TMD's in $p^{\uparrow} l \longrightarrow \pi + X$

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Outline

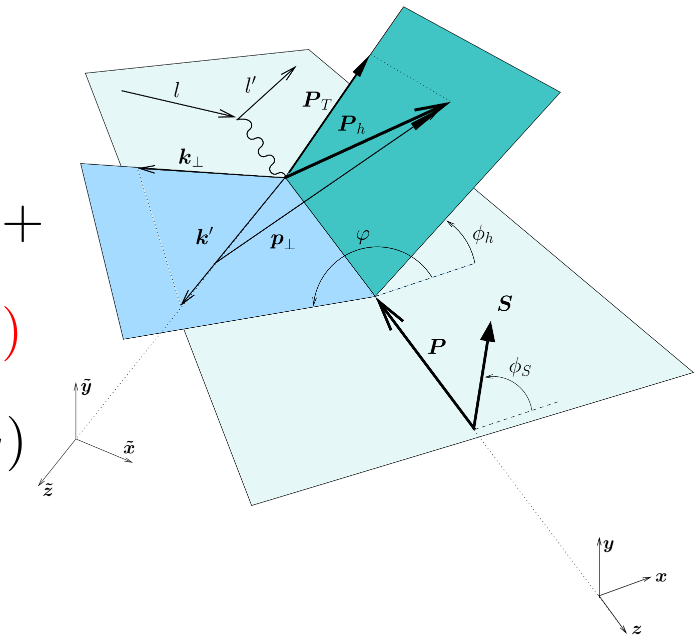
- ◇ SIDIS vs inclusive hadron production
- ◇ The Single Spin Asimmetry A_N
- ◇ Sivers contribution to A_N
- ◇ Transversity-Collins contribution to A_N
- ◇ Conclusions

Polarized SIDIS

➢ Asymmetry A_{UT} in the $\gamma^* p$ c.m. frame:

$$A_{UT} = \frac{d^6\sigma^{lp^\uparrow \to l'hX} - d^6\sigma^{lp^\downarrow \to l'hX}}{\frac{1}{2}[d^6\sigma^{lp^\uparrow \to l'hX} + d^6\sigma^{lp^\downarrow \to l'hX}]} \equiv 2\frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow}$$

where $d^6\sigma^{lp^\uparrow \to l'hX} = d^6\sigma / dx_B dy dz_h d^2\boldsymbol{P}_T d\phi_h$



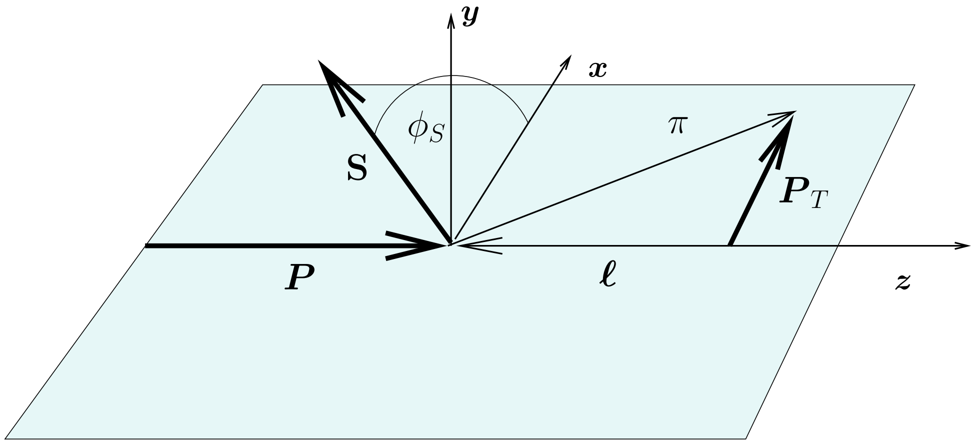
$$d\sigma^\uparrow - d\sigma^\downarrow \propto \Delta^N f_{q/p^\uparrow} \otimes d\hat{\sigma} \otimes D_{h/q} \sin(\phi_h - \phi_S) +$$

$$+ \Delta_T q \otimes \Delta\hat{\sigma}^\uparrow \otimes \Delta^N D_{h/q^\uparrow} \sin(\phi_h + \phi_S)$$

$$+ h_{1T}^\perp \otimes \Delta\hat{\sigma}^\uparrow \otimes \Delta^N D_{h/q^\uparrow} \sin(3\phi_h - \phi_S)$$

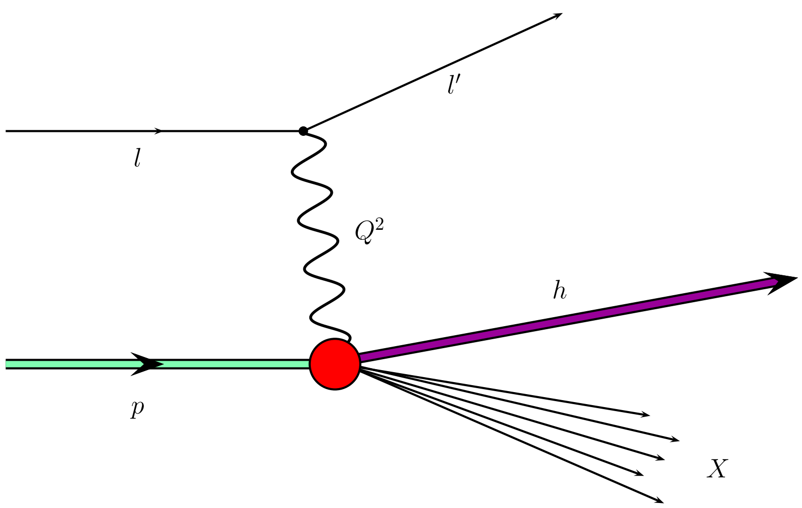
$\Rightarrow$ Separation of the Sivers and Collins effects

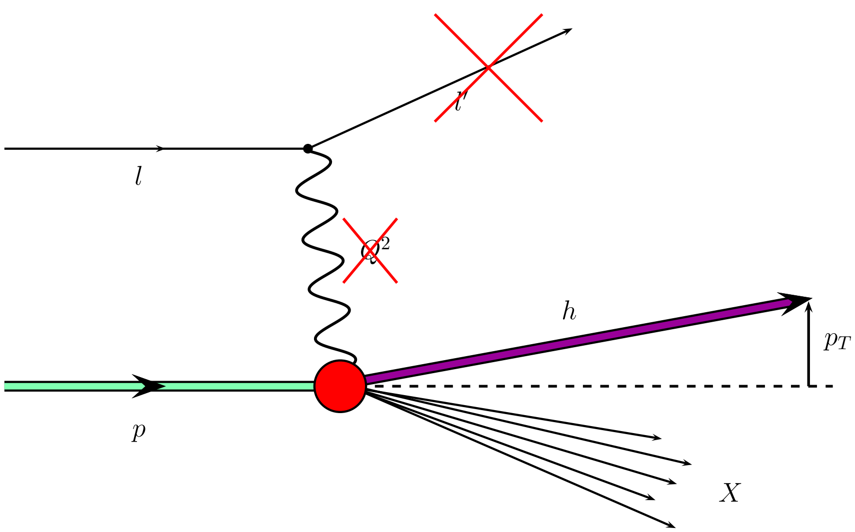
$p^{\uparrow} l \to h + X$



- proton-lepton c.m. frame
- p is along the $+Z$-axis,
- ϕ_S is the azimuthal of S_T
- h in the XZ plane
- Only h is detected

➢ If $P_T \gtrsim 1$ GeV then we are in a "perturbative" regime.





