Spin transfer coefficient $D_{LL'}$ to Λ hyperon

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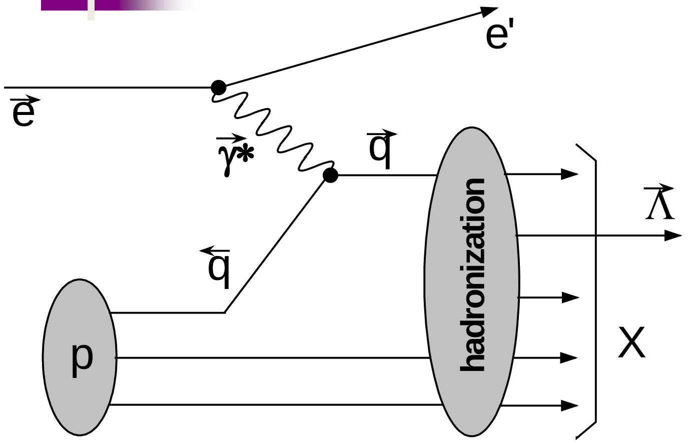
Content

Motivation

$$\Lambda^0 = (uds)$$

- **Constituent quark model (CQM)** $\Delta u = \Delta d = 0,\ \Delta s = 1$
  - *Fails for proton, what about Λ ?*
- **SU(3) flavor symmetry** $\Delta u = \Delta d = -0.09 \pm 0.06,\ \ \Delta s = 0.47 \pm 0.07$
  - *Used SU(3) rotation for proton data*
- **Burkard/Jaffe** $\Delta u = \Delta d = -0.23 \pm 0.06,\ \Delta s = 0.58 \pm 0.07$
  - *Also SU(3) rotation for proton data with $\Delta\overline{s} \equiv 0$ in proton*
- **Lattice QCD** $\Delta u = \Delta d = -0.02 \pm 0.04,\ \Delta s = 0.68 \pm 0.04$
  - *Breaking SU(3) symmetry*

Definition of $D_{LL'}$



$$\vec{\gamma}^* + p \rightarrow \vec{\Lambda} + X$$
$$\hookrightarrow p\pi^-$$

DIS regime
$\boldsymbol{Q^2 > 0.8\ \mathrm{GeV}^2}$

$$Q^2 = -(k-k')^2 \qquad \nu = E - E' \qquad x = \frac{Q^2}{2M\nu}$$

$$x_F = \frac{p_{\parallel}^{\Lambda}}{p_{\parallel,max}^{\Lambda}} \qquad y = \frac{\nu}{E} \qquad z = \frac{E_{\Lambda}}{\nu}$$

$$P_{L'}^{\Lambda} = P_L^{\gamma^*} \cdot D_{LL'}^{\Lambda} \qquad P_L^{\gamma^*} = P_B D(y) = P_L^q$$

$$D(y) = \frac{y(2-y)}{y^2 + 2(1-y)}$$

Purity

$$D_{LL'}^{\Lambda}(x,z) = \sum_f D_{LL',f}^{\Lambda}(z)\,\omega_f^{\Lambda}(x,z)$$

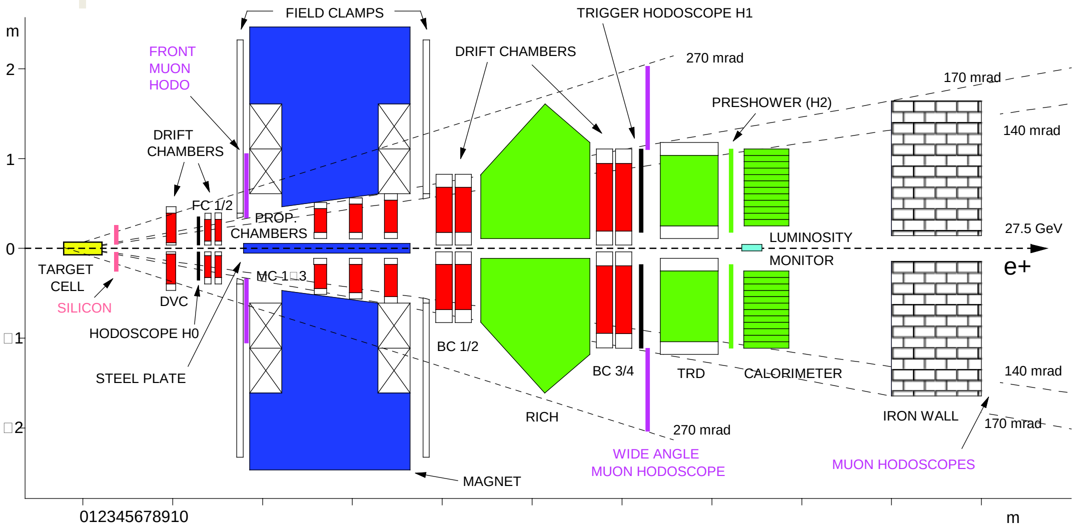
Partial spin transfer

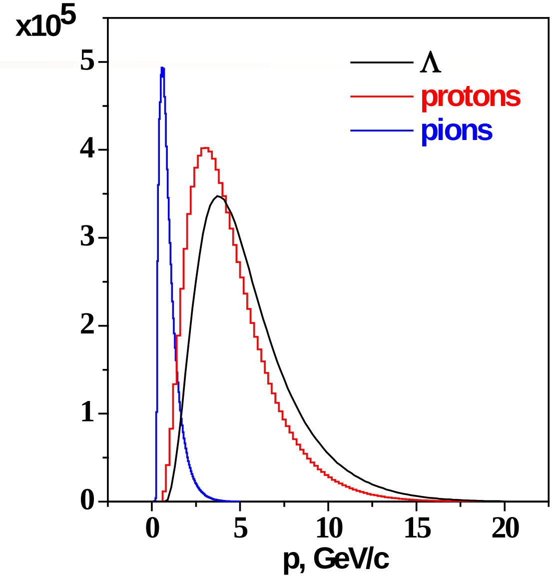
$$\omega_f^{\Lambda}(x,z) = \frac{e_f^2 q_f(x) F_f^{\Lambda}(z)}{\sum_{f'} e_{f'}^2 q_{f'}(x) F_{f'}^{\Lambda}(z)}$$

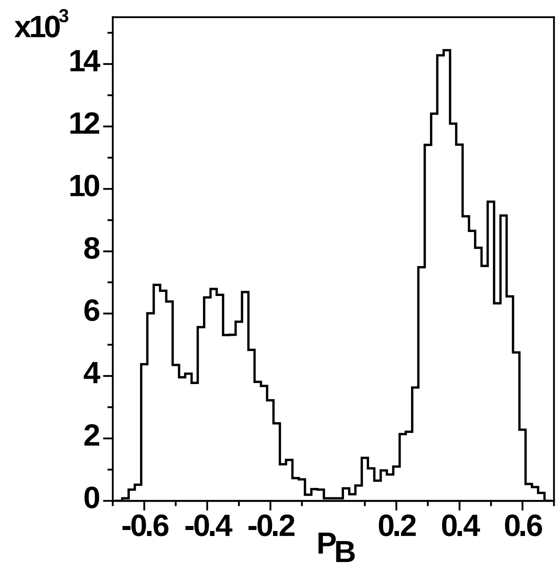
Jaffe assumption

$$D_{LL',f}^{\Lambda}(z) = \frac{F_{f+}^{\Lambda+} - F_{f+}^{\Lambda-}}{F_{f+}^{\Lambda+} + F_{f+}^{\Lambda-}} \cong \frac{\Delta q_f^{\Lambda}}{q_f^{\Lambda}}$$

