Transversity, Collins and Sivers Effects from COMPASS, HERMES and BELLE Data: New Global Analysis

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XII Workshop on High Energy Spin Physics

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Outline of this talk

1. Introduction
2. Collins effect in SIDIS and e^+e^- annihilation
   - The model for Collins FF and transversity
   - Description of the data & Predictions
3. Sivers effect in SIDIS
   - The model for the Sivers function
   - Description of the data & Predictions
4. Conclusions

The fundamental distributions of partons inside a nucleon

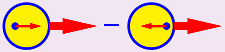
Unpolarised Distribution

$f_1(x)$ or $q(x)$

Distribution of unpolarised partons in an unpolarised nucleon.
Well known

Helicity Distribution

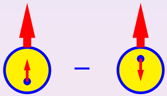
$g_1(x)$ or $\Delta q(x)$



Distribution of longitudinally polarised partons in a longitudinally polarised nucleon.
Known

Transversity Distribution

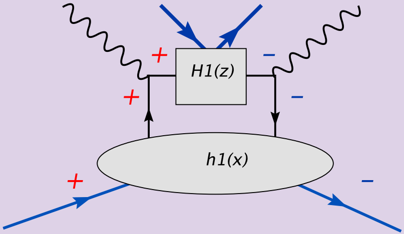
$h_1(x)$ or $\Delta_T q(x)$



Distribution of transversely polarised quarks in a transversely polarised nucleon.
Little known!
HERMES and COMPASS first experimental measurements

Transversity in SIDIS

Transversity in Semi inclusive Deep Inelastic Scattering $lN \to l'hX$



Transversely polarised quark fragments into an unpolarised hadron:

$$D_{h/q^\uparrow}(z, \mathbf{p}_\perp) = D_{h/q}(z, |p_\perp|) + \frac{1}{2} S_{q'} \cdot (\hat{p}_{q'} \times \hat{\mathbf{p}}_\perp) \Delta^N D_{h/q^\uparrow}(z, |p_\perp|),$$

where $\mathbf{p}_\perp$ is transverse momentum of produced hadron with respect to fragmenting quark $\longrightarrow$ non-perturbative effect.

Collins FF

Collins Fragmentation Function

There are two different notations for Collins FF:

$$D_{h/q^\uparrow}(z, \mathbf{p}_\perp) = D_{h/q}(z, |p_\perp|) + \frac{1}{2} S_{q'} \cdot (\hat{p}_{q'} \times \hat{\mathbf{p}}_\perp) \Delta^N D_{h/q^\uparrow}(z, |p_\perp|)$$

and

$$D_{h/q^\uparrow}(z, \mathbf{p}_\perp) = D_{h/q}(z, |p_\perp|) + \frac{S_{q'} \cdot (\hat{p}_{q'} x \mathbf{p}_\perp)}{z M_\pi} H_1^{\perp q}(z, |p_\perp|),$$

both $\Delta^N D_{h/q^\uparrow}(z, |p_\perp|)$ and $H_1^{\perp q}(z, |p_\perp|)$ refer to Collins FF

Collins FF

Collins Fragmentation Function

There are two different notations for Collins FF:

$$D_{h/q^\uparrow}(z,\mathbf{p}_\perp) = D_{h/q}(z,|p_\perp|) + \frac{1}{2} S_{q'} \cdot (\hat{p}_{q'} \times \hat{\mathbf{p}}_\perp) \Delta^N D_{h/q^\uparrow}(z,|p_\perp|)$$

and

$$D_{h/q^\uparrow}(z,\mathbf{p}_\perp) = D_{h/q}(z,|p_\perp|) + \frac{S_{q'} \cdot (\hat{p}_{q'} x \mathbf{p}_\perp)}{z M_\pi} H_1^{\perp q}(z,|p_\perp|),$$

Relation

$$\Delta^N D_{h/q^\uparrow}(z,|p_\perp|) = \frac{2|p_\perp|}{z M_\pi} H_1^{\perp q}(z,|p_\perp|) \, .$$

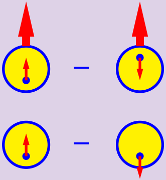
Trento conventions: A. Bacchetta, U. D'Alesio, M. Diehl, and C. A. Miller, Phys. Rev. **D70**, 117504 (2004).

Collins effect

Collins effects $A \propto sin(\phi_h + \phi_S)$

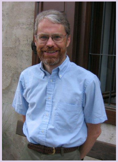
The azimuthal asymmetry arises due to modulation in fragmentation function, the Collins function $\Delta^N D_{h/q^\uparrow}(z, |p_\perp|)$ couples to transversity $\Delta_T q(x)$

$A_N \sim sin(\phi_h + \phi_S) \cdot \Delta_T q(x) \otimes \Delta^N D_{h/q^\uparrow}(z, |p_\perp|)$



$= \Delta_T q(x)$

$= \Delta^N D_{h/q^\uparrow}(z)$



J. C. Collins, *Nucl. Phys.* **B396** (1993) 161

Collins effect

Collins effects $A \propto sin(\phi_h + \phi_S)$

$$A_{UT}^{sin(\phi_h+\phi_S)}(x,z) \sim \frac{\sum_q e_q^2 x \Delta_T q(x) \Delta^N D_{h/q^\uparrow}(z)}{\sum_q e_q^2 x f_q(x) D_{h/q}(z)},$$

$$Positivity \quad constraints:$$

$$|\Delta^N D_{h/q^\uparrow}(z, \mathbf{p}_\perp)| \leq 2 D_{h/q}(z, \mathbf{p}_\perp)$$

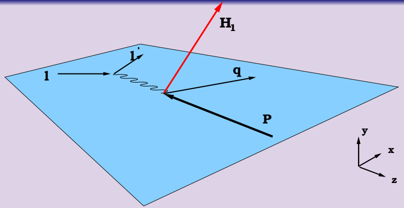
$$Soffer \quad bound:$$

$$|\Delta_T q(x)| \leq \frac{1}{2}\left[f_{q/p}(x) + \Delta q(x)\right]$$

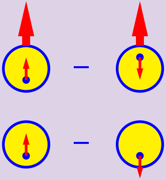
J. C. Collins, *Nucl. Phys.* **B396** (1993) 161

