Kaon Electromagnetic Production in Hall B

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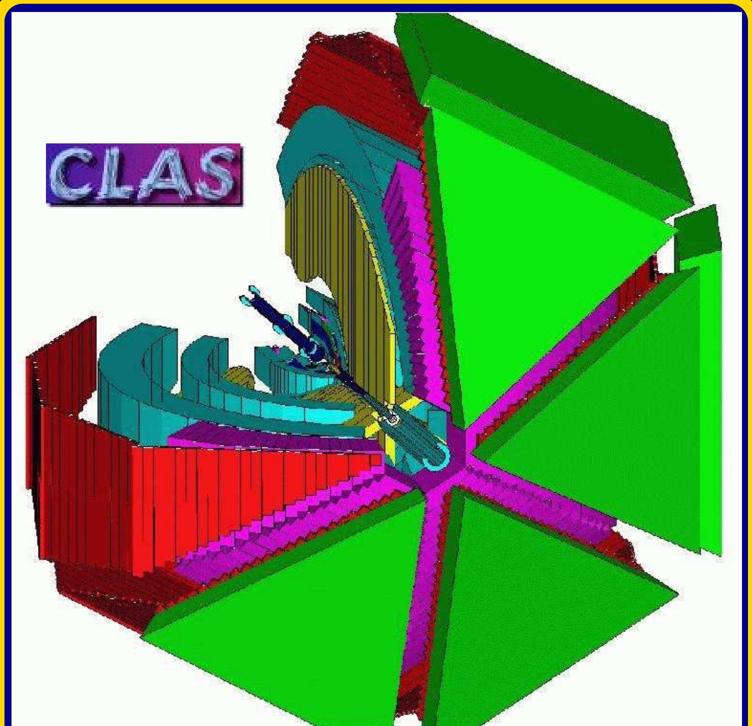
Ohio University

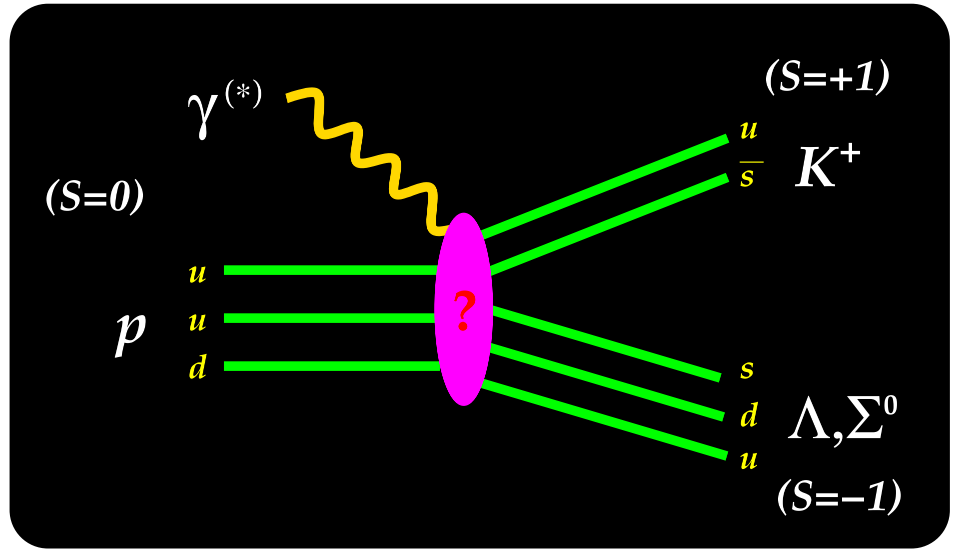


Outline

- *The Strangeness Program*
- *The CLAS Detector*
- *Formalism and Models*
- *Program Highlights*
- *Summary and Outlook*

Hall B Programs

The CLAS strangeness physics program is focussing on associated production of ground–state hyperons.



Photoproduction

- *Total & differential cross sections*
- *Induced polarization*

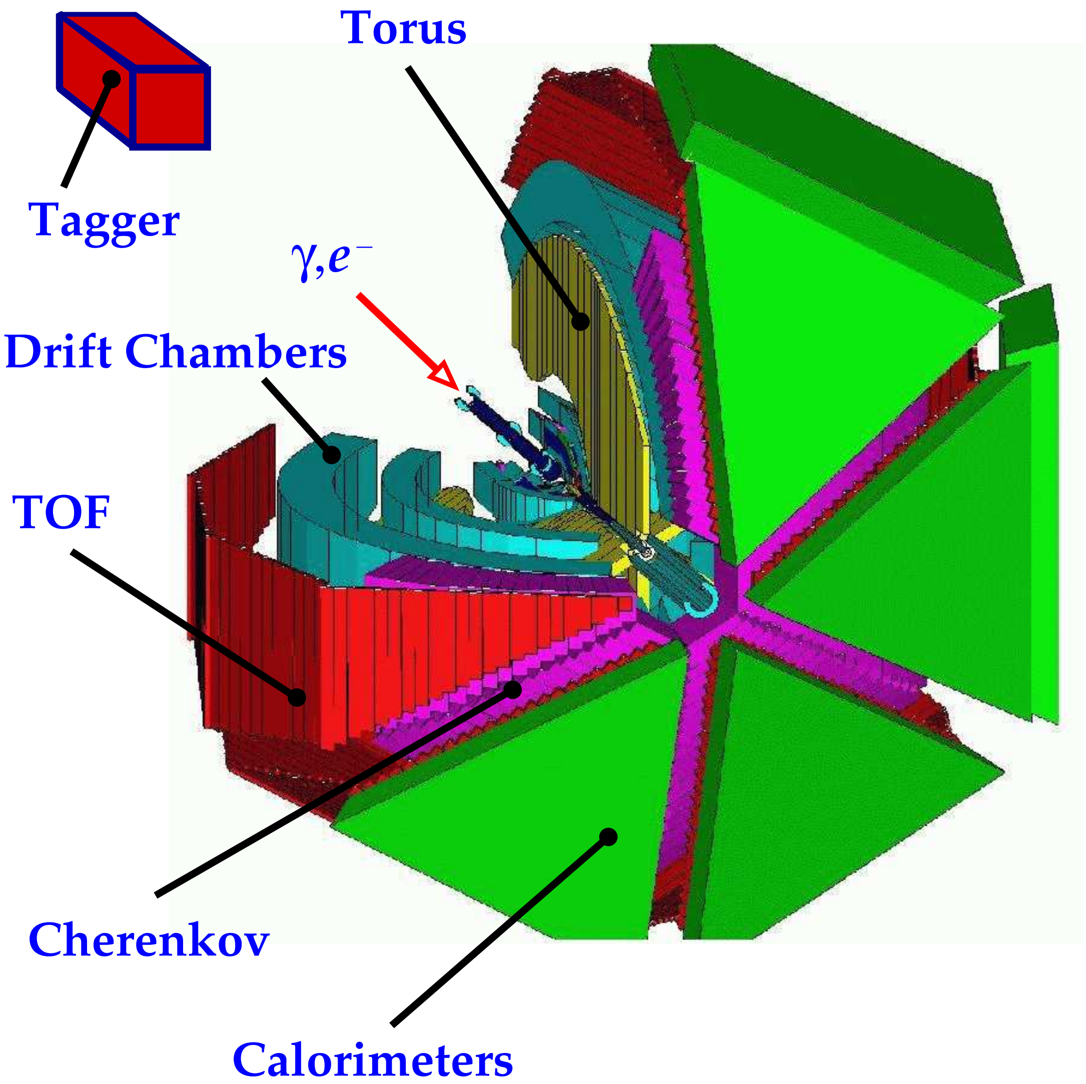
  circular & linear polarization
- *Beam–recoil polarization*
- *Polarized target measurements*

  frozen–spin target

Electroproduction

- *Differential cross sections*
- *Induced polarization*
- *Beam–recoil polarization*
- *Beam asymmetry*
- *Polarized target measurements*
- *Global multi–dataset analysis*

CLAS Spectrometer



Characteristics:

Hadron Coverage:

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

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

Electron Mode:

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

$\mathcal{L} = 1 \times 10^{34}\ cm^{-2} sec^{-1}$

Photon Mode:

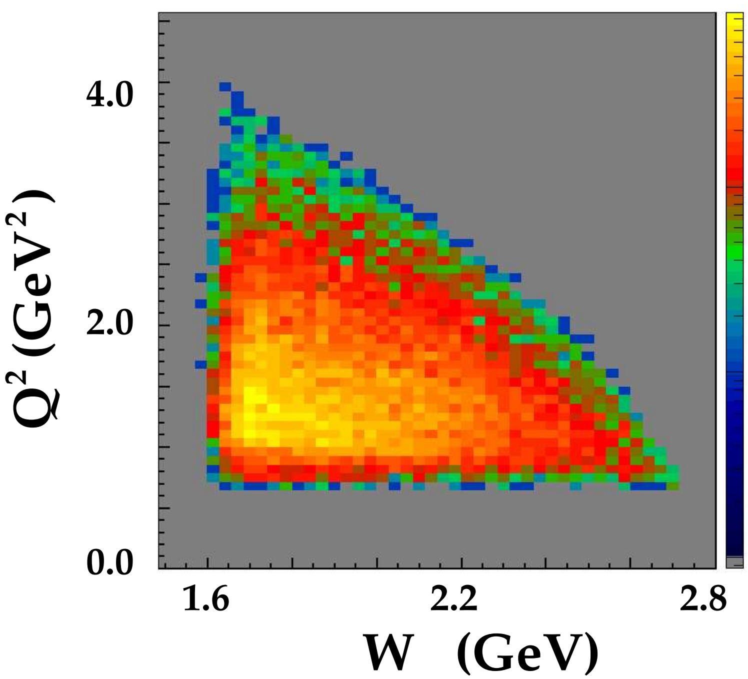
Bremsstrahlung tagger : $10^{7}\ \gamma/s$

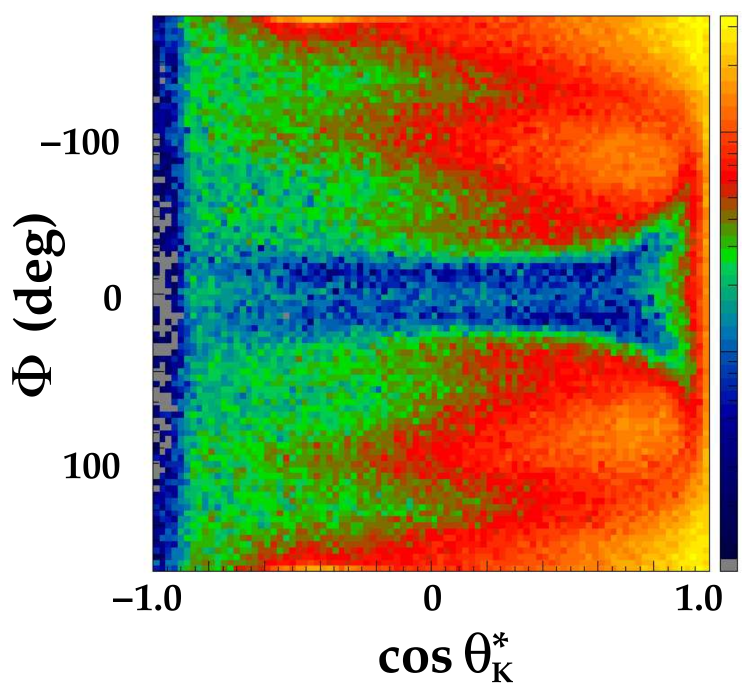
Kinematic Coverage

- The measurement program is designed to study the full nucleon resonance region,

  W: 1.6 - 3.0 GeV

  while spanning the full kaon angular range in θ^* / Φ for each of the different observables.





