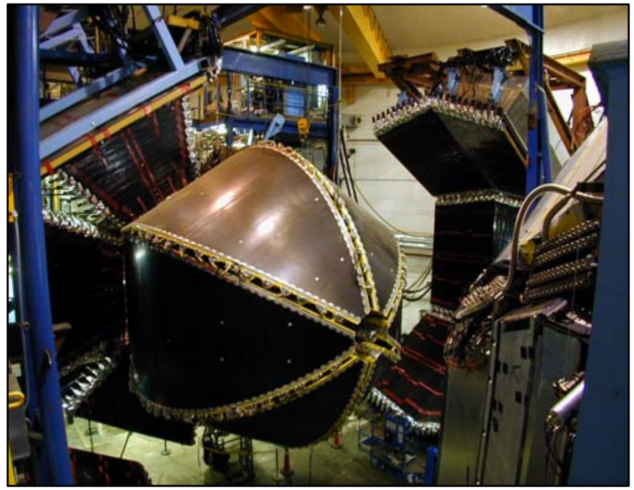


September 17. 2009
Tokai, Japan

Hyperon Photo- and Electro-Production Experiments at CLAS

Reinhard Schumacher

Carnegie Mellon

Jefferson Lab

Overview:

- Motivation for K Y study in N* resonance physics
- $\gamma\, p \rightarrow K^{+}\Lambda$ & $\gamma\, p \rightarrow K^{+}\Sigma^{0}$ Cross Sections: old and new
- Spin Observables
  - P_y – recoil polarization results: older and new
  - O_x, O_z, Σ – preliminary results
  - C_x, C_z – impact of recent CLAS measurements
  - Electroproduction case
- $\Lambda(1405)$ non-standard lineshape ← NEW Result
  - Likely signature of non-qqq structure
- $\Xi^{0,-(*)}$ production
- Future prospects
  - CLAS g13 data set, $\gamma\, n \rightarrow K^{0}\ \Lambda,\Sigma^{0}$ cross sections
  - FROST & HD Ice targets

N* Physics via KY Channels

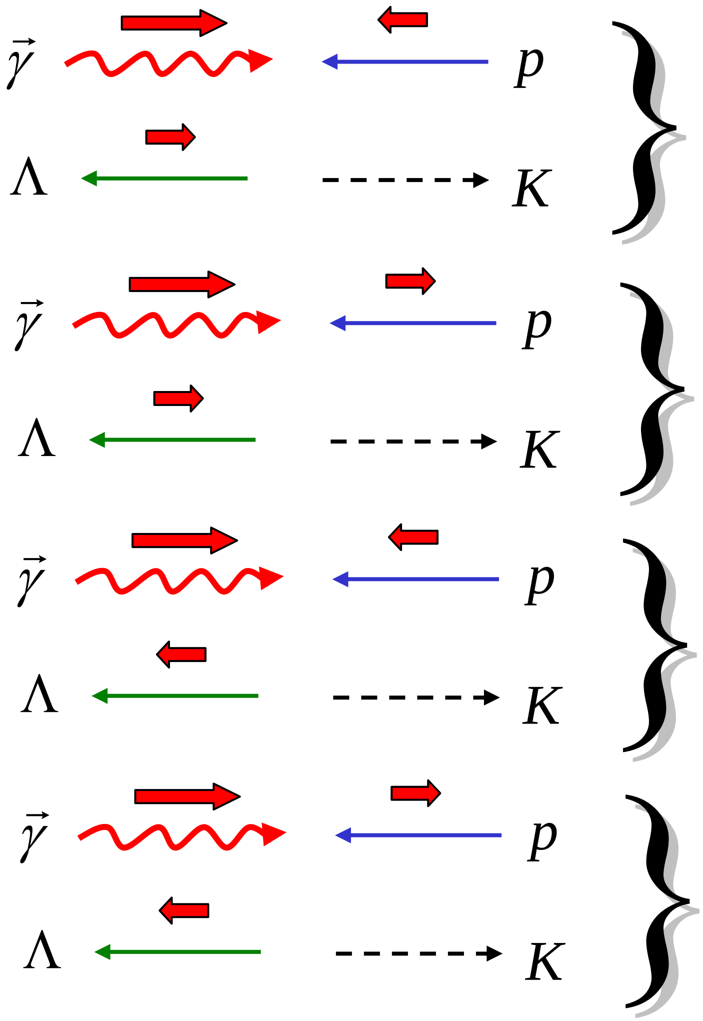
- N*→KY decays are significant two-body decay channels in the mass range of the "missing" resonances (few μb near 1.6 to 2 GeV).
- Hyperons have PV weak decays, "self-analyzing", induced and transferred polarization are measured easily
- Full experimental decomposition of reaction amplitudes → models can divine the N* content of the reactions.

The Observables: 0^- mesons

- Photoproduction described by 4 complex amplitudes
- Bilinear combinations define 16 observables
- 8 measurements* needed to separate amplitudes at any given energy, W
  - differential cross section: $d\sigma/d\Omega$
  - 3 single polarization observables: P, T, Σ
  - 4 double polarization observables…

* W-T. Chiang and F. Tabakin Phys Rev. C 55 2054 (1997)

4 Helicity Amplitudes



N — No overall helicity flip $= |\gamma - (p - \Lambda)|$

S_1 — Single helicity flip

S_2 — Single helicity flip

D — Double helicity flip

16 Pseudoscalar Meson Photoproduction Observables

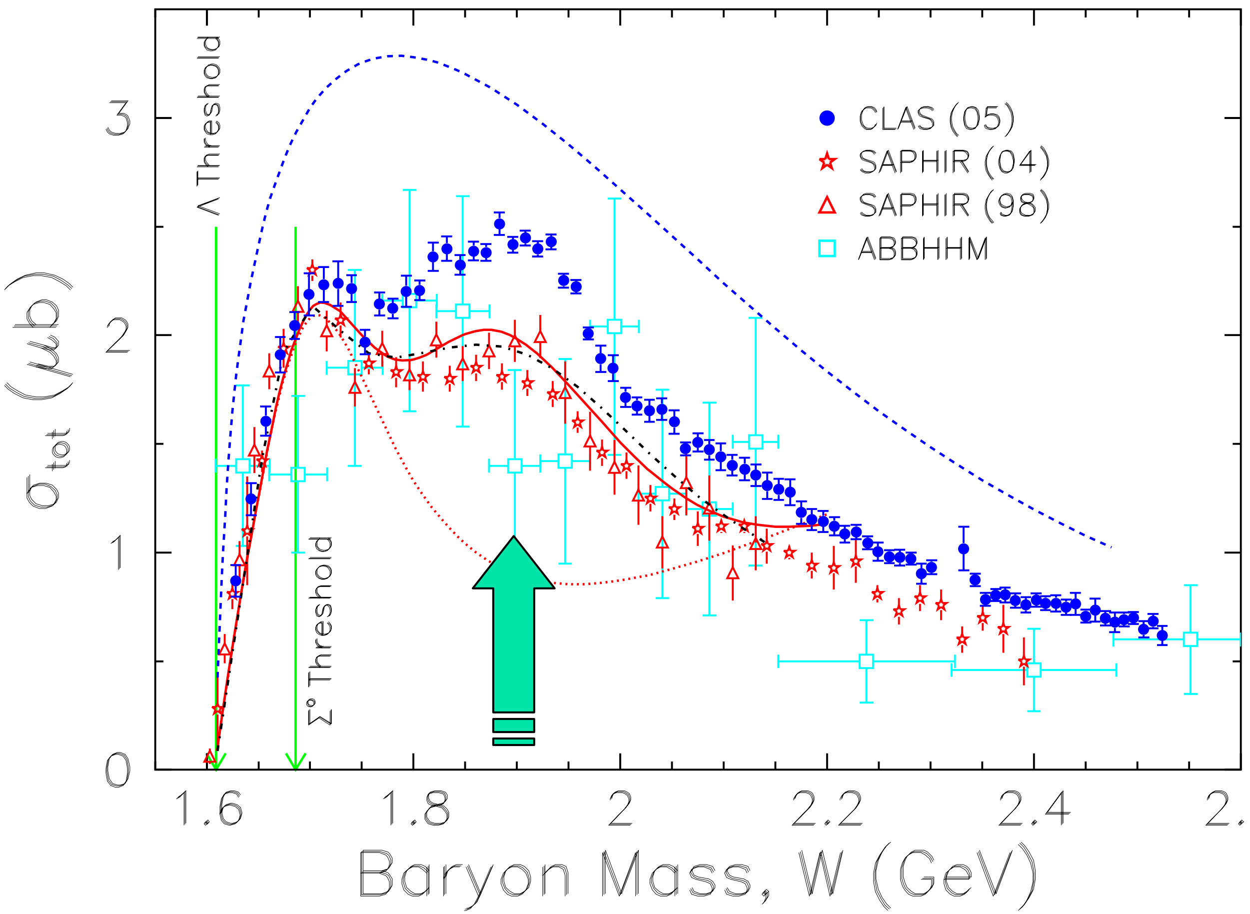
For $\gamma + p \rightarrow K^+ \Lambda$:

Table 1
Observables

	Usual symbol	Helicity representation	Experiment required a)	
Single Polarization	$d\sigma/dt$	$\lvert N\rvert^2+\lvert S_1\rvert^2+\lvert S_2\rvert^2+\lvert D\rvert^2$	$\{-;-;-\}$	R. Bradford *et al.* Phys. Rev. C **73** 035202 (2006)
	$\Sigma\, d\sigma/dt$	$2\mathrm{Re}(S_1^* S_2 - ND^*)$	$\{L(\frac{1}{2}\pi,0);-;-\}$ $\{-;y;y\}$	C. Paterson *et al.* (Glasgow), to be published
	$T\, d\sigma/dt$	$2\mathrm{Im}(S_1N^* - S_2D^*)$	$\{-;y;-\}$ $\{L(\frac{1}{2}\pi,0);0;y\}$	
	$P\, d\sigma/dt$	$2\mathrm{Im}(S_2N^* - S_1D^*)$	$\{-;-;y\}$ $\{L(\frac{1}{2}\pi,0);y;-\}$	J. McNabb *et al.* Phys Rev C **69** 042201 (2004)
Beam & Target	$G\, d\sigma/dt$	$-2\mathrm{Im}(S_1S_2^* + ND^*)$	$\{L(\pm\frac{1}{4}\pi);z;-\}$	FROST (g9a) under analysis
	$H\, d\sigma/dt$	$-2\mathrm{Im}(S_1D^* + S_2N^*)$	$\{L(\pm\frac{1}{4}\pi);x;-\}$	FROST (g9b) data in 2010
	$E\, d\sigma/dt$	$\lvert S_2\rvert^2-\lvert S_1\rvert^2-\lvert D\rvert^2+\lvert N\rvert^2$	$\{c;z;-\}$	FROST (g9a) under analysis
	$F\, d\sigma/dt$	$2\mathrm{Re}(S_2D^* + S_1N^*)$	$\{c;x;-\}$	FROST (g9b) data in 2010
Beam & Recoil	$O_x\, d\sigma/dt$	$-2\mathrm{Im}(S_2D^* + S_1N^*)$	$\{L(\pm\frac{1}{4}\pi);-;x'\}$	C. Paterson *et al.* (Glasgow), to be published
	$O_z\, d\sigma/dt$	$-2\mathrm{Im}(S_2S_1^* + ND^*)$	$\{L(\pm\frac{1}{4}\pi);-;z'\}$	C. Paterson *et al.* (Glasgow), to be published
	$C_x\, d\sigma/dt$	$-2\mathrm{Re}(S_2N^* + S_1D^*)$	$\{c;-;x'\}$	R. Bradford *et al.* Phys. Rev. C **75** 035205 (2007)
	$C_z\, d\sigma/dt$	$\lvert S_2\rvert^2-\lvert S_1\rvert^2-\lvert N\rvert^2+\lvert D\rvert^2$	$\{c;-;z'\}$	R. Bradford *et al.* Phys. Rev. C **75** 035205 (2007)
Target & Recoil	$T_x\, d\sigma/dt$	$2\mathrm{Re}(S_1S_2^* + ND^*)$	$\{-;x;x'\}$	FROST (g9b) data in 2010
	$T_z\, d\sigma/dt$	$2\mathrm{Re}(S_1N^* - S_2D^*)$	$\{-;x;z'\}$	FROST (g9b) data in 2010
	$L_x\, d\sigma/dt$	$2\mathrm{Re}(S_2N^* - S_1D^*)$	$\{-;z;x'\}$	FROST (g9a) under analysis
	$L_z\, d\sigma/dt$	$\lvert S_1\rvert^2+\lvert S_2\rvert^2-\lvert N\rvert^2-\lvert D\rvert^2$	$\{-;z;z'\}$	FROST (g9a) under analysis

