Measurement of polarization observables for Lambda hyperon in the $\gamma p \rightarrow K^+ \Lambda$

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Outline

- Motivation
- Experiment
- Data analysis
- Preliminary results for C_x, C_z and P.
- Conclusion and outlook.

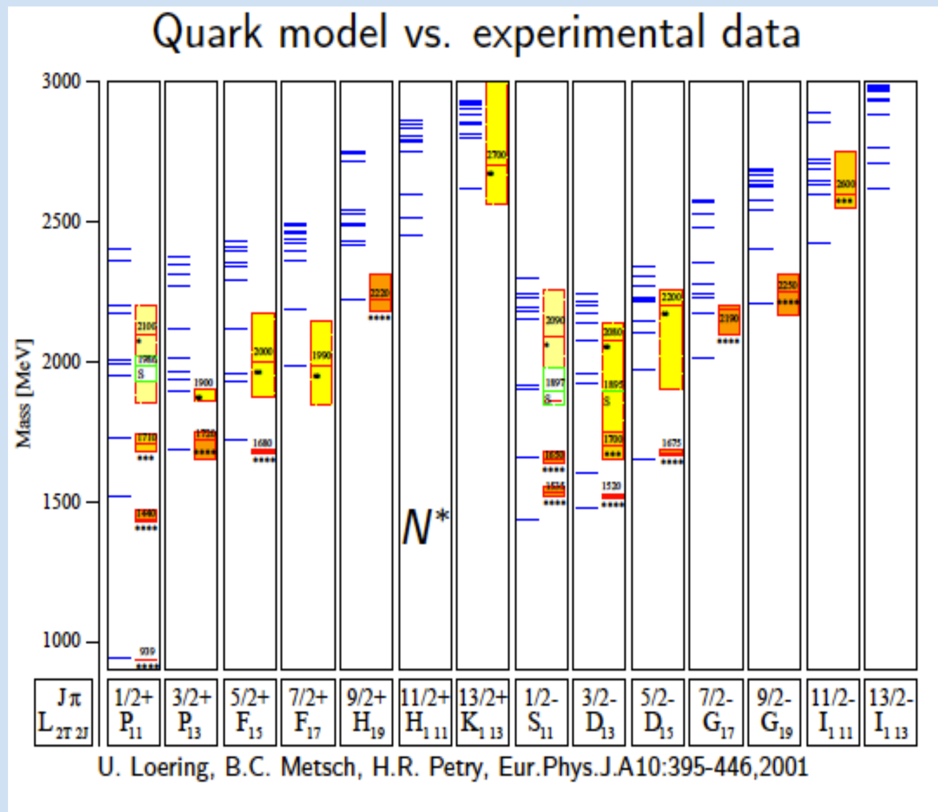
Introduction

- ❖ Study of the **baryon resonances** are important to understand the fundamental degrees of freedom inside hadrons.
- ❖ Missing Baryon Problem:
  - a lot of predicted resonances from models (Quark, Lattice etc.) are not observed yet.

**** Existence is certain
*** Existence is very likely
** Evidence of existence is only fair.
* Evidence of existence is poor.

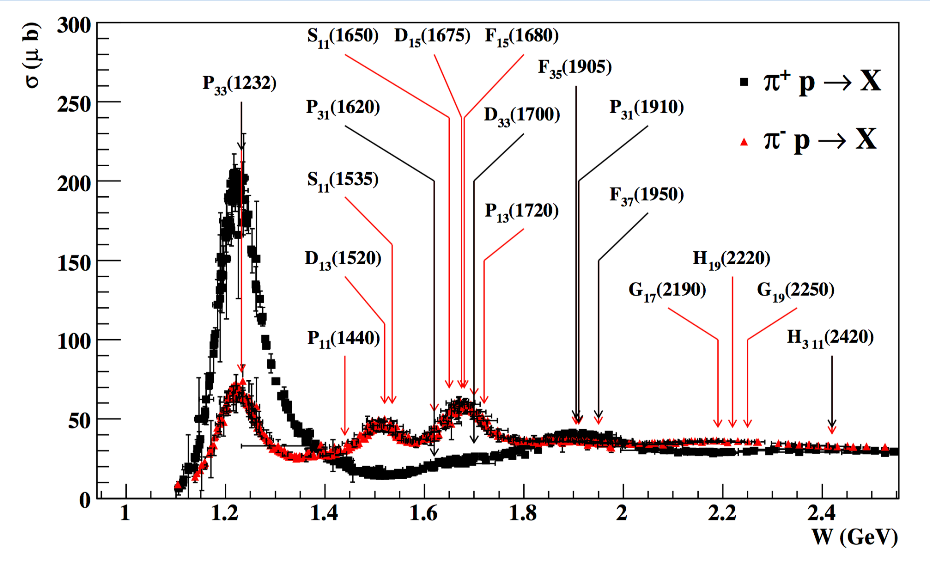
PDG rating for N^*

		overall
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+	**



Motivation

- Pion beams was the primary tool to study resonances.
- Not all resonances couple strongly to the Nπ channel.
- Interference of states:
  Resonances are broad and overlapping, possible interference between *N* and *Δ* states.



- $K^+\Lambda$ channel is important that;
  - only contribute to *N** with I = 1/2.
  - Λ -> $p\pi^-$, self-analyzing nature of Λ hyperon allow us to measure polarization observables from its decay products.
- Polarization observables are sensitive to interference from different states.

Polarization Observables

- Meson photoproduction describes by 4 complex amplitudes that includes 16 spin observable.

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

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

For the case of circularly polarized photon beam and polarized hyperon:

Transferred polarization from circularly polarized photon beam

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

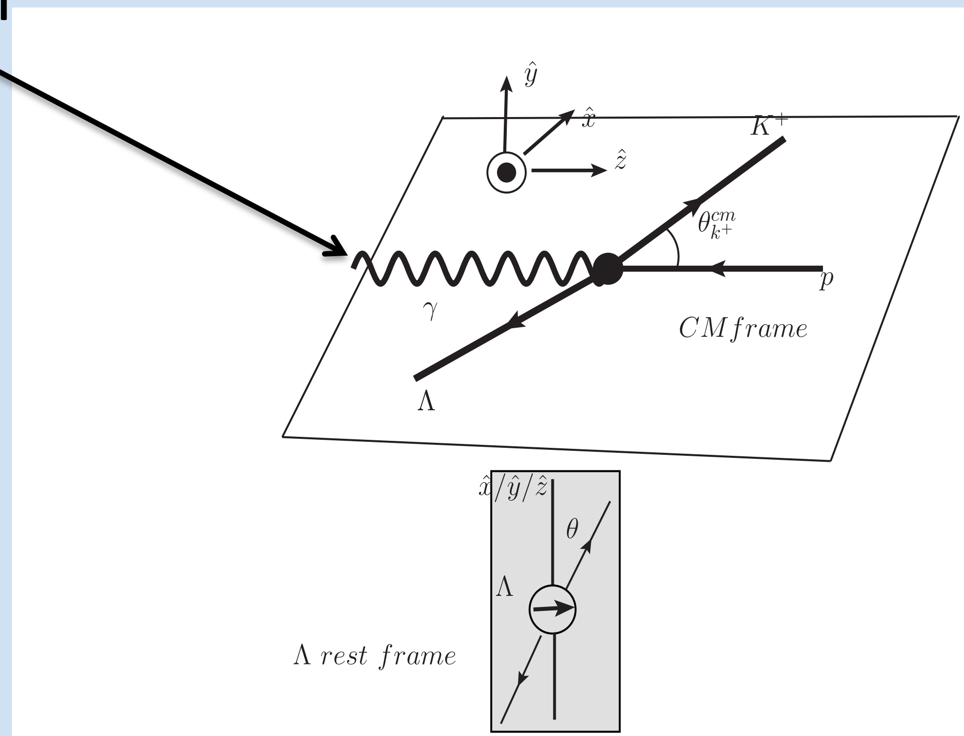
recoil hyperon polarization

P_{beam} : Photon beam polarization

C_x, C_z and P observables

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

Circularly polarized real photon



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

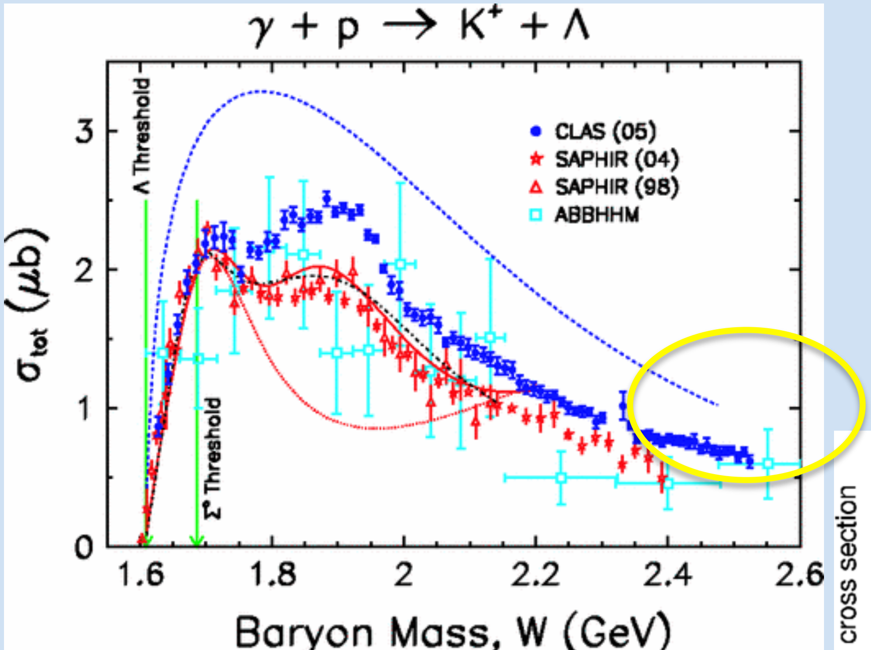
$$\hat{y} = \frac{\hat{p}_\gamma \times \hat{p}_K}{|\hat{p}_\gamma \times \hat{p}_K|}$$

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

Measure polarization transfer from Υ to Λ in the production plane along "x" and "z" , and induced polarization perpendicular to production plane.

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

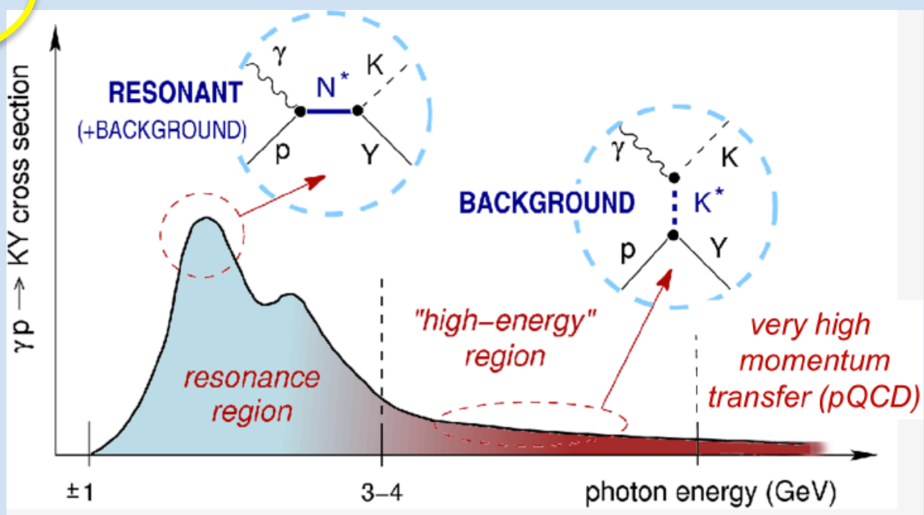
Experiment was in ELSA, JLAB, MAMI



Already verified existence of N(1900).

More data for Polarization observables are included.

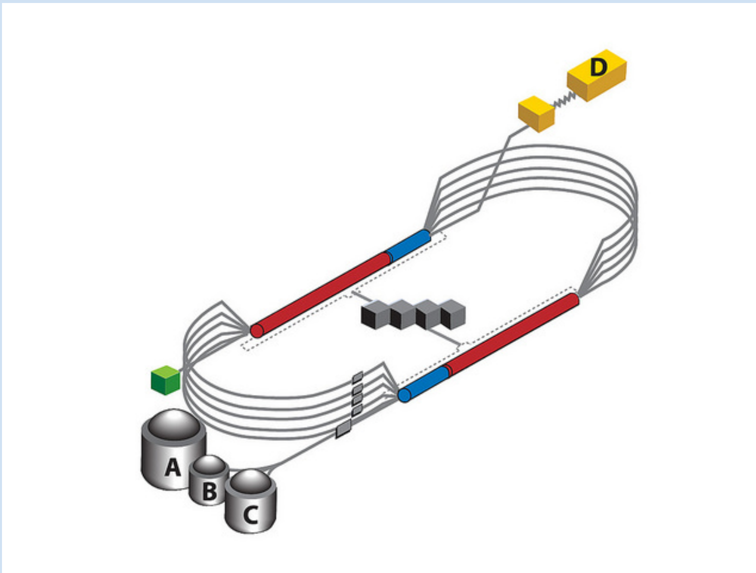
Suitable to study higher mass states.

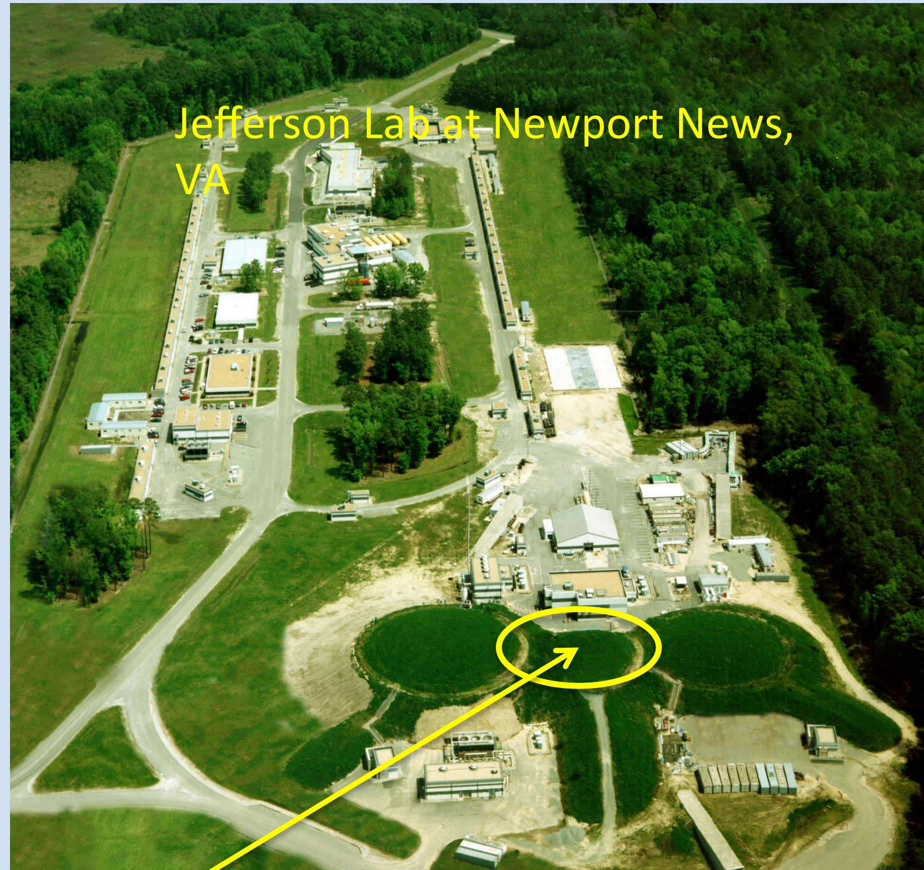


R. Bradford et al., Phys. Rev. C 73, 035202 (2006)

Can be used to constrain non-resonant (t-channel) contribution.

