# *Lambda polarization at HERMES*

**Yu. Naryshkin (PNPI)**

**On behalf of the HERMES collaboration**

**IX International Conference on Hyperons, Charm and Beauty Hadrons**
**21-26 June 2010, Aula Magna, University of Perugia**
**Perugia, Italy**

# $\Lambda$ production and polarization study at HERMES

Semi-inclusive $\Lambda$ and $\Lambda$-bar production ($Q^2 > 0.8$ GeV$^2$ )

- Multiplicity $n^{\Lambda}(z)$, $n^{\Lambda}(p_T)$ and fragmentation function $D_u^{\Lambda}(z)$
- Spin transfer $D_{LL}'$ from the longitudinally polarized beam
  A. Airapetian et al., Phys.Rev.D64,2001; A. Airapetian et al., Phys.Rev.D74,2006.

  Full statistics result for $\Lambda$ and for $\Lambda$-bar to be published
  ($D_{LL}' = 0.187 \pm 0.040$stat. $\pm 0.020$syst. )

Quasi-real photoproduction ($Q^2 \sim 0$ GeV$^2$ )

- heavy hyperon yields of $\Sigma_0$, $\Sigma(1385)$, $\Xi$
- Spin transfer $K_{LL}'/K_{NN}'$ from longitudinally/ transversely polarized target
  ($K_{LL}' = 0.024 \pm 0.008$stat. $\pm 0.003$syst. Fotr $\Lambda$ and $K_{LL}' = 0.002 \pm 0.019$stat. $\pm 0.003$syst. For $\Lambda$-bar )
- Transverse (spontaneous) $\Lambda$, $\Lambda$–bar polarization $P_n$
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- A-dependence of the transverse $\Lambda$ polarization $P_n$
  (publication in progress)

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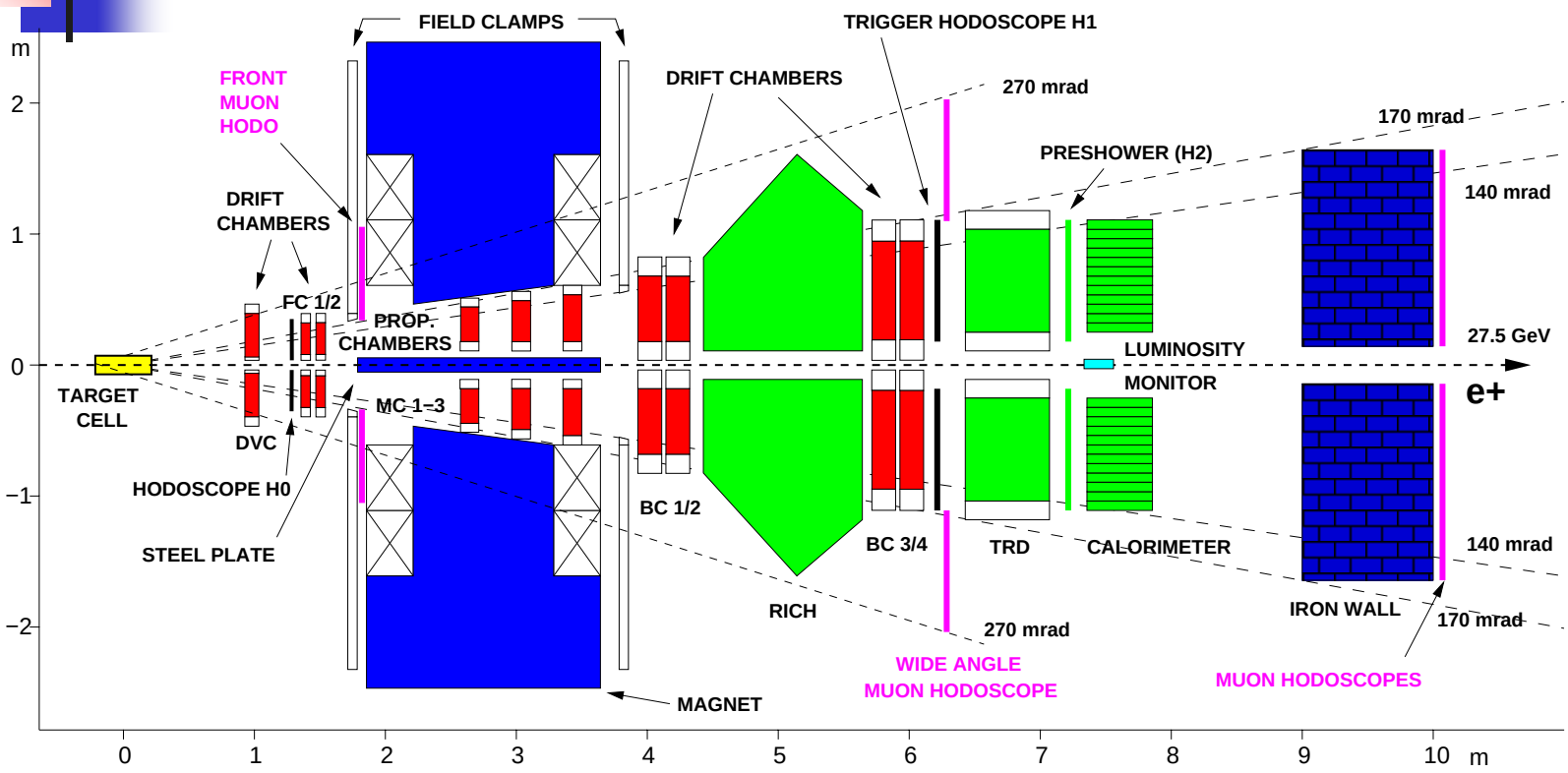
# HERMES experiment

