Transverse Momentum Distributions

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If you are curious:

TMD handbook: 2304.03302

Vladimirov et al: JHEP 01 (2022) 110

Moos et al: 2305.07473

MAP-collaboration: JHEP 10 (2022) 127

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Outline

Transverse-momentum dependent distributions
Why? What? How?

Why going to next-to-leading power?

Why we need TMD distributions?

Allow for more information on the internal structure of the proton

Spin-orbit correlations between proton spin and parton's transverse momentum

⇔

Sivers distribution

They enters the description of measured physical processes

Their scaling properties are related to the structure of QCD vacuum

Drell-Yan

proton, proton → lepton, lepton, X

SIDIS

proton, lepton → lepton, H, X

Can be accessed partially from lattice calculations

Why we need TMD distributions?

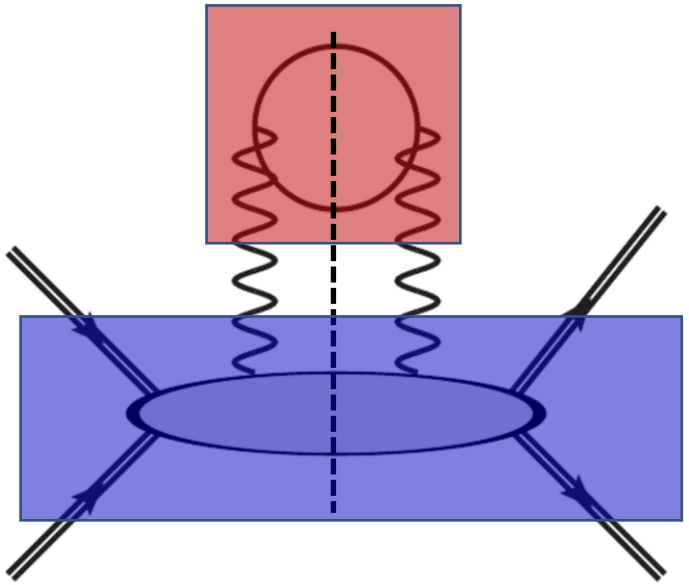
The language

Hadronic tensor

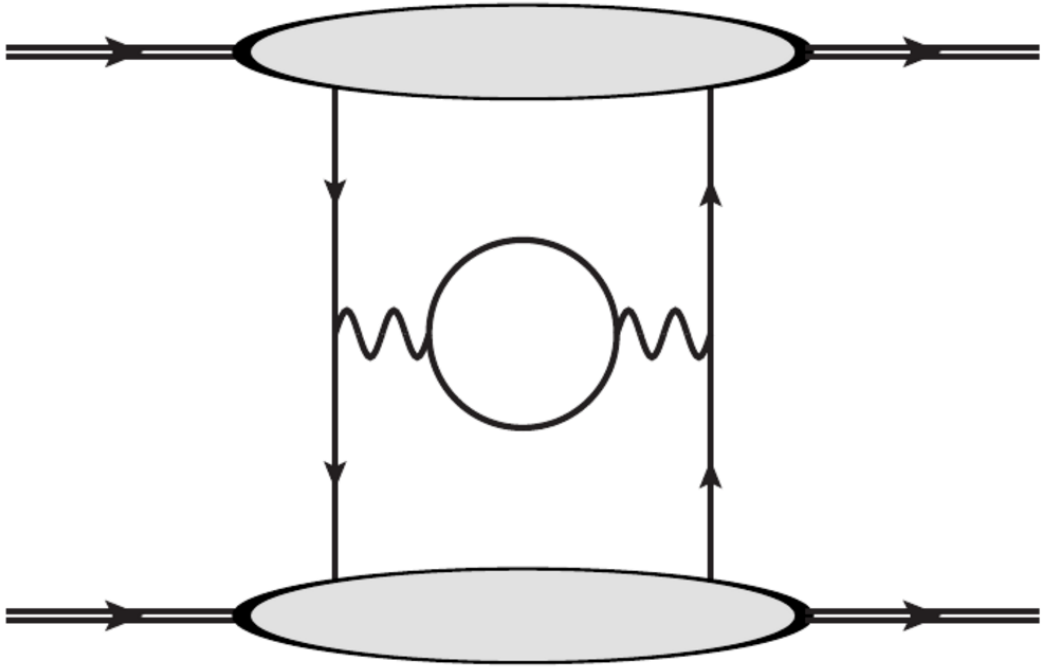
$$H^{\mu\nu} = \sum_X \langle p_1, p_2 | J^\mu(y) | X \rangle \langle X | J^\nu(0) | p_1, p_2 \rangle$$

