UNICA UNIVERSITÀ DEGLI STUDI DI CAGLIARI

INFN CAGLIARI

Updates on transversity extractions

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Transversity 2024
Università di Trieste
June 3rd, 2024

U. D'Alesio, CF, A. Prokudin, PLB 803 (2020) 135347
M. Boglione, U. D'Alesio, CF, J.O. Gonzalez-Hernandez, F. Murgia, A. Prokudin, PLB 854 (2024) 138712

Introduction - Transversity function

- collinear transversity function $h_1^q(x)$ describes the collinear structure of spin-$\frac{1}{2}$ hadrons at leading twist
- chiral-odd quantity $\Rightarrow$ not accessible in inclusive DIS
- extracted in SIDIS together with Collins FF (TMD framework) or in two-hadron production with dihadron FF (collinear pQCD)
- Soffer Bound [J. Soffer, PRL74 (1995) 1292–1294]

$$|h_1^q(x, Q^2)| \leq \frac{1}{2}\left[f_{q/p}(x, Q^2) + g_{1L}^q(x, Q^2)\right] \equiv SB^q(x, Q^2)$$

- bound preserved by Q^2 evolution up to NLO in QCD

[V. Barone, PLB 409 (1997) 499–502; W. Vogelsang, PRD 57 (1998) 1886–1894]

Introduction - tensor charges (I)

- quarks contribute to nucleon tensor charge via the first Mellin moment of the non-singlet quark combination, δq

$$\delta q = \int_0^1 \left[h_1^q(x) - h_1^{\bar{q}}(x) \right] dx$$

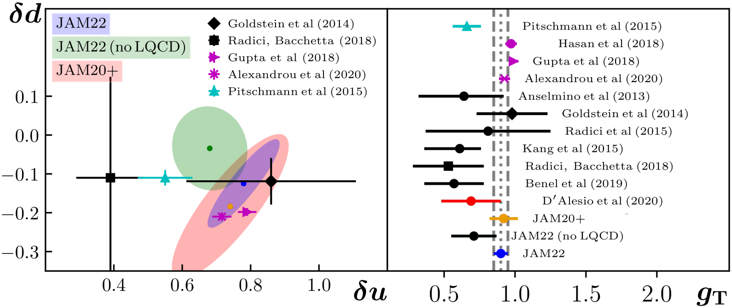
- isovector combination of tensor charges, g_T

$$g_T = \delta u - \delta d$$

- δq and g_T computed in lattice QCD as a matrix element over $0 < x < 1$, also estimated starting from phenomenological extractions

- g_T is related to BSM effects: a bridge between QCD phenomenology, lattice QCD and BSM physics

Introduction - tensor charges (II)



Adapted from Fig. 3 of [L. Gamberg *et al.*, PRD 106 (2022) 3, 034014]

- different parametrizations for different phenomenological analyses
- experimental data not available for the full x-range
- lattice QCD estimates done with different settings, computed as matrix element over $0 < x < 1$

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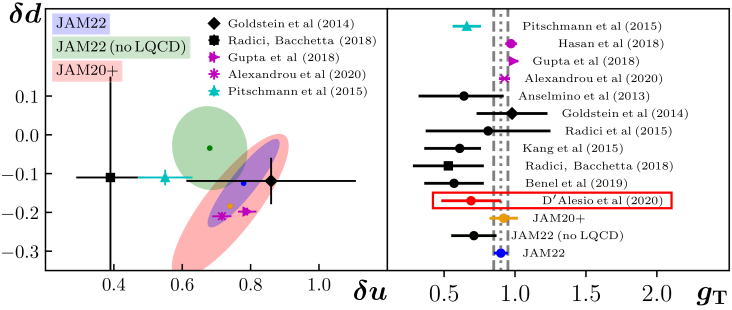

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Soffer Bound & phenomenological fits

- adopting

$$h_1^q(x, Q_0^2) \propto SB^q(x, Q_0^2)$$

is very common in phenomenological fits, both in collinear QCD and TMD physics

[M. Anselmino *et al.*, PRD 75 (2007) 054032 & PRD 92 (11) (2015) 114023]
[A. Bacchetta, A. Courtoy, M. Radici, JHEP03 (2013) 119; M. Radici, A. Bacchetta, PRL120 (19) (2018) 192001]