I. S. Barker, A. Donnachie, J. K. Storrow, Nucl. Phys. B95 347 (1975).

$\gamma p \rightarrow K^+\Lambda$ Cross Sections

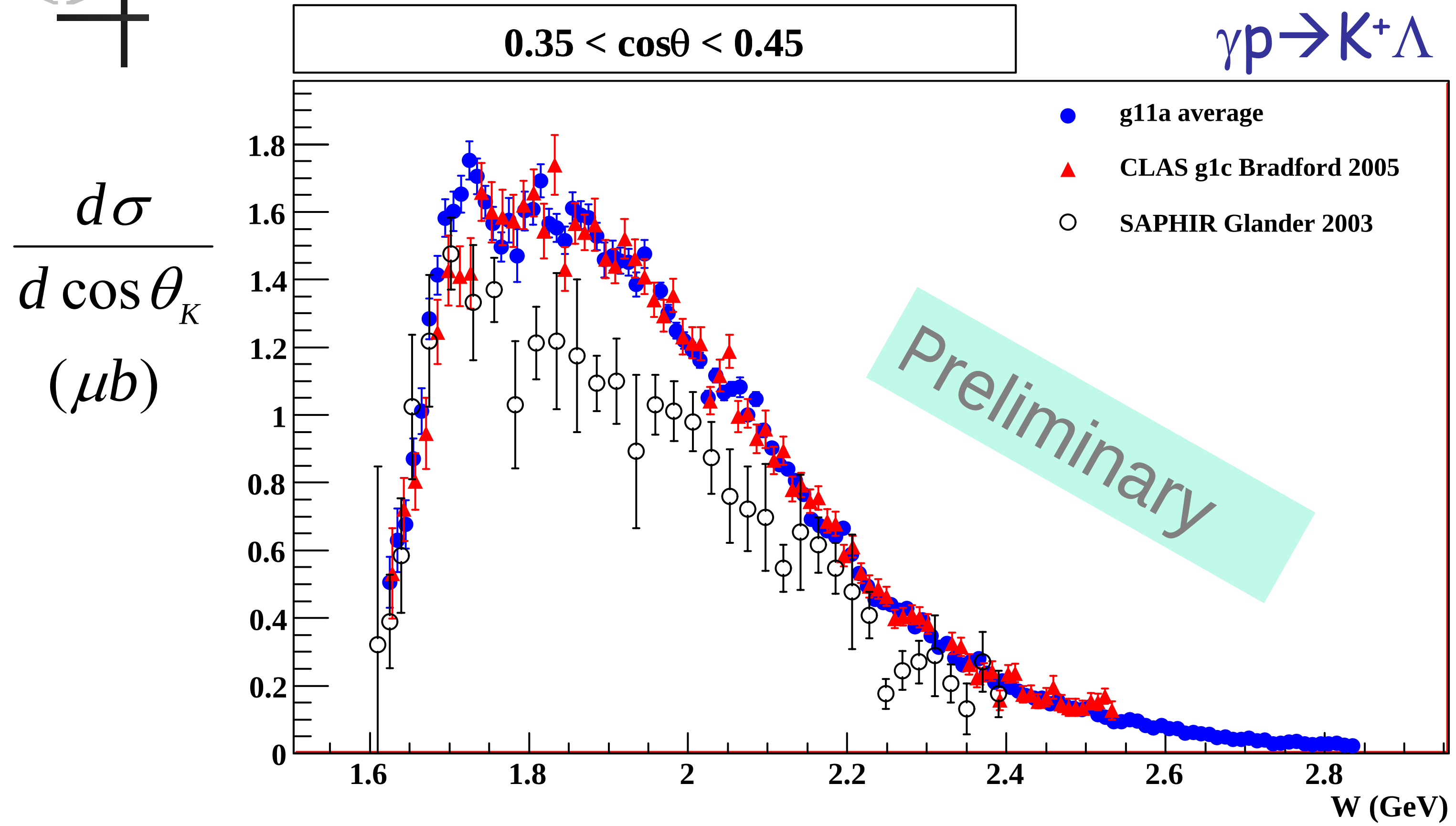


- Two bump structure seen
- Resonance-like structure at 1.9 GeV:
  - D_{13} (Bennhold & Mart)
  - P_{13} (Nikanov et al.)
  - P_{11} (Ghent model)
  - $K\bar{K}N$ bound state*
- CLAS/SAPHIR disagreement: can it be resolved? Yes… via new data

R. Bradford *et al*. Phys. Rev. C**73** 035202 (2006)
K. H. Glander *et al*. Eur. Phys. J. A**19** 251 (2004)

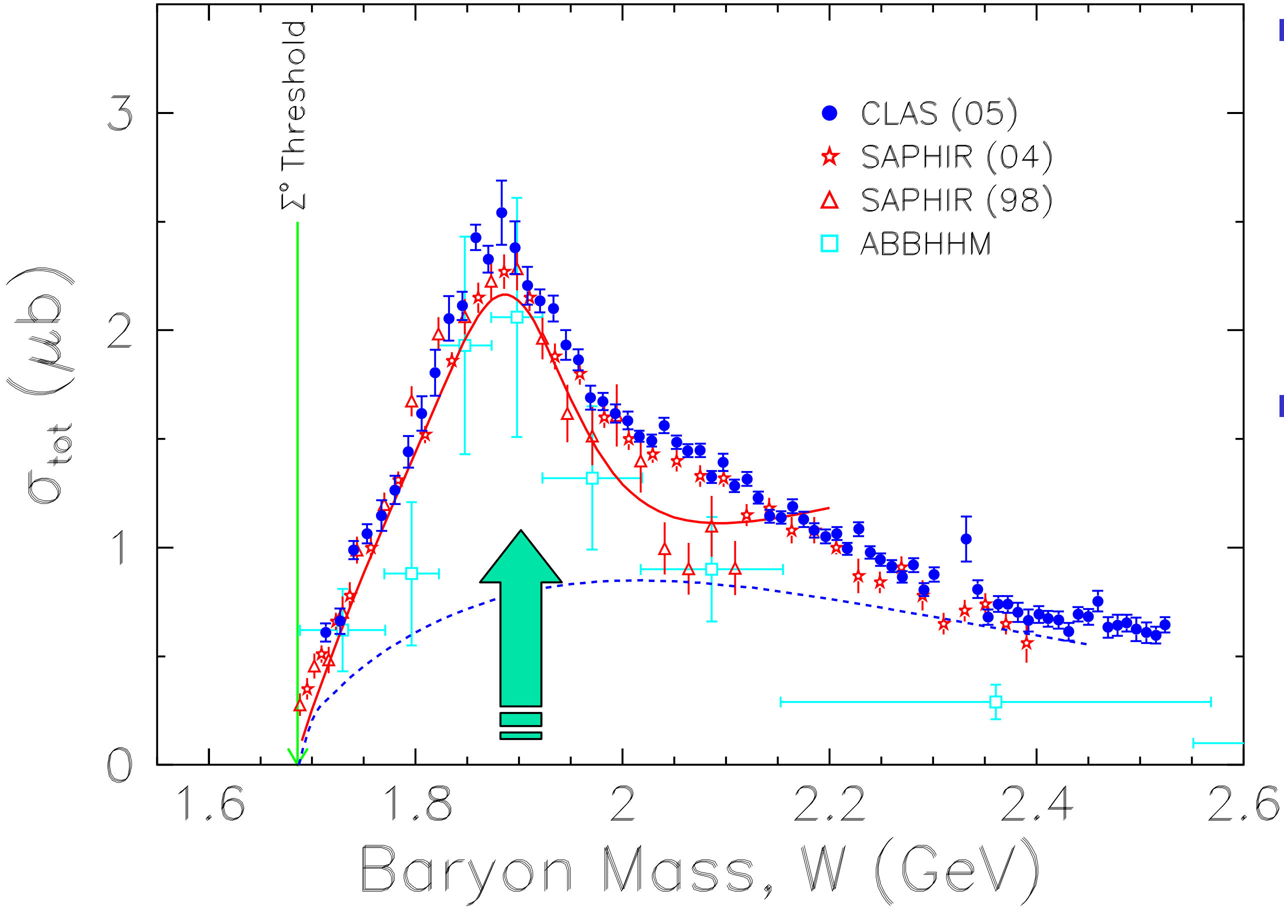
*A. Martinez Torres, K.P. Khemchandani, Ulf-G. Meissner, E. Oset **arXiv:0902.3633** [nucl-th]

Compare CLAS'05, CLAS'09, SAPHIR



- CLAS 'g11' data: broader energy range, better statistics, good agreement with 'g1c' (Bradford *et al.*)
  - Different data set, different trigger, different analysis chain
  - Ph.D. work of Mike McCracken, Carnegie Mellon; PWA in progress

$\gamma p \rightarrow K^+\Sigma^0$ Cross Sections

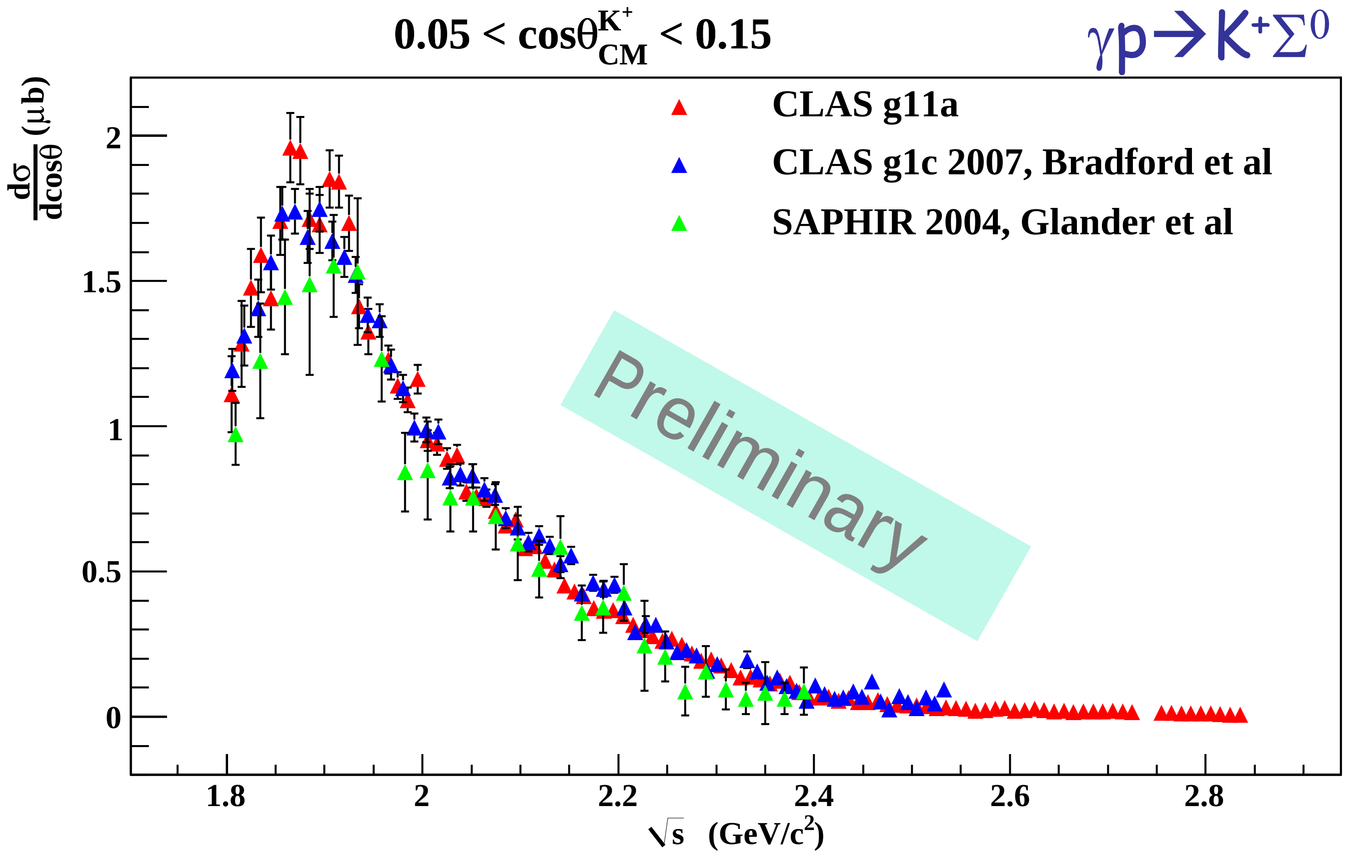


- Single-bump: resonance-like structure near 1.9 GeV
  - N* & Δ resonances
- CLAS agreement with SAPHIR: can it be resolved? Yes…via new data

R. Bradford *et al*. Phys. Rev. C**73** 035202 (2006)

K.H. Glander *et al*. Eur. Phys. J. A**19** 251 (2004)

