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Overview of recent HERMES results on longitudinal spin asymmetries

D. Veretennikov on behalf of the HERMES collaboration

eman ta zabal zazu
Universidad del País Vasco
Euskal Herriko Unibertsitatea

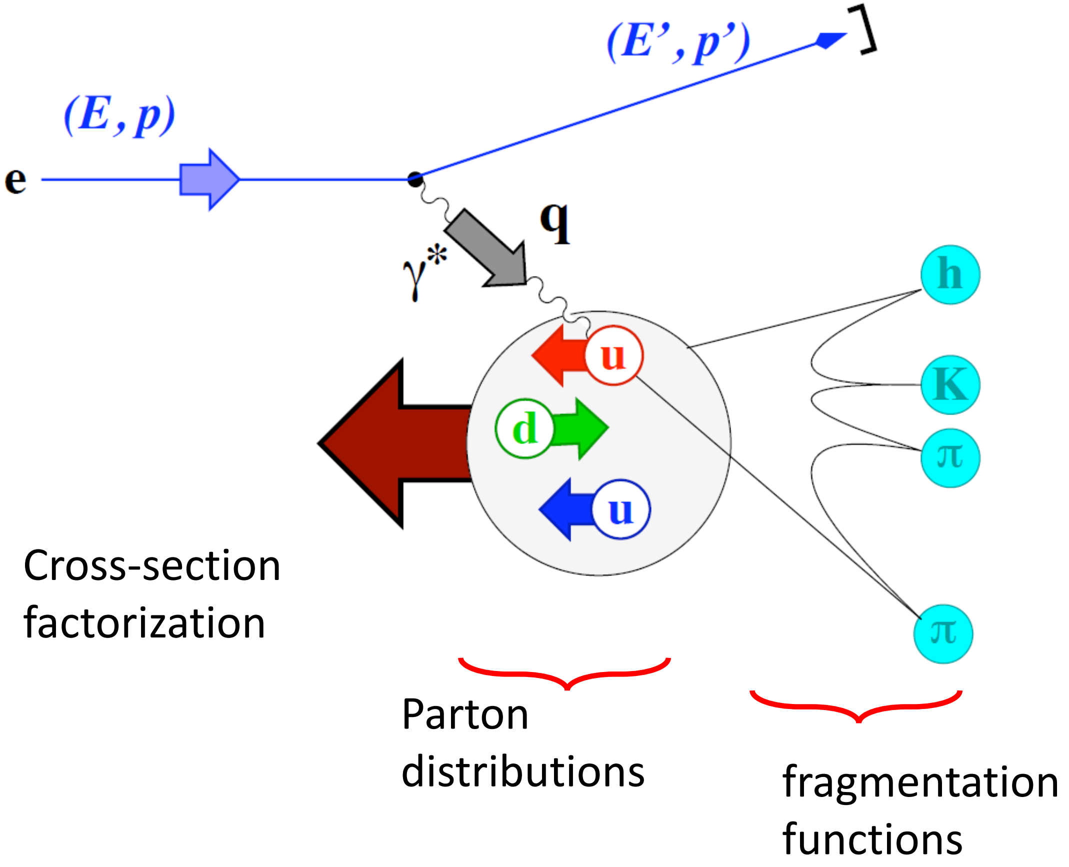
University of the Basque Country
UPV/EHU

Introduction

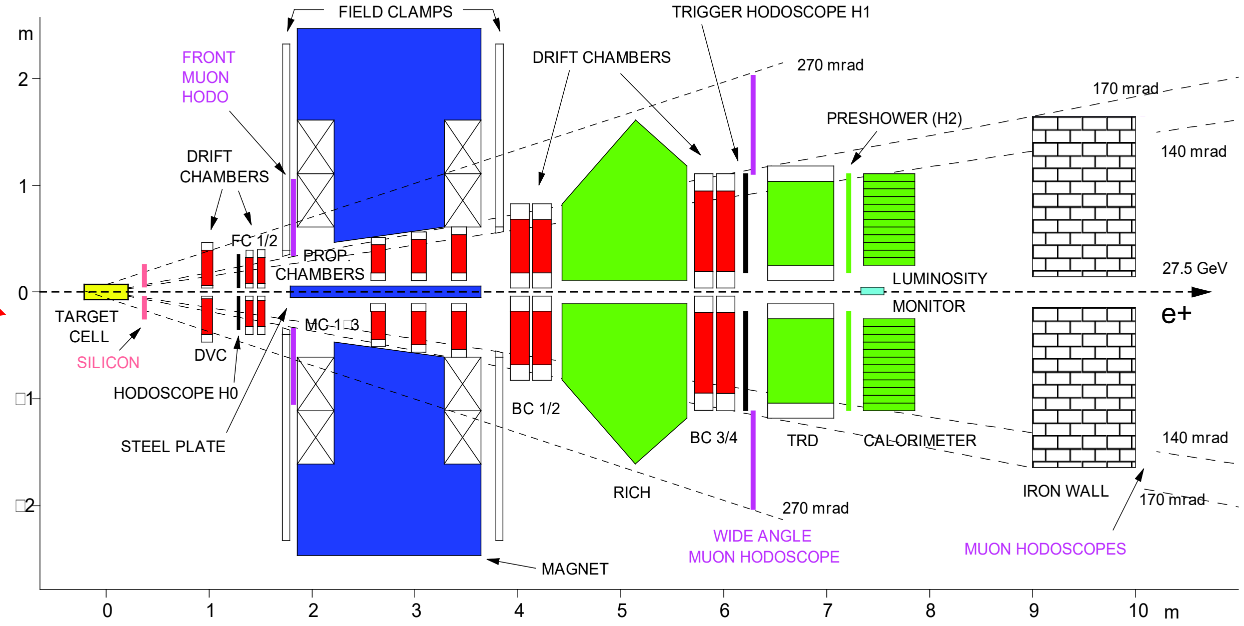
Deep-inelastic scattering (DIS) with charged lepton beams is the key tool for probing the structure of the nucleon. With polarized beams and targets the spin structure of the nucleon becomes accessible

<u>What we need:</u>

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



HERMES experiment

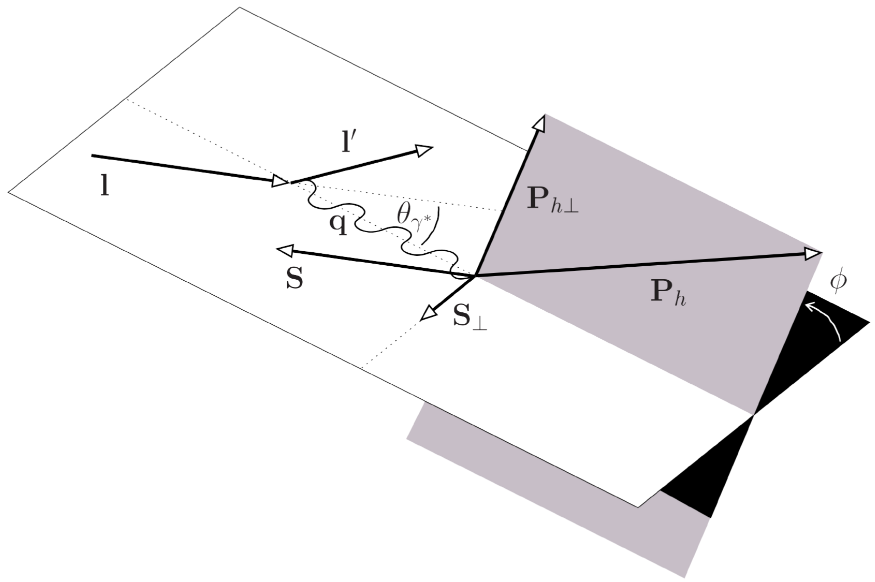


- Located at DESY, Hamburg
- 27.6 GeV **longitudinally polarized** (up to 60%) e+/e- beam
- **Longitudinally polarized** (up to 85%) pure H, D, ^{3}He gas target, flip ~ 90 sec
- Transversely polarized H gas target
- Unpolarized H, D, Ne, … Xe gas target
- Data taking end at 2007

