SIDIS and Jets at a 2nd IR

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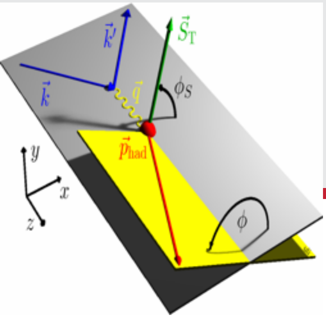
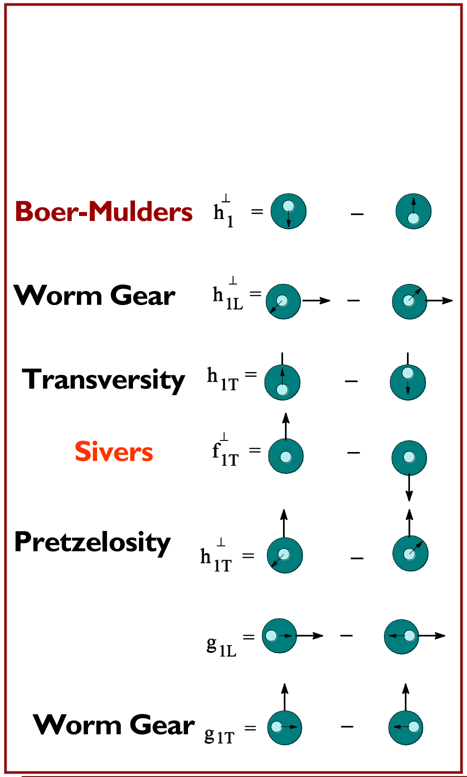


TMD PDFs from SIDIS

N \ q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$



$$d^6\sigma = \frac{4\pi\alpha^2 sx}{Q^4}\times$$

$$\{[1+(1-y)^2]\sum_{q,\bar{q}} e_q^2 f_1^q(x) D_1^q(z,P_{h\perp}^2)$$
$$+(1-y)\frac{P_{h\perp}^2}{4z^2M_NM_h}\cos(2\phi_h^l)\sum_{q,\bar{q}} e_q^2 h_1^{\perp(1)q}(x) H_1^{\perp q}(z,P_{h\perp}^2)$$

Unpolarized

$$-|S_L|(1-y)\frac{P_{h\perp}^2}{4z^2M_NM_h}\sin(2\phi_h^l)\sum_{q,\bar{q}} e_q^2 h_{1L}^{\perp(1)q}(x) H_1^{\perp q}(z,P_{h\perp}^2)$$
$$+|S_T|(1-y)\frac{P_{h\perp}}{zM_h}\sin(\phi_h^l+\phi_S^l)\sum_{q,\bar{q}} e_q^2 h_1^q(x) H_1^{\perp q}(z,P_{h\perp}^2)$$
$$+|S_T|(1-y+\frac{1}{2}y^2)\frac{P_{h\perp}}{zM_N}\sin(\phi_h^l-\phi_S^l)\sum_{q,\bar{q}} e_q^2 f_{1T}^{\perp(1)q}(x) D_1^q(z,P_{h\perp}^2)$$
$$+|S_T|(1-y)\frac{P_{h\perp}^3}{6z^3M_N^2M_h}\sin(3\phi_h^l-\phi_S^l)\sum_{q,\bar{q}} e_q^2 h_{1T}^{\perp(2)q}(x) H_1^{\perp q}(z,P_{h\perp}^2)$$
$$+\lambda_e|S_L|y(1-\frac{1}{2}y)\sum_{q,\bar{q}} e_q^2 g_1^q(x) D_1^q(z,P_{h\perp}^2)$$

Polarized target

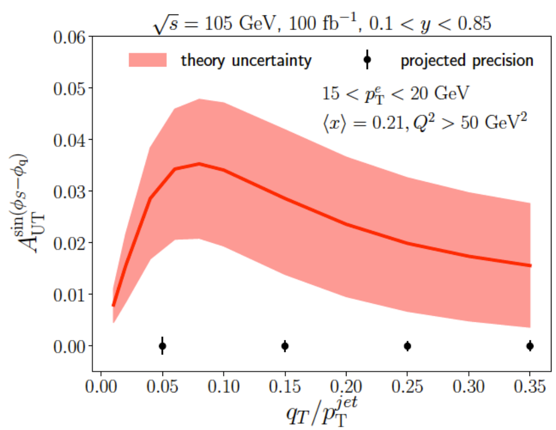
$$+\lambda_e|S_T|y(1-\frac{1}{2}y)\frac{P_{h\perp}}{zM_N}\cos(\phi_h^l-\phi_S^l)\sum_{q,\bar{q}} e_q^2 g_{1T}^{(1)q}(x) D_1^q(z,P_{h\perp}^2)\}$$

Polarzied beam and target

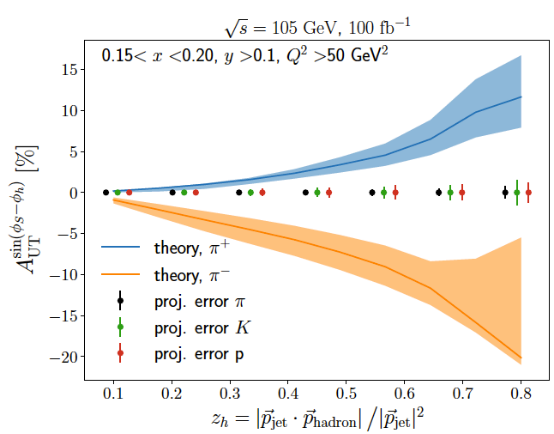
S_L and S_T: Target Polarizations; λe: Beam Polarization
x: momentum fraction carried by struck quark, z: fractional energy of hadron

Accessing TMD PDFs and FFs with Jets

- Jets can be used as proxy for outgoing parton
  →Decouple PDF and Fragmentation function (FF)
  →breaks convolution of transverse momenta
- Enables to
  - measure TMD w/o FF contribution
  - FF w/o TMD contribution
- Additional dependency on q_T



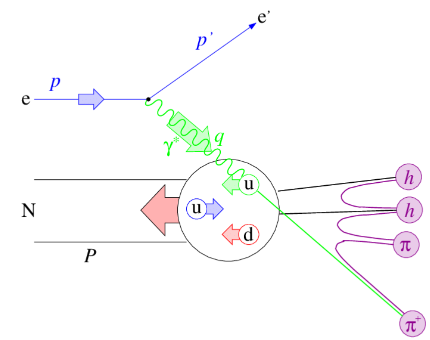
Sivers asymmetry



Collins asymmetry

Phys.Rev.D 102 (2020) 7, 074015

Evolution of TMDs



$$F_{UT}^{\sin(\phi-\phi_s)} = \sum_q e_q^2 |C_V(Q)|^2 [R(Q,\mu_0) \otimes f_{1T,q}^{\perp}(x;\mu_0) \otimes D_{1,q}(z;\mu_0)](p_T),$$

Evolution Kernel

TMD PDF

TMD FF

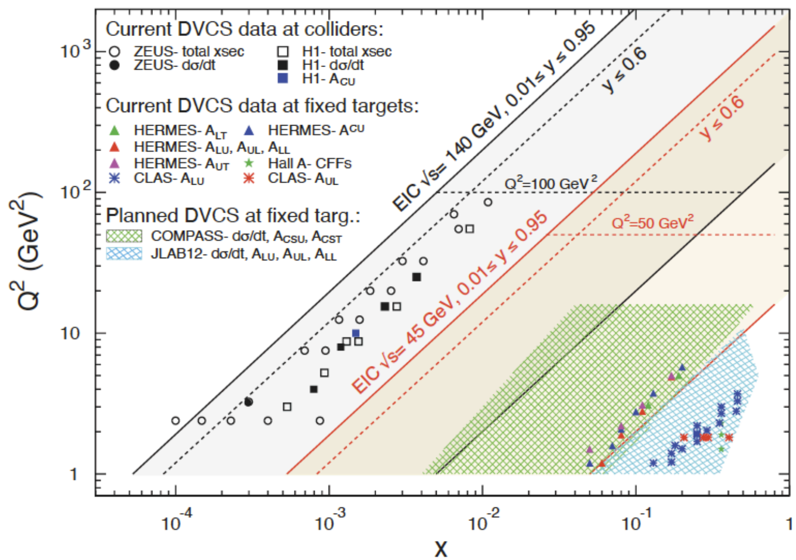
- Need larger lever arm in Q^2, x, k_T to determine evolution kernel, TMDs
- Large p_T coverage → larger b coverage, where TMDs are unconstrained

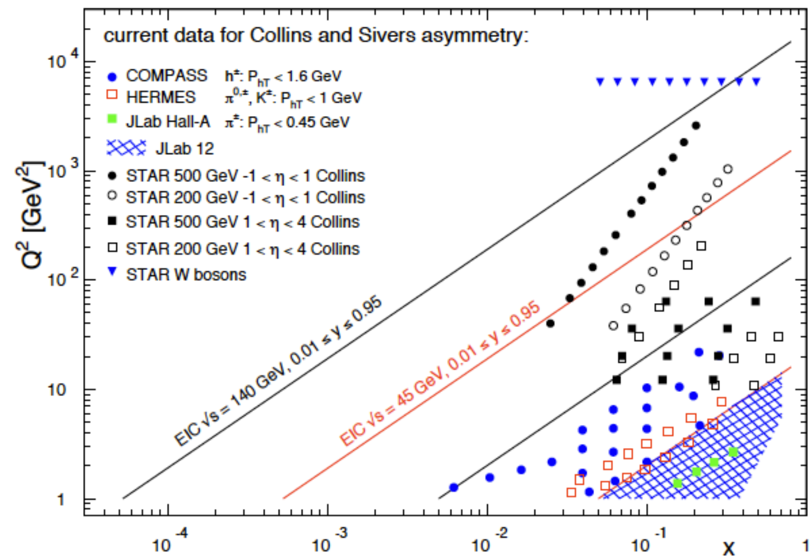
SIDIS physics at an EIC: Coverage

Slide from AV YR Imaging summary talk

- Common theme on EIC impact
  - Extended kinematic coverage and precision, along with polarization and possible beam charge degrees of freedom allow multi-pronged approach →needed to extract multidimensional objects
  - TMD factorization is valid

