# Proton 3D tomography at the EIC
# TMD gluon distributions

**Electron-Ion Collider @ Snowmass**


## Francesco Giovanni Celiberto

for the **HAS QCD PAVIA Group**

Università degli Studi di Pavia & INFN


HAS QCD
HADRONIC STRUCTURE AND QUANTUM CHROMODYNAMICS

3DSPIN
MAPPING THE PROTON IN 3D

INFN
Istituto Nazionale di Fisica Nucleare
Sezione di Pavia

UNIVERSITÀ DI PAVIA

# Gluon TMDs: a largely unexplored territory

* ***Theory***: different **gauge-link** structures…

  …more diversified kind of **modified universality**!

* ***Pheno***: golden channels for extraction of quark TMDs

  are subleading for gluon TMDs

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* Gluon-TMD PDFs: *core* sector of **EIC** studies
* Need for a *flexible* model, suited to *pheno*
* **Unpolarized** and **polarized gluon TMDs**
* *Consistent* framework for quark TMDs

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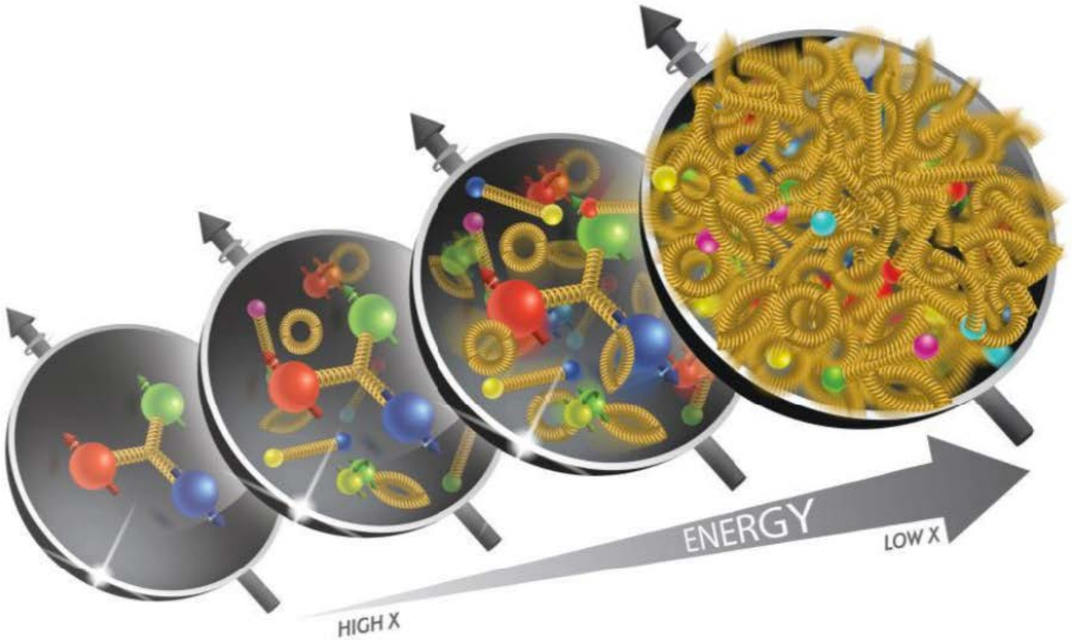


Significance of gluon-TMD studies
in a wide range of $x$

# *T*-even and *T*-odd gluon TMDs at twist-2

| nucleon pol. \ gluon pol. | U | circ. | lin. | |
|---|---|---|---|---|
| U | $f_1^g$ | | $h_1^{\perp g}$ | *T*-even |
| L | | $g_1^g$ | $h_{1L}^{\perp g}$ | |
| T | $f_{1T}^{\perp g}$ | $g_{1T}^g$ | $h_1^g,\ h_{1T}^{\perp g}$ | *T*-odd |

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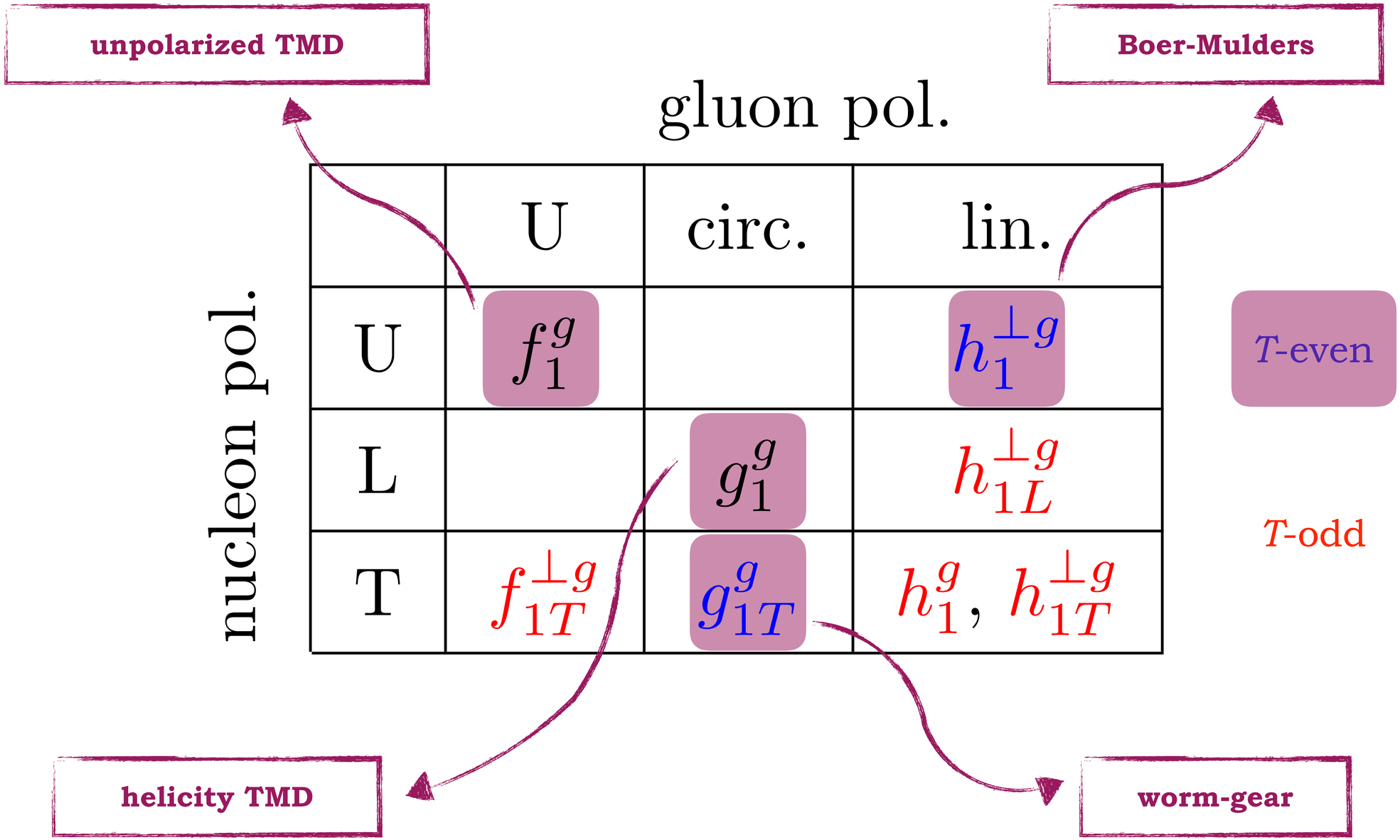

