

Hall D Highlights

Andrew Smith

Postdoctoral Research Fellow – Hall D

2025 DNP Fall Meeting - JLUO Satellite Meeting

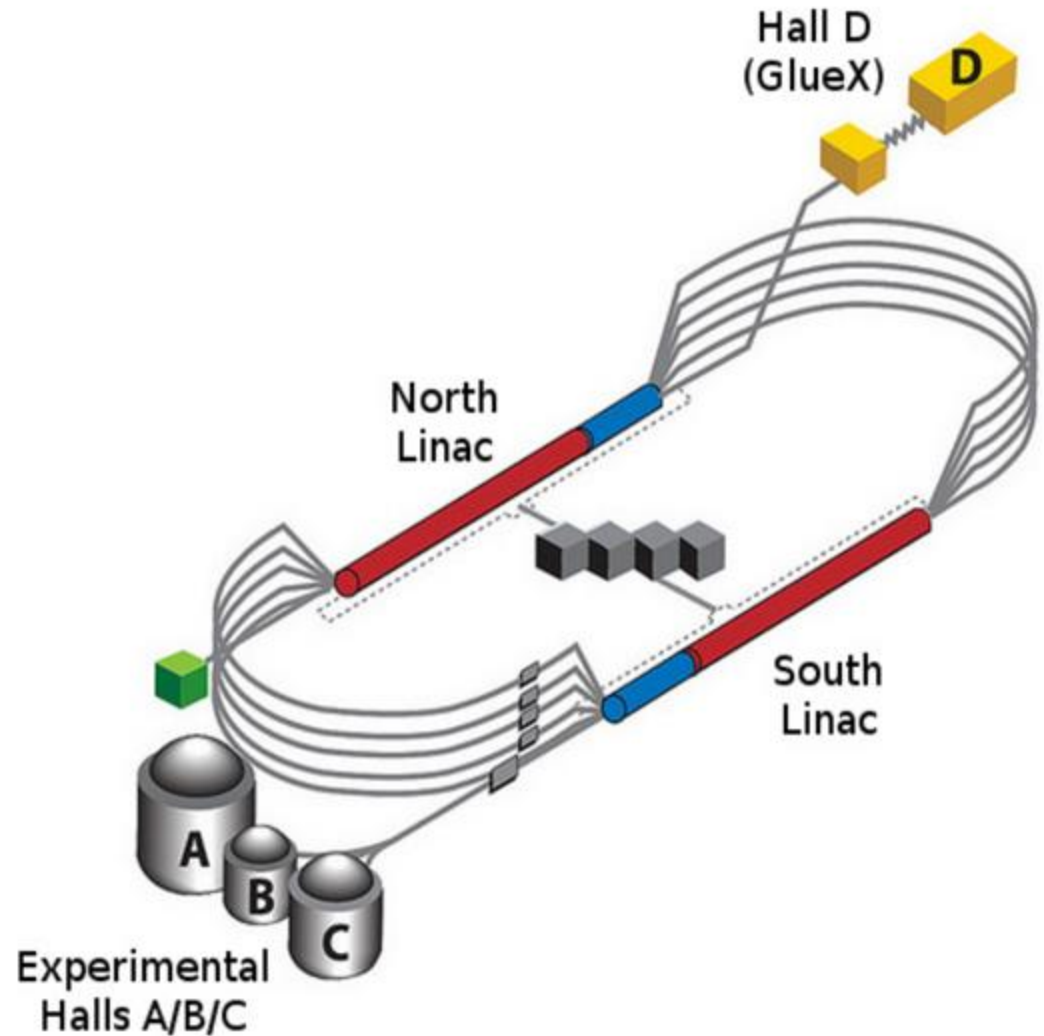
Saturday, October 18, 2025

Talk Outline

- 1) 2025 Run – GlueX-II / JEF
 - Commissioning and development of new detectors
- 2) Recent Physics Results
 - 5 publications in 2025
- 3) Future Plans/Outlook



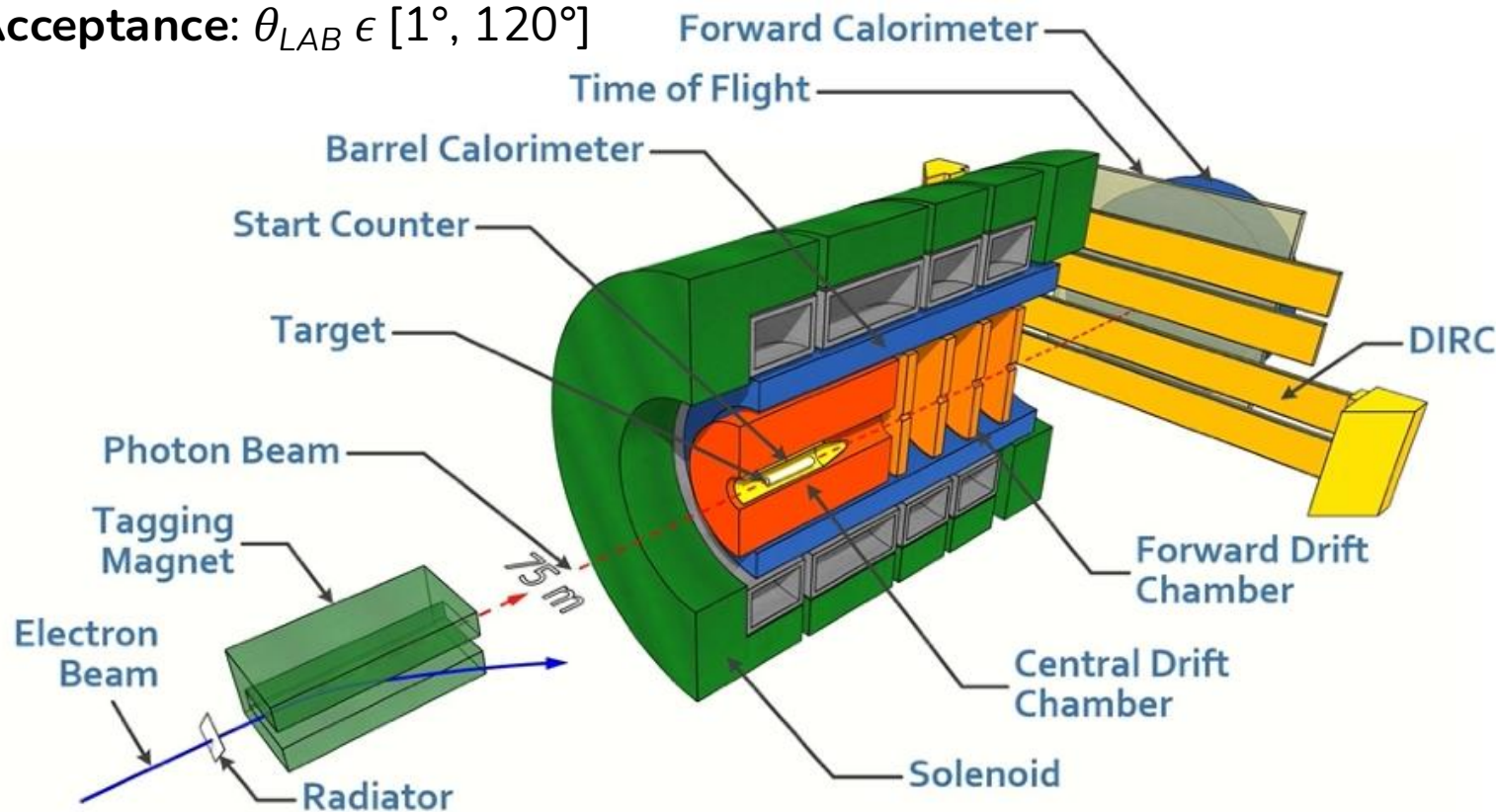
Thomas Jefferson National Accelerator Facility



Hall D Beamline and GlueX Spectrometer

[Nucl. Instrum. & Meth. A, 987, 164807(2021)]

Large Acceptance: $\theta_{LAB} \in [1^\circ, 120^\circ]$



$$\text{(neutrals)} \quad \sigma_E/E \approx \frac{6\%}{\sqrt{E}} \oplus 4.5\%$$

$$\text{(charged)} \quad \sigma_P/P \approx 2 - 5\%$$

Over 600 pb⁻¹ total luminosity collected so far

Hall D Program

Experiment	name	Collab.	Title	PAC rating	PAC days	data taken
E12-06-102	GlueX-I	GlueX	Mapping the Spectrum of ... and Gluonic Excitations	A	120	100%
E12-12-002 A	GlueX-II JEF	GlueX	A study of meson and baryon decays to strange final states	A	220	80%
		GlueX	Rare η Decays: The JLab η Factory (JEF experiment)	Grp	100	75%
E12-10-011	PrimeX- η	GlueX	Measurement of the $\eta \rightarrow \gamma\gamma$ Decay Width via Primakoff	A-	79	100%
E12-13-008	CPP/NPP	GlueX	Measuring the Pion Polarizability in the $\gamma\gamma \rightarrow \pi\pi$ Reaction	A-	25	100%
E12-19-003	SRC/CT	SRC	Studying Short-Range Correlations with Real Photon Beam	B+	15	100%
<i>Not yet scheduled</i>						
E12-19-001	KLF	KLF	Strange Hadron Spectroscopy with Secondary KL Beam	A-	200	
E12-20-011	REGGE	GlueX	The high-energy contribution to the GDH sum rule	A-	33	
E12-24-006	GlueX-III	GlueX	Photoproduction of Charmonia at High Luminosity	A	200	
E12-25-002	Nuclear J/ψ	SRC	Photoproduction of J/ψ as a Probe of Nuclear Gluons	B+	85	
E12-25-005		GlueX	GlueX with a 1-4 GeV Photon Beam	A-	28	
E12-25-012		GlueX	ϕ Production off Tensor Polarized Deuteron	A-	65	
Remaining approved program: 700 PAC days \approx 8 years of running						

 - considerable installation / new equipment required

 - finished data taking

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2025 Run: GlueX-II / JEF

JLab Eta Factory (JEF) Experiment

Mode	Branching Ratio	Physics Highlight	Photons
priority:			
$\gamma + B'$	beyond SM	leptophobic dark boson	4
$\pi^0 2\gamma$	$(2.7 \pm 0.5) \times 10^{-4}$	χ PTh at $\mathcal{O}(p^6)$	4
$3\pi^0$	$(32.7 \pm 0.2)\%$	$m_u - m_d$	6
$\pi^+ \pi^- \pi^0$	$(22.9 \pm 0.3)\%$	$m_u - m_d$, CV	2
3γ	$< 1.6 \times 10^{-5}$	CV, CPV	3

Search for sub-GeV dark boson:

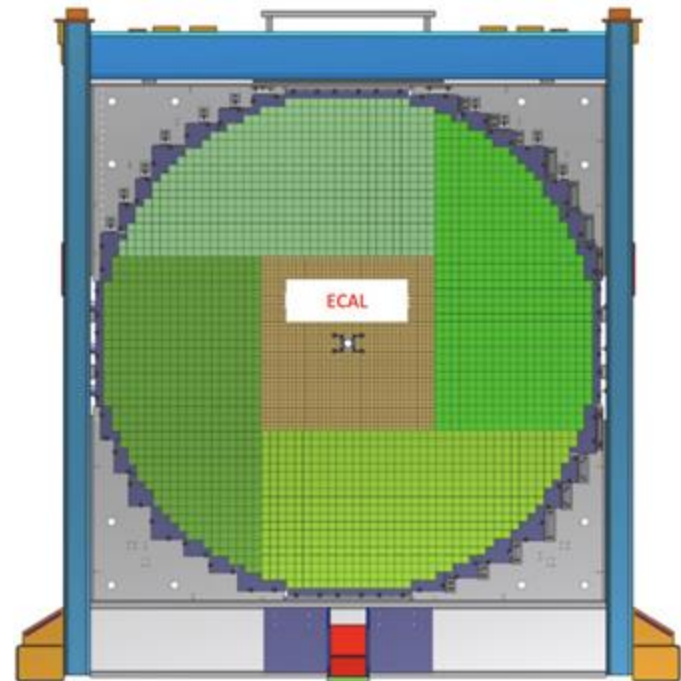
- $\eta, \eta' \rightarrow B' \gamma \rightarrow \pi^0 \gamma \gamma$
- $0.14 < m_{B'} < 0.54$ GeV

Precision tests of low-energy QCD

- Interplay of VMD & scalar dynamics in ChPT

Major upgrade to Forward Calorimeter

- Lead-tungstate insert
- More precise detection of multi-photon final states in forward direction
- Improved cluster separation



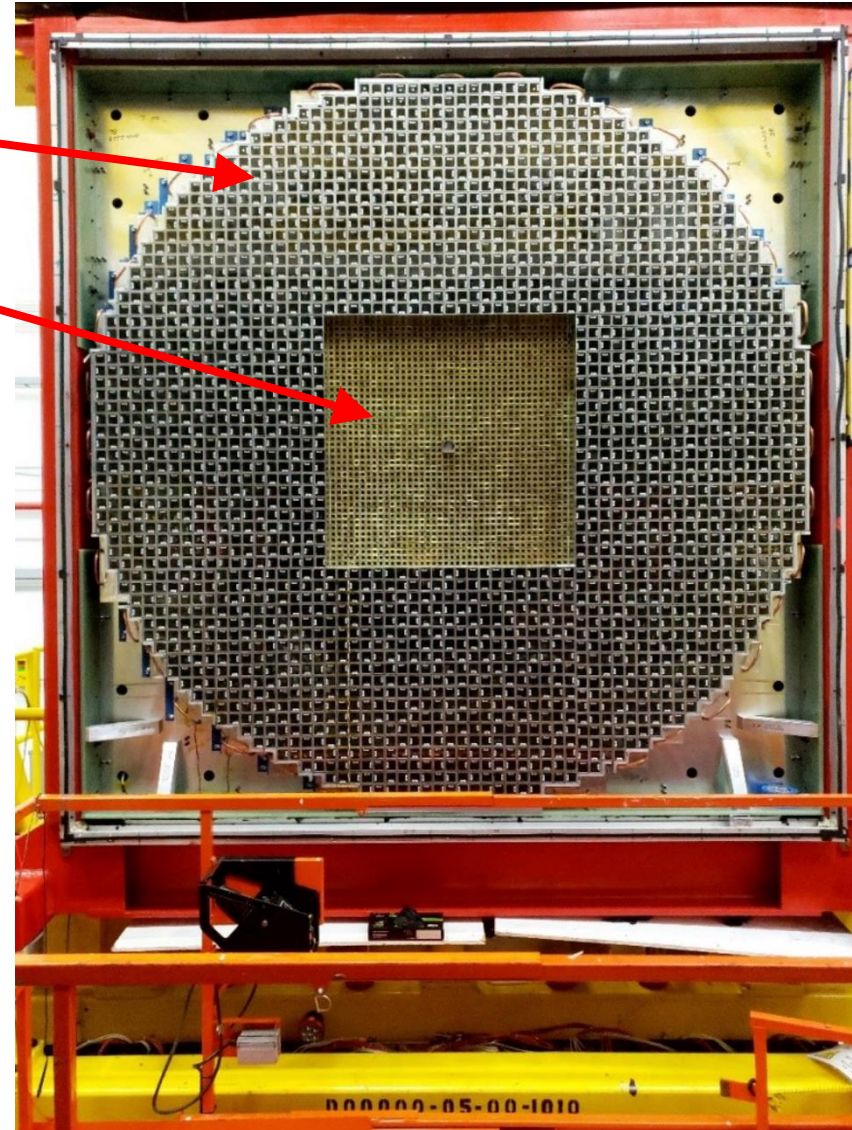
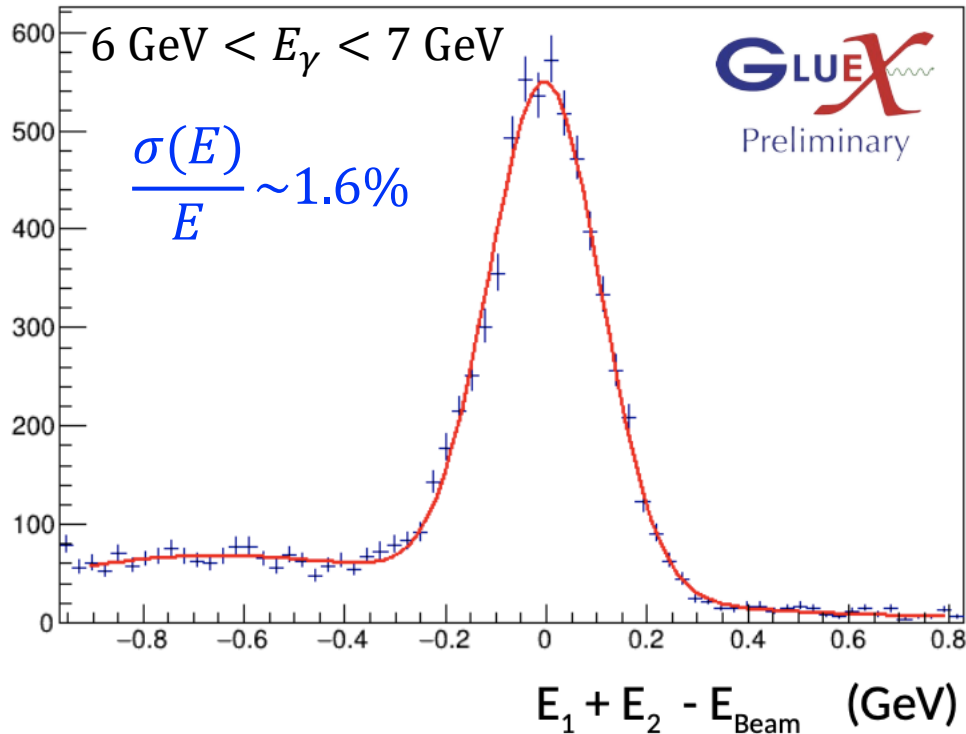
FCAL-II Detector Commissioning

