Strangeness Electroproduction on the Nucleon at CLAS

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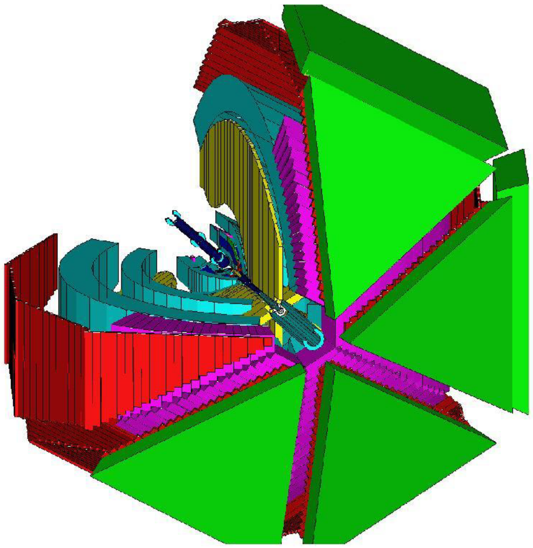
Outline

- Introduction and Models
- CLAS Photoproduction Data
- CLAS Electroproduction Data
- Ambiguities and Outlook
- Summary / Conclusions

Introduction

- One of the foundational cornerstones of the physics program in Hall B with CLAS is the N* program.

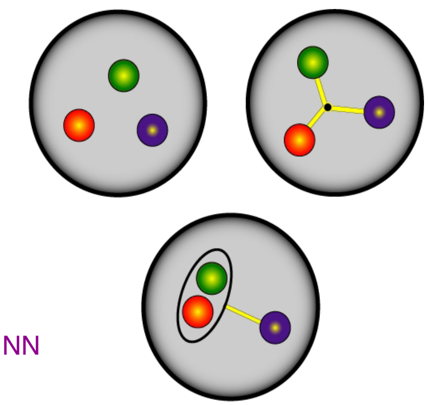


- *CLAS was designed to measure γN and γ*N cross sections and spin observables over a broad kinematic range via measurement of exclusive reaction channels.*

$$\pi N,\ \omega N,\ \phi N,\ \rho N,\ \eta N,\ \eta' N,\ \pi\pi N$$
$$K\Lambda,\ K\Sigma,\ K^*Y,\ KY^*$$

  - *probe relevant degrees of freedom vs. distance scale*
  - *study non–perturbative strong interactions in QCD*

- *The constituent quark model predicts a spectrum of states, many of which have not been seen experimentally.*
  - *N* studies dominated by pionic channels*
  - *KY channels important contributors in resonance region*
  - *Coupling to strange final states – complementary probe* g_{KYN} vs. $g_{\pi NN}$



- *Part of larger international / multi–lab effort:*
  - *ELSA/Crystal Barrel*
  - *Grenoble/GRAAL*
  - *SPring–8/LEPS*
  - *Mainz/MAMI*

Model Status / Issues

- Coupled–channel models developed by several groups.

  Giessen, Saclay/Pitt/ANL, KVI, Bonn–Jülich

  Fits include CLAS photoproduction data, but electroproduction data has not been included as of yet.

  Issues

  (more later)

- Tree–level isobar models currently provide the best possibility to study both reactions in the same framework.

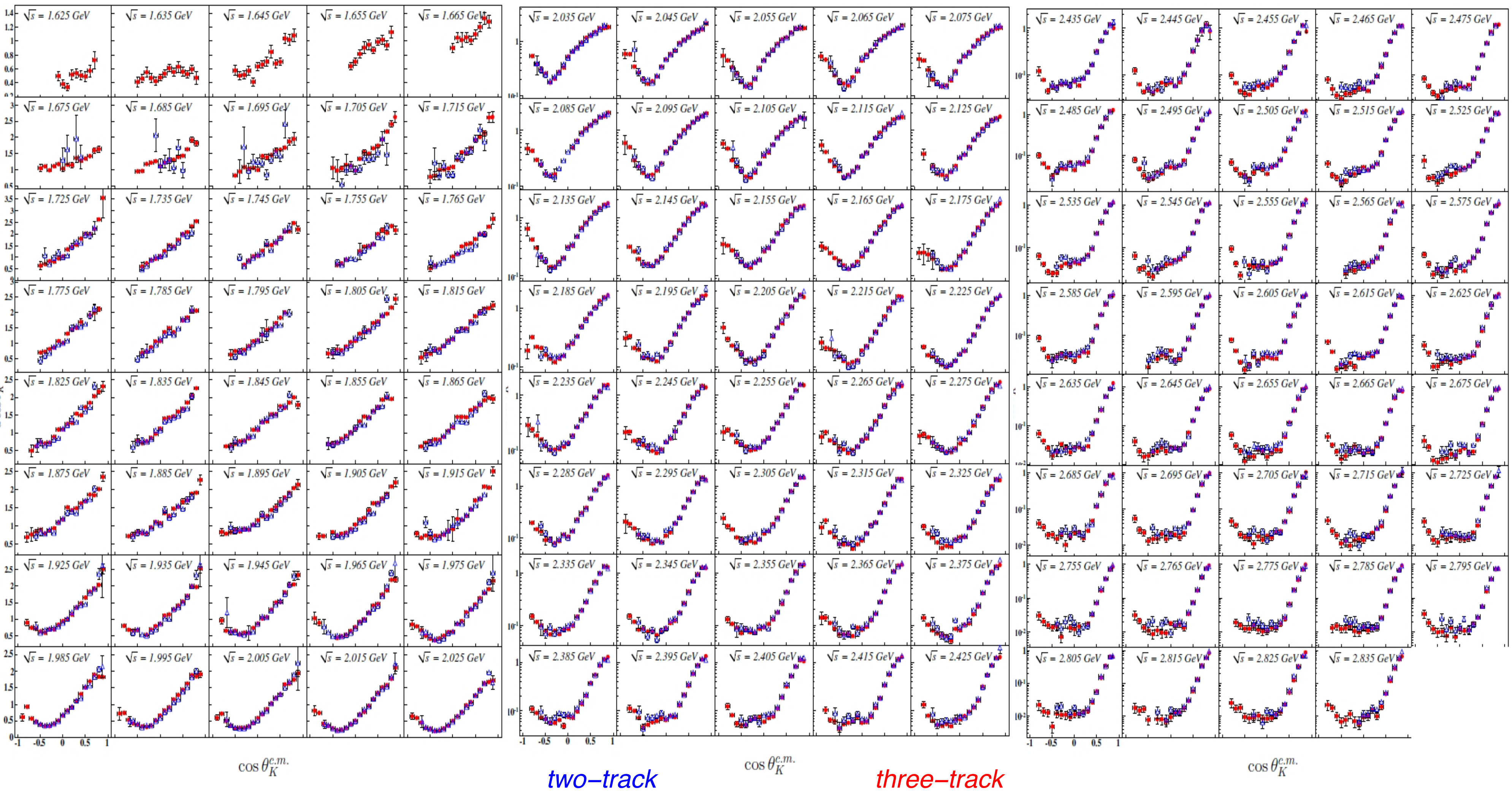
  → *"Simple", identify dominant trends*

  – Lack of predictive power – large number of free parameters
  – Lack of systematic procedure to select resonance set
  – Issues with introducing hadronic FFs to limit Born strength
  – Contributions of "effective" u–channel resonances – interplay with FFs
  – Gauge invariance restoration procedures
  – Coupling constants: SU(3) values, broken symmetry, ...
  – Inclusion of higher–spin resonances
  – Channel coupling
  – Final state interactions / rescattering effects
  – Multiple valid fit solutions

