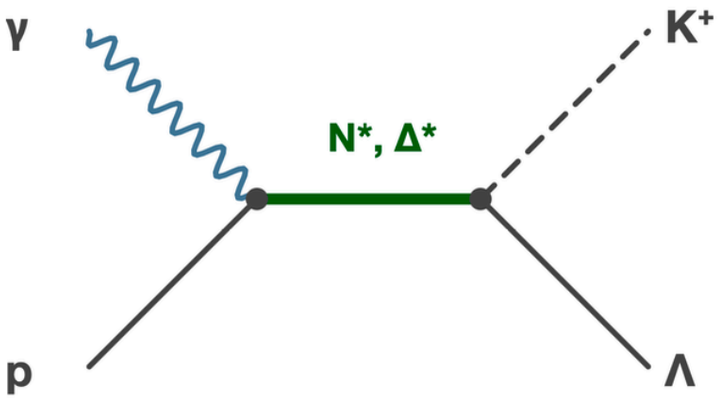
CLAS/GlueX input to hyperon production

Justin Stevens



WILLIAM & MARY
CHARTERED 1693

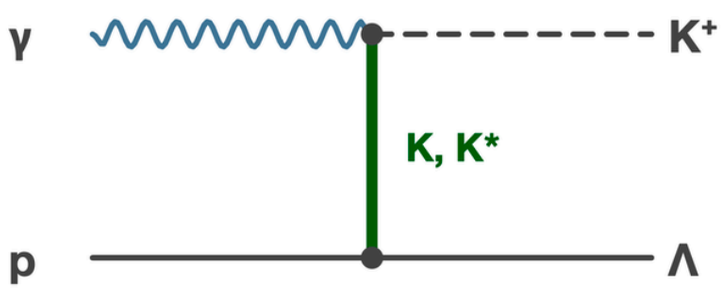
Hyperon production physics



s-channel

An N* or Δ* forms and decays to $K^+\Lambda$. Resonance region, $W \lesssim 2.5$ GeV: the CLAS domain.

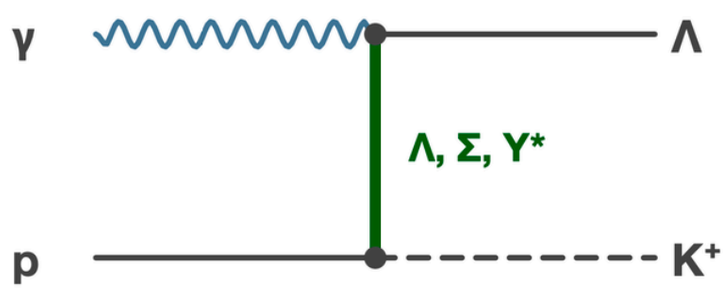
$s = W^2$



t-channel

K or K* exchange: the K^+ leaves with the photon's momentum. Forward peak at high s.

small –t

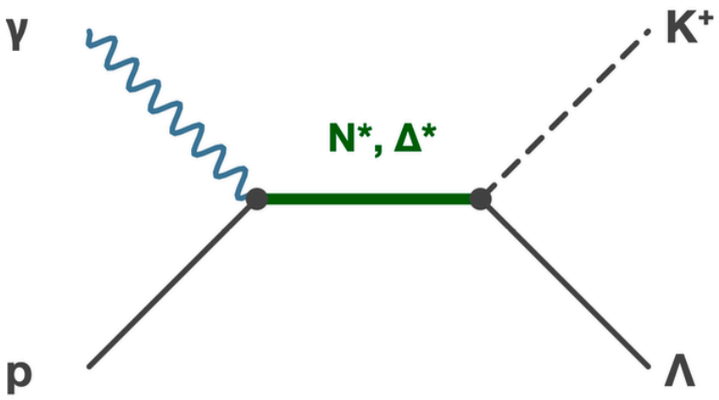


u-channel

Hyperon exchange: the Λ leaves with the photon's momentum, the K^+ goes backward.

small –u

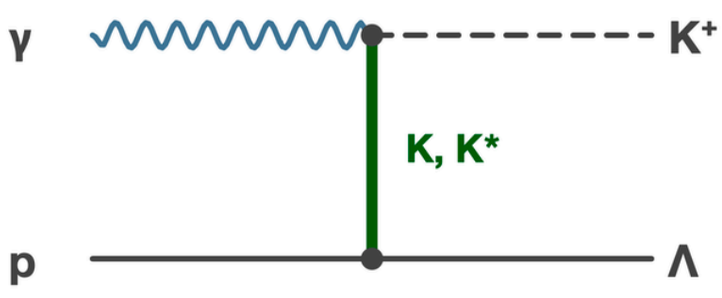
Hyperon production physics



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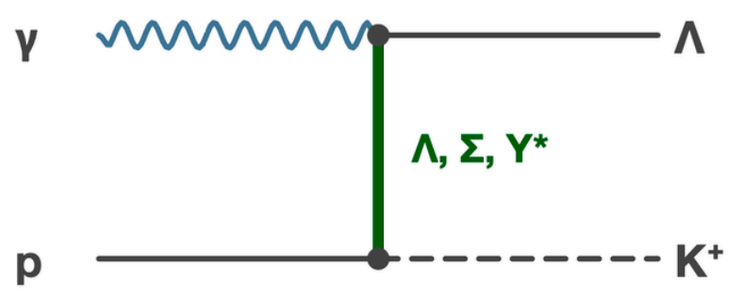
$s = W^2$



t-channel

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small –t



u-channel

Hyperon exchange: the Λ leaves with the photon's momentum, the K^+ goes backward.

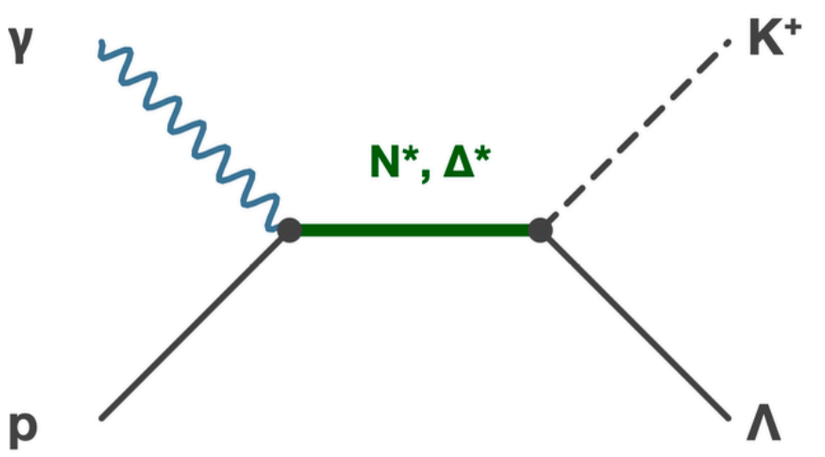
small –u

Polarized intensity

$$I(\Phi, \theta_{x',y',z'}) = 1 + \alpha_- \cos\theta_{y'} P - P_L^\gamma \cos(2\Phi)(\Sigma + \alpha_- \cos\theta_{y'} T) - P_L^\gamma \sin(2\Phi)(\alpha_- \cos\theta_{x'} O_{x'} + \alpha_- \cos\theta_{z'} O_{z'}) - P_C^\gamma(\alpha_- \cos\theta_{x'} C_{x'} + \alpha_- \cos\theta_{z'} C_{z'})$$

s-channel: hyperon production

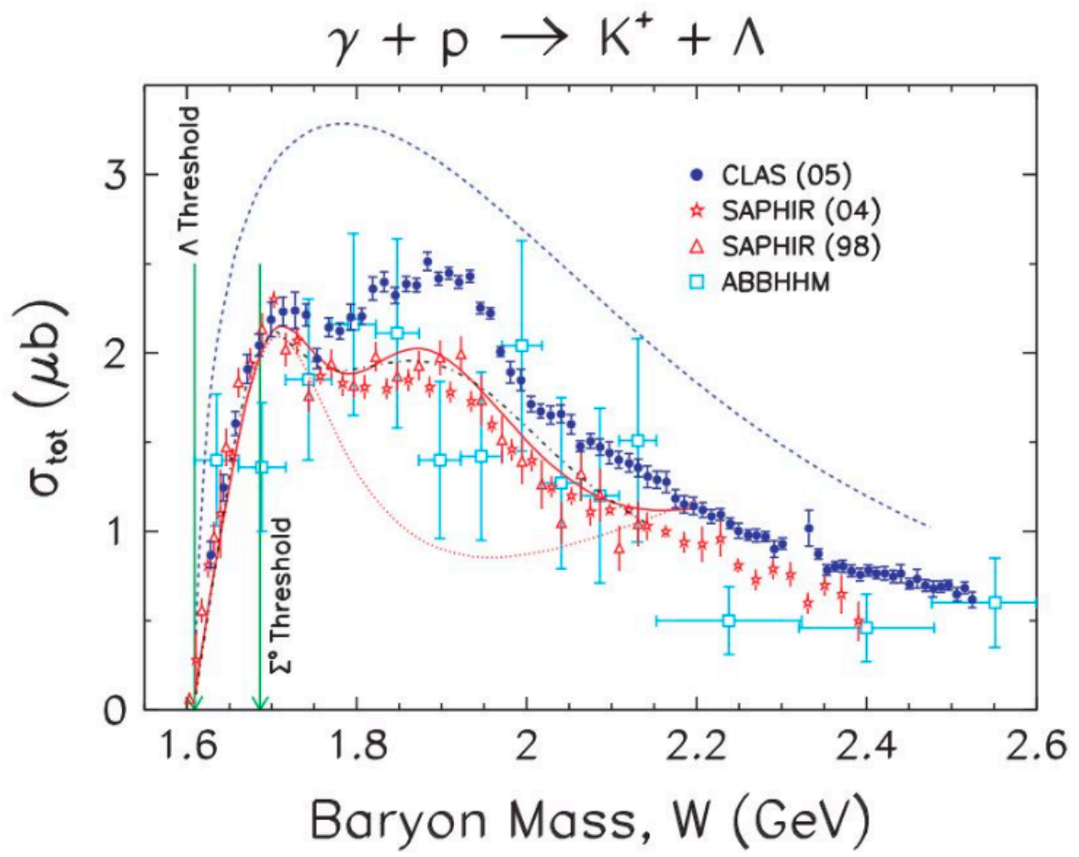
CLAS: PRC 73, 035202 (2006)



s-channel

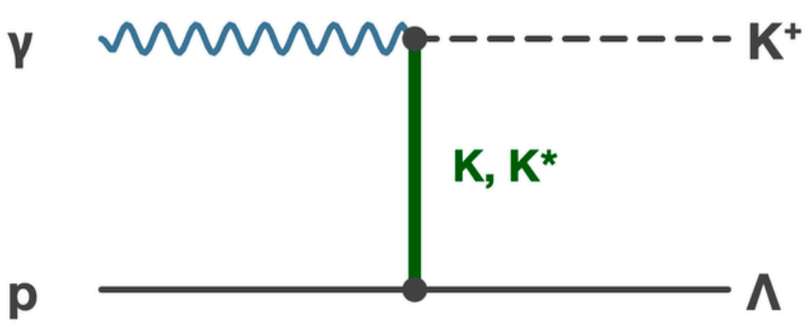
An N* or Δ* forms and decays to $K^+\Lambda$. Resonance region, $W \lesssim 2.5$ GeV: the CLAS domain.