- Particle ID detectors allow for:
  - - lepton/hadron separation
  - - Ring Imaging Cherenkov 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



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

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

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

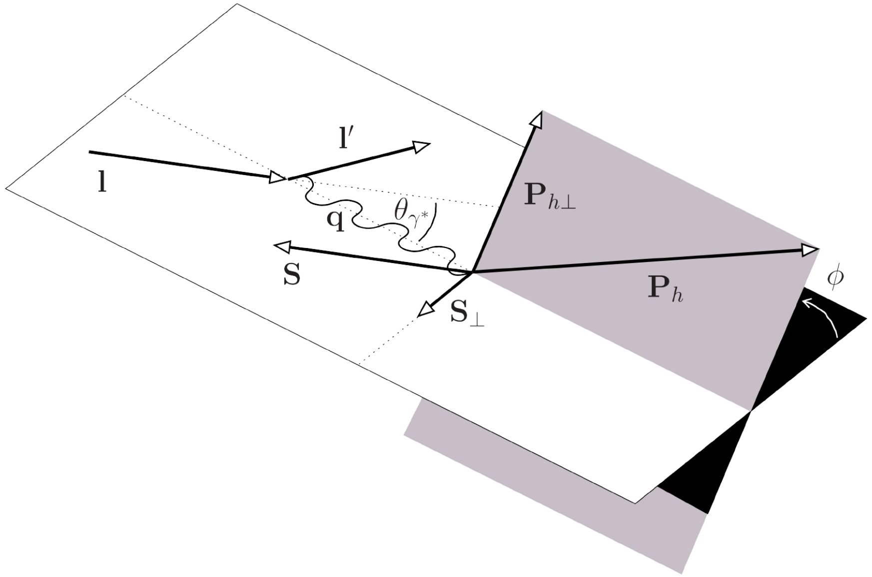
$$+\sqrt{2\epsilon}\left[\lambda\Lambda\sqrt{1-\epsilon}\,F_{LL}^{h,\cos\phi} + \sqrt{1+\epsilon}\,F_{UU}^{h,\cos\phi}\right]\cos\phi$$

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

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



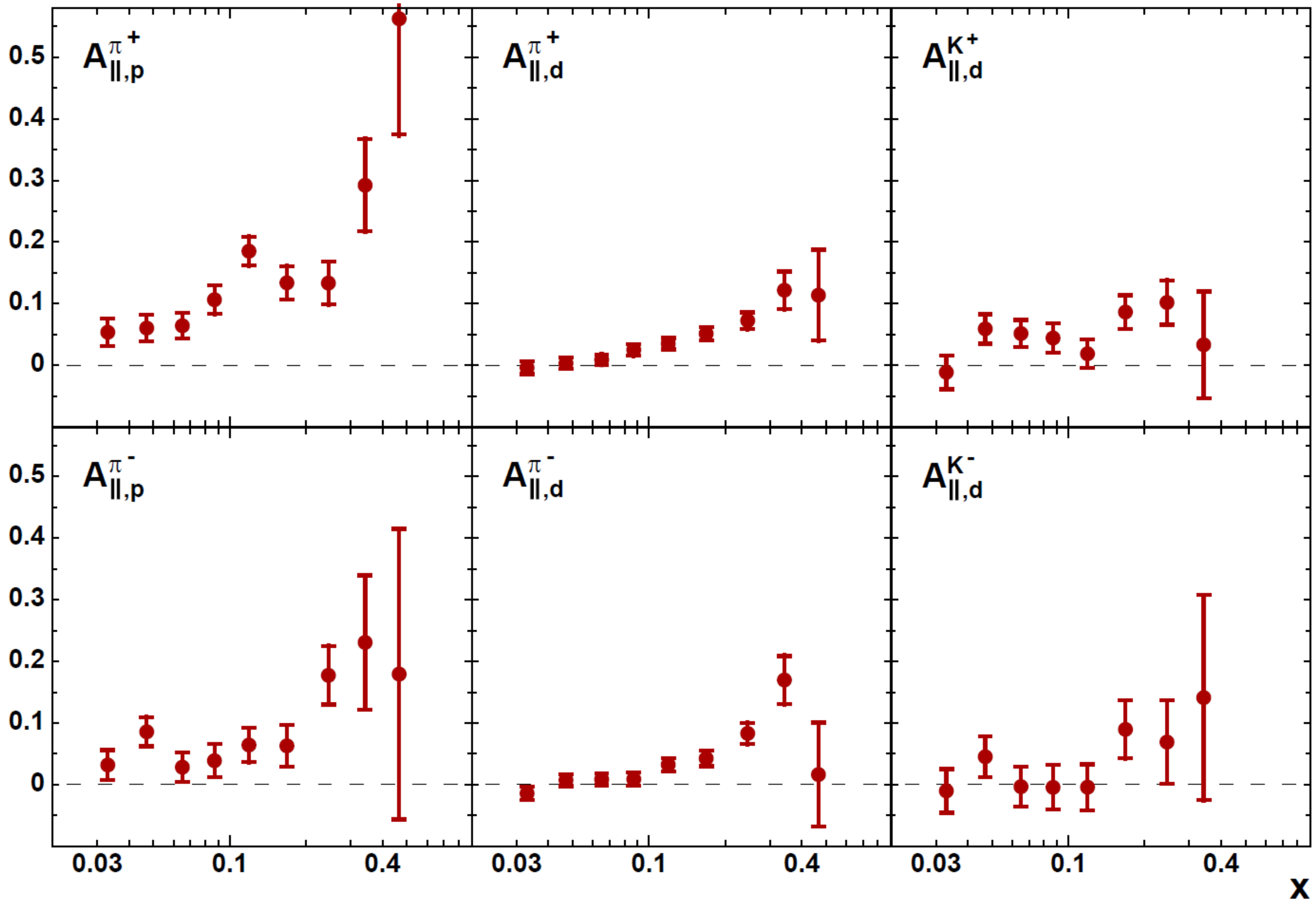
- In experiment extract instead $A_{||}$ which differs from A_{LL} in the way the target polarization is measured:
  - A_{LL}: along virtual-photon direction
  - $A_{||}$: along beam direction (results in small admixture of transverse target polarization and thus contributions from A_{LT})
- $A_{||}$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

$$A_1^h \equiv \frac{\sigma^h_{1/2} - \sigma^h_{3/2}}{\sigma^h_{1/2} + \sigma^h_{3/2}} = \frac{1}{D(1+\eta\gamma)} A_\parallel^h$$

