International Workshop on Hadron Structure and Spectroscopy, Freiburg March 19–21

Transverse Spin Effects (Sivers and Collins)

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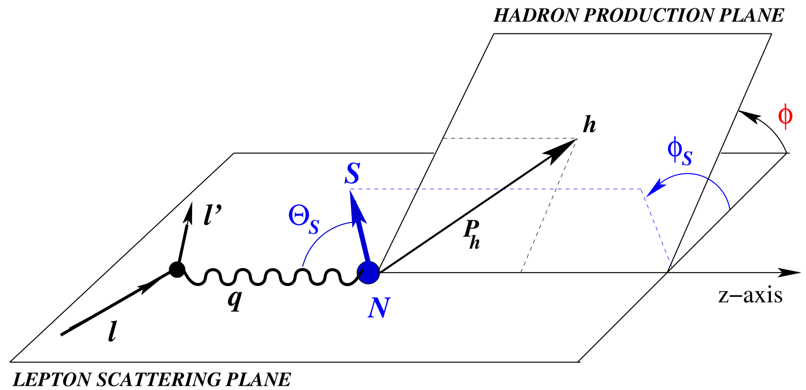
Based on PLB 612 (2005) 233, PRD 73 (2006) 014021, PRD 73 (2006) 094023, PRD 73 (2006) 094025.

Overview:

- What is Sivers effect?
- Sivers effect in SIDIS & Drell-Yan $\longrightarrow$ testing QCD predictions.
- Sivers effect for kaons — daily impact of new data!
- What is Collins effect?
- Collins effect in SIDIS & e^+e^--annihilation.
- Emerging picture of Collins function & transversity.
- Summary & conclusions.

SIDIS on transv. polarized target

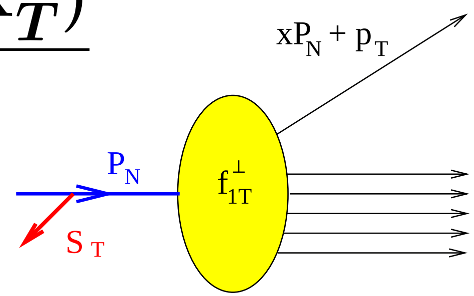


Expressions in LO $1/Q$ (Kotzinian, Boer, Mulders, ... 90s)
Factorization with k_T (Ji, Ma, Yuan&Collins, Metz 2004)

$$\frac{d^3\sigma_T}{dx\,dz\,d\phi} = \frac{d^3\sigma_{unp}}{dx\,dz\,d\phi}\{1 + S_T\,[\,\underbrace{\sin(\phi-\phi_S)\;A_{UT}^{\sin(\phi-\phi_S)}}_{\text{Sivers effect}} + \cdots]\}$$

- Sivers function $f_{1T}^{\perp}(x, \mathbf{p}_T^2)$ "twist-2", naively/artificially "T-odd".

Sivers SSA: $$A_{UT}^{\sin(\phi-\phi_S)} \propto \frac{f_{1T}^{\perp a}(x,\mathbf{p}_T^2)\otimes D_1^a(z,\mathbf{K}_T^2)}{f_1^a(x)D_1^a(z)}$$



(Sivers 1991, Brodsky, Hwang, Schmidt & Collins 2002)

(Belitsky, Ji, Yuan & Boer, Mulders, Pijlman 2003)

- Remarkable **universality** property $\boxed{f_{1T}^{\perp}|_{DIS} = -f_{1T}^{\perp}|_{DY}}$ (Collins 2002).

Of absolute importance to be tested experimentally!

Sivers effect in SIDIS

HERMES	**proton**	**clearly seen**	PRL 94 (2005) 012002, AIP 792 (2005) 933
COMPASS	**deuteron**	$\sim \mathbf{0}$ within error bars	PRL 94 (2005) 202002

Questions:

- $A_{UT}^{\sin(\phi-\phi_S)} \propto \dfrac{f_{1T}^{\perp a}(x,\mathbf{p}_T^2) \otimes D_1^a(z,\mathbf{K}_T^2)}{f_1^a(x) D_1^a(z)}$ $\quad \underbrace{f_1^a(x),\ D_1^a(z)\ \text{known}}_{\text{(e.g. GRV, Kretzer)}} \Rightarrow$ allow to extract $f_{1T}^{\perp}$?

- Are COMPASS and HERMES data compatible ?

- Possible to test $f_{1T}^{\perp}|_{DIS} = -f_{1T}^{\perp}|_{DY}$?

Answers: Yes. Yes. Yes.

Our works
Anselmino et al., PRD 71 (2005) 074006 and 72 (2005) 094007
Vogelsang and Yuan, PRD72 (2005) 054028
See also Anselmino *et al.*, "Comparing extractions of Sivers functions", Como-proceeding, hep-ph/0511017

Our study of HERMES data (P_{hT}-unweighted!) (PRL 94 (2005) 012002):

- Neglect soft factors (Ji, Ma, Yuan & Collins, Metz 2004)
- Assume Gaussian $f_{1T}^{\perp a}(x, \mathbf{p}_T^2) \equiv f_{1T}^{\perp a}(x) \dfrac{\exp(-\mathbf{p}_T^2/p_{\text{Siv}}^2)}{\pi\, p_{\text{Siv}}^2} \quad \Longrightarrow$

$$A_{UT}^{\sin(\phi-\phi_S)} = -\frac{a_{\text{Gauss}} \sum_a e_a^2\, f_{1T}^{\perp(1)a}(x)\, D_1^a(z)}{\sum_b e_b^2\, f_1^b(x)\, D_1^b(z)} \quad \text{with} \quad f_{1T}^{\perp(1)}(x) = \int d^2p_T \frac{p_T^2}{2M_N^2} f_{1T}^{\perp}(x, p_T^2)$$

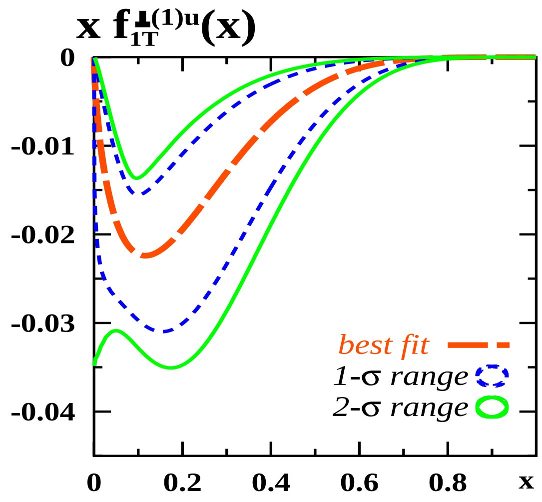
$$\& \quad 0.72 < a_{\text{Gauss}} = \frac{\sqrt{\pi}\, M_N}{\sqrt{p_{\text{Siv}}^2 + K_{D_1}^2/z^2}} < 0.83$$

- $x f_{1T}^{\perp(1)u} = -x f_{1T}^{\perp(1)d} = A x^b (1-x)^5 \overset{\text{fit}}{=} -0.18 x^{0.66} (1-x)^5$

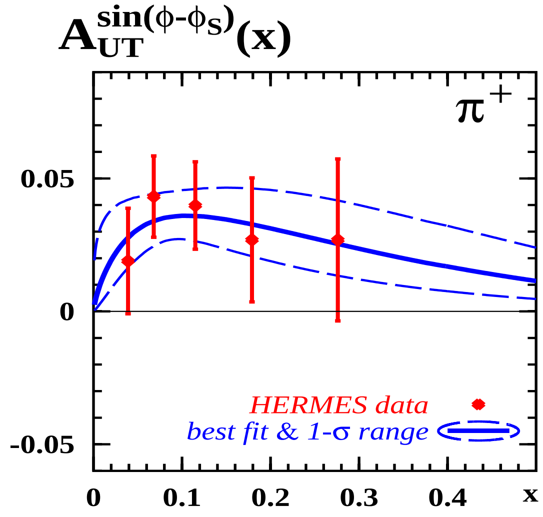
  ↑ in large-N_c limit (Pobylitsa 2003), and neglect $\bar{q}$, s, ...

