SnowMass 2021, January 26th

Proton structure at the precision frontier: Transverse-momentum-dependent parton distribution functions

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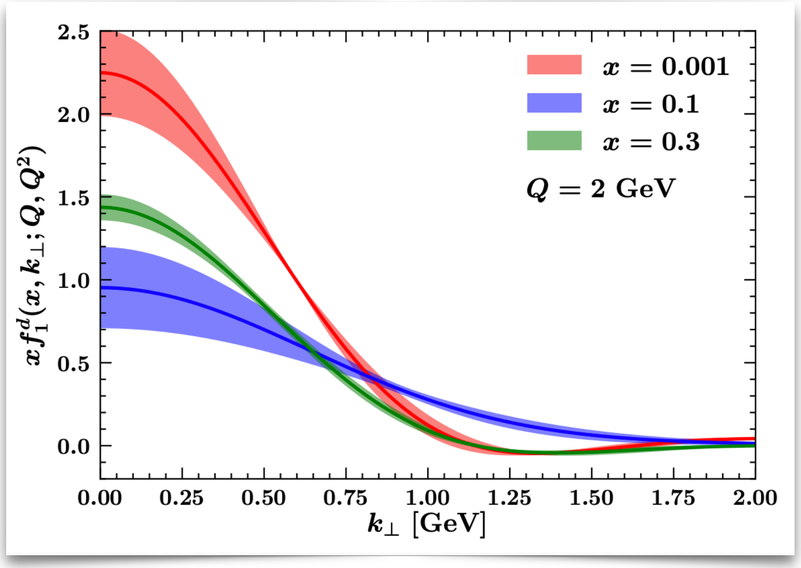
3D proton tomography via TMD quark distributions

* N^{3}LL extraction of f_1 [DY]

  🔗 [A. Bacchetta *et al.* (2020)]



$$\chi^2/N_{\text{dat}} = 1.02$$

353 points

w/o *ad hoc* normalization

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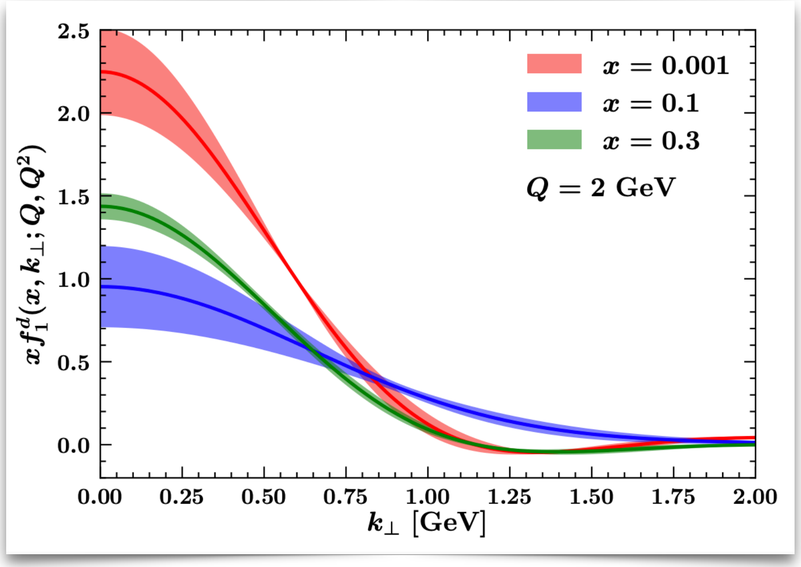

