

Polarization Observables in Hyperon Production at CLAS

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CLAS Collaboration at Jefferson Lab

- Motivation: why study **polarization observables**?
 - electro-, photo-production?
 - **exclusive K - Hyperon** final states?
 - CLAS Detector: acceptance, particle i.d.
 - Analysis Methods: induced and transferred Λ polarization
 - Results:
 - $\gamma P \rightarrow \vec{\Lambda} K^+$ (polarization normal to prod'n plane)
 - $\vec{e} P \rightarrow e' \vec{\Lambda} K^+$ (transferred polarization)
- 2 expt's
- Conclusions: Polarization → production dynamics
interference terms
 - 2 explanations → spin-alignment in
quark-pair creation

Polarization Observables in Hyperon Production at CLAS

What are the **effective degrees of freedom** describing hadro-production ?
--- and the associated **fundamental questions** ?

Current quarks and gluons? QCD, many diagrams, lattice calculations ?

Baryons and mesons? many parameters, currents not fundamental, mature phenomenology

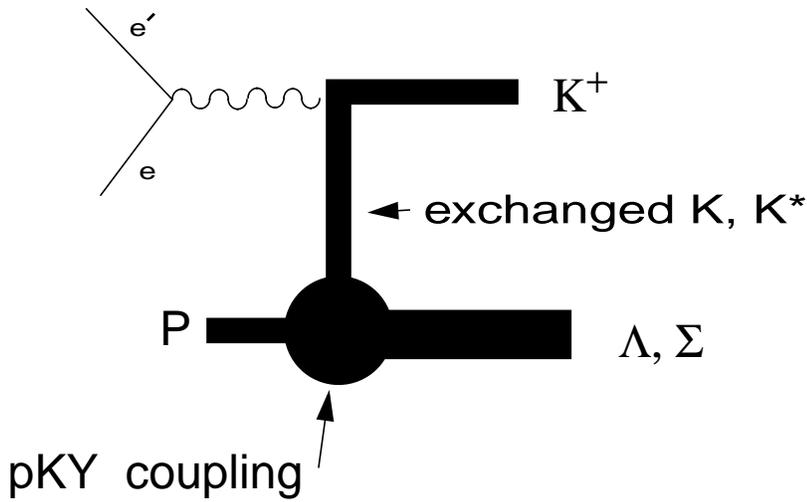
- Which **baryons** and **mesons** are excited in the intermediate state ?
 - coupling constants and form-factors
 - can **interference terms** shed light ?

Constituent quarks and flux-tubes ? not fundamental, effective description of hadronization, linear potential, glueballs and hybrids

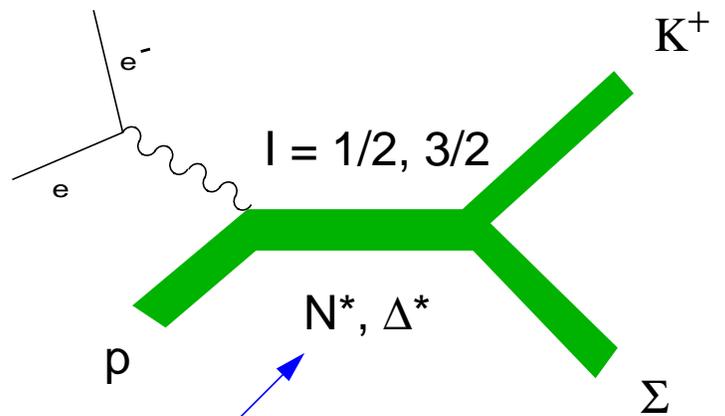
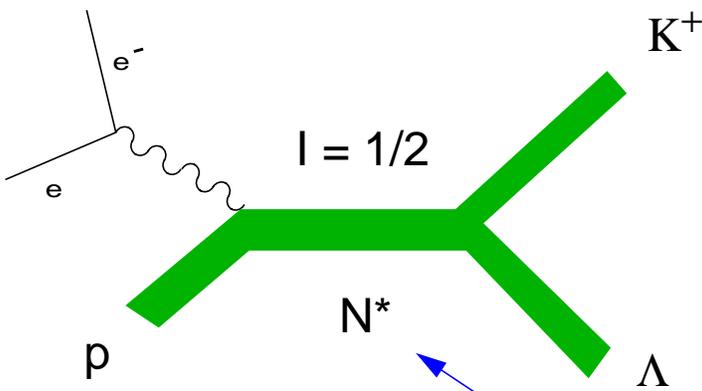
- How is the **flux-tube broken?** quark pair in a **vacuum**, 3P_0 state ??
 - can **polarized hyperons** tell us anything ?

Hadro - Dynamic Model

structure functions, spectra , vertex couplings



Polarization dynamics -
interfering amplitudes

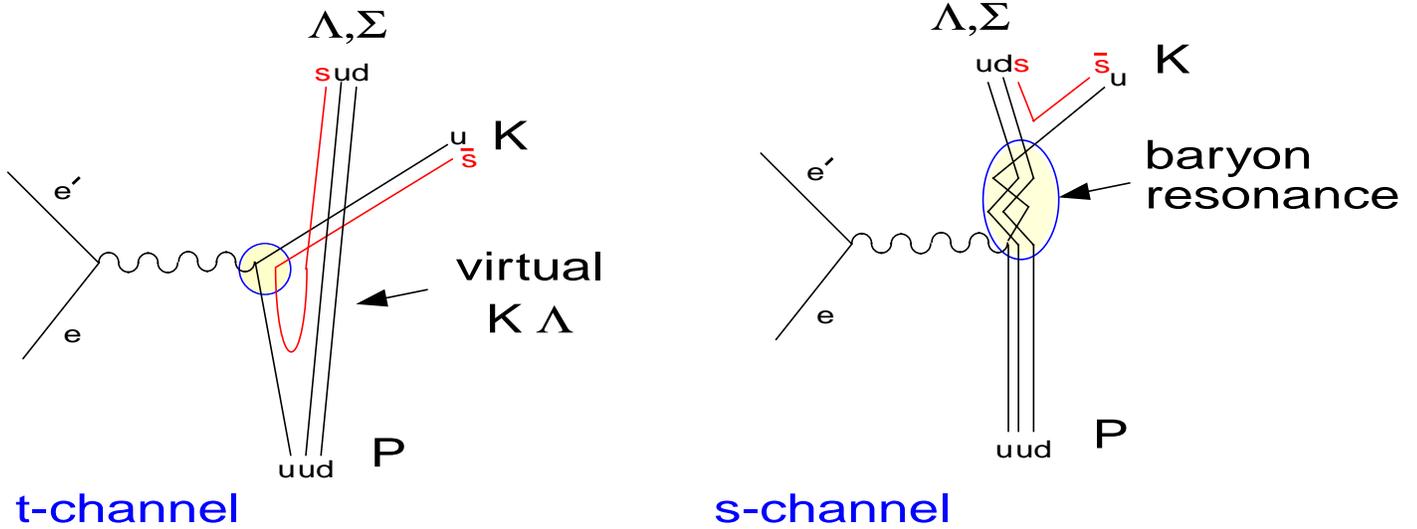


isospin selectivity

Which resonances contribute to S-channel ? missing ones?

Quark Model Dynamics

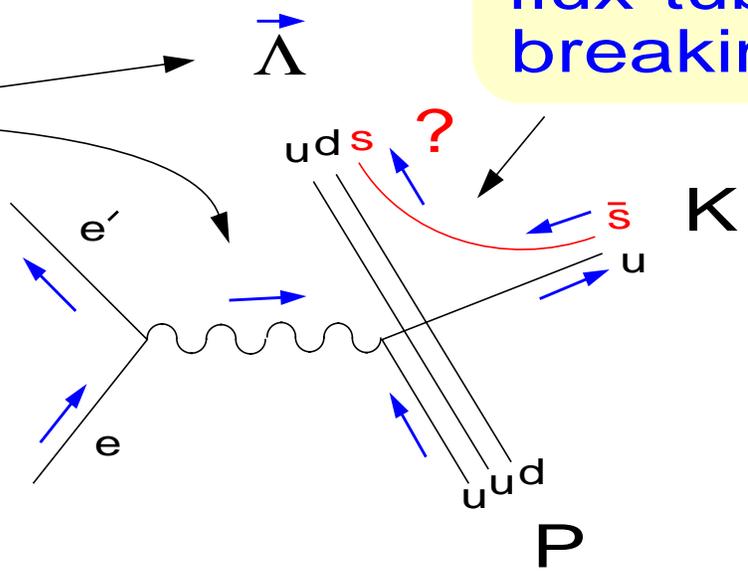
structure functions, spectra , quark pair creation



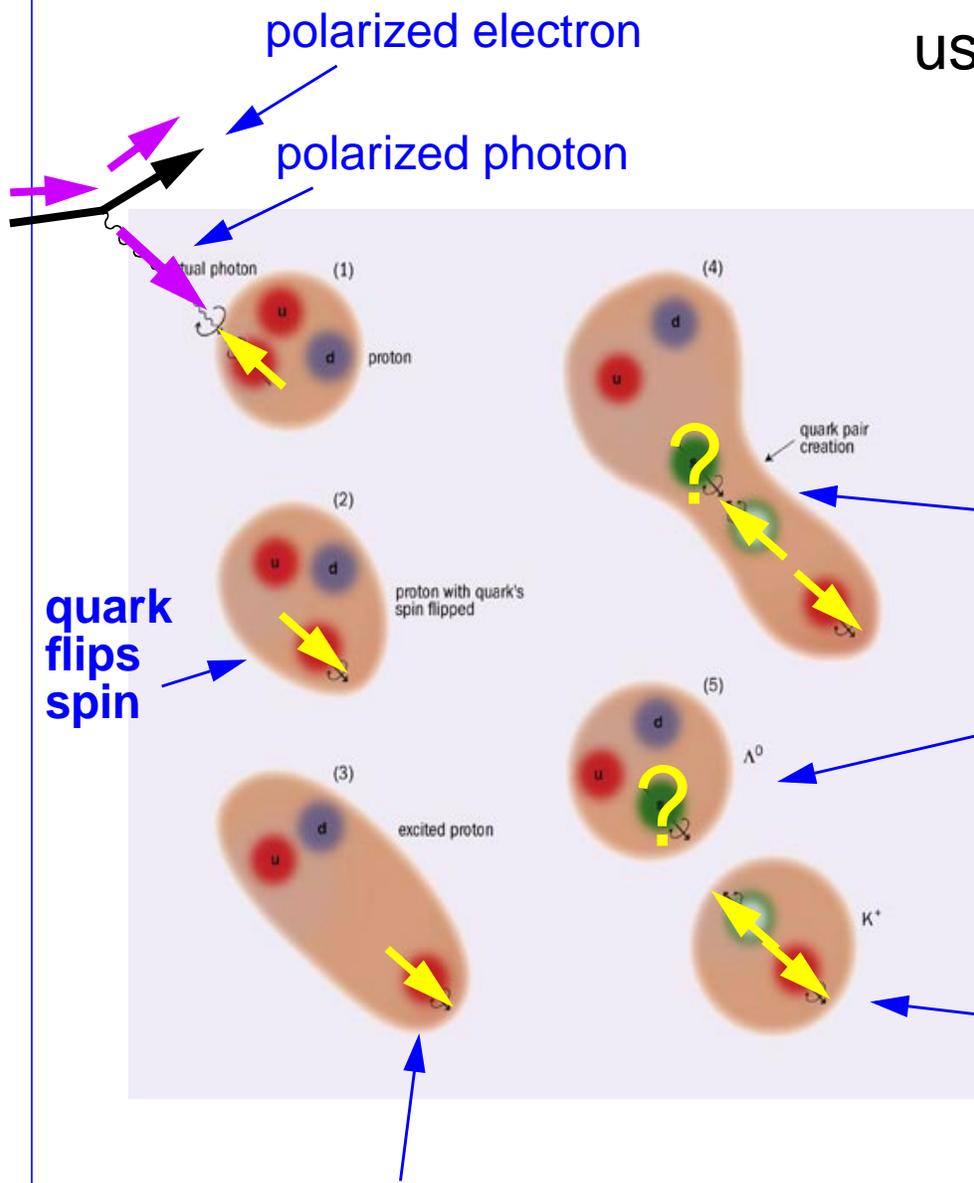
Polarization observables

flux-tube breaking

What is role of $q\bar{q}$ wave-function?



