Overview of HERMES results

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(on behalf of the HERMES Collaboration)

XVIII WORKSHOP ON HIGH ENERGY SPIN PHYSICS
DSPIN – 19
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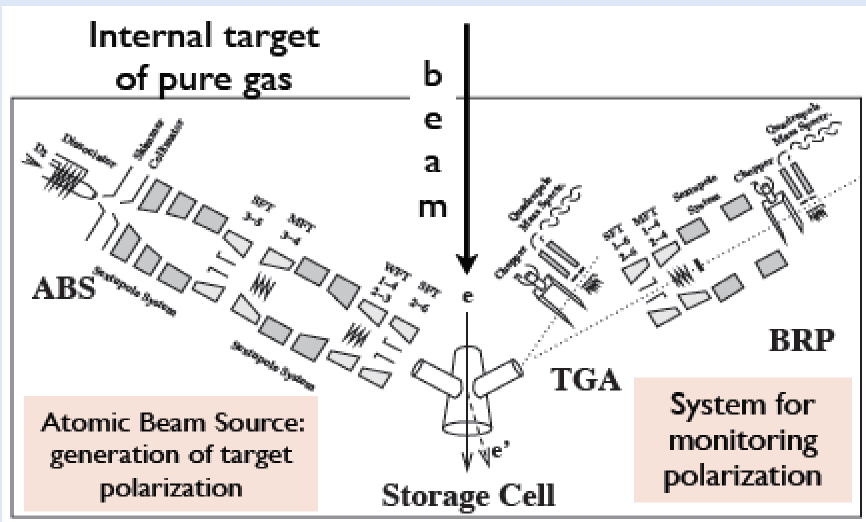
- The HERMES experiment.
- 3D picture of the nucleon:
  - A_{UT} & A_{LT} asymmetries in semi-inclusive DIS,
  - A_{LL} asymmetry in semi-inclusive DIS,
  - A_{LU} asymmetry in semi-inclusive DIS.
- Symmary

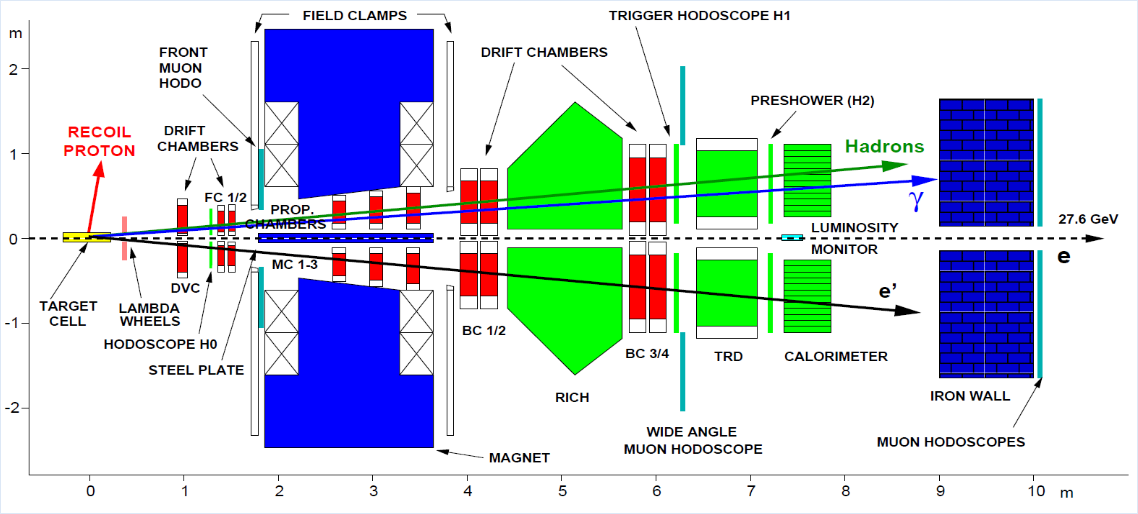
HERMES at DESY

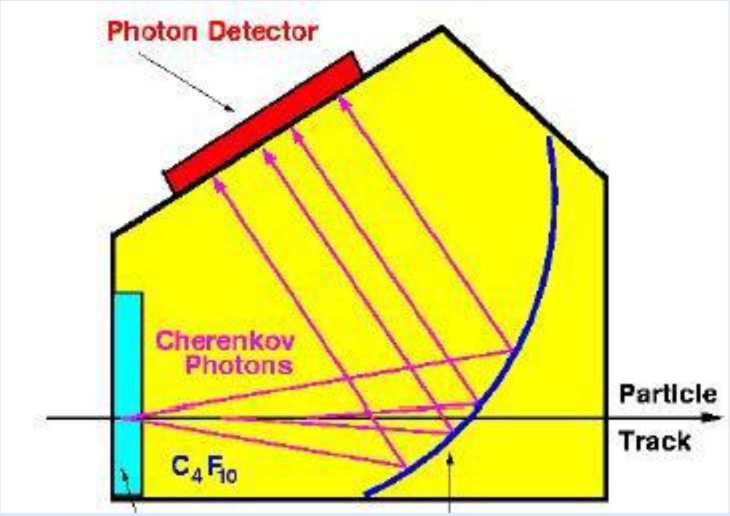
Self-polarized e^+ and e^- beams
27.6 GeV
Helicity switched every few months



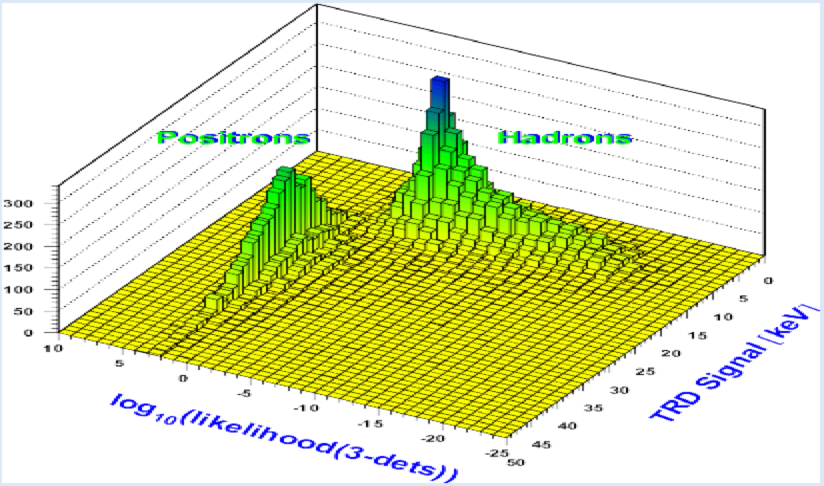
Polarized hydrogen (Long.,Trans.), deuterium (Long.)
Polarization flipped at 60-180 s time interval
Unpolarized *H,D,He,N,Ne,Kr,Xe*

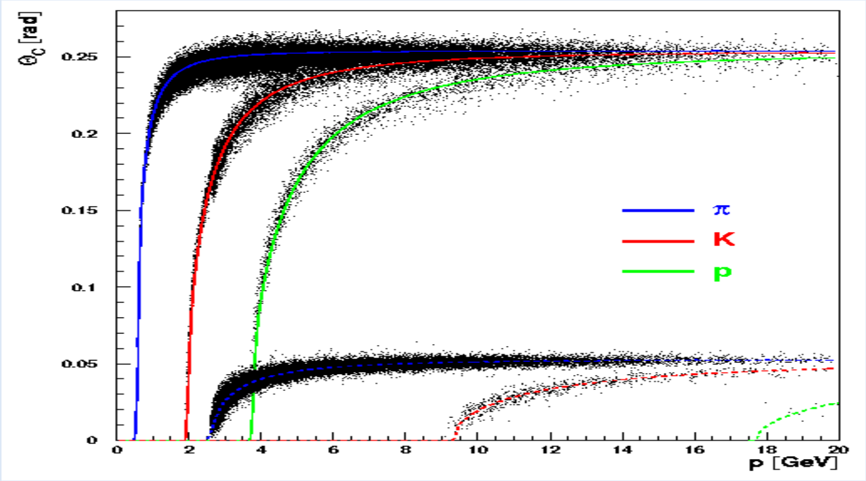
The HERMES Spectrometer





Aerogel Mirror

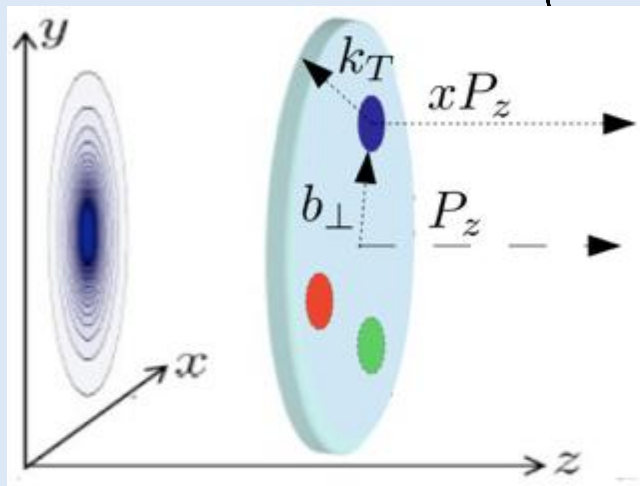




- PID: RICH, TRD, Preshower and Calorimeter; lepton-hadron > 98%
- Momentum resolution of charged particles: $\delta P/P \simeq 1.5\%$

3D picture of the nucleon

Wigner distributions $W\left(x,\vec{k}_T,\vec{b}_\perp\right)$



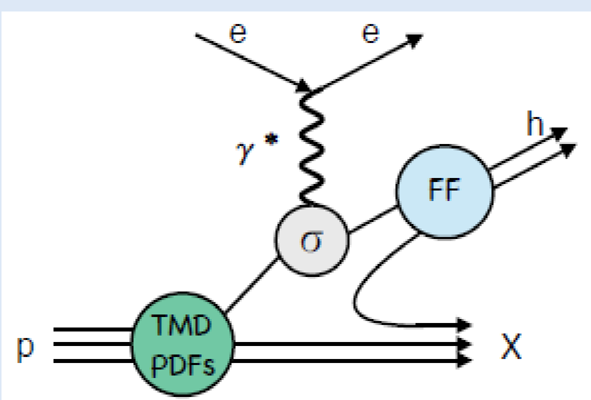
$\int d^2\vec{b}_\perp$ $\int d^2\vec{k}_T$

TMD PDFs: $f_p^q(x,k_T)$,...

GPDs: $H_p^q(x,\xi,t)$, ...