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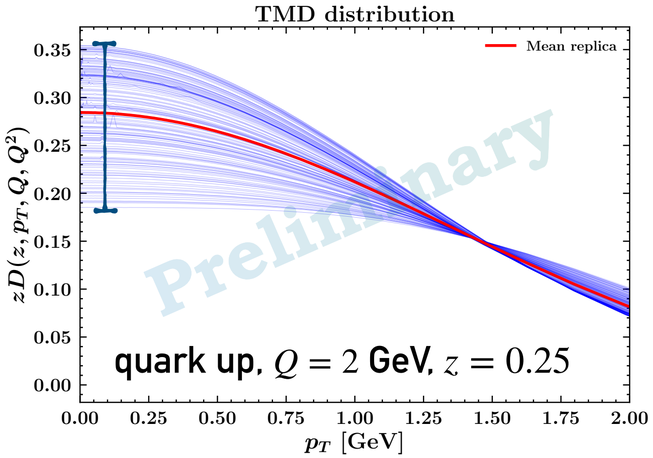
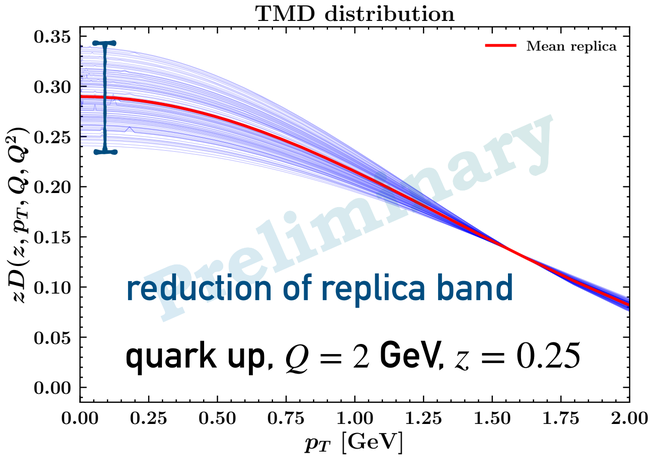
* **EIC** impact on TMD FFs

PV17 baseline



PV17baseline + EIC



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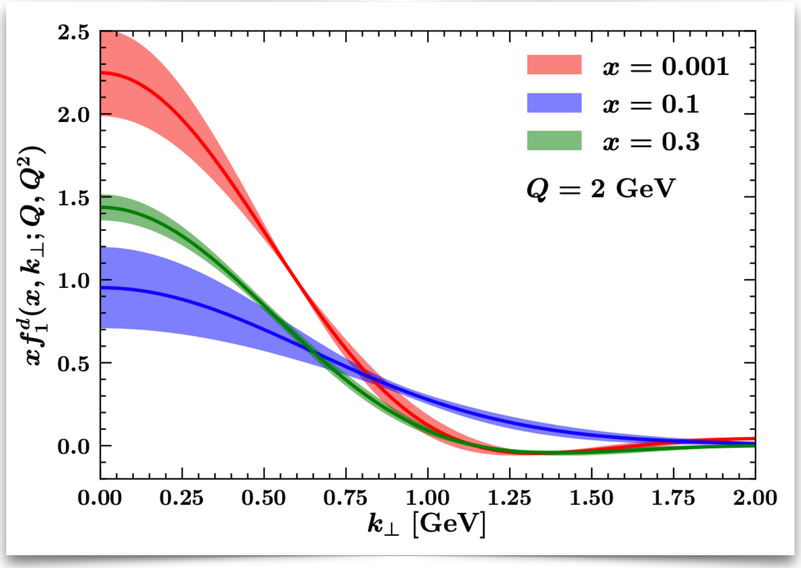

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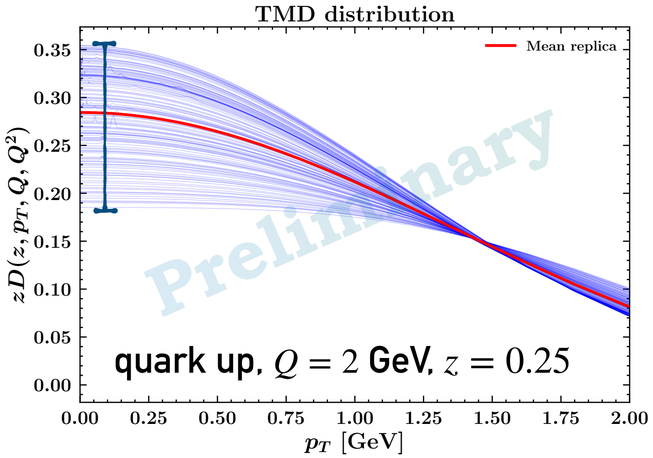

