Preliminary HERMES results on the beam-spin induced polarization of Lambda and anti-Lambda hyperons produced in SIDIS

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hermes

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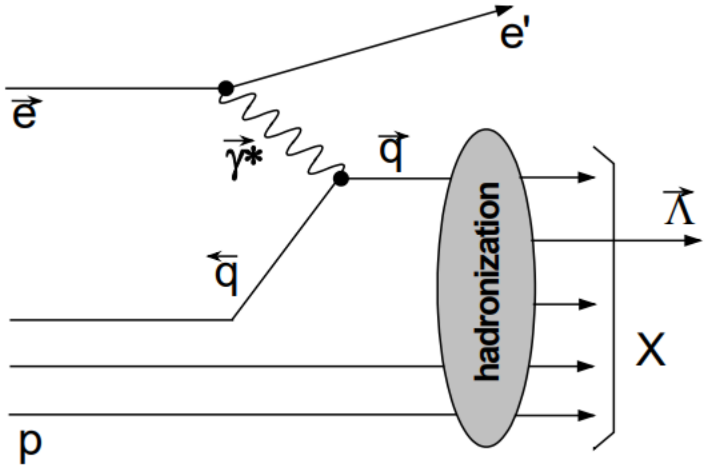
Longitudinal spin transfer $D_{LL'}$ in SIDIS

$$P_{L'}^{\Lambda} = P_{\gamma^*} D_{LL'} = P_b D(y) D_{LL'}$$

$$\vec{e} + N \rightarrow e' + \vec{\Lambda} + X$$

Spin transfer $D_{LL'}$ is correlation between beam polarization and final state hadron polarization or in other word double beam spin asymmetry



Why use Λ hyperon as final state hadron?

- Relatively good statistic
- Easy to detect with $\Lambda \rightarrow p + \pi$
- Weak decay ("self" analyzing particle), polarization of Λ can be extracted by measuring decay proton angular distribution, no additional scattering needed

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

Angle between proton momentum and Λ spin in Λ rest frame

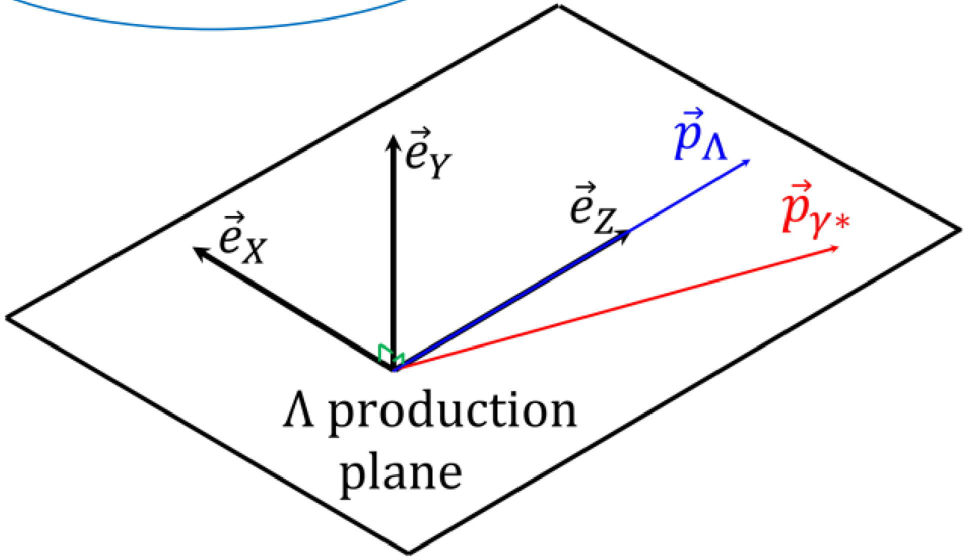
Spin transfer $D^{\Lambda}_{LL'}$

$$P_X^{\Lambda} = P_B D_X(y)\left\{-\frac{M}{Q}\frac{\sum_q e_q^2 x_B e^q(x_B) H_1^q(z)}{\sum_q e_q^2 x_B f_1^q(x_B) D_1^q(z)} - \frac{M^{\Lambda}}{Q}\frac{\sum_q e_q^2 x_B f_1^q(x_B)\tilde{G}_1^q(z)}{\sum_q e_q^2 x_B f_1^q(x_B) D_1^q(z)}\right\} = P_B D_X(y) D_{LX}(x_B, z, Q^2)$$

$$P_Y^{\Lambda} = D_Y(y)\frac{M}{Q}\frac{\sum_q e_q^2 x_B f_1^q(x_B) D_{1T}^{\perp(1)q}(z)}{\sum_q e_q^2 x_B f_1^q(x_B) D_1^q(z)}$$

$$P_Z^{\Lambda} = P_B D_Z(y)\frac{\sum_q e_q^2 x_B f_1^q(x_B) G_1^q(z)}{\sum_q e_q^2 x_B f_1^q(x_B) D_1^q(z)} = P_B D_Z(y) D_{LZ}(x_B, z, Q^2)$$

