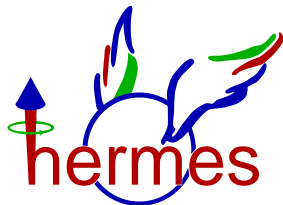# Transversity at HERMES

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M. Diefenthaler, L. Pappalardo,
X. Lu, P. Van der Nat

University of Michigan / HERMES Collaboration

3rd Joint Meeting of the APS Division of Nuclear Physics
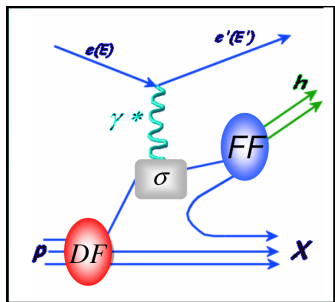and the Physical Society of Japan
Waikoloa, Hawaii
13 October, 2009

Outline

- Motivation and Background
- Single hadron production
- Two hadron production
- Other distribution functions
  - Sivers function
  - Pretzelocity
  - Boer-Mulders function
- Conclusion

Motivation and Background

Transverse Momentum Dependent Functions

- ▶ SIDIS cross section can be written
  $$\sigma^{ep \to ehX} = \sum_q DF \otimes \sigma^{eq \to eq} \otimes FF$$
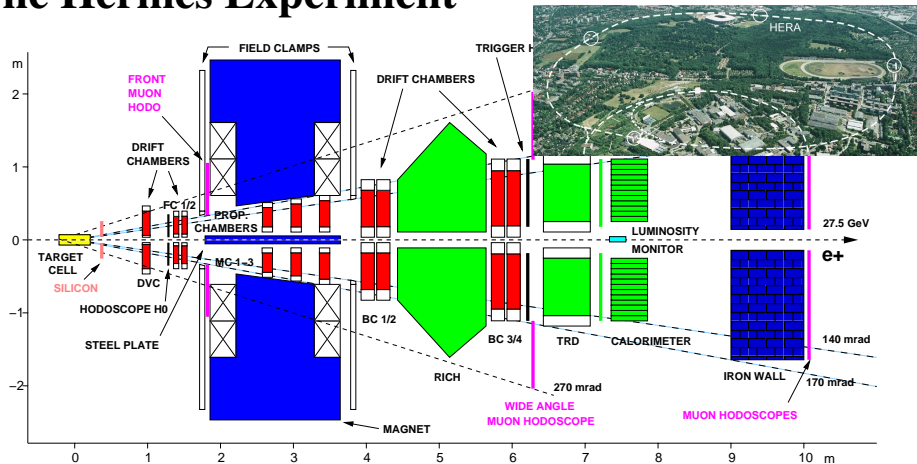- ▶ Access integrals of DFs and FFs through azimuthal asymmetries in ϕ_h, ϕ_S, $\phi_{R\perp}$
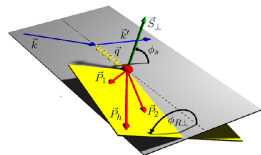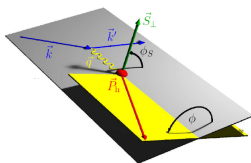
Distribution Functions (DF)

		quark		
		U	**L**	**T**
n u c l e o n	**U**	f_1 ⊙		$h_1^\perp$ ⊙ - ⊙
	L		g_1 ⊙→ - ←⊙	$h_{1L}^\perp$ ⊙→ - ←⊙
	T	$f_{1T}^\perp$ ⊙ - ⊙	$g_{1T}^\perp$ ⊙ - ⊙	h_1 ⊙ - ⊙ / $h_{1T}^\perp$ ⊙ - ⊙

Fragmentation Functions (FF)

quark		
U	**L**	**T**
D_1	$G_1^\perp$	$H_1^\perp$

The Hermes Experiment

Beam	Long. pol. $e^{\pm}$ at 27.6 GeV	Lep.-Had. Sep.	High efficiency $\approx 98\%$
Target	Trans. pol. H ($\approx 75\%$)		Low contamination (<2%)
	Log. pol. H ($\approx 85\%$)	Hadron PID	2-15 GeV
	Unpol. H,D,Ne,Kr,...		