TMD distributions

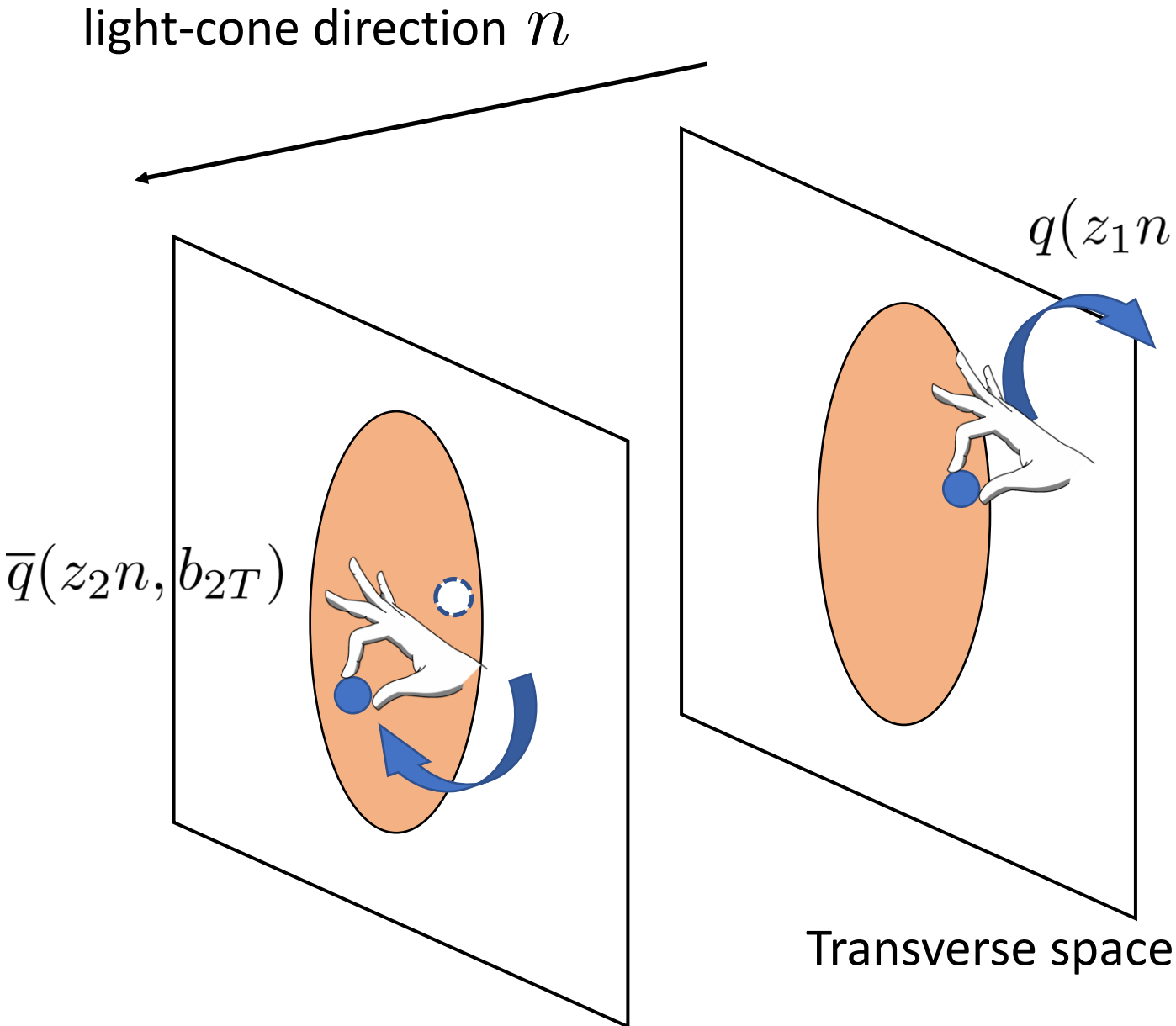
Leptonic tensor $L^{\mu\nu}$



Leading-power factorization



What are TMD distributions?



