Overview of Hyperon Physics in Photoproduction at GlueX

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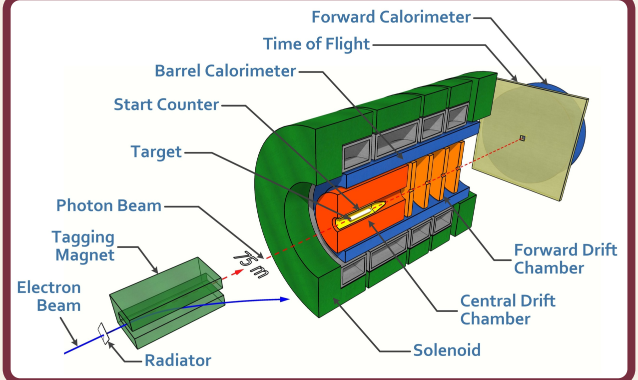
On behalf of the GlueX Collaboration

Hadron Spectroscopy with Strangeness Workshop
University of Glasgow
Apr 3-5, 2024

Outline

Beamline and GlueX Spectrometer

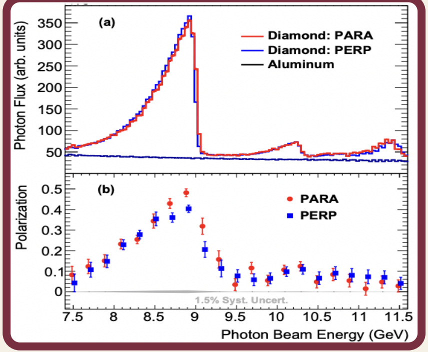
Nucl. Instrum. Meth. A **987**, 164807 (2021)



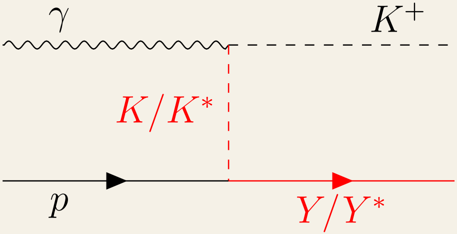
- The GlueX spectrometer is almost fully hermetic detector.
- Houses a liquid hydrogen target.
- All final state particles are measured exclusively.

GlueX-I Data

- Total luminosity: 439.6 pb^{-1} for $E_\gamma > 6.0$ GeV.
- Coherent Peak Luminosity: 125 pb^{-1} for $E_\gamma = (8.2, 8.8)$ GeV.
- Linearly polarized photon beam.



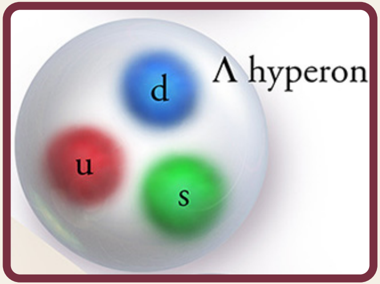
Hyperon (S=1) Overview



Direct Hyperon Production Mechanism

- Naturality of exchange particles with parity, P, and spin, J, encode the t-channel production Regge trajectories:

$$\eta = P(-1)^J = \begin{cases} +1, & \text{natural} \\ -1, & \text{unnatural} \end{cases}$$



Publications

- $K^+\Sigma^0$ beam asymmetry at $E_\gamma = 8.5$ GeV.
- $\Lambda(1520)$ spin density matrix elements (SDMEs).

Ongoing Work

- $\Lambda(1520)$ Cross Sections
- $\Lambda(1405)$ Line Shape Measurements
- $\Lambda\overline{\Lambda}$ Production (Hao Li, Session 2)

A Strange Section

Beam Asymmetry for $\vec{\gamma} p \to K^+ \Sigma^0$

Phys. Rev. C. **101**, 065306 (2020)
(GlueX Collaboration)

Formalism

- Produced via exchange of $K^*(892)$(natural-parity) and $K(494)$(unnatural-parity) trajectories.
- Photon beam asymmetry, Σ, is:

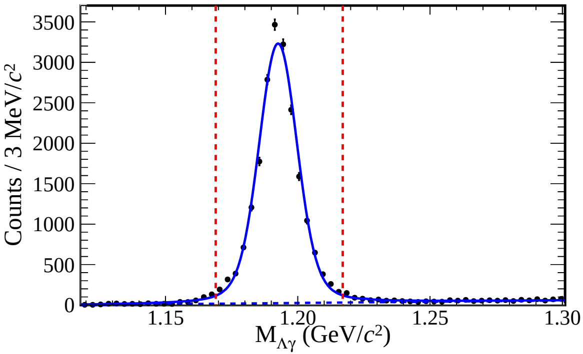
$$\Sigma = \left[\frac{d\sigma_\perp}{dt} - \frac{d\sigma_\parallel}{dt}\right] \Big/ \left[\frac{d\sigma_\perp}{dt} + \frac{d\sigma_\parallel}{dt}\right]$$

$$= \frac{(|f_1^+|^2 + |f_2^+|^2) - (|f_1^-|^2 + |f_2^-|^2)}{f_1^+|^2 + |f_2^+|^2 + |f_1^+|^2 - |f_2^-|^2}$$

- Direct measurement of natural- and unnatural-parity contributions.

Event Selection

- Final state reaction: $\gamma p \to K^+\Sigma^0$, $\Sigma^0 \to \Lambda^0\gamma$, $\Lambda^0 \to p\pi^-$.
- $\sim 20\%$ of GlueX-I data for E_γ (GeV): (8.2,8.8).



$K^+\Sigma^0$ Beam Asymmetry Results

Phys. Rev. C. **101**, 065306 (2020) (GlueX Collaboration)

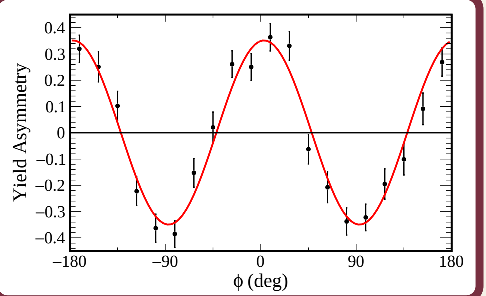
Yield Asymmetry

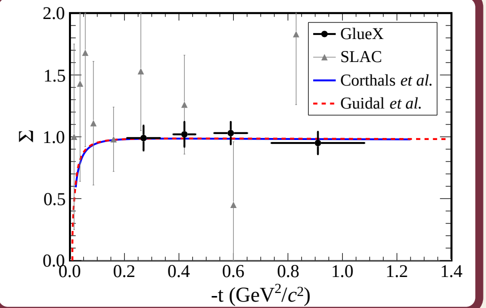
$$\frac{Y_\perp - F_R Y_\parallel}{Y_\perp + F_R Y_\parallel} = \frac{(P_\perp + P_\parallel)\Sigma\cos 2(\phi - \phi_0)}{2 + (P_\perp - P_\parallel)\Sigma\cos 2(\phi - \phi_0)},$$

ϕ angle between a plane parallel to the laboratory floor and the K^+ production plane.

Results

- Mean value for t-range $(0.1 - 1.4)(\mathrm{GeV})^2$: $\mathbf{\Sigma = 1.00 \pm 0.04}(\mathrm{stat}) \mathbf{\pm 0.03}(\mathrm{syst}) \mathbf{\pm 0.02}(\mathrm{pol})$
- Consistent with natural-parity exchange from theoretical predictions.
- Low u-region, $-u < 2.0$ GeV^2 result: $\mathbf{\Sigma = 0.41 \pm 0.07}(\mathrm{stat}) \mathbf{\pm 0.06}(\mathrm{syst}) \mathbf{\pm 0.02}(\mathrm{pol})$
- u-channel hyperon exchanges of Σ and Y^* contribute.





Spin Density Matrix Elements (SDMEs) in $\Lambda(1520)$

Event Selection

- Final state $\gamma p \to K^+\Lambda^*,\ \Lambda^* \to K^- p$
- $\sim 20\%$ of GlueX-I data for $E_\gamma = (8.2 - 8.8)$ GeV.
- sPlot technique used for background subtraction.
- $\sim 32,200$ events after subtraction.

