TMD distributions
and
TMD evolution

Alexey Vladimirov

IR2@EIC:

Science and Instrumentation of the 2nd IR for the EIC

Universität Regensburg

SIDIS cross-section

EIC will measure many structure functions (many of which are presently unknown)
I will concentrate on two (best studies) cases

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+ \varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h} + \lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+ S_\parallel\left[\sqrt{2\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]$$

$$+ S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$

$$+ |\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

$$+ \varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+ \sqrt{2\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S} + \sqrt{2\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

$$+ |\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+ \sqrt{2\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}, \qquad (2.7)$$

Unpolarized
COMPASS, JLab, HERMES
(DY) LHC, Tevatron, Fermilab

Sivers
COMPASS, JLab, HERMES
(DY) RHIC

TMD factorization formula

Rapidity anomalous dimension

$$\mathcal{D} \sim \langle 0|\frac{\mathrm{Tr}}{N_c}F_{+b}[\text{staple link}]|0\rangle$$

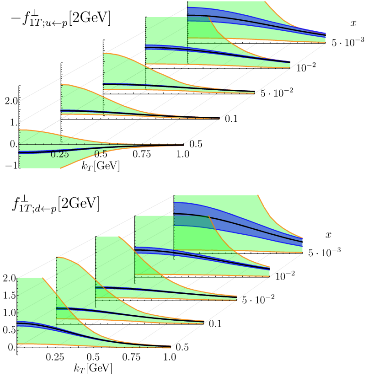
N \ q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

$$F \sim \langle P|\bar{q}[\text{staple link}]q|0\rangle$$

$$\boxed{F_{XY}(x,z,q_T) = \sum_{ff'} H_{ff'}\left(\frac{Q}{\mu}\right)\int d^2b\, e^{i(\mathbf{b}\cdot\mathbf{q}_T)}\left(\frac{Q^2}{\zeta_\mu[\mathcal{D}]}\right)^{-2\mathcal{D}(b,\mu)} F_{f\leftarrow h}(x,b)D_{f'\leftarrow h}(z,b)}$$

- Each function is responsible for a separate kinematic variable
  - Rapidity AD: $\mathcal{D}$ $\rightarrow$ Q and b
  - TMD PDF: F $\rightarrow$ x and b
  - TMD FF: D $\rightarrow$ z and b

Large coverage in (x,z,Q,q_T) decorrelate these components



The impact studies for YR were made using all energies $5\times41,\ 5\times100,\ 10\times100,$ $18\times100,\ 18\times275$

Unbelievable reduction of uncertainty band!

Time to compare high-s (IR1) vs. low-s (IR2)

All studies are made with pseudodata generated by R.Sield

Used setup: HB_opt6 (handbook detector, default PID)

https://github.com/VladimirovAlexey/EIC_YR_TMD

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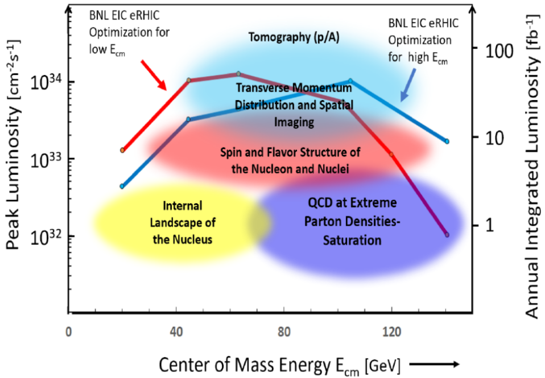
The 2^{nd} interaction region (possibly) will be optimized for lower-s.
Main question: where is anticipated impact for IR1 vs. IR2?



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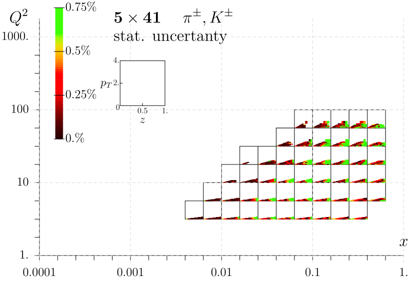
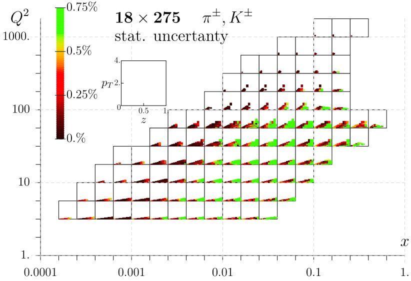
Comparing two extreme regimes (both at 10fb^{-1})

