Hermes and Compass contribution to Sivers function

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Transverse Momentum Distributions: TMD PDF

quark pol.

nucleon pol.	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

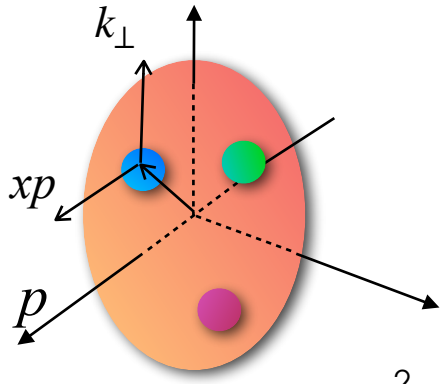
Sivers function

dependence on:

longitudinal momentum fraction x

transverse momentum $k_\perp$

energy scale

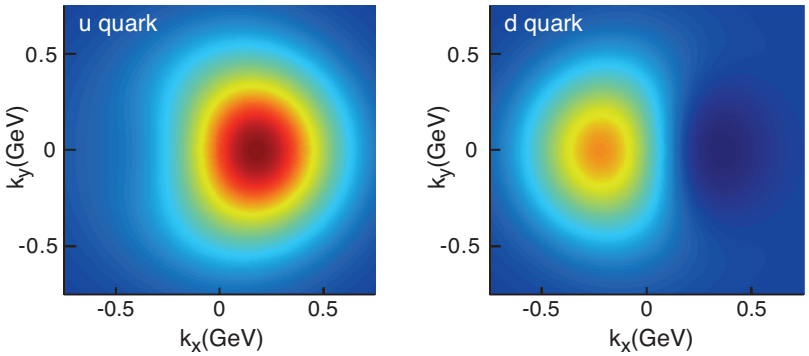


Phenomenology of polarized TMDs

⇒ presence of a non-zero Sivers function $f_{1T}^{\perp}$

will induce a dipole deformation of f_1

x $f_1(x, k_T, S_T)$

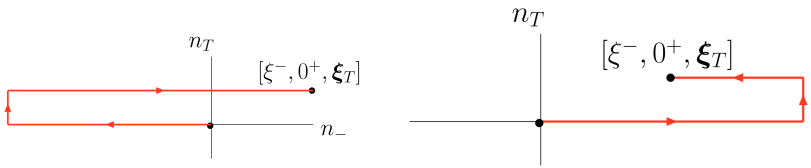


[EIC White Paper]

Sign change in Sivers function

DY
past-pointing

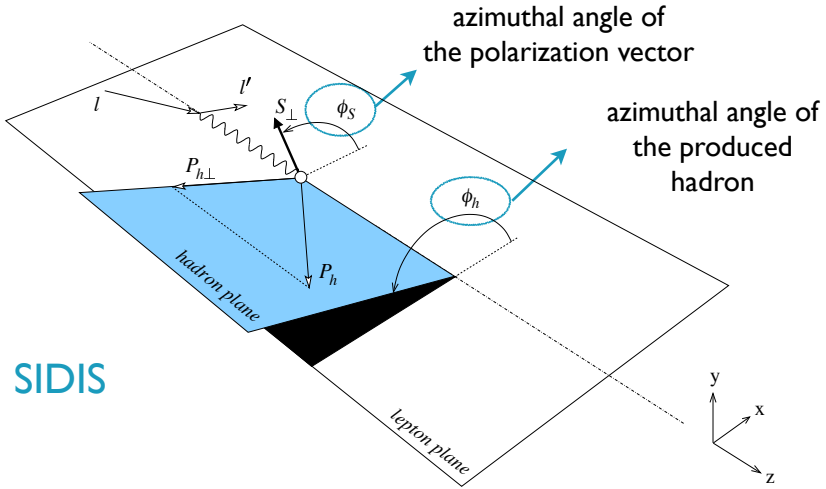
SIDIS
future-pointing



$$f_{1T,DIS}^{\perp} = -f_{1T,DY}^{\perp}$$

Extraction of Sivers Function

Determined through its contributions to the cross section of polarized SIDIS



SIDIS

LO - NLL

$$A_{UT}^{\sin(\phi_h-\phi_S)} \equiv \langle \sin(\phi_h - \phi_S) \rangle \sim \frac{f_{1T}^{\perp} \otimes D_1^{a\to h}}{f_1^a \otimes D_1^{a\to h}}$$

universality

Parametrization of Sivers function

Sivers function parametrized in terms of its first moment

$$f_{1T}^{\perp}(x,k_{\perp}^2) = f_{1T}^{\perp(1)}(x) f_{1TNP}^{\perp}(x,k_{\perp}^2)$$

Its nonperturbative part is arbitrary, but constrained by the positivity bound.

$$f_{1TNP}^{\perp}(x,k_{\perp}^2) = \frac{1}{\pi K_f}\frac{1}{F_{max}}\frac{(1+\lambda_S k_{\perp}^2)}{(M_1^2+\lambda_S M_1^4)} e^{-k_{\perp}^2/M_1^2} f_{1NP}(x,k_{\perp}^2)$$

following the definition to the nonperturbative part of the unpolarized TMD distribution

$$f_{1\mathrm{NP}}(x,b_T^2) \propto \text{F.T. of } \left(e^{-\frac{k_{\perp}^2}{g1A}} + \lambda_B k_{\perp}^2 e^{-\frac{k_{\perp}^2}{g1B}} + \lambda_C e^{-\frac{k_{\perp}^2}{g1C}}\right)$$

from MAP22 TMD extraction

Free parameters λ_S, M_1

Parametrization of Sivers function

normalization (abs.value <1)

