Production of the Strangest Baryons on the Proton with CLAS12

(PR12-12-008)

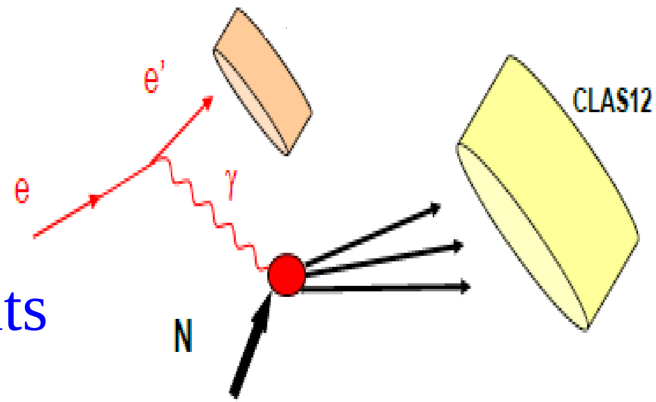
Michael Dugger, Arizona State University
Dan Watts, Edinburgh University
John Goetz, University of California at Los Angeles
Lei Guo, Florida International University
Eugene Pasyuk, Jefferson Lab
Igor Strakovsky, George Washington University
Veronique Ziegler, Jefferson Lab

the Very Strange Collaboration and the CLAS Collaboration

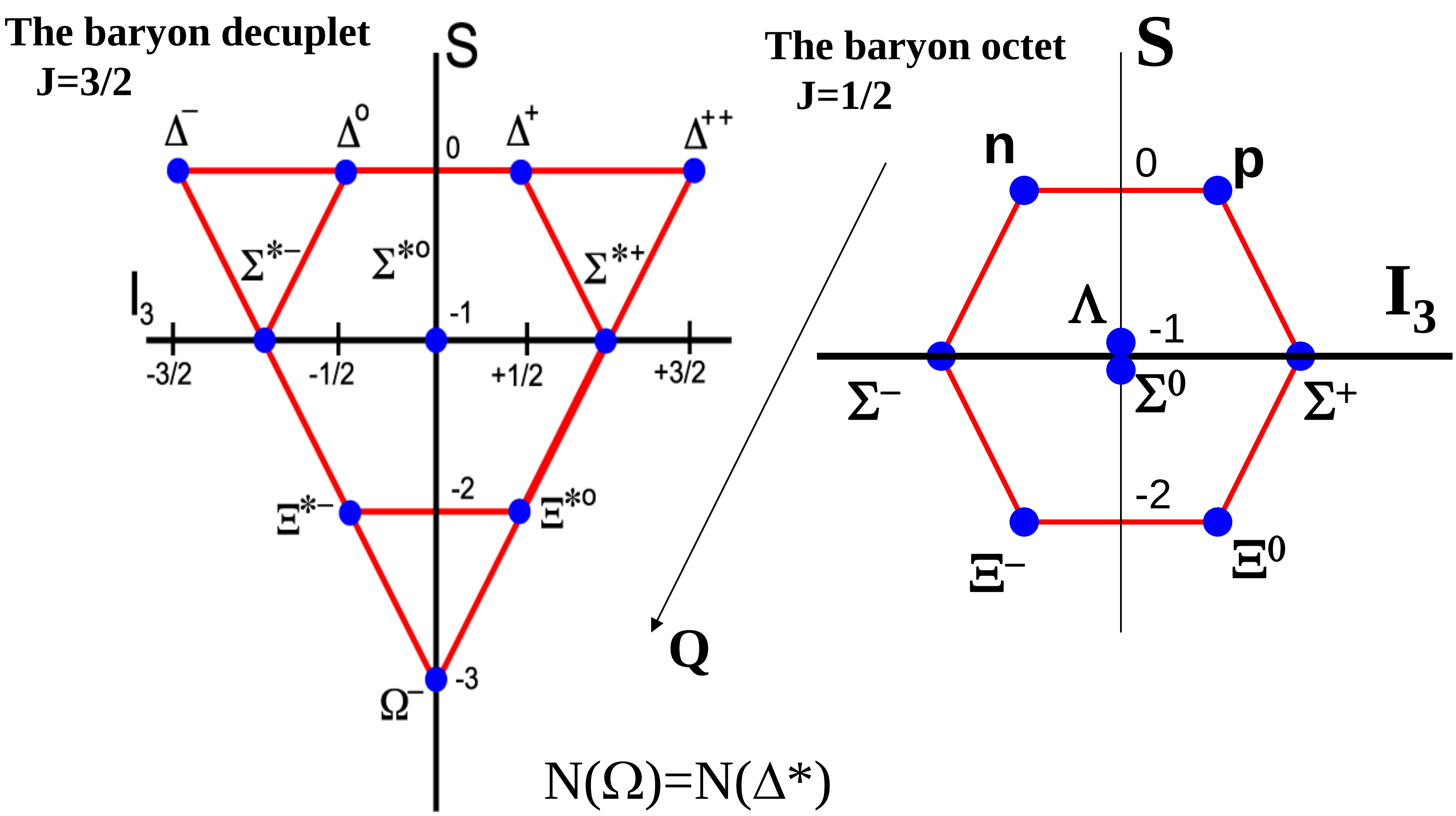
Production of the Strangest Baryons on the Proton with CLAS12

- Motivation
  - Ω^- Cross section measurement of $\gamma p \rightarrow \Omega^- K^+ K^+ K^0$ and study of production mechanism ($\Delta S=-3$)
  - Cascade physics
    - Excited cascade resonances (Spin-parity measurements, searches for missing states)
    - Polarization measurement of Ξ^-
- Existing Data (CLAS)
- Simulation
  - Rate and background estimation
- Experimental setup and projected results

Forward tagger



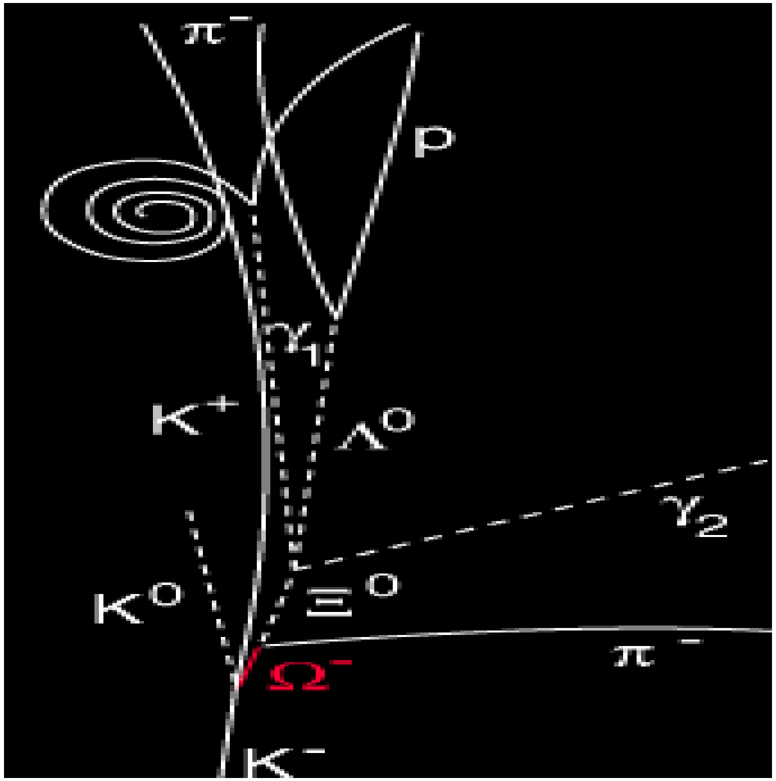
Motivation:
The baryon Ground States in the Quark Model



N(Ω)=N(Δ*)

N(Ξ)=N(N*)+N(Δ*)

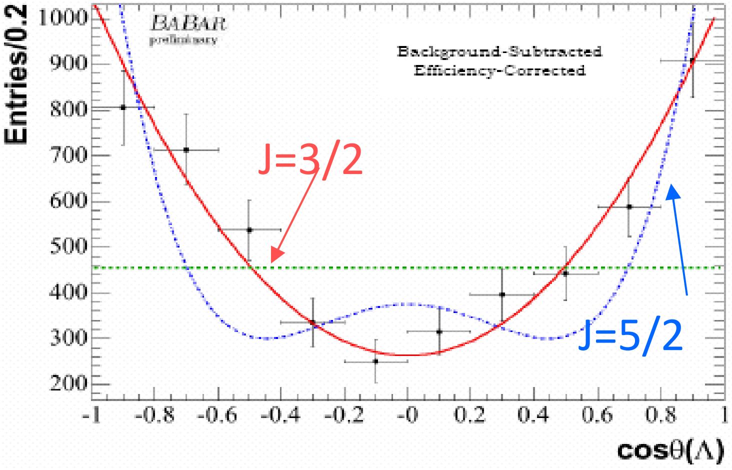
Motivation:
History of the Ω^- (sss) Baryon



Barnes et al, PRL 12:204, 1964

$K^- p$□$K^0 K^+\Omega^-$

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



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

Aubert et al, PRL.97:112001, 2006

Motivation:

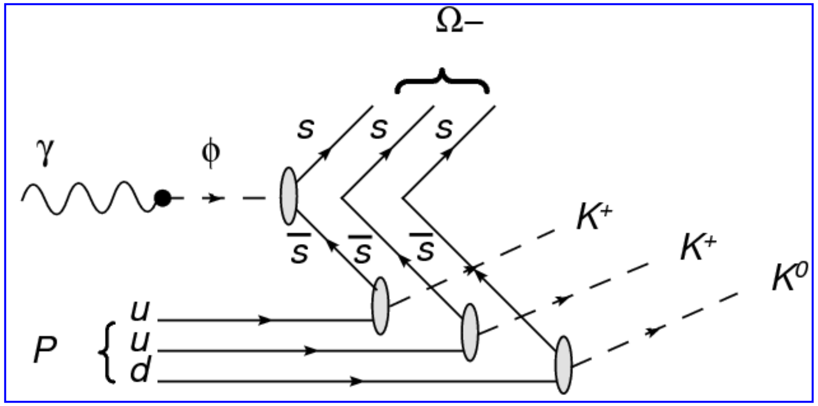
Excited (PDG***) Ω/Ξ baryons (half a century later)

