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Transverse momentum dependent distributions studied by hermes

Multi dimensional analysis of SSA, DSA, BSA

Y. Miyachi, YAMAGATA UNIVERSITY

for the hermes collaboration

Contents

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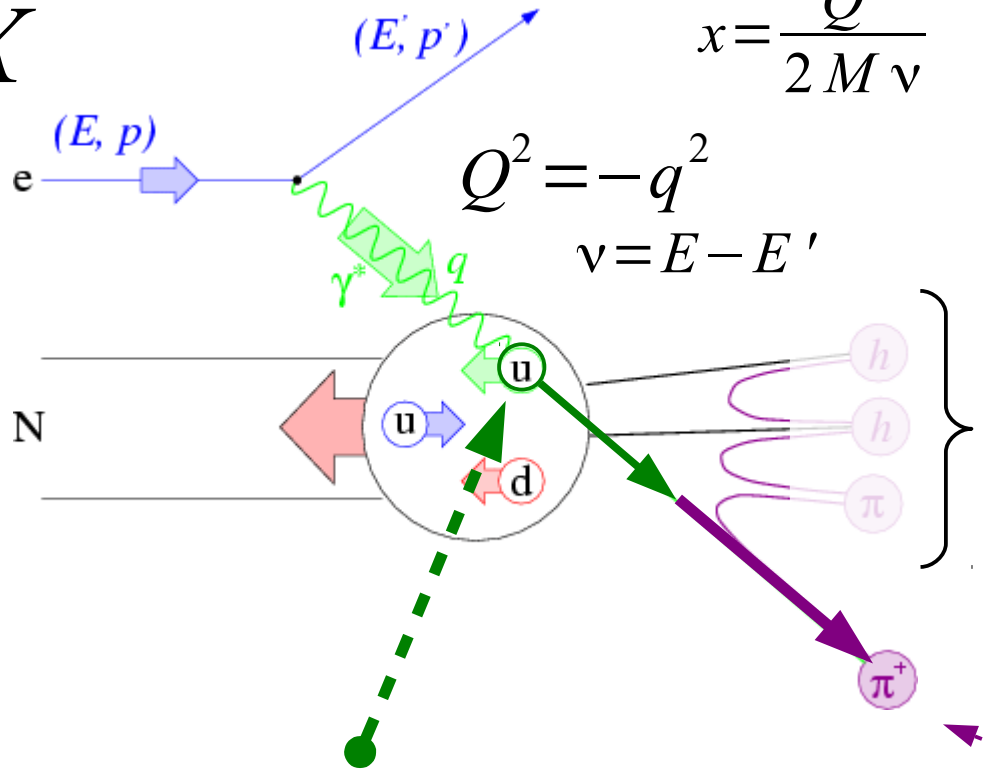
- HERMES experiment
- Spin structure of the proton studied at HERMES
  - Semi-inclusive measurements of DIS
    - Transverse momentum dependent PDF
- TMD stuided @ HERMES
  - Multi dimensional analysis SSA & DSA
  - Multi dimensional analysis BSA: A_{LU}
- Summary

Semi-inclusive measurement of DIS

$$e\,N \rightarrow e'\,h\,X$$



$$x = \frac{Q^2}{2\,M\,\nu}$$

$$Q^2 = -q^2$$

$$\nu = E - E'$$

$$z = \frac{E_h}{\nu}$$

$$\sigma^{eN \rightarrow e'hX} = \sum_q f^{N \rightarrow q} \otimes \hat{\sigma}^{eq \rightarrow e'q} \otimes F^{q \rightarrow h}$$

Parton Distribution Function

$$f\left(x, Q^2\right)$$

Fragmentation Function

$$F\left(z, Q^2\right)$$

HERMES experiment

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Targets: **Unpolarized H, D**, nuclei

Longitudinally polarized H, D (P ~ 85 %)

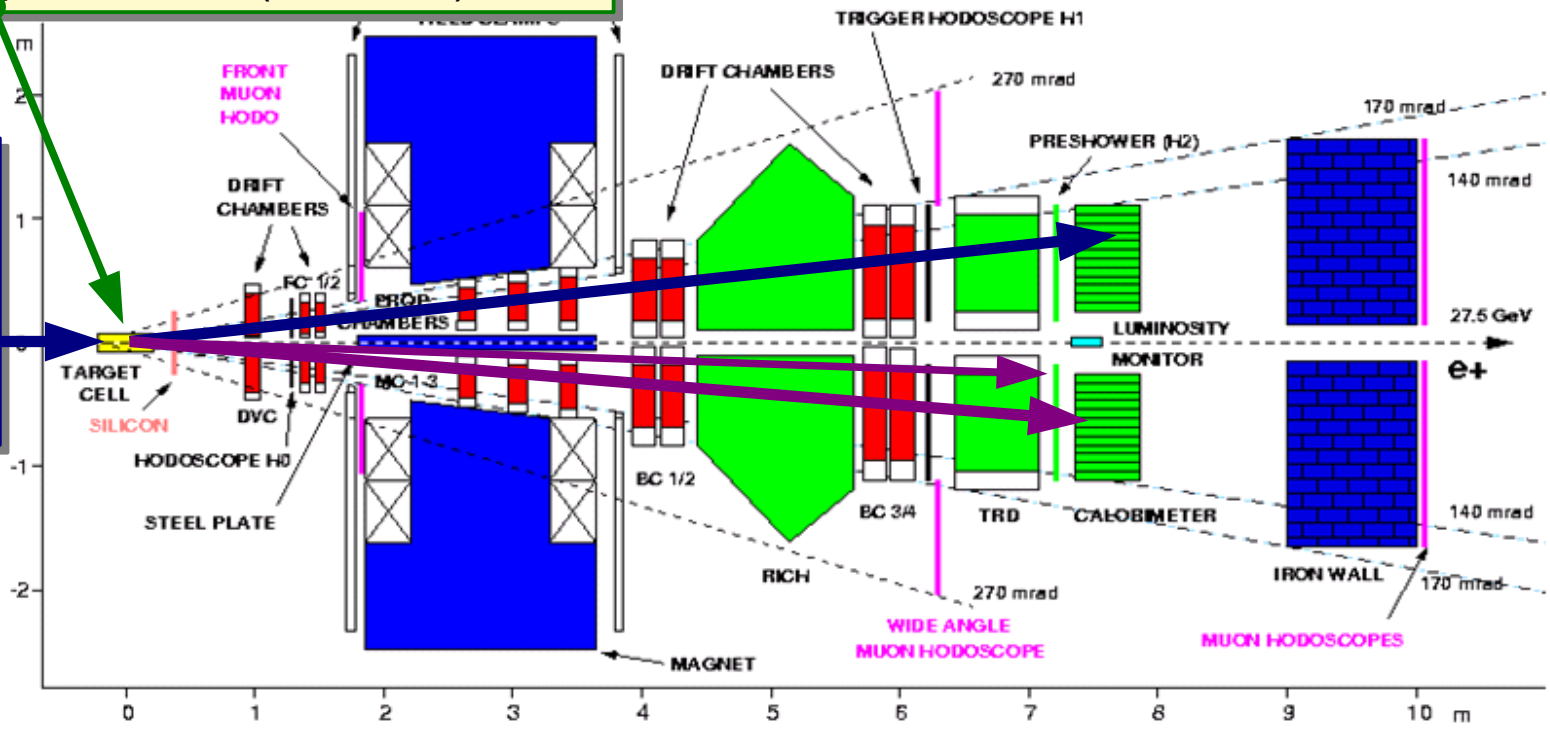
Transversely polarized H (P ~ 75%)