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  [U. D'Alesio, CF, A. Prokudin, PLB 803 (2020) 135347]

h_1^q & $H_1^{\perp q}$ global fit (I)

U. D'Alesio, CF, A. Prokudin, PLB 803 (2020) 135347

- global fit of TMD transversity and Collins functions from SIDIS and e^+e^- data
- $h_1^q(x, k_\perp^2)$ accessible through SIDIS azimuthal asymmetries:

$$A_{UT}^{\sin(\phi_h+\phi_S)} = \frac{2(1-y)}{1+(1-y)^2} \frac{F_{UT}^{\sin(\phi_h+\phi_S)}}{F_{UU}}$$

  where $F_{UU} = \mathcal{C}[f_1 D_1]$ and $F_{UT}^{\sin(\phi_h+\phi_S)} = \mathcal{C}[h_1^q H_1^{\perp q}]$
- Collins function also accessible from $\cos(2\phi_0)$ modulation of $e^+e^- \to h_1 h_2 X$ cross sections via $A_0^{UL(C)} \propto \mathcal{C}[H_1^{\perp \bar{q}} H_1^{\perp q}]$
- baseline fit: [M. Anselmino *et al.*, PRD 92 (2015) 11, 114023]
- dataset:
  (a) $A_{UT}^{\sin(\phi_h+\phi_S)}$ data from HERMES and COMPASS
  (b) $A_0^{UL(C)}$ measurements from BELLE, BABAR and BESIII
- $N_{\text{pts}} = 278$

h_1^q & $H_1^{\perp q}$ global fit (II)

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- Gaussian parametrization:

$$h_1^q(x,k_\perp^2) = h_1^q(x)\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}\,, \qquad h_1^q(x,Q_0^2) = \mathcal{N}_q^T(x)\,SB^q(x,Q_0^2)$$

$$\mathcal{N}_q^T(x) = N_q^T x^\alpha(1-x)^\beta\,\frac{(\alpha+\beta)^{\alpha+\beta}}{\alpha^\alpha\beta^\beta}\,, \quad (q = u_v,\, d_v)$$

- upon constraining

$$|N_q^T| \leq 1$$

SB is automatically fulfilled

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- two cases: "using SB" ($|N_q^T| \le 1$ a posteriori) or "no SB" ($\not{|N_q^T| \le 1}$)

h_1^q & $H_1^{\perp q}$ global fit - results

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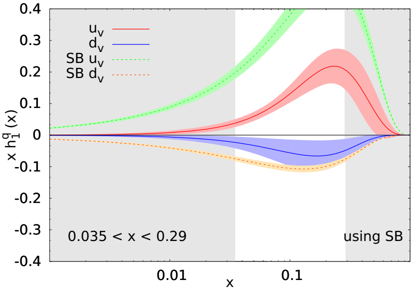

- shaded grey areas correspond to regions where data is not available
- almost same $\chi^2_{\rm dof} \approx 0.93$
- out of 10^5 MC sets produced for the "noSB" case, $\approx$ 16% fulfill $|N_q^T| \leq 1 \Rightarrow$ sets for "using SB" case
- $h_1^{u_v}(x)$ does not change while relaxing the SB constraint, $h_1^{d_v}(x)$ apparently violates SB
- violation is less than 1σ statistically significant where data is available

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h_1^q & $H_1^{\perp q}$ global fit - tensor charges

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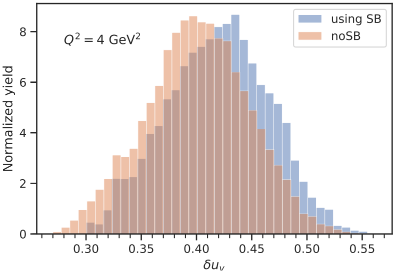