Study flux-tube breaking using spin observables



quark flips spin

Polarized u quark stretches flux-tube

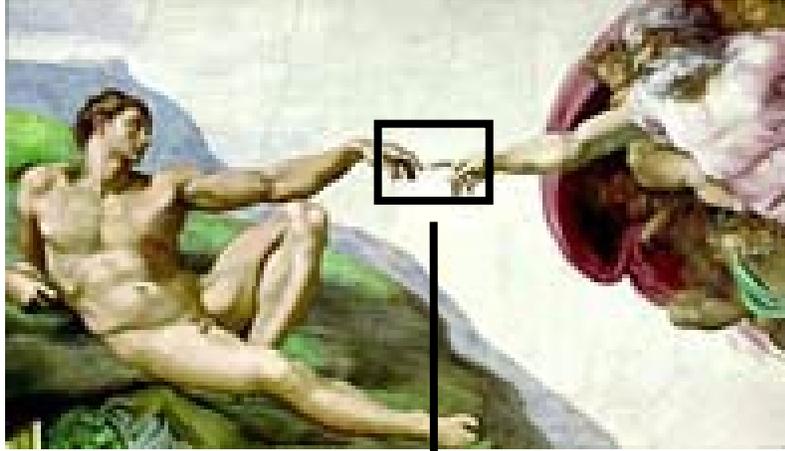
What is spin-alignment of $q\bar{q}$ which breaks tube?

What is polarization direction of Λ ?

spin-0 K^+

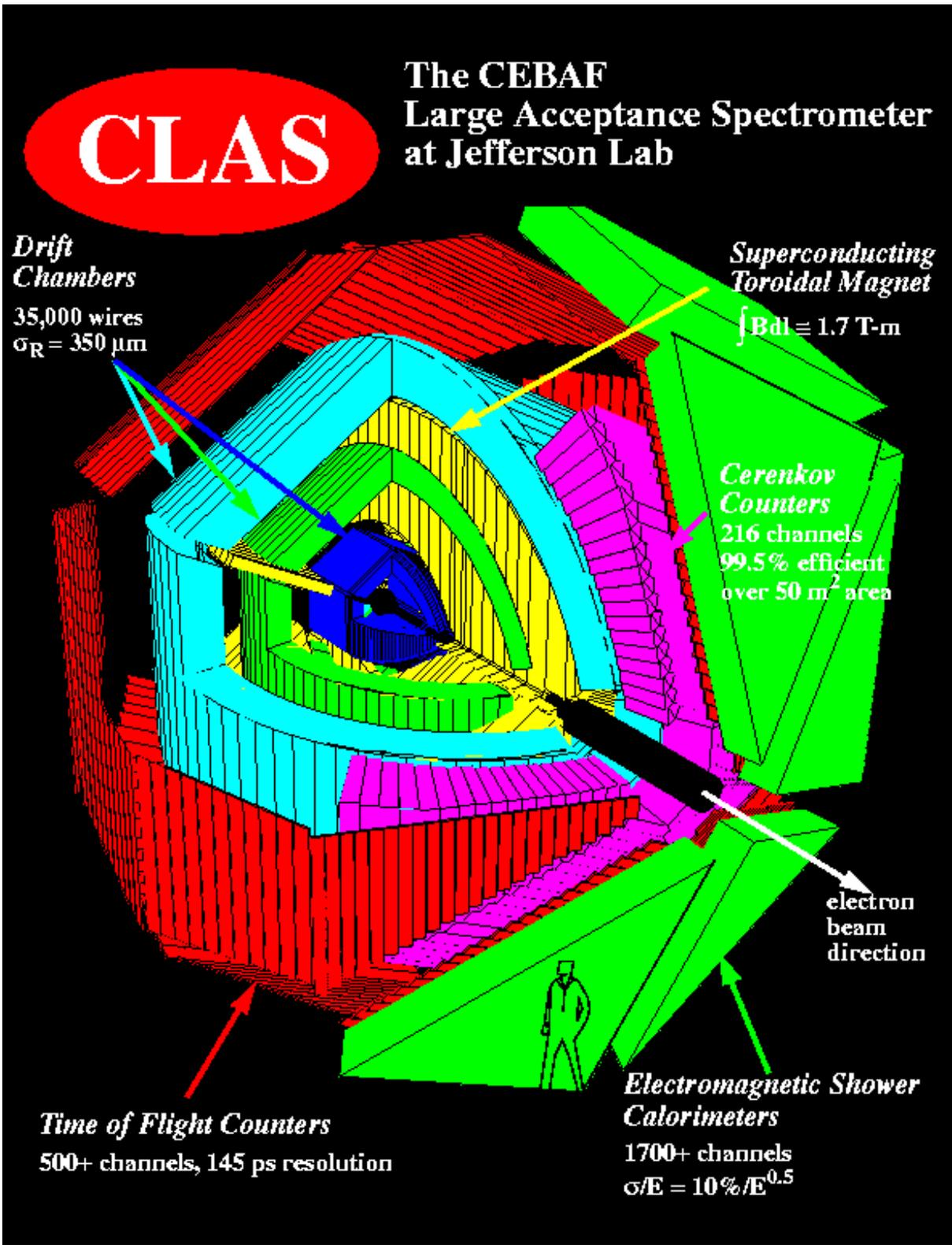
Experiment : use $s\bar{s}$
 → $K^+\Lambda$ or Σ final state
 → $s\bar{s}$ not valence
 → Λ decay is self-analysing

'Creation' in art and religion



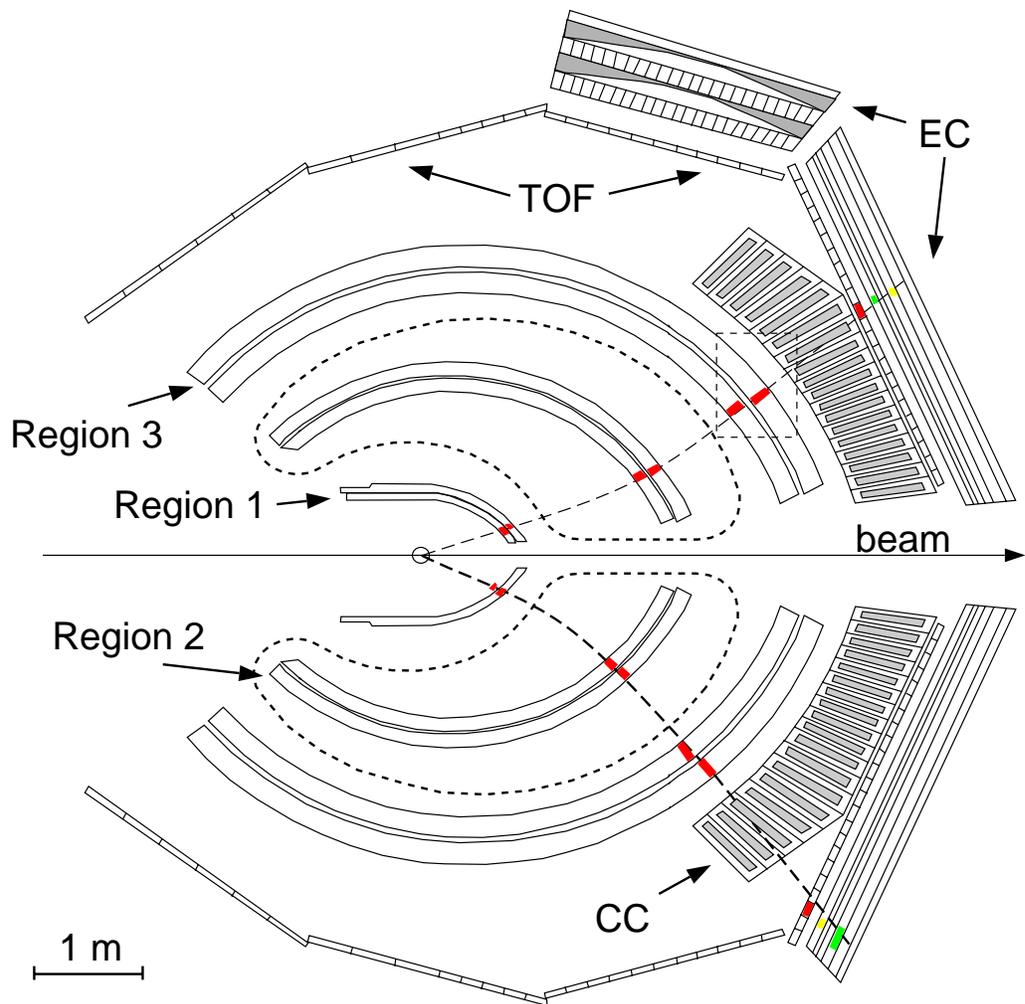
A closer look !