Results:

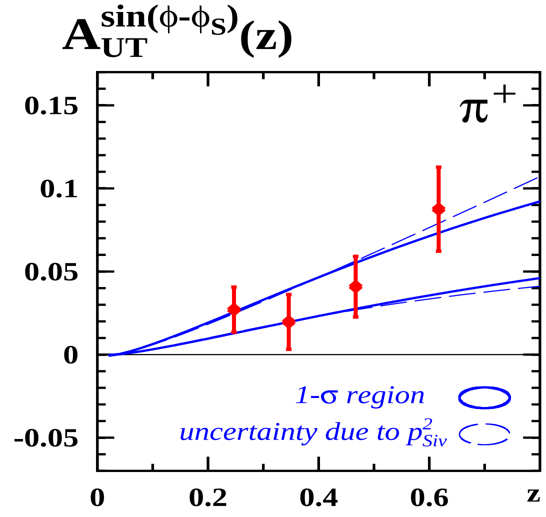
$\chi^2_{/\text{d.o.f.}} \sim 0.3$



Sivers function



x-dependence (input)
Good description!

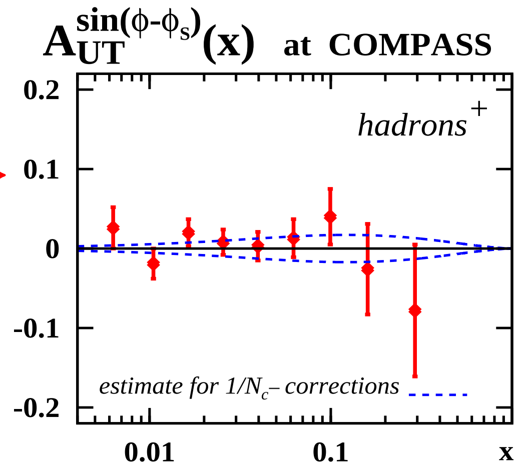


z-dependence (not used)
Cross-check: Ok!

What do we learn?

- Good fit to HERMES **possible** with large-N_c $f_{1T}^{\perp u} = -f_{1T}^{\perp d}$
- COMPASS: deuteron target

$$f_{1T}^{\perp u/\mathrm{deut}} \approx \underbrace{f_{1T}^{\perp u} + f_{1T}^{\perp d}}_{1/N_c\text{-correction}} \overset{\text{assume}}{=} \pm\frac{1}{N_c}|f_{1T}^{\perp u} - f_{1T}^{\perp d}| \longrightarrow$$



$1/N_c$ useful for HERMES & COMPASS

. . . at present stage!

- Supports intuitive picture (Burkardt 2002)

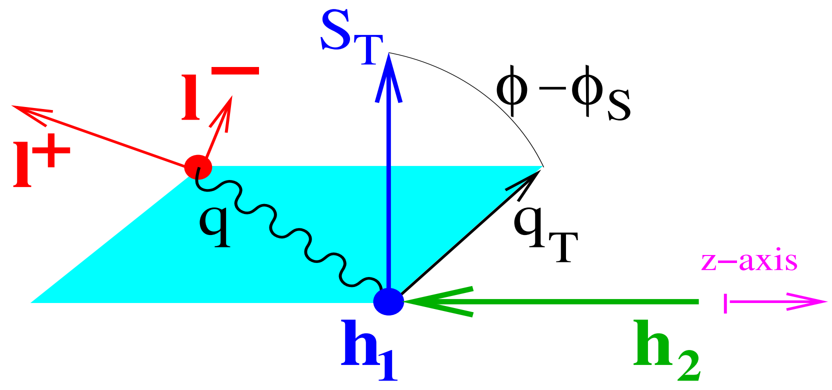
$$\int dx\; f_{1T\,\mathrm{SIDIS}}^{\perp(1)u}(x) \propto -\kappa^u < 0, \quad \int dx\; f_{1T\,\mathrm{SIDIS}}^{\perp(1)d}(x) \propto -\kappa^d > 0$$

Suspicion: Maybe large-N_c works *particularly well* for Sivers function since it *works* particularly well for anomalous magnetic moments ??? **Will see!**

Recall: $$\underbrace{|\kappa^u - \kappa^d| \sim 3.706}_{\mathcal{O}(N_c^2)} \gg \underbrace{|\kappa^u + \kappa^d| \sim 0.360}_{\mathcal{O}(N_c)}$$

- **Have a first idea of $f_{1T}^{\perp q}|_{\mathrm{SIDIS}}$!!!**

Sivers effect in DY $h_1^\uparrow h_2 \to l^+ l^- X$

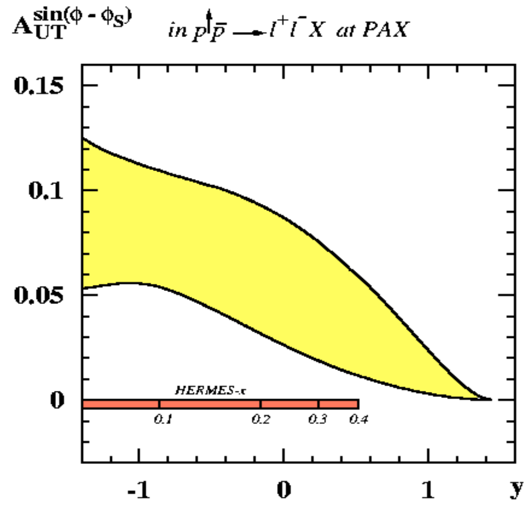


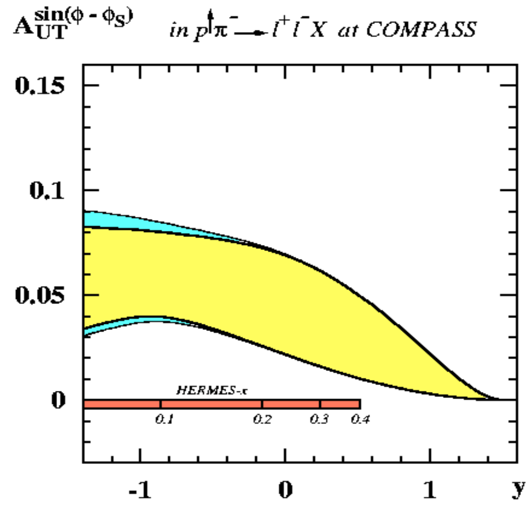
$$A_{UT}^{\sin(\phi-\phi_S)} = + \frac{a_{\text{Gauss}}^{\text{DY}} \sum_a e_a^2 f_{1T\,\text{DY}}^{\perp(1)a}(x_1) f_1^{\bar a}(x_2)}{\sum_a e_a^2 f_1^a(x_1) f_1^{\bar a}(x_2)}$$

$$y = \frac{1}{2}\ln(p_1\cdot q/p_2\cdot q), \quad x_{1,2} = (Q^2/s)^{1/2} e^{\pm y} \quad , \; a_{\text{Gauss}}^{\text{DY}} = \frac{\sqrt{\pi}}{2}\frac{M_N}{\sqrt{\langle p_T^2\rangle_{\text{Siv}} + \langle p_T^2\rangle_{\text{unp}}}}$$