  Issues

Differential Cross Sections

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

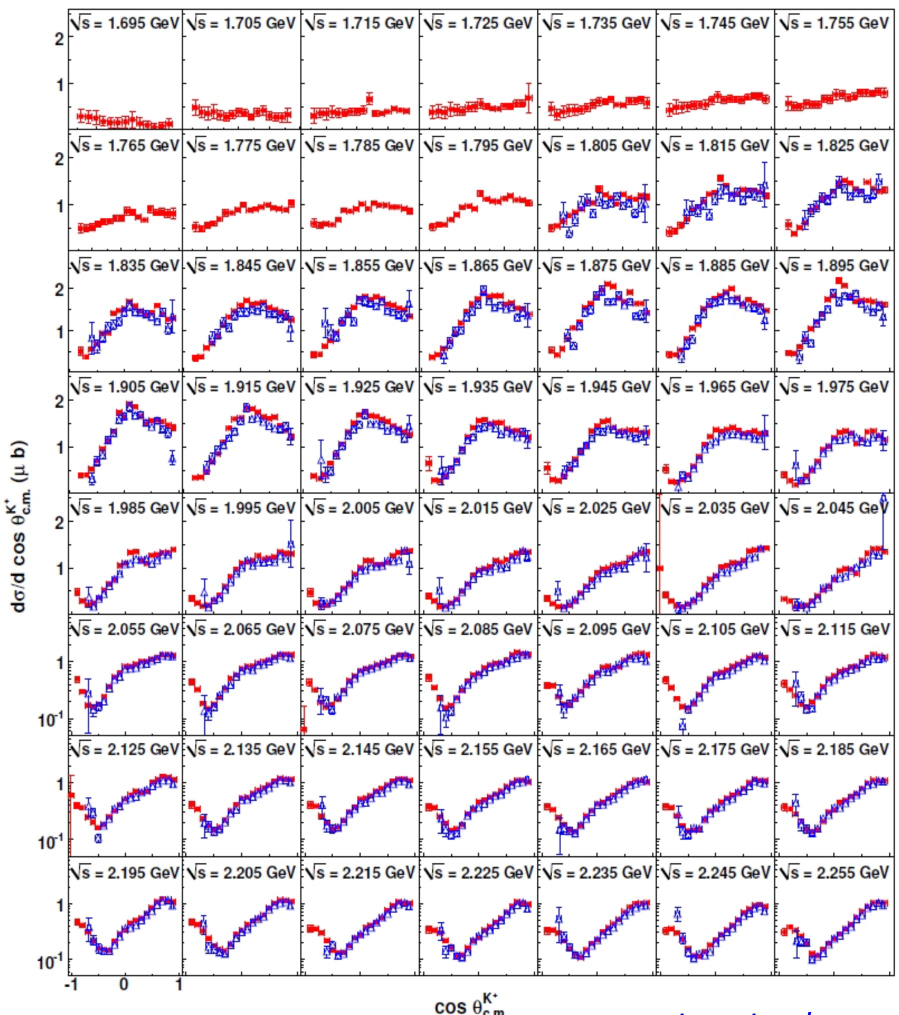


W : 1.625 – 2.835 GeV

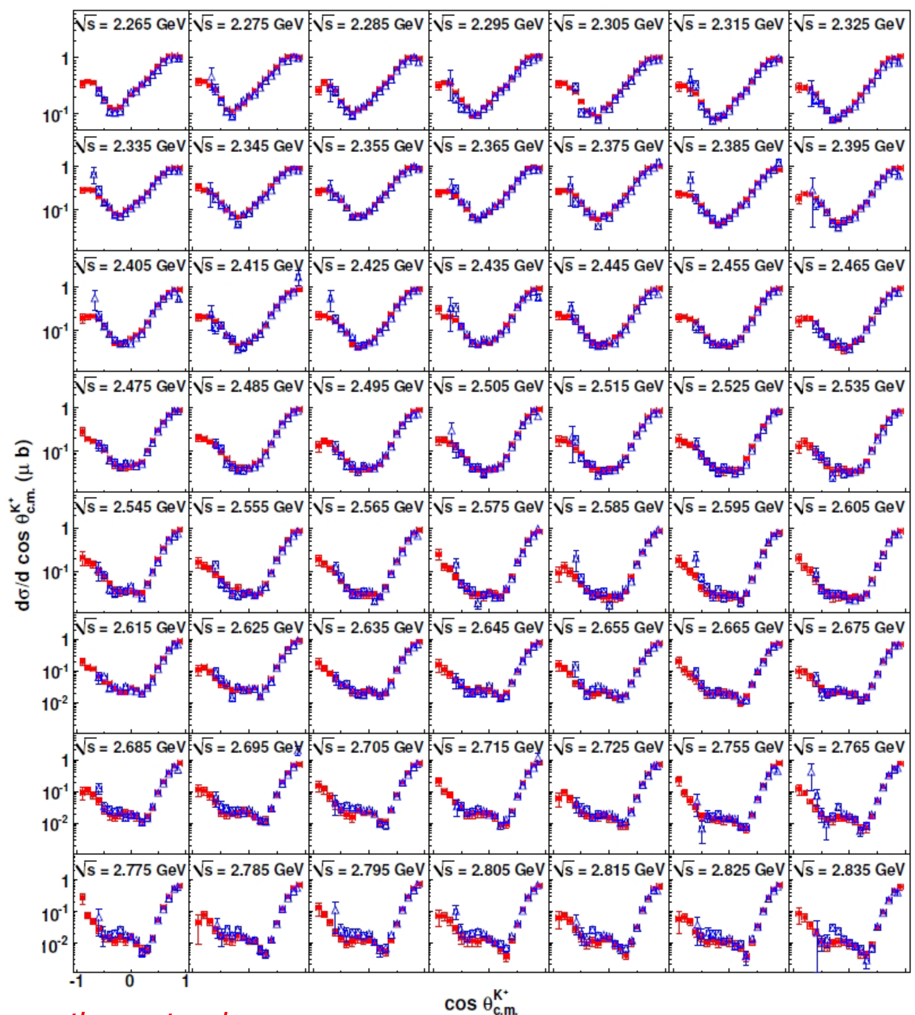
[McCraken et al., PRC 81, 025201 (2010)]

