Measurement of polarization observables for the Λ hyperon for photon energies up to 5.45 GeV.

Shankar Adhikari
Florida International University

Outline

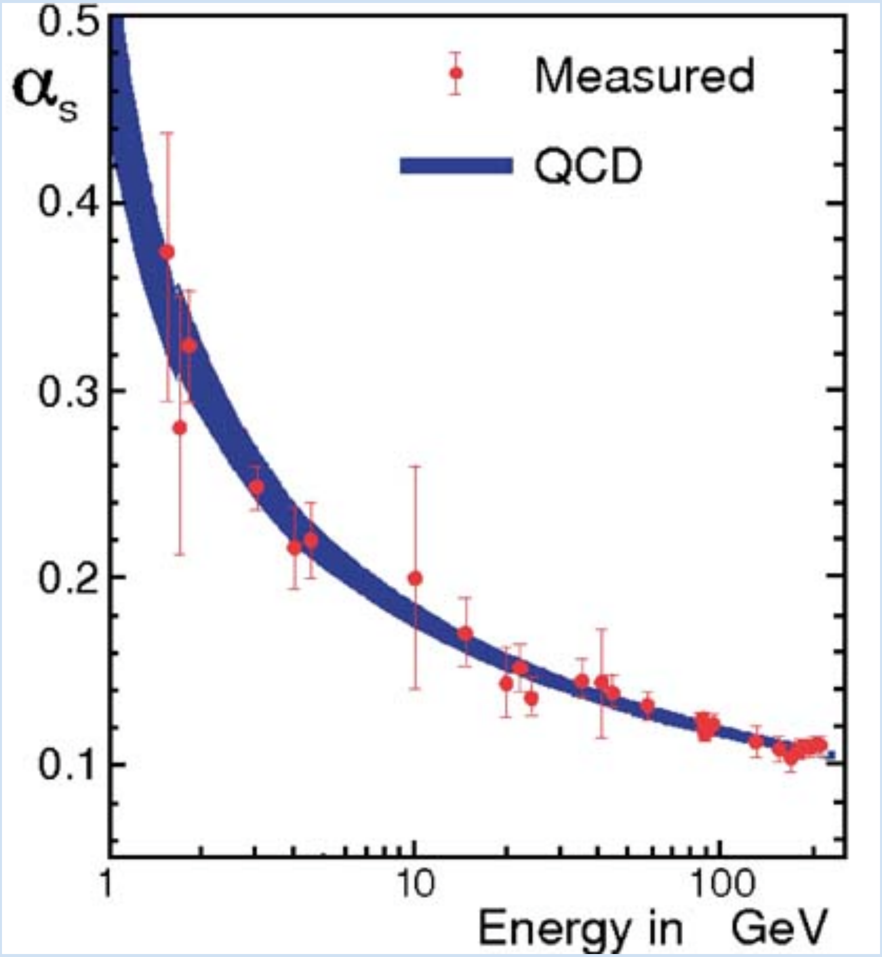
- Introduction
- Motivation
- Experiment overview
- Very preliminary
  - C_X and C_Z
- Conclusion

Introduction

- For high energy, QCD has perturbative series expansion.

- The equation of QCD remains unsolved at energy scales relevant for describing the atomic nuclei. Such as hadron relevant degree.

- Hadron spectroscopy: Study properties of hadron such as mass, decay and classify based on quantum number.



Motivation

- Constituent Quark Model predict large numbers of resonance spectrum.
- Predicted states are not observed.
- Higher densities for $N\pi$ channel, whereas resonance are broad and overlapping.

$K^+\Lambda$ channel could couple with resonance and it is easier to measure polarization observables.

Table 1. The status of the N resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table.

Particle	J^P	overall	Status as seen in $N\gamma$	$N\pi$	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
N	$1/2^+$	****									
$N(1440)$	$1/2^+$	****	****	****		***				*	***
$N(1520)$	$3/2^-$	****	****	****	***					***	***
$N(1535)$	$1/2^-$	****	****	****	****					**	*
$N(1650)$	$1/2^-$	****	****	****	***			***	**	**	***
$N(1675)$	$5/2^-$	****	****	****	*			*		*	***
$N(1680)$	$5/2^+$	****	****	****	*	**				***	***
$N(1700)$	$3/2^-$	***	**	***	*			*	*	*	***
$N(1710)$	$1/2^+$	****	****	****	***		**	****	**	*	**
$N(1720)$	$3/2^+$	****	****	****	***			**	**	**	*
$N(1860)$	$5/2^+$	**		**						*	*
$N(1875)$	$3/2^-$	***	***	*			**	***	**		***
$N(1880)$	$1/2^+$	**	*	*		**		*			
$N(1895)$	$1/2^-$	**	**	*	**			**	*		
$N(1900)$	$3/2^+$	***	***	**	**		**	***	**	*	**
$N(1990)$	$7/2^+$	**	**	**					*		
$N(2000)$	$5/2^+$	**	**	*	**			**	*	**	
$N(2040)$	$3/2^+$	*		*							
$N(2060)$	$5/2^-$	**	**	**	*				**		
$N(2100)$	$1/2^+$	*		*							
$N(2120)$	$3/2^-$	**	**	**				*	*		
$N(2190)$	$7/2^-$	****	***	****			*	**		*	
$N(2220)$	$9/2^+$	****		****							
$N(2250)$	$9/2^-$	****		****							
$N(2300)$	$1/2^+$	**		**							
$N(2570)$	$5/2^-$	**		**							
$N(2600)$	$11/2^-$	***		***							
$N(2700)$	$13/2^+$	**		**							

**** Existence is certain, and properties are at least fairly well explored.
*** Existence is very likely but further confirmation of decay modes is required.
** Evidence of existence is only fair.
* Evidence of existence is poor.

Polarization observables

General form of cross section including polarization observables:

$$
\begin{aligned}
d\sigma = \frac{1}{2}\Big(& d\sigma_0 + \hat{\Sigma}[-P_L^\gamma \cos(2\phi_\gamma)] + \hat{T}[P_y^T] + \hat{P}[P_{y'}^R] \\
&+ \hat{E}[-P_c^\gamma P_z^T] + \hat{G}[P_L^\gamma P_z^T \sin(2\phi_\gamma)] + \hat{F}[P_c^\gamma P_x^T] + \hat{H}[P_L^\gamma P_x^T \sin(2\phi_\gamma)] \\
&+ \hat{C}_{x'}[P_c^\gamma P_{x'}^R] + \hat{C}_{z'}[P_c^\gamma P_{z'}^R] + \hat{O}_{x'}[P_L^\gamma P_{x'}^R \sin(2\phi_\gamma)] + \hat{O}_{z'}[P_L^\gamma P_{z'}^R \sin(2\phi_\gamma)] \\
&+ \hat{L}_{x'}[P_z^T P_{x'}^R] + \hat{L}_{z'}[P_z^T P_{z'}^R] + \hat{T}_{x'}[P_x^T P_{x'}^R] + \hat{T}_{z'}[P_x^T P_{z'}^R]\Big).
\end{aligned}
$$

Observable	Required Polarization		
	Beam	Target	Hyperon
Single Polarization			
$\frac{d\sigma}{d\Omega}$	-	-	-
Σ	linear	-	-
T	-	along y'	-
P	-	-	along y'
Beam and Target Polarization			
G	linear	along z	-
H	linear	along x	-
E	circular	along z	-
F	circular	along x	-
Beam and Hyperon Polarization			
$O_{x'}$	linear	-	along x'
$O_{z'}$	linear	-	along z'
$C_{x'}$	circular	-	along x'
$C_{z'}$	circular	-	along z'
Target and Hyperon Polarization			
$T_{x'}$	-	along x	along x'
$T_{z'}$	-	along x	along z'
$L_{x'}$	-	along z	along x'
$L_{z'}$	-	along z	along z'

