

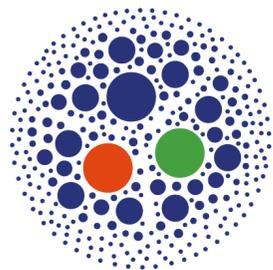
3D tomography of the nucleon Transverse-momentum-dependent gluon distributions

106° Congresso Nazionale SIF
Sezione 1 - Fisica nucleare e subnucleare

Francesco Giovanni Celiberto

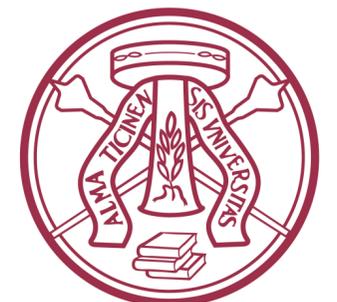
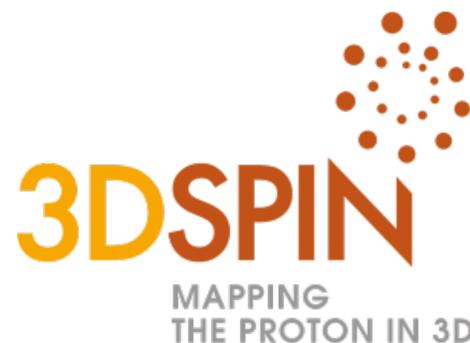
Università degli Studi di Pavia & INFN

In collaboration with **Alessandro Bacchetta**, **Marco Radici** and **Pieter Tael**s



