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

Nick Zachariou

Briscoe, Strakovski, Workman, Schmidt, Kim, Fegan, Bashkanov, Watts

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	$T_{x'}$	$T_{z'}$	$L_{x'}$	$L_{z'}$	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{z'}$
									Proton targets							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

Stolen from V. Crede

	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										
$p\pi^0$	✓	✓	✓	(✓)	✓	✓	✓	✓								
$n\pi^+$	✓	✓	✓	(✓)	✓	✓	✓	✓								
$p\eta$	✓	✓	✓	(✓)	✓	✓	✓	✓								
$p\eta'$	✓	✓	✓	(✓)	✓	✓	✓	✓								
$p\omega\,(\phi)$	✓	✓	✓	(✓)	✓	✓	✓	✓								
$K^+\Lambda$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^+\Sigma^0$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\Sigma^+$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
						Neutron (deuteron) targets										
$p\pi^-$	✓	✓			✓		✓									
$K^+\Sigma^-$	✓	✓	✓	✓	✓	✓	✓									
$K^0\Lambda$	✓	✓	✓	✓	✓*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓	✓	✓	✓*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓ published

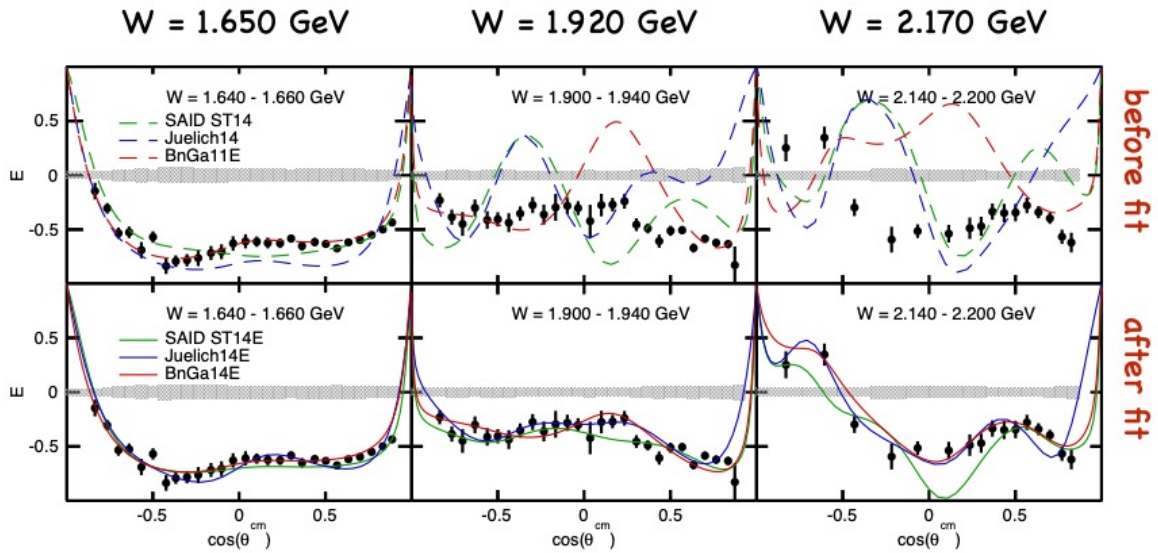
✓ acquired or under analysis

Tensor polarization, SDMEs

Phys. Lett. B **817,** 136304

Beam-Helicity Asymmetry

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



- 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).

S. Strauch et al. (CLAS Collaboration), Phys. Lett. B **750**, 53 (2015) and A.V. Anisovich et al., arXiv:1503.05774.

Beam-Helicity Asymmetry

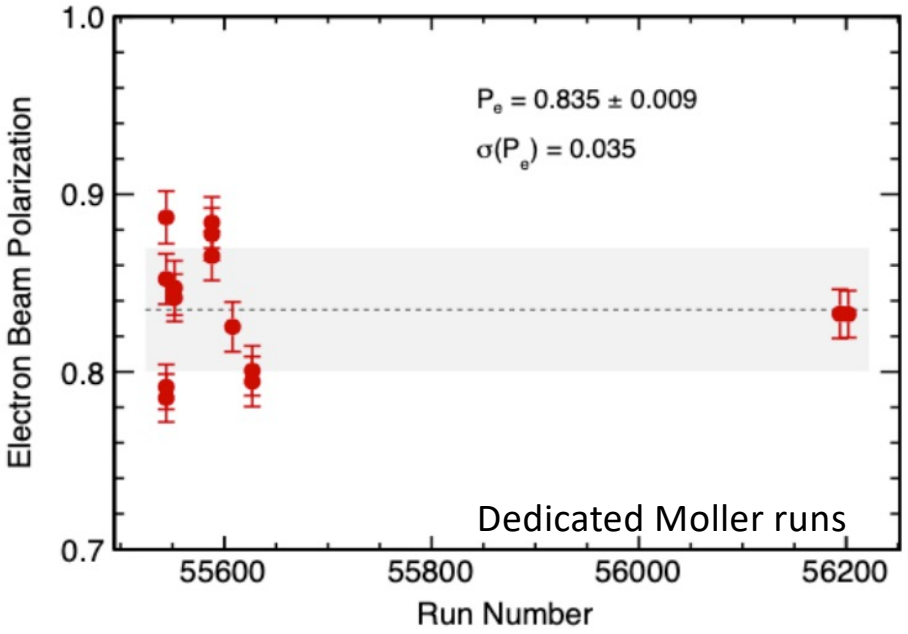
$$\frac{d\sigma}{d\Omega}(E_\gamma, \cos\theta) = \sigma_0[1 - P_L\Sigma\cos(2\phi) + P_x(-P_L\mathbb{H}\sin(2\phi) + P_\odot\mathbb{F})$$
$$-P_y(-\mathbb{T} + P_L\mathbb{P}\cos(2\phi)) - P_z(-P_L\mathbb{G}\sin(2\phi) + P_\odot\mathbb{E})]$$

