Measurement of polarization observables for the Λ hyperon.

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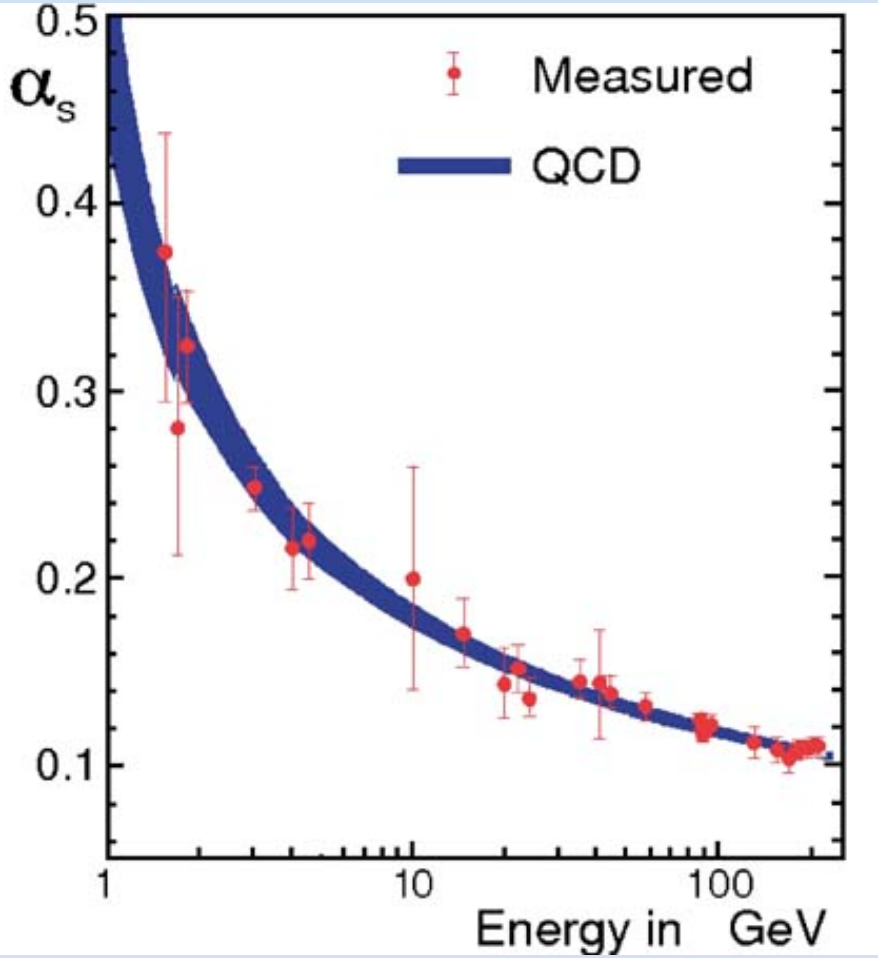
Outline

- Motivation
- Experiment
- Events Selection
- Preliminary results for C_x, P and C_z.
- Conclusion and outlook.

Strong Interaction

- Large *Q*; perturbative theory (asymptotic freedom)
- Small *Q*; perturbative theory is not possible (confinement)



GOAL:

Better understand QCD at low *Q*.

-> How does QCD give rise to hadrons?

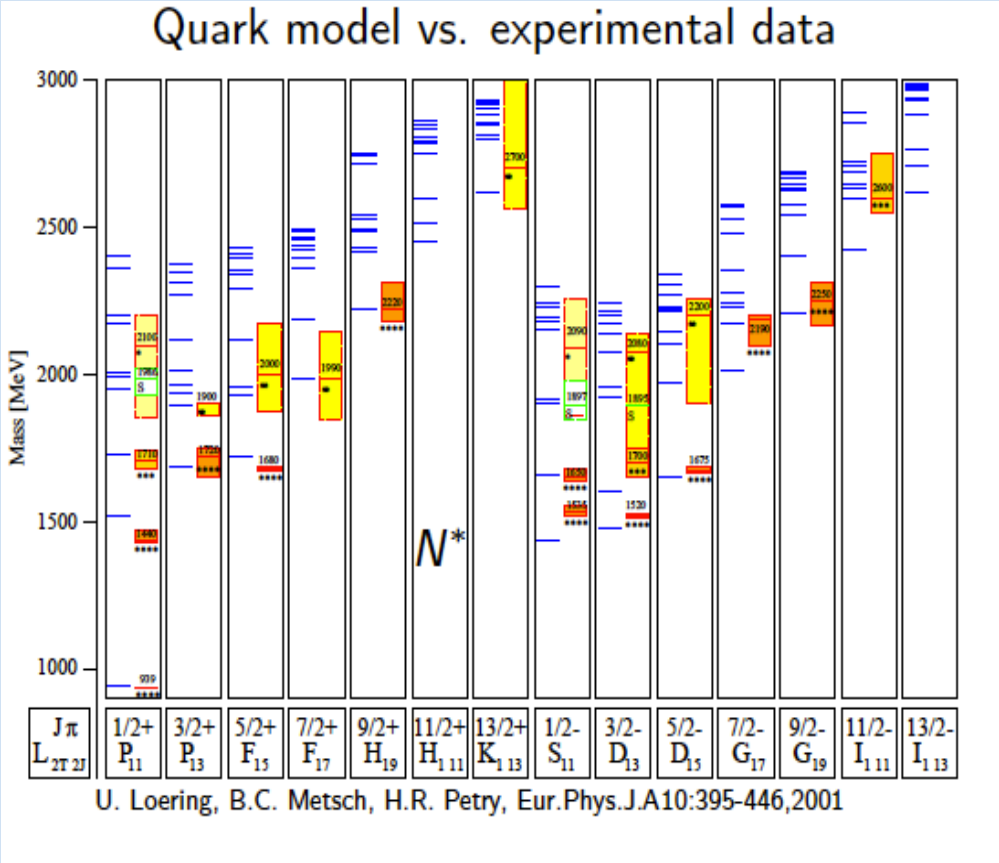
-> What are the relevent hadronic degrees of freedom?

-> What are the effective forces?

Method: Baryon spectroscopy

Baryon Spectroscopy

- The goal is to understand dynamics of the constituents inside the nucleon (relevant hadronic degrees of freedom).
  - understand nucleon excitation spectra (*N**).
- Missing baryon problem;
  - predicted resonance are not conclusively observed (eg. CQM and Lattice-QCD).
  - Resonances are broad and overlapping.
  - May not be coupled with Nπ (where most of the world data's available).
- KY channel has been recently used to understand *N**.



Why $K^+\Lambda$?

- Observed *N** (excited state of nucleon), already been verified coupled with $K^+\Lambda$.
- $K^+\Lambda$ Isospin I = ½ ;
  - couple with *N** not with *Δ**(no interference)
- few density of states compare to Nπ .
- Self analyzing lambda decay, spin observables can be measured by decay product of $\Lambda \rightarrow p\pi^-$.
- Add more data point *W* > 2.6 GeV.

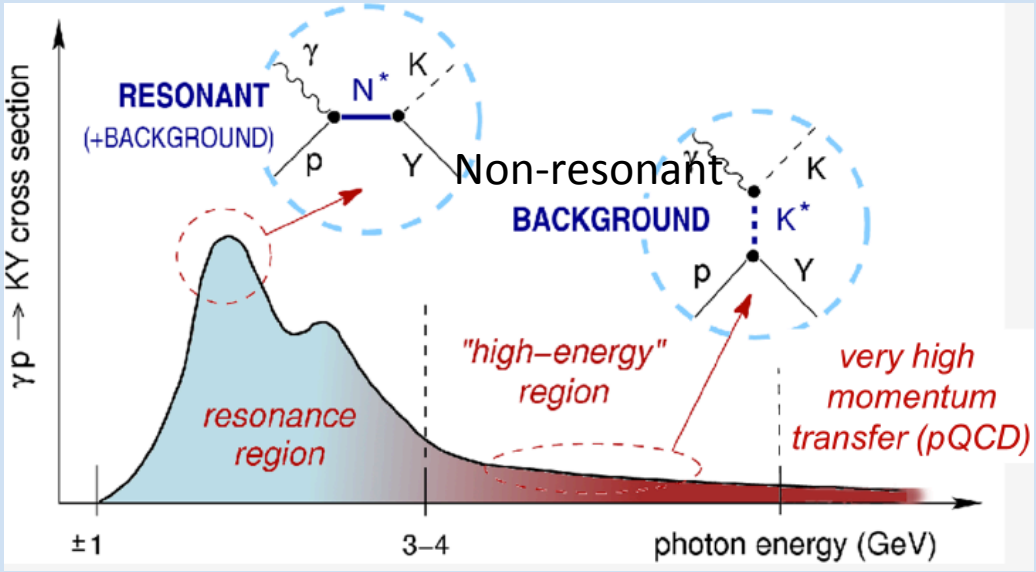
Table 1. The status of the N resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table.

			Status as seen in								
Particle	J^P	overall	$N\gamma$	$N\pi$	$N\eta$	$N\sigma$	$N\omega$	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.

Why $K^+\Lambda$?

- Why high energy part is also important?



High energy non-resonant background contribution can be measure.

Polarization observables

- Photo-production describes by 4 complex amplitudes.
- Total 16 observables.
  - 3 single pol. observables.
  - 4 double pol observables.
  - 8 observables need to separate amplitude at given *W* along with differential cross section.

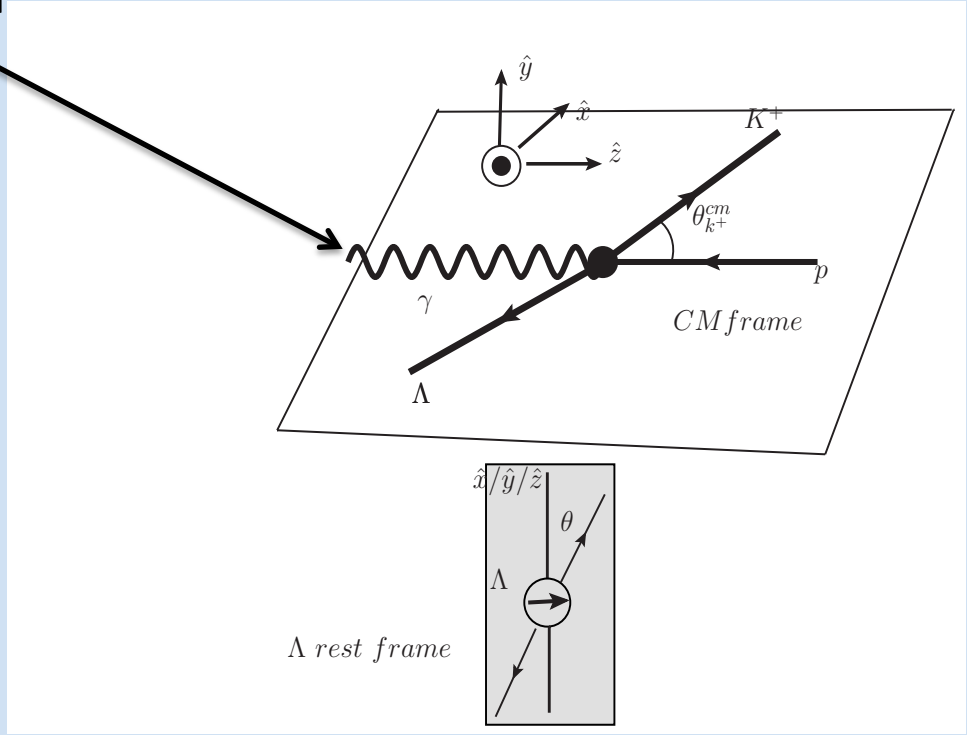
Polarized	Beam	Target	Hyperon
	unpol. linear circular	x y' z	x' y' z'
Unpolar.	σ		
Beam: linear circular	Σ	H G F E	$O_{x'}$ $O_{z'}$ $C_{x'}$ $C_{z'}$
Target: x z		T	$T_{x'}$ $T_{z'}$ $L_{x'}$ $L_{z'}$
Hyperon:			P

- Polarization observables are sensitive to interference from different states and different process.
- This analysis : Transferred Polarization C_x , C_z and induced polarization P is measured.

