SIDIS summary of inclusive and jet related topics

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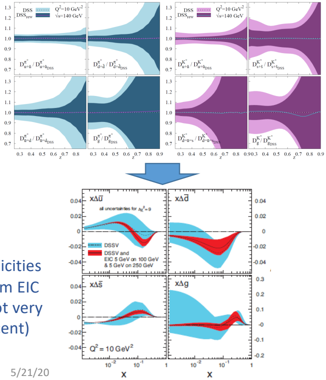
with inputs from Miguel Arratia and Liang Zheng

Pavia YR Meeting

Helicity studies in the SIDIS WG (R. Seidl)

PRD 99 (2019), 094004

FFs from EIC

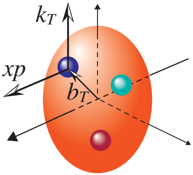


helicities from EIC (not very recent)

5/21/20

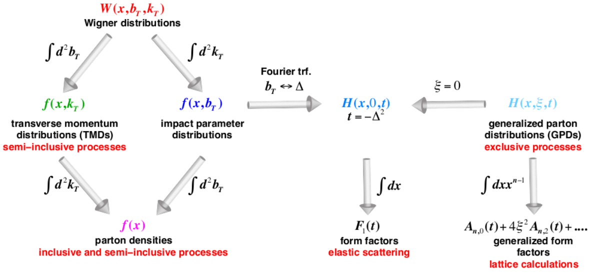
- Work will follow ongoing sensitivity studies by Elke's group + Argentinian global fitters
- See unpol FF and PDF sensitivity studies developed using SIDIS
- Update on helicity impacts using also SIDIS, currently concentration on CC and $D/^3He$
- Implementation of detector smearing, etc ongoing, but so far no new impact studies on SIDIS

3D Tomography



gluon pol.

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



$W(x,b_T,k_T)$
Wigner distributions

$\int d^2b_T$

$\int d^2k_T$

$f(x,k_T)$
transverse momentum distributions (TMDs)
semi–inclusive processes

$f(x,b_T)$
impact parameter distributions

Fourier trf.
$b_T \leftrightarrow \Delta$

$H(x,0,t)$
$t=-\Delta^2$

$\xi=0$

$H(x,\xi,t)$
generalized parton distributions (GPDs)
exclusive processes

$\int d^2k_T$

$\int d^2b_T$

$\int dx$

$\int dx x^{n-1}$

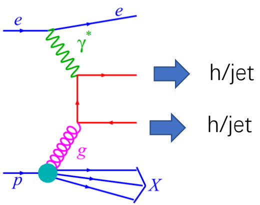
$f(x)$
parton densities
inclusive and semi–inclusive processes

$F_1(t)$
form factors
elastic scattering

$A_{n,0}(t)+4\xi^2 A_{n,2}(t)+....$
generalized form factors
lattice calculations

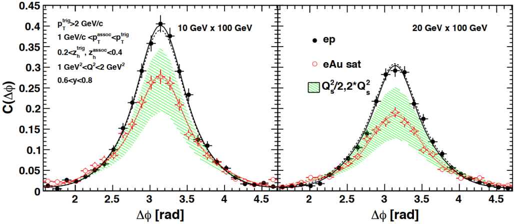
- Diffractive dijet at EIC ⇒ gluon Wigner distribution (currently under study by the exclusive WG (Z. Zhang)).
- Unpolarized gluon TMD at small-x and gluon Sivers can be directly probed via dijet/dihadron at EIC.

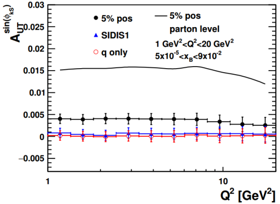
Accessing gluon TMD at EIC (L. Zheng)



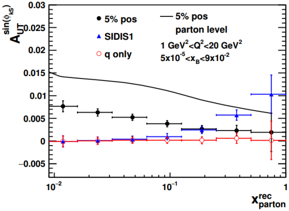
- Gluon distribution accessed via dihadron/dijet
- Precisely determine gluon Sivers and gluon saturation effects

Phys. Rev. D 89, 074037 (2014)