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

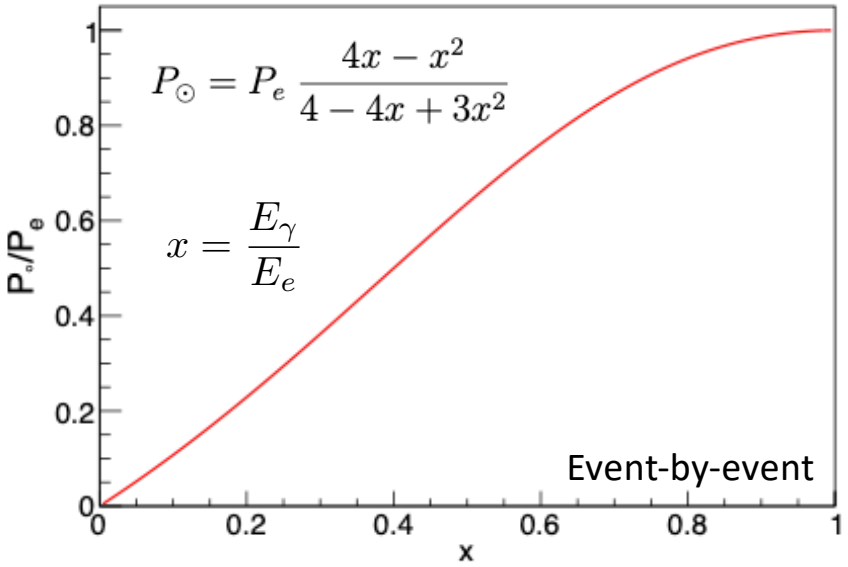
$$\mathbb{E} = \frac{1}{P_z P_\odot}\frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$$

Experiment -- g9

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

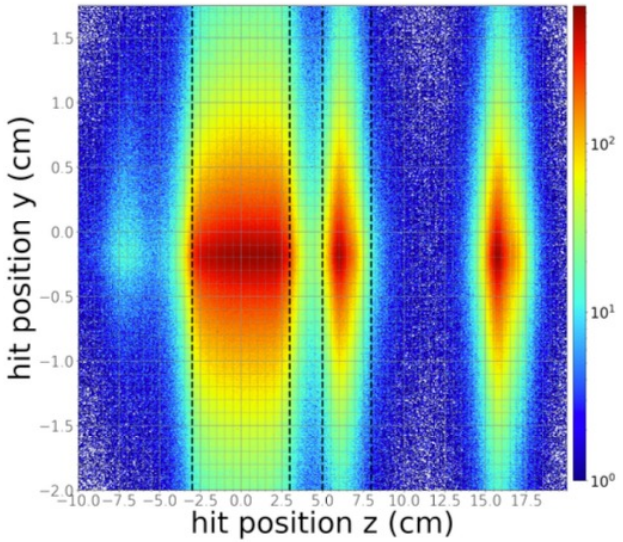


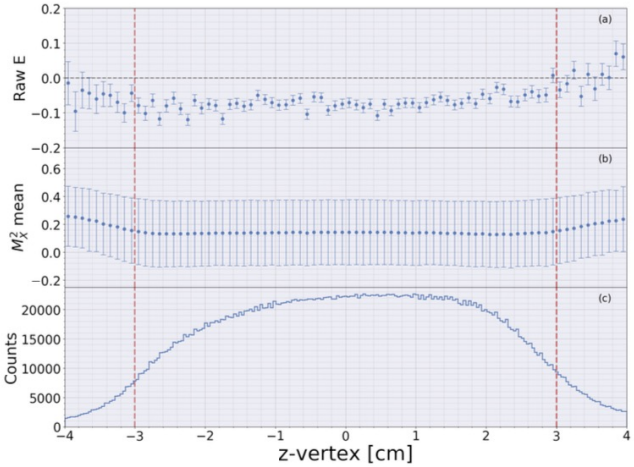
Electron Beam Energy (GeV)	Photon Beam Polarization	# of Events (B)	Observable
1.645	Circular	~1	$\mathbb{E}$
2.478	Circular	~2	$\mathbb{E}$
2.751	Linear	~1	$\mathbb{G}$
3.538	Linear	~2	$\mathbb{G}$
4.599	Linear	~3	$\mathbb{G}$

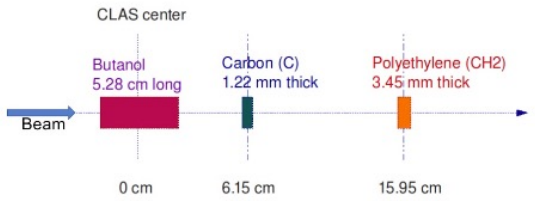


Experiment -- g9

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



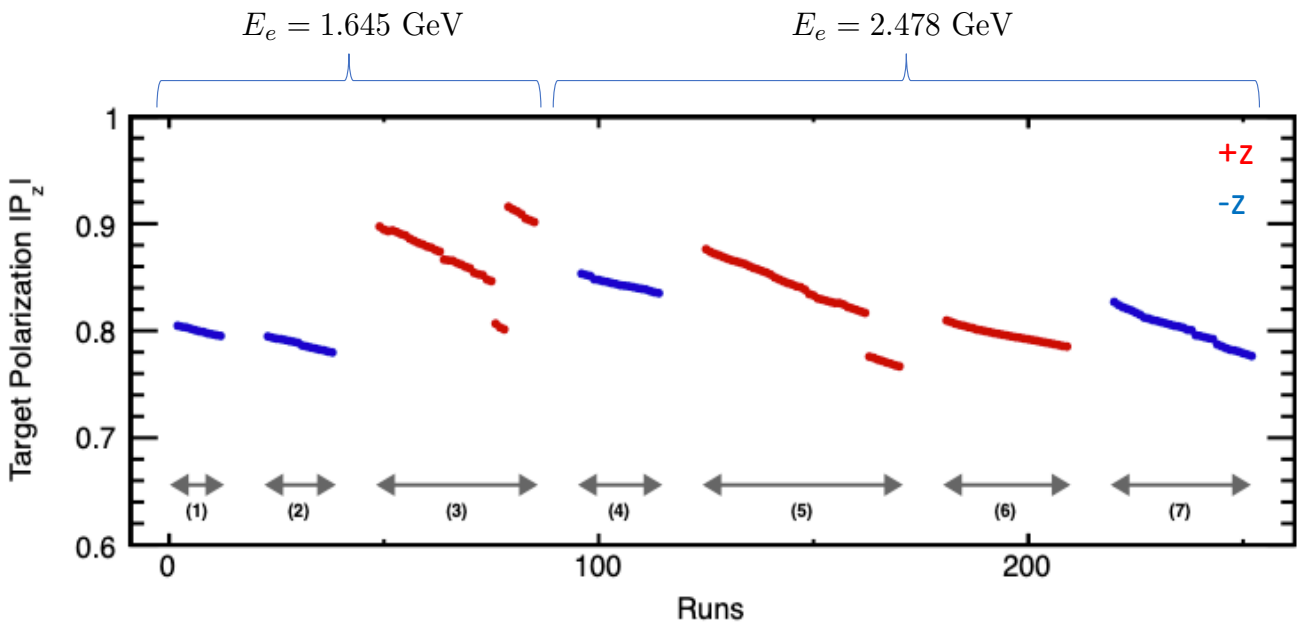




See C. Keith talk here 22nd Spin Symposium

Frost Experiment

- Target Polarization
  - NMR measurement
  - Run-by-run basis
  - Loss of polarization ~1%/day

