Overview of HERMES results on longitudinal spin asymmetries

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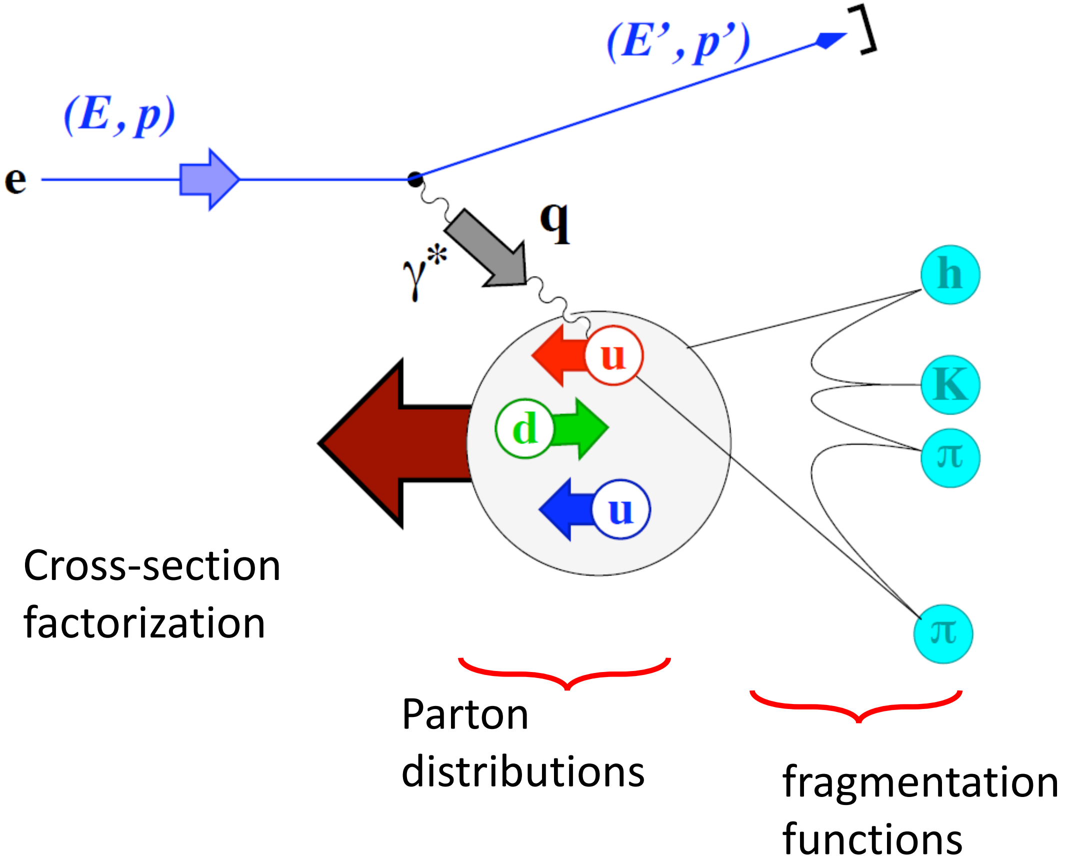
Introduction

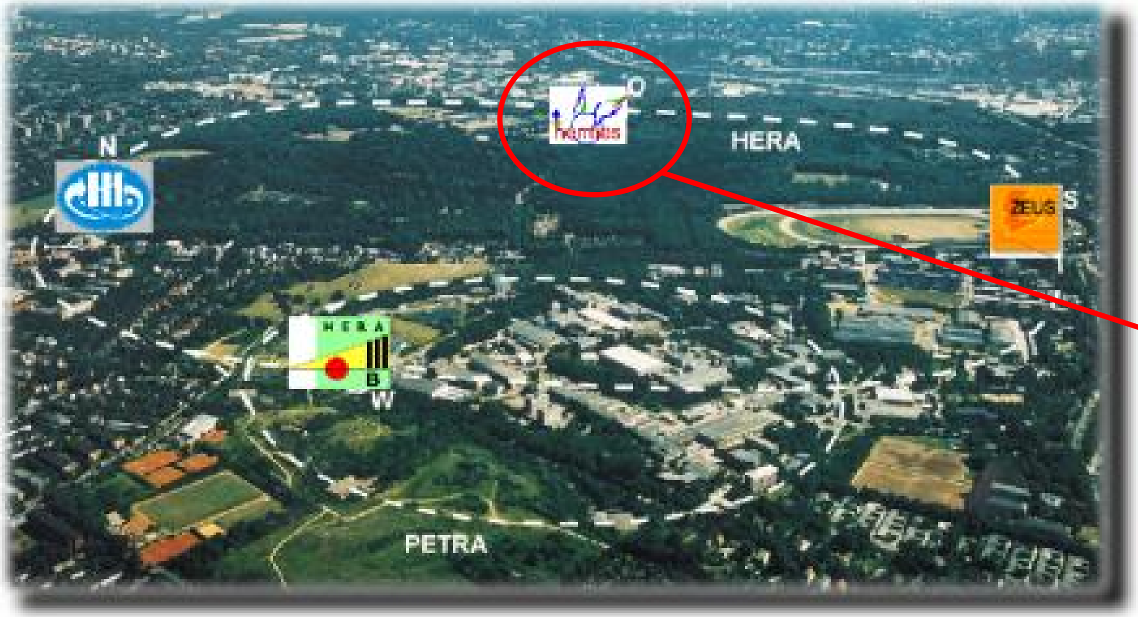
Deep-inelastic scattering (DIS) with charged lepton beams is the key tool for probing the structure of the nucleon. With polarized beams and targets the spin structure of the nucleon becomes accessible

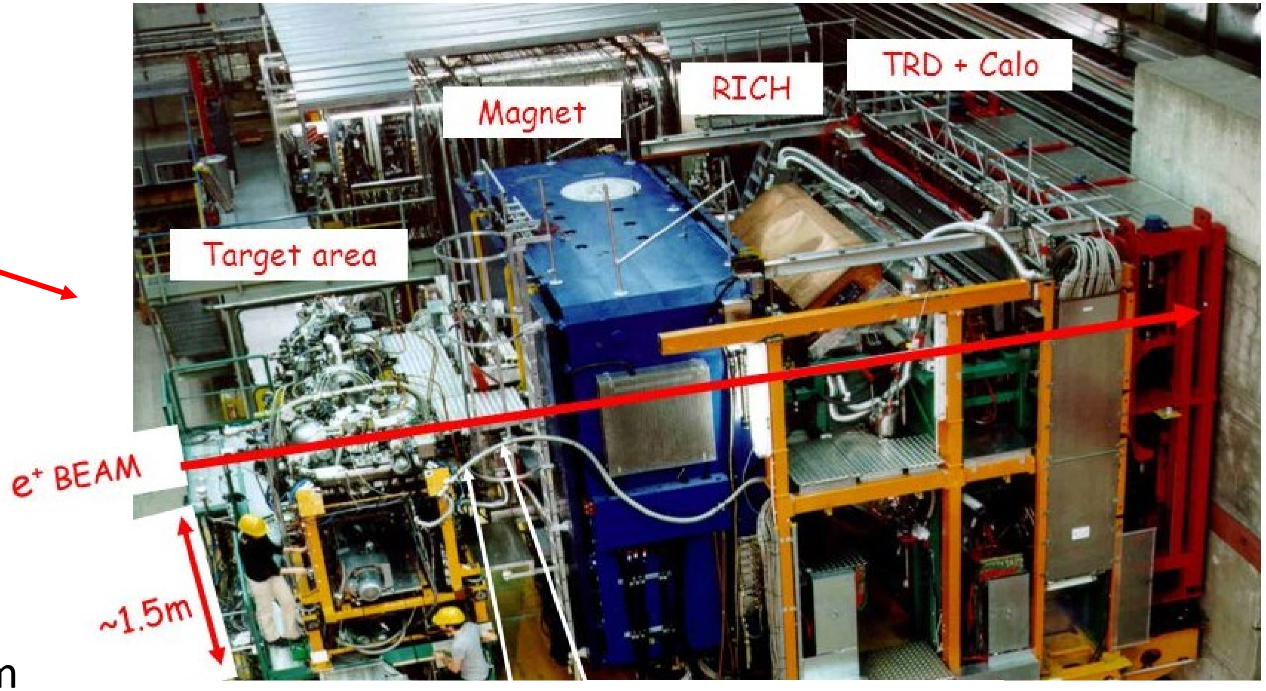
<u>What we need:</u>

- polarized lepton beams
- polarized targets
- large-acceptance spectrometer
- good particle identification (PID)