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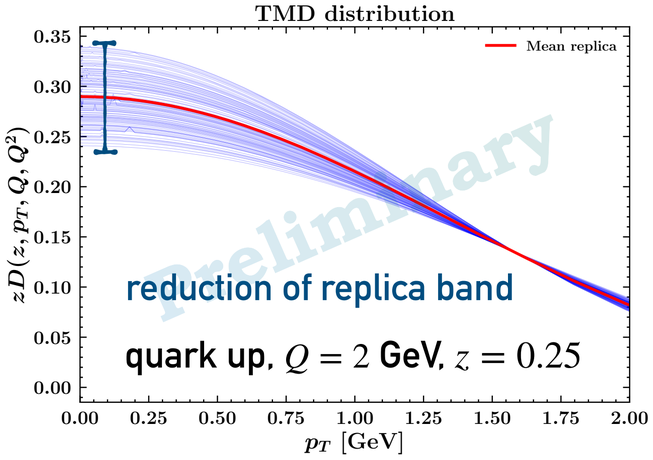

* NLL Sivers effect from SIDIS

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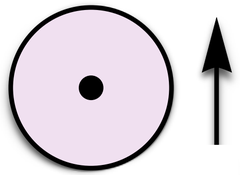

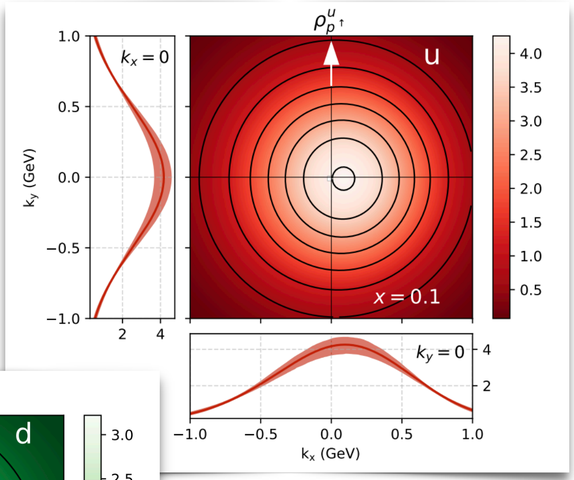

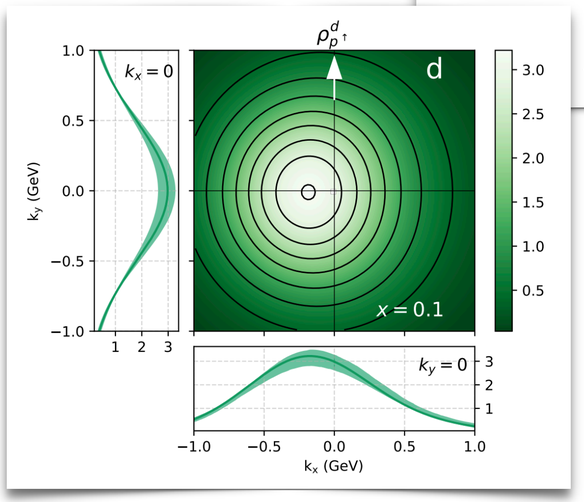

Quark contribution to nucleon spin

Different distortion: u and d quarks

3D proton tomography via TMD gluon distributions

* Unpolarized gluon TMD

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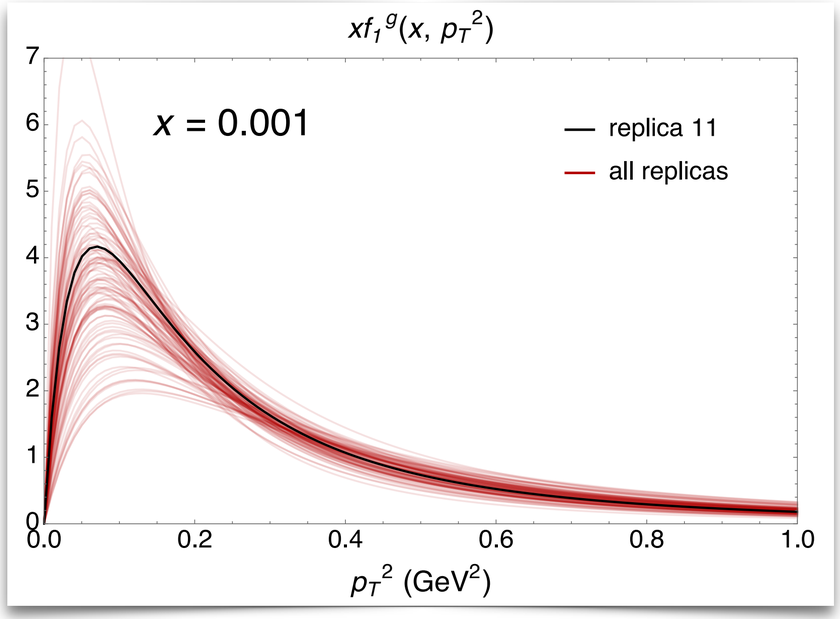

