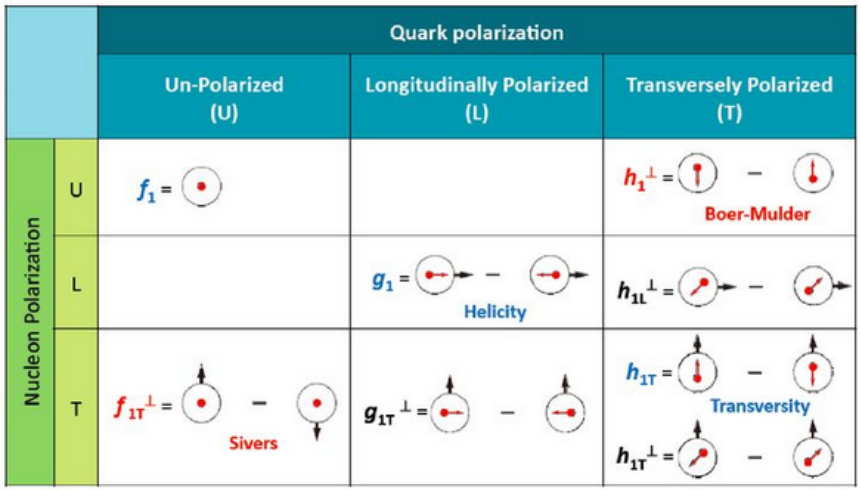
Precision TMD studies (theory)

Alexey Vladimirov

Science at the Luminosity Frontier: Jefferson Lab at 22 GeV
January 24, 2023

Leading Twist TMDs

: Nucleon Spin : Quark Spin



Twist 3 TMDs

	U	L	$T_{J=0}$	$T_{J=1}$	$T_{J=2}$
U	$f_\bullet^\perp$	$g_\bullet^\perp$		$h_\bullet$	$h_\bullet^\perp$
L	$f_{\bullet L}^\perp$	$g_{\bullet L}^\perp$	$h_{\bullet L}$		$h_{\bullet L}^\perp$
T	$f_{\bullet T}$, $f_{\bullet T}^\perp$	$g_{\bullet T}$, $g_{\bullet T}^\perp$	$h_{\bullet T}^{D\perp}$	$h_{\bullet T}^{A\perp}$	$h_{\bullet T}^{S\perp}$, $h_{\bullet T}^{T\perp}$

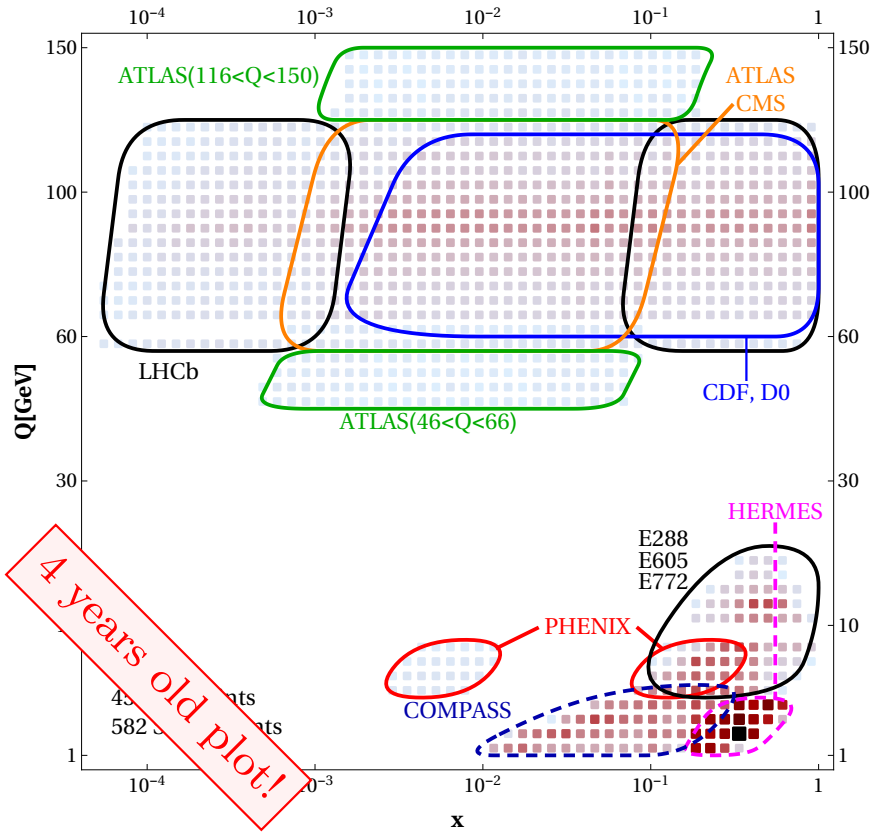
[S.Rodini,AV,2204.03856]

Theory state:

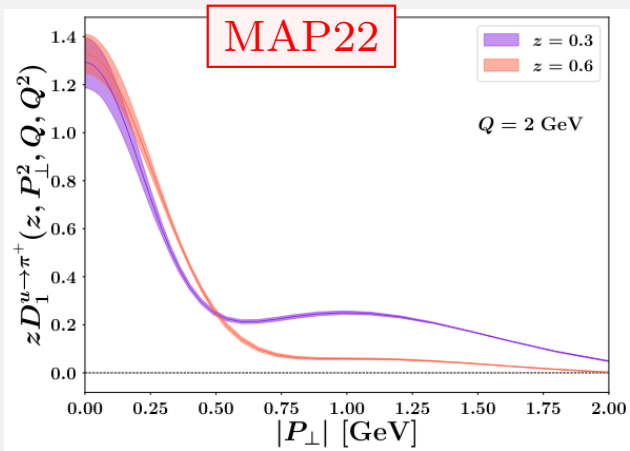
- LP TMD factorization
  - N^4LO evolution
  - Small-b matching for all TMDs is known at NLO (at least) (except pretzelocity)
- NLP TMD factorization
  - Complete (no open questions)
  - Full NLO (coeff.functions, evolution)
  - It is not the same as "naively" expected
- Present frontier:
  - NNLP factorization
  - quasi TMDs (lattice)
  - CS kernel (interpretation?)