SIDIS and e^+e^- annihilation

SIDIS $lN \to l' H_1 X$



Collins effect gives rise to azimuthal Single Spin Asymmetry

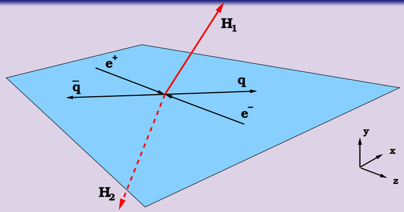


$= \Delta_T q(x, Q^2)$

$= \Delta^N D_{h/q^\uparrow}(z, Q^2)$

J. C. Collins, *Nucl. Phys.* **B396** (1993) 161

$e^+e^- \to H_1 H_2 X$



Collins effect gives rise to azimuthal asymmetry, q and $\bar{q}$ Collins functions are present in the process:

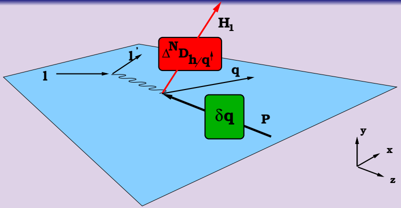
$\Delta^N D_{h/q^\uparrow}(z_1, Q^2)$

$\Delta^N D_{h/\bar{q}^\uparrow}(z_2, Q^2)$

D. Boer, R.Jacob and P. J. Mulders *Nucl. Phys.* **B504** (1997) 345

SIDIS and e^+e^- annihilation

SIDIS $lN \to l' H_1 X$

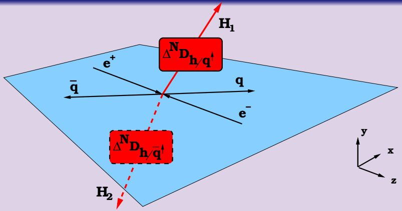


Cross Section $\sim sin(\phi_H + \phi_S) \cdot$
$\Delta_T q(x, Q^2) \otimes \Delta^N D_{h/q^\uparrow}(z, Q^2)$

?

$\Delta_T q(x, Q^2) \neq 0$?
$\Delta^N D_{h/q^\uparrow}(z, Q^2) \neq 0$?

$e^+e^- \to H_1 H_2 X$



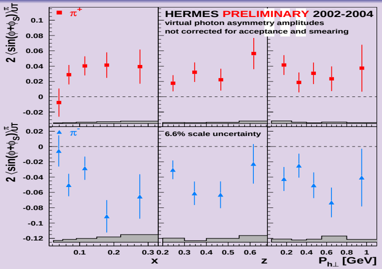
Cross Section $\sim cos(\phi_{H_1} + \phi_{H_2}) \cdot$
$\Delta^N D_{h/q^\uparrow}(z_1) \otimes \Delta^N D_{h/\bar{q}^\uparrow}(z_2)$

?

$\Delta^N D_{h/q^\uparrow}(z_1, Q^2) \neq 0$?
$\Delta^N D_{h/\bar{q}^\uparrow}(z_2, Q^2) \neq 0$?

SIDIS and e^+e^- annihilation

SIDIS $lN \to l' H_1 X$



HERMES, proton target,

$p_{lab} = 27.5$ (GeV)

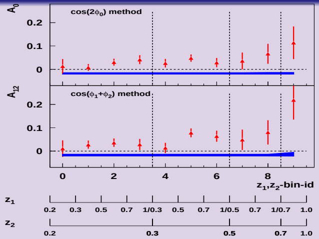
HERMES

$\Delta_T q(x, Q^2) \neq 0$!

$\Delta^N D_{h/q^\uparrow}(z, Q^2) \neq 0$!

HERMES Collaboration, A. Airapetian *et al.* *Phys. Rev. Lett.* **94** 94 (2005) 012002

$e^+e^- \to H_1 H_2 X$



BELLE, $\sqrt{s} = 10.52$ (GeV),

BELLE

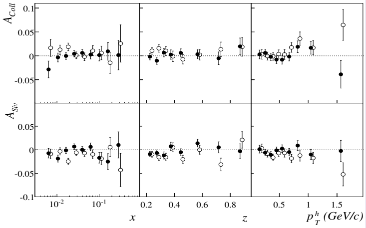
$\Delta^N D_{h/q^\uparrow}(z_1, Q^2) \neq 0$!

$\Delta^N D_{h/\bar{q}^\uparrow}(z_2, Q^2) \neq 0$!

Belle Collaboration,
K. Abe *et al.*, *Phys. Rev. Lett.* **96**(2006)232002

SIDIS and e^+e^- annihilation

SIDIS $IN \to l' H_1 X$



COMPASS, deutron target

$p_{lab} = 160$ (GeV)

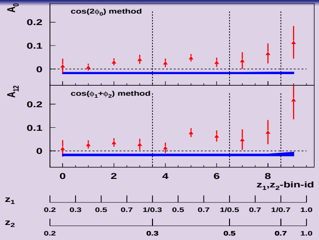
COMPASS

$\Delta_T q(x, Q^2) \neq 0$?

$\Delta^N D_{h/q^\uparrow}(z, Q^2) \neq 0$?

COMPASS Collaboration, E. S. Ageev *et al.*, Nucl. Phys. **B765**, 31 (2007).

$e^+e^- \to H_1 H_2 X$



BELLE, $\sqrt{s} = 10.52$ (GeV),

BELLE

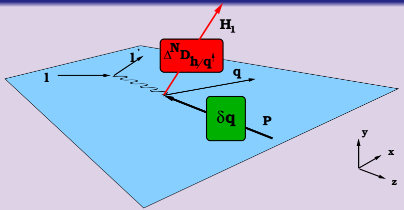
$\Delta^N D_{h/q^\uparrow}(z_1, Q^2) \neq 0$!

$\Delta^N D_{h/\bar{q}^\uparrow}(z_2, Q^2) \neq 0$!

Belle Collaboration,
K. Abe *et al.*, *Phys. Rev. Lett.* **96**(2006)232002

SIDIS and e^+e^- annihilation

SIDIS $lN \to l' H_1 X$

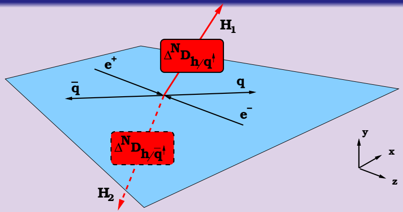


?

Are HERMES and COMPASS data compatible?

Fit HERMES & BELLE and check if we describe COMPASS data.

$e^+e^- \to H_1 H_2 X$



?

$\Delta^N D^{SIDIS}_{h/q^\uparrow}(z) = \Delta^N D^{e^+e^-}_{h/q^\uparrow}(z)$?

Fit simultaneously HERMES, COMPASS and BELLE data sets.

Unpolarised distribution and fragmentation functions.

