The Strangeness Physics Program at CLAS

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Outline:

- Introduction & Current Landscape
- Physics Results (Sample)
- Interpretation
- The Future
- Summary/Conclusions

Motivation

- One of the main goals of CLAS is to probe the structure of the nucleon and its excited states.

  - *The N* spectrum is a direct reflection of the underlying degrees of freedom of the nucleon.*

  - *The constituent quark model predicts many more states than have been seen experimentally.*

    "missing resonances"

  - *Strange final states are a complementary way to probe this structure.*

- CLAS program designed to obtain accurate electromagnetic production cross sections and spin observables over a broad kinematic range.

  → *Complete coverage of hadronic decay final state.*

The Current Landscape

$N^* \to KY$					
State	PDG	B.R. ($K\Lambda$)	B.R. ($K\Sigma$)	$A_{1/2}$ (GeV$^{1/2}$)	$A_{3/2}$ (GeV$^{1/2}$)
$N^*(1650)\ S_{11}$	****	3-11%	-	0.053±0.016	
$N^*(1675)\ D_{15}$	****	<1%	-	0.019±0.008	0.015±0.009
$N^*(1680)\ F_{15}$	****	-	-	-0.015±0.006	0.133±0.012
$N^*(1700)\ D_{13}$	***	<3%	-	-0.018±0.013	-0.002±0.024
$N^*(1710)\ P_{11}$	***	5-25%	-	0.009±0.022	
$N^*(1720)\ P_{13}$	***	1-15%	-	0.018±0.03	-0.019±0.020
$N^*(1900)\ P_{13}$	**	-	-	-	-
$N^*(1990)\ F_{17}$	**	-	-	-	-
$N^*(2000)\ F_{15}$	**	-	-	-	-

$\Delta^* \to K\Sigma$				
State	PDG	B.R. ($K\Sigma$)	$A_{1/2}$ (GeV$^{1/2}$)	$A_{3/2}$ (GeV$^{1/2}$)
$\Delta^*(1900)\ S_{31}$	**	-	?	
$\Delta^*(1905)\ F_{35}$	****	-	0.026±0.011	-0.045±0.020
$\Delta^*(1910)\ P_{31}$	****	-	0.003±0.014	
$\Delta^*(1920)\ P_{33}$	***	2.1%	?	?
$\Delta^*(1930)\ D_{35}$	***	-	-0.009±0.028	-0.018±0.028
$\Delta^*(1940)\ D_{33}$	*	-	?	?
$\Delta^*(1950)\ F_{37}$	****	-	-0.076±0.012	-0.097±0.010

We have significant room for improvement!!

Electroproduction Formalism

$$\frac{d\sigma}{d\Omega_{E'} d\Omega_K^* dE'} = \Gamma_v \frac{d\sigma_v}{d\Omega_K^*}$$

(unpolarized target)

$$\frac{d\sigma_v}{d\Omega_K^*} = \sigma_0 \left[1 + h\ A_{TL'} + \vec{S} \cdot \vec{P}^0\ +\ h\ (\vec{S} \cdot \vec{P}')\right]$$

Unpolarized Cross Section

$$\sigma_0 = \mathcal{K}(R_T^{00} + \epsilon R_L^{00} + \epsilon R_{TT}^{00} \cos 2\Phi + \sqrt{\epsilon(1+\epsilon)}\ R_{TL}^{00} \cos\Phi)$$

$$A_{LT'} = \frac{\mathcal{K}}{\sigma_0}\sqrt{\epsilon(1-\epsilon)}\ R_{TL'}^{00} \sin\Phi$$

Polarized Beam

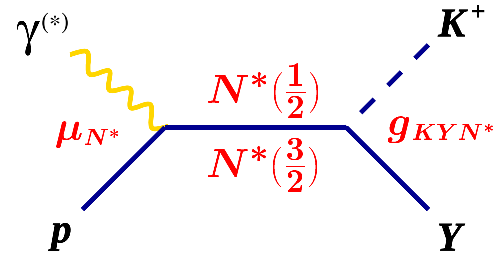
$$\begin{pmatrix} P_{x'}^0 \\ P_{y'}^0 \\ P_{z'}^0 \end{pmatrix} = \frac{\mathcal{K}}{\sigma_0} \begin{pmatrix} \sqrt{\epsilon(1+\epsilon)}\ R_{TL}^{x'0} \sin\Phi + \epsilon R_{TT}^{x'0} \sin 2\Phi \\ R_T^{y'0} + \epsilon R_L^{y'0} + \sqrt{\epsilon(1+\epsilon)}\ R_{TL}^{y'0} \cos\Phi + \epsilon R_{TT}^{y'0} \cos 2\Phi \\ \sqrt{\epsilon(1+\epsilon)}\ R_{TL}^{z'0} \sin\Phi + \epsilon R_{TT}^{z'0} \sin 2\Phi \end{pmatrix}$$

Induced Polarization

$$\begin{pmatrix} P'_{x'} \\ P'_{y'} \\ P'_{z'} \end{pmatrix} = \frac{\mathcal{K}}{\sigma_0} \begin{pmatrix} \sqrt{\epsilon(1-\epsilon)}\ R_{TL'}^{x'0} \cos\Phi + \sqrt{1-\epsilon^2}\ R_{TT'}^{x'0} \\ \sqrt{\epsilon(1-\epsilon)}\ R_{TL'}^{y'0} \sin\Phi \\ \sqrt{\epsilon(1-\epsilon)}\ R_{TL'}^{z'0} \cos\Phi + \sqrt{1-\epsilon^2}\ R_{TT'}^{z'0} \end{pmatrix}$$

Transferred Polarization

Hadrodynamic Models



- Isobar models based on effective Lagrangian.

  (Mart/Bennhold, Univ. Ghent)

- Features primarily due to s−channel resonances.
  - *t−channel contains only K and K*.*
  - *Coupling strengths set by fits to existing data.*
  - *Parameters set by coupled−channels study.*
  - *Recent addition of u−channel Y* resonances.*
- Effective at low to moderate energies.

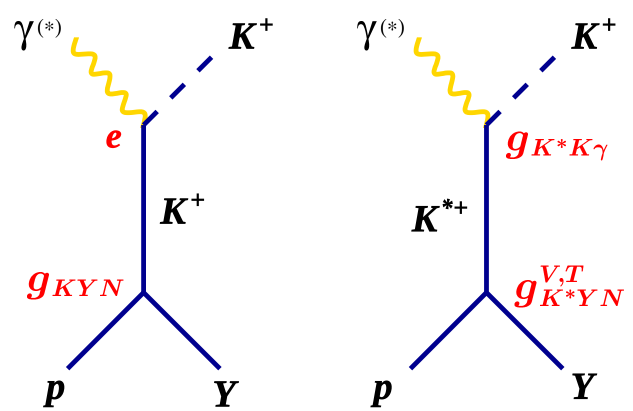
	MB	JB	MB	JB
Resonance	$K^+\Lambda$		$K^+\Sigma^0$	
$N^*(1650)\ (S_{11})$	★	★	★	★
$N^*(1710)\ (P_{11})$	★	★	★	★
$N^*(1720)\ (P_{13})$	★	★	★	★
$N^*(1895)\ (D_{13})$	★	★	★	★
$K^*(892)$	★	★	★	★
$K_1^*(1270)$	★	★	★	★
$\Lambda^*(1800)\ (S_{01})$		★		
$\Lambda^*(1810)\ (P_{01})$		★		
$\Delta^*(1900)\ (S_{31})$			★	★
$\Delta^*(1910)\ (P_{31})$			★	★

