Photoproduction of $K^0\Sigma^+$ From CLAS-g12

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The CLAS Collaboration Meeting

3-6 October 2017

Outline

- Motivation
- CLAS-g12 Experiment
- Data Analysis
- Result and Discussion
- Summary & Outlook

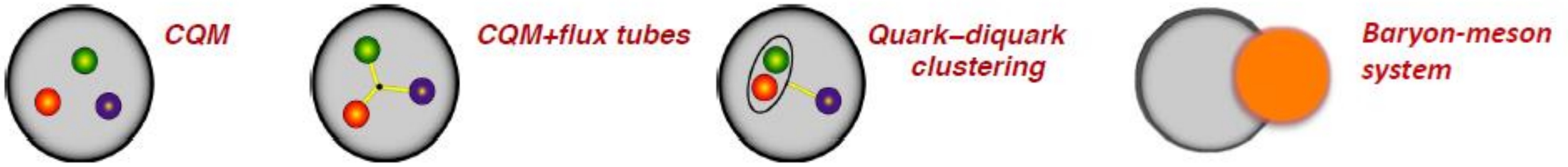
Motivation

- Nucleon Resonance Spectrum
- Status of N* in Particle Data Group 2016
- The need of $\gamma p \rightarrow K^0\Sigma^+$ Channel

Motivation : Nucleon Resonance Spectrum

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

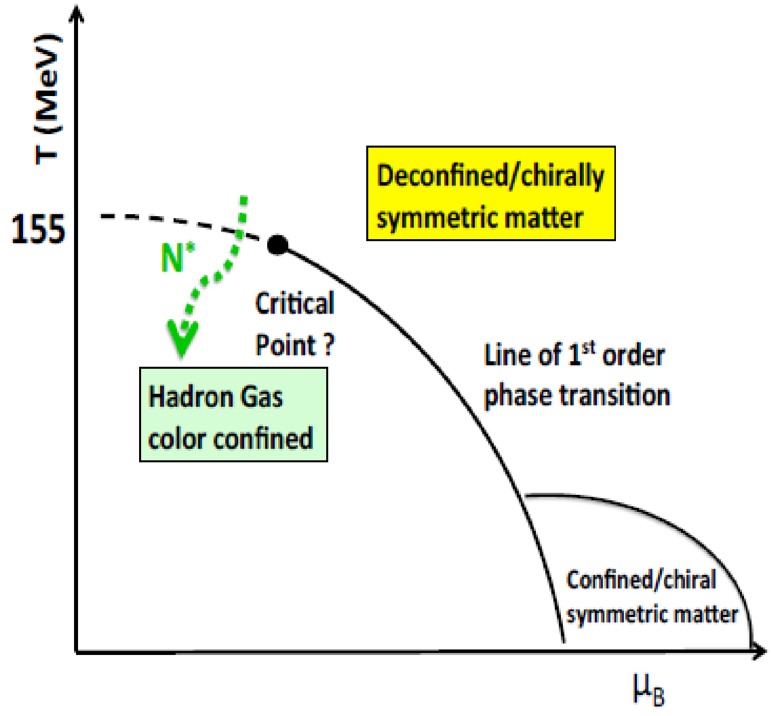
- How does the behavior of quarks determine the properties of hadrons?
- How does the quark dynamics give rise to the spectrum of hadrons?
- What are the fundamental degrees of freedom inside hadrons?



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

Motivation : Nucleon Resonance Spectrum

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



Courtesy of Volker D. Burkert

At T ~ 10^{-6} s

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

Status of N* in PDG 2016

KY channel are promising

- A set of 8 resonances claimed by BnGa-PWA from this chanel

But there are still plenty of room to explore

γp→KY

...

	Total	CLAS
$\gamma p \to K^+\Lambda$	9026	6046
$\gamma p \to K^+\Sigma^0$	6876	4343
$\gamma p \to K^0\Sigma^+$	304	48

Courtesy of E. Pasyuk

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

**** Existence is certain, and properties are at least fairly well explored.
*** Existence is very likely but further confirmation of decay modes is required.
** Evidence of existence is only fair.
* Evidence of existence is poor.

Why The γp -> $K^0\Sigma^+$ Measurement From CLAS Are Important ?

- Parameter constraint through Isospin related channel.

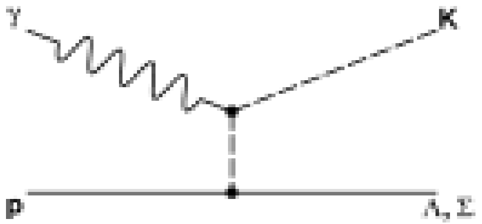
$$g_{K^0\Sigma^+p} = \sqrt{2}\, g_{K^+\Sigma^0 p}$$

- Lack of the charge hyperon (Σ^+) data in comparison to the neutral hyperon.

Observable	N_{data}	χ^2	χ^2/N_{data}
$\sigma(\gamma p \to \Lambda K^+)$	720	804	1.12
$\sigma(\gamma p \to \Lambda K^+)$	770	1282	1.67
$P(\gamma p \to \Lambda K^+)$	202	374	1.85
$\Sigma(\gamma p \to \Lambda K^+)$	45	62	1.42
$\sigma(\gamma p \to \Sigma^0 K^+)$	660	834	1.27
$\sigma(\gamma p \to \Sigma^0 K^+)$	782	2446	3.13
$P(\gamma p \to \Sigma^0 K^+)$	95	166	1.76
$\Sigma(\gamma p \to \Sigma^0 K^+)$	45	20	0.46
$\sigma(\gamma p \to \Sigma^+ K^0)$	48	104	2.20
$\sigma(\gamma p \to \Sigma^+ K^0)$	120	109	0.91

The photoproduction of *KY* data used in BnGa PWA fit.

- Cleaner probe to s-channel resonances



$$\mathcal{M}_{Regge}(\gamma\, p \to K^+\Sigma^0) = \mathcal{M}^{K}_{Regge} + \mathcal{M}^{K^*(892)}_{Regge}$$

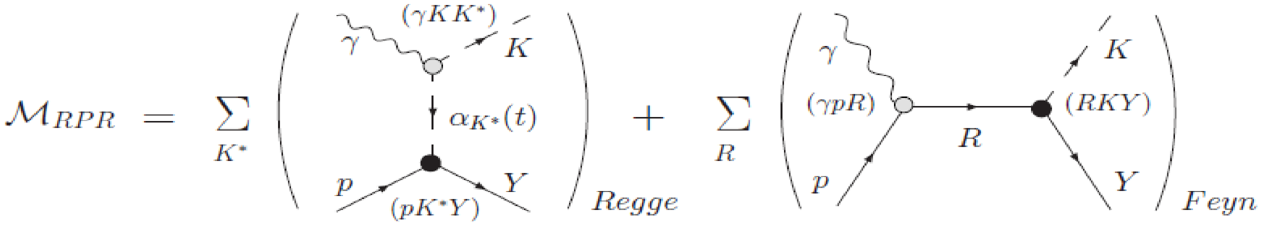
$$\mathcal{M}_{Regge}(\gamma\, p \to K^0\Sigma^+) = \mathcal{M}^{K^*(892)}_{Regge}$$

- Address the discrepancy issue on previous CLAS measurement.

- The charged hyperon channel is important to disentangle contributions from N* and Δ* resonances.

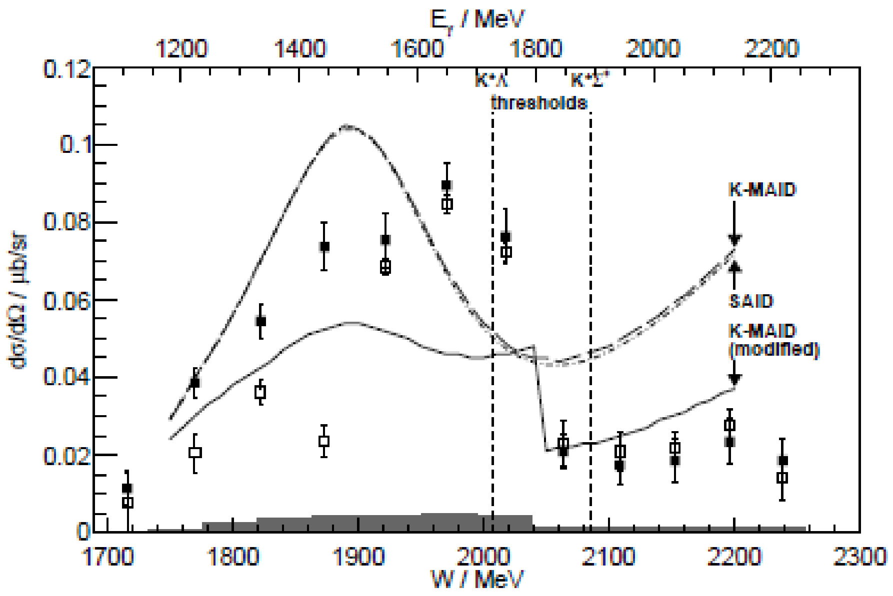
$$A(\gamma + p \to K^0 + \Sigma^+) = \sqrt{2}\left[A_p^{(1/2)} - \tfrac{1}{3} A^{(3/2)}\right]$$

- The high energy data is required for Regge Plus Resonances (RPR) model -> Available from CLAS-g12

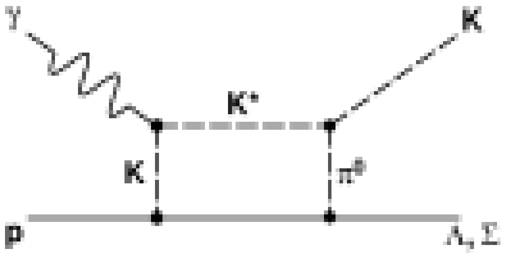


- The channels involved in Kaon production (as well as η) give the opportunity to assess the validity of the SU(3) symmetry of the quark model in describing the decay of the resonances