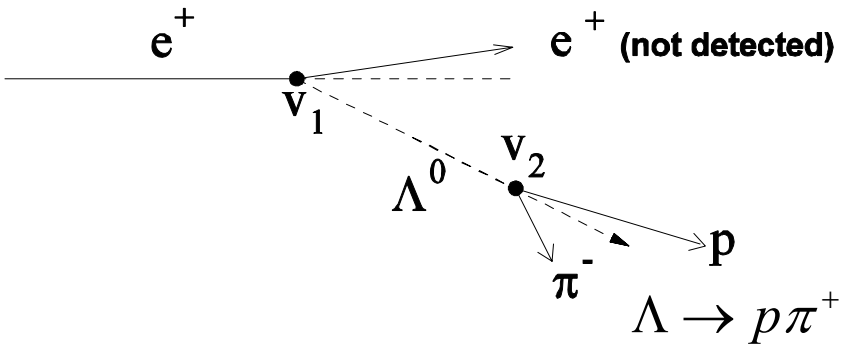



- *polarized positron (and electron) beam $E_e$ = 27.5 GeV,*
- *average beam polarization $P_b$~45%*
  *beam helicity is reversed about monthly*
- *polarized and unpolarized internal gas targets: H, D, He, Ne, N, Kr, Xe*
- *up/down symmetric (important for transverse $\Lambda$ polarization)*