$$\mathrm{Tr}\left[\Gamma\Phi(z_2, z_1, b)\right] = \langle P|\bar{q}(z_2 n + b)\Gamma q(z_1 n + b)|P\rangle$$

$$\Phi(x, b) = \int \frac{dz}{\pi} e^{-i2xz(Pn)}\Phi(z, -z, b)$$

A bit more formally

$$\mathrm{Tr}\left[\Phi(x,b)\Gamma\right]$$

$$\Gamma \in \{\gamma^+, \gamma^+\gamma_5, i\sigma^{\alpha+}\gamma_5\}$$

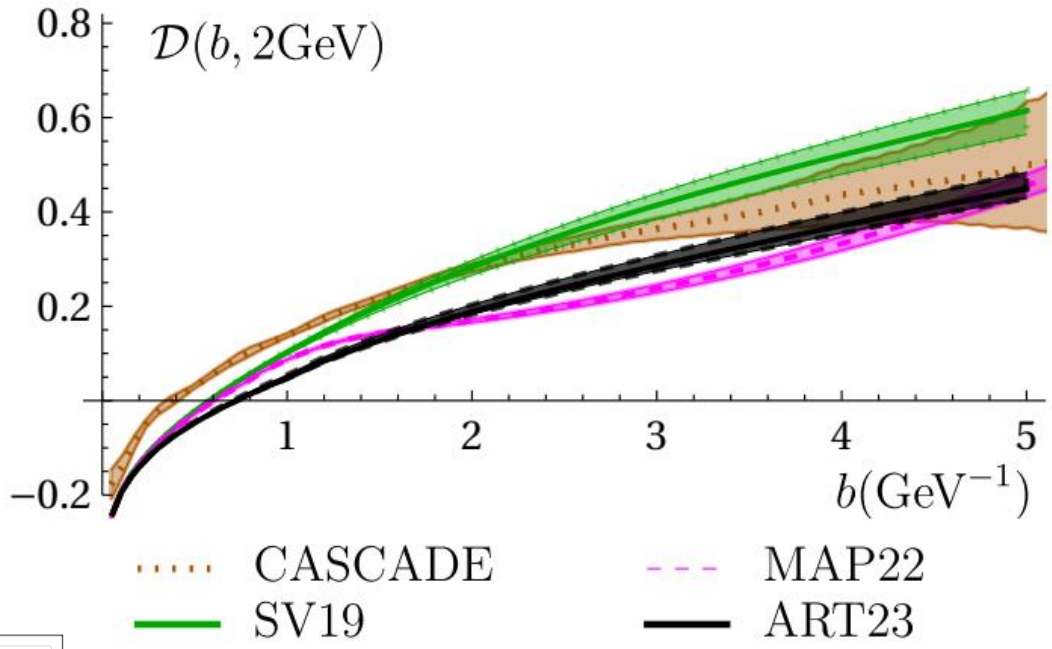
	U	H	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

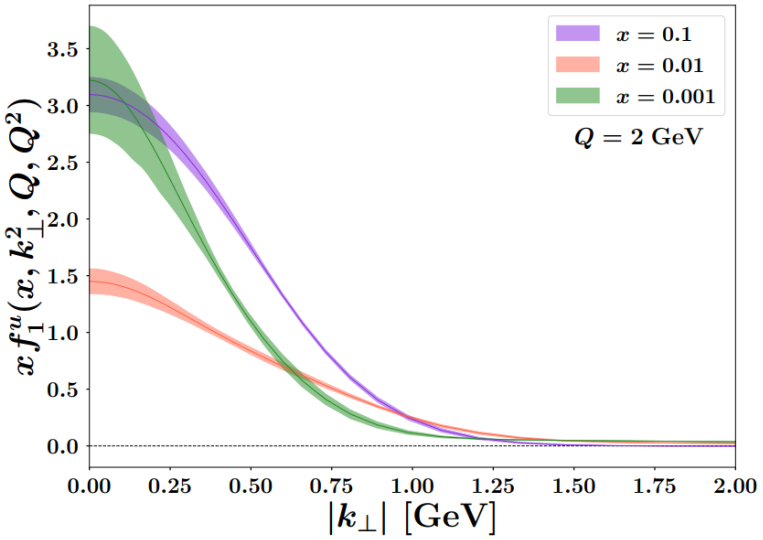
Well-defined (they have close evolution equations)