Outer layer:

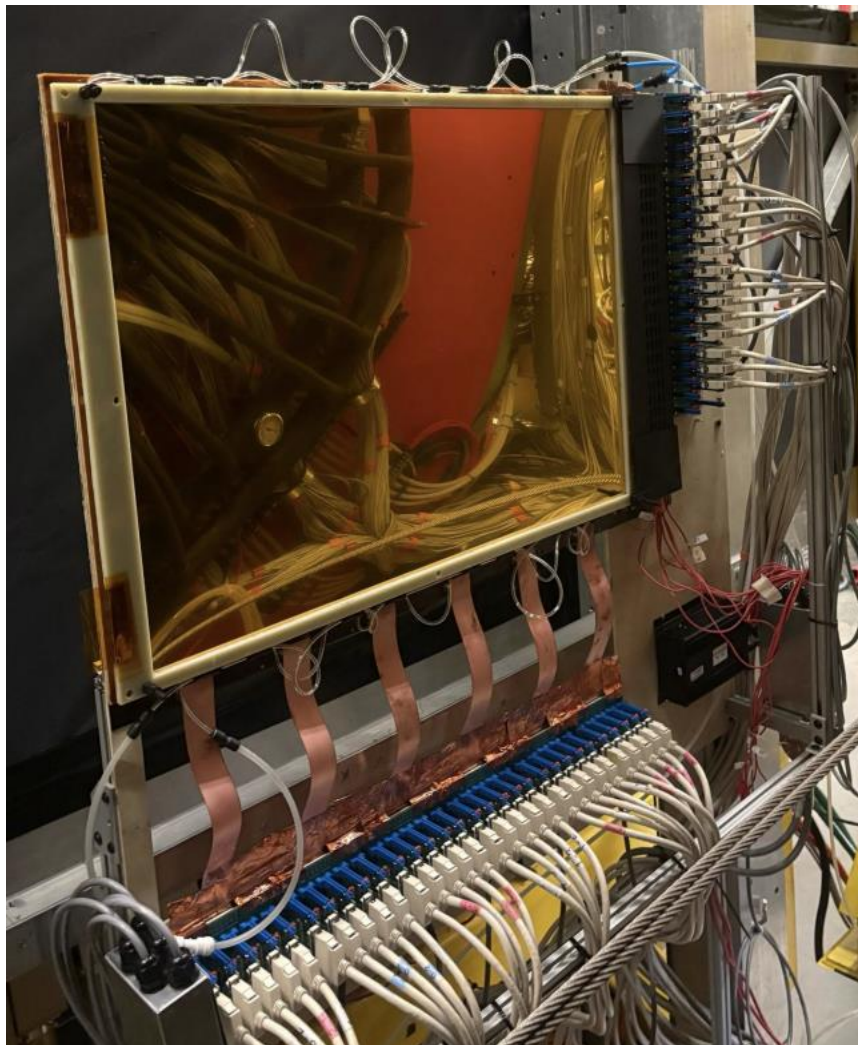
- Pb-glass (4 x 4 x 45cm)

Inner region (ECAL):

- PbWO_4 crystals (2 x 2 x 20cm)

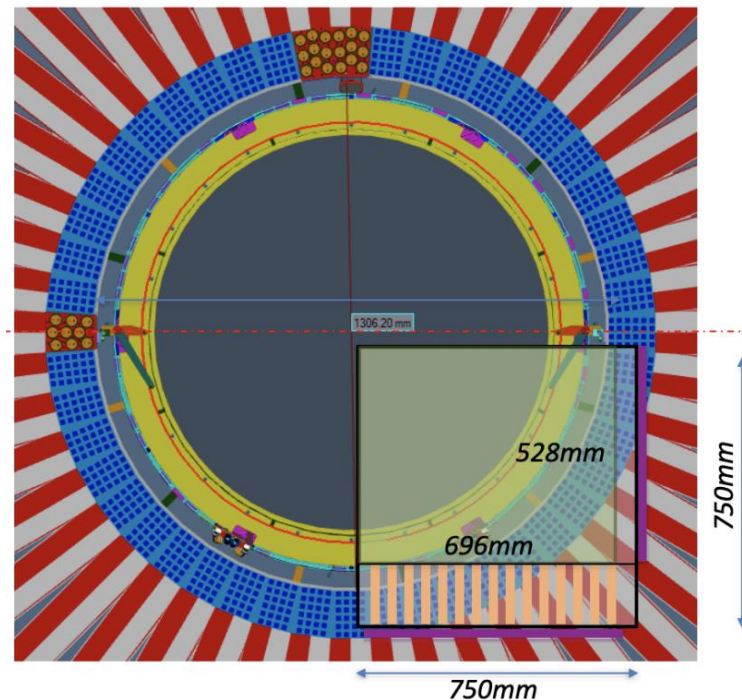


GEM-TRD Large-Scale Prototype



Gaseous Electron Multiplier (GEM) –
Transition Radiation Detector (TRD)

- New detector proposed for GlueX-III
- Improve e/π separation for $J/\psi \rightarrow e^+e^-$



Overview of GlueX Physics

Photoproduction experiment provides opportunity to do broad range of physics

- Beam asymmetries
- Spin Density Matrix Elements (SDMEs)
- Baryon Spectroscopy
- J/Ψ photoproduction near threshold
- Electric and Magnetic polarizabilities of the pion (CPP/NPP)
- Fundamental symmetries from η decays (JEF)
 - Radiative decay width (PrimEx-eta)
 - Rare decays to test ChPT
- More...

Introduction & Motivation for GlueX

Conventional hadrons: Baryons (qqq), Mesons (qq)

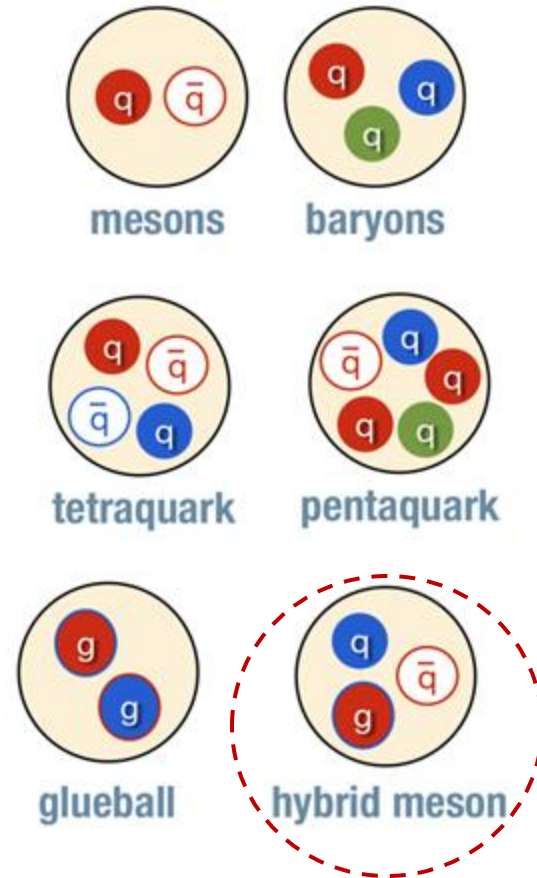
- For mesons: $P = (-1)^{L+1}$, $C = (-1)^{L+S}$

Exotic quantum numbers are “smoking gun” for exotic hybrid mesons

Primary goal of GlueX: *Contribute to the search for and study of exotic hybrid mesons*

Photoproduction experiment:

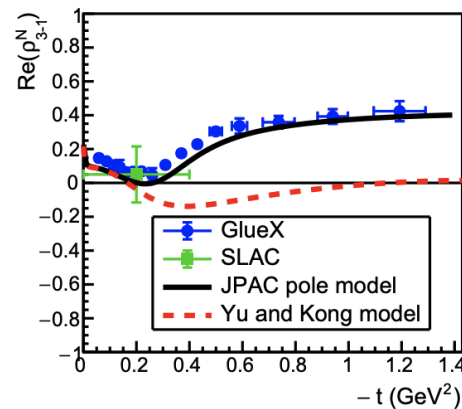
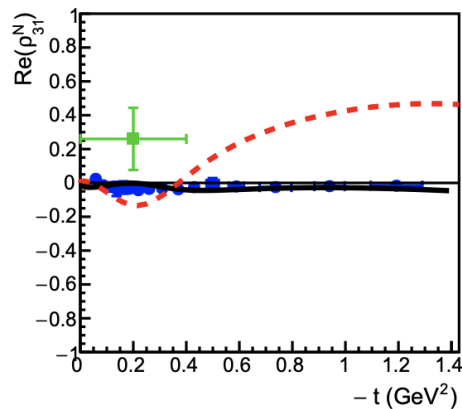
- Complementary dataset for pion beam experiments (e.g. COMPASS)
- Polarized photons - isolate specific quantum states



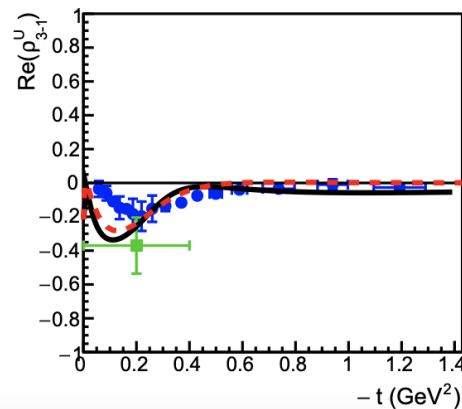
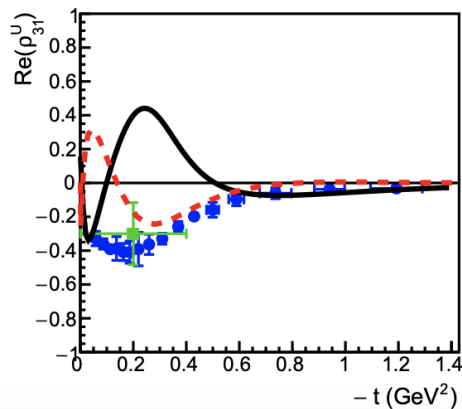
Spin-Density Matrix Elements

"Measurement of Spin-Density Matrix Elements in $\Delta^{++}(1232)$ Photoproduction", *Phys. Lett. B* **863**, 139368 (2025)

"Measurement of SDME in $\phi(1020) \rightarrow K_S^0 K_L^0$ photoproduction...", *Phys. Rev. C* **112**, 025203 (2025)



Natural Parity Exchange

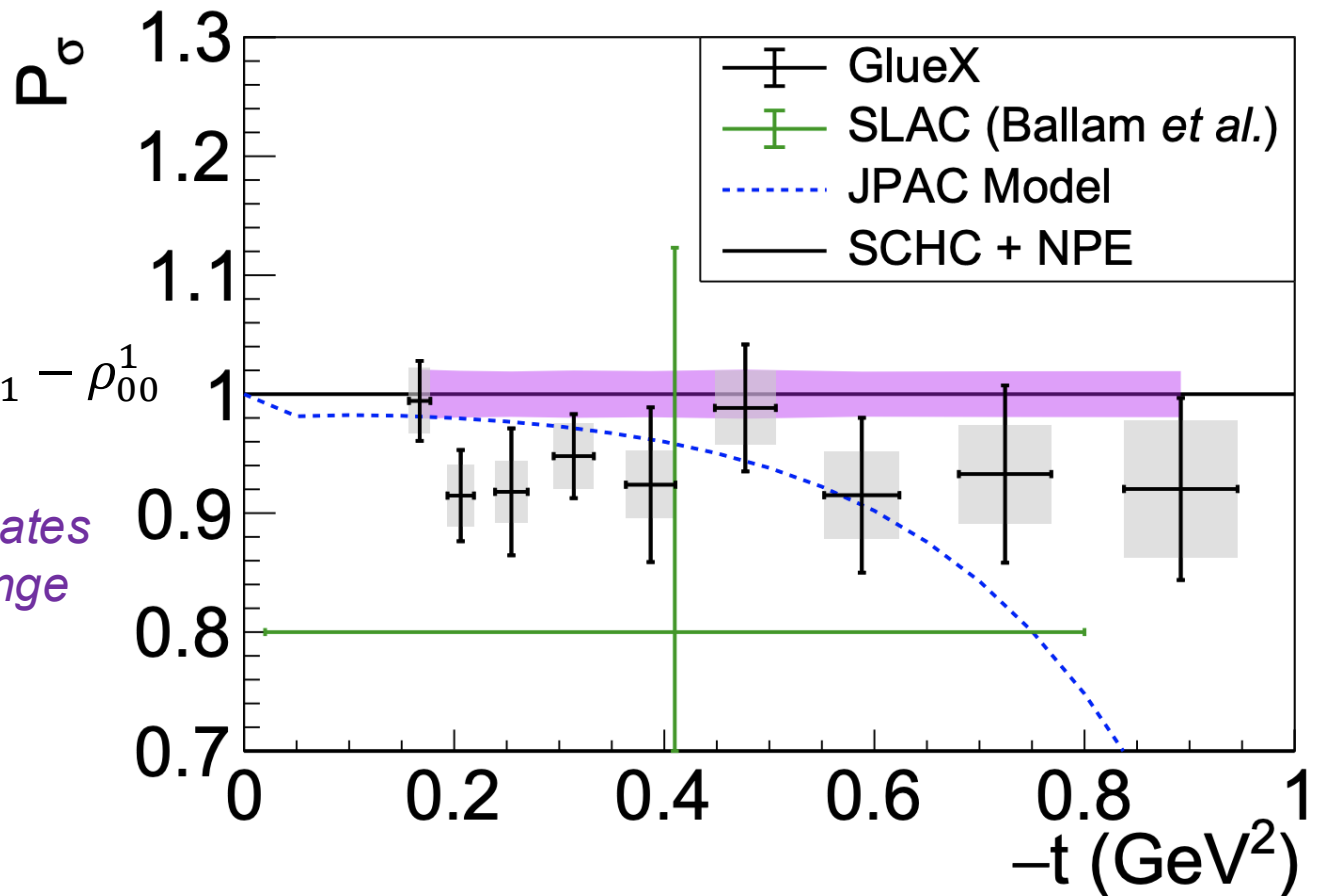


Unnatural Parity Exchange

Spin-Density Matrix Elements

"Measurement of Spin-Density Matrix Elements in $\Delta^{++}(1232)$ Photoproduction", *Phys. Lett. B* **863**, 139368 (2025)

