

Photoproduction of Cascade baryons and Charmonia at

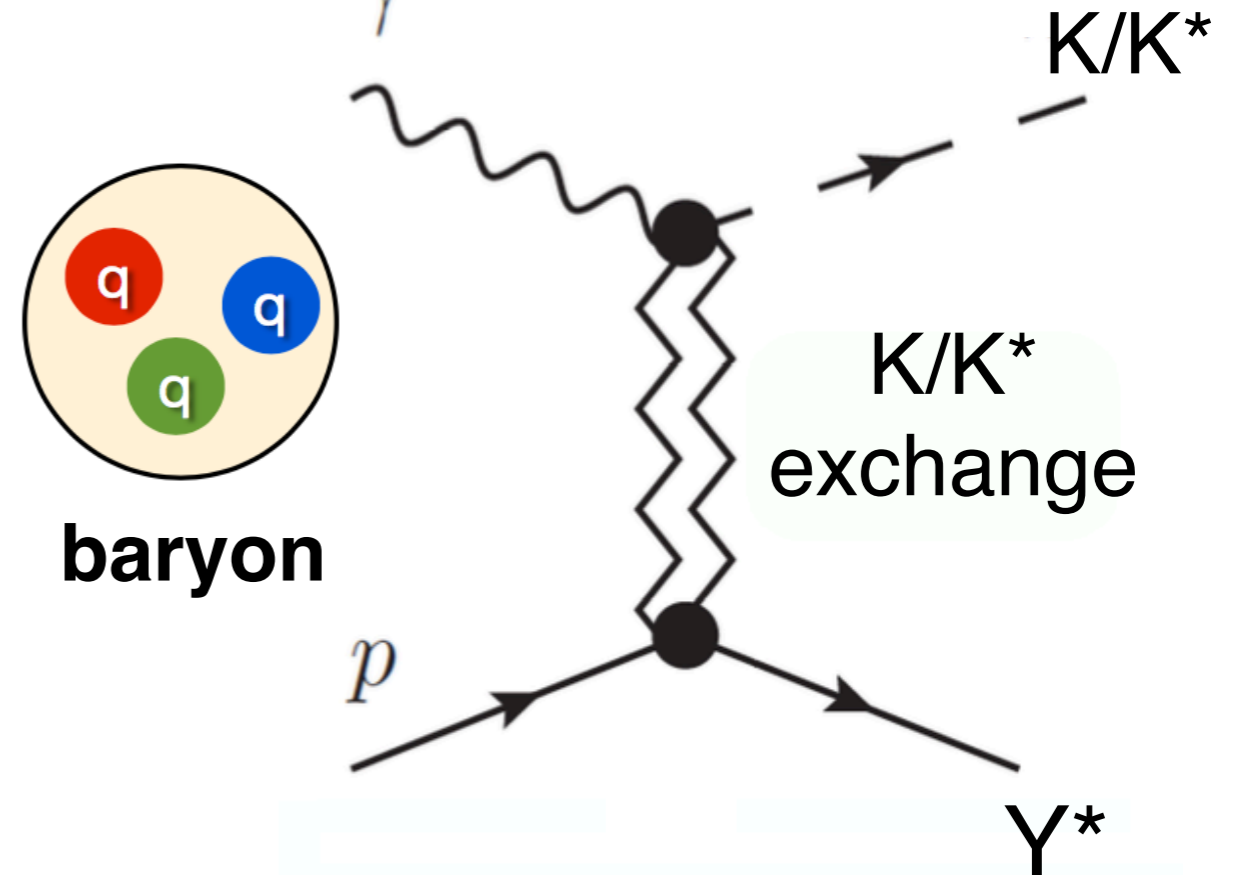
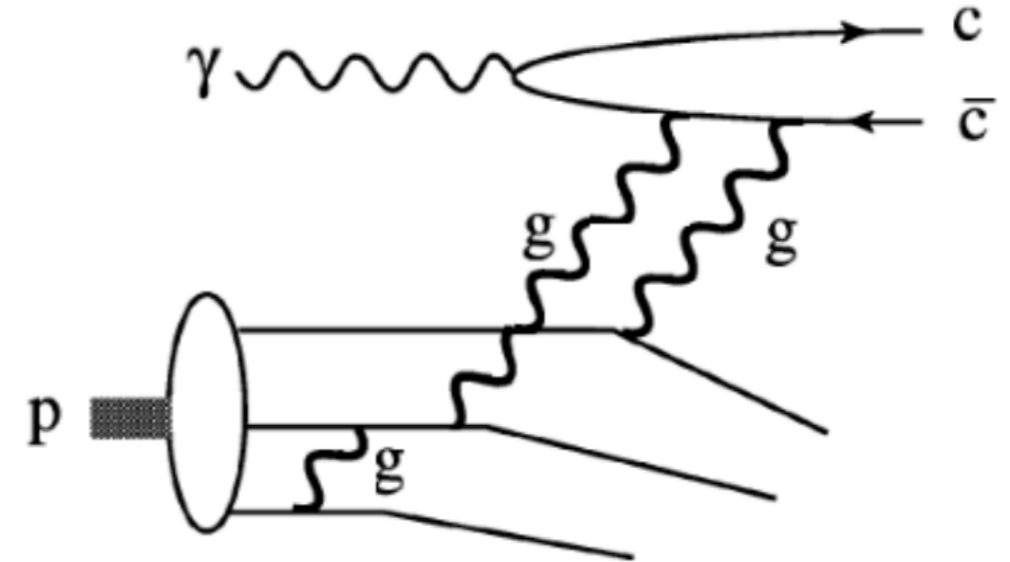
Sean Dobbs
Florida State U.

NSTAR2024
June 21, 2024



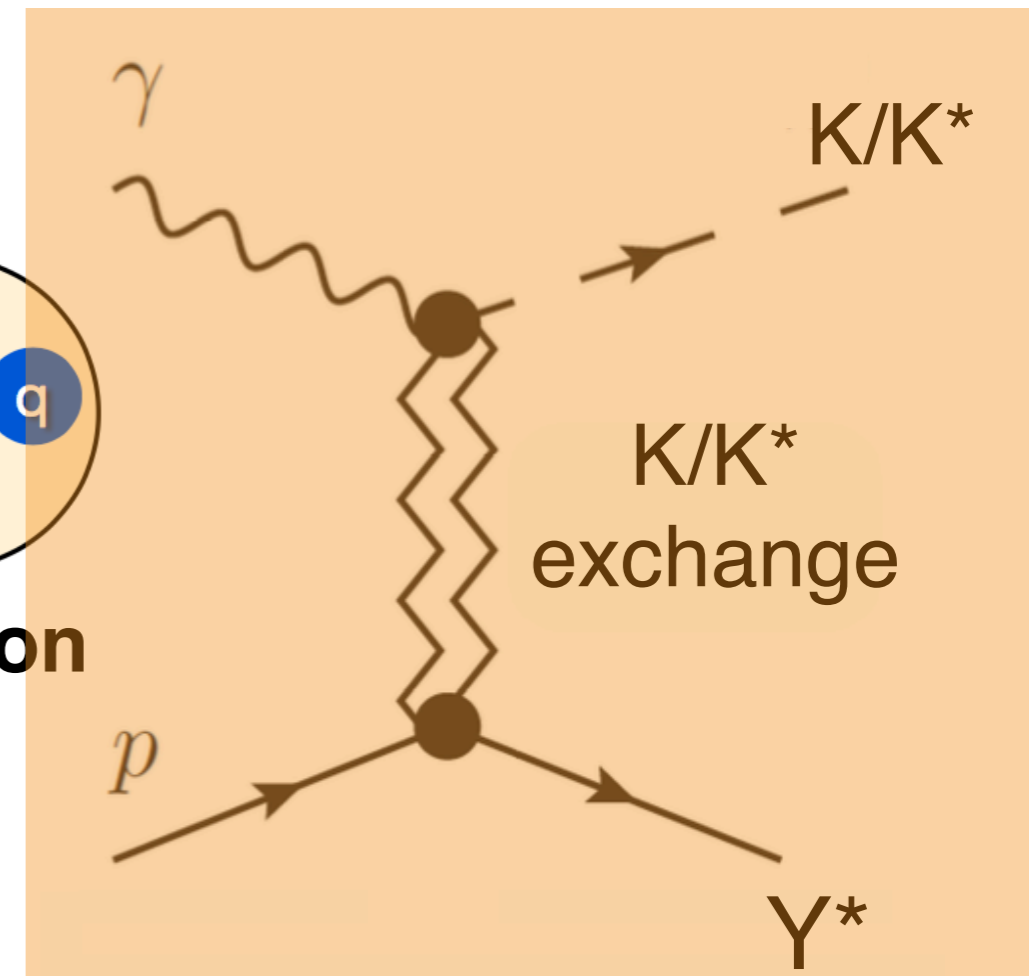
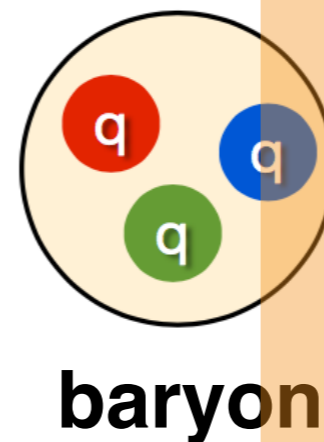
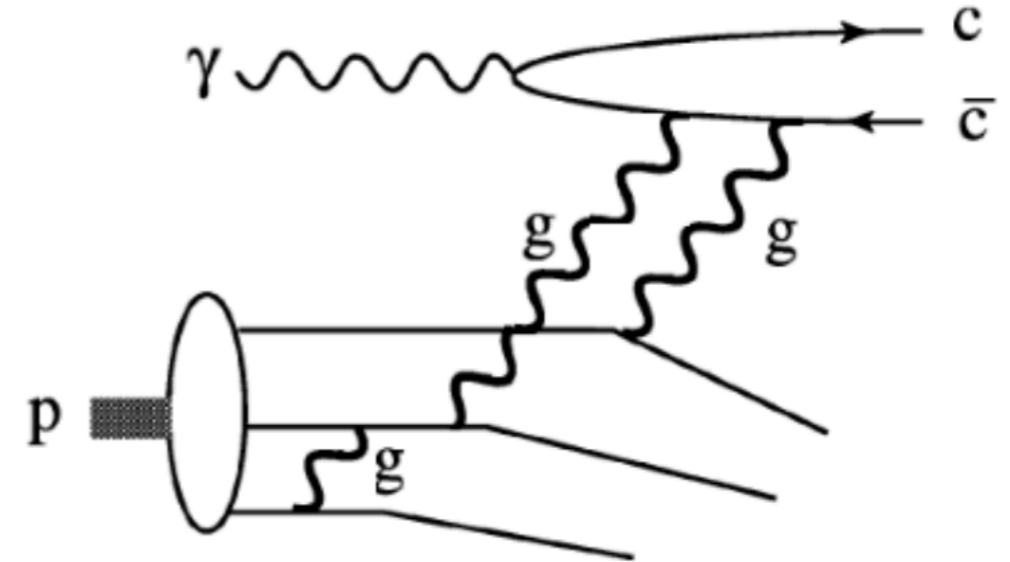
Baryons in Photoproduction at GlueX

- Baryons are fundamental 3-body QCD system
- Open questions about baryons include:
 - What is the spectrum of excited baryons?
(N , Δ , Λ , Σ , Ξ , Ω)
 - What is the internal structure of the nucleon? What role do **gluons** play?
- Photoproduction can shed light on to these questions
 - Intense beams give access to rare processes
 - Polarized photons give insight to production processes
 - Other GlueX talks on Λ^* :
 - P. Hurck (Mon. @ 15:45)
 - R. Schumacher (Tue. @ 14:00)



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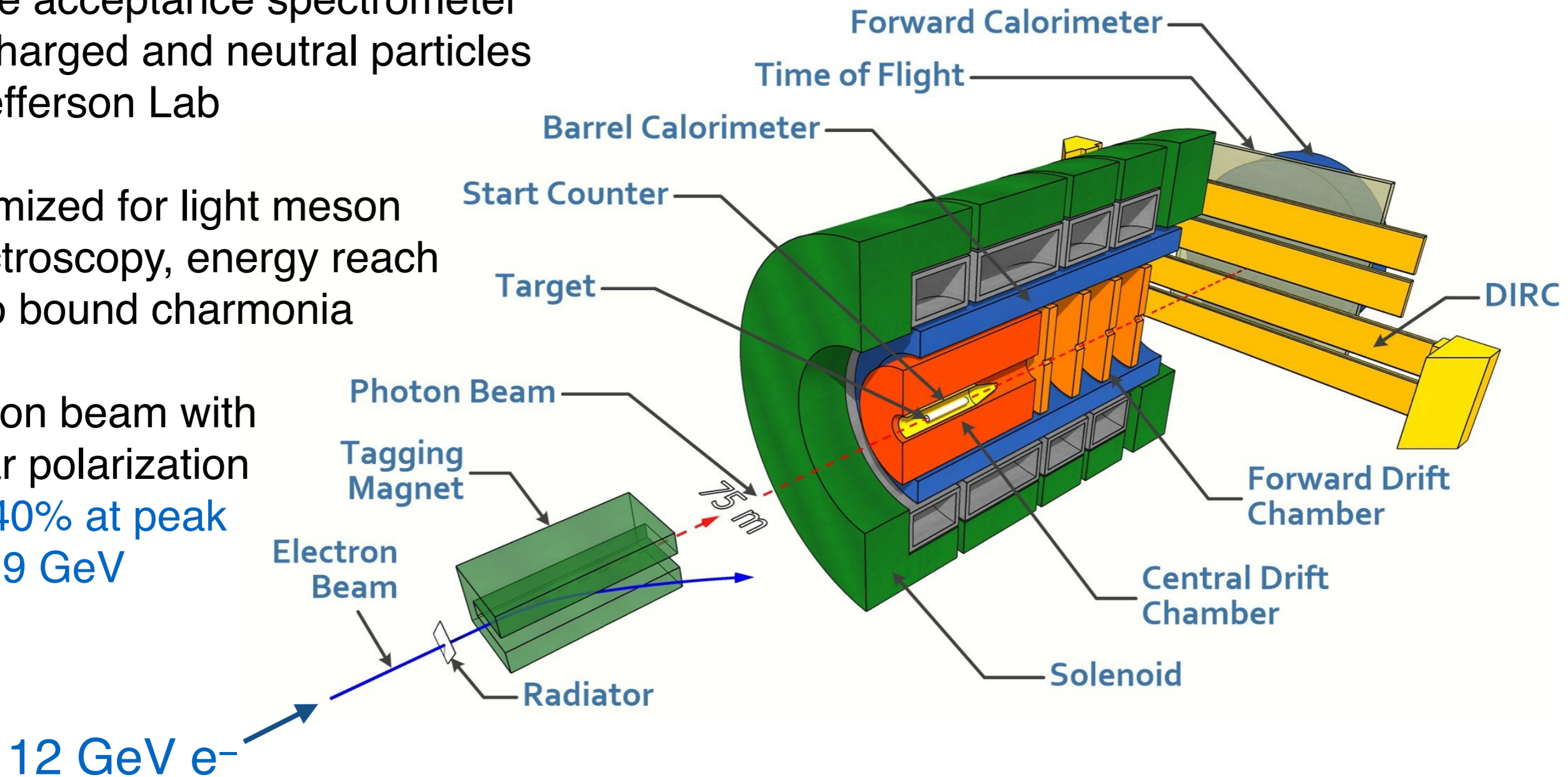


The GlueX Experiment

Large acceptance spectrometer for charged and neutral particles at Jefferson Lab

Optimized for light meson spectroscopy, energy reach up to bound charmonia

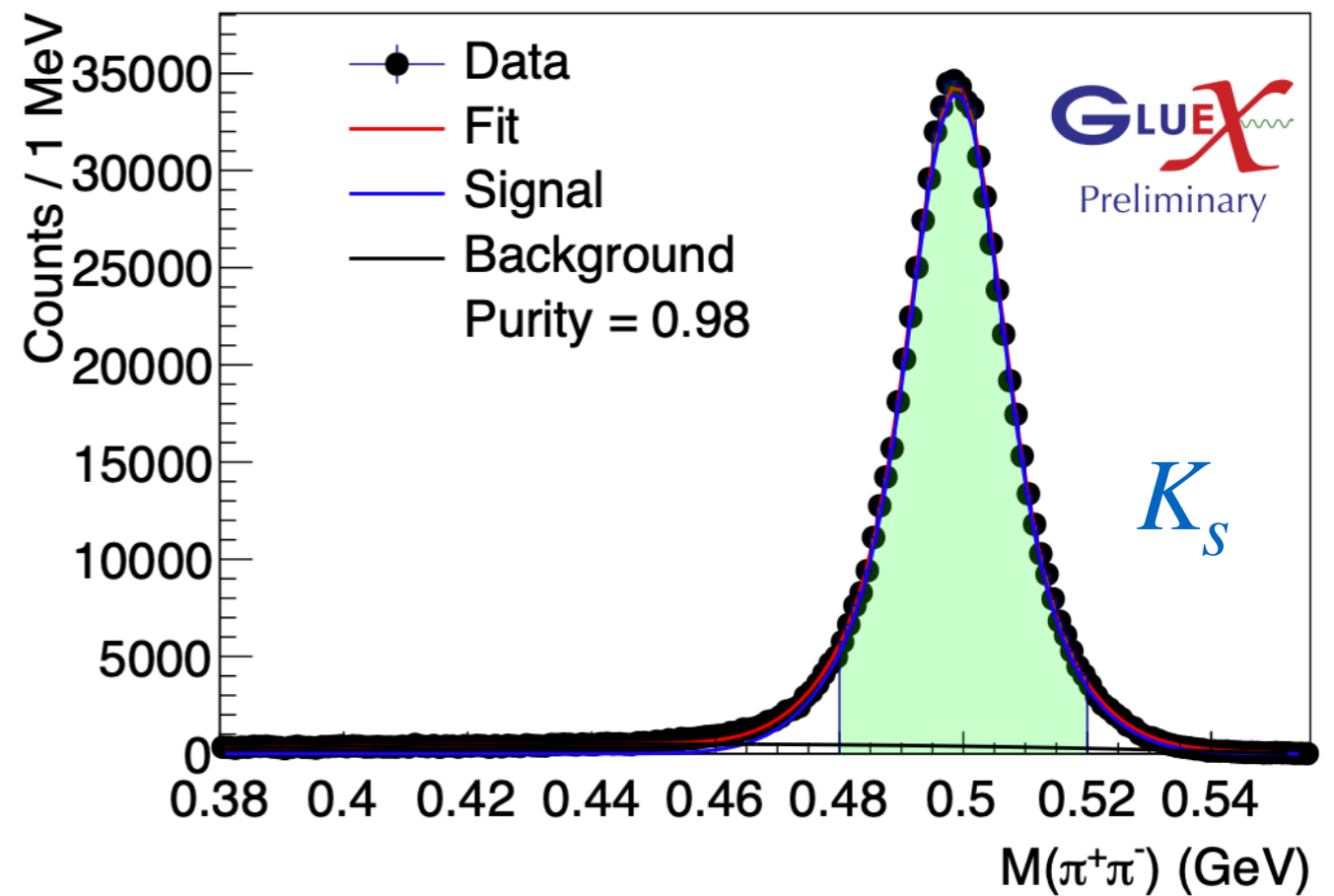
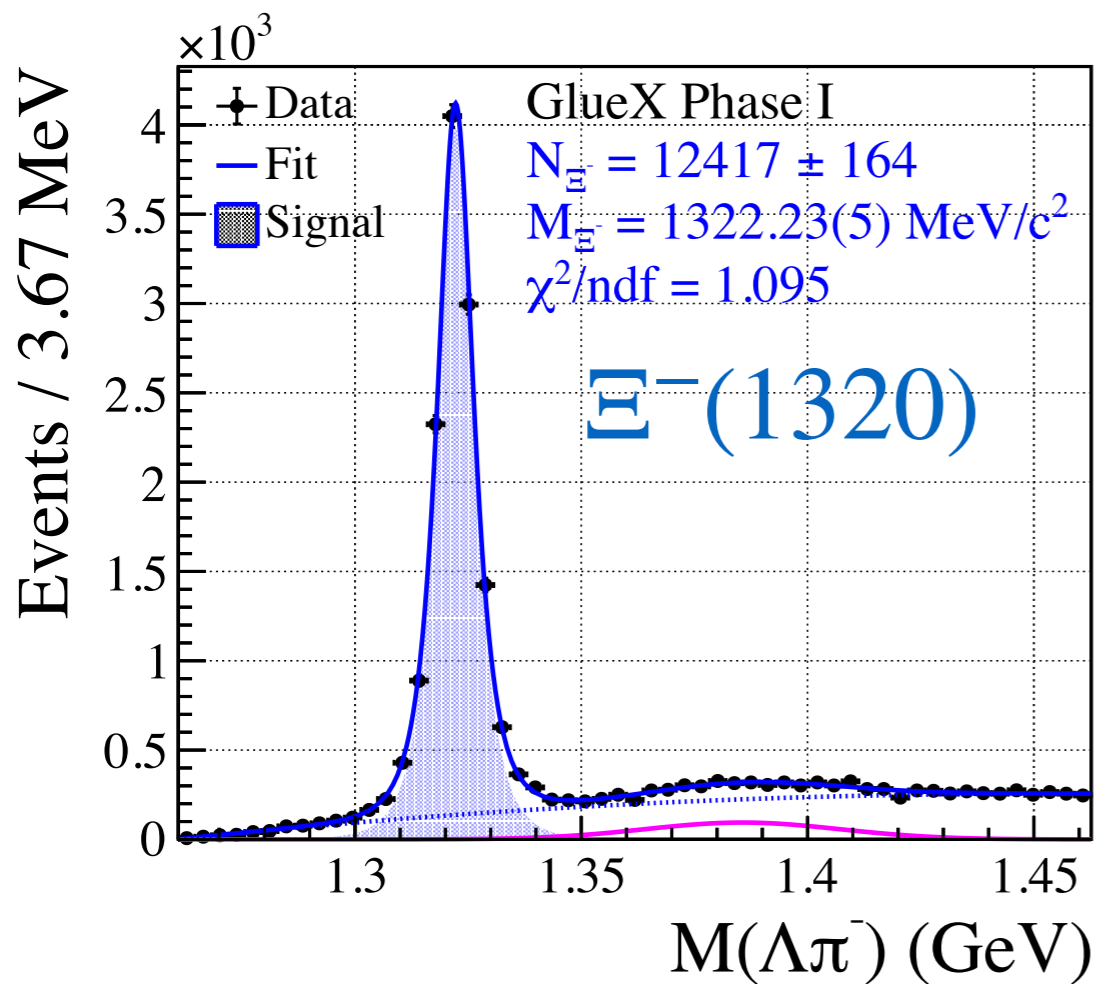
Photon beam with linear polarization $P \approx 40\%$ at peak $E_\gamma \approx 9$ GeV



- **GlueX-I (2017–2018):** $E_\gamma = 8–11.4$ GeV, $L = 330$ pb $^{-1}$ [$E_\gamma > 8$ GeV]
- **GlueX-II (2020–):** expect $L=3–4x$ GlueX-I, $E_{\gamma,max} = 11.2 \rightarrow 11.8?$ GeV