# Reconstruction of Λ events

**Quasi-real photoproduction, $Q^2$ <0.05 GeV$^2$ for 80% of the events (MC)**

$\langle E_\gamma \rangle$ =15.6 GeV

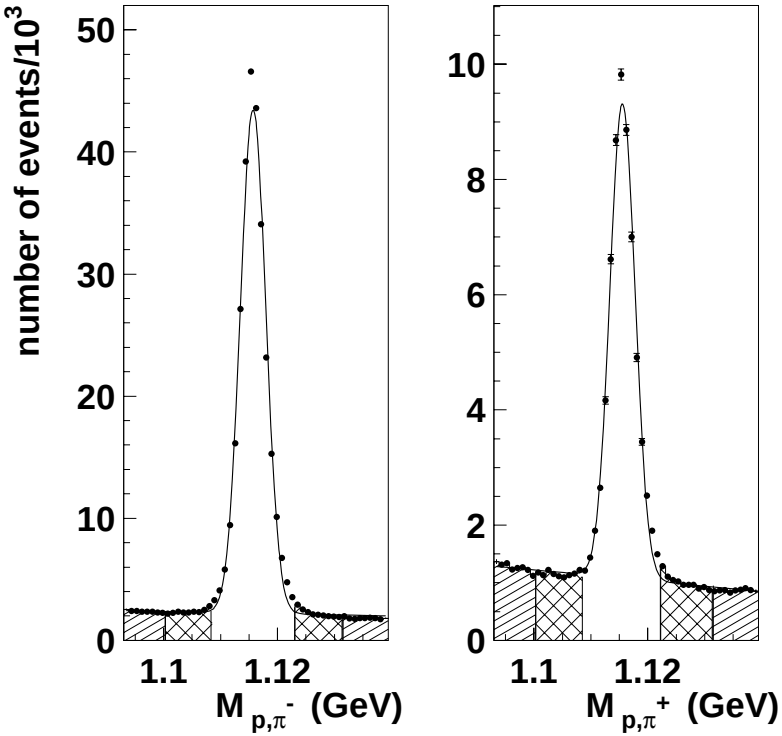



**Background suppression cuts:**

Threshold Cherenkov / Ring imaging Cherenkov detector

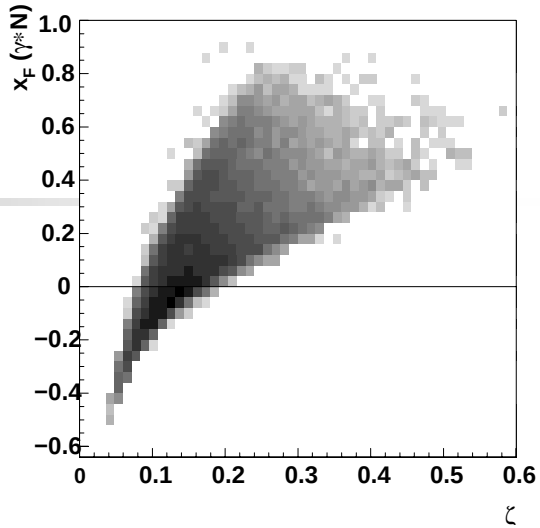
$z_2 - z_1 > 15\,cm$ *for* $\Lambda$

$z_2 - z_1 > 20\,cm$ *for* $\overline{\Lambda}$

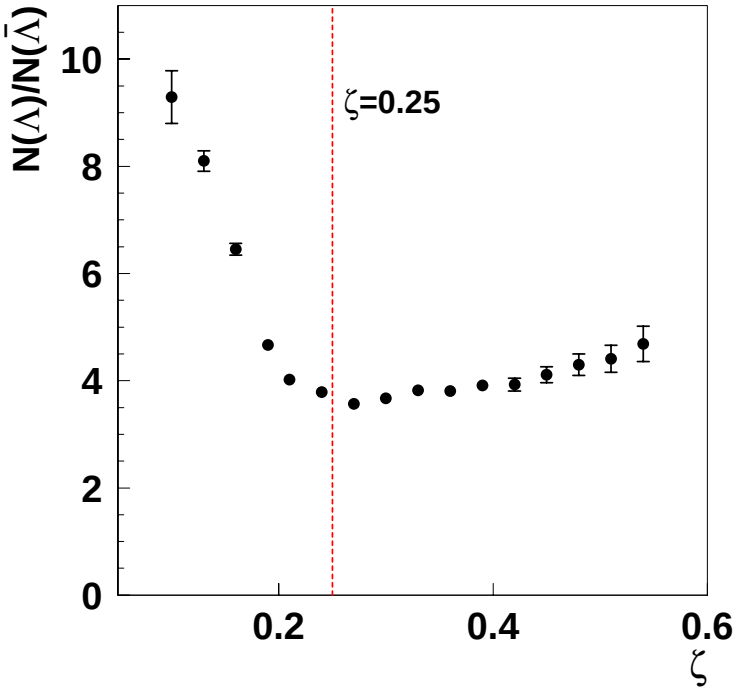


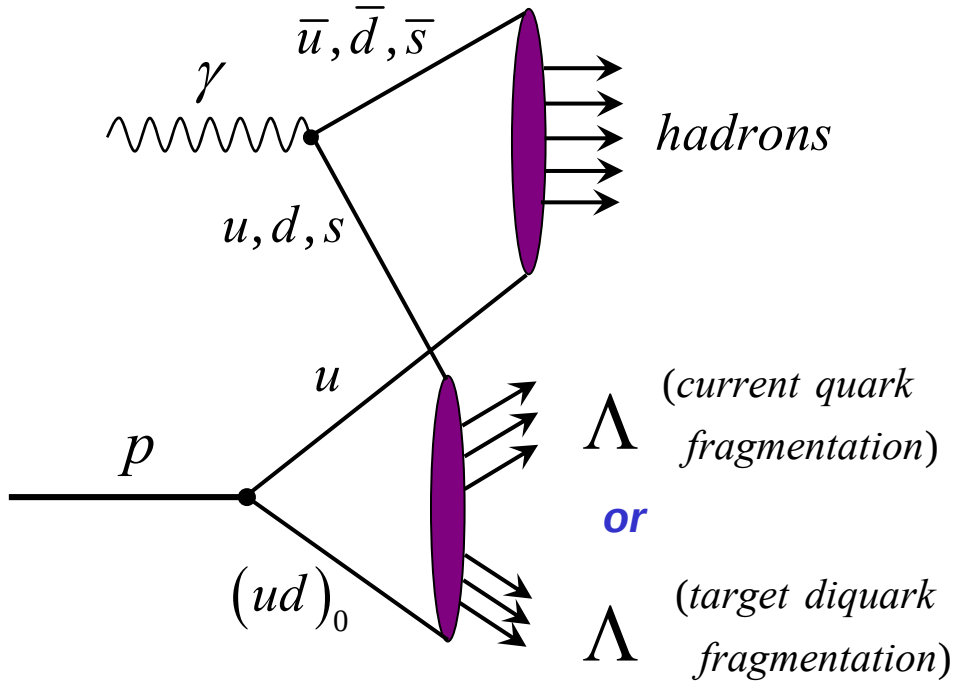
# Kinematic regimes

$$x_F = \frac{p_{\parallel}}{p_{\parallel \max}} \Rightarrow \zeta = \frac{E_\Lambda + p_{\Lambda,z}}{E_e + p_{e,z}}$$




**HERMES data**



# *Polarized Λ- decay decay (Λ rest frame)*

**$\Lambda^0$ is "self analyzing" particle due to its parity violation decay:**

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

**Angular distribution of proton from $\Lambda^0$ decay is:**

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

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

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

$\theta_p$ **is the angle between proton momentum in the Λ rest frame and the Λ polarization**

# Transverse Λ polarization

Quasi-real photoproduction: $e + N \Rightarrow \Lambda\uparrow + X$ at 27.6 GeV

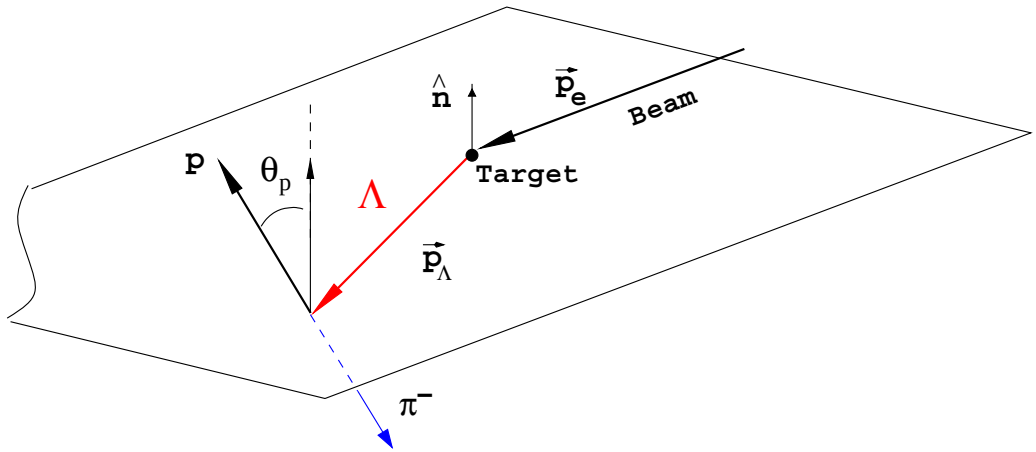
Transverse $\Lambda$ polarization is directed along $\hat{n} = \dfrac{\vec{p}_e \times \vec{p}_\Lambda}{|\vec{p}_e \times \vec{p}_\Lambda|}$

