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Understanding transverse spin asymmetries at HERMES

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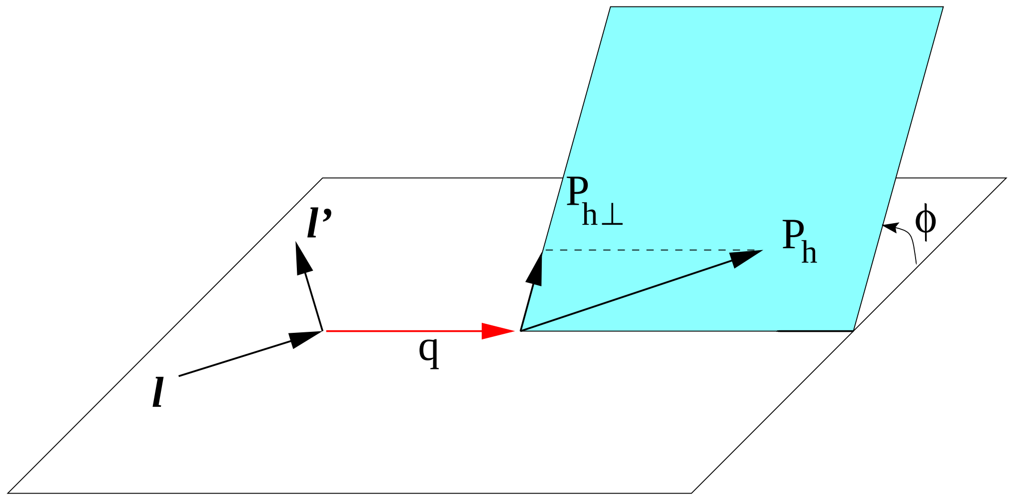
Overview:

- A_{UL}
- A_{UT}
- Conclusions

Remark: HERMES A_{UT} data PRELIMINARY
$\longrightarrow$ present "intermediate" comments & considerations

$A_{UL}^{\sin\phi}$: Manifestation of Collins effect (?)



with $S \parallel$ beam. I.e. components:
$S_L \parallel \gamma^*$ *which is* $\mathcal{O}(1)$,
$S_T \perp \gamma^*$ *which is* $\mathcal{O}(\frac{M_N}{Q})$.

$$\frac{N^{\rightarrow} - N^{\leftarrow}}{\frac{1}{2}(N^{\rightarrow} + N^{\leftarrow})} \propto \sin\phi \cdot \left\{ S_L \underbrace{h_L(x) H_1^{\perp}}_{\text{twist-3}} - S_T \underbrace{h_1(x) H_1^{\perp}}_{\text{twist-2}} \right\}$$

- "T-odd" fragmentation function $H_1^{\perp}$, J. Collins, Nucl. Phys. **B396** (1993) 161.
- Transverse parton momenta crucial $\Rightarrow$ <u>assume</u> generalized factorization theorem.
- Tree-level expressions derived by Mulders and Tangerman, Nucl. Phys. B **461** (1996) 197, ...
- Involved since $A_{UL}^{\sin\phi} = \mathcal{O}(\frac{M_N}{Q})$ = "twist-3": $h_1(x)$, $h_L(x)$, $H_1^{\perp}$, ...

(Among) First attempts to understand $A_{UL}^{\sin\phi}$

- Assume factorization & Collins effect only & tree-level formalism
- simplified description of transverse momenta $f(x, k_T^2) = f(x)\,\mathcal{G}(k_T^2)$, k_T-weighting (!)
- $h_1(x)$ from chiral quark soliton model [P.S. *et al.*, PRD **64** (2001) 034013.]
- $h_L(x) = 2x\int_x^1 \mathrm{d}x' \frac{h_1(x')}{x'^2} + \underbrace{\tilde{h}_L(x)}_{\text{negligible}}$ from instanton vacuum [Dressler and Polyakov, PRD **61** (2000) 097501.]
- $\langle H_1^\perp\rangle/\langle D_1\rangle = (12-14)\%$ & favoured flavour fragmentation

