



# QCHSC 2024

The XVth Quark Confinement and the Hadron Spectrum Conference

## Measurement of $\Xi^-$ Polarization in the $(K^-, K^+)$ Reaction at 1.8 GeV/c

Byungmin Kang(Korea University)

for the E42 Collaboration

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# Outline

- Hyperon polarization
- $\Xi^-$  production from  $(K^-, K^+)$  reaction of the proton and  $^{12}\text{C}$  at E42
- $\Xi^-$  reconstruction with E42 detector
- Preliminary results on  $\Xi^-$  polarization in the  $p(K^-, K^+)$  reaction at 1.8 GeV/c

# Decay Asymmetry in $\Xi^- \rightarrow \Lambda\pi^-$

Assume a polarized  $\Xi$  baryon decays into  $\Lambda\pi^-$ .

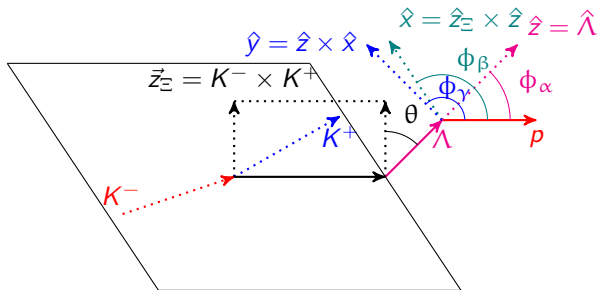
$$\left| \frac{1}{2}, \frac{1}{2} \right\rangle_{\Xi} \rightarrow A \left| \frac{1}{2}, \frac{1}{2} \right\rangle_{\Lambda} Y_0^0 + B \left[ \sqrt{\frac{1}{3}} \left| \frac{1}{2}, \frac{1}{2} \right\rangle_{\Lambda} Y_1^0 - \sqrt{\frac{2}{3}} \left| \frac{1}{2}, -\frac{1}{2} \right\rangle_{\Lambda} Y_1^0 \right]$$

S-wave and P-wave takes complex Amplitude A and B. Taking into normalization condition, these parameter can be described in 3 real parameters:

$$\alpha_{\Xi} = \frac{2\text{Re}(A * B)}{|A|^2 + |B|^2}, \beta_{\Xi} = \frac{2\text{Im}(A * B)}{|A|^2 + |B|^2}, \gamma_{\Xi} = \frac{|A|^2 - |B|^2}{|A|^2 + |B|^2}$$

- Decay parameters are a measure of the relative magnitude and phase shift between final decay states.
- Daughter  $\Lambda$  takes angular spectrum as :  $I = 1 + \alpha_{\Xi} \vec{P}_{\Xi} \cdot \hat{\Lambda}$

# Angular Distribution



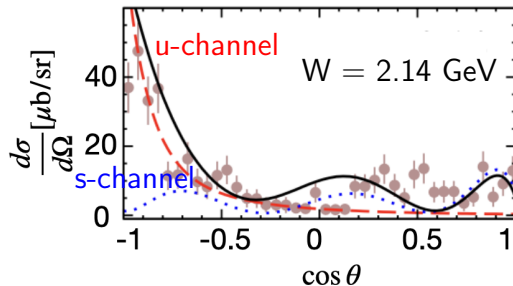
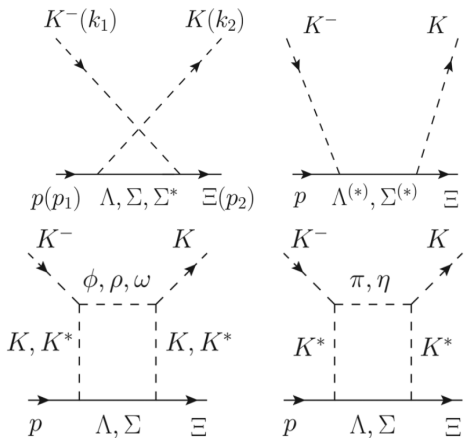
As  $\Lambda$  spin state inherits from  $\Xi$  polarization state, Joint distribution for  $\Xi \rightarrow \Lambda\pi^-; \Lambda \rightarrow p\pi^-$  can be expressed as:

$$\begin{aligned}
 I &= 1 + \alpha_\Xi \vec{P}_\Xi \cdot \hat{\Lambda} + \alpha_\Lambda \hat{p} \cdot [(\alpha_\Xi + \vec{P}_\Xi \cdot \hat{\Lambda}) \hat{\Lambda} \\
 &\quad + \beta_\Xi (\vec{P}_\Xi \times \hat{\Lambda}) + \gamma_\Xi \hat{\Lambda} \times (\vec{P}_\Xi \times \Lambda)] \\
 &= 1 + \alpha_\Xi P_\Xi \cos \theta + \alpha_\Lambda [(\alpha_\Xi + P_\Xi \cos \theta) \hat{p} \cdot \hat{z} \\
 &\quad + \beta P_\Xi \sin \theta \hat{p} \cdot \hat{x} + \gamma P_\Xi \sin \theta \hat{p} \cdot \hat{y}]
 \end{aligned}$$

Averaging the intensity over  $\theta$ , we have

$$\begin{cases}
 I(\phi_\alpha) = 1 + \alpha_\Xi \alpha_\Lambda \cos \phi_\alpha \\
 I(\phi_\beta) = 1 + \frac{\pi}{4} P_\Xi \beta_\Xi \alpha_\Lambda \cos \phi_\beta \\
 I(\phi_\gamma) = 1 + \frac{\pi}{4} P_\Xi \gamma_\Xi \alpha_\Lambda \cos \phi_\gamma
 \end{cases}$$

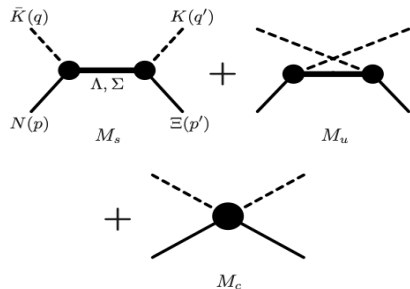
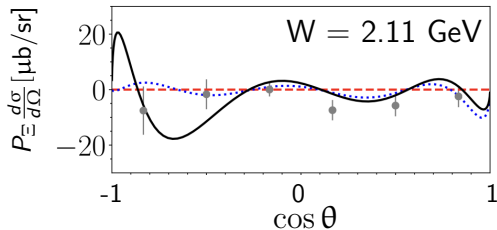
# Effective Lagrangian Approach to $K^-p \rightarrow K^+\Xi^-$ Reaction



- Forward peaking structure of  $p(K^-, K^+)\Xi$  can be explained by s-channel  $\Lambda$  and  $\Sigma$  resonances, and meson-baryon rescattering diagram.

[1] Sang-Ho Kim *et al.*, Phys. Rev. C107, 065202(2023)

# [1] Polarization in Reaction Amplitude



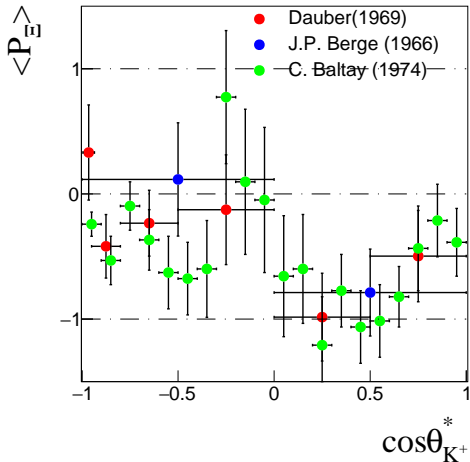
- The model predicts small  $P_{\Xi}$  in forward region.
- $P_{\Xi}$  measurement in E42 can validate the model

- Polarization have great effect on imaginary part of reaction amplitude, regardless of model specification.[2]

[1] Sang-Ho Kim *et al.*, Phys. Rev. C107, 065202(2023)

[2] BC Jackson. *etal*, Phys. Rev. C91, 065208(2015)

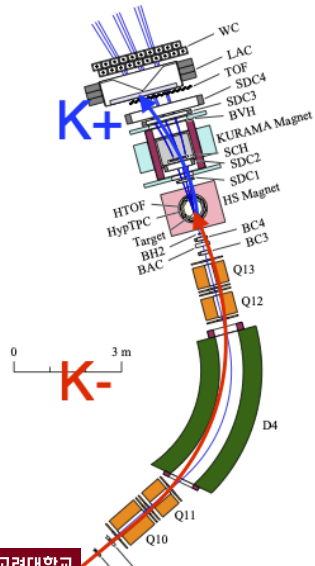
# Earlier measurements $K^-p \rightarrow K^+\Xi^-$ Polarization



- Only old bubble chamber data from 60s - 70s are available.
- Decay parameter  $\alpha_{\Xi}$  was scaled to newest value.

