ECCE single transverse spin Asymmetries for single hadrons impact paper preparation

ECCE bi-weekly meeting
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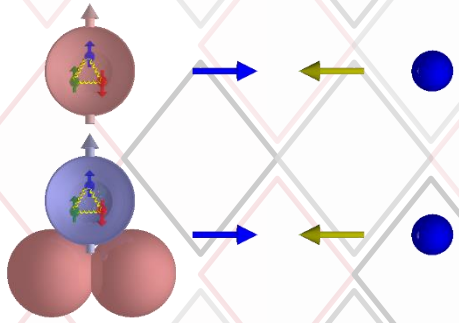
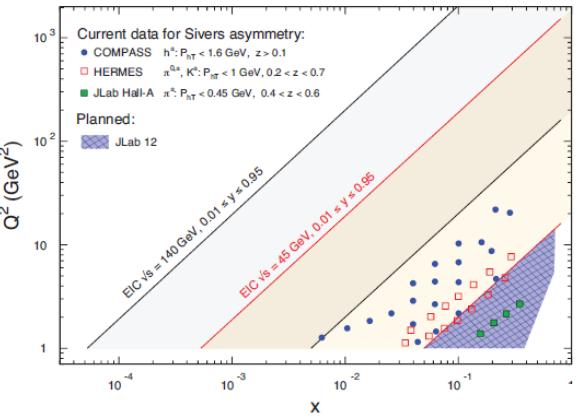
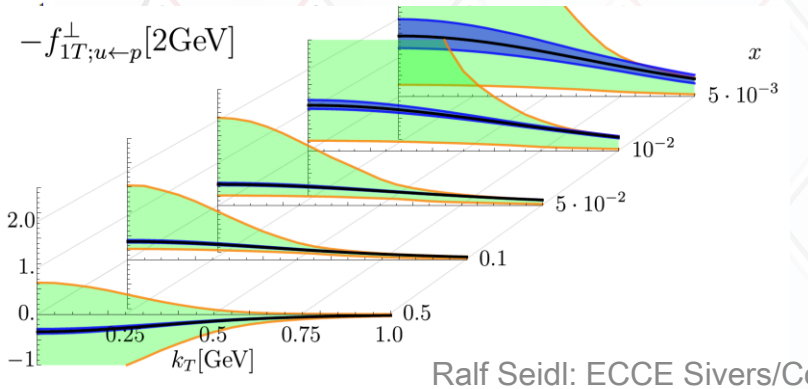
Motivation: 3D Transverse spin and momentum structure

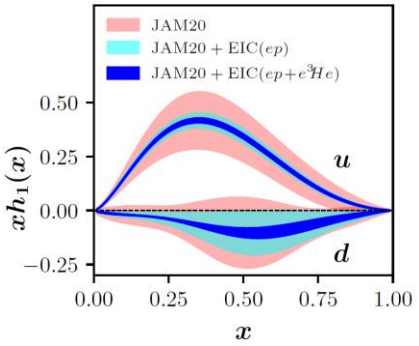


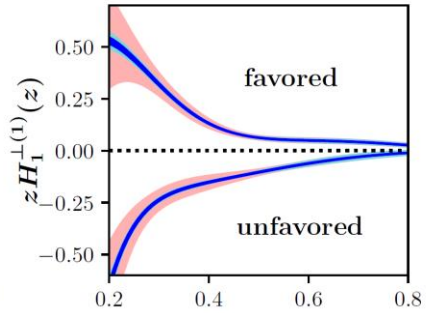
Deliverables	Observables	What we learn	Stage I	Stage II
Sivers & unpolarized TMD quarks and gluon	SIDIS with Transverse polarization; di-hadron (di-jet)	Quantum Interference & Spin-Orbital correlations	3D Imaging of quarks valence+sea	3D Imaging of quarks & gluon; Q^2 (P_{hT}) range QCD dynamics
Chiral-odd functions: Transversity; Boer-Mulders	SIDIS with Transverse polarization	3rd basic quark PDF; novel hadronization effects	valence+sea quarks	Q^2 (P_{hT}) range for detailed QCD dynamics

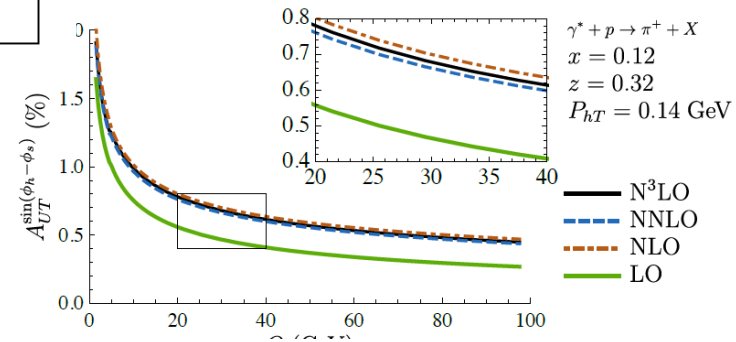


From EIC Yellow Report:



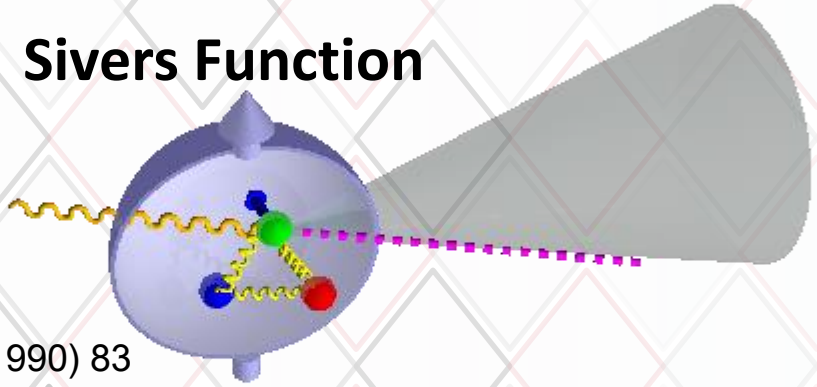






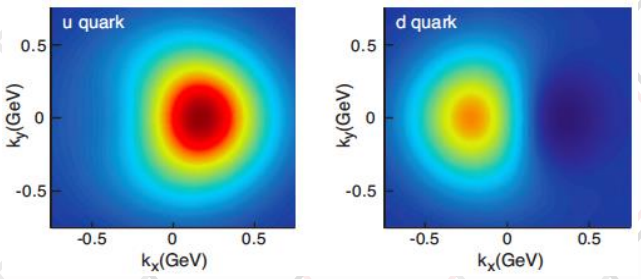
[Gamberg et al *Phys.Lett.B* 816 (2021) 136255]

