TMD factorization at next-to-leading power

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In collaboration with Alexey Vladimirov

Based on:

SR, A. Vladimirov JHEP 08 (2022) 031, JHEP 09 (2023) 117, 2306.09495

SR, B. Pasquini, A.C. Alvaro PLB 845 (2023) 138163

Limitations of leading-power approach

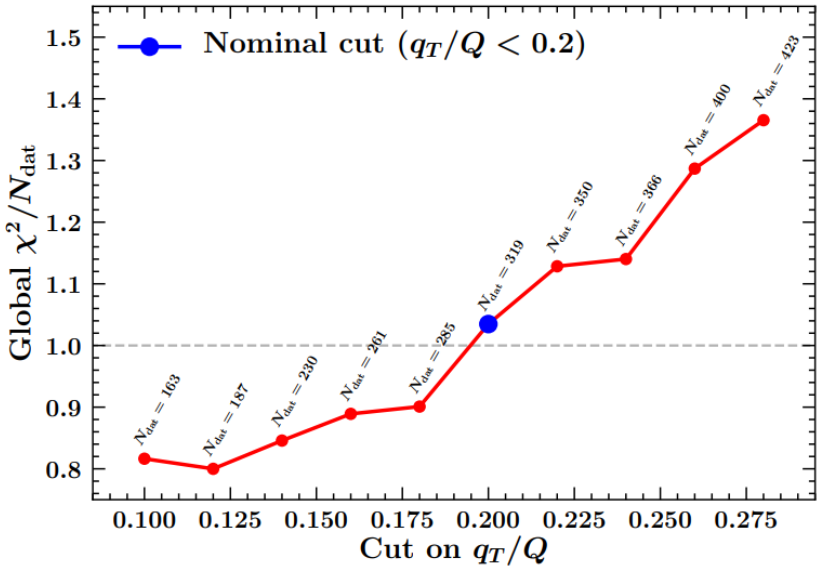
New phenomena at next-to-leading power

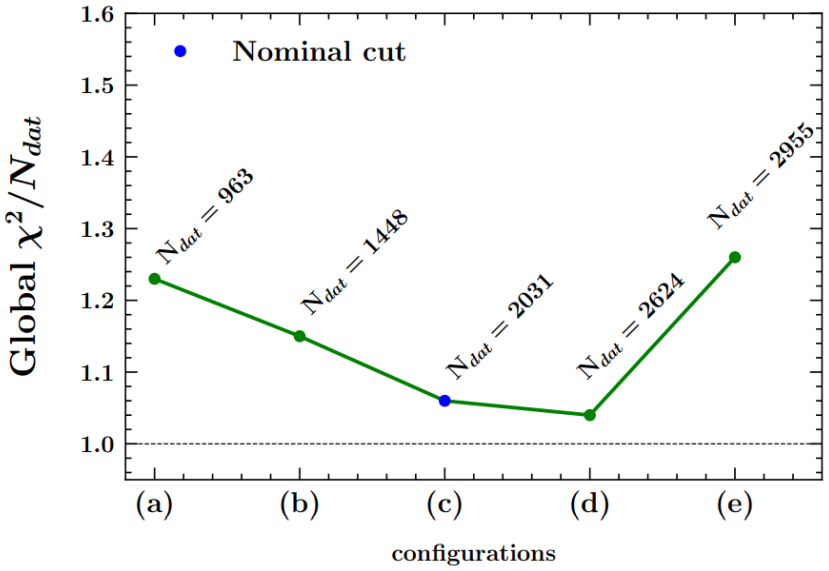
