Photo-production of ω Mesons using CLAS at Jefferson Laboratory

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Outline

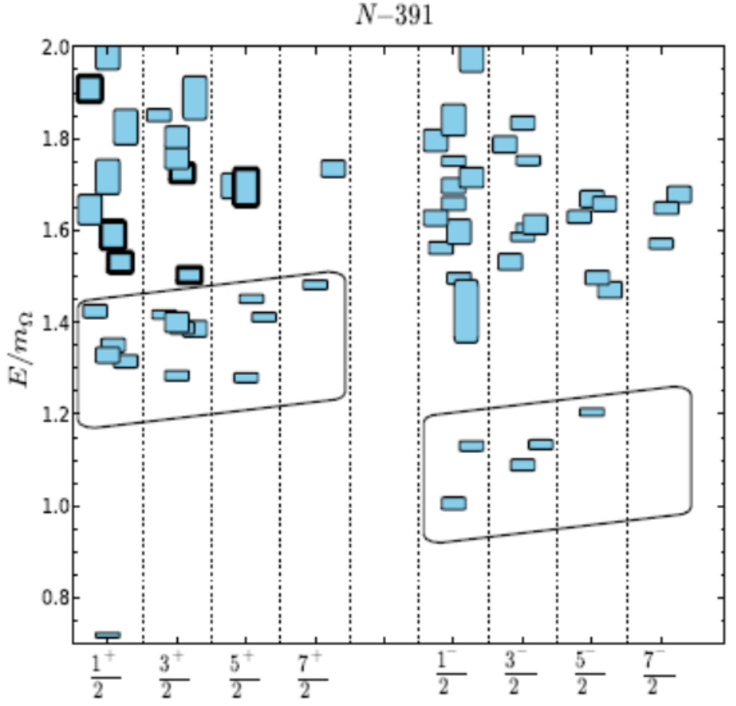
- Background
- CLAS-g12 and CLAS-FROST Experiment
- Data Analysis Technique
- Result and Discussion
- Summary and Outlook

BACKGROUND

- Motivation
- Previous Study and Measurement

Motivation : Missing Baryon Resonance

- A lot of baryon resonances that is predicted by Constituent Quark Model (CQM) and Lattice QCD have not been observed vet.



Lattice calculation by R. G. Edwards *et al*

J^P	M_{CQM}	M_{PDG}	Rating	J^P	M_{CQM}	M_{PDG}	Rating
$1/2^-$	1460	1535	****	$1/2^+$	1540	1440	****
$1/2^-$	1535	1650	****	$1/2^+$	1770	1710	***
$1/2^-$	1945	2090	*	$1/2^+$	1880		
$1/2^-$	2030			$1/2^+$	1975		
$1/2^-$	2070			$1/2^+$	2065	2100	*
$1/2^-$	2145			$1/2^+$	2210		
$1/2^-$	2195						
$3/2^-$	1495	1520	****	$3/2^+$	1795	1720	****
$3/2^-$	1625	1700	***	$3/2^+$	1870		
$3/2^-$	1960	2080	**	$3/2^+$	1910		
$3/2^-$	2055			$3/2^+$	1950		
$3/2^-$	2095			$3/2^+$	2030		
$3/2^-$	2165						
$3/2^-$	2180						
$5/2^-$	1630	1675	****	$5/2^+$	1770	1680	****
$5/2^-$	2080			$5/2^+$	1980	2000	**
$5/2^-$	2095	2200	**	$5/2^+$	1995		
$5/2^-$	2180						
$5/2^-$	2235						
$5/2^-$	2260						
$5/2^-$	2295						
$5/2^-$	2305						
$7/2^-$	2090	2190	****	$7/2^+$	2000	1990	**
$7/2^-$	2205			$7/2^+$	2390		
$7/2^-$	2255			$7/2^+$	2410		
$7/2^-$	2305			$7/2^+$	2455		
$7/2^-$	2355						
$9/2^-$	2215	2250	****	$9/2^+$	2345	2220	****
$11/2^-$	2600	2600	***				
$11/2^-$	2670						
$11/2^-$	2700						
$11/2^-$	2770						
$13/2^-$	2715						

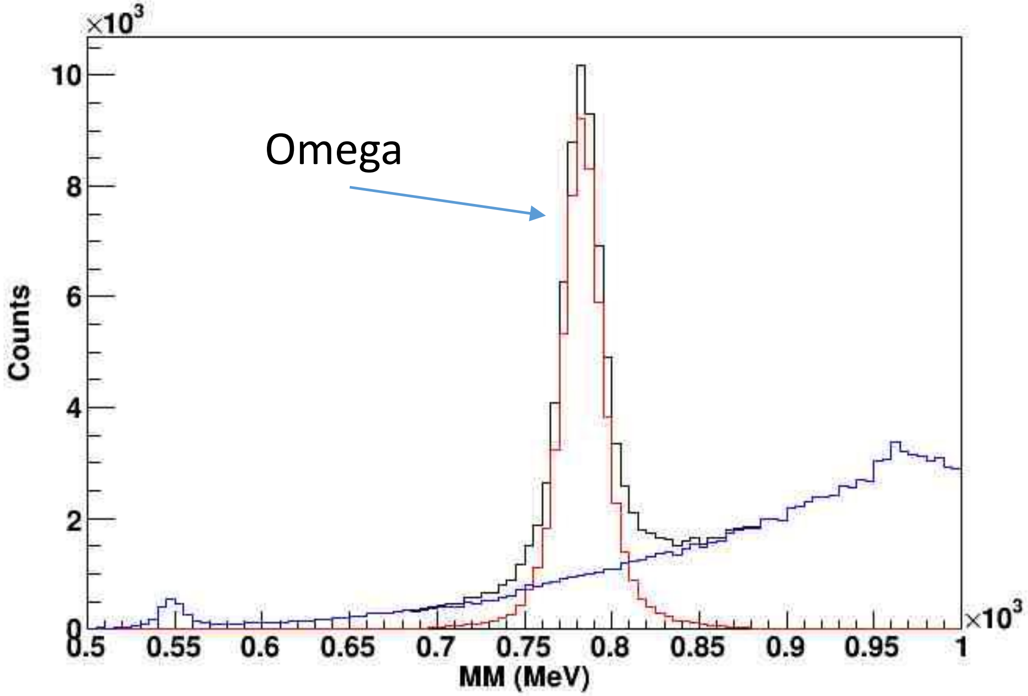
Resonance predicted by Capstick & Robert using CQM

Motivation : The need of Photo-production and Omega Channel

- **Why photo-production?** A lot of previous experiments have been conducted using *N*π channel. Koniuk and Isgur suggested that missing resonances may not coupled strongly to *N*π system. Capstick also predicted that missing *N** coupled fairly strong to γp (photo-production).
- **Why omega?** A lot of effort has been put to study *N** resonances through pseudoscalar meson channel. We need to complete those effort by studying *N** through vector meson production channel (pω, pρ, pφ).
- Vector meson and photon share the same quantum number ($J^{PC} = 1^{--}$). It is highly expected that vector mesons play significant role in Baryon spectroscopy through Photo-production.
- ω meson is still under explored (PDG 2014).

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

- Furthermore, the ω is isoscalar (*I* = 0), only *N** resonances contribute in s channel processes, No interference from Δ* resonances.
- The ω threshold lie at the higher lying third resonance region (and the missing baryon resonance is most noticeably at the relatively high lying states)
- Moreover, the narrow width of the ω (8 MeV) enables a clean detection over background.

