Measurement of the Double Polarization Observables C_x and C_z for the Final-State Interactions in $\vec{\gamma} d \to K^+ \vec{\Lambda} n$

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Motivation and Goal

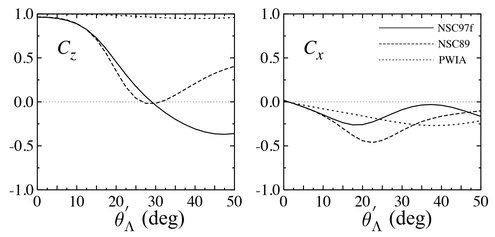
Motivation:

1. Building a comprehensive picture of the strong interaction is the goal of the modern nuclear physics. While considerable progress has been made in the past decades for the nucleon-nucleon interaction, we are still far from a comprehensive picture of the hyperon-nucleon (YN) interaction, which plays a key role in hypernuclear matter and neutron stars.
2. One can access the dynamics of the YN interaction by studying nuclear reactions in which hyperons are produced. While performing YN scattering experiments is a daunting task due to the short lifetime of the hyperons, hyperon photoproduction on the deuteron is an alternative nuclear reaction for testing the available YN potential models.

Goal:

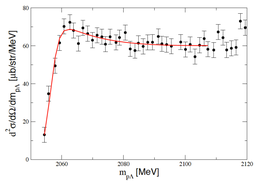
1. This work aims to extract the polarization observables C_x and C_z for final-state interactions in the reaction $\vec{\gamma} d \to K^+ \vec{\Lambda} n$.
2. The final results will be used to constrain the free parameters of theoretical models for the hyperon-nucleon potential.

Theoretical Predictions



Different YN potentials make different predictions for observables.

Model Calculations: K. Miyagawa et al., Phys. Rev. C 74, 034002 (2006).



Applied to cross section data of $pp \to K^+ X$

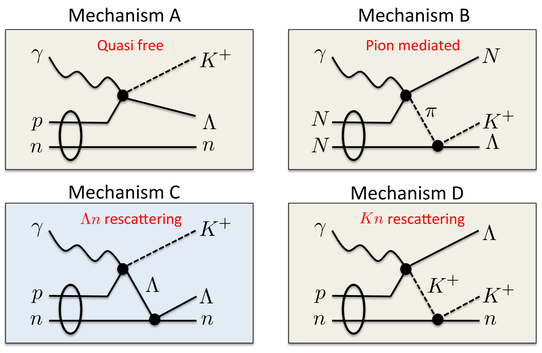
Extract a spin-averaged scattering length of the inclusive K⁺ hadroproduction:

$$a = -1.5 \pm 0.15 \pm 0.3\ fm$$

Figure from: A. Gasparian et al., Phys. Rev. C 69, 034006(2004).

Method of Study

The main mechanisms of the reaction are quasi free scattering, Kn rescattering, Λn rescattering and pion mediated rescattering.

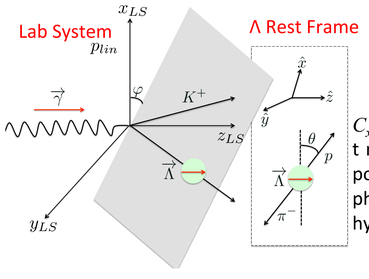


Our objective is to gain information about the dynamics of the Λn re-scattering by eliminating the quasi-free mechanism from data and determining observables only for final-state interactions.

Polarization Observables C_x and C_z

General polarized differential cross section for hyperon photoproduction off the nucleon:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_{|unpol}[1 - P_{lin}\Sigma\cos 2\varphi + \alpha\cos\theta_x(-P_{lin}O_x\sin 2\varphi + P_{cir}C_x) - \alpha\cos\theta_y(-P_y + P_{lin}T\cos 2\varphi) - \alpha\cos\theta_z(P_{lin}O_z\sin 2\varphi - P_{cir}C_z)],$$