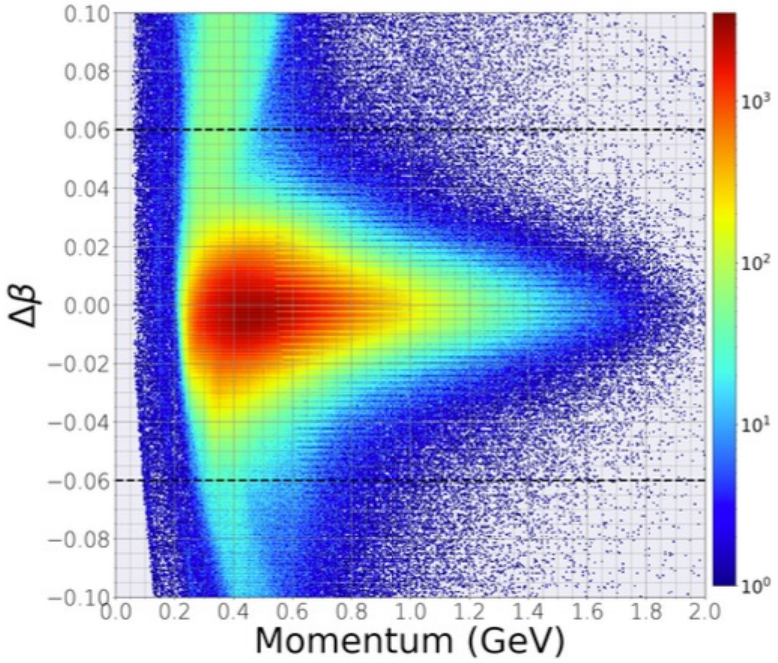


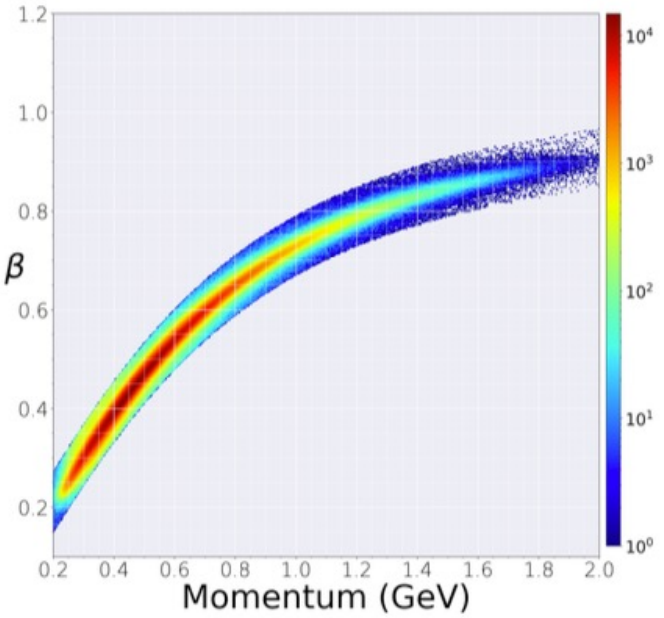
Event Reconstruction
$\gamma p \rightarrow pX$

- Particle identification

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

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



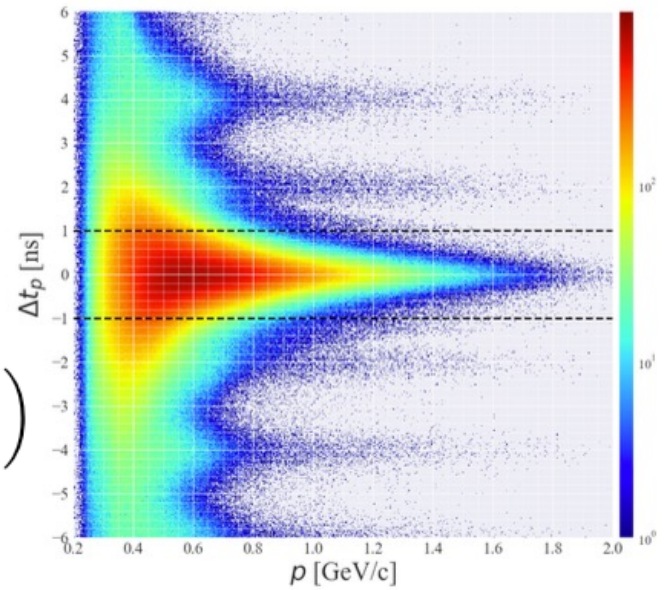


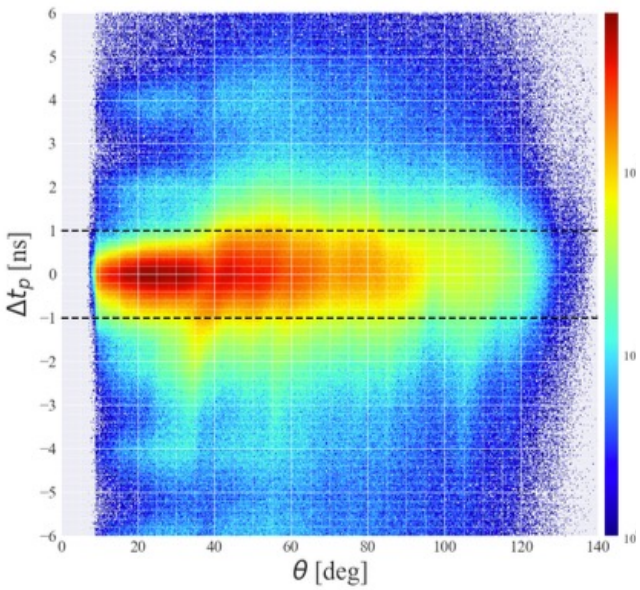
Event Reconstruction

- Photon Selection

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

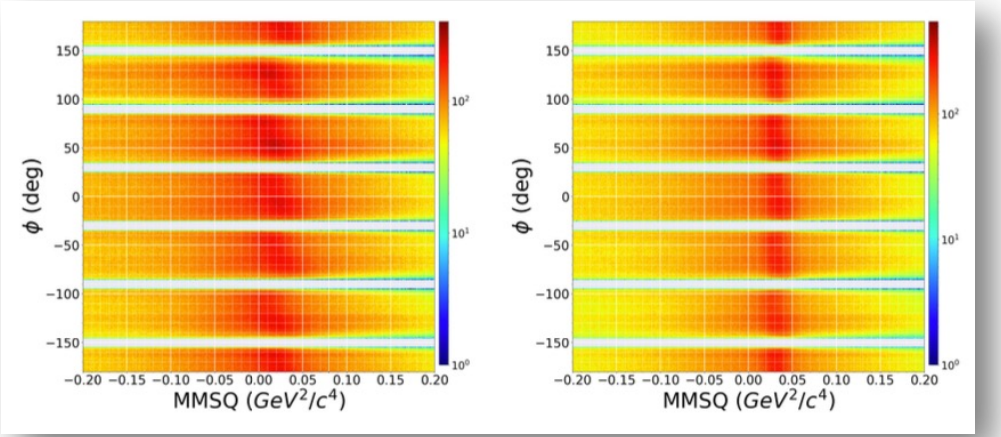
$$\Delta t = t_{v,\gamma} - t_{v,p} = \left(t_\gamma + \frac{z}{c}\right) - \left(t_{p,sc} - \frac{l_{sc}}{\beta_{calc} c}\right)$$

