Sivers and Collins effects: from SIDIS to proton-proton scattering

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A (complicated) work in progress …

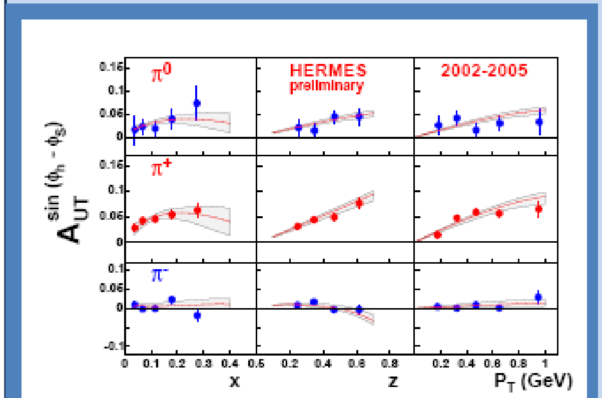
… based on a simple idea

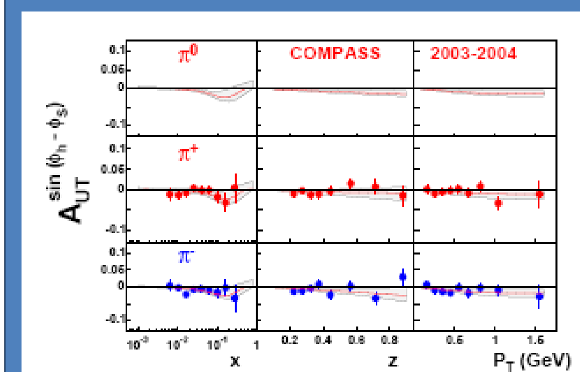
- STEP ONE: take Sivers, transversity and Collins functions as extracted from fitting SIDIS and $e^+e^- \to h_1h_2X$ processes, in a non collinear, factorized pQCD scheme

- STEP TWO: Assuming a similar scheme, use them to calculate single spin asymmetries in polarized proton-proton scattering

SIDIS and e^+e^- scattering experimental data allow us to extract the transversity and Sivers distribution functions, and the Collins fragmentation function

- Sivers azimuthal asymmetry from HERMES and COMPASS data:





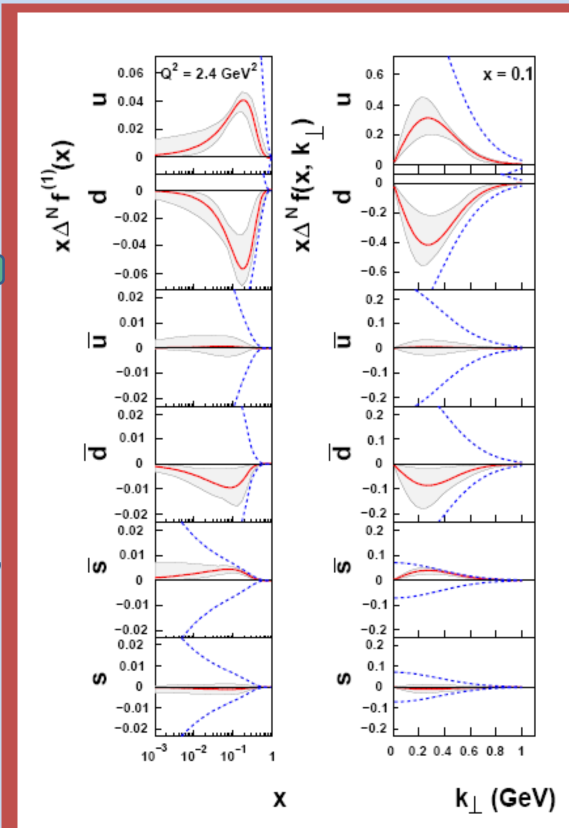
Sivers distribution function

DSS SET

$$A_{UT}^{Sivers} \propto \frac{\sum_q e_q^2 \, \Delta^N f_{q/p^\uparrow} \otimes \frac{d\hat{\sigma}^{\ell q\to \ell q}}{dQ^2} \otimes D_{h/q}}{\sum_q e_q^2 \, f_{q/p^\uparrow} \otimes \frac{d\hat{\sigma}^{\ell q\to \ell q}}{dQ^2} \otimes D_{h/q}}$$

$$\Delta^N f_{q/p^\uparrow} \propto N \, x^{\alpha_q} \, (1-x)^{\beta_q} \, f_{q/p}(x) \, g(k_\perp)$$