The single spin asimmetry A_N

➢ We can define the single spin asymmetry A_N:

$$A_{TU}(\phi_S) \equiv \frac{d\sigma(\phi_S) - d\sigma(\phi_S + \pi)}{\frac{1}{2}[d\sigma(\phi_S) + d\sigma(\phi_S + \pi)]}\,; \qquad A_{TU}(\phi_S) = 2\,|S_T| A_N \sin\phi_S$$

➢ Therefore A_N can be written as:

$$A_N = \sum_i \frac{1}{2|S_T|\sin\phi_{Si}}\; A^i_{TU}$$

or weighting A_{TU} with $\sin\phi_S$:

$$A_N = \frac{1}{2|S_T|[\sum_i \sin^2\phi_{Si}]} \sum_i A_{TU}^{\sin\phi_{Si}}$$

The single spin asimmetry A_N

➢ Assuming the factorization, at born level, A_N can be written as:

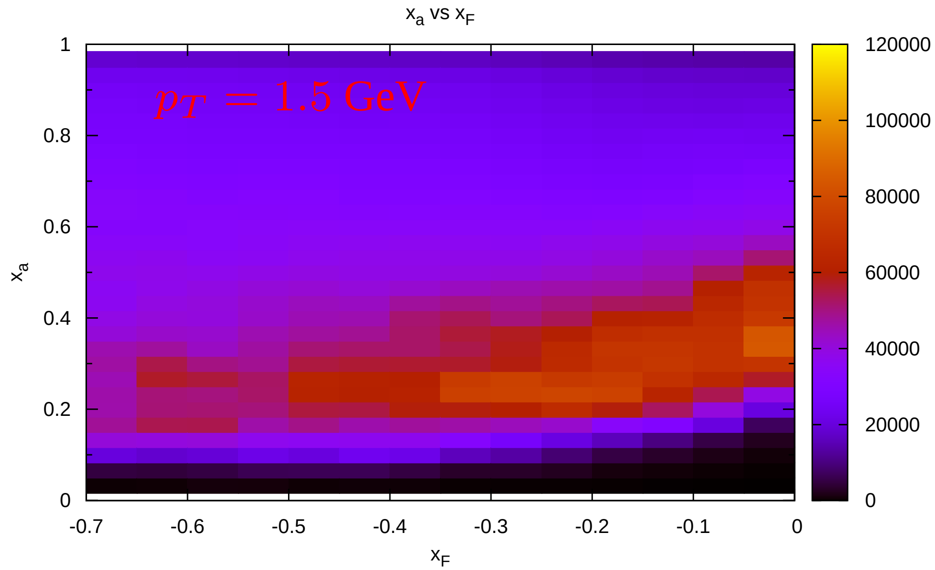
$$A_N \propto \frac{1}{2d\sigma^{unp}}\Big[\Delta^N f_{q/p^\uparrow} \otimes d\hat{\sigma} \otimes D_{h/q} + \Delta_T q \otimes \Delta\hat{\sigma}^\uparrow \otimes \Delta^N D_{h/q^\uparrow} + h_{1T}^\perp \otimes \Delta\hat{\sigma}^\uparrow \otimes \Delta^N D_{h/q^\uparrow}\Big]$$

- The Sivers and the Collins effect add up, $h_{1T}^\perp$ contribution is negligible
- $d\sigma$ is differential in $d^3\boldsymbol{p}_h$ ($x_F = \frac{2p_L}{\sqrt{s}}$ and p_T): x_a integrated from x_a^{min} to 1

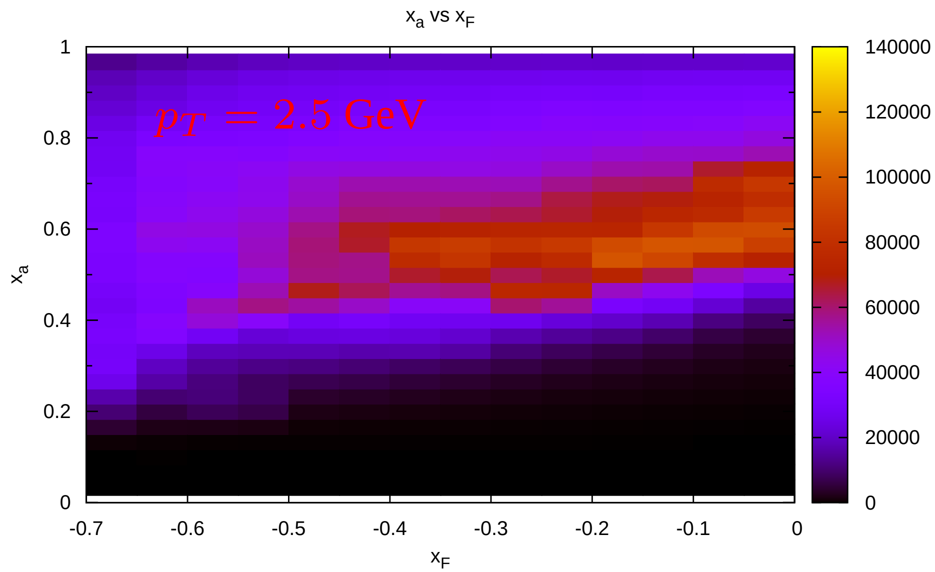
  In collinear approximation: $x_a^{min} = \frac{\sqrt{(P_T^2+P_L^2)}+P_L}{\sqrt{s}}$

➢ Possibility to extend the x_a region explored?? (consistently to exp. cuts)

Kinematics at HERMES:



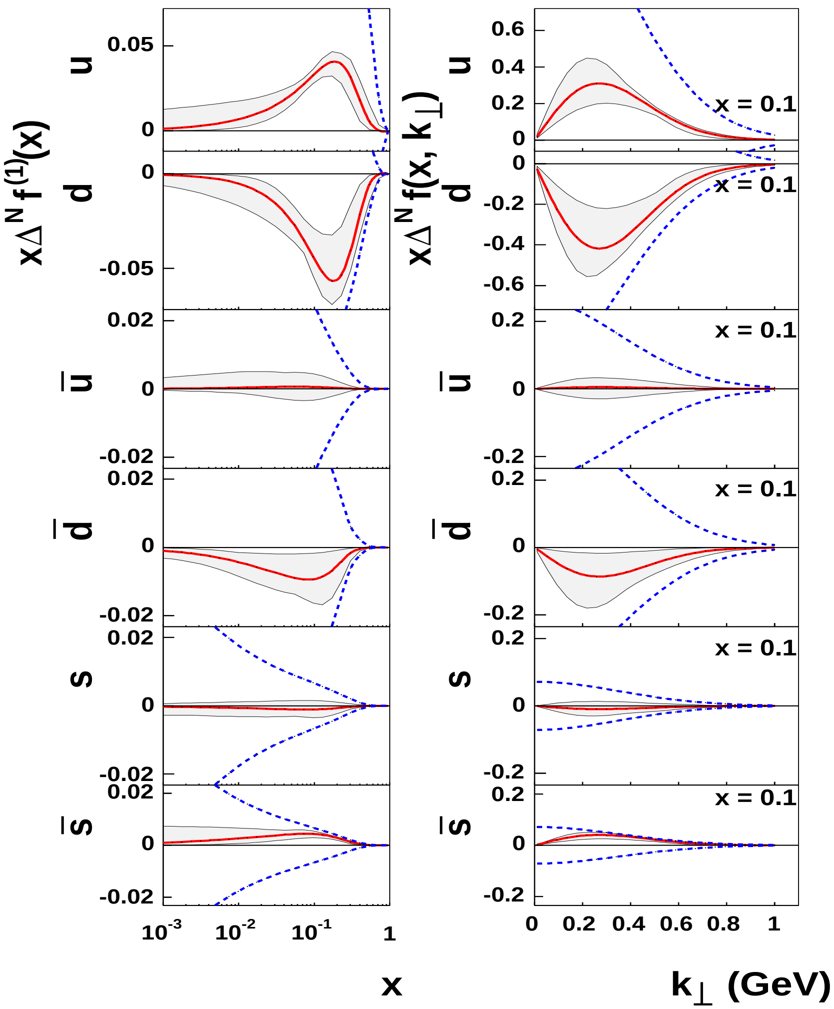
- x_a vs x_F at $\sqrt{s} = 7.24$ GeV and $p_T = 1.5$ GeV