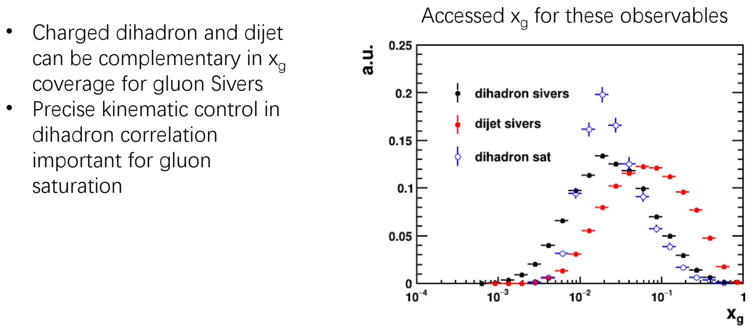


Gluon sivers dijet



Phys. Rev. D 98, 034011 (2018)

x_g coverage (L. Zheng)



- Charged dihadron and dijet can be complementary in x_g coverage for gluon Sivers
- Precise kinematic control in dihadron correlation important for gluon saturation

Accessed x_g for these observables

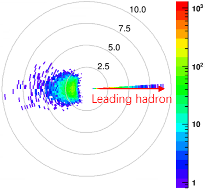
- Wide x_g coverage (ep 18 × 275 GeV) for the gluon Sivers measurement.
- Focus on low-x (ep/eA 18 × 110 GeV) events for the gluon saturation.

Kinematic map for gluon Sivers via dihadron (L. Zheng)

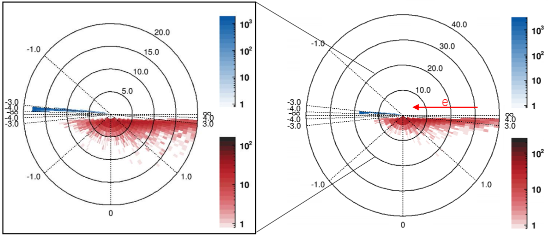
ep 18x275 GeV
$0.01<y<0.95$, $1<Q^2<2$ GeV^2
charged hadron, $|\eta|<4.5$, $p_T^*>1.4$ GeV, $z_h>0.1$,
$k^*_T/P^*_T<0.7$, * indicates γ^*p c.m.s frame

- Scattered e$^-$ p range: 1~20 GeV, η range: -4~-1
- Hadron p range: mostly several GeV, η range: widely distributed

p_T vs $\Delta\phi$ for associate hadron relative to leading hadron



p vs η for scattered electron and charged hadron pairs (blue for e-, red for hadron)

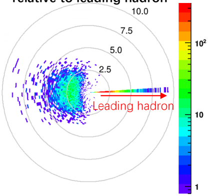


Kinematic map for gluon Sivers via dihadron(L. Zheng)

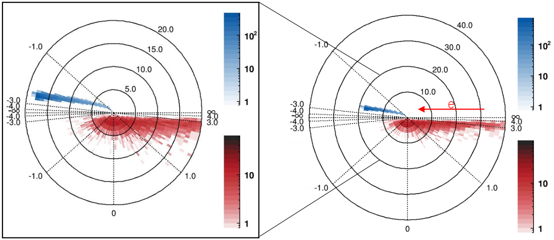
ep 18x275 GeV
$0.01<y<0.95$, $10<Q^2<20$ GeV^2
charged hadron, $|\eta|<4.5$, $p_T^*>1.4$ GeV, $z_h>0.1$,
$k^*_T/P^*_T<0.7$, * indicates $\gamma^*\mathbf{p}$ c.m.s frame

- Scattered e$^-$ p range: 1~20 GeV, η range: -4~-1
- Hadron p range: mostly several GeV, η range: widely distributed

p_T vs $\Delta\phi$ for associate hadron relative to leading hadron



***p* vs *η* for scattered electron and charged hadron pairs (blue for e-, red for hadron)**

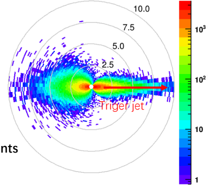


Kinematic map for gluon Sivers via dijet (L. Zheng)

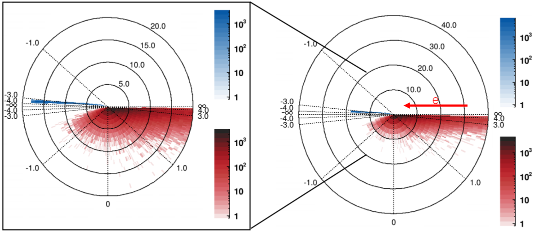
ep 18x275 GeV $0.01<y<0.95$, $1<Q^2<2$ GeV^2
all final, $|\eta|<4.5$, $p_{T\,\mathrm{lab}}>0.25$ GeV,
$p_{T\,\mathrm{jet1}}^*>4.5$ GeV, $p_{T\,\mathrm{jet2}}^*>4$ GeV, * indicates γ^*p c.m.s frame

