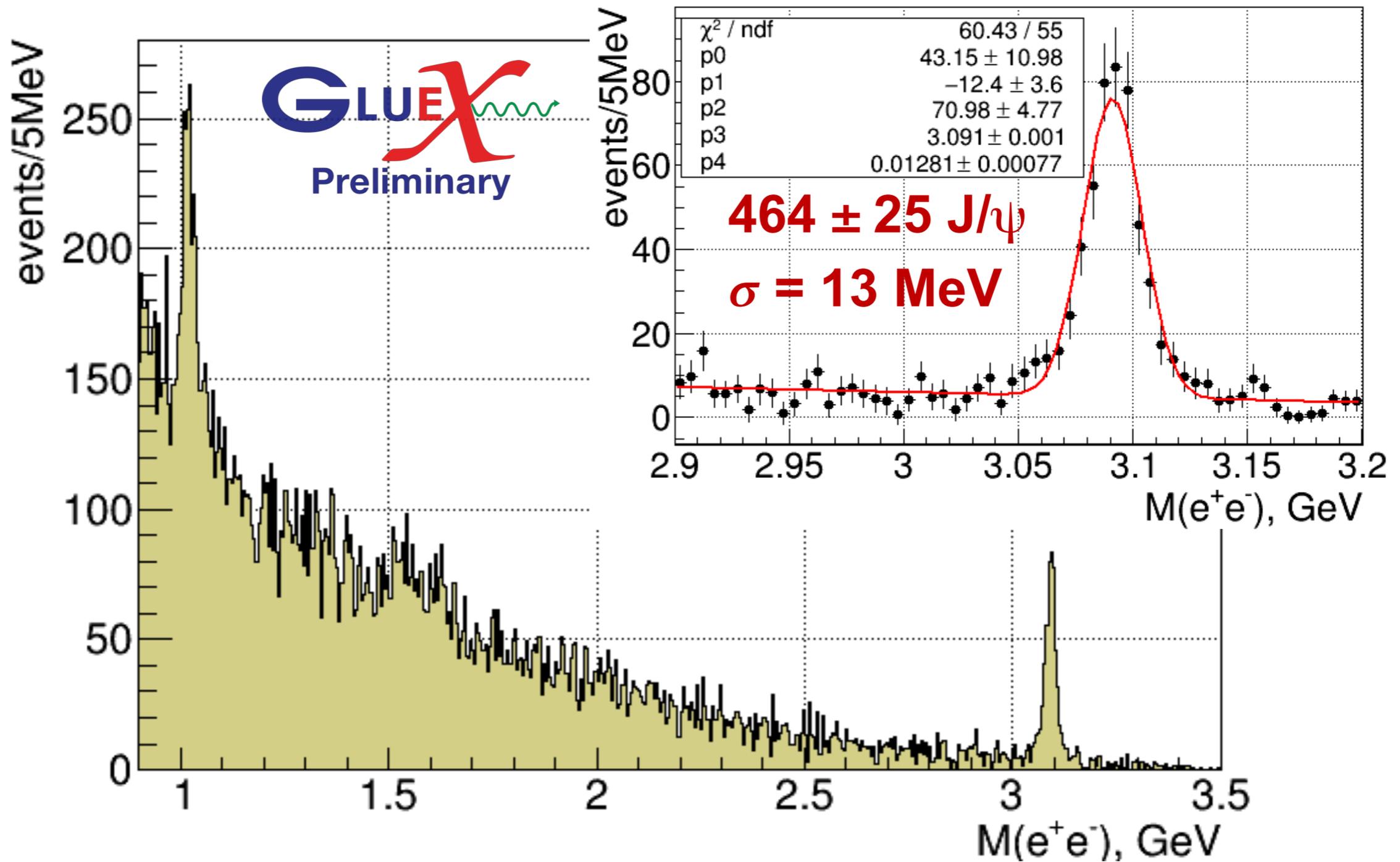
- Reconstruct  $p \gamma \rightarrow p + J/\psi, J/\psi \rightarrow e^+e^-$
- Kinematically fit fully reconstructed events