"Measurement of SDME in $\phi(1020) \rightarrow K_S^0 K_L^0$ photoproduction...", *Phys. Rev. C* **112**, 025203 (2025)

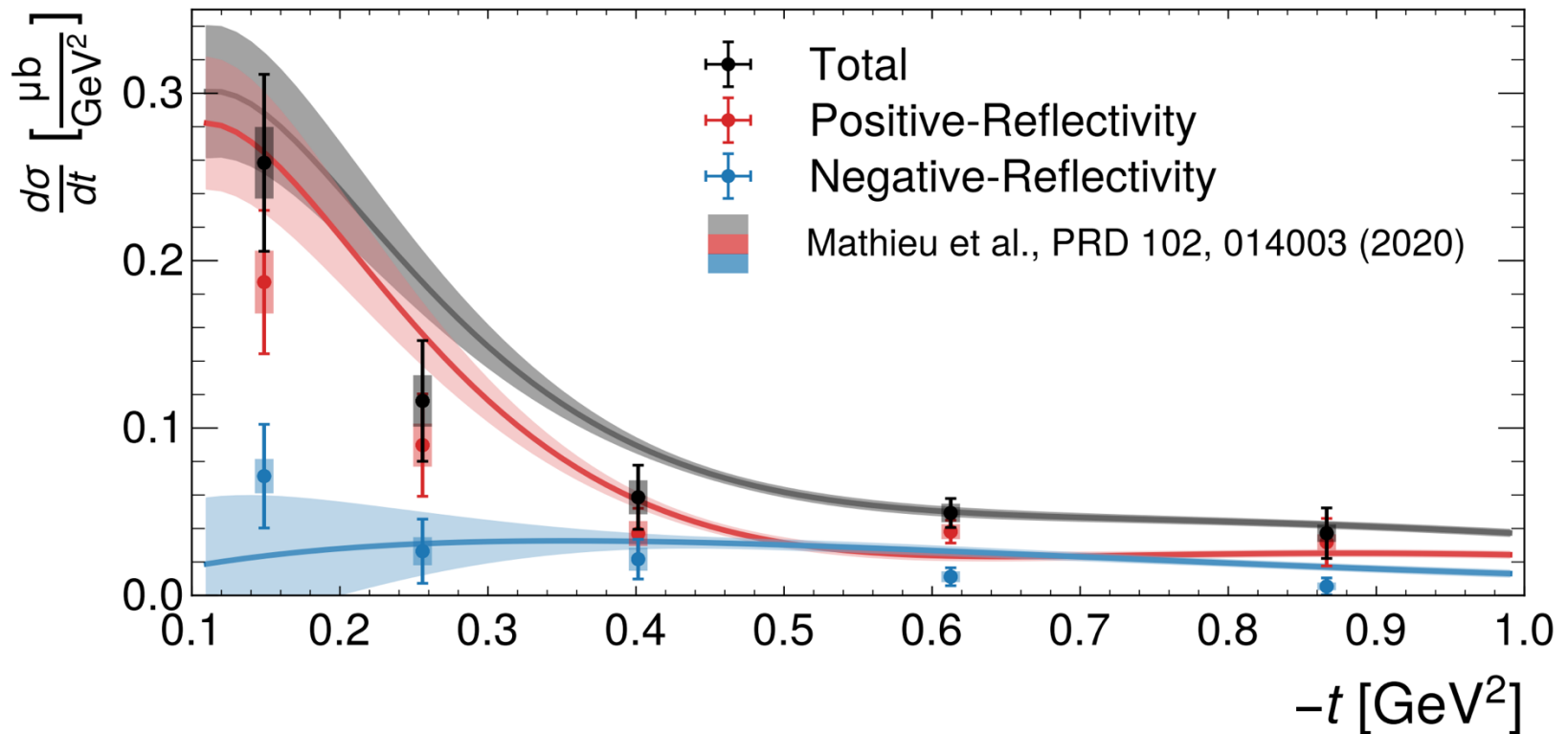


$$P_\sigma = \frac{\sigma_N - \sigma_U}{\sigma_N + \sigma_U} = 2\rho_{1-1}^1 - \rho_{00}^1$$

Parity asymmetry indicates unnatural parity exchange contribution is small

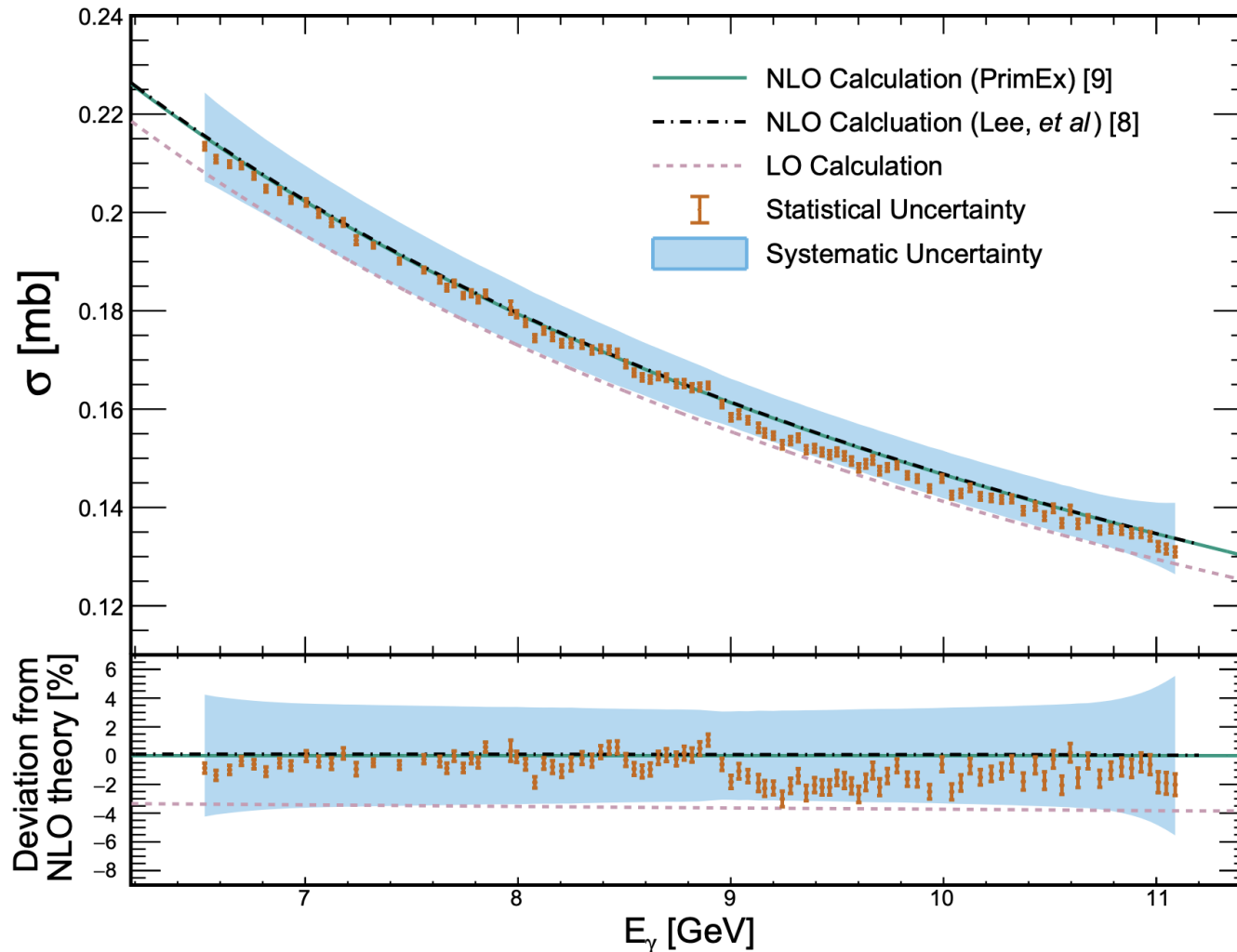
a_2^0 Cross Section

"First Measurement $a_2^0(1320)$ Polarized Photoproduction Cross Section", *Phys. Rev. C* **112**, 015204 (2025)



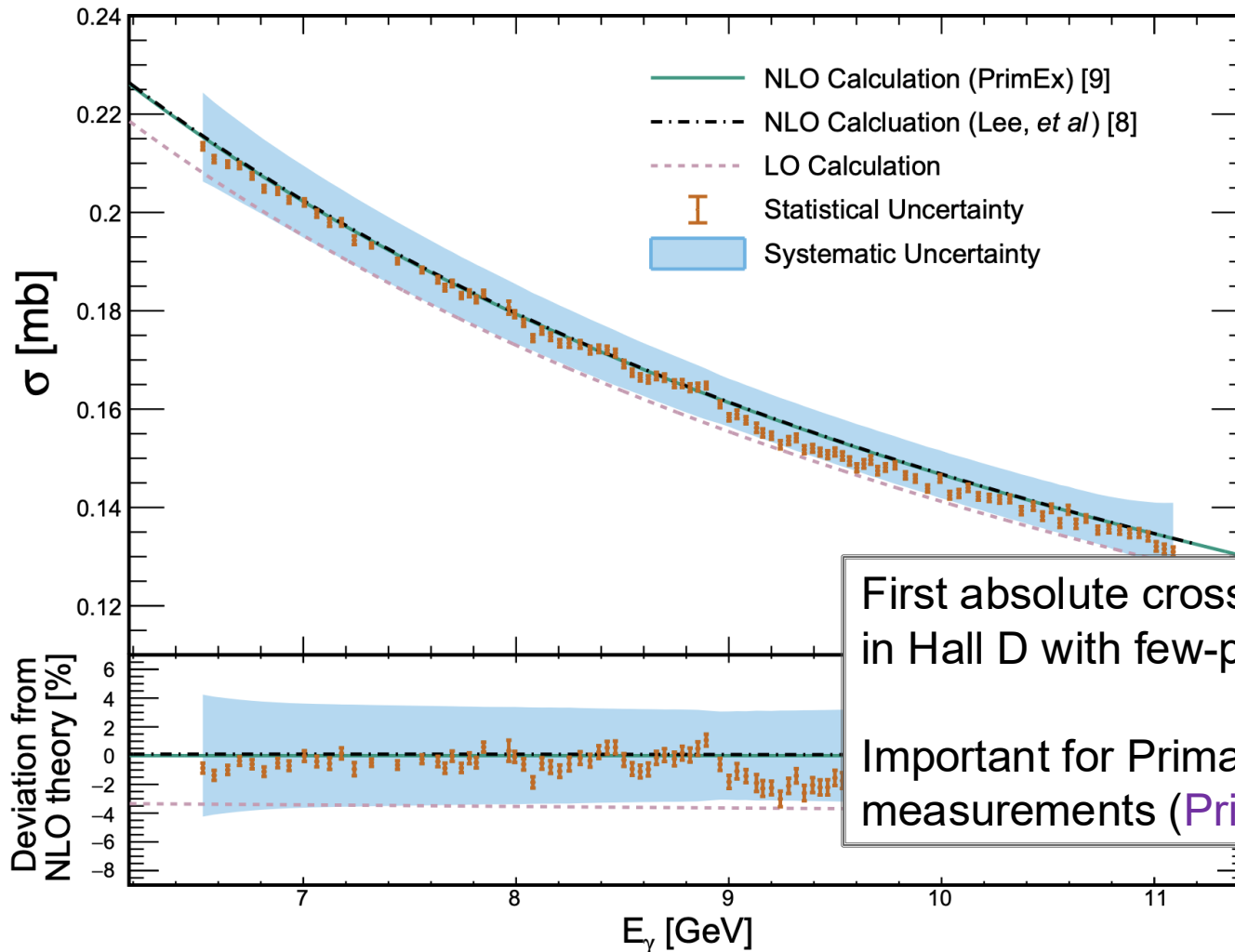
Compton Scattering ($\gamma + e^- \rightarrow \gamma + e^-$)

"Measurement of Total Compton Scattering Cross Section", *Phys. Lett. B* (pre-print) (2025)



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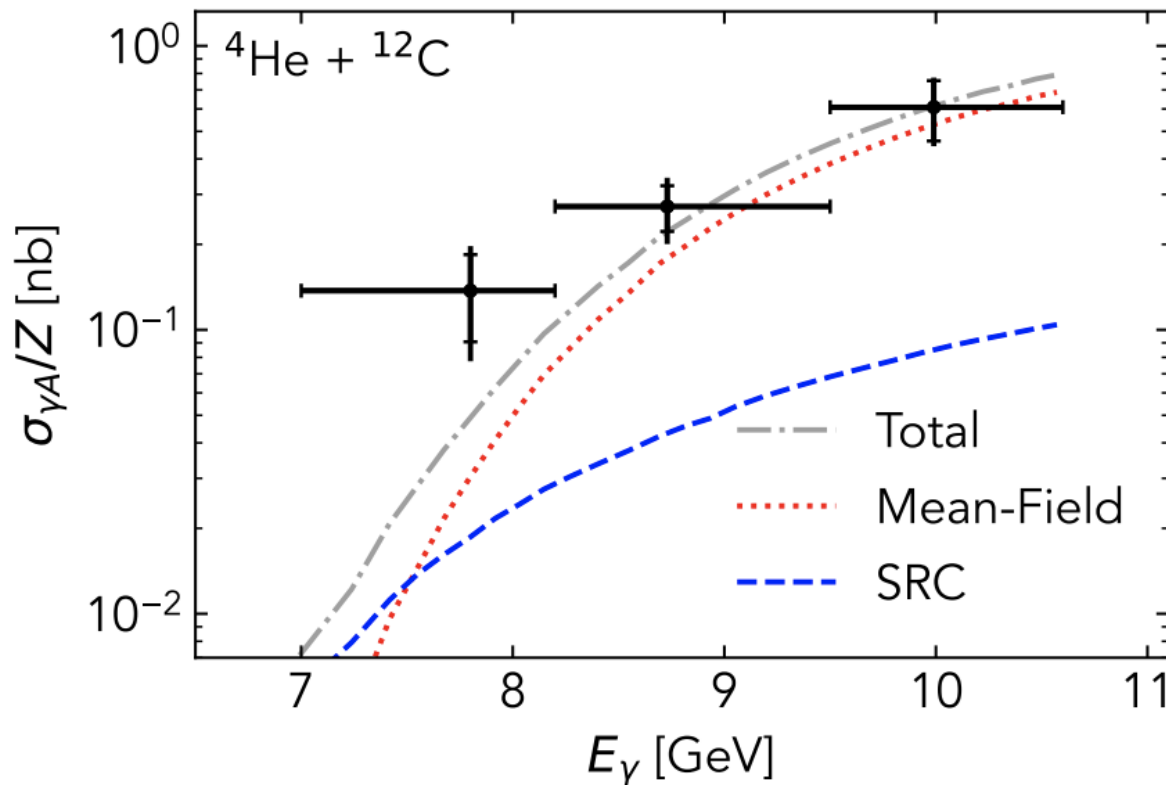
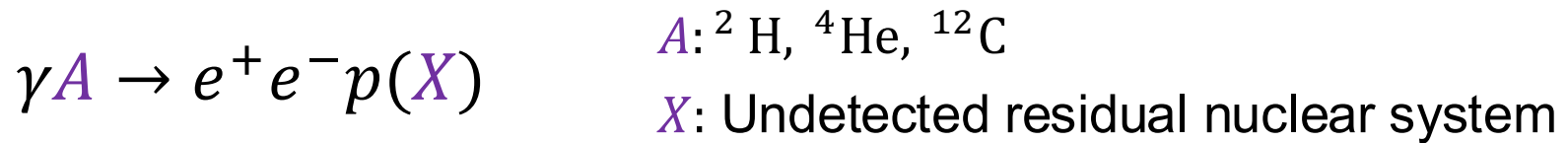