  first DELPHI [Efremov *et al.*, Nucl. Phys. Proc. Suppl. **74** (1999) 49],

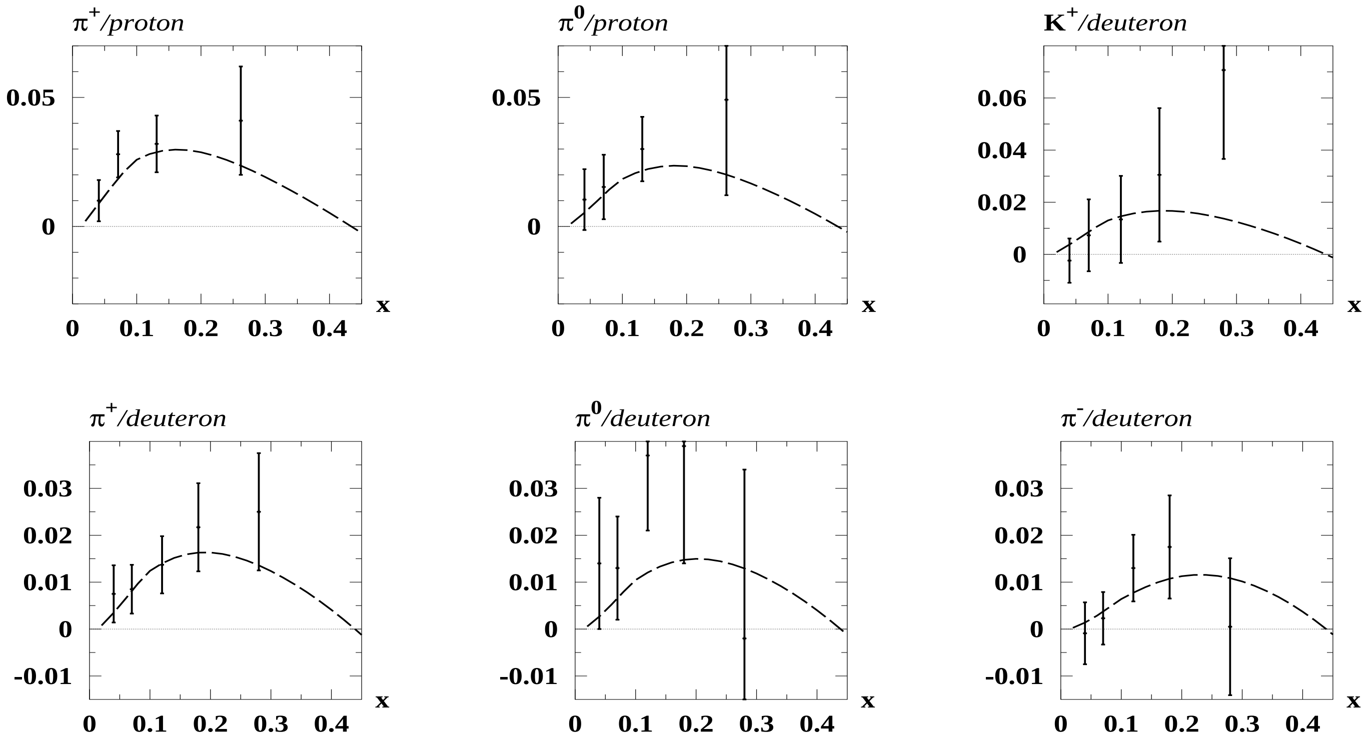
  HERMES indirectly [Efremov, Goeke, P.S., PLB **522** (2001) 37, **544** (2002) 389E].

Advantage of our approach

- no free adjustable parameters
- $h_1(x)$, $h_L(x)$ from a consistent effective non-perturbative field theoretic approach

  which well describes known distributions $f_1(x)$, $g_1(x)$ (and many other nucleonic properties)

$A_{UL}^{\sin\phi}(x)$



HERMES data: A. Airapetian *et al.* PRL **84** (2000) 4047, PRD **64** (2001) 097101, PLB **562** (2003) 182.

Our approach: Efremov, Goeke and P.S., PLB **522** (2001) 37, **544** (2002) 389, EPJC **24** (2002) 407.

Also other approaches: Ma, Schmidt and Yang, PRD **66** (2002) 094001; De Sanctis *et al.*, PLB **483** (2000) 69, ...

$A_{UL}^{\sin 2\phi}(x)$ (independent observable!)

- Small in approach, not in contradiction to HERMES.
- Indication that for π^+ $A_{UL}^{\sin 2\phi} < 0$ and right magnitude from preliminary CLAS data

  [Avakian, CIPANP 2003, New York.]

Did we understand longitudinal target SSA? No!

- "Gluon rescattering mechanism" Brodsky, Hwang and Schmidt, PLB **530** (2002) 99

  $\Leftrightarrow$ T-odd distribution function $f_{1T}^{\perp}$ "Sivers effect" Collins, PLB **536** (2002) 43, . . .

- Phenomenologically anticipated

  Sivers, PRD **41** (1990) 83; Anselmino et al. PLB **362** (1995) 164; Boer, PRD **60** (1999) 014012.

