Λ and $\bar{\Lambda}$ polarization and spin transfer in photoproduction at HERMES

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(for HERMES collaboration)

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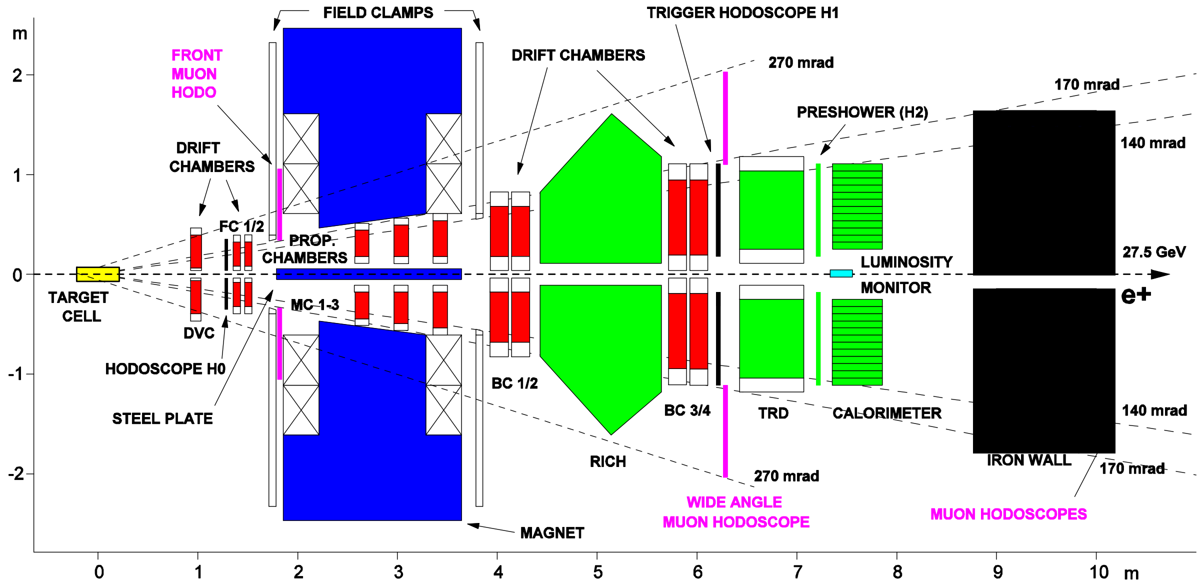
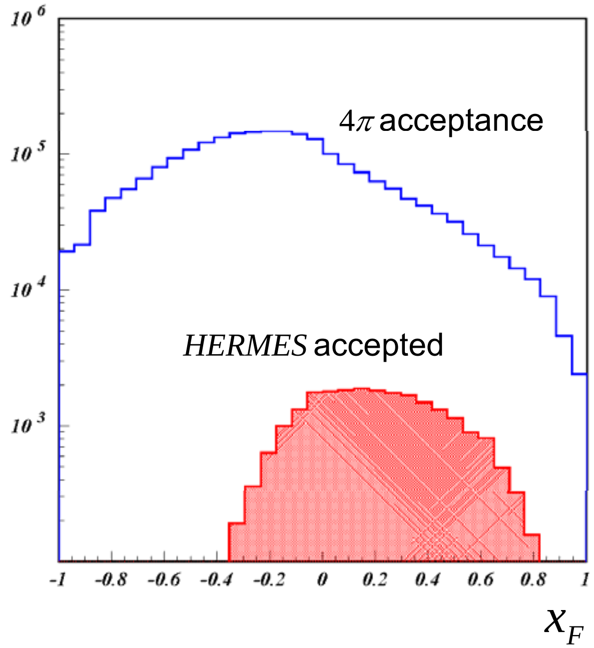
Polarized Λ physics at HERMES

- **DIS**, $e + p \rightarrow e' + \Lambda + X$
  - D_{LL} – spin transfer from longitudinally polarized beam in semi-inclusive / *Publish P.R. D 74 (2006)* /
- **Photoproduction**, $e + p \rightarrow \Lambda + X$
  - P_n – spontaneous transverse Λ polarization / *Submitted P.R. D* /
  - K_{LL} – spin transfer from longitudinally polarized target
  - D_{LL} – spin transfer from longitudinally polarized beam
  - K_{NN} – spin transfer from transversally polarized target

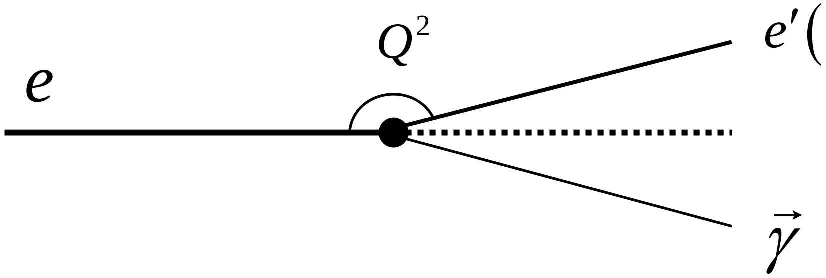
HERMES experiment

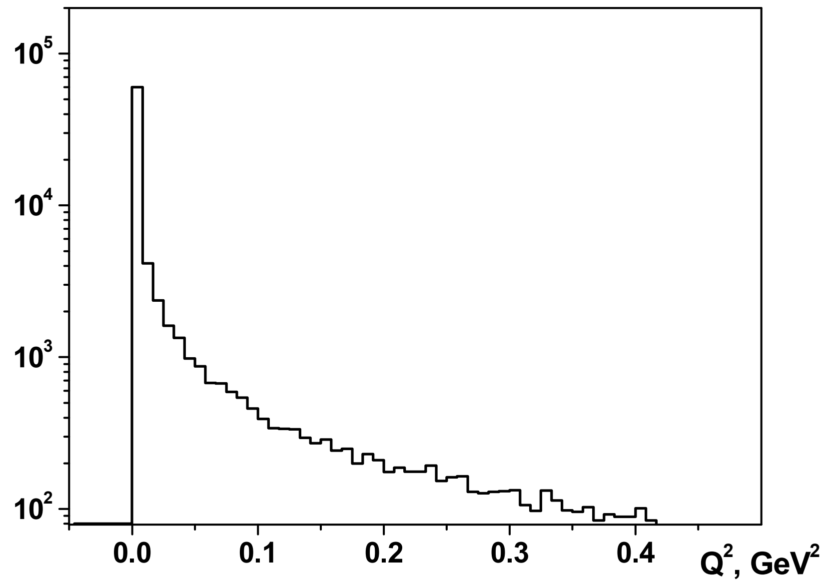




- *Polarized e^+ / e^- beam with E_e = 27.5 GeV flipped every 2-3 month*
- *Longitudinally / transversally polarized and unpolarized internal gas targets H, D, He, Ne, N, Kr*
- *Detector is up / down symmetric → transverse polarization*
  target flip every 90 s → spin transfer
- *Good RICH PID for hadrons separation: π / K / p*

