

Measurement of the helicity asymmetry E for $\vec{\gamma} \vec{p} \rightarrow p \pi^0$

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Hadron Spectroscopy

Composite nature of baryons gives rise to a rich excitation spectrum

- Provide resonance properties for all accessible baryon states
- Understanding the internal structure of the nucleon and its fundamental degrees of freedoms



TABLE II. The new nucleon resonances listed by the Particle Data Group [2].

State	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
$N(1860)$	$5/2^+$	**	*	**		*	*					
$N(1875)$	$3/2^-$	***	**	**	*	**	*	*	*	*	*	*
$N(1880)$	$1/2^+$	***	**	*	**	*	*	**	**	**	**	
$N(1895)$	$1/2^-$	****	*****	*	*	*	*****	**	**	*	*	****
$N(2080)$	$5/2^-$	***	***	**	*	*	*	*	*	*	*	*
$N(2120)$	$3/2^-$	***	***	***	**	**		**	*	*	*	*

V. Crede AIP Conf. Proc.

Hadron Spectroscopy

Goal: Constrain the four complex amplitudes

“Complete experiment”:
8 well chosen observables
(single, and double)

	σ	Σ	T	P	E	F	G	H	$T_{x'}$	$T_{z'}$	$L_{x'}$	$L_{z'}$	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{z'}$	Stolen from V. Crede
$p\pi^0$	✓	✓	✓	(✓)	✓	✓	✓	✓									
$n\pi^+$	✓	✓	✓	(✓)	✓	✓	✓	✓					✓	published			
$p\eta$	✓	✓	✓	(✓)	✓	✓	✓	✓					✓	acquired or under analysis			
$p\eta'$	✓	✓	✓	(✓)	✓	✓	✓	✓									
$p\omega(\phi)$	✓	✓	✓	(✓)	✓	✓	✓	✓								Tensor polarization, SDMEs	
$K^+\Lambda$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
$K^+\Sigma^0$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
$K^0\Sigma^+$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
																Neutron (deuteron) targets	
$p\pi^-$	✓	✓			✓												
$K^+\Sigma^-$	✓	✓	✓	✓	✓	✓	✓	✓									
$K^0\Lambda$	✓	✓	✓	✓	✓*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
$K^0\Sigma^0$	✓	✓	✓	✓	✓*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

“Claims of evidence for new baryon states must be based on a sufficiently complete set of partial waves in the fit.” PDG 22

Hadron Spectroscopy -- FROST

This Work

Phys. Lett. B 750, 53

Phys. Lett. B 755, 64

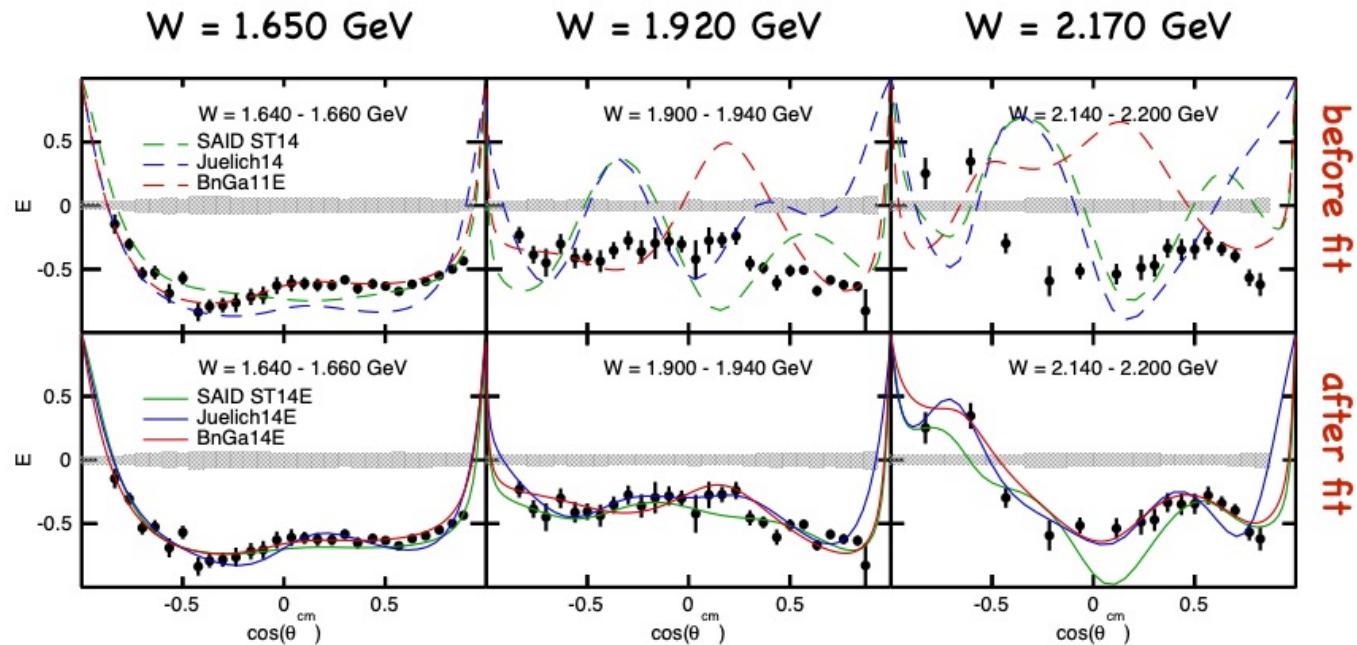
Phys. Rev. C 96, 065209

	σ	Σ	T	P	E	F	G	H	$T_{x'}$	$T_{z'}$	$L_{x'}$	$L_{z'}$	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{z'}$
Proton targets																
$p\pi^0$	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$n\pi^+$	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$p\eta$	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$p\eta'$	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$p\omega(\phi)$	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tensor polarization, SDMEs																
$K^+\Lambda$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^+\Sigma^0$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\Sigma^+$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Neutron (deuteron) targets																
$p\pi^-$	✓	✓			✓											
$K^+\Sigma^-$	✓	✓	✓	✓	✓	✓	✓	✓								
$K^0\Lambda$	✓	✓	✓	✓	✓*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓	✓	✓	✓*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Phys. Lett. B 817, 136304

Beam-Helicity Asymmetry

Selected results of FROST Experiment $\vec{\gamma} \vec{p} \rightarrow \pi^+ n$



- FROST experiment produced 900 data points of the **double-polarization observable E** in π^+ photoproduction with circularly polarized beam on longitudinally polarized protons for $W = 1240 - 2260$ MeV.
- Significant improvements of the description of the data in SAID, Jülich, and BnGa partial-wave analyses after fitting.
- **New evidence found in this data for a $\Delta(2200)7/2^-$ resonance (BnGa analysis).**

Beam-Helicity Asymmetry

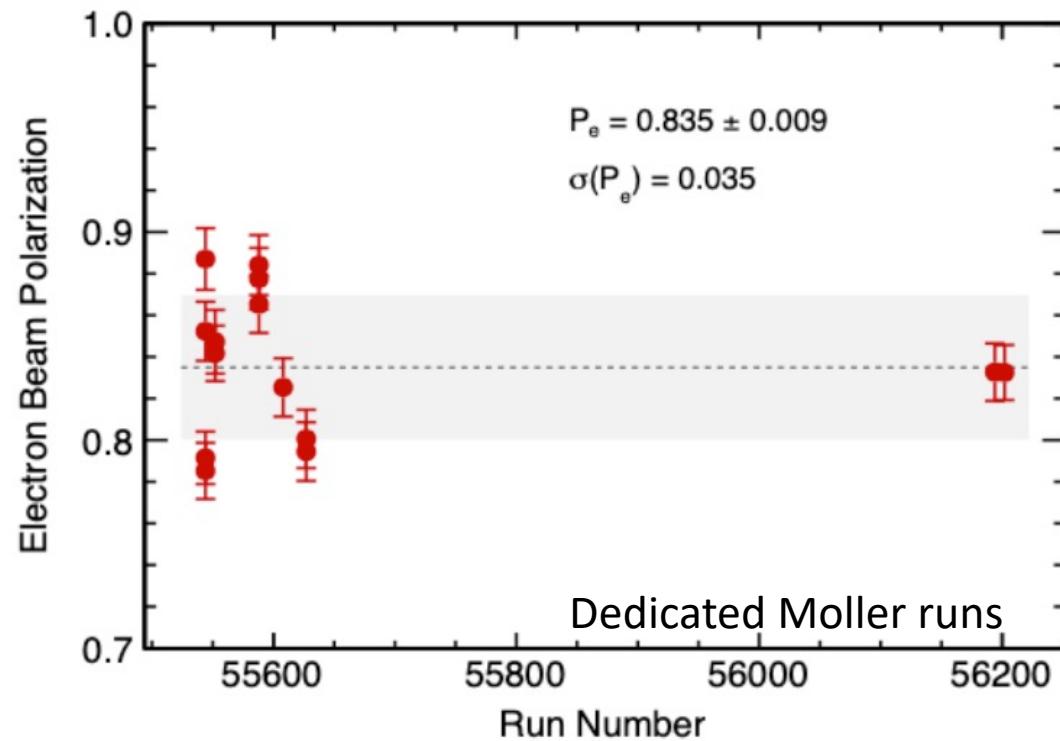
$$\frac{d\sigma}{d\Omega}(E_\gamma, \cos\theta) = \sigma_0 [1 - P_L \Sigma \cos(2\phi) + P_x (-P_L \mathbb{H} \sin(2\phi) + P_\odot \mathbb{F}) \\ - P_y (-\mathbb{T} + P_L \mathbb{P} \cos(2\phi)) - \underline{P_z} (-P_L \mathbb{G} \sin(2\phi) + \underline{P_\odot \mathbb{E}})]$$

$$\frac{d\sigma}{d\Omega}(E_\gamma, \cos\theta) = \sigma_0 [1 - P_z P_\odot \mathbb{E}]$$

$$\mathbb{E} = \frac{1}{P_z P_\odot} \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$$