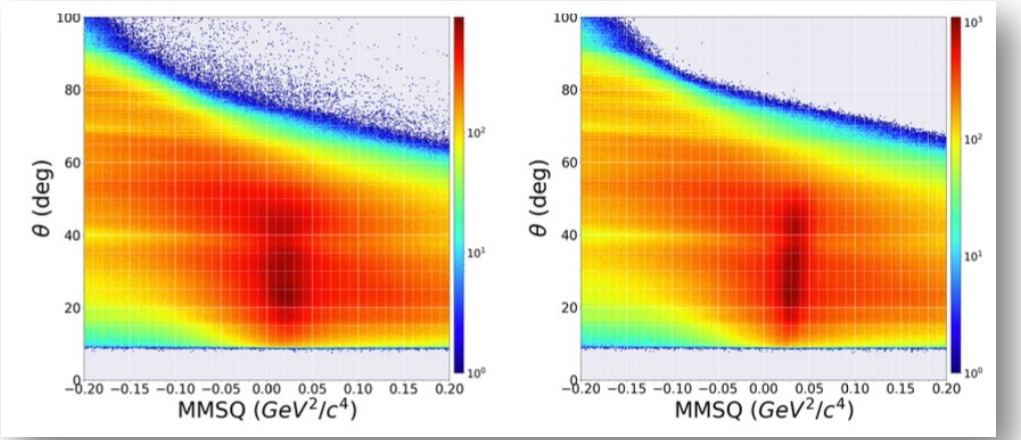




Data corrections
$\gamma p \rightarrow pX$

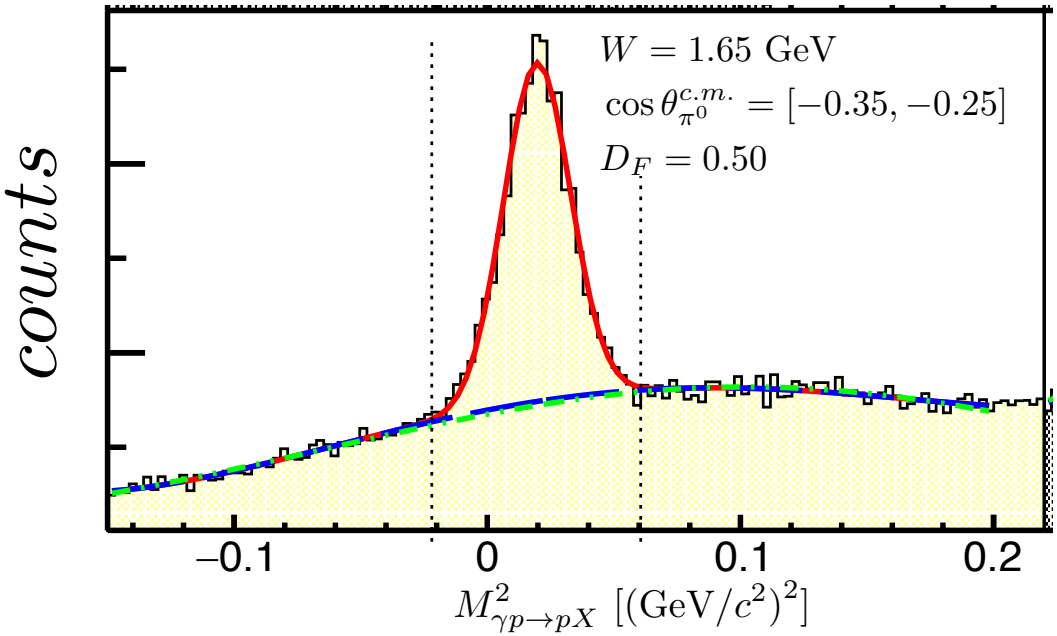
- Energy loss and momentum correction
  - ELOSS package
  - FROST momentum corrections (CLAS Analysis Note 2014-101)

