SIDIS helicity/tensor charge related measurements and fits

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IR2@EIC: Science and Instrumentation of the 2nd IR for the EIC (Joint Argonne and CFNS Workshop)
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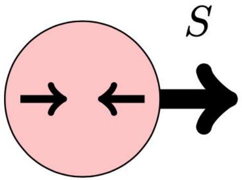
Jefferson Lab

Outline

- Helicity PDFs
- Transversity (tensor charge)
- QED effects



$$\Delta f = f_{\rightarrow} - f_{\leftarrow}$$

Helicity PDFs

Low Q vs high Q

$$\gamma^2 = 4M^2x^2/Q^2,$$

$$A_{\parallel} = \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}} = D(A_1 + \eta A_2),$$

$$A_{\perp} = \frac{\sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}}{\sigma^{\downarrow\Rightarrow} + \sigma^{\uparrow\Rightarrow}} = d(A_2 - \zeta A_1)$$

$$\Rightarrow$$

$$A_1 = \frac{(g_1 - \gamma^2 g_2)}{F_1}$$

$$A_2 = \gamma \frac{(g_1 + g_2)}{F_1}$$

$$\Rightarrow$$

$$g_1 = g_1^{(\tau 2)} + g_1^{(\tau 3)} + g_1^{(\tau 4)}$$

???

$$g_2 = g_2^{(\tau 2)} + g_2^{(\tau 3)}$$

High-Q physics is much simpler

Low-Q physics is more interesting (TMCs, HTs,...)

$$A_1 = \frac{(g_1 - \cancel{\gamma^2} g_2)}{F_1}$$

$$A_2 = \gamma \frac{\cancel{(g_1 +} g_2)}{F_1}$$

$$g_1 = g_1^{(\tau 2)} + \cancel{g_1^{(\tau 3)}} + \cancel{g_1^{(\tau 4)}}$$

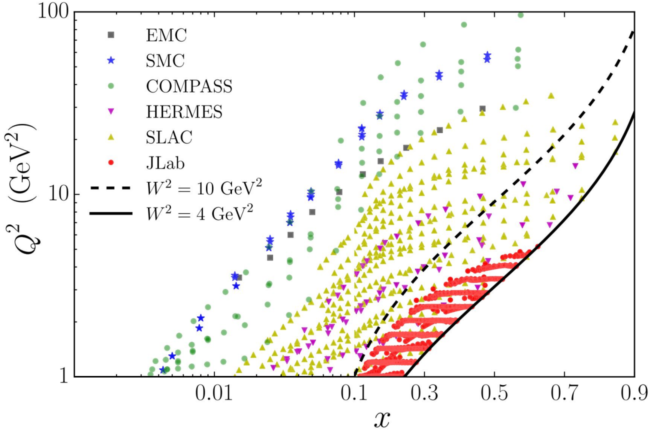
$$\cancel{g_2} = \cancel{g_2^{(\tau 2)}} + \cancel{g_2^{(\tau 3)}}$$