Kinematics for photoproduction





Most events are within photoproduction peak

$(\sim 80\%$ events have $Q^2 < 0.05\,\text{GeV}^2)$

so photon is quasi-real $(\langle \nu \rangle = 15.3\,\text{GeV})$

Only reconstructed are p_z^Λ **and** $p_t^\Lambda = \sqrt{(p_x^\Lambda)^2 + (p_y^\Lambda)^2}$

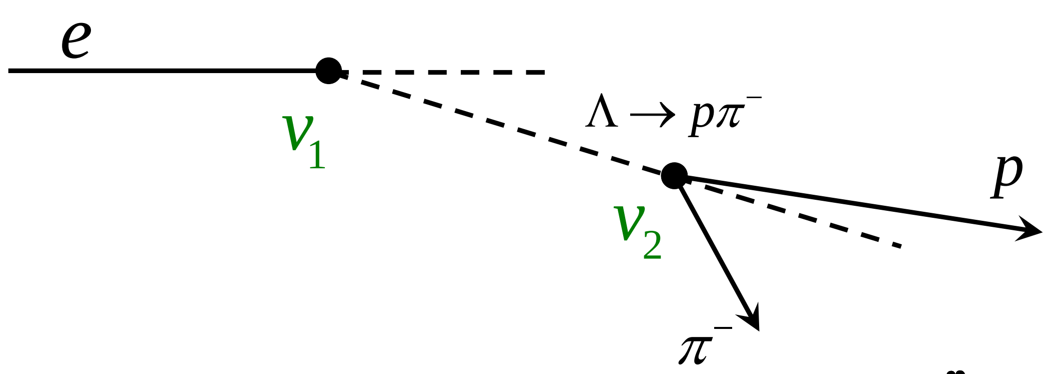
$x_F = \frac{p_z^\Lambda}{p_{\max}^\Lambda}$, p_z^Λ **and** $p_{\max}^\Lambda$ **in** (γp) **rest frame** $\mapsto$ **not known**

$\Rightarrow$

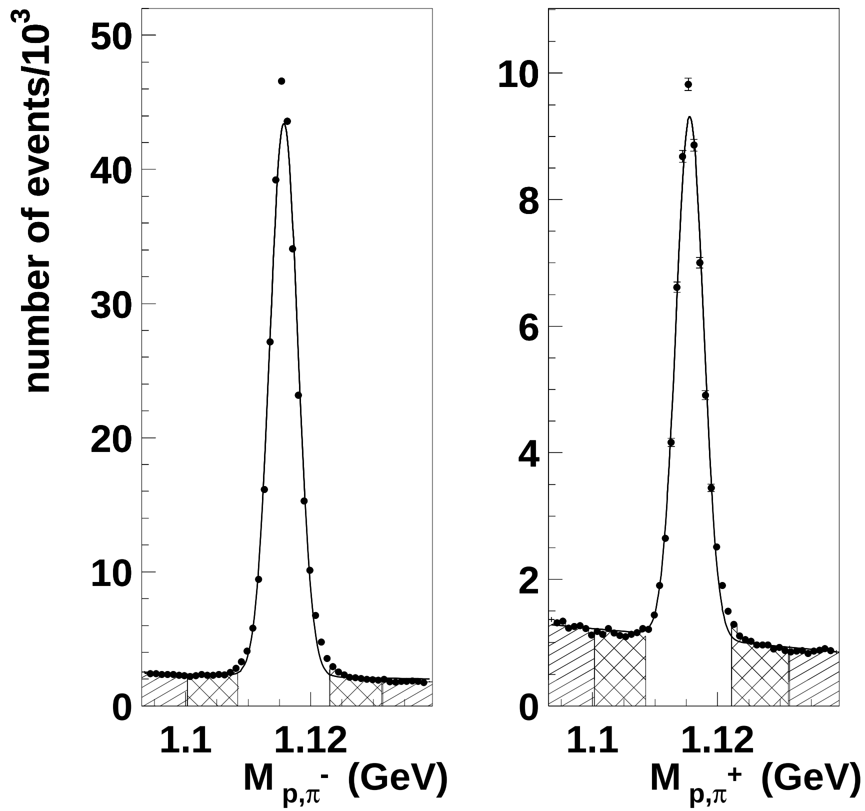
$$\zeta = \frac{E_\Lambda + p_{\Lambda z}}{E_e + p_e} \approx \frac{E_\Lambda}{E_e}$$

$$t = -(p_\Lambda - p_p)^2$$

Reconstruction of Λ events



In HERMES acceptance
proton always leading



Background suppression cuts:

Leading π rejection

- ***Threshold Cherenkov det. 1996-1997***
- ***Ring imaging Cherenkov 1999-2000***

h^+h^- pair background rejection

- ***Vertex separation $d(v_1v_2) > 15$ cm***

Polarized Λ decay (Λ rest frame)

Λ^0 is "self analyzing" particle due to its parity violation decay

$$\Lambda^0 \to p + \pi^-$$

Proton angular distribution

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p}(1 + \alpha P_\Lambda \cos\theta_p)$$

$$\alpha = 0.642 \text{ for } \Lambda$$

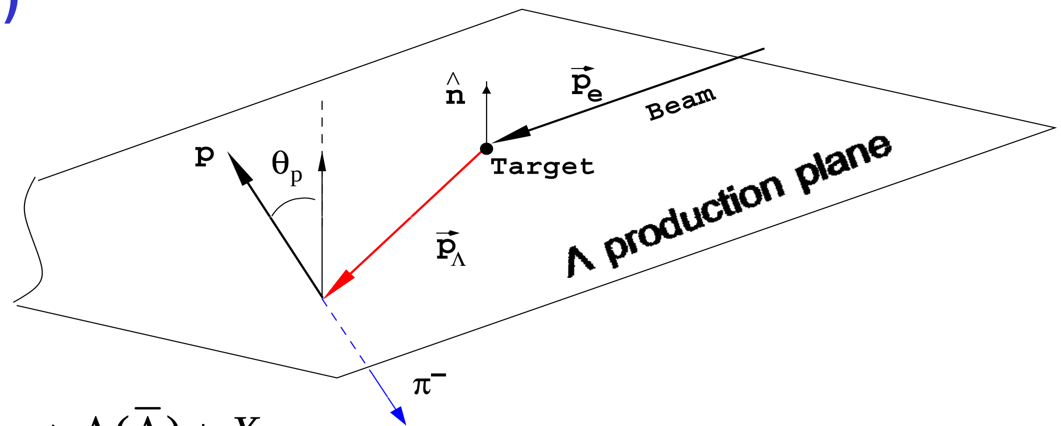
$$\alpha = -0.642 \text{ for } \overline{\Lambda}$$

θ_p **- angle between proton momentum in the Λ rest frame and the Λ polarization vector**