Regge Models

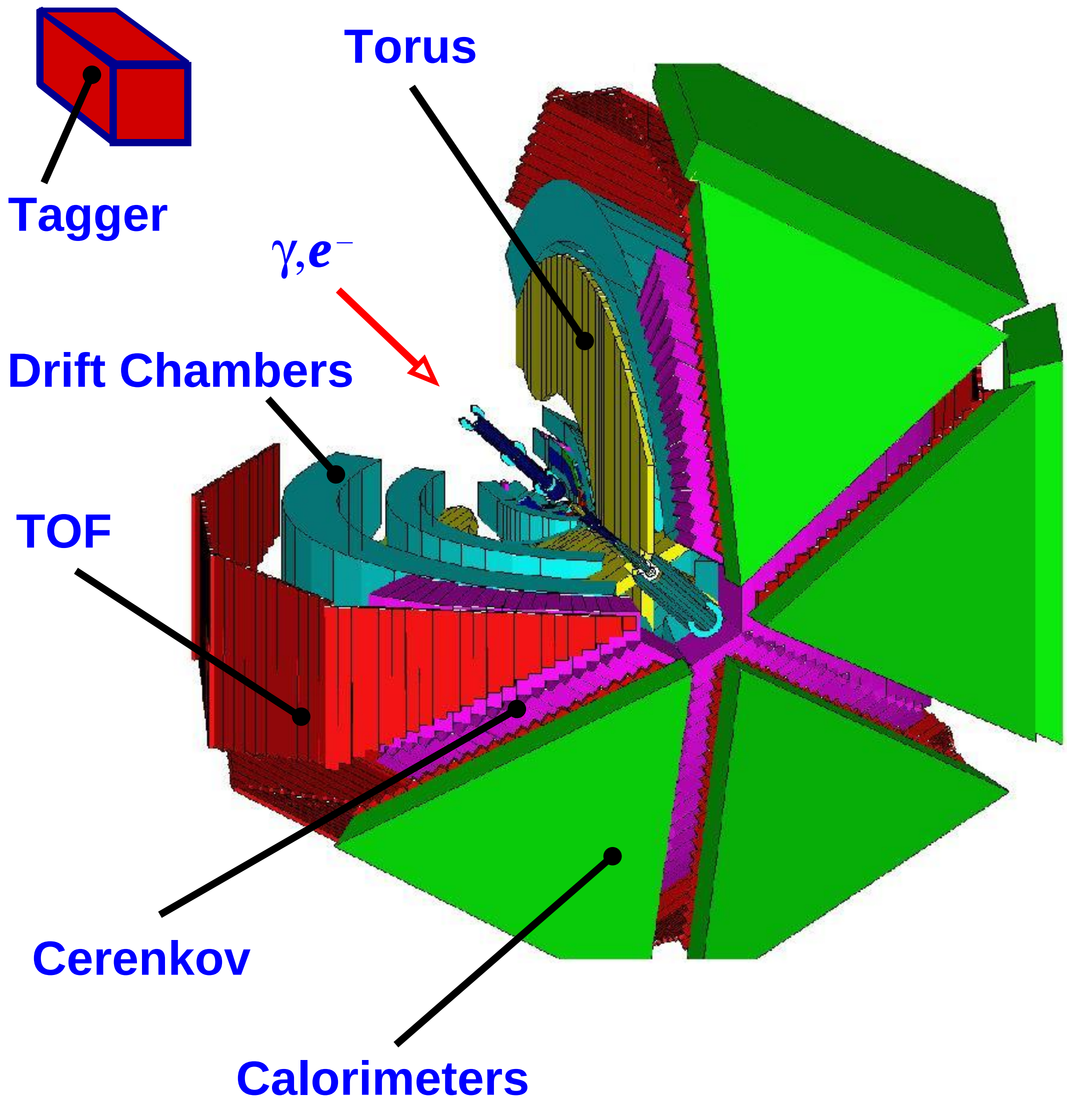
- Models based on t−channel Regge exchange.

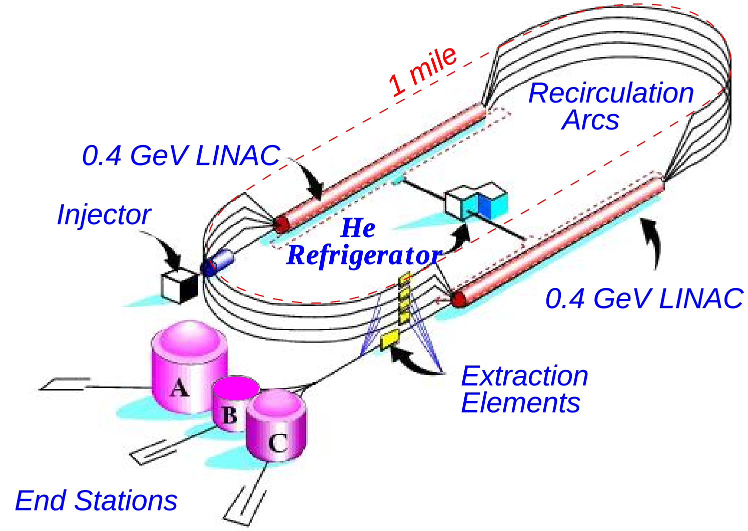
  (Guidal, Laget, Vanderhaeghen)

- NO s−channel resonances included.
- Very few adjustable parameters.
- Effective at moderate to higher energies.



CLAS Spectrometer





CHARACTERISTICS:

Electron Coverage: $\theta : 15\text{–}50^{o}$

Hadron Coverage:

$\theta : 15\text{–}140^{o},\ \phi : 80\%\ 2\pi$

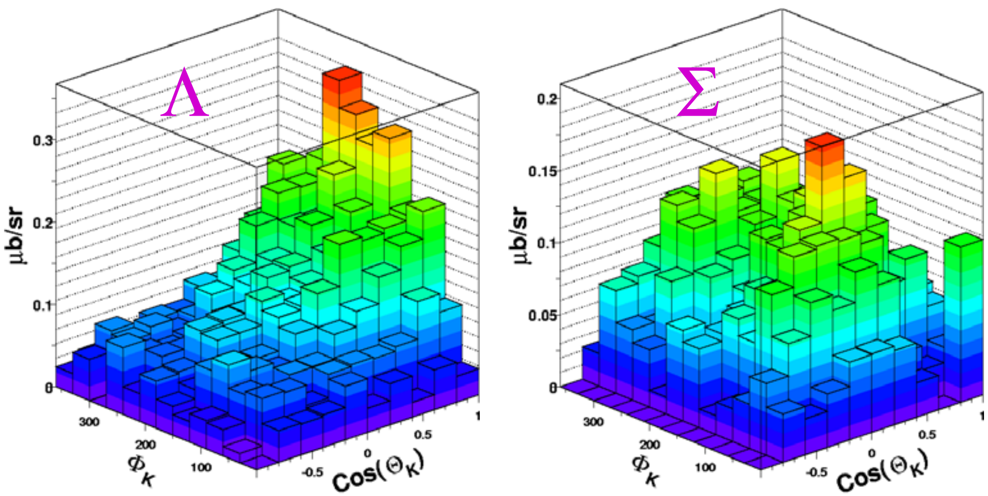
Resolution : $\Delta p/p \sim 1\text{–}2\%$
$\Delta\theta,\Delta\phi \sim 2\ mrad$

$$\mathcal{L} = 1 \times 10^{34}\ cm^{-2}sec^{-1}$$
$$\mathcal{F}_{\gamma} = 1 \times 10^{7}/s$$

Structure Functions in Electoproduction

$$\frac{d\sigma}{dQ^2 dW d\Omega_K^*} = \Gamma_v \left[\sigma_T + \epsilon\sigma_L + \epsilon\sigma_{TT}\cos 2\Phi + \sqrt{\epsilon(1+\epsilon)}\sigma_{LT}\cos\Phi\right]$$

$$\sigma_i = f(Q^2, W, \cos\theta_K^*) \text{ only}$$



- For each bin in W, Q^2, $\cos\theta_K^*$ perform fit of the form:

$$\sigma = A + B\cos 2\Phi + C\cos\Phi$$

- Provide tomography of structure functions over full kinematic space of the nucleon resonance region.