(neither beam nor target is polarized )

$$\vec{P}_\Lambda = P_\Lambda \cdot \hat{n}$$

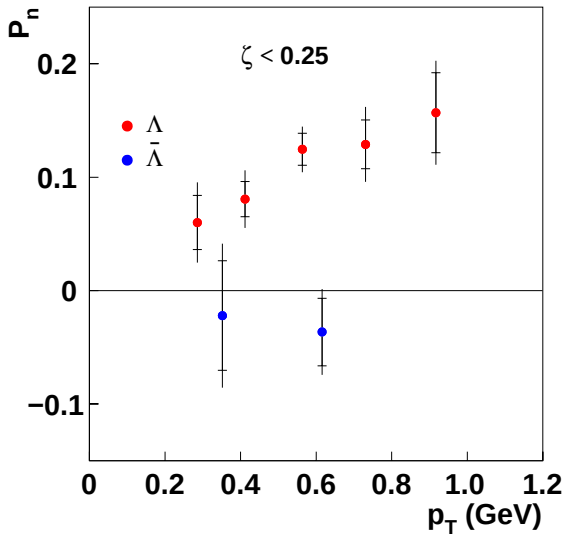
Formalism of $\Lambda$ polarization extraction is based on up/down mirror (geometrical) symmetry of the detector

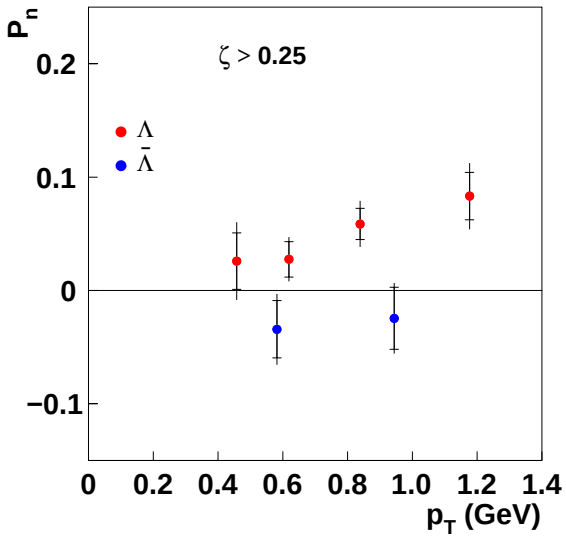
No Monte-Carlo simulations of the spectrometer is used

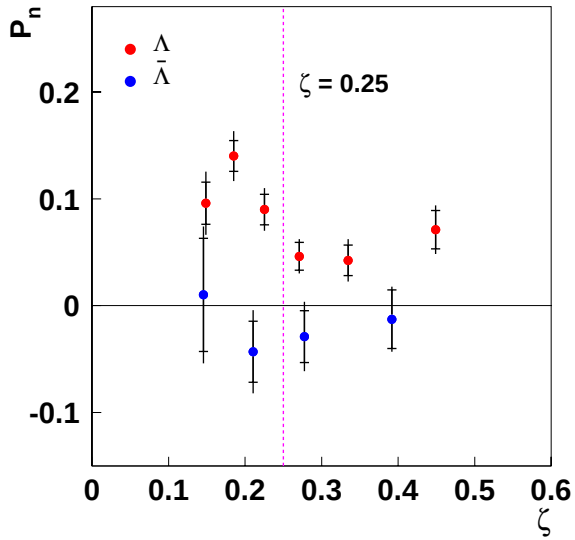



$$P_\Lambda = \frac{<\cos\theta_p>}{\alpha <\cos^2\theta_p>} = \frac{\frac{1}{N_\Lambda}\sum_{i=1}^{N_\Lambda}\cos\theta_p}{\alpha\frac{1}{N_\Lambda}\sum_{i=1}^{N_\Lambda}\cos^2\theta_p}$$