- x_a vs x_F at $\sqrt{s} = 7.24$ GeV and $p_T = 2.5$ GeV

Estimation of A_N from the Sivers and the Collins effects

First moment of the Sivers functions



◇ For valence quarks:

- $\Delta^N f_{u/p^\uparrow} > 0$
- $\Delta^N f_{d/p^\uparrow} < 0$

◇ For sea quarks:

- $\Delta^N f_{\bar{s}/p^\uparrow} > 0$

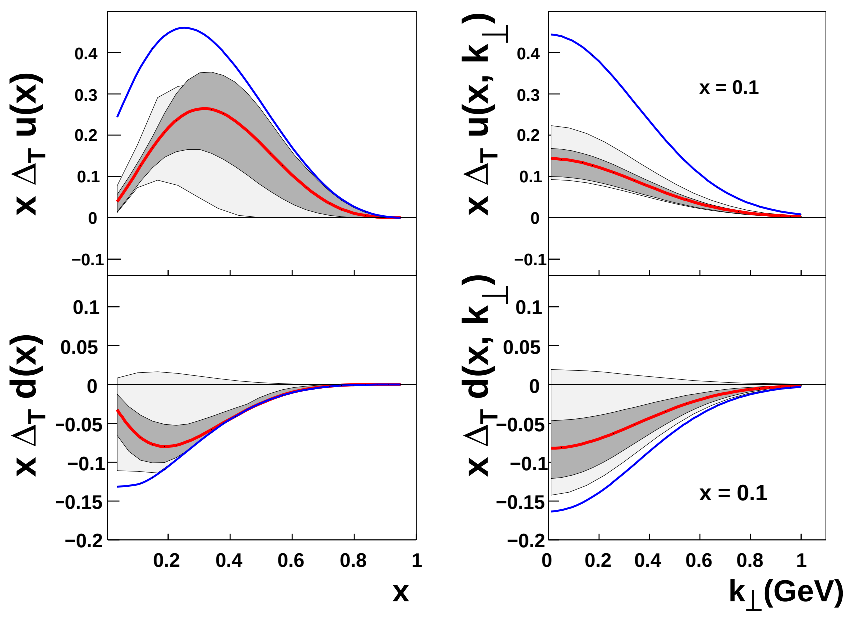
◇ $\Delta^N f_q^{(1)}(x) \equiv \int d^2\boldsymbol{k}_\perp \frac{k_\perp}{4m_p} \Delta^N f_{q/p^\uparrow}(x, k_\perp) = -f_{1T}^{\perp(1)q}(x)$

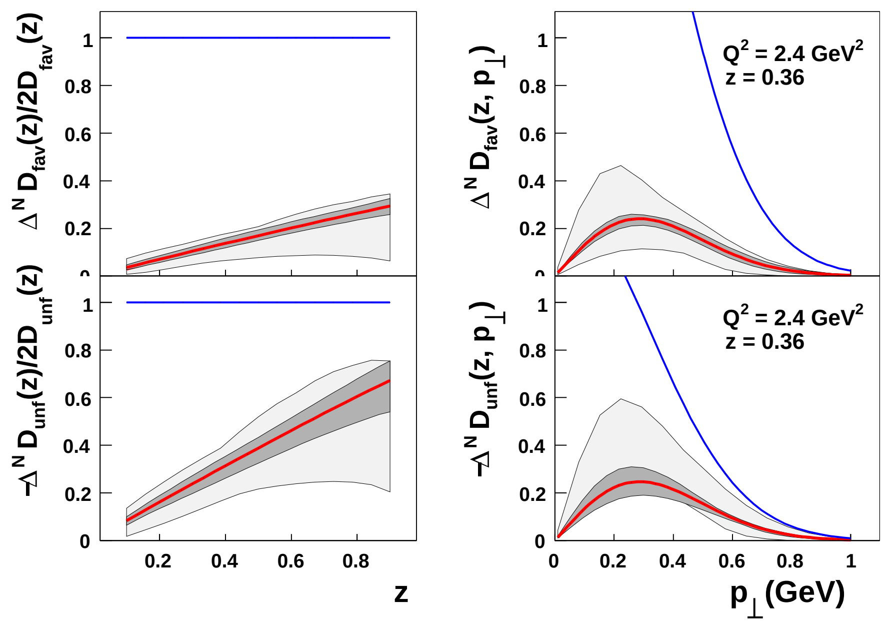
Anselmino et al., Eur.Phys.J.A39:89-100,2009