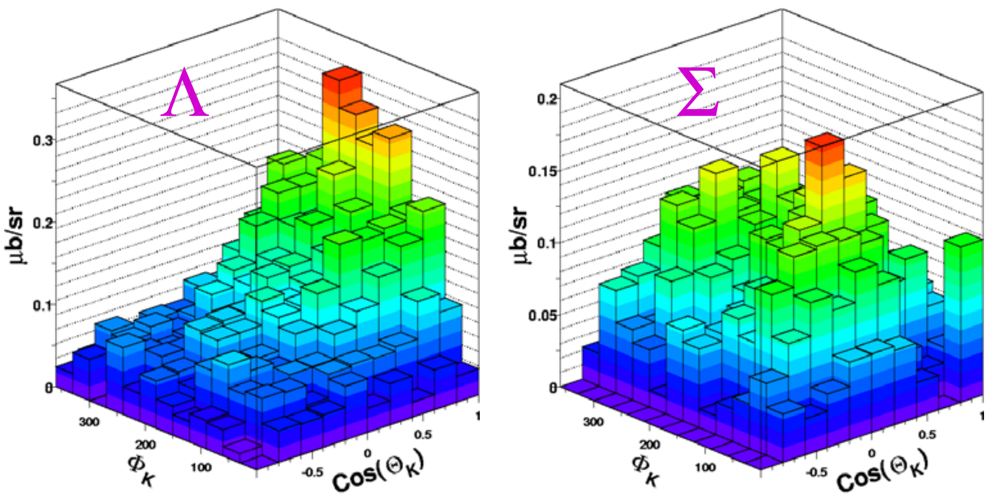
$$Q^2 : 0.5 \rightarrow 3.0 \text{ GeV}^2 \quad W : 1.6 \rightarrow 2.4 \text{ GeV}$$

Full coverage in K^+ solid angle

Structure Functions in Electoproduction

$$\frac{d\sigma}{dQ^2 dW d\Omega_K^*} = \Gamma_v \left[\underbrace{\sigma_T + \epsilon\sigma_L}_{A} + \underbrace{\epsilon\sigma_{TT}}_{B} \cos 2\Phi + \underbrace{\sqrt{\epsilon(1+\epsilon)}\sigma_{LT}}_{C} \cos\Phi \right]$$

$$\sigma_i = f(Q^2, W, \cos\theta_K^*) \ \ \text{only}$$



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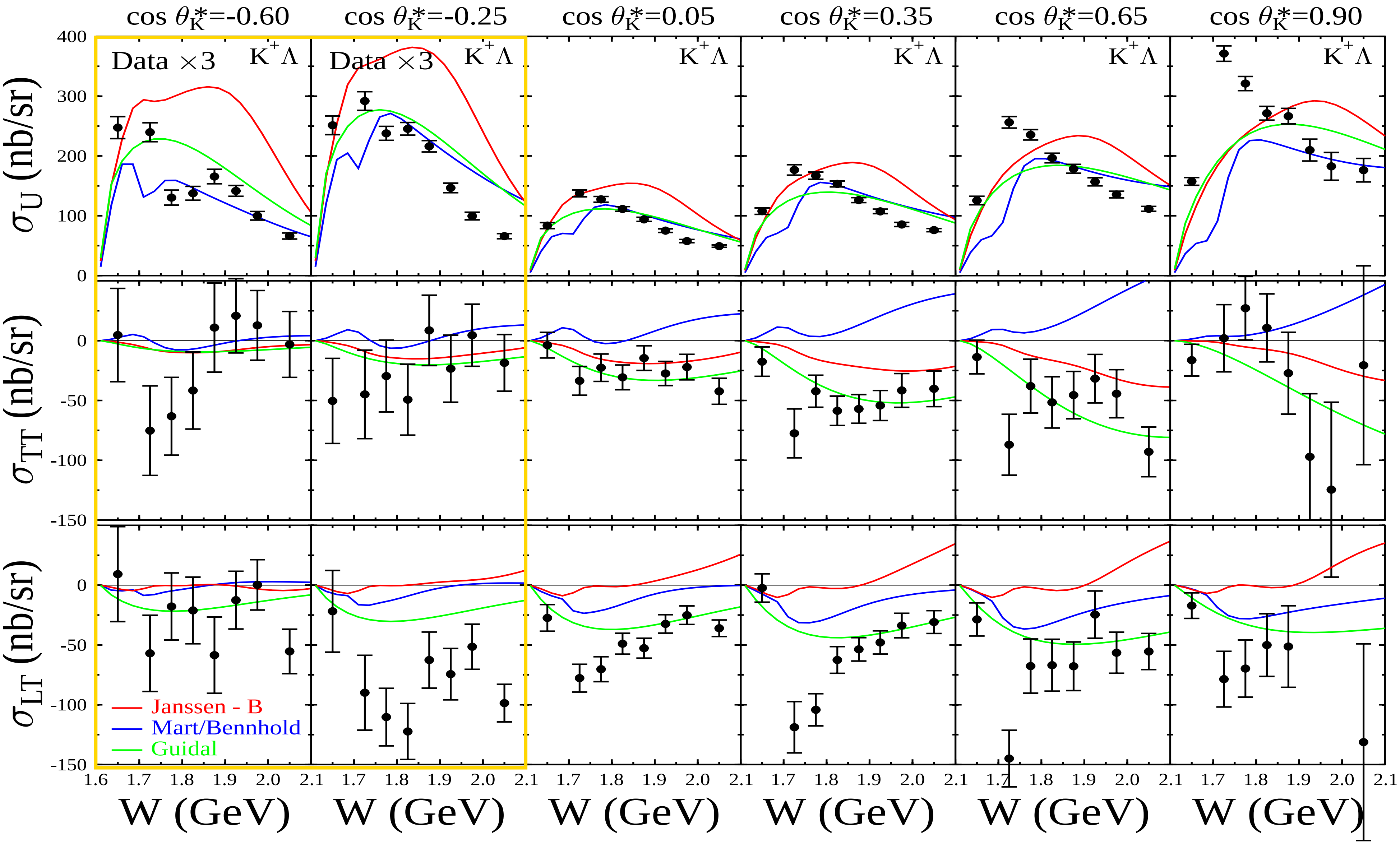
Full coverage in K^+ solid angle