SIDIS Single Hadron Production and Transversity
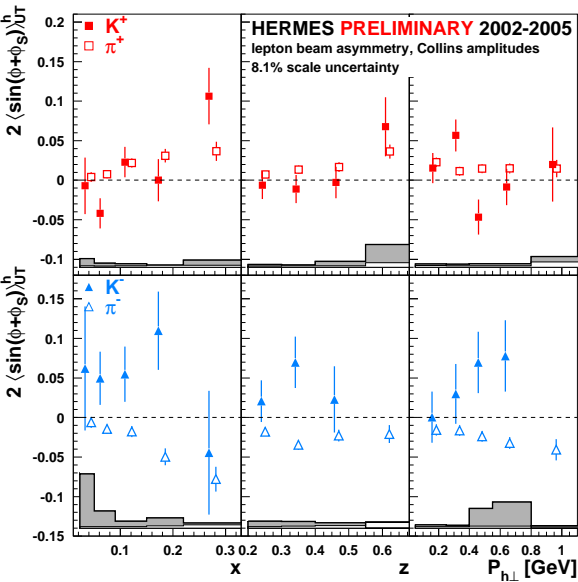
HERMES Collins Moments for Pions
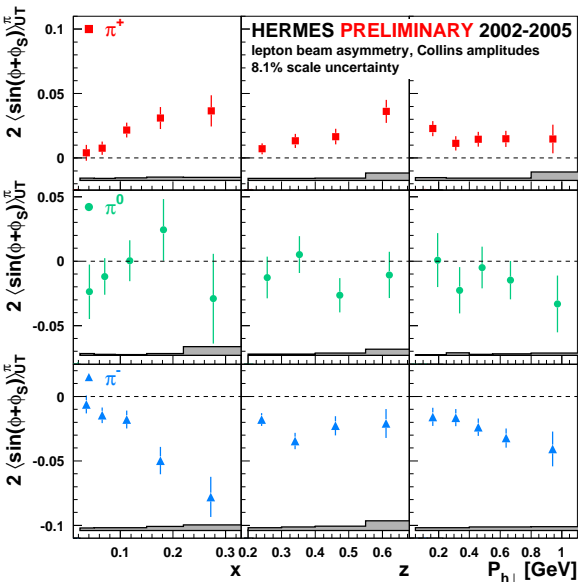
- Increased statistics over published results
  A. Airapetian et al, Phys. Rev. Lett. 94 (2005) 012002

- Non-zero transversity (h_1) and Collins ($H_1^\perp$) functions

- Positive for π^+, negative for π^-, as might be expected

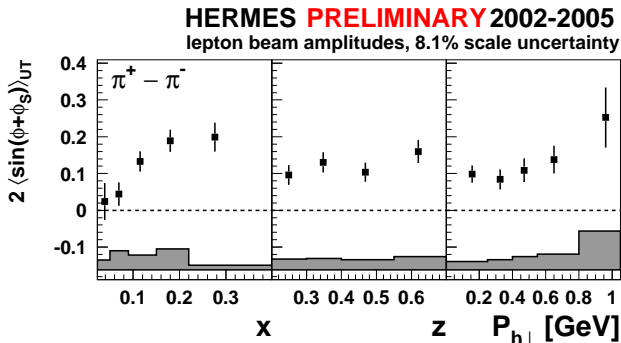$$\delta u \ := \ h_1^u > 0$$
$$\delta d \ := \ h_1^d > 0$$

- Large π^- asymmetry implies $H_1^{\perp,disf} \approx -H_1^{\perp,fav}$

- Isospin symmetry among pions fulfilled

HERMES Pion Kaon Comparison

- π^+ and K^+ consistent (u-quark dominance)

- π^- and K^- opposite sign (But $K^- = \bar{u}s$ originates from sea quarks)