$s = W^2$



- Primarily focused on baryon spectroscopy in CLAS 6 GeV era
- Precision measurements of cross sections and polarization observables

t-channel: hyperon production

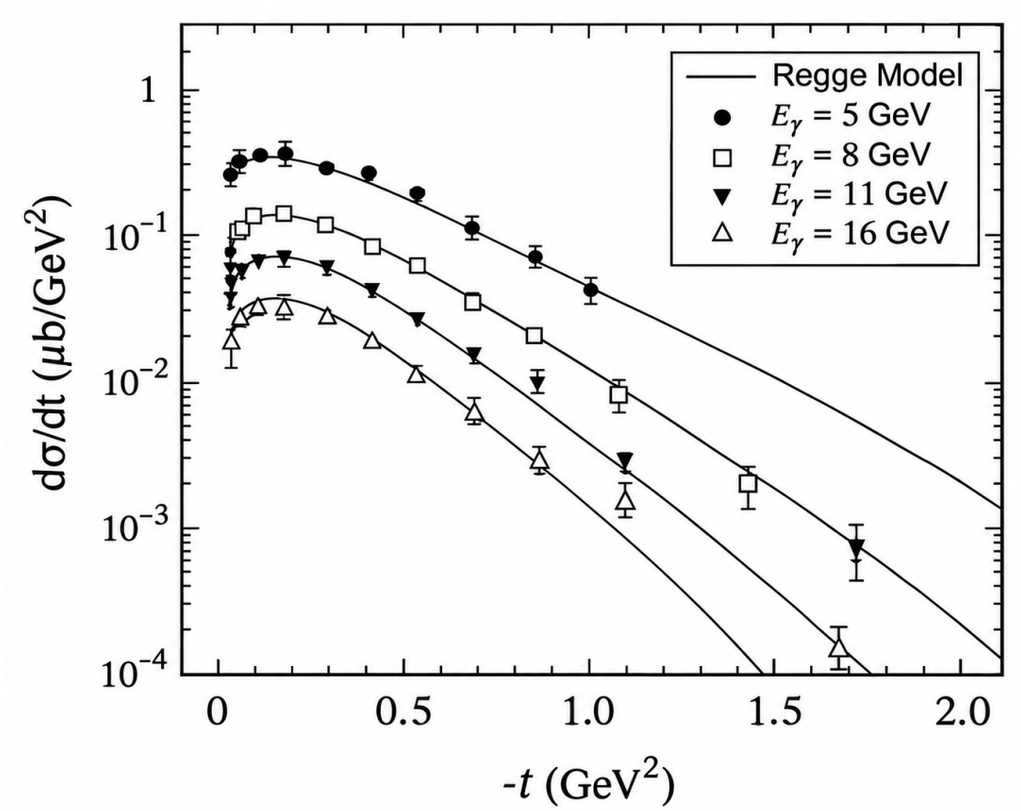


t-channel

K or K* exchange: the K^+ leaves with the photon's momentum. Forward peak at high s.

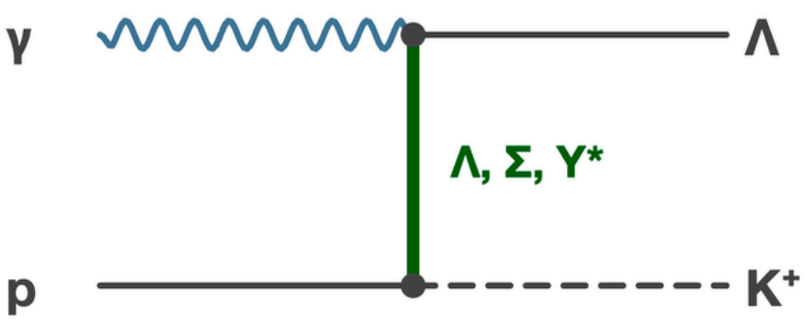
small –t

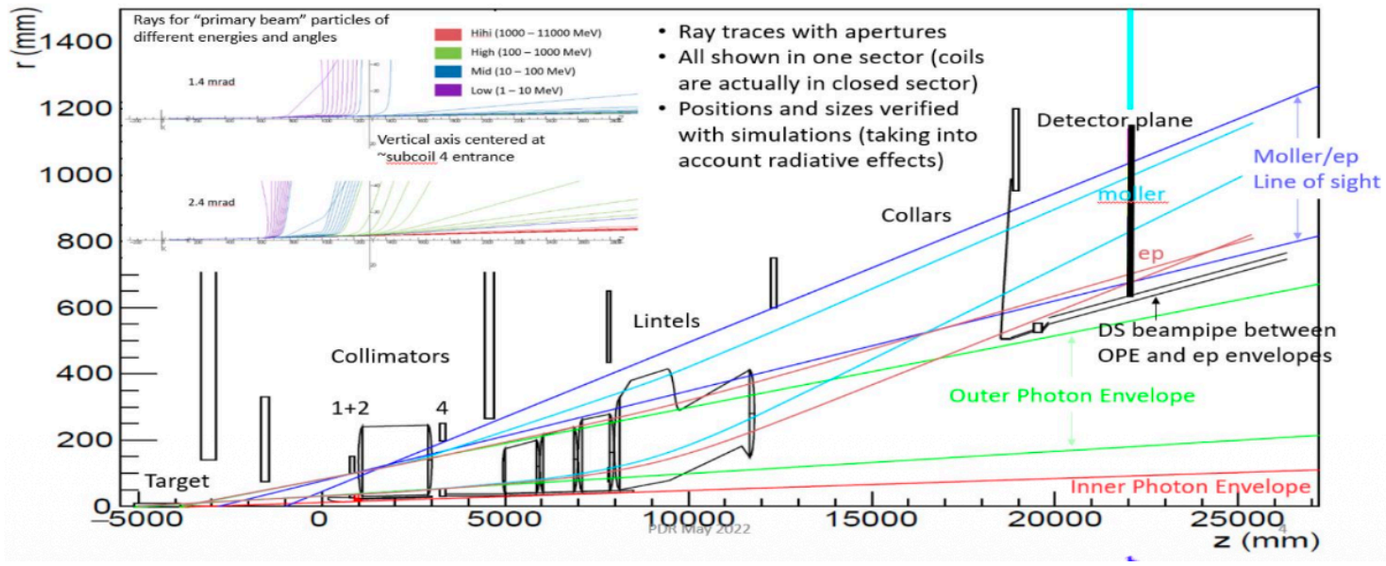
Data from SLAC: PRL 22, 1131 (1969)
Regge Model: PRC 73, 045207 (2006)



- For $E_\gamma \gtrsim 5$ GeV low-t region well described by Regge theory
- Early data from SLAC, but accessible at CLAS12 and GlueX

u-channel: hyperon production





u-channel

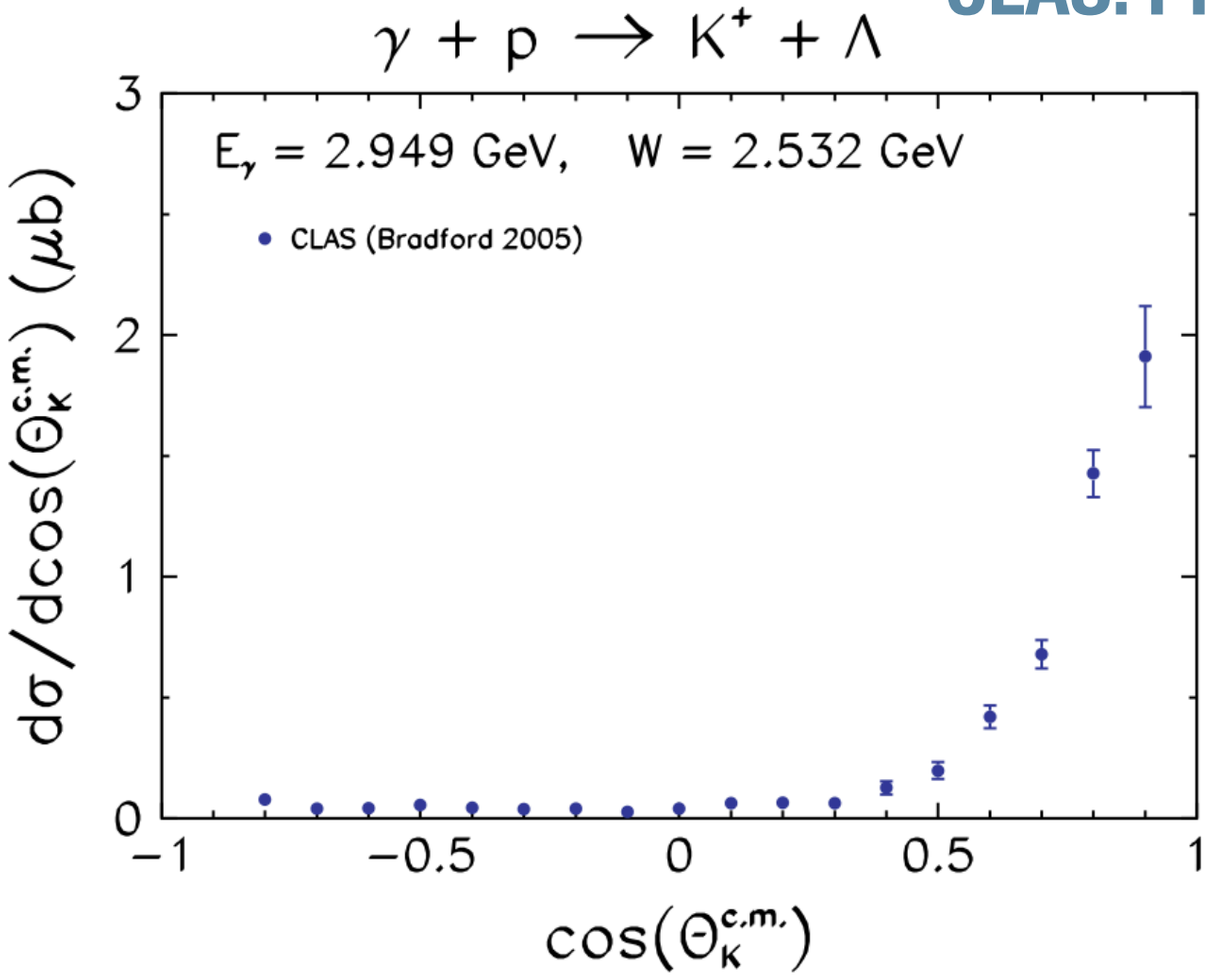
Hyperon exchange: the Λ leaves with the photon's momentum, the K^+ goes backward.

small –u

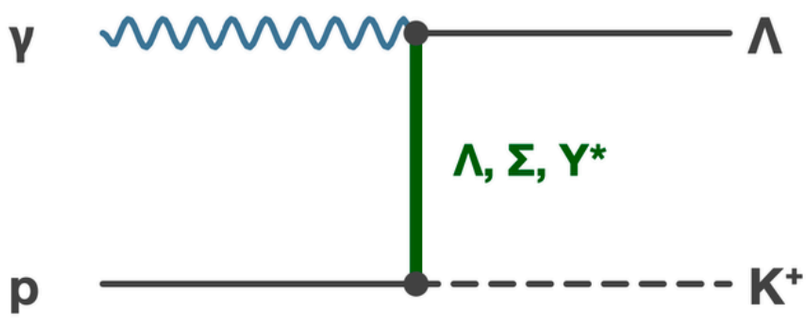
- Most relevant production mechanism for MOLLER with high momentum π^- from boosted Λ
- Relatively unexplored, but very accessible for CLAS12 and GlueX!