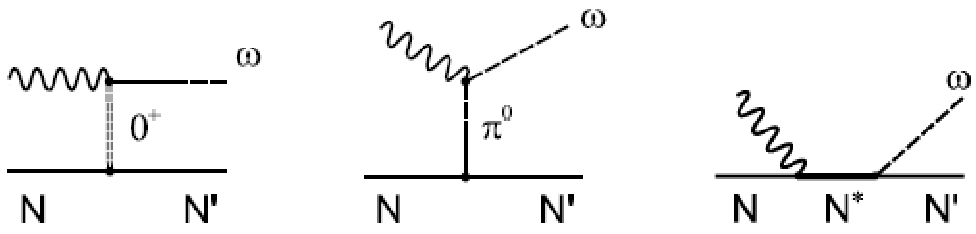


3π invariant mass

Therefore, the photoproduction of ω mesons is well suited to investigate the missing *N resonances issue.**

Previous Study and Measurement

- The photoproduction of ω meson at high energy is successfully described as a diffractive scattering process : The photon converts into ω and then scatter off the proton by the exchange of Pomerons (left figure).
- At intermediate energy (E<5 GeV), pomeron exchange is not sufficient to describe the data. It is suggested that pseudo scalar meson exchange also contribute significantly (middle figure).
- However, both processes are not able to describe the data at smaller energy. This indicates the s-channel resonance contribution (right).



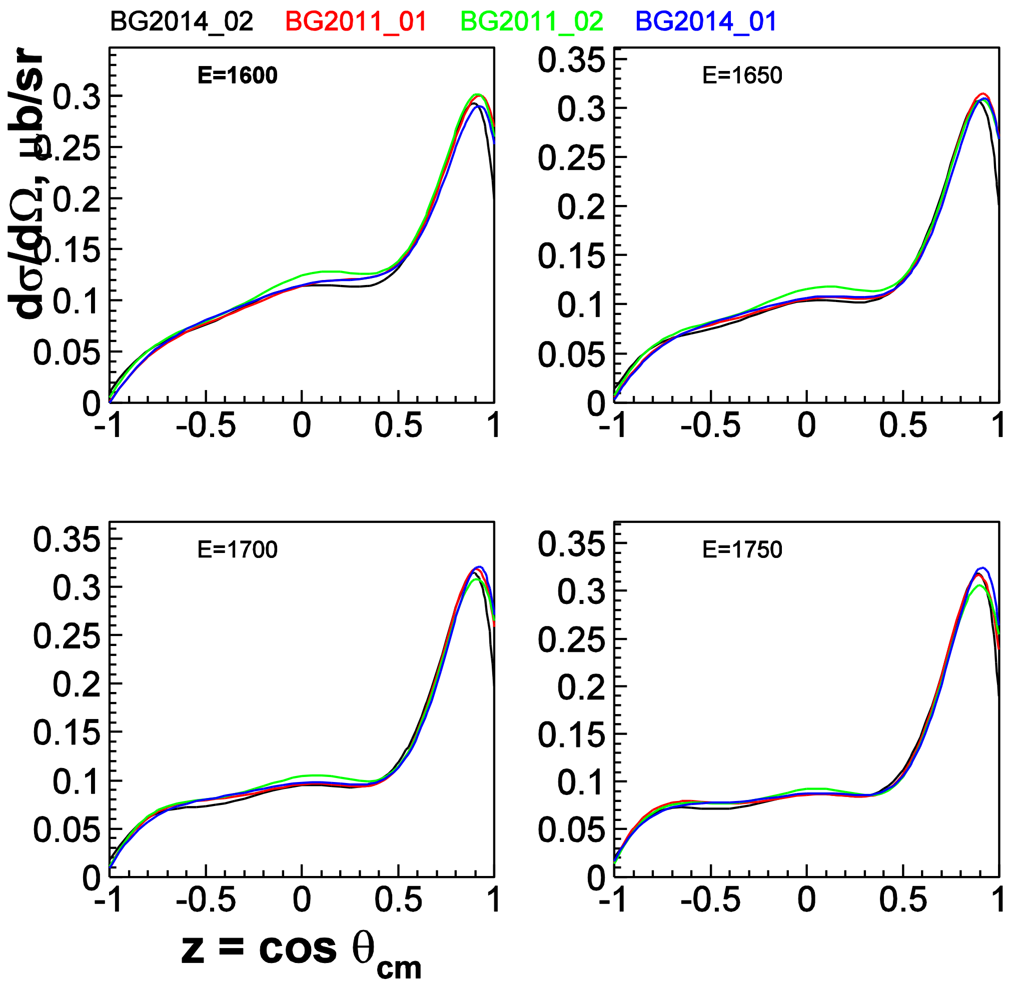
Some different mechanism of ω photoproduction : t-channel pomeron exchange (left), t-channel pion exchange (middle) and s-channel intermediate resonance excitation (right).

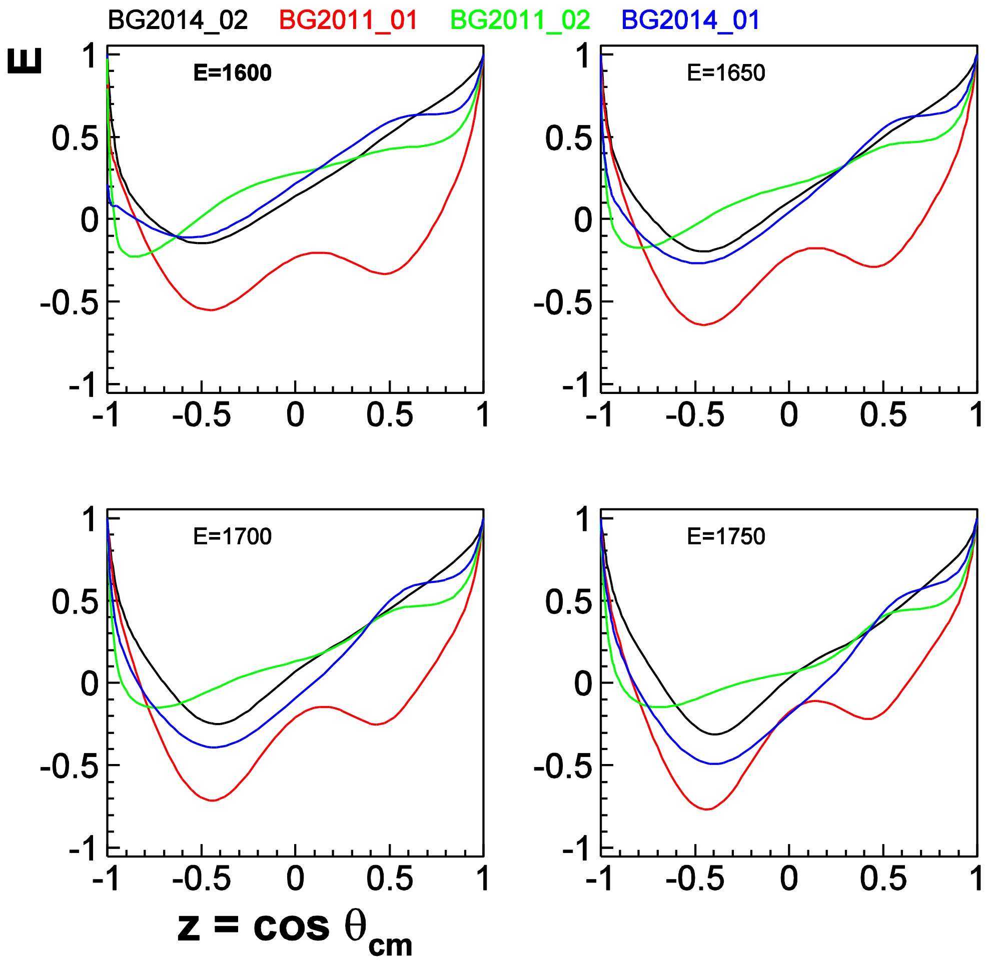
- However, several previous measurements with high statistics data only covering the energy range up to 3.8 GeV :