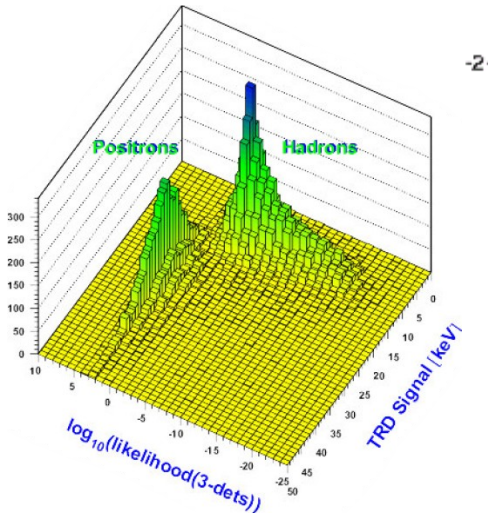
$$e + N \rightarrow e' + h + X$$

HERA: 27.6 GeV

polarized

electron/positron





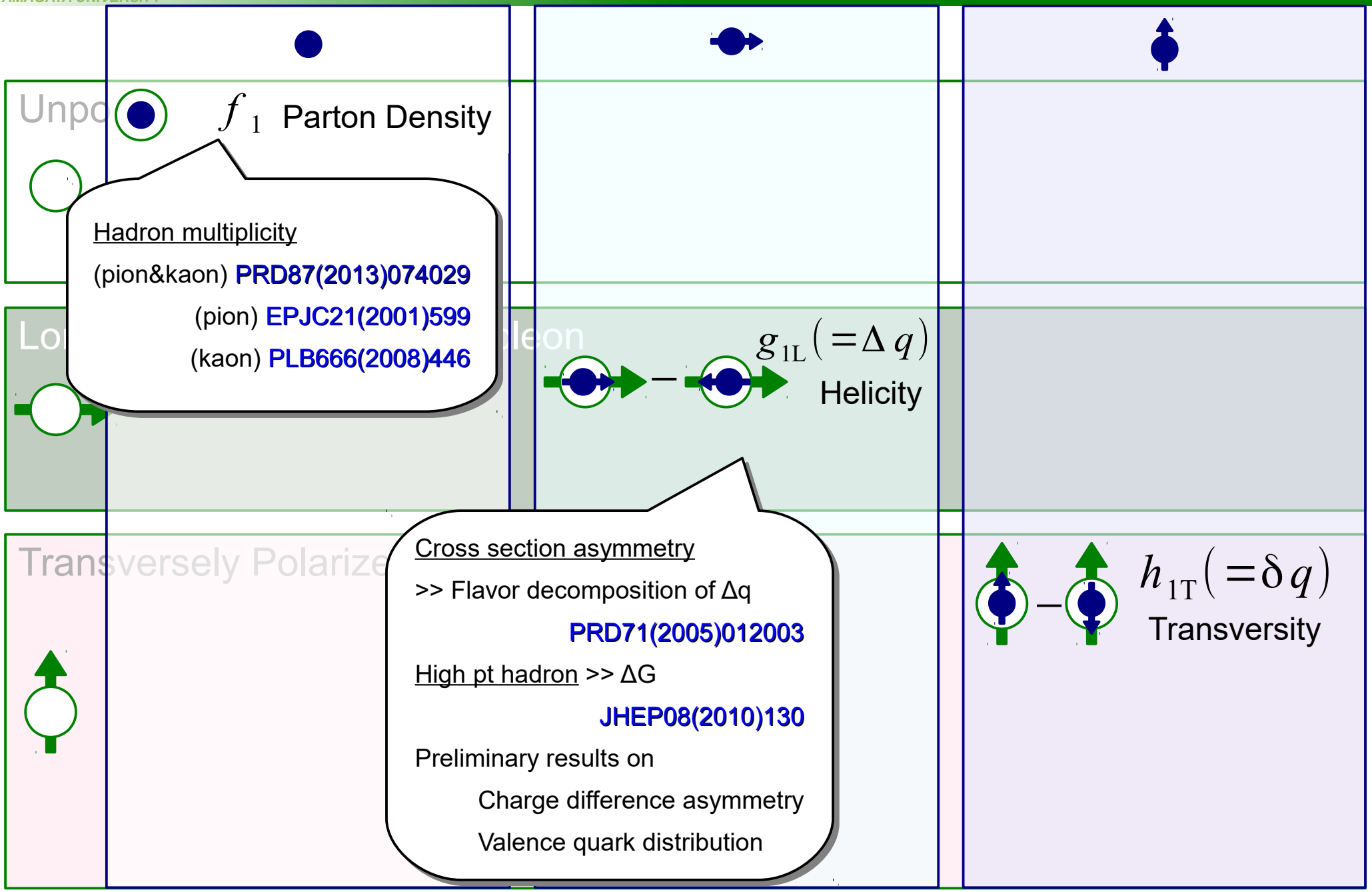
Reconstruction: Δp/p < 2%, Δθ<0.6 mrad

Lepton selection efficiency: > 99%

with hadron contamination < 1%

Hadron ID with RICH: π, K, p in 2 < p < 15 GeV/c

Parton distribution functions: from SIDIS



SIDIS cross section

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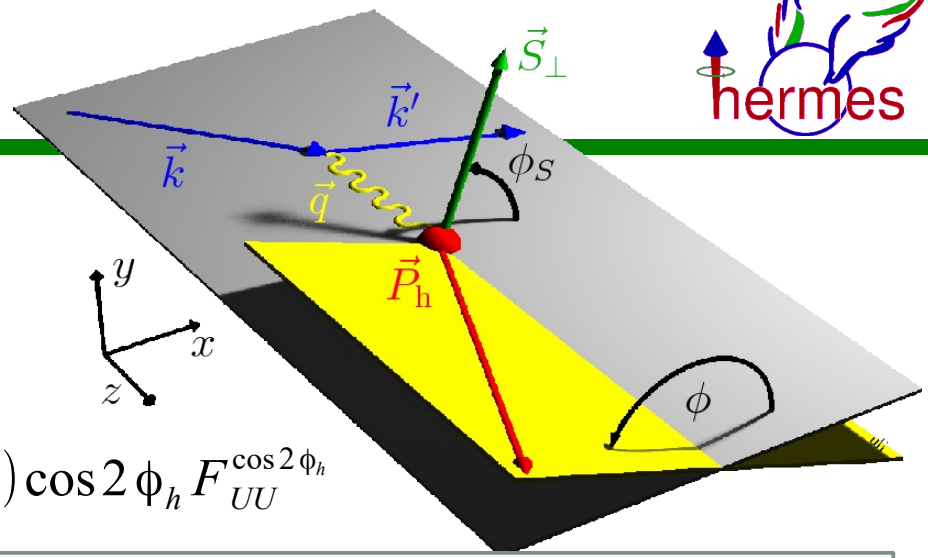
$$e + N \rightarrow e' + h + X$$



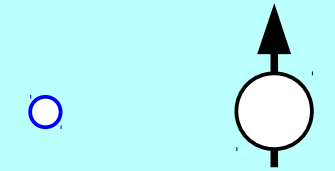
$$d\sigma \propto$$

$$\frac{1+(1-y)^2}{2} F_{UU} + (2-y)\sqrt{1-y}\cos\phi_h F_{UU}^{\cos\phi_h} + (1-y)\cos 2\phi_h F_{UU}^{\cos 2\phi_h}$$

$$+ S_L \left[(1-y)\sin 2\phi_h F_{UL}^{\sin 2\phi_h} + (2-y)\sqrt{1-y}\sin\phi_h F_{UL}^{\sin\phi_h} \right]$$

$$+ S_L P_z^l \left[\frac{1-(1-y)^2}{2} F_{LL} + y\sqrt{1-y}\cos\phi_h F_{LL}^{\cos\phi_h} \right]$$

$$+ S_T \left[\frac{1+(1-y)^2}{2} \sin(\phi_h - \phi_S) F_{UT}^{\sin(\phi_h-\phi_S)} \right.$$
$$+ (1-y)\left(\sin(\phi_h + \phi_S) F_{UT}^{\sin(\phi_h+\phi_S)} + \sin(3\phi_h - \phi_S) F_{UT}^{\sin(3\phi_h-\phi_S)} \right)$$
$$\left. + (2-y)\sqrt{1-y}\left(\sin\varphi_S F_{UT}^{\sin\phi_S} + \sin(2\phi - \phi_S) F_{UT}^{\sin(2\phi-\phi_S)} \right) \right]$$



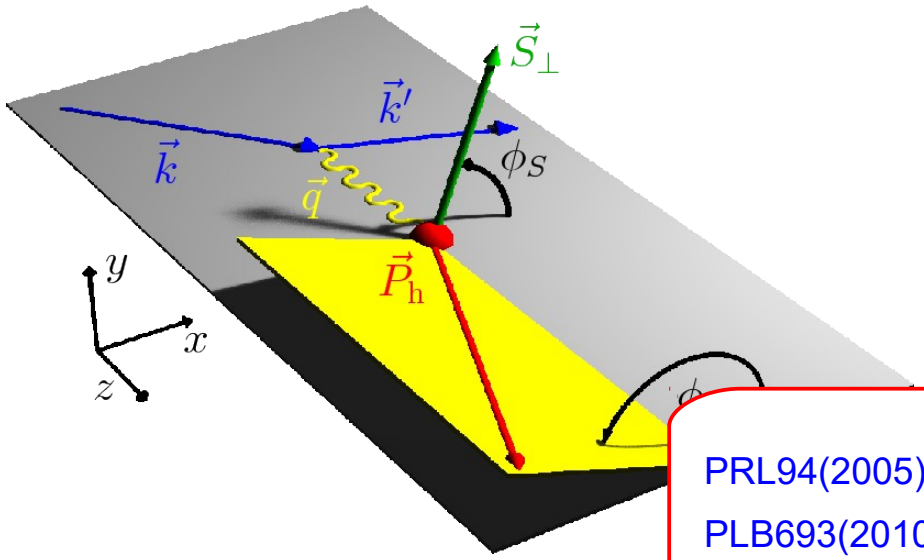
$$+ S_T P_z^l \left[\frac{1-(1-y)^2}{2} \cos(\phi_h - \phi_S) F_{LT}^{\cos(\phi_h-\phi_S)} + y\sqrt{1-y}\left(\cos\phi_S F_{LT}^{\cos\phi_S} + \cos(2\phi - \phi_S) F_{LT}^{\cos(2\phi-\phi_S)} \right) \right]$$