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

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

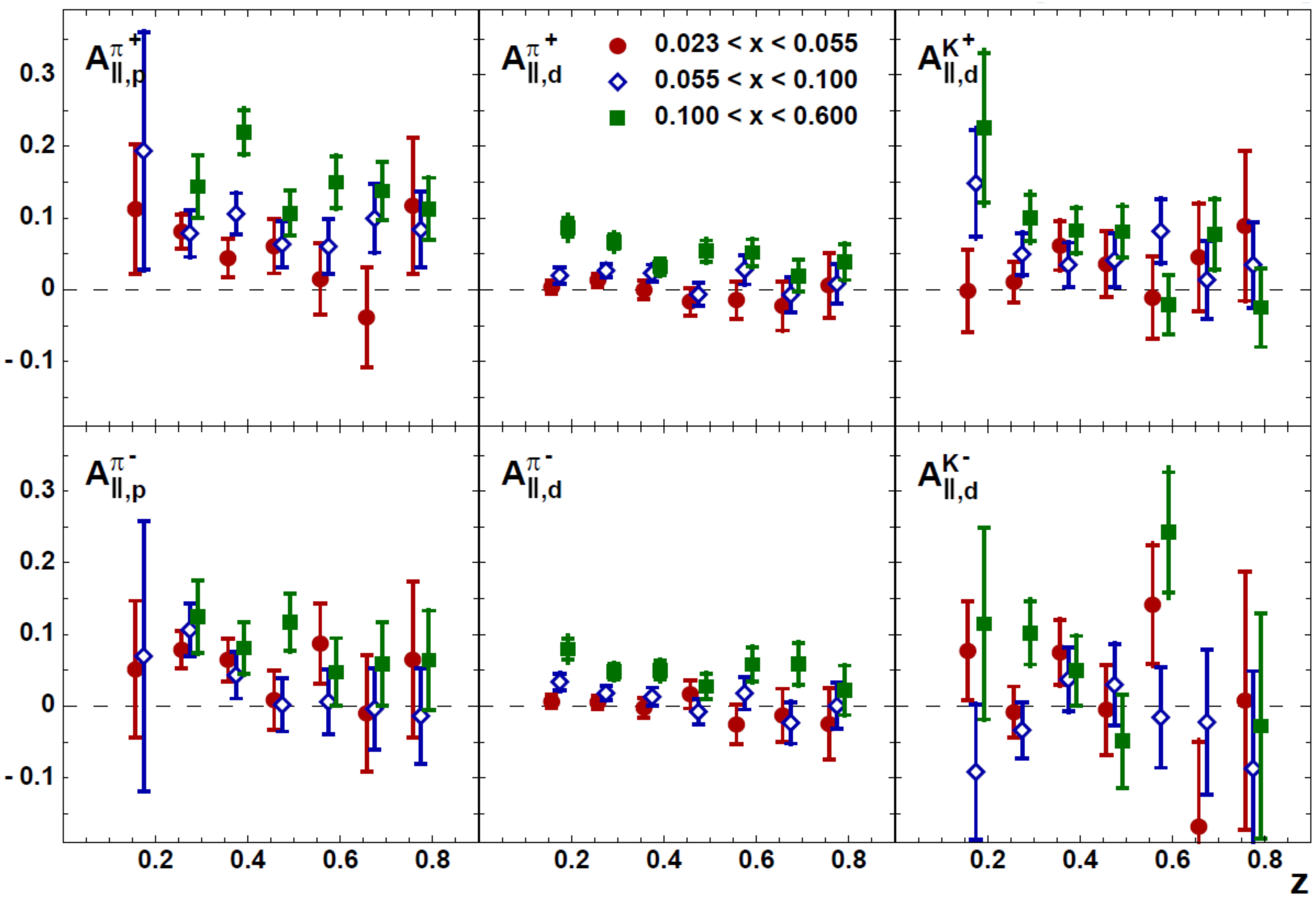
x dependence of $A_{||}$



Phys.Rev.D99 (2019) 11, 112001

- Results are fully consistent with previous analysis (Phys.Rev.D71:012003,2005)
- slightly larger data set
- results for $A_{||}$ and A_1
- 2D and 3D dependences
- extracted twist-3 cosine modulation

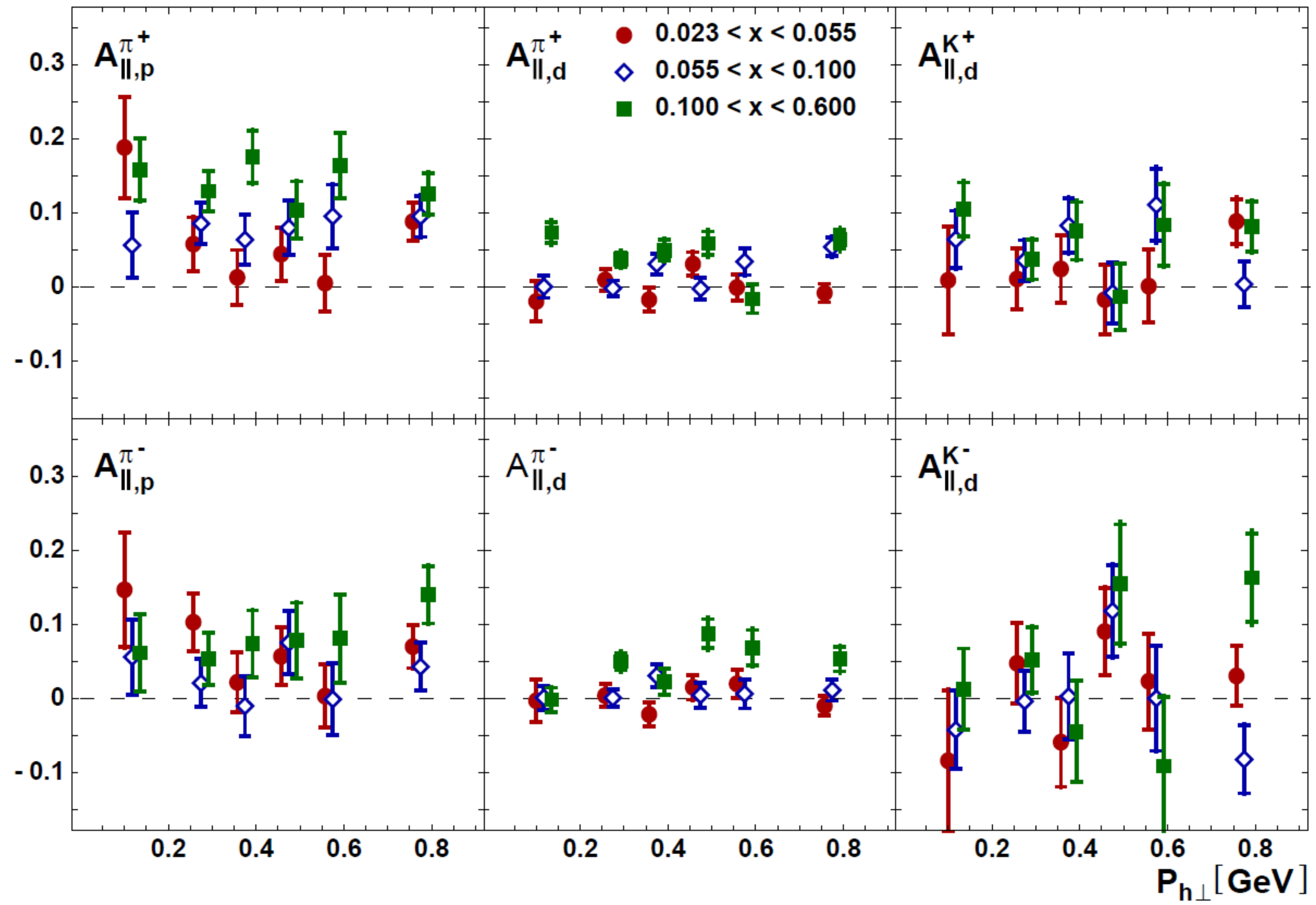
x-z dependence of $A_{||}$



Phys.Rev.D99 (2019) 11, 112001

- No strong z-dependence visible
- Asymmetries bigger for high x value
- On deuteron $A_{||}$ lower due to neutron contribution

