Early science with SIDIS

ePIC collaboration meeting, Frascati,
January 22, 2025,
Ralf Seidl (RIKEN)
Stefan Diehl (Uconn)

SIDIS Measurements

Spin of the nucleon:

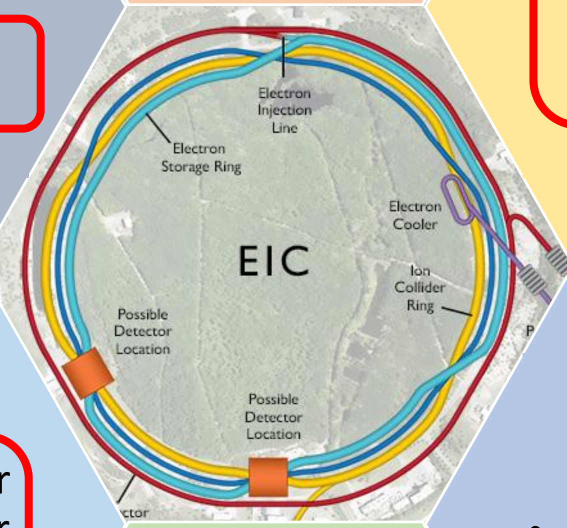
- Gluon spin
- Role of Sea quarks

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)

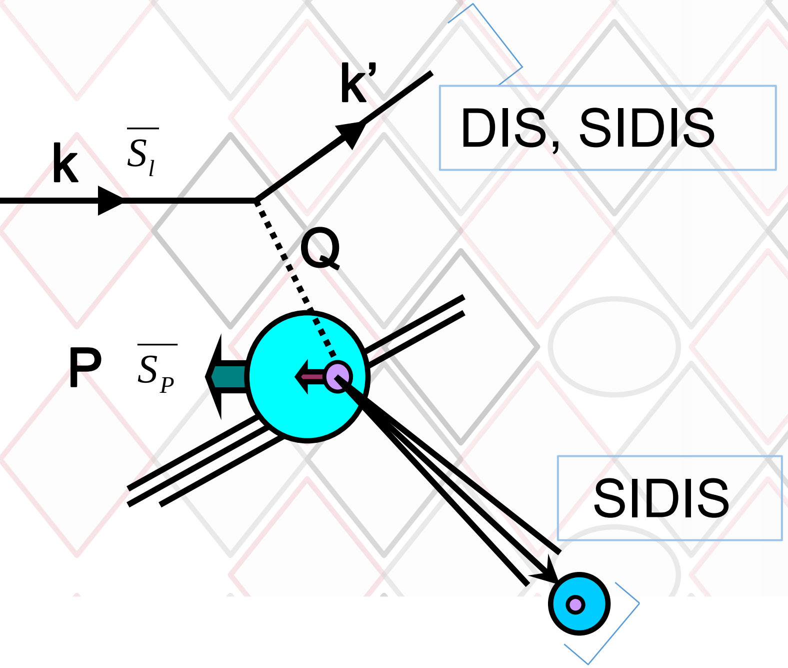
Origin of the Mass

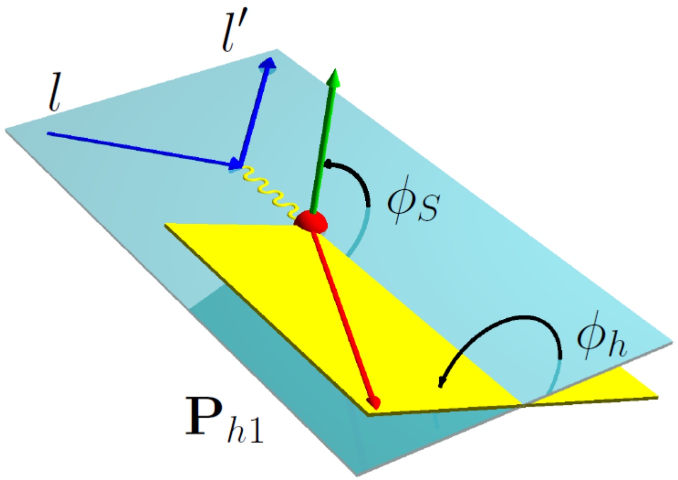
- Axial anomaly contributions
- Hadron structure