Transverse Momentum Dependent PDF

Unpo

Long

Transversely Polarized Nucleon



$h_1^\perp$ Boer-Mulders

$h_1^\perp \otimes H_1^\perp \sim \cos 2\phi$

$h_{1L}^\perp$ Mulders-Kotzinian

$h_{1L}^\perp \otimes H_1^\perp \sim \sin 2\phi$

PRL94(2005)012002

PLB693(2010)11

$f_{1T}^\perp$ Sivers

PRL94(2005)012002

PRL103(2009)152002

$f_{1T}^\perp \otimes D_1 \sim \sin(\phi - \phi_S)$

g_{1T} Worm-gear

$g_{1T} \otimes D_1 \sim \cos(\phi - \phi_S)$

$h_{1T}(=\delta q)$ Transversity

$h_{1T} \otimes H_1^\perp \sim \sin(\phi + \phi_S)$

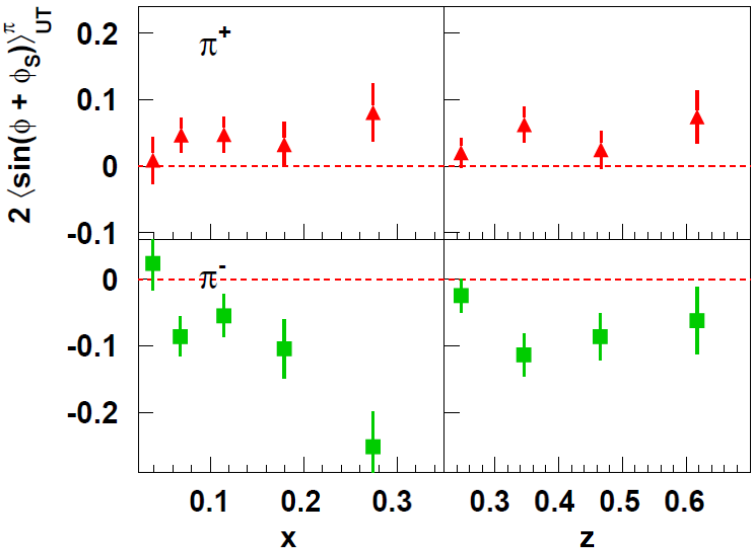
$h_{1T}^\perp$ Pretzelosity

$h_{1T}^\perp \otimes H_1^\perp \sim \sin(3\phi - \phi_S)$

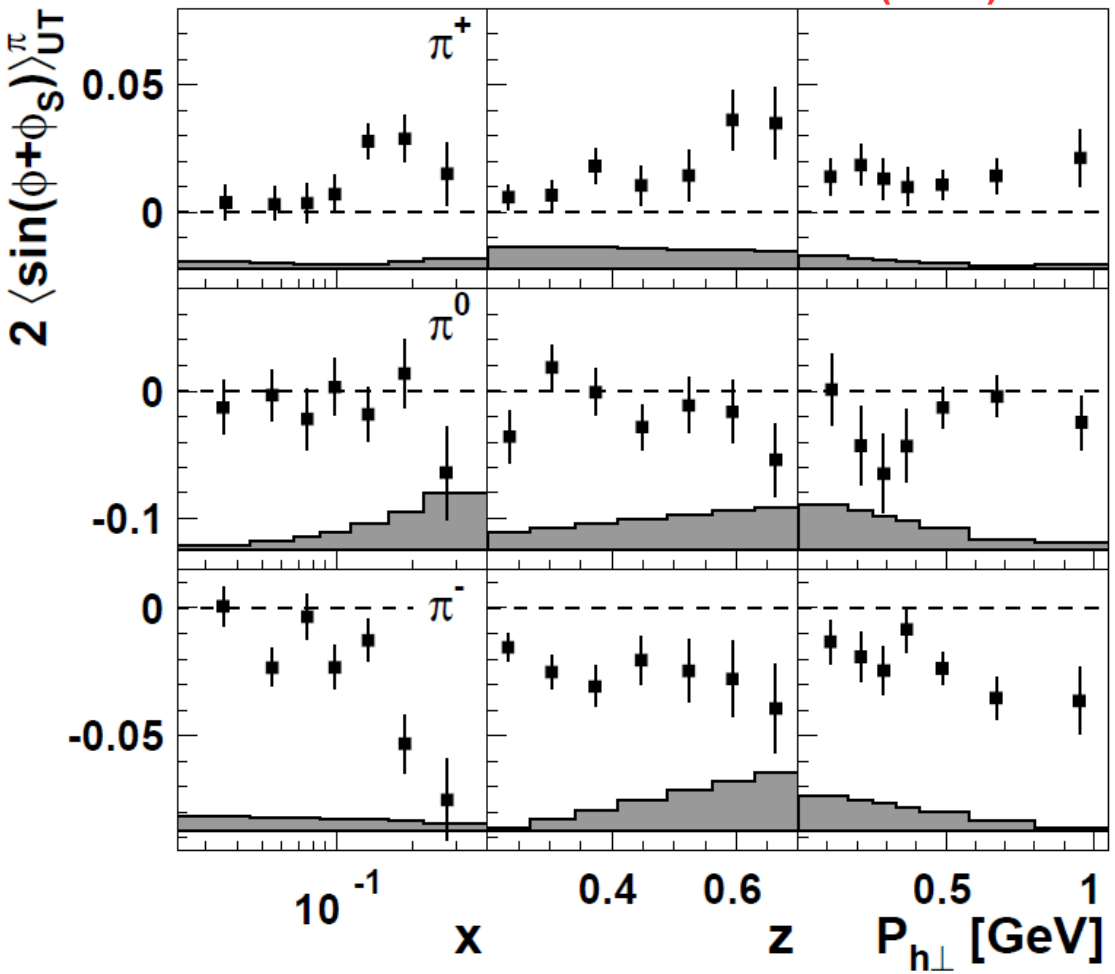
Transversity: Collins asymmetry

$$h_{1T} \otimes H_1^{\perp} \sim \sin\left(\phi + \phi_S\right)$$

PRL94(2005)012002



PLB693(2010)11-16



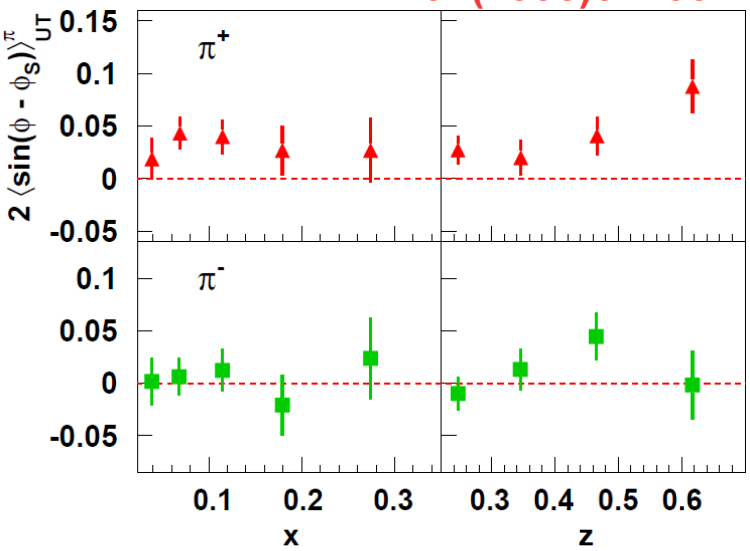
- 2002, 2003 data
- $\pi^{\pm}$

- Full data set
- $\pi^{\pm,0}$, $K^{\pm}$

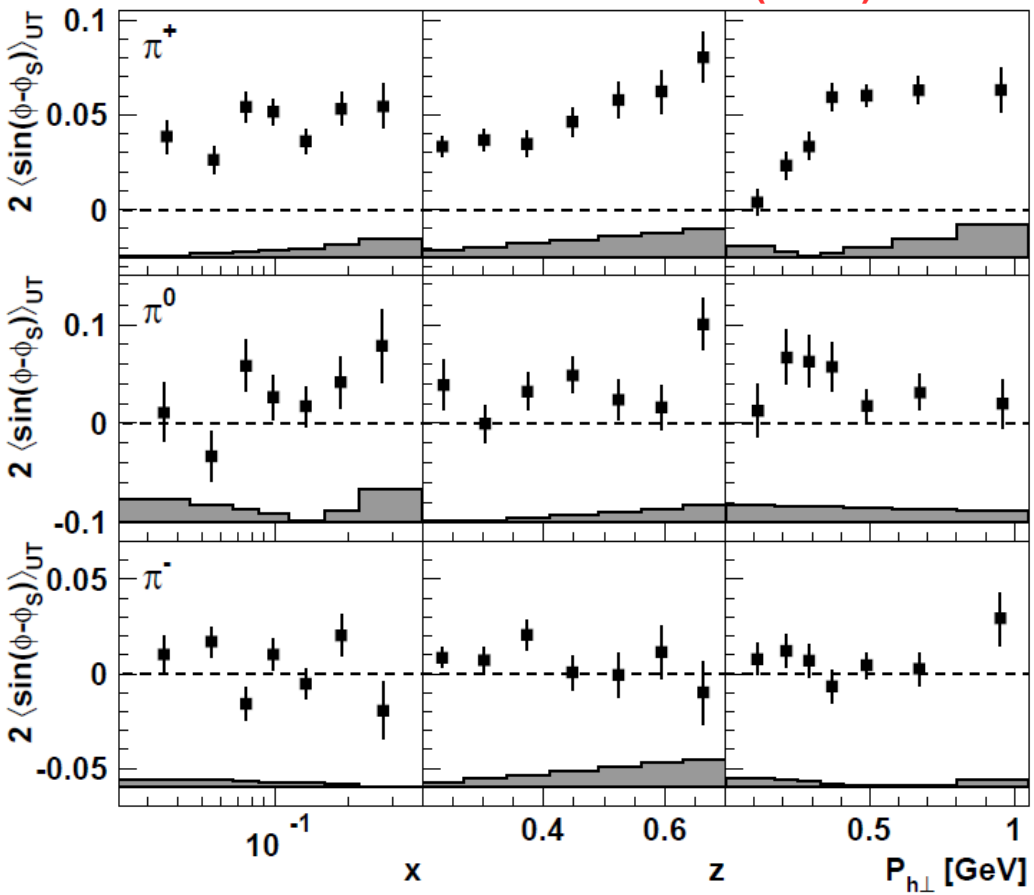
Siverse asymmetry

$$f_{1T}^{\perp} \otimes D_1 \sim \sin(\phi - \phi_S)$$

PRL94(2005)012002



PRL103(2009)152002



- 2002, 2003 data
- $\pi^{\pm}$

- Full data set
- $\pi^{\pm,0}$, $K^{\pm}$

Multi dimensional analysis of SSA & DSA

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Year	π^+	K^+	p	π^-	K^-	$\bar{p}$
2002	67k	13k	8k	49k	5k	1k
2003	35k	6k	5k	25k	3k	1k
2004	205k	37k	25k	149k	15k	4k
2005	447k	81k	56k	320k	34k	9k
Total	**755k**	**136k**	**93k**	**543k**	**57k**	**15k**

3D binning: $(x_{Bj}, z, P_{h\perp})$

x_{Bj}	0.023 0.023	0.072 0.073	0.098 0.017	0.138 0.157	0.600 0.600
z	0.20 0.20	0.28 0.34	0.37 0.43	0.49 0.52	0.70 0.70
$P_{h\perp}$ (GeV)	0.00 0.00	0.23 0.24	0.36 0.40	0.54 0.57	2.00 2.00

SSA

$$2\langle \sin(\phi+\phi_S)\rangle_{UT}$$
$$2\langle \sin(\phi-\phi_S)\rangle_{UT}$$
$$2\langle \sin(\phi_S)\rangle_{UT}$$
$$2\langle \sin(2\phi-\phi_S)\rangle_{UT}$$
$$2\langle \sin(3\phi-\phi_S)\rangle_{UT}$$
$$2\langle \sin(2\phi+\phi_S)\rangle_{UT}$$

DSA

$$2\langle \cos(\phi+\phi_S)\rangle_{LT}$$
$$2\langle \cos(\phi-\phi_S)\rangle_{LT}$$
$$2\langle \cos(\phi_S)\rangle_{LT}$$
$$2\langle \cos(2\phi-\phi_S)\rangle_{LT}$$

Transversity: Collins asymmetry (1D)

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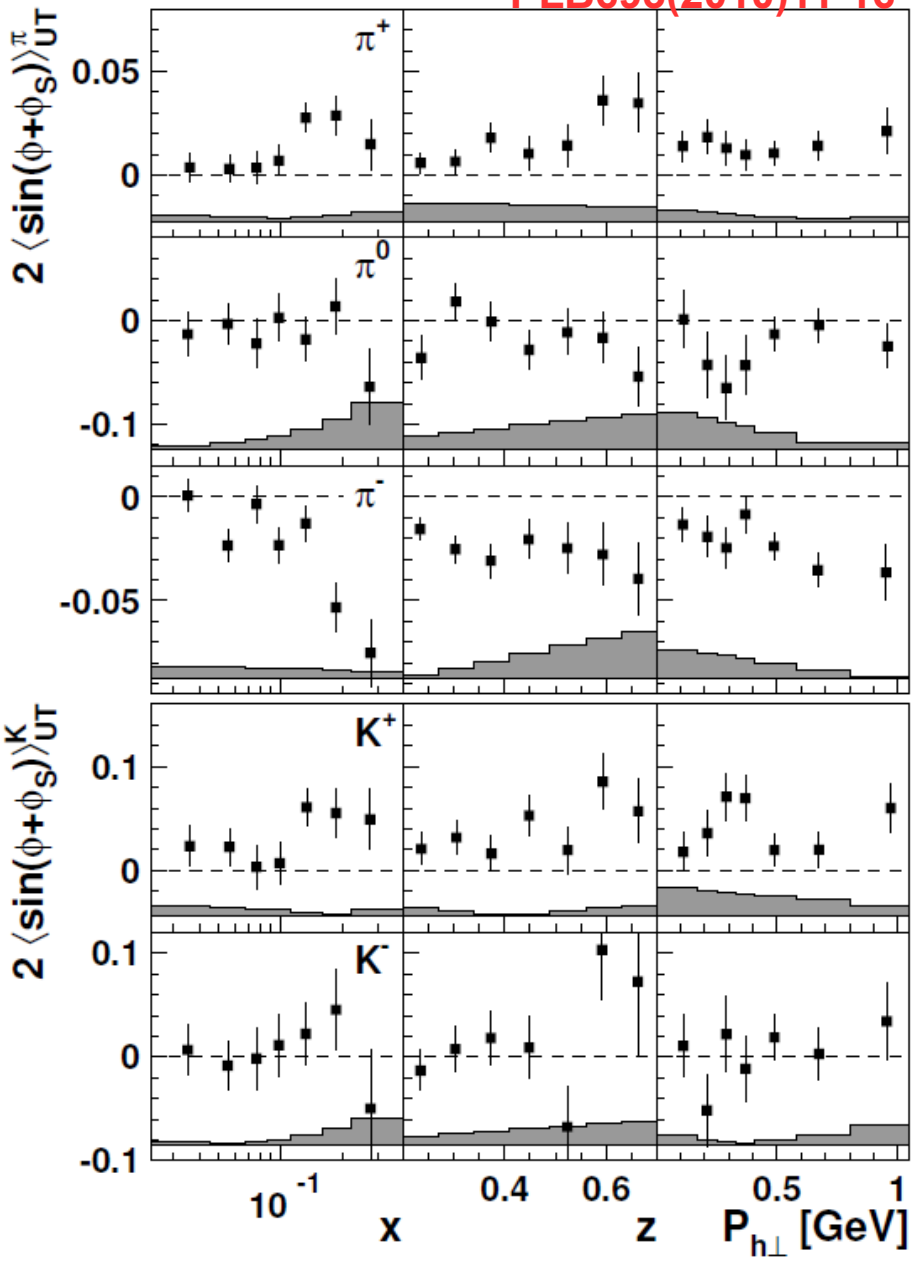