Experiment	Energy Range	Decay Channel	Observables
CLAS-g11 (M. Williams *et al*)	Threshold – 3.8 GeV	$p\omega \to p\pi^+\pi^-(\pi^0)$	• Differential Cross Section • Spin Density Matrix Element (SDME) : ρ^0_{00} , ρ^0_{1-1} , ρ^0_{10}
CBELSA/TAPS (A. Wilson *et al*) (H. Eberhardt *et al*)	Threshold-2.5 GeV	$p\omega \to p\,\pi^0\gamma$	• Differential Cross Section • SDME : ρ^0_{00} , ρ^0_{1-1} , ρ^0_{10} • Polarization Observables E and G.
MAMI (A2 collaboration) (I. I. Strakovsky *et al*)	Treshold-1.4 GeV	$p\omega \to p\,\pi^0\gamma$	• Differential Cross Section

Therefore, the differential cross section of $\gamma p \to p\omega$ from CLAS-g12 that extend the energy range up to 5.4 GeV is very important to study the production mechanism of omega photoproduction, especially the contribution from non Pomeron exchange.

The differential cross section alone is not sufficient to describe the data without ambiguity. As an example, four different models with different physics content could result in similar description of the cross section of γp -> pη (left), but different description of polarization observable E (right). Therefore, Polarization observable is important to constraint the PWA solutions, and it is sensitive to the presence of resonance. We will present the polarization observable E of γp -> pω from CLAS-FROST along with the differential cross section from CLAS-g12.

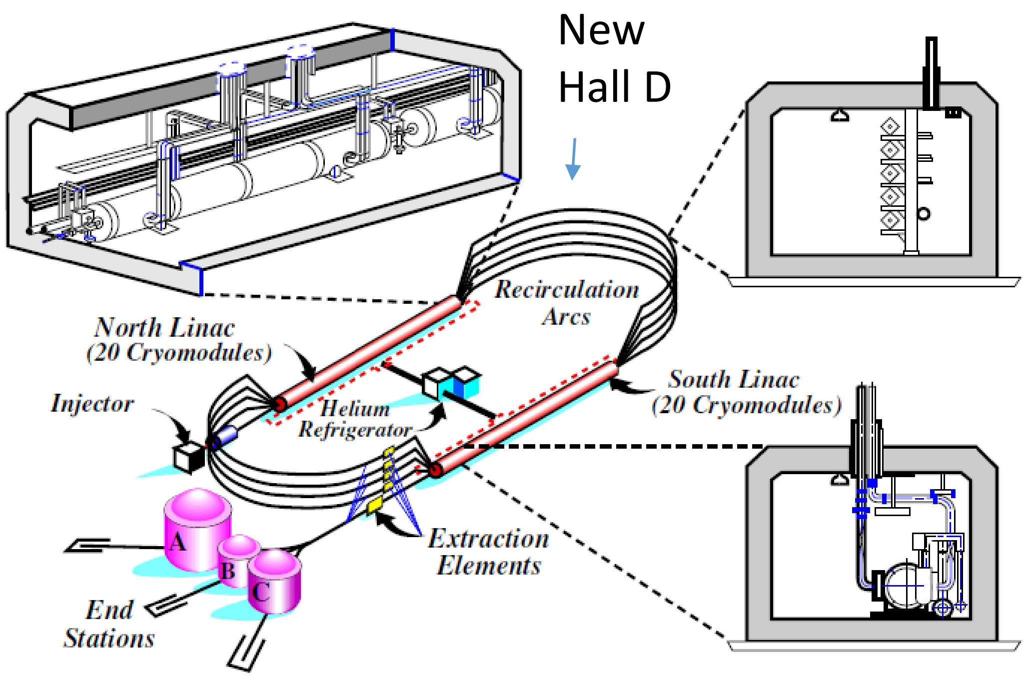


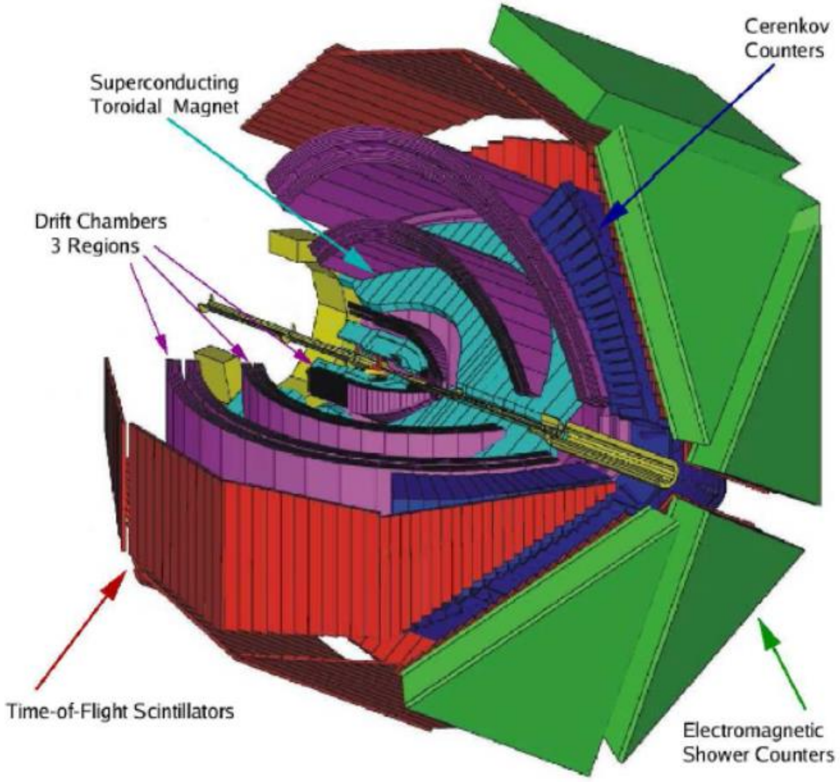


CLAS-g12 and CLAS-FROST Experiment

- CLAS Detector at JLAB
- CLAG-g12 and CLAS-FROST Experiment

CLAS Detector at JLAB





Schematic diagram of Continuous Electron Beam Accelerator Facility (CEBAF). The electron beam is accelerated to (now upgraded) 12 GeV before delivered to the Hall. CLAS detector was located in Hall B.

Schematic diagram of CEBAF Large Acceptance Spectrometer. With the (almost) full coverage of solid angle, CLAS was well suited for spectroscopy program . Converting the electron beam to photon beam was handled by Hall B tagging system.