Spectator-model calculation

Standard CSS evolution

Link with collinear factorization

TMD replicas to constrain coll. PDFs

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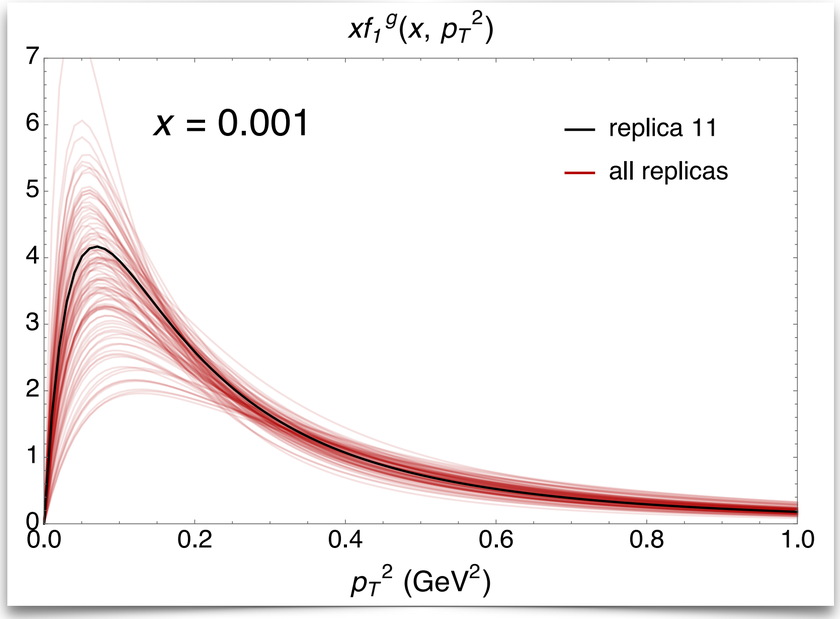

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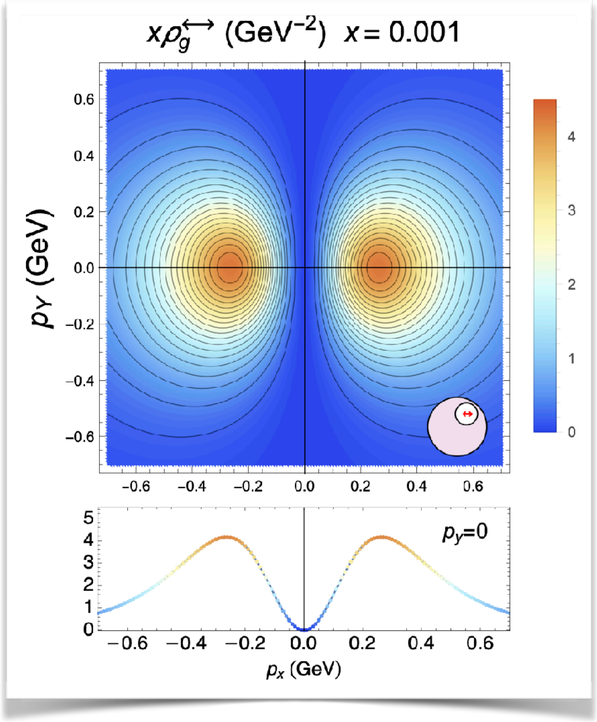

Intrinsic gluon pol. in *pp*

$$\frac{f_1^g(x,p_T^2)}{h_1^{\perp g}(x,p_T^2)} \underset{x\to 0^+}{\sim} \text{constant}$$