Other

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

SIDIS Kinematics





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

$$\frac{d^6\sigma}{dx dQ^2 dz dP_{hT} d\phi_S d\phi_h} \overset{LO}{\propto} \sum_{q,\bar{q}} e_q^2 q(x, Q^2, k_t) \otimes D_{1,q}^h(z, Q^2, p_t)$$

z:	Fractional hadron momentum wrt 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 nucleon (transverse) spin wrt to scattering plane, along virtual photon axis
ϕ_h:	Azimuthal angle of hadron wrt to scattering plane, along virtual photon axis

- Current fragmentation: related to struck quark (favored fragmentation u→π^+ , d→π^-, s→K^- , etc)
- Transverse momentum and angles rely also on correct boost to hadron rest system

Early science matrix

SIDIS uses fragmentation functions to add flavor, spin and transverse momentum sensitivity to DIS measurements

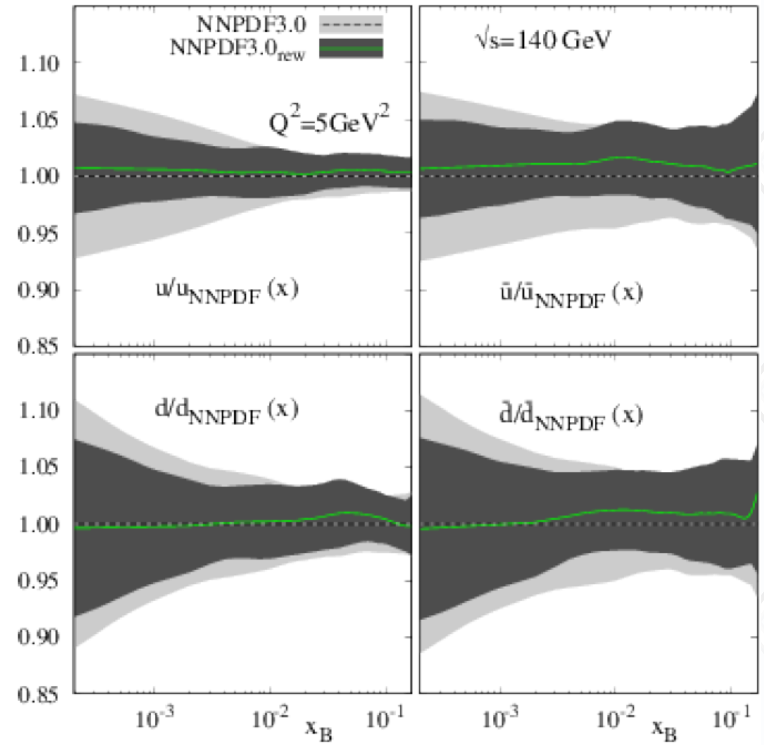
➔prerequisites: DIS + hadron momentum reconstruction + PID

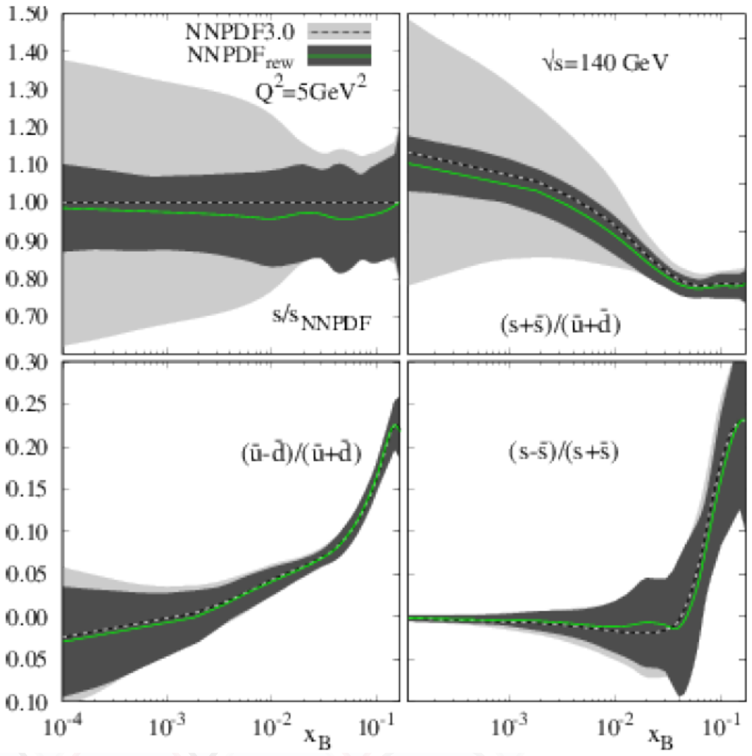
➔Kinematic variables x,Q2,z,(P_{hT},ϕ_S,ϕ_h) →higher dimensional binnings required