Collins Pion Yield difference

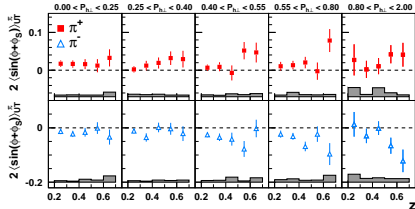**HERMES PRELIMINARY 2002-2005**
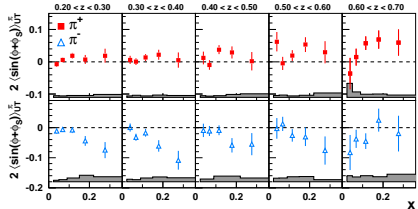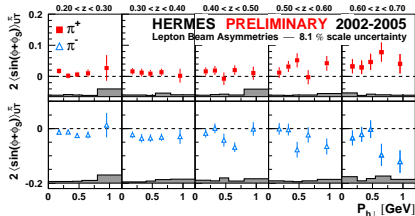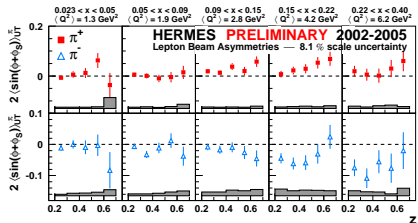lepton beam amplitudes, 8.1% scale uncertainty

- Non-negligible contribution from exclusive vector meson production.
- New observable "pion-difference target-spin asymmetry"

$$A_{UT}^{\pi^+ - \pi^-} := \frac{1}{S_T} \frac{\left(\sigma_{U\uparrow}^{\pi^+} - \sigma_{U\uparrow}^{\pi^-}\right) - \left(\sigma_{U\downarrow}^{\pi^+} - \sigma_{U\downarrow}^{\pi^-}\right)}{\left(\sigma_{U\uparrow}^{\pi^+} - \sigma_{U\uparrow}^{\pi^-}\right) + \left(\sigma_{U\downarrow}^{\pi^+} - \sigma_{U\downarrow}^{\pi^-}\right)}.$$
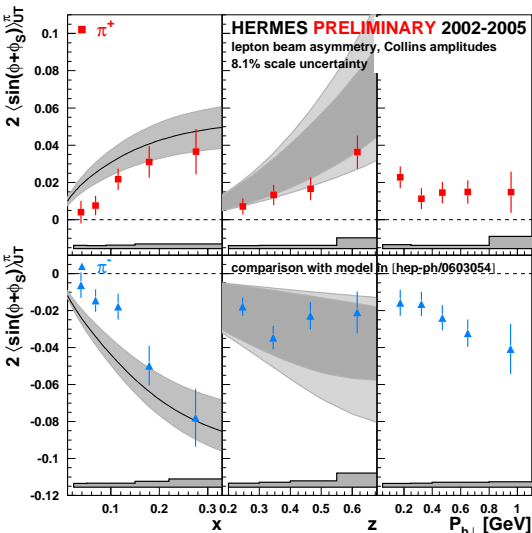
- Vector meson contribution approximately cancels.
- Non-zero asymmetries not due to vector mesons.
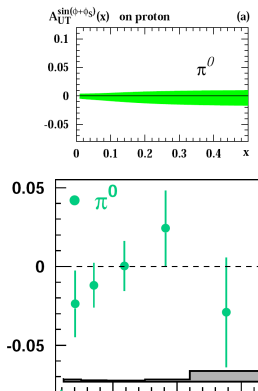
2D Binning of HERMES Collins Results

► Kinematic dependencies may not factorize

► Bin in as many independent variables as possible to extract the most information
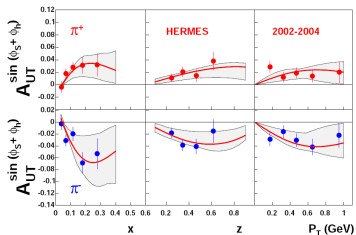
Efremov/Goeke/Sweitzer Extraction