Electroproduction Cross Sections

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

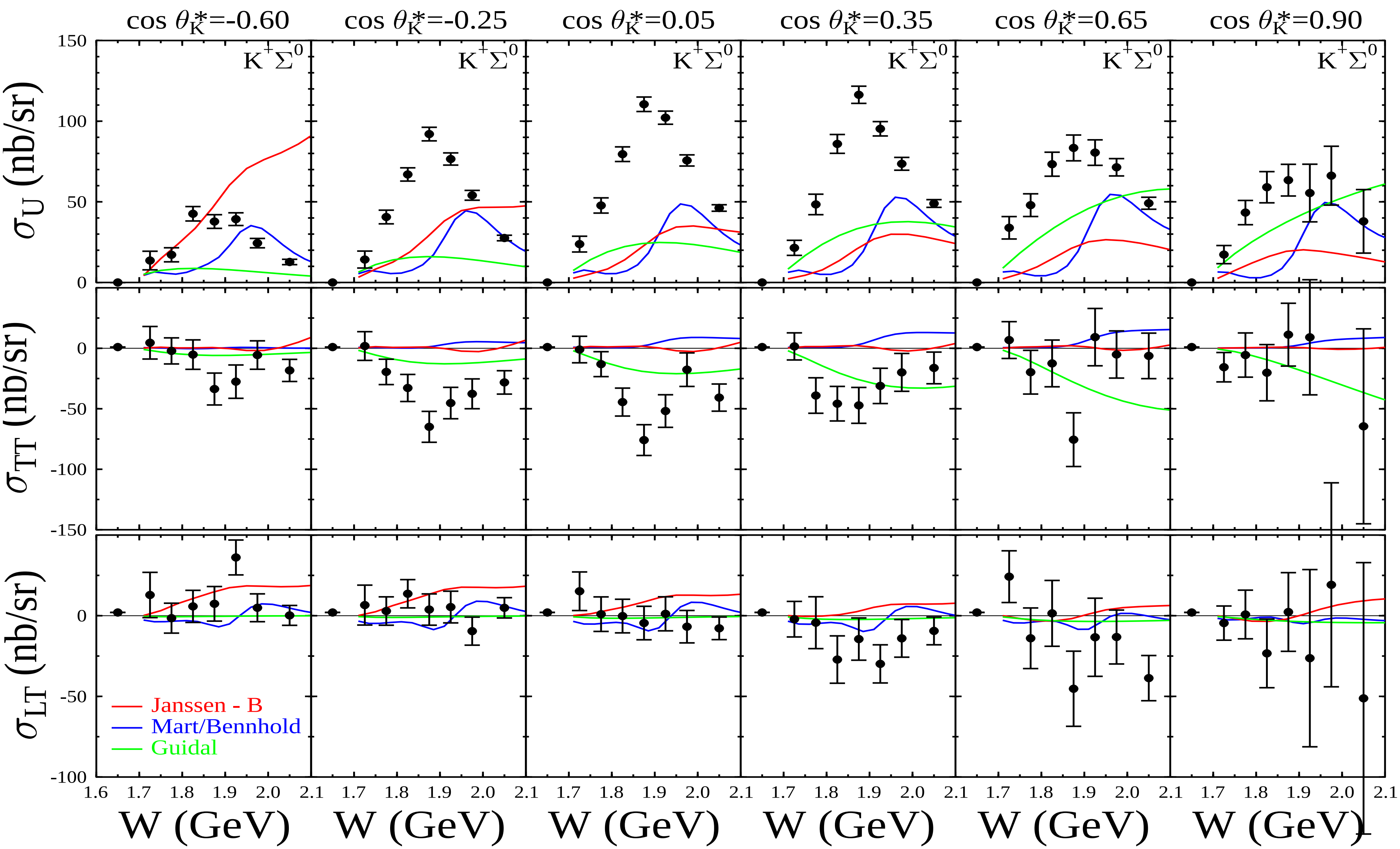


Ambrozewicz (CLAS), PRC 75, 045203 (2007).

$Q^2 = 0.65\ (\mathrm{GeV/c})^2$

Electroproduction Cross Sections

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

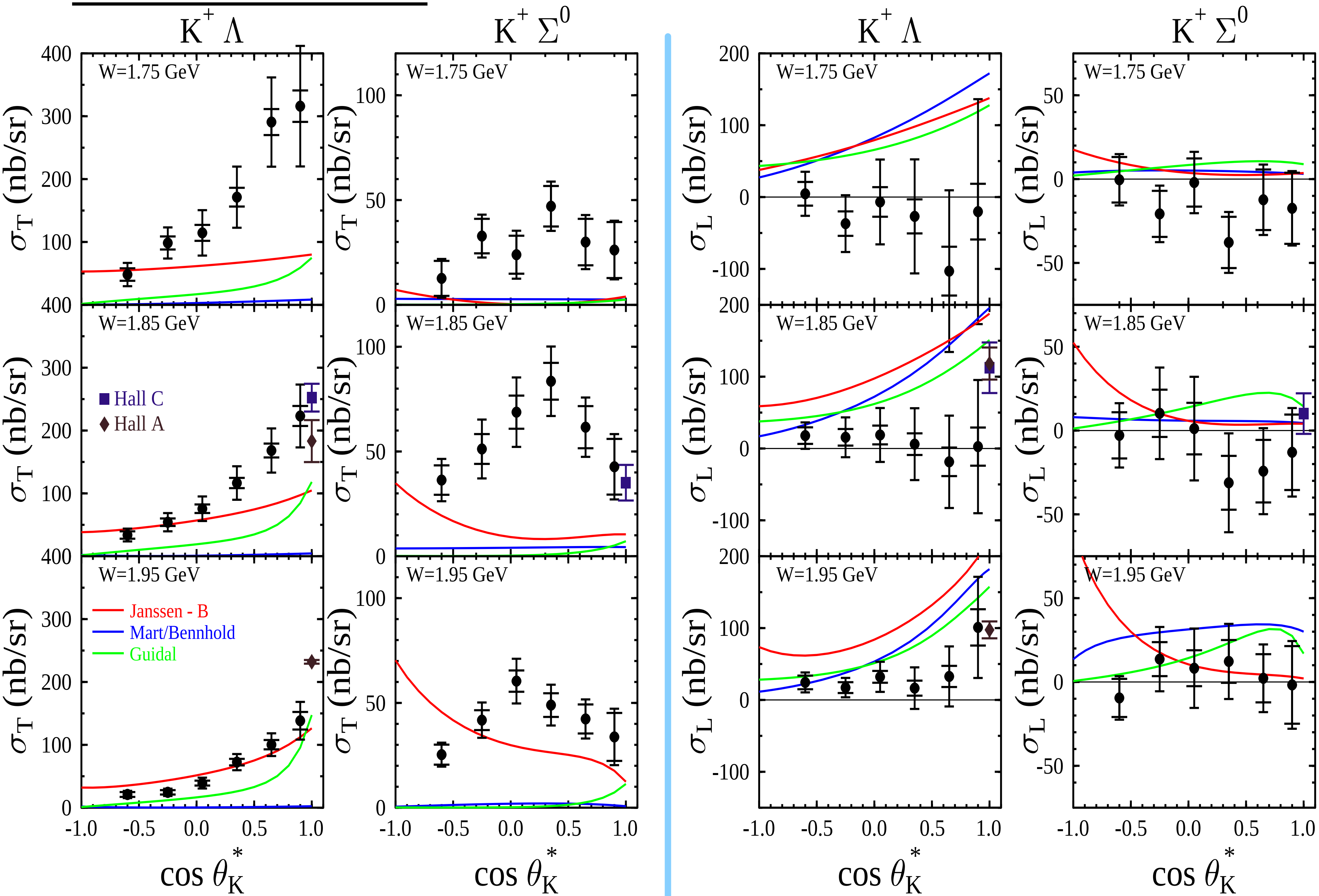


Ambrozewicz (CLAS), PRC 75, 045203 (2007).