# Kinematical dependences of the transverse Λ polarization



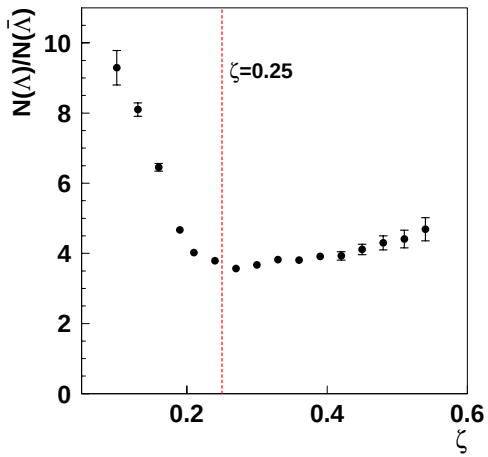

$$For \quad \Lambda$$

$$P_{\Lambda} = 0.078 \pm 0.006_{stat.} \pm 0.012_{syst.}$$

$$For \quad \bar{\Lambda}$$

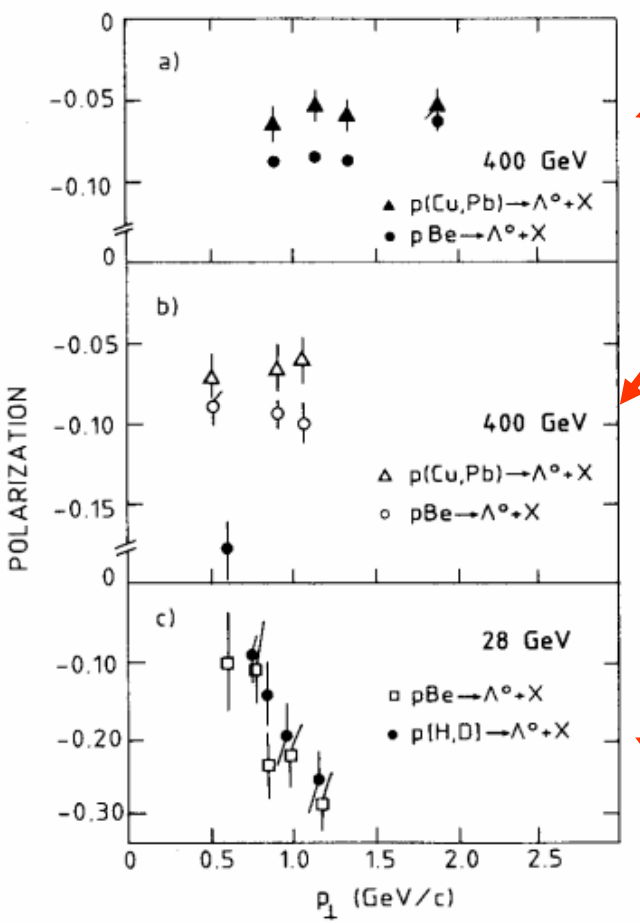
$$P_{\bar{\Lambda}} = -0.025 \pm 0.015_{stat.} \pm 0.018_{syst.}$$