Defining C_x, C_z

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

Circularly polarized real photon



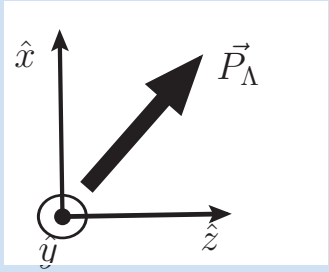
$$\hat{z} = \hat{p}_\gamma$$
$$\hat{y} = \frac{\hat{p}_\gamma \times \hat{p}_K}{|\hat{p}_\gamma \times \hat{p}_K|}$$
$$\hat{x} = \hat{y} \times \hat{z}$$

Measure polarization transfer from γ to Λ in the production plane along "x" and "z".

Defining C_x, C_z and P

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

P_{beam} = Photon beam polarization.



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

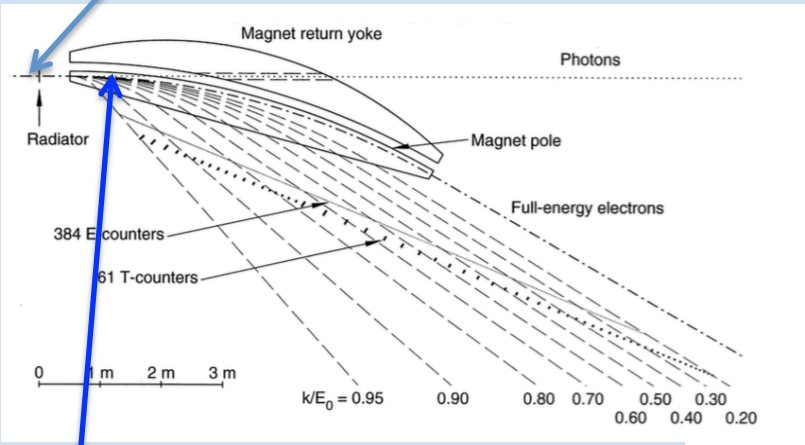
$P_{\Lambda_X} = P_{beam} C_X$; transferred polarization along x.

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

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

CEBAF Large Acceptance Spectrometer (CLAS)

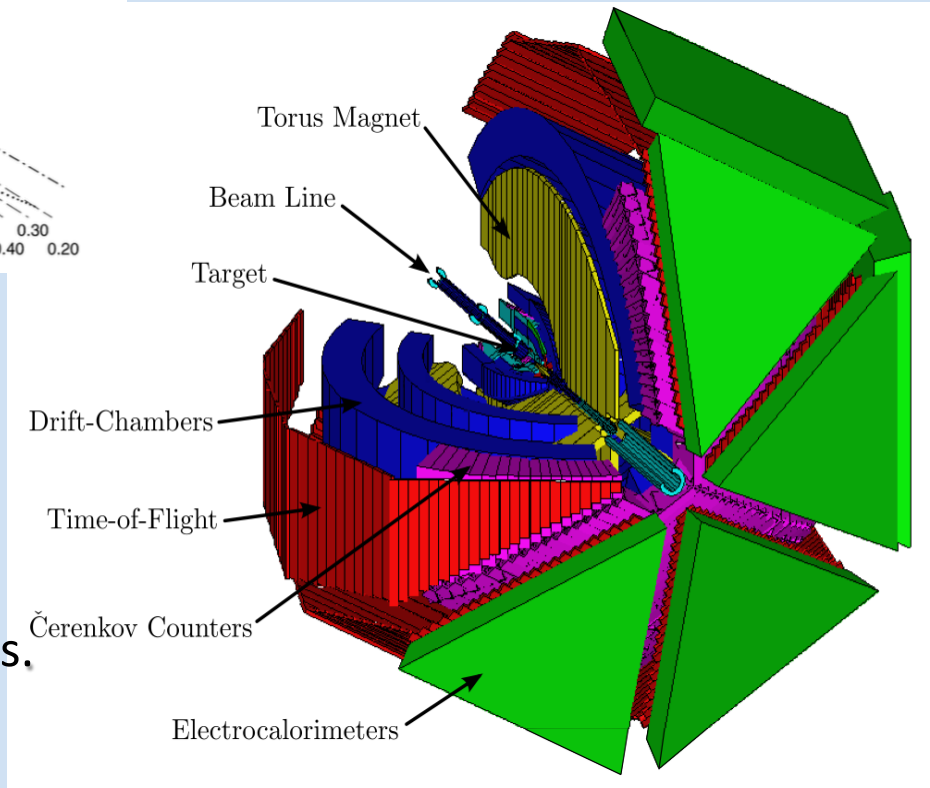
60-65 nA electron beam



Geometry of tagging system

Produce real photon beam through Bremsstrahlung process.

Hall B detector

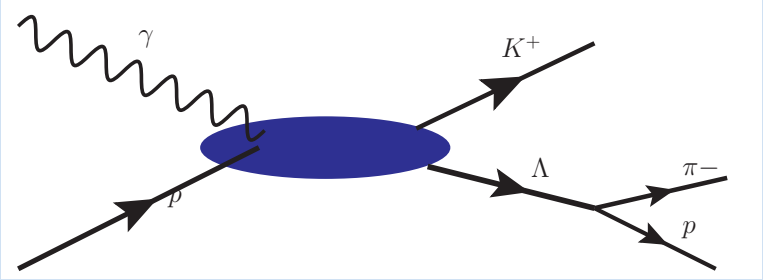


g12 Experiment and Analysis Reaction

- 60-65 nA electron beam.
- Circularly polarized photon beam.
- Photon beam energy up to 5.5 GeV.
- Average beam pol. 0.7±0.05.
- 40 cm long unpolarized hydrogen target.
- Large amount of meson photo-production data were collected.

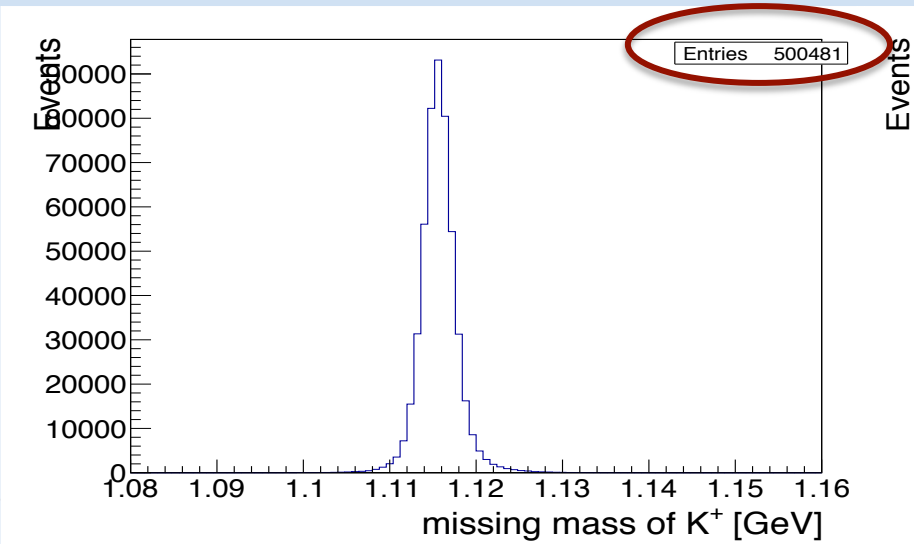
$$\gamma p \rightarrow K^+ \Lambda$$

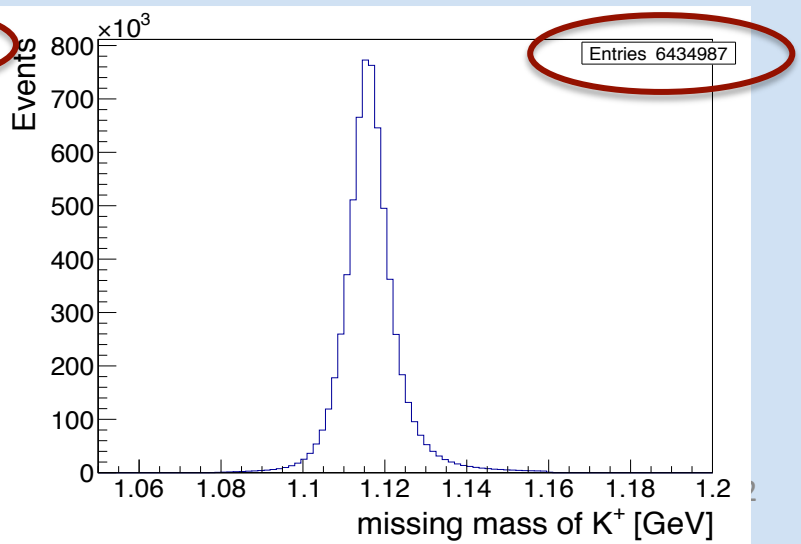
Decay mode Λ --> pπ$^-$



Event Selection

3track $K^+p\pi^-$		2track $K^+p(\pi^-)$
☑	❖Standard Timing Cut	☑
☑	❖ Vertex Cut	☑
☑	❖ Fiducial Cut	☑
☑	❖ Time of Flight Knockout	☑
☑	❖ Energy loss correction	☑
☑	❖ g12 momentum correction	☑
☑	❖ PID cut	☑
☑	❖ Missing mass around π^-	☑
☑ prob > 1%	❖ Kinematic fitting	☑ prob > 5%





Observables extraction Methods

- 1d fit method

$$A(\cos\theta^p_{x/z}) = \frac{N^+ - N^-}{N^+ + N^-} = \alpha P_\circ C_{x/z} \cos\theta^p_{x/z}$$

α = Weak decay asymmetry 0.642

- 2d fit method

$$A(\cos\theta^p_x, \cos\theta^p_z) = \frac{N^+ - N^-}{N^+ + N^-} = \alpha P_\circ C_x \cos\theta^p_x + \alpha P_\circ C_z \cos\theta^p_z$$

- Maximum likelihood method
  - Event by event basis.
  - Reduce the bias comes from acceptance because of event wise analysis.

