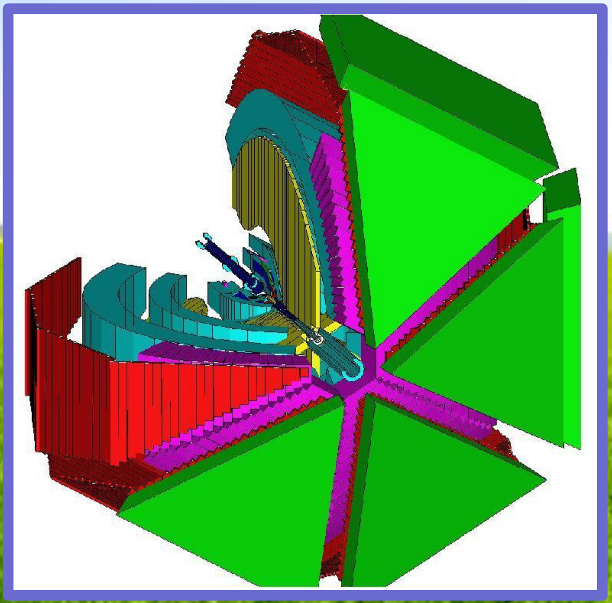
Measurement of Beam-Recoil Observables Cx and Cz for K+Lambda Photoproduction

Outline

- History of Measurement
- Motivation
- Analysis Details
- Data Presentation
- Theory Comparisons
- Summary/Conclusions



Jefferson Lab

FIU FLORIDA INTERNATIONAL UNIVERSITY

clas

Existing Data from CLAS


PHYSICAL REVIEW C **75**, 035205 (2007)

First measurement of beam-recoil observables C_x and C_z in hyperon photoproduction

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First measurement of beam-recoil observables C(x) and C(z) in hyperon photoproduction #19

CLAS Collaboration • R.K. Bradford (Carnegie Mellon U.) et al. (Nov, 2006)

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pdf links DOI cite datasets claim reference search 221 citations

One of our most cited CLAS papers

g1c dataset:

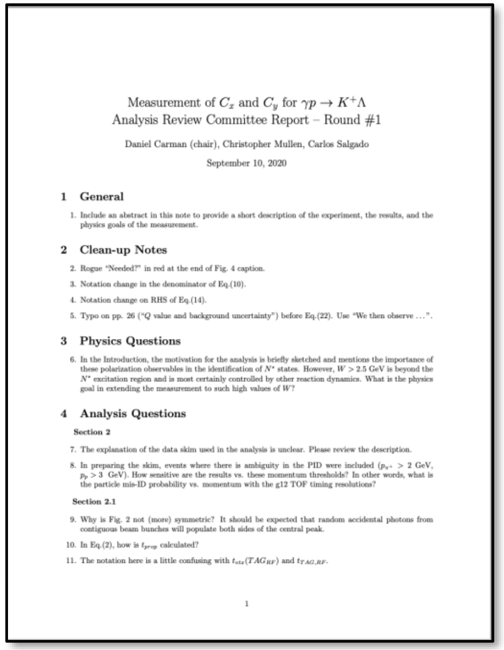
- Acquired Oct. – Nov. 1999
- Electron beam energy 2.9 GeV
- 18 cm lH_2 target, $\langle i \rangle = 10$ nA
- C_x, C_z data:
  - W: 1.6 → 2.53 GeV
  - $\cos\theta_K^{CM}$: -0.85 → 0.95
- Data sort:
  - C_x,C_z vs. W binned in $\cos\theta_K^{CM}$
  - C_x,C_z vs. $\cos\theta_K^{CM}$ binned in W

A Bit of History of this Work

Shankar Adhikari
Ph.D. thesis FIU 2018


Florida International University
FIU Digital Commons
FIU Electronic Theses and Dissertations — University Graduate School
11-1-2018
Polarization Observables for γp -> K+Λ at Photon Energies up to 5.45 GeV
Shankar Dayal Adhikari

Working Group analysis review
Sep. 2020 – Jul. 2023


Measurement of C_x and C_y for $\gamma p \to K^+\Lambda$
Analysis Review Committee Report – Round #1
Daniel Carman (chair), Christopher Mullen, Carlos Salgado
September 10, 2020


Measurement of C_x and C_y for $\gamma p \to K^+\Lambda$
Analysis Review Committee Report – Round #2
Daniel Carman (chair), Stuart Fegan, Susan Schadmand
January 17, 2023


Measurement of C_x and C_y for $\gamma p \to K^+\Lambda$
Analysis Review Committee Report – Round #3
Daniel Carman (chair), Stuart Fegan, Susan Schadmand
July 3, 2023

Paper draft prepared
Mar. – May 2025
Ad hoc review June 2025


CLAS Ad Hoc Review - #6155502
Measurement of Beam-Recoil Observables C_x and C_z for $K^+\Lambda$ Photoproduction
D.S. Carman, Jefferson Laboratory
L. Guo, Florida International University
B.A. Raue, Florida International University
(Dated: June 26, 2025)
Abstract
Replies to round #1 questions, comments, and suggestions from the CLAS Collaboration ad hoc review committee: Gabriel Niculescu, Susan Schadmand, Veronique Ziegler (chair)

g12 dataset:

- Acquired Apr. – Jun. 2008
- Electron beam energy 5.715 GeV
- 40 cm lH_2 target, $\langle i \rangle$ = 60 nA
- C_x, C_z data:
  - W: 1.6 → 3.33 GeV
  - $\cos\theta_K^{CM}$: -1.0 → 1.0
- Data sort:
  - C_x,C_z vs. W binned in $\cos\theta_K^{CM}$
  - C_x,C_z vs. $\cos\theta_K^{CM}$ binned in W

Motivation

1. A lot of high-quality data has been collected from exclusive meson photo- and electroproduction experiments.
   - This advancement has allowed for marked progress in mapping out the N* spectrum and in understanding the internal structure of these resonant states.

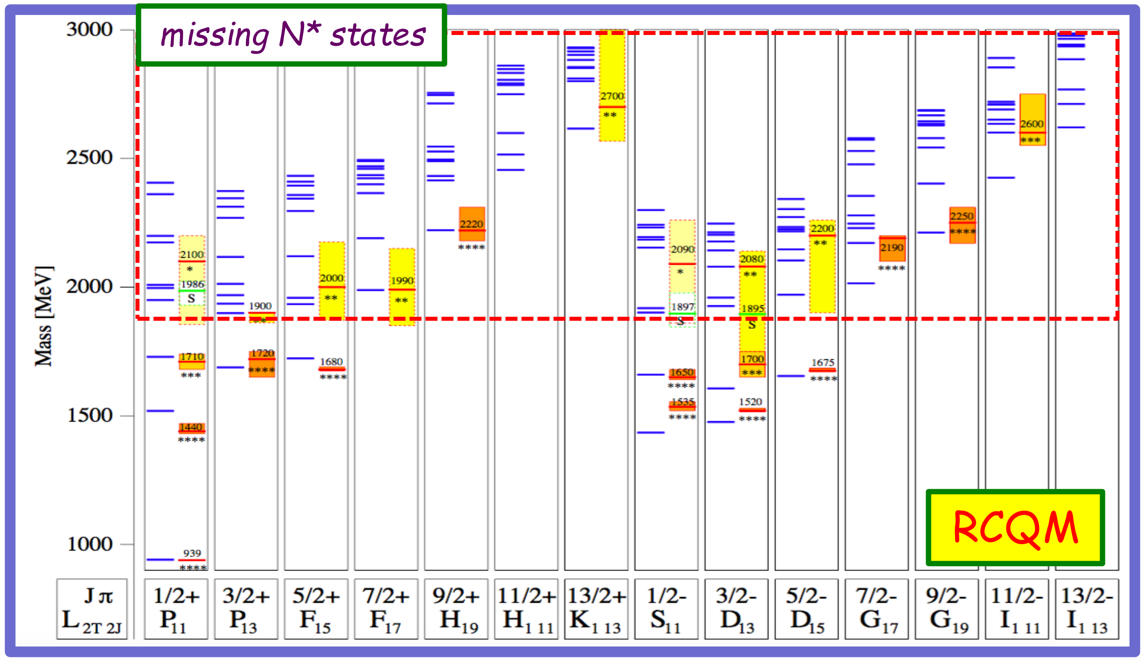
2. The high-precision data from CLAS on exclusive K^+Y photoproduction have proven crucial in this advancement.
   - With these data, roughly a dozen N* states have been confirmed within global multi-channel analyses with a decisive impact from the hyperon polarization observables.

3. Gaining insight into QCD in the non-perturbative regime requires not only high-precision experimental data, but advanced reaction models that accurately describe the data over a broad kinematic range.
   - The constraints that reaction models provide are only as good as the quality of the data.

4. This work is an extension of previously published CLAS photoproduction data on the Λ polarization observables C_x and C_z.
   - Extend W from 2.5 to 3.33 GeV - much improved statistics in overlap region $1.78 < W < 2.5$ GeV.

Evidence for New N* in KY Channels

State N(mass)J^P	PDG 2010	PDG 2024	πN	$K\Lambda$	$K\Sigma$	γN
$N(1710)1/2^+$	***	****	****	**	*	****
$N(1875)3/2^-$		***	**	*	*	**
$N(1880)1/2^+$		***	*	**	**	**
$N(1895)1/2^-$		****	*	**	**	****
$N(1900)3/2^+$	**	****	**	**	**	****
$N(2000)5/2^+$	*	**	*			**
$N(2060)5/2^-$		***	**	*	*	***
$N(2100)1/2^+$	*	***	***	*		**
$N(2120)3/2^-$		***	**	**	*	***
$\Delta(1600)3/2^+$	***	****	***			****
$\Delta(1900)1/2^-$	**	***	***		**	***
$\Delta(2200)7/2^-$	*	***	**		**	***



U. Löring, B. Metsch, H.R. Petry, Eur. Phys. J. A 10, 395 (2001)

LQCD predictions support CQM

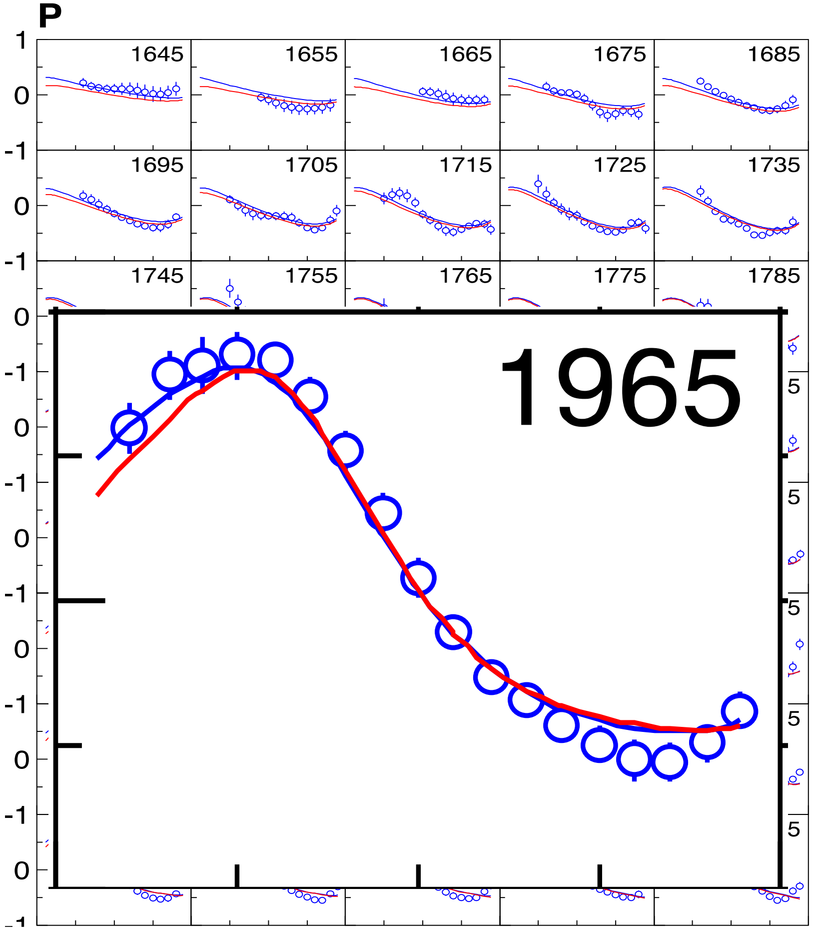
J. Dudek, R. Edwards, PRD 85, 054016 (2012)