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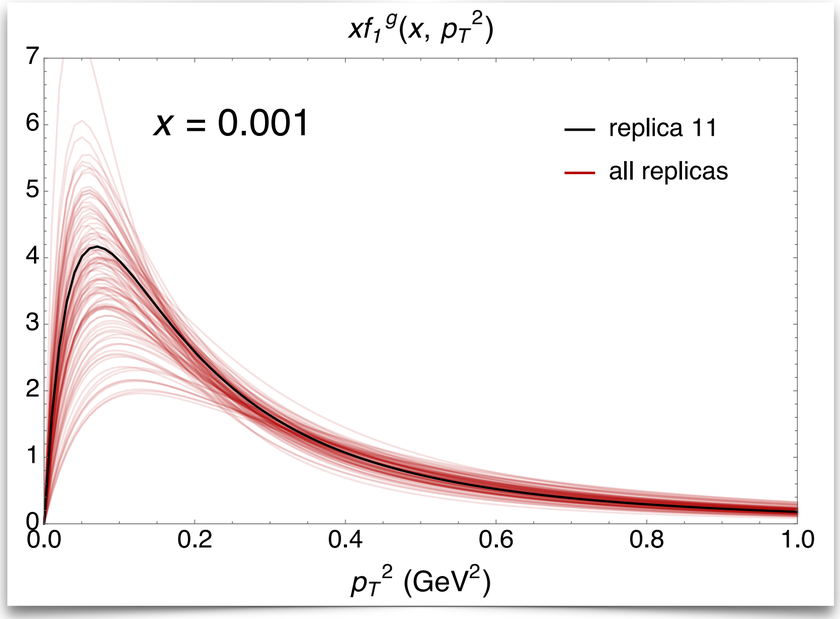

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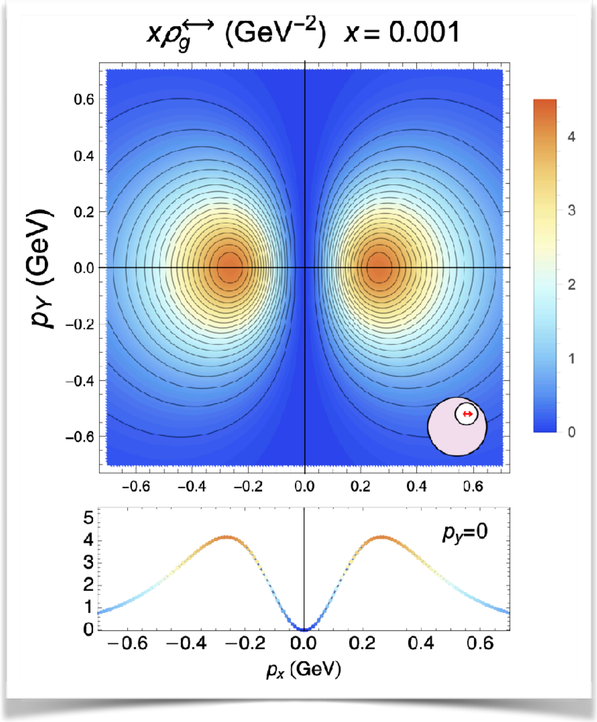

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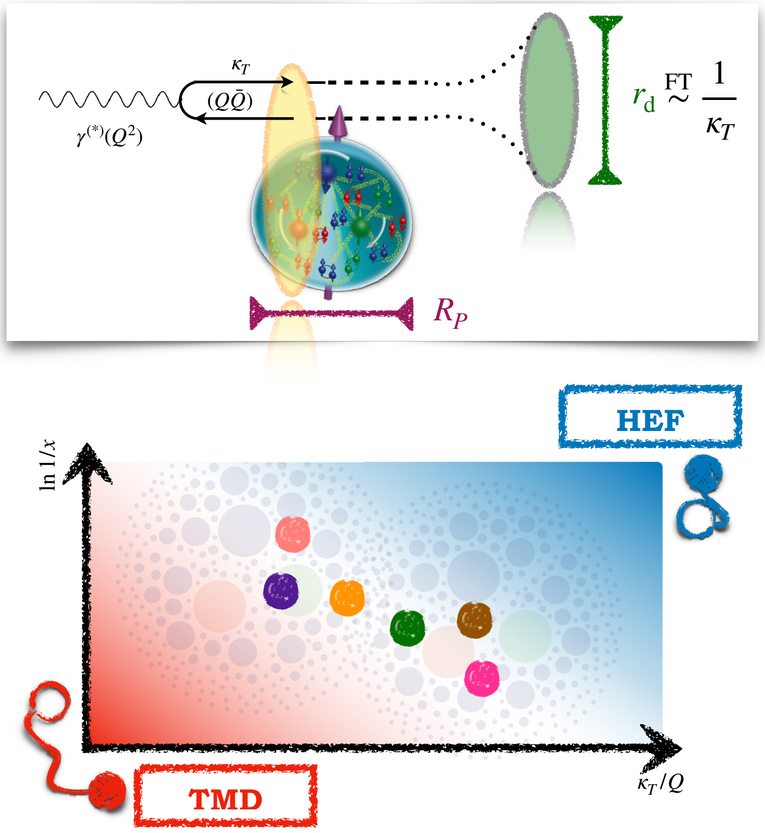
* 3D tomography at low x



