On the potential role of Collins effect in A_N in $pp \to \pi X$ processes

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Outline

- SSAs in $pp \to hX$: experimental status and theoretical approaches
- Twist-3 vs. TMD approach
- Reconsideration of the Collins effect in pp collisions
- Results and consequences
- Open issues

Motivations:

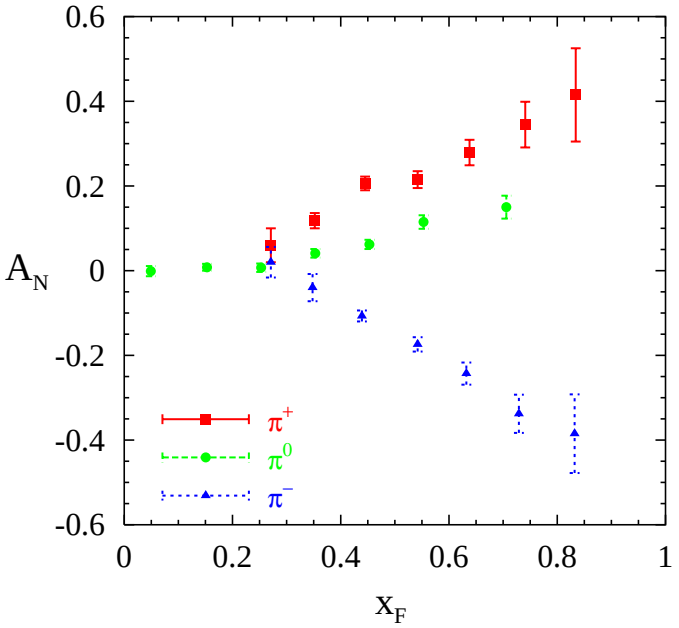
- sign correction in one partonic channel [Transversity 2008]
  suppression of the Collins effect [*Anselmino et al. 05*] REVISED!

- use of phenomenological information gathered from SIDIS and e^+e^- data
  role of Collins effect in A_N in $pp \to \pi\, X$

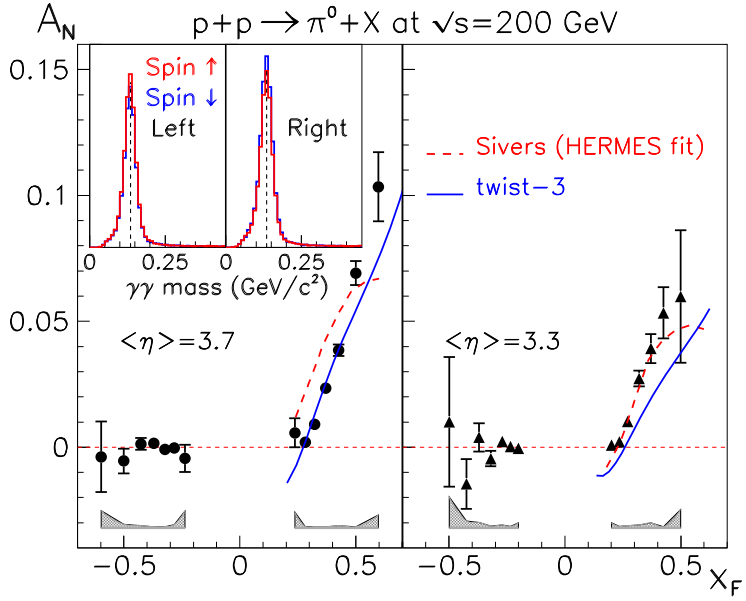
- sign mismatch issue
  Twist-3 qgq-correlation funct. from SIDIS Sivers funct.: wrong sign in A_N

SSAs in $p^{\uparrow}p \to h + X$

$A_N \equiv \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$ still challenging $\qquad x_F = 2p_L/\sqrt{s}$



$\sqrt{s} = 20$ GeV [*E704 coll. (1991)*]



$\sqrt{s} = 200$ GeV [*STAR coll. (2008)*]

- A_N: sizeable at large rapidity, increasing with x_F and P_T (RHIC)

- collinear pQCD factorization at twist-3:
  universal quark-gluon-quark correlators, $T_q(x,x)$
  [Efremov-Teryaev 82,85; Qiu-Sterman 91,92,98; Kouvaris et al. 06; Kanazawa- Koike 00,10; Kang et al. 11]