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}	****	Year 1+2
Unpol TMDs (start)		e+p	10 x ~100	U/U			N	~fb^{-1}	***	Year 2
HT A_Ns		e+p	10 x 100	U/T				~fb^{-1}	***	Year 3
TMD Evolution		e+p	10x100, (5x41, 18x275)	U/U				~fb^{-1}	***	Year 3+4
Sivers/Collins/IFF		e+p, (e+^{3}He)	10x100, (5x41, 18x275)	U/T				~ 10 fb^{-1}	**	Year 3+4
Helicities		e+p, (e+^{3}He)	10x100, (5x41, 18x275)	L/L				~ 10 fb^{-1}	**	
Di-hadrons (g Sivers/saturation)		e+p, e+A	18x275, (10x100)	U/(T)				~ 10 fb^{-1}	*	

Unpolarized PDFs

- Impact on unpolarized PDFs from plain (NC) DIS and SIDIS
- SIDIS (flavor sensitivity)→Sea quarks, especially strangeness suppression
- Also, potential access to intrinsic charm?

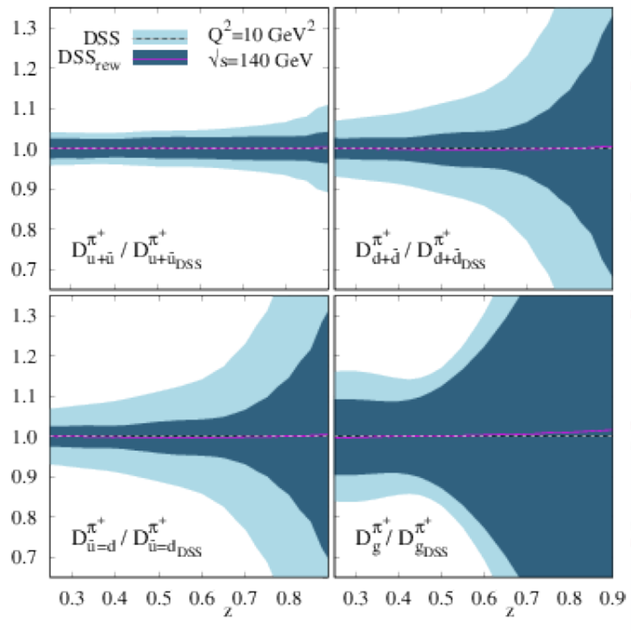


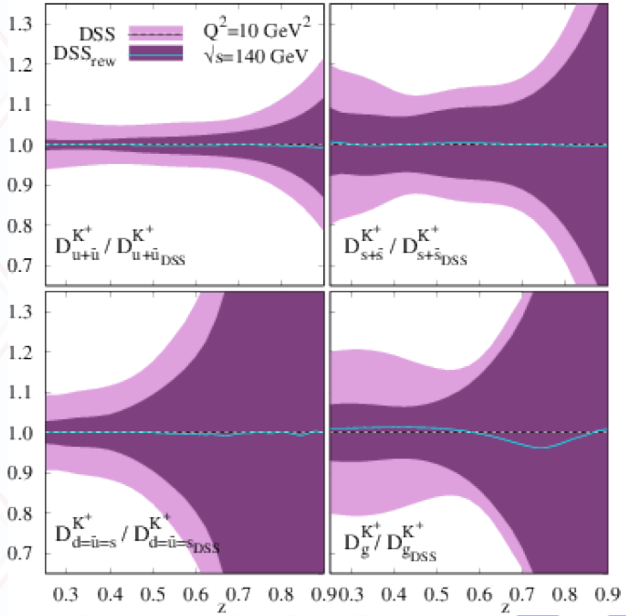


YR Figs 7.8, Aschenauer

FFs

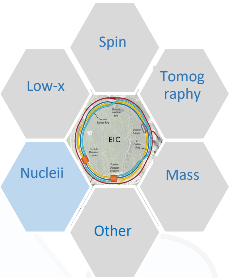
- Fragmentation functions provide information on struck parton, its flavor and spin
- They are a staple of all SIDIS measurements
- Also their understanding will improve further with the EIC



