Helicity Asymmetry Measurement for π^0 Photoproduction on the CLAS Frozen Spin Target

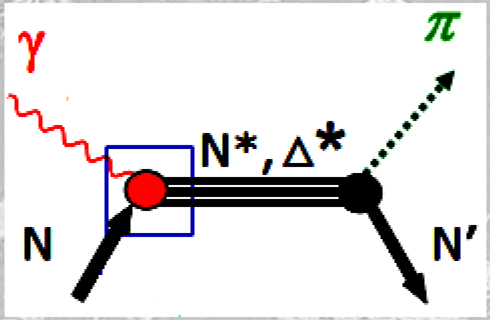
Diane Schott, William Briscoe, Igor Strakovsky

The George Washington University

For CLAS Collaboration

- Single Pion photoproduction.
- Experimental Facilities at JLab Hall B.
  - CLAS.
  - Photon Tagger.
  - Circular polarized beam.
  - Linearly polarized beam.
  - FROST.
- The Experiment.
- Double Polarized measurements for $\vec{\gamma}\vec{p}\rightarrow\pi^0p$.
- Summary.

Single Pion Photo Production



Status of Non-strange Resonances: PDG14

K.A. Olive *et al* (PDG) Chin Phys C **38**, 090001 (2014)

GW SAID Contribution

I = 1/2

Particle	J^P	Status overall	πN	γN	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
N	$1/2^+$	****									
$N(1440)$	$1/2^+$	****	****	****		***				*	***
$N(1520)$	$3/2^-$	****	****	****	***					***	***
$N(1535)$	$1/2^-$	****	****	****	****					**	*
$N(1650)$	$1/2^-$	****	****	***	***			***	**	**	***
$N(1675)$	$5/2^-$	****	****	***	*			*		*	***
$N(1680)$	$5/2^+$	****	****	****	*	**				***	***
$N(1685)$	$?^?$	*									
$N(1700)$	$3/2^-$	***	***	**	*			*	*	*	***
$N(1710)$	$1/2^+$	***	***	***	***		**	***	**	*	**
$N(1720)$	$3/2^+$	****	****	***	***			**	**	**	*
$N(1860)$	$5/2^+$	**	**							*	*
$N(1875)$	$3/2^-$	***	*	***			**	***	**		***
$N(1880)$	$1/2^+$	**	*	*		**		*			
$N(1895)$	$1/2^-$	**	*	**	**			**	*		
$N(1900)$	$3/2^+$	***	**	***	**		**	***	**	*	**
$N(1990)$	$7/2^+$	**	**	**					*		
$N(2000)$	$5/2^+$	**	*	**	**			**	*	**	
$N(2040)$	$3/2^+$	*									
$N(2060)$	$5/2^-$	**	**	**	*				**		
$N(2100)$	$1/2^+$	*									
$N(2150)$	$3/2^-$	**	**	**				**			**
$N(2190)$	$7/2^-$	****	****	***				**		*	
$N(2220)$	$9/2^+$	****	****								
$N(2250)$	$9/2^-$	****	****								
$N(2600)$	$11/2^-$	***	***								
$N(2700)$	$13/2^+$	**	**								

26 N*
11 ****
5 ***
7 **
3 *

- More than half of states have **poor evidence**.
- Most of **QCD** models predict more states than observed.
- **Where are missing resonances**?

I = 3/2

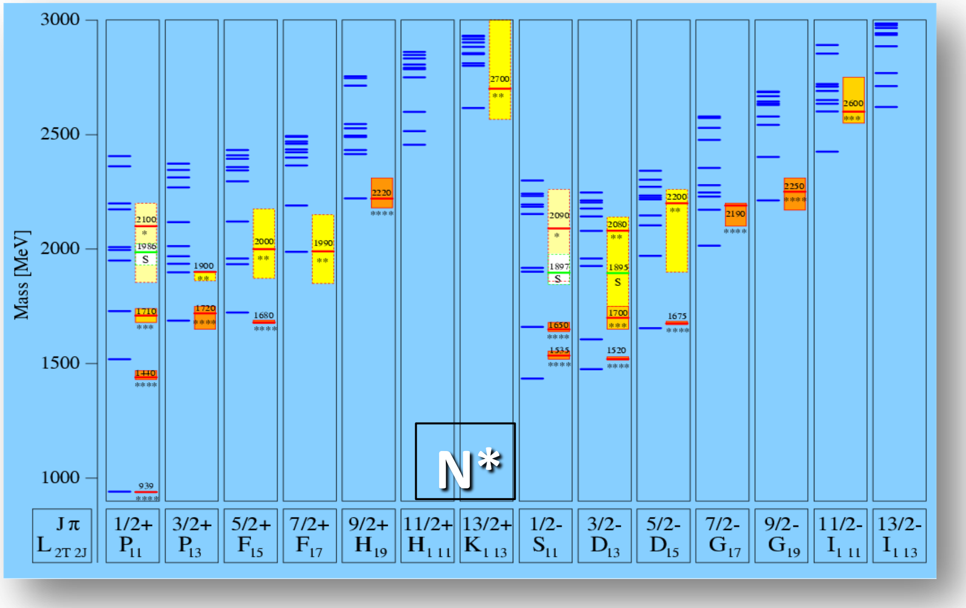
Particle	J^P	Status overall	πN	γN	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
$\Delta(1232)$	$3/2^+$	****	****	****	F						
$\Delta(1600)$	$3/2^+$	***	***	***	o					*	***
$\Delta(1620)$	$1/2^-$	****	****	***		r				***	***
$\Delta(1700)$	$3/2^-$	****	****	****		b				**	***
$\Delta(1750)$	$1/2^+$	*	*				i				
$\Delta(1900)$	$1/2^-$	**	**	**			d		**	**	**
$\Delta(1905)$	$5/2^+$	****	****	****			d		***	**	**
$\Delta(1910)$	$1/2^+$	****	****	**				e	*	*	**
$\Delta(1920)$	$3/2^+$	***	***	**				n	***		**
$\Delta(1930)$	$5/2^-$	***	***								
$\Delta(1940)$	$3/2^-$	**	*	**	F				(seen	in	$\Delta\eta$)
$\Delta(1950)$	$7/2^+$	****	****	****	o				***	*	***
$\Delta(2000)$	$5/2^+$	**				r					**
$\Delta(2150)$	$1/2^-$	*	*			b					
$\Delta(2200)$	$7/2^-$	*	*				i				
$\Delta(2300)$	$9/2^+$	**	**				d				
$\Delta(2350)$	$5/2^-$	*	*				d				
$\Delta(2390)$	$7/2^+$	*	*					e			
$\Delta(2400)$	$9/2^-$	**	**					n			
$\Delta(2420)$	$11/2^+$	****	****								
$\Delta(2750)$	$13/2^-$	**	**								
$\Delta(2950)$	$15/2^+$		**								