- Generalized Parton Model (GPM): TMDs (*assuming* factorization)
  [Anselmino-Boglione-Murgia 95, Anselmino et al. 06; UD-Murgia 04,08]
  Description of A_N by TMDs from SIDIS? *[Boglione-UD-Murgia 08]*

Twist-3 approach

Three contributions to A_N (schematic view)

$\Phi^{(3)}_{q/p^\uparrow} \otimes f_{q/p} \otimes \sigma \otimes D_{h/q}$ ✓ able to describe A_N [*Kouvaris et al. 06*]

$\Delta_T q \otimes \Phi^{(3)}_{q^\uparrow/p} \otimes \sigma' \otimes D_{h/q}$ ✓ negligible [*Kanazawa-Koike 00*]

$f_{q/p} \otimes \Delta_T q \otimes \sigma'' \otimes D^{(3)}_{h/q^\uparrow}$ **?** likely large, under study [*Kang-Yuan-Zhou 10*]

Notice:

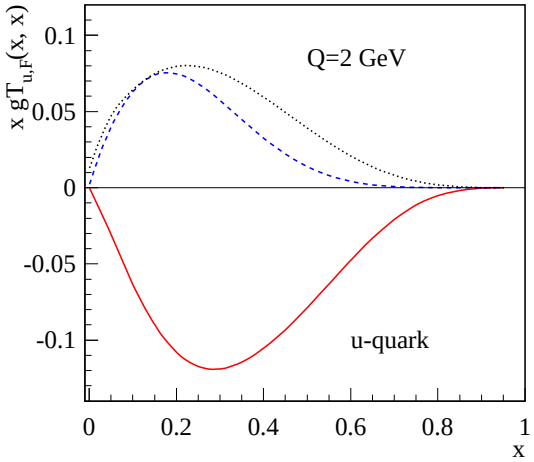
- $\Phi^{(3)}_{q/p^\uparrow} \to T_q(x,x)$ Efremov-Teryaev-Qiu-Sterman correlation function

- Correction of an overall sign in the definition of gT_q *[Kang et al. 11]*

The sign mismatch issue

Link between Sivers and ETQS functions *[Boer-Mulders-Piljman 03]*

$$\int d^2\boldsymbol{k}_\perp \left(\frac{\boldsymbol{k}_\perp^2}{M}\right) f_{1T}^{\perp q}(x, \boldsymbol{k}_\perp^2)|_{\rm SIDIS} = -g\, T_q(x,x)$$



T_q from pp vs. T_q via $f_{1T}^\perp$

★ sign mismatch! *Kang et al. '11*

solutions?:
- node in x [*Kang-Prokudin 12*] and/or in $k_\perp$ (likely ruled out)
- study of A_N in $lp \to l'X$ via $q\gamma q \Longleftrightarrow qgq$ correlators [*Metz et al. 12*] $\to T_q$
- additional twist-3 effects?

still an open an intriguing issue!

TMD approach

Many contributions from nonplanar partonic kinematics (helicity formalism)

[*Anselmino et al. 06*]

$\Delta^N f_{q/p\uparrow} \cos\phi_q \otimes f_{q/p} \otimes \sigma \otimes D$ Sivers effect ($f_{1T}^{\perp}$)

$\Delta_T q \otimes \Delta^N f_{q\uparrow/p} \sigma' \otimes D_{h/q} \cos\psi'$ Boer-Mulders effect ($h_1^{\perp}$)

$\Delta_T q \otimes f_{q/p} \otimes \sigma'' \otimes \Delta^N D_{h/q\uparrow} \cos\psi''$ Collins effect ($H_1^{\perp}$)

plus others and plus contributions from gluon TMDs

$\otimes$: convolutions on x, $\boldsymbol{k}_\perp$; ψ's *complicate* calculable azimuthal phases