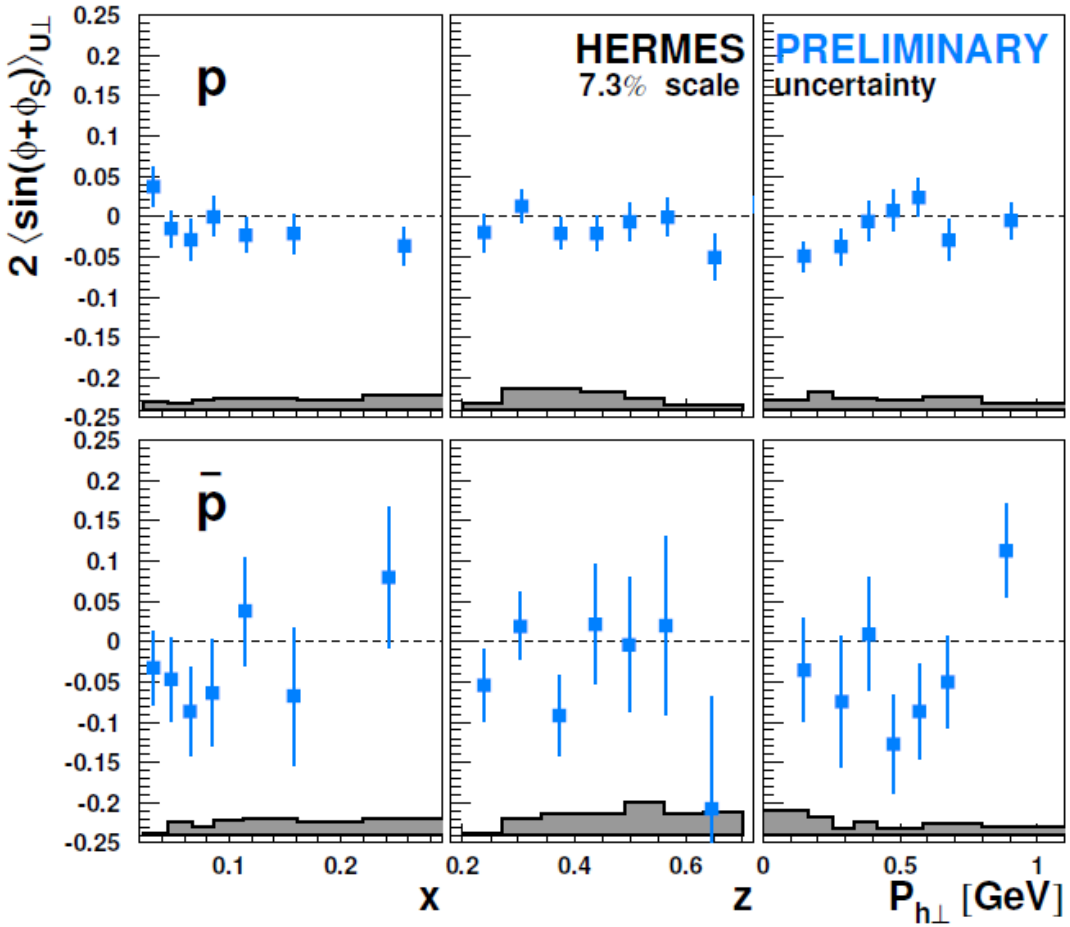

Sivers asymmetry (1D)

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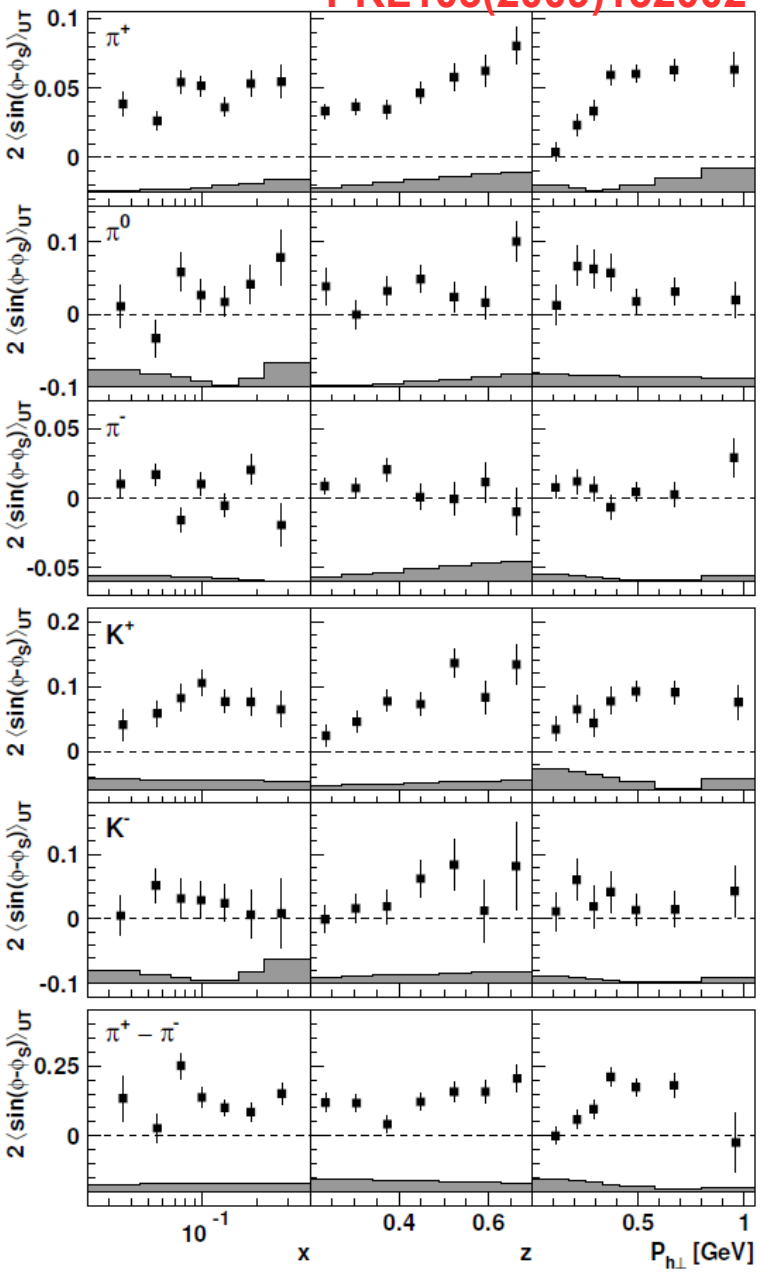
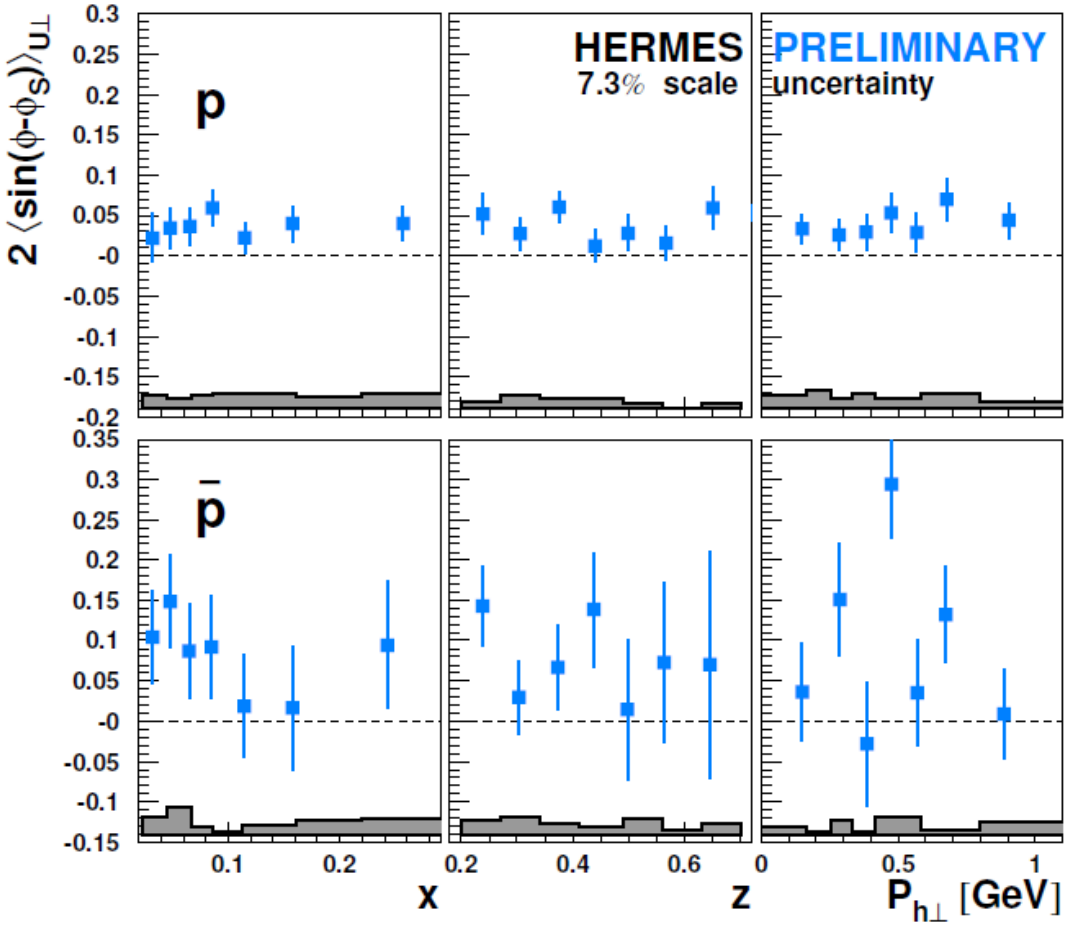
PRL103(2009)152002





Transversity: Collins asymmetry (3D)

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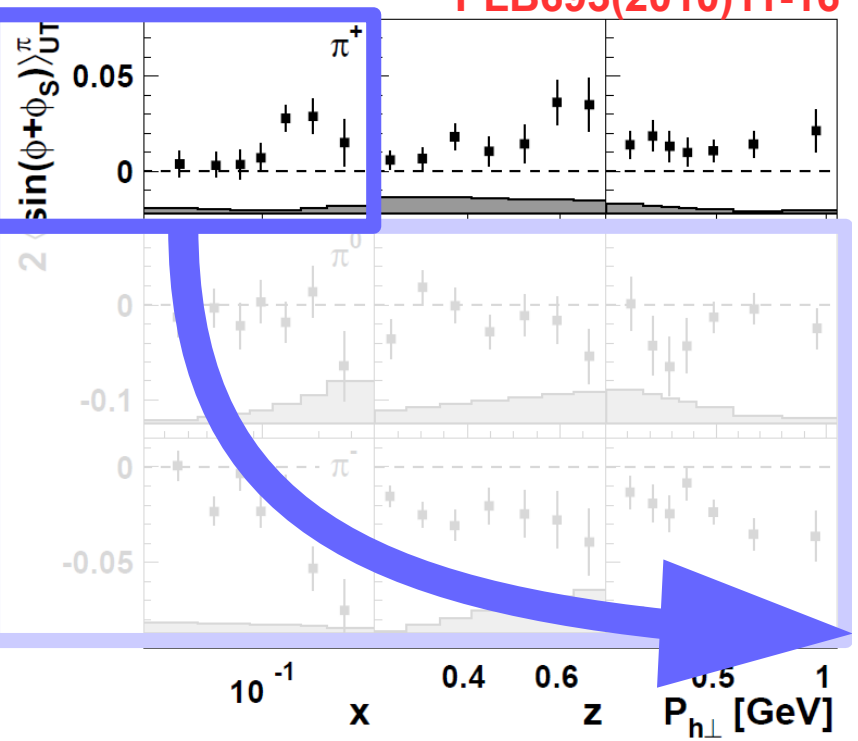

