The Search for N* Resonances:

Measurement of the Helicity Asymmetry E in $\omega \rightarrow \pi^+\pi^-\pi^0$ Photoproduction

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CLAS Collaboration Meeting

9 March 2018

Outline

- Introduction and Motivation
- CLAS-FROST Experiment
- Data Analysis
- Result
- Physics Impacts
- Outlook

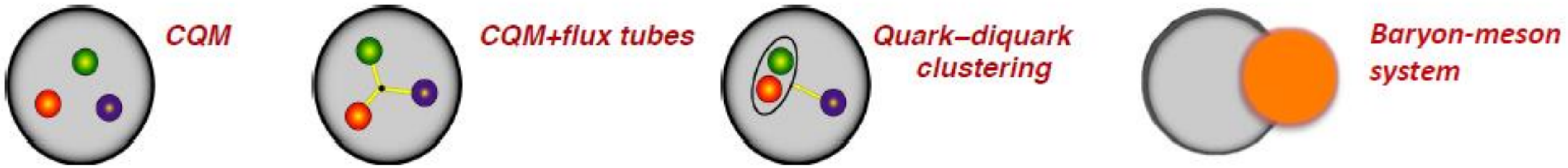
Introduction & Motivation

- Why is it important to map out the N* spectrum?
- Where do we start?

Why is it important?

Mapping out the whole spectrum of resonances is very important to understand:

- How does the behavior of quarks determine the properties of hadrons?
- How does the quark and gluon dynamics give rise to the spectrum of hadrons?
- What are the fundamental degrees of freedom inside hadrons?

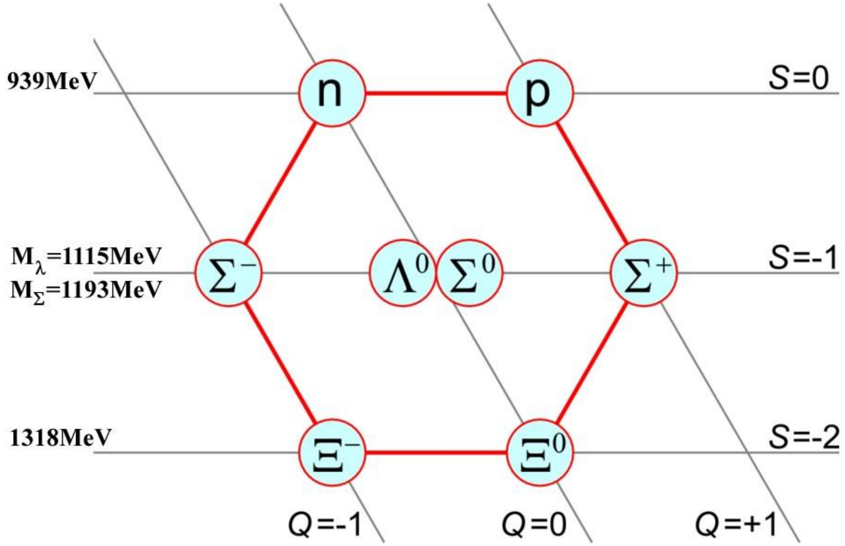


And many more : Lattice QCD, Hybrid Baryons, Holographic QCD, …

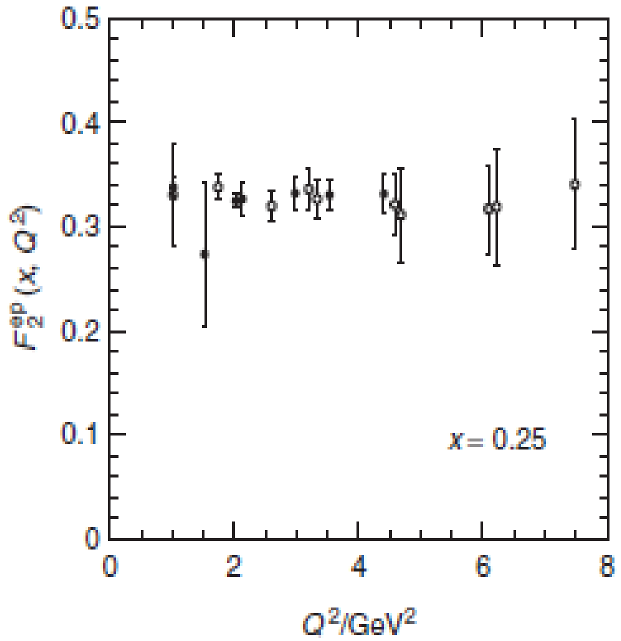
Why is it important?

Spectroscopy studies are complementary to nucleon structure studies

Past



Baryon Spectrum



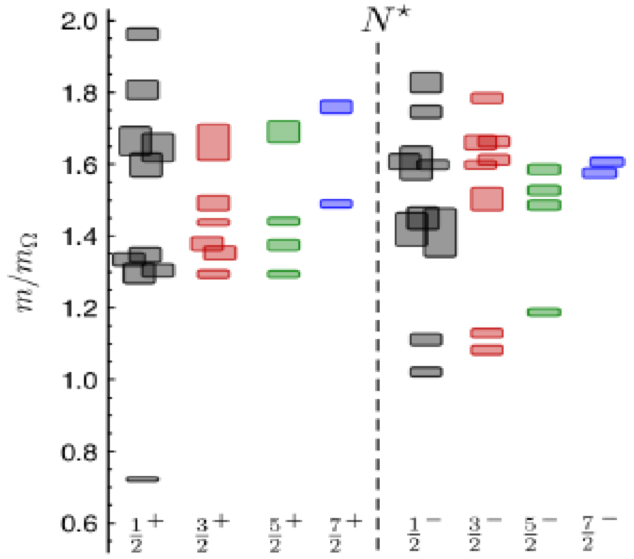
Structure Functions

Established the existence of 3 valence quarks

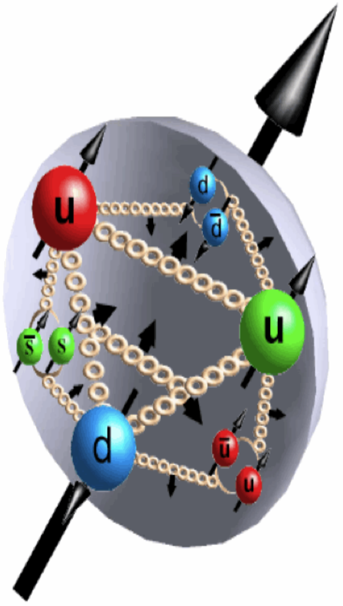
Why is it important?