- Scattered e$^-$ same as dihadron
- Hadron constituents p range: mostly around 1 GeV,
  η range: widely distributed

p_T vs $\Delta\phi$ for associate and trigger jets constituents relative to trigger jet direction



p vs η for scattered electron and jet constituents (blue for e-, red for jet constituents)

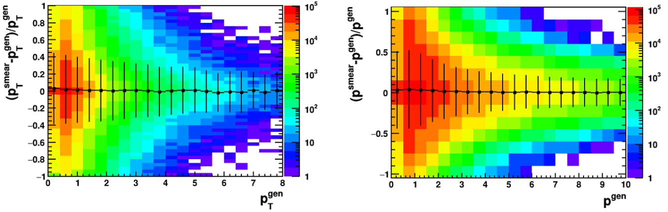


Detector Requirement from gluon Sivers measurement:

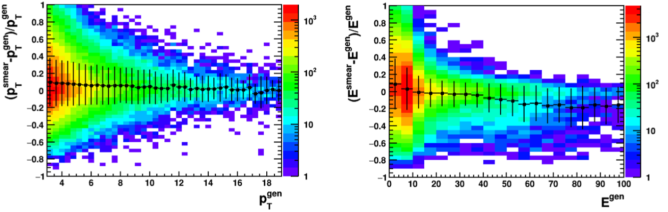
- Hermetic acceptance, sufficiently high momentum (mainly high pT) and angular (need 2π azimuthal coverage) resolution.

Detector Response with EIC-smear (L. Zheng)

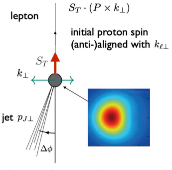
ep 18x275 Charged hadron smearing in Lab frame(z>0.1)



Jet smearing in Lab frame



Requirements of “Jets for 3D imaging" program (Miguel Arratia)



Electron-jet corretions

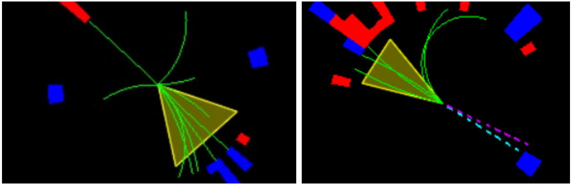


Table 1: Channels listed are increasingly demanding. For every row consider all requirements above as well. The (x, Q^2) dependence of the observables is omitted for brevity. Date: May 20, 2020, Miguel Arratia

Channel	Observable	Goal	Physics-driven requirement	Category	numbers
e-jet (NC) 100 fb^{-1}	$d\sigma$, $A_{UT}(\Delta\phi)$	k_T-dependence of quark Sivers	$\Delta\phi$ res. << intrinsic width $\sigma(\Delta\phi) < 0.02$ rad $R = 1.0 \rightarrow$ had. corr. $O(1)\%$ particle-flow reco	Jet res. Acceptance Granularity	jet $dE/E < 20\%/\sqrt{E}$ $\rightarrow$ ECAL&HCAL $dE/E < 60\%/\sqrt{E}$ 2π, $\lvert\eta\rvert < 3.5$ HCAL and ECAL endcap $\Delta\phi \times \Delta\eta \leq 0.025 \times 0.025$
h-in-jet (NC) 100 fb^{-1}	$d\sigma$, $A_{UT}(z_h, j_T)$	q-transversity	dp/p at high $z <$ jet dE/E	Tracker PID	$dp/p < 3\%$ at 50 GeV, up to $\eta = 3.0$ up to $\eta < 3.5$ and 50 GeV
ν-jet (CC) 100 fb^{-1}	$d\sigma$, A_{UT}	u Sivers	$\Delta\phi << 0.3$ rad Bkg. rej. to phot and NC >70% survival prob. for 5 bins per-decade in x, Q^2	E_T^{miss} res. Acceptance Jet/E_T^{miss} res.	$dE_T^{miss}/E_T^{miss} < 15\%$ 2π, $\lvert\eta\rvert < 3.5$ HCAL and ECAL E>100 MeV thres. ECAL E>400 MeV thres. HCAL $p_T > 100$ MeV tracker $dx/x < 20\%$, $dE_T^{miss}/E_T^{miss} < 15\%$
h-in-jet (CC) 100 fb^{-1}	$d\sigma$, $A_{UT}(z_h, j_T)$	u-transversity	—	—	—
c-jet (CC) 100 fb^{-1}	$d\sigma$, A_{LL}	s PDF& helicity	charm-tagging	Tracker PID	c-jet tag at $> 10\%$ (<0.05%) $\sigma(DCA) = 20$ μm, up to $\lvert\eta\rvert = 3$ $\approx 100\%$ eff. TBD
h-in-c-jet (CC) 100 fb^{-1}	$d\sigma$, $A_{UT}(z_h, j_T)$	s-transversity	—	—	—
c-jet (e^+ CC) 100 fb^{-1}	$d\sigma$, A_{LL}	$s/\bar{s}$ asymmetry	positrons	—	—

