Measurement of Hyperon Polarization at GlueX

PRESENTATION FOR THE TALK AT
HADRON SPECTROSCOPY WITH STRANGENESS

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(on behalf of the GlueX Collaboration)

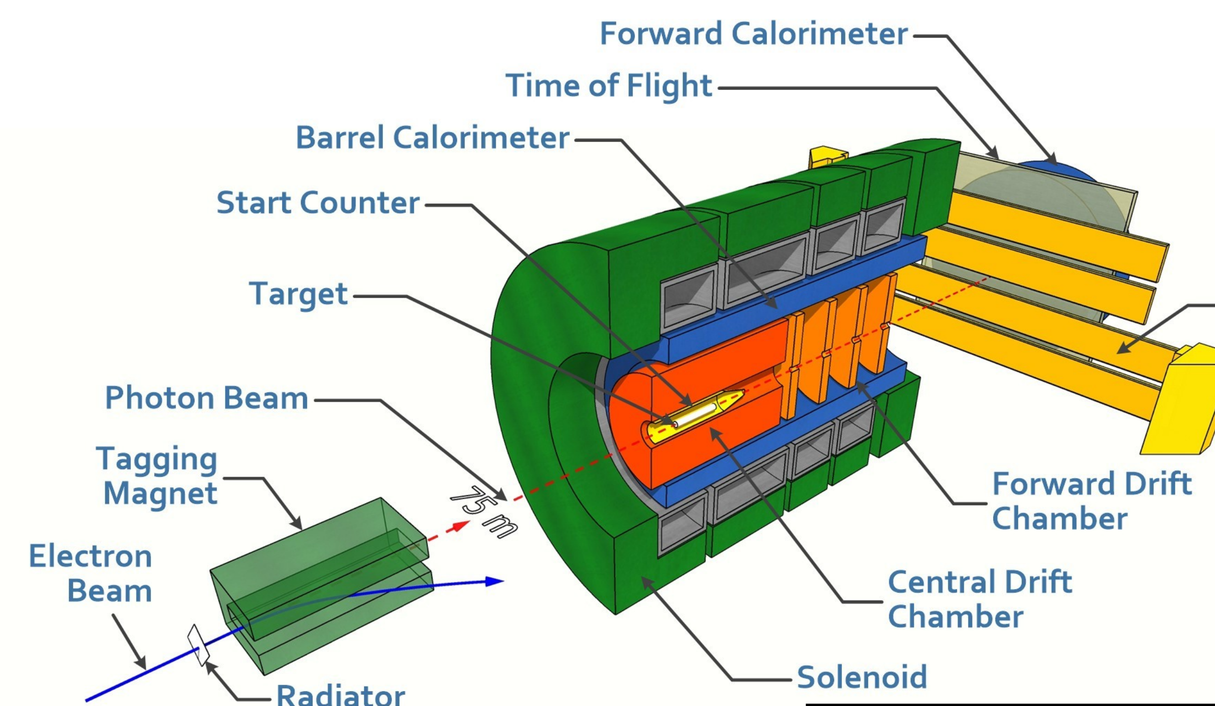
GlueX Experiment at Jefferson Lab Hall D

Hall D at *JLab*

- Receive **12 GeV** electron beam from Continuous Electron Beam Accelerator Facility (CEBAF)

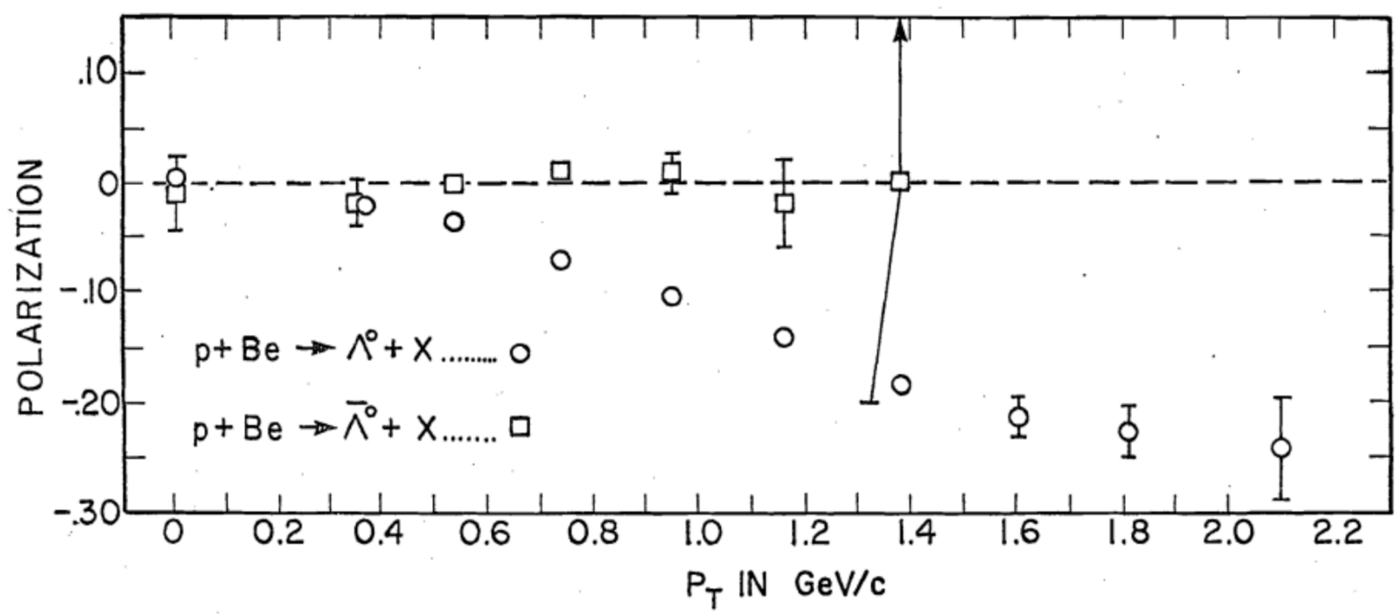
GlueX Beamline and Detector System

- GlueX Phase-I Data ~ $439.6\ pb^{-1}$
- Charged particle acceptance range: $1^{\circ} < \theta_{LAB} < 128^{\circ}$
- Momentum resolution for charged particles: $1\% - 3\ \%$
- Linearly polarized beam photon at ~9 GeV
- Unique advantage in strange hadron spectroscopy:
  - $3\sigma\ \pi/K$ separation (charged tracks with $p > 3$ GeV)
  - Kinematic fitting of displaced vertices for weakly decaying particle
- **See Session 6 for an "*Overview of Hyperon Physics in Photoproduction at GlueX*" by Jesse Hernandez**



Nucl. Instrum. & Meth. A987, 164807 (2021)

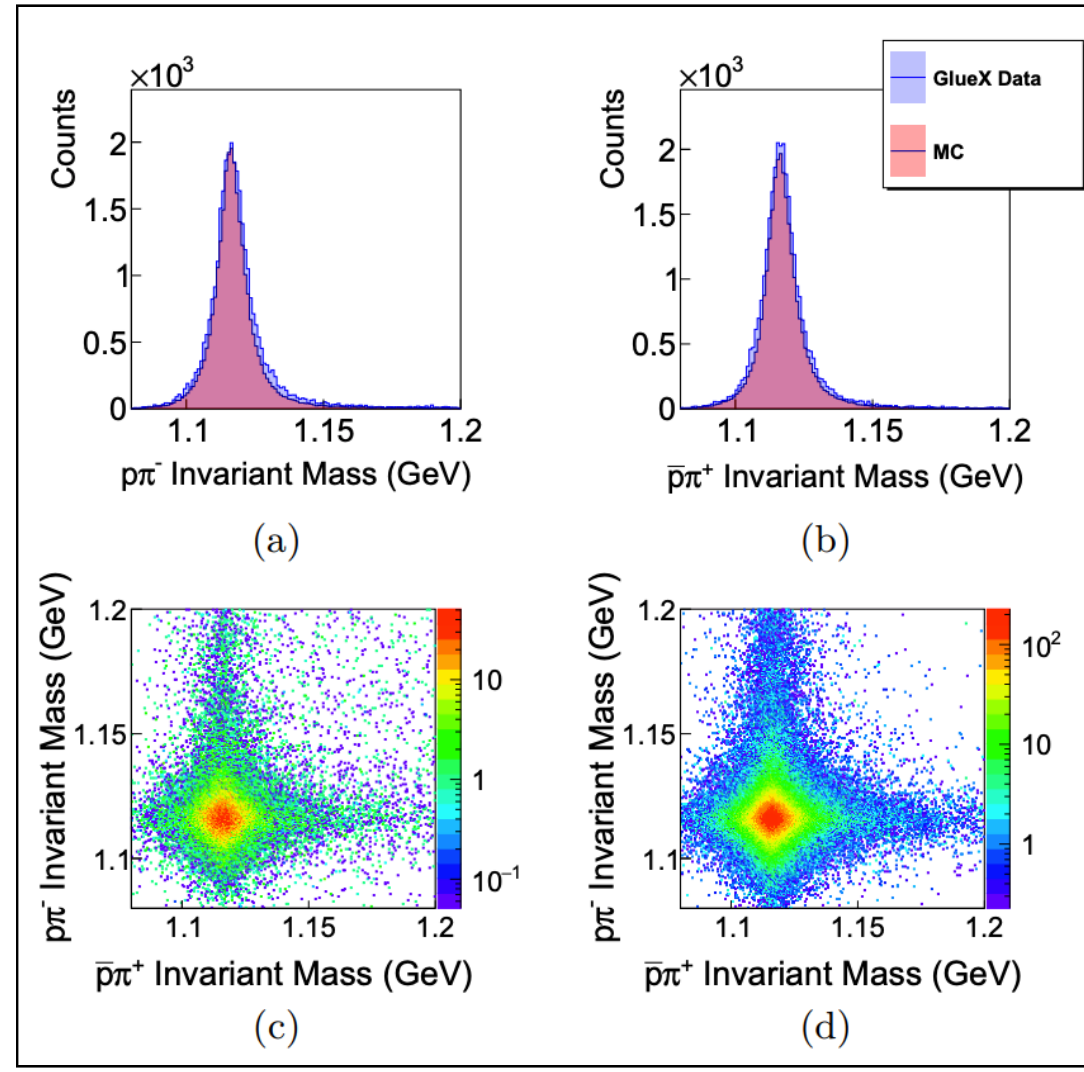
Previous Studies of the $\Lambda\bar{\Lambda}$ Polarization