Spectroscopy studies are complementary to Nucleon Structure studies

Now



- Mapping N* resonances
- Mapping unconventional hadrons: hybrid baryons, exotic mesons, etc

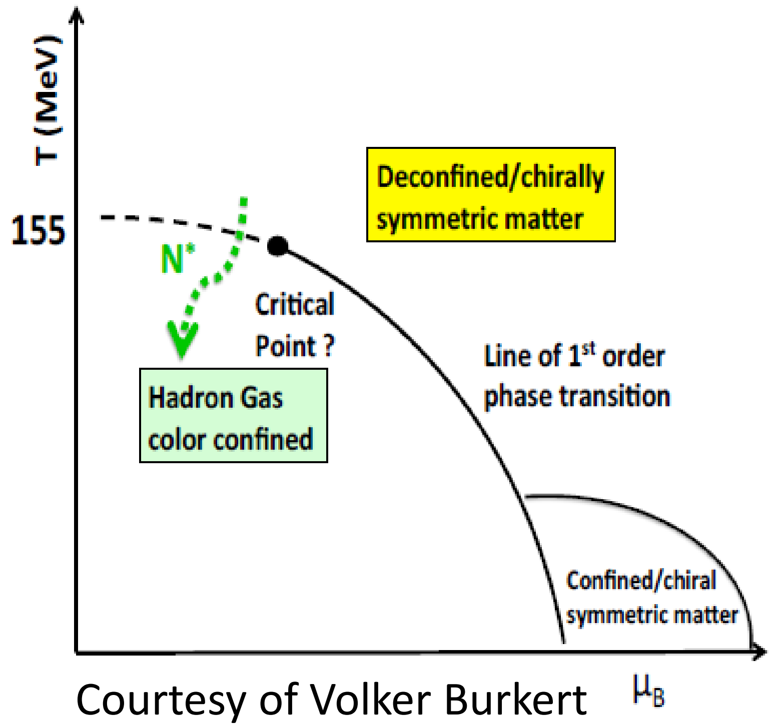


Parton Distribution Functions

Establish the whole dynamics of quarks and gluons in making the hadron

Why is it important?

In particular the N* resonances play significant role in the evolution of the universe



Courtesy of Volker Burkert

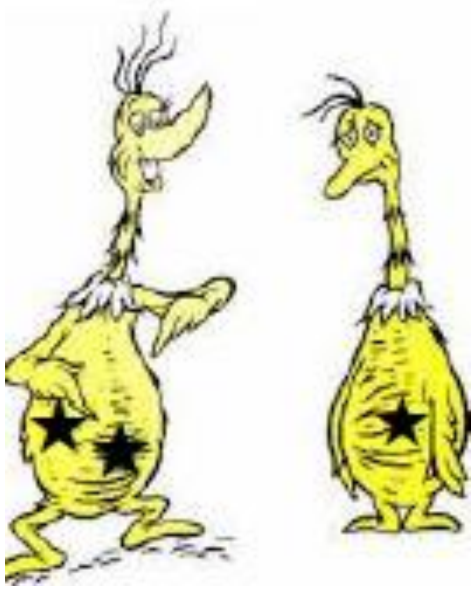
At T ~ 10^{-6} s

- Transition from Quark-Gluon Plasma to Nucleons
- Chiral symmetry breaking
- Quark mass generation
- Color confinement
- Complete spectrum of resonances is required to explain the transition, including resonances with the strangeness content.

Where do we start?

- The ω-channel is under explored
- The ω mesons share the same quantum number as photon
- The ω photoproduction is an isospin filter for *N**
- The ω photoproduction threshold lies in the higher lying third resonance region at ~ 1800 MeV

Many poorly established resonances lie above γp -> pω threshold:



γp -> pω threshold

Particle	J^P	Status overall	Status πN	Status γN	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
					Status as seen in —						
N	$1/2^+$	****									
$N(1440)$	$1/2^+$	****	****	****		***				*	***
$N(1520)$	$3/2^-$	****	****	****	***					***	***
$N(1535)$	$1/2^-$	****	****	****	****					**	*
$N(1650)$	$1/2^-$	****	****	***	***			***	**	**	***
$N(1675)$	$5/2^-$	****	****	***	*			*		*	***
$N(1680)$	$5/2^+$	****	****	****	*	**				***	***
$N(1685)$	??	*									
$N(1700)$	$3/2^-$	***	***	**	*			*	*	*	***
$N(1710)$	$1/2^+$	***	***	***	***		**	***	**	*	**
$N(1720)$	$3/2^+$	****	****	***	***			**	**	**	*
$N(1860)$	$5/2^+$	**	**							*	*
$N(1875)$	$3/2^-$	***	*	***			**	***	**		***
$N(1880)$	$1/2^+$	**	*	*		**		*			
$N(1895)$	$1/2^-$	**	*	**	**			**	*		
$N(1900)$	$3/2^+$	***	**	***	**		**	***	**	*	**
$N(1990)$	$7/2^+$	**	**	**					*		
$N(2000)$	$5/2^+$	**	*	**	**			**	*	**	
$N(2040)$	$3/2^+$	*									

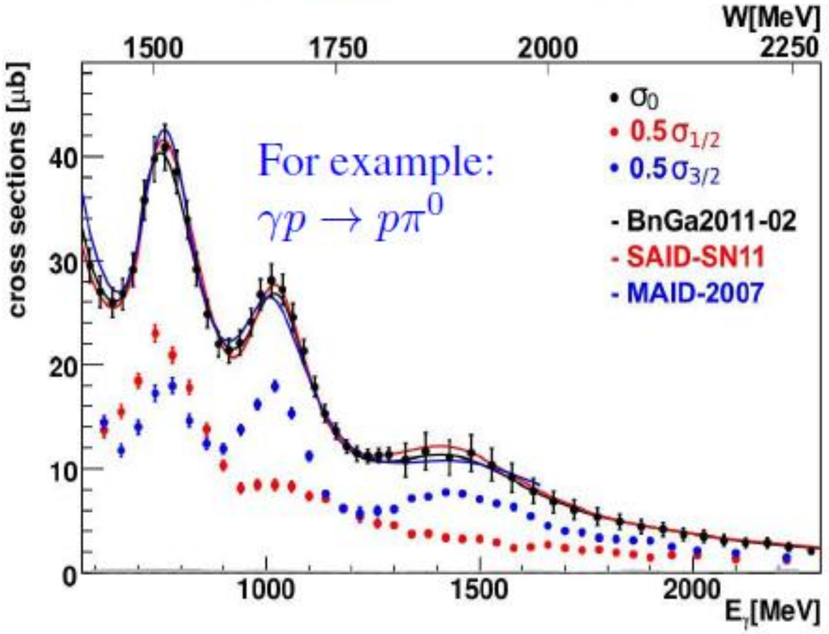
PDG 2014

Where do we start?