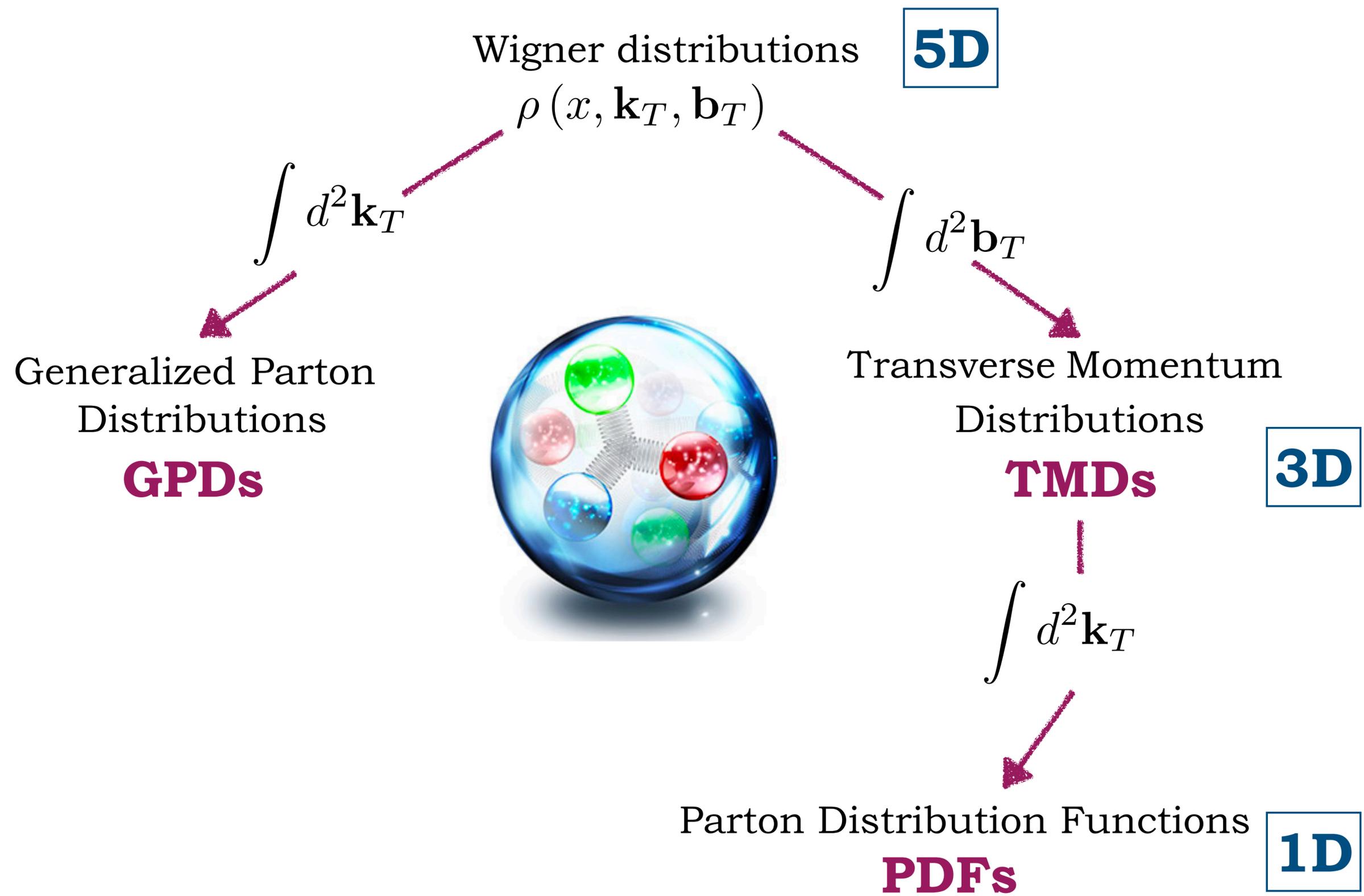
HAS QCD

HADRONIC STRUCTURE AND
QUANTUM CHROMODYNAMICS

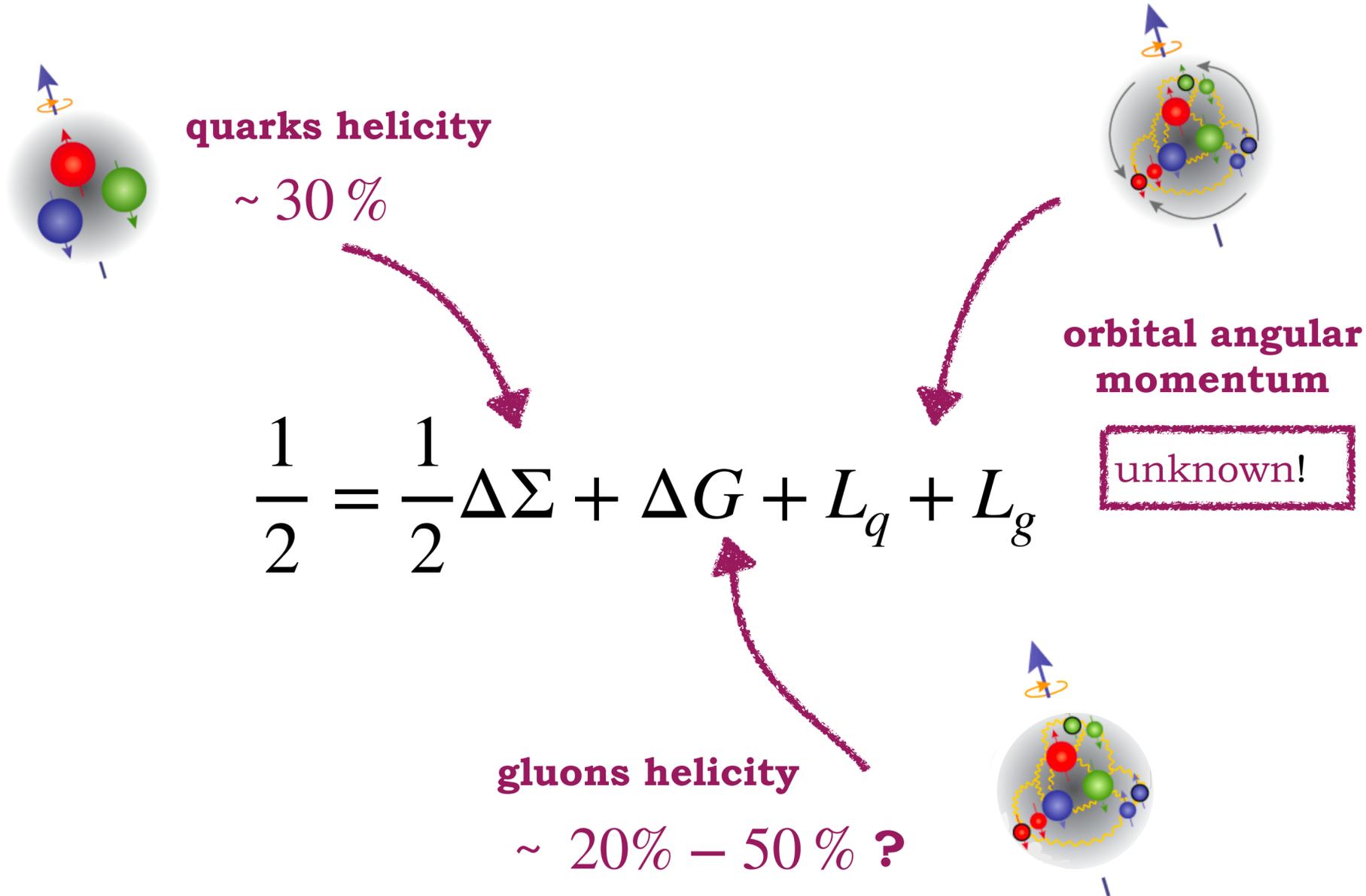


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Parton densities: an incomplete family tree

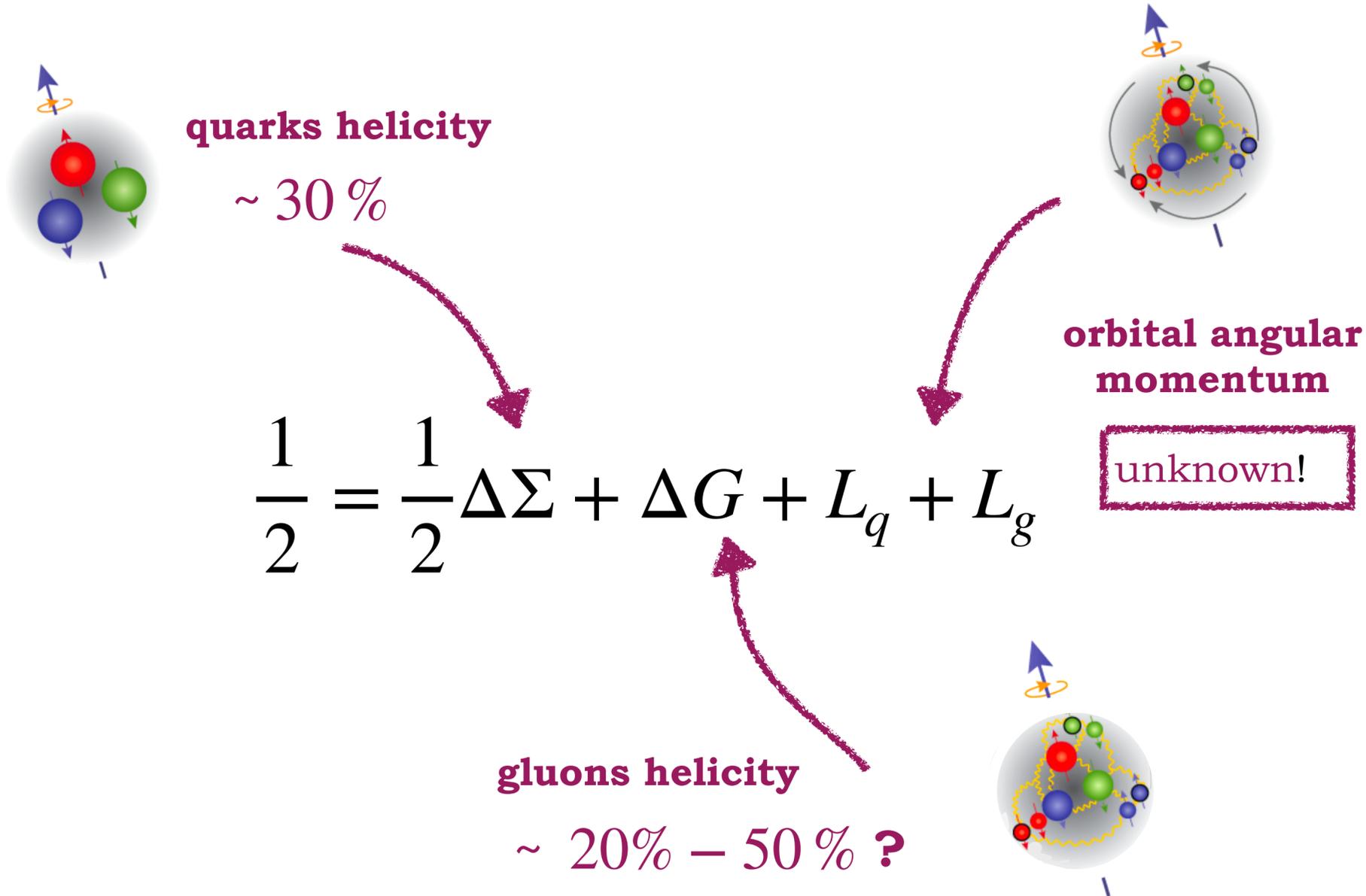


The proton spin crisis



Total spin carried by quarks and gluons does not amount to 1/2, one needs orbital angular momentum, then a 3D description...

The proton spin crisis



...many other effects in hadronic interactions cannot be understood in the purely collinear approach

Total spin carried by quarks and gluons does not amount to 1/2, one needs orbital angular momentum, then a 3D description...

(proton spin crisis) [EMC Collaboration, CERN (1987)]

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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Motivation

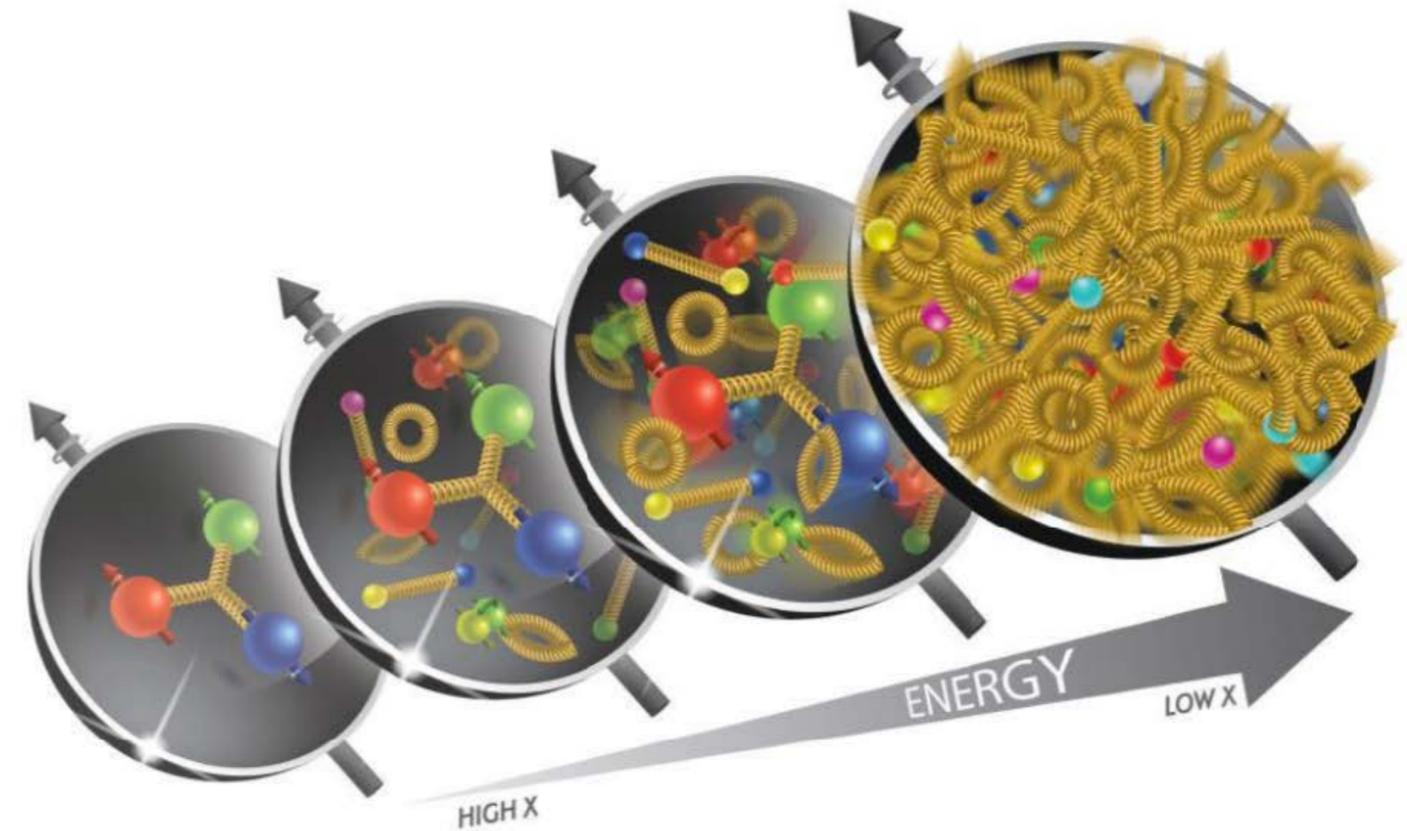
- * Gluon-TMD PDFs: *core* sector of **EIC** studies
- * Need for a *flexible* model, suited to *pheno*
- * **Unpolarized** and **polarized gluon TMDs**
- * *Consistent* framework for quark TMDs