(electroproduction plots at 4.2 GeV)

Publication Status

Electroproduction

- **S.P. Barrow** *et al.* *(CLAS Collaboration)*, **"Electroproduction of the $\Lambda(1520)$ Hyperon", Phys. Rev. C 64, 044601 (2001).**
- **D.S. Carman** *et al.*, *(CLAS Collaboration)*, **"First Measurement of Transferred Polarization in the Exclusive $\vec{e}p \to e'K^+\vec{\Lambda}$ Reaction", Phys. Rev. Lett. 90, 131804 (2003).**
- **R. Feuerbach** *et al.*, *(CLAS Collaboration)*, **"Electroproduction of $K^+\Lambda$ and $K^+\Sigma^0$ at CLAS", in CLAS Working Group review.**

Photoproduction

- **J. McNabb** *et al.*, *(CLAS Collaboration)*, **"Hyperon Photoproduction in the Nucleon Resonance Region", Pre-print nucl-ex/0305028, submitted to Phys. Rev. Lett., (2003).**

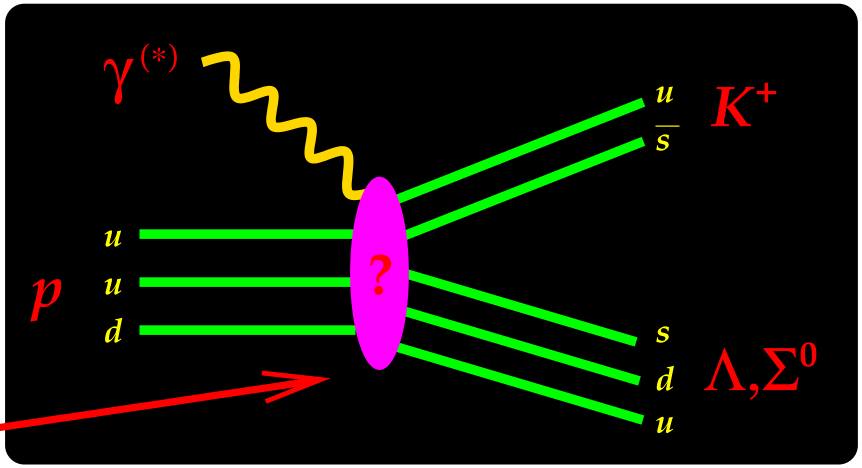
Still a very active and ongoing program

Reaction Mechanism

- **Comprehensive description of reaction mechanism not yet available.**
  - ***Progress hindered by lack of data and theoretical support.***

(programs at SPring–8, SAPHIR, GRAAL, CLAS)

- **Study contribution of s, t, and u channels to the reaction dynamics.**



- **Study structure of intermediate mesons and baryons.**
  - ***Determine masses, widths, helicity amplitudes, partial decay widths.***
  - Λ/Σ^0 ***selection acts as isospin filter.***
  - Λ/Σ^0 ***production allows polarization measurements.***

"Missing" Quark Model Baryons

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

Perhaps these "missing" states decay into KY channels.

Complementary to other mechanisms.

Baryon	*** and **** Resonances	* and ** Resonances
N^*	$S_{11}(1535)$, $S_{11}(1650)$, $P_{11}(1440)$, $P_{11}(1710)$, $P_{13}(1720)$, $D_{13}(1520)$, $D_{13}(1700)$, $D_{15}(1675)$, $F_{15}(1680)$, $G_{17}(2190)$, $G_{19}(2250)$, $H_{19}(2220)$	$S_{11}(2090)$, $P_{11}(2100)$, $P_{13}(1900)$, $D_{13}(2080)$, $D_{15}(2200)$, $F_{15}(2000)$, $F_{17}(1990)$
Λ^*	$S_{01}(1405)$, $S_{01}(1650)$, $S_{01}(1800)$, $P_{01}(1600)$, $P_{01}(1810)$, $P_{03}(1890)$, $D_{03}(1520)$, $D_{03}(1690)$, $D_{05}(1830)$, $F_{05}(1820)$, $F_{05}(2110)$, $G_{07}(2100)$, $H_{09}(2350)$	$D_{03}(2325)$, $F_{07}(2020)$
Σ^*	$S_{11}(1750)$, $P_{11}(1660)$, $P_{11}(1880)$, $P_{13}(1385)$, $D_{13}(1670)$, $D_{13}(1940)$, $D_{15}(1775)$, $F_{15}(1915)$, $F_{17}(2030)$	$S_{11}(1620)$, $S_{11}(2000)$, $P_{11}(1710)$, $P_{11}(1880)$, $P_{13}(1840)$, $P_{13}(2080)$, $D_{13}(1580)$, $F_{15}(2070)$, $G_{17}(2100)$

– Focus on W>1.6 GeV.

Fertile area for discovery.

– Supported by recent quark model calculations.

Capstick and Roberts, PRD 58 (1998).

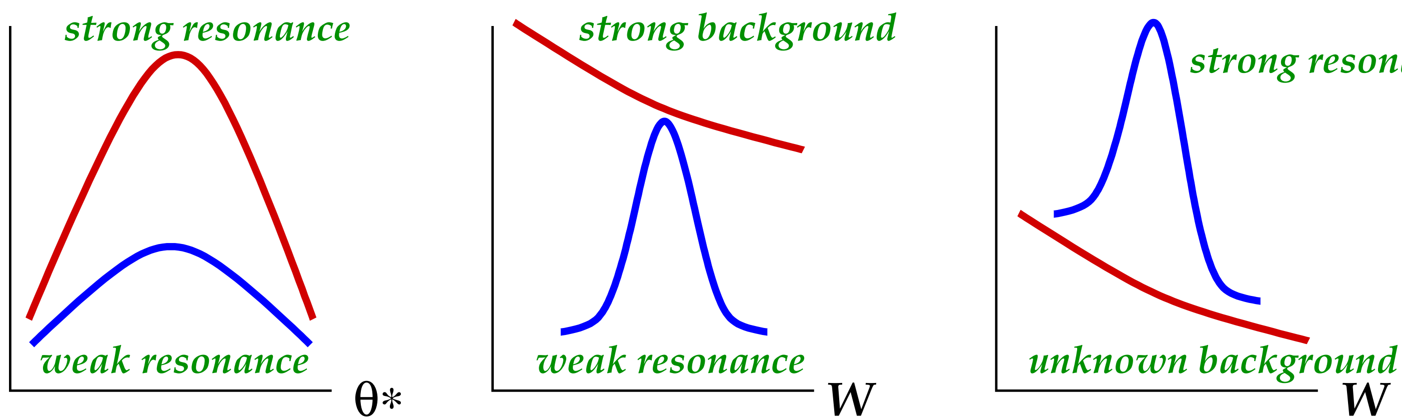
– Supported by recent data.

(SAPHIR, GRAAL, SPring–8, CLAS)

Polarization Observables

- **Most of our understanding about the reaction mechanism comes from unpolarized experiments.**
  - *This gives access only to limited information.*

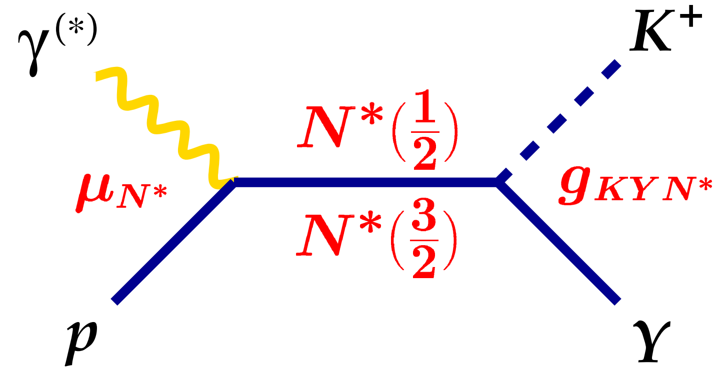
- **Polarization provides information about the contributing amplitudes.**



- **Access underlying dynamics via both single and double polarization.**
  - $\vec{\gamma}^{(*)} + p \to K^+ + Y$ **Beam asymmetry**
  - $\gamma^{(*)} + p \to K^+ + \vec{Y}$ **Induced polarization**
  - $\vec{\gamma}^{(*)} + p \to K^+ + \vec{Y}$ **Transferred polarization**

polarized target data coming too.

Hadrodynamic Models

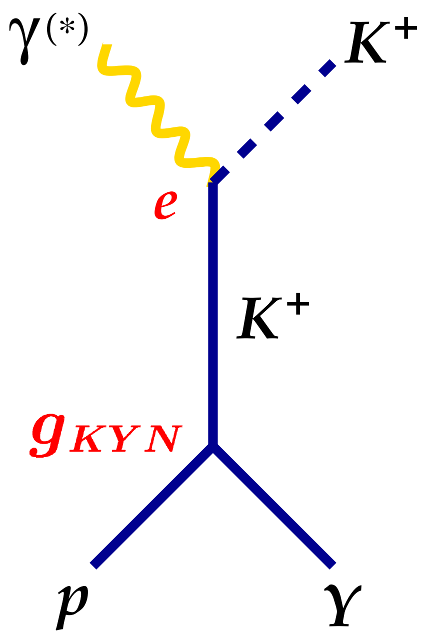


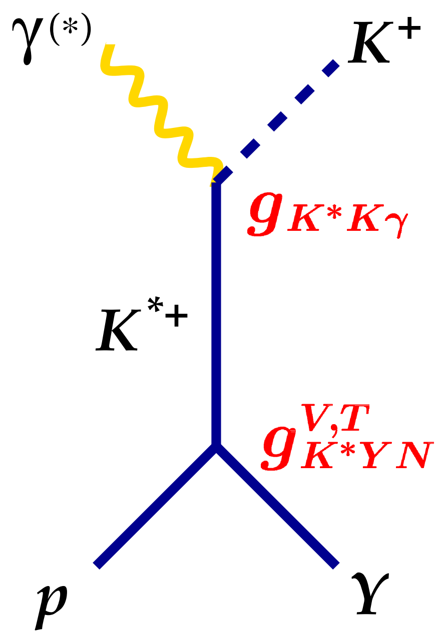
Isobar models based on effective Lagrangian.

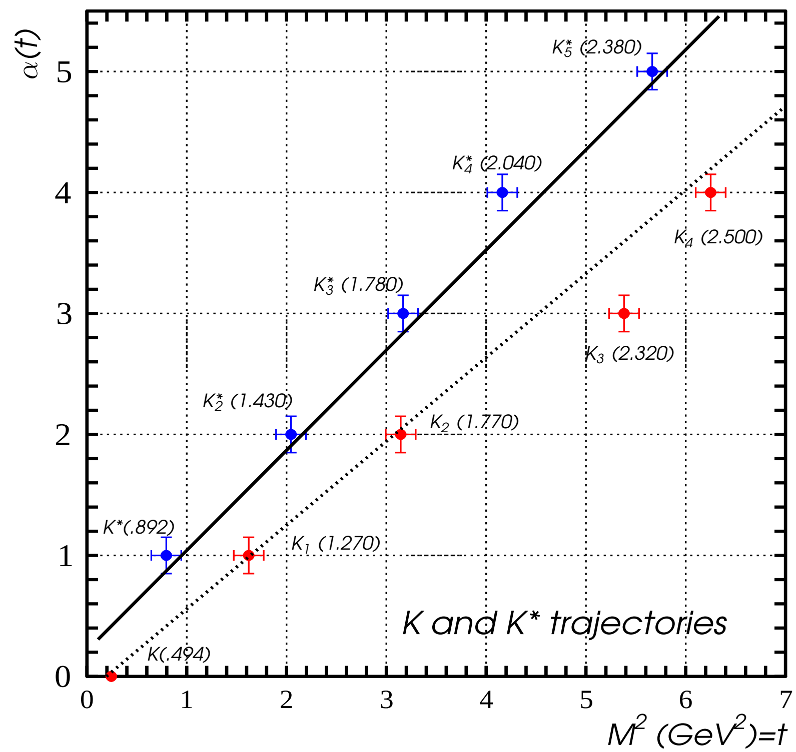
(Mart, Bennhold, Janssen, Saghai, Williams)

- **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.*
  - *"Loose" SU(3) constraints in effect.*
- **Recent addition of u–channel Y* resonances.**
  - *Gives more realistic hadronic form factor cut–off.*
  - *Affects polarization at large angles.*
- **Effective at low to moderate energies.**

Regge Models







- **Models based on parameterized t−channel exchange.**

  Regge trajectories *(Guidal, Laget, Vanderhaeghen)*

- **NO s−channel resonances included (only Born terms).**
- **Very few adjustable parameters.**
- **Effective at moderate to higher energies.**