HERMES experiment





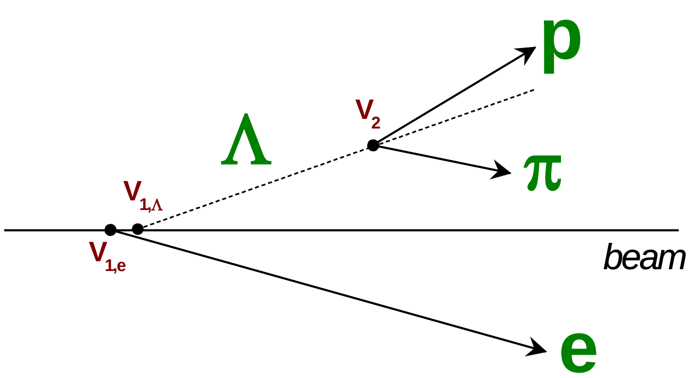


$$-170 < \theta_x < +170\, mrad$$

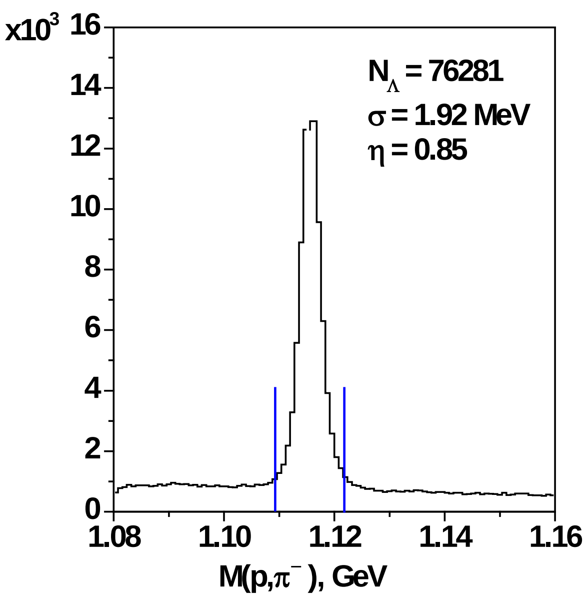
$$40 < |\theta_y| < 140\, mrad$$

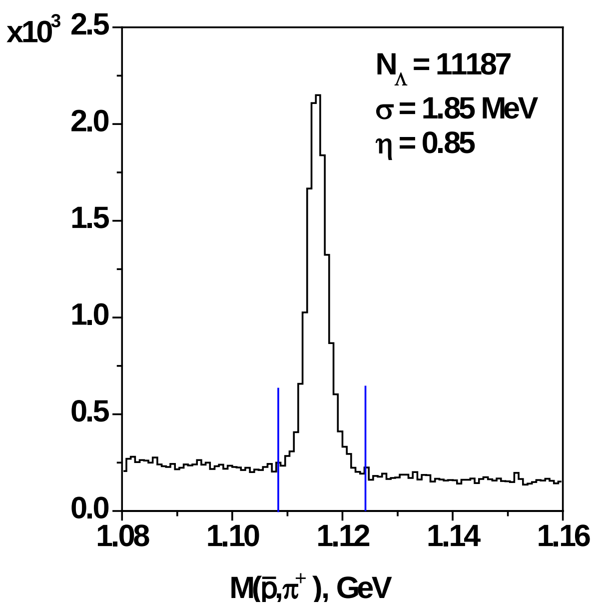
- ✓ ***Long. polarized lepton (e^-/e^+) beam E_e = 27.5 GeV***
- ✓ ***Beam spin flipped on a month basis***

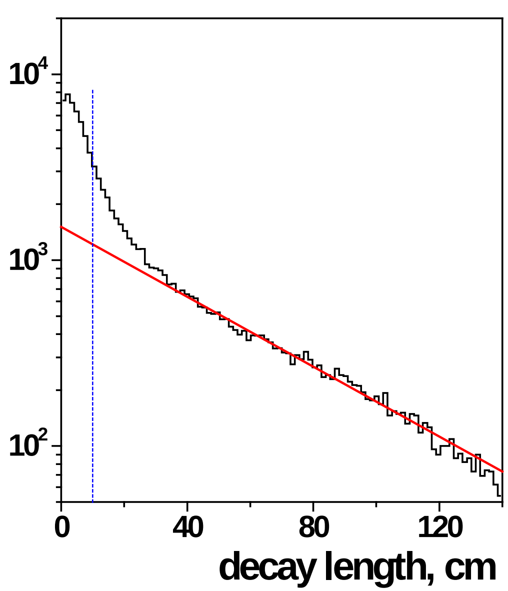
Events selection



- leading π rejection (in HERMES kinematics proton is always leading) :
  - *Threshold Cherenkov det. 1996-1997*
  - *Ring imaging Cherenkov 1998-2007*
- h^+h^- pair background rejection :
  - *Vertex separation $d(V_1,V_2)$ > 5 cm*







Extraction of $D_{LL'}$

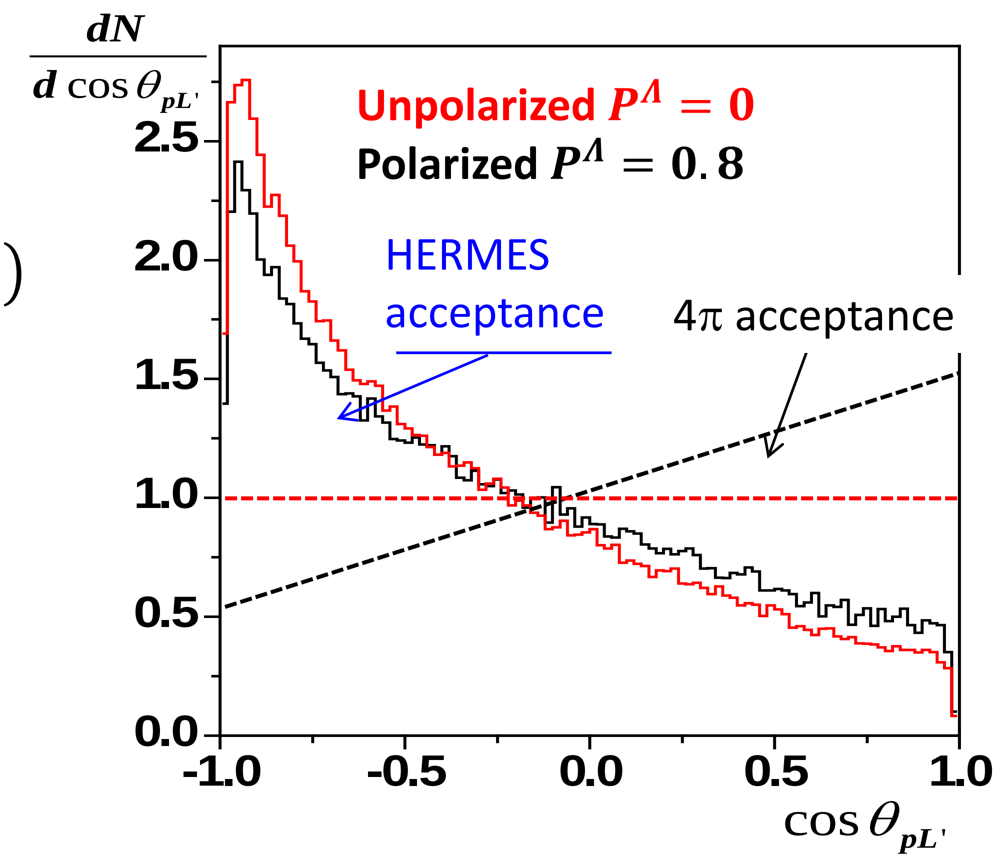
- **Angular distribution of decay protons at Λ rest frame**

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

Unknown, need MC simulation of acceptance

↓

Main source of systematic uncertainty !



Formalism extraction of $D^{\Lambda}_{LL'}$

- **Helicity balanced data sample** $[\![P_B]\!] = \frac{1}{L}\int P_B\, dL = 0$ $\qquad \frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p}\left(1 + \alpha P^{\Lambda}_{L'} \cos\theta_{pL'}\right)$
- **Moment method in simple 1Dim case**

$$\langle P_B \cos\theta_{pL'}\rangle = \frac{[\![P_B]\!]\langle\cos\theta_{pL'}\rangle_0 + \alpha D_{LL'}[\![P_B^2]\!]\langle\cos^2\theta_{pL'}\rangle_0}{1 + \alpha D_{LL'}[\![P_B]\!]\langle\cos\theta_{pL'}\rangle_0} \overset{[\![P_B]\!]=0}{=} \alpha D_{LL'}[\![P_B^2]\!]\langle\cos^2\theta_{pL'}\rangle_0$$