First absolute cross section measurement in Hall D with few-percent-level precision

Important for Primakoff cross section measurements (PrimEx-eta experiment)

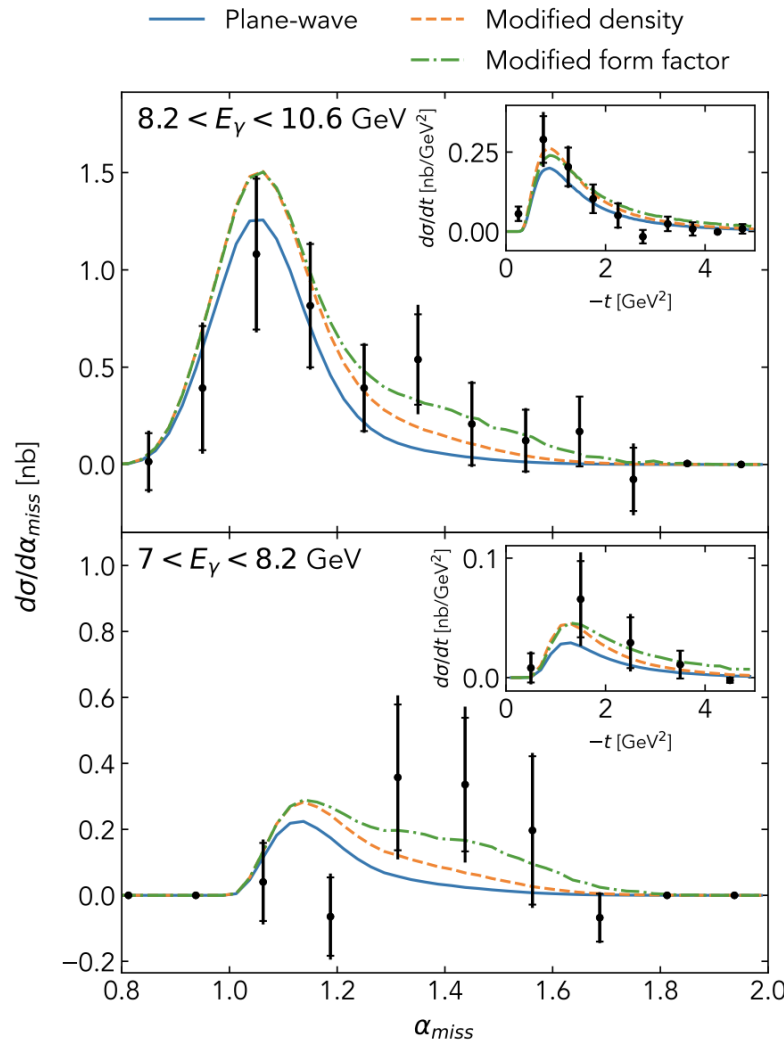
Sub-Threshold J/ψ Photoproduction (SRC/CT)

"First Measurement of Near- and Sub-Threshold J/ψ Photoproduction off Nuclei",
J. Pybus, et al., Phys. Rev. Lett. **134** 201903 (2025)



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 J. Pybus, et al., Phys. Rev. Lett. **134** 201903 (2025)



Glueonic radius of bound protons:

$$\sqrt{\langle r^2 \rangle} = 0.85 \pm 0.14 \text{ fm}$$

Further measurement needed to understand origin of excess at large momentum-fraction, α_{miss}

PAC 53 Results

E12-25-002 (SRC/CT): J/ψ off nuclei; 85 days approved; B+

- Requires GEM-TRD (under development for GlueX-III)

E12-25-005: (GlueX) at 1-4 GeV; 28 days approved; A-

- Opportunity for low-energy running in 2026
- ERR scheduled for November, 2025

E12-25-012: (GlueX) off Tensor-Polarized H; 65 days approved; A-

- Novel tensor-polarized deuterium target

J12-19-001: K-Long Facility (KLF); remain active (A-)

J12-20-011: (REGGE) GDH-Sum Rule; remain active (A-)

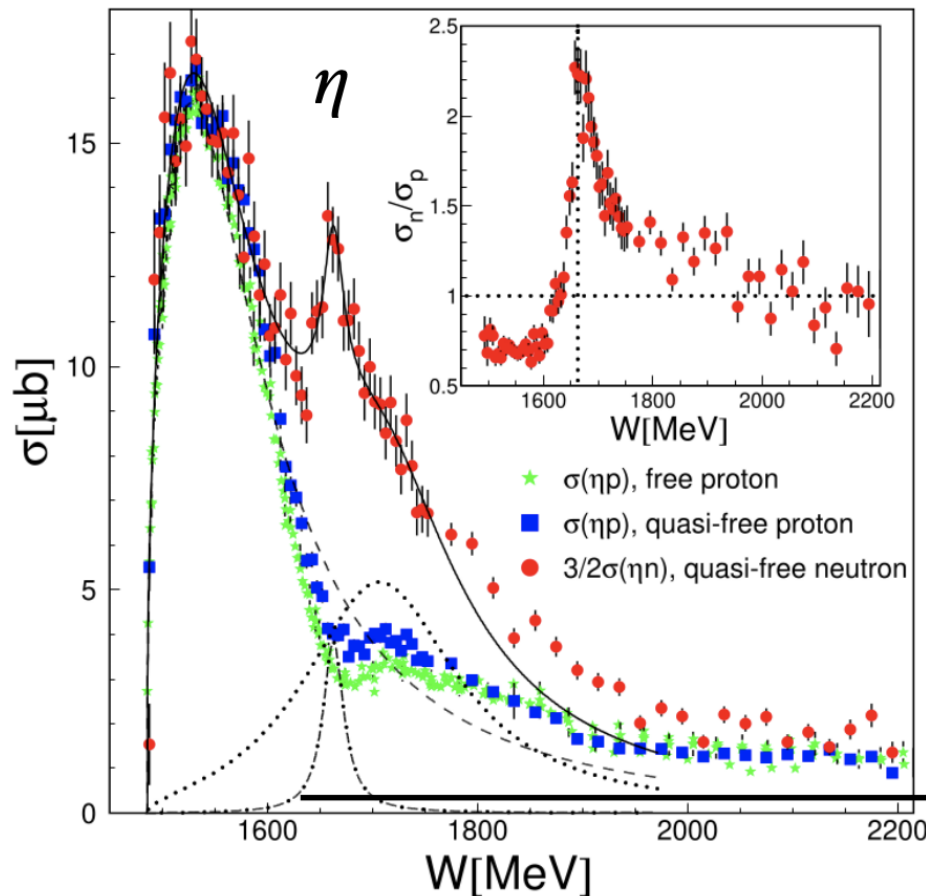
Low-Energy Run

Proposed to run in Feb 2026 (ERR)

~Equal time spent running on liquid Hydrogen and Deuterium targets

Physics Goals:

- Study $N(1685)$ using polarization observables
- Measure α_- parameter from $\Lambda \rightarrow p\pi^-$ decay
- Measure differential cross sections and study isospin decomposition of strong production amplitudes in transition between resonance and Regge regions

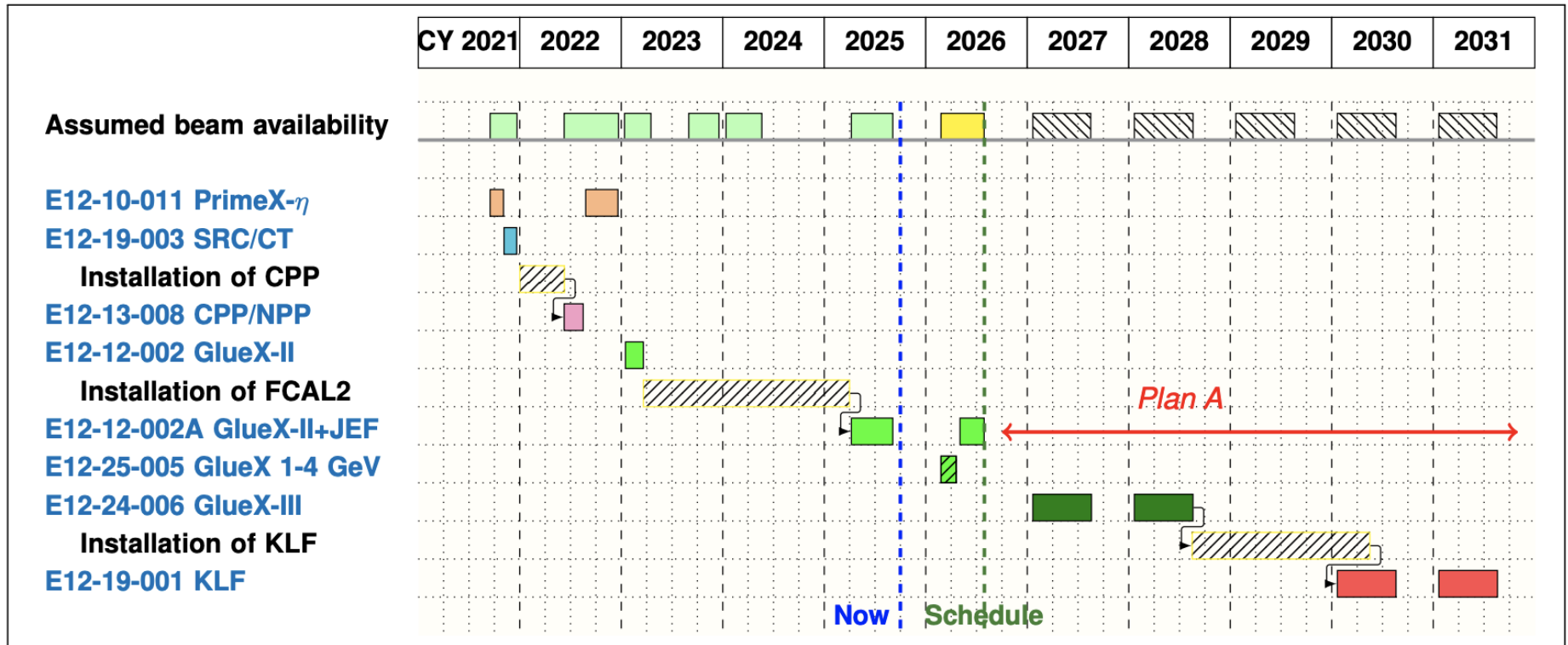


expand measurement to

$$E_\gamma = 3764 \text{ MeV}$$

$$W = 2818 \text{ MeV}$$

Potential Scheduling Outlook



Upcoming experiments are required to pass ERR

Final schedule for upcoming years not finalized, but the above timeline shows the preferred option for Hall D

Summary

Photoproduction at GlueX/related experiments span a diverse program

GlueX Phase 1 - Completed in 2018

GlueX Phase 2 – 80% complete after 2025, remaining data to be collected in 2026

GlueX Phase 3 – Will feature higher luminosity and GEM-TRD. Tentatively planned to start in 2027

Many exciting physics results are starting to emerge from GlueX analyses, many more to come!

Related upcoming session:

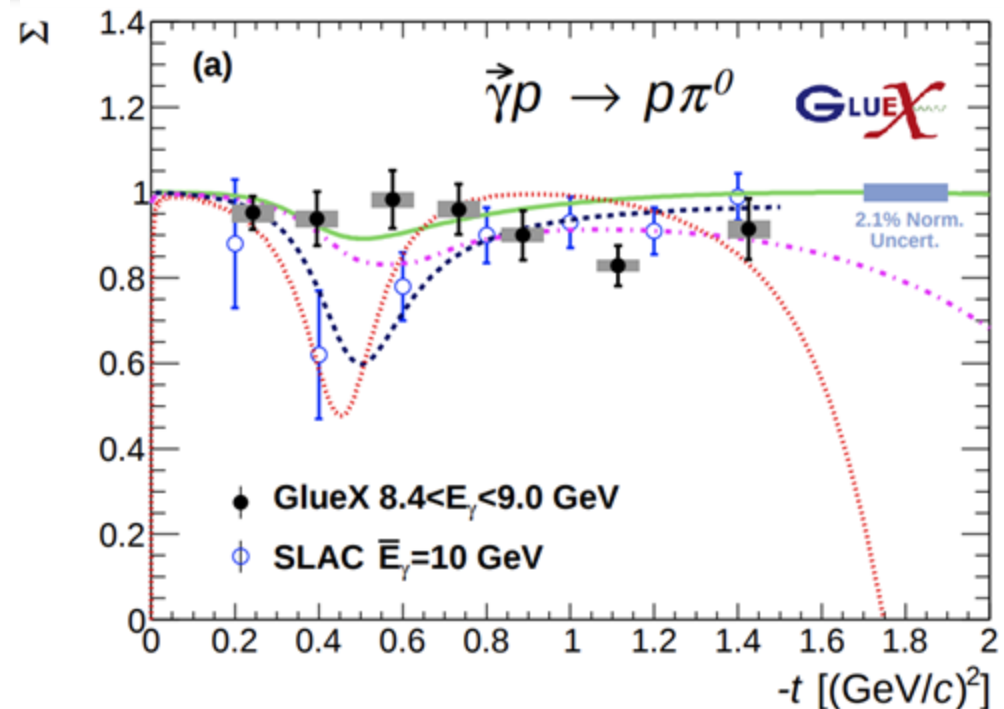
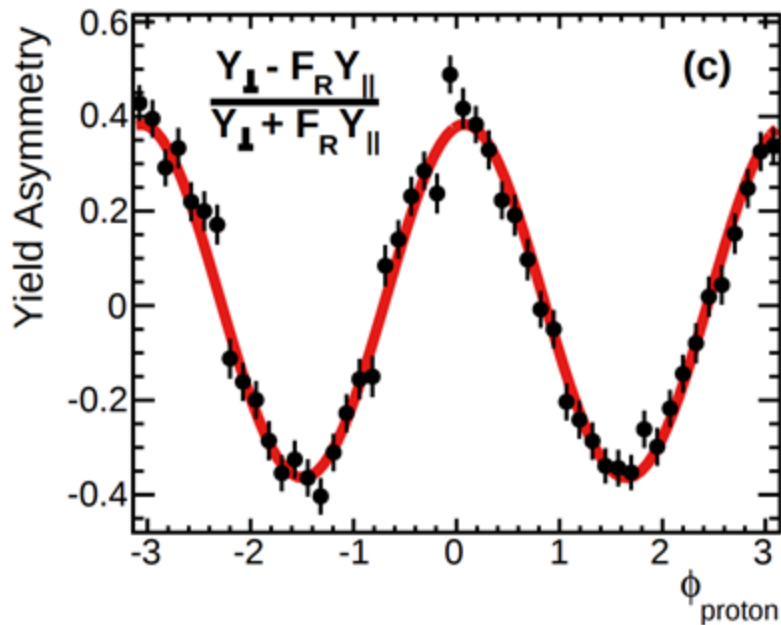
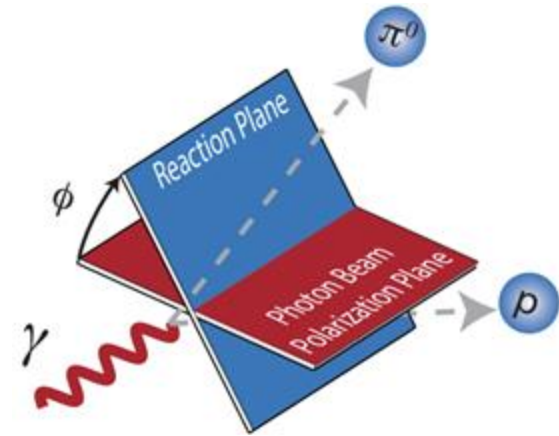
- Session S01 (Monday, 8:30AM) – *Recent Results from GlueX at Jefferson Lab*