Differential Cross Sections

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



two–track



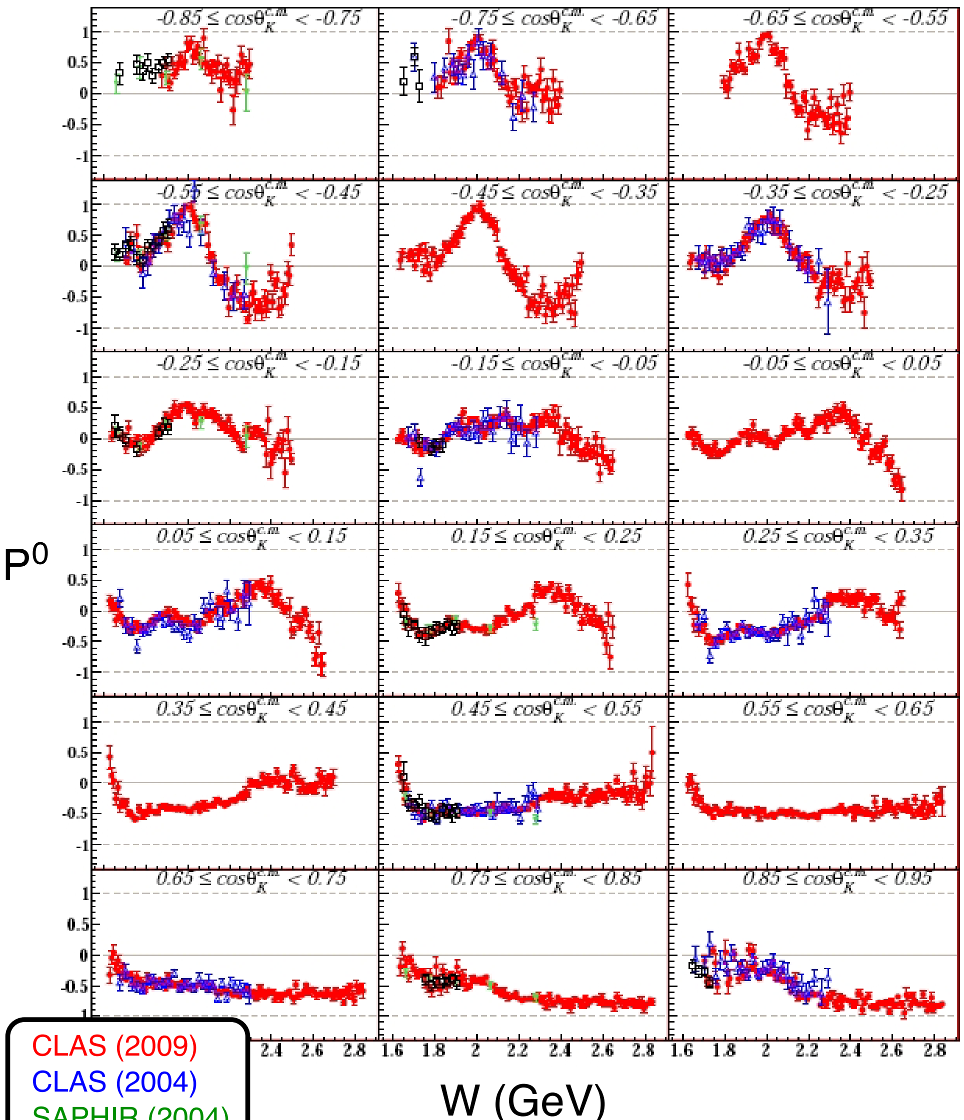
three–track

W : 1.695 – 2.835 GeV

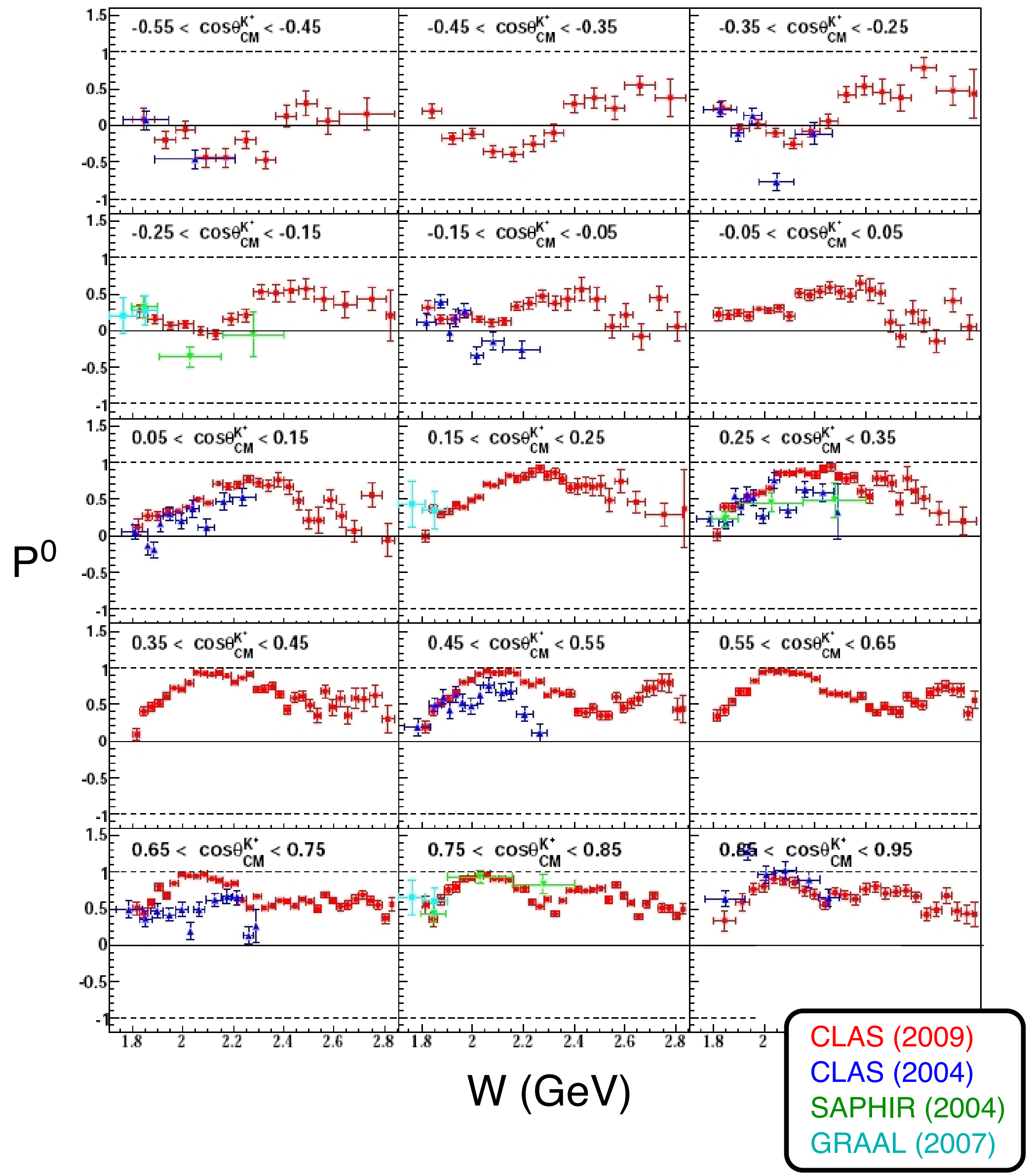
[Dey et al., PRC 82, 025202 (2010)]

Recoil Polarization

$\gamma p \rightarrow K^+ \vec{\Lambda}$



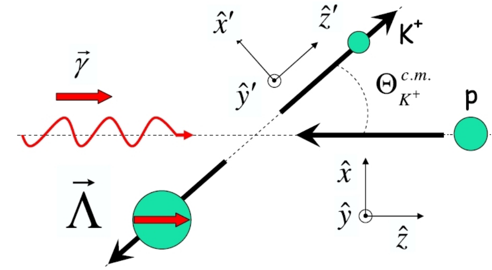
$\gamma p \rightarrow K^+ \vec{\Sigma^0}$



[McCracken et al., PRC 81, 025201 (2010)]

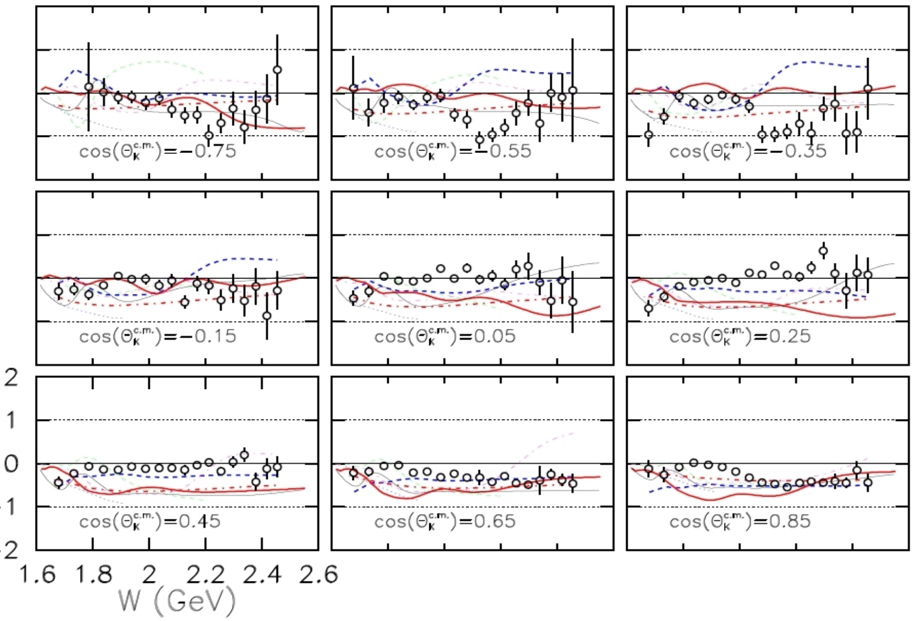
[Dey et al., PRC 82, 025202 (2010)]