	$(J)^P$	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

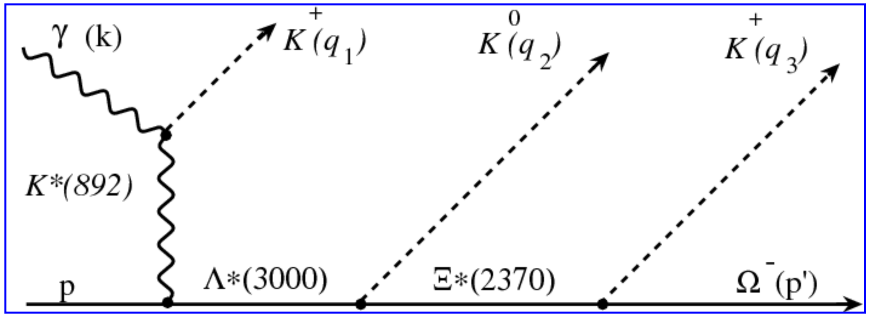
- Very few Ω/Ξ baryons have been identified in the last 50 years.
- Even fewer have their quantum numbers determined
- Mass splitting measurement for Ξ needs corroboration
- Kaon beam was the primary source for these states discoveries
- Photon beam could be a powerful alternative

Motivation:
Ω^- (sss) Cross section and production mechanism

A. Afanasev (VMD):



V. Shklyar (Effective Lagragian)

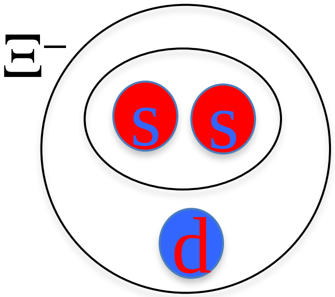


- Production mechanism for Ω^- in photoproduction unknown but extremely interesting: None of the constituent quark (s) is from the target ($\Delta S=-3$)
- Cascading decay from intermediate Y*?
- Various models (by co-authors) predict σ~0.3-2nb at Eγ~7GeV SLAC upper limit: 17nb@20GeV Abe et al, PRD32, 2869 (1985)

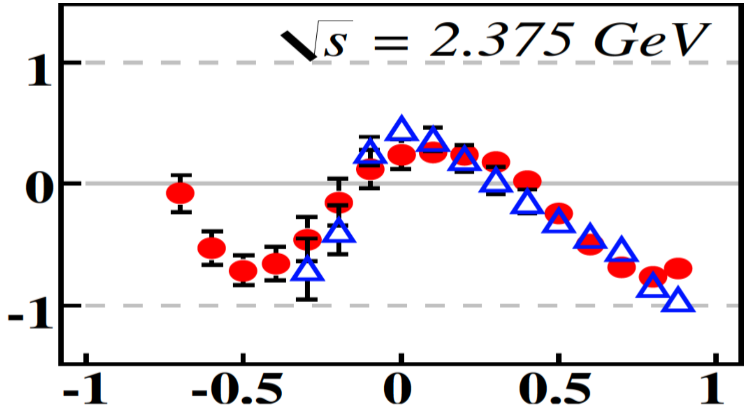
Results from W. Roberts are comparable

Motivation: Hyperon polarization

- 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?

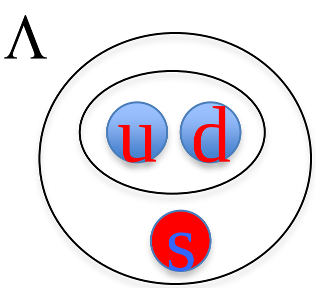


- Purpose of studying Ξ polarization
  - Probe production mechanism (Hadronic/partonic)
  - Understand the origin of hyperon polarization



Induced Λ polarization

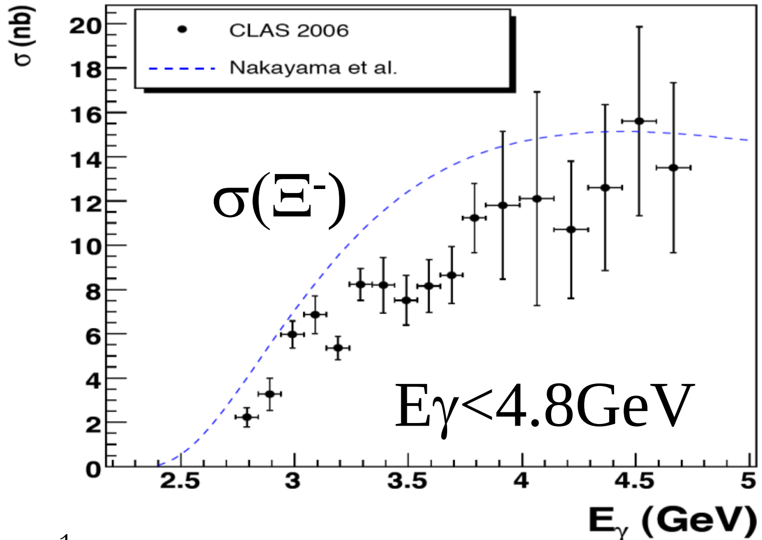
(CLAS Collaboration PRC81, 025201(2010))

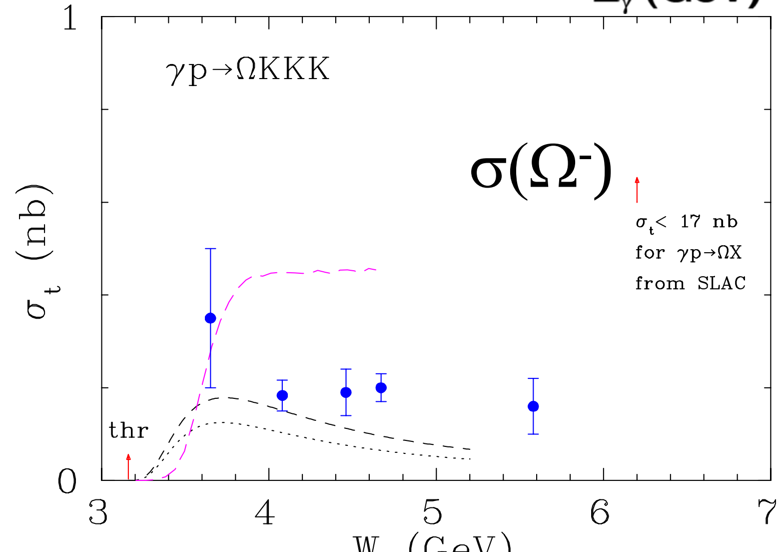


Cross sections: Rate Estimation

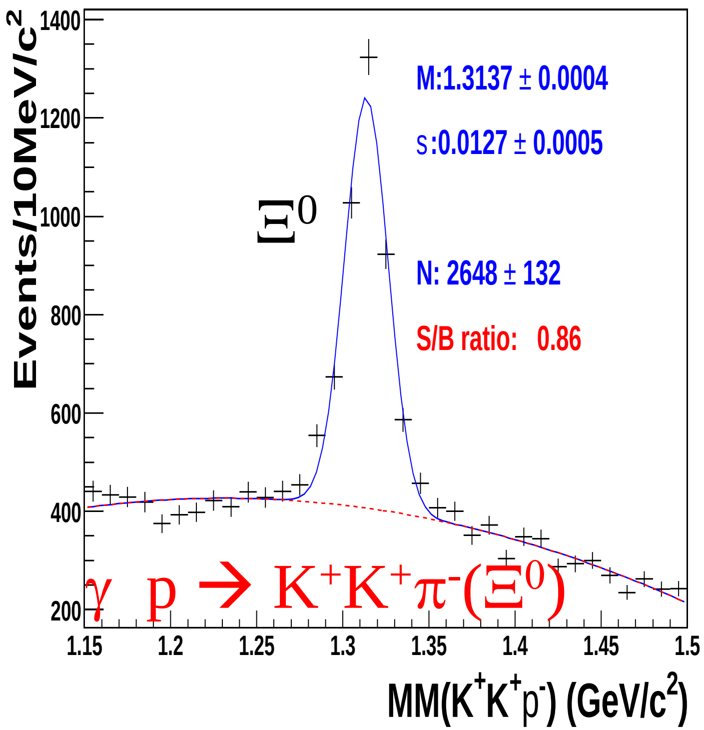
- Assuming $\sigma(\Omega^{-})\sim 0.3$nb (Afanasev, Roberts, Shklyar)
- $\sigma(\Xi^{-})\sim 15$nb (Oh, Nakayama, et al.)
  - SLAC inclusive: 117nb@20GeV
- $\sigma(\Xi^{-}(1820/1690))$: 1-5nb (Oh et al)
- Luminosity: 10^{35}cm^{-2}s^{-1}
- FT acceptance: 2.5~4.5^{o} (θ)
  0.5~5.0GeV ($E_{e'}$)
- Ω^{-} rate: 90/hr
- Ξ- rate: 3.6k/hr
- $\Xi^{-}(1690)/\Xi^{-}(1820)$: 0.2-0.9k/hr