Complex coefficient function

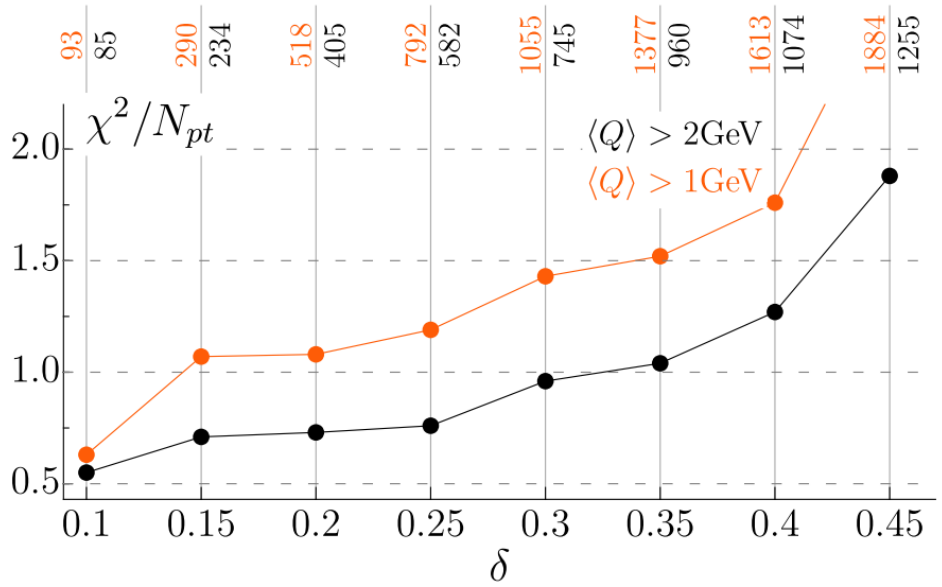
Complex TMDs

Special rapidity divergences

Leading power factorization has problems







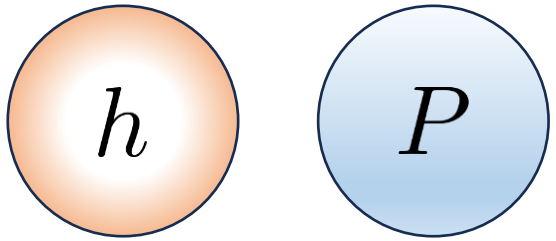
$$\delta = \frac{q_T}{Q} \lesssim 0.25$$

Images courtesy of Scimemi, Vladimirov, JHEP 06 (2020) 137

MAP-coll., JHEP 10 (2022) 127 Bacchetta et al., JHEP 07 (2020) 117

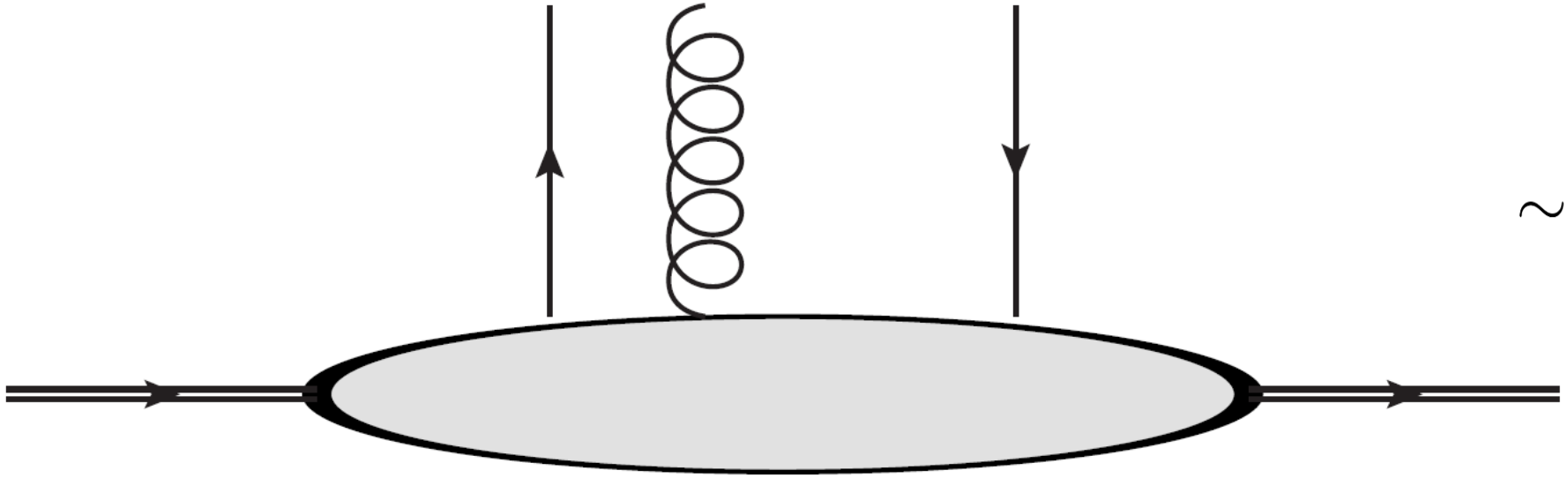
What are the assumptions of LP factorization?