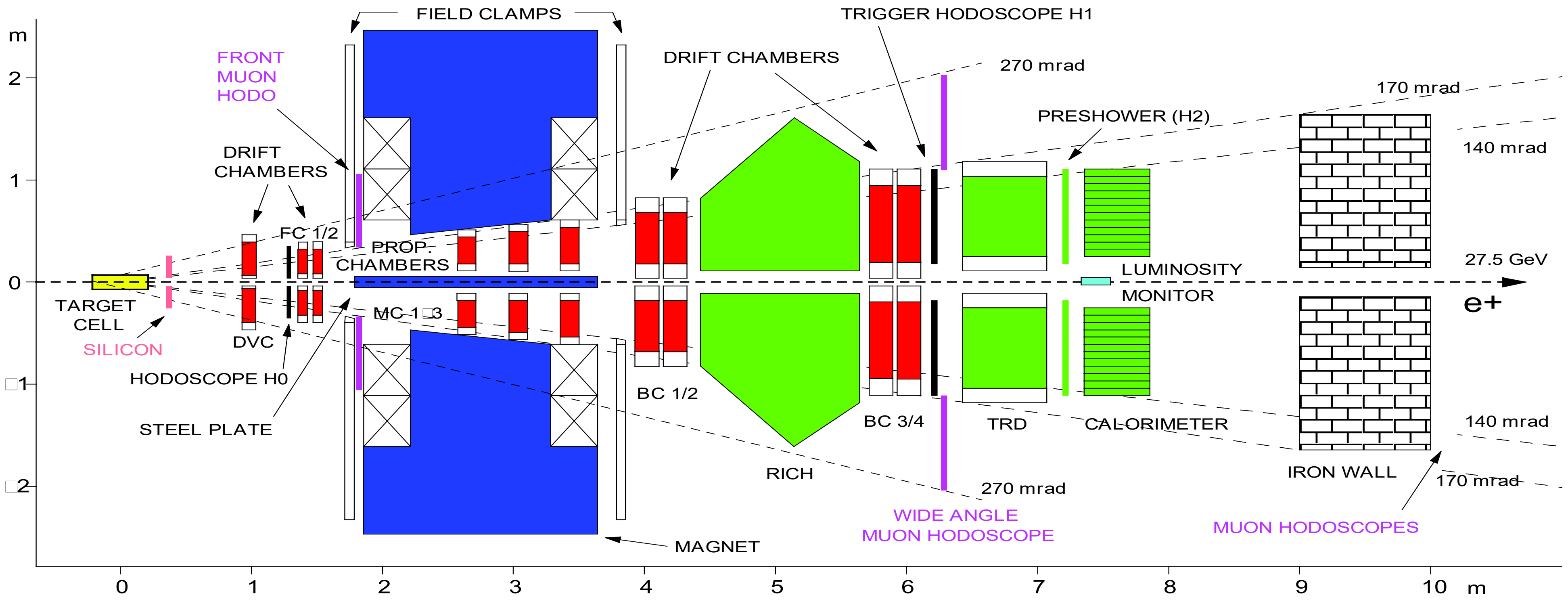
HERMES experiment





- Located at DESY, Hamburg
- 27.6 GeV **longitudinally polarized** (up to 60%) e+/e- beam
- **Longitudinally polarized** (up to 85%) H, D, ^{3}He gas target, flip ~ 90 sec
- Transversely polarized H gas target
- Unpolarized H, D, Ne, … Xe gas target
- Data taking end at 2007

HERMES experiment

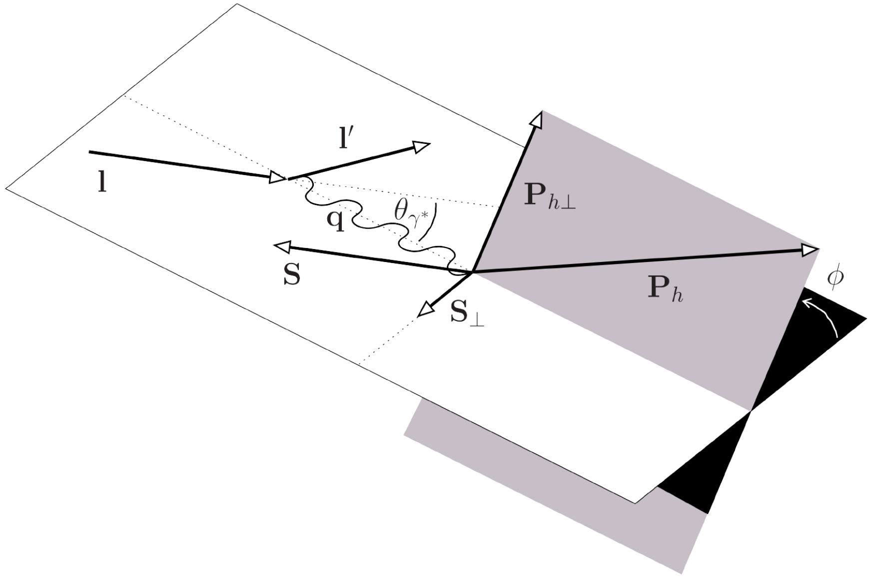


- Top/bottom symmetry
- 40 mrad< θ <220 mrad

- Particle ID detectors allow for:
  - - lepton/hadron separation
  - - Ring Cerenkov detector (RICH): pion/kaon/proton discrimination 2 GeV < p < 15 GeV

Longitudinal double-spin asymmetries

- Cross-section excluding transverse polarization
  - λ - beam helicity
  - Λ - target helicity
  - U/L – unpolarized/longitudinally polarized



$$\frac{d\sigma^h}{dx\,dy\,dz\,dP_{h\perp}^2\,d\phi} = \frac{2\pi\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

$$\Big\{F_{UU,T}^h + \epsilon F_{UU,L}^h + \lambda\Lambda\sqrt{1-\epsilon^2}F_{LL}^h$$

$$+\sqrt{2\epsilon}\left[\lambda\sqrt{1-\epsilon}\,F_{LU}^{h,\sin\phi} + \Lambda\sqrt{1+\epsilon}\,F_{UL}^{h,\sin\phi}\right]\sin\phi$$

$$+\sqrt{2\epsilon}\left[\lambda\Lambda\sqrt{1-\epsilon}\,F_{LL}^{h,\cos\phi} + \sqrt{1+\epsilon}\,F_{UU}^{h,\cos\phi}\right]\cos\phi$$

$$+\Lambda\epsilon\,F_{UL}^{h,\sin 2\phi}\sin 2\phi + \epsilon\,F_{UU}^{h,\cos 2\phi}\cos 2\phi\Big\}$$

double-spin asymmetry

$$A_{LL}^h \equiv \frac{\sigma_{++}^h - \sigma_{+-}^h + \sigma_{--}^h - \sigma_{-+}^h}{\sigma_{++}^h + \sigma_{+-}^h + \sigma_{--}^h + \sigma_{-+}^h}$$