The GlueX Experiment

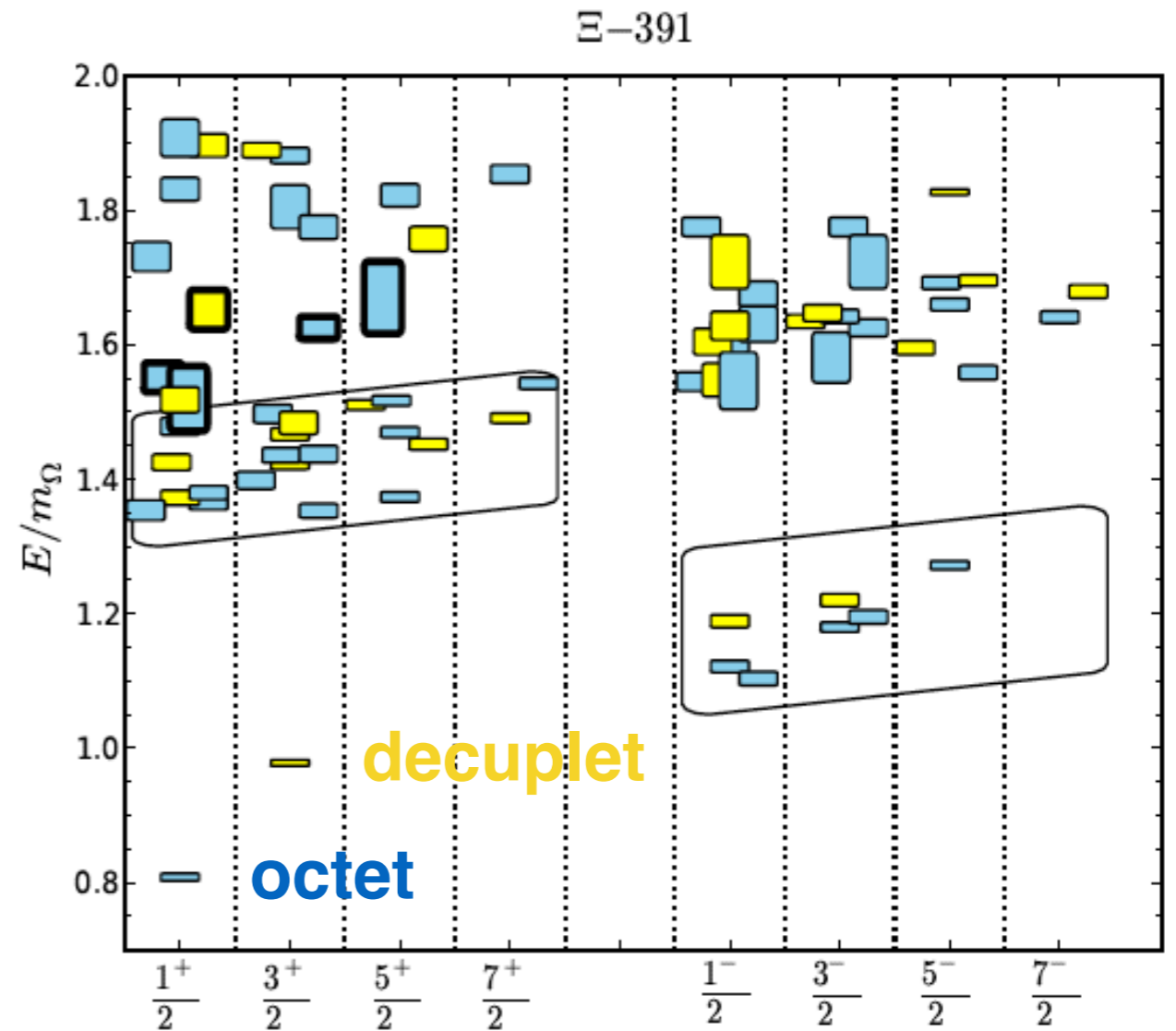
Excellent ability to reconstruct weakly-decaying particles in exclusive reactions



Status of the Cascade Spectrum

- Most Ξ (ssn) with $M < 2$ GeV expected to be narrow ($\Gamma < 25$ MeV)
- Patterns of decay branchings can give insight into internal structure

Particle	J^P	Overall status	Seen in	
			$\Xi\pi$	ΛK
$\Xi(1318)$	$1/2^+$	****		
$\Xi(1530)$	$3/2^+$	****	****	
$\Xi(1620)$	$1/2^-?$	**	**	
$\Xi(1690)$	$1/2^-?$	***	**	***
$\Xi(1820)$	$3/2^-$	***	**	***
$\Xi(1950)$	$3/2^-?$	***	**	**
$\Xi(2030)$	$5/2^-?$	***		**

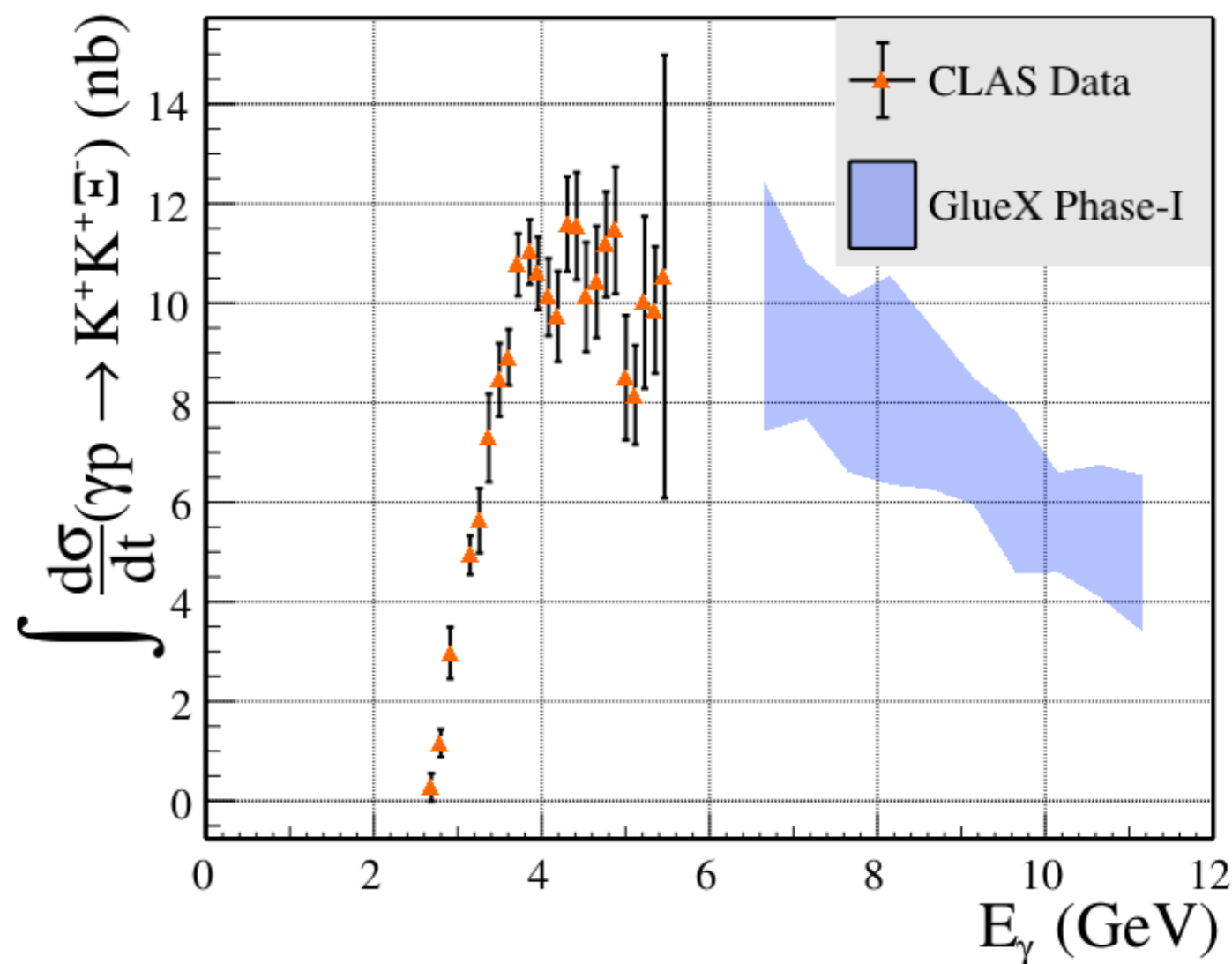
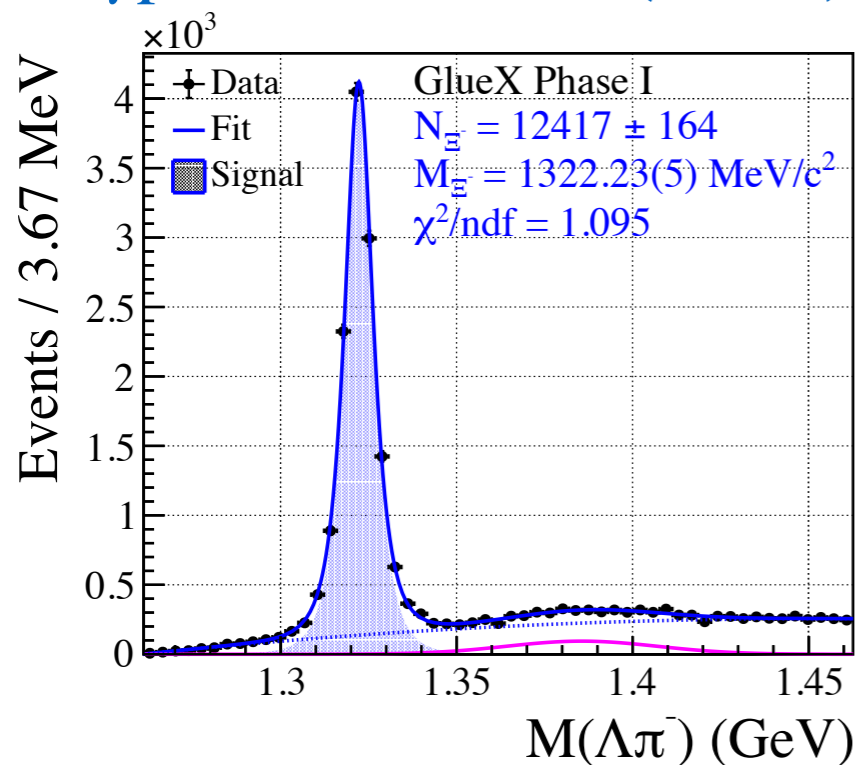
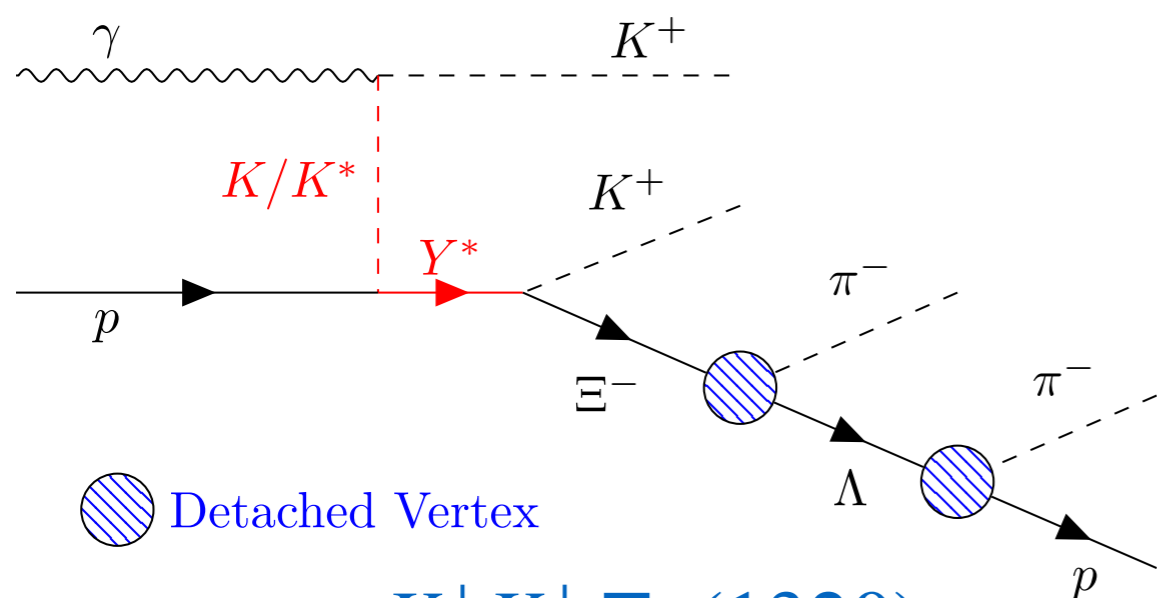


HadSpec, PRD 87, 054506 (2013)

PDG 2024

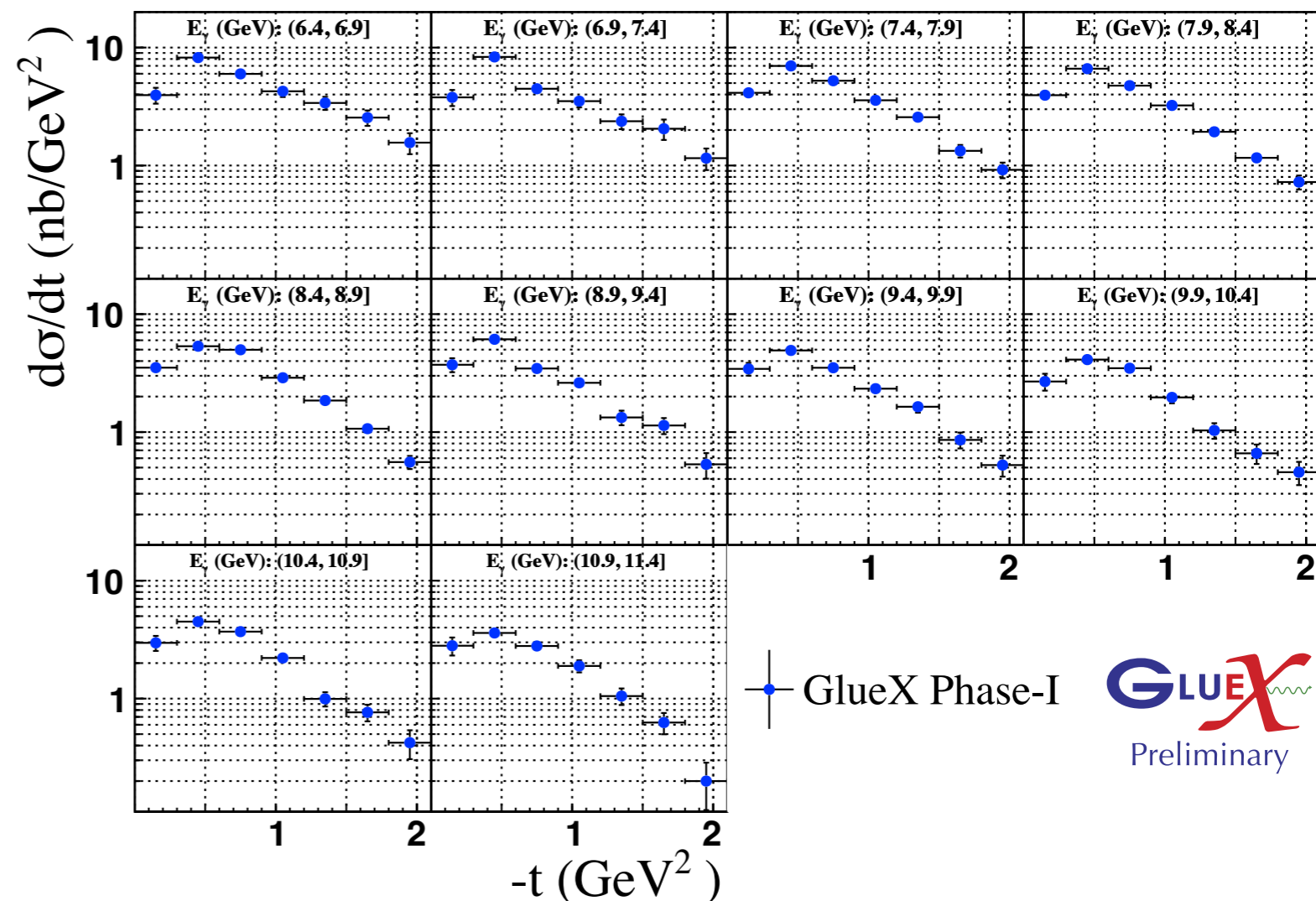
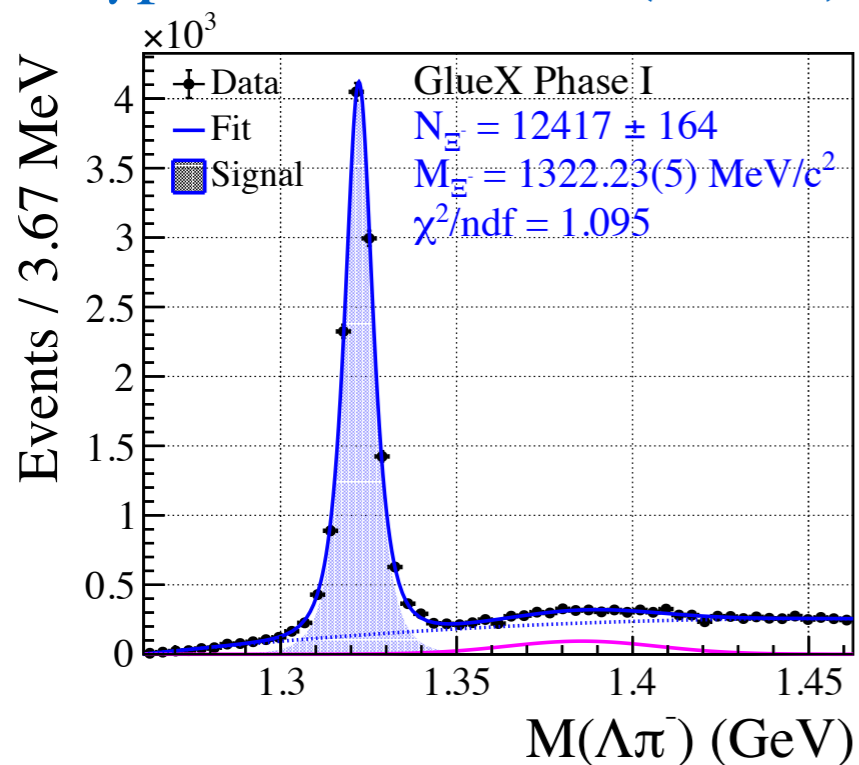
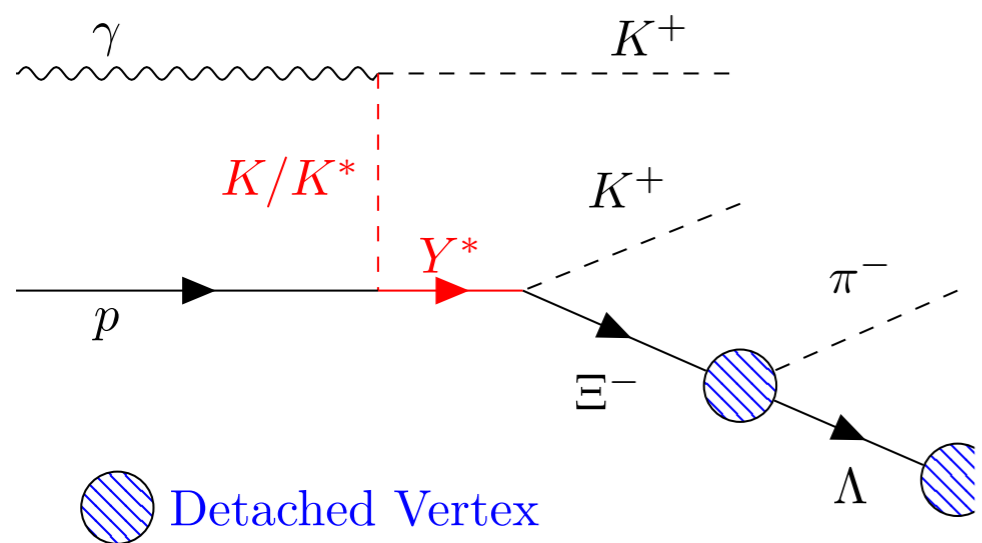
$\Xi^-(1320)$ Photoproduction

- Detailed $\Xi^-(1320)$ cross section measurements provide baseline for Ξ program, insight into Y^* contributions



