Polarization effects in 3D structure

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What is epic about ePIC?

First machine that will answer the proton spin puzzle (?)

Transverse Momentum Distributions: TMD PDF

unpolarized

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

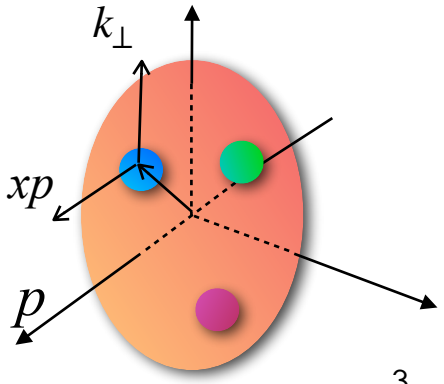
Sivers function

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

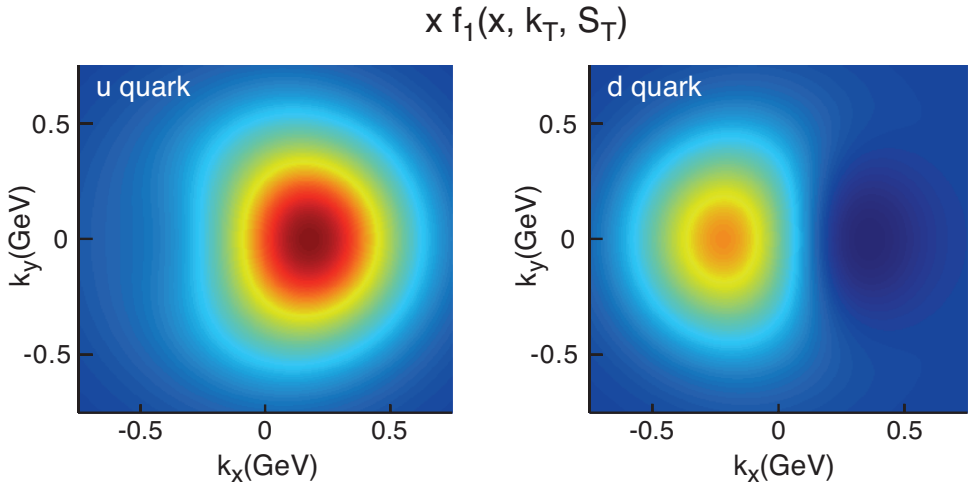
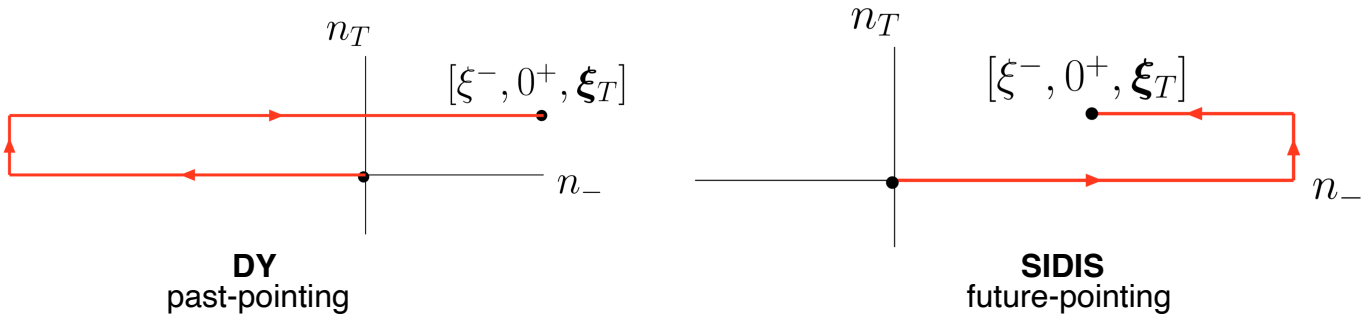


Figure 2.13: The density in the transverse-momentum plane for unpolarized quarks with $x = 0.1$ in a nucleon polarized along the $\hat{y}$ direction. The anisotropy due to the proton polarization is described by the Sivers function, for which the model of [77] is used. The deep red (blue) indicates large negative (positive) values for the Sivers function.

[EIC White Paper]

Sivers function sign change

vanishing Sivers function? → Final state interactions and Wilson lines to consider