Hyperon production summary

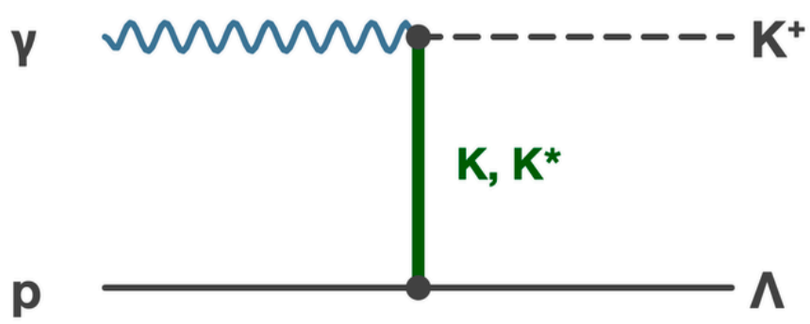
CLAS: PRC 73, 035202 (2006)



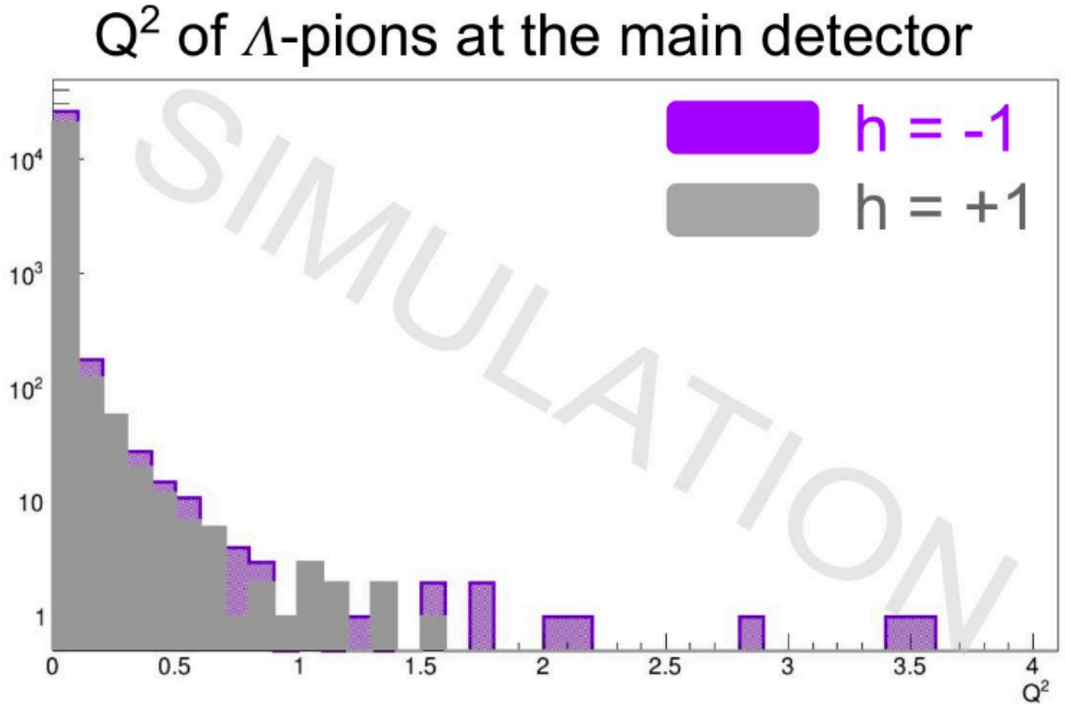
u-channel: $cos(\theta_K) \rightarrow -1$

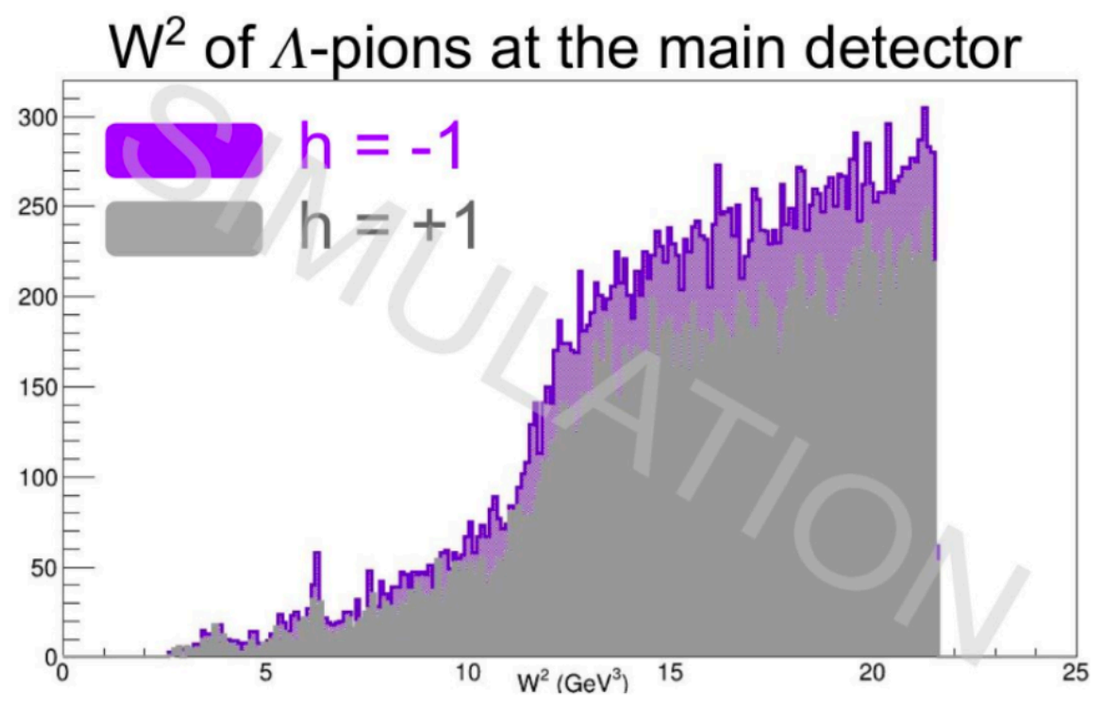


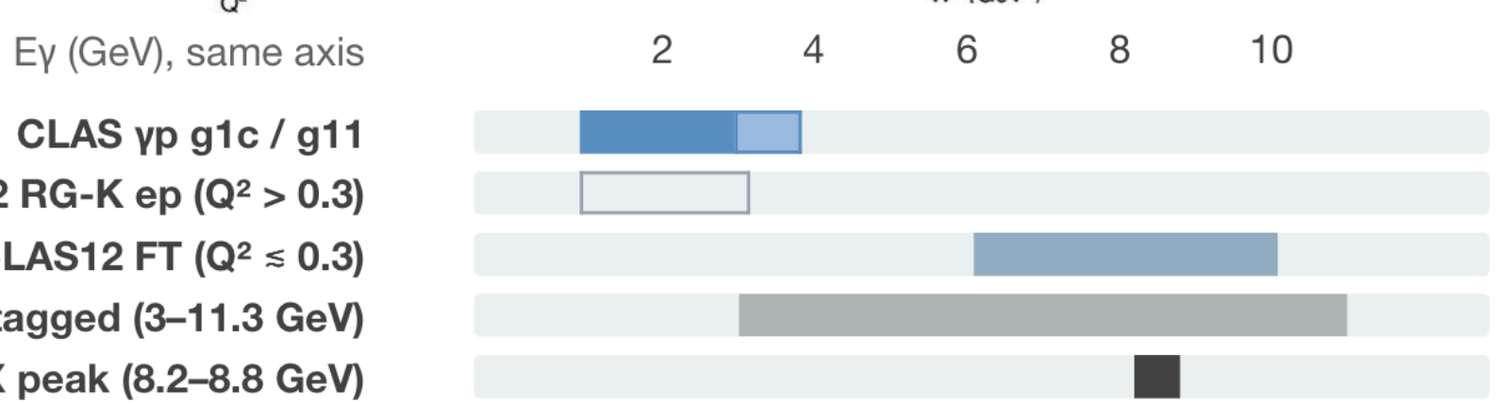
t-channel: $cos(\theta_K) \rightarrow 1$



MOLLER kinematic coverage







- I'll review some CLAS 6 GeV, but focus for MOLLER should be overlap with u-channel at CLAS12 and GlueX

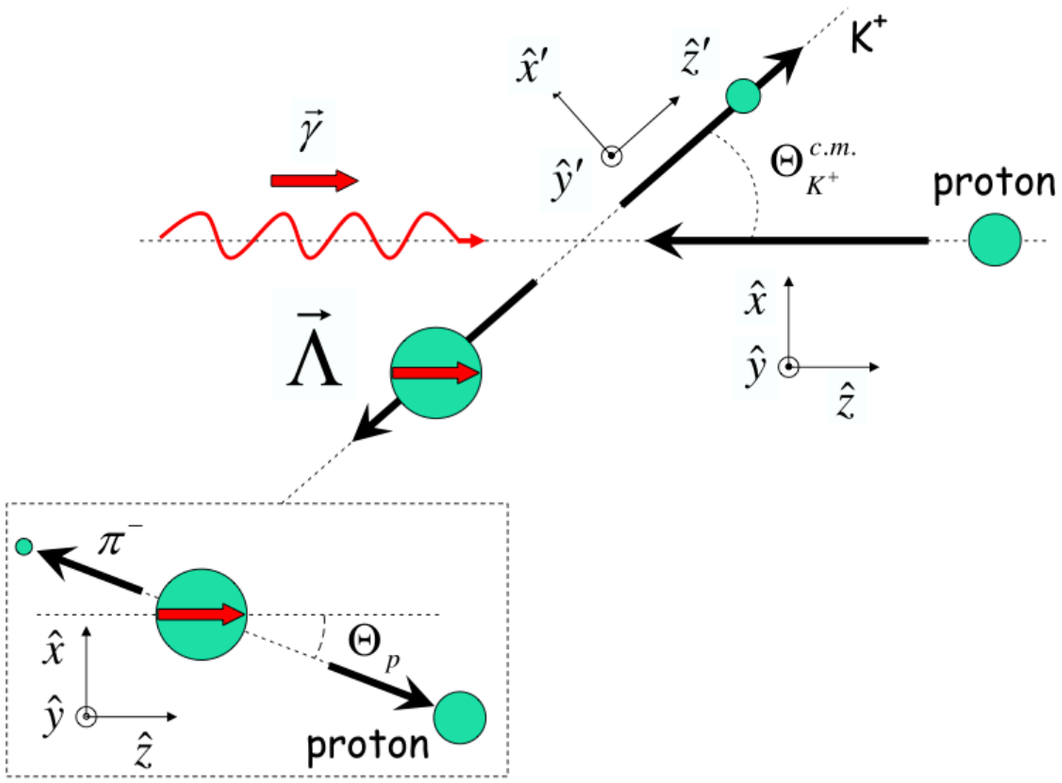
Observables in $K^+\Lambda$ photoproduction

- Alphabet soup: what's relevant for MOLLER?
- Circular pol. P_C^γ (or $P_\odot$) and related observables

$$I(\Phi, \theta_{x',y',z'}) = 1 + \alpha_- \cos\theta_{y'} P - P_L^\gamma \cos(2\Phi)(\Sigma + \alpha_- \cos\theta_{y'} T)$$
$$- P_L^\gamma \sin(2\Phi)(\alpha_- \cos\theta_{x'} O_{x'} + \alpha_- \cos\theta_{z'} O_{z'})$$
$$- P_C^\gamma (\alpha_- \cos\theta_{x'} C_{x'} + \alpha_- \cos\theta_{z'} C_{z'})$$