- Investigate the anomaly (sudden drop) seen on previous measurement



The anomaly seen in the total cross section of γp -> $K^0\Sigma^+$ from CBELSA/TAPS



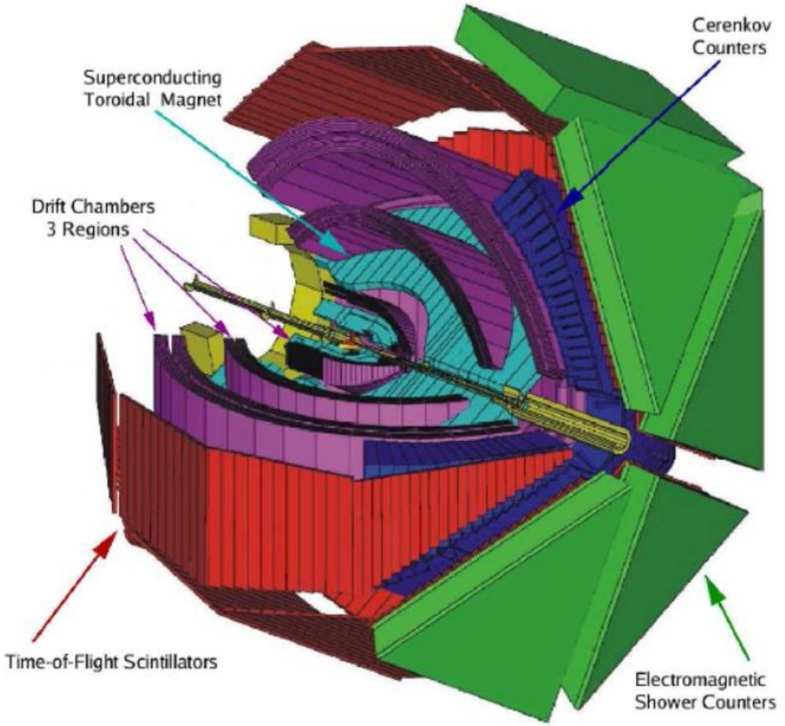
The diagram behind the anomaly

“The goal of this analysis are to measure the differential cross section and the recoil polarization of $\gamma p \rightarrow K^0\Sigma^+$ from CLAS-g12“

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

The g12 experiment provide high statistic and high energy data !



CEBAF Large Acceptance Spectrometer (CLAS)

Data Analysis

We have $\pi^+\pi^-\pi^0$ in the final state since :

$\gamma p \rightarrow K^0\Sigma^+$ → $\Sigma^+ \rightarrow p\,\pi^0$

→ $K^0 \rightarrow \pi^+\pi^-$

The preparation of the final states have been presented on previous CLAS meeting.

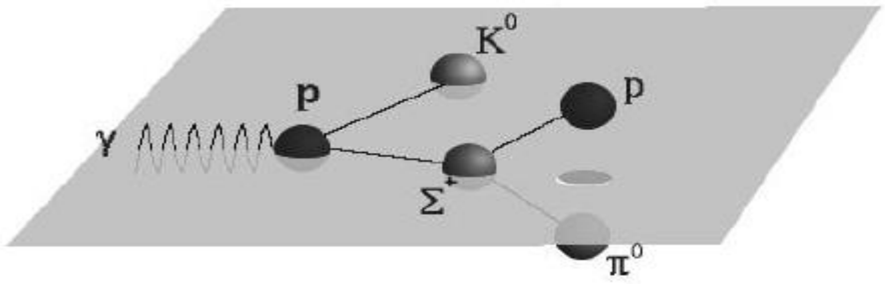
The signal-background separation was done using event-based Q-factor method (backup slide)

$\Sigma^+ \rightarrow p\,\pi^0$ decay via parity violating weak interaction. We can access the recoil polarization of the Σ^+

The recoil polarization P can be expressed as

$$P = \frac{2}{\alpha}\frac{N_{up} - N_{down}}{N_{up} + N_{down}}$$

Up and down defined from the proton momentum vector in the Σ^+ rest frame and the production plane.



Production Plane

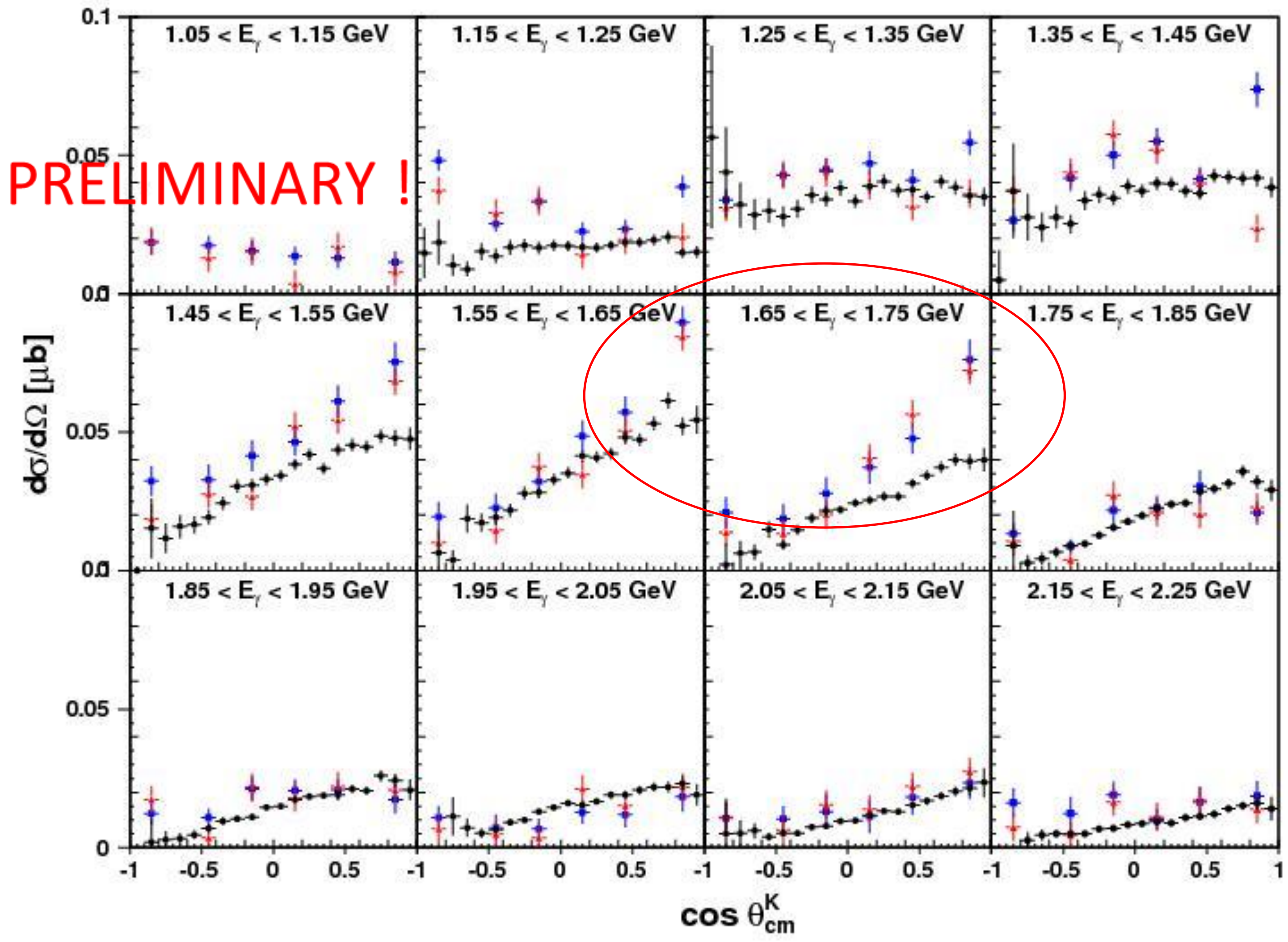
Result and Discussion

Preliminary results and comparison with previous measurement from:

- CBELSA/TAPS
- Cristal Barrel
- CLAS-g11

Quality Check of the results

Differential cross section of $\gamma p \rightarrow K^0\Sigma^+$

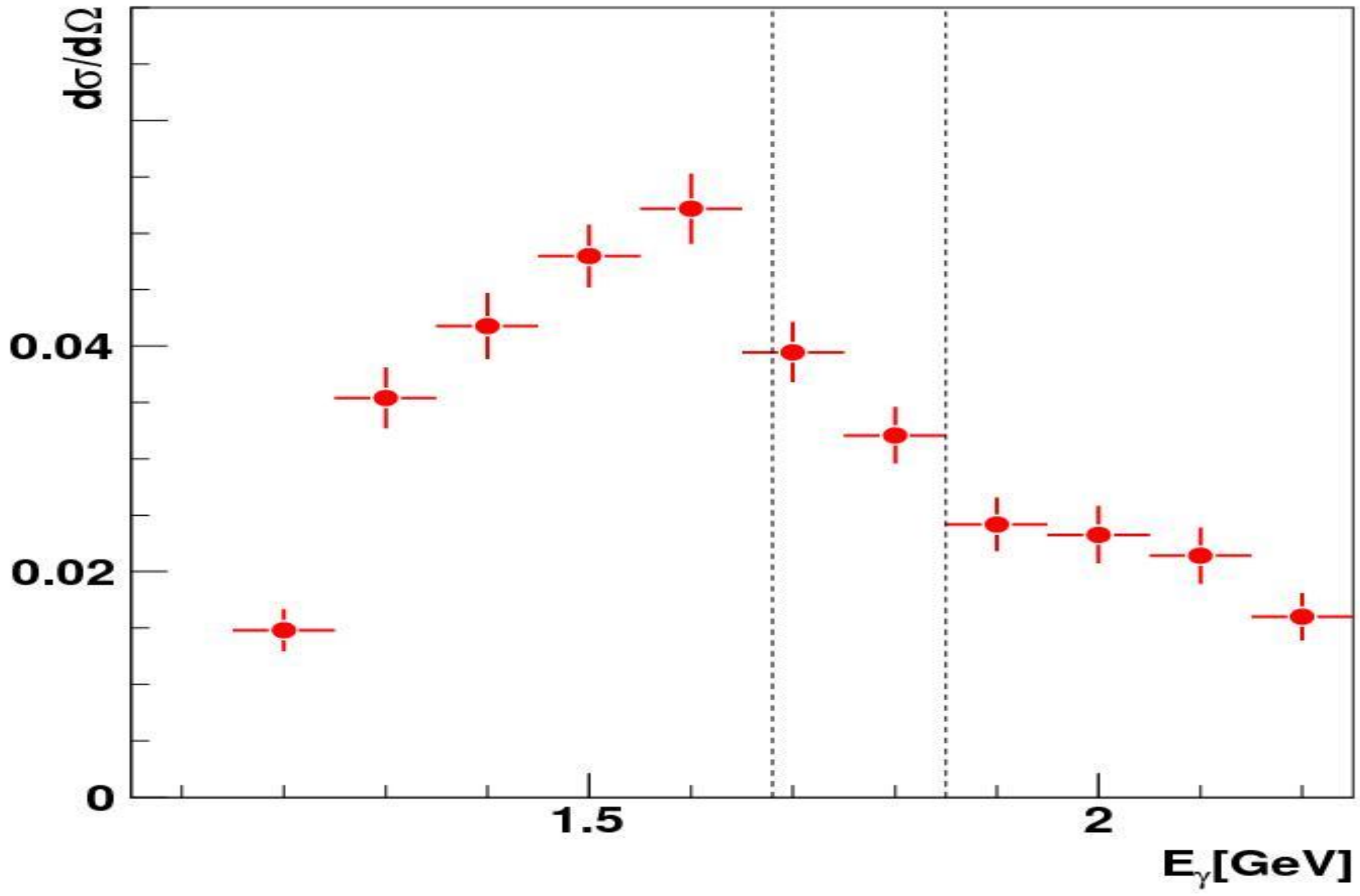


The CLAS-g12 data :

- Smooth transition between energy bin
- No indication of cusp-like structure (anomaly)
- In general has fair agreement with the previous CBELSA/TAPS and Cristal Barrel result except in the anomaly region

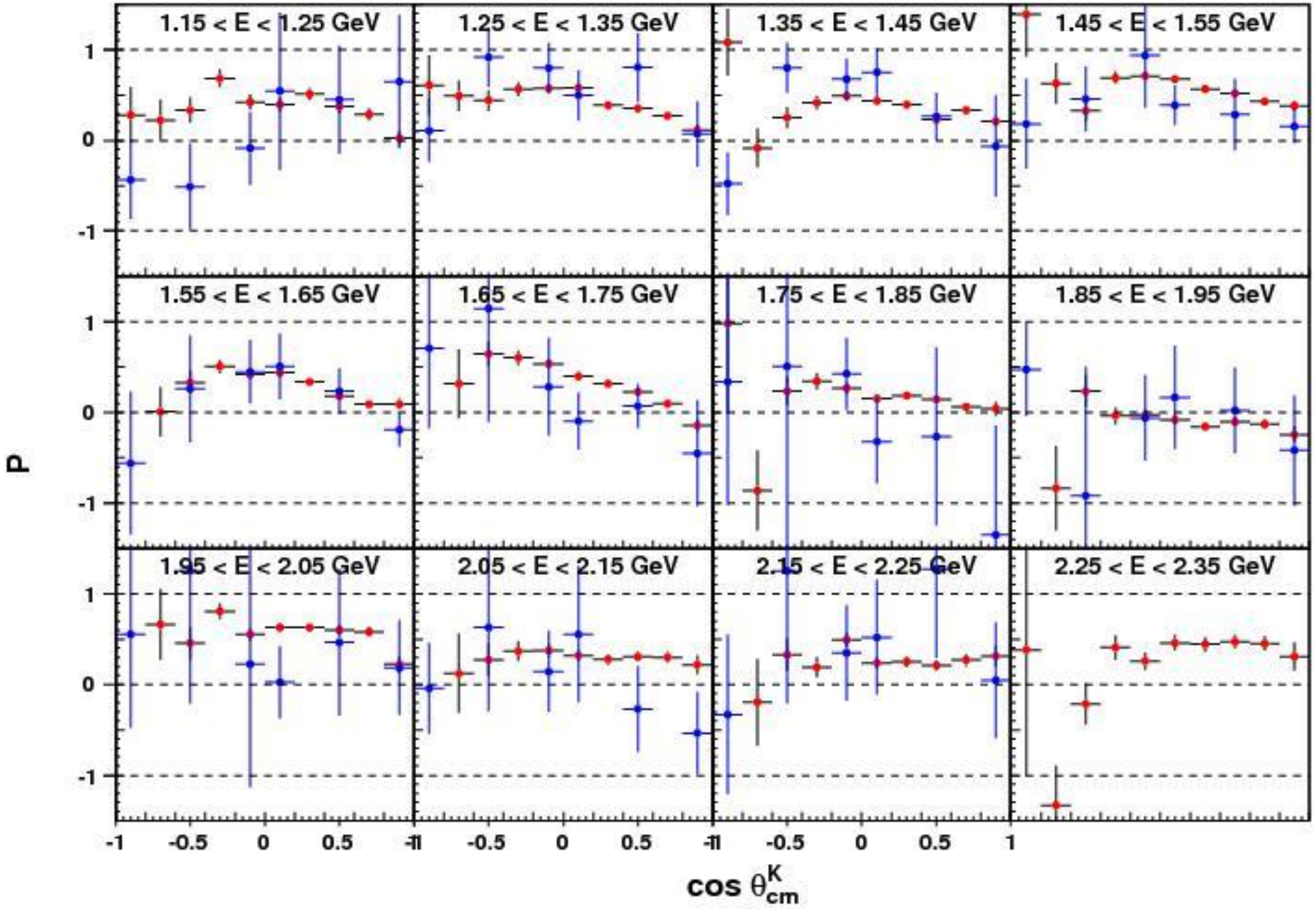
The figure shows the differential cross section of $\gamma p \rightarrow K^0\Sigma^+$ from CLAS-g12 (**BLACK**) in comparison with the previous measurement from CBELSA/TAPS (**BLUE**) and Cristal Barrel (**RED**)

Differential cross section of $\gamma p \to K^0\Sigma^+$ at forward angle



The figure shows the differential cross section of $\gamma p \to K^0\Sigma^+$ at forward angle from CLAS-g12. The transition is smooth, no sudden drop is observed.

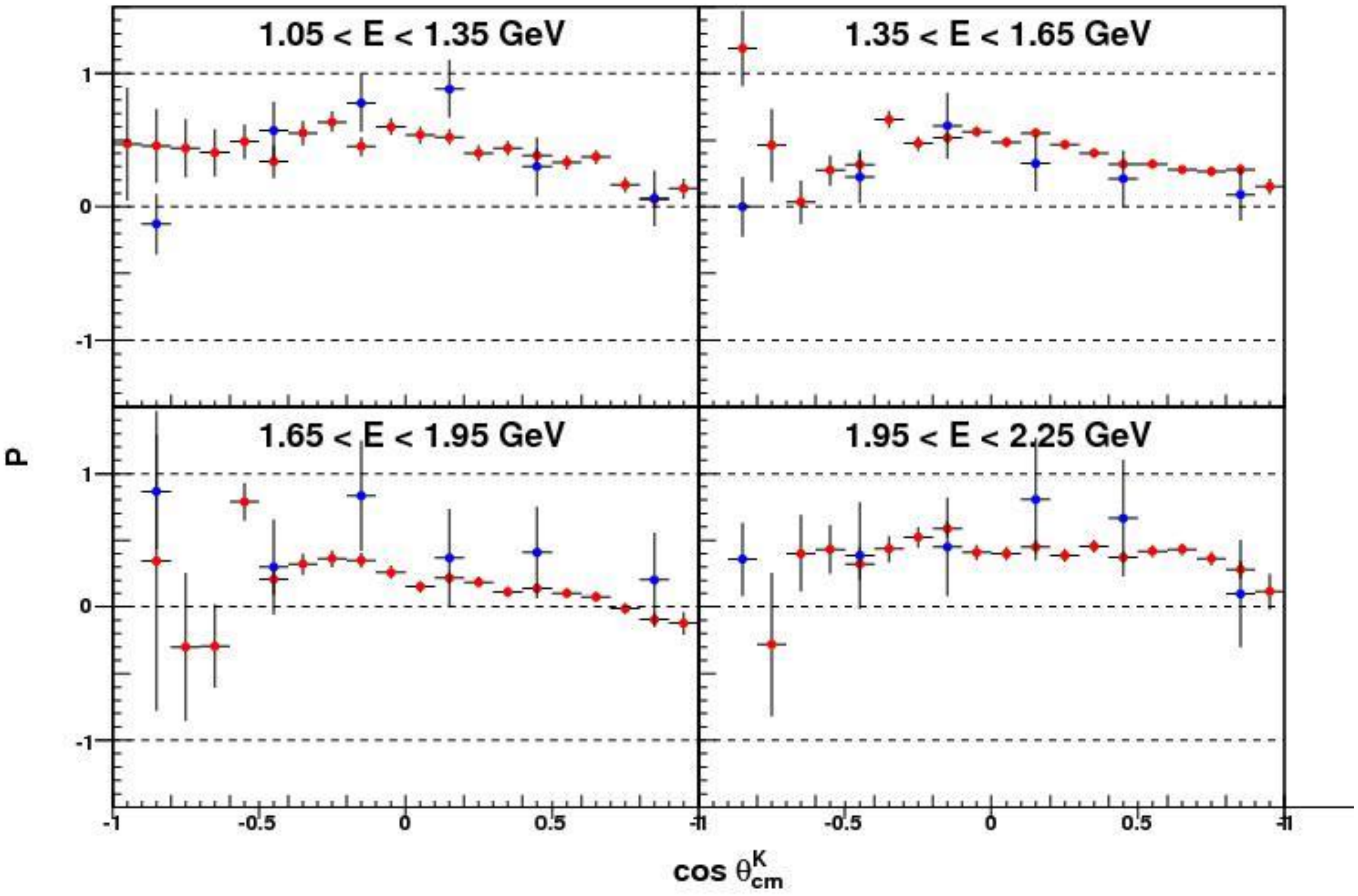
The Recoil Polarization of Σ^+



The figure shows the Recoil Polarization of Σ^+ from CLAS-g12 (**RED**) in comparison with the previous measurement from Cristal Barrel (**BLUE**)