- [1] Dauber et al., Phys. Rev. 179, 1262(1969)  
[2] J.P. Berge et al., Phys. Rev. 147, 945 (1966)  
[3] C. Baltay et al., Phys. Rev. D9, 49(1974)

# $\Xi^-$ Polarization Measurement at J-PARC E42



## $\Xi^-$ Polarization measurement requires...

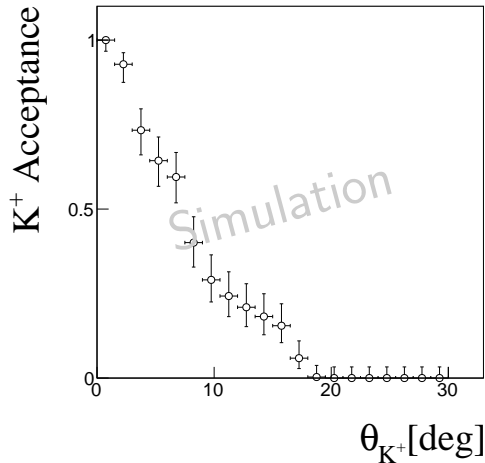
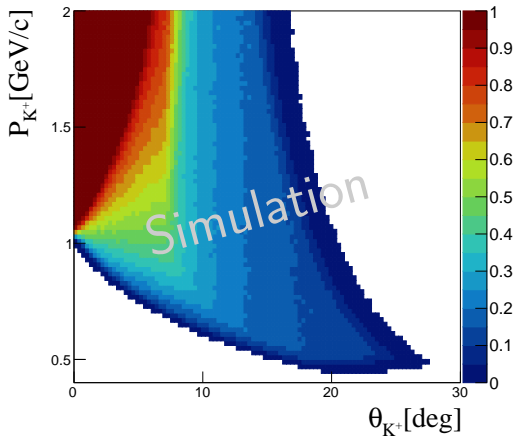
- Precise measurement for all momentum vectors in  $p(K^-, K^+)\Xi^-$ ;  $\Xi^- \rightarrow \Lambda\pi^-$ ,  $\Lambda \rightarrow p\pi^-$
- Wide angular acceptance for decaying particles
- Good enough statistics to override previous data

	$P_{K^-}$	Target	Detector	$N_{\Xi^-} (\cos \theta_{K^+}^* > 0.8)$
Berge	1.7 GeV/c	LH <sub>2</sub>	BC	13
Dauber	1.7 GeV/c	LH <sub>2</sub>	BC	~20
Baltay	1.75 GeV/c	LH <sub>2</sub>	BC	~200
E42	1.8 GeV/c	CH <sub>2</sub>	TPC	~800

J-PARC E42 meets the requirement!

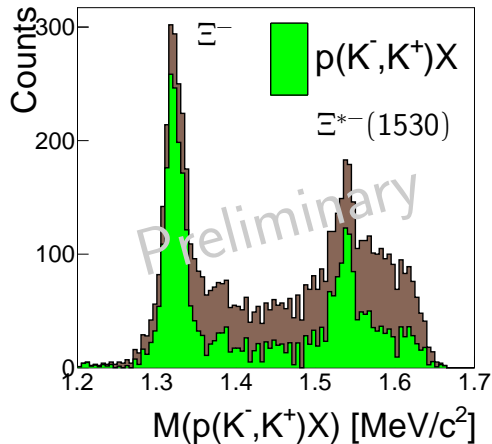
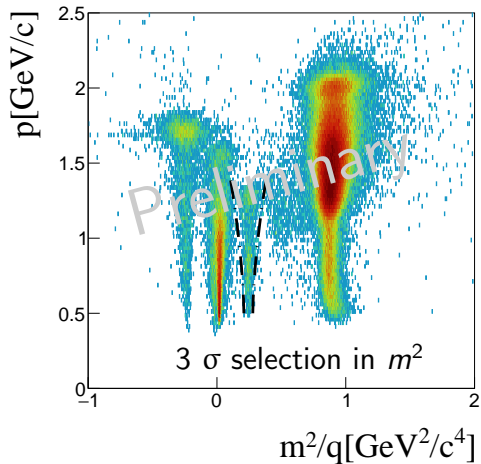