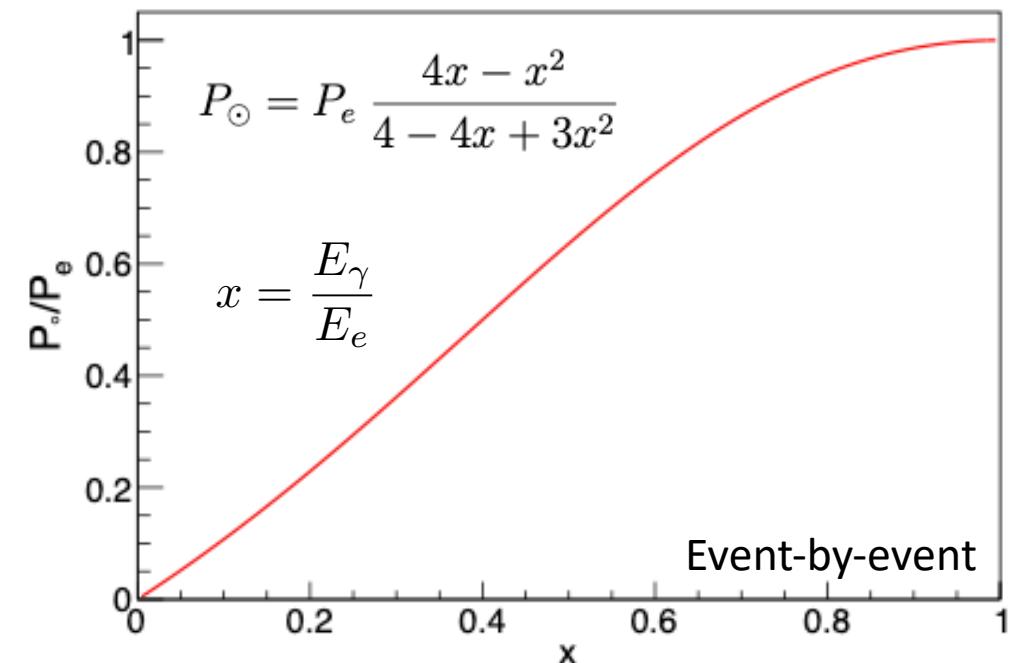
Experiment -- g9

- Tagged Photon beam (Polarised)
 - Helicity flip at 30 Hz



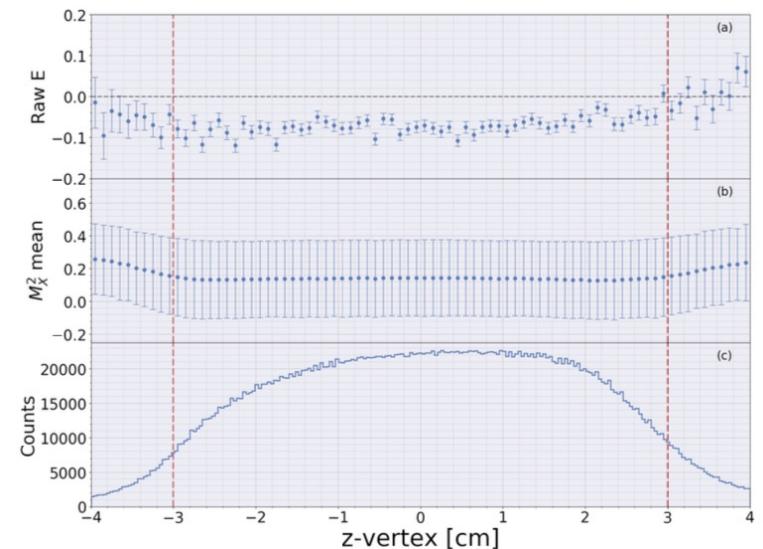
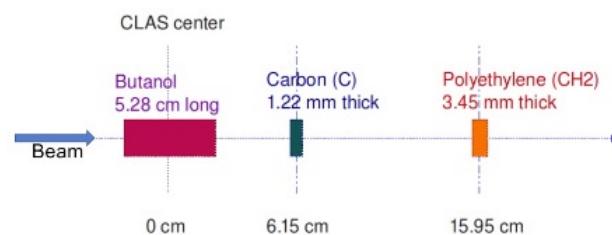
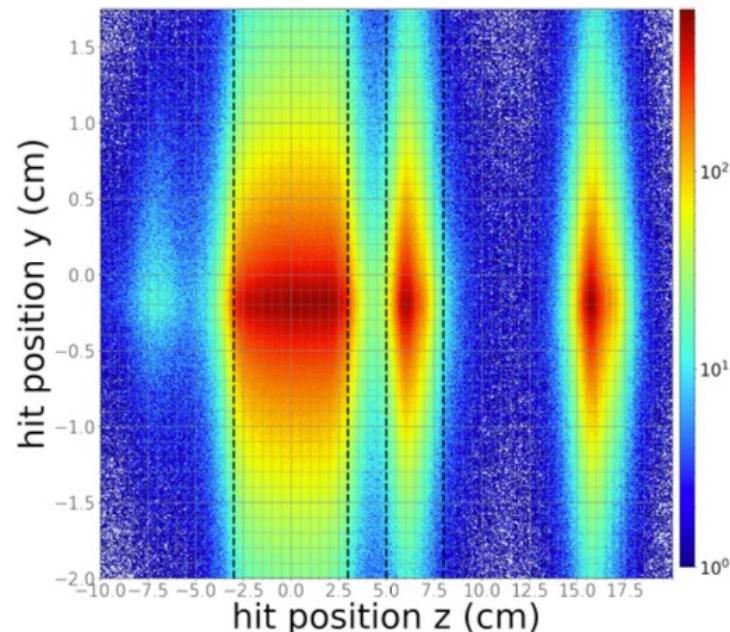
CLAS Collaboration March 2

Electron Beam Energy (GeV)	Photon Beam Polarization	# of Events (B)	Observable
1.645	Circular	~1	E
2.478	Circular	~2	E
2.751	Linear	~1	G
3.538	Linear	~2	G
4.599	Linear	~3	G