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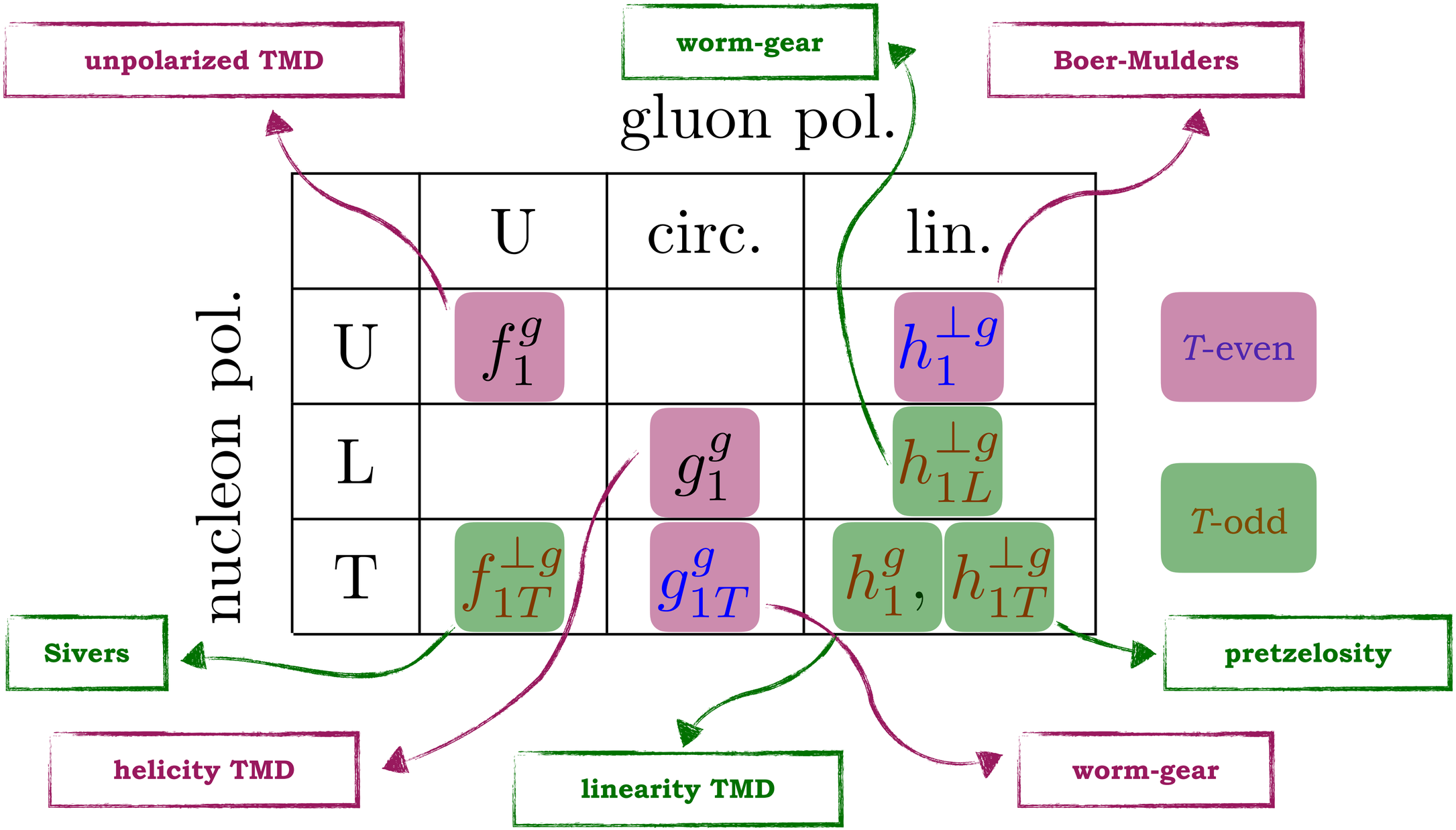
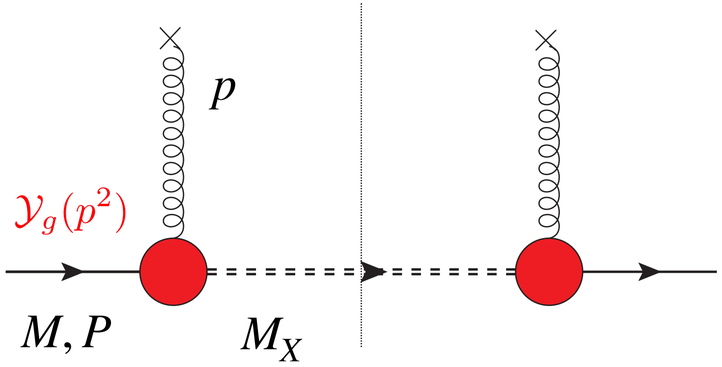