Sivers Function



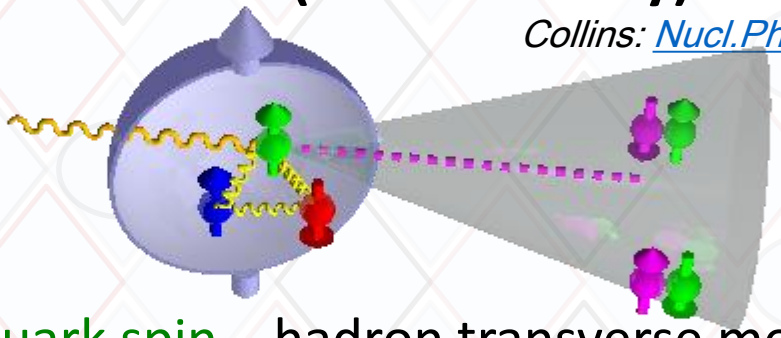
Sivers: Phys.Rev.D 41 (1990) 83

- Proton–spin – quark orbit (k_T) correlation (relation to orbital angular momentum)
- Transverse momentum imbalance in nucleon creates asymmetry
- Suggested by Sivers (1990), initially dismissed by Collins, resurrected by Brodsky (2002), Collins →special process dependence (sign change DY↔SIDIS)



Collins Function (x Transversity)

Collins: Nucl.Phys.B 396 (1993) 161

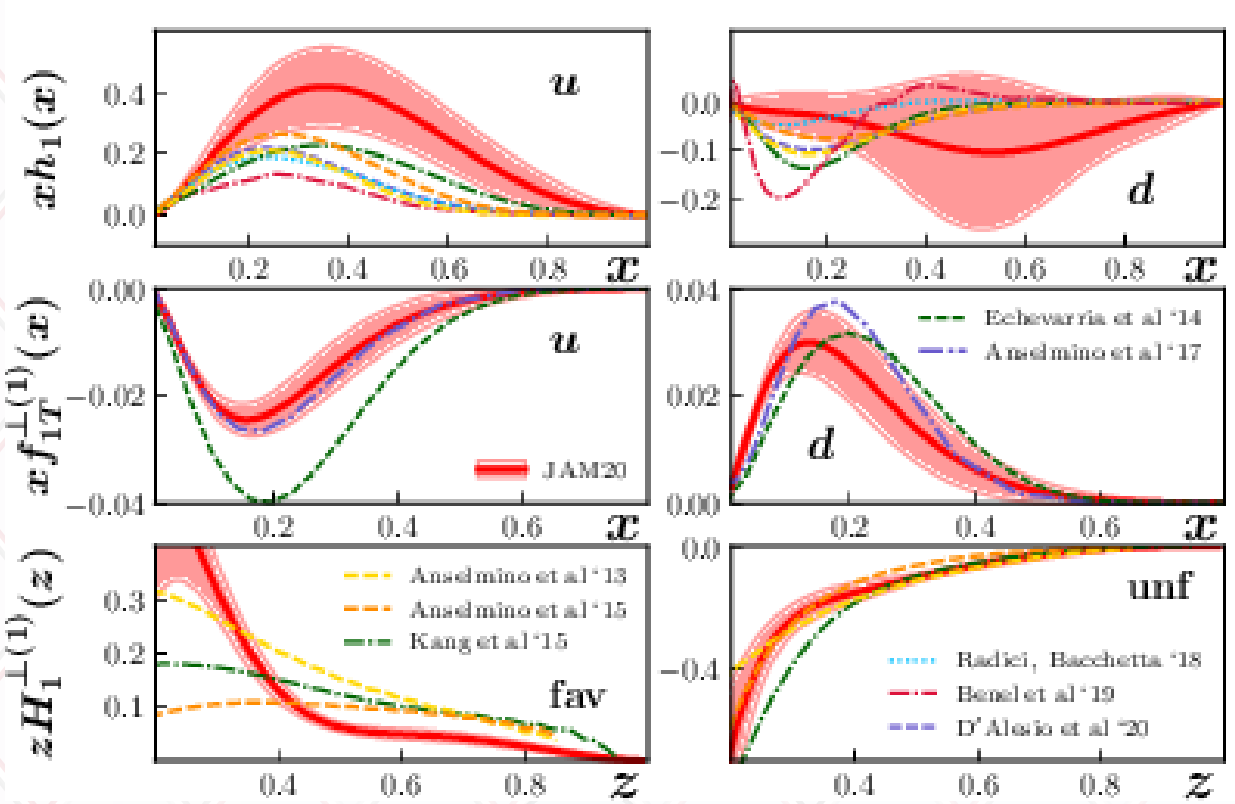


- Quark spin – hadron transverse momentum correlation (in fragmentation)
- Preferred direction of hadron creates asymmetry
- Analyzer for quark transversity (transverse quark spin) → access to tensor charge (Lattice, BSM?)
- A polarized (ie signed) fragmentation function

Both effects measured separately for quarks in SIDIS, FFs in e^+e^-

Current knowledge on these functions

- Only valence quark Sivers and Transversity functions known at this time with substantial uncertainties
- Experimentally covered range 0.01 < x < 0.3
- So far no sensitivity to sea quarks and gluons* and lower x



Cammarota et al, PRD 102 (2020) 054002

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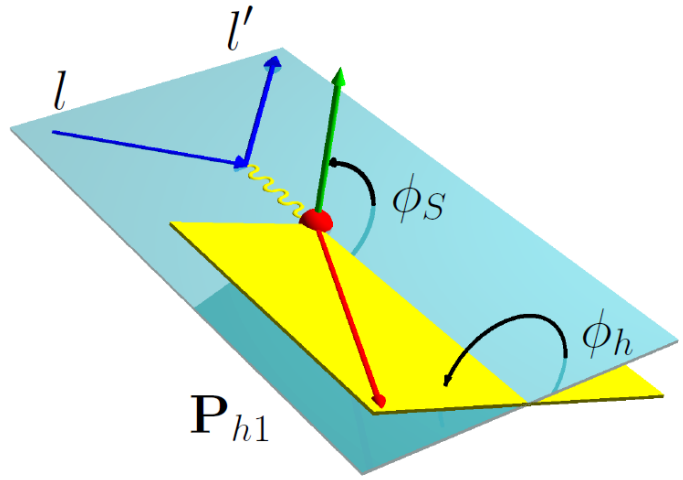
Experimental access to transversity and Sivers function