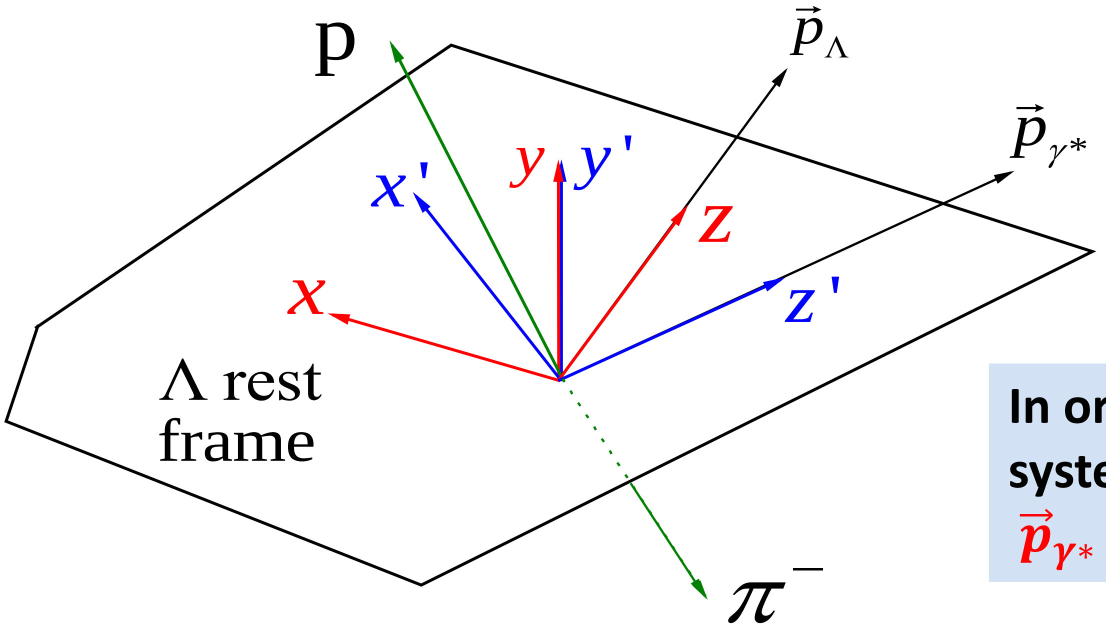
$$\langle\cos^2\theta_{pL'}\rangle = \frac{\langle\cos^2\theta_{pL'}\rangle_0 + \alpha D_{LL'}[\![P_B]\!]\langle\cos^3\theta_{pL'}\rangle_0}{1 + \alpha D_{LL'}[\![P_B]\!]\langle\cos\theta_{pL'}\rangle_0} \overset{[\![P_B]\!]=0}{=} \langle\cos^2\theta_{pL'}\rangle_0$$

$$D^{\Lambda}_{LL'} = \frac{1}{\alpha\,[\![P_B^2]\!]} \cdot \frac{\langle P_B \cos\theta_{pL'}\rangle}{\langle \cos^2\theta_{pL'}\rangle}$$

No MC simulation of acceptance needed

- **Slightly more complicated iteration procedure used in case of unbalanced P_B**
- **3 projection *of* $D^{\Lambda}_{LL'}$ calculated**
- **3Dim extraction formalism verified with help of MC**

Definition of coordinate system



$$\vec{\gamma}^* + p \to \vec{\Lambda} + X$$

In order to build coordinate system for Λ at rest two vectors: $\vec{p}_{\gamma*}$ and $\vec{p}_\Lambda$ are used

2 variants of system

$$\vec{k}_z = \hat{\vec{p}}_\Lambda, \quad \vec{k}_y = \hat{\vec{p}}_\Lambda \times \hat{\vec{p}}_{\gamma*}, \quad \vec{k}_x = \vec{k}_y \times \vec{k}_z$$

$$\vec{k}_z = \hat{\vec{p}}_{\gamma*}, \quad \vec{k}_y = \hat{\vec{p}}_\Lambda \times \hat{\vec{p}}_{\gamma*}, \quad \vec{k}_x = \vec{k}_y \times \vec{k}_z$$

3 dimensional analysis

System of linear equations $\sum_k D_{L,k} a_{i,k} = c_i$

$$\sum_{k=x,y,z} D_{Lk} \underbrace{\left\langle \frac{D^2(y)\cos\theta_k \cos\theta_i}{1+\alpha D(y) \sum_{j=x,y,z} P_{B,i} D_{Lj} \cos\theta_j} \right\rangle}_{a_{i,k}} = \underbrace{\frac{1}{\alpha} \frac{\langle P_B D(y)\cos\theta_i\rangle - [\![P_B]\!]\langle D(y)\cos\theta_i\rangle}{[\![P_B^2]\!] - [\![P_B]\!]^2}}_{c_i}$$

Here $\langle \dots \rangle$ average over experimental data set

$[\![\dots]\!]$ average with luminosity

$\theta_{(x,y,z)}$ angle between proton and corresponding axis

Iteration procedure is used to find D_{Lk}

$$D_{Lk}^{(0)} \xrightarrow{\text{calculate } a_i^k} a_i^{k(0)} \xrightarrow{\text{solve } a_i^k D_{Lk} = c_i} D_{Lk}^{(1)} \rightarrow \dots$$

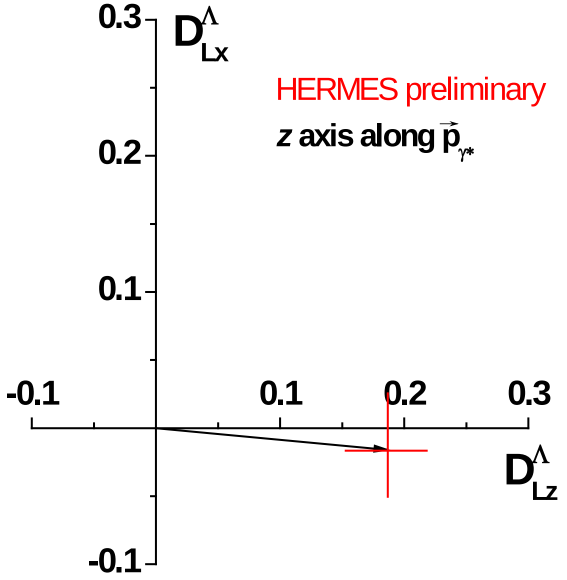
Convergence in three steps

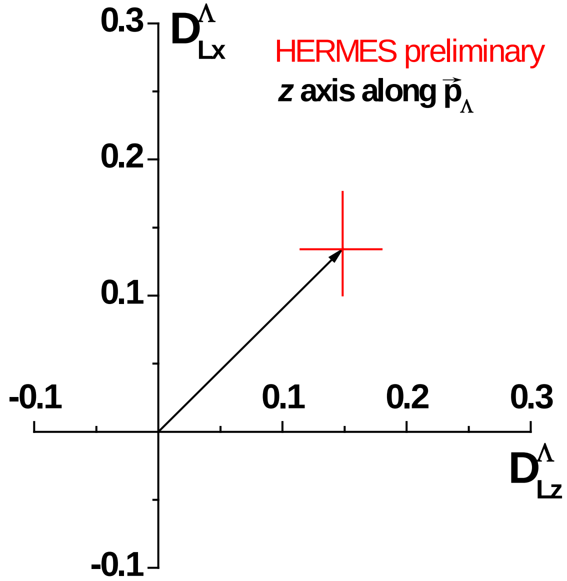
Integrated over kinematics result

$$D_{Lx}^{\Lambda} = -0.016 \pm 0.042_{stat} \pm 0.017_{syst}$$
$$D_{Ly}^{\Lambda} = 0.037 \pm 0.037_{stat} \pm 0.016_{syst}$$
$$D_{Lz}^{\Lambda} = 0.186 \pm 0.040_{stat} \pm 0.012_{syst}$$
$$\left|D_{LL'}^{\Lambda}\right| = 0.187 \pm 0.040_{stat} \pm 0.012_{syst}$$

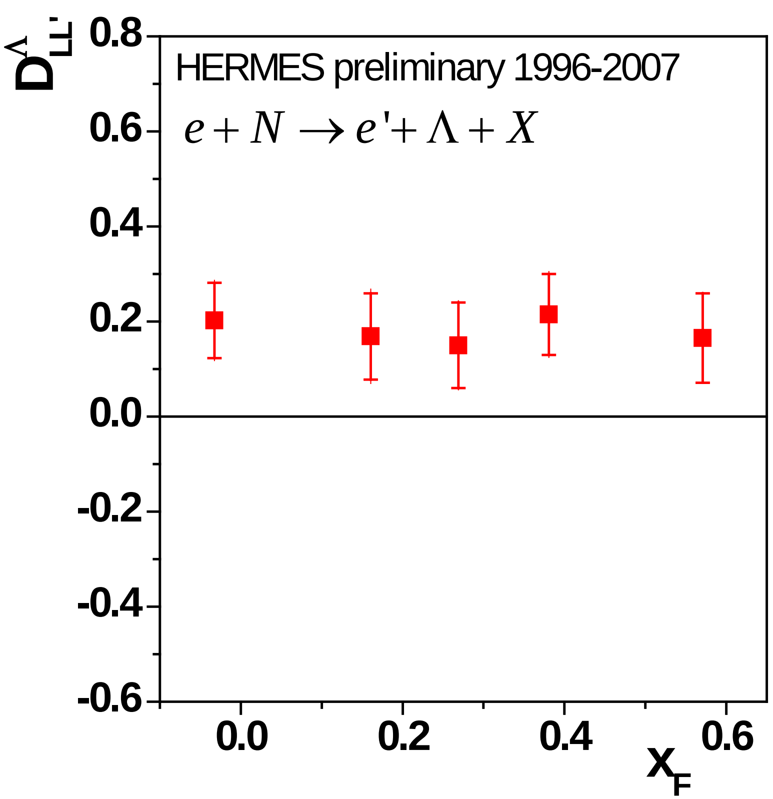
$$D_{Lx}^{\Lambda} = -0.133 \pm 0.039_{stat} \pm 0.015_{syst}$$
$$D_{Ly}^{\Lambda} = 0.037 \pm 0.037_{stat} \pm 0.016_{syst}$$
$$D_{Lz}^{\Lambda} = 0.147 \pm 0.038_{stat} \pm 0.015_{syst}$$
$$\left|D_{LL'}^{\Lambda}\right| = 0.197 \pm 0.039_{stat} \pm 0.015_{syst}$$

