TMDs from SIDIS data: role of different choices in phenomenological analyses

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Outline

1. Introduction
2. A case study: fitting quark Sivers function
3. Transversity function
4. Conclusions

1. Introduction

Introduction (I)

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- TMD theory got tremendous developement
- TMD phenomenology is the bridge connecting theory and experiment

Introduction (II)

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$$\Downarrow$$

Different amount of information for TMD physics

2. A case study: fitting quark Sivers function

Sivers fit

M. Boglione, U. D'Alesio, CF and J. O. Gonzalez-Hernandez, JHEP07 (2018) 148

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- study visibility of TMD effects in the data
- test different choices based on different input from theory

Sivers fit- model (I)

- Sivers function:

$$\Delta^N f_{q/p^\uparrow}(x, k_\perp) = 4N_q\, x^{\alpha_q}\,(1-x)^{\beta_q}\,\frac{M_p}{\langle k_\perp^2\rangle_S} k_\perp \frac{e^{-k_\perp^2/\langle k_\perp^2\rangle_S}}{\pi\langle k_\perp^2\rangle_S}$$

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- Parameters:

$$N_u,\ \alpha_u,\ \beta_u,\ N_d,\ \alpha_d,\ \beta_d,\ \langle k_\perp^2\rangle_S$$

Sivers fit - model (II)

Within the GPM, the SIDIS azimuthal asymmetry reads:

$$A_{UT}^{\sin(\phi_h-\phi_S)} = 2\frac{\int d\phi_S d\phi_h [d\sigma^{\uparrow} - d\sigma^{\downarrow}] \sin(\phi_h - \phi_S)}{\int d\phi_S d\phi_h [d\sigma^{\uparrow} + d\sigma^{\downarrow}]} = \frac{F_{UT}^{\sin(\phi_h-\phi_S)}}{F_{UU}}$$

where

$$F_{UT}^{\sin(\phi_h-\phi_S)}(x, P_T, z) = 2z \frac{P_T M_p}{\langle P_T^2 \rangle_S} \frac{e^{-P_T^2/\langle P_T^2\rangle_S}}{\pi \langle P_T^2 \rangle_S} \sum_q e_q^2 \left(N_q \, x^{\alpha_q} \, (1-x)^{\beta_q}\right) D_{h/q}(z)$$

$$F_{UU}(x, P_T, z) = \frac{e^{-P_T^2/\langle P_T^2\rangle}}{\pi \langle P_T^2 \rangle} \sum_q e_q^2 \, f_{q/p}(x) D_{h/q}(z)$$

$$\langle P_T^2 \rangle = \langle p_\perp^2 \rangle + z^2 \langle k_\perp^2 \rangle, \qquad \langle P_T^2 \rangle_S = \langle p_\perp^2 \rangle + z^2 \langle k_\perp^2 \rangle_S$$

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  - HERMES ($\pi^\pm, \pi^0, K^+$ production off proton target)
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$\Rightarrow$ 220 data points

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We tested different scenarios:

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3. “reference fit” + collinear twist-3 evolution
4. “reference fit” + Q^2-dependence of Sivers width:
   $\langle k_\perp^2 \rangle_S = g_1 + g_2 \log \frac{Q^2}{Q_0^2}$

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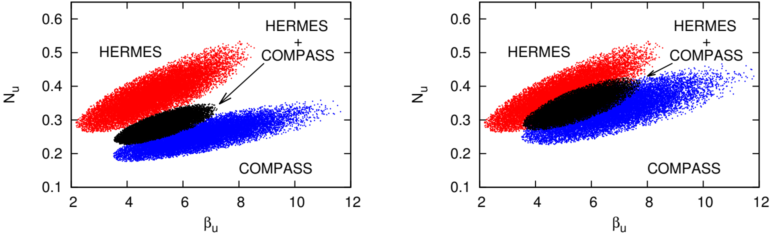
Sivers fit - widths

We used two different pair of widths as extracted from SIDIS multiplicities [Anselmino et al., JHEP04 (2014) 005]

- HERMES: $\langle k_\perp^2 \rangle = 0.57\,\mathrm{GeV}^2$, $\langle p_\perp^2 \rangle = 0.12\,\mathrm{GeV}^2$
- COMPASS: $\langle k_\perp^2 \rangle = 0.60\,\mathrm{GeV}^2$, $\langle p_\perp^2 \rangle = 0.20\,\mathrm{GeV}^2$