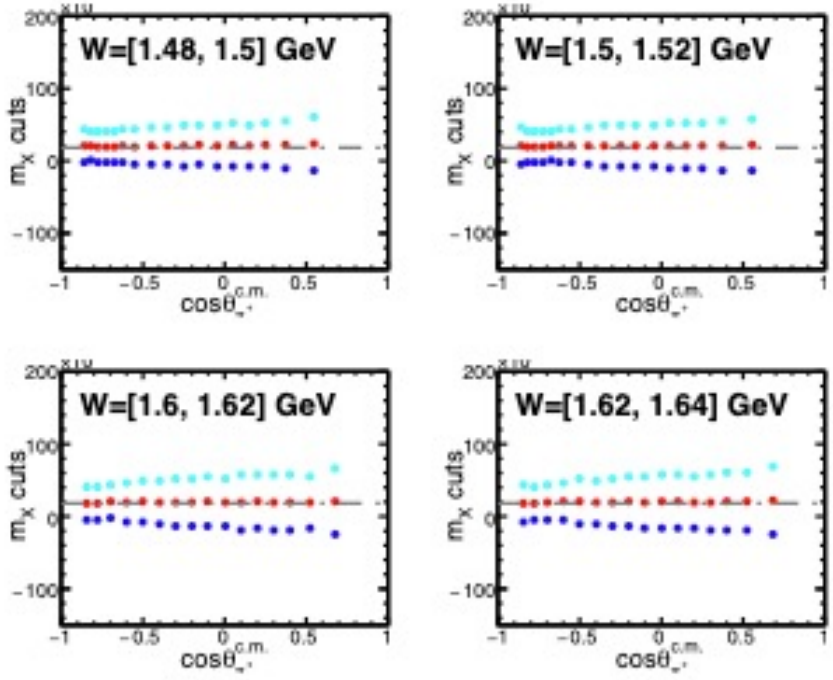




Reaction Reconstruction

- 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

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

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

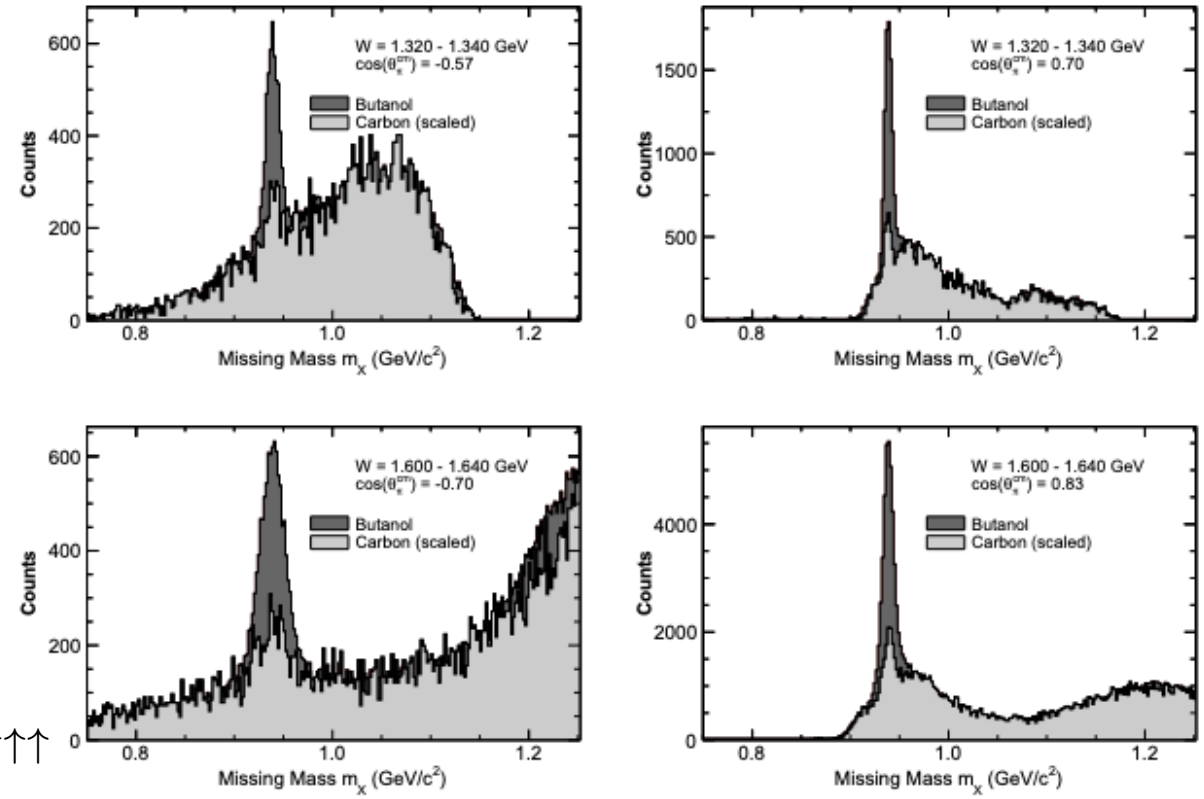


Figure from CLAS Analysis Note 2014-101

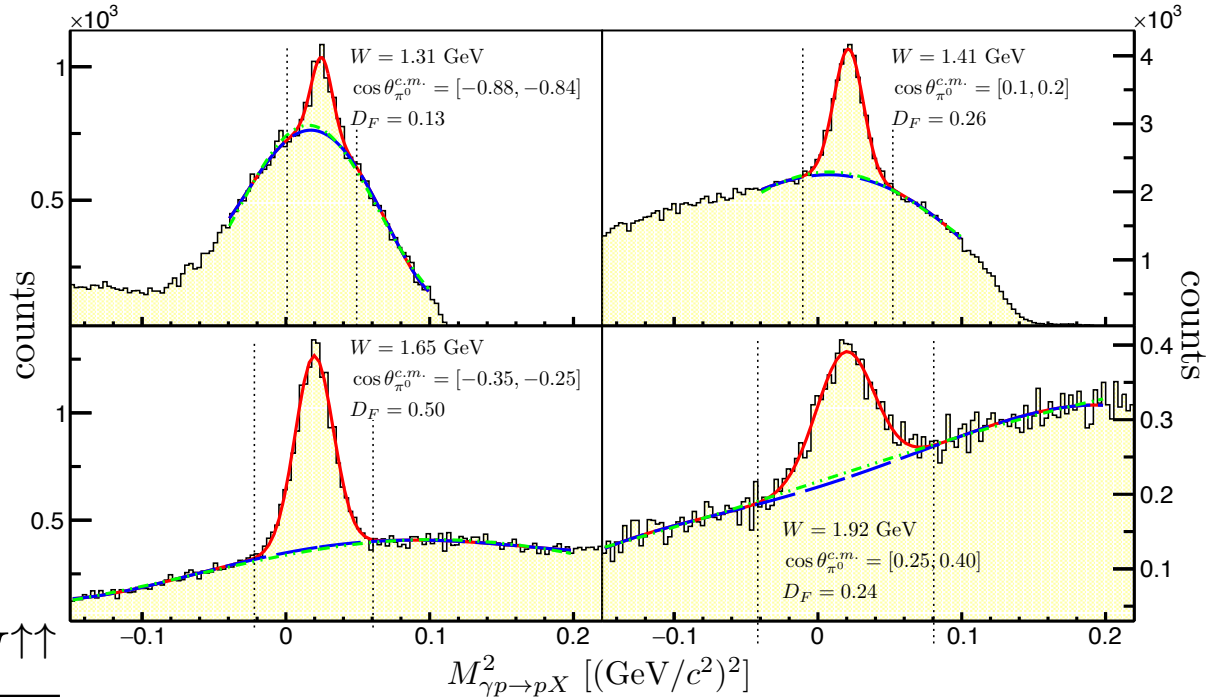
Dilution Factor

Dilution Extracted from fits to missing mass

Constrain Bound Nucleon PDF using Carbon and Butanol sidebands