Decisive impact from CLAS KY photoproduction data

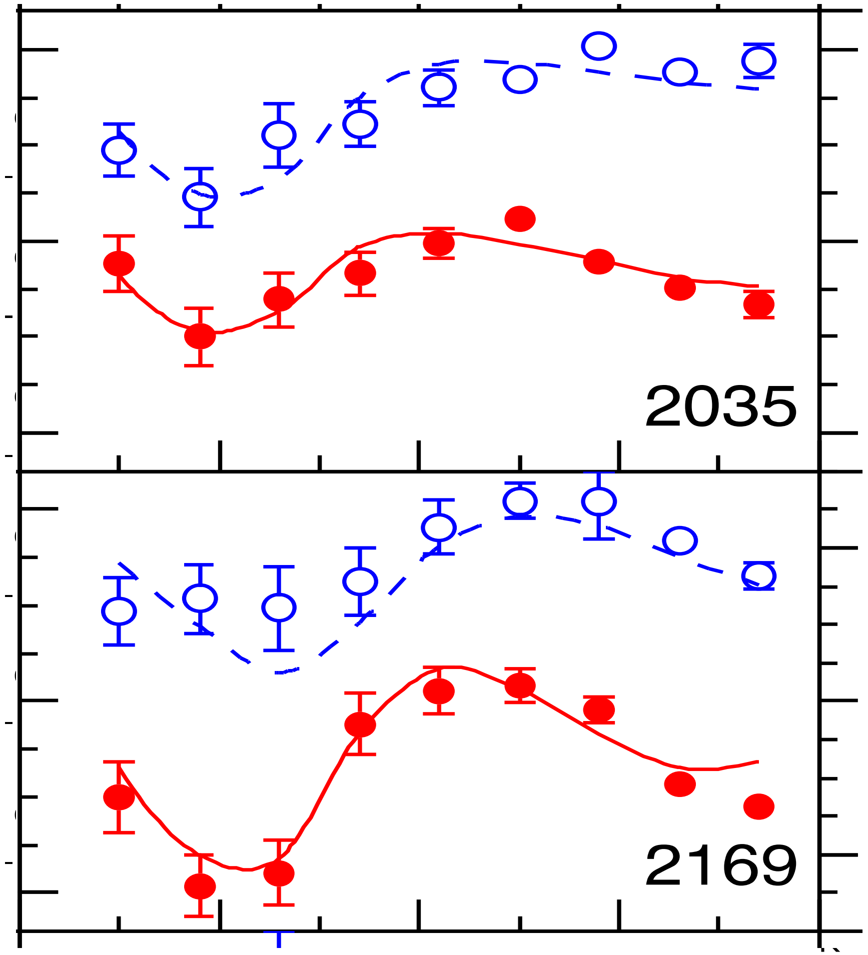
- Extend studies to KY electroproduction and to higher masses

Importance of Λ Polarization Observables

Λ Recoil Polarization



M. McCracken et al. (CLAS), PRC 81, 025201, 2010



R.K. Bradford et al. (CLAS), PRC 75, 035205, 2007

A.V. Anisovich et al. (BnGa), EPJ A48, 15 (2012)

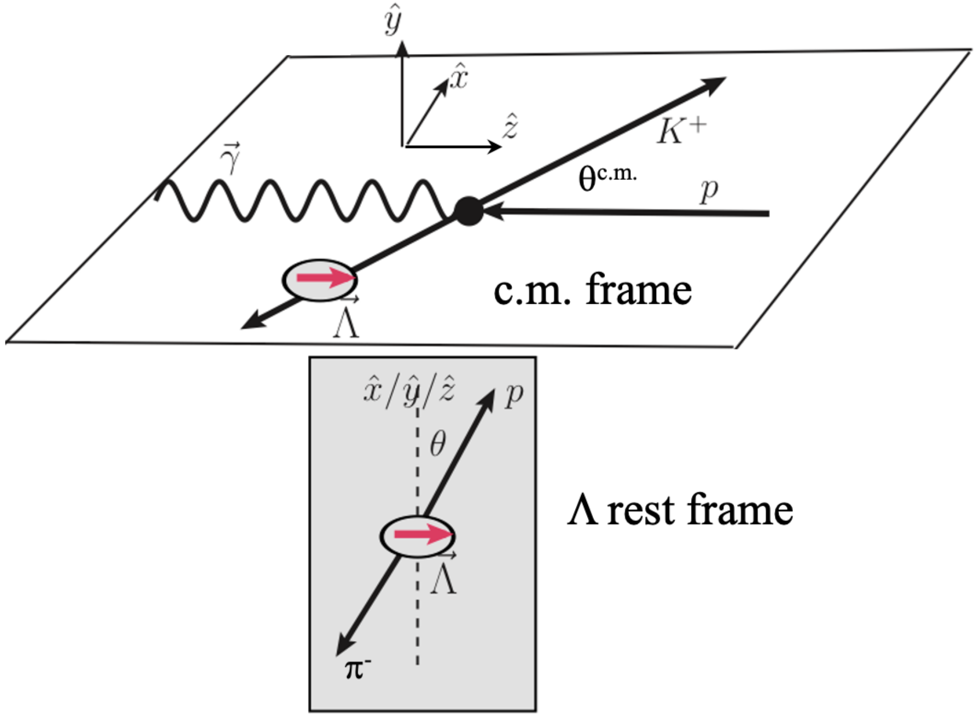
Slide from V. Burkert

Hyperon Photoproduction Polarization Observables

Most general form for photoproduction of pseudoscalar mesons

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

		Target (P^T)			Recoil (P^R)			Target (P^T) + Recoil (P^R)								
					x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
γ beam (P^γ)		x	y	z				x	y	z	x	y	z	x	y	z
unpol :	σ_0		$\hat{T}$			$\hat{P}$		$\hat{T}_{x'}$		$\hat{L}_{x'}$		$\hat{\Sigma}$		$\hat{T}_{z'}$		$\hat{L}_{z'}$
$P_L^\gamma \sin 2\phi_\gamma$:		$\hat{H}$		$\hat{G}$	$\hat{O}_{x'}$		$\hat{O}_{z'}$		$\hat{C}_{z'}$		$\hat{E}$		$\hat{F}$		$-\hat{C}_{x'}$	
$P_L^\gamma \cos 2\phi_\gamma$:	$-\hat{\Sigma}$		$-\hat{P}$			$-\hat{T}$		$-\hat{L}_{z'}$		$\hat{T}_{z'}$		$-\sigma_0$		$\hat{L}_{x'}$		$-\hat{T}_{x'}$
cir P_c^γ :		$\hat{F}$		$-\hat{E}$	$\hat{C}_{x'}$		$\hat{C}_{z'}$		$-\hat{O}_{z'}$		$\hat{G}$		$-\hat{H}$		$\hat{O}_{x'}$	



Simplification/reduction for the case of circularly polarized beam and polarized recoil

$$\frac{d\sigma}{d\Omega_K^{CM}} = \sigma_0\left(1 + \alpha P^\gamma C_x \cos\theta_x + \alpha P^\gamma C_z \cos\theta_z + \alpha P \cos\theta_y\right)$$

Focus of this work

Data Analysis

Topologies:

- Two-track K^+, p
- Three-track K^+, p, π^- (cross check only)

Standard Cuts and Corrections:

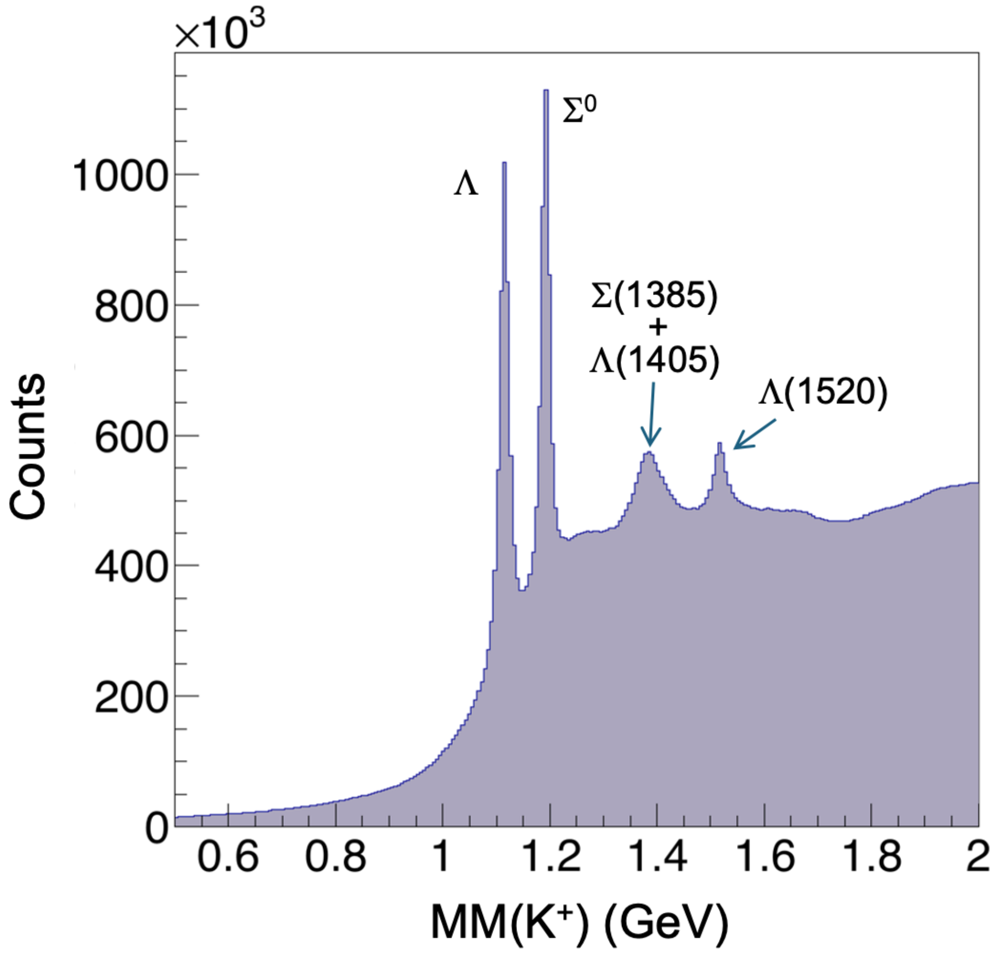
- Track vertex timing cut
- Track vertex coordinate cut
- Fiducial cuts
- Bad element knockout
- Multiple photon cut
- Energy, momentum corrections