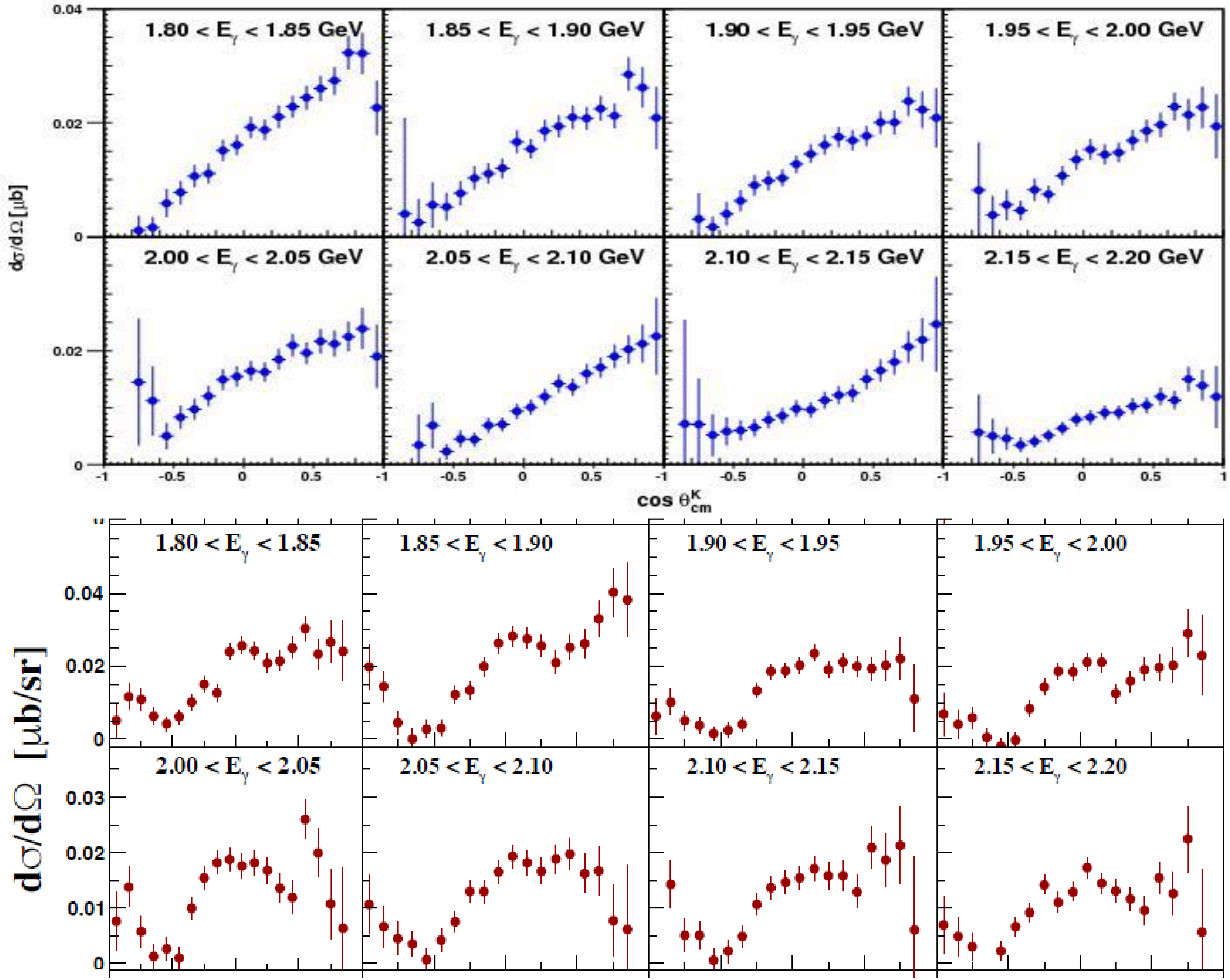
PRELIMINARY !

The Recoil Polarization of Σ$^+$



The figure shows the Recoil Polarization of Σ$^+$ from CLAS-g12 (**RED**) in comparison with the previous measurement from CBELSA/TAPS (**BLUE**)

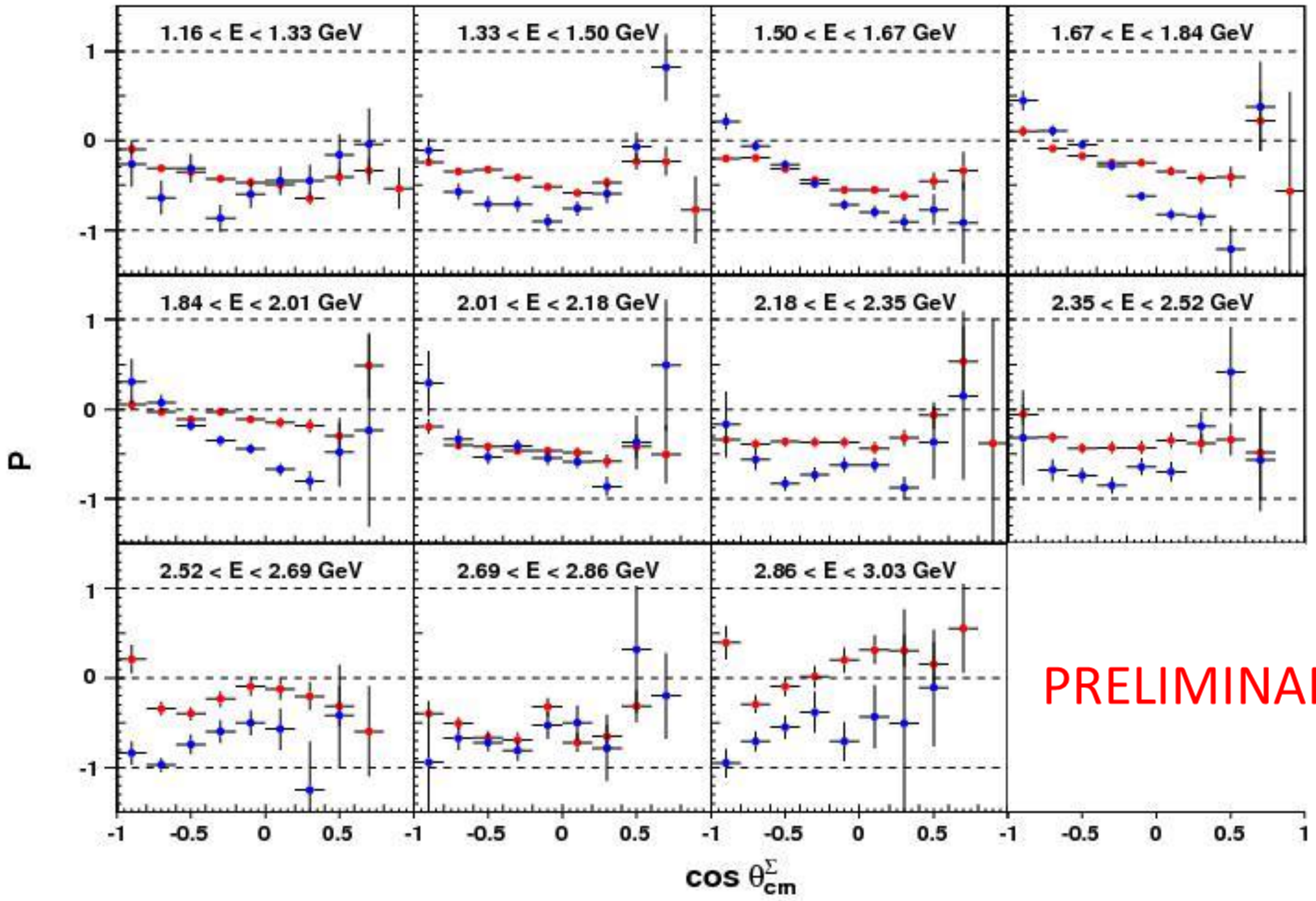
PRELIMINARY !



The figure shows the differential cross section of $\gamma p \to K^0\Sigma^+$ from CLAS-g12 (**TOP : BLUE**) in comparison with the previous measurement from CLAS-g11 (**BOTTOM : RED**).

Disagreements are clearly seen!

PRELIMINARY !



PRELIMINARY !

The figure shows the Recoil Polarization of $\gamma p \to K^0\Sigma^+$ from CLAS-g12 (**RED**) in comparison with the previous measurement from CLAS-g11 (**BLUE**).

Disagreements are also seen!