Jefferson Lab



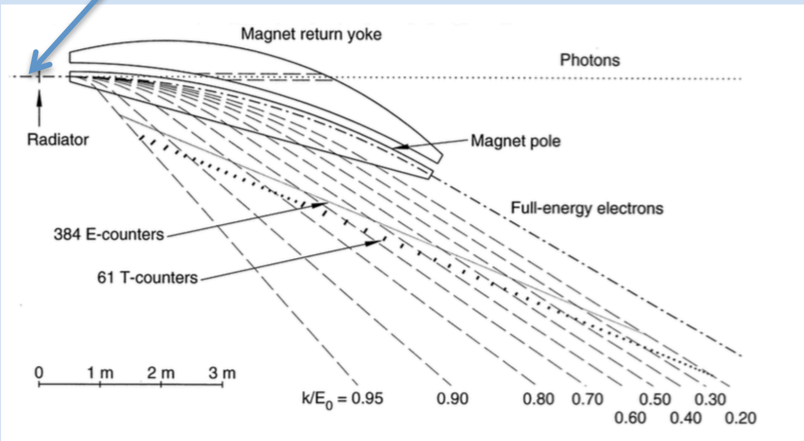


Hall B

Linear accelerator for Jlab.
-> Continuous electron beam.
-> 5.71 GeV
-> Delivered simultaneously to all halls.

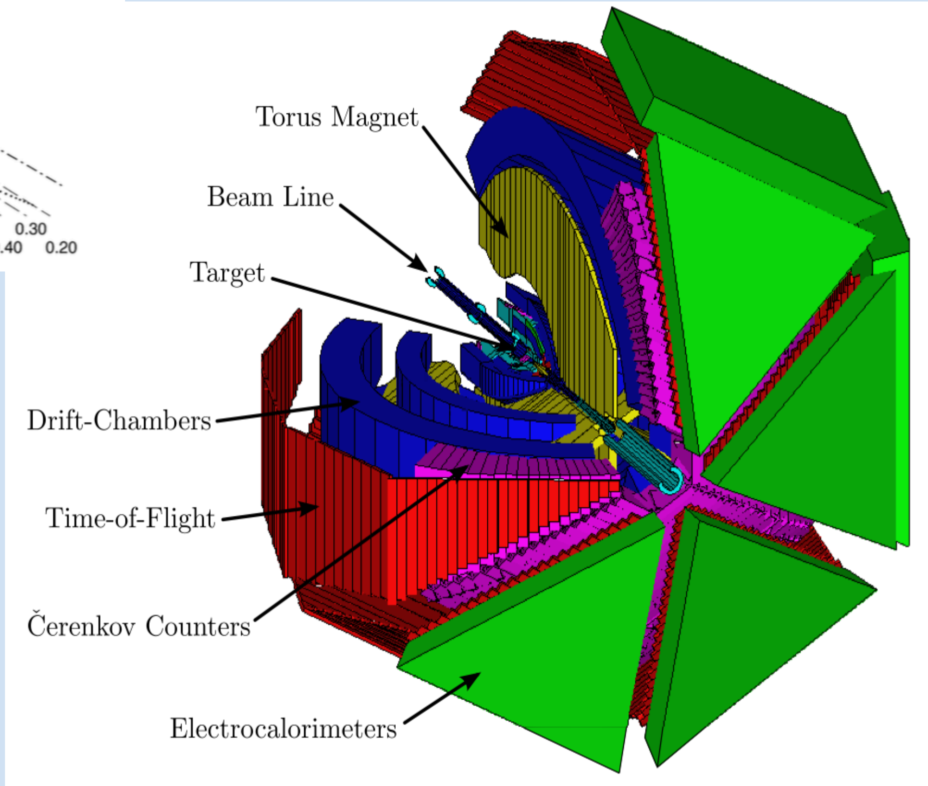
CEBAF Large Acceptance Spectrometer (CLAS)

60-65 nA electron beam (5.71 GeV)



Geometry of tagging system

Hall B detector



G12 experiment

- Photoproduction experiment; beam energy up to 5.45 GeV.
- Circularly polarized photon beam.
- 40 cm long unpolarized hydrogen target.

Data Analysis: Event selection

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

$$\Lambda \rightarrow p\pi^{-} \text{and } n\pi^{\circ} \text{with } 64\% \text{ and } 36\%.$$

Analysis done with two topologies;

3track $\gamma p \rightarrow K^{+} p \pi^{-}$

2track $\gamma p \rightarrow K^{+} p (\pi^{-})$

Selection;