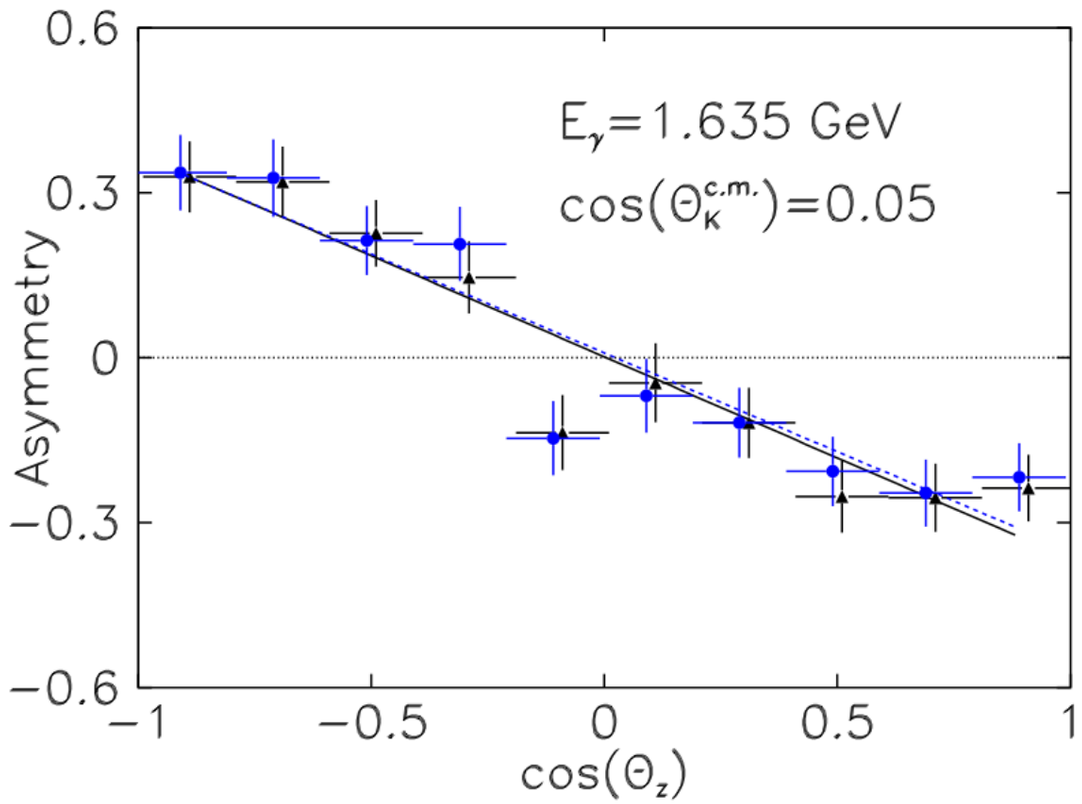
Observable	Needs	Helicity-odd?	Role for MOLLER
dσ/du, dσ/d cos θK	unpolarized	no	Sets the rate fYπ
P, induced (normal to the reaction plane)	unpolarized	no	Cancels in Aπ; bounds the total polarization
Σ, T, Ox, Oz	linear γ or polarized target	no	Constrains amplitudes for model fits
Cx, Cz (photo) ↔ P′x, P′z (electro)	circular γ or polarized e^-	yes	The MOLLER input: P′ = D(y) · (Cx, Cz)

Measuring helicity asymmetries: C_x, C_z



$$I_i(\cos\theta_i) = \tfrac{1}{2}(1 + \nu\alpha P_{Y\,i}\cos\theta_i)$$

$$A(\cos\theta_i) = \frac{N_+ - N_-}{N_+ + N_-} = \alpha\nu P_\odot C_i \cos\theta_i$$

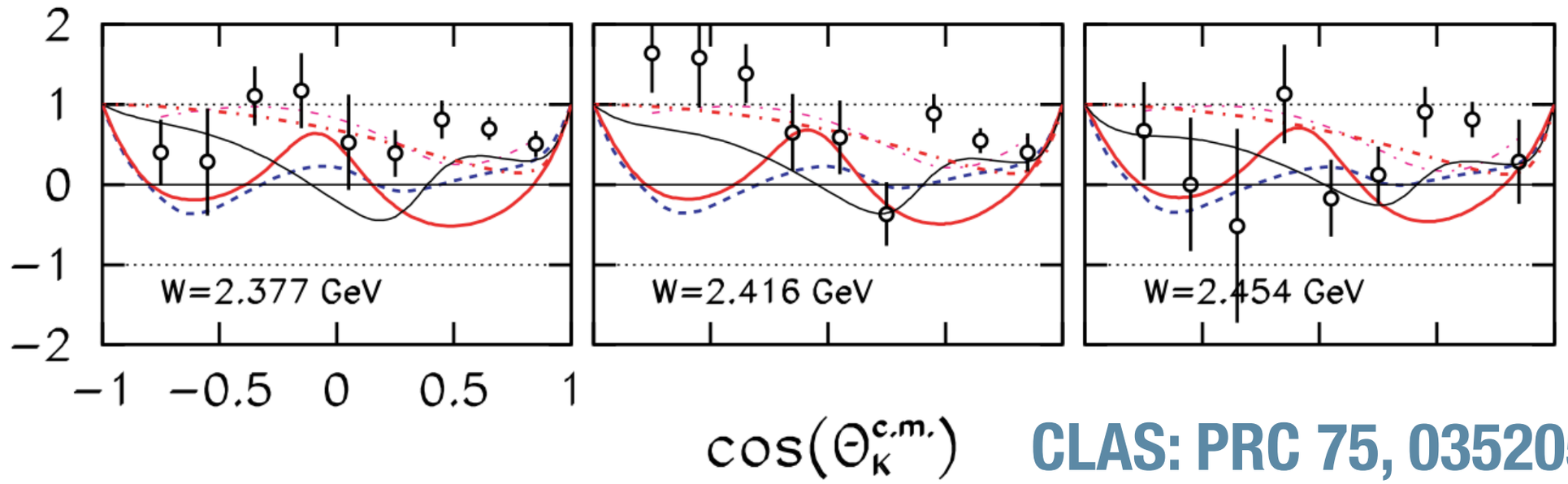


- Helicity asymmetry Λ decay angles $cos(\theta_i)$
- Linear fit to asymmetry obtains C_x, C_z

CLAS: PRC 75, 035205 (2007)

CLAS 6 GeV photoproduction

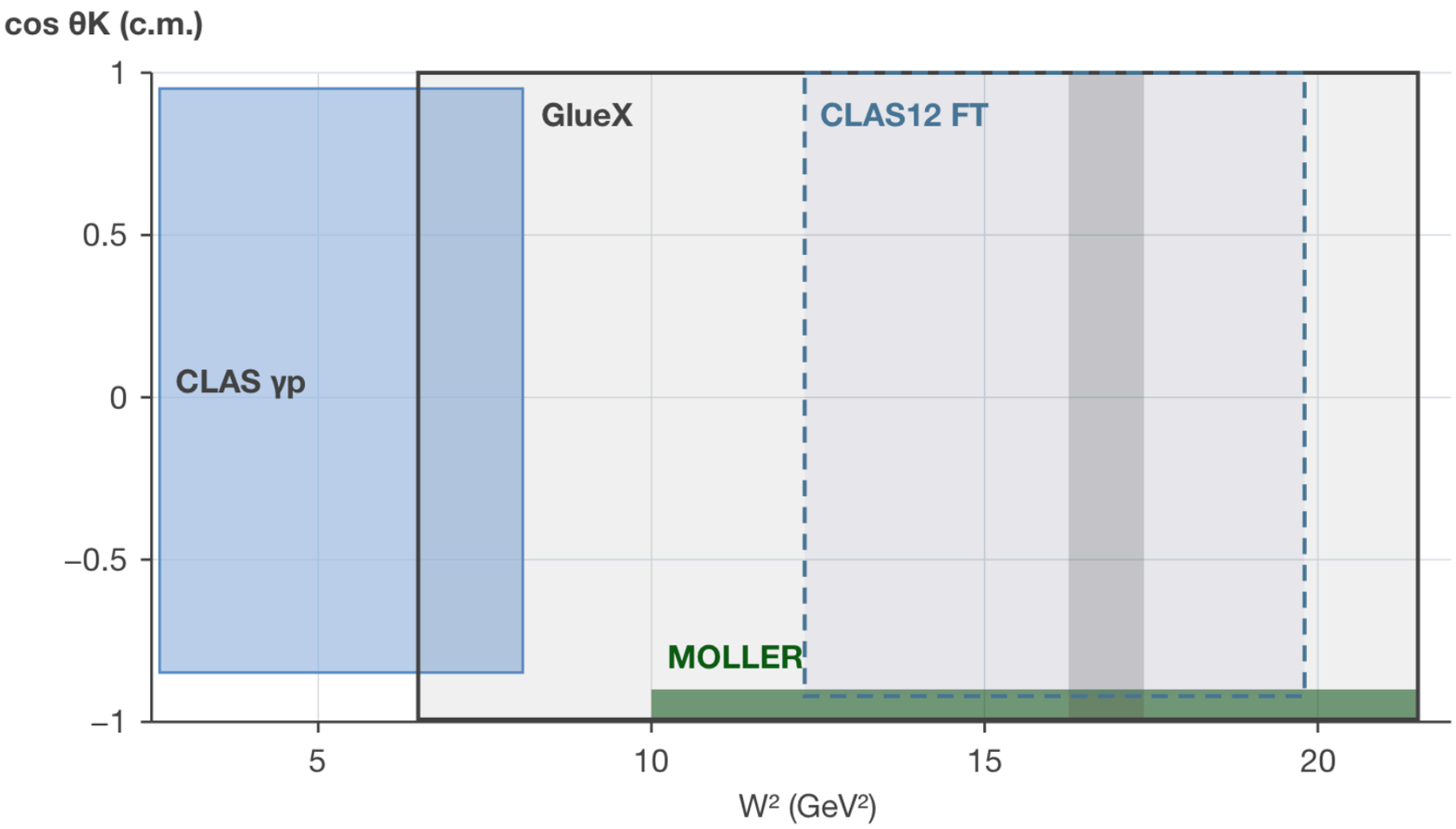
- Polarization observables measured in bins of W and $cos(\theta_K)$, remember equivalent to t or u
- Primarily sensitive to baryon resonances



CLAS: PRC 75, 035205 (2007)

Run	Reach (GeV, GeV²)	K⁺Λ, K⁺Σ⁰ observables
g1c	Eγ ≤ 2.95 (W² ≤ 6.4)	dσ/d cos θK, P, Cx, Cz
g11	Eγ ≤ 3.84 (W² ≤ 8.1)	dσ/d cos θK, P
g8b	W² ≈ 2.9–4.8	Σ, T, Ox, Oz