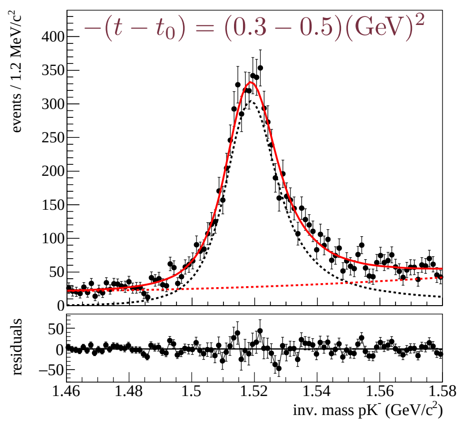
Formalism

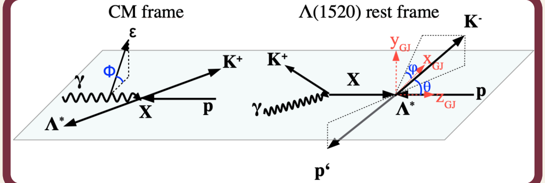
- Spin Density Matrix:

$$\rho = \rho^0 - P_\gamma \cos 2\Phi \rho^1 - P_\gamma \sin \Phi \rho^2.$$

- 10 SDMEs for linearly polarized photon with unpolarized fixed target.

(GlueX Collaboration), Phys. Rev. C. **105**, 035201



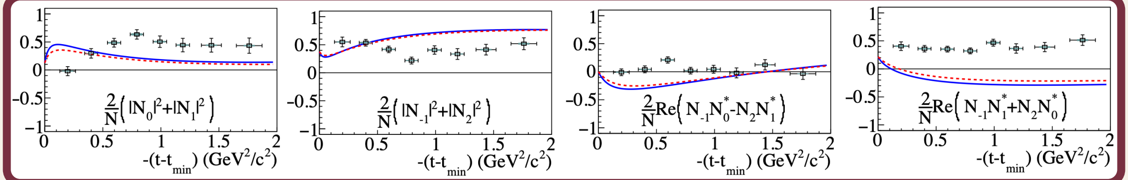


$\Lambda(1520)$ SDME Interpretation

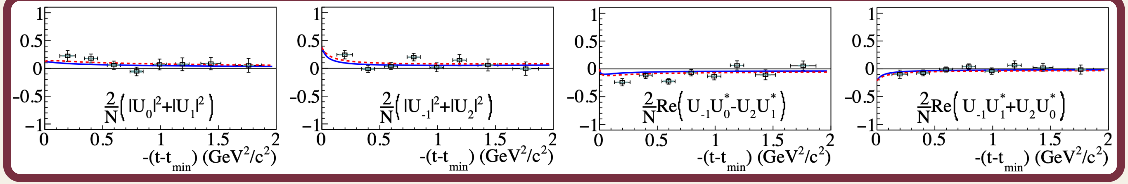
Phys. Rev. C. **105**, 035201 (2022)
(GlueX Collaboration)

- SDMEs can be rewritten in terms of purely natural and unnatural exchange.
- Measured SMDEs are dominated by natural exchange amplitudes.
- Results agree quantitatively with predictions using K^*, K_2^* exchanges.

Natural exchange ($\eta = 1$)

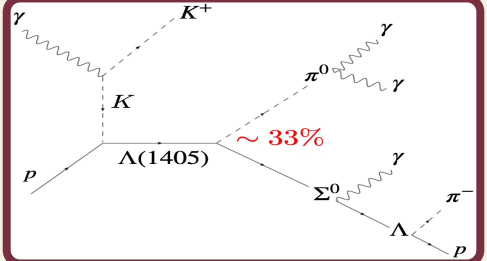


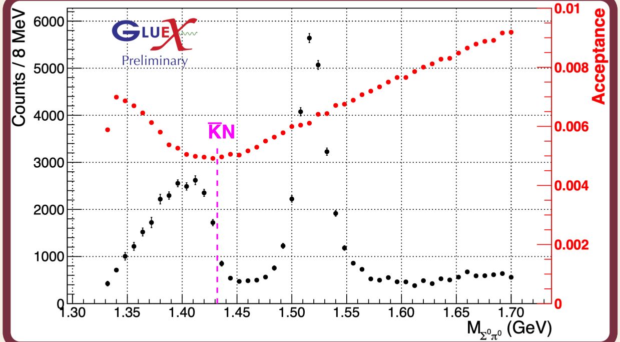
Unnatural exchange($\eta = -1$)