Quality Check of The Results

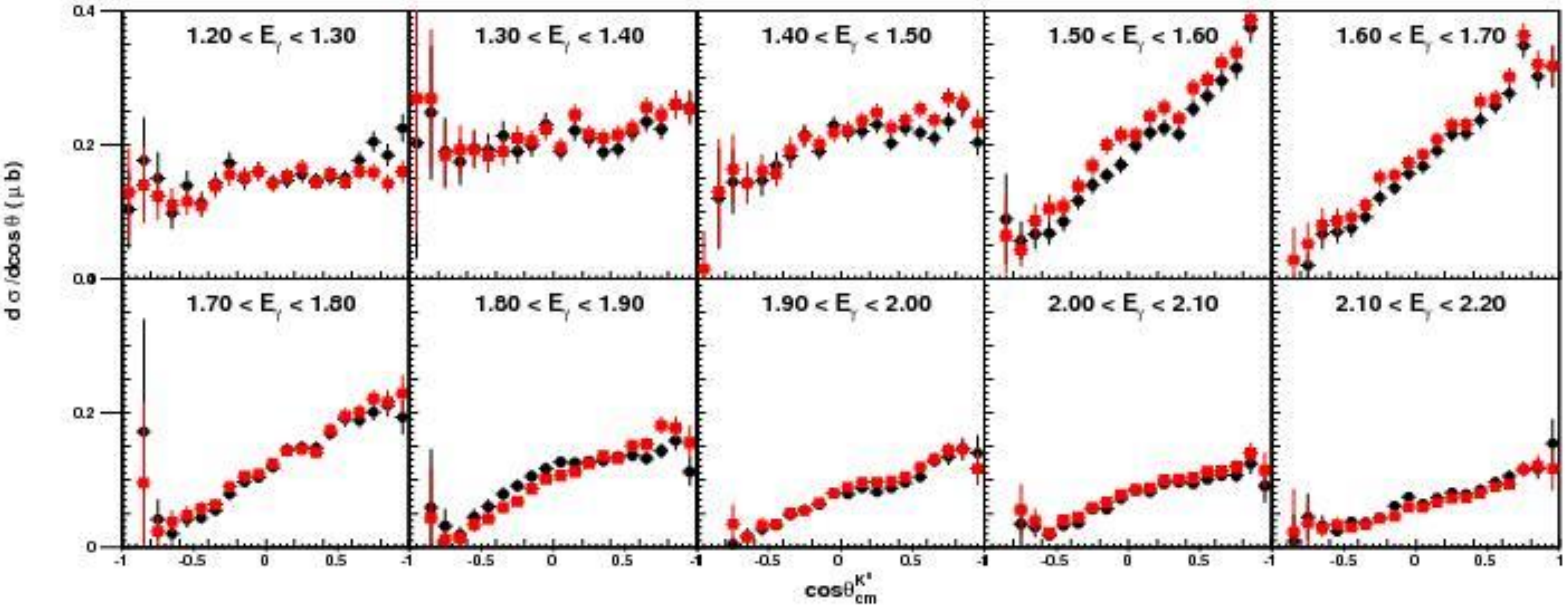
Cross section is proportional to the number of events normalized by flux and acceptance correction.

The quality of the cross section depends on the quality of :

- Signal-Background separation
- Monte Carlo simulation
- Normalization

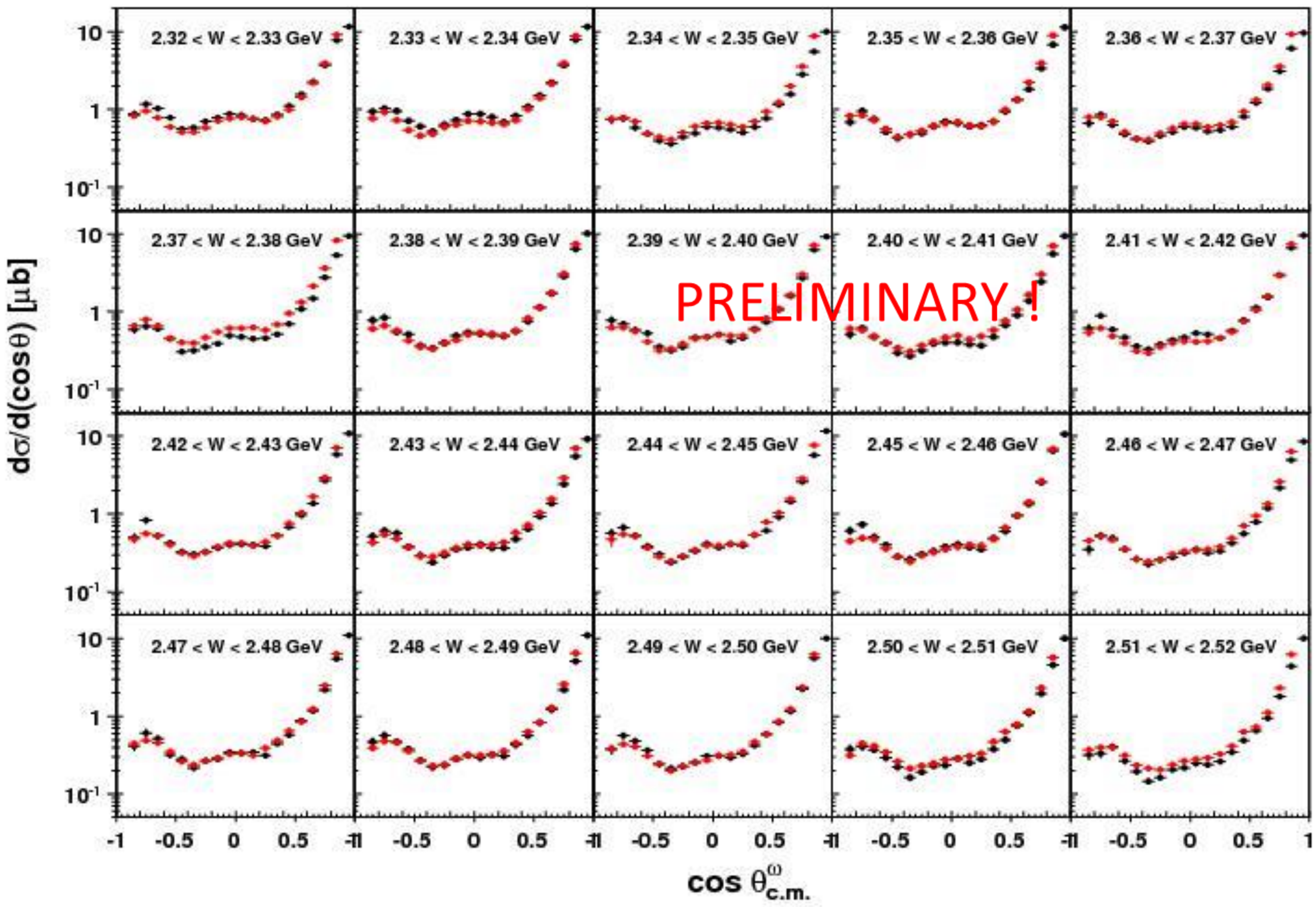
We check the quality of the signal-background separation by performing event based Q-factor method both on the Sigma ($M_{P\pi^0}$) and Kaon ($M_{\pi^+\pi^-}$) peak.

The overall quality of the normalization and the Monte Carlo simulation can be studied using two others channel that share the same final states : $\gamma p \rightarrow p\omega/p\eta/\ K^0\Sigma^+ \rightarrow p\pi^+\pi^-\pi^0$



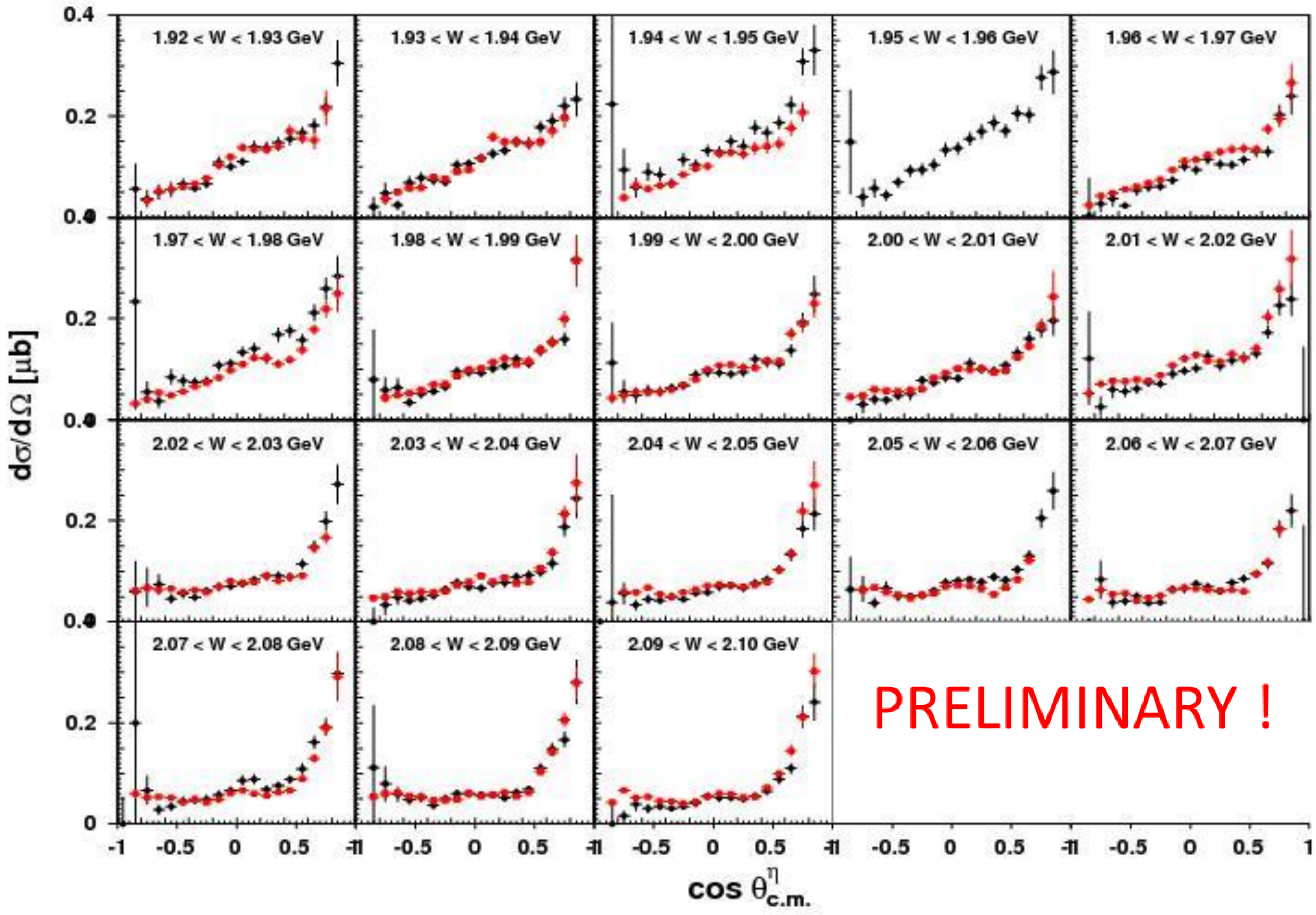
The figure shows the differential cross section of $\gamma p \to K^0\Sigma^+$ at from CLAS-g12 using two different coordinate of reference : Sigma peak/$M_{P\pi^0}$ (**RED**) and Kaon peak/$M_{\pi^+\pi^-}$ (**BLACK**). Both methods are consistent.