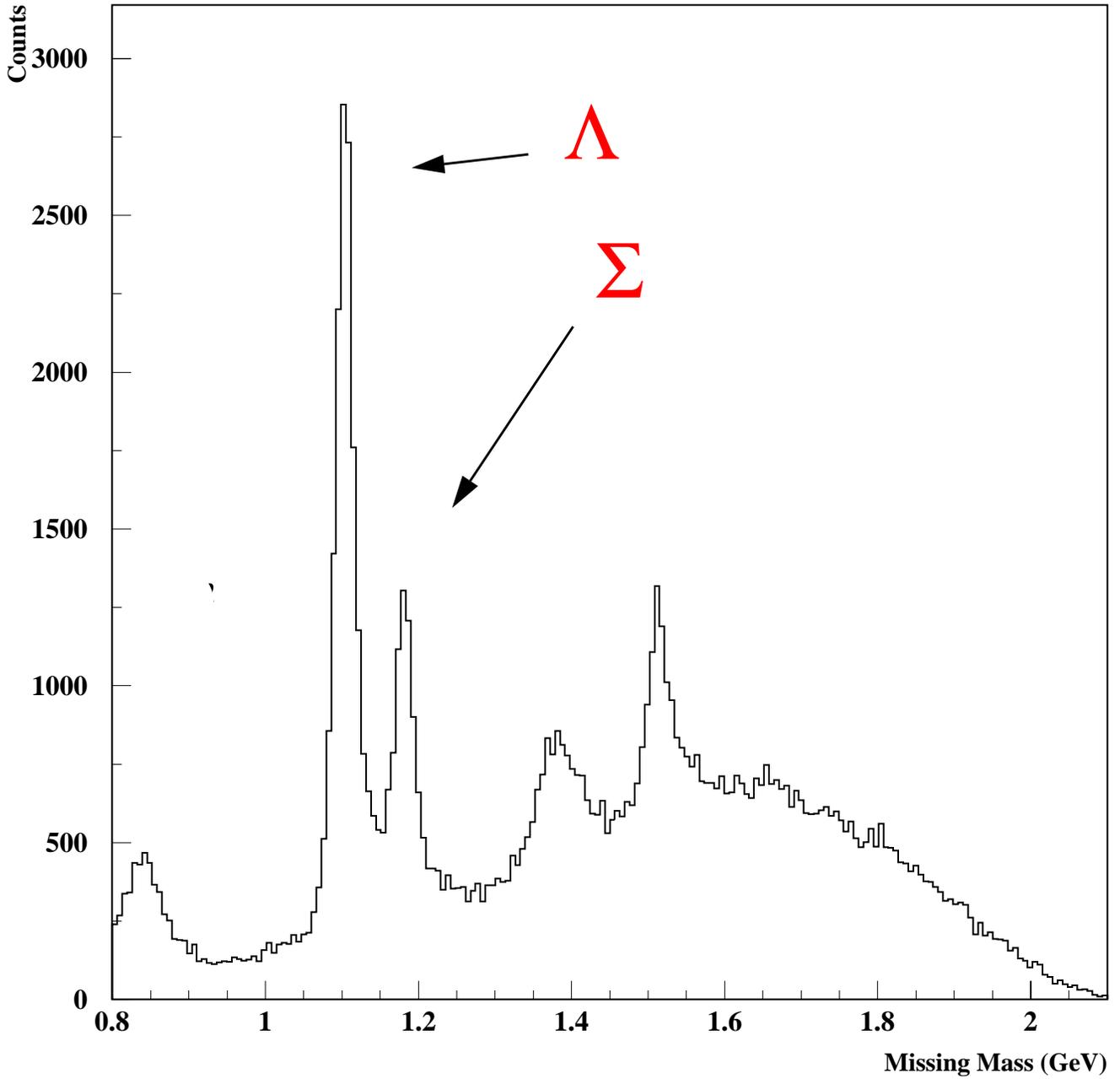


CLAS Detector:

- Large acceptance --> multi-particle
- Hadron identification by **flight-time**, electrons by CC, EC, Tagger
- **K/ π separation** to 2 GeV/c
- Good resolution --> **missing-mass**, e.g., $ep \rightarrow e'K^+(\Lambda)$



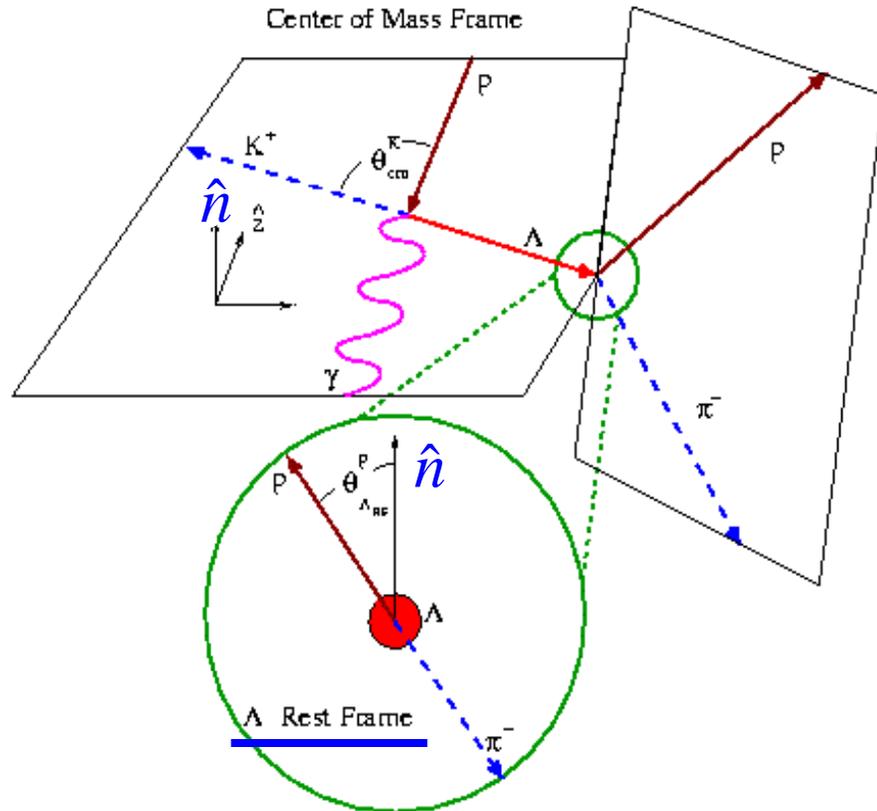
Missing Hyperon Mass



Hyperon Polarization in Exclusive $K^+ \Lambda$ Photo - Production: **Method**

- Coordinate system**

$$\hat{n} = \hat{q} \times \hat{p}_K$$



- Polarization only allowed **normal** to plane by parity conservation
- Calculate Θ_p , angle of proton in the Λ center-of mass, relative to the normal to the hadronic plane

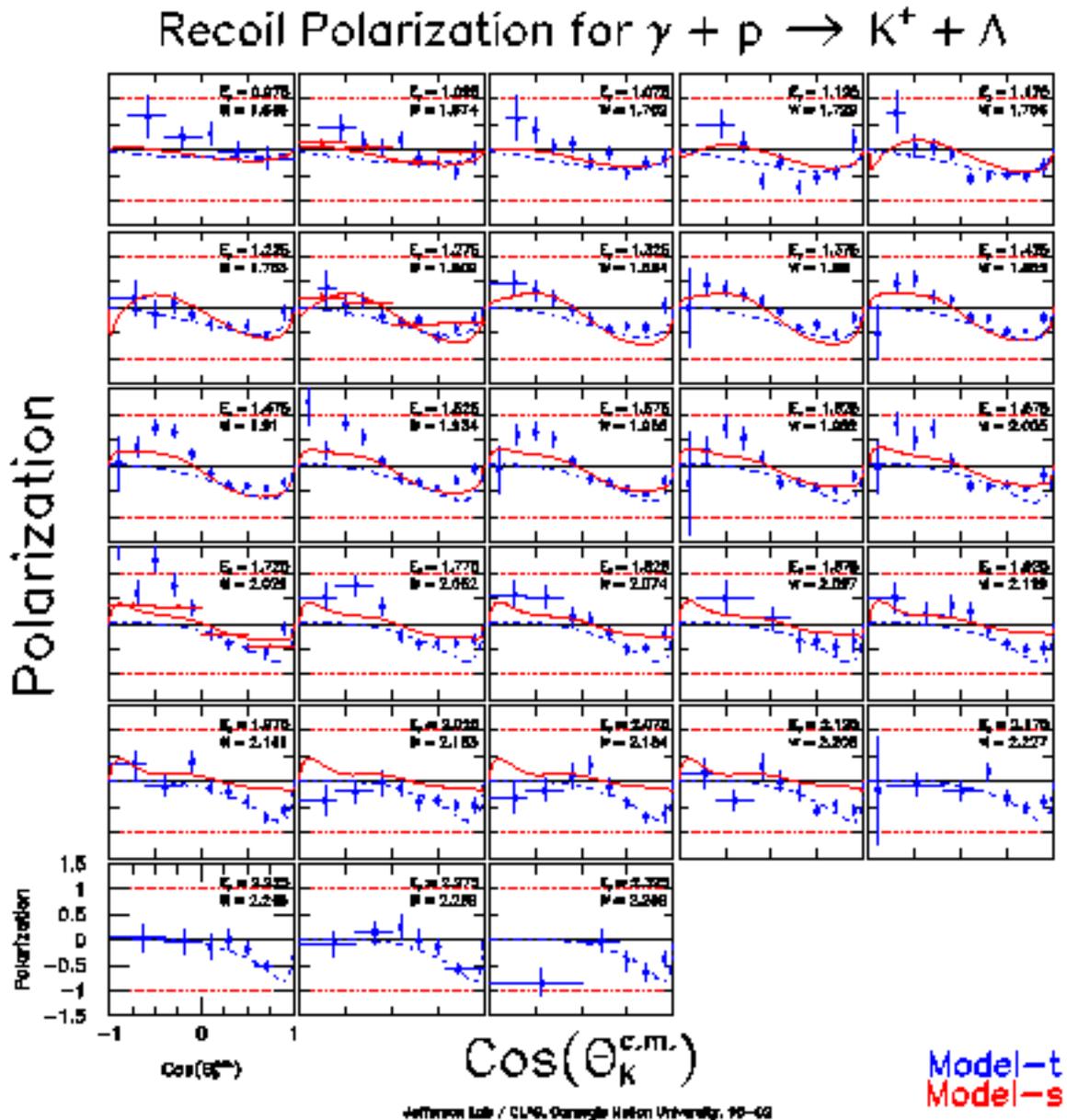
- Fit Θ_p distribution to:

$$1 + \alpha \cdot P_{\Lambda} \cdot \cos \Theta_p$$

Recoil Λ Polarization ($\gamma p \rightarrow K^+ \Lambda$) vs. $\cos\Theta_K$

- Λ polarization **normal** to hadronic production plane
- measured for **different photon energies**