MOLLER kinematics: CLAS12 and GlueX



MOLLER Λ-π region: cos θK < −0.9, $W^2 \approx 10$–21.5 GeV²

GlueX tagged, to cos θK ≈ −0.99; dark band = 8.2–8.8 GeV

CLAS12 FT, Λ in the Forward Detector: to cos θK ≈ −0.92

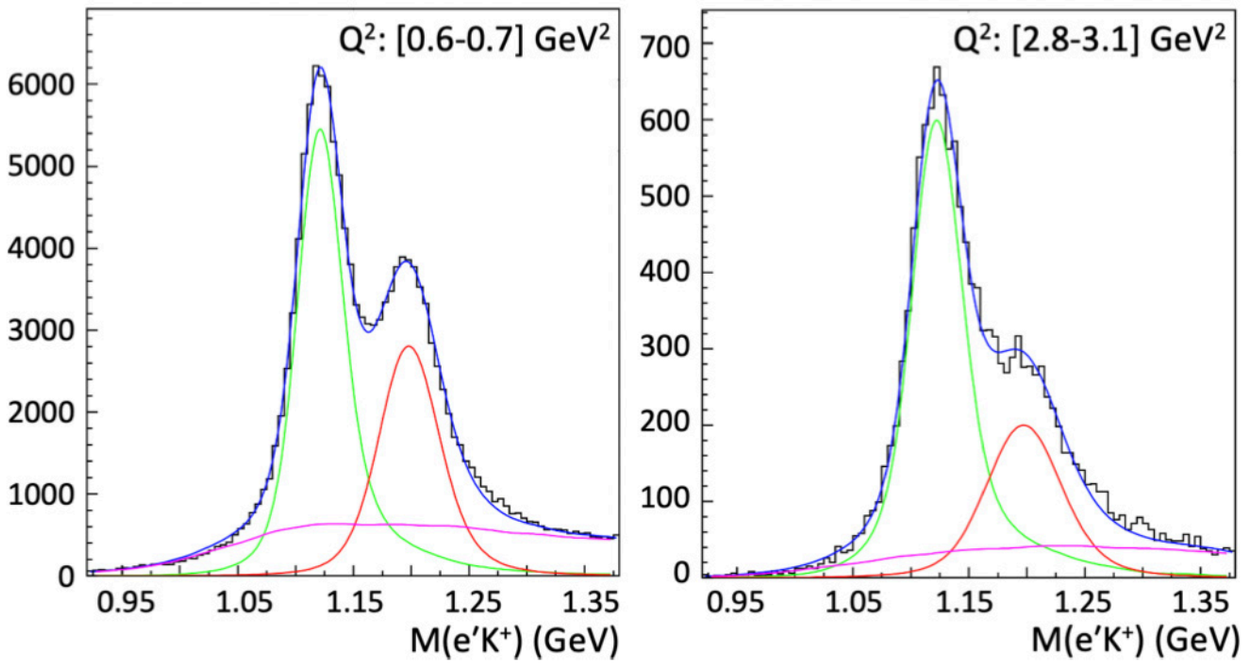
CLAS g1c/g11: $W^2 \leq 8.1$ GeV², cos θK ≳ −0.85

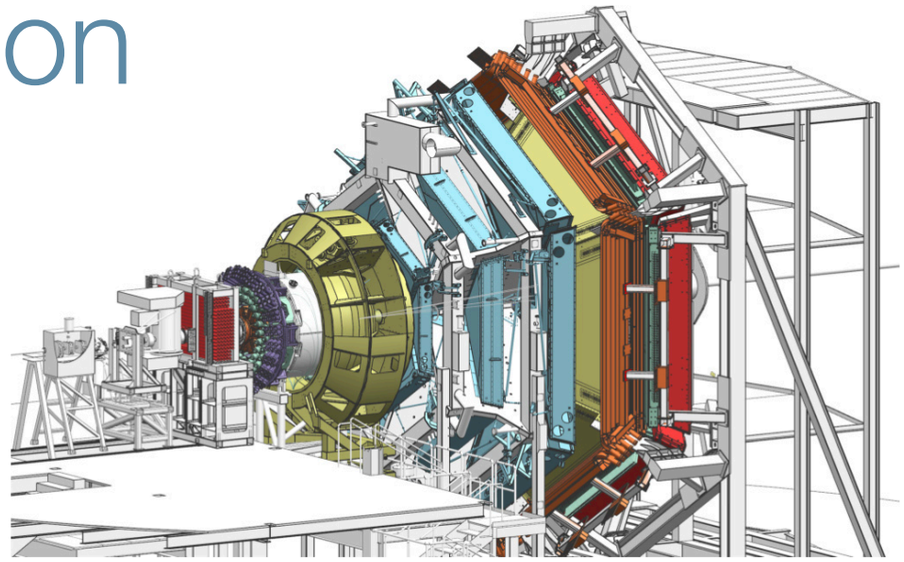
Schematic; acceptance edges approximate. Accepted events concentrate at the bottom of the MOLLER band, cos θK → −1.

- Low-Q^2 at CLAS12 and real photons at GlueX offer
  - $W^2 > 10$ GeV i.e. $E_\gamma > 5$ GeV
  - $cos(\theta_K) \rightarrow -1$ i.e. u-channel regime

CLAS12 electroproduction

$$ep \rightarrow e'K^+X$$





- CLAS12 RG-K well-suited for polarization observables for Λ and Σ^0 with missing mass

- Binned in Q^2, W, $cos(\theta_K)$

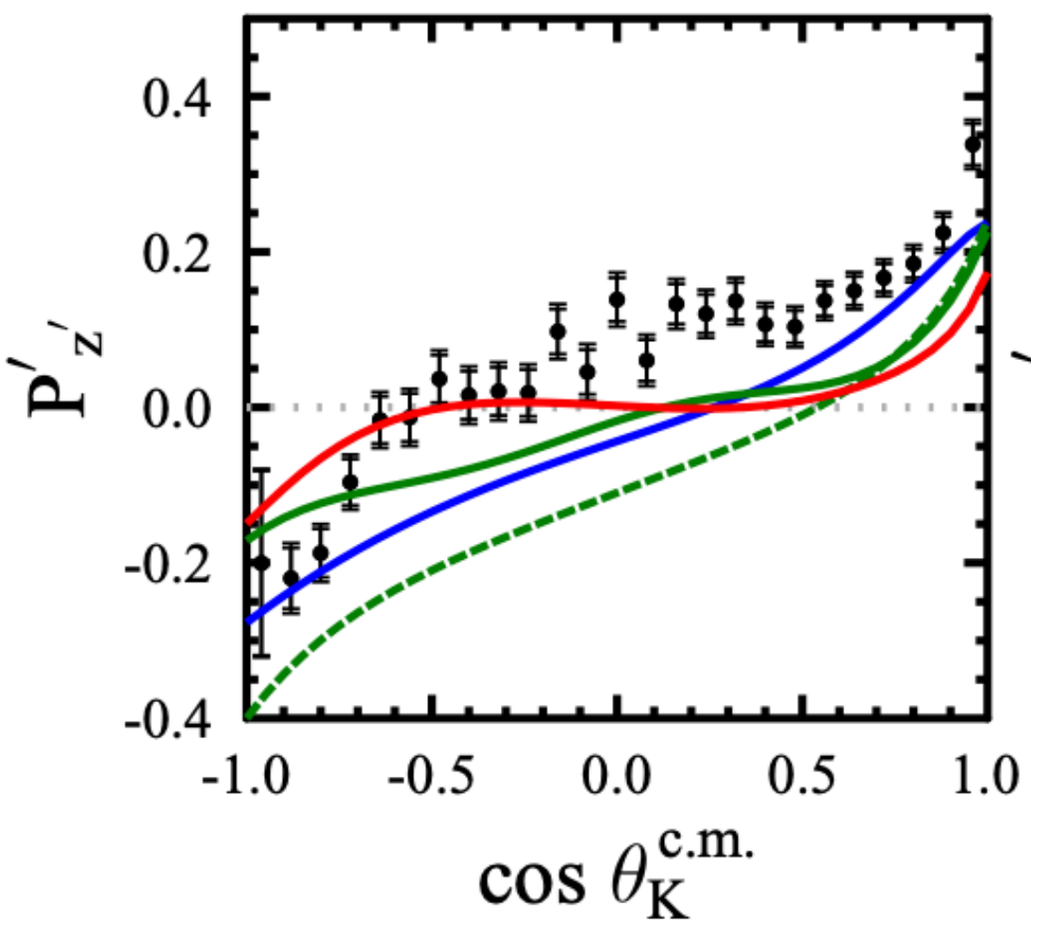
CLAS12: PRC 105, 065201 (2022)

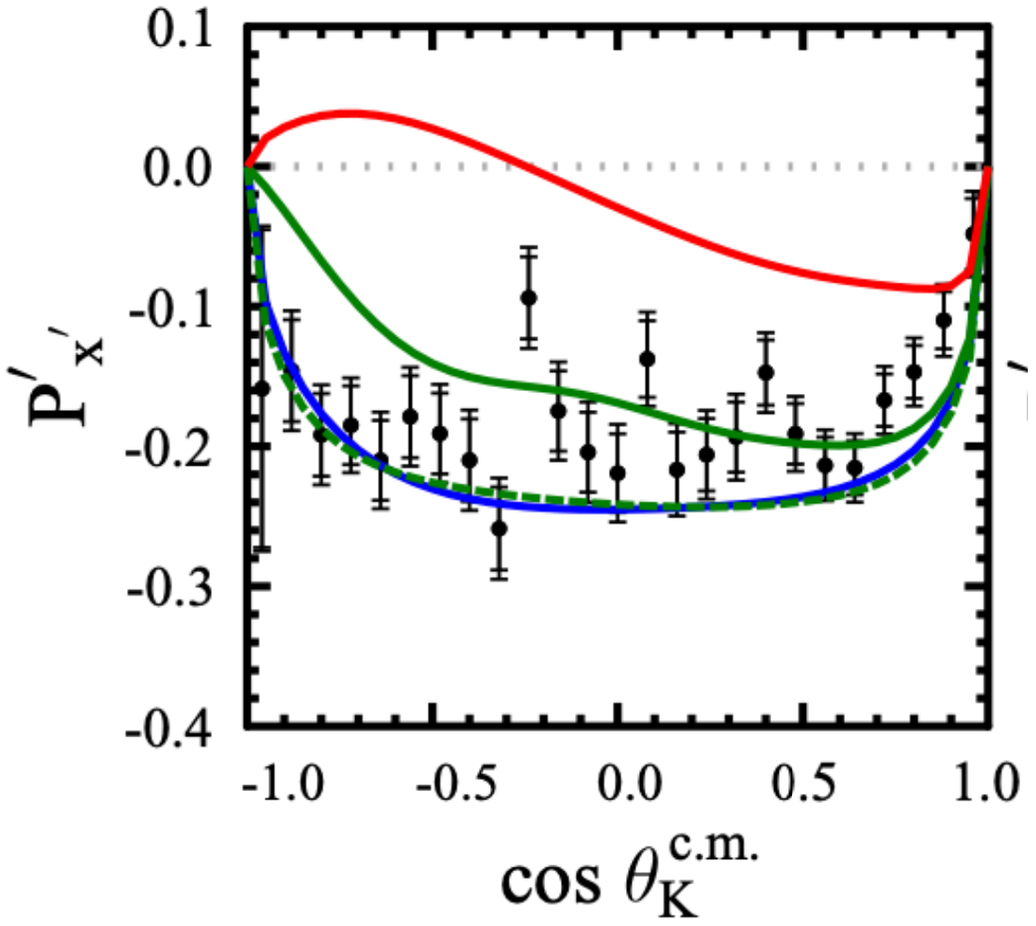
Data set	Beam (GeV)	Observables	In the model
CLAS	2.567–5.754	P′ (beam-recoil transfer)	—
CLAS	2.567, 5.499	σU, σLT, σTT, σLT′	5.499 GeV set
CLAS	5.499	induced P^0	—
CLAS12 RG-K	6.535, 7.546	P′ in 1D and 3D (Q^2, W, cos θK)	1D, as a guide