$T_n(x)$ Chebyshev polynomials

$$f_{1T}^{\perp(1)}(x) = \frac{N_{Siv}^a}{G_{max}^a} x^{\alpha_a}(1-x)^{\beta_a}\left(1 + A_a T_1(x) + B_a T_2(x)\right) f_1(x, Q^2)$$

maximum value of the function

Free parameters $N_{Siv}^a, \alpha_a, \beta_a, A_a, B_a$

Flavor dependent: distinct for up, down, sea

Evolution of Sivers function first moment

evolved Sivers function first moment

$$\tilde{f}_{1T}^{\perp(1)a}(x, b_T^2; Q^2) =$$

$$= \sum_i \left(\tilde{C}_{a/i} \otimes f_1^i\right)\left(x, \bar{b}_*; \mu_b\right) e^{\tilde{S}(\bar{b}_*; \mu_b, \mu)} e^{g_K(b_T)\ln(\mu/\mu_0)} \hat{f}_{1TNP}^{\perp(1)a}\left(x, b_T\right)$$

nonperturbative part of TMD

(Wilson Coefficient)

collinear PDF

(Sudakov form factor)

pQCD

nonperturbative part of evolution

Fourier transform: b_T space

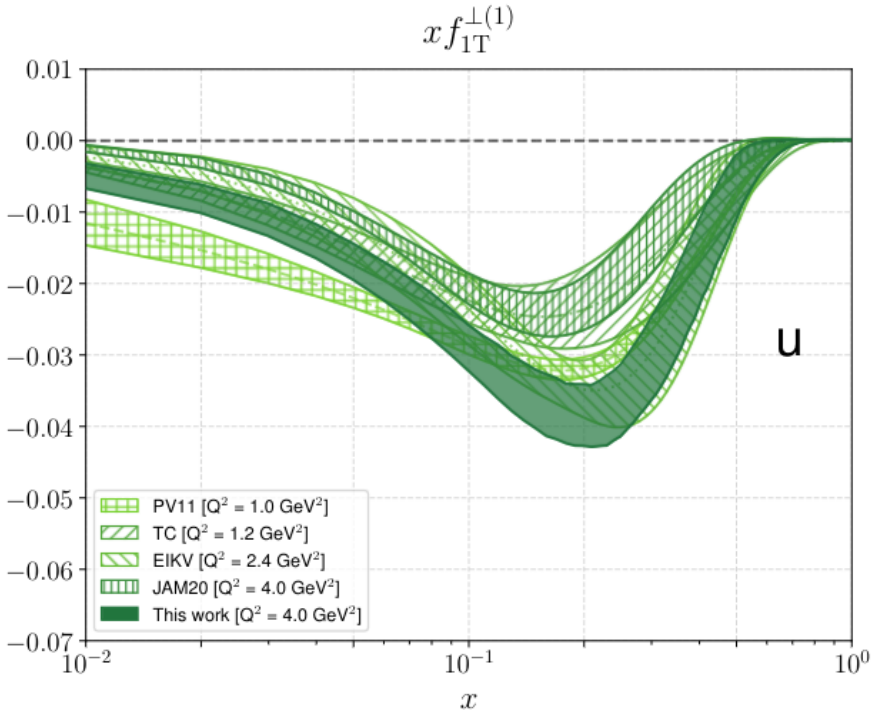
Free parameters g_2

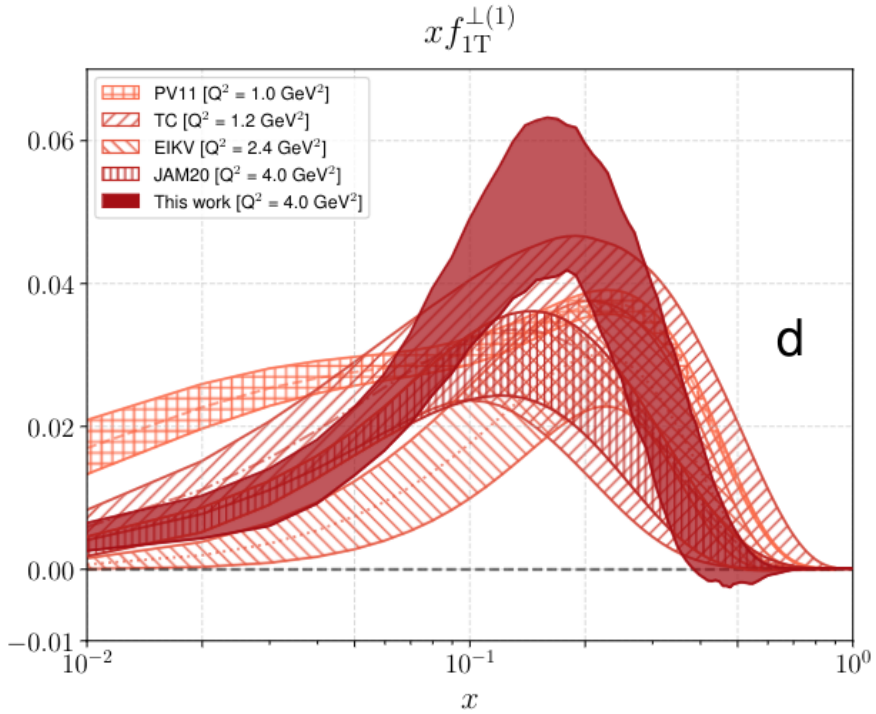
PV20Sivers: Polarized TMDs

$$\chi^2 = 1.12$$

125 data points from SIDIS, DY

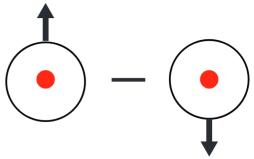
LO-NLL





TMDs

PV20Sivers

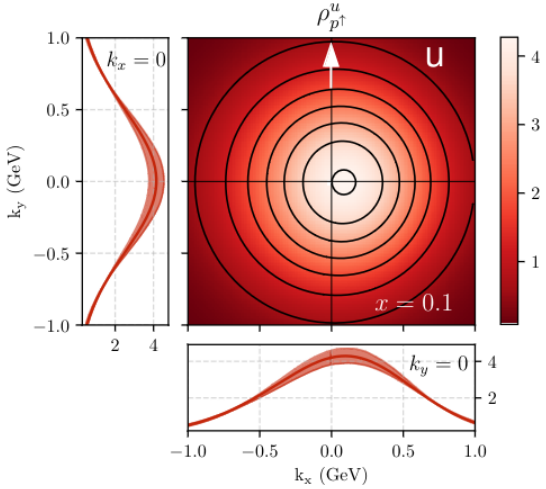


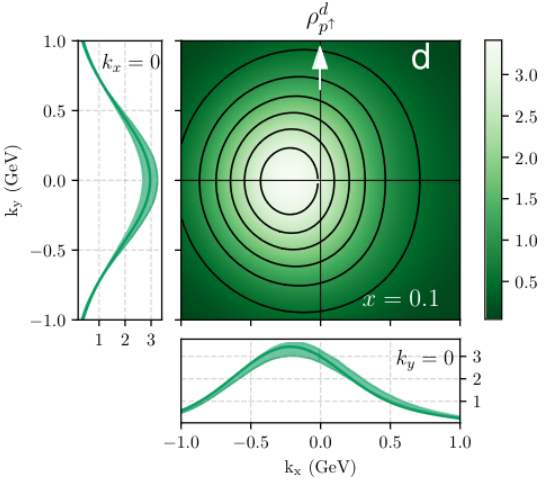
polarized

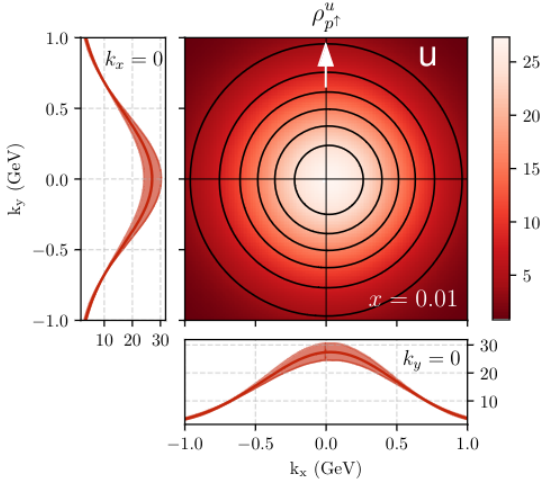
$$f_1(x,k_\perp;Q^2) - f_{1T}^{\perp}(x,k_\perp;Q^2)$$

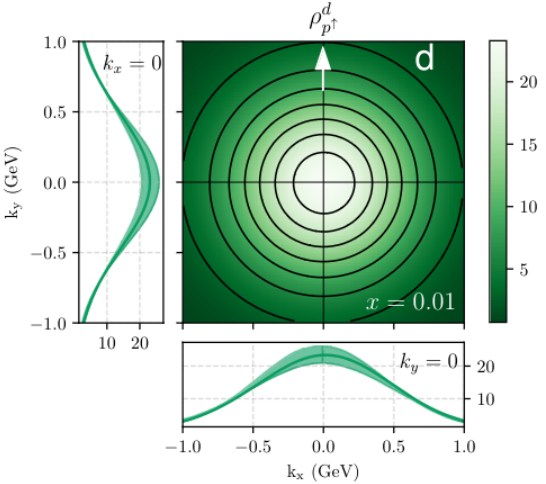
PV17

unpolarized









Updated Sivers extraction

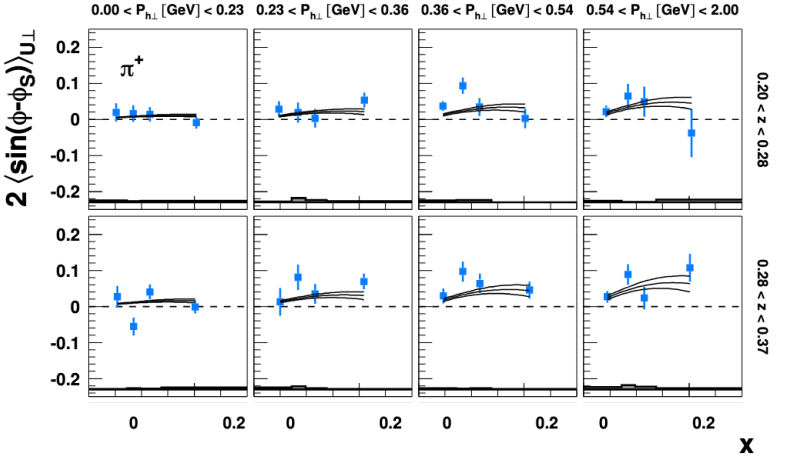
Additional data

2020

[JHEP12(2020)010]