Massless



~ 0

$$\frac{q_T}{Q}, \frac{k_T}{Q} \sim 0$$



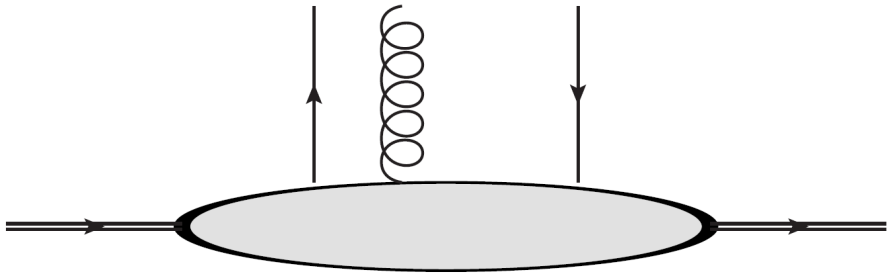
~ 0

Extension to next-to-leading power

Massless

Assume h P ~ 0

Include kinematic and genuine corrections



$$\frac{k_T}{Q}$$

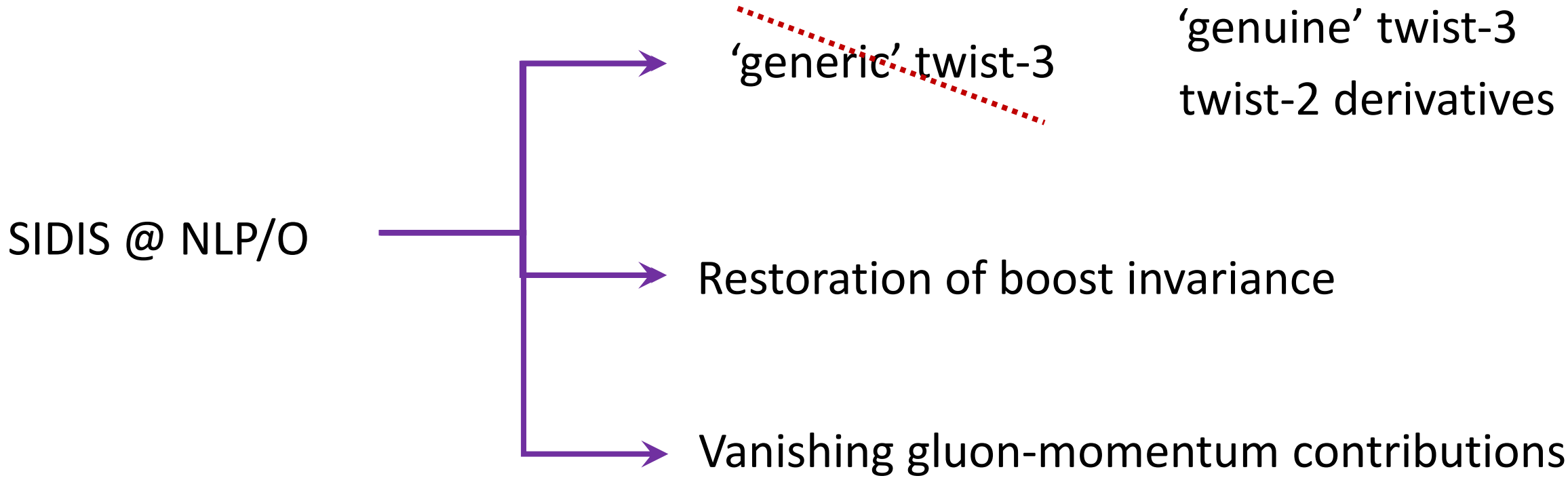
Complete tower

Vladimirov, 2307.13054