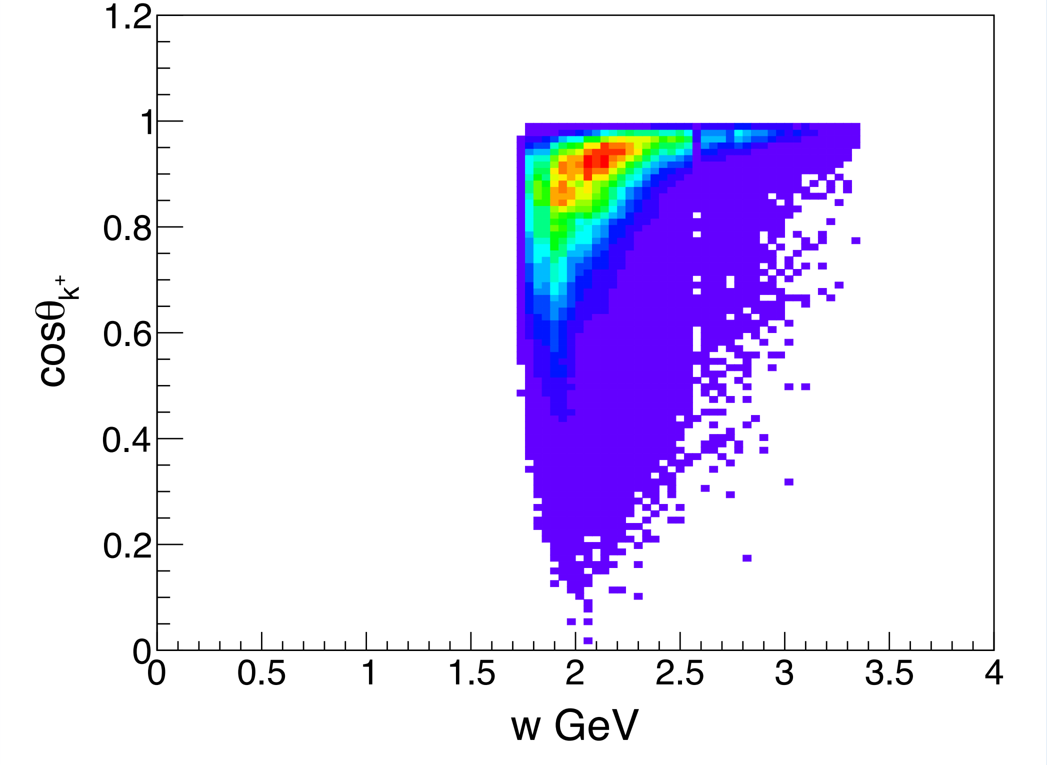
- Total 16 observables.
  3 single polarization observables.

  4 double polarization observables.

- Polarization observables are sensitive to interference from different states.
- With this experiment we are measuring 3 polarization observables.

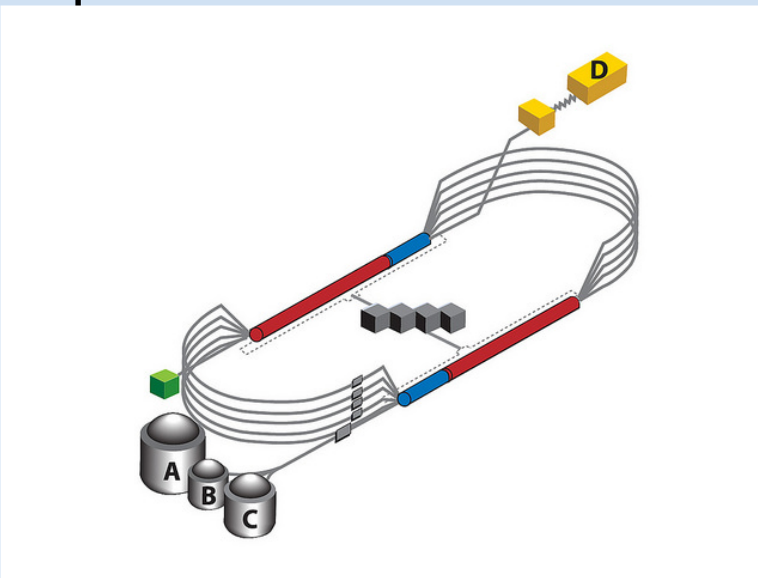
Previous Measurements

- Pre-existing data for $\gamma + p \rightarrow K^{+} + \Lambda$ on polarization observables and cross sections from CLAS(JLab), LEPS, SAPHIR, GRAAL.
- Kinematic coverage:
  - CM energy up to 2.6 GeV.
- Extracting polarization observables w > 2.6 GeV, where previous measurements are missing.
- Higher energies measurement helps us to constrain on non-resonant contribution.

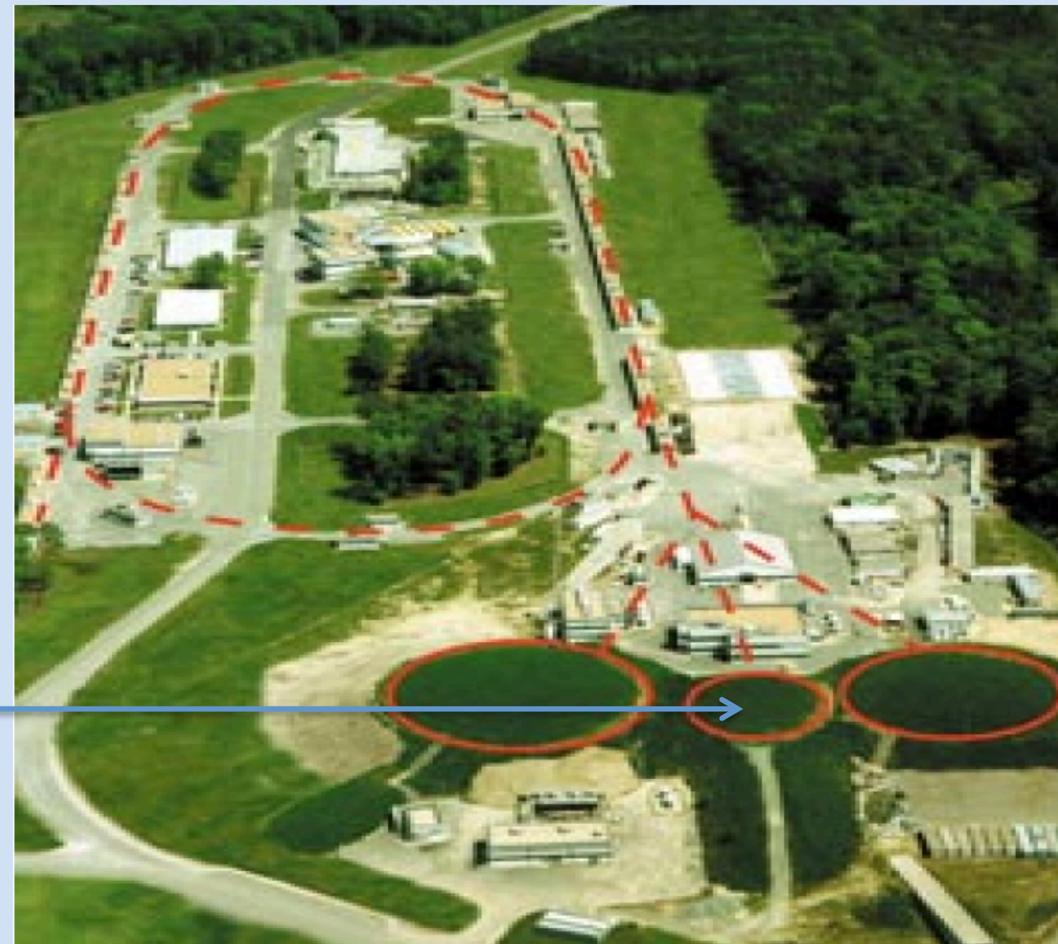


Jefferson Lab

Electron beam with energies 5.71GeV for this experiment.



