Re-assessment of the nucleon Boer-Mulders function

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The Sivers function: correlation between

$$\boldsymbol{S}_N \cdot (\boldsymbol{k}_q \times \boldsymbol{P}_N)$$

The BM function: correlation between

$$\boldsymbol{s}_q \cdot (\boldsymbol{k}_q \times \boldsymbol{P}_N)$$

Extraction from data on various symmetries in SIDIS:

$$l_{\mathsf{U}} + N_{\mathsf{T}} \to l' + h(\phi_h) + X$$

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$$(\mathrm{BM})_q = \lambda_q (\mathrm{Siv})_q$$

for each quark and antiquark and fit λ_q.

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Incorrect theoretically: leads to

gluon contribn to flavour non-singlet $(\text{BM})_{(q-\bar{q})}$

unless

$$\lambda_q = \lambda_{\bar{q}}$$

which is not the case.

To avoid complication of gluons we work with asymmetry differences

$$A^{h-\bar{h}} \equiv \frac{\Delta\sigma^h - \Delta\sigma^{\bar{h}}}{\sigma^h - \sigma^{\bar{h}}}.$$

Involve only VALENCE contributions q_V.
Try analogue of Eq. (1) for deuterons

$$(\text{BM})_{Q_V} = \lambda_{Q_V} (\text{Siv})_{Q_V} \tag{2}$$

$$Q_V = u_V + d_V$$

Leads to two relations between the unpolarised asymmetries $A_{UU}^{\cos\phi_h,h-\bar{h}}, A_{UU}^{\cos 2\phi_h,h-\bar{h}}$ and the polarised Sivers asymmetry $A_{UT}^{Siv,h-\bar{h}}$. For deuterons we had:

$$A_{UU}^{\cos\phi_h,h-\bar{h}}(x) = \Phi(x)\left\{C_{Cahn}^{h} + C_{BM}^{h}\, A_{UT}^{Siv,h-\bar{h}}(x)\right\}$$

$$A_{UU}^{\cos 2\phi_h,h-\bar{h}}(x) = \hat{\Phi}(x)\left\{\hat{C}_{Cahn}^{h} + \frac{M_d^2}{< Q^2 >}\hat{C}_{BM}^{h}\, A_{UT}^{Siv,h-\bar{h}}(x)\right\}$$

where $\Phi(x)$, $\hat{\Phi}(x)$ are known functions.

The C^h_{Cahn}, $\hat{C}^h_{Cahn}$, C^h_{BM}, $\hat{C}^h_{BM}$ are constants, which depend on:

$$< k_\perp^2 >_{PDF}, < p_\perp^2 >_{FF}$$

and on M_C, M_S which determine the transverse momentum dependence of the Collins and Sivers functions respectively.

Several different sets of values for these parameters exist in the literature.

We used COMPASS deuteron data for the asymmetries and found that our relations were well satisfied for the sets of values

$< k_\perp^2 >_{PDF} = 0.18$ or 0.25 with $< p_\perp^2 >_{FF} = 0.25$

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We published our results in Phys. Rev. D. in 2018

We were shocked to learn later that the COMPASS asymmetries do NOT correspond to the $A_{UU}^{\cos\phi_h}, A_{UU}^{\cos 2\phi_h}$ in the literature!
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COMPASS pleaded NOT GUILTY on two grounds:

1) The COMPASS symbols were $A^{UU}_{\cos\phi_h}$ and NOT $A^{\cos\phi_h}_{UU}$ etc

The Judge dismissed this as irrelevant.

2) COMPASS claimed we should have read their Eq. (1) more carefully.

It reads:

..........given in the one-photon exchange approximation [17] by:

$$d\sigma = \sigma_0 \left(1 + \epsilon_1 \, A^{UU}_{\cos\phi_h} \, cos\phi_h + ...\right)$$

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The Judge commented that he was unable to find this equation in reference [17].

NONETHELESS the Judge pronounced COMPASS NOT GUILTY, but asked them to take more care to warn readers of potential misunderstandings in future.

Hence my intention today was to announce that our results in PR D97, 056018 (2018) are TOTAL RUBBISH.

However MIRACLES DO HAPPEN!