# Experimental Acceptance



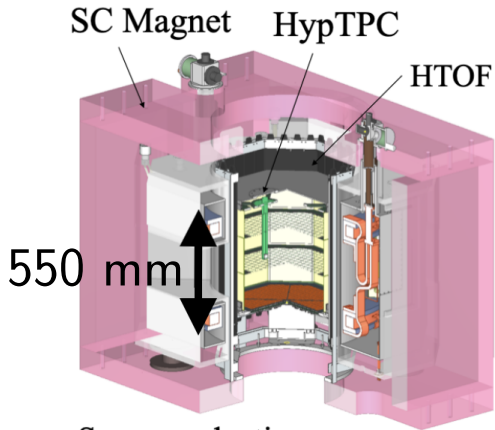
Angular acceptance in  $\Xi^-$  production region

# $(K^-, K^+)X$ Event Reconstruction

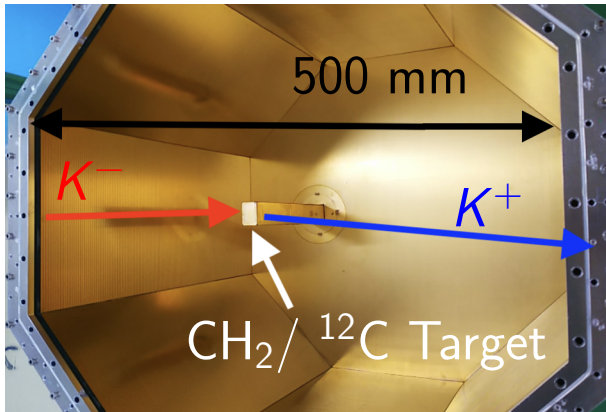


- Carbon background in CH<sub>2</sub> can be estimated from <sup>12</sup>C target data.

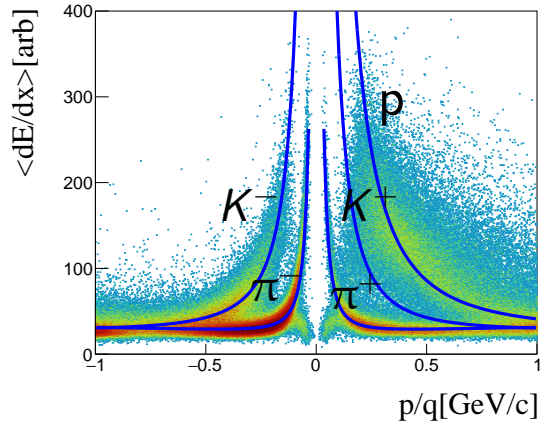
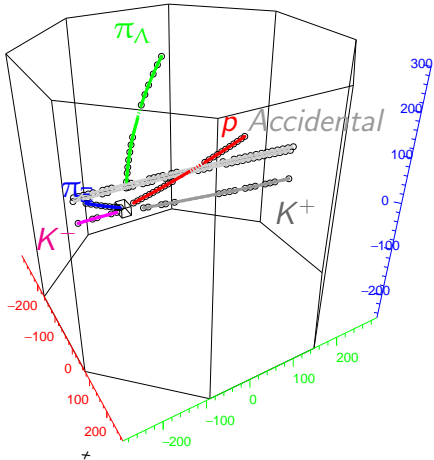
# Hyperon Spectrometer