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



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- again, no strong dependence

Charge-difference asymmetries

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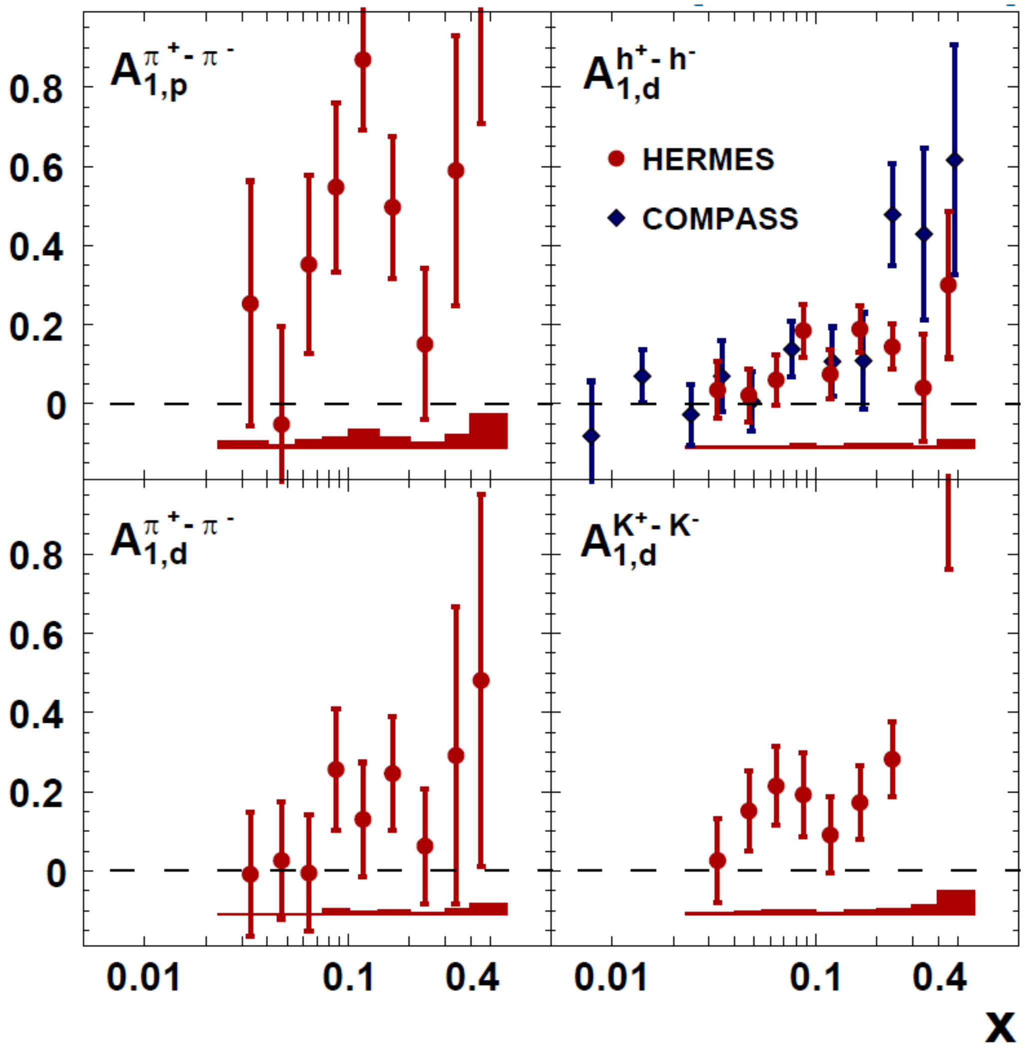
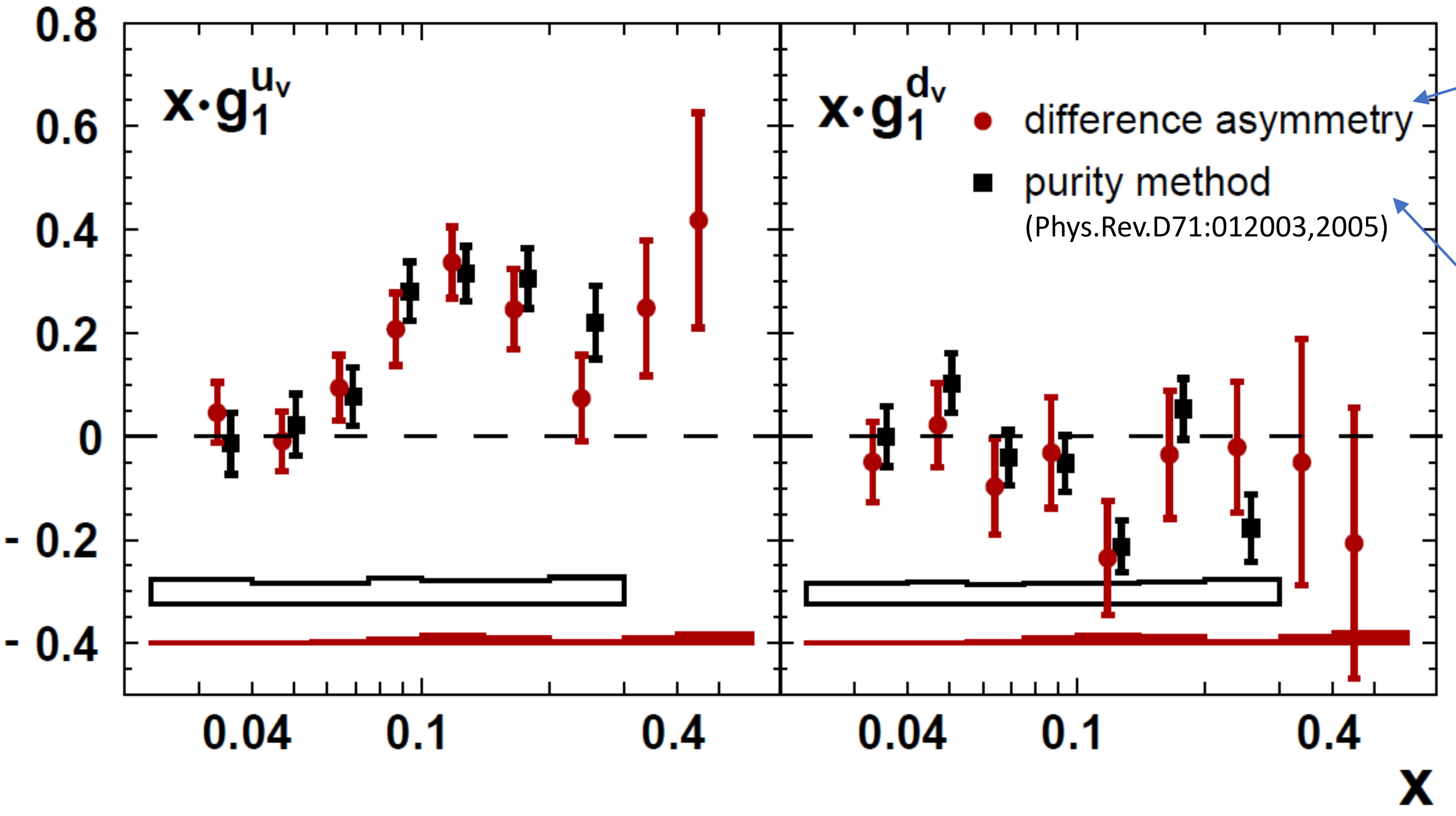
$$A_1^{h^+-h^-}(x) \equiv \frac{\left(\sigma_{1/2}^{h^+} - \sigma_{1/2}^{h^-}\right) - \left(\sigma_{3/2}^{h^+} - \sigma_{3/2}^{h^-}\right)}{\left(\sigma_{1/2}^{h^+} - \sigma_{1/2}^{h^-}\right) + \left(\sigma_{3/2}^{h^+} - \sigma_{3/2}^{h^-}\right)}$$