$Q^2 = 0.65\ (\mathrm{GeV/c})^2$

L/T Separation

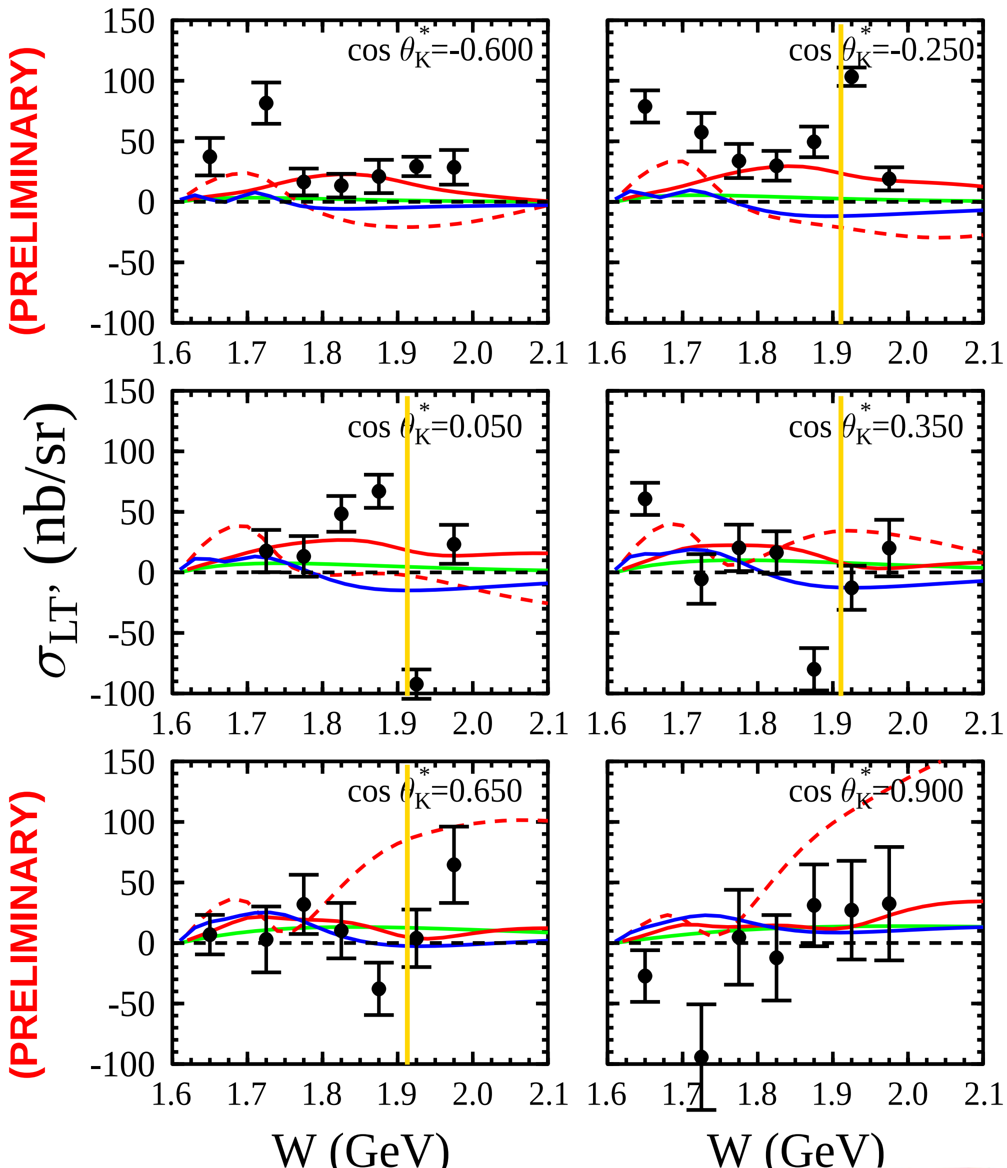
Ambrozewicz (CLAS), PRC 75, 045203 (2007).



Fifth Structure Function

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

- Measure polarized beam asymmetry to extract fifth structure function.



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

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

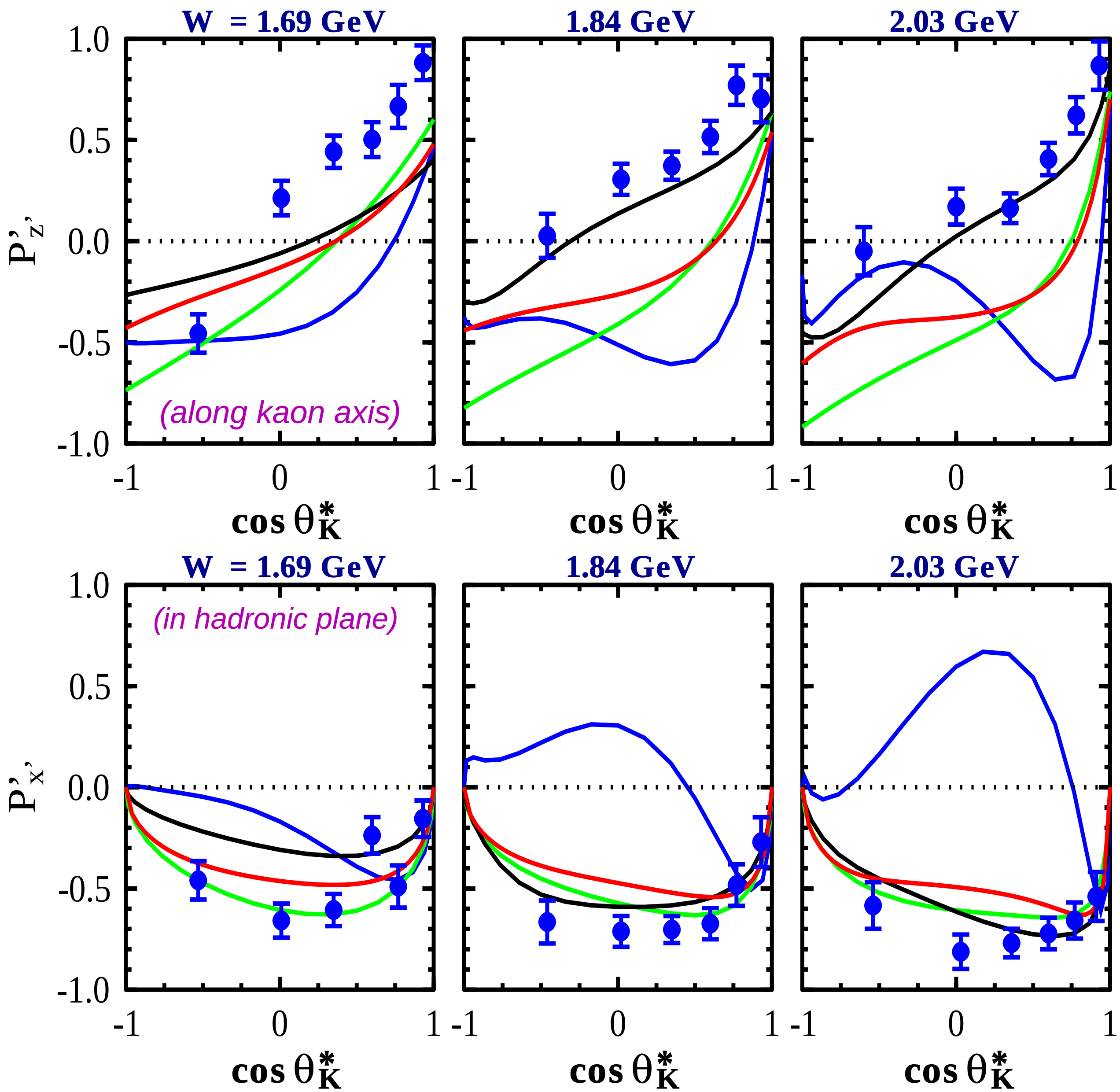
- Calculations from:
  - Mart/Bennhold –– Isobar
  - Ghent –– Regge + Resonance
    D13 (solid), P11 (dashed)
    → *Rule out P11 assumption.*
  - Guidal/Laget/Vanderhaeghen –– Regge

2.567 GeV $Q^2 = 1.00\ (\text{GeV}/c)^2$

Nasseripour (CLAS), to be submitted (2007).
(under final CLAS review)

Transferred Polarization

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



Williams – 1992
Bennhold – 2002
Janssen – 2002
Guidal – 1999

Resonance	WJC92	BM02	J02
$N^*(1650)$	★	★	★
$N^*(1710)$	★	★	★
$N^*(1720)$		★	★
$N^*(1895)$		★	★
$K^*(892)$	★	★	★
$K_1(1270)$	★	★	★
$\Lambda(1405)$	★		
$\Lambda(1800)$			★
$\Lambda(1810)$			★

2.567 GeV
Summed over Q^2, Φ

Carman (CLAS), PRL 90, 131804 (2003)

What Has Been Learned?