GRV98 SET

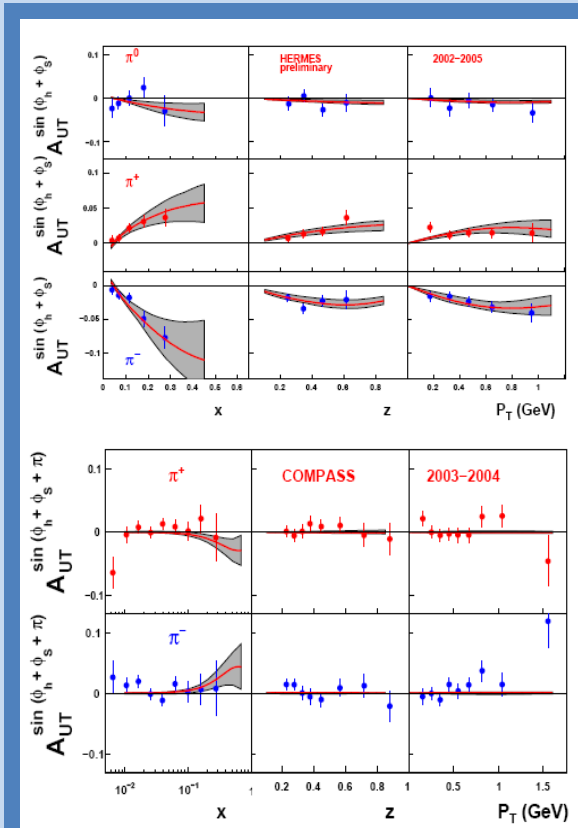


Anselmino et al., Phys. Rev. D77, 051502 (2008)

SIDIS and e^+e^- scattering experimental data allow us to extract the transversity and Sivers distribution functions, and the Collins fragmentation function

- Transversity distribution function and Collins fragmentation function from a simultaneous fit of SIDIS and e^+e^- scattering experimental data

Anselmino et al., Proceedings of Ringberg Workshop On New Trends in HERA Physics 2008, Germany

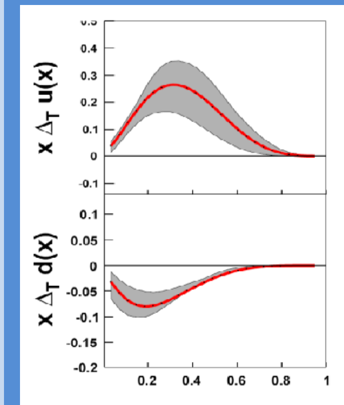


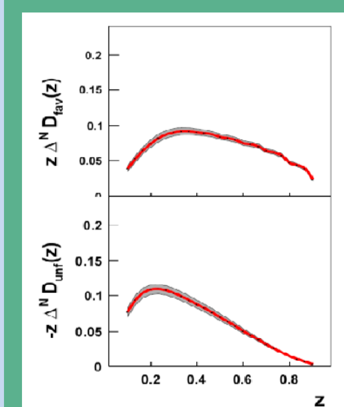
Transversity distribution function

Collins fragmentation function

$$A_{UT}^{Collins} \propto \frac{\sum_q e_q^2\, \Delta_T q \otimes \frac{\Delta d\hat{\sigma}}{dQ^2} \otimes \Delta^N D_{h/q^\uparrow}}{\sum_q e_q^2\, f_{q/p} \otimes \frac{d\hat{\sigma}}{dQ^2} \otimes D_{h/q}}$$