Left: HERMES widths for both HERMES and COMPASS
Right: corrispondent widths for HERMES and COMPASS

Sivers fit - reference fit (I)

Baseline: $\alpha_u = \alpha_d = 0 \Longrightarrow \Delta^N f^{(1)}_{q/p^\uparrow}(x) = N_q\,(1-x)^{\beta_q}$

$\chi^2_{\rm tot} = 212.8$ $\chi^2_{\rm dof} = 0.99$ $\Delta\chi^2 = 11.3$	n. of points $= 220$ n. of free parameters $= 5$	
HERMES, JLab	$\langle k_\perp^2 \rangle = 0.57\,{\rm GeV}^2$	$\langle p_\perp^2 \rangle = 0.12\,{\rm GeV}^2$
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$\langle k_\perp^2 \rangle_S = 0.30 \pm 0.15\,{\rm GeV}^2$		

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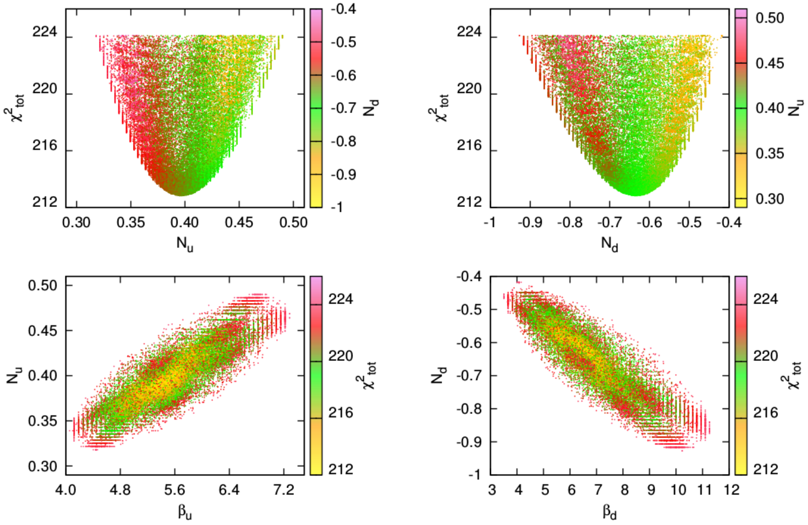

Sivers fit - "α-fit" (I)

Low-x uncertainties: $\Delta^N f^{(1)}_{q/p^\uparrow}(x) = N_q\, x^{\alpha_q}(1-x)^{\beta_q}$