Semi-inclusive measurements
Direct info about momentum distribution

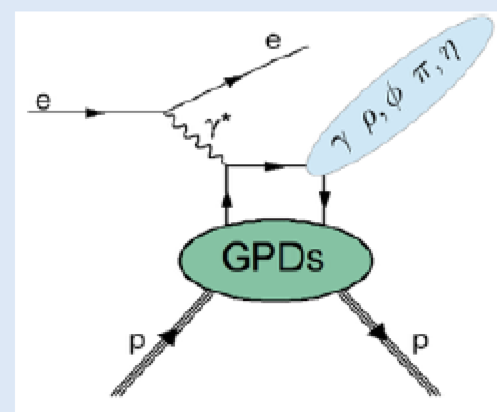
Exclusive Measurements
Direct info about spatial distribution



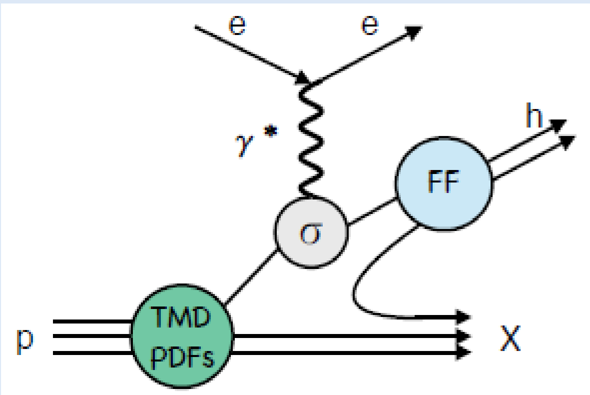
$\int d^2\vec{k}_T$

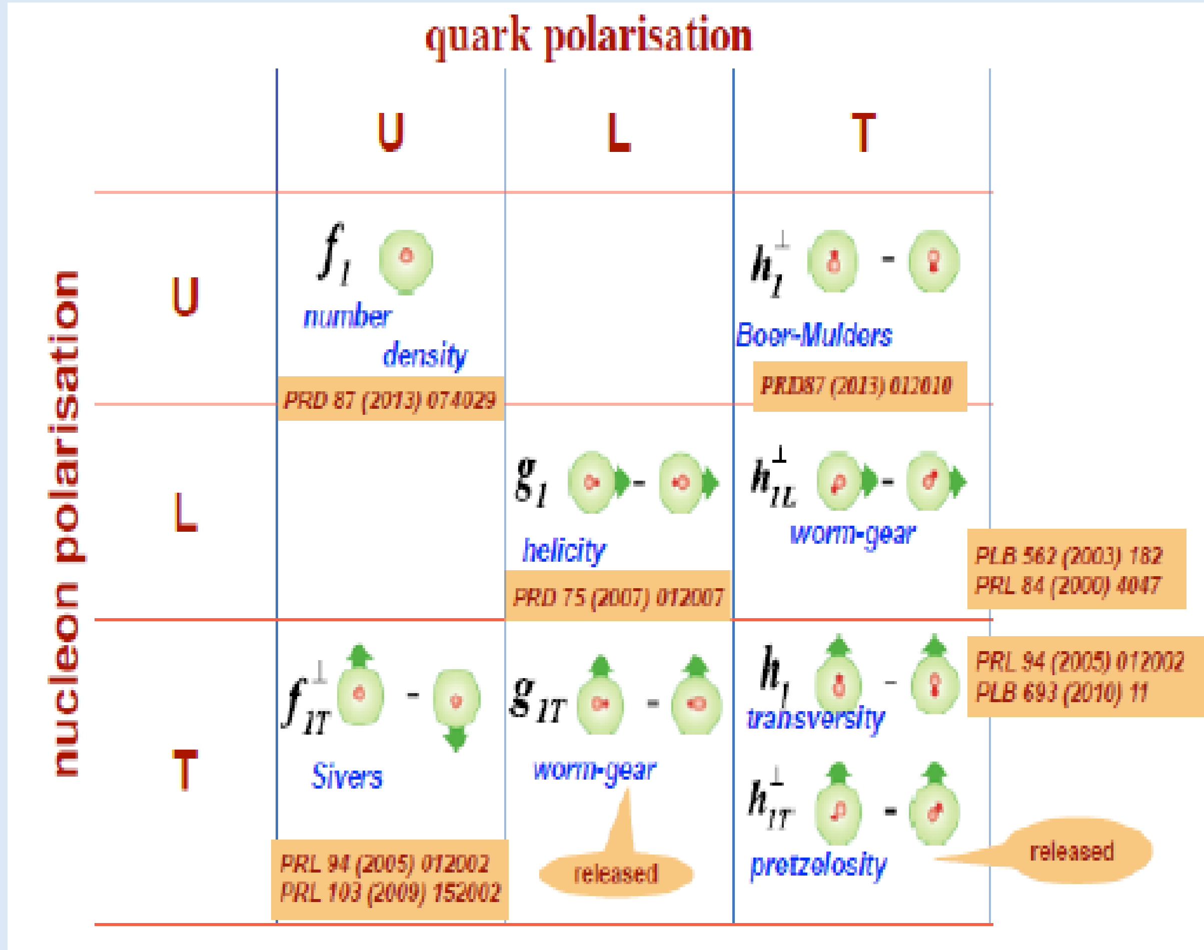
ξ=0, t=0

PDFs $f_p^q(x)$,...



Semi-inclusive DIS processes (SIDIS)





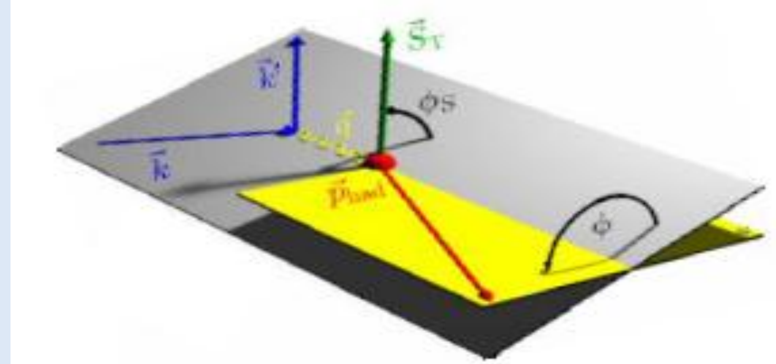
<u>SIDIS processes</u>:

- Describe spin-orbit correlation: correlations between the hadron transverse momentum and quark or nucleon spin
- Sensitive to quark orbital angular momentum

The SIDIS cross-section

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

$$
\begin{aligned}
\Big\{ & \Big[F_{\mathrm{UU,T}} + \epsilon F_{\mathrm{UU,L}} \\
& + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi)F_{\mathrm{UU}}^{\cos(\phi)} + \epsilon\cos(2\phi)F_{\mathrm{UU}}^{\cos(2\phi)}\Big] \\
+ \quad \lambda_l & \Big[\sqrt{2\epsilon(1-\epsilon)}\sin(\phi)F_{\mathrm{LU}}^{\sin(\phi)}\Big] \\
+ S_L & \Big[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi)F_{\mathrm{UL}}^{\sin(\phi)} + \epsilon\sin(2\phi)F_{\mathrm{UL}}^{\sin(2\phi)}\Big] \\
+ S_L\,\lambda_l & \Big[\sqrt{1-\epsilon^2}F_{\mathrm{LL}} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi)F_{\mathrm{LL}}^{\cos(\phi)}\Big] \\
+ S_T & \Big[\sin(\phi-\phi_S)\left(F_{\mathrm{UT,T}}^{\sin(\phi-\phi_S)} + \epsilon F_{\mathrm{UT,L}}^{\sin(\phi-\phi_S)}\right) \\
& + \epsilon\sin(\phi+\phi_S)F_{\mathrm{UT}}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)F_{\mathrm{UT}}^{\sin(3\phi-\phi_S)} \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S)F_{\mathrm{UT}}^{\sin(\phi_S)} \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S)F_{\mathrm{UT}}^{\sin(2\phi-\phi_S)}\Big] \\
+ S_T\,\lambda_l & \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{\mathrm{LT}}^{\cos(\phi-\phi_S)} \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S)F_{\mathrm{LT}}^{\cos(\phi_S)} \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{\mathrm{LT}}^{\cos(2\phi-\phi_S)}\Big] \quad \Big\}
\end{aligned}
$$



$F_{XY,Z} \propto \mathrm{PDF} \otimes \mathrm{FF}$

X=beam, Y=target,

Z=γ^*polarization

TMD PDFs

nucleon \ quark	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

FFs

h \ quark	U	L	T
U	D_1		$H_1^\perp$

The SIDIS cross-section

$$
\begin{aligned}
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\Big\{ & \Big[F_{\rm UU,T} + \epsilon F_{\rm UU,L} \\
& + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi) F_{\rm UU}^{\cos(\phi)} + \epsilon\cos(2\phi) F_{\rm UU}^{\cos(2\phi)}\Big] \\
+ {} & \lambda_l \Big[\sqrt{2\epsilon(1-\epsilon)}\sin(\phi) F_{\rm LU}^{\sin(\phi)}\Big] \\
+ S_L {} & \Big[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi) F_{\rm UL}^{\sin(\phi)} + \epsilon\sin(2\phi) F_{\rm UL}^{\sin(2\phi)}\Big] \\
+ S_L\,\lambda_l {} & \Big[\sqrt{1-\epsilon^2} F_{\rm LL} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi) F_{\rm LL}^{\cos(\phi)}\Big] \\
+ S_T {} & \Big[\sin(\phi-\phi_S)\left(F_{\rm UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{\rm UT,L}^{\sin(\phi-\phi_S)}\right) \\
& + \epsilon\sin(\phi+\phi_S) F_{\rm UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S) F_{\rm UT}^{\sin(3\phi-\phi_S)} \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S) F_{\rm UT}^{\sin(\phi_S)} \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S) F_{\rm UT}^{\sin(2\phi-\phi_S)}\Big] \\
+ S_T\,\lambda_l {} & \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S) F_{\rm LT}^{\cos(\phi-\phi_S)} \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S) F_{\rm LT}^{\cos(\phi_S)} \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S) F_{\rm LT}^{\cos(2\phi-\phi_S)}\Big] \quad \Big\}
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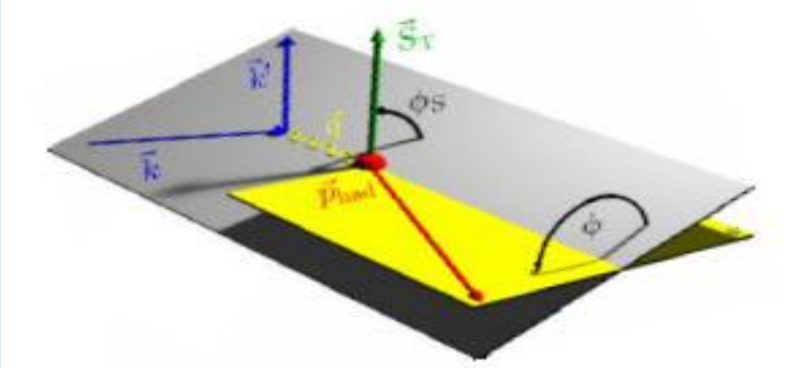
$$



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		quark U	quark L	quark T
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nucleon	L		g_1	$h_{1L}^\perp$
nucleon	T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1, $h_{1T}^\perp$

FFs

		quark U	quark L	quark T
h	U	D_1		$H_1^\perp$

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$$\Big\{ \Big[F_{\mathrm{UU,T}} + \epsilon F_{\mathrm{UU,L}} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi) F_{\mathrm{UU}}^{\cos(\phi)} + \epsilon\cos(2\phi) F_{\mathrm{UU}}^{\cos(2\phi)}\Big]$$