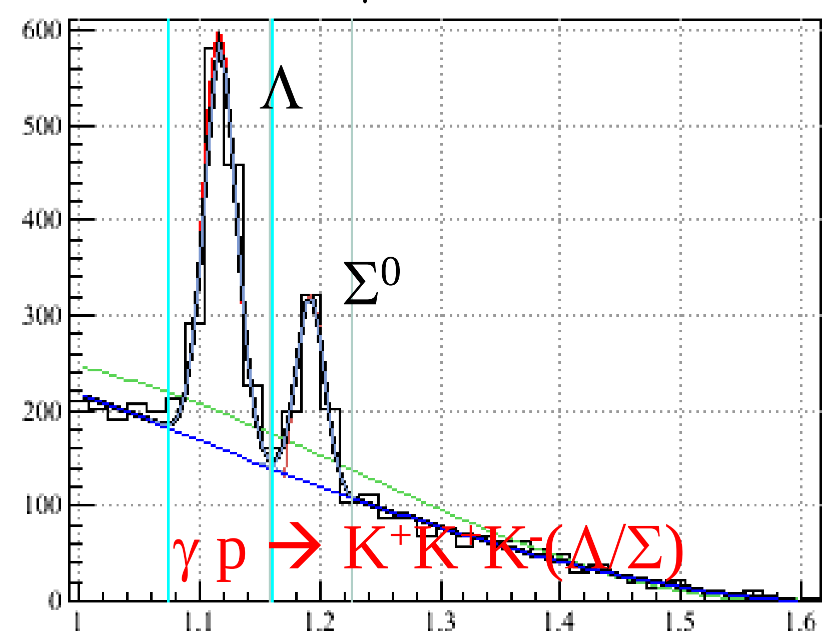
CLAS12 acceptance not yet folded in





Existing CLAS data $\Xi^{*-} \rightarrow \pi^- \Xi^0$, Λ/Σ K
Search for excited cascade resonances





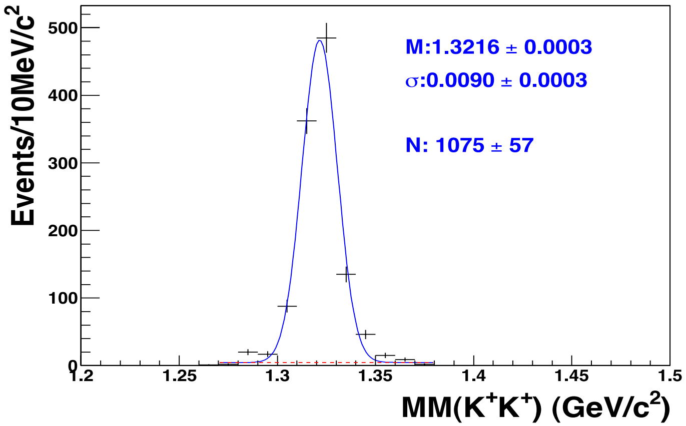
$\Xi^0/\Lambda/\Sigma$ decay chain not detected (=> can not determine J^P)

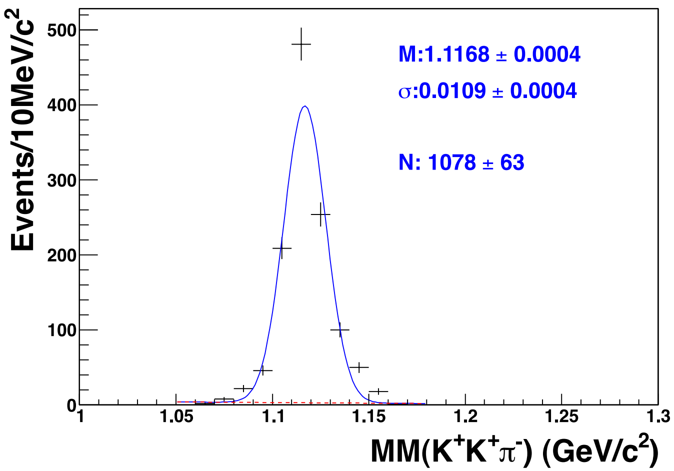
Limited by beam energy, excited states other than Ξ(1530) unlikely in CLAS

Expected total number of Ω^-: 1 @ CLAS/g12 data

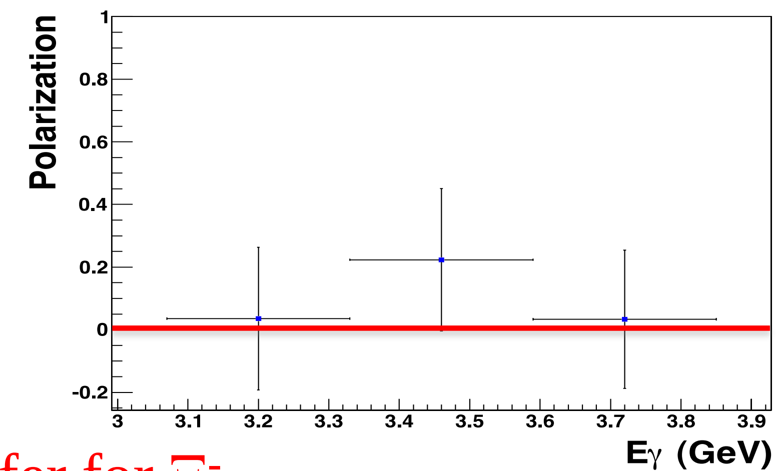
We NEED CLAS12: predicted cross sections at higher E_γ, better acceptance …!

Existing CLAS results:
Ξ^- induced polarization in photoproduction



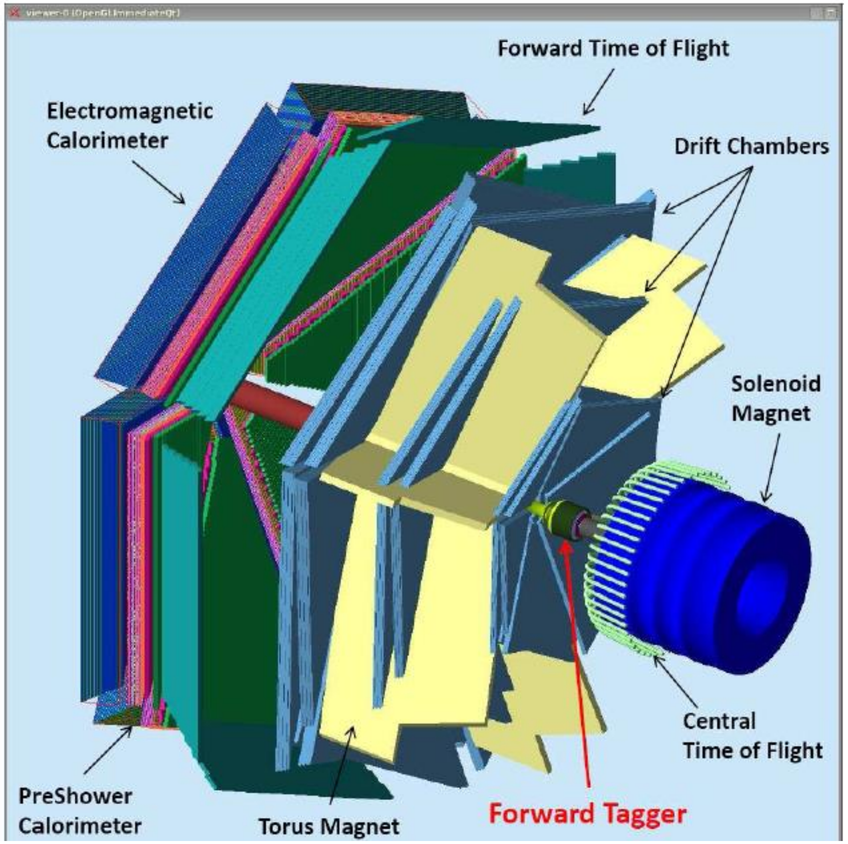


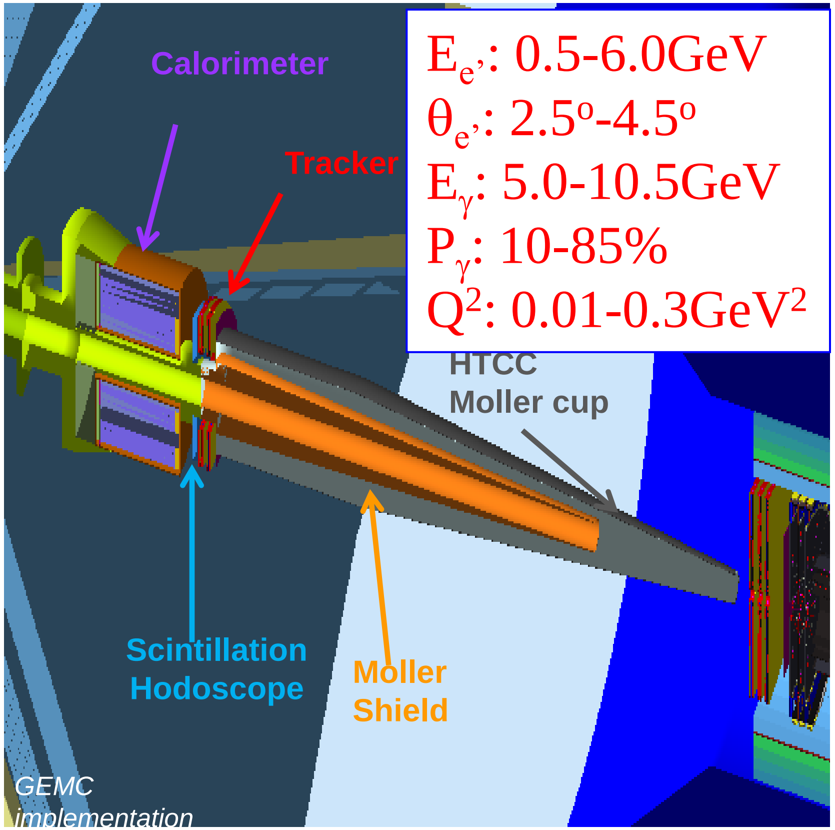
- Data virtually background free
  (double kinematic constraints)
- Without beam/target polarization,
  Ξ^- should not be polarized,
  If our naïve di-quark picture is correct,
- Statistics limited to study P(cosθ*)



CLAS12 (with FT): polarization transfer for Ξ^-
P_γ(10-85%), known on a event by event basis

