$K^*(892)^0 \Lambda$ and $K^+ \Sigma^*(1385)^-$ Photoproduction on the Deuteron

Paul Mattione, Carnegie Mellon University
for the CLAS Collaboration
supported by the DOE Office of Science

Outline

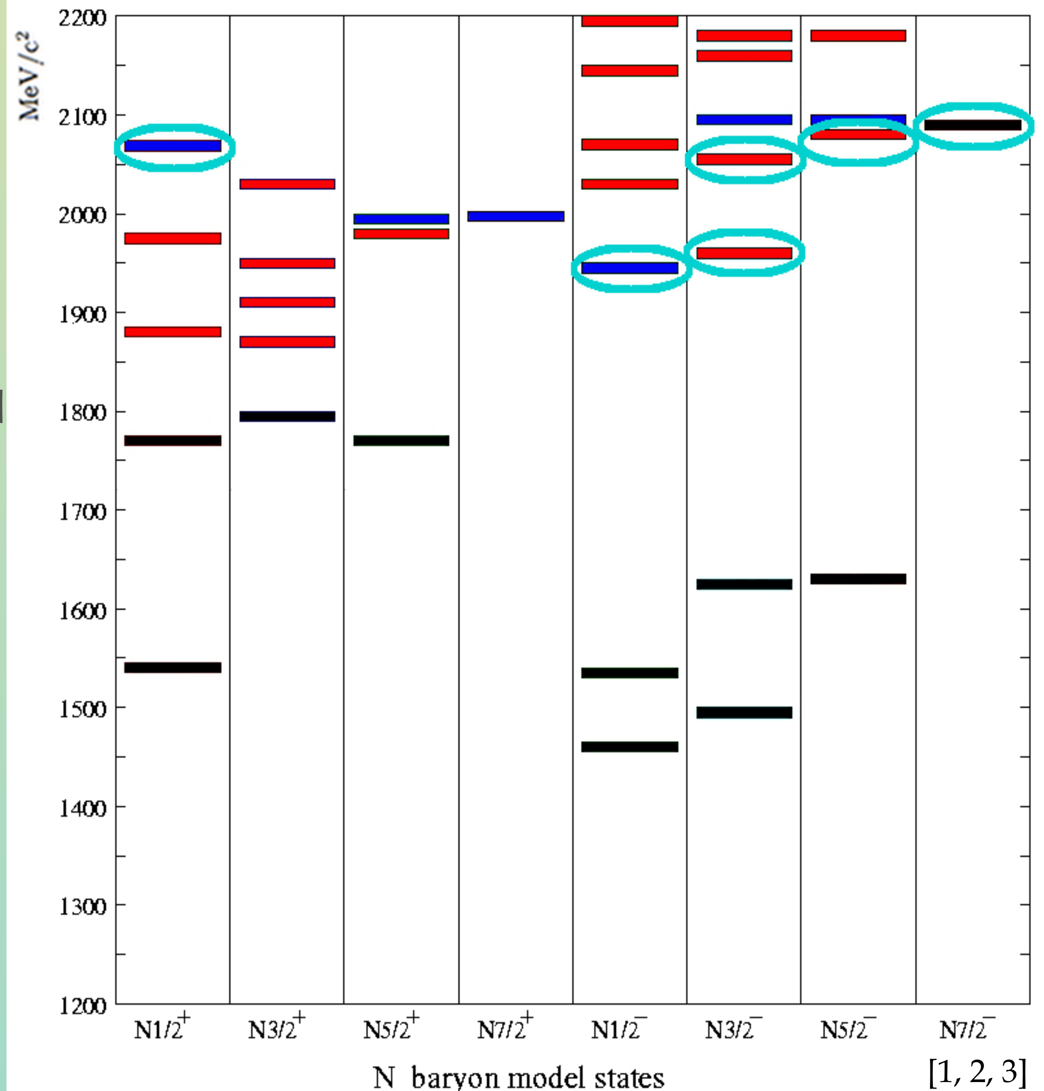
- Introduction to N*'s
- CLAS g13 experiment & analysis
- Results
  - $\gamma n \longrightarrow p \pi^-$ differential cross section (not shown)
    - Compared to published data: validated g13 data, analysis procedures
  - $\gamma n \longrightarrow K^*(892)^0 \Lambda$ & $\gamma n \longrightarrow K^+ \Sigma^*(1385)^-$ differential cross sections
  - $\gamma n \longrightarrow K^*(892)^0 \Lambda$ & $\gamma n \longrightarrow K^+ \Sigma^*(1385)^-$ potential interference
- Summary & conclusions

Introduction to N*'s

Searching for N* Resonances

- "Missing" N* resonances [1]
  - Wide, overlapping
  - Correlated quark-pair? [4]
- N* decays: KY, **K*Y**, KY*
  - Couplings sizable vs. Nπ [3]
  - Sparse γn data vs. γp
    - Amplitudes (isospin)
- No known $\gamma n \rightarrow K^*(892)^0 \Lambda$ cross section measurements

Legend
Black: Established [3]
Blue: Inconclusive [3]
Red: Unobserved [3]
Cyan: $\gamma N \rightarrow K^*(892)\Lambda$ [5]

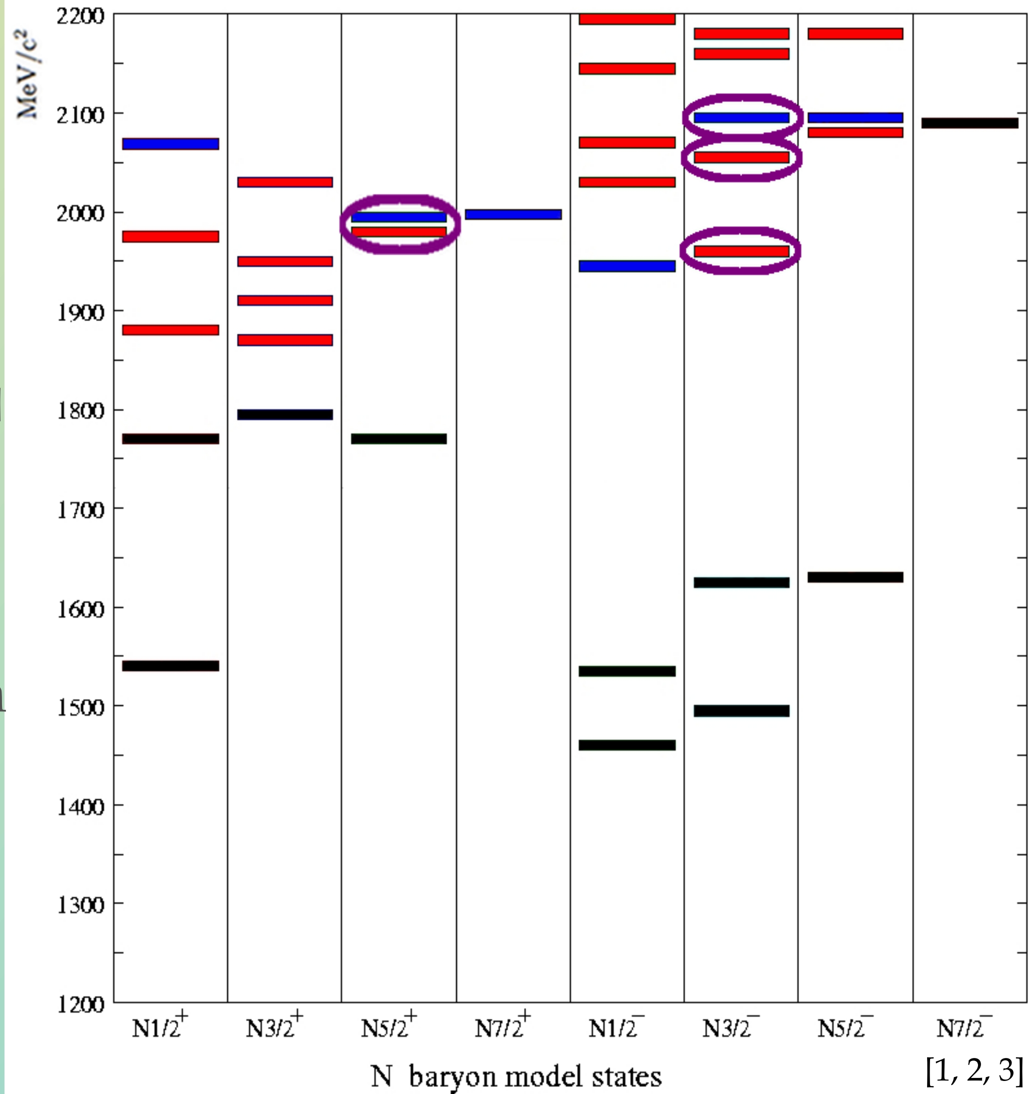


[1, 2, 3]

Searching for N* Resonances

- "Missing" N* resonances [1]
  - Wide, overlapping
  - Correlated quark-pair? [4]
- N* decays: KY, **K*Y**, KY*
  - Couplings sizable vs. N π [3]
  - Sparse γ n data vs. γ p
    - Amplitudes (isospin)
- LEPS $\gamma n \longrightarrow K^+ \Sigma^*(1385)^-$ data limited to low-θ [6]

Legend
Black: Established [3]
Blue: Inconclusive [3]
Red: Unobserved [3]
Violet: $\gamma N \longrightarrow K \Sigma^*(1385)$ [5]

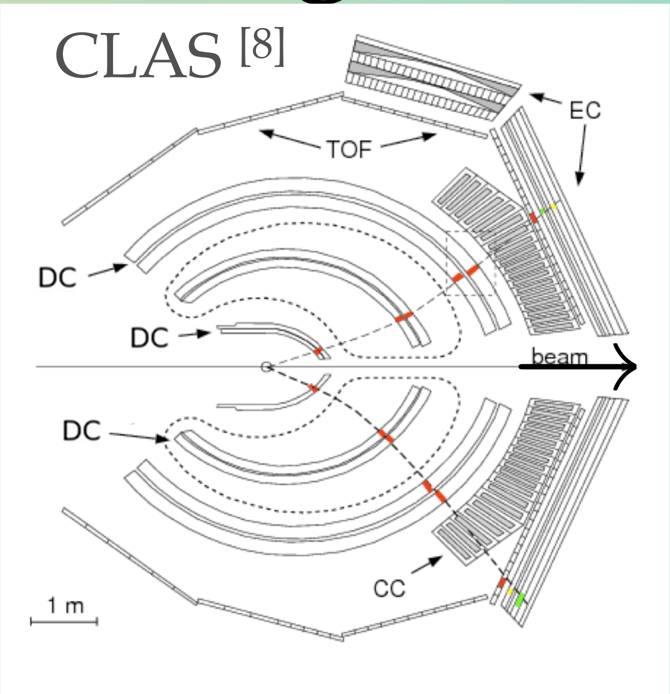


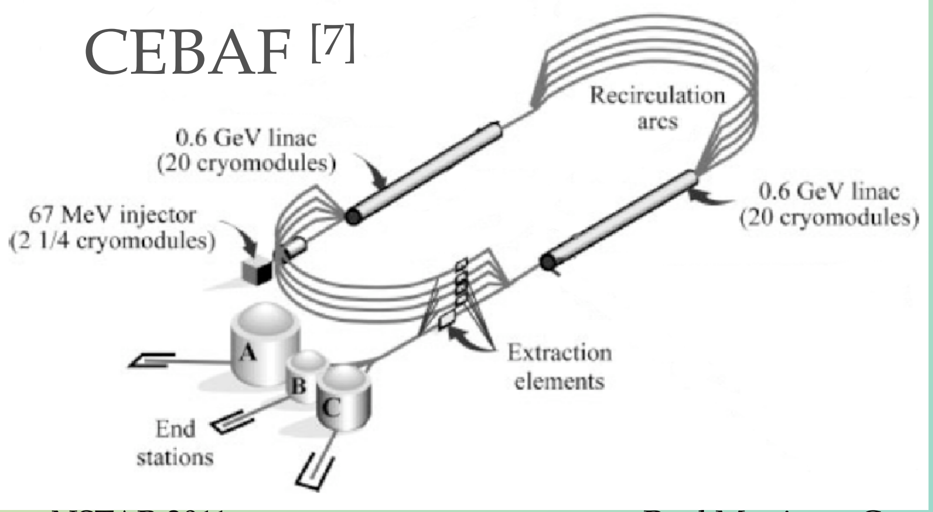
[1, 2, 3]

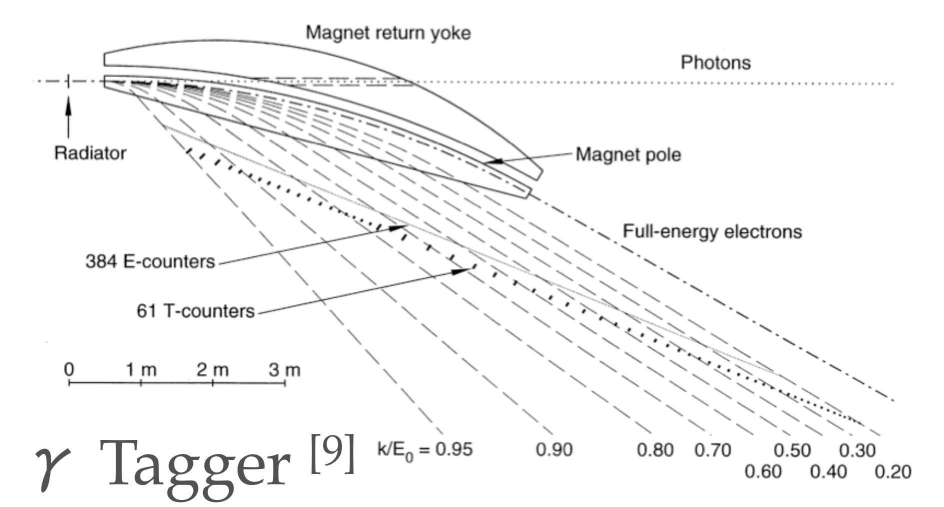
CLAS g13 Experiment and Analysis

JLab: CEBAF, CLAS, & g13

- JLab CEBAF accelerator: up to 6 GeV e⁻ [7]
- CLAS detector (Hall B) [8]
  - DC: Tracking, TOF: Timing
- g13 experiment: 10/06 – 06/07, LD_2 target
  - Analysis: E_{e-} = 2.655 GeV, circularly polarized γ's
- γ beam: radiator, γ tagger detects e⁻ [9]