- **PAX at GSI**
  $p^\uparrow \bar p \to l^+ l^- X$ (byproduct)
- **COMPASS**
  $p^\uparrow \pi^- \to l^+ l^- X$

Annihilations of valence dominate
$\Rightarrow$ not sensitive to Sivers sea, good!





Sivers-$\bar q$ matter! Assume

$$f_{1T}^{\perp \bar q} = \pm 25\,\%\; f_{1T}^{\perp q} \quad \text{model I}$$

$$\frac{f_{1T}^{\perp \bar q}(x)}{f_{1T}^{\perp q}(x)} = \frac{f_1^{\bar q}(x)}{f_1^q(x)} \quad \text{model II}$$

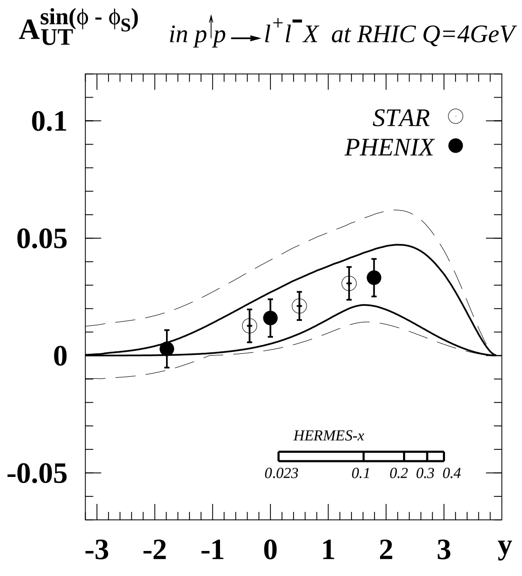
} just for illustration.

- **RHIC**

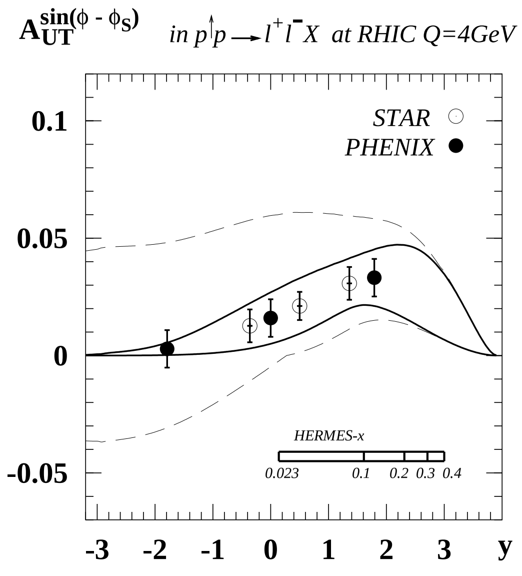
$p^\uparrow p \;\to\; l^+ l^- X$

Can test "change of sign" Sivers-q at $y > 0$ & provide information on Sivers-$\bar{q}$ at $y < 0$.

Error bars $\int \mathrm{d}t\, \mathcal{L} \sim 125\,\mathrm{pb}^{-1}$ realistic till 2012, later RHIC II.



Model I



Model II

$\Longrightarrow$ RHIC, COMPASS & PAX can test change of sign of Sivers-q
RHIC in addition can provide information on Sivers-$\bar{q}$.

For some while (Como workshop September 2005 — DIS'06 in Tsukuba April 2006) happy with situation: first rough understanding of Sivers in SIDIS, predictions for DY done, wait till 2012.

But then . . .!

Kaon Sivers effect in SIDIS at HERMES (Diefenthaler, Kyoto-06, hep-ex/0612010)

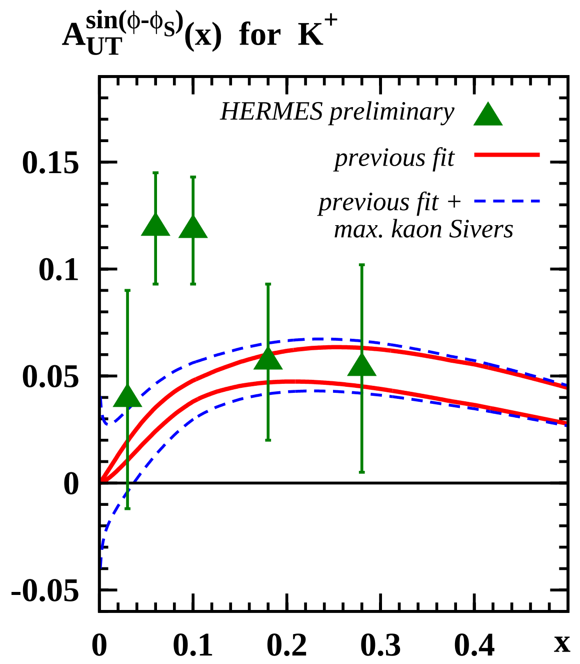
Observation: **(Sivers K^+ SSA) $\approx 2\times$(Sivers π^+ SSA) at small-x.**

How to explain?

- "Only difference" between π^+ and K^+ is $\bar{d} \leftrightarrow \bar{s}$,

$$R = \frac{A(K^+)}{A(\pi^+)} \approx \frac{B(x)+0.35 f_{1T}^{\perp\bar{s}}(x)}{B(x)+0.09 f_{1T}^{\perp\bar{d}}(x)} \,.$$

$$B(x) \approx f_{1T}^{\perp u} + 0.15(f_{1T}^{\perp d} + 4 f_{1T}^{\perp\bar{u}} + f_{1T}^{\perp\bar{d}} + f_{1T}^{\perp s} + f_{1T}^{\perp\bar{s}})$$



- Include previously neglected strange sea Sivers!?
- Let s, $\bar{s}$ Sivers saturate positivity bound?
  (Bacchetta, Boglione, Henneman and Mulders, PRL85(00)712)
- Definitely does not explain factor of 2!
- Reasonable to consider s, $\bar{s}$ but to neglect $\bar{u}$ and $\bar{d}$? No!

Recall: sizeable Sivers-$\bar{q}$ (see models used in DY)
within error bars of $\pi^\pm$ Sivers SSA!