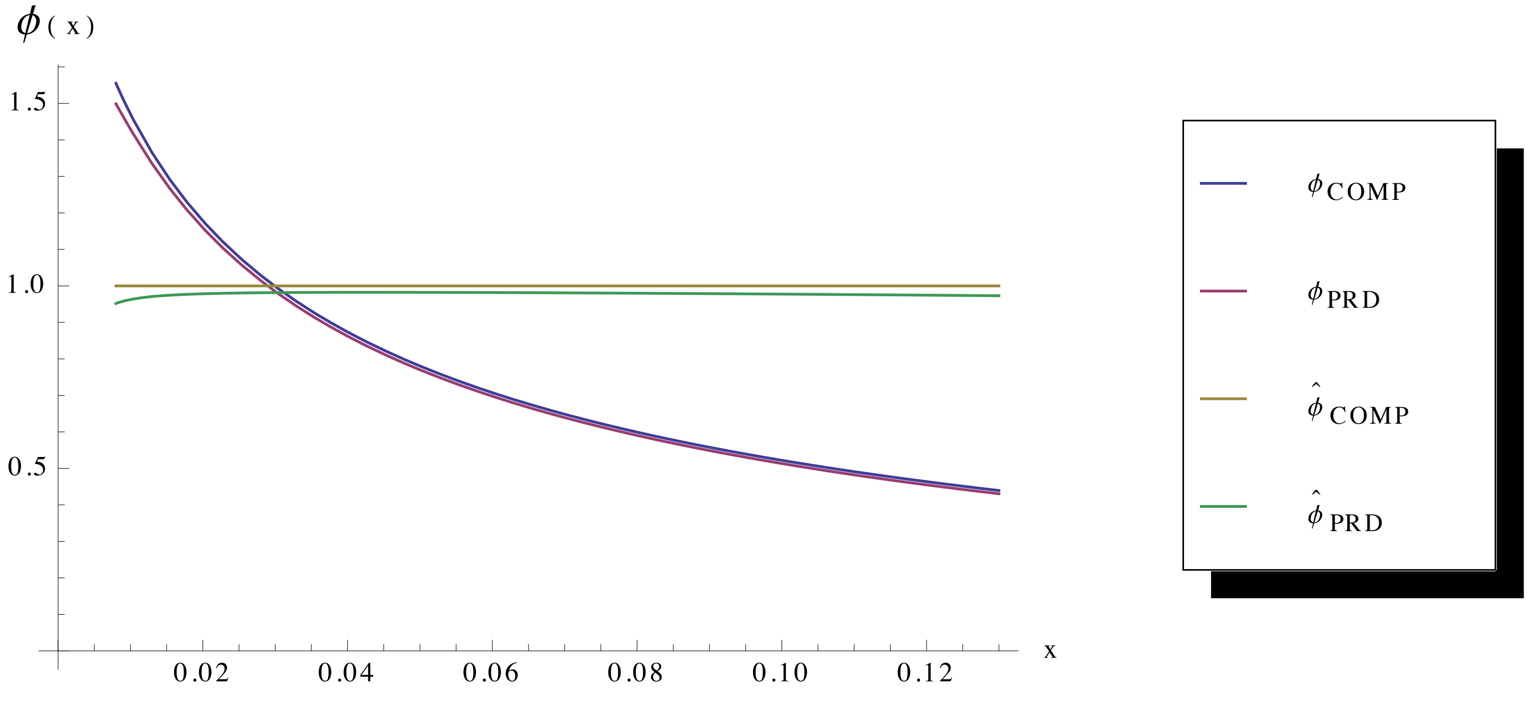
With the COMPASS definitions of the asymmetries the incorrect (PRD) and correct (COMP) relations for deuterons read:

$$A_{UU}^{\cos\phi_h,h-\bar{h}}(x)|_{COMP} = \Phi_{PRD,COMP}\left\{C^h_{BM}\, A_{UT,d}^{Siv,h-\bar{h}}(x) + C^h_{Cahn}\right\},$$

$$A_{UU}^{\cos 2\phi_h,h-\bar{h}}(x)|_{COMP} = \widehat{\Phi}_{PRD,COMP}\left\{\widehat{C}^h_{BM}\, A_{UT,d}^{Siv,h-\bar{h}}(x) + \frac{M_d^2}{< Q^2 >}\widehat{C}\right.$$