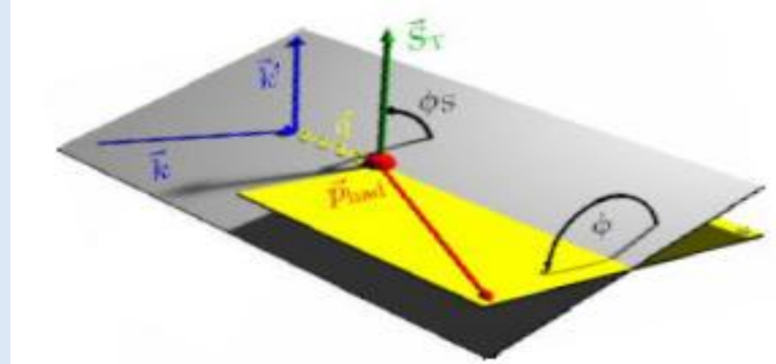
$$+ \lambda_l \Big[\sqrt{2\epsilon(1-\epsilon)}\sin(\phi) F_{\mathrm{LU}}^{\sin(\phi)}\Big]$$

$$+ S_L \Big[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi) F_{\mathrm{UL}}^{\sin(\phi)} + \epsilon\sin(2\phi) F_{\mathrm{UL}}^{\sin(2\phi)}\Big]$$

$$+ S_L\,\lambda_l \Big[\sqrt{1-\epsilon^2} F_{\mathrm{LL}} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi) F_{\mathrm{LL}}^{\cos(\phi)}\Big]$$

$$+ S_T \Big[\sin(\phi-\phi_S)\left(F_{\mathrm{UT,T}}^{\sin(\phi-\phi_S)} + \epsilon F_{\mathrm{UT,L}}^{\sin(\phi-\phi_S)}\right) + \epsilon\sin(\phi+\phi_S) F_{\mathrm{UT}}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S) F_{\mathrm{UT}}^{\sin(3\phi-\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S) F_{\mathrm{UT}}^{\sin(\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S) F_{\mathrm{UT}}^{\sin(2\phi-\phi_S)}\Big]$$

$$+ S_T\,\lambda_l \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S) F_{\mathrm{LT}}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S) F_{\mathrm{LT}}^{\cos(\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S) F_{\mathrm{LT}}^{\cos(2\phi-\phi_S)}\Big] \Big\}$$



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FFs

h \ quark	U	L	T
U	D_1		$H_1^\perp$

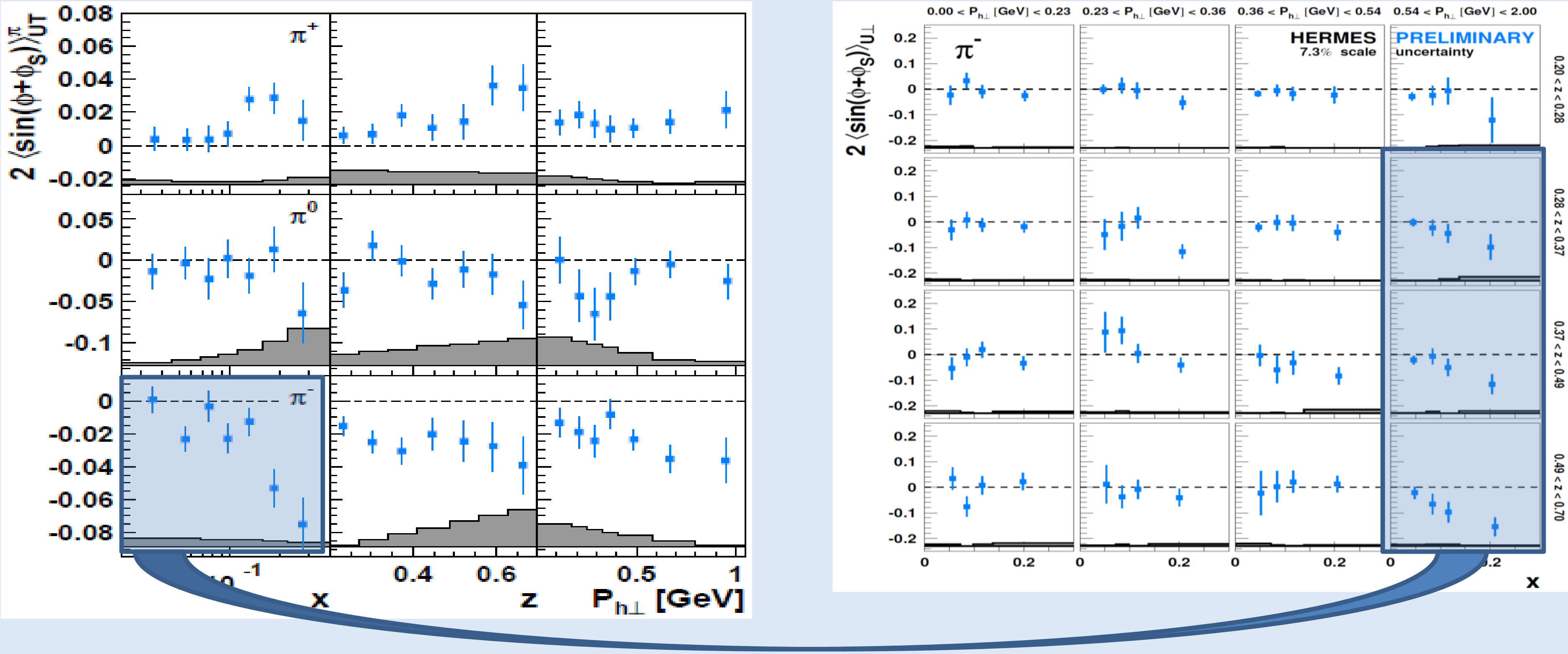
A_{UT} & A_{LT} in semi-inclusive DIS

- *Unpolarized* & longitudinally polarized e^+/e^- beam
- Transversely polarized H target

Transversely polarized quarks: Collins effect for pions

Phys. Lett. B 693 (2010) 11

$$F_{UT}^{\sin(\phi_h+\phi_S)} \propto h_1\left(x, p_T^2\right) \otimes H_1^{\perp}\left(z, k_T^2\right)$$

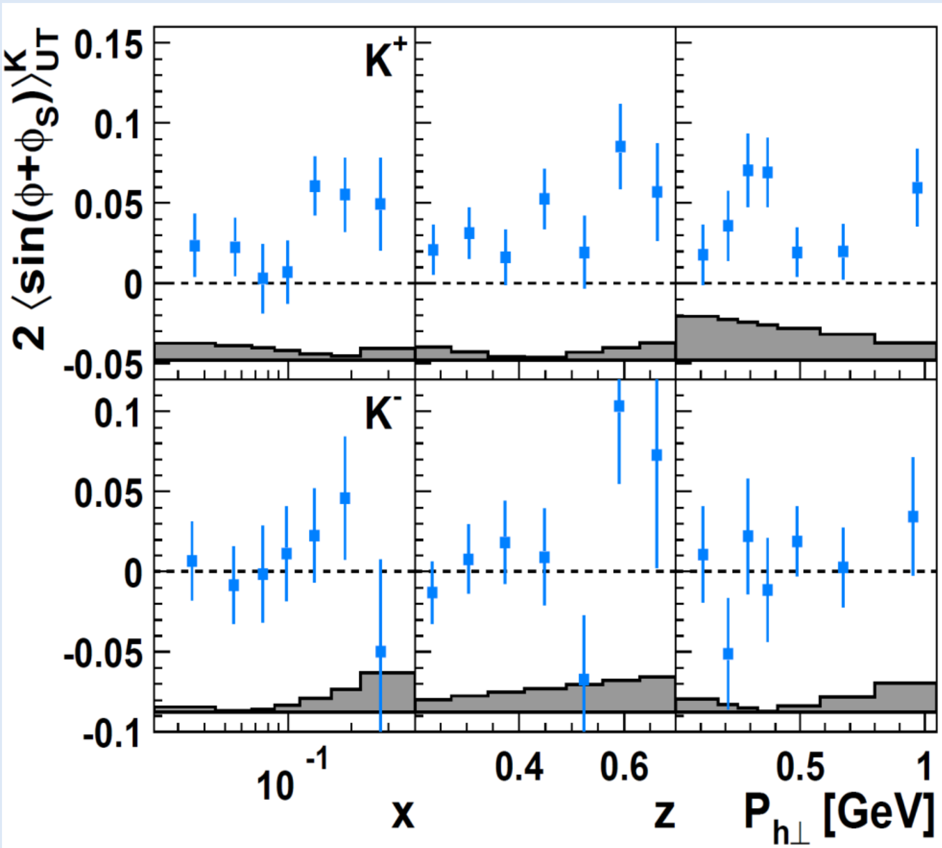


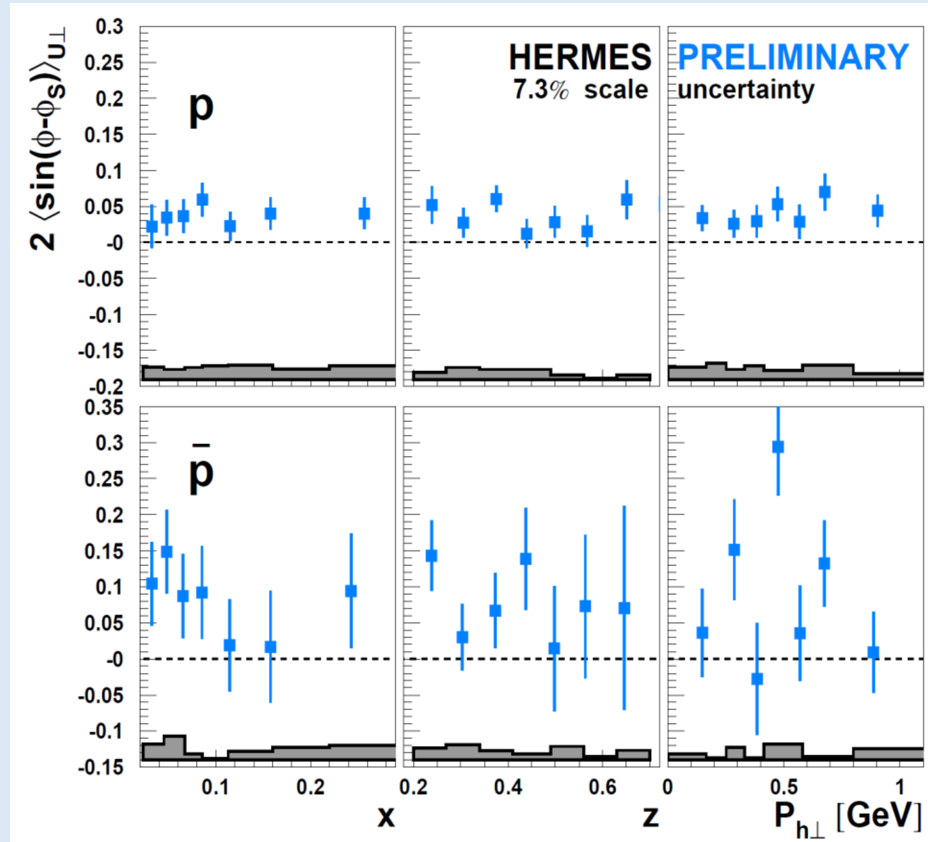
- Opposite in sign for charged pions,
- Disfavored Collins FF large and opposite in sign to favored one,
- 3D projections allow to constrain global fits in a more profound way,
- π^- amplitudes increasing with x at large $P_{h\perp}$.