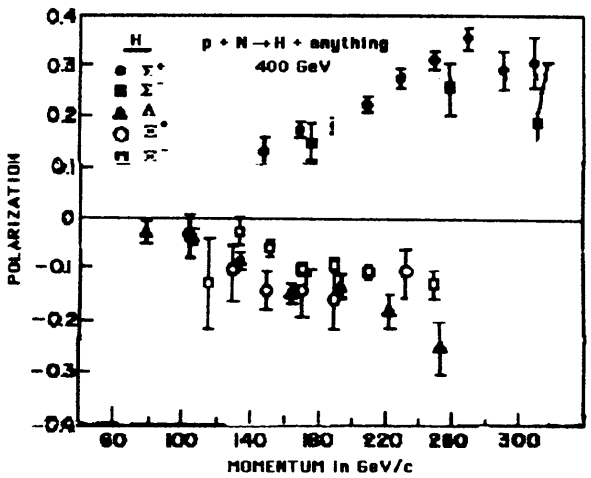
Spontaneous transverse Λ polarization

Λ is polarized $\perp$ to the reaction plane (neither beam nor target polarized)

$$\overrightarrow{P_\Lambda} = P_\Lambda \cdot \vec{n}, \quad \vec{n} = \frac{\vec{p}_e \times \vec{p}_\Lambda}{\left|\vec{p}_e \times \vec{p}_\Lambda\right|}$$

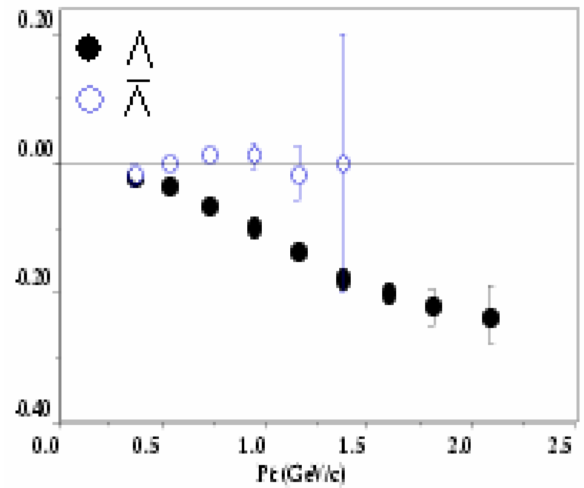


$p + N \to Y\uparrow + X$

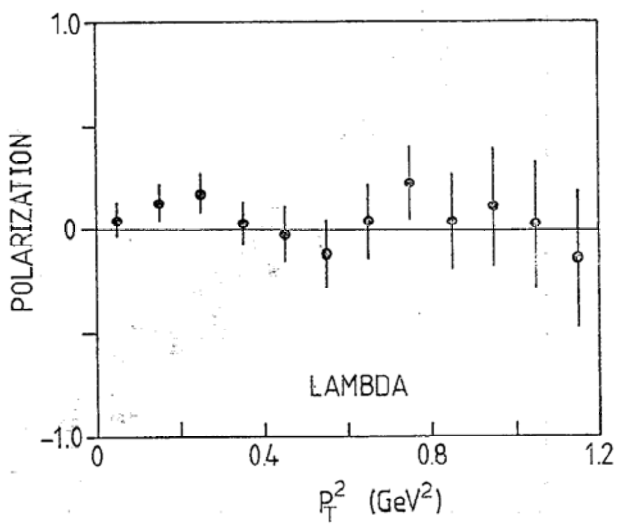


$p + Be \to \Lambda(\bar{\Lambda}) + X$,

FNAL E440



$\gamma p \to \Lambda X$, CERN



Extraction of the polarization

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p}(1+\alpha P_\Lambda \cos\theta_p) \quad \Rightarrow \quad \langle\cos\theta_p\rangle = \frac{\langle\cos\theta_p\rangle_0 + \alpha P_n^{\Lambda}\langle\cos^2\theta_p\rangle_0}{1+\alpha P_n^{\Lambda}\langle\cos\theta_p\rangle_0}$$

$\langle\cos\theta_p\rangle_0, \langle\cos^2\theta_p\rangle_0$ – avareges over unpolarized Λ data set, not known

up / down symmetry

$$P_n^{\Lambda} = \frac{1}{a}\cdot\frac{c_+ / \langle\cos^2\theta_p\rangle}{1-\langle\cos\theta_p\rangle_0^{top} c_- / \langle\cos^2\theta_p\rangle} \approx \frac{\langle\cos\theta_p\rangle}{\alpha\langle\cos^2\theta_p\rangle}$$

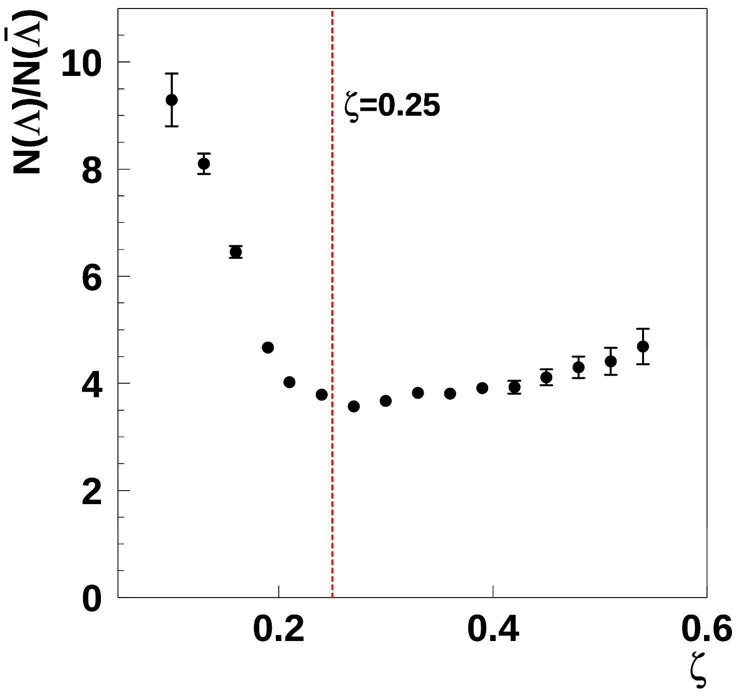
$$\langle\cos\theta_p\rangle_0^{top} = \frac{c_-}{1-c_+\alpha P_n^{\Lambda}}$$

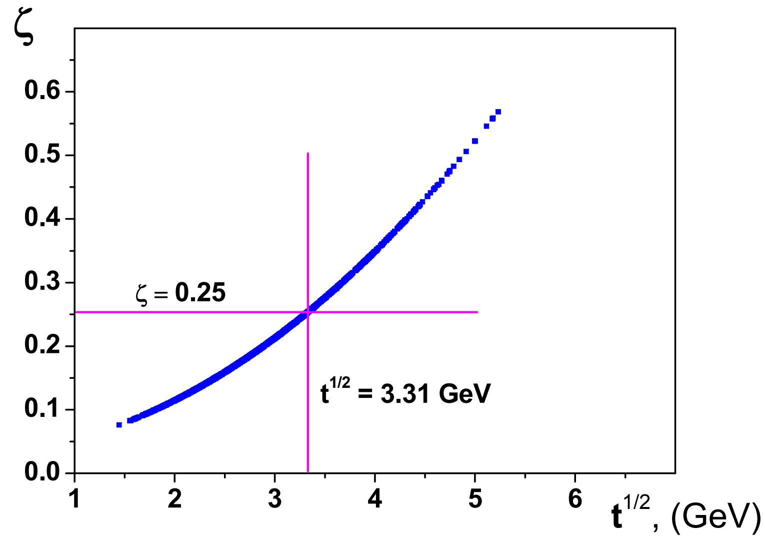
$$2c_- = \langle\cos\theta_p\rangle^{top} - \langle\cos\theta_p\rangle^{bot}$$