# J/ $\psi$ Photoproduction at GlueX: Mass Spectrum

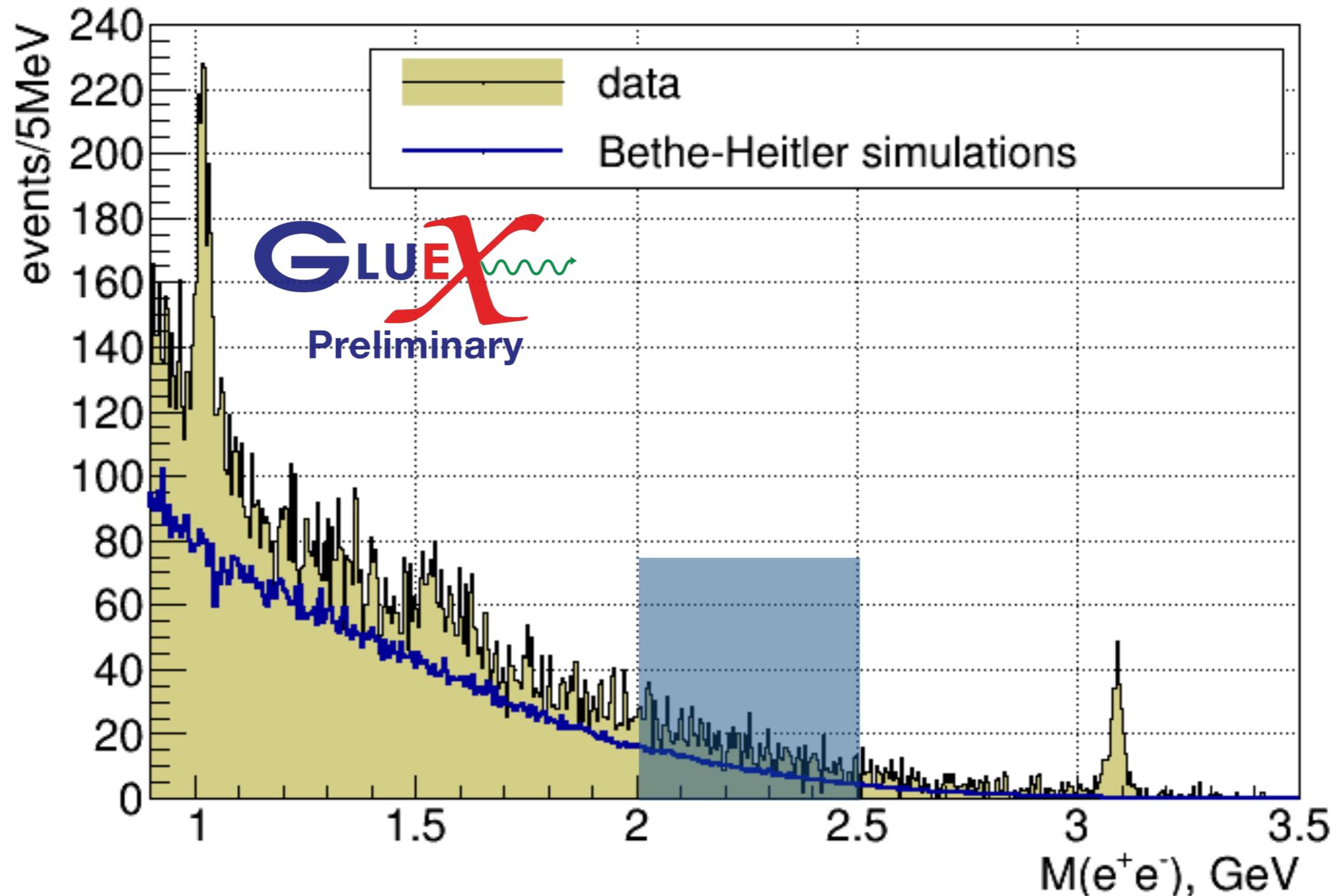


# J/ψ Photoproduction at GlueX: Mass Spectrum



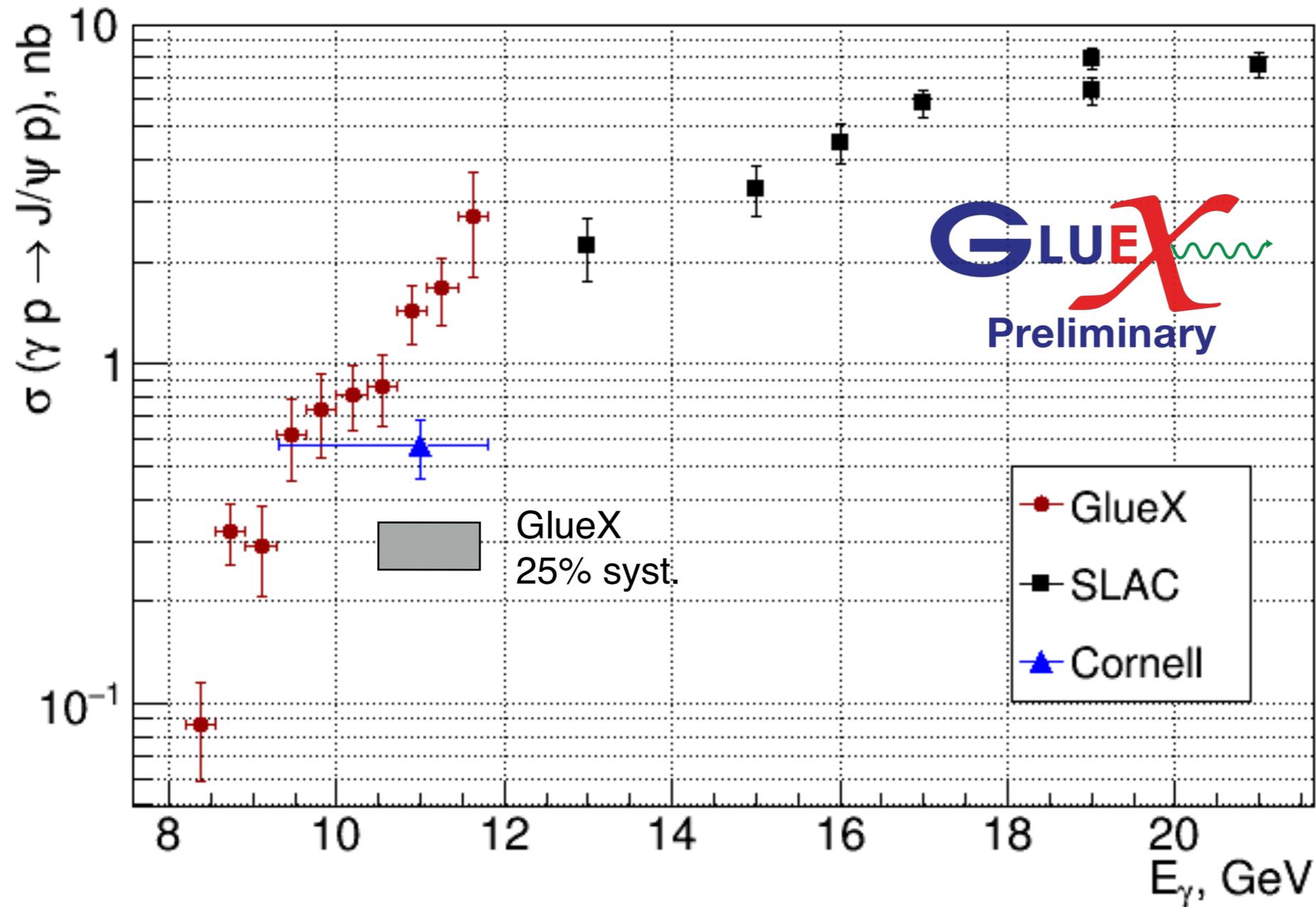
- Reconstruct  $p \gamma \rightarrow p + J/\psi, J/\psi \rightarrow e^+e^-$

# J/ $\psi$ Photoproduction at GlueX: Mass Spectrum



- Calculate  $J/\psi$  cross sections normalized by non-resonant  $e^+e^-$
- Absolute acceptances and efficiencies currently under study

# J/ψ @ GlueX: Cross sections vs. theory



SLAC:

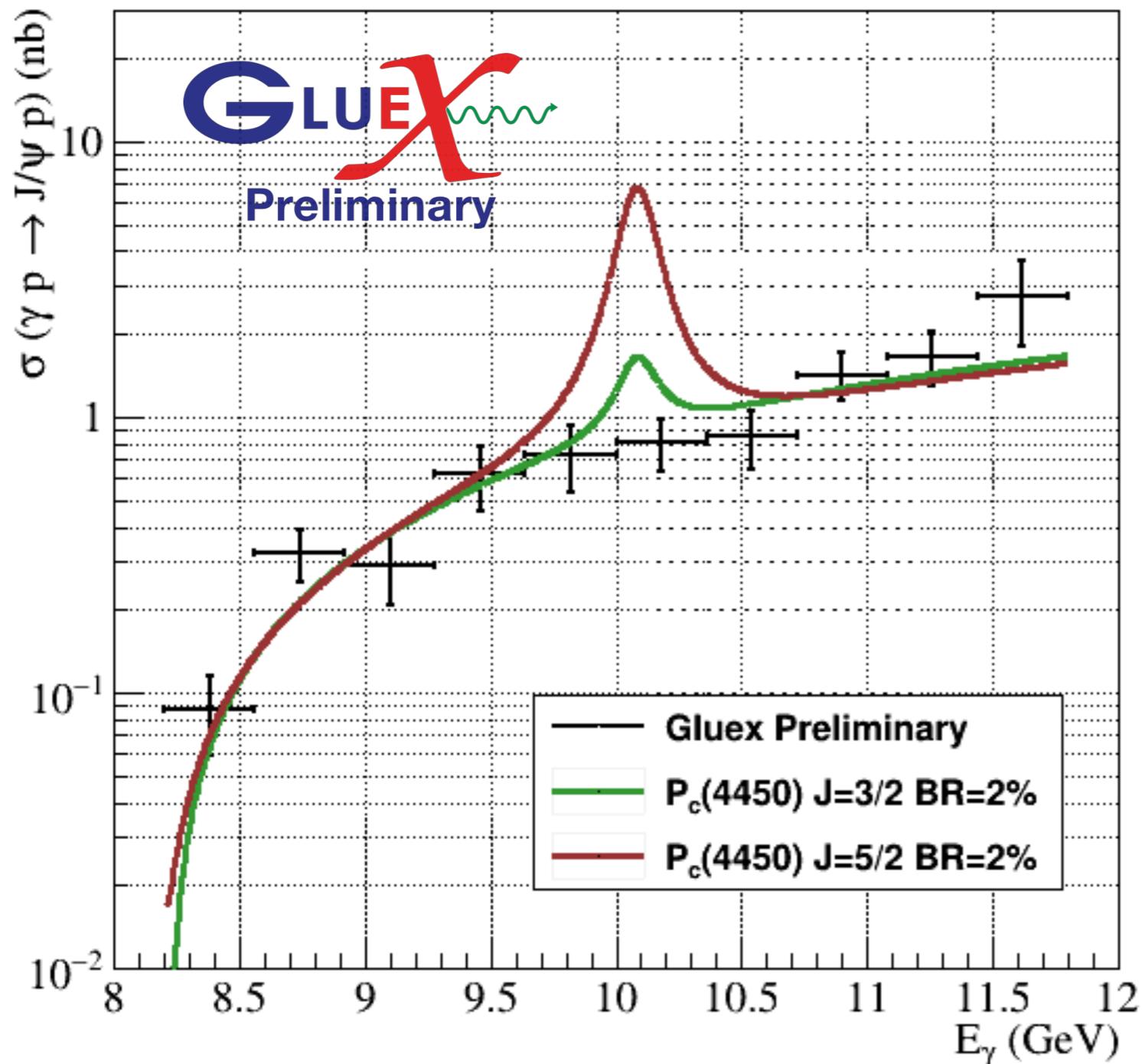
U. Camerini et al.  
PRL 35, 1975

Cornell:

B. Gittelmann et al.  
PRL 35, 1975

- SLAC points calculated from measured  $d\sigma/dt$  and dipole  $t$ -dependence
- Cornell horizontal error bars illustrate acceptance

# J/ψ @ GlueX: Comparison with Pentaquark Predictions

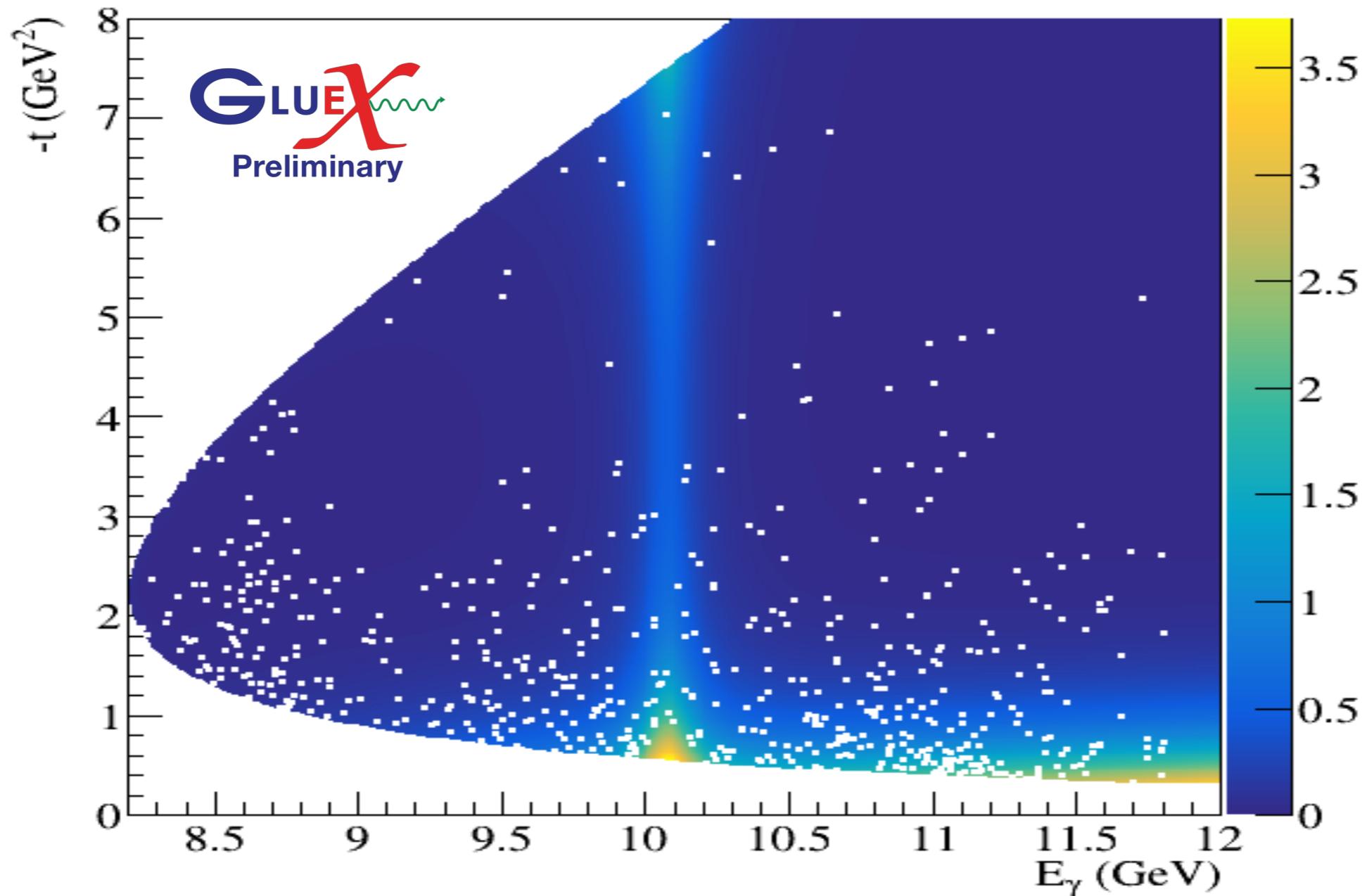


- JPAC model includes non-resonant production and pentaquark B-W via VMD
  - Sensitive to  $\text{Br}(P_c \rightarrow J/\psi p)$
- Simple analysis indicates we can set limits ( $3\sigma$  separation) for  $P_c(4450)$  production of **2% for  $J^P = 3/2^-$  and less for  $J^P = 5/2^+$**
- Final UL systematics will include:
  - Description of t-channel
  - Interference between s- and t-channels



A.N. Hiller Blin, et al., PRD 94, 034002 (2016).

# J/ψ @ GlueX: Unbinned E(γ) vs. t



Not corrected  
for beam  
spectrum or  
acceptance

No evidence  
for s-channel  
production

- JPAC model: 2%  $P_c(4450)$ ,  $J^P = 5/2^+$
- Points: GlueX data in J/ψ mass region

# Where do we go from here? (Near-threshold edition)

- GlueX has made the first measurement of  $J/\psi$  production near threshold — currently under internal review
  - Full GlueX-I data on tape should increase statistics by  $\sim 3$
- Opens door to measuring other reactions
  - $p \gamma \rightarrow \Delta^{++} J/\psi$       Isospin-dependence of production
  - $p \gamma \rightarrow p \pi^0 J/\psi$       Test exclusivity near threshold

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  - $p \gamma \rightarrow (p\pi^0/n\pi^+) J/\psi$  Test exclusivity near threshold
  - Other pentaquark searches
    - $p \gamma \rightarrow p X_{c1}, X_{c1} \rightarrow \gamma J/\psi$  [need more data]
    - $p \gamma \rightarrow p \eta_c$  [need DIRC?]