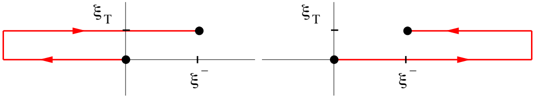
A Tale of Two Gluon Distributions

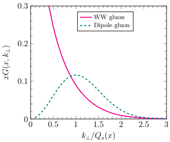
I. Weizsäcker Williams gluon distribution: conventional gluon distributions

$$xG_{\rm WW}(x,k_\perp)=2\int\frac{d\xi^-d\xi_\perp}{(2\pi)^3P^+}e^{ixP^+\xi^--ik_\perp\cdot\xi_\perp}{\rm Tr}\langle P|F^{+i}(\xi^-,\xi_\perp)\mathcal{U}^{[+]\dagger}F^{+i}(0)\mathcal{U}^{[+]}|P\rangle .$$

II. Color Dipole gluon distributions: not probability density

$$xG_{\rm DP}(x,k_\perp)=2\int\frac{d\xi^-d\xi_\perp}{(2\pi)^3P^+}e^{ixP^+\xi^--ik_\perp\cdot\xi_\perp}{\rm Tr}\langle P|F^{+i}(\xi^-,\xi_\perp)\mathcal{U}^{[-]\dagger}F^{+i}(0)\mathcal{U}^{[+]}|P\rangle .$$



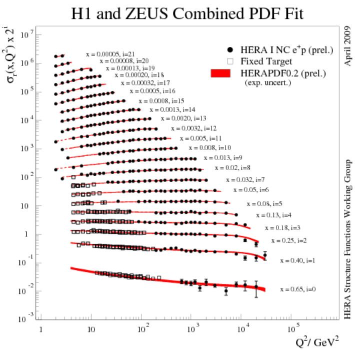


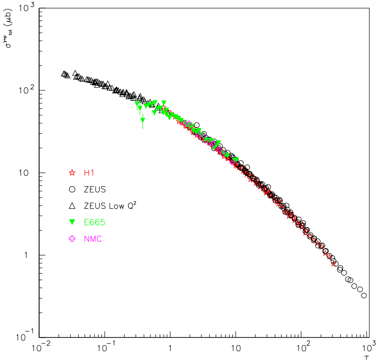
- Modified Universality for Gluon Distributions: $\times \Rightarrow$ Do Not Appear. $\surd \Rightarrow$ Apppear.

	Inclusive	Single Inc	DIS dijet	γ +jet	dijet in pA
$xG_{\rm WW}$	$\times$	$\times$	$\surd$	$\times$	$\surd$
$xG_{\rm DP}$	$\surd$	$\surd$	$\times$	$\surd$	$\surd$

- Complementarity in inclusive DIS (strong constraints on Dipole) and SIDIS (probe WW).

DIS inclusive cross-section and Geometrical Scaling





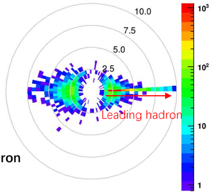
- Geometric Scaling (hint of gluon saturation) at EIC with both *ep* and *eA*.
- Indirect probe of the dipole gluon TMD, beyond LO fit. [Lappi, Mantysaari; Ducloue, Iancu, Soyez, Triantafyllopoulos]
- Currently not pursued in SIDIS WG, need inputs from the inclusive WG.