$\Rightarrow$ Consider all of them $f_{1T}^{\perp u}$, $f_{1T}^{\perp d}$, $f_{1T}^{\perp\bar{u}}$, $f_{1T}^{\perp\bar{d}}$, $f_{1T}^{\perp s}$, $f_{1T}^{\perp\bar{s}}$

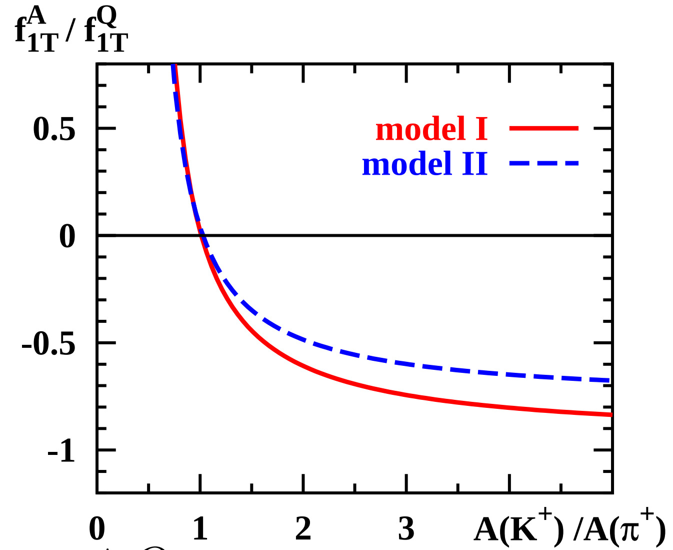
Understand K^+ Sivers effect qualitatively (AE, Goeke, Schweitzer, hep-ph/0702155)

Admittedly many free parameters. $\Rightarrow$ Consider models:

- Model I: $f_{1T}^{\perp Q} \equiv f_{1T}^{\perp u} \approx -f_{1T}^{\perp d}$, $\quad f_{1T}^{\perp A} \equiv f_{1T}^{\perp \bar{u}} \approx f_{1T}^{\perp \bar{d}} \approx f_{1T}^{\perp s} \approx -f_{1T}^{\perp \bar{s}}$
- Model II: $f_{1T}^{\perp Q} \equiv f_{1T}^{\perp u} \approx -2 f_{1T}^{\perp d}$ $\quad f_{1T}^{\perp A} \equiv$ same as above

(Q motivated by our works and by Anselmino et al., Vogelsang & Yuan)

At given x, $\quad R = \dfrac{A(K^+)}{A(\pi^+)}$ is function of $\dfrac{f_{1T}^{\perp A}(x)}{f_{1T}^{\perp Q}(x)}$



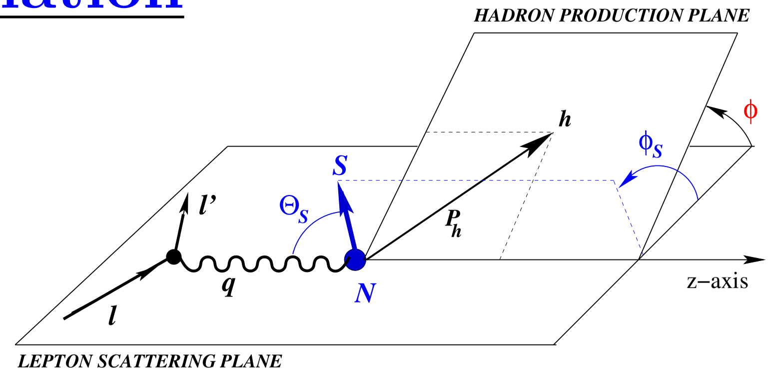
How much Sivers-$\bar{q}$ needed to explain K^+/π^+?

- At large x, $R \approx 1$; thus $f_{1T}^{\perp A}(x) \approx 0$.
- At small x, $R \approx (2-3)$; then $f_{1T}^{\perp A}(x) \approx -(0.5-0.7) f_{1T}^{\perp Q}$.
  Not unusual in small-x region!

1. K^+ **data show importance of Sivers sea quarks.**
2. **Even sizeable R compatible with Sivers-$\bar{q}$&s of natural size.**

Illustrative study to be confirmed later by simultaneous fit of $\pi^\pm$ and $K^\pm$ SSAs. COMPASS contribution would be very important!

Collins effect in SIDIS & e^+e^--annihilation



- **SIDIS, transversely polarized target**
- Expressions in LO $1/Q$ (Boer, Mulders, ... 1990s)
- k_T–factorization (Ji, Ma, Yuan&Collins, Metz 2004)

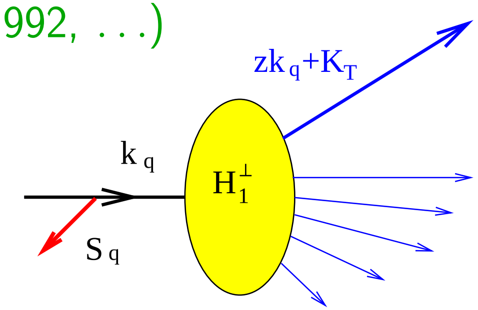
$$\frac{d^3\sigma_{UT}}{dx\,dz\,d\phi} = \frac{d^3\sigma_{\rm unp}}{dx\,dz\,d\phi}\{1 + S_T\,[\cdots + \underbrace{\sin(\phi+\phi_S)\;A_{UT}^{\sin(\phi+\phi_S)}}_{\text{Collins effect}} + \cdots]\}$$

- $H_1^\perp(z, K_T^2)$ **"twist-2", chirally odd & "naively T-odd"**

(Collins 1992 or interf. fragm. (transv. handedness) Efremov, Mankiewicz, Tornquist 1992, ...)

- $h_1^a(x)$ **twist-2, chirally odd**

(Ralston&Soper 1979, ...)



$\Rightarrow$ **Collins SSA :**

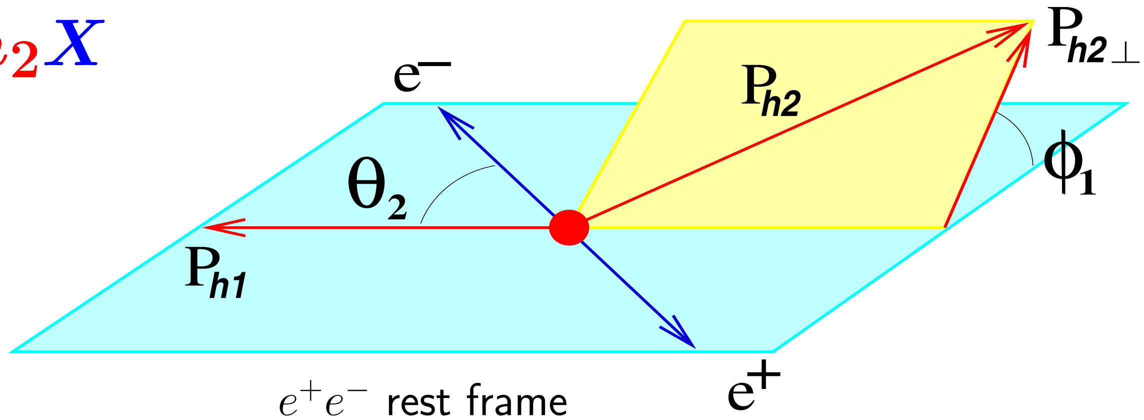
$$A_{UT}^{\sin(\phi+\phi_S)} \propto \frac{h_1^a(x, p_T^2)\otimes H_1^{\perp a}(z, K_T^2)}{f_1^a(x)\,D_1^a(z)}$$

- **Long. polarized target**: $A_{UL}^{\sin 2\phi} \propto H_1^\perp$ at HERMES ~ 0; promising preliminary CLAS data.