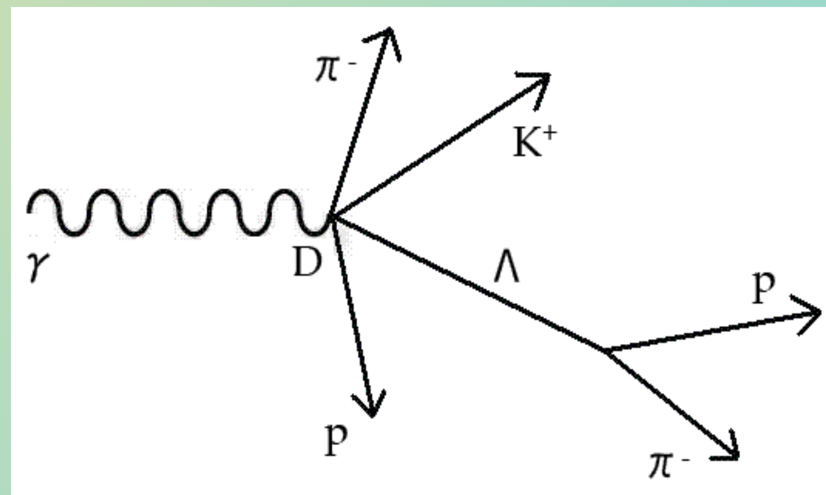


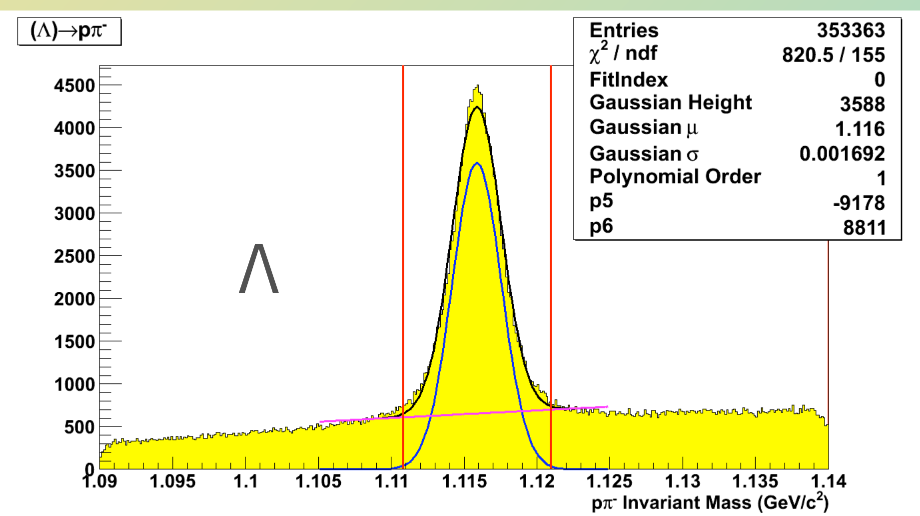


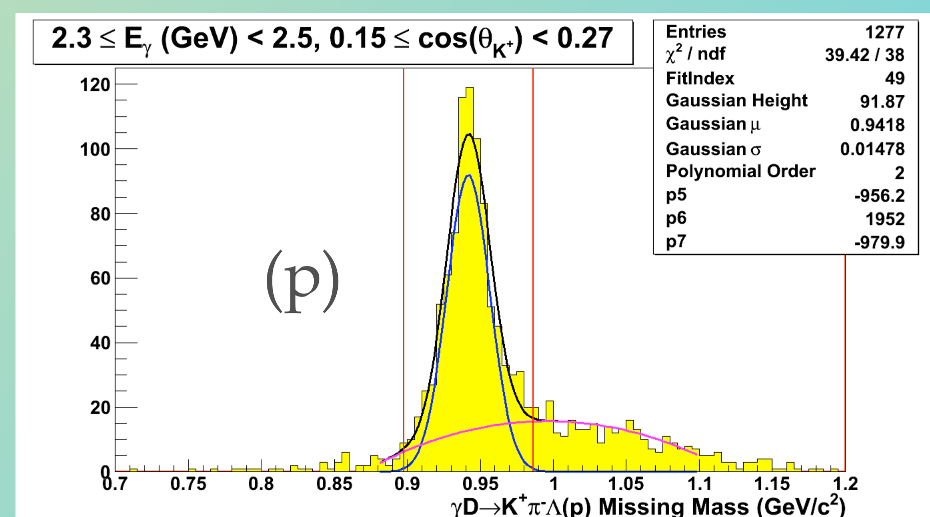


Event Selection

- $\gamma n \rightarrow K^*(892)^0 \Lambda$ & $\gamma n \rightarrow K^+ \Sigma^*(1385)^-$
  - $K^{*0} \rightarrow K^+ \pi^-$, $\Sigma^{*-} \rightarrow \Lambda \pi^-$
  - Λ, final state: (p), p, K^+, π^-, π^-
  - Similar, studied simultaneously
- Λ invariant mass
- Spectator proton missing mass

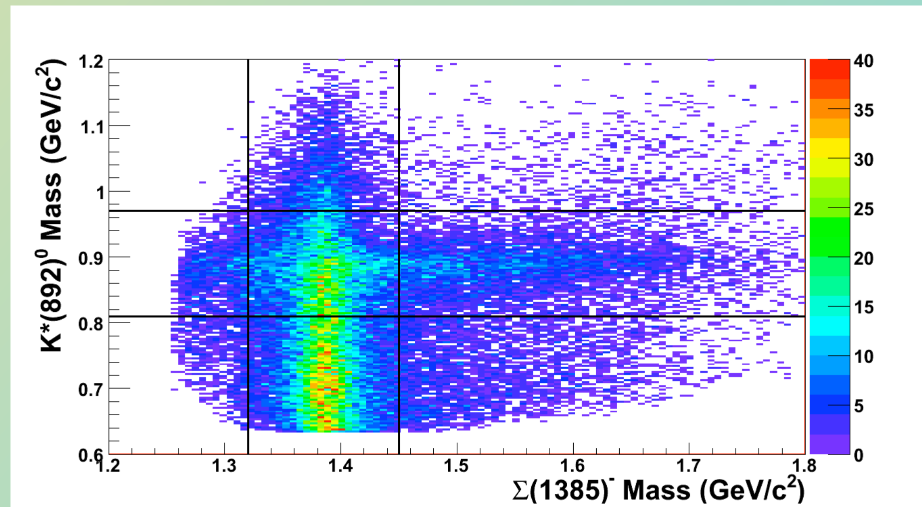


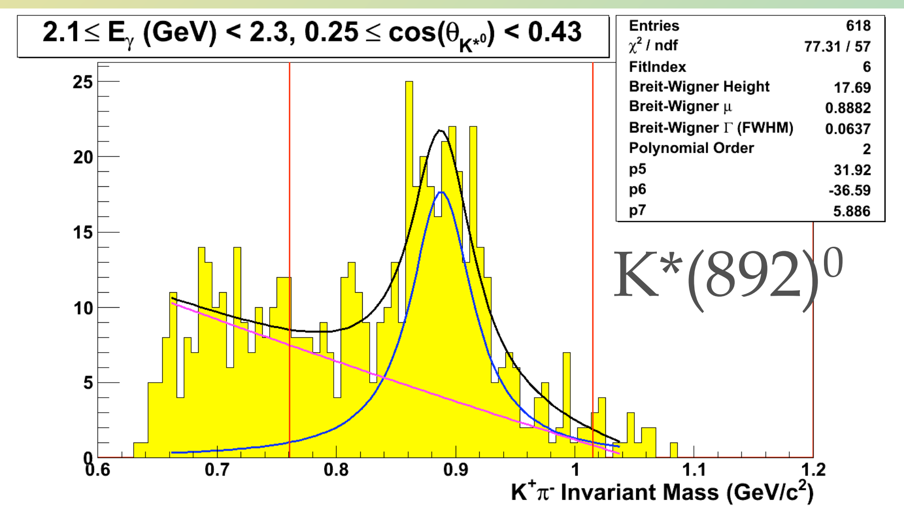


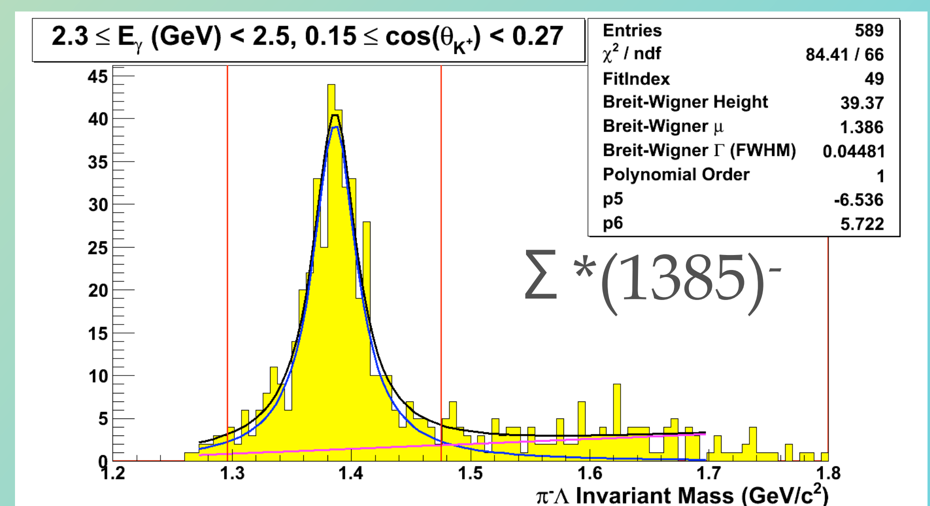


Yield Extraction

- Reactions may interfere, cut majority of overlap
  - ±1 Γ K^{*0}, Σ^{*-} Cuts (70.5%)
- Yield: $K^*(892)^0$, $\Sigma^*(1385)^-$ mass cuts
- (γ), (π^0) backgrounds ($K^{*0}\,\Sigma^0$)
  - Scale $\delta\sigma$'s assigned







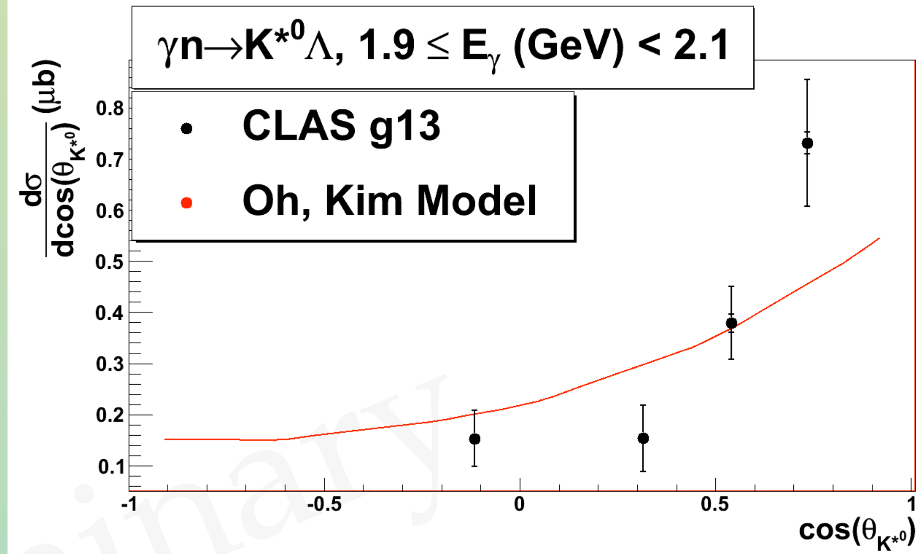
~ 4100 $\gamma n \longrightarrow K^*(892)^0 \Lambda$ events

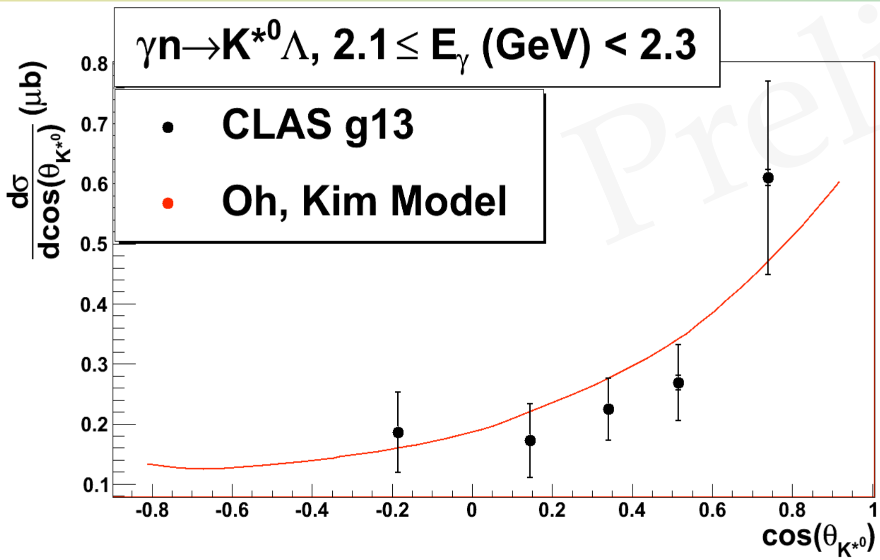
~ 18000 $\gamma n \longrightarrow K^+ \Sigma^*(1385)^-$ events

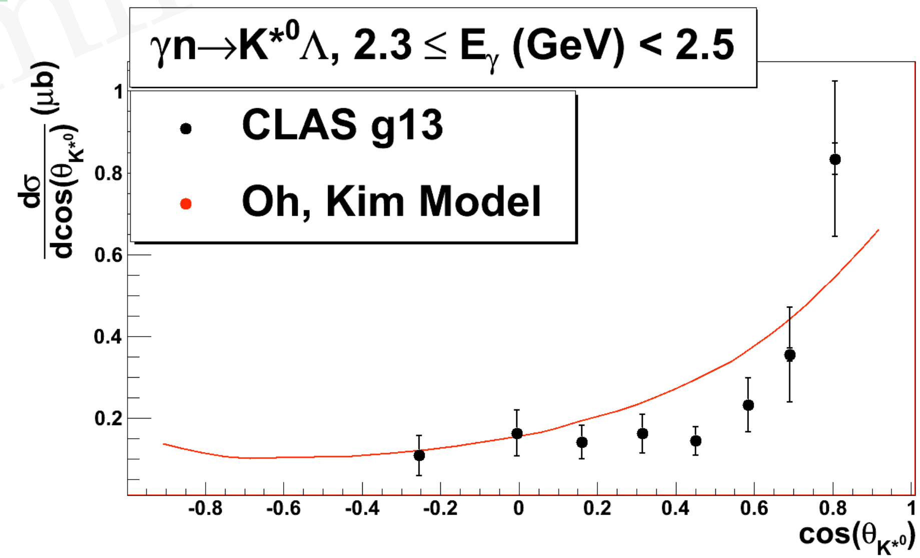
Results

$\gamma n \to K^*(892)^0 \Lambda$ Cross Section

- Preliminary, no published data
- (γ), (π^0) background scale $\delta\sigma$'s:
  - By E_γ: ~5.4%, ~15.0%, ~18.0%
- Total $\delta\sigma$'s: ~16.9% - ~45.6%