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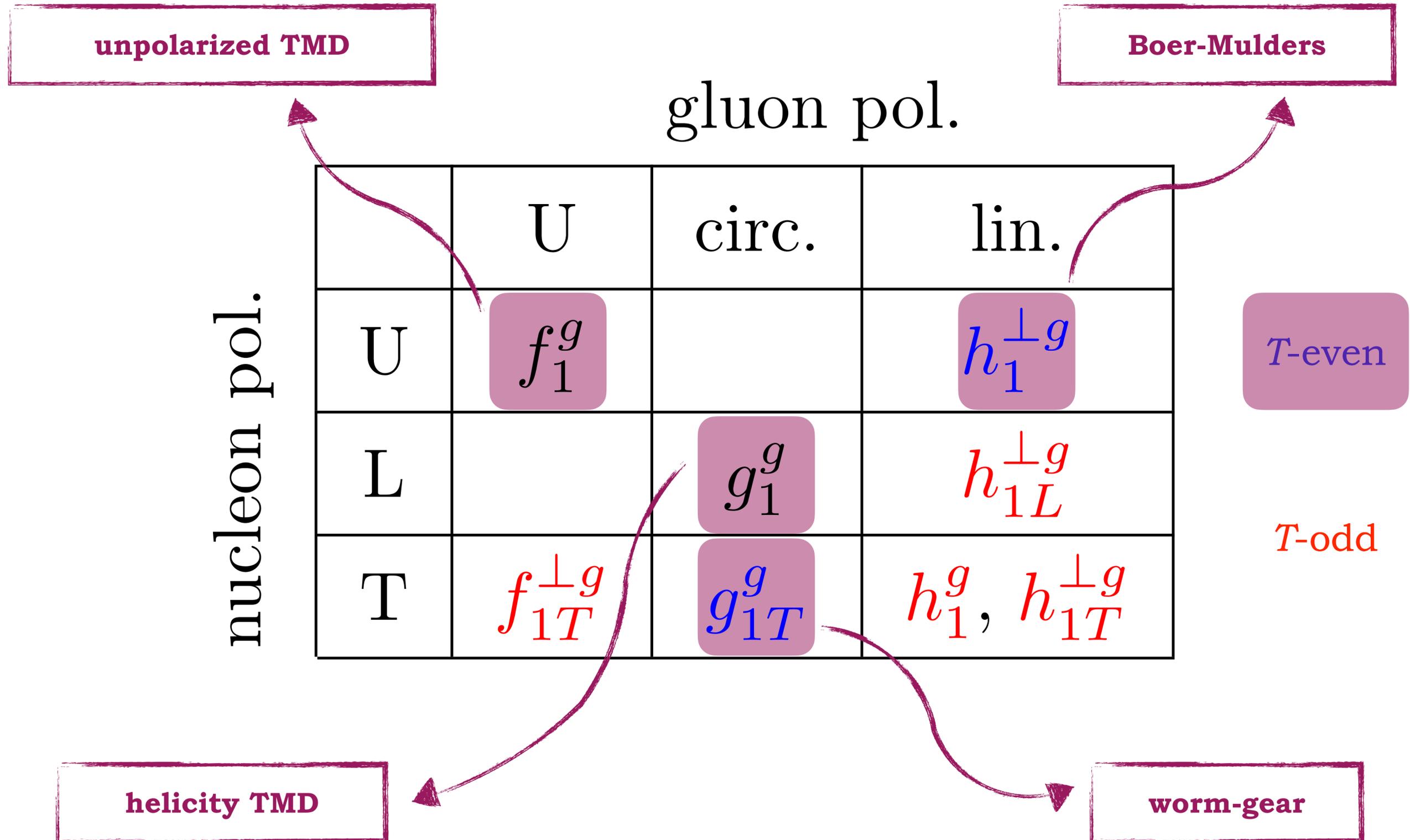
Significance of gluon-TMD studies
in a wide range of x

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

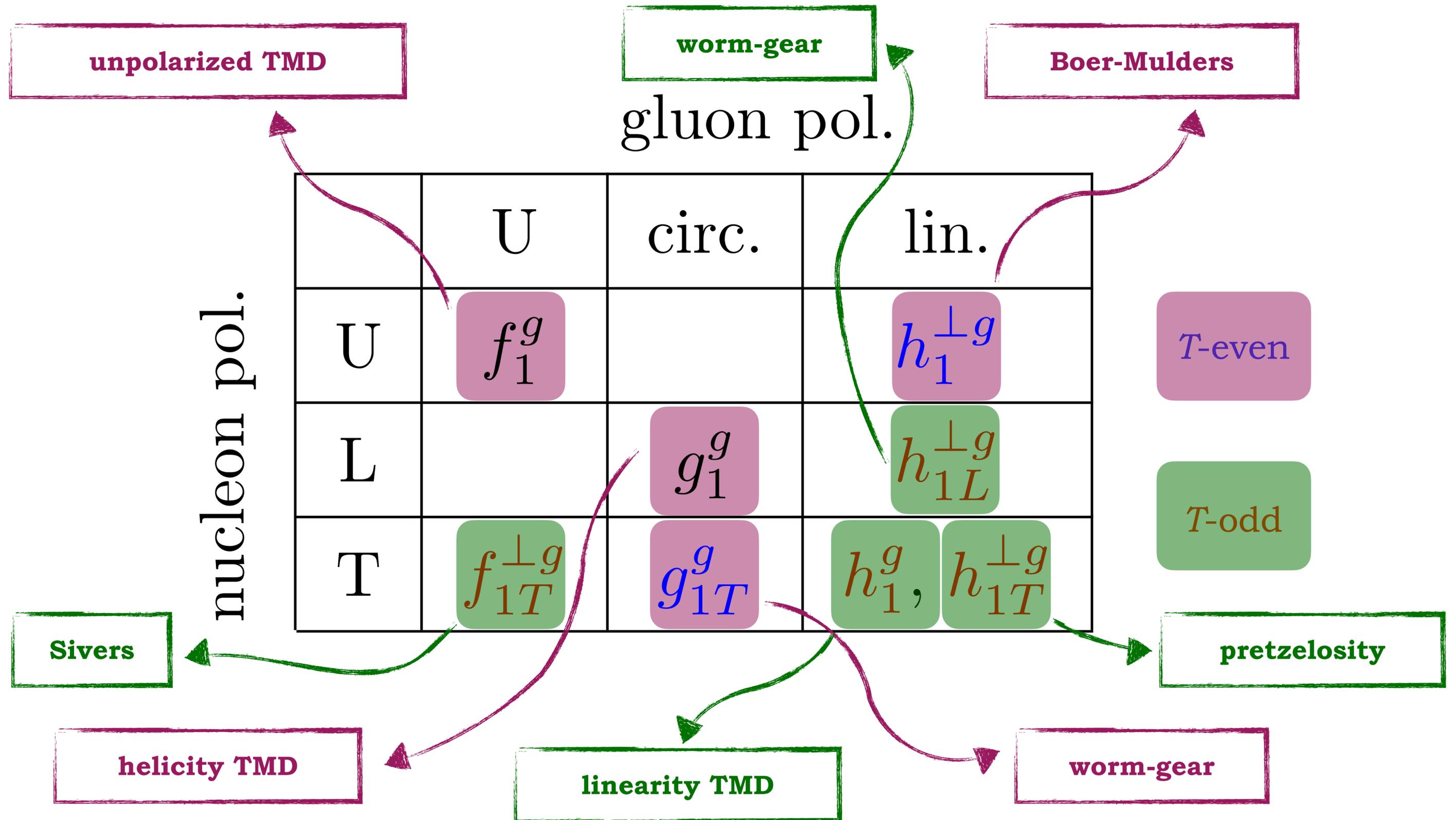
gluon pol.