Located Newport News, Virginia

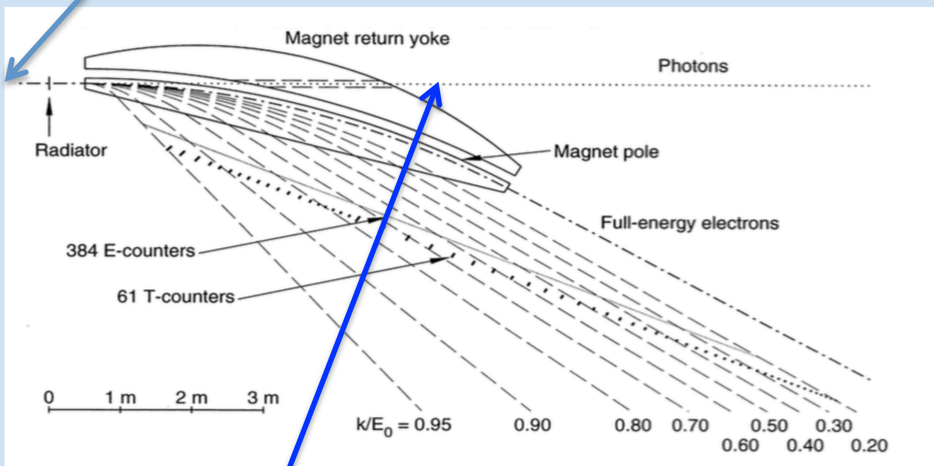


CEBAF "race track" accelerator with linacs and arcs.

Hall B

CEBAF Large Acceptance Spectrometer (CLAS)

60-65 nA electron beam

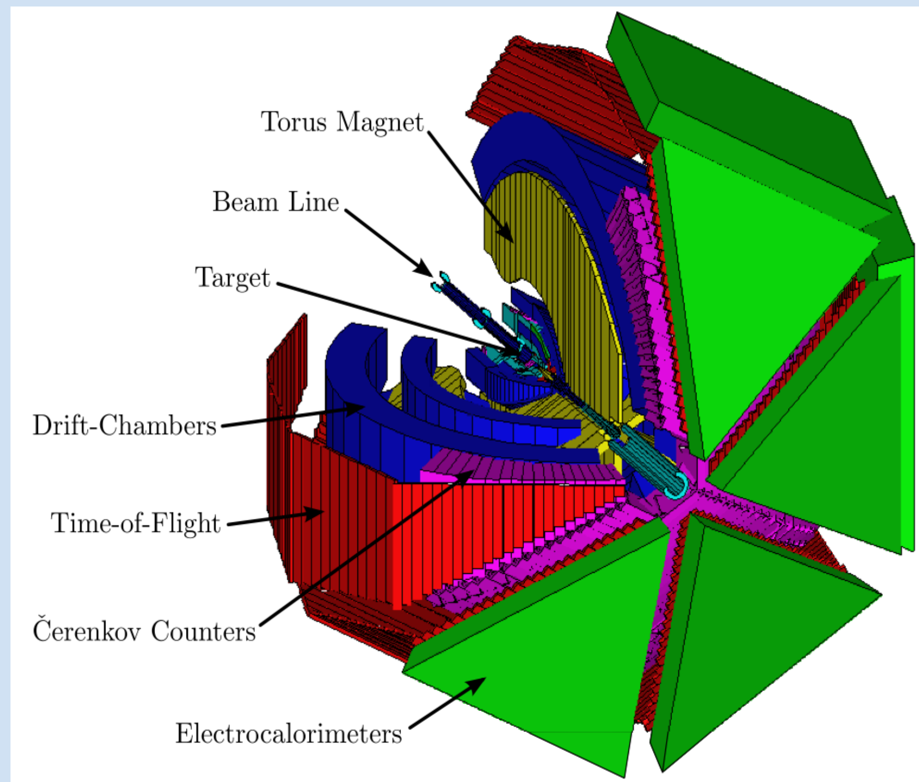


Geometry of tagging system

Produce real photon beam through Bremsstrahlung process.

Photons passed to the hall were tagged.

Hall B detector

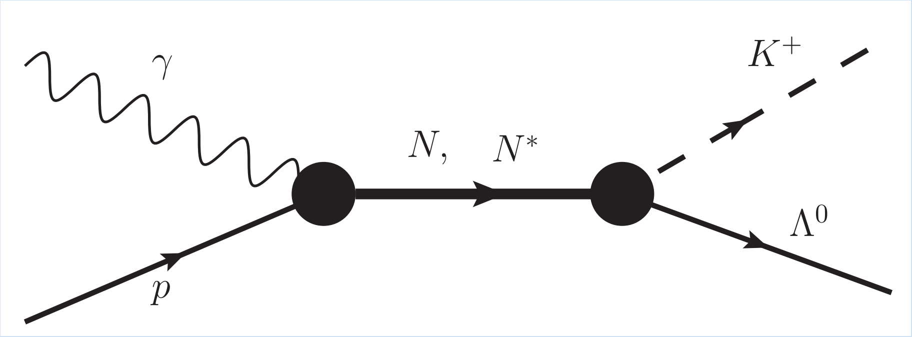


g12 Experiment and Analysis Reaction

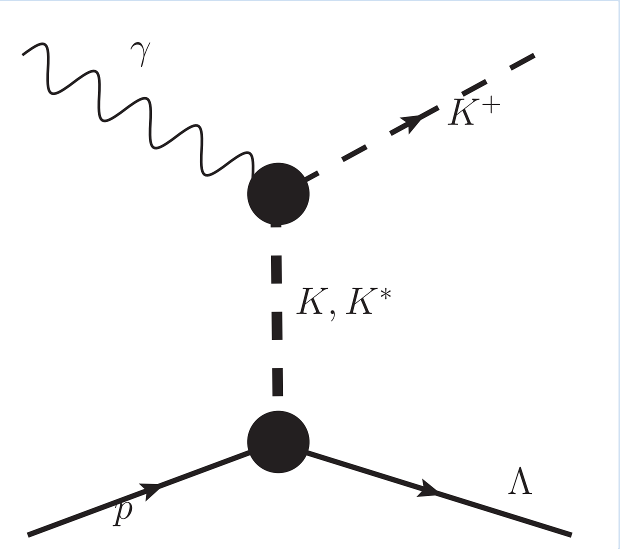
- Circularly polarized photon beam.
- Photon beam energy range 1.1 to 5.5 GeV.
- 40 cm long unpolarized hydrogen target.
- Large amount of meson photo-production data were collected.