Large Q^2 lever arm: probe evolution, disentangle contributions to σ

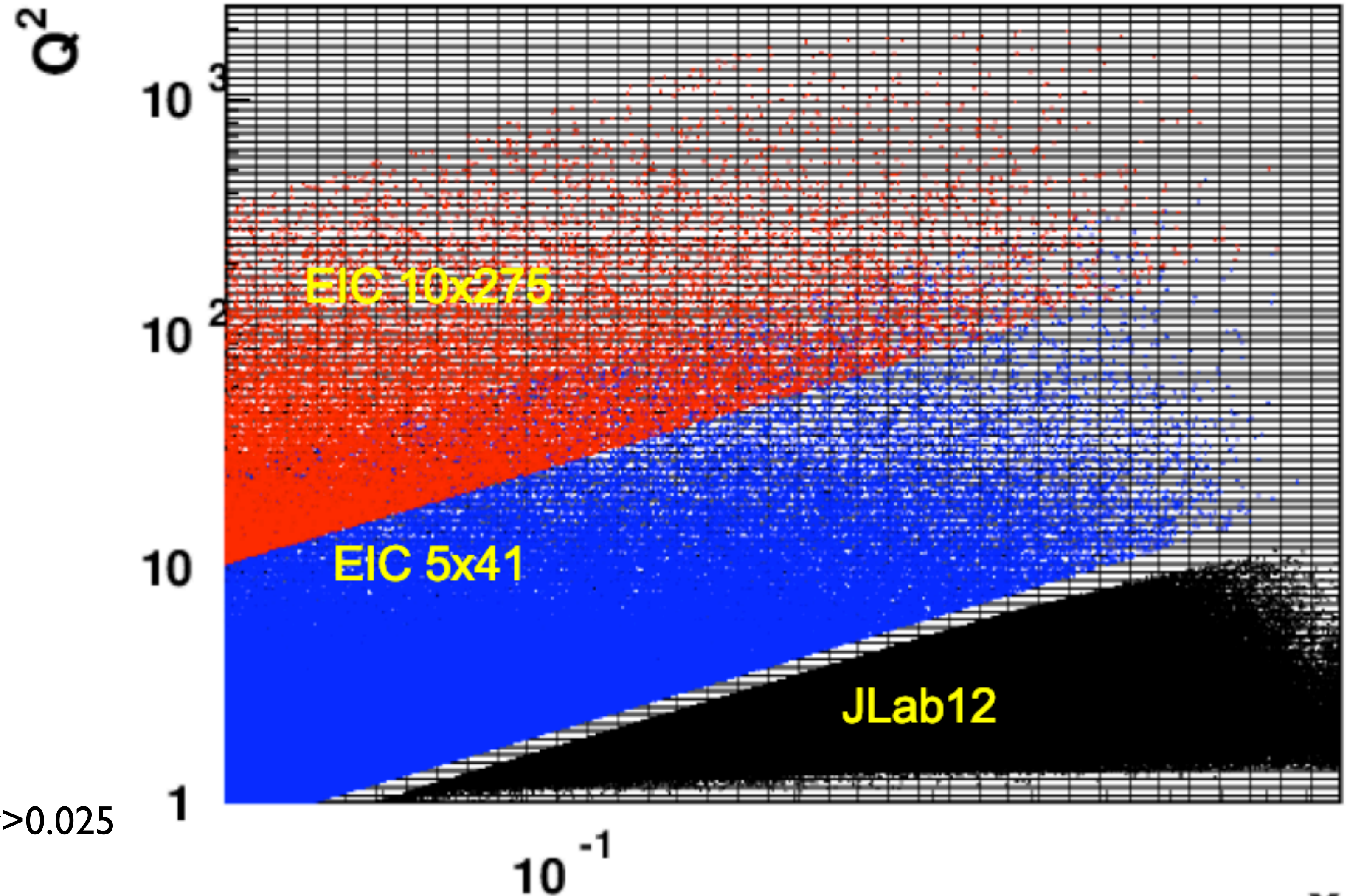




Coverage to low x: access sea and gluon distributions

Need 2nd IR to cover full phase space and maximize physics impact!

Big picture: Kinematics low/high



y_m

y>0.025

Non overlapping ranges of EIC and Jlab may be a problem for evolution st

From H. Avakian

A 2nd IR with high luminosity at moderate Q^2 would…

- Provide precision measurements where TMD effects are expected to be large
- Provide continuity between Jlab12 and EIC program→transition region between current/target collinear/TMD regions
- Map out complete Q^2 range at high x
  - Important
    - for TMD evolution
    - For Jets to understand evolution of hadronization corrections

- Be more sensitive to higher twist and in-medium effects
- TMD and jet measurements are multi-differential→statistics hungry!

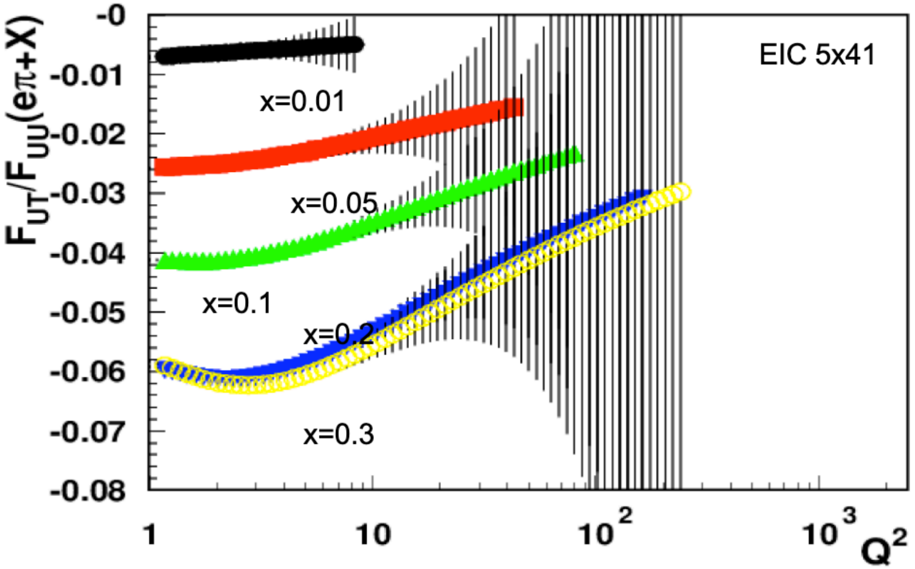
- Will have acceptance and PID at high x/high z
- Might have beneficial acceptance for heavy flavor and di-jet/di-hadron Sivers

- Would be a natural candidate to use existing magnet < 3T

  ➔Increase acceptance for low momentum particles

Example Expected TMD signal

Sivers Effect vs Q^2 (Pavia)



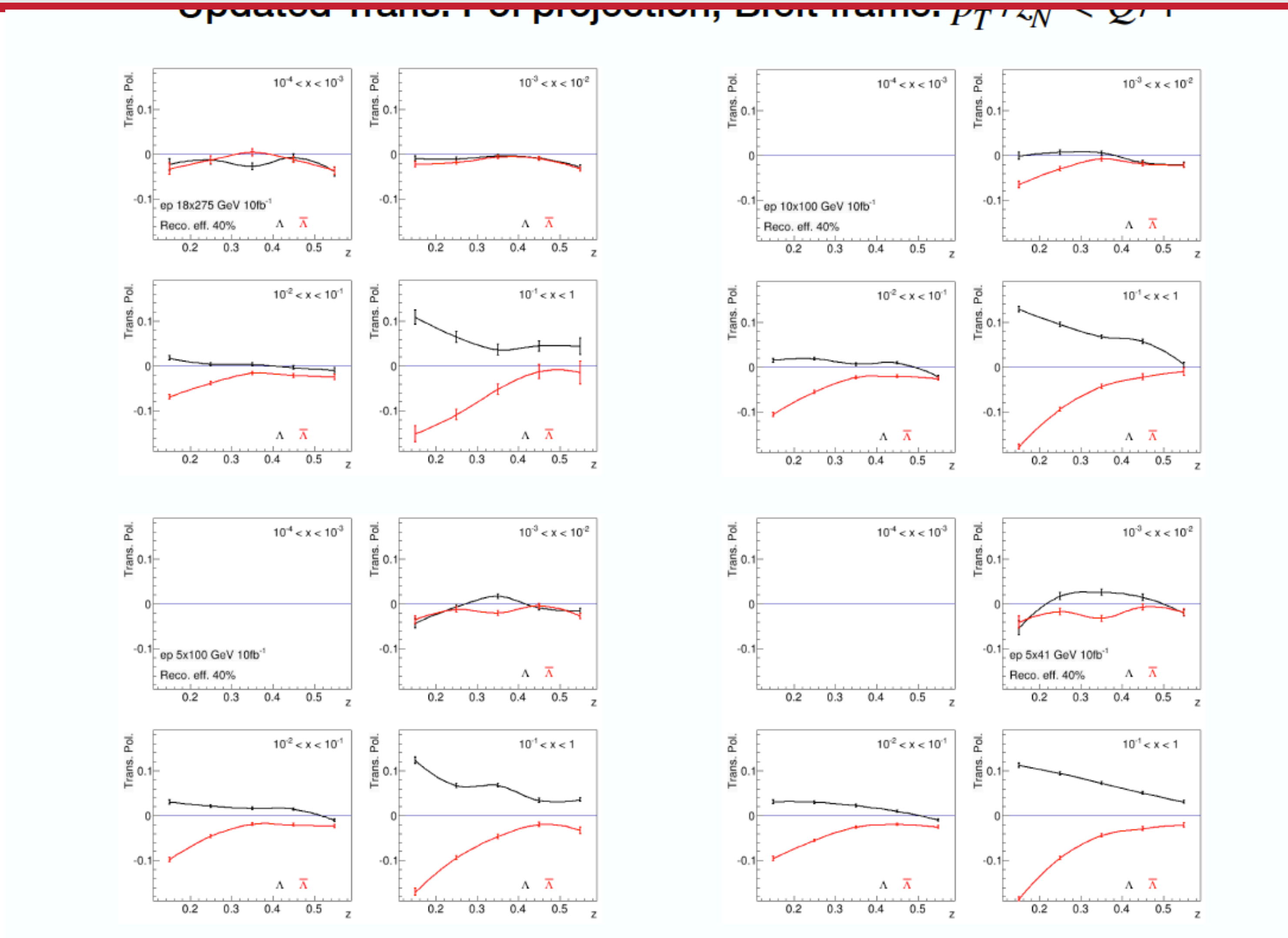
Measuring Sivers evolution may need large x, low y and large statistics in a wide range Q^2

From A Signori by way of Harut

Evolution doesn't quite cancel.