Differential cross section of γp ->pω



- The figure shows the Differential cross section of γp ->pω (**BLACK**) from CLAS-g12 in comparison with the previous measurement from CLAS-g11 (RED)
- In general, both cross sections are in a good agreement

Differential cross section of γp ->pη



- The figure shows the Differential cross section of γp ->pη (**BLACK**) from CLAS-g12 in comparison with the previous measurement from CLAS-g11 (RED)
- In general, both cross sections are in a good agreement

Summary

- We have obtained the high statistic differential cross section and the high statistic recoil polarization of $\gamma p \to K^0\Sigma^+$ from CLAS-g12.
- The preliminary results show a fair agreement with previous measurement from CBELSA/TAPS and Crystal Barrel but clear disagreement with previous measurement from CLAS-g11.

Outlook

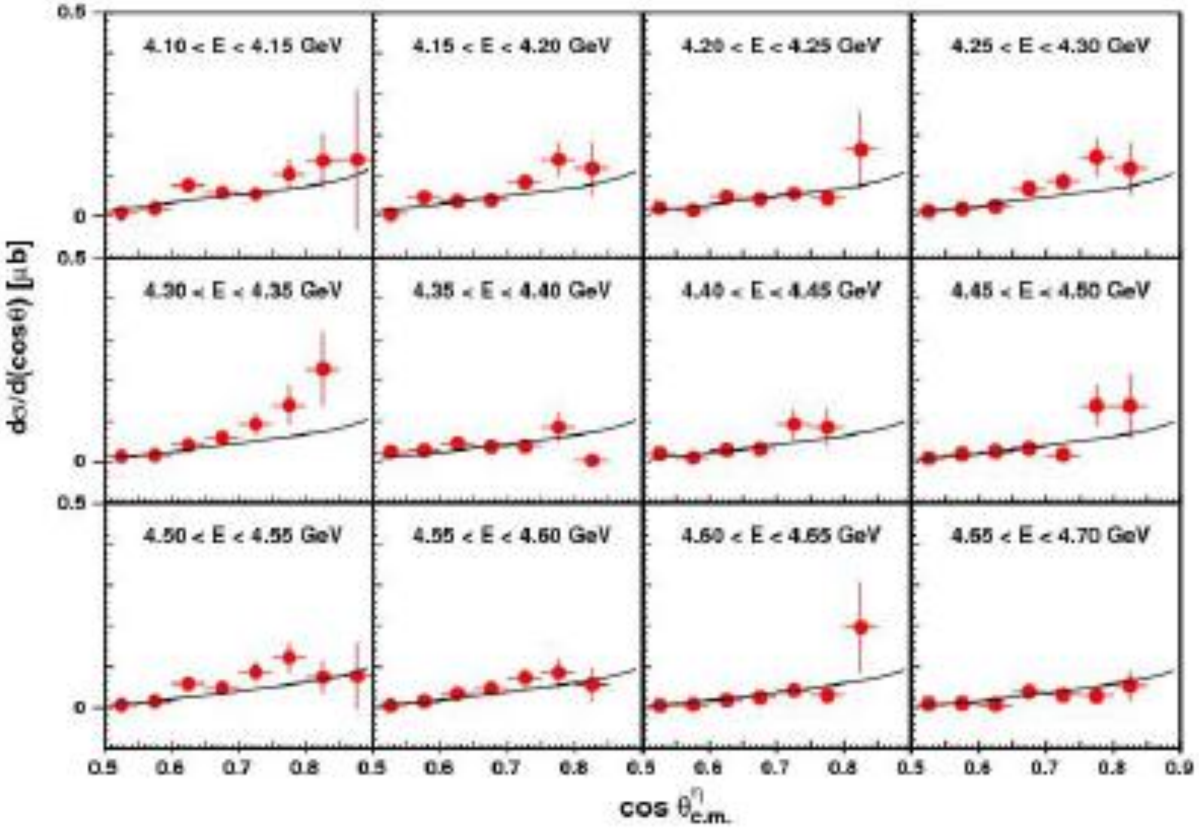
“Analysis Note is Coming (Very) Soon!”

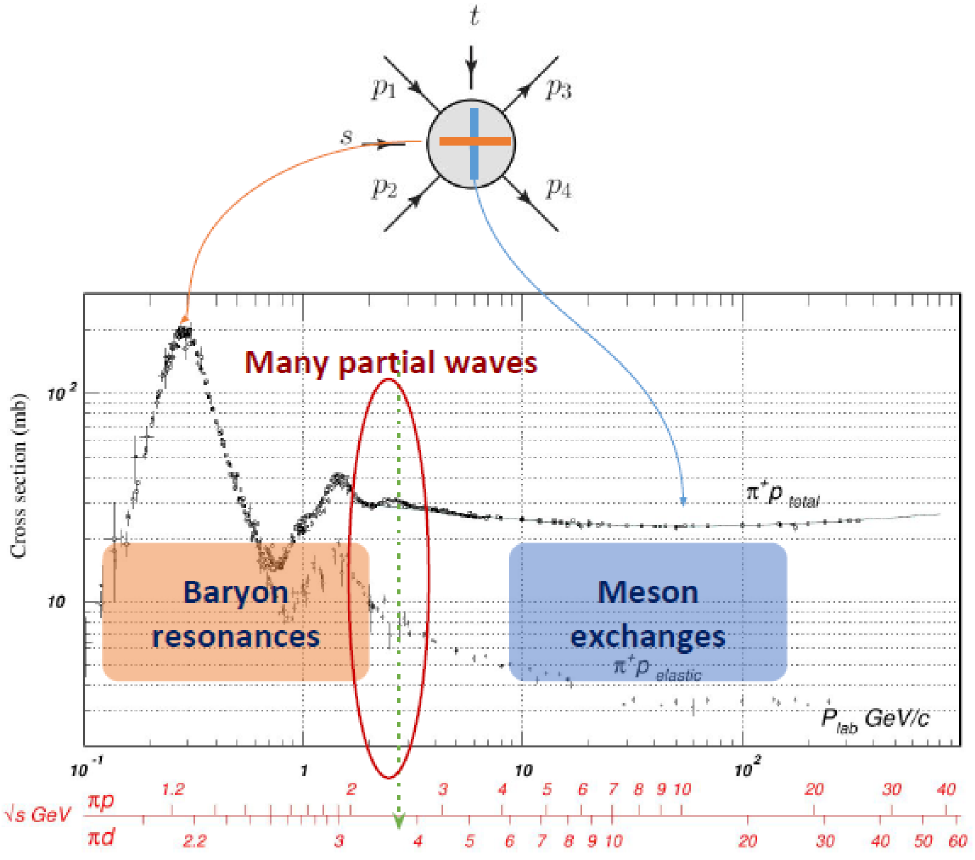
THANK YOU

Backup Slide

- Update on the $\gamma p \rightarrow p\eta$ and $\gamma p \rightarrow p\omega$ Channels
- Data Analysis : Event Based Q-factor Method

Differential cross section of γp ->pη at High Energy





Connect low- and high-energy dynamics.