a. $MM(K^{+}) < 1.4$ GeV

b. $MM^{2}(K^{+}p) < 300$ MeV and $MM^{2}(K^{+}p) > -300$ MeV

c. Photon selection timing cut

d. Vertex cut

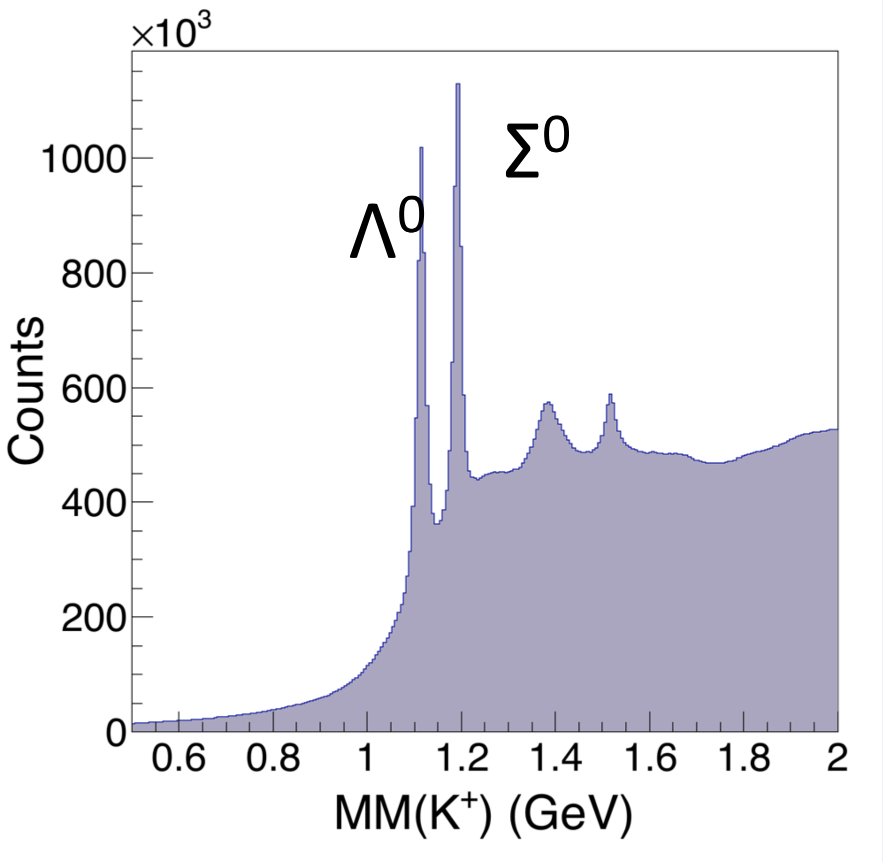
e. Fiducial cut

f. Time-of-flight knockout

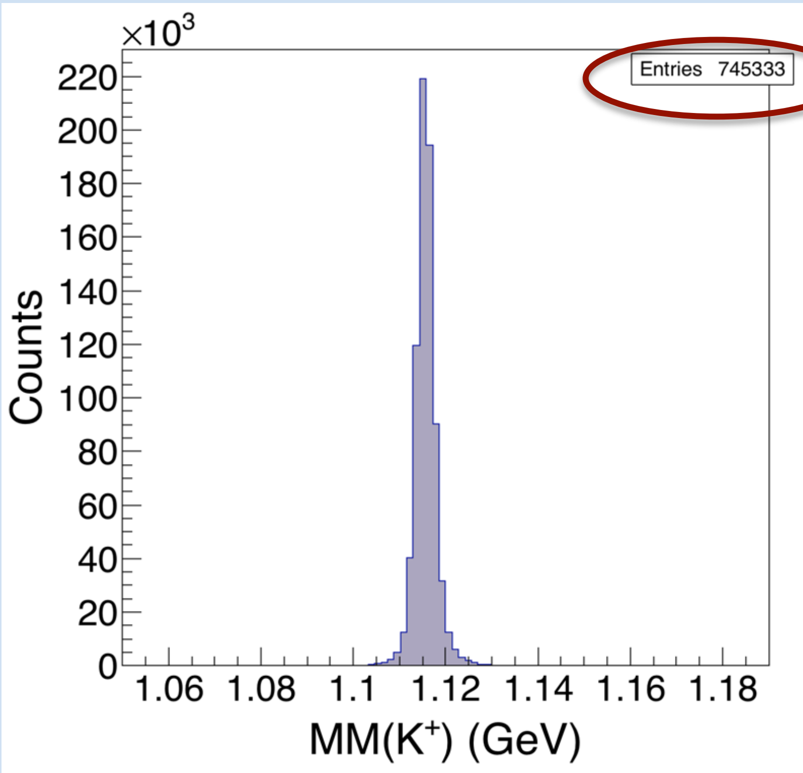
g. Kinematic fitting

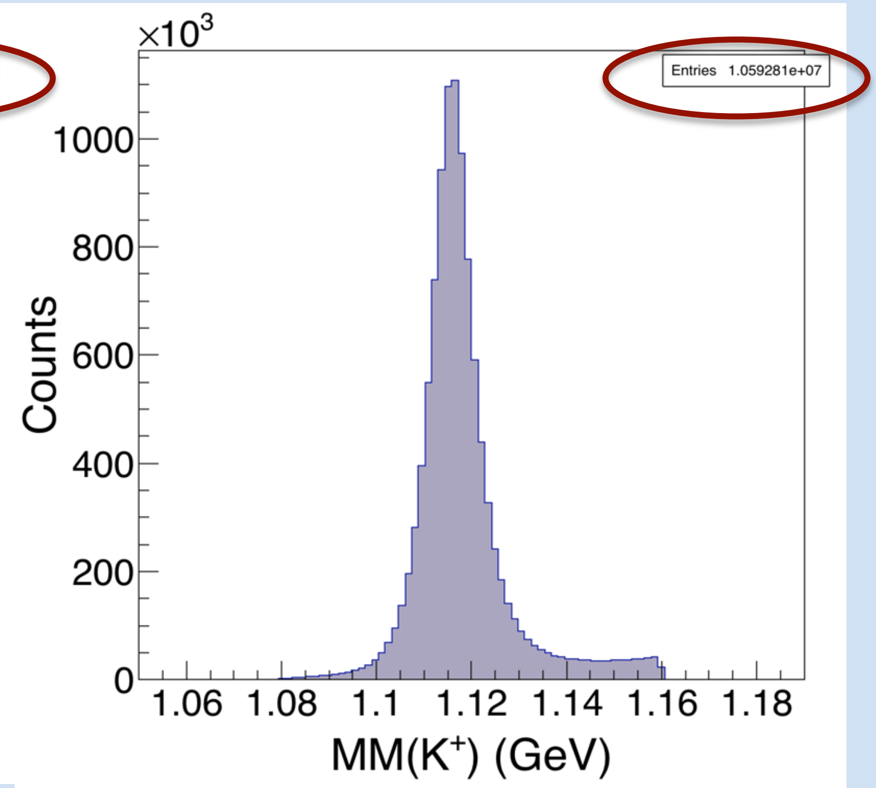
prob > 1% for 3track and

prob > 5% for 2track



Physics Events

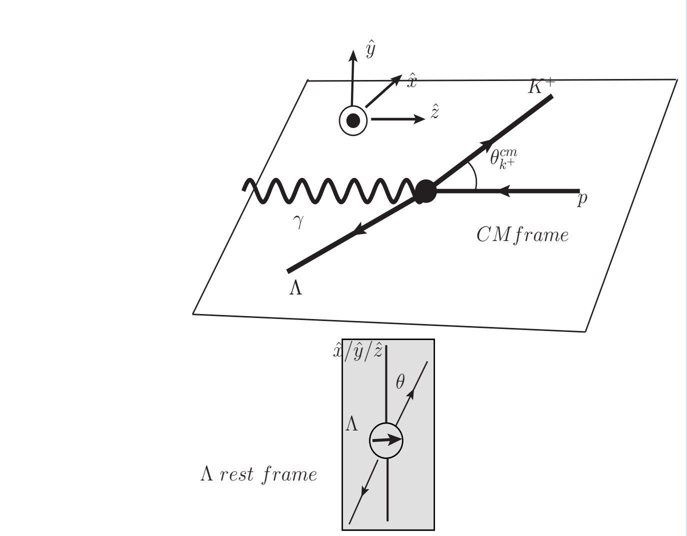




Low efficiency for negative
charge particle in CLAS

C_x, C_z and P observables are measured on these events.

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.

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

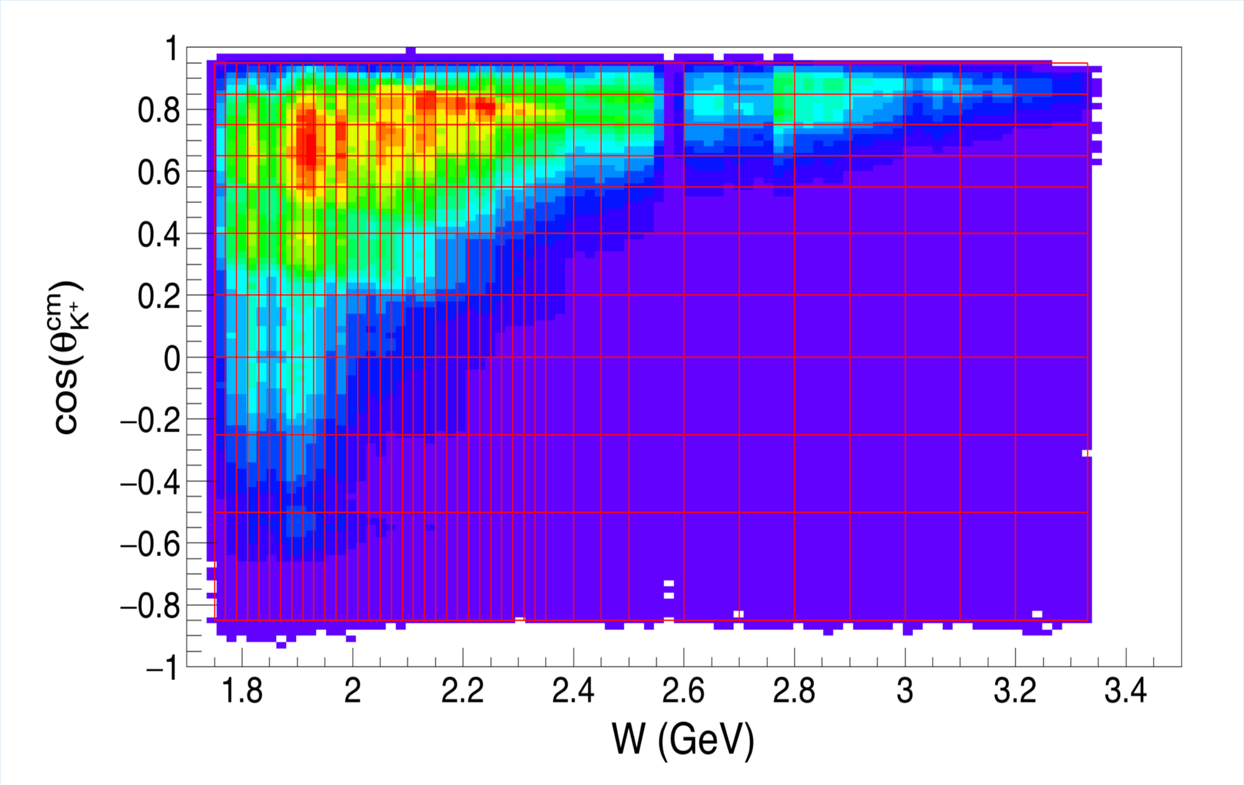
$$L(C_x, C_z) = \prod_{i=1}^{n} f(\cos\theta^p_x, \cos\theta^p_z)$$