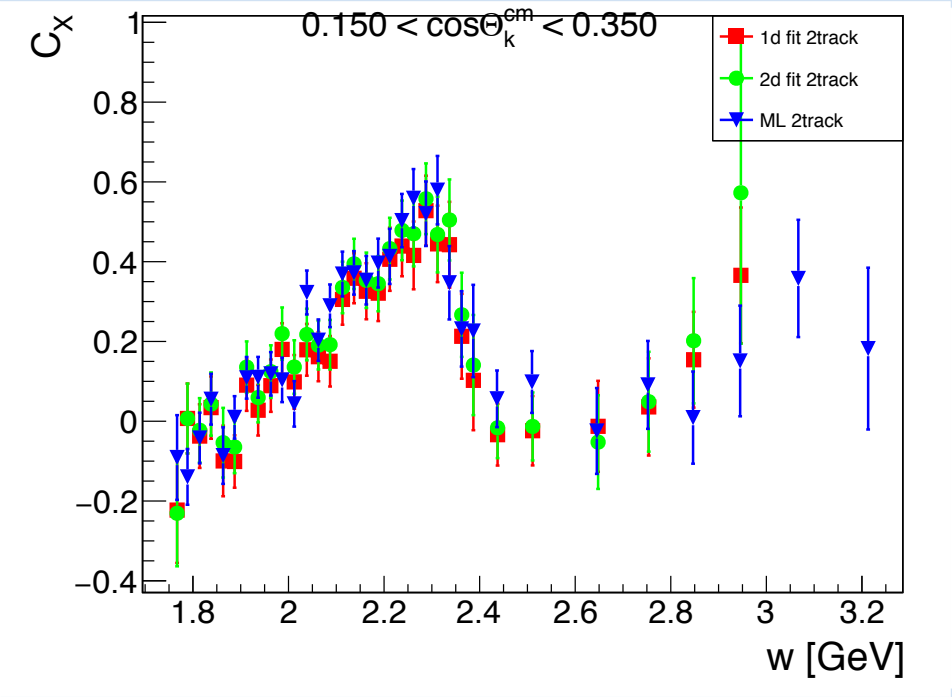
$$f(\cos\theta^p_x, \cos\theta^p_z) = (1 + \alpha P_\circ (C_x \cos\theta^p_x + C_z \cos\theta^p_z))$$

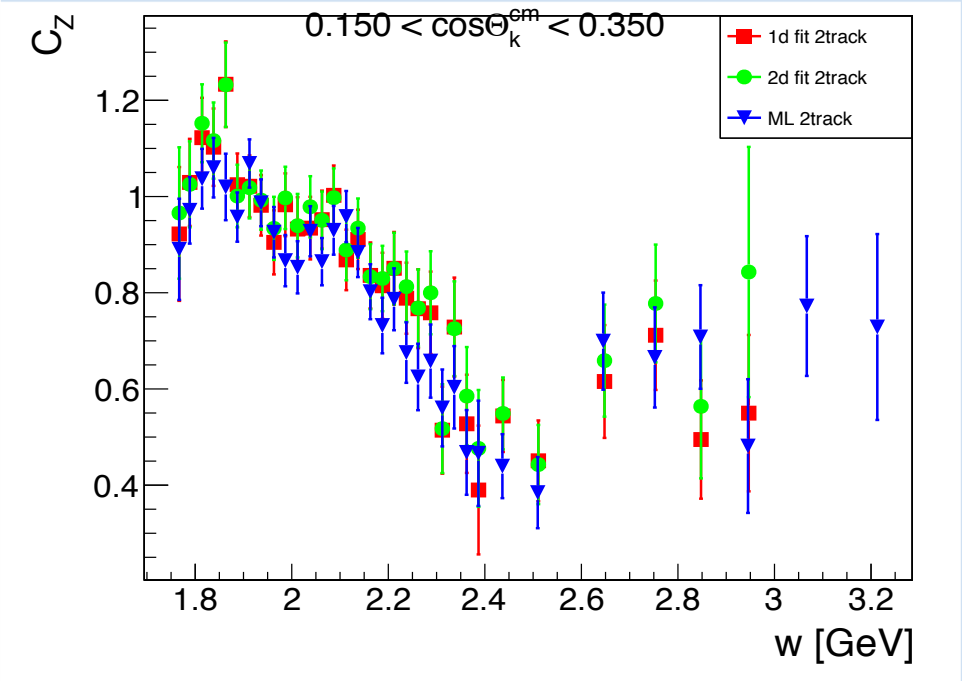
$$L(C_x, C_z) = \prod_{i=1}^n f(\cos\theta^p_x, \cos\theta^p_z)$$

  - Minimize negative log likelihood to fit the data;

$$l = -\sum_{i=1}^n \log f(\cos\theta^p_x, \cos\theta^p_z)$$

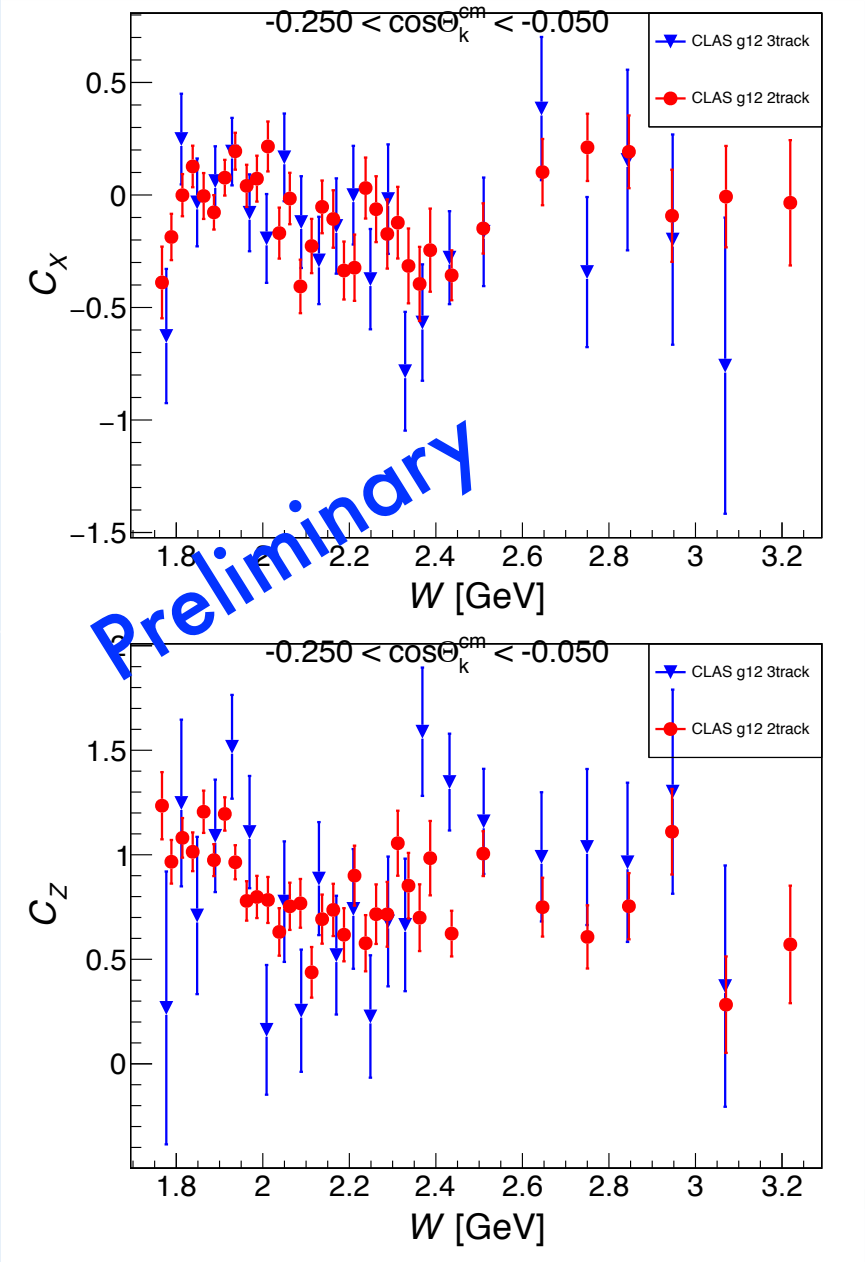
Comparision of 3 methods





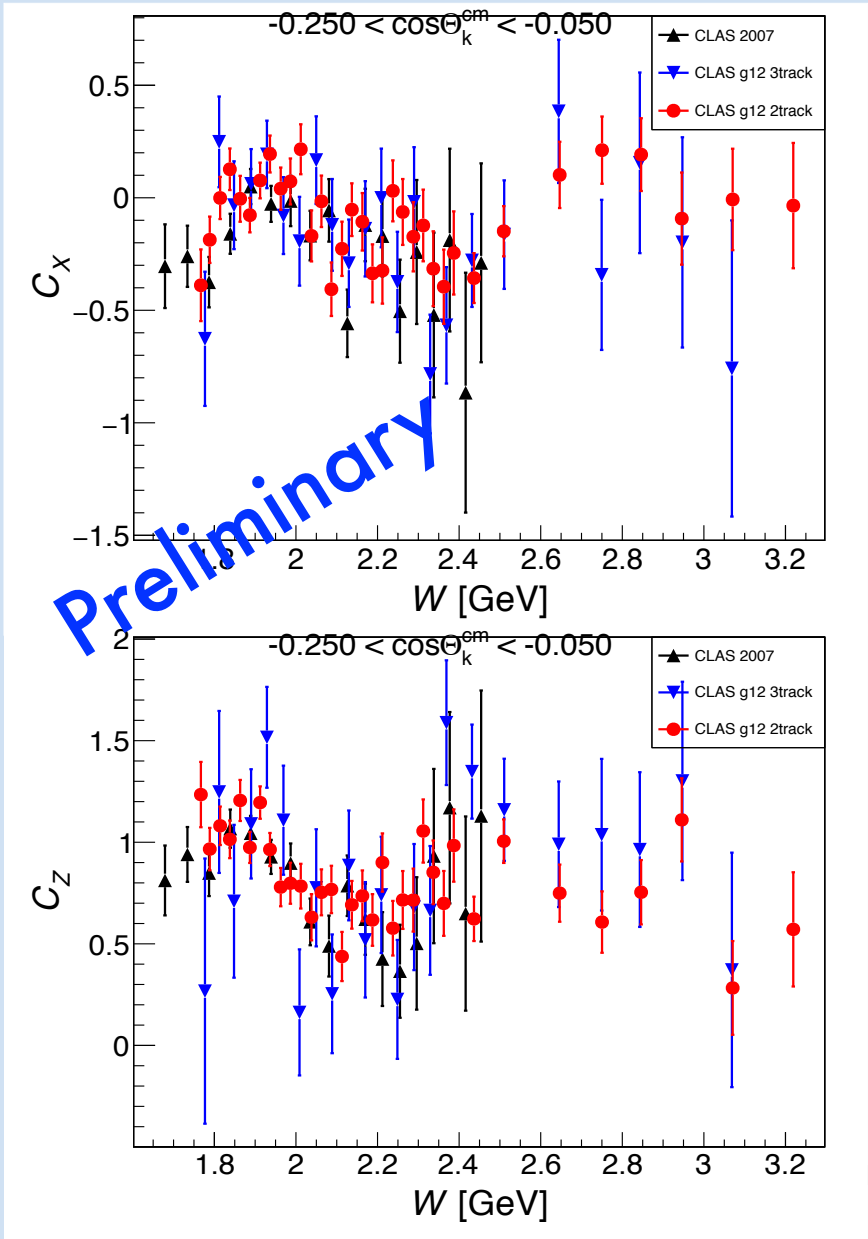
- Shows excellent agreements. Later showing results only for maximum likelihood method.
- Why ML? applicable even with low statistics/bin.