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



- The advantage of the charge difference asymmetry is that at leading order the fragmentation functions cancel and one is mainly sensitive to the PDFs
- no significant hadron-type dependence for deuterons
- deuteron results (unidentified hadrons) consistent with COMPASS

Helicity distributions for valence quarks



$$A_{1,d}^{h^+-h^-} \stackrel{\text{LO LT}}{=} \frac{g_1^{u_v} + g_1^{d_v}}{f_1^{u_v} + f_1^{d_v}}$$

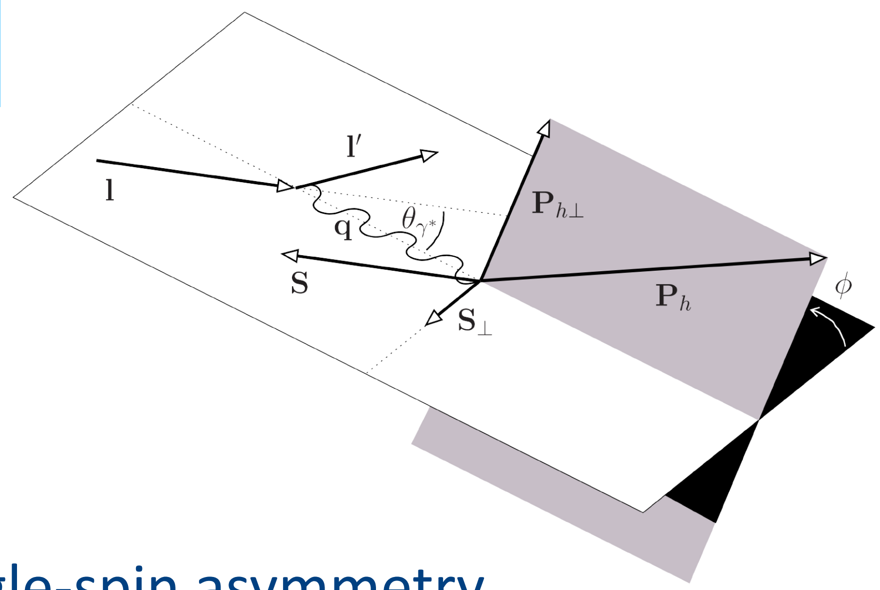
$$A_{1,p}^{h^+-h^-} \stackrel{\text{LO LT}}{=} \frac{4g_1^{u_v} - g_1^{d_v}}{4f_1^{u_v} - f_1^{d_v}}$$

$$A_1^h(x) = \sum_q \mathcal{P}_q^h(x) \frac{\Delta q(x)}{q(x)}$$

MC calculation

Two different methods and model assumptions give very consistent results.

Beam-helicity asymmetries



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

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

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

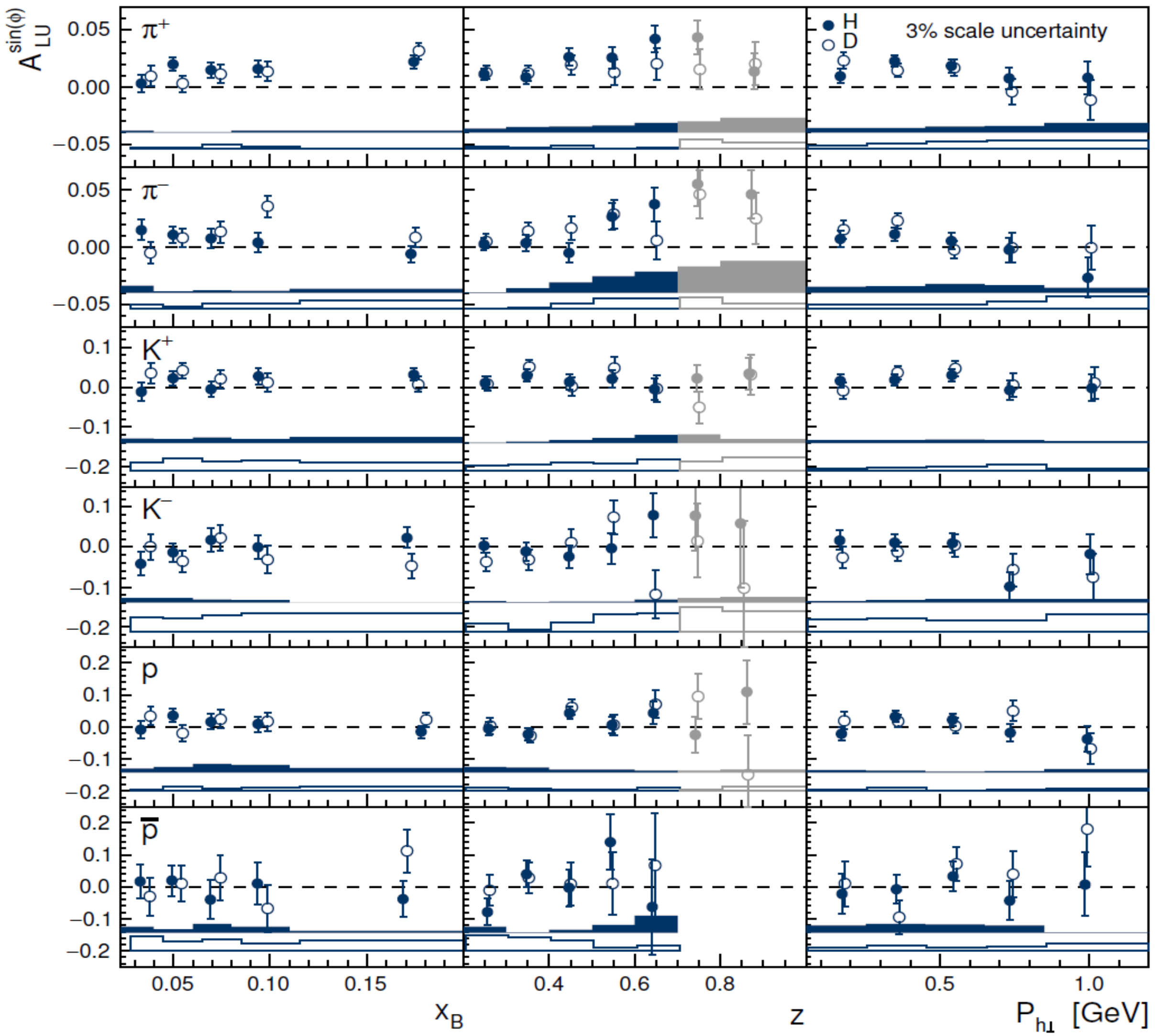
Describe intrinsic motion of quarks and gluons inside target nucleon due to correlations of p_T and its spin s with the spin of the target nucleon S

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.