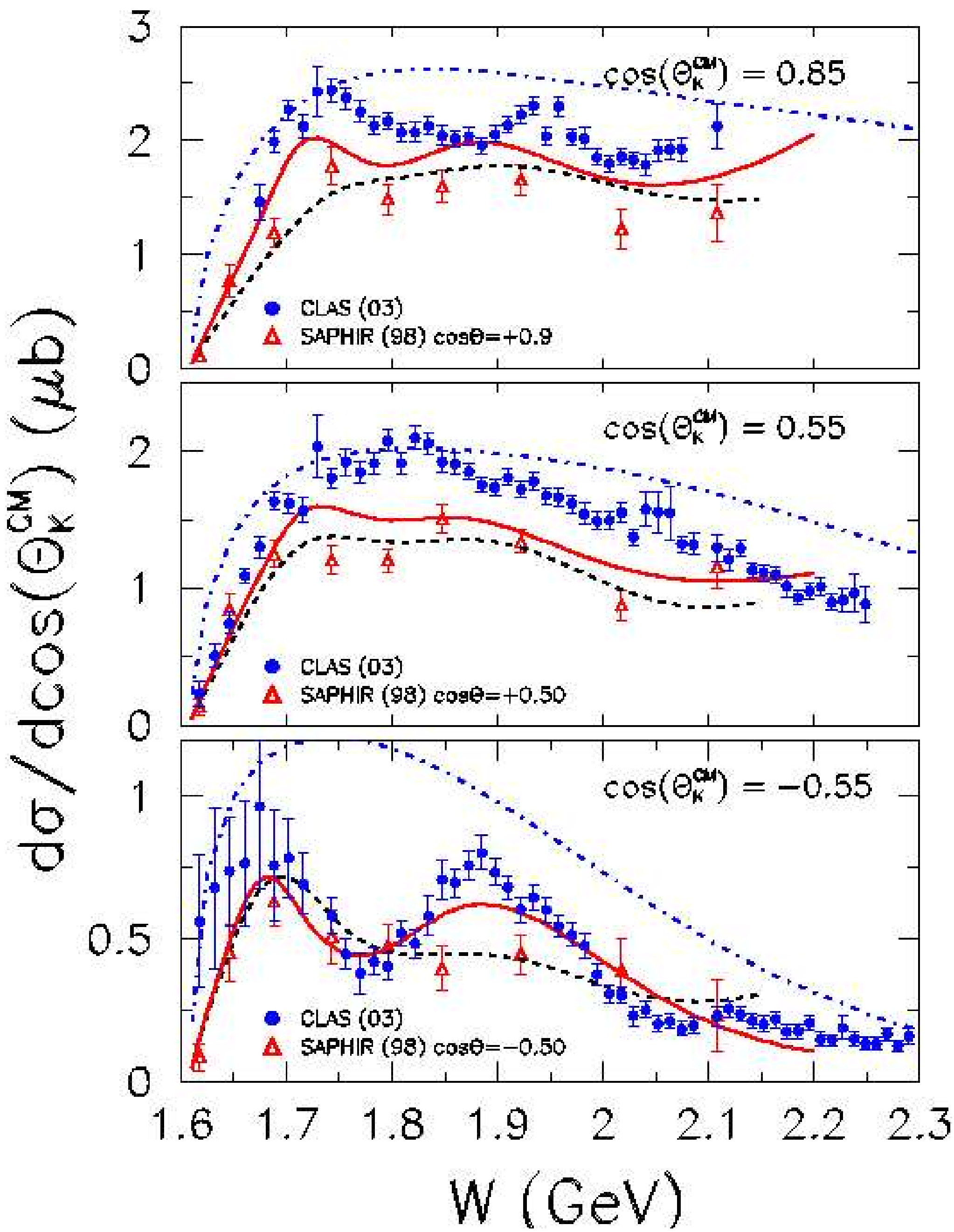
Energy Distributions

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

Sample of ~900 CLAS points.

Forward angles	**Backward angles**
M=1950 MeV Γ=100 MeV	M=1890 MeV Γ=200 MeV

Guidal – 1999
Bennhold – 2002
Janssen – 2002



– Existing models perform poorly

But, NOT yet fit to this CLAS data!!

R.A. Schumacher and J. McNabb

Energy Distributions

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

Sample of ~750 CLAS points.

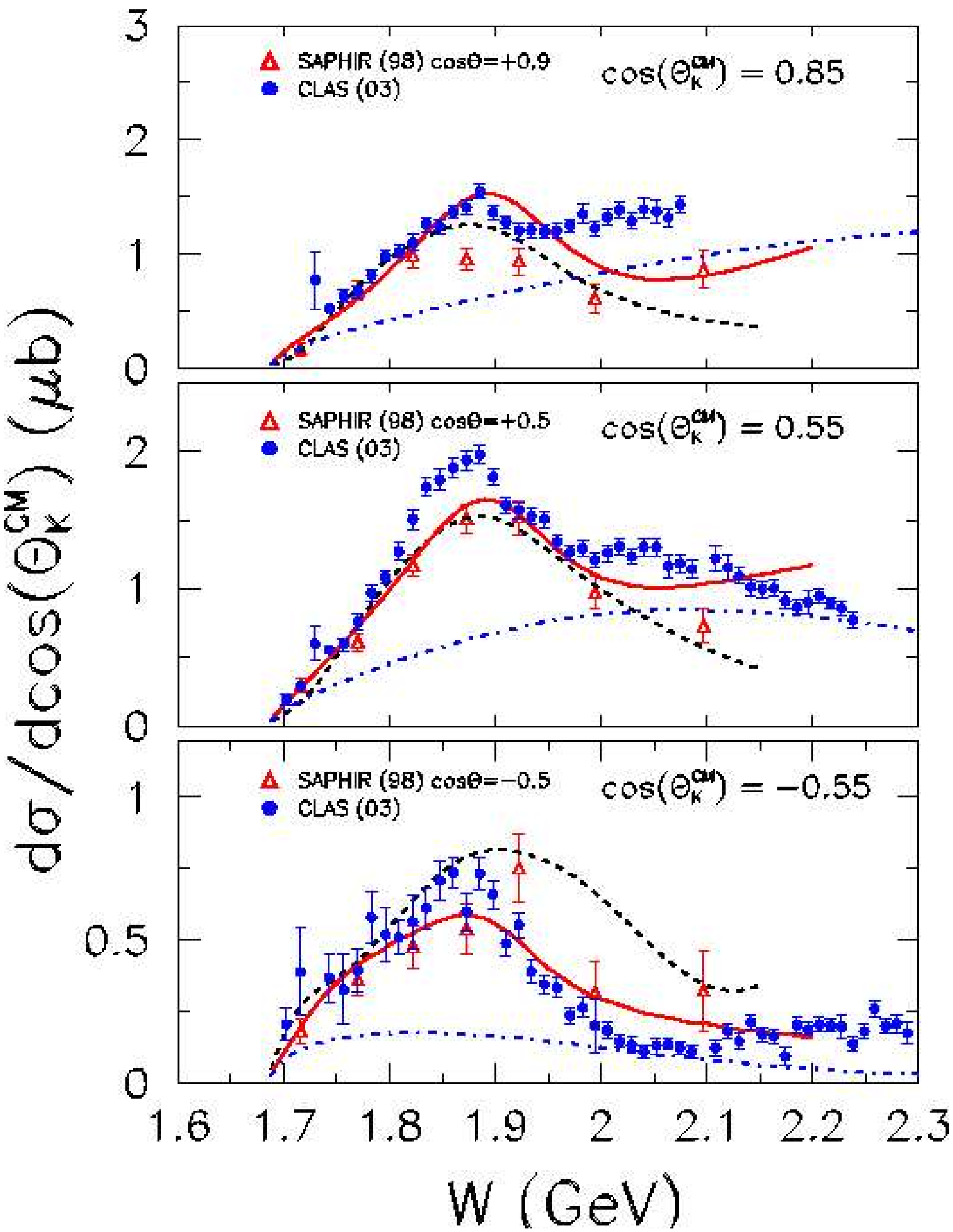
One peak at 1.9 GeV with an angle–dependent shape.

Guidal – 1999
Bennhold – 2002
Janssen – 2002

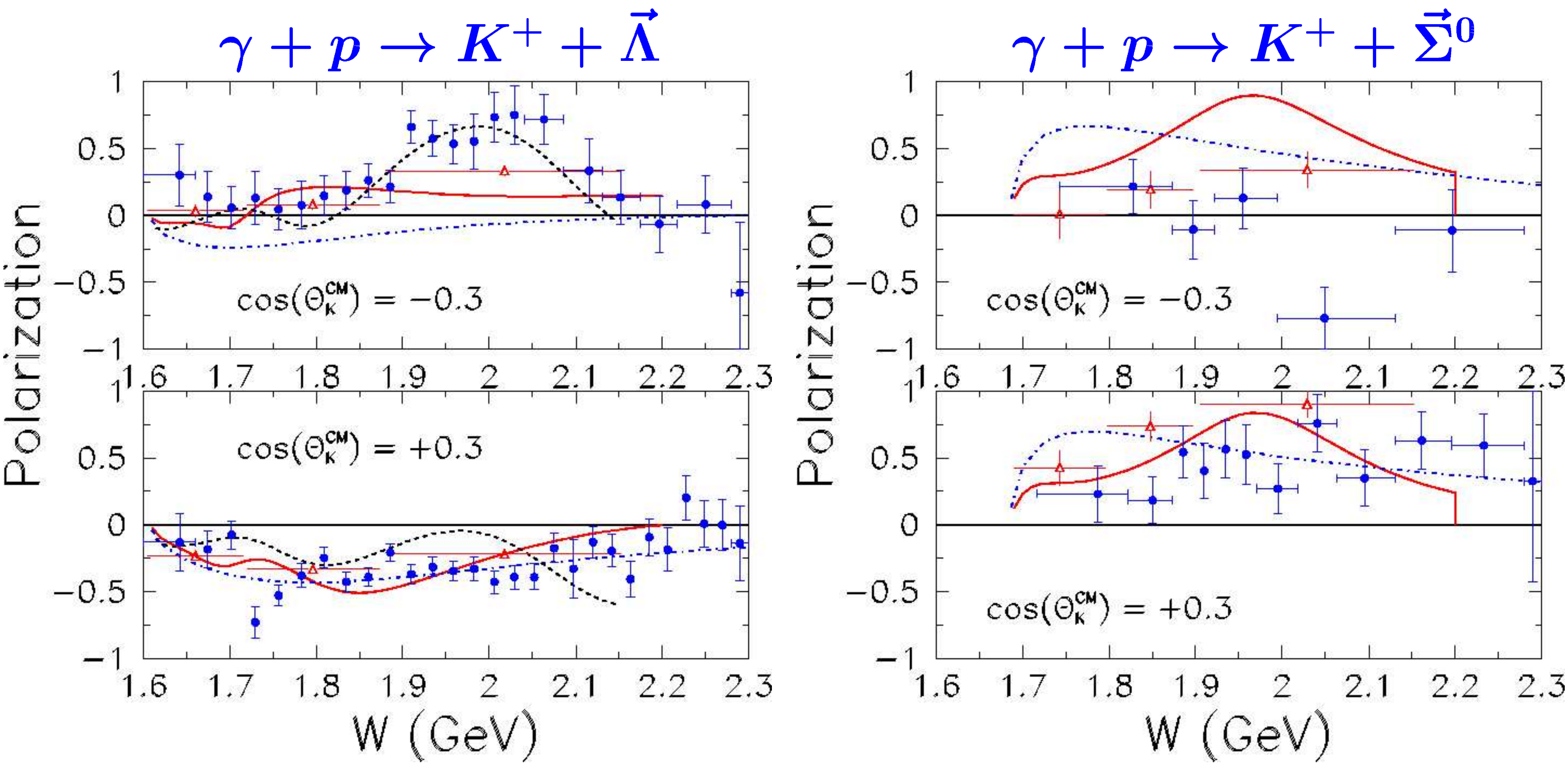
– Existing models perform poorly

But, NOT yet fit to this CLAS data!!

R.A. Schumacher and J. McNabb



Induced Polarization



Guidal – 1999
Bennhold – 2002
Janssen – 2002

– Full CLAS data set

– SAPHIR data set

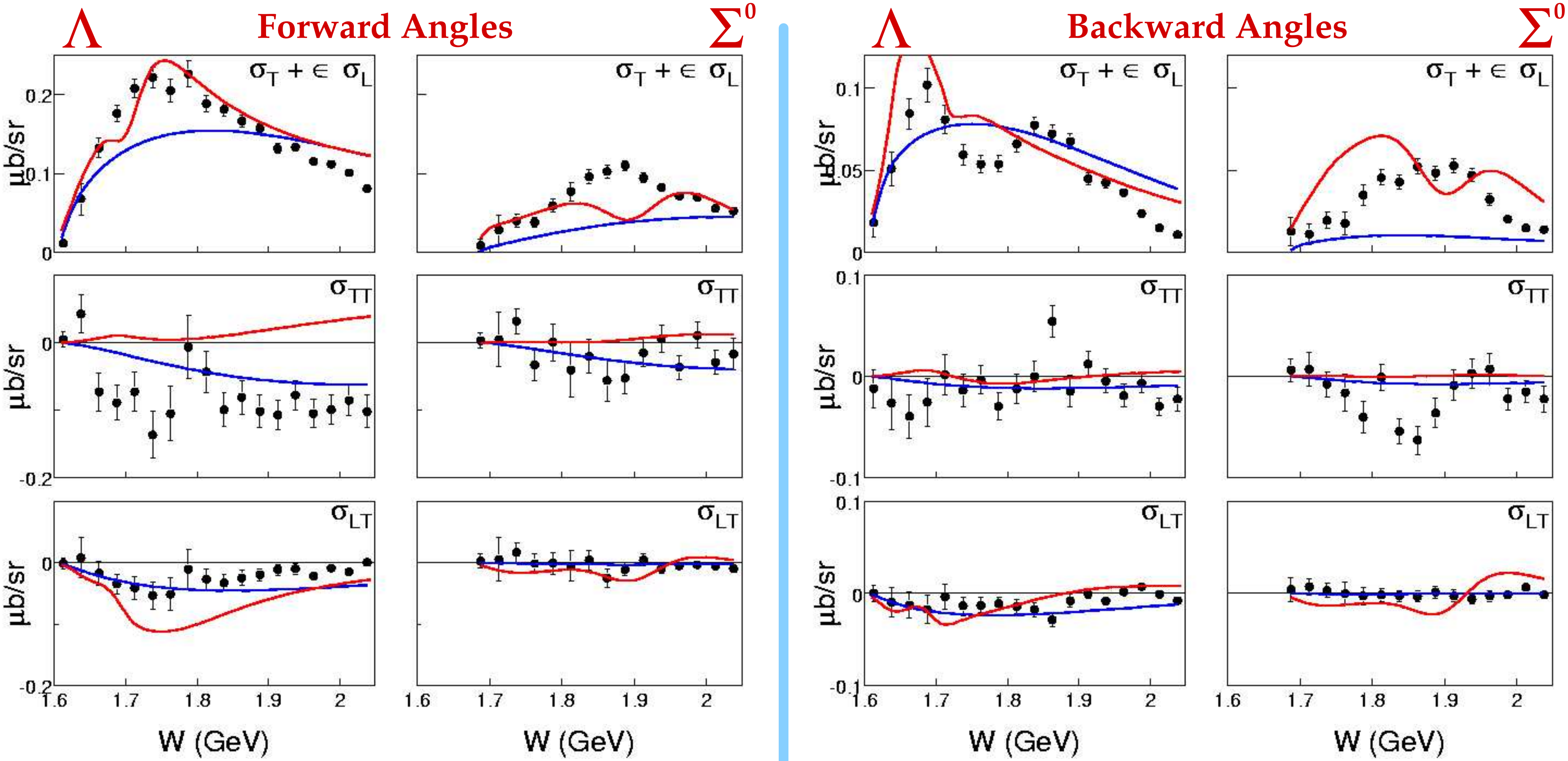
– Deviations apparent with models over full kinematics.