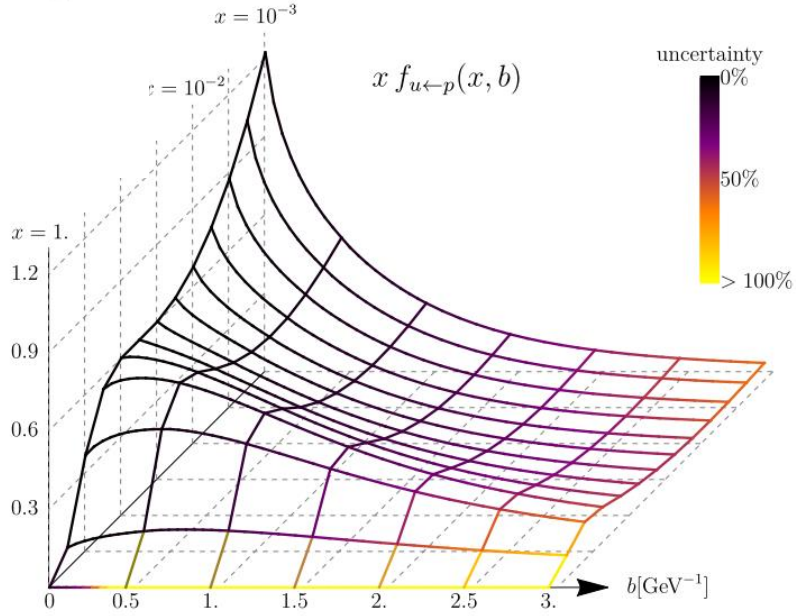
Two-scale problem: UV and rapidity $\quad \zeta\frac{\partial}{\partial\zeta}\Phi(x,b) = -\mathcal{D}(b)\Phi(x,b)$

(For all other possible choices of Gamma this is not true anymore)

A bit more formally







MAP-collaboration: JHEP 10 (2022) 127

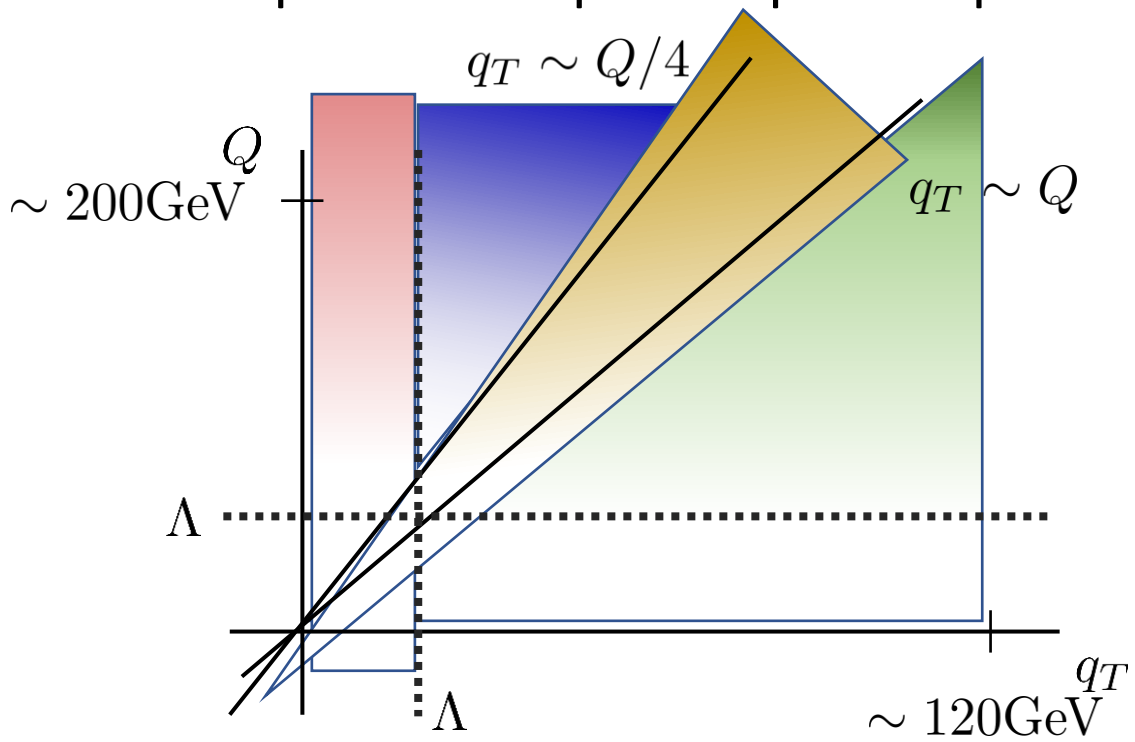
Moos et al: 2305.07473

Is this the end of the story?