Submitted to
PRL
nucl-ex/0305028

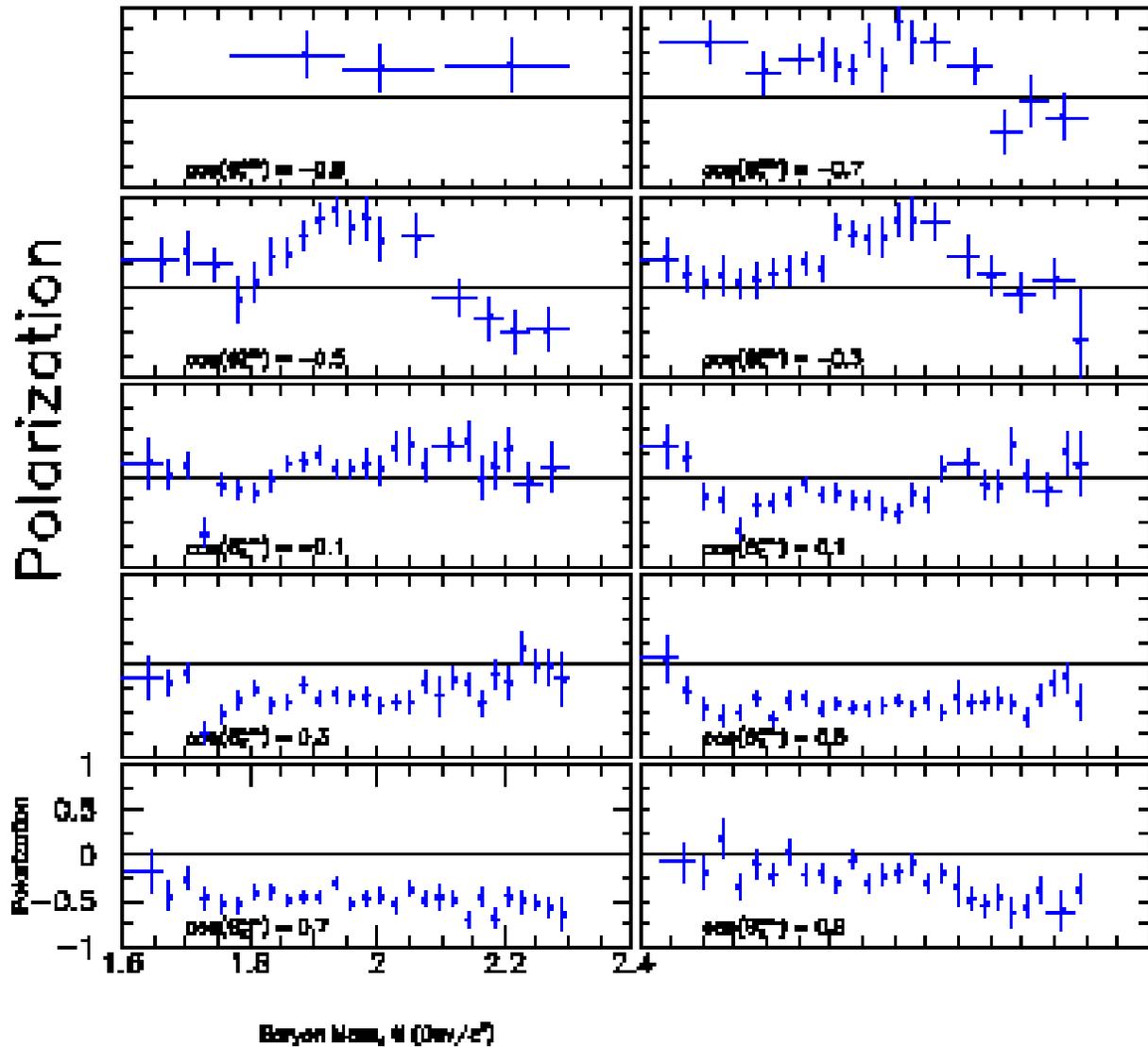


Recoil Λ Polarization ($\gamma P \rightarrow K^+ \Lambda$) vs. W

- measured for different K^+ angles

Submitted to
PRL
nucl-ex/0305028

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



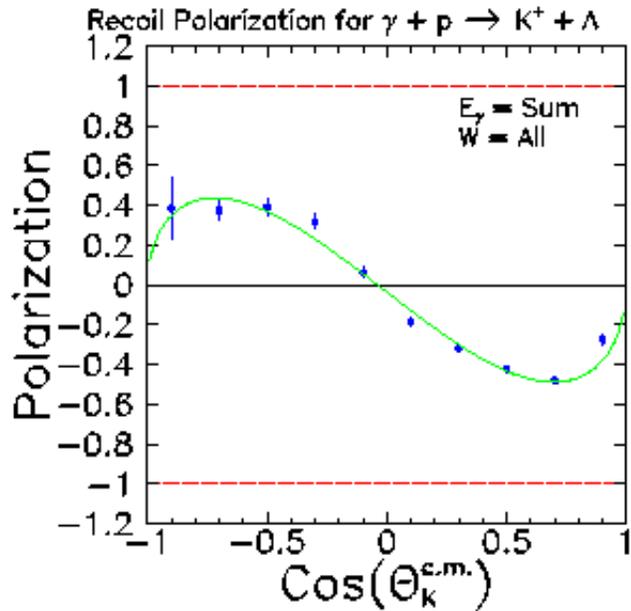
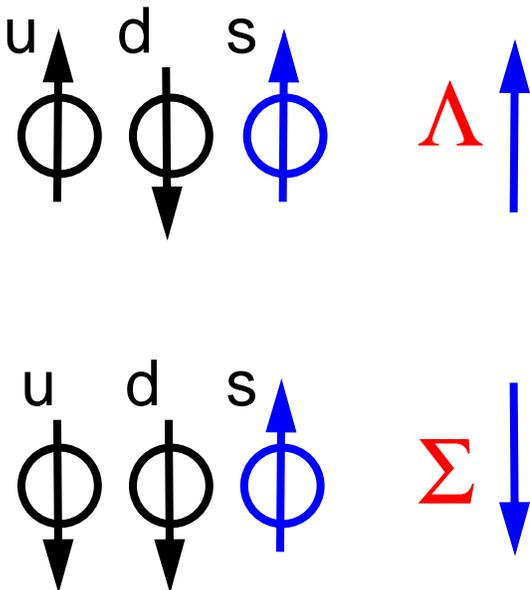
Baryon Mass, W (GeV/c^2)

Induced Λ, Σ Polarization - Photoproduction

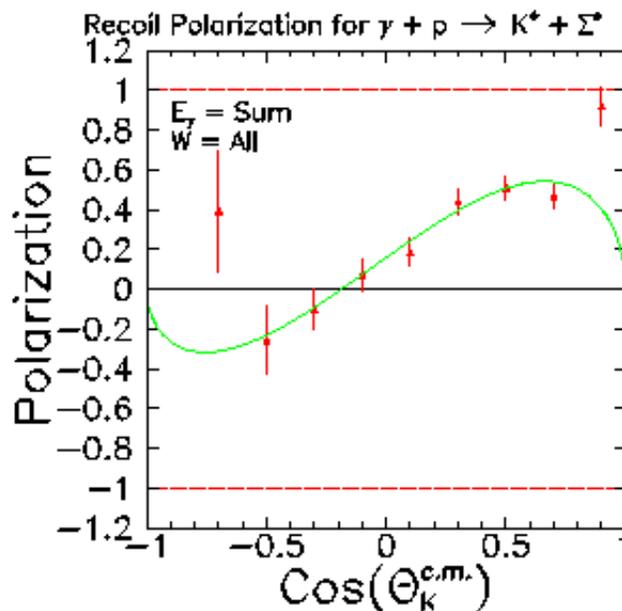
Submitted to
PRL
nucl-ex/0305028

- comparison of Λ to Σ
- averaged over W
- $\text{Pol}(\Lambda) \sim -\text{Pol}(\Sigma)$

- common mechanism - s-quark polarization ?



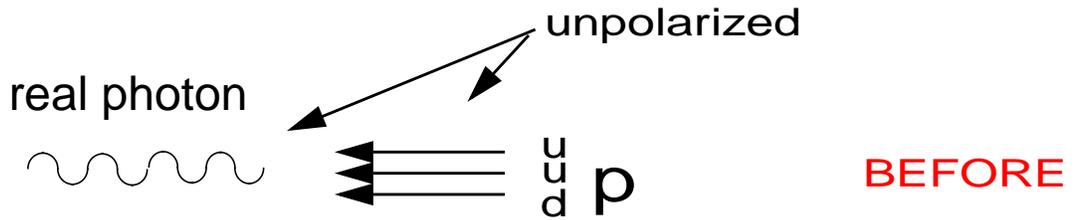
Λ



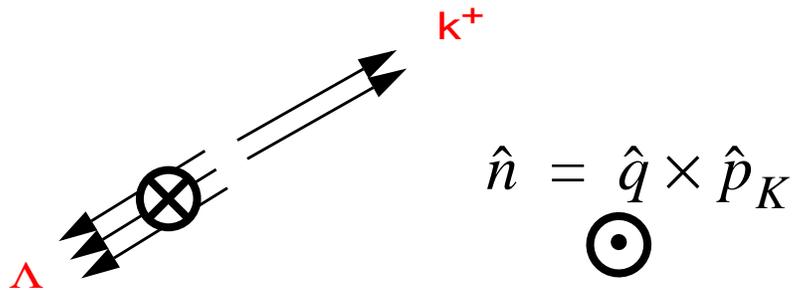
Σ

Hyperon Induced Polarization

Simple phenomenology:



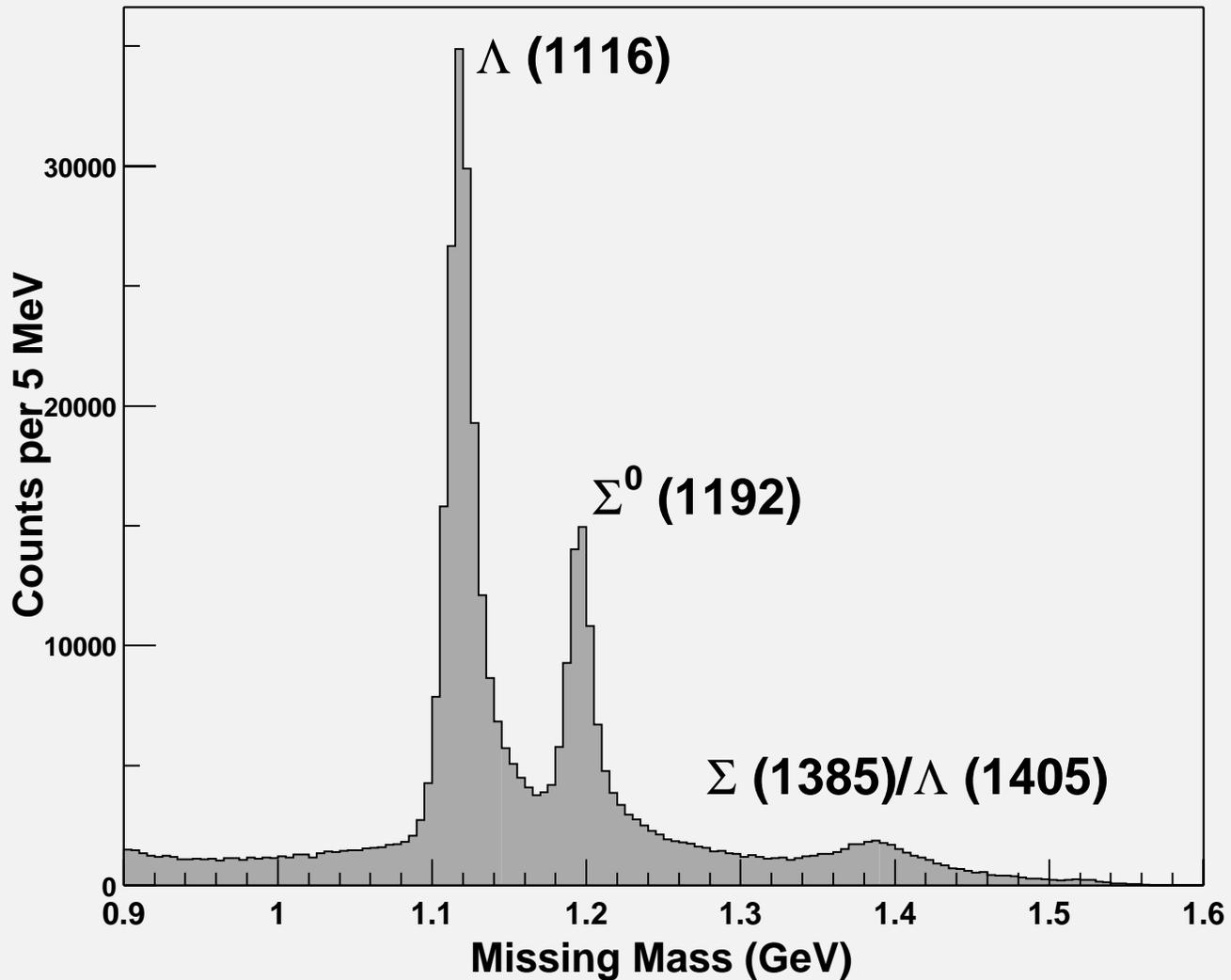
K goes left



What physical process can cause this?