Collins effect in $e^+e^- \to h_1 h_2 X$

$\mathbf{h_1} \in$ jet$_1$, $\mathbf{h_2} \in$ jet$_2$

(Boer, Jakob, Mulders, 1997)



e^+e^- rest frame

Assume Gaussian again

$$\frac{d^2\sigma^{e^+e^-\to h_1 h_2 X}}{d\phi_1 d\cos\theta_2} = \frac{d^2\sigma_{\text{unp}}}{d\phi_1 d\cos\theta_2}\Big[1 + \underbrace{\cos(2\phi_1)\frac{\sin^2\theta_2}{1+\cos^2\theta_2} C_{\text{Gauss}} \frac{\sum_a e_a^2 H_1^{\perp a(1/2)} H_1^{\perp \bar{a}(1/2)}}{\sum_a e_a^2 D_1^a D_1^{\bar{a}}}}_{\equiv A_1}\Big]$$

$$C_{\text{Gauss}}(z_1, z_2) = \frac{16}{\pi}\frac{z_1 z_2}{z_1^2 + z_2^2}$$

Actually same angular dependence from radiative effects, acceptance effects

Trick used at BELLE: $\dfrac{A_1^U}{A_1^L} \equiv 1 + \cos(2\phi_1)\; P_1$

Universality: expect the same Collins function in e^+e^- and SIDIS

(Metz 2002, Collins & Metz 2005)

though . . . (Amsterdam group)

Available data

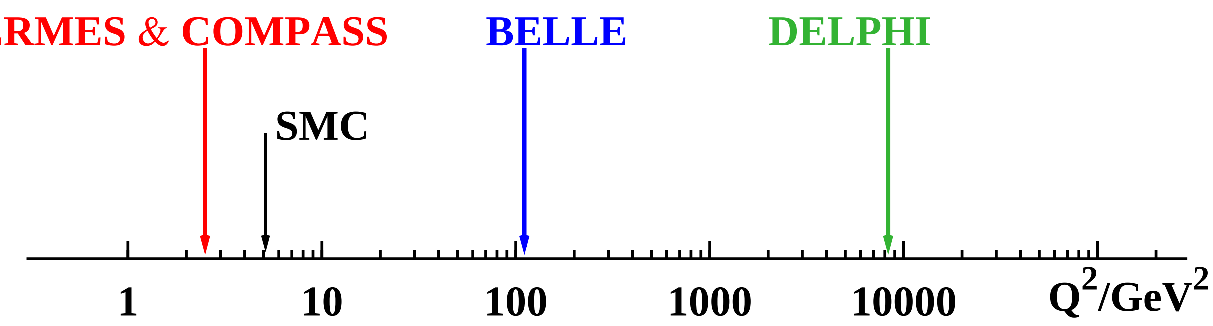
- SIDIS: HERMES (PRL94,012002(2005), hep-ex/0408013 & AIP 792,933(2005), hep-ex/0507013)
- SIDIS: COMPASS (PRL94,202002(2005), hep-ex/0503002)
- e^+e^- BELLE, A_1^U/A_1^L (hep-ex/0507063, hep-ex/0605085).
- e^+e^- BELLE, very recently A_1^U/A_1^C was reported (Ogava, DIS 2006, hep-ex/0607014).

Also:

- SIDIS: SMC preliminary (Bravar, Nucl.Phys.Proc.Suppl.**79**(1999)520)
- e^+e^- DELPHI preliminary (Efremov,Smirnova,Tkachev, Nucl.Phys.Proc.Suppl.**79**(1999)554)

Question : **Are all these data due to the same Collins effect?**

Problems :



- Different scales.
- Sudakov suppression.
- Soft factors.
- Unknown functions $H_1^{\perp}(z, K_T)$, $h_1^a(x, p_T)$.
- Unknown k_T-dependence.

Way out:

- Neglect soft factors, disregard Sudakov suppression.
- Different scales $\Rightarrow$ **compare** $\boldsymbol{H_1^\perp/D_1}$, presumably less scale-dependent.
- $f_1^a(x)$ from GRV98, $D_1^a(z)$ from Kretzer2000; Kretzer,Leader,Christova2001.
- $h_1^a(x)$ from chiral quark-soliton model (PRD64(2001)034013) — about 20% accuracy.
- $\boldsymbol{F(x,k_T) = F(x)\cdot G(k_T)}$ & Gaussian, if $\langle P_{h\perp}\rangle \ll \langle Q\rangle$ ✓ & at HERMES ✓ (D'Alesio&Murgia2004)

$\Rightarrow$ **Basically one unknown** $\boldsymbol{H_1^\perp}$ can be extracted — modulo uncertainties due to our assumptions.

Emerging picture of Collins function & transversity

$$A_{UT}^{\sin(\phi+\phi_S)} = 2\,\frac{\sum_a e_a^2\, x h_1^a(x)\; B_{\rm Gauss} H_1^{\perp(1/2)a}(z)}{\sum_a e_a^2\, x f_1^a(x)\; D_1^a(z)}$$

$$H_1^{\perp(1/2)a}(z) = \int d^2\mathbf{K}_T \frac{|\mathbf{K}_T|}{2 z m_\pi} H_1^{\perp a}(z,\mathbf{K}_T) \le \tfrac{1}{2} D_1^a(z)$$

$$B_{\rm Gauss}(z) = \frac{1}{\sqrt{1+z^2\,\langle \mathbf{p}_{h_1}^2\rangle / \langle \mathbf{K}_{H_1}^2\rangle}} \le 1$$

For pions, two functions :

$$H_1^{\perp \rm fav} = H_1^{\perp u/\pi^+} = H_1^{\perp d/\pi^-} = \dots$$
$$H_1^{\perp \rm unf} = H_1^{\perp u/\pi^-} = H_1^{\perp d/\pi^+} = \dots$$

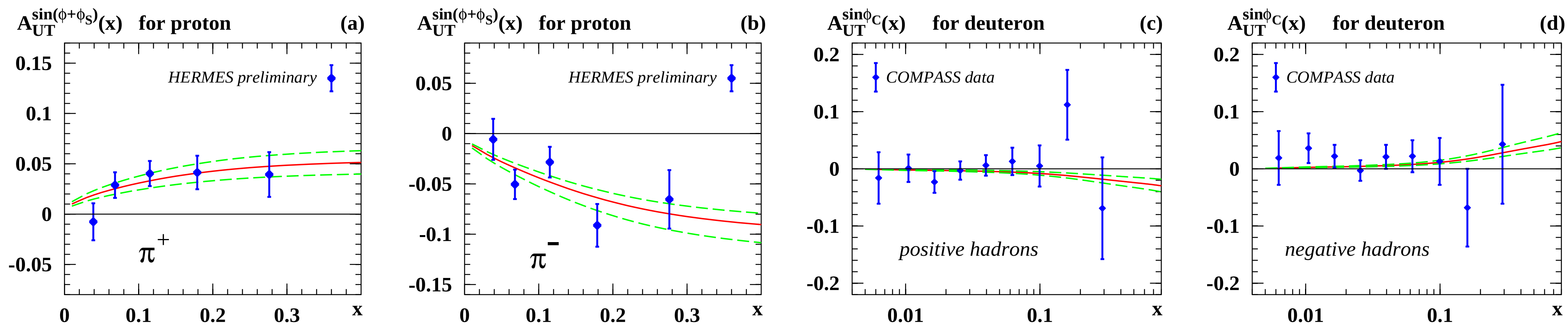
natural (?) to expect $|H_1^{\perp \rm fav}| \gg |H_1^{\perp \rm unf}|$

