Status update: impact studies for EIC Sivers function

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Work in progress! These are preliminary results!

Plan of the talk

- ▶ Part 1: Extraction of Sivers function
- ▶ Part 2: Impact studies



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Part 1: Extraction of Sivers function based on SV19 unpolarized TMDs using artemide

M.Bury, A.Prokudin, AV



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A bit of theory: Sivers asymmetry in TMD factorization

In TMD factorization the Sivers structure function reads

$$F_{UT}^{\sin(\phi_h - \phi_s)} = -M|C_V(-Q^2, \mu^2)|^2 \sum_f e_f^2 \int \frac{db}{2\pi} b^2 J_1(b|q_T|) \underbrace{\frac{\text{Sivers}}{f_{1T}(x, b; \mu, \zeta_1)} \frac{\text{unpol.TMDFF}}{D_1(z, b; \mu, \zeta_2)}}_{D_1(z, b; \mu, \zeta_2)},$$

$$F_{UU}^{\sin(\phi_h-\phi_s)} = |C_V(-Q^2,\mu^2)|^2 \sum_f e_f^2 \int \frac{db}{2\pi} b J_0(b|q_T|) \underbrace{f_1(x,b;\mu,\zeta_1)}_{\text{unpol.TMDPDF}} \underbrace{D_1(z,b;\mu,\zeta_2)}_{\text{unpol.TMDFF}},$$

 with

$$\mu \sim Q, \qquad \zeta_1 \zeta_2 = Q^4$$

The Sivers asymmetry is

$$A_{UT}^{\sin(\phi_h - \phi_s)} = -M \frac{\sum_f e_f^2 \int \frac{db}{2\pi} b^2 J_1(b|q_T|) f_{1T}(x,b;Q,Q^2) D_1(z,b;Q,Q^2)}{\sum_f e_f^2 \int \frac{db}{2\pi} b J_0(b|q_T|) f_1(x,b;Q,Q^2) D_1(z,b;Q,Q^2)}$$
(1)
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A bit of theory: TMD evolution

$$F(x,b;\mu,\zeta) = R[b;(\mu,\zeta) \leftarrow (\mu_0,\zeta_0)]F(x,b;\mu_0,\zeta_0),$$

where

$$R[b;(\mu_1,\zeta_1)\leftarrow(\mu_0,\zeta_0)] = \exp\left[\int_{(\mu_0,\zeta_0)}^{(\mu_1,\zeta_1)} dt \left(\gamma_F(\mu,\zeta)\frac{d\ln\mu}{dt} - \mathcal{D}(b,\mu)\frac{d\ln\zeta}{dt}\right)\right]$$
(2)



$$F(x,b;\mu,\zeta) = R[b;(\mu,\zeta) \leftarrow (\mu_0,\zeta_0)]F(x,b;\mu_0,\zeta_0),$$

where

$$R[b;(\mu_1,\zeta_1)\leftarrow(\mu_0,\zeta_0)] = \exp\left[\int_{(\mu_0,\zeta_0)}^{(\mu_1,\zeta_1)} dt \left(\gamma_F(\mu,\zeta)\frac{d\ln\mu}{dt} - \mathcal{D}(b,\mu)\frac{d\ln\zeta}{dt}\right)\right]$$
(2)

$\zeta\text{-} \text{prescription}$

- Evolution along vertical trajectory to the equi-evolution curve
- ► TMD on the equi-evolution curve is Scaleless ("optimal" TMD [I.Scimemi,AV,1803.11089])

$$F(x,b;\mu,\zeta) = \left(\frac{\zeta}{\zeta_{\mu}[\mathcal{D}]}\right)^{-\mathcal{D}(b,\mu)} \underbrace{F(x,b)}_{\text{"optimal"}}$$

► The evolution prefactor is a known function of non-perturbative D (exact transcendental/algebraic) [AV,1907.10356]