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

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

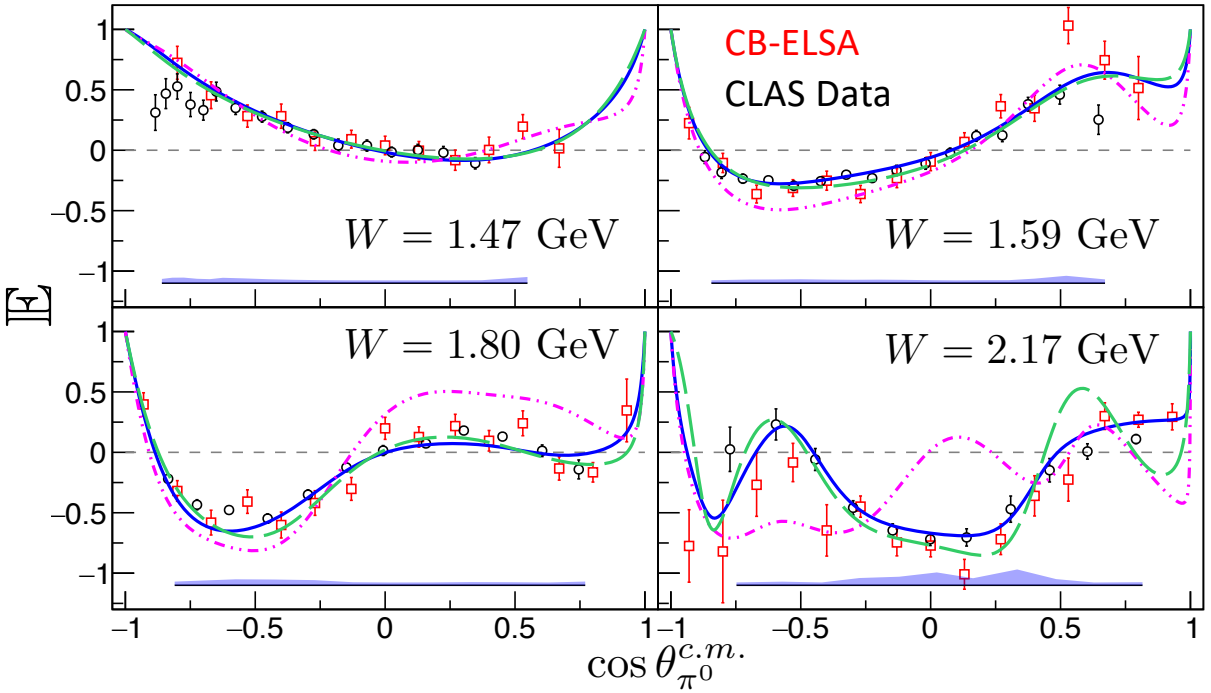


Systematic Studies

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

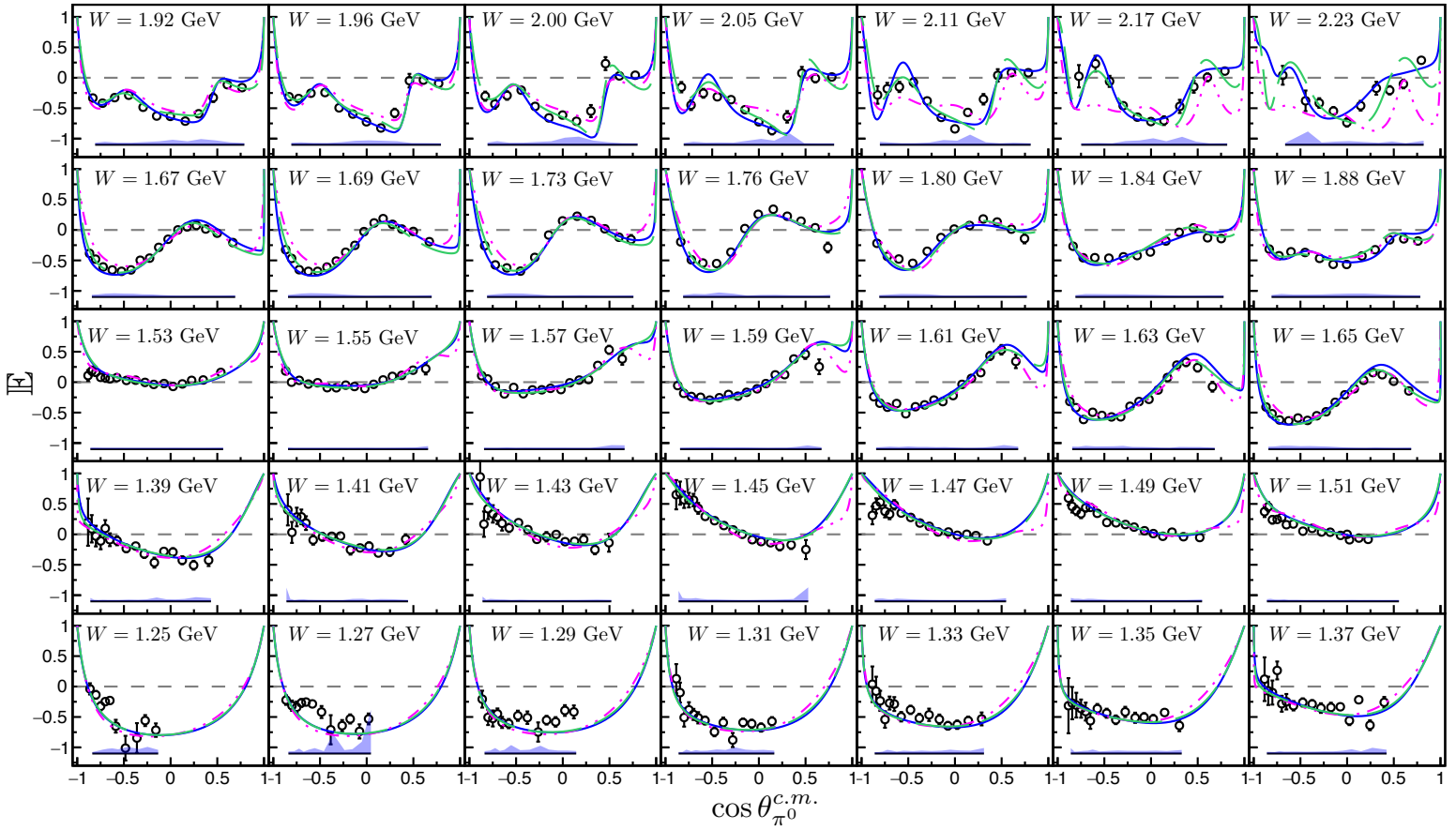
- Reasonable agreement between published data and CLAS
- CLAS data provide larger kinematic coverage (to higher/lower W) with higher precision
- PWA (SAID, Bonn-Gatchina, MAID) predict data well at lower W



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)