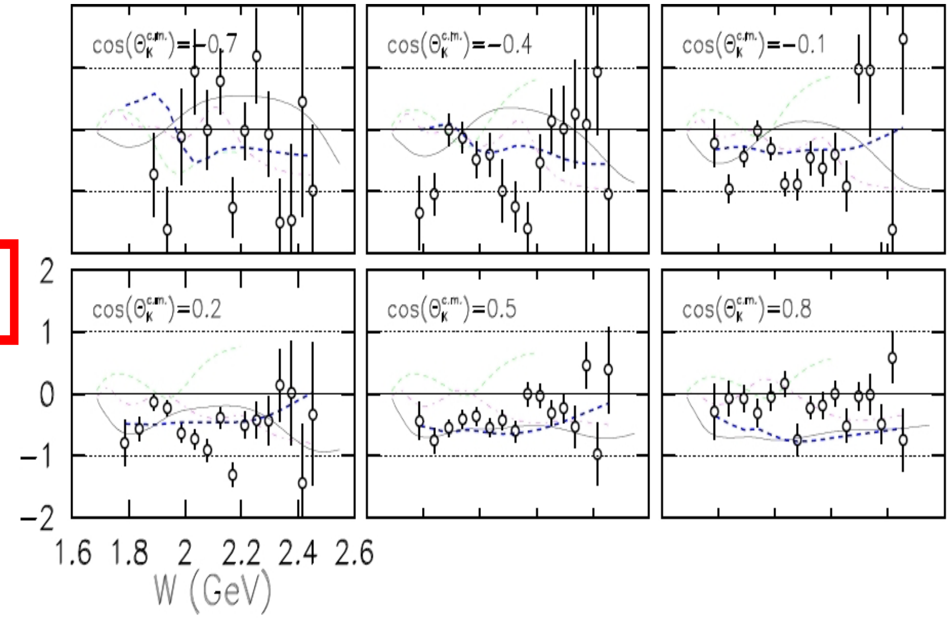
Transferred Polarization



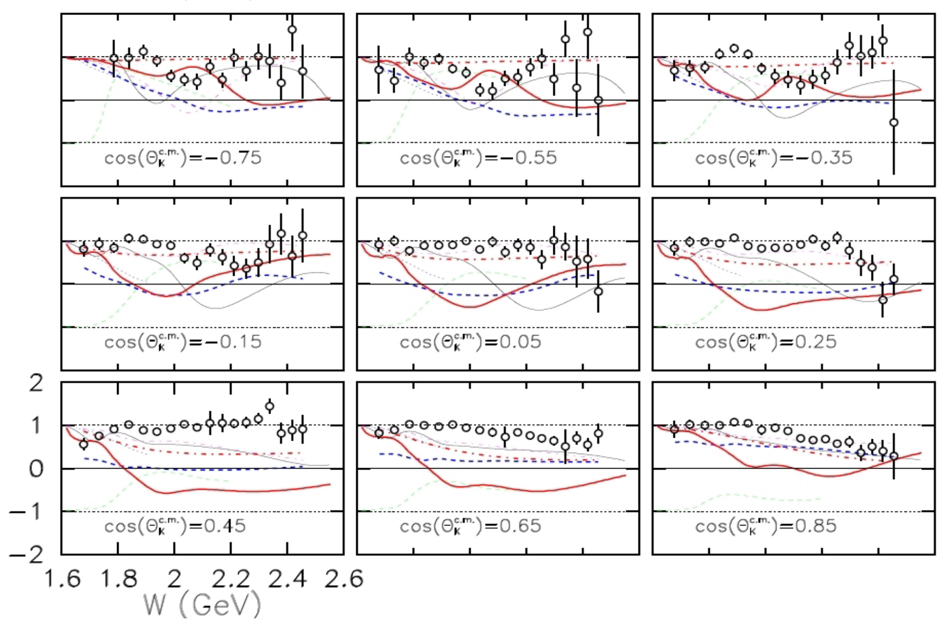
$\vec{\gamma} p \rightarrow K^+ \vec{\Lambda}$

$\vec{\gamma} p \rightarrow K^+ \vec{\Sigma}^0$

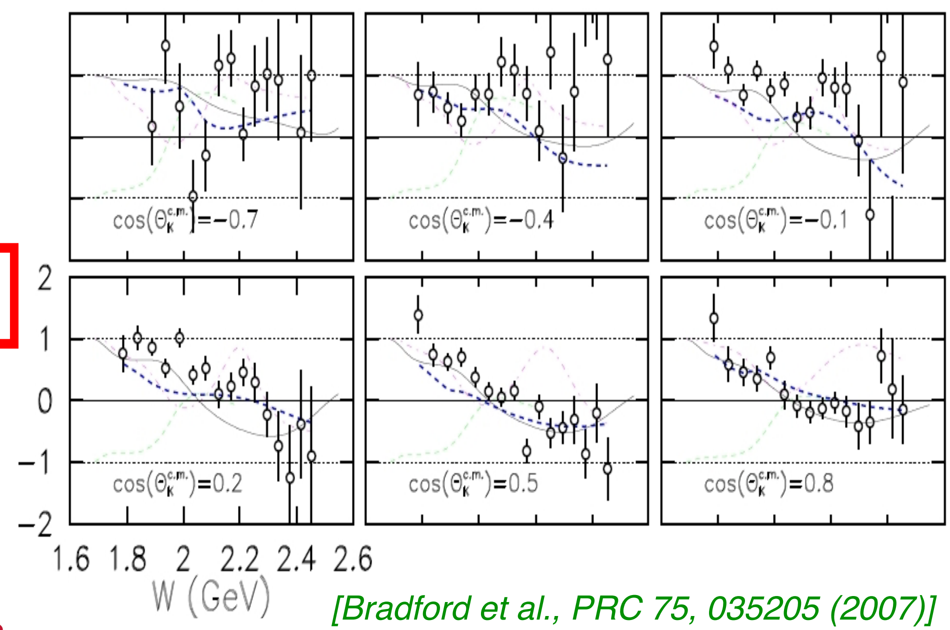




C_x



C_z



[Bradford et al., PRC 75, 035205 (2007)]

CLAS $\gamma N \rightarrow KY$ Program

COMPLETE EXPERIMENTS

Photon Beam		Target			Recoil			Target – Recoil								
					x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
		x	y	z				x	y	z	x	y	z	x	y	z
unpolarized	σ_o		T			P		$T_{x'}$		$L_{x'}$		Σ		$T_{z'}$		$L_{z'}$
linearly P_γ	Σ	H	P	G	$O_{x'}$	T	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	E		F	$L_{x'}$	$C_{x'}$	$T_{x'}$
circular P_γ		F		E	$C_{x'}$		$C_{z'}$		$O_{z'}$		G		H		$O_{x'}$	

γp

- Circularly polarized photons/unpolarized target:

  G1 / G11

- Linearly polarized photons/unpolarized target:

  G8

- Polarized beam/longitudinal–tranvserse target:

  FROST

γn

- Polarized beam / longitudinally polarized target:

  G13

- Polarized beam/longitudinal–transverse target:

  HD-ICE

  (last CLAS experiment in 6 GeV era)