CLAS12 RG-K results

- Similar helicity asymmetry in Λ decay angles as C_x, C_z

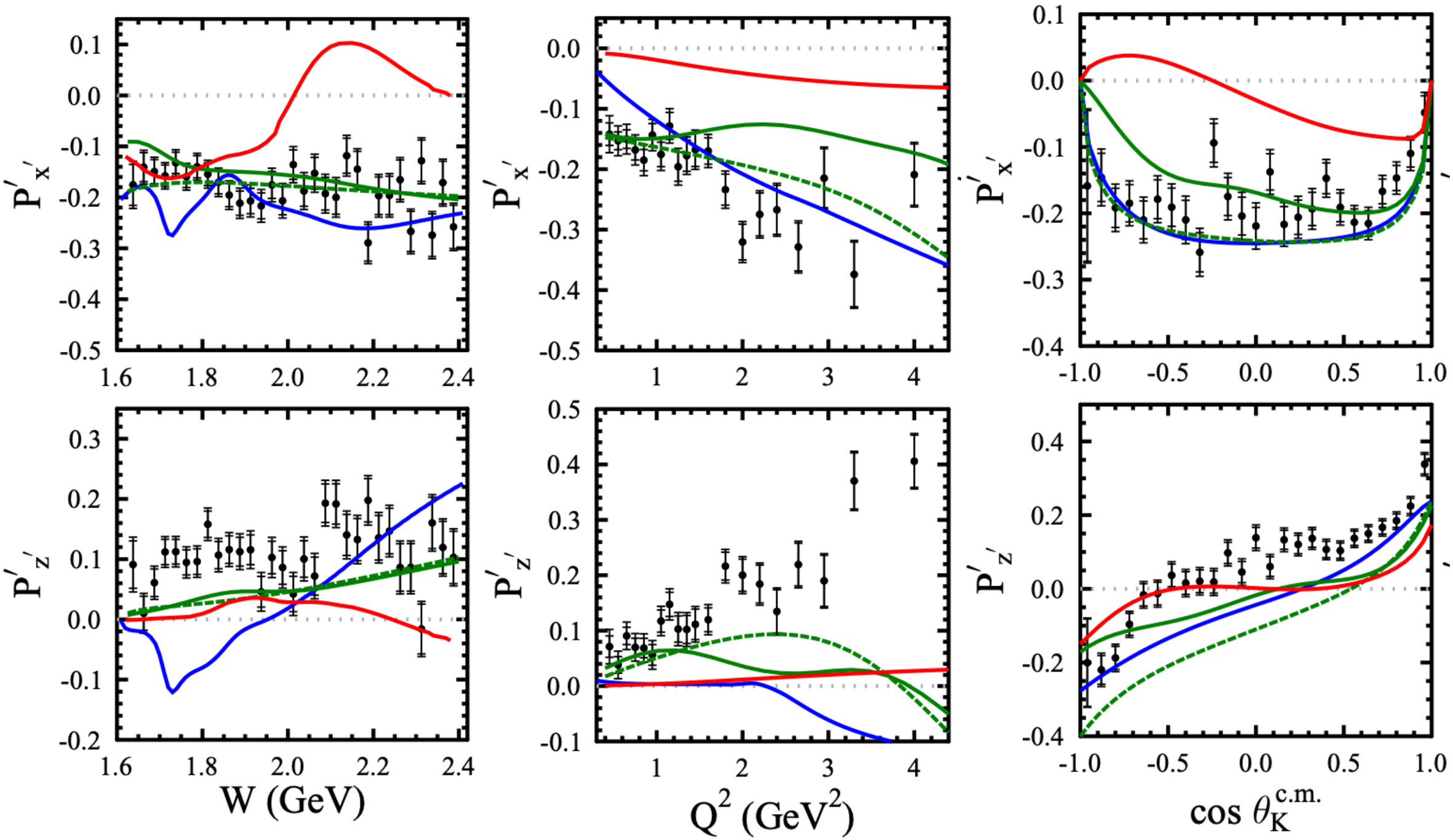
$$A = \frac{N^+ - N^-}{N^+ + N^-} = \nu_Y \alpha P_b \mathcal{P}'_Y \cos\theta_p^{RF}$$





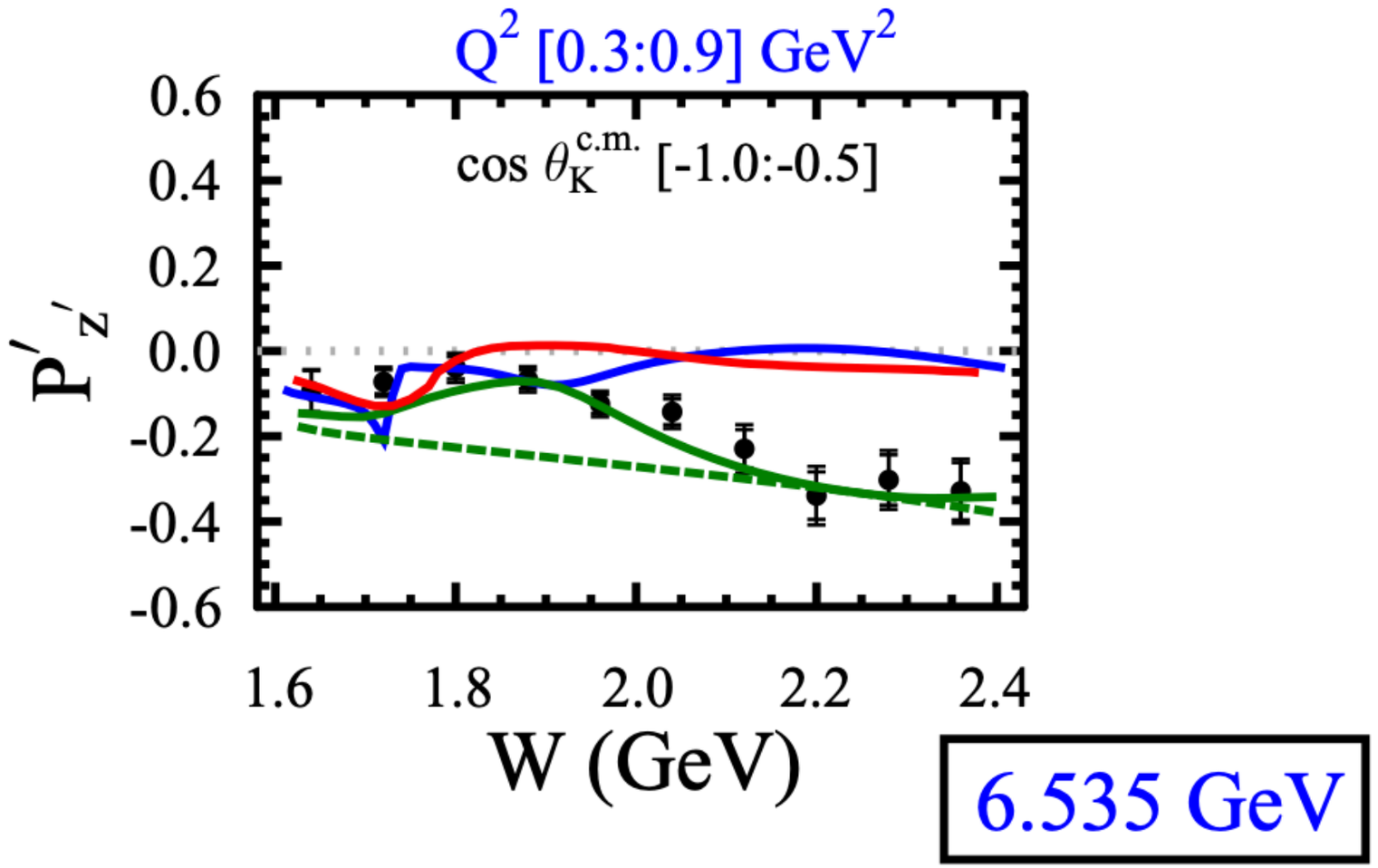
CLAS12: PRC 105, 065201 (2022)

CLAS12 RG-K binned in Q^2, W, $cos(\theta_K)$



CLAS12: PRC 105, 065201 (2022)

CLAS12 RG-K 3D binning

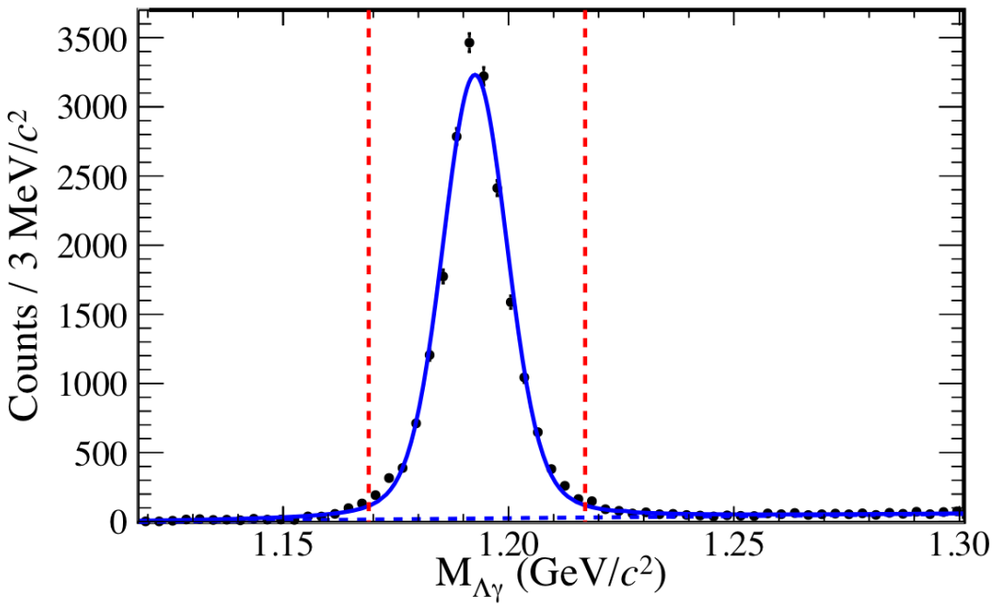


- Impressive precision, but limited applications to MOLLER
  - $Q^2 > 0.3$ GeV^2
  - $W^2 < 6$ GeV^2