$f_{q/p}(x, k_\perp)$ and $D_{h/q}(z, p_\perp)$ TMD distribution and fragmentation functions are used.
We assume the $k_\perp$ and $p_\perp$ dependences to be factorized in a Gaussian form

$$f_{q/p}(x, k_\perp) = f_{q/p}(x) \frac{e^{-k_\perp^2/\langle k_\perp^2 \rangle}}{\pi \langle k_\perp^2 \rangle}$$

$$D_{h/q}(z, p_\perp) = D_{h/q}(z) \frac{e^{-p_\perp^2/\langle p_\perp^2 \rangle}}{\pi \langle p_\perp^2 \rangle}$$

$$\langle k_\perp^2 \rangle = 0.25 \ \ (\mathrm{GeV}^2)$$

$$\langle p_\perp^2 \rangle = 0.2 \ \ (\mathrm{GeV}^2)$$

M. Anselmino, M. Boglione, U. D'Alesio, A. Kotzinian, F. Murgia, A. Prokudin, Phys. Rev. **D71**, 074006 (2005).

Unpolarised distribution and fragmentation functions.

$f_{q/p}(x, k_\perp)$ and $D_{h/q}(z, p_\perp)$ TMD distribution and fragmentation functions are used.
We assume the $k_\perp$ and $p_\perp$ dependences to be factorized in a Gaussian form

Distribution functions:

$f_{q/p}(x)$ GRV LO 1998

M. Gluck, E. Reya, and A. Vogt, Eur. Phys. J. **C5**, 461 (1998).

Fragmentation functions:

$D_{h/q}(z)$ Kretzer

S. Kretzer, Phys. Rev. **D62**, 054001 (2000).

Collins function

Model for Collins FF

$\Delta^N D_{h/q^\uparrow}(z, |p_\perp|) \Longrightarrow$ we use factorization of z and $p_\perp$ and Gaussian dependence on $p_\perp$

$$\Delta^N D_{h/q^\uparrow}(z, p_\perp) = 2\,\mathcal{N}_q^C(z)\; D_{h/q}(z)\; h(p_\perp)\; \frac{e^{-p_\perp^2/\langle p_\perp^2\rangle}}{\pi\langle p_\perp^2\rangle}\;,$$

with

$$\mathcal{N}_q^C(z) = N_q^C\, z^\gamma (1-z)^\delta\, \frac{(\gamma+\delta)^{(\gamma+\delta)}}{\gamma^\gamma \delta^\delta}$$

$$h(p_\perp) = \sqrt{2e}\,\frac{p_\perp}{M}\, e^{-p_\perp^2/M^2},$$

where N_q^C, γ, δ, and M are parameters.

Collins function

Model for Collins FF

$\Delta^N D_{h/q^\uparrow}(z, |p_\perp|) \Longrightarrow$ we use factorization of z and $p_\perp$ and Gaussian dependence on $p_\perp$

$$\Delta^N D_{h/q^\uparrow}(z, p_\perp) = 2\mathcal{N}_q^C(z)\, D_{h/q}(z)\, h(p_\perp)\, \frac{e^{-p_\perp^2/\langle p_\perp^2\rangle}}{\pi\langle p_\perp^2\rangle} \;,$$

with

$$\mathcal{N}_q^C(z) \le 1$$
$$h(p_\perp) \le 1$$

positivity constraint $|\Delta^N D_{h/q^\uparrow}(z, \mathbf{p}_\perp)| \le 2D_{h/q}(z, \mathbf{p}_\perp)$ is fulfilled.

Transversity

$$\Delta_T q(x, k_\perp) = \frac{1}{2} \mathcal{N}_q^T(x) \left[f_{q/p}(x) + \Delta q(x)\right] \frac{e^{-k_\perp^2/\langle k_\perp^2 \rangle_T}}{\pi \langle k_\perp^2 \rangle_T},$$

where

$$\mathcal{N}_q^T(x) = N_q^T \, x^\alpha (1-x)^\beta \, \frac{(\alpha+\beta)^{(\alpha+\beta)}}{\alpha^\alpha \beta^\beta},$$

N_q^T, α, β and $\langle k_\perp^2 \rangle_T$ are parameters.

$$\mathcal{N}_q^T(x) \leq 1$$

thus Soffer bound

$$|\Delta_T q(x)| \leq \frac{1}{2} \left[f_{q/p}(x) + \Delta q(x)\right]$$

is fulfilled.

Description of $A_{UT}^{sin(\phi_h+\phi_S)}$

We use HERMES and COMPASS data sets on $A_{UT}^{sin(\phi_h+\phi_S)}$ in the fitting procedure, we use one of the two sets of data from BELLE corresponding to either $\cos(\varphi_1+\varphi_2)$ or $\cos(2\varphi_0)$ extraction method.

Favored and unfavored fragmentation functions are defined as follows:

$$D^{fav}(z) \equiv D^{u\to\pi^+}(z) = D^{d\to\pi^-}(z) = D^{\bar{u}\to\pi^-}(z) = D^{\bar{d}\to\pi^+}(z)$$
$$D^{unfav}(z) \equiv D^{u\to\pi^-}(z) = D^{d\to\pi^+}(z) = D^{\bar{u}\to\pi^+}(z) = D^{\bar{d}\to\pi^-}(z)$$

HERMES Collaboration, L. Pappalardo *et al.*, in the proceedings of the XIV International Workshop on Deep Inelastic Scattering, Tsukuba city, Japan, April 20th - April 24th. (2006).
COMPASS Collaboration, E. S. Ageev *et al.*, Nucl. Phys. **B765**, 31 (2007).

Belle Collaboration, R. Seidl *et al.*, Phys. Rev. Lett. **96**, 232002 (2006).

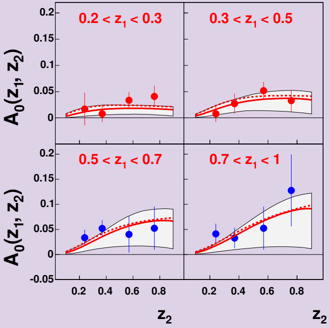
Description of the data Anselmino *et al* Phys.Rev.D75:054032,2007

Table: FIT I $\cos(\varphi_1 + \varphi_2)$ and FIT II $\cos(\varphi_0)$ are within 1σ