Unpolarized SIDIS





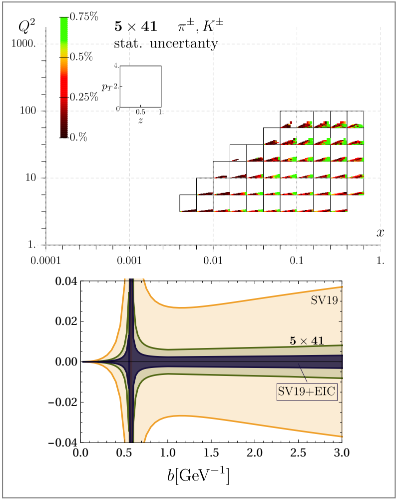
$10^{-2} < x, \quad Q < 10\text{GeV}$ $\qquad$ $5. \cdot 10^{-5} < x, \quad Q < 40\text{GeV}$

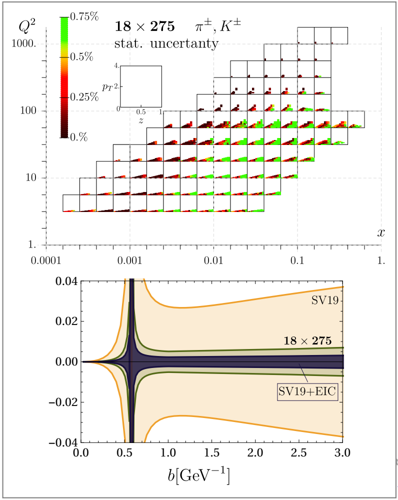
IR1 and IR2 are complimentary to each other

TMD evolution

- **IR1**: Larger-Q coverage but larger-p_T
- **IR2**: Smaller-Q coverage but smaller-p_T

Similar impact
A more sophisticated model
is requared

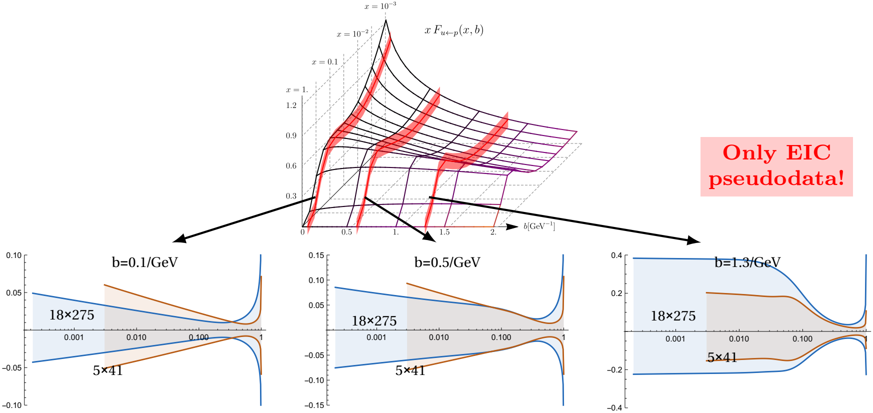




Unpolarized TMD

- **IR1**: Smaller-x, smaller-b/larger-k_T
- **IR2**: Larger-x, larger-b/smaller-k_T

$\Big\}$ Complimentary coverage!

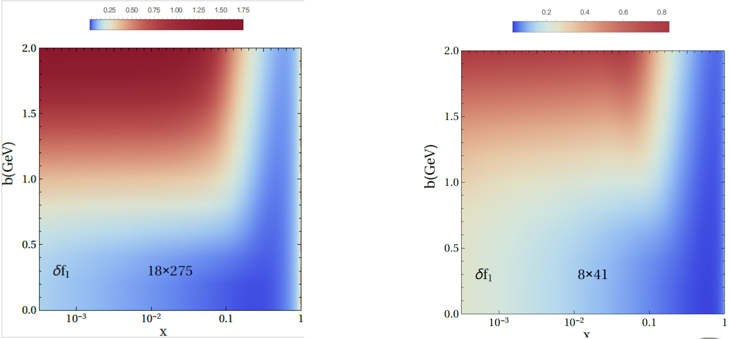


Only EIC pseudodata!

Unpolarized TMD

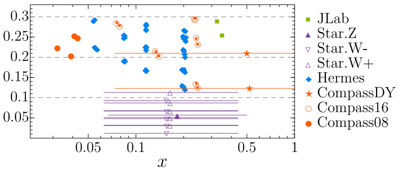
- **IR1**: Smaller-x, smaller-b/larger-k_T
- **IR2**: Larger-x, larger-b/smaller-k_T

$\Big\}$ Complimentary coverage!



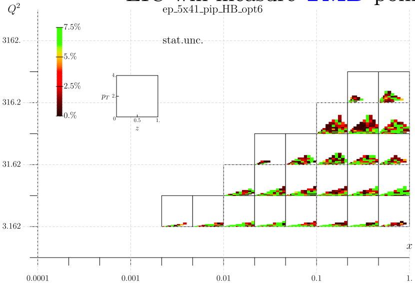
Present **TMD** data for Sivers.
$\sim 70-80$ points.