CLAS-Note 2017-002:

g12 Analysis Procedures, Statistics, and Systematics

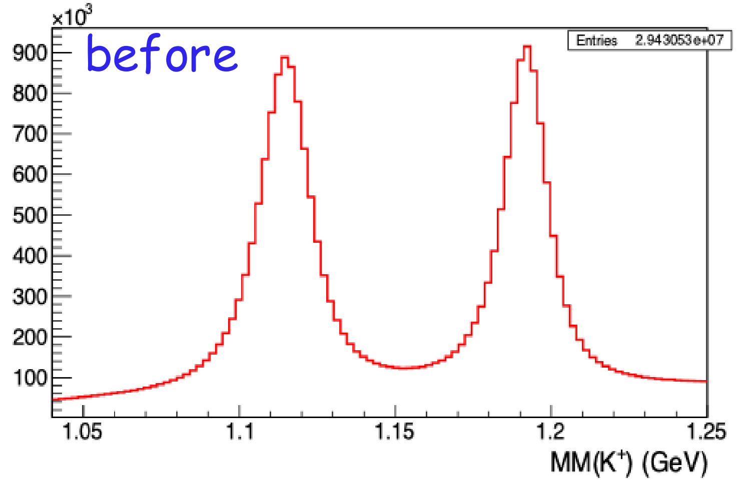
g12 Standard Analysis Checklist

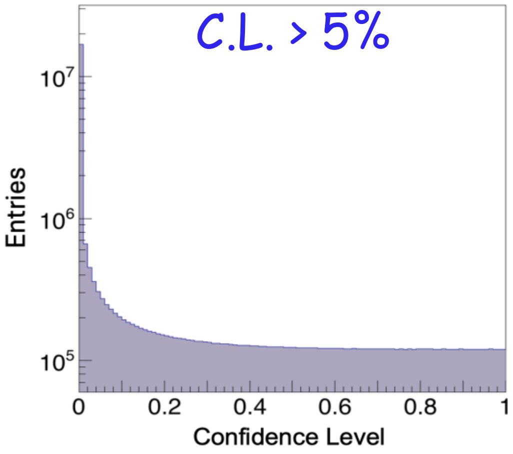
Procedure	N/A	Yes	No
Used PART bank reconstruction for the analysis. EVNT was NOT used	☐	☑	☐
Momentum corrections as described in the g12 note	☐	☑	☐
Beam energy correction as described in the g12 note	☐	☑	☐
Inclusive "Good" run list as described in table 7. Individual analysis may use a subset of it	☐	☑	☐
Target density and its uncertainty as described in the g12 note	☑	☐	☐
Photon flux calculation procedure as described in the g12 note	☑	☐	☐
Lower limit for the systematic uncertainty of normalized yield is 5.7%	☑	☐	☐
Photon polarization calculation procedure as described in the g12 note	☐	☑	☐
Systematic uncertainty of the photon polarization as described in the g12 note	☐	☑	☐
gsim parameters	☑	☐	☐
gpp smearing parameters	☑	☐	☐

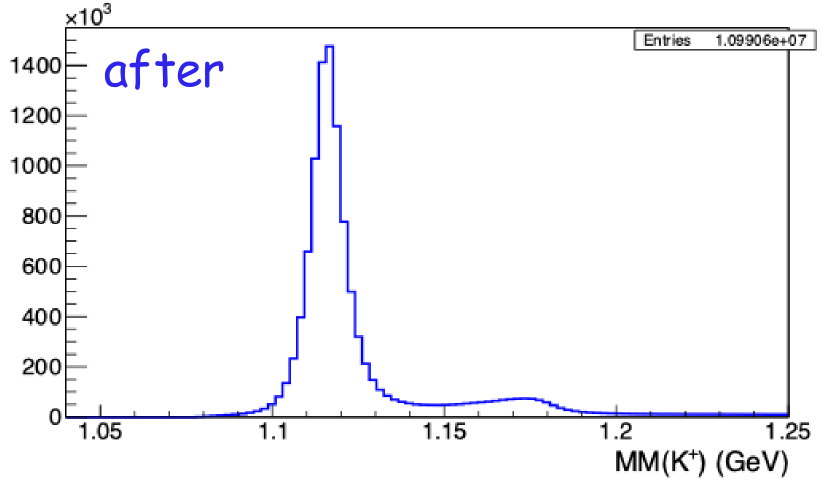


Kinematic Fitting

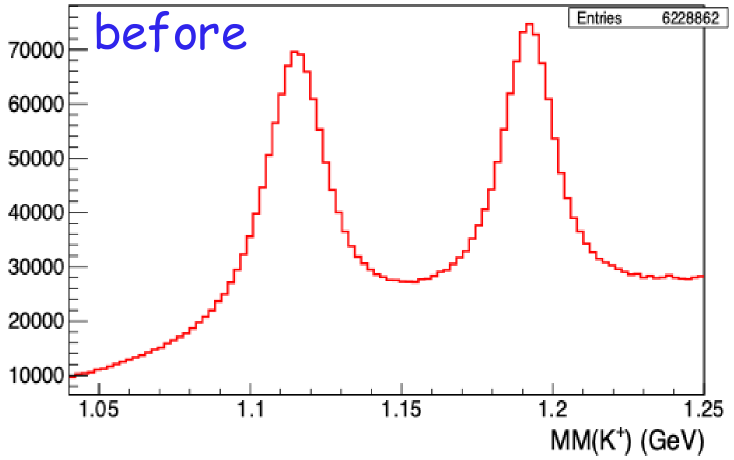
Two-Track

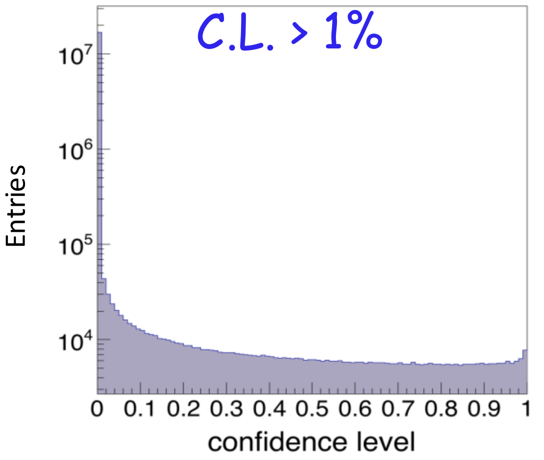


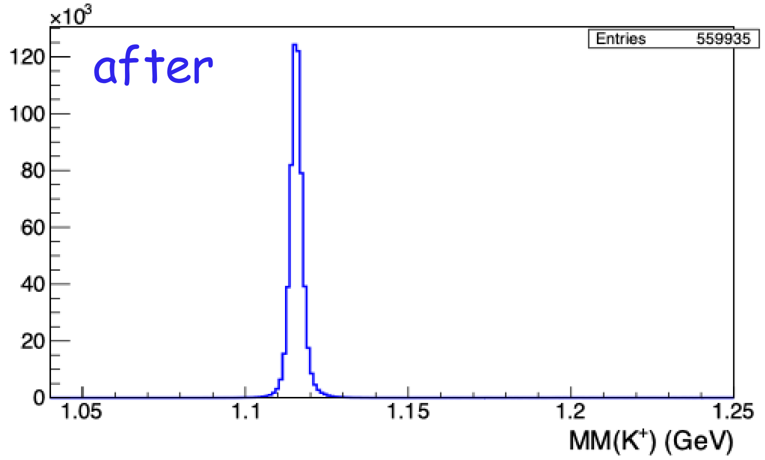




Three-Track

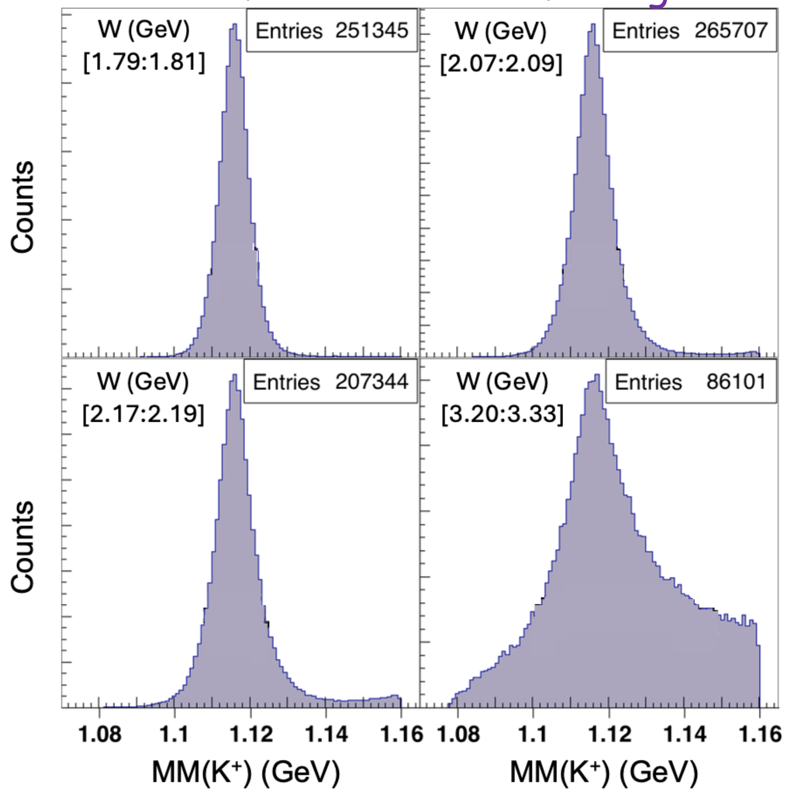




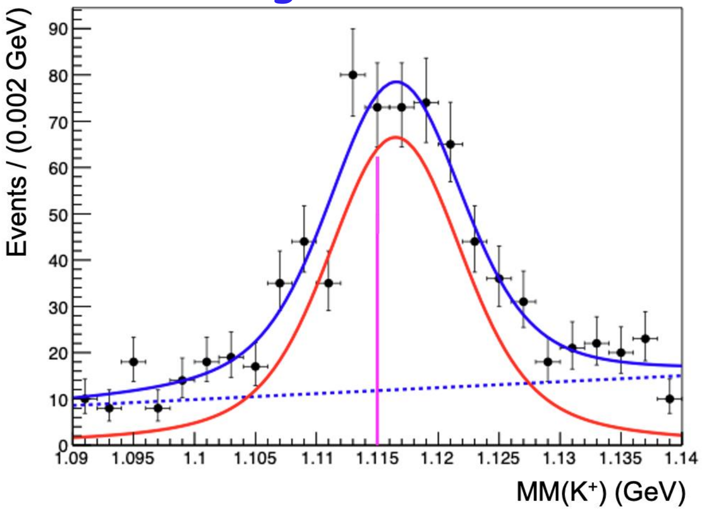


Yield Determination

W-dependent spectra after kinematic fitting

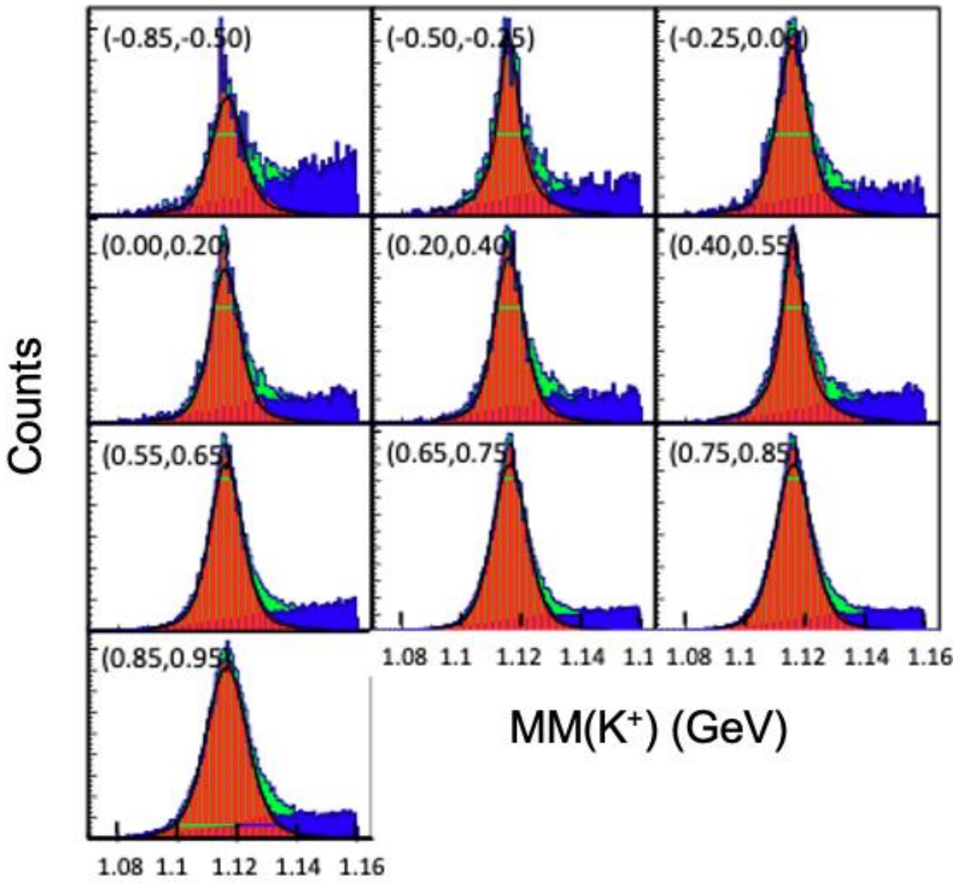


Signal: Voigtian
Background: linear



$$Q = \frac{f_s \cdot S(MM)}{f(MM)}$$

Example fits: W [3.1:3.2] GeV



<u>Q-factor method (multi-variate analysis)</u>:

- Separate signal from background
- For each event, find N nearest neighbors in kinematic space ($\cos\theta_K^{CM}$, $\cos\theta_p^{CM}$, Φ_p, W)
- For each event: $f(MM) = f_s \cdot S(MM) + (1 - f_s) \cdot B(MM)$

Final Λ yields from Q-weighted distributions

Polarization Extraction

Traditional Extraction Approach:

$$A(\cos\theta_p^{x/z}) = \frac{N_+ - N_-}{N_+ - N_-} = \alpha P_\odot C_{x/z} \cos\theta_p^{x/z}$$

Alternate approach:

- Perform simultaneous extraction of C_x, C_z
- Define likelihood function in terms of "PDFs"

$$\mathcal{L} = \prod_{i=1}^{N} \mathcal{P}_i$$

Likelihood function

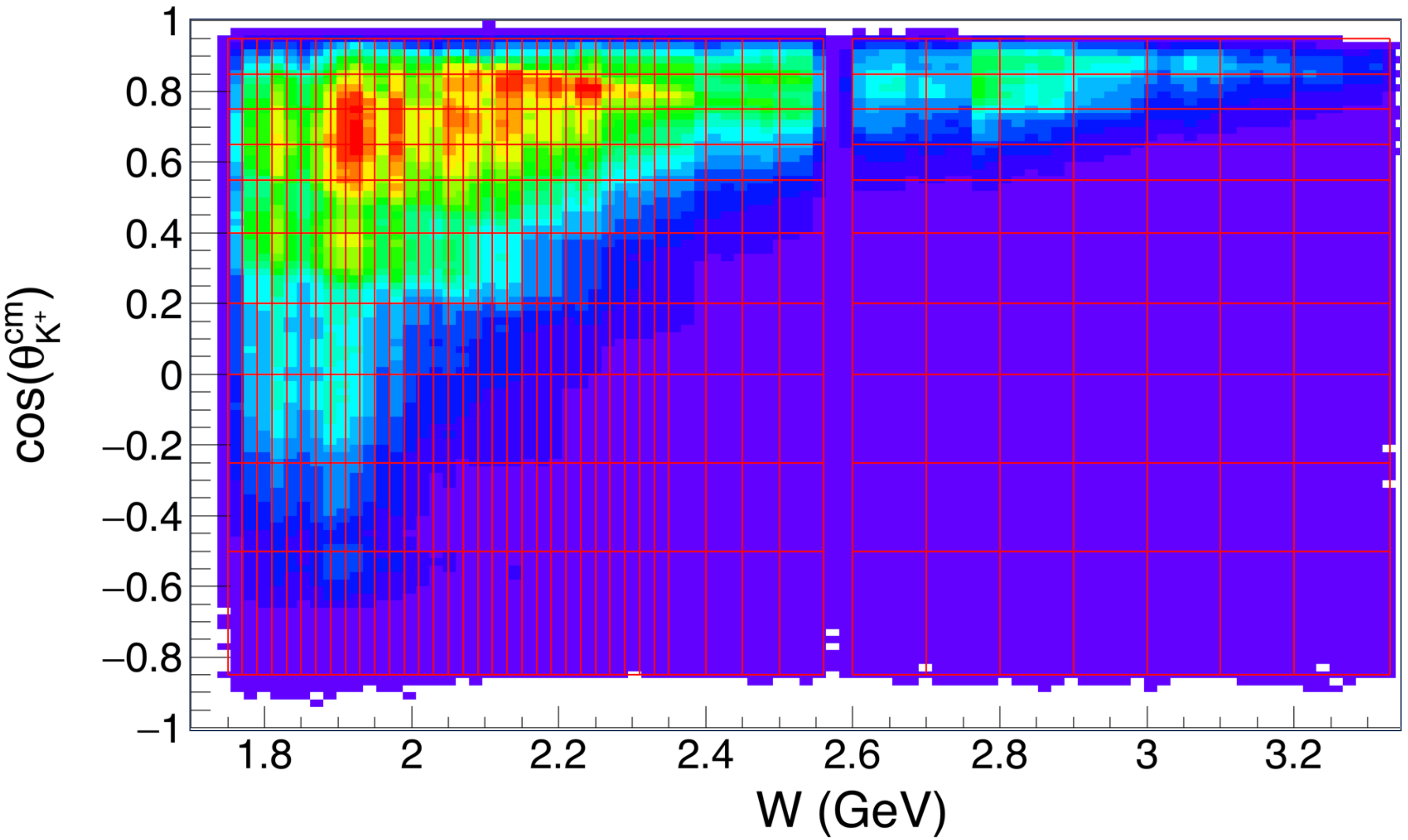
Probability density function

$$\mathcal{P}_C(\cos\theta_p^x, \cos\theta_p^z | C_x, C_z) = 1 \pm \alpha P_\odot \left(C_x \cos\theta_p^x + C_z \cos\theta_p^z\right)$$

Extract C_x, C_z minimizing the log likelihood using the event defined Q-factors

$$-\log\mathcal{L}_C = -\sum_i^N Q_i \log\left(P_\odot \alpha \left(C_x \cos\theta_p^x + C_z \cos\theta_p^z\right)\right)$$

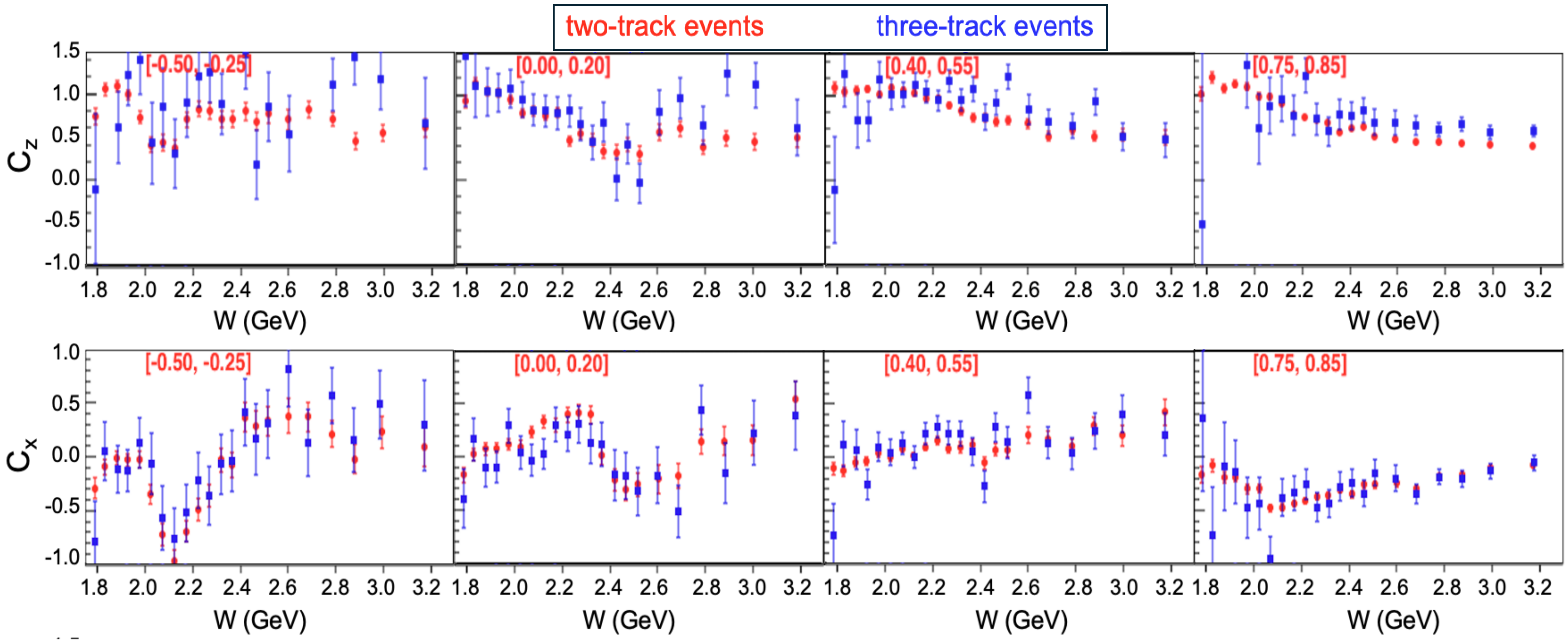
Data Binning



W Range (GeV)	No. of Bins	Width (MeV)
$[1.75, 2.35)$	30	20
$[2.35, 2.50)$	3	50
$[2.50, 2.56)$	1	60
$[2.60, 3.20)$	6	100
$[3.20, 3.33)$	1	130

$\cos\theta_K^{c.m.}$ Range
$[-0.85, -0.65)$, $[-0.65, -0.45)$, $[-0.45, -0.25)$, $[-0.25, -0.05)$, $[-0.0, 0.15)$, $[0.15, 0.35)$, $[0.35, 0.55)$, $[0.55, 0.65)$, $[0.65, 0.75)$, $[0.75, 0.85)$, $[0.85, 0.95]$