Sign change in Sivers function

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

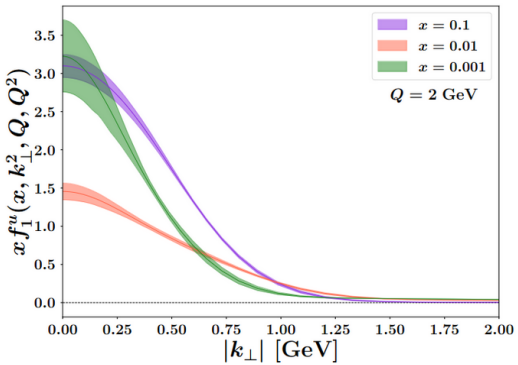
Predictions for future experiments

Existing data

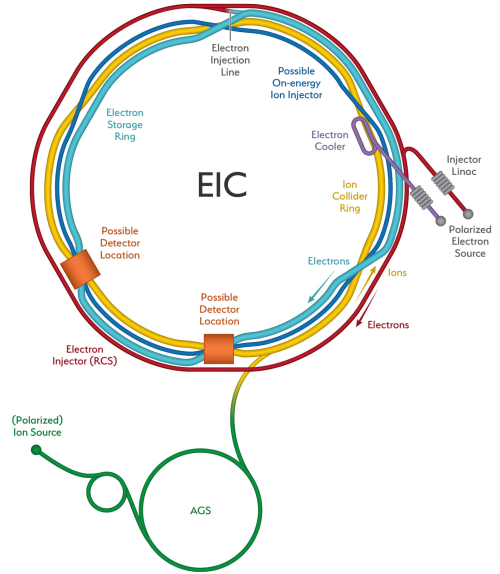
Future measurements

TMDs

extraction



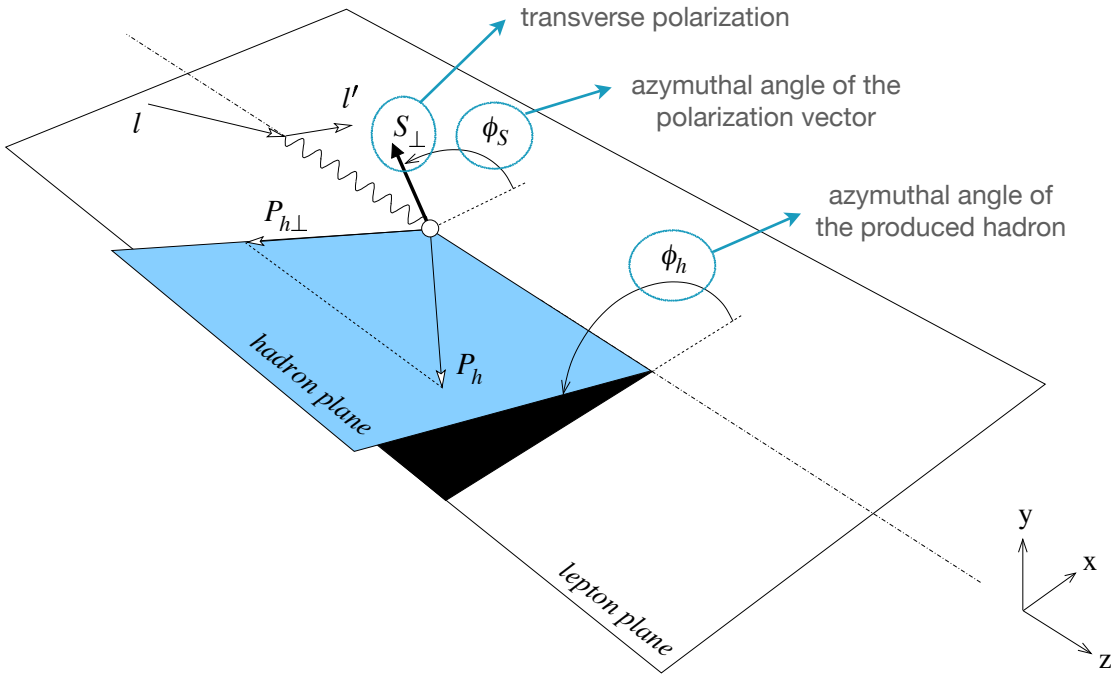
prediction



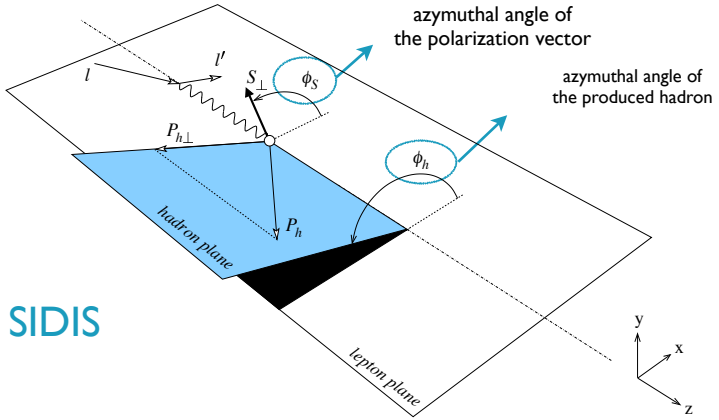
EIC Yellow Report

Extraction of Sivers Function

Determined through its contributions to the cross section of polarized SIDIS



Extraction of Sivers Function



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

first Sivers extraction with unpolarised TMDs extracted from data

Elements of Sivers function first moment

Parametrize the 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)