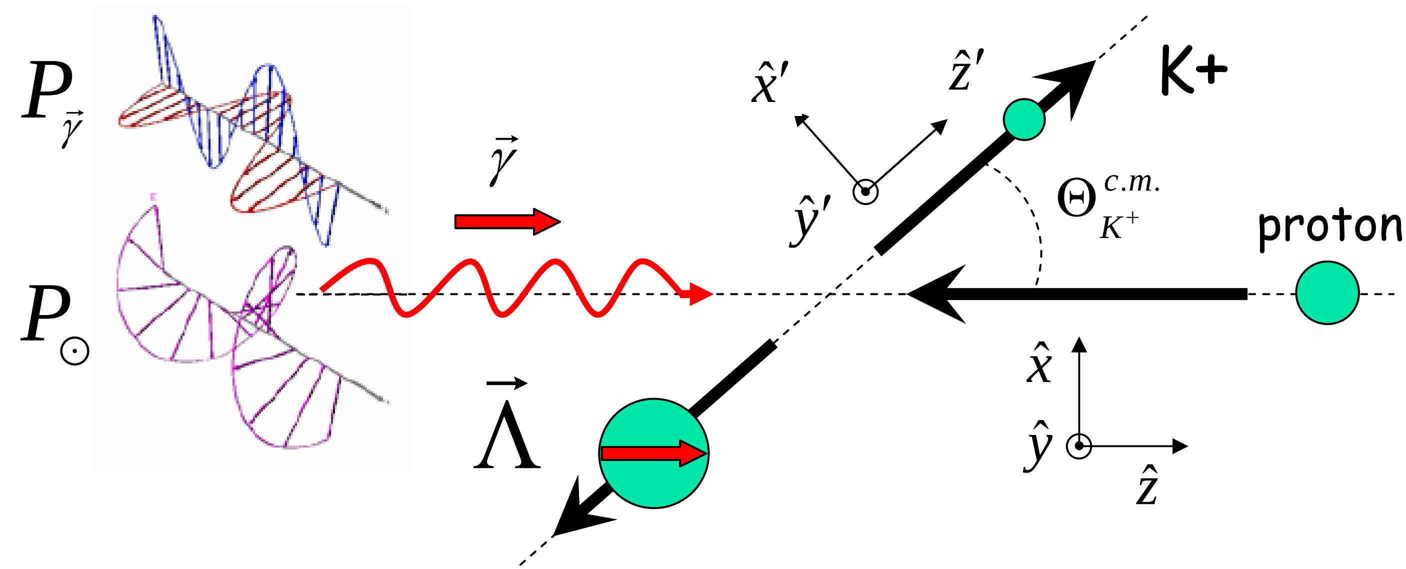
Compare CLAS'05, CLAS'09, SAPHIR

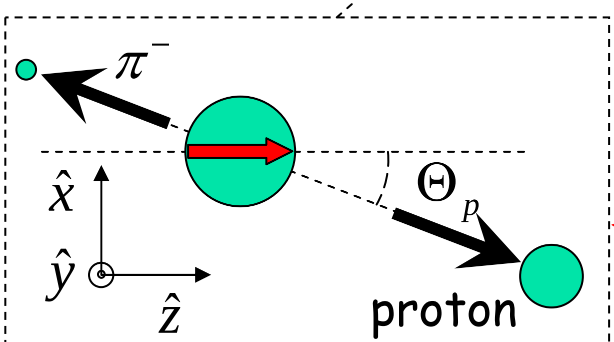


- CLAS 'g11' data: broader energy range, better statistics, good agreement with 'g1c' (Bradford *et al.*)
  - Different data set, different trigger, different analysis chain
  - Ph.D. work of Biplab Dey, Carnegie Mellon

Define the Spin Observables

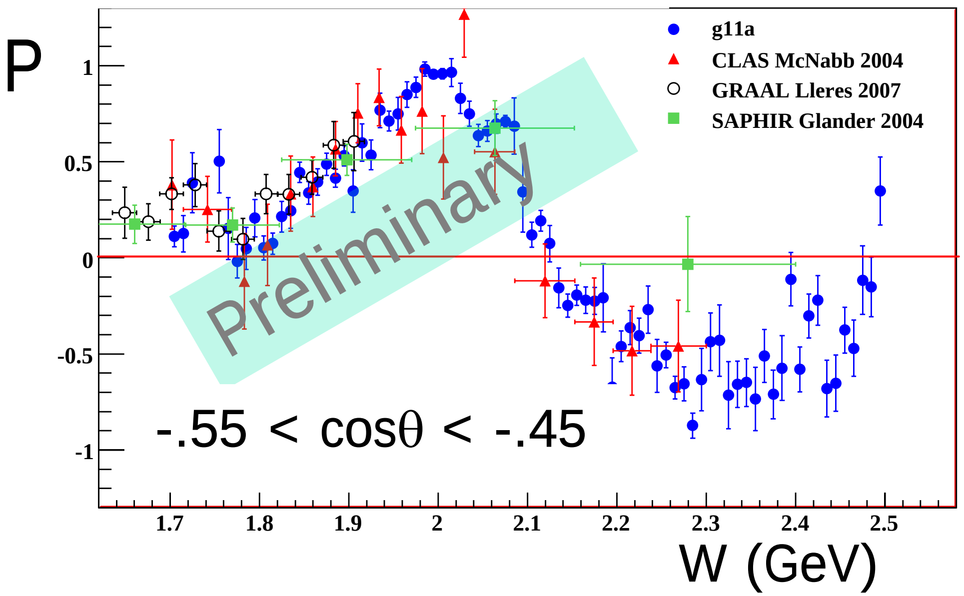
(for target polarization zero)

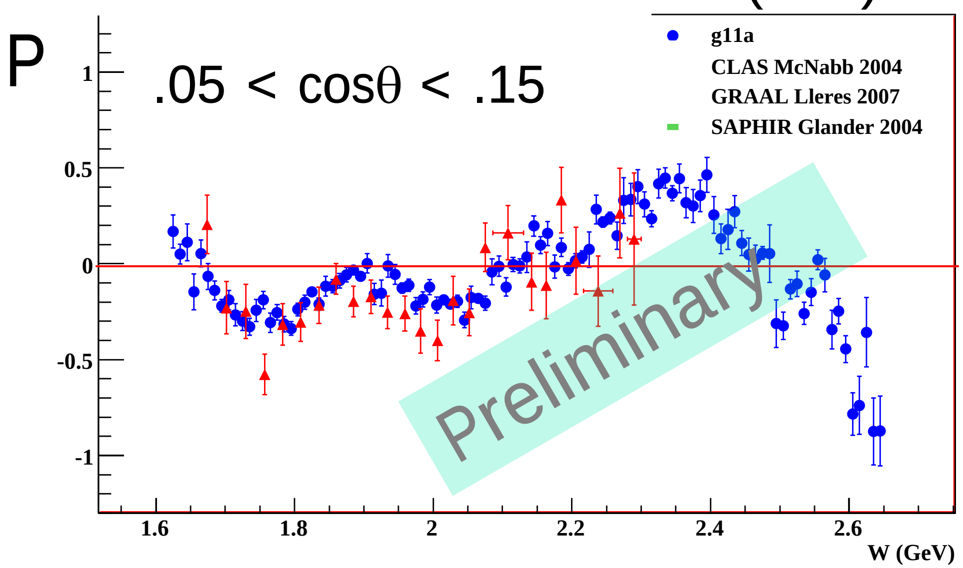




$$\frac{d\sigma}{d\Omega} = \sigma_0 \left\{ \begin{array}{l} 1 - P_{\vec{\gamma}}\Sigma\cos 2\phi \\ -\alpha\cos\theta_{x'}\sin 2\phi P_{\vec{\gamma}} O_{x'} - \alpha\cos\theta_{x'} P_{\odot} C_{x'} \\ -\alpha\cos\theta_{z'}\sin 2\phi P_{\vec{\gamma}} O_{z'} - \alpha\cos\theta_{z'} P_{\odot} C_{z'} \\ +\alpha\cos\theta_{y'} P - \alpha\cos\theta_{y'} P_{\vec{\gamma}} T\cos 2\phi \end{array} \right\}$$

$\gamma p \rightarrow K^+\Lambda$ Hyperon Recoil Polarization

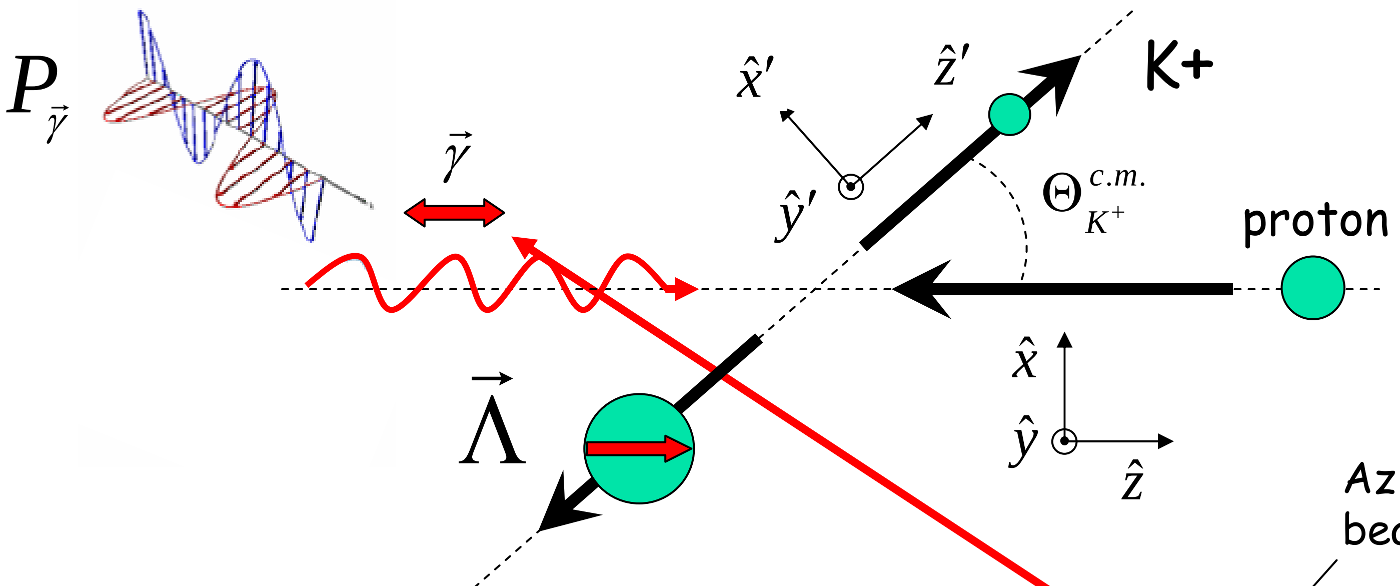


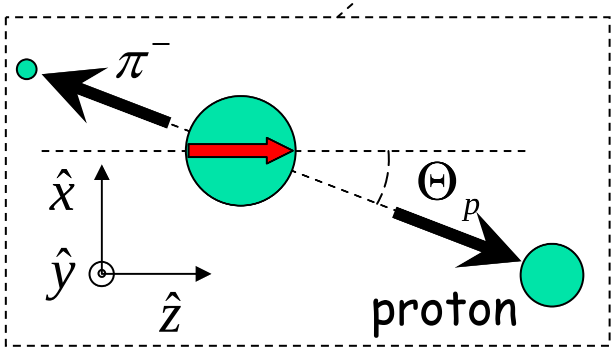


- Preliminary CLAS'09 has best coverage yet
- Good agreement with CLAS'04 and GRAAL
- Agrees also with CLAS g8b set (C. Paterson)
- More detailed structure now visible!
- CLAS PWA in progress
- PhD work of M. McCracken, CMU

cf. J. McNabb *et al.* Phys Rev C **69** 042201 (2004).

Beam Asymmetry

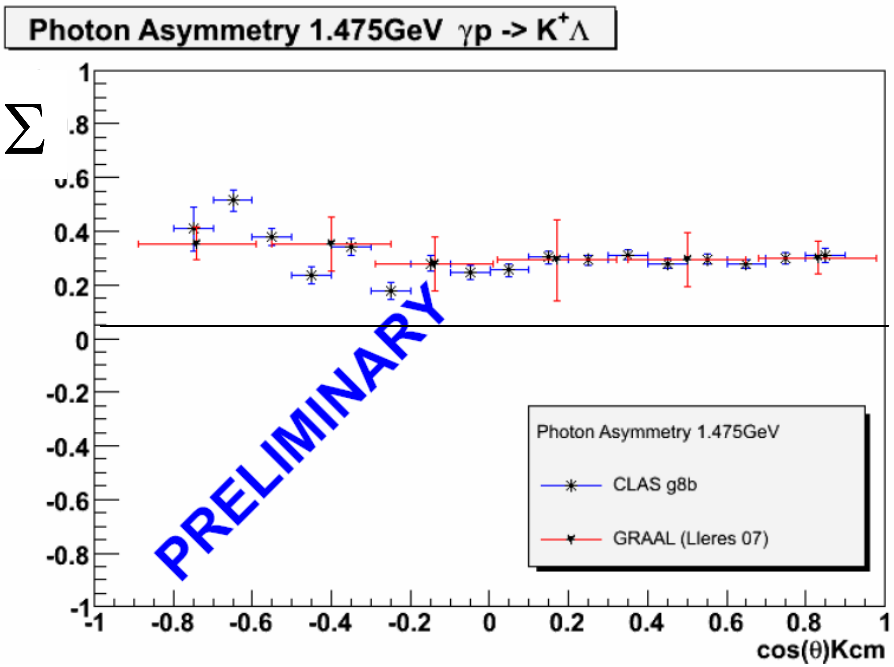


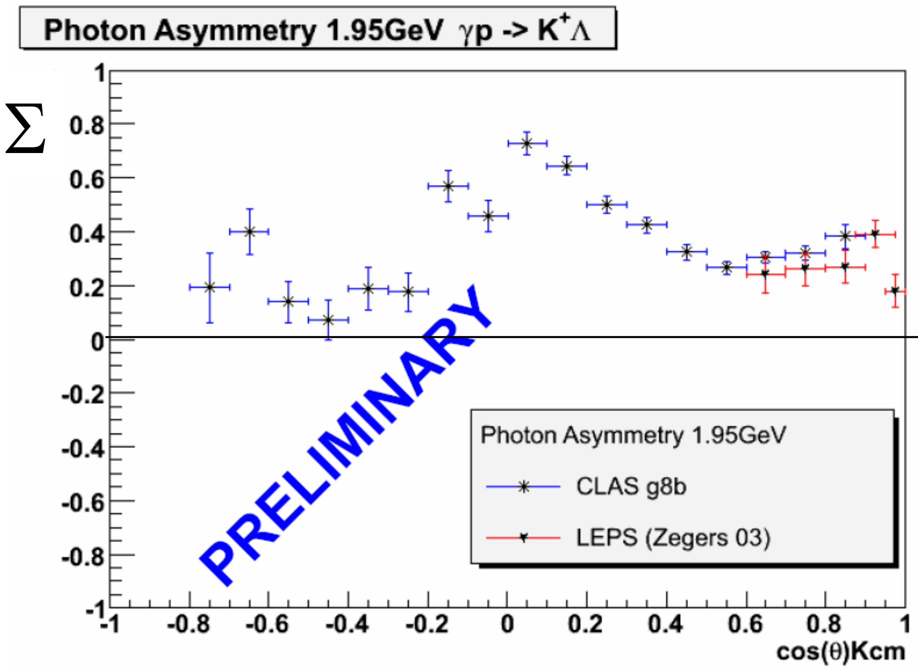


Azimuthal angle w.r.t. beam polarization

$$\frac{d\sigma}{d\Omega} = \sigma_0 \begin{Bmatrix} 1 - P_{\vec{\gamma}} \Sigma \cos 2\phi \\ - \alpha \cos\theta_{x'} \sin 2\phi P_{\vec{\gamma}} O_{x'} - \alpha \cos\theta_{x'} P_{\odot} C_{x'} \\ - \alpha \cos\theta_{z'} \sin 2\phi P_{\vec{\gamma}} O_{z'} - \alpha \cos\theta_{z'} P_{\odot} C_{z'} \\ + \alpha \cos\theta_{y'} P - \alpha \cos\theta_{y'} P_{\vec{\gamma}} T \cos 2\phi \end{Bmatrix}$$