Comparision between 2 topology: C_x,C_z



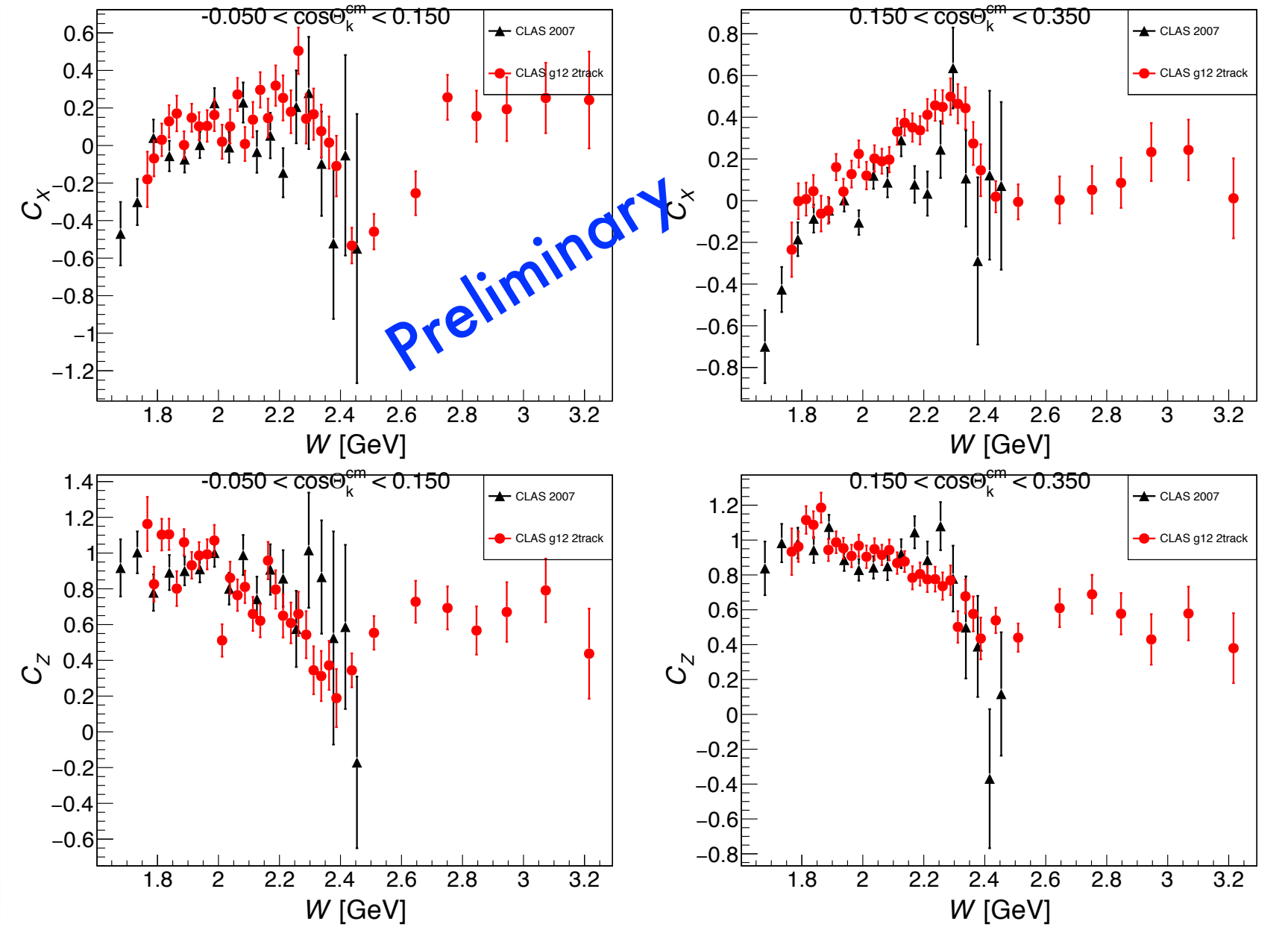
- Comparing 2 and 3 track:
  - High statistics for 2 track
  - Small statistical uncertainity
  - Self consistent between 2 topology.

Comparision with CLAS (2007): C_x,C_z

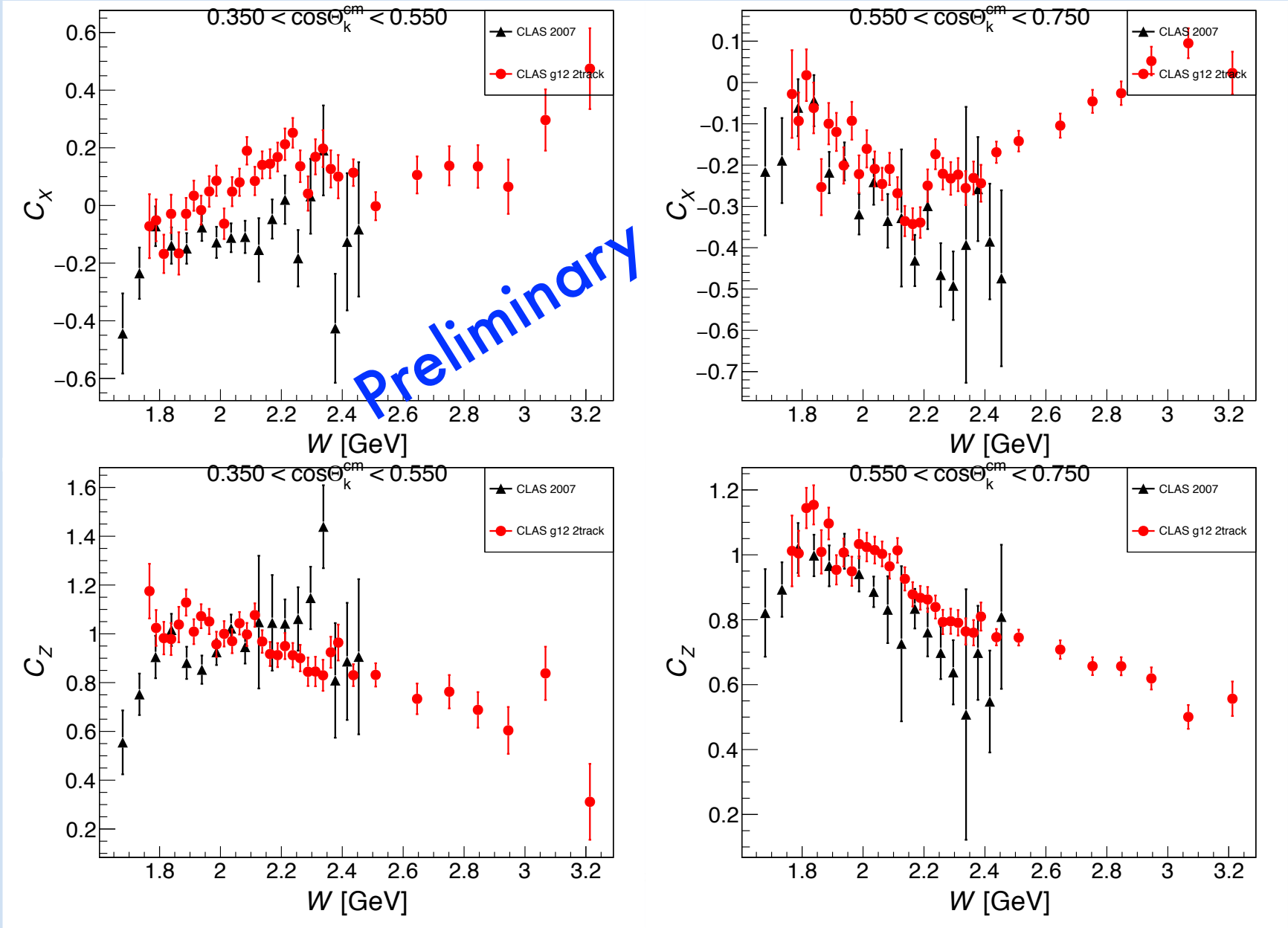


- Comparing 2 and 3 track:
  - High statistics for 2 track
  - Small statistical uncertainity
- Comparing 2, 3 track with CLAS (2007) results:
  - Much more statistics than previous measurement.
  - 2 track topology has smaller statistical uncertainity.
  - Good agreements.
- Higher kinematic coverage:
  - Include results W > 2.6 GeV.

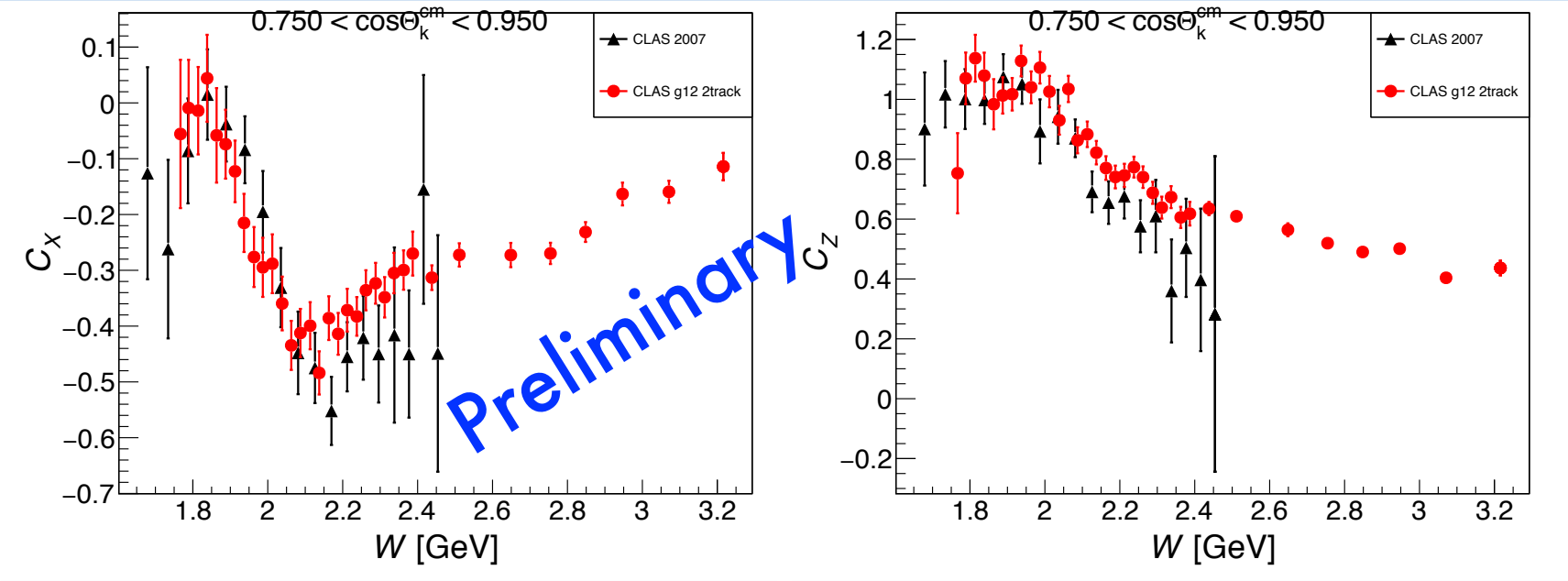
C_x, C_z cont…


-0.050 < cosΘ$_k^{cm}$ < 0.150
0.150 < cosΘ$_k^{cm}$ < 0.350
CLAS 2007
CLAS g12 2track
C_x
C_z
W [GeV]
Preliminary

C_x, C_z cont…


0.350 < cosΘ$_k^{cm}$ < 0.550
0.550 < cosΘ$_k^{cm}$ < 0.750
CLAS 2007
CLAS g12 2track
C_x
C_z
W [GeV]
Preliminary

C_x, C_z cont… P?