Experimental set up:
CLAS12 Forward tagger(FT)





FT: not CLAS12 baseline equipment.
Under construction

Benchmark reactions and Trigger

- Ω^- measurement

  $\gamma\, p \rightarrow K^+K^+K^0K^-(\Lambda)$

  $\gamma\, p \rightarrow K^+K^+K^0(\Omega^-)$

  $\gamma\, p \rightarrow K^+K^+K^0K^-p(\pi)$

- Ξ^- polarization measurement

  $\gamma\, p \rightarrow K^+K^+\Xi^-,\ \Xi^- \rightarrow \Lambda\pi^-$

- Excited Cascade resonances

  $\gamma\, p \rightarrow K^+K^+K^-(\Lambda/\Sigma)$

  $\gamma\, p \rightarrow K^+K^+\pi^-(\Xi^0)$

Trigger setup

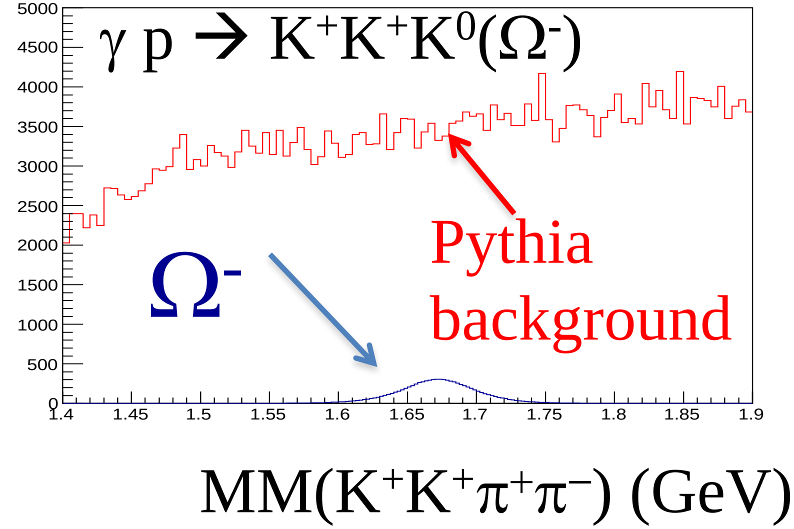
- All reactions of interest need multiple charged hadrons detected
- Minimum requirement:
  - 2-prong+FT
  - Similar to the E12-11-005 (CLAS12 meson spectroscopy) requirement
  - Expected trigger rate <10KHz

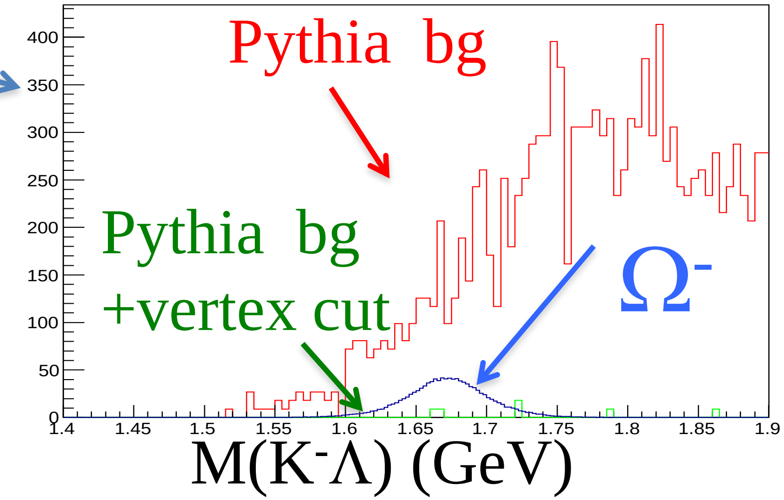
Simulation and Background Estimation (Ω^-)

- Main source:
  Hadronic background
- Pythia Simulation:
  γ p → p+anything
- S/B ratio 1:10

↓ Λ cut and vertex cut

- γ p → $K^+K^+K^0K^-(\Lambda)$
- Data almost background free if vertex cut is included
- Vertex resolution: 1.0mm
- Detached vertex cut: 5mm
  (5-10% loss of data)





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^P
- Double Moment Analysis (DMA)

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

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

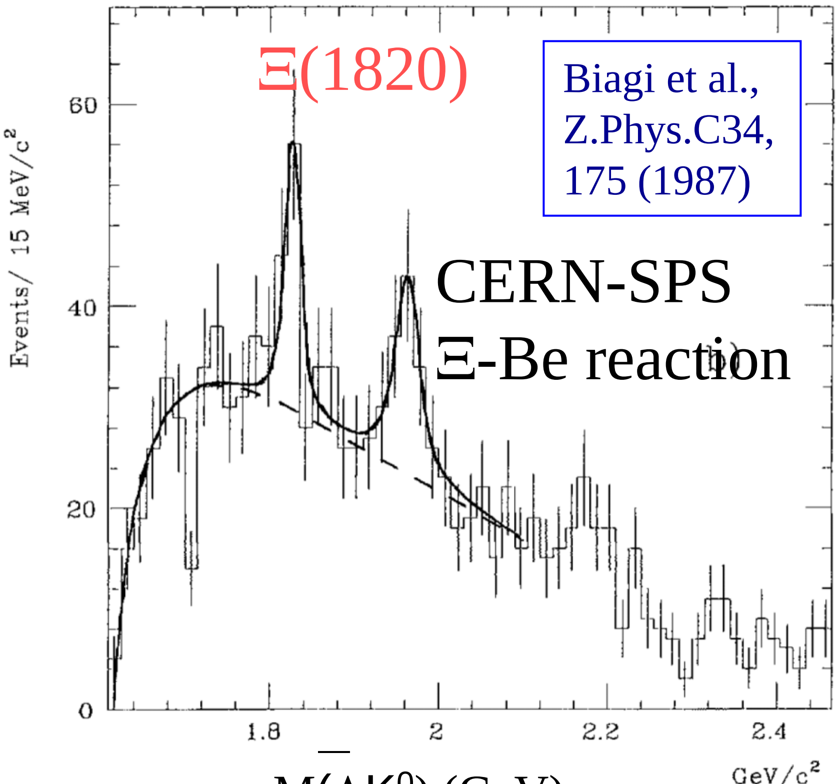
  DMA:

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

Linear dependence gives simple, multiple tests for J, P

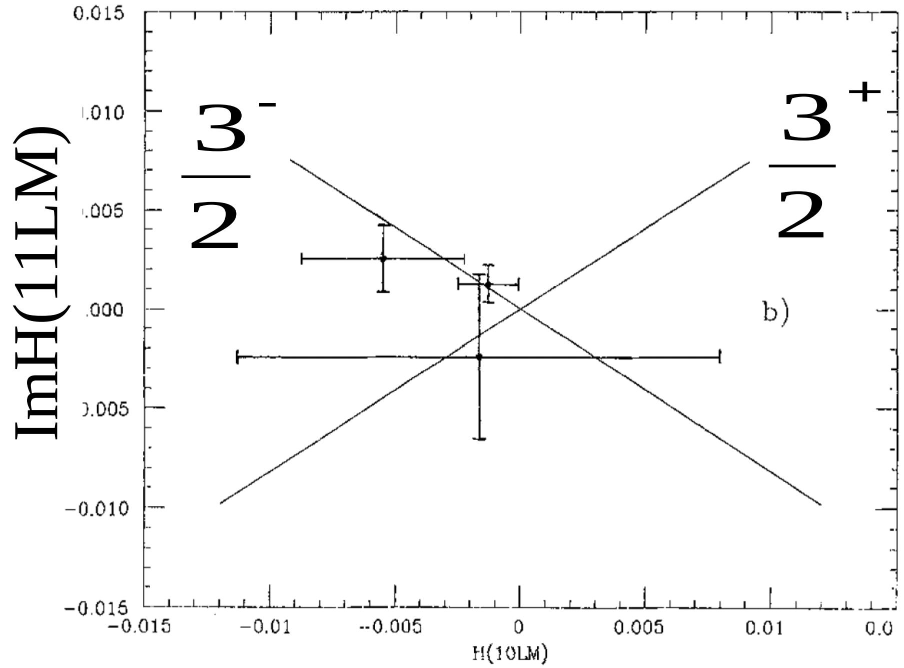
For any odd $L \le 2J$ and $M \le L$

Example: Parity measurement of Ξ(1820)



$M(\overline{\Lambda K^0})$ (GeV)

Needs corroboration



ImH(10LM)

Ξ(1820) $\frac{3}{2}^-$ counts: ~50

Need to detect whole decay chain

CLAS12 estimate: ~12k Ξ(1820) with complete decay chain At CLAS12 (80 beam days)

Beam time and Expected Particle Rate

	Detected particles	Measured Decays	Overall Efficiency	Rate/hr	Total Detected
Ω^-	$K^+K^+K^0$		~3.9%	~3.6	~7k
Ω^-	$K^+K^+K^0K^-$	Ω^-	~0.5%	~0.5	~1k
Ξ^-	$K^+K^+\pi^-$	Ξ^-	~9.3%	~440	~0.9M
$\Xi^-(1530)$	$K^+K^+\pi^-$	$\Xi^-(1530)$	~7.4%	~140	~270K
$\Xi^-(1820)$	$K^+K^+K^-p$	$\Xi^-(1820)\Lambda$	~0.63%	~6	~12K

Assuming half field
FastMC used
Vertex Efficiency/Branching Ratio included

Approved 80days for E12-11-005
is sufficient for us to achieve all goals.