R.A. Schumacher and J. McNabb

Structure Functions

$e + p \rightarrow e' + K^+ + Y$

$$\sigma_0 = \boxed{\sigma_T + \epsilon_L \sigma_L} + \boxed{\epsilon \sigma_{TT}} \cos 2\Phi + \boxed{\sqrt{2\epsilon_L(1+\epsilon)}\, \sigma_{LT}} \cos \Phi$$



$\cos\theta^*_K$: (0.3,0.7)

$\cos\theta^*_K$: (–0.7:–0.3)

Guidal – 1999
Bennhold – 2002

2.567 GeV $Q^2 = 0.70\ (\mathrm{GeV}/c)^2$

R. Feuerbach and G. Niculescu

Five Structure Function Analysis

$$\sigma = \sigma_T + \epsilon_L \sigma_L + \epsilon \sigma_{TT} \cos 2\Phi + \sqrt{2\epsilon_L(1+\epsilon)}\, \sigma_{LT} \cos \Phi + h\sqrt{2\epsilon_L(1-\epsilon)}\, \sigma_{LT'} \sin \Phi$$

NEW INITIATIVE

Perform simultaneous fit to ALL existing CLAS e+p data sets for five structure functions.

CLAS data sets at: 2.6, 3.2, 4.0, 4.2, 4.4, 4.8, 5.7 GeV

ADVANTAGES

* **Better accounts for correlated errors in the fits.**
* **Allows for reduced statistical uncertainties.**
* **Gets the most out of the CLAS data sets.**

Q^2 range: 0.3 to 6.0 GeV^2

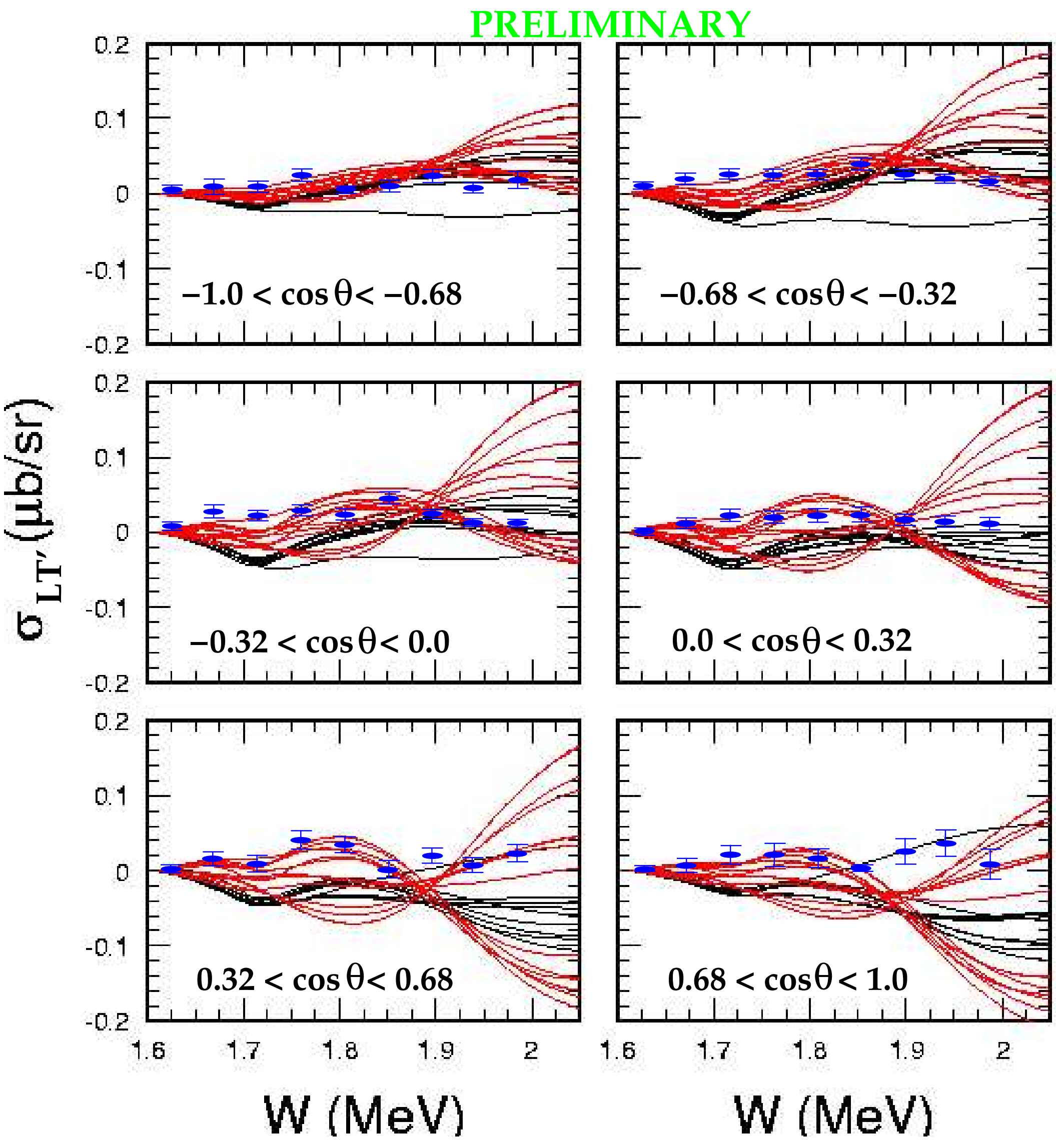
W range: 1.6 to 3.0 GeV

Fit Function: $f(\epsilon, h, W, Q^2, \cos\theta_K^*, \Phi)$

Beam Asymmetry

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

- Measure polarized beam asymmetry to extract fifth structure function.



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

$$= \frac{1}{\sigma_0}\sqrt{2\epsilon_L(1-\epsilon)}\,\sigma_{LT'}\sin\Phi$$

Curves all from Janssen model.

(same resonances included)

Phys. Lett. B 562, 51 (2003)
Phys. Rev. C 67, 052201 (R) (2003)

All curves within acceptable χ^2.

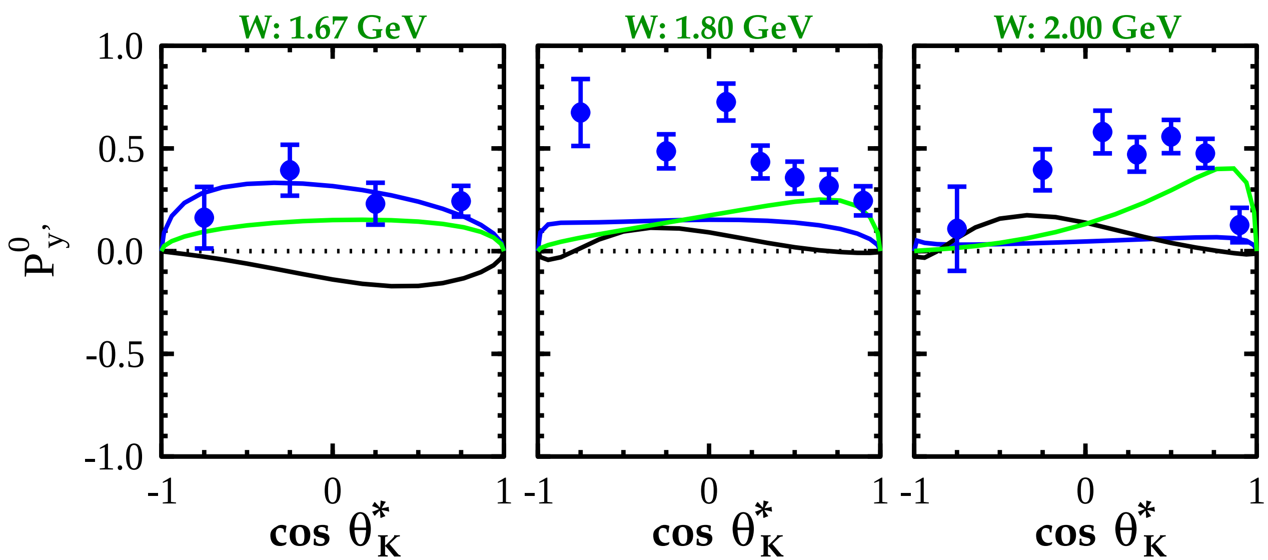
$\Longrightarrow$ **Substantial differences in the reaction dynamics.**