Beyond Leading Power

one cannot assume

strictly positive parton's momenta

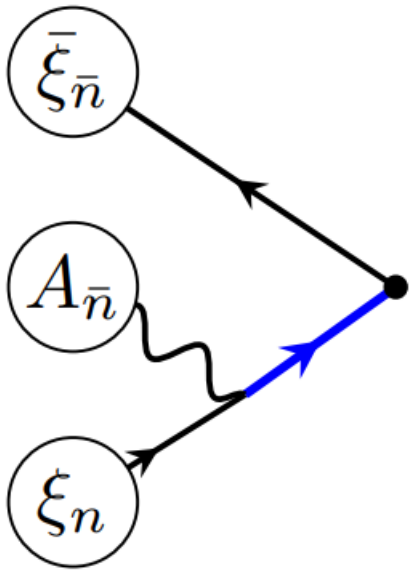


New phenomenon #1: complex coefficient functions

Imaginary part starts at LO(!) $\propto \delta(x_{\text{gluon}})$

Qiu-Sterman-like contributions

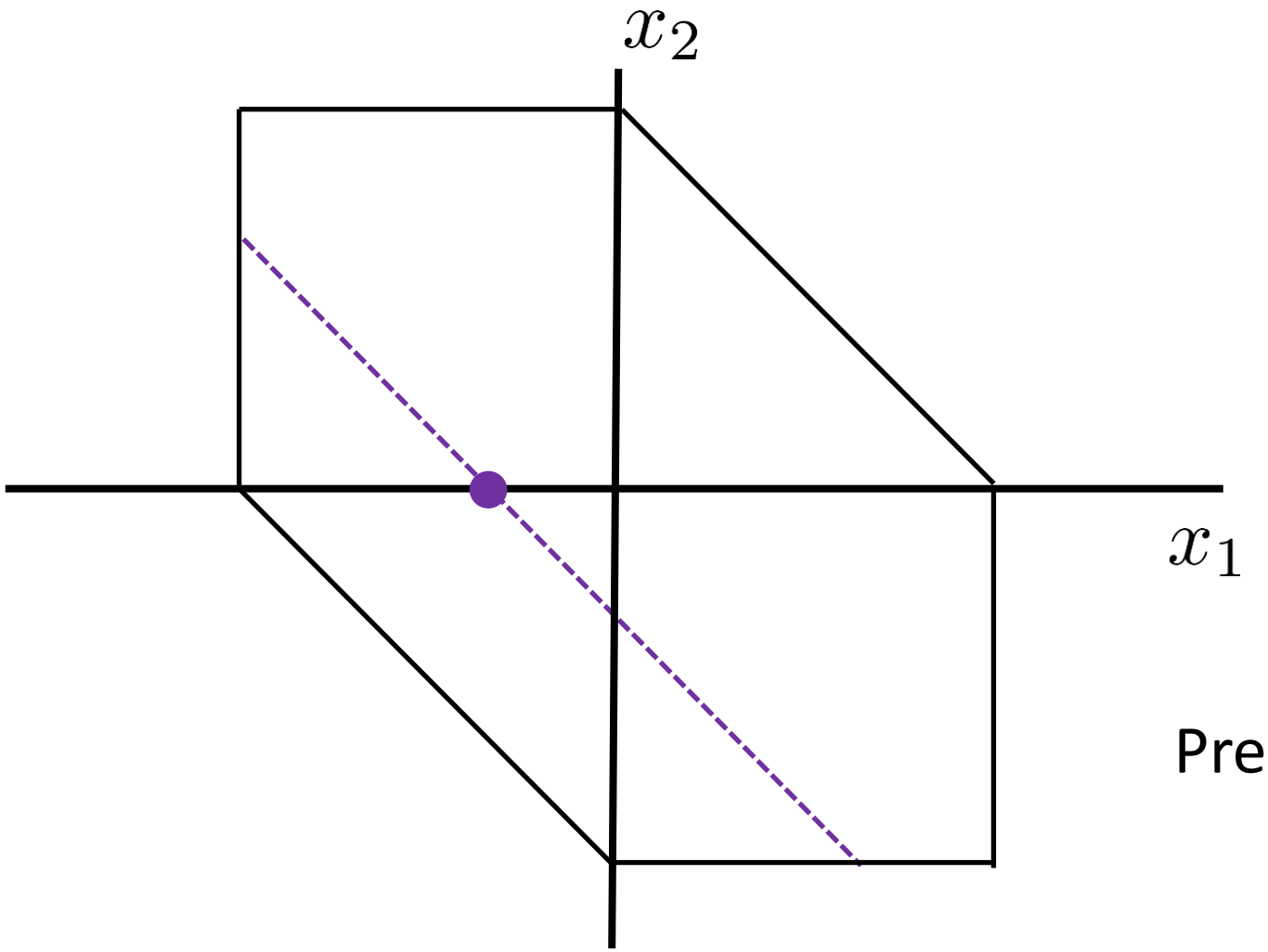
Why does this happen?