Fourier transform: b_T space

pQCD

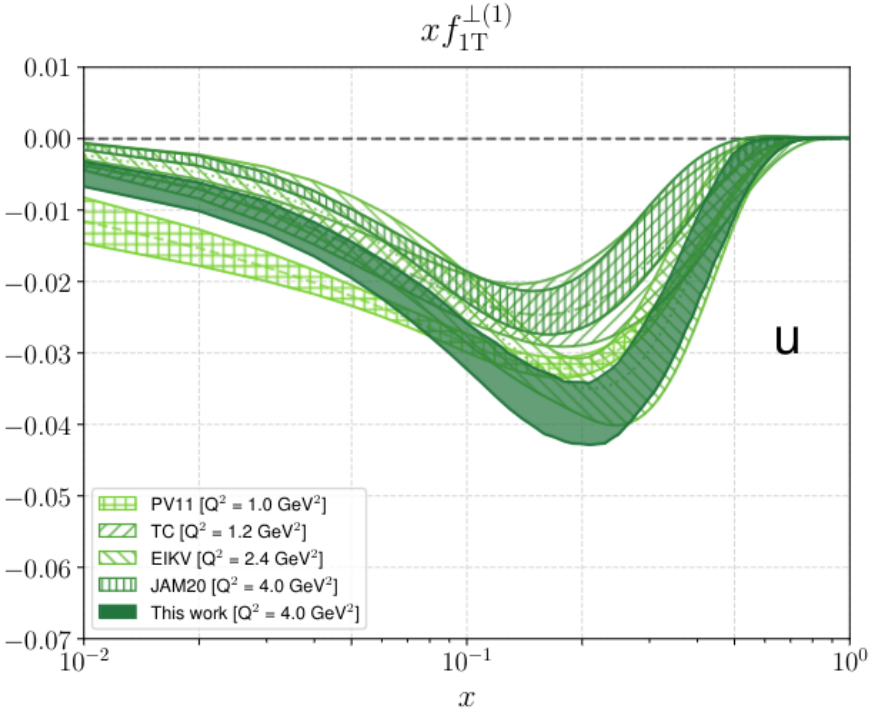
nonperturbative part of evolution

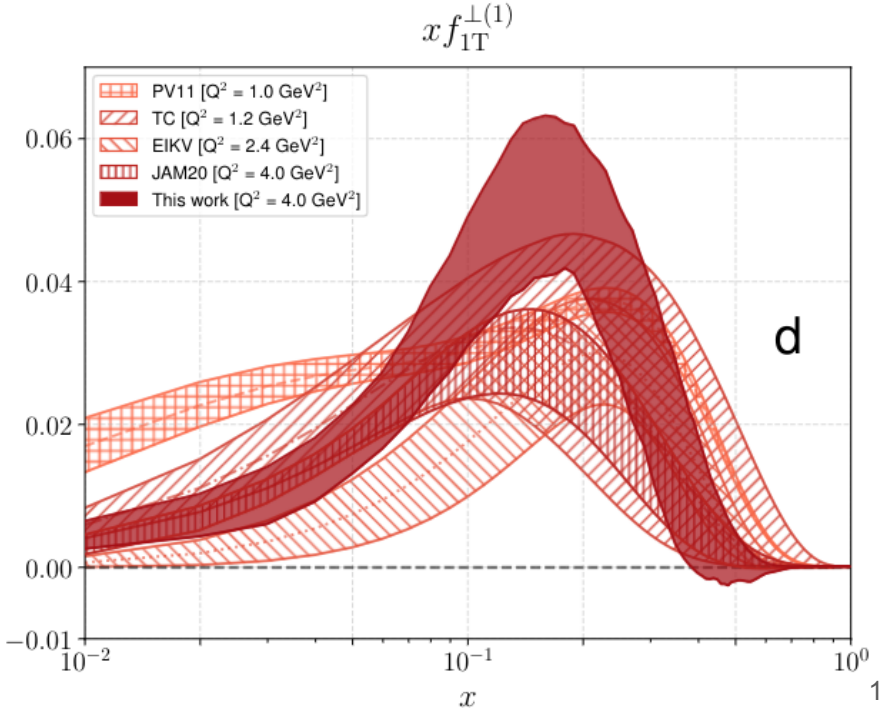
PV20Sivers: Polarized TMDs

$$\chi^2 = 1.12$$

125 data points from SIDIS, DY

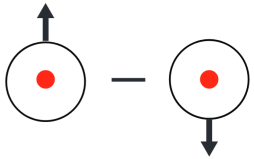
LO-NLL





TMDs

PV20Sivers

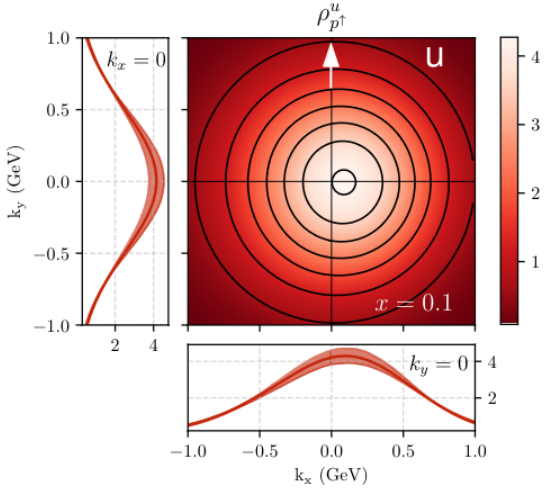


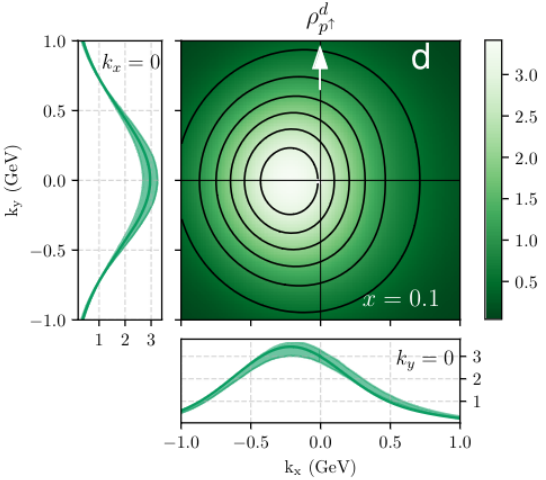
polarized

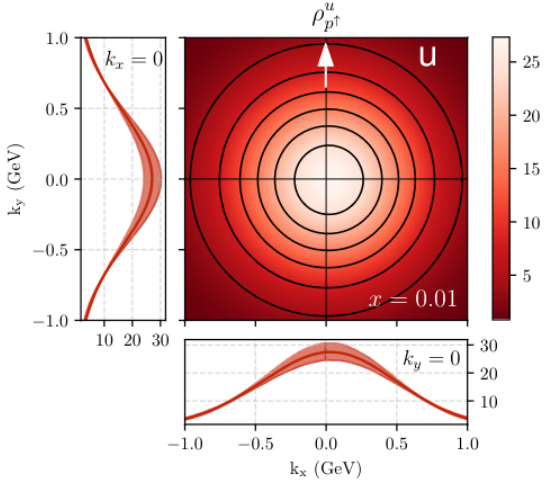
$$f_1(x, k_\perp; Q^2) - f_{1T}^{\perp}(x, k_\perp; Q^2)$$

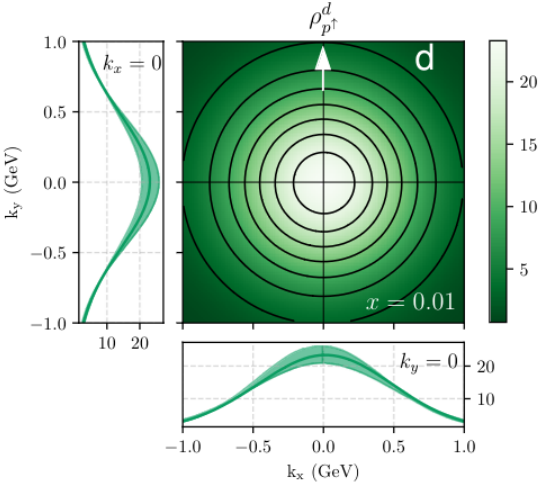
PV17

unpolarized



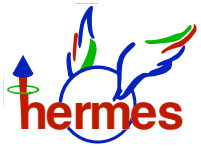






Updated Sivers extraction

Additional data



2020

SIDIS

Multidimensional data x, P_{hT}, Q_2

[JHEP12(2020)010]

2022

SIDIS

projected in x

2015-2018

pion-induced DY

[PRL133]

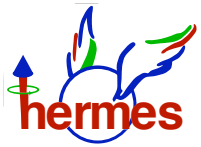
2011

SIDIS

^{3}He target

Updated Sivers extraction

Additional data



2020

[JHEP12(2020)010]

2022

2015-2018

[PRL133]

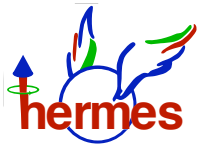
More accurate unpolarized TMDs

MAPTMD22

pionMAPTMD

Updated Sivers extraction

Additional data



2020

[JHEP12(2020)010]

2022

2015-2018

[PRL133]

More accurate unpolarized TMDs

MAPTMD22

pionMAPTMD

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

Extraction of proton quark unpolarized TMDs: MAPTMD22

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: 2031 data points
- Perturbative accuracy: N^3LL^-
- Normalization of SIDIS multiplicities beyond NLL
- Number of fitted parameters: 21
- Really good description: $\chi^2/N_{data} = 1.06$