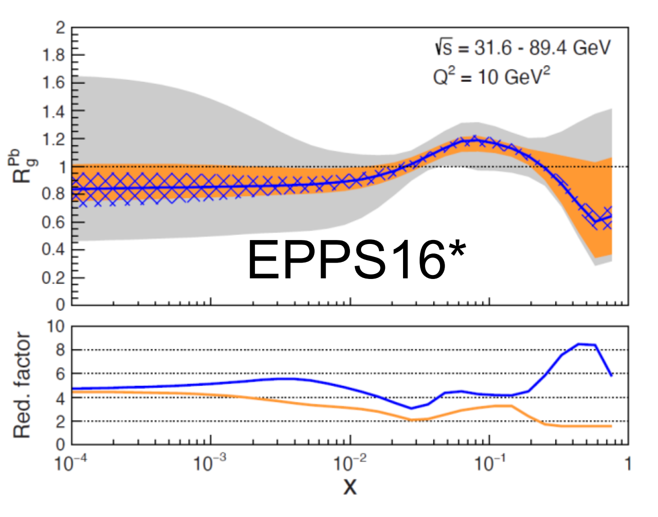


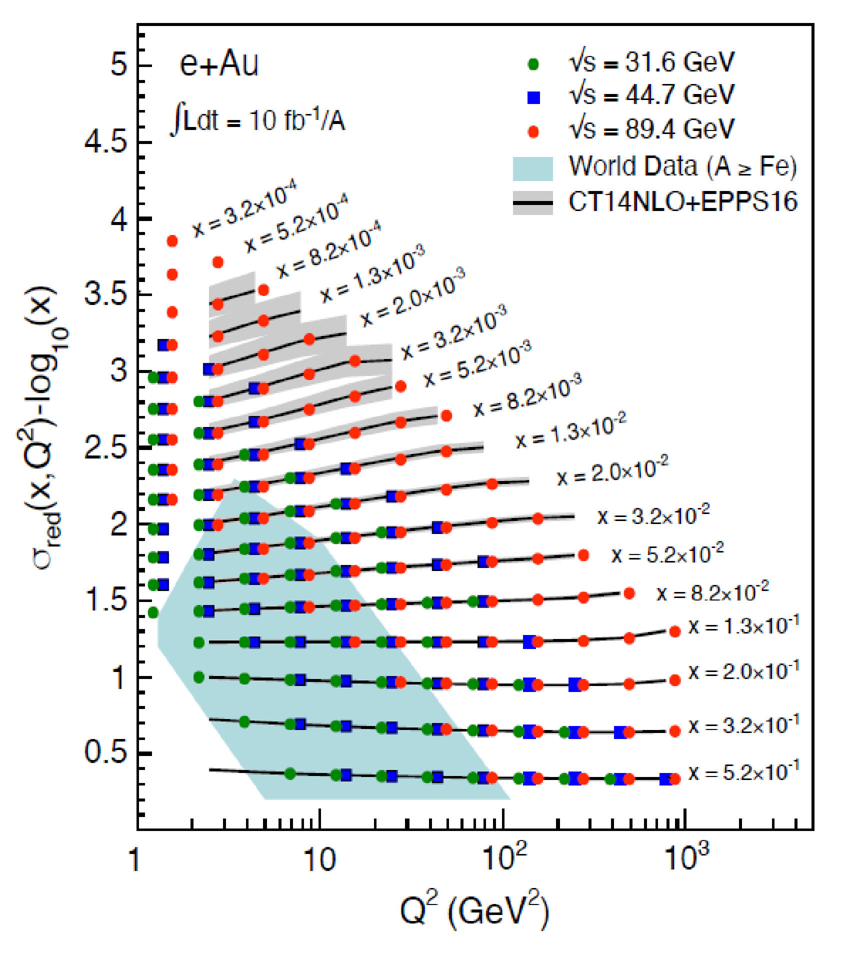
YR Fig 7.84, Aschenauer

Nuclear PDFs



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

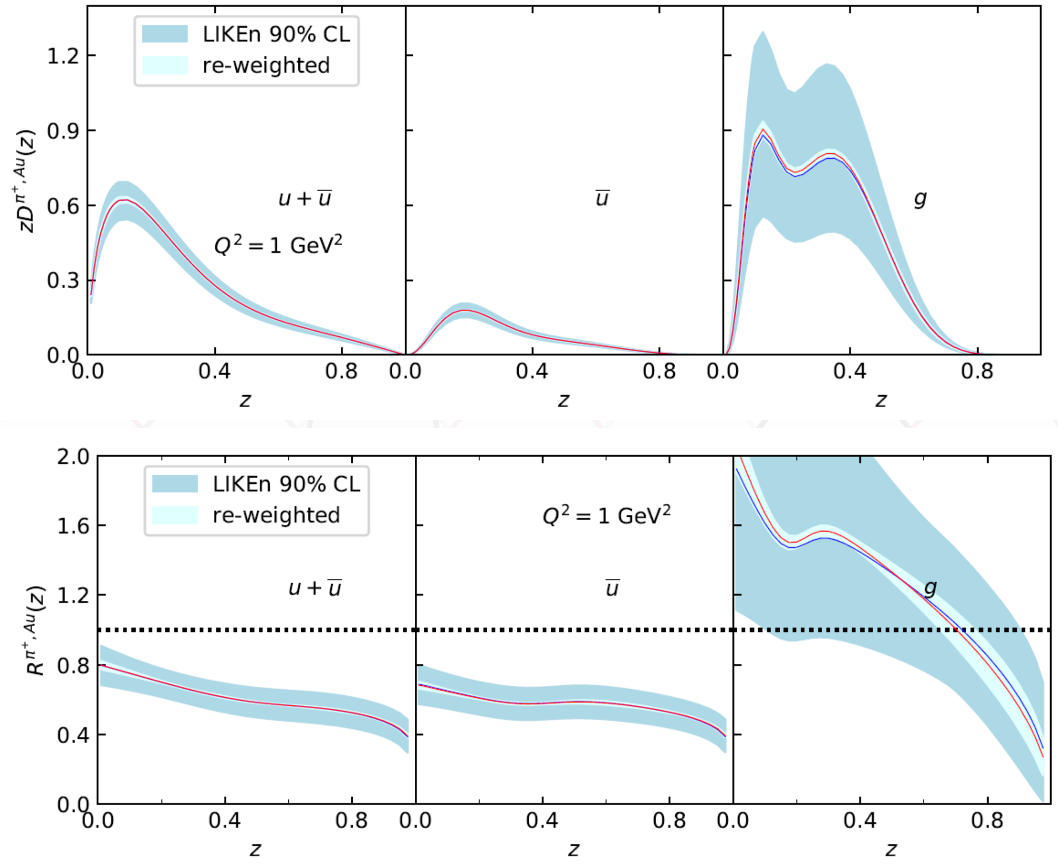