$$\gamma p \rightarrow K^+ \Lambda \hookrightarrow p\pi^-$$

Examples of Feynman diagram



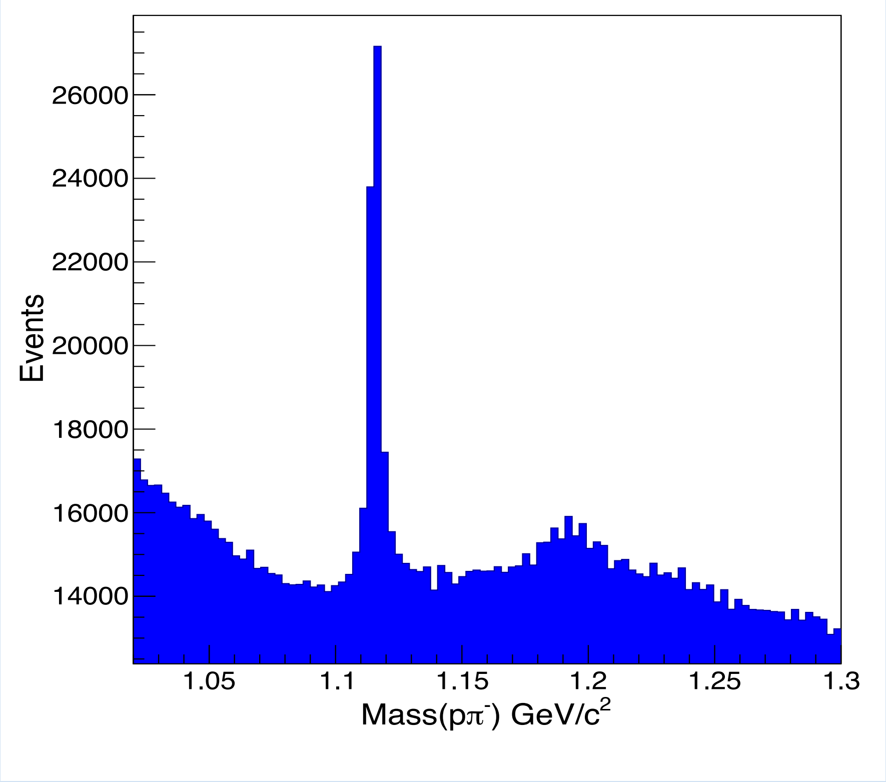
s – channel

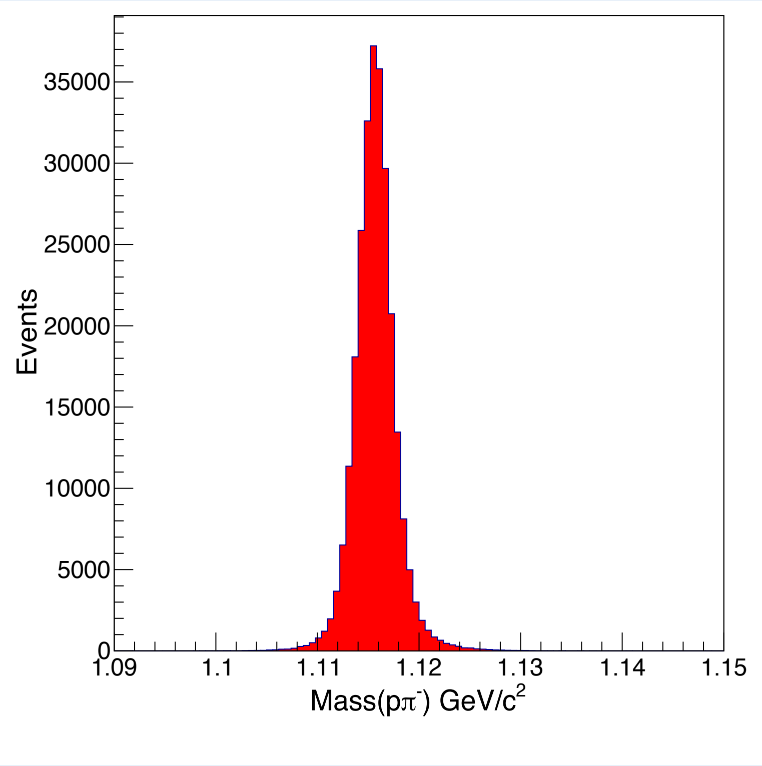


t – channel

Event Selection

Background comes from other reaction channels with same final states.





Background reduction process:

- Vertex cut
- Timing cut
- Fiducial cuts
- Mass cuts.

Photon beam Polarization

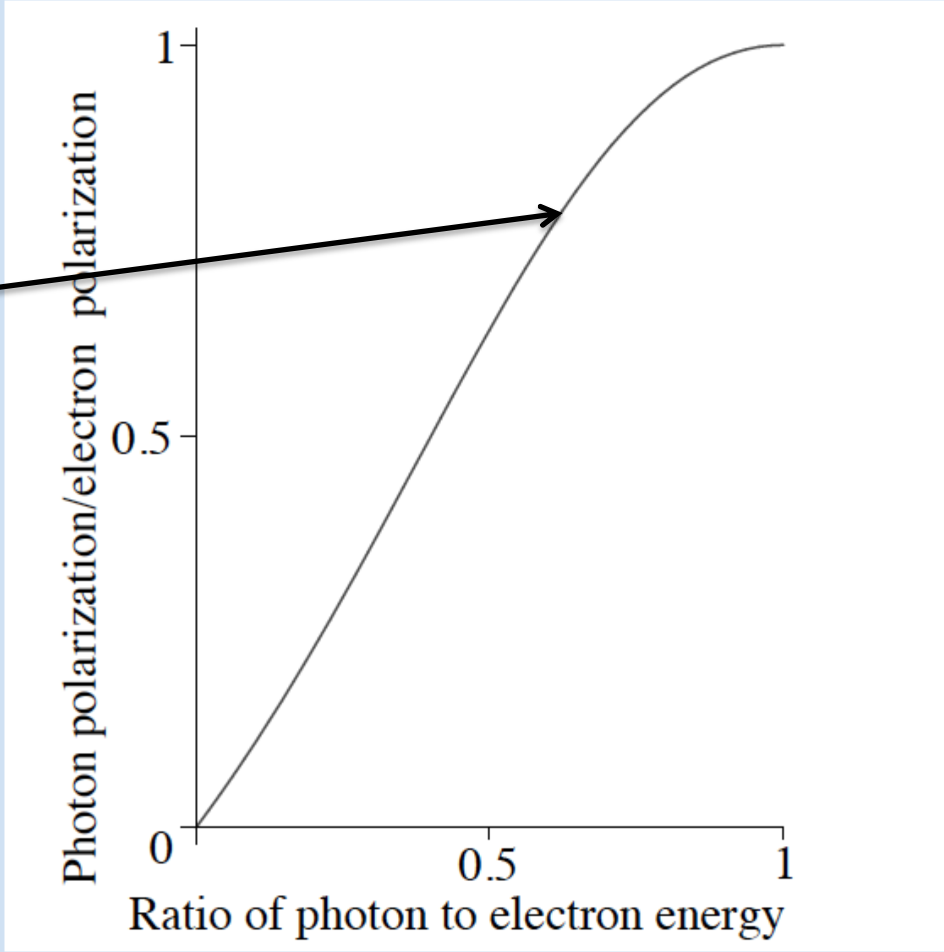
- In order to measure the polarization observables, the polarization of photon beam need to be measure.

- Electron beam polarization measured by Moller Polarimeter.

Olsen and Maximon

$$P_{beam}(E_\gamma) = \frac{x(4-x)}{4-4x+3x^2} P_{elec}$$

Where $x = \frac{E_\gamma}{E_{elec}}$, ratio of Photon to electron energy.



Measurement of Polarization

- If the produced particle is polarized then, we can extract polarization observables from its decay particles.

- It is possible when there is weak decay of polarized particle such as Lambda.

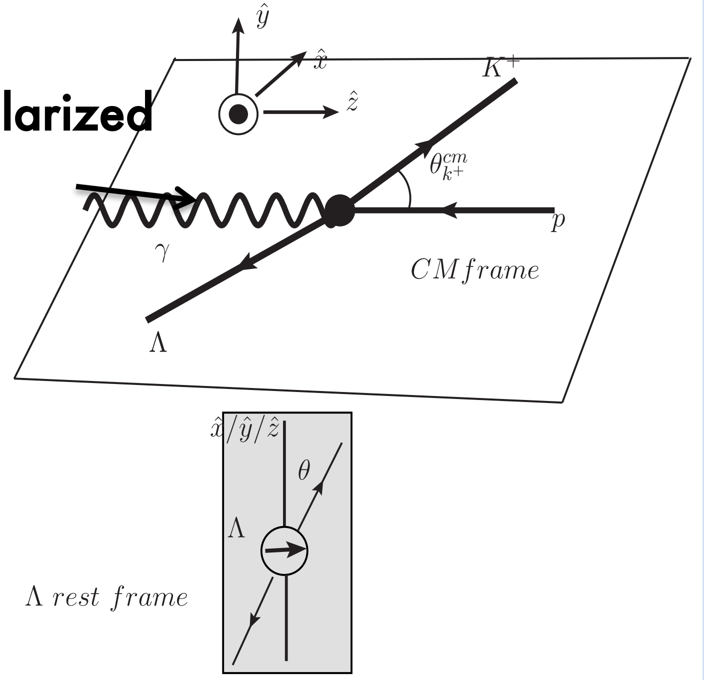
$$\gamma p \rightarrow K^+ \Lambda$$

$$\hat{z} = \hat{p}_\gamma$$

$$\hat{y} = \frac{\hat{p}_\gamma \times \hat{p}_K}{|\hat{p}_\gamma \times \hat{p}_K|}$$

$$\hat{x} = \hat{y} \times \hat{z}$$

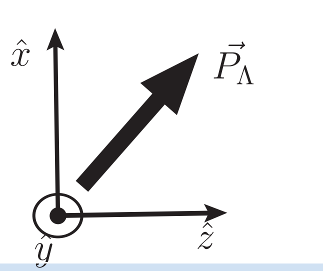
Circularly polarized real photon



Defining Cx, Cz and P

$$\rho_\Lambda \frac{d\sigma}{d\Omega}_{K+} = \frac{d\sigma}{d\Omega}_{K+}\Big|_{unpol} \{1 + \sigma_y P + P_{beam}(C_x\sigma_x + C_x\sigma_x)\}$$

$$\rho_\Lambda = \left(1 + \vec{\sigma}.\vec{P_\Lambda}\right)$$ Density matrix.