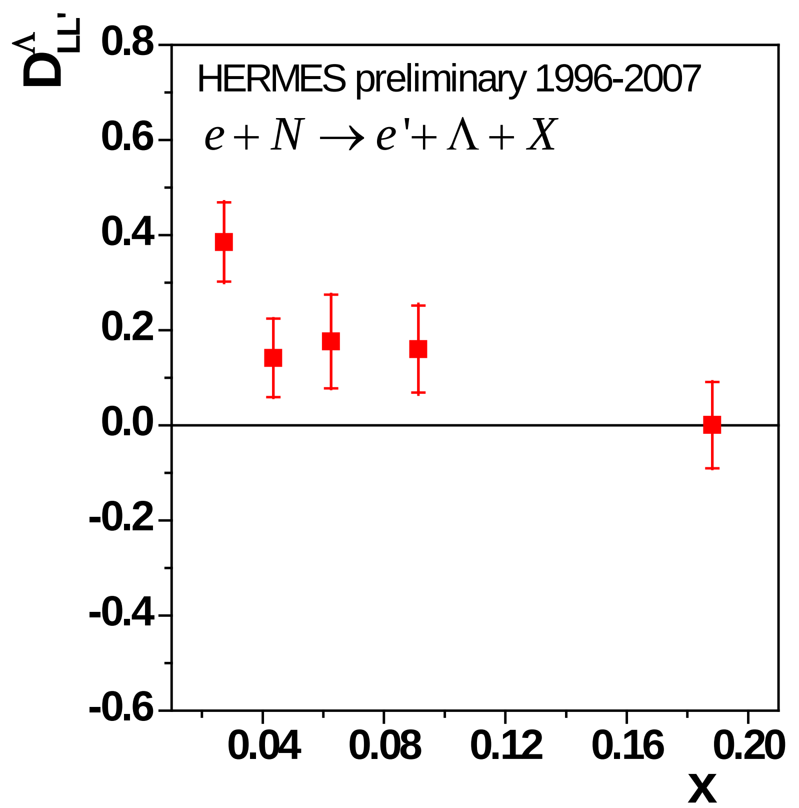
Due to parity conservation *y* - component must be zero