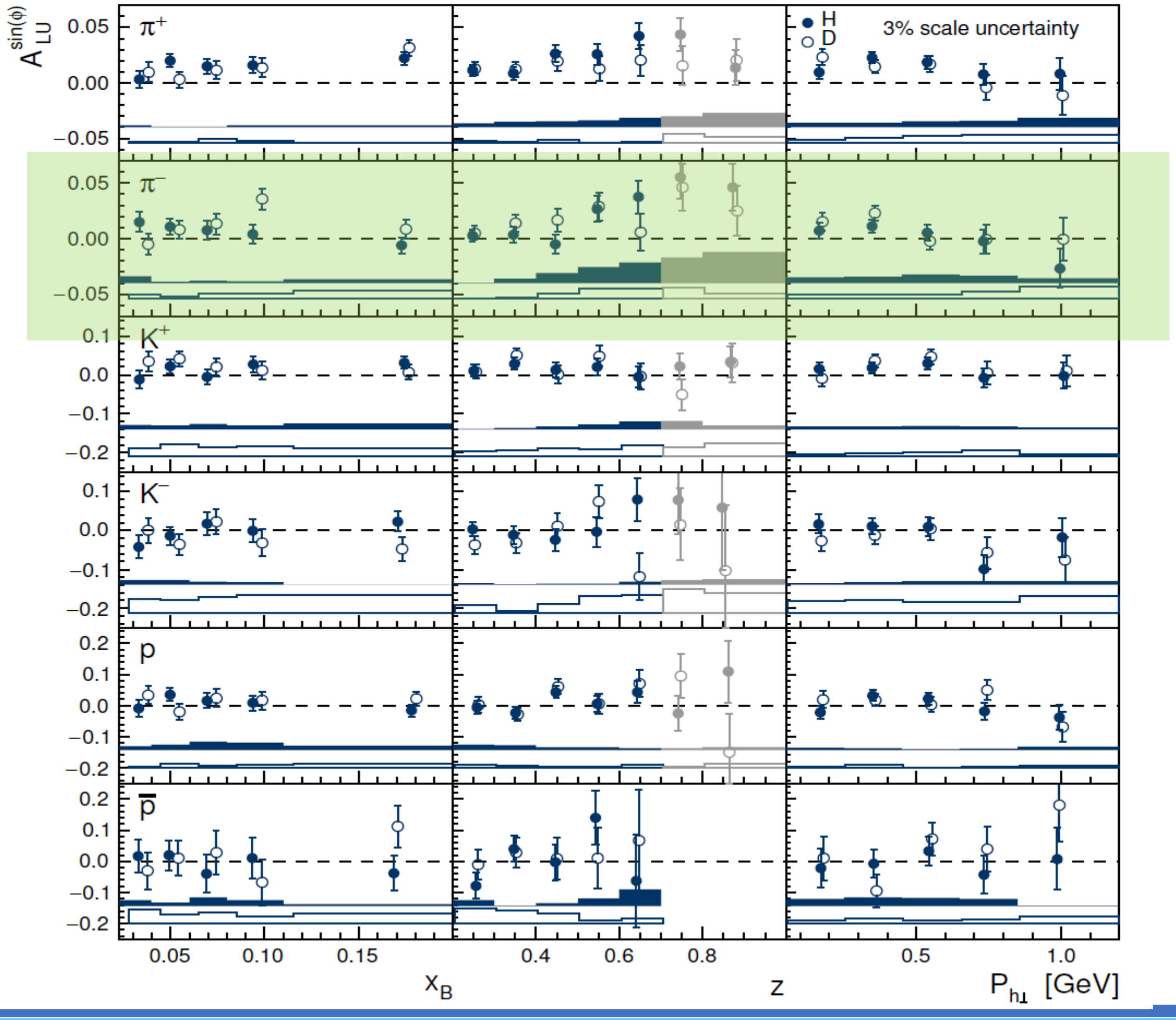
Beam-helicity asymmetry



Phys.Lett.B 797 (2019) 134886

Results also available in 3D (x, z, $P_{h\perp}$) binning

Beam-helicity asymmetry



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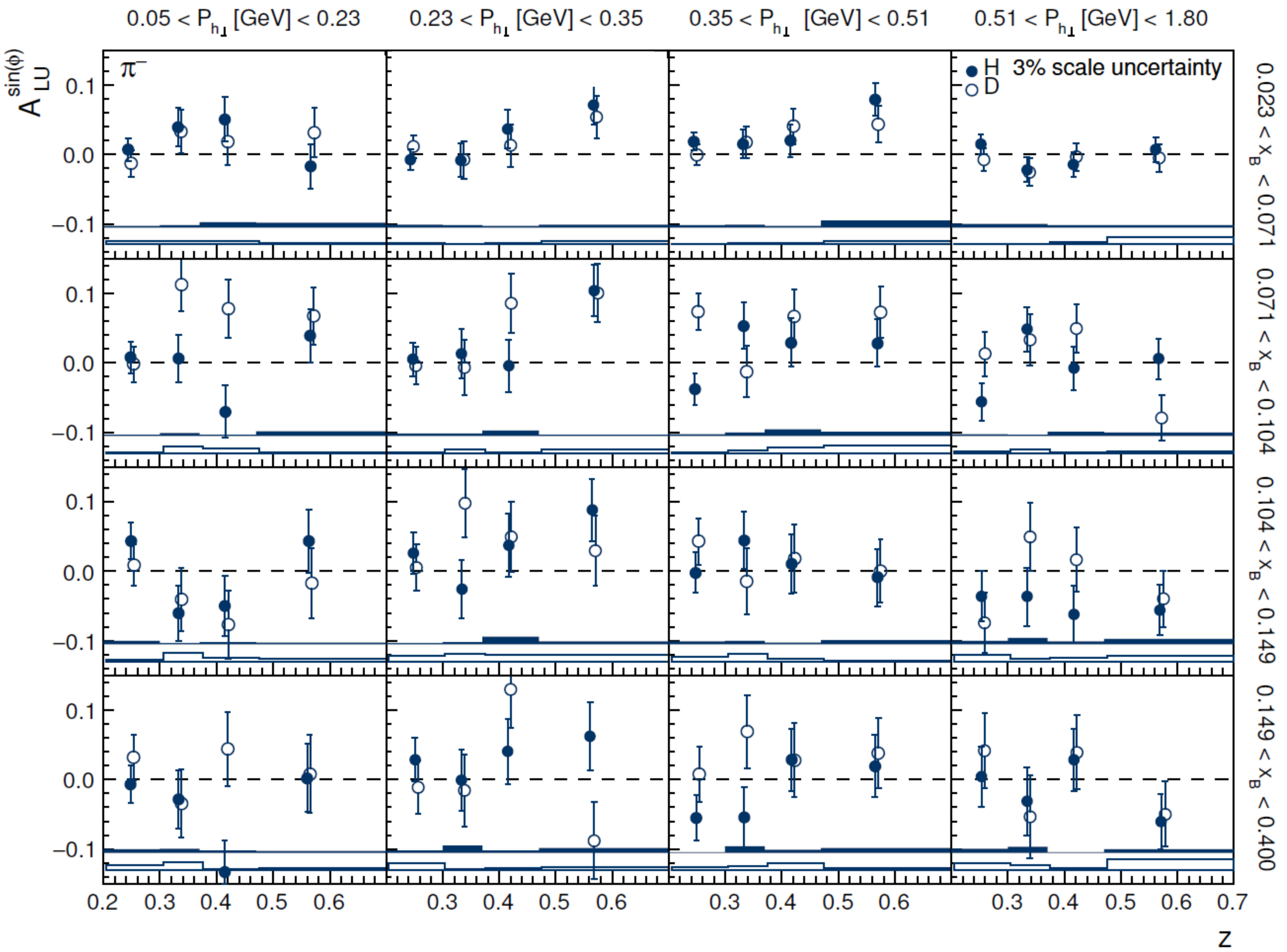
3D beam-helicity asymmetry for π-