Collins effect for kaons and (anti) protons

Phys. Lett. B 693 (2010) 11

$$F_{UT}^{\sin(\phi_h+\phi_S)} \propto h_1\left(x, p_T^2\right) \otimes H_1^{\perp}\left(z, k_T^2\right)$$



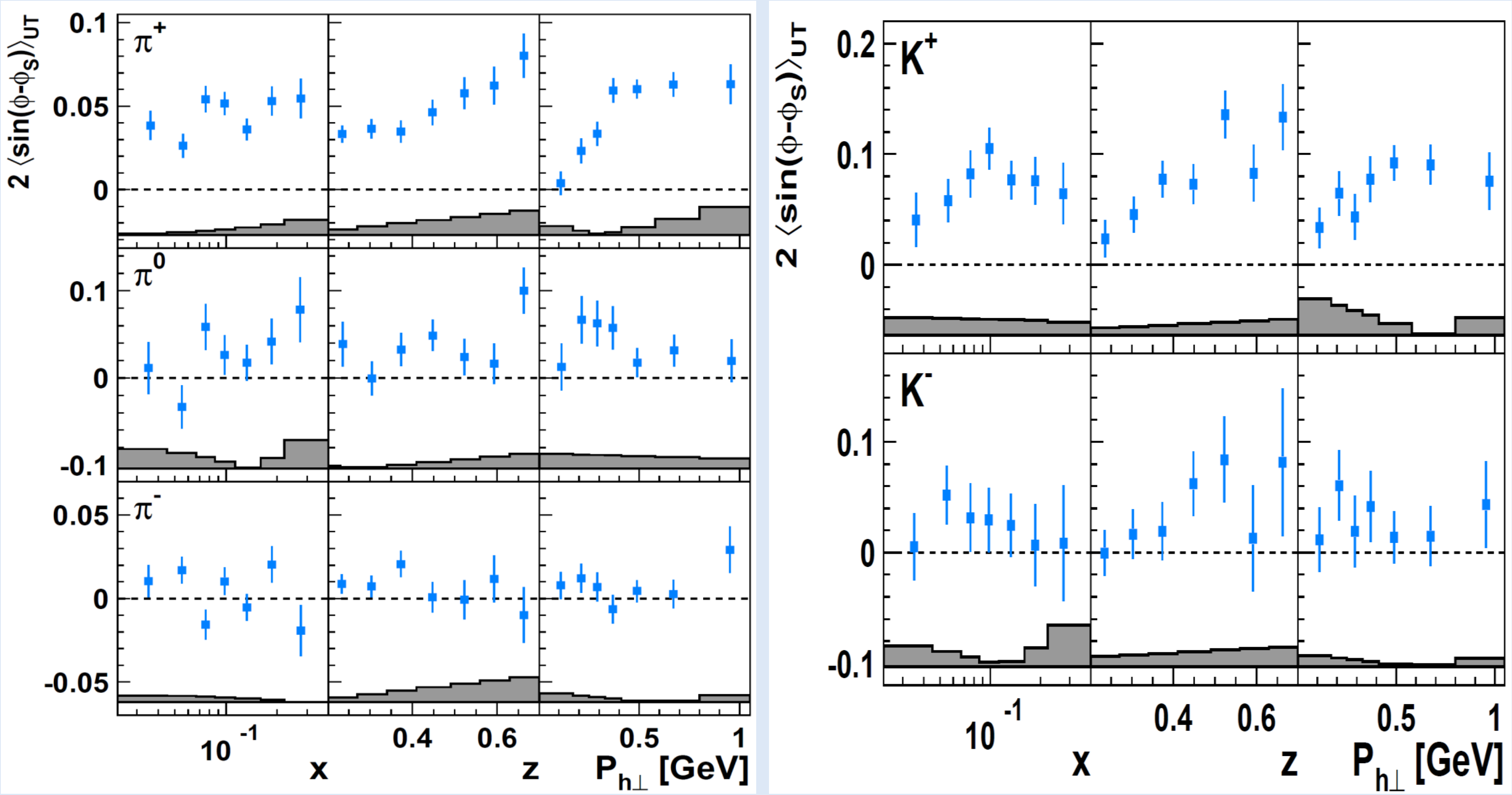


- Positive Collins SSA amplitude for positive kaons,
- Consistent with zero for negative kaons and (anti)protons,
- Vanishing sea-quark transversity?

Sivers amplitudes for mesons

Phys. Lett. B 693 (2010) 11

$$F_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp}\left(x, p_T^2\right) \otimes D_1\left(z, k_T^2\right)$$

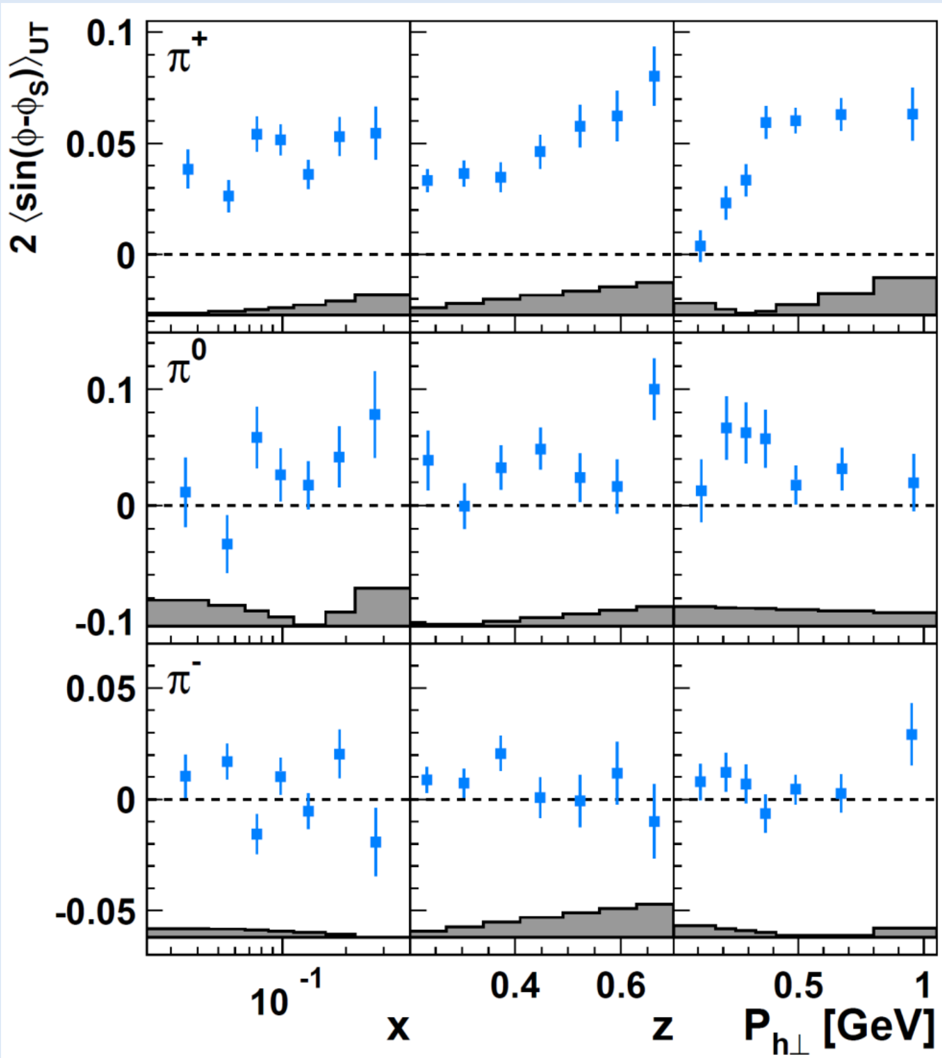


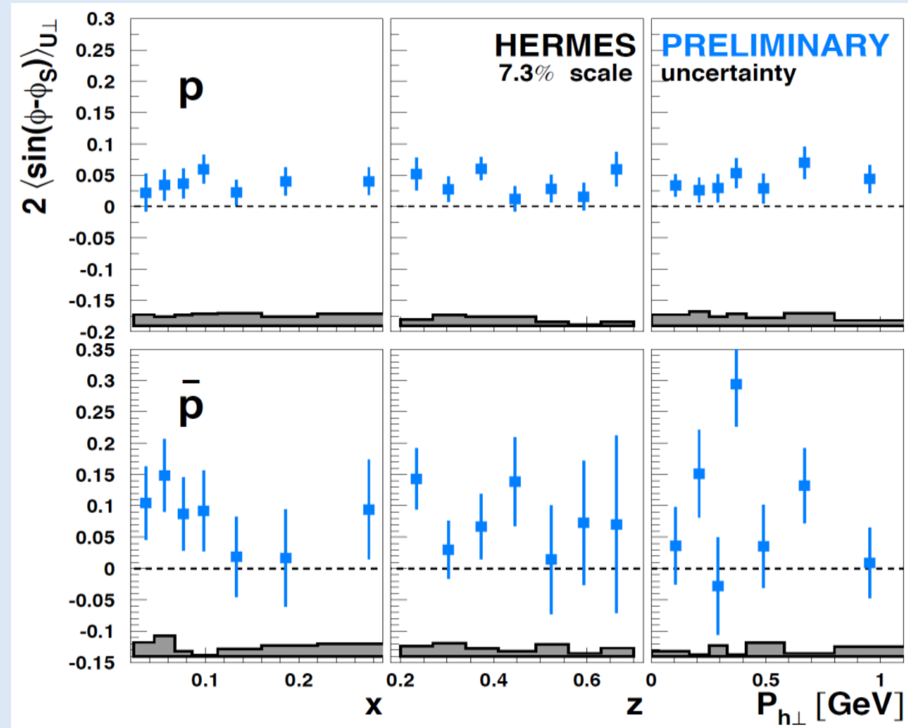
- Larger amplitudes for positive kaons vs. pions.

Sivers amplitudes for baryons

Phys. Lett. B 693 (2010) 11

$$F_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp}\left(x, p_T^2\right) \otimes D_1\left(z, k_T^2\right)$$





- Similar amplitudes for positive pions and Protons,
- u-quark dominance (and not a FF effect)?

A_{LL} in semi-inclusive DIS

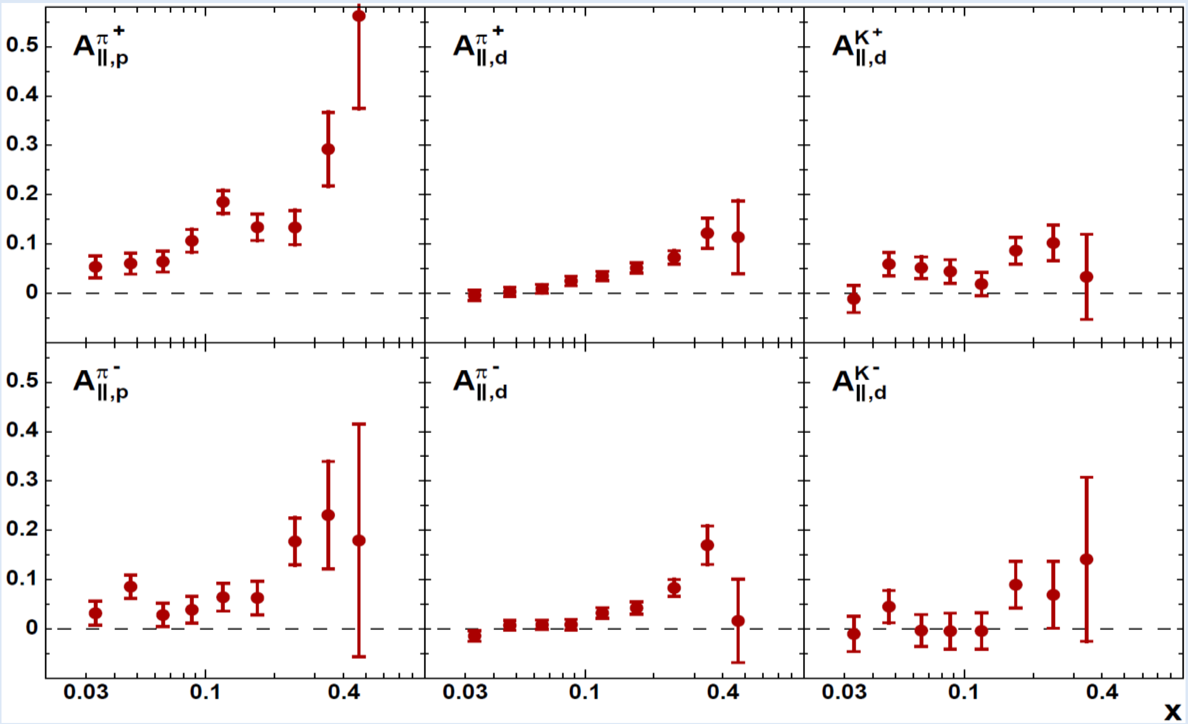
- Longitudinally polarized e^+/e^- beam
- Longitudinally polarized H & D targets