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

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



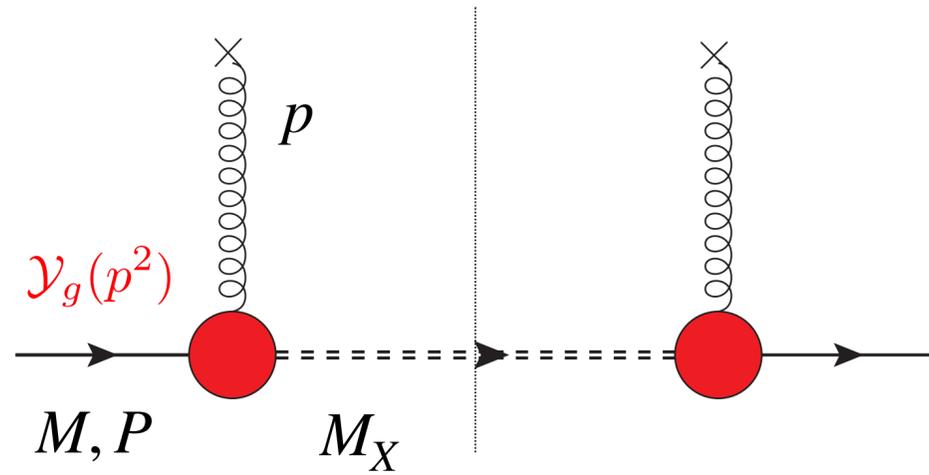
T-even and T-odd gluon TMDs at twist-2



Our model

Spectator model

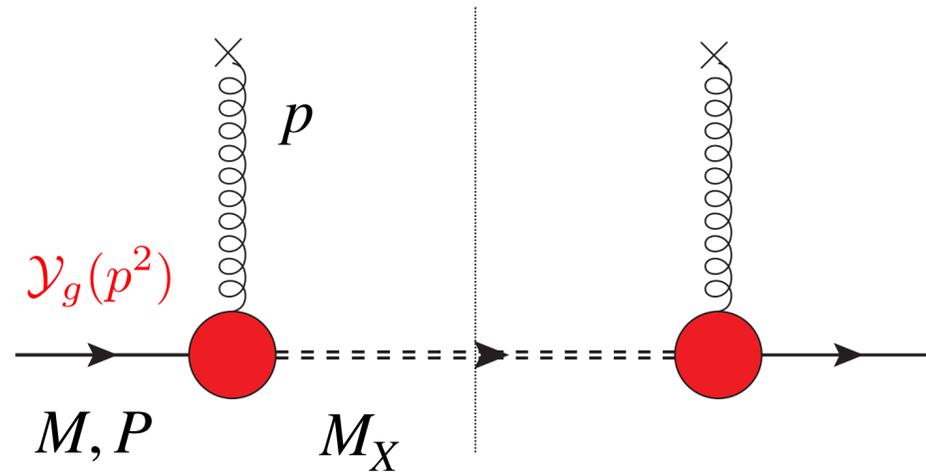
Lowest Fock state:
tri-quark spectator
on-shell and
with mass M_X



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 on-shell and
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Spin-1/2 spectator

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

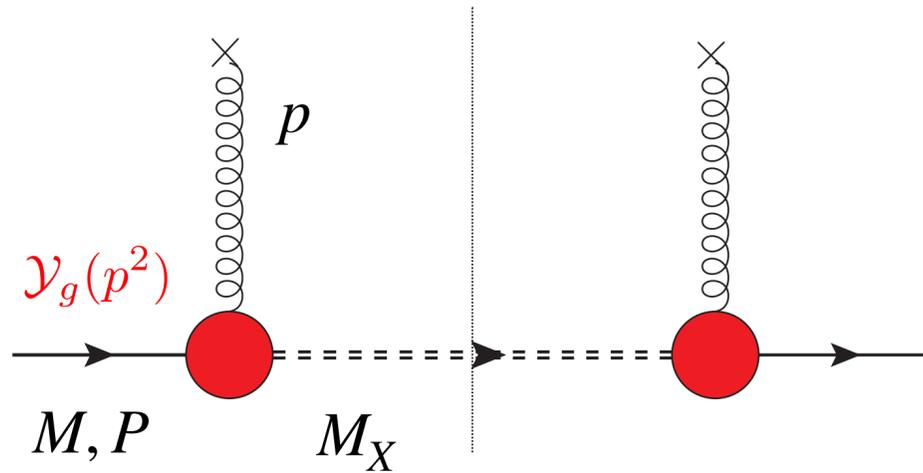
$$\mathcal{Y}_g^\mu = g_1(p^2) \gamma^\mu + i \frac{g_2(p^2)}{2M} \sigma^{\mu\nu} p_\nu$$

mimics proton form factors
 (conserved EM current
 of a free nucleon)

Our model

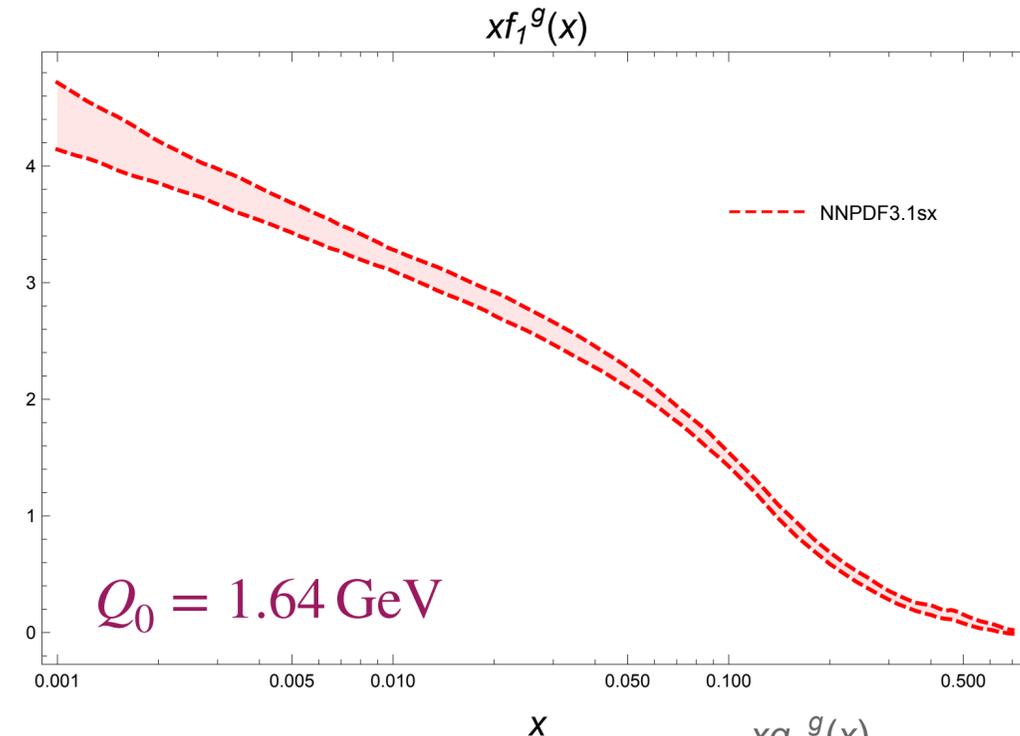
Spectator model

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Link with collinear factorization