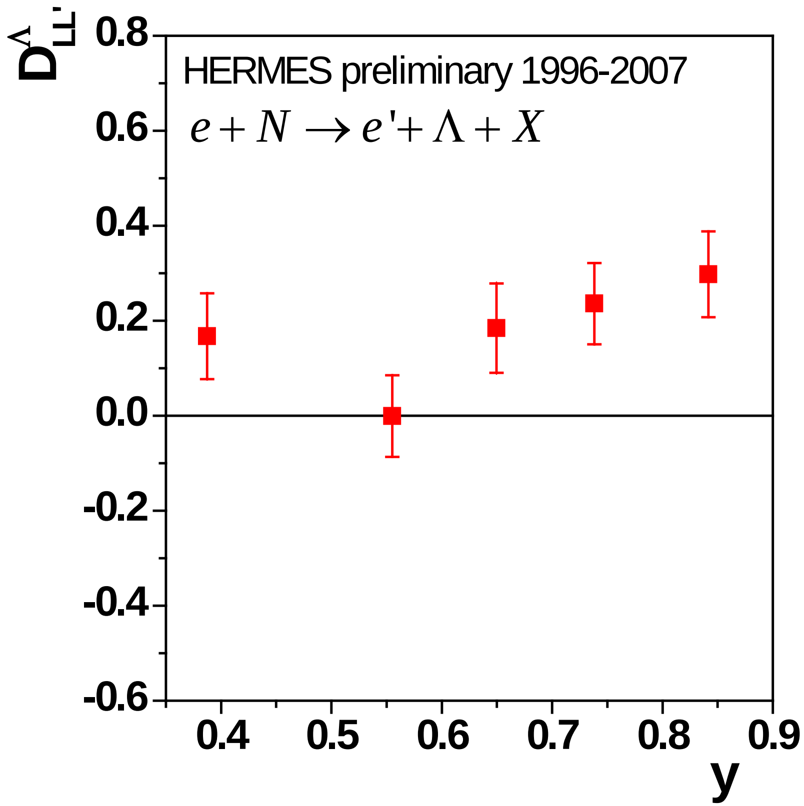


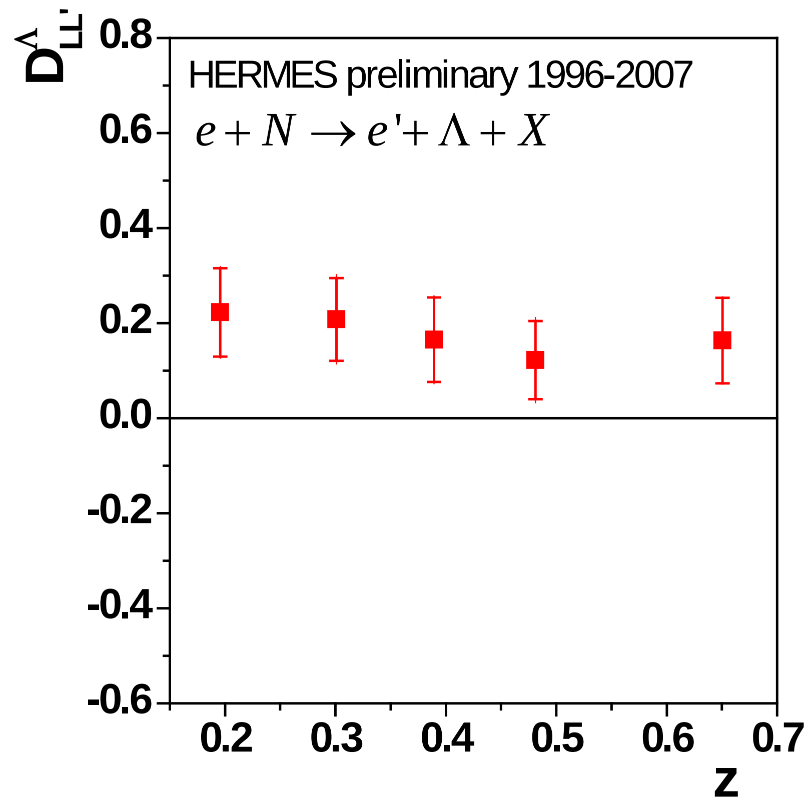
Dependences on kinematic variables





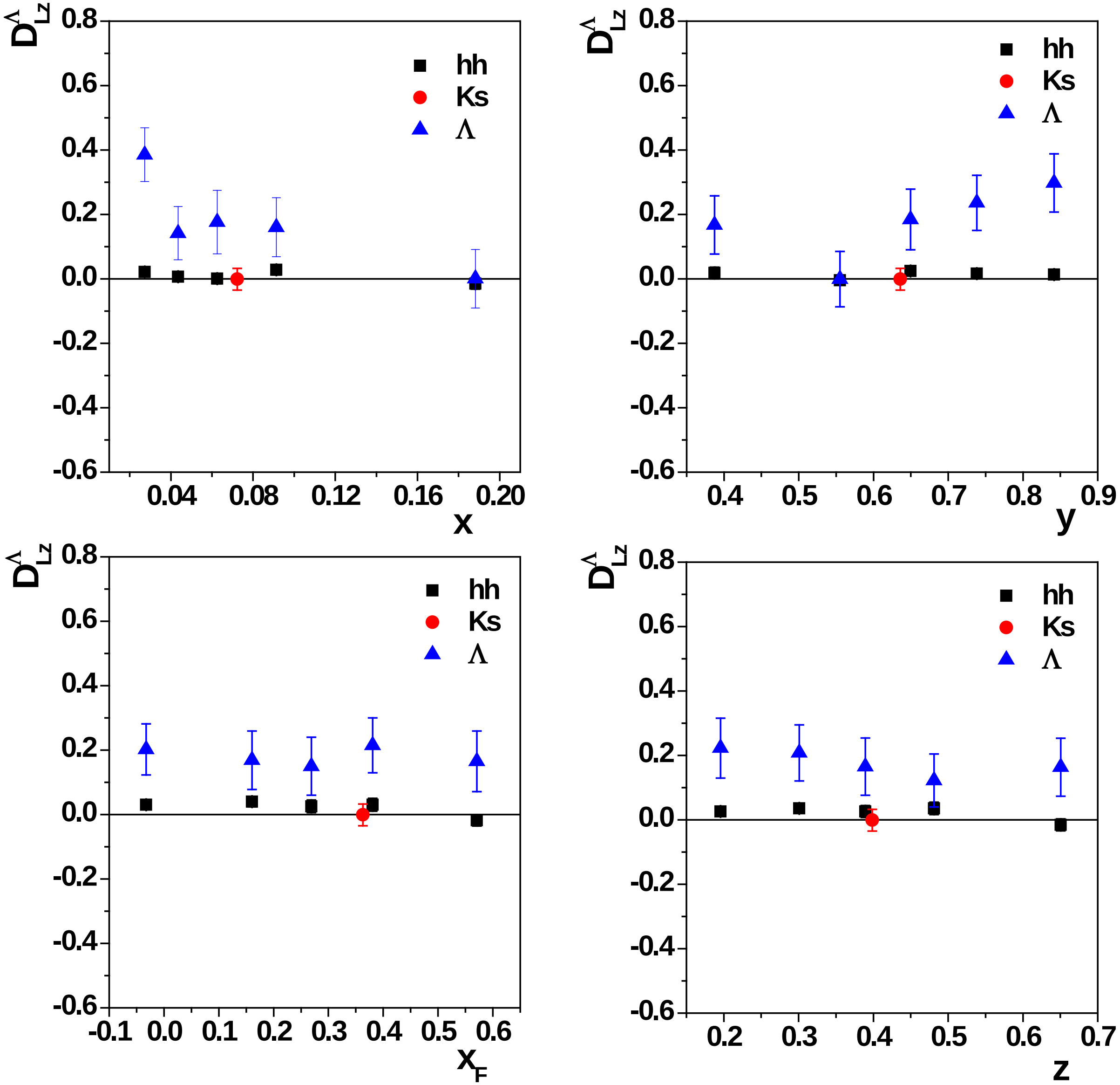
Dependences on kinematic variables





✓ ***$D^{\Lambda}_{LL'}$ must not depend on y if single scattering model of DIS is valid***

Systematic studies



$$D_{Lx}^{hh} = 0.017 \pm 0.006$$

$$D_{Ly}^{hh} = 0.015 \pm 0.006$$

$$D_{Lz}^{hh} = 0.012 \pm 0.006$$

$$D_{Lx}^{Ks} = 0.019 \pm 0.030$$

$$D_{Ly}^{Ks} = 0.015 \pm 0.031$$

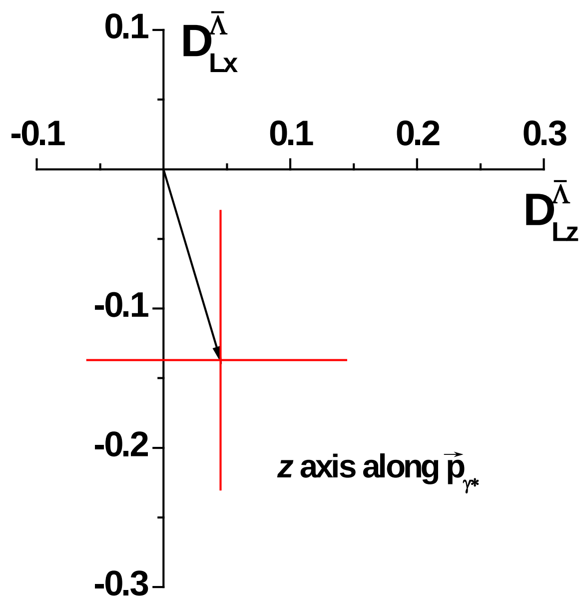
$$D_{Lz}^{Ks} = -0.001 \pm 0.033$$

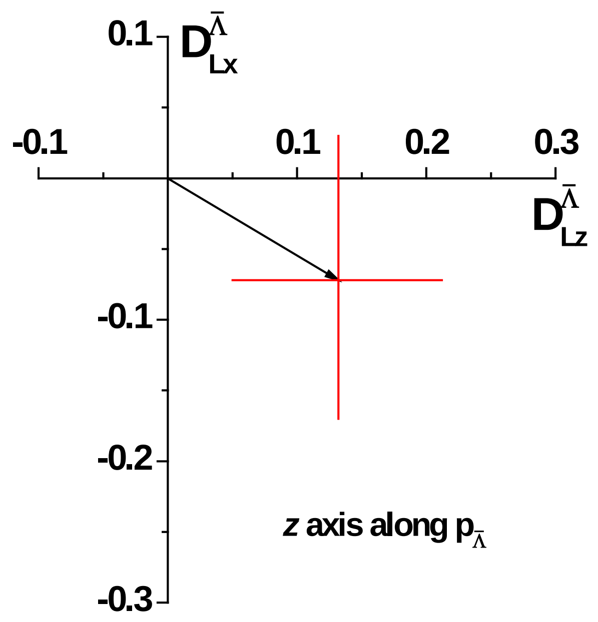
Integrated over kinematics result

$$D_{Lx}^{\bar{\Lambda}} = -0.14 \pm 0.11_{stat} \pm 0.02_{syst}$$
$$D_{Ly}^{\bar{\Lambda}} = 0.05 \pm 0.10_{stat} \pm 0.02_{syst}$$
$$D_{Lz}^{\bar{\Lambda}} = 0.05 \pm 0.10_{stat} \pm 0.02_{syst}$$
$$\left|D_{LL'}^{\bar{\Lambda}}\right| = 0.15 \pm 0.11_{stat} \pm 0.02_{syst}$$

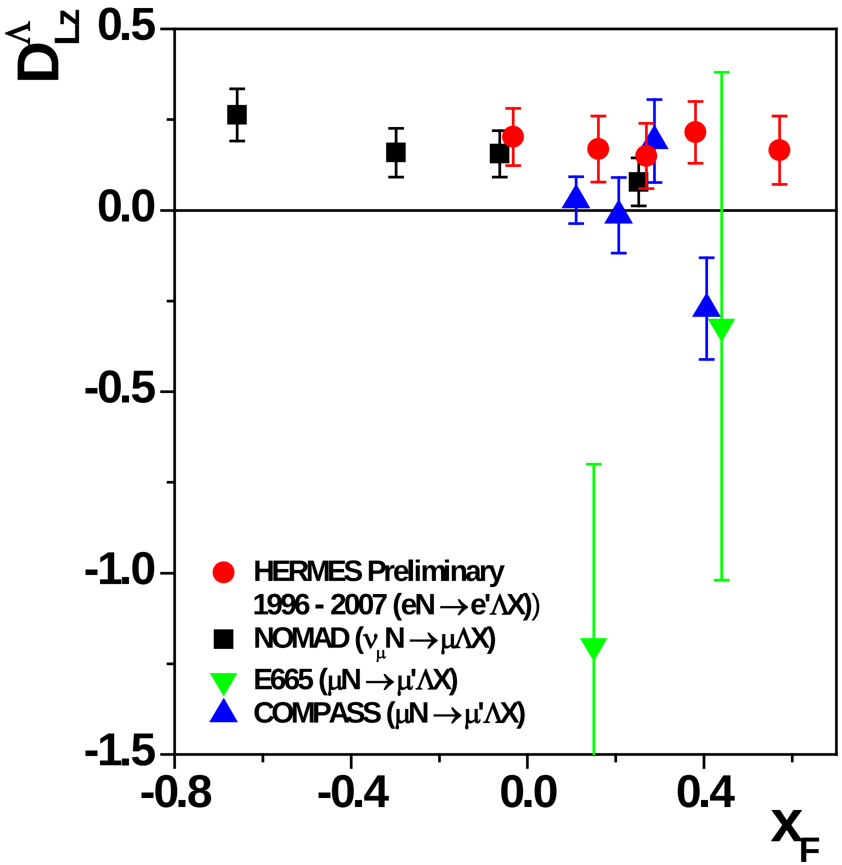
$$D_{Lx}^{\bar{\Lambda}} = -0.07 \pm 0.10_{stat} \pm 0.02_{syst}$$
$$D_{Ly}^{\bar{\Lambda}} = 0.05 \pm 0.10_{stat} \pm 0.02_{syst}$$
$$D_{Lz}^{\bar{\Lambda}} = 0.13 \pm 0.08_{stat} \pm 0.02_{syst}$$
$$\left|D_{LL'}^{\bar{\Lambda}}\right| = 0.15 \pm 0.09_{stat} \pm 0.02_{syst}$$

