Hyperon Physics at Hall B, Jefferson Lab

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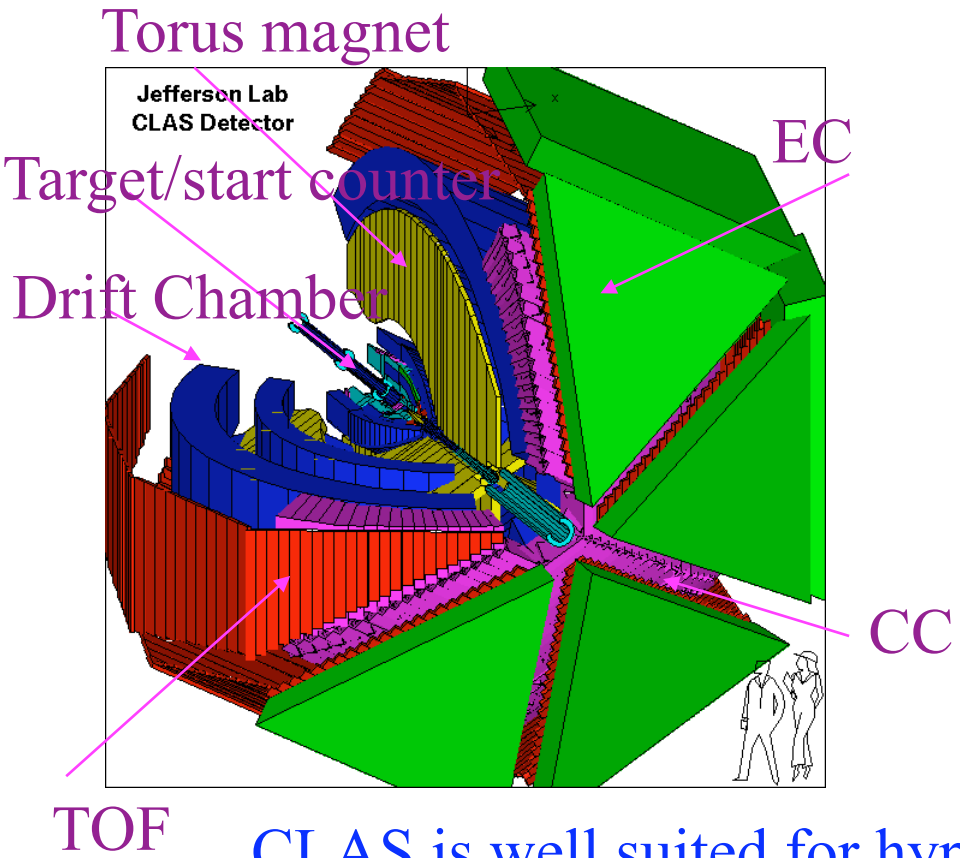
For the CLAS Collaboration

Overview

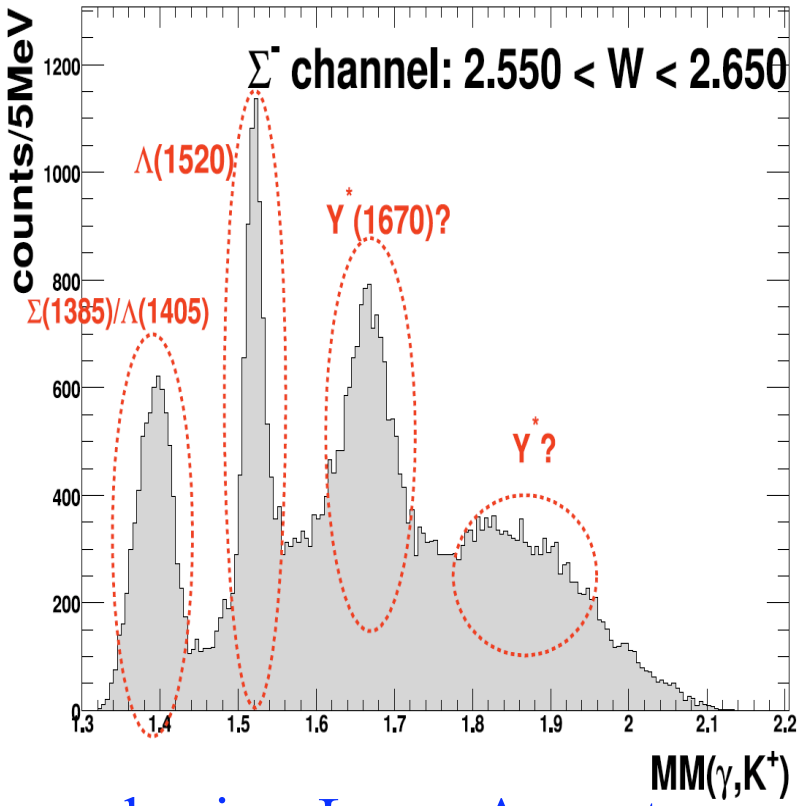
- Why study hyperons at CLAS
  - KY contribution to the nucleon resonances
  - Hyperon Polarization
  - Unanswered questions in hadron physics
  - Cascade physics
- Existing CLAS results
- Upcoming CLAS results
- The Future