  - Minimize negative log likelihood to fit the data;

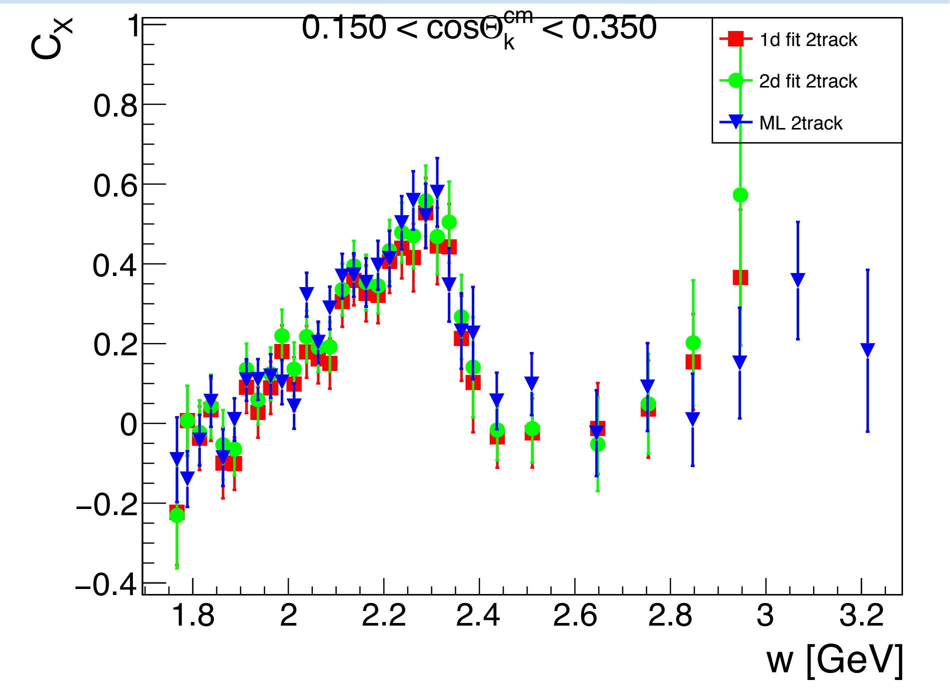
$$l = -\sum_{i=1}^{n} \log f(\cos\theta^p_x, \cos\theta^p_z)$$

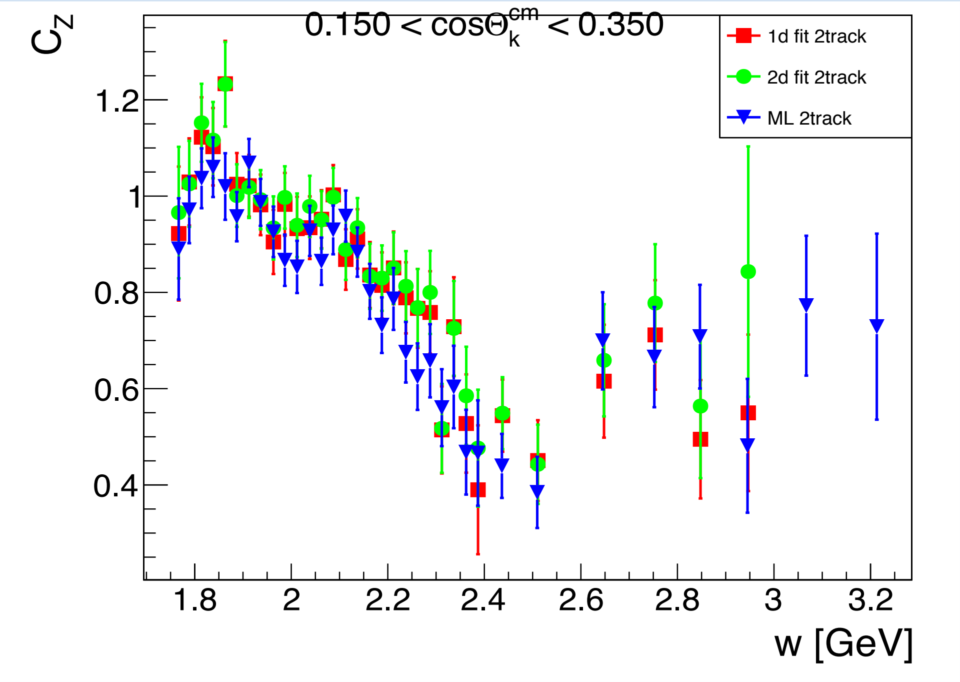
Binning

Two dimensional binning;
-> Center mass energy (W) and
-> Angular distribution of kaon in cm frame.