Longitudinal double-spin asymmetries

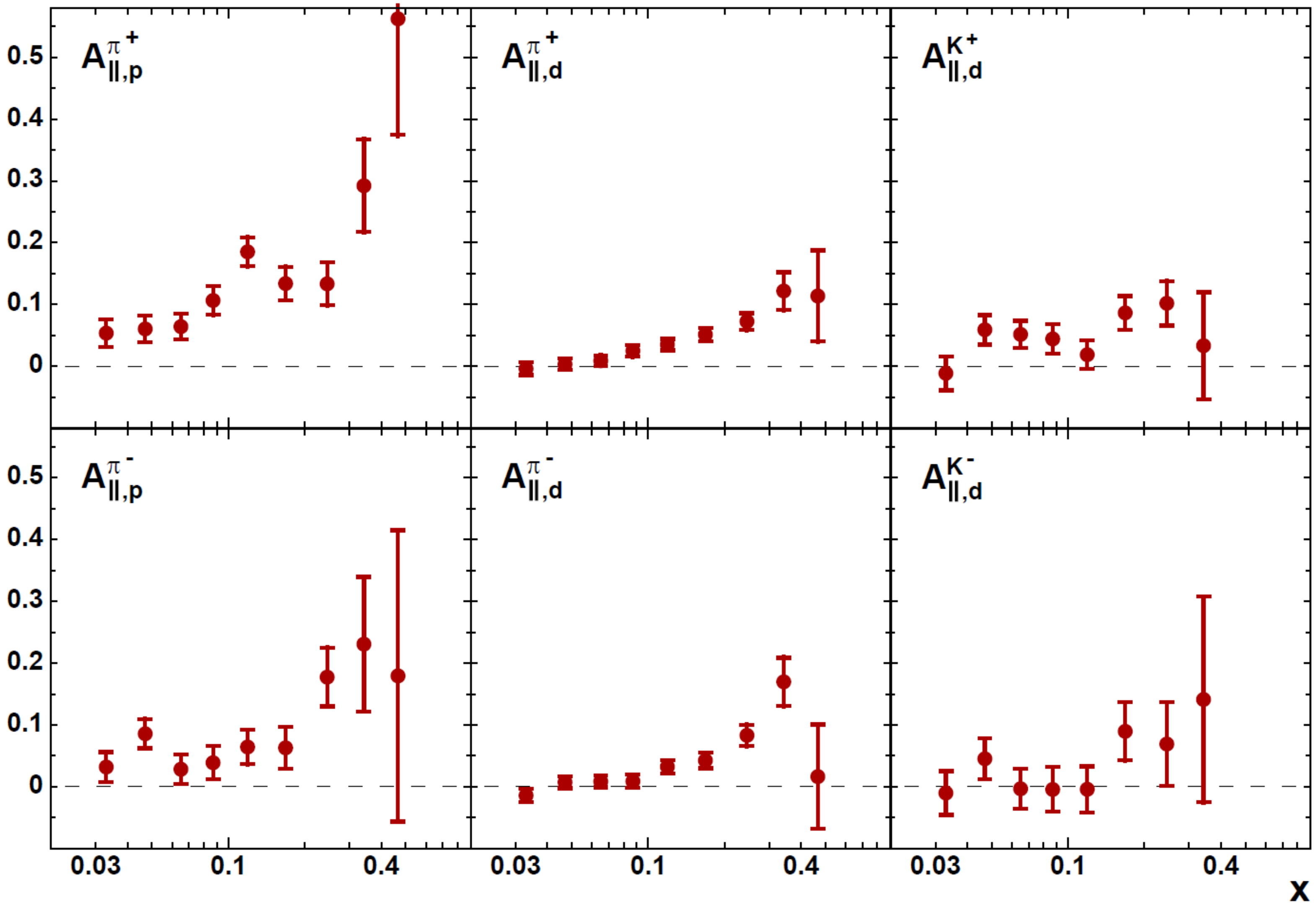
- In experiment extract instead $A_{||}$ which differs from A_{LL} in the way the polarization is measured:
  - A_{LL}: along virtual-photon direction
  - $A_{||}$: along beam direction (results in small admixture of transverse target polarization and thus contributions from A_{LT})
- $A_{||}$ related to virtual-photon–nucleon asymmetry A_1

$$A_1^h = \frac{1}{D(1+\eta\gamma)} A_{\parallel}^h$$

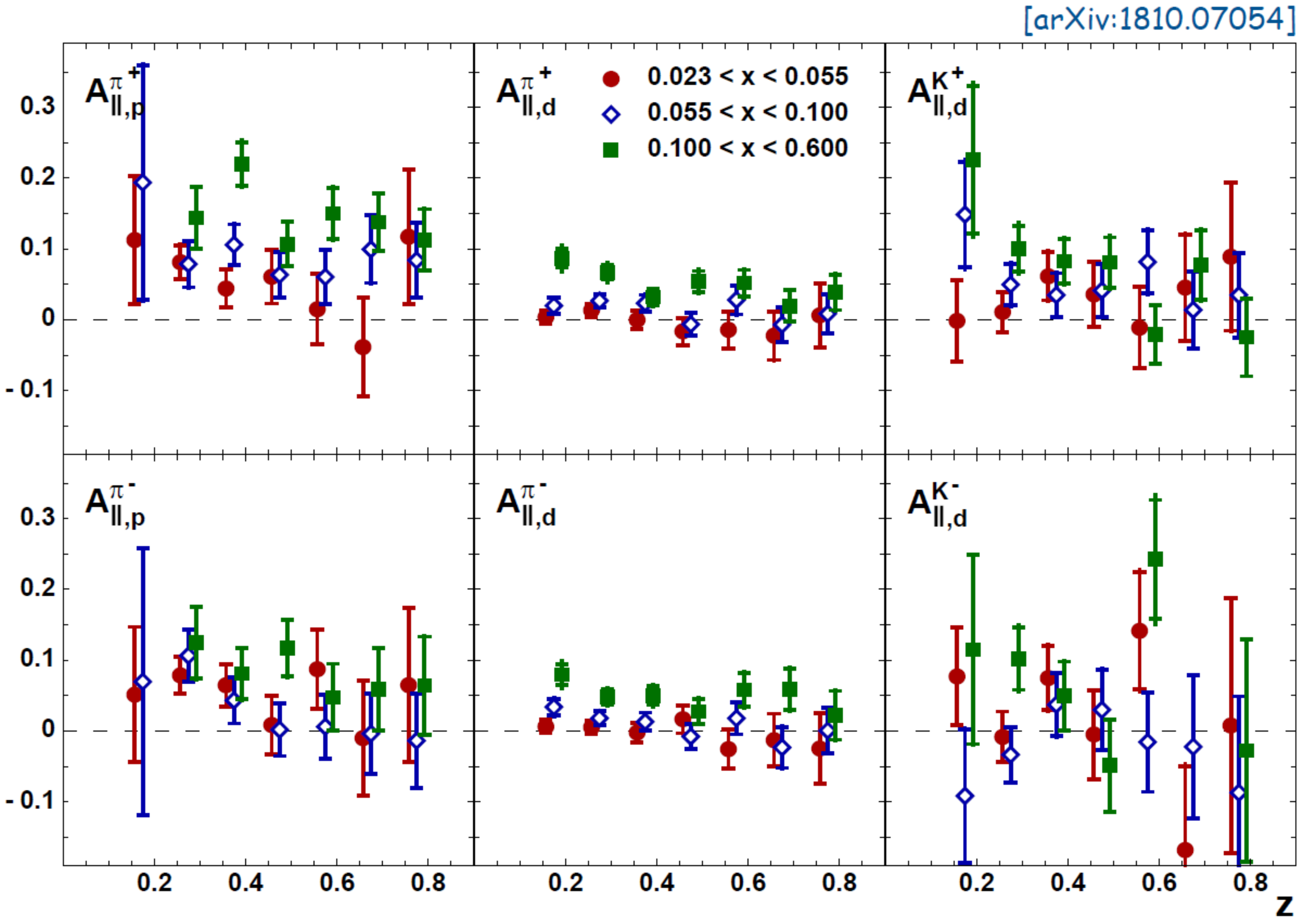
$$D = \frac{1-(1-y)\epsilon}{1+\epsilon R}$$