Expected results for
Ξ⁻ polarization and Ξ⁻(1820) spin-parity

- Ξ⁻ polarization measurement: (should be E_γ dependent)

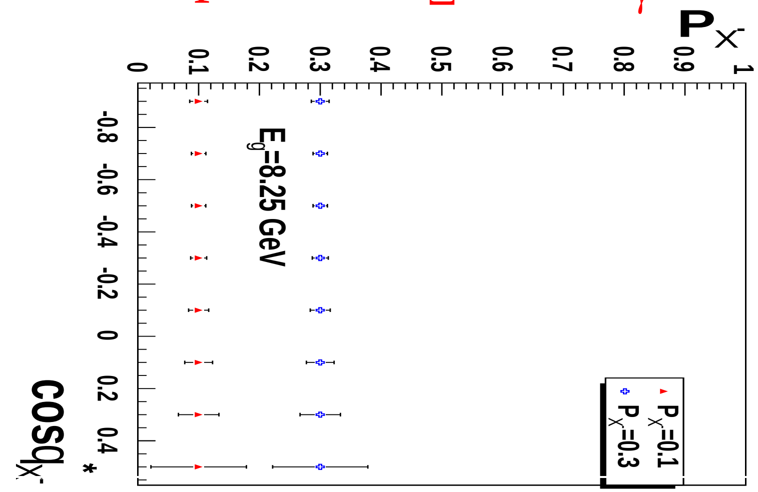
$$gp \rightarrow K^+K^+X^- \rightarrow K^+K^+p^- (L)$$

- Ξ⁻(1820) double moments

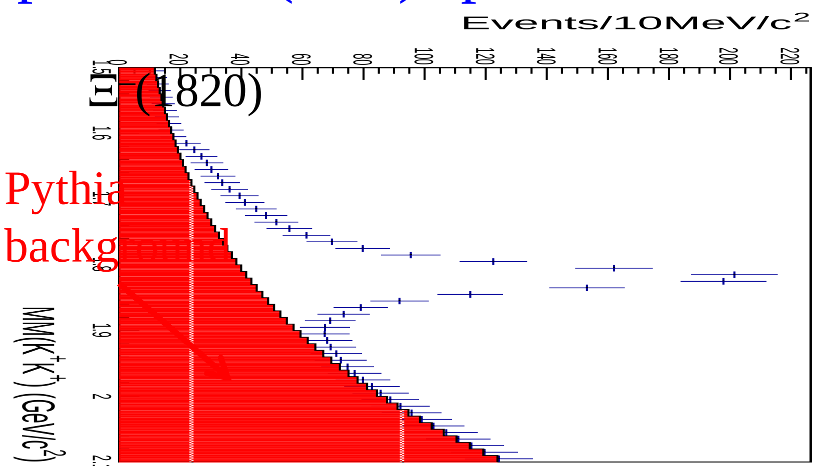
$$gp \rightarrow K^+K^+X^- (1820)$$

$$X^- (1820) \rightarrow K^- (L \rightarrow p^- p)$$

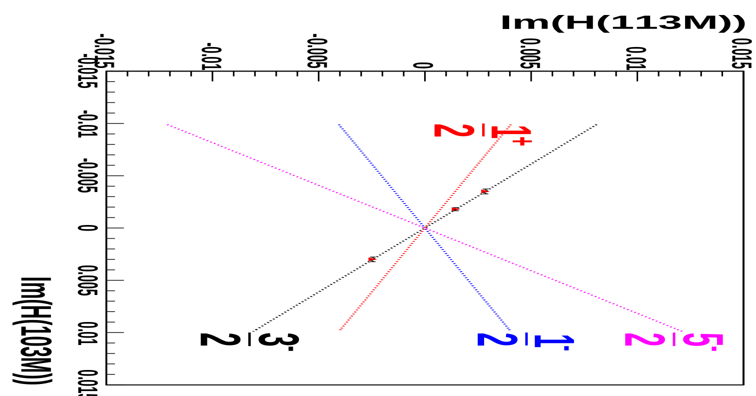
Expected P_{Ξ^-} VS E_γ



Expected M(ΛK⁻) spectrum



Expected DoubleMoments (L=3)



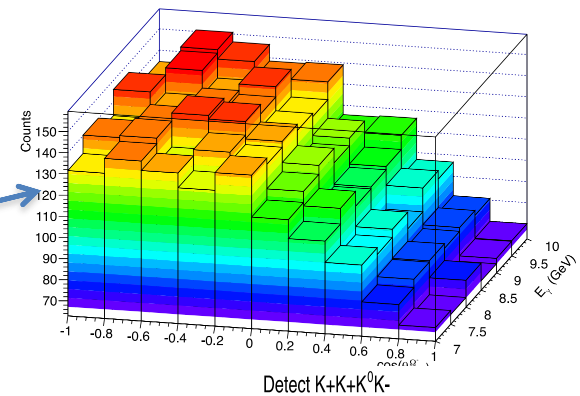
(statistical uncertainty only)

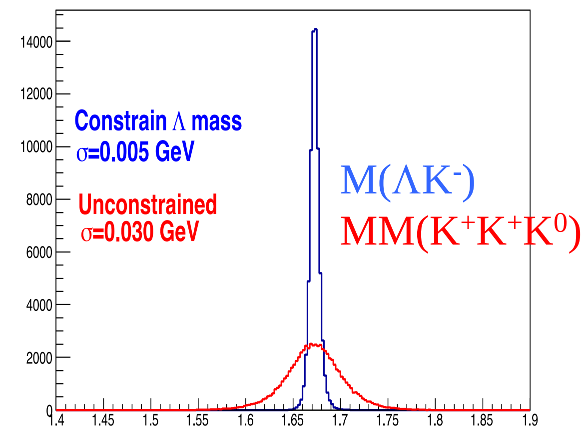
Expected results: Ω^- mass spectrum and Cross sections

- Ω^- Measurement:
  - When four kaons detected, spectra is expected to be background FREE

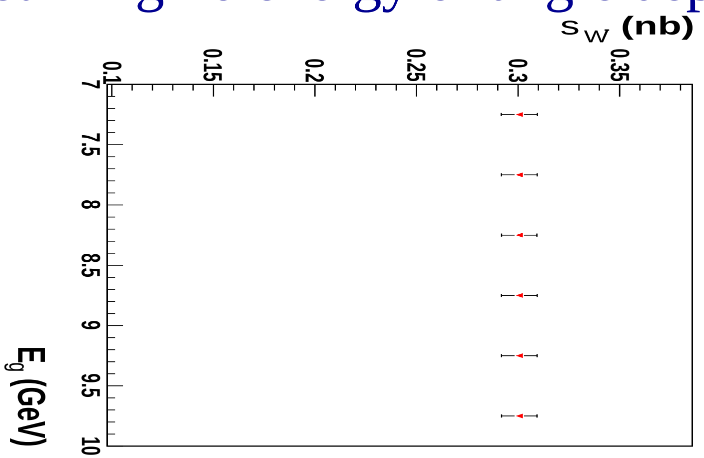
$$gp \rightarrow K^+K^+K^0(W)$$

$$gp \rightarrow K^+K^+K^0K^-(L)$$





Expected Cross section Measurements
(Assuming no energy or angle dependence)



Constraining the Λ mass improves the resolution. Further improvement expected with kinematic fitting

Expected results:
Ξ and Ξ(1530) cross section measurements

- Ξ⁻ Measurement:

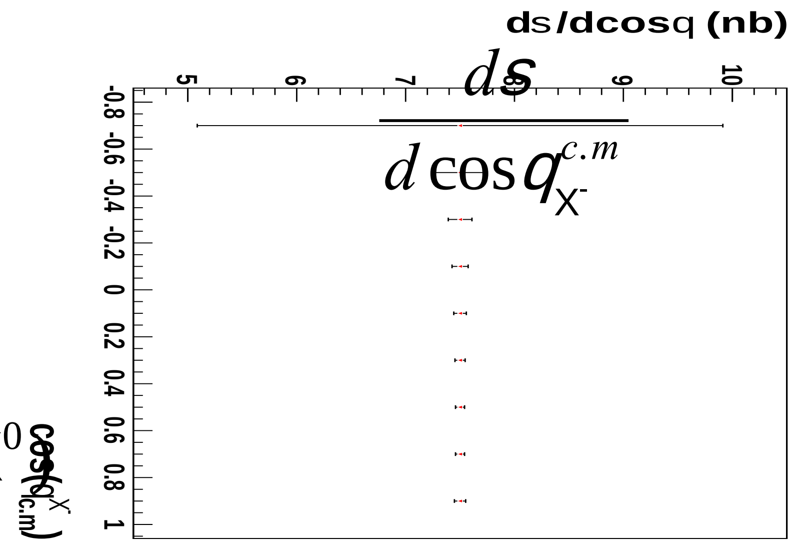
$$gp \rightarrow K^{+}K^{+}X^{-} \rightarrow K^{+}K^{+}p^{-}\ (L)$$

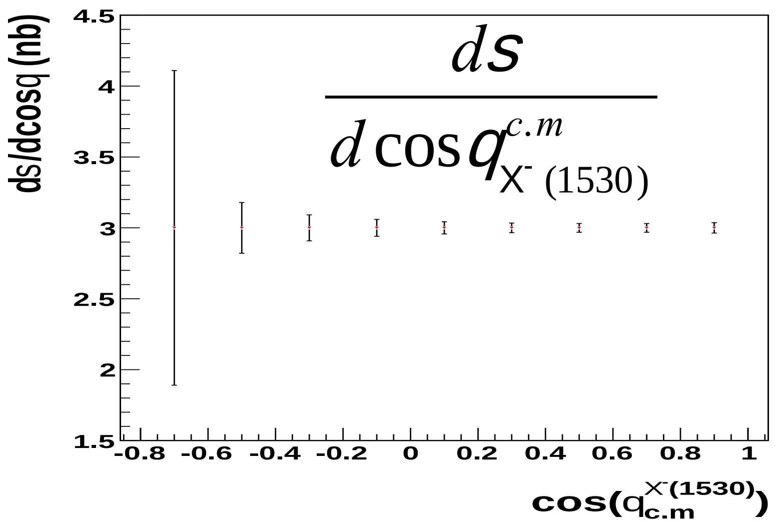
$$gp \rightarrow K^{+}K^{+}(X^{-})$$

- Ξ⁻(1530) Measurement

$$gp \rightarrow K^{+}K^{+}X^{-}(1530) \rightarrow K^{+}K^{+}p^{-}\ (X^{0})$$

$$gp \rightarrow K^{+}K^{+}(X^{-}(1530))$$





- Simulation assumed no angular dependence:
- Measurement in backward angle (c.m) should have smaller uncertainty then shown due to expected larger cross section