CLAS-g12 and CLAS-FROST (g9a) Experiment

FROST-g9a Experiment :

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
Photon Polarization	Circular and Linear

g12 Experiment :

Electron Energy	5.7 GeV
Electron Degree of Polarization	67.2 %
Tagged Photon Energy	1.1 – 5.45 GeV
Target Material	Liquid Hydrogen
Target Polarization	Unpolarized
Photon Polarization	Circular

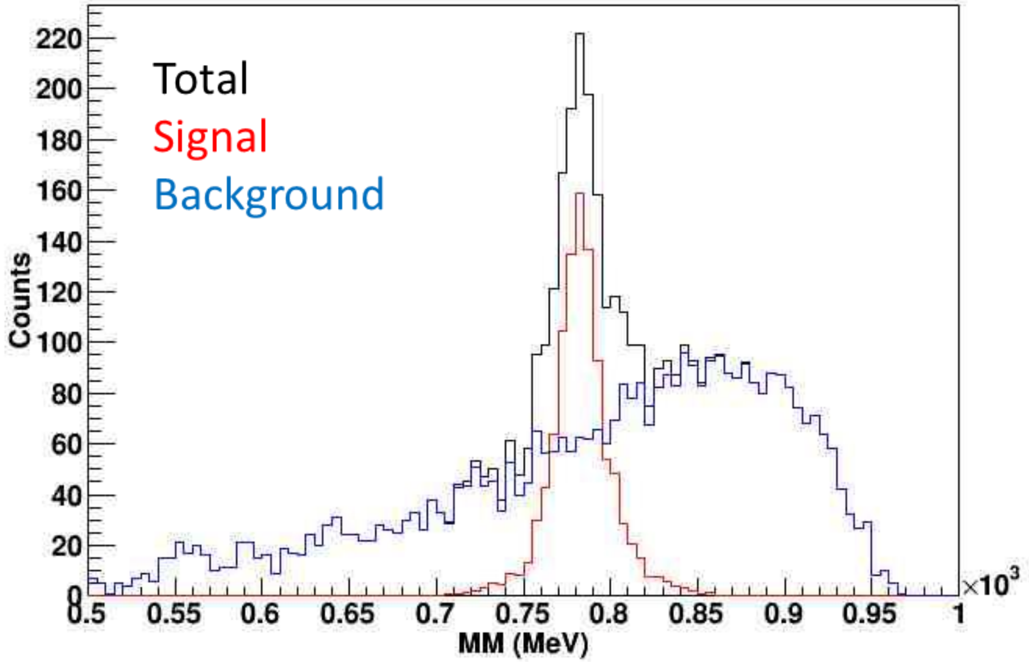
FROST experiment designed to do a “complete measurement”. It consist of g9a experiment that utilized longitudinal frozen spin butanol target and circular/linear polarized photon beam, and also g9b experiment that used transverse polarized target and circular/linear polarized photon beam. We use g9a-circular beam (longitudinal polarized target) dataset to measure the polarization observable E of $\gamma p \to p\omega$ reaction.

Data Analysis Technique

- Events selection
- Standard Cut and Correction
- Signal-Background Separation
- Differential Cross Section Measurement
- Double Polarization Observable E measurement

Data Analysis Technique

- **Event Selection :** The topology that we use is $\gamma p \to p\pi^+\pi^-(\pi^0)$, All events who have $p\pi^+\pi^-$ in the final state is kinematically fit to missing π^0. We then select the event using confidence level cut.
- **Standard Cut and Correction :** Energy loss and momentum correction, vertex and timing cut, delta beta cut, fiducial cat.
- **Signal-Background separation :** We Apply event based method for signal (omega)-background separation. Each event is weighted by a quality factor (Qvalue), ranging from 0 (pure background) to 1 (pure signal).



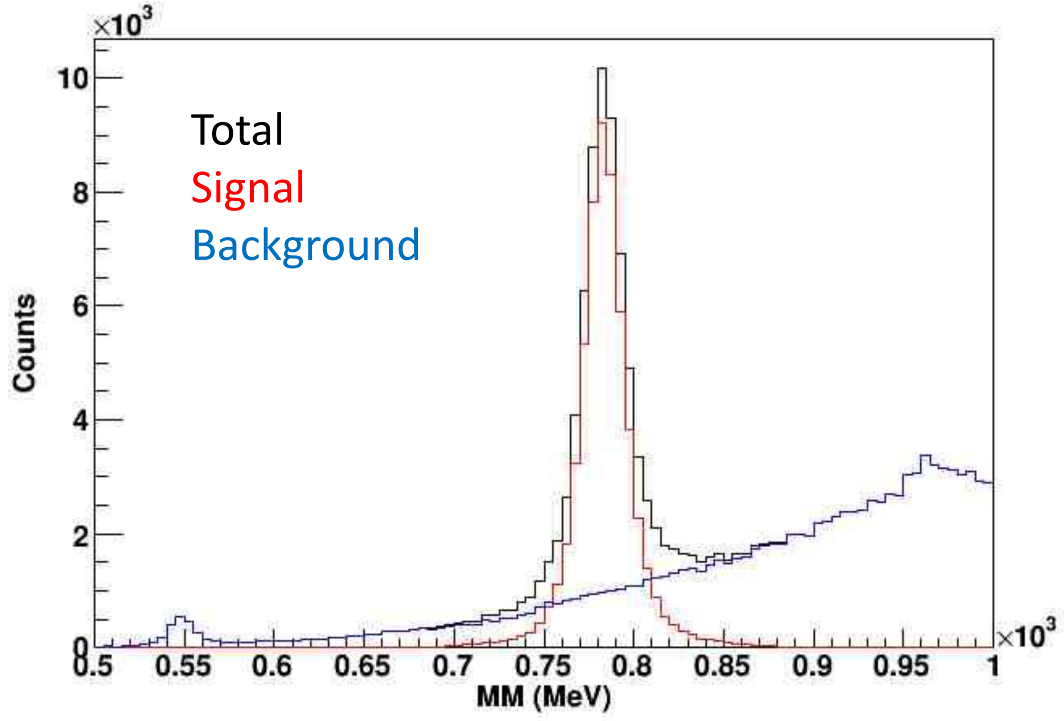
3π invariant mass for g9a

- **Differential Cross Section Measurement :** The measurement require detector acceptance that determined by monte carlo simulation. The differential cross section is calculated using :

$$\frac{d\sigma}{dcos\theta^{\omega}_{CM}} = \left(\frac{A_{target}}{\rho_{target} \cdot l_{target} \cdot N_A \cdot \text{Flux}}\right)\frac{\sum_i^n Q_i}{\Delta cos\theta^{\omega}_{CM} \cdot \varepsilon_{MC} \cdot BR}$$

- **Polarization observable E Measurement :** The beam-target helicity asymmetry, E, is extracted using the combination of two datasets: parallel data (N_+), when the beam and target polarizations point the same direction and anti parallel data (N_-), when the beam and target polarization point the opposite direction. The E observable is calculated using :