The longitudinal double-spin asymmetries $A_{\parallel,N}^{h}$

Refined studies ⟹ extend the results published in PRD 71 (2005) 012003

$$A_{\parallel}^{h} \equiv \frac{C_{\varphi}^{h}}{f_D}\left[\frac{L_{\overset{\rightarrow}{\Rightarrow}} N^{h}_{\overset{\leftarrow}{\Rightarrow}} - L_{\overset{\leftarrow}{\Rightarrow}} N^{h}_{\overset{\rightarrow}{\Rightarrow}}}{L_{\overset{\rightarrow}{\Rightarrow}} N^{h}_{\overset{\leftarrow}{\Rightarrow}} + L_{\overset{\leftarrow}{\Rightarrow}} N^{h}_{\overset{\rightarrow}{\Rightarrow}}}\right]_B$$

Phys. Rev. D99 (2019) no.11, 112001



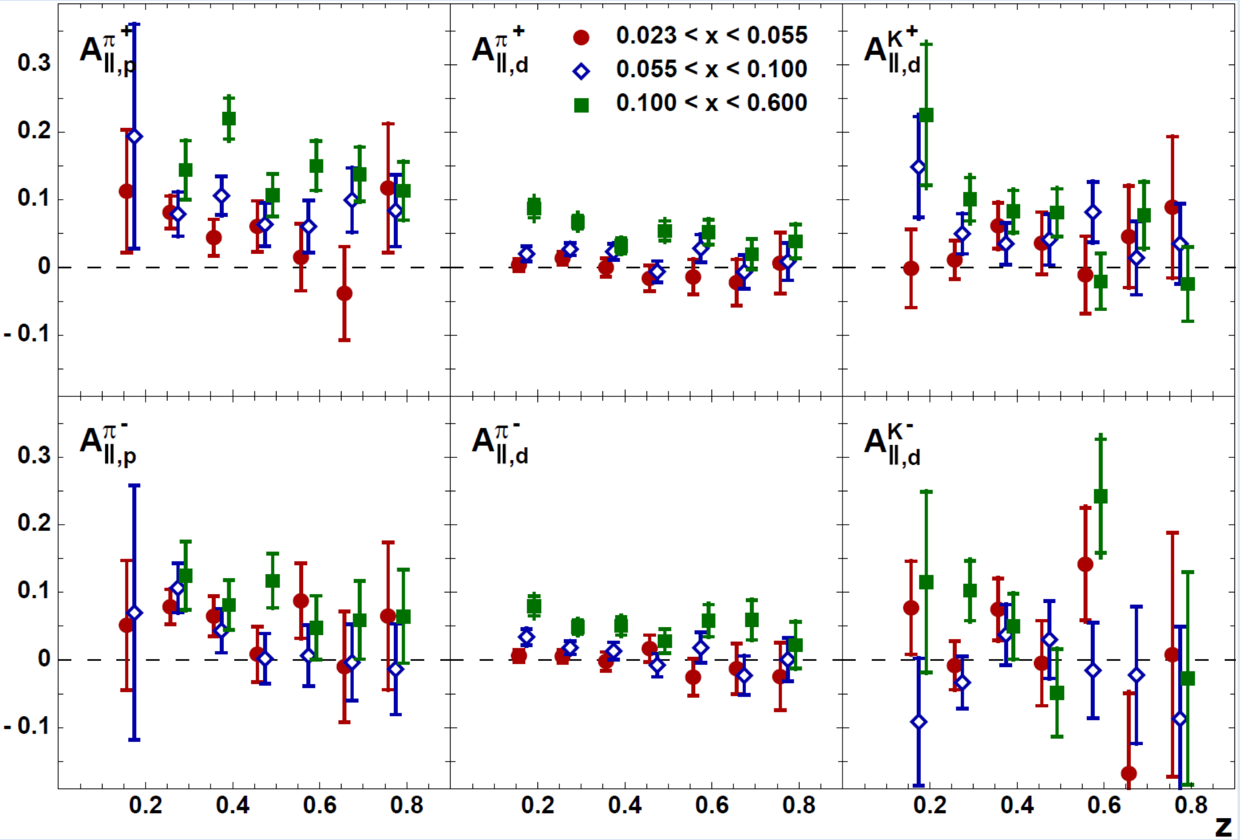
$$\sigma_{LL} \propto g_{1L}^{q} \otimes D_1^{q\rightarrow h}$$

- The x dependence of the asymmetries were found to be essentially identical to those in prior HERMES analyses (A. Airapetian et al. Phys.Rev.D71 012003 (2005)).
- The low-Q^2 bin was added, spanning 0.5 to 1 GeV^2 , to allow for a better control of migration of events in the unfolding procedure.

The longitudinal double-spin asymmetries $A_{\parallel,N}^{h}$

$$A_{\parallel}^{h} \equiv \frac{C_{\varphi}^{h}}{f_D}\left[\frac{L_{\rightarrow\atop\rightarrow} N_{\leftarrow\atop\rightarrow}^{h} - L_{\leftarrow\atop\rightarrow} N_{\rightarrow\atop\rightarrow}^{h}}{L_{\rightarrow\atop\rightarrow} N_{\leftarrow\atop\rightarrow}^{h} + L_{\leftarrow\atop\rightarrow} N_{\rightarrow\atop\rightarrow}^{h}}\right]_B$$

Phys. Rev. D99 (2019) no.11, 112001

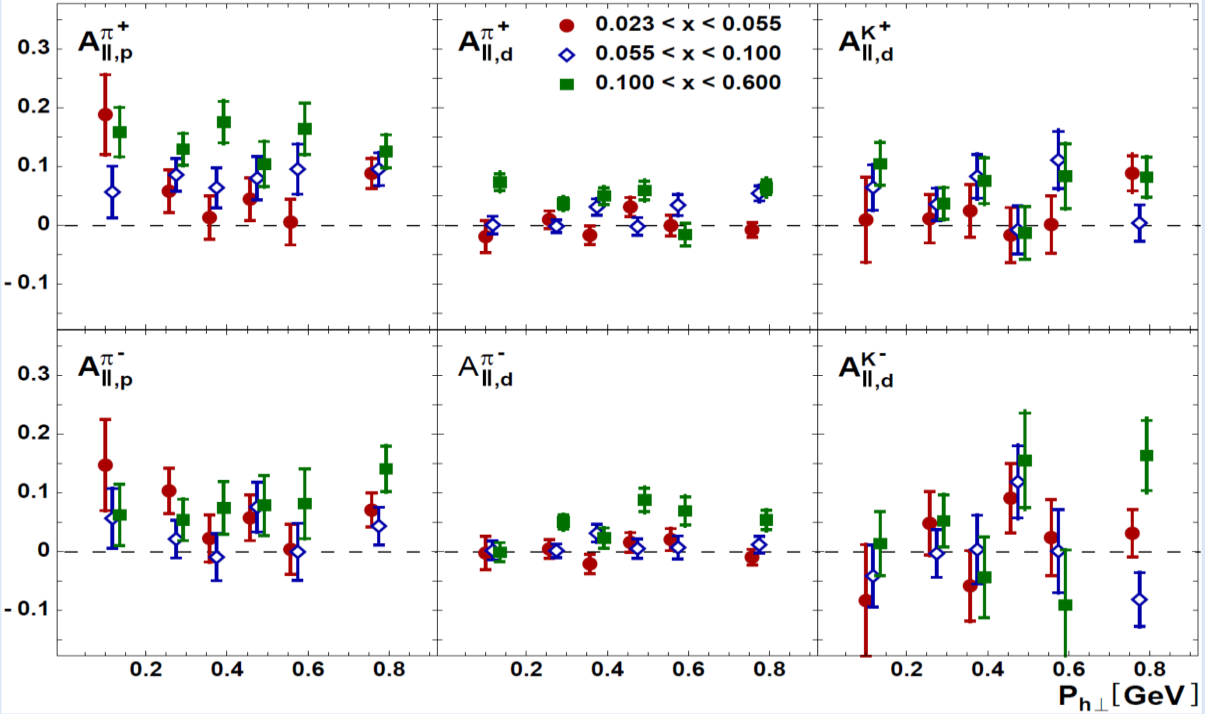


- No strong dependence on z is visible.
- Agreement with COMPASS results for $h^{\pm}$ production from longitudinally polarized deuterons.

The longitudinal double-spin asymmetries $A_{\parallel,N}^{h}$

$$A_{\parallel}^{h} \equiv \frac{C_{\varphi}^{h}}{f_D}\left[\frac{L_{\overrightarrow{\rightarrow}} N_{\overleftarrow{\rightarrow}}^{h} - L_{\overleftarrow{\rightarrow}} N_{\overrightarrow{\rightarrow}}^{h}}{L_{\overrightarrow{\rightarrow}} N_{\overleftarrow{\rightarrow}}^{h} + L_{\overleftarrow{\rightarrow}} N_{\overrightarrow{\rightarrow}}^{h}}\right]_{B}$$

Phys. Rev. D99 (2019) no.11, 112001



- No strong dependence on $P_{h\perp}$ is visible.
- Consistent with weak dependence reported by CLAS (H. Avakian et al. Phys. Rev. Lett. 105 62002 (2010)) and COMPASS (Alekseev et al. Eur. Phys. J. C70, 39 (2010), C. Adolph et al. (2016) ArXiv: 1609.06060[hep-ex]).