Currently no SIDIS impact studies available → create

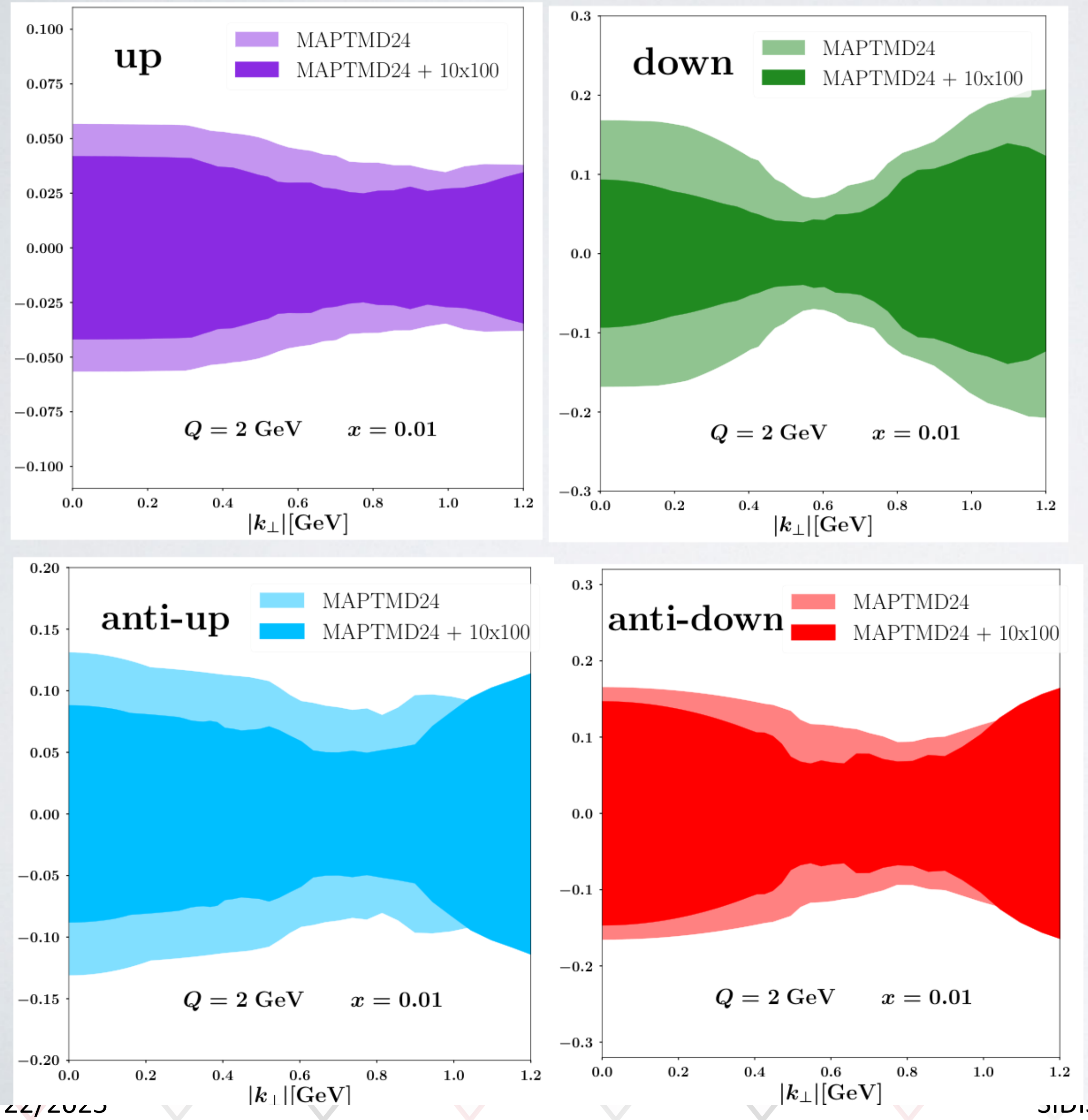
nFFs

- Expected impact from EIC on light hadron nuclear FFs
- More sophisticated studies ongoing (transverse momentum broadening, nu dependence, etc)