MAPTMD22: datasets included

Drell-Yan: 484 data points

Fixed-target low-energy DY

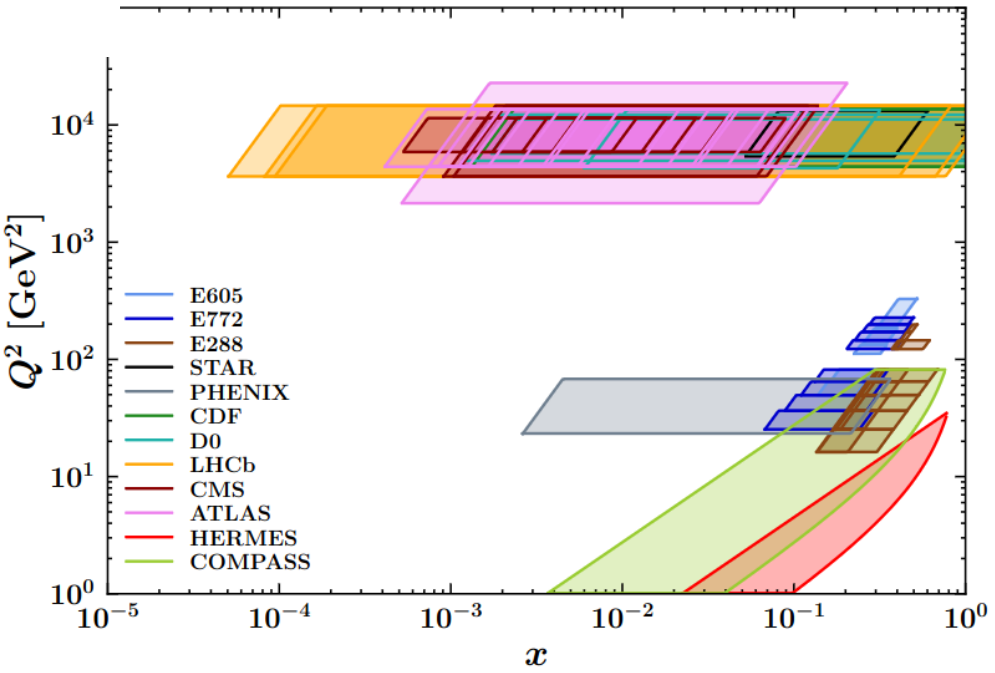
RHIC data

LHC and Tevatron data

SIDIS: 1547 data points

HERMES data

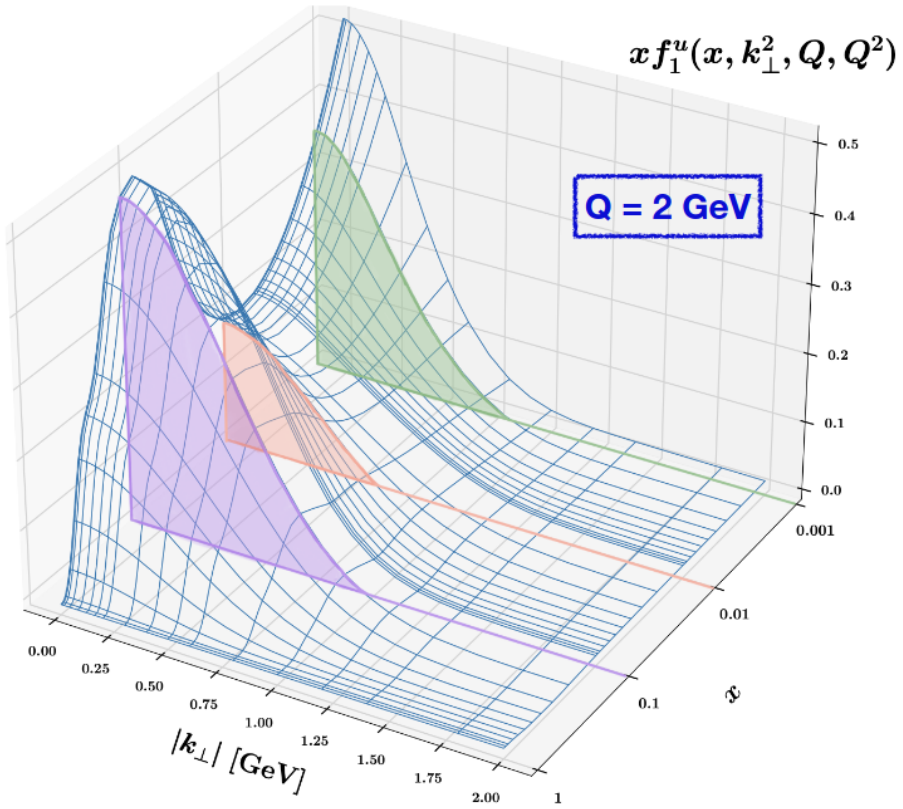
COMPASS data

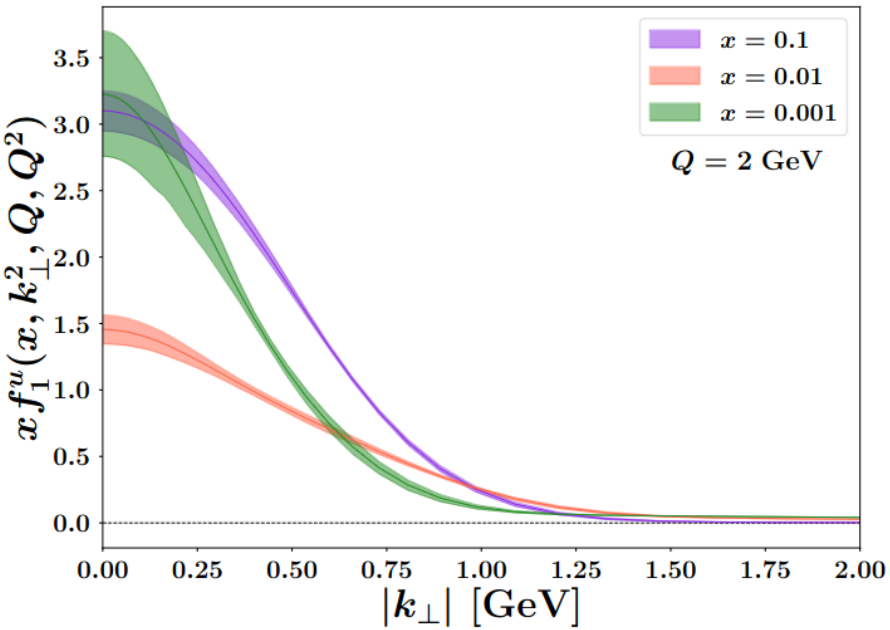


[JHEP,07(2020),117]

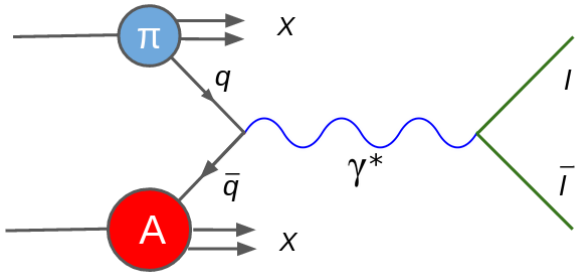
Total: 2031 fitted points

MAPTMD22: visualization of TMD evolution





$$\pi^- + W \to \mu_+ + \mu_- + X$$



$$\frac{d\sigma^{DY}}{d|\boldsymbol{q}_T|dydQ} \propto \int d|\boldsymbol{b}_T||\boldsymbol{b}_T|J_0(|\boldsymbol{q}_T||\boldsymbol{b}_T|)\hat{f}^{\,a}_{1\pi}(x_A, \boldsymbol{b}_T^2; \mu, \zeta_A)\hat{f}^{\,\bar{a}}_{1p}(x_B, \boldsymbol{b}_T^2; \mu, \zeta_B)$$

$\hat{f}^{\,\bar{a}}_{1p}(x_B, \boldsymbol{b}_T^2; \mu, \zeta_B)$ taken from MAP collaboration global extraction at N^{3}LL