Global analysis

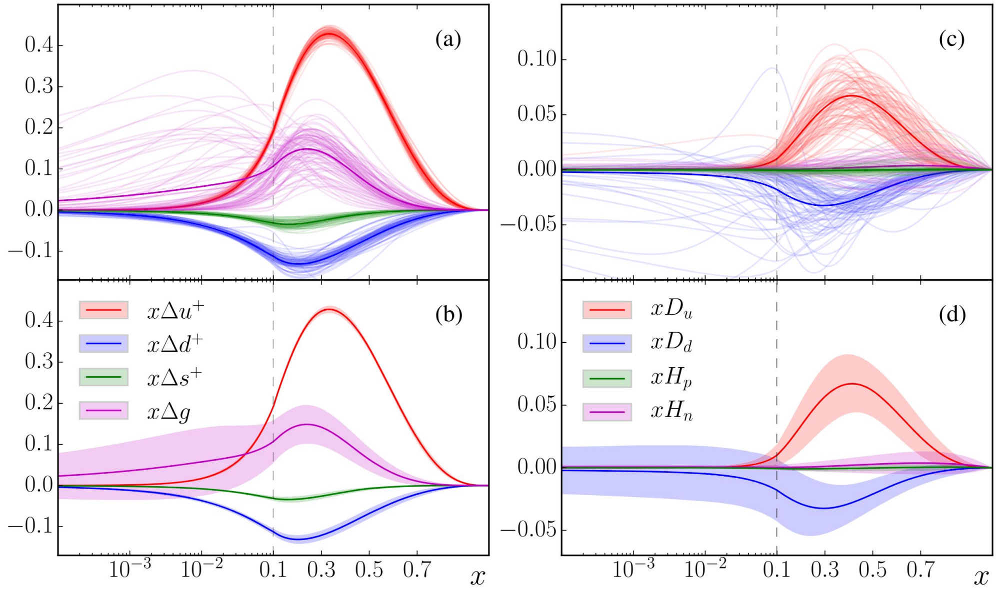
https://arxiv.org/abs/1601.07782

JAM15

NS, Melnitchouk, Kuhn, Ethier, Accardi



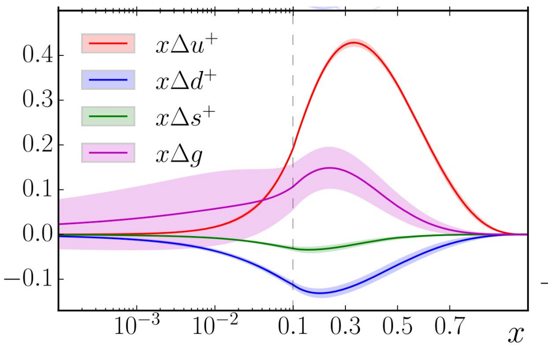
World's **highest-x** data



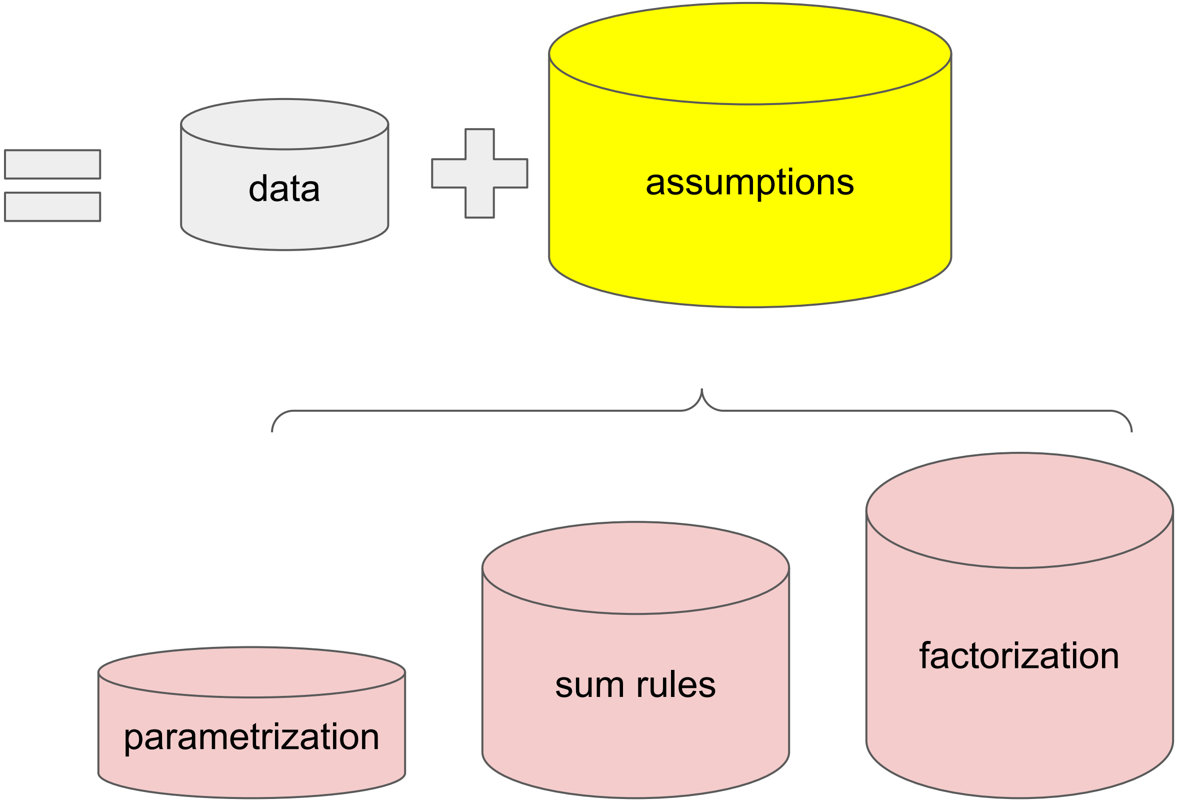
Relatively well constrained PDFs

Twist-3 effects

At present



$x\Delta u^+$
$x\Delta d^+$
$x\Delta s^+$
$x\Delta g$
0.4
0.3
0.2
0.1
0.0
−0.1
10^{-3}
10^{-2}
0.1
0.3
0.5
0.7
x

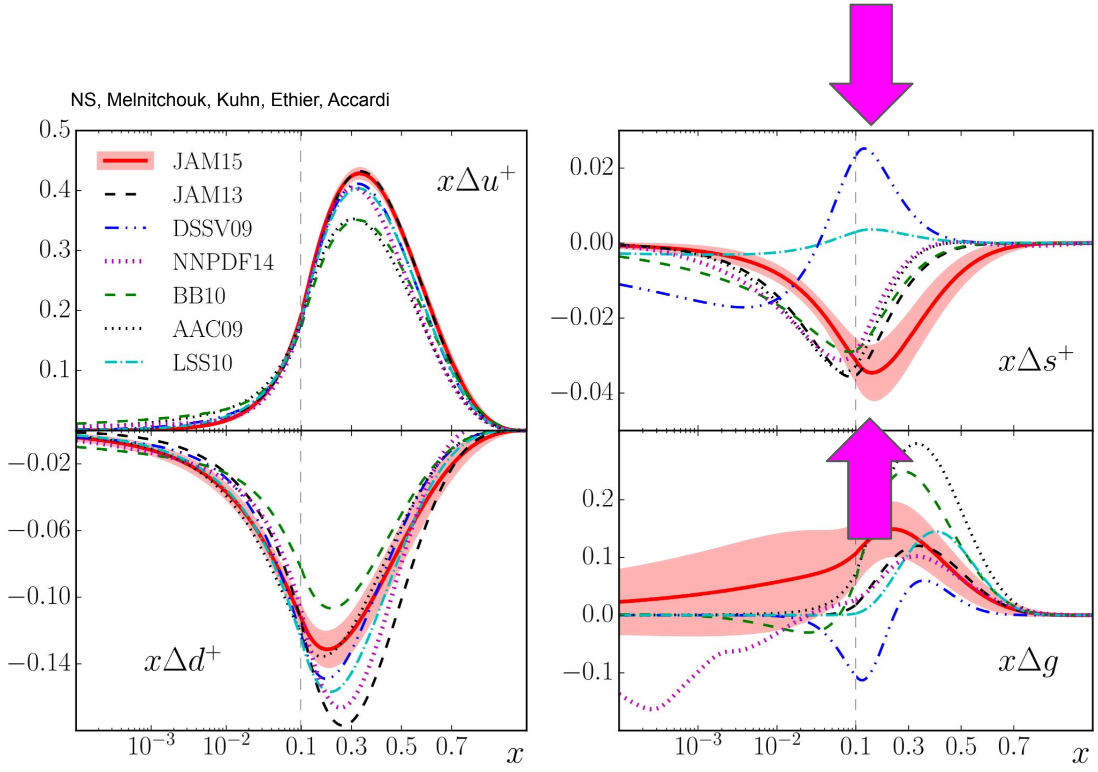


data
assumptions
parametrization
sum rules
factorization

https://arxiv.org/abs/1103.5979

Strange puzzle

NS, Melnitchouk, Kuhn, Ethier, Accardi



A Possible Resolution of the Strange Quark Polarization Puzzle ?

Elliot Leader, Alexander V. Sidorov, Dimiter B. Stamenov

The strange quark polarization puzzle, i.e. the contradiction between the negative polarized strange quark density obtained from analyses of inclusive DIS data and the positive values obtained from combined analyses of inclusive and semi-inclusive SIDIS data using de Florian et. al. (DSS) fragmentation functions, is discussed. To this end the results of a new combined NLO QCD analysis of the polarized inclusive and semi-inclusive DIS data, using the Hirai et. al. (HKNS) fragmentation functions, are presented. It is demonstrated that the polarized strange quark density is very sensitive to the kaon fragmentation functions, and if the set of HKNS fragmentation functions is used, the polarized strange quark density obtained from the combined analysis turns out to be negative and well consistent with values obtained from the pure DIS analyses.

"...It is demonstrated that the polarized strange quark density is very sensitive to Kaon FF."