Defining C_X, C_Z and P

$P_{\Lambda_X} = P_{beam}C_X$; transferred polarization along x.

$P_{\Lambda_Y} = P$; induced polarization along y.

$P_{\Lambda_Z} = P_{beam}C_Z$; transferred polarization along z.

Asymmetry

- Construct beam helicity asymmetries from extracted yields.

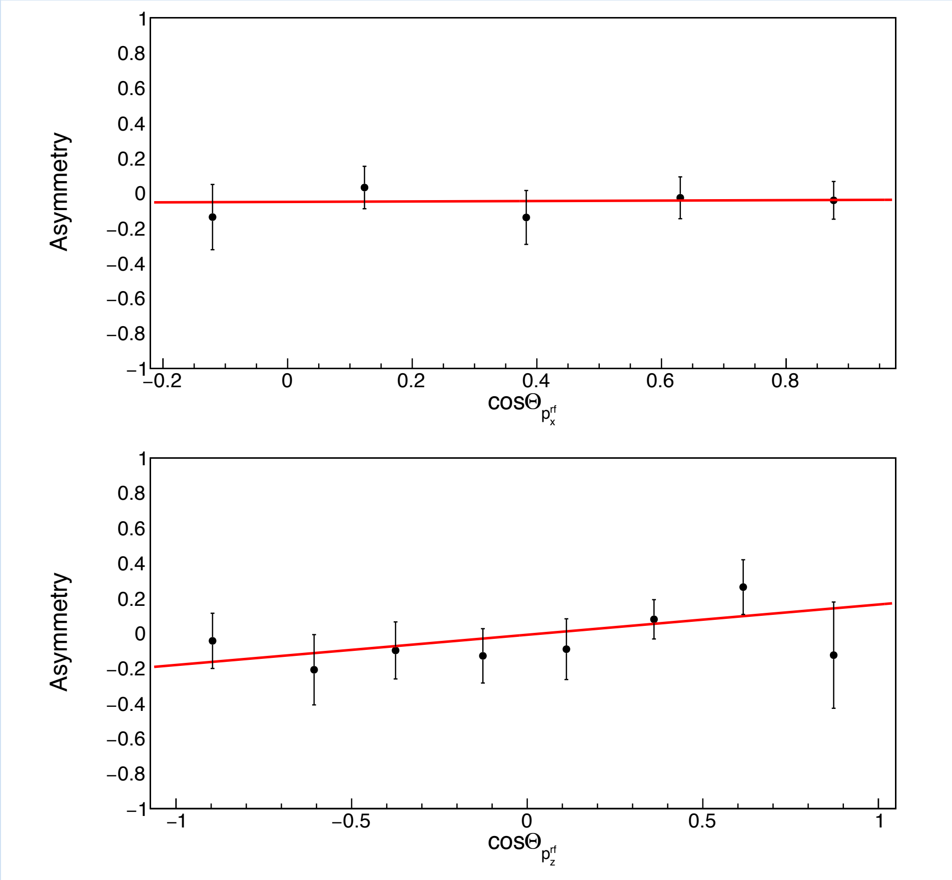
- Slope of asymmetry distribution is proportional to C_X and C_Z observables.

$$A(\cos\theta_{p^{rf}_{X/Z}}) = \frac{N_+ - N_-}{N_+ + N_-}$$

$$= \alpha P_{beam} C_{X/Z} \cos\theta_{X/Z}$$

Photon beam polarization.

Weak decay asymmetry = 0.642



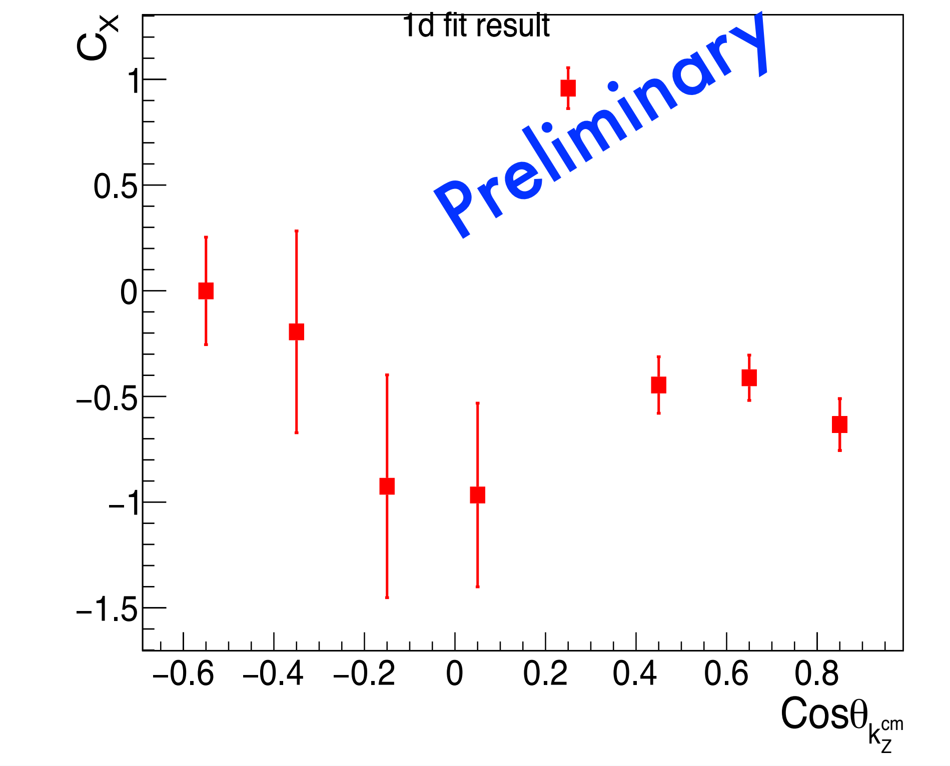
Beam energy = [2.642, 2.741] GeV
Kaon cosine angle in CM frame = -0.25 to -0.45

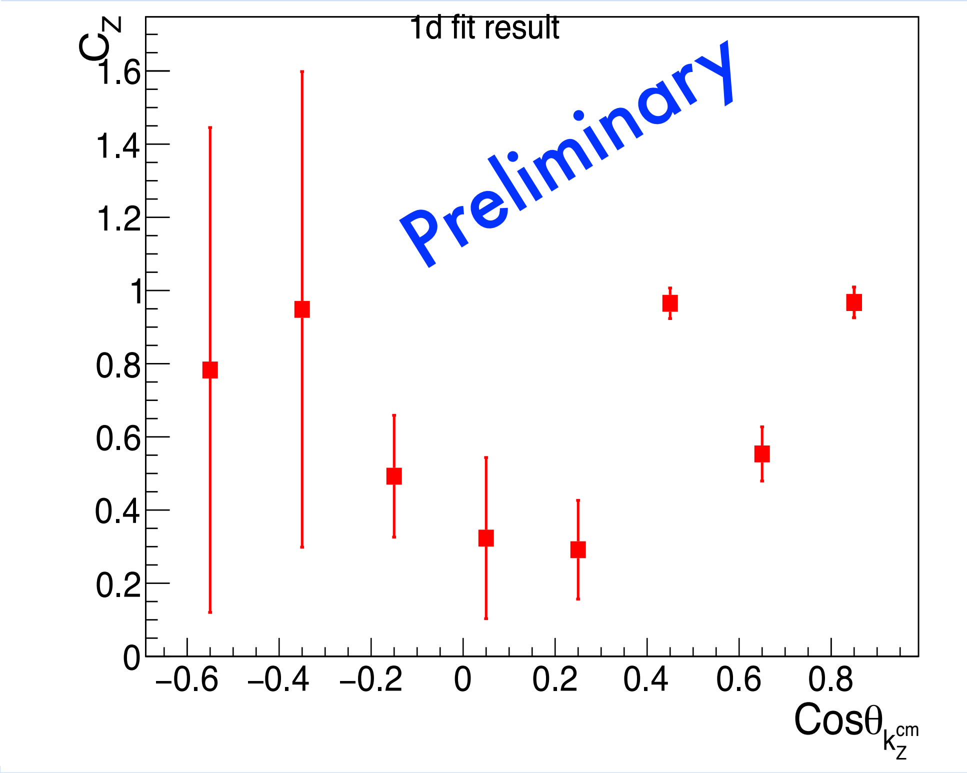
N± = helicity dependent yields.