2.567 GeV $Q^2 = 0.70$ (GeV/c)^2

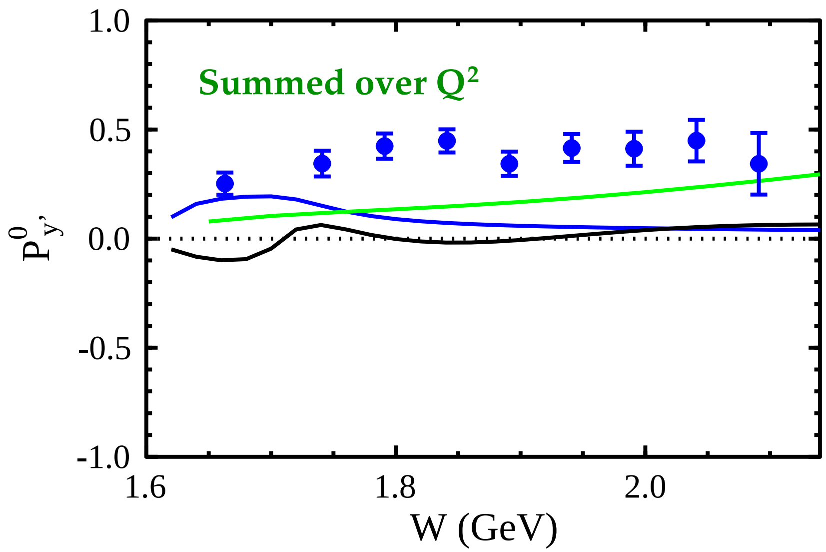
B.A. Raue and R. Nasseripour

Induced Polarization

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



PRELIMINARY



2.567+4.247 GeV, Summed over $d\Omega^*_K$

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

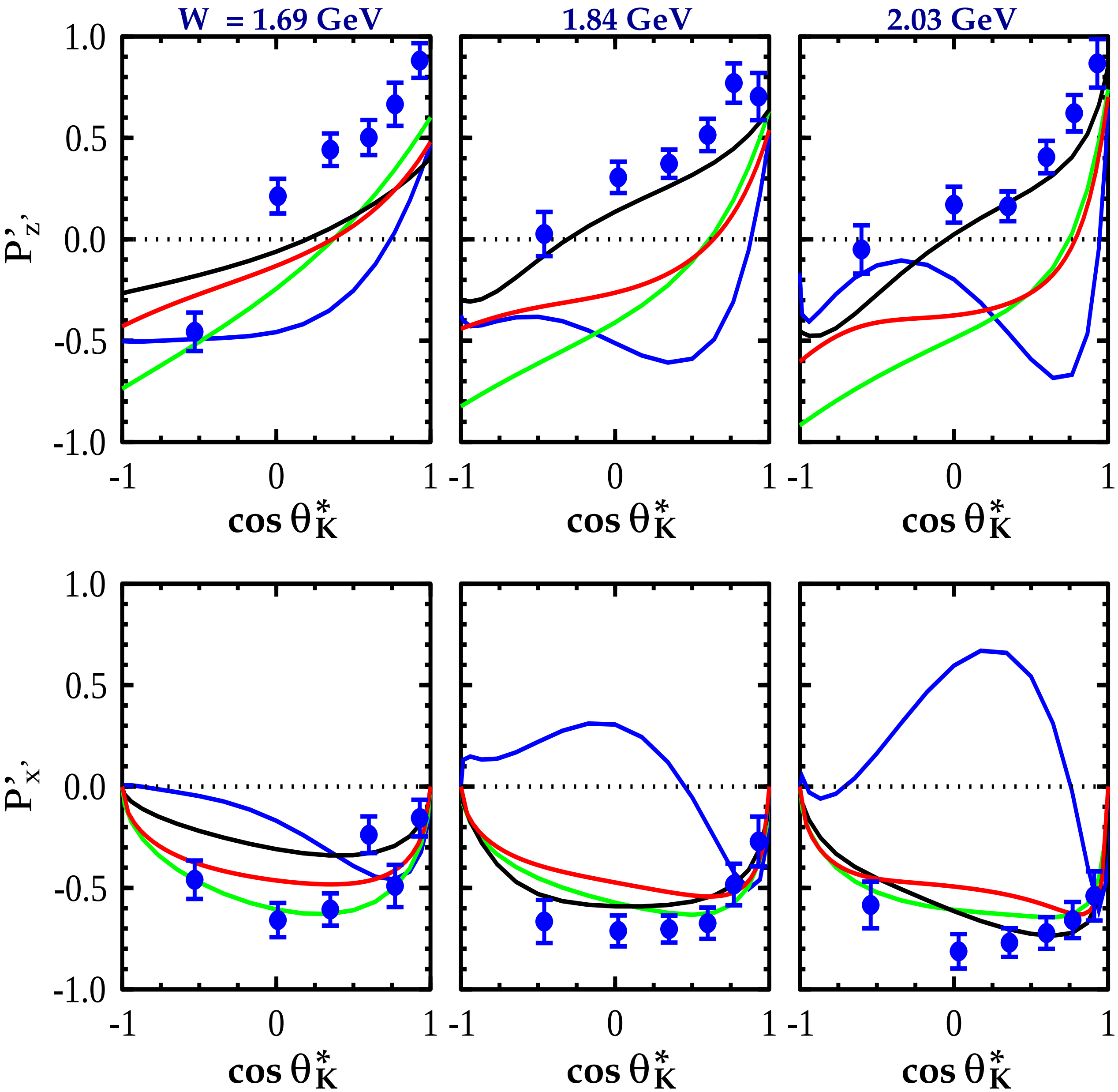
Very different angular dependence vs. photoproduction.

S. McAleer

Transferred Polarization

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

(x′,y′,z′) system



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

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

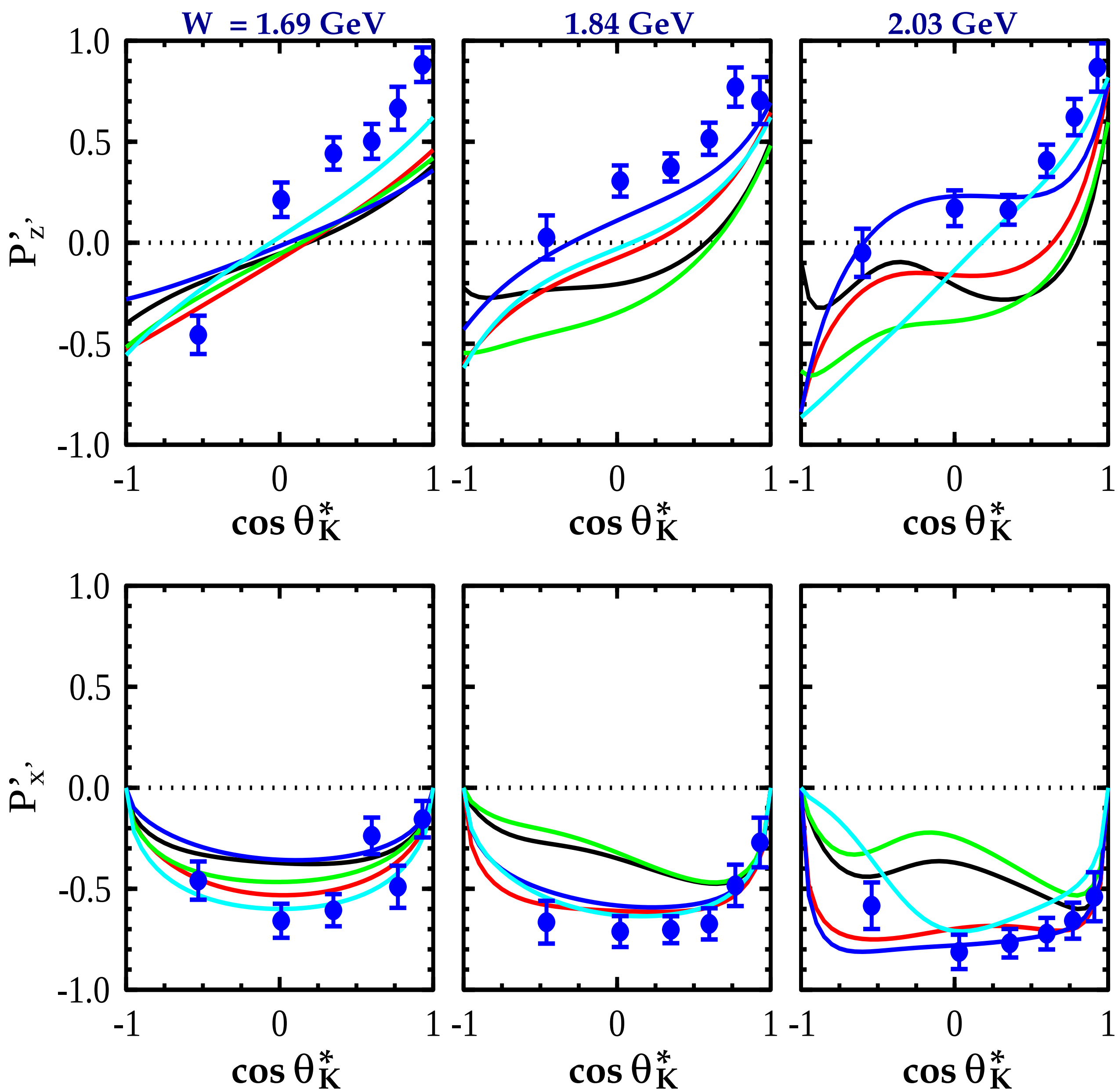
2.567 GeV
Summed over Q^2, Φ

DSC, PRL 90, 131804 (2003)

Transferred Polarization

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

(x′,y′,z′) system



Janssen – 2002

No 1.9 GeV resonance
S11(1895)
P11(1895)
P13(1895)
D13(1895)

Model fit to existing data:

SAPHIR (1998)
SPring–8 (2003)
Hall C (2003)
Harvard–Cornell
Orsay

2.567 GeV
Summed over Q^2, Φ

DSC, PRL 90, 131804 (2003)

Summary/ Conclusions

- The Hall B strangeness physics program:
  - – Designed to measure all combinations of beam, target, recoil polarization states.
  - – Sensitive to high–mass baryons (>1.6 GeV) with large K–Y couplings.

KEY GOAL: Understand nucleon structure and excited nucleon states.

- – Clear evidence of resonant structures in the energy and angle dependences of photo– and electroproduction data.
- – Existing theoretical models do not describe the data well over the broad kinematic phase space measured.

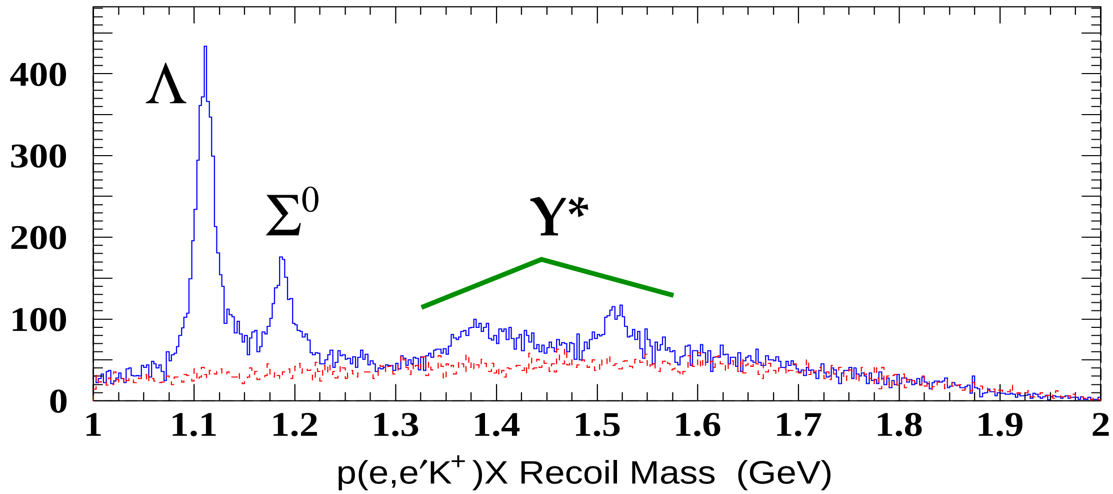
Productive new round of fitting/modeling

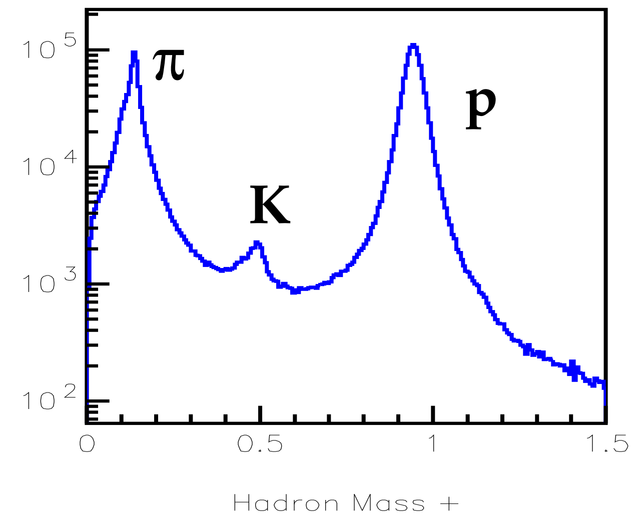
Improved PWA analysis now possible.

Now underway

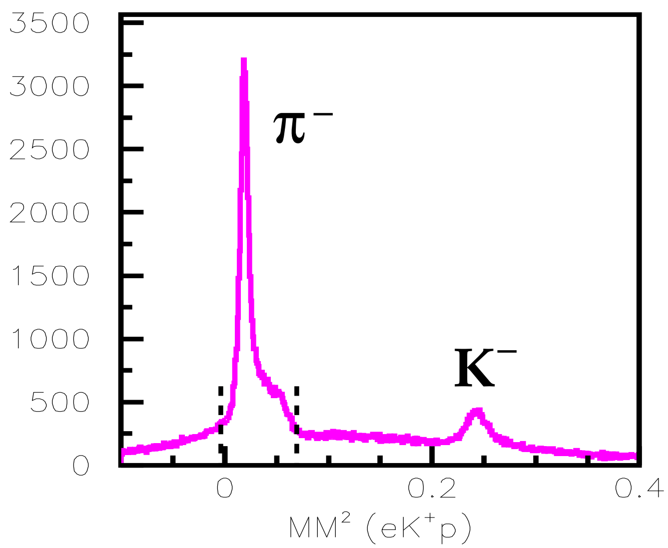
Wealth of data $\Longrightarrow$ Tight constraints

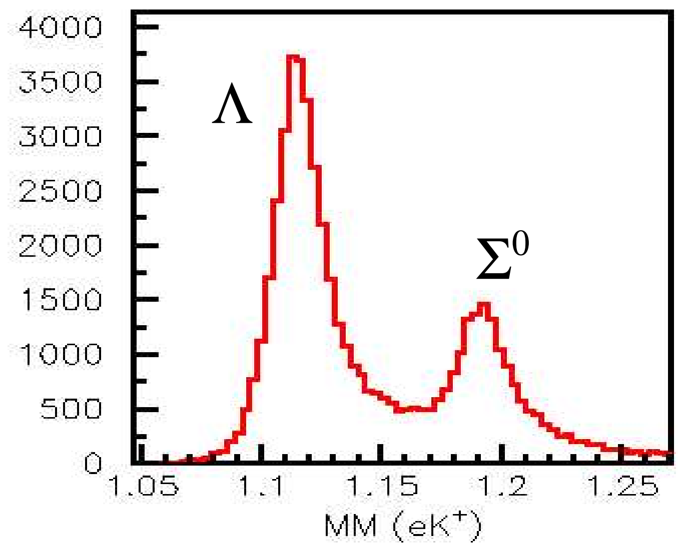
Final State Reconstruction





4.247 GeV





Formalism

$$\frac{d^5\sigma}{d\Omega_{E'} d\Omega_K^* dE'} = \Gamma_v \frac{d^2\sigma_v}{d\Omega_K^*}$$