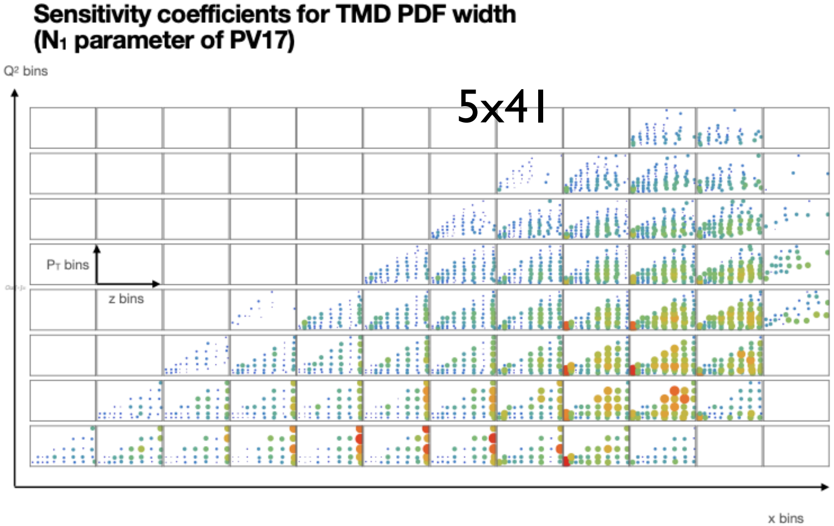
- STAR W results should shed more light

Also shown in $\Lambda^{\uparrow}$ projections

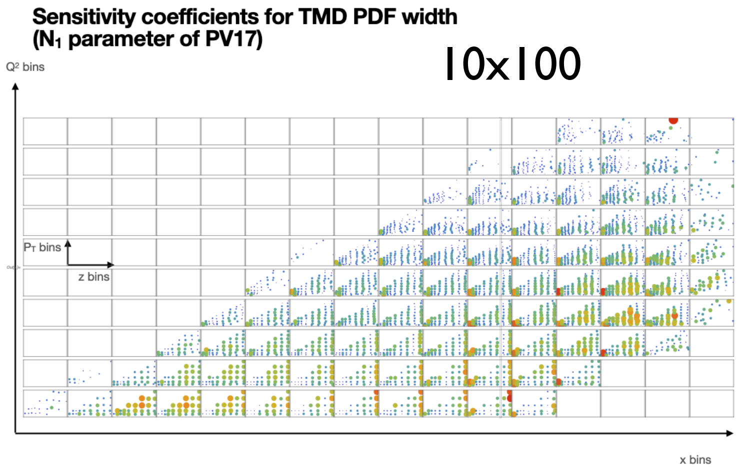


Plots provided by Jinlong Zhang

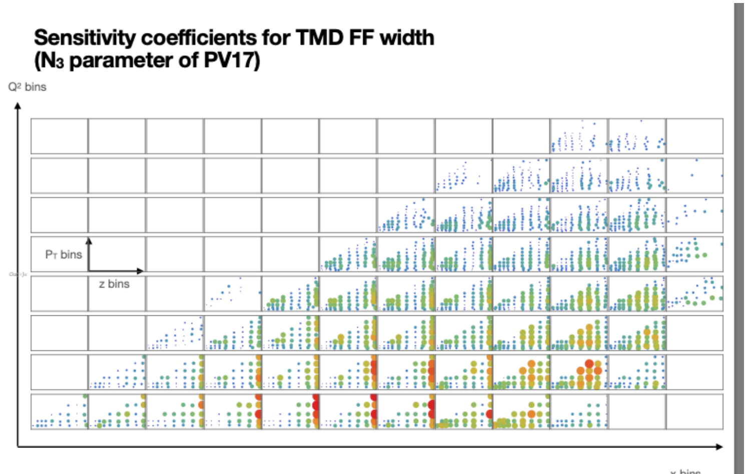
Sensitivity coefficients for PV17



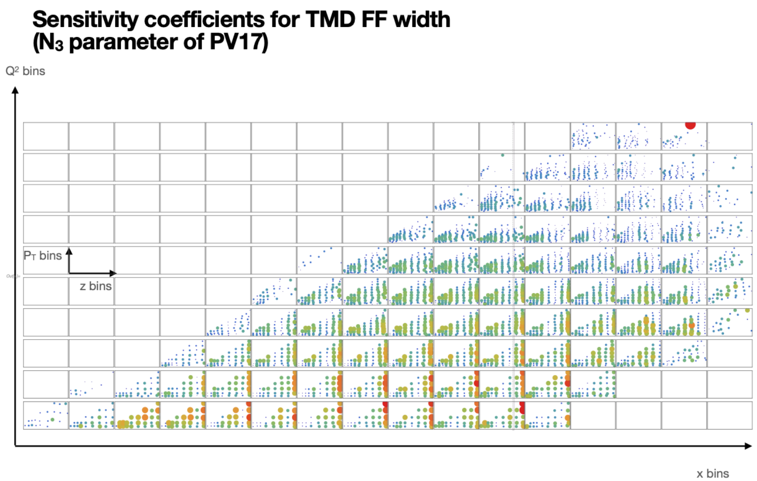
5x41 beam configuration



10x100 beam configuration

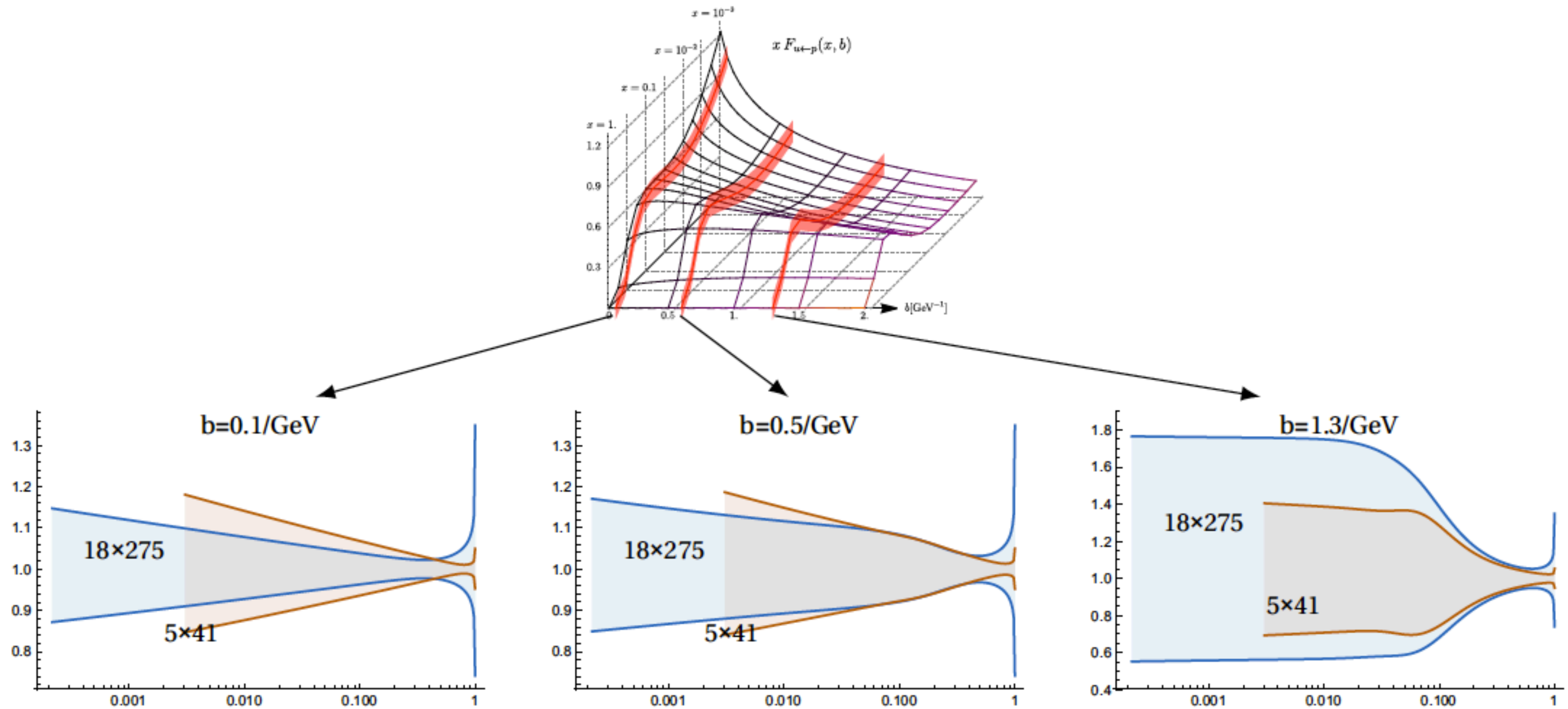


5x41 beam configuration



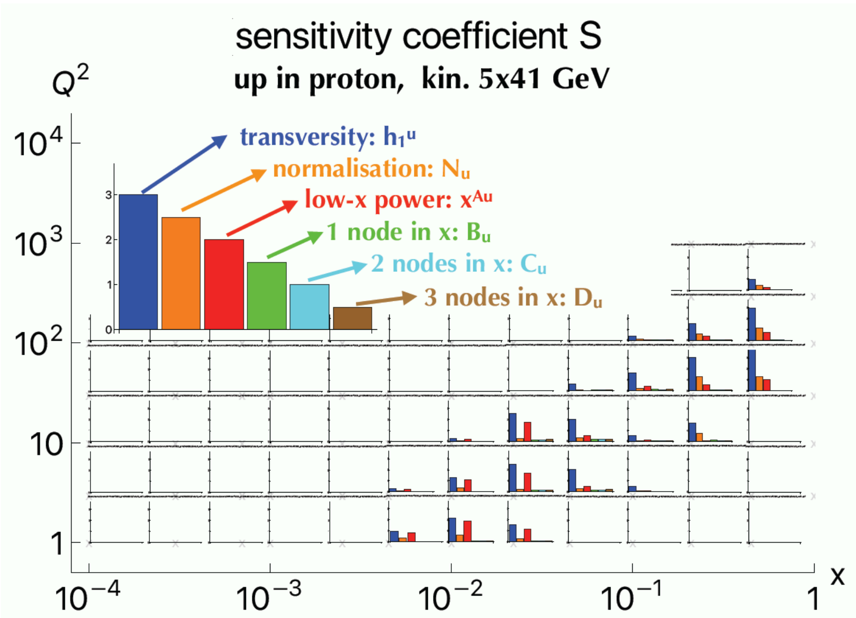
Impact at high x, low k_t/Q (see backup)

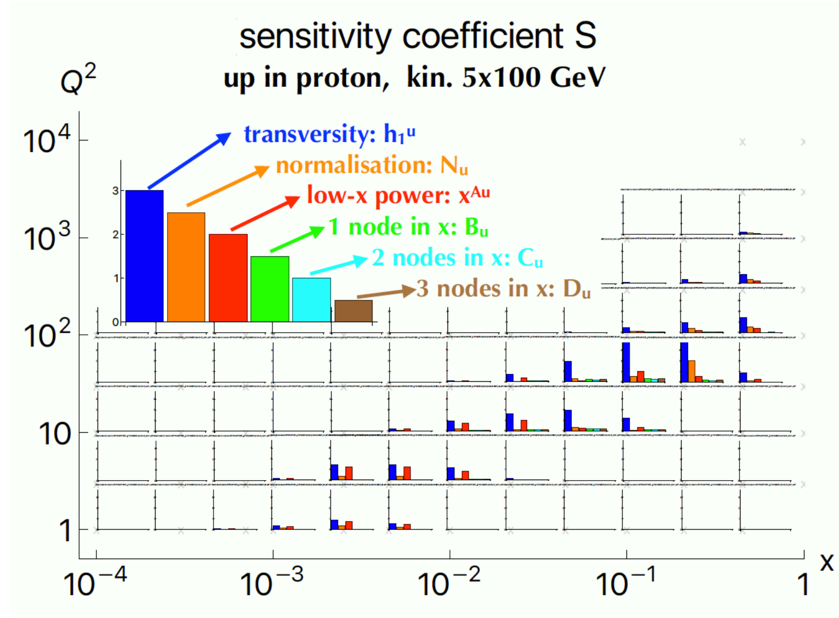
From A. Bacchetta at YR meeting