Electron Beam Event Reconstruction:

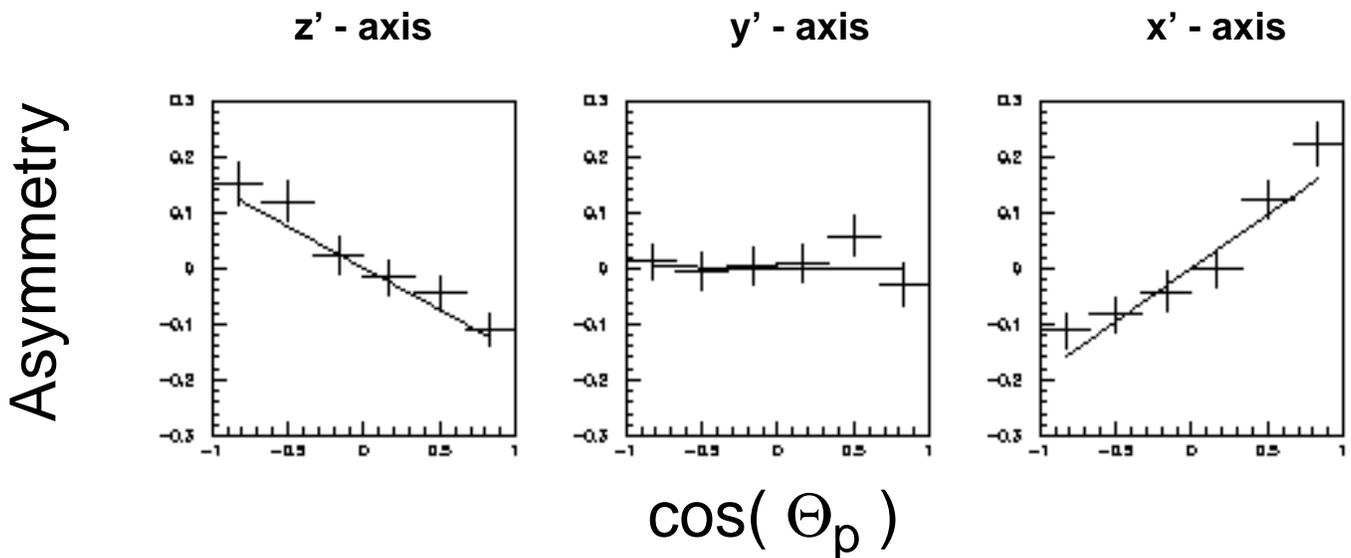
- Detect electron --> neg. track matched with outer detector
- Detect K^+ --> pos. track, flight time consistent with mass
- Calculate missing mass from detected electron, K^+



Transferred Lambda Polarization: Method

- Choose axis,
e.g. z' -axis along K^+ momentum in Λ center-of-mass
- Bin asymmetry $[\text{Yield}(+) - \text{Yield}(-)] / [+]$ vs. $\cos\Theta_p$,
where Θ_p is the angle between proton and chosen axis
(Note: integrated over $\Phi \rightarrow y'$ components vanish)
- Fit Θ_p asymmetry distribution to :

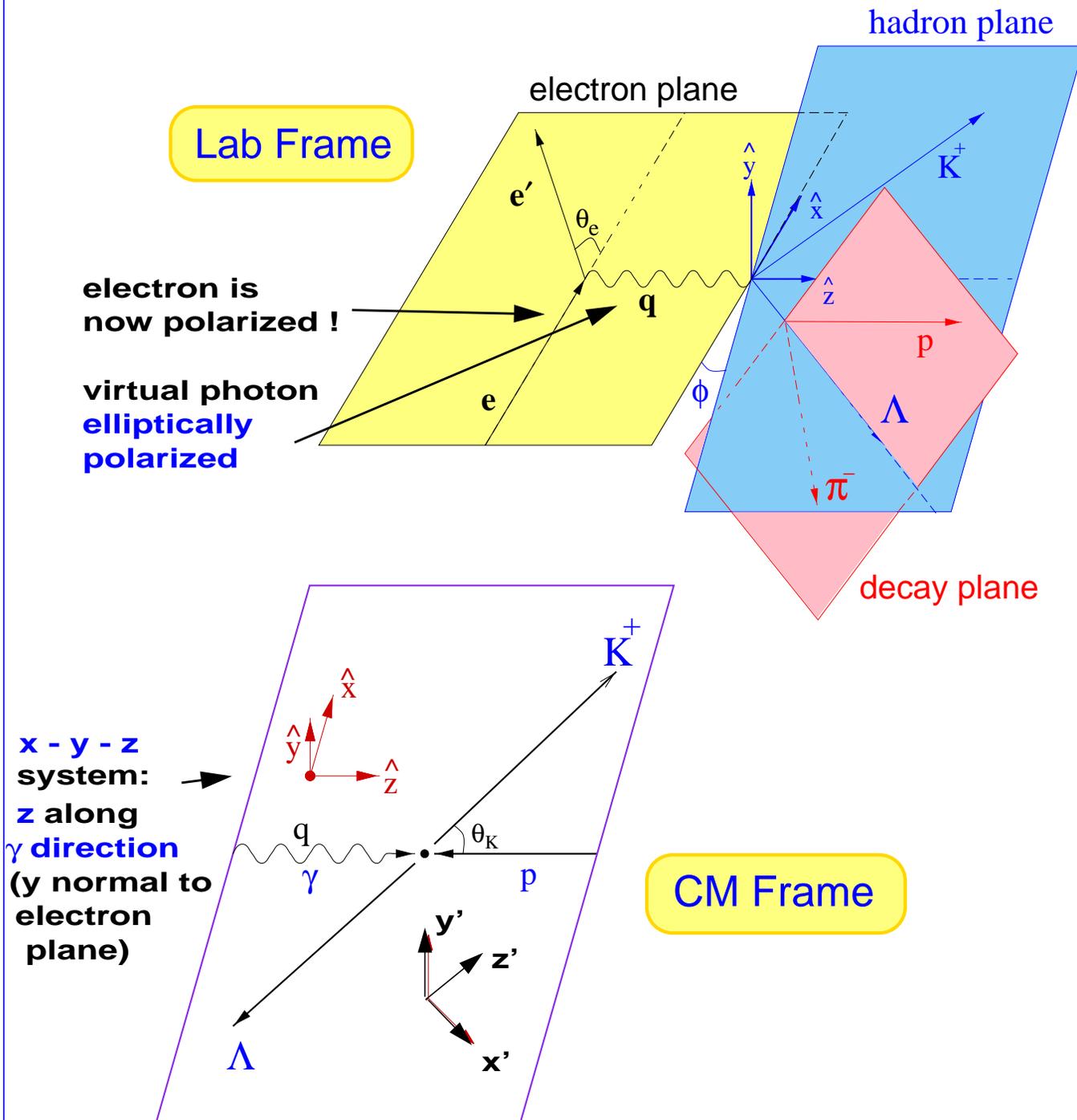
$$\alpha \bullet P_{beam} \bullet P_{transfer} \bullet \cos\Theta_p$$



- Sample fit at $W = 1.85$ GeV, integrated over $Q^2, \Phi, \cos(\Theta_K)$

Λ Polarization Transfer in Exclusive $K^+ \Lambda$ Production

Coordinate Systems



Cross Section

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

$$\frac{d\sigma_v}{d\Omega_K^*} = \sigma_0 + P_e \cdot \sigma_{TL'} + \sum_i (P_i^0 + P_e \cdot P_i') \sigma_0$$

**Unpolarized
Cross Section**

$$\sigma_0 = \sigma_T + \epsilon\sigma_L + \epsilon\sigma_{TT} \cos 2\Phi + \sqrt{\epsilon(1+\epsilon)/2} \sigma_{TL} \cos \Phi$$

$$\sigma_{TL'} = \sqrt{2\epsilon_L(1-\epsilon)} R_{TL'} \sin \Phi$$

Polarized beam

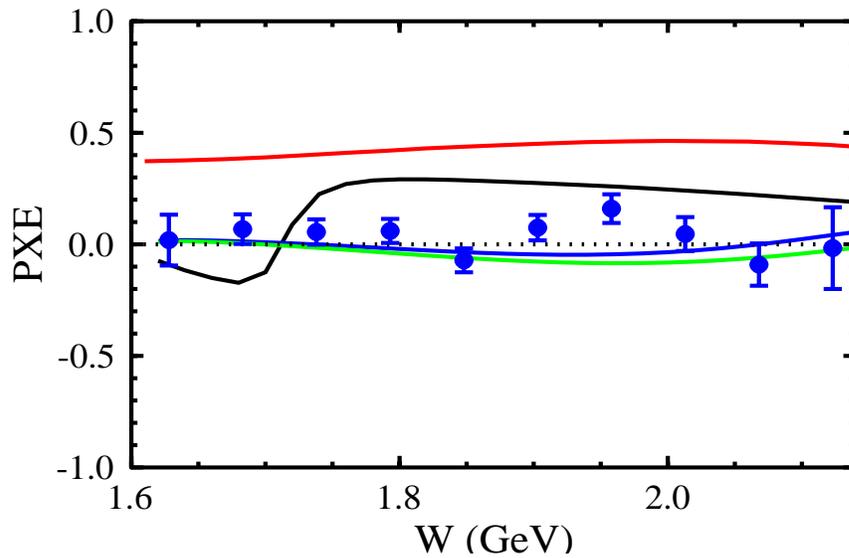
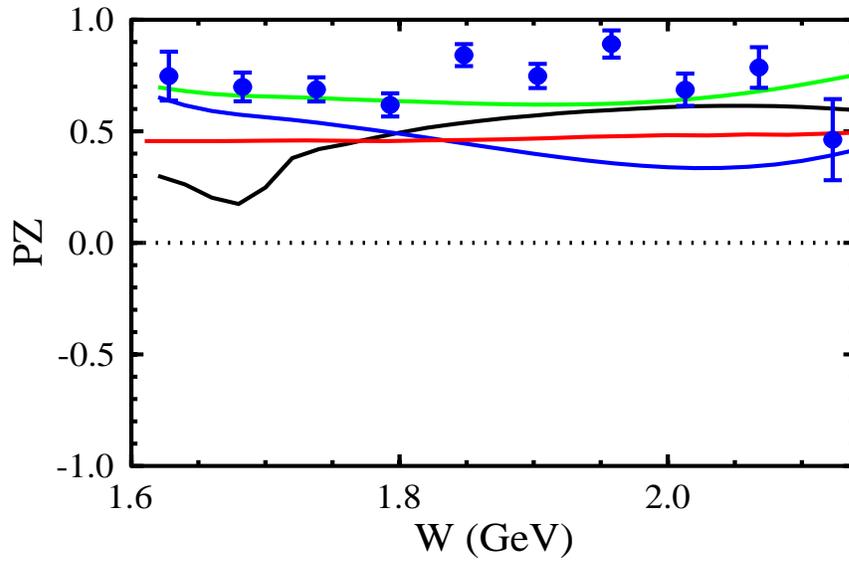
Hyperon polarization