MAP22 [2206.07598]

updated Sivers Fit results

Total number of data

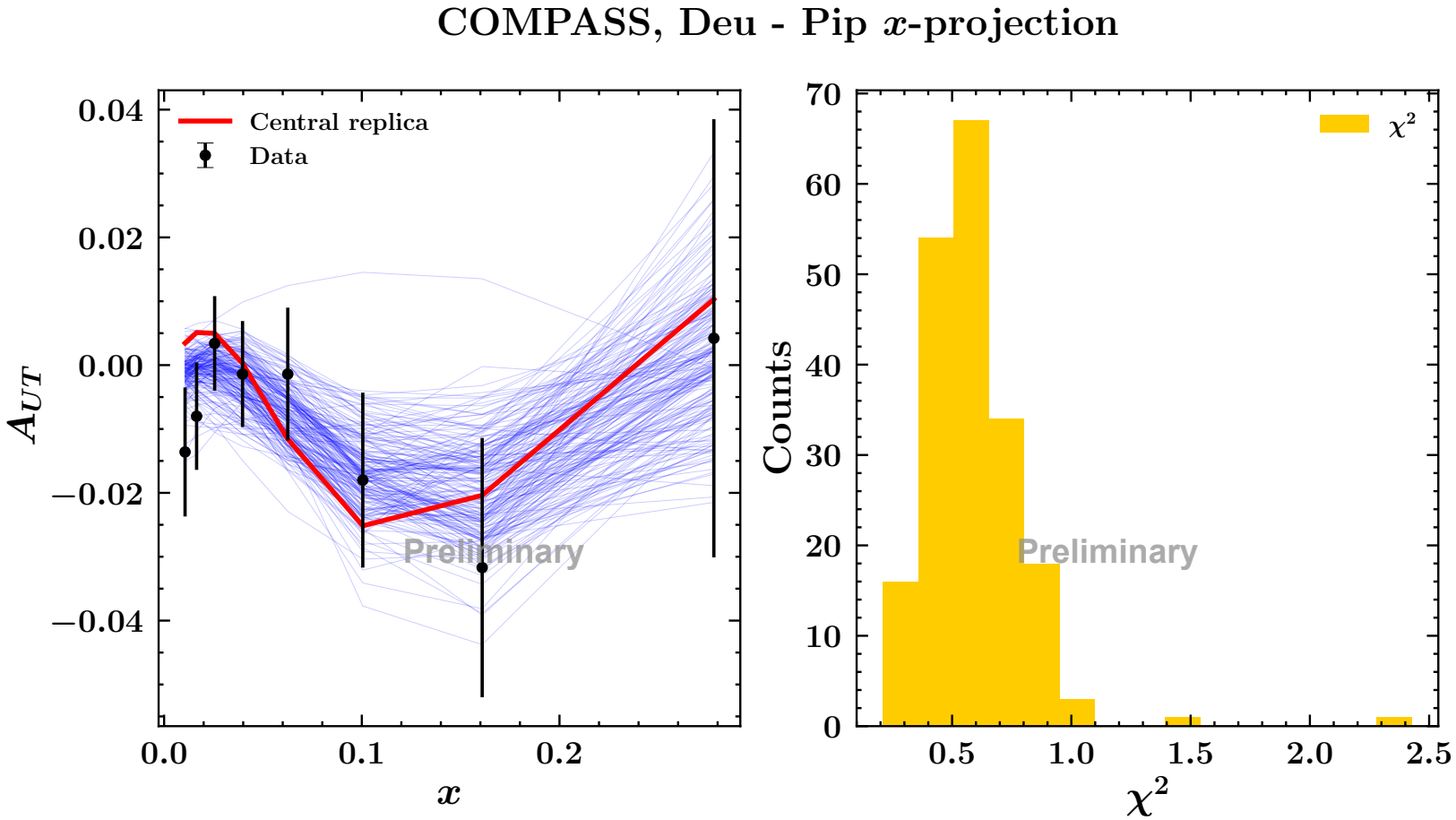
379

$$\chi^2 = 1.23$$

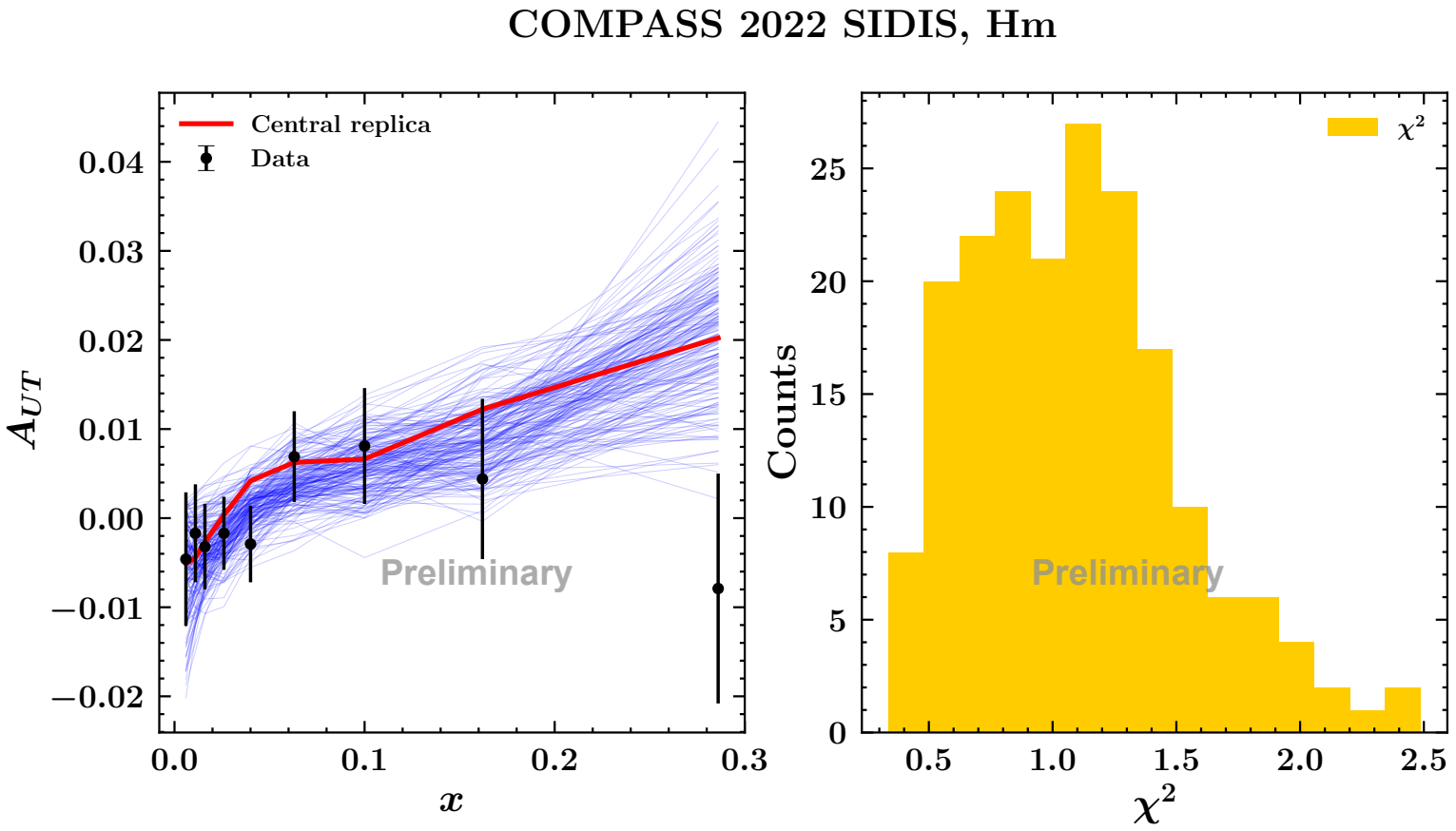
from
- semi-inclusive DIS,
- pion-induced Drell-Yan,
- W-Z boson production