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



3π invariant mass for g12 data at 2.15 GeV

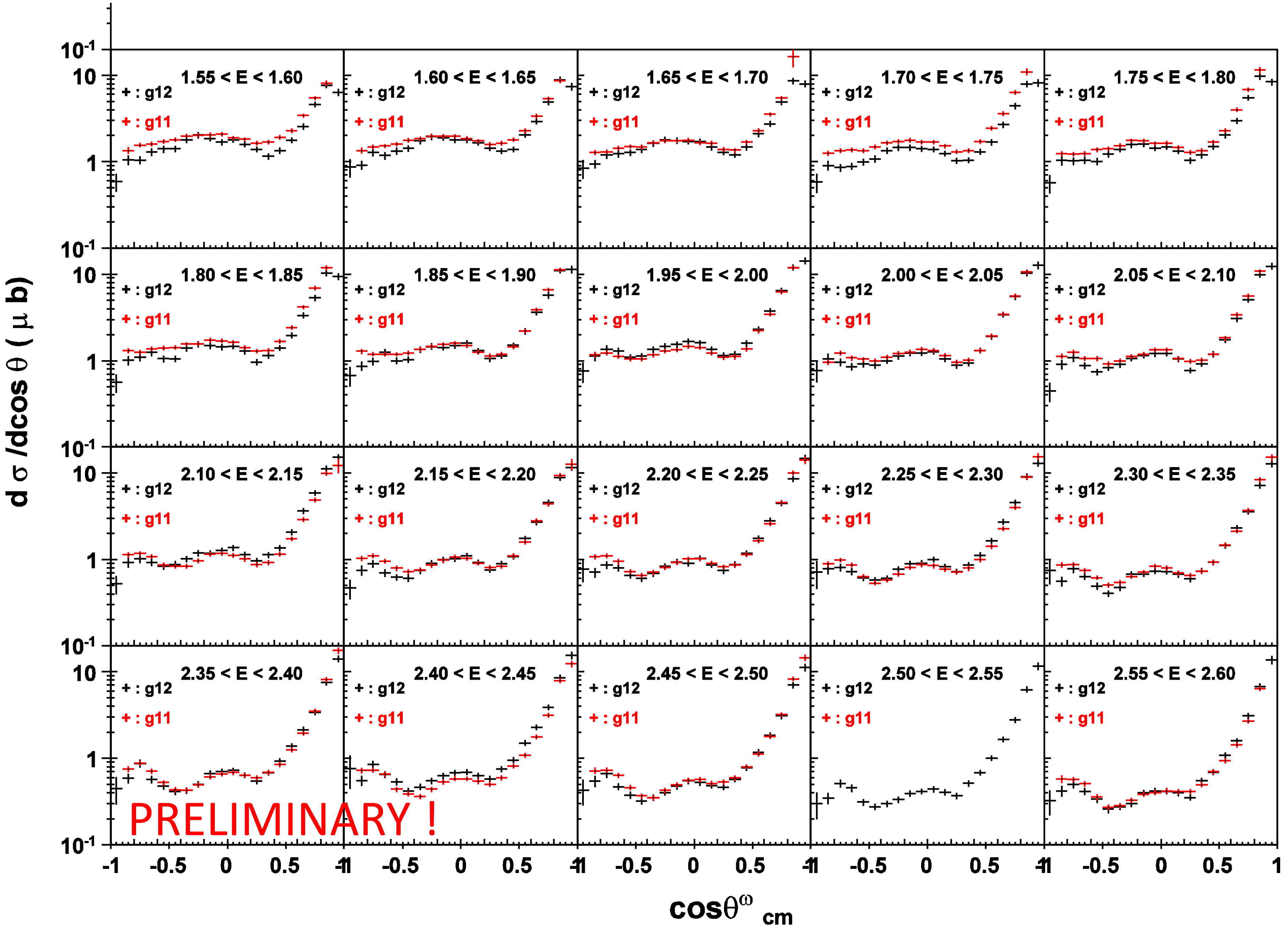
Result And Discussion

- Differential Cross Section from CLAS-g12.
- Double polarization observable E from CLAS-g9a (FROST)

Differential Cross Section from CLAS-g12 (Black) in comparison with previous measurement from CLAS-g11 (Red), at 1.55 GeV < E < 2.60 GeV.

Very prominent forward peaking indicates t channel exchange.

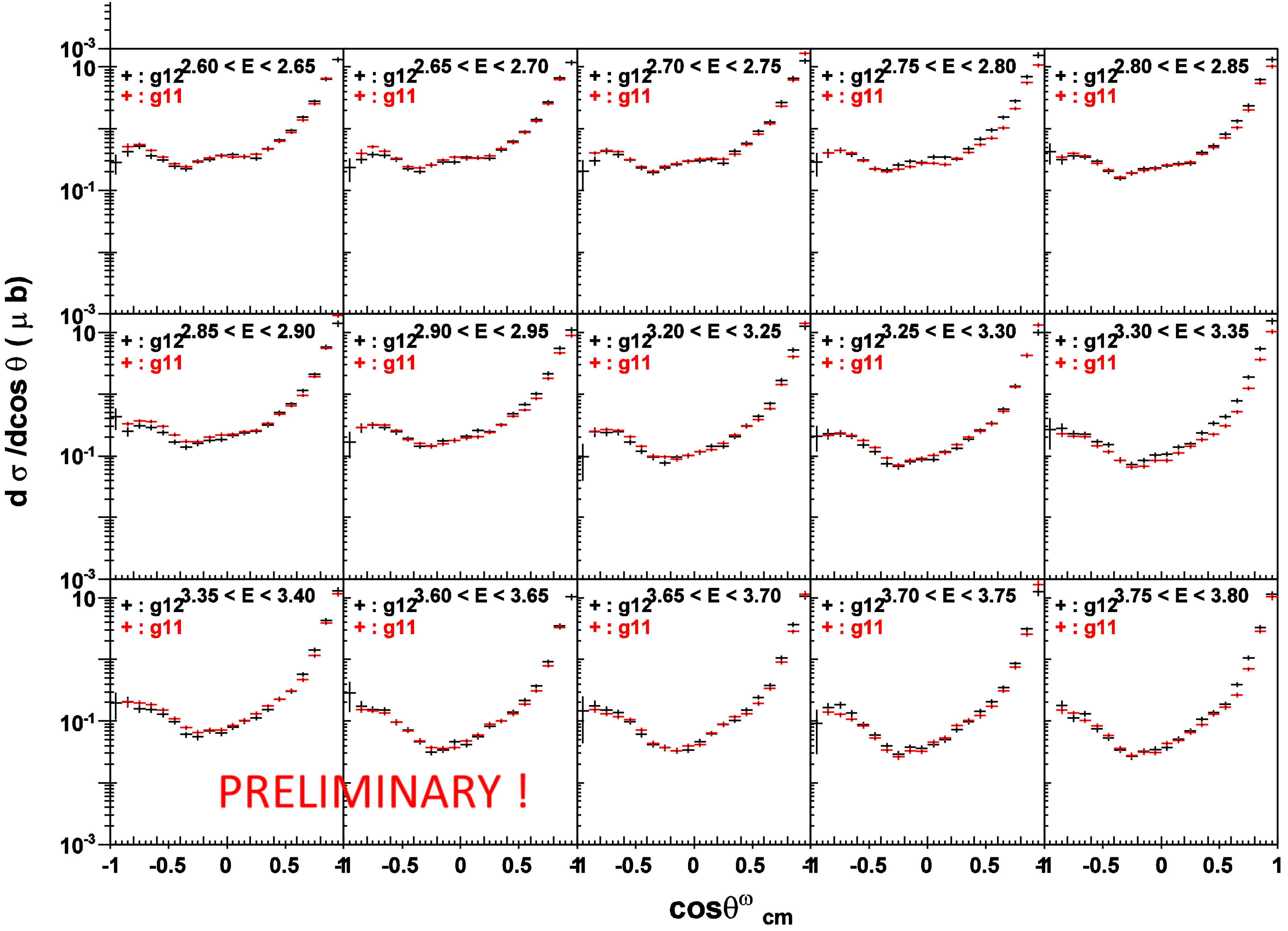
The presence of backward peak that appear from around 2.1 GeV, may indicate u channel contribution