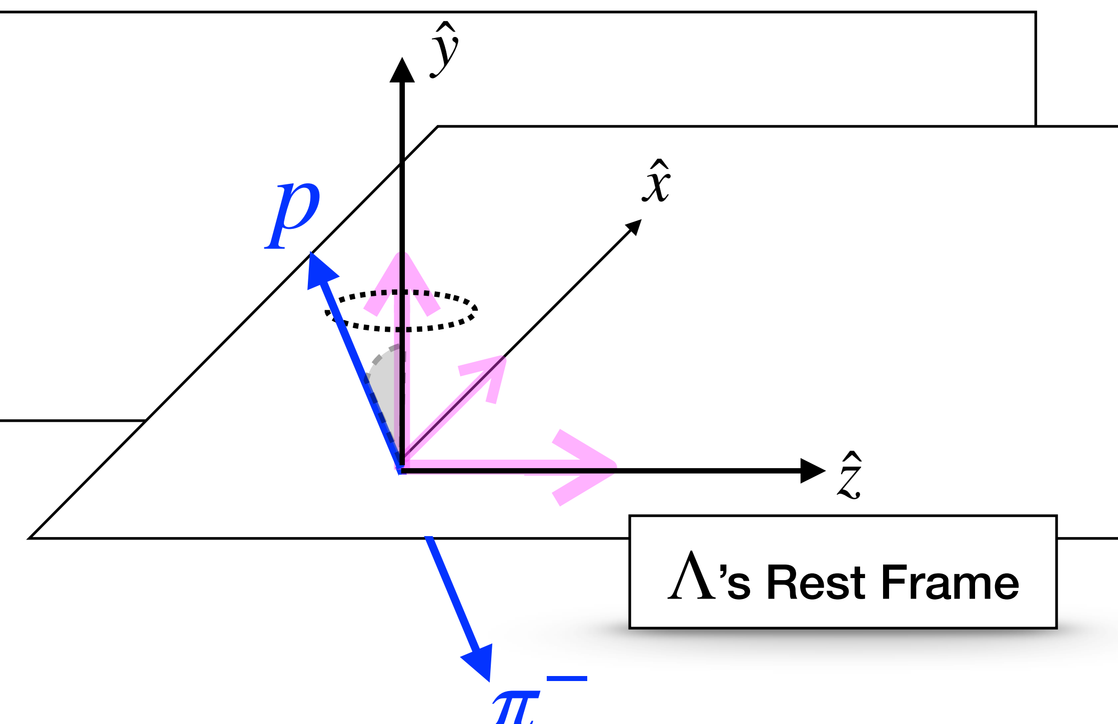
- Inclusive channels seeing different polarizations between Λ and $\bar{\Lambda}$ *[Heller, K., et al. PRL 41.9 (1978): 607]*
- Exclusive channel (PS185 at LEAR): $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$
  - Spin polarization, spin correlations, singlet fraction *[P. Barnes et al., PRC 54.4 (1996): 1877]*
  - Complete spin structure *[K. D. Paschke et al. PRC 74.1 (2006): 015206]*
- Theoretical framework *[Tabakin, F., & Eisenstein, R. A. PRC, 31(5), 185]*
- No measurement of $\gamma p \rightarrow \Lambda\bar{\Lambda}p$ before GlueX, nor any theoretical prediction on the polarization of the final states…

Event Selection: $\gamma p \to \Lambda\bar{\Lambda}p$

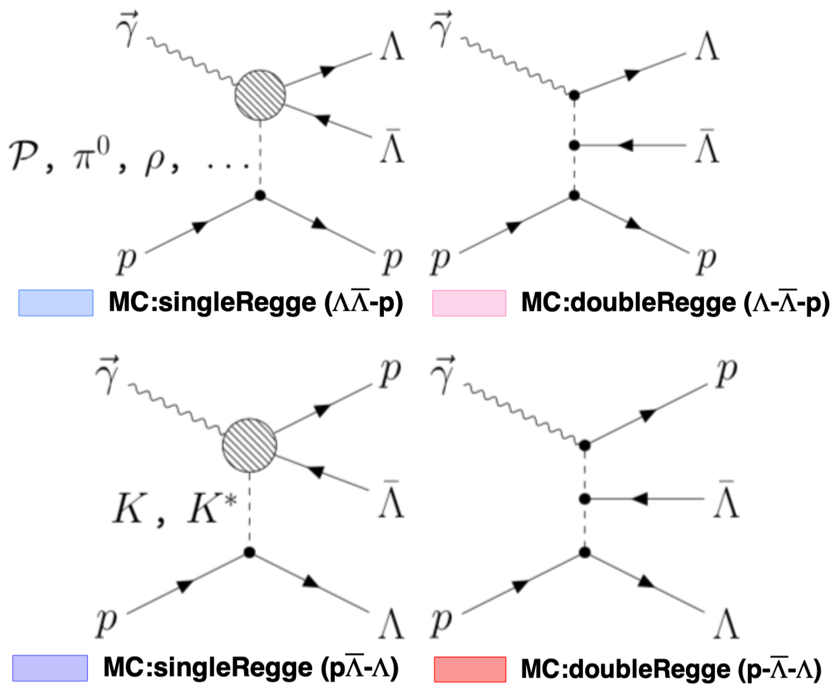
- Decay as $\Lambda \to p\pi^-$, $\bar{\Lambda} \to \bar{p}\pi^+$
- Clean mass peak reconstructed from (anti-) protons and pions
- Entangled $\Lambda - \bar{\Lambda}$ system produced in pairs, against a recoiling proton
- Data shows $p - \bar{\Lambda}$ system against Λ, too



- **Weakly decaying** hyperons allow ***polarization*** measurement
- Possible ***spin correlations*** in entangled Λ-$\bar{\Lambda}$ system
- Summed over all possible spin states for the recoil proton



Phenomenological Modeling of $\gamma p \to \Lambda\bar{\Lambda}p$

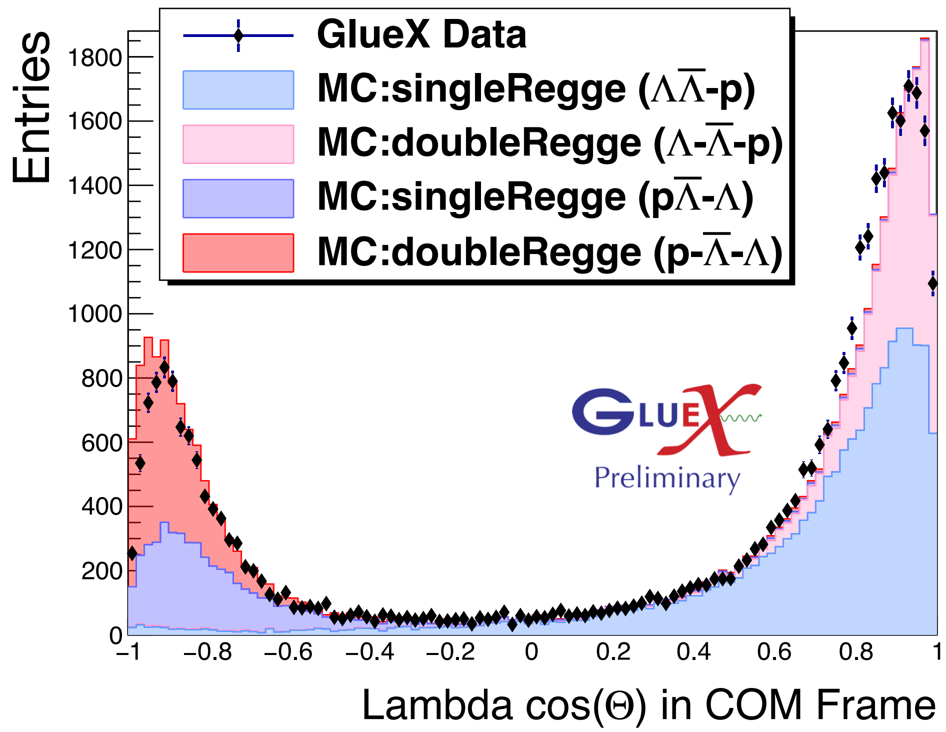


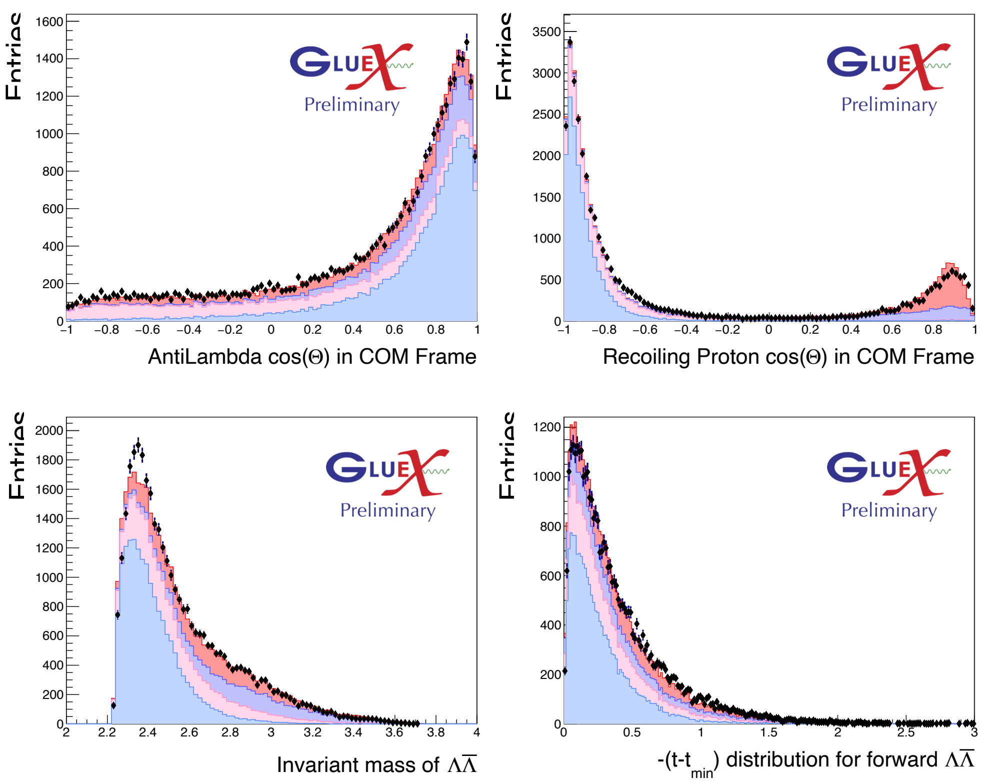
Use **four mechanisms** to model the intensity