$$\bar{q}F^{\mu+}q$$

$$\frac{1}{x_{\text{gluon}} \pm i0}$$

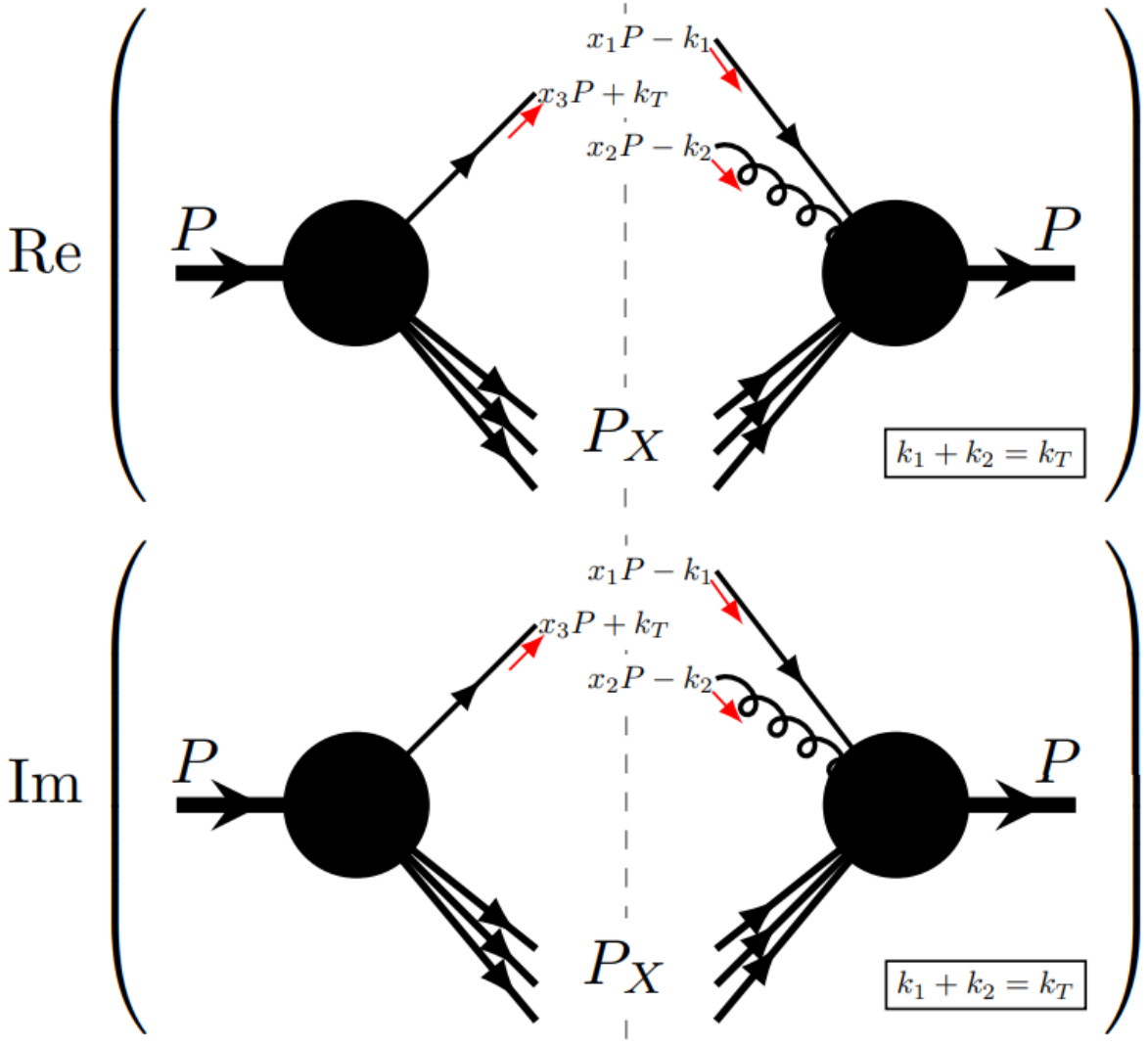
Characteristic of TMD PDFs $\Delta(z_1, 0, z_3) = 0$