- N* resonances are broad and overlapping
- Polarization observables are required in addition to the cross section to disentangle the resonance contributions

As an example, 3 different models agree with the unpolarized cross sections -> leads to ambiguous solutions:

M. Gottschall *et al.* PRL 112 (2014)



Total cross section with polarized beam and/or target:

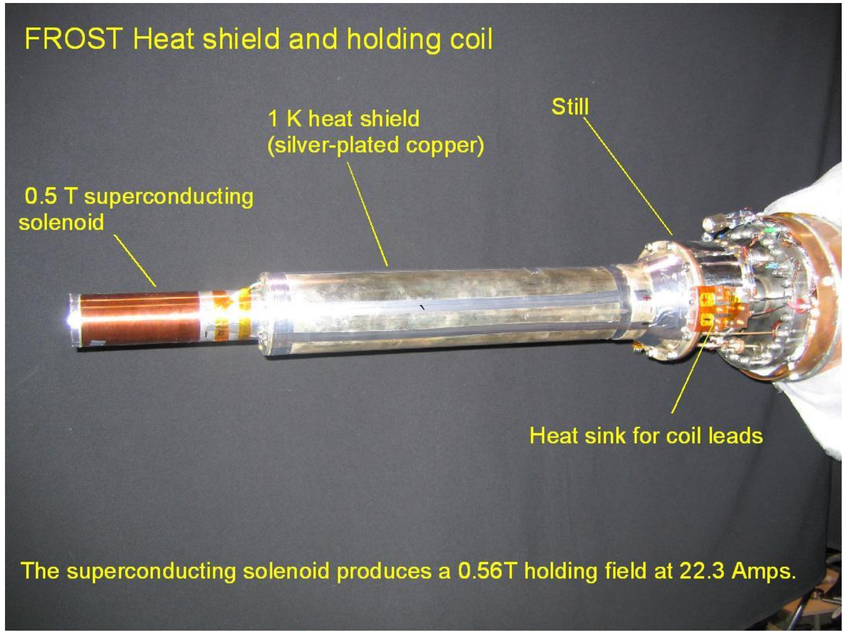
$$\frac{d\sigma}{dx_i} = \sigma_0 \{ 1 - \delta_l \Sigma \cos 2\phi + \Lambda_x (-\delta_l \mathrm{H} \sin 2\phi + \delta_\odot \mathrm{F}) - \Lambda_y (- \mathrm{T} + \delta_l \mathrm{P} \cos 2\phi) - \Lambda_z (-\delta_l \mathrm{G} \sin 2\phi + \delta_\odot \mathrm{E}) \}.$$

Helicity Asymmetry:

$$E = -\frac{1}{\Lambda_z \delta_o} \left(\frac{N_+ - N_-}{N_+ + N_-} \right)$$

Goal: "Measure the helicity asymmetry E for γp -> pω using ω -> $\pi^+\pi^-\pi^0$ decay channel from CLAS-FROST"

CLAS-FROST (g9a) Experiment



Frozen Spin Butanol Target (FROST)

Electron Energy	Maximum at 2.4 GeV
Electron Degree of Polarization	Maximum 84.8 %
Tagged Photon Energy	Maximum 2.3 GeV
Target Material	Frozen Spin Butanol
Target Polarization	Longitudinal
Degree of target Polarization	Maximum 87 %
Photon Polarization	Circular and Linear

CLAS-FROST was designed to perform an (almost) complete measurement for various channel. It consists of the g9a experiment and g9b experiment that used transversely polarized target and circularly/linearly polarized photon beam. We used g9a-circularly beam (longitudinally polarized target) dataset to measure the helicity asymmetry E for the γp -> pω reaction.

Data Analysis

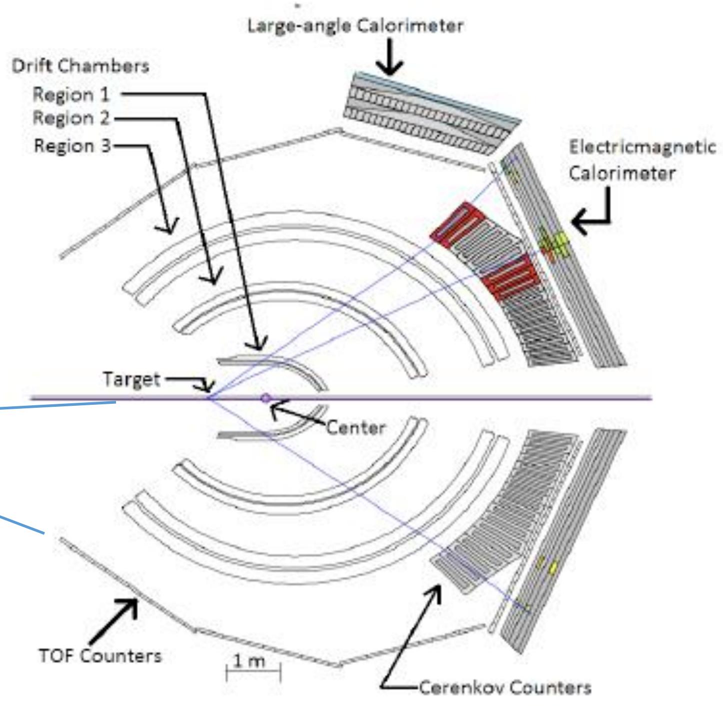
- PID
- Event Selection
- Background Substraction

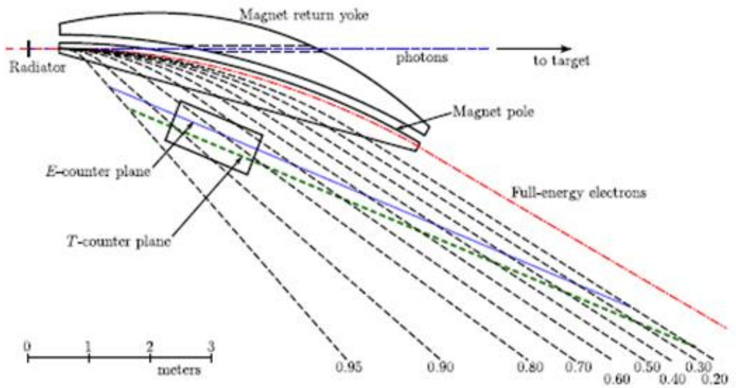
Data Analysis

1. Vertex Identification : ST & TOF provide the flight time of a particle. DC provide momentum and track. Hence particle speed, vertex time and position can be determined (propagated inward through ST).

$$\Delta t = |t_v - t_\gamma| < 1ns,$$

2. Photon identification : T-Scintillator on the tagger has photon time information. Then it is propagated to the vertex to get photon vertex time. We choose photon who has coincidence with particle's vertex time within 1 ns.