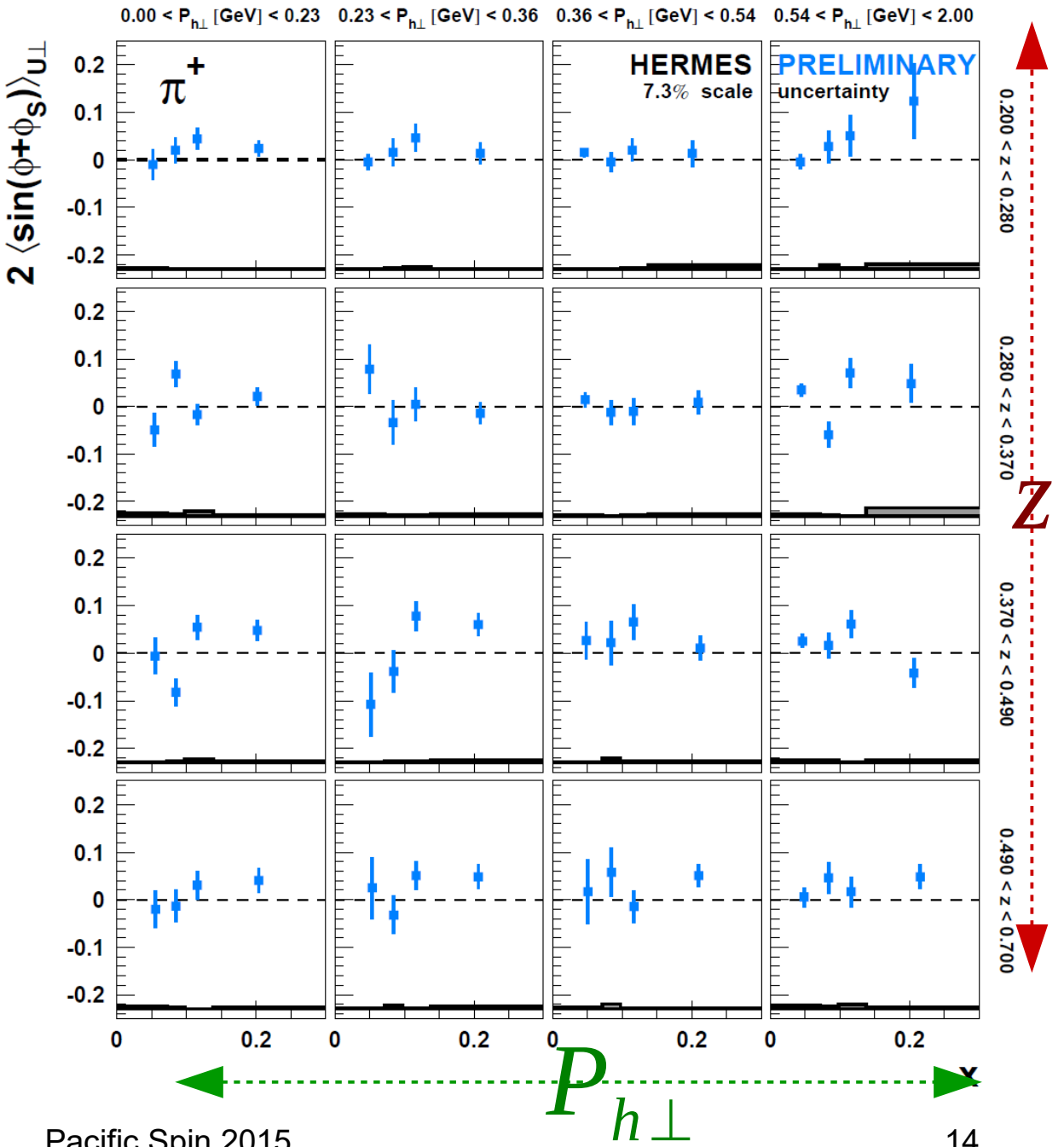

Available

- for π^{+-}, K^{+-} and p
- for vs x, z and $P_{h\perp}$

Sivers asymmetry (3D)

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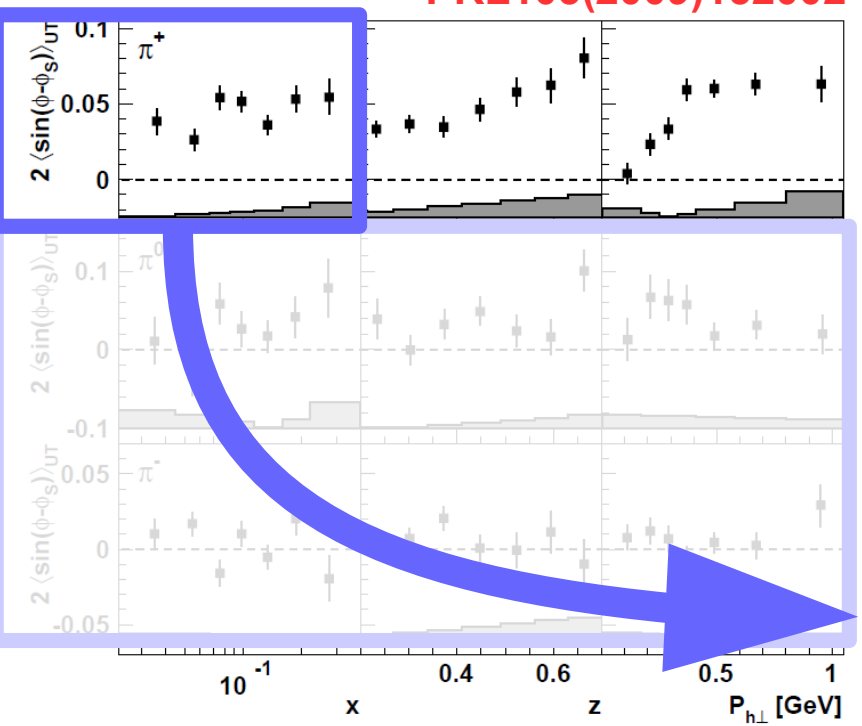
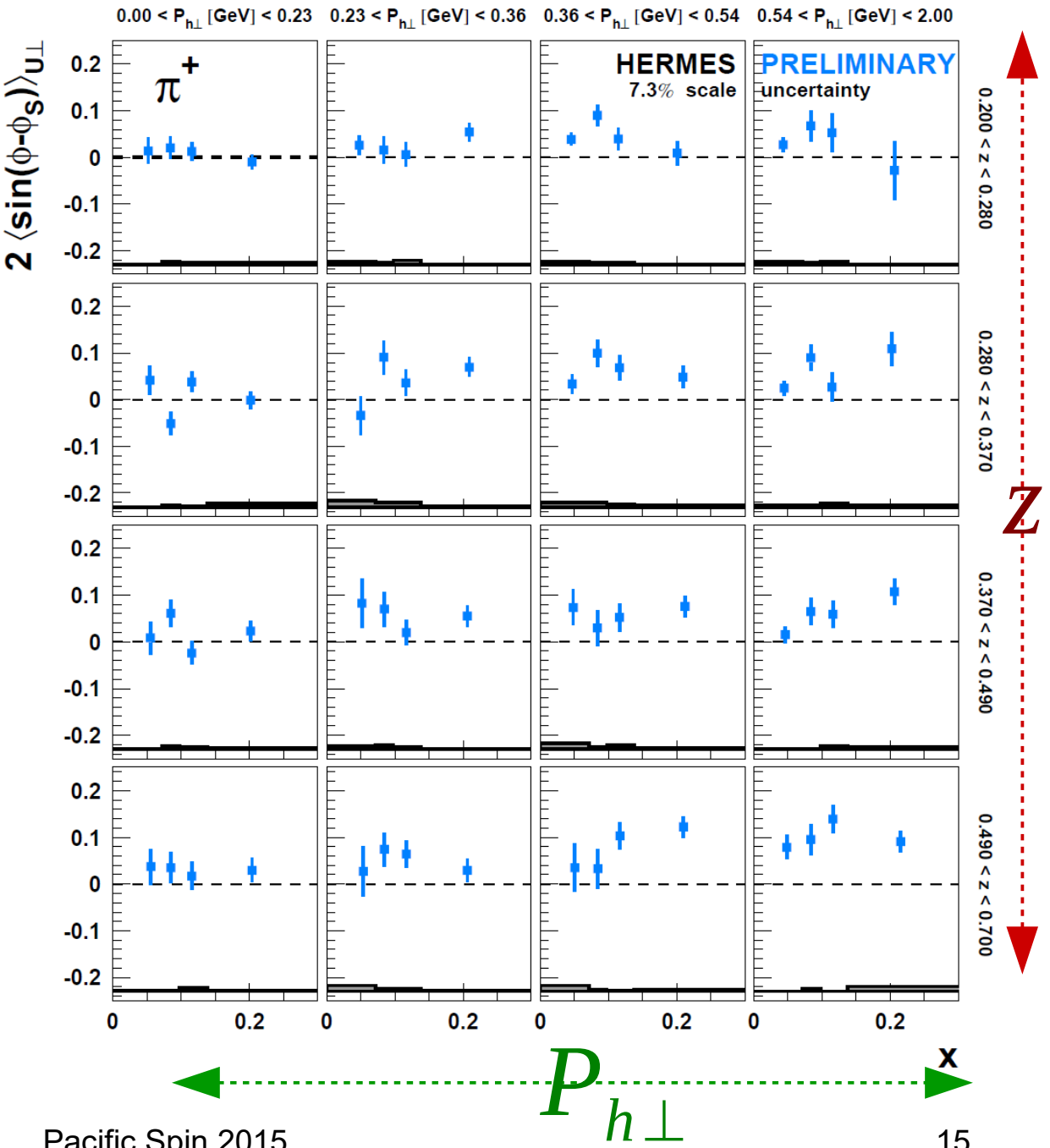
PRL103(2009)152002





Available

- for π^{+-}, K^{+-} and p
- for vs x, z and $P_{h\perp}$

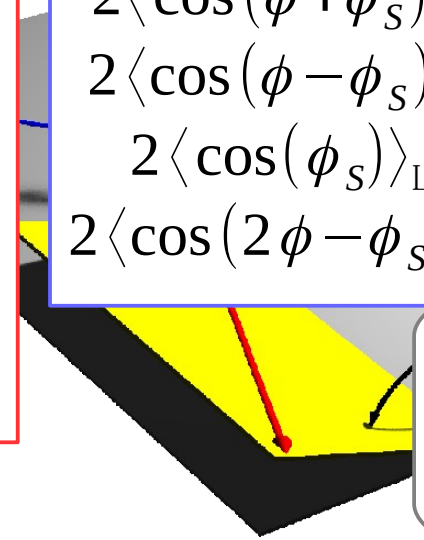
Leading-twist Transverse Momentum Dependent PDF