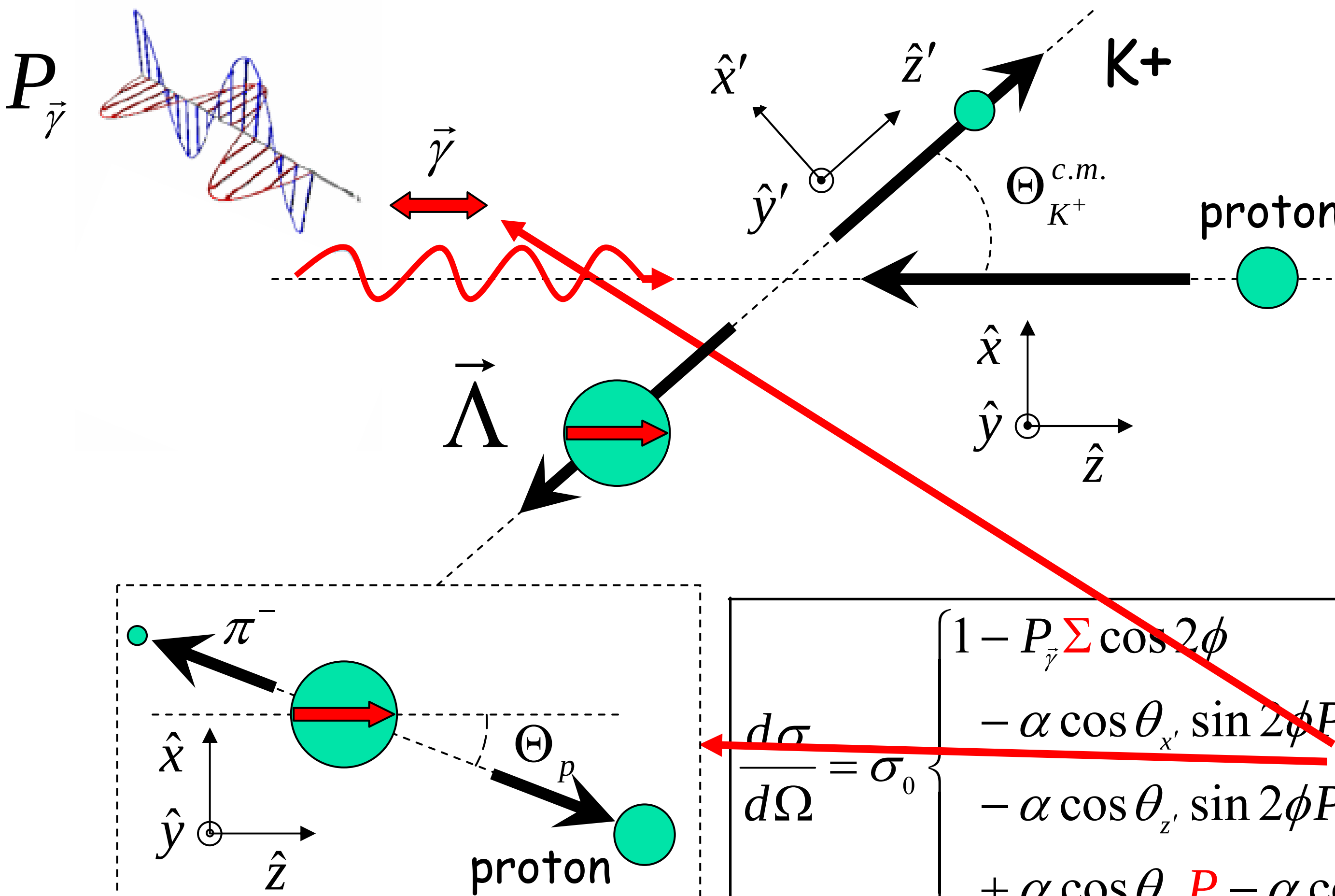
$\gamma p \rightarrow K^+\Lambda$ Photon Beam Asymmetry





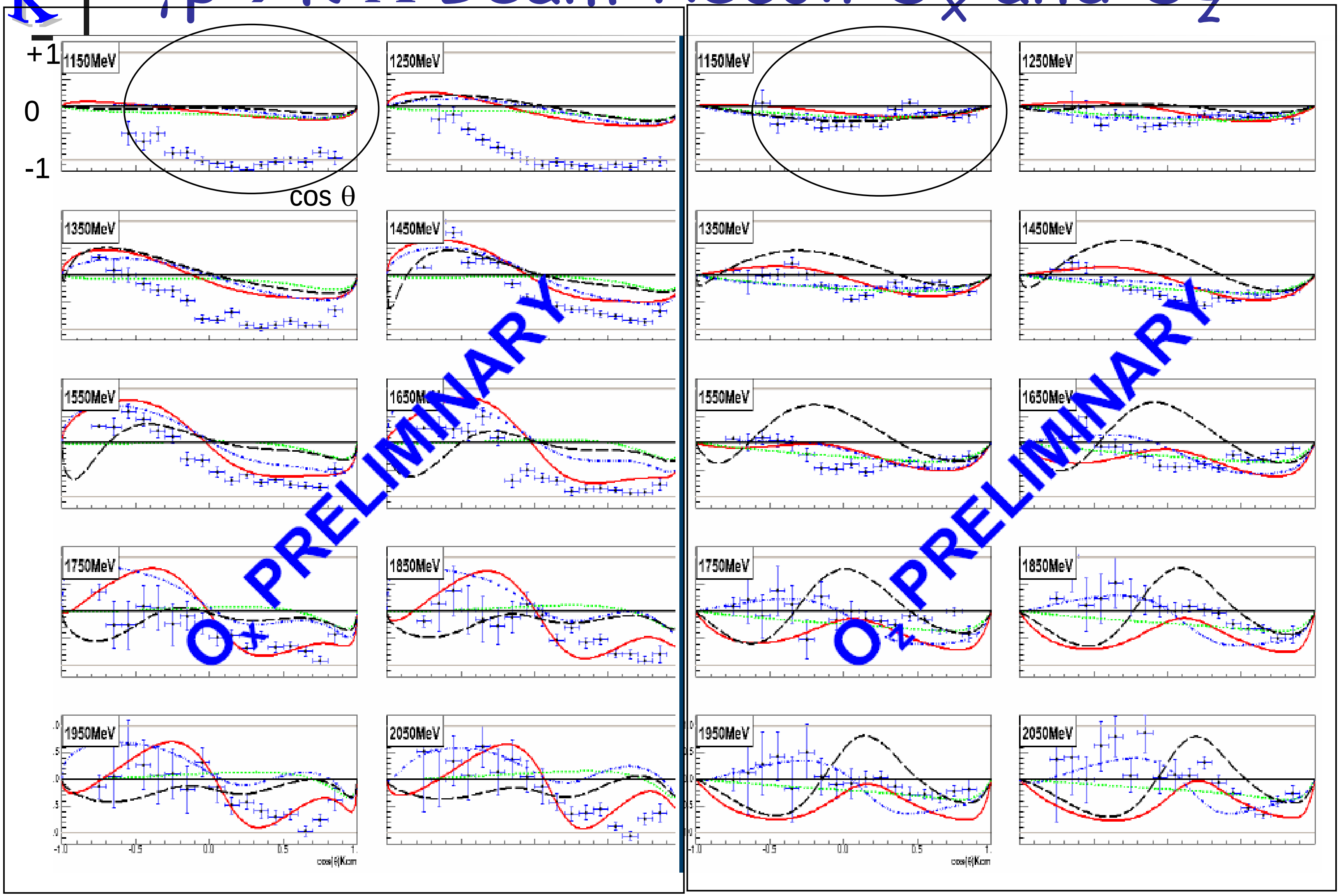
- Good agreement among CLAS, GRAAL and LEPS
- Results for $\gamma p \rightarrow K^+\Sigma^0$ coming as well
- Thesis work of Craig Paterson (Glasgow)

Polarization Transfer for Linear Beam Polarization



$$\frac{d\sigma}{d\Omega} = \sigma_0 \left\{ \begin{array}{l} 1 - P_{\vec{\gamma}} \Sigma \cos 2\phi \\ - \alpha \cos\theta_{x'} \sin 2\phi P_{\vec{\gamma}} O_{x'} - \alpha \cos\theta_{x'} P_{\odot} C_{x'} \\ - \alpha \cos\theta_{z'} \sin 2\phi P_{\vec{\gamma}} O_{z'} - \alpha \cos\theta_{z'} P_{\odot} C_{z'} \\ + \alpha \cos\theta_{y'} P - \alpha \cos\theta_{y'} P_{\vec{\gamma}} T \cos 2\phi \end{array} \right\}$$

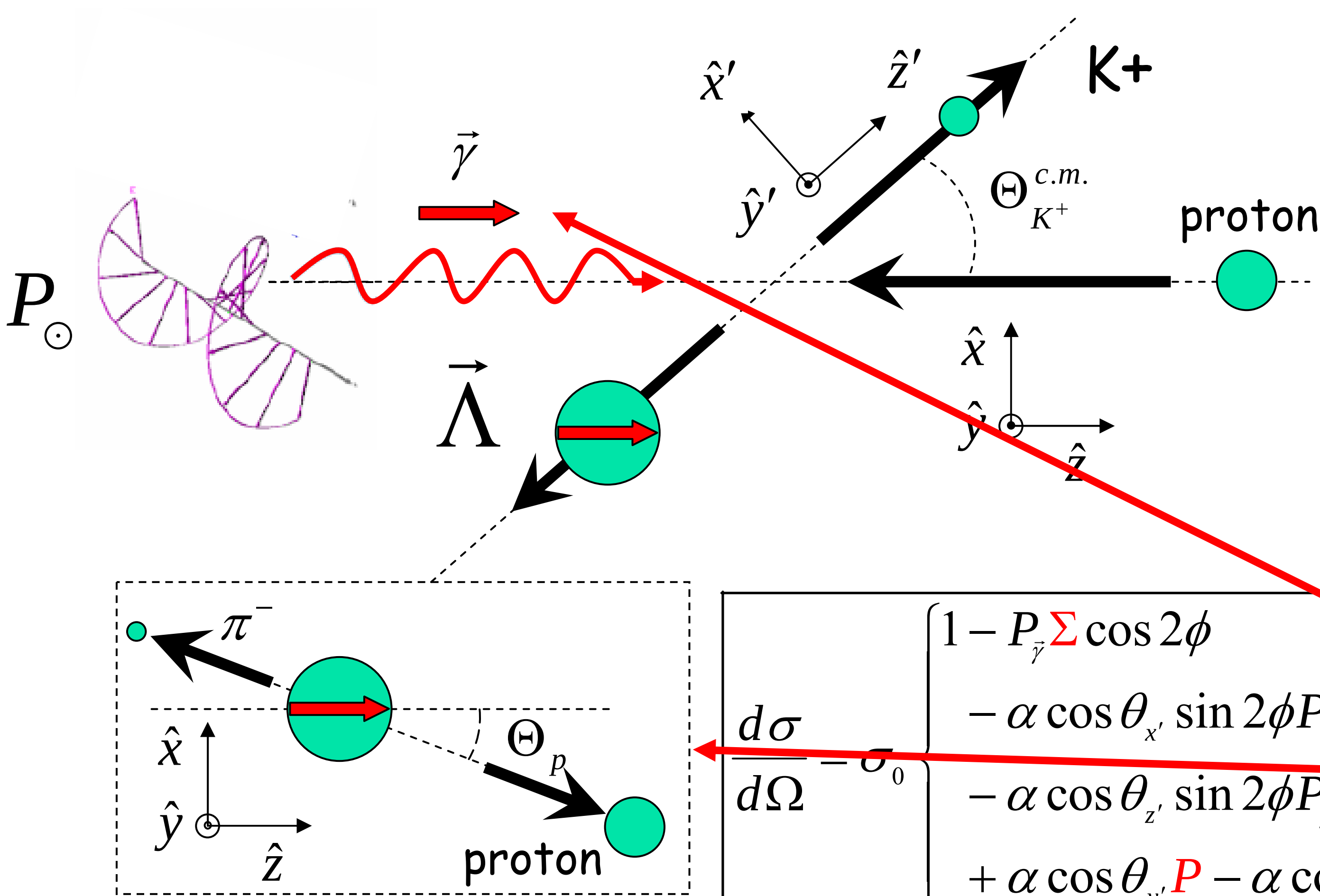
$\gamma p \rightarrow K^+\Lambda$ Beam-Recoil O_x and O_z