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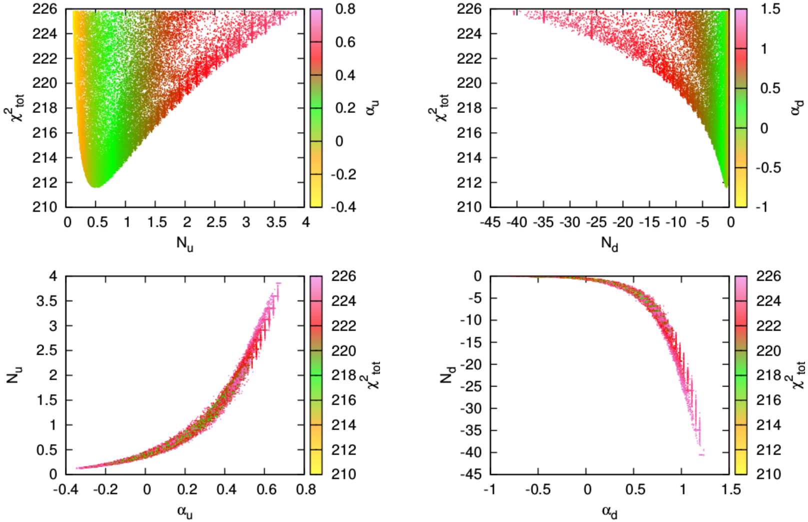
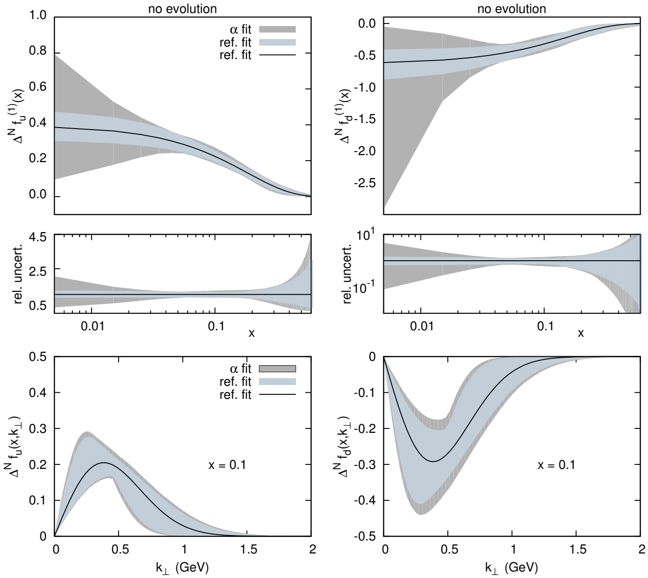
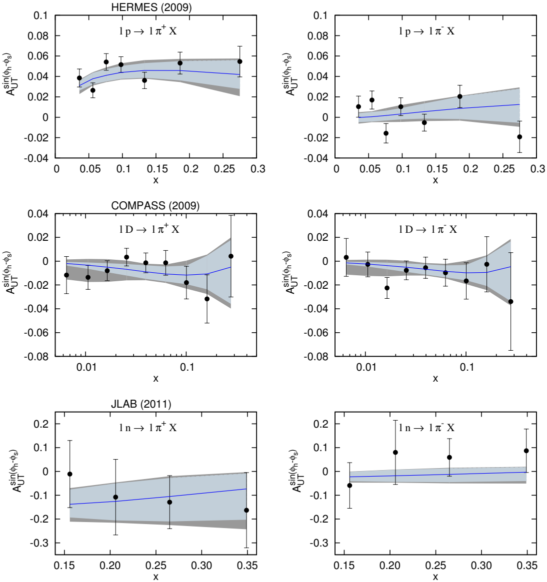


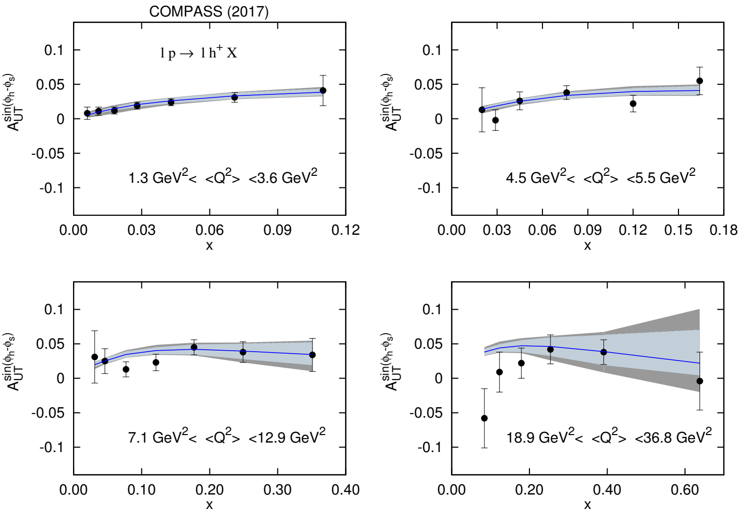
Sivers fit - results (I)



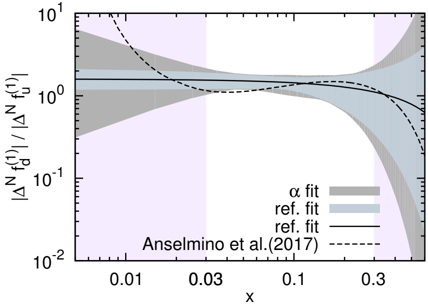
Sivers fit - results (II)



Sivers fit - results (III)



Sivers fit - uncertainties

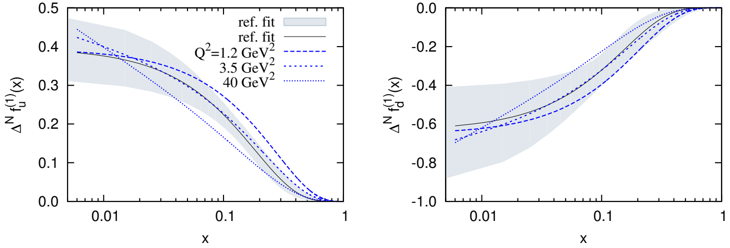


- Sivers function is largely unconstrained where there is no data
- model dependence has an important effect outside the bounds of experimental information
- future measurements at low-x (COMPASS, EIC) and at large-x (JLab12) will help to deepen the knowledge on the Sivers function