$\stackrel{\text{Fit}}{\Longrightarrow}$

$$\langle B_{\rm Gauss} H_1^{\perp(1/2)\rm fav}\rangle = (3.5 \pm 0.8)\cdot 10^{-2}$$
$$\langle B_{\rm Gauss} H_1^{\perp(1/2)\rm unf}\rangle = -(3.8 \pm 0.7)\cdot 10^{-2}$$

$$H_1^{\perp \rm unf} \approx -H_1^{\perp \rm fav}$$

$\longrightarrow$ string fragmentation (Artru,Czyżewski,Yabuki,ZPhysC73(1997)527)



- Good description of HERMES
- compatible with COMPASS

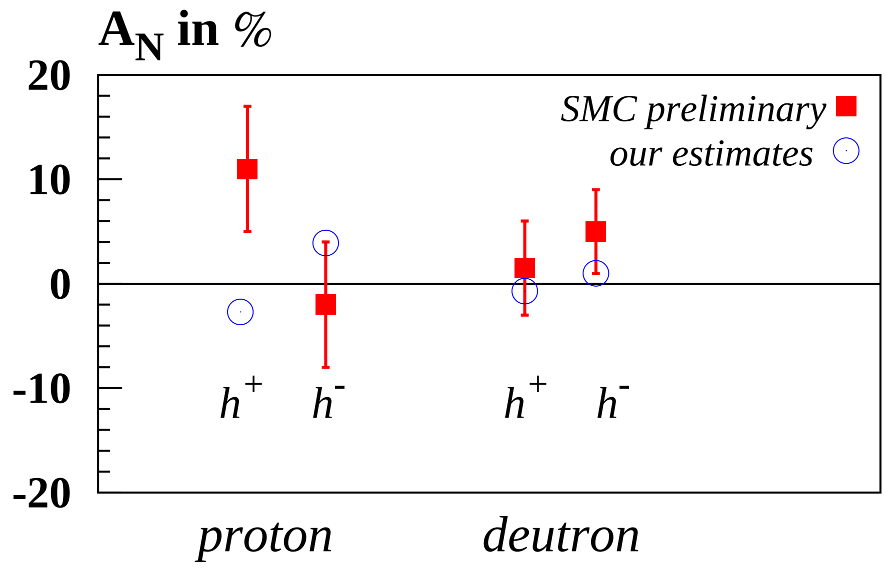
- **Grain of salt: preliminary SMC**

  charged hadrons

  $\langle Q^2\rangle \sim 5\,\mathrm{GeV}^2, \quad \langle x\rangle \sim 0.08$

  $\langle z\rangle \sim 0.45$ and $\langle P_{h\perp}\rangle \sim (0.5-0.8)\,\mathrm{GeV}$

  Reason to worry? Data are preliminary . . .



- **Emerging picture of transversity from SIDIS**

  How model dependent is our result?

  Compare to Vogelsang & Yuan, (PRD72,054028(2005))

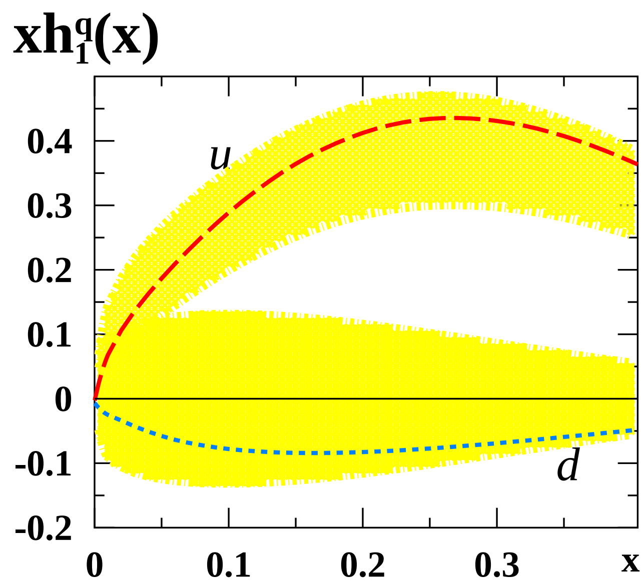
  same $\langle B_{\rm Gauss} H_1^{\perp a}\rangle$ (different p_T-dependence)

  but assume saturation of Soffer bound.

  $|h_1^a(x)| \le \frac{1}{2}(f_1^a + g_1^a)(x)$

  Look closer: demand extracted $\langle B_{\rm Gauss} H_1^{\perp}\rangle$ to vary within 1-σ.

  Question: How much is $h_1^a(x)$ allowed to vary?



$h_1^a(x)$ from chiral quark soliton model

$\Rightarrow$ **Picture:** $h_1^u(x)$ within 30% of Soffer bound, other $h_1^a(x)$ unconstrained.

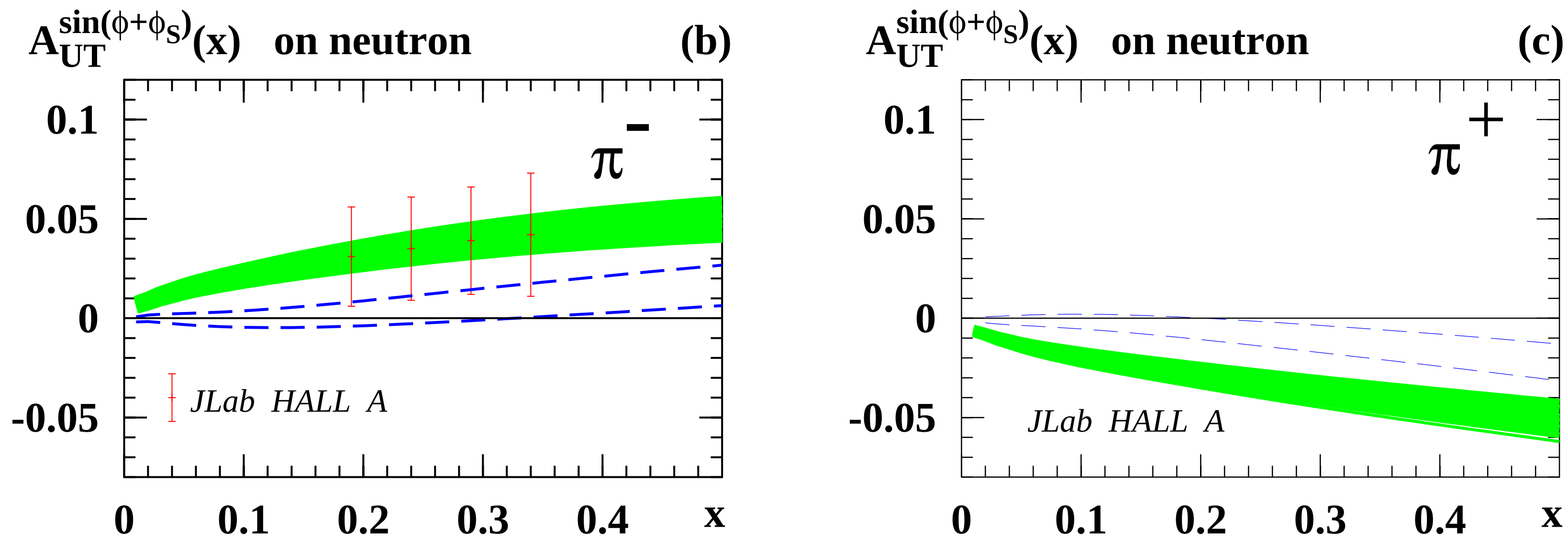
(supported by lattice QCDSF)