# Our model

**Effective vertex**

Lowest Fock state:
**tri-quark** spectator
on-shell and
with mass $M_X$



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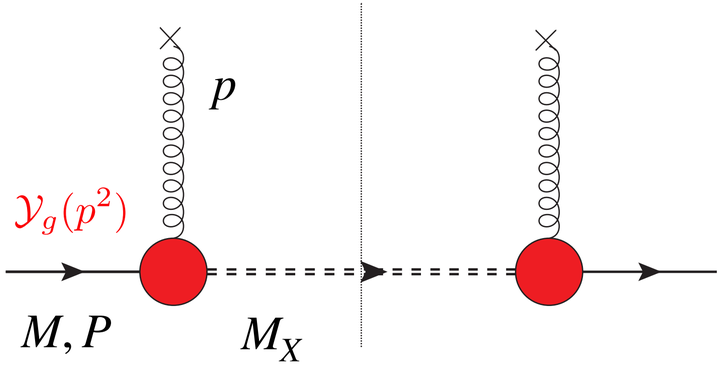


## Spin-1/2 spectator (gluon)

$$\Phi_g = \frac{1}{2(2\pi)^3(1-x)P^+} Tr\left[(\not{P}+M)\frac{1+\gamma^5\not{S}}{2}G^*_{\mu\rho}(p)G^{\nu\sigma}(p)\mathcal{Y}_g^{\rho *}\mathcal{Y}_{g\sigma}(\not{P}-\not{p}+M)\right]$$

$$\mathcal{Y}_g^\mu = g_1(p^2)\gamma^\mu + i\frac{g_2(p^2)}{2M}\sigma^{\mu\nu}p_\nu$$

mimics proton form factors
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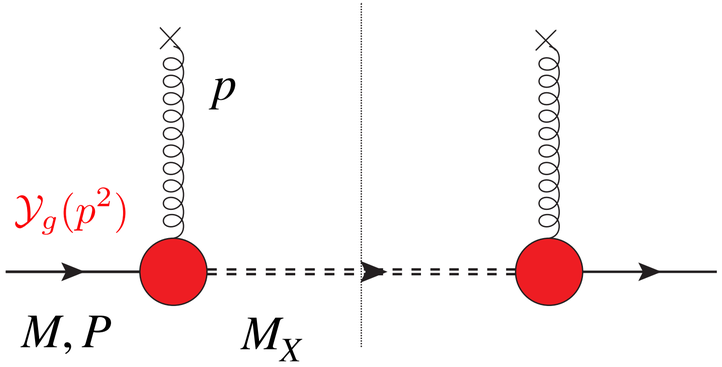


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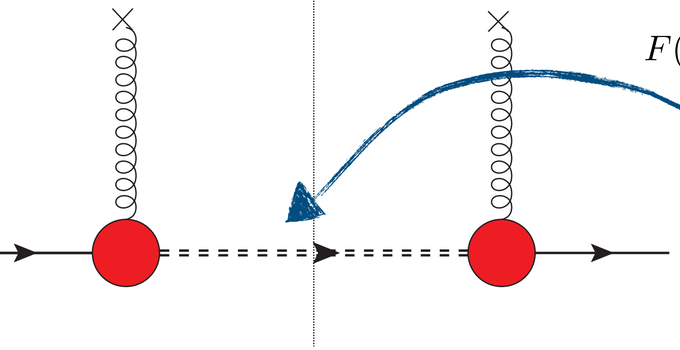

$$F(x, \boldsymbol{p}_T^2) = \int_M^\infty \mathrm{d}M_X \, \rho_X(M_X) \, \hat{F}(x, \boldsymbol{p}_T^2; M_X)$$

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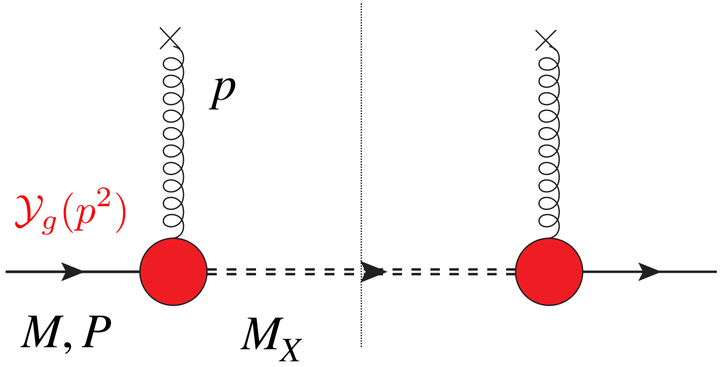


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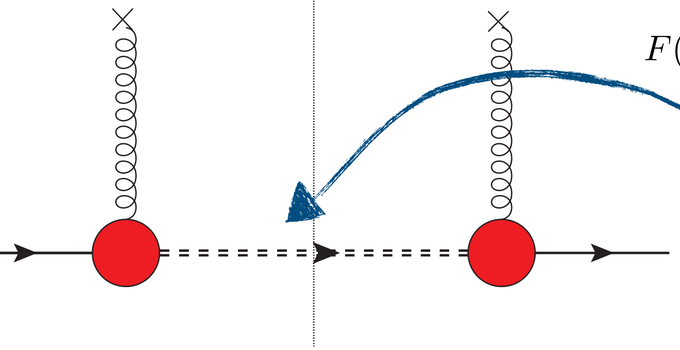