Decay of $\Lambda(1405)$

N. Wickramaarachchi DNP 23'
(GlueX Collaboration)





Event Selection

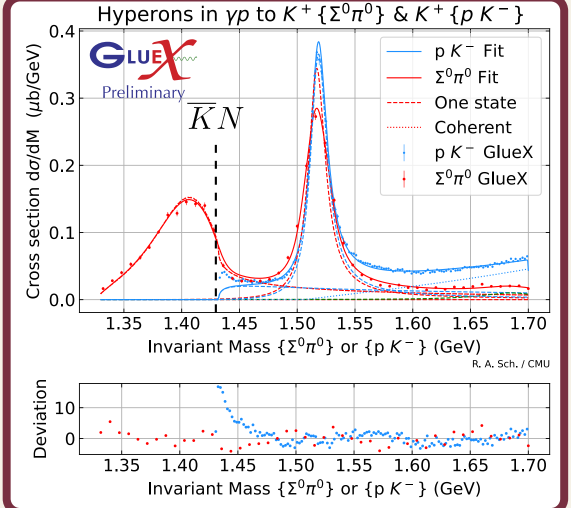
- All GlueX-I data for E_γ (GeV): (6.5,11.6).
- t-channel production for $0 < -(t - t_{min}) < 1.5$ GeV^2.
- $\sim 25,000$ counts for $M_{\Sigma^0\pi^0} < 1.46$ GeV.
- Statistical uncertainties only.

- $\Lambda(1405) \rightarrow \Sigma^0\pi^0$ is pure $I = 0$.
- GlueX can reconstruct neutral showers and charged particles for simultaneous fits to $\Sigma^0\pi^0$ and pK^- decay modes.