Hyperons in CLAS

CEBAF Large Acceptance Spectrometer

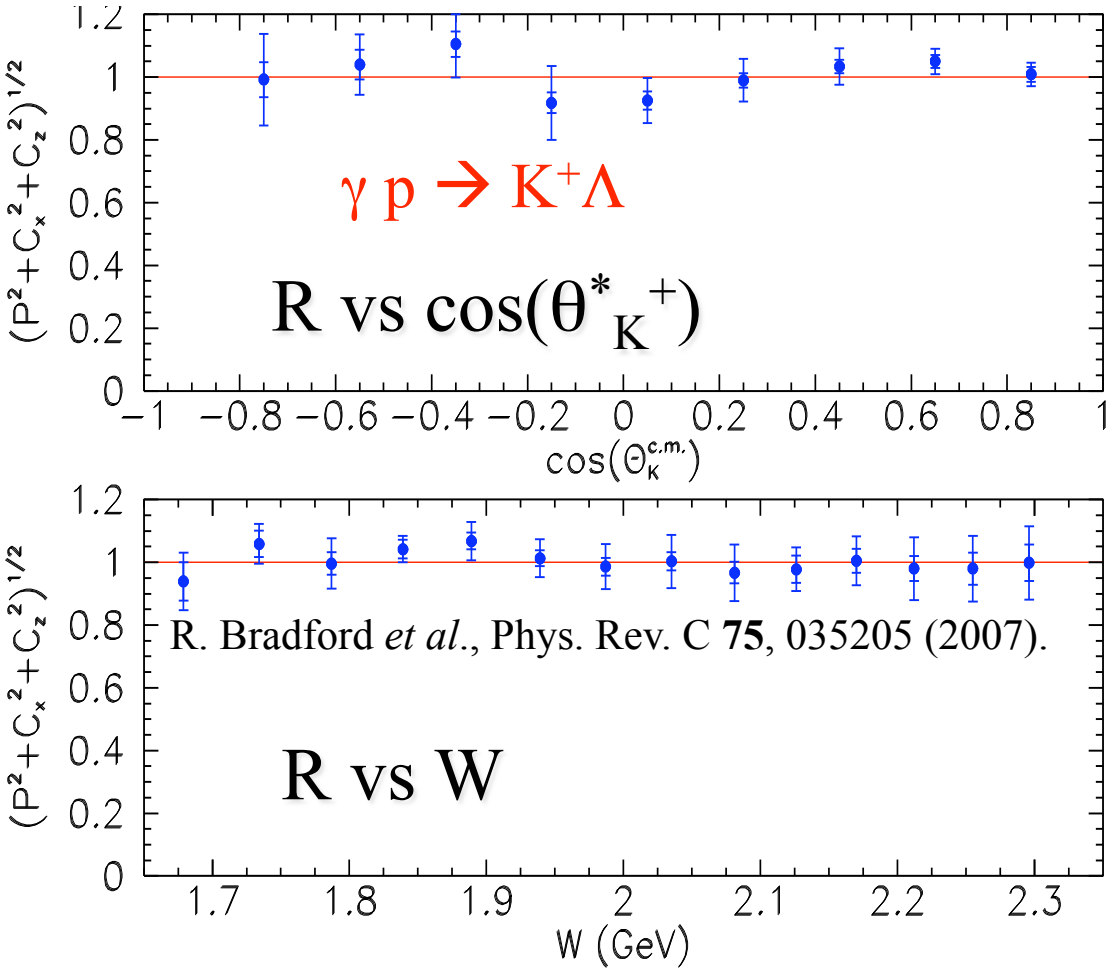


A small sample of CLAS hyperon data



CLAS is well suited for hyperon physics: Large Acceptance
Good K/π separation

Λ Polarization: Photoproduction



R. Bradford *et al.*, Phys. Rev. C **75**, 035205 (2007).

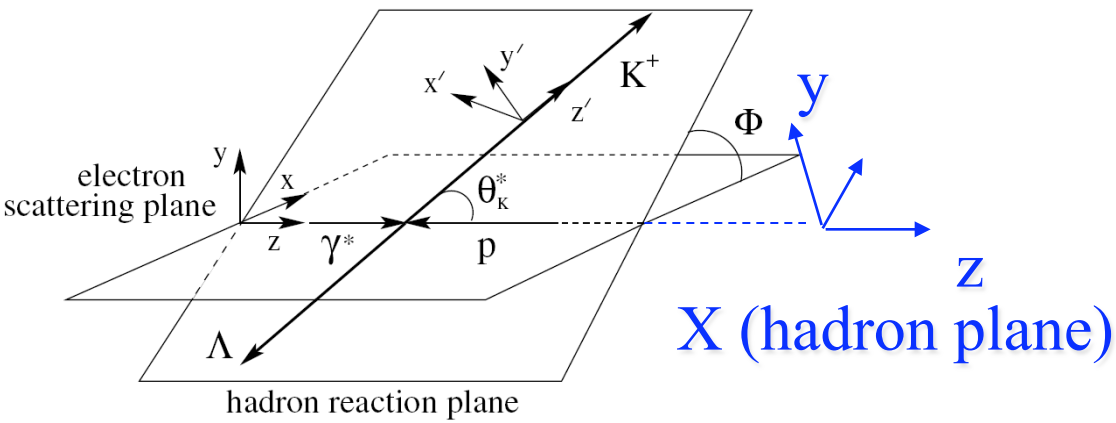
$$R \equiv \sqrt{P^2 + C_x^2 + C_z^2}$$

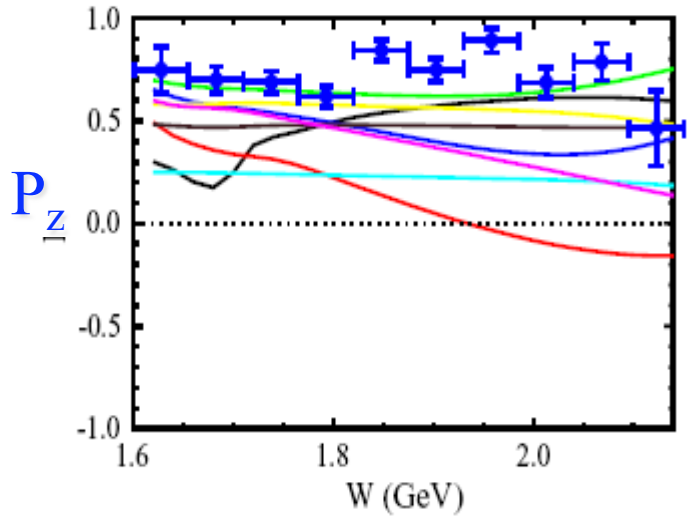
$$\bar{R} = 1.01 \pm 0.01$$

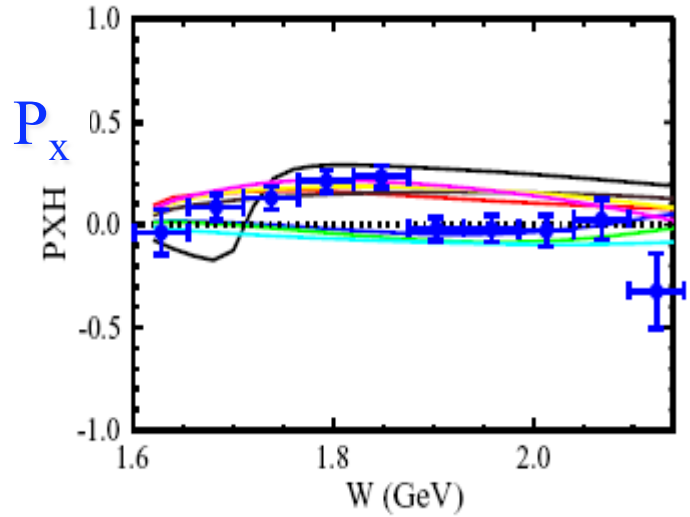
- consistent with unity
- 100% polarization with circularly polarized beam