SSA

$2\langle \sin(\phi+\phi_S)\rangle_{UT}$
$2\langle \sin(\phi-\phi_S)\rangle_{UT}$
$2\langle \sin(\phi_S)\rangle_{UT}$
$2\langle \sin(2\phi-\phi_S)\rangle_{UT}$
$2\langle \sin(3\phi-\phi_S)\rangle_{UT}$
$2\langle \sin(2\phi+\phi_S)\rangle_{UT}$

DSA

$2\langle \cos(\phi+\phi_S)\rangle_{LT}$
$2\langle \cos(\phi-\phi_S)\rangle_{LT}$
$2\langle \cos(\phi_S)\rangle_{LT}$
$2\langle \cos(2\phi-\phi_S)\rangle_{LT}$



7(2013)012010

PLB562(2003)182
PRL84(2000)4047

$h_1^\perp$ Boer-Mulders

$h_1^\perp \otimes H_1^\perp \sim \cos 2\phi$

$h_{1L}^\perp$ Mulders-Kotzinian

$h_{1L}^\perp \otimes H_1^\perp \sim \sin 2\phi$

Transversely Polarized Nucleon

$f_{1T}^\perp$ Sivers

$f_{1T}^\perp \otimes D_1 \sim \sin(\phi-\phi_S)$

Preliminary results from 3D analysis

g_{1T} Worm-gear

$g_{1T} \otimes D_1 \sim \cos(\phi-\phi_S)$

$h_{1T}(=\delta q)$ Transversity

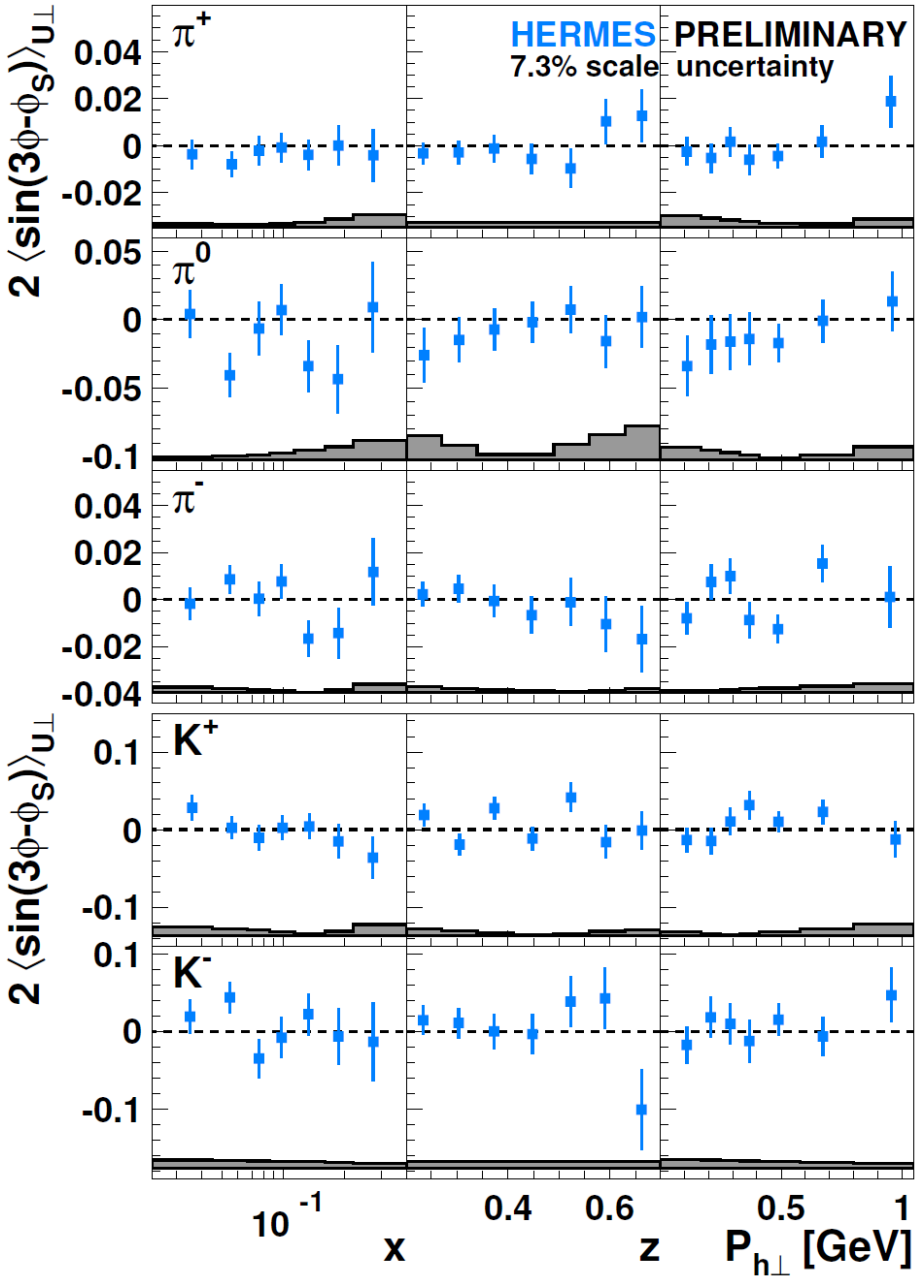
$h_{1T} \otimes H_1^\perp \sim \sin(\phi+\phi_S)$

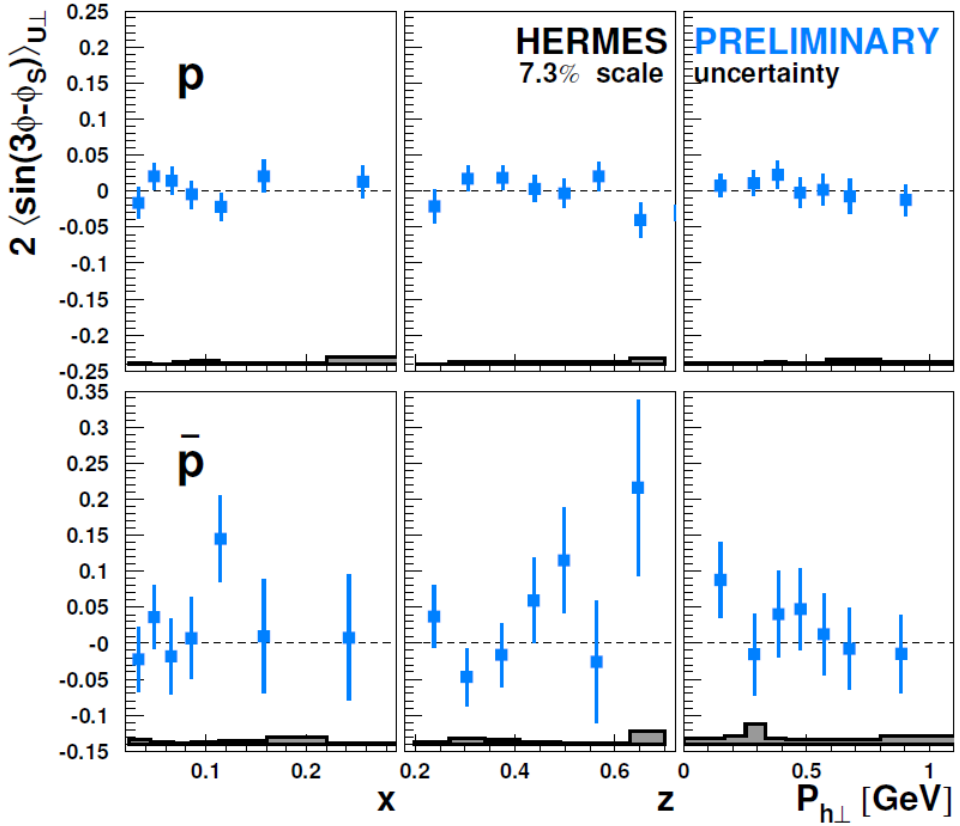
Preliminary results from 3D analysis

$h_{1T}^\perp$ Pretzelosity

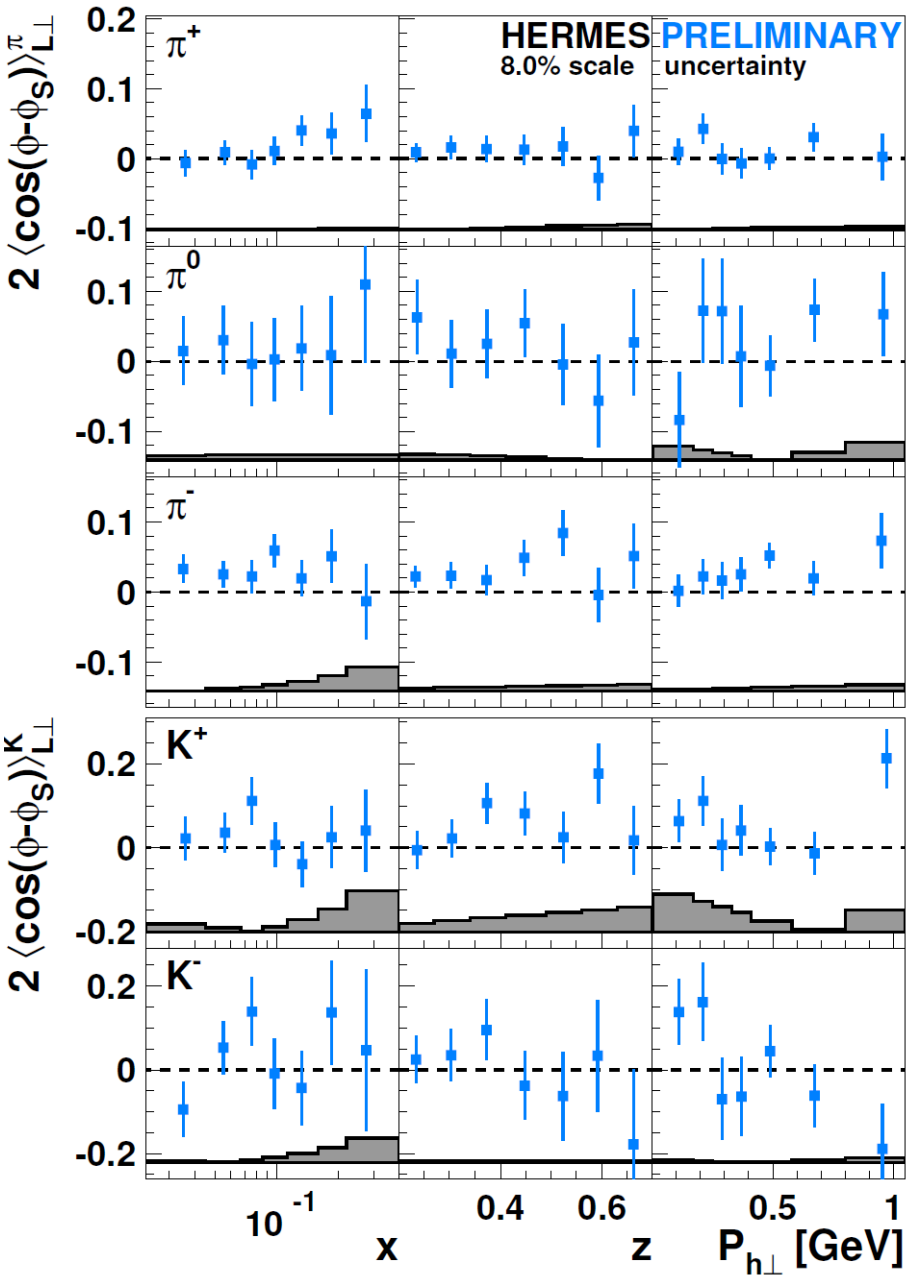
$h_{1T}^\perp \otimes H_1^\perp \sim \sin(3\phi-\phi_S)$