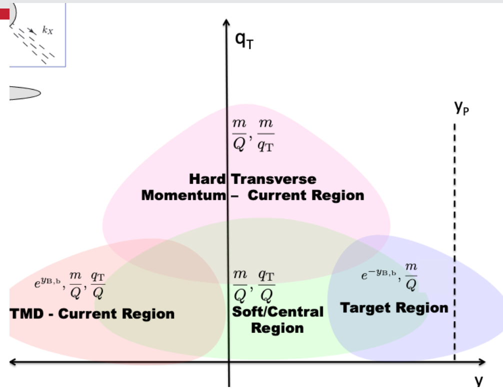
From Alexey Vladimirov
→see parallel session

Sensitivity of transversity extraction via di-hadrons

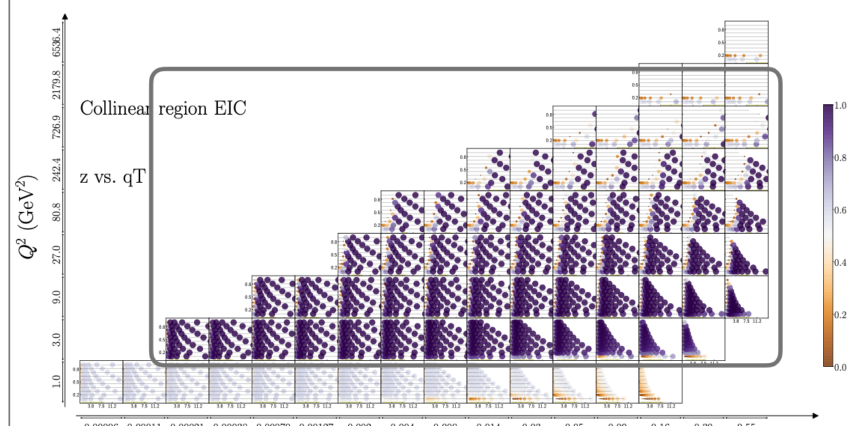




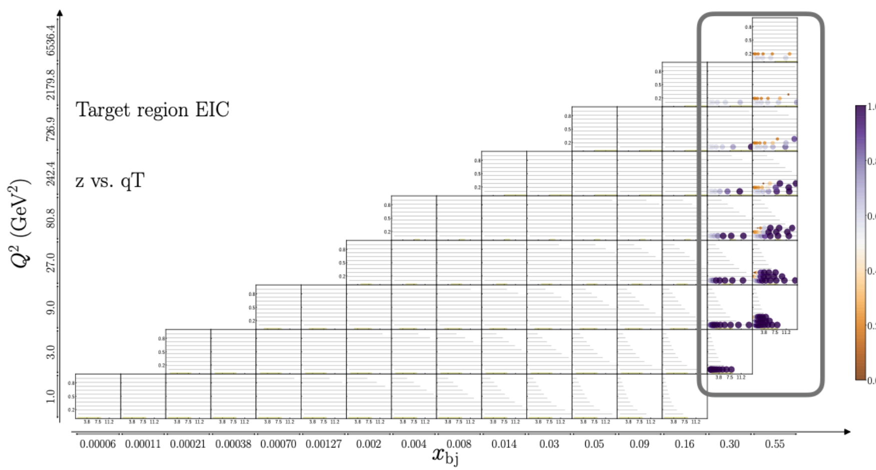
From Marco Radici



Relatively large x_{Bj}, z_h, Q



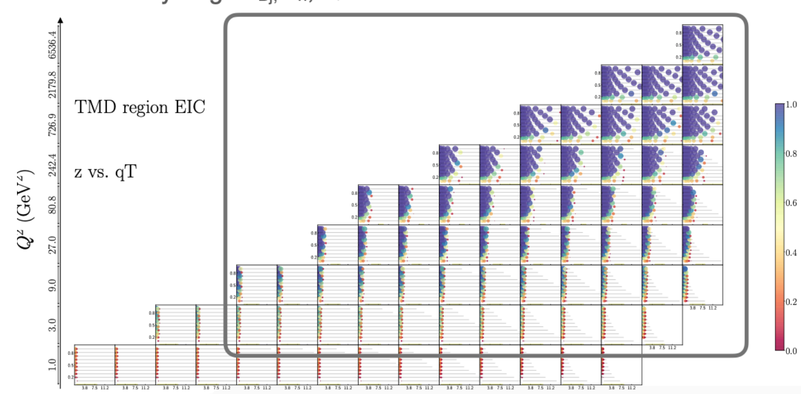
Large x_{Bj} and small z_h, Q



EIC: CURRENT REGION

Current study

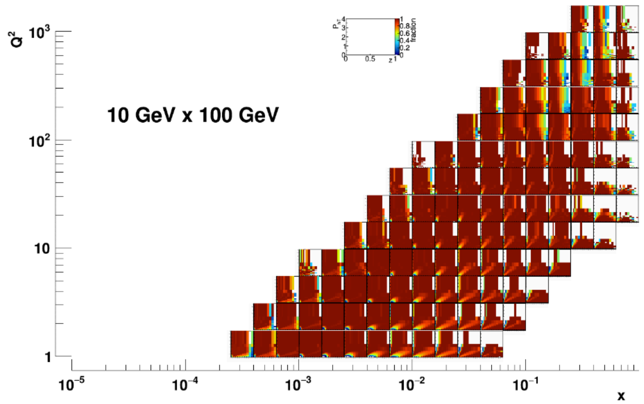
Relatively large x_{Bj}, z_h, Q

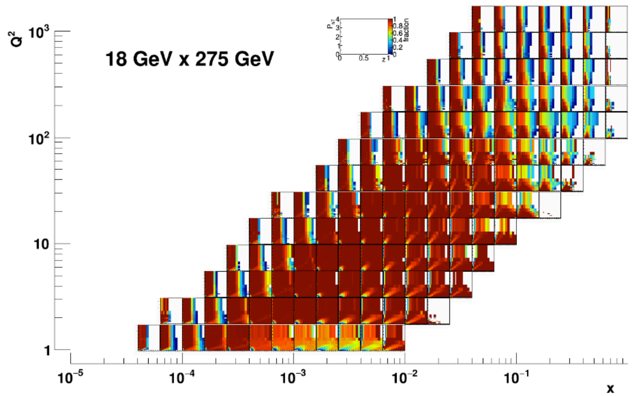


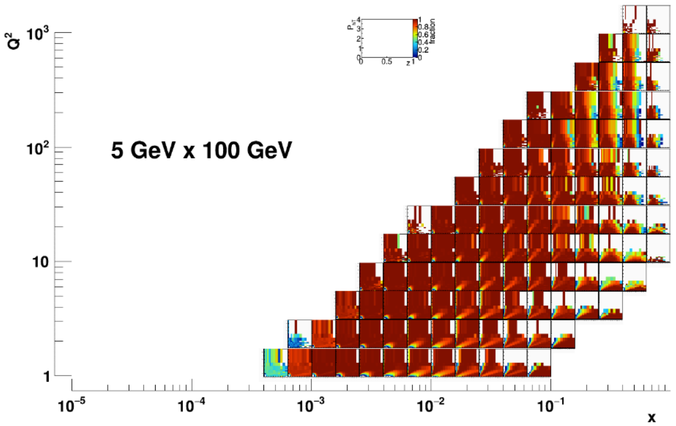
- 2^{nd} IR data will be in transition region collinear/TMD, target/current