Totally unexpected by hadrondynamic models

Λ Polarization Electroproduction



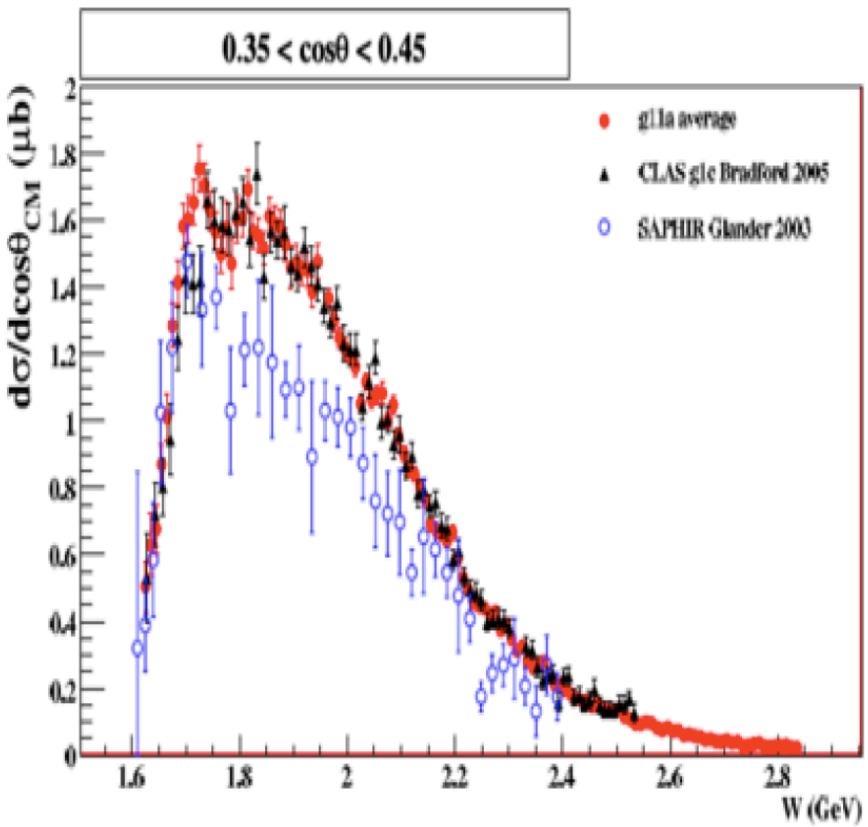


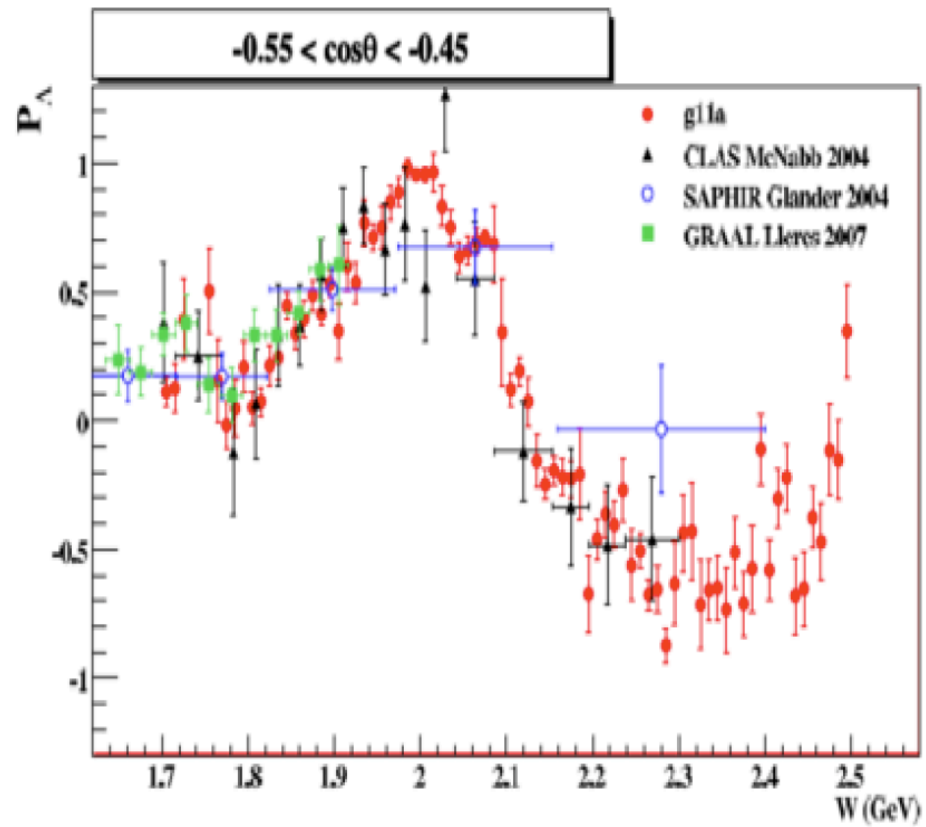


Large polarization transfer along virtual photon direction

D. S. Carman et al. (CLAS)
Phys. Rev. Lett. 90, 131804 (2003).

KΛ contribution to the N* resonances

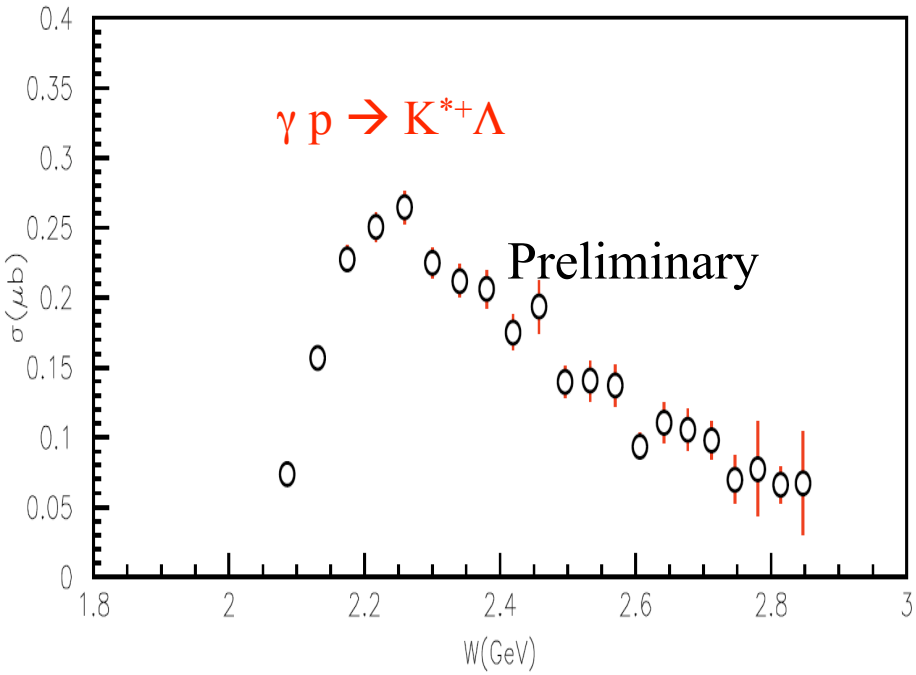


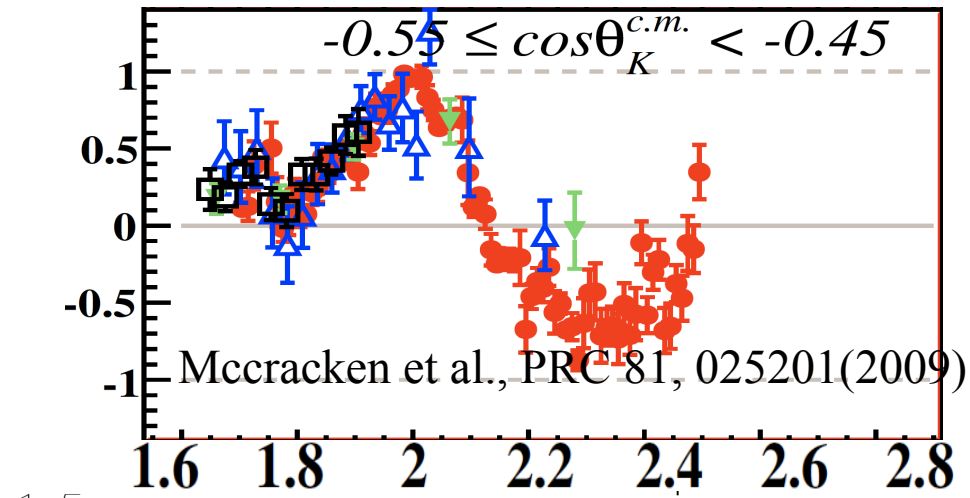


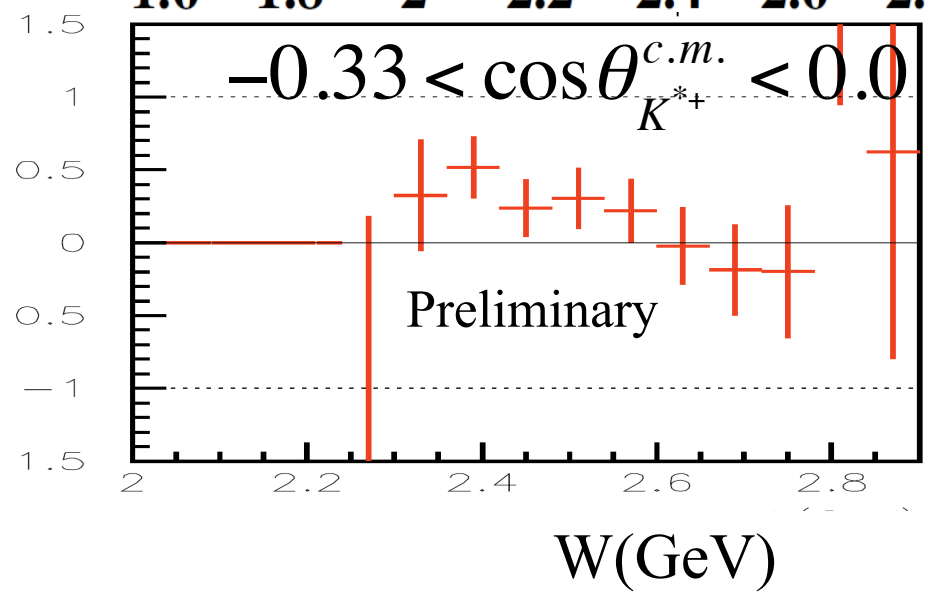
Cross section results shows hint of N*→KΛ

This contribution is corroborated By the motion of the recoil polarization of Λ

Induced polarization of Λ in $\gamma p \rightarrow K^{+}/K^{*+}\Lambda$



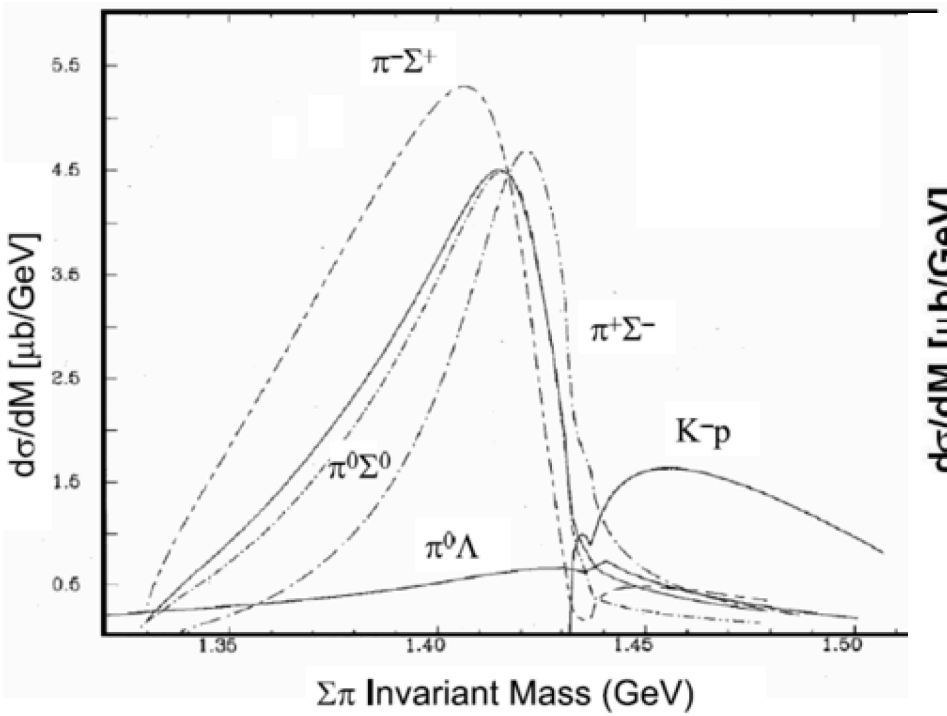


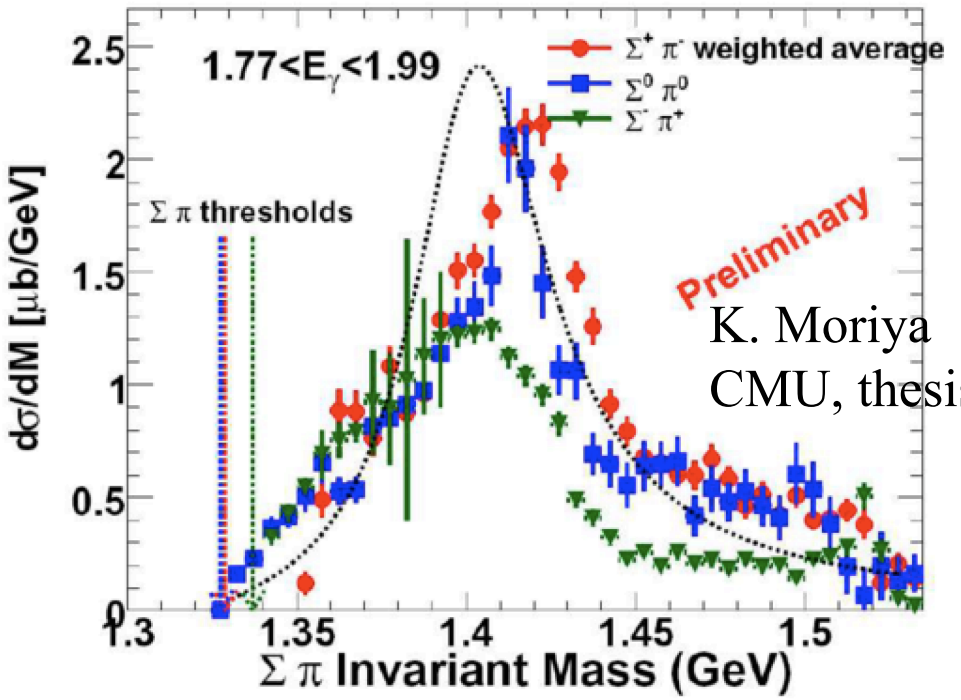


$K^{+}/K^{*+}\Lambda$ contribution to N* are comparable

Λ recoil polarization shows 0-crossing in both channels

Line shape of Λ(1405)





K. Moriya
CMU, thesis

What is the nature of Λ(1405): 3-quark state with well defined Isospin?
Or ss it dynamically generated (I=0 VS I=1 contributions):
Interference causes difference line shapes for different decays!