SIDIS

Multidimensional
x, P_{hT}, *z*



2022

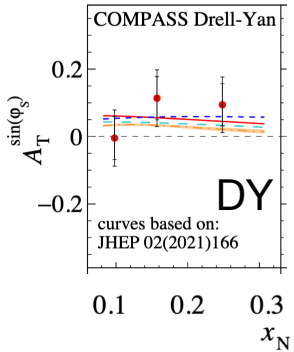
2015-2018

[PRL133]

SIDIS

pion-induced
DY

projected in *x*



Updated Sivers extraction

included datasets

SIDIS

[JHEP12(2020)010]

target: proton [H]

final state hadron

π^+, π^-, K^+, K^-

250 data points

[PRL107,072003(2011)]

Jefferson Lab

t: neutron [^{3}He]

6 data points

[PLB673,127(2009)]
[PLB770,138(2017)]
[PRL133]

2009 t: deuteron [^{6}LiD]

2017 t: Proton [NH_3]

2022 t: deuteron [^{6}LiD]

f.s.h

h^+, h^-

98 data points

DY

W-Z production
2016

[PRL116,132301(2016)]

7 data points

2015-2018

pion-induced DY
t: Proton [NH_3]

3 data points

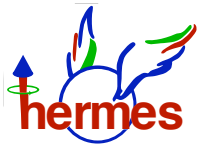
[PRL133]

Total number of data

364

Updated Sivers extraction

Additional data



2020

[JHEP12(2020)010]

2022

2015-2018

[PRL133]

More accurate unpolarized TMDs

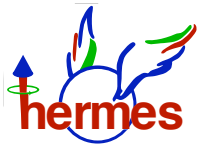
for a self-consistent global extraction

MAPTMD22 [JHEP10(2022)127]

pionMAPTMD [PRD.107.014014]

Updated Sivers extraction

Additional data



2020

[JHEP12(2020)010]

2022

2015-2018

[PRL133]

Accurate unpolarized TMDs

MAPTMD22

[JHEP10(2022)127]

pionMAPTMD

[PRD.107.014014]

Revised fitting framework

NangaParbat

Nanga Parbat: MAP framework

Nanga Parbat: a TMD fitting framework

Nanga Parbat is a fitting framework aimed at the determination of the non-perturbative component of TMD distributions.