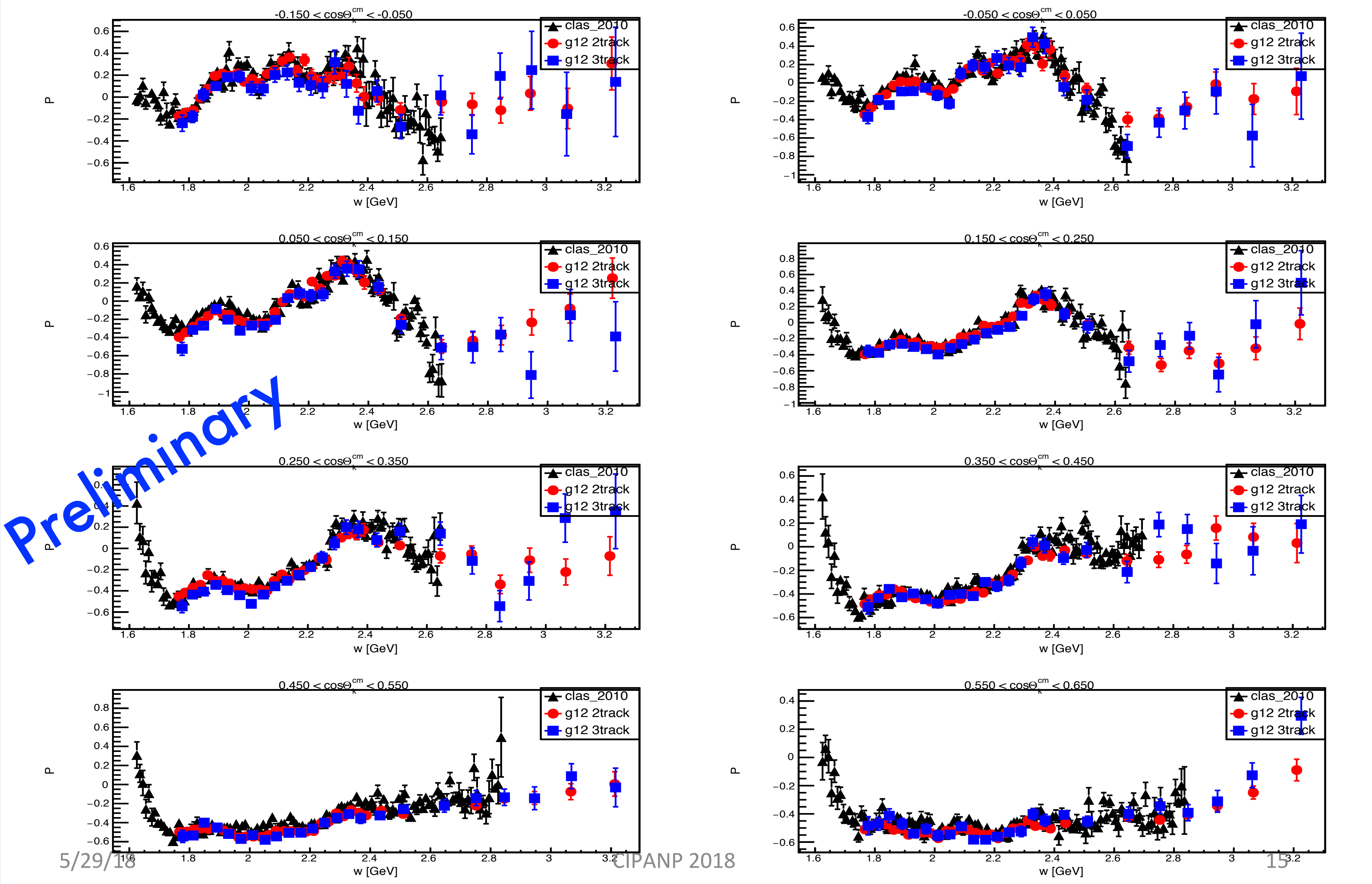
Comparision of 3 methods



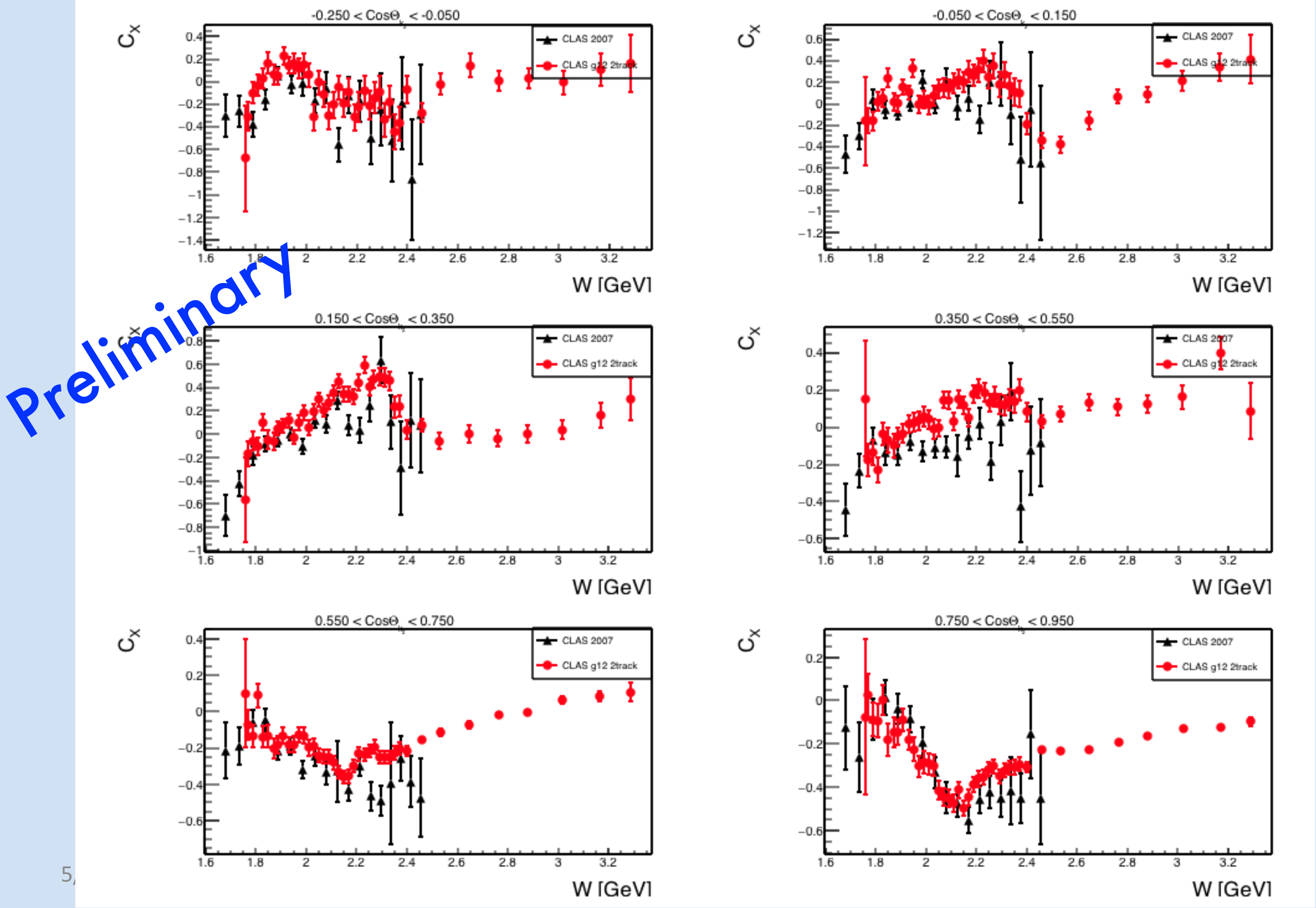


- Shows excellent agreements. Later showing results only for maximum likelihood method.
- Why ML? Applicable even when low statistics per bin.

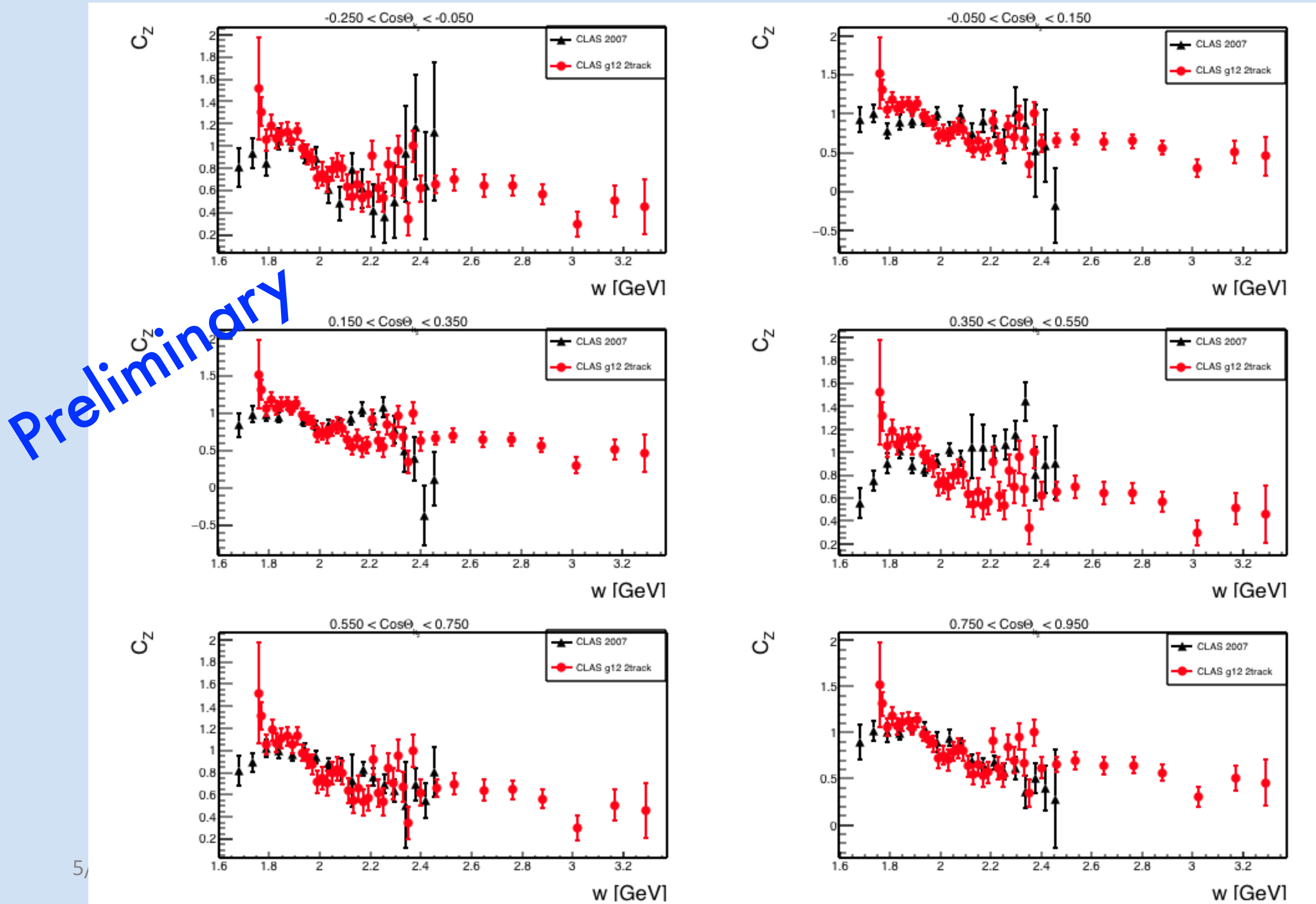
P results and comparision(CLAS 2010)