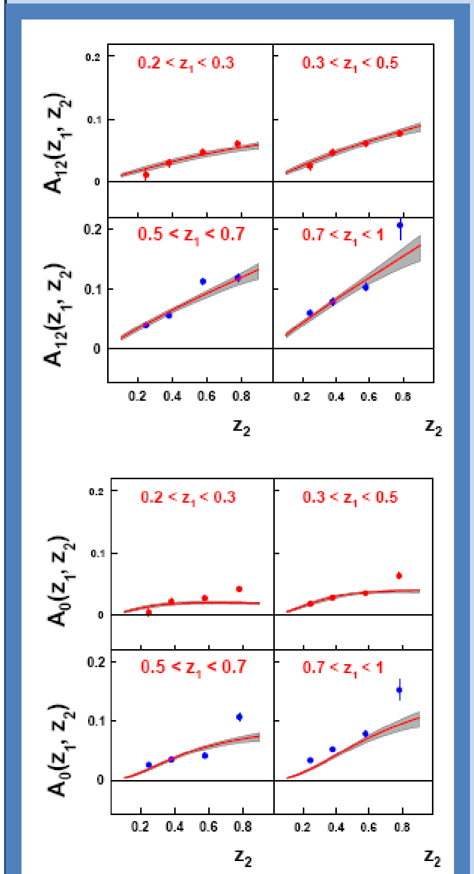
$$\frac{\Delta d\hat{\sigma}}{dQ^2} = \frac{d\hat{\sigma}^{\ell q^\uparrow \to \ell q^\uparrow} - d\hat{\sigma}^{\ell q^\uparrow \to \ell q^\downarrow}}{dQ^2}$$





SIDIS and e⁺e⁻ scattering experimental data allow us to extract the transversity and Sivers distribution functions, and the Collins fragmentation function

- Transversity distribution function and Collins fragmentation function from a simultaneous fit of SIDIS and e⁺e⁻ scattering experimental data



Collins fragmentation functions

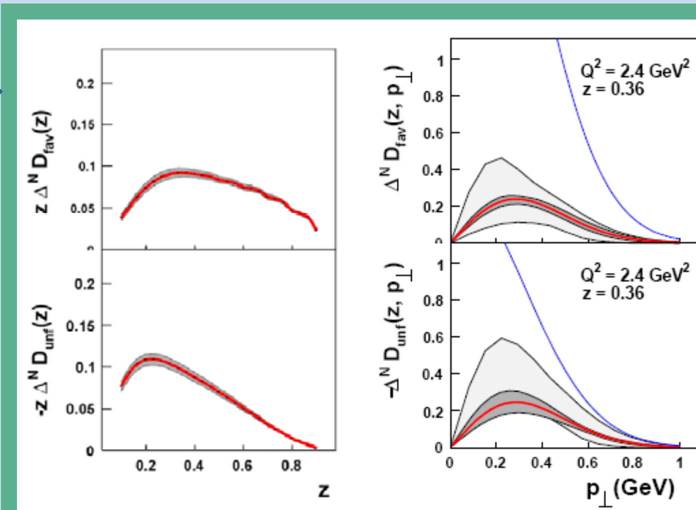
$$A_{12} \propto \cos(\varphi_1 + \varphi_2) \frac{\sum_q e^2 \Delta^N D_{h_1/q^\uparrow} \Delta^N D_{h_2/\bar{q}^\uparrow}}{\sum_q e^2 D_{h_1/q} D_{h_2/\bar{q}}}$$

Different azimuthal dependence

Collins fragmentation functions

$$A_{12} \propto \cos(2\varphi_0) \frac{\sum_q e^2 \Delta^N D_{h_1/q^\uparrow} \Delta^N D_{h_2/\bar{q}^\uparrow}}{\sum_q e^2 D_{h_1/q} D_{h_2/\bar{q}}}$$