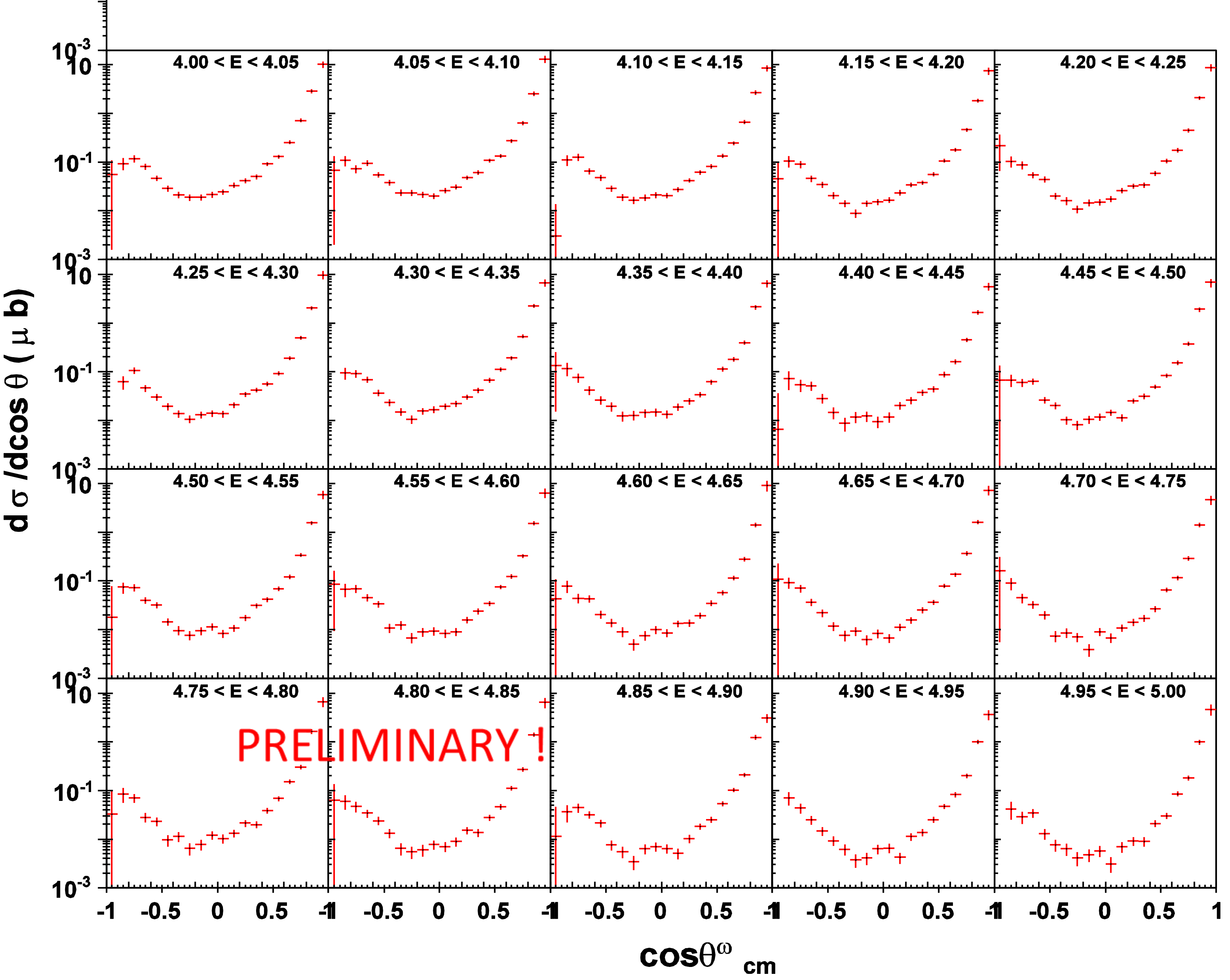
Differential Cross Section at 2.6 GeV < E < 3.8 GeV

The forward peak continue to be dominant feature up to higher energy.

The backward peak also rises but always one magnitude smaller than the forward peak.



Differential Cross Section at 4.0 < E < 5.0 GeV.

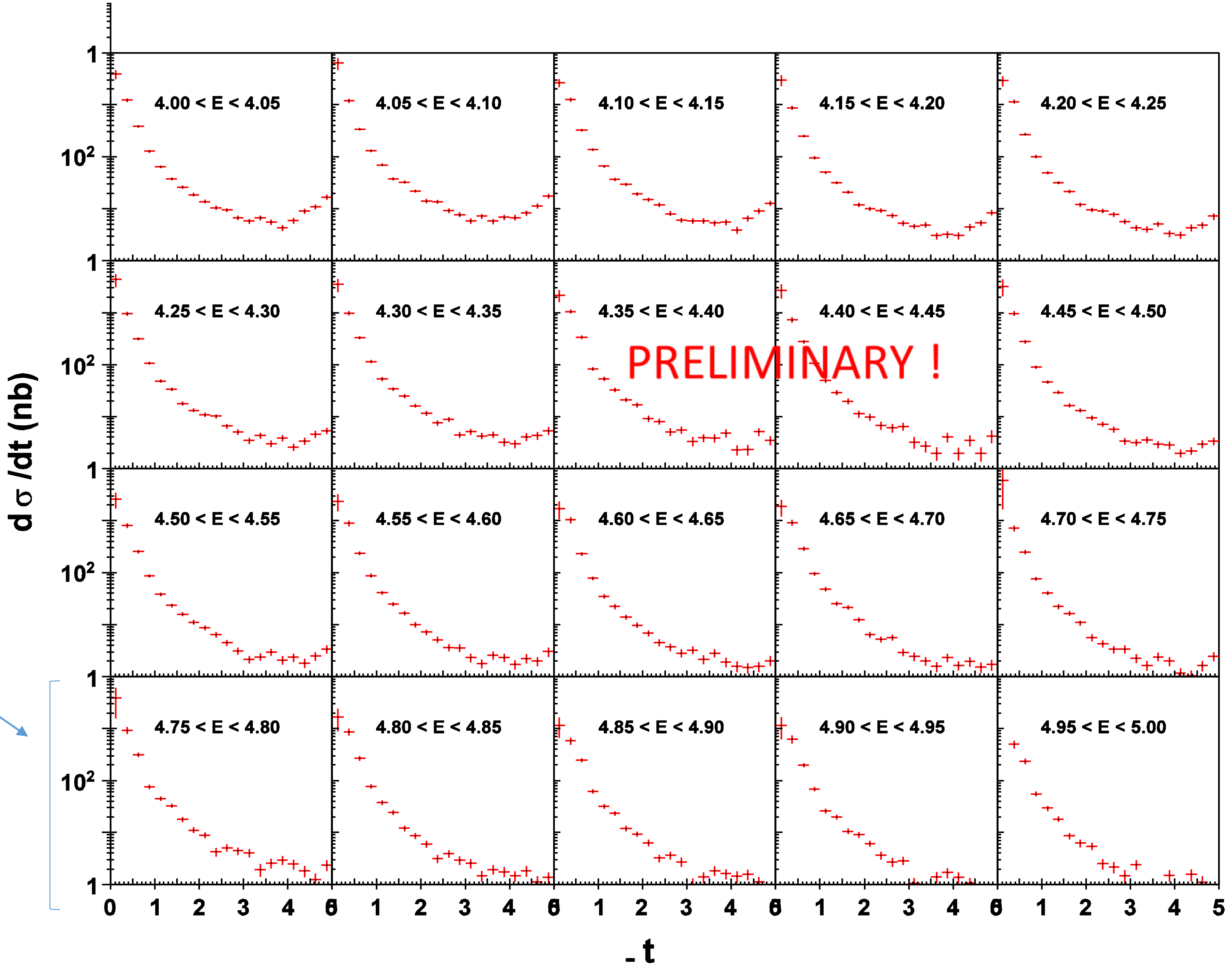


Differential cross section as a function of –t at 4.0 GeV < E < 5.0 GeV.

The cross section behavior due to the t channel pomeron exchange is expected to falling off exponentially at low t.

We see that the pomeron exchange contribution is more dominant when the energy is increasing.

But there are still significant contributions from non Pomeron exchange at the region 4.0 – 4.5 GeV).