- single Regge (non-strange or strange exchange)
- double Regge process

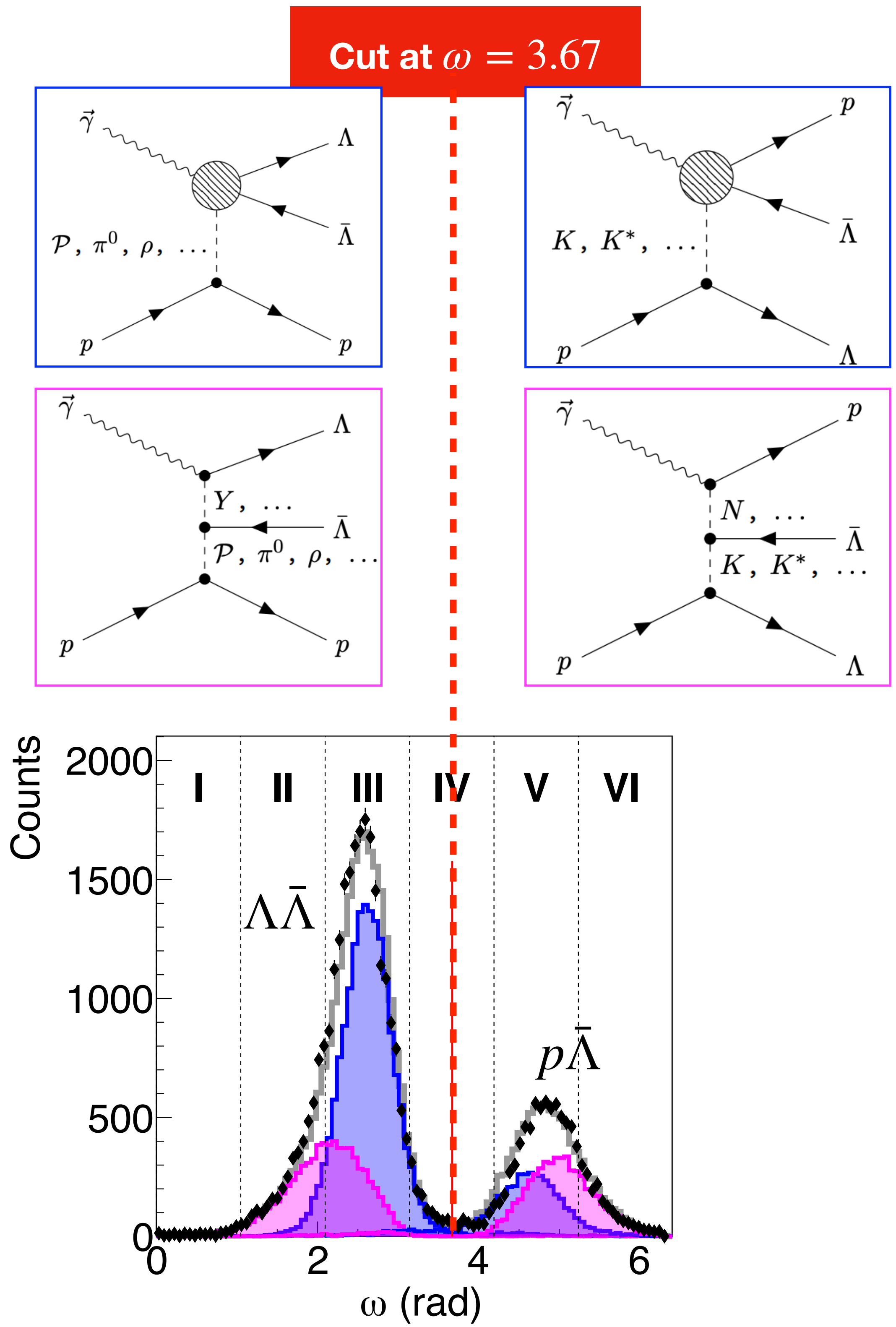
Fit with **GlueX Phase-I Data** in Beam energy range $6.4 - 11.6\ GeV$

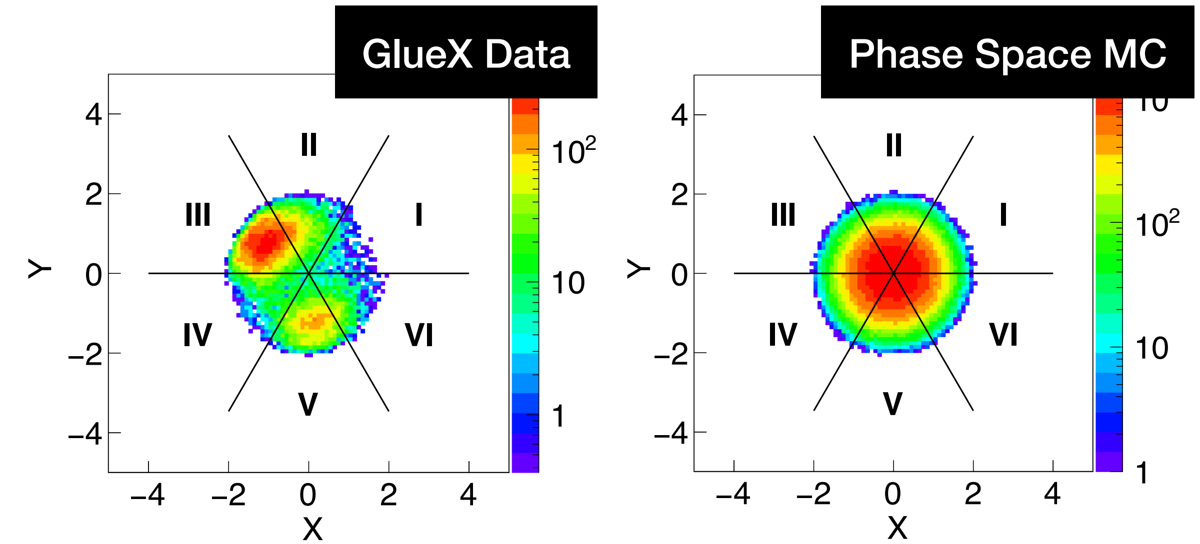
Good agreement between Monte Carlo simulation and GlueX data in most of the kinematic variables