3. Proton and Pion Identification : we can measure the empirical mass of a particle : $m = \frac{p}{\gamma\beta_m}$,

and assign the particle ID according to the table :

particle ID	mass
Pion (π)	$m < 0.3$ GeV
Kaon (K)	$0.35 < m < 0.65$ GeV
Proton (p)	$0.8 < m < 1.2$ GeV
Deuteron (d)	$1.75 < m < 2.2$ GeV

4. Delta Beta Cut : The calculated beta is

$$\beta_{calc} = \sqrt{\frac{p^2}{m_{PDG}^2 + p^2}}.$$

$$\Delta\beta = |\beta_{calc} - \beta_m| < 3\sigma.$$

In summary, the PID processes were done using the information from Start counter (ST), Time of flight (TOF), Drift Chamber (DC) and Tagger.

5. Kinematic Fitting:

- We select all $\gamma p \rightarrow p\pi^+\pi^-(X)$ events.
- Selection of $\gamma p \rightarrow p\pi^+\pi^-(\pi^0)$ events ($X = \pi^0$) using kinematic fitting. The π^0 is reconstructed by imposing energy and momentum conservation.
- All $\gamma p \rightarrow p\pi^+\pi^-(\pi^0)$ events have CL > 0.01.

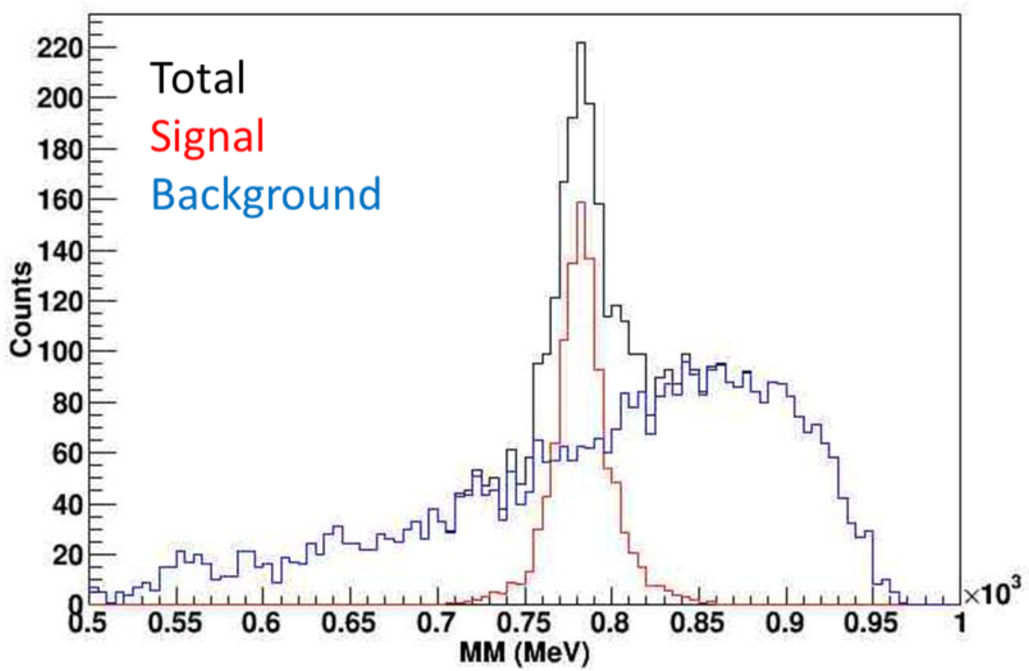
Normalized by the degree of target/beam polarization:

$$E = -\frac{1}{\Lambda_z \delta_o}\left(\frac{N_+ - N_-}{N_+ + N_-}\right)$$

- Λ_z = Degree of target polarization
- δ_o = Degree of photon polarization

6. Signal-Background separation using Q-factor methods:

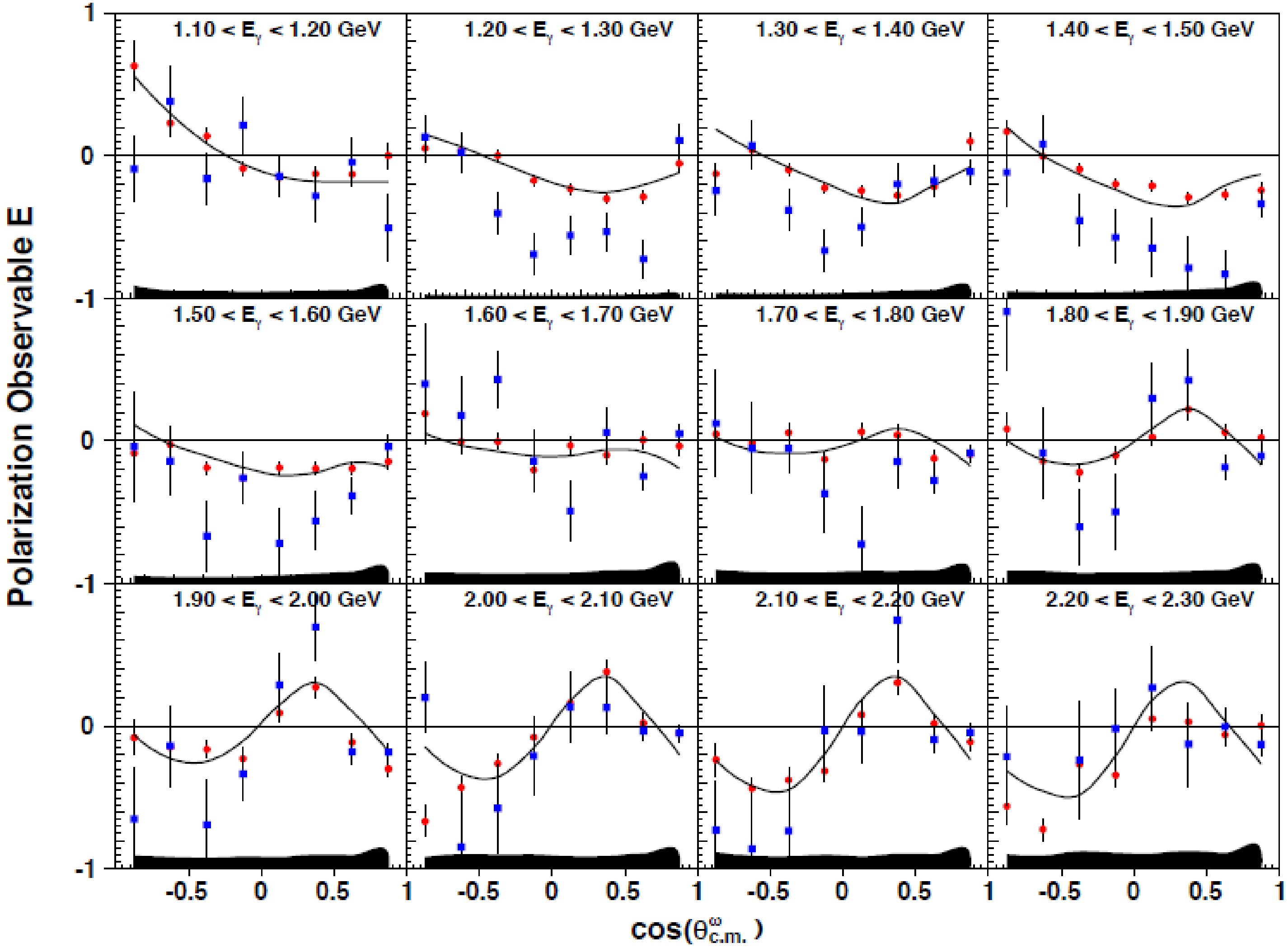
- Locating the peak
- Define kinematic distance to find the nearest neighbor
- Fit using signal and background pdf
- Determine the signal/background fraction and Q-value