- Extract $H_1^\perp$ separately from BELLE and HERMES
- Results from both experiments consistent
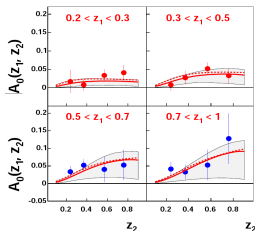- Predicted zero π^0 asymmetry

Model from Phys.Rev.D 73:094025, 2006
(arXiv:hep-ph/0603054v2)
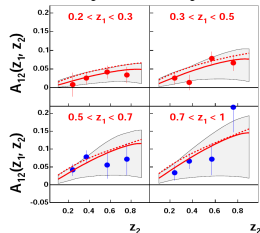
Anselmino Transversity Extraction
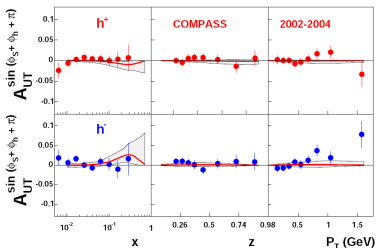
HERMES Proton Data

COMPASS Deuteron Data

BELLE A_0 Asymmetry

BELLE A_{12} Asymmetry
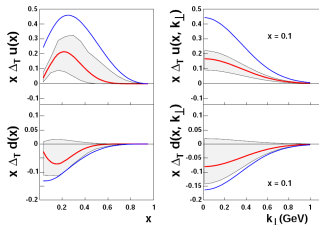

- Anselmino, *et al.*, (PRD 75:054032,2007) simultaneously fit data from
  - BELLE $e^+ e^- \rightarrow h^+ h^- X$
  - HERMES SIDIS w/ proton target
  - COMPASS SIDIS w/ deuteron target

- Extracted transversity and Collins, made prediction for COMPASS w/ proton target

Anselmino Transversity Extraction and COMPASS Prediction

Transversity

Collins FF
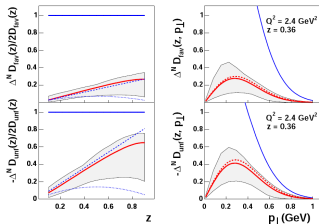
COMPASS Proton Results

- As expected, transversity has opposite signs for *u* and *d*
- COMPASS results consistent with prediction, i.e. strong agreement between all three experiments

Transversity through Two Hadron Production

SIDIS Two Hadron and Vector Meson Production

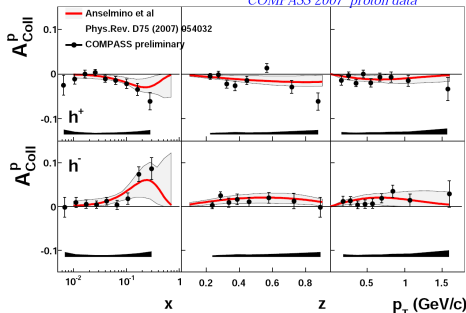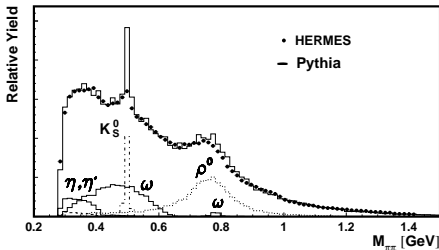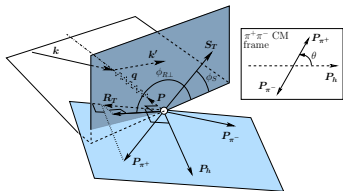- Can expand cross section in moments of four angles ϕ_h, ϕ_S, ϕ_R, θ
- Transversity target term in non-transverse-momentum-dependent cross section (A. Bacchetta, arXiv:hep-ph/0212025v1)

$$d^7\sigma_{UT} = \sum_q \frac{\alpha^2 e_q^2}{2\pi sxy^2} B(y) |S_\perp| \frac{|\boldsymbol{R}|}{M_{hh}} \sin(\phi_R + \phi_S) \sin\theta \, h_1(x)$$
$$\times \left(H_{1,UT}^{\sphericalangle sp}(z, M_{hh}^2) + \cos\theta H_{1,LT}^{\sphericalangle pp}(z, M_{hh}^2) \right).$$

- Transversity appears with interference fragmentation functions.