p_T -integrated TMDs **have to** reproduce PDFs
 at the lowest scale (Q_0) *before* evolution

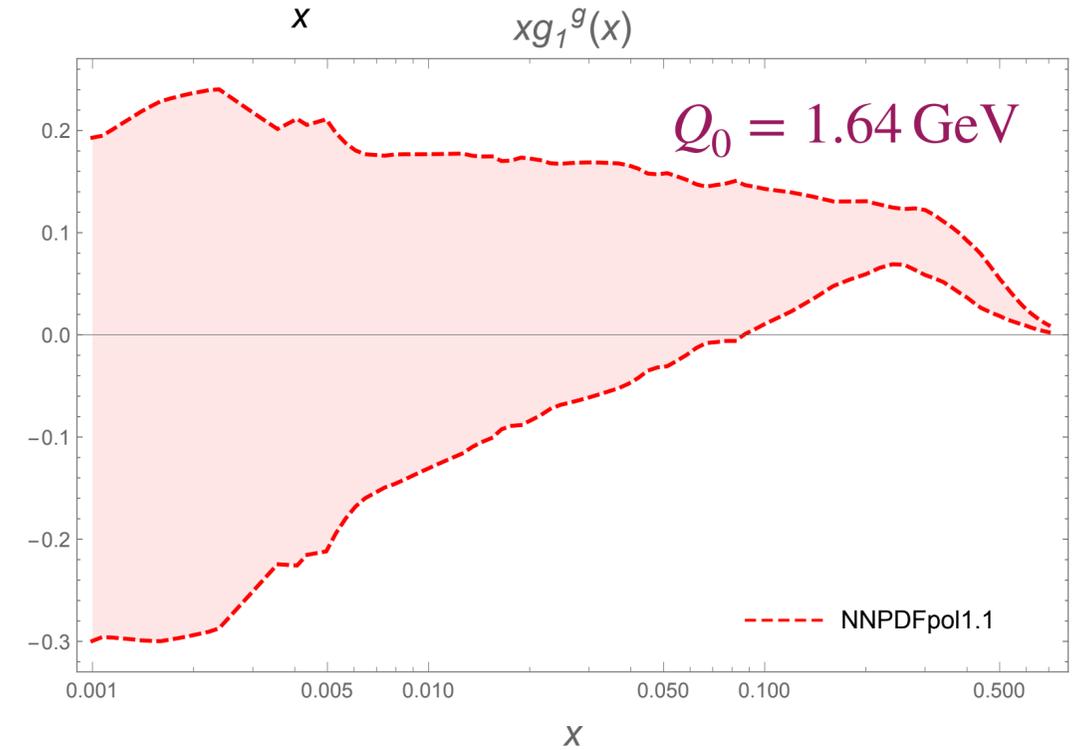


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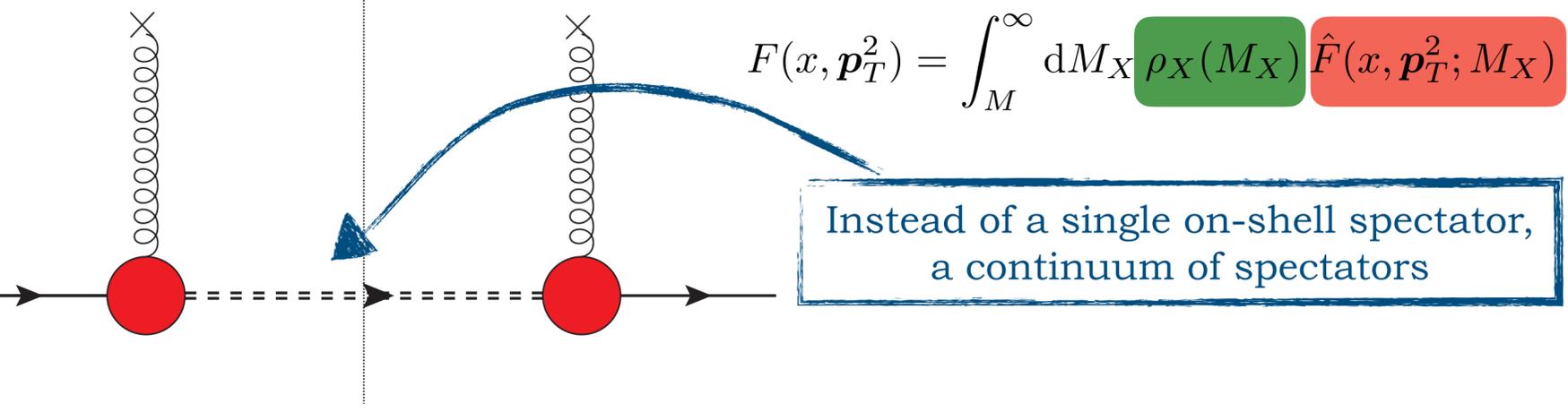
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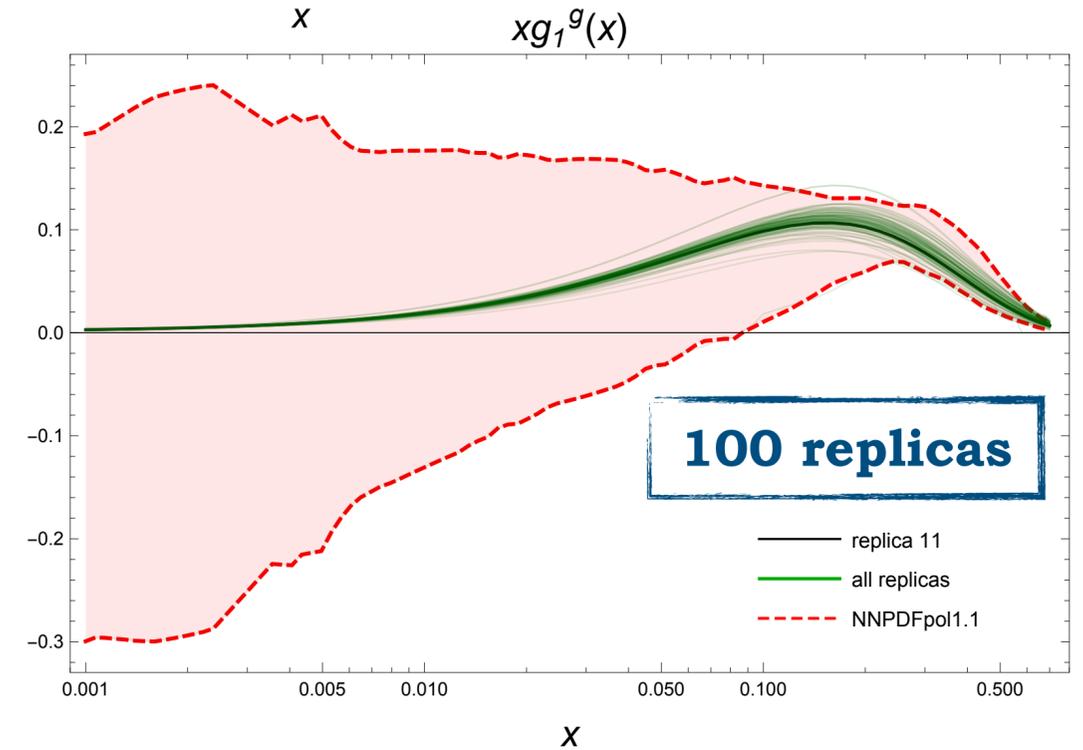
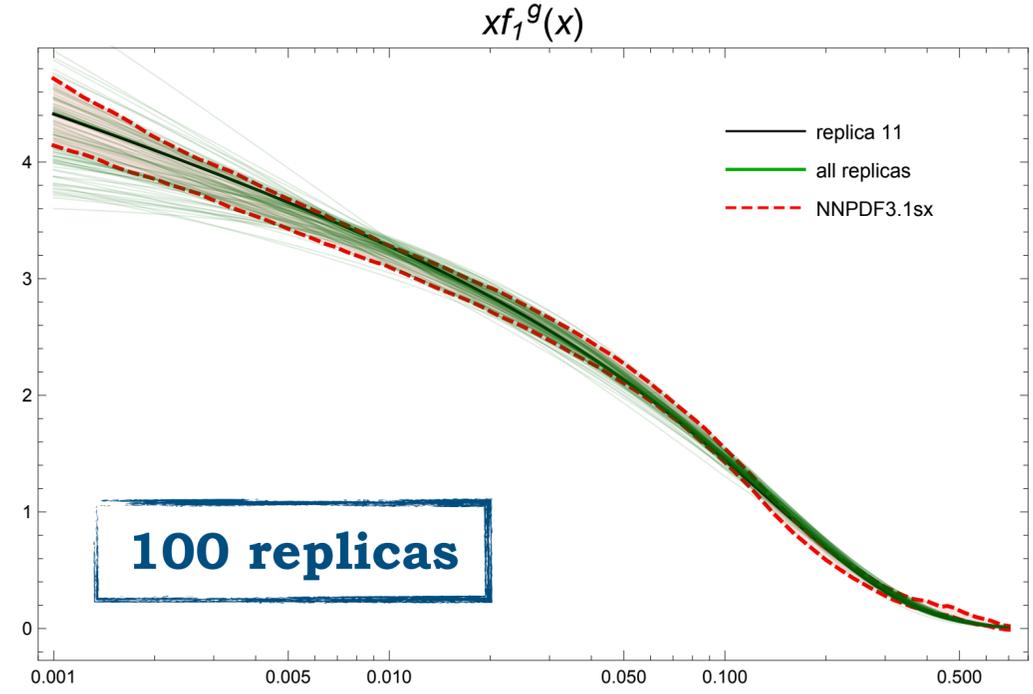
Spectator-system spectral-mass function