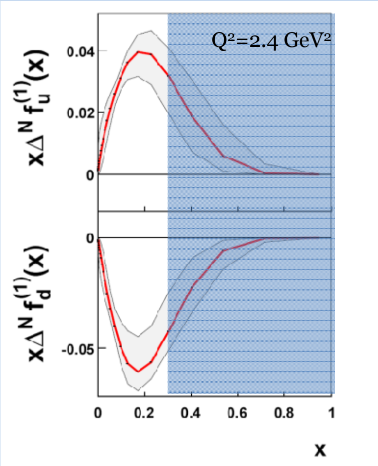
Anselmino et al., Proceedings of Ringberg Workshop On New Trends in HERA Physics 2008, Germany

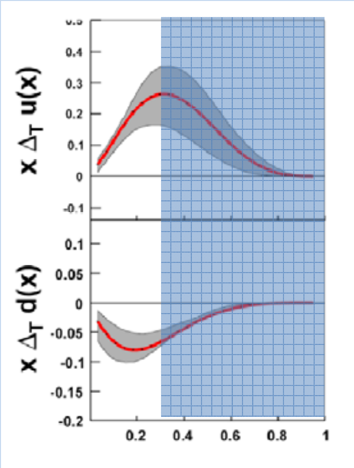


Notice the tiny size of the error bars !

What do we learn from this exercise ?

- The favoured and unfavoured Collins fragmentation functions are strictly constrained, thanks to the high statistics of the BELLE data.
- The transversity and Sivers distribution functions are constrained by SIDIS data ONLY in a range of relatively low values of x ($x<0.3$).
- Therefore, the SIDIS data are unable to fix the free parameters (β) which control the large-x behavior of the transversity and of the Sivers distribution functions. As a consequence, in these fits the β parameters are chosen to be flavour independent.





Polarized proton-proton scattering: $p^{\uparrow}p \to \pi X$

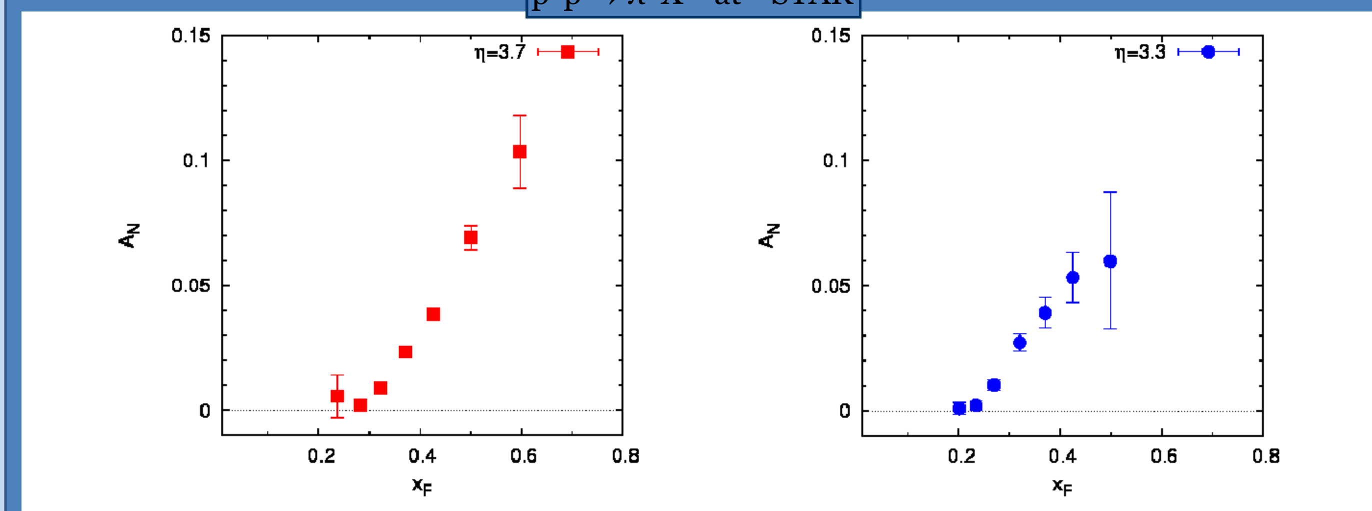
$$A_N^{Sivers} \propto \frac{\sum_q \Delta^N f_{q/p_1^{\uparrow}} \otimes f_{q/p_2} \otimes \frac{d\hat{\sigma}^{qq\to qq}}{dt} \otimes D_{h/q}}{\sum_q f_{q/p_1} \otimes f_{q/p_2} \otimes \frac{d\hat{\sigma}^{qq\to qq}}{dt} \otimes D_{h/q}}$$