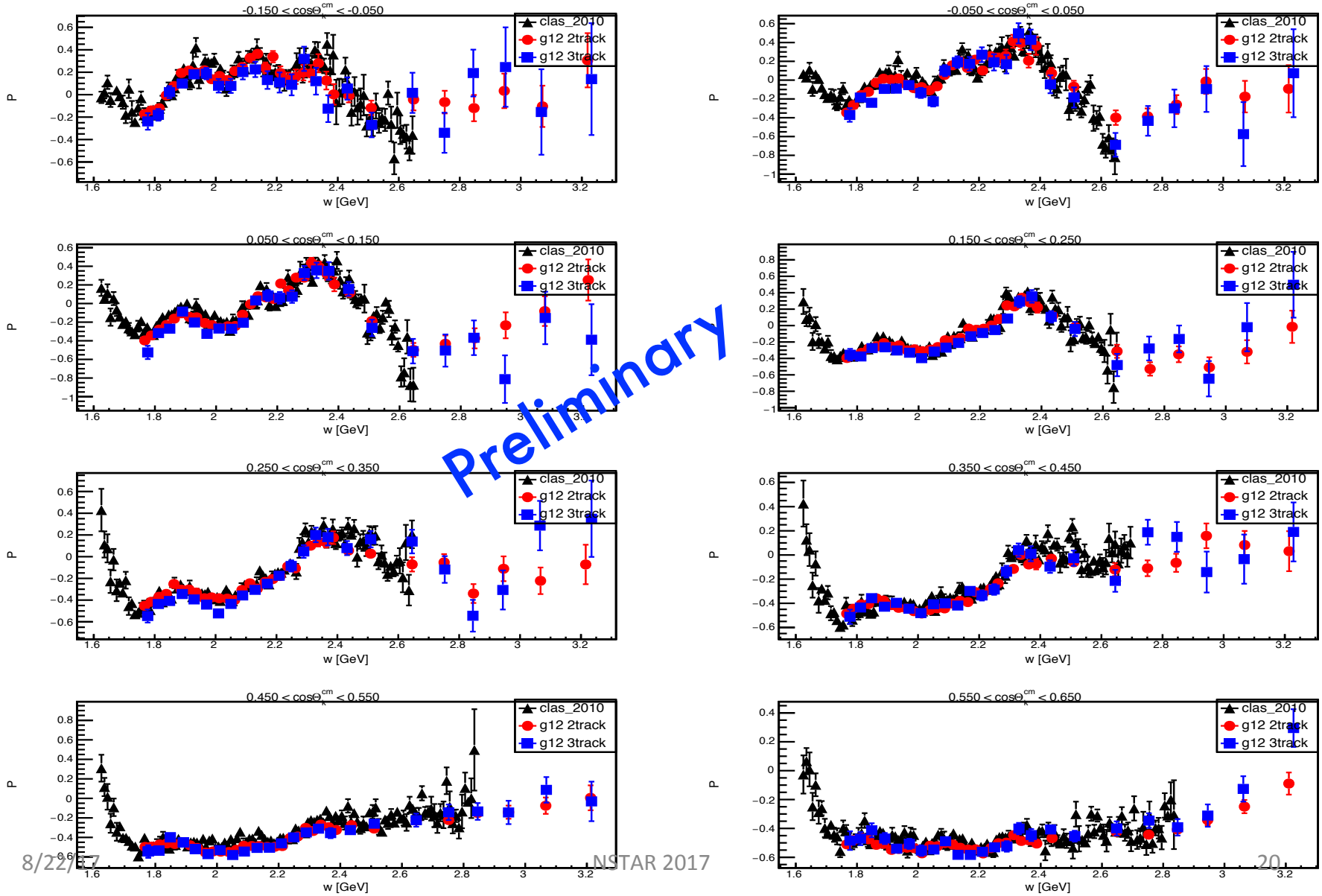


Induced Polarization of Λ → *P*

- Independent with photon beam polarization.
- Measure simultaneously with C_x *and* C_z *using ML*.

$$f(\cos\theta_x^p, \cos\theta_y^p, \cos\theta_z^p) = (1 + \alpha P \cos\theta_y^p + \alpha P_\circ (C_x \cos\theta_x^p + C_z \cos\theta_z^p))$$

P comparision with CLAS (2010)



Conclusion and Outlook

- Measured Λ polarization observables C_x, P and C_z using g12 dataset for $1.75 < W < 3.3$ GeV.
  - 3 method: 1d/2d/ML methods, all showing consistent results.
  - 2 topologies analyzed: results are mostly self-consistent.

- Preliminary C_x/C_z results:
  - Statistical uncertainty are smaller than previous g1c results for w < 2.6 GeV.
  - In the good agreement with earlier CLAS results.
  - First time measurement for $W > 2.6$ GeV.
  - ❖ Preliminary P results:
  - Agree well with CLAS 2010 results.
  - ❖ Can be used to constrain non-resonant (t-channel) contribution.

Thank You!

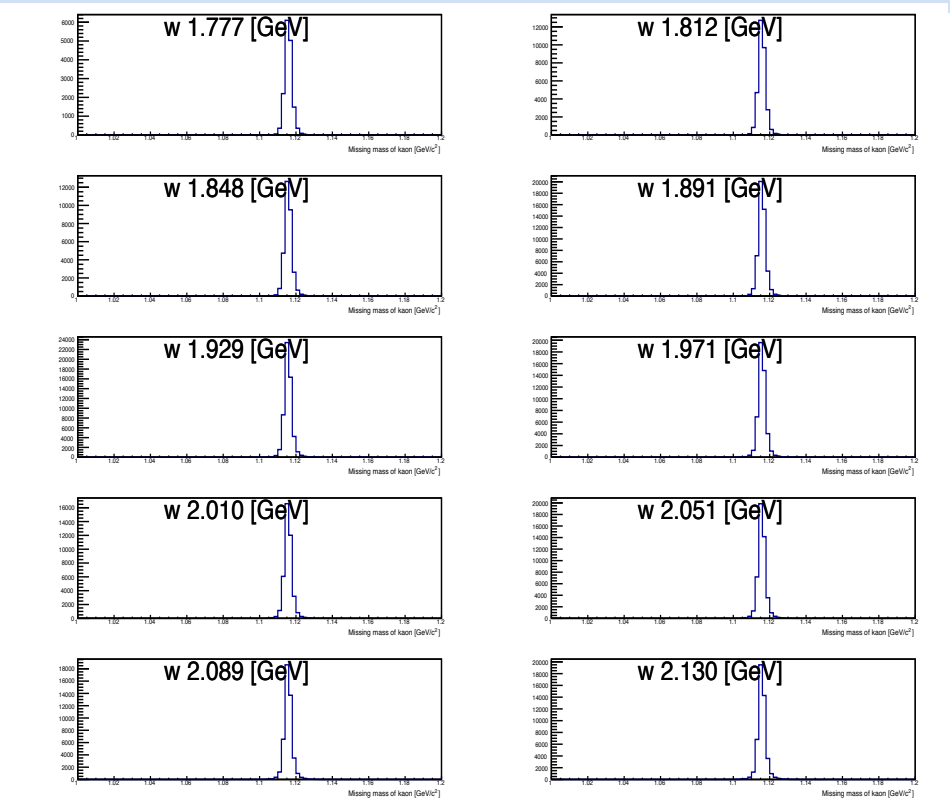
Energy dependent mass distribution for $K^+p\pi^-$ vs $K^+p(\pi^-)$

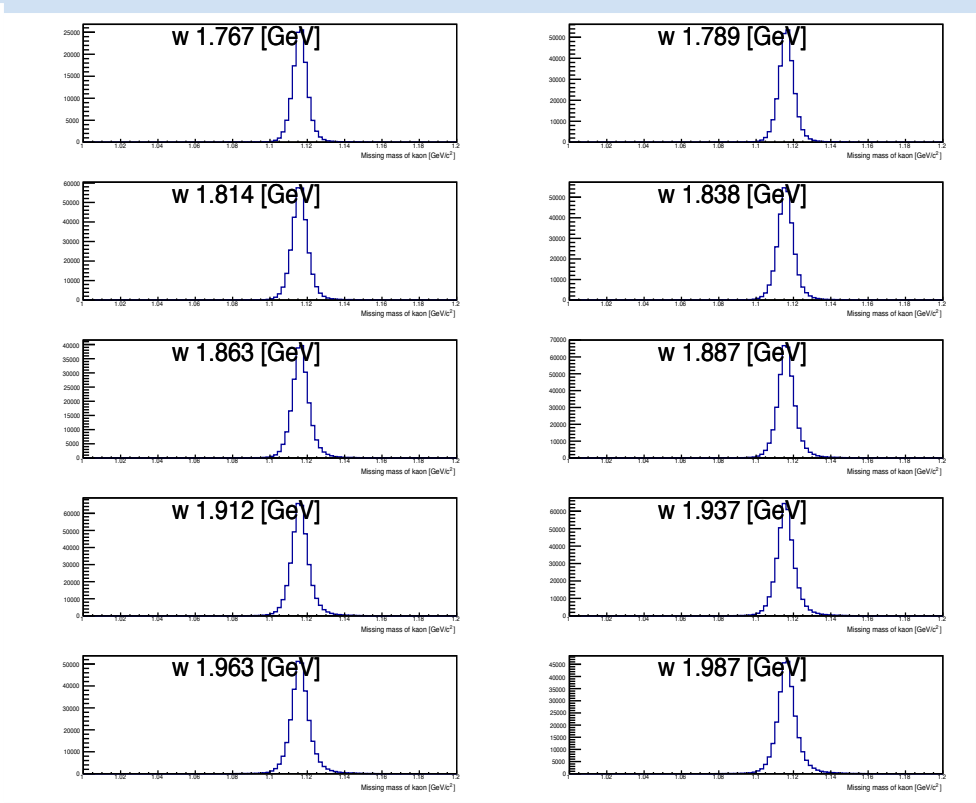
Binning: $K^+p\pi^-$ | $K^+p(\pi^-)$

w[1.75, 2.4) = 16 | **w[1.75, 2.4) = 26**

w[2.4,3.3] = 8 | **w[2.4,3.3] = 8**

Missing mass of kaon.