Result

- CLAS Result & Comparison with previous measurement
- BnGa Partial Wave Analysis
- Resonances contributions

The helicity asymmetry E of γp -> pω along with the Bonn-Gatchina Partial Wave Analysis result



- The figure shows the helicity asymmetry E from CLAS-FROST at 1.1 – 2.3 GeV (red point) along with the Bonn-Gatchina PWA fit result (**solid line**), in comparison with the previous measurement from CBELSA/TAPS (blue point)
- The dominant contribution from N(1720) 3/2$^+$ is found.
- The background is dominated by the t-channel contributions (pomeron-exchange and a smaller π-exchange).
- The full description of the data also needs the contributions
  N(1680) 5/2$^+$ (∗∗∗∗)
  N(2000) 5/2$^+$ (∗∗)
  N(1895) 1/2$^-$ (∗∗)
  N(2100) 3/2$^-$ (∗∗)

Published in Phys. Rev. C 96,065209 (2017)

Physics Impacts

- Discover the poorly established resonances
- Rule out the CQM with static quark-diquark picture

Physics Impacts: Discover the poorly established resonances

Courtesy of Eberhard Klempt

The impact of photoproduction on baryon resonances		Decay modes of nucleon resonances		
	black:	PDG 2004	****	Existence is certain.
	red:	PDG 2018	***	Existence is very likely.
	blue:	BESIII resonances	**	Evidence of existence is fair.
			*	Evidence of existence is poor.

		overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$	$N_{1440}\pi$	$N_{1520}\pi$	$N_{1535}\pi$	$N_{1680}\pi$
N	$1/2^+$	****														
$N(1440)$	$1/2^+$	****	****	****	****	***										
$N(1520)$	$3/2^-$	****	****	****	****	**	****									
$N(1535)$	$1/2^-$	****	****	****	***	*	****									
$N(1650)$	$1/2^-$	****	****	****	***	*	****	***					*			
$N(1675)$	$5/2^-$	****	****	****	****	***	*	*	*	**				*		
$N(1680)$	$5/2^+$	****	****	****	****	***	*			****						
$N(1700)$	$3/2^-$	***	**	***	***	*	*	**	*	*						
$N(1710)$	$1/2^+$	****	****	****	**		***	**	*	*	*				*	
$N(1720)$	$3/2^+$	****	****	****	***	*	*	****	*	**	*					
$N(1860)$	$5/2^+$	**	*	**		*	*									
$N(1875)$	$3/2^-$	***	**	**	*	**	*	*	*	*	*	*	*			
$N(1880)$	$1/2^+$	***	**	*	**	*	*	**	**		**				*	
$N(1895)$	$1/2^-$	****	****	*	*	*	****	**	**	*	*	****	*			
$N(1900)$	$3/2^+$	****	****	**	**	*	*	**	**	*	*	**				
$N(1990)$	$7/2^+$	**	**	**	*	*	*	**	**							
$N(2000)$	$5/2^+$	**	**	**	**	*	*	*	*		*					
$N(2040)$	$3/2^+$	*		*												
$N(2060)$	$5/2^-$	***	***	**	*	*	*	*	*	*	*		*	*		*
$N(2100)$	$1/2^+$	***	**	***	**	**	*	*		*	*	**			***	
$N(2120)$	$3/2^-$	***	***	***	**	**		**	*		*	*	*	*	*	
$N(2190)$	$7/2^-$	****	****	****	****	**	*	**	*	*	*					
$N(2220)$	$9/2^+$	****	**	****			*	*	*							
$N(2250)$	$9/2^-$	****	**	****			*	*	*							
$N(2300)$	$1/2^+$	*		*												
$N(2570)$	$5/2^-$	*		*												
$N(2600)$	$11/2^-$	***		***												
$N(2700)$	$13/2^+$	**		**												