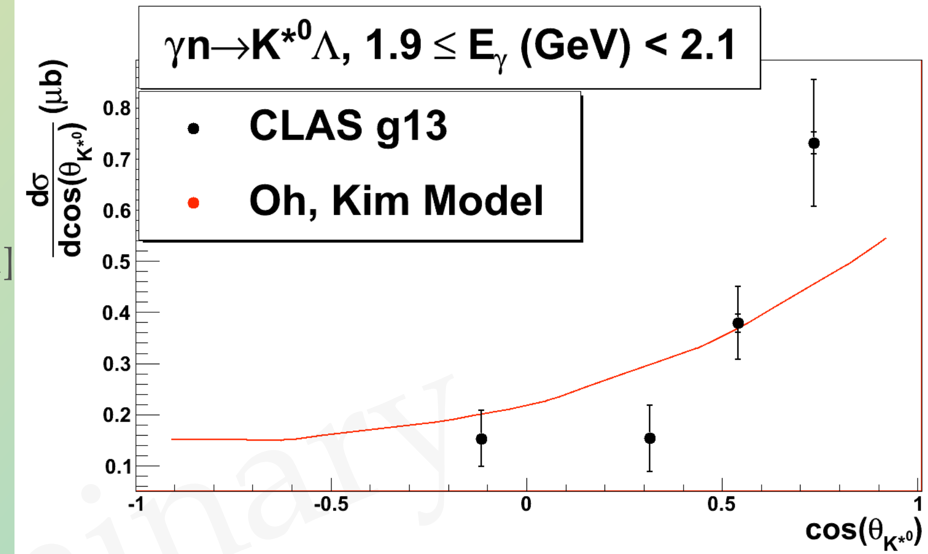


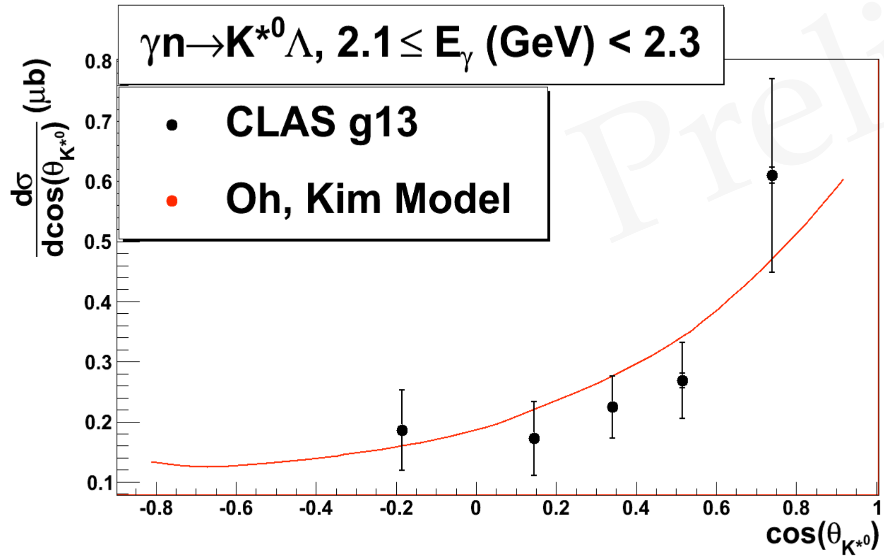


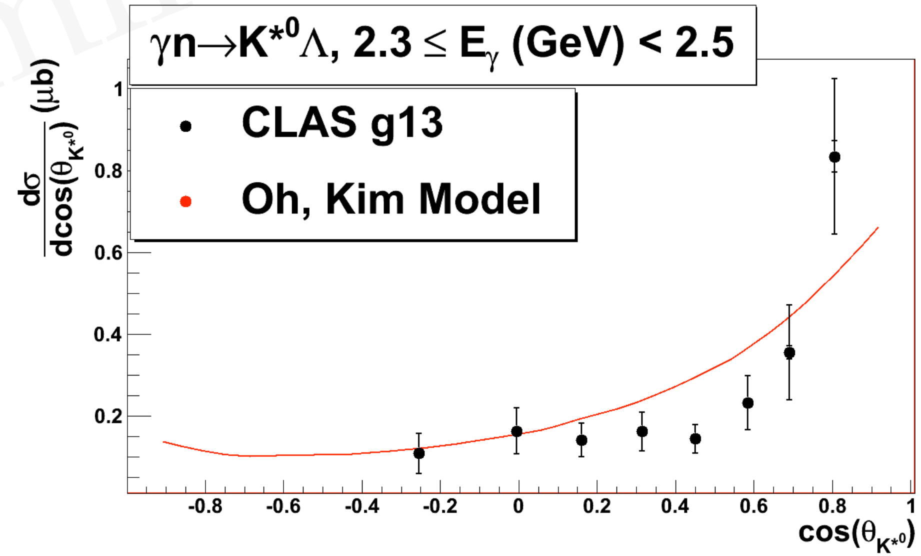


$\gamma n \rightarrow K^*(892)^0 \Lambda$ Cross Section

- Oh, Kim model [10]:
  - Effective Lagrangians
  - Partial constraint: $\gamma p \longrightarrow K^{*+} \Lambda$ preliminary total cross section [11]
  - Dominated by t-channel K^0
  - No resonances included
  - $\delta\sigma$'s not quoted

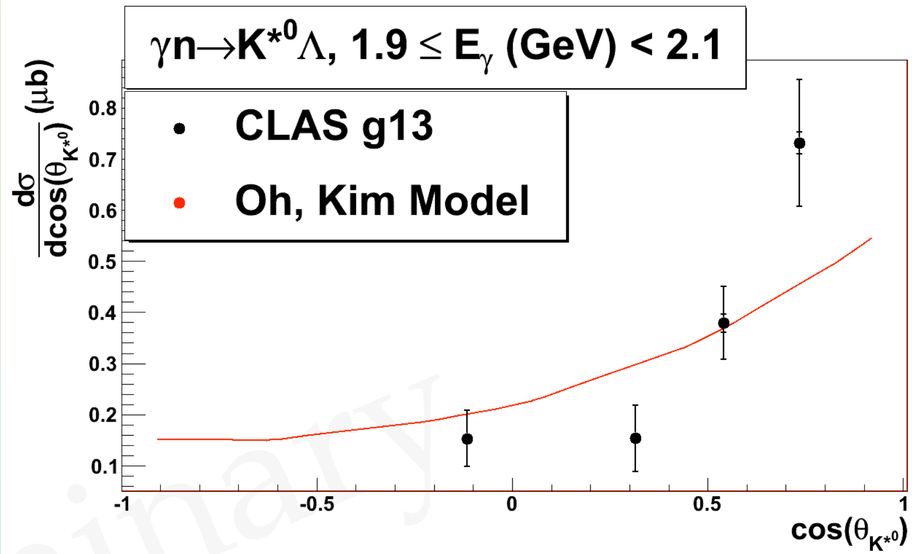


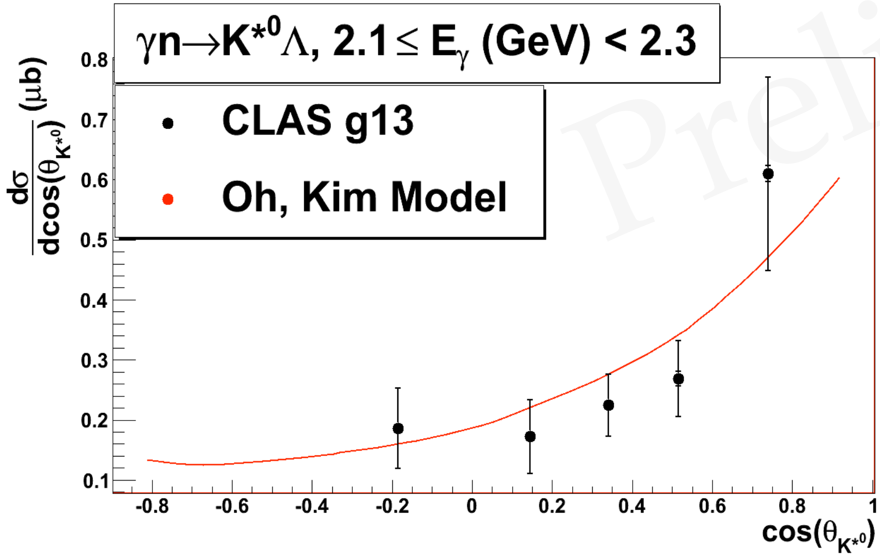


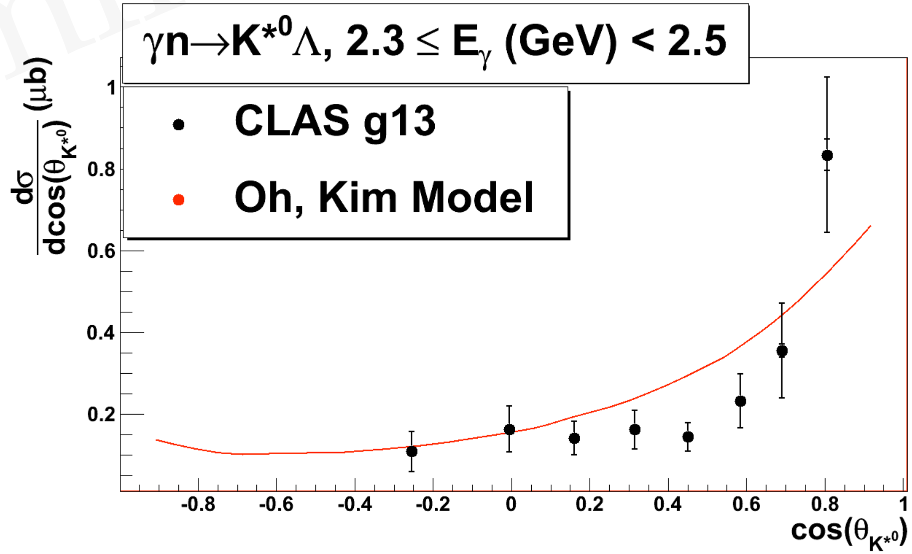


$\gamma n \rightarrow K^*(892)^0 \Lambda$ Cross Section

- Preliminary $\gamma p \longrightarrow K^{*+} \Lambda$ corrected (1.5x larger [12])
  - Interpretation difficult
- Low-θ : t-channel dominated
- g13 t-slope > model t-slope
- Model ~12.1% < g13, within $\delta\sigma$'s

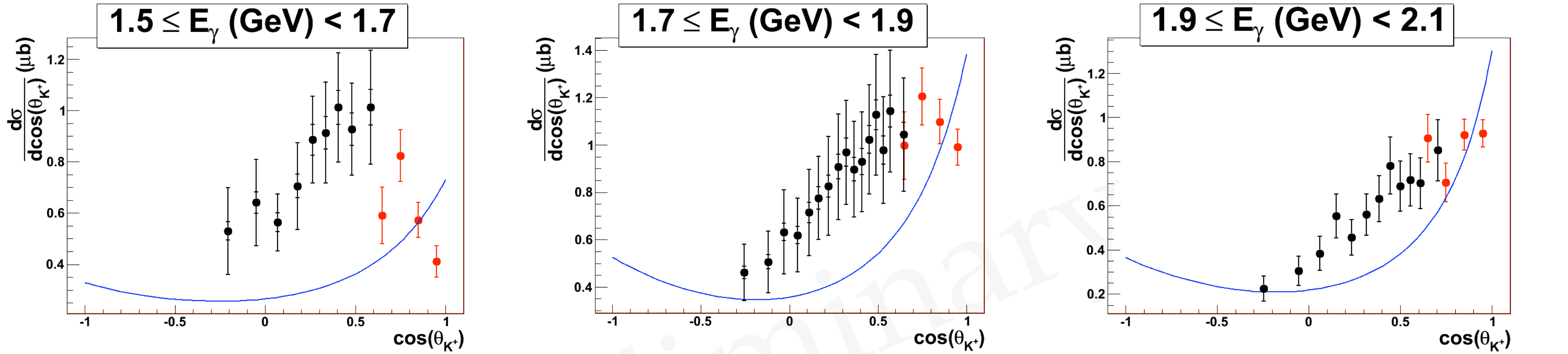


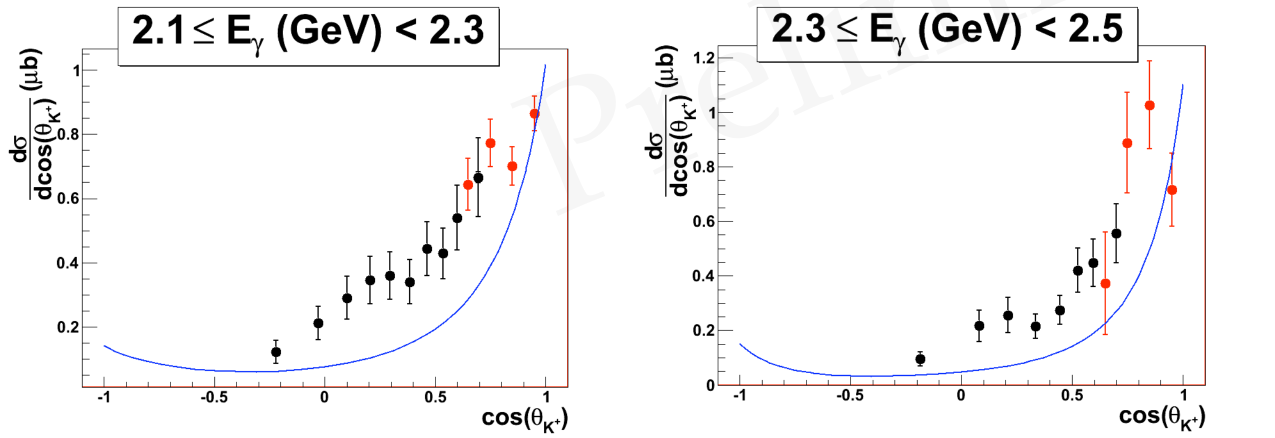




$\gamma n \rightarrow K^+ \Sigma^*(1385)^-$ Cross Section

- Data: preliminary CLAS g13, LEPS
- g13 total $\delta\sigma$'s: ~16% – ~32%
- (γ), (π^0) background scale $\delta\sigma$'s: ~4.0% – ~6.8%