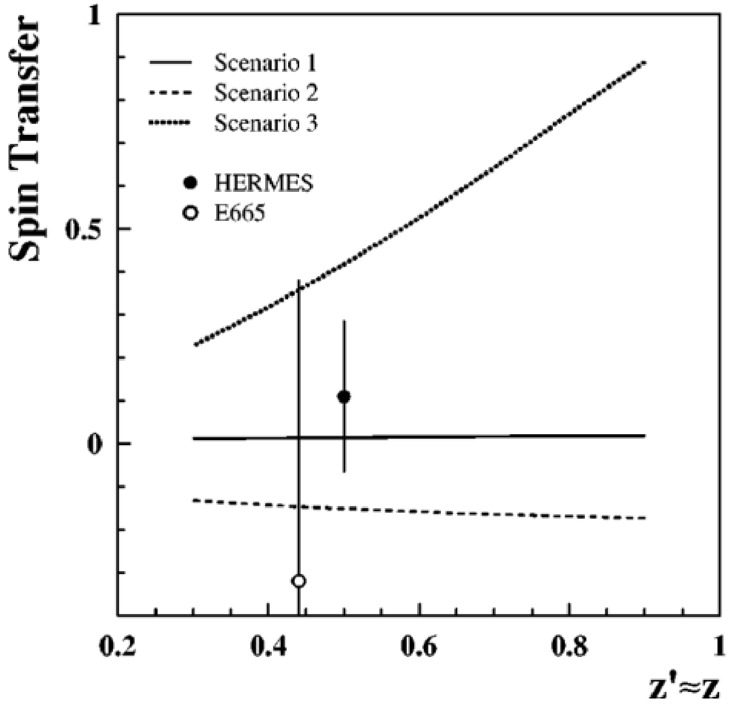
$$\boldsymbol{P_X^{\Lambda} = P_B D_X(y) D_{LX}(x_B, z, Q^2)}$$
$$\boldsymbol{P_Z^{\Lambda} = P_B D_Z(y) D_{LZ}(x_B, z, Q^2)}$$

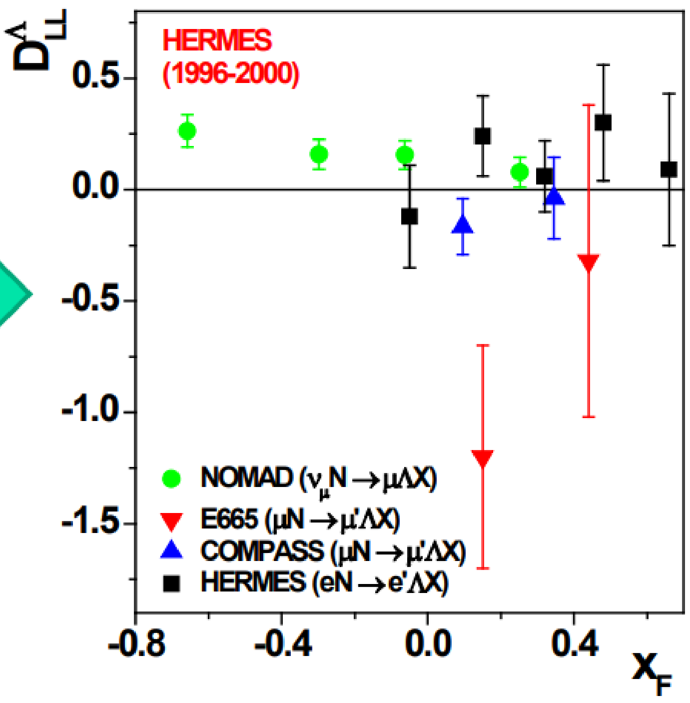


- $D_{LX}(x_B, z)$ and $D_{LZ}(x_B, z)$ called spin transfer coefficients
- P_Y^{Λ} is independent of beam polarization P_B $\rightarrow$ only 2 components $D_{LX}(x_B, z)$ and $D_{LZ}(x_B, z)$

Previous publication

- Phys.Rev. D64 (2001) ~2000 Λs. $D_{LL} = 0.11 \pm 0.17_{stat} \pm 0.03_{syst}$ (1996-1997 data)
- Phys.Rev. D74 (2006), ~8200 Λs. $D_{LL} = 0.11 \pm 0.10_{stat} \pm 0.03_{syst}$ (1996-2000 data)





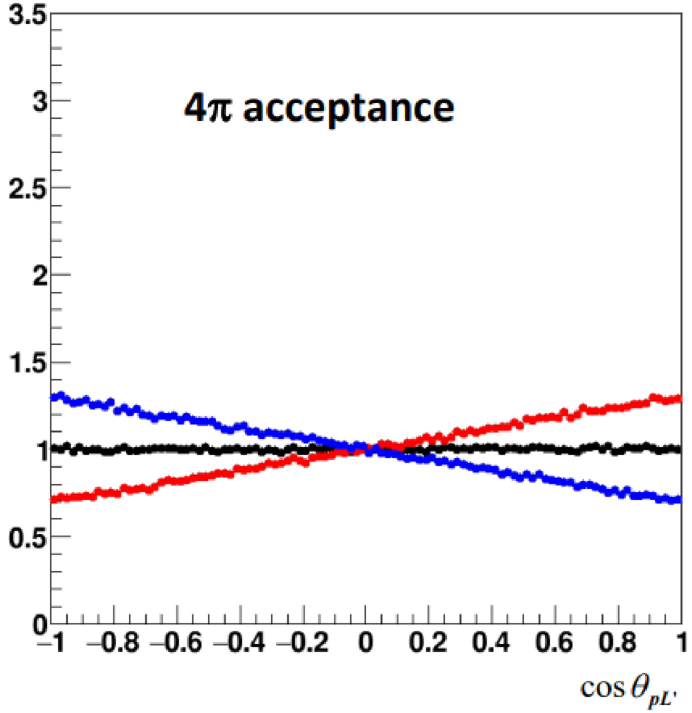
- For full data set we have ~**46000** Λs and ~**6500** $\bar{\Lambda}$s
- More then two time better statistical uncertainty on Λ
- First HERMES result on $\bar{\Lambda}$
- Also possible to extract kinematical dependences for $\bar{\Lambda}$