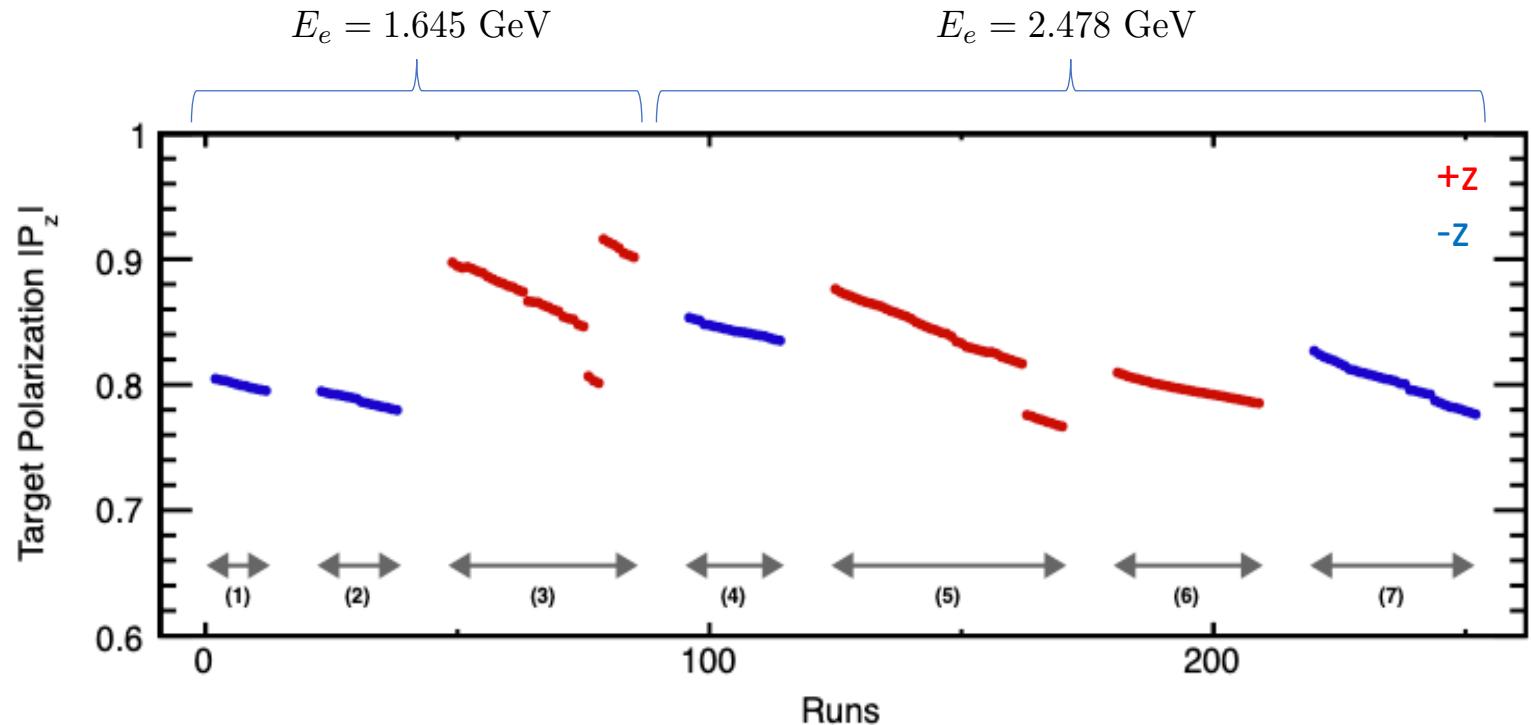
Experiment -- g9

- Frozen Spin Target
 - Butanol target
 - Dynamically Polarized
 - Spin frozen when target cooled at very low temp



Frost Experiment

- Target Polarization
 - NMR measurement
 - Run-by-run basis
 - Loss of polarization $\sim 1\%/\text{day}$



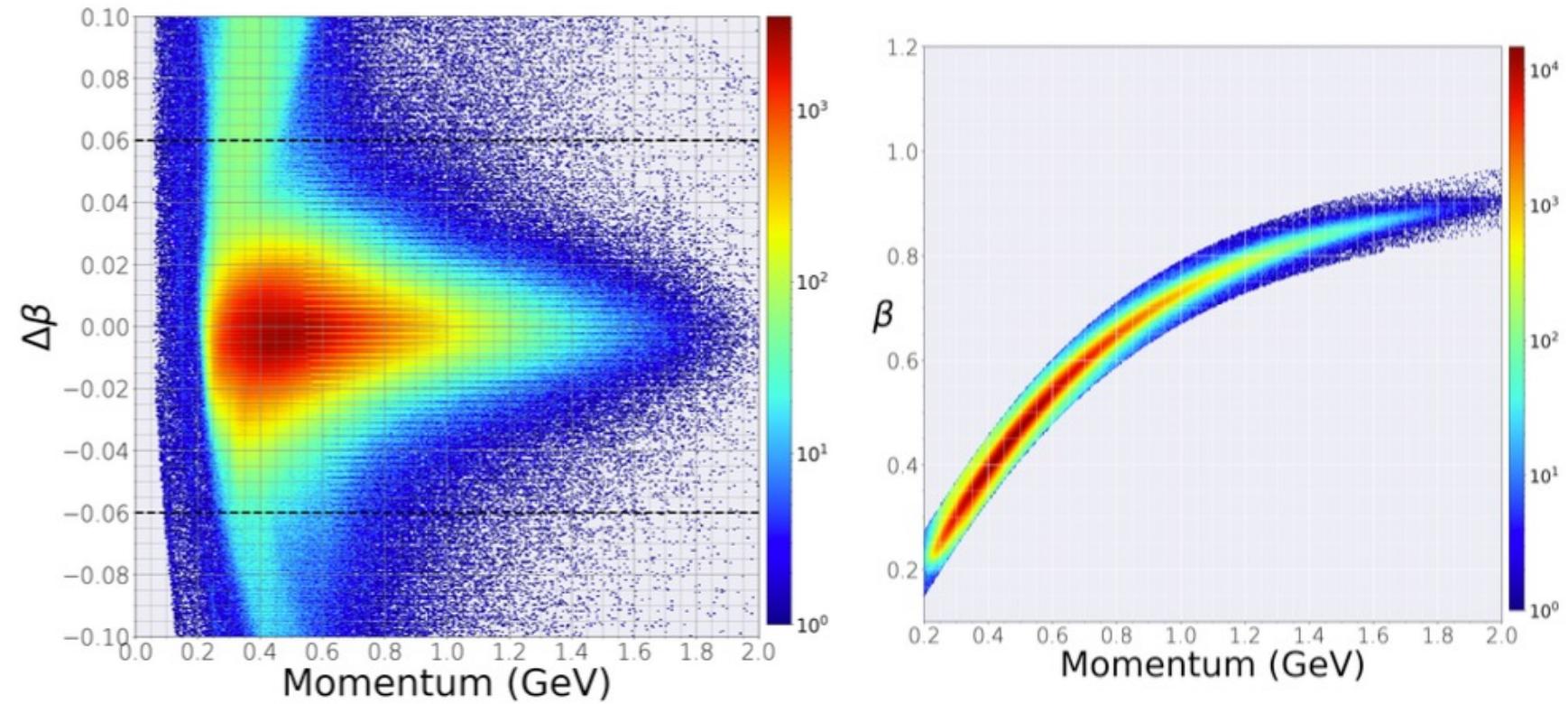
Event Reconstruction

$\gamma p \rightarrow pX$

- Particle identification

$$\Delta\beta = \beta_{meas} - \beta_{calc}$$

$$\beta_{calc} = \frac{p}{\sqrt{p^2 + m^2}}$$

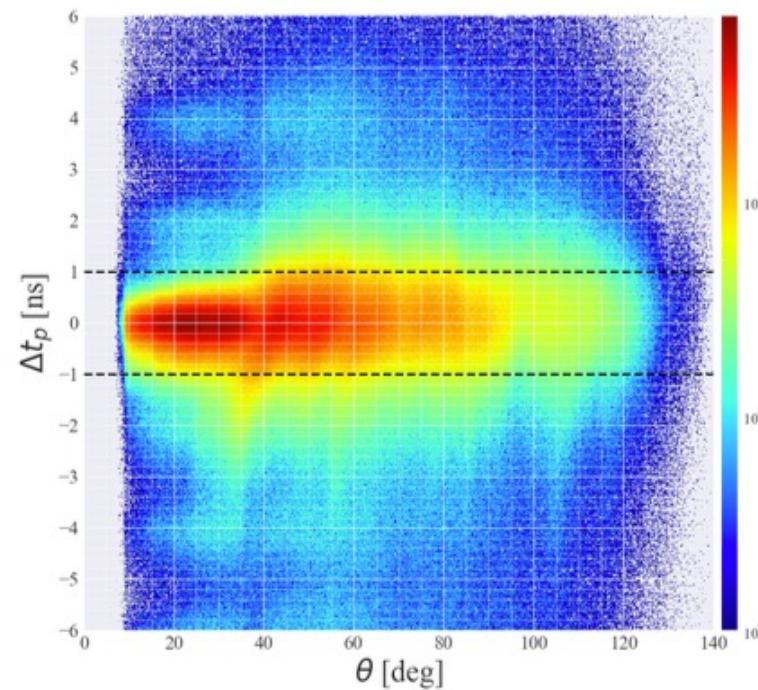
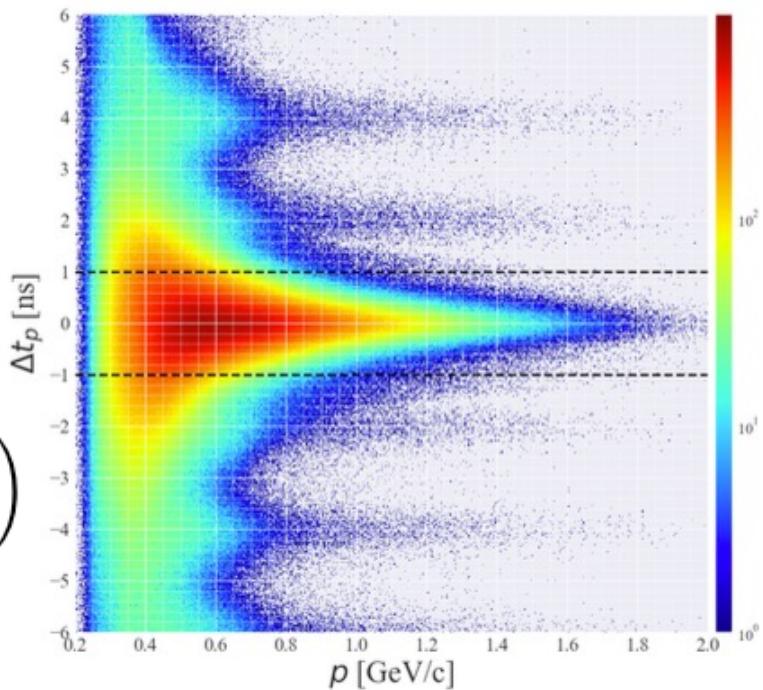