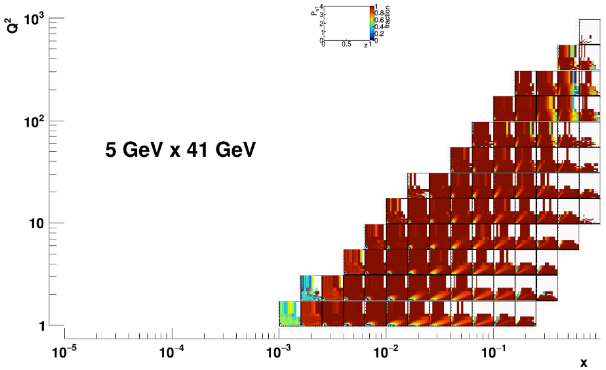
A. Prokudin et al. (YR SIDIS meeting)
See also *JHEP* 10 (2019) 122, JHEP10(2019)122

Acceptance I $(y > 0.01)$







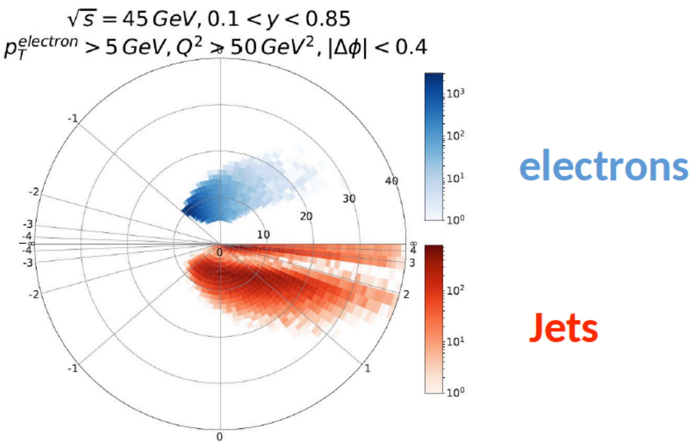


- At full energy Acceptance at high x, Q^2 might also be impacted by PID capabilities

Jets

- TMD through jets
  → similar motivation as single/di-hadron SIDIS: TMD effects largest at high x, explore full phase space
  → Statistics Hungry:
  – higher W
  – More differential observables
    - e.g. $x, Q^2, j_T, q_T, \phi_h, \phi_S$

  → Statistics famished channels
    - Exclusive di-jets to access GTMDs
    - …
- Exploring transition region for jets
  – Study role of hadronization corrections
  – …



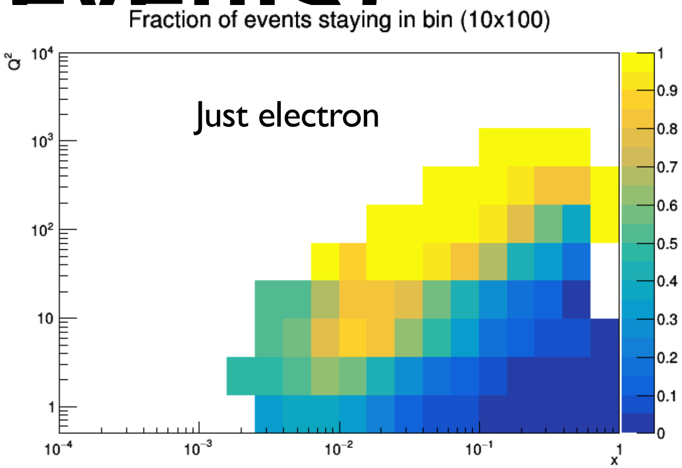
M.Arratia

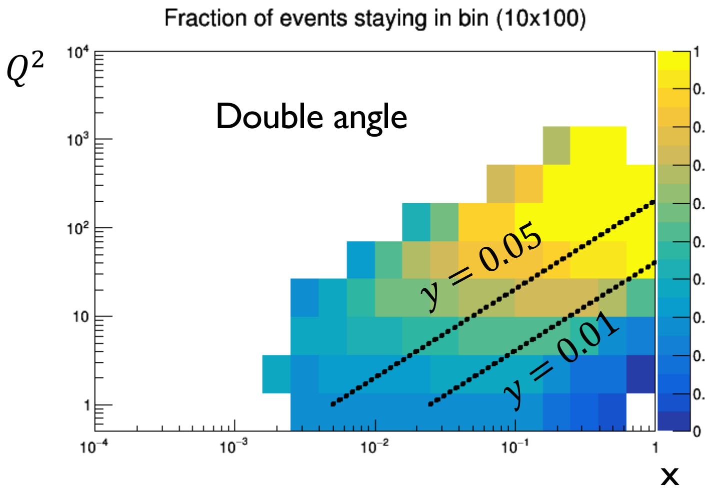
Summary and Conclusion

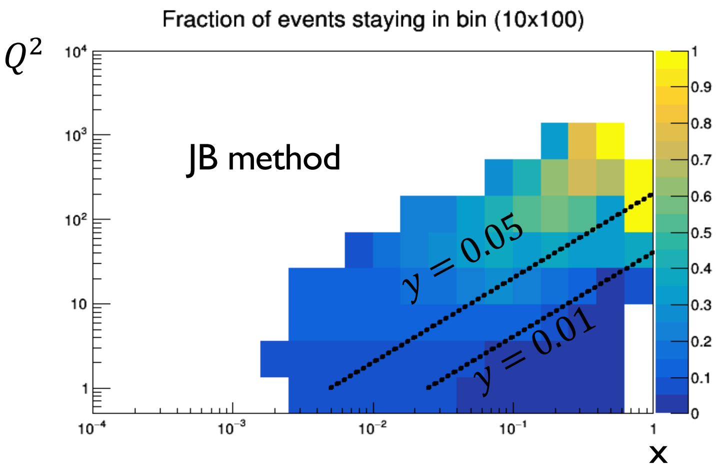
- Physics motivation for a 2nd IR optimized for a lower $\sqrt{s}$ very strong
- Map out Q^2 at high x
- Moderate Q^2 means less smearing by hard QCD radiation:
  - Enhanced TMD effects
  - Higher sensitivity to twist3 effects
  - Enhanced in-medium effects
- Acceptance might be complimentary to 1st IR for high x, high z where TMD effects are large
- Lower minp_T advantageous for
  - Λ program
  - IFF
  - Heavy flavor
- Meson form factors…

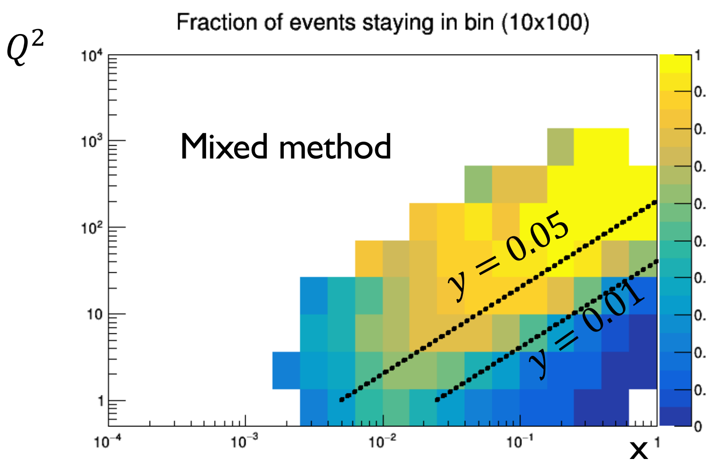
Backup

Results with EIC smear (100k events)