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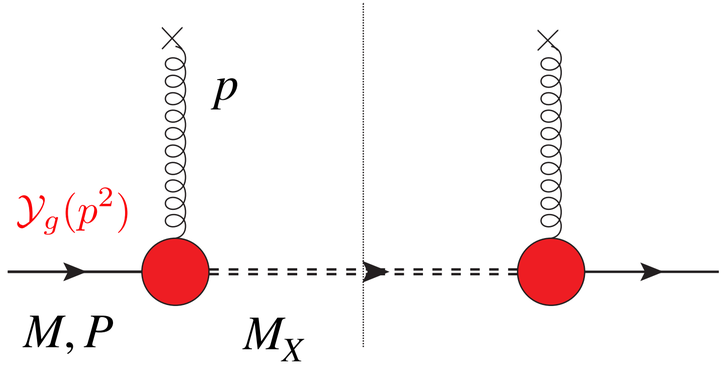


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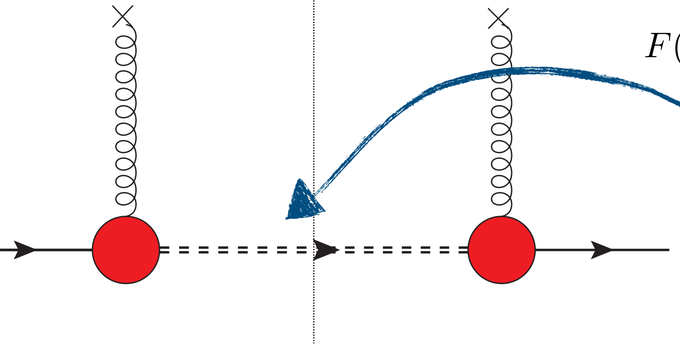

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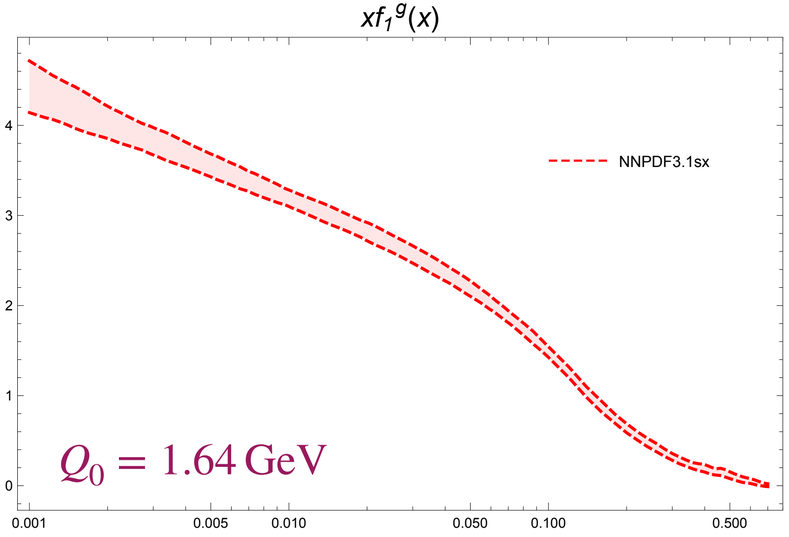


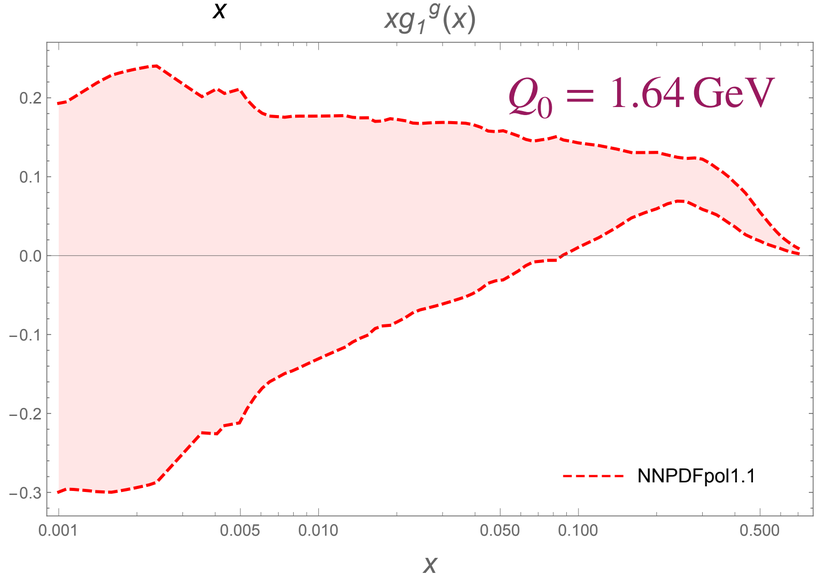

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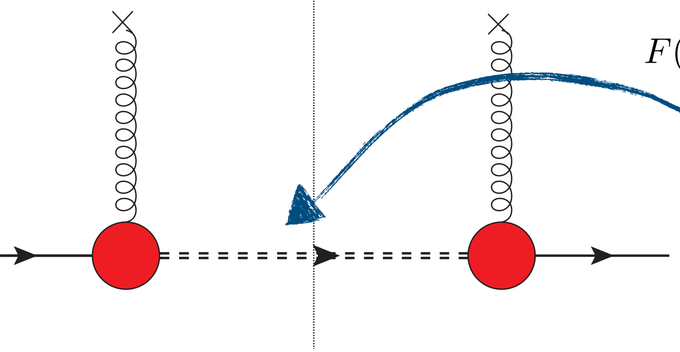