- Both functions are accessible as different azimuthal modulations in transversely polarized SIDIS of single hadrons
- Other TMD PDFs are similarly accessible via different modulations and spin orientations (though often higher twist effects present)
- Gluon Sivers via di-jet/di-HF TSSAs (only partially studied in ECCE so far → needs to be addressed soon)



$$A_{UT}^{\sin(\phi_h+\phi_S)}(x,z,P_T) \propto \mathbf{S}_T \frac{\sum_{q,\overline{q}} e_q^2 \delta q(x,k_t) \otimes H_1^{\perp}(z,p_t)}{\sum_{q,\overline{q}} e_q^2 q(x,k_t) \otimes D_1(z,p_t)}$$

$$A_{UT}^{\sin(\phi_h-\phi_S)}(x,z,P_T) \propto \mathbf{S}_T \frac{\sum_{q,\overline{q}} e_q^2 f_{1T}^{\perp,q}(x,k_t) \otimes D_1(z,p_t)}{\sum_{q,\overline{q}} e_q^2 q(x,k_t) \otimes D_1(z,p_t)}$$

ECCE simulation setup and binning

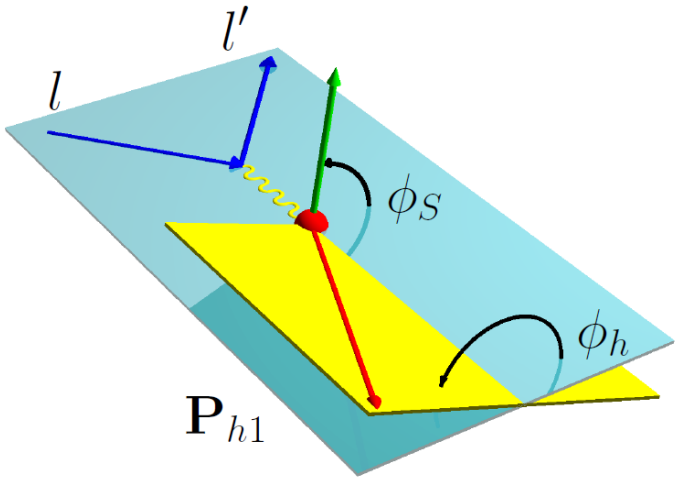
- pythiaeRHIC (Pythia 6) simulations for e+p collisions at 4 energies similar to YR
- Generator output simulated through GEANT4 (prop4)
- Analyzed via slightly modified EventEvaluator TTrees
- Scattered lepton ($|\eta|<3.5$) DIS kinematic reconstruction using reco track momenta (assuming perfect eID)
- DIS cuts: $0.01<y<0.95$, $Q^2>1$, $W^2>10\text{GeV}^2$
- SIDIS cuts: pions and kaons ($|\eta|<3.5$), using true PID (assuming successful unfolding)
- Initially 12x8x12x12 kinematic bins (x, Q^2, z, P_T) and 16x16 azimuthal bins

Energy	Q^2 range	events	Luminosity (fb^{-1})
18x275	1 - 100	38.71M	0.044
	>100	3.81M	1.232
18x100	1 - 100	14.92M	0.022
	>100	3.72M	2.147
10x100	1 - 100	39.02M	0.067
	>100	1.89M	1.631
5x41	1 - 100	39.18M	0.123
	>100	0.96M	5.944

Kinematic variable	Bin boundaries
x	$1.0x10^{-4}$, $2.154x10^{-4}$, $4.641x10^{-4}$, $1.0x10^{-3}$, $2.154x10^{-3}$, $4.641x10^{-3}$, $1.0x10^{-2}$, $2.154x10^{-2}$, $4.641x10^{-2}$, $1.0x10^{-1}$, $2.154x10^{-1}$, $4.641x10^{-1}$, $1.0x10^{0}$
Q^2	$1.0x10^{0}$, $3.162x10^{0}$, $1.0x10^{1}$, $3.162x10^{1}$, $1.0x10^{2}$, $3.162x10^{2}$, $1.0x10^{3}$, $3.162x10^{3}$, $1.0x10^{4}$
z	0, 0.05, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0
P_T	0, 0.05, 0.1, 0.2, 0.3, 0.5, 0.7, 0.9, 1.2, 1.5, 1.8, 2.4 ,4.0