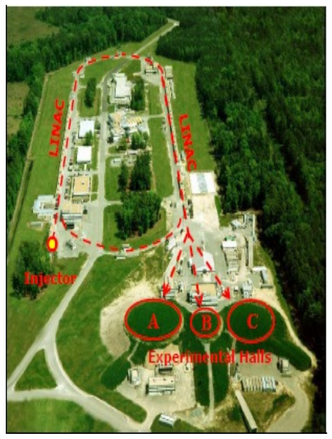


$$\hat{y} = \frac{\hat{z} \times \vec{p}_K}{|\hat{z} \times \vec{p}_K|}$$

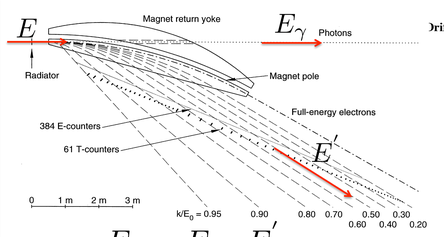
C_x and C_z characterize the transfer of the polarization from incident photon to the produced hyperons.

Jefferson Lab Hall B

CEBAF: Continuous Electron Beam Accelerator Facility



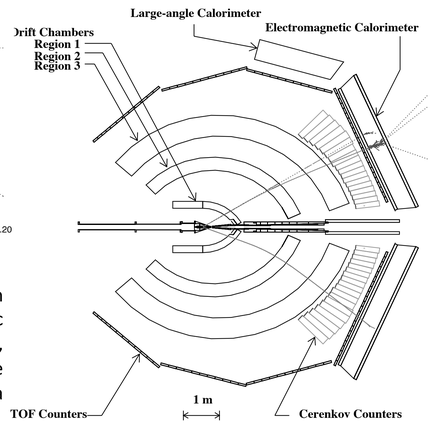
The photon tagger



$$E_\gamma = E - E'$$

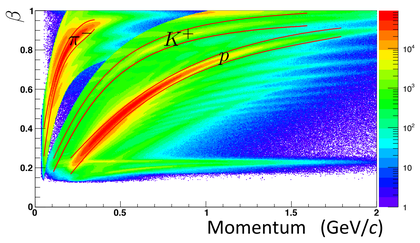
Jefferson Lab Hall B is equipped with an advanced beam line to produce energetic photon beams and a unique detector, the CLAS, that has a large acceptance. This allows the determination of the charged-particle momenta over a large fraction of the full solid angle.

CLAS: CEBAF Large Acceptance Spectrometer

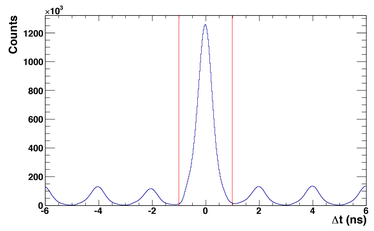


Reaction Identification and Yield Extraction

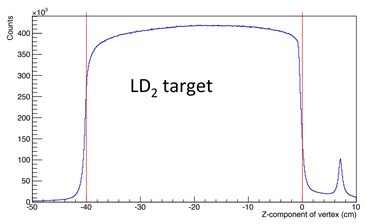
Particle identification for $\vec{\gamma} d \to K^+ \vec{\Lambda} n$, $\Lambda \to p\pi^-$



Photon Selection

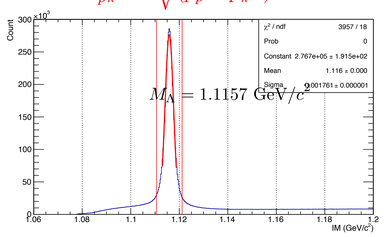


Vertex Cut



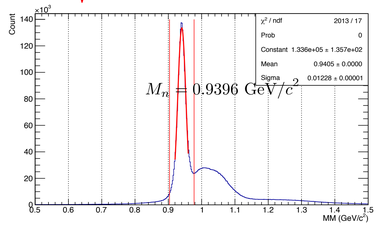
Invariant Mass (IM) cut

$$M_{p\pi^-} = \sqrt{(\tilde{p}_p + \tilde{p}_{\pi^-})^2}$$



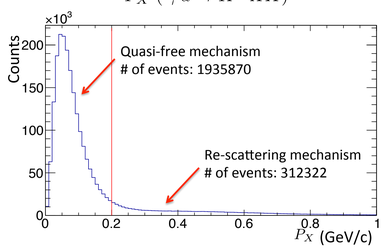
Missing Mass (MM) cut

$$M_X = \sqrt{(\tilde{p}_\gamma + \tilde{p}_d - \tilde{p}_{K^+} - \tilde{p}_p - \tilde{p}_{\pi^-})^2}$$