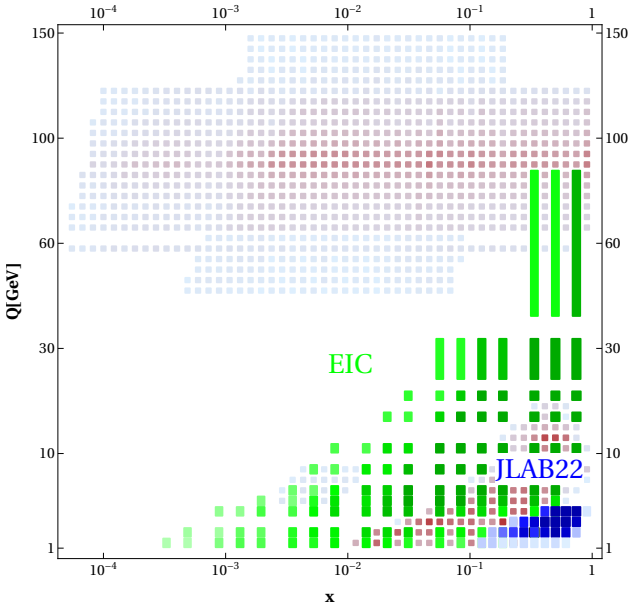
The theory is far beyond the phenomenology.

Unpolarized TMDs



- Plentiful data
- Global DY+SIDIS fits at N^{3}LO
  - SV19 [Scimemi, AV, 1912.06532]
  - MAP22 [Bacchetta, et al, 2206.07598]





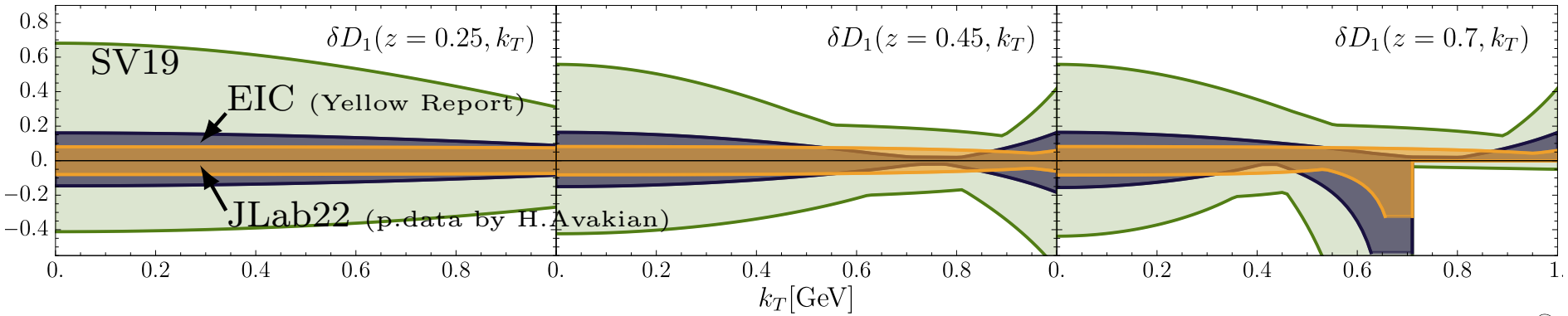
EIC:

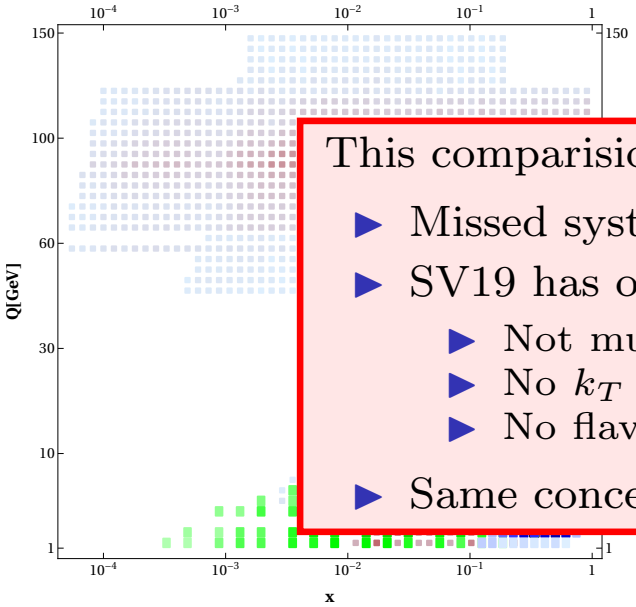
- Large kinematic coverage

JLab22:

- Extreme statistical precision

Estimation of impact using SV19





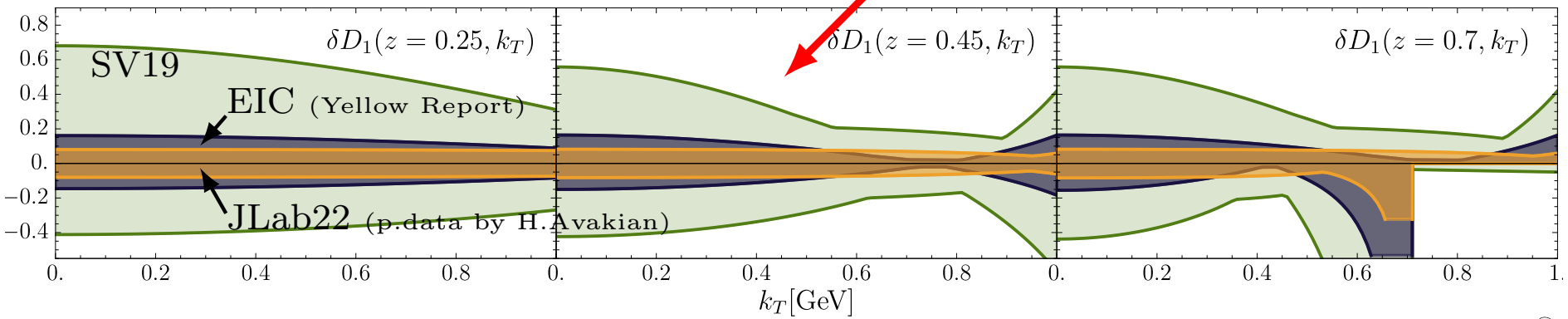
EIC:

- Large kinematic coverage

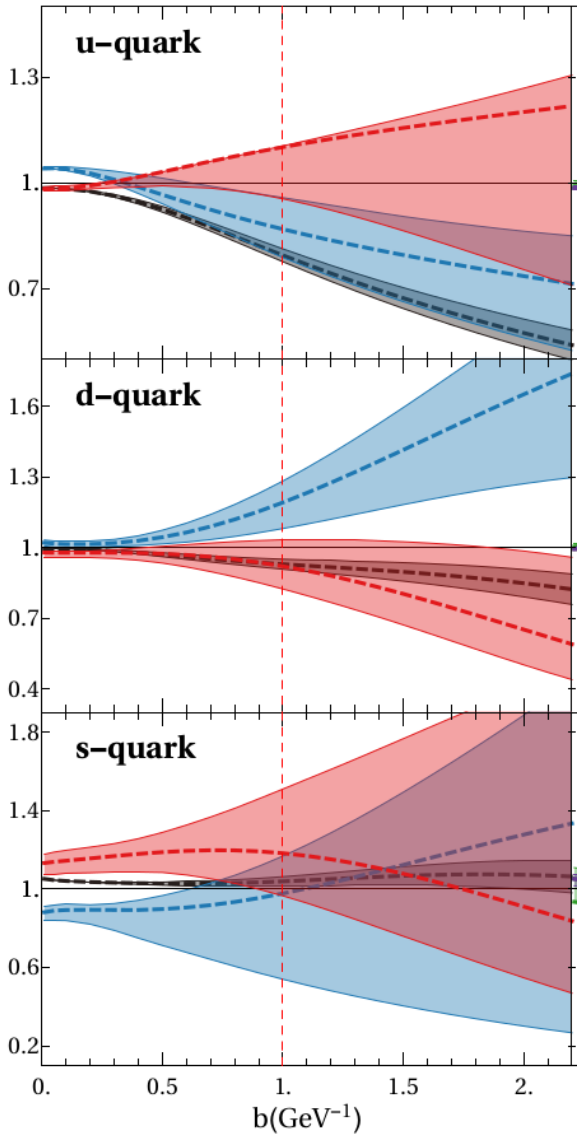
This comparision is not correct, and should not be trusted.

- Missed systematics
- SV19 has only 4 parameters
  - Not much x/z dependance
  - No k_T sensetivity
  - No flavor dependance
- Same concerning e.g. MAP22

Estimation of impact using SV19



[Bury, et al,2201.07114]



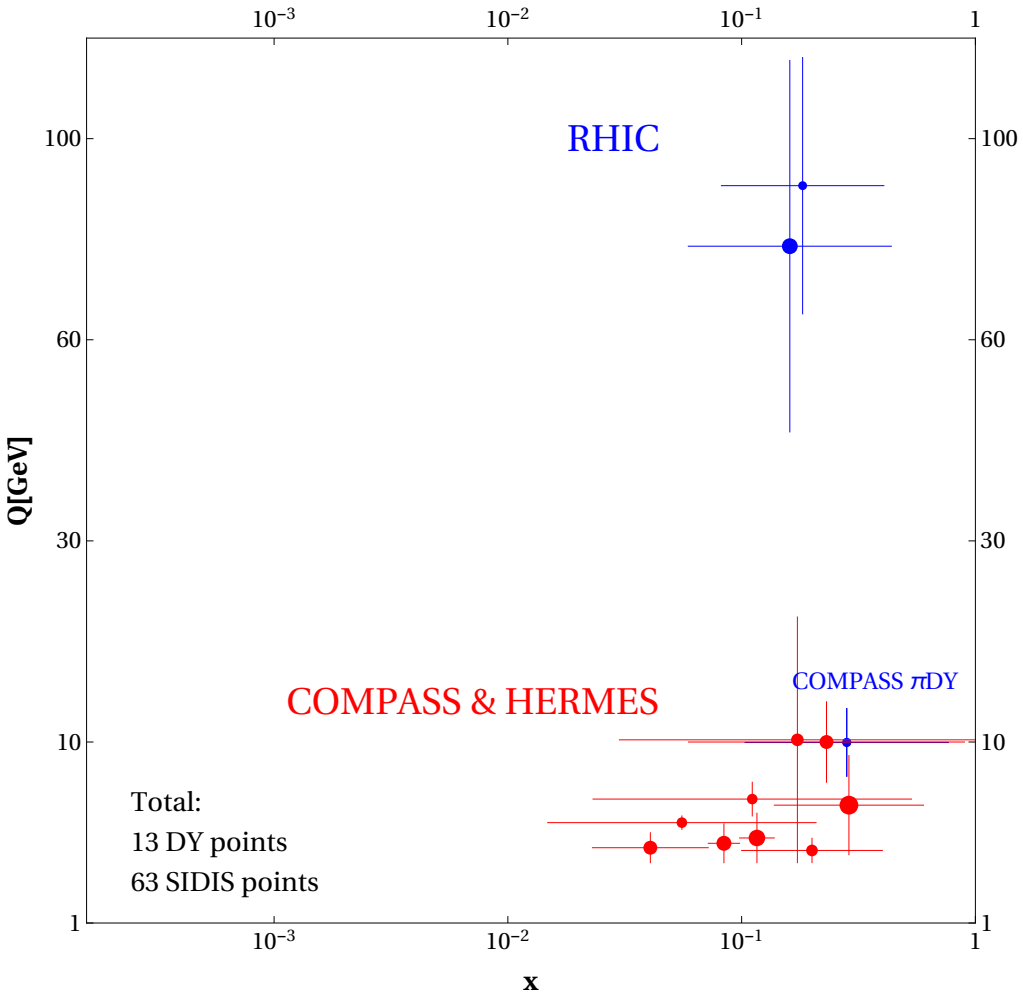
Main problems

- Uncertainties of previous extractions were essentially under-estimated
  - Flavor-dependence
  - PDF-bias
- Unclear situation with low-energy data
  - SV19: negative tails
  - MAP22: problems with normalization