Sivers/Collins measurements in SIDIS

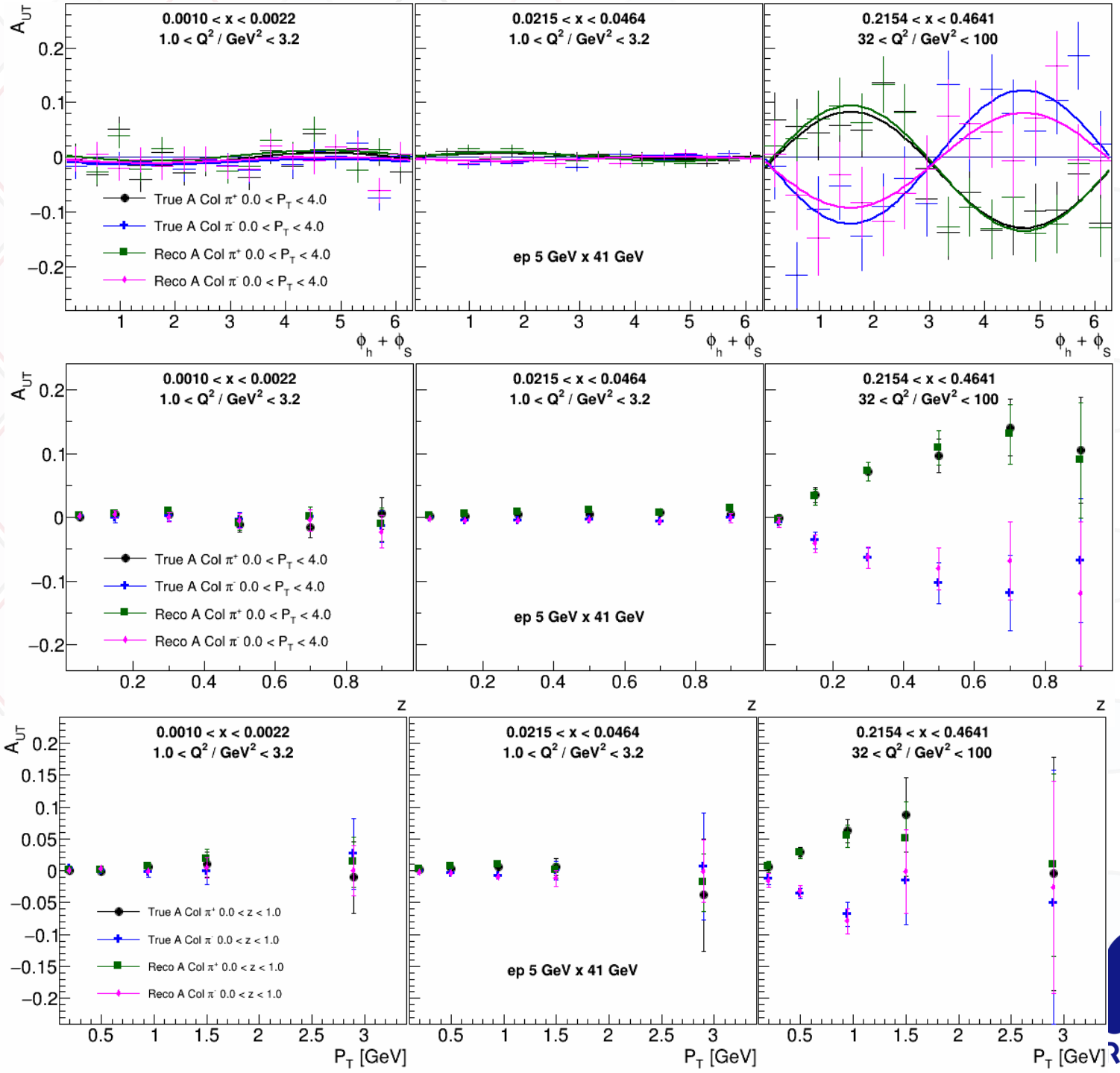
- Reweight events according to true parton flavor q, hadron h, x, z, Q^2, P_{hT}, azimuthal angles and random spin orientiation
- $ep^{\uparrow} \rightarrow e'hX$
- A_{UT} asymmetries (Unpolarized lepton beam, Transversely polarized target)
- Different azimuthal modulations related to Sivers effect ($\sin(\phi-\phi_s)$) and Collins effect ($\sin(\phi+\phi_s)$)
- Fit simultaneously in the reconstructed events and calculate asymmetries



- Input structure functions (polarized and unpolarized) from Torino global fits (arXiv:0812.4366, arXiv:0805.2677) as in https://github.com/prokudin/tmd-parametrizations/

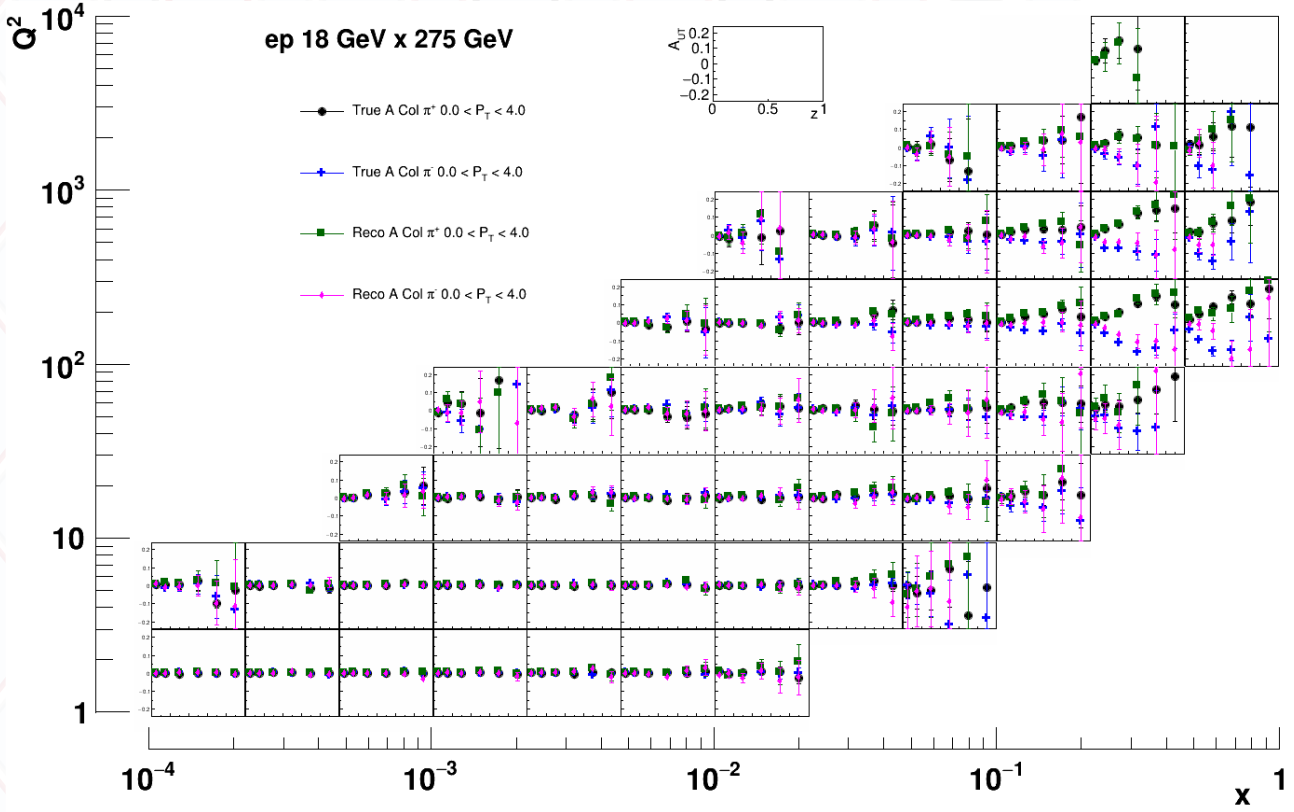
Example figures

- Examples in 3 x and Q2 bins: on top for the Collins angular combination for charged pions true and reconstructed in an intermediate z bin
- Lower figures: same, either projected vs z or vs Pt