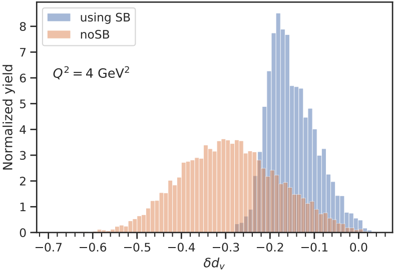

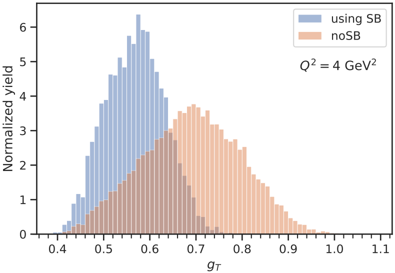

$Q^2 = 4$ GeV^2		
	using SB	no SB
δu_v	0.42 ± 0.09	0.40 ± 0.09
δd_v	-0.15 ± 0.11	-0.29 ± 0.22
g_T	0.57 ± 0.13	0.69 ± 0.21

A_N in inclusive $p^{\uparrow}p$ processes

U. D'Alesio, F. Murgia PRD 70 (2004) 074009; M. Anselmino *et al.*, PRD 73 (2006) 014020
L. Gamberg, Z.-B. Kang, PLB 696 (2011) 109; U. D'Alesio *et al.*, PRD 96 (2017) 036011 ...

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$$A_N = \frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow} = \frac{d\Delta\sigma}{2d\sigma} \simeq \frac{d\Delta\sigma_{\text{Siv}} + d\Delta\sigma_{\text{Col}}}{2d\sigma}$$

with

$$d\Delta\sigma_{\text{Col}} \propto \sum_{a,b,c,d} h_1^a(x_a, k_{\perp a}) \otimes f_{b/p}(x_b, k_{\perp b}) \otimes d\Delta\sigma^{a^\uparrow b \to c^\uparrow d} \otimes H_1^{\perp c}(z, k_{\perp h})$$

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- apply Bayesian simultaneous reweighting on Sivers, transversity and Collins function extractions from SIDIS and e^+e^- data

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A_N simultaneous reweigthing

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- The simultaneous reweighting is perfomed on A_N data:
  - BRAHMS for $\pi^{\pm}$ production at $\sqrt{s} = 200$ GeV

    allow for a direct flavor separation
  - STAR for π^0 production at $\sqrt{s} = 200$ GeV
  - latest STAR data for non-isolated π^0's at $\sqrt{s} = 200$ GeV and $\sqrt{s} = 500$ GeV

    kinematics aligned with SIDIS and e^+e^-

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$$0.1 \lesssim x_F \lesssim 0.7$$

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- median as cental value, 2σ CL asymmetric uncertainties

A_N simultaneous reweigthing - priors - h_1^q

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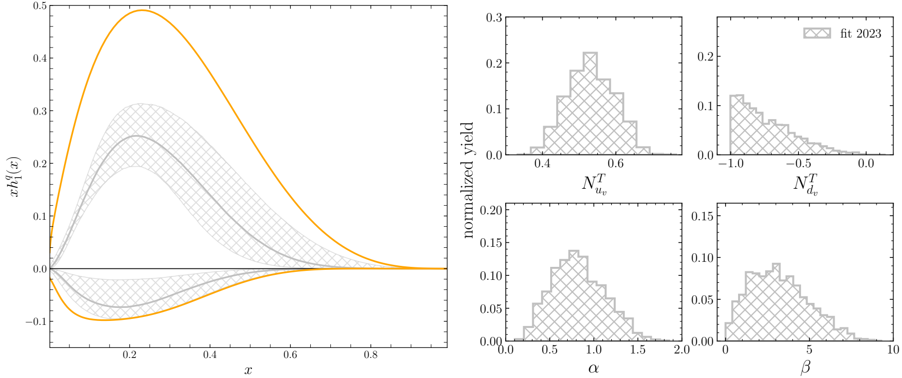