Sivers fit - collinear twist-3 evolution

Reference fit: $\Delta^N f^{(1)}_{q/p^\uparrow}(x) = N_q\,(1-x)^{\beta_q}$

- Sivers first moment is proportional to collinear twist-3 quark gluon correlation function $T_{q,F}(x,x)$
- Q^2-evolution kernels for $T_{q,F}(x,x)$ are known $\Rightarrow$ test Q^2-dependence of Sivers function



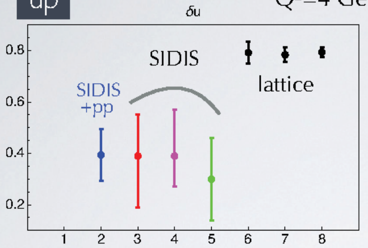
- $Q^2 = 3.5$ GeV^2 is the experimental average value
- twist-3 evolution affects only x-dependent part of the Sivers function
- hint on visible signals of evolution in the data

3. Transversity function

tensor charge : separate flavors

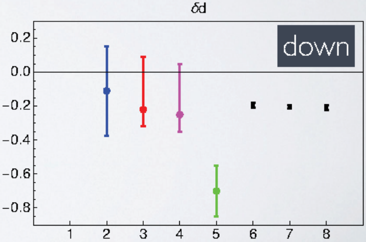
up

Q^2=4 GeV^2 *



incompatibility for up

compatibility for down
but within large errors
(except JAM)



2- global fit *Radici & Bacchetta, P.R.L. 120 (18) 192001*

3- TMD fit *Kang et al., P.R. D93 (16) 014009* *** Q^2=10**

4- Torino *Anselmino et al., P.R. D87 (13) 094019* *** Q^2=1**

5- JAM fit *Lin et al., P.R.L. 120 (18) 152502* *** Q_0^2=2**

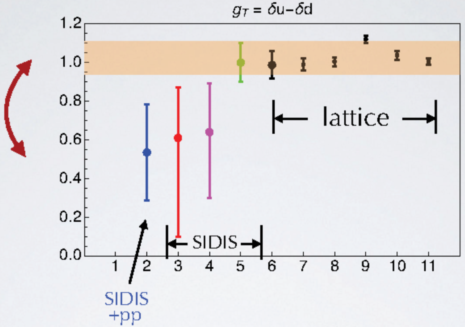
6- PNDME16 *Bhattacharya et al., P.R. D94 (16) 054508*

7- PNDME18 *Gupta et al., arXiv:1808.07597*

8- ETMC17 *Alexandrou et al., P.R. D95 (17) 114514; E P.R. D96 (17) 099906*

isovector tensor charge $g_T = \delta u - \delta d$

?



Q^2=4 GeV^2 *

JAM includes
"lattice data"

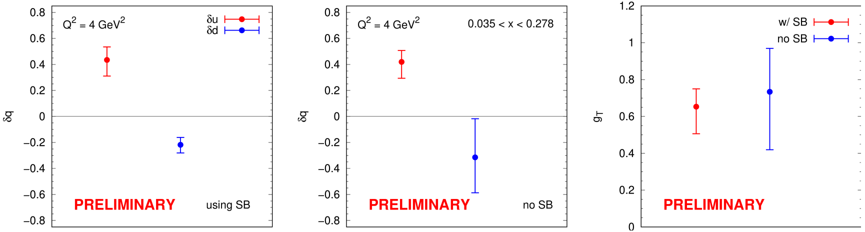
Radici & Bacchetta, P.R.L. 120 (18) 192001	2) **global fit '17**	6) PNDME '16	*Bhattacharya et al., P.R. D94 (16) 054508*
Kang et al., P.R. D93 (16) 014009	3) **"TMD fit" * Q^2=10**	7) PNDME '18	*Gupta et al., P.R. D98 (18) 034503*
Anselmino et al., P.R. D87 (13) 094019	4) **Torino fit * Q^2=1**	8) ETMC '17	*Alexandrou et al., P.R. D95 (17) 114514; E P.R. D96 (17) 099906*
Lin et al., P.R.L. 120 (18) 152502	5) **JAM fit '17 * Q_0^2=2**	9) NPLQCD '18	*Chang et al., P.R.L. 120 (18) 152002*
		10) LHPC '12	*Green et al., P.R. D86 (12)*
		11) RQCD '14	*Bali et al., P.R. D91 (15)*