Only Sivers and Collins effects survive under integration over angular depend.s

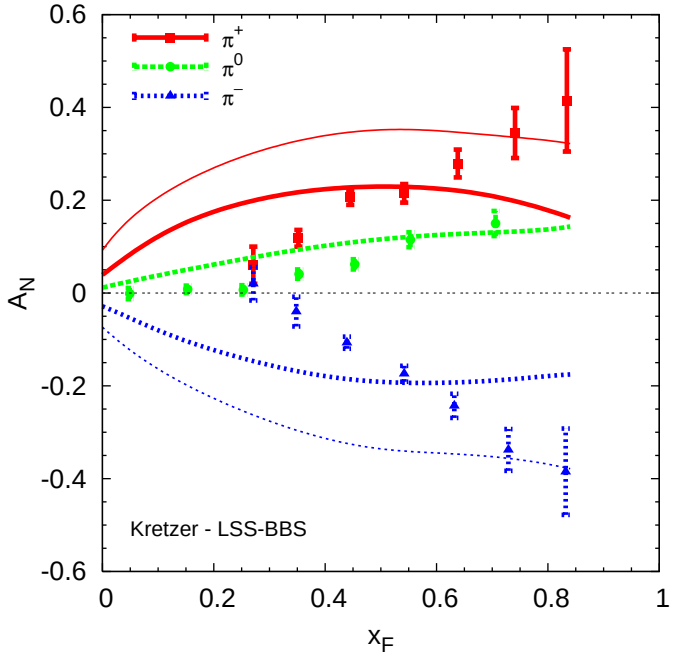
Here we revise* a previous statement on the suppression of the Collins effect.
*thanks to Yuan 08

impact of the sign correction

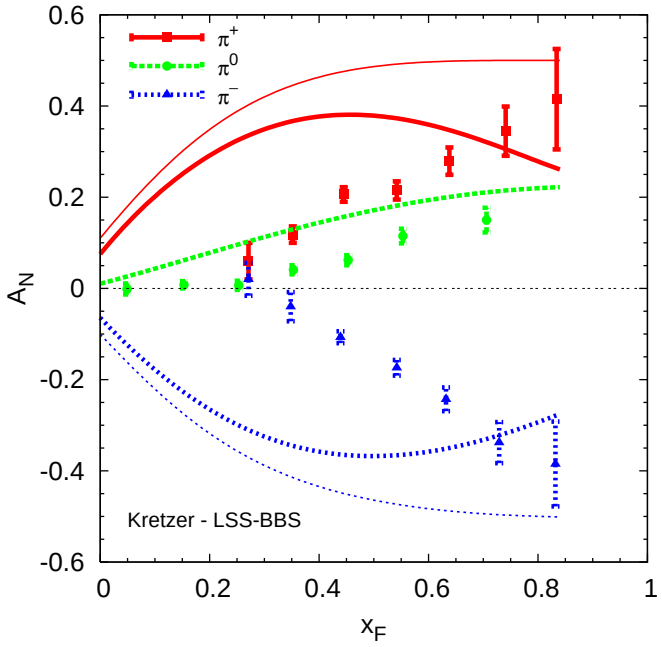
- wrong sign in the spin transfer for $qg \to qg$: one of the most important channels

- relative cancelation with other channels: $qq \to qq$ and $q\bar{q} \to q\bar{q}$.

An example (E704, $\sqrt{s} = 20$ GeV, saturating all positivity bounds)



Wrong sign



corrected

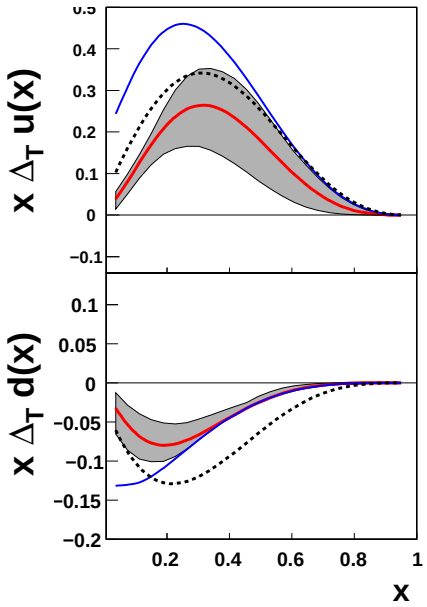
Phenomenology

- use of available information on the Collins effect from SIDIS and e^+e^- data

- global fit not worth at this stage (non separable effects in pp)

- universality of the Collins function [*Collins-Metz 04, Yuan 08*]

- $\Delta_T q$ not constrained at large x (SIDIS data $x \leq 0.3$) relevant for A_N at large x_F



Present status - large error bands

large x behaviour $\simeq (1-x)^{\beta}$ with
SIDIS-1 $\beta = 4.74 \pm 5.45$ [*Anselmino et al. 07*]
SIDIS-2 $\beta = 0.84 \pm 2.30$ [*Anselmino et al. 09*]

Let's focus on the large x behaviour of transversity.