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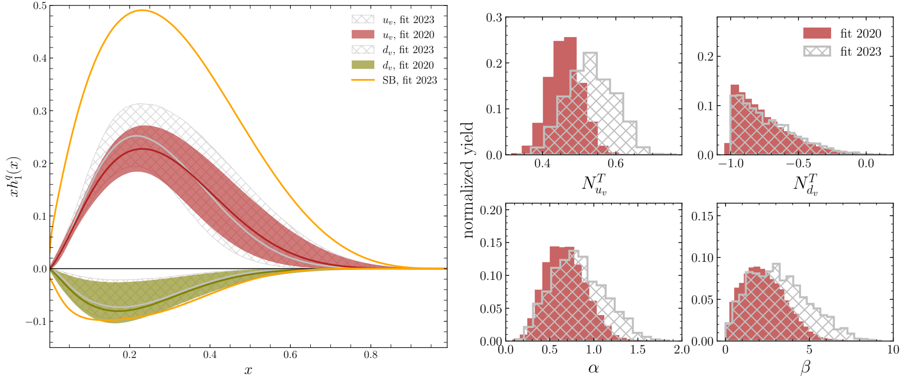

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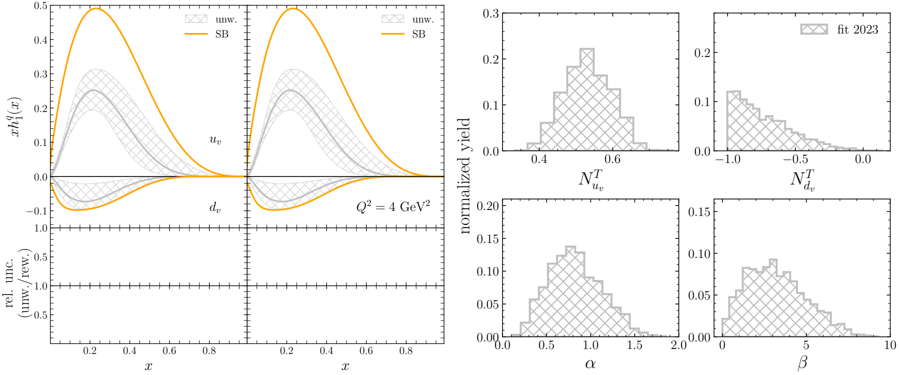

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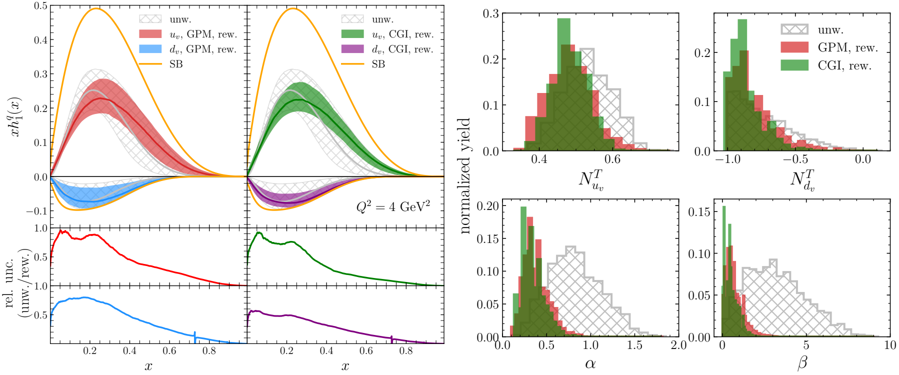

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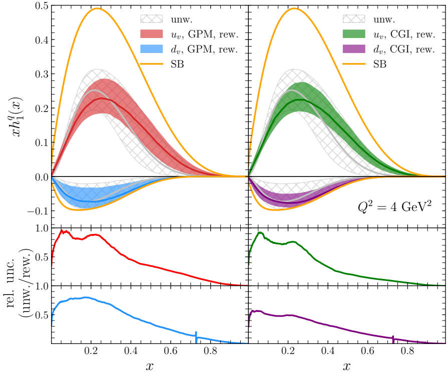