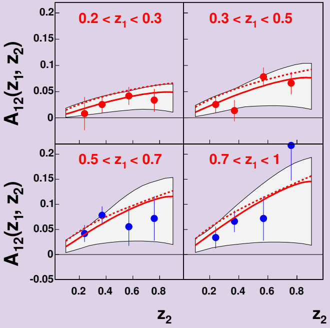
			Transversity			
FIT I	N_u^T	=	0.48 ± 0.09	N_d^T	=	-0.62 ± 0.30
FIT II	N_u^T	=	0.42 ± 0.09	N_d^T	=	-0.53 ± 0.28
FIT I	α	=	1.14 ± 0.68	β	=	4.74 ± 5.45
FIT II	α	=	1.20 ± 0.83	β	=	5.09 ± 5.87
			Collins FF			
FIT I	$N_{\rm fav}^C$	=	0.35 ± 0.16	$N_{\rm unf}^C$	=	-0.85 ± 0.36
FIT II	$N_{\rm fav}^C$	=	0.41 ± 0.10	$N_{\rm unf}^C$	=	-0.99 ± 1.24
FIT I	γ	=	1.14 ± 0.38	δ	=	0.14 ± 0.36
FIT II	γ	=	0.81 ± 0.40	δ	=	0.02 ± 0.37
FIT I	M^2	=	0.70 ± 0.65 GeV^2			
FIT II	M^2	=	0.88 ± 1.15 GeV^2			

Description of BELLE data

BELLE $\cos(\varphi_0)$



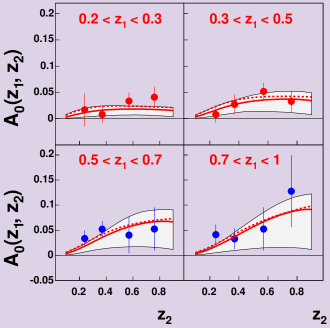
BELLE $\cos(\varphi_1 + \varphi_2)$



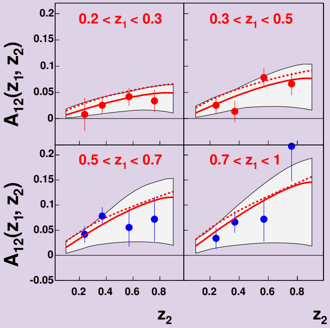
Solid line corresponds to FIT II, dashed line corresponds to FIT I

Description of BELLE data

BELLE $\cos(\varphi_0)$



BELLE $\cos(\varphi_1 + \varphi_2)$

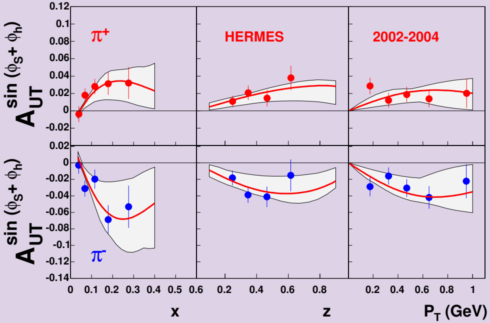


FIT I and FIT II are compatible

Description of HERMES data $A_{UT}^{sin(\phi_h+\phi_S)}$

HERMES $A_{UT}^{sin(\phi_h+\phi_S)}$

$ep \to e\pi X$, $p_{lab} = 27.57$ GeV.

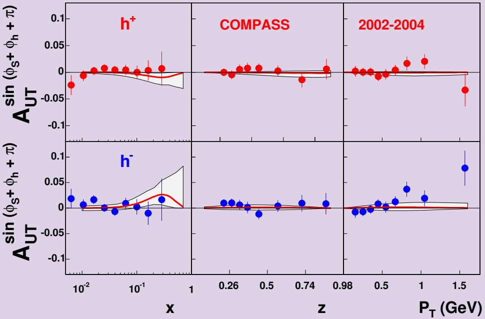


HERMES Collaboration, L. Pappalardo *et al.*, in the proceedings of the XIV International Workshop on Deep Inelastic Scattering, Tsukuba city, Japan, April 20th - April 24th. (2006).

Description of COMPASS data $A_{UT}^{sin(\phi_h+\phi_S+\pi)}$

COMPASS $A_{UT}^{sin(\phi_h+\phi_S+\pi)}$

$\mu D \to \mu h X$, $p_{lab} = 160$ GeV.

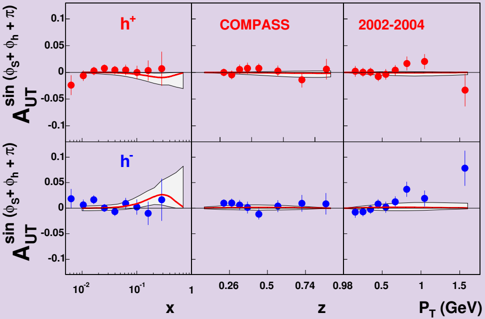


COMPASS Collaboration, E. S. Ageev *et al.*, Nucl. Phys. **B765**, 31 (2007).

Description of COMPASS data $A_{UT}^{sin(\phi_h+\phi_S+\pi)}$

COMPASS $A_{UT}^{sin(\phi_h+\phi_S+\pi)}$

$\mu D \to \mu h X$, $p_{lab} = 160$ GeV.

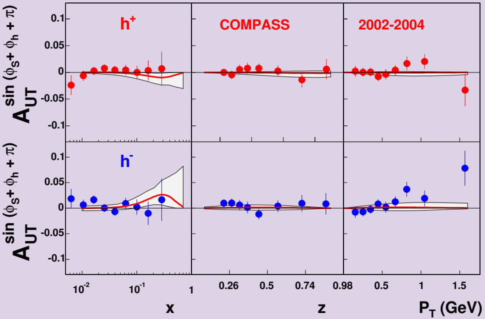


Why $A_{UT}^{sin(\phi_h+\phi_S+\pi)} \sim 0$? One of the reasons is that $< x > \sim 0.03$ $(< x >_{HERMES} \sim 0.1)$is very small and $\Delta_T q(x) \to 0$.

Description of COMPASS data $A_{UT}^{sin(\phi_h+\phi_S+\pi)}$

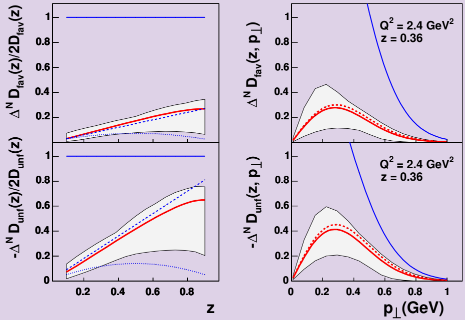
COMPASS $A_{UT}^{sin(\phi_h+\phi_S+\pi)}$

$\mu D \to \mu h X$, $p_{lab} = 160$ GeV.



But deuteron target allows us to fit $\Delta_T d(x)$ as combination of $\Delta_T u(x) + \Delta_T d(x)$ enters into the asymmetry.