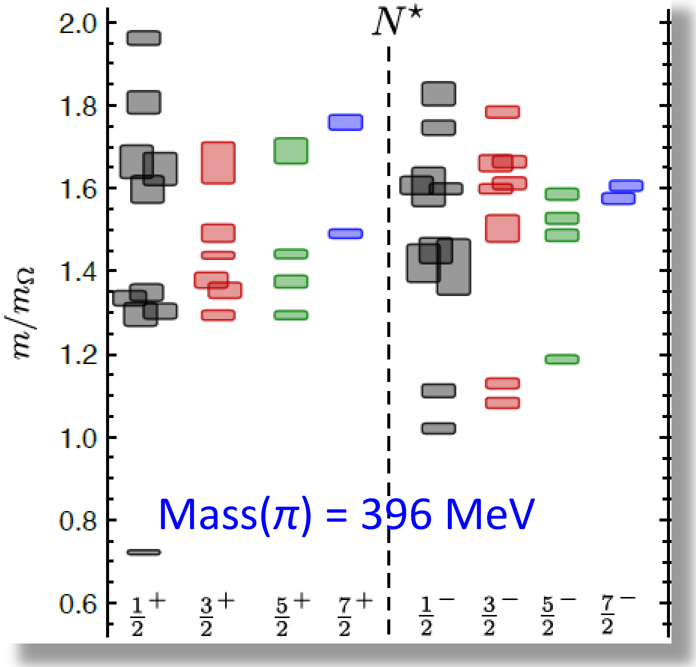
22 Δ*
7 ****
3 ***
7 **
5 *

BnGa Additional States

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

Baryon Resonance Spectrum





- Masses, widths, and coupling constants not well known for many resonances.
- Most **models** predict more resonance states than observed.

R.G. Edwards *et al.* Phys Rev D **84,** 074508 (2011)

Baryon Resonances

- The **three light quarks** can arranged in **6** baryonic families, **N***, **Δ***, Λ*, Σ*, Ξ*, and Ω*.
- The number of family members that can exist is not arbitrary.
- Rather, the following proportionally is expected when the **$SU(3)_F$** symmetry of **QCD** is the controlling symmetry:

2 N*, **1 Δ***, 3 Λ*, 3 Σ*, 3 Ξ*, and 1 Ω*

  - The number of experimentally identified resonances of each baryon family is **26 N***, **22 Δ*** and so on.
  - **Constituent quark** models predict the existence of no less than **64 N*** and **22 Δ*** states with **mass < 3** GeV^2.

- The seriousness of the ``**missing-states**" problem is obvious from these numbers.
- Recently, the **hypothesis** of a very **small πN** coupling of missing states should await the results of more realistic, coupled-channel calculations.

Ben Nefkens, πN Newsletter, **14**, 150 (1997)

Isospin Combinations for Reactions involving π^0 and π^+

- Differing isospin for **N*** and Δ^+ for **π^0p** and **π^+n** states.
- The **π^0p** and **π^+n** final states can help distinguish between the Δ^+ and **N***.

$$\underline{\pi^0 + p} : \sqrt{2/3}\,\overset{\boxed{\Delta^+}}{\overset{\downarrow}{\left|I=\tfrac{3}{2},I_3=\tfrac{1}{2}\right\rangle}} - \sqrt{1/3}\,\overset{\boxed{N^*}}{\overset{\downarrow}{\left|I=\tfrac{1}{2},I_3=\tfrac{1}{2}\right\rangle}}$$

$$\underline{\pi^+ + n} : \sqrt{1/3}\left|I=\tfrac{3}{2},I_3=\tfrac{1}{2}\right\rangle + \sqrt{2/3}\left|I=\tfrac{1}{2},I_3=\tfrac{1}{2}\right\rangle$$