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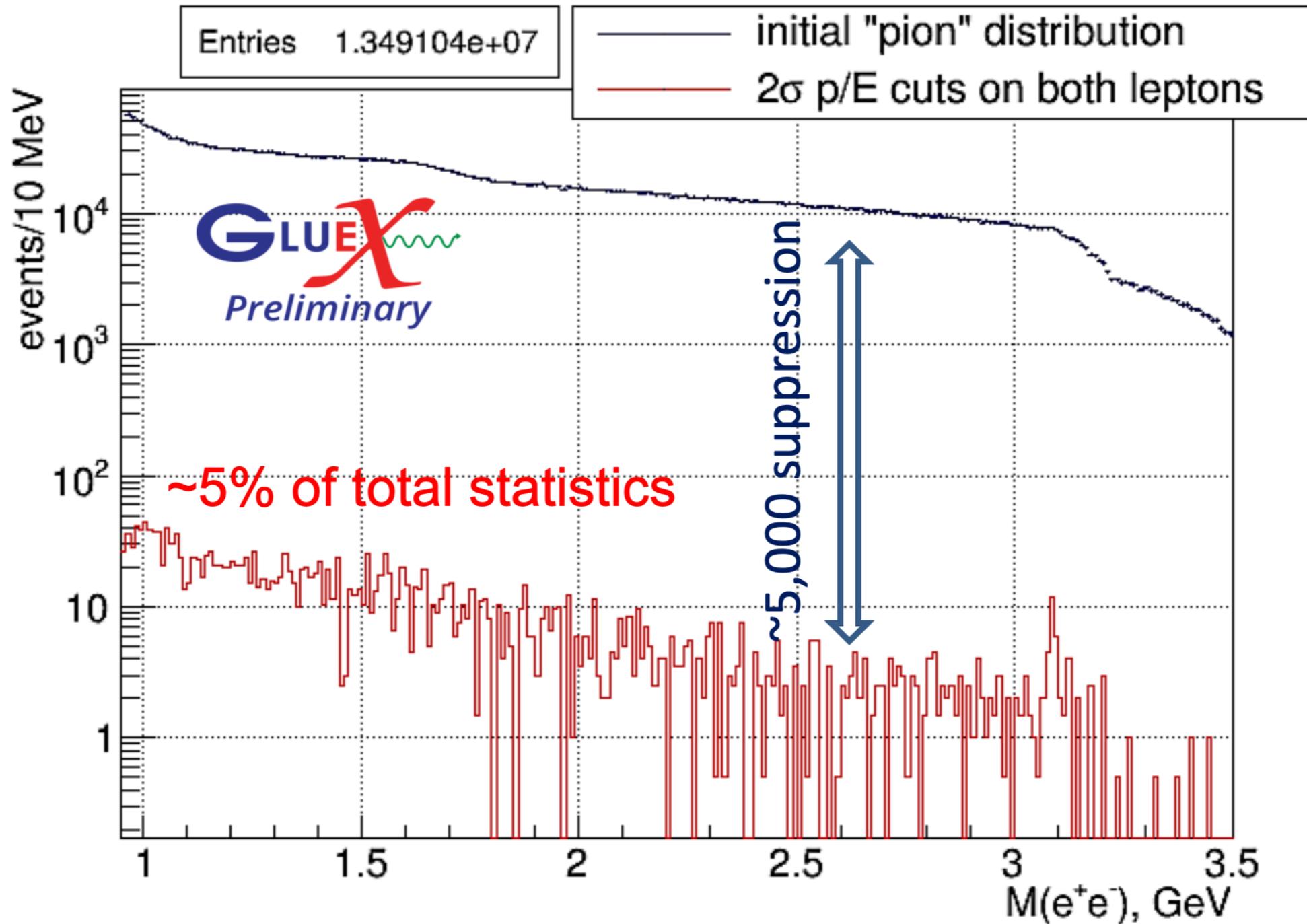
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  - Other targets
    - $d \gamma \rightarrow J/\psi + X$  Neutral partners, others [PLB 498, 23 (2001)]
    - $Z \gamma \rightarrow J/\psi + X$  Nuclear effects

# Where do we go from here? (Near-threshold edition)

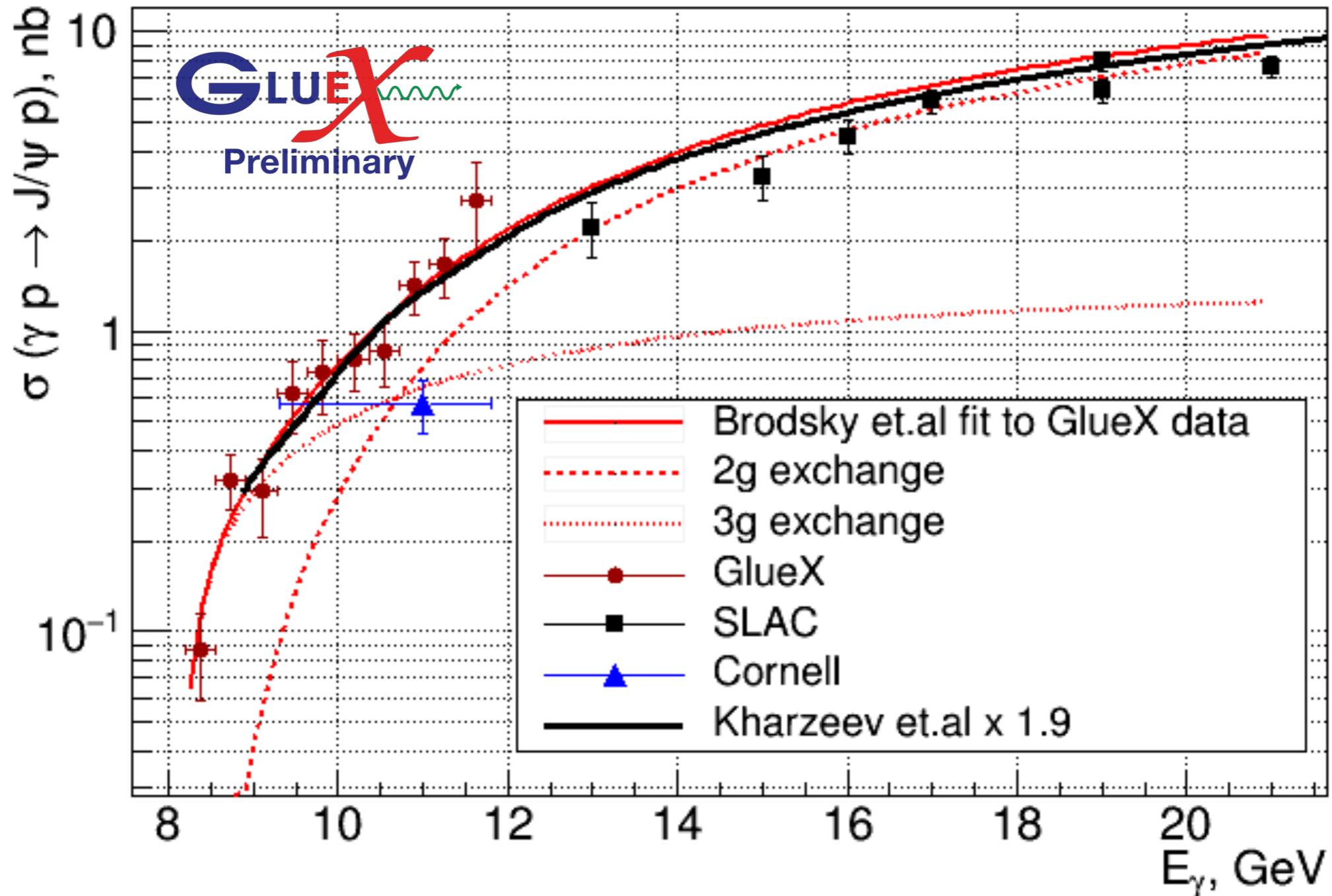
- Measurement of open charm production provides complementary view to hidden-charm production
  - At higher energies, open charm xsec's are  $\sim 10x$  J/ $\psi$
  - Look for  $p \gamma \rightarrow \Lambda_c^+ D^{(*)0}$  [e.g. PRD 69, 094015; arXiv:1604.05969]
  - Pentaquarks in  $p \gamma \rightarrow \Sigma_c^+ D^{(*)0}$  [e.g. arXiv:1811.03992]
- Electron beams of 20 GeV would allow fixed target studies of states beyond DDbar threshold
  - Threshold for  $Z_c(3900) - 12.0$  GeV
  - Threshold for  $Y(4660) - 16.2$  GeV
- Studying bottomonium production would give clearer insight into nature of multiquark states