$$F(x, p_T^2) = \int_M^\infty dM_X \rho_X(M_X) \hat{F}(x, p_T^2; M_X)$$

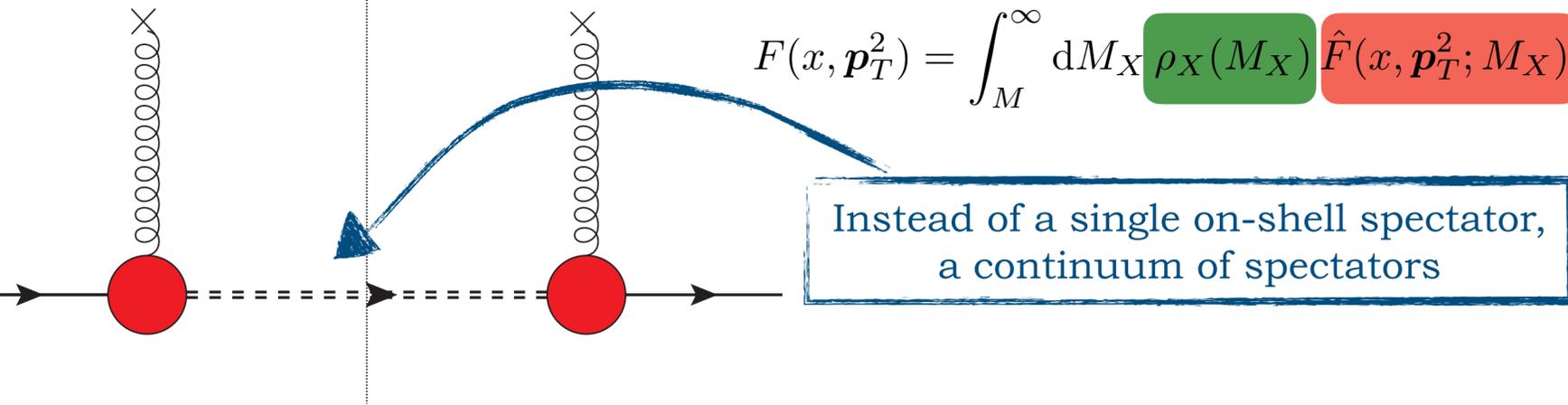
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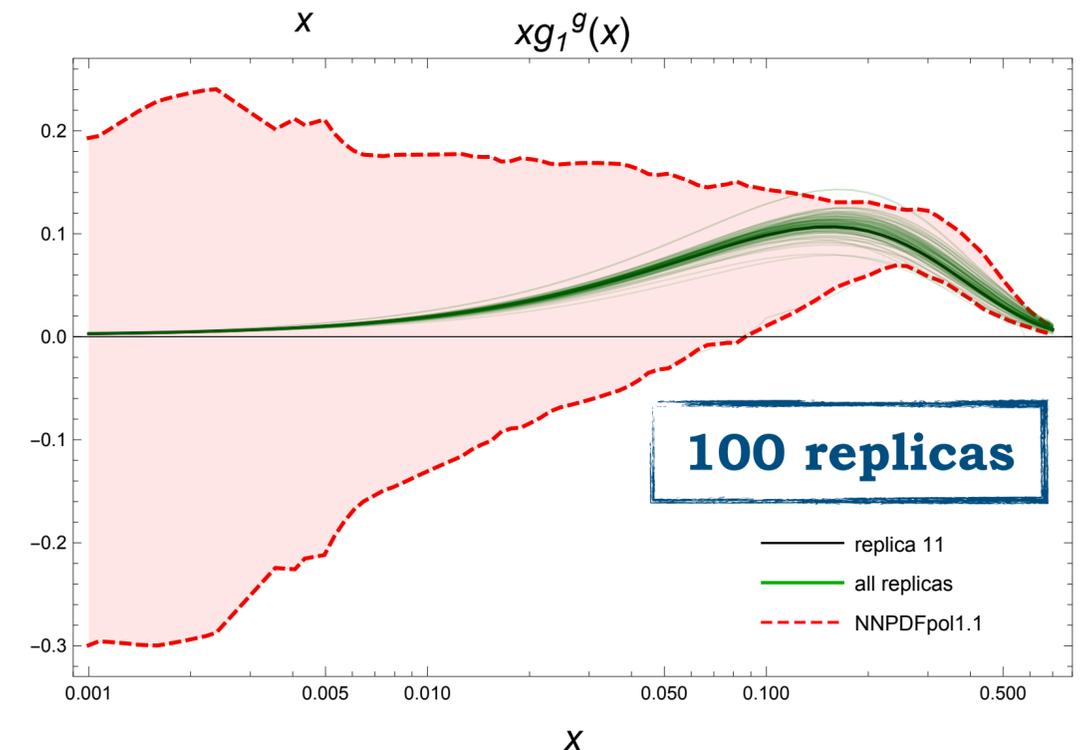
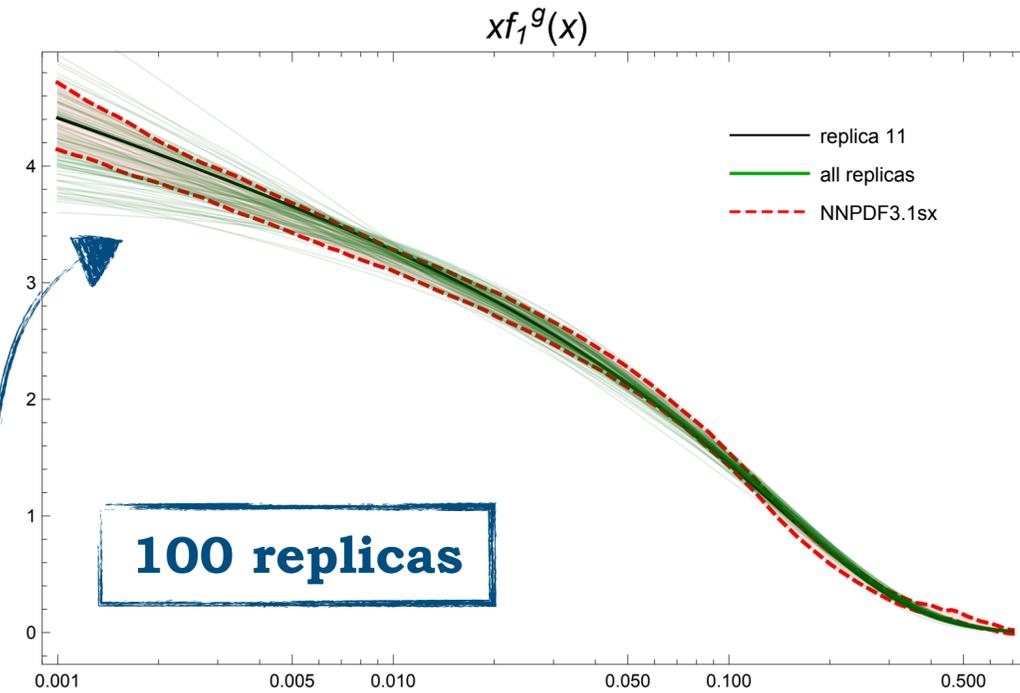
Spectator-system spectral-mass function