Statistics is not enough to solid conclusion

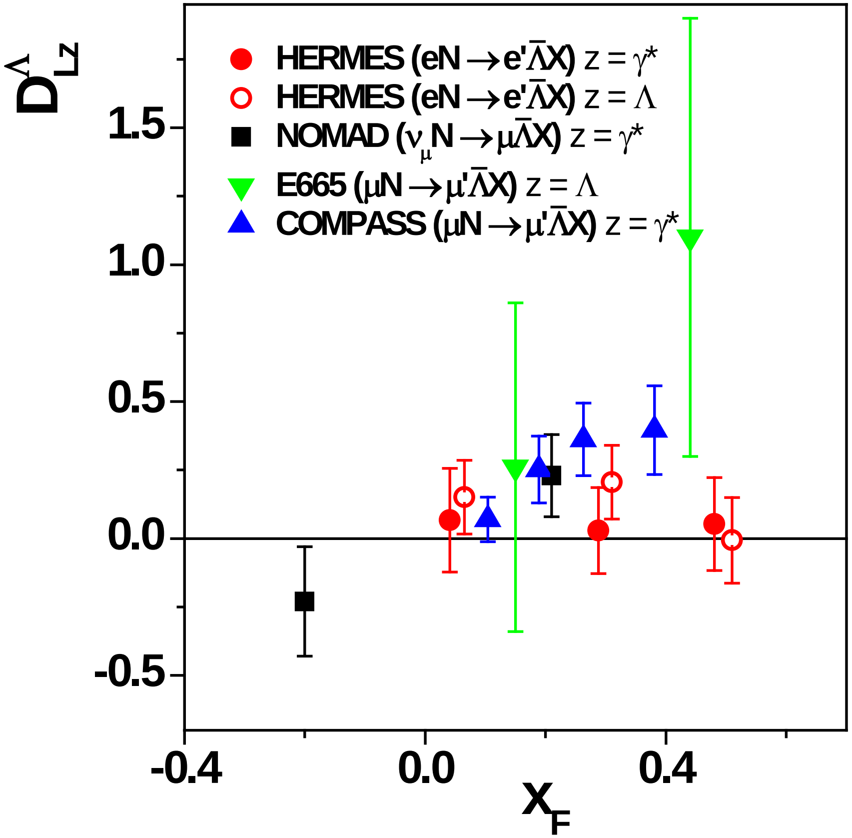




World data



HERMES Preliminary
1996 - 2007 (eN→e'ΛX))
NOMAD (ν_μN→μΛX)
E665 (μN→μ'ΛX)
COMPASS (μN→μ'ΛX)
x_F



HERMES (eN→e'Λ̄X) z = γ*
HERMES (eN→e'Λ̄X) z = Λ
NOMAD (ν_μN→μΛ̄X) z = γ*
E665 (μN→μ'Λ̄X) z = Λ
COMPASS (μN→μ'Λ̄X) z = γ*
x_F

Theoretical models

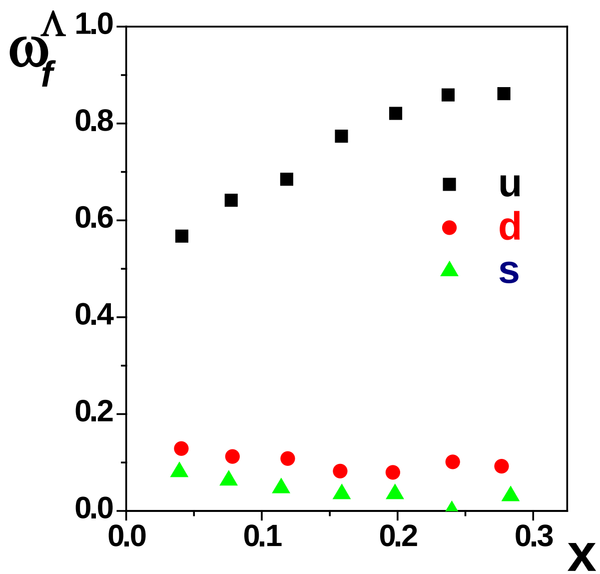
Λ spin structure

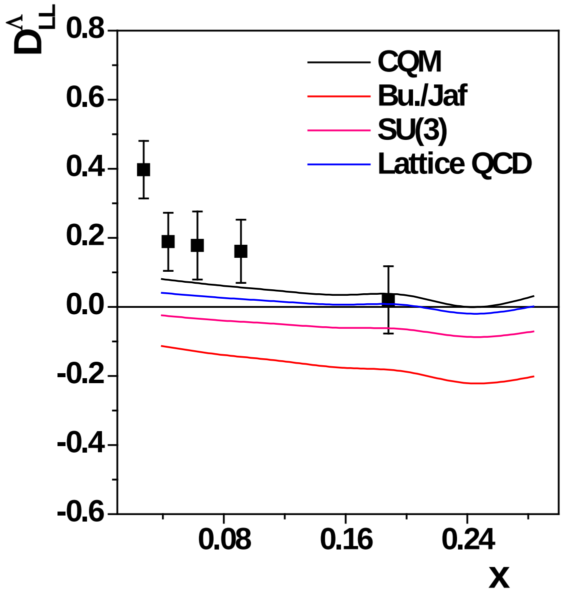
- Constituent quark model (CQM) Δu=Δd=0, Δs=1
- Burkard/Jaffe Δu=Δd=-0.23±0.06, Δs=0.58±0.07
- SU(3) flavor symmetry Δu=Δd=-0.09±0.06, Δs=0.47±0.07
- Lattice QCD Δu=Δd=-0.02±0.04, Δs=0.68±0.04

$$D^{\Lambda}_{LL'} = \sum_f D^{\Lambda}_{LL',f}\,\omega^{\Lambda}_f$$

$$\textbf{Jaffe} \rightarrow D^{\Lambda}_{LL',f} \simeq \frac{\Delta q^{\Lambda}_f}{q^{\Lambda}_f}$$