- In chiral soliton models $f_{1T}^{\perp} = 0$ [Pobylitsa, hep-ph/0212027]

  $\overset{!?}{\Rightarrow}$ suppressed in instanton model (like $\tilde{h}_L$) [Efremov, Goeke and P.S., PLB **568** (2003) 63]

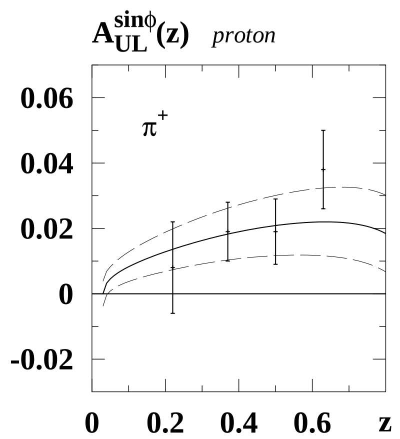
  Even if: $\mathcal{O}(f_{1T}^{\perp} D_1) \approx \mathcal{O}(h_1 H_1^{\perp})$ can be compatible!

- Question:

How could we obtain a satisfactory description of $A_{UL}^{\sin\phi}(x)$ without Sivers effect?

- $f_{1T}^{\perp}$ as large as allowed by positivity*
  cannot be resolved within error bars!

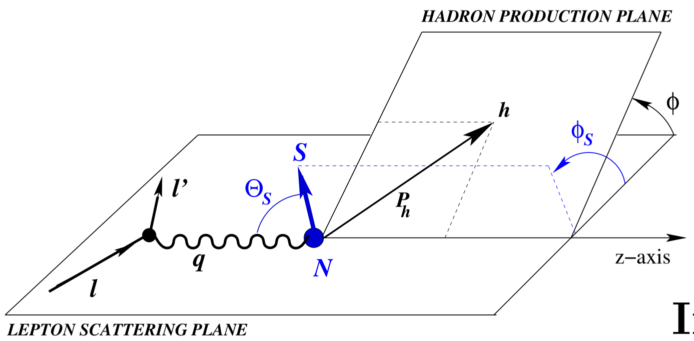
  Bacchetta and P.S., NPA **732** (2004) 106, using model calculation for $H_1^{\perp}$ by Bacchetta et al., PRD **65** (2002) 094021.



* Bacchetta *et al.*, PRL **85** (2000) 712.

- Remark: Also interpretation of $A_{LU}^{\sin\phi} \propto e(x) H_1^{\perp}$ modified
  CLAS hep-ex/0301005 [Efremov, Goeke and P.S., PRD **67** (2003) 114014]
  $\longrightarrow$ Afanasev and Carlson, hep-ph/0308163; Yuan, hep-ph/0310279; Metz and Schlegel, hep-ph/0403182.

Transverse target asymmetries



$$\frac{N^{\uparrow} - N^{\downarrow}}{\frac{1}{2}(N^{\uparrow} + N^{\downarrow})} = \sin(\phi + \phi_s) \cdot \text{Collins effect}$$

$$= \sin(\phi - \phi_s) \cdot \text{Sivers effect}$$

in A_{UL}: $\quad \phi_s = \pm\pi$

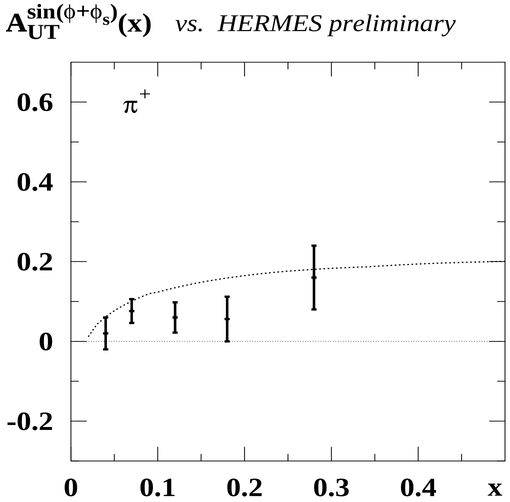
Ingredients:

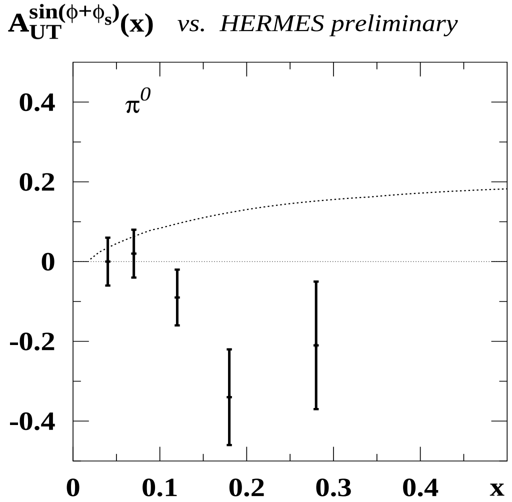
- simplified description of k_T
- $h_1(x)$ from chiral quark soliton model
- favoured flavour fragmetation
- $\langle H_1^{\perp} \rangle / \langle D_1 \rangle = (13.8 \pm 2.8)\%$ ("from" HERMES $A_{UL}^{\sin\phi}$)

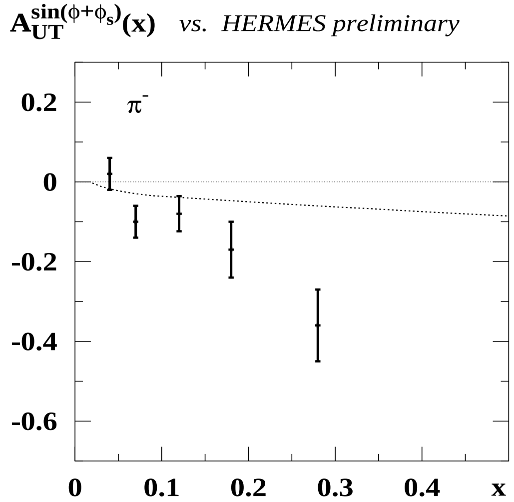
$\Longrightarrow$ even if precise value incorrect: Only overall factor!

$$A_{UT}^{\sin(\phi+\phi_s)} \propto \sum_a e_a^2 \, h_1^a(x) \, H_1^{\perp a}$$

Caution! Preliminary SMC data [Bravar, Nucl. Phys. Proc. Suppl. **79** (1999) 520]: Opposite sign!







π^+

- Ok!

π^0

- No unfavoured fragm.!
- Requires $4h_1^u \ll -h_1^d$

  in contradiction to models

π^-

- Not unexpected!
  Here unfavoured
  fragmentation
  can change a lot

Due to u-quark dominance (in all models) one would expect $A_{UT\,\pi^+}^{\sin(\phi+\phi_s)} \approx A_{UT\,\pi^0}^{\sin(\phi+\phi_s)}$
(as for $A_{UL}^{\sin\phi}$). Why not here?

Let us try model-independent analyses.

$A_{UT}^{\sin(\phi+\phi_s)}$

3 Observables & 1 Relation (isospin invariance)
$\Longrightarrow$ 2 independent pieces of information

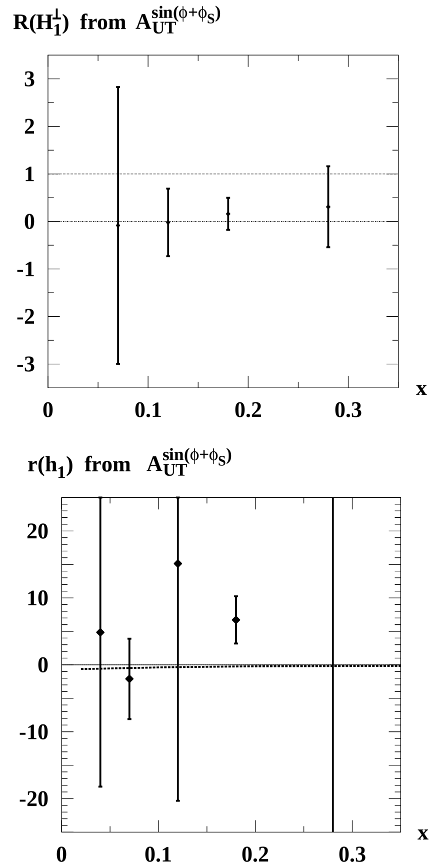
Define $F_{\text{Col}}(\pi) := A_{UT\,\pi}^{\sin(\phi+\phi_s)} \cdot \sum_a e_a^2\, f_1^a(x)\, \langle D_1^{a/\pi} \rangle$, then

$$R(H_1^\perp) := \frac{F_{\text{Col}}(\pi^+) + F_{\text{Col}}(\pi^-)}{F_{\text{Col}}(\pi^0)} = 1 + \frac{\langle H_1^{\perp\text{unf}} \rangle}{\langle H_1^{\perp\text{fav}} \rangle}$$

$$r(h_1) := 4\frac{F_{\text{Col}}(\pi^0) - F_{\text{Col}}(\pi^+)}{F_{\text{Col}}(\pi^0) - F_{\text{Col}}(\pi^-)} = \frac{h_1^d + 4h_1^{\bar{u}}}{h_1^u + \frac{1}{4}h_1^{\bar{d}}} \approx \frac{h_1^d}{h_1^u}$$

Model-independent! (Vague since error bars large.)