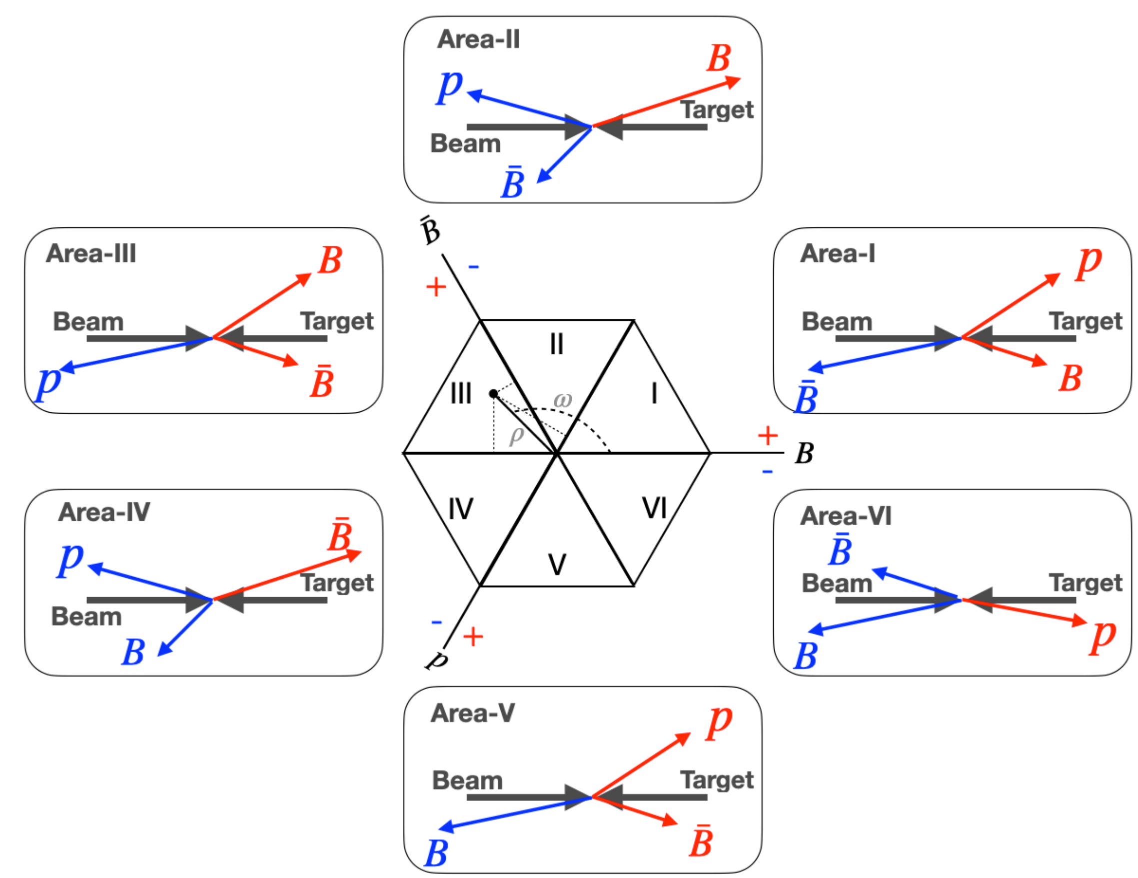




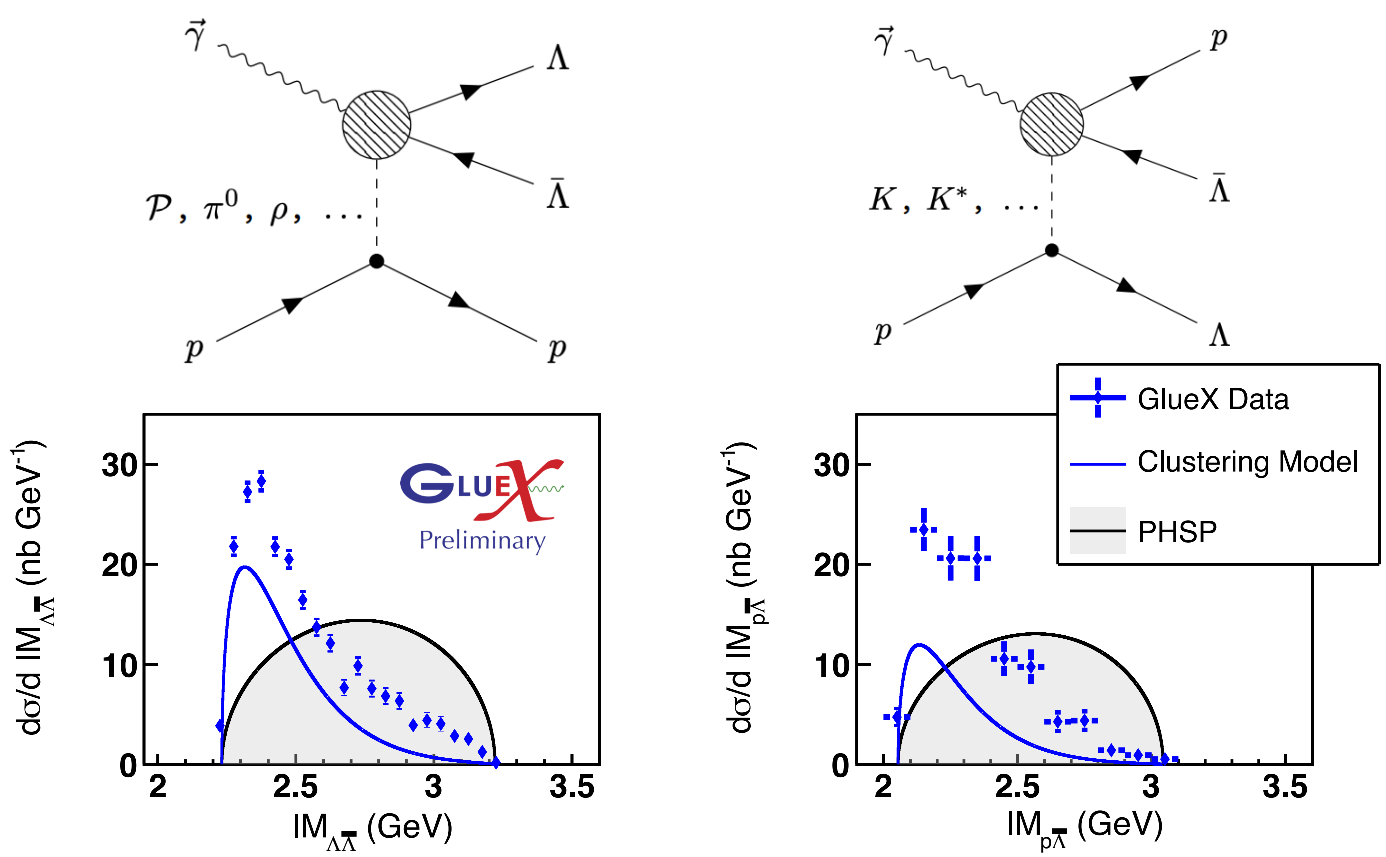
Comparison between $\Lambda\bar{\Lambda}$ and $p\bar{\Lambda}$ systems

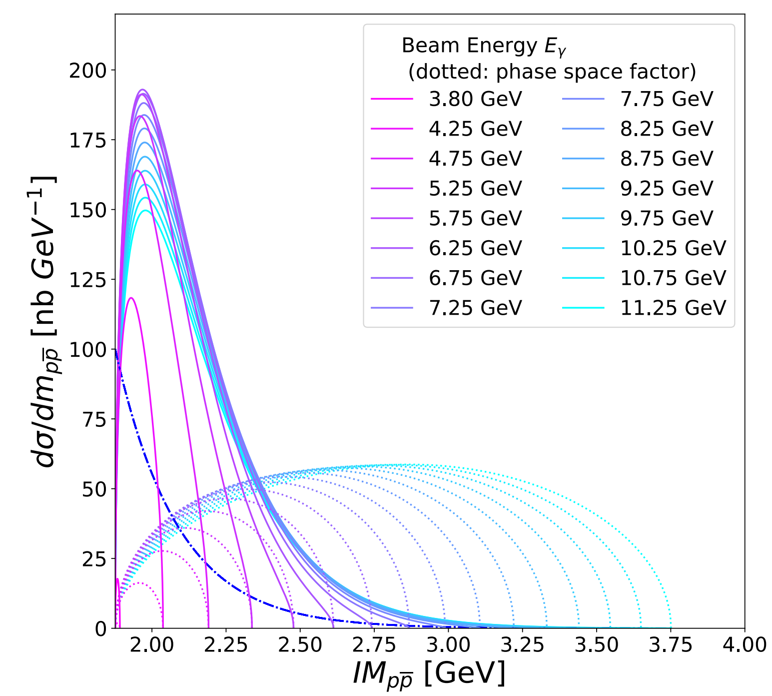






Cross Section Differential in $\Lambda\bar{\Lambda}$- and $p\bar{\Lambda}$ Mass



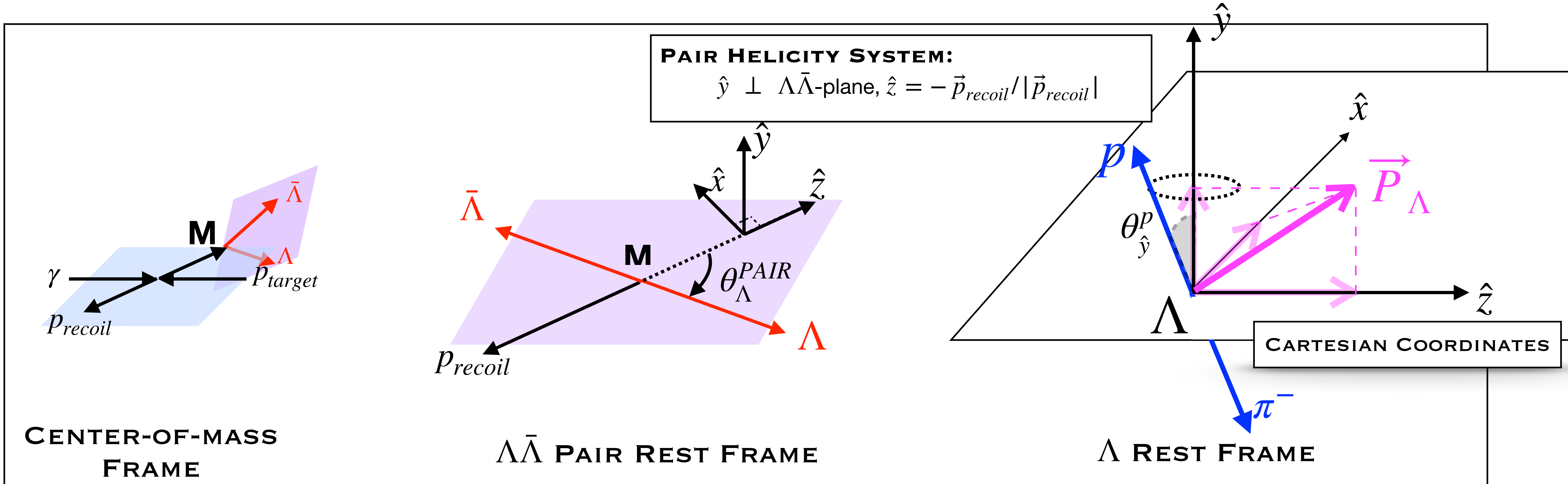


Differential cross section in $\Lambda\bar{\Lambda}$ and $p\bar{\Lambda}$ mass at beam energy 8.5-9.0 GeV, summed over all t

H. Li and R. Schumacher (GlueX Collab.), Baryon anti-Baryon Photoproduction Cross Sections off the Proton, (publication in preparation))

- **No visible invariant mass structure** observed in GlueX data
- Similar **broad near-threshold enhancement** seen in $\Lambda\bar{\Lambda}$ and $p\bar{\Lambda}$ invariant mass comparing to phase space
- **Attractive potential** in both baryon-antibaryon systems —> **strong correlation** between two polarized hyperons
- Double-Regge background remain where Λ and $\bar{\Lambda}$ less correlated

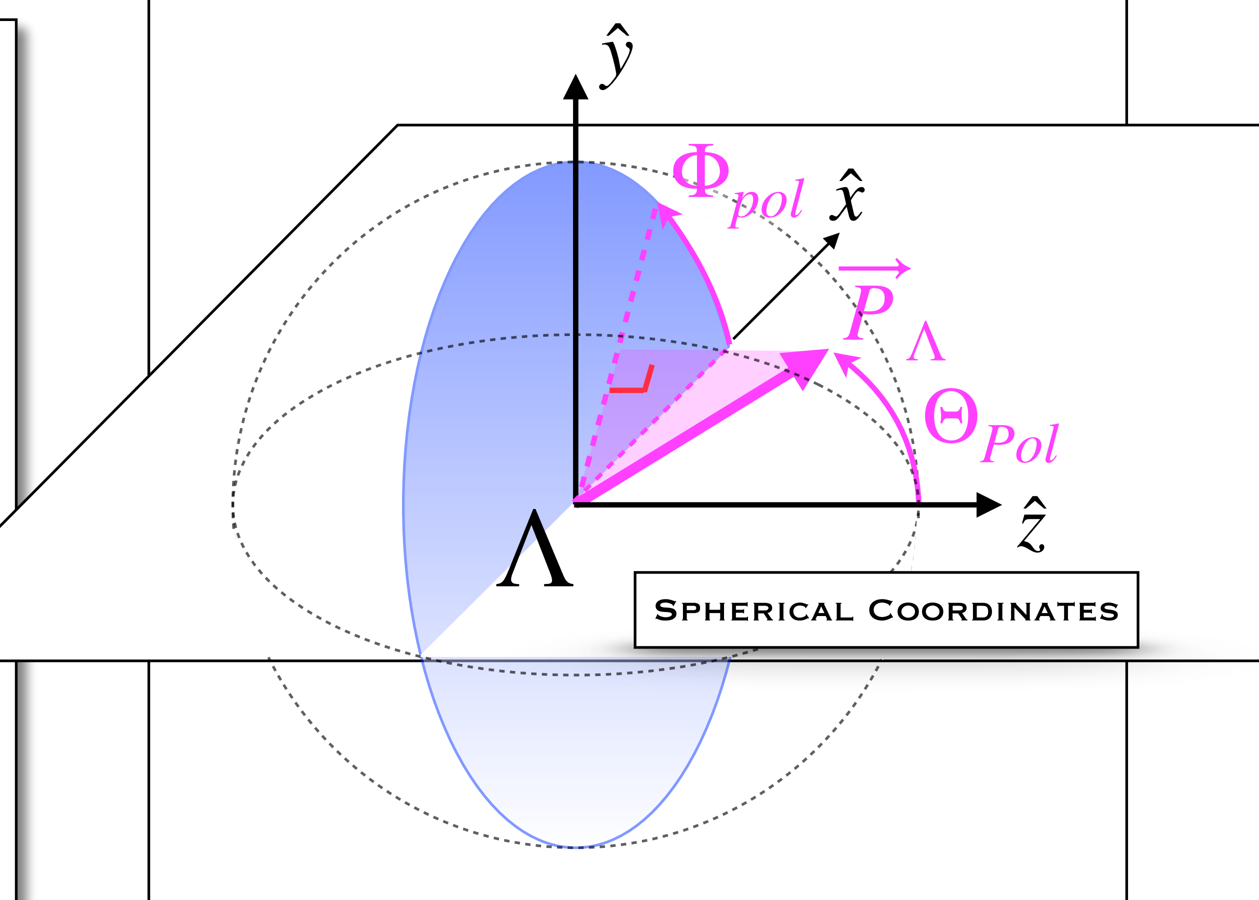
Measurement of $\Lambda\bar{\Lambda}$ Polarization