Electroproduction Data

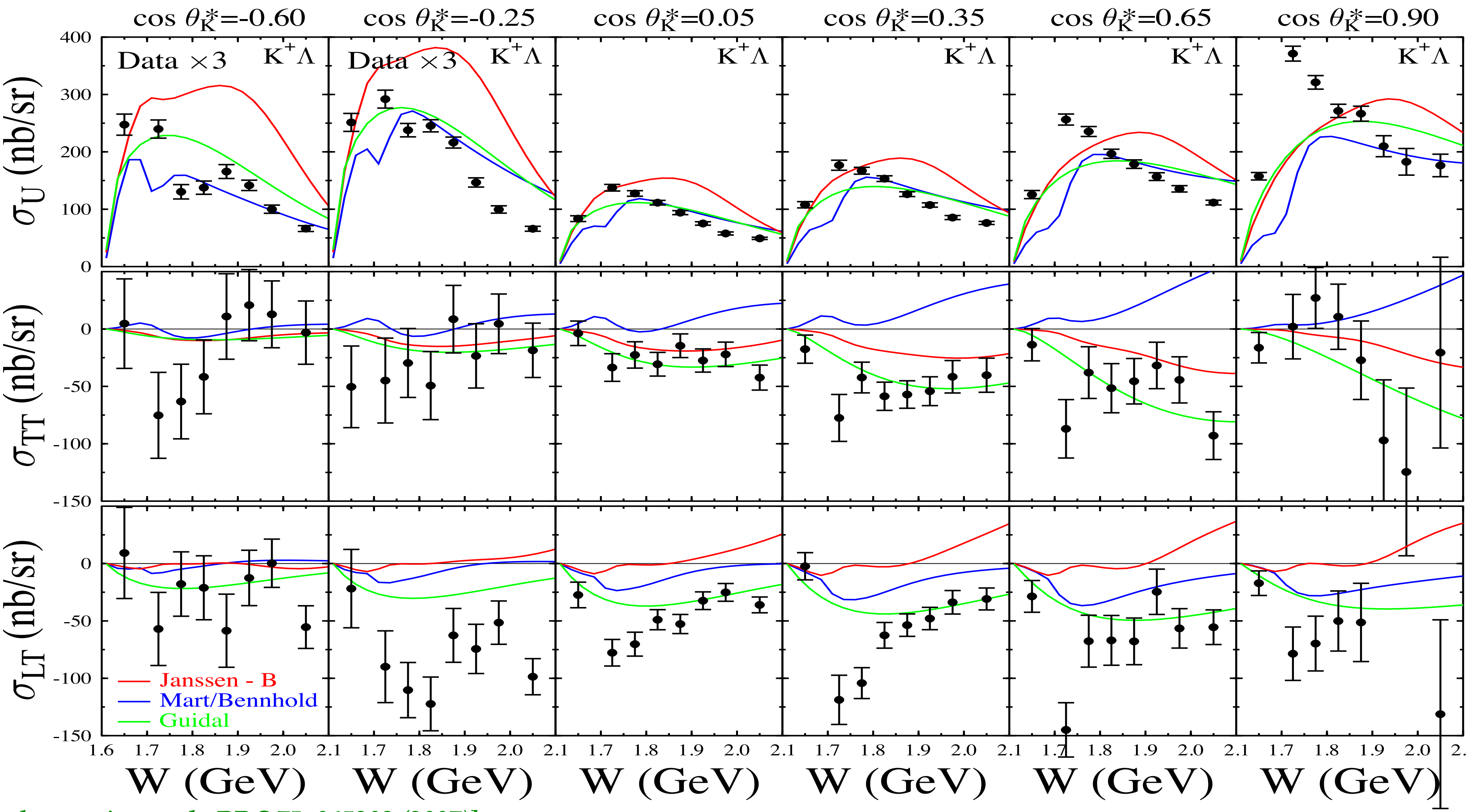
- At present there has been very limited use of the CLAS electroproduction data.
  - *U. Ghent – isobar model / Regge plus resonance (RPR) model*
  - *Mart – multipole/isobar model* (included in fit)

- Electroproduction data a richer source of information concerning N* coupling to KY final states.
  - *Involves N* coupling to both longitudinal and transverse photons*
  - *Access to γNN* transition helicity amplitudes (electrocouplings) vs. Q^2*
  - *Sensitively depends on EM form factors*
  - *Very useful for constraining background from t–channel exchanges*
  - *Supplementary/complementary information on N* couplings relative to γp*

- Suggested approach (Ghent, Mart):
  - *Leading class of diagrams is assumed to be identical for γp and γ^*p*
  - *Fix coupling constants to values from photoproduction fits*
  - *Use parameterizations of EM FFs*
  - *Partially fix parameters and then refit with γp and γ^*p data*

Electroproduction Cross Sections

$ep \to e'K^+\Lambda$



[Ambrozewicz et al., PRC 75, 045203 (2007)]

$$\frac{d\sigma}{d\Omega} = \sigma_U + \epsilon\sigma_{TT}\cos 2\Phi + \sqrt{\epsilon(\epsilon+1)}\sigma_{LT}\cos\Phi$$

E = 2.567 GeV

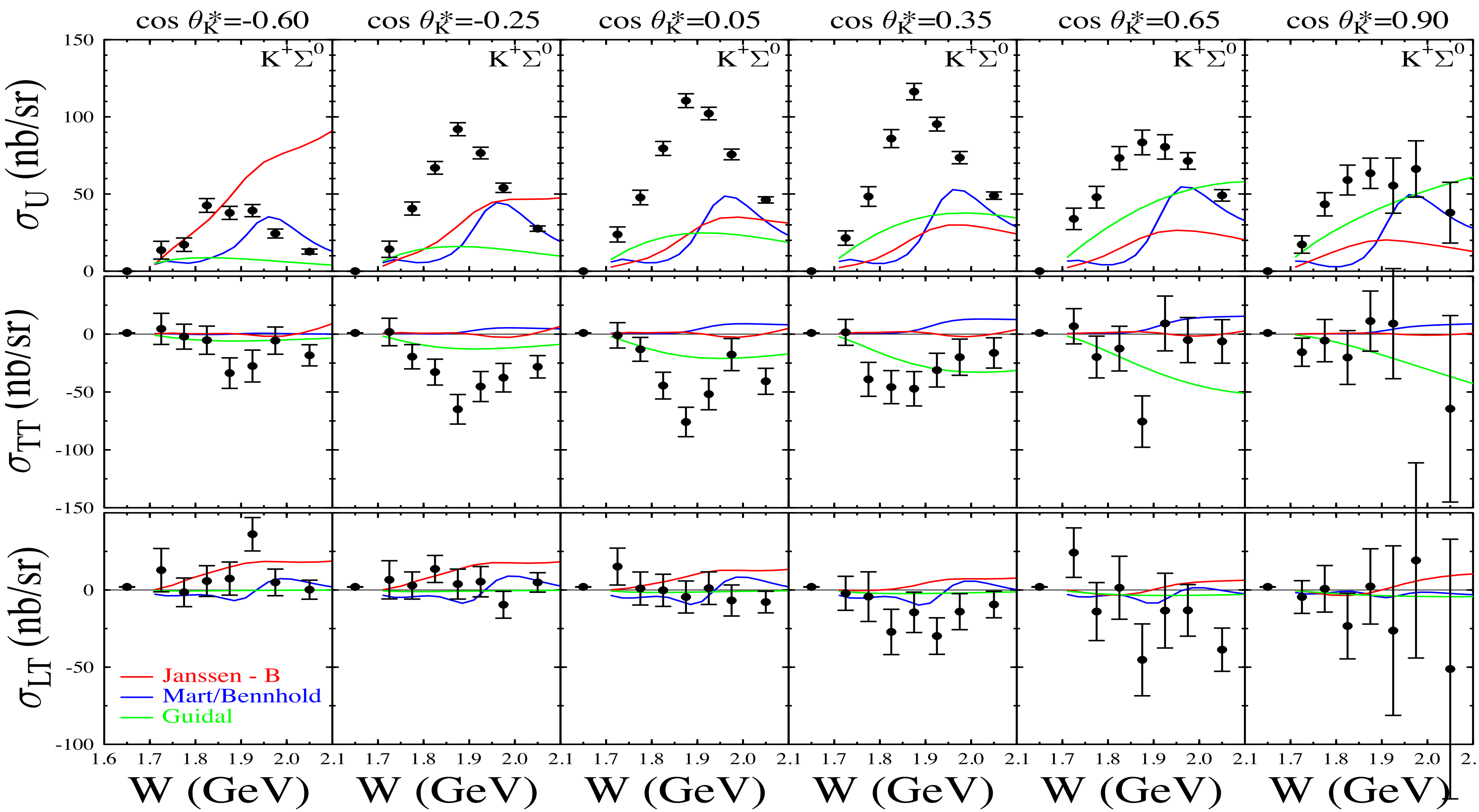
W: 1.65 – 2.05 GeV, Q^2= 0.65, 1.00 GeV^2

E = 4.056 GeV

W= 1.65 – 2.35 GeV, Q^2= 1.00, 1.55, 2.05, 2.55 GeV^2

Electroproduction Cross Sections

$ep \to e'K^+\Sigma^0$



[Ambrozewicz et al., PRC 75, 045203 (2007)]

$$\frac{d\sigma}{d\Omega} = \sigma_U + \epsilon\sigma_{TT}\cos 2\Phi + \sqrt{\epsilon(\epsilon+1)}\sigma_{LT}\cos\Phi$$