$$\Delta_T q(x,k_\perp) \simeq N_q^T\, x^{\alpha_q}\,(1-x)^{\beta_q}\,\frac{[q(x)+\Delta q(x)]}{2}\,g(k_\perp) \qquad q=u,d$$

$$\Delta^N D_{\pi/q^\uparrow}(x,p_\perp) \simeq N_q^C\, z^{\gamma_q}\,(1-z)^{\delta_q}\,2D_{\pi/q}(z)\,h(p_\perp/M_h)$$

- use of isospin symmetry in FFs and only favoured and unfavoured FFs

- flavour independence for α, γ, δ, except β_q

- $\delta = 0$ (consistent with all previous fits)

- proper evolution for $\Delta_T q$, unpolarized-like one for $\Delta^N D$

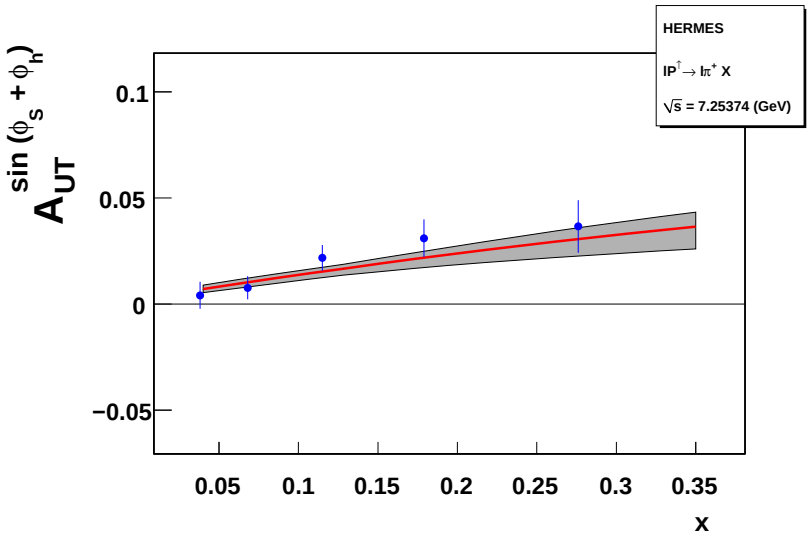
- use of two sets of FFs: [*Kretzer 00, de Florian-Sassot-Stratmann 07*]

9 parameters to be fitted: $N_u^T,\ N_d^T,\ N_{\rm fav}^C,\ N_{\rm unf}^C,\ \alpha,\ \beta_u,\ \beta_d,\ \gamma, M_h$.