C_x Results and comparision(CLAS 2007)



C_z Results and comparision(CLAS 2007)



Conclusion and Outlook

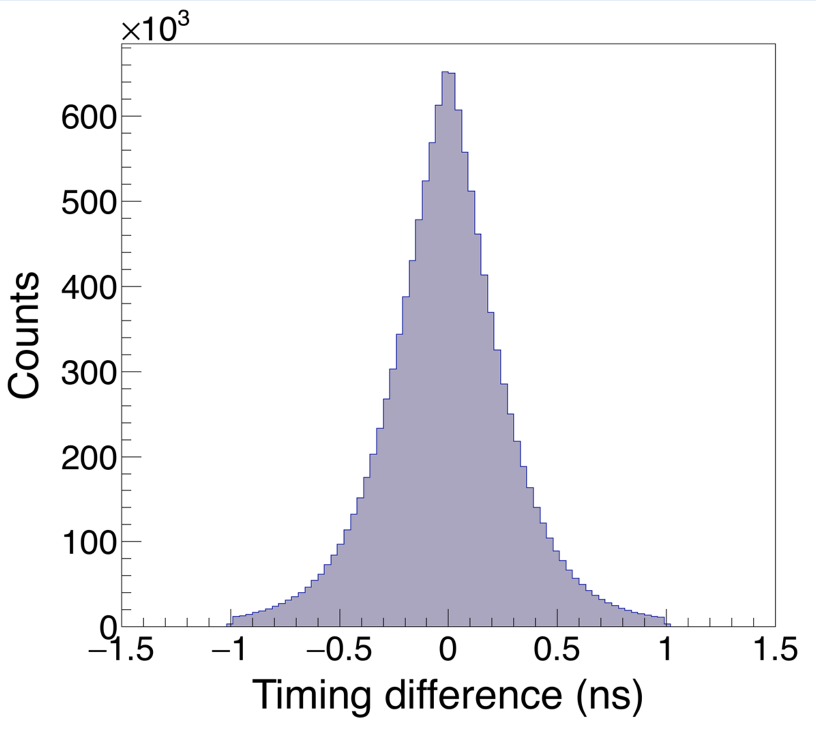
- Measured Λ polarization observables C_x ,P and C_z using g12 dataset for 1.75 < W < 3.3 GeV.
  - 3 method: 1d/2d/ML methods, all showing consistent results.
  - 2 topologies analyzed: results are mostly self-consistent.

- Preliminary C_x/C_z results:
  - More data has been added to the previous measurements.
  - Statistical uncertainty are smaller than previous g1c results for W < 2.54 GeV.
  - In the good agreement with earlier CLAS results.
  - First time measurement for W > 2.54 GeV.

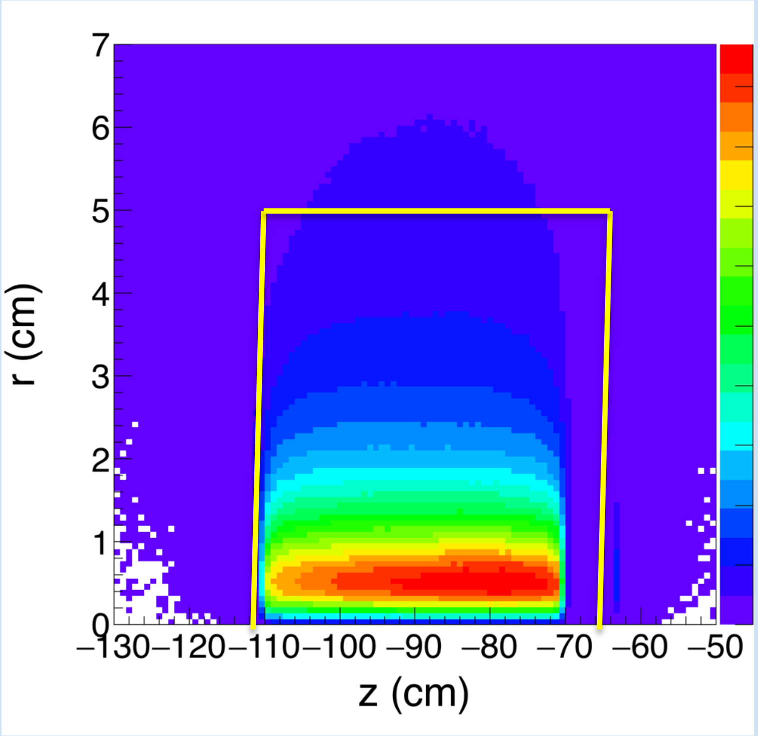
  P results:
  - agree well with CLAS 2010 results.
- Can be used to constrain non-resonant (t-channel) contribution.
- Suitable to study the higher mass resonances.

Thank You!

Event selection (cont…)

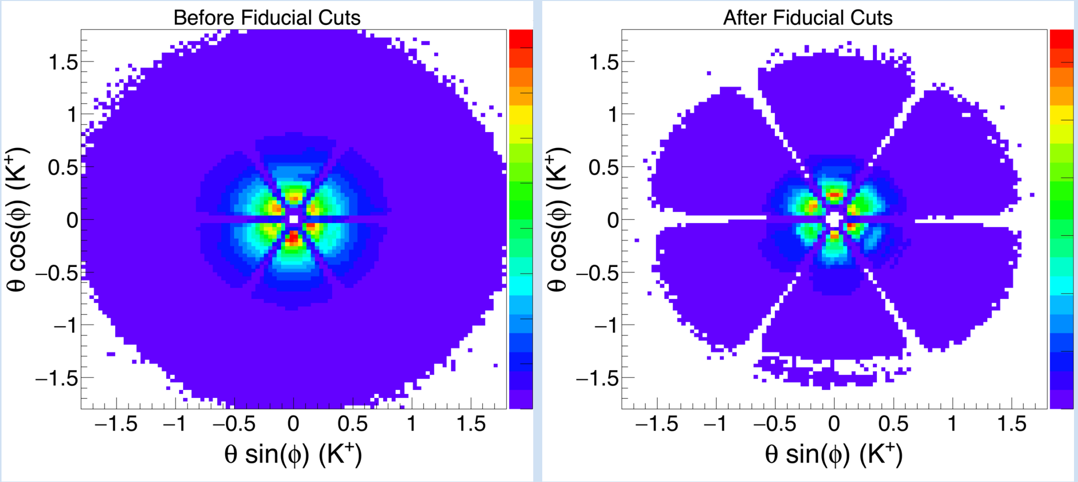


Timing difference between event start time from tagger and start counter. (< 1ns)

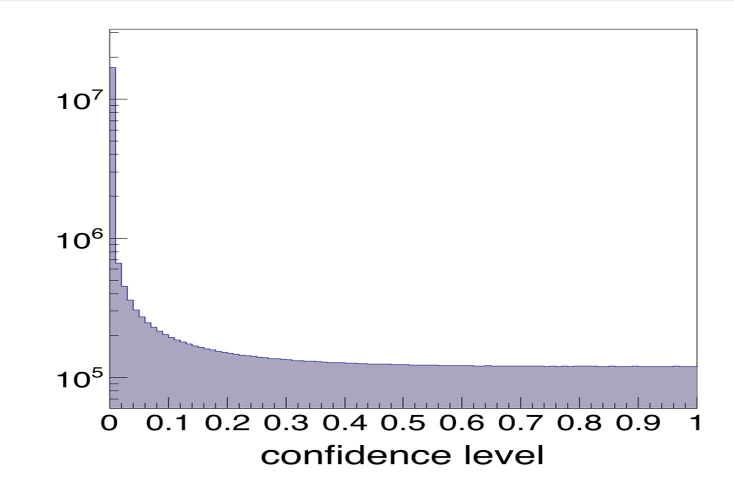


Vertex distribution

Event selection (cont…)