What we have learned in the S=1 hyperons at CLAS

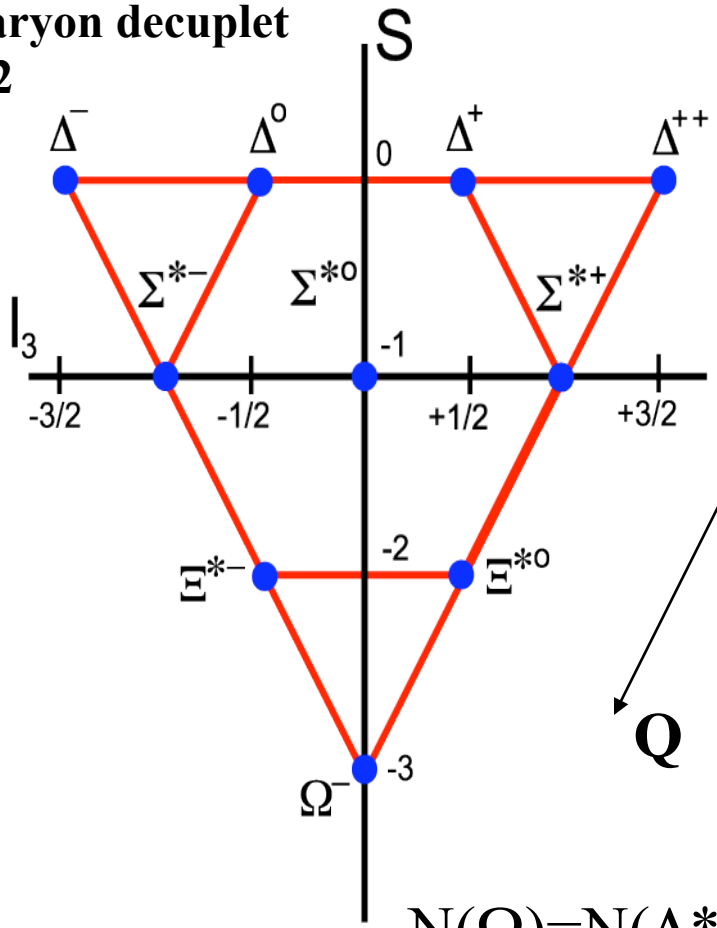
- CLAS has collected the largest data set of hyperons in photoproduction/electroproduction
- Hyperons are usually produced polarized, sometimes in very unexpected ways
- KY/K*Y contributes to the N* resonances
- In order to extract the Quantum Numbers of the N* resonances:

  We need Partial wave analysis, Coupled channel analysis

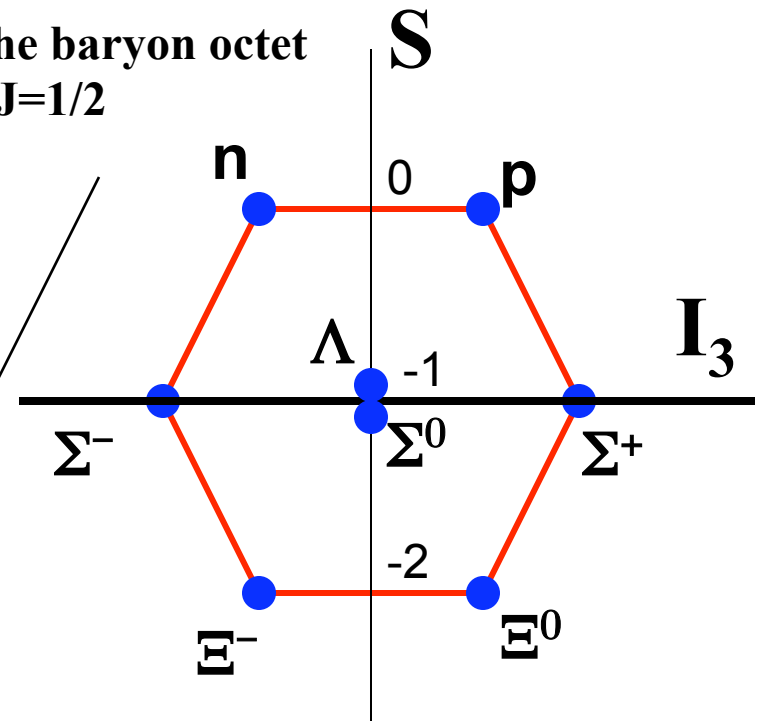
  And more observables: Beam/target asymmetry, polarization transfer (circular/linear polarized photons, polarized p/n targets, ….), all under way
- Plenty to do during the Shut-down

From S=1 to S=2,3 hyperons

The baryon decuplet
J=3/2



The baryon octet
J=1/2

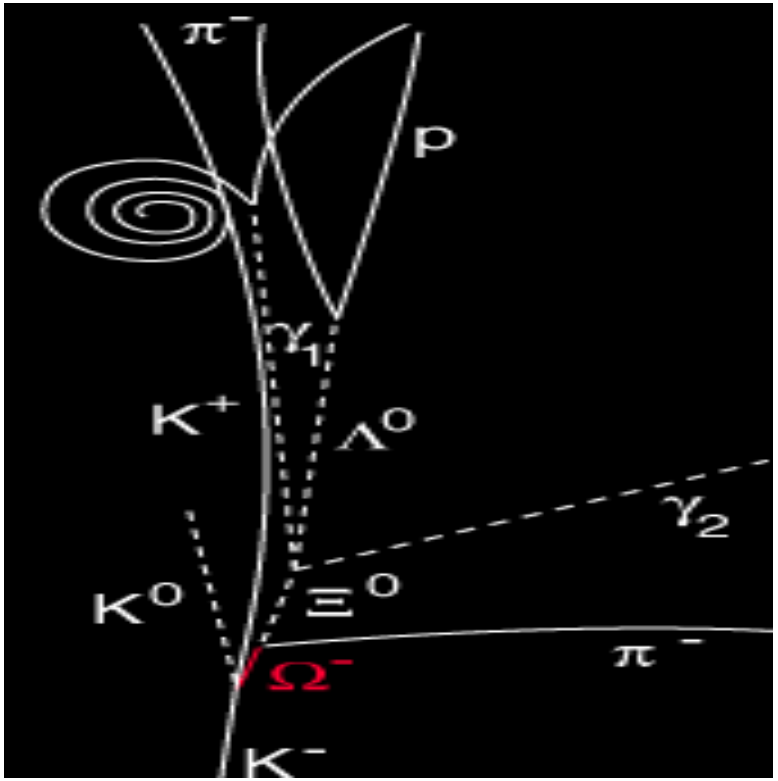


Q

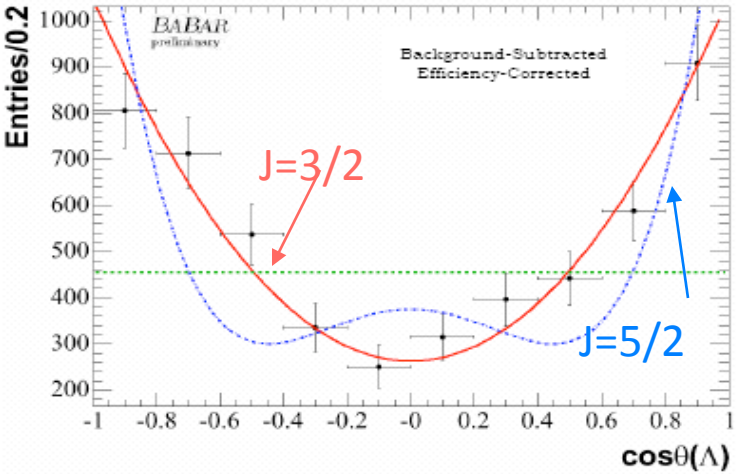
$N(\Omega)=N(\Delta^*)$

$N(\Xi)=N(N^*)+N(\Delta^*)$

Some historical perspective: History of Ω^- (sss) Baryon



First measurement of $J(\Omega^-)$ at SLAC: $\Xi_c^0 \rightarrow \Omega^- K^+$, $\Omega^- \rightarrow \Lambda K^-$