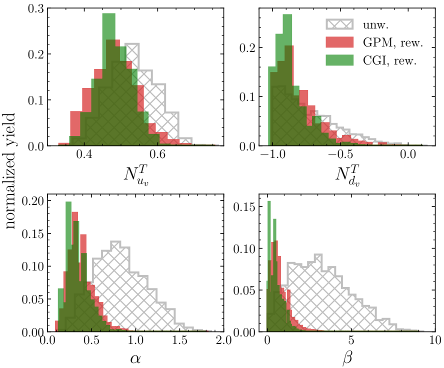

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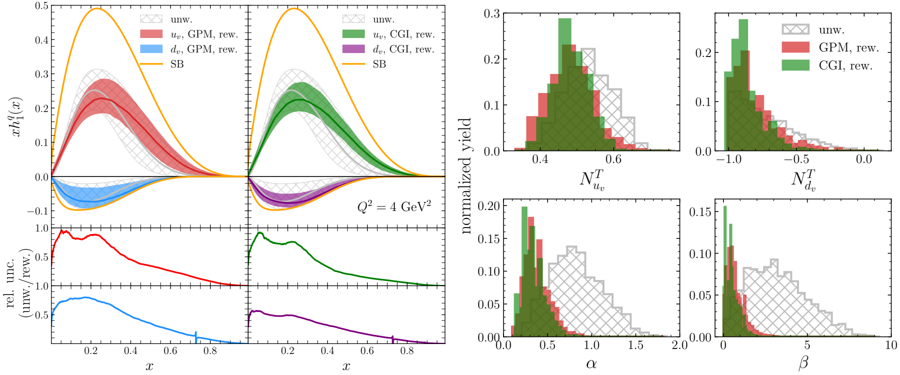

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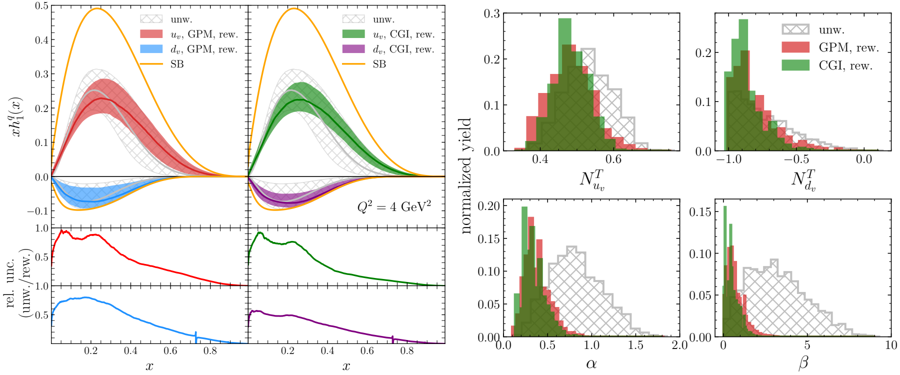

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- reweighted transversity functions follow SB rather closely at large x
- uncertainty reduction up to $80-90\%$ for h_1^q at large x
- dominant contribution to A_N from the Collins mechanism

not seen before SB application a posteriori

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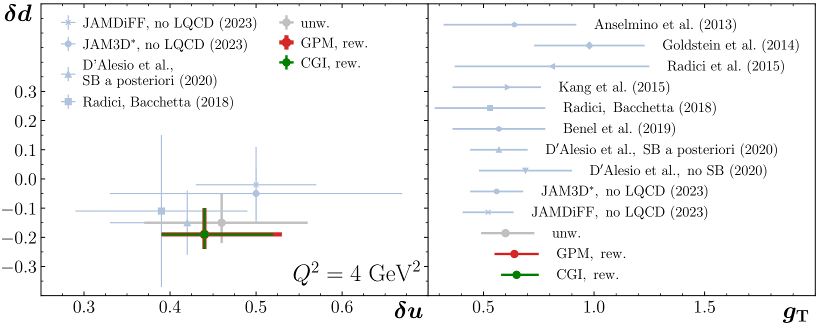
A_N simultaneous reweigthing - tensor charges

M. Boglione, U. D'Alesio, CF, J.O. Gonzalez-Hernandez, F. Murgia, A. Prokudin, PLB 854 (2024) 138712



$$\delta q = \int_0^1 \left[h_1^q(x) - h_1^{\bar{q}}(x) \right] dx \,, \quad g_T = \delta u - \delta d$$

- consistency of different h_1^q extractions within different approaches exploiting a variety of experimental data