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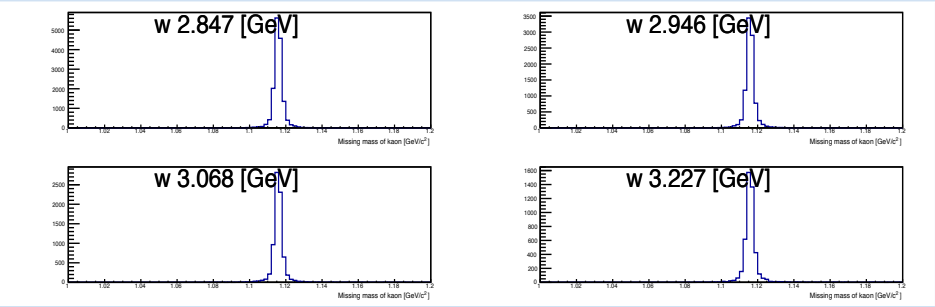
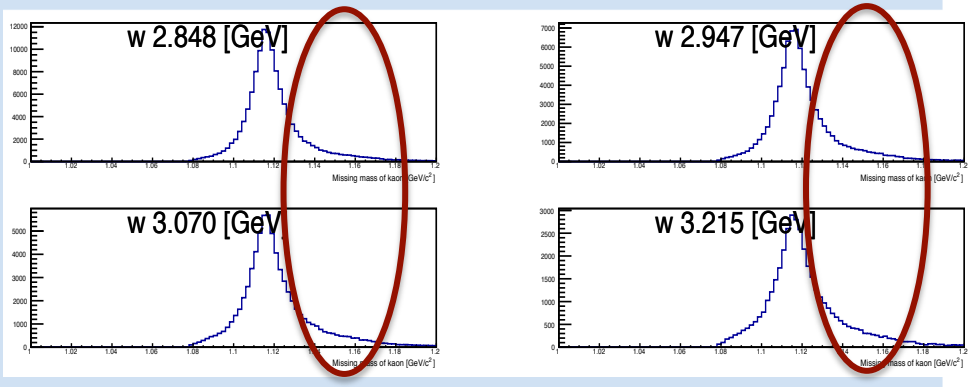
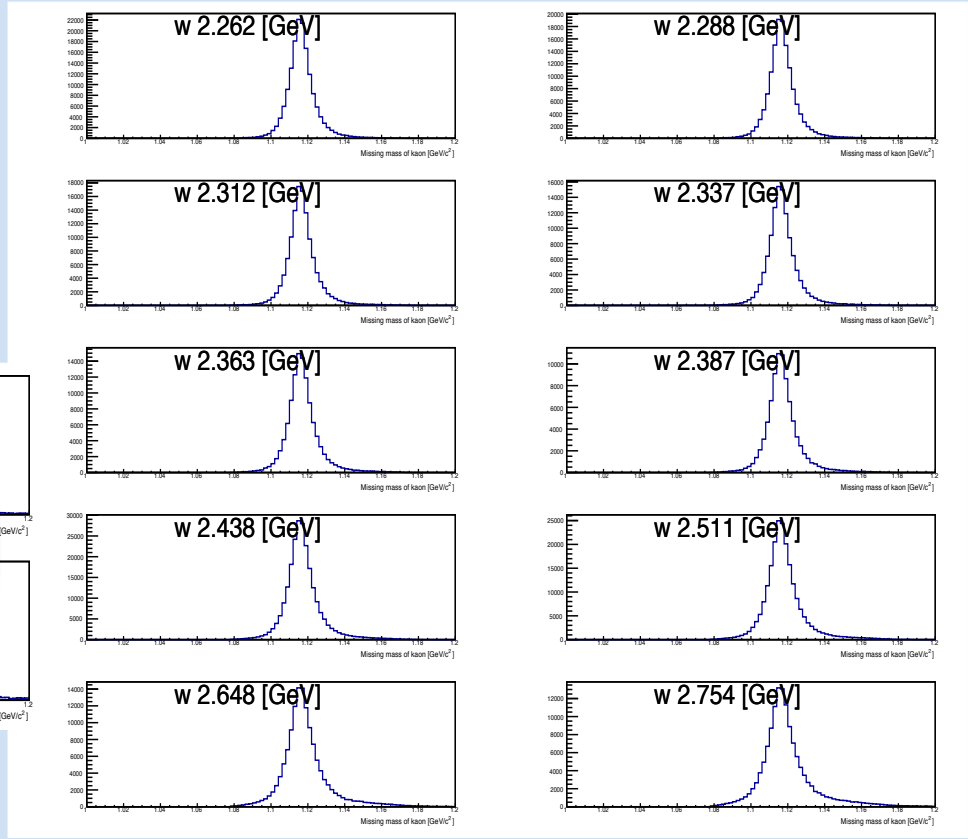


High energy mass distribution
top; 3track, bottom; 2track



Future work: Background substraction



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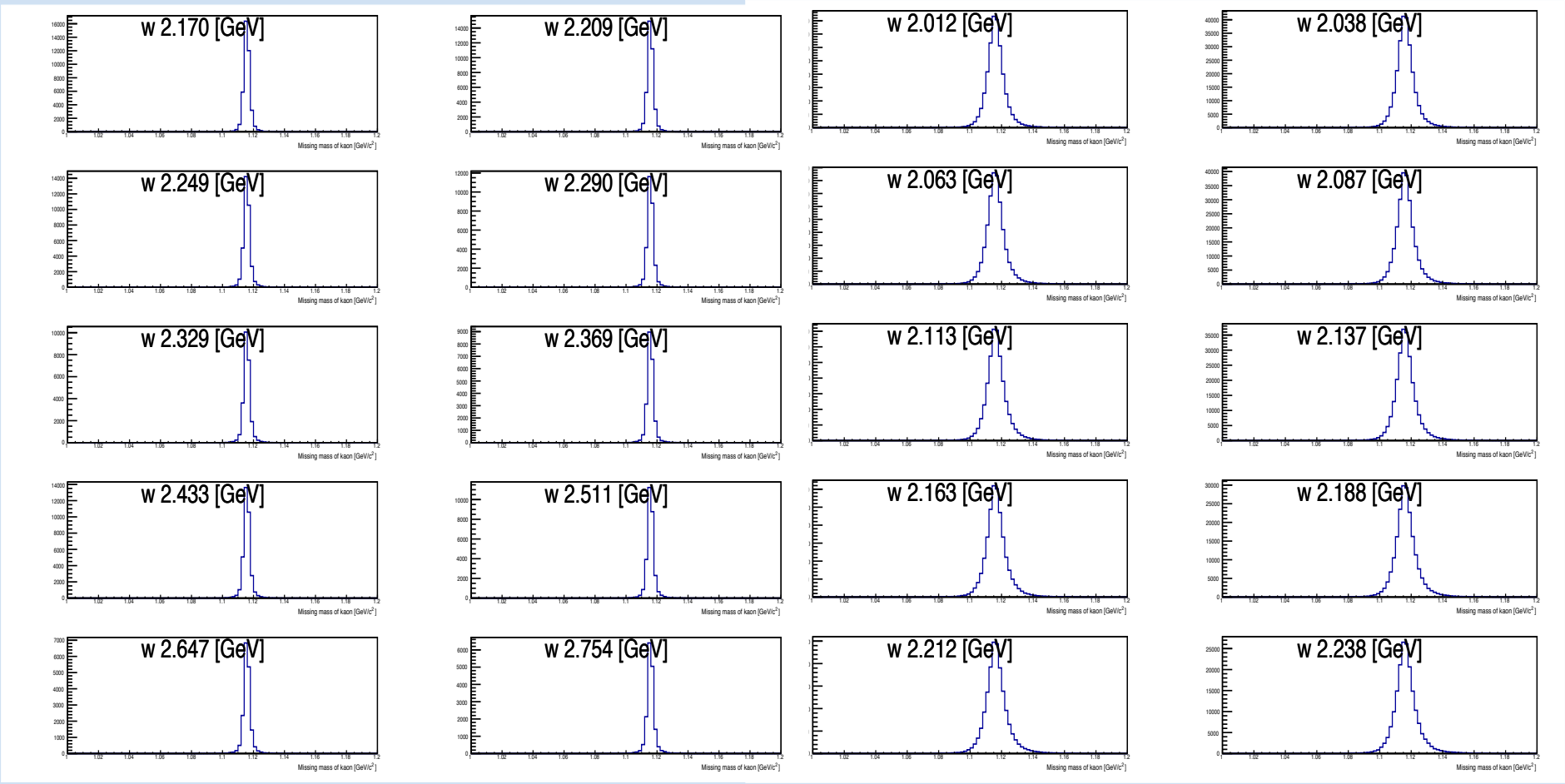
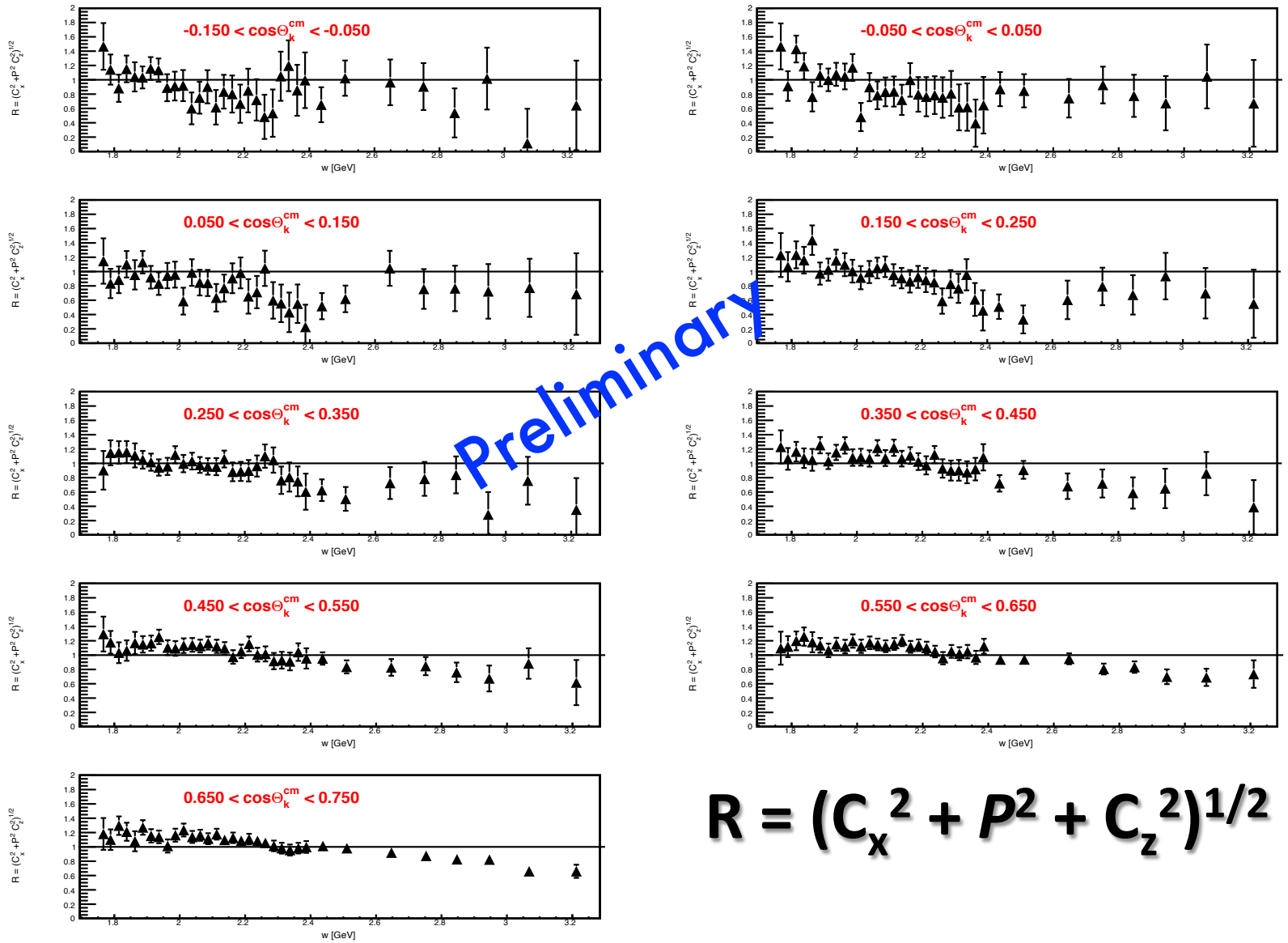


