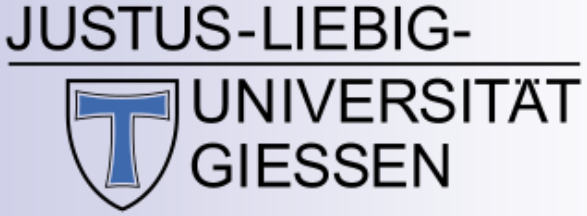
ePIC/EIC Early Science Workshop

Center for Frontiers in Nuclear Science
Stony Brook University

April 24 – 25 2025

Early science from SIDIS measurements



Stefan Diehl (JLU Giessen + UCONN)
Ralf Seidl (RIKEN)

04/25/2025

SIDIS Measurements

Spin of the nucleon:

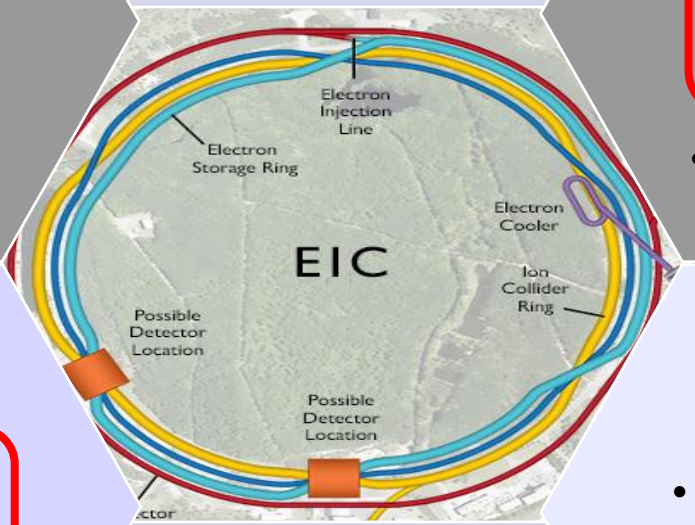
- Gluon spin
- Role of Sea quarks

QCD at high gluon densities

- Saturation effects

Tomography :

- 3D momentum structure (q, g Sivers, Tensor charge, TMD Evolution)
- 3D spatial structure



Nucelar effects

- Nuclear PDFs
- Passage of color through nuclear matter (nFFs, pT broadening)

Origin of the Mass

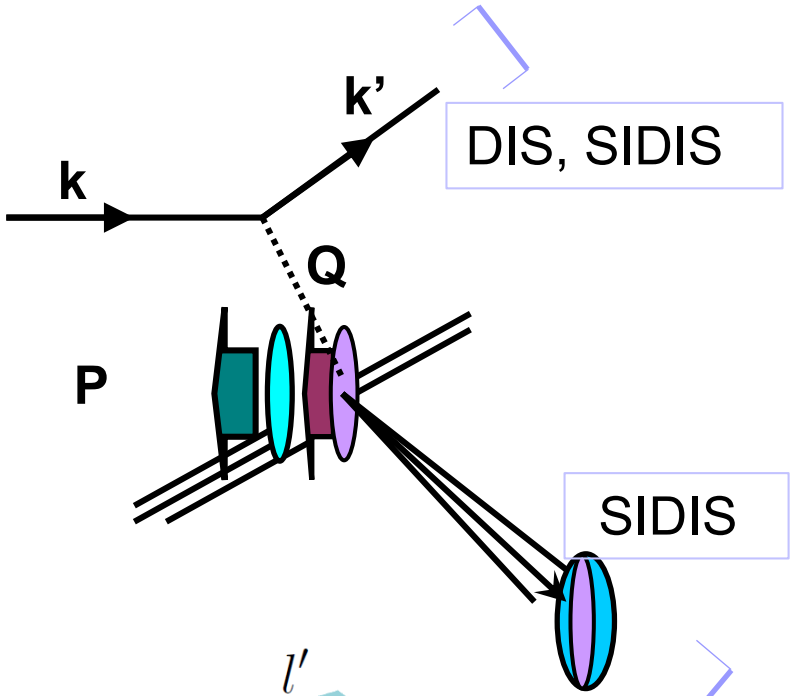
- Axial anomaly contributions
- Hadron structure