JLab Hall B

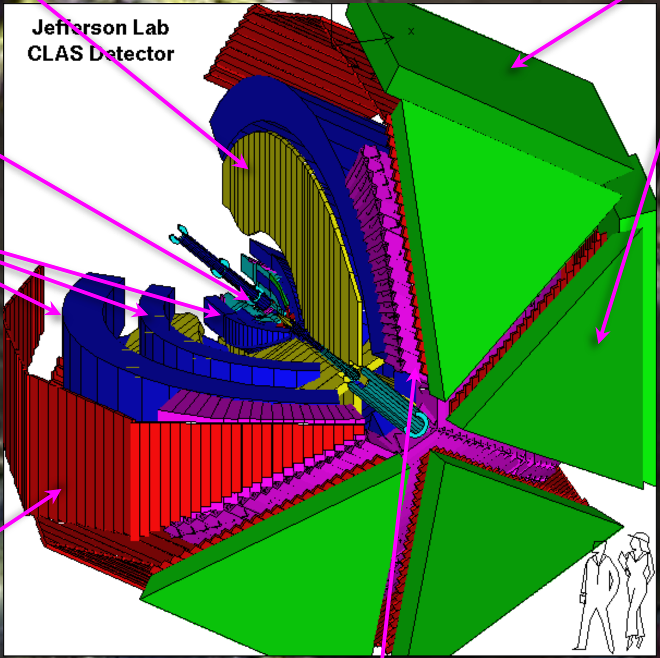
Experimental Facilities

CEBAF Large Acceptance Spectrometer 1997-2012

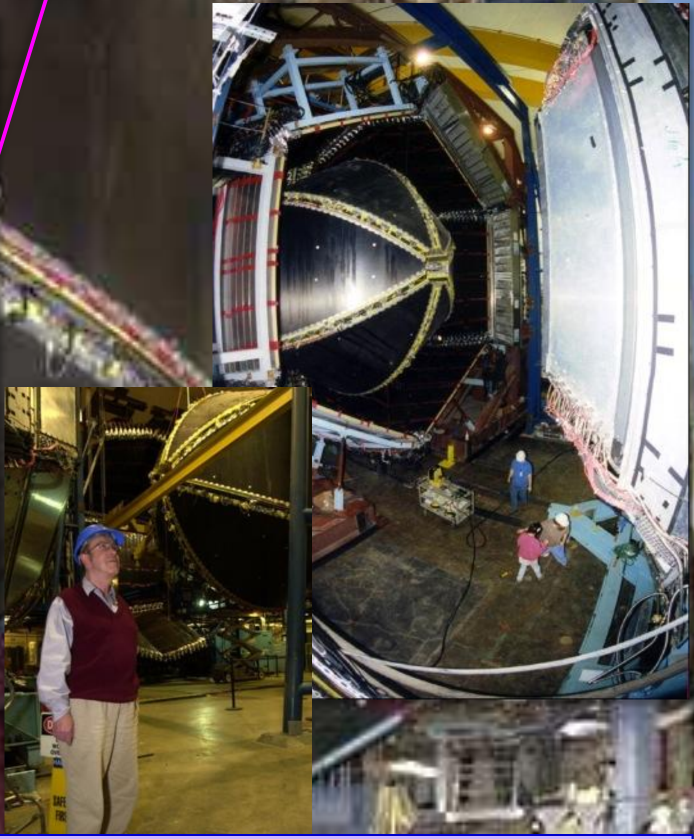
Torus Magnet
6 superconducting coils

Target + Start Counter

Drift Chambers
35,000 cells



Electromagnetic calorimeters
Lead/Scintillator, 1296 photomultipliers

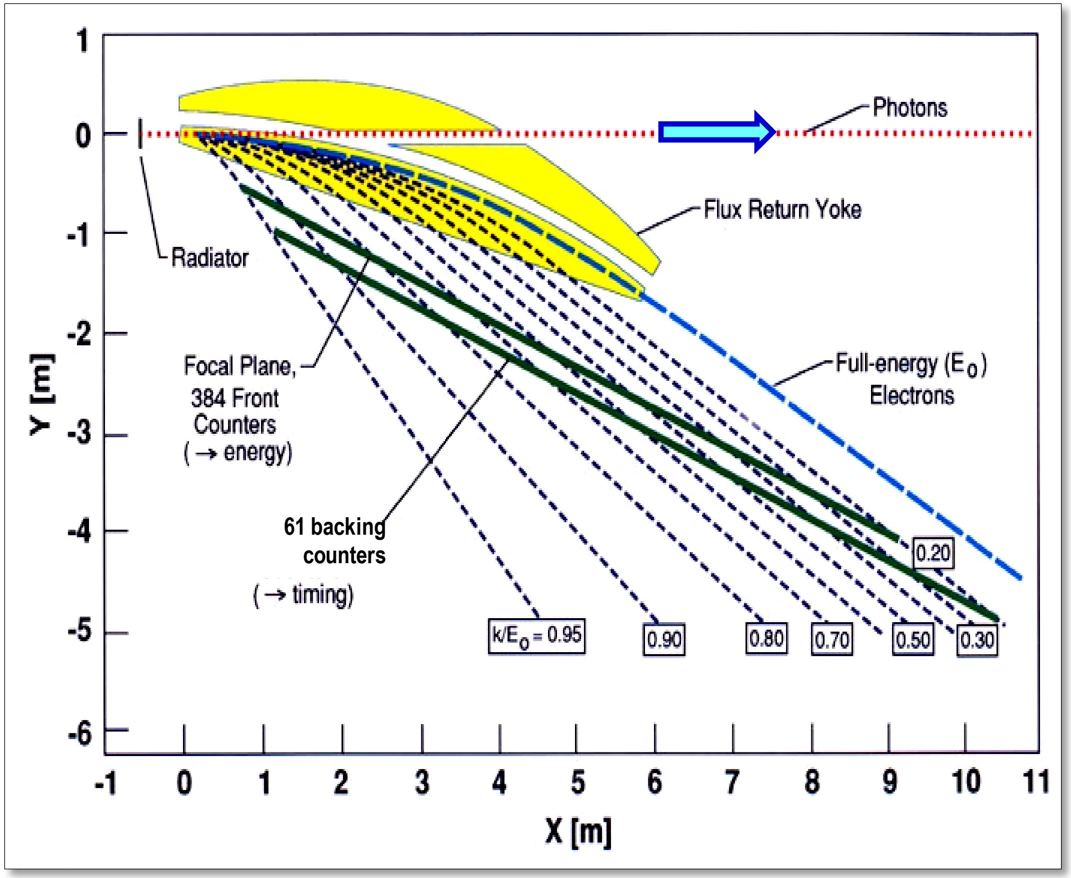


Time-of-Flight Counters
plastic scintillators, 684 photomultipliers

Gas Cherenkov Counters
e/π separation, 256 PMTs

B. A. Mecking *et al*. Nucl Instrum Meth A 503, 513 (2003)

Hall B Photon Tagger



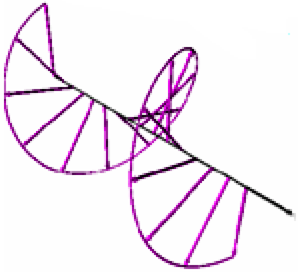
JLab Hall B Bremsstrahlung Photon Tagger had:

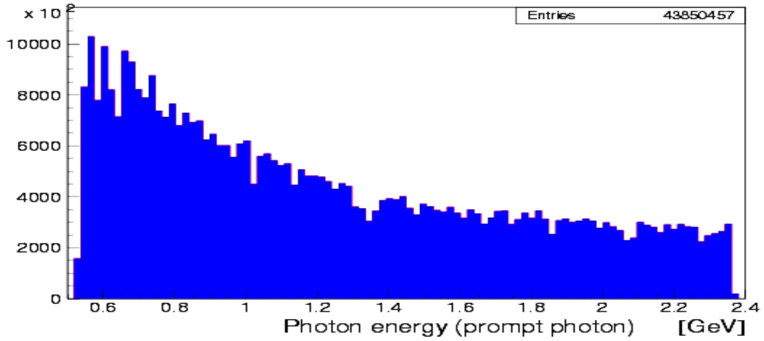
- E_γ = (**0.20–0.95**) x E_0
- E_γ up to ~**5.8 GeV**
- **ΔE/E** ~ **10^{-3}** x E_0
- **Circular** polarized photons with longitudinally polarized electrons.
- Oriented diamond crystal for **linearly** polarized photons.