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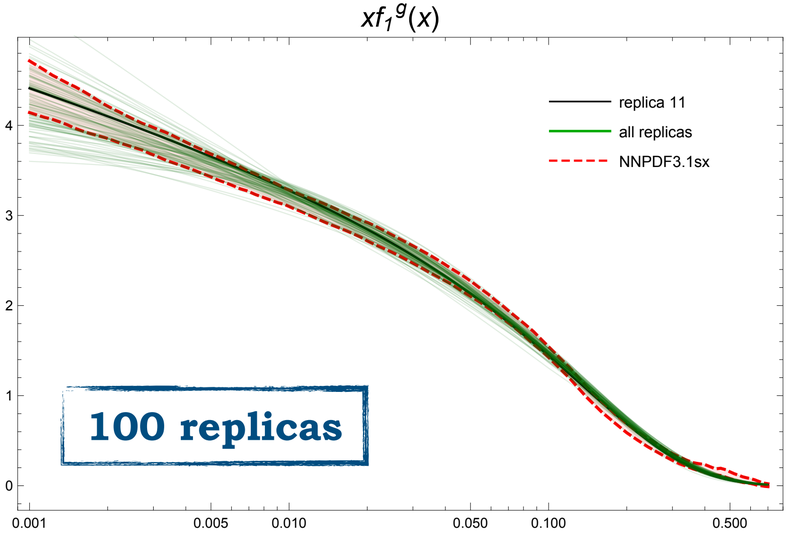


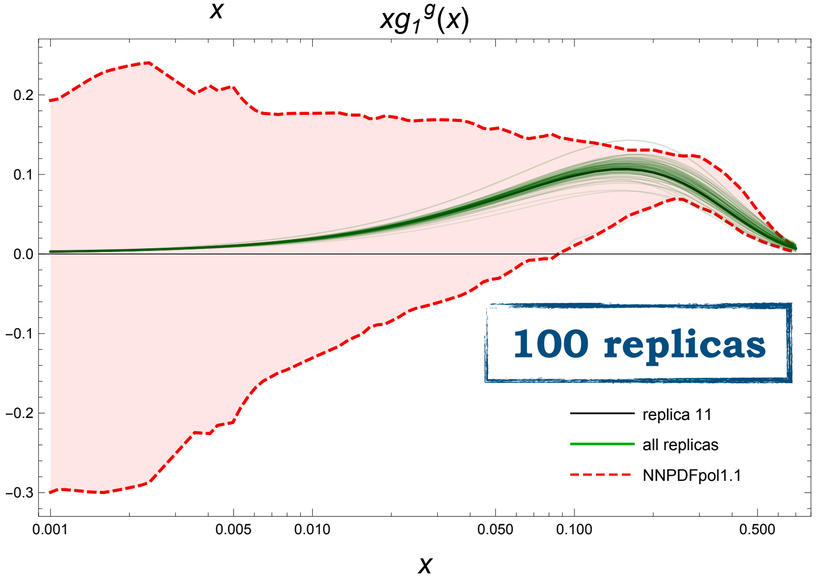

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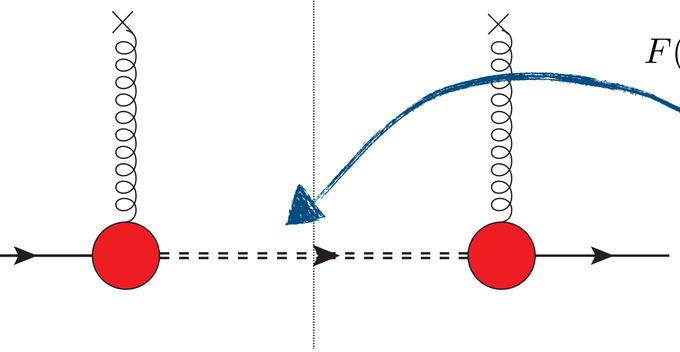

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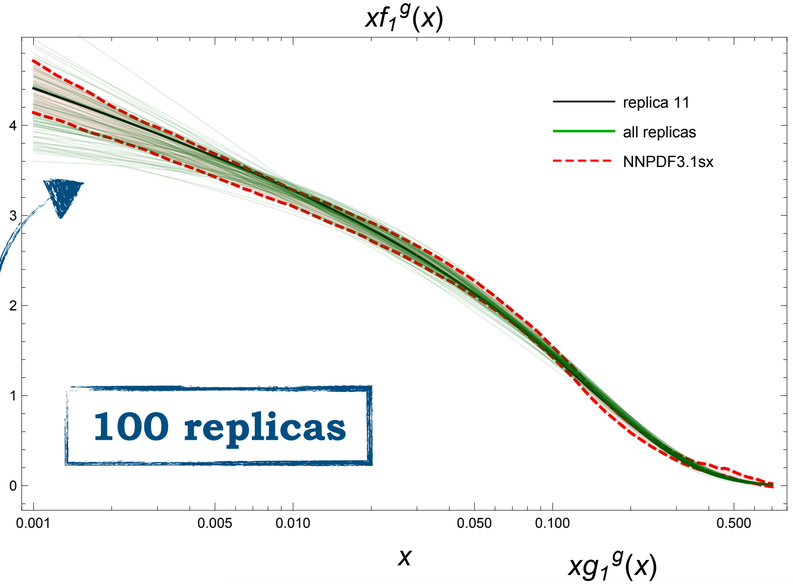