KaonMAID; RPR2-Regge only; RPR2-core; RPR2-w/D13

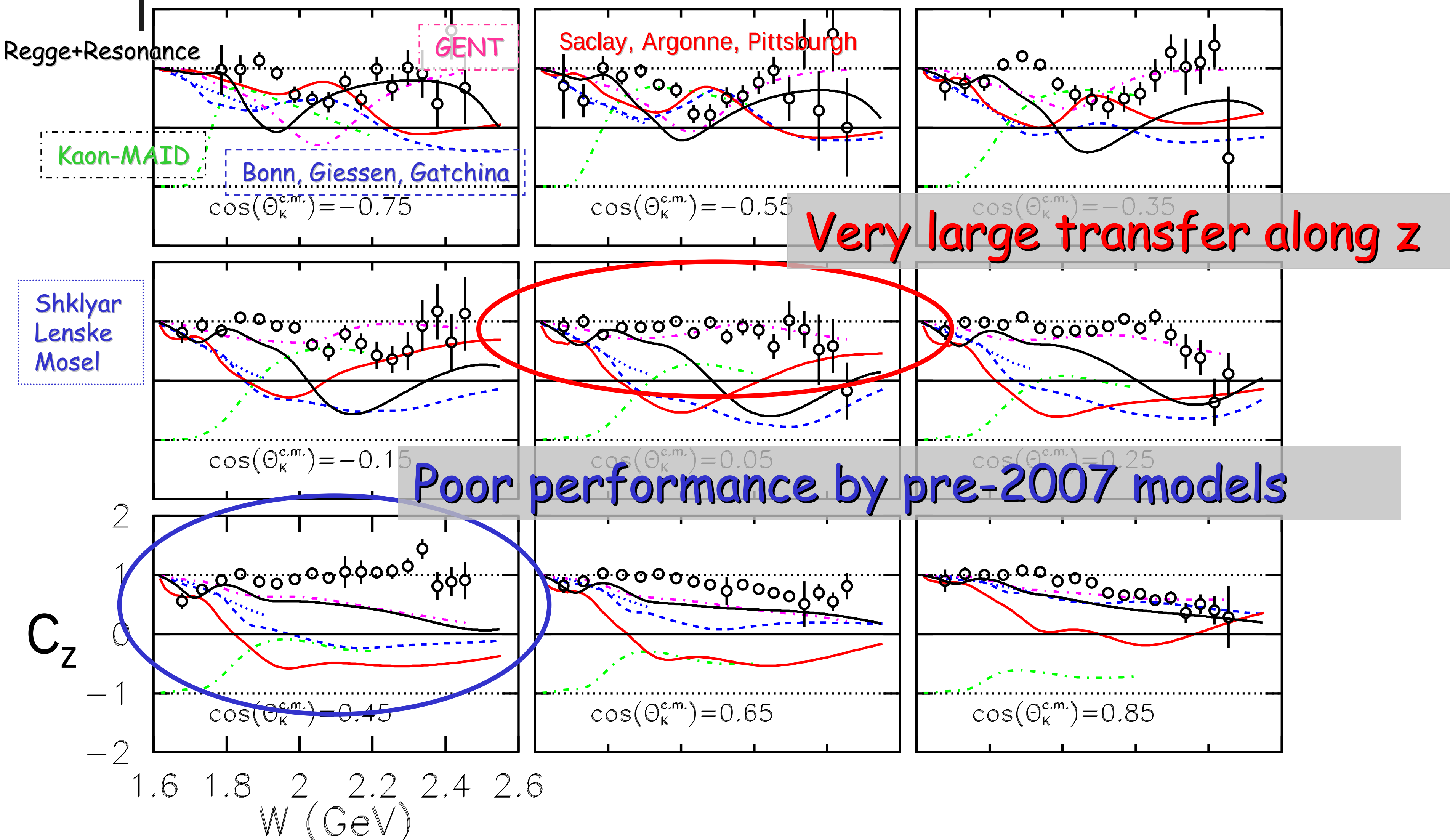
Craig Paterson (Glasgow)

Polarization Transfer for Circular Beam Polarization



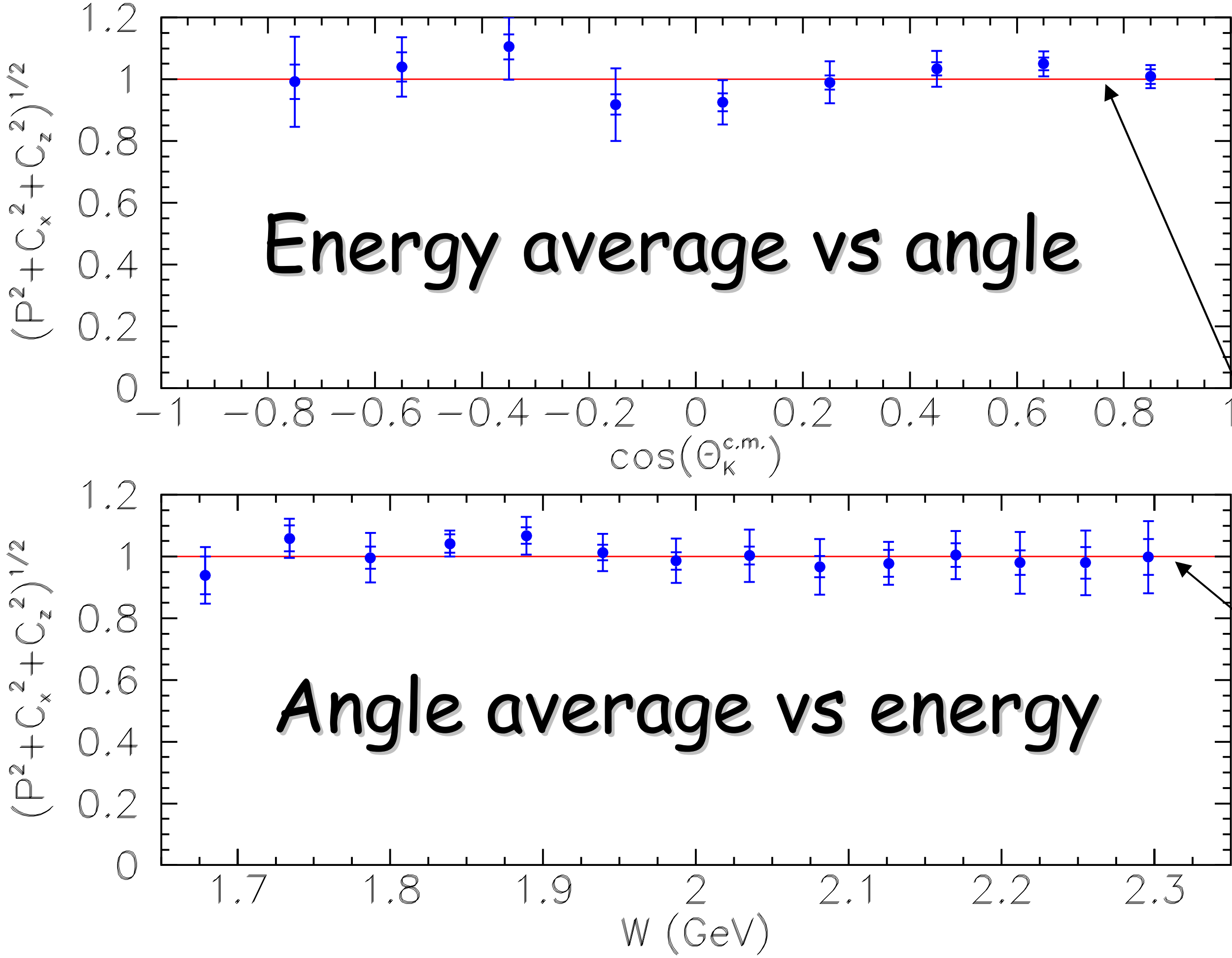
$$\frac{d\sigma}{d\Omega} = \sigma_0 \begin{Bmatrix} 1 - P_{\vec{\gamma}} \Sigma \cos 2\phi \\ - \alpha \cos\theta_{x'} \sin 2\phi P_{\vec{\gamma}} O_{x'} - \alpha \cos\theta_{x'} P_\odot C_{x'} \\ - \alpha \cos\theta_{z'} \sin 2\phi P_{\vec{\gamma}} O_{z'} - \alpha \cos\theta_{z'} P_\odot C_{z'} \\ + \alpha \cos\theta_{y'} P - \alpha \cos\theta_{y'} P_{\vec{\gamma}} T \cos 2\phi \end{Bmatrix}$$

C_z vs. W: Results for Λ



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

Average R Values for the Λ



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

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

"Fully Polarized Λ"

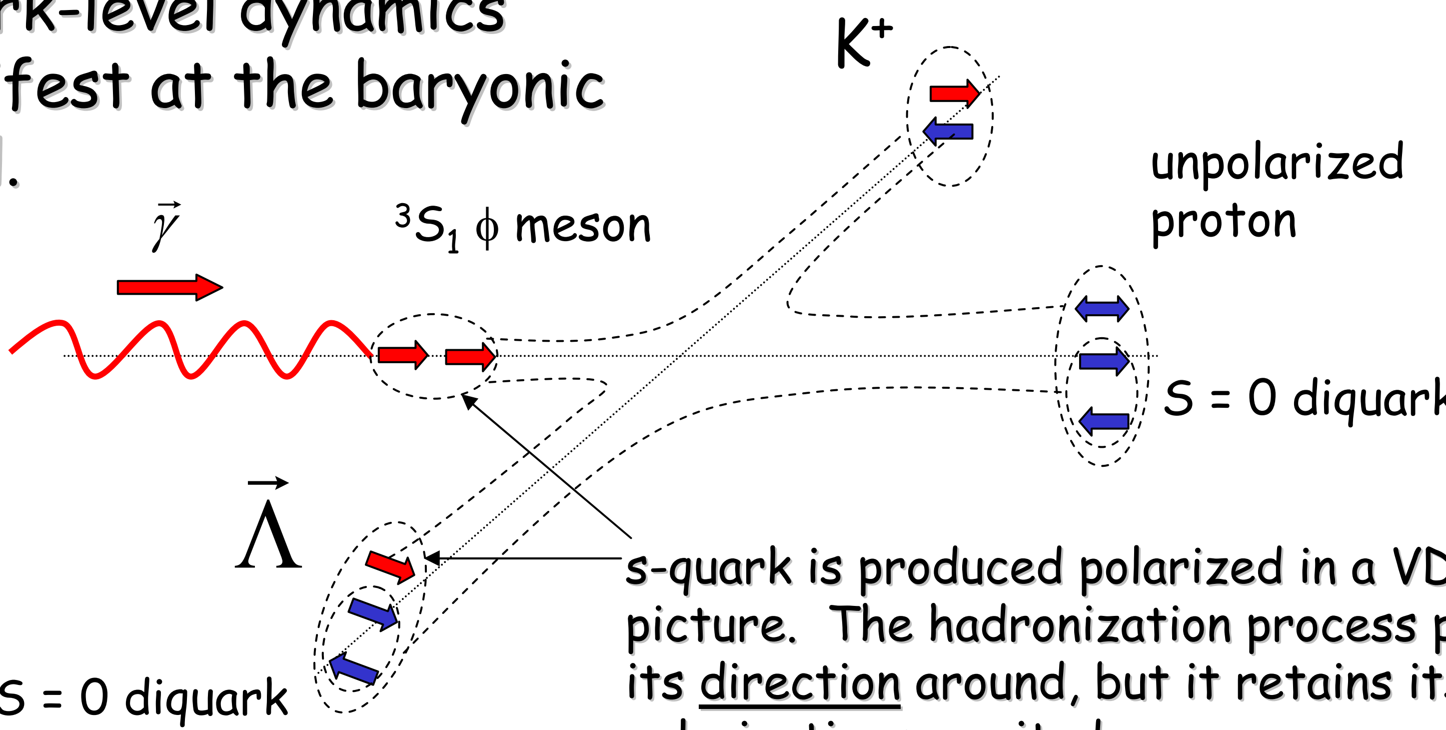
Energy and angle averages are consistent with unity.

No model predicted this CLAS result.

Confirmed by GRAAL:
A. Lleres *et al.* Eur. Phys. J. **A 39**, 149 (2009).

Quark-Picture Explanation

Quark-level dynamics manifest at the baryonic level.