Summary

- Ω/Ξ baryons are underexplored
- CLAS12 is well suited to study Ω/Ξ physics using the forward tagger
- Ω^- : Cross section can be measured (almost background free)

  production mechanism can be investigated
- Excited cascade resonances:

  Spin-Parity can be determined
- $\Xi(1320)$ polarization: Insight to the production mechanisms
- Mass splitting for multiple Ξ doublets can be measured
- Experimental set-up compatible with the meson experiment
- Total request beam time: 80 days in parallel with the meson experiment

The Very Strange Collaboration

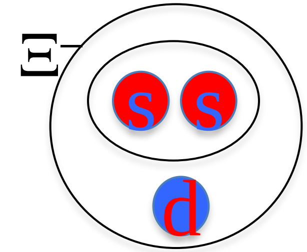
A.Afanasev[1,2], M. Amaryan[3)], Ya.I. Azimov[4)], N. Baltzell[5)], M. Battaglieri[6)], V. Baturin[2)],W. Boeglin[7)], J. Bono[7)], B.Briscoe[8)] V. Burkert[2)], S. Capstick[9)], D. Carman[2)], A. Celentano[6)], V. Crede[9)], R. De Vita[6)], M. Dugger[10,*)], G. Fedotov[11)], G. Gavalian[3)] J. Goetz[12,*)], L. Guo[7, **)], D. Glazier[13)], H. Haberzettl[8)], S. Hasegava[14)], K. Hicks[15)], D. Ireland[16)], P. Khetarpal[7)], F. Klein[17)], A. Kubarovsky[18)], V. Kubarovsky[2)], M. Kunkel[3)], K. Livingston[16)], H. Lu[19)], P. Markowitz[7)], P. Mattione[19)], V. Mokeev[2)], K. Nakayama[20)], B. Nefkens[12)], Y. Oh[21)], M. Osipenko[6)], M. Paolone[22)], E. Pasyuk[2,*)], J. Price[23)], B. Raue[7)], M. Ripani[6)], B. Ritchie[10)], W. Roberts[9)], F. Sabatie[24)], H. Sako[14)], C. Salgado[25)], S. Sato[14)], K. Shirotori[14)], V. Shklyar[26)], S. Stepanyan[2)], I. Strakovsky[8,*)], M. Taiuti[6)], N. Walford[17)], D. Watts[13, *)], D. Weygand[2)], R. Workman[8)], V. Ziegler[2, *)]

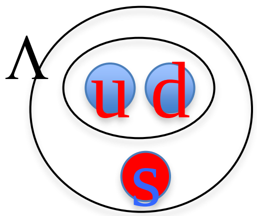
[1)] *Hampton University, USA*
[2)] *Thomas Jefferson National Accelerator Facility, USA*
[3)] *Old Dominion University, USA*
[4)] *Petersburg Nuclear Physics Institute,, Russia*
[5)] *Argonne National Laboratory, USA*
[6)] *INFN Genova, Italy*
[7)] *Florida International University, USA*
[8)] *The George Washington University, USA*
[9)] *Florida State University, USA*
[10)] *Arizona State University, USA*
[11)] *University of South Carolina, USA*
[12)] *University of California at Los Angeles, USA*
[13)] *Edinburgh University, United Kingdom*
[14)] *Japan Atomic Energy Agency, Japan*
[15)] *Ohio University, USA*
[16)] *University of Glasgow, United Kingdom*
[17)] *Catholic University of America, USA*
[18)] *Rensselaer Polytechnic Institute, USA*
[19)] *Carneige Mellon University, USA*
[20)] *University of Georgia, USA*
[21)] *Kyungpook National University, Republic of I*
[22)] *Temple University, USA*
[23)] *California State University, Dominguez Hills,*
[24)] *CEA-Saclay, France*
[25)] *Norfolk State University,, USA*
[26)] *Giessen UniversityGermany*

Backup slides

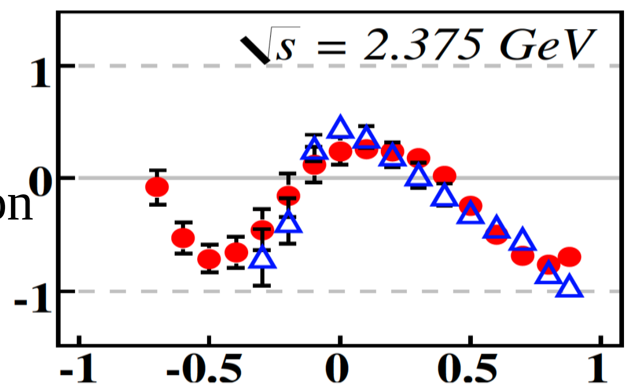
Motivation: Hyperon polarization

- 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 (Hadronic/partonic)
  - Understand the origin of hyperon polarization



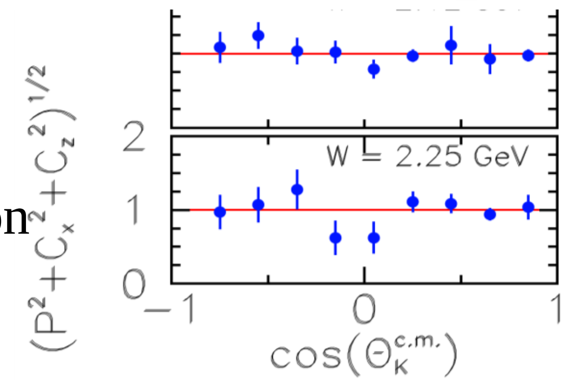


Induced Λ polarization



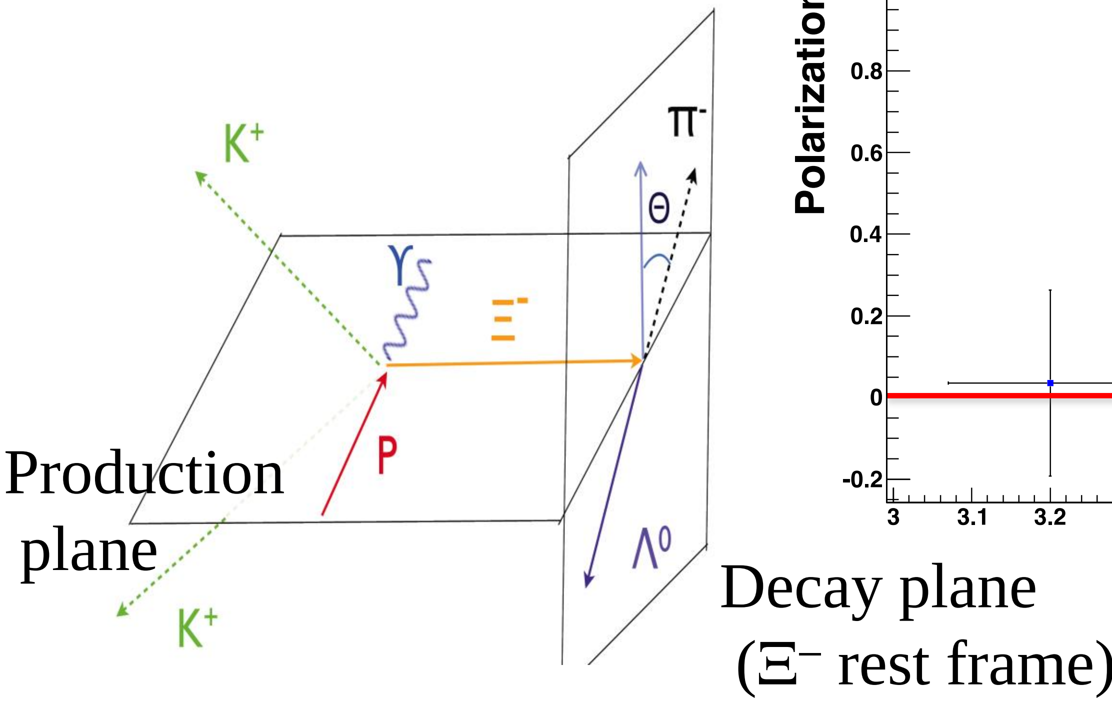
(PRC81, 025201(2010))

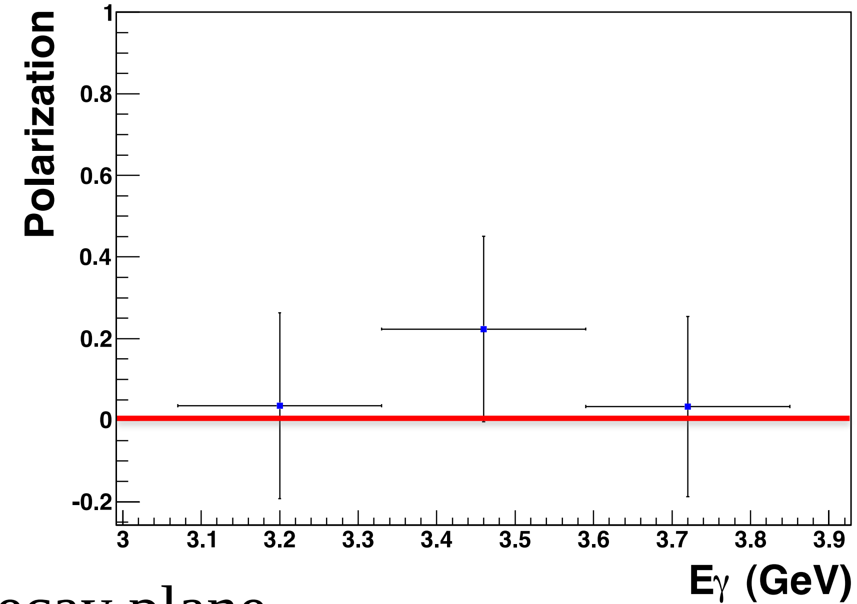
Transferred Λ polarization



(PRC75, 035205(2007))