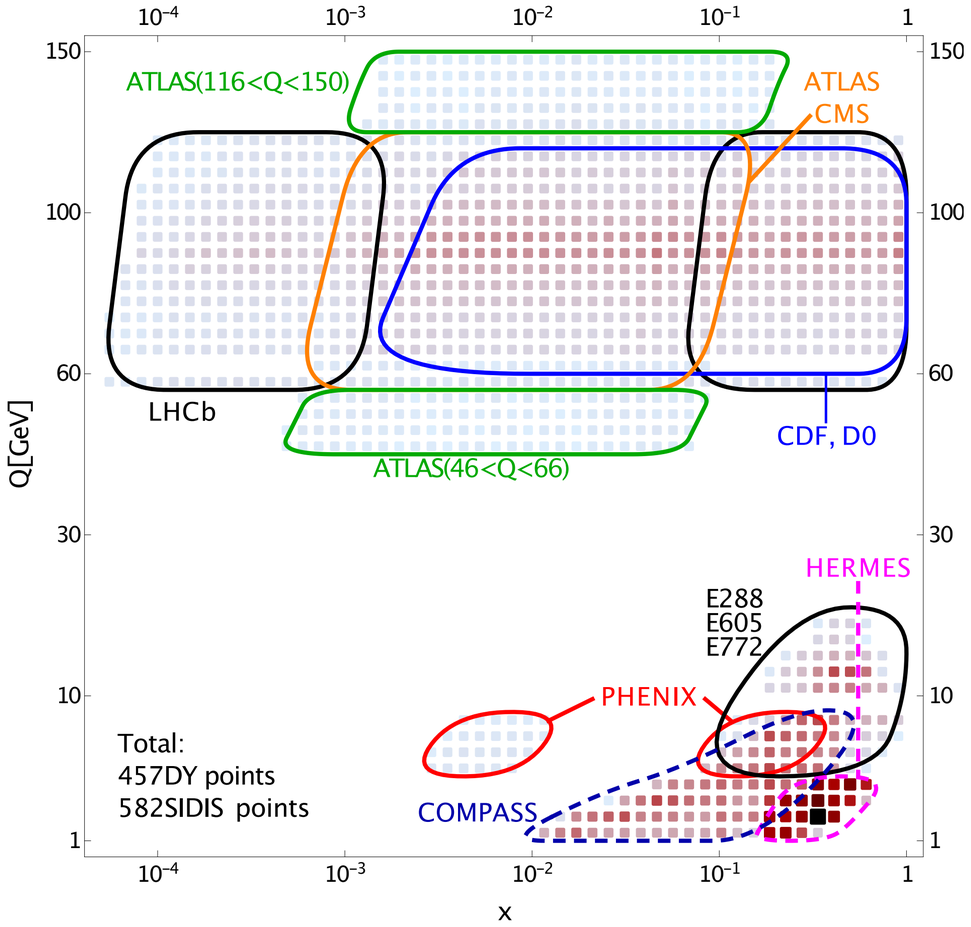
HEF → linear low-x evolution

$$f_1^g(x,p_T^2) = h_1^{\perp g}(x,p_T^2) + \text{higher twist}$$

Experimental prospects

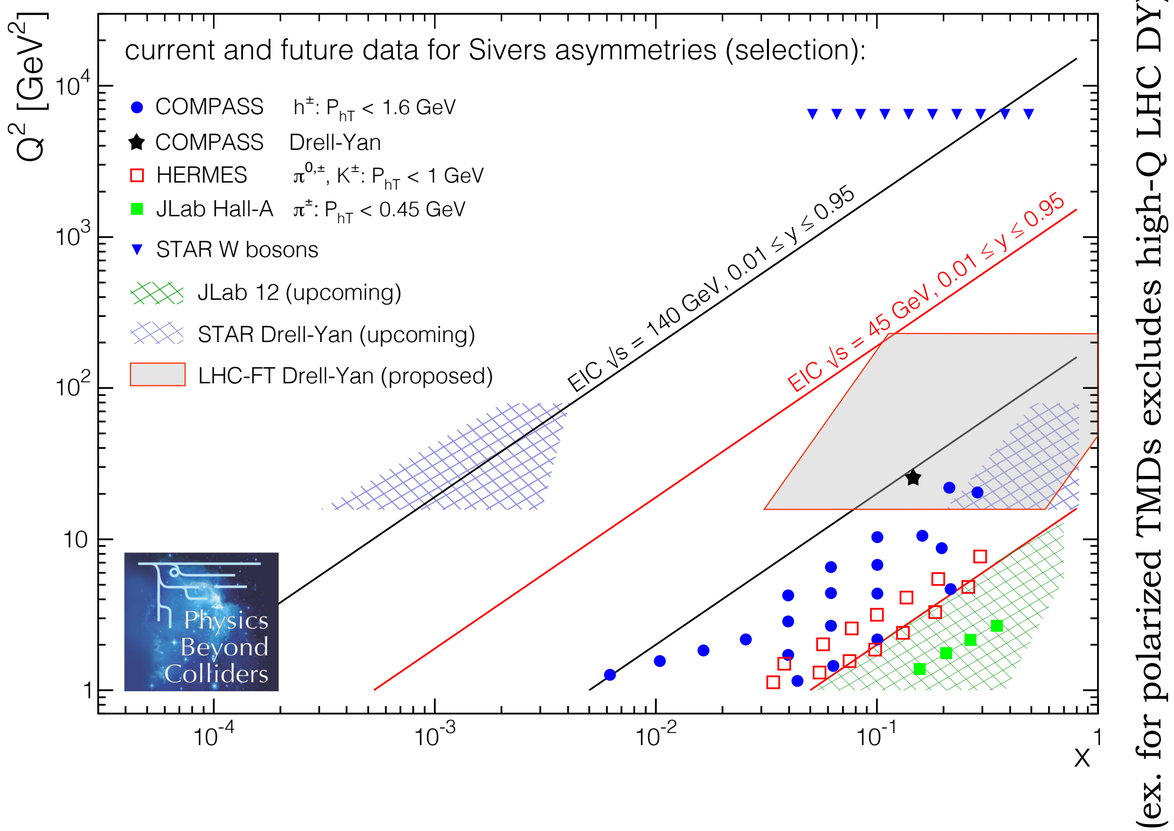
* Unpolarized TMDs exp. landscape

[I. Scimemi & A. Vladimirov JHEP06(2020)137]



* Future data from colliders (EIC, LHC, SuperKEKB) and fixed-target exp. (JLab12, Fermilab, LHC-FT,...)

[A. Dainese et al., arXiv:1901.04482]



EIC but also DY and JLab12 data will contribute substantially and fill current phase-space holes

Perturbative Regime of TMDPDFs

TMDPDFs can be OPEd onto collinear PDFs for $q_T \gg \Lambda_{\rm QCD}$

$$\underbrace{B_i(x,q_T)}_{\text{TMDPDF}} \sim \sum_j \underbrace{\mathcal{I}_{ij}(x,q_T)}_{\text{Matching Kernel}} \otimes_x \underbrace{f_j(x)}_{\text{PDF}} + \mathcal{O}(\Lambda_{\rm QCD}/q_T)$$

Matching kernels calculated in fixed order perturbation theory

State of the art is N3LO for quark and unpolarized gluon TMDs

[Luo, Yang, Zhu, Zhu 1912.05778]
[Ebert, Mistlberger, Vita 2006.05329]