Notice that these two effects add up in A_N

$$A_N^{Collins} \propto \frac{\sum_q \Delta_T q \otimes f_{q/p_2} \otimes \frac{\Delta d\hat{\sigma}^{qq\to qq}}{dt} \otimes \Delta^N D_{h/q}}{\sum_q f_{q/p_1} \otimes f_{q/p_2} \otimes \frac{d\hat{\sigma}^{qq\to qq}}{dt} \otimes D_{h/q}}$$

Further contributions, proportional to the Boer-Mulders and pretzelosity functions, are negligible (checked numerically)

$p^{\uparrow}p \to \pi^o X$ at STAR



NOTE:pp data cover a range of larger x values compared to SIDIS data

Polarized proton-proton scattering: $p^{\uparrow}p \to \pi X$

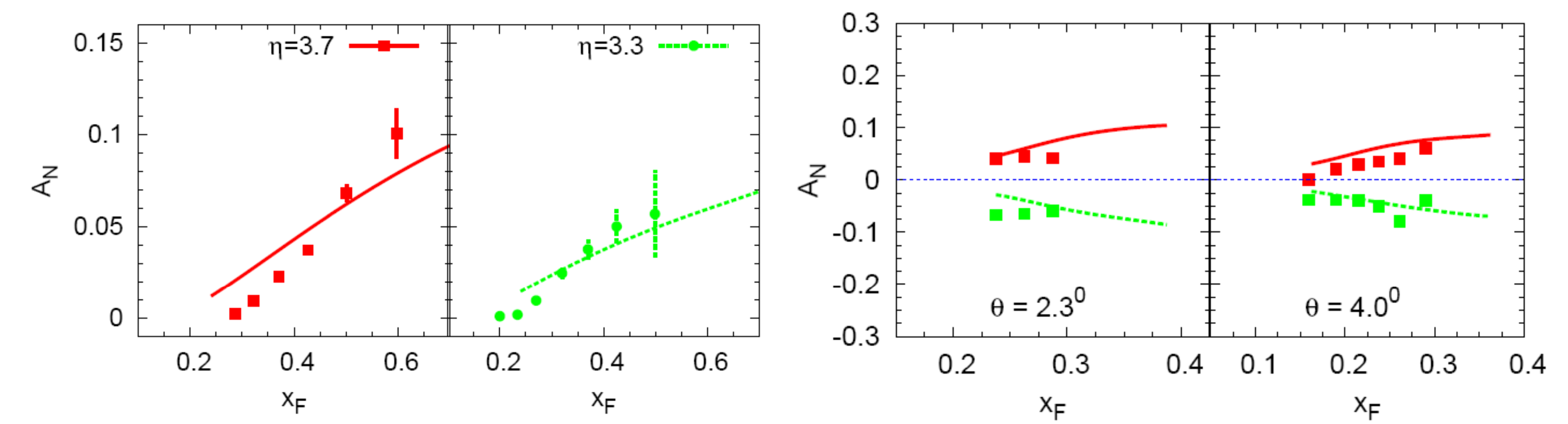
- Maximized Sivers effect at RHIC

Proper sign

$$\Delta^N f_u = +(2) f_u \qquad \Delta^N f_d = -2 f_d$$

STAR (π^0)