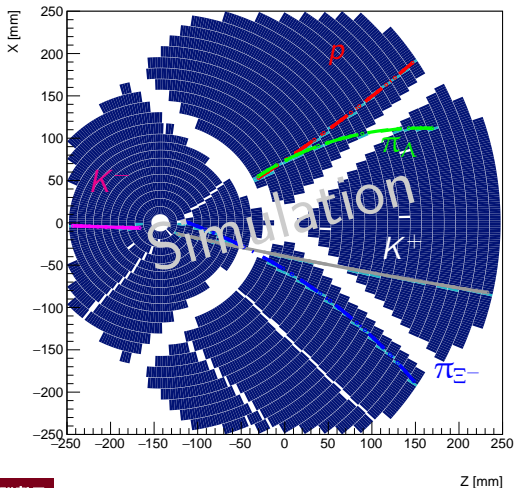
Superconducting  
Hyperon Spectrometer



# Hyperon Spectrometer

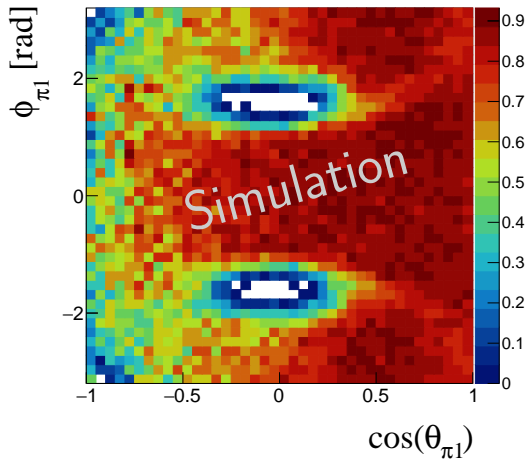


# Monte Carlo Simulation for HypTPC



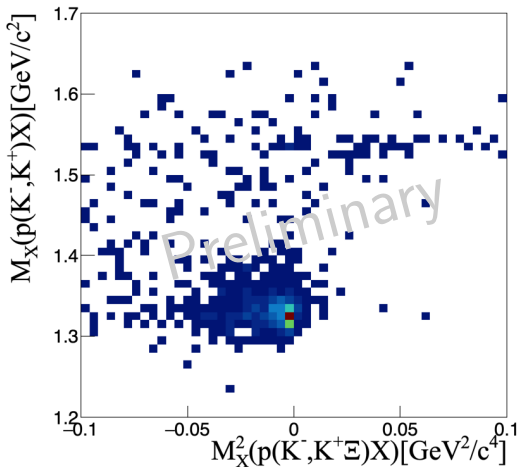
- $\Xi^-$  momentum vector was generated based on measured  $p(K^-, K^+)X$ .
- Polarization vector along reaction plane  $K^- \times X / |K^- \times X|$  were given to generated  $\Xi^-$
- $P_{\Xi} = 0$  was assumed for the event generation.

# HypTPC Acceptance



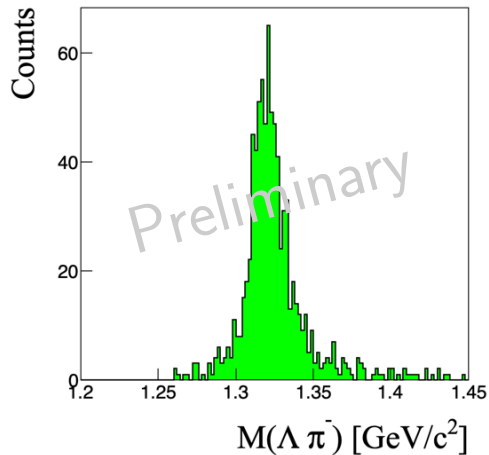
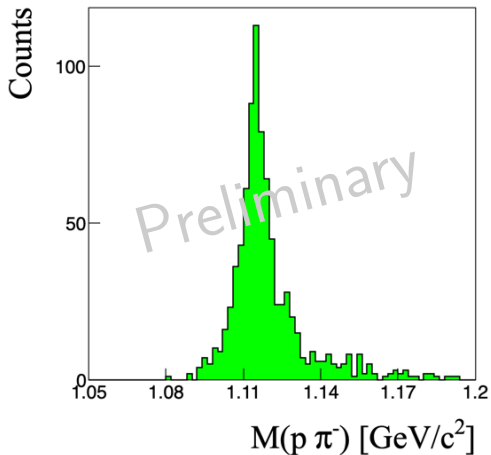
- Azimuth and Zenith angle of decaying  $\pi$ s were selected to define the acceptance.
- HypTPC covers wide angular region, which is essential for polarization measurement.
- Straight upward/downward tracks are insensitive.