# Backup Slides

# J/ψ @ GlueX: Background Rejection

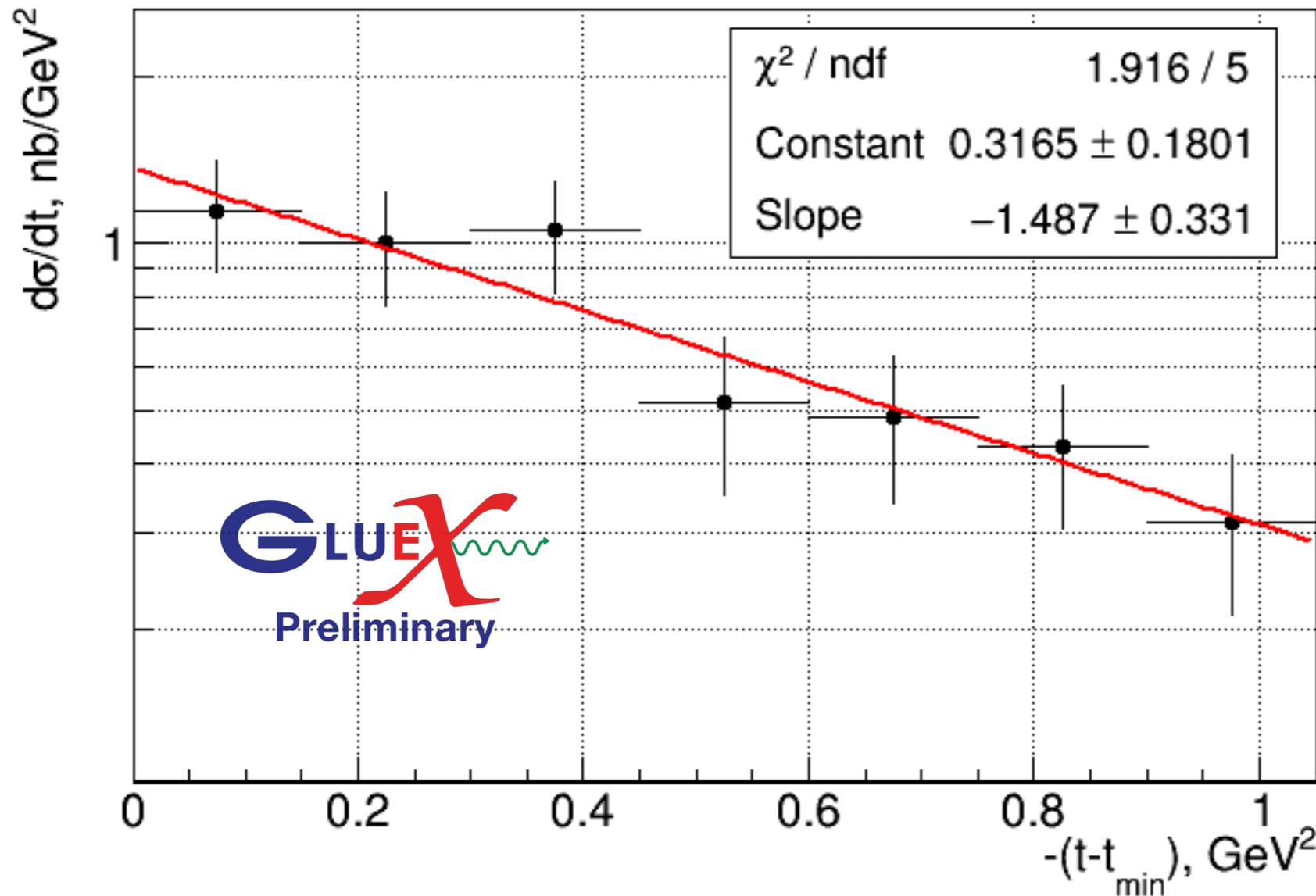


# J/ψ @ GlueX: Cross sections vs. theory



- Evidence for higher-order processes near threshold

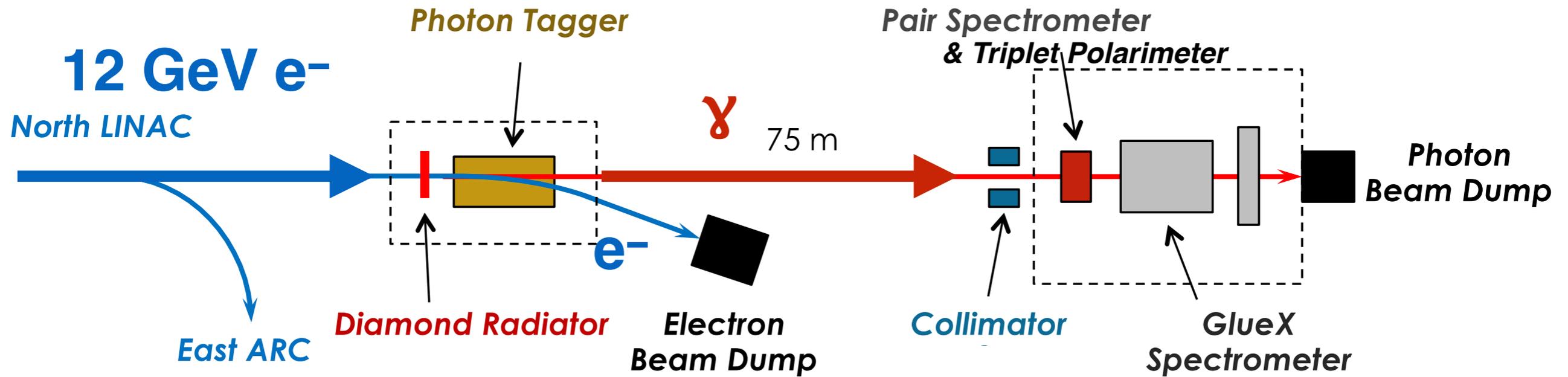
# J/ψ @ GlueX: t-slope



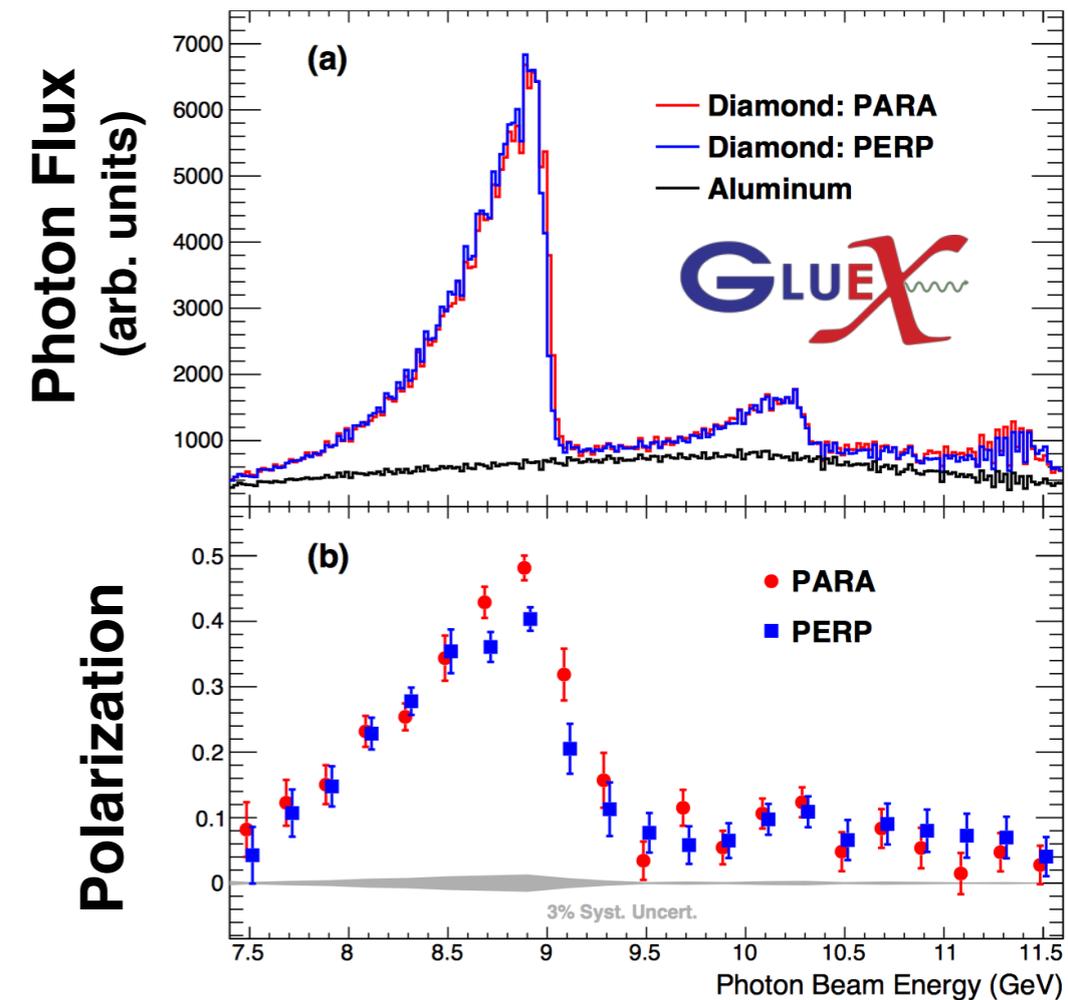
## Measurements near threshold

- Cornell at ~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