Kinematic map for dihadron measurements on gluon saturation (L. Zheng)

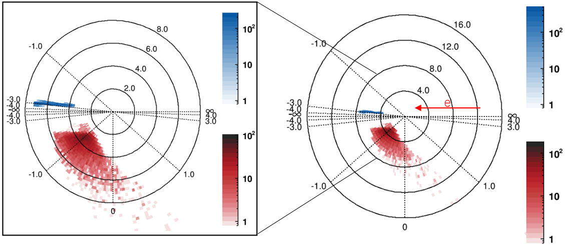
ep/Au 18x110 GeV
$0.6<y<0.8$, $1<Q^2<2$ GeV^2
charged hadron, $|\eta|<4.5$, $p_{T\,trig}{}^*>2$ GeV, $p_{T\,assc}{}^*>1$ GeV,
$0.2<z_h<0.4$, * indicates γ^*p c.m.s frame

- Scattered e$^-$ p range: 4~7 GeV, η range: -3~-2 (tight Q^2, y cuts)
- Hadron p range: 3~8 GeV, η range: backward rapidity

p_T vs $\Delta\phi$ for associate hadron relative to leading hadron

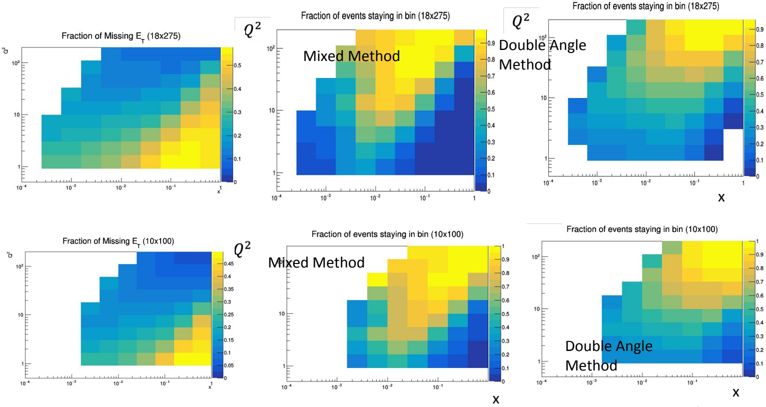


p vs η for scattered electron and charged hadron pairs (blue for e-, red for hadron)



- Backward hadron acceptance, sufficiently high resolution for the momentum (mainly high pT) and azimuthal angle (need 2π coverage).

Various reconstruction method (A. Vossen)

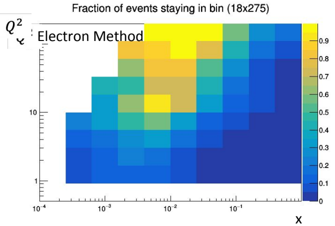


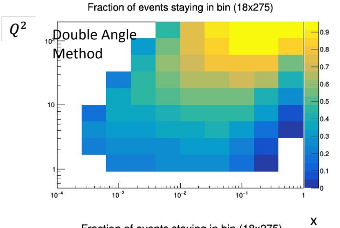
- Combination of mixed and double angle method perform significantly better than electron method at high x low Q^2
- Might be used to expand phase space to Resolution strongly correlated with missing E_T:
  →Explore impact of expanding coverage beyond η =3.5 (handbook)
- Caveat: p, E information not optimally used. Explore in Delphes with particle flow

Summary and Discussion

- Overlaps and connections with the inclusive WG in helicity and saturation physics.
- Gluon TMDs via dijet. (Heavy flavor not discussed)
- Question: jet reconstruction in the lab frame or γ^*-hadron frame?
- Inputs, comments and complaints are very much welcome.

Various reconstruction method (A. Vossen)