- Similar studies for heavy flavor



YR Figs 7.90, 7.91, Zurita

The EIC impact with 10x100 at x=0.01

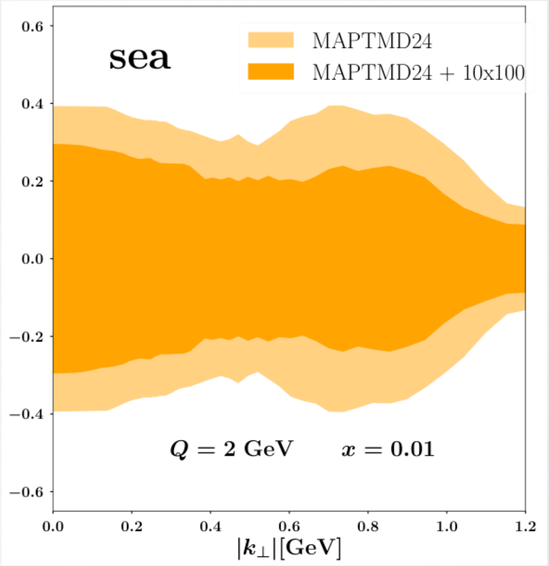


$$\frac{\text{TMD}^q - \langle \text{TMD}^q \rangle}{\langle \text{TMD}^q \rangle}$$