The measurement has to be differential in a ‘transverse’ variable

For DY the transverse component of the virtual photon respect to the proton-proton plane

For SIDIS the transverse component of the produced hadron respect to the proton-photon plane



Need to select the appropriate kinematic region

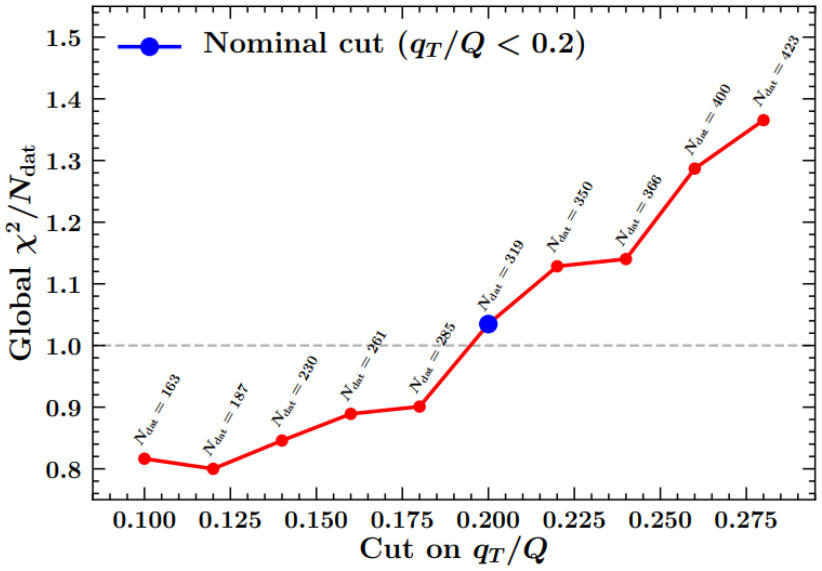
Fixed order

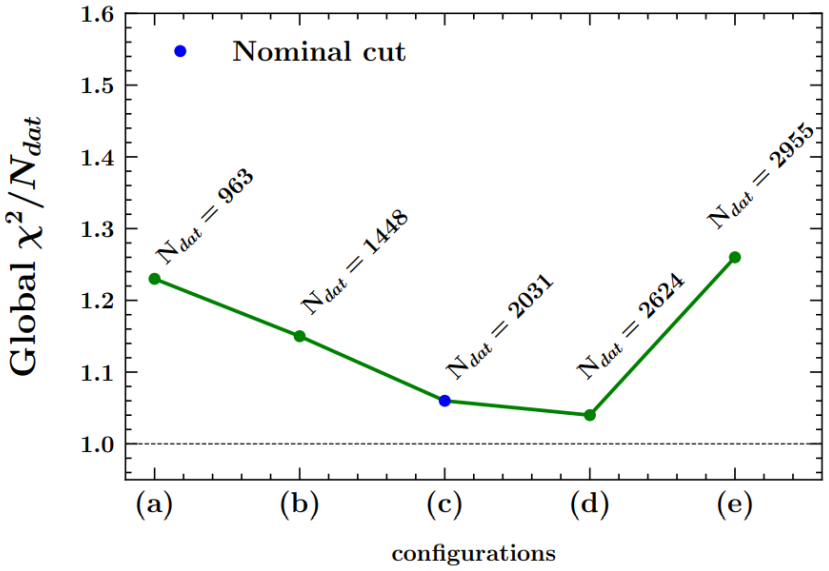
Non-perturbative TMD

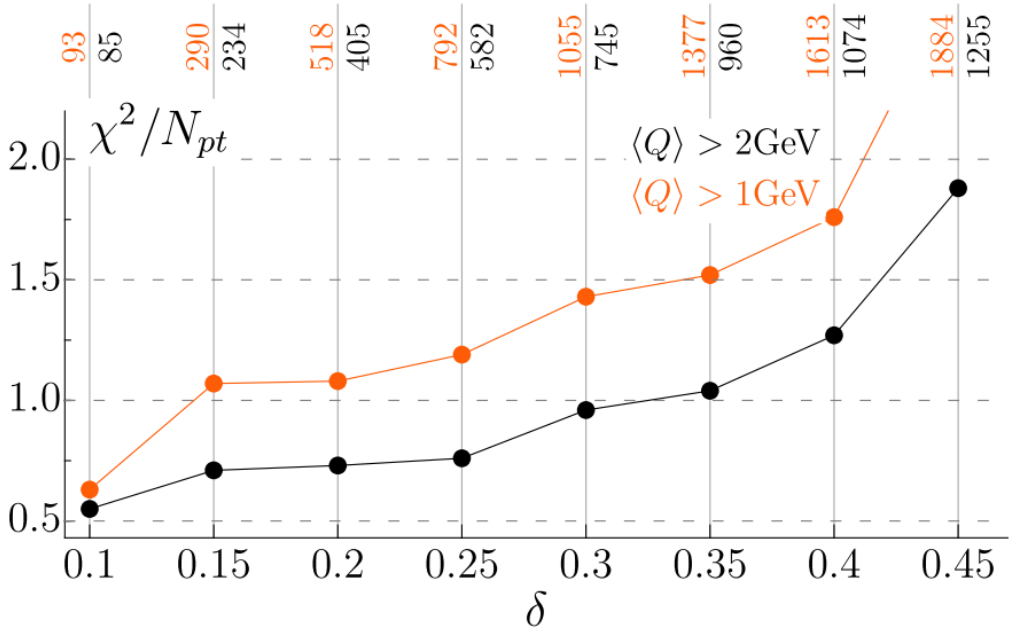
Resummation

Next-to-leading power

No







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