Collins fragmentation function

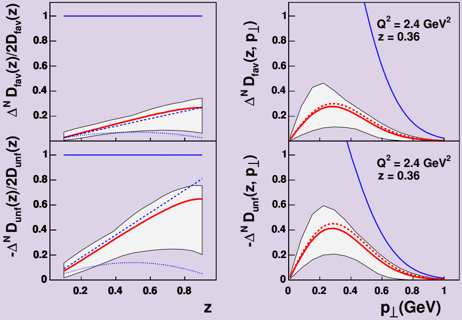


compared to Ref. [1] (dashed line) and Ref. [2] (dotted line)

[1] A. V. Efremov, K. Goeke, and P. Schweitzer, Phys. Rev. **D73**, 094025 (2006).

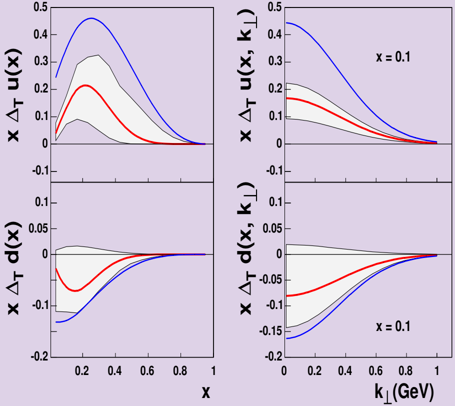
[2] W. Vogelsang and F. Yuan, Phys. Rev. **D72**, 054028 (2005).

Collins fragmentation function



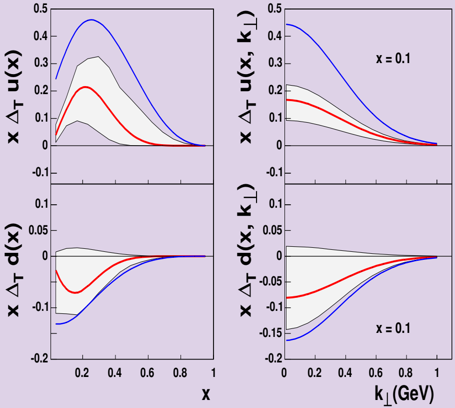
Right panel: solid line corresponds to FIT II, dashed line corresponds to FIT I

Transversity



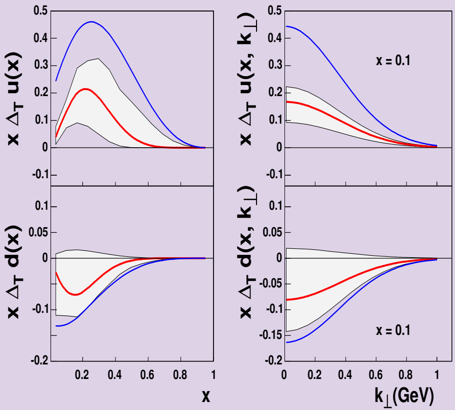
- This is the first extraction of transversity from experimental data.
- $\Delta_T u(x) > 0$ and $\Delta_T d(x) < 0$
- Both $\Delta_T u(x)$ and $\Delta_T d(x)$ do not saturate Soffer bound.
- HERMES data alone fixes well $\Delta_T u(x)$ while HERMES+COMPASS allows us to extract $\Delta_T d(x)$.

Transversity



- This is the first extraction of transversity from experimental data.
- $\Delta_T u(x) > 0$ and $\Delta_T d(x) < 0$
- Both $\Delta_T u(x)$ and $\Delta_T d(x)$ do not saturate Soffer bound.
- HERMES data alone fixes well $\Delta_T u(x)$ while HERMES+COMPASS allows us to extract $\Delta_T d(x)$.

Transversity



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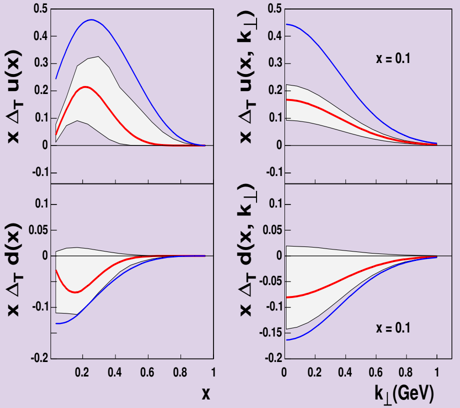

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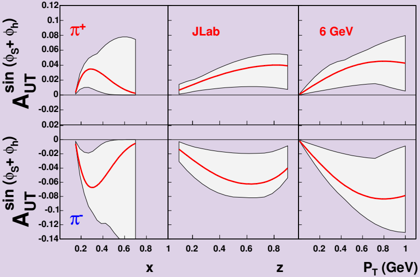
PREDICTIONS

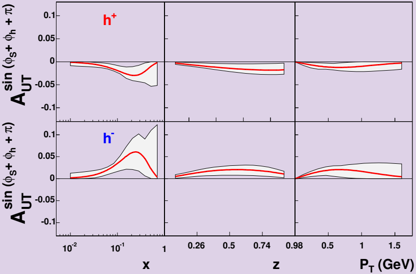
JLab

$ep \rightarrow e\pi X$, $p_{lab} = 6$ GeV.



COMPASS

$\mu p \rightarrow \mu h X$, $p_{lab} = 160$ GeV.



JLab can improve our knowledge of transversity in high x region. COMPASS operating on proton target is expected to measure 5% asymmetry at $x \sim 0.2$

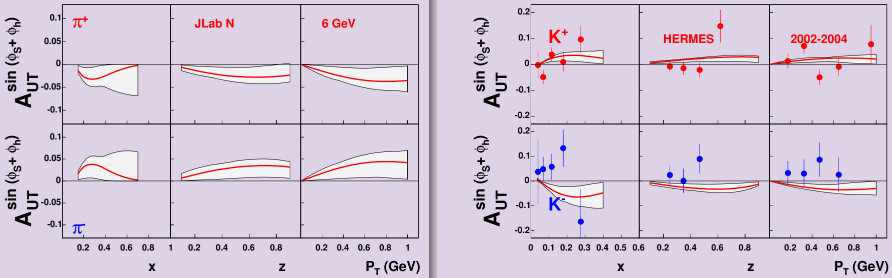
PREDICTIONS

JLab

$eN \to e\pi X$, $p_{lab} = 6$ GeV.

HERMES

$ep \to eKX$, $p_{lab} = 27.57$ GeV.

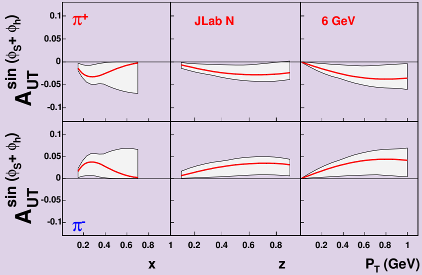


JLab can improve our knowledge of $\Delta_T d(x)$ transversity using neutron target. Prediction of the model are compatible with Kaon data from HERMES.