Event Reconstruction

- Photon Selection

Events with 1 photon in 2ns beam bucket where selected for further analysis (10% of events removed)

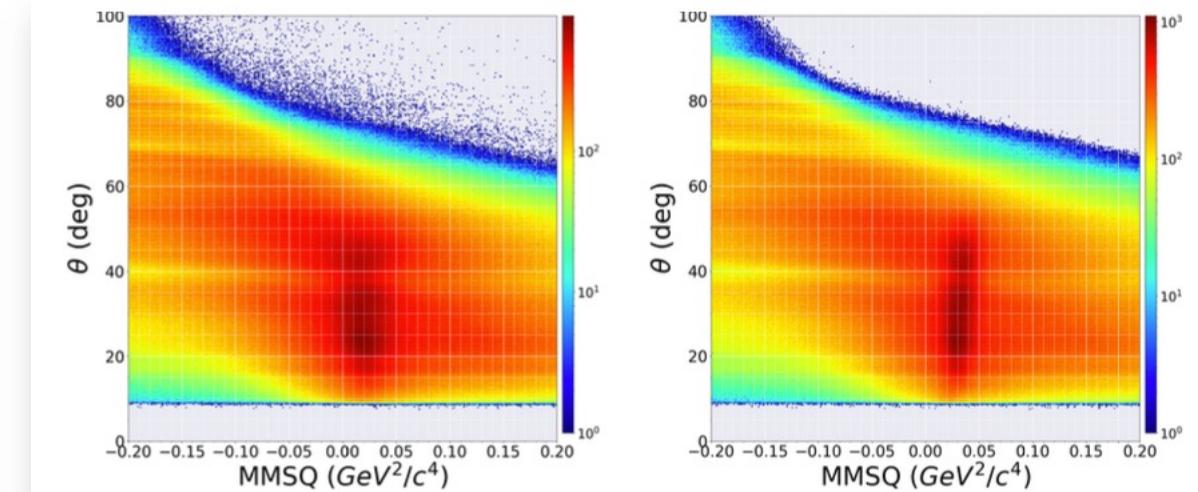
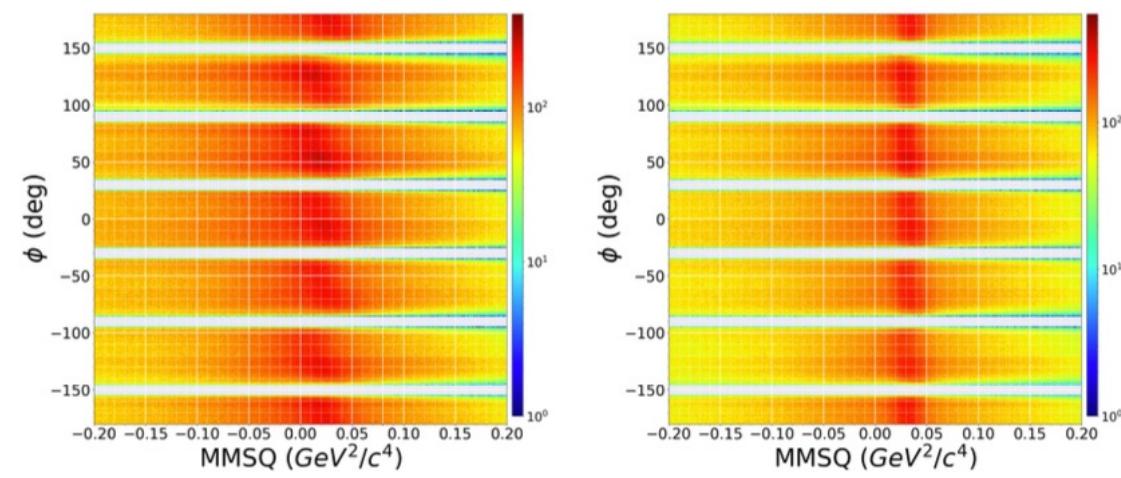
$$\Delta t = t_{v,\gamma} - t_{v,p} = \left(t_\gamma + \frac{z}{c} \right) - \left(t_{p,sc} - \frac{l_{sc}}{\beta_{calc} c} \right)$$



Data corrections

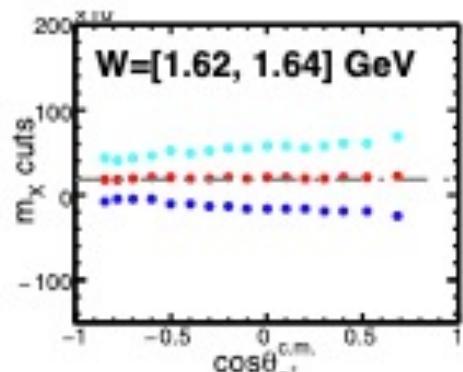
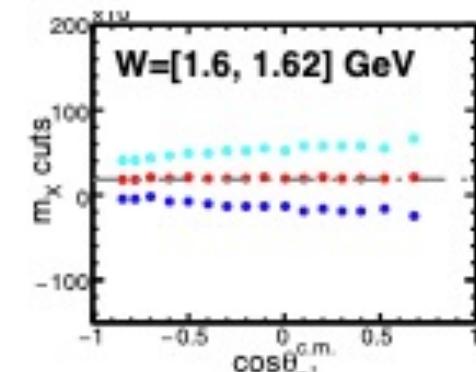
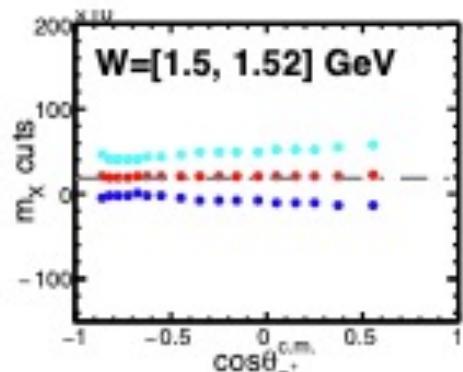
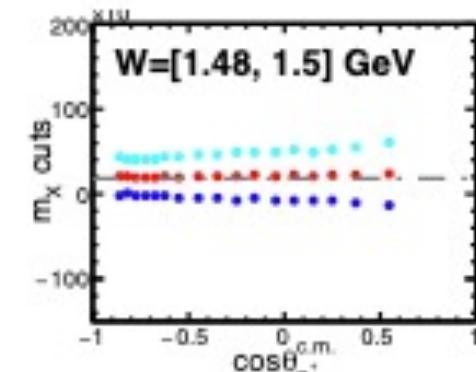
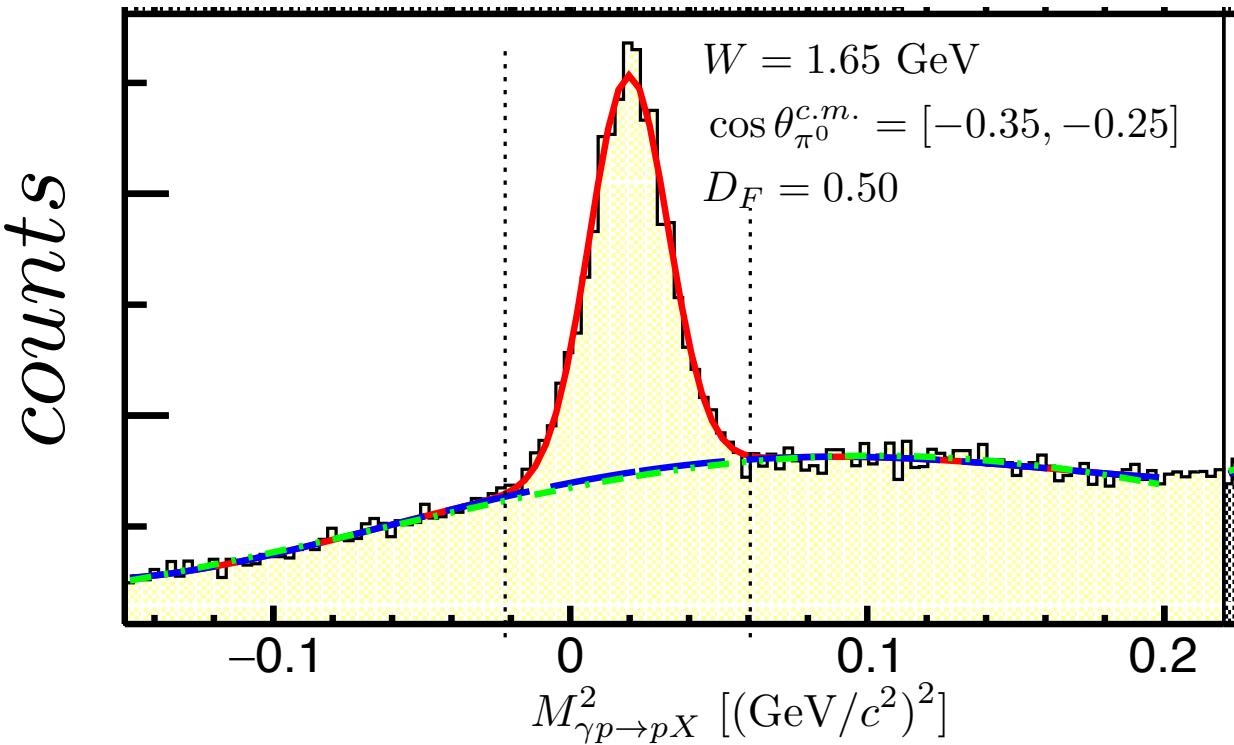
$$\gamma p \rightarrow pX$$