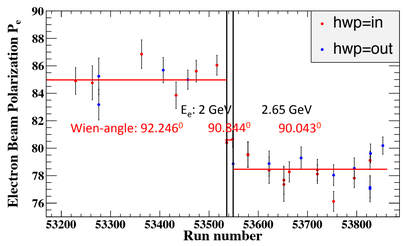
Missing Momentum (P_X) cut

$P_X\ (\vec{\gamma} d \to K^+ \vec{\Lambda} X)$



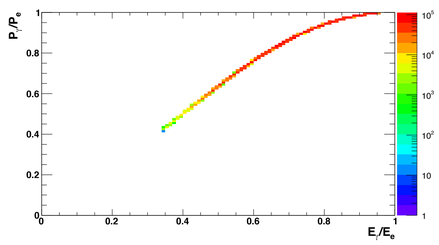
Photon Beam Polarization

The electron polarization for some special runs were measured by the M ller polarimeter.



The polarization of the photon beam was calculated using the Maximon and Olson relation

$$P_{cir} = \frac{E_\gamma(E + \frac{1}{3}E')P_e}{E^2 + E'^2 - \frac{2}{3}EE'}$$



Preliminary Results

Helicity asymmetry: The analysis strategy for extracting C_x and C_z relies on the beam helicity asymmetry distribution which is derived using differential cross section.

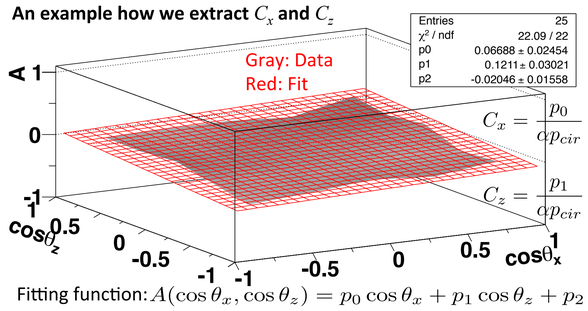
$$\sigma(\cos\theta_x, \cos\theta_z) = \frac{d\sigma}{d\Omega}_{|unpol}(1 \pm \alpha P_{cir}C_x\cos\theta_x \pm \alpha P_{cir}C_z\cos\theta_z)$$

$$A(\cos\theta_x, \cos\theta_z) = \frac{N^+ - N^-}{N^+ + N^-} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \alpha P_{cir}C_x\cos\theta_x + \alpha P_{cir}C_z\cos\theta_z$$

A: Photon beam helicity asymmetry.
N^+, N^-: Helicity-dependent reaction yields in a given kinematic bin.
α: The self-analyzing power of Λ, 0.642 ± 0.013.
P_{cir}: Polarization of circularly polarized photon beam.
C: Constant.
F^+_γ, F^-_γ: The helicity-dependent incident photon flux, and their value are the same.
A_{ccp}: The acceptance of the detector system.