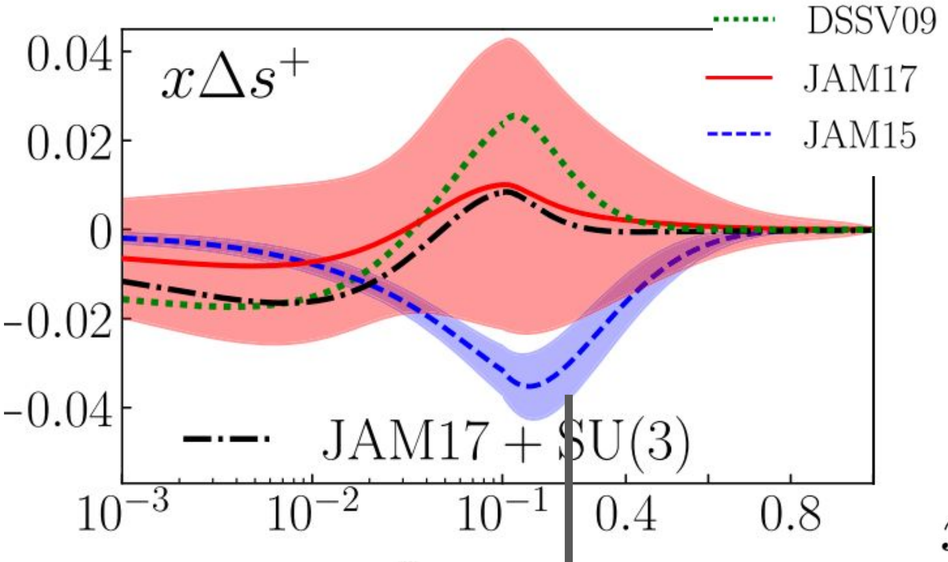
SU(3) constraints:

$$\Delta u^+(1, Q^2) + \Delta d^+(1, Q^2) - 2\Delta s^+(1, Q^2) = a_8,$$

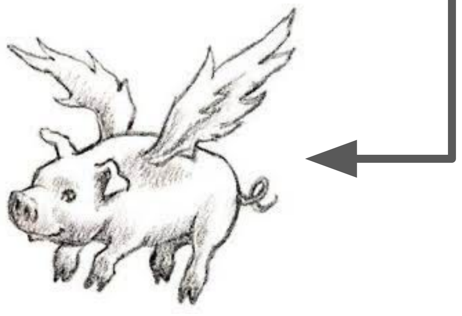
Role of SIDIS and SIA ?

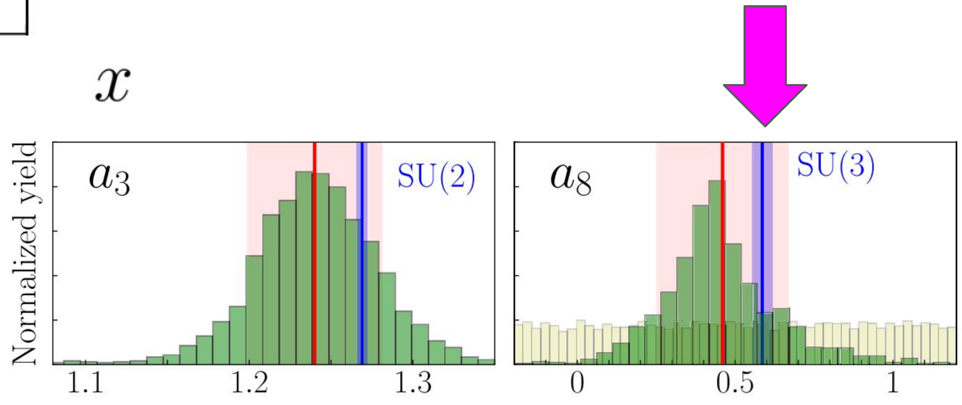
JAM’17 (towards more data-driven analysis)

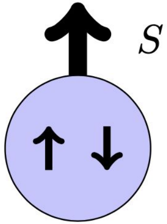
Ethier, NS, Melnitchouk
https://arxiv.org/abs/1705.05889



- Use of pol. **DIS, SIDIS and SIA**
- No SU(2) or SU(3) constraints
- Empirical evidence of g_3 ~ g_A 2%
- **No strange puzzle - need more data!**







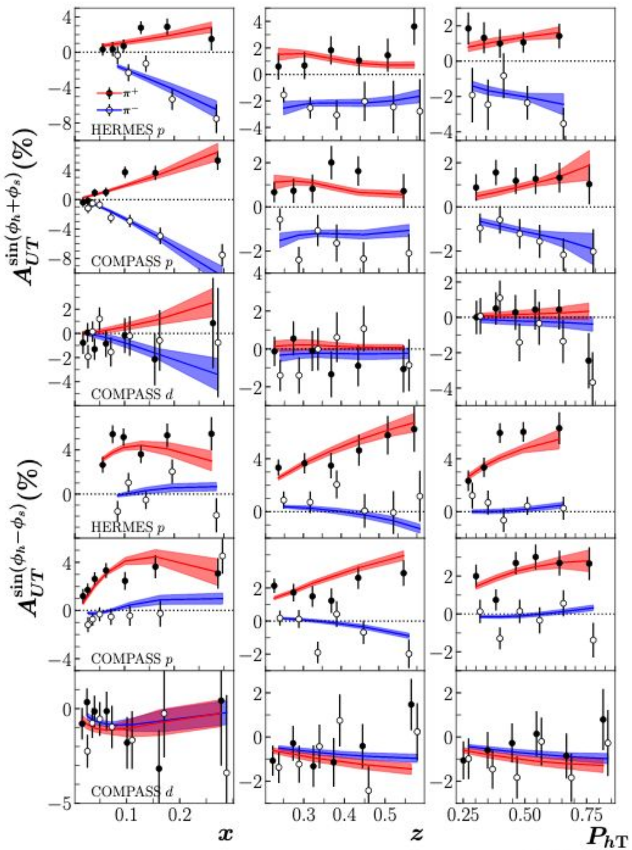
$$\delta_{\mathrm{T}} f = f_{\uparrow} - f_{\downarrow}$$