Two-Track vs. Three-Track Comparison



Systematic Uncertainties

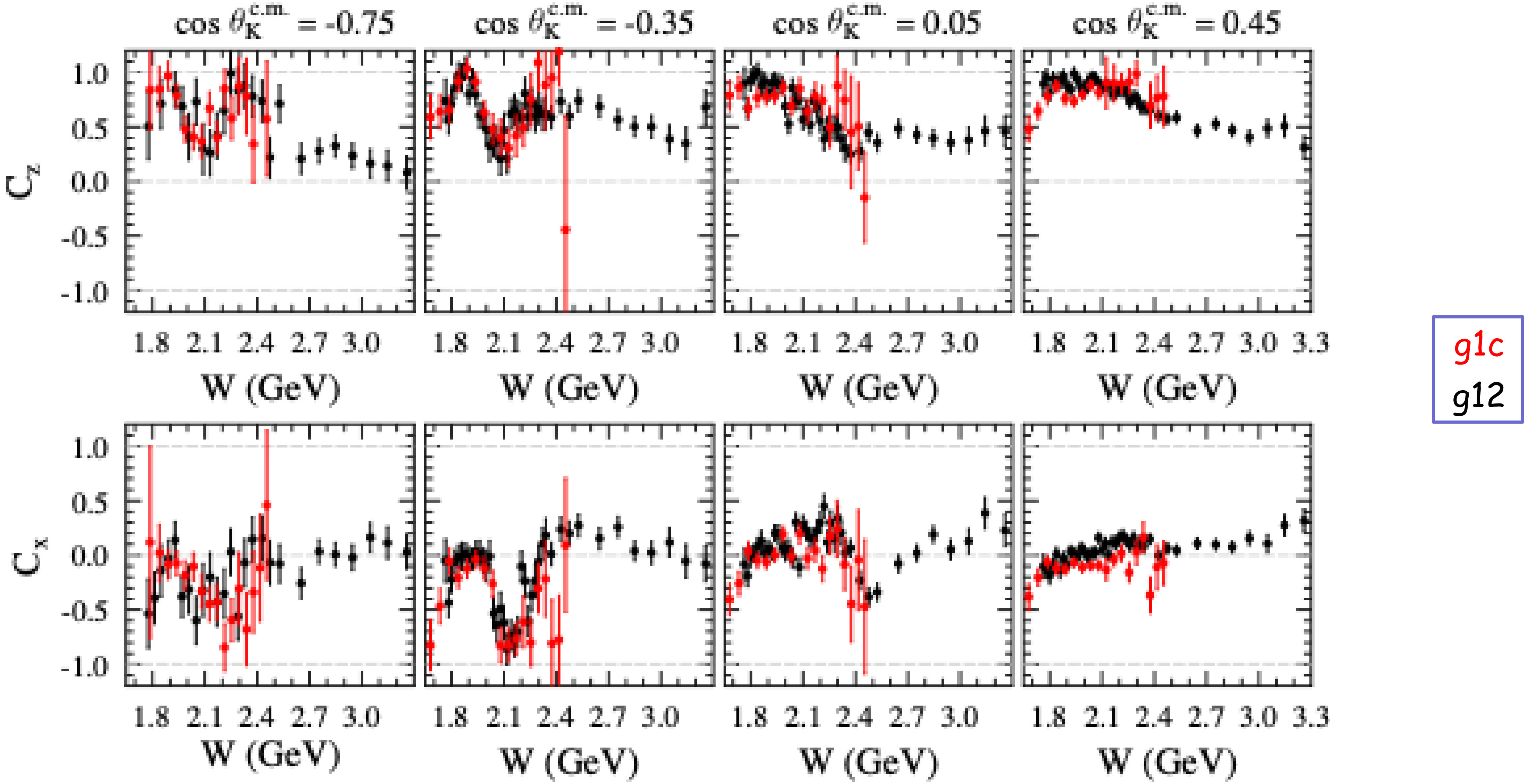
Method for assignment:

$$\delta\mathcal{O}_{sys} = \sqrt{\frac{\sum_i \left(\frac{\mathcal{O}^i_{nom} - \mathcal{O}^i_{alt}}{\delta\mathcal{O}^i_{nom}}\right)^2}{\sum_i \left(\frac{1}{\delta\mathcal{O}^i_{nom}}\right)^2}}$$

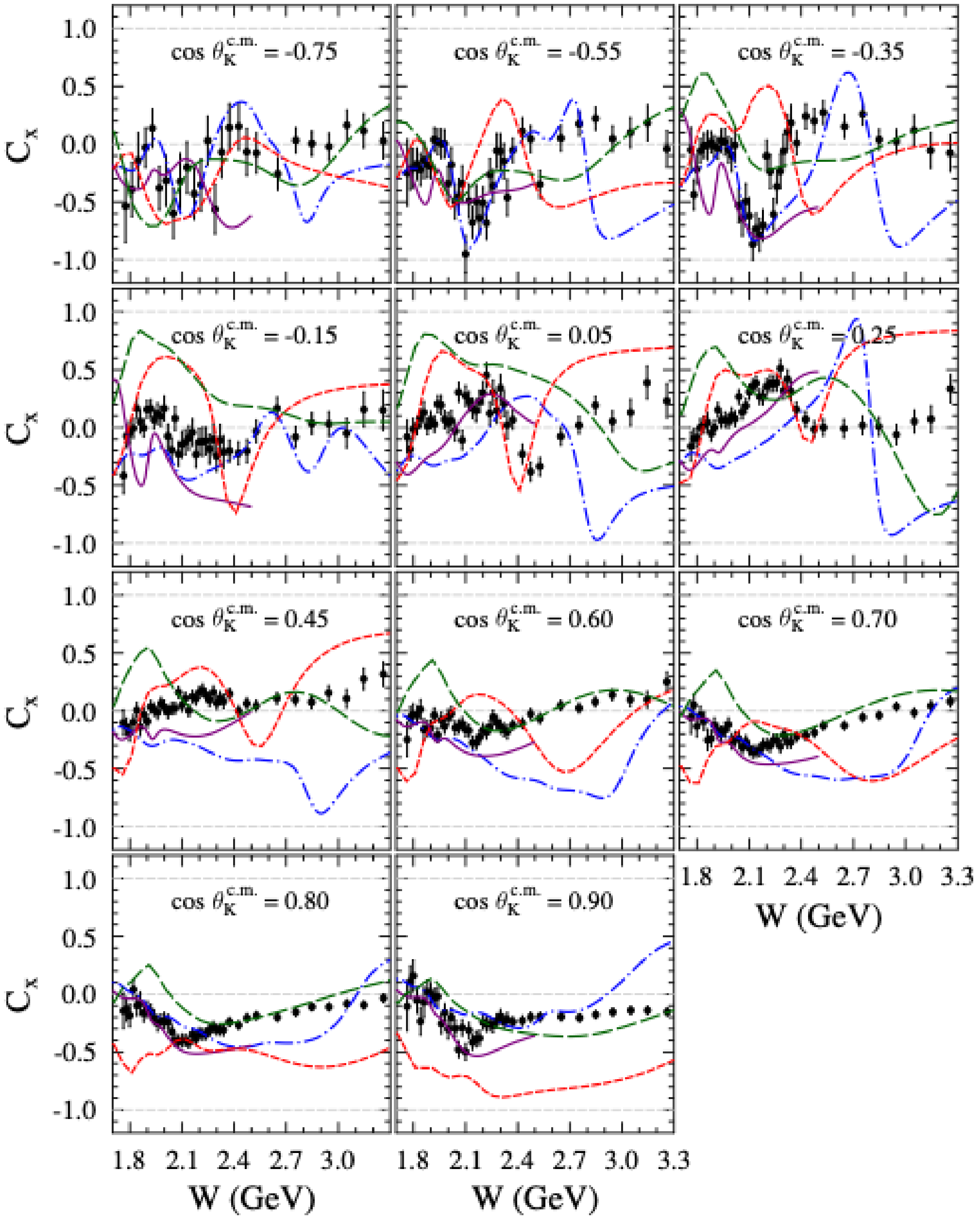
Measurement uncertainty is dominated by counting statistics

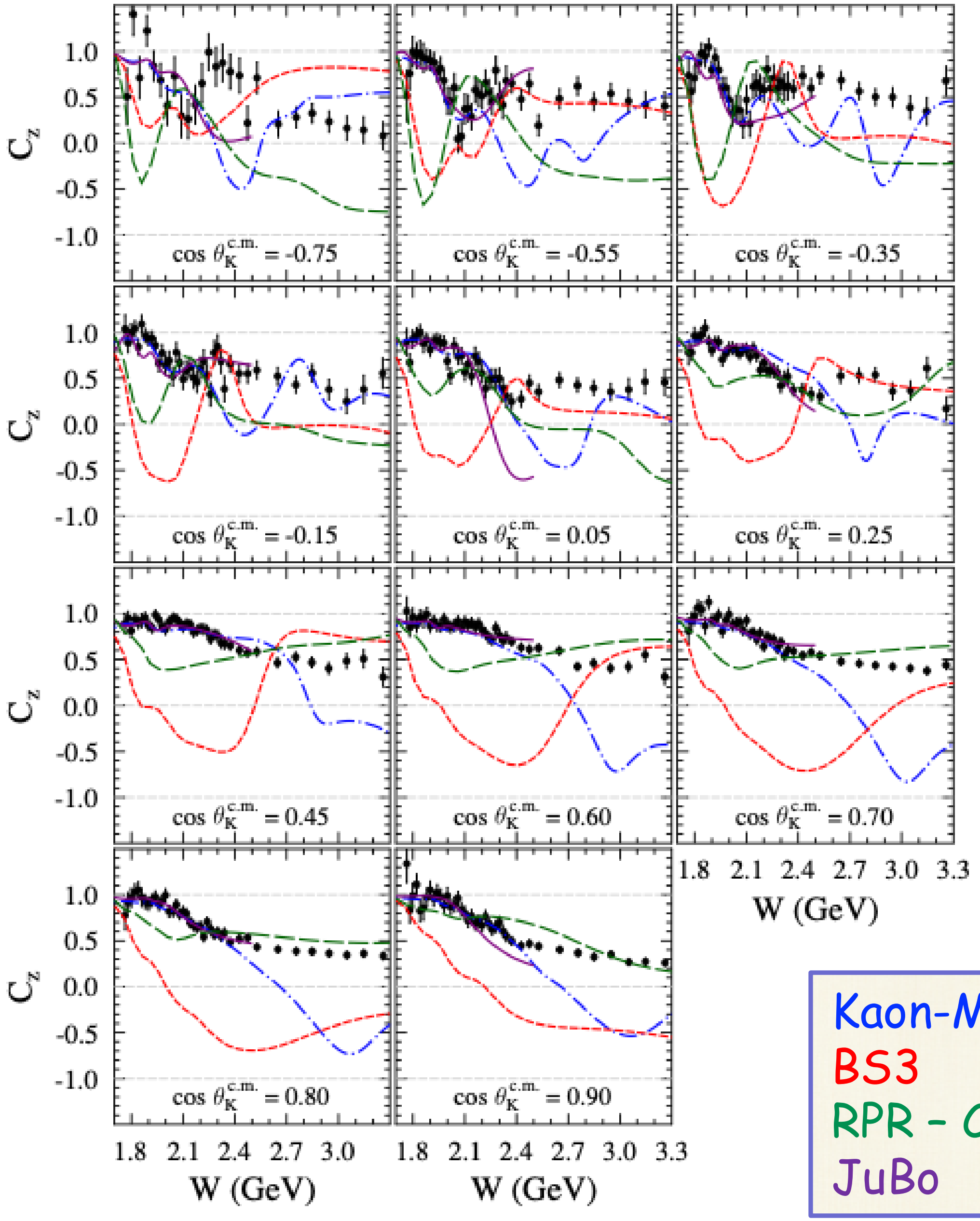
Point-to-Point Uncertainties		
Source	δC_x	δC_z
Timing cut	0.0034	0.0034
Vertex z cut	0.0134	0.0120
Vertex r cut	0.0075	0.0073
Fiducial cuts	0.0087	0.0084
Confidence level cut	0.0172	0.0236
Q-value	0.0128	0.0145
Total	0.028	0.032
Relative Scale-Type Uncertainties		
$P_\odot$	$0.05C_x$	$0.05C_z$
α	$0.009C_x$	$0.009C_z$
Total	$0.051C_x$	$0.051C_z$