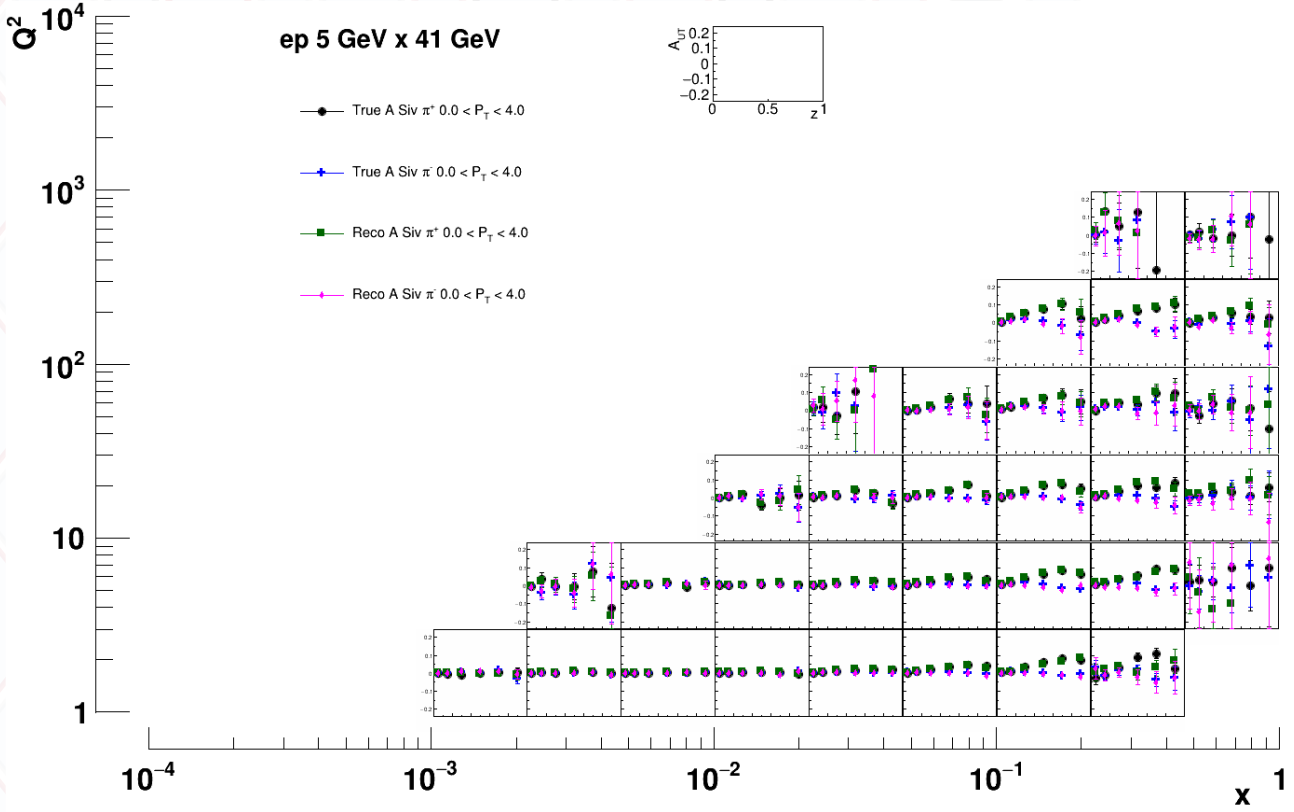
Collins asymmetries at highest energies

- Example of the level of reconstruction and uncertainties give the simulated statistics
- Nonzero asymmetries well reproduced at higher x
- Opposite sign for π^+/π^- seen as expected
- High precision at lower (yet hardly measured) x



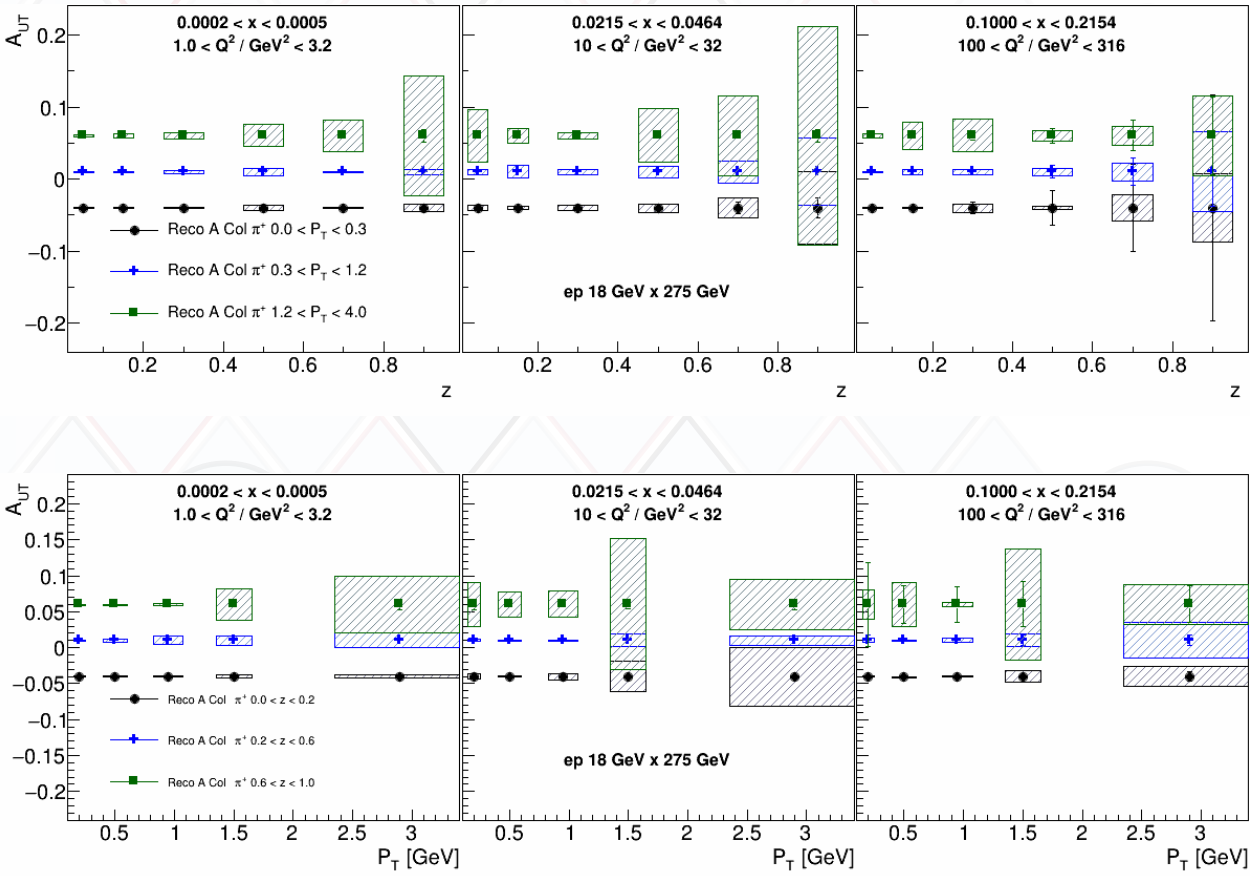
Sivers asymmetries at lowest energies

- Similar figure for the Sivers asymmetries
- Positive asymmetries seen for π^+ at higher x
- π^- asymmetries compatible with zero due to up/down/favored/disfavored cancellation
- High precision already with simulated statistics