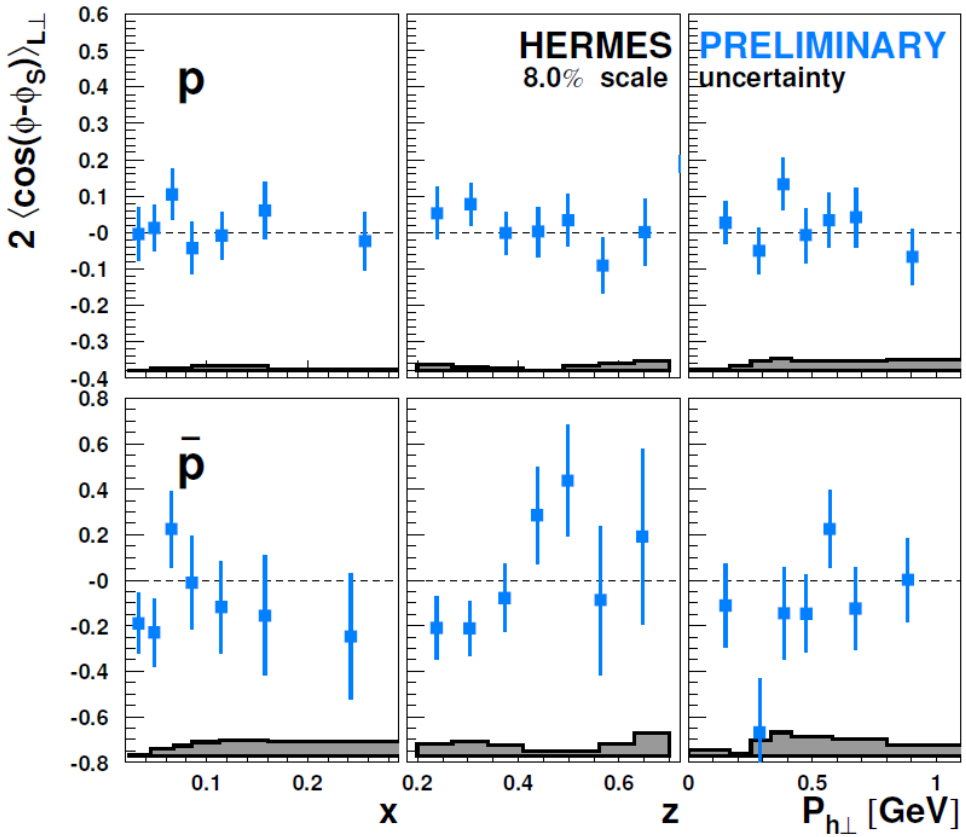
Multi dimensional analysis of SSA: $A_{UT}^{\sin(3\phi-\phi_s)}$





Multi dimensional analysis of SSA: $A_{LT}^{\cos(\phi-\phi_s)}$





Pretzelosity & Worm-Gear in 3D

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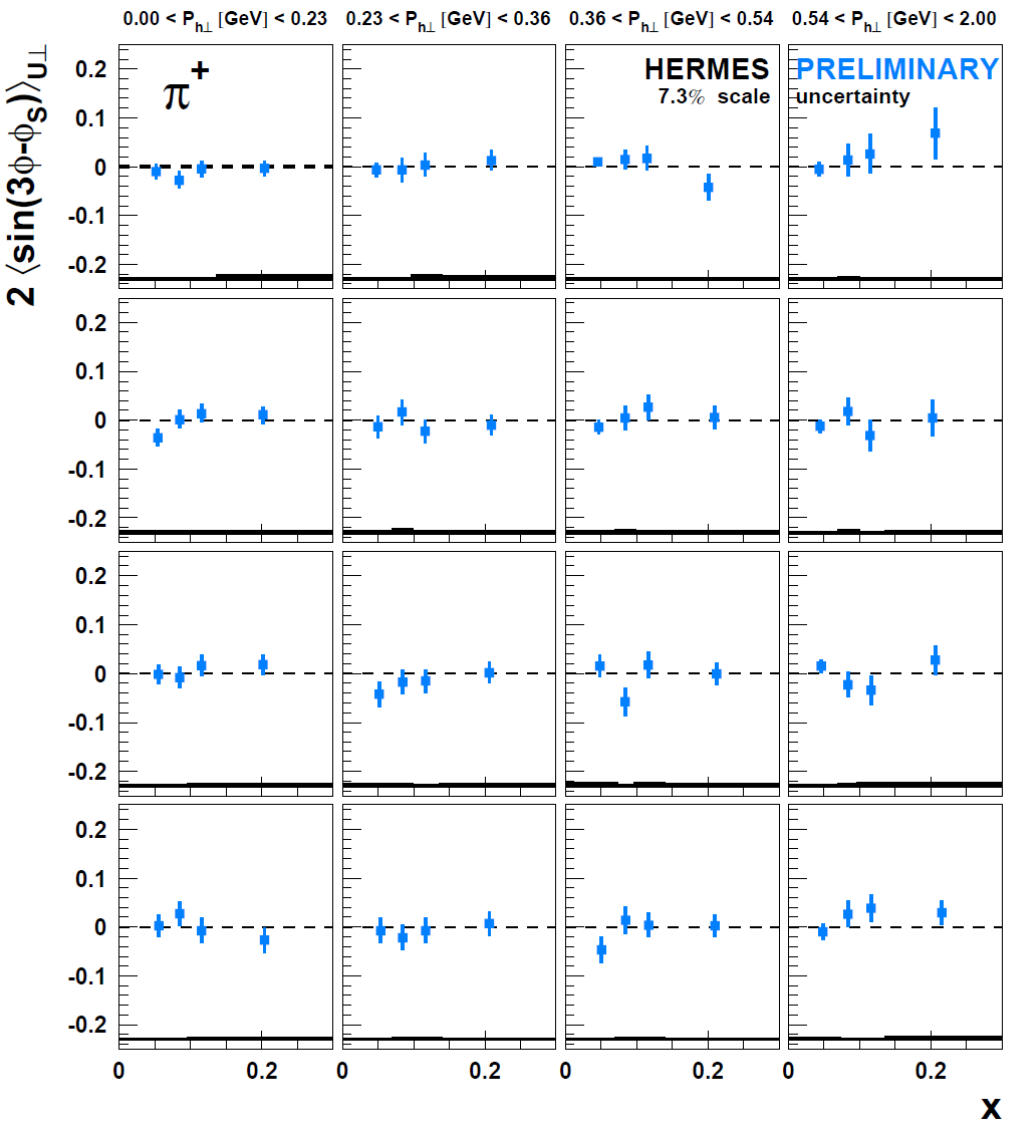
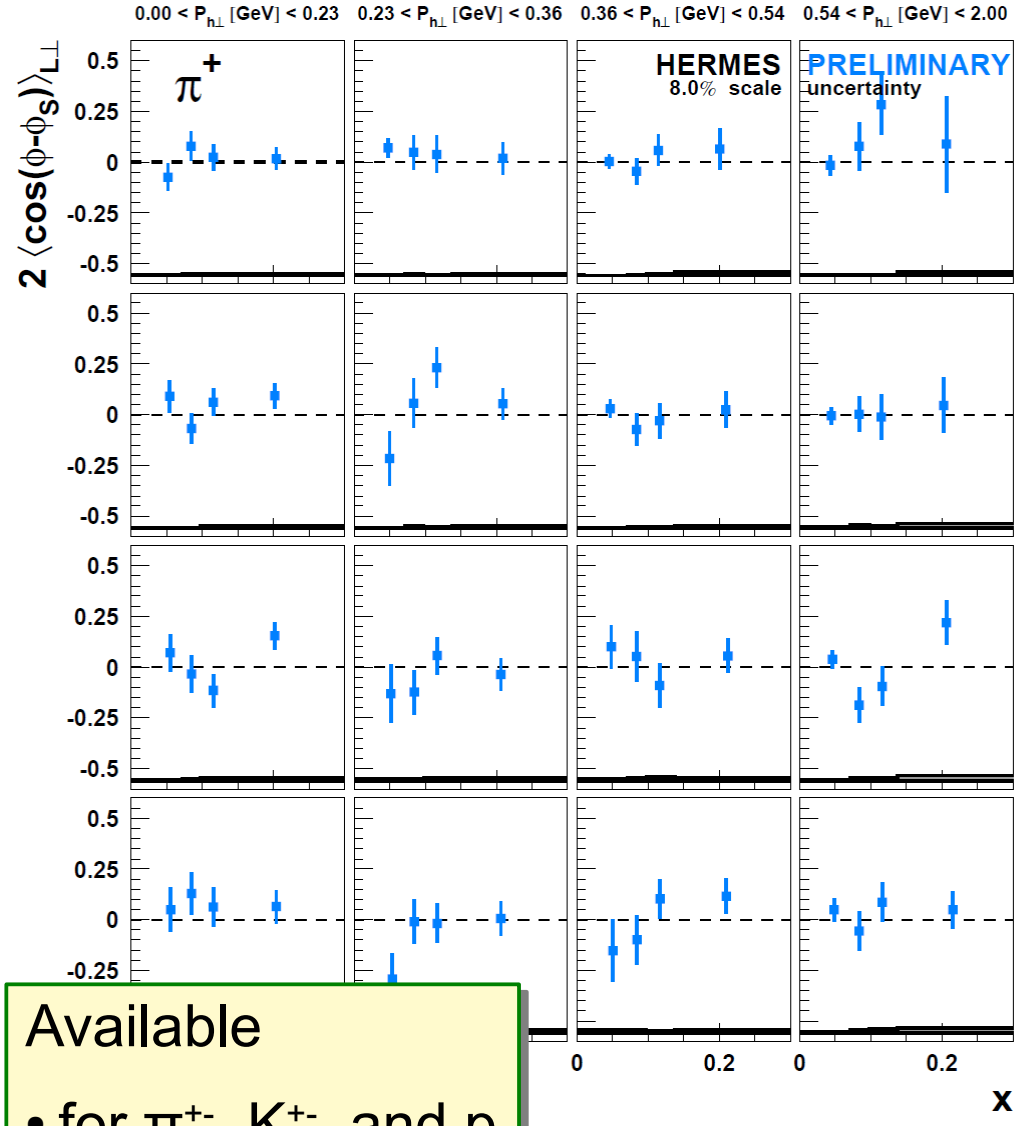