- **Emerging picture of transversity from SIDIS will improve**
  - Data on π^0 & kaons.
  - More data from HERMES proton & deuteron target.
  - More data from COMPASS deuteron & proton target.
  - Data from CLAS with transv. pol. target.
  - Data from HALL-A, transv. ^{3}He $\approx$ neutron target, $\langle Q^2 \rangle \sim 2\ \mathrm{GeV}^2$, $\longrightarrow \boldsymbol{h_1^d(x)}$

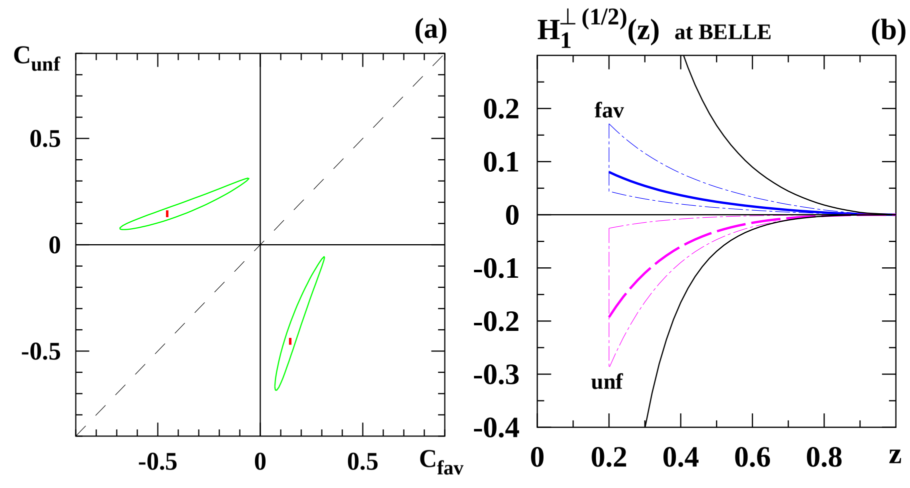
    green: $h_1^d(x) < 0$ from chiral quark-soliton model,

    dashed: $h_1^d(x)$ of opposite sign,

    error bars: projections for 24 days of beam time (Chen, et al. nucl-ex/0511031).



Collins effect in e^+e^-



- **BELLE** $e^+e^- \to h_1 h_2 X$ with $h_{1,2} = \pi^\pm$

$$\frac{A_1^U(\phi)}{A_1^L(\phi)} \approx 1 + \cos(2\phi_1)\, \mathbf{P_1}$$

with $\mathbf{P_1}(z_1, z_2) = F(H_1^{\rm fav}, H_1^{\rm unf}, \text{Gauss})$

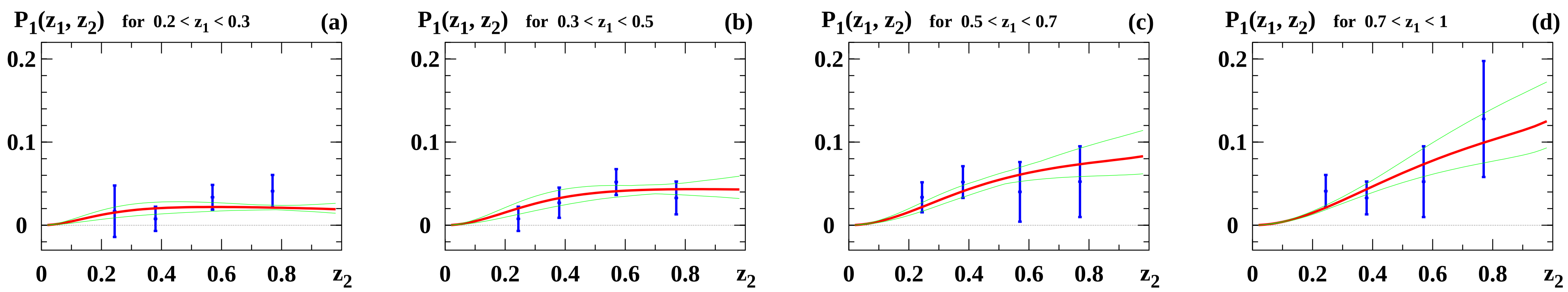
include $s, \bar{s} \to H_1^{\rm unf}$ (fine for D_1)

symmetric $z_1 \leftrightarrow z_2$ or fav $\leftrightarrow$ unf

Best Ansatz $H_1^{\perp(1/2)a} = C_a z D_1^a(z)$, other Ansätze not excluded

Best fit results: $C_{\rm fav} = 0.15, \quad C_{\rm unf} = -0.45$ or vice versa: fav $\leftrightarrow$ unf

sign preferred by HERMES

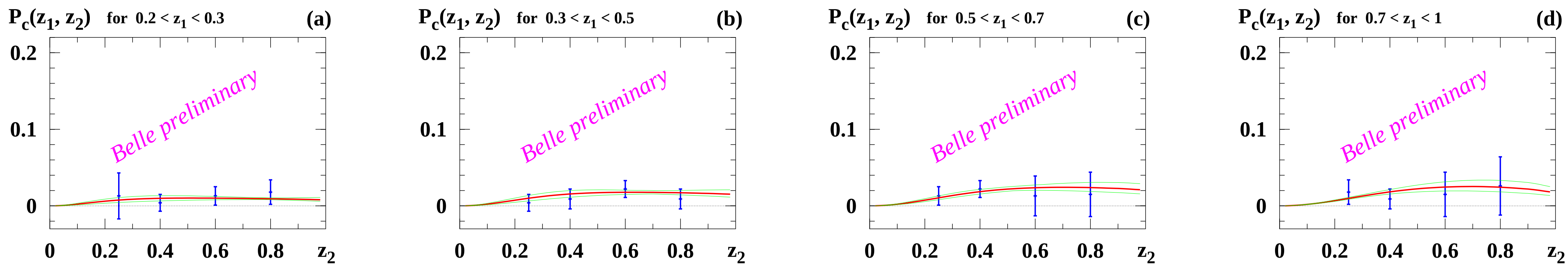


Good description !

Important most recent news from BELLE (hep-ex/0607014)

New double ratio is measured

$$\frac{A_1^U(\phi)}{A_1^C(\phi)} \approx 1 + \cos(2\phi_1)\ \mathbf{P_c}$$



Excellent confirmation of our picture of Collins effect!

Faith in our first understanding of Collins effect strengthened.
New (preliminary) data, will provide valuable constraints and improve the fits after officially released.