Induced

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

Transferred

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



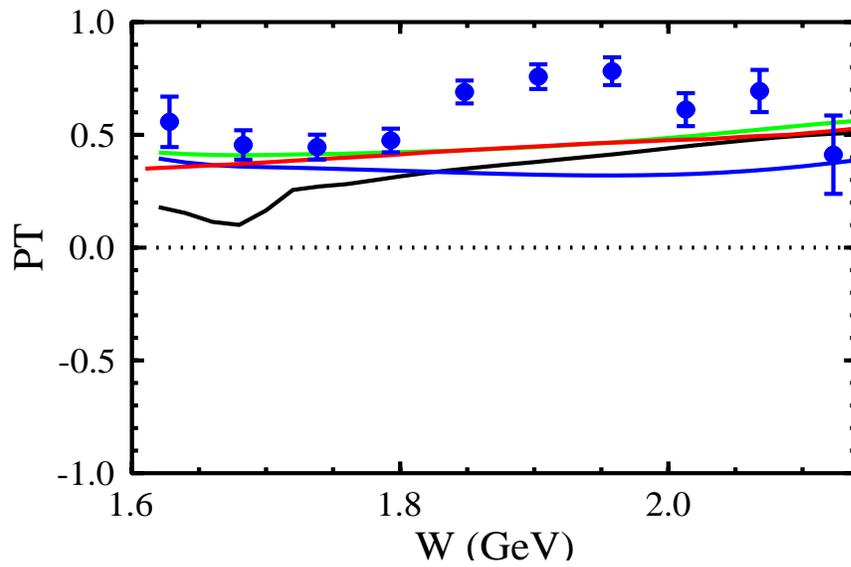
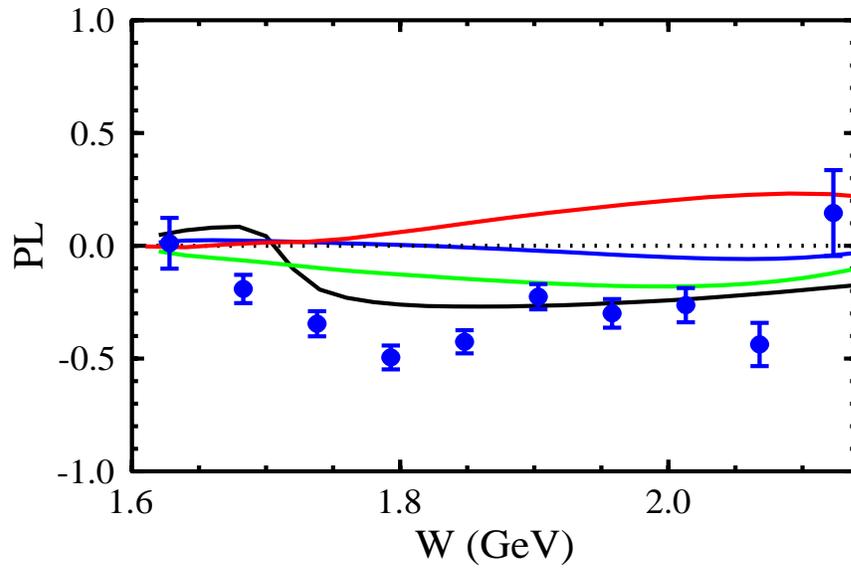
2.567 GeV
Summed over $Q^2, d\Omega_K^*$

Adelseck and Wright - 1988

Cotanch - 1992

Bennhold and Mart - 2002

Janssen - 2002

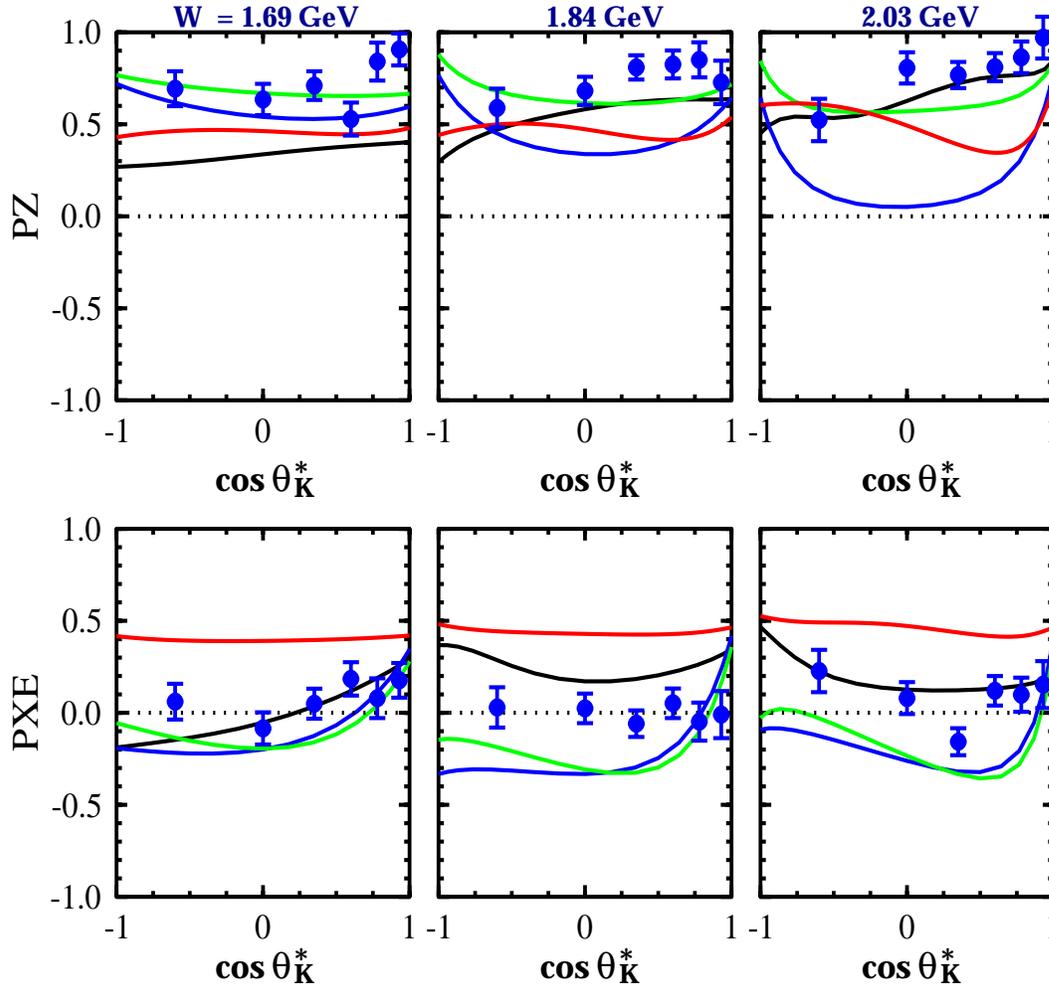


2.567 GeV
Summed over $Q^2, d\Omega_K^*$

Adelseck and Wright - 1988
Cotanch - 1992
Bennhold and Mart - 2002
Janssen - 2002

Λ Polarization Transfer

- X - Y - Z system: defined in **electron plane**, Z along γ direction



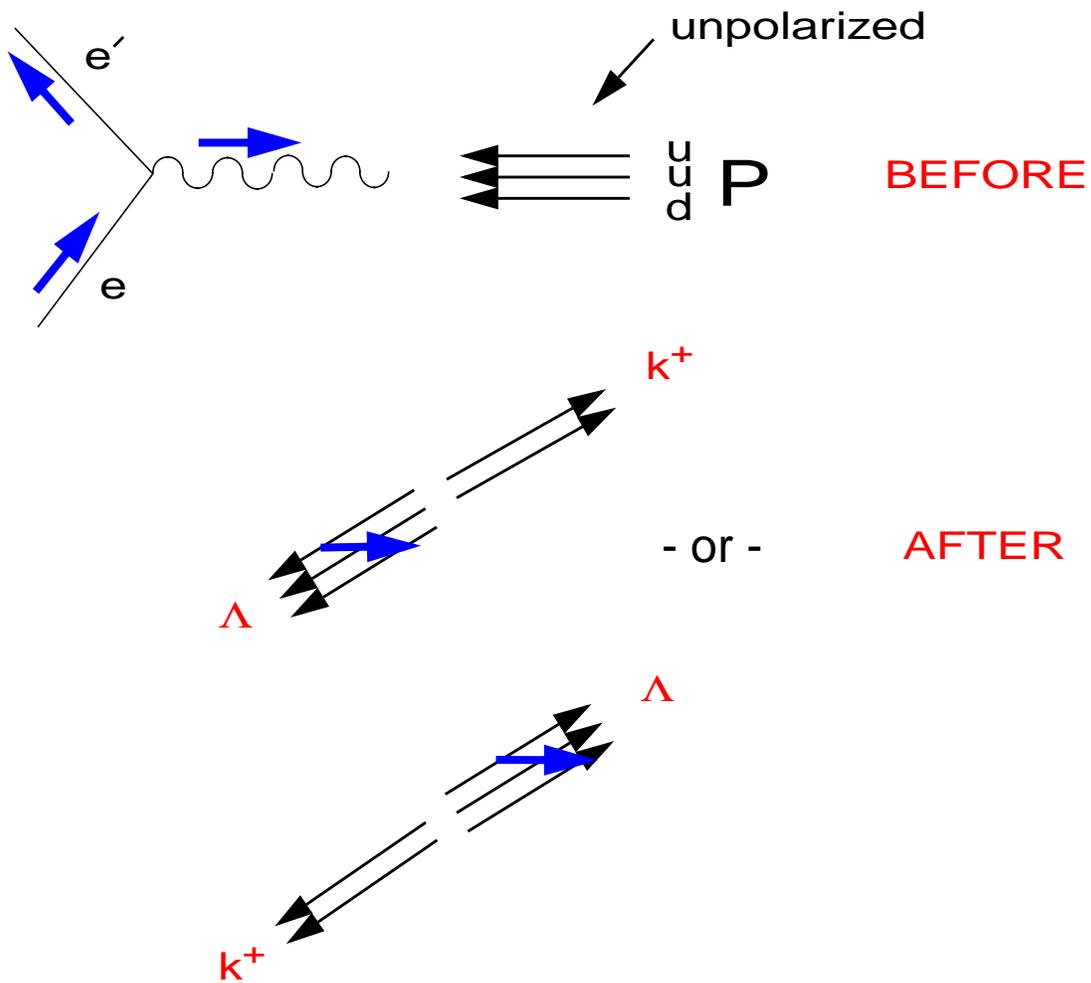
2.567 GeV
Summed over Q^2, Φ

Adelseck and Wright - 1988
Cotanch - 1992
Mart and Bennhold - 2002
Janssen - 2002

- Polarization transfer is near maximal ($\sim 75\%$)
- Little dependence on Θ_K or W

Carman, et al
PRL **90**,131804
(2003)

Hyperon Polarization Transfer:



Simple phenomenology \rightarrow simple physics ?