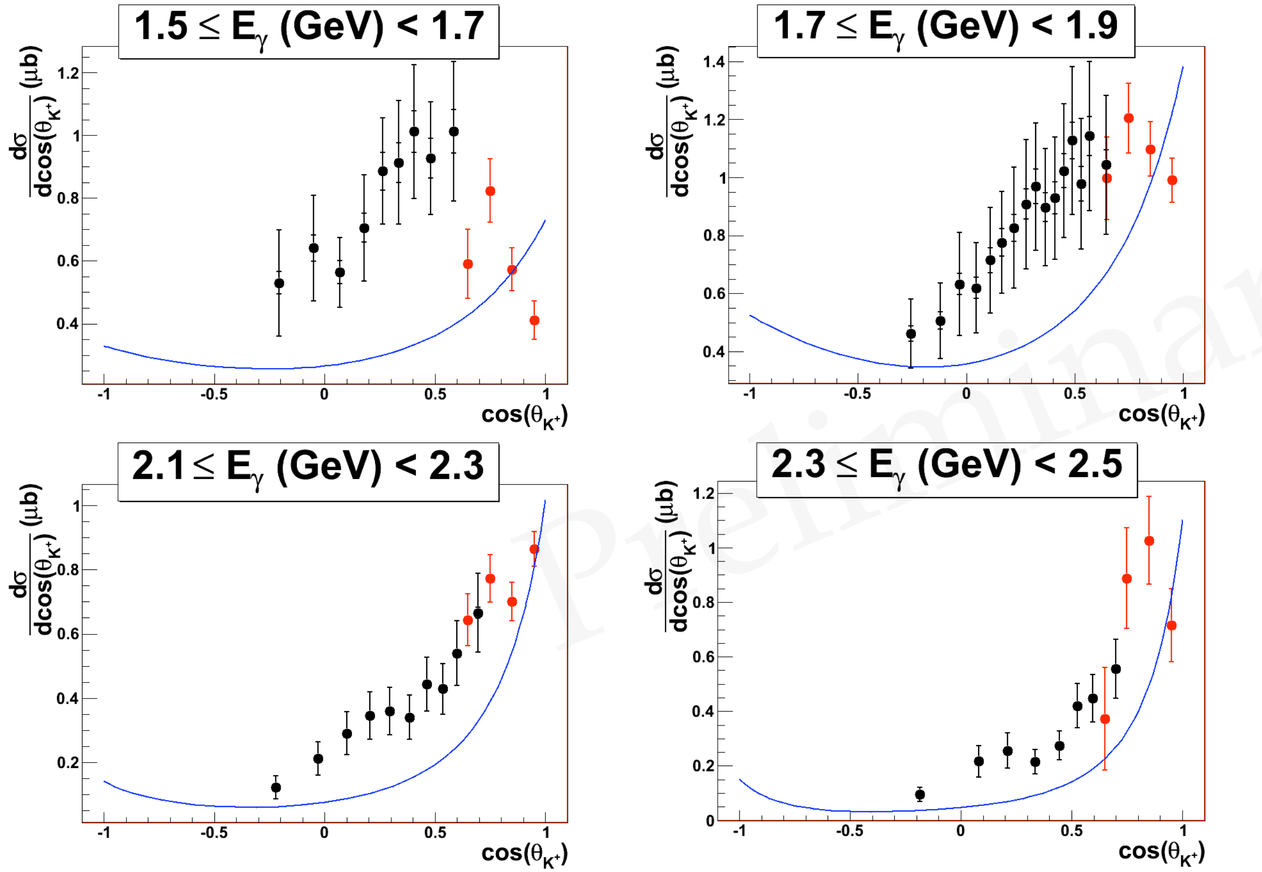




Legend
Black: CLAS g13 (preliminary)
Blue: Oh, *et. al* Model [13]
Red: LEPS [6]

$\gamma n \rightarrow K^+ \Sigma^*(1385)^-$ Cross Section

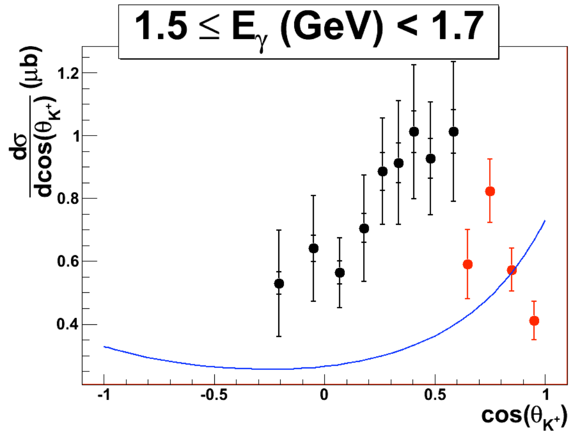
- Oh, *et. al* model [13]: effective Lagrangians, model $\delta\sigma$'s not quoted
  - Partially constrained by $\gamma p \rightarrow K^+ \Sigma^{*0}$ preliminary total cross section [11]
  - Dominated by t-channel K^+ and K^{*+}, some N^*'s and Δ^*'s included
    - $N\frac{1}{2}^-(1945), N\frac{3}{2}^-(1960), N\frac{3}{2}^-(2095), N\frac{5}{2}^-(2095), N\frac{5}{2}^+(1980)$

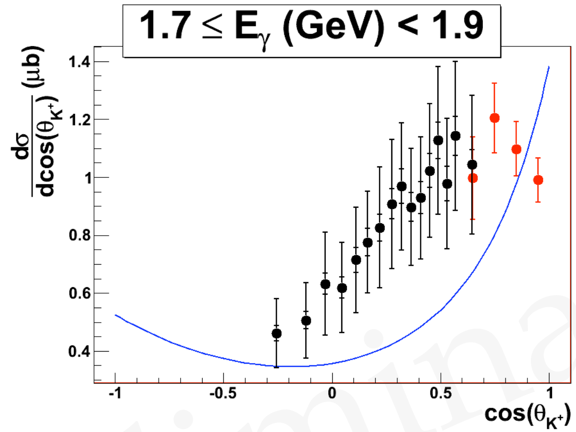


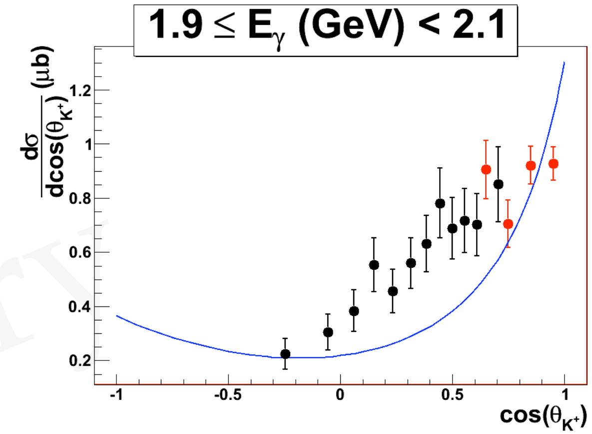
Legend
Black: CLAS g13 (preliminary)
Blue: Oh, *et. al* Model [13]
Red: LEPS [6]

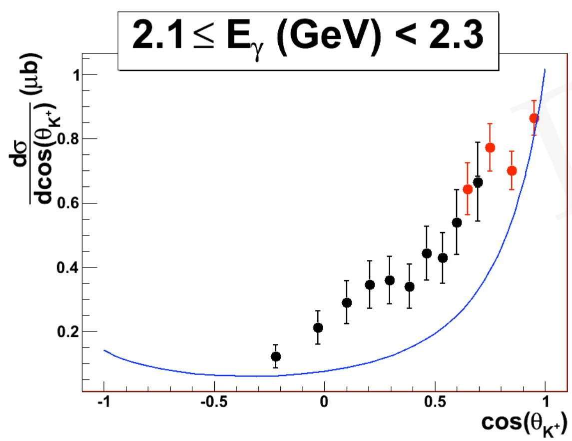
$\gamma n \rightarrow K^+ \Sigma^*(1385)^-$ Cross Section

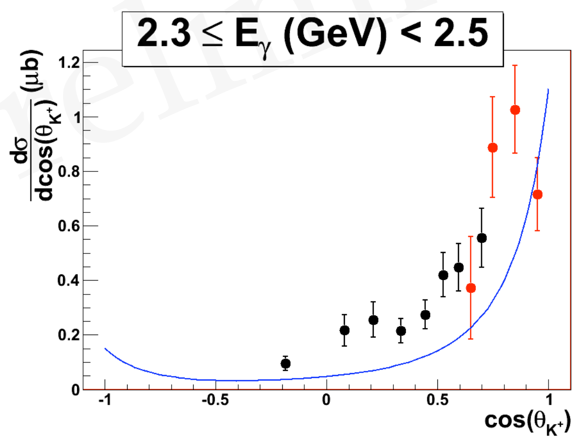
- Low-θ : t-channel dominated
- Matching: g13 & LEPS close, model ~57% < g13
- Difference with model: not necessarily N*'s: t-channel?







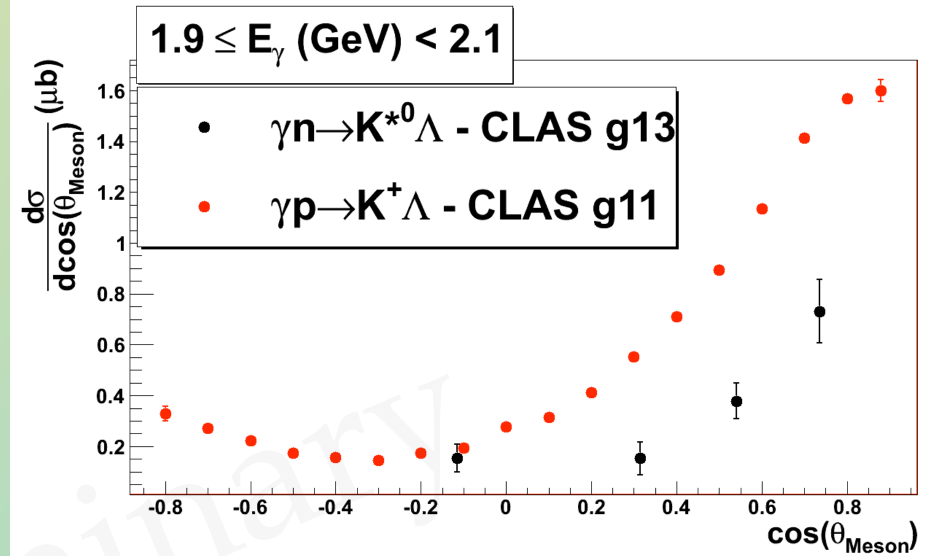


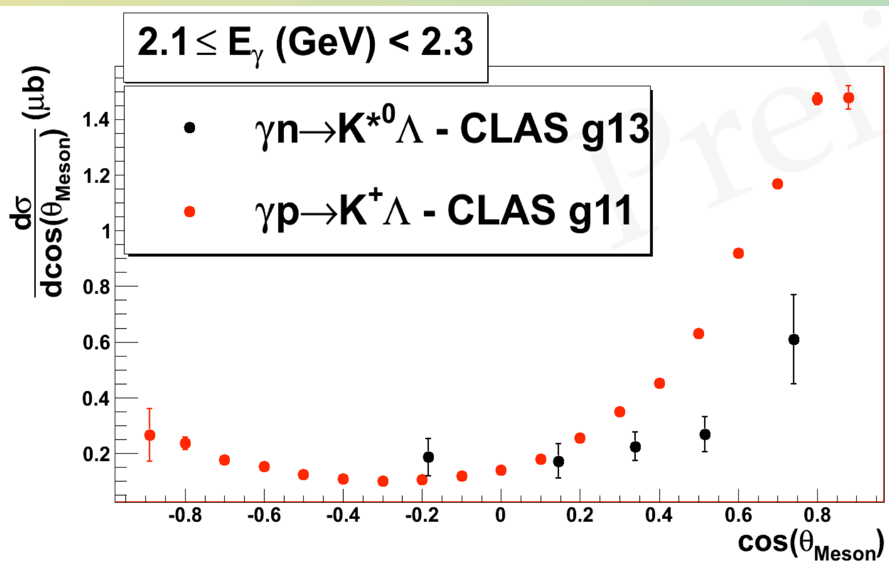


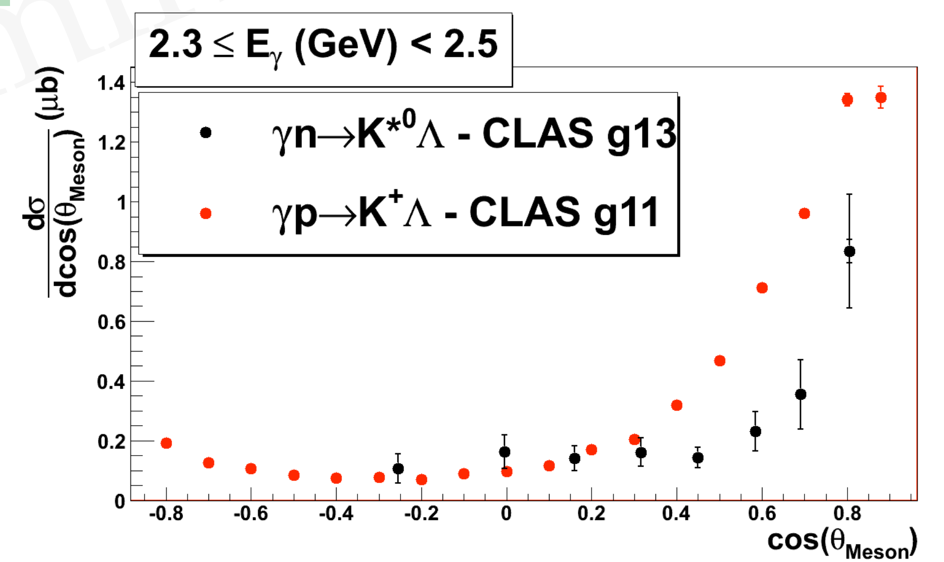
Legend
Black: CLAS g13 (preliminary)
Blue: Oh, *et. al* Model [13]
Red: LEPS [6]

$\gamma n \rightarrow K^*(892)^0 \Lambda$ vs. $\gamma p \rightarrow K^+ \Lambda$

- ~Comparison vs. ground state [14] (no $\gamma n \rightarrow K^0 \Lambda$ yet)
  - Low-θ : $K^+ \Lambda$ ~56% > $K^{*0} \Lambda$
  - Mid-θ, high-E_γ: similar
- Rescattering through πN:
  - ~20% effect on $K \Lambda$ [15]
  - $K^* \Lambda$ sizable vs. $K \Lambda$
  - $K^{*0} \Lambda$: N* coupled-channels