Virtual-photon–nucleon asymmetry A_1^h

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

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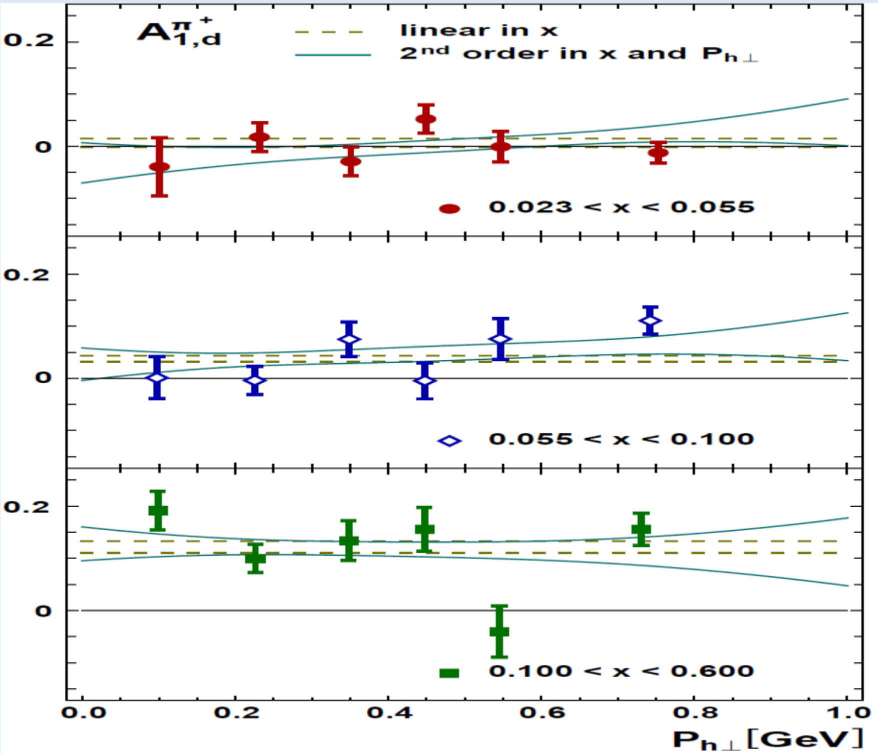
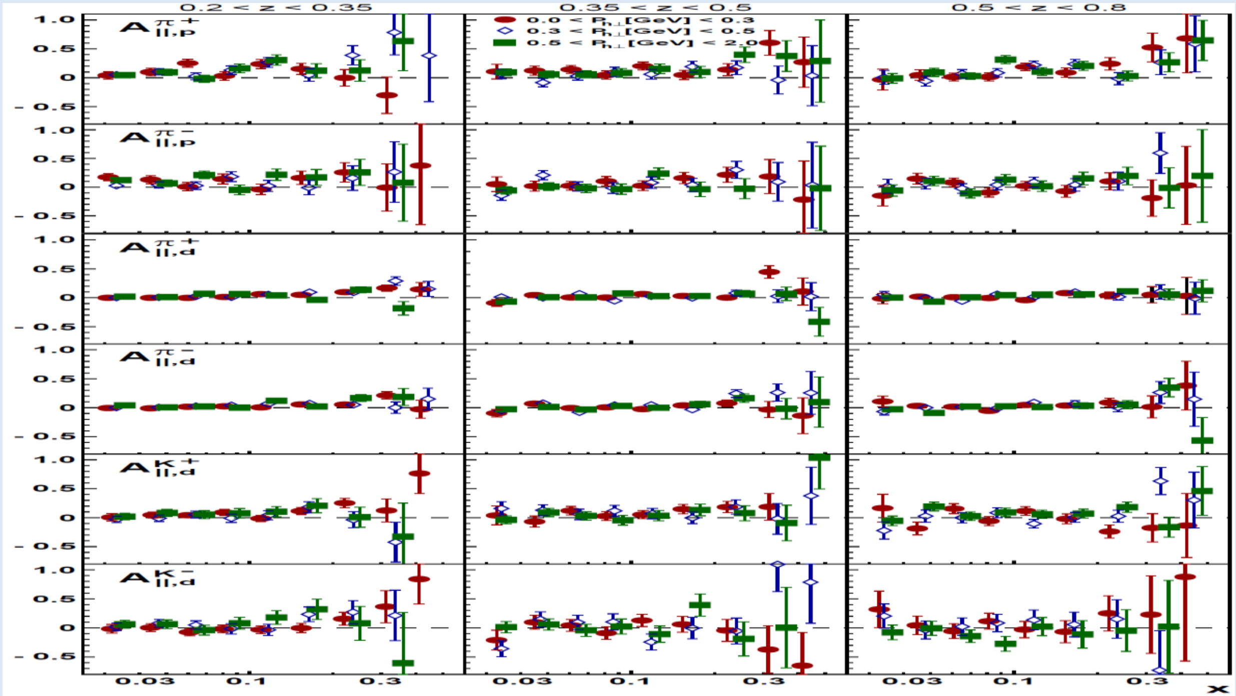


- The asymmetries $A^h_{\parallel,N}$ was transformed into a corresponding A^h_1 asymmetry, fit with a set of polynomial functions: one linear in x only, one linear in both x and $P_{h\perp}$, and second order in both variables.
- No clear preference for any of the functional forms.

Hadron-tagged longitudinal double-spin asymmetry

Phys. Rev. D99 (2019) no.11, 112001

asymmetry binned simultaneously in x, z, and $P_{h\perp}$



- The asymmetry is binned in a grid with nine bins in x, three bins in $P_{h\perp}$, and three bins in z.
- Within the precision of the measurements no obvious dependence on the hadron variables.
- There is possibly an indication that the non-vanishing asymmetry for π^- from protons observed in the one-dimensional binning in x is caused to a large extent by low-z pions.
- Three-dimensionally binned asymmetries are the most complete, unintegrated, longitudinally polarized double-spin dataset to date.

Azimuthal moments of asymmetries

Azimuthal moments of asymmetries are potentially sensitive to unique combinations of distribution and fragmentation functions.

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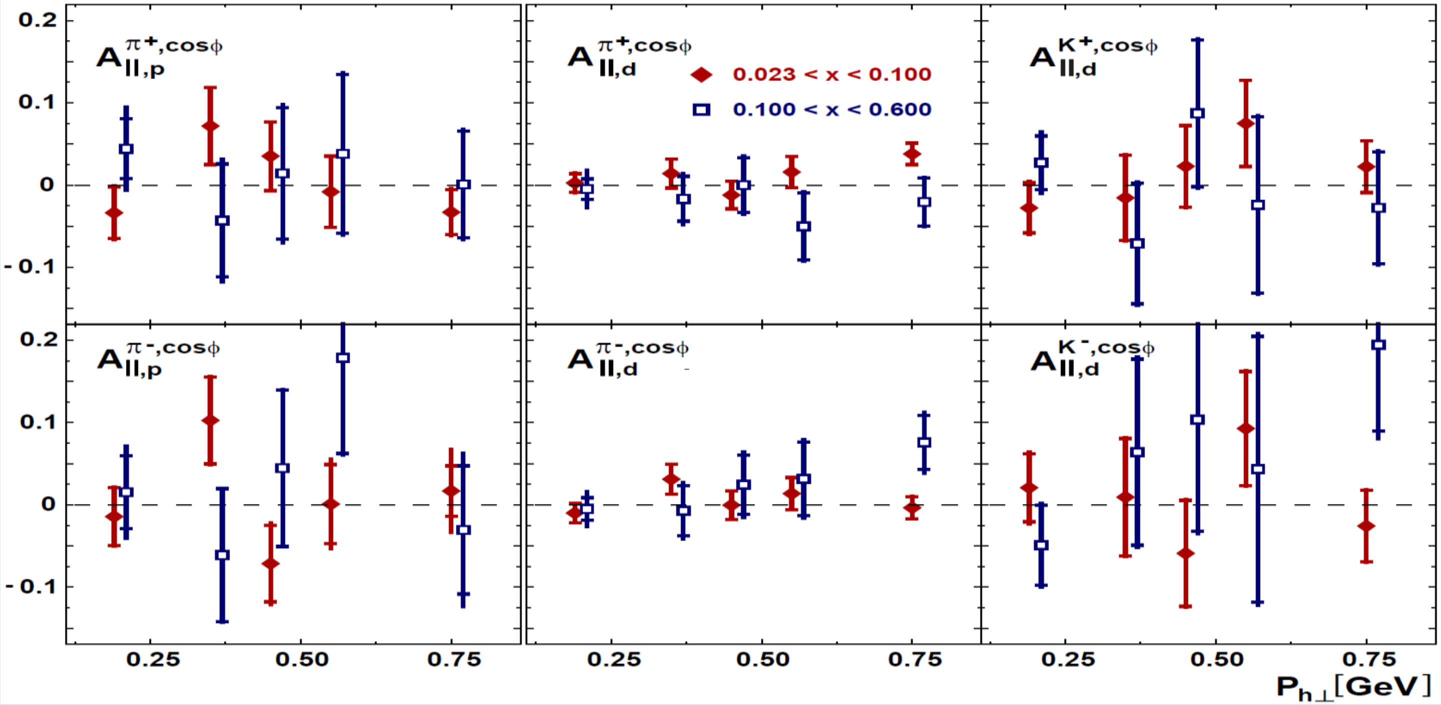
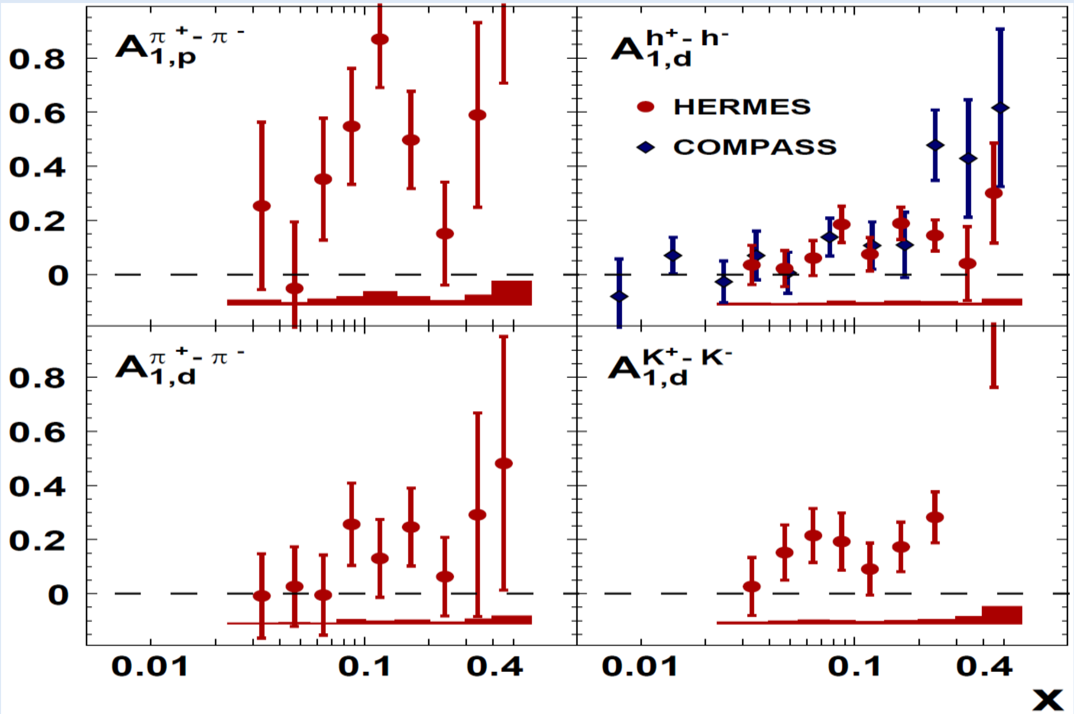


- The functional form used included constant, cos ϕ, and cos 2ϕ terms.
- Each of these cosine moments is found to be consistent with zero. (A similar result was obtained for unidentified hadrons for deuteron data from the COMPASS experiment .
- A vanishing cos 2ϕ asymmetry as found here can be expected: in the one-photon-exchange approximation there is no $A^{h,\cos 2\phi}_{LL}$ contribution to the cross section.