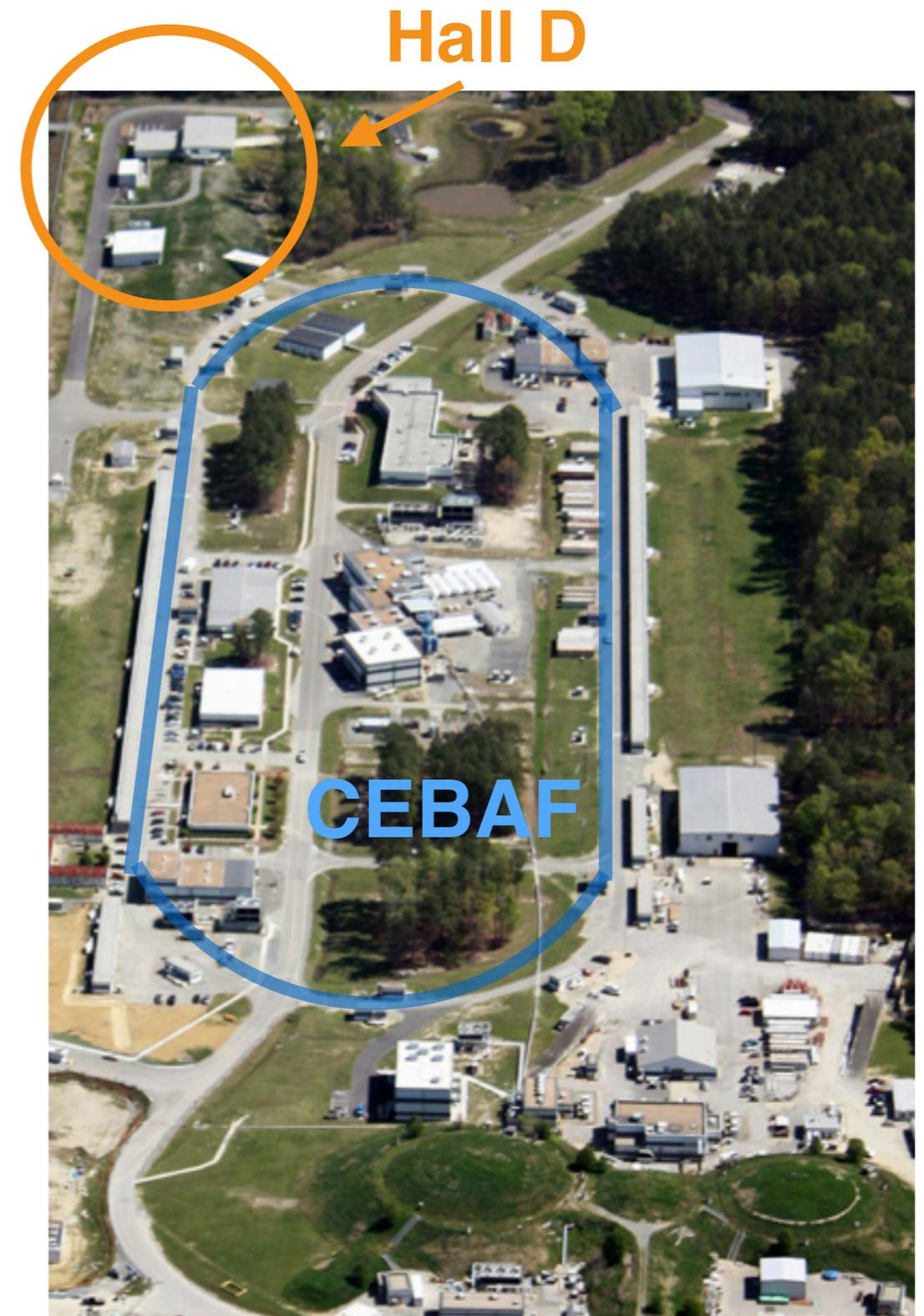


- Photon beam generated via coherent bremsstrahlung off thin diamond radiator
- Photon energies tagged by scattered electrons
  - Energy measurement precision  $< 25$  MeV
- Photon linear polarization  $P_\gamma \sim 40\%$  in peak
- Intensity of  $\sim 1-5 \times 10^7$   $\gamma/s$  in peak