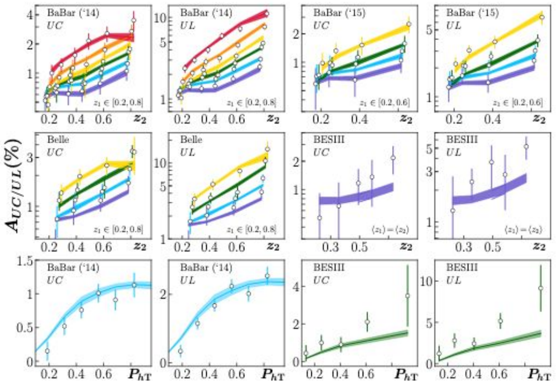
Transversity

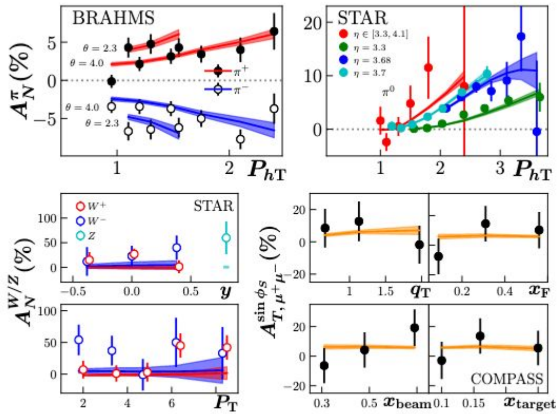
Global TMD analysis

https://arxiv.org/abs/2002.08384

Cammarota, Gamberg, Kang, Miller, Pitonyak, Prokudin, Rogers, NS



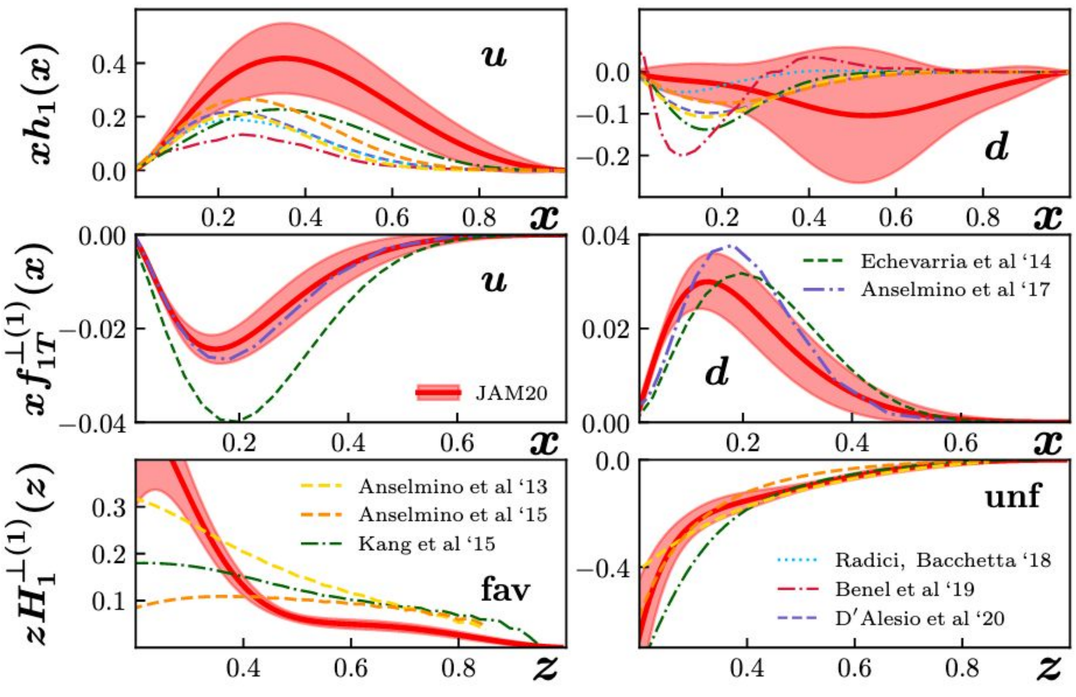


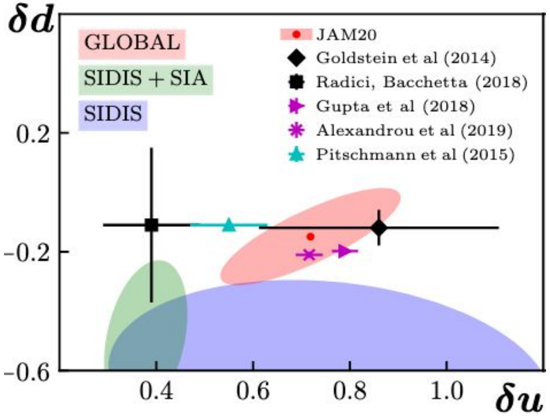


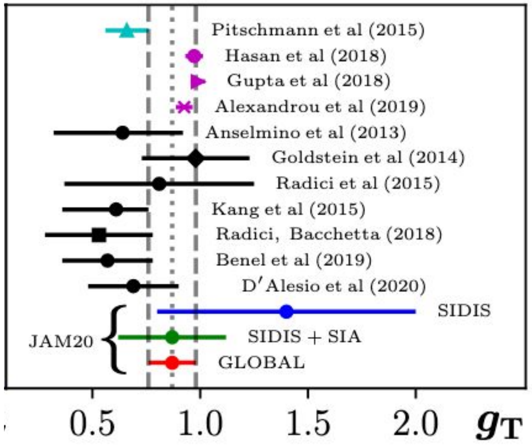
Observable	Reactions
$A_{\text{SIDIS}}^{\text{Siv}}$	$e+(p,d)^{\uparrow}\rightarrow e+(\pi^+,\pi^-,\pi^0)+X$
$A_{\text{SIDIS}}^{\text{Col}}$	$e+(p,d)^{\uparrow}\rightarrow e+(\pi^+,\pi^-,\pi^0)+X$
$A_{\text{SIA}}^{\text{Col}}$	$e^+ + e^- \rightarrow \pi^+\pi^-(UC,UL)+X$
$A_{\text{DY}}^{\text{Siv}}$	$\pi^- + p^{\uparrow}\rightarrow \mu^+\mu^- + X$
$A_{\text{DY}}^{\text{Siv}}$	$p^{\uparrow}+p\rightarrow (W^+,W^-,Z)+X$
A_N^h	$p^{\uparrow}+p\rightarrow(\pi^+,\pi^-,\pi^0)+X$