Existing data(CLAS): Ξ^{-} induced polarization in photoproduction





Existing data: No beam/target polarization

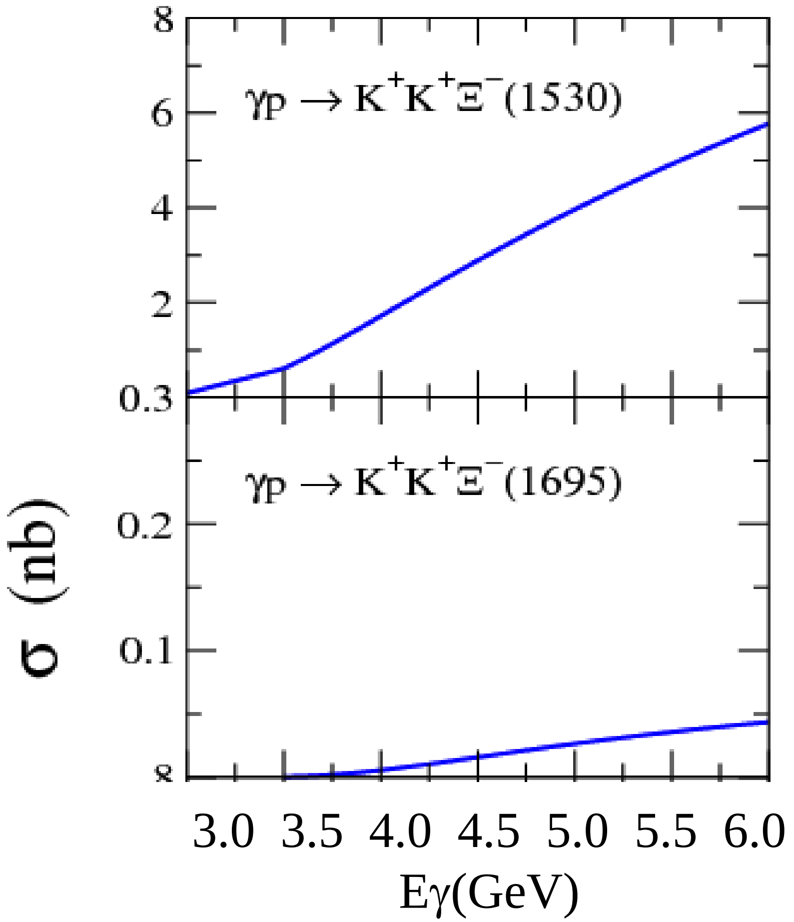
The only direction X can be polarized is out of plane

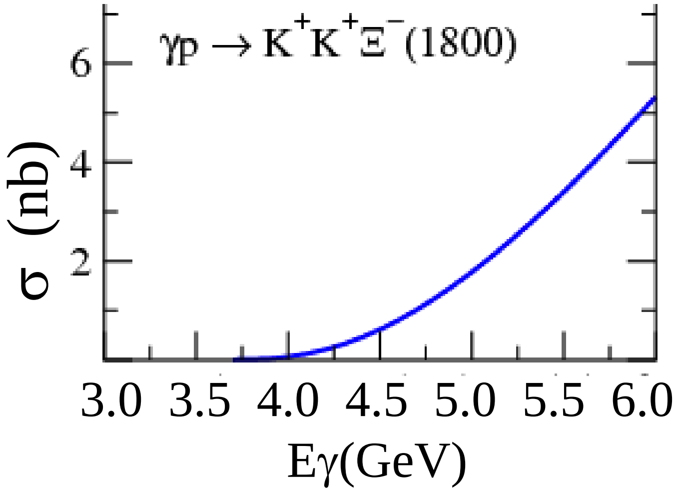
(Parity conservation)

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

P_{γ} known on an event by event basis

Excited cascade production (Prediction)



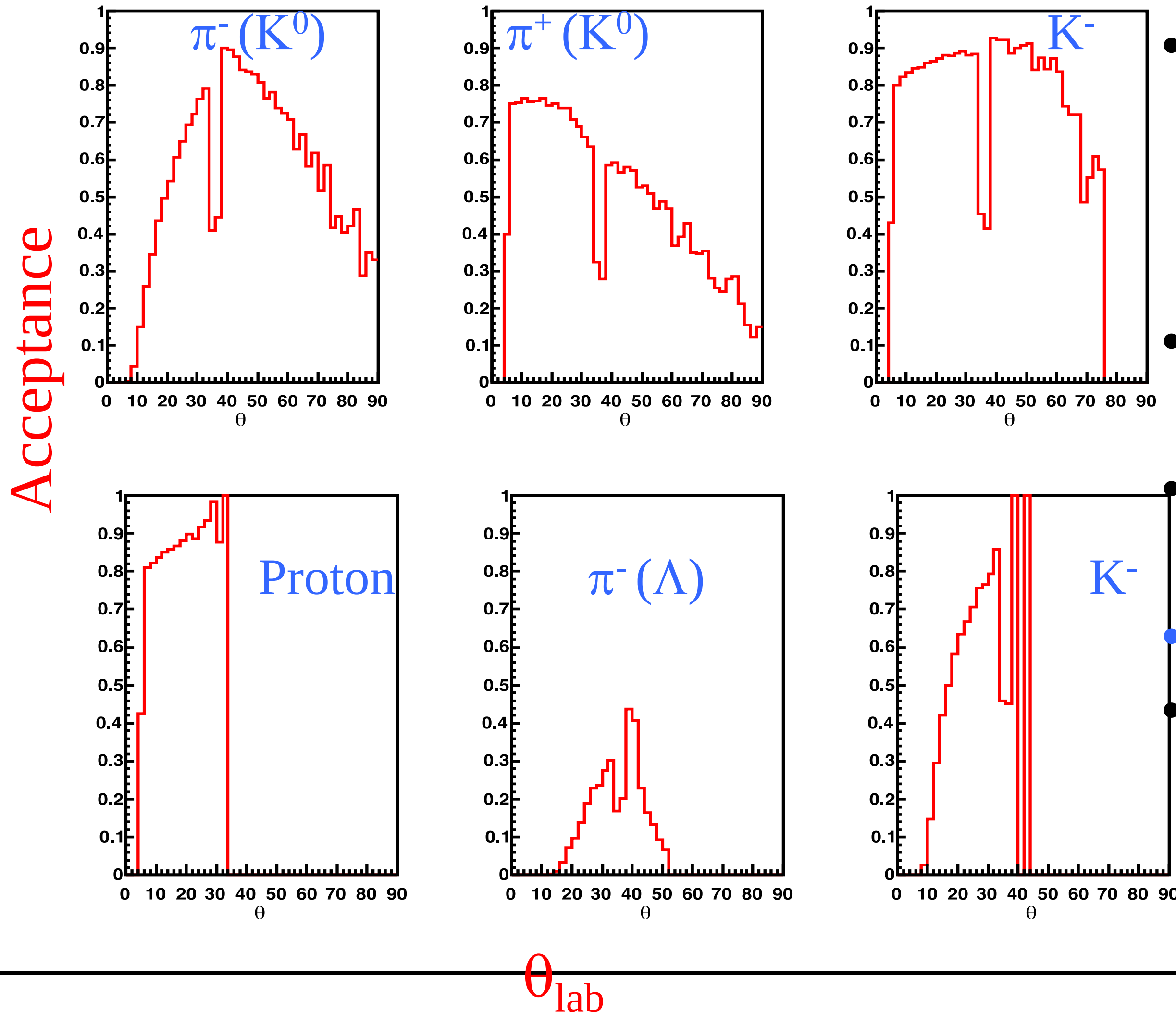


K. Nakayama, Y. Oh, and H. Haberzettl results obtained using parameters obtained from PRC74, 032505(2006)

Predictions for the Ξ(1820) IS consistent with CLAS data:

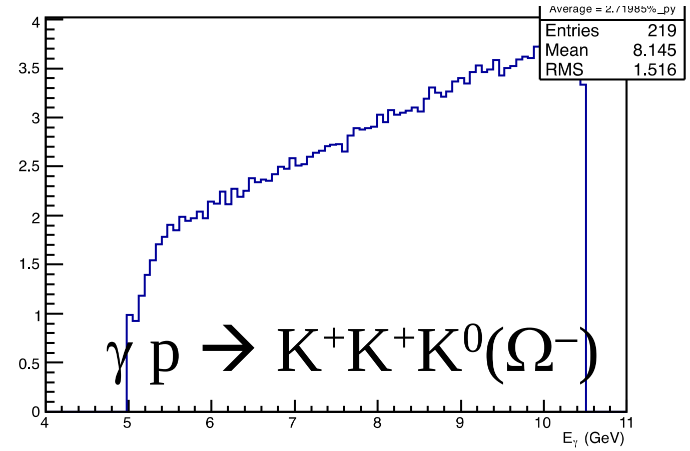
signal would have been insignificant

Simulation and acceptance

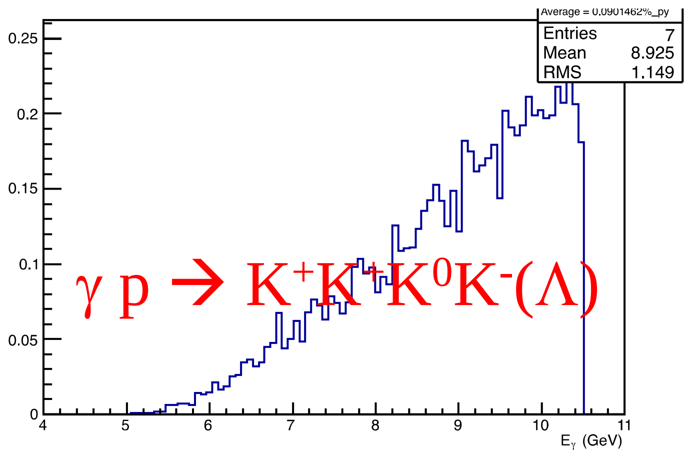


- Reaction simulated
  $\gamma\ p \rightarrow K^+K^+K^0K^-(\Lambda)$
  $K^0 \rightarrow \pi^-\pi^+$
  $\Lambda \rightarrow p\pi^-$
- The π^- (from Λ) has the smallest acceptance
- Its detection is unnecessary
- Half-field is assumed
- Consistent with the meson-experiment requirement