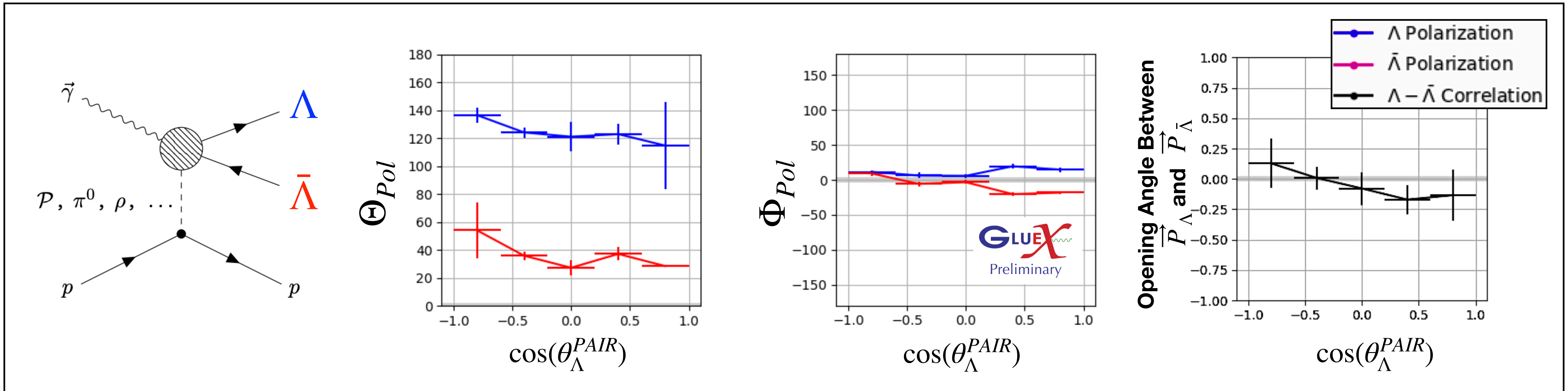
Λ *Polarization projected on Cartesian & Spherical coordinate:*

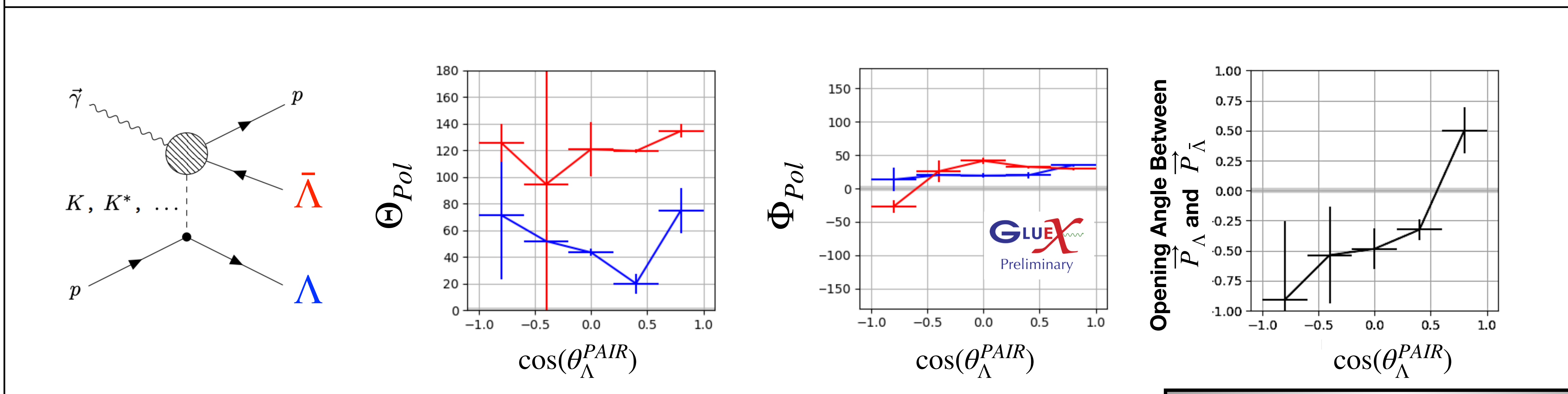
$$\vec{P}_{\Lambda}^{\text{Cartesian}} = \begin{Bmatrix} \vec{P}_{\Lambda}\cdot\hat{x} \\ \vec{P}_{\Lambda}\cdot\hat{y} \\ \vec{P}_{\Lambda}\cdot\hat{z} \end{Bmatrix} = \frac{3}{\alpha}\begin{Bmatrix} \langle\cos\theta^{p}_{\hat{x}}\rangle \\ \langle\cos\theta^{p}_{\hat{y}}\rangle \\ \langle\cos\theta^{p}_{\hat{z}}\rangle \end{Bmatrix}_{(\Lambda\ \text{Rest Frame})}$$

$$\vec{P}_{\Lambda}^{\text{Spherical}} = \begin{Bmatrix} R_{\text{Pol}} \\ \Theta_{\text{Pol}} \\ \Phi_{\text{Pol}} \end{Bmatrix} = \frac{3}{\alpha}\begin{Bmatrix} \sqrt{P_{\hat{x}}^2 + P_{\hat{y}}^2 + P_{\hat{z}}^2} \\ \arccos\frac{P_{\hat{z}}}{R_{\text{Pol}}} \\ \arccos\frac{P_{\hat{x}}}{\sqrt{P_{\hat{x}}^2+P_{\hat{y}}^2}} \end{Bmatrix}_{(\Lambda\ \text{Rest Frame})}$$

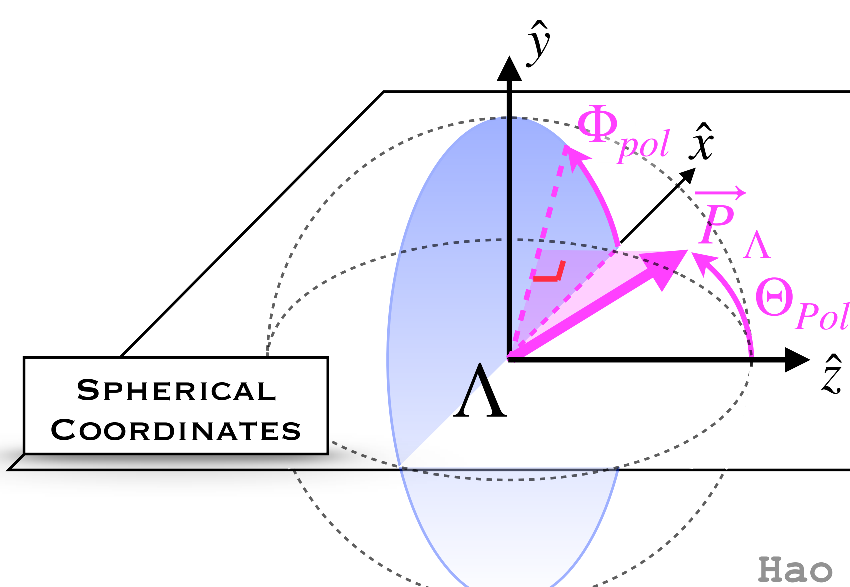


Polarization Vector Projected in Spherical Coordinates



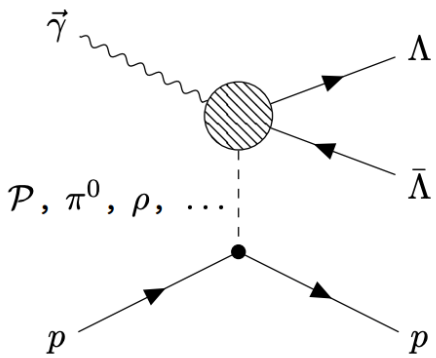


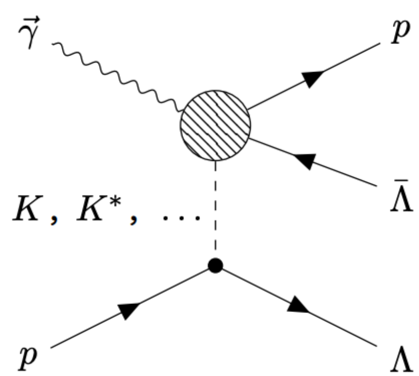
GlueX-I Data, statistical uncertainties only



- **Key observation** of the $\Lambda\bar{\Lambda}$ system:
  - Strong difference in net polarization between Λ and $\bar{\Lambda}$
  - Polar angle of $\vec{P}_\Lambda$ and $\vec{P}_{\bar{\Lambda}}$ are roughly at $130°$ and $40°$
  - Consistent opening angle around $90°$ between $\vec{P}_\Lambda$ and $\vec{P}_{\bar{\Lambda}}$ at all production angle θ_Λ^{PAIR}