Hadron charge-difference asymmetries

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

Phys. Rev. D99 (2019) no.11, 112001



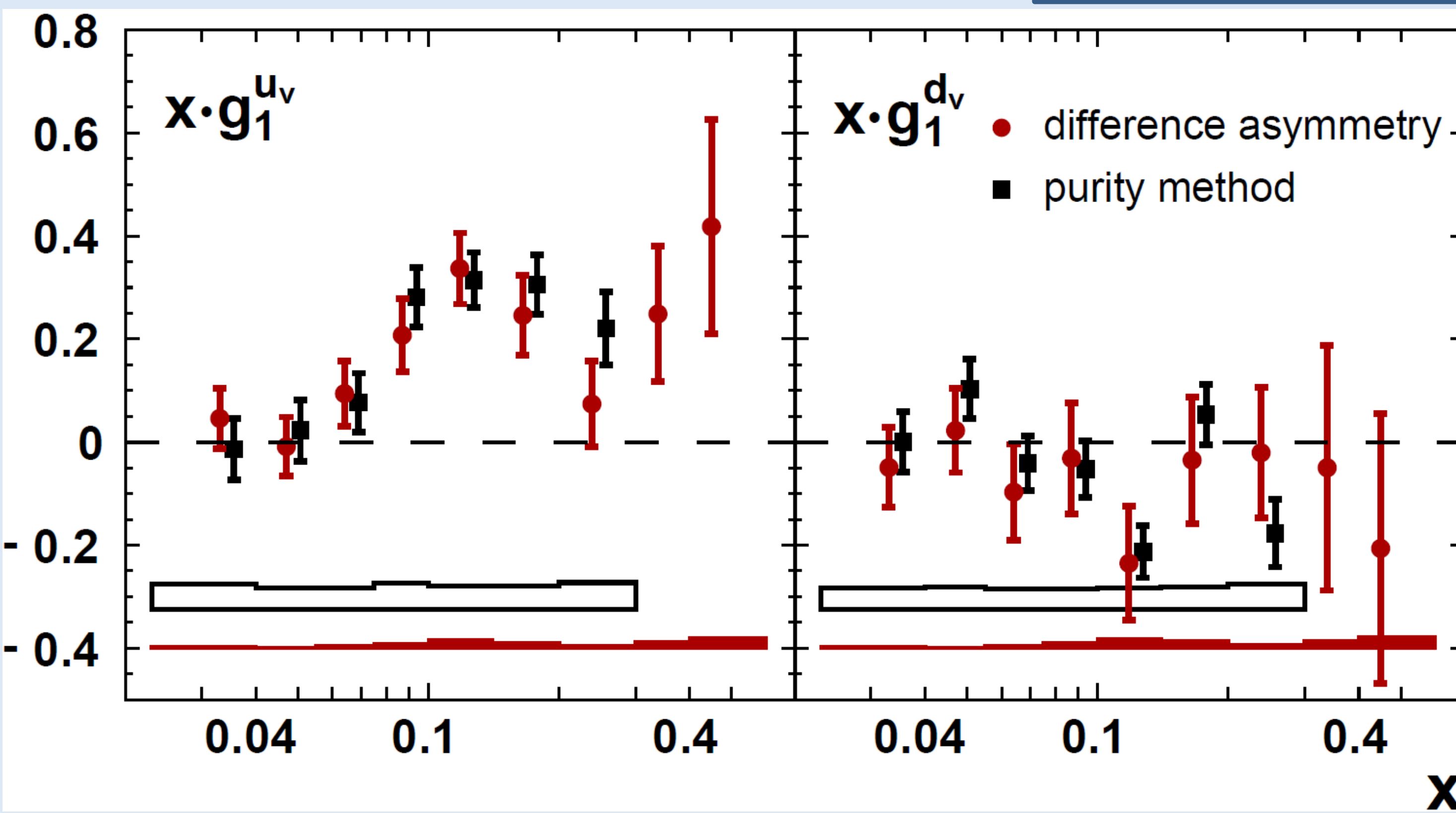
- Unexpected feature: the uncertainties for the kaon asymmetry are considerably smaller than those on the pion asymmetry despite the smaller sample size.
- This is a result of the larger difference between yields of charged kaons compared to that of the charged pions (as K^- shares no valence quarks with the target), which causes a significantly larger denominator in the asymmetry.

Helicity distributions for valence quarks

$$D_1^{q\to h^+} = D_1^{\bar{q}\to h^-}$$

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

Phys. Rev. D99 (2019) no.11, 112001



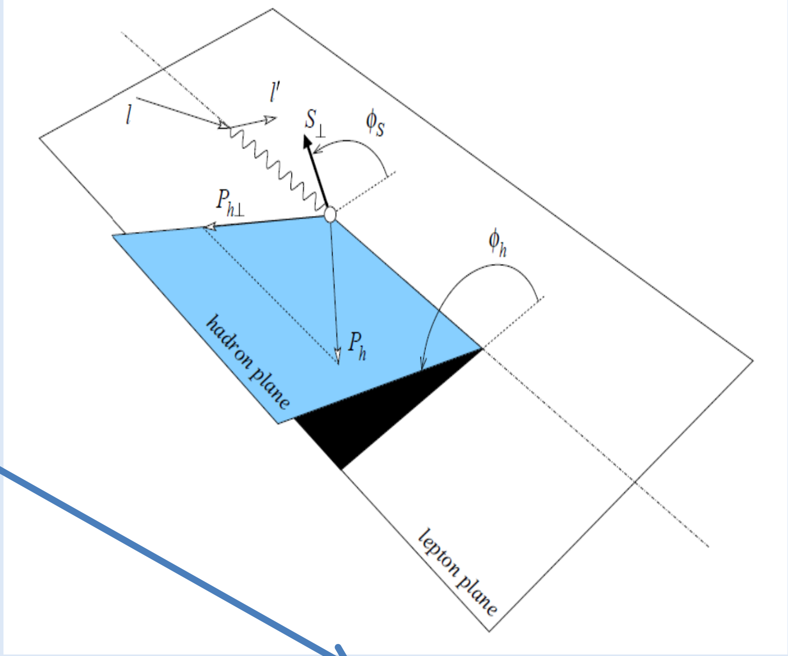
- The results are largely consistent using two methods that have very different and quite complementary model assumptions:
  no significant deviation from the factorization hypothesis.

A_{LU} in semi-inclusive DIS

- Longitudinally polarized e^+/e^- beam
- Unpolarized H & D targets

The SIDIS cross-section: A_{LU} amplitudes

$$
\begin{aligned}
\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = {} & \frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h} \\
& +\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h} \\
& +S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right] \\
& +S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right] \\
& +|\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right) \\
& \quad+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} \\
& \quad+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] \\
& +|\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S} \\
& \quad+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},
\end{aligned}
$$



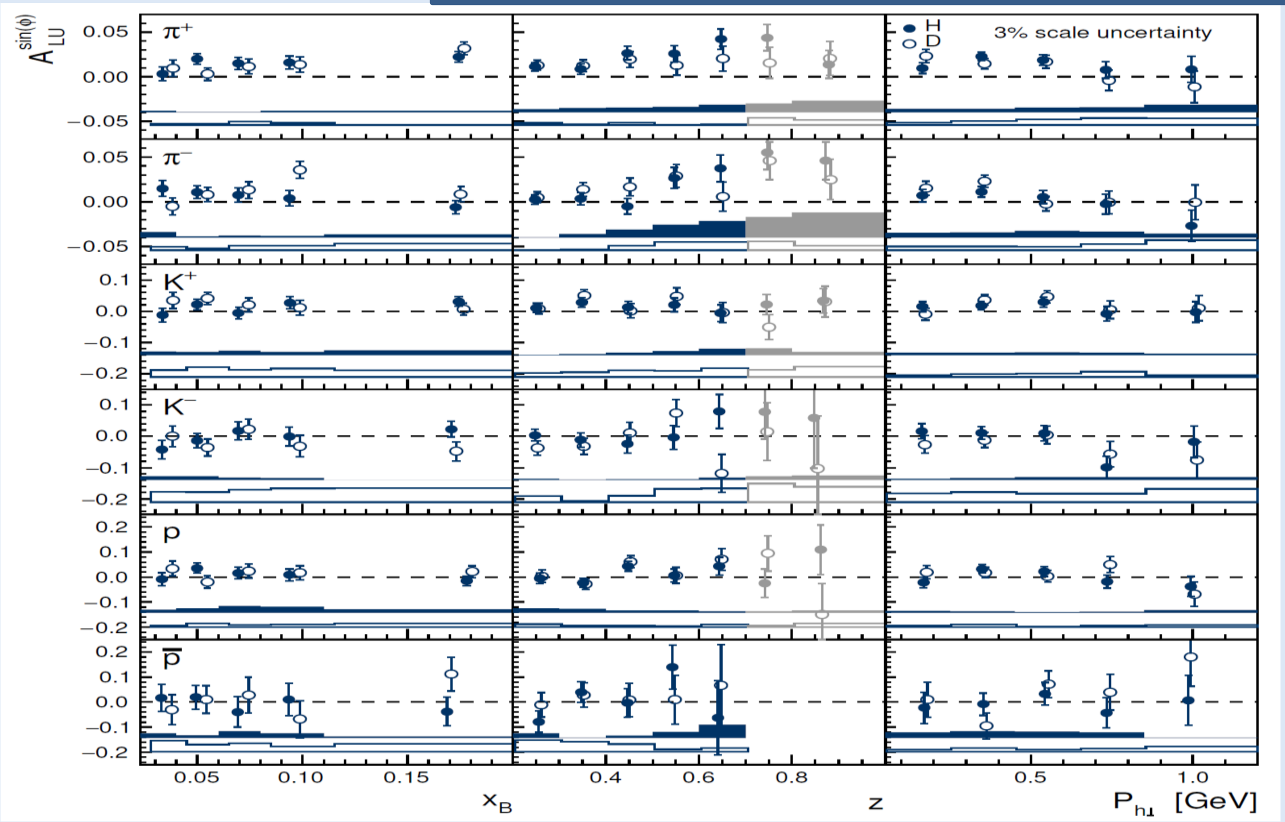
In case of longitudinal beam (L) and unpolarized target (U) only target spin-independent parts can contribute to the asymmetry. The structure function of interest :

$$F_{LU}^{\sin\phi_h}$$

A_{LU} amplitudes: Subleading twist

ArXiv:1903.08544[hep-ex]

$$F_{LU}^{\sin(\phi_h)} \propto xeH_1^{\perp} \oplus \frac{M_h}{M_z} f_1\tilde{G}^{\perp} \oplus xg^{\perp}D_1 \oplus \frac{M_h}{M_z} h_1^{\perp}\tilde{E}$$

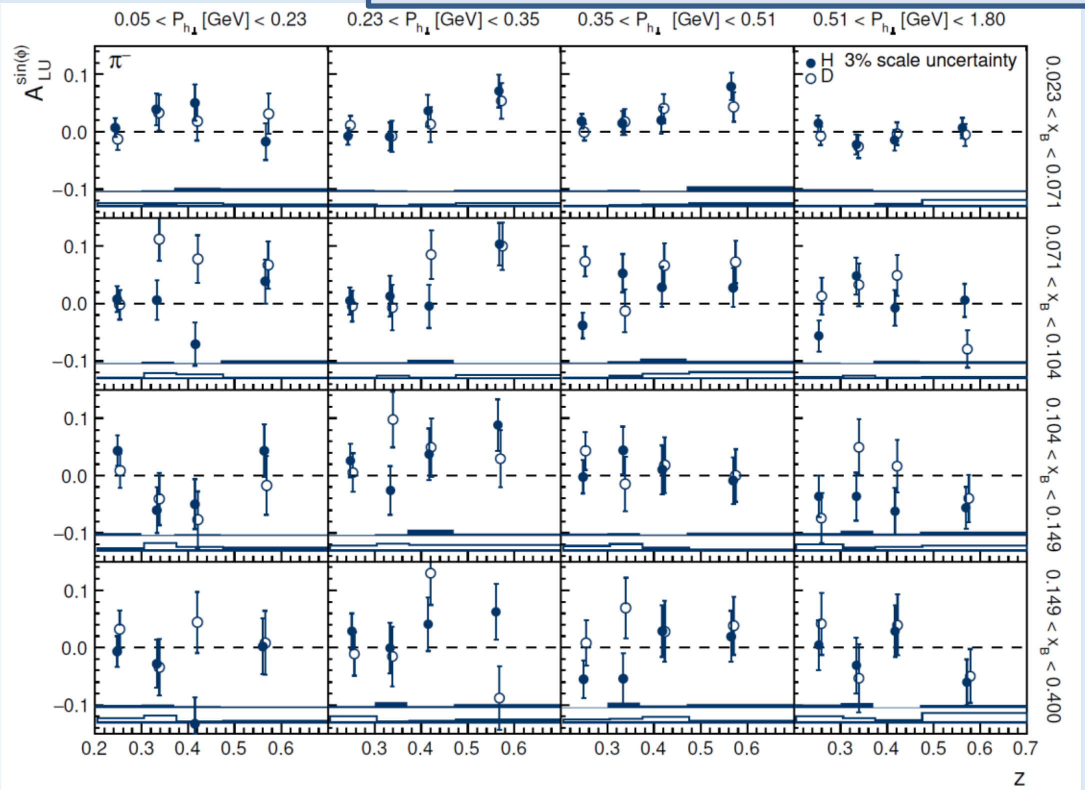


- Significant positive amplitudes for (in particular positive) pions, rising as a function of z.
- Possible increase of the amplitude vs. $P_{h\perp}$ for low values of $P_{h\perp}$, decrease at high $P_{h\perp}$ for $\pi^{\pm}$.
- For K^+ a small, positive amplitude is seen, for K^-. proton and anti-proton compatible with 0.