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

Lorenzo Rossi (Pavia) using pseudo-data from Gregory Matousek (Duke)

- Unpolarized TMD impact significant at intermediate to low x and only 10x100
- Probably still relevant improvements with limited early data

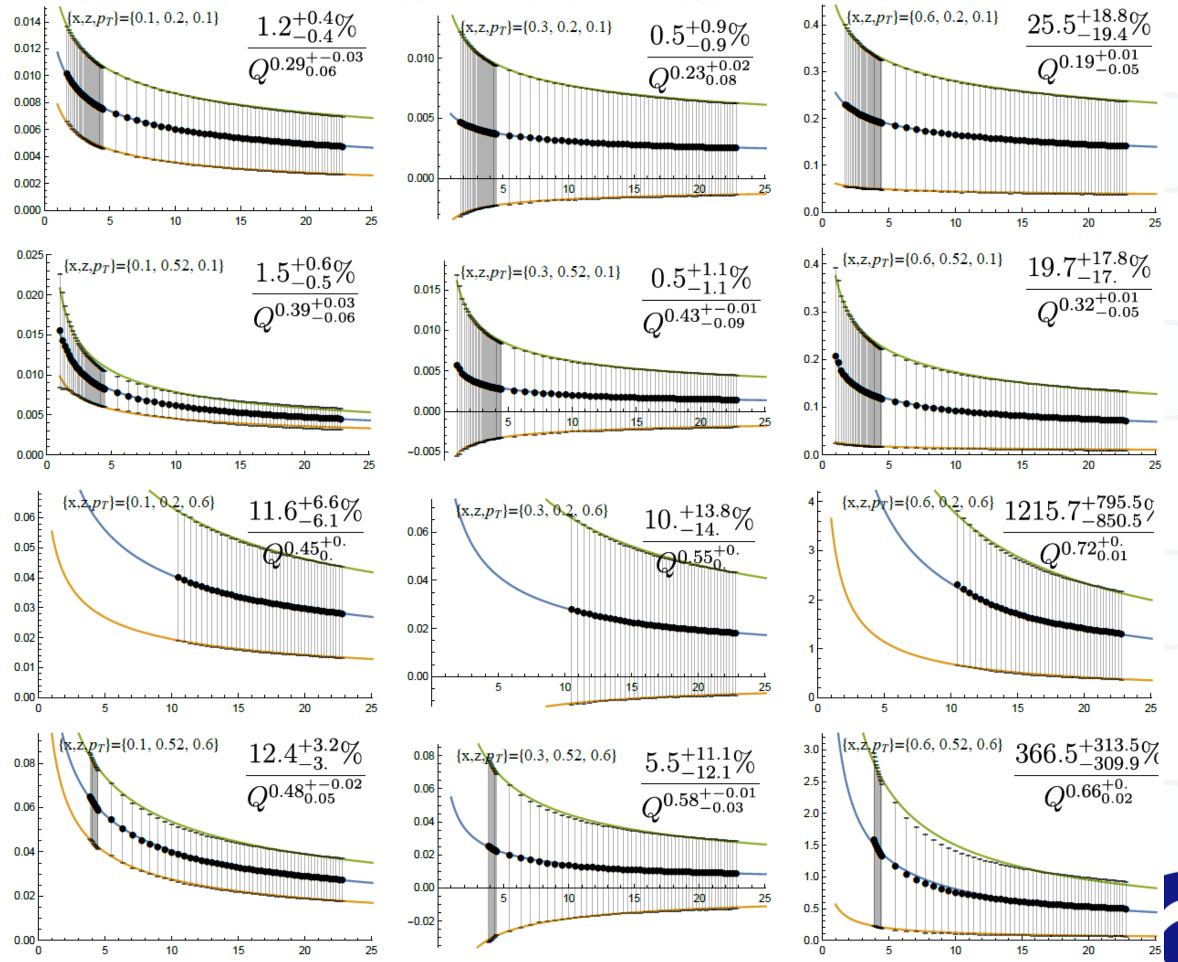
EIC access to TMD evolution

- Very important aspect is the study of TMD evolution
- Sivers asymmetries are expected to decrease at higher scales, but only logarithmically (ie they do NOT “disappear”)
- At higher x Asymmetries of several % expected