Result of 1d Fit

Beam energy = 2.642 – 2.741 GeV

Kaon cosine angle in CM frame = -0.05 to -0.45

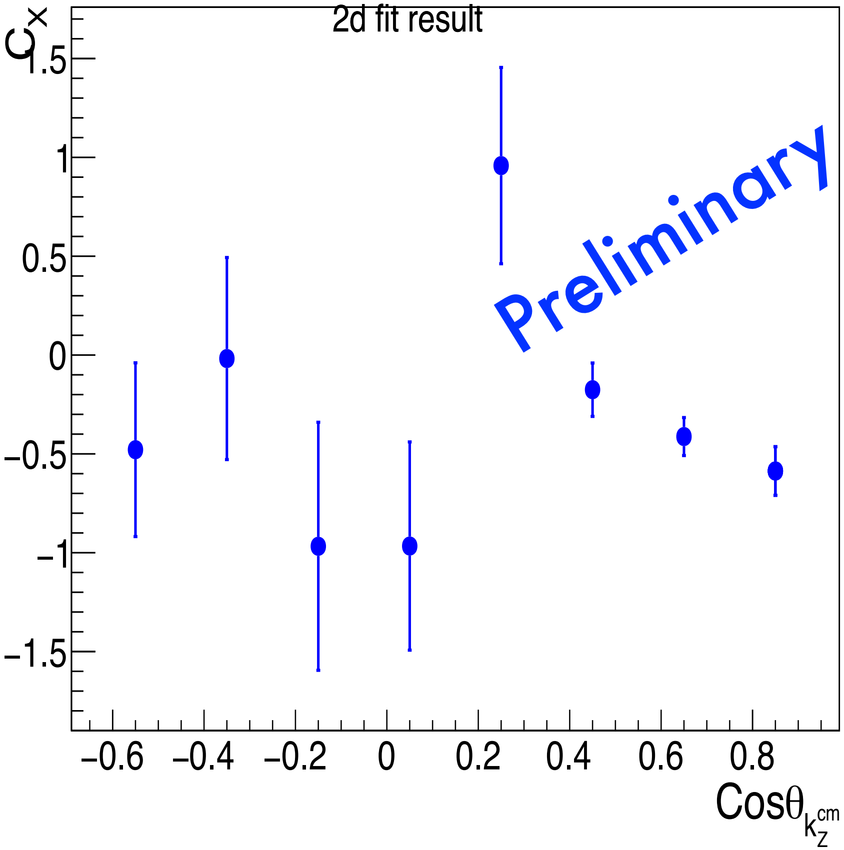


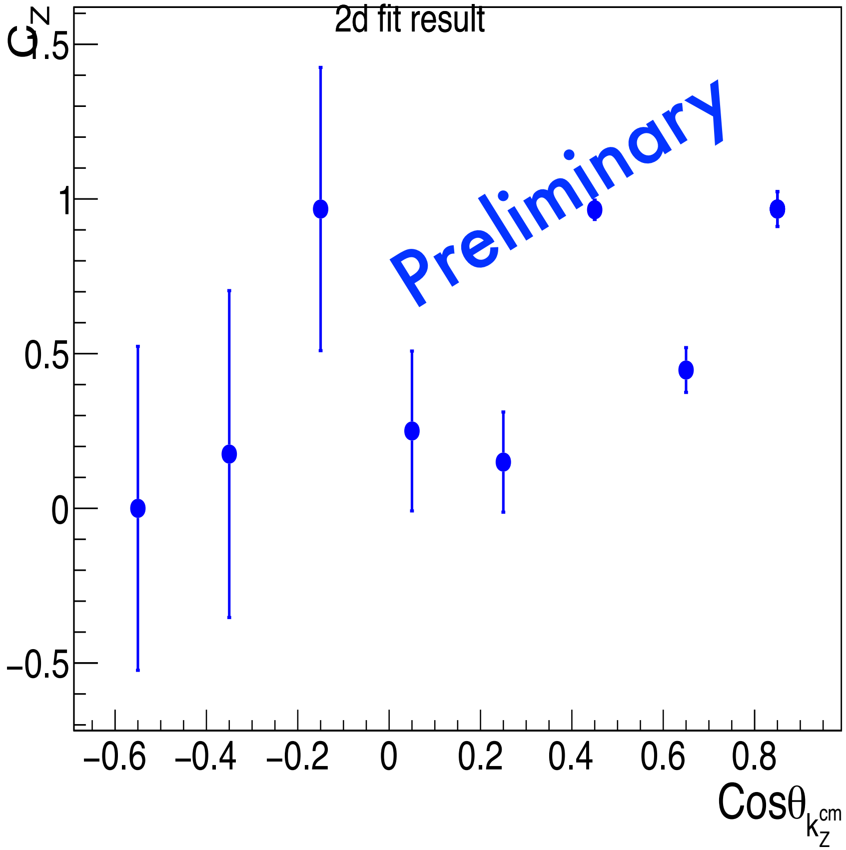


2d Fit Method

2d fit method is same as 1d fit but with simultaneous measurement of observables.

$$A(\cos\theta_x, \cos\theta_z) = \alpha P_{beam} C_x \cos\theta_x + \alpha P_{beam} C_z \cos\theta_z$$