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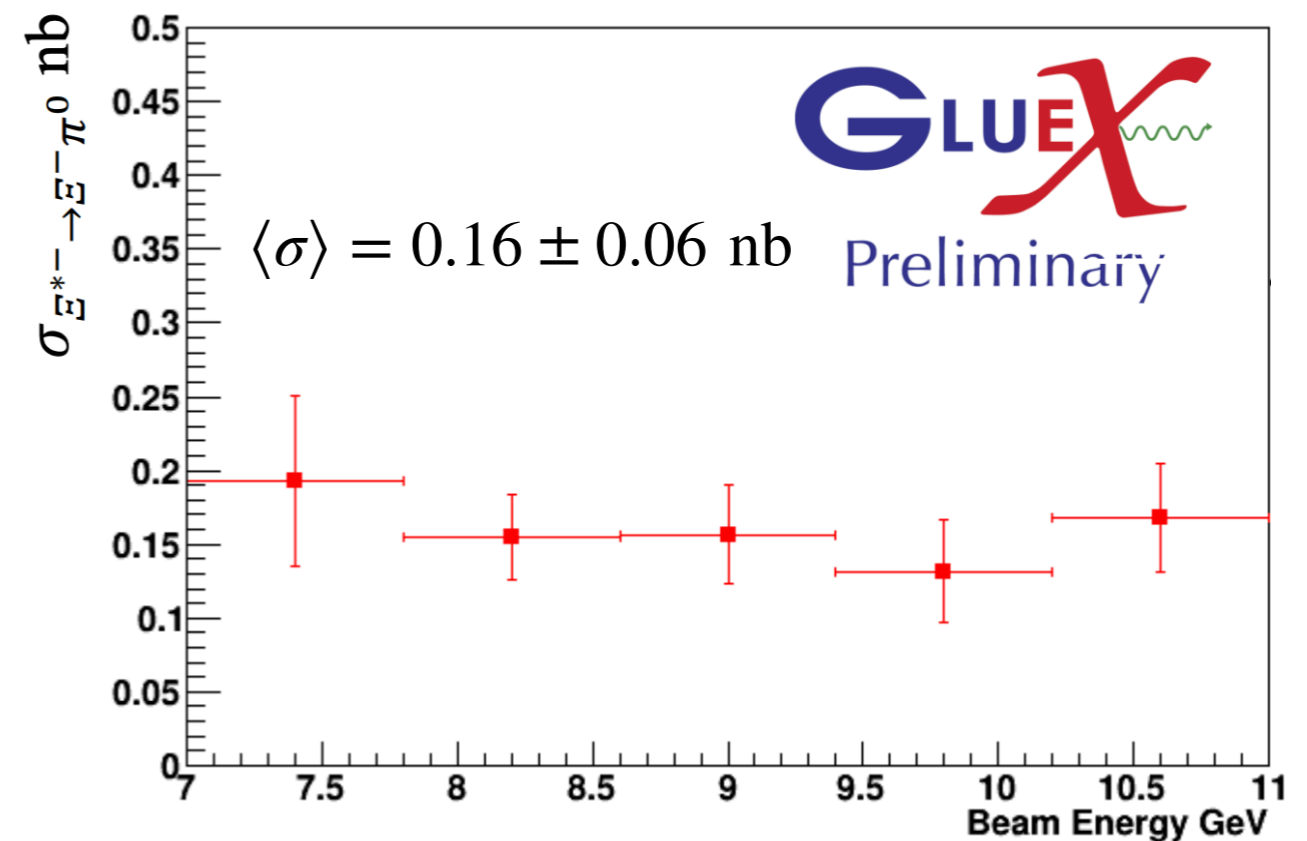
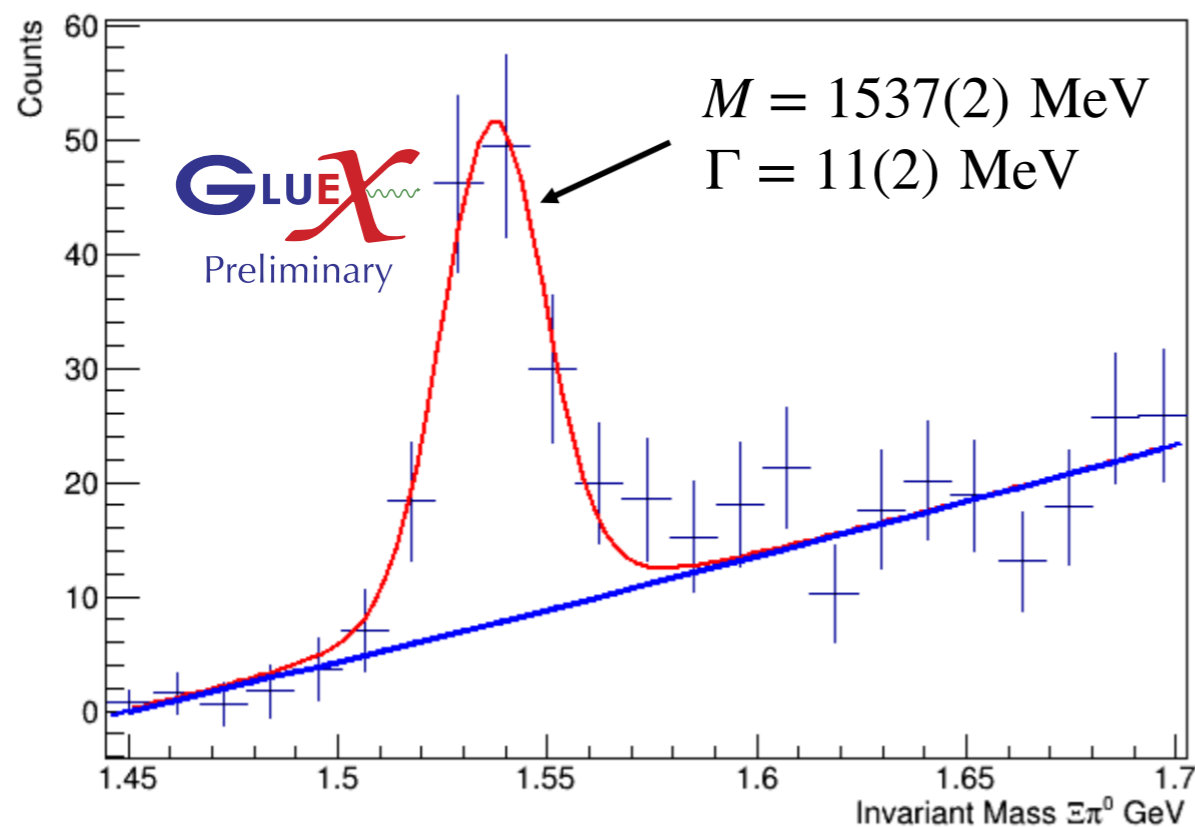


Inputs to photoproduction models!

$\Xi^-(1530)$ Photoproduction

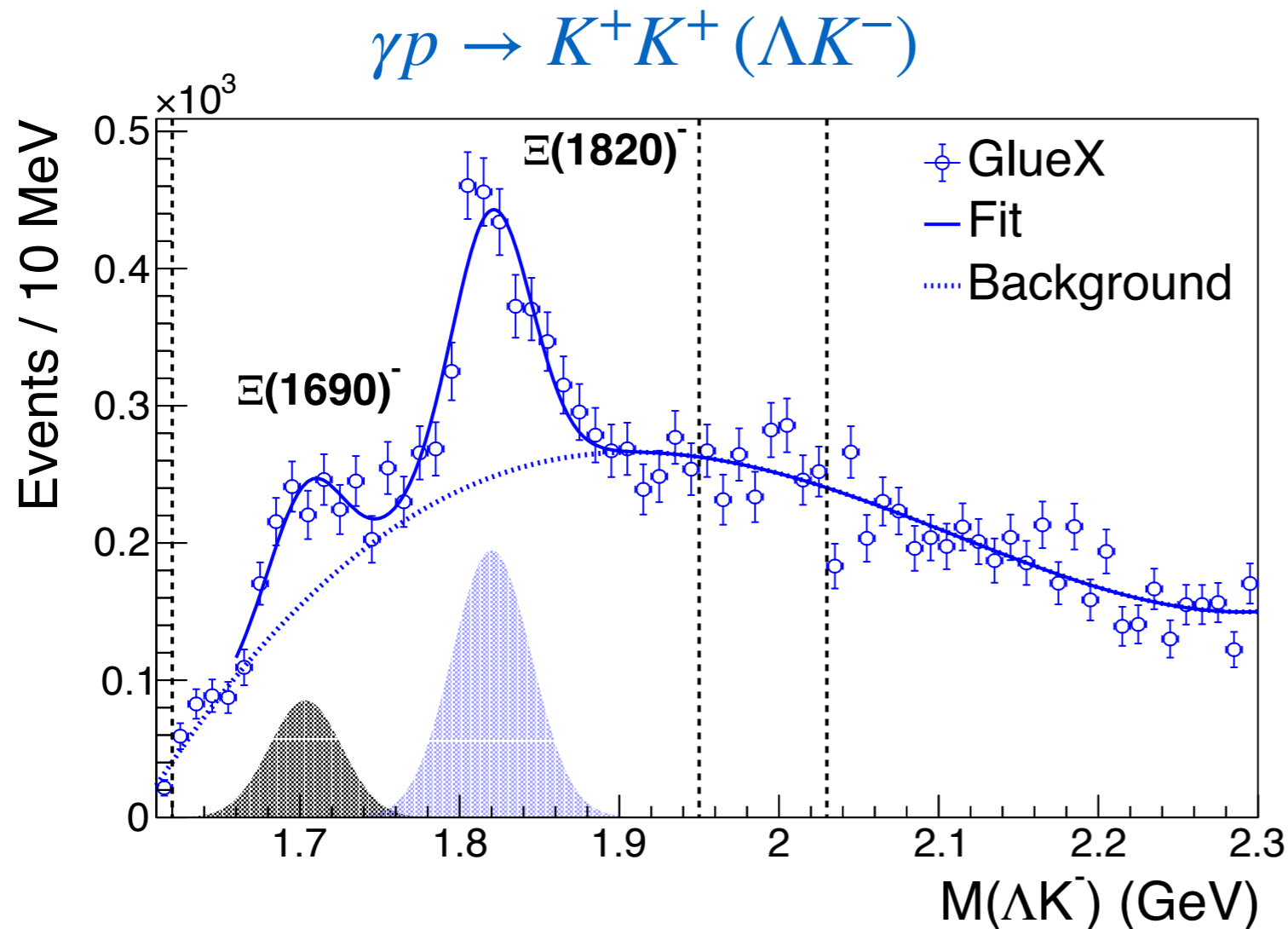
- Ground state decuplet $\Xi(1530)$ measured with 50% GlueX-I data
- Cross section shows no significant energy dependence

$$\gamma p \rightarrow K^+ K^+ \Xi(1530)^-, \quad \Xi(1530)^- \rightarrow \Xi(1320)^- \pi^0$$

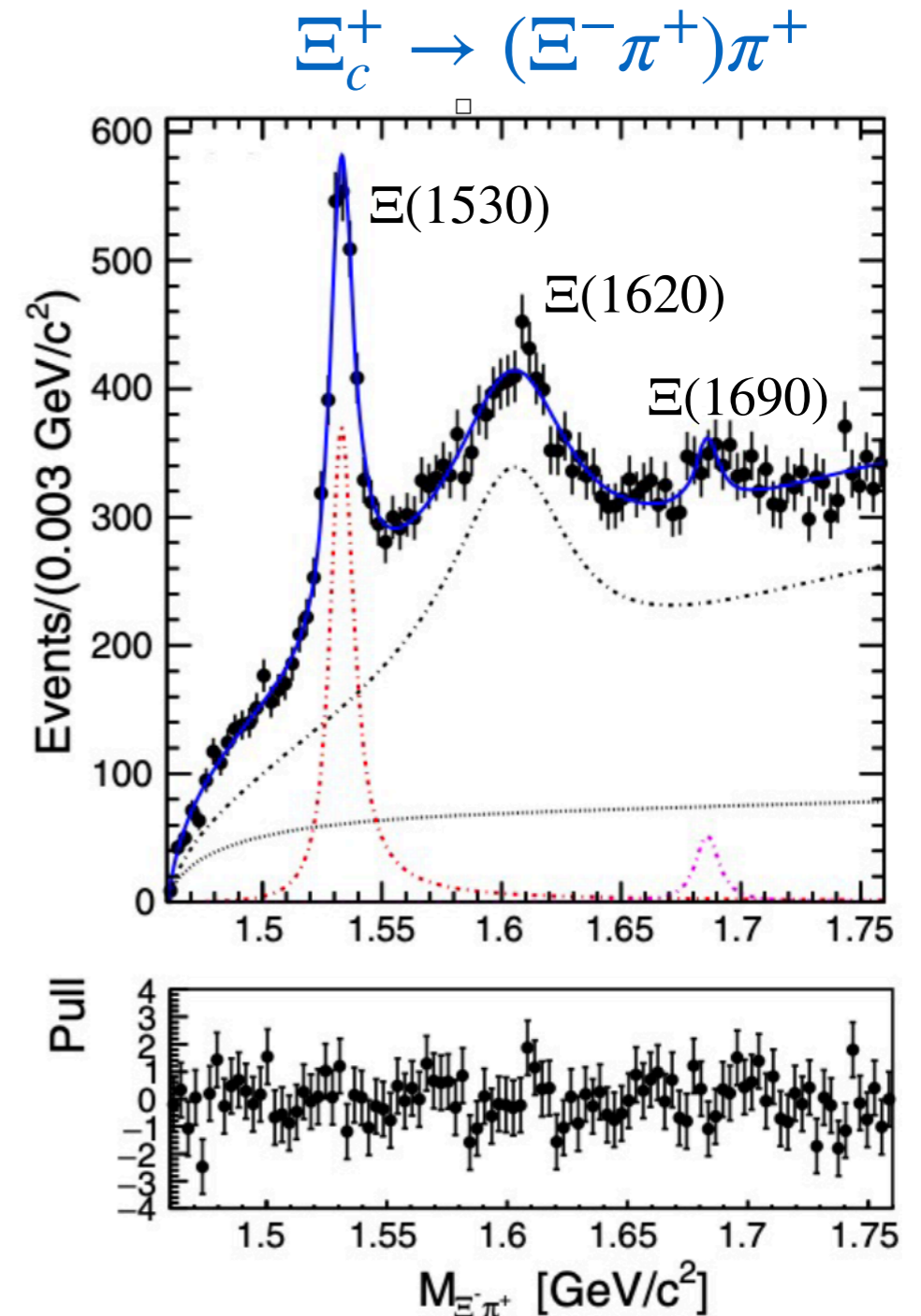


Hunting for Excited Cascades

- GlueX finds strong evidence for $\Xi(1690)$ and $\Xi(1820)$ in the ΛK channel



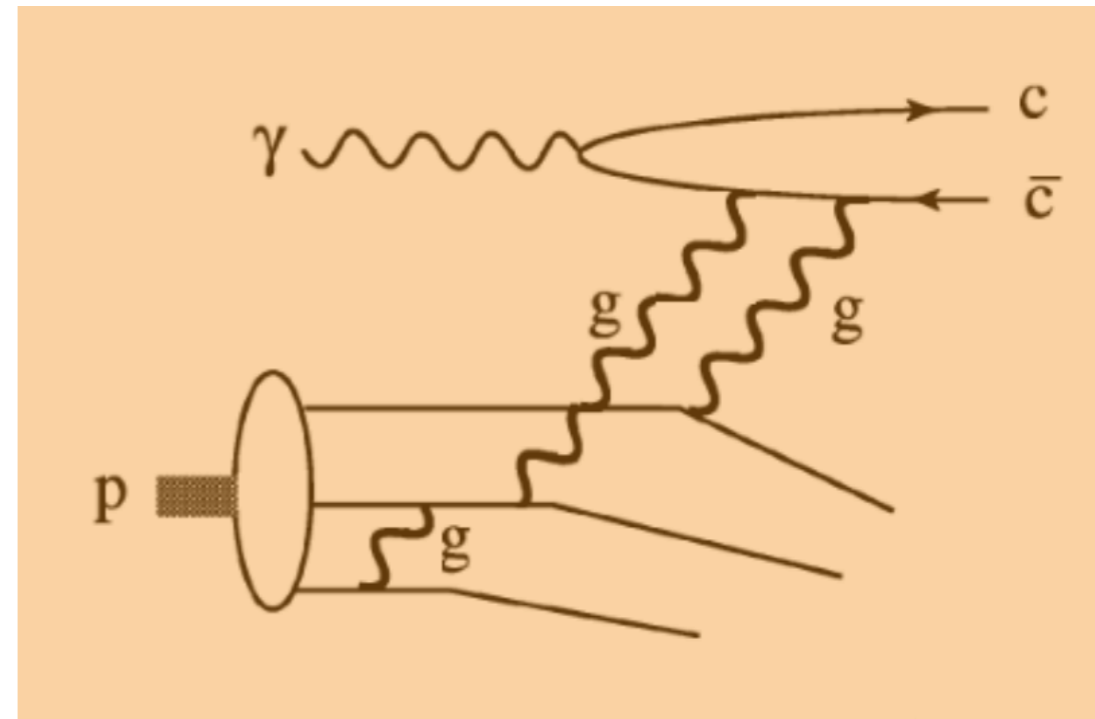
V. Crede and J. Yelton, submitted to Rep. Prog. Phys.



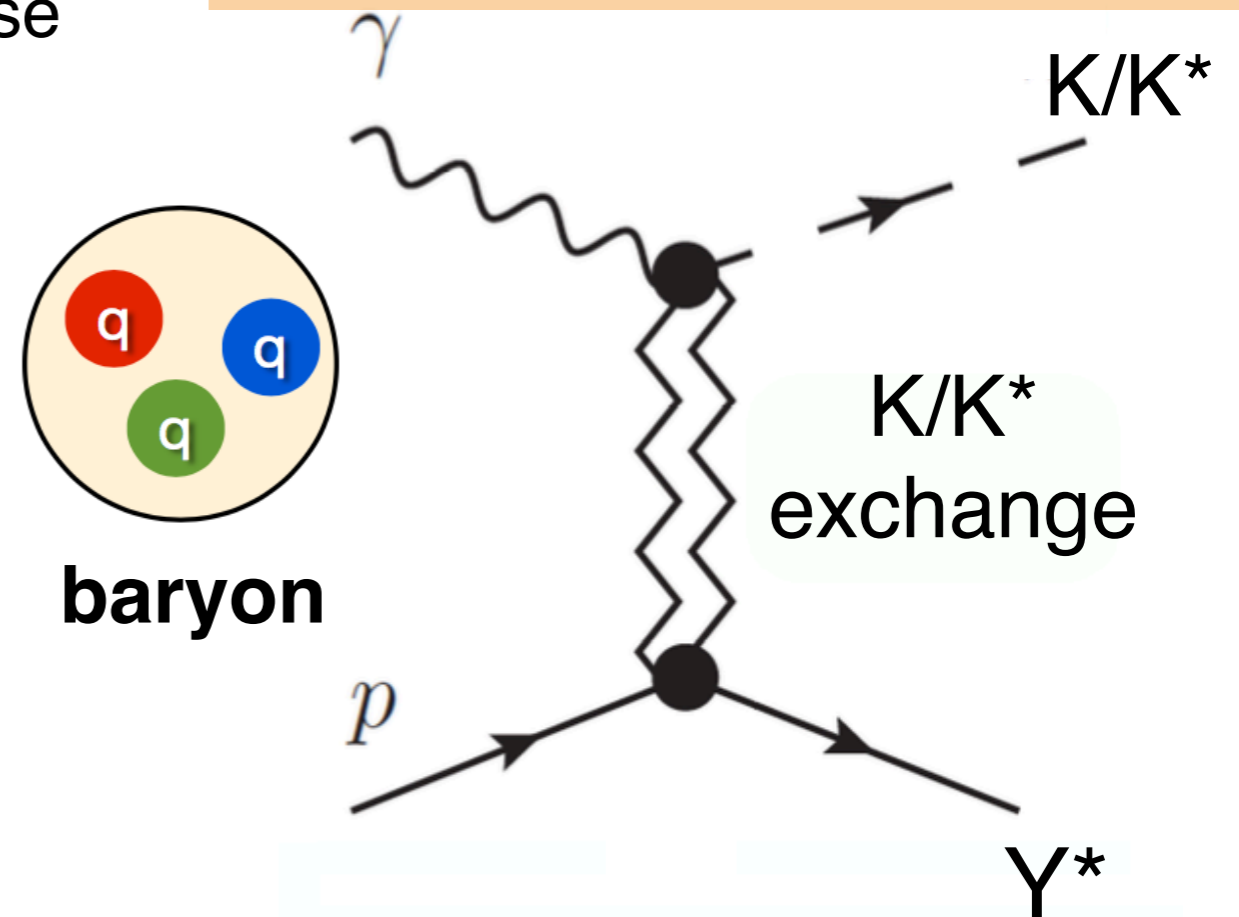
Belle, PRL 122, 072501 (2019)

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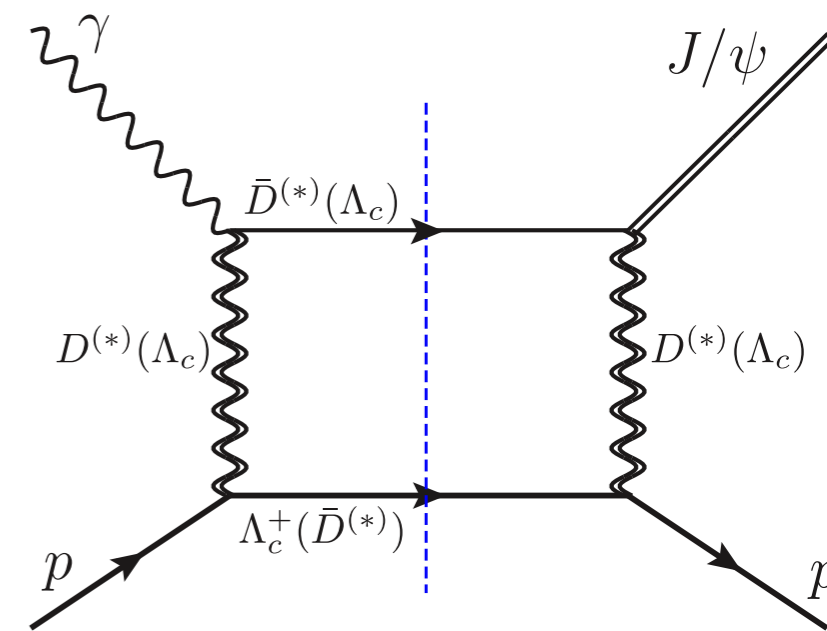
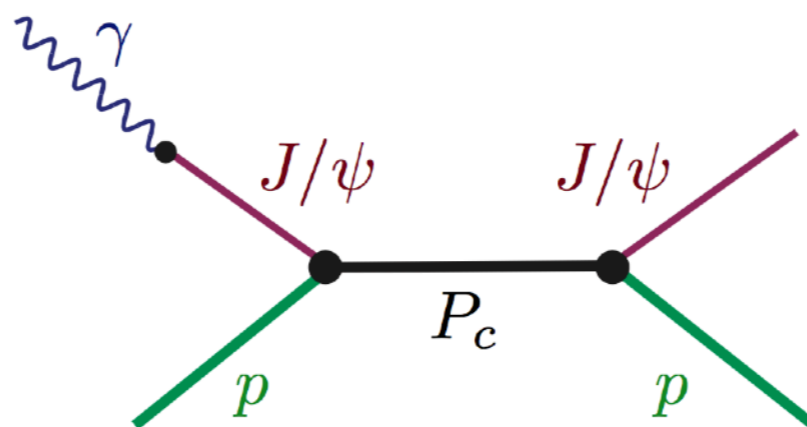
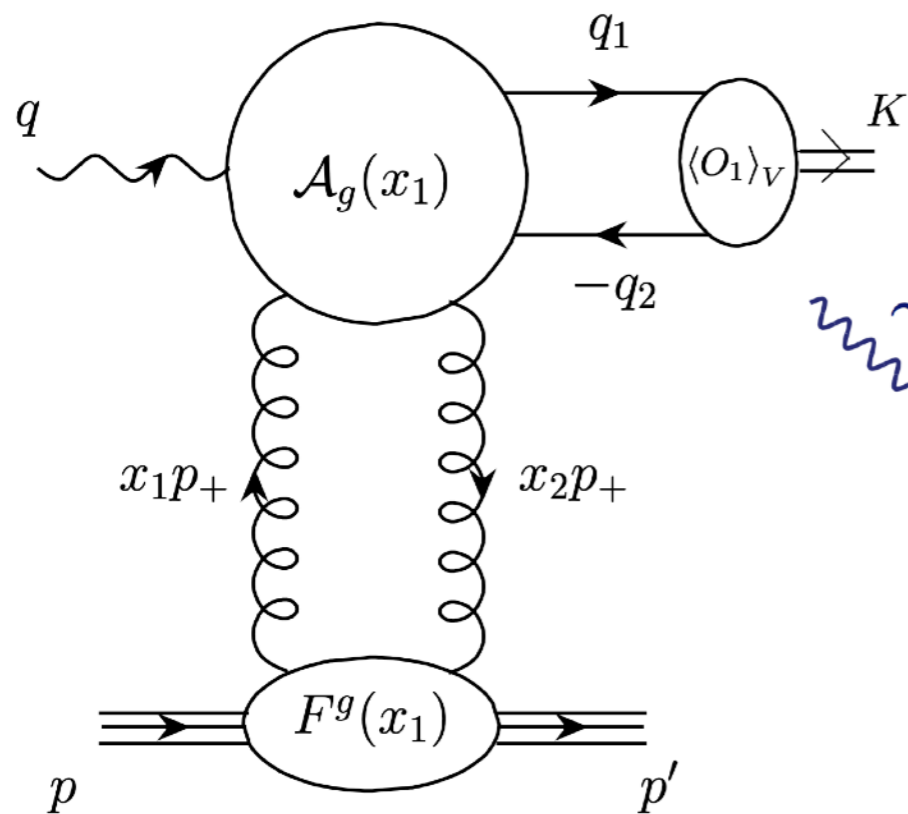
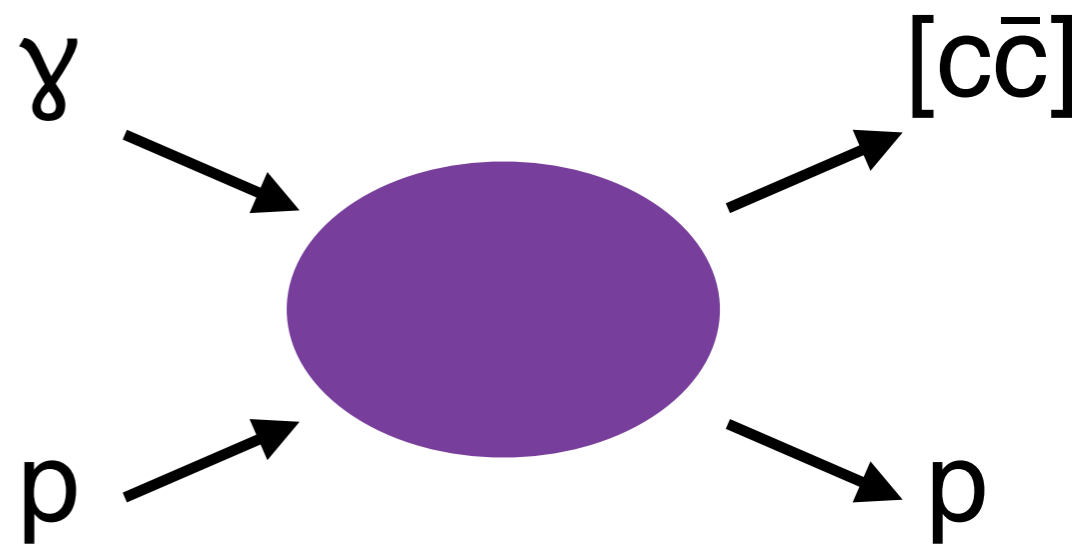