A_{LU} amplitudes: Subleading twist; 3D extraction

ArXiv:1903.08544[hep-ex]

$$F_{LU}^{\sin(\phi_h)} \propto xeH_1^{\perp} \oplus \frac{M_h}{M_z} f_1\tilde{G}^{\perp} \oplus xg^{\perp}D_1 \oplus \frac{M_h}{M_z} h_1^{\perp}\tilde{E}$$

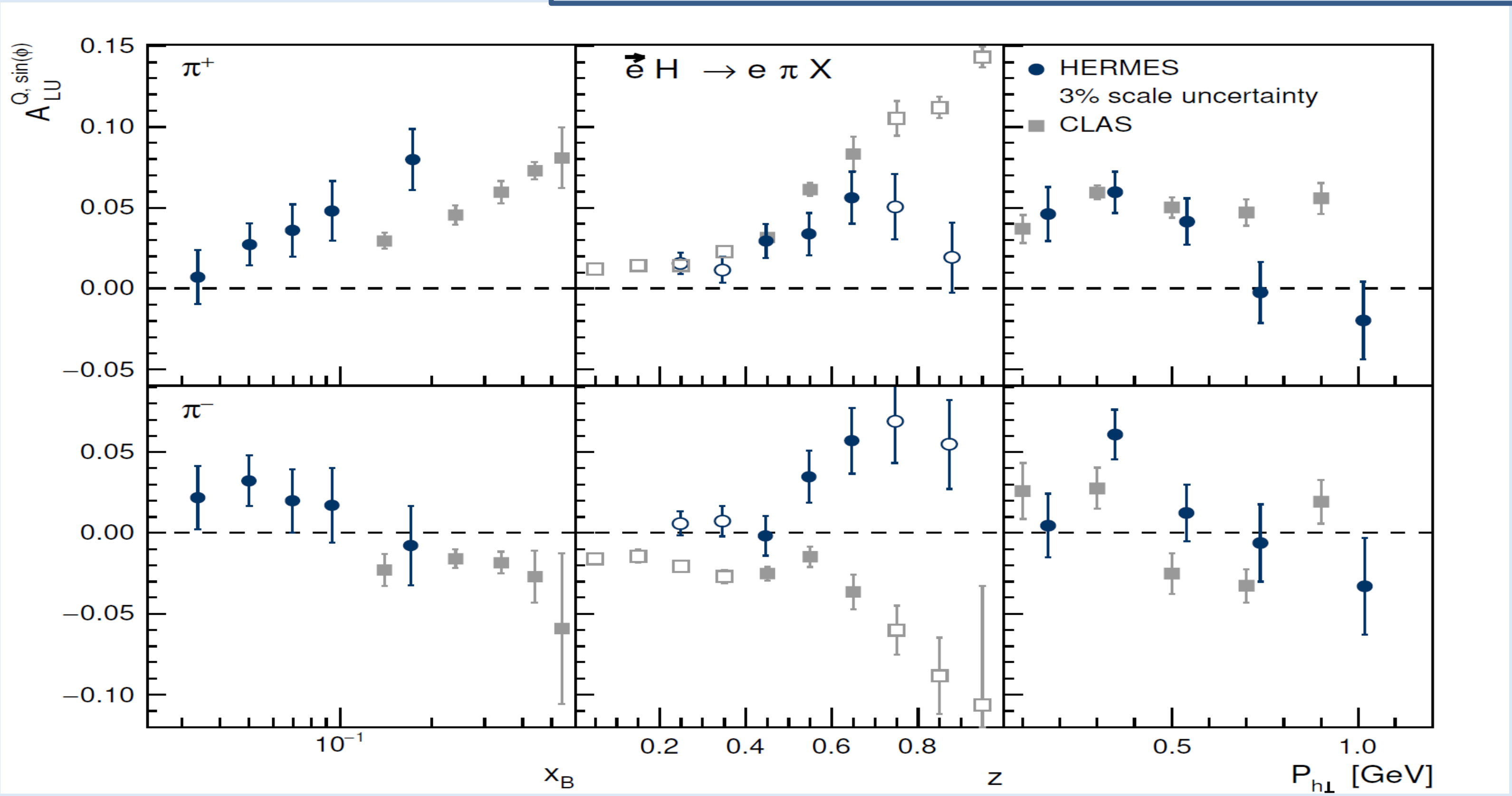


- The rise of the asymmetry amplitude as a function of z seen in the one-dimensional extraction is observed here for certain regions in x_B and $P_{h\perp}$.
- Other hadrons: no distinctive kinematic dependence is visible.
- 3D projections allow to constrain global fits in a more profound way.

A_{LU} amplitudes: Subleading twist

ArXiv:1903.08544[hep-ex]

$$F_{LU}^{\sin(\phi_h)} \propto xeH_1^{\perp} \oplus \frac{M_h}{M_z} f_1\tilde{G}^{\perp} \oplus xg^{\perp}D_1 \oplus \frac{M_h}{M_z} h_1^{\perp}\tilde{E}$$

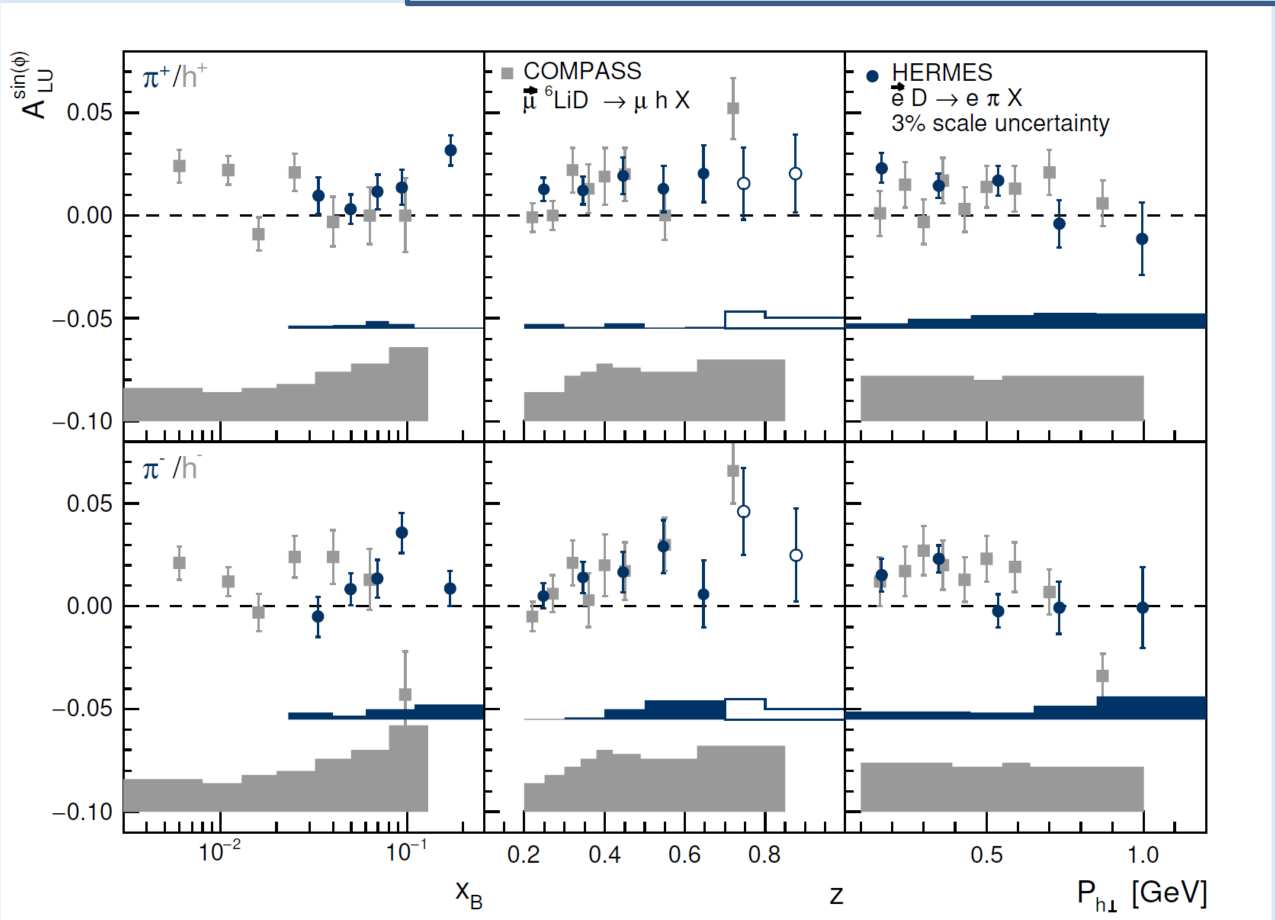


- Opposite behavior at HERMES/CLAS negative pions in z projection due to x-range probed in different experiments.
- Hint at the dominance of contributions from different pairs of PDFs and FFs.

A_{LU} amplitudes: Subleading twist

ArXiv:1903.08544[hep-ex]

$$F_{LU}^{\sin(\phi_h)} \propto xeH_1^{\perp} \oplus \frac{M_h}{M_z} f_1\tilde{G}^{\perp} \oplus xg^{\perp}D_1 \oplus \frac{M_h}{M_z} h_1^{\perp}\tilde{E}$$



- Consistent behavior for charged pions (hadrons) at HERMES/COMPASS for isoscalar targets

Summary

- 3D picture of the nucleon:

  - A_{UT} and A_{LT} in semi-inclusive DIS: 3D extraction, including protons: contribute to understanding of various TMD PDFs @ twist 2 and twist 3.

  - A_{LL} in semi-inclusive DIS:
    - Refined studies $\Longrightarrow$ Extend the results of double-spin asymmetries early published by HERMES;
    - One-dimensional binning in x $\Longrightarrow$ Extended 3D extraction;
    - Three-dimensionally binned asymmetries are the most complete, unintegrated, longitudinally polarized double-spin dataset to date;
    - Hadron charge-difference asymmetries $\Longrightarrow$ Helicity distributions for valence quarks.

  - A_{LU} in semi-inclusive DIS:
    - Subleading twist: 3D extraction.
    - Hint at the dominance of contributions from different pairs of PDFs and FFs.

Thank You