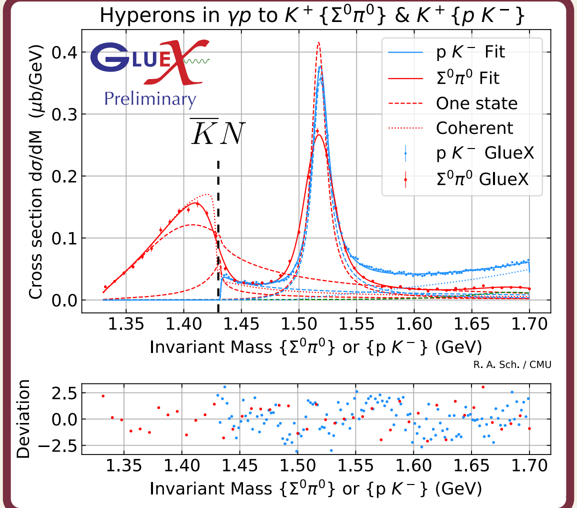
$\Lambda(1405)$ Line Shape Measurement

N. Wickramaarachchi DNP 23'
(GlueX Collaboration)

Single $\Lambda(1405)$ with $\chi^2 = 8.14$



Compound coherent $\Lambda(1405)$s with $\chi^2 = 1.96$

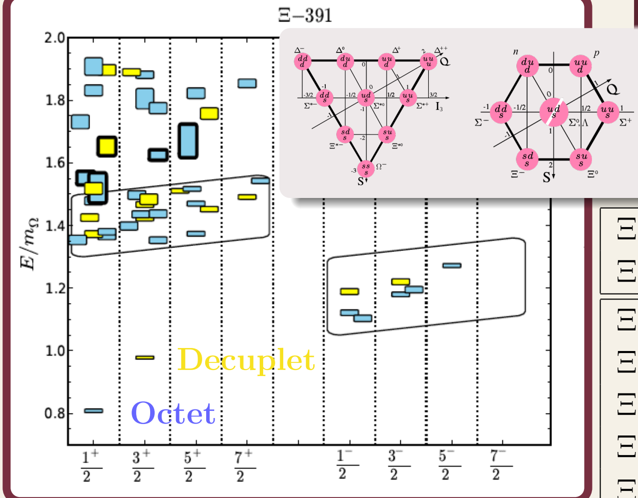


- Coupled channel K-matrix fit to $\Sigma^0\pi^0$ and pK^- favors two-pole $\Lambda(1405)$ hypothesis.

The Very Strange Section

Revealing the Ξ Spectrum

Phys. Rev. D **87**, no. 5, 054506 (2013)



Quark Model Level Scheme (^{2S+1}M)

'Ground State' ($L = 0$)

$$\Longleftrightarrow \quad 56 = {}^4 10 \oplus {}^2 8$$

'First Excitation' ($L = 1$)

$$70 = {}^2 10 \oplus {}^4 8 \oplus {}^2 8 \oplus {}^2 1$$

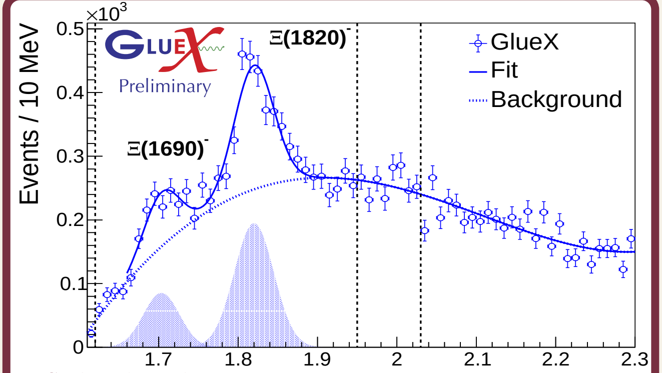
$\Xi(1320)$	****	$\Rightarrow \Lambda\pi$	$J^P = \frac{1}{2}^+$
$\Xi(1530)$	****	$\Rightarrow \Xi\pi$	$J^P = \frac{3}{2}^+$
$\Xi(1620)$	**	$\Rightarrow \Xi\pi?$	$J^P = \frac{1}{2}^-$?
$\Xi(1690)$	***	$\Rightarrow Y\overline{K}$	$J^P = \frac{1}{2}^-$?
$\Xi(1820)$	***	$\Rightarrow \Lambda\overline{K}$	$J^P = \frac{3}{2}^-$
$\Xi(1950)$	***	$\Rightarrow \Xi\pi, Y\overline{K}$	$J^P = \frac{3}{2}^-$?
$\Xi(2030)$	***	$\Rightarrow Y\overline{K}$	$J^P \geq \frac{5}{2}^?$

R.L. Workman *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2022**, 083C01

- Lattice QCD level counting is consistent with quark models.

Ξ Excitation Spectrum

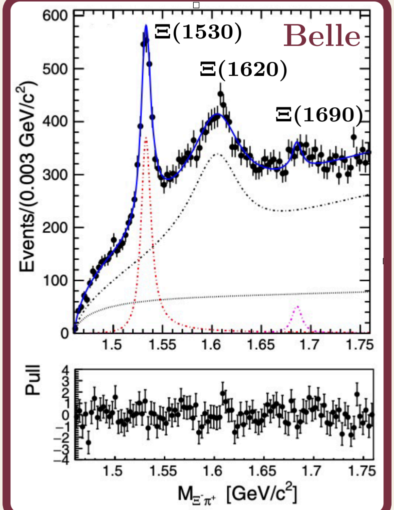
$\gamma p \to K^+K^+\Xi^* \to K^+K^+(\Lambda K^-)$