PREDICTIONS

JLab

$eN \to e\pi X$, $p_{lab} = 6$ GeV.



HERMES

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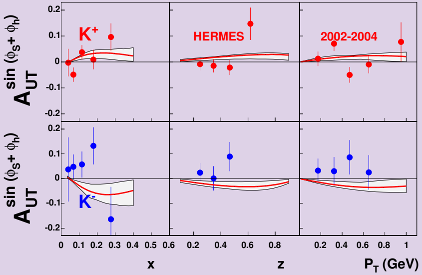


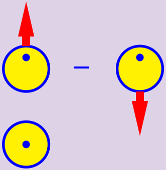
$$A_{UT}^{sin(\phi_h+\phi_S)}|_{proton} \sim 4\Delta_T u(x)\Delta^N D_{h/u^\uparrow}(z) + \Delta_T d(x)\Delta^N D_{h/d^\uparrow}(z)$$
$$A_{UT}^{sin(\phi_h+\phi_S)}|_{neutron} \sim 4\Delta_T d(x)\Delta^N D_{h/u^\uparrow}(z) + \Delta_T u(x)\Delta^N D_{h/d^\uparrow}(z)$$

Sivers effect

Sivers effect $A \propto sin(\phi_h - \phi_S)$

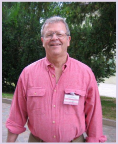
The azimuthal asymmetry arises due to modulation in parton density, the so called Sivers function $\Delta^N f_{q/p^\uparrow}$ is the difference of parton distributions in a polarized hadron.

$A_N \sim sin(\phi_h - \phi_S) \cdot \Delta^N f_{q/p^\uparrow}(x, k_\perp) \otimes D_{h/q}(z)$



$= \Delta^N f_{q/p^\uparrow}$

$= D_{h/q}$



D. Sivers, *Phys. Rev.* **D41** (1990) 83

Sivers effect

Sivers effect $A \propto sin(\phi_h - \phi_S)$

$$A_{UT}^{sin(\phi_h-\phi_S)}(x,z) \sim \frac{\sum_q e_q^2 x z \Delta^N f_{q/p^\uparrow}(x) D_{h/q}(z)}{\sum_q e_q^2 x f_q(x) D_{h/q}(z)},$$

$$Positivity \quad constraints:$$

$$|\Delta^N f_{q/p^\uparrow}(x,k_\perp)| \leq 2 f_q(x,k_\perp)$$

Two different notations:

$$f_{q/p^\uparrow}(x,\mathbf{k}_\perp) = f_{q/p}(x,k_\perp) + \frac{1}{2}\,\Delta^N f_{q/p^\uparrow}(x,k_\perp)\,\mathbf{S}_T \cdot (\hat{\mathbf{P}} \times \hat{\mathbf{k}}_\perp)$$

$$= f_{q/p}(x,k_\perp) - f_{1T}^{\perp q}(x,k_\perp)\,\frac{\mathbf{S}_T \cdot (\hat{\mathbf{P}} \times \mathbf{k}_\perp)}{m_p},$$

Sivers effect

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$$Positivity \quad constraints:$$

$$|\Delta^N f_{q/p^\uparrow}(x, k_\perp)| \le 2 f_q(x, k_\perp)$$

Two different notations:

Relation

$$\Delta^N f_{q/p^\uparrow}(x, k_\perp) = -\frac{2|k_\perp|}{m_p} f_{1T}^{\perp q}(x, k_\perp) \,.$$

Trento conventions: A. Bacchetta, U. D'Alesio, M. Diehl, and C. A. Miller, Phys. Rev. **D70**, 117504 (2004).

Sivers function

Model for Sivers function

$\Delta^N f_{q/p^\uparrow}(x, k_\perp) \Longrightarrow$ we use factorization of x and $k_\perp$ and Gaussian dependence on $k_\perp$

$$\Delta^N f_{q/p^\uparrow}(x, k_\perp) = 2\,\mathcal{N}_q(x)\; f_q(x)\; h(k_\perp)\, \frac{e^{-p_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}\;,$$

with

$$\mathcal{N}_q(x) = N_q\, x^{a_q}(1-x)^{b_q}\, \frac{(a_q+b_q)^{(a_q+b_q)}}{a_q^{a_q}\, b_q^{b_q}}$$

$$h(k_\perp) = \sqrt{2e}\,\frac{k_\perp}{M'}\; e^{-k_\perp^2/M'^2},$$

where N_q, a_q, b_q, and M' are parameters.

Sivers function

Model for Sivers function

$\Delta^N f_{q/p^\uparrow}(x, k_\perp) \Longrightarrow$ we use factorization of x and $k_\perp$ and Gaussian dependence on $k_\perp$

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with

$$\mathcal{N}_q(x) \le 1$$
$$h(k_\perp) \le 1$$

positivity constraint $|\Delta^N f_{q/p^\uparrow}(x, k_\perp)| \le 2 f_q(x, k_\perp)$ is fulfilled.

Description of $A_{UT}^{\sin(\phi_h-\phi_S)}$

We use HERMES and COMPASS data sets on $A_{UT}^{\sin(\phi_h-\phi_S)}$ in the fitting procedure.

u, *d* and *sea* Sivers functions are fitted.

For sea Sivers functions we use

$$\Delta^N f_{\bar{u}/p^\uparrow}(x, k_\perp)\,, \Delta^N f_{\bar{d}/p^\uparrow}(x, k_\perp)\,, \Delta^N f_{s/p^\uparrow}(x, k_\perp)\,, \Delta^N f_{\bar{s}/p^\uparrow}(x, k_\perp).$$

HERMES Collaboration, Diefenthaler M., HERMES measurements of Collins and Sivers asymmetries from a transversely polarised hydrogen target, arXiv:0706.2242
COMPASS Collaboration, Martin A. COMPASS results on transverse single-spin asymmetries Czech. J. Phys. **B56**, F33-F52 (2006).

Description of the data

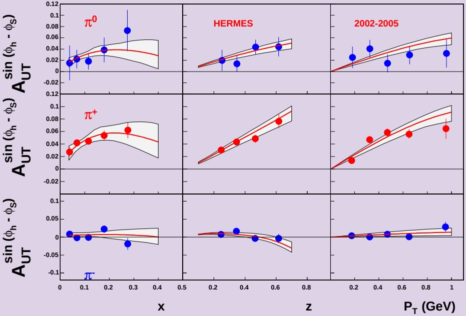
Table: Best values of the free parameters for the *u*, *d* and *sea* Sivers functions.