- Energy loss and momentum correction
 - ELOSS package
 - FROST momentum corrections (CLAS Analysis Note 2014-101)



Reaction Reconstruction

- Missing Mass $\gamma p \rightarrow p\pi^0$



Dilution Factor

Events originating from bound (unpolarized) nucleons dilute the observable

- Utilize Carbon data to estimate contributions
- **Ice build-up complicated method**

$$D_F = \frac{N_{pol}}{N_{tot}}$$

$$E = \frac{1}{D_F} E^{eff} = \frac{1}{D_F} \frac{1}{P_z P_\odot} \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$$

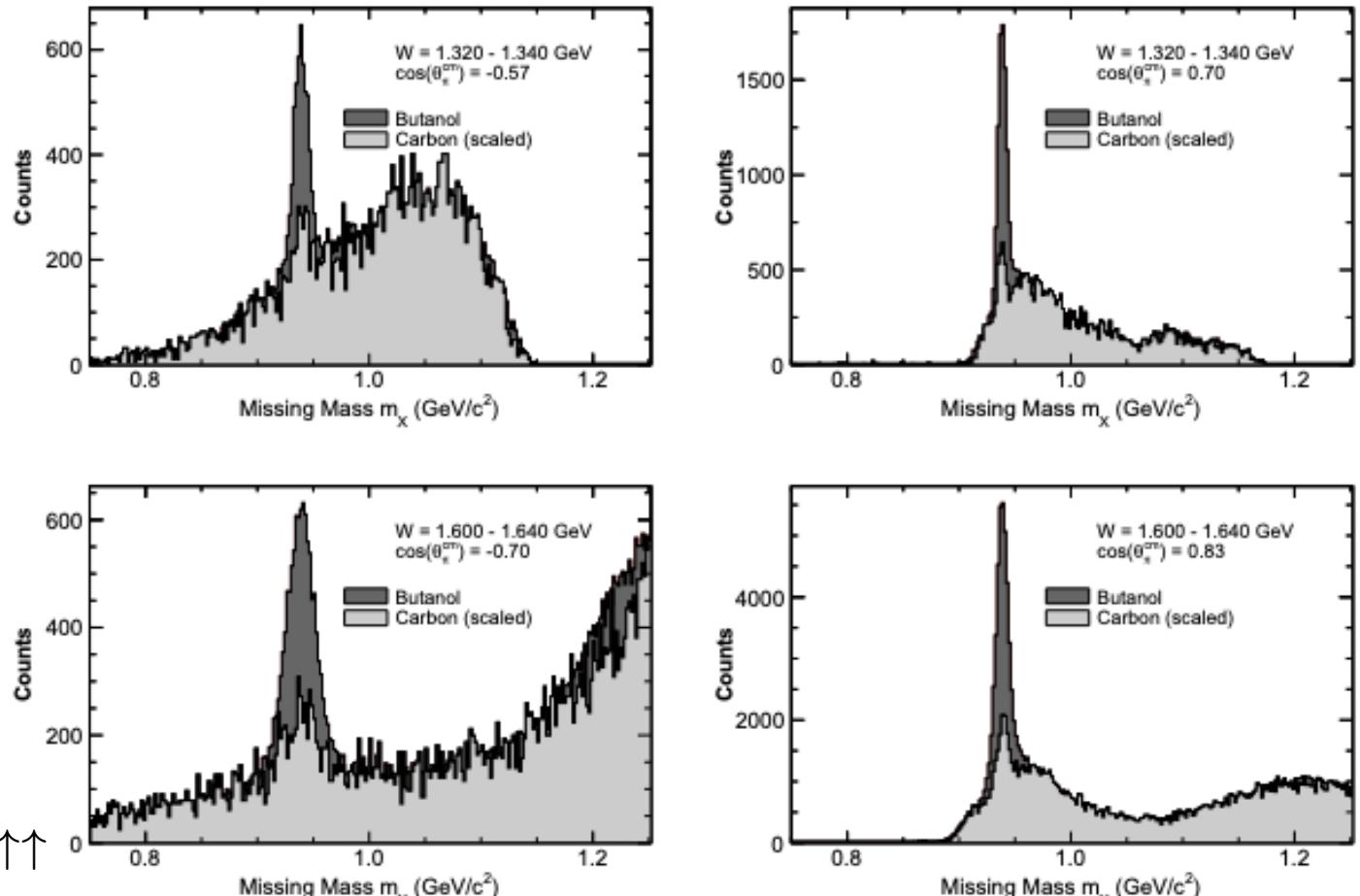


Figure from CLAS Analysis Note 2014-101

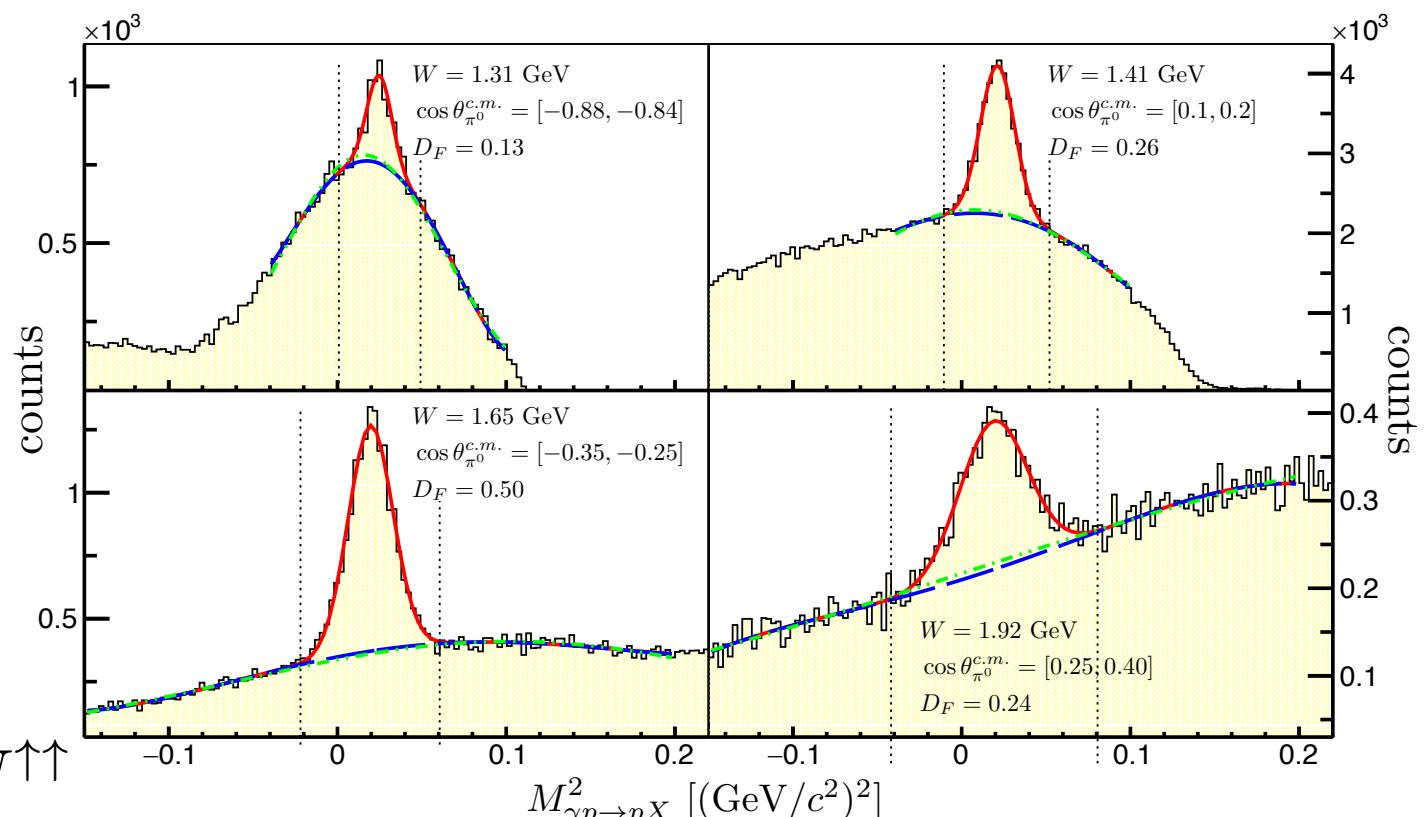
Dilution Factor

Dilution Extracted from fits to missing mass

Constrain Bound Nucleon PDF using Carbon and Butanol sidebands

$$D_F = \frac{N_{pol}}{N_{tot}}$$

$$E = \frac{1}{D_F} E^{eff} = \frac{1}{D_F} \frac{1}{P_z P_\odot} \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$$