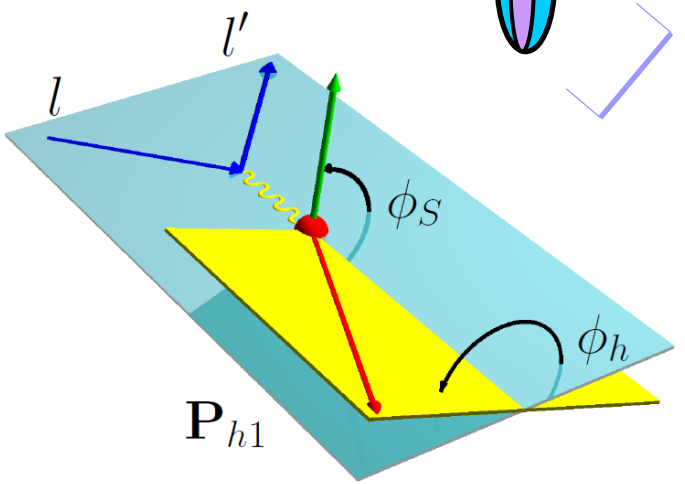
Other

- Spectroscopy (XYZ)
- EW physics
- Fragmentation
- Unpol PDFs

SIDIS process

Detect electron and final-state hadron(s): Additional benefit of flavor, spin and transverse momentum sensitivity via fragmentation functions





$$\frac{d^6\sigma}{dxdQ^2dzdP_{hT}d\phi_S d\phi_h} \overset{LO}{\propto} \sum_{q,\overline{q}} e_q^2 q(x,Q^2,k_t) \otimes D_{1,q}^h(z,Q^2,p_t)$$

z:	Fractional hadron momentum relative to parton momentum (0<z<1)
P_{hT}:	Transverse hadron momentum wrt to virtual photon (convolution over intrinsic transverse momenta of PDFs and FFs)
ϕ_S:	Azimuthal angle of the nucleons (transverse) spin wrt to the scattering plane, along the virtual photon axis
ϕ_h:	Azimuthal angle of hadron wrt to scattering plane, along virtual photon axis