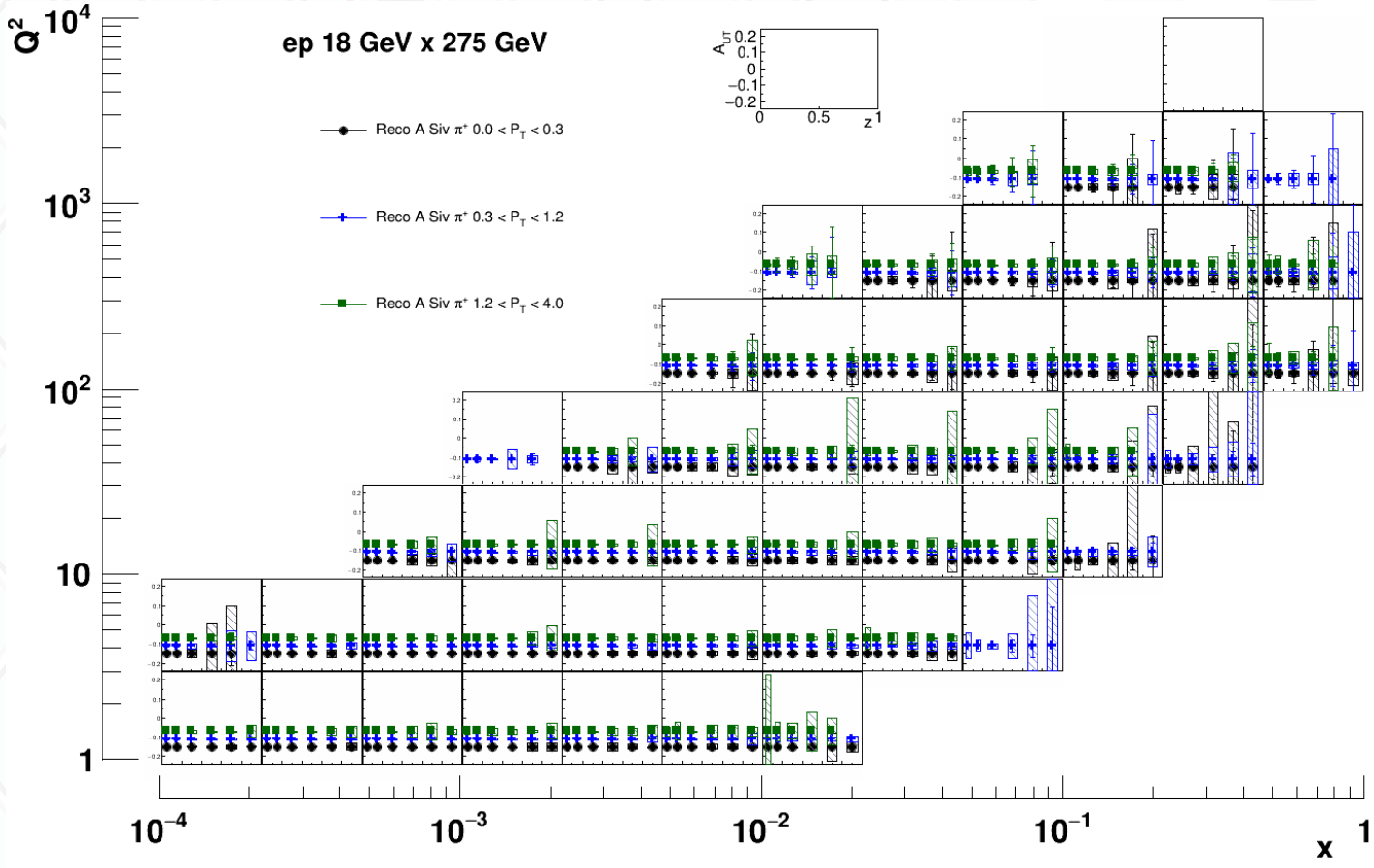
Projections to 10fb^{-1}

- Systematic uncertainties estimated from differences between true and reconstructed asymmetries → they are likely largely overestimated since most of the kinematic smearing would be unfolded, but give a sense of where uncertainties still might be larger due to that unfolding