(For unpolarized target)

$$\frac{d^2\sigma_v}{d\Omega_K^*} = \sigma_0 \left[1 + h\ A_{TL'} + \vec{S}\cdot\vec{P}^0\ +\ h\ (\vec{S}\cdot\vec{P}')\right]$$

Unpolarized Cross Section

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

$$\boxed{A_{TL'} = \frac{\mathcal{K}}{\sigma_0}\sqrt{2\epsilon_L(1-\epsilon)}\ R_{TL'}^{00}\sin\Phi}$$

Polarized beam

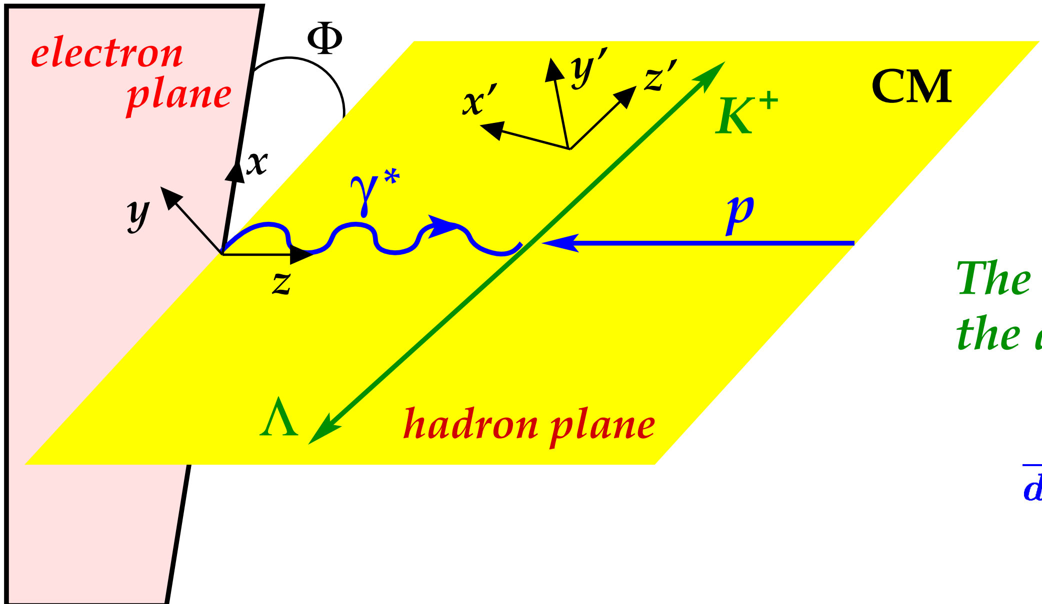
$$\begin{pmatrix} P_{x'}^0 \\ P_{y'}^0 \\ P_{z'}^0 \end{pmatrix} = \frac{\mathcal{K}}{\sigma_0}\begin{pmatrix} \sqrt{2\epsilon_L(1+\epsilon)}\ R_{TL}^{x'0}\sin\Phi + \epsilon R_{TT}^{x'0}\sin 2\Phi \\ R_T^{y'0} + \epsilon_L R_L^{y'0} + \sqrt{2\epsilon_L(1+\epsilon)}\ R_{TL}^{y'0}\cos\Phi + \epsilon R_{TT}^{y'0}\cos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

Induced polarization

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

Transferred polarization

Polarization Extraction



- **Hyperon decays weakly via:**

$$\Lambda \rightarrow p\pi^-$$

The polarization of the Λ is "betrayed" by the angular distribution of the proton.

$$\frac{dN_p^{\pm}}{d(\cos\theta_p^*)} = N^{\pm}[1 + \alpha P_\Lambda \cos\theta_p^*]$$

("self–analyzing" decay)

$$\vec{P}_\Lambda = \vec{P}^o \pm P_b \vec{P}'$$

Transferred

Induced

- **Projecting the polarization vector onto different axes provides sensitivity to different contributing amplitudes.**

(x,y,z) system *(x′,y′,z′) system*

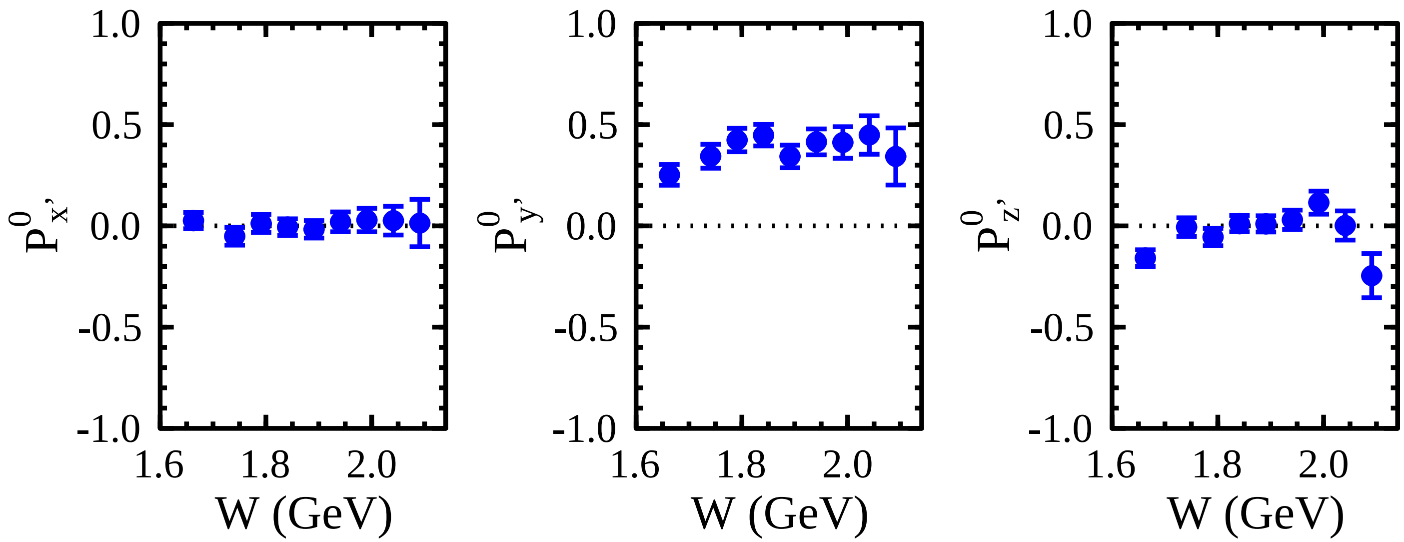
Note: $P'_{y,y'} = 0$, but other components can be non–zero.

Polarization Details

2.567 GeV

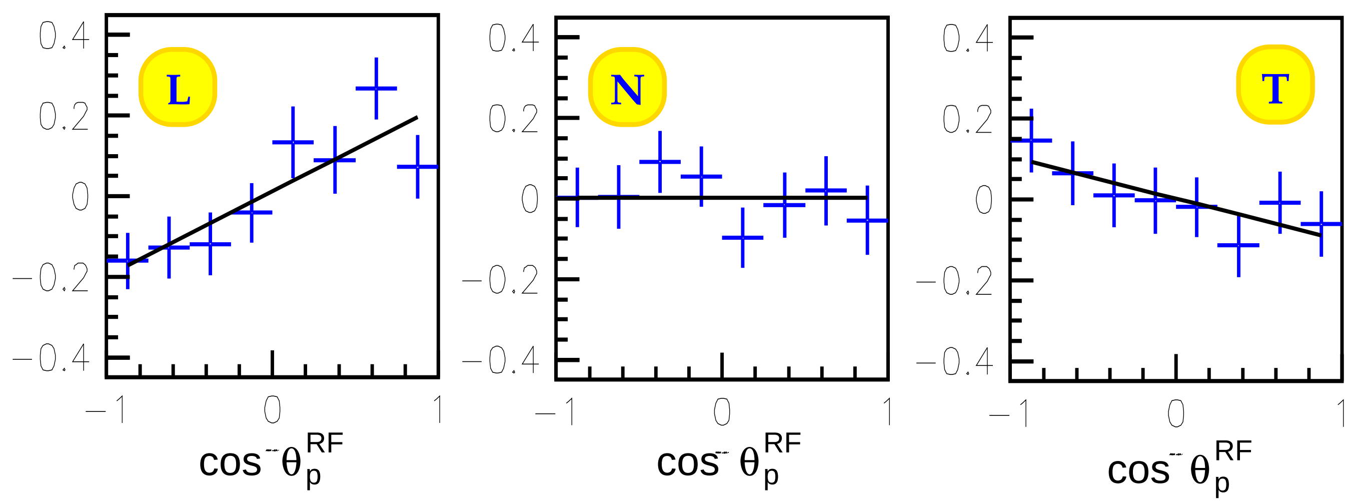
- **Induced Polarization Observables:**

[Summed over other kinematics]



- **Transferred Polarization Observables:**

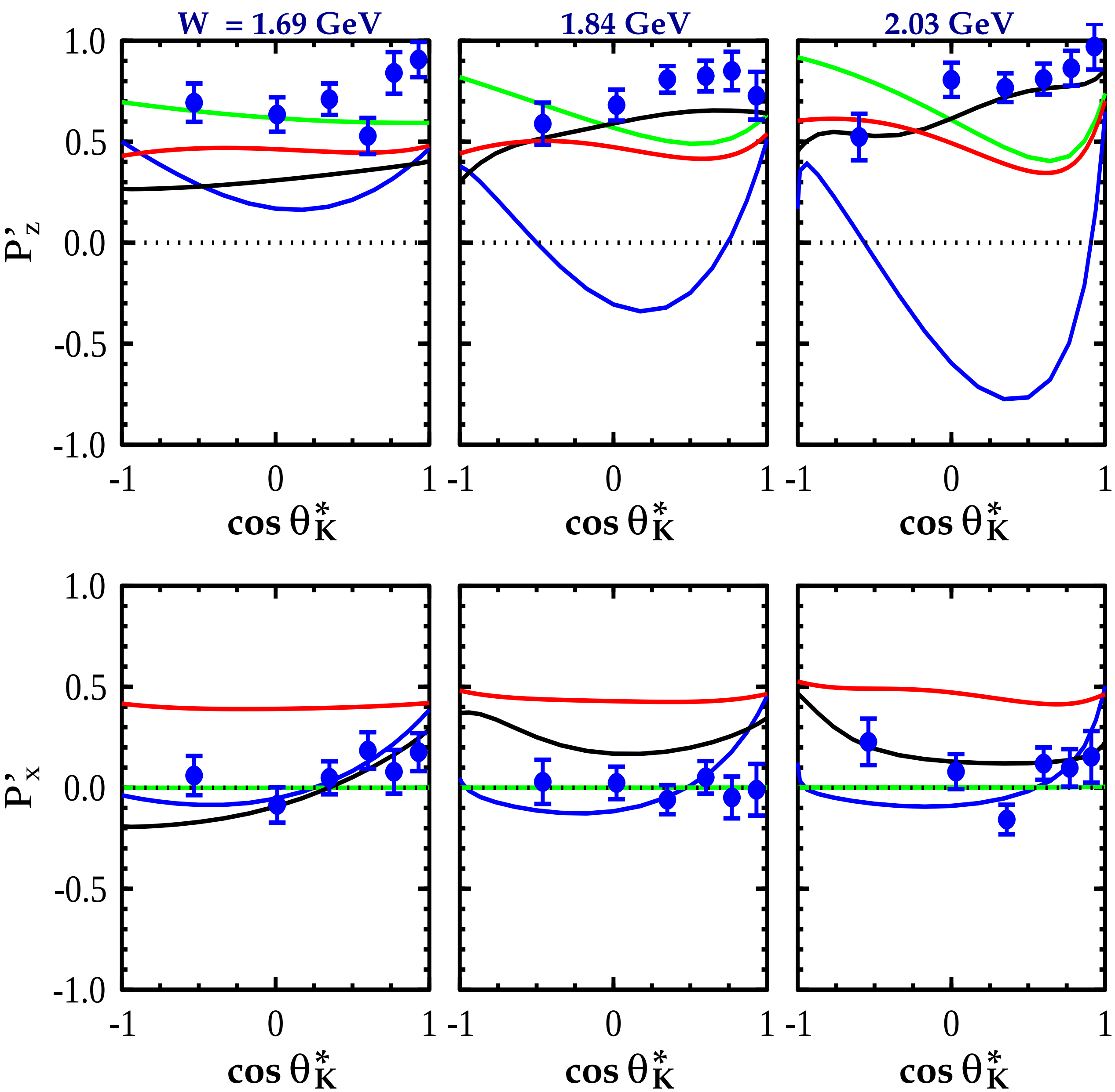
[W = 1.75 GeV, Q^2 = 1.05 $(GeV/c)^2$, $\Phi = 0 - 2\pi$]