- **Tagger** was built by the **GW**, **CUA, and ASU** nuclear physics groups.

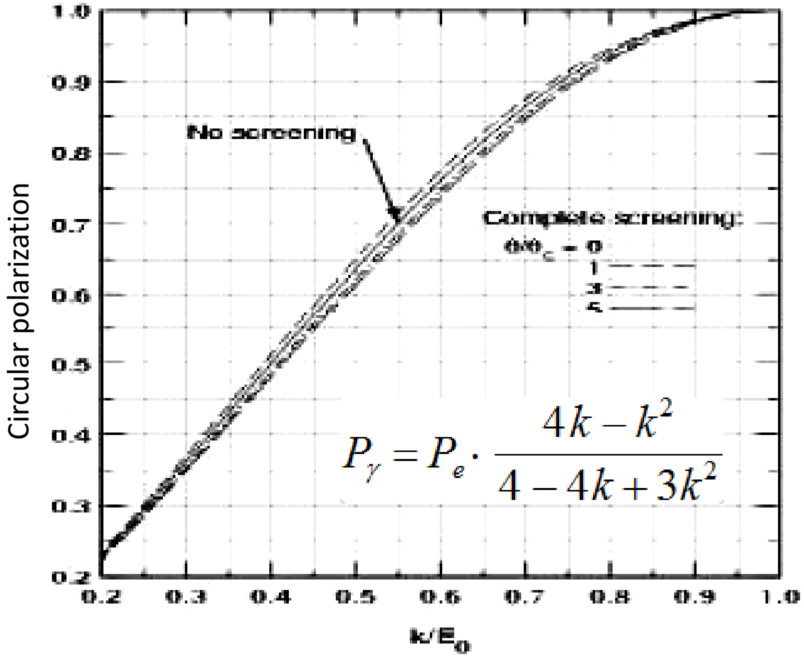
D. Sober *et al.* Nucl Instrum Meth A **440**, 263 (2000)

Circular Photon Beam Polarization





Circular polarization from 100% polarized electron beam

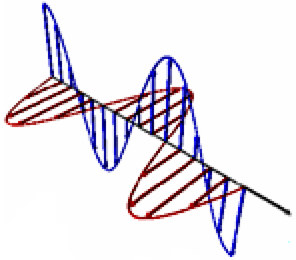


$$P_\gamma = P_e \cdot \frac{4k - k^2}{4 - 4k + 3k^2}$$

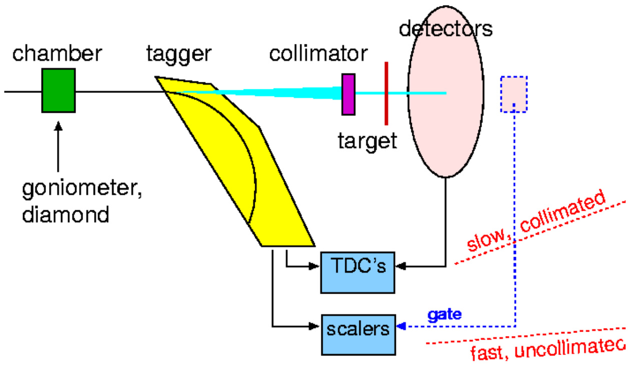
- **Circular** polarized **photons** with longitudinally polarized electrons.
- CEBAF **electron beam** polarization >**85%**.
- Tagged flux ~**50** – **100** MHz for **k > 0.5 E_0**