$J(\Omega^-)=3/2$, if $J(\Xi_c^0)=1/2$

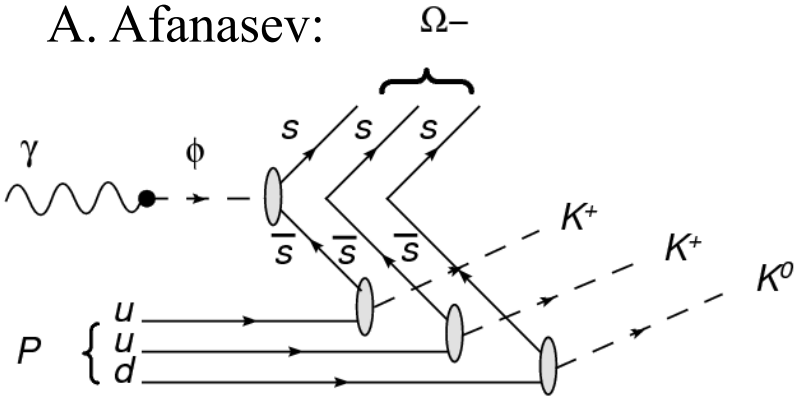
Barnes et al, PRL 12:204, 1964,

$K^- p \rightarrow K^0 K^+ \Omega^-$

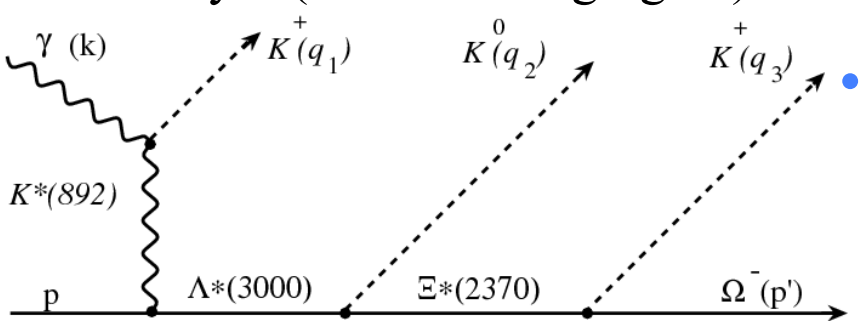
Aubert et al, PRL.97:112001,2006

Ω^- (sss) Cross section and production mechanism

A. Afanasev:



V. Shklyar (Effective Lagragian)



- Production mechanism for Ω^- in photoproduciton unknown but extremely interesting:
  None of the constituent quark (s) is from the target ($\Delta S=+3$)
- Cascading decay from intermediate Y*?
- Various models predict
  $\sigma \sim 0.4$-2nb at $E\gamma \sim 7$GeV
  SLAC upper limit: 17nb@20GeV
  Abe et al, PRD32, 2869 (1985)

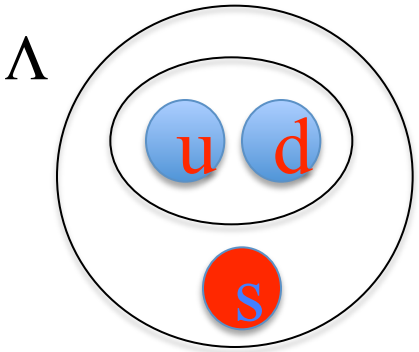
The status of excited (PDG***) Ω/Ξ baryons
(half a century later)

	$(J)^P$	M(MeV)	Γ(MeV)
Ω(2250)	$?^?$	2250	
Ξ(1530)	$(3/2)^+$	1530	9.1
Ξ(1690)	$(1/2?)^?$	1690	<30
Ξ(1820)	$(-3/2?)^-$	1823	24
Ξ(1950)	$(?)^?$	1950	60
Ξ(2030)	$(>=5/2)^?$	2025	20

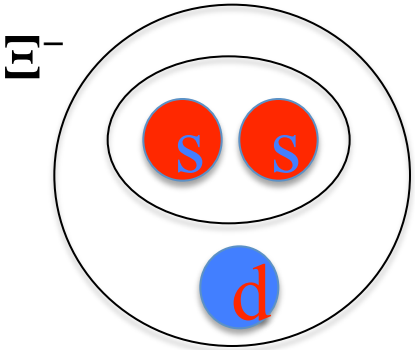
- Very few Ω/Ξ baryons have been identified in the last 50 years.
- Even fewer have their quantum numbers determined
- Kaon beam was the primary source for these states discoveries
- Photon beam could be a powerful alternative

Are Ξ and Λ polarized the same way?

- Diquark models:
  - Good diquark: isospin 0 and spin 0
  - Λ((ud)s) polarization comes from s
  - Ξ(u/d(ss)), polarization comes from u/d?



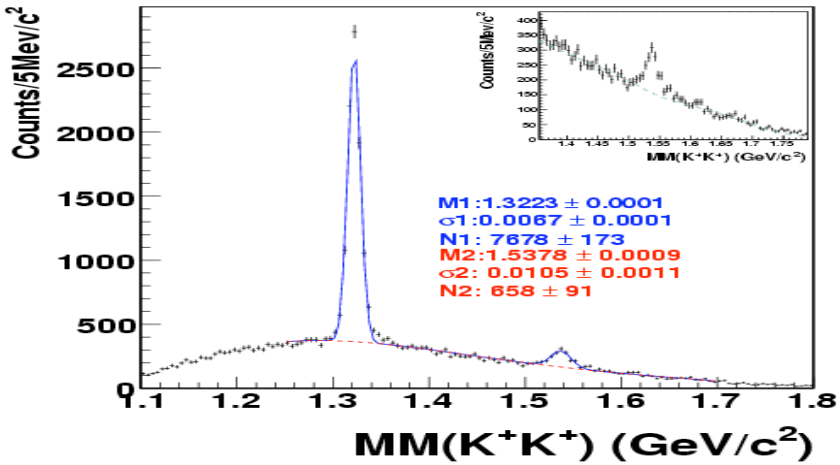
- Purpose of studying Ξ polarization
  - Probe production mechanism
  - Understand the origin of hyperon polarization



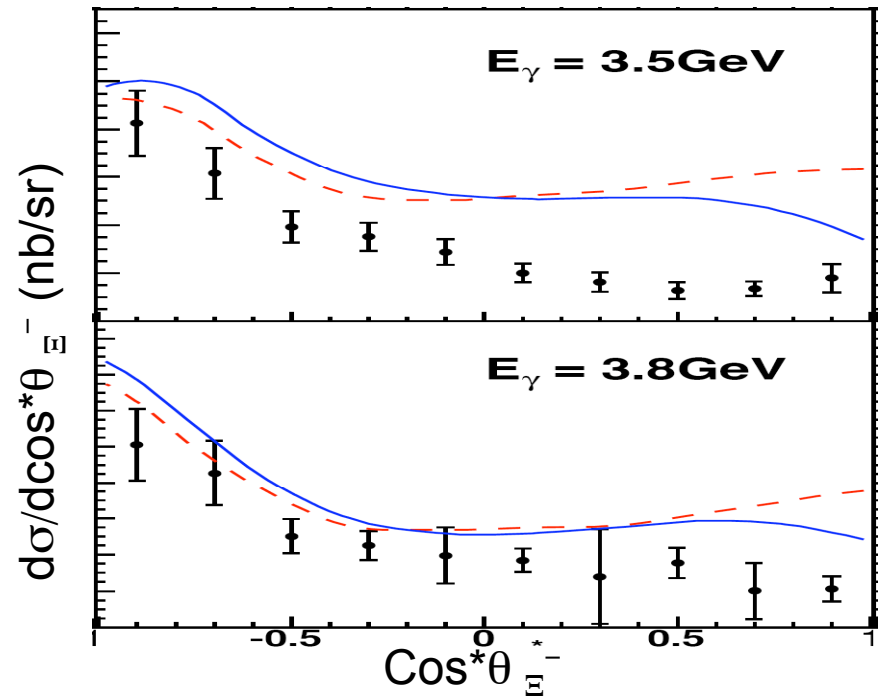
Recent CLAS6 results on Ξ

E_γ: 2.8-3.8GeV

Guo et al, Phys.Rev.C76:025208 (2007)



- Non-dedicated data, low beam energy, no vertex detector …
- First high statistics exclusive γp experiment
- Future dedicated program at JLAB feasible and promising



- Data qualitatively consistent with t-channel hyperon production
- High spin hyperon resonances needed (J>=3/2)