Scan Procedure

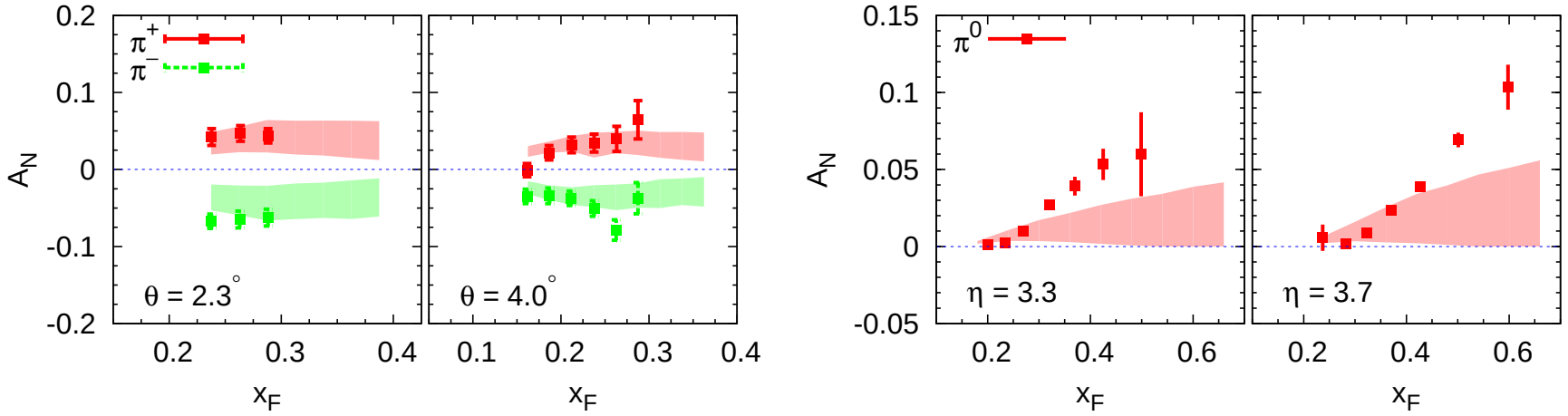
I step

1. 9-parameter reference fit on SIDIS (HERMES, COMPASS) and e^+e^- (Belle) data
2. grid (scan) of the parameters, β_u, β_d within the range (0.0-4.0)
3. 7-parameter fit to SIDIS and e^+e^- data adopting the β_q-grid
4. selection via $\chi^2_{\rm scan} \leq \chi^2_{\rm min} + \Delta\chi^2|_{\rm ref.fit}$ (stat. uncert. band) [fulfilled by all fits]
5. computation of Collins pion SSA for pp collisions



example of the fit with β fixed:
scan band on HERMES π^+ data

Results



BRAHMS@RHIC 2007 $\sqrt{s} = 200$ GeV STAR@RHIC 2008

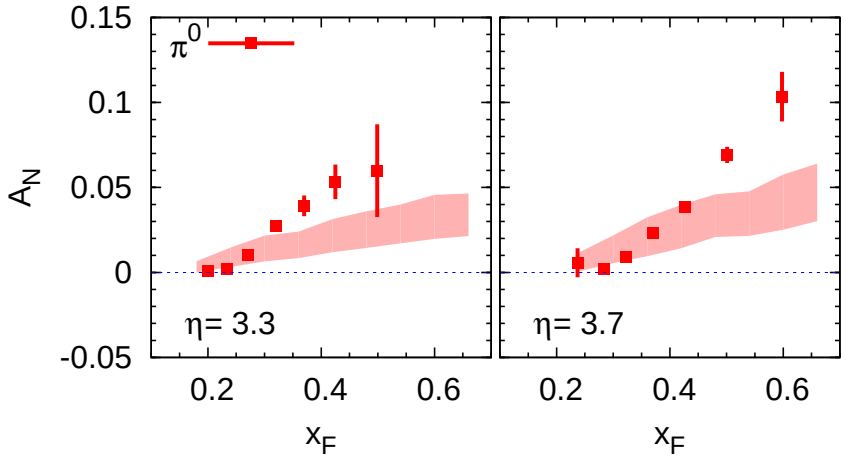
Envelope curves (scan band) of the Collins contribution

able to describe A_N for charged pions, but not the large-x_F neutral pion SSA data

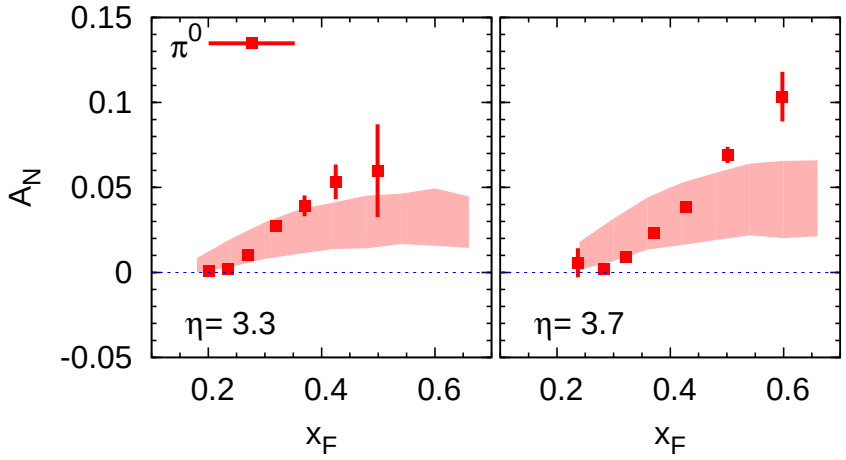
II step: further tests

1. best curve and computation of its statistical error band (π^0-STAR)
2. allowance for flavour depend. of α, γ, δ and back to I (all parameters free: 13)
3. also tried: a transversity-like evolution for the Collins function (not relevant)

Statistical uncertainty bands



flavour-independent par.