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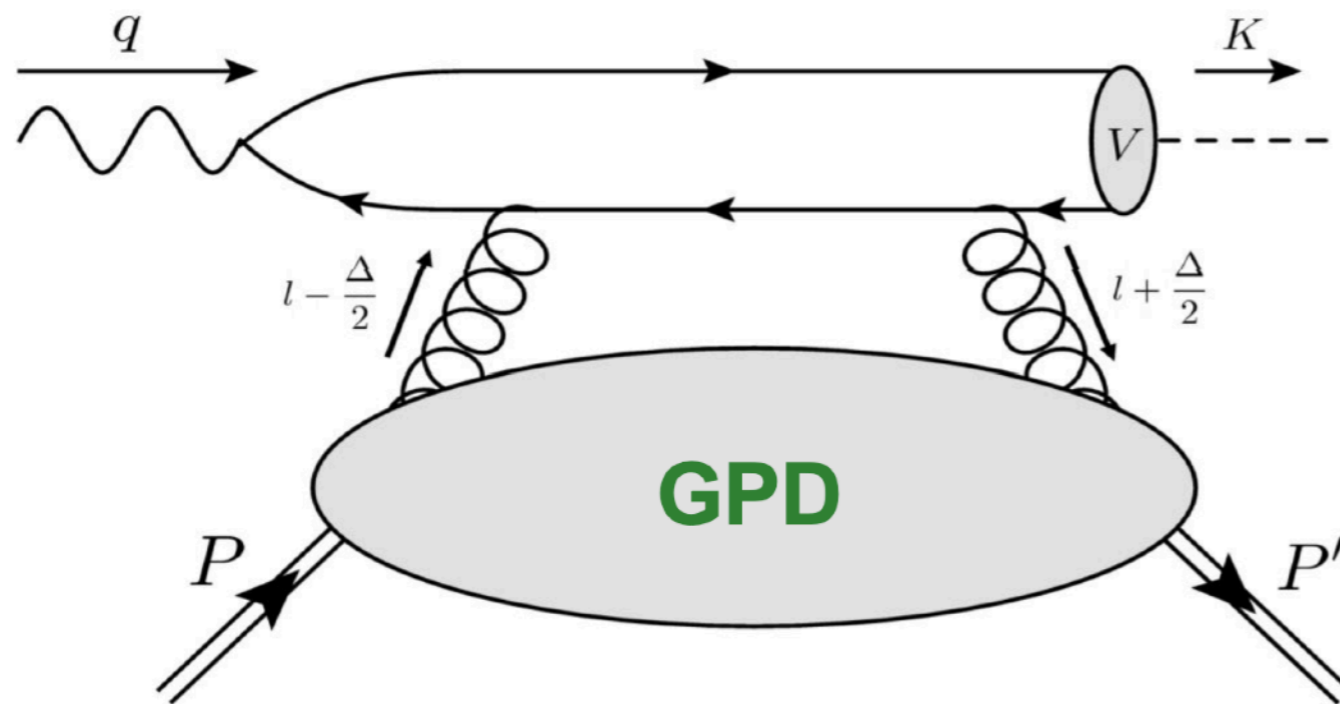
J/ψ Photoproduction Near Threshold

- At high energies, J/ψ production proceeds diffractively via gluon exchange
- Interest in using J/ψ production near threshold as a probe of proton structure, search for P_c resonances, etc...
- Many model-dependent statements can be made, but are these models correct?

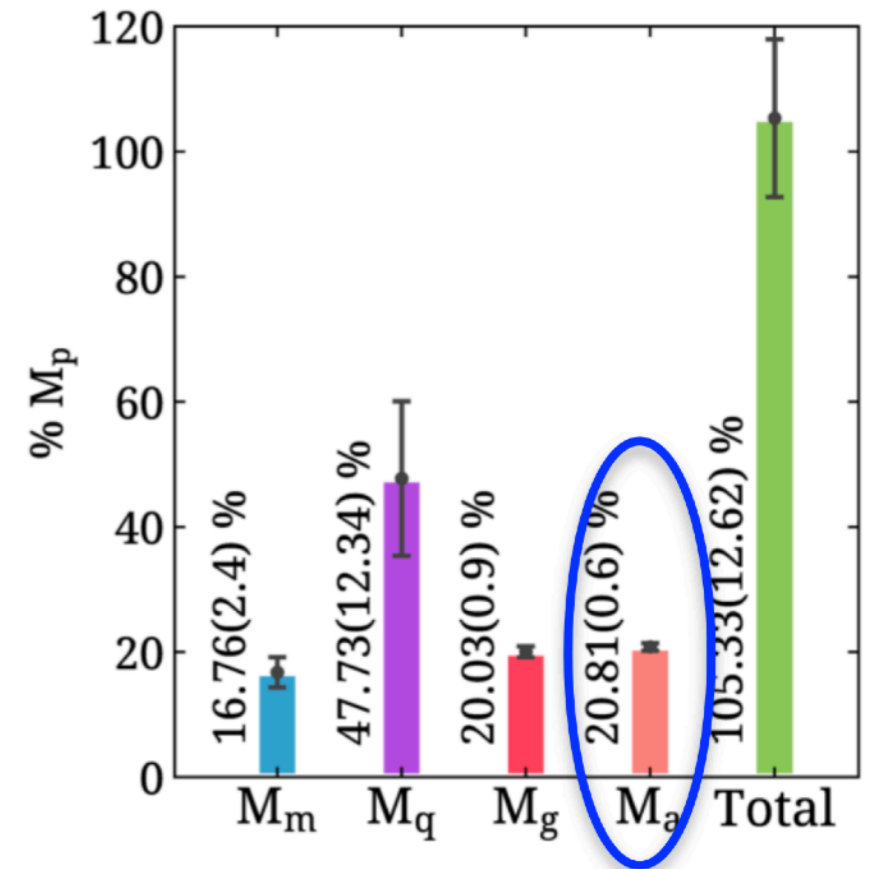


J/ψ Photoproduction and the Gluonic Structure of the Proton

- Near-threshold J/ψ produced near rest, real part of scattering amplitude dominates
- Arguments based on factorization in pQCD (large ξ) and holographic QCD connect to
 - Gravitational form factors
 - Proton mass trace anomaly



Guo, Ji & Liu, PRD 103, 096010 (2021)
 Hatta & Yang, PRD 8, 074003 (2018)
 Mamo & Zahed, PRD 101, 086003 (2020)



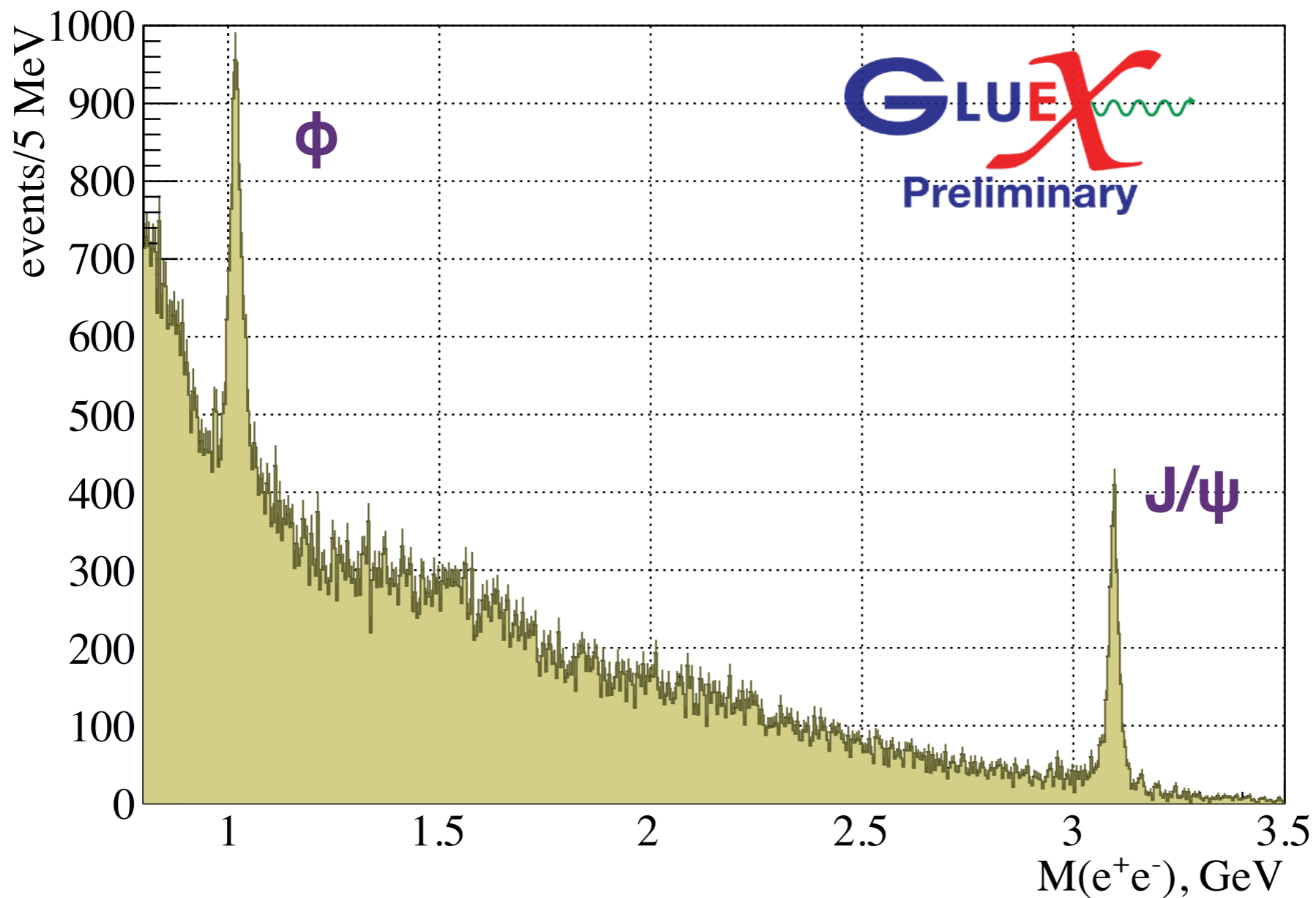
C. Alexandrou *et al.*, (ETMC), PRL 119, 142002 (2017)
 C. Alexandrou *et al.*, (ETMC), PRL 116, 252001 (2016)

$$\langle R_m^2 \rangle = \frac{6}{M} \left. \frac{dG}{dt} \right|_{t=0},$$

“Proton mass radius”

Khazeev, PRD 104, 054015 (2021)
 Mamo & Zahed, PRD 103, 094010 (2021)

J/ ψ Photoproduction at GlueX: Mass Spectrum

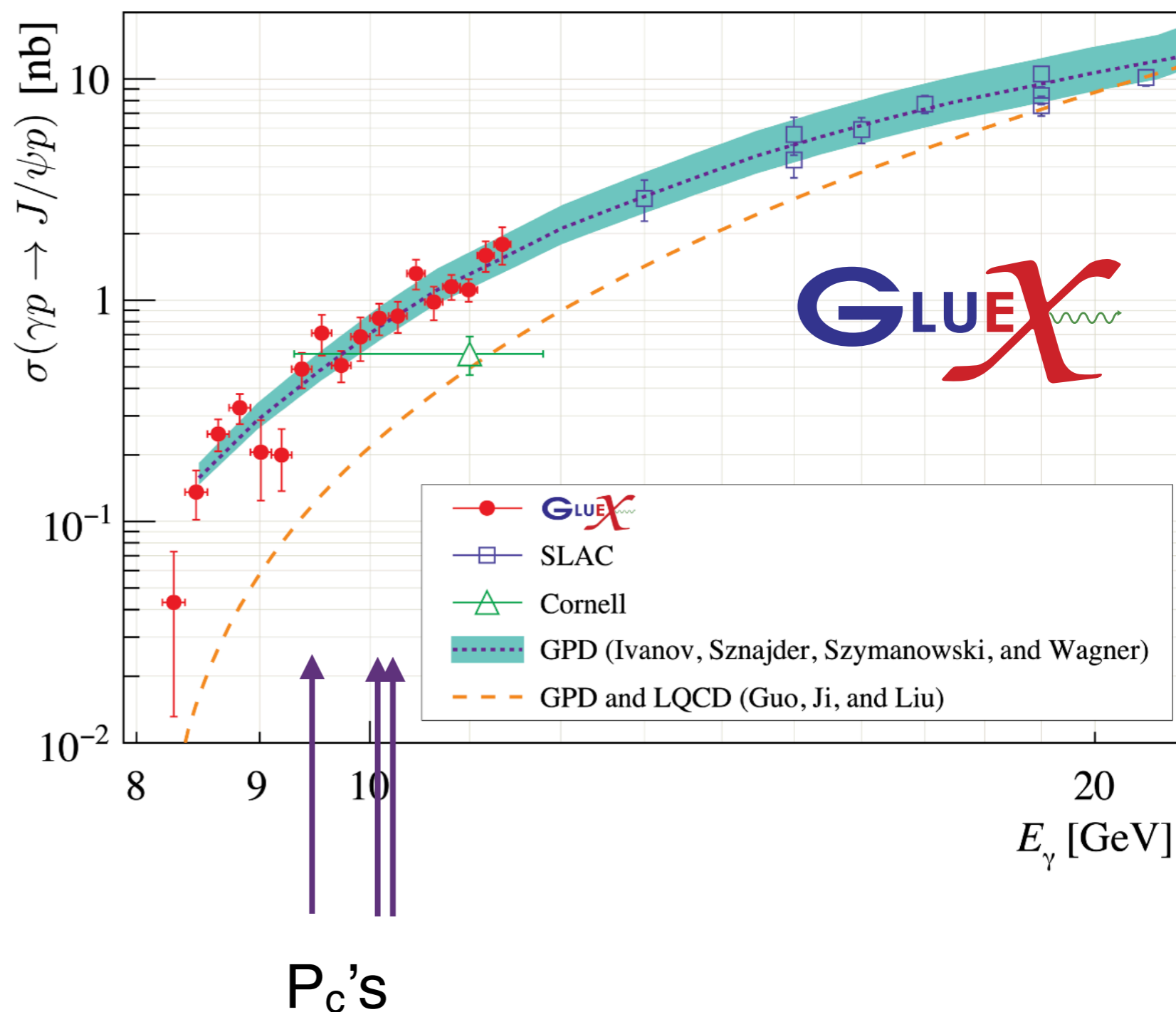


- Reconstruct $p \gamma \rightarrow p + J/\psi, J/\psi \rightarrow e^+e^-$
- Calculate J/ψ cross sections normalized by non-resonant e^+e^-

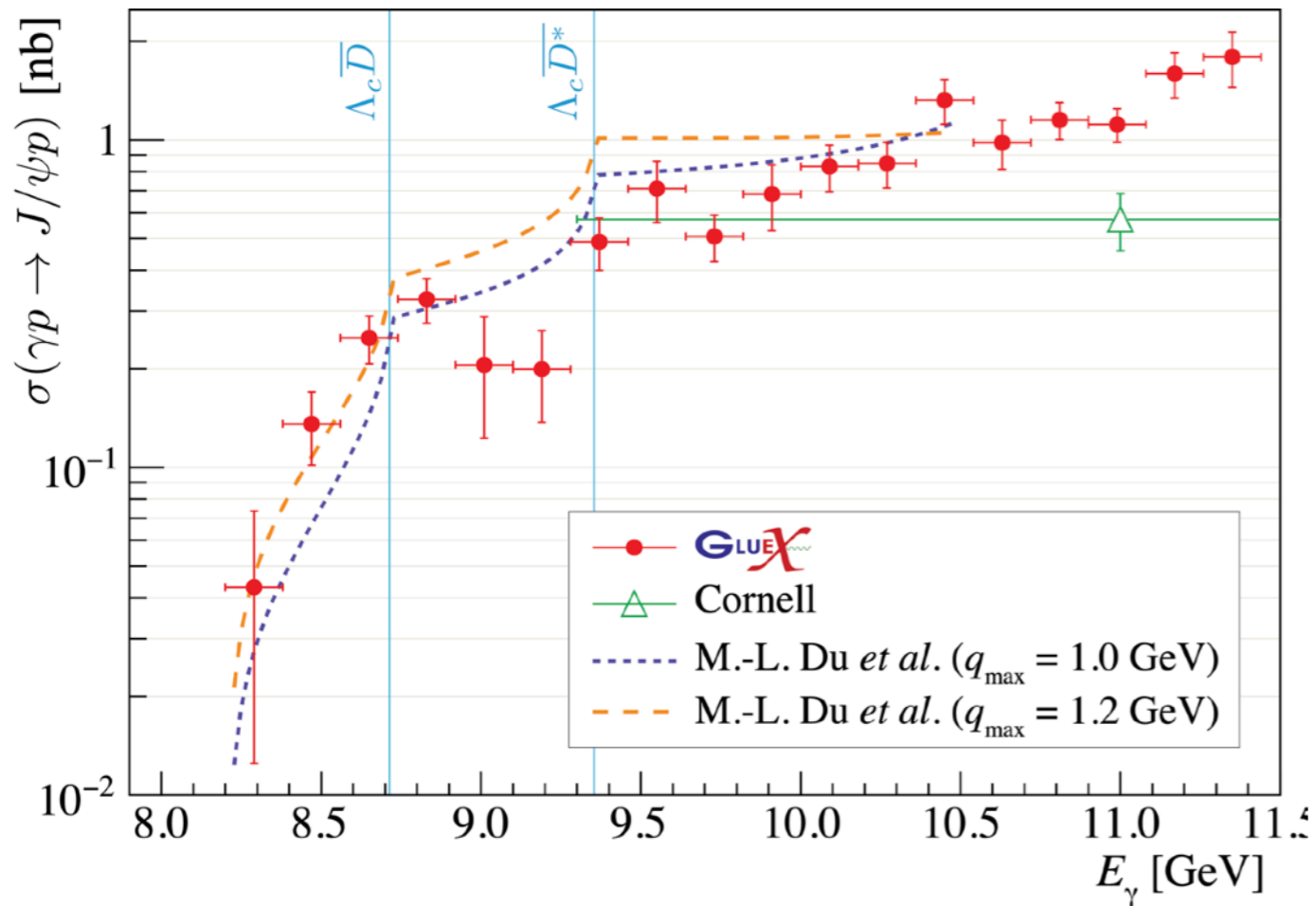
Latest GlueX-I $J/\psi \rightarrow e^+e^-$ Photoproduction Results

GlueX, PRC 108, 025201 (2023)

- Full GlueX-I data yields 2270 ± 58 J/ψ 's
- Overall normalization uncertainty $\sim 20\%$
- “Dip” above 9 GeV has 2.6σ (1.3σ) local (global) significance
- No evidence of narrow P_c production



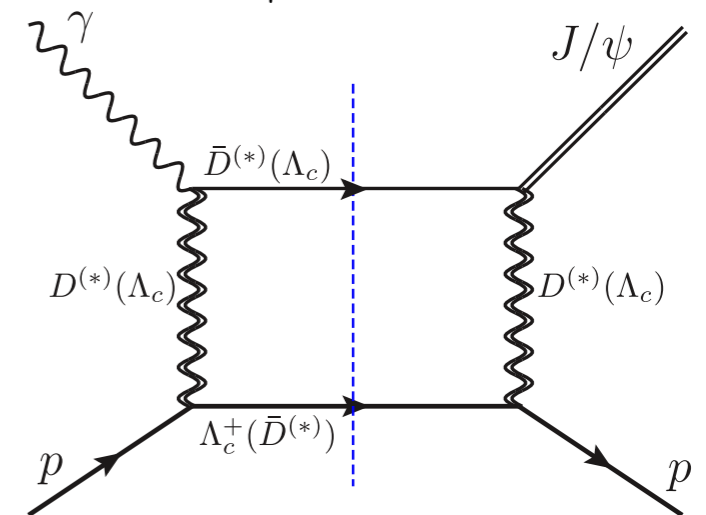
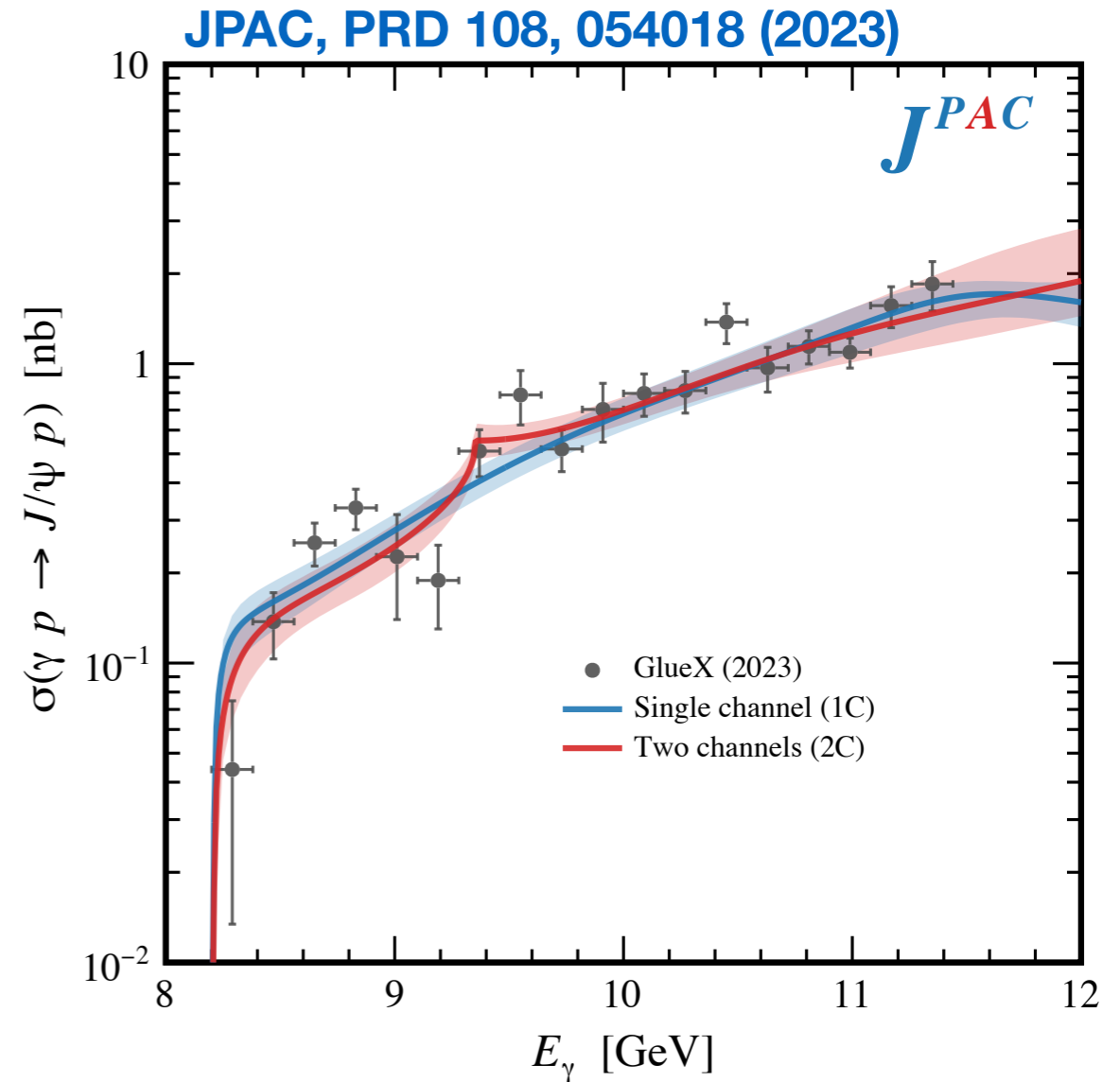
Threshold Effects?