$$\eta = \frac{\epsilon\gamma y}{1-(1-y)\epsilon}$$

x dependence of $A_{||}$

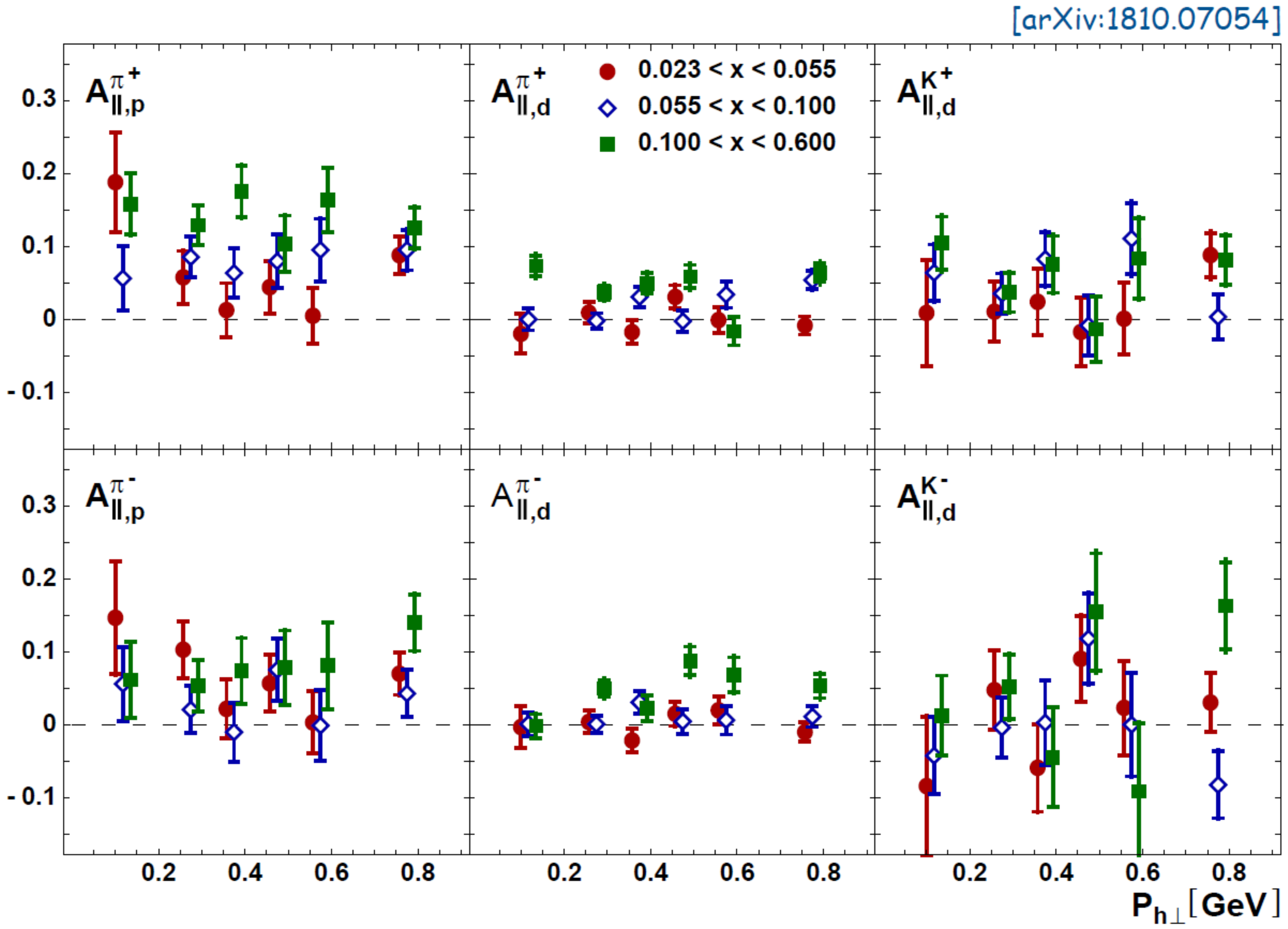


z dependence of $A_{||}$



in general, no strong z-dependence visible

$P_{h\perp}$ dependence of $A_{||}$



again, no strong dependence

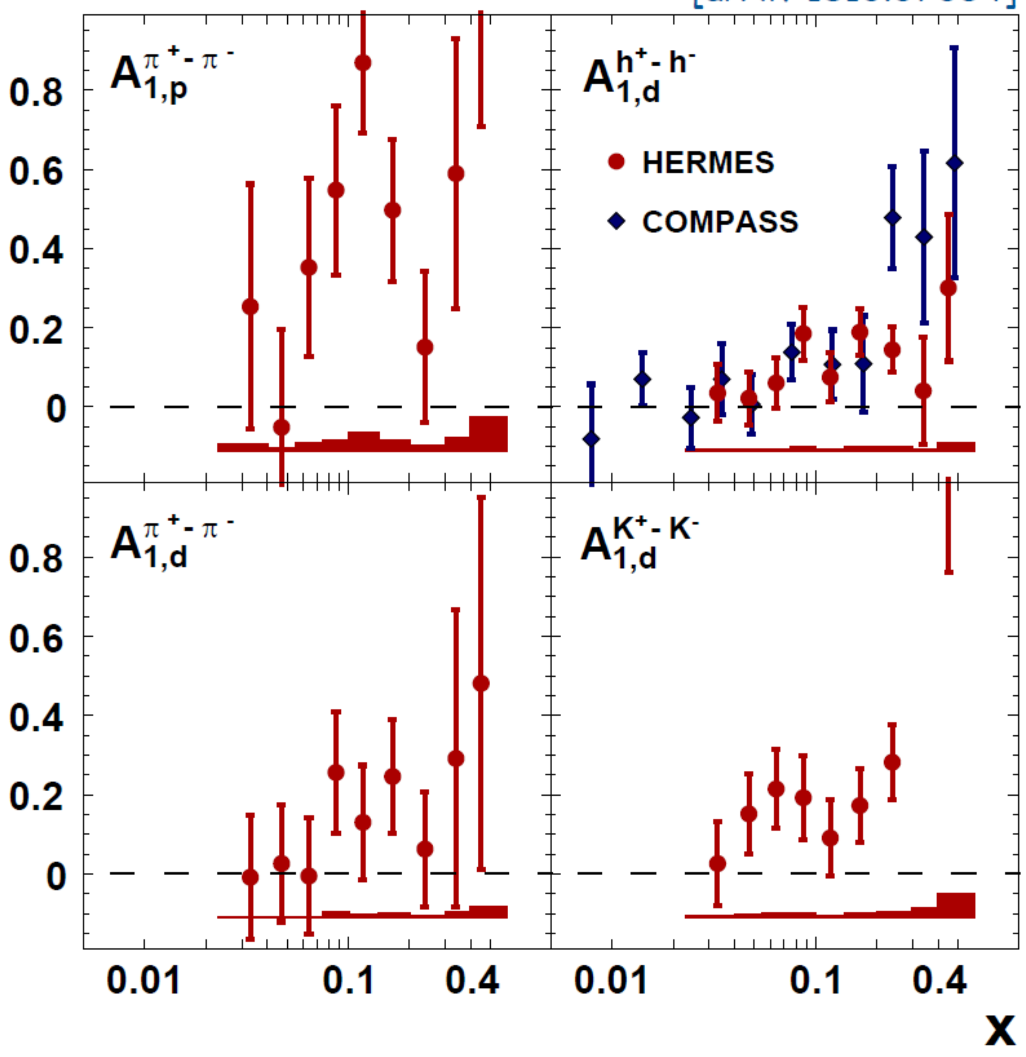
Charge-difference asymmetries

$$A_1^{h^+-h^-}(x) \equiv \frac{\left(\sigma_{1/2}^{h^+} - \sigma_{1/2}^{h^-}\right) - \left(\sigma_{3/2}^{h^+} - \sigma_{3/2}^{h^-}\right)}{\left(\sigma_{1/2}^{h^+} - \sigma_{1/2}^{h^-}\right) + \left(\sigma_{3/2}^{h^+} - \sigma_{3/2}^{h^-}\right)}$$

1/2(3/2) – denotes beam and target spins antiparallel (parallel)

- no significant hadron-type dependence for deuterons
- deuteron results (unidentified hadrons) consistent with COMPASS

[arXiv:1810.07054]



Summary

- several longitudinal double-spin asymmetries in SIDIS have been presented that:
  - extend the analysis of previous HERMES publications to include also transverse-momentum dependence
  - provide $A_{||}$ in addition to A_1
- within precision of the measurements, the virtual-photon-nucleon asymmetries display no significant dependence on z and $P_{h\perp}$
- hadron-charge difference asymmetries in agreement with COMPASS