Fraction of events staying in bin (18x275)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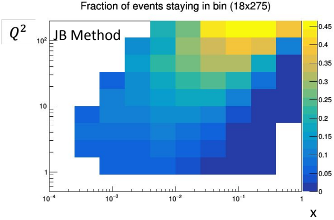
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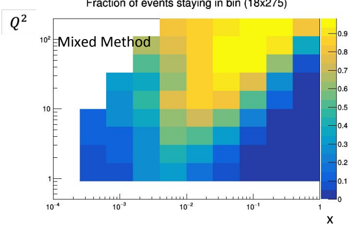
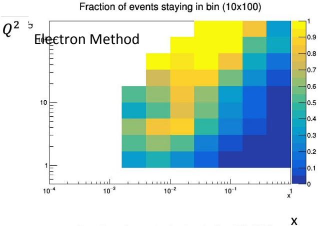
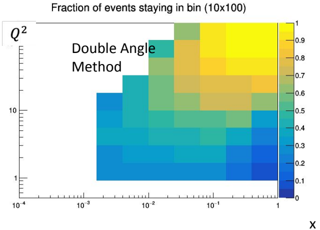
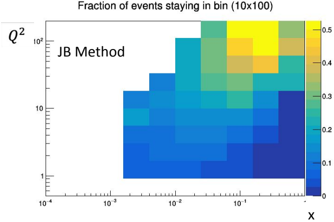
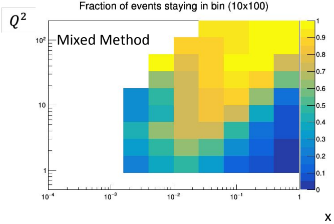

Fraction of events staying in bin (18x275)

Various reconstruction method (A. Vossen)





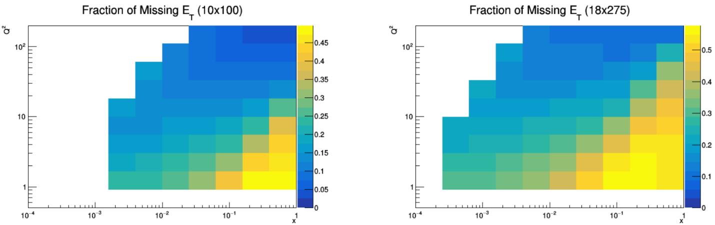




Various reconstruction method (A. Vossen)

Fraction of missing energy, from acceptance limits

Larger fraction at low-y → correlates to inaccuracy of (x,Q^2)

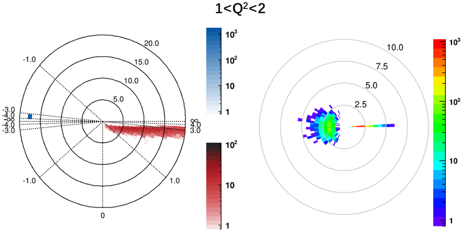


Helicity studies in the SIDIS WG (R. Seidl)

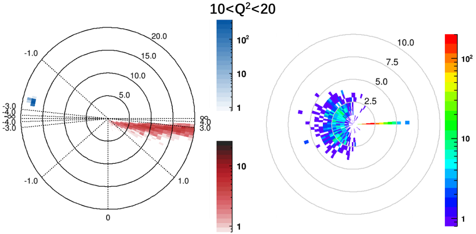
Measurement/process	Main detector requirements	Anticipated plot	**Comments**
Sea quark helicity measurements →flavor separated (anti)quark helicity distributions over wide range of x Ralf Seidl	hadron momentum and energy resolution in forward direction ($2 < \eta < 4$) for CC events	Update of previous sea quark helicity PDF uncertainty plots	Work will follow ongoing sensitivity studies by Elke's group + Argentinian global fitters. • Implementation of detector smearing, etc needs to be added to existing studies. • Concentration on CC and $D/3He$.
FFs/nFFs/nPDFs via single hadron FF →Single hadron fragmentation functions for ep and eA for FFs, nFFs, nPDFs Ralf Seidl	See TMD SIDIS reqs	nPDF uncertainty expectation, (n)FF Expectation	Simulations prepared using official 4 ep and 3 eAu beam energy combinations, for smeared simulation BeAST resolutions were used in eicsmear. • reweighted eAu multiplicitis using nFFs from SSZ fit • Not implemented: magnetic field and PID (hadron, momentum, rapidity) impact.

Kinematic map for dihadrons in low y region (L. Zheng)

ep 18x275 GeV
$0.01<y<0.05$
charged hadron,
$|\eta|<4.5$, $p_T^*>1.4$ GeV, $z_h>0.1$,
$k^*_T/P^*_T<0.7$,
* indicates $\gamma^* p$ c.m.s frame



- Scattered e⁻ p range: around 18 GeV, η range: -4~-1
- Hadron p range: mostly several GeV, η range: mostly forward



- Overlap with the fixed target experiments within the y reach of EIC in the low y region ($[0.01, 0.05]$).