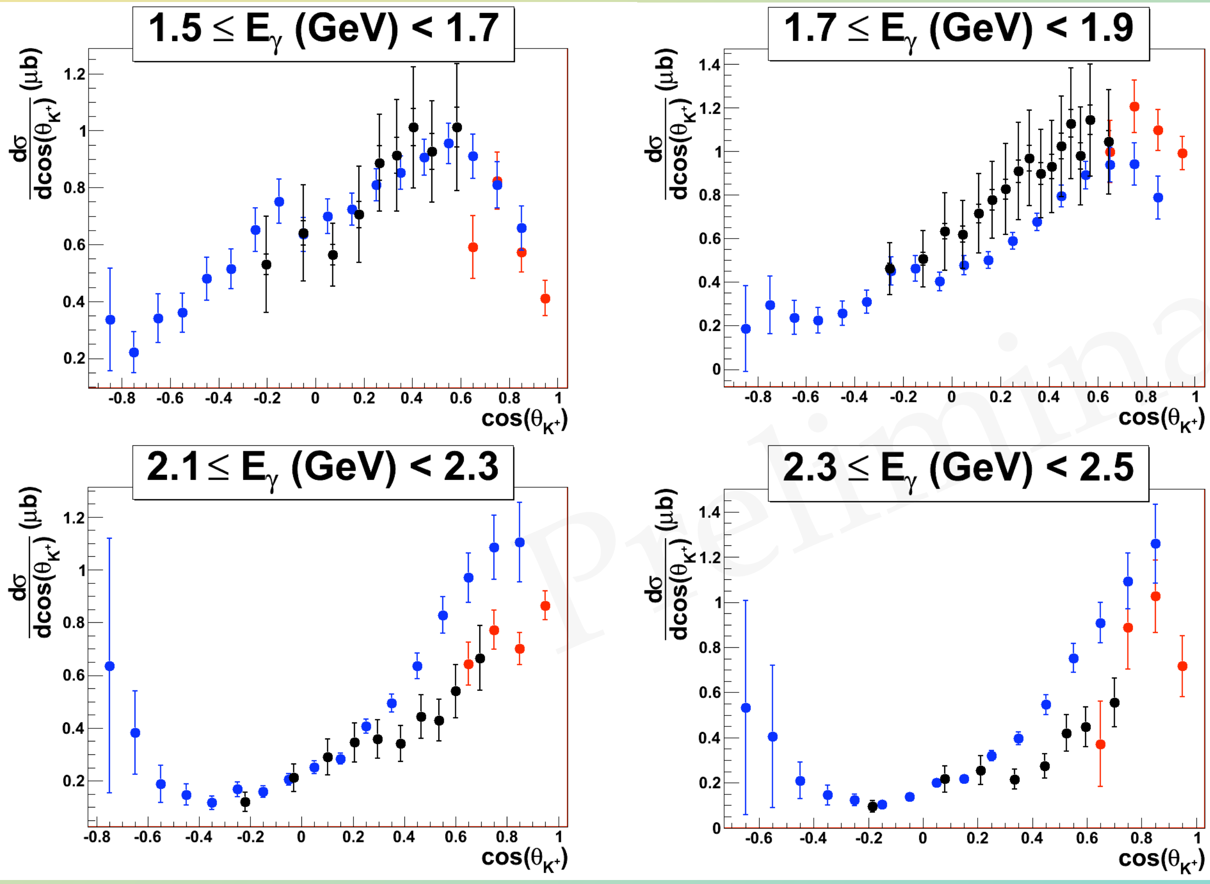






$\gamma n \rightarrow K^+ \Sigma^*(1385)^-$ vs. $\gamma n \rightarrow K^+ \Sigma^-$

- Scale comparison vs. ground state [16]
- $\gamma n \rightarrow K^+ \Sigma^-$ larger at low-θ in high-E_γ bins, similar elsewhere
- $K \Sigma^*(1385)$: N* coupled-channels analyses



Legend

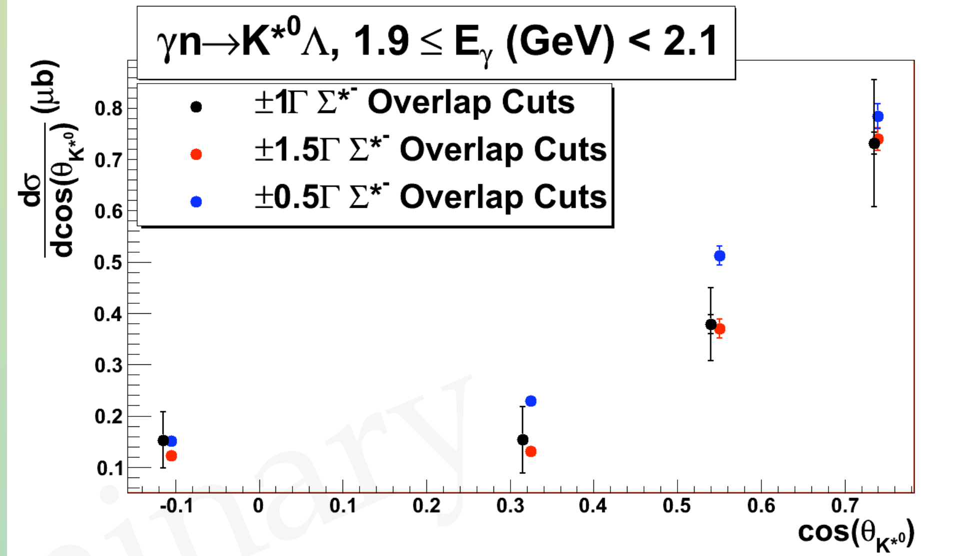
Black: g13 $\gamma n \rightarrow K^+ \Sigma^*(1385)^-$

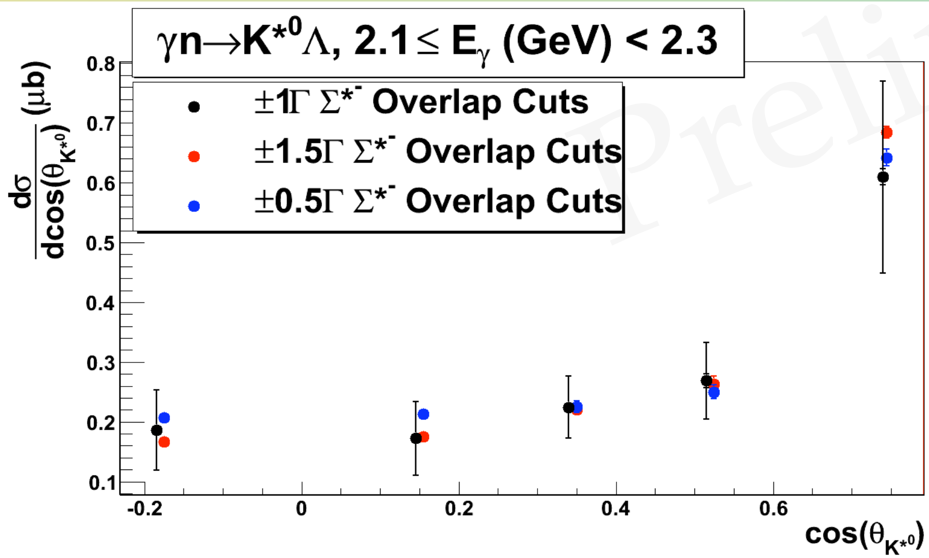
Red: LEPS $\gamma n \rightarrow K^+ \Sigma^*(1385)^-$ [6]

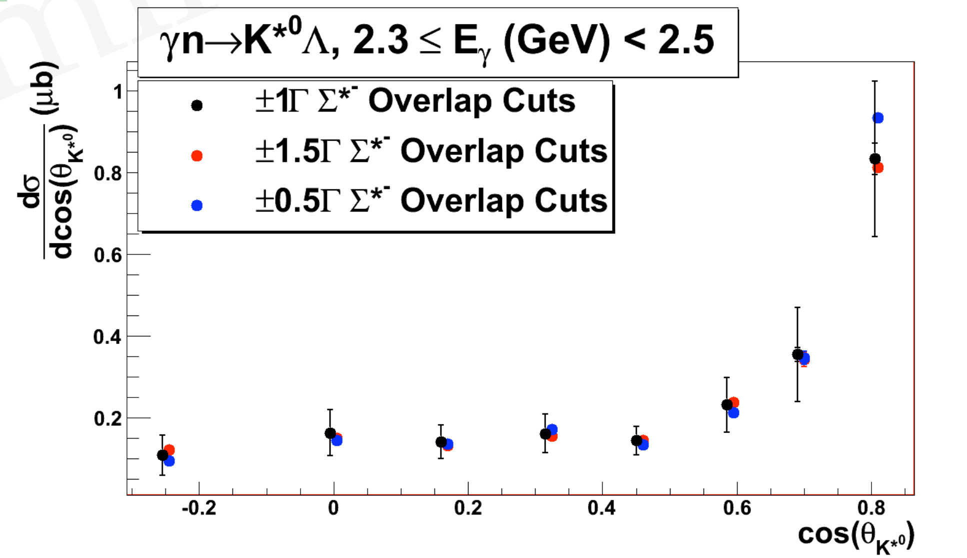
Blue: CLAS g10 $\gamma n \rightarrow K^+ \Sigma^-$ [16]

$\gamma n \to K^{*0} \Lambda$: Σ^{*-} Overlap Cuts

- Studied potential interference:
  - Varied Σ^{*-} overlap cut width
- Nominal Σ^{*-} Cuts: $\pm 1 \Gamma$ (70.5%)
  - $\pm 0.5 \Gamma$ (50.0%) & $\pm 1.5 \Gamma$ (79.5%)
- Differences (< 18%) < K^{*0} Fit $\delta\sigma$'s
  - Potential interference < $\delta\sigma$'s

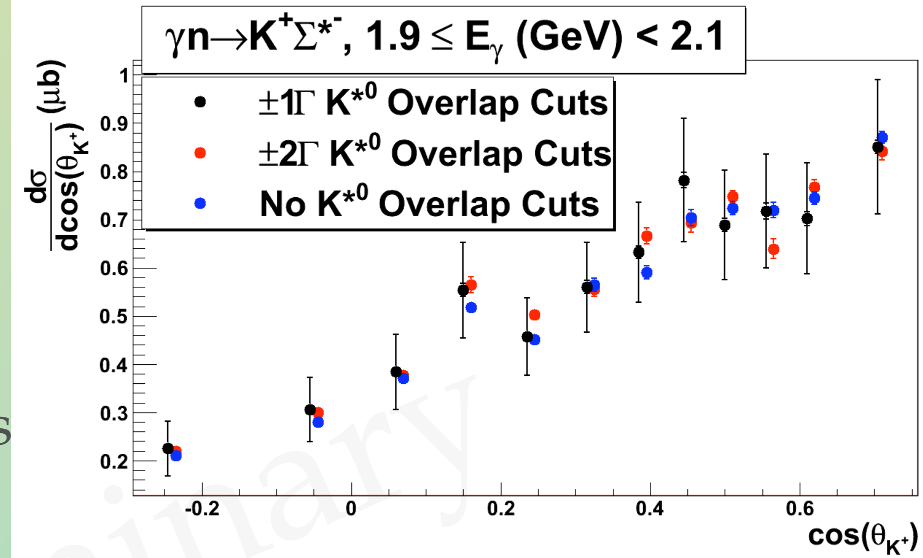


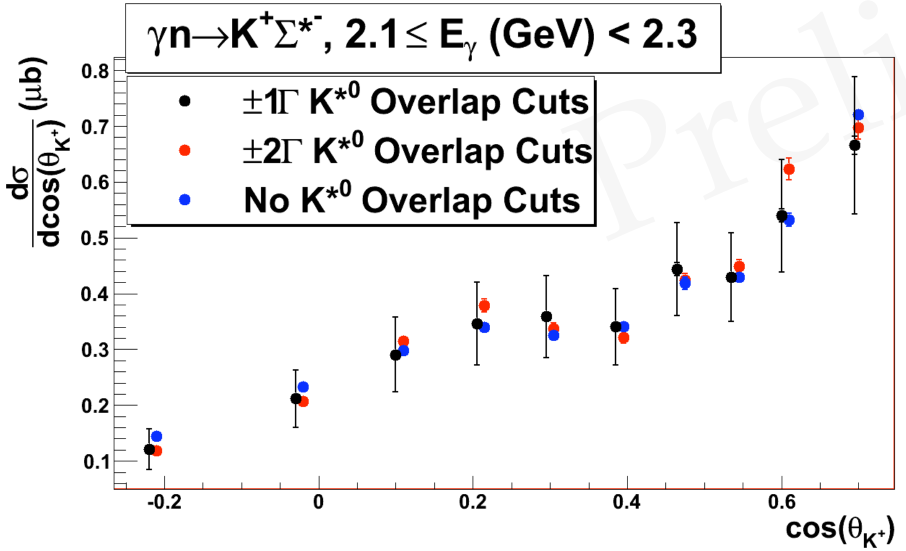


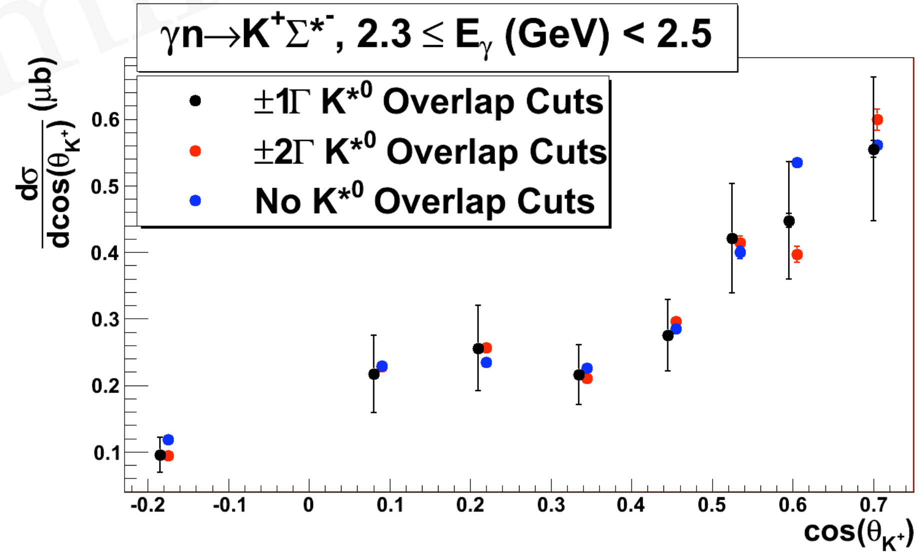


$\gamma\, n \rightarrow K^+ \Sigma^{*-}$: K^{*0} Overlap Cuts

- Studied potential interference:
  - Varied K^{*0} overlap cut width
- Nominal K^{*0} Cuts: $\pm 1\,\Gamma$ (70.5%)
  - No cuts & $\pm 2\,\Gamma$ (84.4%)
- Differences (< 4%) < Σ^{*-} Fit $\delta\sigma$'s
  - Potential interference < $\delta\sigma$'s







Summary & Conclusions

Summary & Conclusions

- N* spectrum: strong force and hadronic structure
  - Role of quark correlations: limit N* spectrum
  - Search in KY, K*Y, and KY* channels
- Preliminary $\gamma n \longrightarrow K^*(892)^0 \Lambda$ & $\gamma n \longrightarrow K^+ \Sigma^*(1385)^-$ cross sections
  - With theorist: N* couplings, greater understanding of interactions
  - Sizable vs. KY: include in coupled-channels analyses (rescattering)
  - Potential interference effects less than $\delta\sigma$'s
  - Can improve further: additional studies can reduce $\delta\sigma$'s to ~10 – ~20%
- These results will be published when the systematic uncertainties are reduced, and will contribute to the search for the N* resonances.