			$\chi^2/\mathrm{d.o.f.}$	=	1.		
u Sivers function	N_u	=	$0.33^{+0.062}_{-0.067}$				
	a_u	=	$0.58^{+0.86}_{-0.46}$		b_u	=	$2.6^{+4.4}_{-2.3}$
d Sivers function	N_d	=	$-1.00^{+0.004}_{-0.000}$				
	a_d	=	$0.75^{+0.65}_{-0.36}$		b_d	=	$1.1^{+2.5}_{-0.92}$
sea Sivers function	$N_{\bar{u}}$	=	$0.005^{+0.24}_{-0.15}$		$N_{\bar{d}}$	=	$-0.36^{+0.39}_{-0.51}$
	N_s	=	$-0.19^{+0.61}_{-0.74}$		$N_{\bar{s}}$	=	$1.00^{+0}_{-0.00059}$
	a_{sea}	=	$1.5^{+2.6}_{-1.2}$		b_{sea}	=	11^{+31}_{-11}
	$\langle k_\perp^2 \rangle$	=	$0.25\ \mathrm{GeV}^2$		M'^2	=	$0.41^{+0.41}_{-0.18}\ \mathrm{GeV}^2$

Description of HERMES data $A_{UT}^{sin(\phi_h-\phi_S)}$

HERMES $A_{UT}^{sin(\phi_h-\phi_S)}$

$ep \to e\pi X$, $p_{lab} = 27.57$ GeV.

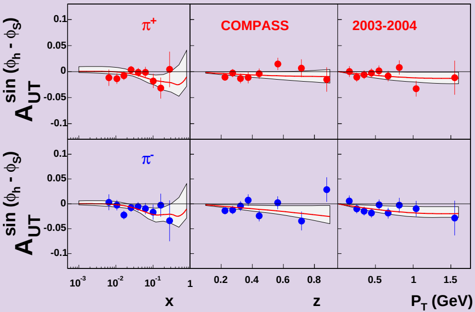


HERMES Collaboration, Diefenthaler M., HERMES measurements of Collins and Sivers asymmetries from a transversely polarised hydrogen target, arXiv:0706.2242

Description of COMPASS data $A_{UT}^{sin(\phi_h-\phi_S)}$

COMPASS $A_{UT}^{sin(\phi_h-\phi_S)}$

$\mu D \to \mu h X$, $p_{lab} = 160$ GeV.



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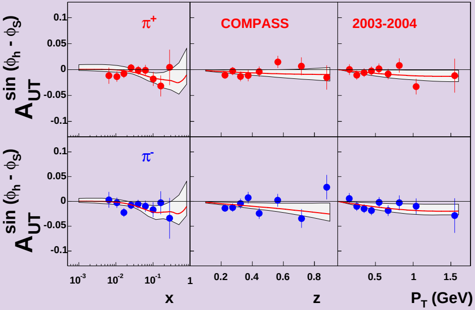

Why $A_{UT}^{sin(\phi_h-\phi_S)} \sim 0$?

Description of COMPASS data $A_{UT}^{sin(\phi_h-\phi_S)}$

COMPASS $A_{UT}^{sin(\phi_h-\phi_S)}$

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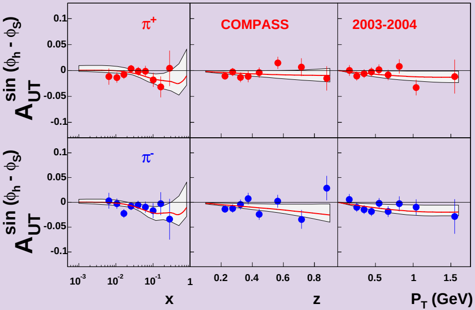

$$\left(A_{UT}^{\sin(\phi_h-\phi_S)}\right)_{\rm hydrogen} \sim 4\,\Delta^N f_{u/p^\uparrow}\, D_u^h + \Delta^N f_{d/p^\uparrow}\, D_d^h$$

Description of COMPASS data $A_{UT}^{sin(\phi_h-\phi_S)}$

COMPASS $A_{UT}^{sin(\phi_h-\phi_S)}$

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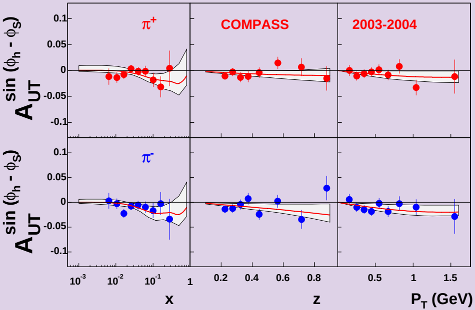

$$\left(A_{UT}^{\sin(\phi_h-\phi_S)}\right)_{\mathrm{deuterium}} \sim \left(\Delta^N f_{u/p^\uparrow} + \Delta^N f_{d/p^\uparrow}\right)\left(4\, D_u^h + D_d^h\right)$$

Description of COMPASS data $A_{UT}^{sin(\phi_h-\phi_S)}$

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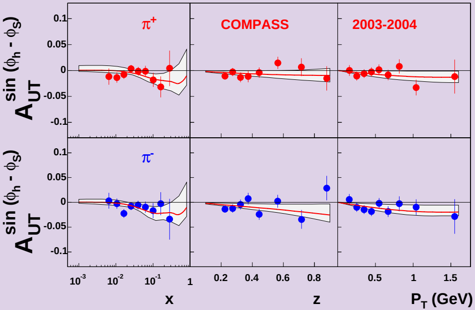
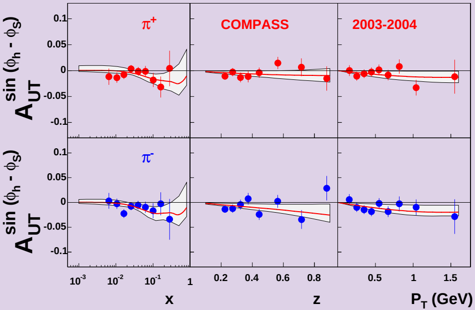


$$\left(A_{UT}^{\sin(\phi_h-\phi_S)}\right)_{\rm deuterium} \sim \left(\Delta^N f_{u/p^\uparrow} + \Delta^N f_{d/p^\uparrow}\right) \sim 0$$

Description of COMPASS data $A_{UT}^{sin(\phi_h - \phi_S)}$

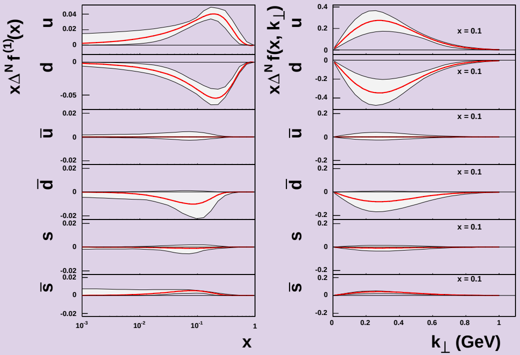
COMPASS $A_{UT}^{sin(\phi_h - \phi_S)}$

$\mu D \to \mu h X$, $p_{lab} = 160$ GeV.