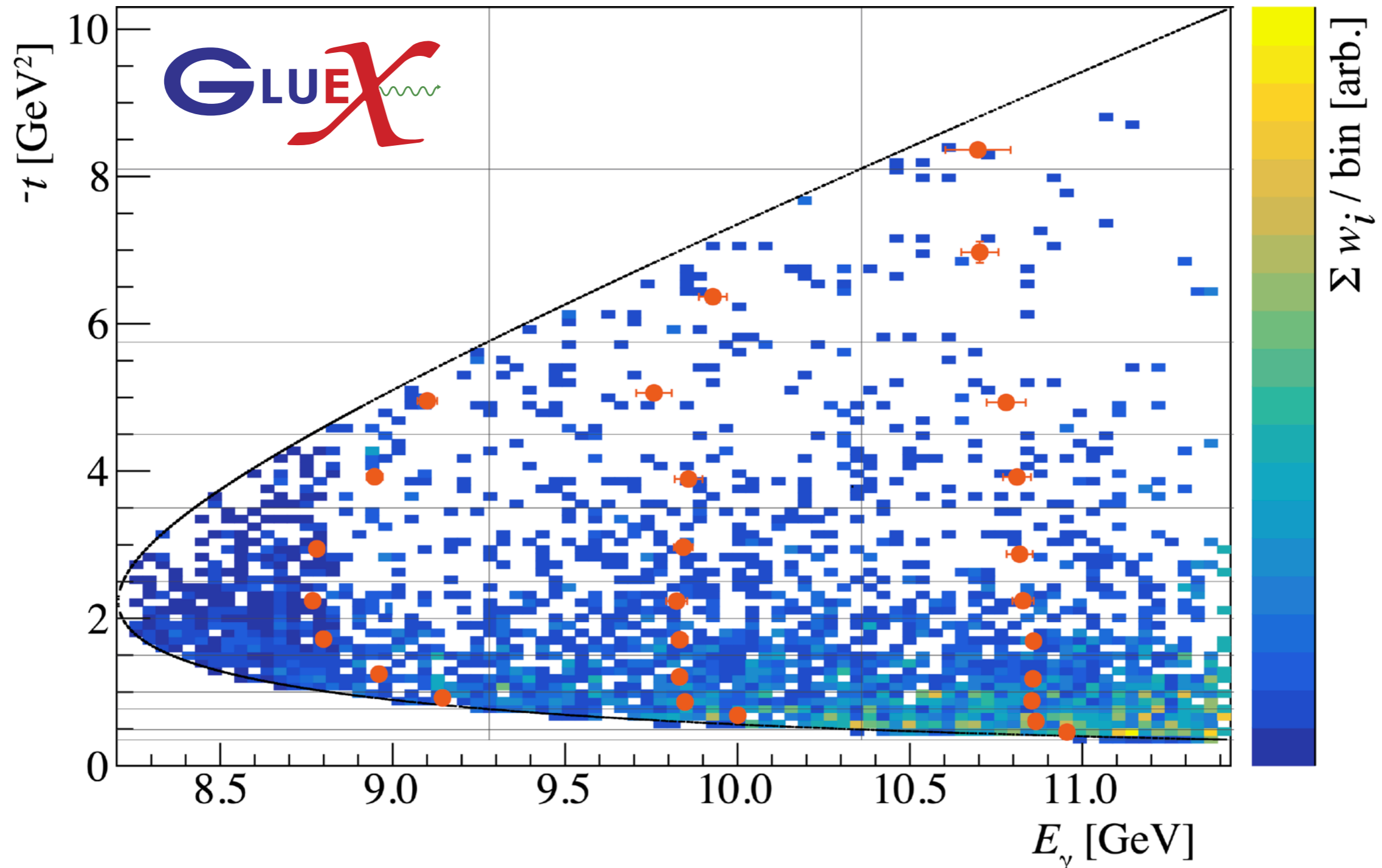
GlueX PRC 108, 025201 (2023)

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

- Structures seen near open-charm thresholds
- More precision required — GlueX-II will provide factor ~ 3 more data

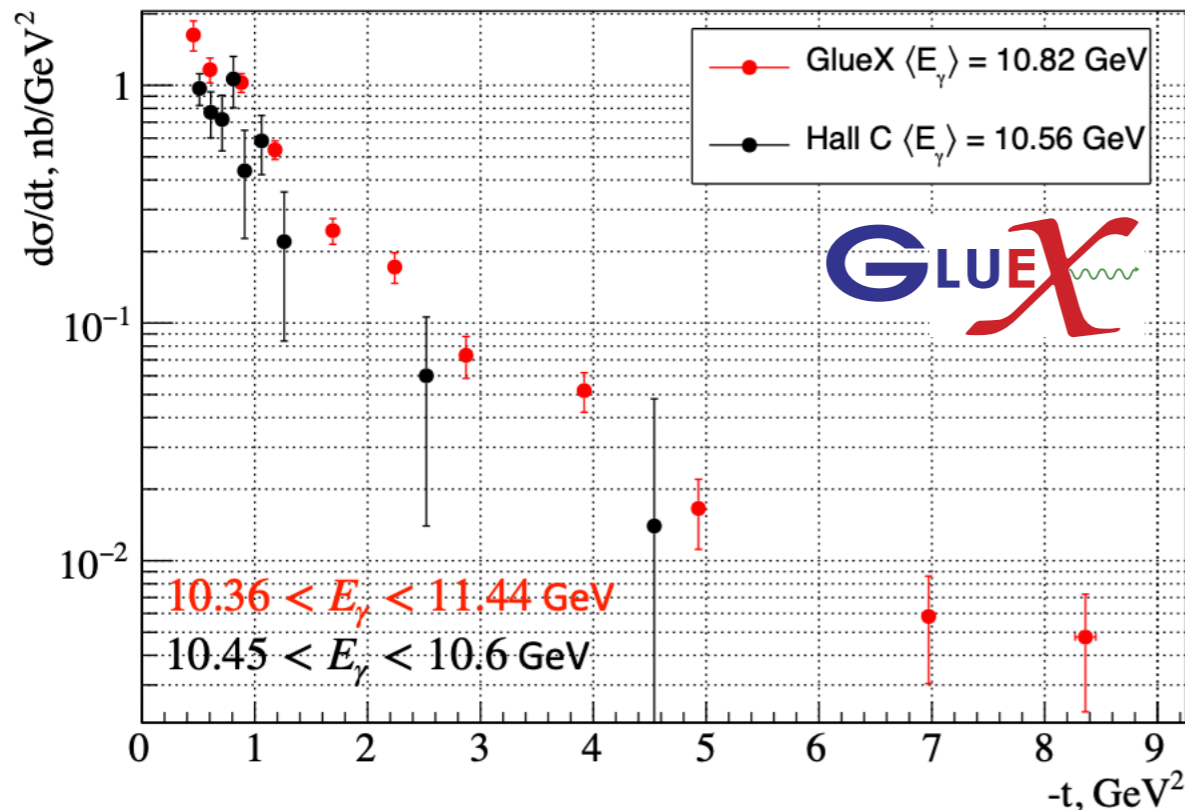
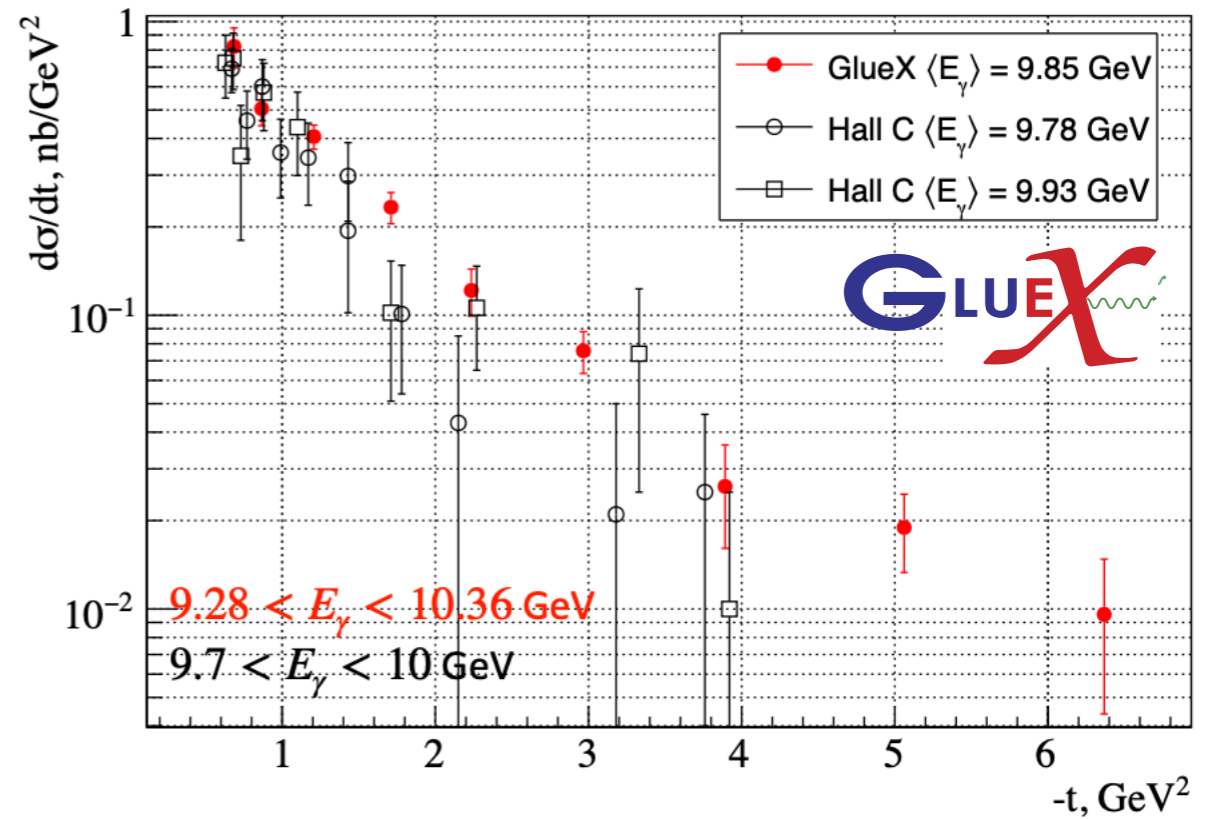
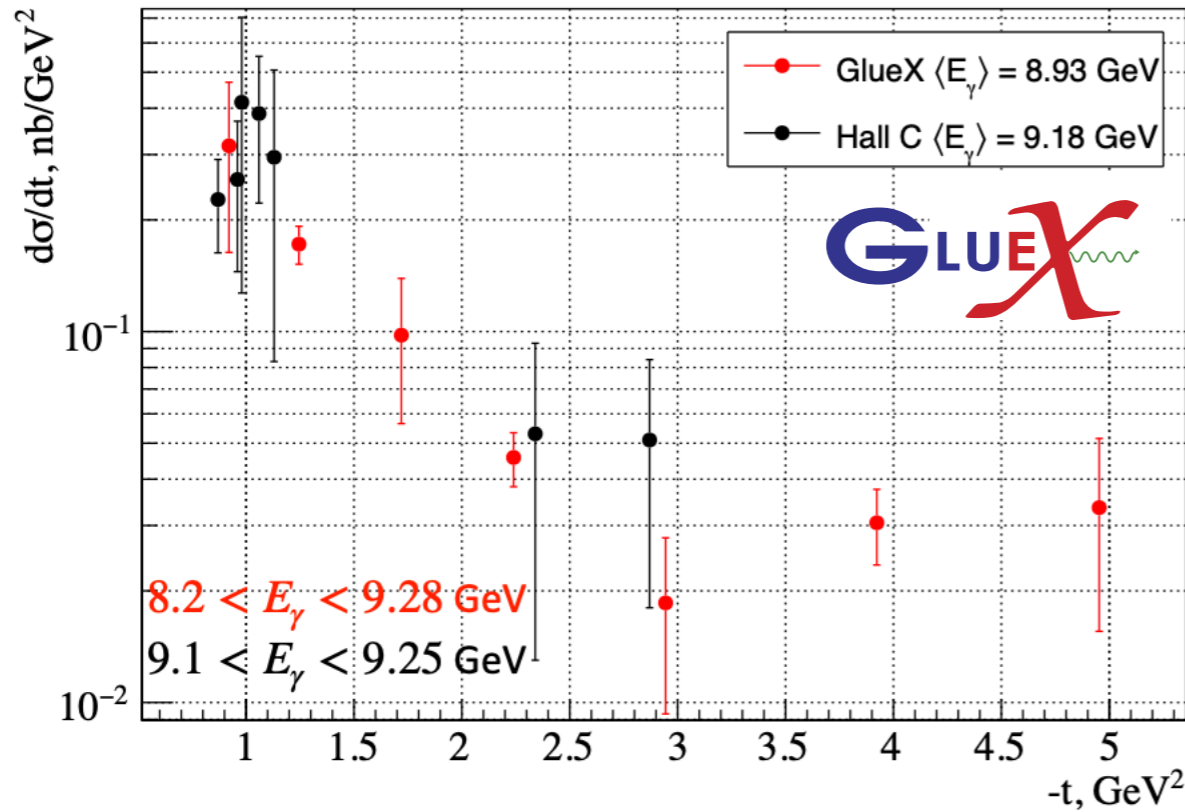


GlueX-I J/ψ Differential Cross Sections



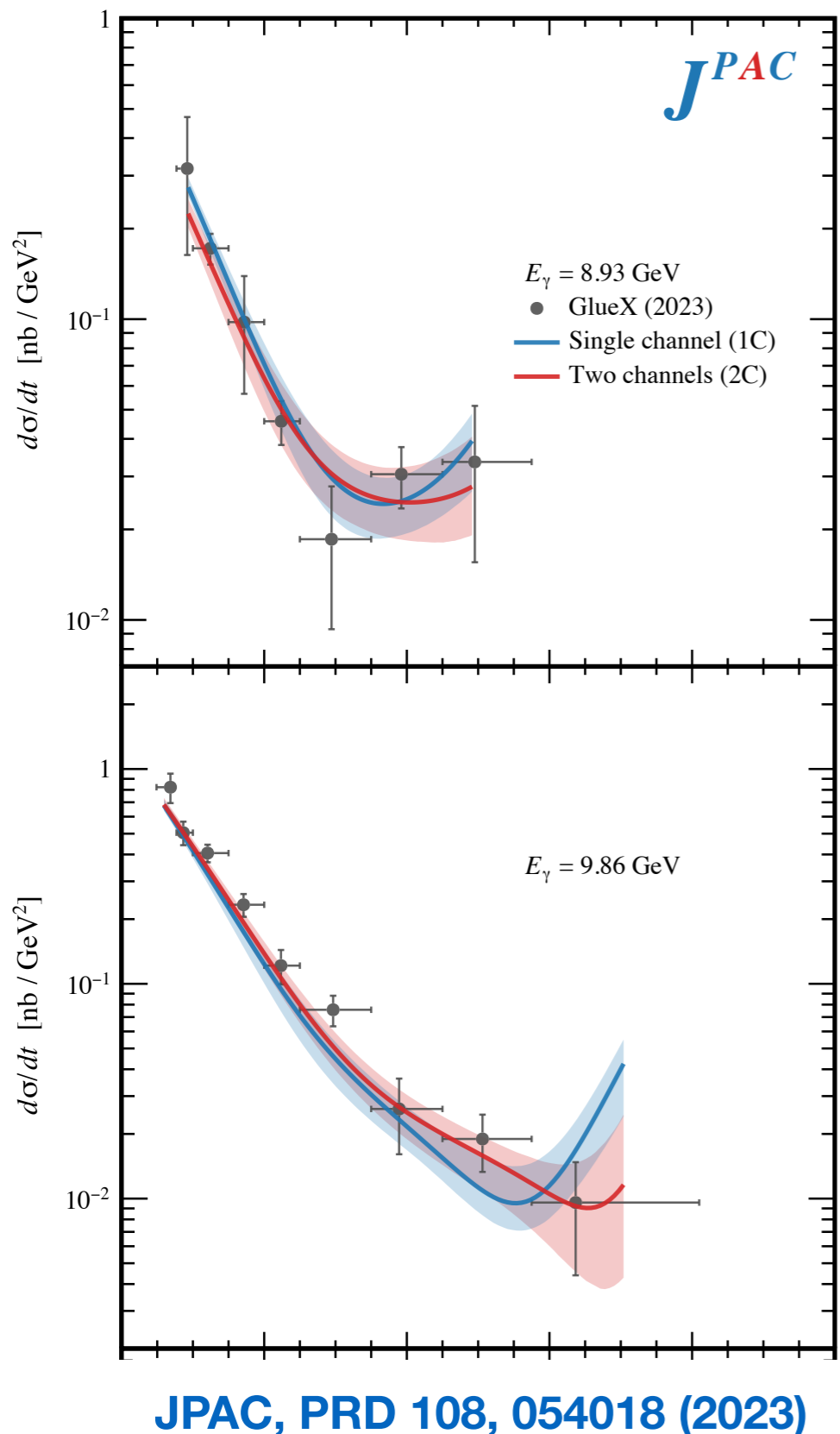
- Calculate $d\sigma / dt$ including event-by-event luminosity weighting
- Report cross sections at bin means (points)

GlueX-I J/ψ Differential Cross Sections

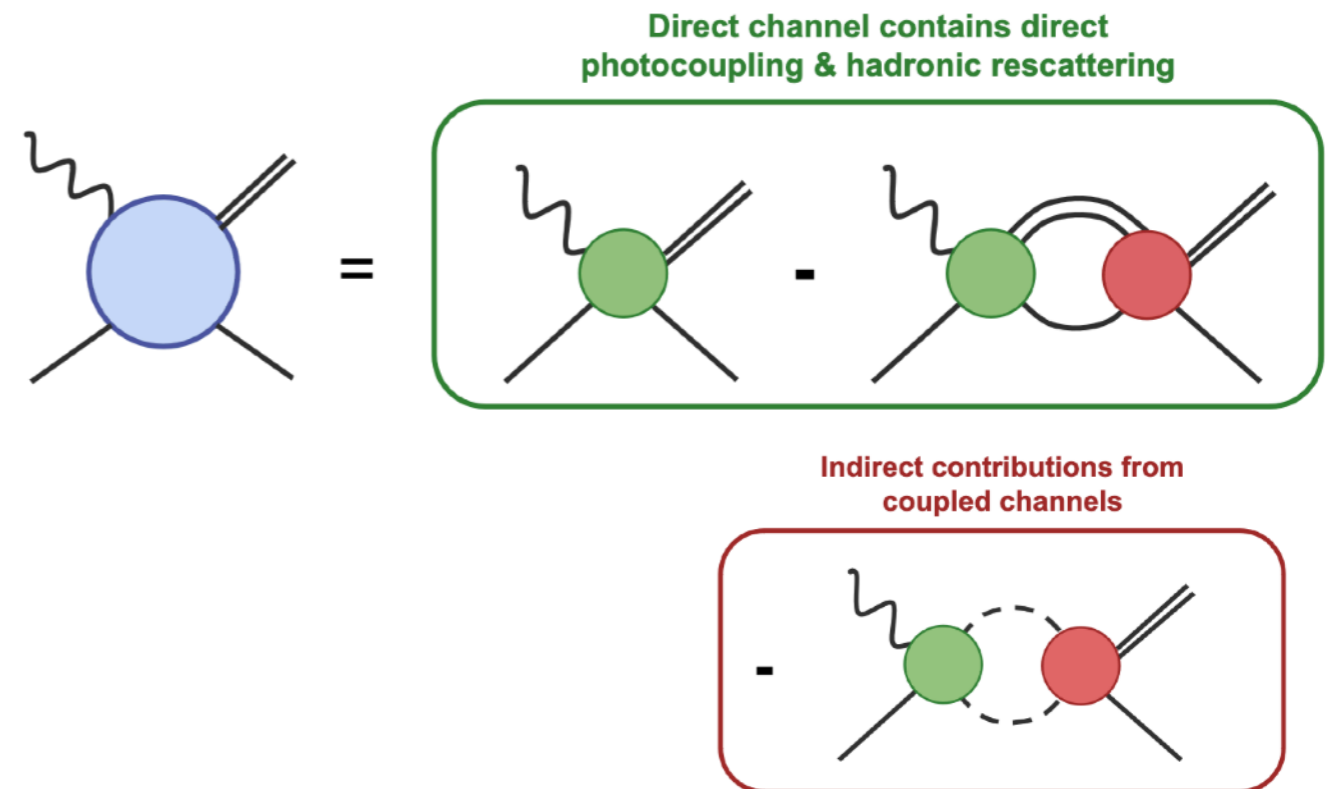


- GlueX and J/ψ – 007 results agree well within uncertainties
- Scale uncertainties:
 - 20% for GlueX
 - 4% for J/ψ – 007
- Enhancement seen at large t near threshold