Global TMD analysis

https://arxiv.org/abs/2002.08384





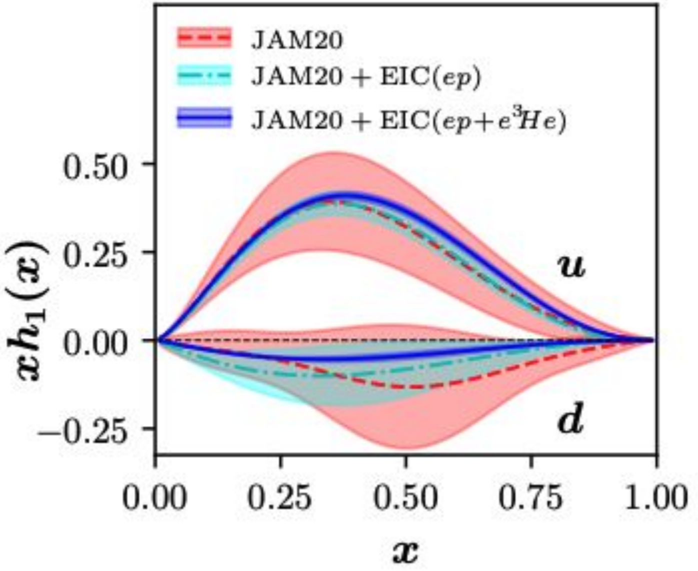


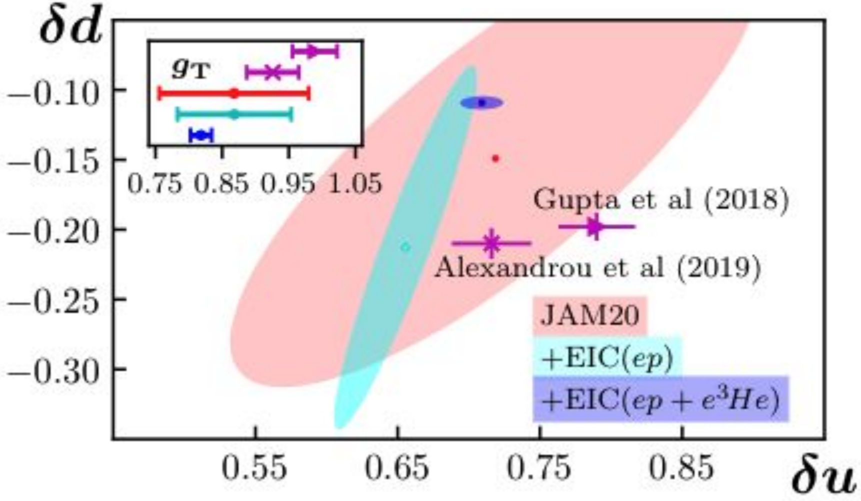
Cammarota, Gamberg, Kang, Miller, Pitonyak, Prokudin, Rogers, NS

Impact of EIC (from YR)

https://arxiv.org/abs/2101.06200

Gamberg, Kang, Pitonyak, Prokudin, NS, Seidl



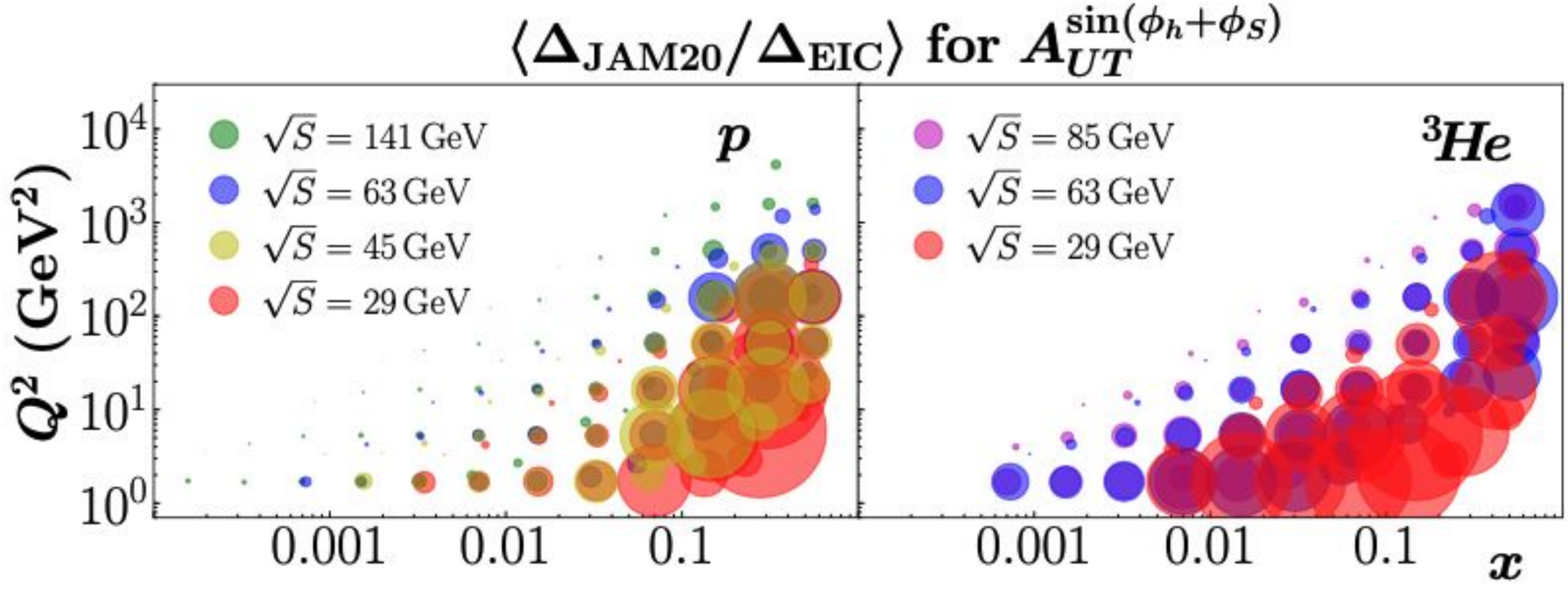


3He data are crucial for
flavor separation

Impact of EIC (from YR)