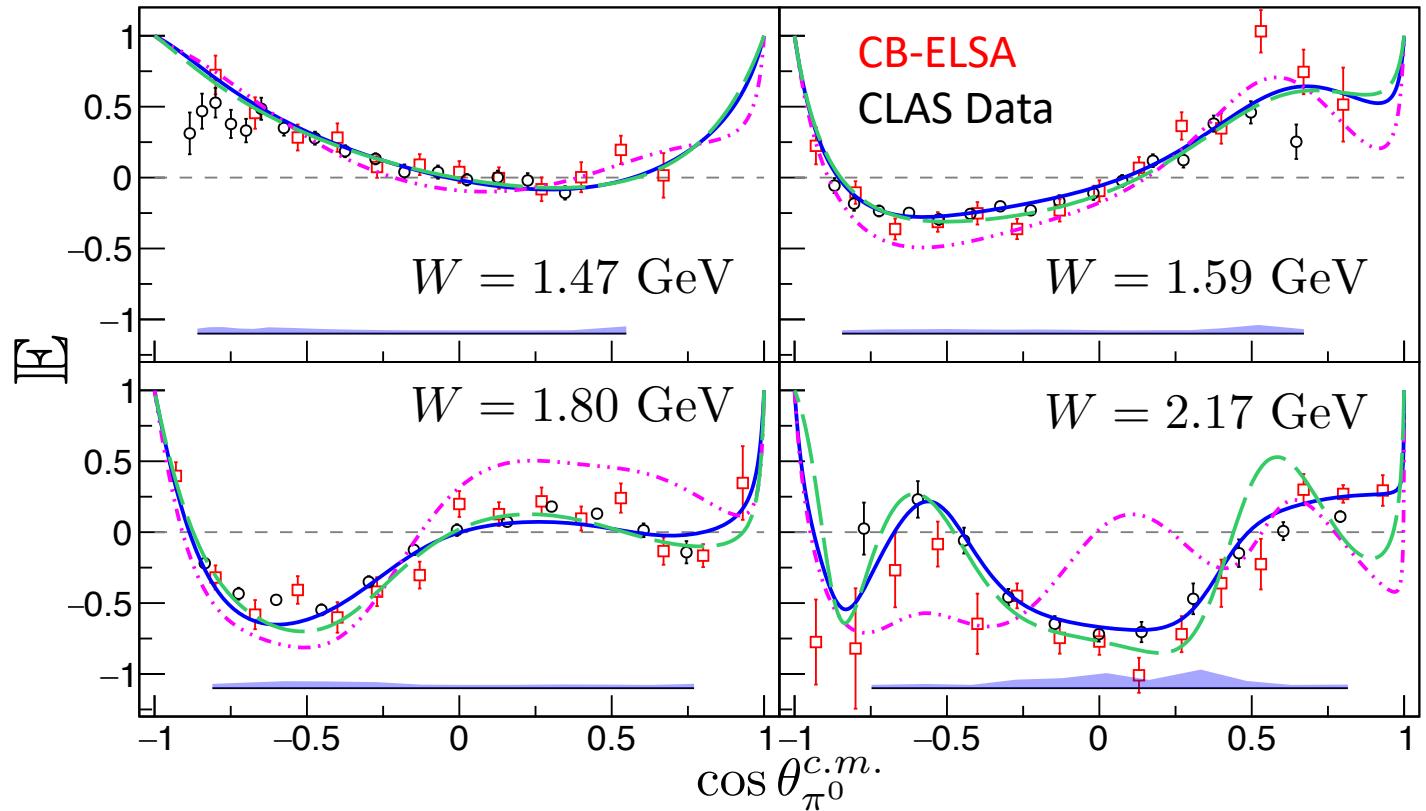


Systematic Studies

Source	σ^{sys}
Particle identification	0.002
Reaction reconstruction / m_X cut	0.008
Photon selection	0.015
Vertex cuts	0.006
Fiducial cuts	0.002
Dilution factor	0.014
Point-to-point D_F	0.0–0.3
Total Point-by-point (absolute) Systematic	0.023
Photon polarization	4%
Target polarization	6%
Global Scale Systematic	7.2%

Results

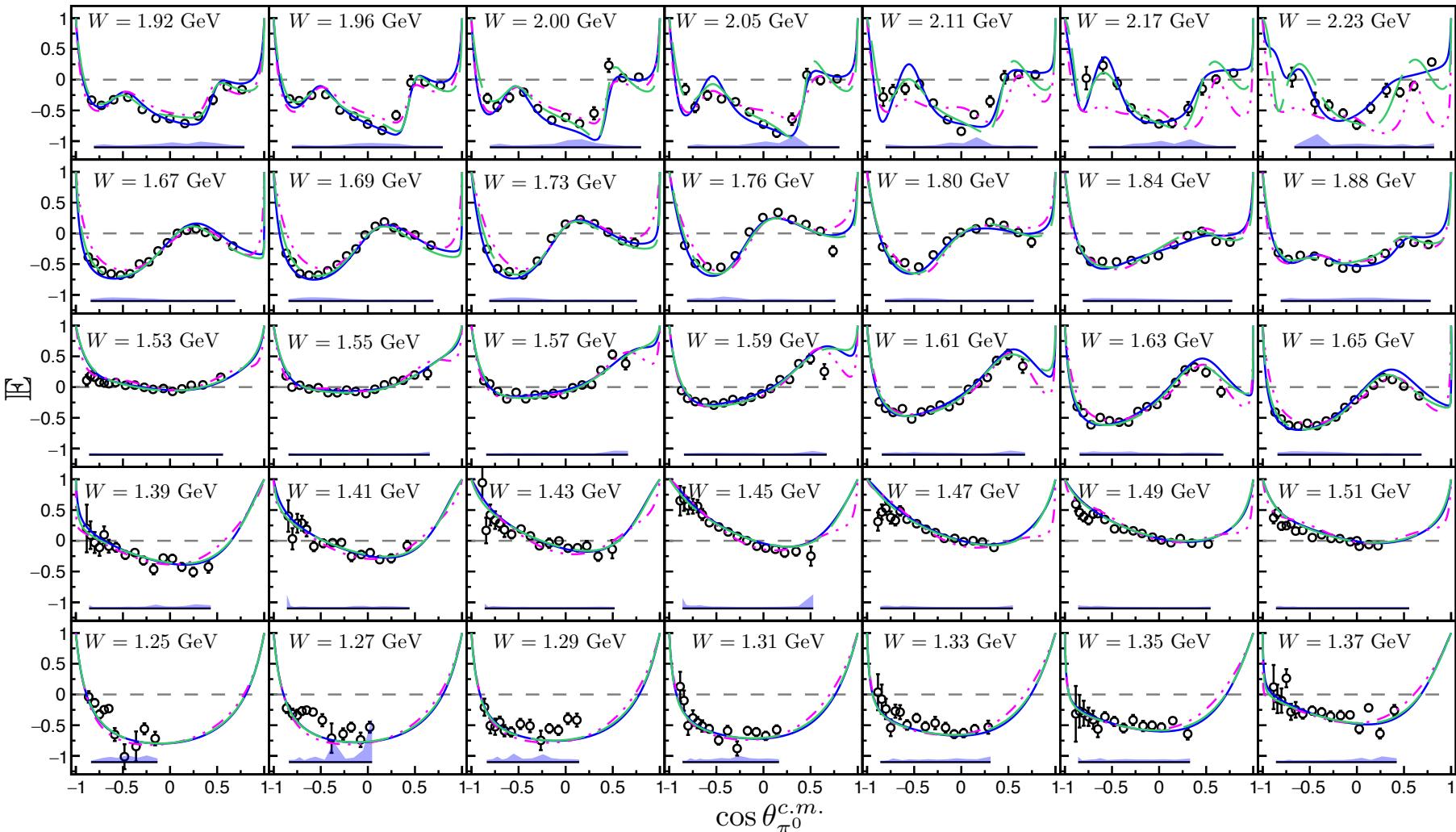
- Reasonable agreement between published data and CLAS
- CLAS data provide larger kinematic coverage (to higher/lower W) with higher precision
- PWA ([SAID](#), [Bonn-Gatchina](#), [MAID](#)) predict data well at lower W