Transferred Polarization

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

(x,y,z) system



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

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

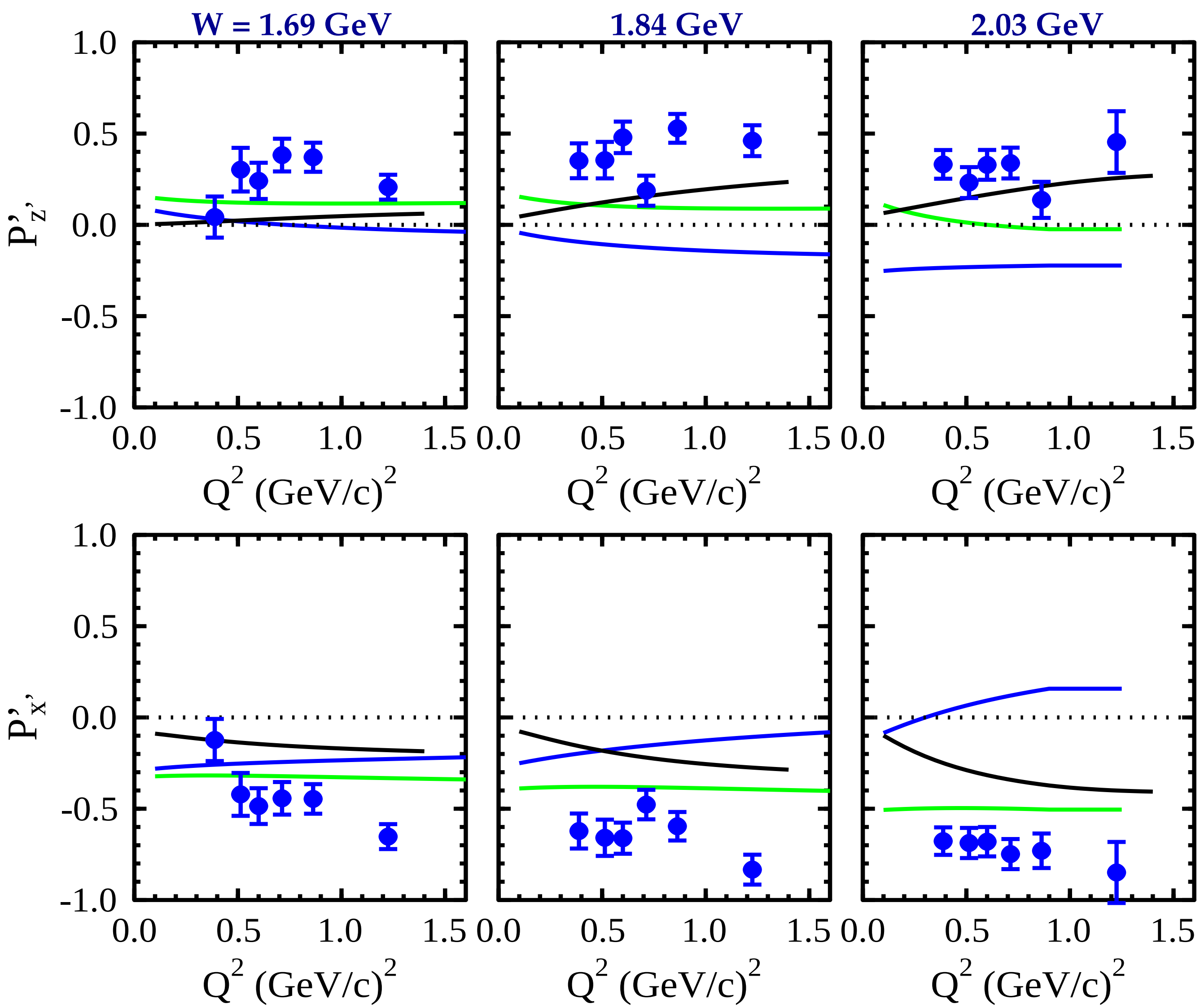
2.567 GeV
Summed over Q^2, Φ

DSC, PRL 90, 131804 (2003)

Transferred Polarization

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

(x′,y′,z′) system



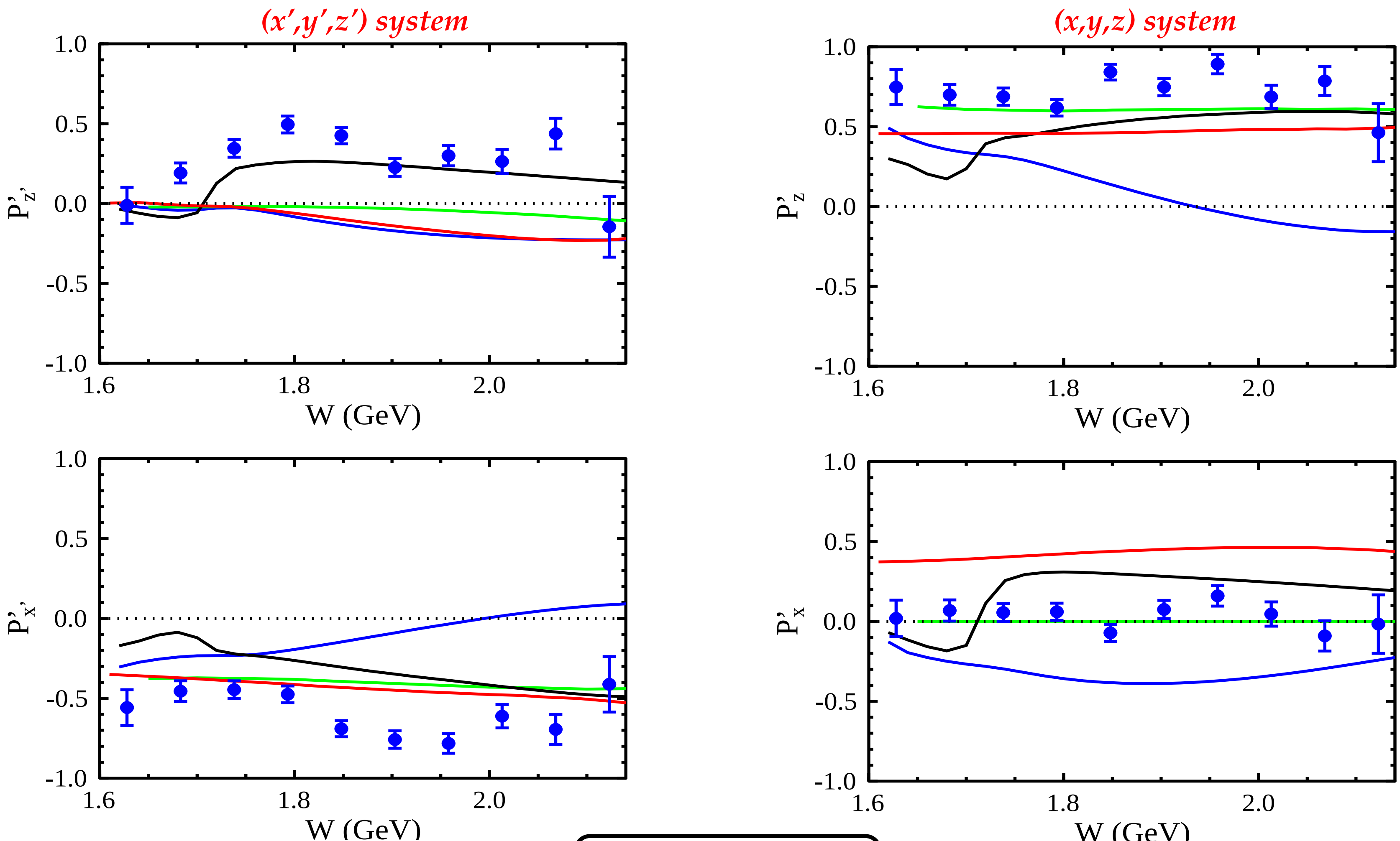
Williams – 1992
Bennhold – 1998
Bennhold – 2002

Resonance	WJC92	BM98	BM02
$N^*(1650)$	*	*	*
$N^*(1710)$	*	*	*
$N^*(1720)$			*
$N^*(1895)$			*
$K^*(892)$	*	*	*
$K_1(1270)$	*		*
$\Lambda(1405)$	*		

2.567 GeV
Summed over Φ

Transferred Polarization

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

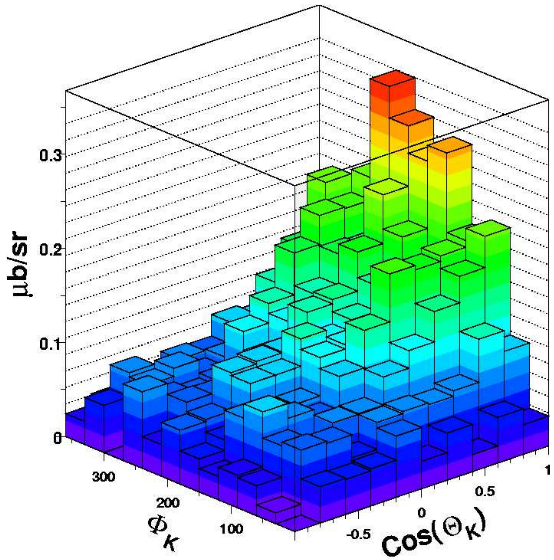


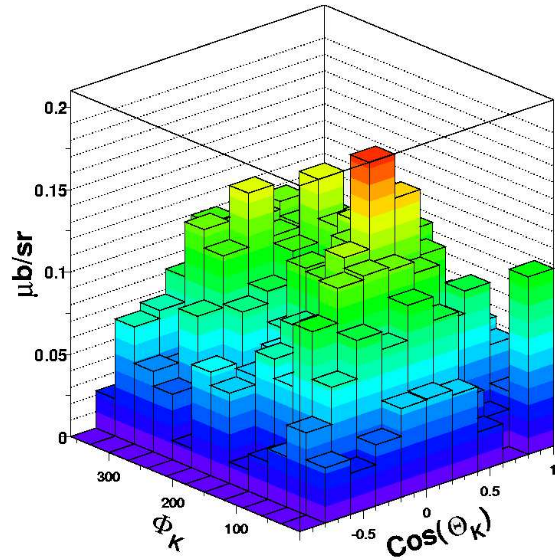
Williams – 1992
Bennhold – 2002
Janssen – 2002
Guidal – 1999

2.567 GeV
Summed over $Q^2, d\Omega_K^*$

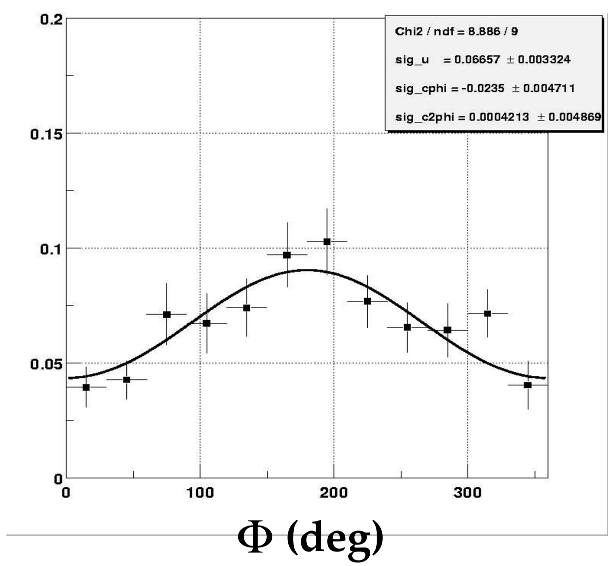
DSC, PRL 90, 131804 (2003)

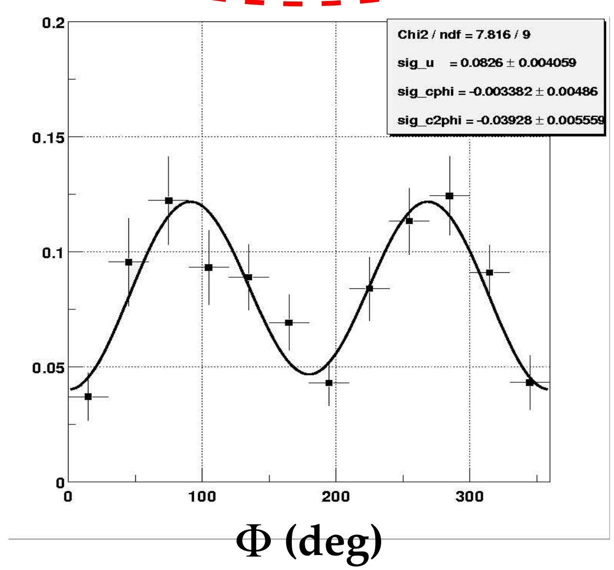
Structure Functions Extraction





$$\sigma_0 = \sigma_T + \epsilon_L \sigma_L + \epsilon \sigma_{TT} \cos 2\Phi + \sqrt{2\epsilon_L(1+\epsilon)}\, \sigma_{LT} \cos \Phi$$