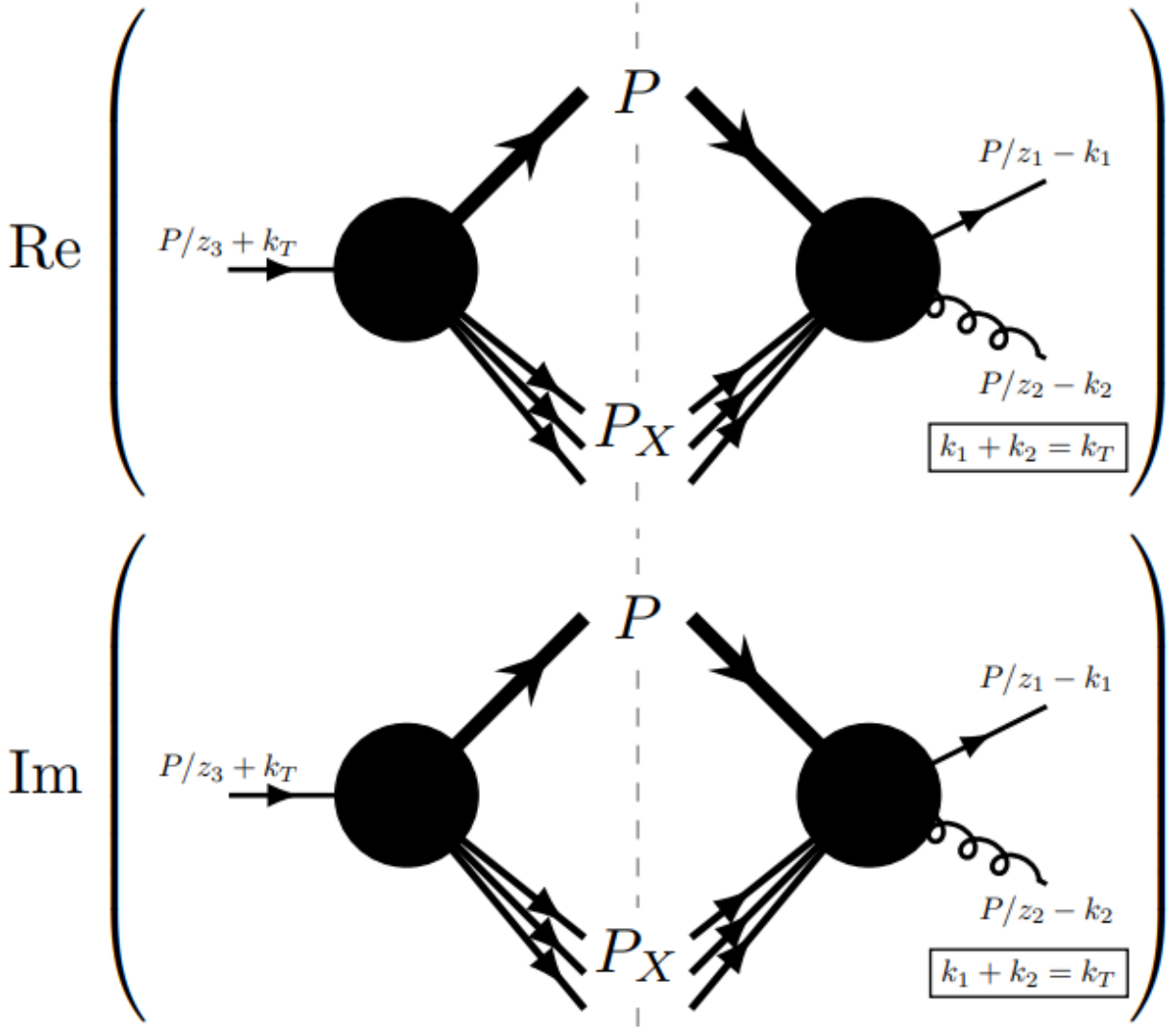


Not stable under evolution

Present in all NLP coefficient functions

New phenomenon #2: complex TMDs





How important these effects are?

From small-b matching of TMDs ~ T(-x,0,x) ~ Sivers function

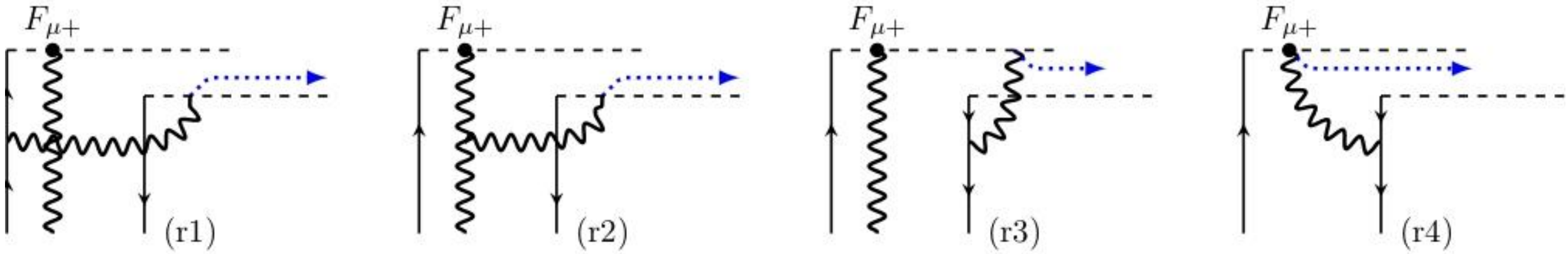
$$F_{UU}^{\cos\phi}\big|_{\text{QS-like}} \gtrsim \frac{2M}{Q} F_{UU}^{\cos 2\phi}$$

Enhanced in Bessel convolution

Small-b matching of TMDs useful

At tree-level only 7 out of 16 At one-loop only 8 have singular part $\frac{1}{b^2}$

New phenomenon #3: ‘special’ rapidity divergences



$$d\sigma_{LP} \sim D_1 \otimes \partial_T f_1$$

$$\partial_T \to \partial_T - \partial_T \mathcal{D} \log\left(\frac{\sqrt{\zeta}}{\sqrt{\bar{\zeta}}}\right) \qquad \zeta\bar{\zeta} = \left(Q^2 - q_T^2\right)^2$$

Complex coefficient function

Complex TMDs

$$F_{UU}^{\cos\phi}\big|_{\text{QS-like}} \gtrsim \frac{2M}{Q} F_{UU}^{\cos 2\phi}$$

Special rapidity divergences

$$\partial_T \to \partial_T - \partial_T \mathcal{D} \log\left(\frac{\sqrt{\zeta}}{\sqrt{\bar{\zeta}}}\right)$$

Both effects comes from vanishing gluon momentum