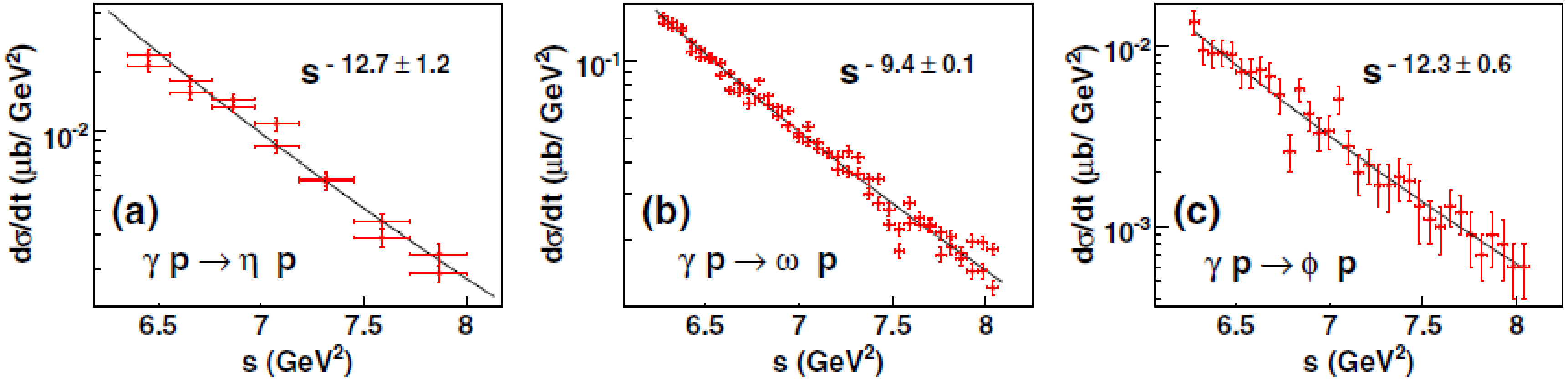
Scaling Behavior in Omega Cross Section

Perturbative QCD predict that the cross section at high energy follow the scaling behavior :

$$(d\sigma/dt)_{AB\to CD} \sim s^{-n+2} f(t/s)$$

n is the total number of elementary field (constituent) that involved in initial and final state reactions.

We see that our cross section has scaling behavior from 6 < s < 10 GeV^2 and s/t = 2.

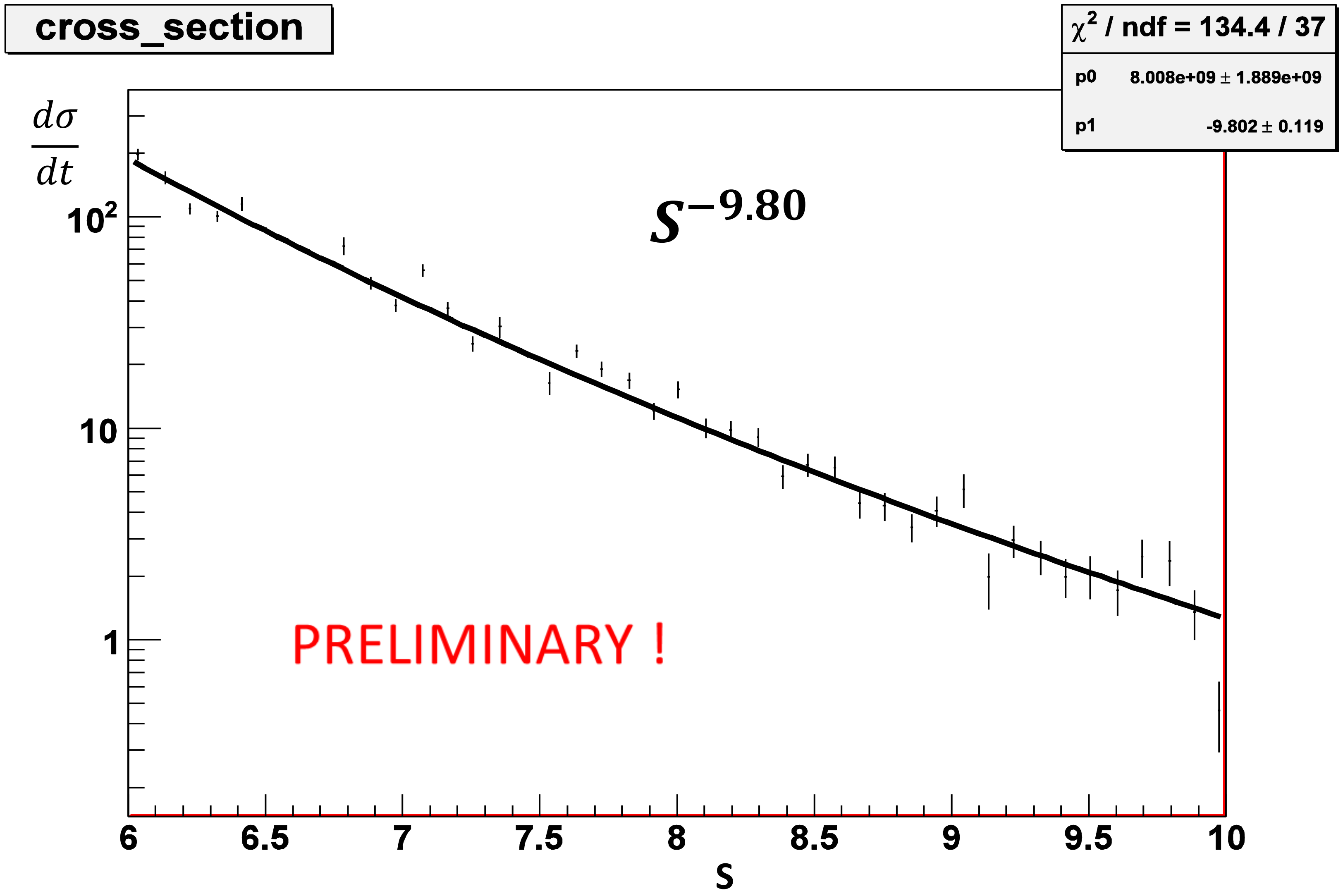


Scaling behavior for some photoproduction reaction (Biplap Dey). The scaling at these reactions differ from the simple of S^{-7} scaling (n = 9, i.e. 6 quarks from two protons, 1 photon field, and 2 quark/antiquark in the meson final state.

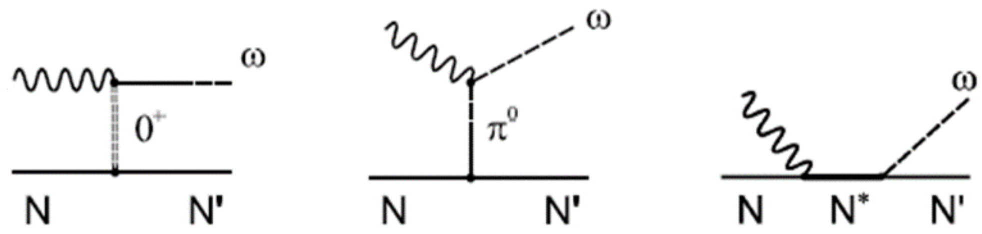
The scaling behavior depend on the production mechanism.