Di-hadron Results

HERMES
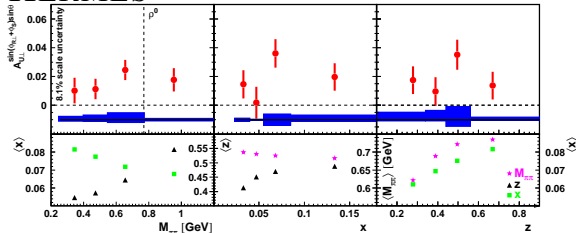
COMPASS
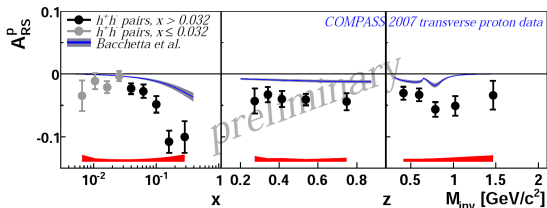
- ▶ Measure asymmetry $2 \langle \sin(\phi_{R\perp} + \phi_S) \sin\theta \rangle$ in π^+, π^- pair production

- ▶ Related to sp interference FF $H_{1,UT}^{\sphericalangle sp}$ and transversity

- ▶ Model based on HERMES results by Bacchetta, *et al.* (PRD 74:114007, 2006)

- ▶ Prediction for COMPASS results yields too small of an asymmetry (arXiv:0907.0961v1)

- ▶ Both experiments indicate non-zero $H_{1,UT}^{\sphericalangle sp}$ and non-zero transversity function

TMD Two Hadron Production

- ▶ Transverse target portion of cross section much more complicated
  - ▶ Leading twist + only ss, sp, and pp interference $\implies$ 27 independent A_{UT} moments
 - ▶ Fourier moments of $(\phi, \phi_R, \phi_S, \theta)$ depend on $(x, y, z, P_{h\perp}, M_{hh})$.
- ▶ Clean access to 4 TMD distribution functions: f_{1T}, $h_1^\perp$, $h_{1T}^\perp$ and g_{1T}
- ▶ Many unexplored distribution functions, including interference, two meson, and single vector meson functions
- ▶ Examples:

Moment	DF	2 had. FF	VM FF
$\sin(\phi_h - \phi_S)$	$f_{1T}^\perp$	$D_{1,UU}$	D_1
$\sin(2\phi_h - \phi_R - \phi_S)\sin\theta$	$f_{1T}^\perp$	$D_{1,UT}^{\perp sp}$	
$\sin(\phi_R - \phi_S)\sin\theta$	g_{1T}	$G_{1,UT}^{\perp sp}$	
$\sin(\phi_h + \phi_S)P_2(\cos\theta)$	h_1	$H_{1,LL}^{\perp pp}$	$H_{1,LL}^\perp$
$\sin(\phi_R + \phi_S)\sin\theta$	h_1	$H_{1,UT}^{\sphericalangle sp}$	
$\sin(2\phi_h + \phi_R - \phi_S)P_2(\cos\theta)$	$h_{1T}^\perp$	$H_{1,LL}^{\perp pp}$	$H_{1,LL}^\perp$
$\sin(3\phi_h - \phi_S)\sin\theta$	$h_{1T}^\perp$	$H_{1,UT}^{\sphericalangle sp}$	

Other Distribution Functions

Pretzelocity
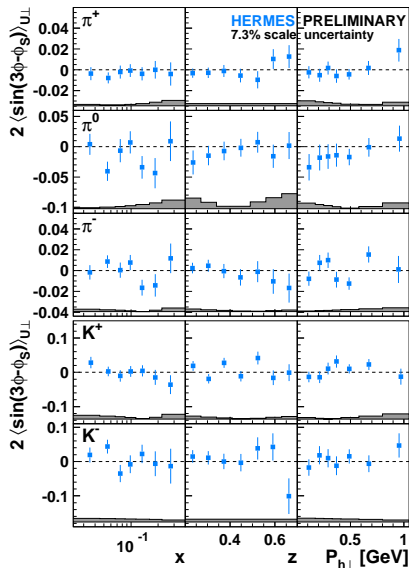
- Non-zero Pretzelocity $h_{1T}^{\perp}$ indicates non-spherical proton, e.g. G. Miller arXiv:0802.3731v1.