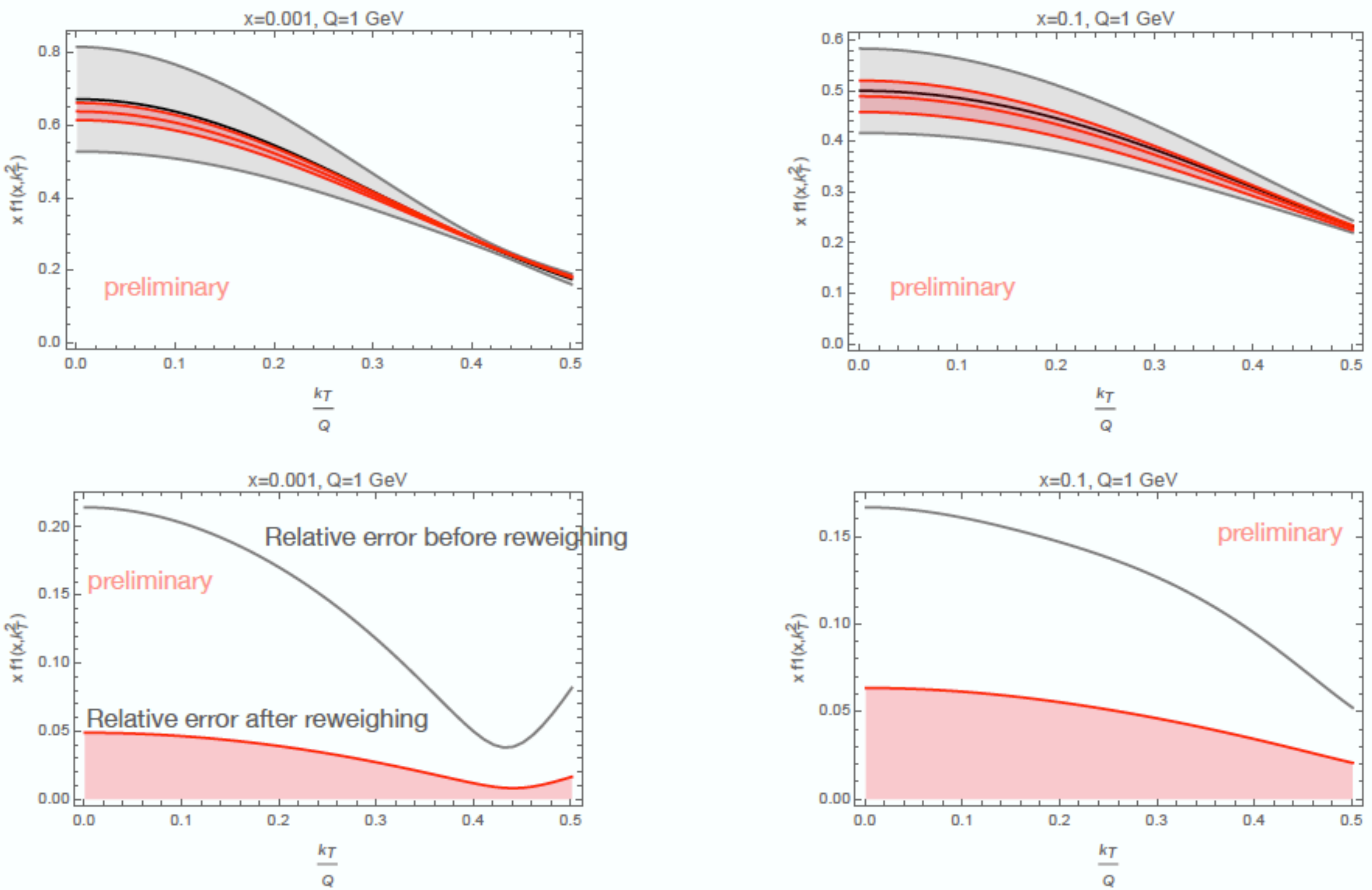






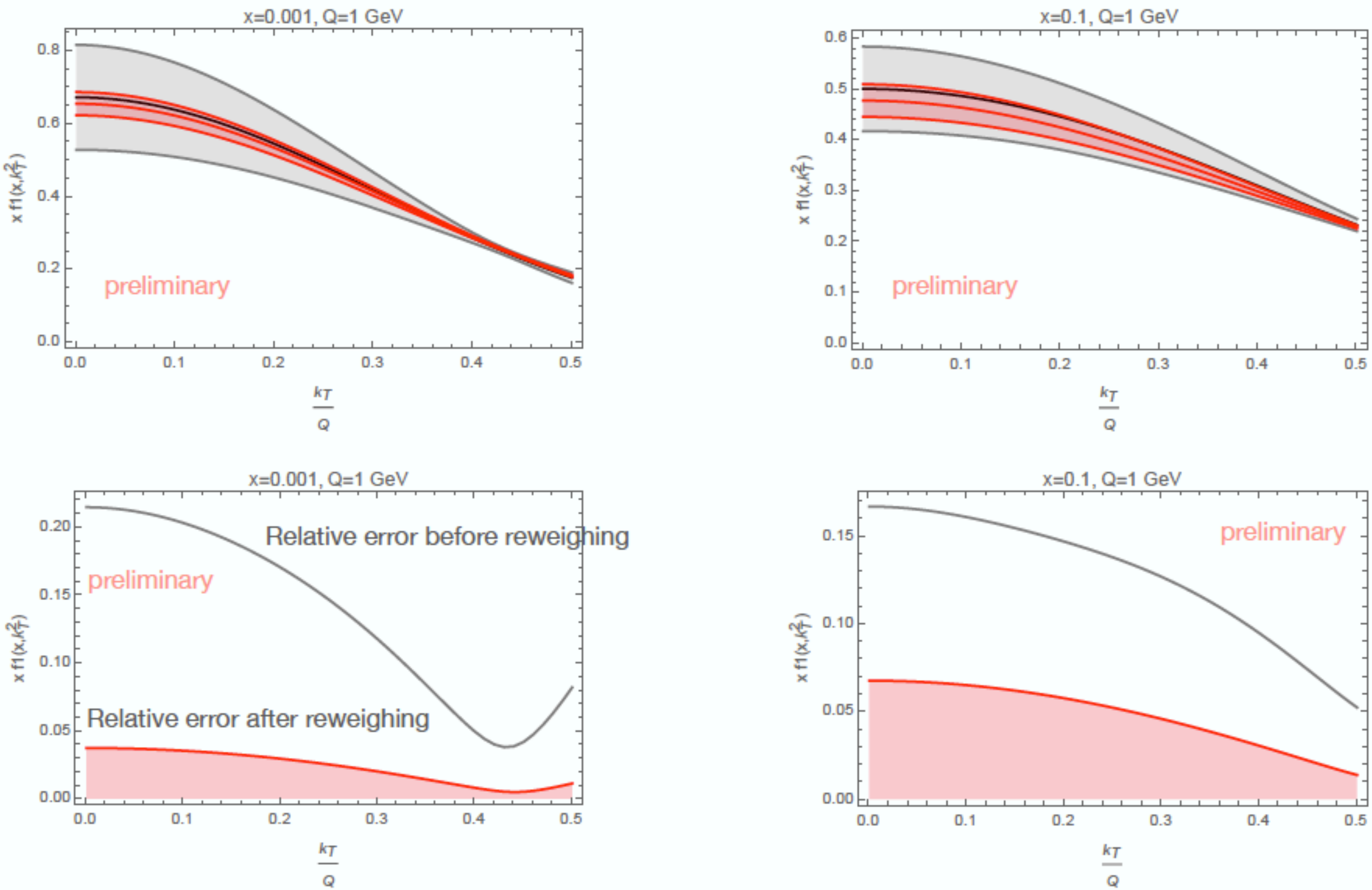
PV17 reweighing: Impact on TMDs

5x100 configuration (0.15 < z < 0.7)



PV17 reweighing: Impact on TMDs

10x100 configuration (0.15 < z < 0.7)



- Less boost (might be in
For some channels, sin
Spectroscopy program)
- PID might be better at h

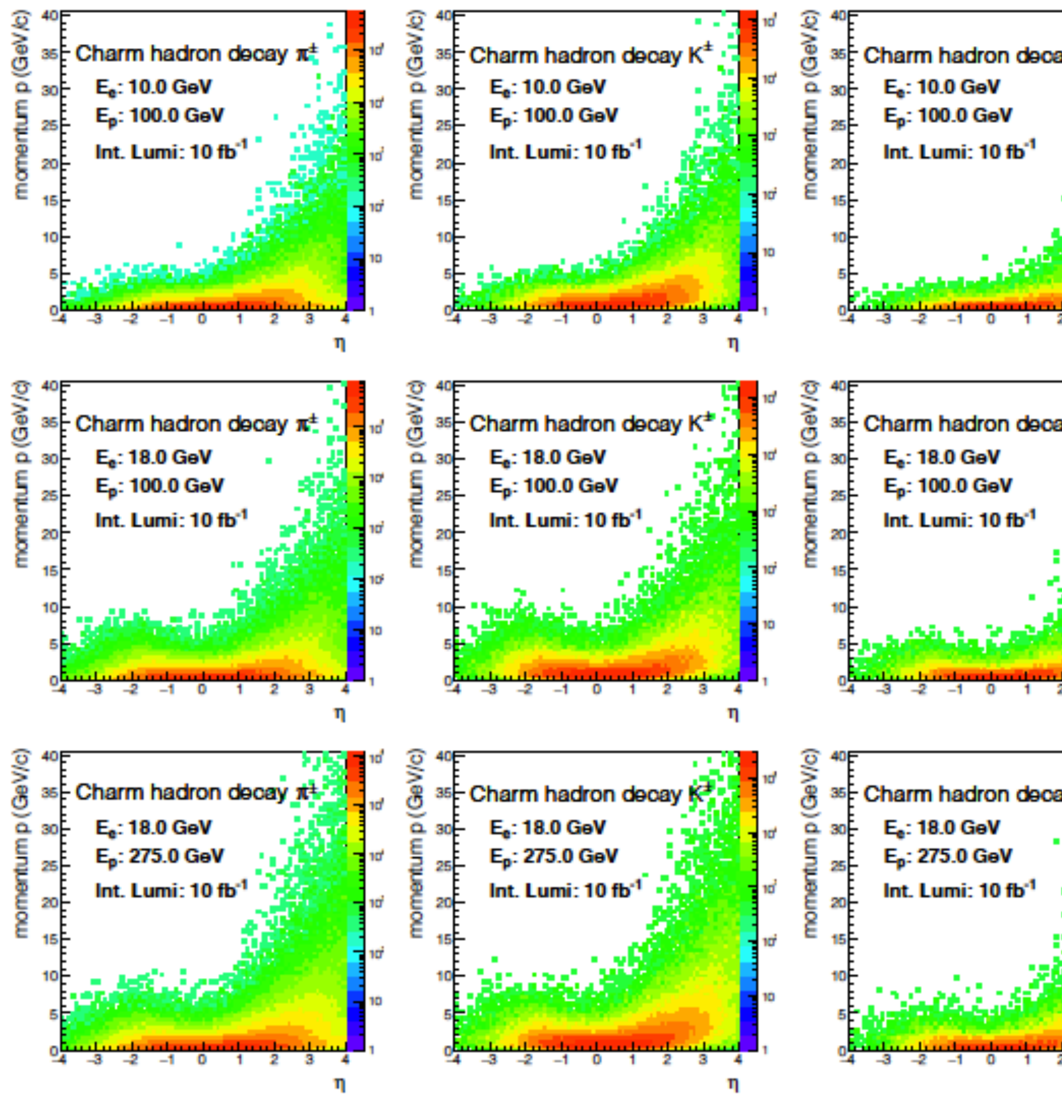
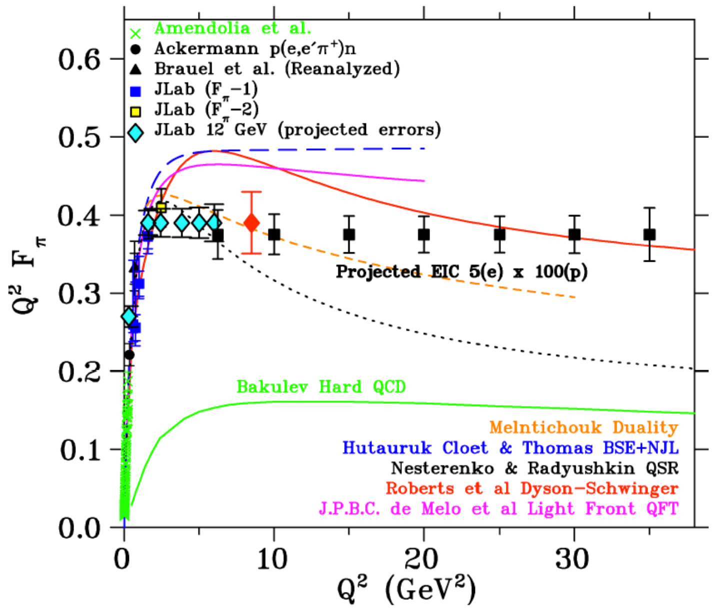