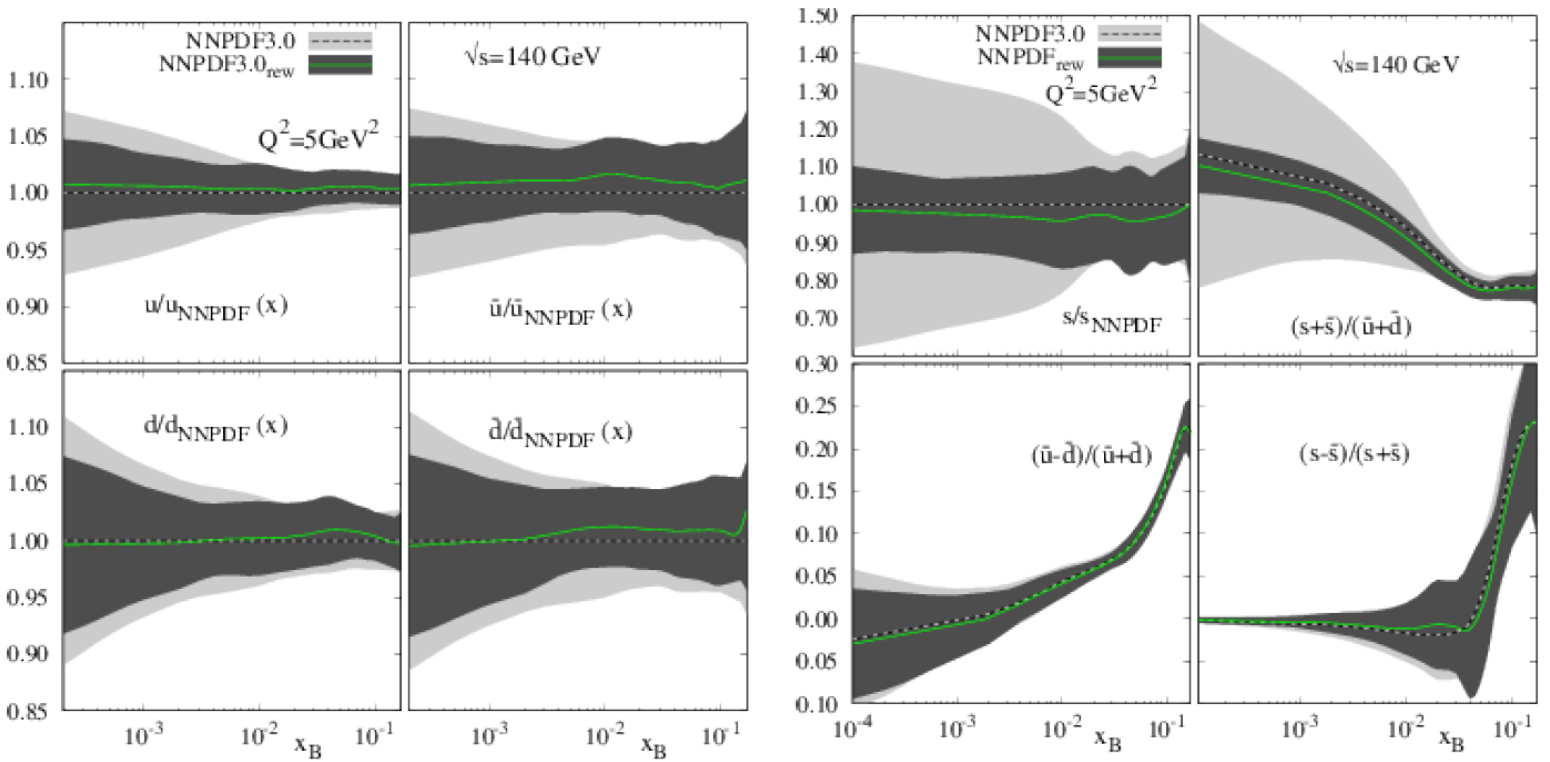
SIDIS early science perspectives

- SIDIS uses fragmentation functions to add flavor, spin and transverse momentum sensitivity to DIS measurements
  - ➔ Prerequisites: DIS + hadron momentum reconstruction + PID
  - ➔ Kinematic variables x, Q^2, z, (P_{hT}, ϕ_S, ϕ_h) → Higher dimensional binning is required

Observable	DIS kine	species	energies	e/h pol	z	P_{hT}	ϕ_s, ϕ_h	Lumi	ES grade
nPDFs + nFFs PDFs + FFs		e+A, (e+p/d)	10 x ~100	U/U		N	N	~fb^{-1}	****
unpol. TMDs (start)		e+p	10 x ~100	U/U			N	~fb^{-1}	***
H_T A_N moments		e+p	10 x 100	U/T				~fb^{-1}	***
TMD Evolution		e+p	10x100, (5x41, 18x275)	U/U				~fb^{-1}	***
Sivers/Collins/IFF		e+p, (e+^{3}He)	10x100, (5x41, 18x275)	U/T				~ 10 fb^{-1}	**
Helicity distributions		e+p, (e+^{3}He)	10x100, (5x41, 18x275)	L/L				~ 10 fb^{-1}	**
Di-hadron SIDIS (g Sivers / saturation)		e+p, e+A	18x275, (10x100)	U/(T)				~ 10 fb^{-1}	*

Unpolarized PDFs

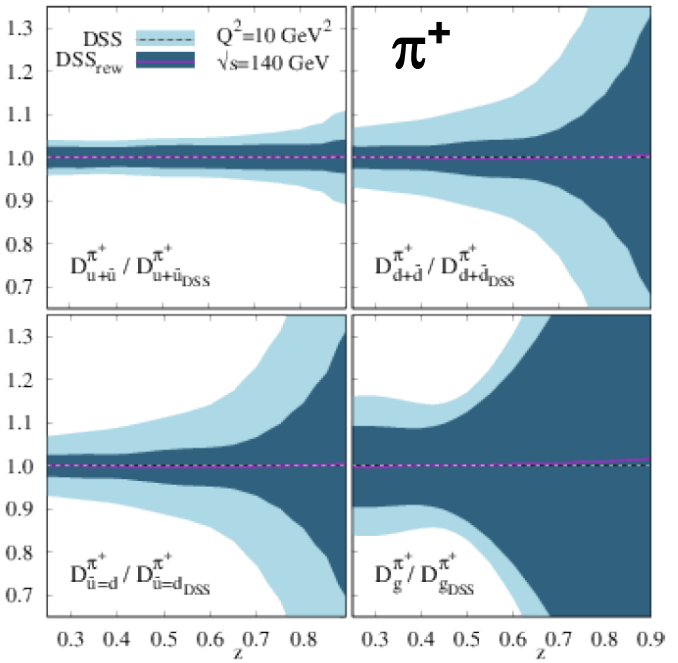
- Unpolarized PDFs:
  Impact from plain DIS and SIDIS
- SIDIS (flavor sensitivity)
  → Sea quarks
- Also, potential access to intrinsic charm?