BRAHMS ($\pi^{\pm}$)



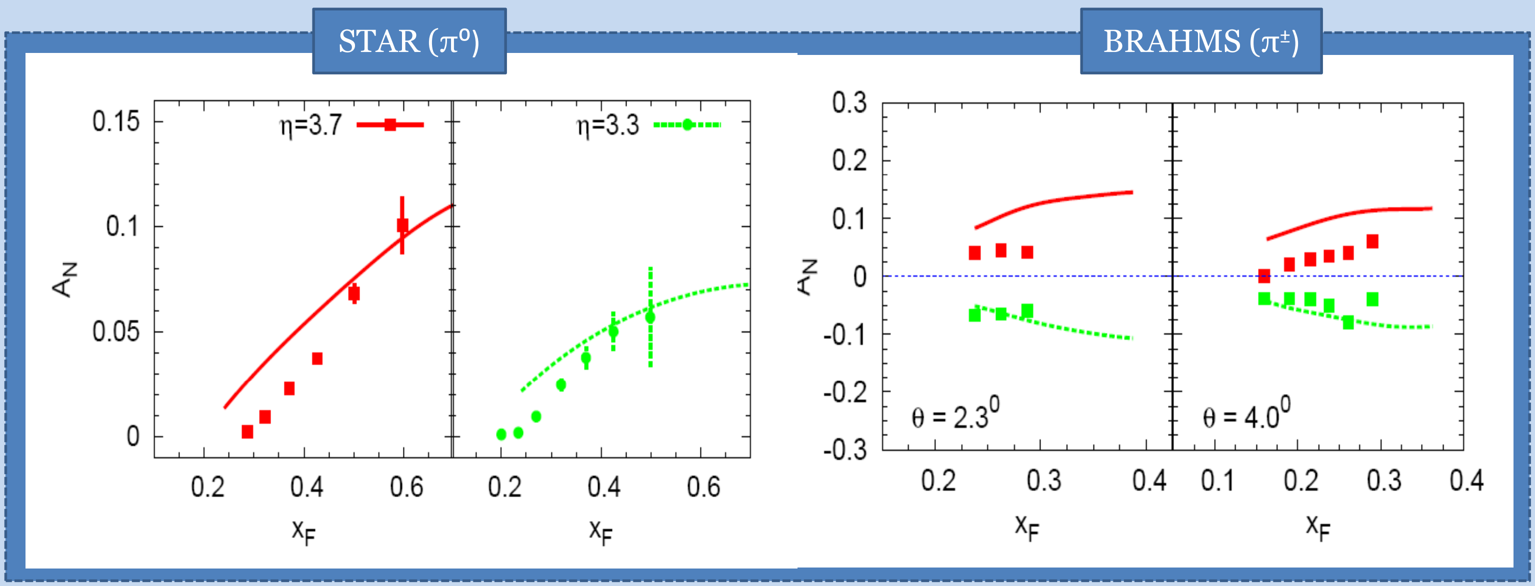
Polarized proton-proton scattering: $p^{\uparrow}p \to \pi X$

- Maximized Collins effect at RHIC

Proper sign

$$h_1^u = +\frac{1}{2}(u + \Delta u) \qquad h_1^d = -\frac{1}{2}(d + \Delta d) \qquad \text{(Soffer bounds)}$$

$$\Delta^N D_{\rm fav} = +2D_{\rm fav} \qquad \Delta^N D_{\rm unf} = -2D_{\rm unf} \qquad \text{(positivity bounds)}$$



Polarized proton-proton scattering: $p^{\uparrow} p \to \pi X$

Conclusion: both Sivers and Collins effects,

when maximized, can separately reproduce

$p\, p \to \pi X$ transverse single spin asymmetries.