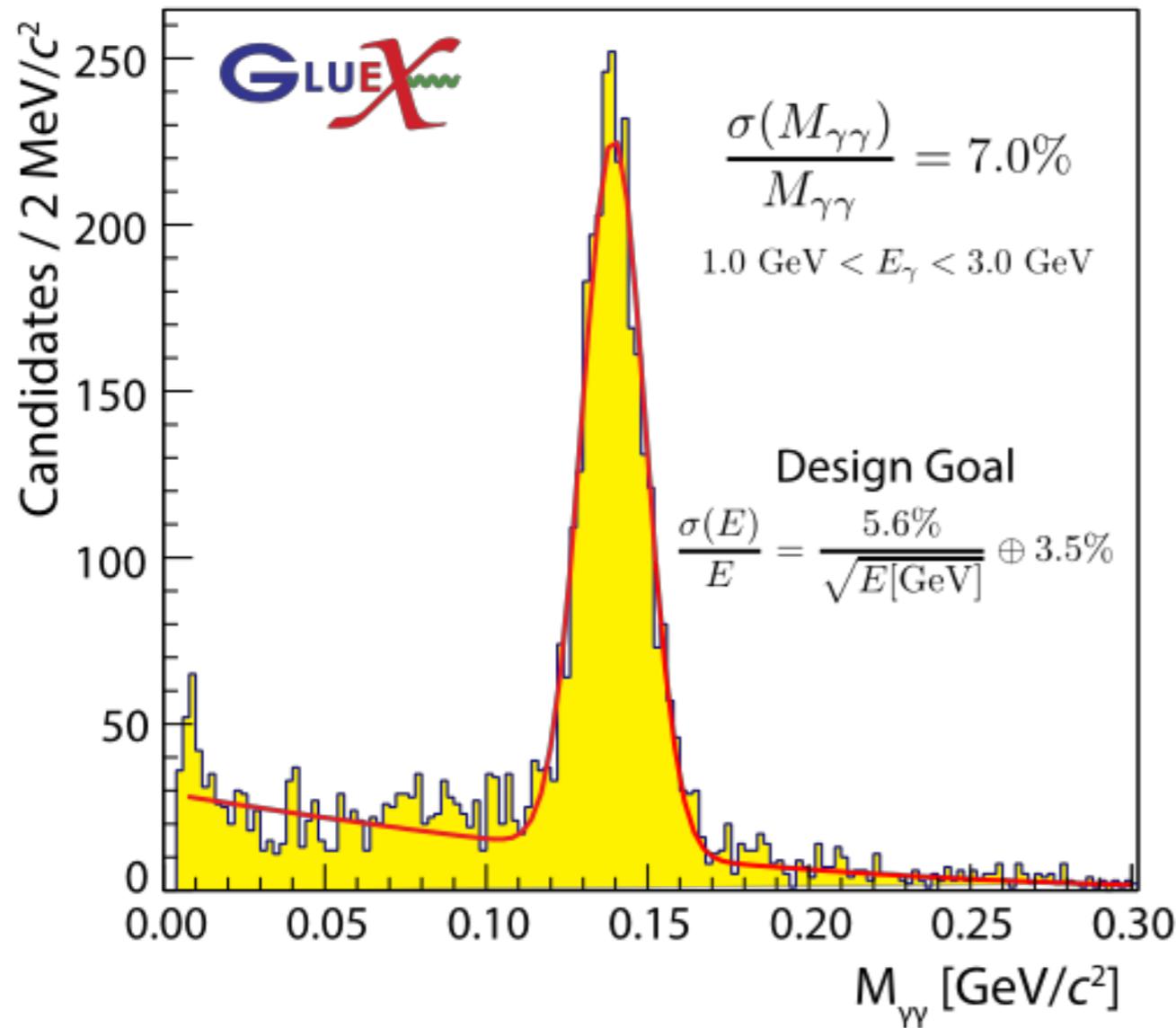
# The GlueX Experiment in Hall D @ JLab

- 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

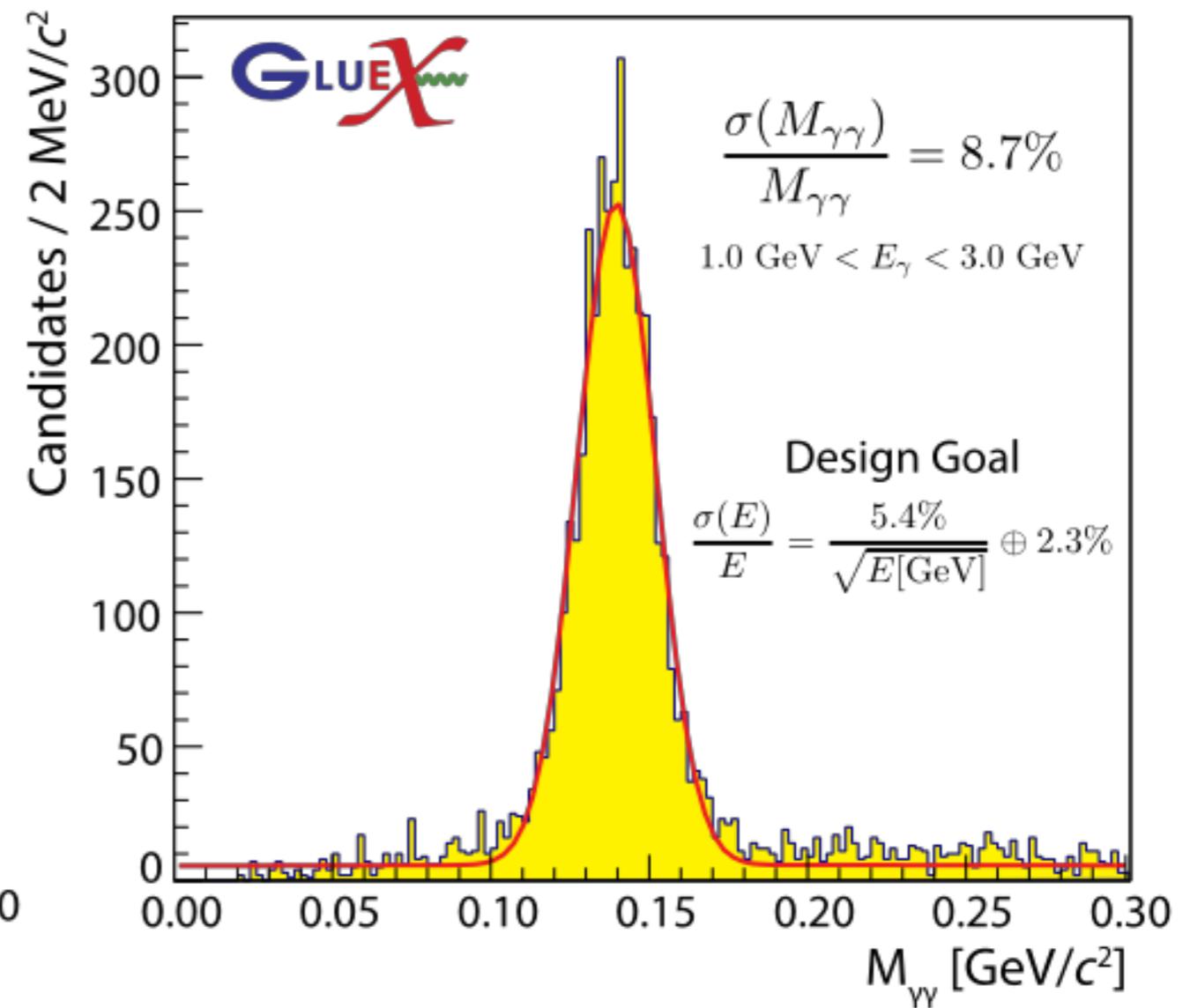


# GlueX Calorimetry Performance

Forward Lead Glass Calorimeter

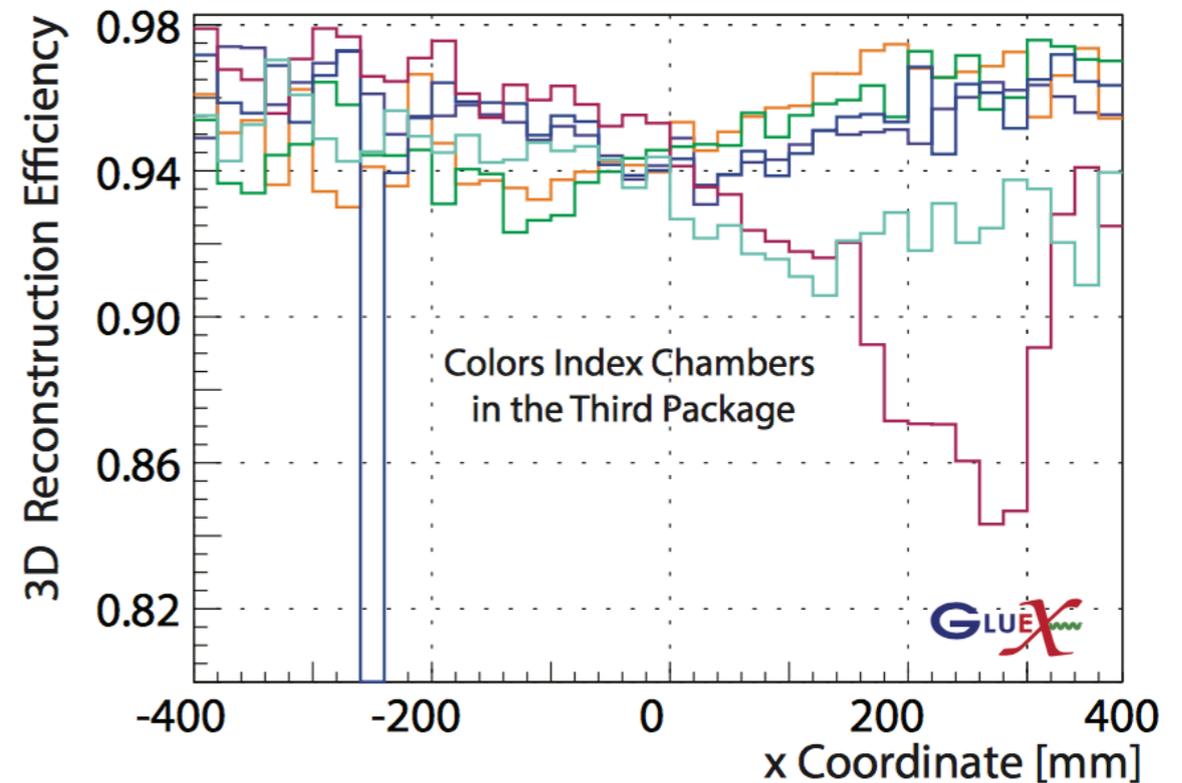