Lambda Polarization from other Experiments

● **Lep experiments (ALEPH and OPAL) : Z decay**

- Λ polarization of -0.3 for $z > .3$
 - s quark polarized in electro-weak decay
 - fully accounts for Λ polarization
- > static (CQM) quark model favored

Phys. Lett. B
374 (1996) 319

Eur. Phys. J. C
2 (1998) 49

● **HERMES semi-inclusive Λ production**

- Small value of polarization (~ 0.1)
- > inconclusive
- > exclusive polarizations larger than for inclusive reactions

Phys. Rev. D
64 (2001) 112005

● **P P --> Λ (x) (CERN R608, several FERMILAB experiments)**

- Polarization negative; increases with P_T to 1. GeV
- Increases with x_F ; as large as -0.40

Phys. Lett. B
185 (1987) 209

● **P P --> Λ K⁺ P (CERN - R608)**

- Polarization negative; as large as -0.64
- > exclusive polarizations larger than for inclusive reactions

Phys. Lett. B
283 (1992) 155

Explanation of Lambda Polarization for Exclusive Production

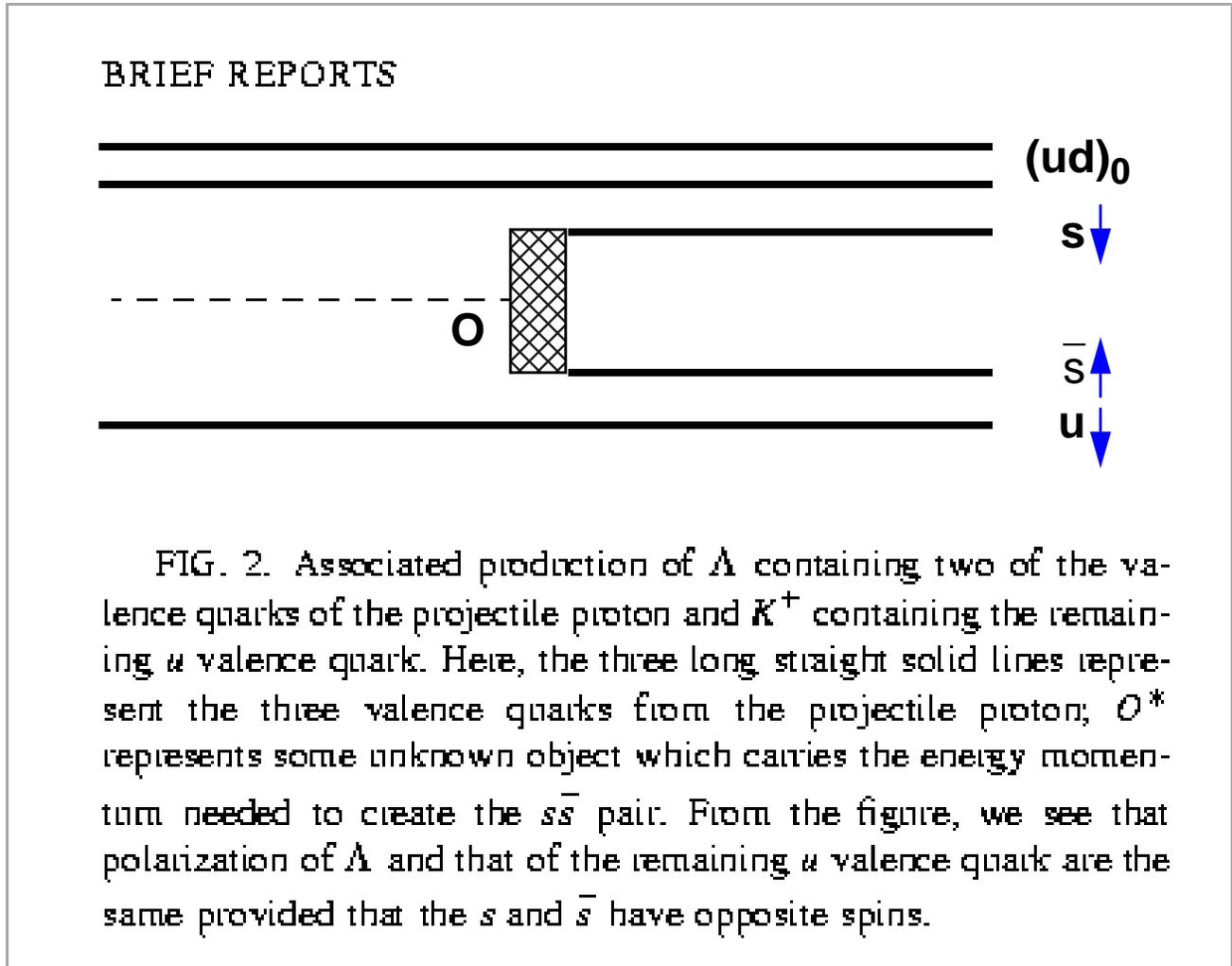
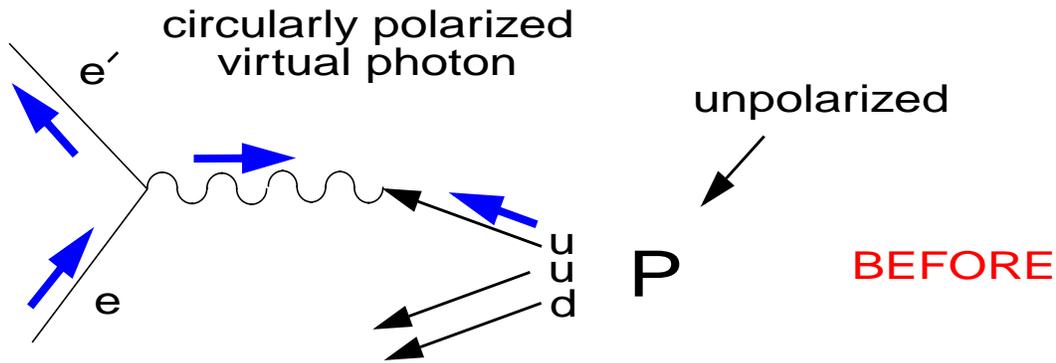


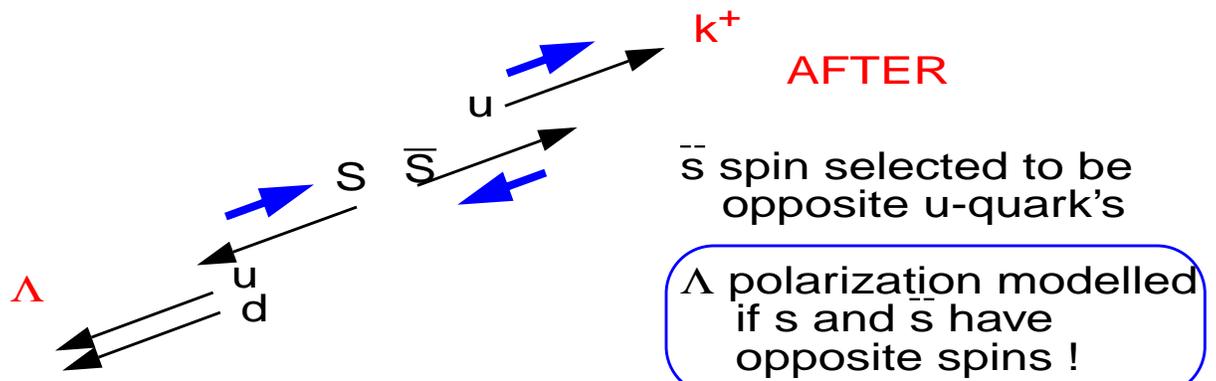
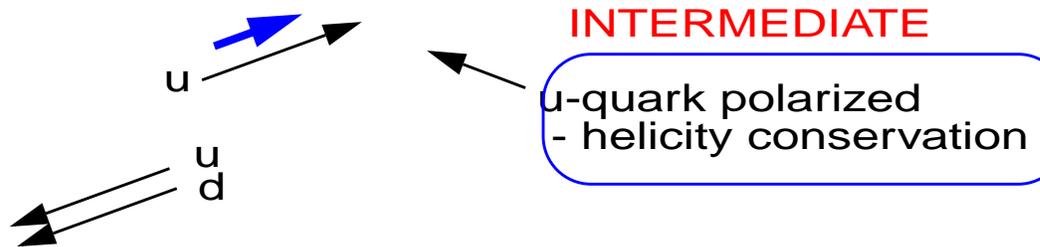
Figure and caption from **Liang Zuo-tang** and **C. Boros**,
Phys. Rev. D 61, 117503, 2000.