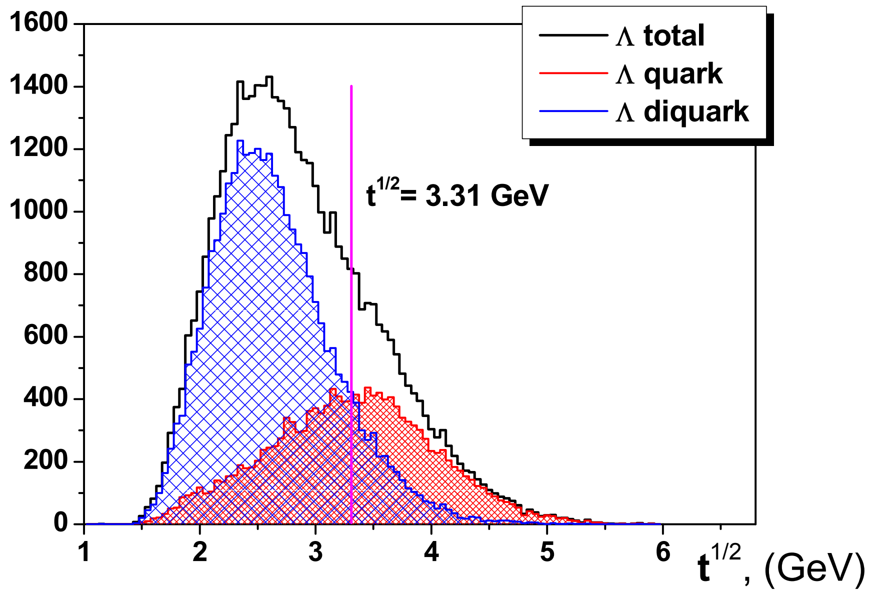
$$2c_+ = \langle\cos\theta_p\rangle^{top} + \langle\cos\theta_p\rangle^{bot}$$