Universality of Sivers and Collins functions

- The Collins fragmentation function is universal (no initial/final state interactions, no effects induced by requiring color gauge invariance)

  J. Collins and A. Metz, Phys. Rev. Lett. 93,252001 (2004), F. Yuan, arXiv:0903.4680

- The Sivers distribution function (naively time reversal odd) is subject to initial/final state interaction – color gauge invariance requirements induce color factors (process dependence).

  C. J. Bomhof, P. J. Mulders,F. Pijlman, Eur. Phys. J. C 47, 147 (2006)

  Example:

$$(\Delta^N f_{q/p^\uparrow})^{SIDIS} = -(\Delta^N f_{q/p^\uparrow})^{Drell-Yan}$$

- Many different elementary scattering amplitudes contribute to pp scattering: each of them is affected by a different color factor (UNDER DEBATE)

  Bacchetta, Bomhof, Mulders, Pijlman, Phys.Rev.D72:034030,2005

  P. Ratcliffe, O.Teryaev (2008)

From SIDIS to Polarized proton-proton scattering

- The behavior of the Sivers and the transversity functions at **large x** is controlled by the β_q parameters

$$\Delta^N f_{q/p^\uparrow}(x,k_\perp) \propto g(k_\perp)\,\underbrace{\Delta^N f_{q/p^\uparrow}(x)}_{\propto\, x^{\alpha_q}(1-x)^{\beta_q}}$$

$$\Delta_T q(x,k_\perp) \propto g'(x,k_\perp)\,\underbrace{\Delta_T q(x)}_{\propto\, x^{\alpha_q}(1-x)^{\beta_q}}$$

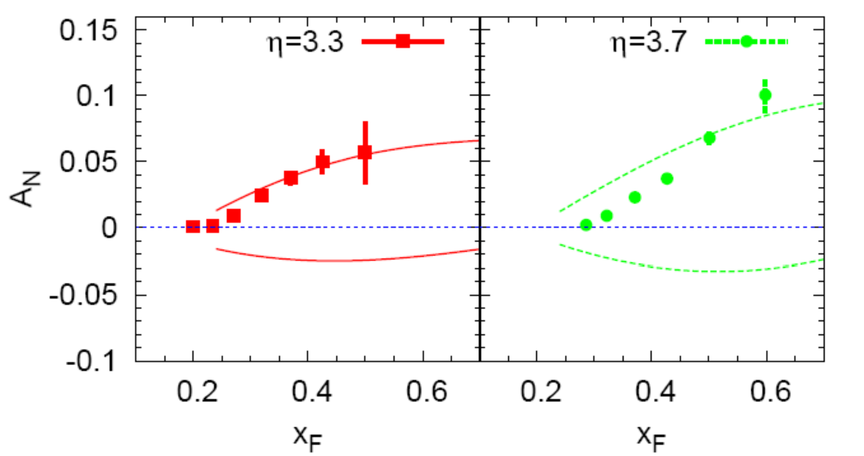
- SIDIS is unable to determine the β_q parameters, because there are no exp. data at **large x**. Therefore we perform a scan over a grid of configurations in which β_u and β_d are fixed from 0 to 4 (in steps of 0.5), and re-run the SIDIS fit. We then select out only the parameter configurations that correspond to a SIDIS fit $\chi^2_{\,d.o.f}$ not larger than about 20% from the minimum original value.
  The accepted configurations turn out to be ~ 85.

- Finally we use all these parameter sets to build a band of for the Sivers and Collins effect in proton-proton scattering