Beam Asymmetry Measurements

[S. Adhikari, et al., Phys. Rev. C, 100, 052201 (2019)]

Cross section measurements with linearly polarized photon beam:

$$\sigma_{\text{pol}}(\phi) = \sigma_{\text{unpol}} [1 - p_{\gamma} \Sigma \cos 2\phi]$$



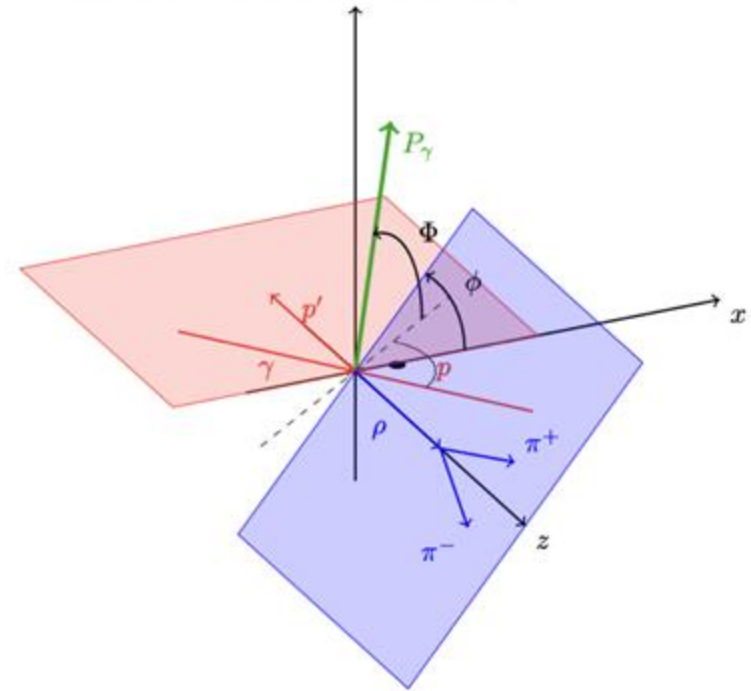
Spin Density Matrix Elements (SDMEs)

Polarization of states in meson photoproduction described by SDMEs

Linear beam polarization

→ Access 9 independent SDMEs

Intensity described as function of Φ , ϕ , θ

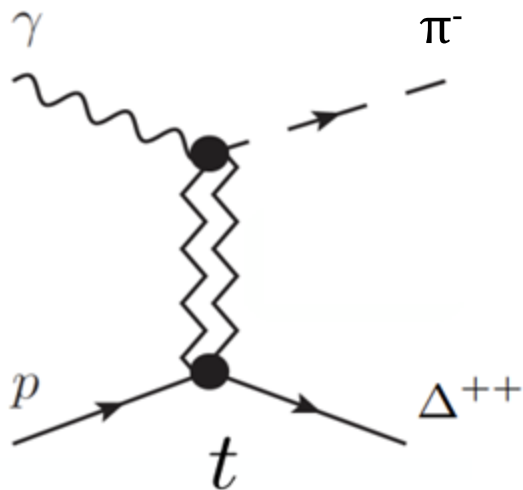


[Phys. Rev. C **108**, 055204 (2023)]

Spin Density Matrix Elements (SDMEs)

Two GlueX publications on SDMEs:

- 1) $\Lambda(1520)$ (Phys. Rev. C 105, 035201 (2022))
- 2) $\rho(770)$ (Phys. Rev. C 108, 055204 (2023))

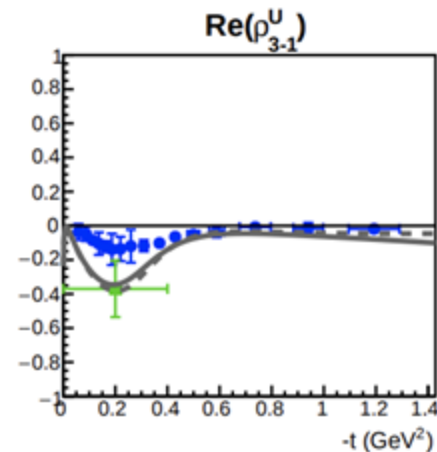
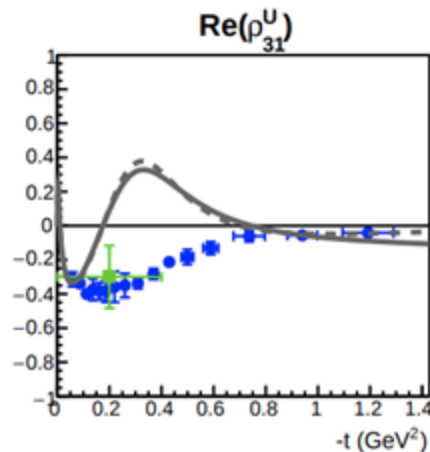
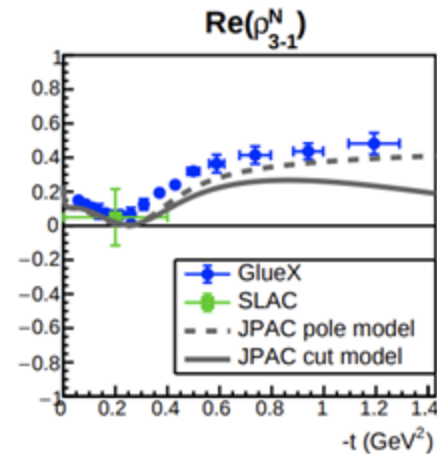
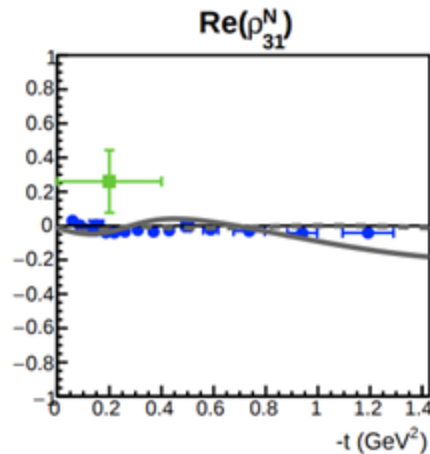


Measurements guide theoretical inputs needed for full amplitude analysis

→ Useful for amplitude analysis of $\eta\pi^-$

One more under review:

- 3) $\Delta^{++}(1232)$ (Submitted to Phys. Lett. B (2024))



Near-threshold J/ψ Photoproduction

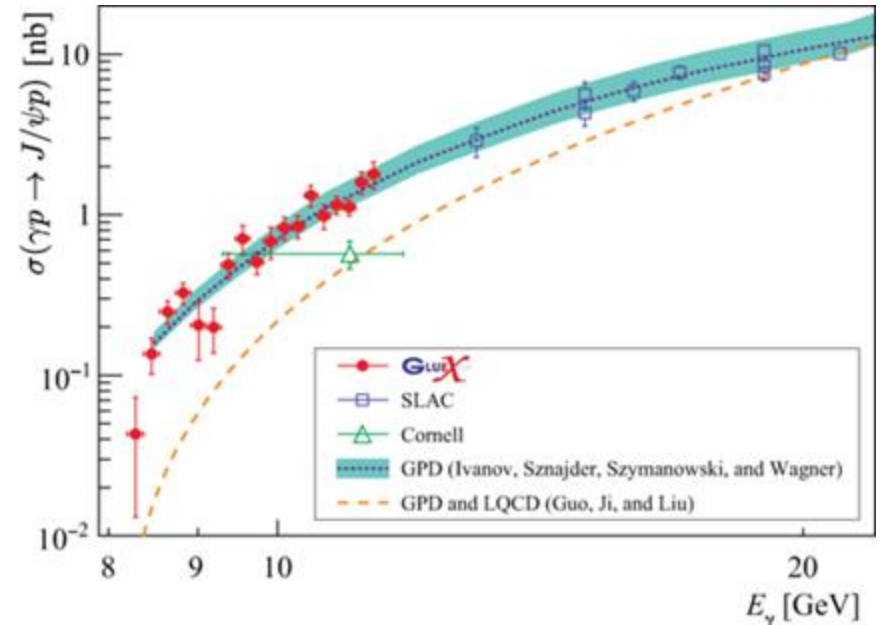
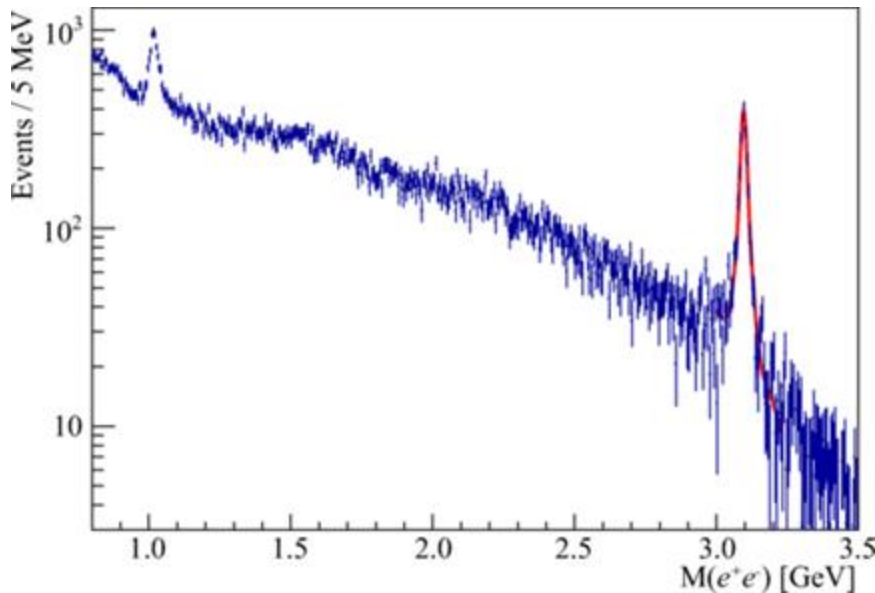
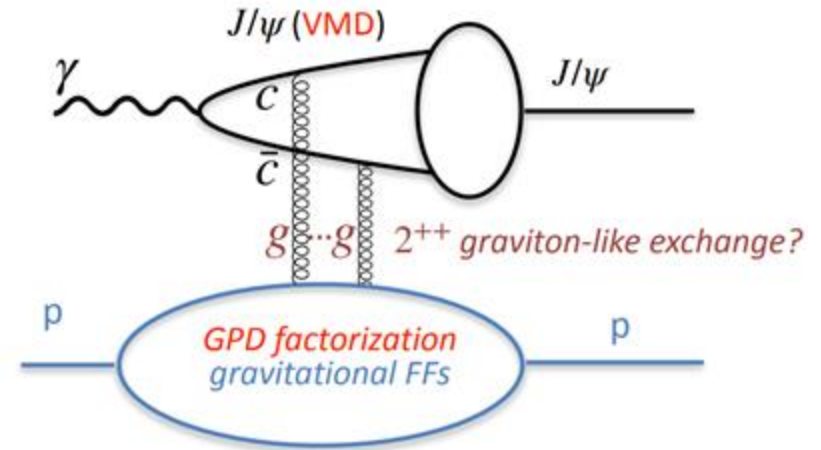
[S. Adhikari, et al., Phys. Rev. Lett., 123, 072001 (2019)] → First measurement near threshold!

[S. Adhikari, et al., Phys. Rev. C, 108, 025201 (2023)]

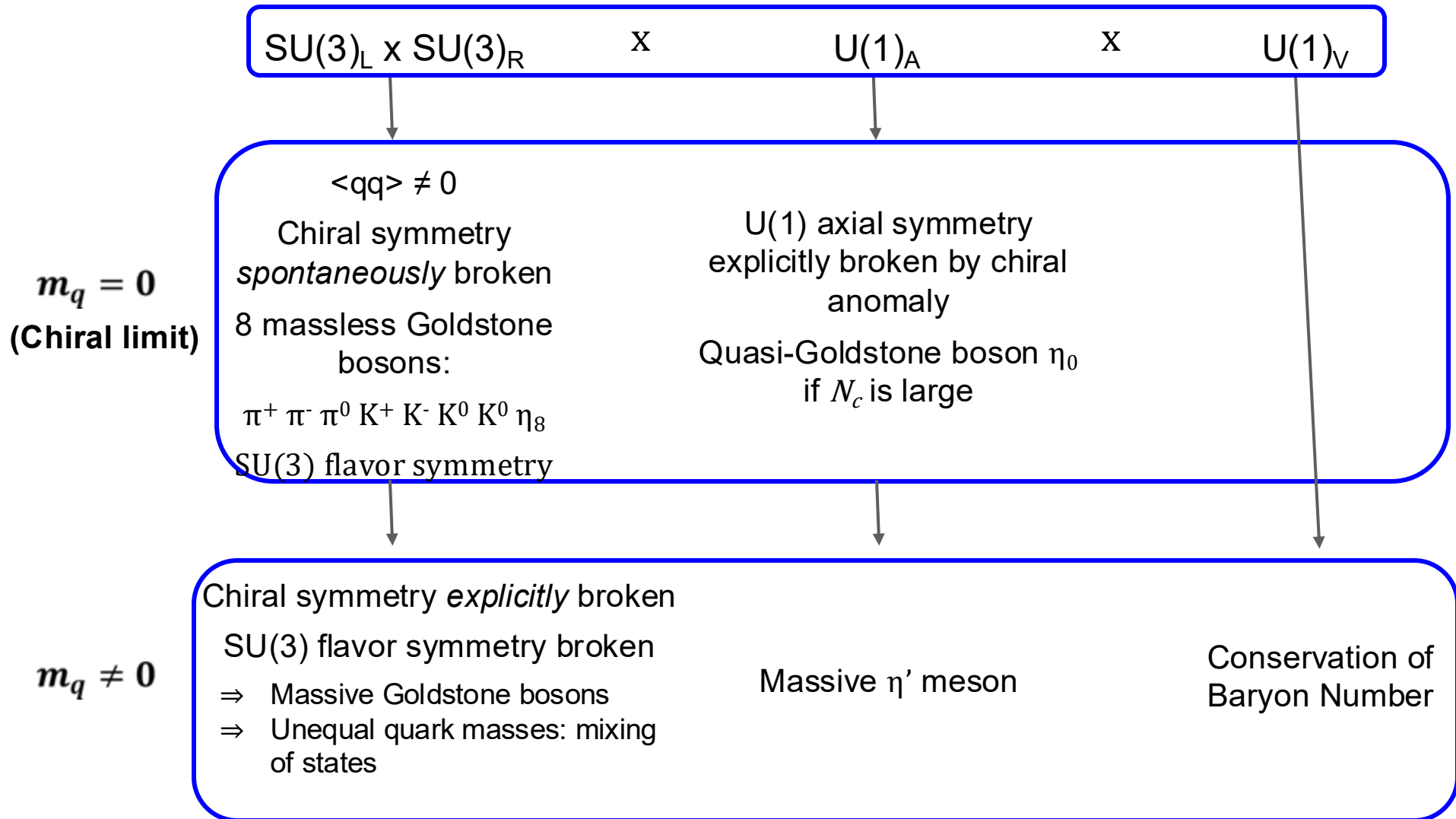
Near threshold, gluon exchange dominates:

J/ψ production related to:

- gluonic GPDs of proton
- mass radius
- trace anomaly contribution to proton mass
- J/ψ interaction length

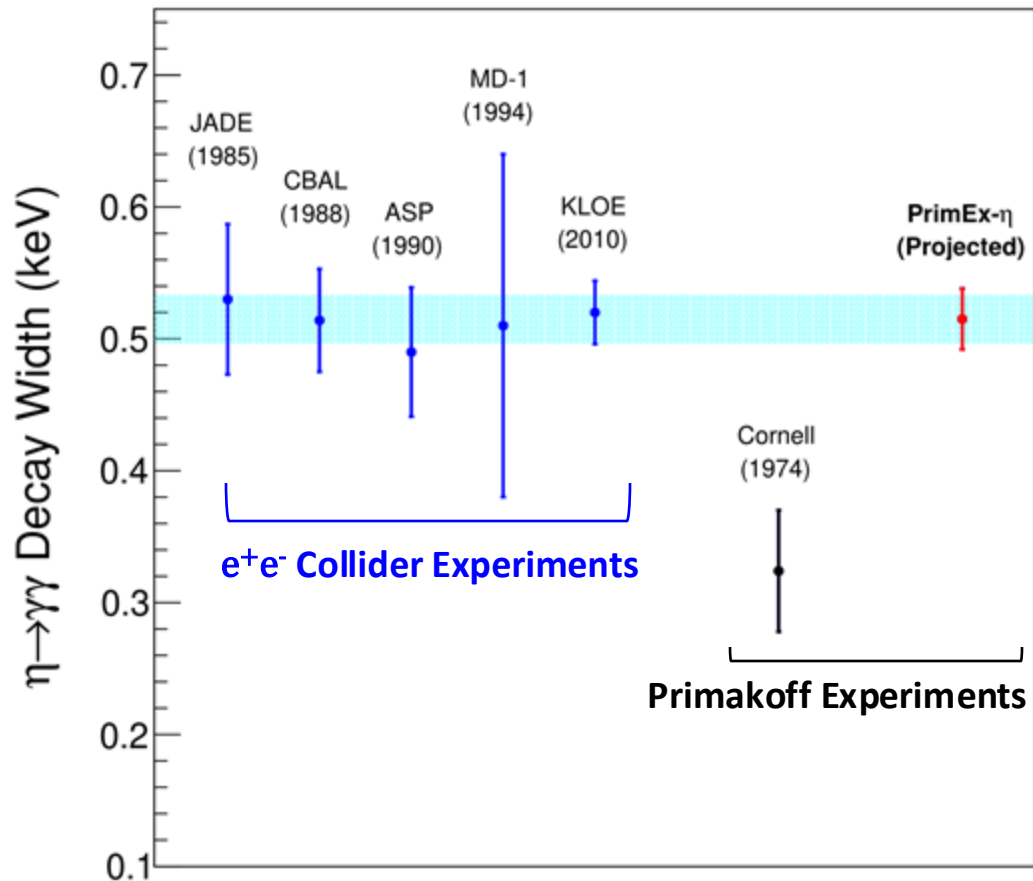


Symmetries in Low-Energy QCD



PrimEx-eta Experiment

Precision measurement of the η meson radiative decay width via the **Primakoff Method**.



PDG Average: $\Gamma(\eta \rightarrow \gamma\gamma) = 0.515 \pm 0.018$ keV

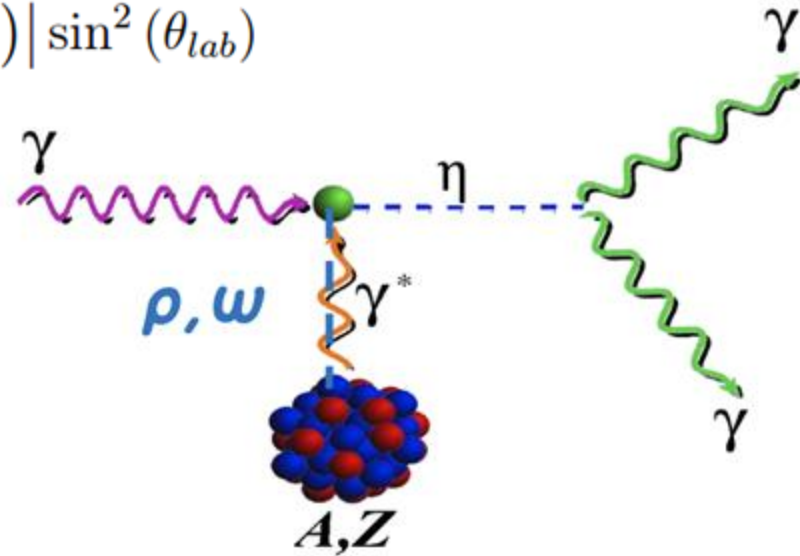
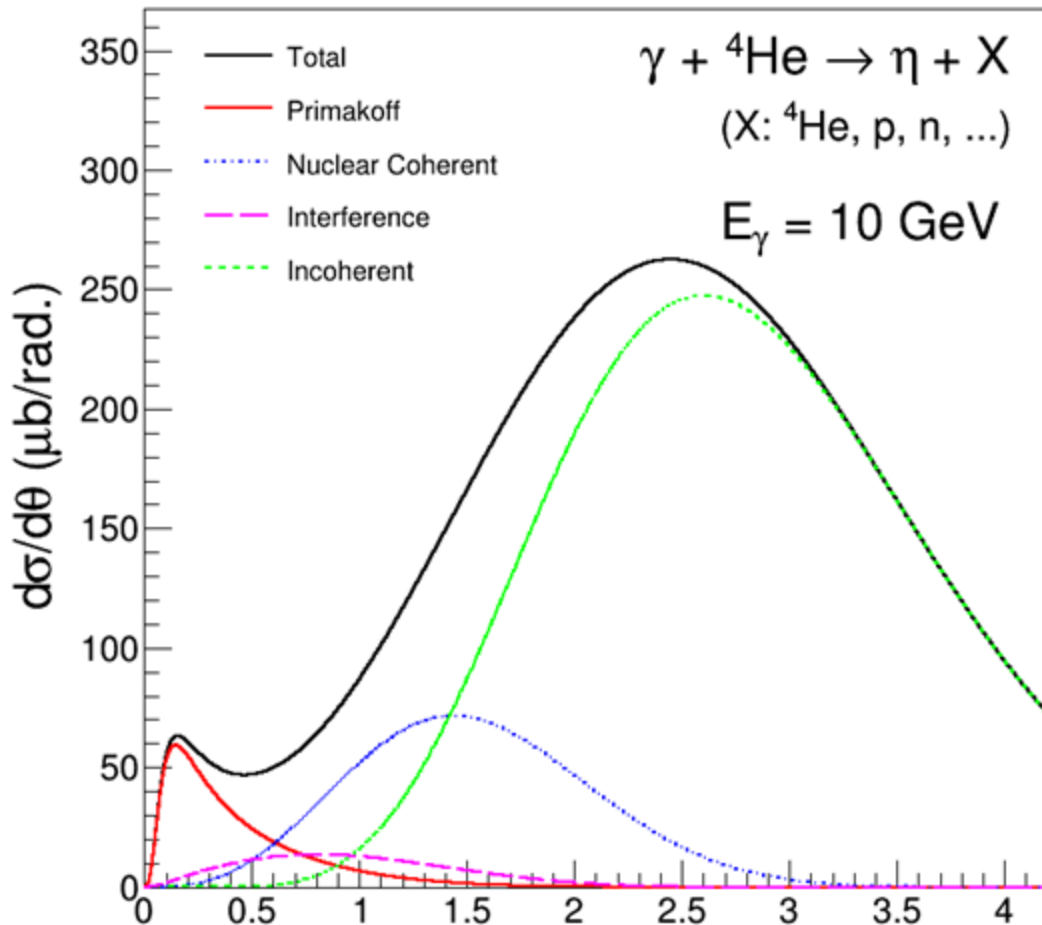
$\eta \rightarrow \gamma\gamma$ proceeds via Chiral Anomaly

Physics Inputs

- Precision test of ChPT
- η - η' mixing angle
- Improvement of all other partial decay widths of the η
 - 3π decay \rightarrow Light quark mass ratio
- Input to hadronic Light-by-Light scattering for muon $g-2$
- Address long-standing discrepancy between experimental techniques

Primakoff Effect

$$\frac{d\sigma_{Prim}}{d\Omega} = \Gamma(\eta \rightarrow \gamma\gamma) \frac{8\alpha Z^2 \beta^3 E^4}{m_\eta^3 Q^4} |F_{em}(Q^2)| \sin^2(\theta_{lab})$$



Primakoff cross section peaks at forward angles

${}^4\text{He}$ Target (cryogenic)

- Z^2 dependence in Primakoff cross section
- Well-known form factor

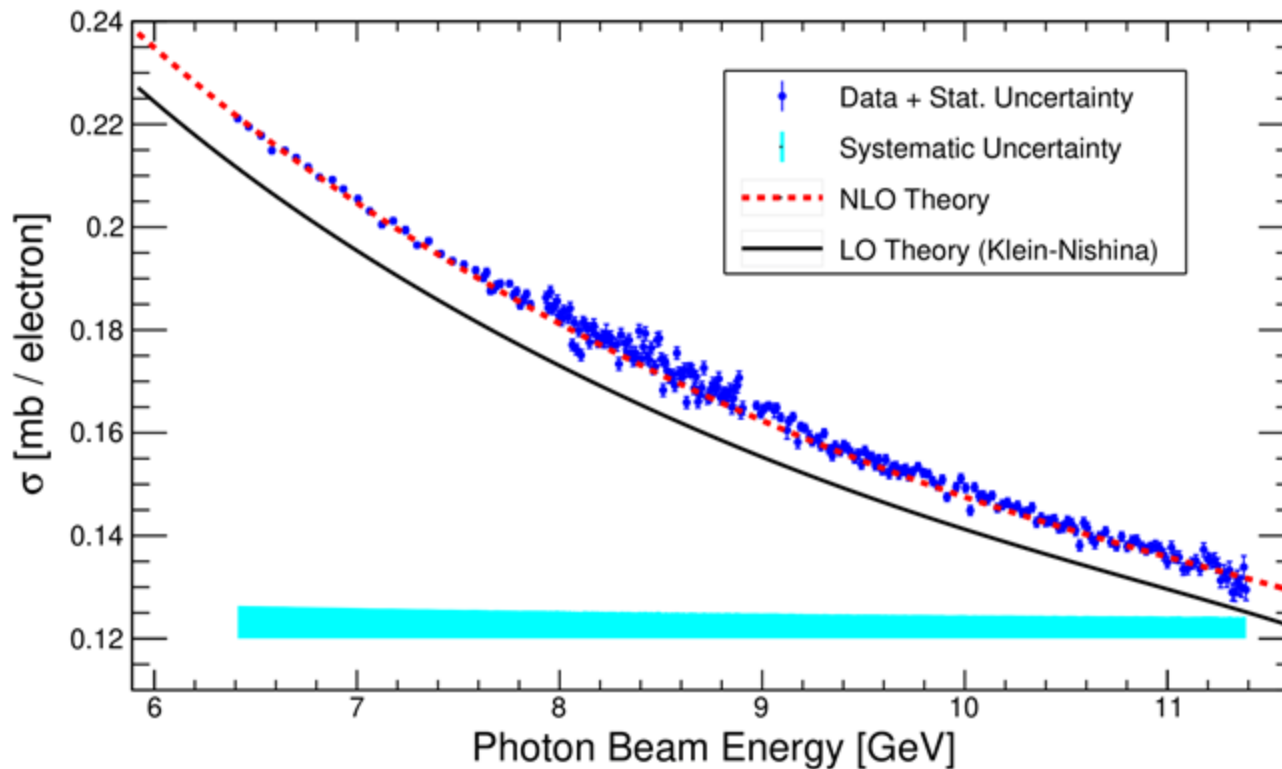
Compton Scattering Cross Section ($\gamma e^- \rightarrow \gamma e^-$)

Well-known QED process to use as a reference:

- Verify overall systematics in absolute cross section measurement
- Monitor changes in luminosity