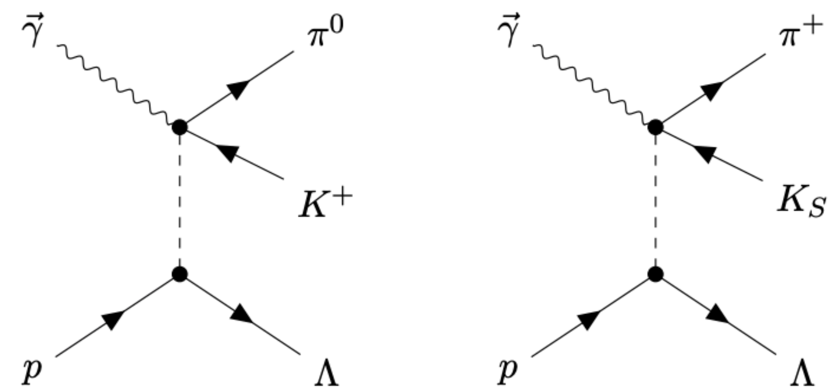
Photoproduction of $K\pi$ system with Recoiling Hyperon at GlueX



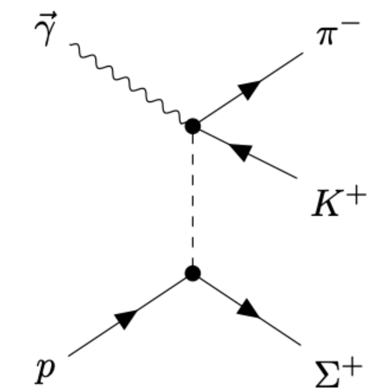


$\Lambda\bar{\Lambda}$ **and** $p\bar{\Lambda}$ **system at GlueX:**

- Possible below-threshold scalar meson [Physical Review D 96.5 (2017): 054024]
- No access to full spin information due to proton
- Recoil polarization of Λ defined w.r.t production plane



Charged kaon exchange

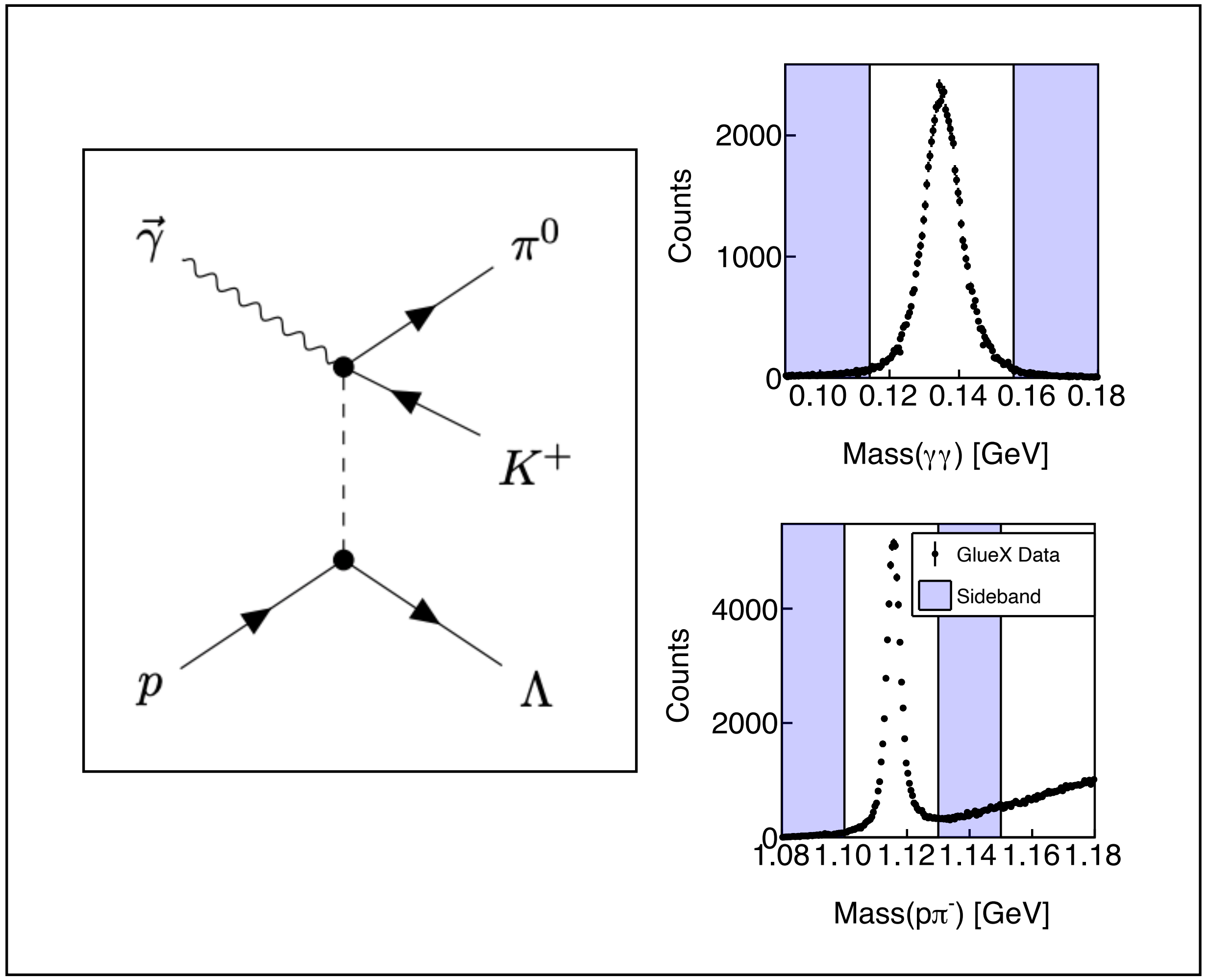


Neutral kaon exchange

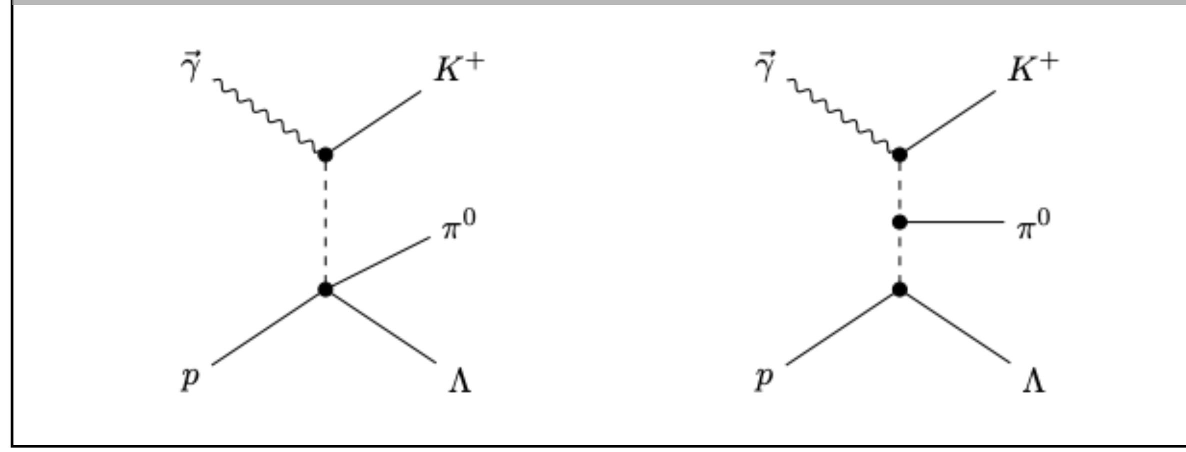
Goal:

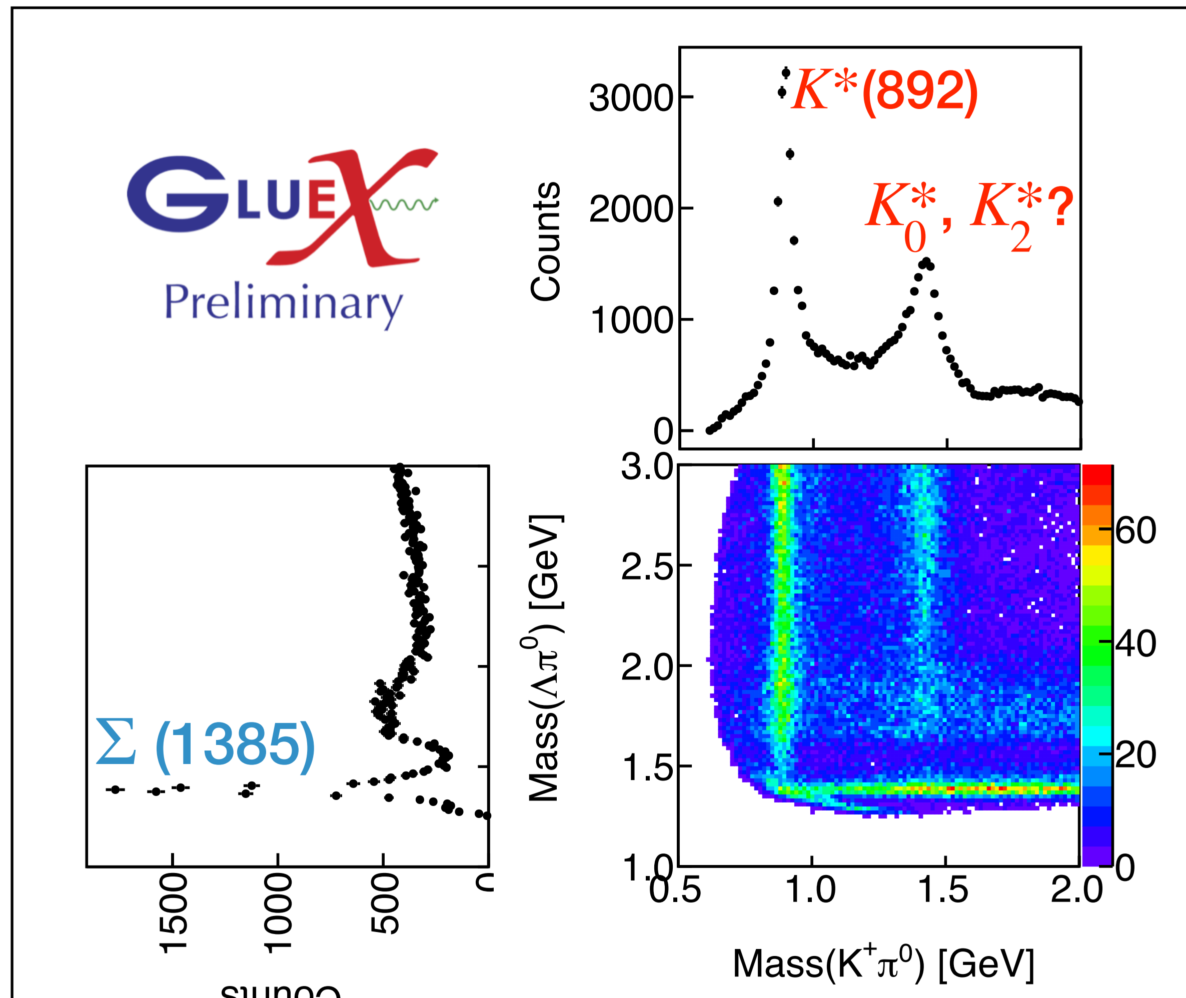
- Understand production mechanism of $K^*(892)$ via SDMEs, analogous to the $\rho(770)$ in $\pi\pi$ system
- Comparison between charged/neutral kaon exchange
- Use polarization of recoil hyperon to constrain the amplitude
- Amplitude analysis to understand excited K^* resonances at higher mass