Transversity and Collins functions

◇ Transversity: u and d

◇ Collins functions: favored and unfavored

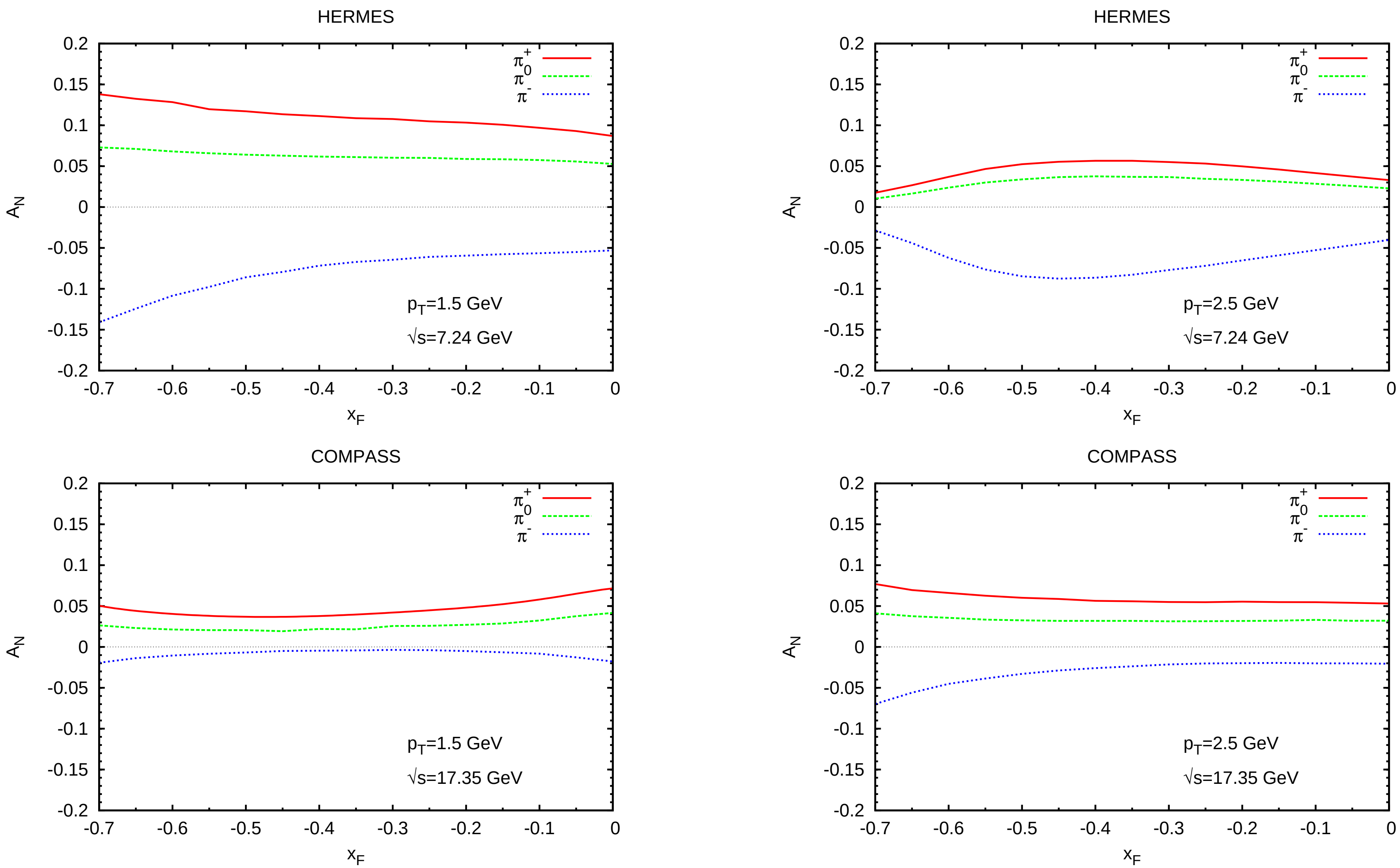




Anselmino et al., ArXiv:0812.4366v1

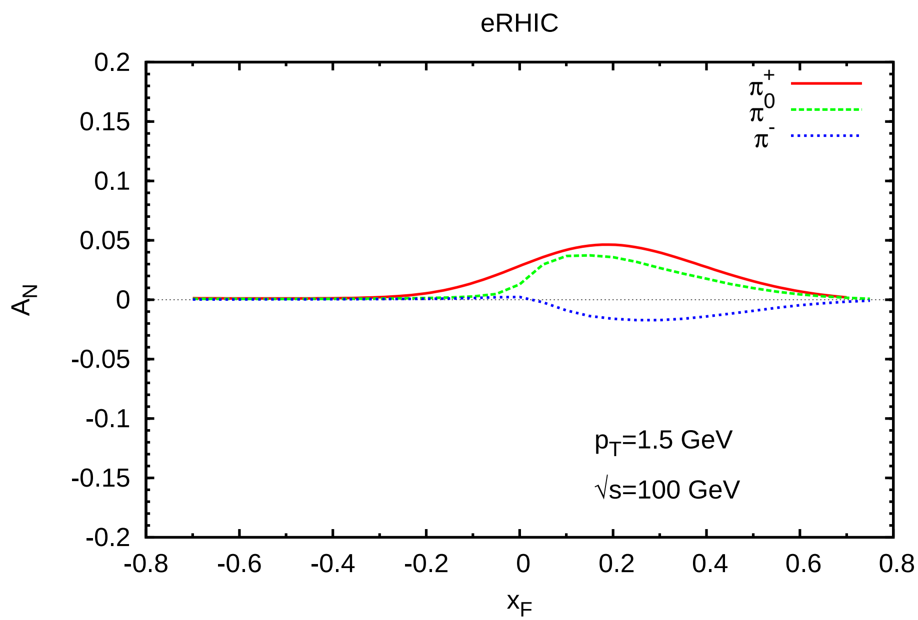
Sivers Effect at HERMES and COMPASS:

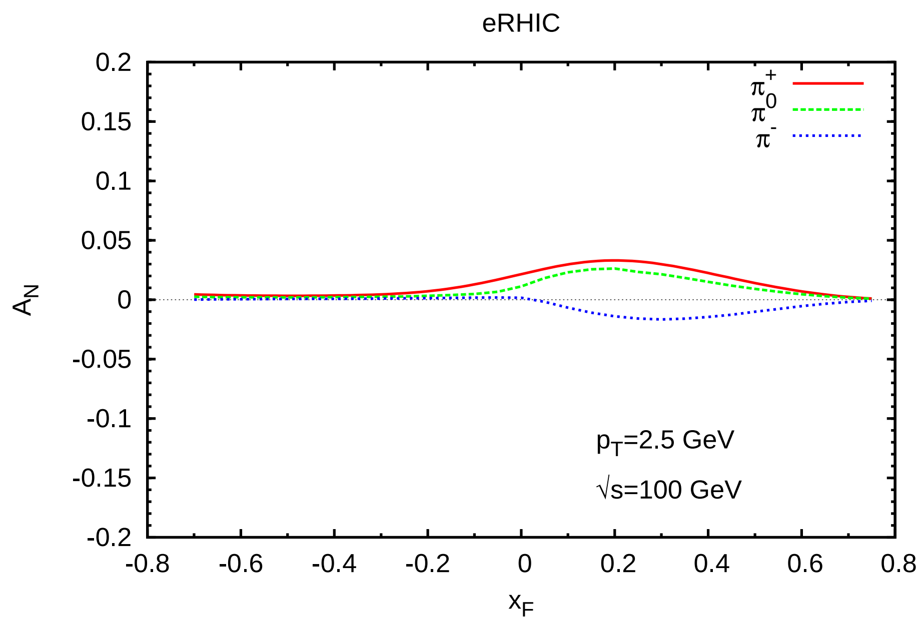
- Sivers effect



Sivers Effect at eRHIC:

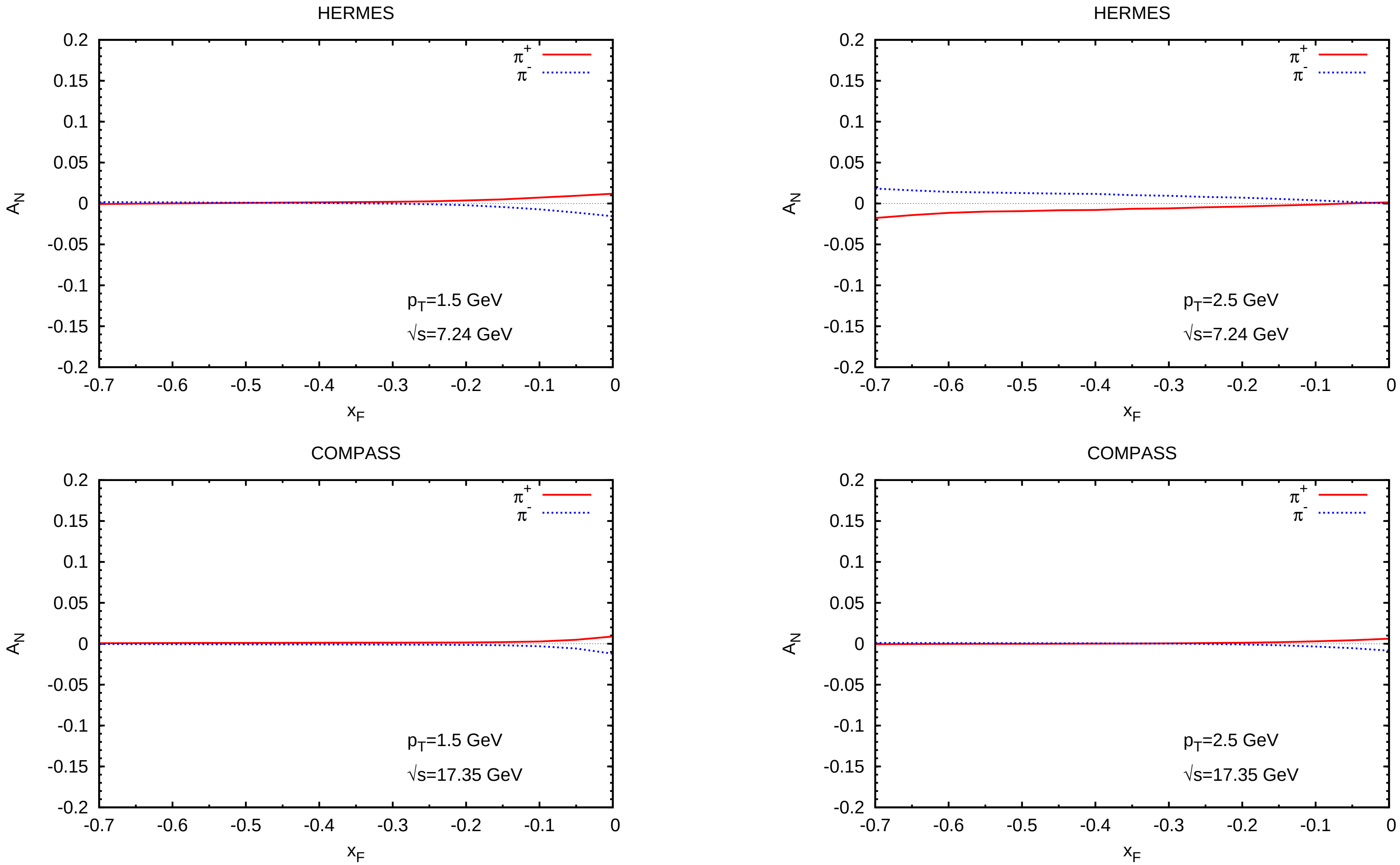
- Sivers effect





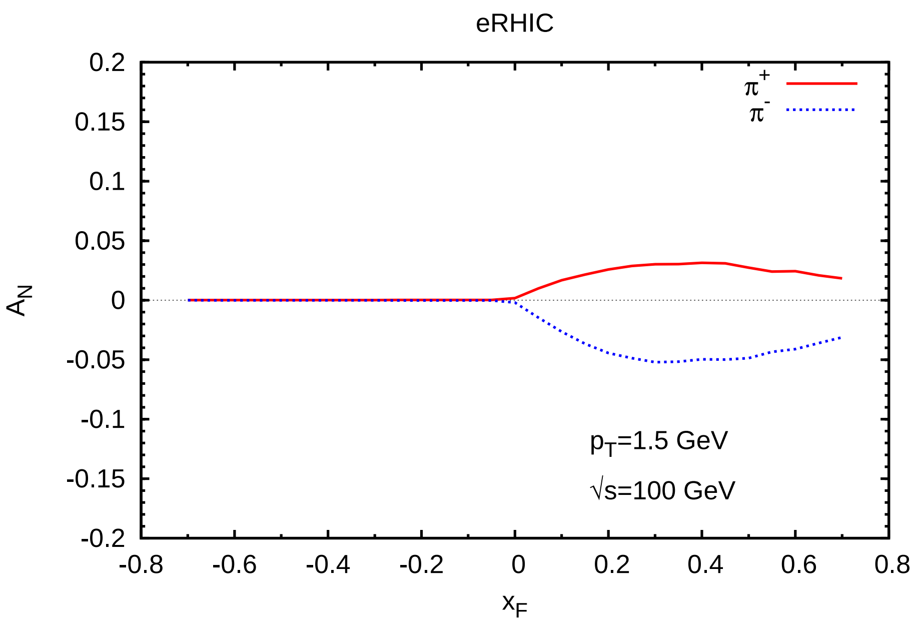
Collins Effect at HERMES and COMPASS:

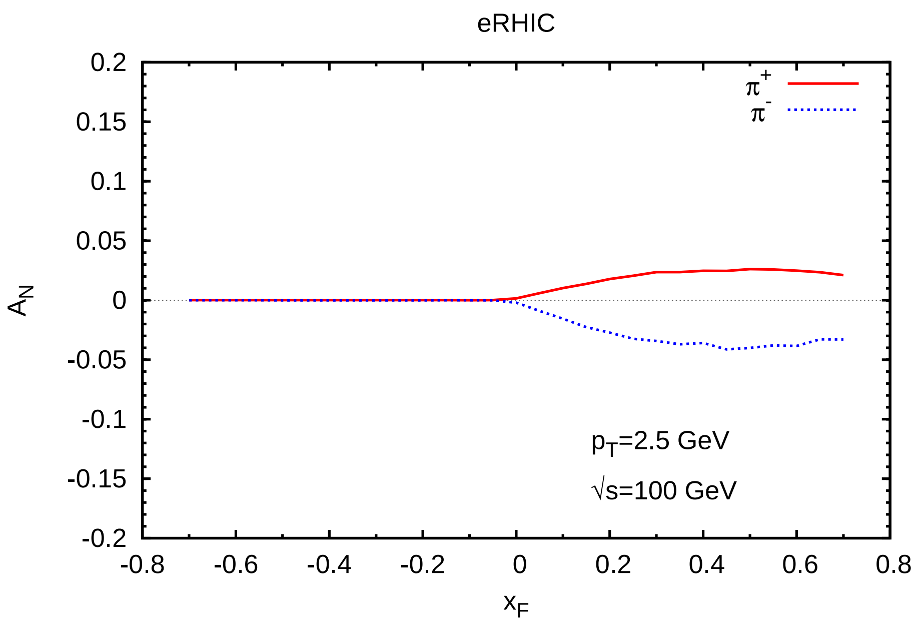
- Collins effect



Collins Effect at eRHIC:

➢ Collins effect





Summary and Conclusions

- Inclusive hadron production in $p^{\uparrow} l$ scattering
- Factorization assumed: experimental test
- Different kinematical regions covered with respect to SIDIS
- Sivers effect can be large
- Transversity$\otimes$ Collins effect small in some kinematical regions
- ...only preliminary results

Parametrizations:

➢ We assume a factorized gaussian smearing for the unpolarized PDF and FF:

$$\diamond\, f_{q/p}(x,k_\perp) = f_q(x)\,\frac{1}{\pi\langle k_\perp^2\rangle}\,e^{-k_\perp^2/\langle k_\perp^2\rangle} \qquad \diamond\, D_q^h(z,p_\perp) = D_q^h(z)\,\frac{1}{\pi\langle p_\perp^2\rangle}\,e^{-p_\perp^2/\langle p_\perp^2\rangle}$$

$$\langle k_\perp^2\rangle = 0.25\ (\mathrm{GeV}/c)^2 \qquad \langle p_\perp^2\rangle = 0.20\ (\mathrm{GeV}/c)^2\ .$$

$\langle k_\perp^2\rangle$ and $\langle p_\perp^2\rangle$ fixed as found in Ref. [1] by analysing the Cahn effect.

➢ Similarly for the Sivers function:

$$\Delta^N f_{q/p^\uparrow}(x,k_\perp) = 2\,\mathcal{N}_q(x)\,h(k_\perp)\,f_{q/p}(x,k_\perp)$$

$$\mathcal{N}_q(x) = N_q\,x^{\alpha_q}(1-x)^{\beta_q}\,\frac{(\alpha_q+\beta_q)^{(\alpha_q+\beta_q)}}{\alpha_q^{\alpha_q}\,\beta_q^{\beta_q}} \le 1\,, \quad h(k_\perp) = \sqrt{2e}\,\frac{k_\perp}{M_1}\,e^{-k_\perp^2/M_1^2} \le 1\,,$$

where N_q, α_q, β_q and M_1 (GeV/c) are free parameters

Fit of HERMES & COMPASS SIDIS data: Sivers functions

- GRV98 set for PDF's
- DSS set for FF's
- $\langle k_\perp^2 \rangle$ and $\langle p_\perp^2 \rangle$ from the Cahn Effect

$$\Delta^N f_{q/p^\uparrow}(x,k_\perp) = 2\,\mathcal{N}_q(x)\,h(k_\perp)\,f_{q/p}(x,k_\perp)$$

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

$$h(k_\perp) = \sqrt{2e}\,\frac{k_\perp}{M_1}\,e^{-k_\perp^2/M_1^2}$$

➢ "Broken sea" ansatz, 11 free parameters:

N_u N_d

$N_{\bar{u}}$ $N_{\bar{d}}$

N_s $N_{\bar{s}}$

α_u α_d α_{sea}

β M_1

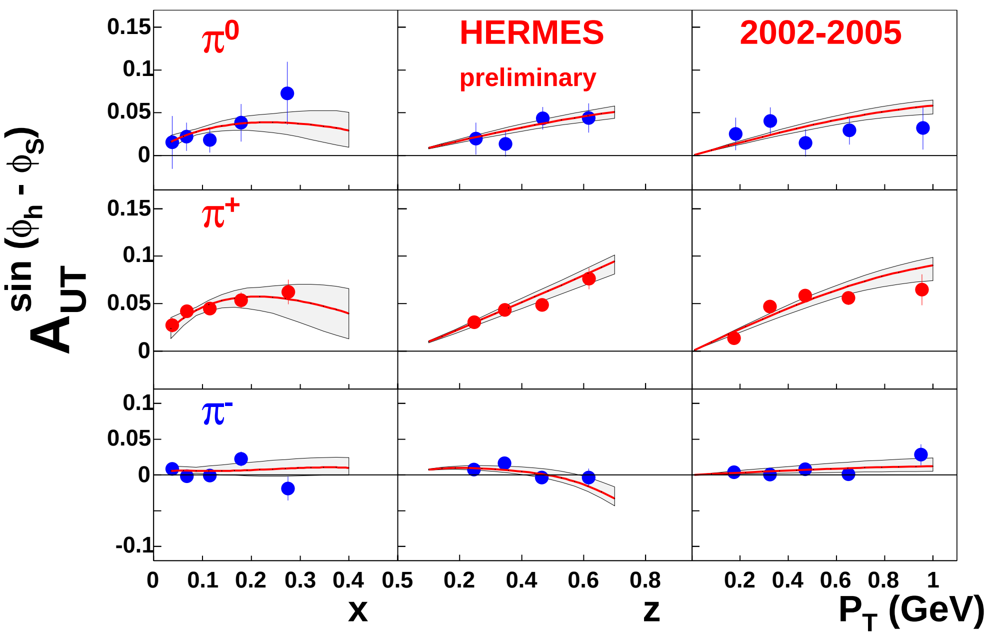
$\chi^2/d.o.f = 1$		
$N_u = 0.35^{+0.078}_{-0.079}$	$N_d = -0.9^{+0.43}_{-0.098}$	$N_s = -0.24^{+0.62}_{-0.5}$
$N_{\bar{u}} = 0.037^{+0.22}_{-0.24}$	$N_{\bar{d}} = -0.4^{+0.33}_{-0.44}$	$N_{\bar{s}} = 1^{+0}_{-0.0001}$
$\alpha_u = 0.73^{+0.72}_{-0.58}$	$\alpha_d = 1.1^{+0.82}_{-0.65}$	$\alpha_{sea} = 0.79^{+0.56}_{-0.47}$
$\beta = 3.5^{+4.9}_{-2.9}$	$M_1^2 = 0.34^{+0.3}_{-0.16}$ GeV^2	

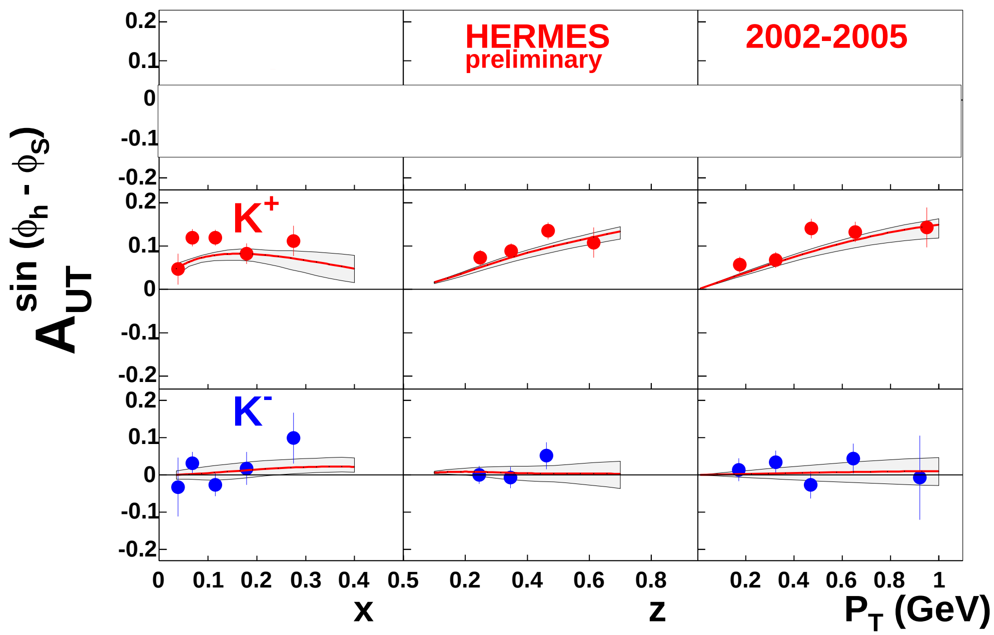
Anselmino et al., Eur.Phys.J.A39:89-100,2009