Download

You can obtain NangaParbat directly from the github repository:

https://github.com/MapCollaboration/NangaParbat

updated MAP Sivers Fit results

Total number of data

364

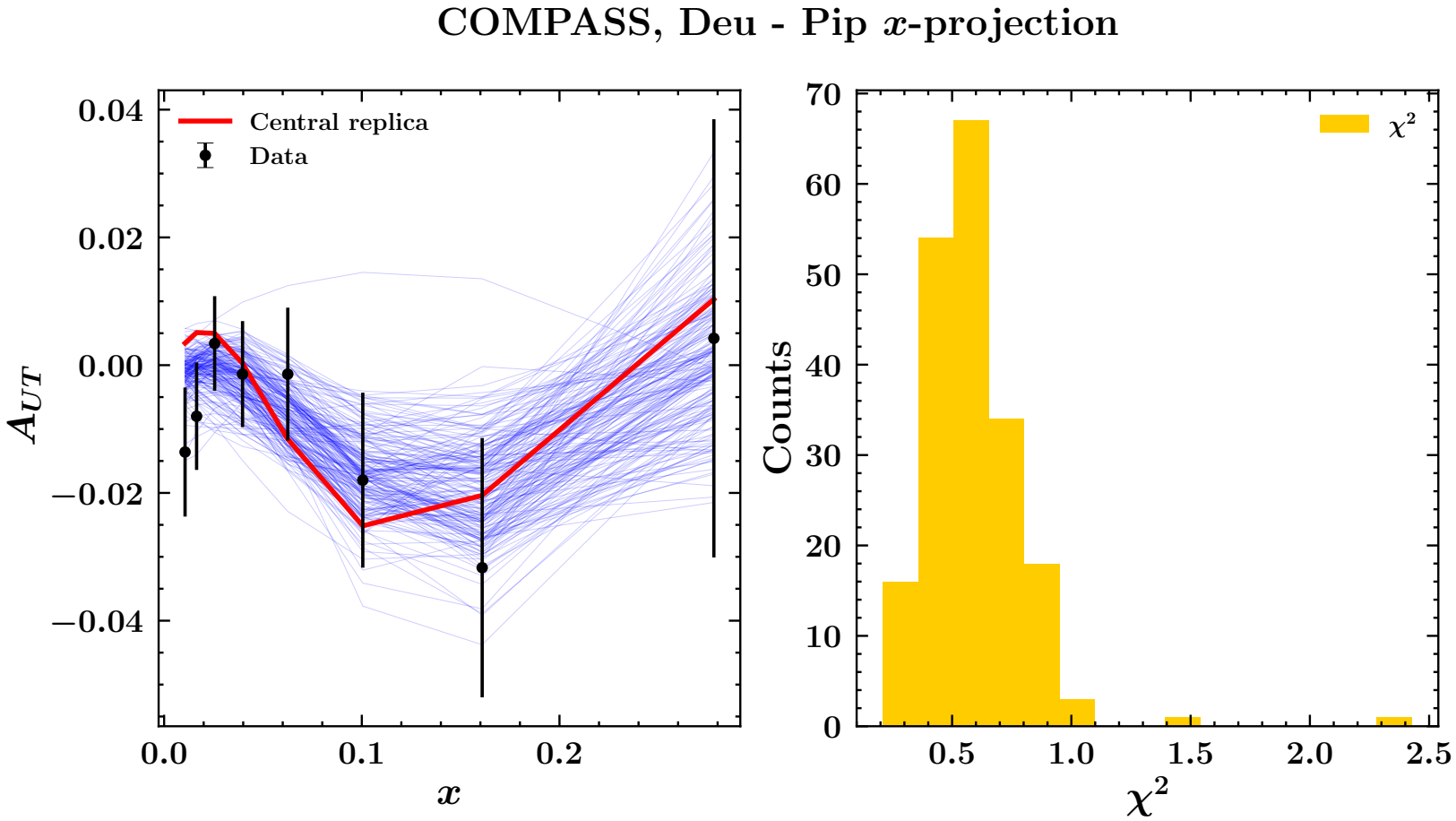
$$\chi^2 = 1.07$$

global fit from

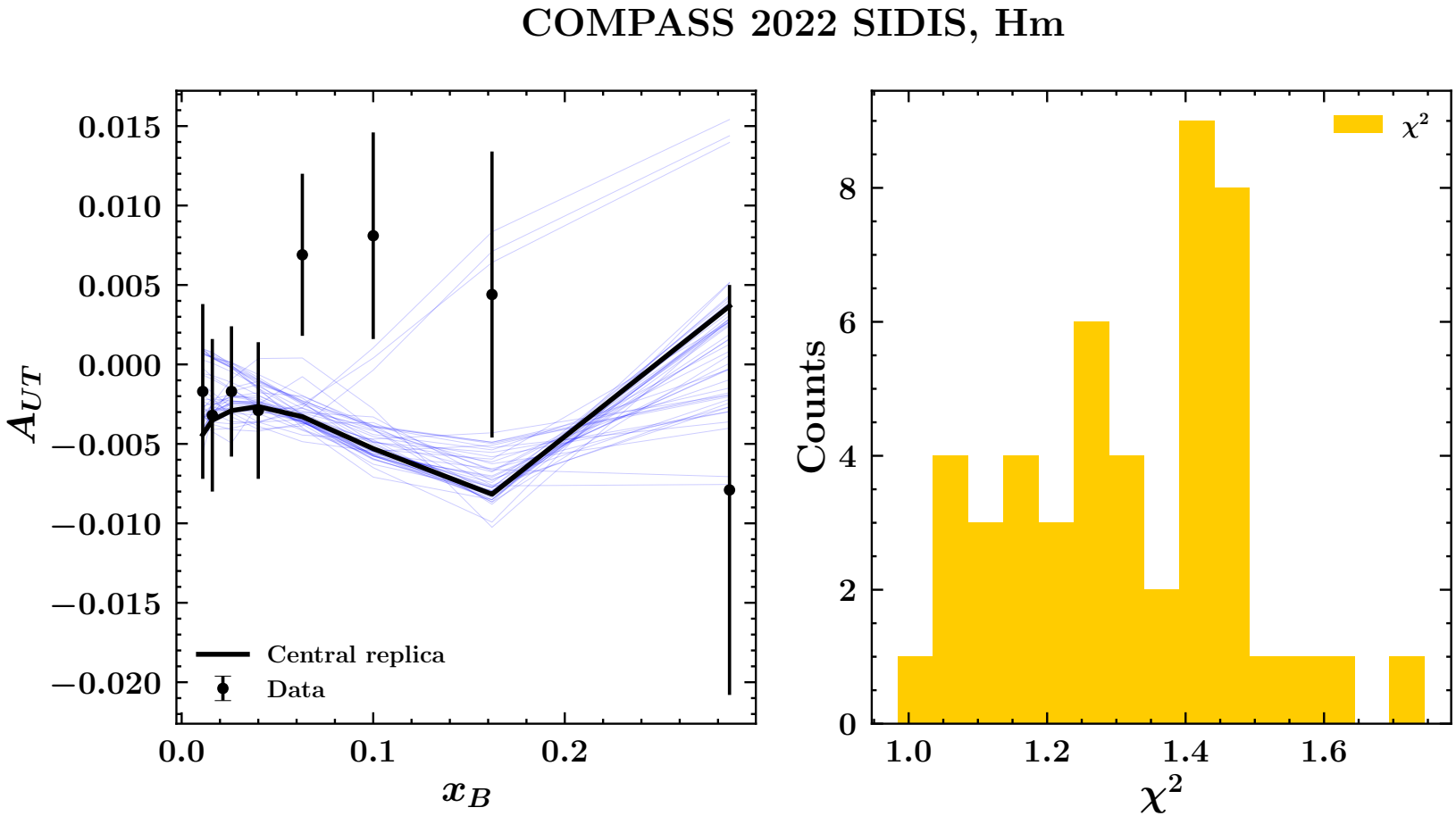
- semi-inclusive DIS,
- pion-induced Drell-Yan,
- W-Z boson production