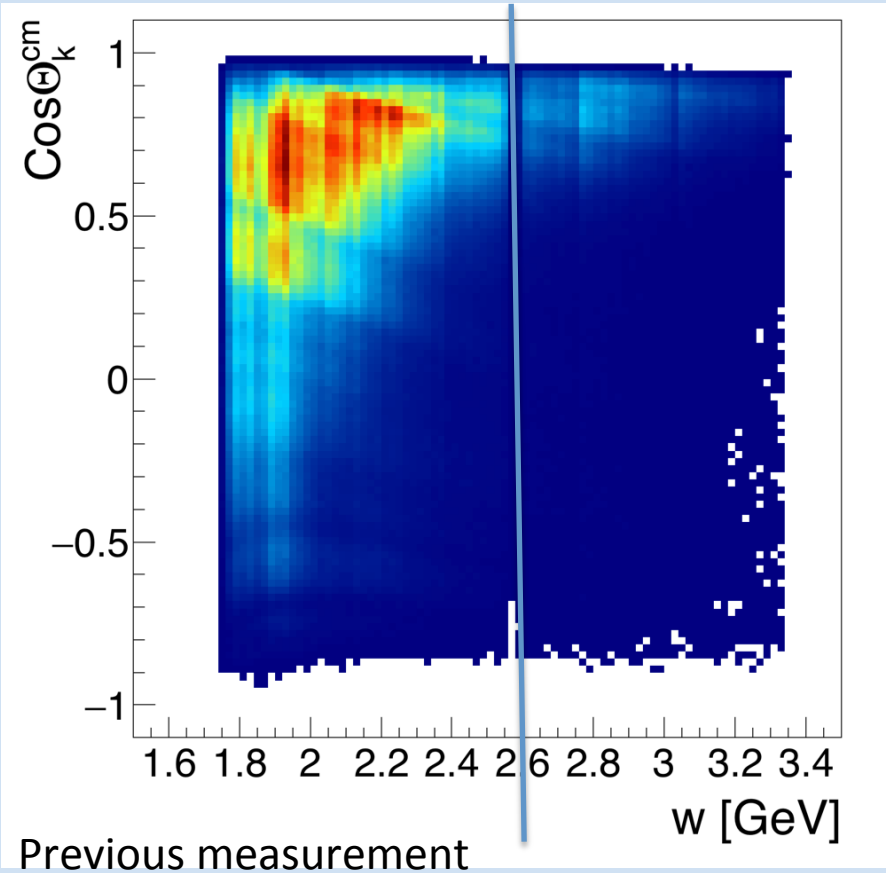
R values for the Λ



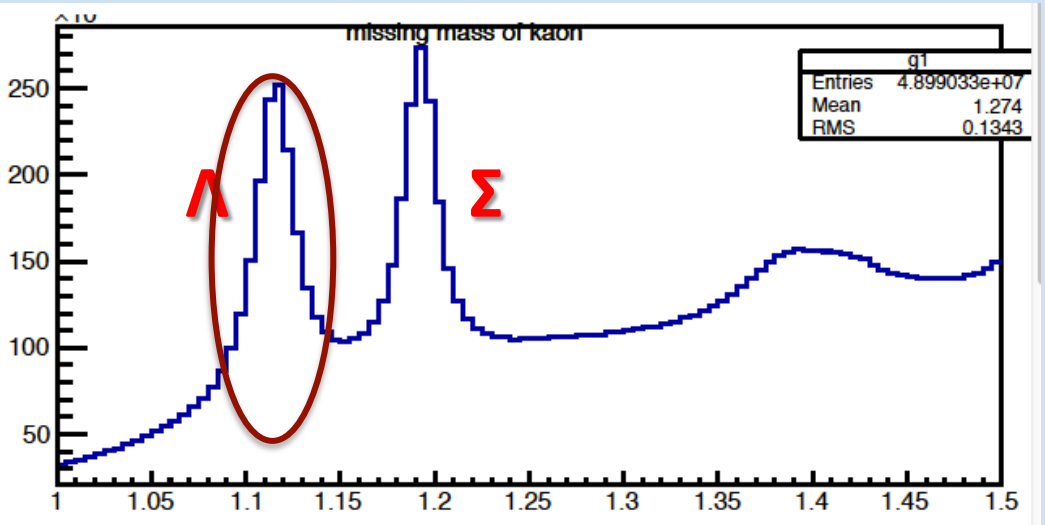
$$R = (C_x^2 + P^2 + C_z^2)^{1/2}$$

Kinematic Coverage

- 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.
- Able to extract polarization observables w > 2.6 GeV, where previous measurements are missing.
- Higher energies measurement helps us to constrain non-resonant contribution.

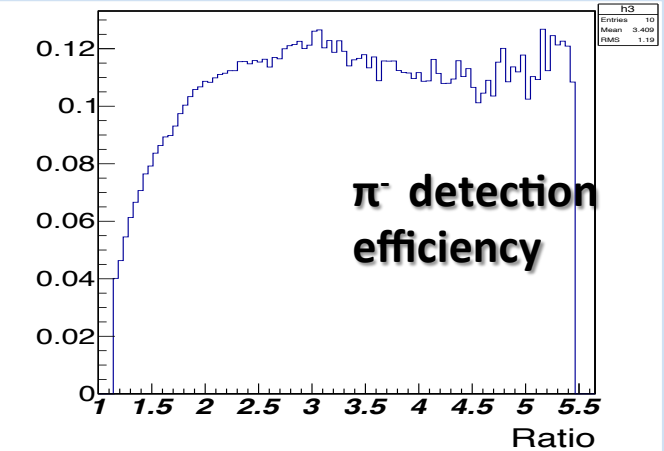


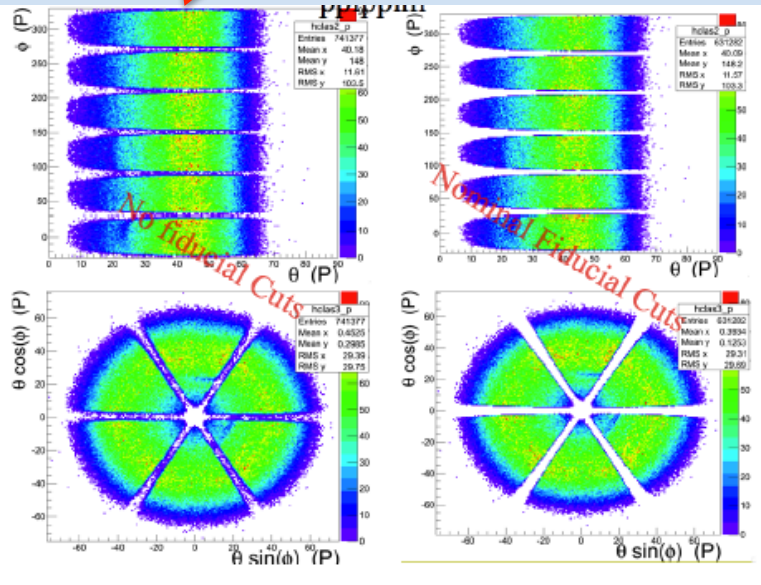
Data Analysis



Selection criteria:
-> Events need to produce from target.
-> Remove events outside physical region of detector.

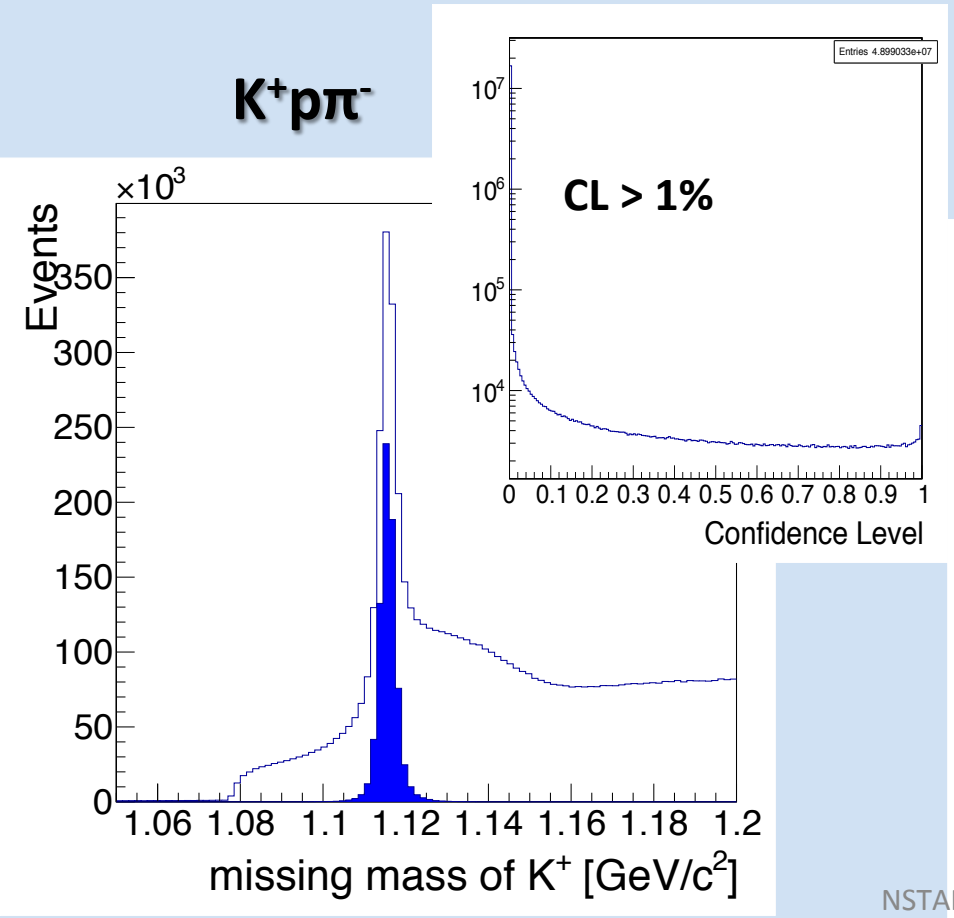
❖ Two sets of topology:
$K^+p\pi^-$ (3track), $K^+p(\pi^-)$ (2track)