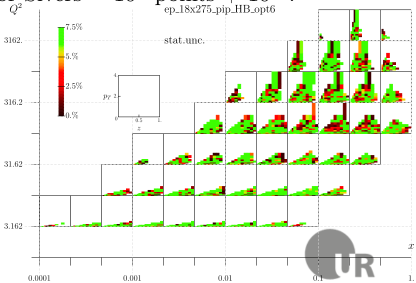
[BPV20,2012.05135]



$+\ 200-300$ **collinear** data for Sivers

EIC will measure **TMD** points for Sivers $\sim 10^3$ points $+\ 10^4$.





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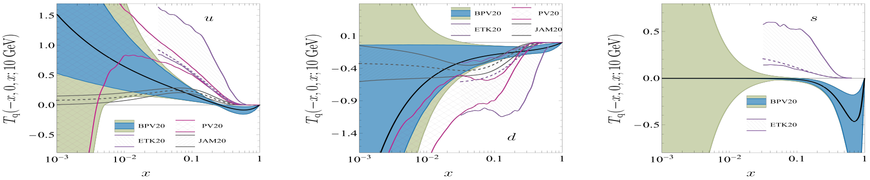
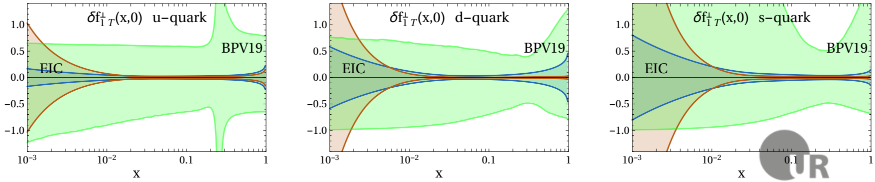
Sivers function

- **IR1**: Smaller-x, smaller-b/larger-k_T
- **IR2**: Larger-x, larger-b/smaller-k_T

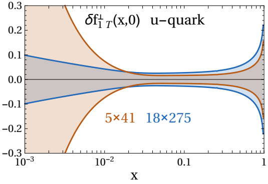
$\Big\}$ Similar to unpolarized case

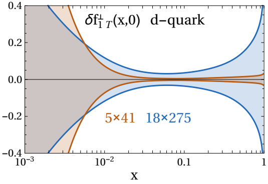


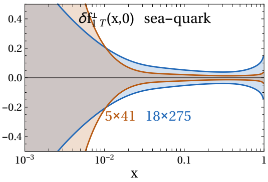
BPV20=[Bury,Prokudin,AV,2012.05135]



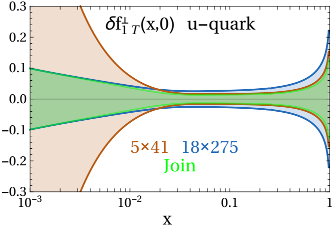
Sivers function







Integrals!



The balance between small/large-x is important for integrated observables

Toy example:

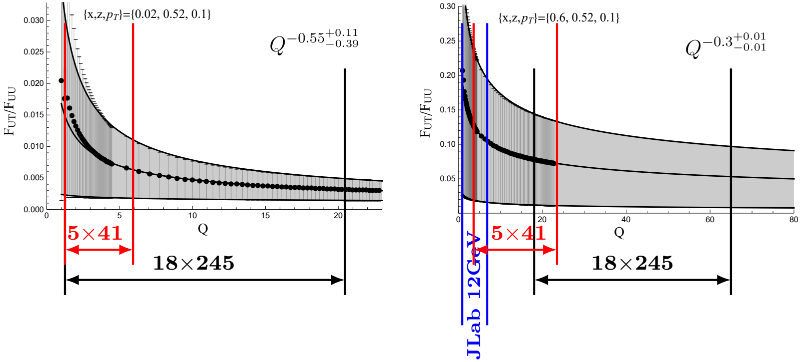
$$A = \int_0^1 dx f_{1T;u}^{\perp}(x,0)$$

$$\delta A_{\mathrm{IR1}} \sim 6\%, \qquad \delta A_{\mathrm{IR2}} \sim 12\%$$

$$\delta A_{\mathrm{IR1}\cup\mathrm{IR2}} \sim 3\%$$

Concerning evolution

How smaller polarized asymmetries at IR1 vs. IR2



Asymmetry reduces, but not that fast

Typical power $Q^{-0.2-0.5}$ (depending on $\{x, z, p_T\}$)

Both IR's are great for studying SIDIS and TMDs, and each promises a great impact.
Together, two detectors will make the picture more homogeneous over x/Q/k_T
Also IR2 is important to connect JLab & COMPASS

IR1 (**18 x 275**)

- Smaller x
- Smaller b/larger k_T
- Gluons
- More collinear physics!

IR2 (**5 x 41**)

- Larger x
- Larger b/smaller k_T
- Higher twists(?)
- More TMD physics!

Warning: all analyses are based on the present data, which are not that good
(what is why we need EIC!)
There is a lot of model dependence/bias in these studies.

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