Fit: HERMES data

➢ HERMES data◇ fit

$ep \to e\pi X$ $p_{lab} = 27.57$ GeV/c $ep \to eKX$



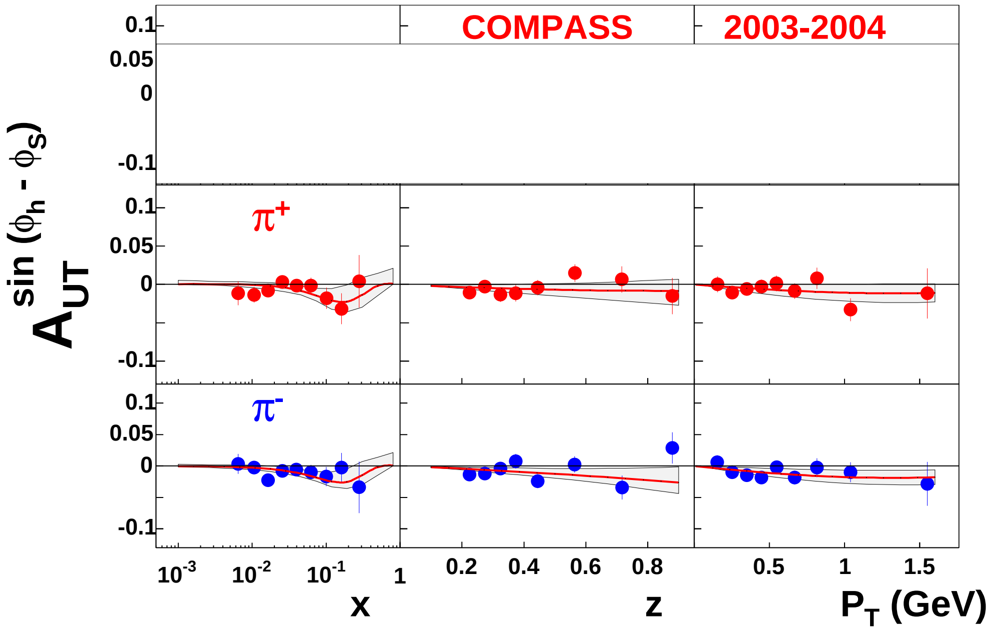


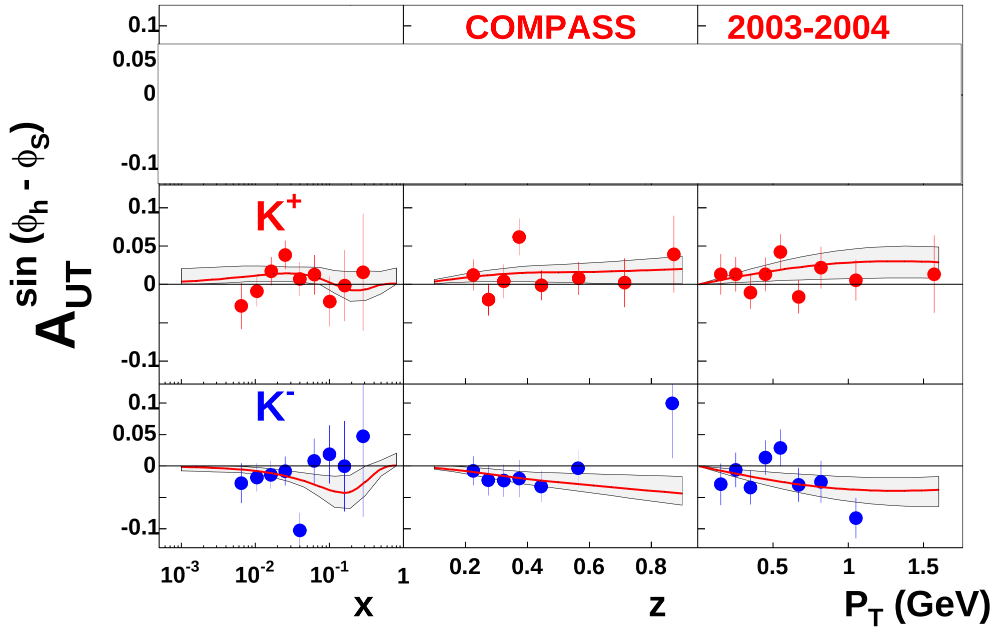
◇ Diefenthaler, hep-ex/0612010 (2006)

Fit: COMPASS data

➢ COMPASS data◇ fit

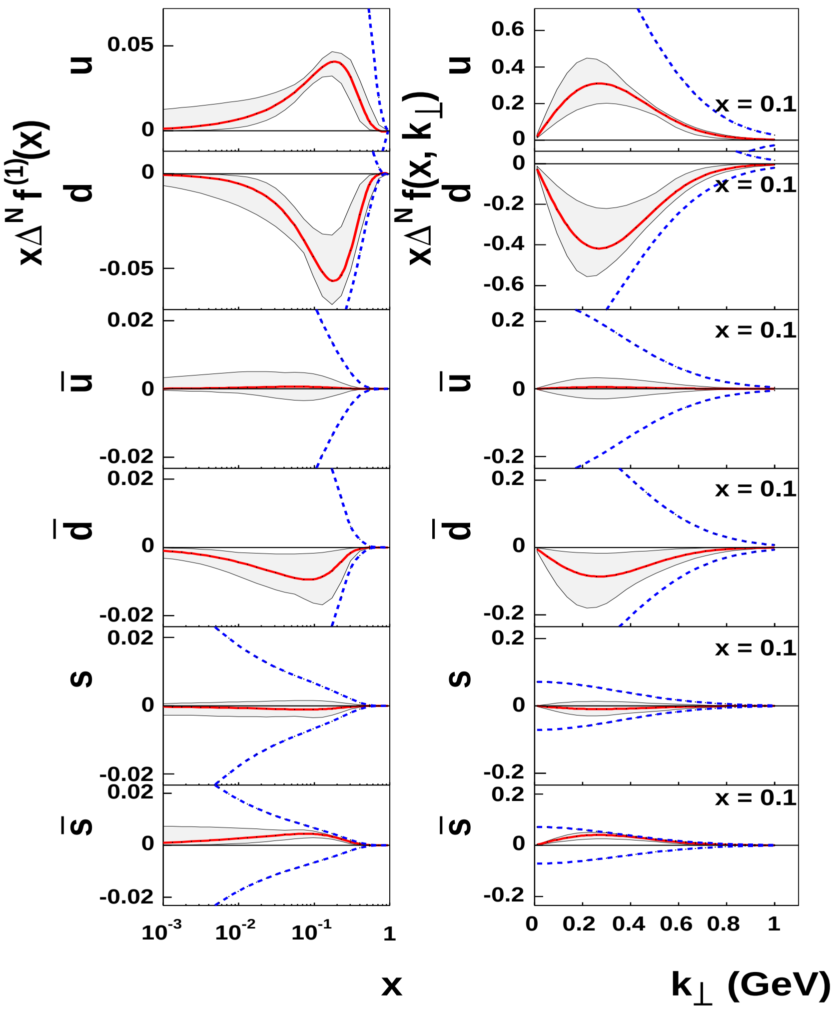
$\mu D \to \mu \pi X$ $\qquad p_{lab} = 160$ GeV/c $\qquad \mu D \to \mu K X$





◇ A. Martin (COMPASS), Czech. J. Phys. 56, F33 (2006)

First moment of the Sivers functions



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Parametrizations of the Transversity and the Collins function

➢ We assume a factorized gaussian smearing for $\Delta_T q(x)$ and $\Delta^N D_{\pi/q^\uparrow}$:

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

$$\diamond\ \Delta^N D_{\pi/q^\uparrow}(z, p_\perp) = 2\mathcal{N}_q^C(z)\,h(p_\perp)\,D_{\pi/q}(z)\,\frac{1}{\pi\langle p_\perp^2\rangle}\,e^{-p_\perp^2/\langle p_\perp^2\rangle}$$

where:

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

$$\mathcal{N}_q^C(x) = N_q^C\,x^{\gamma}(1-x)^{\delta}\,\frac{(\gamma+\delta)^{(\gamma+\delta)}}{\gamma^{\gamma}\,\delta^{\delta}} \qquad h(p_\perp) = \sqrt{2e}\,\frac{p_\perp}{M_h}\,e^{-p_\perp^2/M_h^2}$$

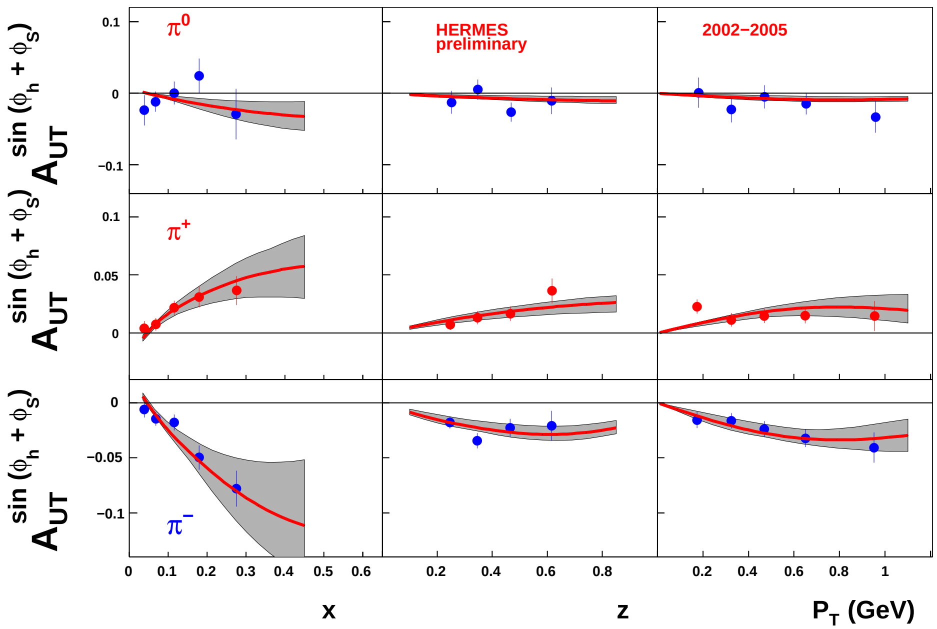
$N_u^T = 0.64 \pm 0.34$	$N_d^T = -1.00 \pm 0.02$
$\alpha = 0.73 \pm 0.51$	$\beta = 0.84 \pm 2.30$
$N_{fav}^C = 0.44 \pm 0.07$	$N_{unf}^C = -1.00 \pm 0.06$
$\gamma = 0.96 \pm 0.08$	$\delta = 0.01 \pm 0.05$
$M_h^2 = 0.91 \pm 0.52\ \mathrm{GeV}^2$	