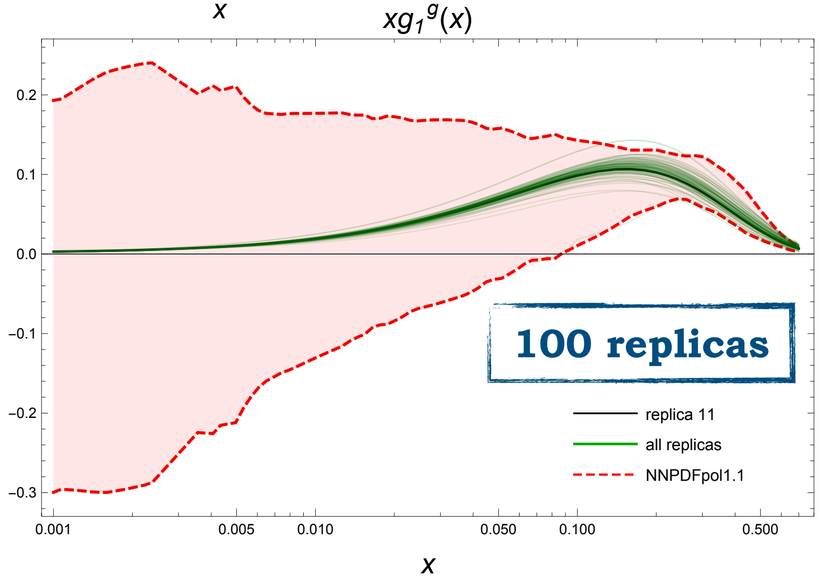

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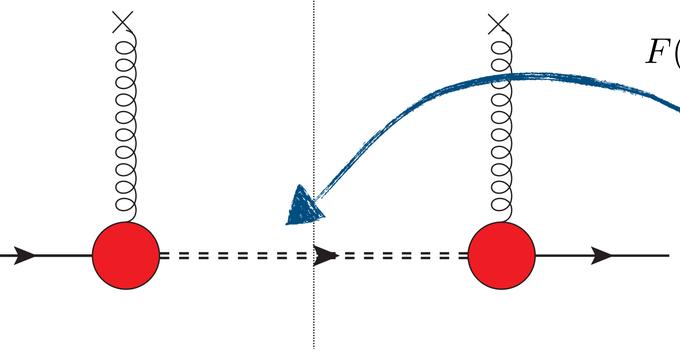

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- ☑ **Simultaneous fit** of $f_1$ and $g_1$ PDFs
- ☑ Inclusion of small-$x$ resummation effects (**BFKL**)
- ☑ Calculation of all twist-2 $T$-even gluon TMDs

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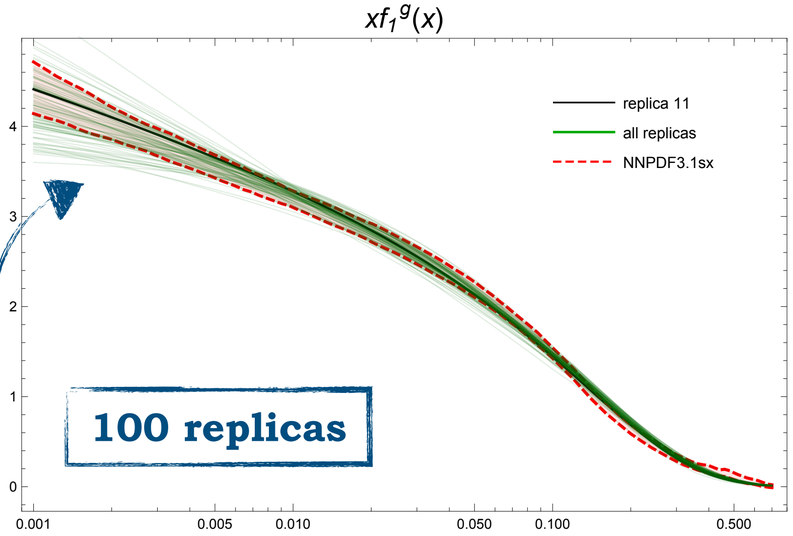