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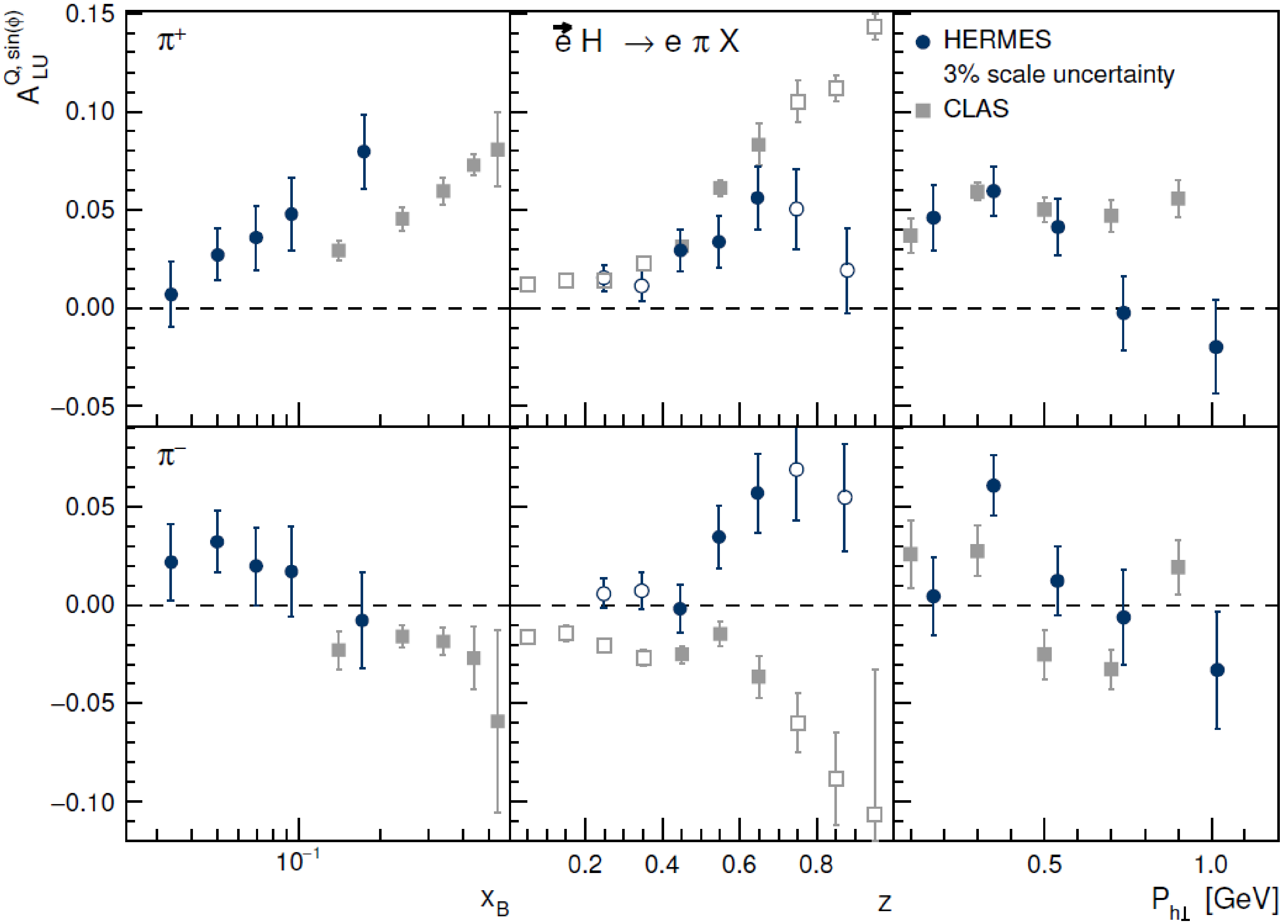
Mainly (non zero contribution) coming from lower *x* and lower $P_{h\perp}$

HERMES - CLAS comparison



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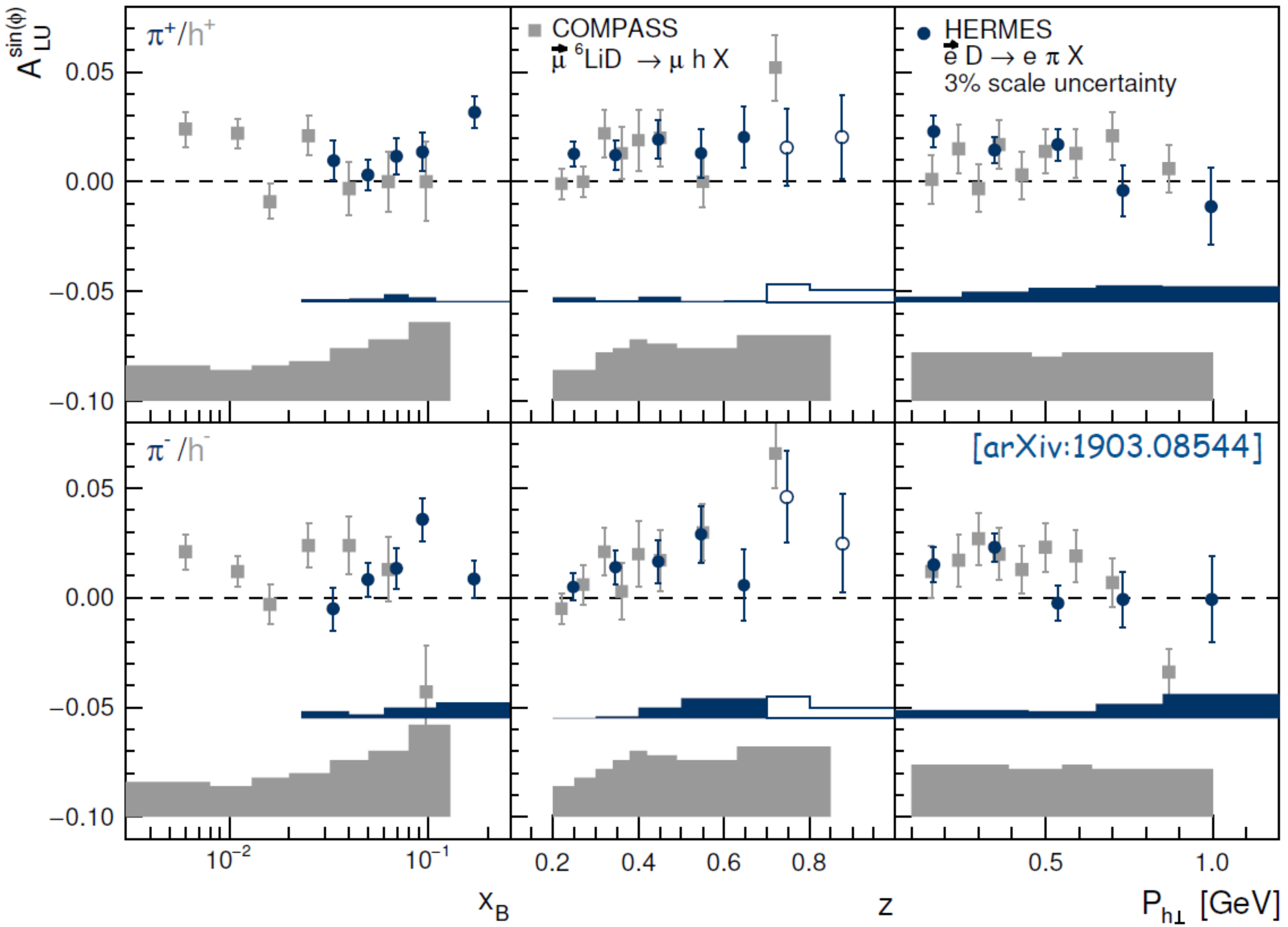
Opposite behavior of negative pions in *z* projection due to different *x*-range