https://arxiv.org/abs/2101.06200

Gamberg, Kang, Pitonyak, Prokudin, NS, Seidl

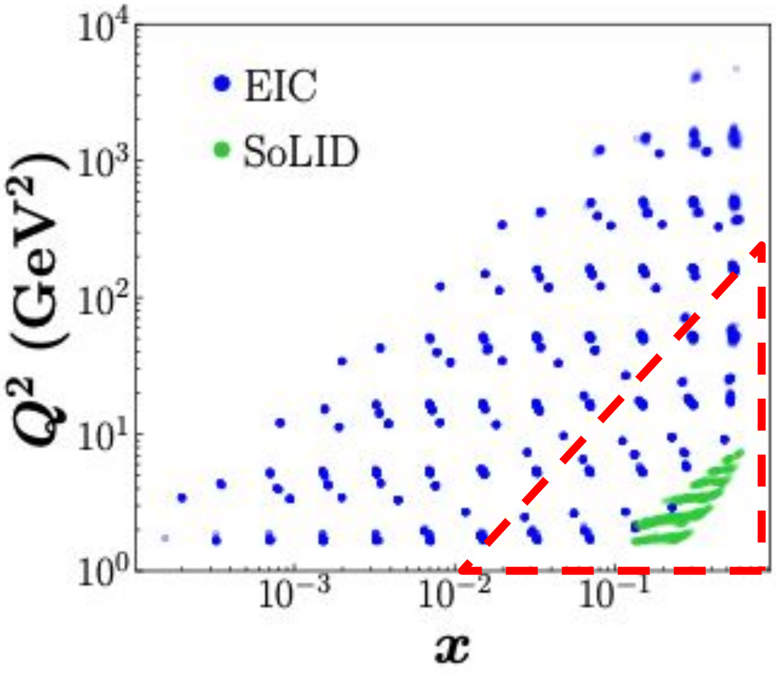


High-x region provides significant constraints

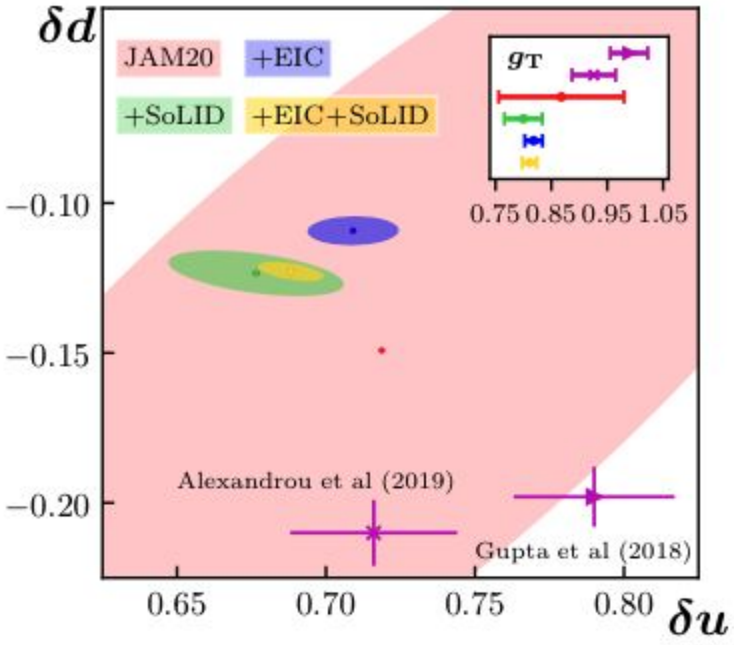
Impact of low Q (from SoLID study)

https://arxiv.org/abs/2101.06200

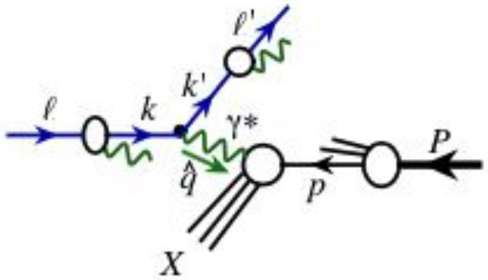
Gamberg, Kang, Pitonyak, Prokudin, NS, Seidl

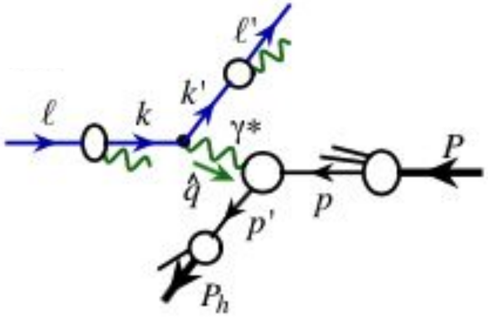


High-x region provides significant constraints

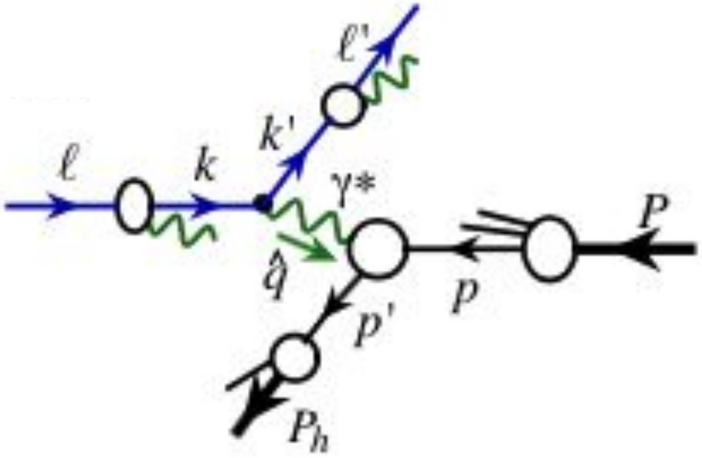


Accuracy vs. Precision





QED effects

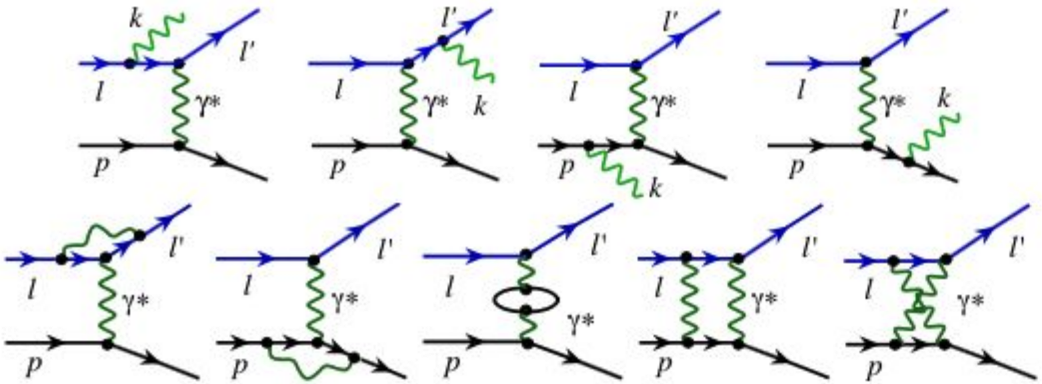


https://arxiv.org/abs/2008.02895

Liu, Melnitchouk, Qiu, NS

The actual probe **cannot be uniquely** determined experimentally

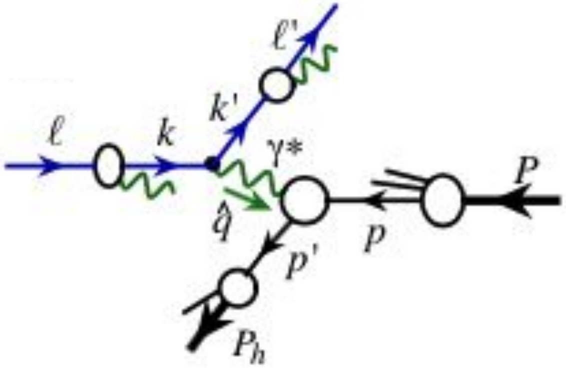
One-photon exchange is **not always a good approximation**
e.g., EW observables