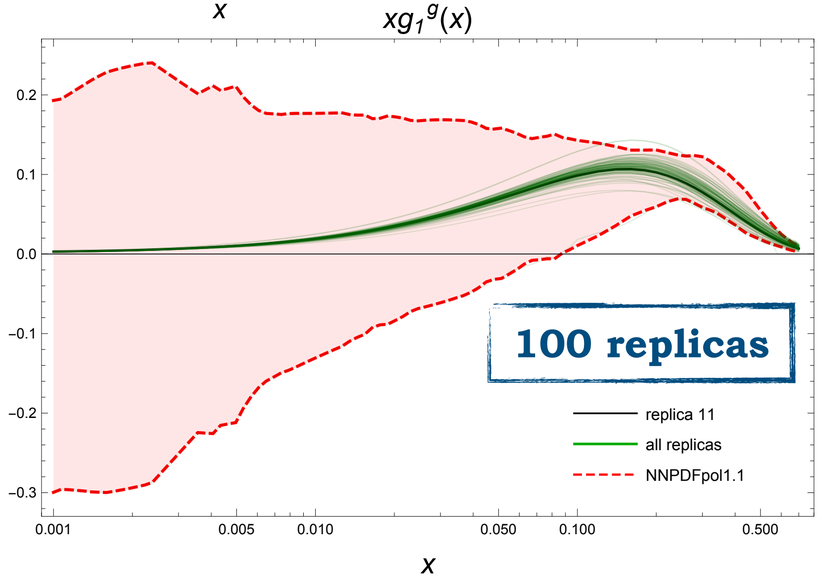

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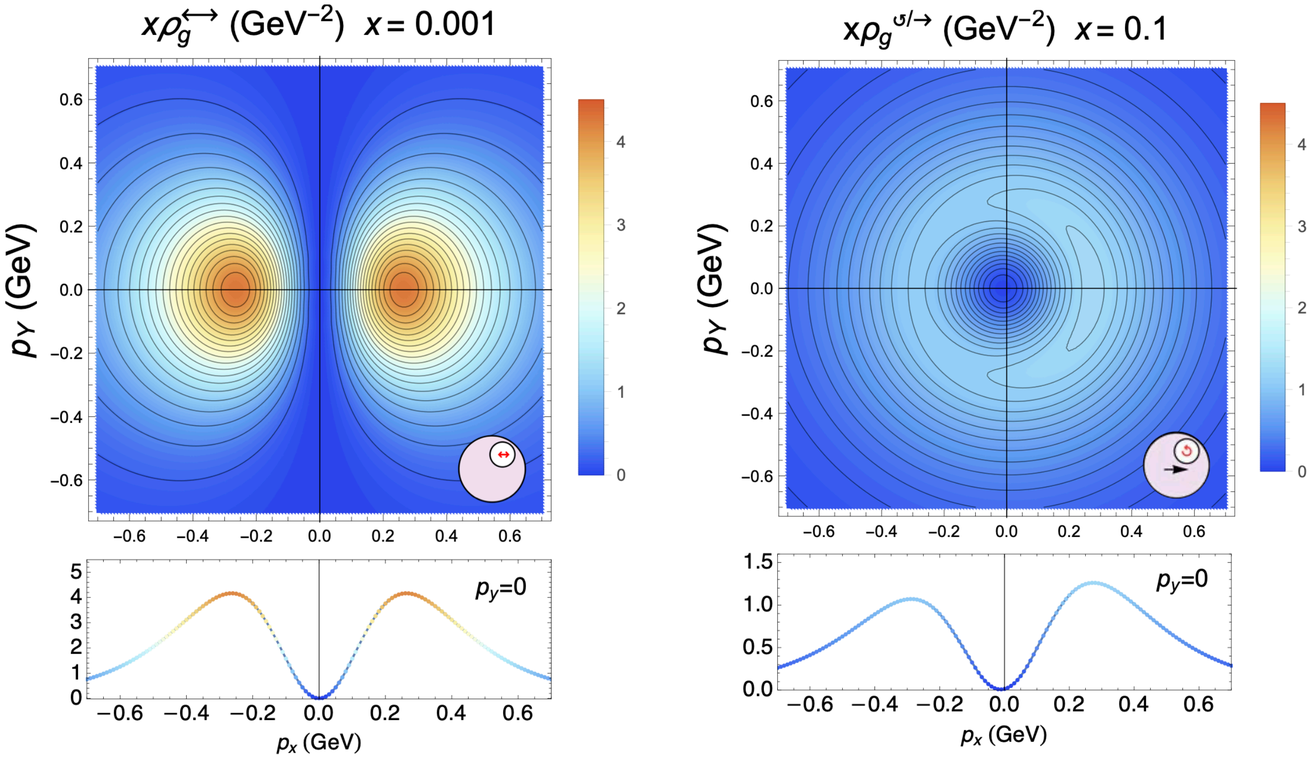


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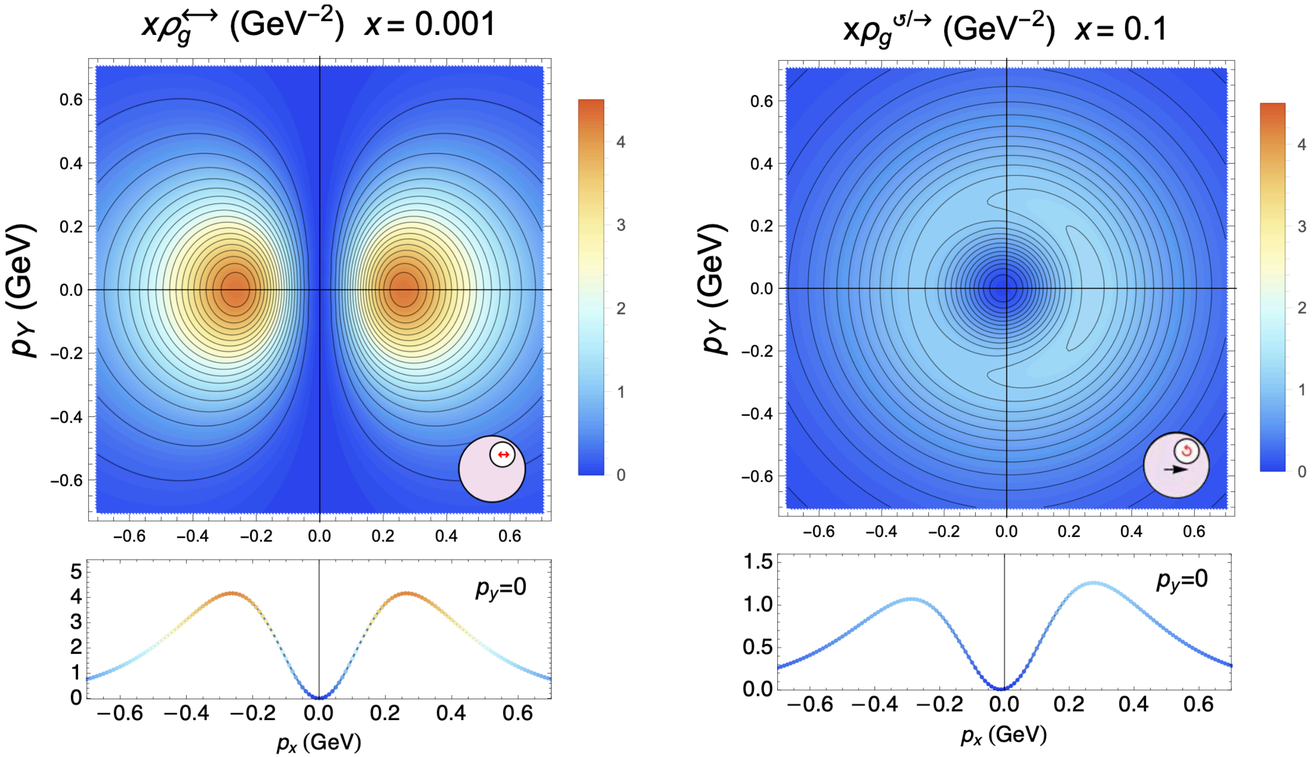


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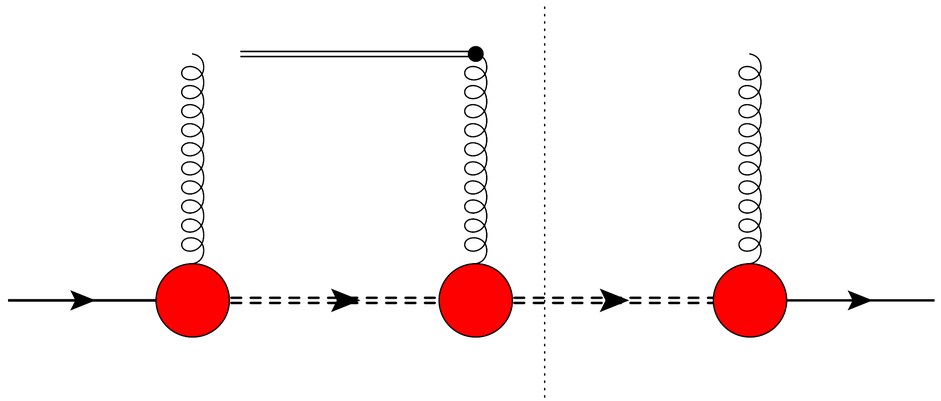
- ❋ *Interference* with one-gluon exchange (*eikonal*)