V. Crede and J. Yelton, submitted to Reports on Progress in Physics, IOP

$\Xi_c^+ \to \Xi^*\pi^+ \to (\Xi^-\pi^+)\pi^+$

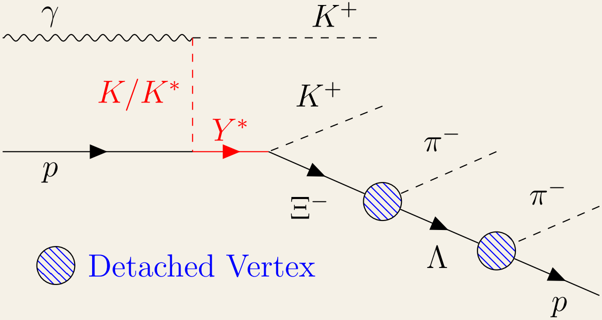
(Kiyoshi Tanida, Session 2)



Phys. Rev. Lett. **122**, 072501 (2019) (Belle Collaboration)

- ΛK channel in photoproduction shows strong evidence for $\Xi(1690)$ and $\Xi(1820)$.
- $\Xi\pi$ channel at Belle shows strong evidence for $\Xi(1530)$, $\Xi(1620)$ and $\Xi(1690)$.

$\Xi(1320)^-$ Production

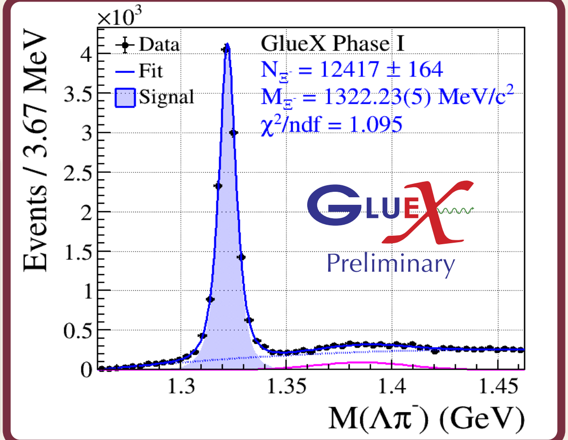


- Identify possible candidates for the intermediate hyperon.

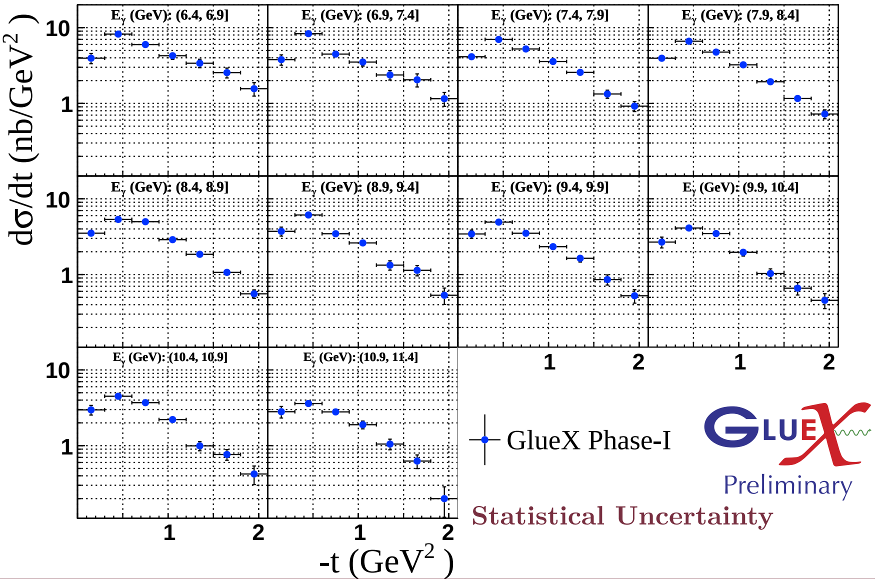
  Theory: Phys. Rev. C. **83**, 055201 (2011)
- Extract the cross section and polarization observables.
- Largest data set of Ξ baryons for photoproduction.

Event Selection

- Kinematic fit to final state particles and vertices, Ξ^- mass unconstrained.
- GlueX-I data for E_γ (GeV): (6.4,11.4).