References

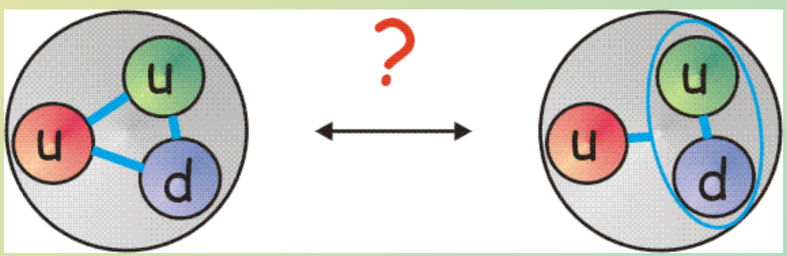
[1] S. Capstick and N. Isgur, Phys. Rev. D **34**, 2809 (1986).
[2] W. Roberts, http://www.physics.fsu.edu/users/roberts/roberts_hadrons.html
[3] K. Nakamura *et al.* (The Particle Data Group), J. Phys. G **37**, 075021 (2010).
[4] E. Santopinto, Phys. Rev. C **72**, 022201(R) (2005).
[5] S. Capstick and W. Roberts, Phys. Rev. D **58**, 074011 (1998).
[6] K. Hicks *et al.* (The LEPS Collaboration), arXiv:0812.0771 [nucl-ex] (2008).
[7] C. W. Leemann, D.R. Douglas, G.A. Krafft, Annu. Rev. Nucl. Part. Sci. **51**, 413 (2001).
[8] B. A. Mecking *et al.* (The CLAS Collaboration), Nucl. Instr. and Meth. A **503**, 513 (2003).
[9] D. I. Sober *et al.* (The CLAS Collaboration), Nucl. Instr. and Meth. A **440**, 263 (2000).
[10] Y. Oh, H. Kim, Phys. Rev. C **73**, 065202 (2006).
[11] L. Guo and D. P. Weygand (The CLAS Collaboration), arXiv:0601010 [hep-ex] (2006).
[12] L. Guo, Florida International University, Private Communication (2011).
[13] Y. Oh, C. M. Ko, K. Nakayama, Phys. Rev. C **77**, 045204 (2008).
[14] M. E. McCracken *et al.* (The CLAS Collaboration), Phys. Rev. C **81**, 025201 (2010).
[15] W-T. Chiang, F. Tabakin, T.-S. H. Lee, and B. Saghai, Phys. Lett. B **517**, 101 (2001).
[16] S. Anefalos Pereira *et al.* (The CLAS Collaboration), Phys. Lett. B **688**, 289 (2010).

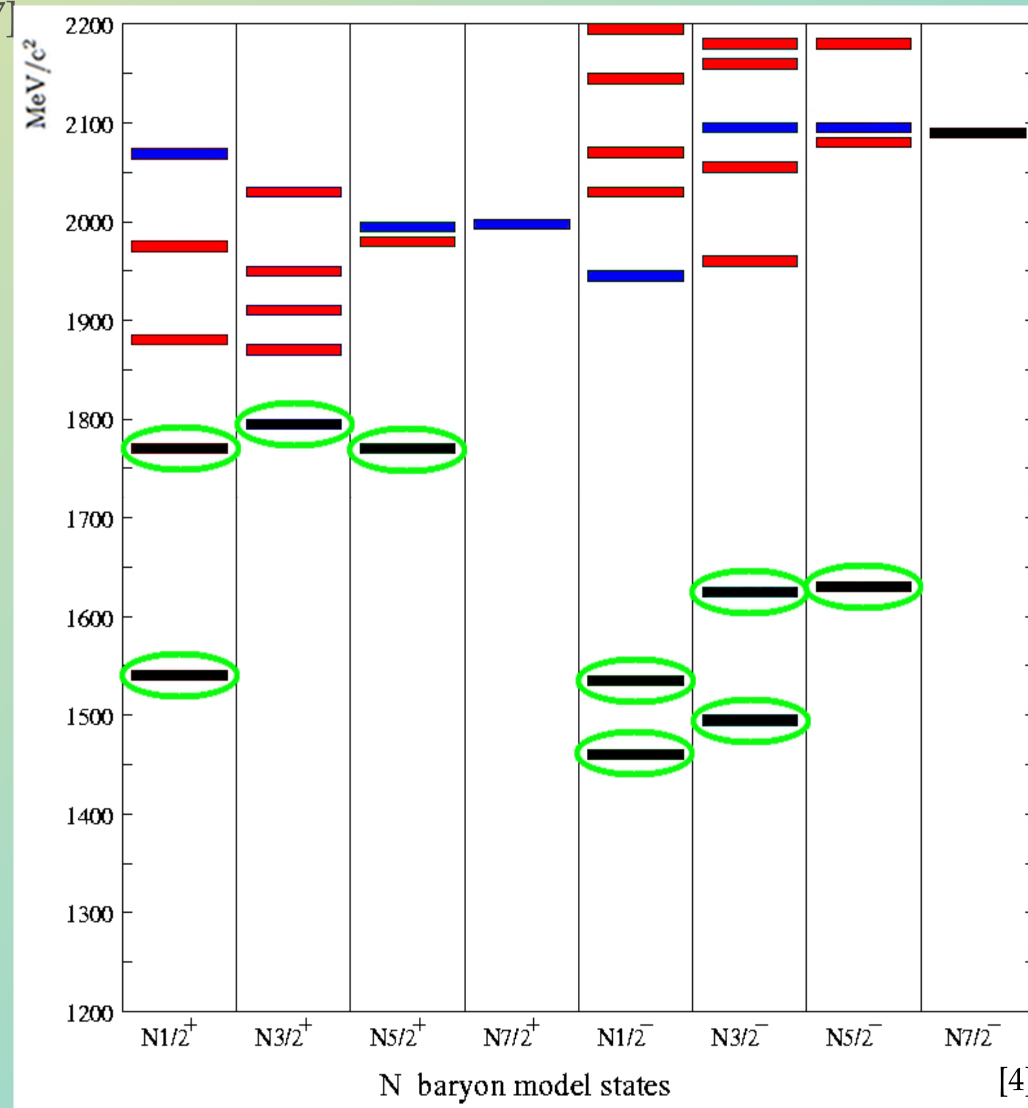
N*'s: Experimental Searches

PDG State (MeV/c^2)	L_{2I-2J}	Overall Status	Status in Channel						
			$N\pi$	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\rho$	$N\gamma$
$N(1440)$	P_{11}	****	****	*			***	*	***
$N(1520)$	D_{13}	****	****	***			****	****	****
$N(1535)$	S_{11}	****	****	****			*	**	***
$N(1650)$	S_{11}	****	****	*	***	**	***	**	***
$N(1675)$	D_{15}	****	****	*	*		****	*	****
$N(1680)$	F_{15}	****	****	*			****	****	****
$N(1700)$	D_{13}	***	***	*	**	*	**	*	**
$N(1710)$	P_{11}	***	***	**	**	*	**	*	***
$N(1720)$	P_{13}	****	****	*	**	*	*	**	**
$N(1900)$	P_{13}	**	**					*	
$N(1990)$	F_{17}	**	**	*	*	*			*
$N(2000)$	F_{15}	**	**	*	*	*	*	**	
$N(2080)$	D_{13}	**	**	*	*				*
$N(2090)$	S_{11}	*	*						
$N(2100)$	P_{11}	*	*	*					
$N(2190)$	G_{17}	****	****	*	*	*		*	*
$N(2200)$	D_{15}	**	**	*	*				
$N(2220)$	H_{19}	****	****	*					
$N(2250)$	G_{19}	****	****	*					
$N(2600)$	$I_{1\,11}$	***	***						
$N(2700)$	$K_{1\,13}$	**	**						

N* Spectrum – Diquark Model

- Alternative: diquark model [7]
  - Correlated quark-pair
  - Less DOF: less N* states
  - Predictions up to 2 GeV/c^2
  - No missing resonances
- Measure N* spectrum
  - Role of quark correlations





Legend
Black: Established
Blue: Inconclusive
Red: Unobserved
Green: Diquark Model

CLAS $\gamma N \to N^* \to KY$ Program

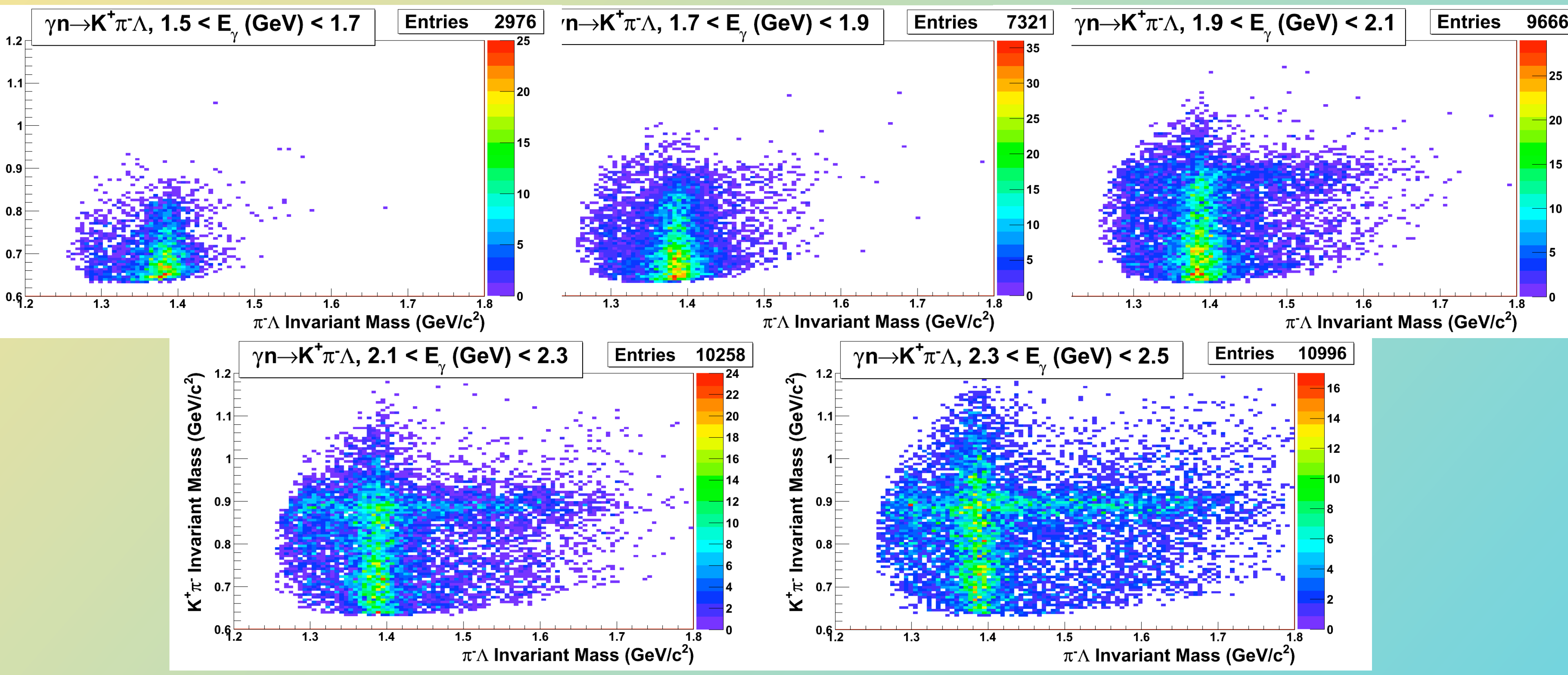
- Large $\gamma N \to KY$ program: σ, polarization observables
  - Polarization observables: spin-dependent constraints for N* extraction
- My analyses: $\gamma n \to K^*(892)^0 \Lambda$ and $\gamma n \to K^+ \Sigma^*(1385)^-$
  - g13 experiment, measure cross sections
- Also LEPS, GRAAL, SAPHIR, CBELSA/TAPS, & MAMI

CLAS Experiment	Beam	Target
g1	$\gamma, \overrightarrow{\gamma_C}$	LH_2
g8	$\overrightarrow{\gamma_L}$	LH_2
g9	$\overrightarrow{\gamma_C}, \overrightarrow{\gamma_L}$	$C_4\overrightarrow{H_9}\overrightarrow{OH}$
g10, eg3	γ	LD_2
g11	γ	LH_2
g13	$\overrightarrow{\gamma_C}, \overrightarrow{\gamma_L}$	LD_2
g14 (2011-2012)	$\overrightarrow{\gamma_C}, \overrightarrow{\gamma_L}$	$H\overrightarrow{D}$

Reaction	Experiment	Published	Analyses in Progress
$\gamma p \to K^+\Lambda$	g1c, g8b, g11, g13, g9	σ, P, C_x, C_z	$\Sigma, T, O_x, O_z, E, G$
$\gamma n \to K^0\Lambda$	g13		Σ
$\gamma p \to K^+\Sigma^0$	g1c, g8b, g11, g13	σ, P, C_x, C_z	Σ, T, O_x, O_z
$\gamma p \to K^0\Sigma^+$	g8b, g11		σ, Σ, P
$\gamma n \to K^+\Sigma^-$	g10, g13	σ	Σ
$\gamma n \to K^0\Sigma^0$	g13		Σ
$\gamma p \to K^*(892)^0\Sigma^+$	g1c	σ	
$\gamma n \to K^*(892)^0\Lambda$	g13		σ
$\gamma p \to K^*(892)^+\Lambda$	g11		σ, P
$\gamma p \to K^+\Sigma(1385)^0$	g11		σ
$\gamma n \to K^+\Sigma(1385)^-$	eg3, g13		σ
$\gamma p \to K^+\Lambda(1520)$	eg3		σ
$\gamma n \to K^0\Lambda(1520)$	eg3		σ