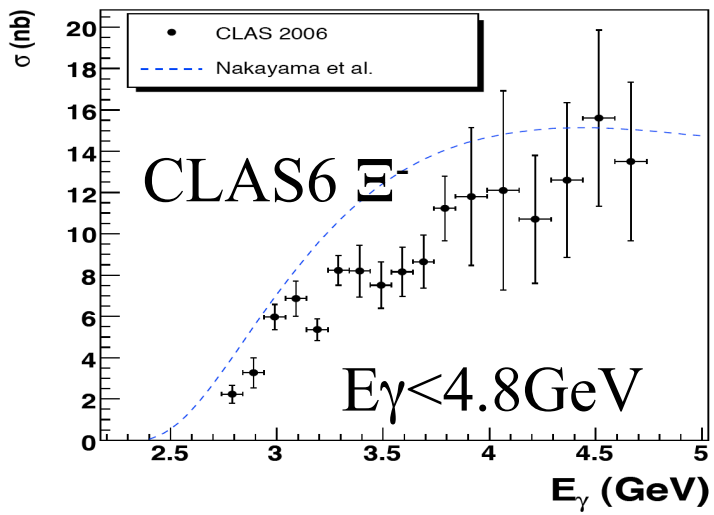
What to expect at CLAS12 for Ξ and Ω

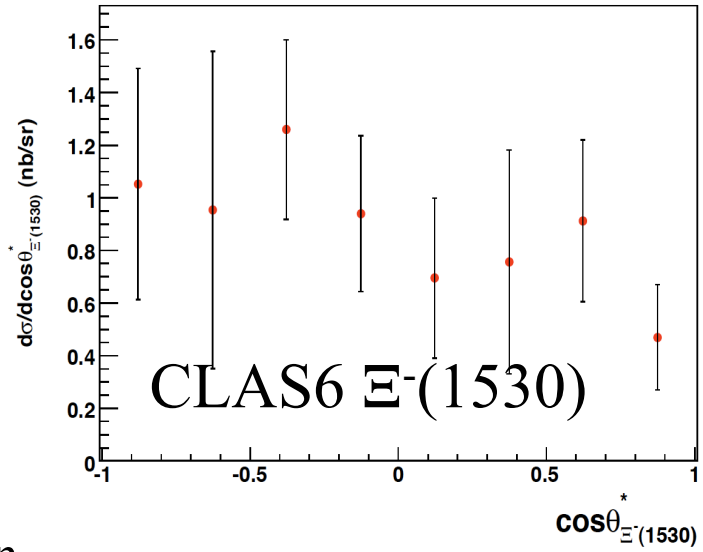
- Assuming $\sigma(\Omega^-) \sim 0.3$nb

(Afanasev, Roberts, Shklyar)

- $\sigma(\Xi^-) \sim 20$nb (Oh, Nakayama)
  - SLAC inclusive: 117nb@20GeV
- $\sigma(\Xi^-(1820/1690))$: around 1-5nb
- Luminosity: 10^{35}cm^{-2}s^{-1}
- FT acceptance: 2.5~4.5^o (θ)

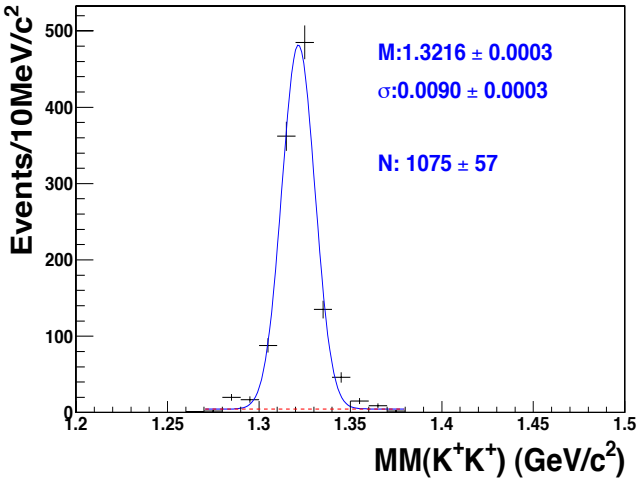
  0.5~4.5GeV ($E_{e'}$)
- Ω^- rate: 90/hr
- Ξ- rate: 3.6k/hr
- $\Xi^-(1690)/\Xi^-(1820$: 0.2-0.9k/hr

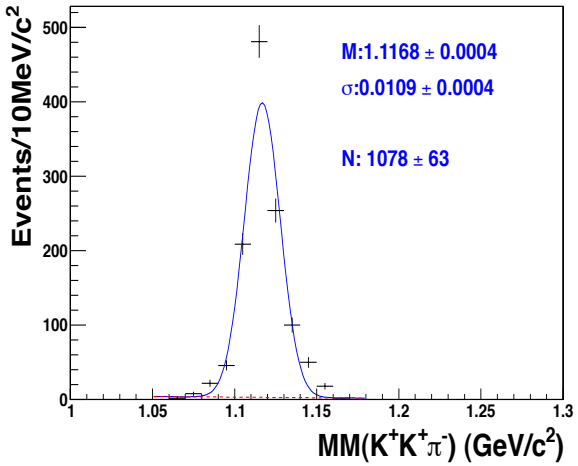




CLAS12 acceptance not folded in

Ξ^- induced polarization in photoproduction

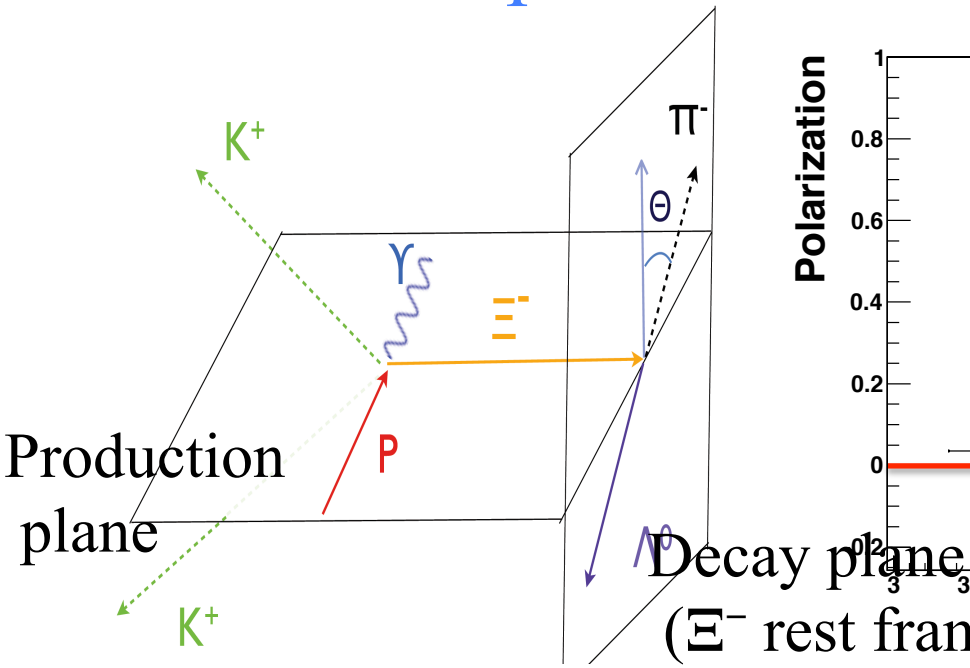


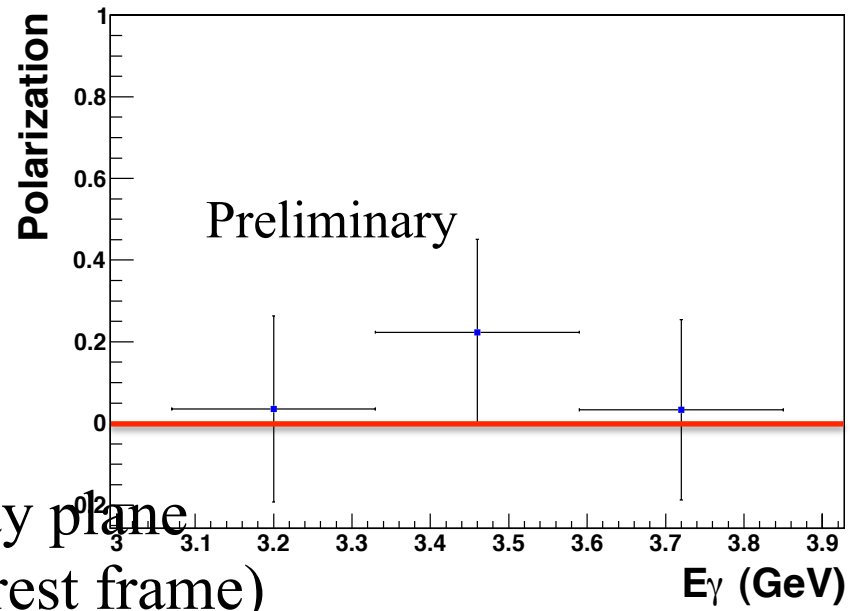


- Data virtually background free (double kinematic constraints)
- g11 Ξ^- should not be polarized, If our naïve di-quark picture is correct,
- Statistics limited to study P(cosθ*)

WE
NEED
CLAS12
(Higher beam energy,
Higher cross section,
Higher acceptance)

Ξ^- induced polarization in photoproduction





This data (2004, 2.8-3.8GeV): No beam/target polarization

New data (2008: 3.6-5.4GeV): Circularly polarized photon beam. Ongoing

The only direction Ξ can be polarized is out of plane (Parity conservation)