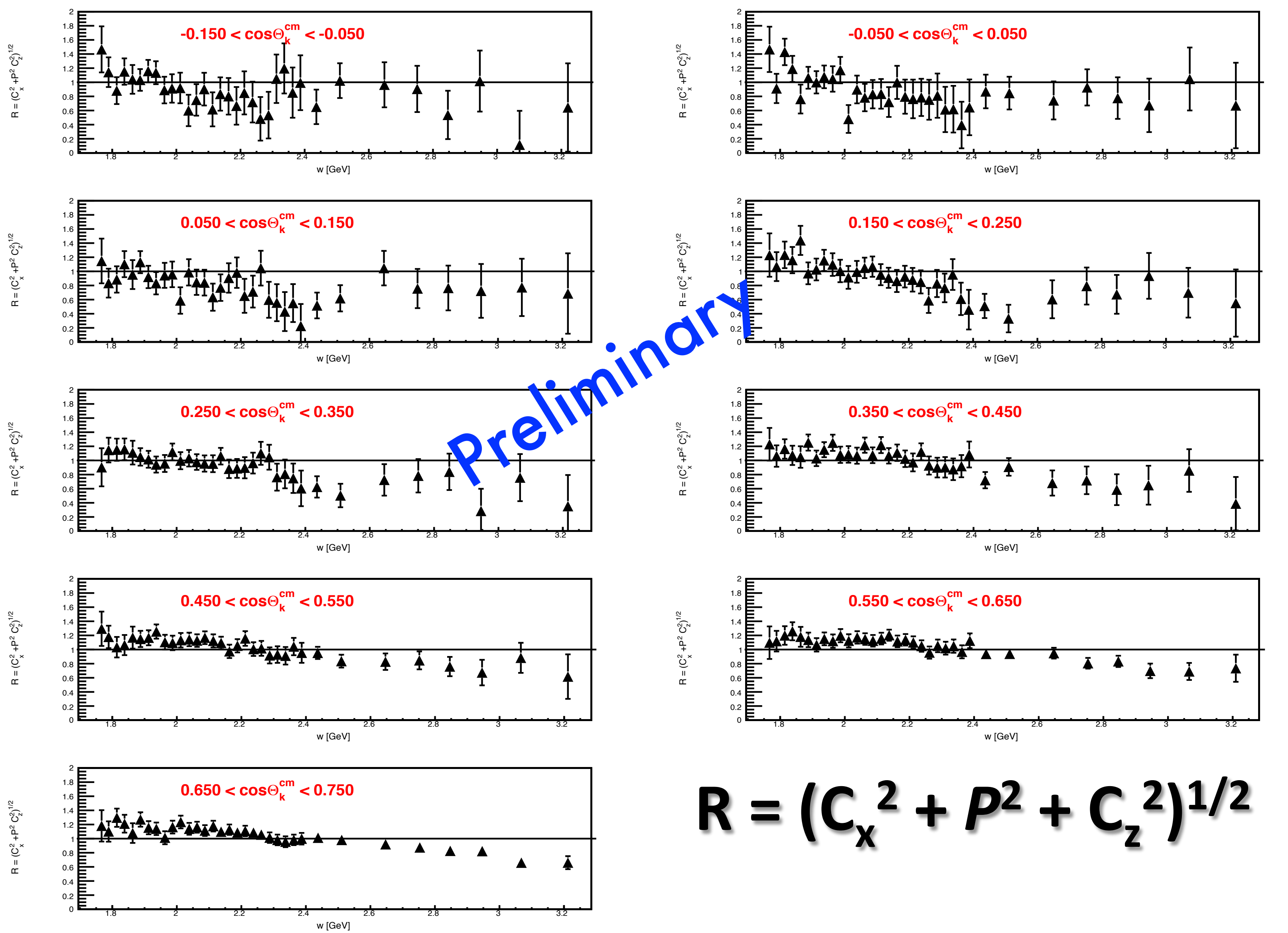


Geometrical time-of-flight fiducial cut



Kinematic fitting

R values for the Λ



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

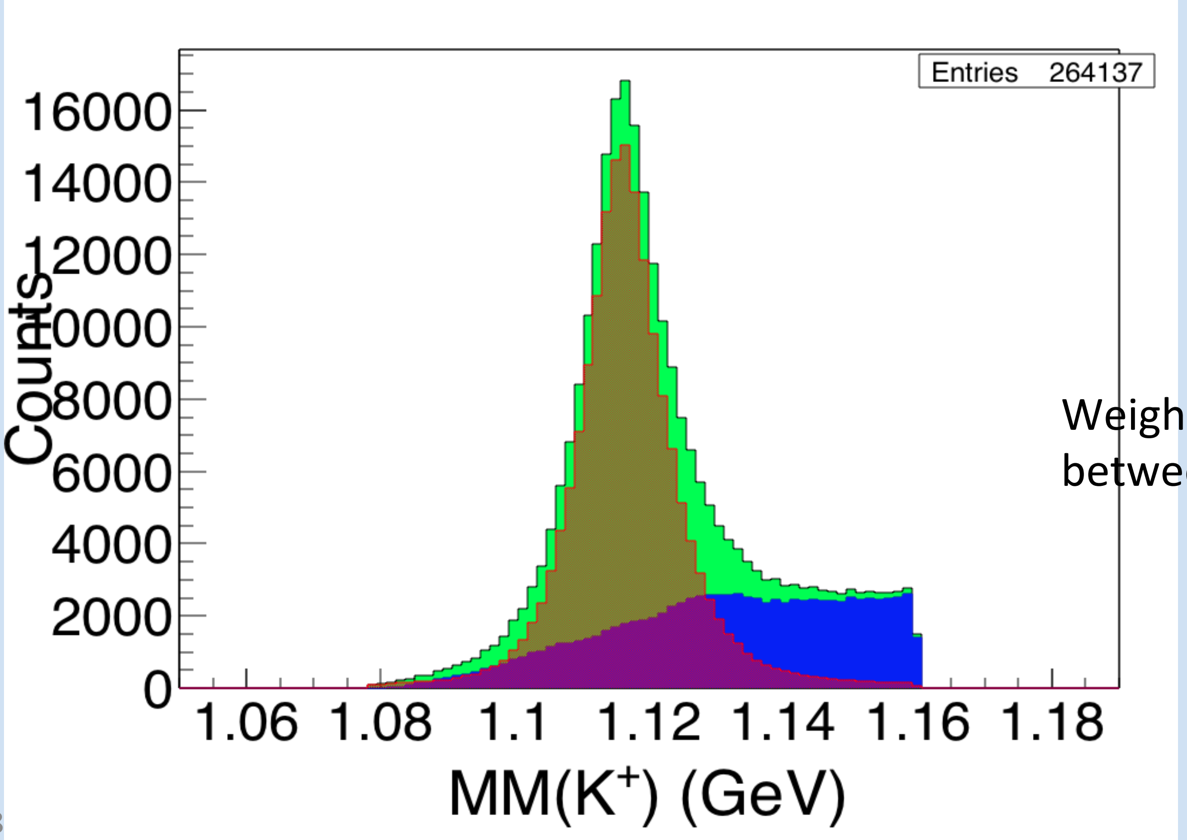
Background Subtraction

For 2Track; energy dependent background appears, binned on energy and applied background subtraction method.

Q Value Method:

Event-by-event basis method determining the signal event using Q-factor.

M. Williams, M. Bellis, and C. A. Meyer, JINST 4, P10003 (2009).



Weighted by q factor ranges between 0 and 1.