Scaling Behavior in γp -> pω from CLAS-g12

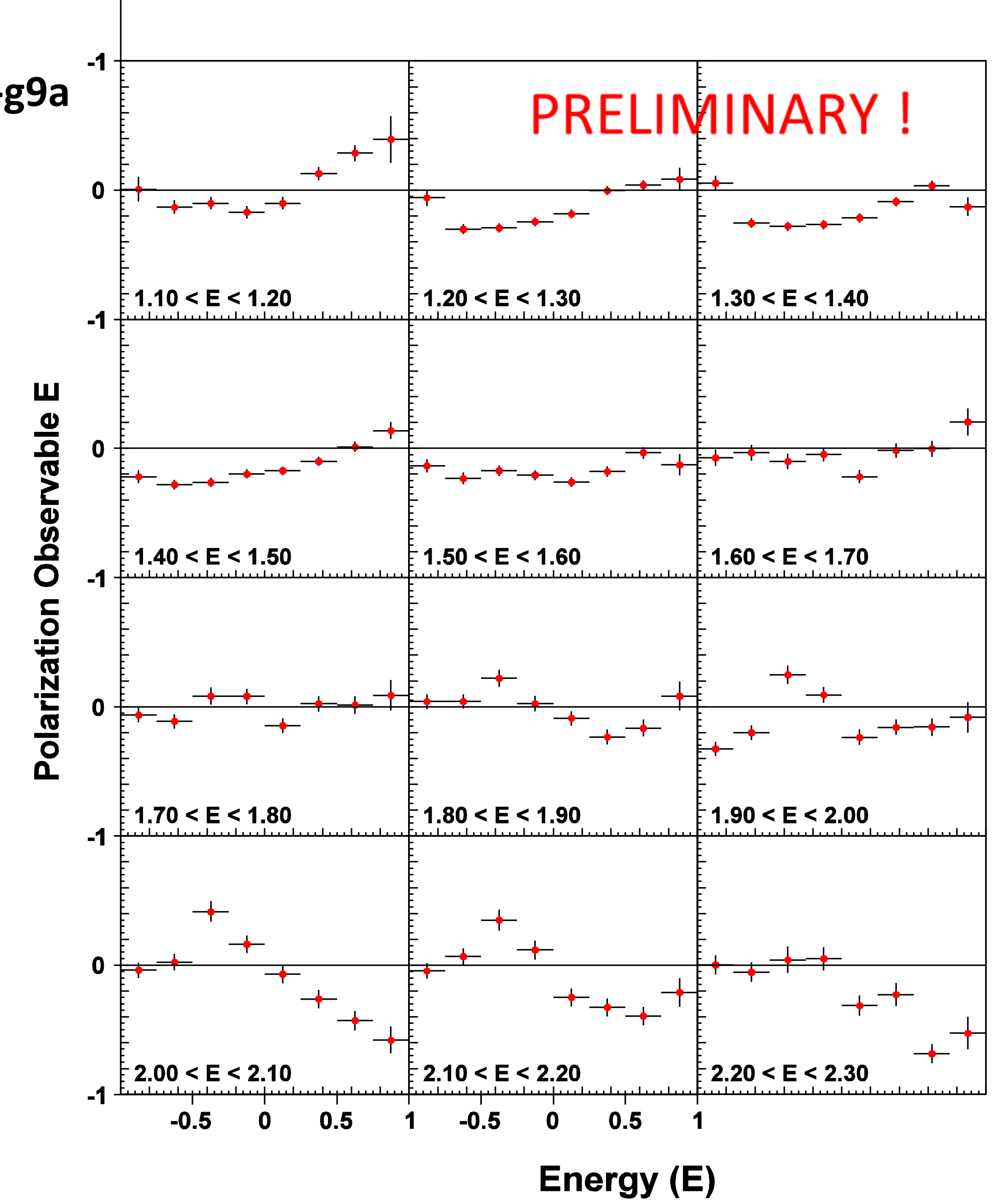
The differential cross section from CLAS-g12 exhibit -9.8 scaling, comparable to the previous result from CLAS-g11 that exhibit -9.4 scaling.



Double Polarization Observable E of γp -> pω from CLAS-g9a



- In the case of pure pomeron or pion exchange (left and middle), photon does not couple directly to nucleon. Since no angular momentum exchange, the value of E will be zero.
- In the case of pomeron AND pion mixing, E will have linear dependence of cos_{CM}^{ω} (A.V. Sarantsev *et al*).
- E will be positive for the case of spin ½ resonance domination, and negative for spin $^3/_2$ resonance domination.
- However, to disentangle all the contributed wave, a Partial Wave Analysis is required.



Summary And Outlook

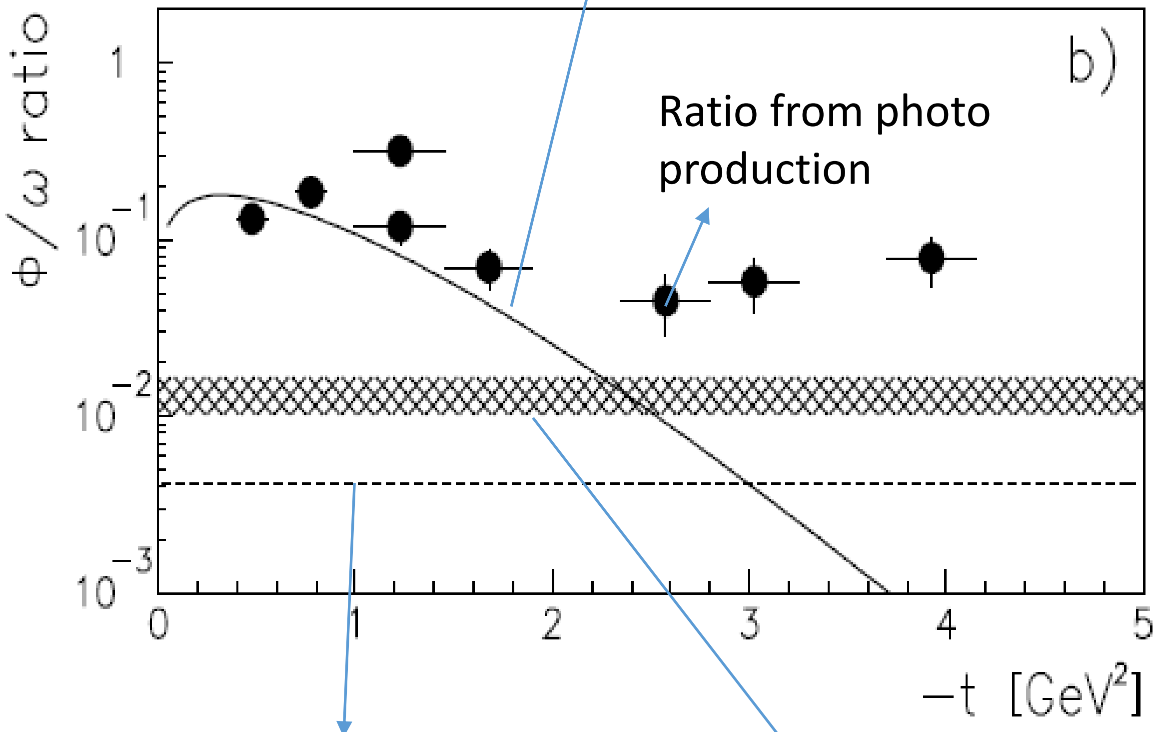
- Summary
- Outlook

Summary

- γp -> $p\omega$ channel is one of the suitable reaction to investigate the missing resonance issue.
- We have performed measurement on differential cross section of γp -> $p\omega$ from CLAS-g12, that extend the energy range up to 5.4 GeV, and polarization observable E from CLAS-FROST.
- The data are very important as an input for partial wave analysis to reveal the resonance contribution as well as others production mechanism.

Outlook : Study of OZI Rule Violation

- The cross section's ratio of omega and phi meson are useful to study OZI Rule violation.
- Recent study by A. Sibirtsev *et al* reveals that photo production has very strong OZI violation.
- The production mechanism of phi and omega meson also not well understood.
- Currently, γp -> pφ cross section through double charge kaon decay mode from g12 is being studied at FSU.
- Along with the γp -> pω cross section from g12, we can extend the previous OZI Violation study to higher energy and higher momentum transfer.



THANK YOU