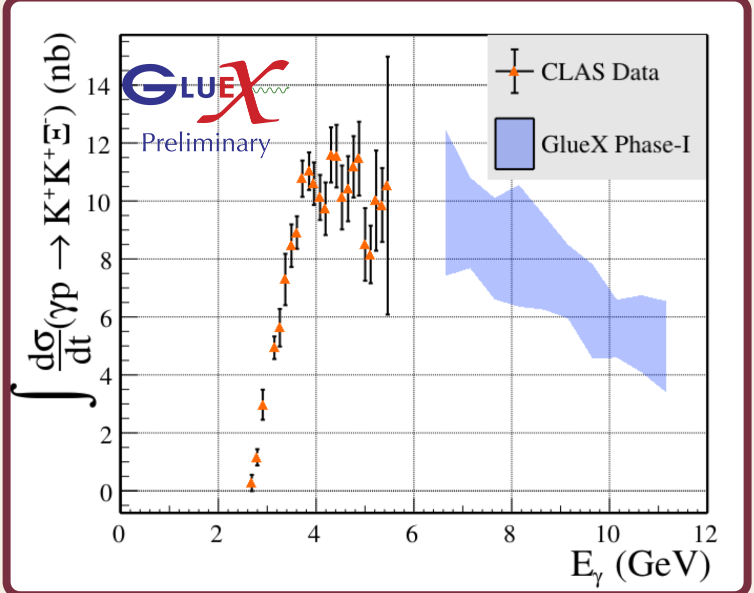


Differential Cross Section



- Can see an exponential decay, evidence of t-channel exchange.
- Model needed to further interpret results.

Integrated Cross Section

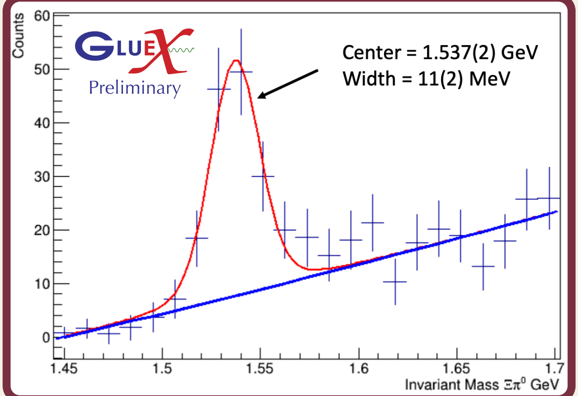


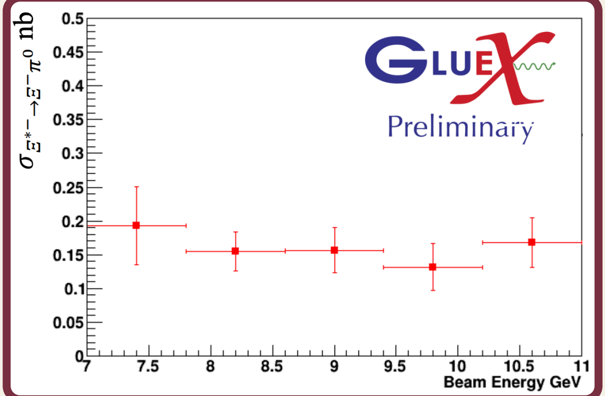
- CLAS Collaboration data up to $E_\gamma = 5.4$ GeV: Phys. Rev. C **98**, 062201(R)
- Differential Cross section integrated up to $-t = 2.0\ (\text{GeV})^2$.
- GlueX-I shows good agreement with CLAS in the energy dependent behavior.

$\Xi(1530)^-$ Production

B. Sumner GHP 23'

- Final state reaction: $\gamma p \rightarrow K^+(K^+\Xi(1530)^-)_{Y^*}$, $\Xi(1530)^- \rightarrow \Xi^-\pi^0$.
- $\sim 50\%$ of GlueX-I data.
- Cross section shows no significant energy dependence: $<\sigma>= 0.16$ nb and standard deviation $= 0.06$ nb.