H. Olsen and L.C. Maximon, Phys Rev **114**, 887 (1959)

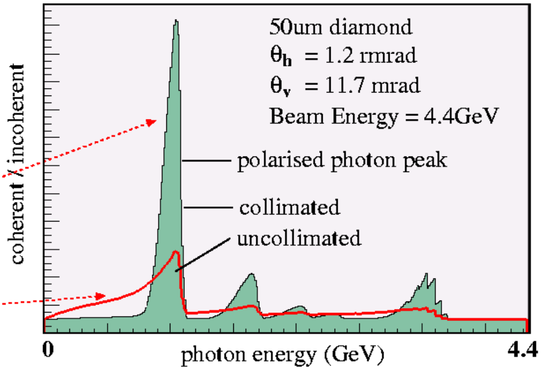
Linearly Polarized Photons

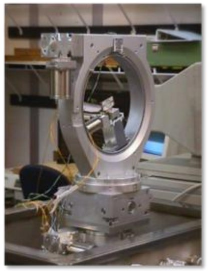


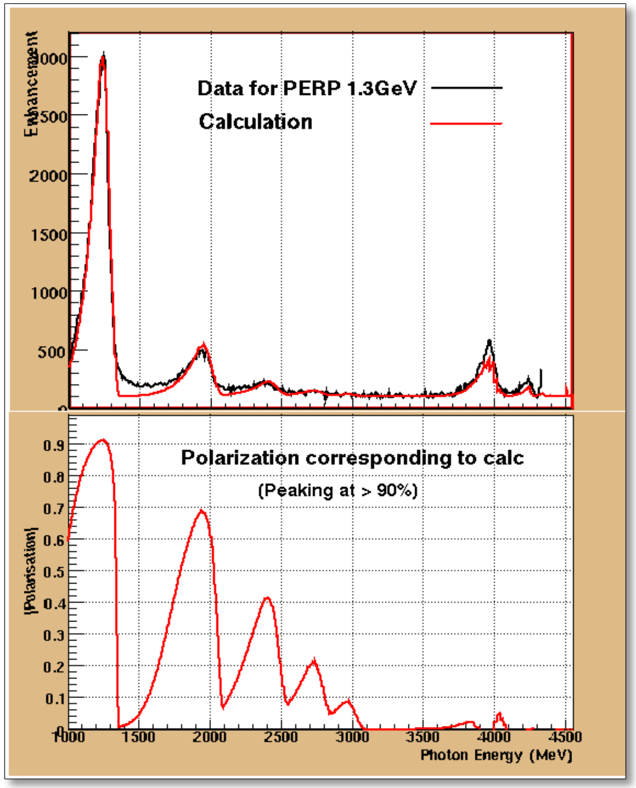
tagged photon facility



simulated coherent brem. spectrum

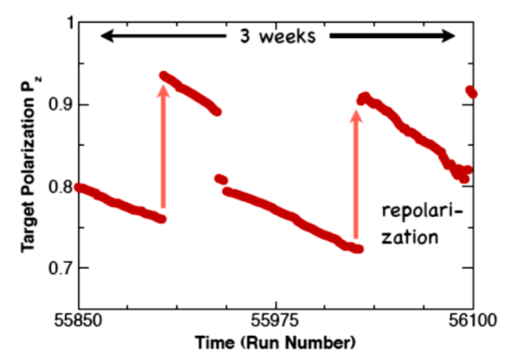






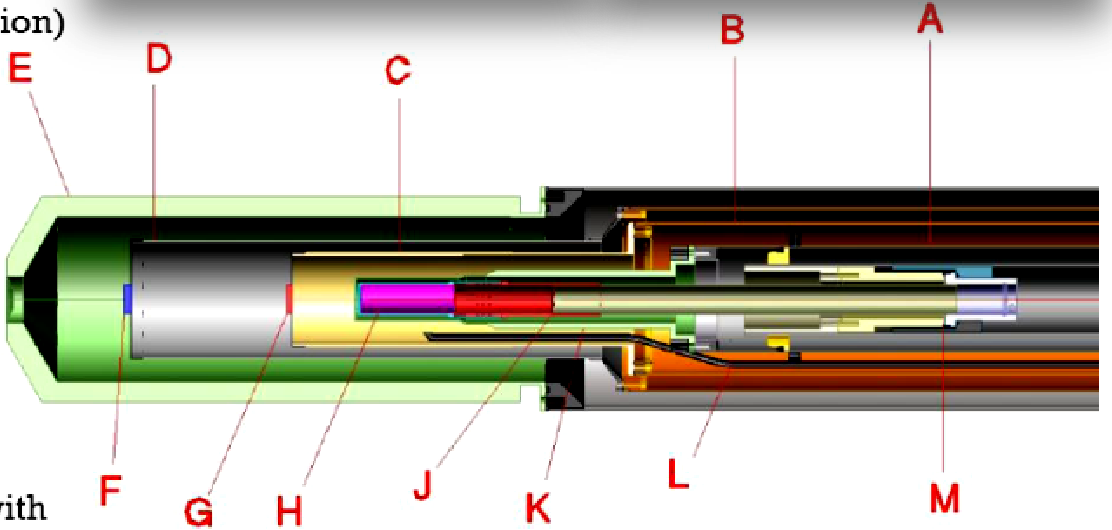
- **Linearly polarized photons**: coherent bremsstrahlung on oriented diamond **crystal** (**50** μm).
- Two **linear** polarized states (**parallel** & **perpendicular**).
- Analytical **QED** coherent bremsstrahlung calculation fit to actual spectrum (**Ken Livingston**/Glasgow U.)
- Perpendicular **1.3 GeV** edge shown.

FroST Target



The FroST target and its components:

A: Primary heat exchanger
B: 1 K heat shield
C: Holding coil
D: 20 K heat shield
E: Outer vacuum can (Rohacell extension)
F: CH2 target
G: Carbon target
H: Butanol target
J: Target insert
K: Mixing chamber
L: Microwave waveguide
M: Kapton coldseal

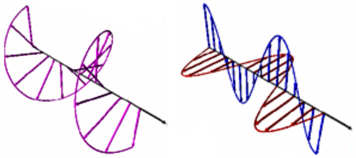


Performance Specs:

Base Temp: 28 mK w/o beam, 30 mK with
Cooling Power: 800 μW @ 50 mK, 10 mW @ 100 mK, and 60 mW @ 300 mK
Polarization: +82%, -90%
1/e Relaxation Time: 2800 hours (+Pol), 1600 hours (-Pol)
Roughly 1% polarization loss per day.

C. Keith *et al*. Nucl Instrum Meth A **684**, 27 (2012)

The Experiment



Battle Plan for Observables

Beam		Target			Recoil			Target + Recoil								
					x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
		x	y	z				x	y	z	x	y	z	x	y	z
unpolarized	$d\sigma_0$		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
$P_L^\gamma \sin(2\varphi_\gamma)$		H		G	$O_{x'}$		$O_{z'}$		$C_{z'}$		E		F		$-C_{x'}$	
$P_L^\gamma \cos(2\varphi_\gamma)$	Σ		$-P$			$-T$		$-L_{x'}$		$T_{z'}$		$-d\sigma_0$		$L_{x'}$		$-T_{x'}$
circular P_c^γ	$d\sigma_0$	F		$-E$	$C_{x'}$		$C_{z'}$		$-O_{z'}$		G		$-H$		$O_{x'}$	

Lorenzo Zana (**6D2**)

FroST

Photon beam	Target		
	x	y	z
Unpolarized	0	T	0
Linearly polarized	H	(-P)	-G
Circularly polarized	F	0	-E