GlueX-I J/ψ Differential Cross Sections



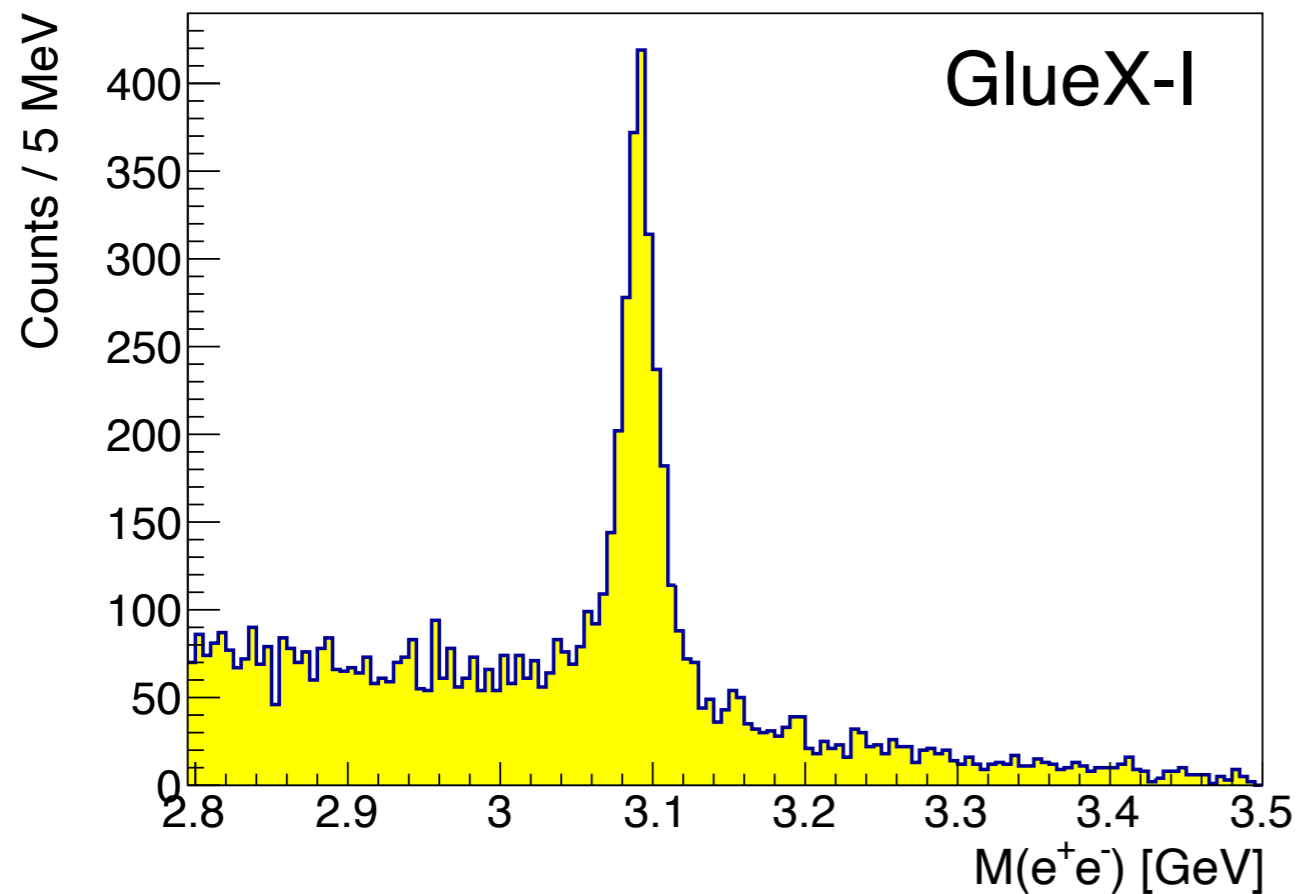
- JPAC fit to GlueX and $J/\psi - 007$ data
 - Up to 3 s-channel partial waves
 - Effective range expansion
 - K-matrix & unitarity
- Describes all observed features well
- Factorization violations $> 25\%$ at 90% CL
- More data needed!



Comparing $J/\psi \rightarrow e^+e^-$ and $J/\psi \rightarrow \mu^+\mu^-$

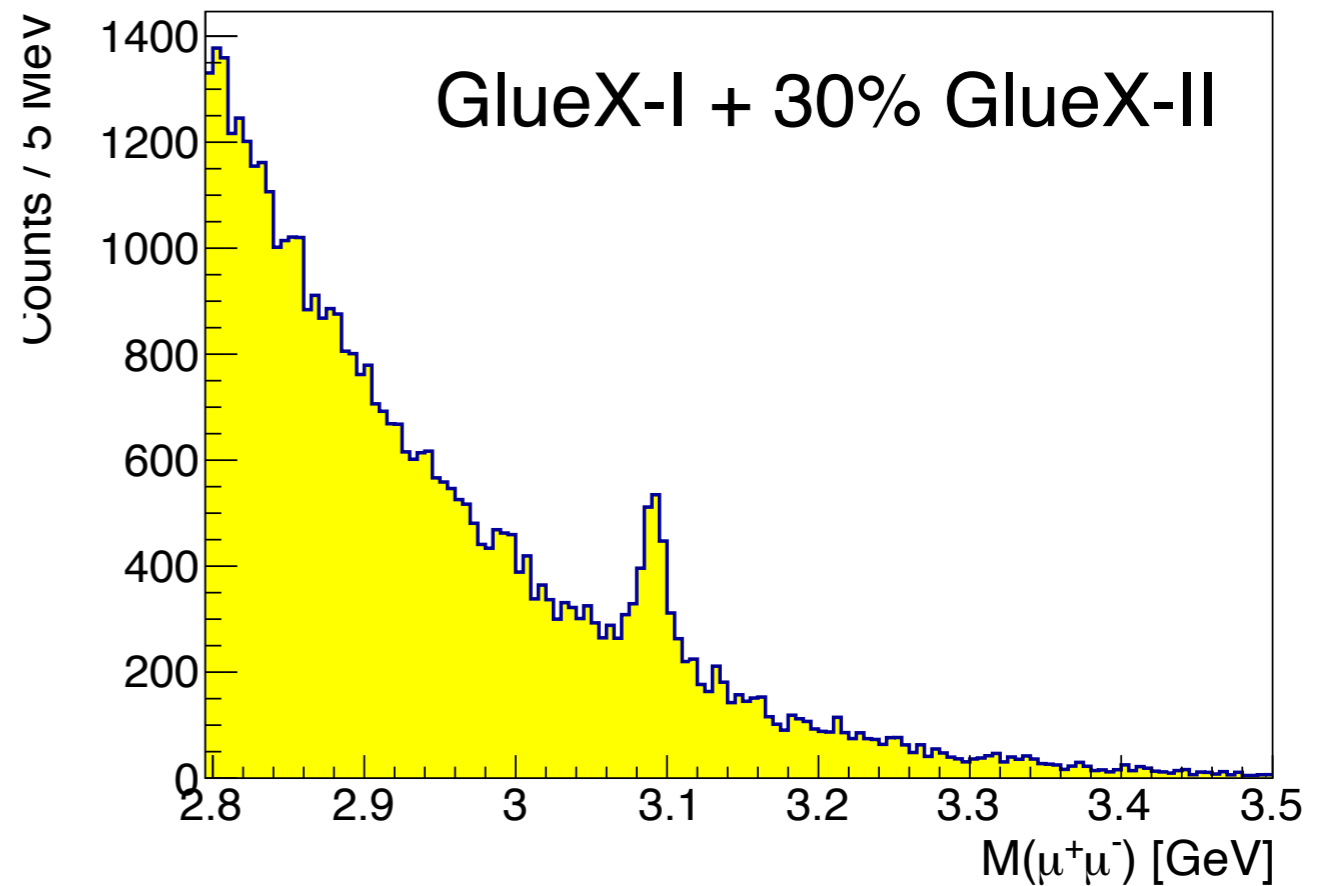
$$J/\psi \rightarrow e^+e^-$$

$$N(J/\psi) = 2270 \pm 58$$



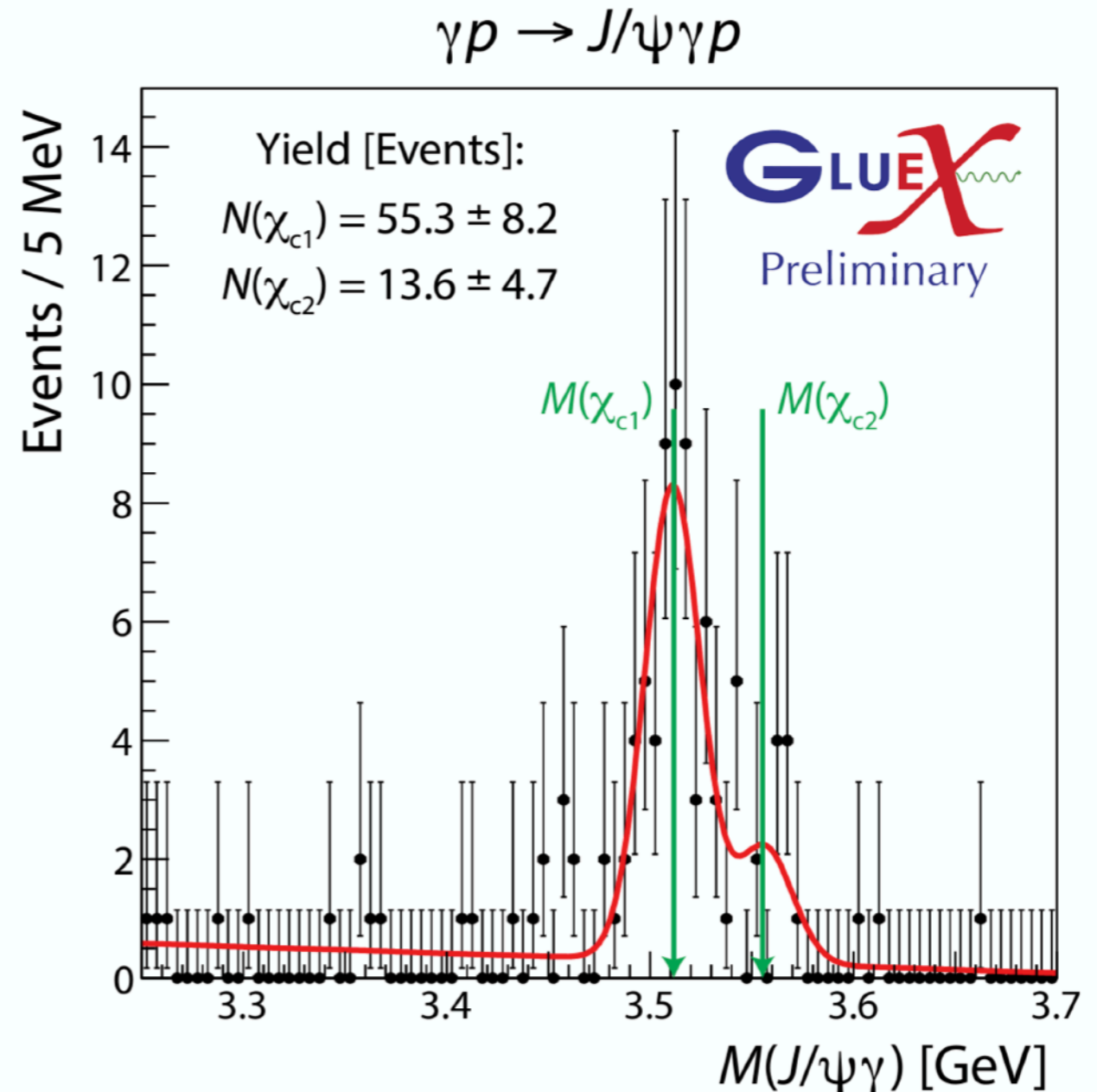
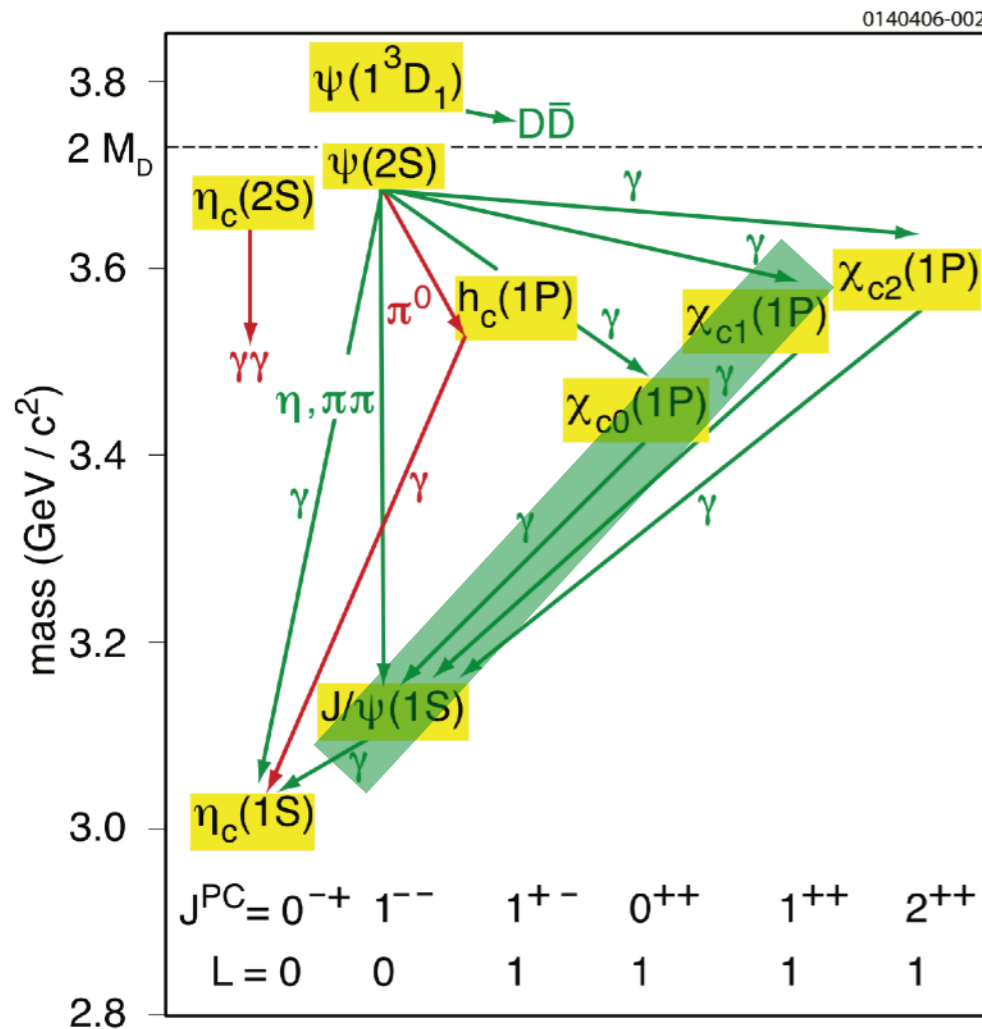
$$J/\psi \rightarrow \mu^+\mu^-$$

$$N(J/\psi) = 1778 \pm 65$$



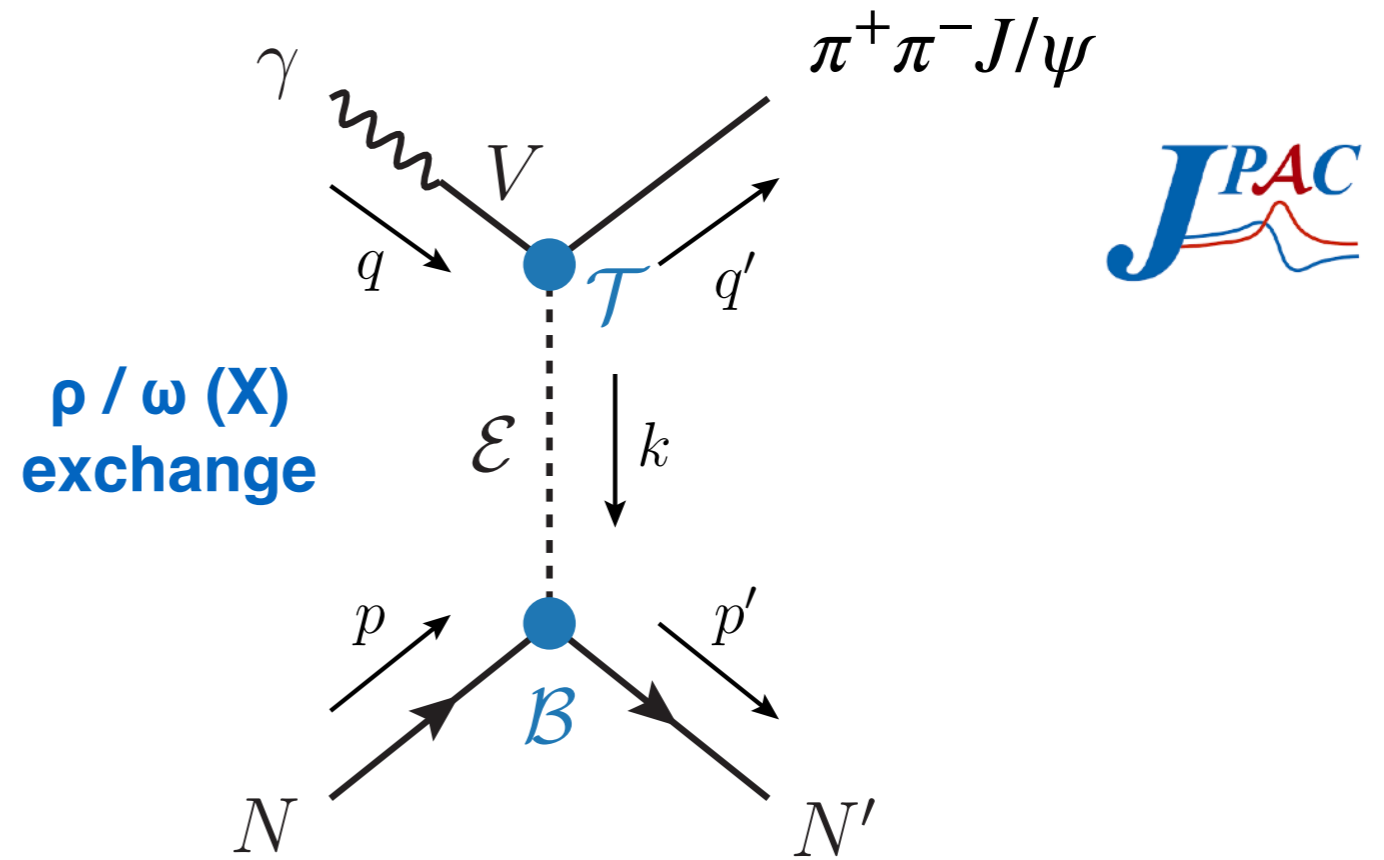
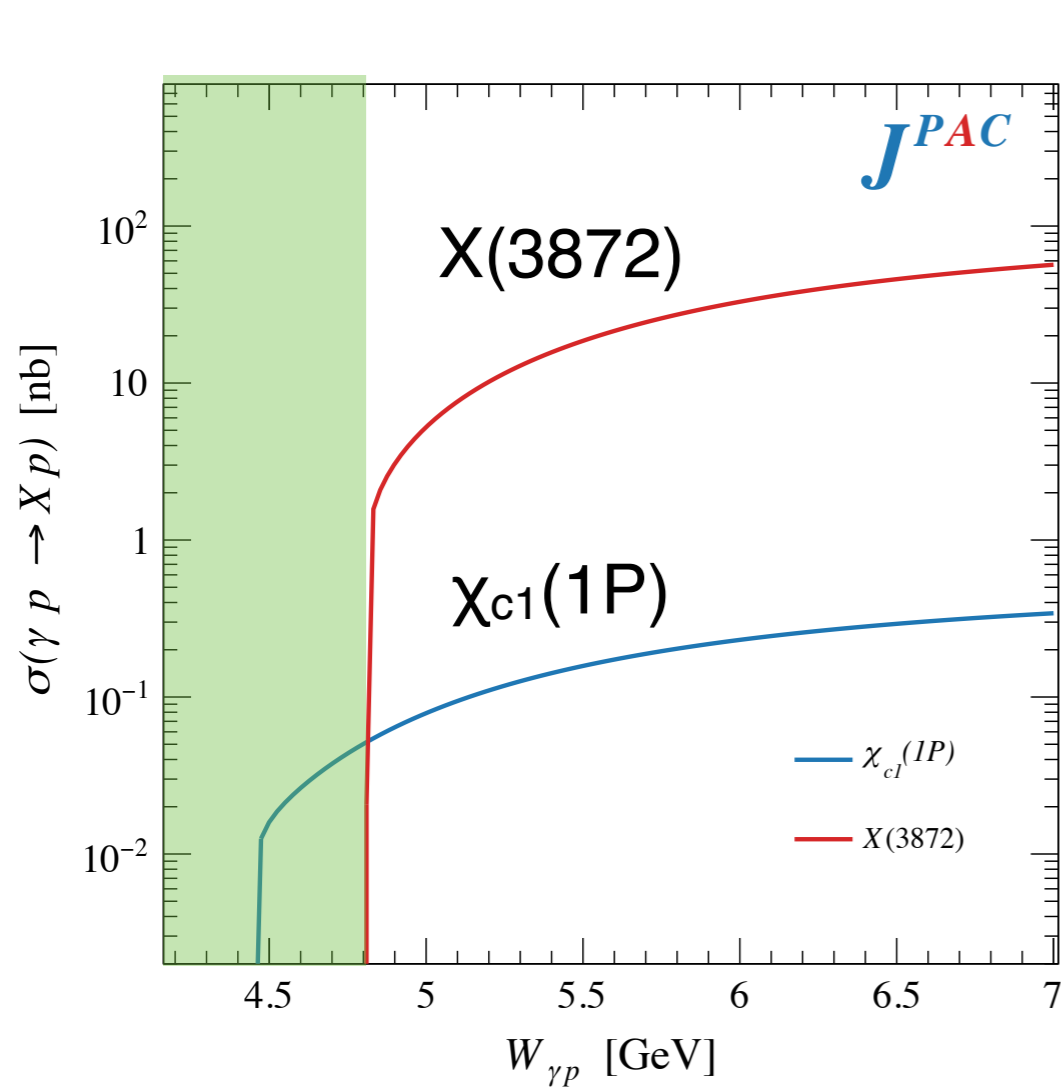
- To confirm the structures observed in the cross section using $J/\psi \rightarrow e^+e^-$ events, we can also use $J/\psi \rightarrow \mu^+\mu^-$ events
- Detailed study of calorimeter and trigger response in progress
- Expect new results from CLAS12, Hall-C. Eventually: GlueX-III, SOLID

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



- $\chi_{c1}(1^{++})$ photoproduction: probe of different parity $C=+$
- Look for $\gamma p \rightarrow \chi_{cJ} p \rightarrow (\gamma J/\psi) p \rightarrow (\gamma e^+ e^-) p$