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Thank you

Backup

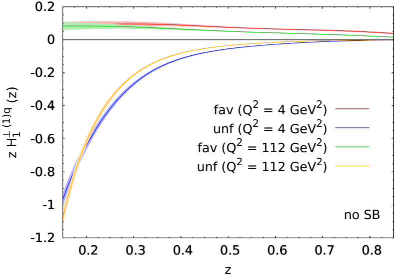
Fit results - Collins function

- parametrization:

$$H_1^{\perp q}(z,p_\perp^2) = \mathcal{N}_q^C(z)\,\frac{z m_h}{M_C}\,\sqrt{2e}\,e^{-p_\perp^2/M_C^2}\,D_{h/q}(z,p_\perp^2)\,,\quad (q = \text{fav}, \text{unf})$$

$$\mathcal{N}_{\text{fav}}^C(z) = N_{\text{fav}}^C\, z^\gamma (1-z)^\delta \frac{(\gamma+\delta)^{\gamma+\delta}}{\gamma^\gamma \delta^\delta}\,, \qquad \mathcal{N}_{\text{unf}}^C(z) = N_{\text{unf}}^C$$

- Collins function mostly constrained by e^+e^- data
  essentially no change between “using SB” and “no SB” cases



$$H_1^{\perp(1)\,q}(z) = z^2 \int d^2\boldsymbol{p}_\perp \frac{p_\perp^2}{2m_h^2}\, H_1^{\perp q}(z, z^2 p_\perp^2)$$

$$= \sqrt{\frac{e}{2}}\,\frac{1}{z m_h}\,\frac{M_C^3 \langle p_\perp^2\rangle}{(\langle p_\perp^2\rangle + M_C^2)^2}\,\mathcal{N}_q^C(z) D_{h/q}(z)$$

A_N simultaneous reweigthing - priors - Collins

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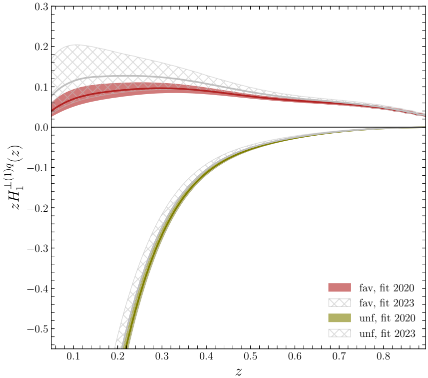

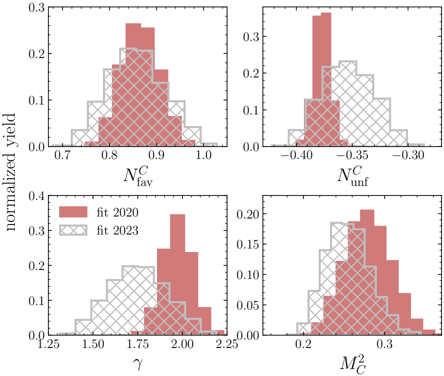

$$H_1^{\perp(1)\,q}(z) = z^2 \int d^2\boldsymbol{p}_\perp \frac{p_\perp^2}{2m_h^2} H_1^{\perp q}(z, z^2 p_\perp^2) = \sqrt{\frac{e}{2}} \frac{1}{z m_h} \frac{M_C^3 \langle p_\perp^2 \rangle}{\left(\langle p_\perp^2 \rangle + M_C^2\right)^2} \mathcal{N}_q^C(z) D_{h/q}(z)$$

A_N and transversity

U. D'Alesio, F. Murgia PRD 70 (2004) 074009; M. Anselmino *et al.*, PRD 73 (2006) 014020
L. Gamberg, Z.-B. Kang, PLB 696 (2011) 109; U. D'Alesio *et al.*, PRD 96 (2017) 036011 ...

- $p^\uparrow p \to h\,X$ processes can be described within the GPM, where a factorized formulation in terms of TMDs is assumed as a starting point
- a color gauge invariant formulation of GPM (CGI-GPM) was developed, with inclusion of initial and final state interaction; process dependence of the Sivers function is recovered
- A_N in $p^\uparrow p \to h\,X$:

$$A_N = \frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow} = \frac{d\Delta\sigma}{2d\sigma} \simeq \frac{d\Delta\sigma_{\rm Siv} + d\Delta\sigma_{\rm Col}}{2d\sigma}$$