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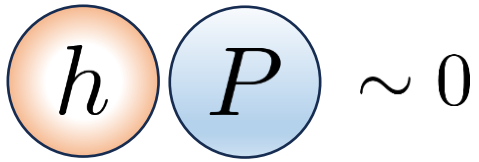
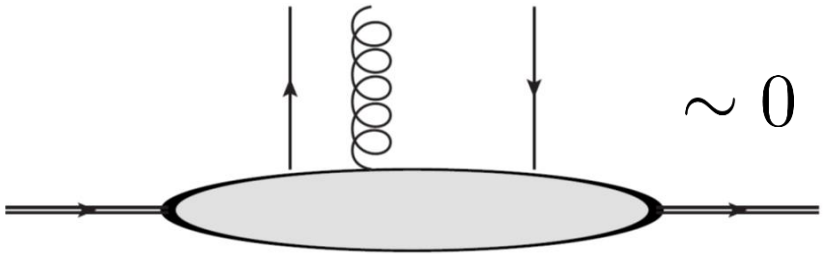
Effort to push beyond leading-power

At leading-power

Massless

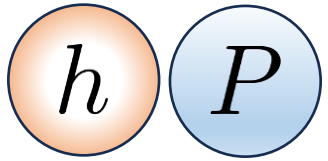


$$\frac{q_T}{Q}, \frac{k_T}{Q} \sim 0$$

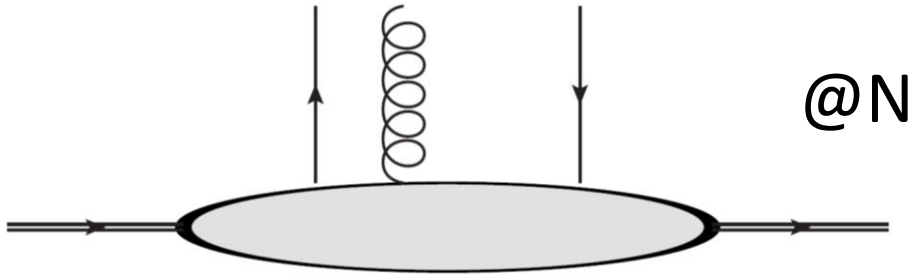


Beyond LP, state of the art:

Massless



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



@NLO

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

Complete tower

Vladimirov, 2307.13054