Anselmino et al., ArXiv:0812.4366v1

Fit: HERMES & COMPASS data

➢ HERMES data◇ fit

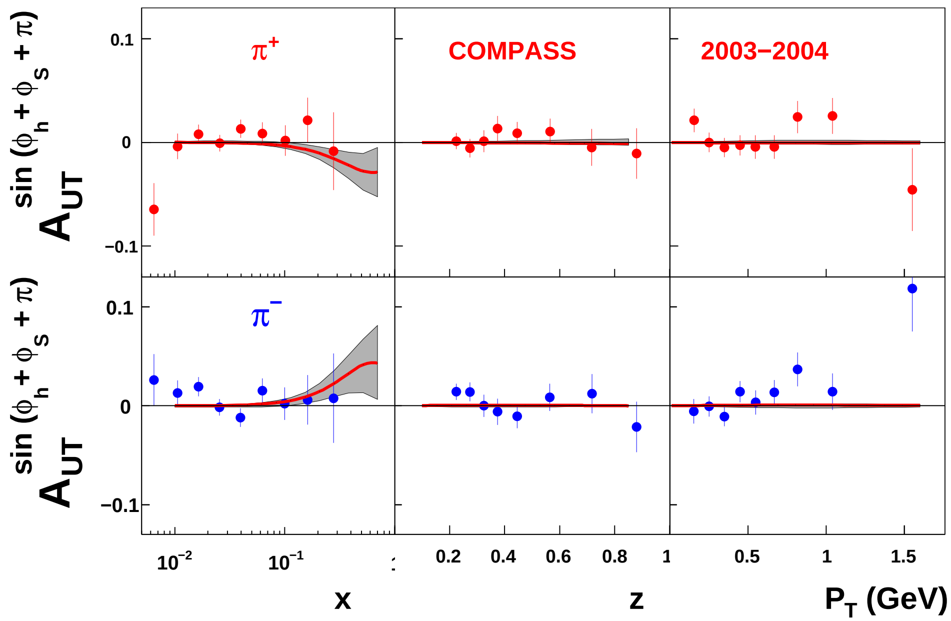
$ep \to e\pi X \qquad p_{lab} = 27.57$ GeV/c



◇ M. Diefenthaler, (2007),arXiv:0706.2242

➢ COMPASS data◇ fit

$\mu D \to \mu\pi X \qquad p_{lab} = 160$ GeV/c

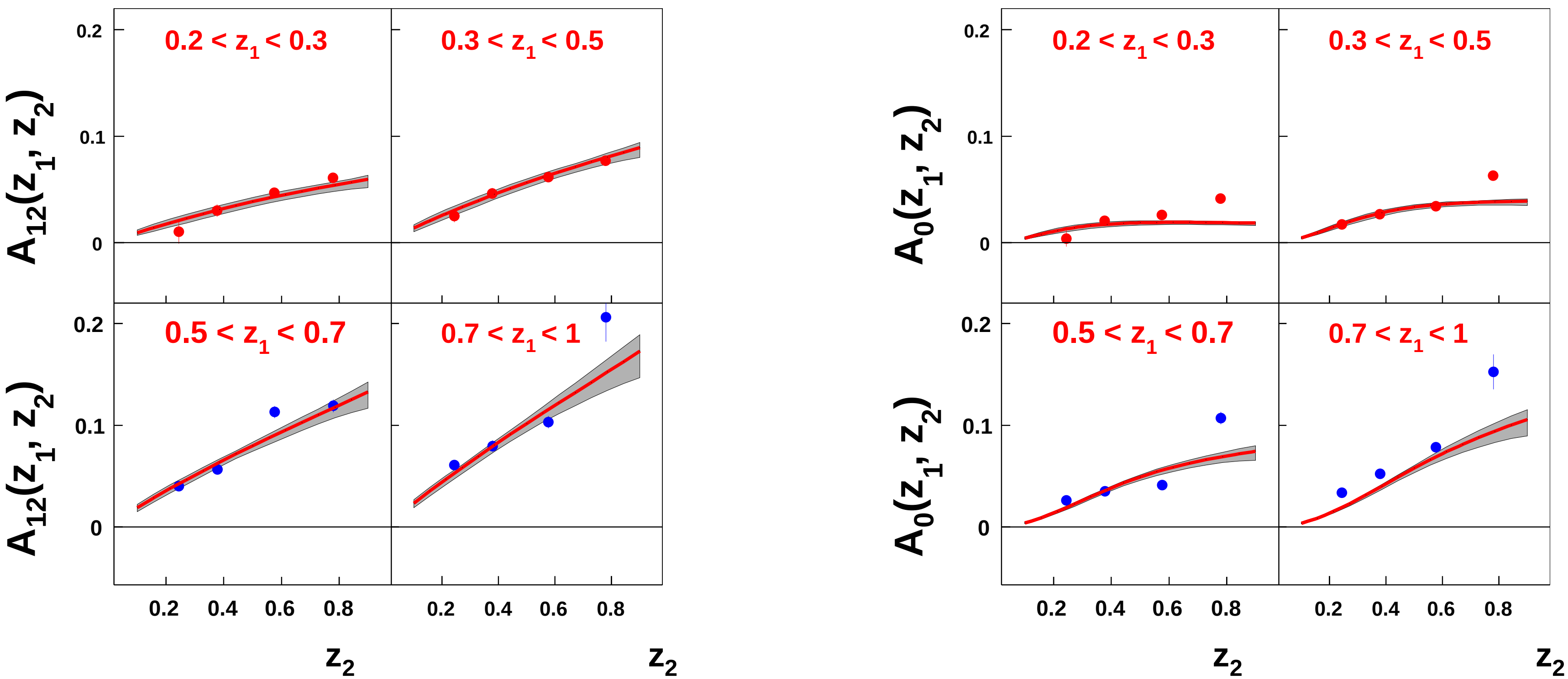


◇ M. Alekseev et al., (2008), arXiv:0802.2160

Fit: BELLE data

➢ BELLE data[◇] fit

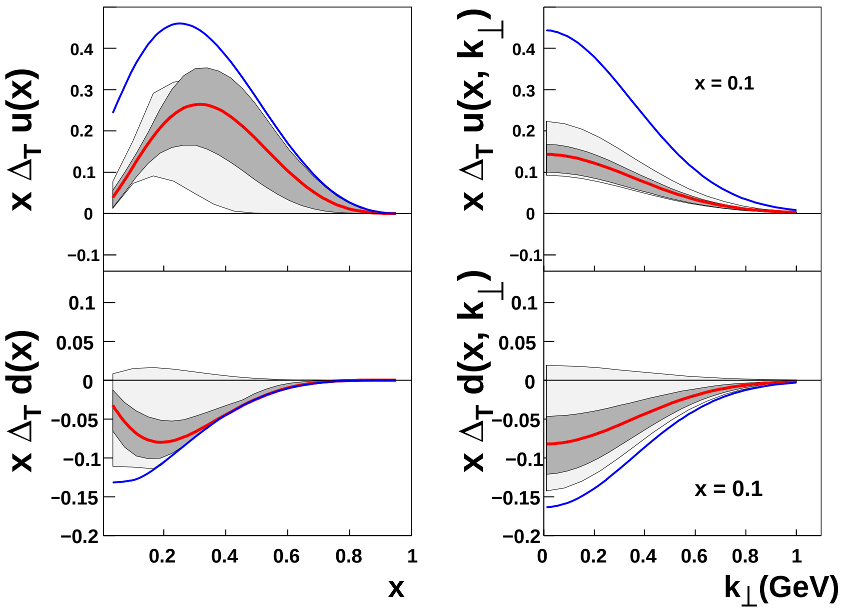
$e^+e^- \to \pi\pi X$ $\qquad$ $\sqrt{s} = 10.58$ GeV/c



◇ R. Seidl et al., Phys. Rev. D78

Transversity and Collins functions

Transversity: u and d



Collins functions: favored and unfavored