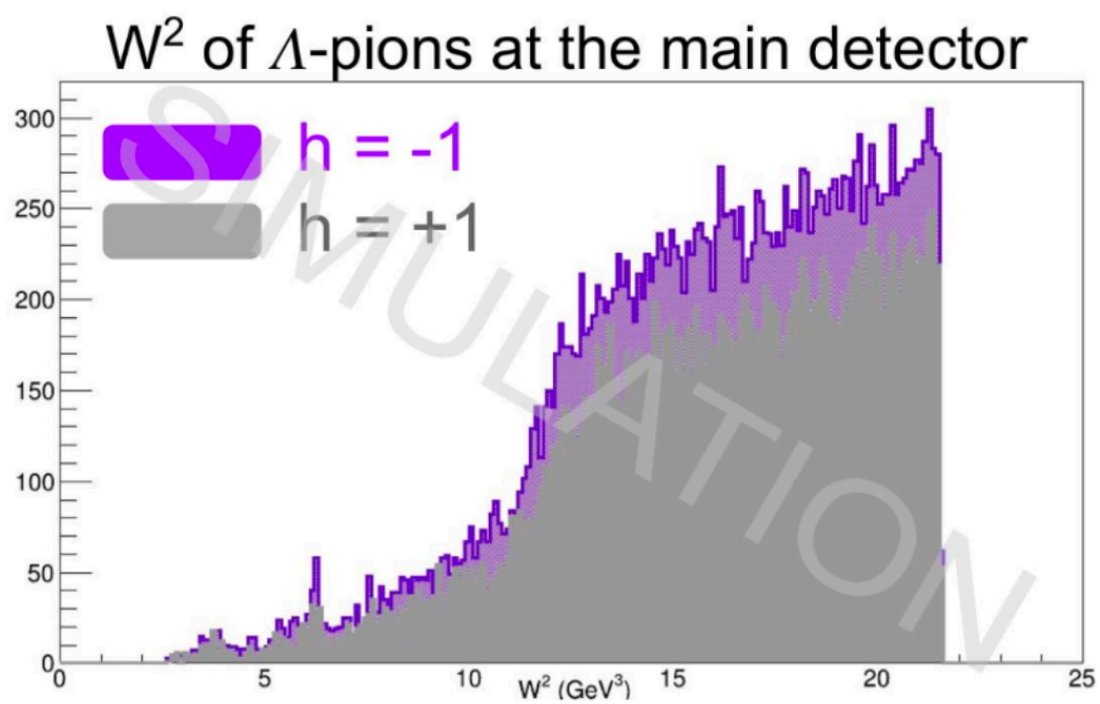
CLAS12: PRC 105, 065201 (2022)

GlueX kinematics

$$\gamma p \to K^+\Sigma^0$$

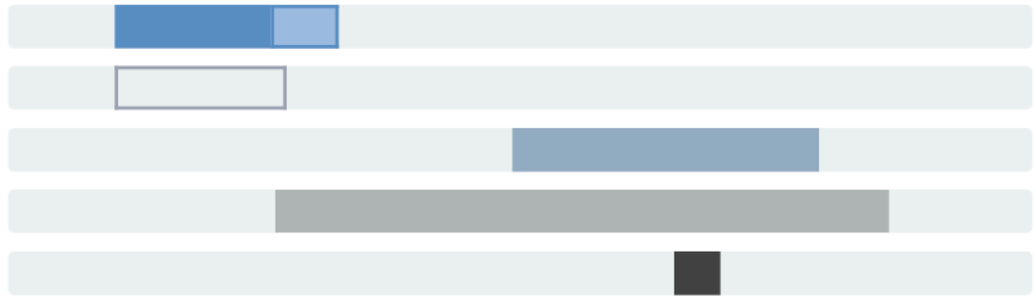


- GlueX well-suited for exclusive reconstruction of Λ and Σ^0 at $Q^2 = 0$ and $W^2 > 6$ GeV^2



Accepted Λ-pions, from A. Hurley's talk

Eγ (GeV), same axis



CLAS γp g1c / g11

CLAS12 RG-K ep ($Q^2 > 0.3$)

CLAS12 FT ($Q^2 \lesssim 0.3$)

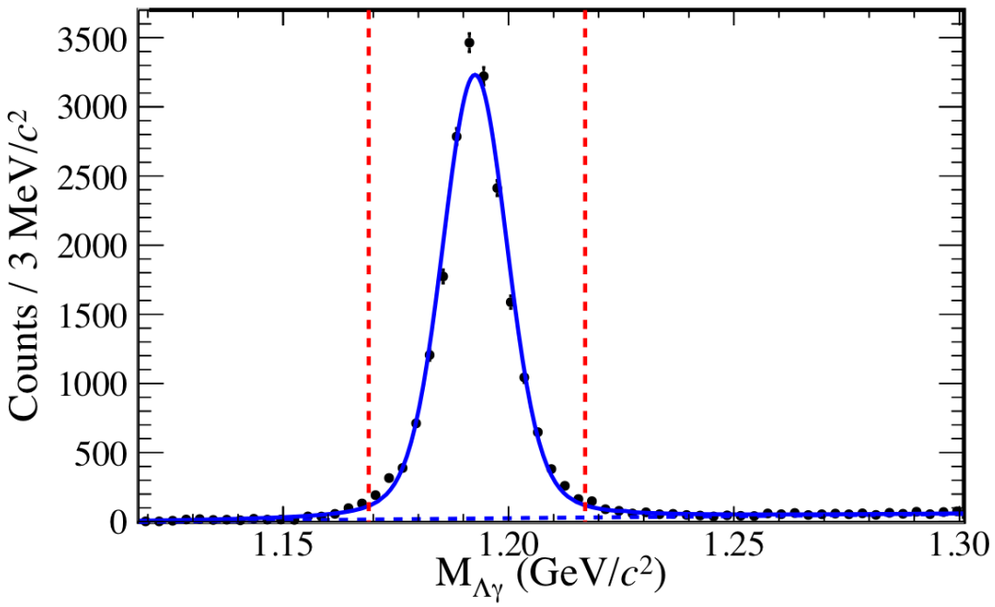
GlueX tagged (3–11.3 GeV)

GlueX peak (8.2–8.8 GeV)

GlueX: PRC 101, 065206 (2020)

GlueX kinematics

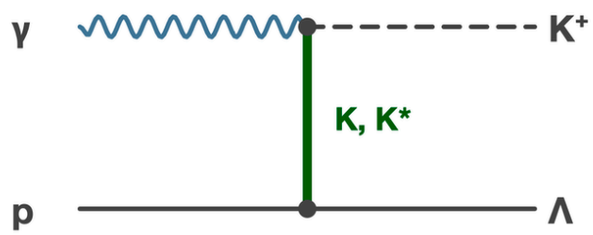
$$\gamma p \to K^+\Sigma^0$$

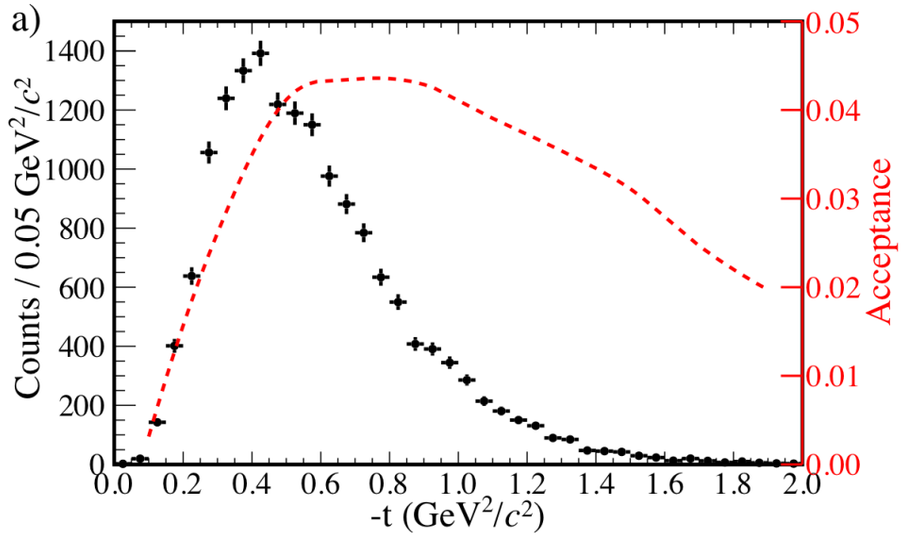


- GlueX well-suited for exclusive reconstruction of Λ and Σ^0 over both and t and u-channel
- Initially focused on linearly polarized asymmetry Σ

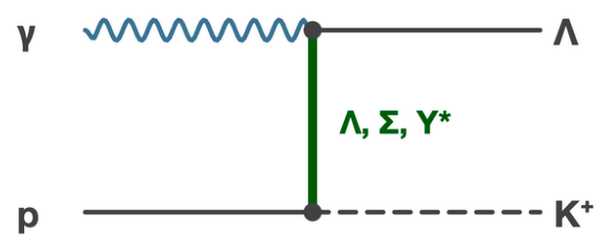
GlueX: PRC 101, 065206 (2020)