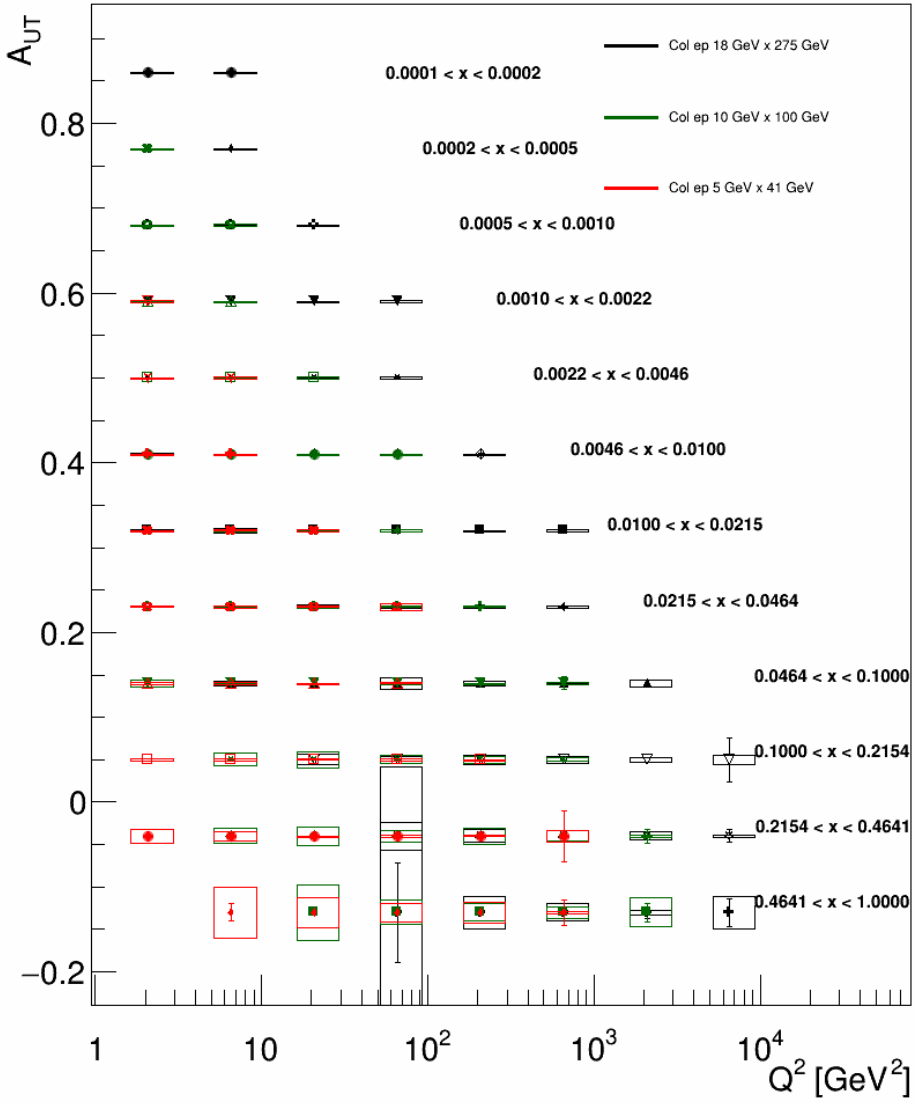
Full projections

- Projected uncertainties in all (accessible) x-Q2 bins as a function of z (or Pt) integrated over Pt (or z)
- Currently shown in paper draft: highest and lowest collision energies and both Sivers and Collins asymmetries



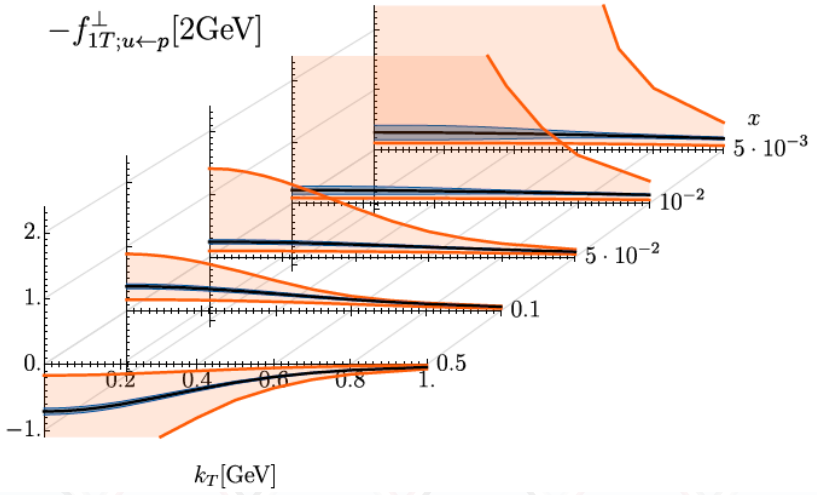
Scale dependence (and interplay of collision energies)

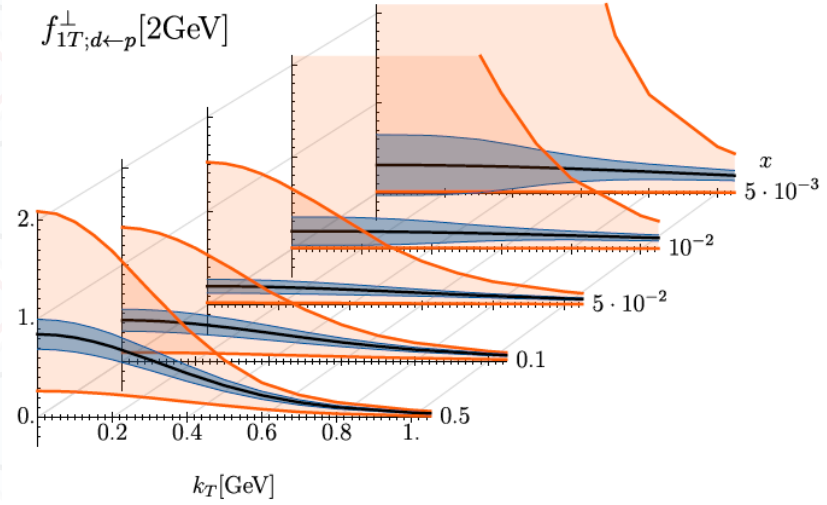
- An example of the expected uncertainties in x and Q^2 to study the scale dependence of the Sivers/Collins asymmetries (as TMD evolution is not very well known/contains other nonperturbative pieces)
- Overlap of the different energies shows how they increase the lever arm
- Note: in future evolution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