- Pretzelocity moment:
$$2\langle\sin(3\phi_h - \phi_S)\rangle = -\frac{\sum_q e_q^2 h_{1T}^{\perp,q} \otimes H_{1,q}^{\perp}}{\sum_q e_q^2 f_1^q D_1^q}$$
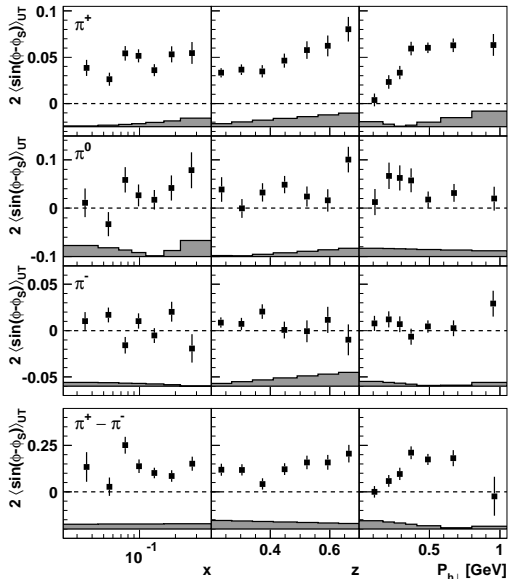
- Similar to Collins moment:
$$2\langle\sin(\phi_h + \phi_S)\rangle = -\frac{\sum_q e_q^2 h_1^{\perp,q} \otimes H_{1,q}^{\perp}}{\sum_q e_q^2 f_1^q D_1^q}$$

- HERMES results just released Sept. 09

- Data imply small or identically zero $h_{1T}^{\perp}$

Pion Sivers Moments

- ▶ Final Sivers results were available June 2009 (arXiv:0906.3918v1)

- ▶ $2 \langle \sin(\phi_h - \phi_S) \rangle =$
  $-\frac{\sum_q e_q^2 f_{1T}^{\perp,q} \otimes D_{1,q}^{\perp}}{\sum_q e_q^2 f_1^q D_1^q}$

- ▶ π^+ significantly non-zero, rises with z

- ▶ Also, π^+ rises and plateaus with $P_{h\perp}$

- ▶ Slightly positive π^0 and zero π^-

- ▶ u quark dominance for π^+ implies $f_{1T}^u < 0$ and $f_{1T}^d > 0$

- ▶ Pion yield difference $\implies$ non-zero asymmetry is not due to vector mesons