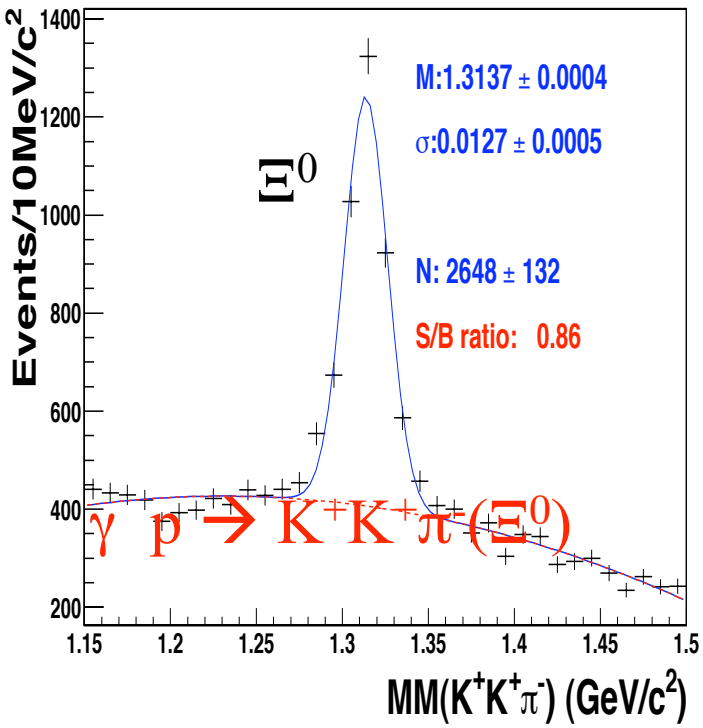
CLAS12 (with FT): polarization transfer for Ξ^-

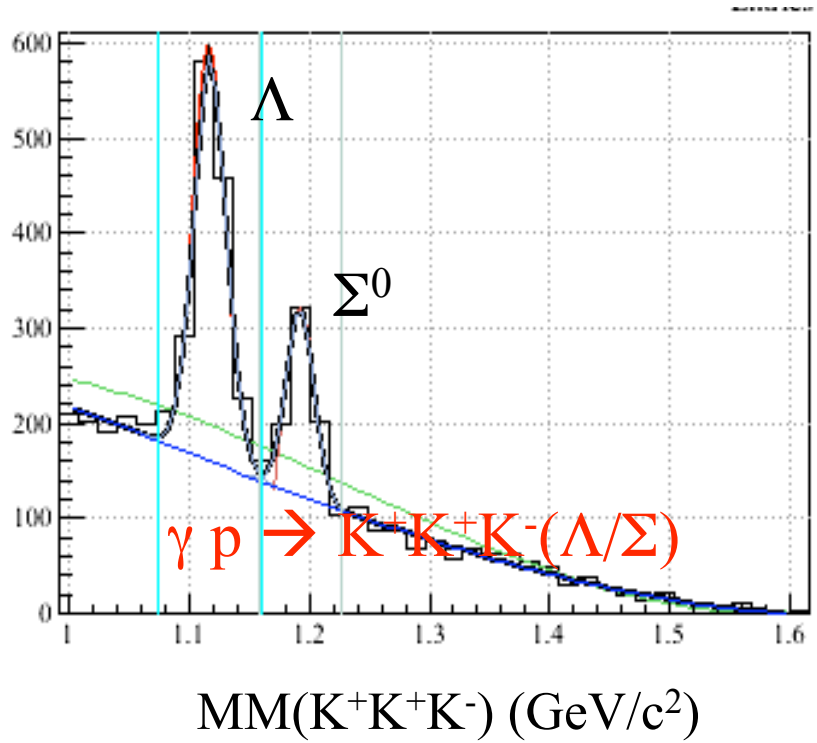
P_γ(10-70%), known on a event by event basis

CLAS6: Searchfor excited cascade resonances

$\Xi^{*-} \rightarrow \pi^- \Xi^0$, $\Lambda/\Sigma\ K^-$

E_γ: 3.6-5.4GeV





$\Xi^0/\Lambda/\Sigma$ Decay chain not detected (can not determine JP)

Limited by beam energy, excited states other than $\Xi(1530)$ unlikely in CLAS6 We NEED CLAS12: Higher Energies, Xsections, acceptance …!

Spin-Parity determination of Ξ*

- Spin can be measured by angular distributions (PWA)
- Parity measurement challenge: Minami ambiguity

  $\Xi^* \rightarrow Y\ (1/2^+)\ + M_1\ (0^-)$: two solutions $J^{\pm P}$
- Double Moment Analysis (DMA)

  $Y\ (1/2^+) \rightarrow B\ (1/2^+) + M_2\ (0^-)$

  Double moments: $H(lmLM) = \Sigma\ D^L_{Mm}(\theta_1, \phi_1)\ D^l_{m0}(\theta_2, \phi_2)$

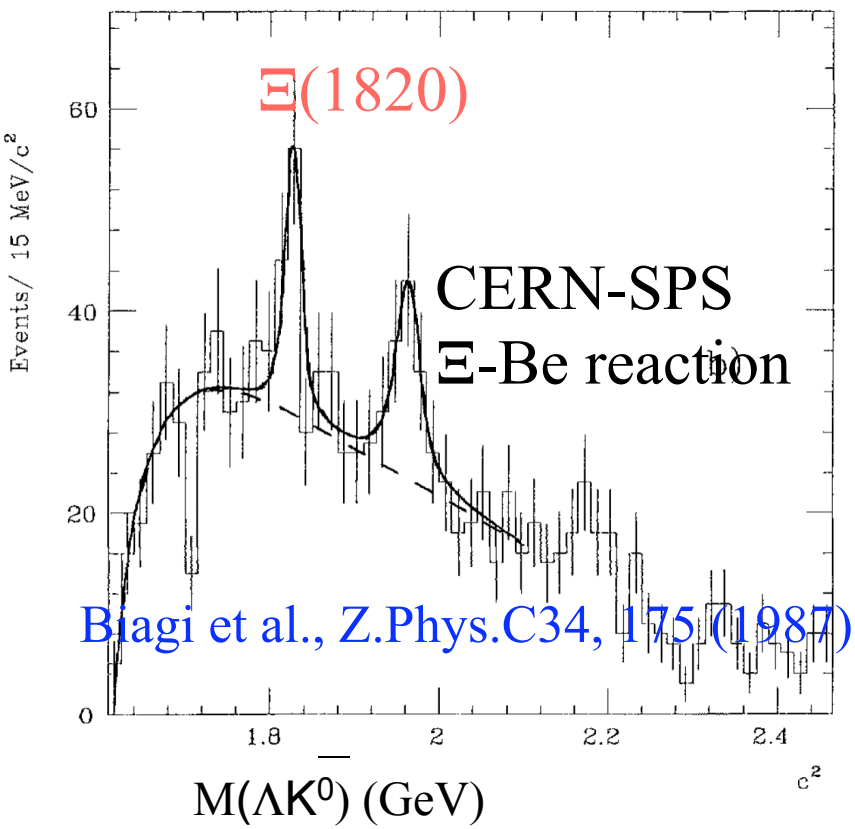
  DMA:

$$H(11LM) = P(-1)^{J+\frac{1}{2}} \frac{2J+1}{\sqrt{2L(L+1)}} H(10LM)$$

  Linear dependence gives simple, multiple tests for J, P

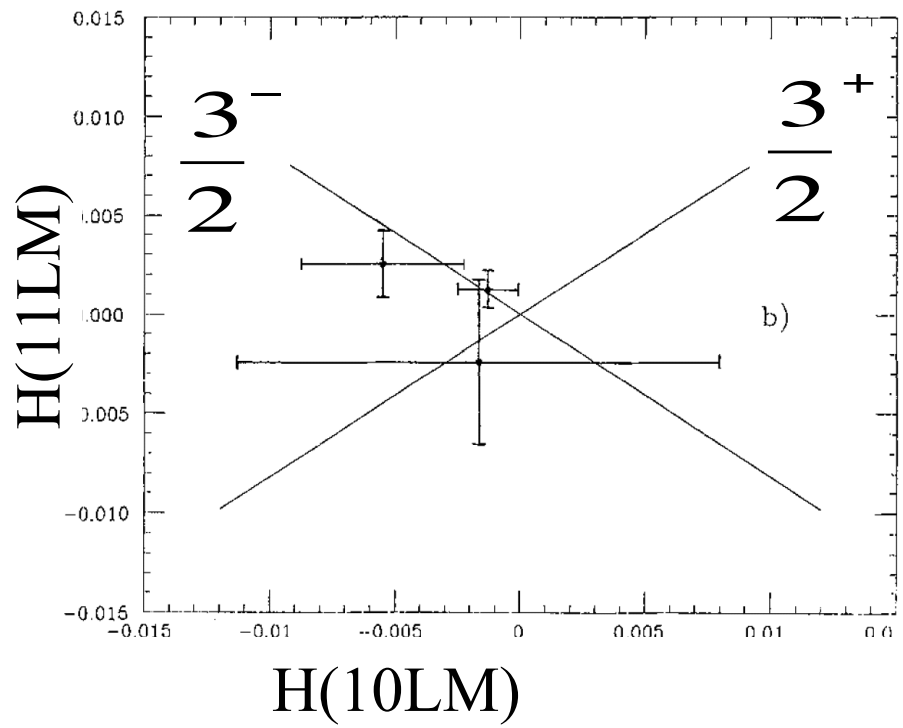
  For any odd $L \leq 2J$ and $M \leq L$

Example: Parity measurement of Ξ(1820)