Accuracy: NLL-LO

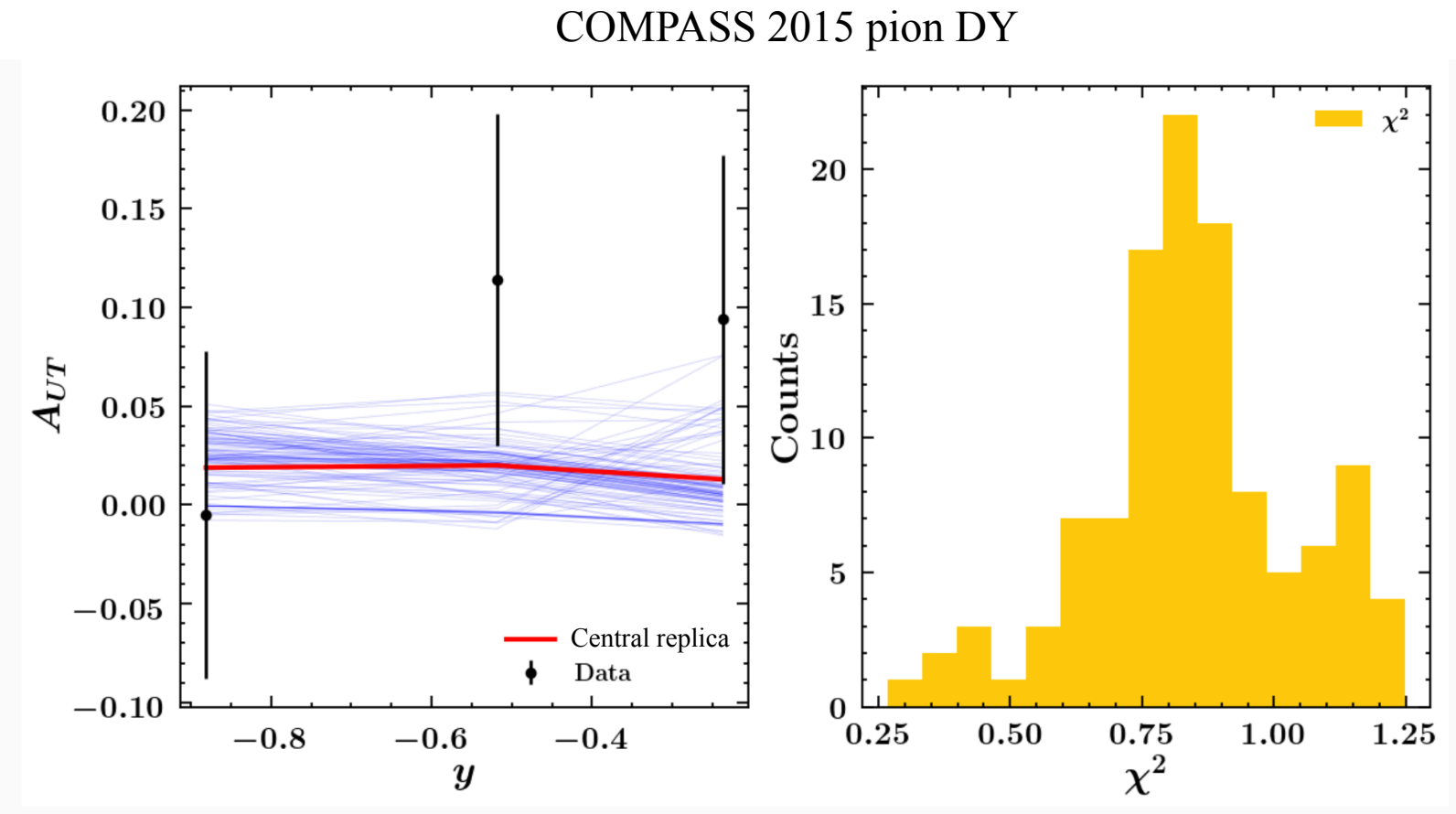
Selected results: Compass 2009



Selected results: COMPASS 2022

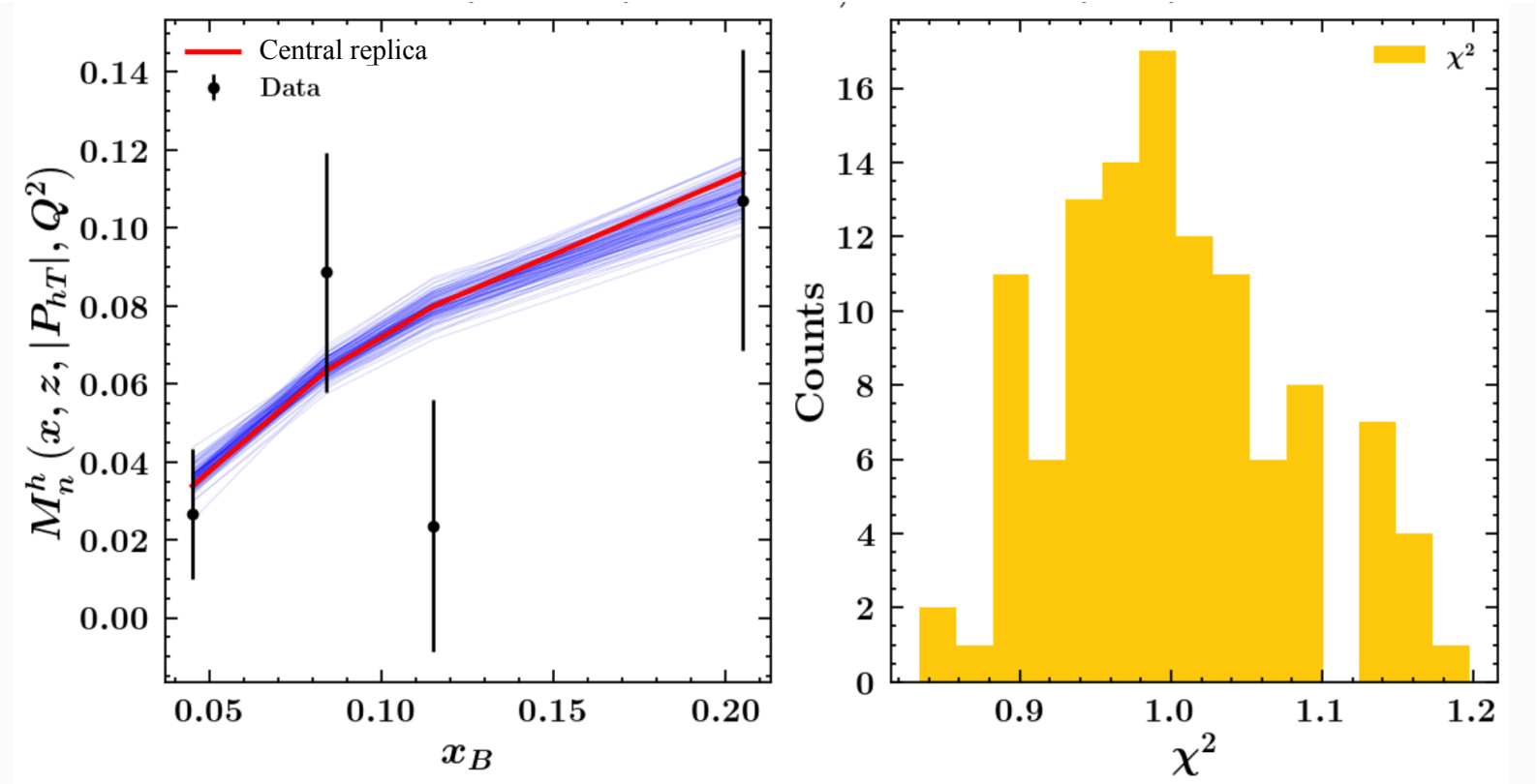


Selected results: COMPASS DY 2015