CLAS g1c vs. CLAS g12



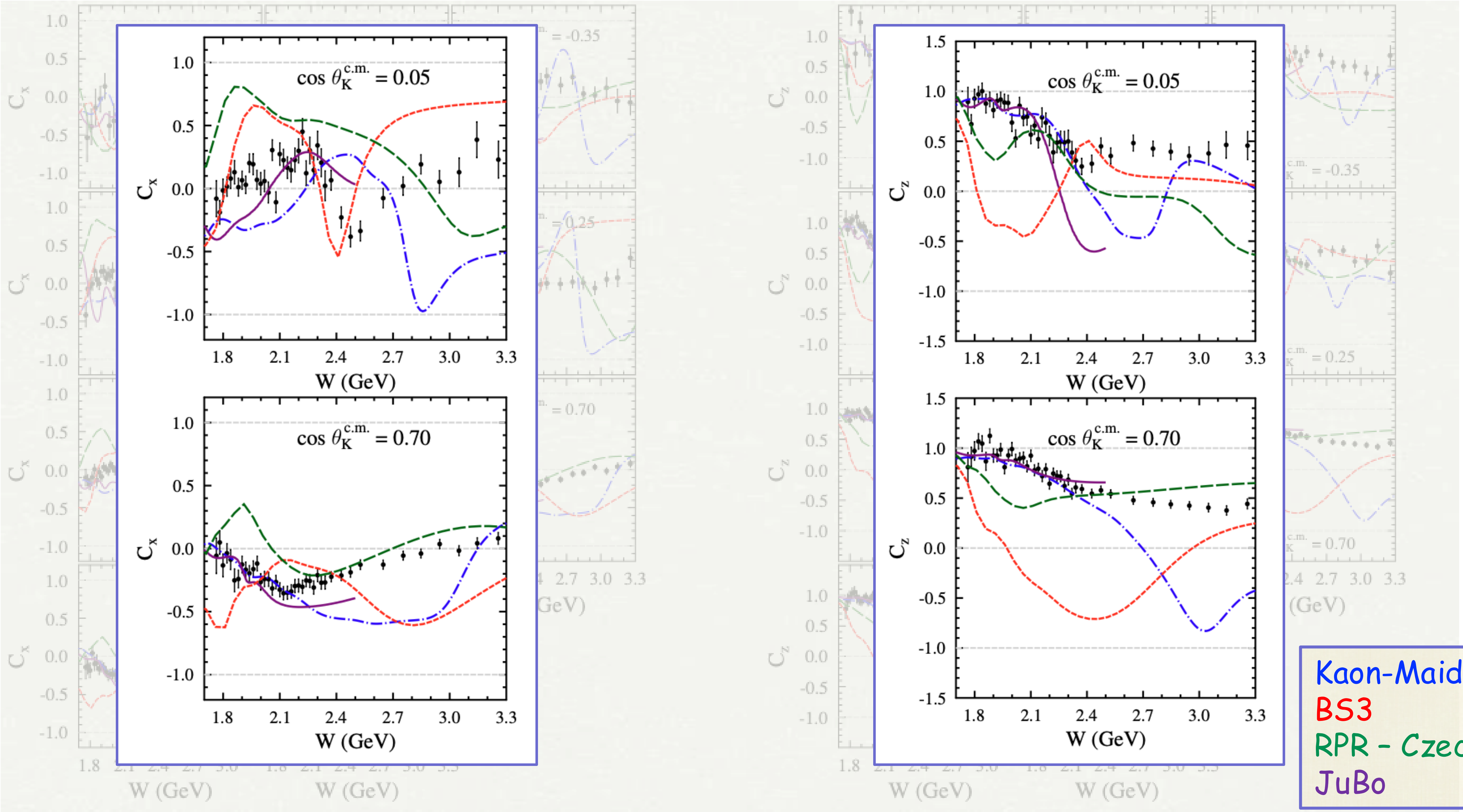
Data Results





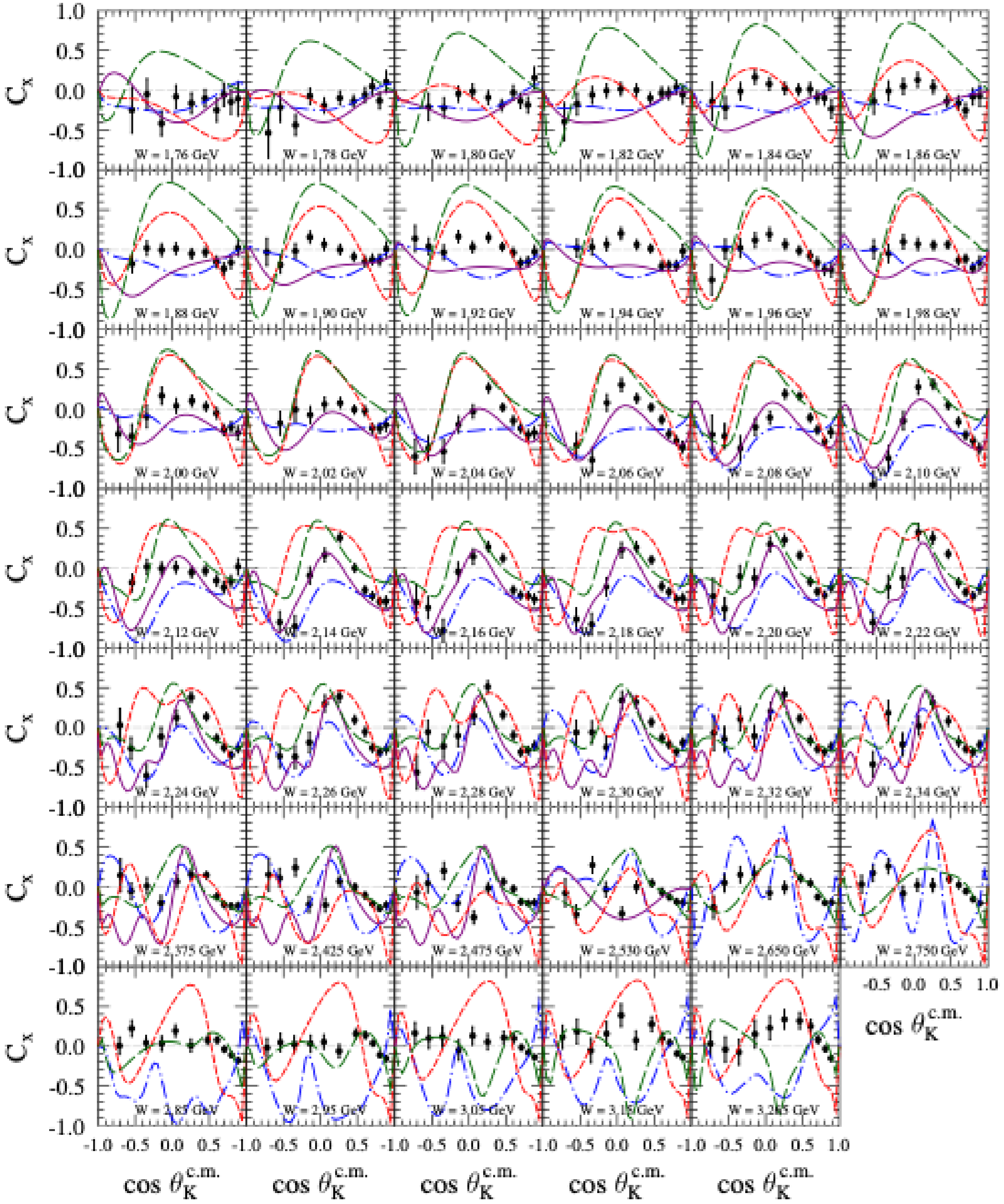
Kaon-Maid
BS3
RPR – Czech
JuBo

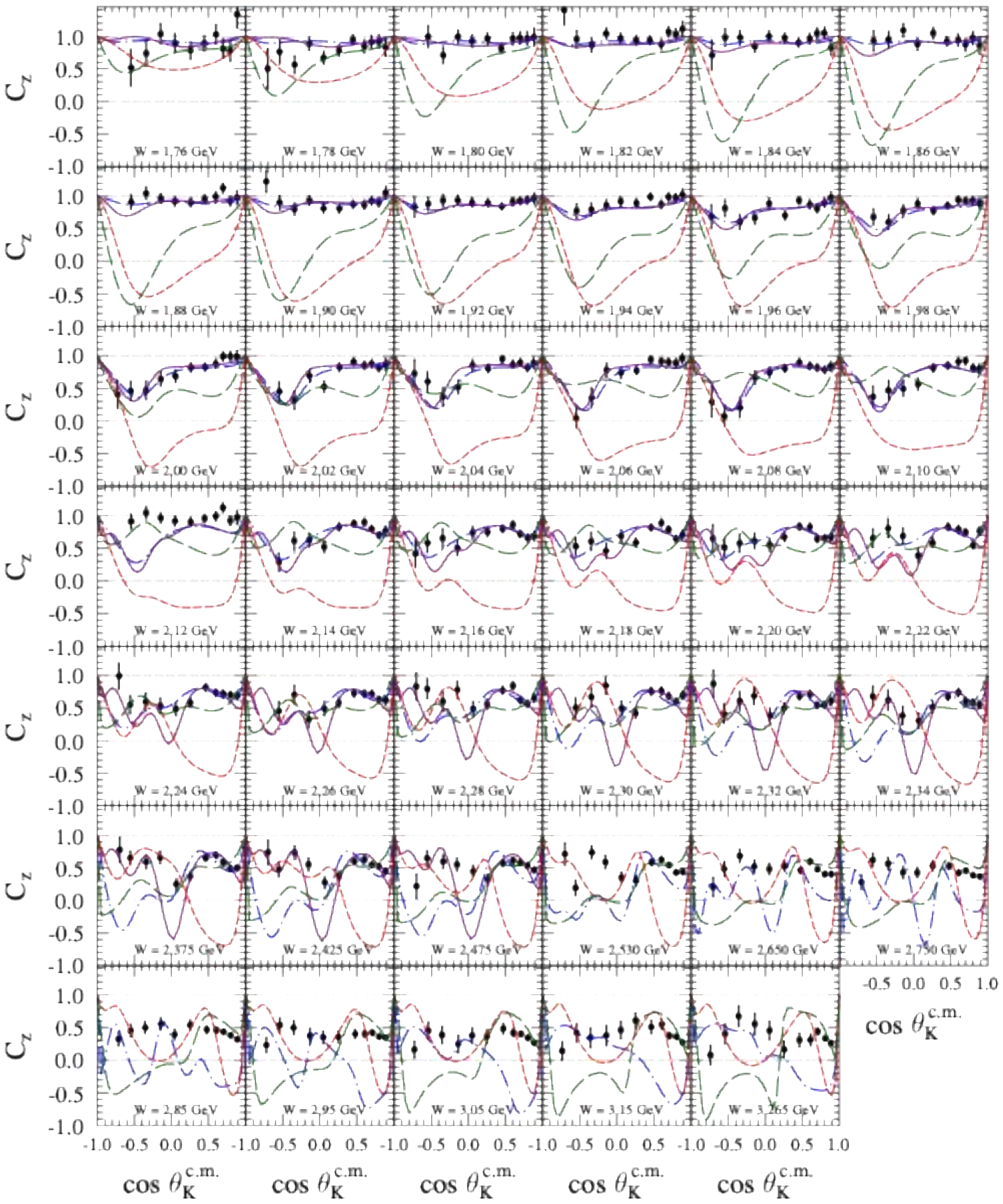
Data Results



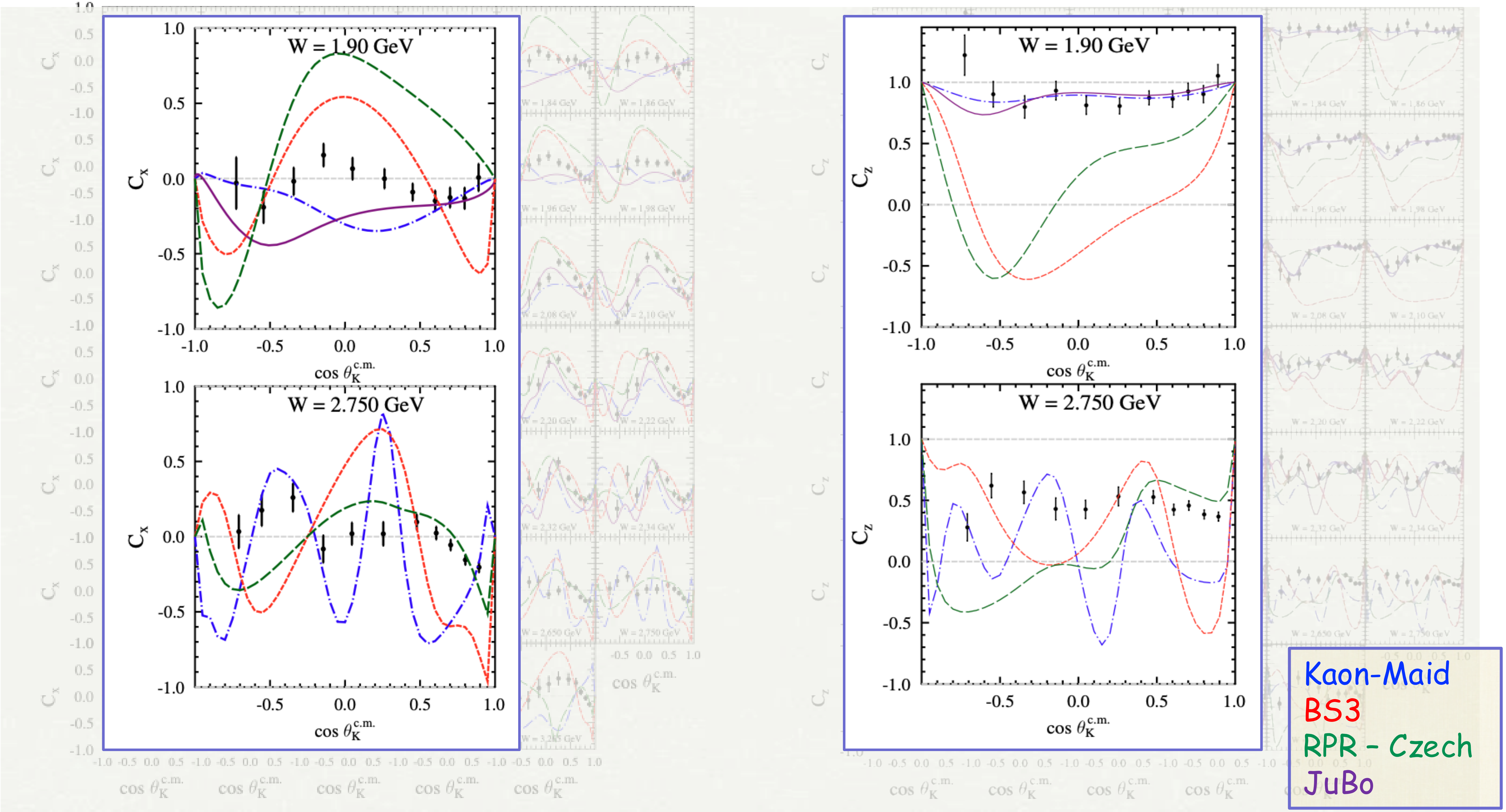
Kaon-Maid
BS3
RPR – Czech
JuBo

Data Results



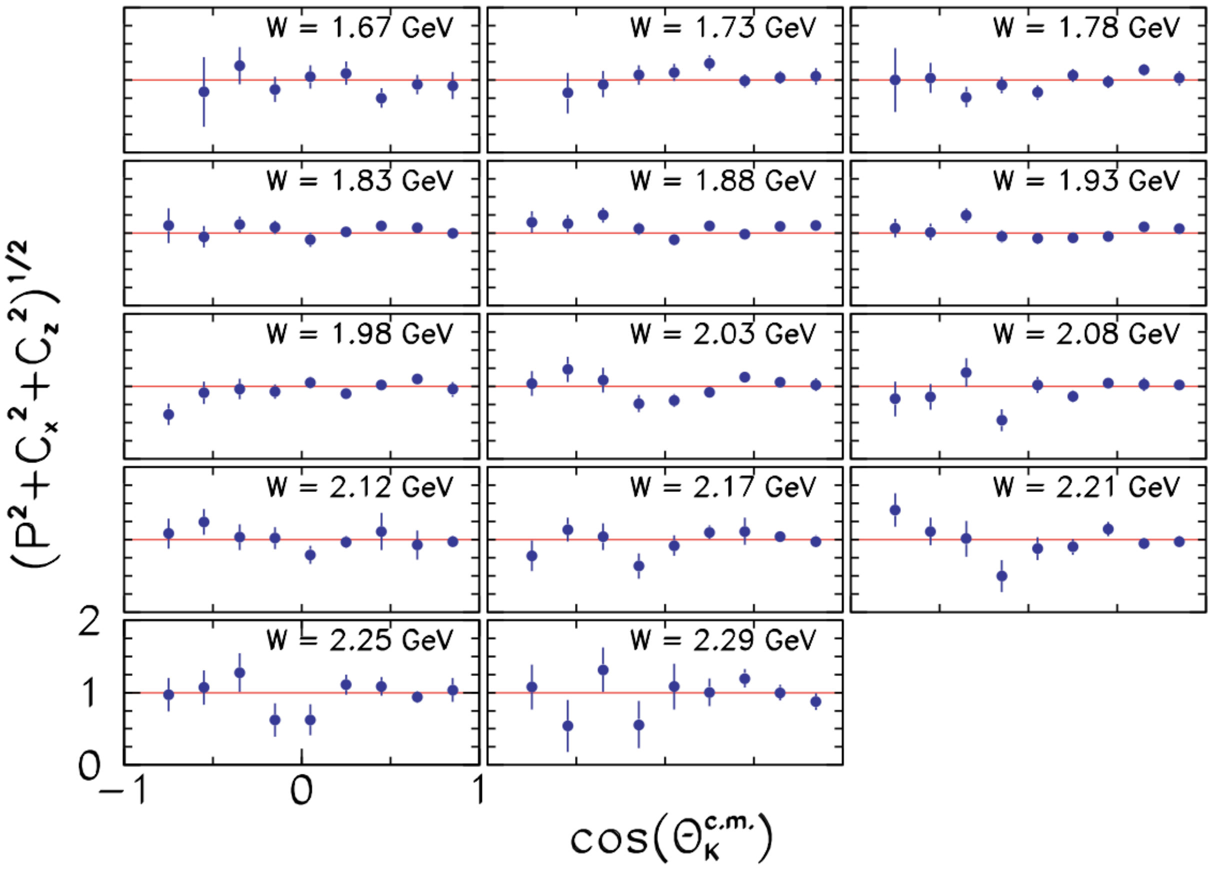


Data Results

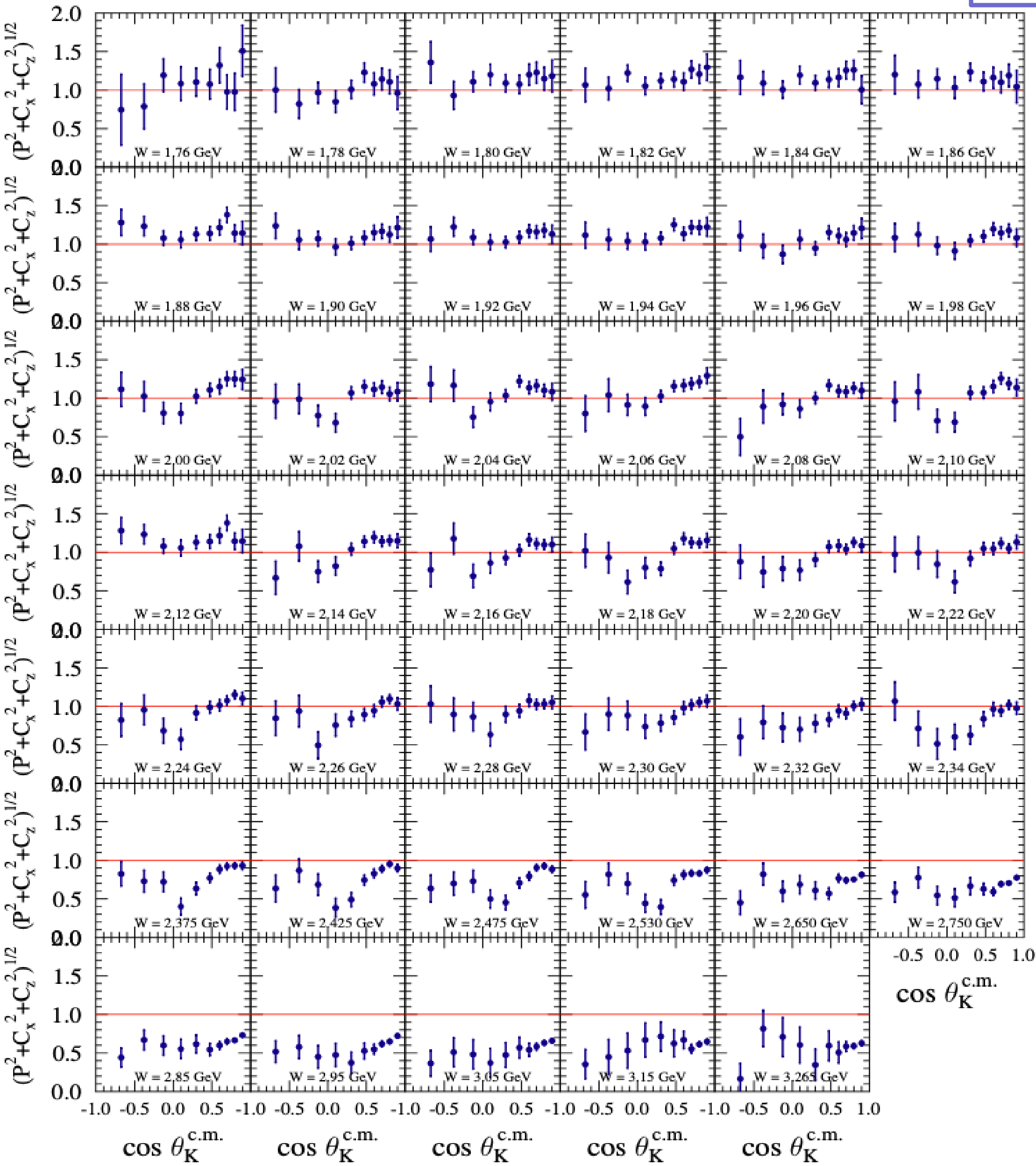


Data Results

g1c



g12

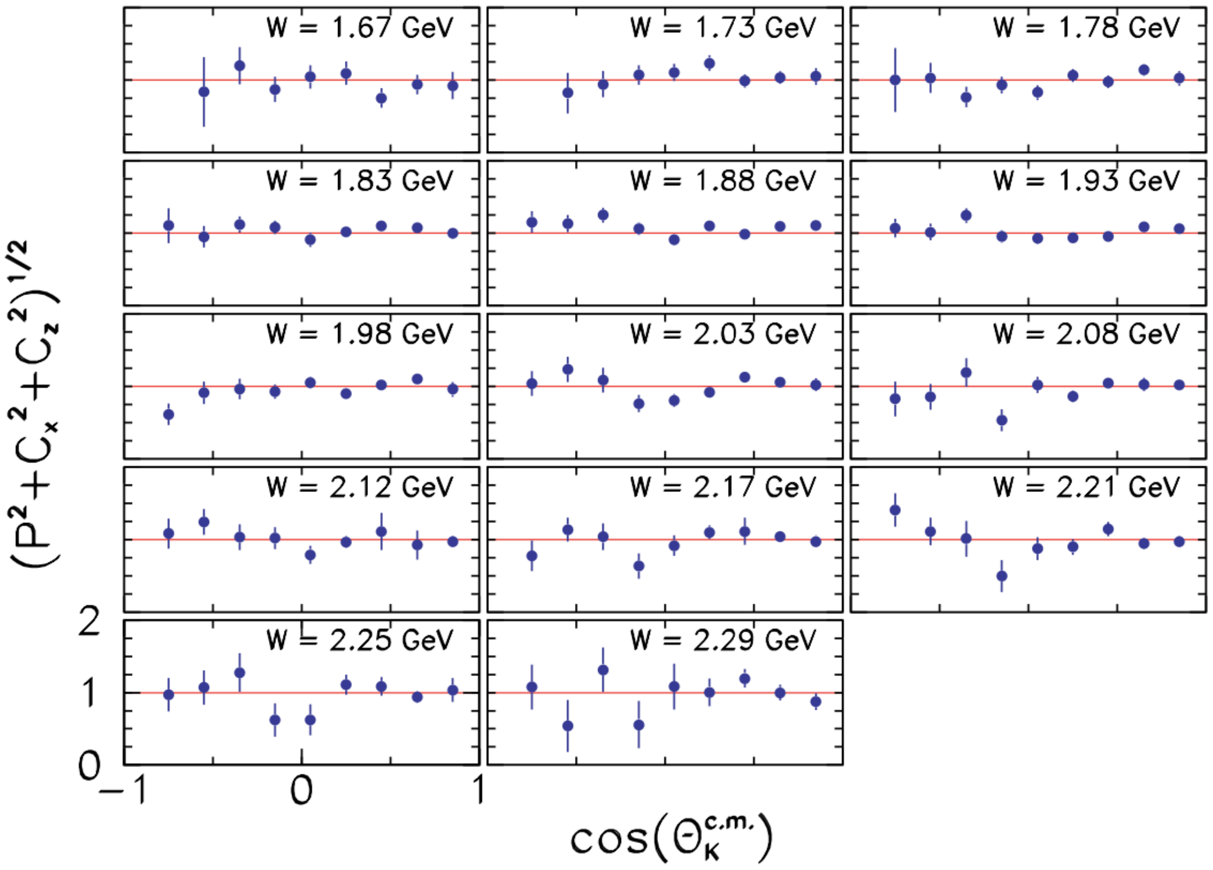


Reinhard Schumacher:

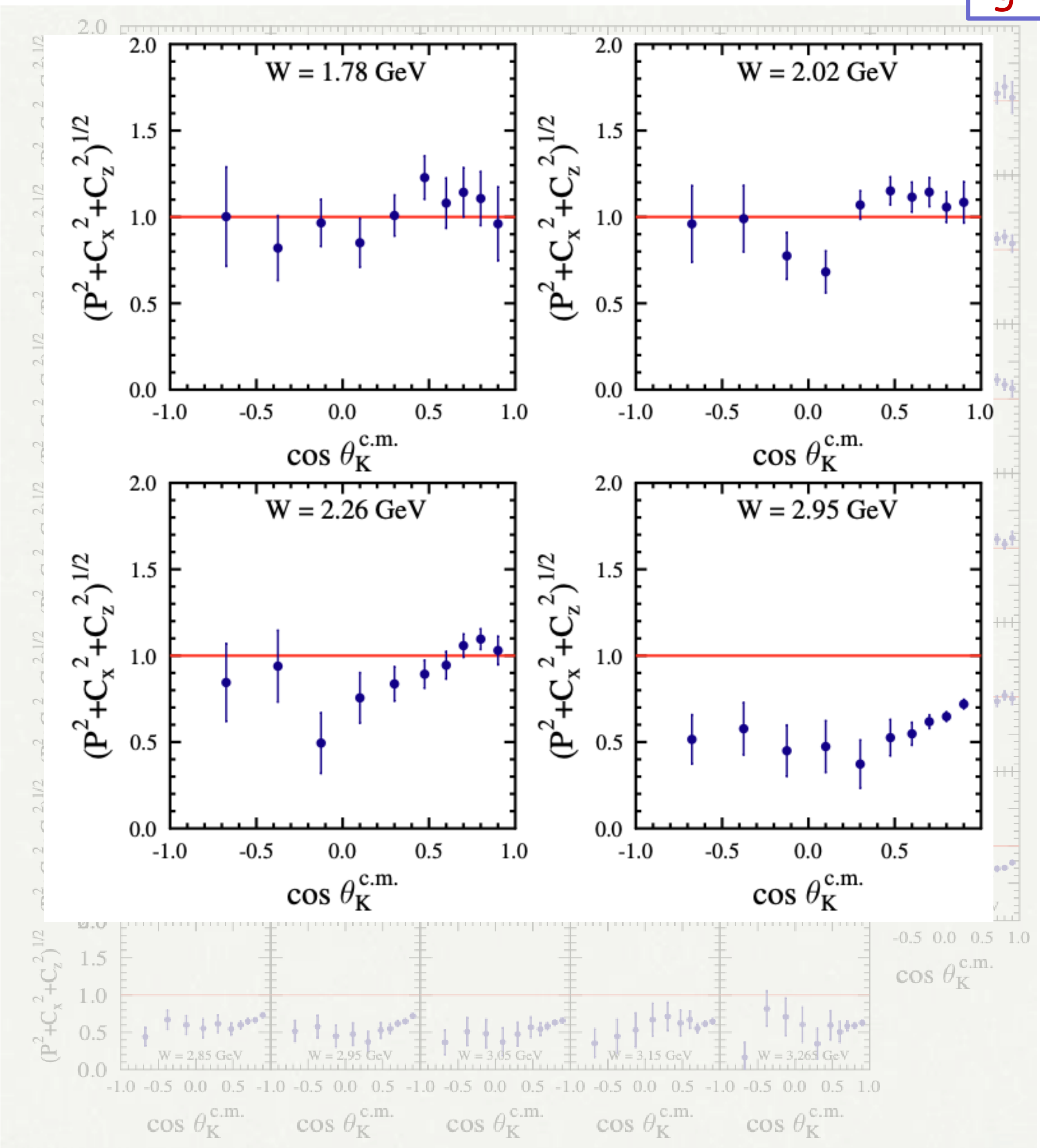
The paper does not discuss the very interesting question of the quantity “R” introduced in the 2007 paper. The three components of the Λ polarization seem to add up quite close to unity. As far as I have seen it is still not something that is explained in a qualitatively convincing way.

Data Results

g1c



g12



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Summary

- New measurement of C_x, C_z beam-recoil transferred polarization data for exclusive photoproduction of $K^+\Lambda$ from the CLAS g12 dataset are now (finally) available.
- New data greatly extend the well-cited/well-known data published by the CLAS collaboration in 2007 in terms of W coverage and in terms of statistical precision.
- No existing models – single channel or coupled-channel - describe the data well over the full kinematic range of the new data, so we expect that reconsideration of these models in view of these new results may lead to new insights into the contributing N* states that couple to $K^+\Lambda$.
- The extended coverage to higher W will enable improved understanding of the non-resonant backgrounds that extend down into the N* domain.
- An important next step is to include these new CLAS data into the model fits.

  This work is now getting underway.
- Paper completed ad hoc review in June and the CLAS-Collaboration review period is now in progress.

Phys. Rev. C

Measurement of Beam-Recoil Observables C_x and C_z for $K^+\Lambda$ Photoproduction

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(Dated: June 25, 2025)

Exclusive photoproduction of $K^+\Lambda$ final states off of a proton target has been an important component in the search for missing nucleon resonances and our understanding of the production of final states containing strange quarks. Polarization observables have been instrumental in this effort. The current work is an extension of previously published CLAS