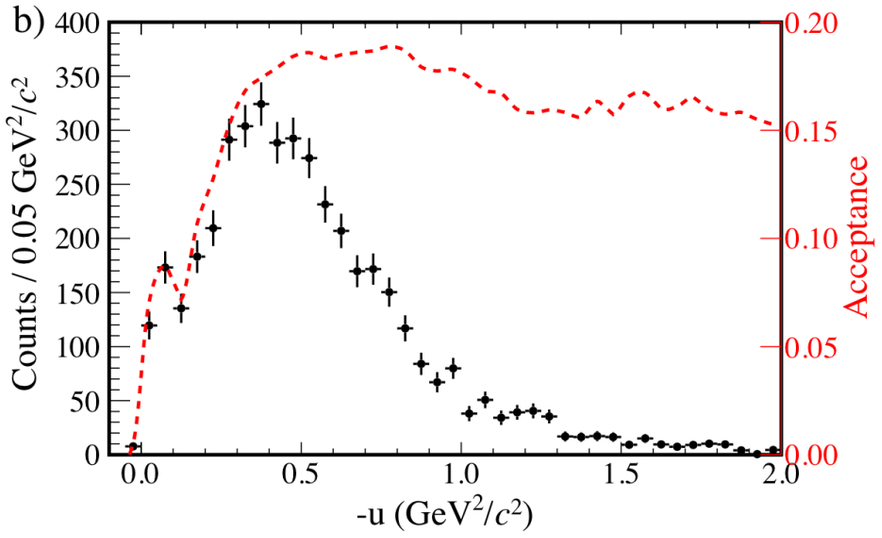
t-channel backward π^-



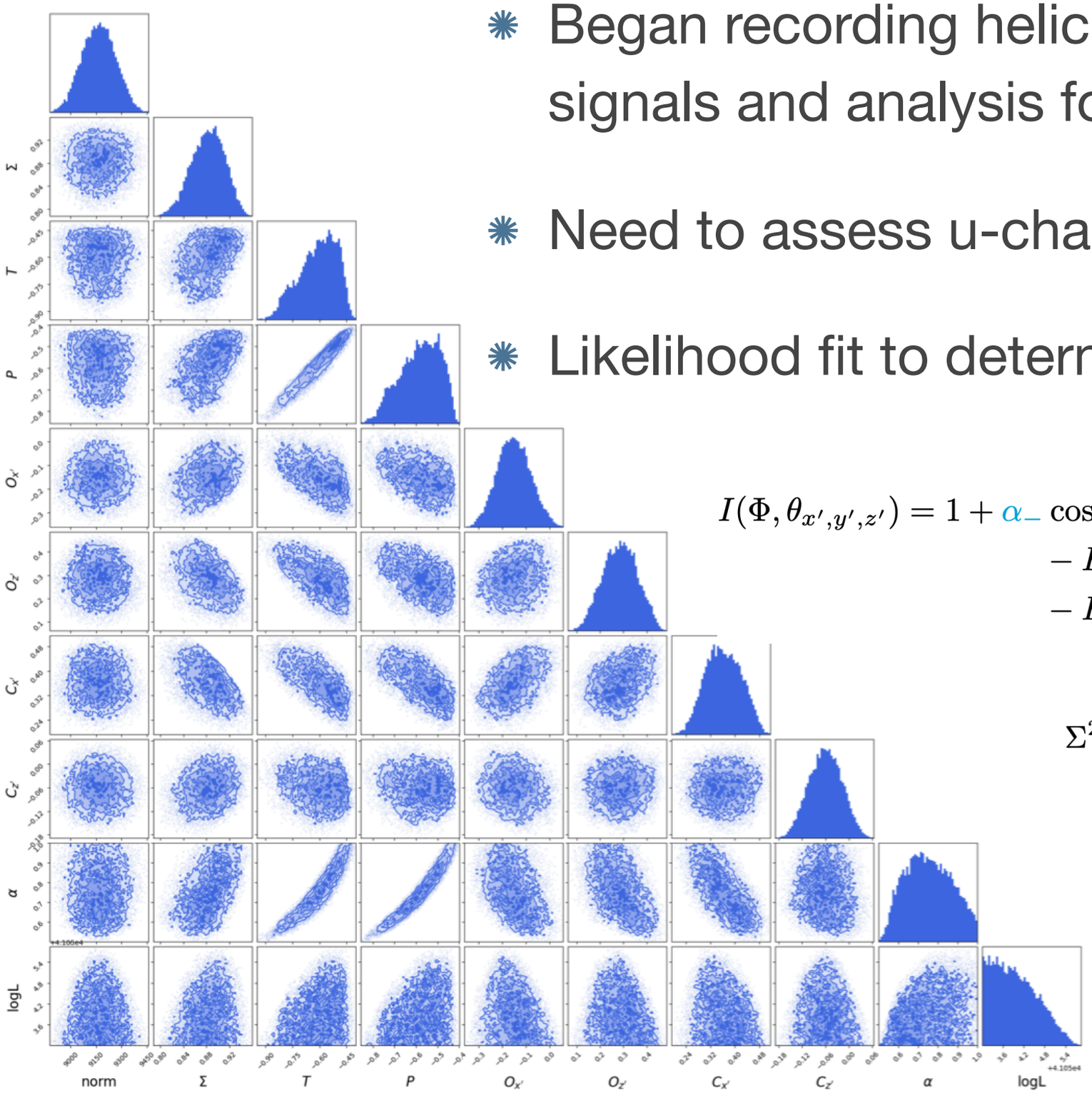


u-channel Forward π^-





Complete measurements at GlueX



- Began recording helicity data in 2023, clear signals and analysis for $K^+\Lambda$ and $K^+\Sigma^0$
- Need to assess u-channel statistics
- Likelihood fit to determine all observables

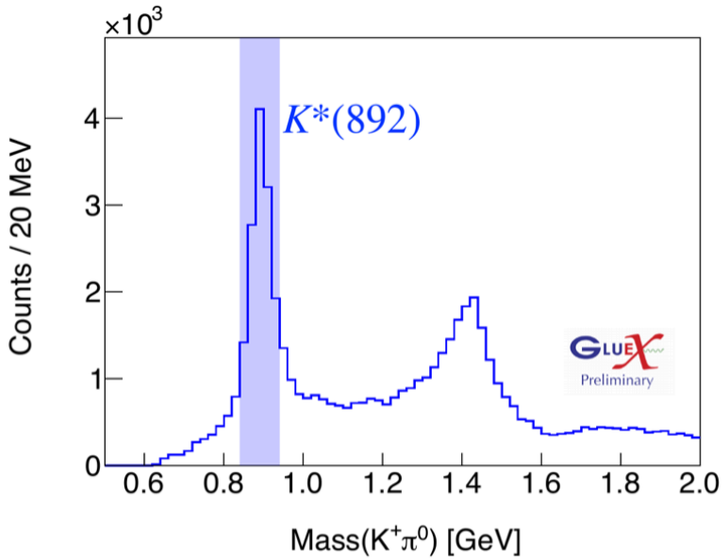
$$I(\Phi,\theta_{x'},_{y'},_{z'}) = 1 + \alpha_- \cos\theta_{y'} P - P_L^\gamma \cos(2\Phi)(\Sigma + \alpha_- \cos\theta_{y'} T) - P_L^\gamma \sin(2\Phi)(\alpha_- \cos\theta_{x'} O_{x'} + \alpha_- \cos\theta_{z'} O_{z'}) - P_C^\gamma(\alpha_- \cos\theta_{x'} C_{x'} + \alpha_- \cos\theta_{z'} C_{z'})$$

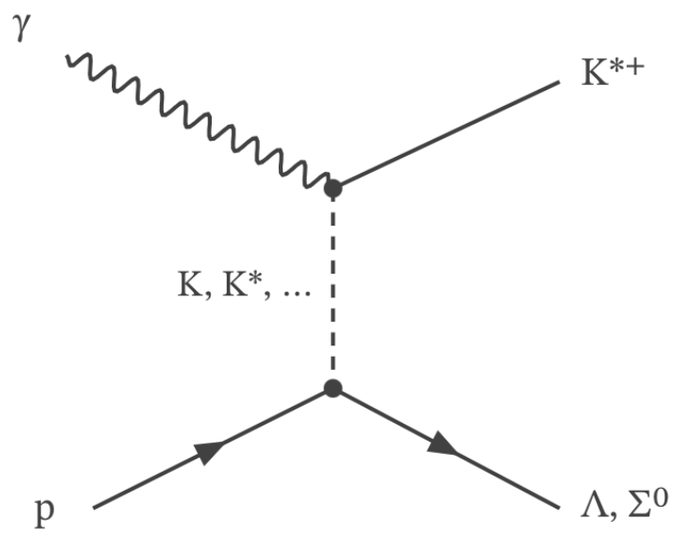
$$\Sigma^2 - T^2 + P^2 + C_{x'}^2 + C_{z'}^2 + O_{x'}^2 + O_{z'}^2 = 1$$
$$\Sigma P - T - C_{x'} O_{z'} + C_{z'} O_{x'} = 0$$

Approved PAC52 Run Group
arXiv:2405.01288

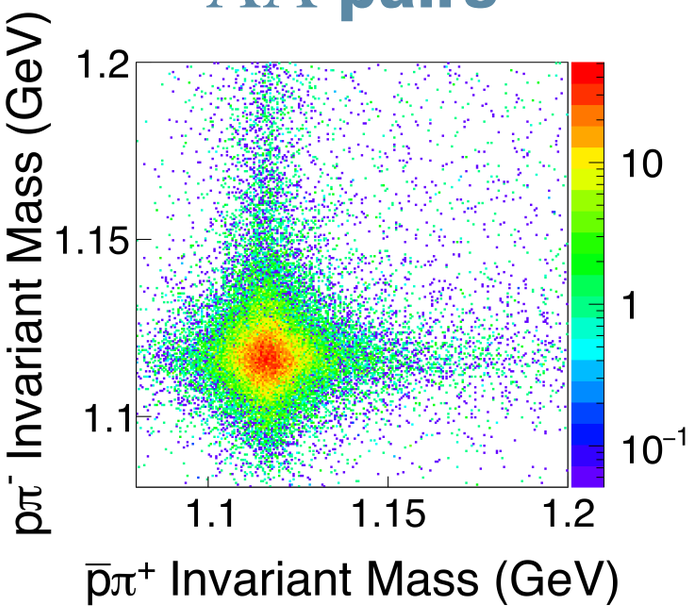
More hyperon production mechanisms

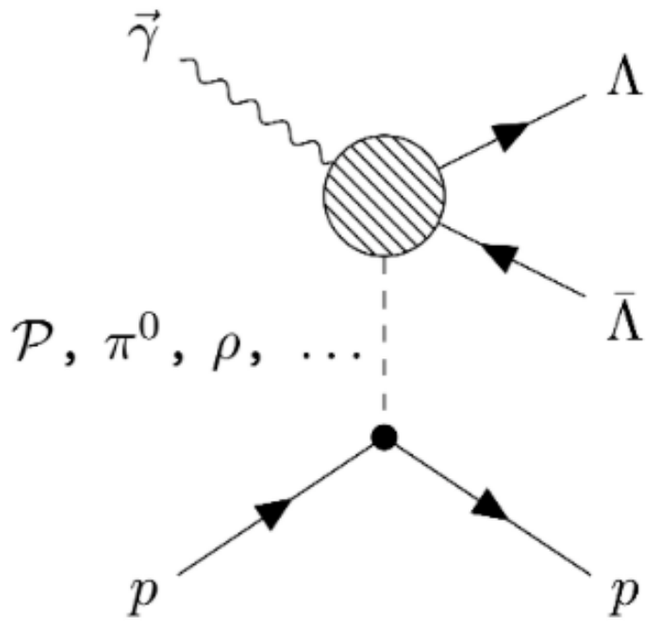
Excited kaons





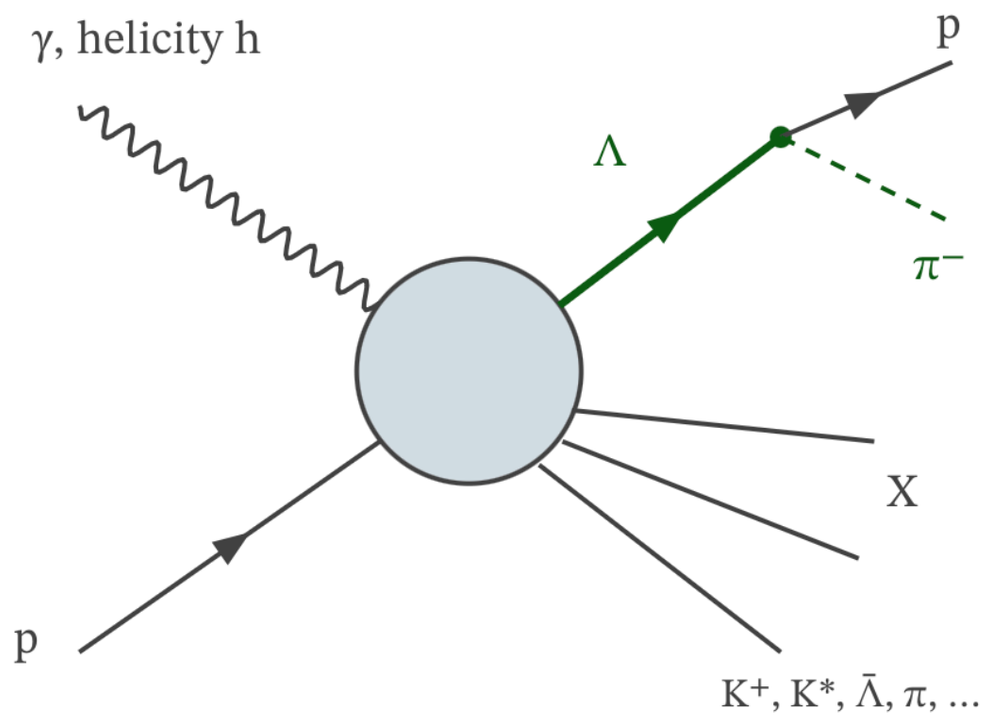
$\Lambda\bar{\Lambda}$ pairs





What about inclusive Λ?

- GlueX typically focused on exclusive topologies
- Some experiments (e.g. STAR) measure inclusive Λ asymmetries D_{LL}
- Would an inclusive Λ asymmetry be useful for MOLLER?



Summary

- Exclusive hyperon production well studied at for small W and in t-channel regime
- MOLLER kinematics directly overlap with CLAS12 and GlueX, but require new measurements
  - GlueX u-channel: $d\sigma/du,\ C_x,\ C_z$
  - CLAS12 low-Q^2
- Many other hyperon production mechanisms could play a role, needs further study

How well do we know $\alpha_$?

- Discrepancy between photoproduction and BESIII J/ψ decays
- Precision measurement at GlueX approved by PAC52