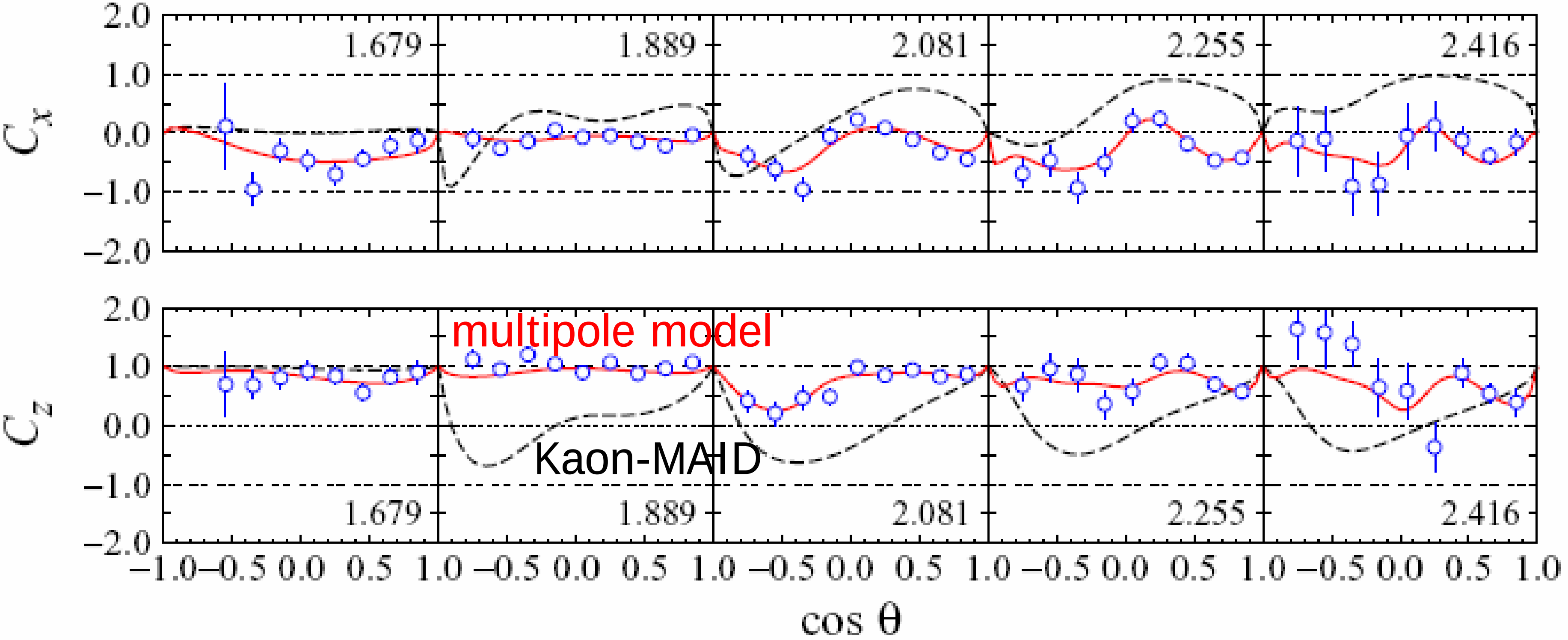


s-quark is produced polarized in a VDM $^3S_1$ picture. The hadronization process pushes its <u>direction</u> around, but it retains its full polarization magnitude.

R. S., Eur.Phys.J. A**35** 299-305 (2008)

Alternative quark-level S=0 (spin singlet) scenario:
D. Carman *et al.*, Phys Rev. Lett 90 131804 (2003).

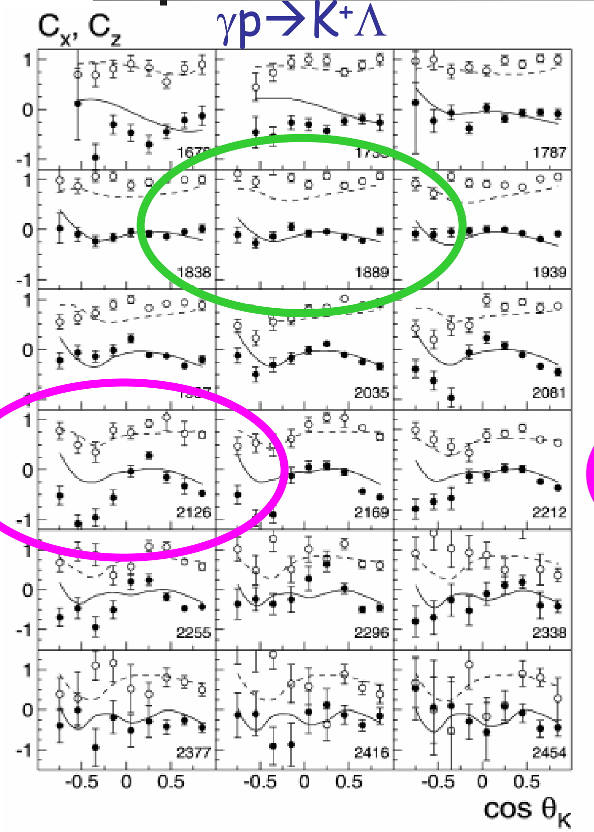
Hadronic-Model Explanation



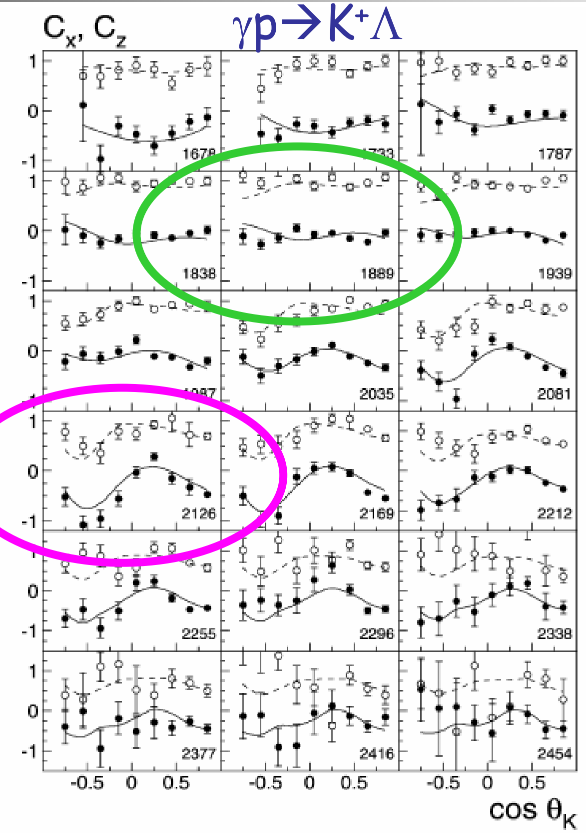
- Mart *et al.*'s refit of isobar and multipole models
- mix includes: S_{11}(1650), P_{11}(1710), P_{13}(1720), P_{13}(1900)
- second resonance "bump" no longer consistent with a D_{13}(2080)

T. Mart, nucl-th 0808.0771 (Aug 2008)

Effect of including C_x C_z in Models



C_xC_z without N*(1900)P_{13}



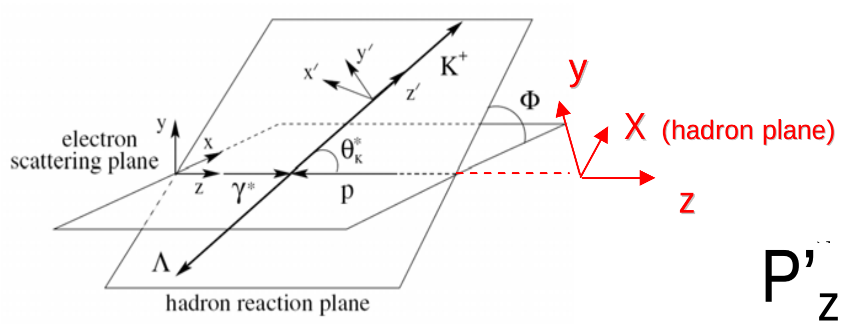
C_xC_z with N*(1900)P_{13}

- Nikanov *et al.*'s refit of Bonn-Gachina multi- coupled-channel isobar model
- mix includes: S_{11}-wave, P_{13}(1720), P_{13}(1900), P_{11}(1840)
- $K^+\Sigma^0$ cross sections also better described with P_{13}(1900)
- Promote this "missing" resonance from ** to **** status.
- P_{13}(1900) is not found in quark-diquark models.

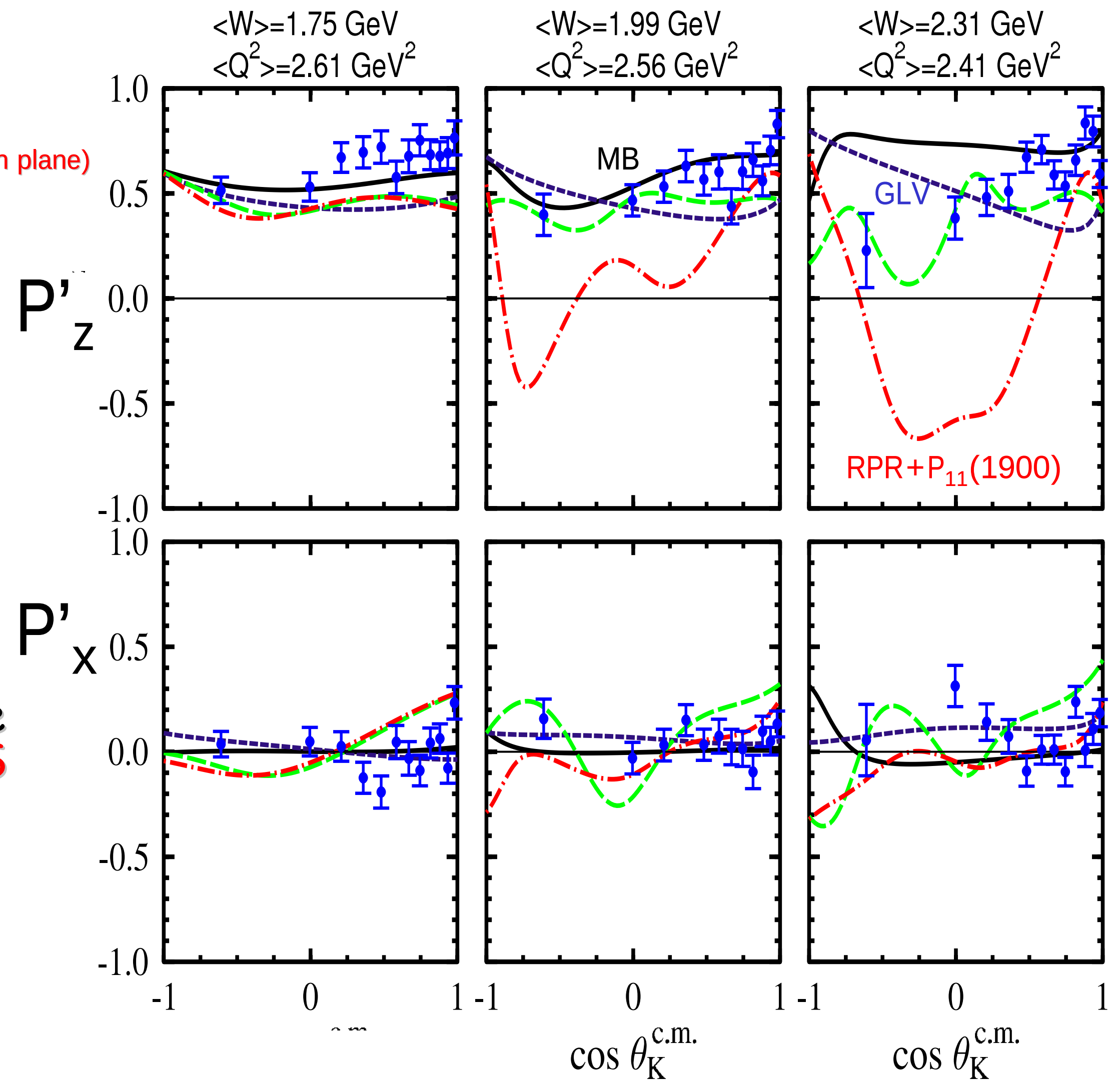
V. A. Nikanov *et al.*, Phys Lett. B **662**, 246 (2008).
see also: A.V. Anisovich *et al.*, Eur. Phys J. A **25** 427 (2005).