New generation of extractions is required

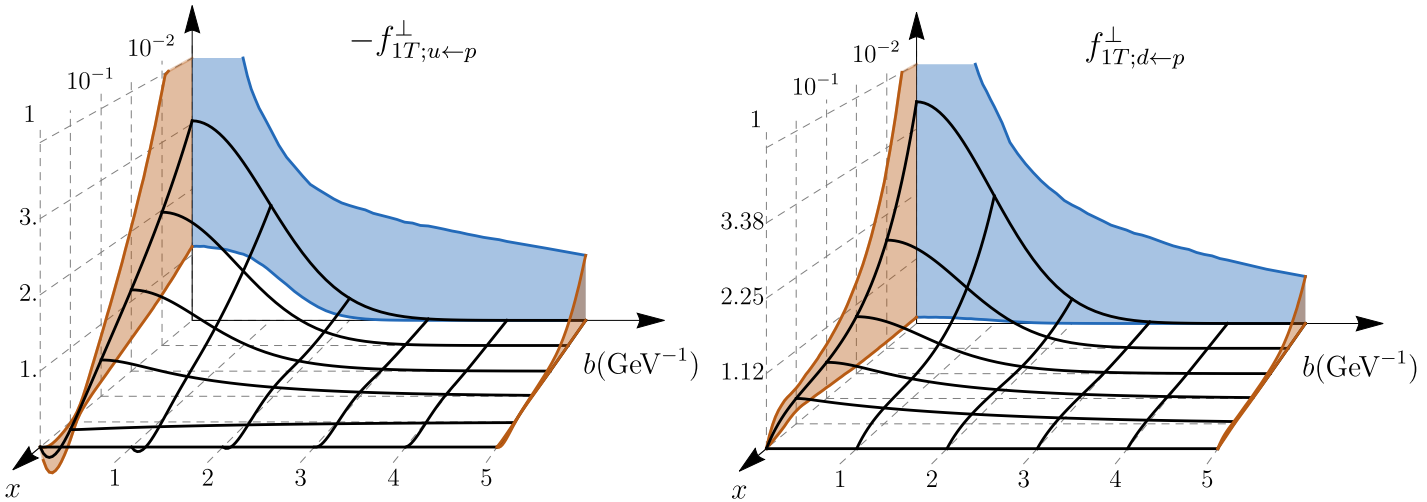
- With PDF-uncertainty (in process)
- Joined TMD+PDF fit

Polarized TMDs (Sivers)



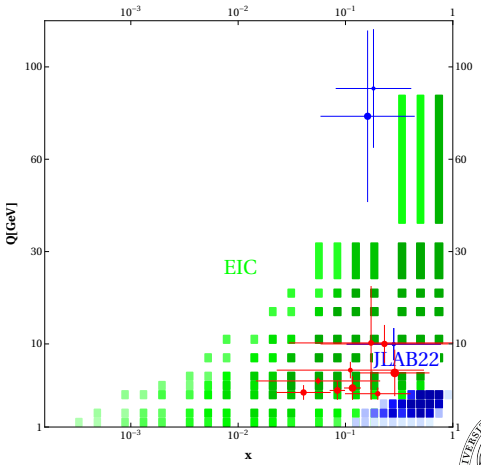
Sivers function

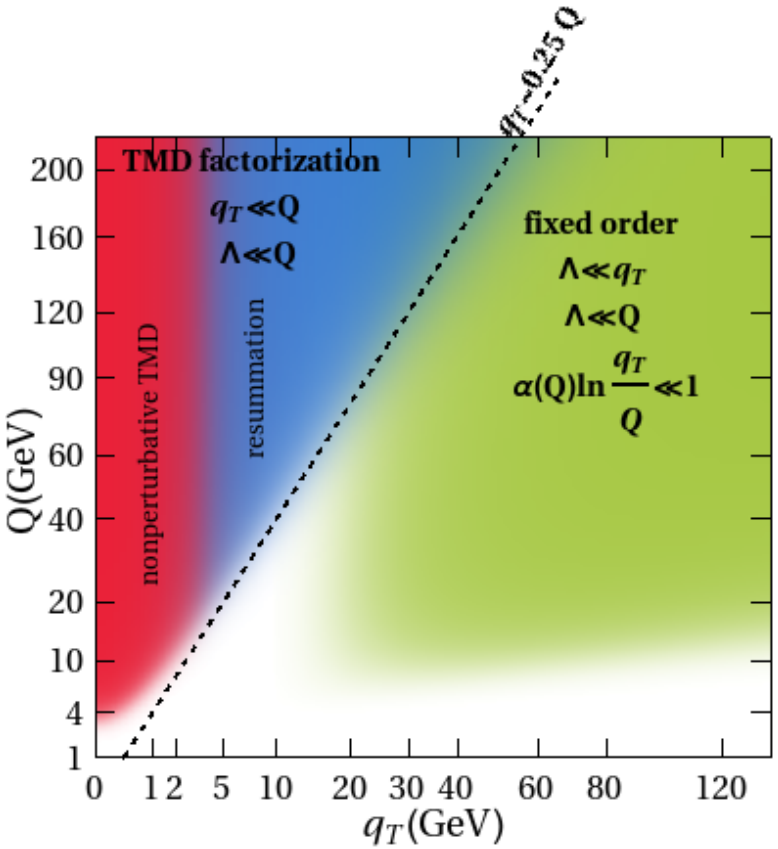
- Data
  - SIDIS
  - + a bit of DY
- Fits
  - [Bury, Prokudin, AV, 2012.05135]
  - [Echevarria, Kang, Terry,2009.10710]
  - [Bacchetta, Delcarro, et al, 2004.14278]
  - [Cammarota, et al 2002.08384]
  - ...
- Theory
  - N^4LO evolution (!)
  - NLO coeff.functions (not used yet)
- All problems with unpolarized TMDs propagate to polarized via denomenator



Uncertainty close to $\pm 100\%$

Any extra data will be essentially important.