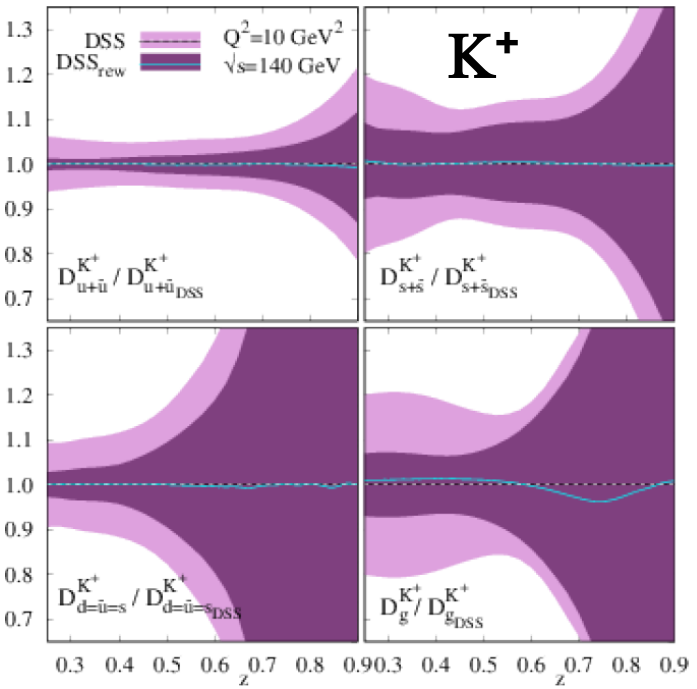
YR Figs 7.8, Aschenauer

Fragmentation Functions

- Fragmentation functions provide information on struck parton, its flavor and spin
- FFs are a staple of all SIDIS measurements
- Also their understanding will improve further with the EIC



unpolarized FF



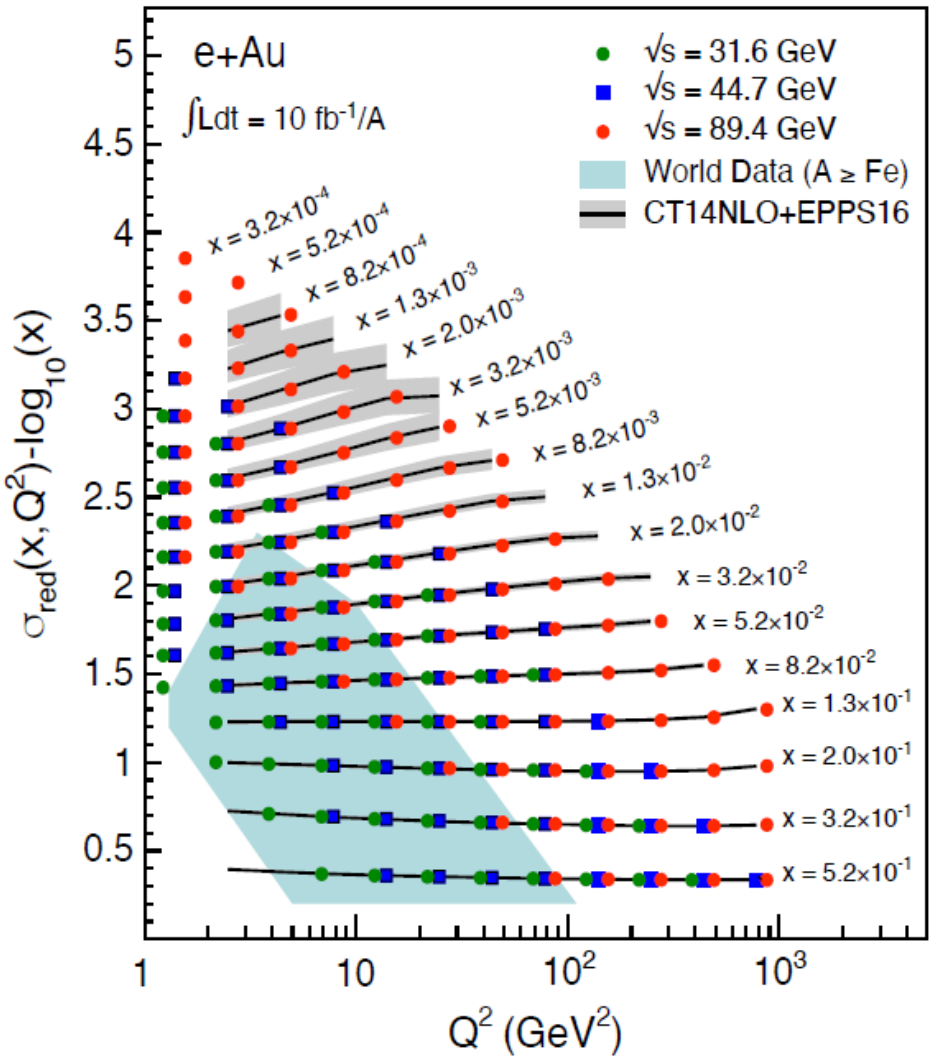
YR Fig 7.84, Aschenauer

Nuclear PDFs

- Very precise nuclear PDFs will open the way to quantitative HI physics

• Currently no EIC SIDIS impact studies available

→ Simulations are planned (awaiting eA MC)