***Systematic error determination: false polarization is studied using $h^+h^-$ pairs and $K_s$ data sample***




$$\zeta = \frac{E_{\Lambda} + p_{\Lambda,z}}{E_e + p_{e,z}}$$

# A-dependence in pA collisions

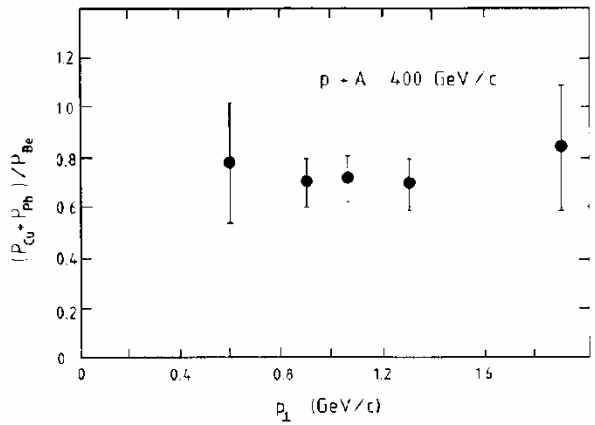



*Experiment @ FNAL*

$p\,A \rightarrow \Lambda\,X$

*(targets Cu, Pb, Be)*

$p_{beam} = 400$ *GeV*



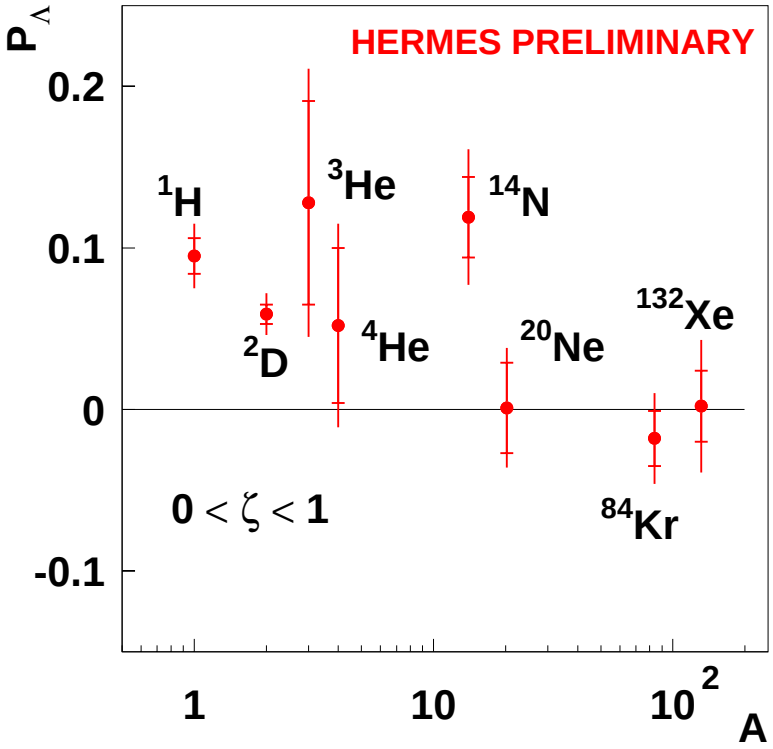

*Experiment @ BNL*

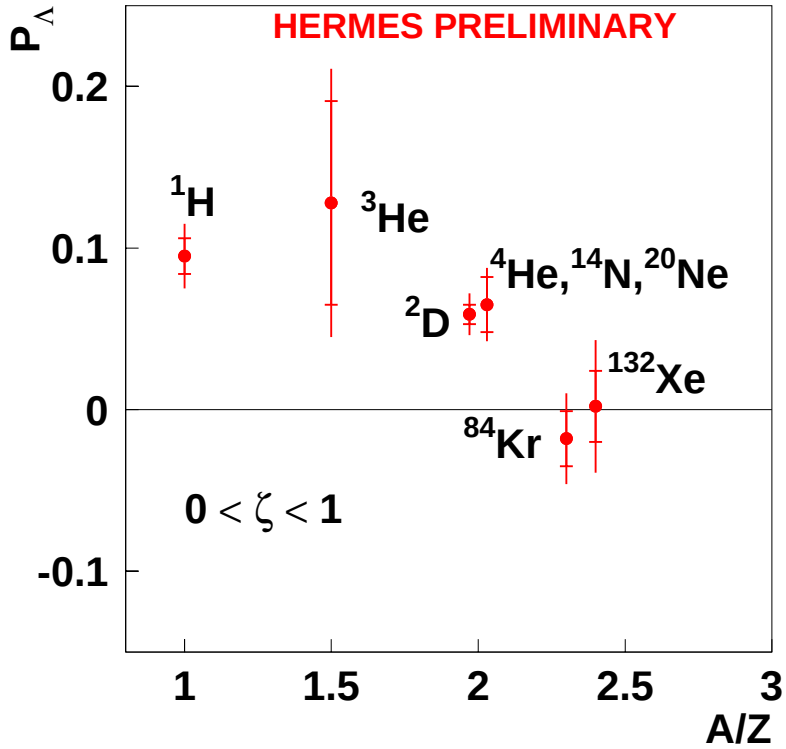
$p\,A \rightarrow \Lambda\,X$

*(targets H, D, Be)*

$p_{beam} = 28$ *GeV*

# *Nuclear effects: A, A/Z-dependence of Λ polarization*



# Conclusion

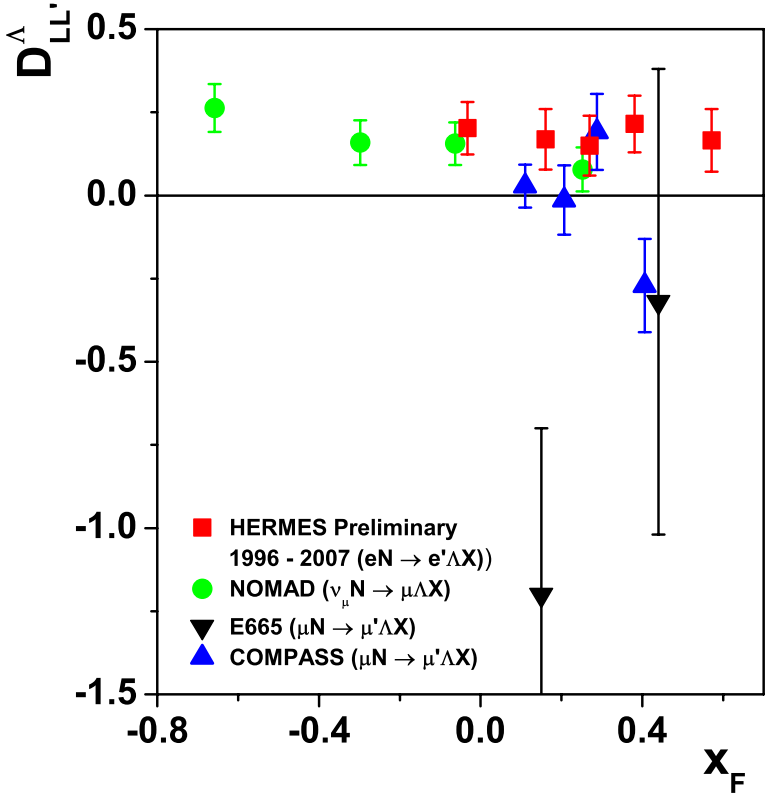
- *Transverse polarization in quasi-real photoproduction regime ( $Q^2 \sim 0$ GeV$^2$ and $\langle E_\gamma \rangle = 15.6$ GeV) is found to be:*
  *for $\Lambda$* $P_n = 0.078 \pm 0.006_{stat.} \pm 0.012_{syst.}$
  *and $\Lambda$-bar* $P_n = -0.025 \pm 0.015_{stat.} \pm 0.018_{syst.}$

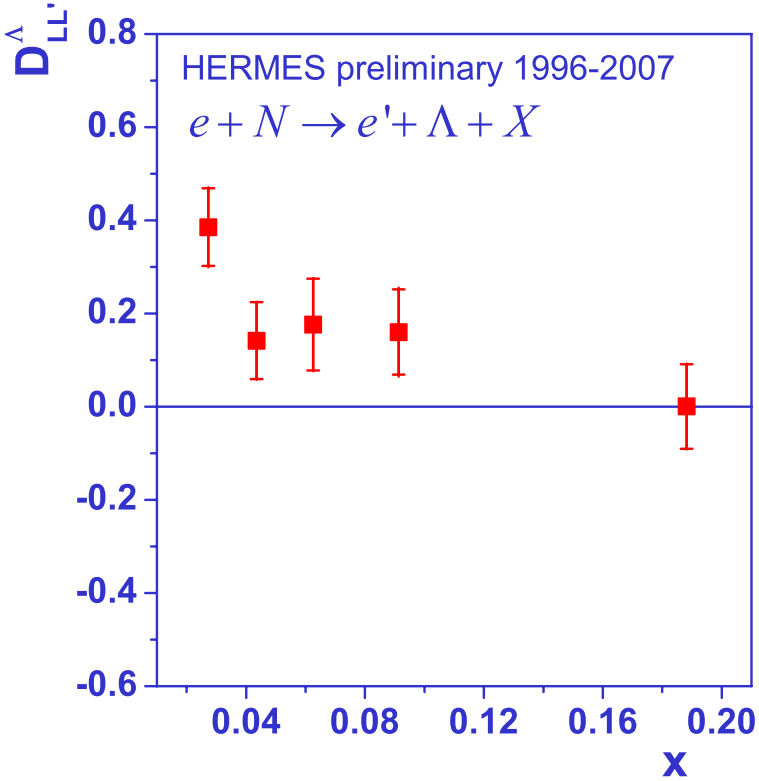
- *The polarization is large for $\zeta < 0.25$ where diquark fragmentation dominates*