THE MIRACLE

Comparison of Φ_{PRD} with Φ_{COMP} and $\hat{\Phi}_{PRD}$ with $\hat{\Phi}_{COMP}$



ϕ(x)
1.5
1.0
0.5
0.02
0.04
0.06
0.08
0.10
0.12
x
ϕ COMP
ϕ PRD
ϕ̂ COMP
ϕ̂ PRD

Conclusion: Results of PR D97, 056018 (2018) are correct!!!!!!!!!!!!!!!!!!

Summary of the PRD conclusions: Two independent tests of the assumption

$$(BM)_{Q_V} \propto (Sivers)_{Q_V}$$

were made using the COMPASS SIDIS data on the difference asymmetries $A_{UU,d}^{\cos\phi_h,h^+-h^-}(x)$, $A_{UU,d}^{\cos 2\phi_h,h^+-h^-}(x)$ and $A_{UT,d}^{Siv,h^+-h^-}(x)$. Both tests are consistent with this assumption in the kinematic interval $x = [0.014, 0.13]$.

The results are very sensitive to the average transverse momentum-squared, $< k^2 >$ and $< p^2 >$ in the unpolarized PDFs and FFs, respectively, with clear preference for the old experimental values, in units of GeV^2:

$< k^2 > \approx 0.18$, or $< k^2 > \approx 0.25$, $< p^2 > \approx 0.20$, $M_S^2 = 0.34$ or $M_S^2 = 0.19$ and $M_C^2 = 0.91$

Our results suggested that the previous (BMS) extraction of the BM function
[Barone, Melis and Prokudin, Phys. Rev. **D 81**, 114026 (2010)]
might be unreliable.

We are in the process of studying the extraction of the VALENCE BM function from $A_{UU,d}^{\cos\phi_h, h^+-h^-}(x)$, and $A_{UU,d}^{\cos 2\phi_h, h^+-h^-}(x)$. Preliminary results support this conclusion.

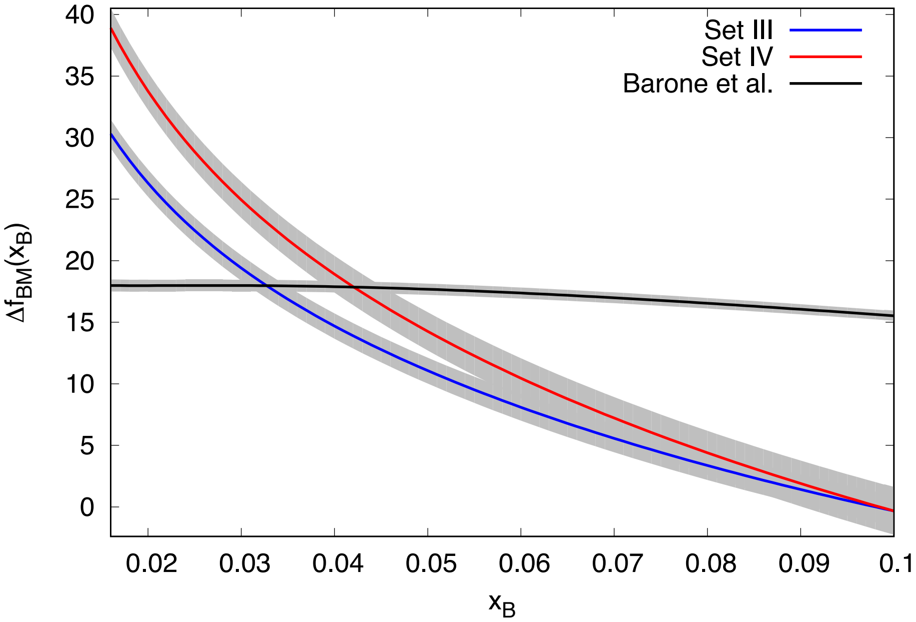


Figure 1: Comparison of $\Delta f^{Q_V}(x)$ and $\Delta f_{BM}^{Q_V}(x)|_{\mathrm{BMS}}$