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In ζ -prescription Sivers asymmetry is

$$A_{UT}^{\sin(\phi_h - \phi_s)} = -M \frac{\sum_{f} e_f^2 \int \frac{db}{2\pi} b^2 J_1(b|q_T|) \left(\frac{Q^2}{\zeta_Q[\mathcal{D}]}\right)^{-2\mathcal{D}(b,Q)} f_{1T}^{\perp}(x,b) D_1(z,b)}{\sum_{f} e_f^2 \int \frac{db}{2\pi} b J_0(b|q_T|) \left(\frac{Q^2}{\zeta_Q[\mathcal{D}]}\right)^{-2\mathcal{D}(b,Q)} f_1(x,b) D_1(z,b)}$$
(3)

All green NP functions are know

- SV19 global fit, DY+SIDIS [I.Scimemi, AV, 1912.06532]
- \rightarrow + π TMDPDF fit [AV,1907.10356]
- ▶ NNLO or N³LO evolution (with NNLO small-b matching)
- The only unknown is Sivers function
 - ▶ Evolution is known (N³LO)
 - Small-b matching is possible but not necessary
 - At small-b Sivers matches twist-3 functions

$$f_{1T}^{\perp}(x,b) = \mp \pi T(-x,0,x) + \alpha_s \underbrace{[T,\Delta T,G^+,G^-]}_{\text{live on hexagon}}$$





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Parameterization of Sivers function

"Model 8.case 2"

$$f_{1T}^{\perp}(x,b) = N_f \frac{(1-x)^{\alpha} x^{\beta_f} (1+\epsilon_f x)}{N(\beta_f,\epsilon_f)} \frac{1}{\cosh((r_0+r_1 x)b)}$$

- ▶ We distinguish only u,d, and sea quarks
- ▶ α is common

$$\blacktriangleright \epsilon_{sea} = 0$$

$$N(\beta,\epsilon) = \int_0^1 dx (1-x) x^\beta (1+\epsilon x)$$



TMD factorization works only for large-Q and small $\delta = q_T/Q$

- ▶ THE MOST data points in SIDIS are with $\delta > 1$
- ▶ THE MOST data points in SIDIS are with $Q \sim 1$ GeV (totally contaminated by mass-corrections)
- ▶ We took only q_T differential data
- ▶ We need to apply mild assumptions

$$\delta$$

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 $\langle Q \rangle > 2 \text{GeV}, \qquad \delta < 0.3$

- ▶ Compass→14 points
- ▶ Hermes→46 points
- ▶ Jlab→3 points
- ▶ Compass $\pi DY \rightarrow 2$ points
- ▶ Star W^{\pm}, Z 10 points

Total: 75 points

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$$\frac{\chi^2}{\#\text{points}} = 1.03 \, (1.02 [\text{SIDIS}] + 1.08 [\text{DY}])$$