First total cross section measurement in 6-11 GeV energy range

Total Compton Scattering Cross Section on ^9Be Target

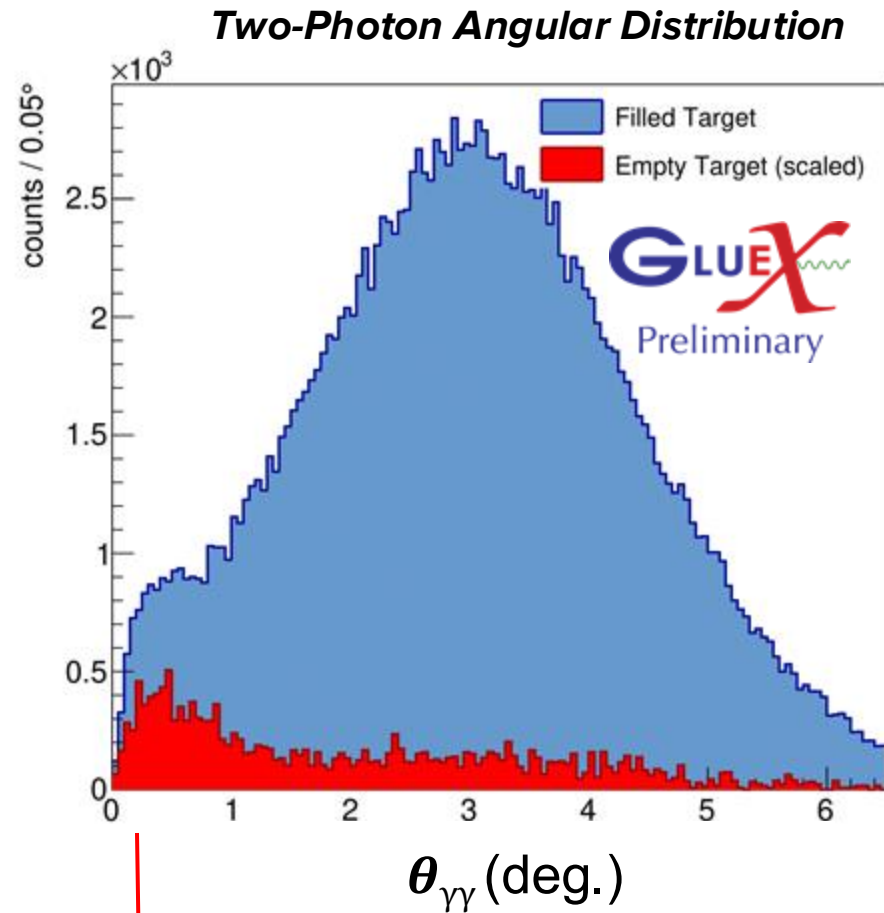
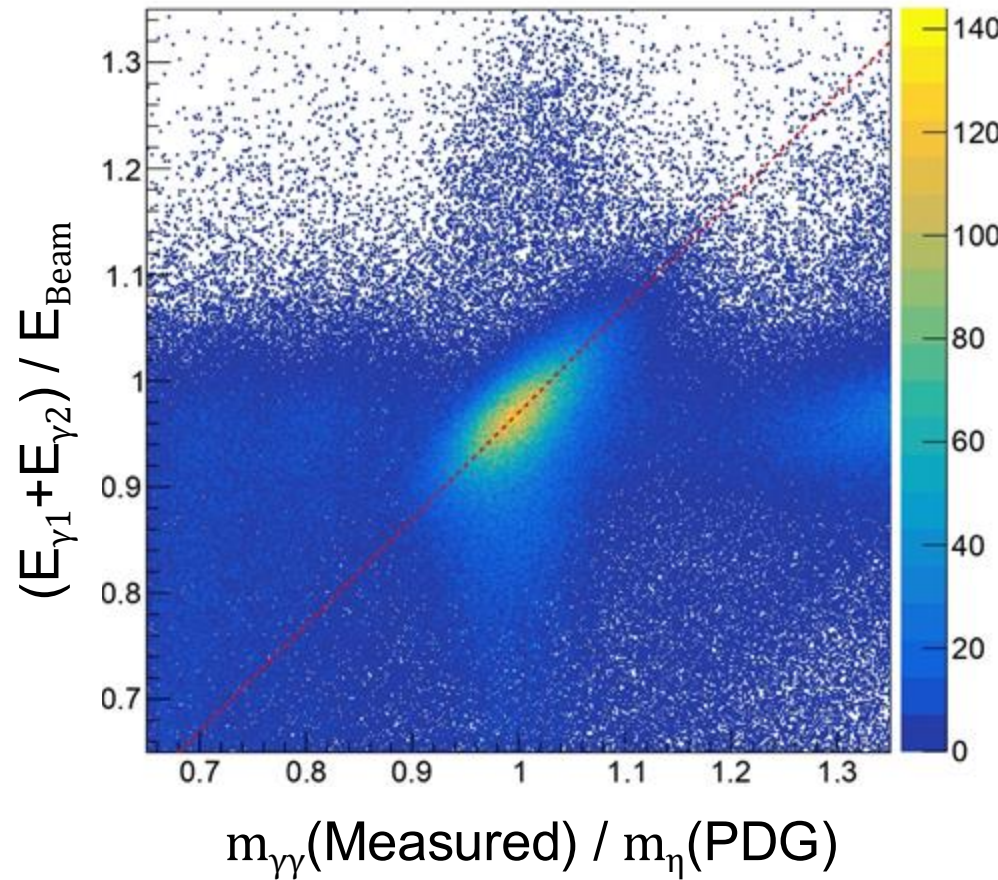


Total combined
uncertainty ~3%.

Publication coming soon!

$\eta \rightarrow \gamma\gamma$ Decay Channel

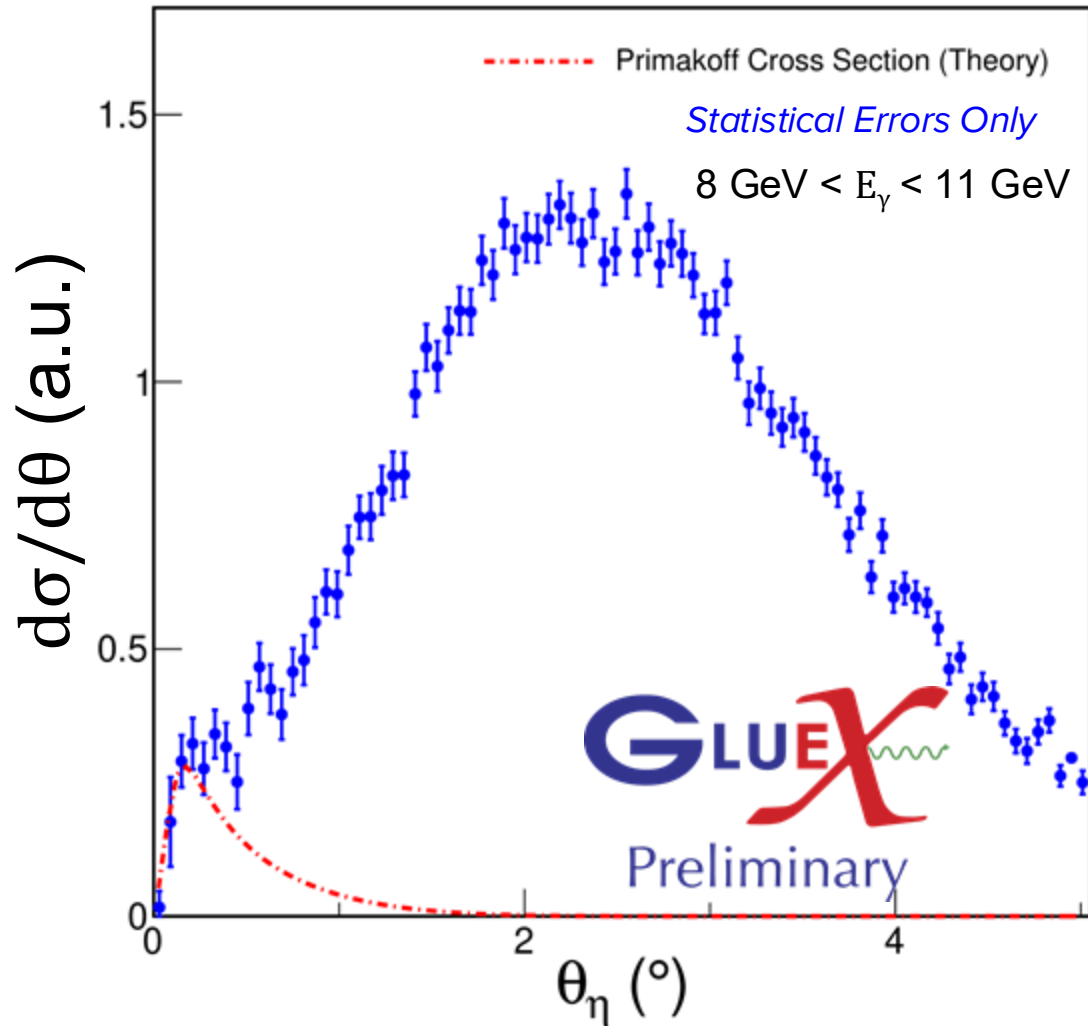
In Primakoff process, most of the beam energy is transferred to the η



Beamline background peaks at forward angles (Primakoff region)

$\gamma + {}^4\text{He} \rightarrow \eta + X$ Cross Section ($\eta \rightarrow \gamma\gamma$)

(X: ${}^4\text{He}$, p, n, ...)



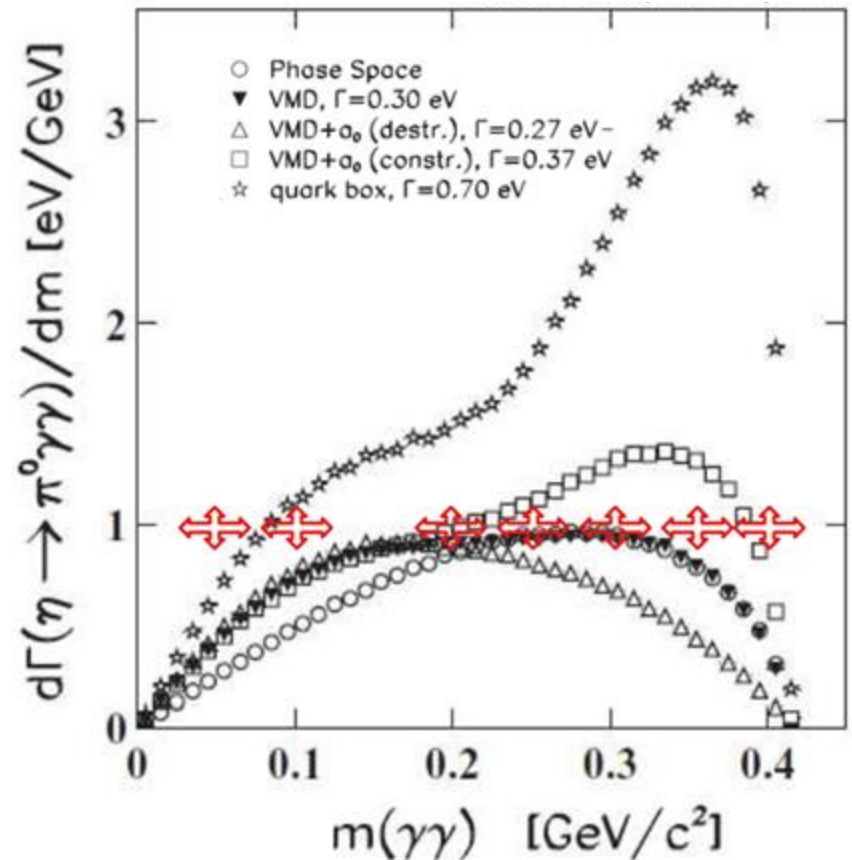
- Preliminary results from first phase of experiment
 - Data processing for final phase is nearly complete
 - >3x statistics to come
- *Decay width will be extracted through a combined fit to the cross sections extracted over all run periods and from multiple decay channels.*

JLab Eta Factory (JEF) Experiment

Mode	Branching Ratio	Physics Highlight	Photons
priority:			
$\gamma + B'$	beyond SM	leptophobic dark boson	4
$\pi^0 2\gamma$	$(2.7 \pm 0.5) \times 10^{-4}$	χ PTh at $\mathcal{O}(p^6)$	4
$3\pi^0$	$(32.7 \pm 0.2)\%$	$m_u - m_d$	6
$\pi^+\pi^-\pi^0$	$(22.9 \pm 0.3)\%$	$m_u - m_d$, CV	2
3γ	$< 1.6 \times 10^{-5}$	CV, CPV	3

Experiment will run in parallel with GlueX beginning early 2025

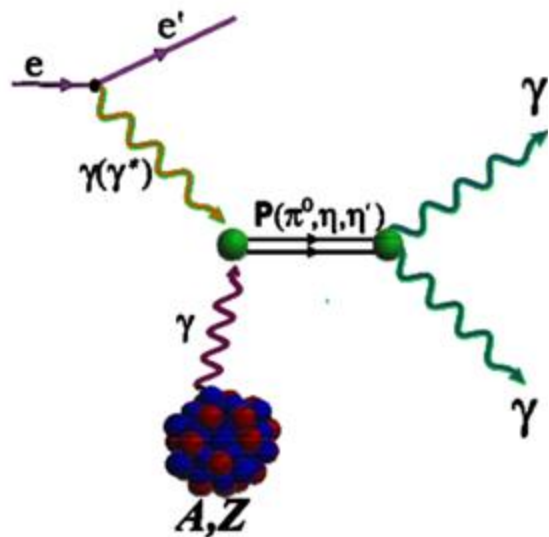
Projected Results for $\eta \rightarrow \pi^0 \gamma \gamma$ decay width:



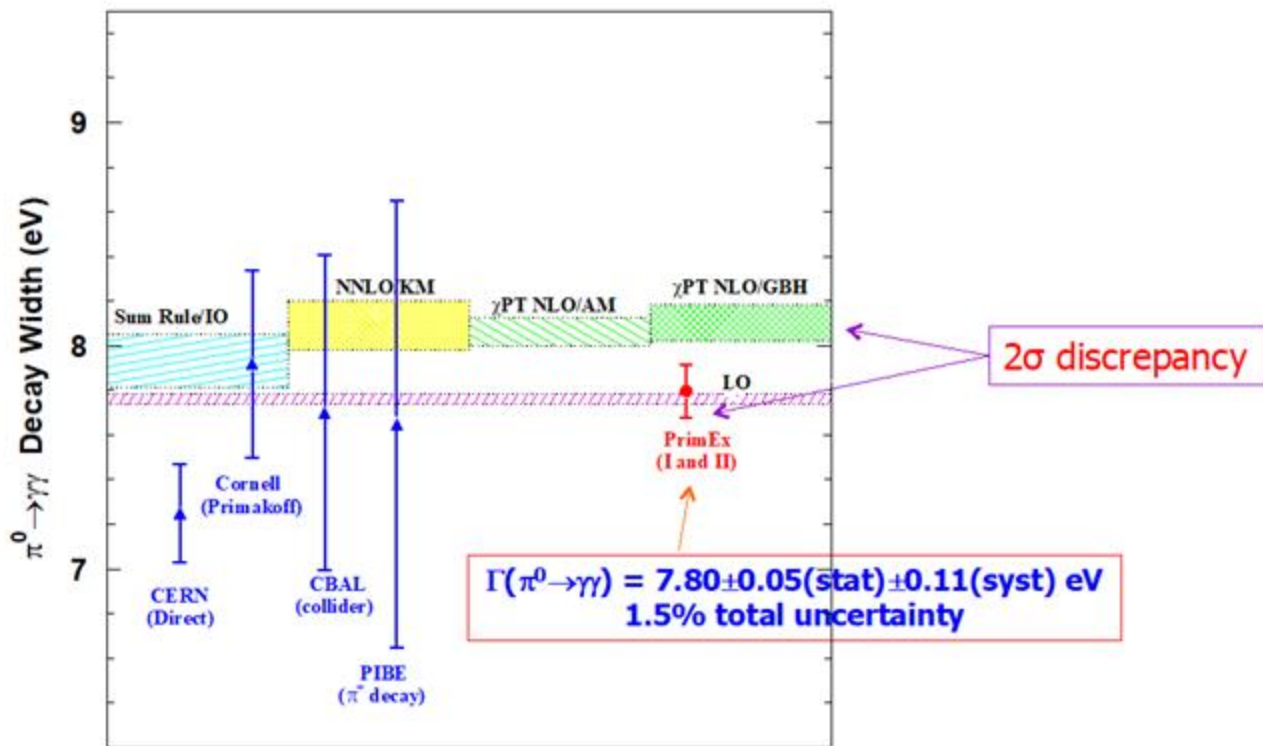
Primakoff Program at JLab

Precision measurements of electromagnetic properties of π^0 , η , η' via Primakoff effect:

- a) Two-Photon Decay Width
- b) Transition Form Factors at Low Q^2 (0.001-0.5 GeV^2/c^2)



PrimEx-I and II in Hall B measured the $\pi^0 \rightarrow \gamma\gamma$ decay width with 1.5% total uncertainty.