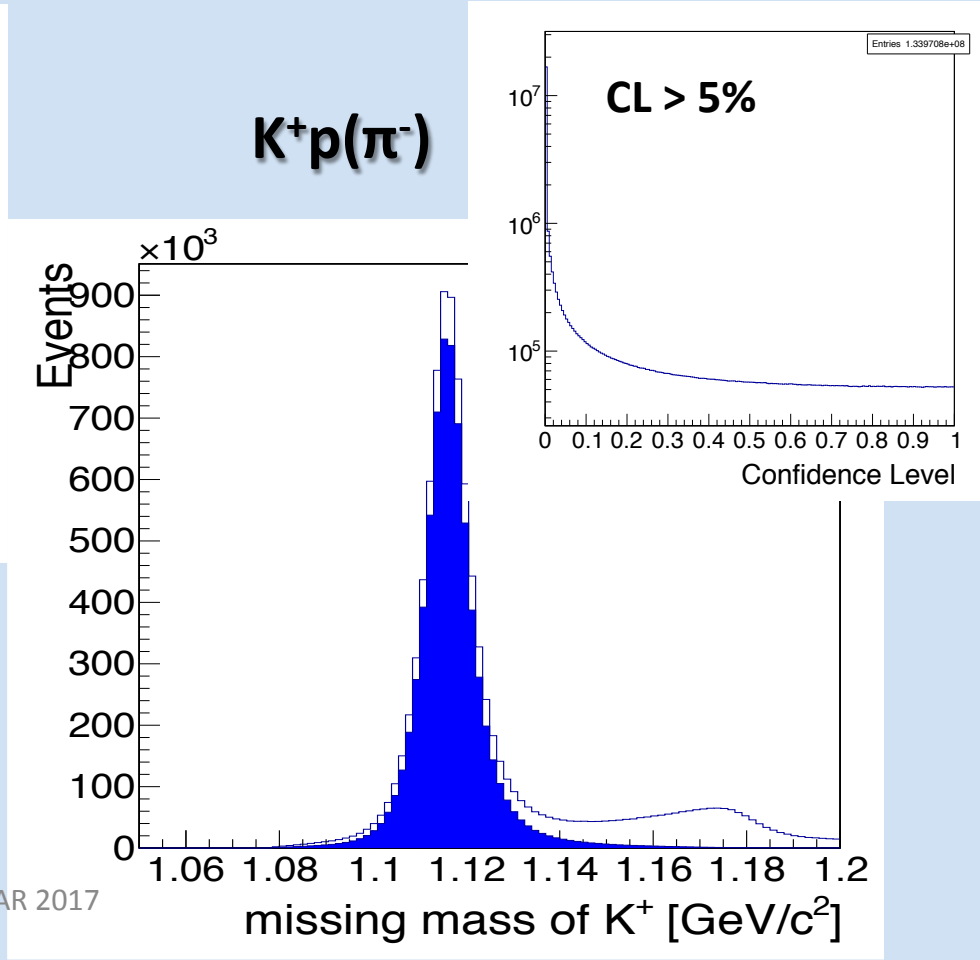




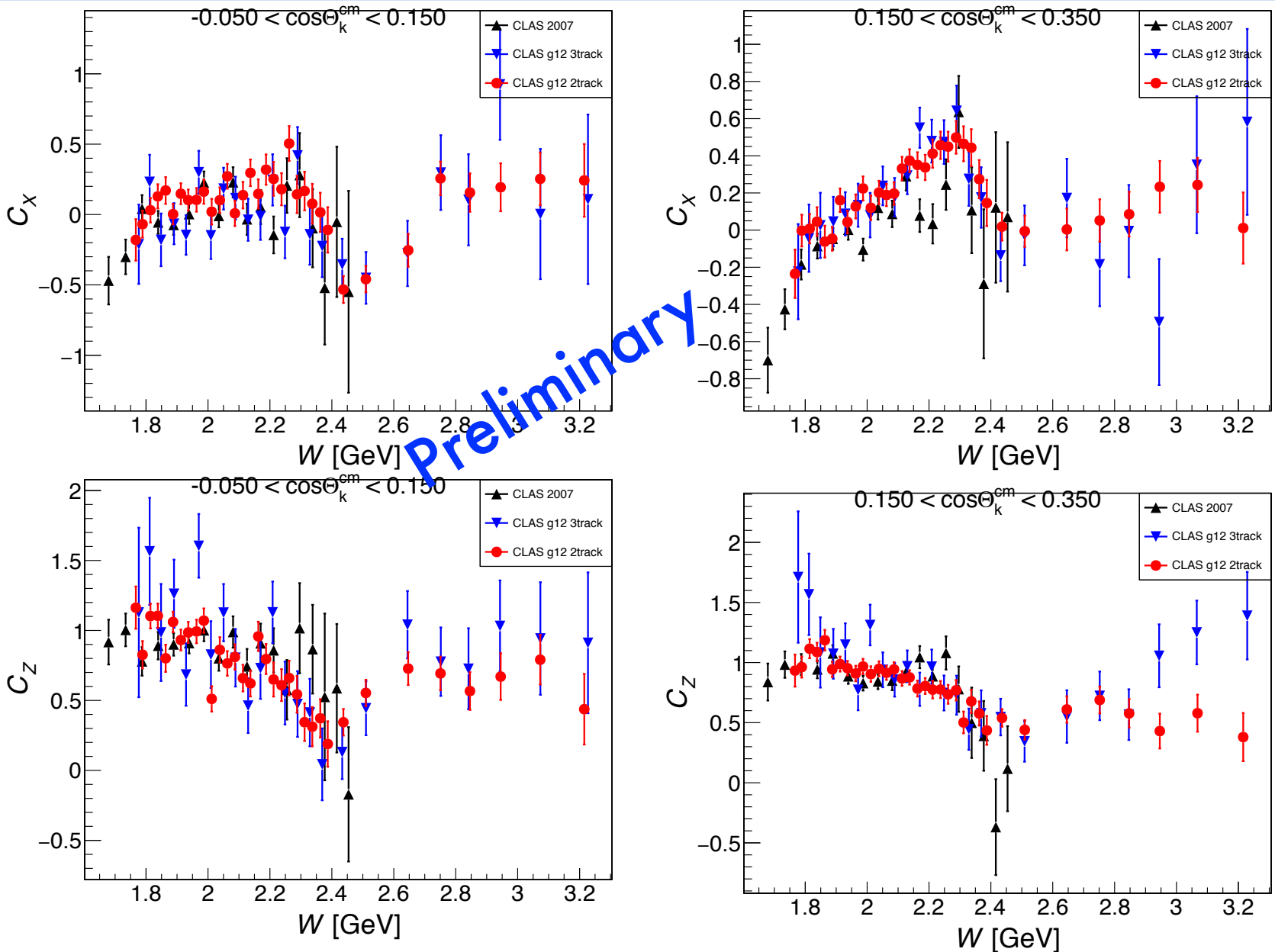
Event Selection

- Ue Momentum and energy along with info. of detector.
- Two hypothesis: $K^+p\pi^-$, $K^+p(\pi^-)$





C_x, C_z cont…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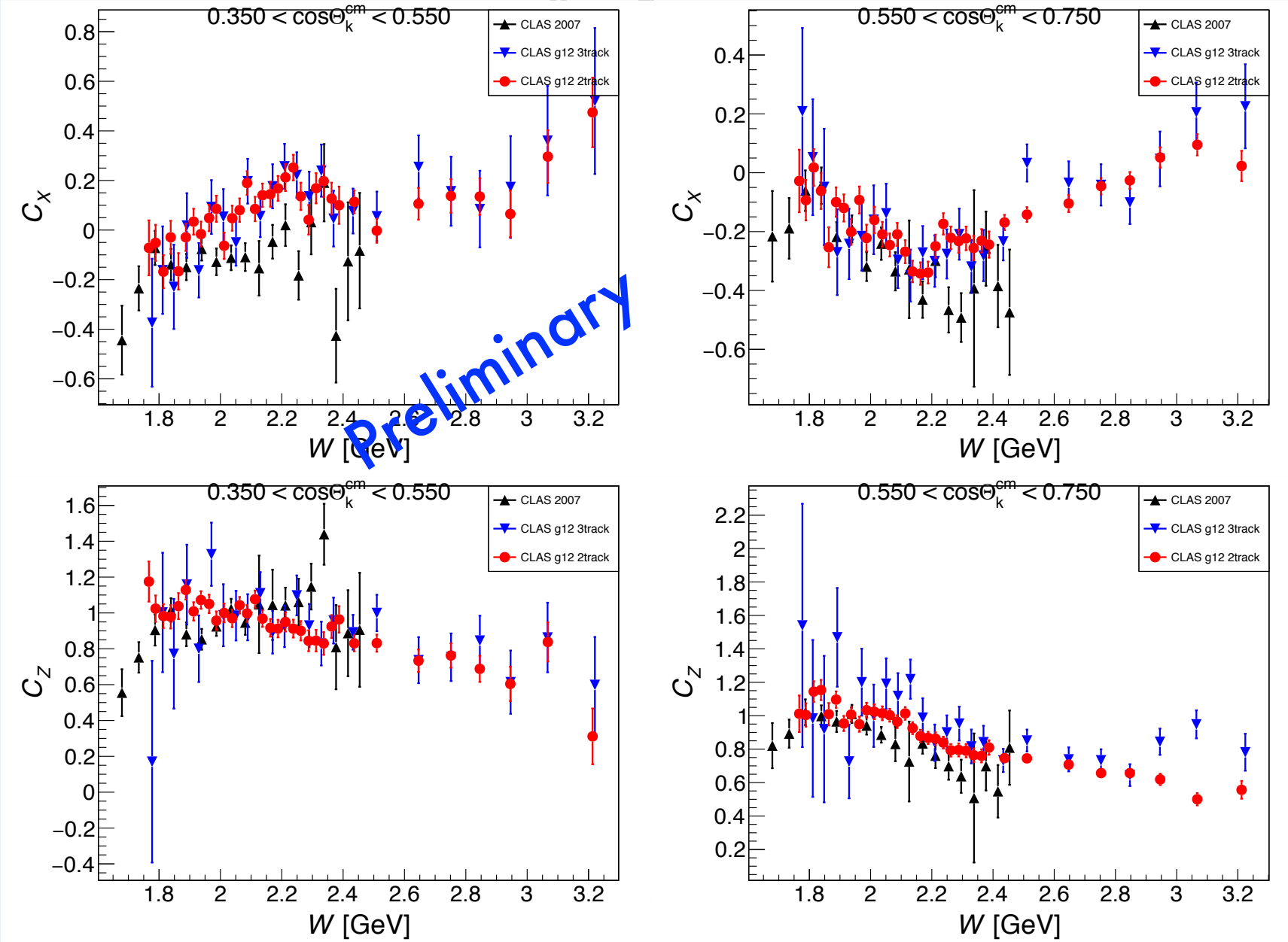
0.150 < cosΘ$_k^{cm}$ < 0.350
CLAS 2007
CLAS g12 3track
CLAS g12 2track
C_X
C_Z
W [GeV]
Preliminary

C_x, C_z cont…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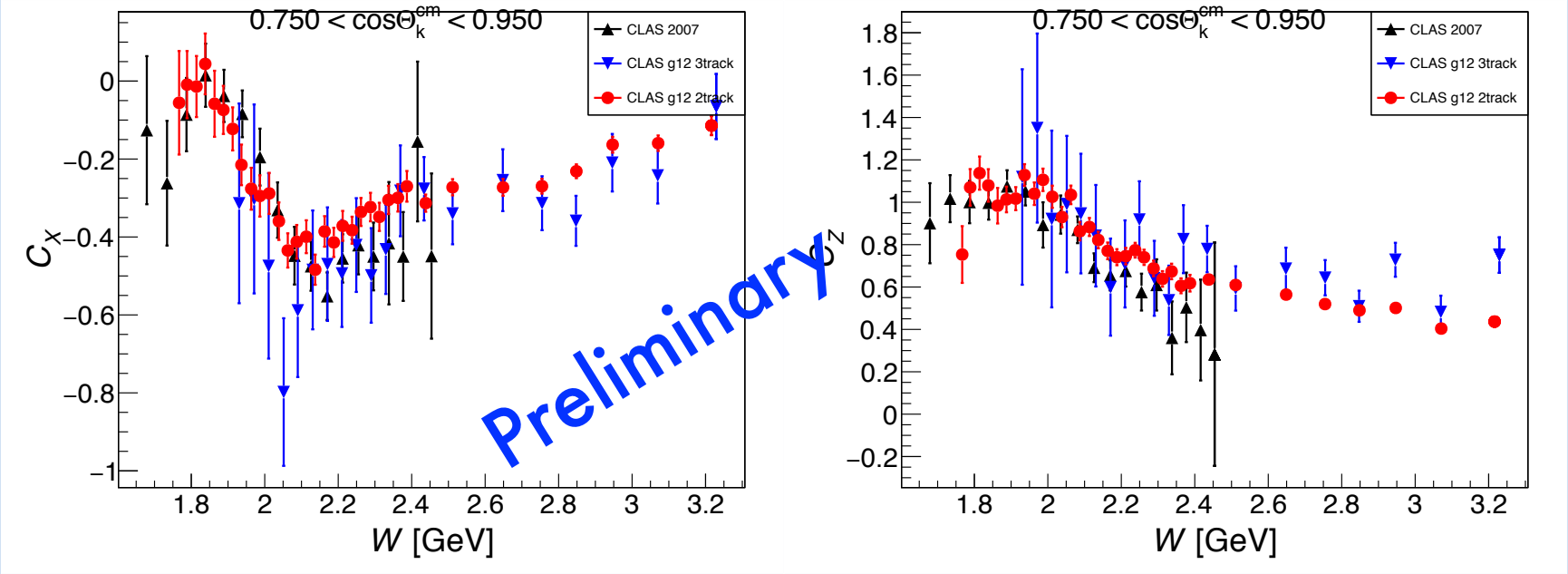

Induced Polarization of Λ → *P*

- Independent with photon beam polarization.
- Measure simultaneously with C_x *and* C_z *using ML*.

$$f(\cos\theta_x^p, \cos\theta_y^p, \cos\theta_z^p) = (1 + \alpha P \cos\theta_y^p + \alpha P_\circ (C_x \cos\theta_x^p + C_z \cos\theta_z^p))$$