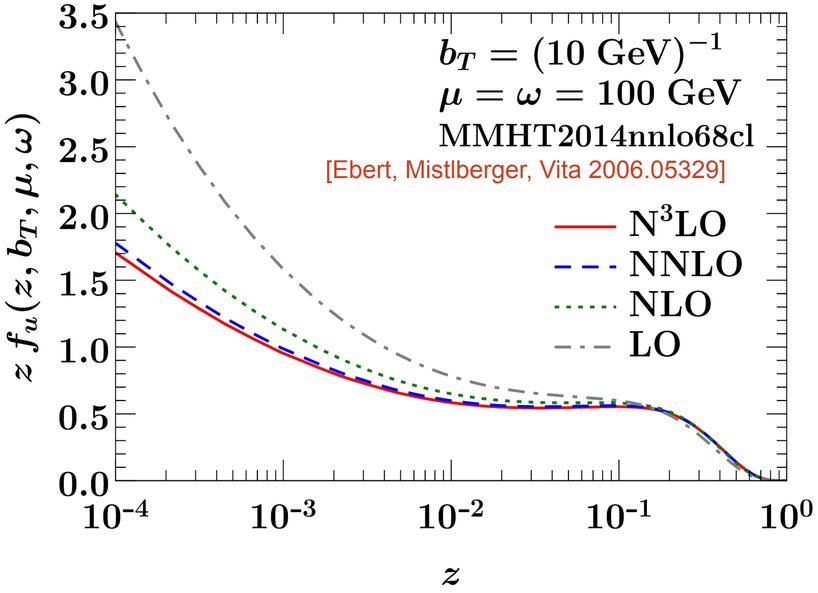
Evolution dictated by 2-d RGE

(due to rapidity divergences)

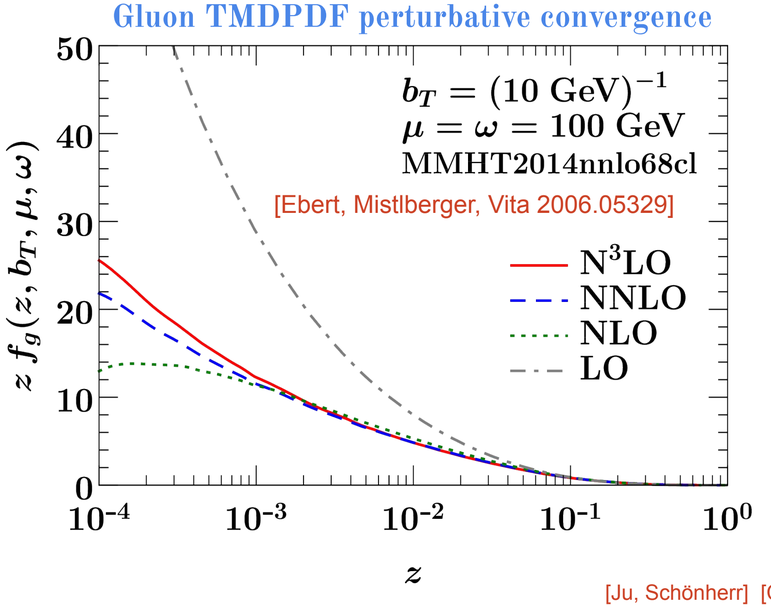
$$\mu\frac{\mathrm{d}}{\mathrm{d}\mu}\tilde{B}_i(x,b_T,\mu,\nu/\omega) = \tilde{\gamma}^i_B(\mu,\nu/\omega)\,\tilde{B}_i(x,b_T,\mu,\nu/\omega)\,,$$
$$\nu\frac{\mathrm{d}}{\mathrm{d}\nu}\tilde{B}_i(x,b_T,\mu,\nu/\omega) = -\frac{1}{2}\tilde{\gamma}^i_\nu(b_T,\mu)\,\tilde{B}_i(x,b_T,\mu,\nu/\omega)$$

Rapidity anomalous dimension/Collins-Soper kernel
(known at N3LO [Li, Zhu 1604.01404])

Up quark TMDPDF perturbative convergence



Gluon TMDPDF perturbative convergence



[Ju, Schönherr] [Camarda, Cieri, Ferrera] [Neumann]

- Enables N3LL' resummation for qT, N3LO differential predictions for Higgs/DY at LHC via qT subtraction, extraction at full N3LL' [Re, Rottoli, Torrielli] [Chen, Gehrmann, Glover, Huss, Yang, Zhu]
- Inclusion of N3LO matching has **large impact** on reduction of uncertainties in fiducial N3LO + N3LL' Higgs qT analysis [Billis et al. 2102.08039]