Beam-helicity asymmetries

- Cross-section excluding transverse polarization
  - λ - beam helicity
  - Λ - target helicity
  - U/L – unpolarized/longitudinally polarized

$$\frac{d\sigma^h}{dx\, dy\, dz\, dP_{h\perp}^2\, d\phi} = \frac{2\pi\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

$$\Big\{F_{UU,T}^h + \epsilon F_{UU,L}^h + \lambda\Lambda\sqrt{1-\epsilon^2}\,F_{LL}^h$$

$$+\sqrt{2\epsilon}\left[\lambda\sqrt{1-\epsilon}\,F_{LU}^{h,\sin\phi} + \Lambda\sqrt{1+\epsilon}\,F_{UL}^{h,\sin\phi}\right]\sin\phi$$

$$+\sqrt{2\epsilon}\left[\lambda\Lambda\sqrt{1-\epsilon}\,F_{LL}^{h,\cos\phi} + \sqrt{1+\epsilon}\,F_{UU}^{h,\cos\phi}\right]\cos\phi$$

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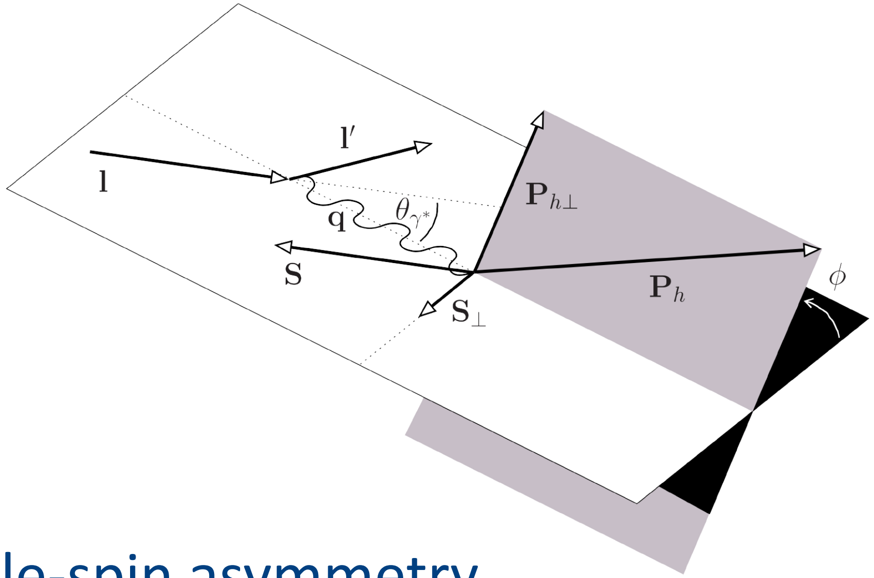


single-spin asymmetry

$$A_{LU}^h \equiv \frac{\sigma_{+-}^h + \sigma_{++}^h - \sigma_{-+}^h - \sigma_{--}^h}{\sigma_{+-}^h + \sigma_{++}^h + \sigma_{-+}^h + \sigma_{--}^h}$$

$$A_{LU}^h \simeq \sqrt{2\epsilon(1-\epsilon)}\,\frac{F_{LU}^{h,\sin\phi}}{F_{UU}^h}\sin\phi$$

Beam-helicity asymmetries

$$F_{LU}^{\sin\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(xe\,H_1^{\perp} + \frac{M_h}{M}\,f_1\frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(xg^{\perp}D_1 + \frac{M_h}{M}\,h_1^{\perp}\frac{\tilde{E}}{z}\right)\right]$$

Describe intrinsic motion of quarks and gluons inside target nucleon due to correlations of p_T and its spin s with the spin of the target nucleon S

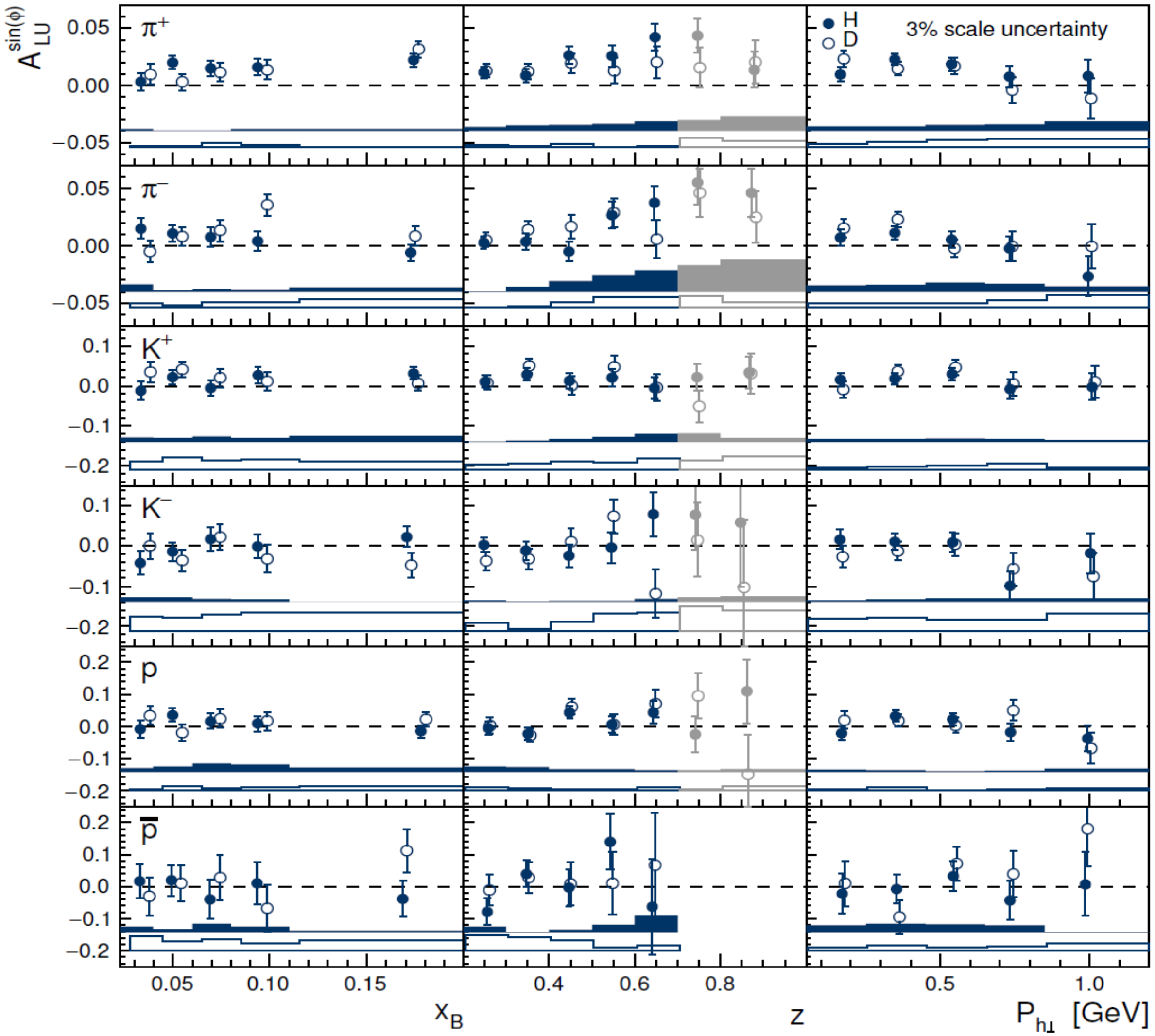
asymmetry amplitudes extracted by minimizing

$$-\ln\mathbb{L} = -\sum_i w_i\,\ln\left[1 + P_{B,i}\,\sqrt{2\epsilon_i(1-\epsilon_i)}\;A_{LU}^{h,\sin(\phi)}\;\sin(\phi_i)\right]$$