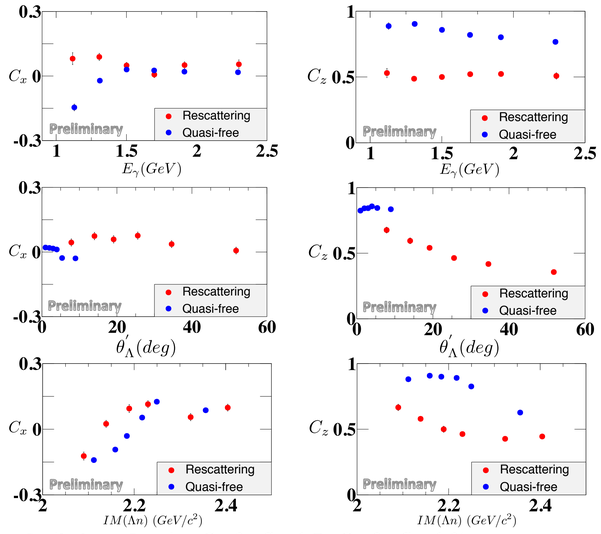
Our analysis consists of determining the beam helicity asymmetry, A, for each kinematic bin, plotting it against $\cos\theta_x$ and $\cos\theta_z$, fitting it by 2-dimension function, and then corresponding parameters dividing out α and P_{cir}. Preliminarily, bins in E_γ and θ_Λ' have been considered.

An example how we extract C_x and C_z

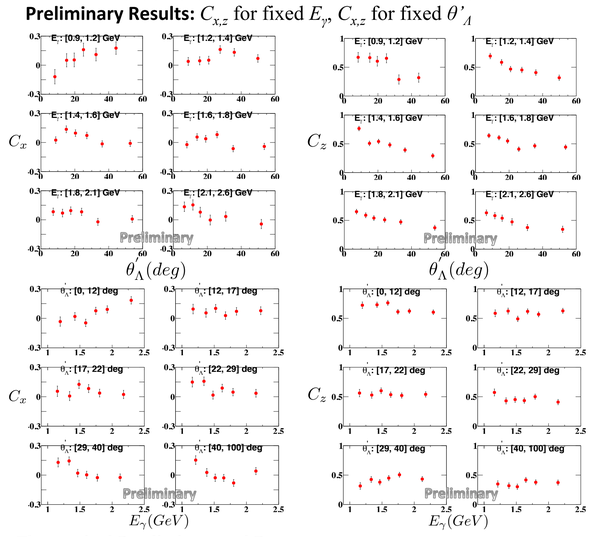


Fitting function: $A(\cos\theta_x, \cos\theta_z) = p_0\cos\theta_x + p_1\cos\theta_z + p_2$

Preliminary Results: $C_{x,z}(E_\gamma)$, $C_{x,z}(\theta'_\Lambda)$, $C_{x,z}$ vs $IM(\Lambda n)$

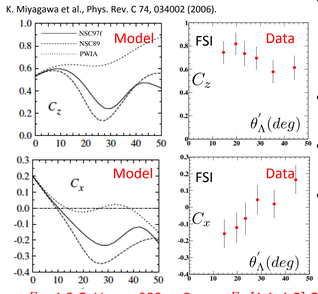


Preliminary Results: $C_{x,z}$ for fixed E_γ, $C_{x,z}$ for fixed θ'_Λ



Theoretical Predictions and Data

K. Miyagawa et al., Phys. Rev. C 74, 034002 (2006).



E_γ = 1.3 GeV, p_K = 900 MeV/c, θ_K = 17 deg

Range: E_γ: [1.1, 1.5] GeV, p_K: [700, 1150] MeV/c, θ_K: [14, 27] deg
Average: E_γ = 1.38 GeV, p_K = 856 MeV/c, θ_K = 23.2 deg

- Qualitative comparison of general features only
  - Data: FSI, Model: QF + FSI
  - $\theta_{K,data} > \theta_{K,model}$
- $C_{z,data}$ consistent with FSI effects
- $C_{x,data}$ consistent with QF predictin
- In collaboration with theorists to match predictions to kinematics of data.

Summary and Outlook

- The available statistics is sufficient to produce meaningful results.
- Re-scattering sample clearly shows different values of the observables than the quasi-free sample.
- Realistic simulations are in progress
  - Comprehensive event generator developed
  - Background subtraction
  - Acceptance effects
- Results for other kinematic variables will be extracted.
- Systematic uncertainties will be analyzed.
- Comparison to theoretical models will be used to interpret our results.