E = 2.567 GeV

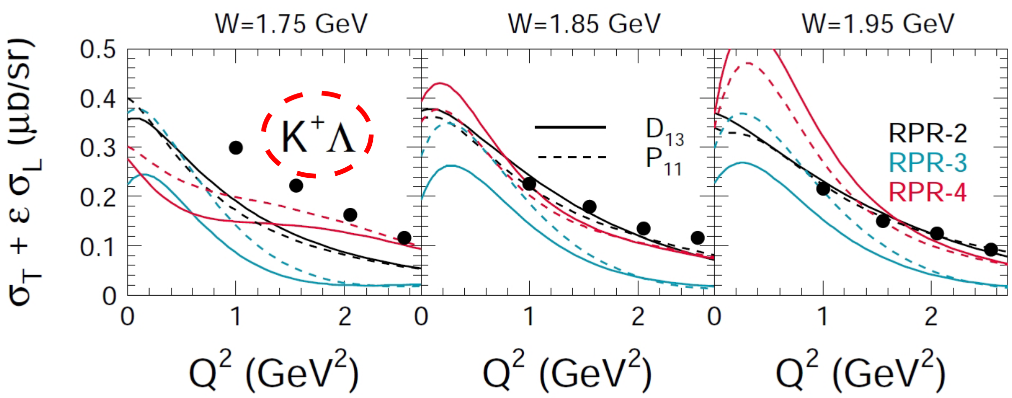
W: 1.72 – 2.05 GeV, Q^2 = 0.65, 1.00 GeV^2