Impact for Sivers functions

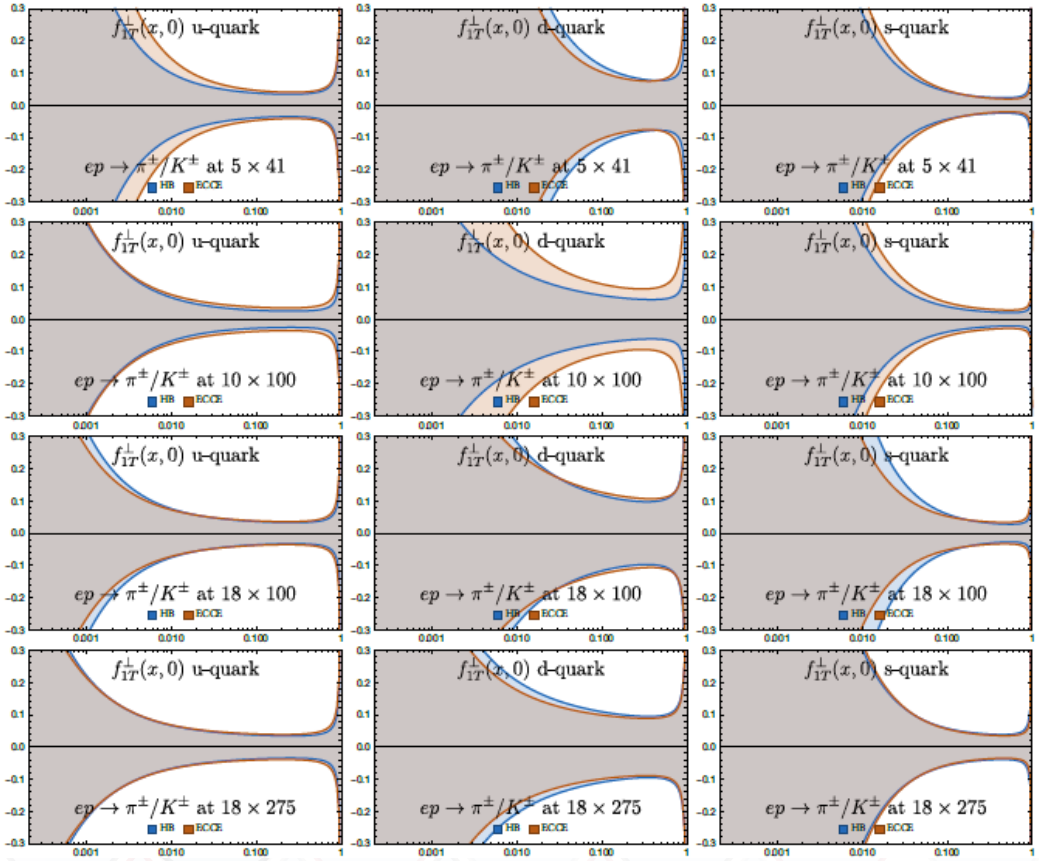
- Similar to YR impact studies following the latest BPV global fit (arXiv:2103.03270) for the Sivers function based on the existing SIDIS +DY data
- Uncertainties are shown for current level of knowledge on up/down Sivers functions at various x vs kt and expected impact from ECCE





ECCE Impact compared to YR handbook detector (pseudo-data parametrized via eic-smear)

- The relative size of the up, down and s quark Sivers function uncertainties compared to the expected uncertainties from the YR studies
- Some minor differences but essentially similar level as YR HB detector (parametrized via eic-smear)

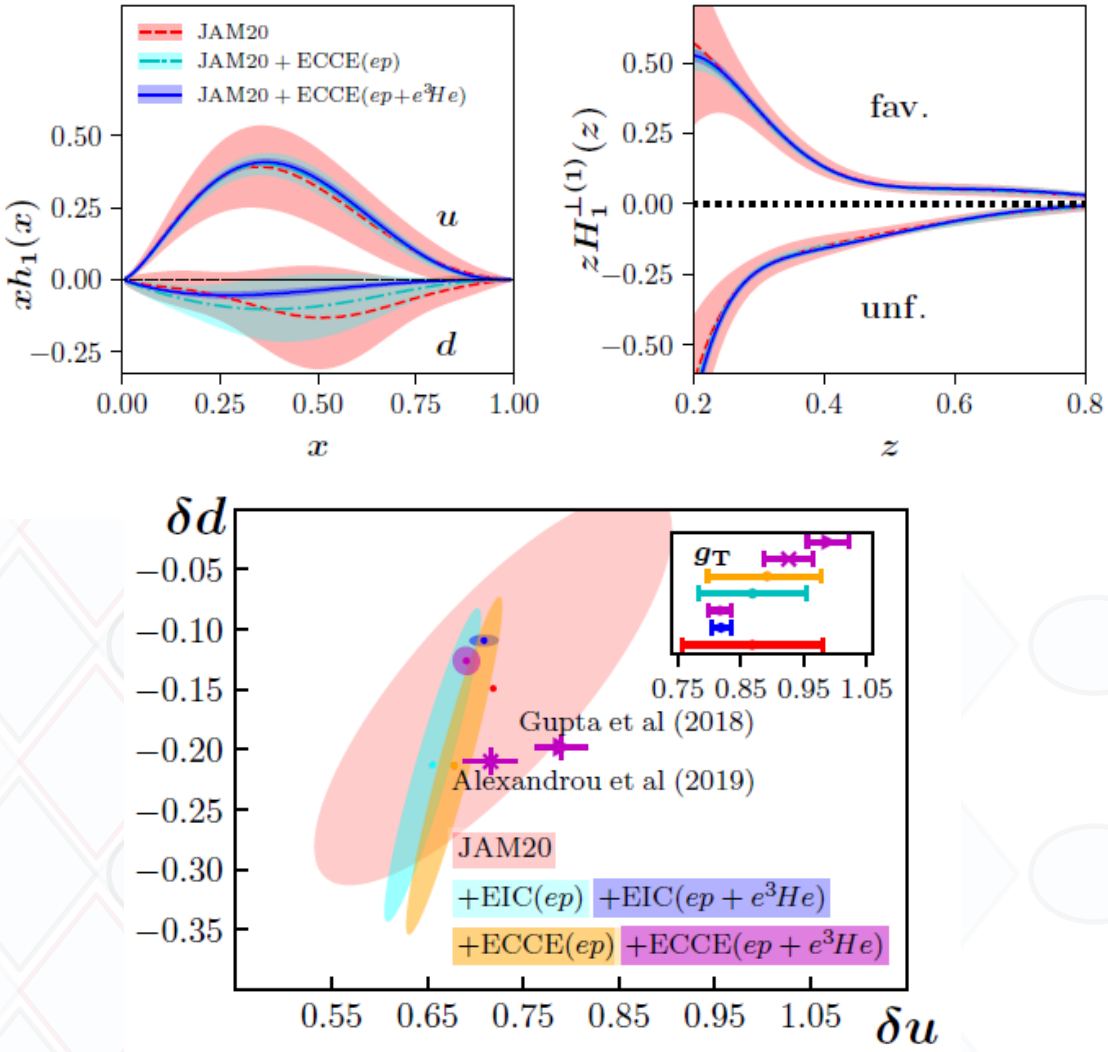


Tensor charge impact

- Similar to Gamberg et al *Phys.Lett.B* 816 (2021) 136255

  (for YR) use fitting code from latest global fit Cammarota et al arXiv:2002.08384 to extract impact on Transversity, Collins functions and tensor charges

- Together with projected JLAB12 data precision to compare with Lattice results (and check for possible discrepancies)



Summary

- Sivers/Collins SIDIS paper essentially ready
- Some reduction in introduction (removal of motivational figures from note)

- Follow up on these studies as ECCE detector evolves and consider studying the proper unfolding of kinematic smearing as well as particle identification
- Similar studies still needed for gluon Sivers channel

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