Results

$$\vec{\gamma} \vec{p} \rightarrow p \pi^0$$

- Data from CLAS were included in the World Data Base
- Fitted within the **SAID**, **MAID**, and **Bonn-Gatchina** PWA
- New solutions describe data well
- No significant changes observed in SAID and MAID analyses
- Small changes in Bonn Gatchina amplitudes (N2120, D1940)



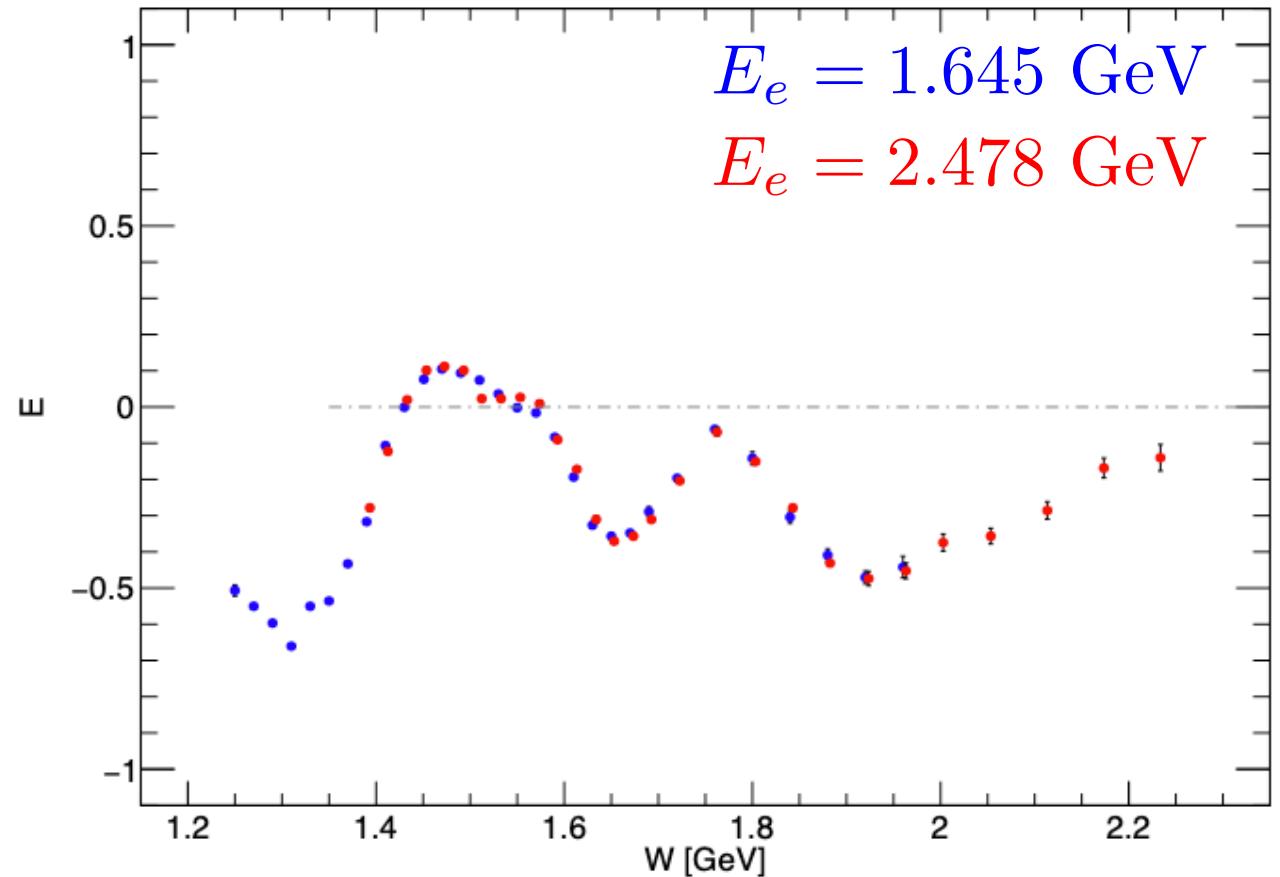
Summary

- Determination of E for $\vec{\gamma}\vec{p} \rightarrow p\pi^0$ using FROST data
- Increased kinematic coverage to lower W
- Increase precision at higher W
- Results provide an independent check
 - consistent with previous measurements (CBELSA)
- Small changes observed in photo decay amplitudes by the Bonn-Gatchina PWA group associated with the N(2120) and Delta(1940) states
- MAID and SAID analyses reported no significant changes
 - A detailed investigation is underway

Thank you

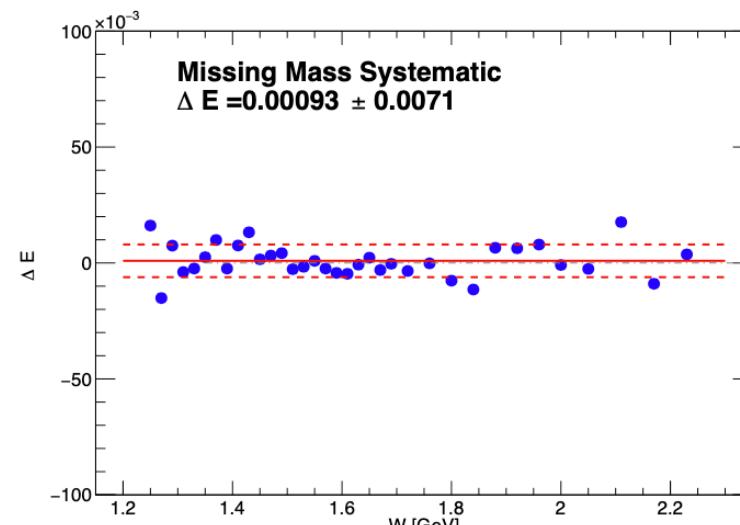
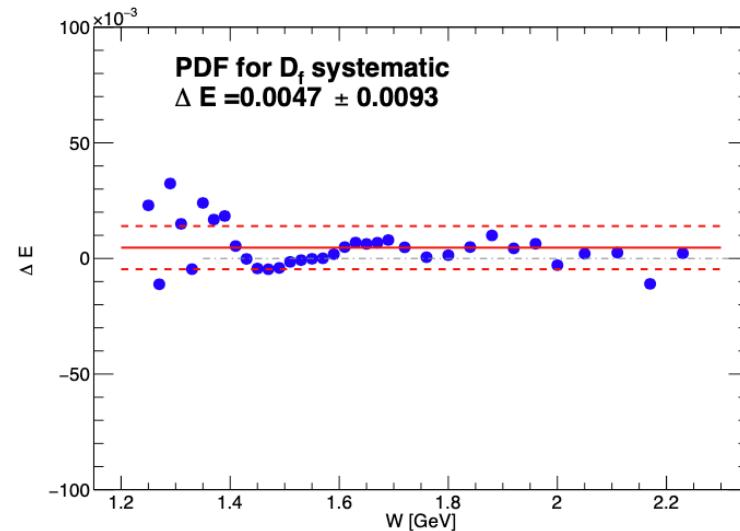
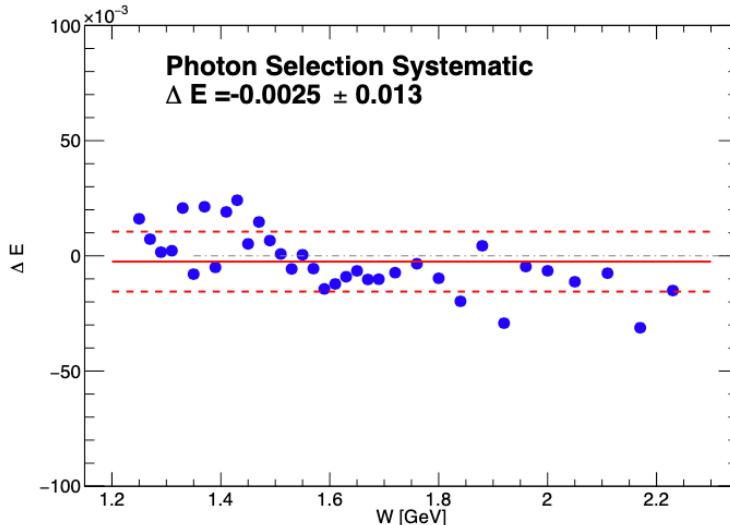
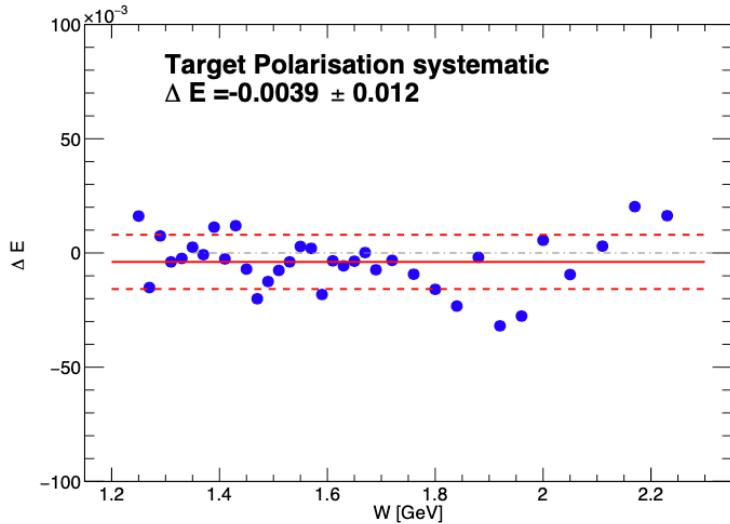
Systematic Studies