results on the polarization observables C_x and C_z. We extend the kinematic range up to invariant mass $W = 3.33$ GeV from the previous limit of $W = 2.5$ GeV with significantly improved statistical precision in the region of overlap. These data provide tighter constraints on the reaction models used to unravel the spectrum of nucleon resonances and their properties by not only improving the statistical precision of the data within the resonance region, but also by constraining t-channel processes that dominate at higher W but extend into the resonance region.

PACS numbers: 25.20.Lj, 13.40.-f, 13.60.Le, 14.20.Gk
Keywords: CLAS, photoproduction, hyperon polarization

I. INTRODUCTION

During the past 20 years a number of groups have collected high-quality data that have provided for a broad array of observables from exclusive meson photo- and electroproduction experiments. This advancement has allowed for marked progress in mapping out the spectrum of the excited states of the nucleon (N^*s) and in understanding their internal structure. It is information from these resonance states that encodes the underlying dynamics of these strongly coupled systems and allows for detailed insights into Quantum Chromodynamics (QCD) in the non-perturbative domain. The majority of the forward progress in this area has been provided by advanced analyses of the πN and $\pi^+\pi^- p$ exclusive reaction channels [1].

However, in recent years the high-precision data from CLAS on exclusive photoproduction of K^+Y ($Y = \Lambda, \Sigma^0$) [2–7] have proven crucial in this advancement, in particular, for the discovery of new baryon states known as the "missing" resonances. In the strangeness photoproduction channels, data are also available from MAMI [8], SAPHIR [9], GRAAL [10, 11], LEPS [12, 13], and BGO-OD [14]. KY exclusive production is sensitive to coupling to higher-lying N^* states for invariant mass $W > 1.6$ GeV, which is precisely the mass range where the understanding of the N^* spectrum is most limited. With these data, roughly a dozen N^* states have been claimed within global multi-channel analyses of the exclusive photoproduction data with a decisive impact from the hyperon polarization observables [15, 16].