$K^+\Lambda$

- **Historical Lore:** Core set of states – $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$

BASED ON FITS TO PHOTOPRODUCTION DATA

- **Coupled-Channel Model (Bonn):**

  Most relevant: $P_{13}(1720)$, $P_{11}(1840)$, $D_{13}(1870)$, $D_{13}(2070)$, $P_{13}(2200)$

  (EPJ A25, 441 (2005))

- **Coupled-Channel Model (Saghai, EBAC):** *(nucl–th/061053)*

  Most relevant: $S_{11}(1535)$, $P_{13}(1900)$, $D_{13}(1520)$, $F_{13}(1680)$, $F_{17}(1990)$

  Other required states: $S_{11}(1650)$, $F_{15}(1680)$, $F_{15}(2000)$, $D_{13}(1954)$, $S_{11}(1806)$, $P_{13}(1893)$

- **Multipole Model: (Mart & Sulaksono)** *(nucl–th/0701007)*

  SAPHIR/LEPS – $S_{11}(1650)$, $P_{13}(1720)$, $D_{13}(1700)$, $D_{13}(2080)$, $F_{15}(1680)$, $F_{15}(2000)$

  CLAS/LEPS – $P_{13}(1900)$, $D_{13}(2080)$, $D_{15}(1675)$, $F_{15}(1680)$, $F_{17}(1990)$

  CLAS data do not require any core states!!

A MURKY SITUATION!

- In principle, the KY photoproduction and electroproduction data should be fit simultaneously with a full set of channels.

  e.g. πN, ηN, ωN, ϕN, $\pi\pi N$ (σN, $\pi\Delta$, ρN)

  (this is too difficult at the current time.)

Near−Term Future Plans

G13

− Linearly and circularly polarized photons on deuterium (1.6 − 2.4 GeV)

$$\gamma n \rightarrow K^0\Lambda, K^0\Sigma^0, K^+\Sigma^-$$

− Measure isospin related processes

− 7 observables

− Running completed in 2007; data processing now beginning

FROST

− Linearly and circularly polarized photons on proton target (1.6 − 2.4 GeV)

− Use novel FRozen Spin Target (longitudinal and transverse polarization)

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

− 8 observables

− Next experiment on the floor at CLAS

HD-ICE

− Linearly and circularly polarized photons on deuterium (1.6 − 2.4 GeV)

$$\gamma n \rightarrow K^0\Lambda, K^0\Sigma^0, K^+\Sigma^-$$

− Use polarized HD−Ice target from BNL modified for CLAS

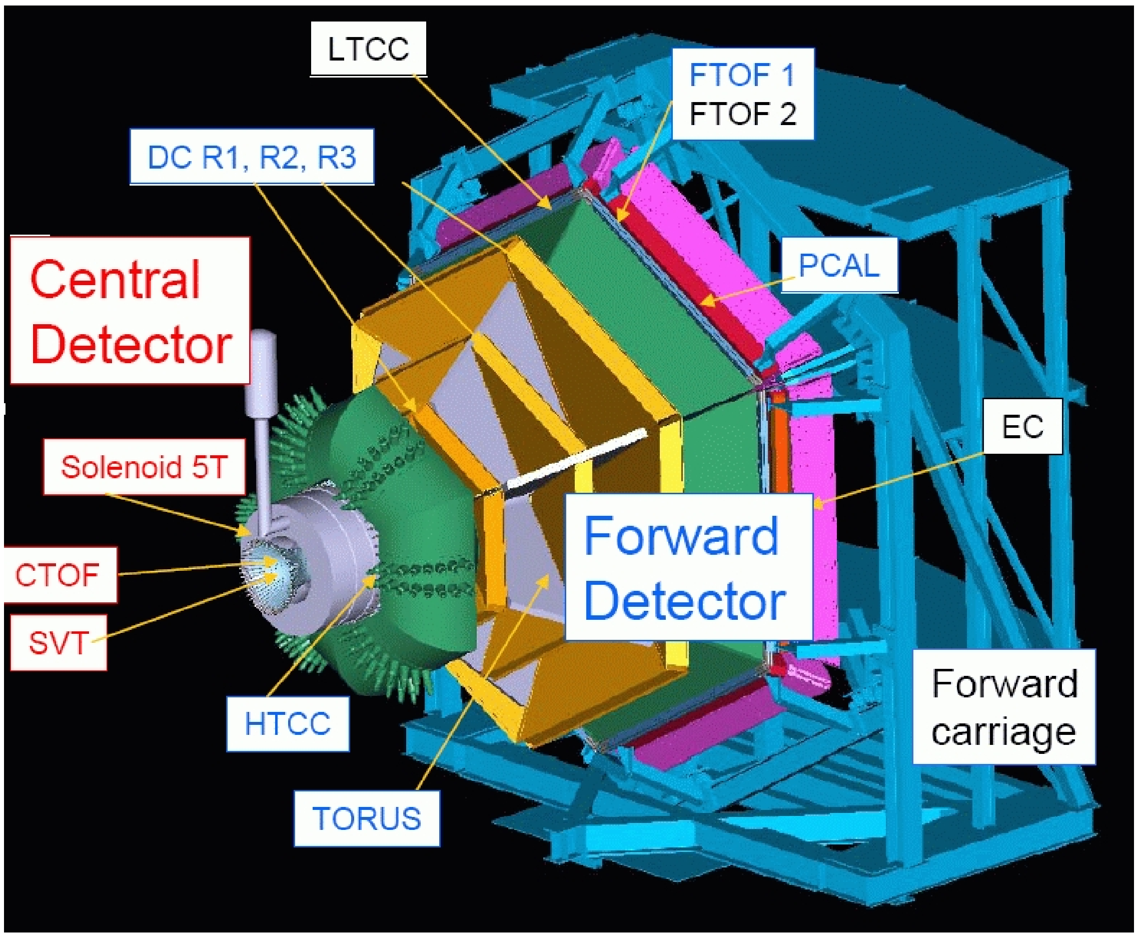
− 13 observables

− run in 2 − 3 years

CLAS12 Upgrade

- Planning is well underway for the energy upgrade of the JLab electron accelerator from 6 GeV to 12 GeV.

The CLAS12 detector will replace the existing CLAS detector.



CLAS12 PHYSICS PROGRAM

- *Quark distribution functions*
- *Nucleon structure functions*
- *Semi−inclusive DIS*
- *Properties of QCD from the nuclear medium*
- *Baryon and meson spectroscopy*
- *Baryon form factors*

Summary/ Conclusions

- **The Hall B strangeness physics program:**
  - Designed to measure cross sections and all combinations of beam, target, and recoil polarization states.
    - *Precision data −− broad kinematic coverage*
  - Sensitive to high−mass baryons (>1.6 GeV) with large K−Y couplings and large photocoupling amplitudes.

(clasweb.jlab.org/physicsdb)

- **So far we have found:**
  - Suggestive evidence of resonant structures in the data.
    - *Both photo− and electroproduction*
  - Existing theoretical models do not describe the data well in our kinematics.
  - Polarization data is quite versatile and useful to study.
  - Work needed to continue to improve the models.
    - *Opportunity for significant new constraints*

BACKUP SLIDES

Coupled−Channels Analysis

Decays of Baryon Resonances into ΛK^+, $\Sigma^0 K^+$ and $\Sigma^+ K^0$

A.V. Sarantsev[1,2], V.A. Nikonov[1,2], A.V. Anisovich[1,2], E. Klempt[1], and U. Thoma[1,3]

[1] Helmholtz–Institut für Strahlen– und Kernphysik, Universität Bonn, Germany
[2] Petersburg Nuclear Physics Institute, Gatchina, Russia
[3] Physikalisches Institut, Universität Gießen, Germany

June 7, 2005

EPJ A25, 441 (2005).