- **DELPHI preliminary**

$e^+e^- \to Z_0 \to h_1 h_2 X$, $\quad h_{1,2}$ = charged hadrons

$$\frac{d\sigma(e^+e^- \to h_1 h_2 X)}{d\phi_1} = P_0\,(1 + \cos(2\phi_1)\; P_2), \qquad P_2 = \tilde{F}(H_1^{\rm fav}, H_1^{\rm unf})$$

with $\boldsymbol{P_{2,\mathrm{DELPHI}}} = -(\mathbf{0.26 \pm 0.18})\% \pm$ unknown systematics.

- Different scales! Assume $\frac{H_1^\perp}{D_1}\Big|_{\text{one scale}} \approx \frac{H_1^\perp}{D_1}\Big|_{\text{another scale}}$
- $H_1^{\perp c}, H_1^{\perp b}$? Since $m_c, m_b \ll M_Z$: **Maybe unfavoured? Maybe zero?**
- Charged hadrons $= \pi^\pm, K^\pm, \ldots$ with $\lim_{m_\pi \to 0} \frac{H_1^{\perp(1/2)a/\pi}}{D_1^{a/\pi}} = \lim_{m_K \to 0} \frac{H_1^{\perp(1/2)a/K}}{D_1^{a/K}}$

$\Rightarrow$ $\boldsymbol{P_{2,}}$ estimate $\approx -(\mathbf{0.06 \ \ldots \ 0.29})\%$

$\Rightarrow$ **Preliminary DELPHI seems not incompatible with BELLE!**

Intermediate STATUS :

SIDIS: HERMES & COMPASS compatible
e^+e^-: BELLE & DELPHI not incompatible
$\Rightarrow$ **What about HERMES vs. BELLE?**

• HERMES vs. BELLE

I.
$$\frac{\langle 2B_{\rm Gauss}H_1^{\perp(1/2){\rm fav}}\rangle}{\langle D_1^{\rm fav}\rangle}\Big|_{\rm HERMES} = (7.2\pm1.7)\% \quad \text{vs.} \quad \frac{\langle 2H_1^{\perp(1/2){\rm fav}}\rangle}{\langle D_1^{\rm fav}\rangle}\Big|_{\rm BELLE} = (5.3\ \dots\ 20.4)\%$$
$$\frac{\langle 2B_{\rm Gauss}H_1^{\perp(1/2){\rm unf}}\rangle}{\langle D_1^{\rm unf}\rangle}\Big|_{\rm HERMES} = -(14.2\pm2.7)\% \quad \text{vs.} \quad \frac{\langle 2H_1^{\perp(1/2){\rm unf}}\rangle}{\langle D_1^{\rm unf}\rangle}\Big|_{\rm BELLE} = -(3.7\ \dots\ 41.4)\%\,.$$

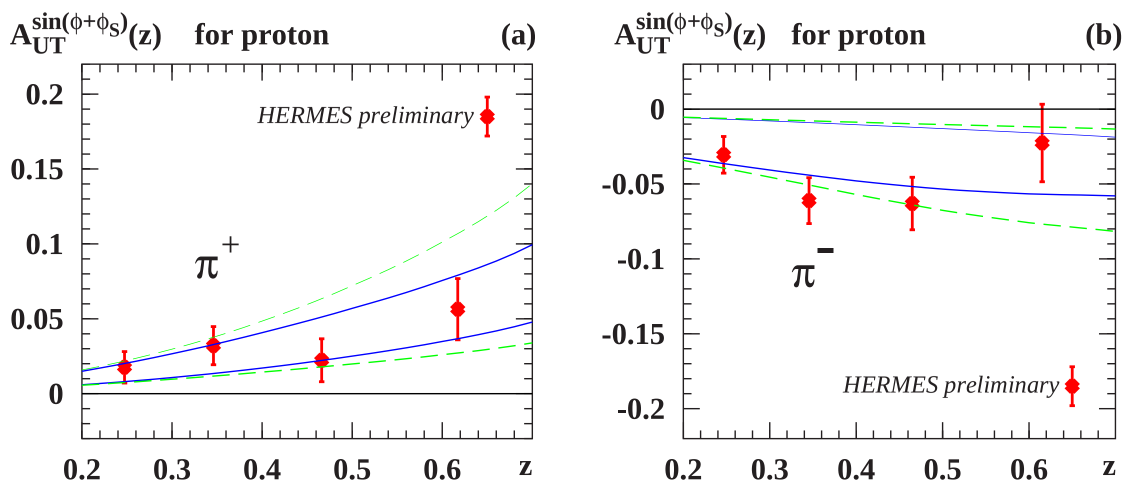
Central values of HERMES systematically lower then of BELLE.
Evolution? But:

1. $\Uparrow$ $B_{\rm Gauss} < 1$ **2.** $\Uparrow$ Errors correlated!

II. ***z*-dependence at HERMES from BELLE fit for $H_1^\perp(z)$.**

Solid lines – 1σ-range.
Dashed line – unknown Gaussian widths

$$1 \lesssim \frac{\langle \mathbf{p}^2_{h_1}\rangle}{\langle \mathbf{K}^2_{H_1}\rangle} \lesssim 4\,.$$



$\Rightarrow$ BELLE & HERMES compatible!

Summary & Conclusions

- HERMES & COMPASS: first data on Sivers effect $\longrightarrow$ first insights.
- SIDIS data from HERMES & COMPASS compatible.
- At present stage large-N_c predictions useful constraint & compatible with data; picture by M. Burkardt $f_{1T}^{\perp q} \sim -\kappa^q$ seems to work.
- Situation improving due to new data from HERMES, COMPASS & JLAB. New impact due to kaons $\rightarrow$ Sivers-$\bar{q}$.
- First understanding $\rightarrow$ Drell–Yan SSA observable at RHIC, COMPASS, PAX, JPARC. Experimental test of $\boldsymbol{f_{1T}^{\perp}|_{DIS} = -f_{1T}^{\perp}|_{DY}}$ possible.
- Lots of work: e.g. what about SSA in $p^\uparrow p \rightarrow \pi X$? (Sivers, Anselmino et al.).

- Collins effect: As good as possible, at present stage, but assumptions & approximations still necessary.
- e^+e^- **BELLE** consistent with SIDIS **HERMES** & **COMPASS**, preliminary DELPHI consistent with those, preliminary SMC seems not.
- Emerging picture: $H_1^{\perp u} \approx -H_1^{\perp d}$. String fragmentation? (Artru et.al, Schäfer&Teryaev).
- $h_1^u > 0$ and within $30\,\%$ of Soffer bound in agreement with lattice.
- Other unknown, soon be improved: HERMES, COMPASS, JLAB & BELLE.
- Use emerging picture to understand other interesting data, e.g. CLAS & HERMES $A_{UL}^{\sin 2\phi}$ or twist-3 $A_{UL}^{\sin\phi}$ and $A_{LU}^{\sin\phi}$ $\longrightarrow$ applications (to be done).

General conclusion

- Encouraging **progress!** (in spite of many forced theoretical uncertainties: soft factor, $1/N_c$, scale dependence, transverse momenta,...). However, **optimism!** New & more precise data coming in, improved analysis necessary. We are **learning**!

Thank you!