Figure 8.42: Momentum vs pseudorapidity for the decay products of D^0 mesons
energies of 10x100 GeV (top row), 18x100 GeV (middle row), and 18x275 Ge
row). Charged pions are in the left column, charged kaons in the middle column
trons/positrons in the right column. Counts have been scaled to correspond to an
luminosity of 10 fb^{-1}.

Meson Form Factors

- Interplay between emergent hadronic mass and Higgs-mass mechanism → π determined due to QCD, $K\ \frac{1}{3}$ from Higgs
- From factors $e + p \rightarrow e' + n + \pi$, at low $-t$ scattering off pion cloud (also can get $\frac{\sigma_L}{\sigma_T}$ from π^-/π^+ ratios)
- K form factor from $e + p \rightarrow e' + \Sigma^0/\Lambda + K^+$
  - Still under investigation if scattering from K cloud dominates at same kinematics a and how σ_L/σ_T can be verified (probably from Σ^0/Λ)
  - Possibility for first quality F_K measurement at $Q^2 > 0.2$

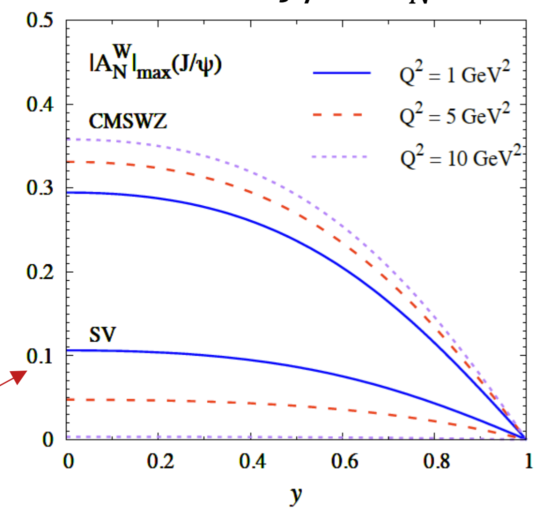


Using $20 fb^{-1}, 5\times100$

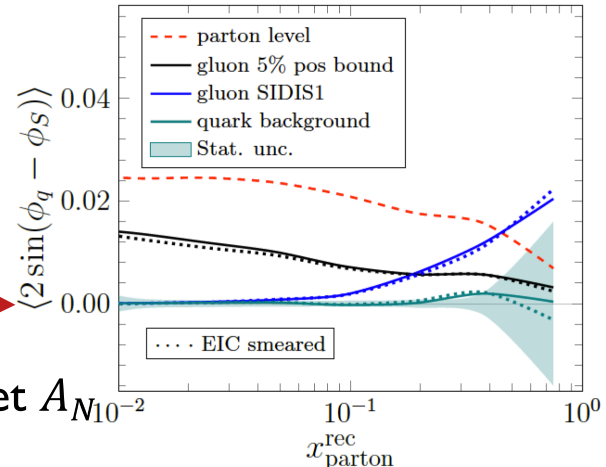
Access to Gluon TMDs with dijets

- Gluon TMDs structure more involved than quark sector
  - 8 TMDs, two types: Weizsacker-Williams (WW) and dipole
  - SIDIS unique for WW type
  - Very little known about unpolarized and polarized gluon TMDs
  - Heavy quarkonium ideal channel, but relation of asymmetries to gluon TMDs model dependent
  - Open heavy quark (e.g. D meson pairs) also good, but large uncertainties →dijet/dihedron most promising
- Example: Gluon Sivers via dijet asymmetries

$J/\Psi\ A_N$



Dijet A_N



$10\ fb^{-1}, 18\times275$

Kinematic map for dihadron measurements on gluon saturation

ep/Au 5x41 GeV

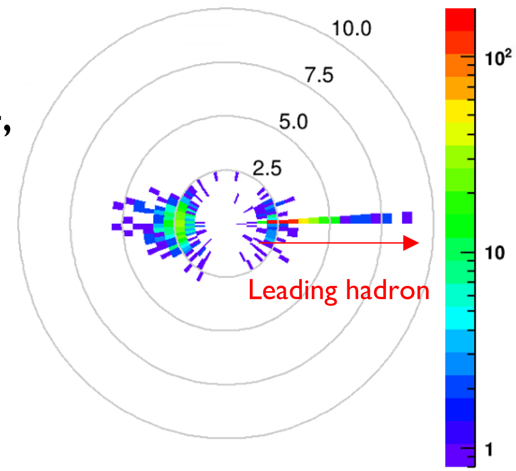
0.6<y<0.8, 1<Q^2<2 GeV^2

charged hadron, |η|<4.5, $p_{T\ trig}^*$>2 GeV, $p_{T\ assc}^*$>1 GeV, 0.2<z_h<0.4,

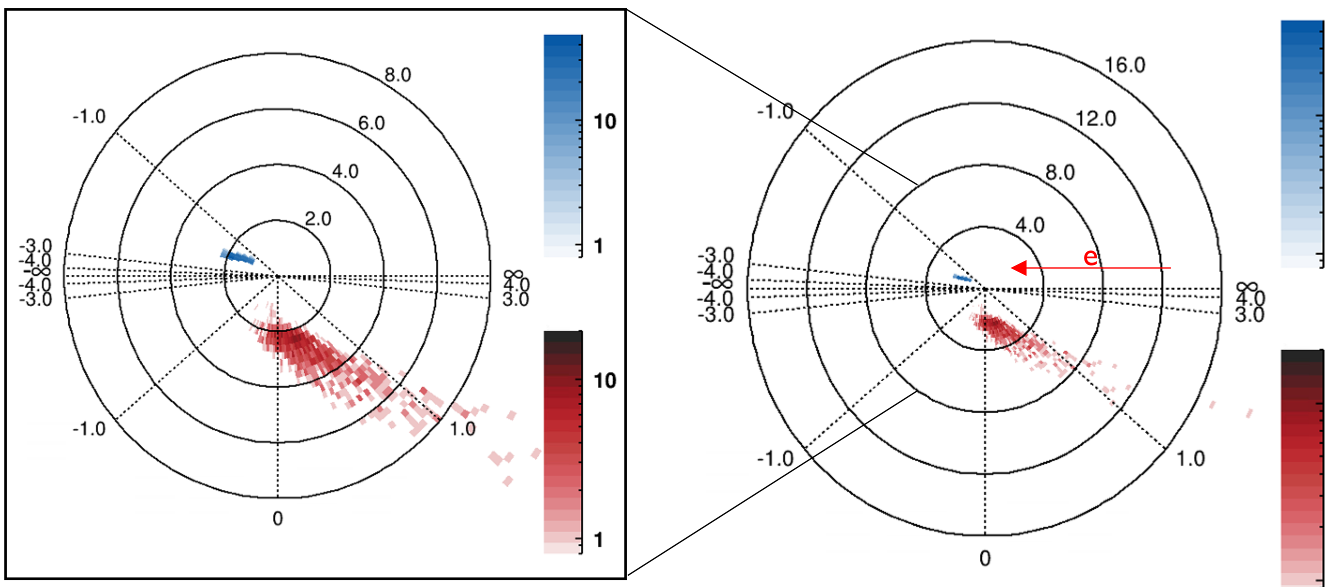
* indicates γ^*p c.m.s frame

- Scattered e^- p range: 1~2 GeV, η range: -2~-1 (tight Q^2, y cuts)
- Hadron p range: 3~6 GeV, η range: forward rapidity