Gaining insight into QCD in the non-perturbative regime requires not only high-precision experimental data, but advanced reaction models that accurately describe the data over a broad kinematic range. These reaction models include single-channel models [17–21] and dynamical coupled-channel models [22, 23]. However, the constraints and insights that such phenomenological reaction models provide to understand strong QCD dynamics are only as good as the quality of the experimental data. The less precise and complete the available data, the larger the uncertainties and ambiguities in the extracted multipoles and photocouplings that encode the nucleon resonance structure information. Improving the statistical and systematic precision, as well as extending the kinematic range of the available data will be critical to foster these efforts and to further understand both the resonant and non-resonant contributions.

The current work is an extension of previously published CLAS photoproduction data on the Λ hyperon polarization observables C_x and C_z [4]. These observables characterize the polarization transfer from a circularly polarized incident photon beam to a recoiling hyperon along orthogonal axes in the hadron reaction plane. We extend the kinematic range up to invariant mass $W = 3.33$ GeV from the previous limit of $W = 2.5$ GeV with significantly improved statistical precision in the region of overlap ($1.78 < W < 2.5$ GeV). While the present results extend beyond what is generally considered the resonance region, it is important to understand this higher W region as it is expected to be dominated by t-channel processes. Such processes extend into the resonance region and are considered to be an underlying background. Therefore, understanding the t-channel processes at higher W and extrapolating them into the resonance region provides an important constraint on missing resonance identification.

The organization for the remainder of this paper is as follows. In Section II the formalism of the beam-recoil transferred polarization and the polarization extraction approach are presented. Section III provides details on the experiment, describes the event selection procedures, data binning, yield extraction method, and discussion of the systematic uncertainty analysis. Section IV presents the measured Λ hyperon C_x and C_z observables com-

Backup

Motivation

Particle	J^P	overall	Status as seen in $N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta\prime$
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.
* * * Existence is very likely.
** Evidence of existence is fair.
* Evidence of existence is poor.