Signal Overlap in E_γ Bins

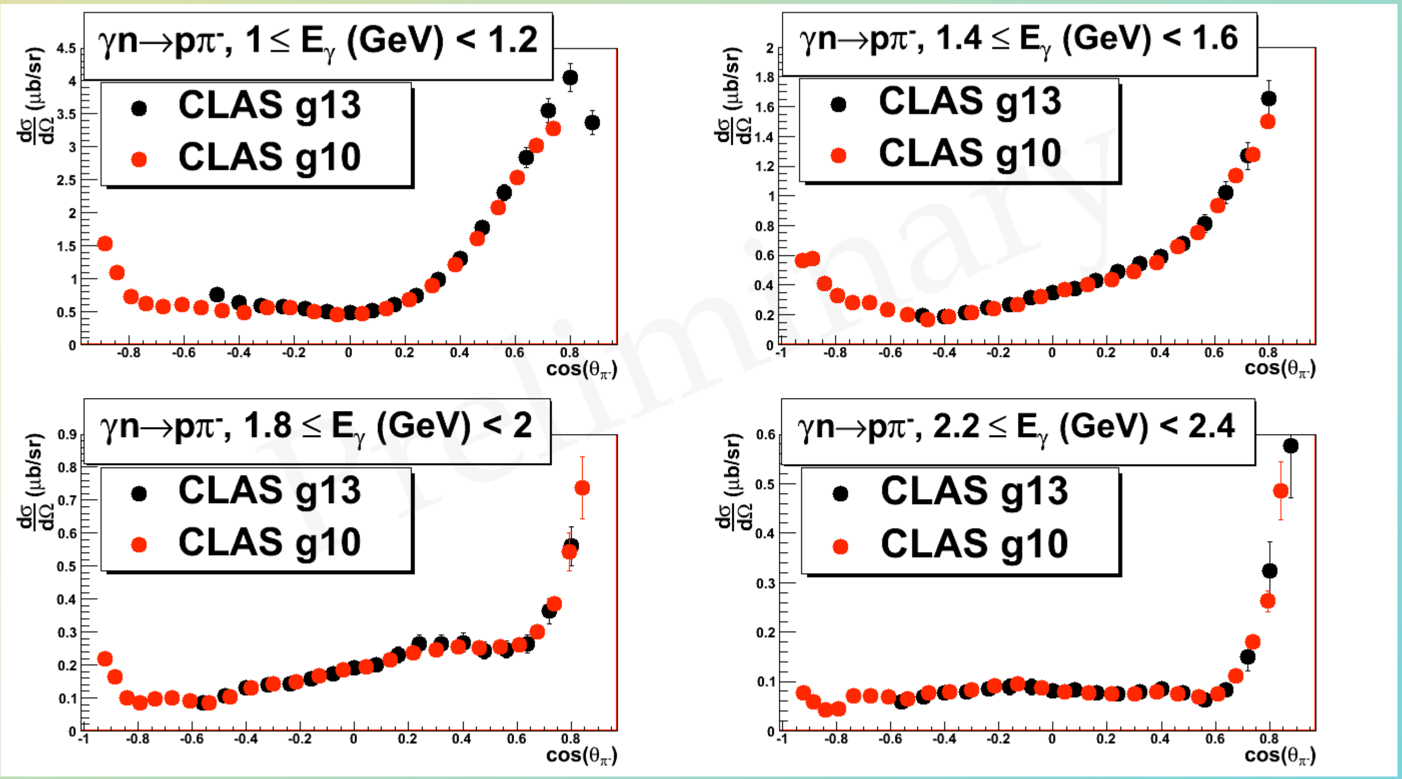
- Overlap cuts contain 70.5% of Breit-Wigner mass peak



$K^*(892)^0$ vs. $\Sigma^*(1385)^-$ Invariant Mass

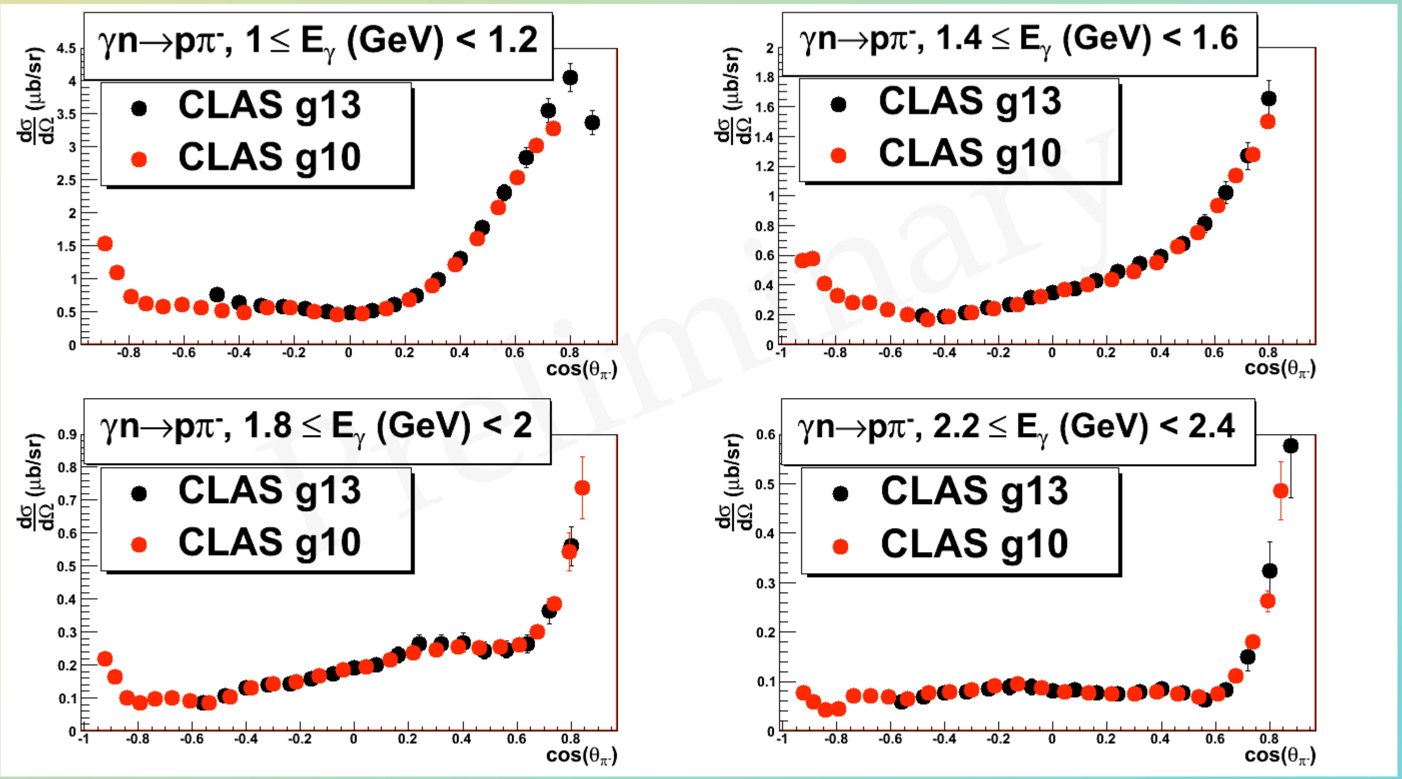
$\gamma n \rightarrow p \pi^-$ Cross Section

- Test reaction: check g13 data & analysis procedures
  - Compared to CLAS g10 (systematic $\delta\sigma$'s unavailable) [8]
  - Preliminary: partial systematic $\delta\sigma$'s, g10
  - Good matching: g13 ~6.5% > g10, partial systematic: ~10.8%

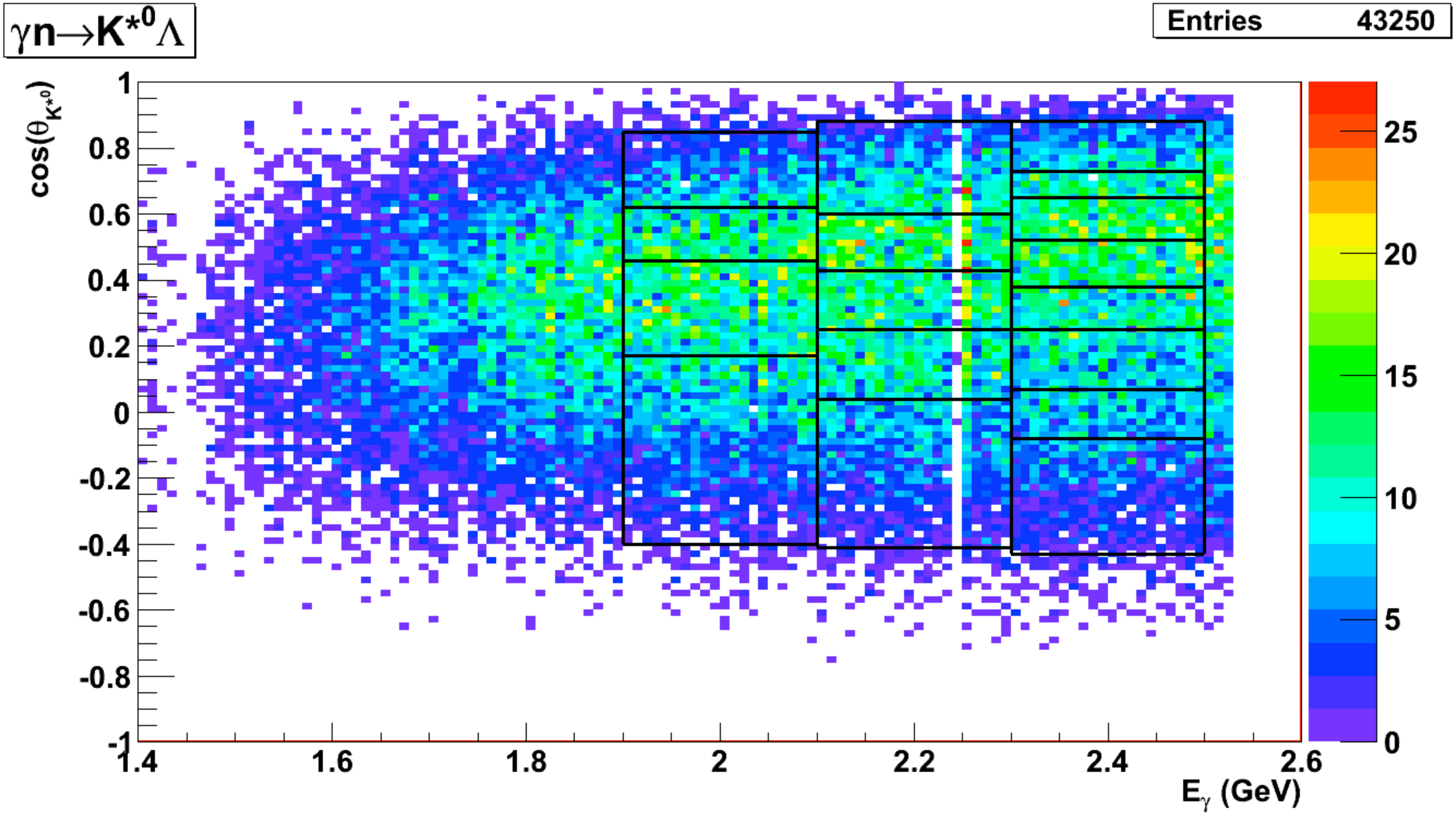


$\gamma n \rightarrow p \pi^-$ Cross Section

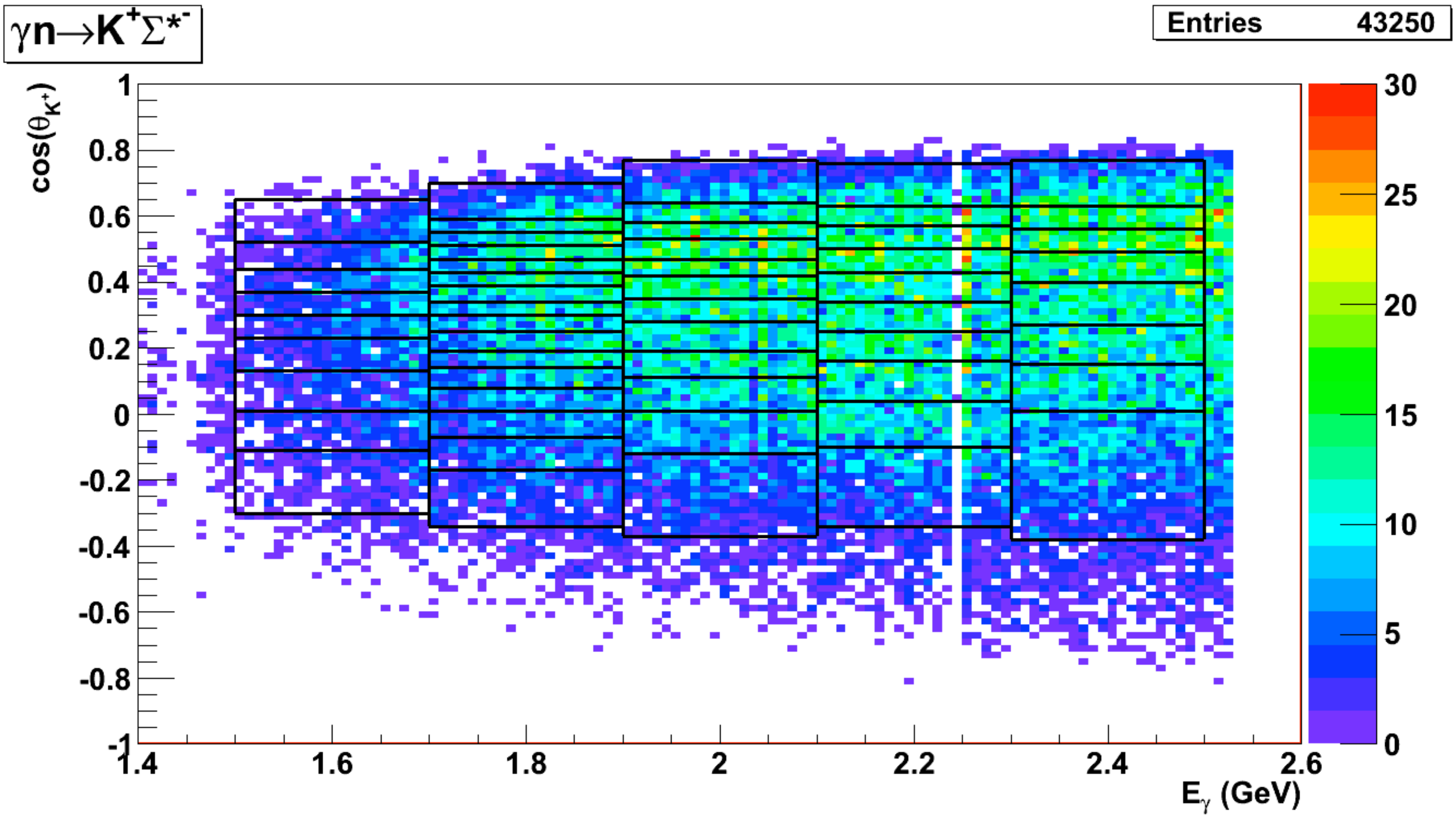
* Will publish when finalized (significant increase to world statistics)
  * ~2% of g13a shown, will have smaller energy bins (E_γ: 0.4 – 2.5 GeV)
* Data will improve:
  * N* couplings to neutron in πN
  * Understanding of rescattering & γn [9]: GWU phenomenologist