E. Santopinto Phys Rev. C **72**, 02201(R), (2005).

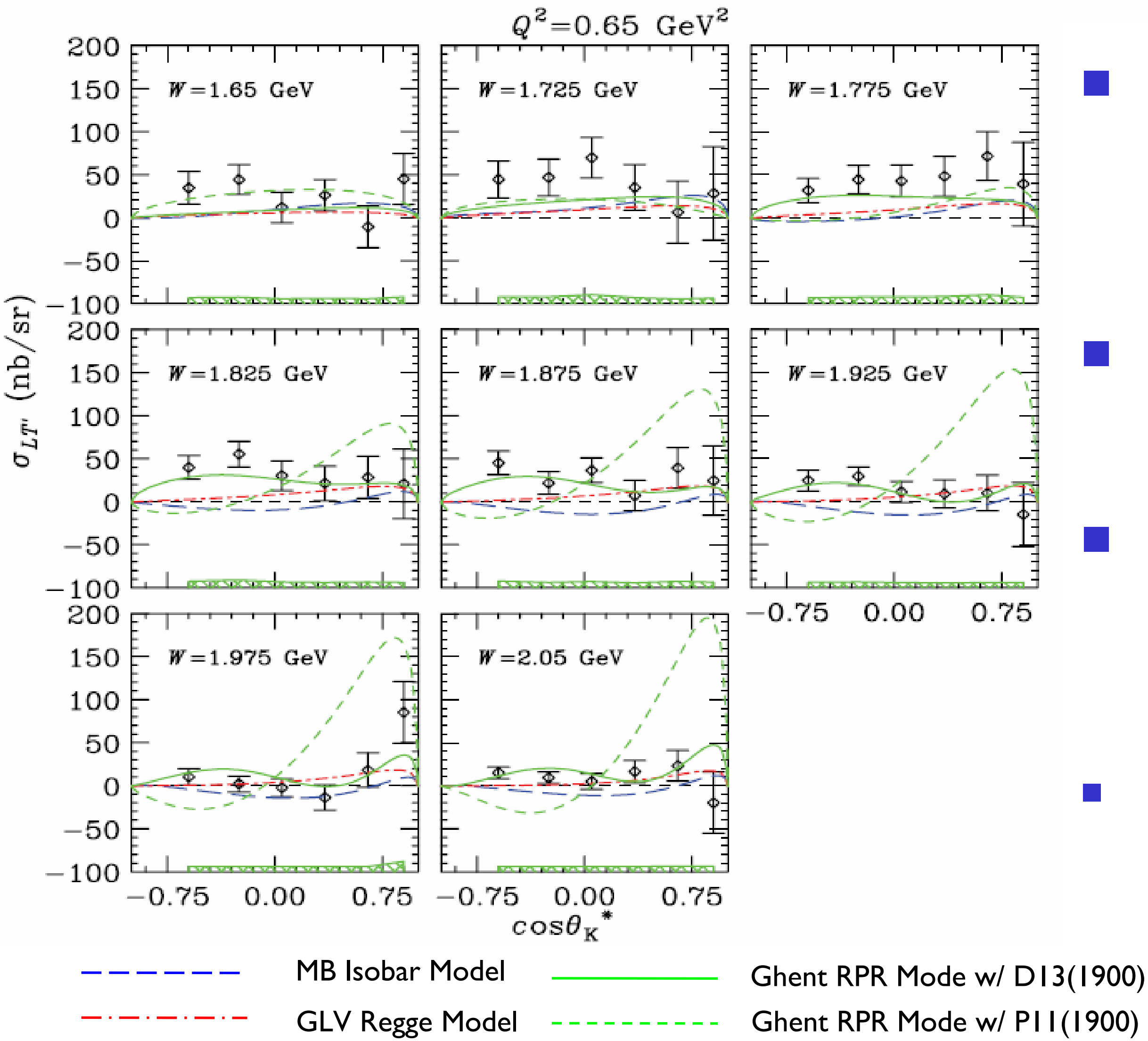
CLAS $p(\vec{e},e'K^+)\vec{\Lambda}$ Transferred Polarization



- Electroproduction analog of C_x and C_z:
- New CLAS results: broader kinematic range
  D. Carman *et al.*, Phys Rev. Lett **90** 131804 (2003).
- Large polarization transfer *along photon direction* (not the z' helicity axis) is seen in CLAS electro-production.
  - Beam depolarization (~0.6) is not divided out in figures.
- Analysis by D. Carman, B. Raue (to be published '09)



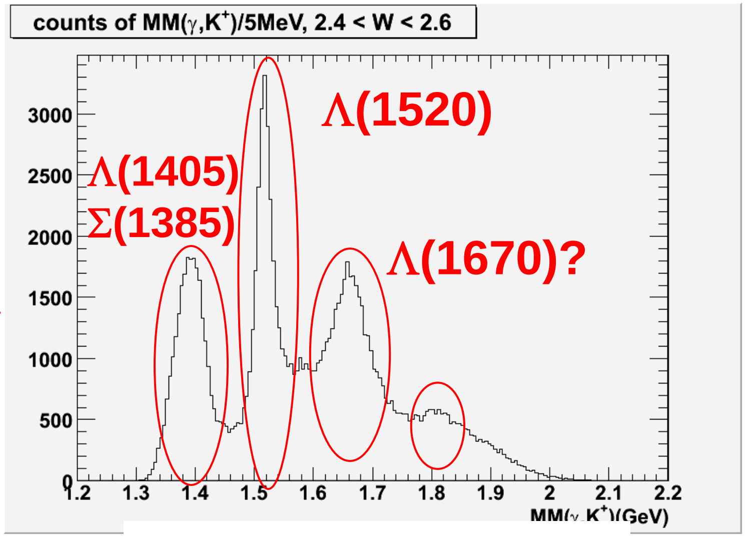
Spin-structure function $\sigma_{LT'}$



- "5th" structure function result for $\vec{e}p \rightarrow e'K^+\vec{\Lambda}$
- P_{11}(1900) seems ruled out
- No models are quantitatively satisfactory
- R. Nasseripour *et al.* Phys. Rev C **77**, 065208 (2008).

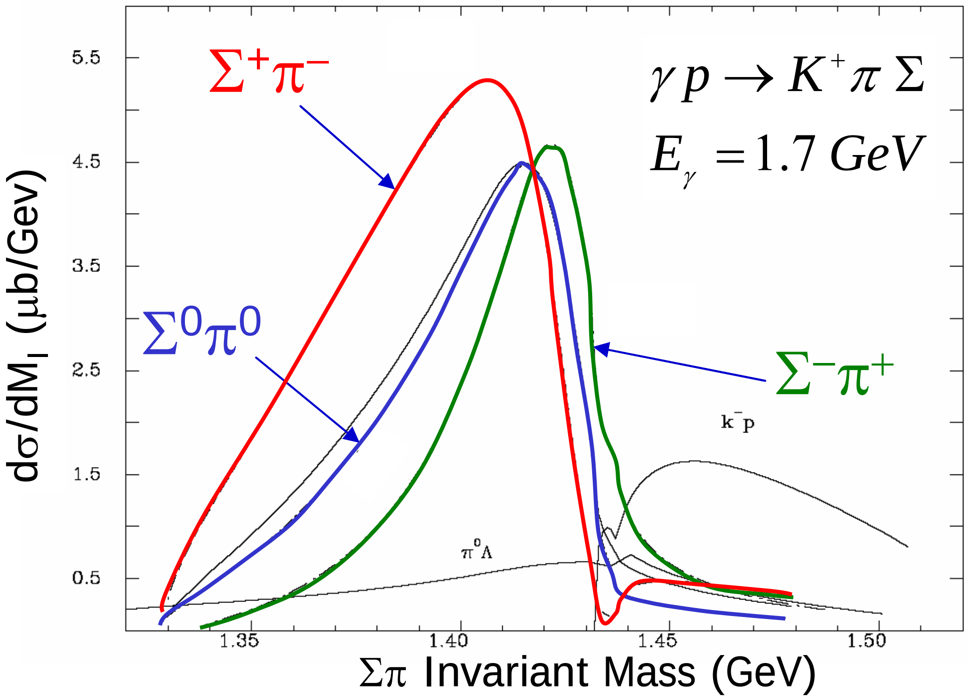
What "is" the $\Lambda(1405)$?

- Structure – an issue since its discovery
  - SU(3) singlet 3q state
    $I=0,\ J^{\pi} = \frac{1}{2}^{-}$
  - $\bar{K}N$ sub-threshold bound state
  - Gluonic (udsg) hybrid $J^{\pi} = \frac{1}{2}^{+}$
    - O. Kittel & G.R.Farrar hep-ph/0010186
  - Dynamically generated resonance, via unitary meson-baryon channel coupling
    - R. Dalitz & S.F.Tuan, Phys. Rev. Lett. **2**, 425 (1959), Ann. Phys. **10** 307 (1960).
    - J. C. Nacher, E. Oset, H. Toki, A. Ramos, Phys. Lett. B **455**, 55 (1999).



(γ,K) Missing Mass (GeV)

Chiral Unitary Model Prediction



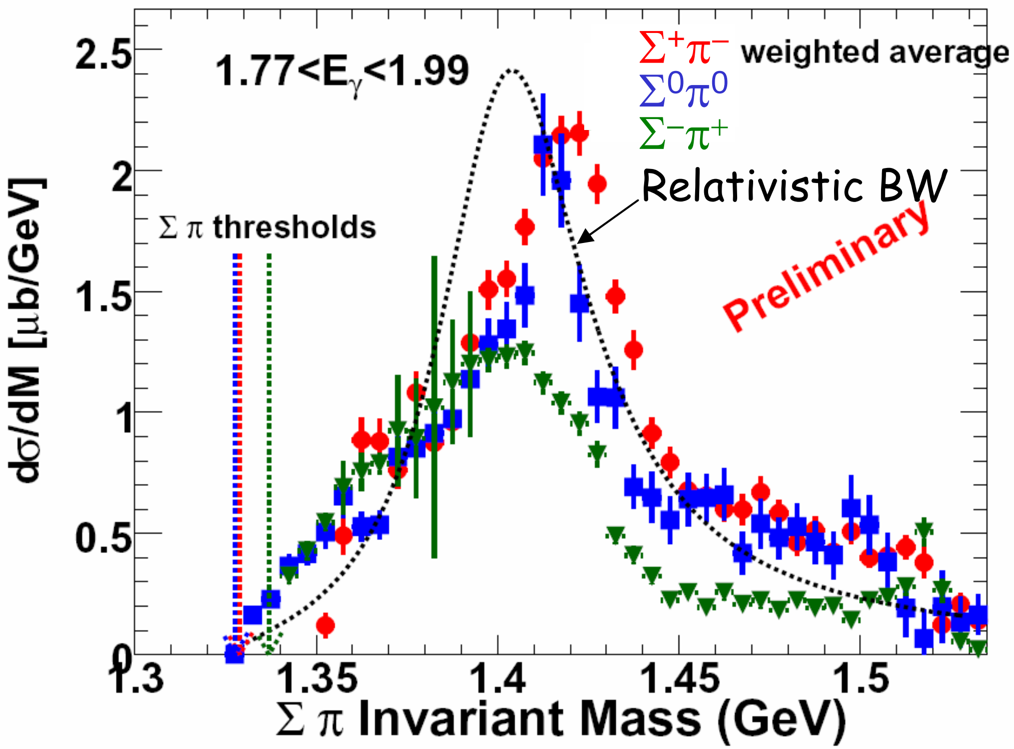
$$\frac{d\sigma(\pi^+\Sigma^-)}{dM_I} \propto \frac{1}{2}\left|T^{(1)}\right|^2 + \frac{1}{3}\left|T^{(0)}\right|^2 + \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

$$\frac{d\sigma(\pi^-\Sigma^+)}{dM_I} \propto \frac{1}{2}\left|T^{(1)}\right|^2 + \frac{1}{3}\left|T^{(0)}\right|^2 - \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

$$\frac{d\sigma(\pi^0\Sigma^0)}{dM_I} \propto \frac{1}{3}\left|T^{(0)}\right|^2 + O\left(T^{(2)}\right)$$

- Lineshape of "Λ(1405)" predicted to depend on πΣ decay channel
- J. C. Nacher, E. Oset, H. Toki, A. Ramos, Phys. Lett. B **455**, 55 (1999).
  - Chiral Lagrangian + mB FSI + Channel Coupling
  - I(π Σ) = {0,1,2} – not in an isospin eigenstate
  - I=2 contributions negligible
  - Interference between I=0 and I=1 amplitudes modifies mass distributions

CLAS result for Λ(1405)



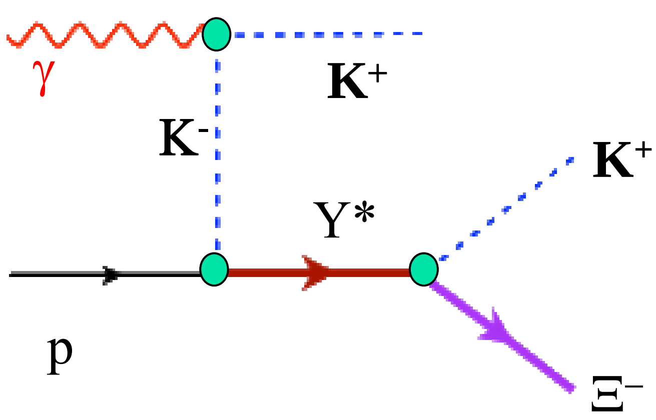
Note that "sign" of the charge asymmetry is opposite to Nacher *et al* prediction

- At this conference:
  - Kei Moriya PhD work
  - Session 1-A, 6
- Decay channel asymmetry of Λ(1405) lineshape confirmed
- "Cross section" varies by charge combo
- Direct Spin-parity measurement: $J^\pi = \frac{1}{2}^-$
- Subtracted backgrounds: Σ(1385), Λ(1520), K*