Mass Spectra in $\vec{\gamma}p \rightarrow \pi^0 K^+ \Lambda$ (charged kaon exchange)



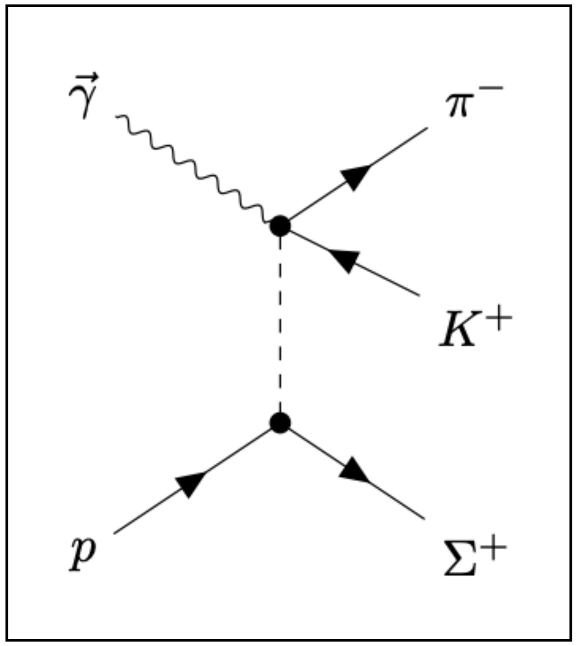
Possible background channel

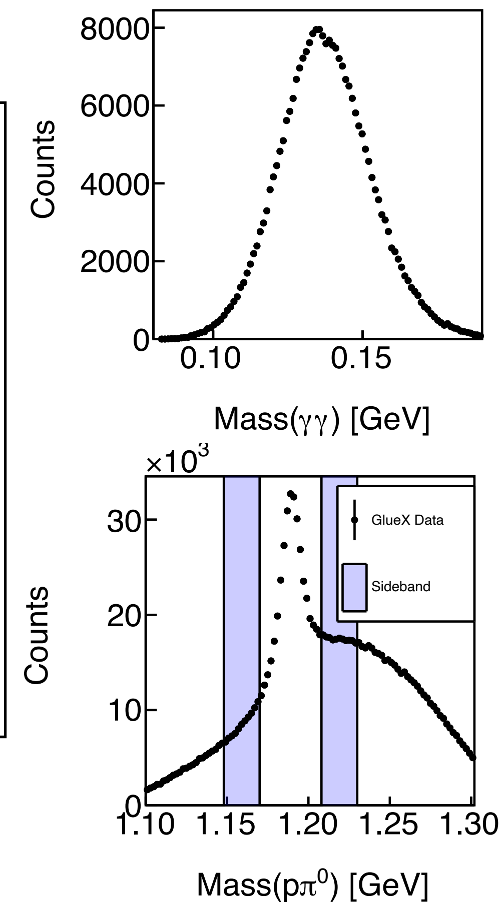




- Clear evidence of charged K^*(892) in $K^+\pi^0$ spectrum
- More structures shown at higher $K^+\pi^0$ mass, need further amplitude analysis to confirm the resonance being K_0^*(1430) or K_2^*(1430)
- Background contributed by Σ(1385) from $\Lambda\pi^0$ system, and possibly other hadronic channels

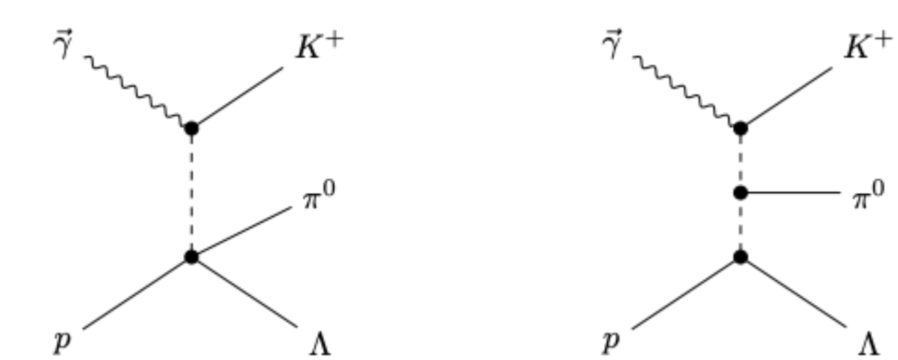
Mass Spectra in $\vec{\gamma}p \to \pi^- K^+ \Sigma^+$ (neutral kaon exchange)

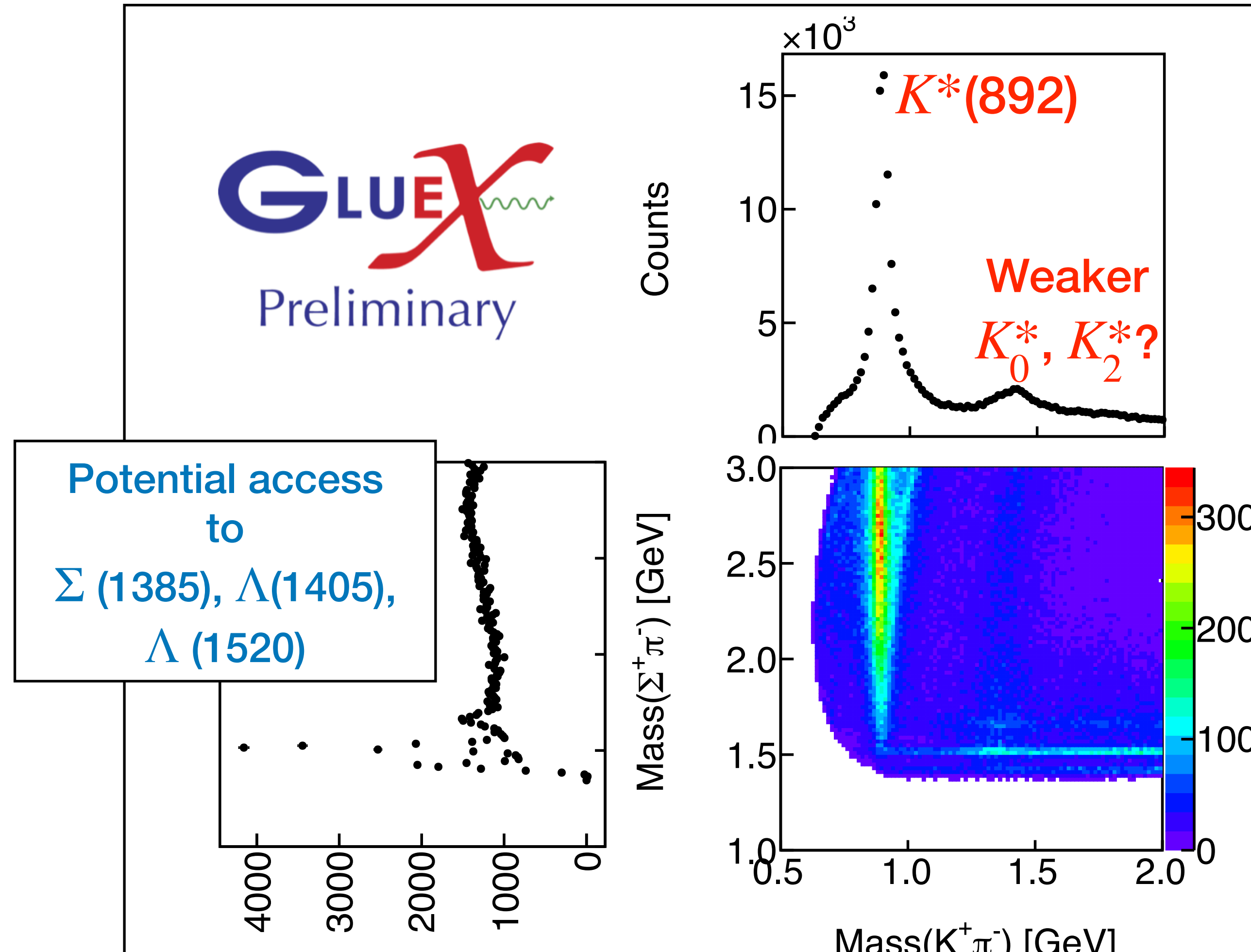




- GlueX Phase-I data
- Clear evidence of charged $K^*(892)$ in $K^+\pi^0$ spectrum
- Weaker structures shown at higher $K^+\pi^0$ mass, need further amplitude analysis to confirm the resonance being $K_0^*(1430)$ or $K_2^*(1430)$
- Background contributed by $\Sigma(1385)$ from $\Lambda\pi^0$ system, and possibly other hadronic channels

POSSIBLE BACKGROUND CHANNEL





Summary

$\Lambda\bar{\Lambda}$ system and $p\bar{\Lambda}$ system

- Phenomenological modeling of the reaction mechanisms helps understanding of the data distributions of both $\Lambda\bar{\Lambda}$ and $p\bar{\Lambda}$ system, and accurate estimation of the acceptance
- Presented cross section measurement of both system, publication in preparation
- Strong difference observed in Λ and $\bar{\Lambda}$ polarization projected on Pair-Helicity system
- Λ - $\bar{\Lambda}$ spin correlation were investigated, showing dependency on production angle
- Comparison between $\Lambda\bar{\Lambda}$ and $p\bar{\Lambda}$ system provides proxy into understanding of proton spin state

$K\pi$ system with Recoiling Hyperon

- Clear evidence of K^*(892) in various $K\pi$ spectra with charged or neutral kaon exchange involved
- More structures seen at higher mass, need further amplitude analysis to confirm the resonance being K_0^*(1430) or K_2^*(1430)

Future plans:

- SDME analysis of K^*(892) as "standard candle" for further study of other excited K^* resonances at higher mass
- Partial wave analysis with full spin information including recoiling hyperon

GlueX acknowledges the support of several funding agencies and computing facilities (http://gluex.org/thanks)