# Missing $p(K^-, K^+\Xi)X$



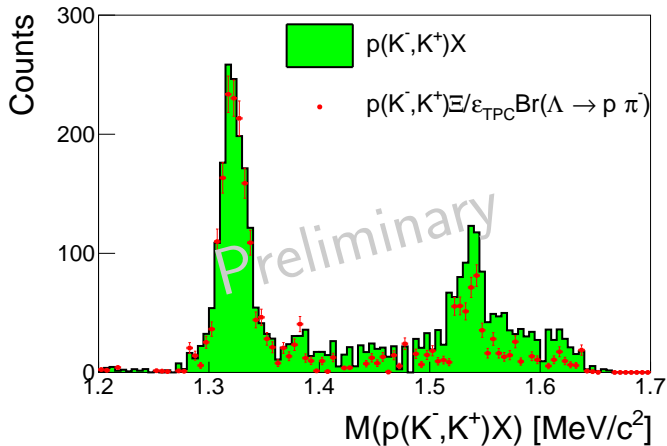
- Event selection for the  $K^-p \rightarrow K^+\Xi^-$  requires that the missing mass squared for  $p(K^-, K^+)X$  be consistent with the missing mass for  $p(K^-, K^+\Xi^-)X$
- Events in the negative side of the missing-mass squared for  $p(K^-, K^+\Xi^-)X$  are due to Fermi motion in  $^{12}\text{C}$  nuclei in  $\text{CH}_2$  target

# Reconstruction of $\Xi^-$ Decays



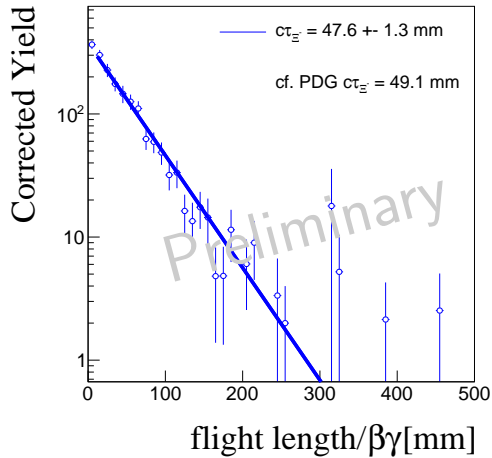
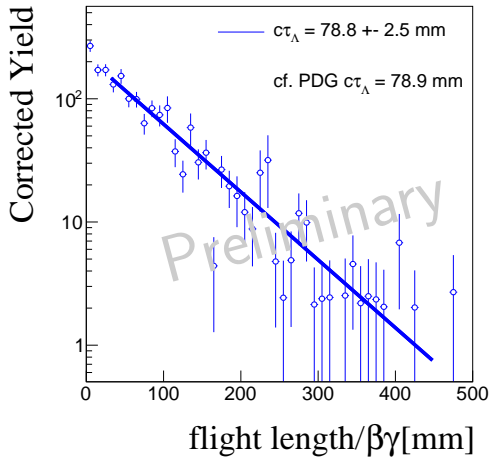


# Recovering $p(K^-, K^+)X$ Spectrum

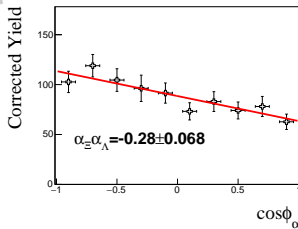
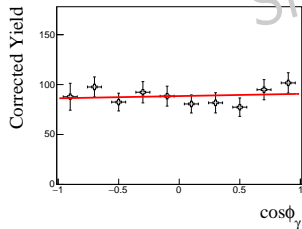
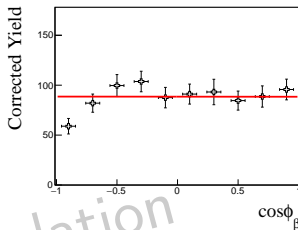
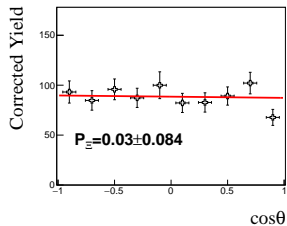


- Acceptance correction almost restores initial missing mass distribution.
- $\Xi^{*-}$  region does not match, for  $\Xi^{*-} \rightarrow \Xi^0 \pi^-$  is not studied yet.