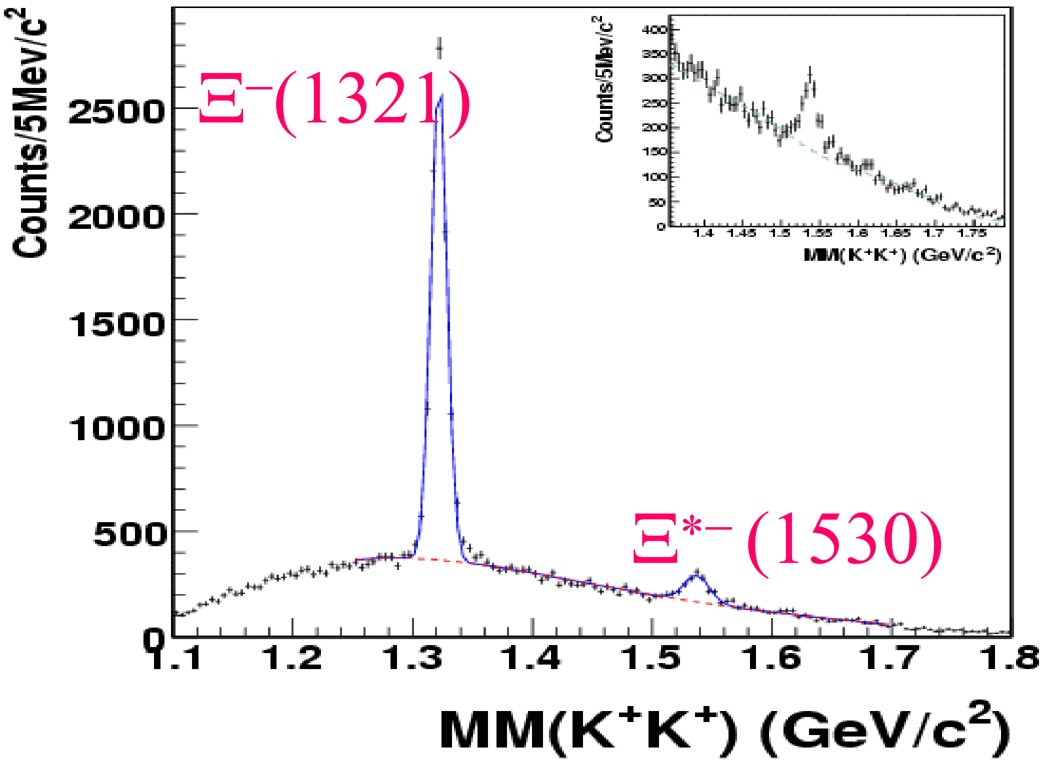
$\Xi^{0,-(*)}$ Production: S=-2 physics

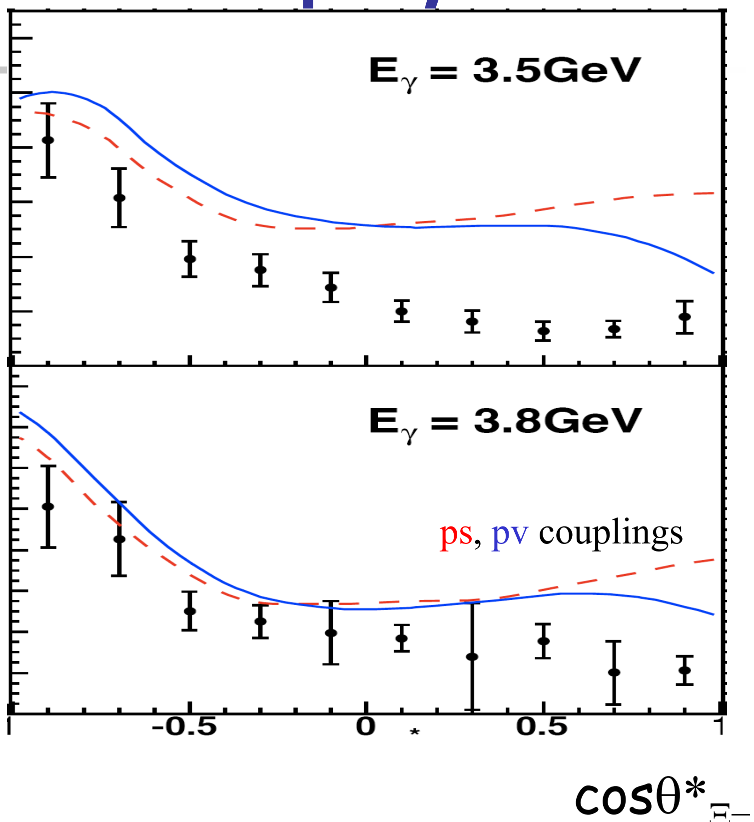
- Cascade physics under-explored
  - Only 6 states with 3 or 4 stars in PDG, most without spin-parity
  - Cross sections very small (few nb)
  - Narrower than S=-1 hyperons and N*
- Measured mass differences of Ξ's

- Model: effective Lagrangian approach:
  - K. Nakayama, Y. Oh, H. Haberzettl, PRC74 (2006) 035205
  - H. Lee GlueX Workshop http://conferences.jlab.org/php2008



$\Xi^{-(*)}$ Production: S=-2 physics





- Detect via $\gamma p \rightarrow K^+K^+(X^-)$
- Possible production through decay of excited hyperons
- High spin hyperon resonances needed ($J \geq 3/2$)

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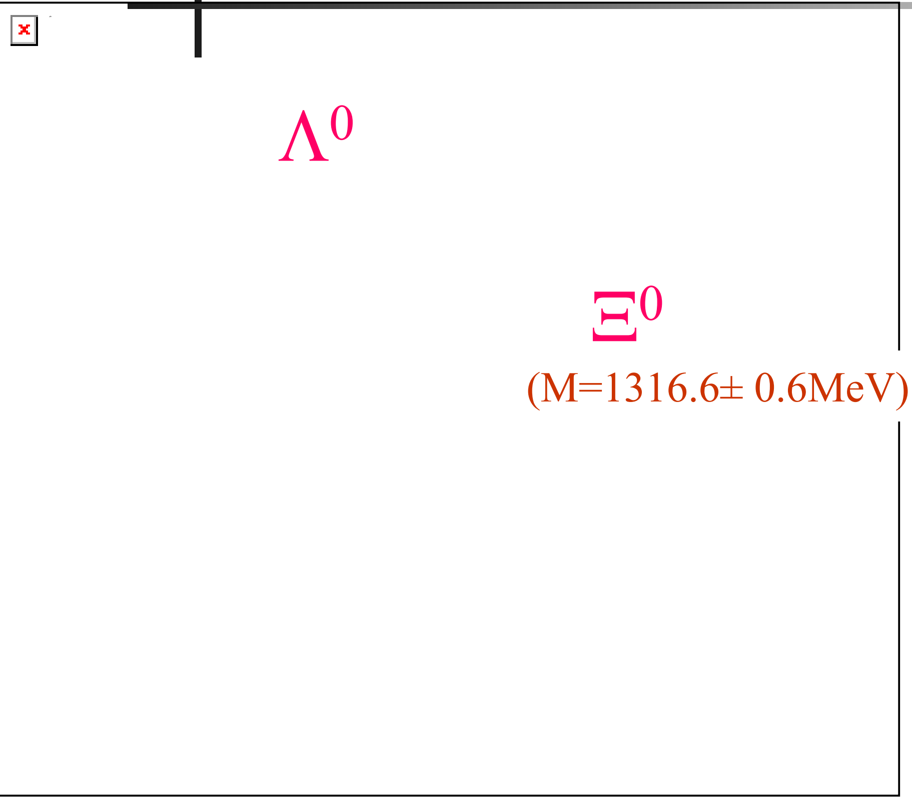
Ξ^0 Production: S=-2 physics



Isospin Multiplet	ΔM (MeV) (PDG)
π^+/π^0	4.5936
D^+/D^0	4.79
p/n	1.293318
Σ^-/Σ^0	4.807
Ξ^-/Ξ^0	6.48±0.24

CLAS: $M(\Xi^-)-M(\Xi^0)=5.5\pm1.8$MeV

- Detect via $\gamma p \rightarrow K^+K^+\pi^-(X^0)$; Λ is from $\Xi^-\rightarrow\Lambda\pi^-$ decay
- Mass splitting consistent with PDG value

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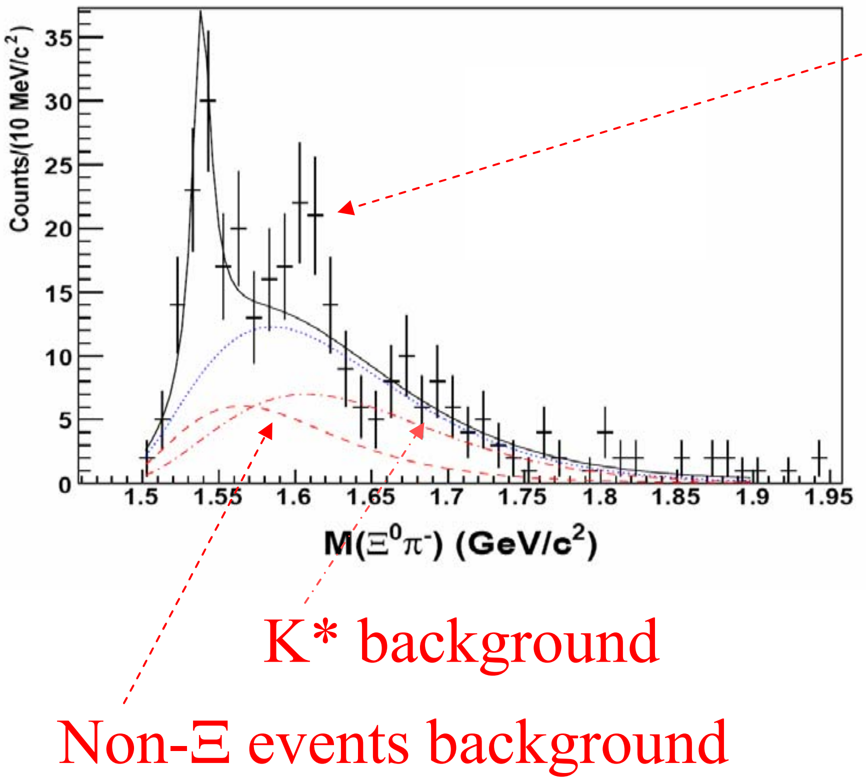
$\pi^-\Xi^0$ Search for excited Ξ states

PDG

Excited cascades	Mass (GeV)	Width (MeV)	BR to $\Xi\pi$
$\Xi^{-0}(1530)$	1.535	9.1	100%
$\Xi^0(1620)$ (*)	1.6-1.63	~22	$\Xi\pi$
$\Xi^{-0}(1690)$ (***)	1.69	<30	seen



$\Xi^-(1620)$ plausible, but not significant
Interest: Dynamical generation of $J^\pi=1/2^-$ meson-baryon resonances à la
Ramos, Oset, Bennhold: PRL **89** 252001 (2002).

Further study of excited states:
- Higher energy/statistics CLAS 'g12' data under analysis now
- CLAS12 and Hall D in the 12 GeV era

Deuteron Target Data: n*'s

- CLAS "g13" data set – analysis in progress…
  - 40cm LD2 target
  - Circular polarized beam, 20G two-sector triggers
    - E_γ up to 2.6 GeV (2006)
  - Linear polarized beam, 30G one-track triggers
    - E_γ in 6 bins between 1.1 and 2.3 GeV (2007)

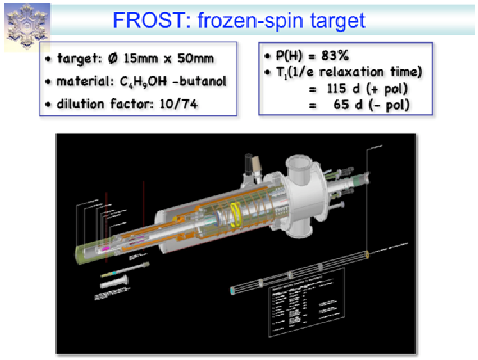
- γ n (p)→K^0 $\{\Lambda,\Sigma^0\}$ (p) neutron cross sections, spin observables
  - Completes the set of isospin channels (P. Nadel-Turonski)

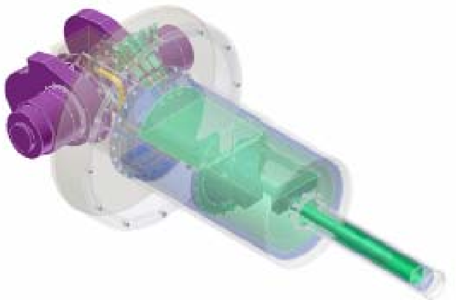
- γ n (p) →K^{+*} $\{\Sigma^-, \Sigma^{-*}\}$ (p) neutron cross sections, beam asymmetry
  - Requires neutron detection (E. Munevar, P. Mattione, PhD work)

- γ p (n)→K^+ $\{\Lambda,\Sigma^0\}$ (n) quasi-free proton cross sections, spin obs.
  - Raw linear polarization asymmetries seen (R. Johnstone PhD work)
  - ΛN potential from rescattering: high missing momentum

Further future prospects

- FROST (g9b)
  - Polarized target (C_4H_9OH)
  - and polarized photon beams: $\vec{\gamma}\ \vec{p}$
  - “complete” experiments
  - Runs 3-10 to 7-10
- HD-ice (g14)
  - New polarized target ($\vec{H}\vec{D}$)
  - Neutron data: $\vec{\gamma}\ \vec{n}$
  - Runs 10-10 to 5-11
- CLAS12
  - RICH detector in planning stages





Other (Omitted) topics

- $\Lambda(1520)$ cross sections
- $\Sigma(1385)$ cross sections
- K* cross section measurements
  - See K. Hicks talk, Session 1-A, 3
- ϕ ($s\bar{s}$) photoproduction at large t
- Pentaquarks
  - Θ^+ ϕ interference signal search

Summary: CLAS Hyperons

- KY photo- and electro-production offer kinematic and analysis advantages in N* physics
- Published CLAS KY results on proton (σ, P, C_x, C_z) have favored a $P_{13}(1900)$ (not $P_{11}(1900)$ or $D_{13}(1900)$)
- More observables to be published soon (more σ, P; Σ, O_x, O_z); others (G, E, L_x, L_z) are in the analysis pipeline (FROST)
- $\Lambda(1405)$ lineshapes into $\Sigma\pi$ showing non-Breit-Wigner structure; $J^\pi = \frac{1}{2}^-$ is confirmed
- Known Ξ hyperons measured in photoproduction
- Results on the neutron (D) coming in 1-2 years (g13, HD-ice)