Abstract. Cross sections, beam asymmetries, and recoil polarisations for the reactions $\gamma p \to K^+\Lambda$; $\gamma p \to K^+\Sigma^0$, and $\gamma p \to K^0\Sigma^+$ have been measured by the SAPHIR, CLAS, and LEPS collaborations with high statistics and good angular coverage for centre-of-mass energies between 1.6 and 2.3 GeV. The combined analysis of these data with data from π and η photoproduction reveals evidence for new baryon resonances in this energy region. A new P_{11} state with mass 1840 MeV and width 140 MeV was observed contributing to most of the fitted reactions. The data demand the presence of two D_{13} states at 1870 and 2170 MeV.
PACS: 11.80.Et, 11.80.Gw, 13.30.-a, 13.30.Ce, 13.30.Eg, 13.60.Le 14.20.Gk

Resonance	$\Gamma_{N\eta}/\Gamma_{N\pi}$	$\Gamma_{\Lambda K}/\Gamma_{N\pi}$	$\Gamma_{\Sigma K}/\Gamma_{N\pi}$
$N(1520)D_{13}$	$1.5 \cdot 10^{-3}$	0	0
$N(1675)D_{15}$	0.05	0.05	0
$N(1680)F_{15}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-4}$	0
$N(1700)D_{13}$	0.80	0.07	$5 \cdot 10^{-3}$
$N(1720)P_{13}$	0.80	0.20	0.01
$N(1840)P_{11}$	0.25	0.11	0.80
$N(1870)D_{13}$	2.0	0.28	1.6
$N(2000)F_{15}$	0.04	$5 \cdot 10^{-3}$	$3 \cdot 10^{-3}$
$N(2070)D_{15}$	0.30	$8 \cdot 10^{-3}$	0.015
$N(2170)D_{13}$	0.04	0.17	0.14
$N(2200)P_{13}$	2.0	0.18	0.11
$\Delta(1700)D_{33}$			$2.5 \cdot 10^{-3}$
$\Delta(1920)P_{33}$			0.04
$\Delta(1940)D_{33}$			0.75
$\Delta(1950)F_{37}$			0.01

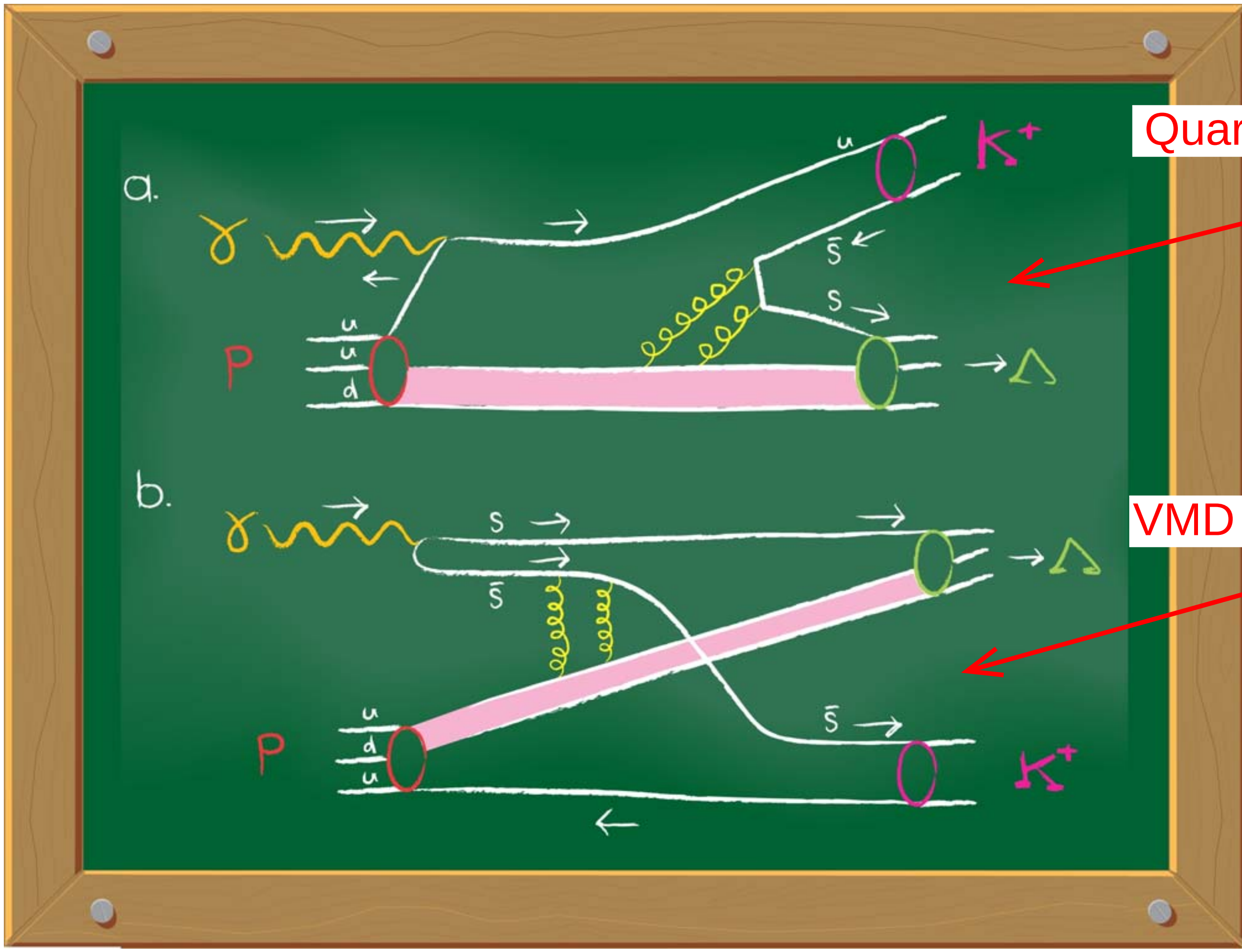
Fits of photoproduction data

Observable	N_{data}	χ^2	χ^2/N_{data}	Weight
$\sigma(\gamma p \to \Lambda K^+)$	720	804	1.12	4
$\sigma(\gamma p \to \Lambda K^+)$	770	1282	1.67	2
$P(\gamma p \to \Lambda K^+)$	202	374	1.85	1
$\Sigma(\gamma p \to \Lambda K^+)$	45	62	1.42	15
$\sigma(\gamma p \to \Sigma^0 K^+)$	660	834	1.27	1
$\sigma(\gamma p \to \Sigma^0 K^+)$	782	2446	3.13	1
$P(\gamma p \to \Sigma^0 K^+)$	95	166	1.76	1
$\Sigma(\gamma p \to \Sigma^0 K^+)$	45	20	0.46	35
$\sigma(\gamma p \to \Sigma^+ K^0)$	48	104	2.20	2
$\sigma(\gamma p \to \Sigma^+ K^0)$	120	109	0.91	5
$\sigma(\gamma p \to p\pi^0)$	1106	1654	1.50	8
$\sigma(\gamma p \to p\pi^0)$	861	2354	2.74	3.5
$\Sigma(\gamma p \to p\pi^0)$	469	1606	3.43	2
$\Sigma(\gamma p \to p\pi^0)$	593	1702	2.87	2
$\sigma(\gamma p \to n\pi^+)$	1583	4524	2.86	1
$\sigma(\gamma p \to p\eta)$	667	608	0.91	35
$\sigma(\gamma p \to p\eta)$	100	158	1.60	7
$\Sigma(\gamma p \to p\eta)$	51	114	2.27	10
$\Sigma(\gamma p \to p\eta)$	100	174	1.75	10

- An emerging issue is that the solutions apparently are not unique.
- Need to reduce ambiguities and improve fits with electroproduction data.

The New Spin Crisis

- A new controversy has developed based on the simple phenomenology seen in the transferred polarization data from CLAS.



Quark spins produced anti−aligned.