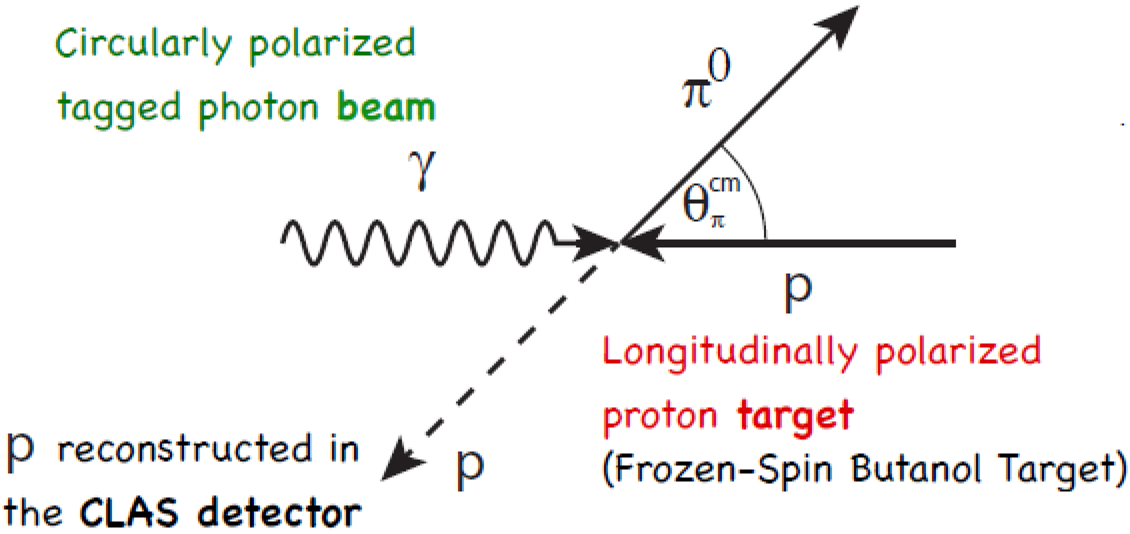
g9b g9a

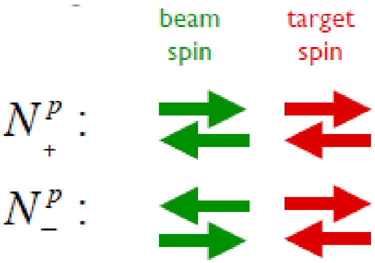
Nov '07 to **Feb '08**

- Every observable can be measured in at least **two** different experiments.
- They are not all independent. There are relations between them known as **Fierz** identities.

The Experiment

W = 1325 – 2075 MeV ΔW = **50** MeV
Cosθ = -0.8 – +0.8 $n_{\cos\theta}$ = **16**





Polarized cross section

$$\left(\frac{d\sigma}{d\Omega}\right)=\left(\frac{d\sigma}{d\Omega}\right)_0\left(1-P_zP_\odot E\right)$$

Maximum likelihood estimator

$$\hat{E}=-\frac{1}{P_zP_\odot}\left(\frac{N_+^p-N_-^p}{N_+^p+N_-^p}\right)$$

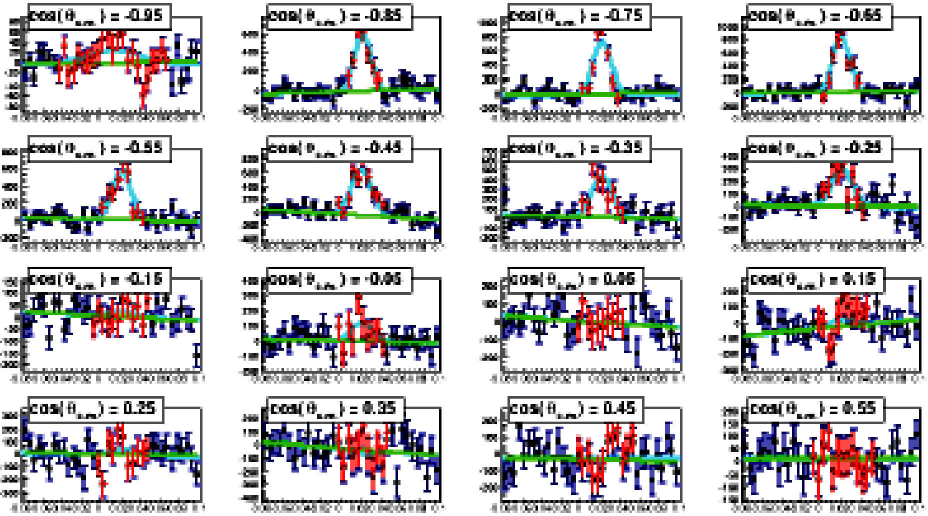
Courtesy of Steffen Strauch

Yields

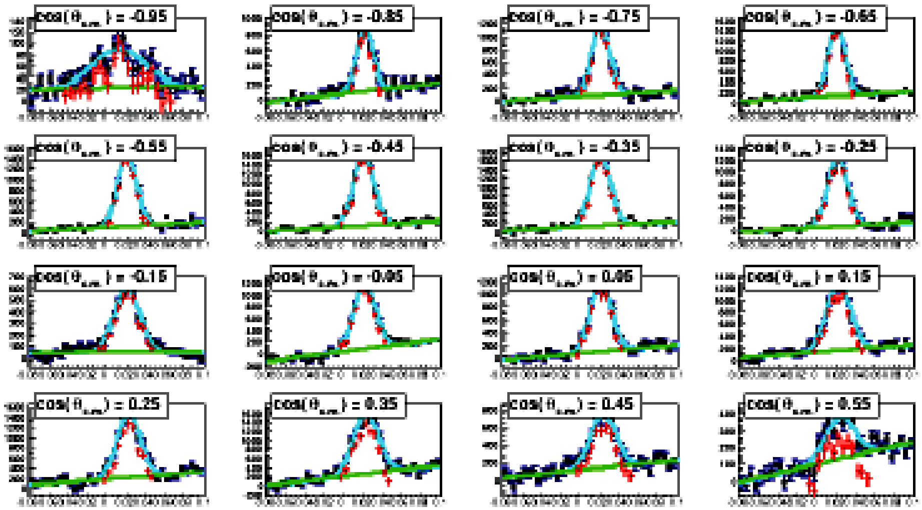
- Gaussian + polynomial to fit **peak**, yield is **2 σ**
- W = 1475 MeV.