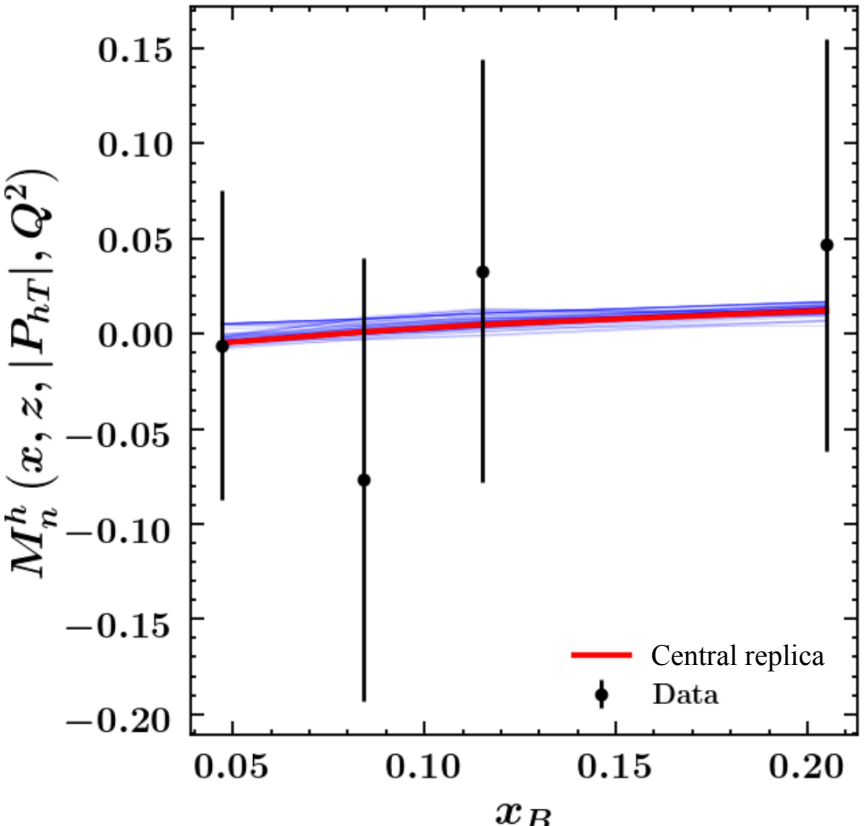
Selected results: HERMES 2020

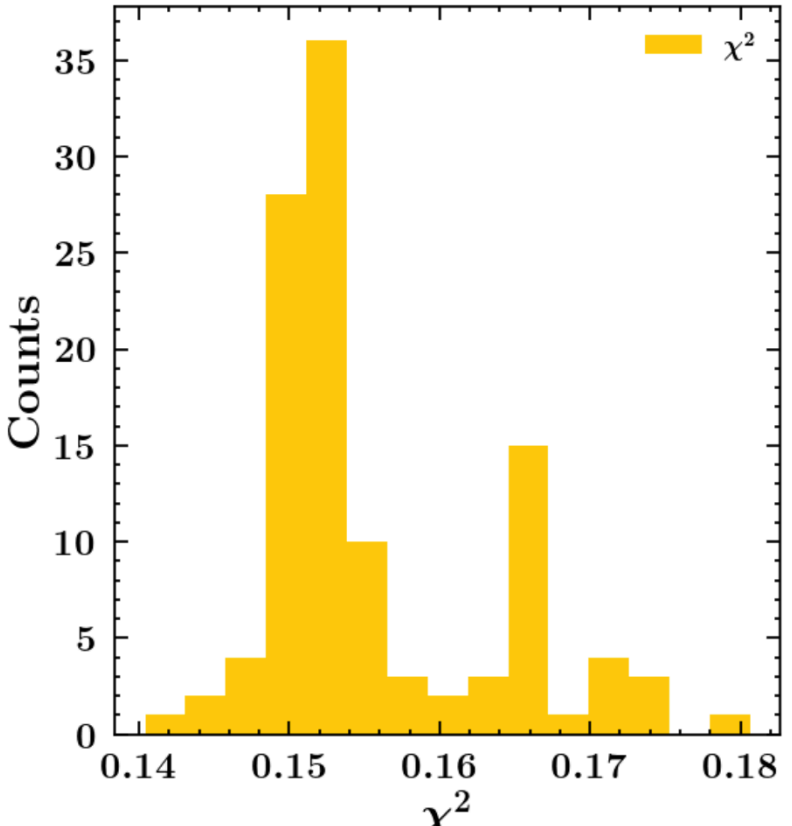
HERMES $p - \pi^+$ $\quad 0.54 < P_{hT} < 2.0, \quad 0.28 < z < 0.37$