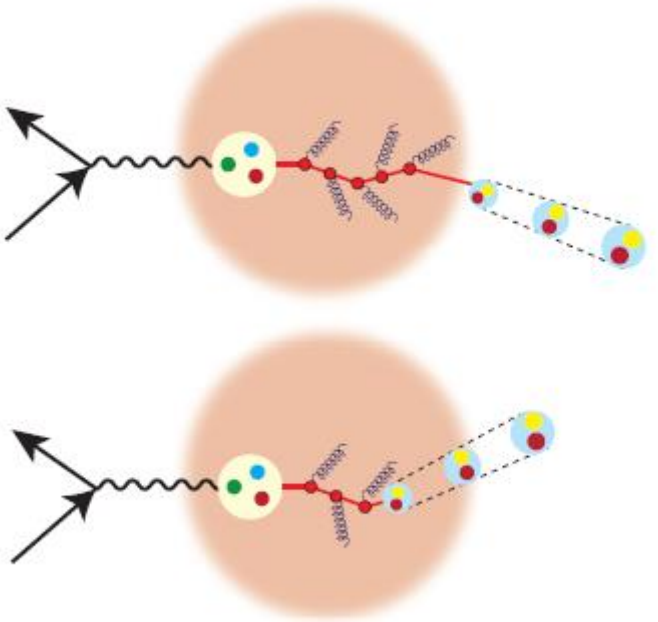


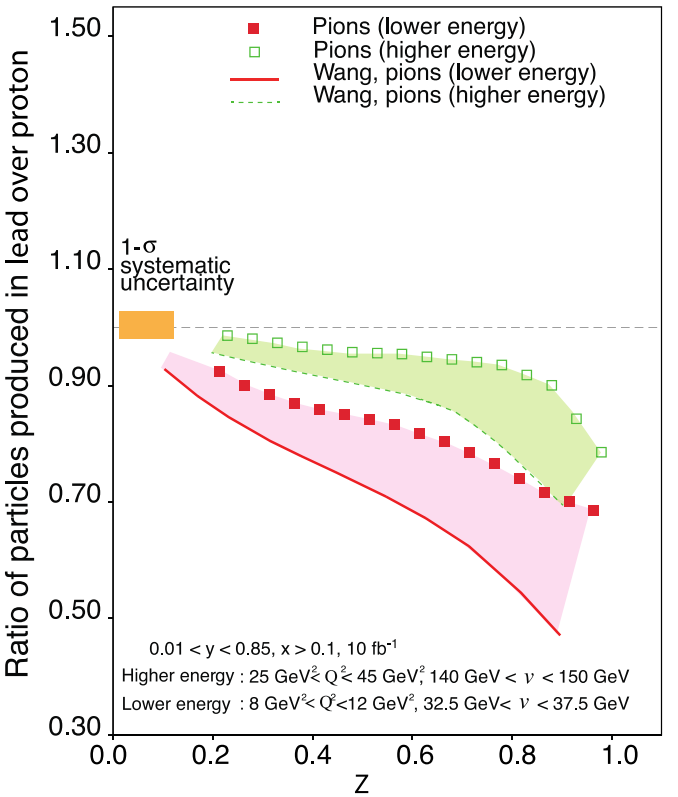
EPPS16*

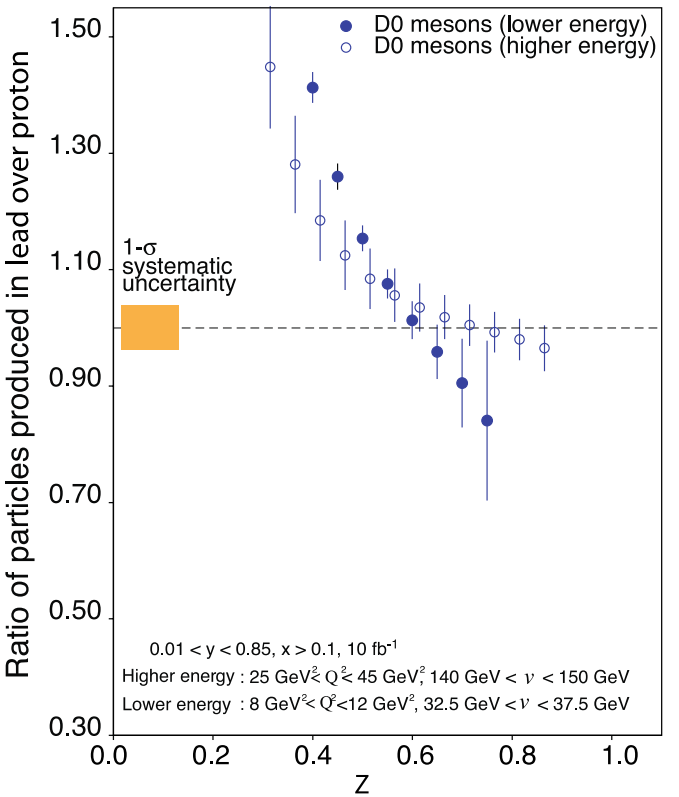
https://doi.org/10.1140/epjc/s10052-017-4725-9

Fragmentation in the nucleus

Does the it affect hadron/quark mass?