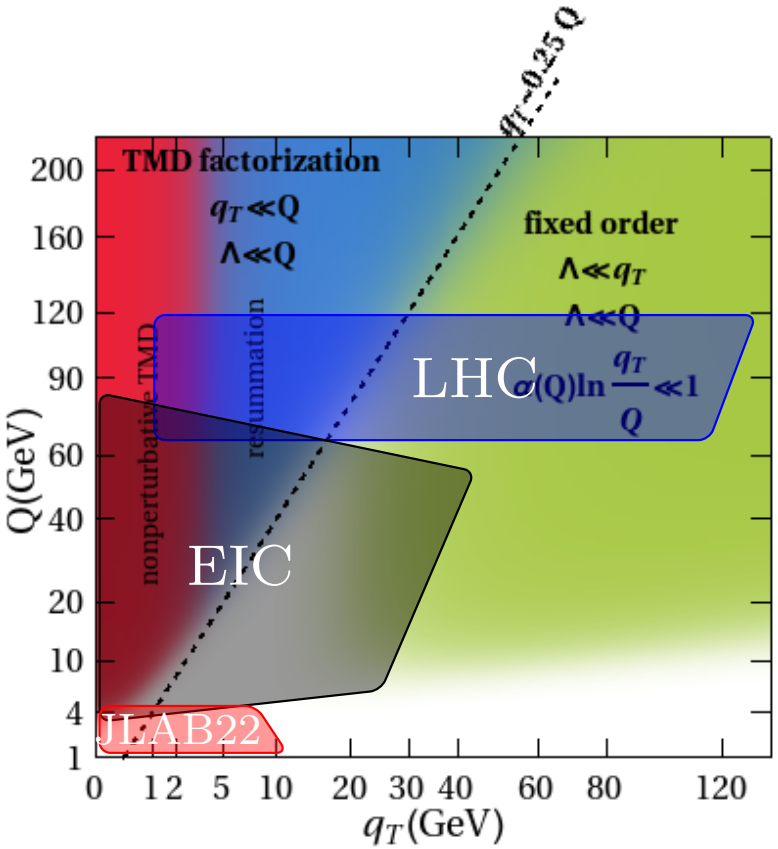
Power corrections:

TMD factorization is very sensitive to data cuts.

$$q_T < 0.25Q$$

Problems in SIDIS

- **SV19:** "too early" negative cross-section
- **MAP22:** problem with normalization



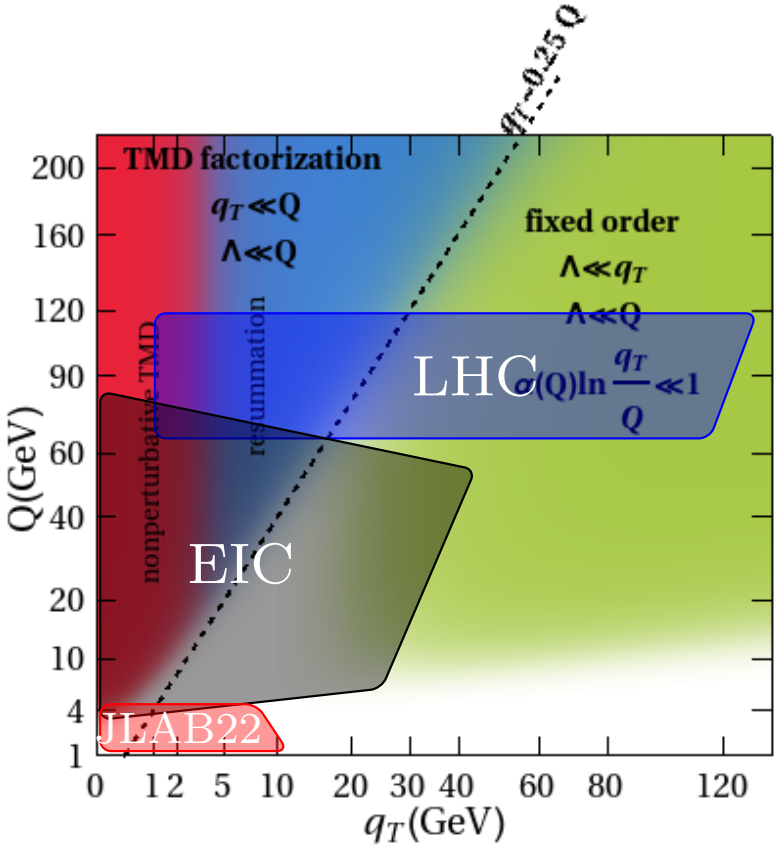
Power corrections:

TMD factorization is very sensitive to data cuts.

$$q_T \; < \; 0.25Q$$

Problems in SIDIS

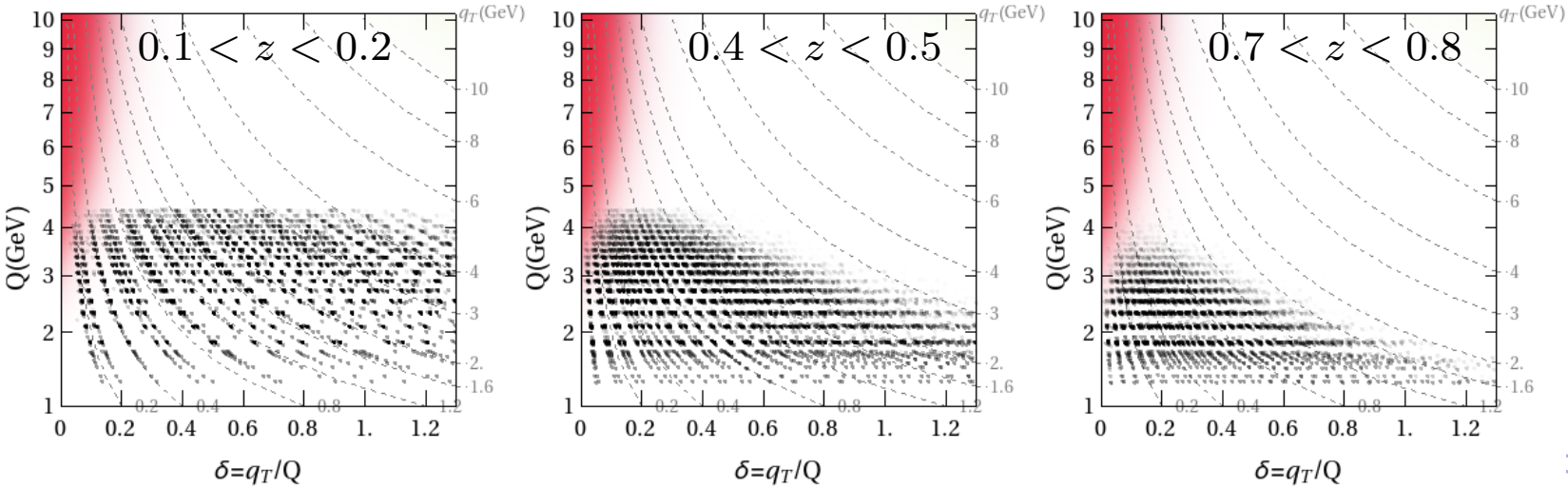
- **SV19:** "too early" negative cross-section
- **MAP22:** problem with normalization