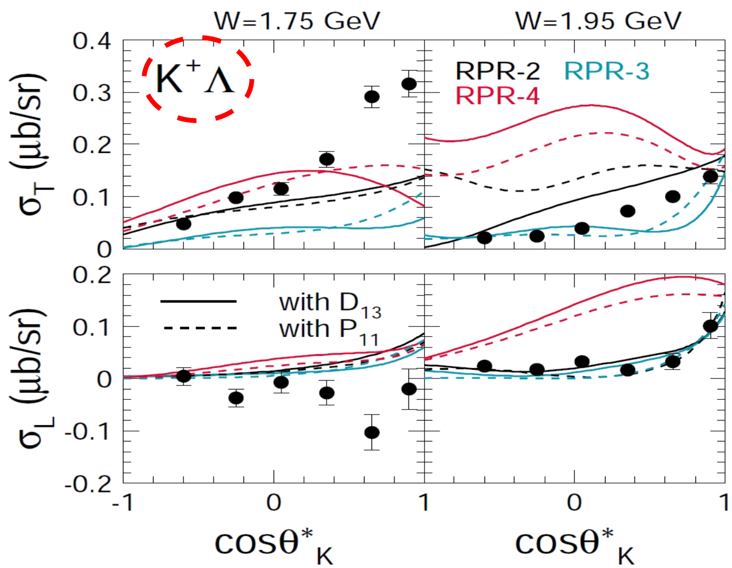
E = 4.056 GeV

W= 1.75 – 2.35 GeV, Q^2= 1.00, 1.55, 2.05, 2.55 GeV^2

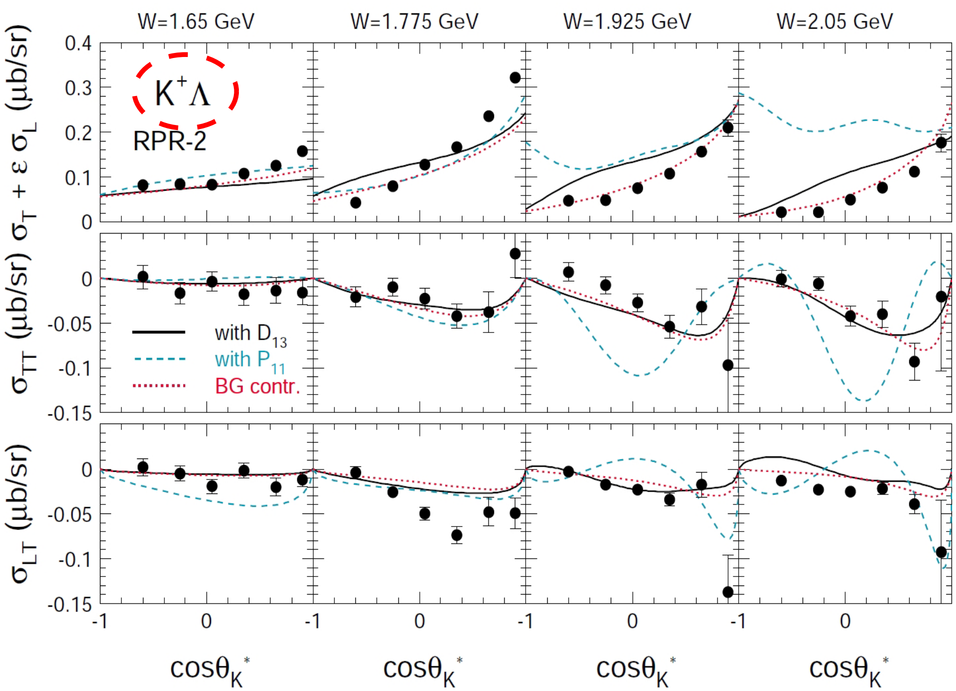
Model Predictions

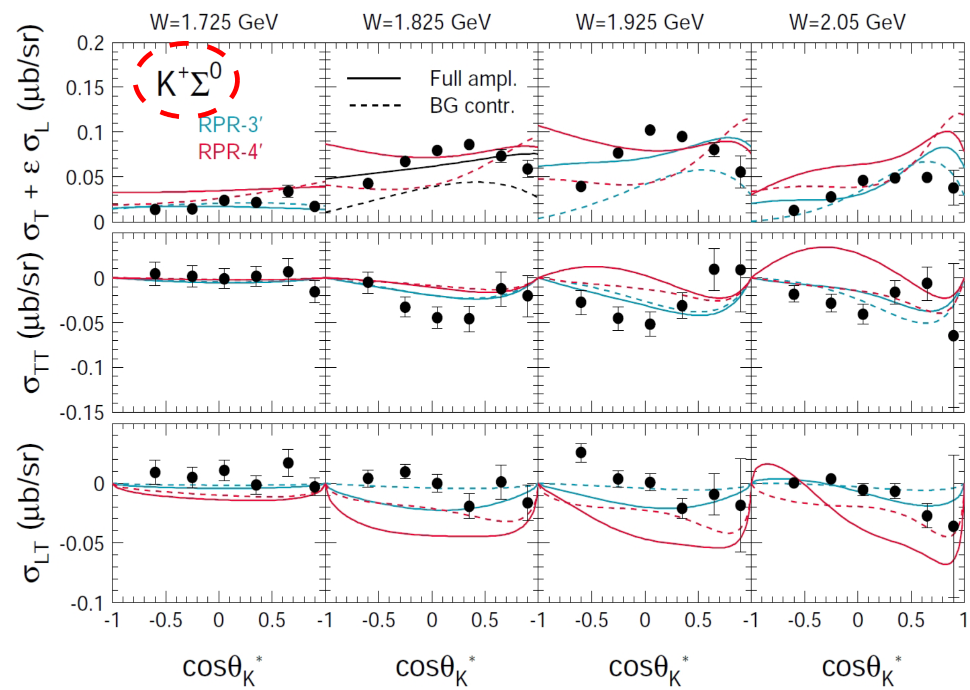
Regge + Resonance Model





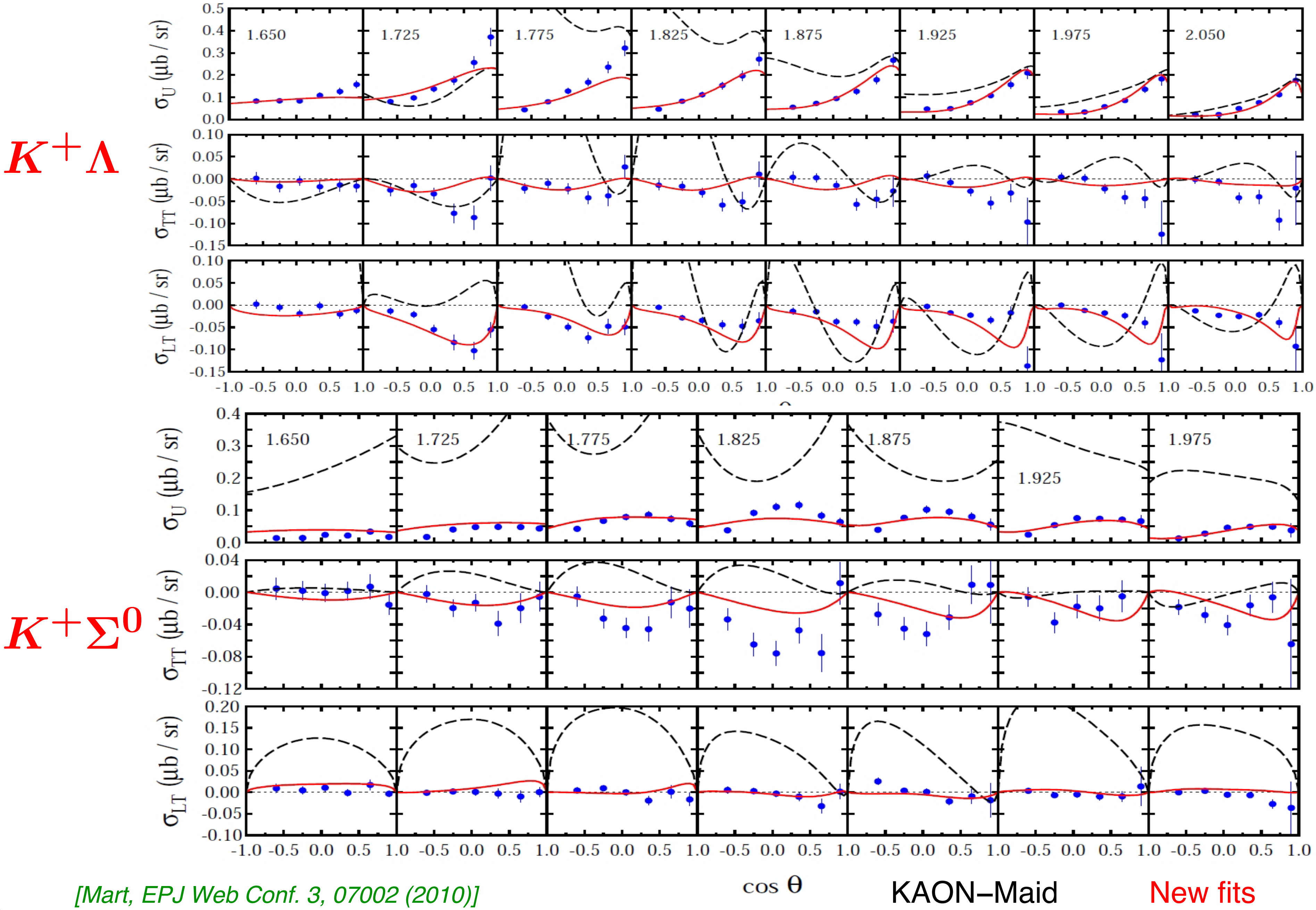
[Corthals et al., PLB 656, 185 (2007)]





Structure Function Fits

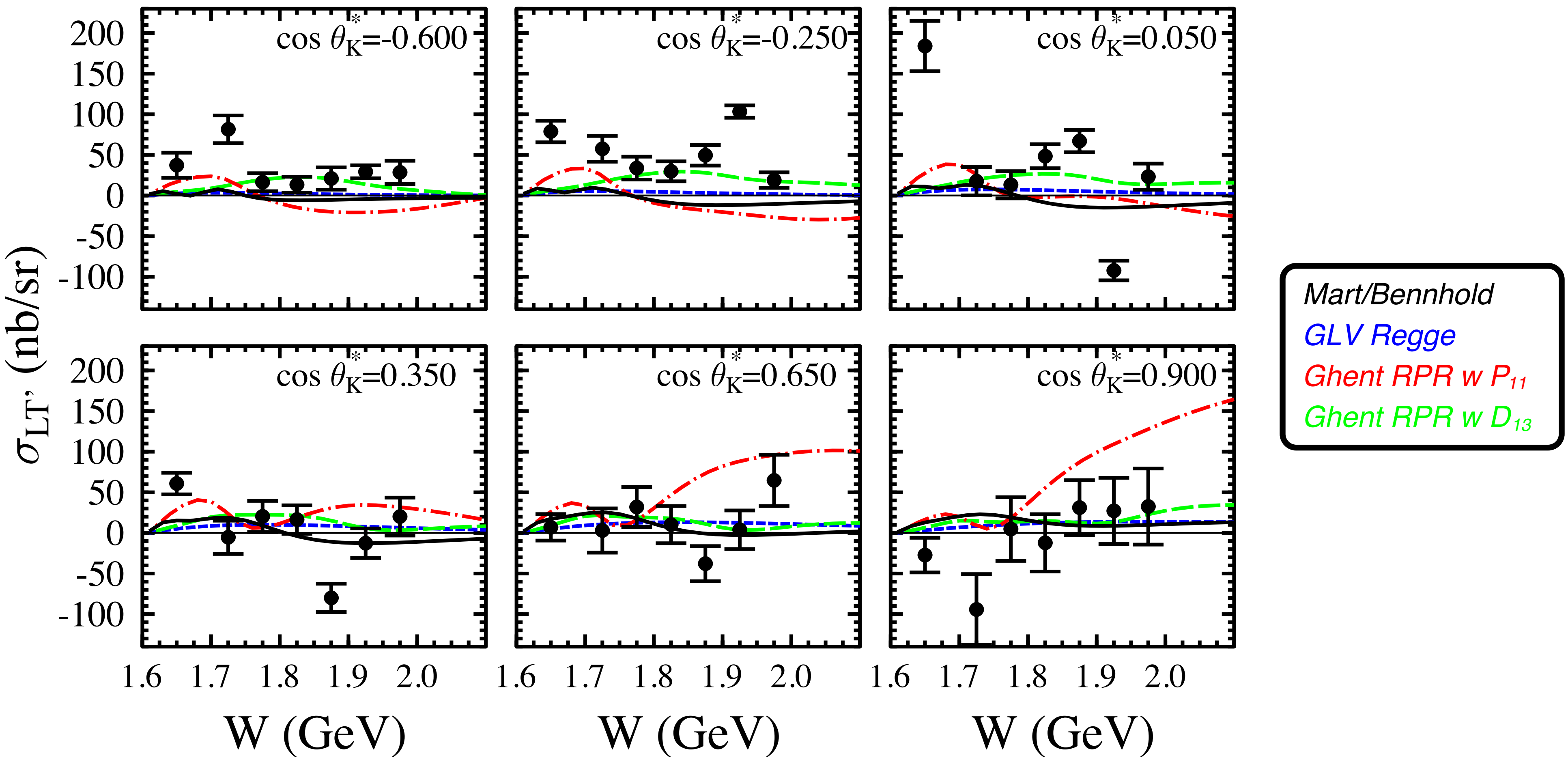
MULTIPOLE MODEL



[Mart, EPJ Web Conf. 3, 07002 (2010)]