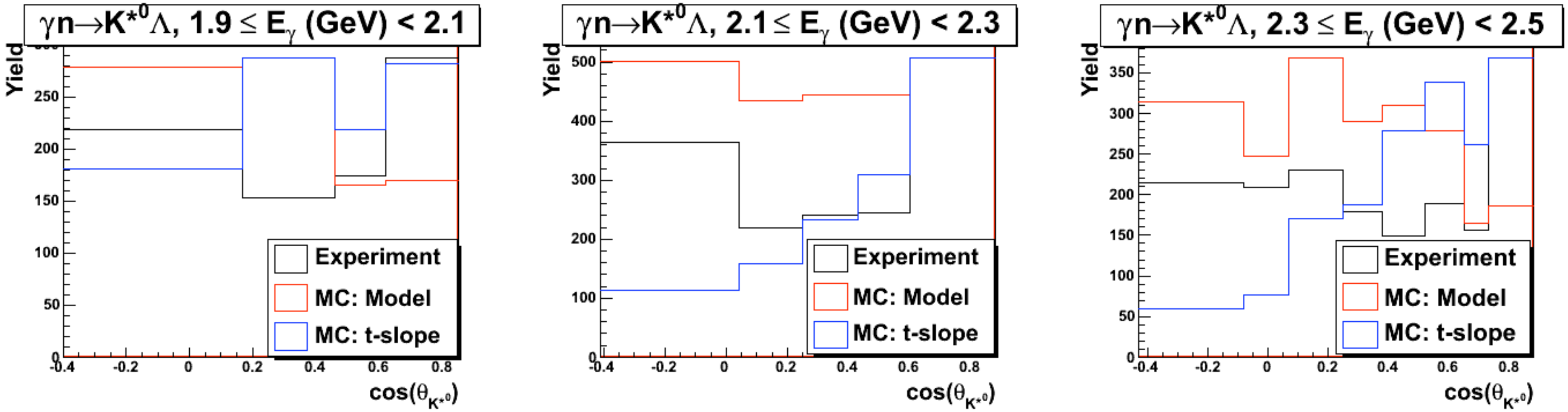
$\gamma n \rightarrow K^*(892)^0 \Lambda$ Binning



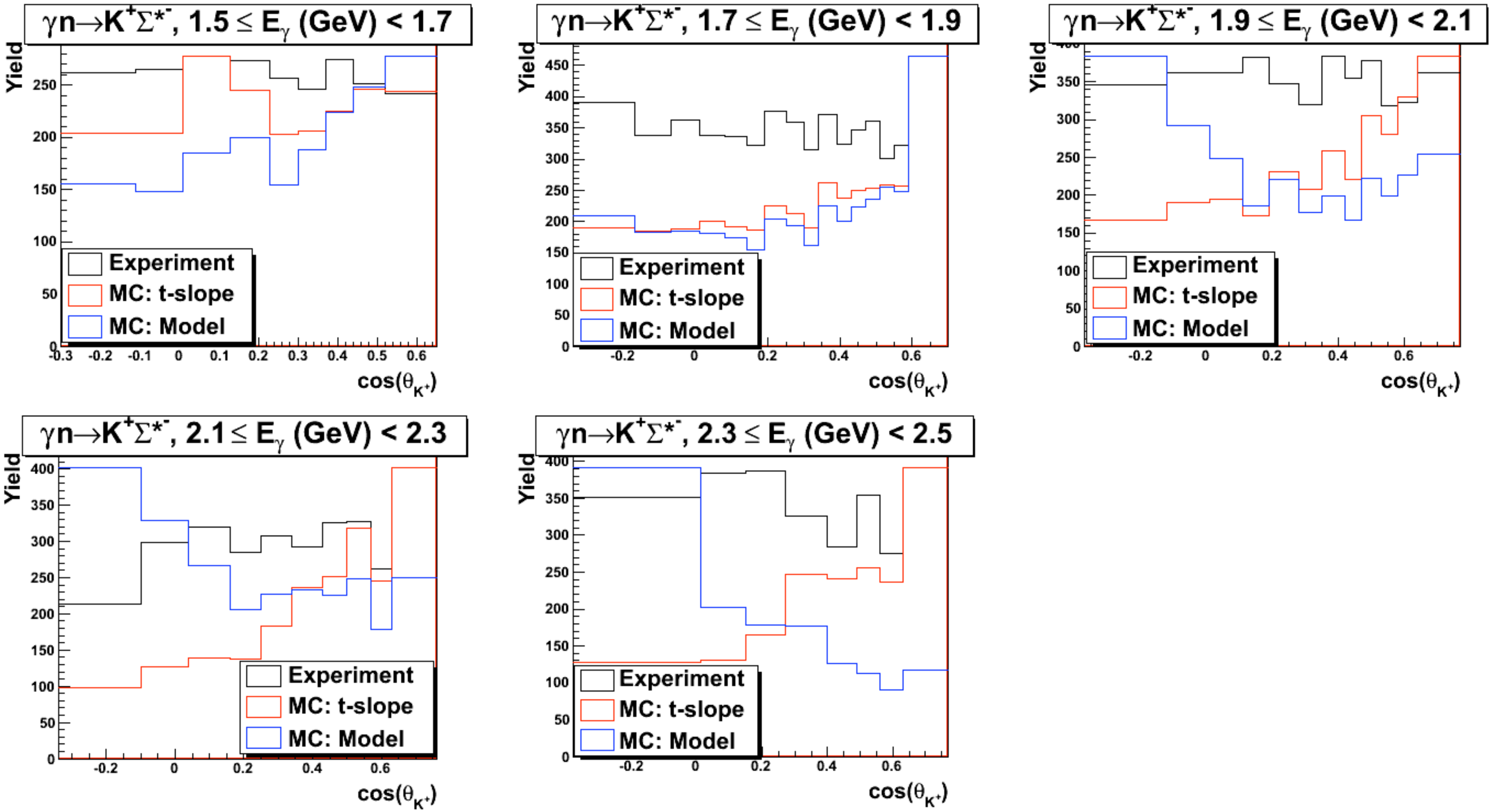
$\gamma n \to K^+ \Sigma^*(1385)^-$ Binning



$\gamma n \rightarrow K^*(892)^0 \Lambda$ Yields

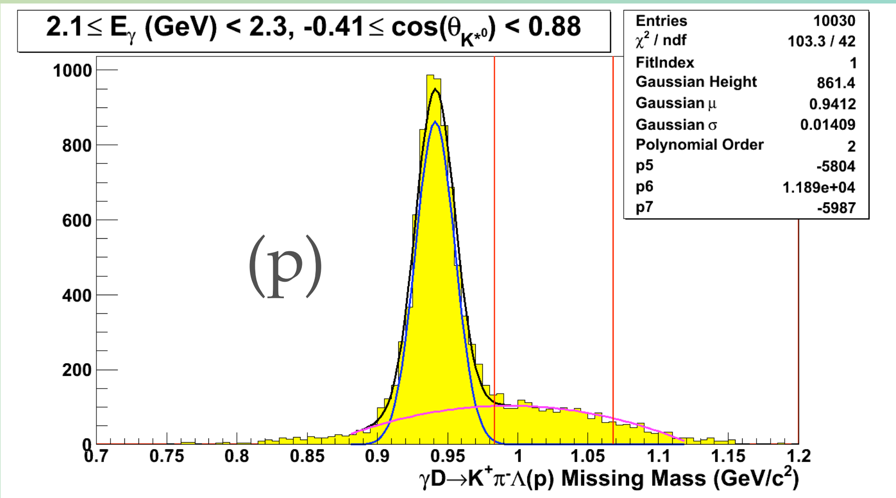


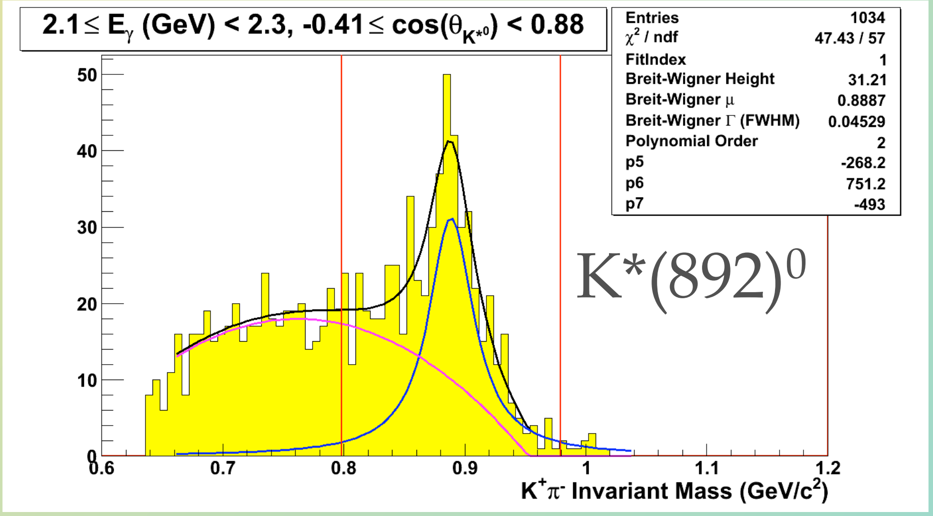
$\gamma n \to K^+ \Sigma^*(1385)^-$ Yields

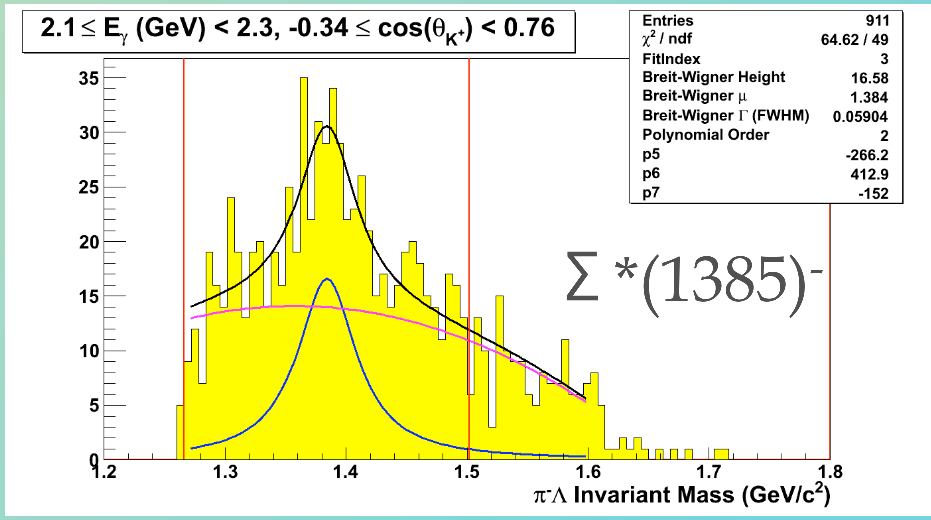


(γ), (π^0) Backgrounds

- (γ), (π^0) backgrounds
  - E.g.: $\gamma n \longrightarrow K^{*0} \Sigma^0$, $\Sigma^0 \longrightarrow \Lambda\gamma$
  - Studied K^{*0} & Σ^{*-} in (p) sideband
- Low statistics: no θ-dependence
  - Assigned as scale $\delta\sigma$'s
  - $K^*(892)^0$: 5.4% - 18.0%
  - $\Sigma^*(1385)^-$: 4.0% – 6.8%







Systematic Uncertainty Studies

* All analysis steps:
  * Vary cuts, procedures
  * Cross section change: $\delta\sigma$'s
* Joint analyses: shared $\delta\sigma$'s
* Dominant sources:
  * Simulation distributions
  * K^{*0} & Σ^{*-} fits
  * (γ), (π^0) backgrounds
* Future studies
  * Backgrounds, acceptance
  * Studies in development
  * Reduce $\delta\sigma$'s to 10% – 20%

Category	Source	Study	$\sim\sigma$ Range
CLAS Acceptance	π^- Momentum Cut	100 vs. 150 (MeV/c)	3.2% - 5.4%
	p & K^+ Momentum Cuts	400 vs. 450 (MeV/c)	0.33% - 0.53%
	Fiducial Cuts	0.02 rad Tighter	1.7% - 6.2%
	Trigger Simulation	K^+, No Simulation	2.3% - 3.4%
Final-State Identification	Particle Identification Cuts	$\pm3\sigma$ vs. $\pm2\sigma$	3.6% - 7.4%
	Time Difference Cuts	$\pm3\sigma$ vs. $\pm2\sigma$	5.0% - 9.3%
	Λ Invariant Mass Cuts	$\pm3\sigma$ vs. $\pm2\sigma$	4.4% - 6.6%
	Missing Momentum Cut	200 vs. 150 (MeV/c)	2.0% - 3.6%
	p Missing Mass Cuts	$\pm3\sigma$ vs. $\pm2\sigma$	2.7% - 6.5%
Specific to $\gamma n \to K^+\Sigma^{*-}$	**Simulation Distribution**	**t-slope vs. Model**	**θ: 0.19% - 23.1%**
	K^{*0} Overlap Cuts	$\pm1\Gamma$ vs. $\pm2\Gamma$	3.8% - 5.6%
	Σ^{*-} Background Fits	**Function Type**	**3.3% - 15.4%**
	Σ^{*-} Invariant Mass Cuts	$\pm2\Gamma$ vs. $\pm1\Gamma$	1.4% - 2.8%
	γ, π^0 Background	Sideband Yield	4.0% - 6.8%
	Overall Systematics	**NA**	**θ: 16.3% - 31.3%**
Specific to $\gamma n \to K^{*0}\Lambda$	**Simulation Distribution**	**Model vs. t-slope**	**θ: 0.036% - 32.2%**
	Σ^{*-} Overlap Cuts	**$\pm1\Gamma$ vs. $\pm1.5\Gamma$**	**θ: 0.067% - 20.3%**
	K^{*0} Background Fits	**Function Type**	**θ: 0.19% - 31.6%**
	K^{*0} Invariant Mass Cuts	**$\pm2\Gamma$ vs. $\pm1\Gamma$**	**θ: 1.5% - 16.5%**
	γ, π^0 Background	**Sideband Yield**	**5.4% - 18.0%**
	Overall Systematics	**NA**	**θ: 16.6% - 45.4%**