Spectral function **learns** small- and moderate- x info encoded in **NNPDF** collinear parametrizations (NNPDF3.1sx + NNPDFpol1.1)

Link with collinear factorization

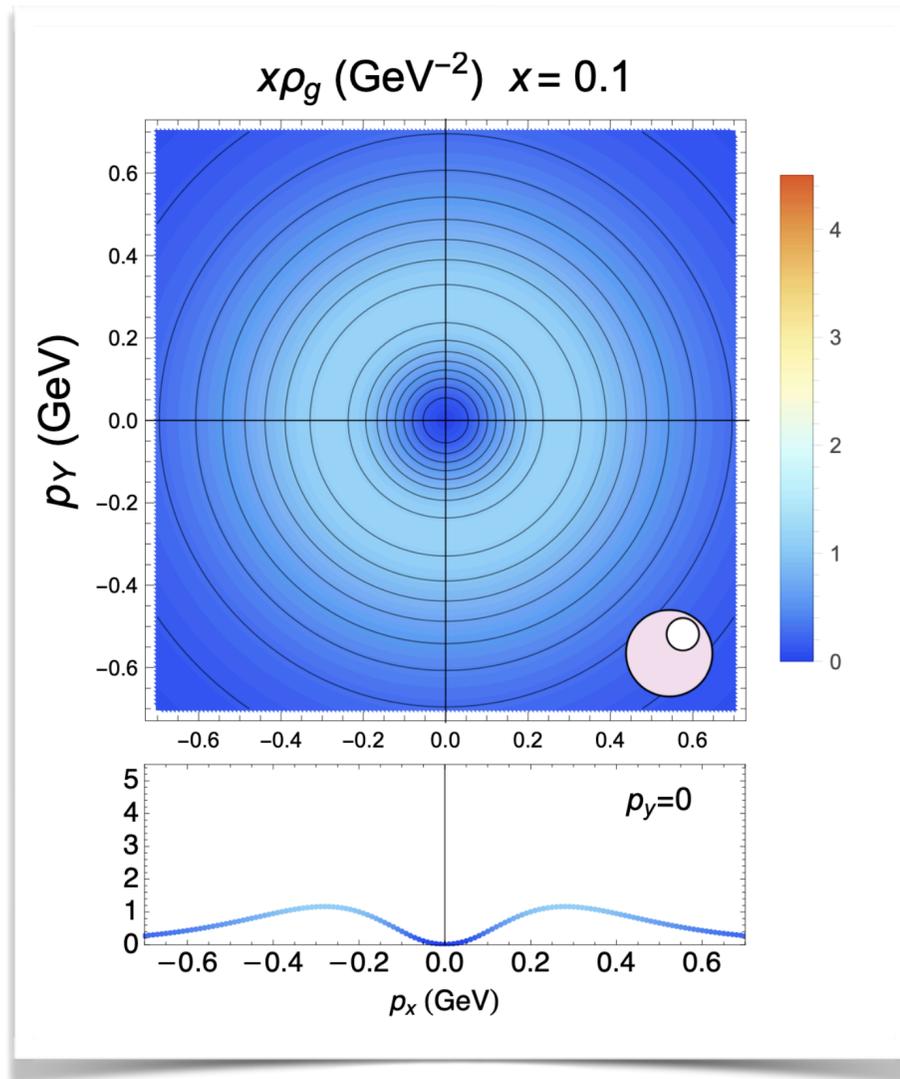
p_T -integrated TMDs **have to** reproduce PDFs at the lowest scale (Q_0) *before* evolution