Kaon Sivers Moments
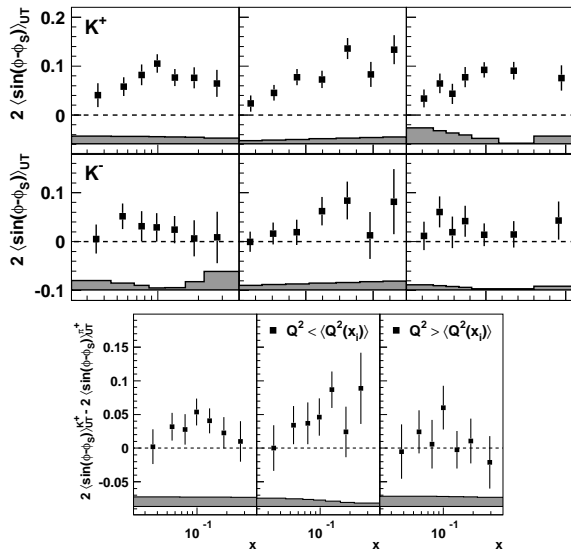
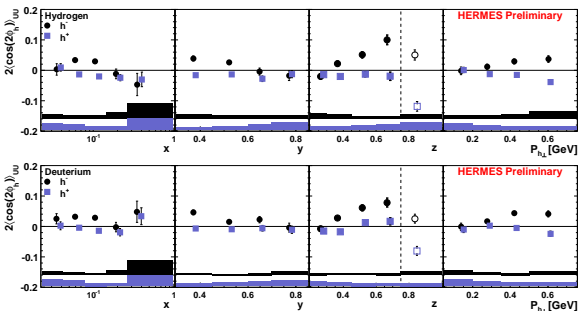- ▶ Similar rise with z as π^+
- ▶ K^+ also has similar dependence on $P_{h\perp}$
- ▶ K^- slightly positive
- ▶ $\pi^+ - K^+$ difference asymmetry largest where sea quarks most vary from light quarks

HERMES and COMPASS Results
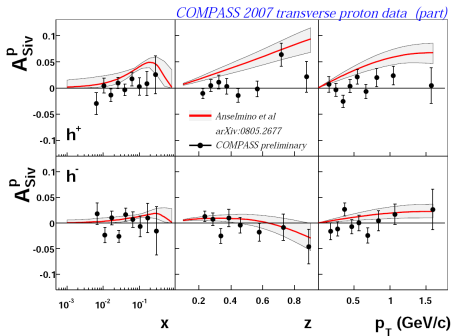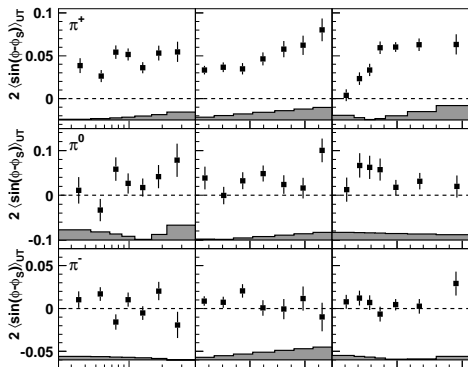
- ▶ COMPASS Results from DIS '09 (arXiv:0907.5508v1)
- ▶ Not as good agreement as for transversity and Collins moments
- ▶ COMPASS has not yet included all data

Boer Mulders and Cahn Effect
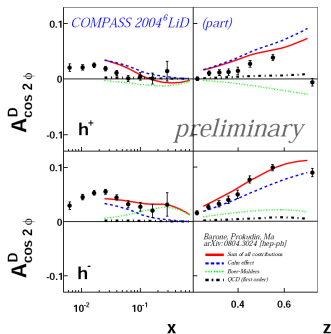
- Access to Boer-Mulders function
- COMPASS results from arXiv:0907.5511v1

$$2 \langle \cos(2\phi_h) \rangle = -\frac{\sum_q e_q^2 h_1^{\perp,q} \otimes H_{1,q}^{\perp}}{\sum_q e_q^2 f_1^q D_1^q}$$

- Model prediction by Ma, *et al.* (arXiv:0804.3024), "a larger asymmetry in π^- production, compared to π^+ production, would represent a signature of the Boer–Mulders effect"

Conclusion

Conclusion

- ▶ Single hadron production
  - ▶ Results from full dataset available
  - ▶ Anselmino, *et al.*, extraction of transversity and Collins FF
  - ▶ Excellent agreement between models, BELLE, COMPASS and HERMES
- ▶ Two hadron production
  - ▶ Results from COMPASS and HERMES qualitatively agree
  - ▶ Some discrepancy in magnitude of asymmetry
  - ▶ More interesting physics awaits
- ▶ Other transverse momentum distribution functions
  - ▶ First pretzelocity results
  - ▶ Final Sivers results
  - ▶ Boer-Mulders results–in process of being finalized
- ▶ HERMES has made significant contributions, with more on the way!