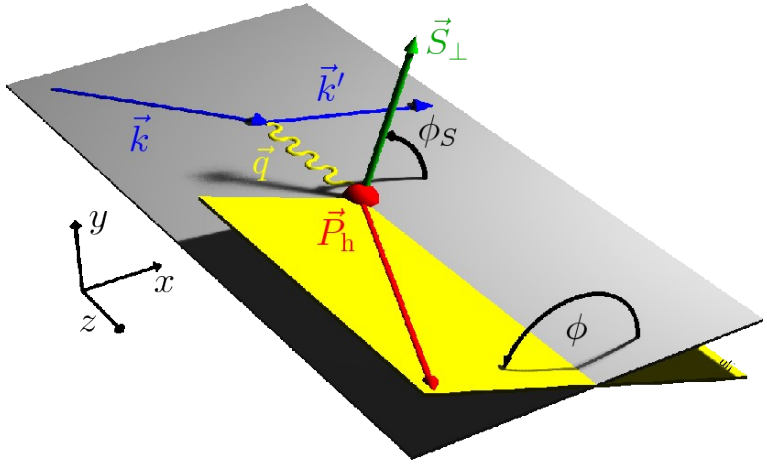


Available

- for π^{+-}, K^{+-} and p
- for vs x, z and $P_{h\perp}$

Beam Spin Asymmetry: $A_{LU}^{\sin\phi_h}$

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



PLB648(2007)164 (data from 1996 and 1997)

New preliminary results:

Full data set (H and D targets)

Hadron identification: pi, K, p

3D binning: x, z, $P_{h\perp}$

	H	D
π+	4.4 M	2.4 M
π-	3.1M	2.0 M
K+	0.75 M	0.39 M
K-	0.30 M	0.18 M
p	0.46 M	0.25 M
$\bar{p}$	69 k	41 k

Beam Spin Asymmetry: $A_{LU}^{\sin\phi_h}$

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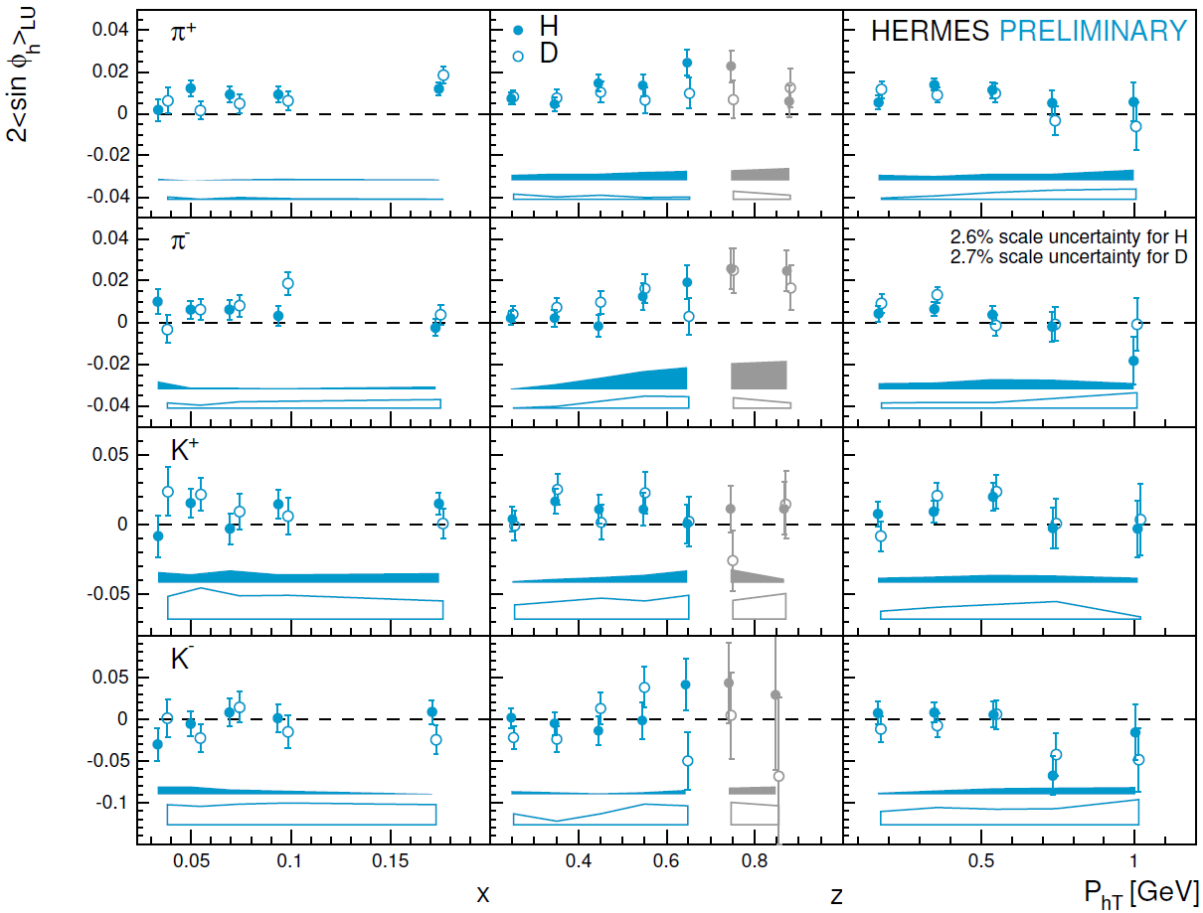
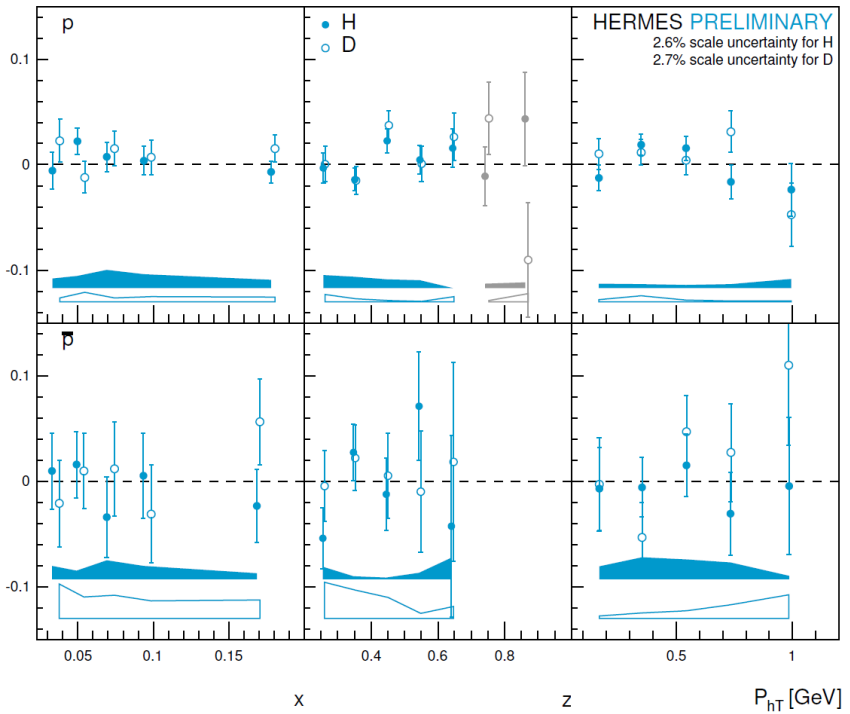
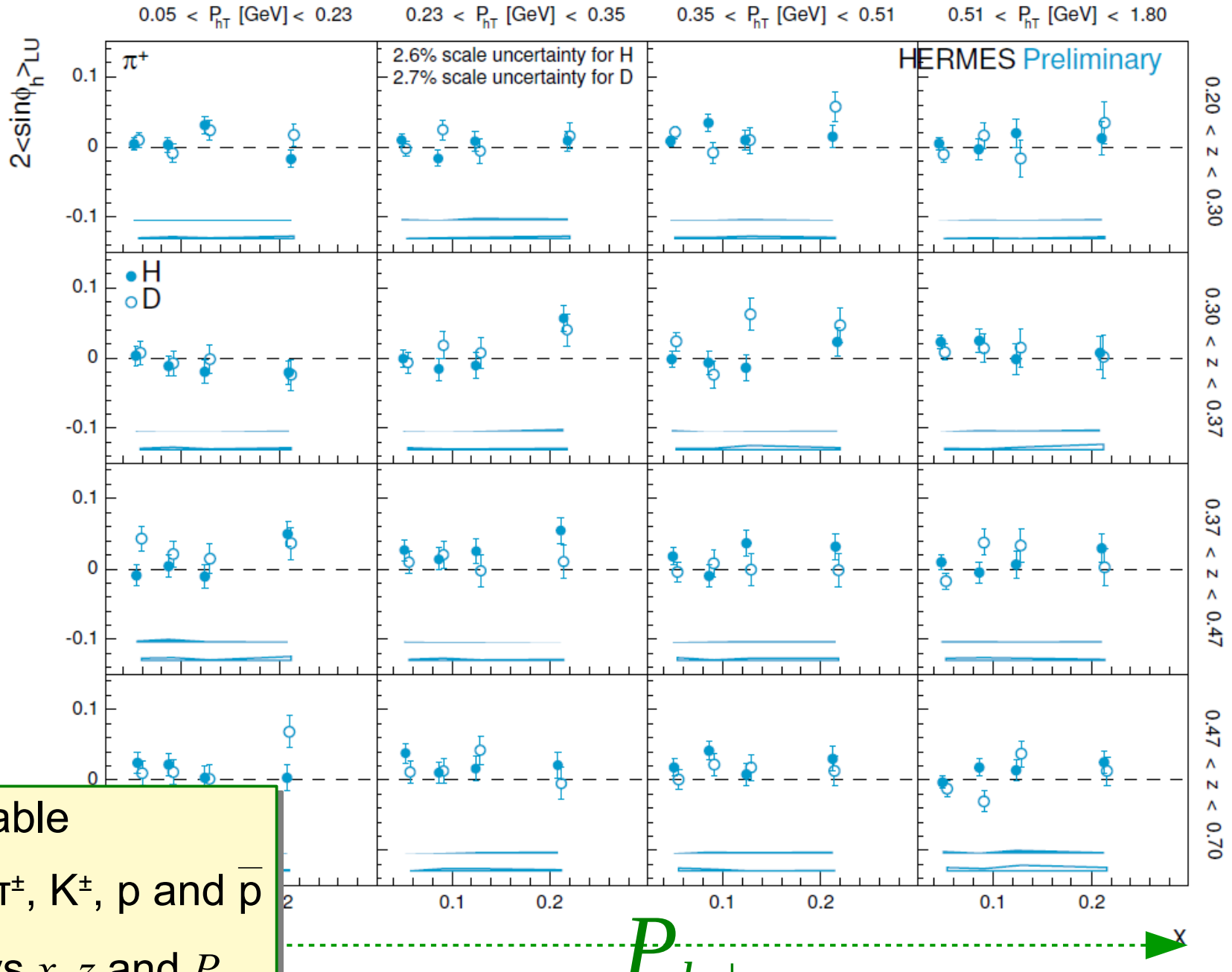
- 1D extraction
- For $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$





Beam Spin Asymmetry: $A_{LU}^{\sin\phi_h}$ vs x



Available

- for $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$
- for vs x, z and $P_{h\perp}$

Summary

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- HERMES has studied TMD with semi-inclusive measurements of DIS
  - Multi dimensional analysis of SSA and DSA
    - Identified hadron: π, K, p
    - 3D binning: 4-x, 4-z, and 4-$P_h\perp$
    - Extracted asymmetries: A_{UT}, A_{LT}, A_{LU}
  - Results will be available for a phenomenological analysis of TMDs
  - Neutral pion asymmetries are on track.

END