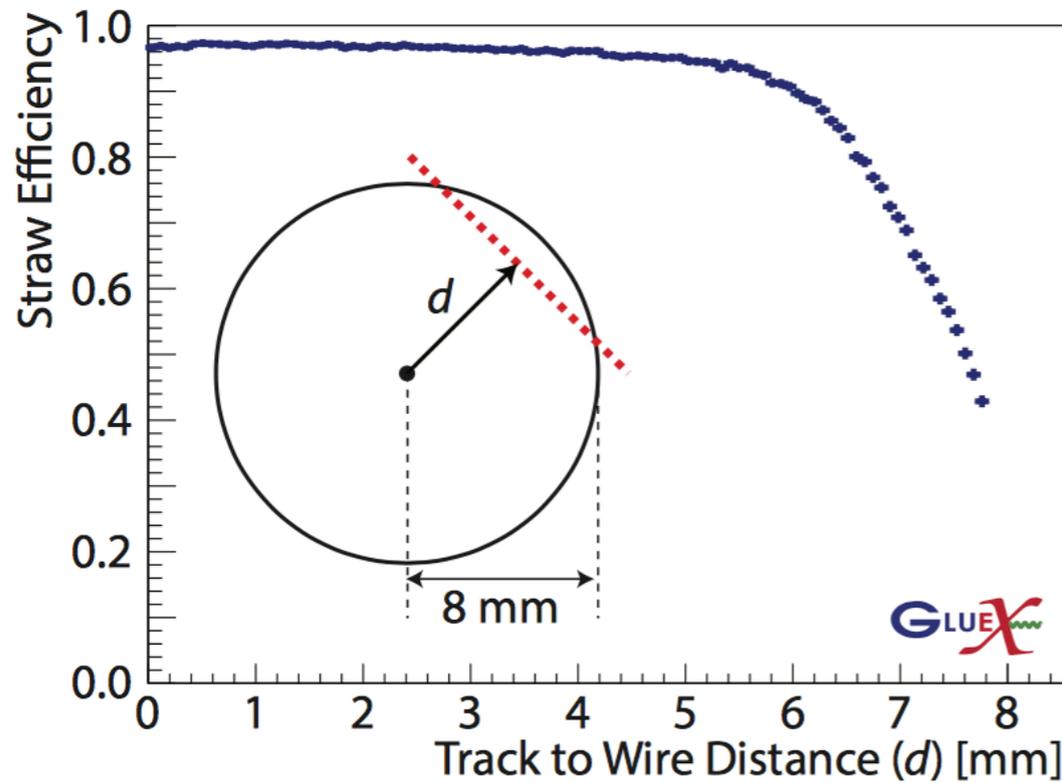
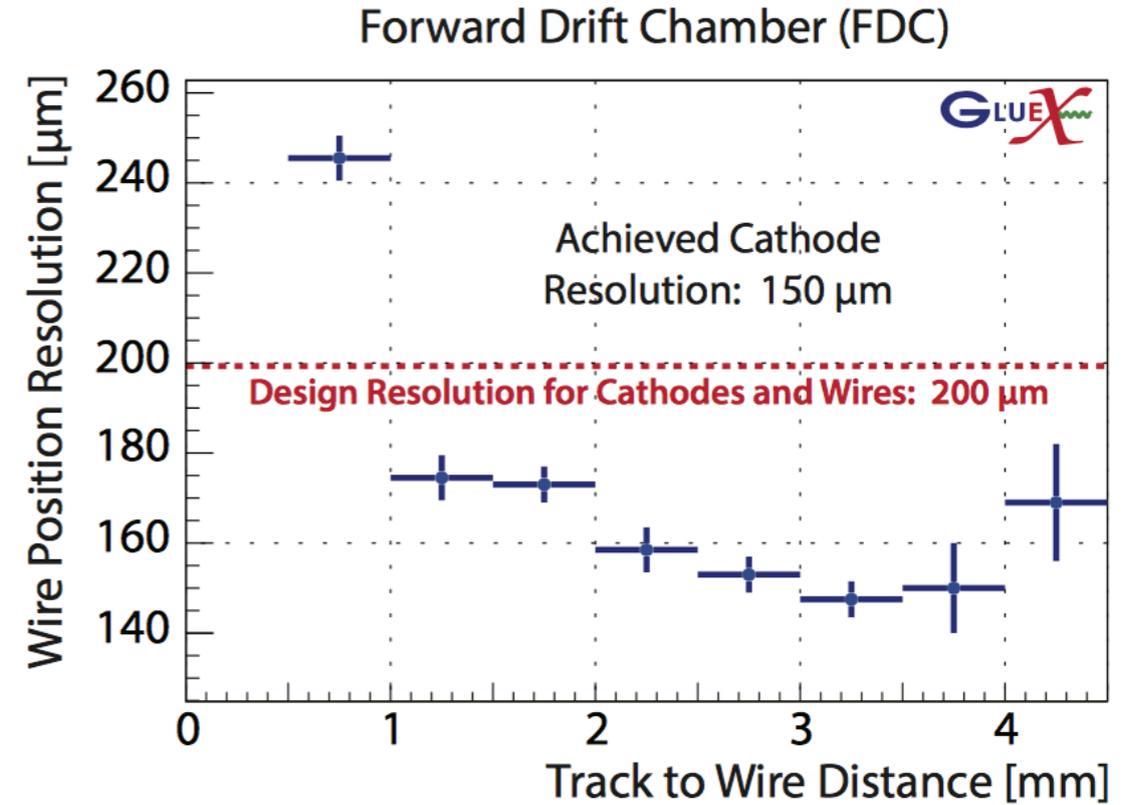
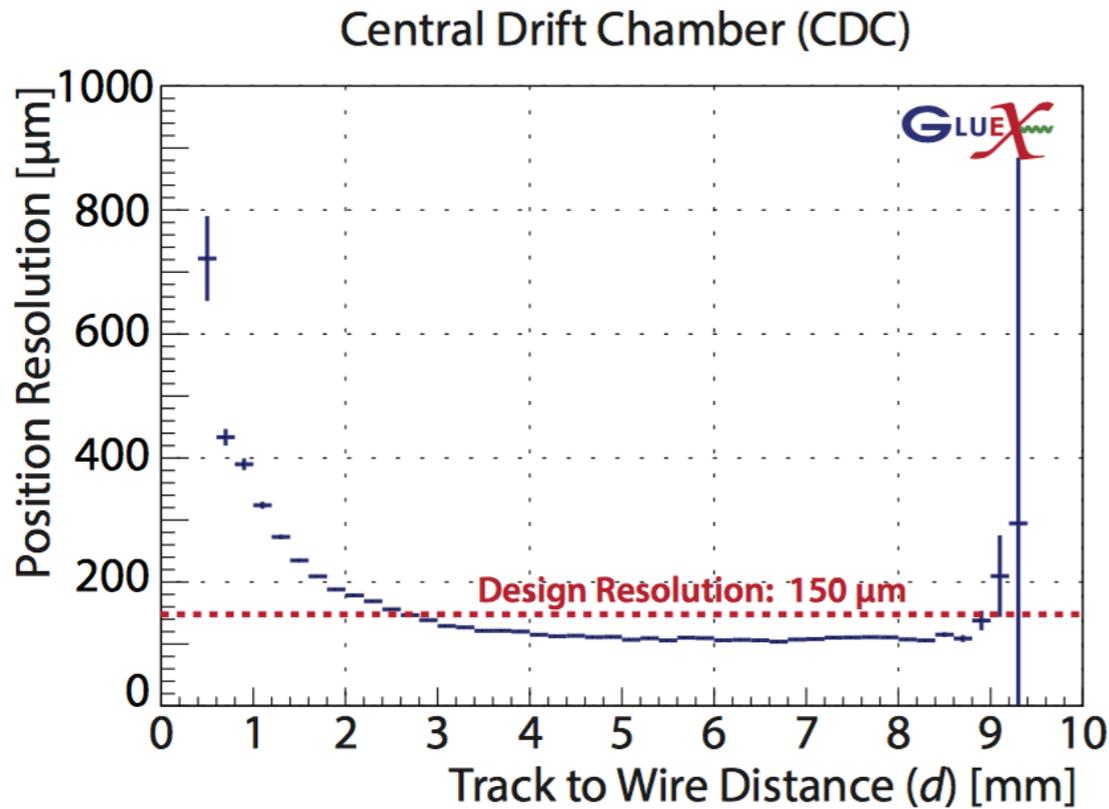


Barrel Lead-Scintillating Fiber Calorimeter



Measured using  $\gamma p \rightarrow p \gamma \gamma \gamma \gamma$  events

# GlueX Tracking Performance



# GlueX Particle ID Performance