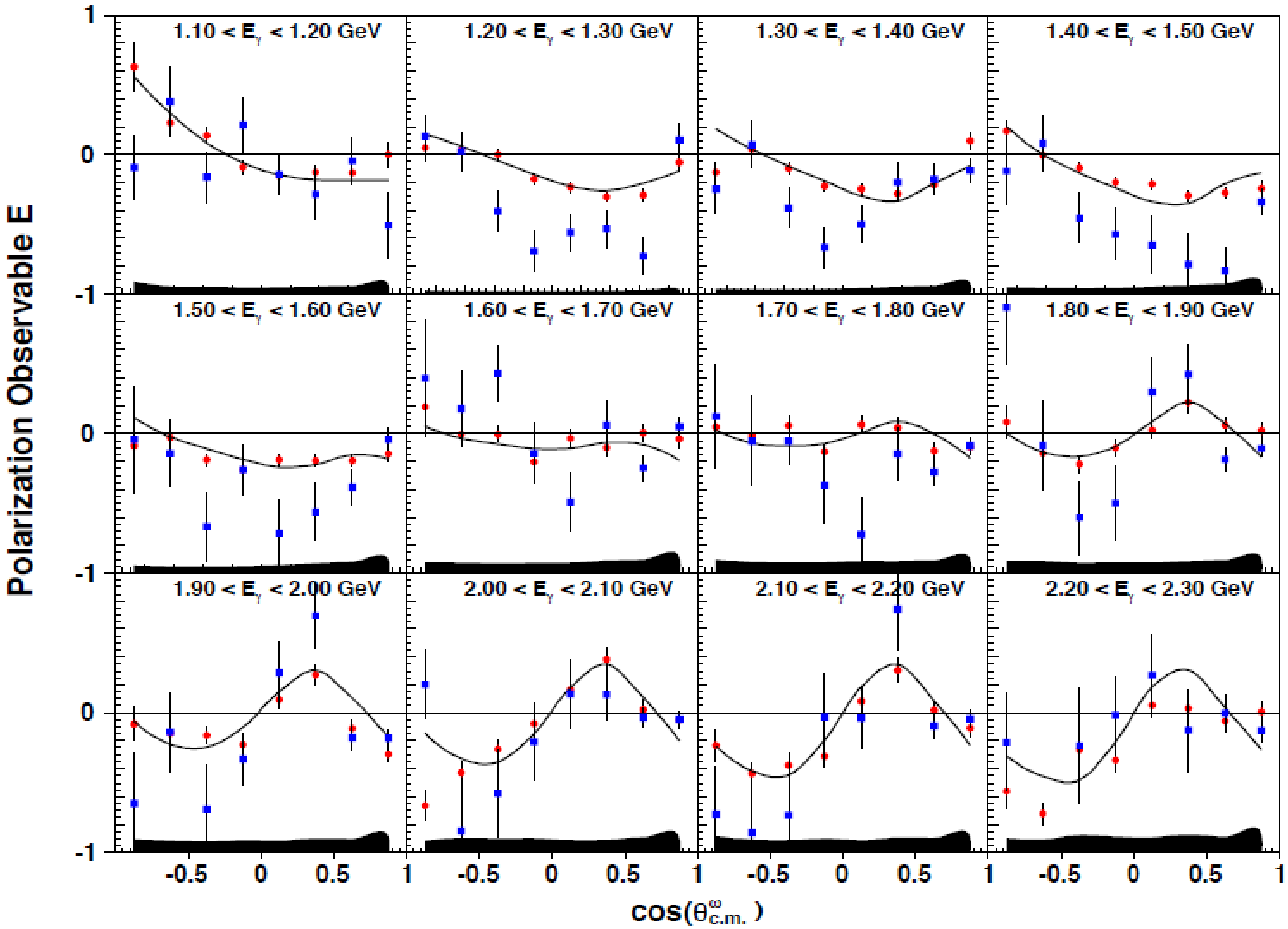
Preliminary (transition region)

The Differential cross section of γp ->pη (**BLACK**) from CLAS-g12 at higher energy along with JPAC model.

$$\pi B_i^\sigma(t)\left(\frac{\nu_M}{\Lambda}\right)^k + \int_{\nu_\pi}^{\Lambda} \mathrm{Im}\, A_i^\sigma(\nu',t)\left(\frac{\nu'}{\Lambda}\right)^k d\nu' = \beta_i^\sigma(t)\,\frac{(\Lambda/\nu_0)^{\alpha(t)}}{\alpha(t)+k}\,\nu_0$$

Nucleon pole | Low-energy model | Regge pole

The double polarization observable E of γp -> pω along with the Bonn-Gatchina Partial Wave Analysis result



- The figure shows the polarization observable 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 need the contribution from:
  N(1680) $5/2^+$
  N(2000) $5/2^+$
  N(1895) $1/2^-$
  N(2100) $3/2^-$

Submitted in PRC
arXiv : 1708.02606v1 [nucl-ex]]

Those *N resonances will fill in :**

Particle	J^P	overall	Status as seen in									
			$N\gamma$	$N\pi$	$N\eta$	$N\sigma$	$N\omega$	ΛK	ΣK	$N\rho$	$\Delta\pi$
N	$1/2^+$	****									
$N(1440)$	$1/2^+$	****	****	****		***				*	***
$N(1520)$	$3/2^-$	****	****	****	***					***	***
$N(1535)$	$1/2^-$	****	****	****	****					**	*
$N(1650)$	$1/2^-$	****	****	****	***			***	**	**	***
$N(1675)$	$5/2^-$	****	****	****	*			*		*	***
$N(1680)$	$5/2^+$	****	****	****	*	**				***	***
$N(1700)$	$3/2^-$	***	**	***	*			*	*	*	***
$N(1710)$	$1/2^+$	****	****	****	***		**	****	**	*	**
$N(1720)$	$3/2^+$	****	****	****	***			**	**	**	*
$N(1860)$	$5/2^+$	**		**						*	*
$N(1875)$	$3/2^-$	***	***	*			**	***	**		***
$N(1880)$	$1/2^+$	**	*	*		**		*			
$N(1895)$	$1/2^-$	**	**	*	**			**	*		
$N(1900)$	$3/2^+$	***	***	**	**		**	***	**	*	**
$N(1990)$	$7/2^+$	**	**	**					*		
$N(2000)$	$5/2^+$	**	**	*	**			**	*	**	
$N(2040)$	$3/2^+$	*		*							
$N(2060)$	$5/2^-$	**	**	**	*				**		
$N(2100)$	$1/2^+$	*		*							
$N(2120)$	$3/2^-$	**	**	**				*	*		
$N(2190)$	$7/2^-$	****	***	****			*	**		*	
$N(2220)$	$9/2^+$	****		****							
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**** Existence is certain, and properties are at least fairly well explored.
*** Existence is very likely but further confirmation of decay modes is required.
** Evidence of existence is only fair.
* Evidence of existence is poor.

Data Analysis

- Signal-Background separation using Q-factor methods
    a. Locating the peak
    b. Define kinematic distance to find nearest neighbor
    c. Fit using signal and background pdf
    d. Determine the signal/background fraction and Q-value
- Normalization
    a. Detector Acceptance (Monte Carlo simulation)
    b. Photon flux normalization
    c. Trigger simulation
    d. Multiple photon correction

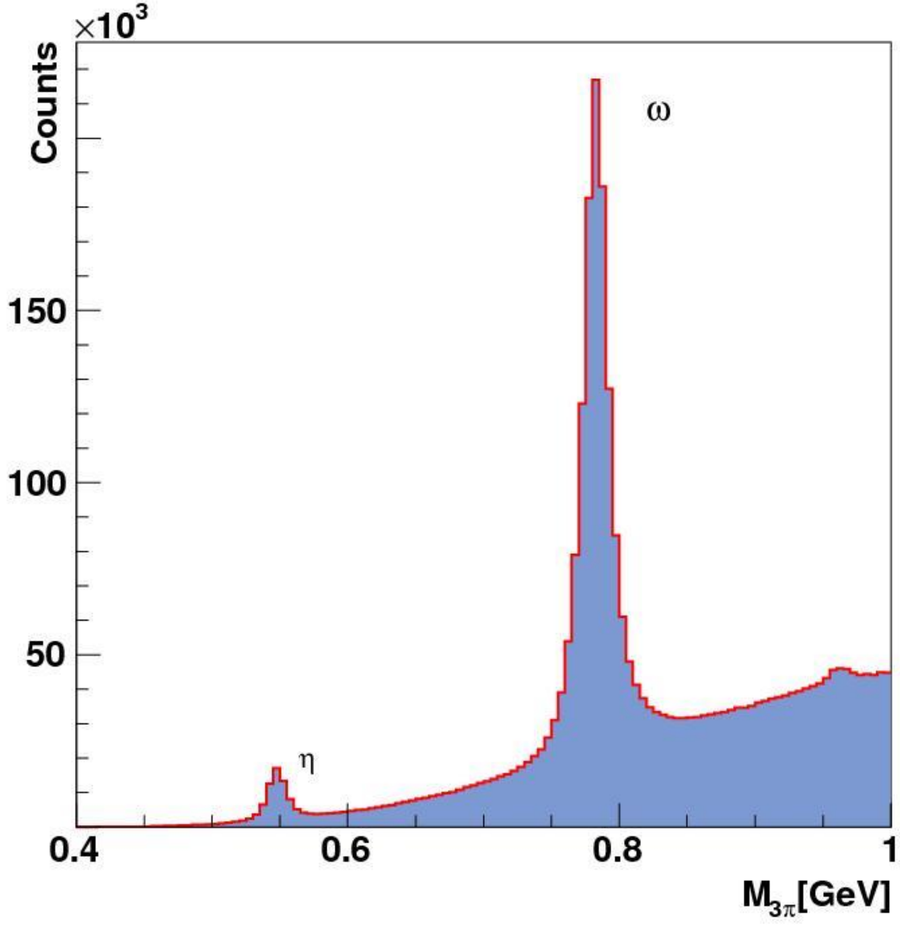
Locating the peak/coordinate reference

Since $\eta/\omega \rightarrow \pi^+\pi^-\pi^0$,we use the $M_{3\pi}$ as the coordinate reference for the $\gamma p \rightarrow p\eta/\omega$ channel.