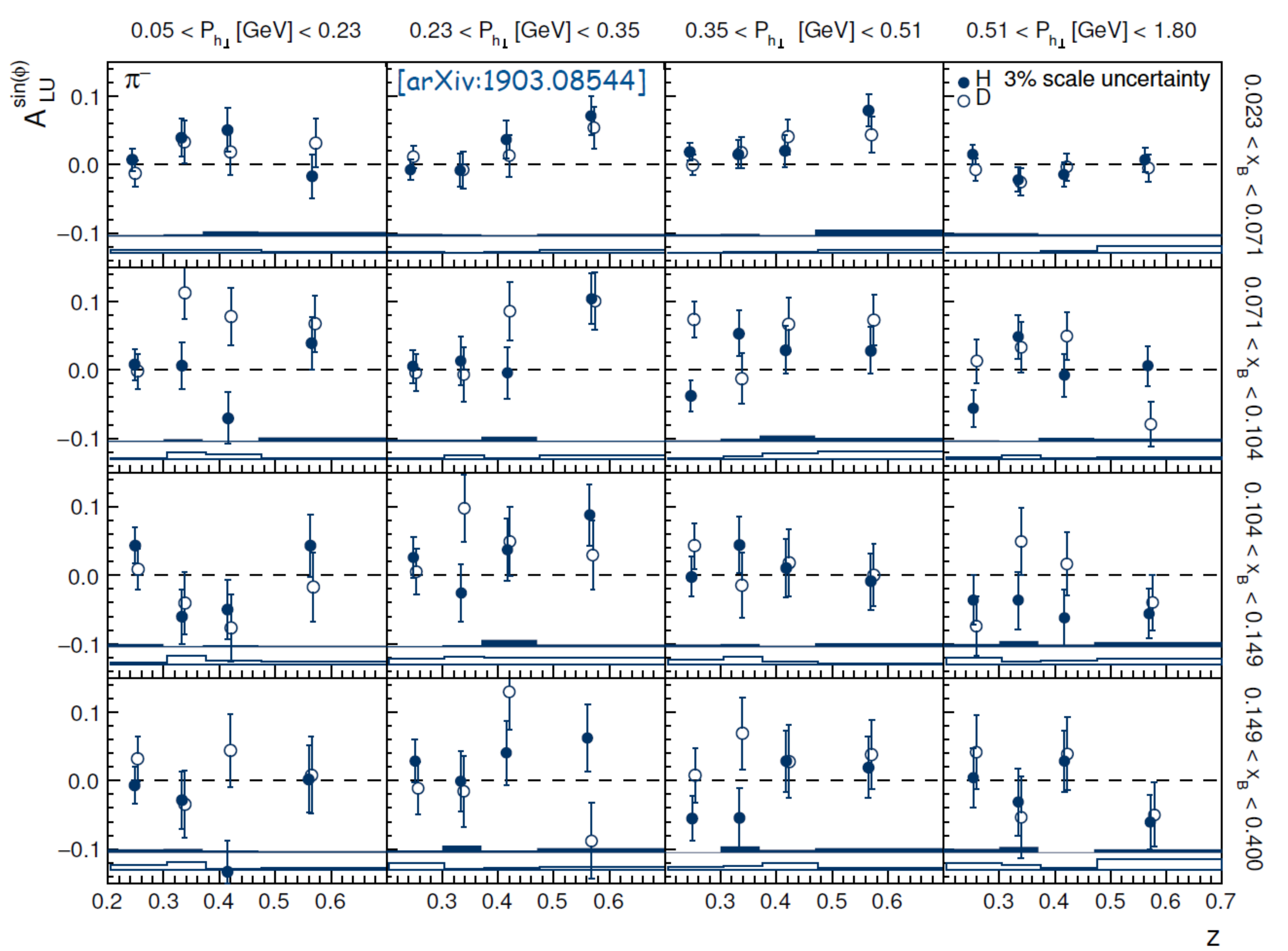
where w_i is event weight from hadron-ID, charge-symmetric background, etc.

Beam-helicity asymmetry

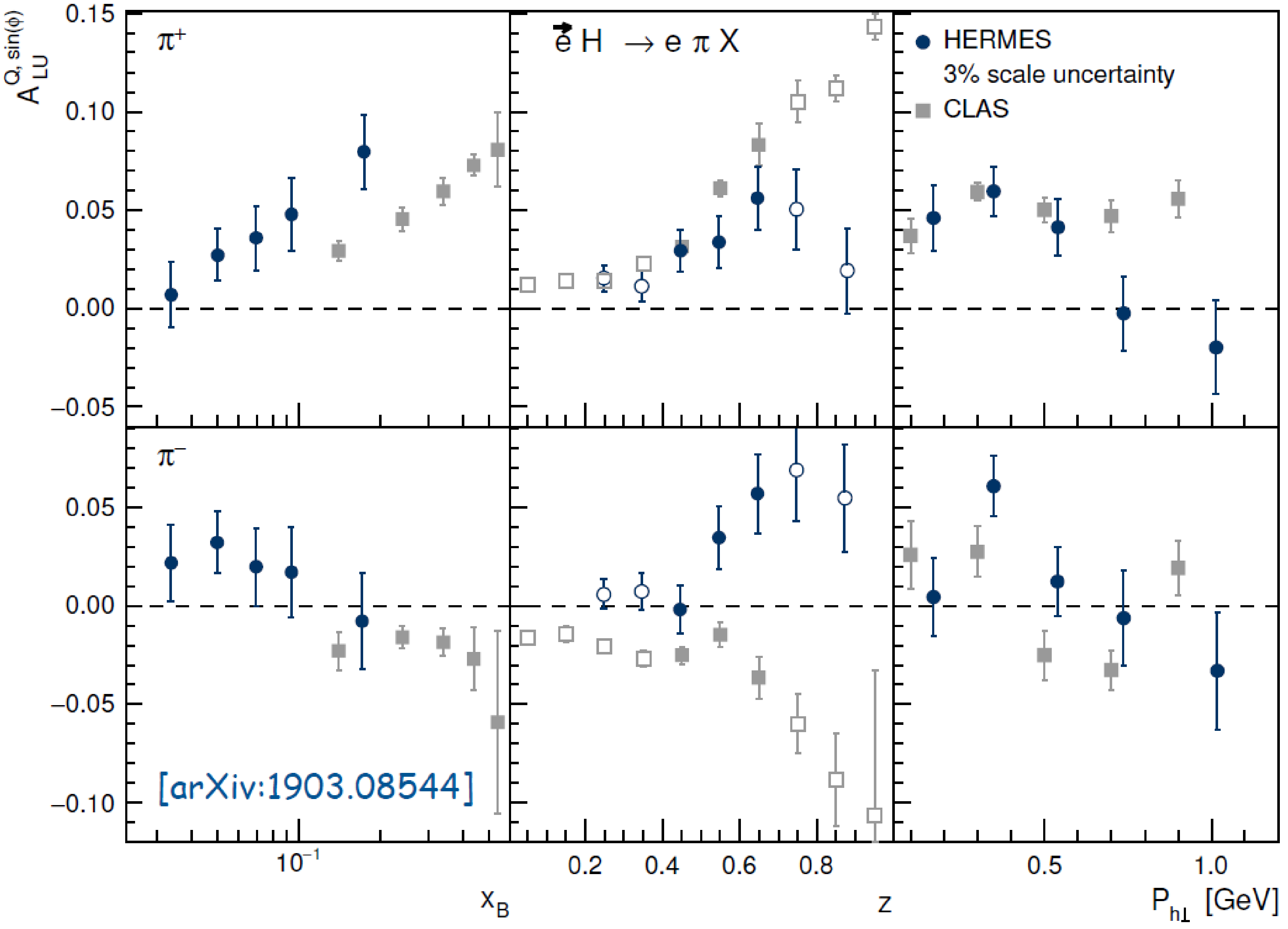
[arXiv:1903.08544]