HERMES - COMPASS comparison



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consistent behavior for charged pions / hadrons at HERMES / COMPASS

Summary

Longitudinal double-spin asymmetries

- 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, and in a 2D and 3D kinematic binning
- the twist-3 cosine modulation of the double-spin asymmetry is found to be consistent with zero
- 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

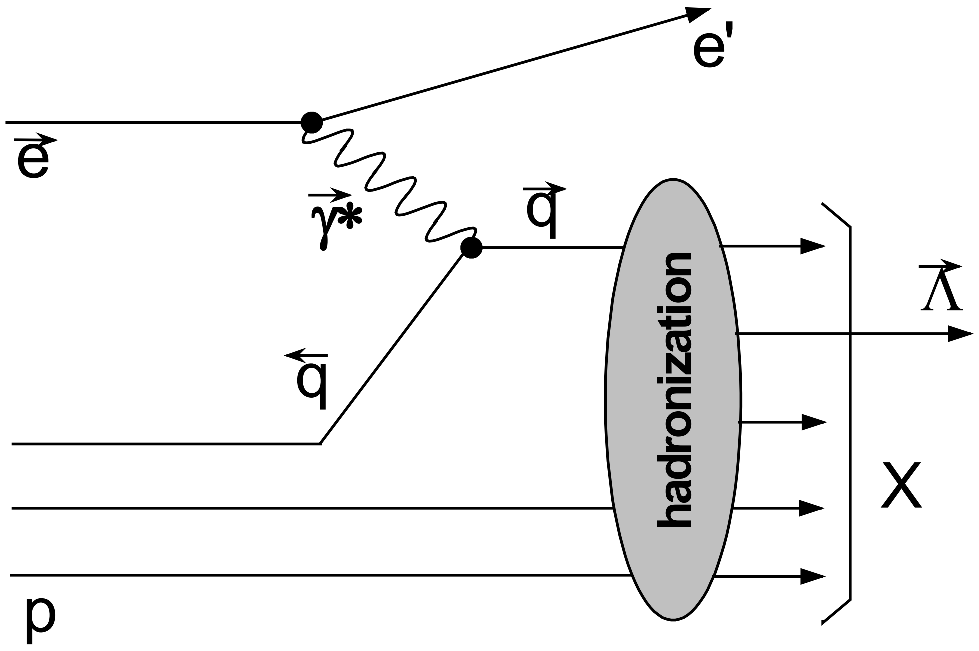
Beam-helicity asymmetries

- First 3D extraction for charge-separated pions, kaons, as well as for (anti)protons
- clearly non-zero and rising as function of *z* beam-helicity asymmetries observed for charged pions
- K^+ asymmetries are slightly positive, but no kinematical dependencies
- high-x behavior in HERMES - CLAS comparison might be driven by TMD e & Collins FF
- COMPASS and HERMES in agreement despite different Q^2 ranges probed

Backup

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

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



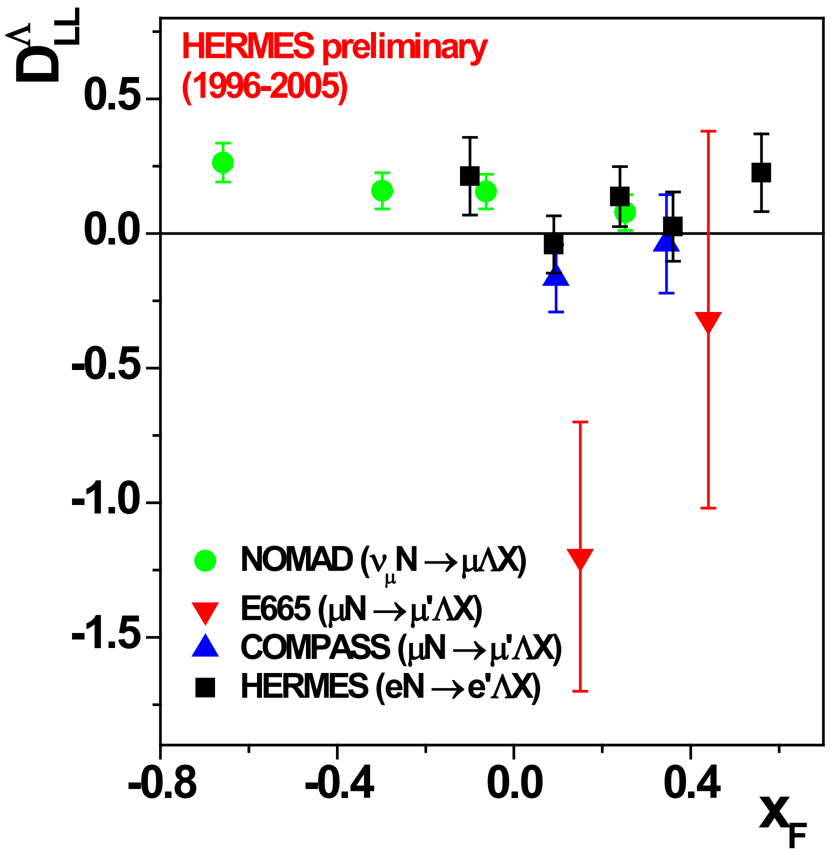
Due to weak decay polarization of the Λ can be extracted by measuring angular distribution of decay proton

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

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

Comparison of HERMES data with other experiments



More data (2006-2007) currently being analysed for final publication.