Kinematic regimes

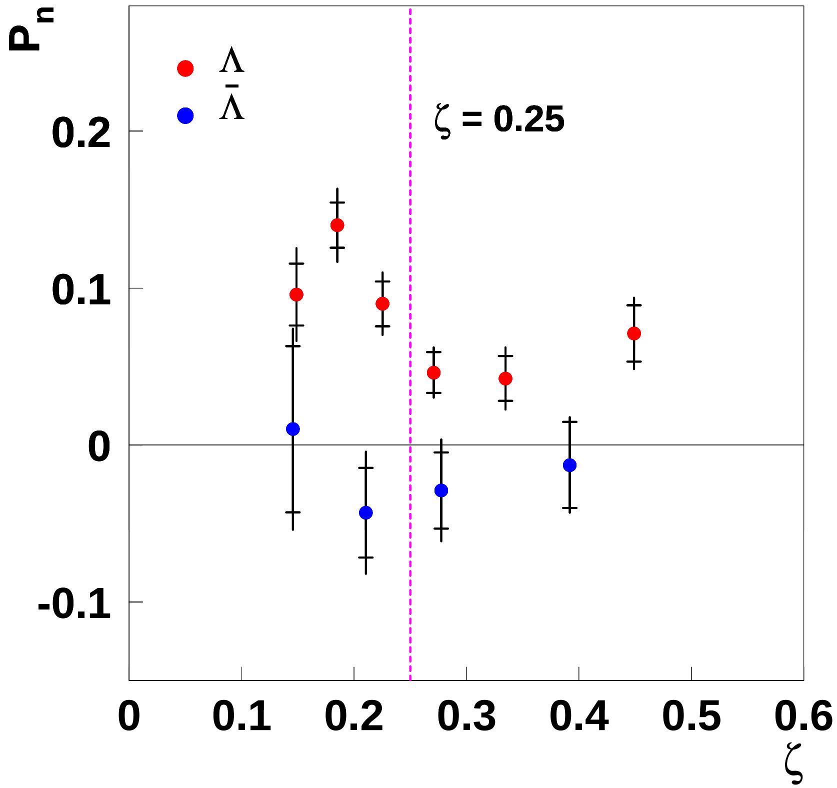
HERMES data







For *ζ < 0.25* (*$t^{1/2}$ < 3.31*)
target diquark fragmentation is
dominating



$$N(\Lambda) = 259 \cdot 10^3$$

$$P_{\Lambda} = 0.078 \pm 0.006(stat) \pm 0.012(syst)$$

***Positive* and statistically significant**

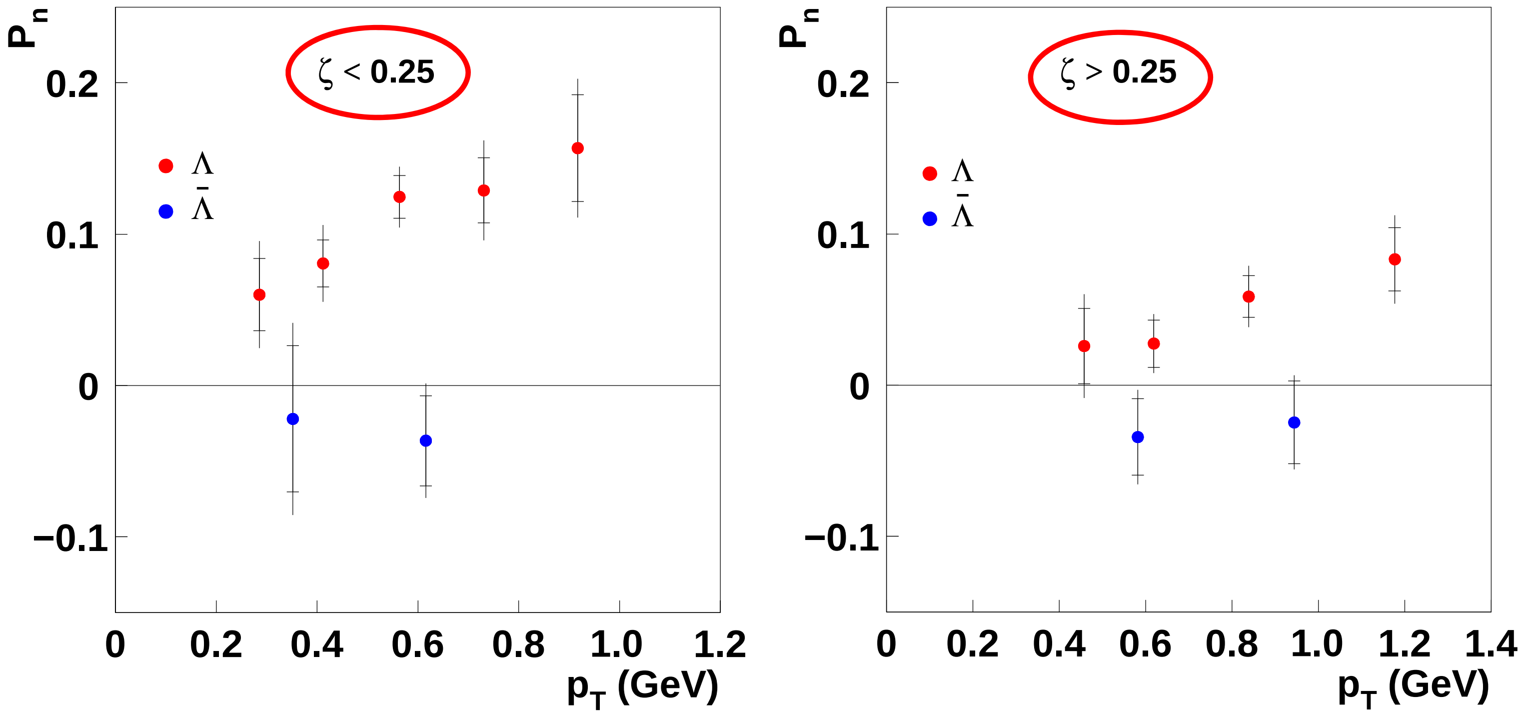
$$N(\bar{\Lambda}) = 51 \cdot 10^3$$

$$P_{\bar{\Lambda}} = -0.025 \pm 0.015(stat) \pm 0.018(syst)$$

consistent with zero

Transverse Λ polarization is large at ζ < 0.25

/ diquark fragmentation mechanism? /



Λ polarization rises linearly with p_T in both regions, effect is most pronounced at $\zeta < 0.25$

$\bar{\Lambda}$ compatible with zero

Longitudinal spin transfer in photoproduction

$P_{\Lambda}^{L'} = K_{LL'} P_{\text{Targ}}$

$K_{LL'}$ – spin transfer from longitudinally polarized proton to Λ

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p}(1 + \alpha K_{LL'} P_{\text{Targ}} \cos\theta_p)$$

$\Downarrow$

Using two data sets with opposite target polarization

$\Downarrow$

$$K_{LL'}^{\Lambda} = \frac{1}{\alpha} \cdot \frac{\langle P_{\text{Targ}} \cos\theta_{pL'} \rangle}{\langle P_{\text{Targ}}^2 \rangle \langle \cos^2\theta_{pL'} \rangle}$$

Primary axis L is selected:

- Along target polarization

Secondary axis L' is selected:

- Along Λ momentum direction

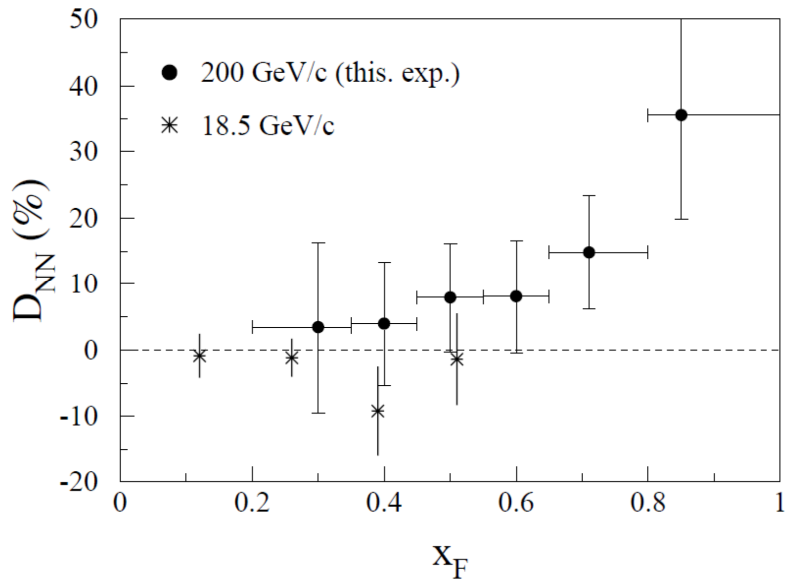
$$\frac{1}{L}\int P_{\text{Targ}}\, dL = 0, \quad L = \int dL$$