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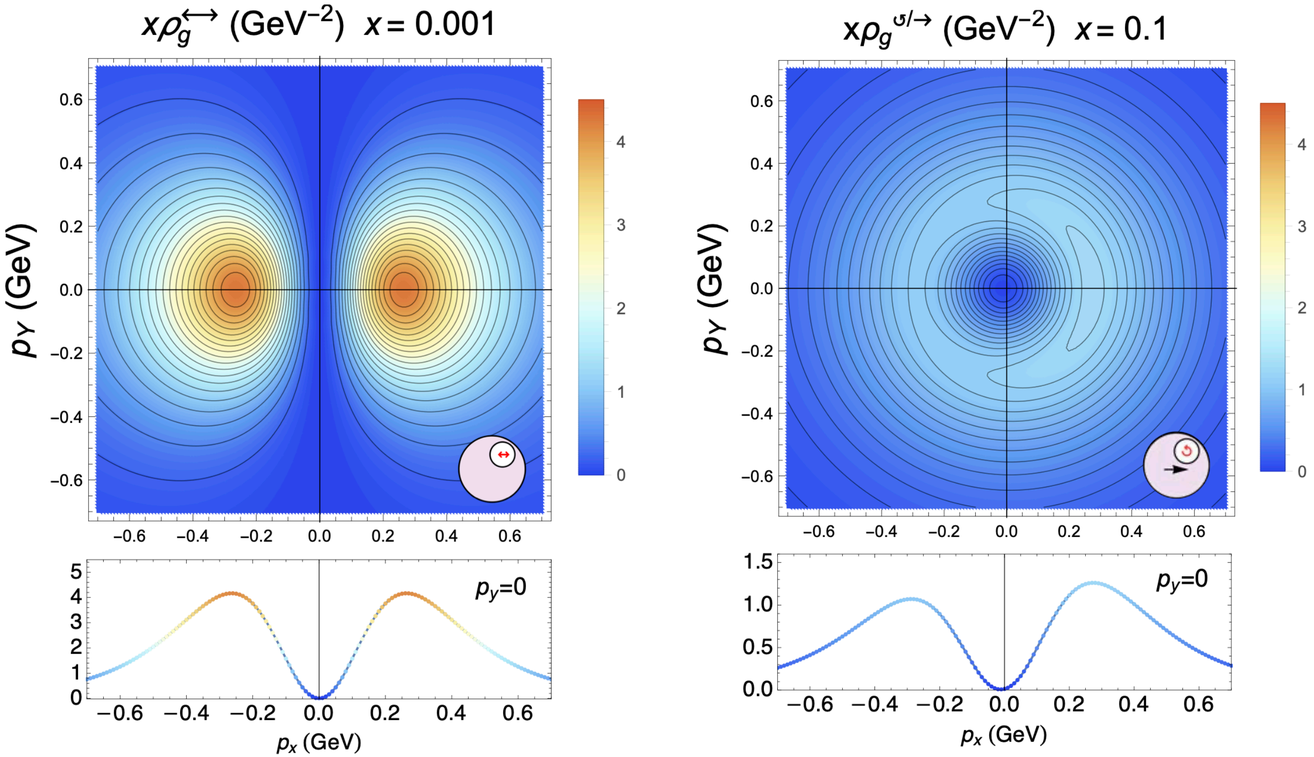


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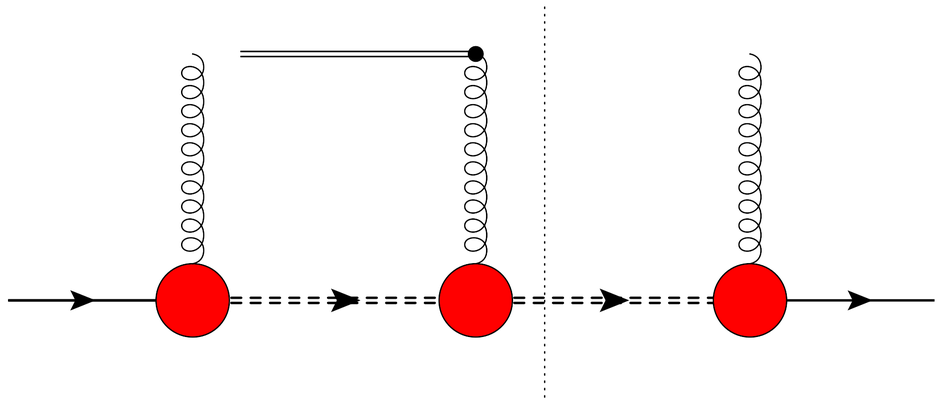

- ❋ Calculation of **Sivers** function *underway*!
  - ✱ Gluon-induced processes
  - ✱ **Spin-asymmetry** studies feasible
  - ✱ Small-*x* physics supported

# Closing statements

- ☑ Systematic calculation of all twist-2 $T$-even gluon TMDs
- ☑ Spectral mass to catch small- and moderate-$x$ effects
- ☑ **Simultaneous fit** of $f_1$ and $g_1$ PDFs via **replica method**

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- ☐ Twist-2 $T$-odd TMDs (**Sivers**, etc.) soon available!
- ☐ Relevant **spin asymmetries** to be identified
- ☐ **Predictions** as inputs to generate **pseudodata**
- ☐ Extension to quark TMDs in the same framework