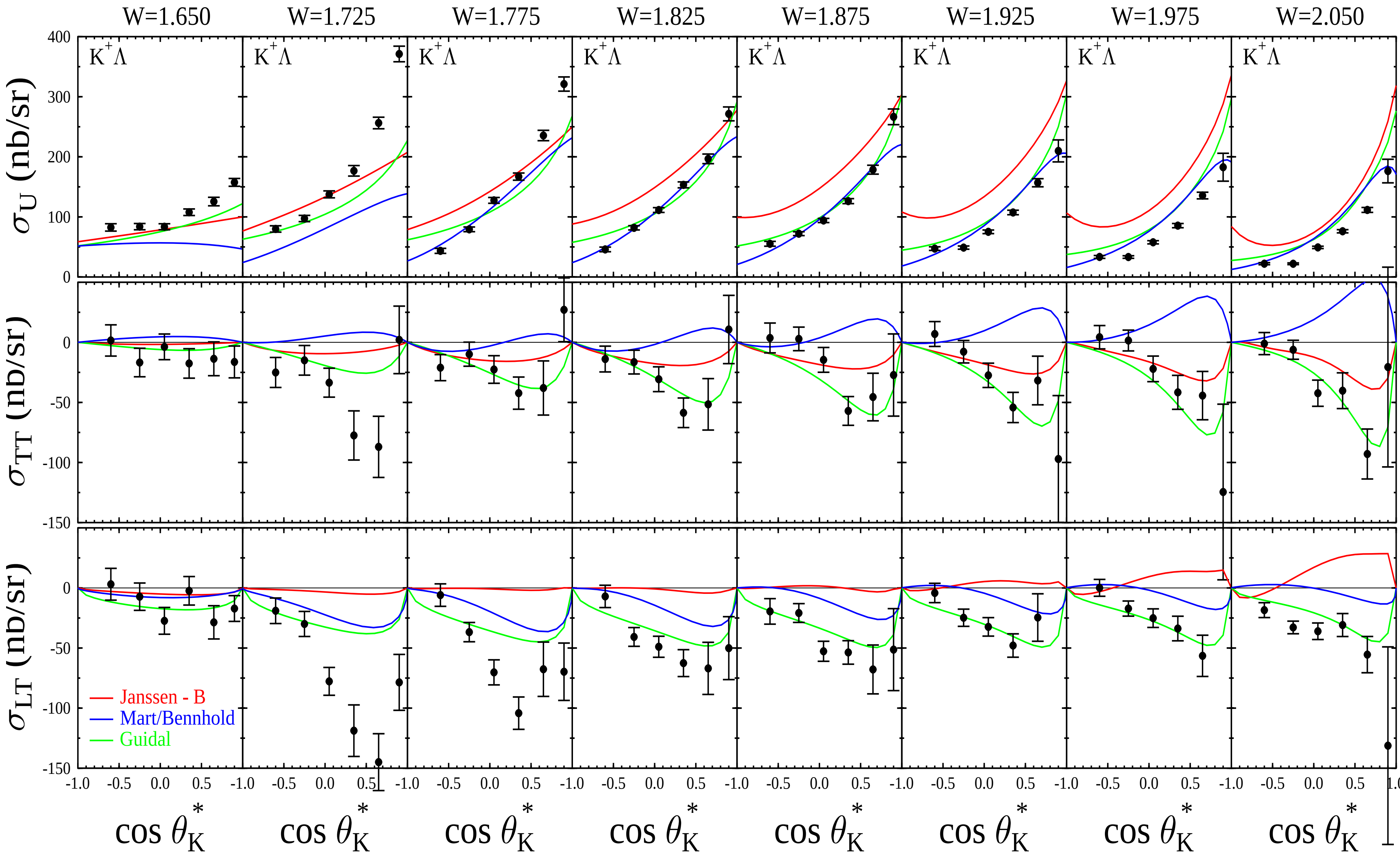
VMD model with quark spins aligned.

- Tests of:
  - *Hadronization/string breaking*
  - *Reaction mechanism*
  - *Associated dynamics*

CERN COURIER *(Sep 2007)*

Electroproduction Cross Sections

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



Ambrozewicz (CLAS), PRC 75, 045203 (2007).

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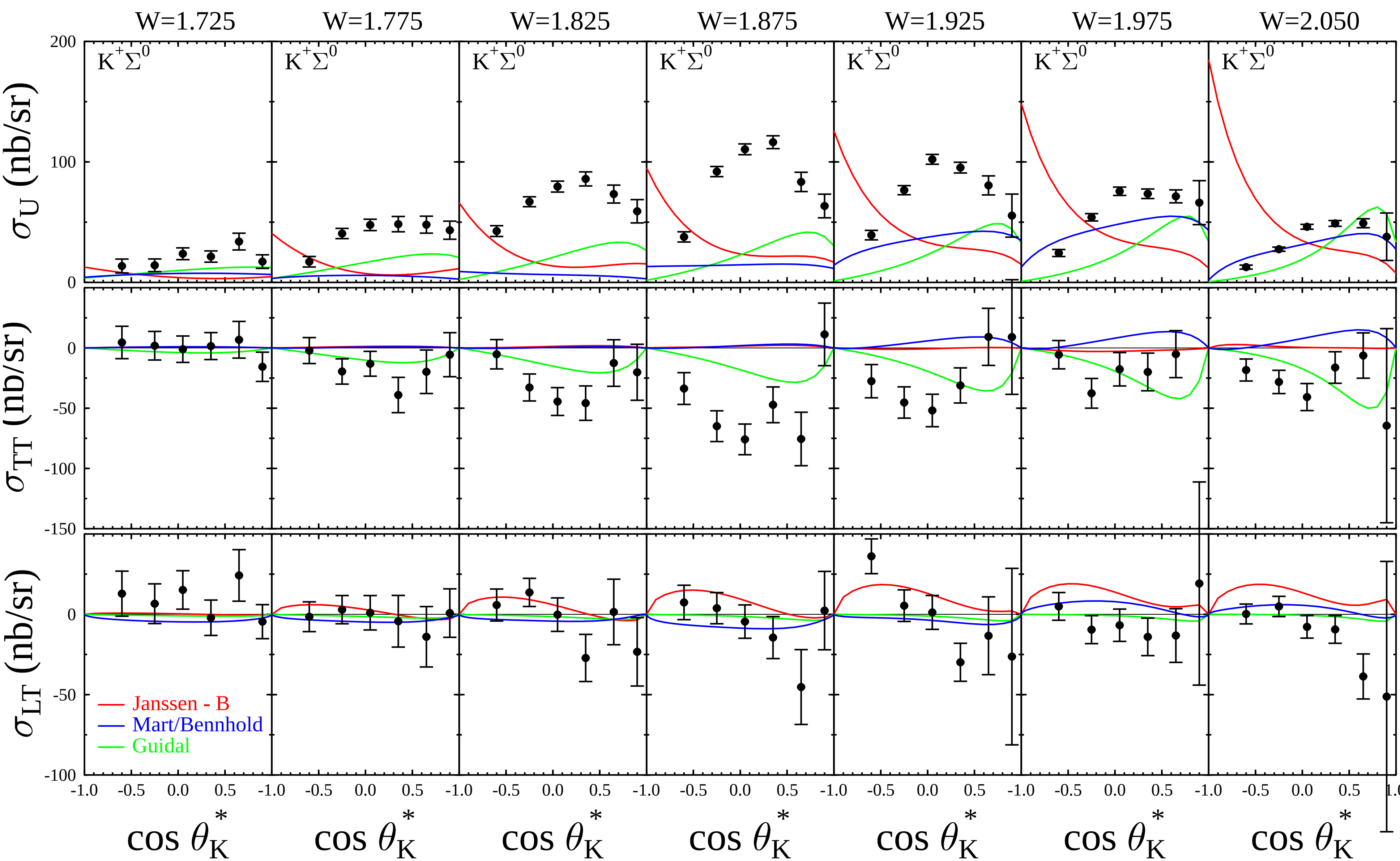
Electroproduction Cross Sections

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



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