3D beam-helicity asymmetry for π-

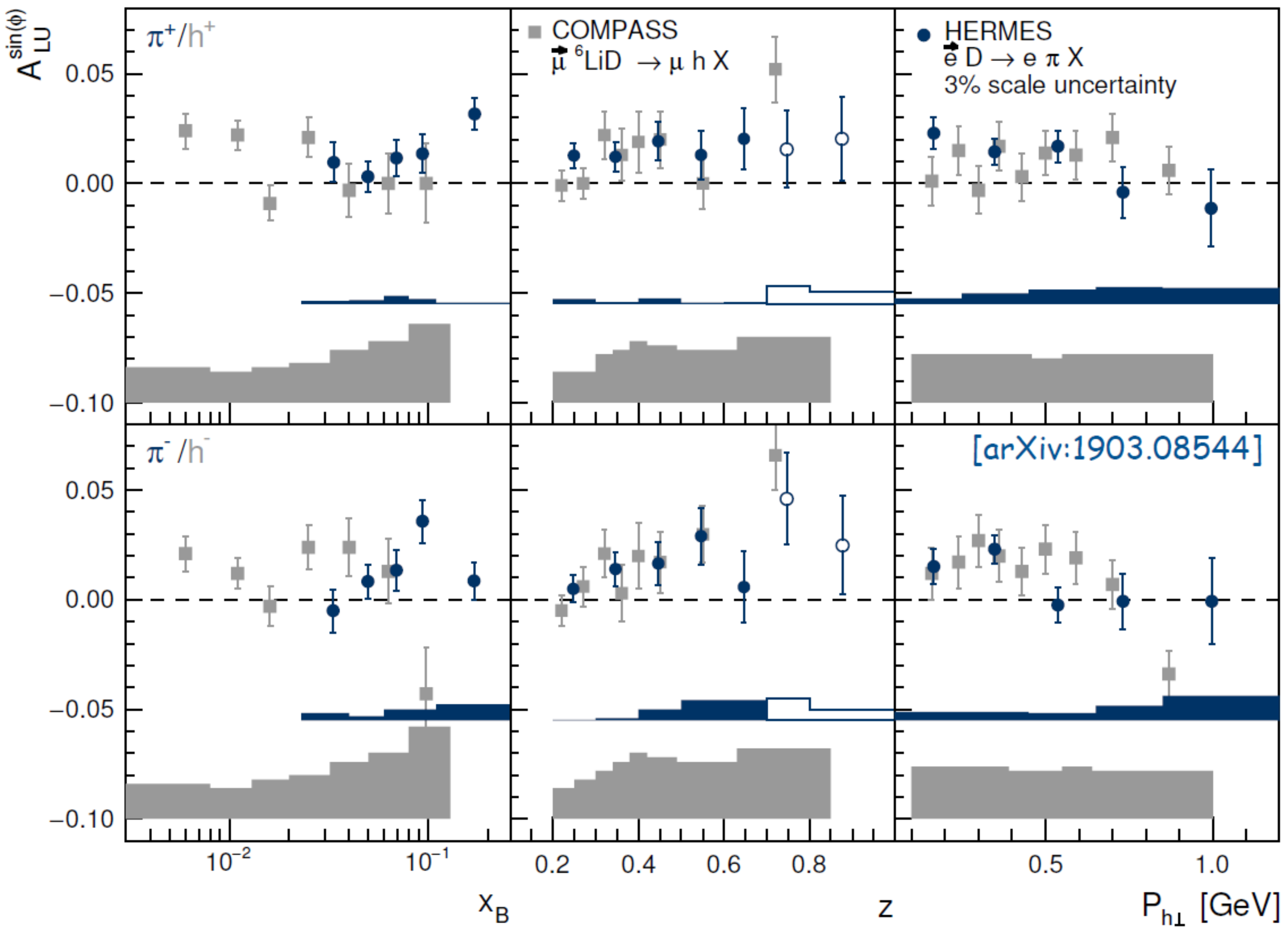


HERMES - CLAS comparison



opposite behavior at HERMES/CLAS of negative pions in z projection due to different x-range

HERMES - COMPASS comparison



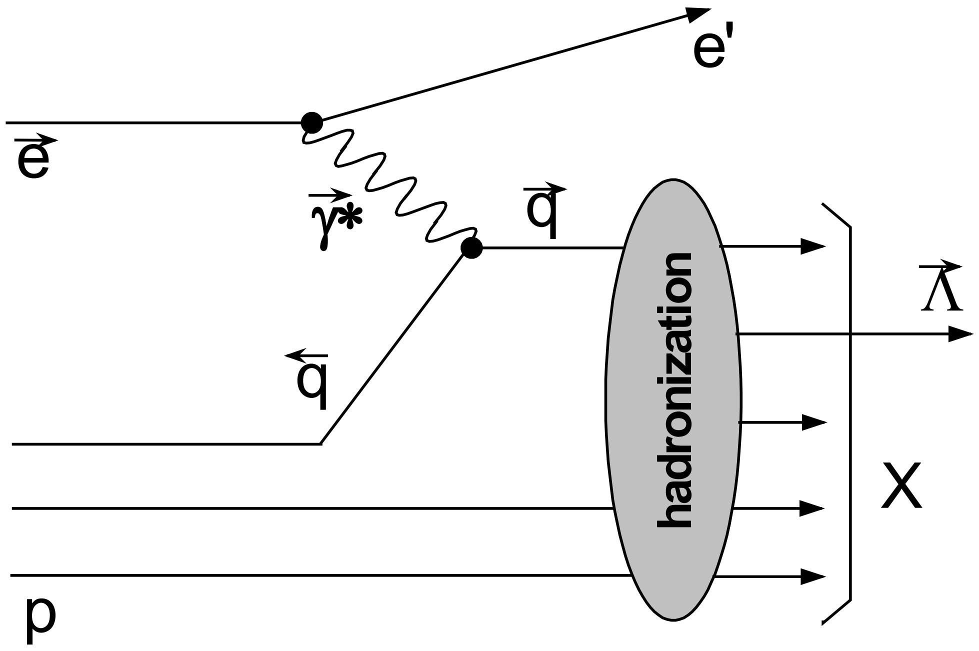
consistent behavior for charged pions / hadrons at HERMES / COMPASS

Summary

- clearly non-zero beam-helicity asymmetries observed for charged pions and K+
- high-x behavior in HERMES - CLAS comparison might be driven by TMD e & Collins FF
- COMPASS and HERMES in agreement despite different Q2 ranges probed

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

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



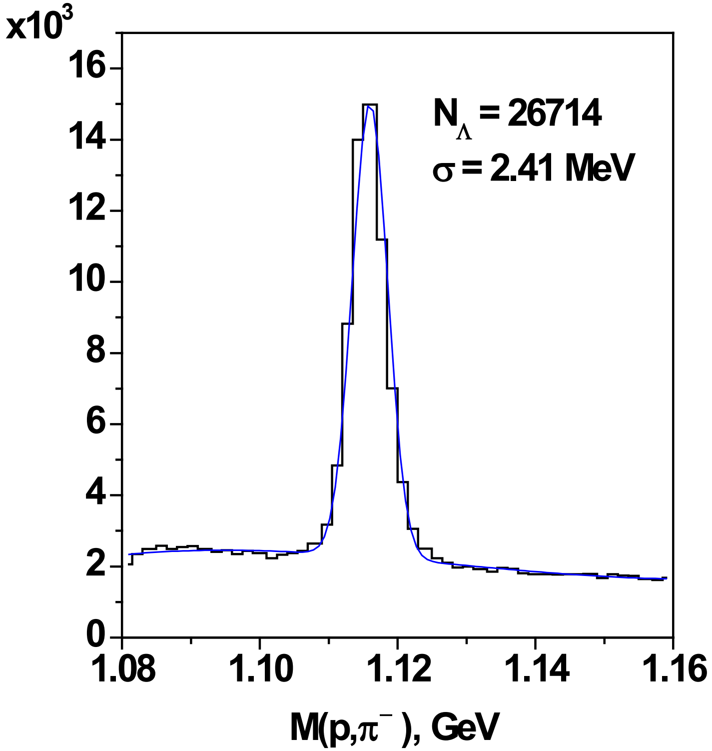
Due to weak decay polarization of the Λ can be extracted by measuring angular distribution of decay proton