free parameters

$\nexists$ a single curve *good* at low and large x_F

Same conclusions for E704 data at $\sqrt{s} = 20$ GeV

Conclusions

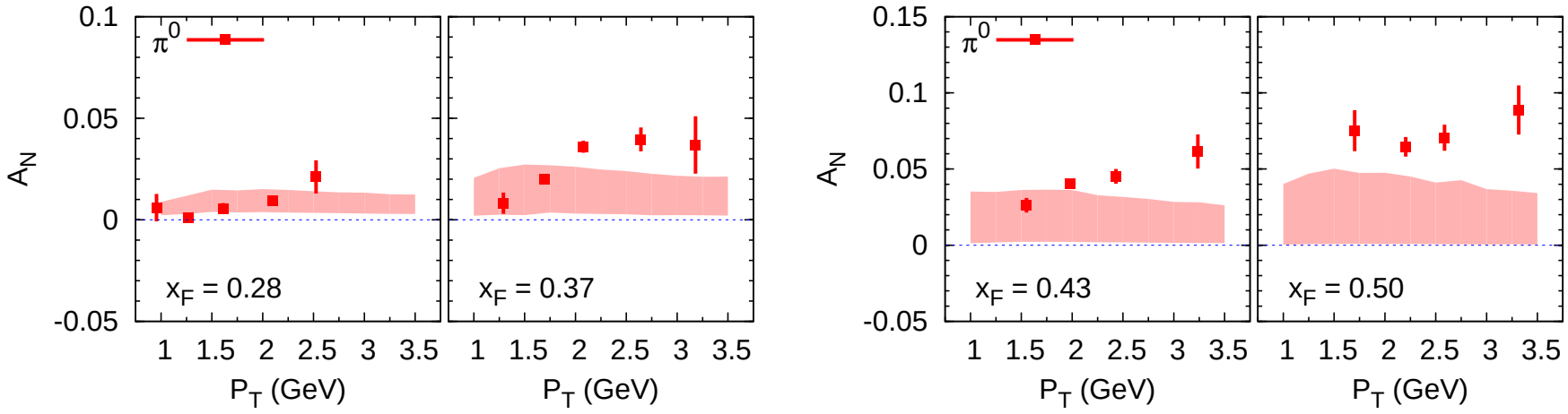
- SSAs in pp collisions: addressed within a TMD factorization scheme

- The Collins effect, corrected, is sizeable
  1. able to reproduce the low x_F RHIC data.
  2. not sufficient at large x_F, where A_N increases

- Additional mechanisms are required: the Sivers effect? But how? Universality?
  1. Its twist-3 counterpart gives sizeable A_N but wrong in sign
  2. including Initial-final interactions results into a "wrong" sign [*Gamberg-Kang 11*]
  3. A *direct* use of SIDIS Sivers functions goes in the right direction (under study)

SSAs in $pp \to hX$: too nice and too large to be left unexplained

Back-up slides



STAR@RHIC: A_N vs. p_T for different x_F bins.

Flavour dependence

$h_1^d < 0$ and $\Delta^N D_{\rm unf} < 0$:

$$A_N(\pi^+) \sim h_1^u \Delta^N D_{\rm fav} + h_1^d \Delta^N D_{\rm unf} = h_1^u \Delta^N D_{\rm fav} + |h_1^d||\Delta^N D_{\rm unf}| > 0$$

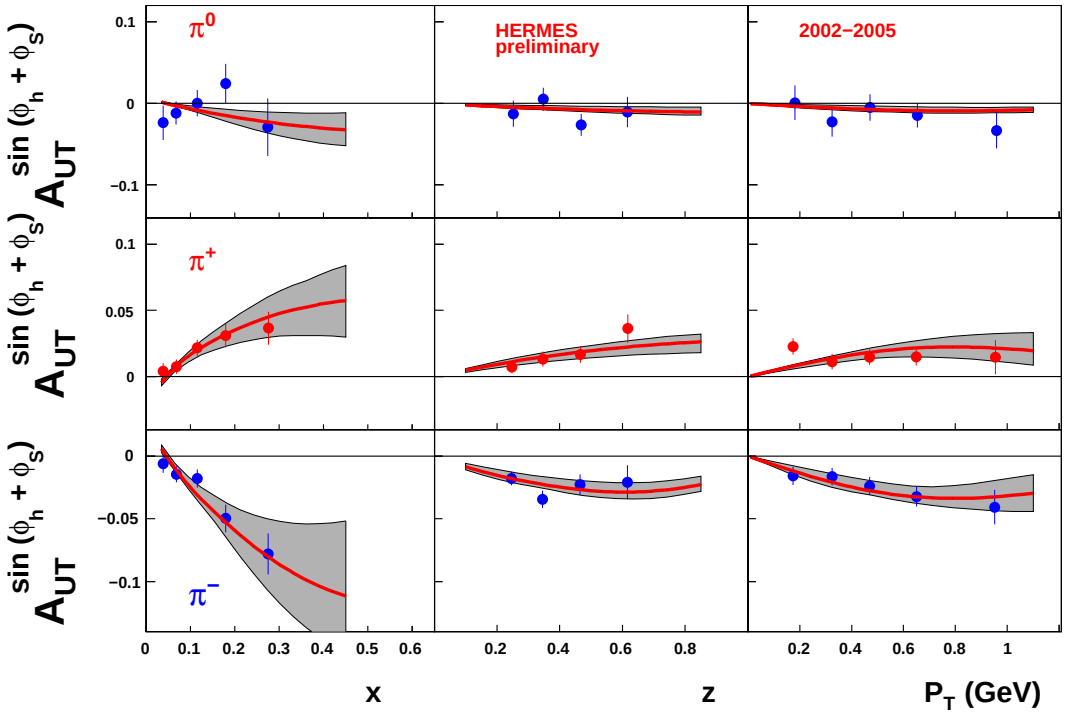
$$A_N(\pi^-) \sim h_1^u \Delta^N D_{\rm unf} + h_1^d \Delta^N D_{\rm fav} = -h_1^u |\Delta^N D_{\rm unf}| - |h_1^d| \Delta^N D_{\rm fav} < 0$$