QED effects in inclusive DIS (collinear factorization)

https://arxiv.org/abs/2008.02895

Liu, Melnitchouk, Qiu, NS



Perturbatively calculable
lepton distribution functions and
lepton fragmentation functions

$$E'\frac{d\sigma_{\mathrm{DIS}}}{d^3\ell'} = \frac{1}{2s}\sum_{i,j,a}\int_{z_L}^{1}\frac{d\zeta}{\zeta^2}\int_{x_L}^{1}\frac{d\xi}{\xi}D_{e/j}(\zeta)\,f_{i/e}(\xi)\times\int_{x_h}^{1}\frac{dx}{x}f_{a/N}(x)\,\widehat{H}_{ia\to j}(\xi,\zeta,x;k')$$

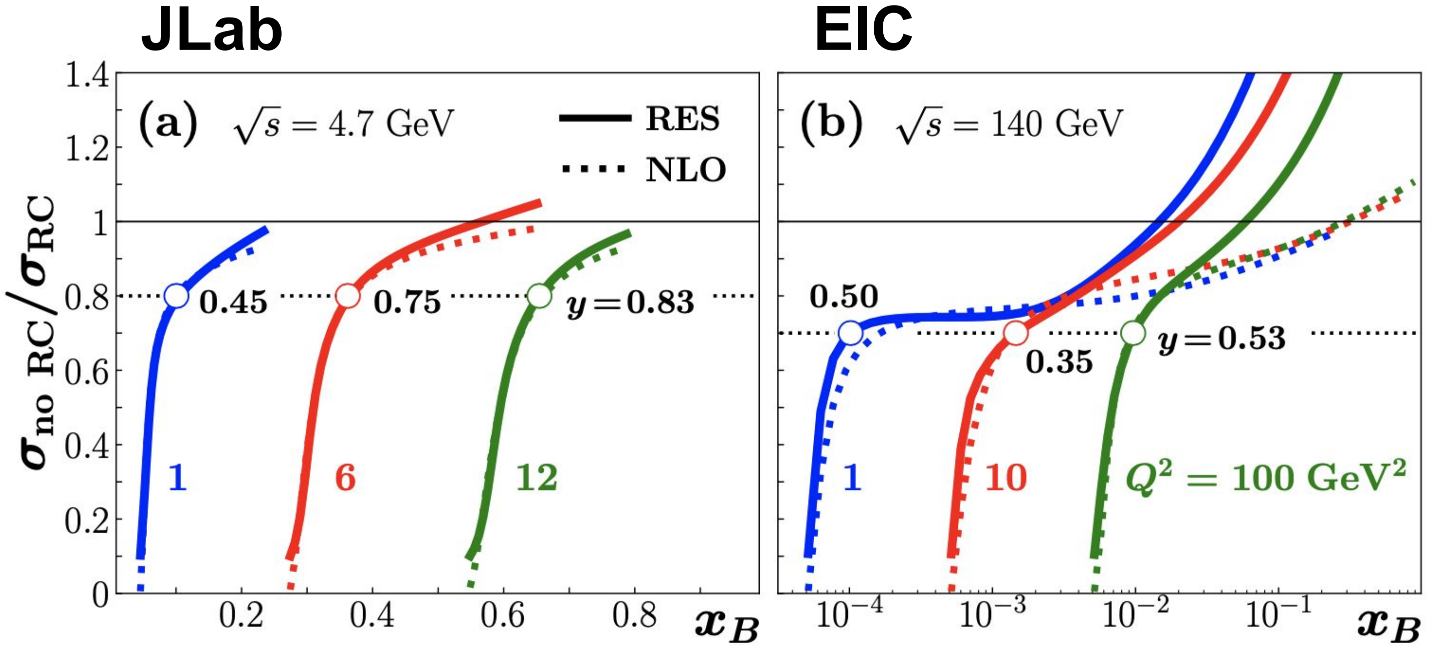
resummation of collinear QED radiation

hadron structure

QED effects in inclusive DIS

https://arxiv.org/abs/2008.02895

Liu, Melnitchouk, Qiu, NS



if life were easy...

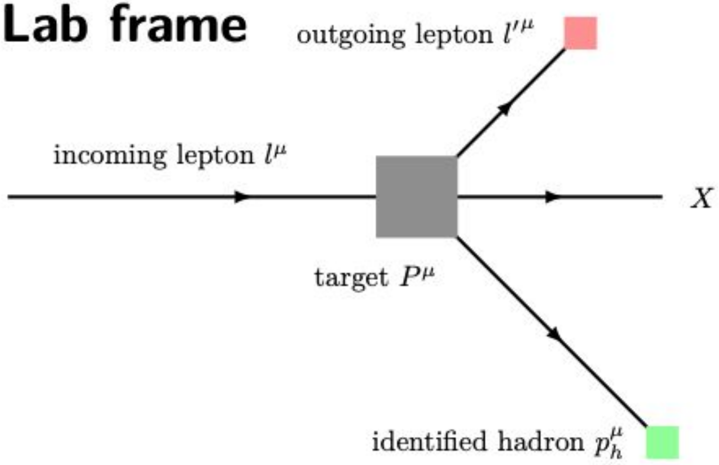
Bottom line: QED effects are **pretty large**

Why is QED so important in SIDIS?

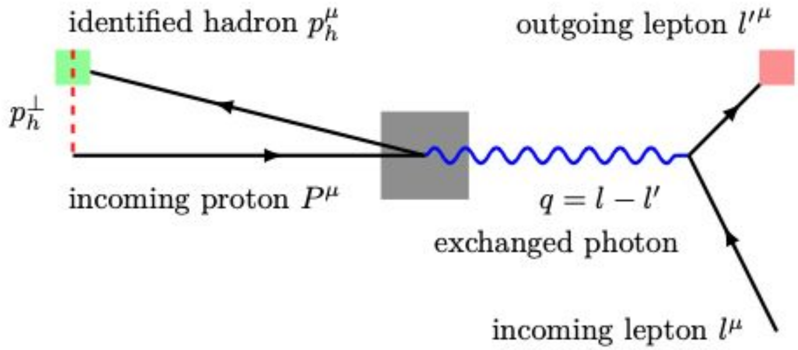
https://arxiv.org/abs/2008.02895

Liu, Melnitchouk, Qiu, NS

Lab frame



Breit frame



Standard factorization theorems are **justified in the Breit frame**

Determining the Breit frame is equivalent to **knowing exactly** the exchanged photon momentum

QED effects in SIDIS (TMD factorization)

https://arxiv.org/abs/2008.02895

Liu, Melnitchouk, Qiu, NS

$$\frac{d\sigma^h_{\rm SIDIS}}{dx_B\,dy\,dz\,dP_{hT}^2} = \int_{\zeta_{\min}}^1 d\zeta \int_{\xi_{\min(\zeta)}}^1 d\xi\, D_{e/e}(\zeta)\, f_{e/e}(\xi)$$
$$\times \left[\frac{\hat{x}_B}{x_B\,\xi\zeta}\right]\left[\frac{(2\pi)^2\,\alpha}{\hat{x}_B\hat{y}\,\widehat{Q}^2}\,\frac{\hat{y}^2}{2(1-\hat{\varepsilon})}F^h_{UU}(\hat{x}_B,\widehat{Q}^2,\hat{z},\widehat{P}_{hT})\right]$$

Only **collinear** QED effects are needed

We used simple Gaussian TMDs

In principle LDFs and LFFs have TMD d.o.f.