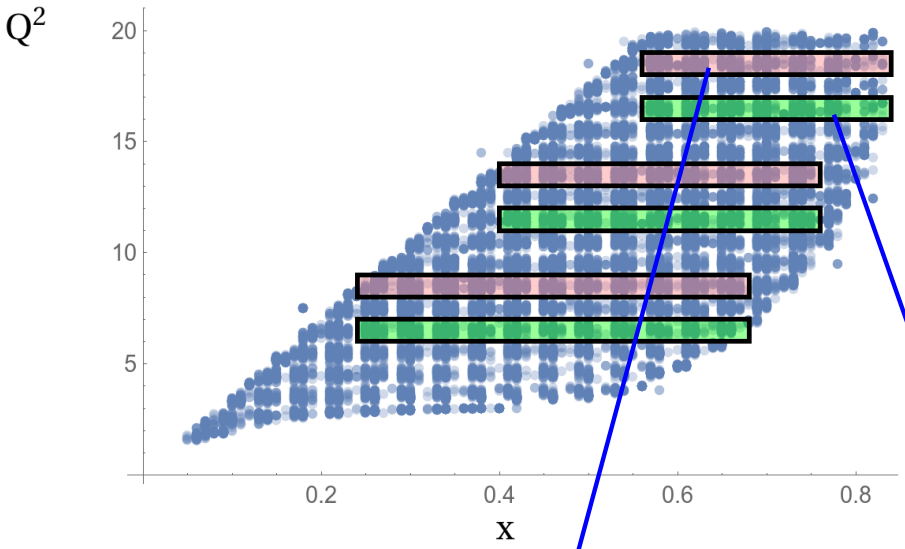


The MOST part of JLab(22) data are in the region with large power corrections.

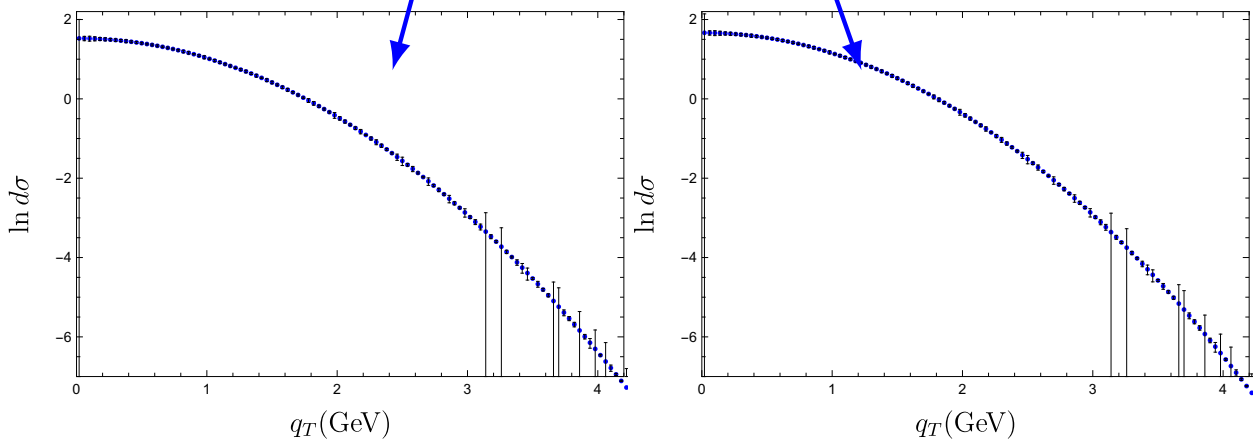
It is not bad!

It is an opportunity to study true QCD, not just a perturbative component

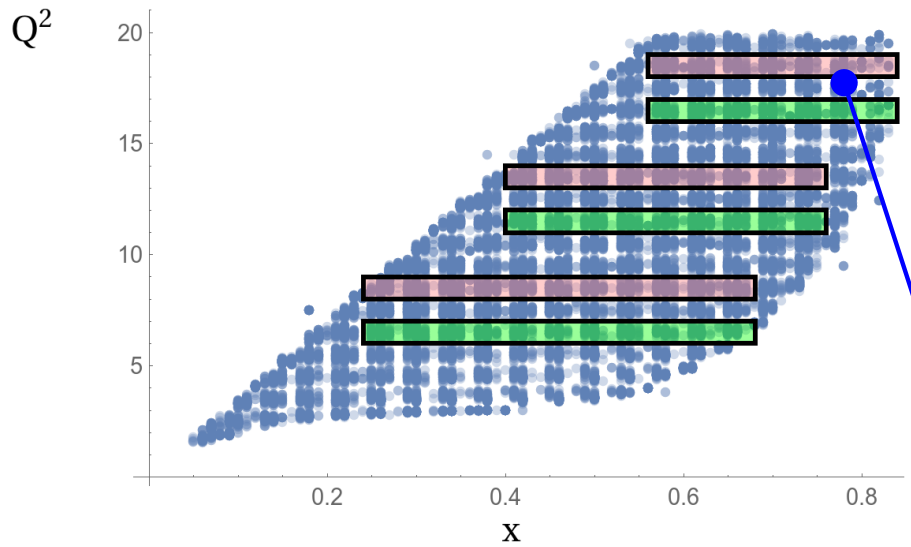




Huge statistics and great resolution will allow for a very fine binning.