from GPD
see also talk by S. Liuti

Transversity fit - a test

- exploratory and preliminary study to fit simultaneously transversity and Collins function
- usual global fit (SIDIS $A_{UT}^{\sin(\phi_h+\phi_S)}$ + e^+e^- $A_O^{UL(C)}$ data)
- test: relax automatic satisfaction of Soffer Bound for transversity
- transversity proportional to SB only at the initial scale, no bound on normalization

Tensor charge



- still incompatibility with lattice for up
- relaxing automatic satisfaction of SB gives compatibility with lattice for g_T

4. Conclusions

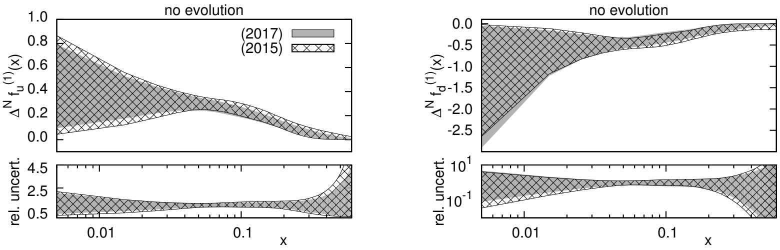
Conclusions

- TMD physics is entering into a new era: more data (and more precise) will come
- in the meanwhile, since the amount of information we have is still not that large, the choices we make in phenomenological extraction can be crucial
- let's not forget what data is telling us now, it is very important for the future
- should we push the bounds?

Thank you

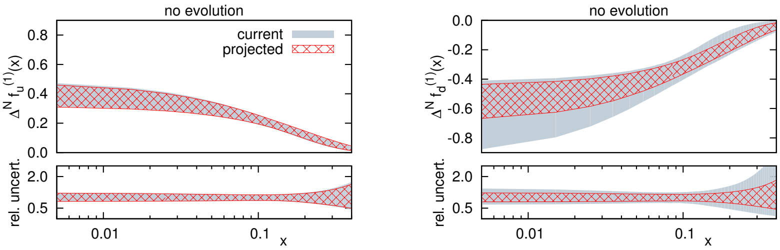
Backup

Sivers fit - impact of Q^2 binned data



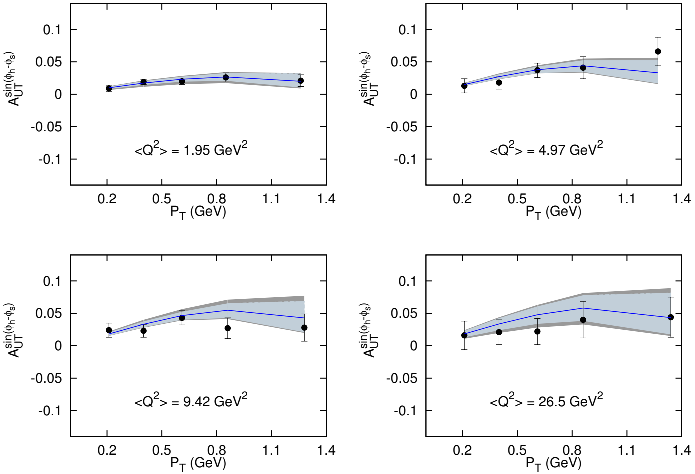
- same measurements but different binning (Q^2-binning, same as Drell-Yan)
- slight reduction on uncertainty bands
- increased degree of information with new binning
- more suitable for scale dependence studies

Sivers fit - COMPASS 2021 projection



- new run of SIDIS measurements proposed by COMPASS collaboration for the 2021 deuteron run
- projected error have no impact on *u*-quark
- uncertainty for *d*-quark is about a factor of 2 for $x < 0.1$

Sivers fit - P_T-dependent results



Sivers fit - TMD-like evolution (I)