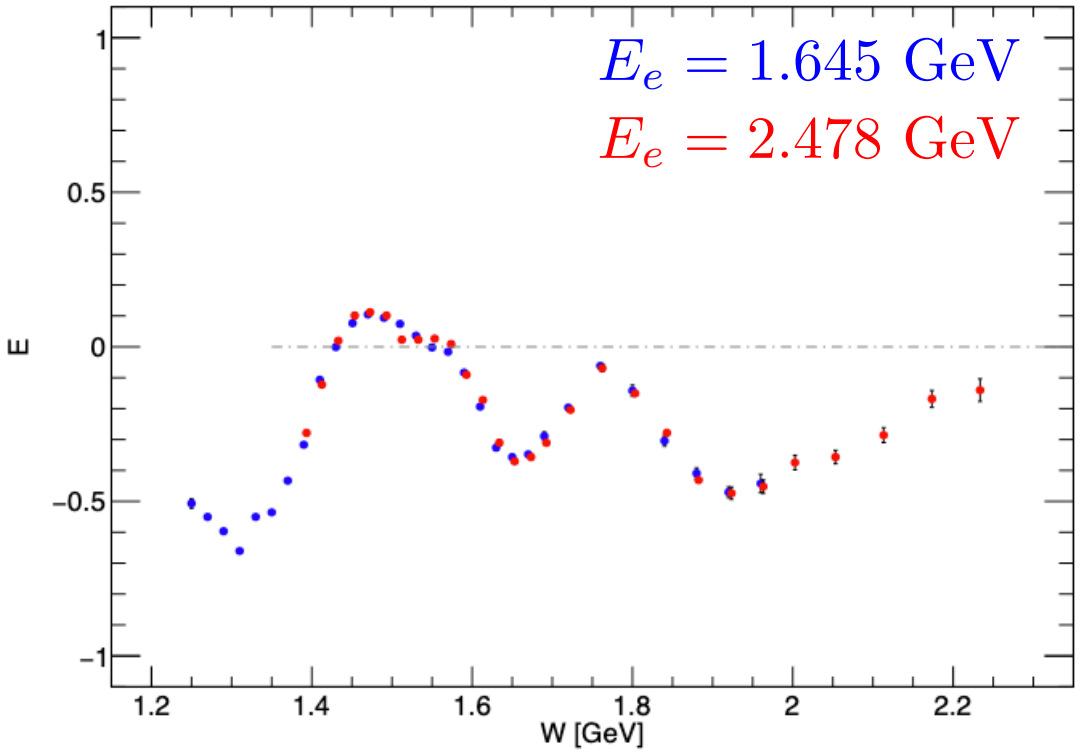
Summary

- 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

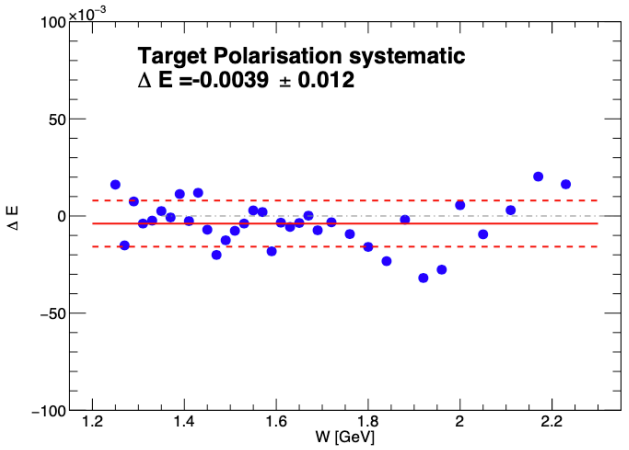
Systematic Studies

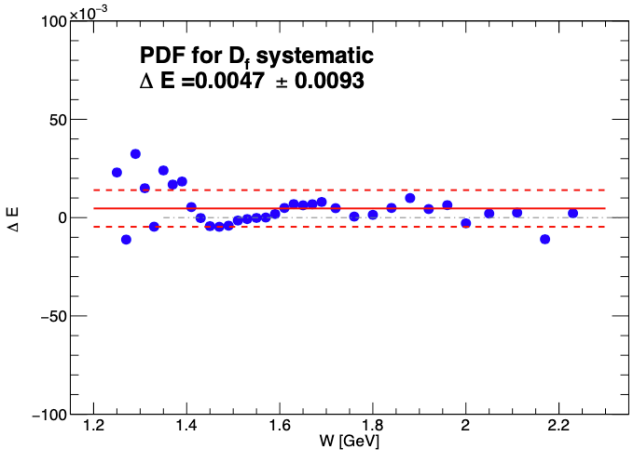
- Comparison of E between two electron energies
  - Consistent NMR measurements
  - Consistent Moller measurements