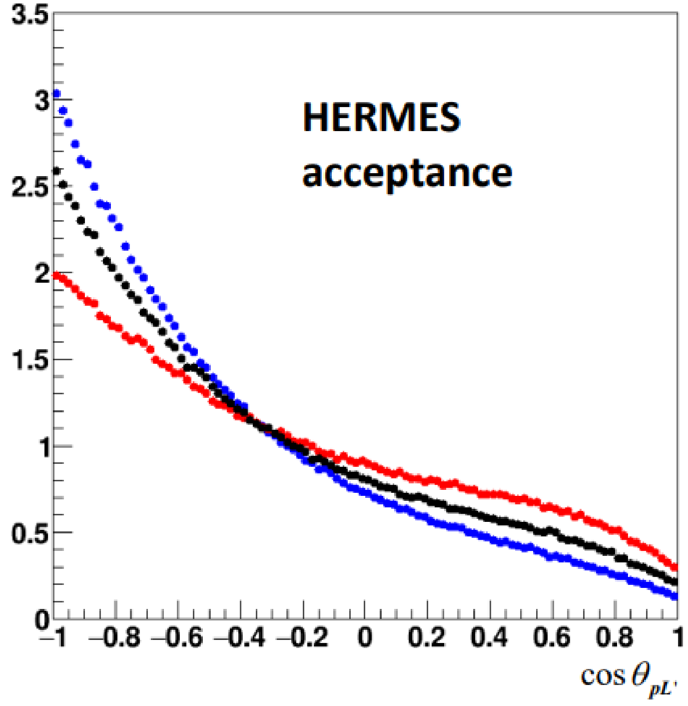
Extraction of Λ polarization

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

Unknown

Unpolarized $P^{\Lambda} = 0$
Polarized $P^{\Lambda} = 0.5$
Polarized $P^{\Lambda} = -0.5$





How to extract polarization?

1. **4π acceptance (NOMAD, "4π" acceptance)**
   - P^{Λ} just a slope from linear fit
2. **Complex acceptance**
   - MC simulation of $\varepsilon(\theta_{pL'} \dots)$ (major source of systematic uncertainty !) (COMPASS)
   - Assume acceptance is stable over time, so we can cancel acceptance effect using positive and negative beam polarization (HERMES)

Extraction formalism of $D_{LL'}^{\Lambda}$

Moment method /Phys.Rev. D64 (2001)/

- calculate $\langle P_B cos\theta_{pL'}\rangle$ and $\langle cos^2\theta_{pL'}\rangle$ with $\frac{d\omega}{d\Omega_p} = \frac{d\omega_0}{d\Omega_p}(1 + \alpha\vec{P}^{\Lambda}\vec{k}_p)$
- In simple 1D case and helicity balanced data sample $[\![P_B]\!] \equiv \frac{1}{\mathcal{L}^{tot}}\int P_B \, d\mathcal{L} = 0$

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

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

Unpolarized moment (unknown, but its reduced)

No MC simulation of acceptance needed

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

- Slightly more complicated iteration procedure used in case of unbalanced P_B
- Extended for 3D case

Extraction of spin transfer in 3D and unbalanced case

$$\sum_{k=x,z} D_{Lk} \left\langle \frac{D_k(y) D_i(y) cos\theta_k cos\theta_i}{1+\alpha[\![P_B]\!] \sum_{j=x,z} D_j(y) D_{Lj}\ cos\theta_j} \right\rangle = \frac{1}{\alpha} \frac{\langle P_B D_i(y) cos\theta_i\rangle - [\![P_B]\!]\langle D_i(y) cos\theta_i\rangle}{[\![P_B^2]\!] - [\![P_B]\!]^2}$$

- System of "linear" equations

$$\sum_k D_{Lk} a_{ik} = c_i$$

$$\begin{bmatrix} a_{xx} & a_{xz} \\ a_{zx} & a_{zz} \end{bmatrix} \begin{bmatrix} D_{Lx} \\ D_{Lz} \end{bmatrix} = \begin{bmatrix} c_x \\ c_z \end{bmatrix}$$

- Coefficients a_{ik} are dependent from D_{Li} (unless helicity balance $[\![P_B]\!] = 0$)
- Denominator in matrix elements are close to unity so we can use iterative procedure to solve it
- To solve given system, an iteration procedure is used