Model8 case2





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	x = 0.224	x = 0.56	$n_{-} = 0.26$	ilah siyora kt	
	x = 0.324 x = 0.249	z = 0.30 z = 0.58	$p_T = 0.20$	ilab sivers pi-	
	x = 0.343 x = 0.349	z = 0.56	$p_T = 0.24$ $p_T = 0.24$	ilab sivers ni+	
	x = 0.043 x = 0.201	z = 0.50 z = 0.571	$p_T = 0.24$ $p_T = 0.294$	Jido.aivera.pi.	
	r = 0.196	z = 0.562	$p_T = 0.154$		
	x = 0.195	z = 0.42	$p_T = 0.149$		
	x = 0.203	z = 0.322	$p_T = 0.146$		
7	x = 0.201	z = 0.241	$p_T = 0.144$		
	x = 0.115	z = 0.563	$p_T = 0.149$		
i i	x = 0.115	z = 0.423	$p_T = 0.149$		
	x = 0.116	z = 0.323	$p_T = 0.142$		
* •	x = 0.085	z = 0.567	$p_T = 0.15$		
	x = 0.084	z = 0.424	$p_T = 0.143$		
	x = 0.055	z = 0.562	$p_T = 0.151$		
	x = 0.054	z = 0.424	$p_T = 0.146$	hermes.sivers.k3d	
· · · · · · · · · · · · · · · · · · ·	x = 0.206	z = 0.577	$p_T = 0.296$		
	x = 0.204	z = 0.576	$p_T = 0.149$		
	x = 0.204	z = 0.424	$p_T = 0.15$		
i →	x = 0.204	z = 0.323	$p_T = 0.142$		
	x = 0.207	z = 0.242	$p_T = 0.138$		
	x = 0.116	z = 0.574	$p_T = 0.15$		
	x = 0.116	z = 0.424	$p_T = 0.148$		
	x = 0.116	z = 0.324	$p_T = 0.142$		
	x = 0.085	z = 0.577	$p_T = 0.15$		
	x = 0.083 x = 0.057	z = 0.423 z = 0.579	$p_T = 0.145$ $v_c = 0.15$		
	x = 0.051	z = 0.072 z = 0.492	$p_T = 0.13$ $p_c = 0.148$	hormon nimore he 2d	
	x = 0.033 x = 0.198	2 = 0.422	$p_T = 0.143$ $p_T = 0.295$	Hermes, Sivers, K+. 3d	
	r = 0.197	z = 0.574 z = 0.574	$p_T = 0.152$		
	x = 0.197	z = 0.422	$p_T = 0.149$ $p_T = 0.149$		
	x = 0.199	z = 0.321	$p_T = 0.148$		
4	x = 0.204	z = 0.239	$p_T = 0.141$		
	x = 0.116	z = 0.579	$p_T = 0.15$		
	x = 0.116	z = 0.422	$p_T = 0.148$		
Ⅰ	x = 0.116	z = 0.321	$p_T = 0.144$		
	x = 0.084	z = 0.579	$p_T = 0.148$		
	x = 0.084	z = 0.423	$p_T = 0.146$		
	x = 0.056	z = 0.579	$p_T = 0.151$	hermes.sivers.pi3d	
	x = 0.2	z = 0.577	$p_T = 0.296$		
	x = 0.2	z = 0.575	$p_T = 0.153$		
7	x = 0.201	z = 0.422	$p_T = 0.15$ 0.147		
31	2 = 0.201	z = 0.321	$p_T = 0.141$		
	x = 0.203	z = 0.239 = 0.577	$p_T = 0.141$		
	x = 0.116 x = 0.116	z = 0.377 z = 0.423	$p_T = 0.151$ $p_T = 0.148$		
	r = 0.116	0.322	$p_T = 0.140$ $p_T = 0.143$		
	r = 0.085	2 = 0.522	$p_T = 0.140$ $p_T = 0.148$		
1	x = 0.085	z = 0.423	$p_T = 0.146$		
	x = 0.056	z = 0.579	$p_T = 0.151$	hermes.sivers.pi+.3d	
	x = 0.24	z = 0.32	$p_T = 0.4$	· · ·	
	x = 0.238	z = 0.31	$p_T = 0.21$		
•	x = 0.132	z = 0.32	$p_T = 0.21$		
4	x = 0.075	z = 0.33	$p_T = 0.21$	compass16.sivers.hz>2.dpt	
· · · · · · · · · · · · · · · · · · ·	x = 0.246	z = 0.34	$p_T = 0.4$		
	x = 0.245	z = 0.33	$p_T = 0.21$		
I III	x = 0.14	z = 0.34	$p_T = 0.21$		
<u> </u>	x = 0.079	z = 0.34	$p_T = 0.21$	compass16.sivers.h+.z>2.dpt	
*	x = 0.233	z = 0.14	$p_T = 0.21$	compass16.sivers.h1 <z<2.d< th=""><th>pe</th></z<2.d<>	pe
1	x = 0.237	z = 0.14	$p_T = 0.21$	compassio.sivers.h+.1 <z<2.d< th=""><th>pr D</th></z<2.d<>	pr D
	x = 0.032 x = 0.029	z = 0.38 z = 0.20	$p_T = 0.154$ $p_T = 0.1542$	compass.sivers.kdpt	- 1 /
T	x = 0.039 x = 0.041	z = 0.39 z = 0.25	$p_T = 0.1543$ $p_T = 0.1545$	compass.sivers.k*.dpt	
I	x = 0.041 x = 0.043	z = 0.35 z = 0.35	$p_T = 0.1543$ $p_T = 0.1547$	compass sivers ni+ dnt	Universität Regensburg
	2 = 0.043	2 = 0.30	pT = 0.1511	company. 011018. p11. upt	
0.0 U	+0.5		• • •	★御▶ ★臣▶ ★臣▶	E 990