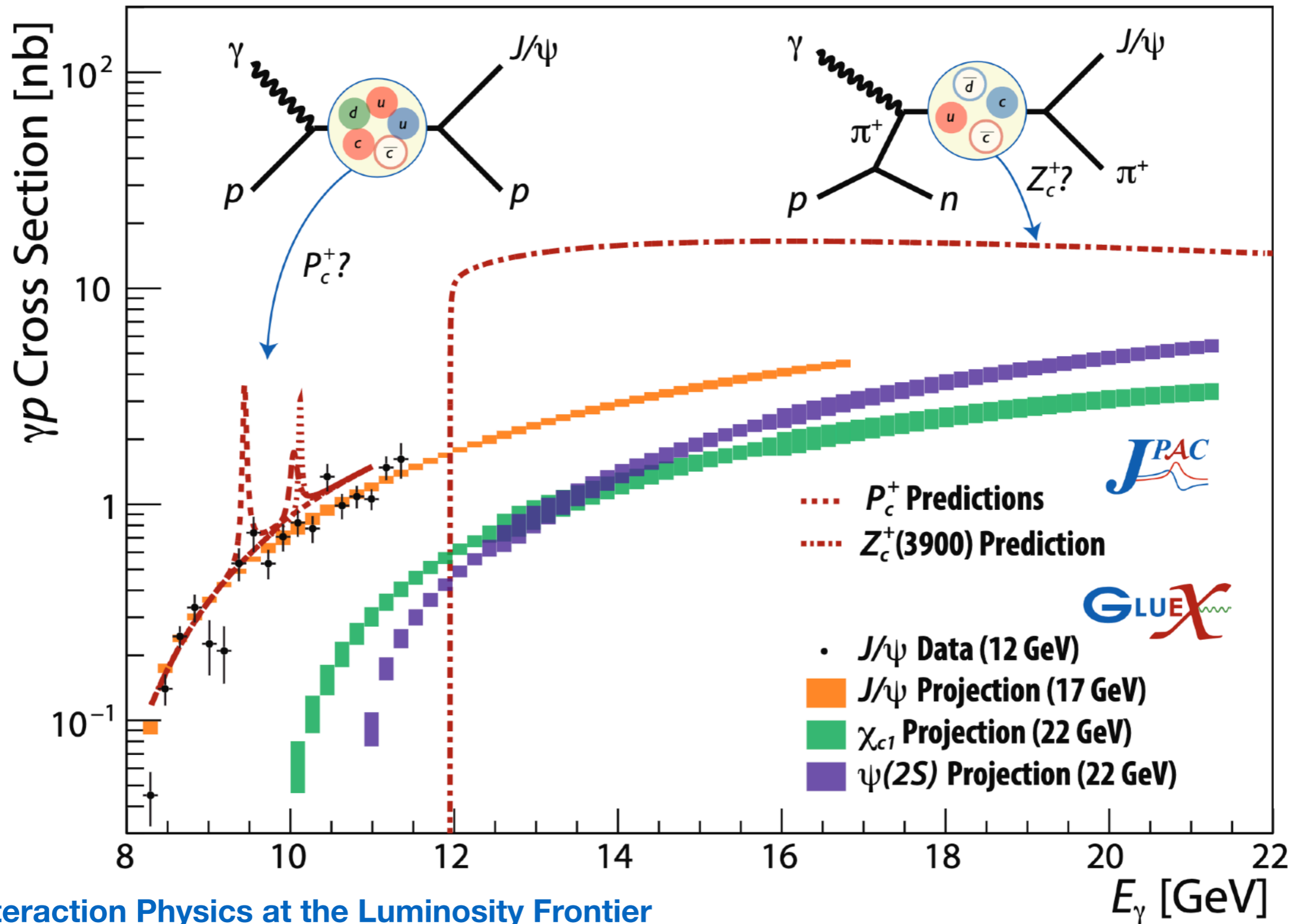
JPAC predictions for charmonium photoproduction



PRD 102, 114010 (2020)

- JPAC predictions for higher energy photoproduction using fixed-spin exchanges near threshold using known $\chi_{c1} \rightarrow \gamma(\rho, \omega, \phi, J/\psi)$ couplings
- GlueX can test model by measuring $\chi_{c1}(1P)$ production
- Also hard exchange model — 3-gluons, “Odderon-like”

Projections for Future JLab Upgrades



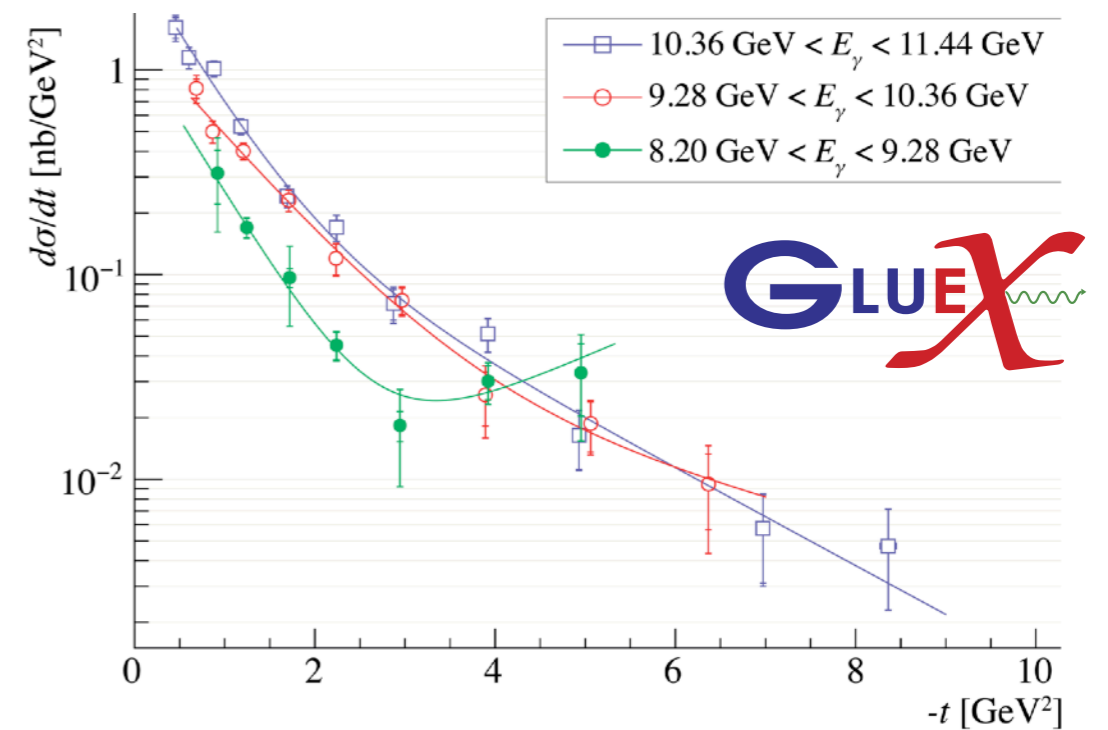
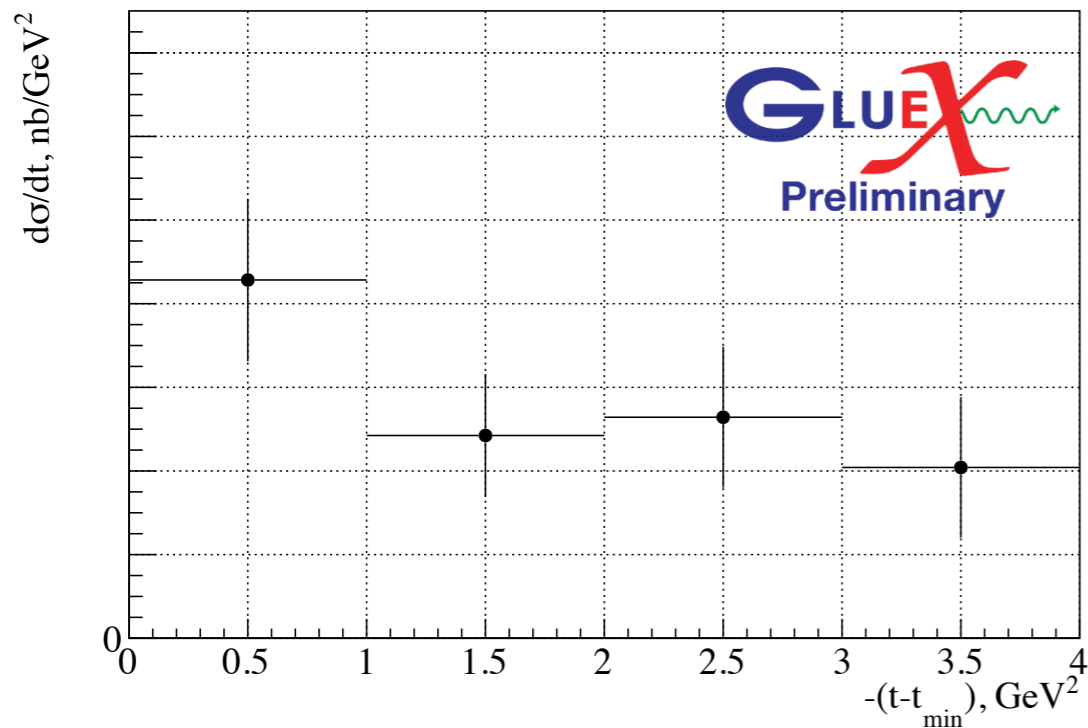
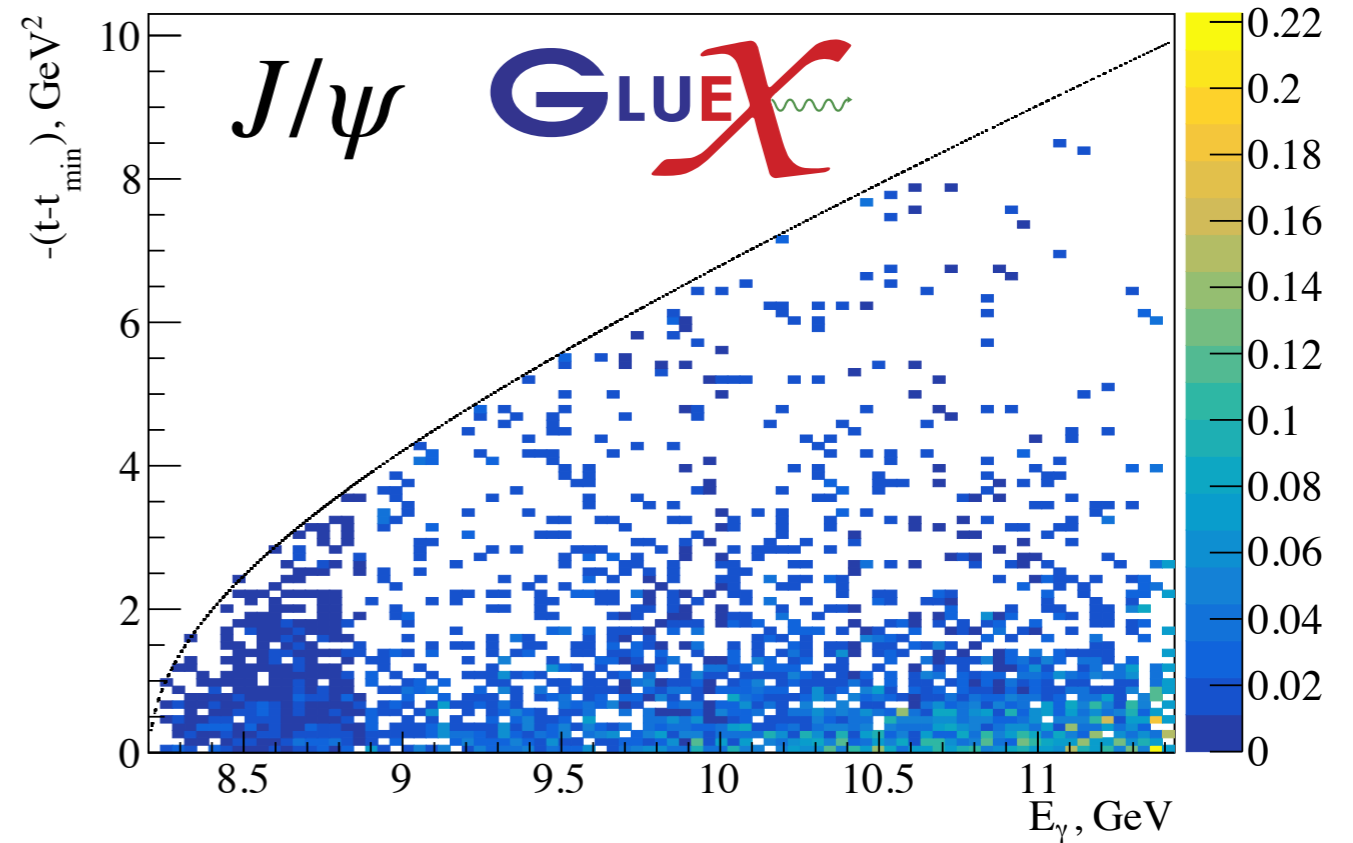
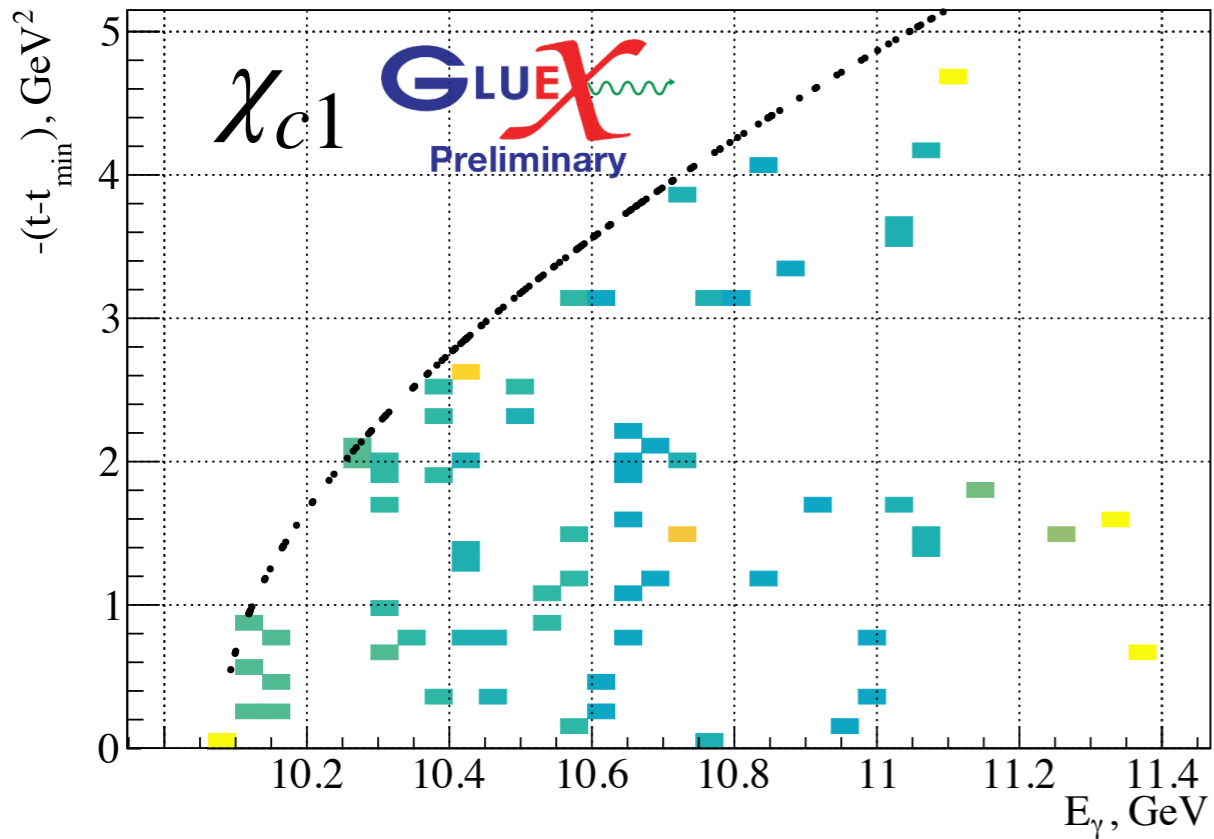
Strong Interaction Physics at the Luminosity Frontier
with 22 GeV Electrons at Jefferson Lab - arXiv:2306.09360

Summary and Prospects

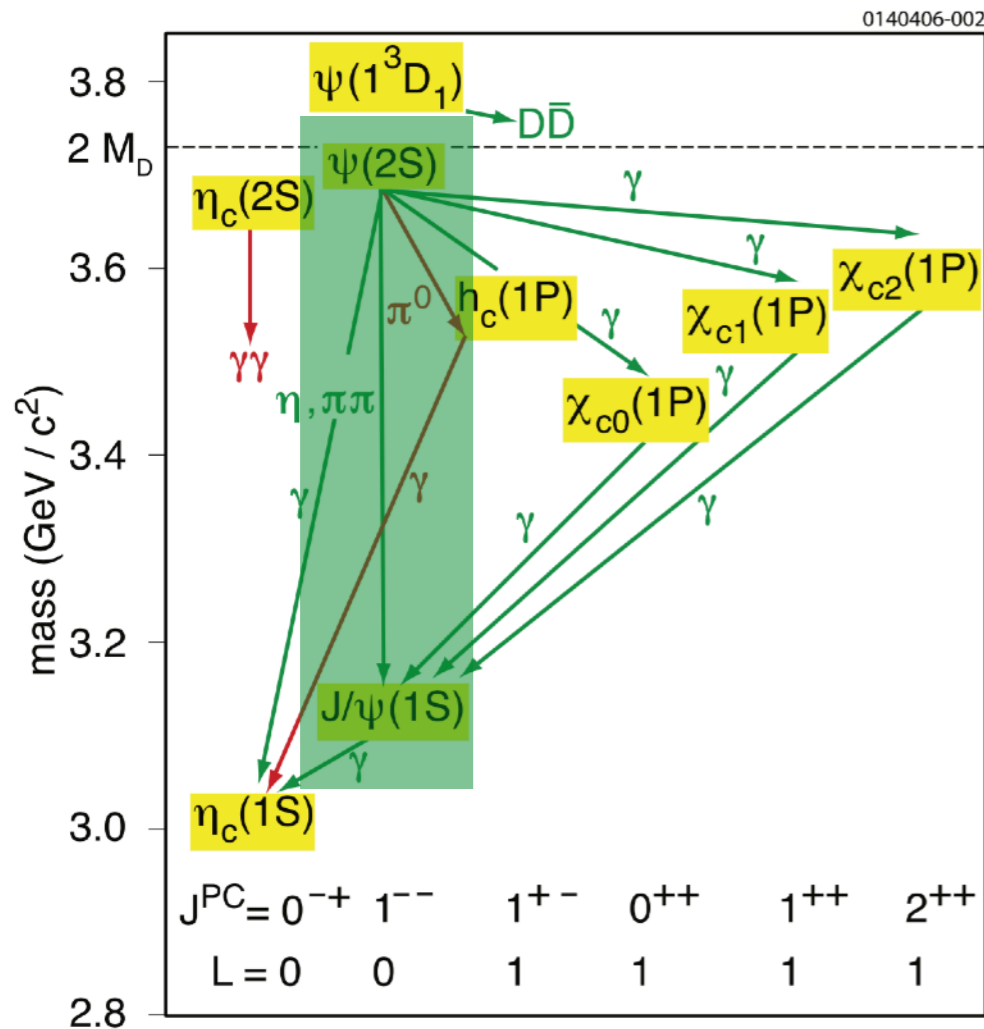
- GlueX has collected a large precision photoproduction dataset
- Studies of low-lying cascade baryons underway
 - Cross sections of $\Xi(1320)$ and $\Xi(1520)$ show interesting features
 - First identification of $\Xi(1690)$ and $\Xi(1820)$ in photoproduction
 - GlueX-II running with DIRC will improve sensitivity
- Measurements of J/ψ production with GlueX near threshold show unexpected features
 - The ongoing GlueX-II run will provide more precision
 - More results expected from CLAS12 and Hall-C/007
 - Need to measure open charm production
 - Photoproduction of $\psi(2S)$ might be better probe for gluonic structure
- Photoproduction of $\chi_{cJ}(1P)$ tests $C = +$ exchanges
- Measurements with linear photon polarization can give fresh insight
- Future possibilities: GlueX-III proposal, SOLID, CEBAF energy upgrade

Backup Slides

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

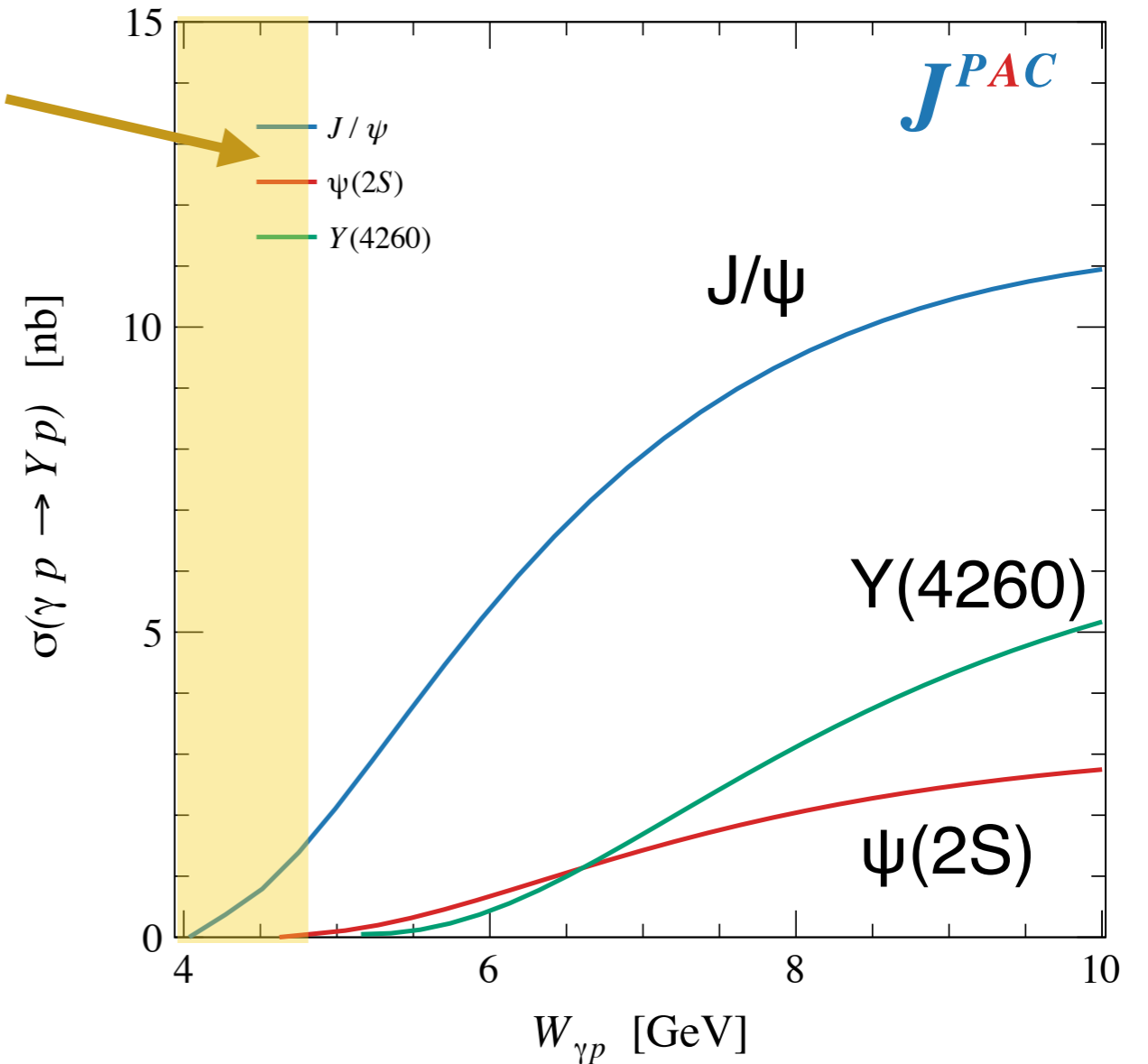


$\psi(2^3S_1)$ Photoproduction at GlueX



GlueX
energy
range

JPAC: PRD 102, 114010 (2020)