Impact of full field on acceptance



Topology	Half-field average Acceptance	Full-field average acceptance
$K^+K^+K^0(\Omega^-)$	5.03%	2.72%
$K^+K^+K^0K^-(\Lambda)$	0.76%	0.09%



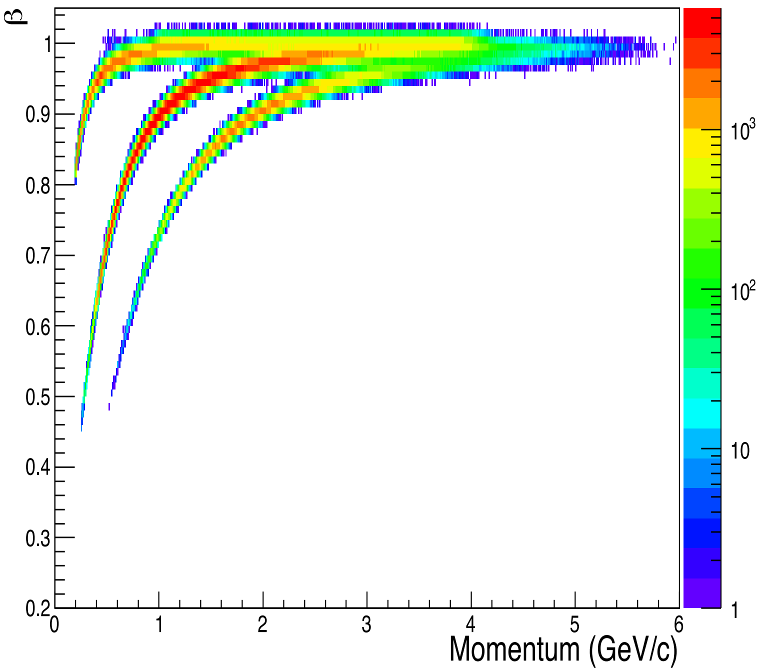
- 4-K channel for Ω^- detection is impacted the most
- Ξ channels are less affected due to higher statistics
- We need half field for the Ω^- measurements

Kinematic coverage/PID

- Most of the multiples kaons in the final state have momenta lower than 2 GeV, where CLAS12 expects excellent K/π separation

Availability of a RICH detector

Would be obviously very beneficial. Without it, we still expect excellent PID

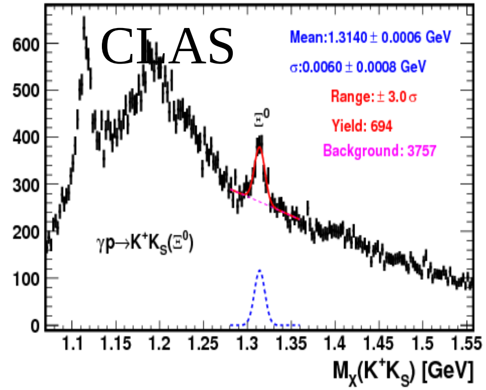


Expected results: mass splitting measurements

- Ξ⁻ Measurement:

$$gp \to K^+K^+X^- \to K^+K^+p^-(L)$$

$$gp \to K^+K^+(X^-)$$



- Ξ⁰ Measurement

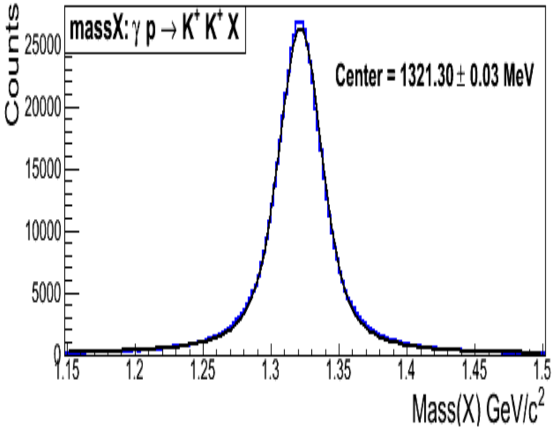
$$gp \to K^+K^+p^-(X^0)$$

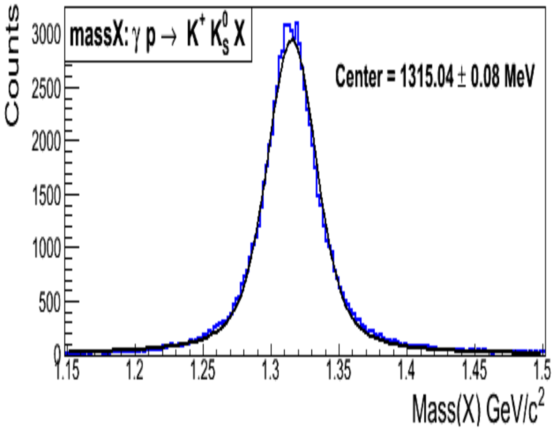
$$gp \to K^+K^0(X^0) \to K^+p^+p^-(X^0)$$

- Measurements feasible in multiple channels to reduce systematic uncertainty

  Calibration can be tuned using other well know states (Λ, Σ, K_s, etc)

  Expected statistical uncertainty:

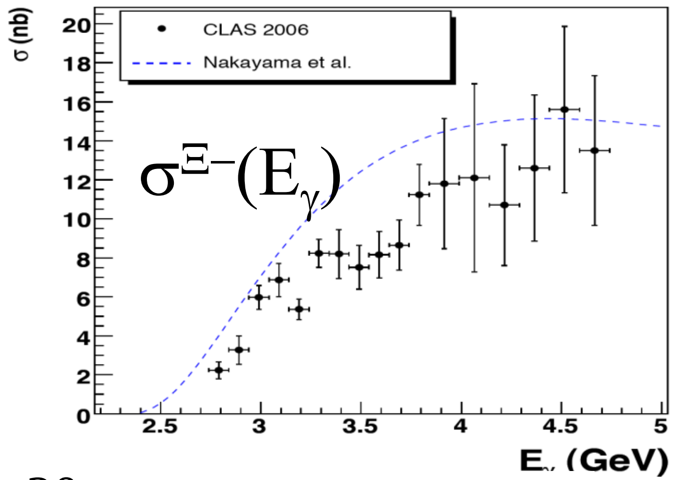


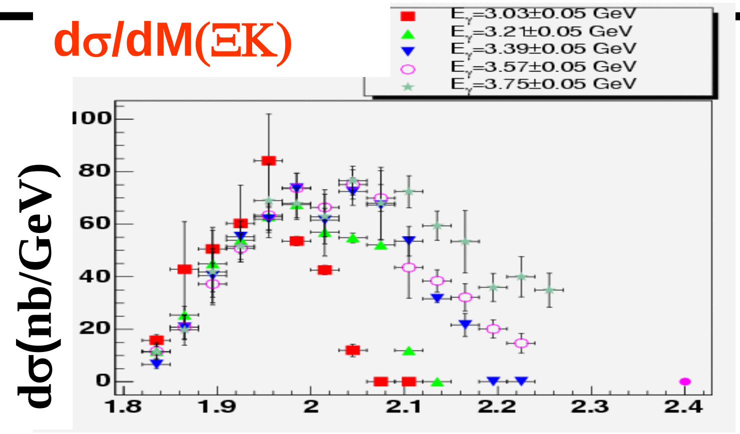


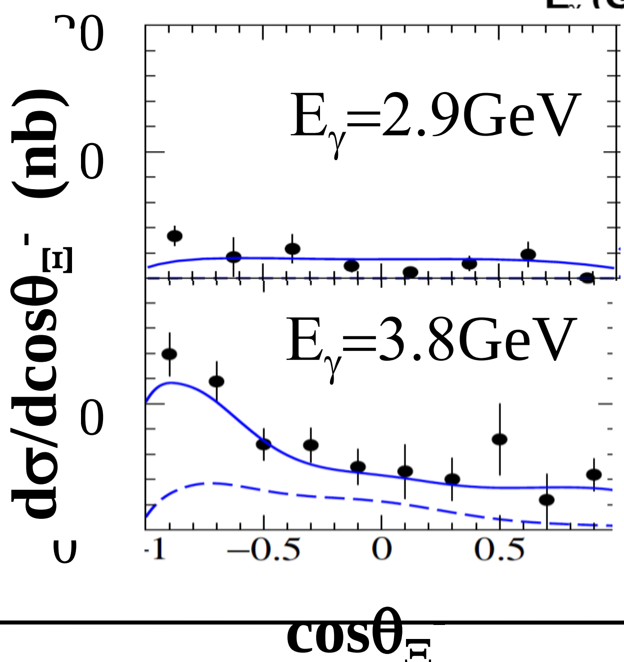
CLAS12/Simulation

$$d^{stat}(M_{X^-} - M_{X^0}) < 0.1 MeV$$

Energy dependence of the Ξ^- cross sections







- Nakayama et al. predicts plateauing behavior at higher beam energies
  PRC 74, 035205 (2006)
  PRC83, 055201(2011)
- Model only included limited number of intermediate hyperons
- The Ξ^- cross section could continue to increase at higher E_γ
- Angular distributions expected to change with E_γ