# Lifetimes of $\Lambda$ and $\Xi^-$

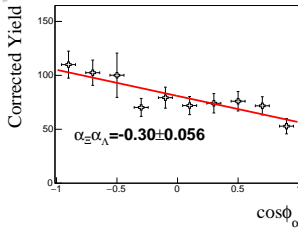
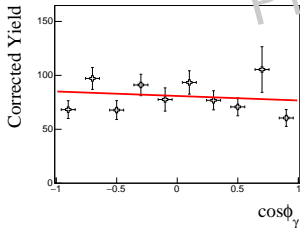
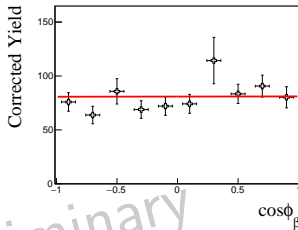
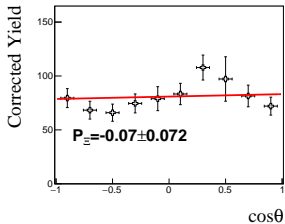


# Simulation Results for Polarization



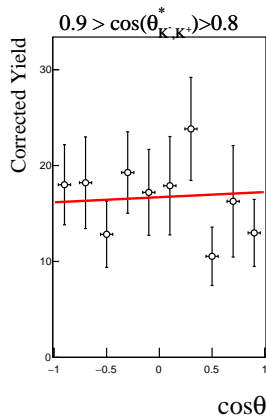
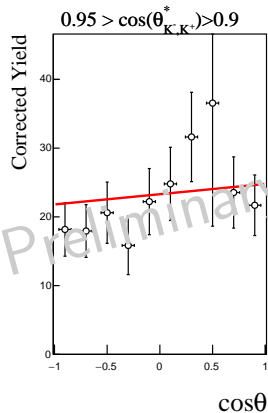
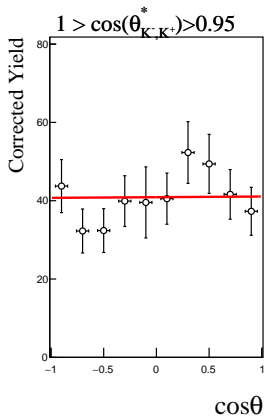
- $P_{\Xi} = 0$  events were generated and reconstructed with statistics comparable to E42 statistics.
- Acceptance was corrected with  $\pi_{\Lambda}$  and  $\pi_{\Xi}$  angles.
- $P_{\Xi}$  was estimated by simultaneous fit of  $\theta$ ,  $\phi_{\beta}$ ,  $\phi_{\gamma}$

# Preliminary Results on $\Xi^-$ polarization



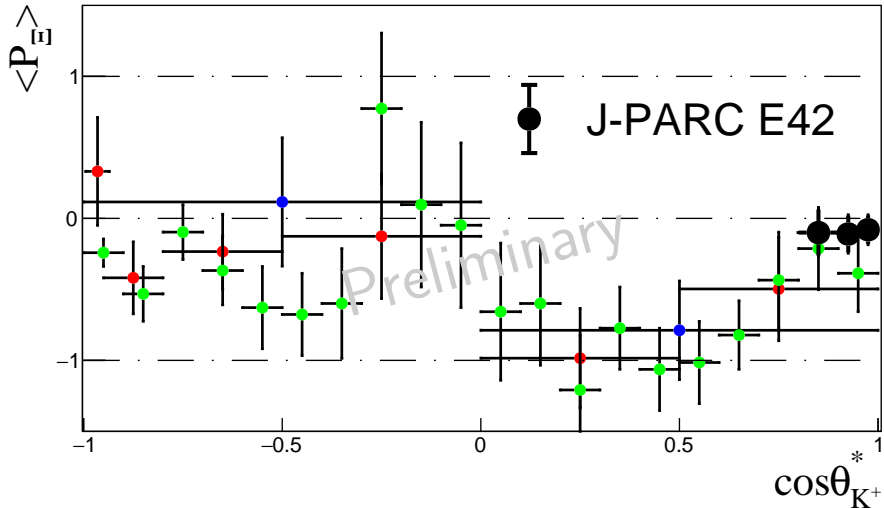
- $\Phi_{\alpha}$  is independent of  $\langle P_{\Xi} \rangle$
- Measured  $\alpha_{\Xi}\alpha_{\Lambda} = -0.30 \pm 0.056$ . (cf. PDG value = -0.291)
- Carbon contribution is not considered yet

# Polarization by Production Angle



- $\phi_\beta$  and  $\phi_\gamma$  were not shown, but was included in simultaneous fit.

# Comparison with Previous data



# Summary

- $\Xi^-$  polarization is important in describing the spin structure of  $KN$  reaction.
- We have acquired precise data with good statistics for  $\Xi^-$  polarization measurement at J-PARC E42
- We present preliminary results on  $\Xi^-$  polarization at  $CH_2$  with E42 data.