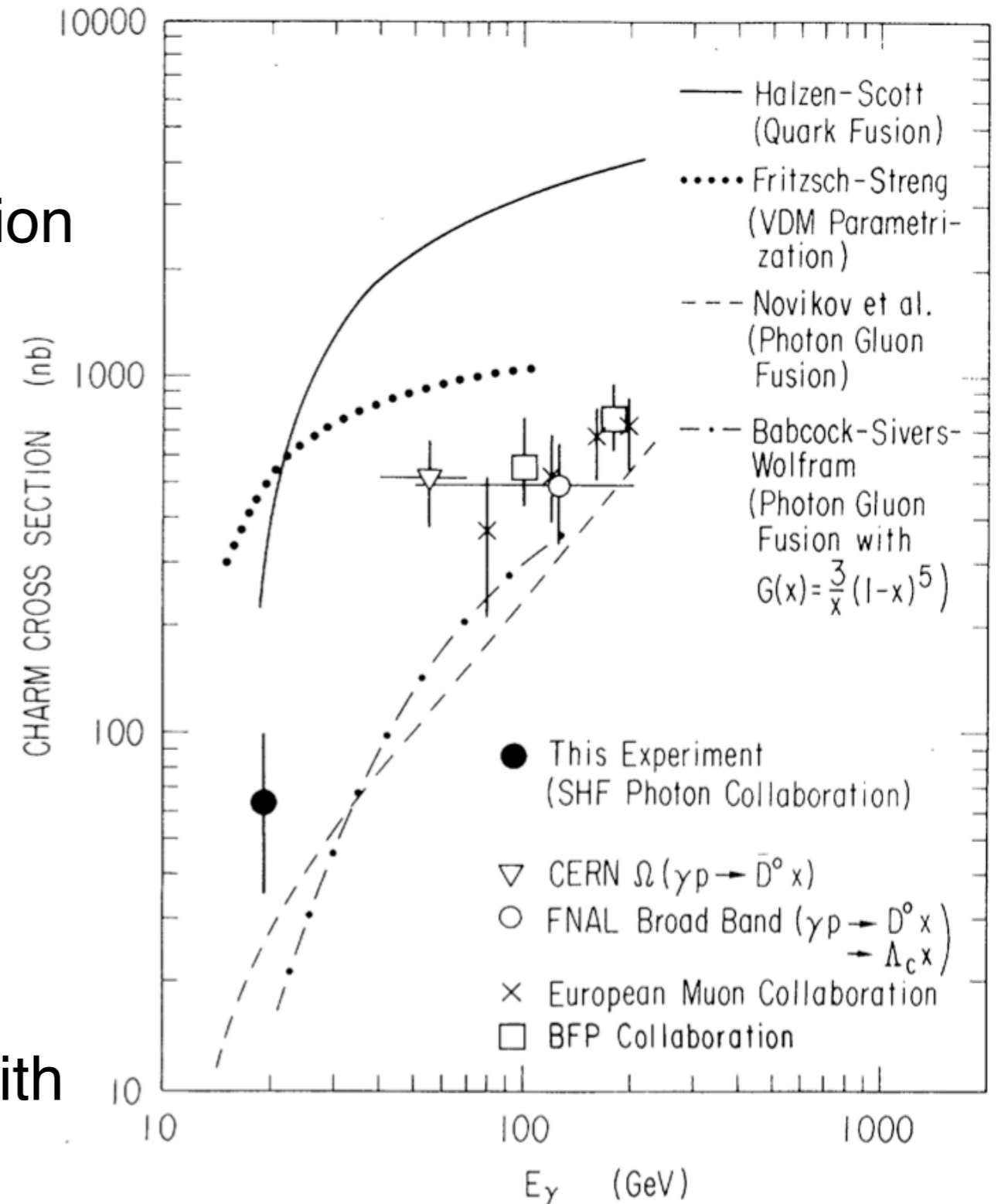


- $\psi(2S)$ photoproduction: probe of wave function dependence
- JPAC model estimates using known $\Gamma_{\gamma gg}(\psi(2S)) / \Gamma_{\gamma gg}(J/\psi)$
- Can search for $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$ and $\psi(2S) \rightarrow e^+ e^-$

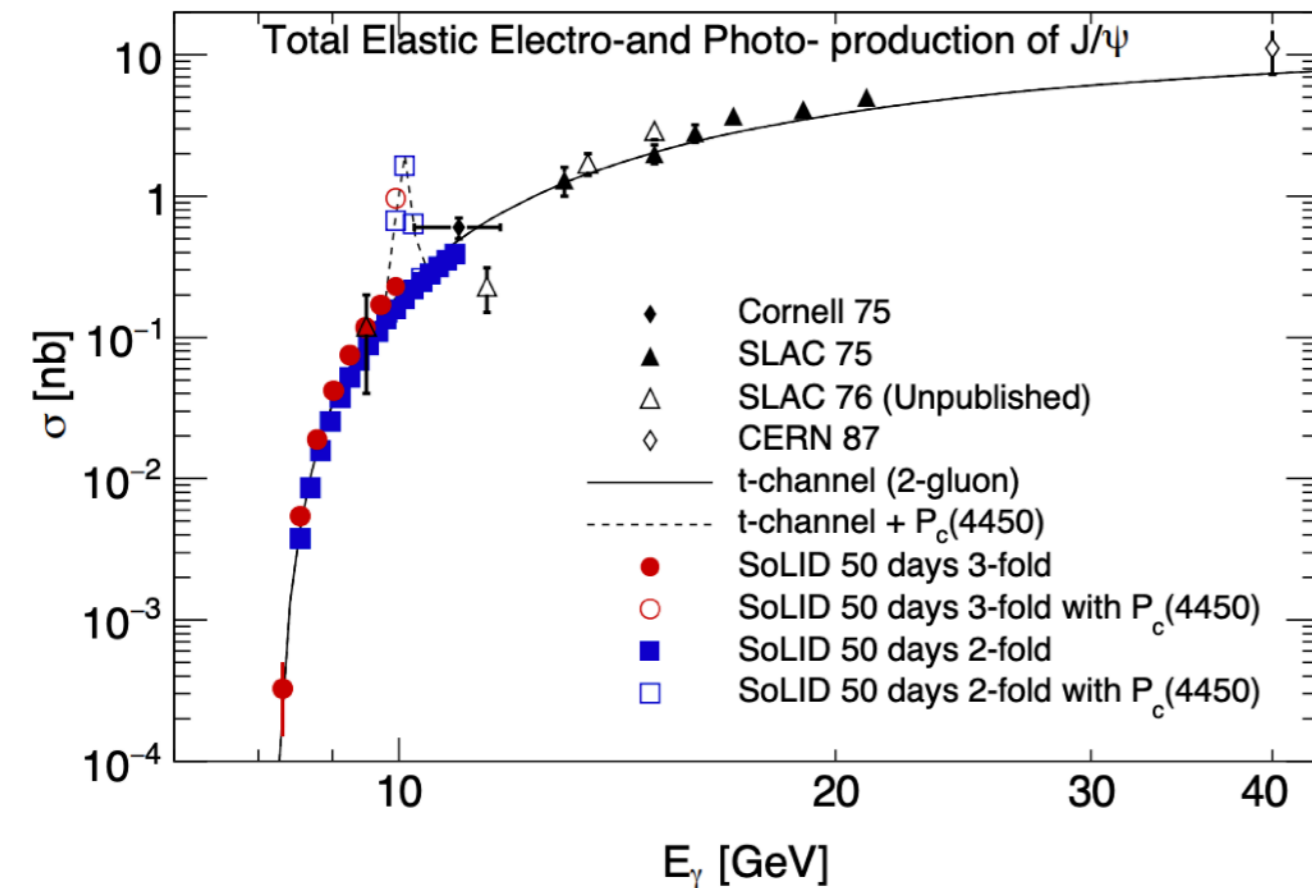
Open Charm Production Near Threshold

PRL 51, 156 (1983)

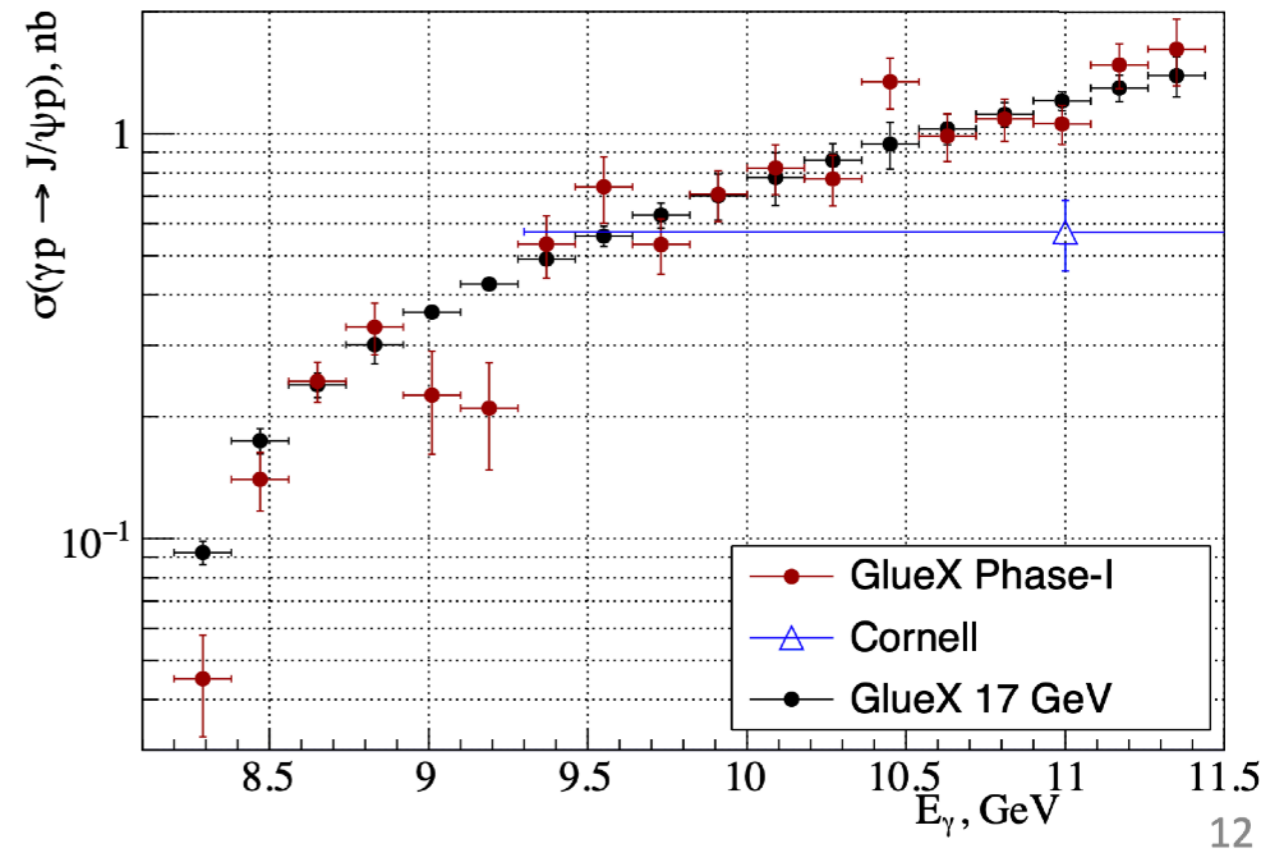
- Hadron ($c\bar{c}$) molecules like to decay to open-charm final states, can we see them at GlueX?
- Also will help with J/ψ interpretation
- Open charm photoproduction cross section measured at SLAC for $E_\gamma \approx 20$ GeV based on ~ 50 events
- Roughly 5-10 larger than J/ψ cross section
- Exclusive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



Prospects for future J/ψ production measurements



S. Joosten and Z.E. Meziani,
PoS QCDEV2017 (2018) 017

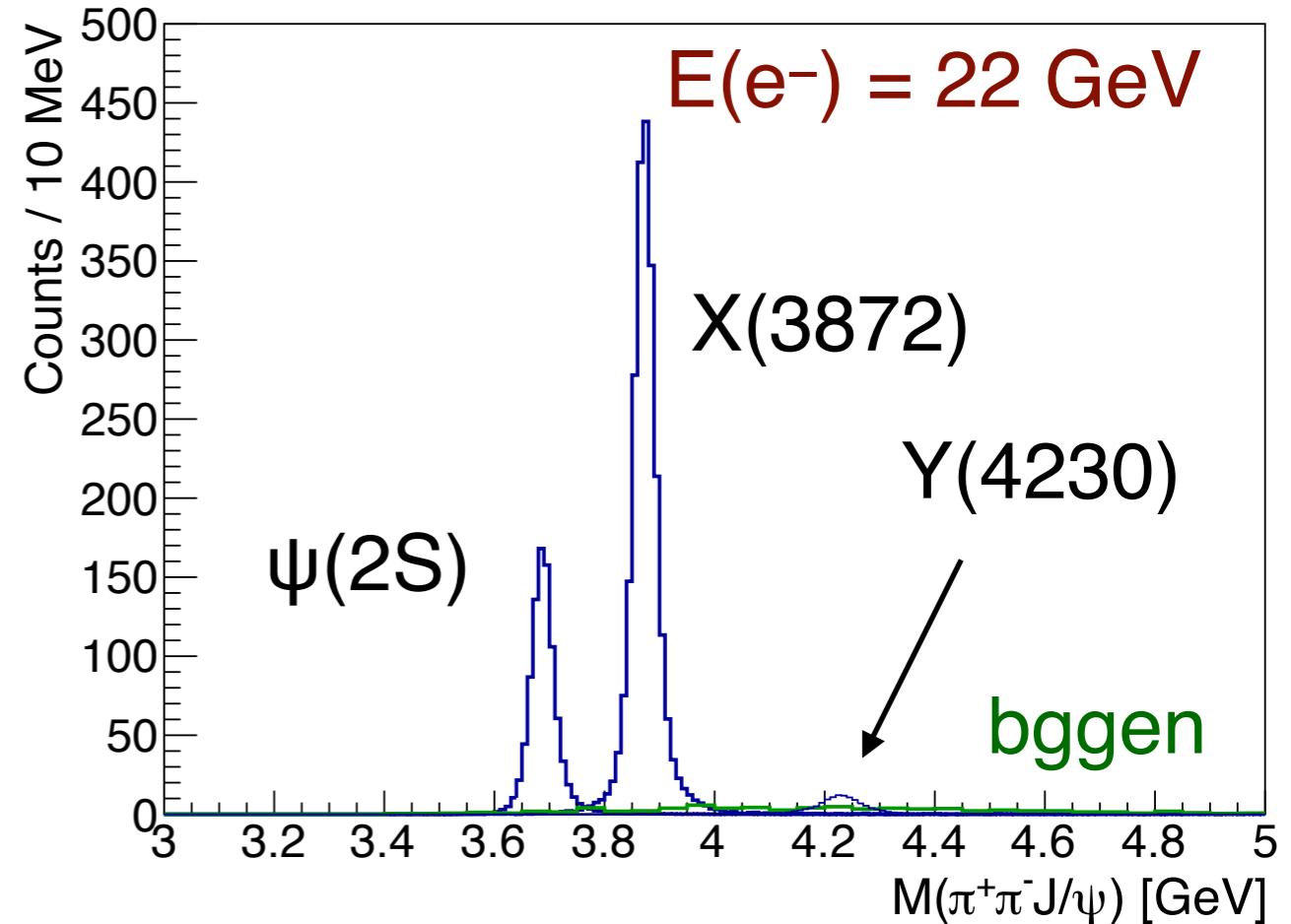
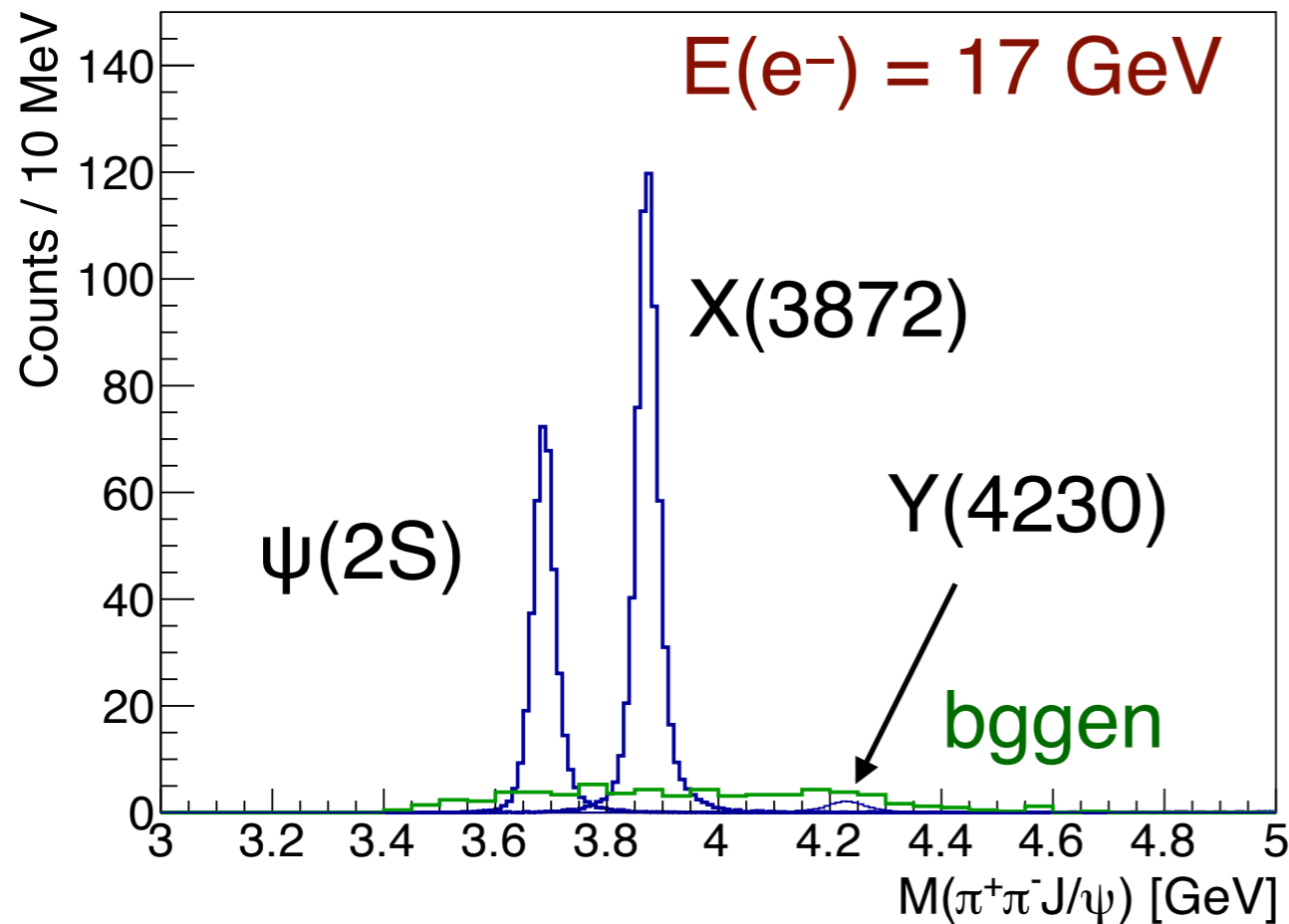


L. Pentchev, J/ψ + Beyond Workshop

- JLab Hall C measurements also see no clear P_c , limits are similarly model-dependent, CLAS12 measurements under way
 - Proposal for double polarization measurements in Hall A
- Future: electro- and photoproduction at SOLID ($\mathcal{L} = 10^{37} \text{cm}^{-2} \text{s}^{-1}$)
- More future: linearly polarized photoproduction at GlueX with energy-upgraded CEBAF

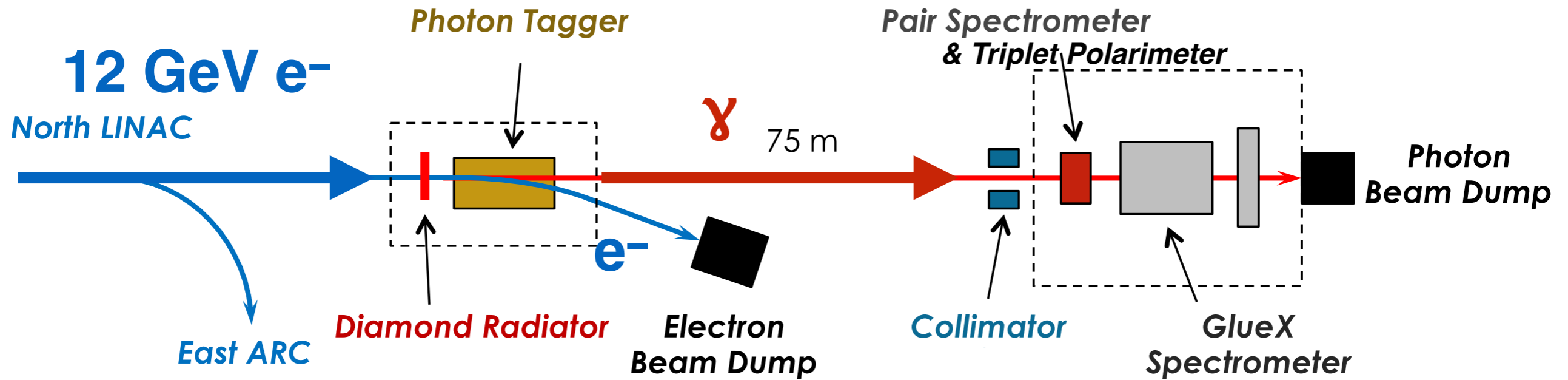
Projections for $J/\psi\pi^+\pi^-$ Photoproduction at GlueX

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



- Assumes 1 year @ 500 pb^{-1} , $\text{Br}(X, Y \rightarrow \pi^+\pi^-J/\psi) = 5\%$
- 17 GeV: $N(\psi(2S)) = 400$, $N(X(3872)) = 650$, $N(Y(4260)) = 20$
- 22 GeV: $N(\psi(2S)) = 900$, $N(X(3872)) = 2300$, $N(Y(4260)) = 120$

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 $\sim 1-5 \times 10^7$ γ/s in peak