Biagi et al., Z.Phys.C34, 175 (1987)

Needs corroboration

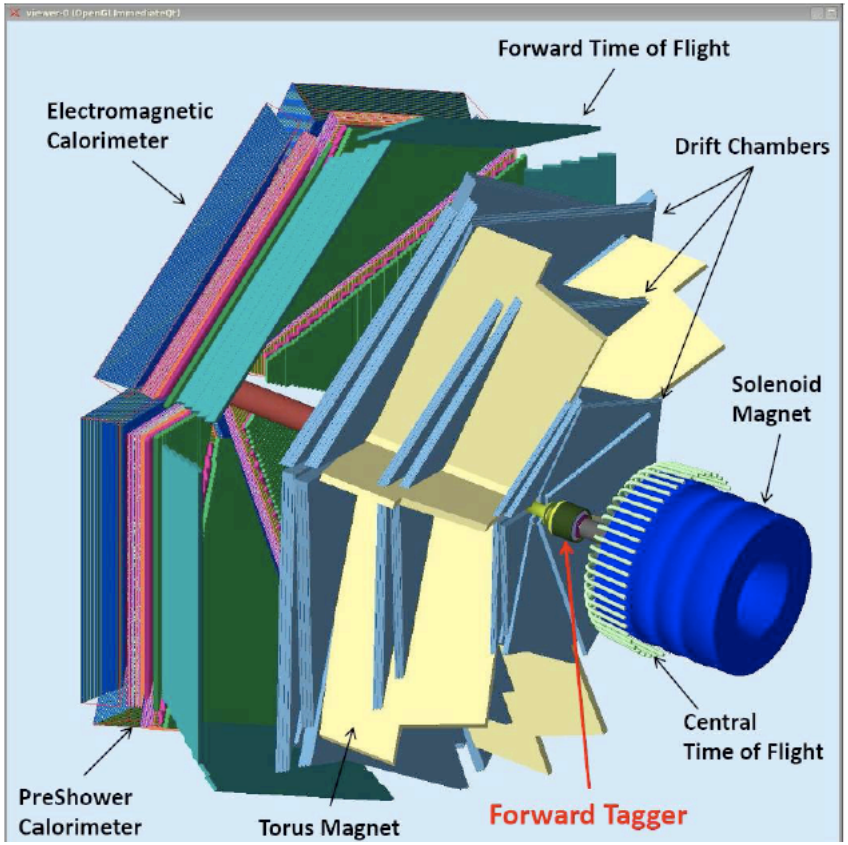


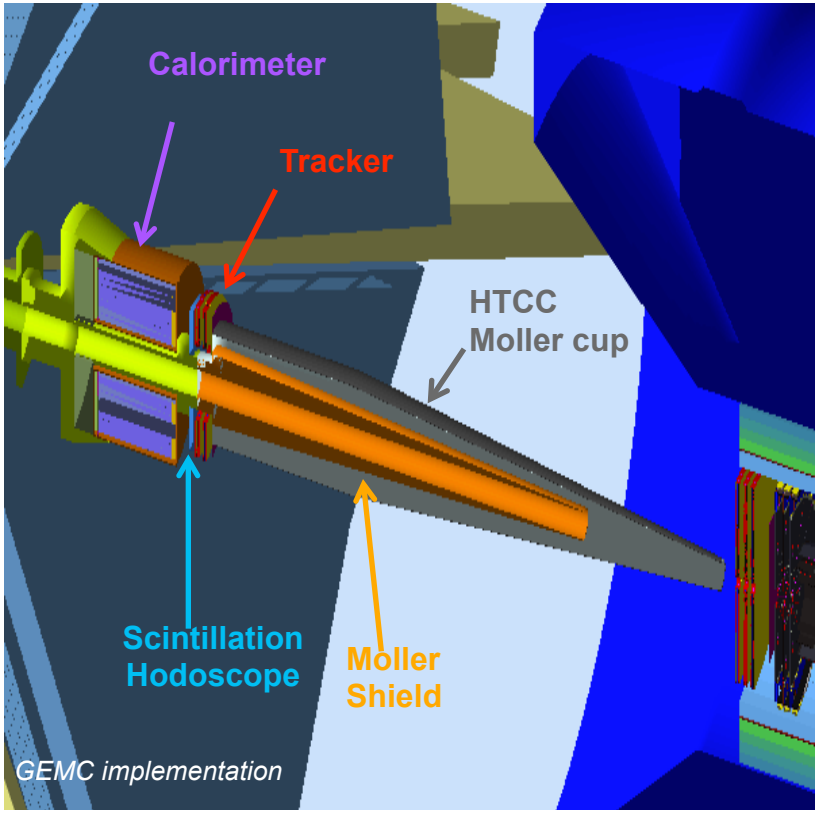
Ξ(1820) $\frac{3}{2}^-$ counts: ~50

Need to detect whole decay chain

CLAS12 estimate: ~20k Ξ(1820) with complete decay chain At CLAS12 (119 beam days)

CLAS12 Forward tagger(FT)





$E_{e'}$: 0.5-4.5GeV
$\Theta_{e'}$: 2.5°-4.5°
E_{γ}: 6.5-10.5GeV
P_{γ}: 10-70%

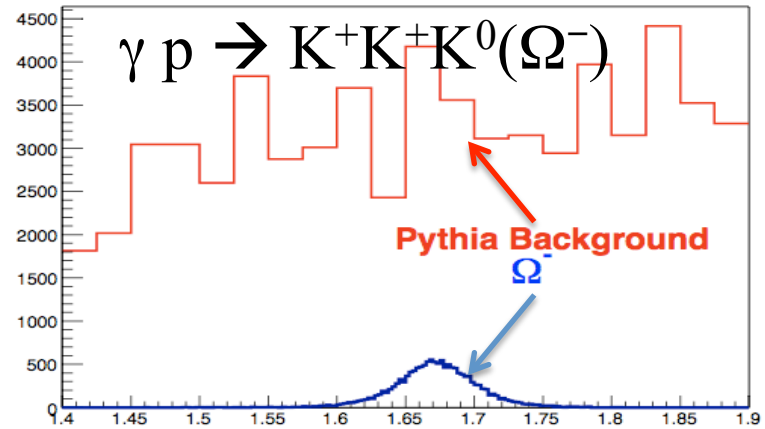
FT: not CLAS12 baseline equipment.
Under construction (INFN et al.)
Vertex detector: 0.5mm

Simulation and Background Estimation:Ω

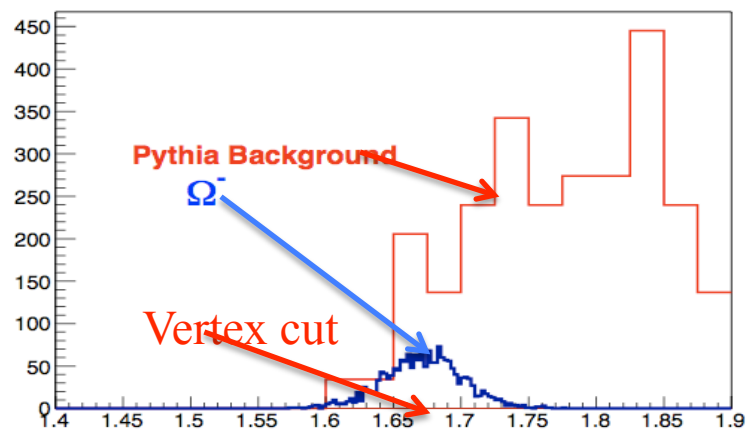
- Main source:
  Hadronic background
- Pythia Simulation:
  $\gamma\, p \rightarrow p$+anything
- S/B ratio 1:10

Λ cut and vertex cut

- $\gamma\, p \rightarrow K^+K^+K^0K^-(\Lambda)$
- Data almost background free if vertex cut is included
- Vertex resolution:0.5mm
- Detached vertex cut: 2mm
  (5-10% loss of data)



$MM(K^+K^+\pi^+\pi^-)$ (GeV)



$M(K^-\Lambda)$ (GeV)

Expected W and X Rate at CLAS12

Preliminary

	Detected particles	Measured Decays	Overall Efficiency	Rate/hr	Total Detected
Ω^-	$K^+K^+K^0$		~4.6%	~4.2	~10k
Ω^-	$K^+K^+K^0K^-$	Ω^-	~0.6%	~0.5	~1k
Ξ^-	$K^+K^+\pi^-$	Ξ^-	~10.0%	~600	~0.2M
$\Xi^-(1820)$	$K^+K^+K^-p$	$\Xi^-(1820)$ Λ	~1.0%	~7	~20K

Vertex Efficiency/Branching Ratio included

Summary

- Many results for S=1 hyperons have been published by CLAS
  - KY contribution to N* being determined
  - Polarization observables yield many interesting, and sometimes unexpected results
- CLAS12 could be a factory for the underexplored Ω/Ξ baryons
  - Ω^- : Cross section can be measured

    production mechanism can be investigated
  - Excited cascade resonances:

    Spin-Parity can be determined
- Ξ(1320) polarization: Insight to the production mechanisms
- Λ/Ξ polarization measurement in target fragmentation region possible at CLAS12
- More exciting hyperon results to come from CLAS6/CLAS12