Backup

Van Hove Diagram for 3-body Final States $B\bar{B}p$ in CM Frame

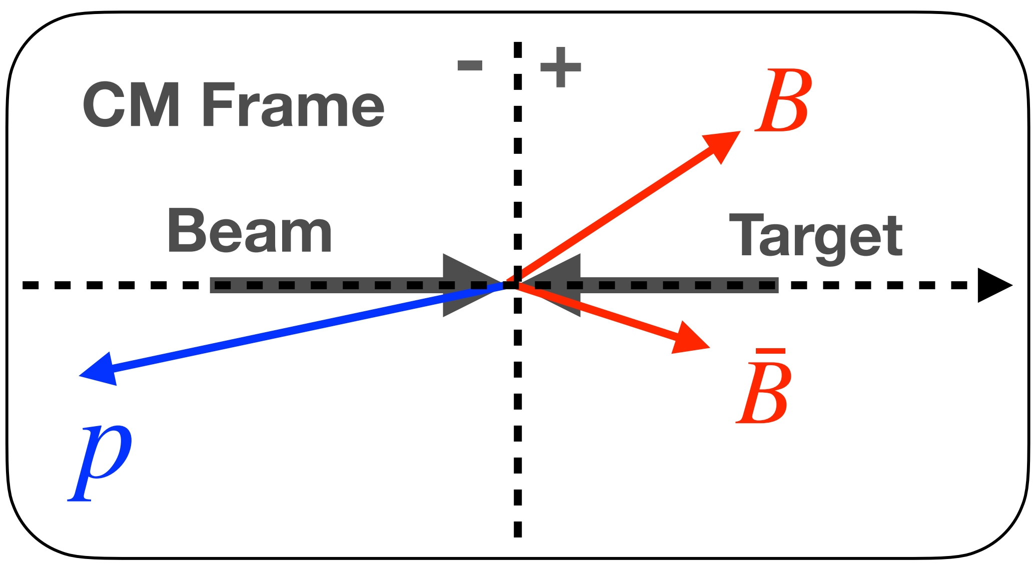
Longitudinal momentums of $B, \bar{B}, p$ in **CM Frame** parametrized with strength ρ and phase ω:

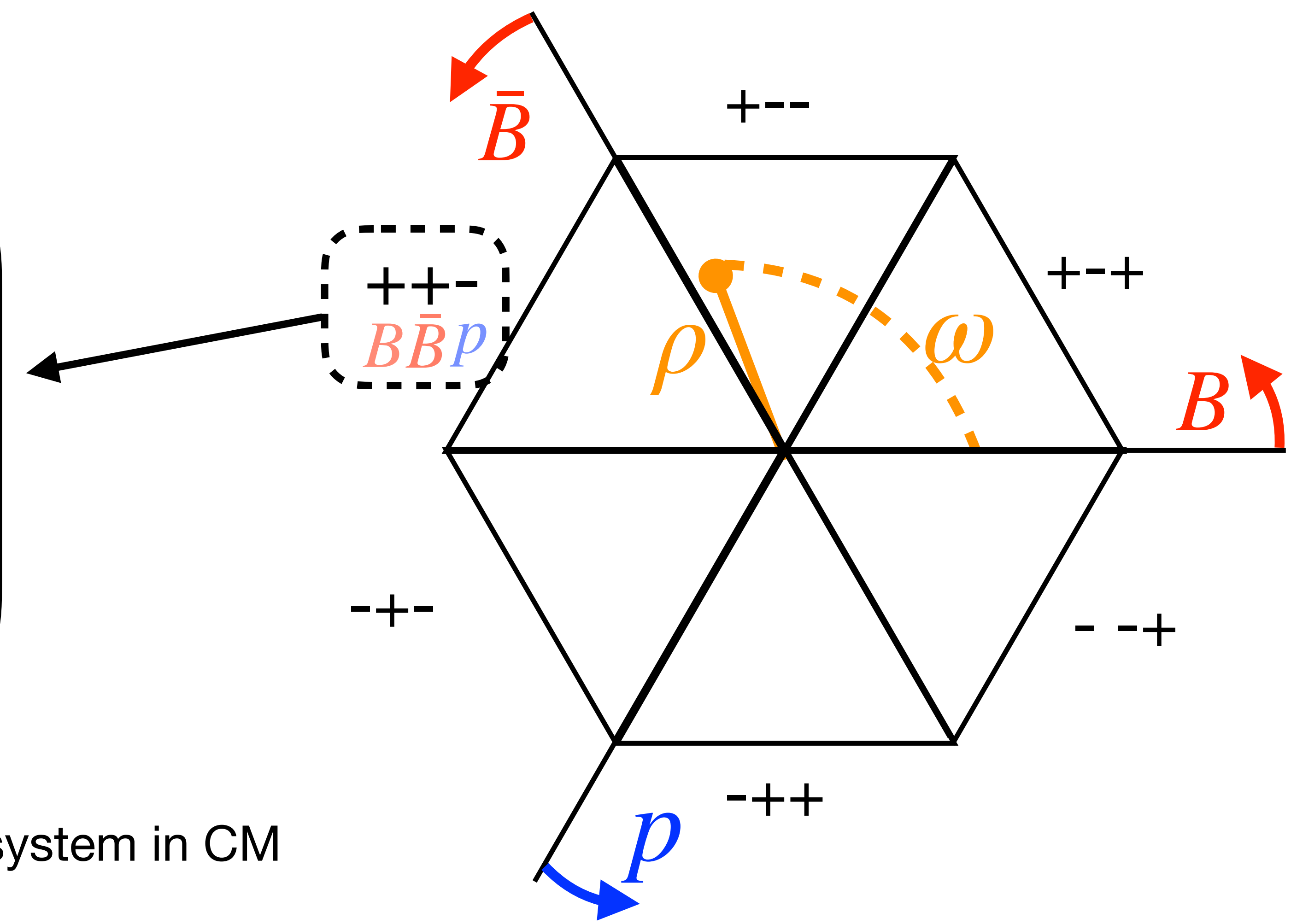
$$\begin{cases} p_z^{CM}(B) = \rho\sin(\omega) \\ p_z^{CM}(\bar{B}) = \rho\sin(\omega - \frac{2}{3}\pi) \\ p_z^{CM}(p) = \rho\sin(\omega - \frac{4}{3}\pi) \end{cases}$$

$$p_z^{CM}(B) + p_z^{CM}(\bar{B}) + p_z^{CM}(p) = 0$$

Solve for ω and ρ

$$\begin{cases} \omega = \arctan\left(\frac{-\sqrt{3}p_z^{CM}(B)}{p_z^{CM}(B) + 2p_z^{CM}(\bar{B})}\right) + \pi \\ \rho = \sqrt{\frac{3}{2}}\sqrt{[p_z^{CM}(B)]^2 + [p_z^{CM}(\bar{B})]^2 + [p_z^{CM}(p)]^2} \end{cases}$$





- Visualize the angular distribution of 3-body system in CM
- Help to identify production mechanisms of different systems ($\Lambda\bar{\Lambda}$ or $p\bar{\Lambda}$)

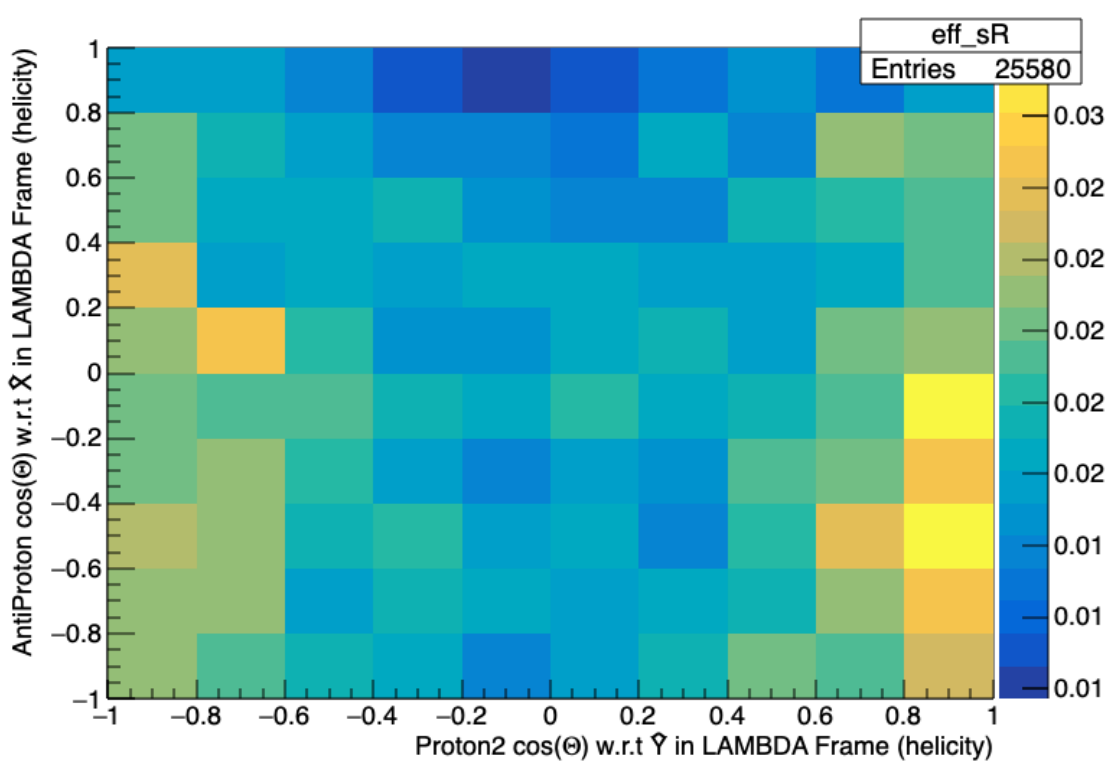
Event-by-event summation (with binned acceptance)

$$P_{\bar{y}} = \frac{3}{\bar{\alpha}} \frac{\sum_{k=1}^{N} \zeta_k \cos\theta^k_{\bar{y}}}{\sum_{k=1}^{N} \zeta_k},$$

$$C_{\bar{m}n} = \frac{9}{\bar{\alpha}\alpha} \frac{\sum_{k=1}^{N} \zeta_k \cos\theta^k_{\bar{m}} \cos\theta^k_n}{\sum_{k} \zeta_k}.$$

Each event interpolates its factor by coordinate $(cos\theta_{\bar{m}}, \cos\theta_n)$

Binned Acceptance



Binned Acceptance Correction Factor