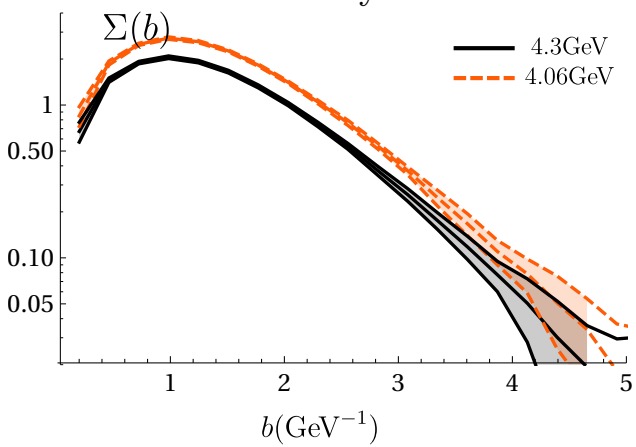
Empty bins are replaced by 200%uncertanty Systematics?



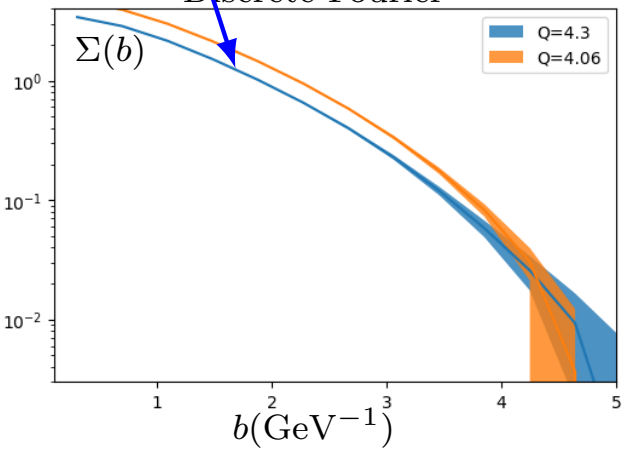
One can study TMDs directly in b space.

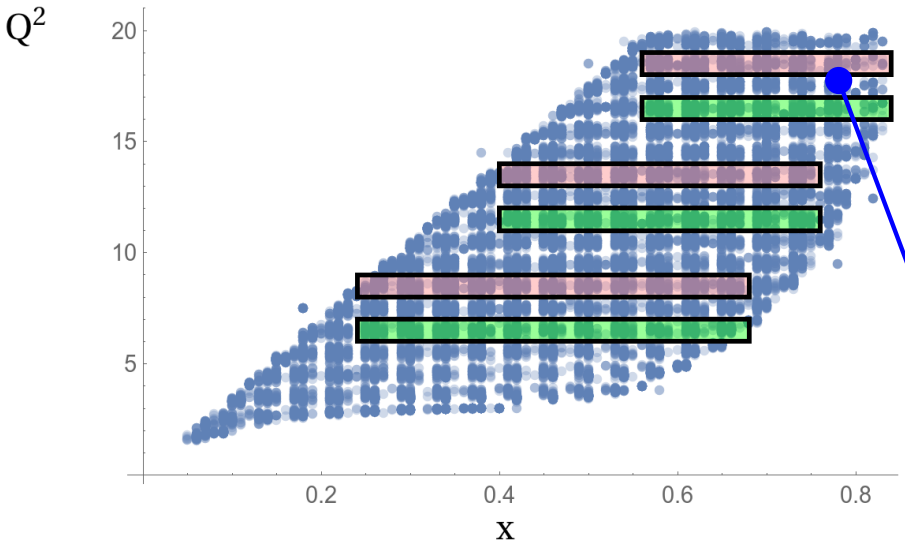
$$\Sigma(b) = \int d^2 q_T d\sigma(q_T) e^{-iq_T b}$$

Theory



Discrete Fourier

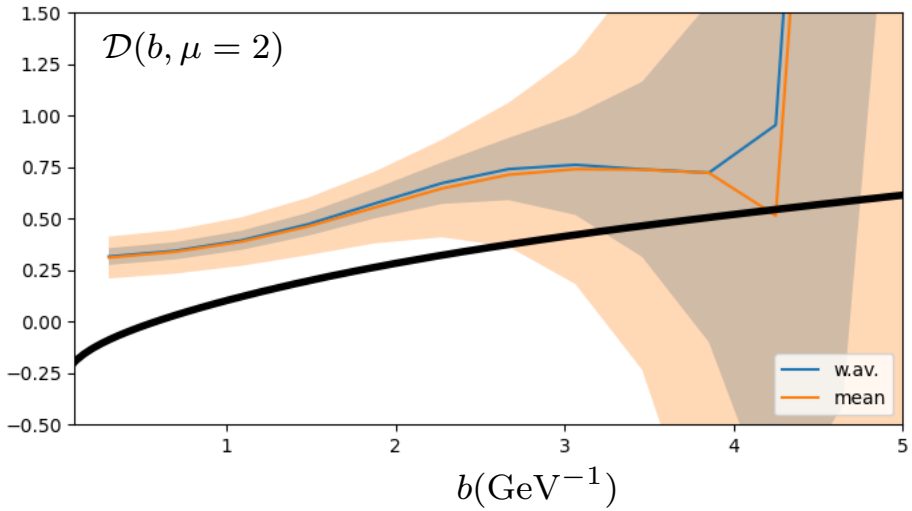


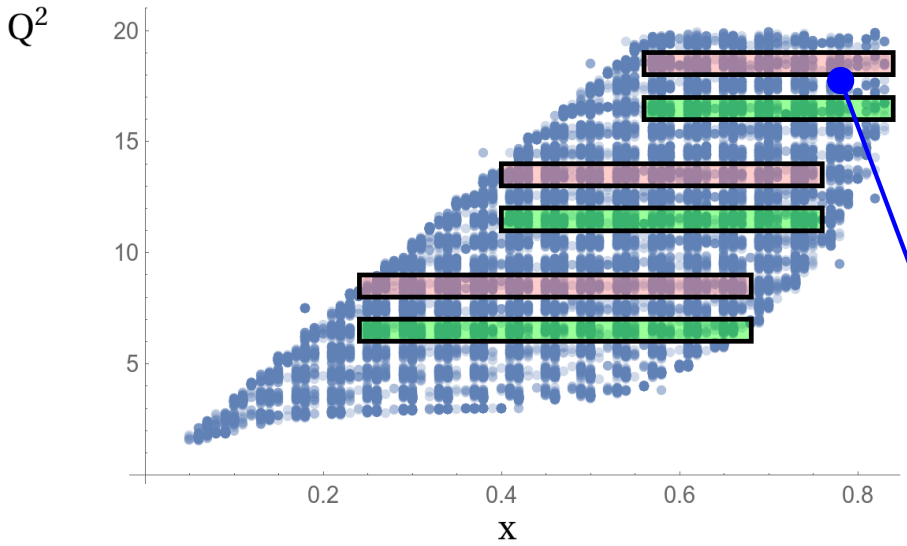


Example:
direct extraction of the Collins-Soper kernel

[A.Martinez, AV, 2206.01105]