All models predict negative or small positive value

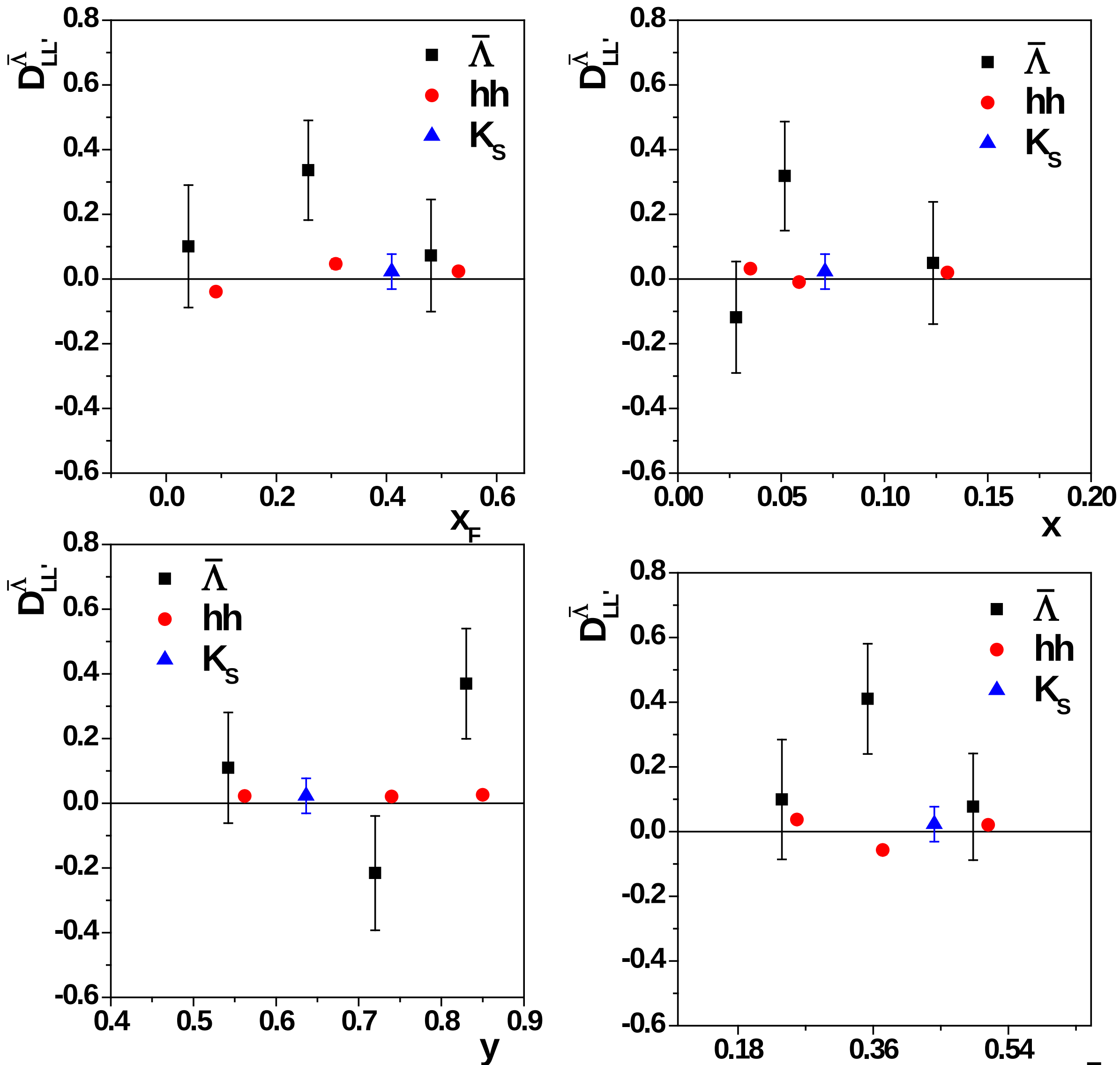




Conclusion and outlook

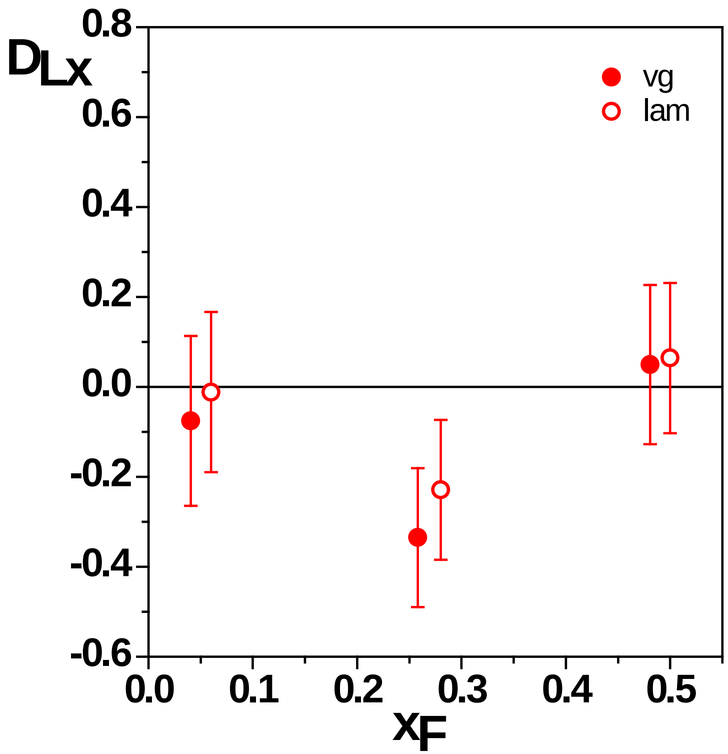
- All three components of spin transfer $D_{LL'}^{\Lambda}$ and $D_{LL'}^{\bar{\Lambda}}$ have been measured in DIS of charge leptons at HERMES
- It is shown that $D_{LL'}^{\Lambda}$ is positive (statistically significant) and mostly directed along the momentum of virtual photon
- It is found that $D_{LL'}^{\bar{\Lambda}}$ is less then $D_{LL'}^{\Lambda}$ or comparable with
- Final paper on $D_{LL'}^{\Lambda}$ and $D_{LL'}^{\bar{\Lambda}}$ at HERMES in progress
- Next step is spin transfer in photoproduction regime $Q^2 \cong 0\ \mathrm{GeV}^2$ from beam ($D_{LL'}$) and target ($K_{LL'}$ partly done)

False $D_{LL'}$ for h^+h^- and K_S

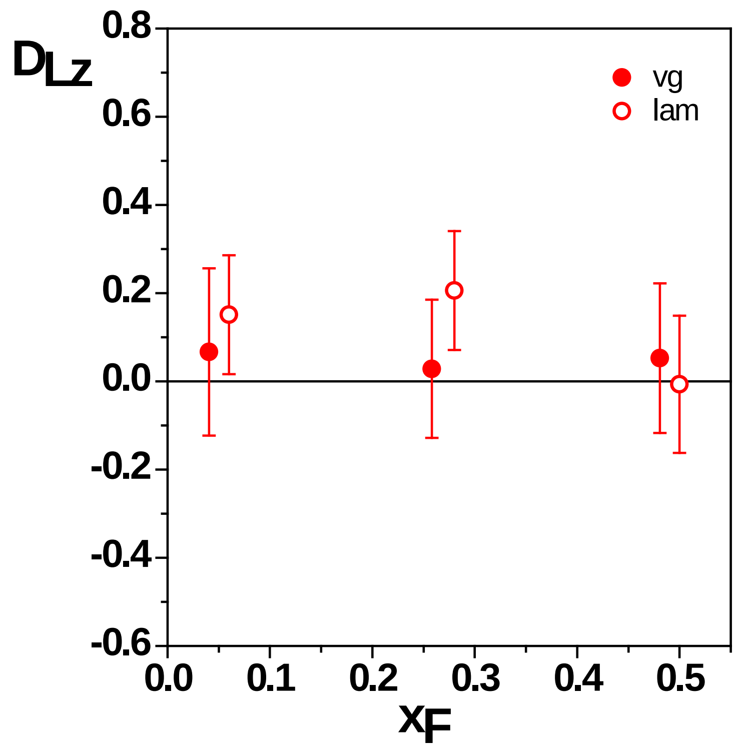


$$D^{hh}_{LL'} = 0.021 \pm 0.006$$

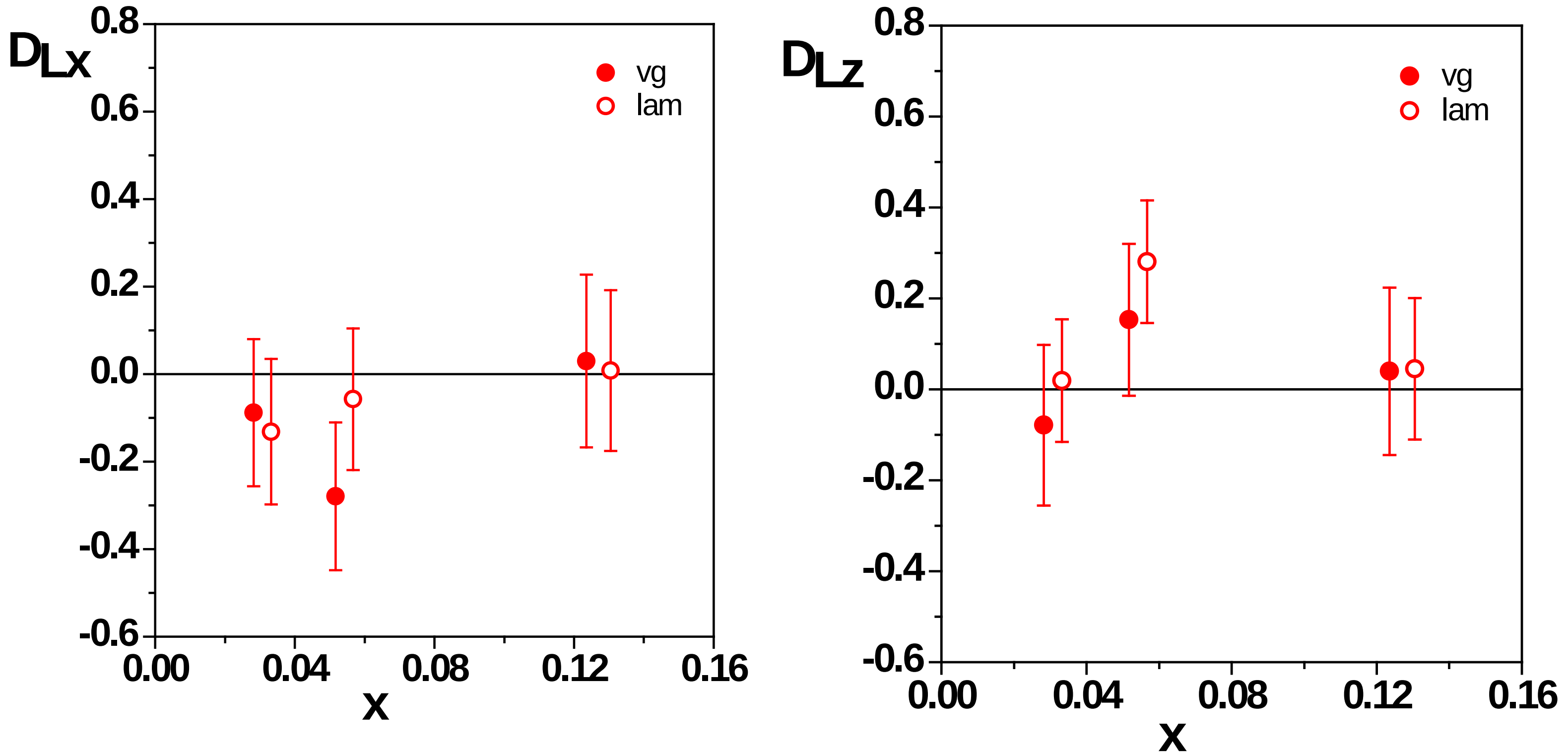
$$D^{Ks}_{LL'} = 0.023 \pm 0.054$$



D_{Lx}
vg
lam
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0.0
0.1
0.2
0.3
0.4
0.5
x_F