However, they peak at *kT*=0!

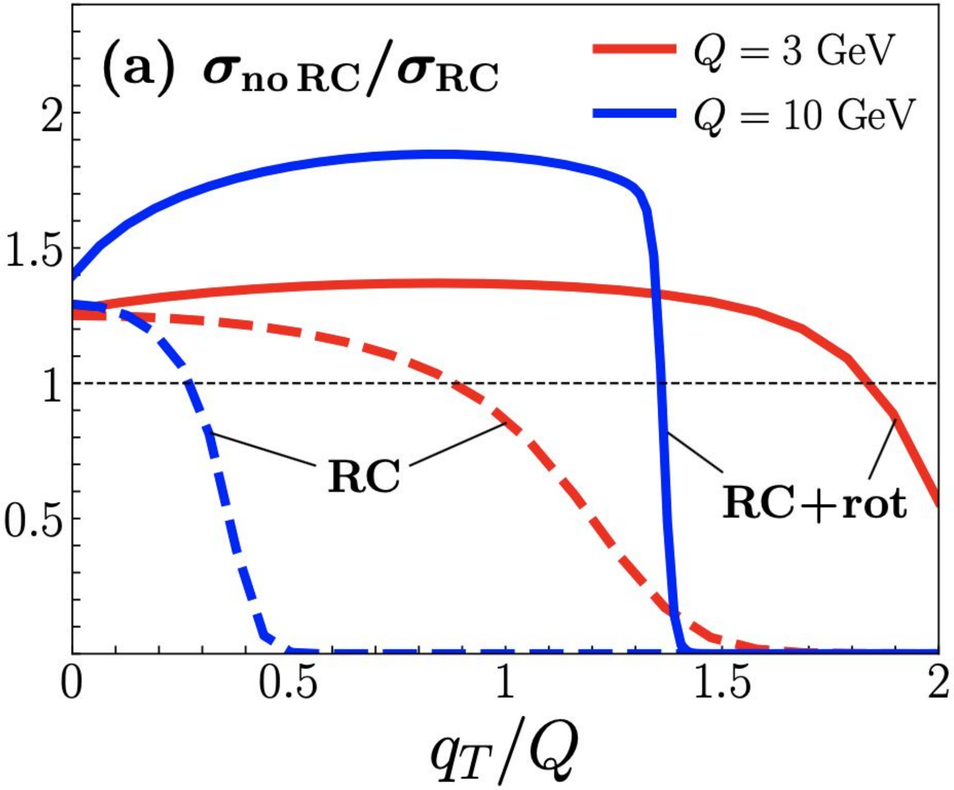
Hadron *pT* in the Breit frame **includes QED effects**

QED effects in SIDIS

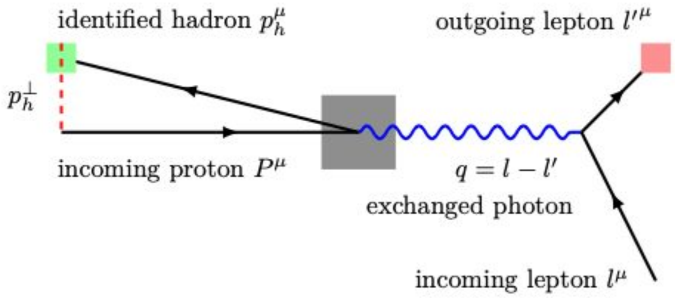
https://arxiv.org/abs/2008.02895

Liu, Melnitchouk, Qiu, NS

EIC



Significant **rotational effect** due to collinear QED radiation

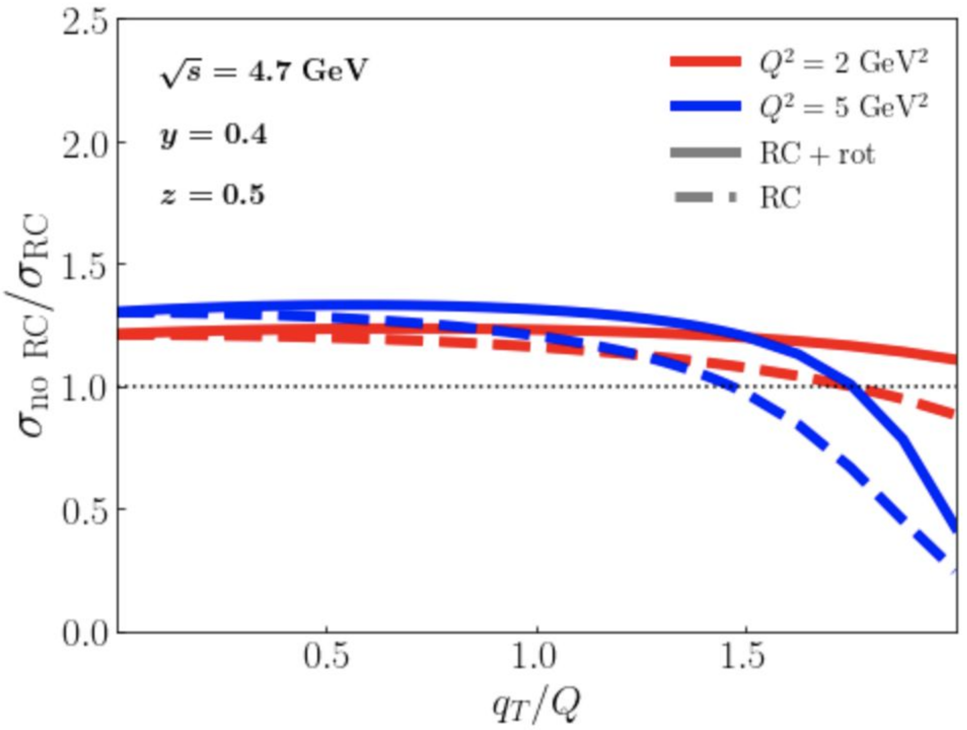


QED effects in SIDIS

https://arxiv.org/abs/2008.02895

Liu, Melnitchouk, Qiu, NS

JLab



For lower root s, **QED effects are moderate**

Summary & outlook

- Precision in **low-Q and high-x region** is essential for spin physics

- Since we supervise on cross sections and not on parton d.o.f., complementarity is essential

- QED effects are increasingly important at large root S --> lower root S **is needed for cross checks**

Accuracy vs Precision
in inverse problems