$$E = -\frac{1}{P_Z^T P_C^\gamma}\left(\frac{N_+ - N_-}{N_+ + N_-}\right)$$

Numerator



Denominator



Polarized Measurements

for $\gamma p \rightarrow \pi^+ n$ & for $\gamma p \rightarrow \pi^0 p$

Double Polarization Observable $\mathbf{E}$ for $\pi^{+}n$

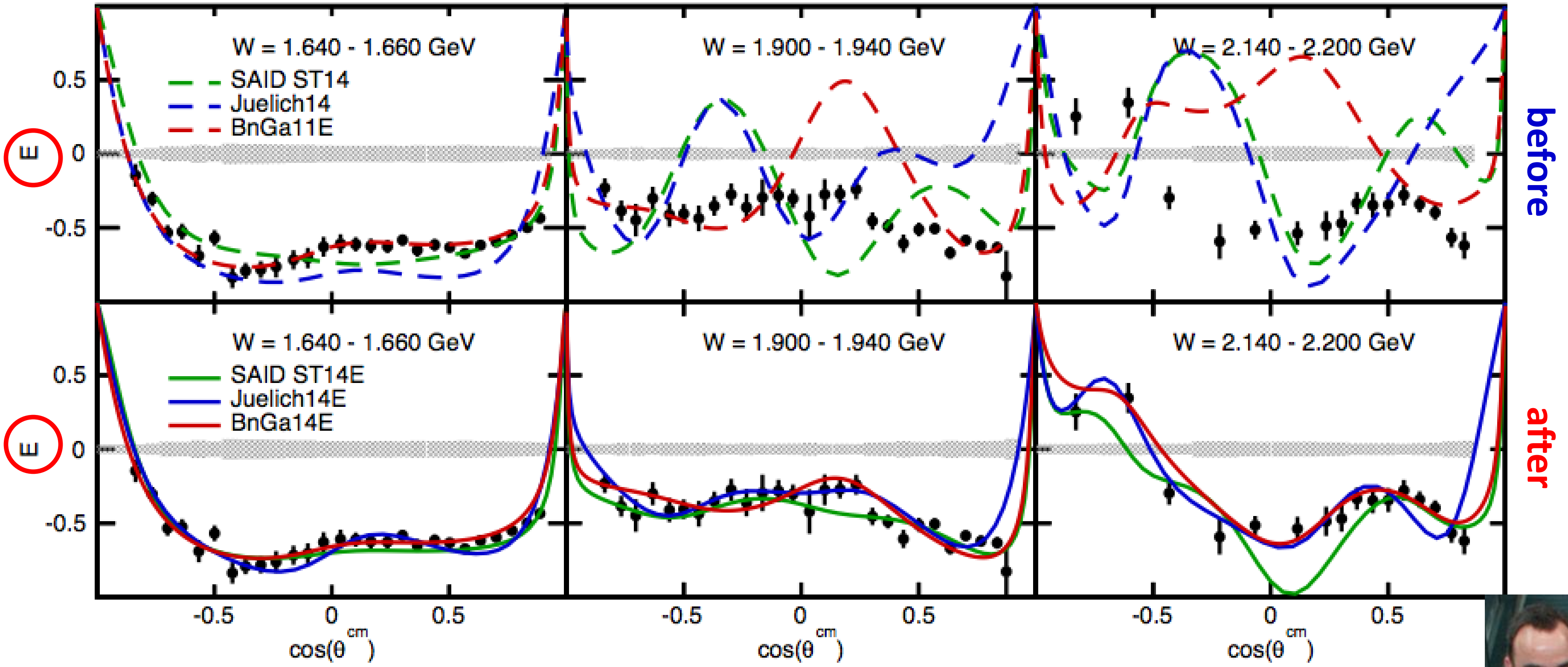
$$\left(\frac{d\sigma}{d\Omega}\right)=\left(\frac{d\sigma}{d\Omega}\right)_0\left(1-P_zP_{\odot}E\right)$$

$W = 1240 - 2260$ MeV

$-0.9 \le \cos(\theta_{\pi}^{cm}) \le +0.9$

$\vec{\gamma}\vec{p} \to \pi^{+}n$

W = 1650 MeV **W = 1920 MeV** **W = 2170 MeV**



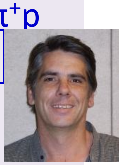
S. Strauch *et al*. (CLAS) Phys Lett B **750**, 53 (2015)