with

$$d\Delta\sigma_{\rm Siv}^{\rm CGI\text{-}GPM} \propto \sum_{a,b,c,d} f_{1T}^{\perp a}(x_a, k_{\perp a}) \otimes f_{b/p}(x_b, k_{\perp b}) \otimes H^{\rm Inc}_{ab\to cd} \otimes D_{h/c}(z, k_{\perp h})$$

$$d\Delta\sigma_{\rm Col} \propto \sum_{a,b,c,d} h_1^a(x_a, k_{\perp a}) \otimes f_{b/p}(x_b, k_{\perp b}) \otimes d\Delta\sigma^{a^\uparrow b\to c^\uparrow d} \otimes H_1^{\perp c}(z, k_{\perp h})$$

and

$$d\sigma \propto \sum_{a,b,c,d} f_{a/p}(x_a, k_{\perp a}) \otimes f_{b/p}(x_b, k_{\perp b}) \otimes H^U_{ab\to cd} \otimes D_{h/c}(z, k_{\perp h})$$

- GPM results (Sivers): $H^{\rm Inc}_{ab\to cd} \to H^U_{ab\to cd}$
- gluon Sivers effect negligible in the region of moderate and forward rapidity

Results - BRAHMS

J. H. Lee, F. Videbæk, AIP Conf. Proc. 915, 533–538 (2007)
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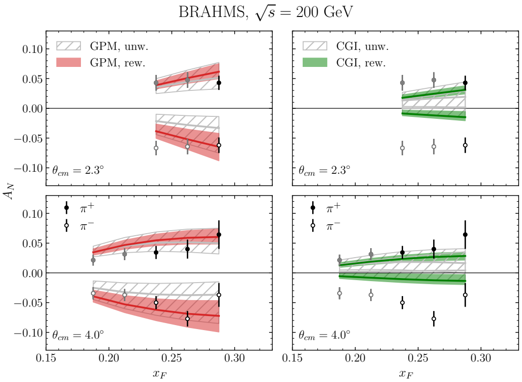

- reweighted curves with reduced uncertainties
- GPM describes these data better than CGI-GPM
- quality of description increases if data with $P_T < 1.5$ GeV (gray points) is not considered

Results - STAR (I)

B. I. Abelev *et al.*, PRL 101, 222001 (2008); J. Adams *et al.*, PRL 92 171801 (2004); L. Adamczyk *et al.*, PRD 86 (2012) 051101
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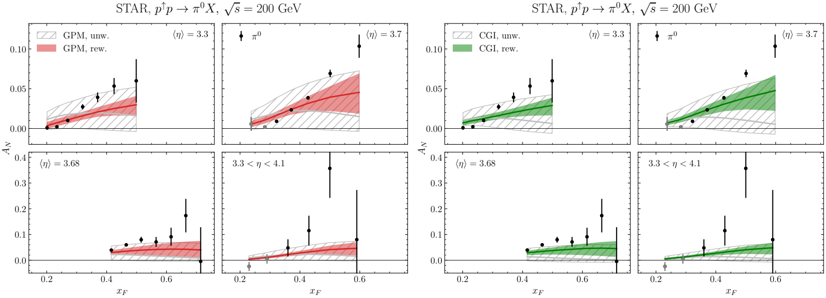

- both GPM and CGI-GPM in qualitative agreement with the data
- reweighted bands able to describe data at moderate x_F
- shape better representing the steady increase of A_N at large x_F

Results - STAR (II)

J. Adams *et al.*, PRD 103 (9) (2021) 092009
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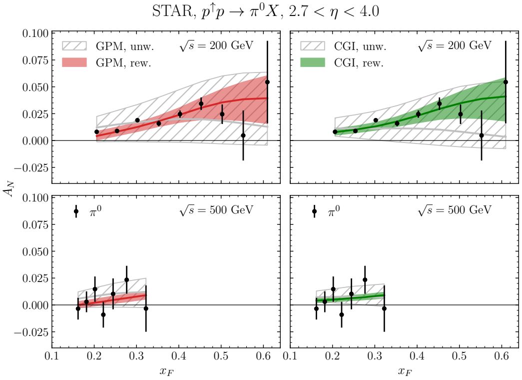

- data not showing the usual steady increase at large x_F
- reweighted curves describe the data
- if reweighting was performed on these data solely, bands would be flatter