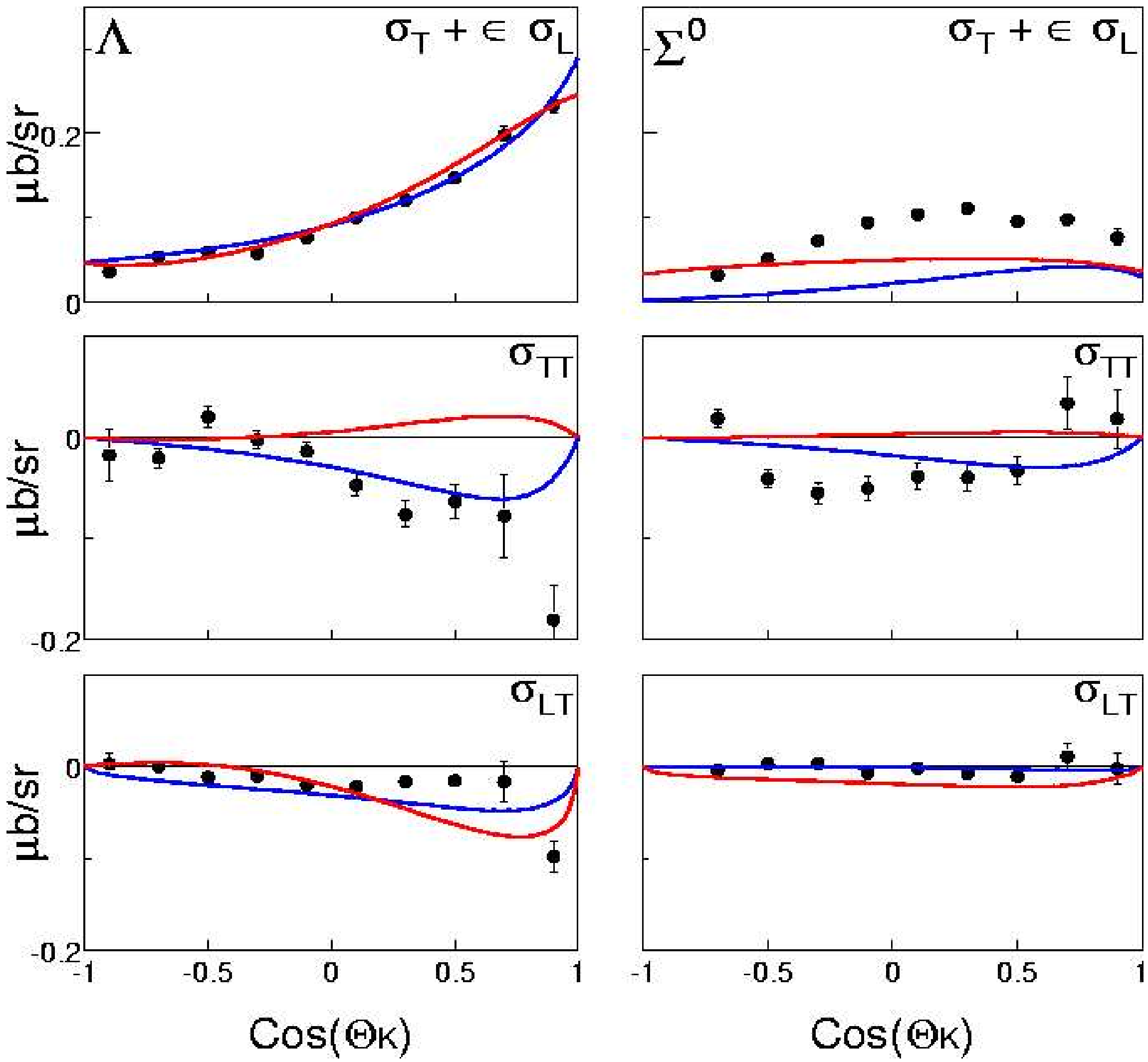




W=1.9 GeV
Q^2=0.7 GeV^2
$\cos\theta^*_K$=0.4

Structure Functions

$$\sigma_0 = \sigma_T + \epsilon_L \sigma_L + \epsilon \sigma_{TT} \cos 2\Phi + \sqrt{2\epsilon_L(1+\epsilon)}\, \sigma_{LT} \cos \Phi$$



W=1.85–1.95 GeV

(2.6 GeV, Q^2: 0.5–0.9 GeV^2)

Bennhold (2002)

Hadrodynamic Model

Guidal (1999)

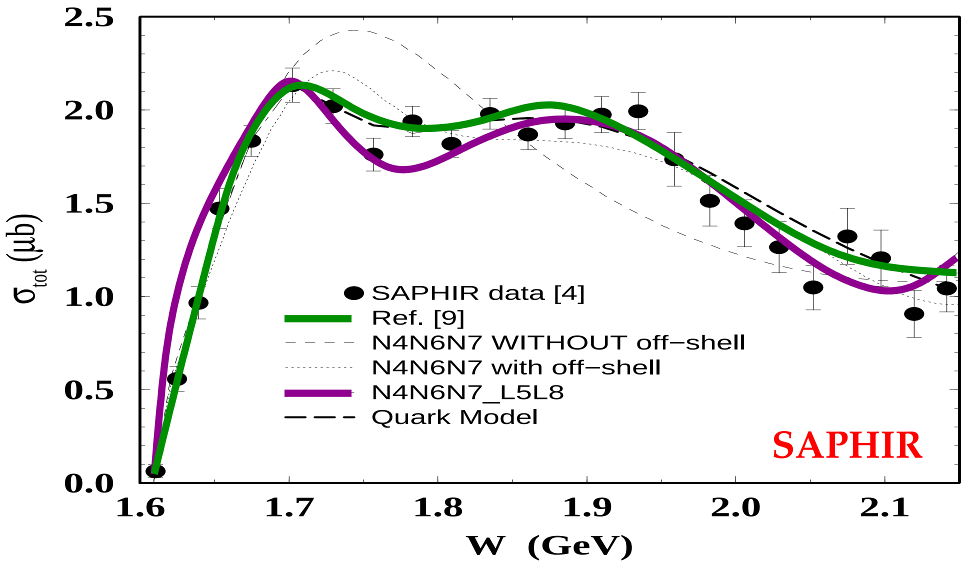
Regge Model

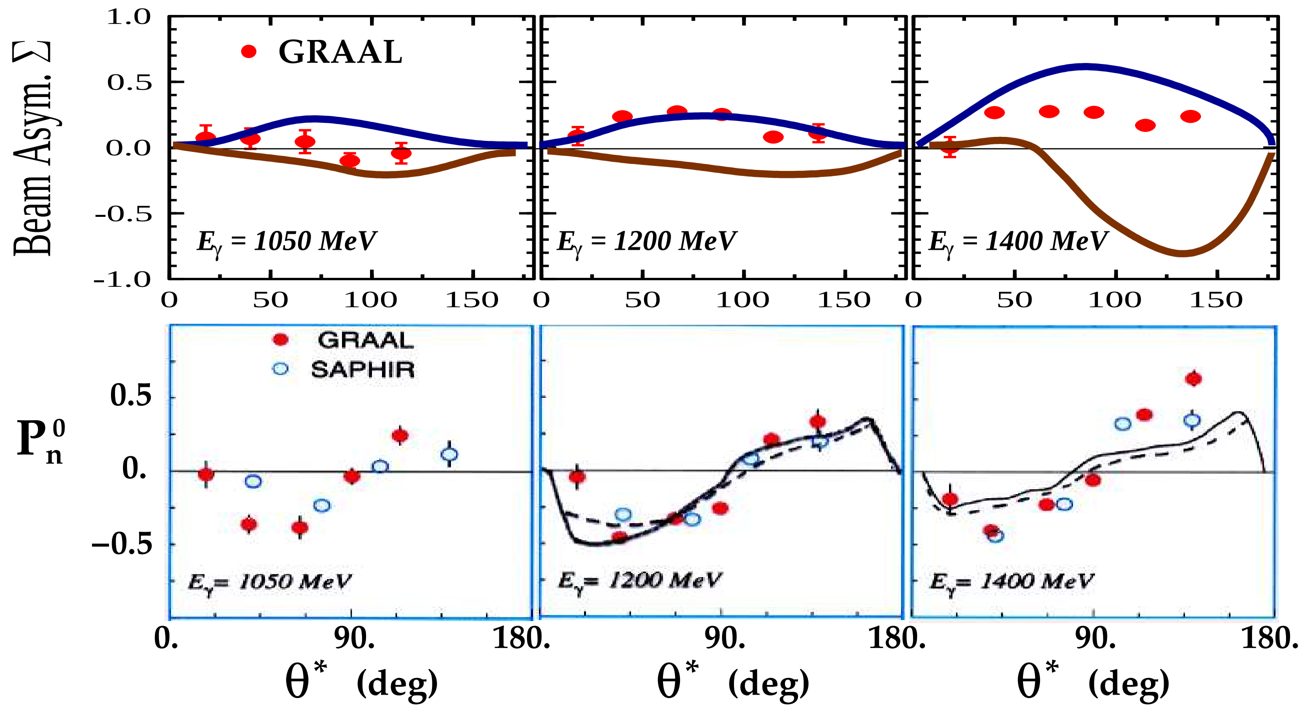
R. Feuerbach and G. Niculescu

"Missing" N* Resonances

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

Ref. B. Saghai
nucl–th/0105001





D_{13} (1895) Study

Ref: Bennhold

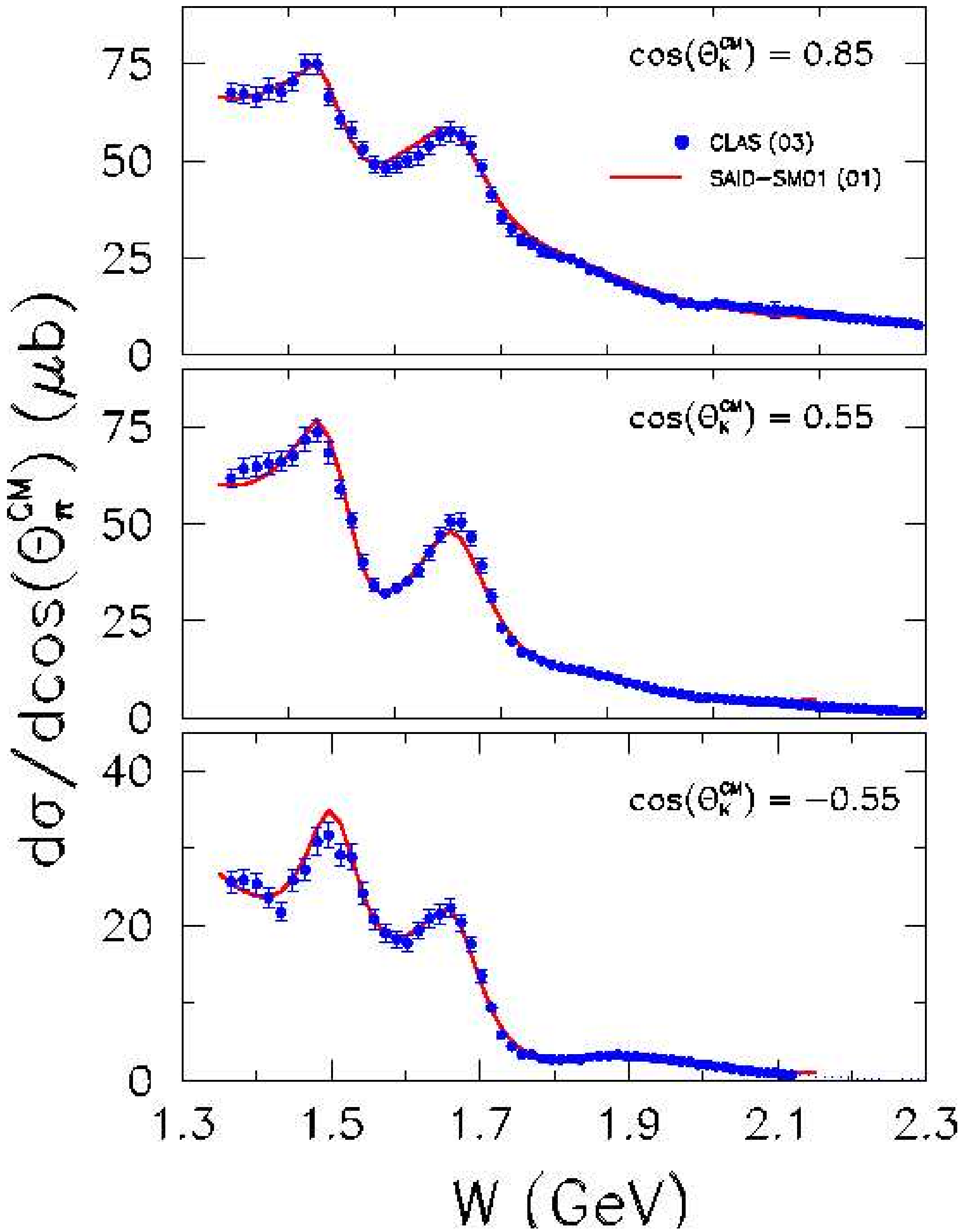
Normalization Check

$$\gamma + p \rightarrow \pi^+ + n$$

CLAS data normalized to pion production.

(photoproduction)

A sampling of the comparison.



R.A. Schumacher and J. McNabb