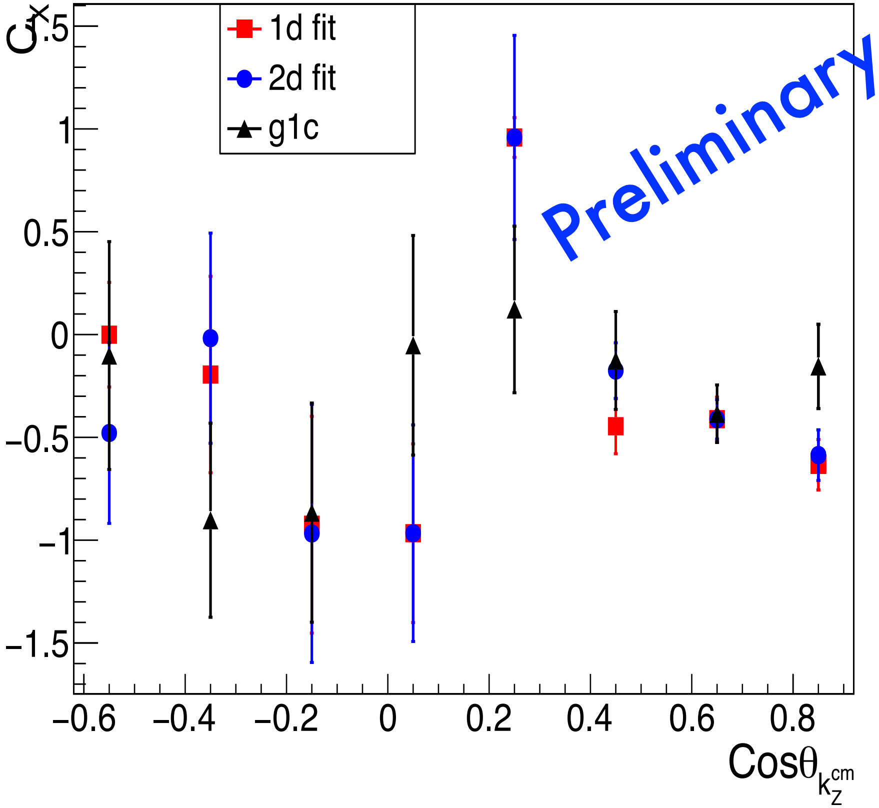


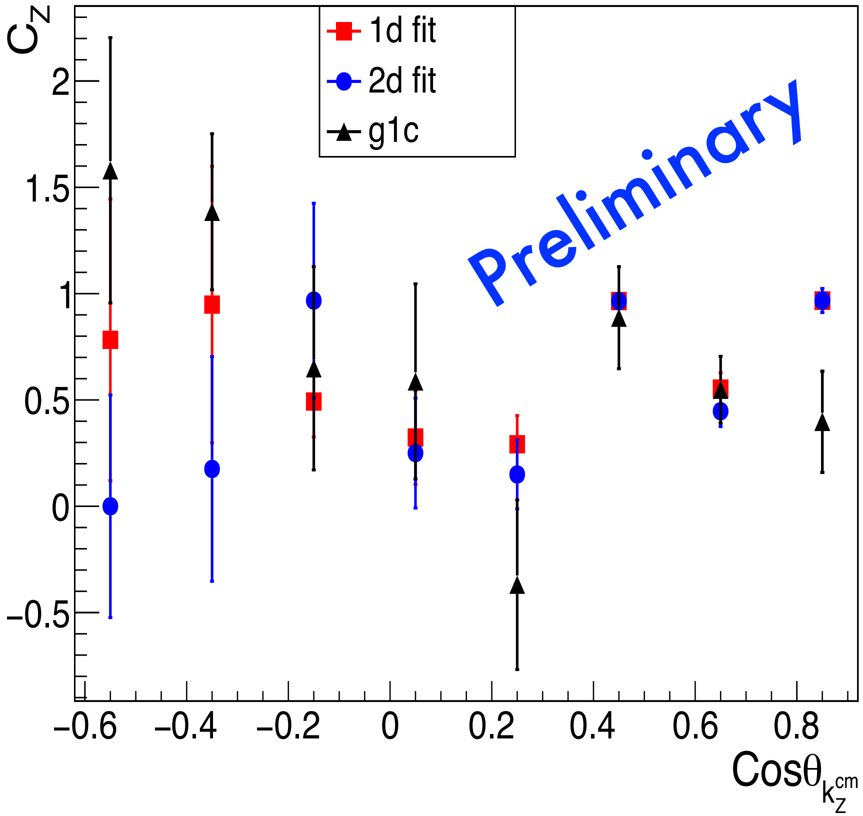
Beam energy 2.642 – 2.741 GeV

Comparision

- Comparing 1d fit method and 2d fit method with g1c, CLAS(Jlab) experiment.

g1c : R. Broadford et al. published PHYSICAL REVIEW C 75, 035205 (2007)





Energy = 2.642 to 2.741 GeV

Maximum likelihood method

- Event by event basis.
- Reduce the bias comes from acceptance because of event wise analysis.
- Define likelihood function as;

$$L(C_i) = \prod_{i=1}^{n} f(Cos\Theta_i, C_i)$$

where C_i, polarization observables. $Cos\Theta_i$ Is the angular distribution of proton at rest frame of lambda.

- Minimize the negative loglikelihood as,

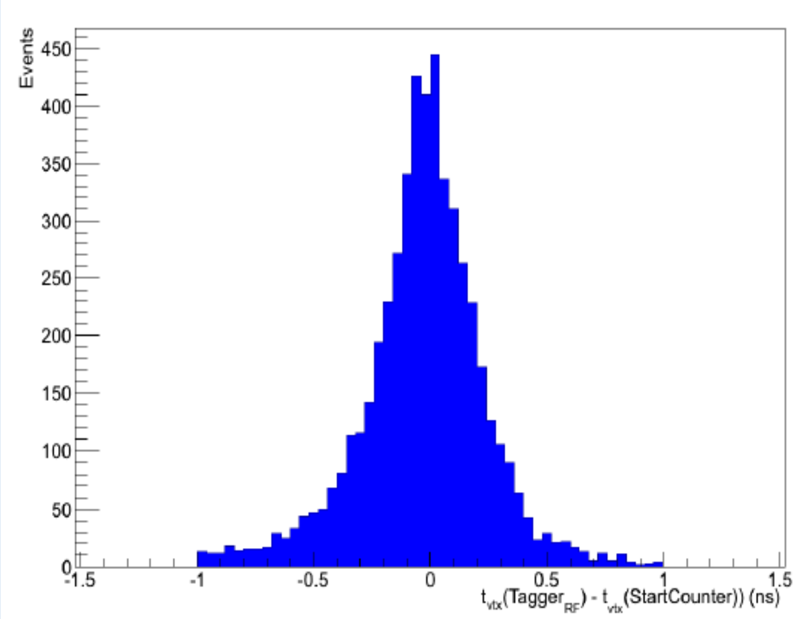
$$\ell = -\sum_{i=1}^{n} \log f(Cos\Theta_i, C_i)$$

Conclusion

- For the polarization observables, no previous measurement exits on high energy regime.
- After verifying our method on low energy region, this will extend to high energy.
- By measuring polarization observables on higher beam energy, we can constrain non-resonant(t-channel) contribution.
- Calculate the induced polarization, which is missing in this part.
- Event based maximum likelihood method will implement in future.

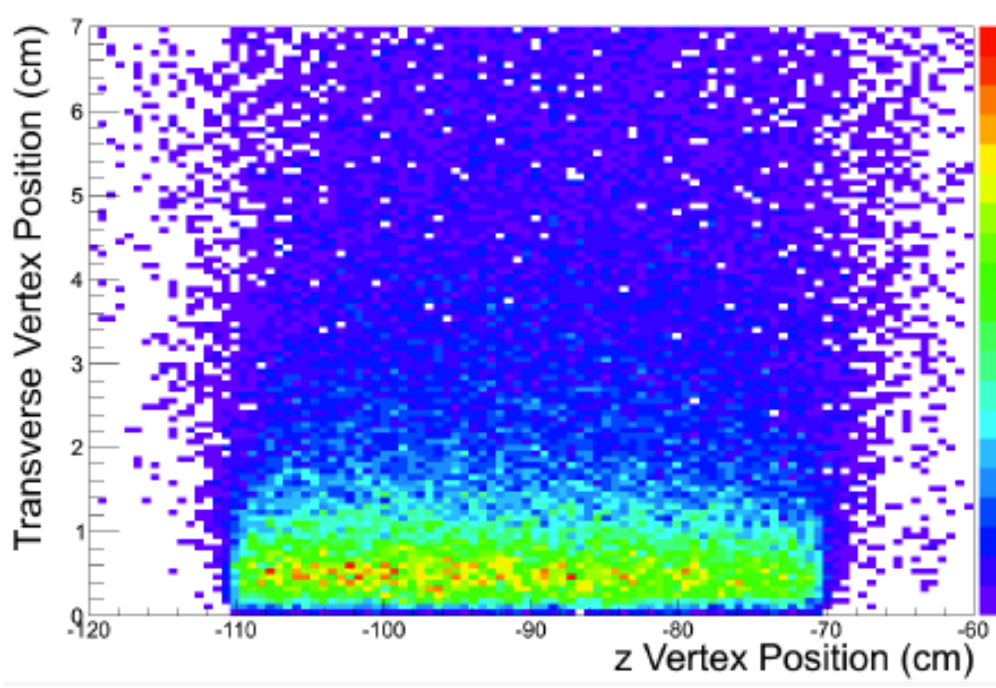
Thank You!

Timing and Vertex Cuts



• 1 ns agreement between time measured by RF corrected - tagger and start counter.