- Comparison of E between two electron energies
 - Consistent NMR measurements
 - Consistent Moller measurements

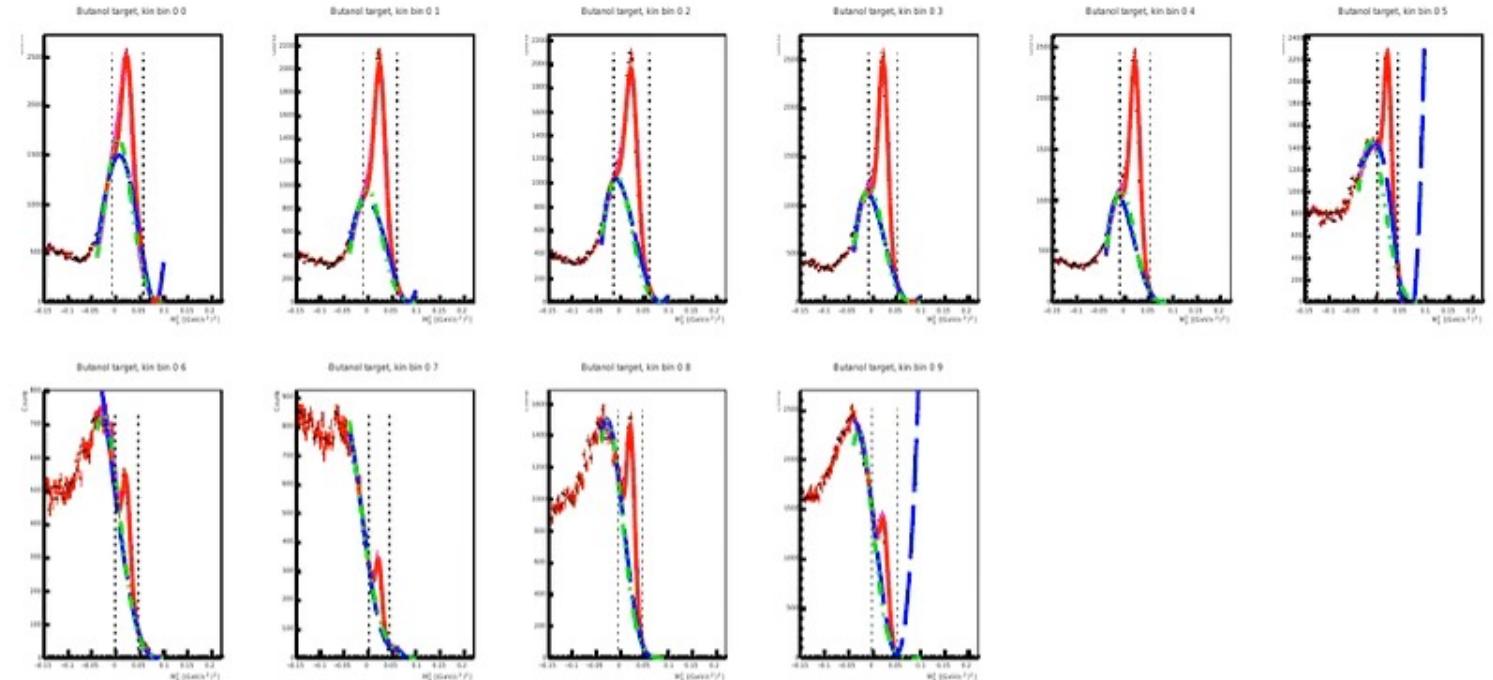


Systematic Studies

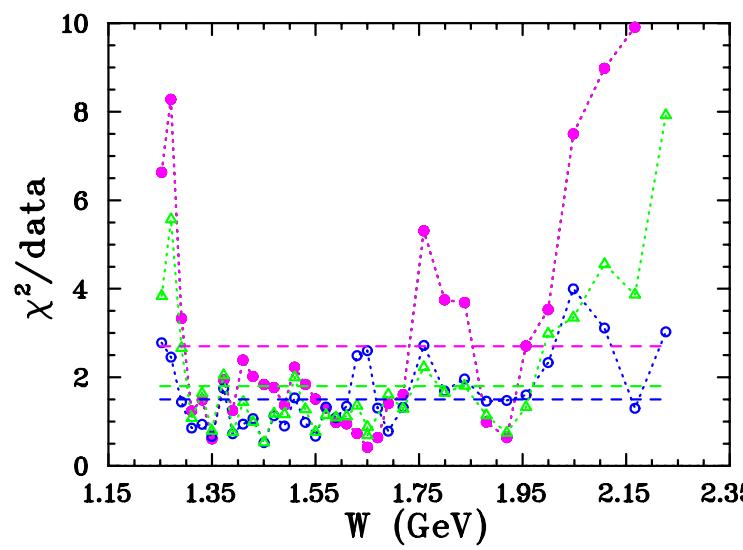
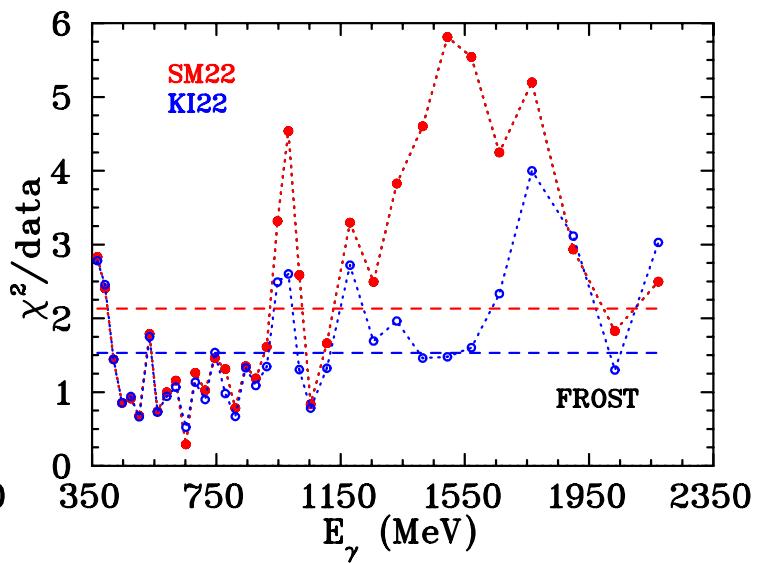
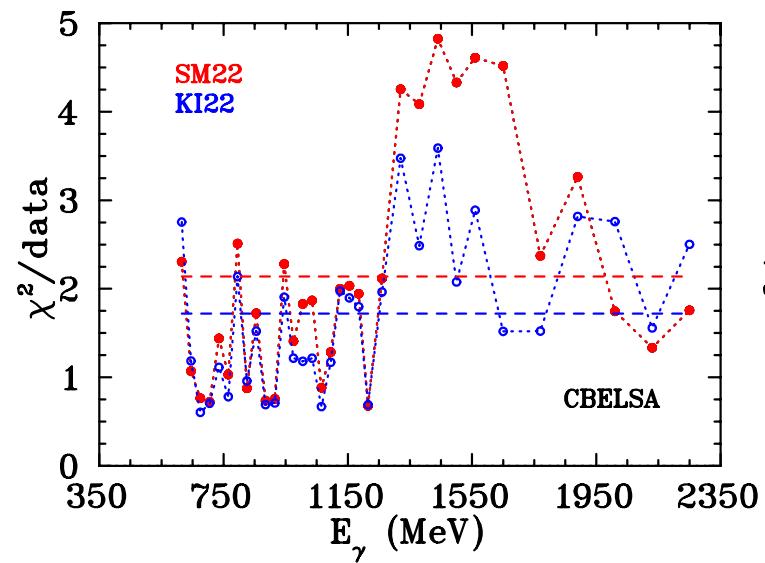
- Established by varying
 - Selection criteria
 - Choice of PDF
 - Removing problematic runs
- Integrated bins → reduction of statistical fluctuations
- Quotes estimates account for spread in the differences



Dilution Factor



SAID fits chi2



Outline

- Beam helicity asymmetry
- Experiment
- Reaction reconstruction
- Results

Circularly polarized
tagged photon beam

p reconstructed in
the **CLAS** detector