Longitudinal spin transfer, world data

Hadron-hadron collisions
with transversely polarized beam

$p + p \rightarrow \Lambda + X$, FNAL E704

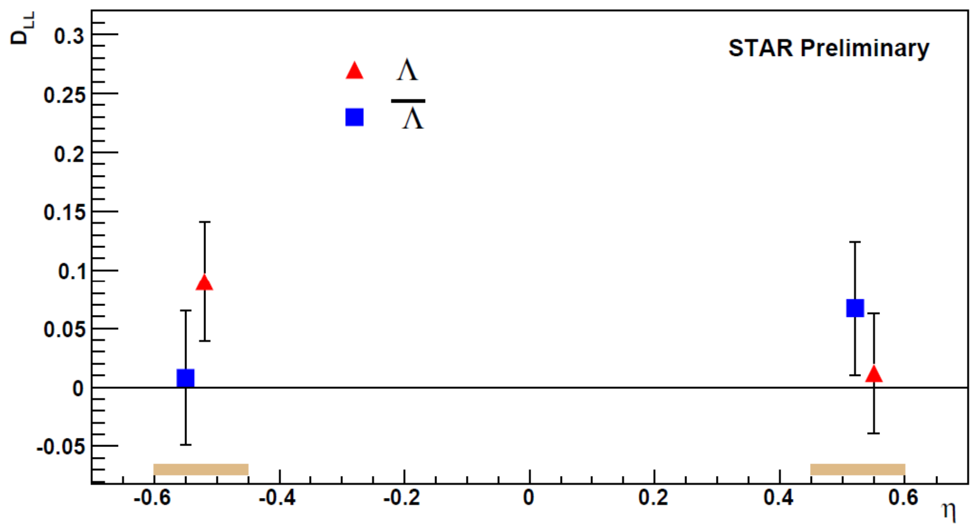
$E_p = 200\,\text{GeV}$

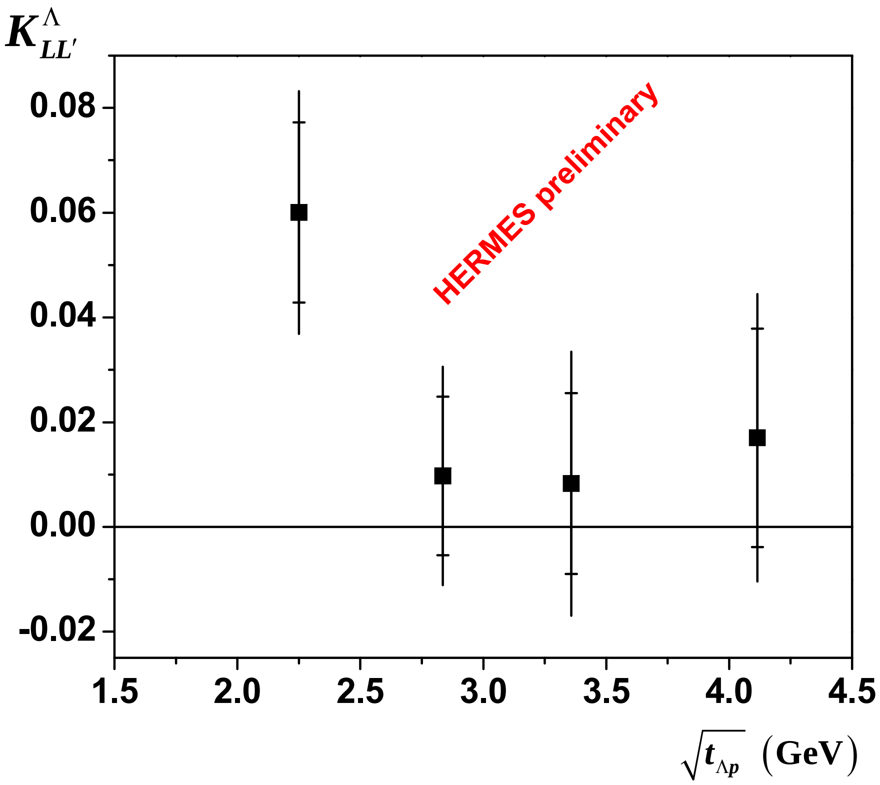


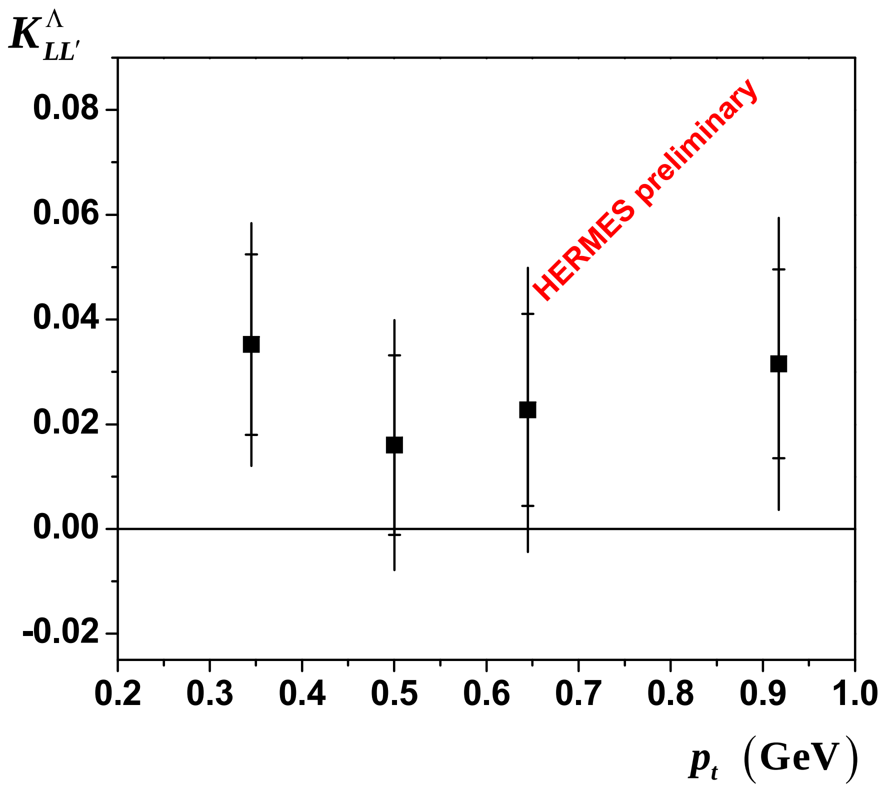
Hadron-hadron collisions
with longitudinally polarized beam

$p + p \rightarrow \Lambda(\bar{\Lambda}) + X$, STAR at RHIC

$\sqrt{s} \simeq 200$ GeV, $\eta = \tanh^{-1}\left(\frac{p_{z\Lambda}}{p_\Lambda}\right)$