$$A_N(\pi^0) \sim (h_1^u + h_1^d)\frac{1}{2}\left[\Delta^N D_{\rm fav} + \Delta^N D_{\rm unf}\right] = \left[h_1^u - |h_1^d|\right]\frac{1}{2}\left[\Delta^N D_{\rm fav} - |\Delta^N D_{\rm unf}|\right]$$

- up and down terms add in sign in $A_N(\pi^\pm)$ while

- cancel each other in $A_N(\pi^0)$

Notice: if $\Delta^N D_{\rm unf} \simeq -\Delta^N D_{\rm fav} \Rightarrow A_N^{\rm Collins}(\pi^0) \simeq 0$



fit to HERMES data and statistical uncertainty band [*Anselmino et al. 09*]

Statistical error band

$$\chi^2 = \sum_{i=1}^{N} \left(\frac{y_i - F(x_i; \boldsymbol{a})}{\sigma_i} \right)^2$$

- N measurements y_i at known points x_i, with variance σ_i^2.
- $F(x_i; \boldsymbol{a})$ depends *non-linearly* on M unknown parameters a_i.
- Best fit: $\chi^2_{\rm min} \to \boldsymbol{a}_0$

Error band: all sets of parameters such that $\chi^2(\boldsymbol{a}_j) \leq \chi^2_{\rm min} + \Delta\chi^2$
- $\Delta\chi^2 = 1 \leftrightarrow 1\text{-}\sigma$: small errors, uncorrelated parameters, linearity, χ^2 parabolic
- $\Delta\chi^2$: fixed according to the coverage probability

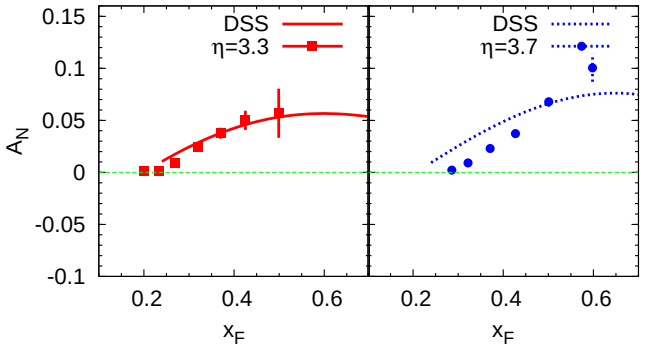
$$P = \int_0^{\Delta\chi^2} \frac{1}{2\Gamma(M/2)} \left(\frac{\chi^2}{2} \right)^{(M/2)-1} \exp\left(-\frac{\chi^2}{2} \right) {\rm d}\chi^2$$

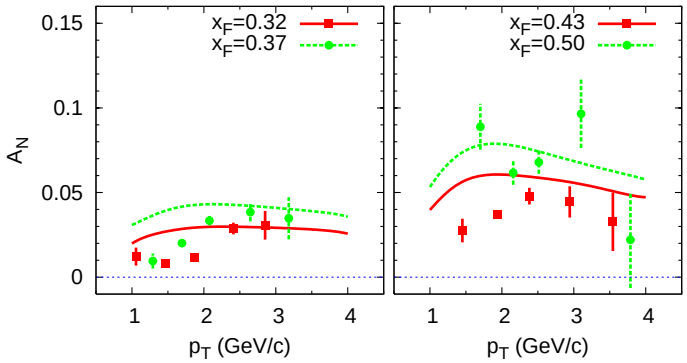
P= probability that true set of parameters falls inside the M-hypervolume