Fifth Structure Function

$\vec{e}p \rightarrow e'K^+\Lambda$



$$A_{LT'} = \frac{1}{P_e}\frac{N^+ - N^-}{N^+ + N^-}$$

$$\sigma_{LT'} \sin\Phi = \frac{\sigma_0 A_{LT'}}{\sqrt{\epsilon(1-\epsilon)}}$$

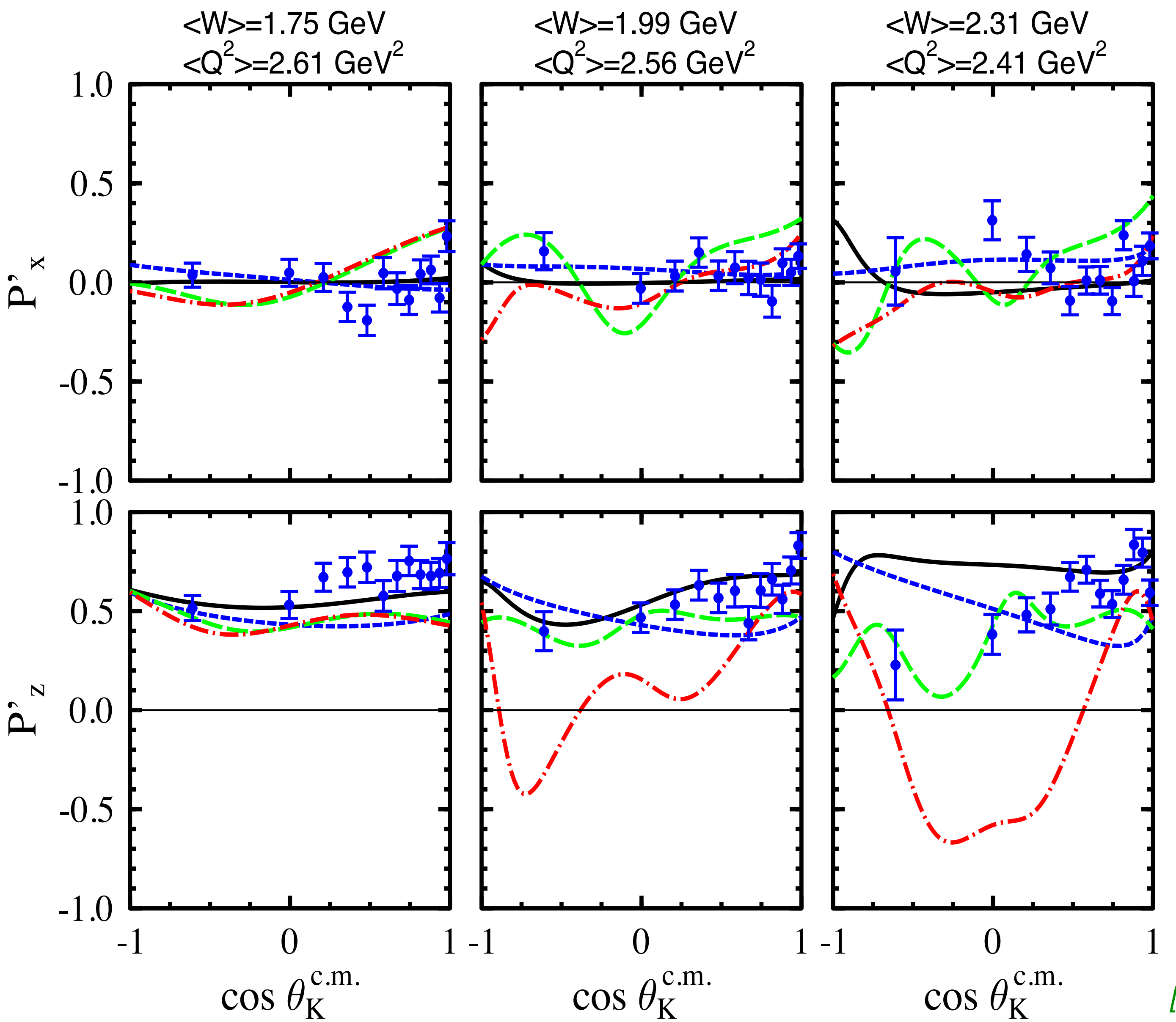
Data not included in fits.

E = 2.567 GeV, Q^2= 0.65, 1.00 GeV^2

[Nasseripour et al., PRC 77, 065208 (2008)]

Transferred Polarization

$\vec{e}p \rightarrow e'K^+\vec{\Lambda}$



5.754 GeV
Summed over Q^2, Φ

- Sensitive to model N* ingredients.
- Rule out P_{11}(1900) assignment.
- Data not included in fits.

Mart/Bennhold
GLV Regge
Ghent RPR w P_{11}
Ghent RPR w D_{13}

RPR: background + S_{11}(1650), P_{11}(1710), P_{13}(1720), P_{13}(1900)

[Carman et al., PRC 79, 065205 (2009)]

$N^* \rightarrow K^+\Lambda$??

- Historical Lore: *Core set of states:* $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$
  Recent emergence of: $P_{13}(1900)$ *(from photoproduction fits)*

BASED ON FITS TO PHOTOPRODUCTION DATA

- Coupled–Channel Model (Bonn): *[PLB 662, 245 (2008)]*
  Most relevant: S_{11} wave, $P_{13}(1720)$, $P_{13}(1900)$, $P_{11}(1840)$
  Other required states: $D_{15}(1675)$, $P_{11}(1710)$, $D_{13}(1875)$, $F_{15}(2000)$, $D_{13}(2170)$, $P_{13}(2200)$

- Coupled–Channel Model (Saclay/Pitt/ANL): *[PRC 73, 055204 (2006)]*
  Most relevant: $S_{11}(1535)$, $D_{13}(1520)$, $P_{13}(1900)$
  Other required states: $S_{11}(1650)$, $F_{15}(1680)$, $S_{11}(1806)$, $D_{13}(1954)$, $F_{15}(2000)$

- Multipole Model (Mart): *[EPJ A33, 243 (2007)]*
  SAPHIR/LEPS: $S_{11}(1650)$, $F_{15}(1680)$, $D_{13}(1700)$, $P_{13}(1720)$, $F_{15}(2000)$, $D_{13}(2080)$
  CLAS/LEPS: $D_{15}(1675)$, $F_{15}(1680)$, $P_{13}(1900)$, $F_{17}(1990)$, $D_{13}(2080)$

RESONANCE SETS NOT CONSISTENT FROM FIT TO FIT

Theory Issues / Ambiguities

- Need to reduce ambiguities and improve fits with "all" available data.
  - Include electroproduction data in fits
  - Apparent normalization issue with SAPHIR $K^+\Lambda$ data
    - *Internal consistency within multiple CLAS analyses of different data sets*
    - *See Bydzovksy and Mart, PRC 76, 065202 (2007)*
- Extraction of resonance coupling depends on approach to model background.
  - CLAS electroproduction shown to constrain background parameters
  - Regge parameterization does a respectable job for $K^+\Lambda$, poor for $K^+\Sigma^0$
- Complications when fitting $K\Sigma$ data – inclusion of N* and Δ* states.

There is little doubt that a combined fit multi–channel approach is ultimately the best path forward.

$$\pi N,\ \gamma N,\ \gamma^* N \rightarrow \pi N,\ \eta N,\ \pi\pi N,\ KY,\ \omega N,\ \phi N$$

COUPLED-CHANNEL FITS

Electroproduction Data Outlook

- Experimental data future:

near-term

  - *Analysis of Lambda recoil polarization from largest CLAS ep dataset in progress*

    → *see M. Gabrielyan talk – parallel session IIIb*

  - *Opportunity to extract $\sigma_{LT'}$ from dataset ~10x larger than published data*

longer-term

  - *Possible program of running electron beam with HD–Ice target*
  - *CLAS12 – baryon spectroscopy program*

    → *opportunity to probe dynamics to Q^2 up to ~8 –10 GeV^2*

- Planned fits of both photo– and electroproduction data:
  - *EBAC coupled–channel fits planned for 2011–2013* (H. Lee "manpower permitting")
  - *RPR fits discussed as future work* (J. Ryckebusch – U. Ghent)
  - *Isobar model fits from O. Maxwell – FIU* *[PRC 80, 065205 (2009)]* (fits in progress)

Summary/ Conclusions

- **The CLAS strangeness physics program:**
  - Designed to measure cross sections and all combinations of beam, target, and recoil polarization states.
    - ∗ *Precision data –– broad kinematic coverage*
    - ∗ *Program includes "complete" experiments on both proton and neutron targets*
  - CLAS data dominates the world's strangeness physics database for both photo– and electroproduction cross section and spin observables.

- **Main points from this talk:**
  - Progress in developing more sophisticated coupled–channels models.
    - ∗ *Issues with inconsistent results from different fits*
    - ∗ *Initial focus on photoproduction data; electroproduction data not used yet*
  - Electroproduction have been shown to provide important constraints:
    - ∗ *non–resonant backgrounds*
    - ∗ *form factor evolution*
    - ∗ *longitudinal response*
    - ∗ *N* electrocouplings*

Electroproduction data will be important to unravel the dominant N* → KY decays.