Reference fit: $\Delta^N f^{(1)}_{q/p^\uparrow}(x) = N_q\,(1-x)^{\beta_q}$, with

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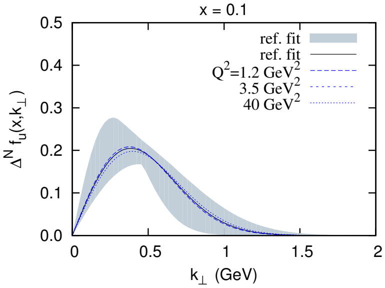
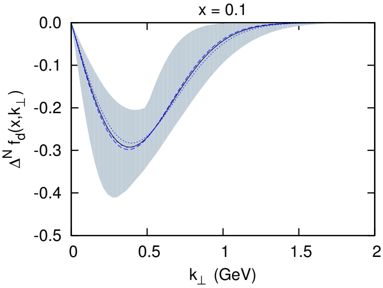
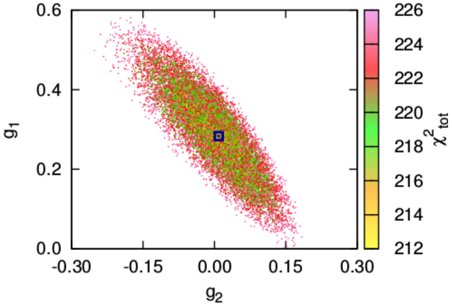
$N_u = 0.40 \pm 0.09$ $N_d = -0.63 \pm 0.26$	$\beta_u = 5.42 \pm 1.70$ $\beta_d = 6.45 \pm 3.89$	
$\langle k_\perp^2 \rangle_S = g_1 + g_2 \log\left(Q^2/Q_0^2\right)$ $g_1 = 0.28 \pm 0.29\ \text{GeV}^2$	$g_2 = 0.01 \pm 0.20\ \text{GeV}^2$	

Sivers fit - TMD-like evolution (II)



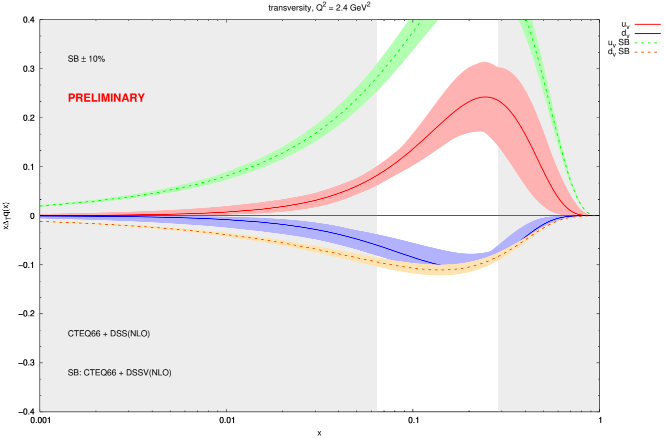


Sivers fit - TMD-like evolution (III)



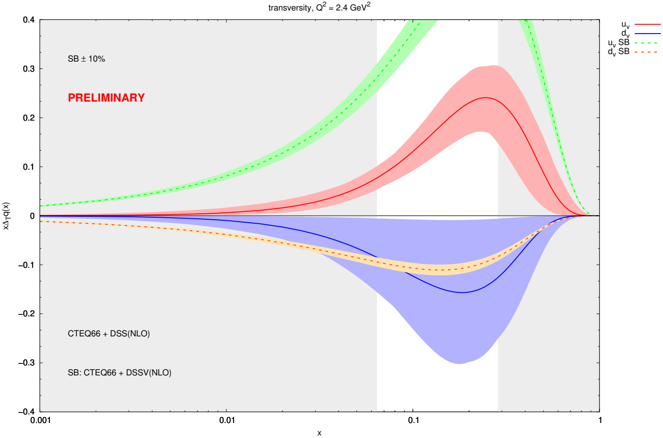
- both parameters are affected by a rather large uncertainty and are strongly correlated
- current Sivers asymmetries will probably not constrain strongly g_K
- g_1 close to the reference fit value; g_2 very small but very large uncertainty $\Rightarrow$ compatibility between Sivers asymmetries and extracted g_K values from other observables is likely to be achieved

Transversity fit - using SB



- relaxing SB does not change u_v transversity
- SB violation for d_v is not statistically significant

Transversity fit - no SB



- relaxing SB does not change u_v transversity
- SB violation for d_v is not statistically significant