$[P = 0.68 \leftrightarrow 1\text{-}\sigma,\ P = 0.95 \leftrightarrow 2\text{-}\sigma]$

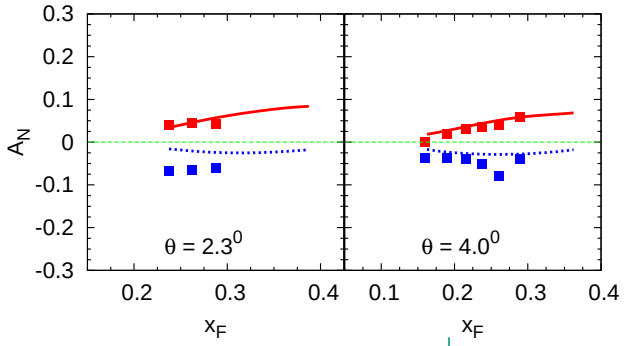
Sivers effect: scan procedure

Sivers functions from SIDIS ($\chi_{\rm dof} \simeq 1.2\chi_{\rm min}$ & DSS) preliminary



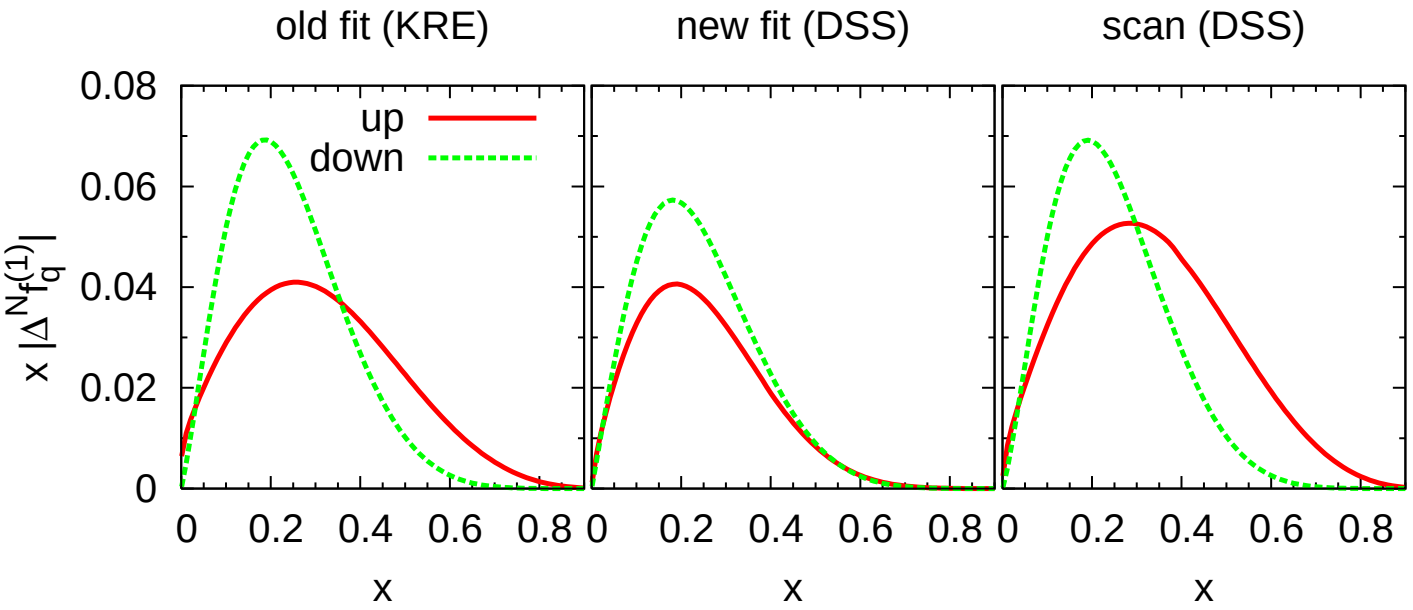


STAR π^0



BRAHMS $\pi^{\pm}$

Sivers functions



First moment of the Sivers function for up and down quarks