- *A (A/Z) - dependence of $P_n$ was observed. For light nuclei it is positive ant statistically significant and for heavy nuclei $P_n$ is compatible with zero.*

# *Backup slides*

# HERMES and world results: $D_{LL'}$ vs $x_F$,$x_{bj}$




*76K* $\Lambda$'*s*

$$D_{LL'} = 0.187 \pm 0.040_{stat.} \pm 0.020_{syst.}$$

*(1996-2007)*

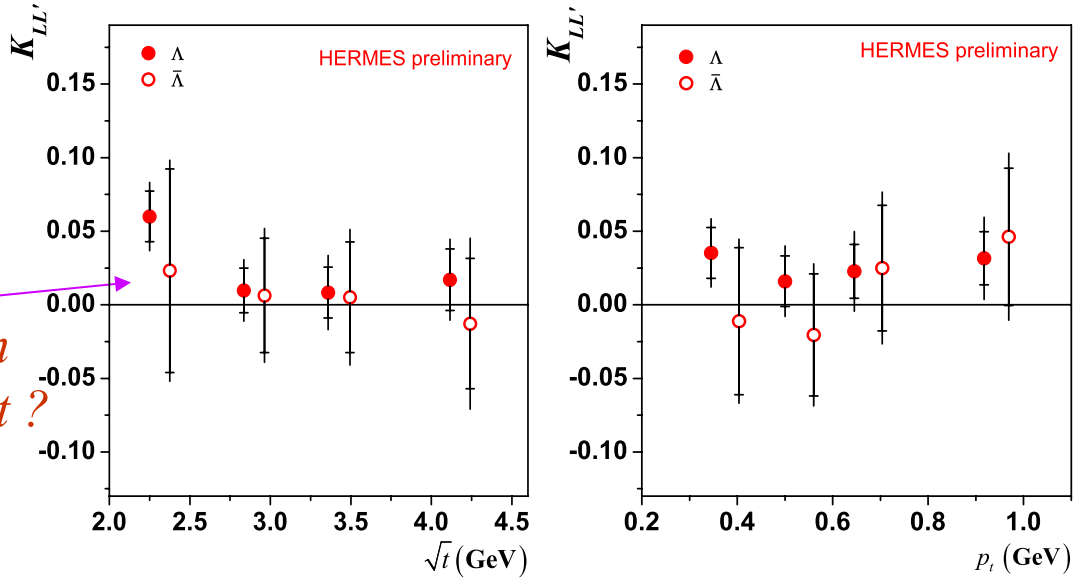
# Spin transfer $K_{LL'}$ from longitudinally polarized target to $\Lambda$ hyperon

$$\gamma + \vec{p}(\vec{n}) \rightarrow \vec{\Lambda} + X \quad \text{at} \langle E_\gamma \rangle = 15,6 \text{ GeV}$$

*(lepton is not detected)*

*for 80% of events*
$Q^2 < 0.05\ GeV^2$ *(MC)*

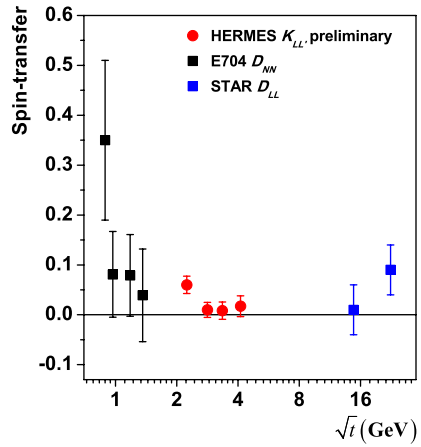
$K_{LL'} = 0.024 \pm 0.008_{stat.} \pm 0.003_{syst.}$ for $\Lambda$
$K_{LL'} = 0.002 \pm 0.019_{stat.} \pm 0.003_{syst.}$ for $\bar{\Lambda}$




*di-quark polarization in the target ?*

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

*World data*




*FNAL, E704*
*pp collisions with transversely polarized beam*
Phys. Rev. Lett., 78:4003–4006, 1997.

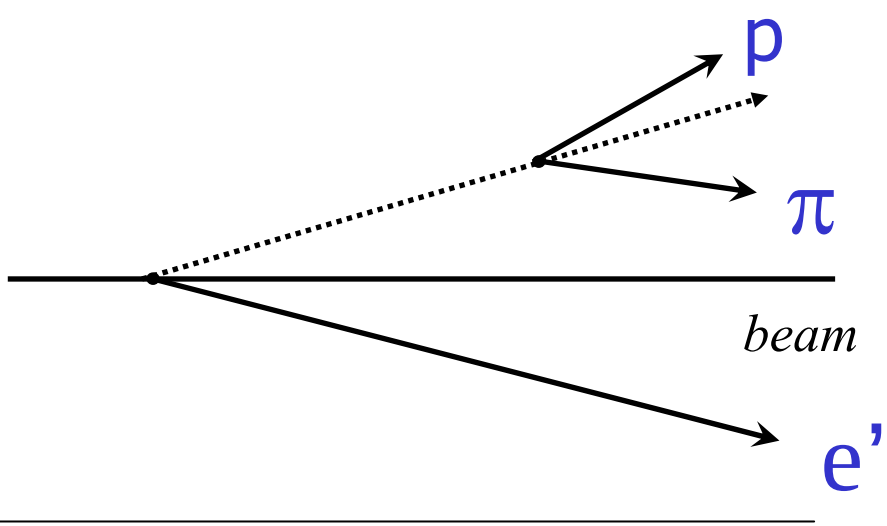
*RICH, STAR*
*pp collisions with longitudinally polarized beam.*
hep-ex/0612035