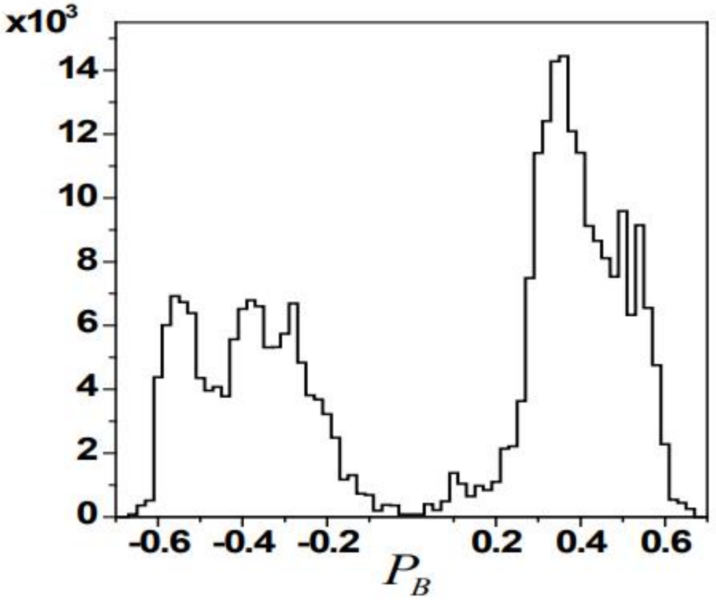
$$D_{Lk}{}^{(0)} \xrightarrow{\text{calculate } a_i^k} a_i^{k\,(0)} \xrightarrow{\text{solve } a_i^k D_{Lk}=c_i} D_{Lk}{}^{(1)} \rightarrow \ldots$$

- 3 steps are sufficient to converge due to $\alpha[\![P_B]\!] \sum_{j=x,z} D_j(y) D_{Lj}\ cos\theta_j \sim 0$

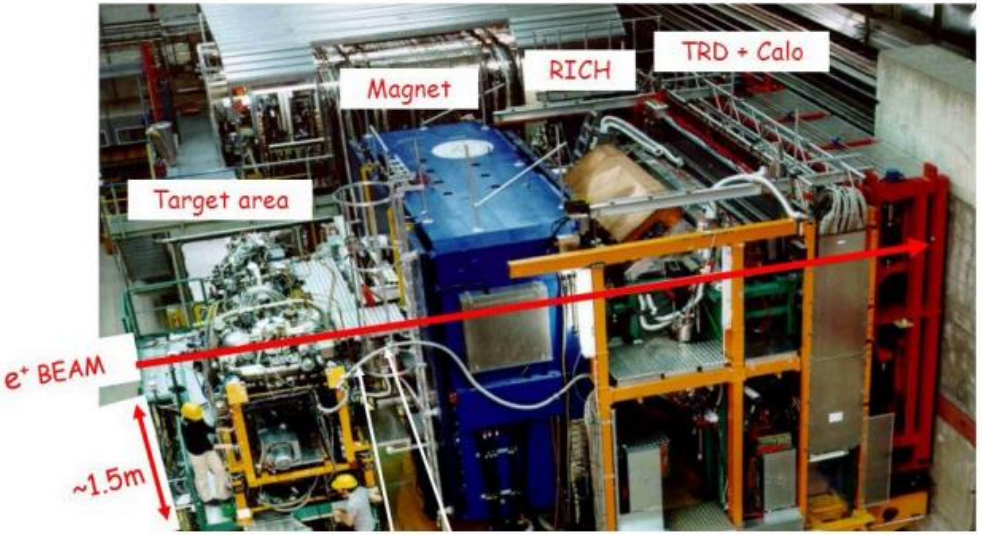
HERMES experiment

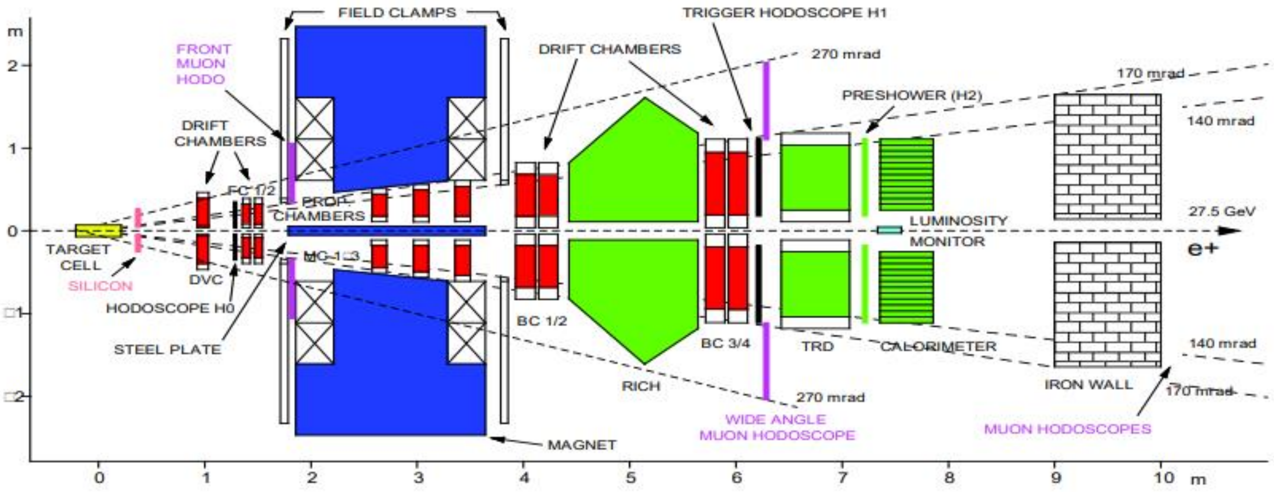
- Located at DESY, Hamburg
- 27.6 GeV e+/e- beam and 920 GeV proton beam (HERMES used only lepton beam)
- Data taking end in 2007