I. Larin, et al. PRL **106**, 162303 (2008)

I. Larin, Y. Zhang, A. Gasparian, L. Gan, et al. Science **368**, 6490 (2020)

Pion Polarizabilities

[R. Miskimen, Talk, Chiral Dynamics 2024]

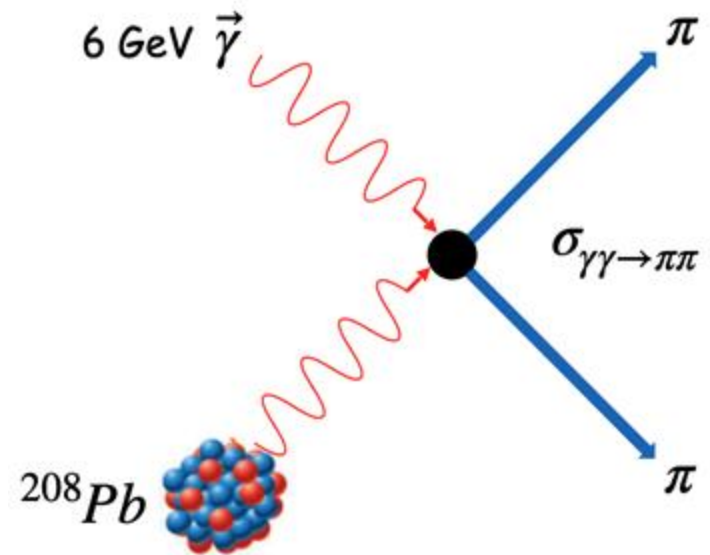
Electric (α_π) and Magnetic (β_π) polarizabilities characterize response of pion to external electric field

Charged Pion Polarizabilities predictions at $O(p^6)$:

$$\alpha_\pi - \beta_\pi = 5.7 \pm 1.0 \times 10^{-4} e fm^3$$

$$\alpha_\pi + \beta_\pi = 0.16 \pm 0.1 \times 10^{-4} e fm^3$$

Neutral Pion Polarizabilities have never been measured!



Primakoff production of $\pi^+\pi^-$ and $\pi^0\pi^0$ directly related to polarizabilities:

$$\frac{d^2\sigma_{Prim}}{d\Omega dM_{\pi\pi}} = \frac{2\alpha Z^2}{\pi^2} \frac{E_\gamma^2 \beta^2}{M_{\pi\pi}} \frac{\sin^2 \theta}{Q^4} |F_{EM}(Q^2)|^2 (1 + P_\gamma \cos 2\phi_{\gamma\gamma}) \left[\sigma_{\gamma\gamma \rightarrow \pi\pi} \right]$$

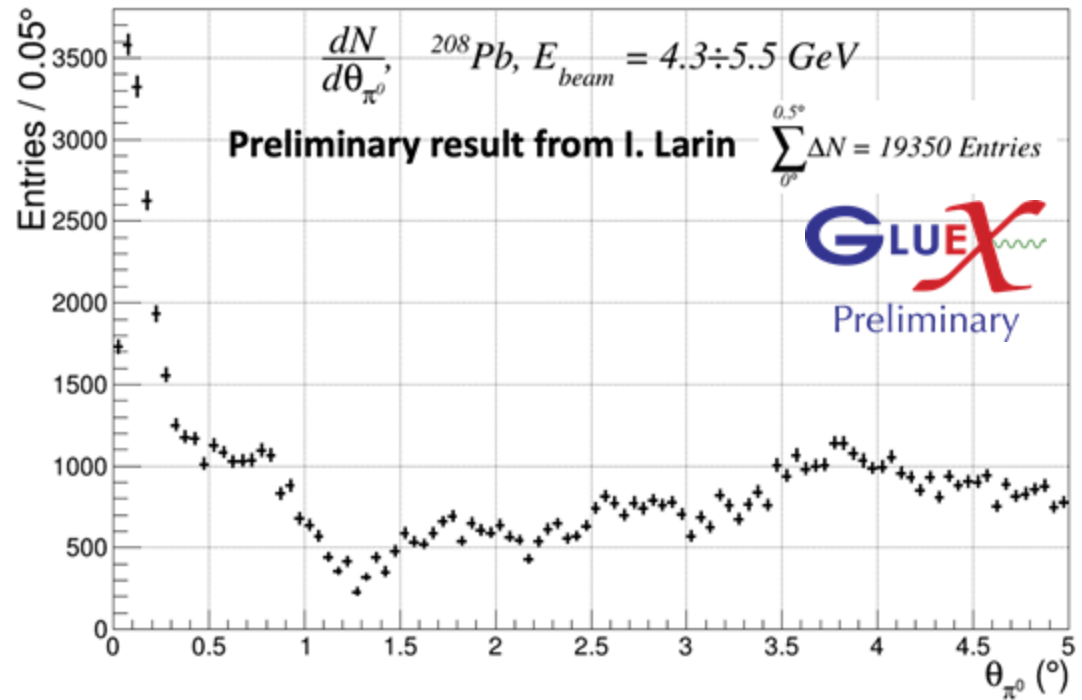
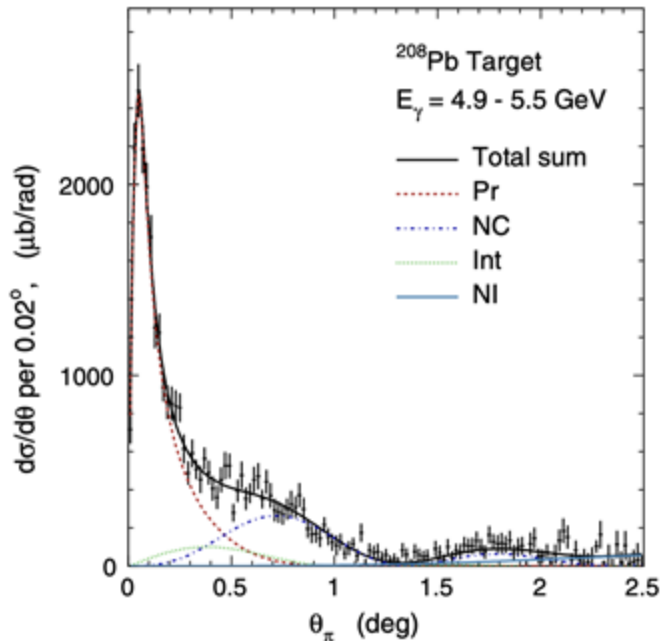
sensitive to $\alpha_\pi - \beta_\pi$

CPP/NPP Experiment

- Data collected in 2022 with 6 GeV polarized photons on ^{208}Pb target
 - 80% polarization
 - New detector to identify μ^\pm, π^\pm
- Calibration and reconstruction of full data set nearly complete, preliminary results forthcoming

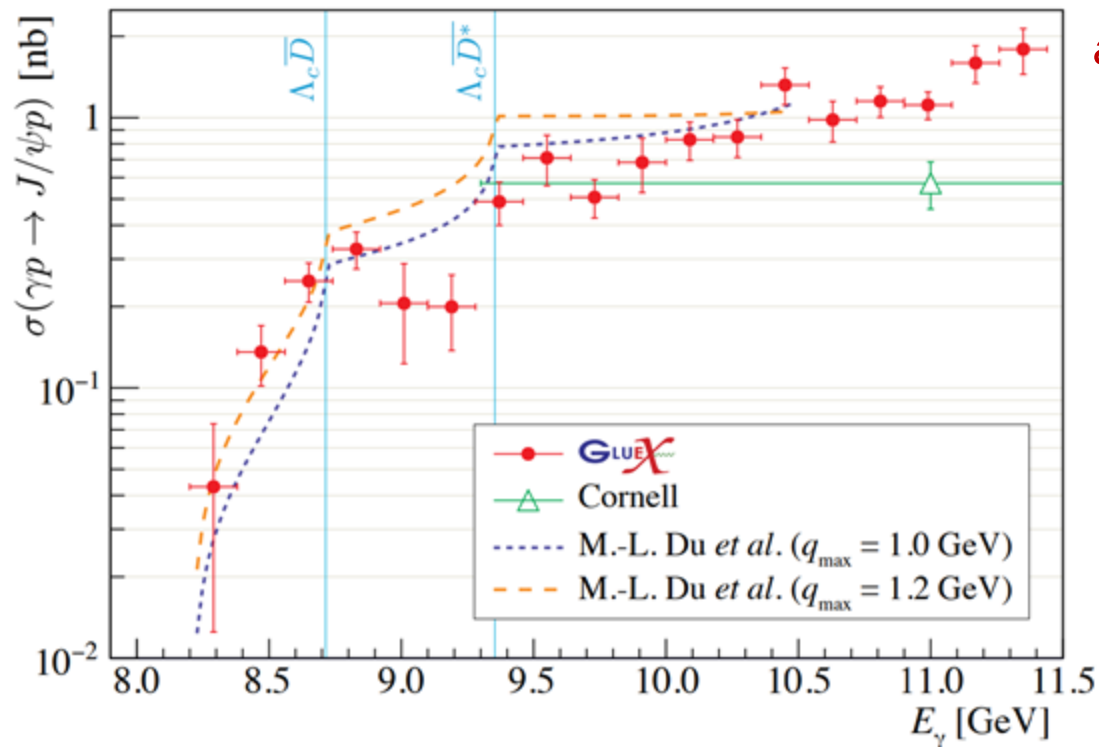
CPP Experiment: $\gamma + \text{Pb} \rightarrow \pi^0 + \text{Pb}$

PrimEx 1: $\gamma + \text{Pb} \rightarrow \pi^0 + \text{Pb}$

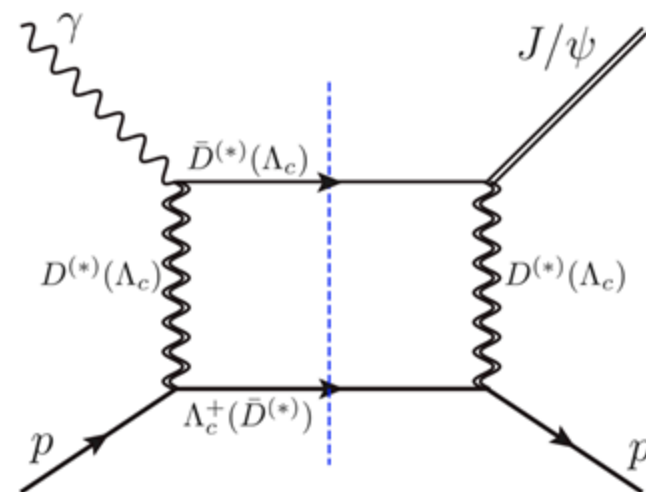


Near-threshold J/ψ Photoproduction

[S. Adhikari, et al., Phys. Rev. C, 108, 025201 (2023)]



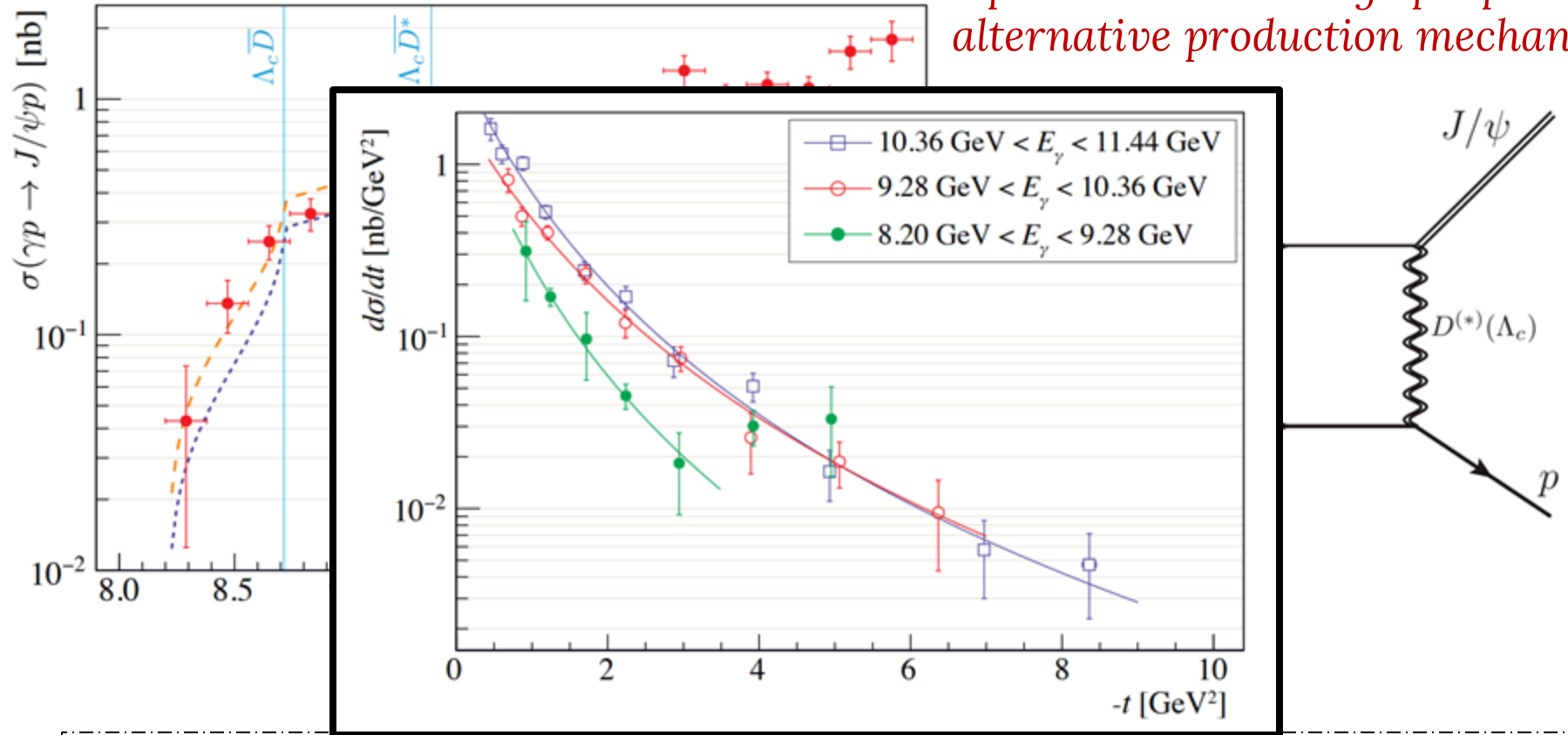
Open charm exchange proposed as alternative production mechanism



Near-threshold J/ψ Photoproduction

[S. Adhikari, et al., Phys. Rev. C, 108, 025201 (2023)]

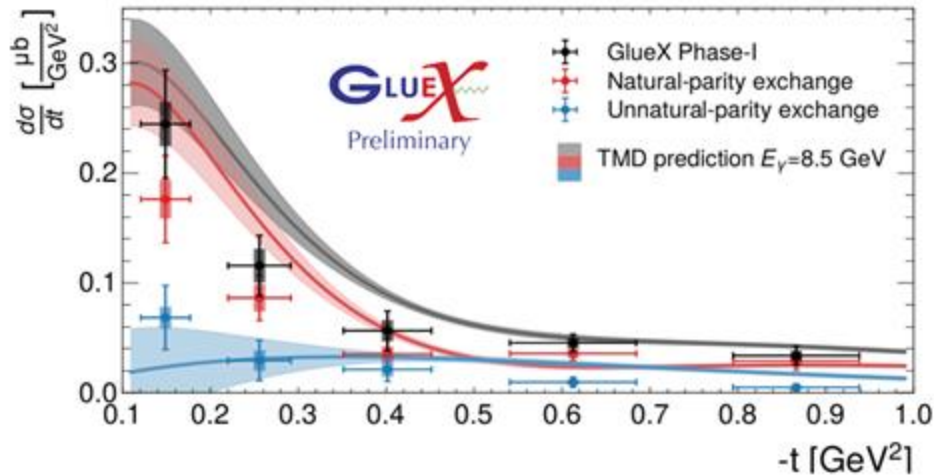
Open charm exchange proposed as alternative production mechanism



- Large t -slopes in differential cross section disagree with dominance of open charm exchange
- Enhancement at high $|t|$ could indicate contribution of these exchanges

Recent Results - Hadron Spectroscopy

$a_2(1320)$ Cross Section



$\pi_1(1600)$ Upper Limits