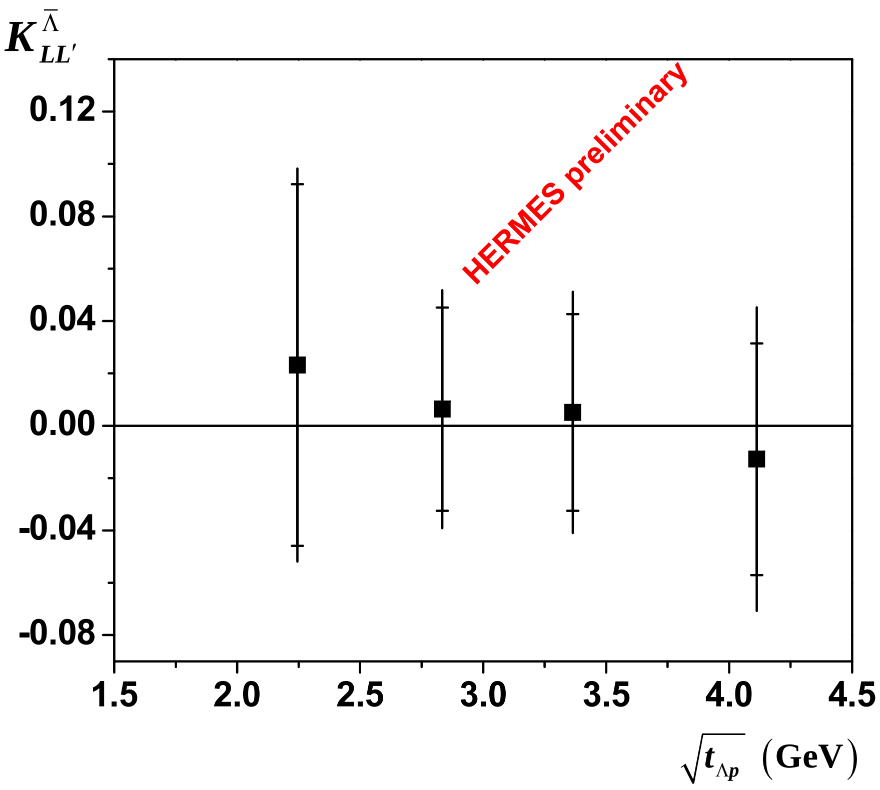


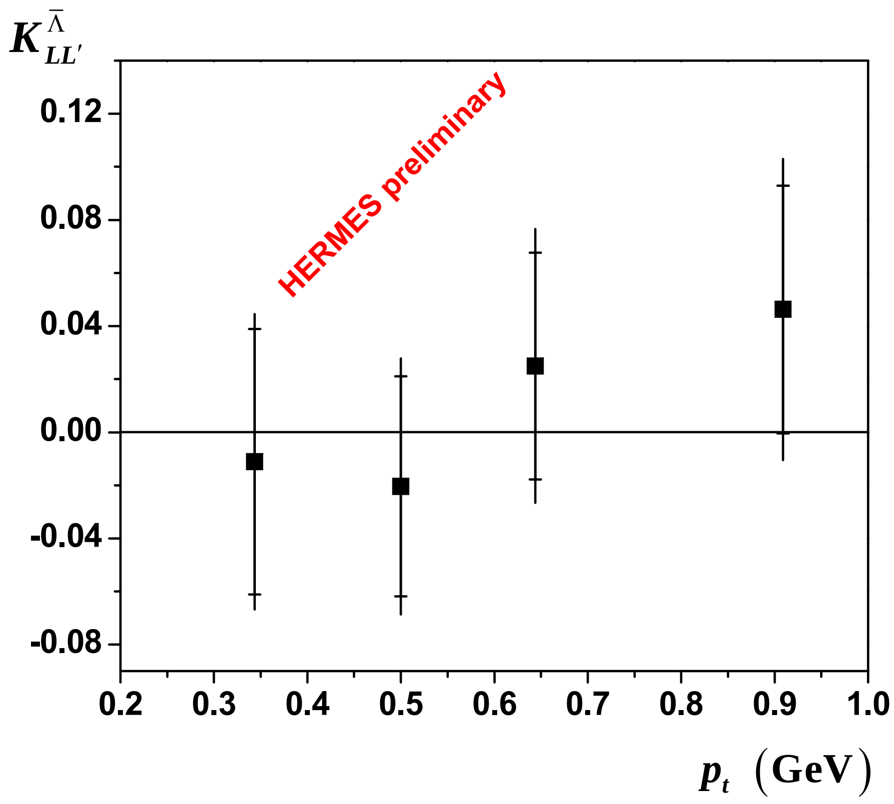


$$N(\Lambda) = 126 \cdot 10^3$$

$$K^{\Lambda}_{LL} = 0.026 \pm 0.009(stat) \pm 0.005(syst)$$

Spin transfer for Λ is increasing for small t (diquark fragmentation) and p_t independent (0 < p_t < 1.2 GeV)



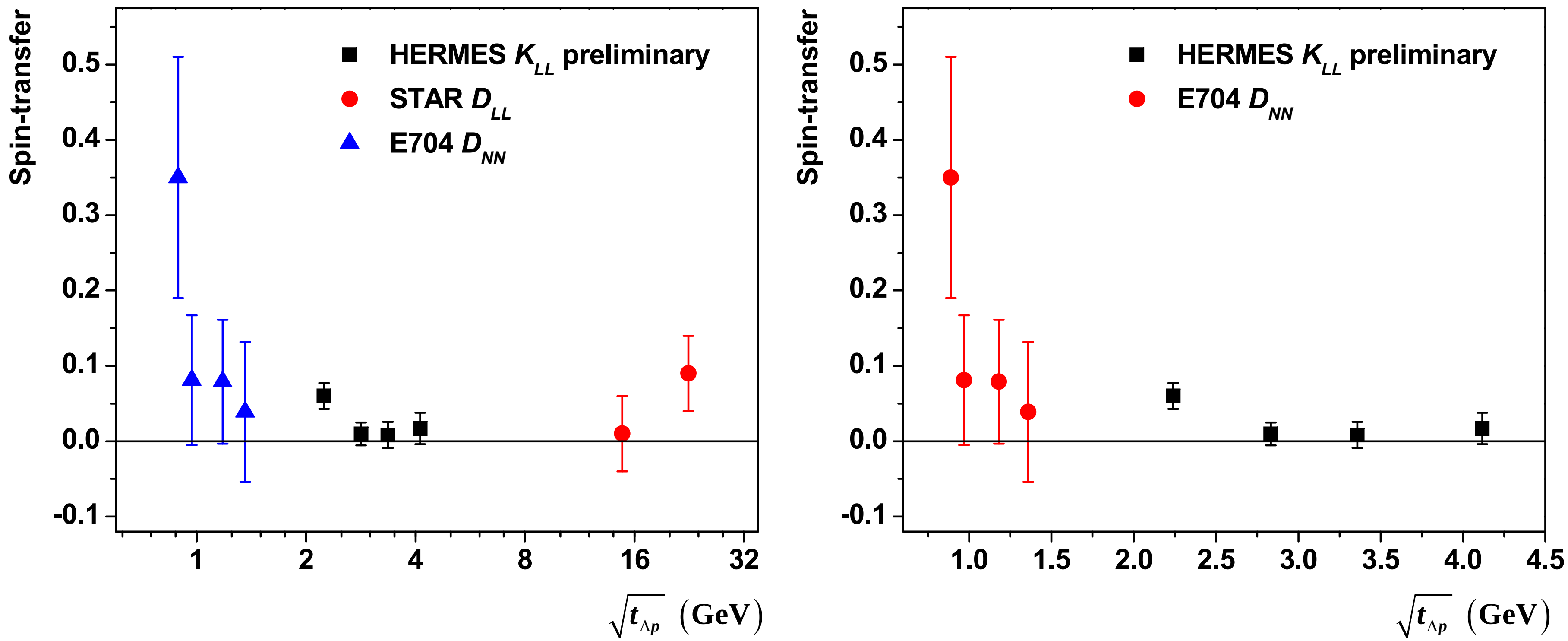


$$N(\bar{\Lambda}) = 25 \cdot 10^3$$

$$K_{LL}^{\bar{\Lambda}} = 0.002 \pm 0.022(stat) \pm 0.008(syst)$$

Spin transfer for $\bar{\Lambda}$ no depended from t and p_t, (small statistic)

World data compilation for spin transfer



FNAL result confirmed the trend to increasing spin transfer at small t !

Conclusion

- *Transverse Λ ($\bar{\Lambda}$) polarization in quasi-real photoproduction is found to be positive for Λ and compatible with zero for $\bar{\Lambda}$*

  $$P_{\Lambda} = 0.078 \pm 0.006\ (stat) \pm 0.012\ (syst)$$

  $$P_{\bar{\Lambda}} = -0.025 \pm 0.015\ (stat) \pm 0.018\ (syst)$$

- *As expected, the measured transverse Λ polarization rises linearly with p_T*
- *The transverse polarization is larger for $\zeta < 0.25$ where diquark fragmentation dominates*
- *Longitudinal spin transfer for Λ is found to be positive and for $\bar{\Lambda}$ compatible with zero*

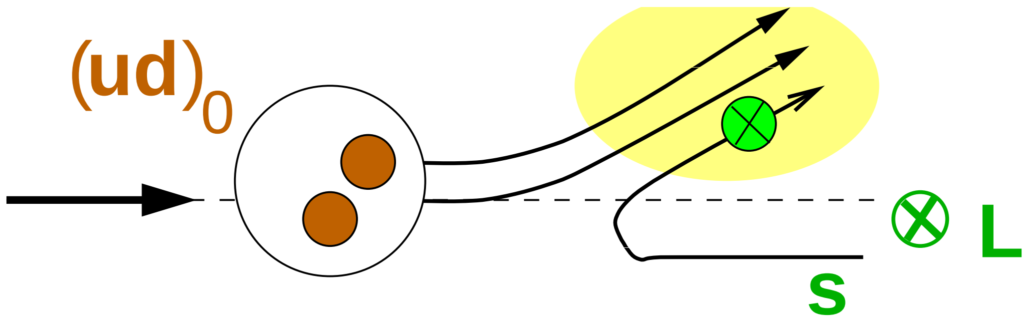
  $$K_{LL}(\Lambda) = 0.026 \pm 0.009\ (stat) \pm 0.005\ (syst)$$