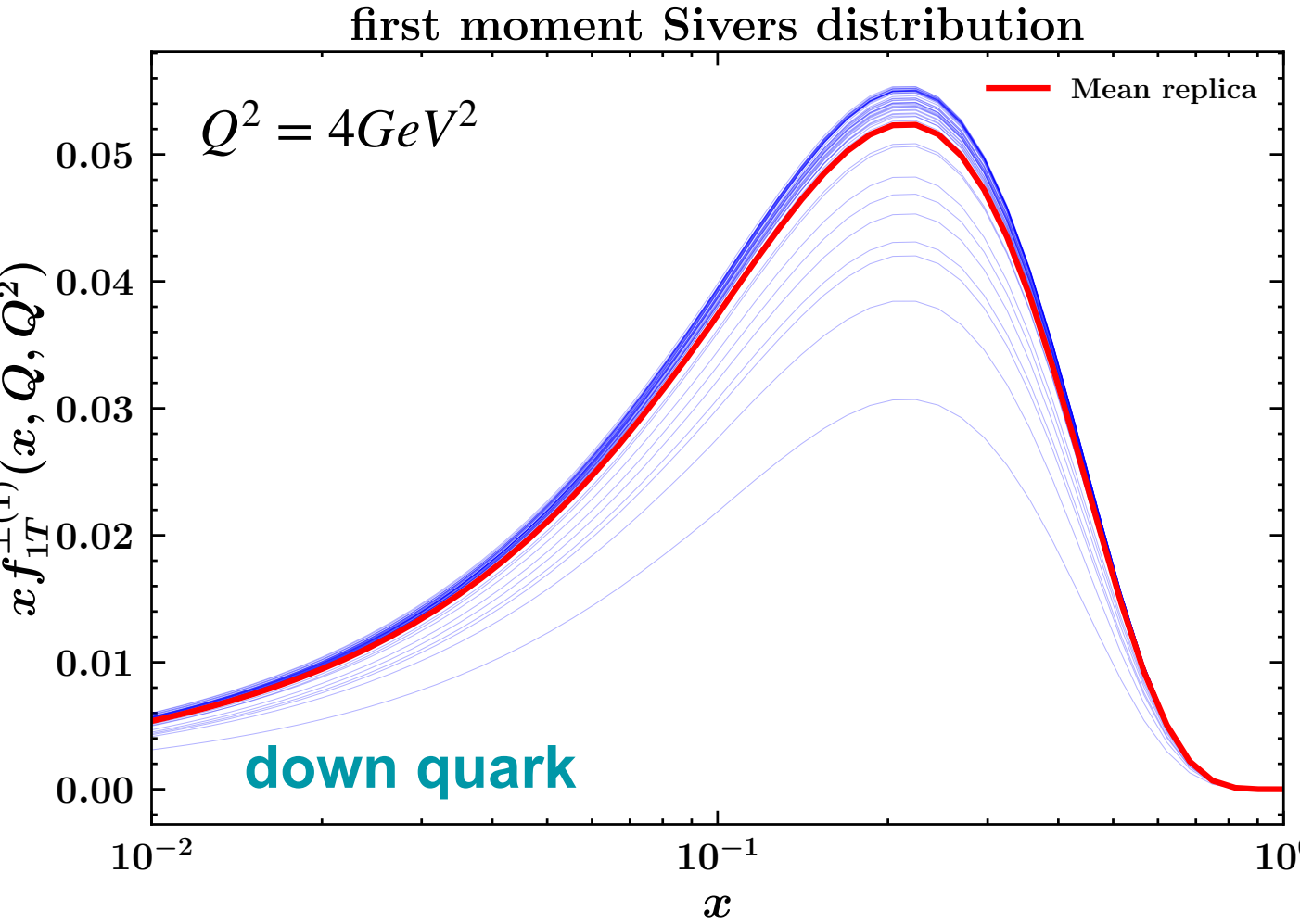
Selected results: HERMES 2020

HERMES $p - K^-$ $0.36 < P_{hT} < 0.54, \quad 0.28 < z < 0.37$

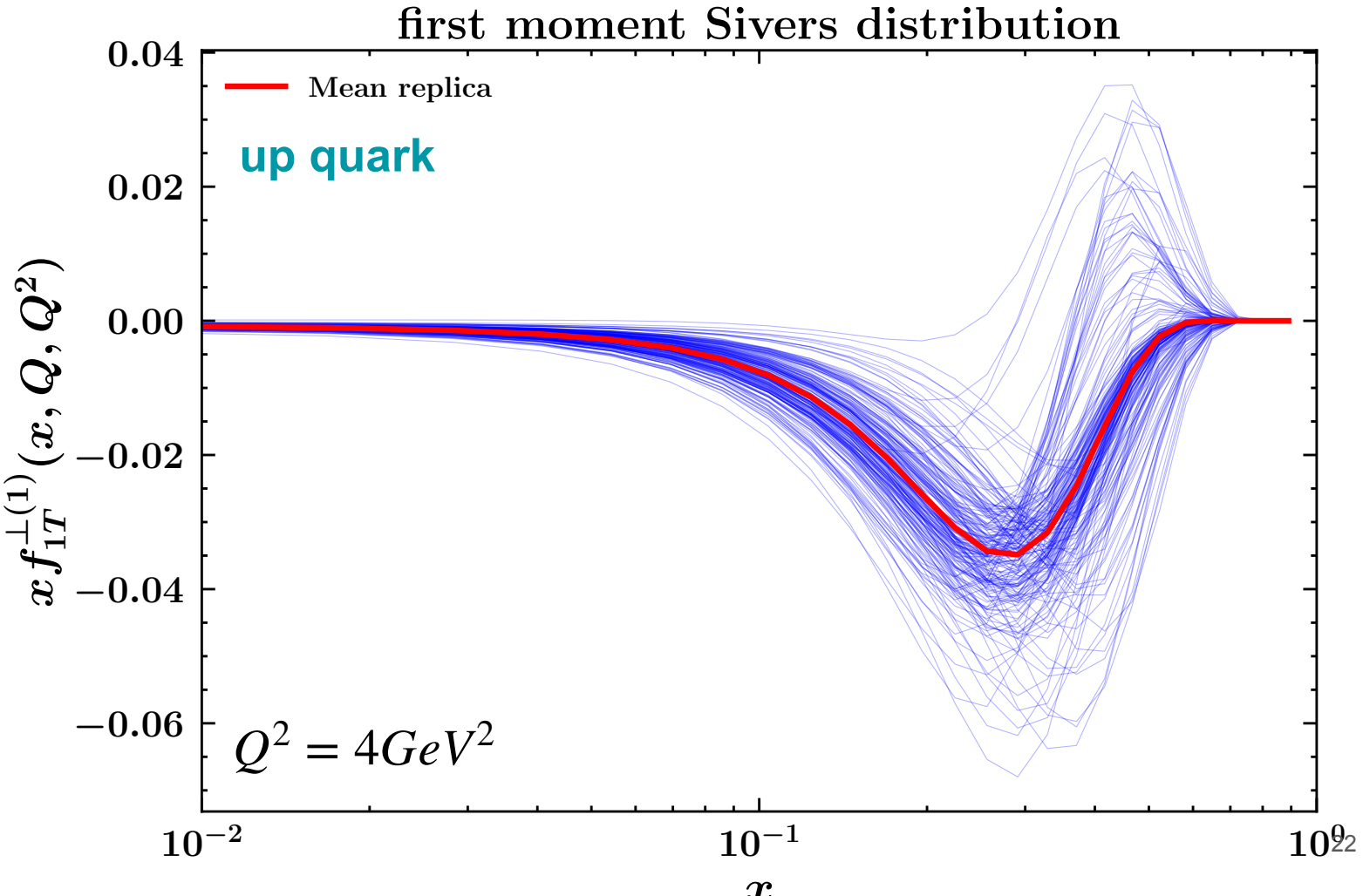




Sivers TMD

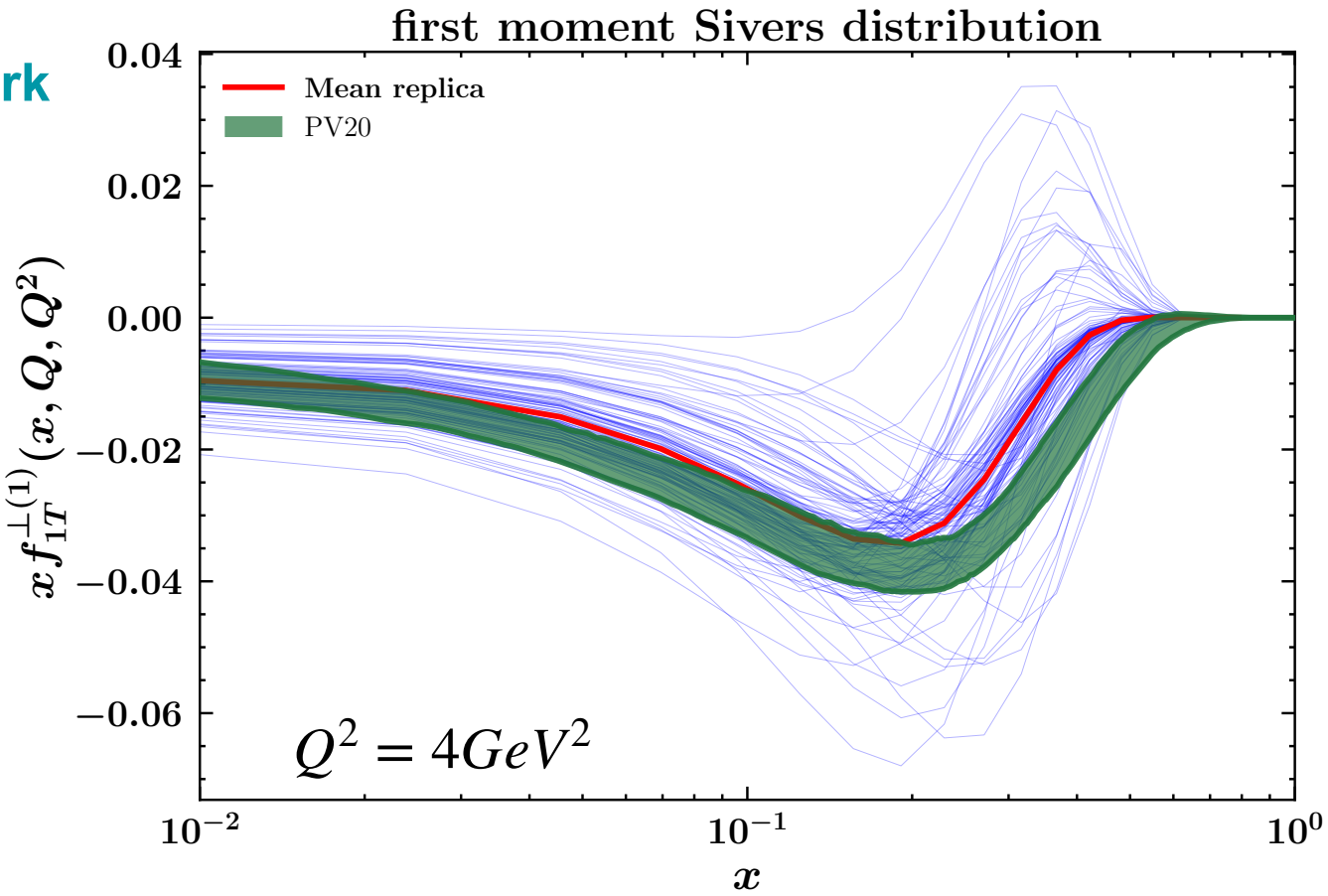

first moment Sivers distribution
$Q^2 = 4GeV^2$
Mean replica
down quark
$x f_{1T}^{\perp(1)}(x, Q, Q^2)$
0.05
0.04
0.03
0.02
0.01
0.00
10^{-2}
10^{-1}
10^{0}
x

Sivers TMD


first moment Sivers distribution
Mean replica
up quark
$Q^2 = 4GeV^2$
$x f_{1T}^{\perp(1)}(x, Q, Q^2)$
0.04
0.02
0.00
−0.02
−0.04
−0.06
10^{-2}
10^{-1}
10^{0}
x

Sivers TMD

up quark



Conclusions

Updated MAP global extraction of Sivers function with a fully consistent TMD framework

COMPASS and Hermes updated measurements help explore new phenomenological aspects of polarized TMDs (multi dim., DY)

New datasets confirm previous works, allowing more flexibility

COMPASS and HERMES covered a long stretch in polarized nucleon structure exploration, and paved the way for EIC to continue the relay race (and reach the goal?)