Courtesy of Steffen Strauch, CIPANP 2015

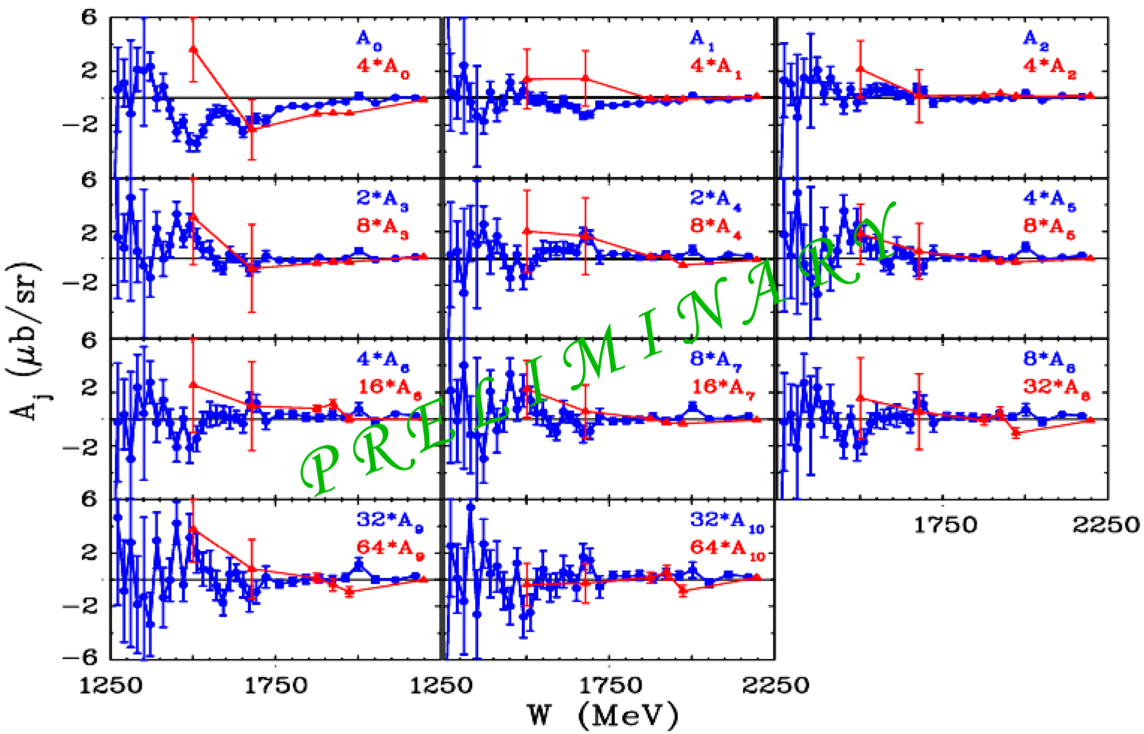
Legendre Polynomial Fit

- Beyond the **SAID PWA**, we plan the **Legendre analysis** for **CLAS E** measurements for both $\gamma p \to \pi^+ p$ and $\gamma p \to \pi^0 p$ as we did recently for the **CLAS Σ** data

M. Dugger *et al.* (CLAS) Phys Rev C **88**, 065203 (2013).

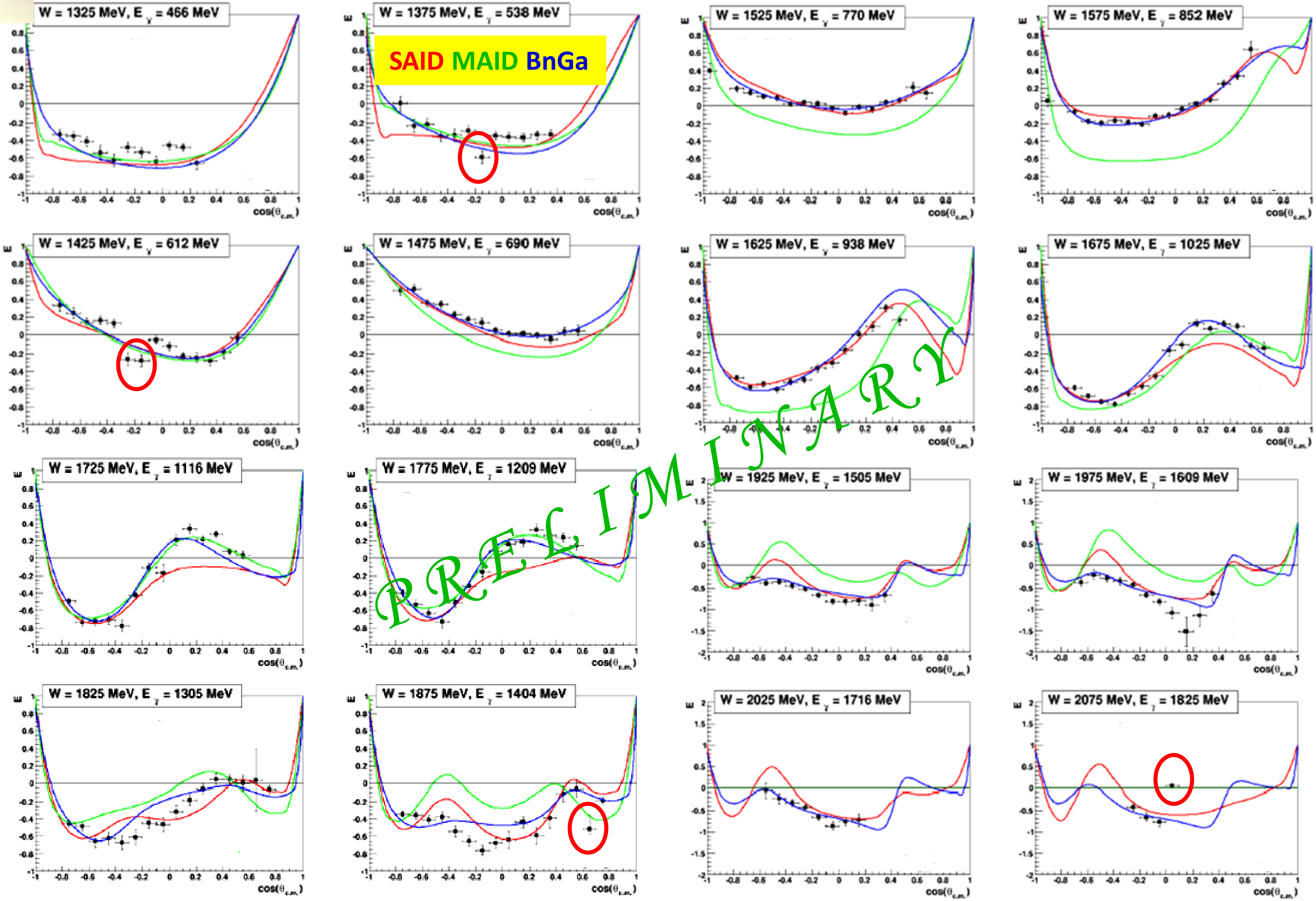


- Unfortunately, recent **CBELSA E** for $\gamma p \to \pi^0 p$ is insufficient for that because of so broad energy binning (Δ**W** = 300 – 500 MeV).



- S. Strauch *et al.* (**CLAS**) Phys Lett B **750**, 53 (2015)
- M. Gottschall *et al.* (**CBELSA/TAPS**) Phys Rev Lett **112**, 012003 (2014)

*Double Polarization Observable **E** for $\pi^0 p$*



- **Predictions are good for low energies while high energies are waiting for fit.**

Summary

- Spin observables will tremendously aid in determining resonance parameters and finding ``**missing resonances**" (if they exist).

- Photon experiments in **Hall B** with **FroST** **at JLab** have acquired hundreds of data points unprecedented statistical quality and covering many reactions.

- For most reaction channels, we will have data sufficient for a nearly **complete experiments**.

- Evidence of **new states** found in **coupled-channel** analyses.

- Data for some reactions and some observables are nearing the **publication stage**, but much work remains.

- High level **analysis tools** (**SAID**, MAID, Juelich, BnGa) are in great demand.

Thank you for the invitation
and your attention

Work in Progress

igor@gwu.edu