- Lepton beam “self” transversely polarized up to 60% due to Sokolov-Ternov effect
- Spin rotators upstream and downstream of HERMES experiment used to get longitudinally polarize beam
- Beam spin flipped every few weeks/months



HERMES experiment





Particle ID:

- lepton/hadron separation
- Ring Cerenkov detector (RICH):

  pion/kaon/proton discrimination 2 GeV < p < 15 GeV

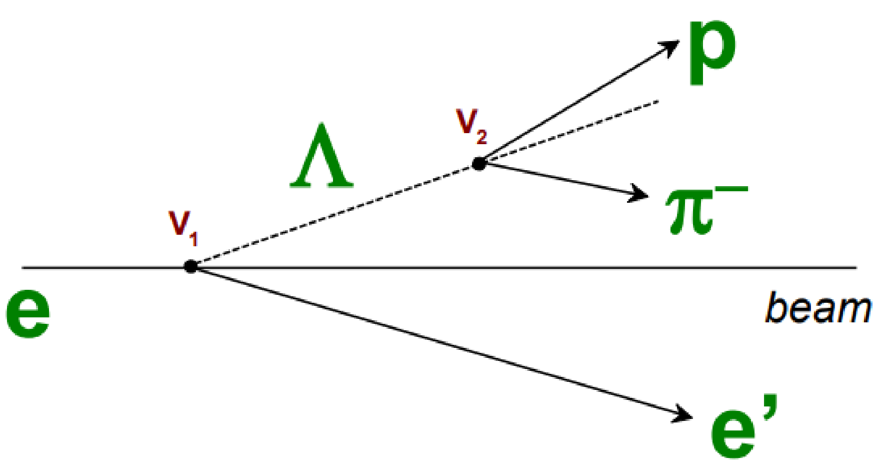
Good momentum and angular resolution

$$\frac{\Delta p}{p} \leq 1\%, \quad \Delta\theta_x, \Delta\theta_y \leq 1mrad$$

- Top/bottom symmetry
- 40 mrad < θ < 220 mrad
- Long. / trans. polarized gas targets H, D, flipped every 60-180 sec, $[\![P_{targ}]\!] \approx 0$
- Unpolarized targets H, D, He, N, Ne, Kr, Xe

Λ event selection

$$x = \frac{Q^2}{2M\nu},\ y = \frac{\nu}{E_e} = \frac{E_e - E'_e}{E_e},\ z = \frac{E^\Lambda}{\nu},\ x_F = \frac{p_\parallel^\Lambda}{p_{max}^\Lambda}$$