Accuracy: NLL-LO

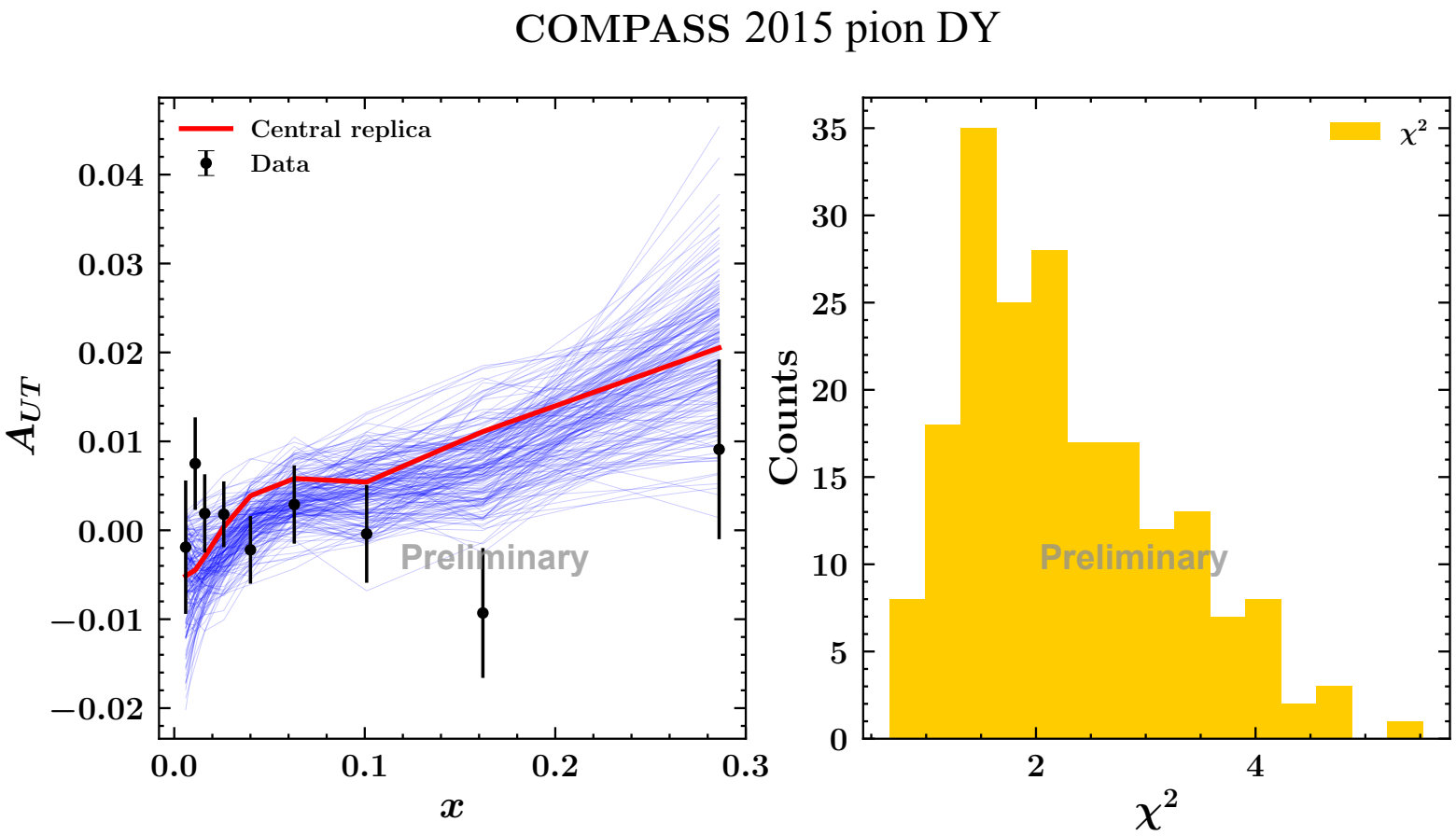
Selected results: Compass 2009



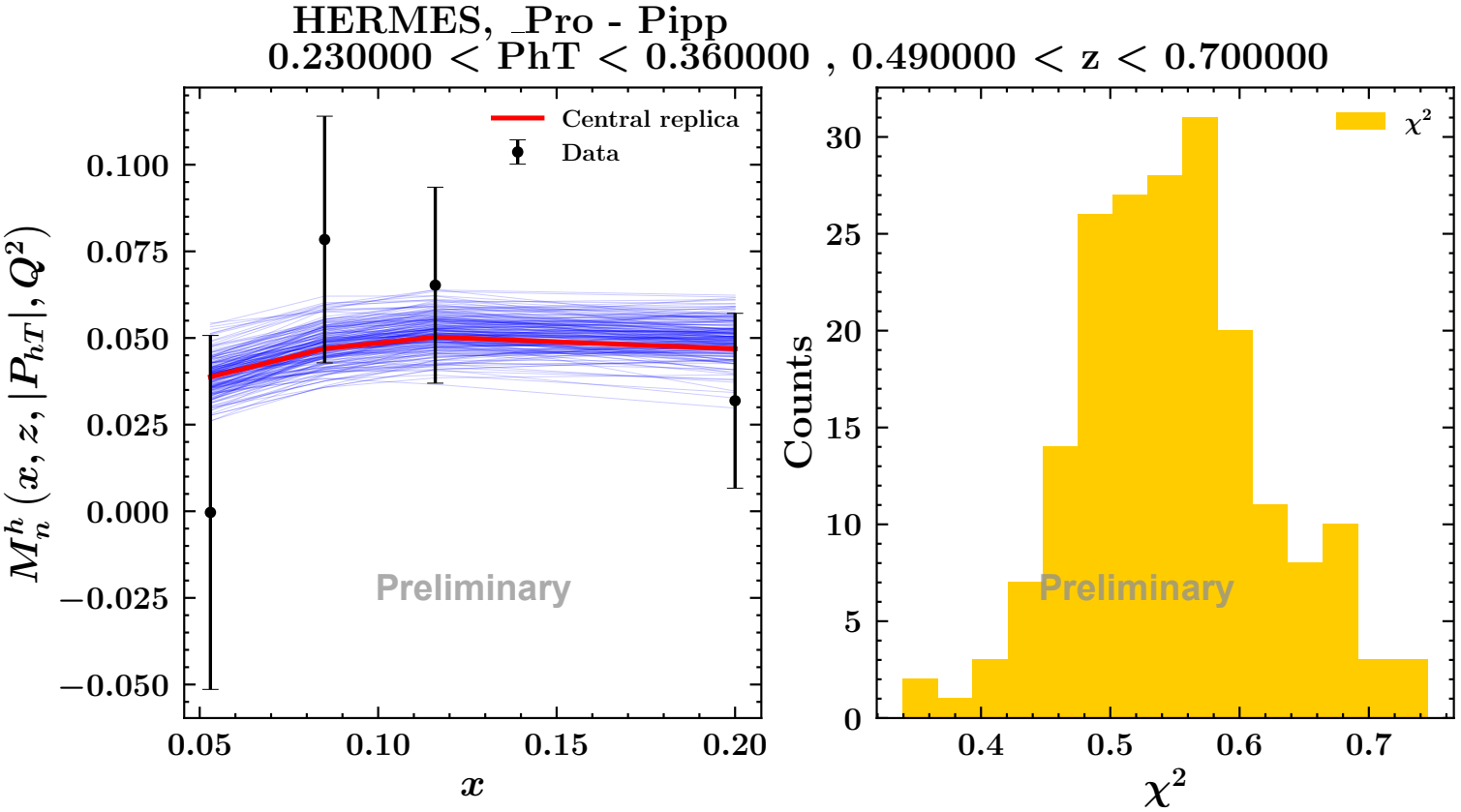
Selected results: COMPASS 2022



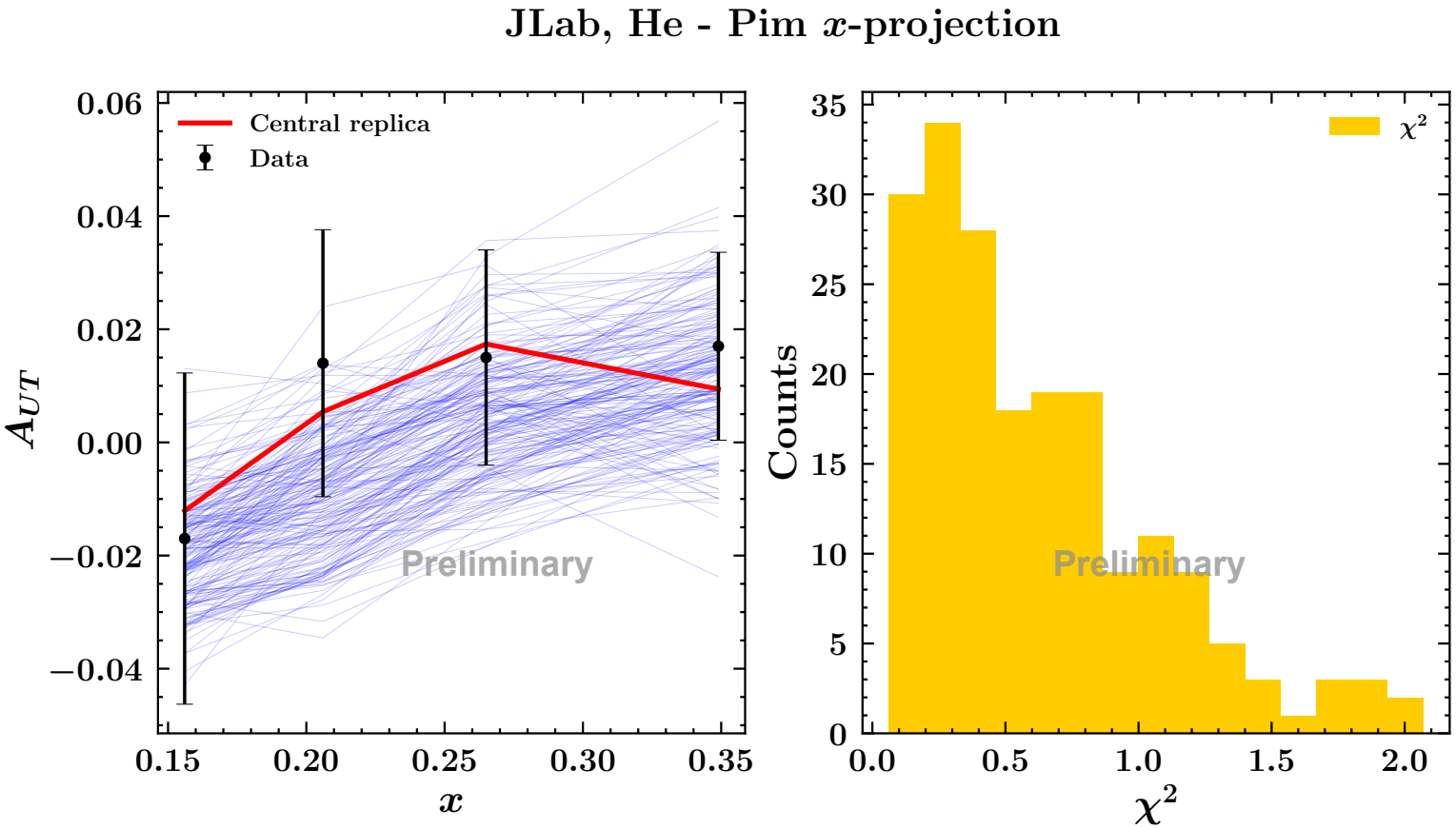
Selected results: COMPASS 2015



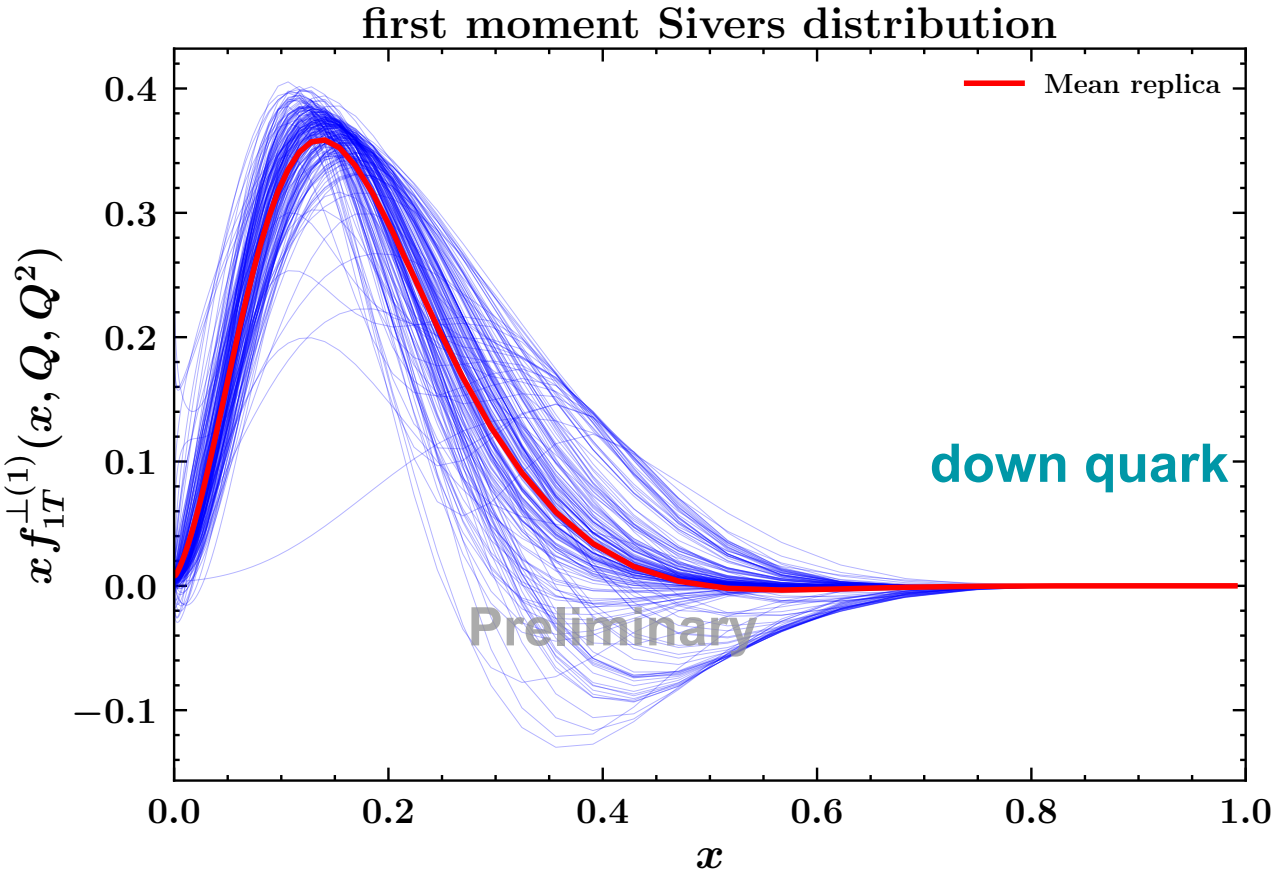
Selected results: HERMES 2020



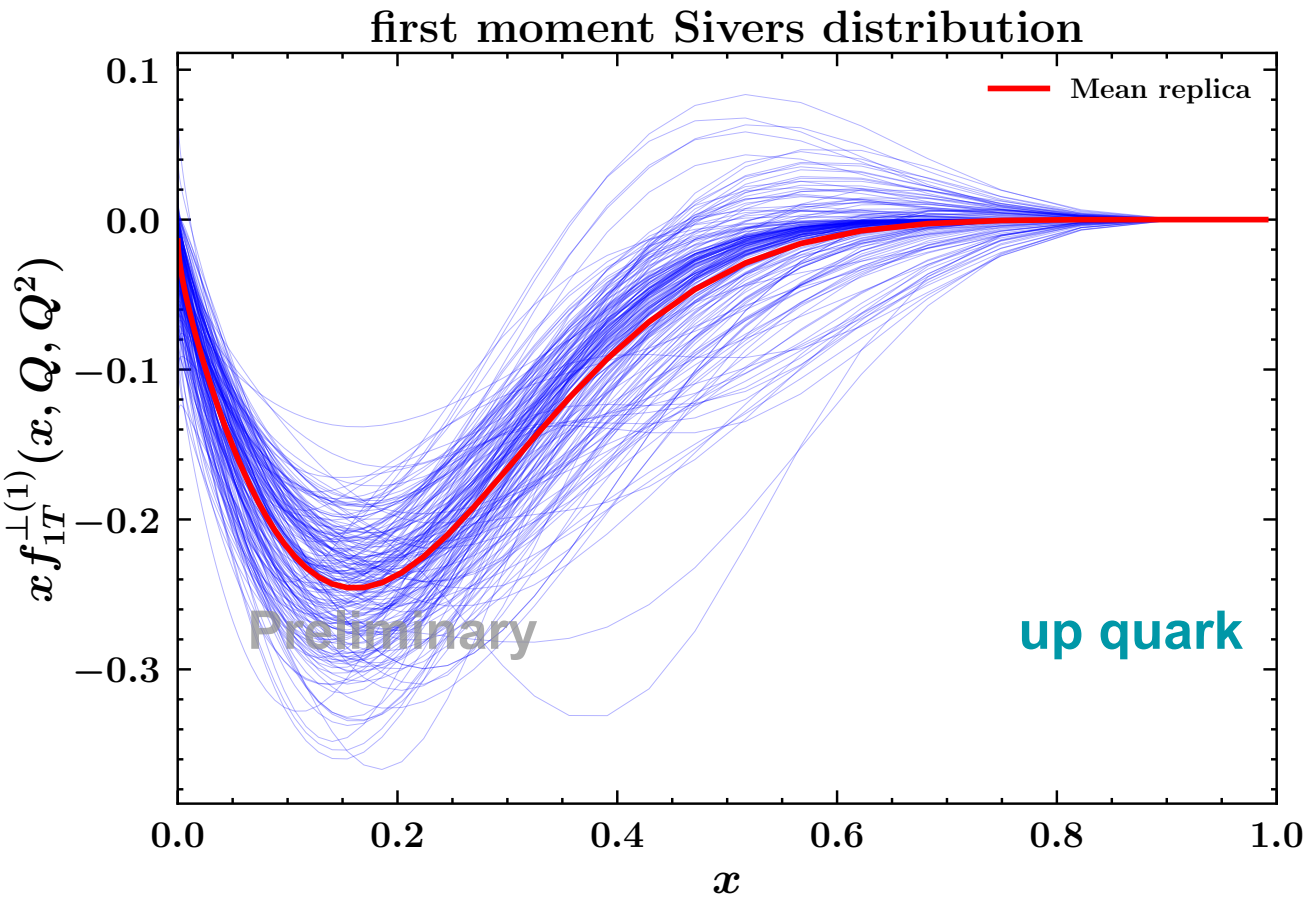
Selected results: JLab ^{3}He



Sivers TMD


first moment Sivers distribution
Mean replica
down quark
Preliminary
$x f_{1T}^{\perp(1)}(x, Q, Q^2)$
x
0.4
0.3
0.2
0.1
0.0
−0.1
0.0
0.2
0.4
0.6
0.8
1.0

Sivers TMD


first moment Sivers distribution
Mean replica
Preliminary
up quark
$x f_{1T}^{\perp(1)}(x, Q, Q^2)$
x
0.1
0.0
−0.1
−0.2
−0.3
0.0
0.2
0.4
0.6
0.8
1.0

Conclusions

TMDs are a fundamental instrument to describe the internal structure of nucleons and the interaction of their partons

Sivers function is a fascinating window on the relation between proton spin and parton dynamics

ePIC will offer us the opportunity to improve this picture with new specific measurements