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

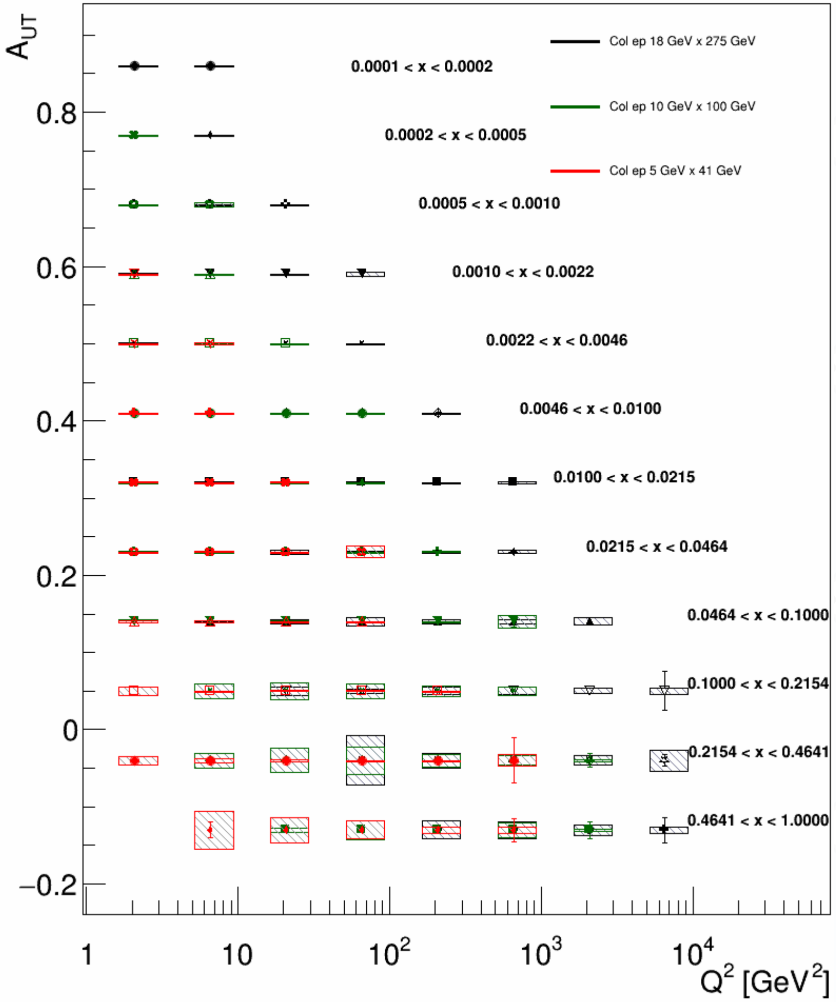
➔Lower x to study sea and glue (both mostly unknown)

Vladimirov et al.



Scale dependence (and interplay of collision energies)

- An example of the expected uncertainties in x and Q^2 to study the scale dependence of the Sivers/Collins asymmetries (as TMD evolution is not very well known/contains other nonperturbative pieces)
- Overlap of the different energies shows how they increase the lever arm
- Note: in future evolution analysis likely more Q^2 bins and maybe not as fine x binning



hep-ex:2207.10890

Summary

- SIDIS gives access to the flavor of PDFs, helicities and TMDs
- Naturally requires more variables in addition to DIS measurements
- Early physics feasibility:
  - nPDFs + nFF measurements – 3D binning (x,Q2,z), no polarization needed
  - Early unpolarized TMD studies – 4D binning, no polarization
  - TMD evolution – 4D binning, no polarization, Q2 range + lumi
- Only start of program for:
  - Polarized TMDs - 5D, UT polarization, different energies + lumi
  - Helicities – 3D, LL polarization, different energies + lumi

RIKEN