The most interesting here is the diviation from the theory



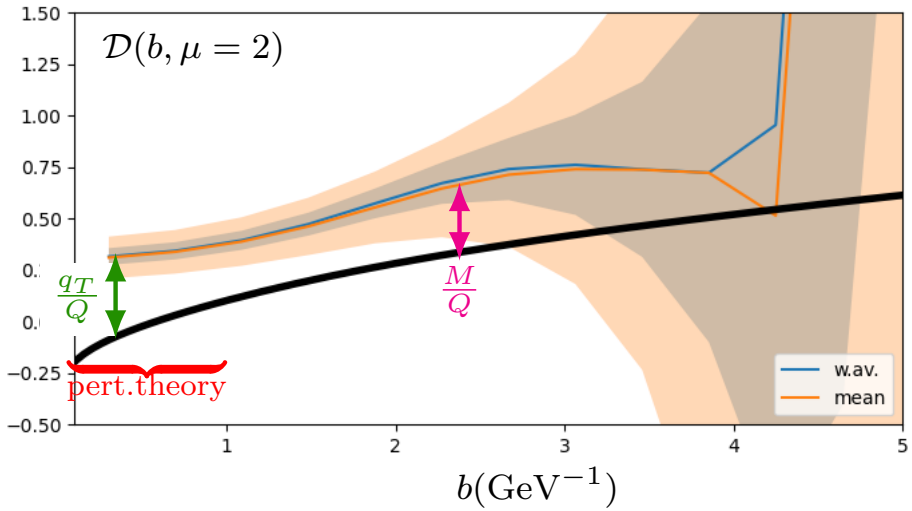


Example:
direct extraction of the
Collins-Soper kernel

[A.Martinez, AV, 2206.01105]

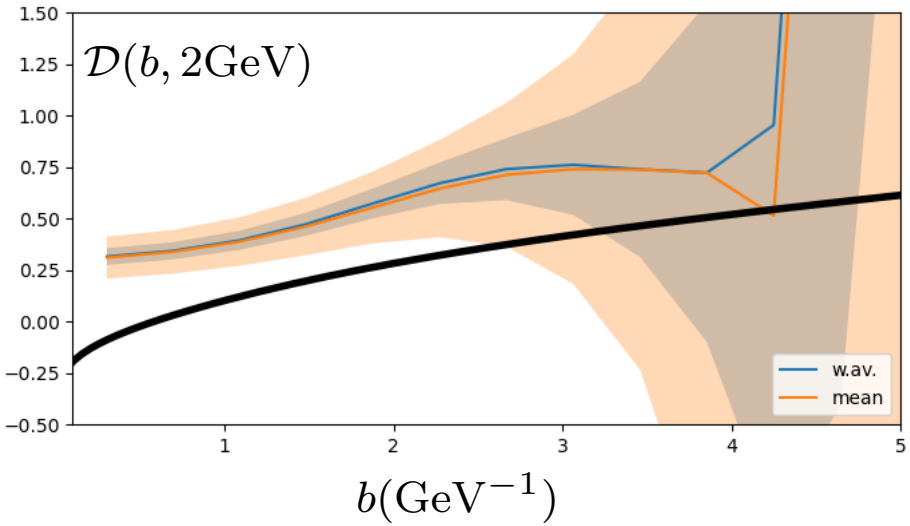
The most interesting here is the diviation from the theory

Comparing such pictures slice-by-slice in Q one can determine effect of power corrections

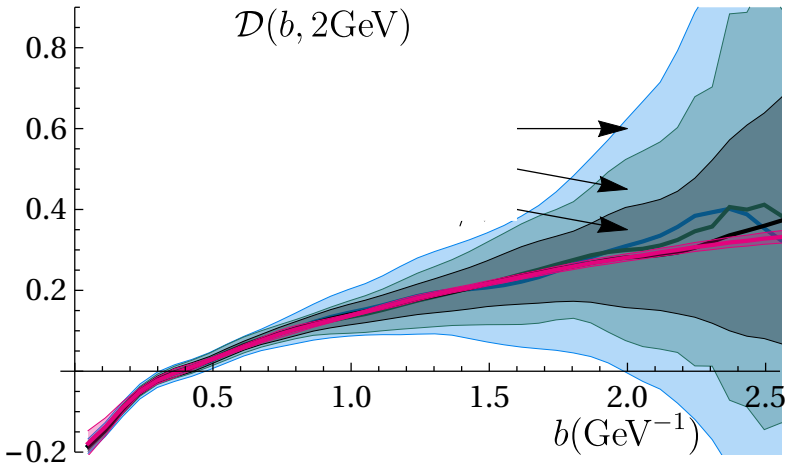


Complementarity to EIC

JLab22
(slices at $Q = 4.03/Q = 4.2$)



EIC
(slices at $Q = 15/Q = 16$)



- EIC: much better small-b (larger-Q $\Rightarrow$ larger-q_T $\Rightarrow$ smaller b)
- JLab: much better large-b (finer-q_T resolution $\Rightarrow$ larger b)

Conclusion

Questions by conveners:

- What is the current status? (open questions in SIDIS)
  - **Unpolarized TMDs:** illusory good
  - **Polarized TMDs:** explicitly bad
- How would the JLab upgrade help? (limitation of existing and future experiments)
  - Yes, definitely. But it is difficult to quantify
- How can the upgrade complement the EIC?
  - Yes, definitely. But it is difficult to quantify

The more definite answers will come with the next generation of extractions, which are currently in process.
Stay tuned