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



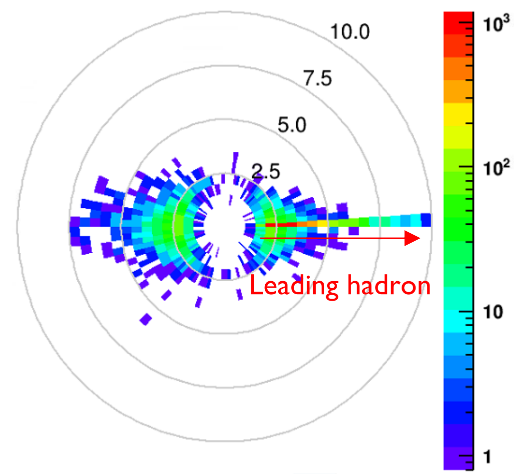
p vs η for scattered electron and charged hadron pairs (blue for e-, red for hadron)



Kinematic map for dihadron measurements on gluon saturation

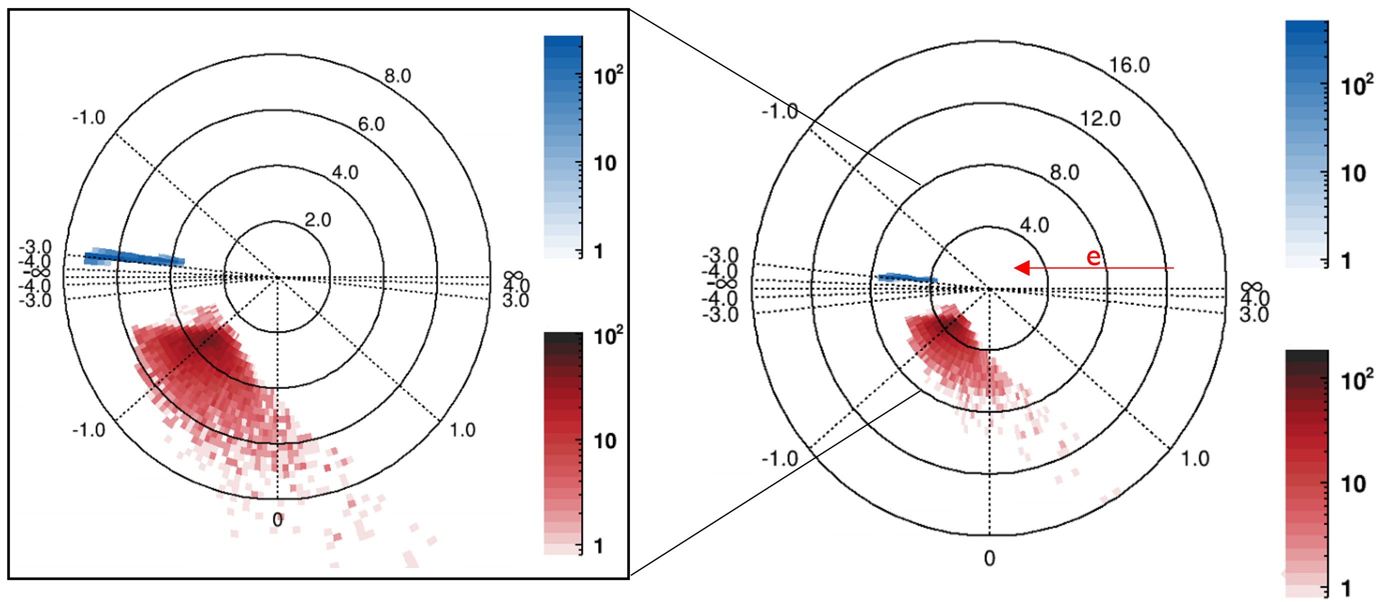
ep/Au 18x110 GeV $0.6<y<0.8$, $1<Q^2<2$ GeV^2 charged hadron, $|\eta|<4.5$, $p_{T\ lab}>0.25$ GeV, $p_{T\ trig}^*>2$ GeV, $p_{T\ assc}^*>1$ GeV,
* indicates γ^*p c.m.s frame

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



- 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

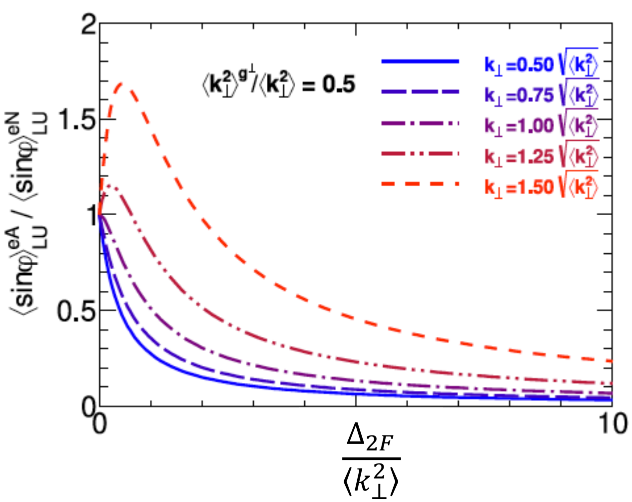
p vs η for scattered electron and charged hadron pairs (blue for e-, red for hadron)

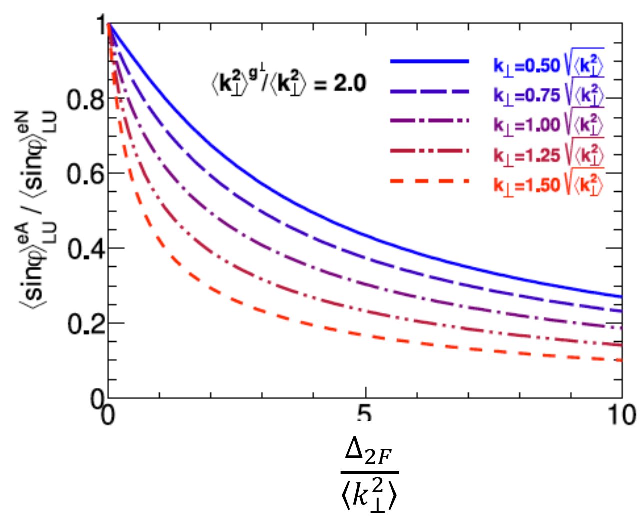


Medium Modification of Azimuthal Asymmetries

- In gaussian approximation
  $f_1^A(x, k_\perp) \approx \frac{A}{\pi\alpha} \mathrm{f}_1^{\mathrm{N}}(\mathrm{x}) \mathrm{e}^{\frac{-\vec{\mathrm{k}}_\perp^2}{\alpha}}$, with $\alpha = \langle k_\perp^2 \rangle + \Delta_{2F}$
  Quark transport parameter Δ_{2F} related to gluon density (due to interaction with gluons)
- Jets are sensitive to TMD PDF k_T only

$$\frac{\langle \sin\phi \rangle_{LU}^{eA}}{\langle \sin\phi \rangle_{LU}^{eN}} \approx \frac{\langle k_\perp^2 \rangle_A}{\langle k_\perp^2 \rangle} \left(\frac{\langle k_\perp^2 \rangle^{g^\perp}}{\langle k_\perp^2 \rangle_A^{g^\perp}} \right)^2 \exp\left[\left(\frac{1}{\langle k_\perp^2 \rangle_A} - \frac{1}{\langle k_\perp^2 \rangle} - \frac{1}{\langle k_\perp^2 \rangle_A^{g^\perp}} + \frac{1}{\langle k_\perp^2 \rangle^{g^\perp}} \right) \vec{k}_\perp^2 \right].$$





Functional form of PV17

arXiv:2007.08300

$$f_{1\mathrm{NP}}^{a}(x,\boldsymbol{k}_\perp^2) = \frac{1}{\pi}\,\frac{\left(1+\lambda \boldsymbol{k}_\perp^2\right)}{g_{1a}+\lambda\, g_{1a}^2}\, e^{-\frac{\boldsymbol{k}_\perp^2}{g_{1a}}}\,,$$

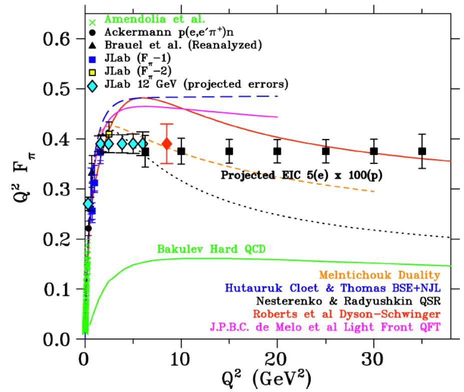
$$D_{1\mathrm{NP}}^{a\to h}(z,\boldsymbol{P}_\perp^2) = \frac{1}{\pi}\,\frac{1}{g_{3a\to h}+\left(\lambda_F/z^2\right)g_{4a\to h}^2}\left(e^{-\frac{\boldsymbol{P}_\perp^2}{g_{3a\to h}}} + \lambda_F\frac{\boldsymbol{P}_\perp^2}{z^2}\, e^{-\frac{\boldsymbol{P}_\perp^2}{g_{4a\to h}}}\right)$$

$$g_1(x) = N_1\,\frac{(1-x)^{\alpha}\; x^{\sigma}}{(1-\hat{x})^{\alpha}\;\hat{x}^{\sigma}}$$

$$g_{3,4}(z) = N_{3,4}\,\frac{(z^{\beta}+\delta)\;(1-z)^{\gamma}}{(\hat{z}^{\beta}+\delta)\;(1-\hat{z})^{\gamma}}$$

Meson form factors

- Elucidating in vis a vis mass generation (see also discussion about mass generation in 7.1) (kaon 1/3 higgs, pion almost 100% QCD)
- (how is F extracted again?)
- Kaon cloud unclear, to be verified by Jlab →sigma0/lambda ratio to ge \sigma_L/sigma_T



TMD

$$F_{UT}^{\sin(\phi-\phi_s)} = \sum_q e_q^2 |C_V(Q)|^2 \int \frac{d^2b}{(2\pi)^2} e^{i(bp_T)/z} R(Q,b,\mu_0) f_{1T,q}^{\perp}(x,b;\mu_0) D_{1,q}(z,b;\mu_0)$$