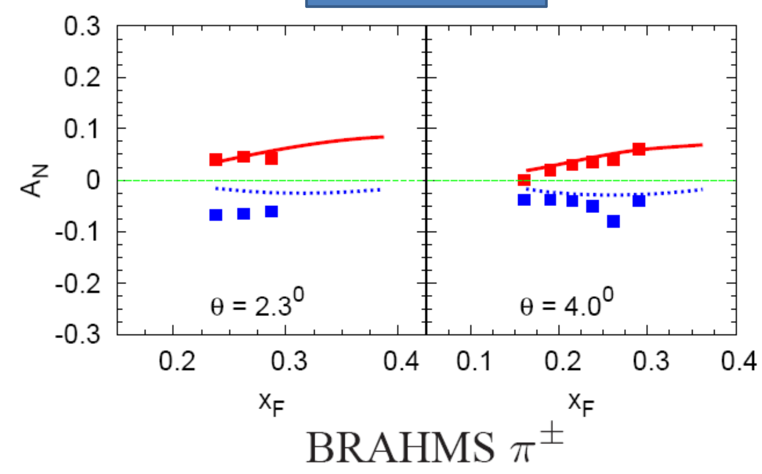
From SIDIS to Polarized proton-proton scattering
β_q parameter scan

Sivers effect

STAR (π^0)

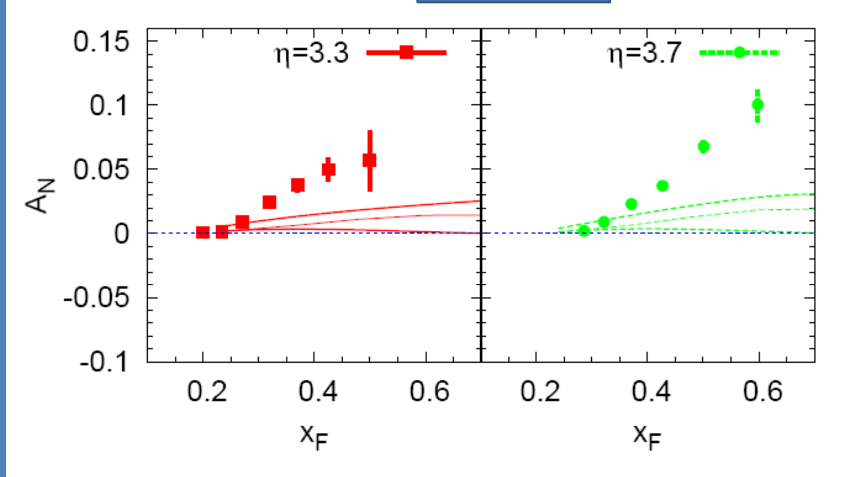


BRAHMS ($\pi^{\pm}$)



Collins effect

STAR (π^0)



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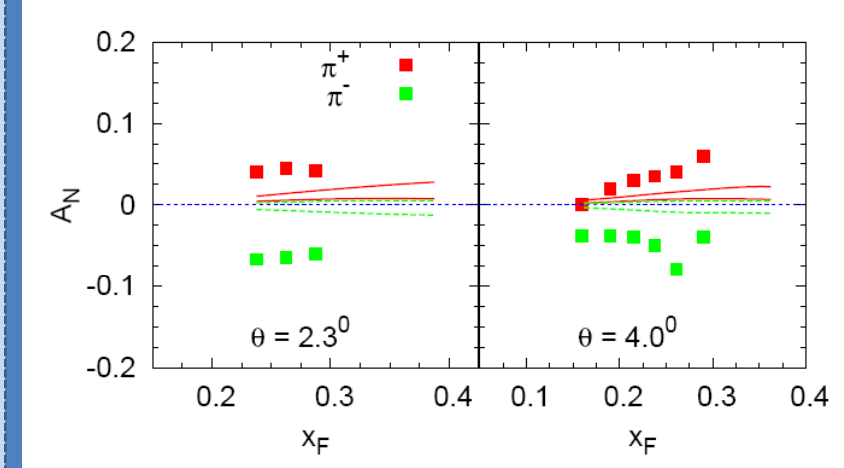

NOTE: Issues on detailed evolution of Collins function to be studied further

Conclusions

- Given the available data, there exists a set of Sivers functions which can explain all single spin asymmetries in SIDIS and pp scattering.
- The Collins effect is suppressed in size with respect to the Sivers effect in polarized proton-proton collisions measured at RHIC.
- Next step: perform a global fit
- Crucial test: Drell-Yan vs. SIDIS