But deuteron target allows us to fit better $\Delta^N f_{d/p^\uparrow}$ as combination of $\Delta^N f_{u/p^\uparrow} + \Delta^N f_{d/p^\uparrow}$ enters into the asymmetry.

Sivers function

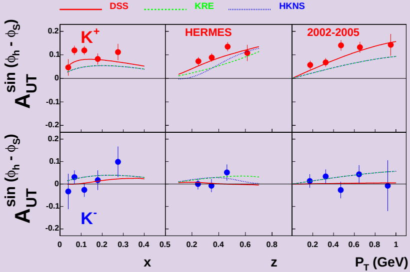


$$\Delta^N f_q^{(1)}(x) \equiv \int d^2\mathbf{k}_\perp \frac{k_\perp}{4m_p} \Delta^N f_{q/p^\uparrow}(x, k_\perp) = -f_{1T}^{\perp(1)q}(x) \, .$$

KAON HERMES AND COMPASS DATA

HERMES

$ep \to eKX$, $p_{lab} = 27.57$ GeV.



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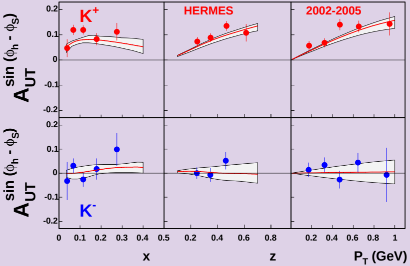
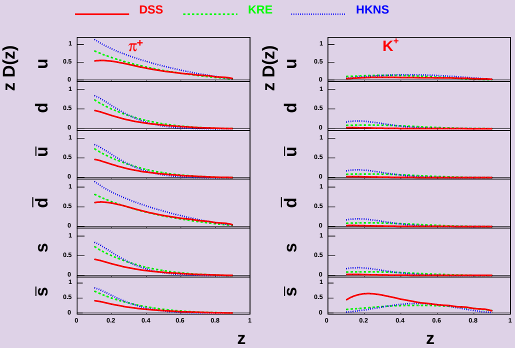


Kaon FF as given by De Florian *et al.* in Ref.

de Florian D., Sassot R., and Stratmann M. Phys. Rev. **D75** 114010 (2007)

(right panel) are compared the Kretzer (dotted lines) and HKNS set (dashed lines) of fragmentation functions (left panel).

Fragmentation function

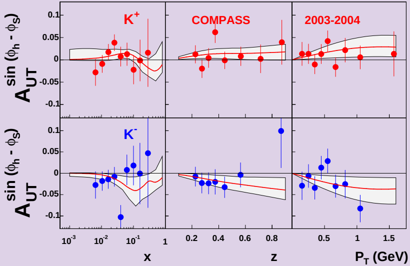


$K^+(u\bar{s})$, $\pi^+(u\bar{d})$ thus knowledge of $\bar{s} \to K^+$ FF is very important

KAON HERMES AND COMPASS DATA

COMPASS

$\mu D \to \mu K X$, $p_{lab} = 160$ GeV.



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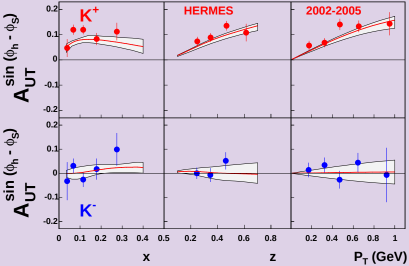

Model description of COMPASS and HERMES Kaon data.

PREDICTIONS

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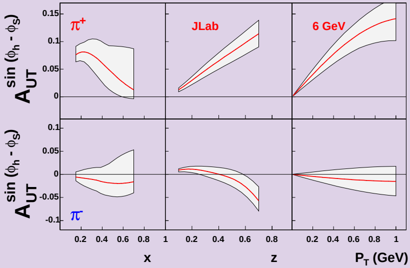
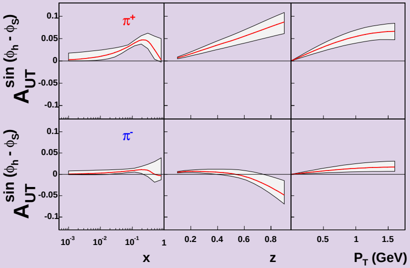


COMPASS

$\mu p \to \mu\pi X$, $p_{lab} = 160$ GeV.



JLab can improve our knowledge of Sivers function in high x region. COMPASS operating on proton target is expected to measure 5% asymmetry for h^+.

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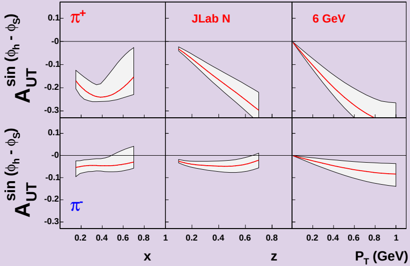

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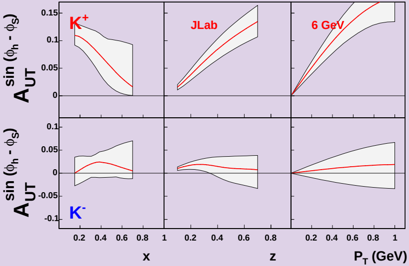

JLab can improve our knowledge of $\Delta^N f_{d/p^\uparrow}$ using neutron target.

CONCLUSIONS

- *First* extraction of transversity for u and d quarks, $\Delta_T u(x)$ and $\Delta_T d(x)$, from HERMES, COMPASS and BELLE data is presented.
- Transversity $\Delta_T q(x)$ is found not to saturate Soffer bound $(q(x) + \Delta q(x))/2$.
  $\Delta_T u(x) > 0$ and $\Delta_T d(x) < 0$
- Estimates of the Collins fragmentation functions for favoured and unfavoured fragmentation have been obtained.
  $\Delta^N D_h^{fav}(z, |p_\perp|) > 0$ and $\Delta^N D_h^{unf}(z, |p_\perp|) < 0$
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THANK YOU!

ed

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