CLAS Hadron Spectroscopy Working Group published 83 paper from 2004 - 2017

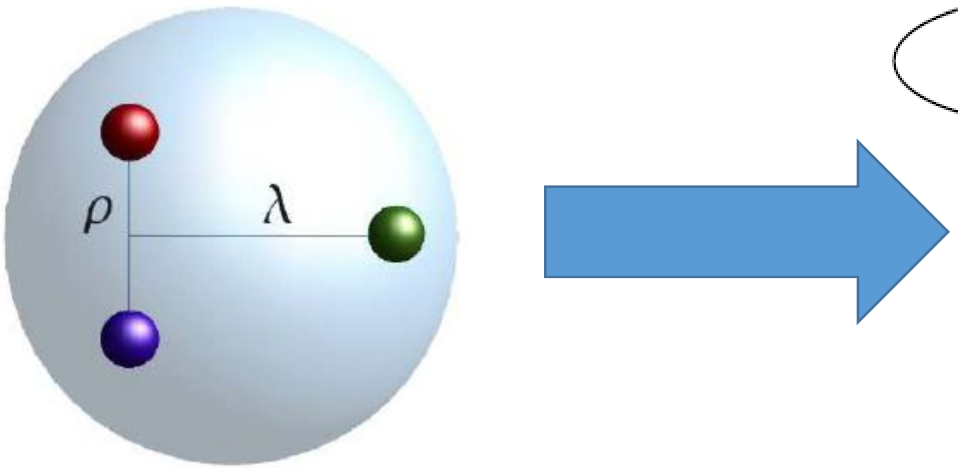
Courtesy of Volker Burkert

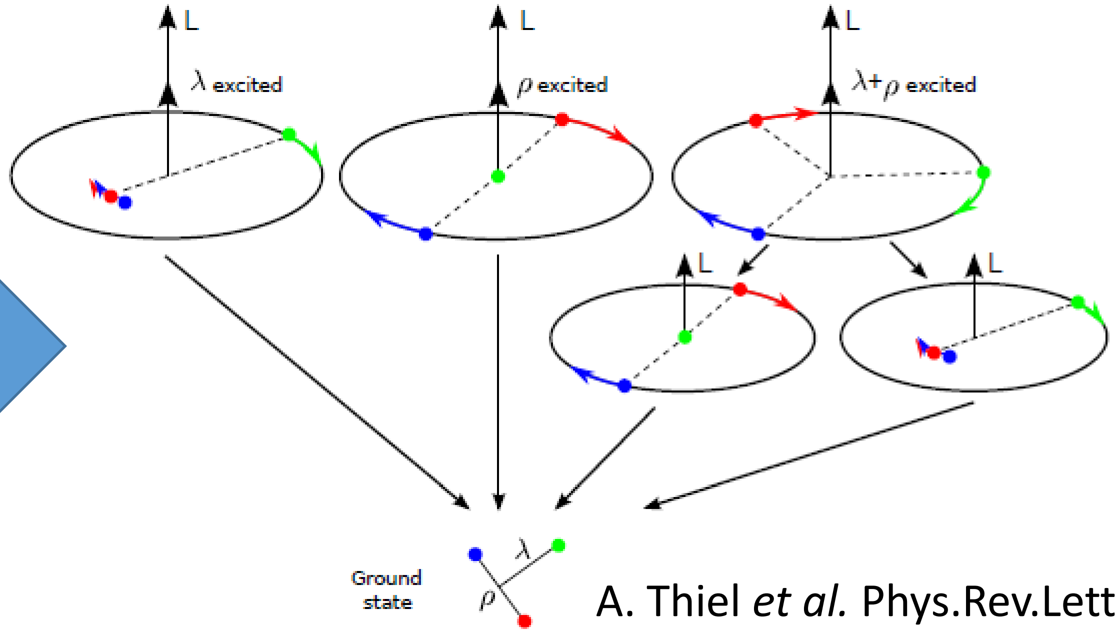
State N((mass)J^P	PDG pre 2012	PDG 2018*
N(1710)1/2$^+$	***	****
N(1880)1/2$^+$		***
N(1895)1/2$^-$		****
N(1900)3/2$^+$	**	****
N(1875)3/2$^-$		***
N(2120)3/2$^-$		**
N(2000)5/2$^+$	*	**
N(2060)5/2$^-$		**
Δ(2200)7/2$^-$	*	***

*) projected

Physics Impacts

Rule out the CQM with static quark-diquark picture





A. Thiel *et al.* Phys.Rev.Lett 144 (2015)

$N(2000)\,5/2^{+}$ is a member of $(\mathbf{70}, 2^{+}_{2})$ where both oscillator need to be excited

Outlook

The BnGa PWA also include the CLAS-FROST (g9b) polarization observables data:

- Beam asymmetry Σ of γp -> pω
- Target asymmetry T of γp -> pω

Submitted to PRC, arXiv: 1711.05176v2 [nucl-ex] 1 Dec 2017

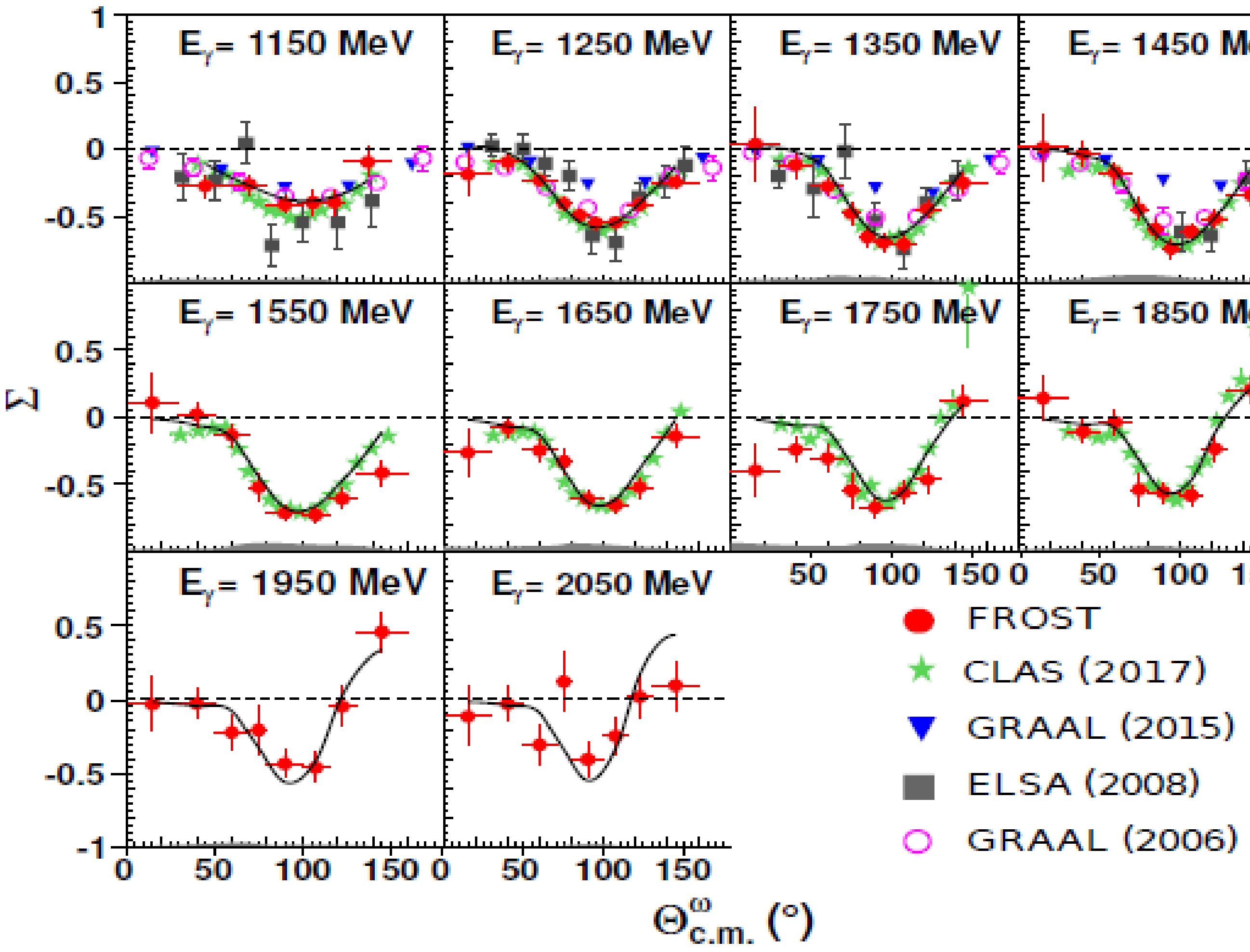
The preliminary results above resonances region from CLAS-g12 are also available:

- Differential cross sections of γp -> pω
- Spin Density Matrix Elements (SDMEs) of γp -> pω

Analysis Note is under review

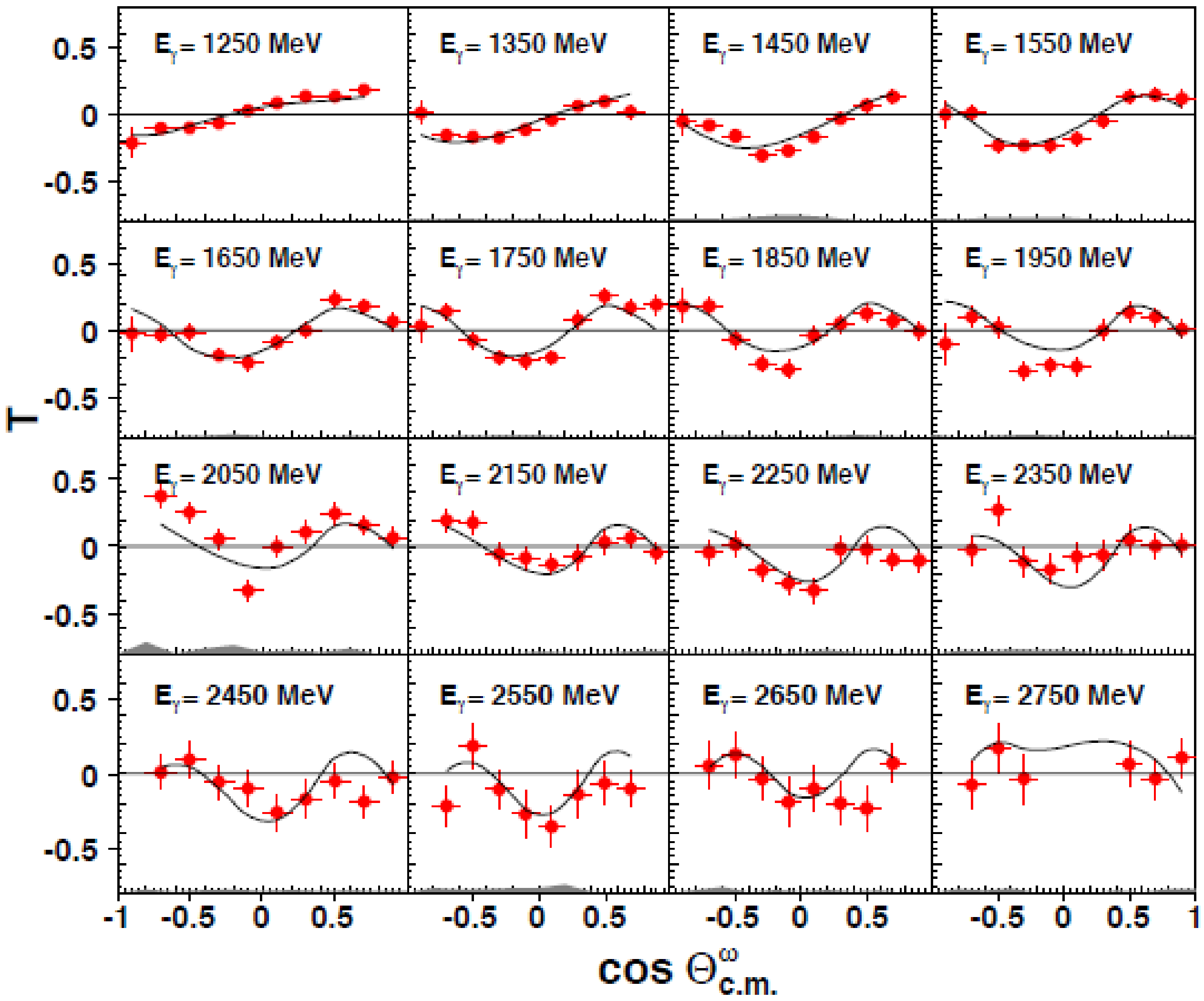
Toward a complete measurement in ω photoproduction