Model8 case2

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Comparison to M.Echevarria, Z.-B.Kang, J.Terry [2009.10710] relative factor $(2M)^{-1}\simeq 1.8$



Comparison to A.Bacchetta, F. Delcarro, C.Pisano, M.Radici, [2004.14278]



Comparison to M.Echevarria, Z.-B.Kang, J.Terry [2009.10710] sea-quarks



Comparison to A.Bacchetta, F. Delcarro, C.Pisano, M.Radici, [2004.14278] sea-quark



Part 2: Impact of EIC In Progress!



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Repository: https://github.com/VladimirovAlexey/EIC_YR_TMD Data by Ralf: /Data1 PID and PID+HB based on reweighed MC by Torino08

Usual TMD cut: $p_T < 0.25zQ$, Q > 2 (and z > 0.05 for technical reasons)

	# points	#points after cut
(5×41)	$\sim 3 \cdot 10^3$	$\sim 1 \cdot 10^3$
(5×100)	$\sim 3.5\cdot 10^3$	$\sim 1.3 \cdot 10^3$
(10×100)	$\sim 3.5\cdot 10^3$	$\sim 1.6\cdot 10^3$
(18×100)	$\sim 4. \cdot 10^3$	$\sim 1.9 \cdot 10^3$
(18×285)	$\sim 4.\cdot 10^3$	$\sim 2.2\cdot 10^3$
		$\sim (7 7.5) \cdot 10^3$
		$\times \{\pi^{\pm}\}$

• (compare to global analysis) ~ 75

Some points has huge error (pseudodata, or theory, or more then 100% disagreement (theory-pseudo data) [~ 3% of data points, mainly on the edges of phase-space]. These are thrown away

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		1		
	-	x=0.15	z=0.94	p_T=0.255
 		x=0.147	z=0.842	p_T=0.249
	<u> </u>	x=0.151	z=0.741	p_T=0.252
· · · · · · · · · · · · · · · · · · ·	 	x=0.149	z=0.642	p_T=0.249
-	•	x=0.148	z=0.541	p_T=0.249
	•	x=0.149	z=0.44	p_T=0.248
	•	x=0.149	z=0.34	p_T=0.25
		x=0.15	z=0.24	p_T=0.249
		x=0.148	z=0.172	p_T=0.249
•		x=0.148	z=0.121	p_T=0.248
		x=0.148	z=0.07	p_T=0.248
	-	x=0.144	z=0.841	p_T=0.147
		x=0.15	z=0.746	p_T=0.154
	-	x=0.146	z=0.64	p_T=0.153
	-	x=0.148	z=0.541	p_T=0.153
4	•	x=0.149	z=0.442	p_T=0.151
1		x=0.149	z=0.341	p_T=0.153
		x=0.149	z=0.24	p_T=0.152
		x=0.149	z=0.171	p_T=0.152
÷ •		x=0.148	z=0.121	p_T=0.152
4		x=0.148	z=0.0696	p_T=0.151

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Impact studies just started (takes some time to evaluate points) Some "morning results" 80 replicas Siv.18x275 pip ACC opt5