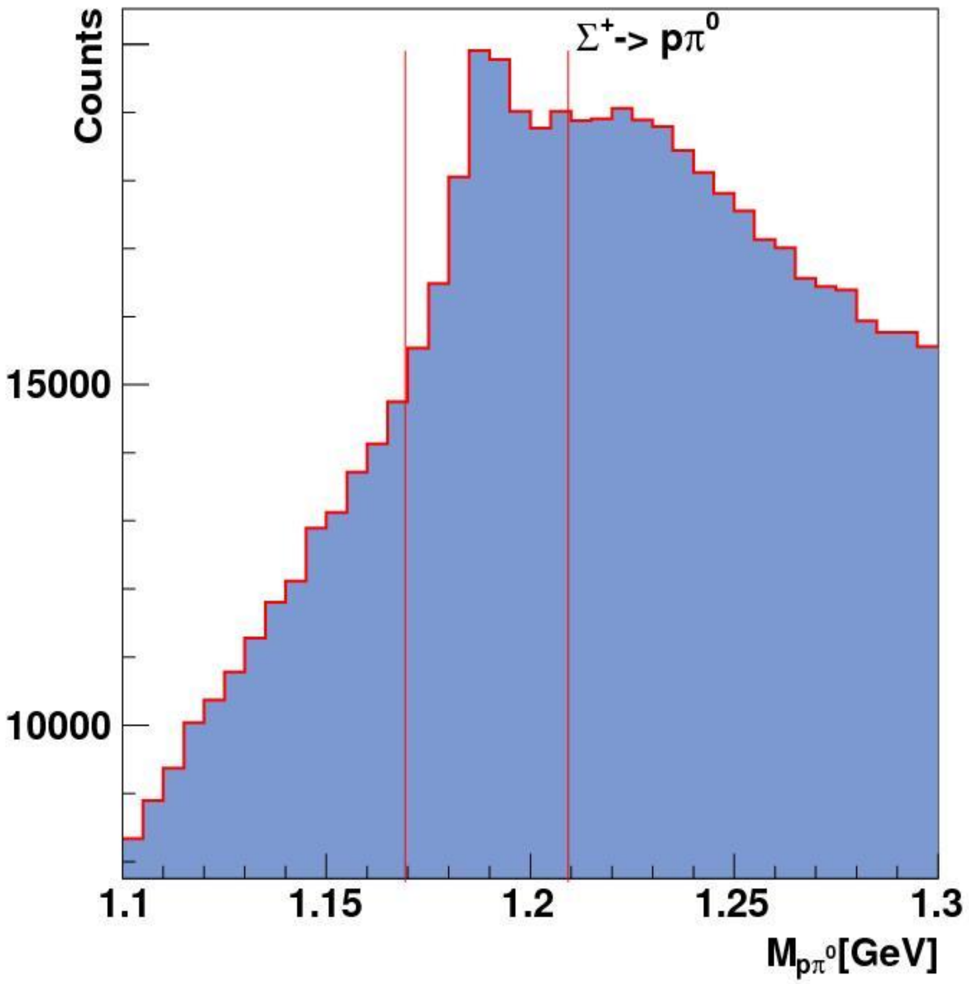
Since $\gamma p \rightarrow K^0\Sigma^+$ → $\Sigma^+ \rightarrow p\,\pi^0$

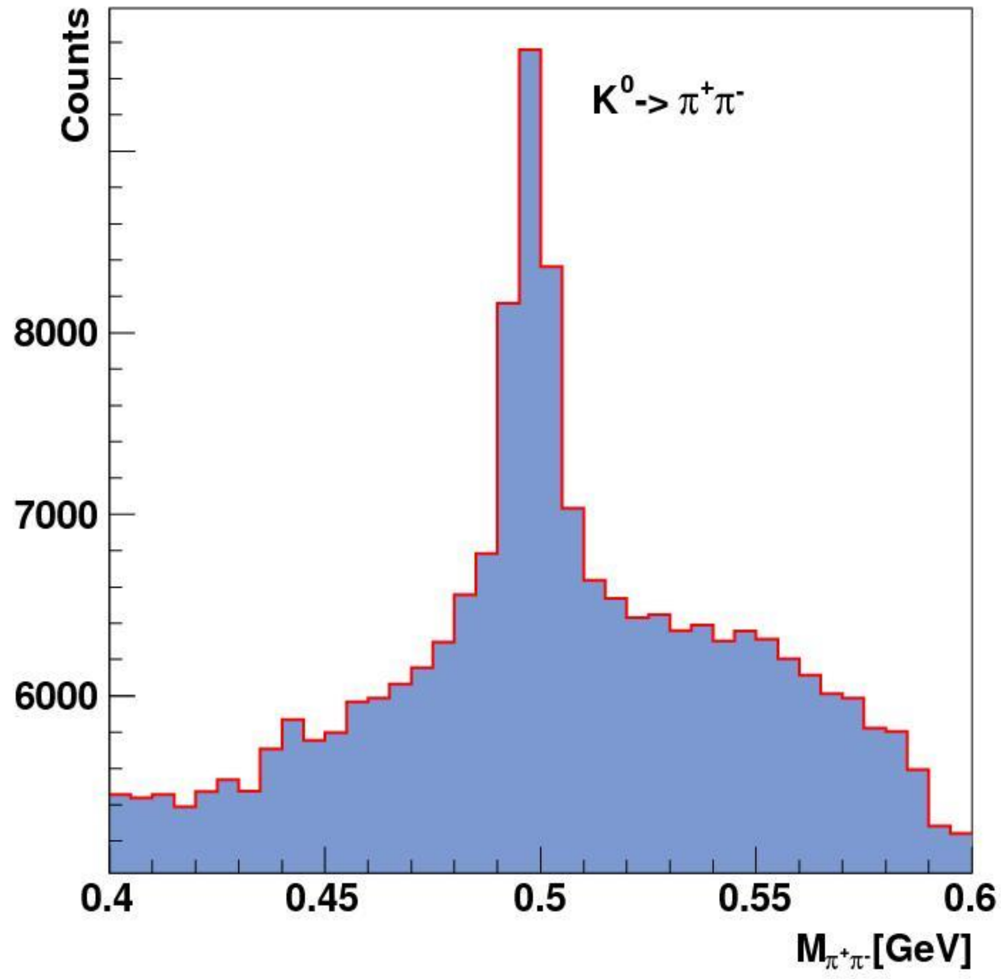
→ $K^0 \rightarrow \pi^+\pi^-$

We use the $M_{\pi\pi}$ as the coordinate reference for the $\gamma p \rightarrow K^0\Sigma^+$ channel after applying a cut on sigma region.



Locating the peak/coordinate reference



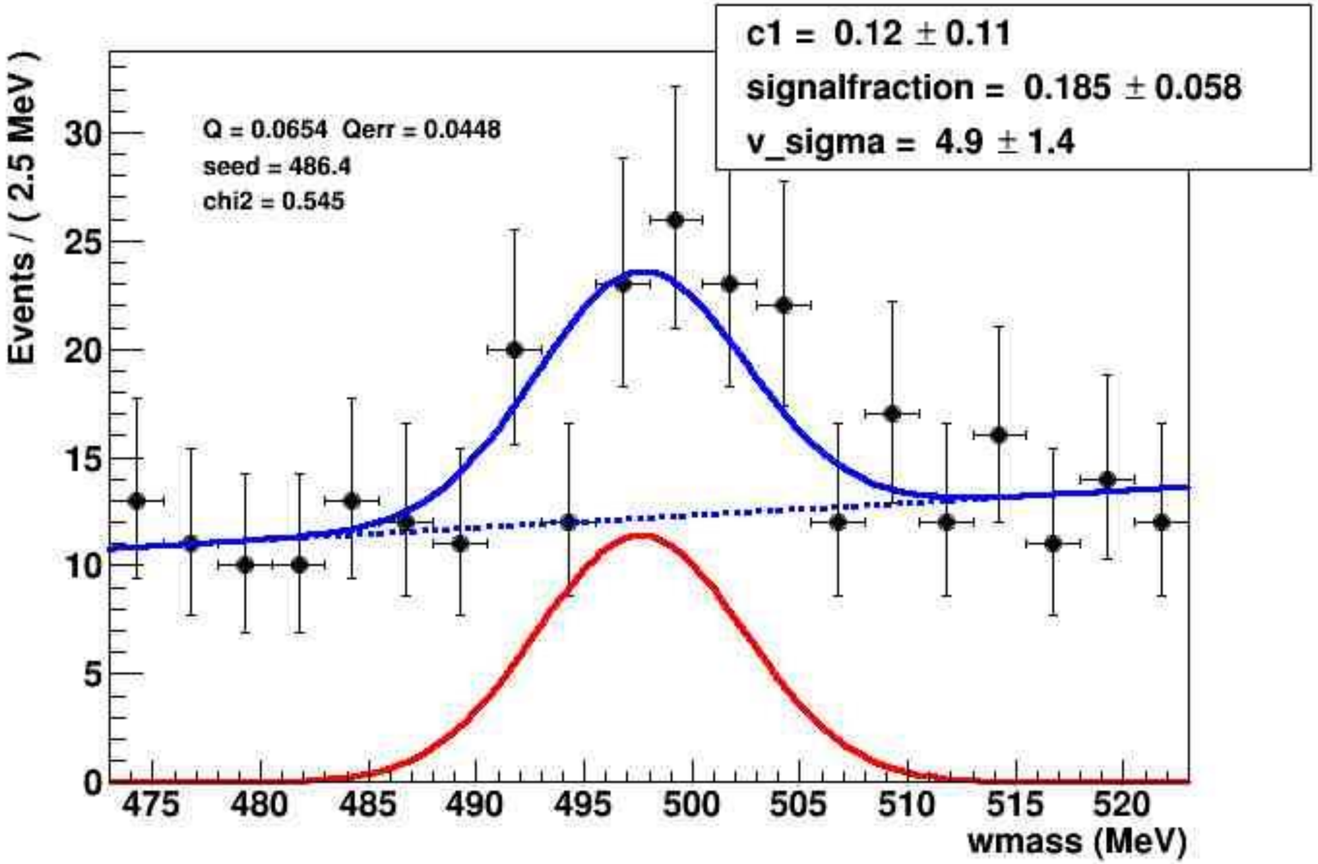


Q-factor methods

	$\gamma p \to p\omega$	$\gamma p \to p\eta$	$\gamma p \to K^0\Sigma^+$
Kinematic distance	$cos\theta^{\omega}_{c.m}$	$cos\theta^{\eta}_{c.m}$	$cos\theta^{K^0}_{c.m}$
	$cos\theta_{HEL}$	$cos\theta_{HEL}$	$cos\theta_{HEL}$
	φ_{HEL}	φ_{HEL}	φ_{HEL}
	λ	λ	E_γ
	φ_{Lab}	φ_{Lab}	φ_{Lab}
			$cos\theta_{K\Sigma}$
Number of neighbor	1000	1000	300
Signal pdf	Voigt function	Bifurcated gaussian	Gaussian
Background pdf	2^{rd} order Chebyshev polynomial	2^{rd} order Chebyshev polynomial	2^{rd} order Chebyshev polynomial

Notes : λ is a property of a vector meson. It is proportional to the decay amplitude and a function of pion momentum and kinetic energy.

Q-factor methods : Fit example



Fit example for a K^0 event.

Data Analysis : Q-factor result for K^0 (E_γ =1.95 GeV & 2.35 GeV)