The beam asymmetry Σ of γp -> pω from CLAS-FROST along with the BnGa PWA result



Submitted to PRC, arXiv: 1711.05176v2 [nucl-ex] 1 Dec 2017

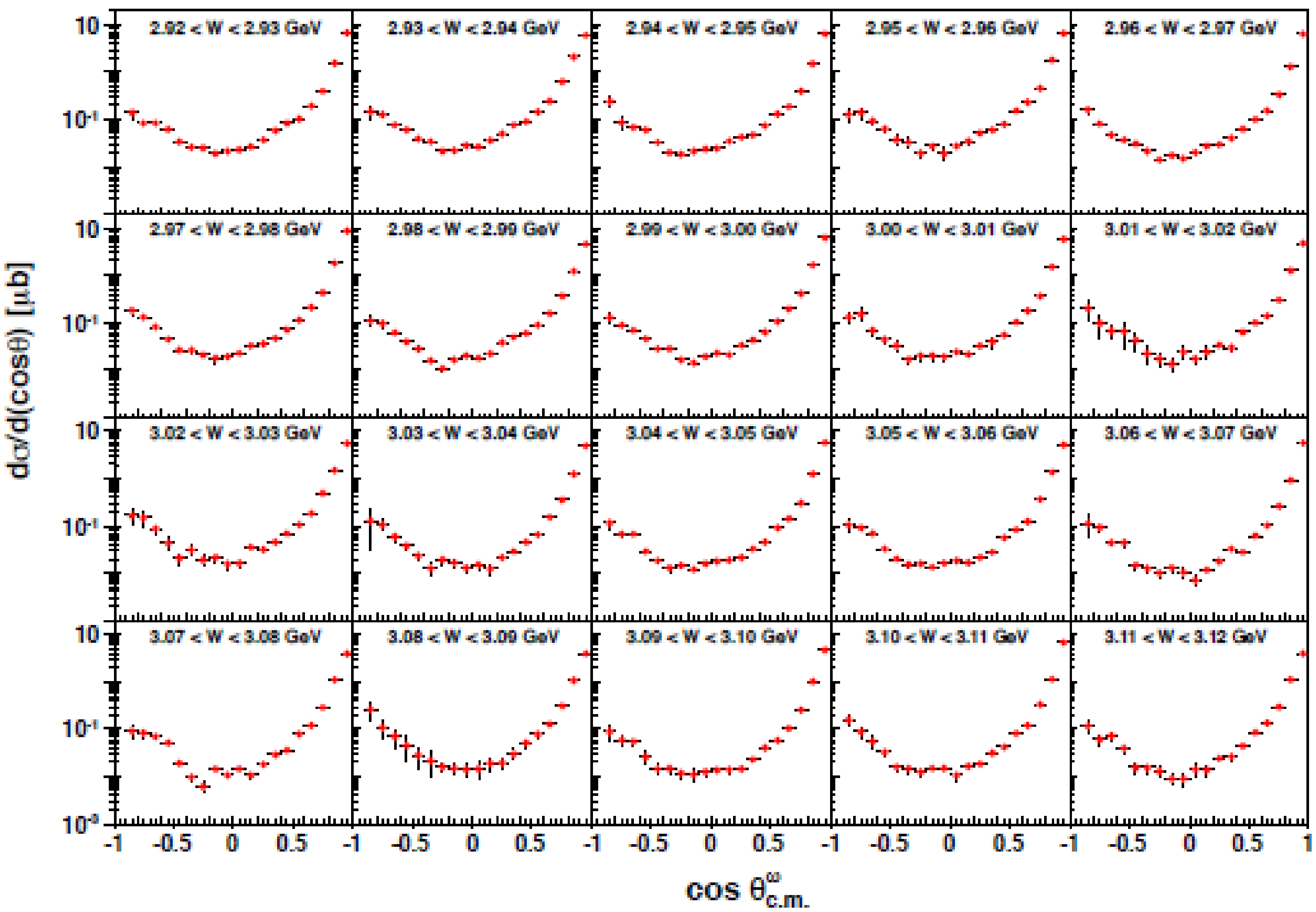
The target asymmetry T of γp -> pω from CLAS-FROST along with the BnGa PWA result



First Measurement!

Submitted to PRC, arXiv: 1711.05176v2 [nucl-ex] 1 Dec 2017

The differential cross section of γp -> pω from CLAS-g12



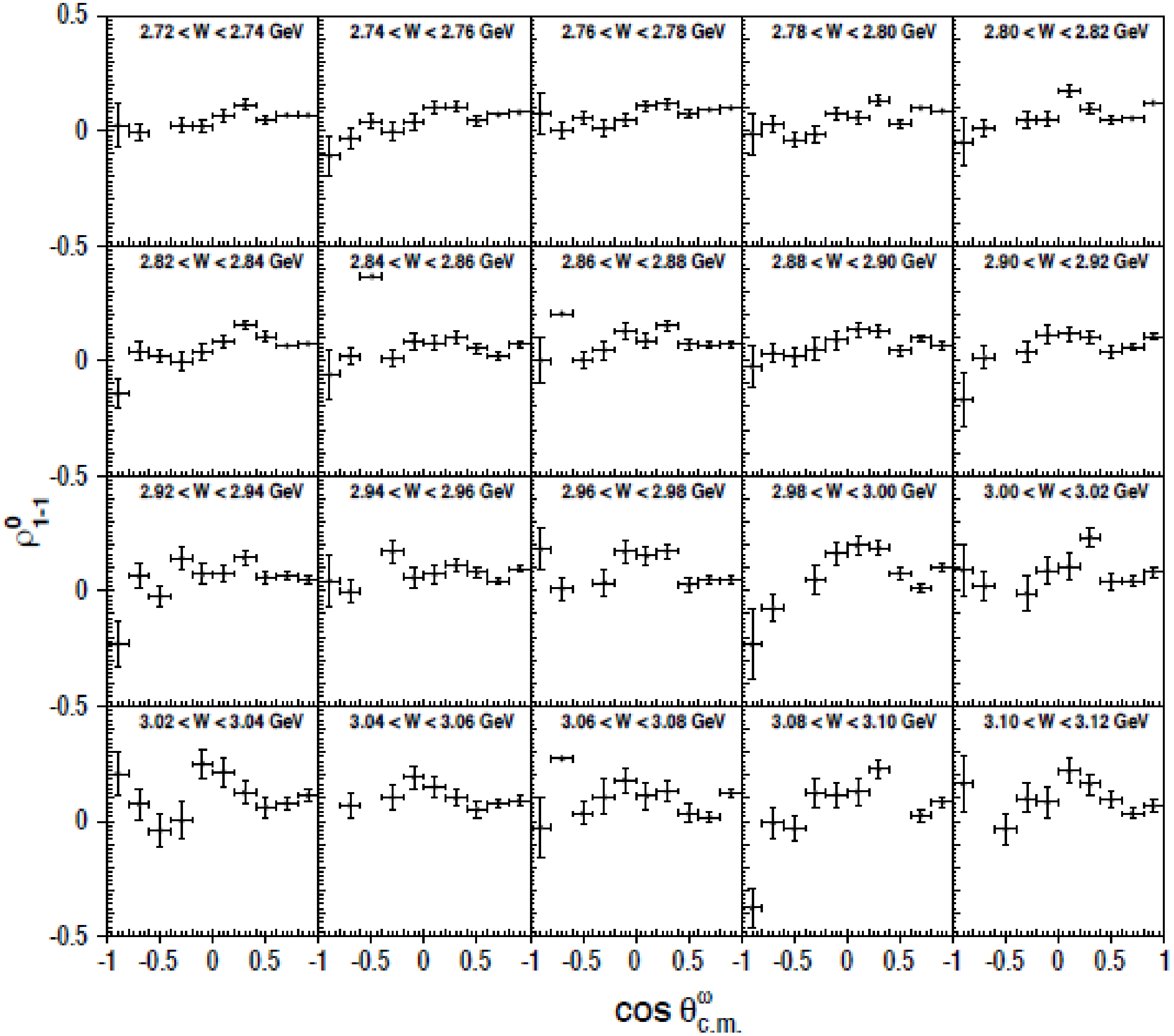
Analysis Note is under review

Unprecendented quality above resonances regime

Physics outlook:

- Reggeon exchange model by JPAC
- Constituent counting rule

The Spin Density Matrix Element of γp -> pω from CLAS-g12



Analysis Note is under review

Unprecendented statistics above resonances regime

Physics outlook:

- Reggeon exchange model by JPAC
- Constituent counting rule

THANK YOU

Special Thanks for CLAS6 detector for the excellent services