- **u-quark is polarized “down” as it scatters to “right”**
 --> note this phenomenology explains single-spin asymmetry data
- **spin of \bar{s} quark is selected to be opposite that of u quark to make spin 0 kaon**
- **spin of s quark must be opposite that of \bar{s} to give correct Λ spin**

Λ Transferred Polarization and the Angular Momentum State of a $q\bar{q}$ Pair



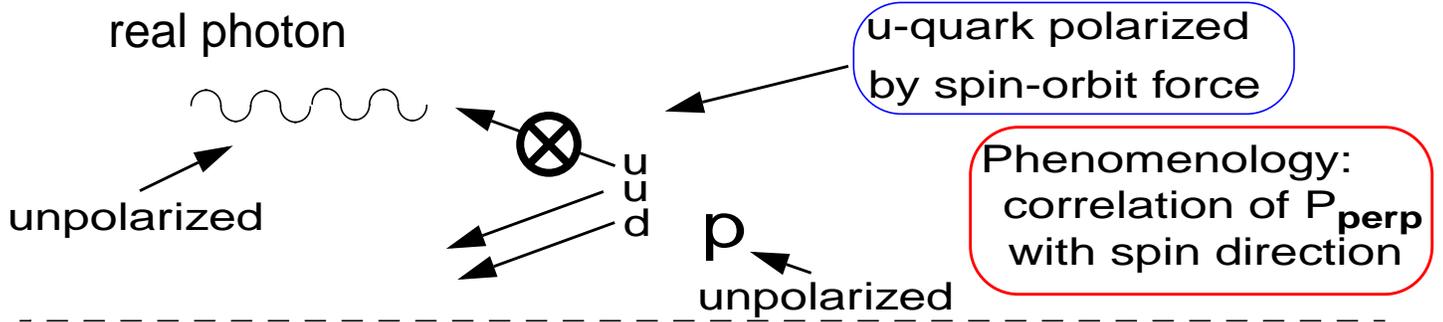
Carman, et al
PRL 90,131804
(2003)



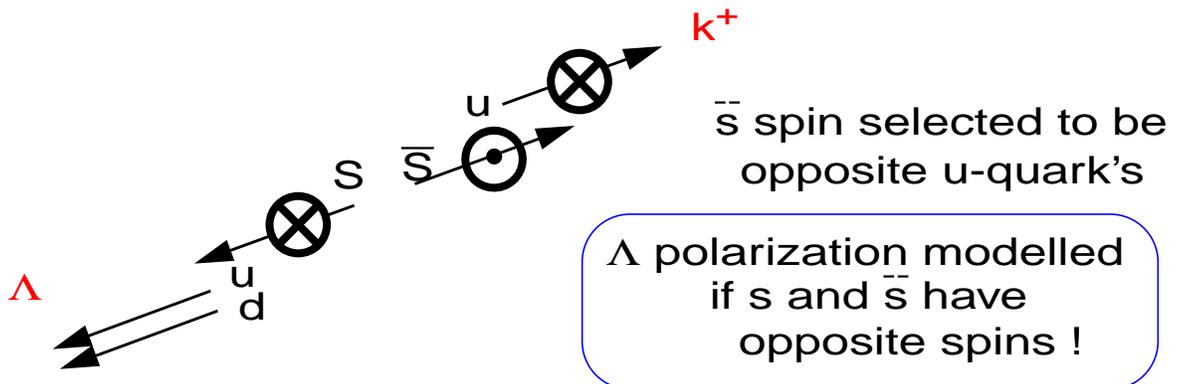
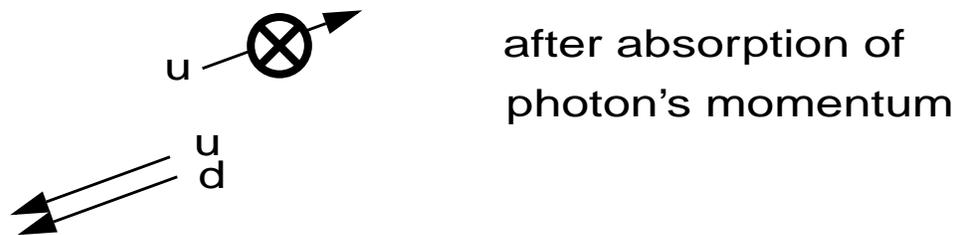
- Inconsistent with 3P_0 quark pair creation operator ?
→ prev. measured in meson-decays

Quark Spins from Induced Polarization ?

- add some perpendicular momentum



Zuo-tang, Boros
PRL79(1997)3608
PRD61(2000)117503



- inconsistent with 3P_0 quark pair creation operator?

Observations

- Induced Polarization
large values, simple Θ_K dependence, little W dependence,
 Σ polarization opposite to Λ 's
- Transferred Polarization
large values, simple Θ_K dependence, little W dependence,
 Λ polarization in same direction as virtual photon

Interpretation

- Hadro-dynamic argument → Λ polarization sensitive to
interference of amplitudes
 - polarization measurements constrain parameters
make theories more reliable
 - better to search for missing resonances
- Quark-model argument → exclusive Λ polarization sensitive
to $s\bar{s}$ spin
 - $s\bar{s}$ produced with spins anti-aligned
 - $q\bar{q}$ not produced with vacuum quantum numbers ?
 - new way to study flux-tube other than spectroscopy

Assume the Flux-tube is Real!

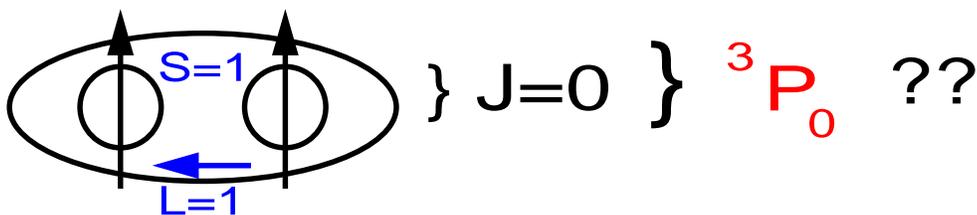
- expected from non-Abelian gluon field
- linear potential in $\bar{Q}Q$ mesons

Measure its Properties!

- excite its oscillations (hybrid mesons)
- BREAK IT via $\bar{q}q$ creation

Quark Pair Creation

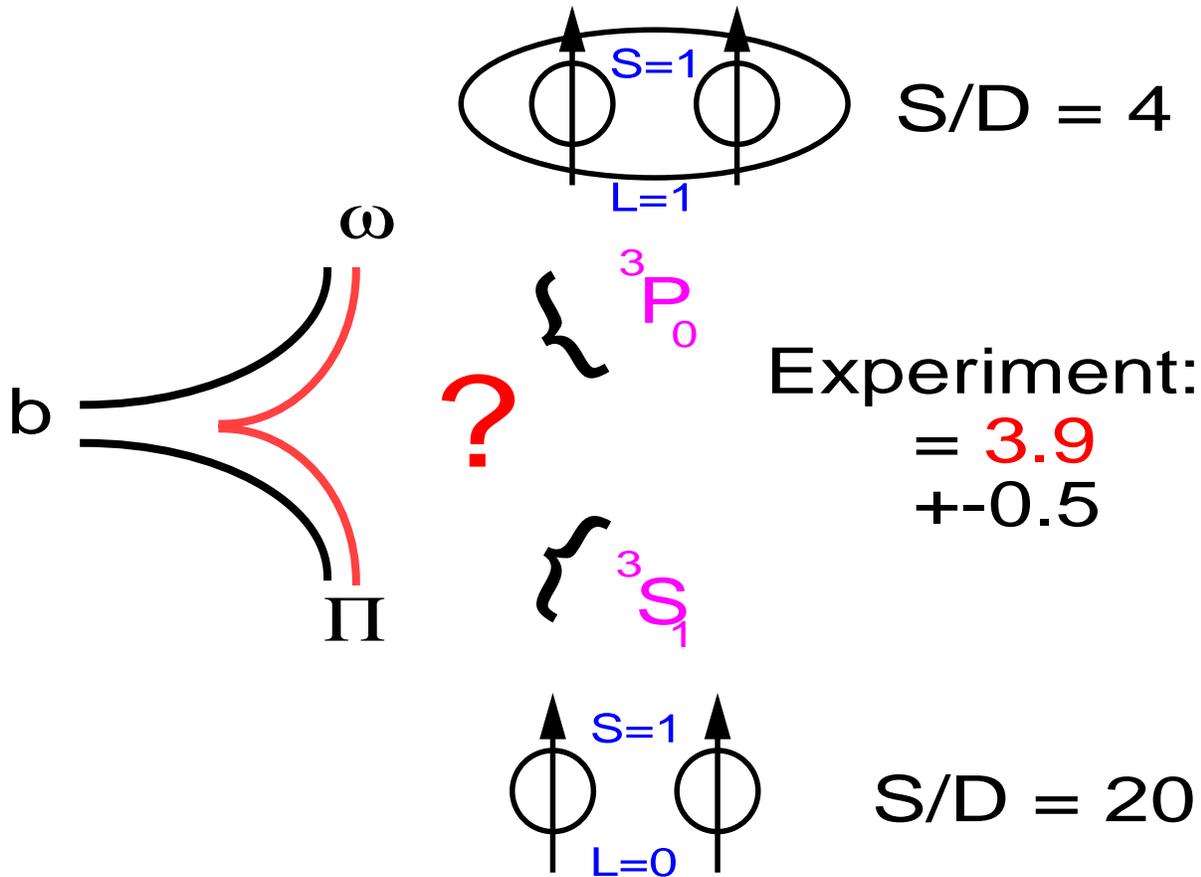
- What is the quantum state of the $\bar{q}q$ pair?



How to Measure the Quantum State of a $Q\bar{Q}$ Pair?

Meson Decay Amplitudes: **different orbital angular momenta**

- D/S wave amplitudes: $V \rightarrow PV + PS$ ($b \rightarrow \omega\pi$)



What is the physics of polarization transfer to the Λ ?

Simple phenomenology:

- depends on $\cos(\Theta_k)$
- little apparent dependence on W , Q^2

> Traditional hadrodynamic models:

- polarization arises from **interference** of s,t and u-channel amplitudes

(e.g. Bennhold, Mart, Saghai, Laget, Cotanch)

> Phenomenological quark-based models:

- dynamics arises from **quark scattering** followed by **hadronization**
- recently extended to exclusive processes
- key feature is that polarization depends on the **correlation of spins** in the quark-pair creation process

(e.g. Boros, Zuo-tang, recent PRD articles, results from CERN experiment R608)

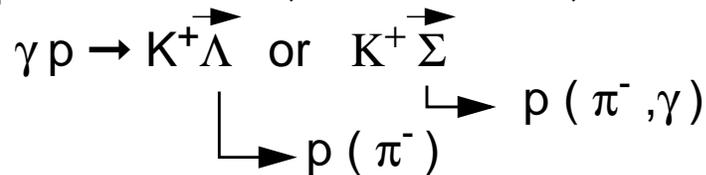
Three CLAS Experiments

- Unpolarized electron beam, hyperon not detected



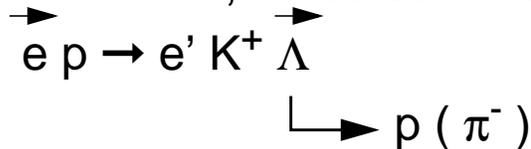
- virtual photon is **linearly polarized**
- hadronic response revealed in **Φ -dependence**
- **PRELIMINARY DATA** (collaboration review) - McNabb thesis, CMU

- Unpolarized photon beam, detected Λ, Σ decay



- Λ **polarization** measured **normal** to hadronic plane
- **PRELIMINARY DATA** (collaboration review) - Feuerbach thesis, CMU

- Polarized electron beam, detected Λ decay



- virtual photon is **circularly polarized + linearly polarized**
- Λ **polarization** measured in **directions other than normal** to hadronic planes
- **PRELIMINARY DATA** (submitted to PRL; preprint: hep-ex/0212014)

Λ Polarization Transfer

- $X' - Y' - Z'$ system: defined in **hadron plane**
- Z' is along K^+ direction, Y' normal to plane, X' transverse in plane
- $P_{y'}$ vanishes after ϕ integration