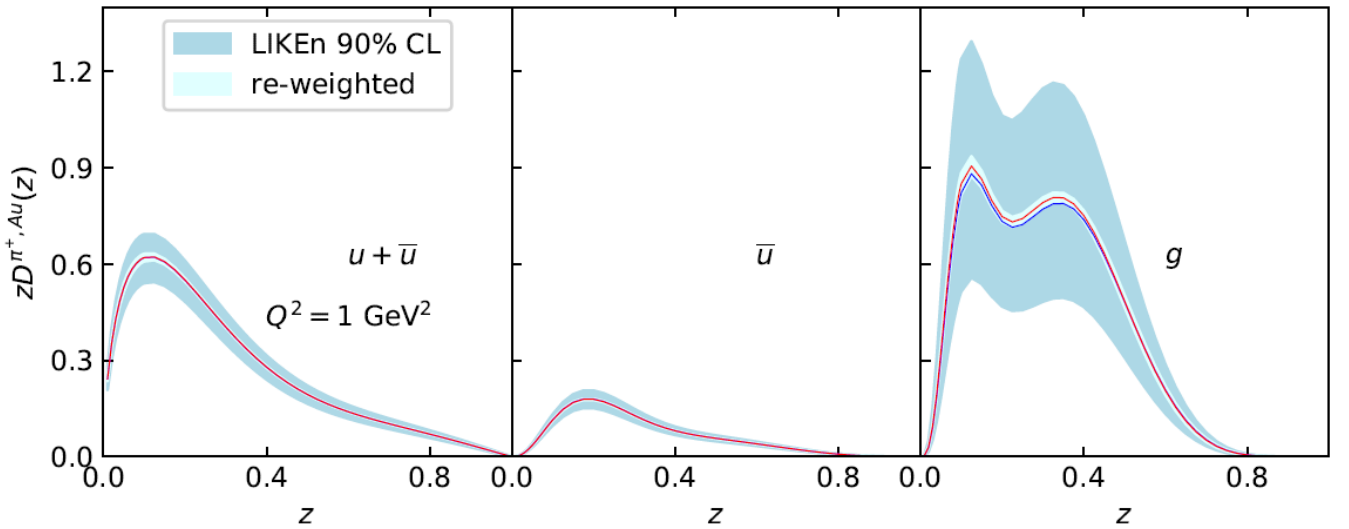


- Comparison of Multiplicity ratios for light and heavy hadrons and various parton energies

nFFs

- Expected impact from the EIC on light hadron nuclear FFs:

unpolarized nuclear FF:

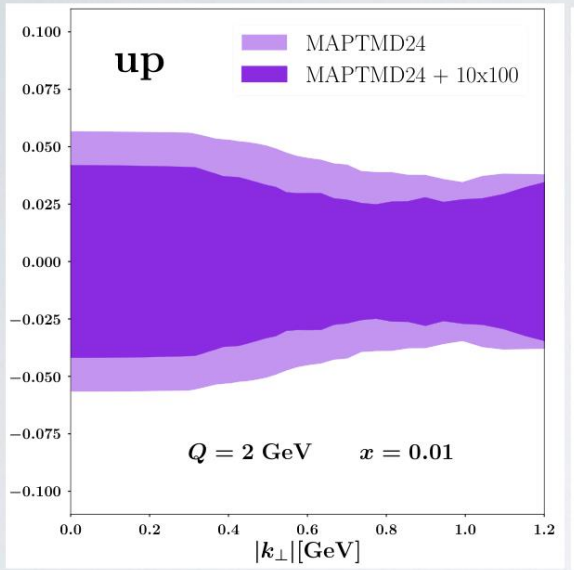


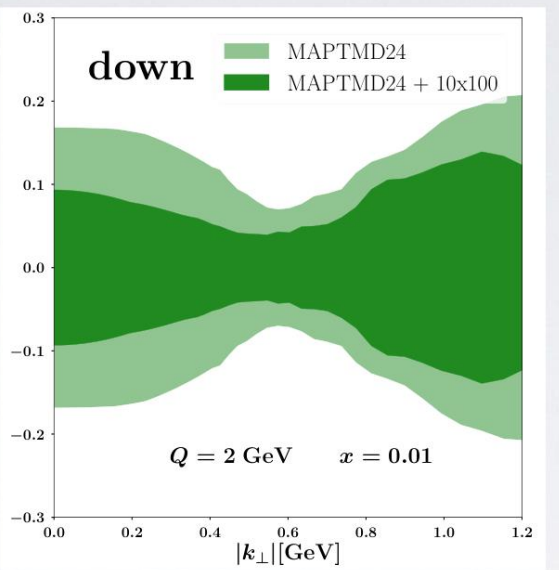
YR Figs 7.90, 7.91, Zurita

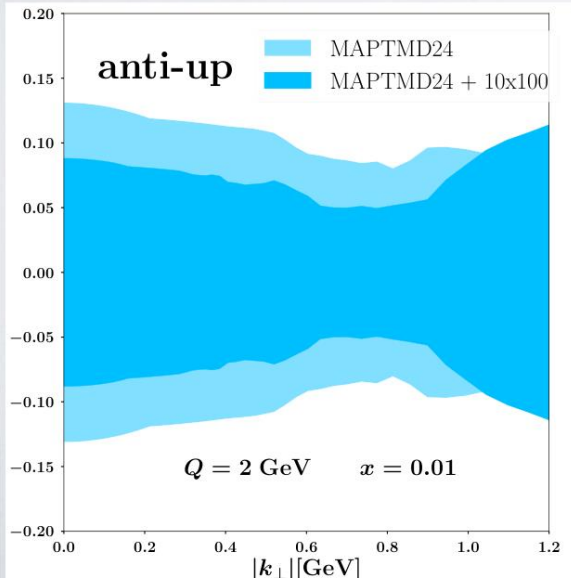
➔ More sophisticated studies ongoing (transverse momentum broadening, h dependence, …)

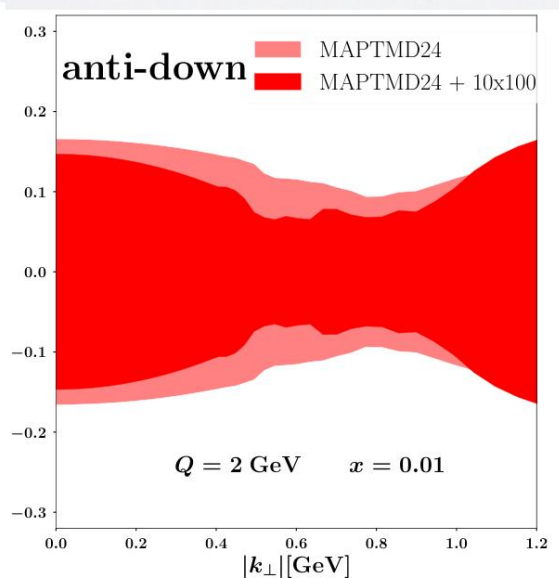
➔ Similar studies for heavy flavor

Unpolarized TMDs







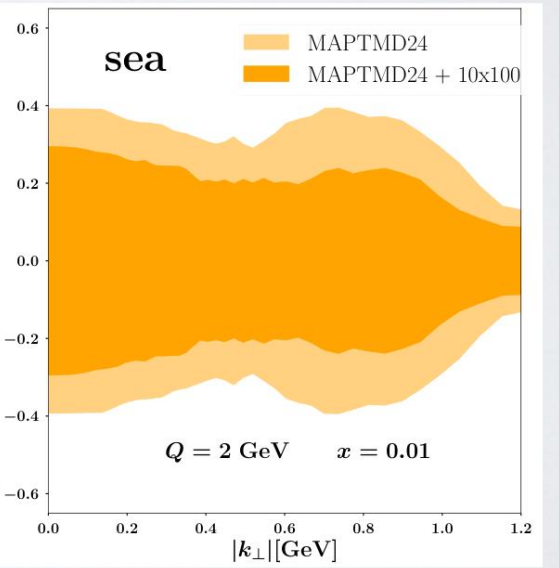


$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$ **x=0.01**

MAPTMD24 2031

EIC	# pts.	lumi [fb^{-1}]
10x100	1611	51.3

(simulation campaign of May 2024)



L. Rossi, Ph.D. Thesis, in preparation

- Significant impact at intermediate to low x with 10x100 only
- Probably still relevant improvements with limited early science data

Lorenzo Rossi
(Pavia)