- "favours" $H_1^{\perp\text{unf}} \approx -H_1^{\perp\text{fav}}$
  Why not?
- "disfavours" $h_1^d(x)/h_1^u(x)$ = small and negative (models!)
  Why!?



$A_{UT}^{\sin(\phi-\phi_s)}$

- Definitely Sivers effect sizeable, too!

- Not incompatible with $p^{\uparrow}p \to \pi X$.

  [Anselmino et al.]

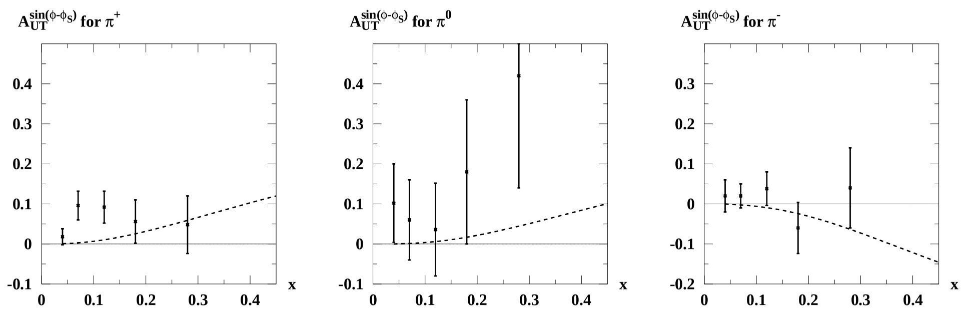
- Really negligible in $A_{UL}^{\sin\phi}$? Have to recheck.

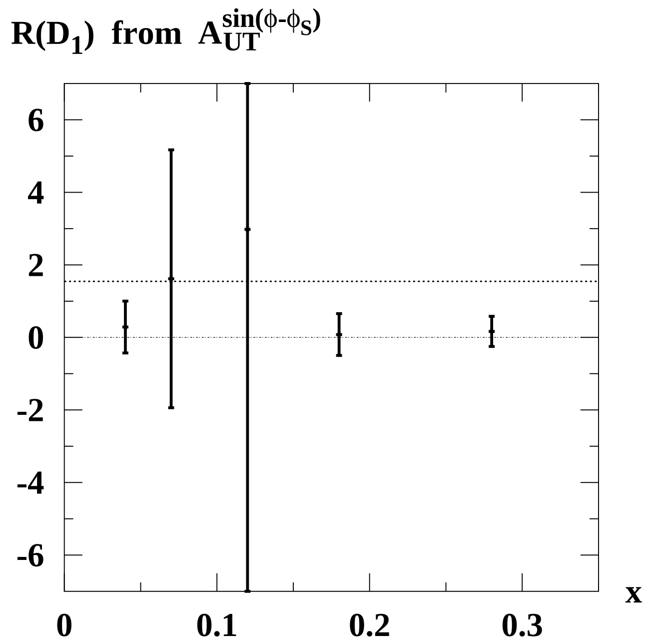
- **But:**

  $F_{\rm Siv}(\pi) := A_{UT\,\pi}^{\sin(\phi-\phi_s)} \cdot \Sigma_a\, e_a^2\, f_1^a(x)\, \langle D_1^{a/\pi} \rangle$

  $$R(D_1) := \frac{F_{\rm Siv}(\pi^+) + F_{\rm Siv}(\pi^-)}{F_{\rm Siv}(\pi^0)} = 1 + \frac{\langle D_1^{\rm unf} \rangle}{\langle D_1^{\rm fav} \rangle}$$

  ≈ 1.55 (must be > 1).
  HERMES data "favours" < 1 ...





Conclusions

Parodoxical situation

- we understand A_{UL} data, but know that description incomplete (since Sivers omitted)
- we have complete description of A_{UT}, but do not understand the (preliminary) data

  – unfavoured fragmentation not sufficient
  – relations based on isospin invariance & positivity seem not to hold
  – is there factorization? (correct weighting!)

But: PRELIMINARY DATA!

- there will be more data from HERMES
- COMPASS, CLAS, HALL-A

  → We soon will know better!

THANK YOU!