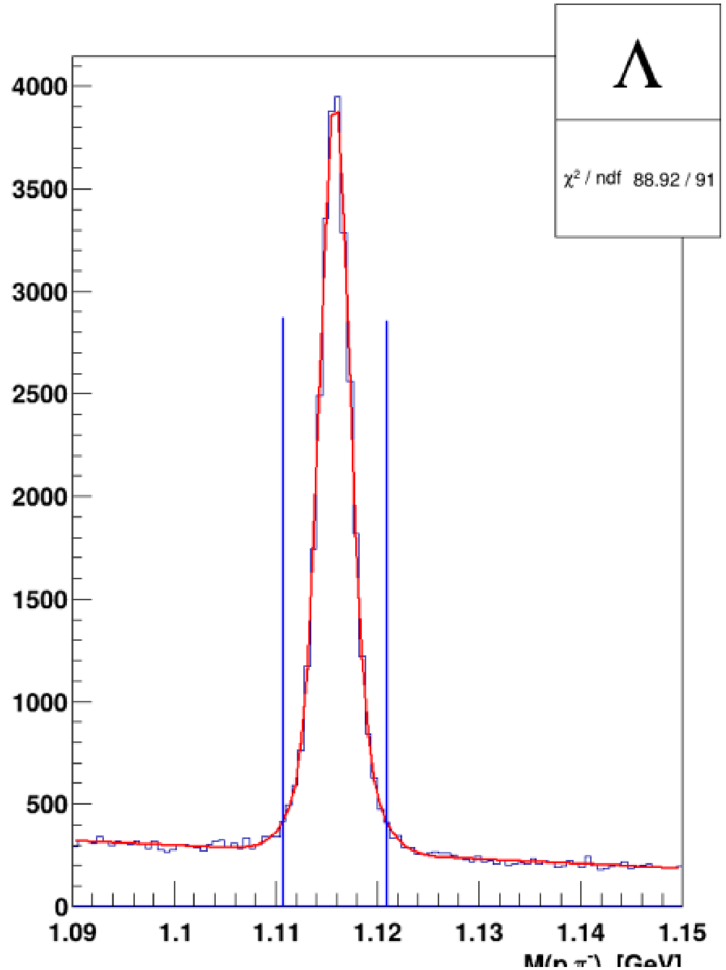
DIS cuts

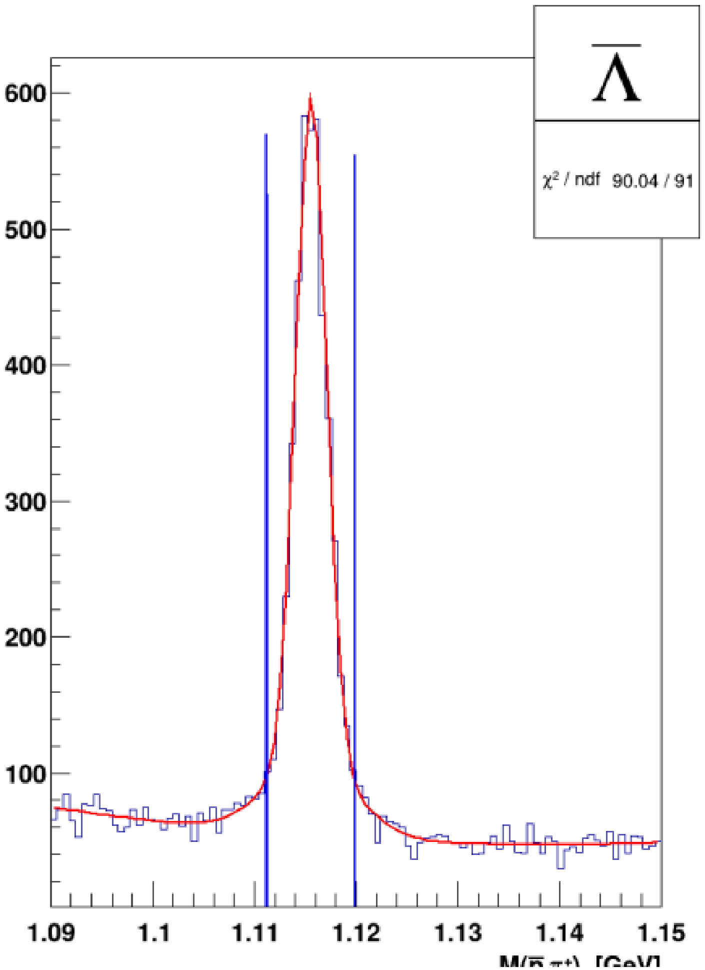
- $0.8\ \mathrm{GeV}^2 < Q^2 < 24\ \mathrm{GeV}^2$
- $W^2 > 10\ \mathrm{GeV}^2$
- $0.2 < y < 0.85$

Background suppression

- leading π rejection (in HERMES kinematics proton is always leading):
- h^+h^- pair background (coming from V_1) rejection, vertex separation:
  - $d(V_1,V_2) > 6$ cm for Λ
  - $d(V_1,V_2) > 10$ cm for $\bar{\Lambda}$

$\Lambda\ \bar{\Lambda}$ invariant mass





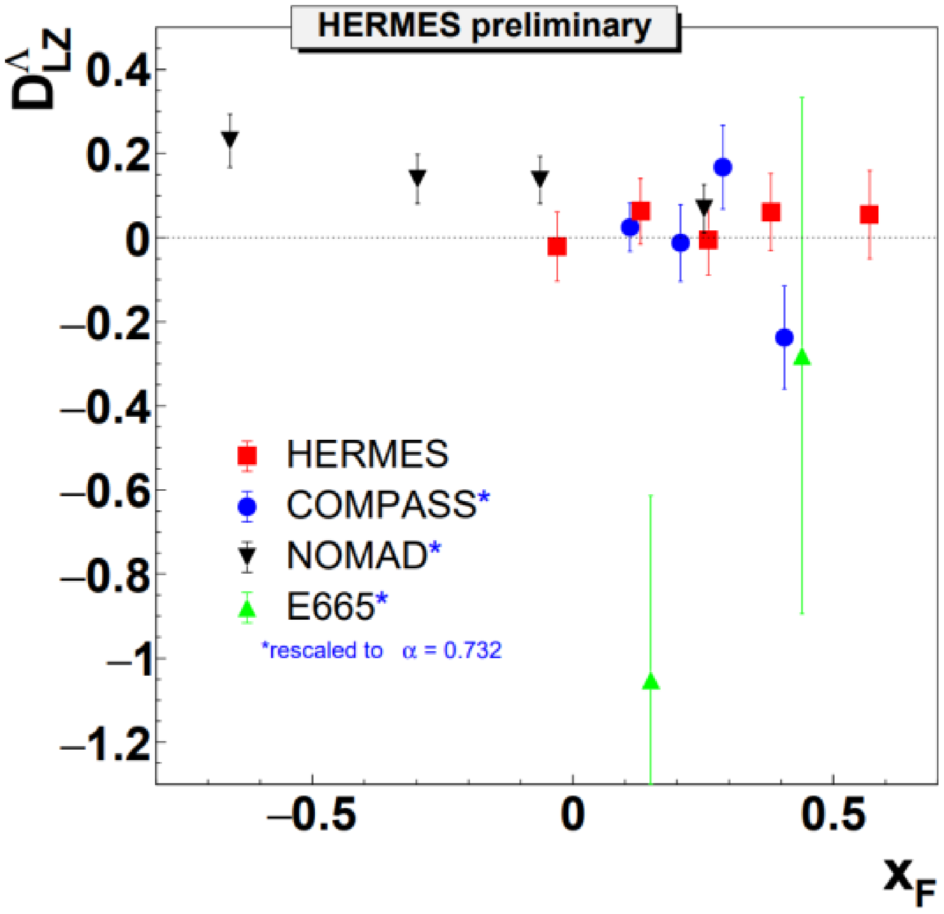
- Just an example for subset of data
- Clear $\Lambda(\bar{\Lambda})$ signal with highly suppressed background
- Background contamination
  - > 5% for Λ
  - > 10% for $\bar{\Lambda}$