# Λ event topology, detection and kinematical variables

***Under study***

$e + p(d,A) \rightarrow e' + \Lambda(\bar{\Lambda}) + X$ *semi-inclusive DIS*

$e + p(d,A) \rightarrow \Lambda(\bar{\Lambda}) + X$ *inclusive Λ(Λ)*




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

$$\bar{\Lambda} \rightarrow \bar{p} + \pi^+$$

*always detected by HERMES spectrometer*

*detected* ➡ *DIS regime:*

$Q^2 > 0.8\ GeV^2 \quad x, y, z, x_F$

*not detected* ➡ *Quasi-real photoproduction regime:*

$Q^2 < 0.05\ GeV^2$, *for 80% of events*

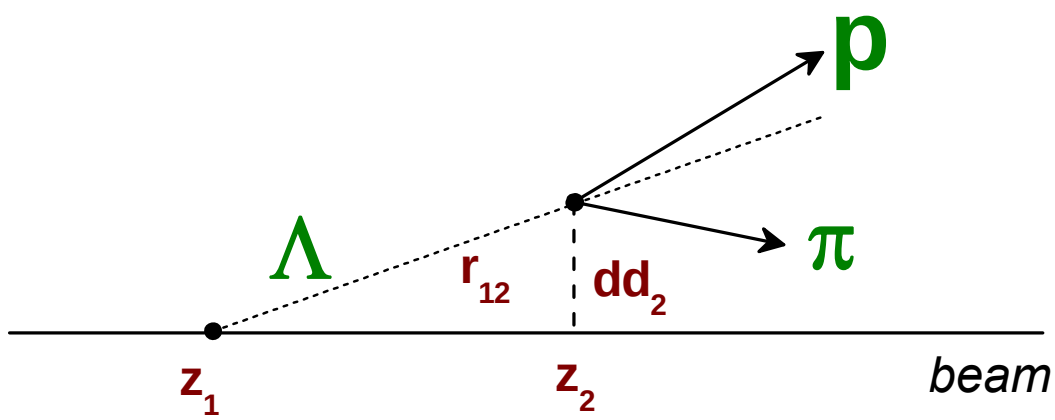
$t^2_{\Lambda p} = -(p_\Lambda - p_N)^2, \quad \zeta = \frac{E_\Lambda + p_{\Lambda z}}{E_e + p_e}, \quad p_{\Lambda T}$

$$x = \frac{Q^2}{2M\nu}, \quad y = \frac{\nu}{E_e} = \frac{E_e - E_{e'}}{E_e}, \quad z = \frac{E_\Lambda}{\nu}, \quad x_F = \frac{\tilde{p}^{\Lambda}_{\parallel}}{\tilde{p}^{\Lambda}_{\max}}$$

*SIDIS variables (lab. frame)*

# Event selection

- *HERA Run I: polarized and unpolarized targets*
- *HERA Run II: only unpolarized targets, no 2006-07 years data*
- *$-18 < z_1 < 25$ cm*
- *$d_2 < 1.5$ cm*
- *$-18 < z_2 < 130$ cm*
- *$1 < dd_2 < 18$ cm*
- *$p_\pi > 0.4$ GeV*




- *Leading particle is not a pion according to Cherenkov and RICH PID*
- *$z_2 - z_1 > 15$ cm*

# $\Lambda$ polarization measurement

$\Lambda^0$ polarization is "self analyzing" due to its parity violation decay:

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

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p}(1 + \alpha P^{\Lambda}_{L'} \cos\theta_{pL'})$$

$\alpha = 0.642$ **for** $\Lambda$ $(\alpha = -0.642$ **for** $\bar{\Lambda})$

$L' \to \Lambda$ *spin direction*

*Longitudinal spin transfer from beam/target*

$$P^{\Lambda}_{L'} = P^{\gamma^*}_{L} \cdot D^{\Lambda}_{LL'} \qquad P^{\Lambda}_{L'} = P_{L,t} \cdot K^{\Lambda}_{LL'}$$

$$P^{\gamma^*}_{L} = P_b D(y)$$

***Maximum likelihood method***

*Helicity balanced data sample* ⇒

$$D_{LL'} = \frac{\sum_{i=1}^{N} P_{b,i} D(y_i) \cos\theta^i_{pL'}}{\alpha \,\|\, P_b^2 \,\|\, \sum_{i=1}^{N} D^2(y_i) \cos^2\theta^i_{pL'}}$$

$$K^{\Lambda}_{LL'} = \frac{\sum_{i=1}^{N} P_{t,i} \cos\theta^i_{pL'}}{\alpha \,\|\, P_t^2 \,\|\, \sum_{i=1}^{N} \cos^2\theta^i_{pL'}}$$

*Systematic error determination: false polarization is studied using $h^+h^-$ pairs and $K_s$ data sample*

*It must be* $D_{LL}(h^+h^-) \Rightarrow 0, \quad D_{LL}(K_s) \Rightarrow 0$