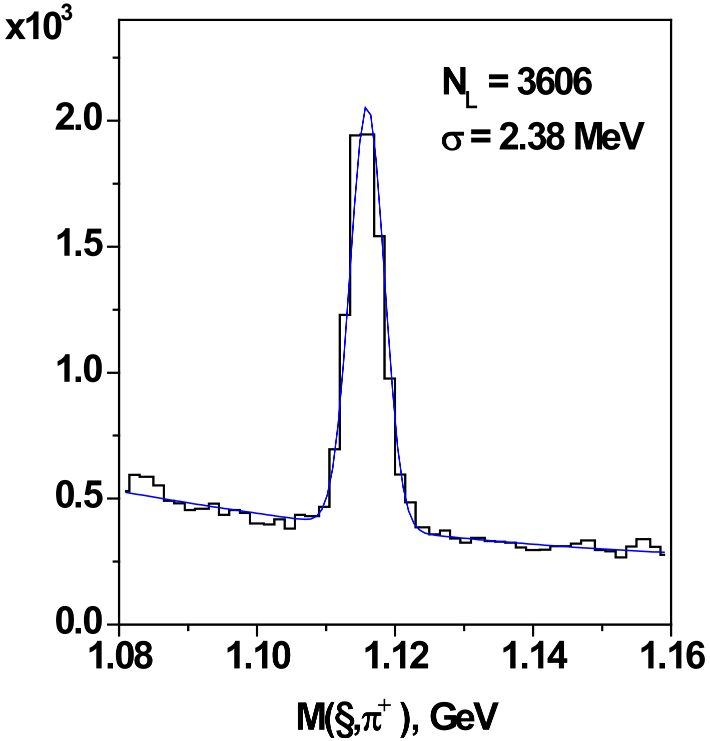
$$P_{L'}^{\Lambda} = P_{\gamma^*} D_{LL'} = P_b D(y) D_{LL'}$$

L – primary axis, along virtual photon
L' – secondary axis, along lambda momentum
$P_{\gamma^*} = P_b D(y)$, virtual gamma polarization
$D(y)$, depolarization factor

Longitudinal spin transfer coefficient give us access to spin structure of Λ hyperon

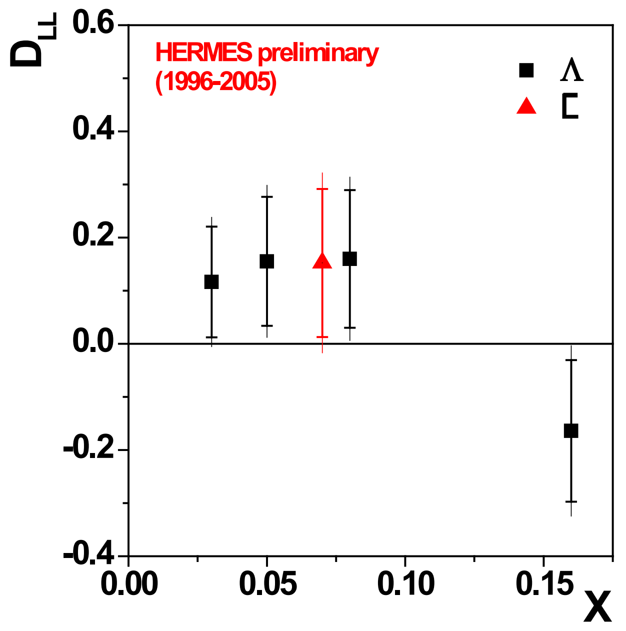
Invariant mass distribution for Λ and $\bar{\Lambda}$

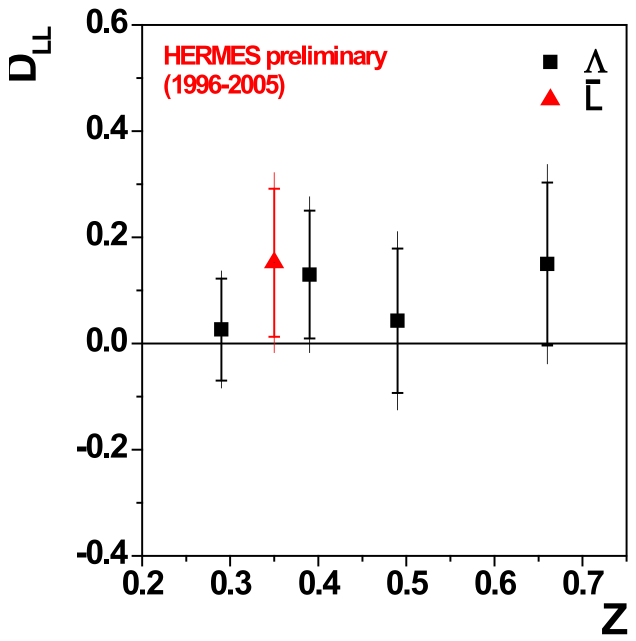


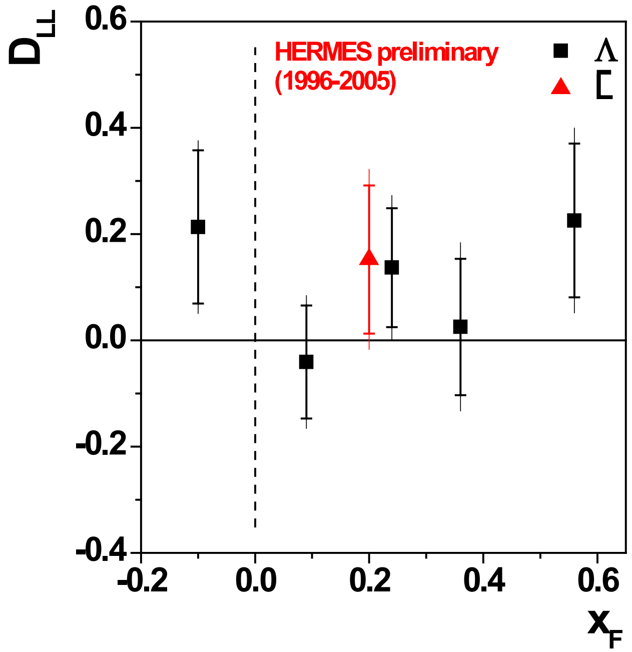


Statistic for $\bar{\Lambda}$ is about 6 times less

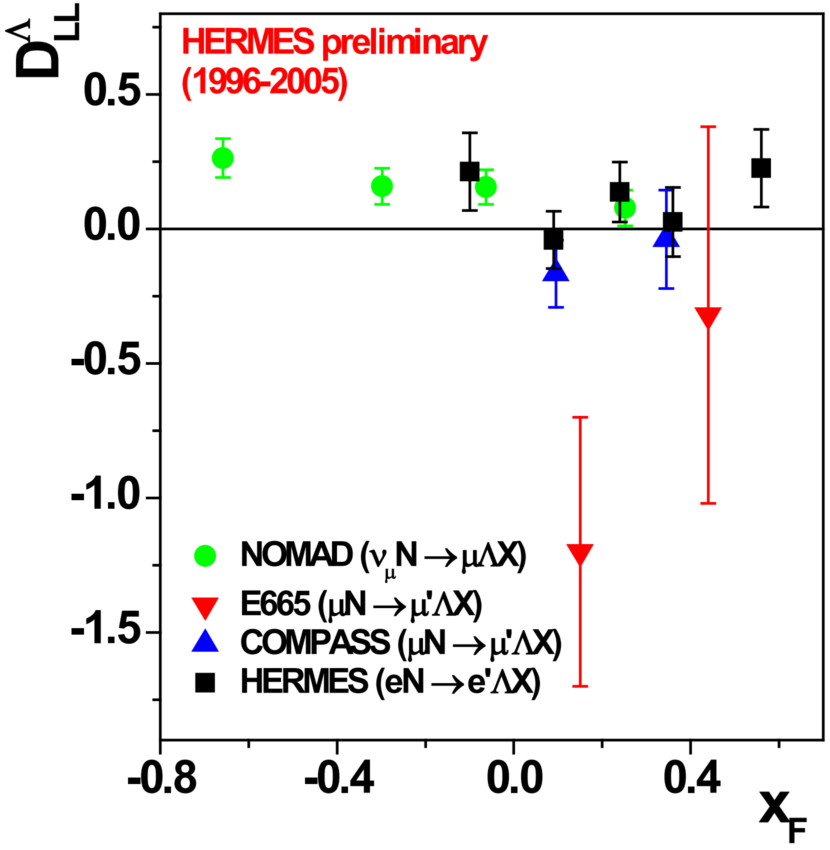
Kinematical dependences of D_{LL}







Comparison of HERMES data with other experiments



Summary

- Kinematical dependencies of spin transfer coefficient have been presented
- All dependencies are practically flat (limited statistic?)
- Comparison with other experiments shows a good agreement