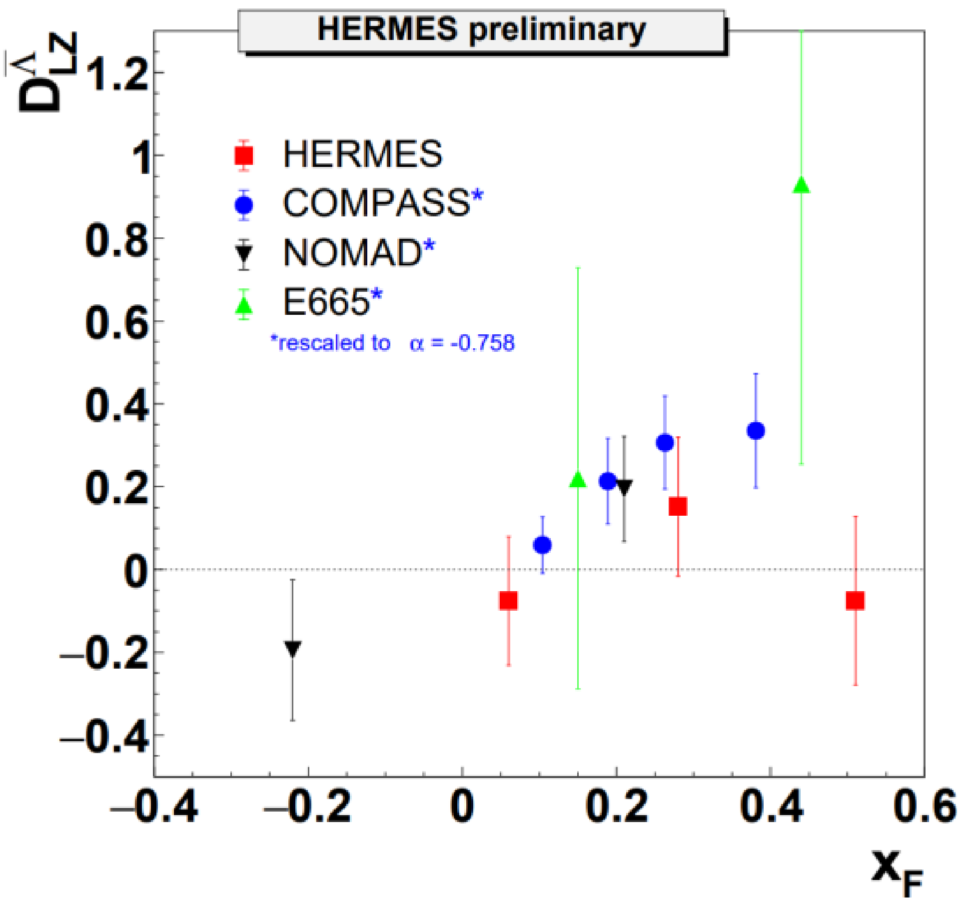
Total numbers of $\Lambda(\bar{\Lambda})$:

$N_{\Lambda} = 46000$

$N_{\bar{\Lambda}} = 6500$

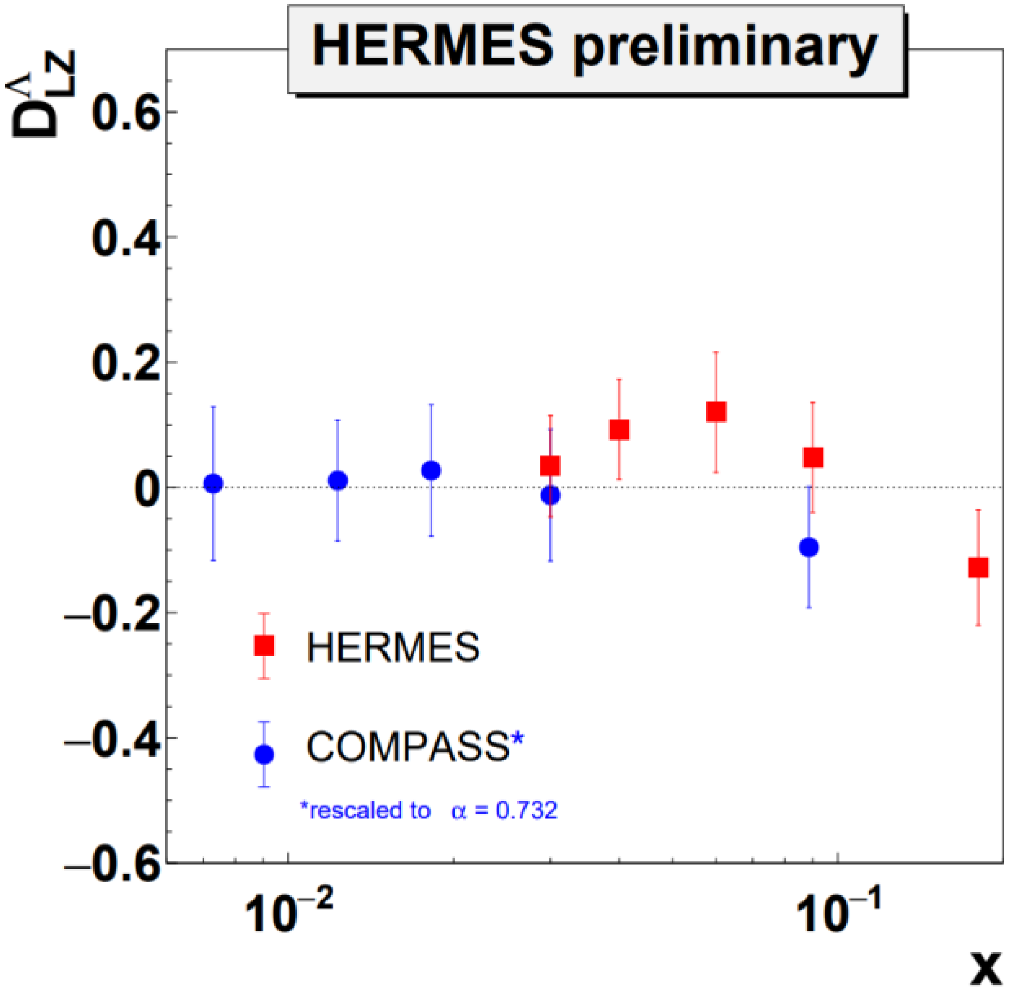
Results

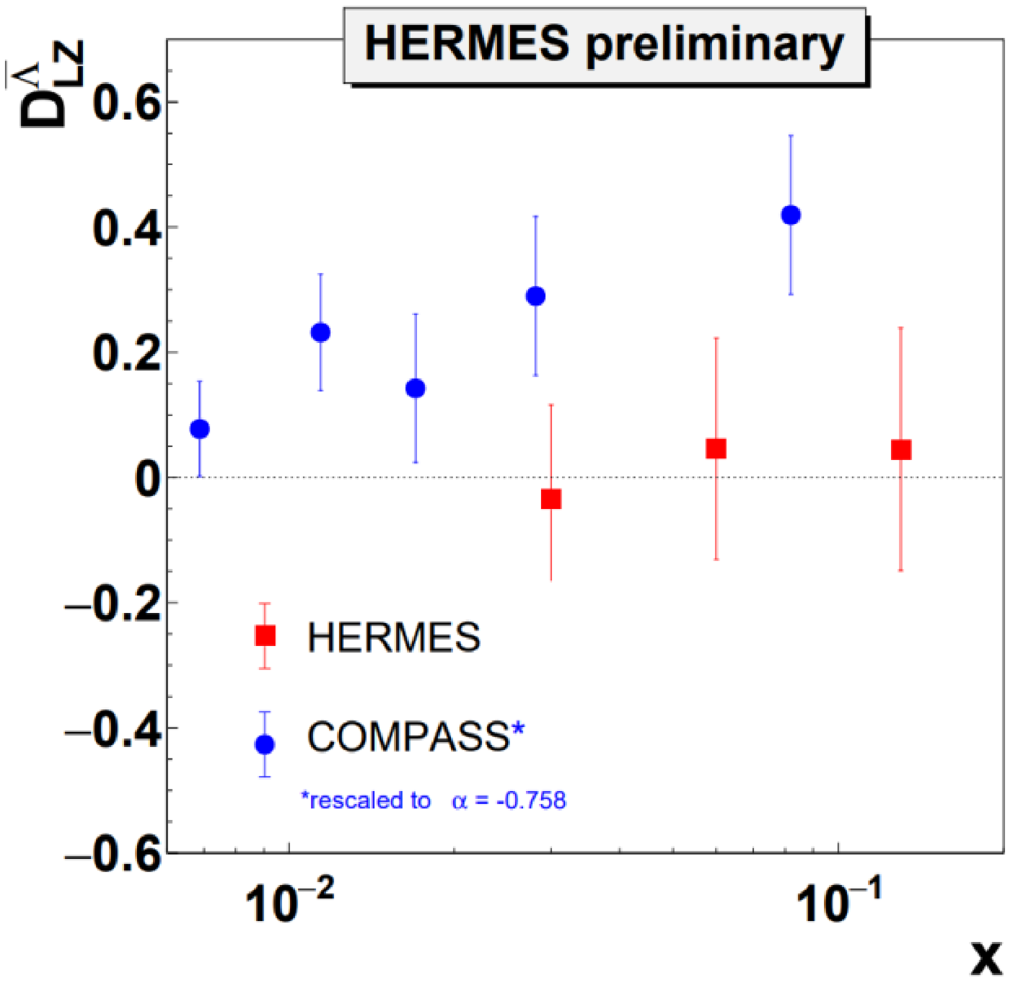




Λ decay constant α has been updated in PDG → use new value and rescale data from other experiment

Results


HERMES preliminary
D_{LZ}^{Λ}
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
HERMES
COMPASS*
*rescaled to α = 0.732
10^{-2}
10^{-1}
x


HERMES preliminary
$D_{LZ}^{\bar{\Lambda}}$
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
HERMES
COMPASS*
*rescaled to α = -0.758
10^{-2}
10^{-1}
x

Conclusion

- Decay of Λ hyperon provides unique possibilities to study spin effects
- Beam-spin transfer to Λ sensitive to various spin-dependent parton distributions and fragmentation functions (e.g. $e(x), G_1^q, \tilde{G}_1^q$ and H_1^q)
- HERMES has a large DIS data set with longitudinal beam polarization
- Availability of both beam-helicity states exploited in novel extraction formalism that does not rely on MC simulations
- Compared to previous HERMES publications, formalism has been extended to 3D case and to data sets that are not helicity-balanced
- Increased data set allows for analysis of also $\bar{\Lambda}$
- This analysis in advanced state, final results/publication to come out soon

Kinematical dependences