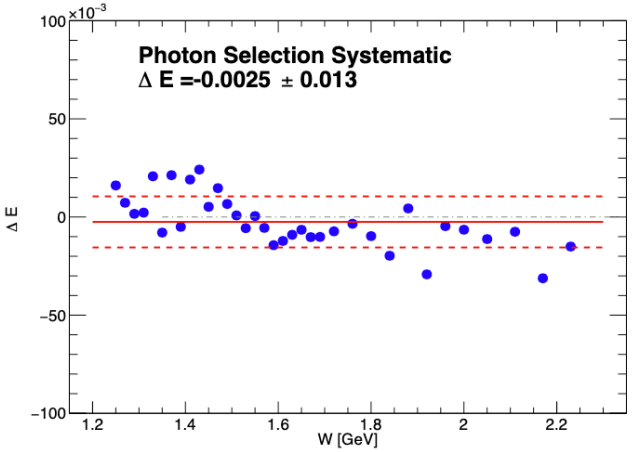


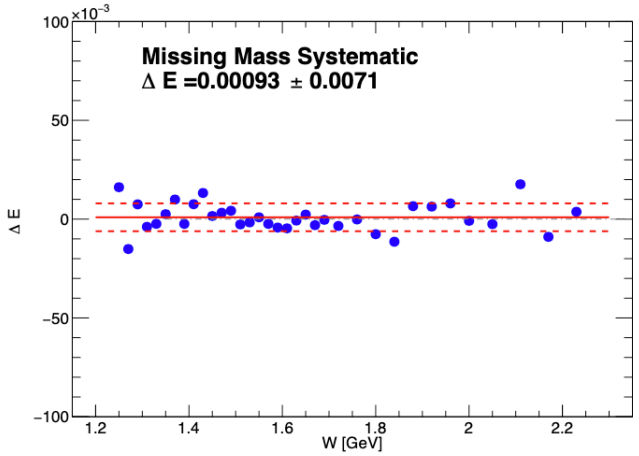
Systematic Studies

- 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

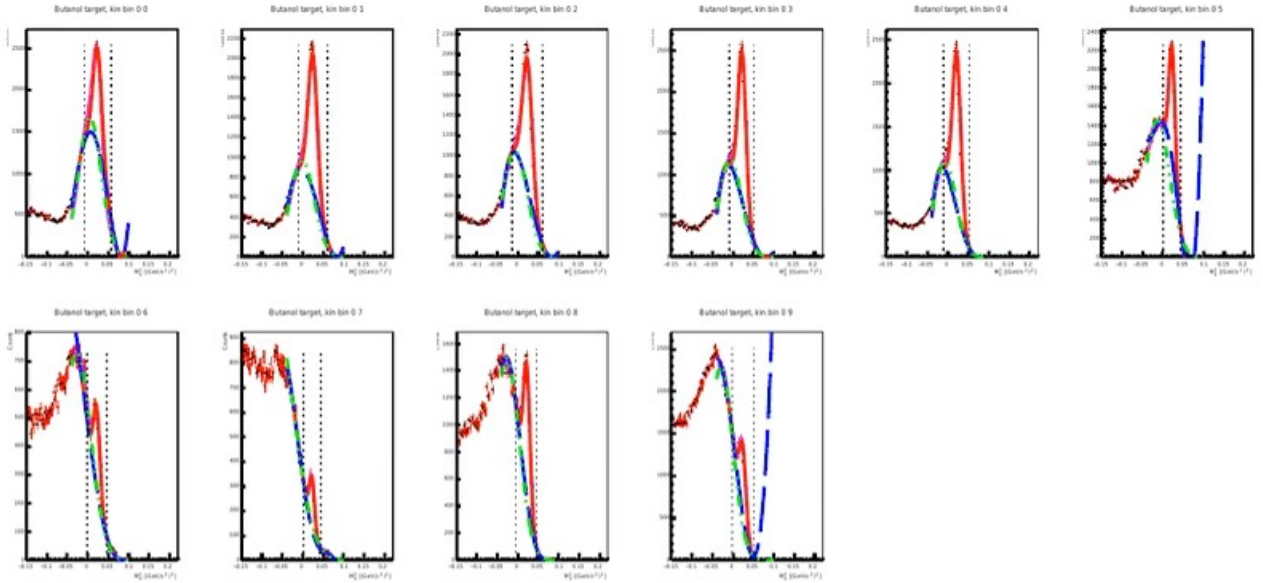




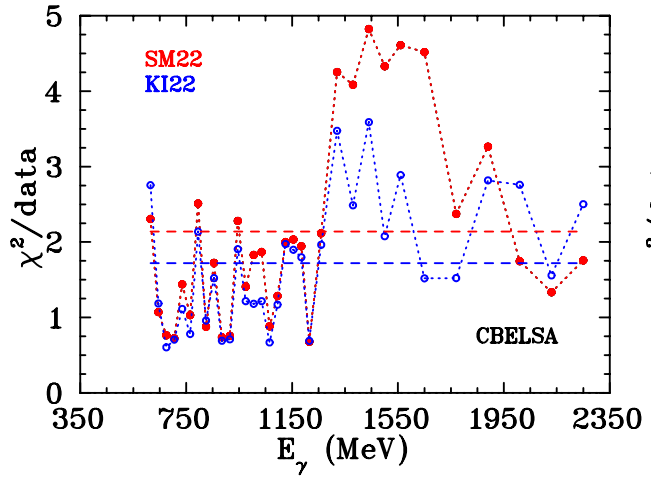


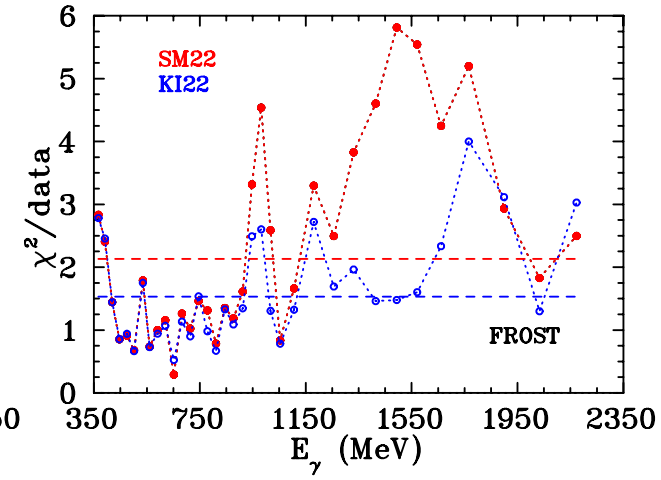


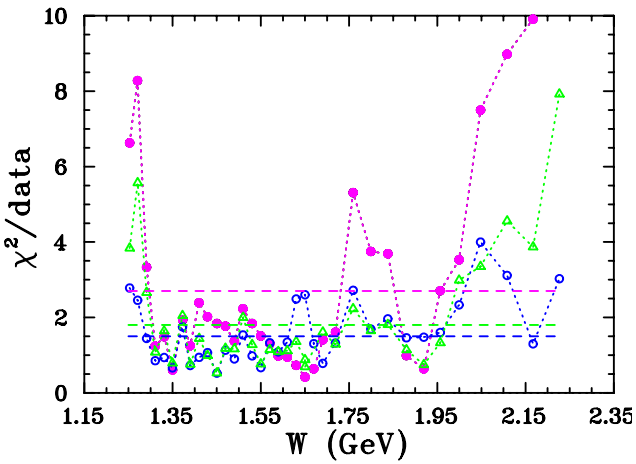
Dilution Factor

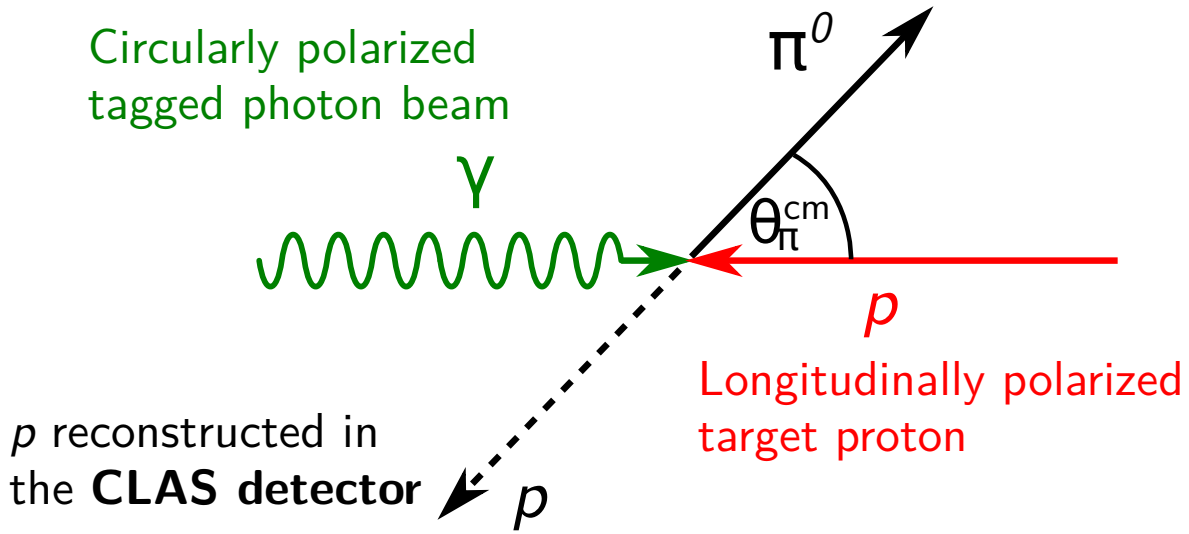


SAID fits chi2







Outline

- Beam helicity asymmetry
- Experiment
- Reaction reconstruction
- Results