  $$K_{LL}(\bar{\Lambda}) = 0.002 \pm 0.022\ (stat) \pm 0.008\ (syst)$$

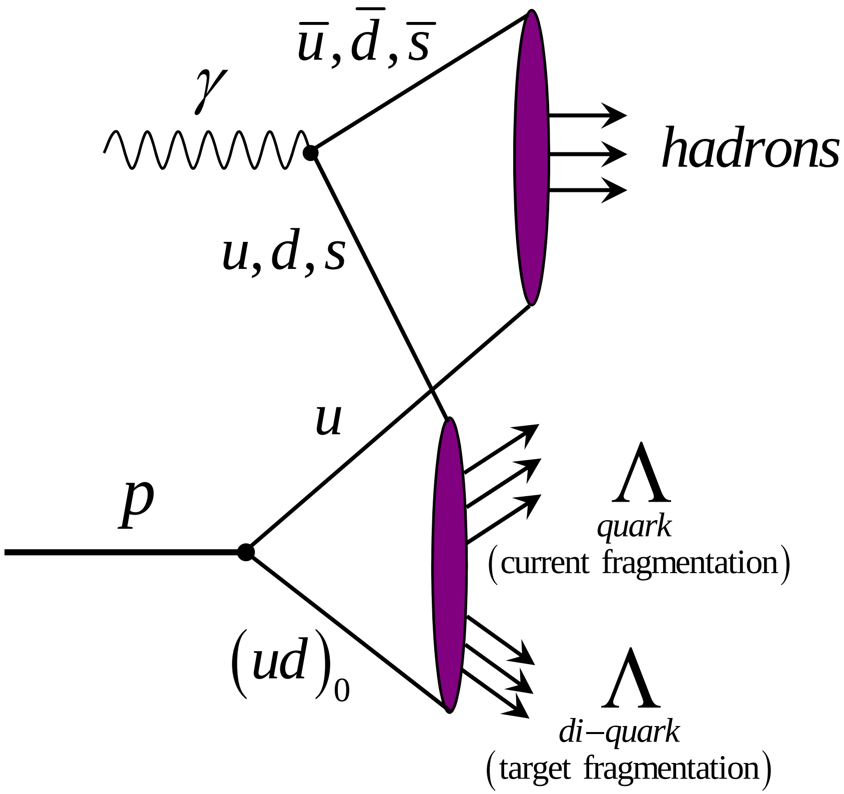
- *The spin transfer is increasing for small t*
- *The measured spin transfer is p_t independent*

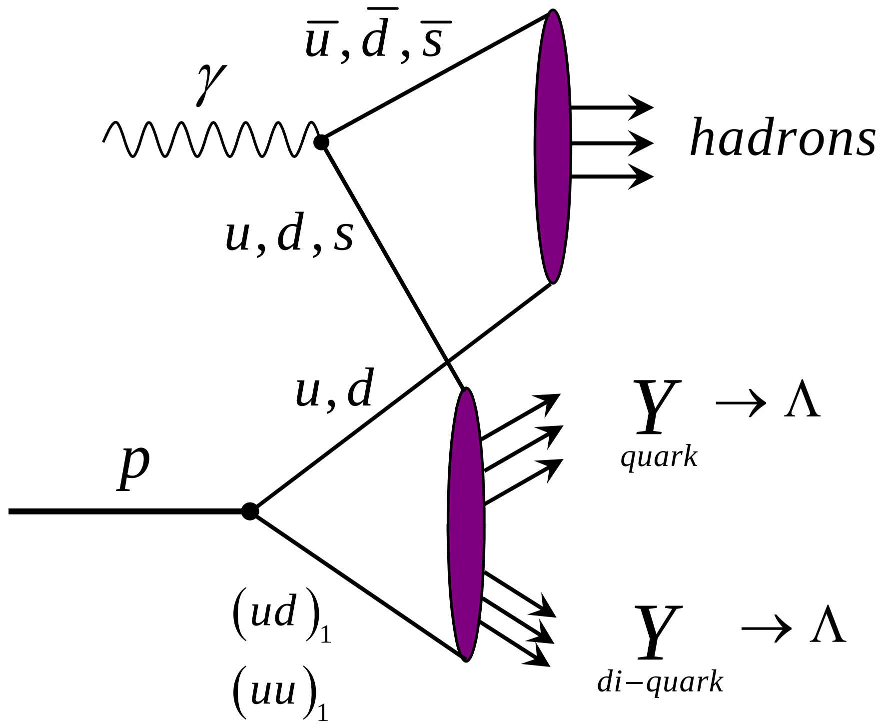
Idea: ***Thomas precession in an attractive potential*** creates a 'spin-orbit' force that tries to align *L and S of an* accelerating quark/diquark.

Λ**: Δ*s = +1 P*Λ *from accelerated sea s quark***



Typical PYTHIA mechanism of Λ production





direct Λ production

(51.1%)

Λ from hyperon decay

$$\underbrace{\begin{array}{l|l|l} \Sigma^0 \Rightarrow \Lambda^0\gamma & \Sigma^{*+} \Rightarrow \Lambda^0\pi^+ & \Sigma^{*0} \Rightarrow \Lambda^0\pi^0 \\ \Xi^0 \Rightarrow \Lambda^0\pi^0 & \Xi^- \Rightarrow \Lambda^0\pi^- & \Sigma^{*-} \Rightarrow \Lambda^0\pi^- \end{array}}_{48.9\%}$$

Results averaged over the kinematics

$$N(\Lambda) = 126 \cdot 10^3$$

$$N(\bar{\Lambda}) = 25 \cdot 10^3$$

$$K_{LL}^{\Lambda} = 0.026 \pm 0.009(stat) \pm 0.005(syst)$$

Positive and statistically significant

$$K_{LL}^{\bar{\Lambda}} = 0.002 \pm 0.022(stat) \pm 0.008(syst)$$

consistent with zero

false polarization:

$$K_{LL}^{h^+h^-} = -0.0005 \pm 0.0028 \qquad K_{LL}^{K_S} = 0.006 \pm 0.008$$

Results averaged over the kinematics

$$N(\Lambda) = 259 \cdot 10^3$$

$$N(\bar{\Lambda}) = 51 \cdot 10^3$$

For Λ

$$P_\Lambda = 0.078 \pm 0.006(stat) \pm 0.012(syst)$$

Positive and statistically significant

For $\bar{\Lambda}$

$$P_{\bar{\Lambda}} = -0.025 \pm 0.015(stat) \pm 0.018(syst)$$

consistent with zero

False polarization studied using h^+h^- pair and K_s data samples:

Λ *case (leading* π^+, h^+*)*

$$P_{K_s} = 0.012 \pm 0.004$$

$$P_{h^+h^-} = 0.012 \pm 0.002$$

$\bar{\Lambda}$ *case (leading* π^-, h^-*)*

$$P_{K_s} = 0.002 \pm 0.004$$

$$P_{h^+h^-} = 0.018 \pm 0.002$$