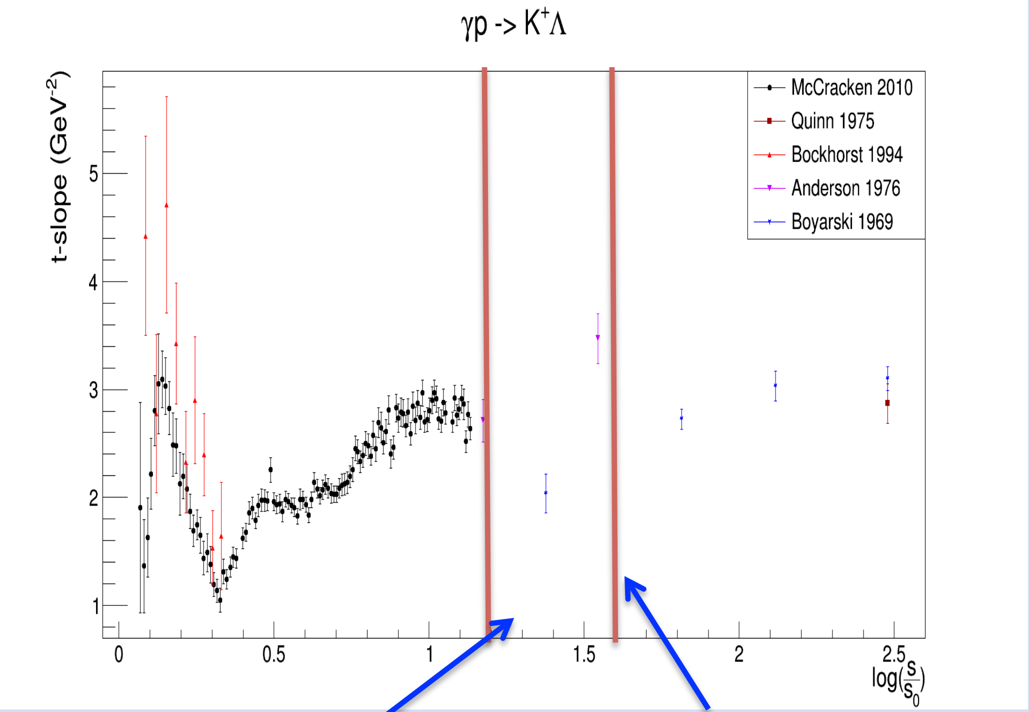
• Vertex selection occupied cylindrical volume around target with -120 to -60 cm along beam and 7 cm radius.



Motivation

Differential cross section

$$\frac{d\sigma}{dt} \simeq \exp^{-bt}$$



Beam energy 3.8 GeV 5.45 GeV

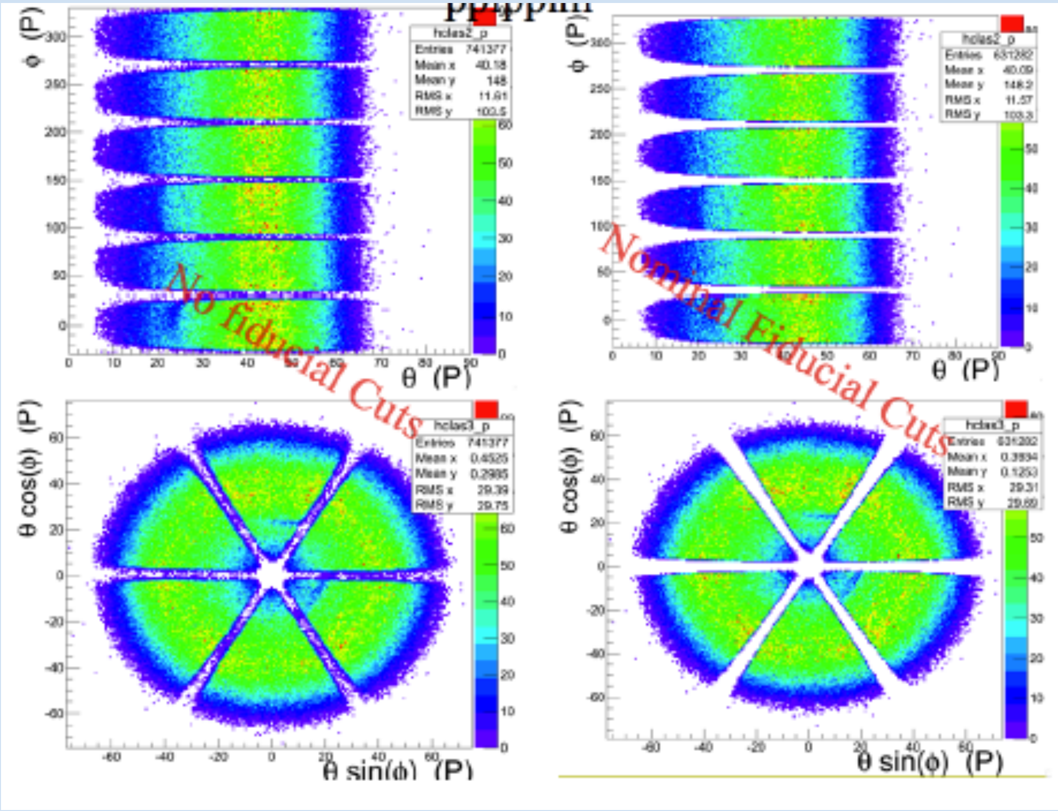
Plotted b along y and log weighted CM energy along x.

Daniel Puentes and et al, FIU

Fiducial cut

Fiducial meaning *Trustworthy*

- Based on CLAS detector geometry.
- Removing the events those lie on non-uniform region; such as between the sector.



1d Fit Method

- Photon beam is circularly polarized with positive and negative helicity.
- Simple idea: To count the number of events in the final state for those positive and negative helicity. $\Lambda \to p\pi^-$
- In order to count, we measure the angular distribution of proton in lambda rest frame.

$A(\cos\theta_{p^{rf}_{X/Z}}) = \frac{N^+ - N^-}{N^+ + N^-}$, is called beam helicity asymmetry.

$N_\pm$ = total number of counts for positive and negative helicity, and X/Z refer to x and z component of angular distribution of proton at lambda rest frame.

Previous Measurements

- Pre-existing data for $\gamma + p \rightarrow K^+ + \Lambda$ on polarization observables and cross sections from CLAS(JLab), LEPS, SAPHIR, GRAAL.
- Kinematic coverage:
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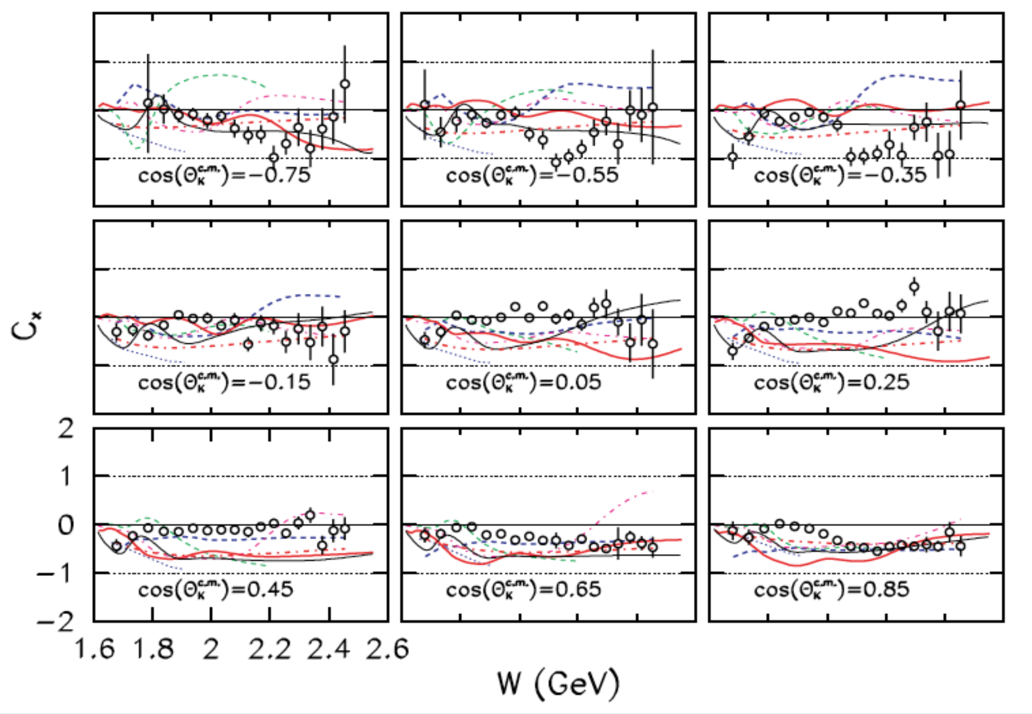

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