D_{Lz}
vg
lam
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0.0
0.1
0.2
0.3
0.4
0.5
x_F



DLx
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0.04
0.08
0.12
0.16
x
DLz
vg
lam
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-0.6
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0.04
0.08
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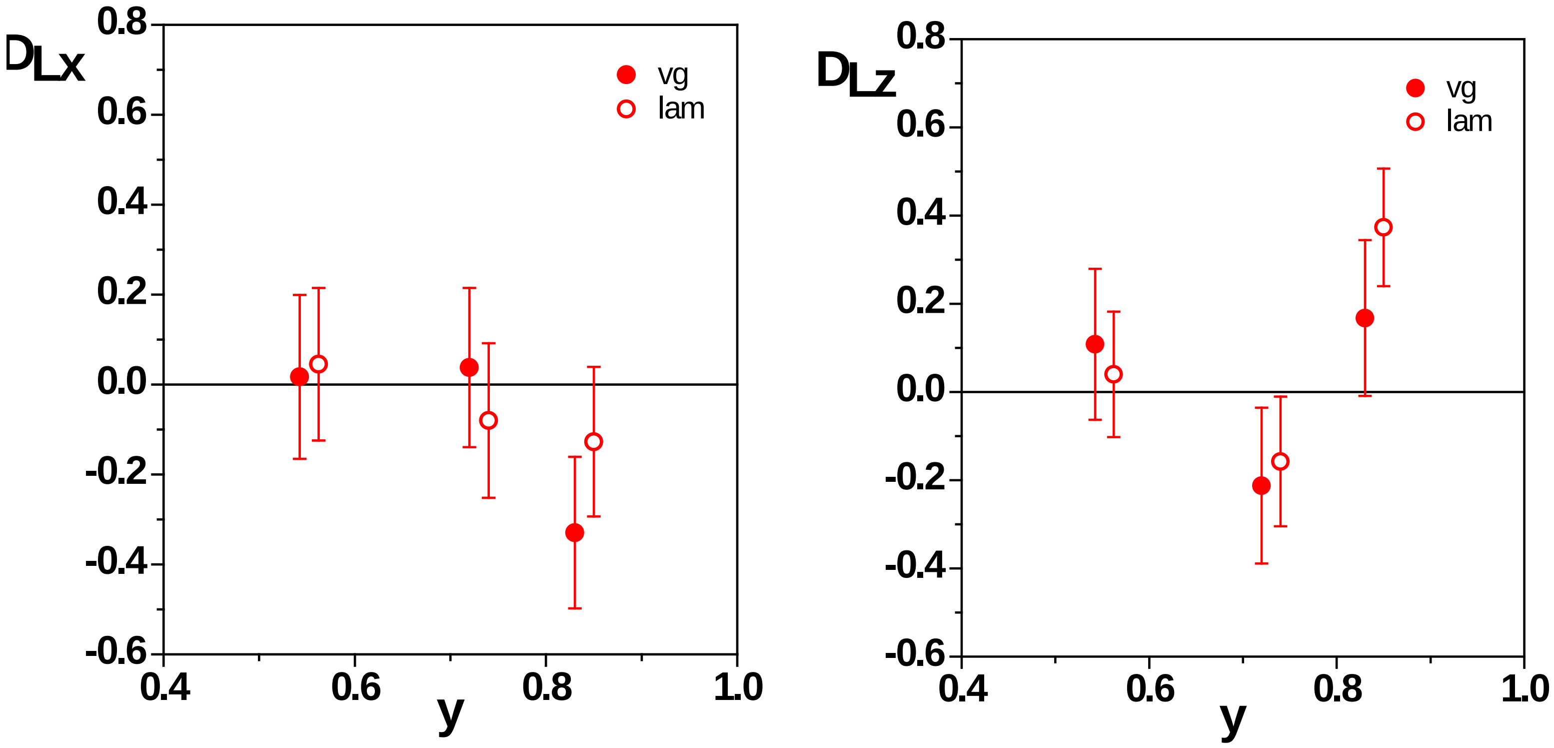
0.16
x



DLx
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0.8
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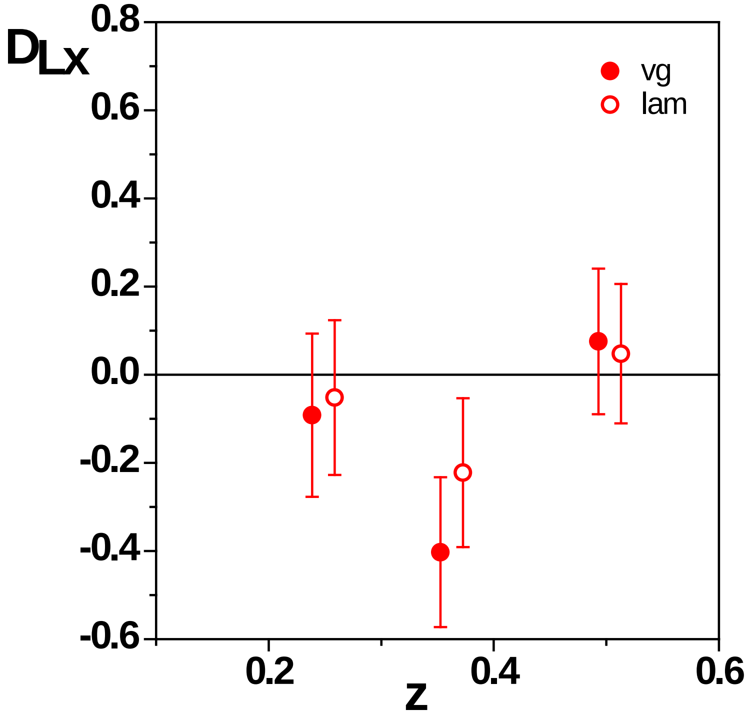
y


DLx
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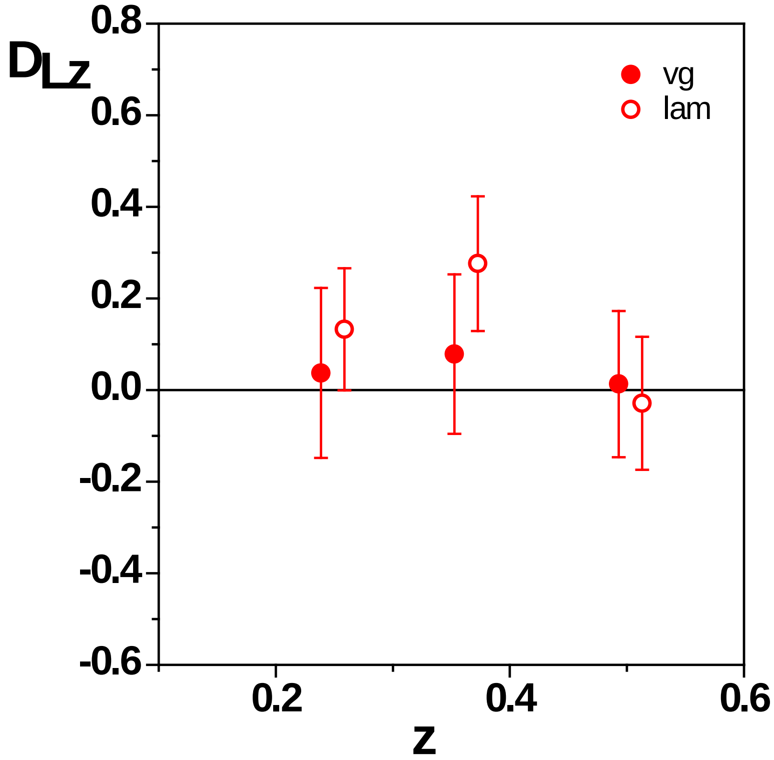
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