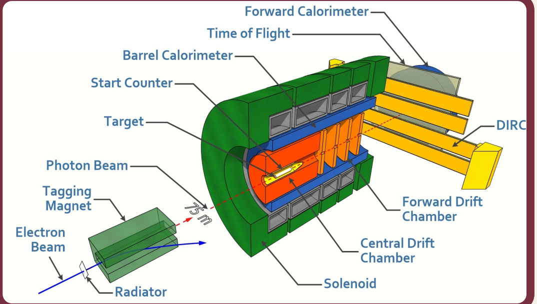




Concluding Remarks

Future Prospects

- GlueX-II with Cherenkov (DIRC) detector for π/K separation up to ~ 4 GeV.
- GlueX-II to quadruple GlueX statistics.
- GlueX with polarized traget (Annika Thiel, Session 8)
- KLong Facility (Stuart Fegan, Session 10)



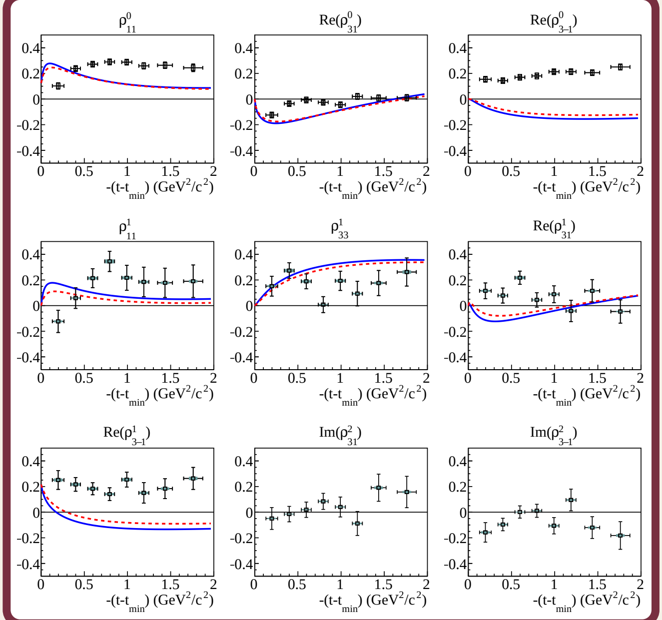
Summary

- Shown the wide ranging efforts of the publications and ongoing analysis with hyperons at GlueX.
- Projects studying the $S = 1$ and $S = 2$ hyperon sector have broad impacts for understanding hadrons in photoproduction.
- GlueX acknowledges the support of several funding agencies and computing facilities:

Backup Slides

Λ(1520) SDME Results

Phys. Rev. C. **105**, 035201 (2022) (GlueX Collaboration)



- The nine independent SDMEs are measured and shown on left.
- First measurement of polarized SDMEs and unpolarized SDMEs at these energies for Λ(1520).
- Models in red and blue from Phys. Rev. C. **96**, 025208 (2017) using a reggeized framework.
- Measurements SDMEs will provide strong constraints on Λ(1520) production mechanism in models.

Cross Section Review

Differential Cross Section

$$\frac{d\sigma(E_\gamma, t)}{dt} = \frac{N_\Xi(E_\gamma, t)}{\rho_t \; N_\gamma(E_\gamma) \; BR(\Lambda \to \Lambda\pi^-)\epsilon(\Lambda \to \Lambda\pi^-) \; \Delta t}.$$

$$\epsilon = \frac{N_{recon}(E_{\gamma,t})}{N_{thrown}(E_{\gamma,t})}, \qquad t = \left(\boldsymbol{P}_\gamma - \boldsymbol{P}_{K^+_{high}}\right)^2$$

Total Cross Section

$$\sigma(E_\gamma) = \int_{t_{min}}^{t_{max}} \frac{\partial\sigma(E_\gamma, t)}{\partial t} \; dt,$$

$$= \frac{N_\Xi(E_\gamma)}{\rho_t \; N_\gamma(E_\gamma) \; BR(\Lambda \to \Lambda\pi^-)\epsilon(\Lambda \to \Lambda\pi^-)}$$

- Use full signal Monte Carlo to calculate detector efficiency.
- Need to divide mass distributions into energy and t bins for yield and efficiency extractions.