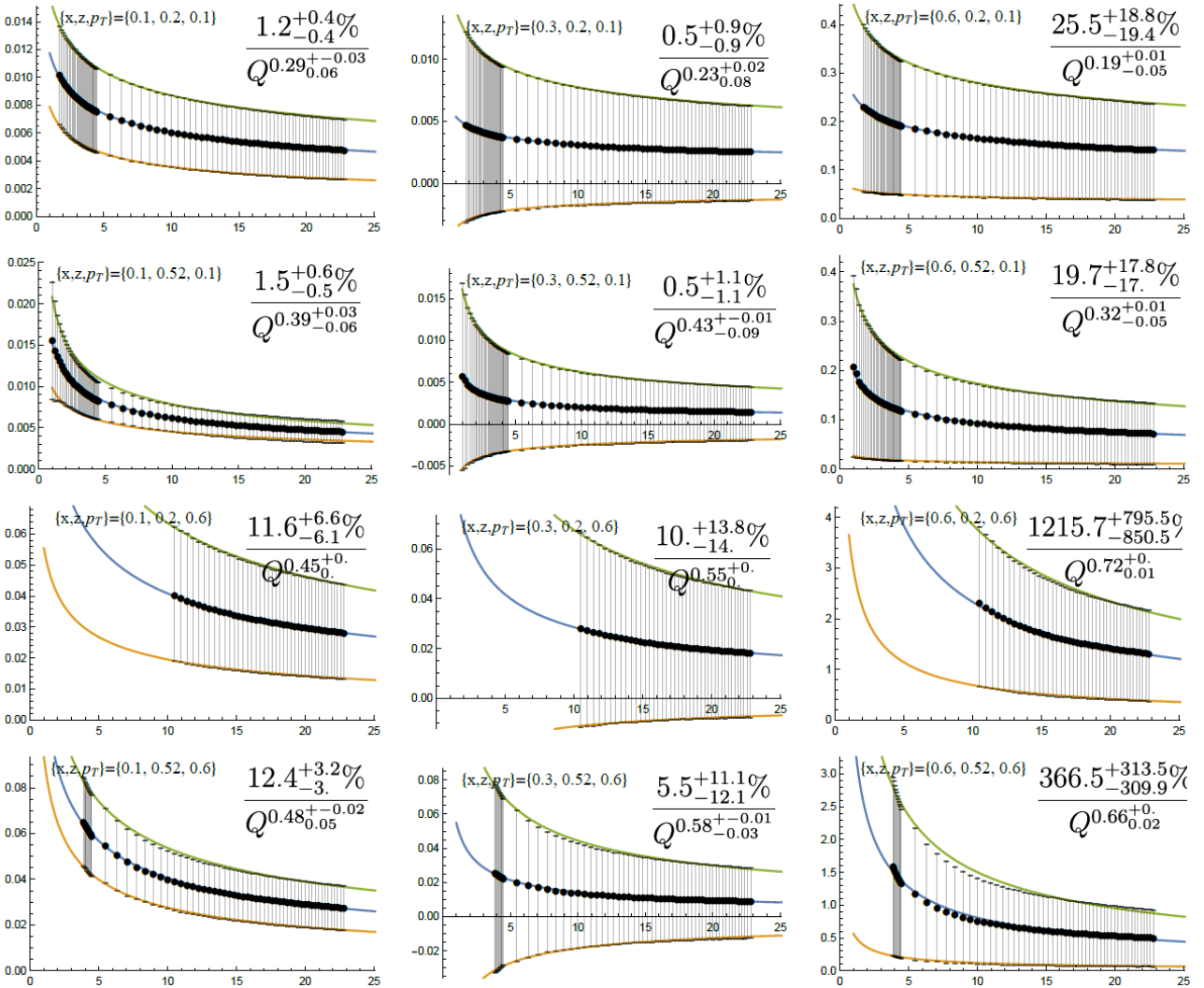
EIC access to TMD evolution

- Sivers asymmetries are expected to decrease at higher scales, but only logarithmically
  ➔ They do NOT “disappear”

- At higher x, asymmetries of several percent are expected

  ➔ Well accessible with EIC over wide range in x and Q^2

  ➔ Lower x the sea quark and gluon contributions can be studied (both mostly unknown)



Vladimirov et al.

Summary

- SIDIS gives access to the flavor of PDFs, helicity distributions and TMDs
- Naturally requires more variables in addition to DIS measurements
- Early physics feasibility:
  - nPDFs + nFF measurements – 3D binning (x,Q^2,z), no polarization needed
  - Early unpolarized TMD studies – 4D binning, no polarization
  - TMD evolution – 4D binning, no polarization, limited Q^2 range (depending on lumi)
- Only start of program for:
  - Polarized TMDs - 5D binning, UT polarization, different energies + high luminosity
  - Helicity distributions – 3D binning, LL polarization, different energies + high luminosity