- ✓ **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

3D tomography: the gluon content in the proton

unpolarized TMD

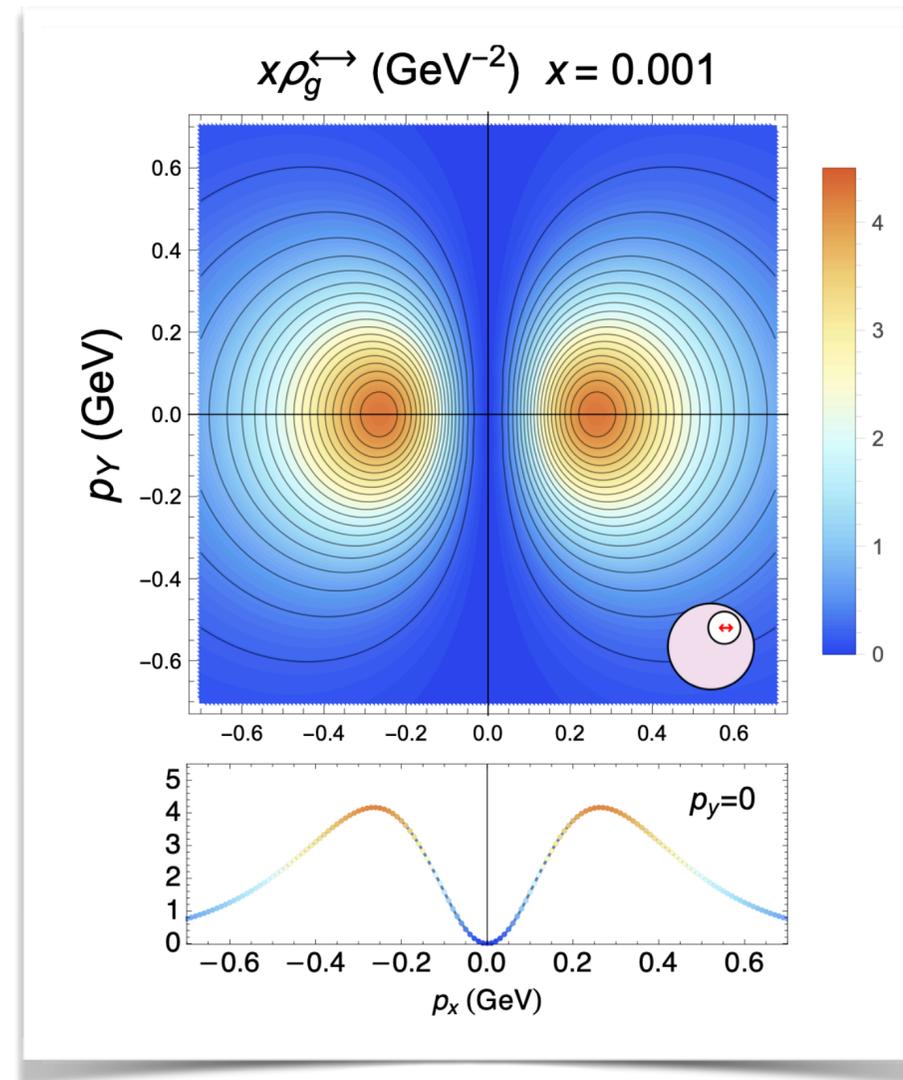
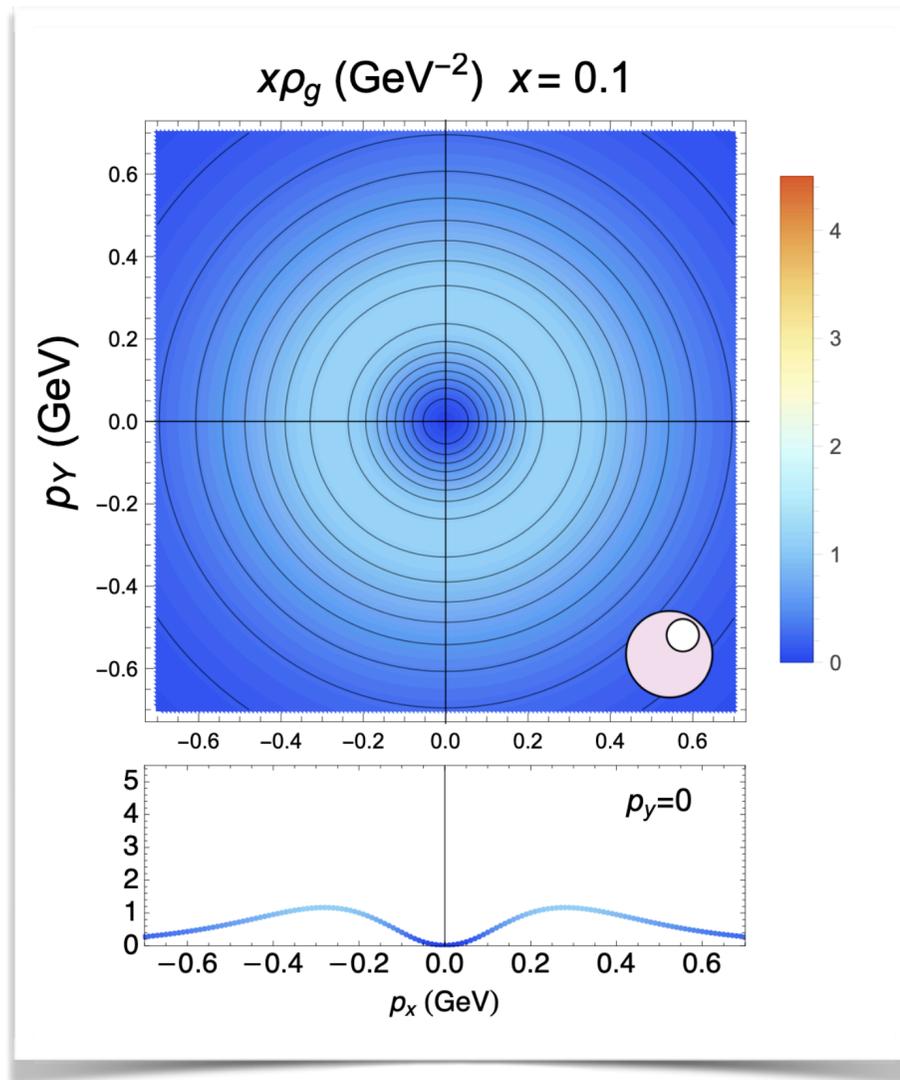


 [A. Bacchetta, F.G.C., M. Radici, P. Tael, *Eur. Phys. J. C* **80** (2020) no.8 [[arXiv:2005.02288](https://arxiv.org/abs/2005.02288)]]

3D tomography: the gluon content in the proton

unpolarized TMD

Boer-Mulders



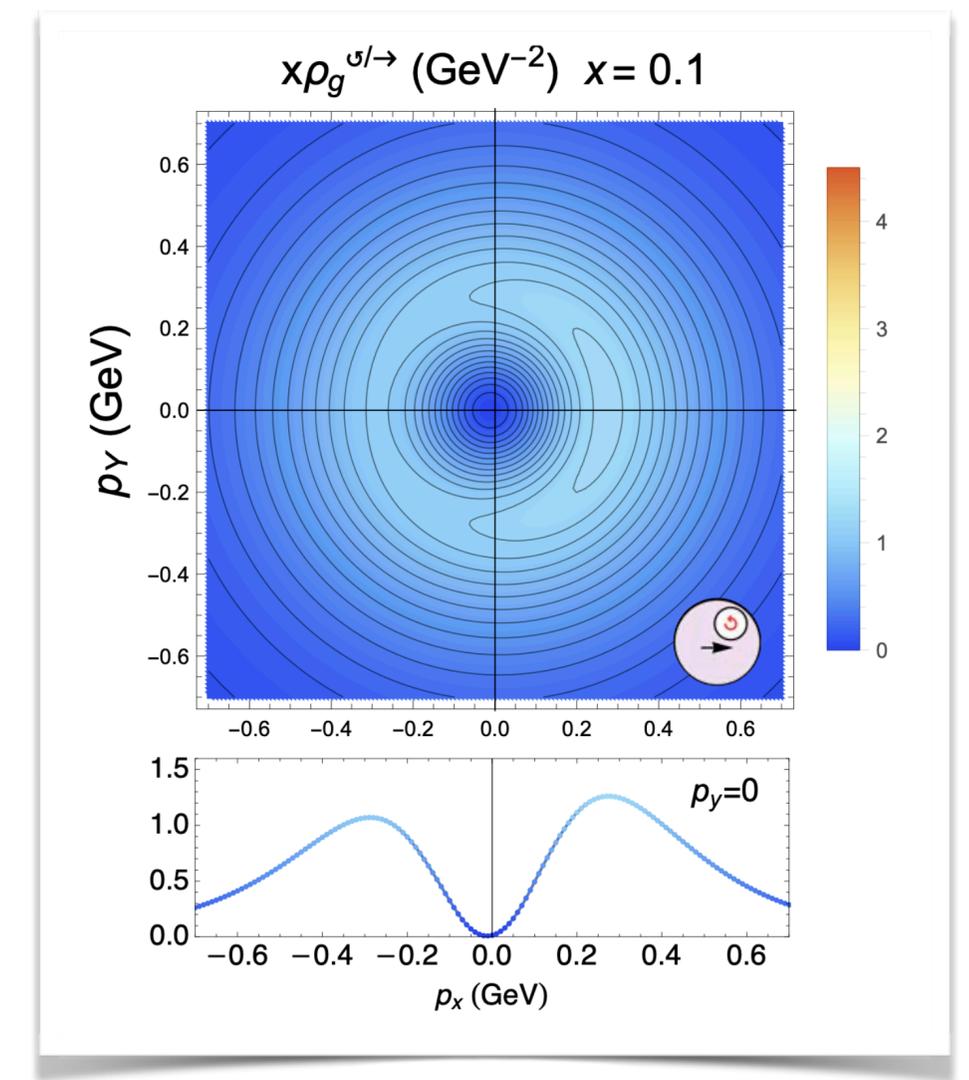
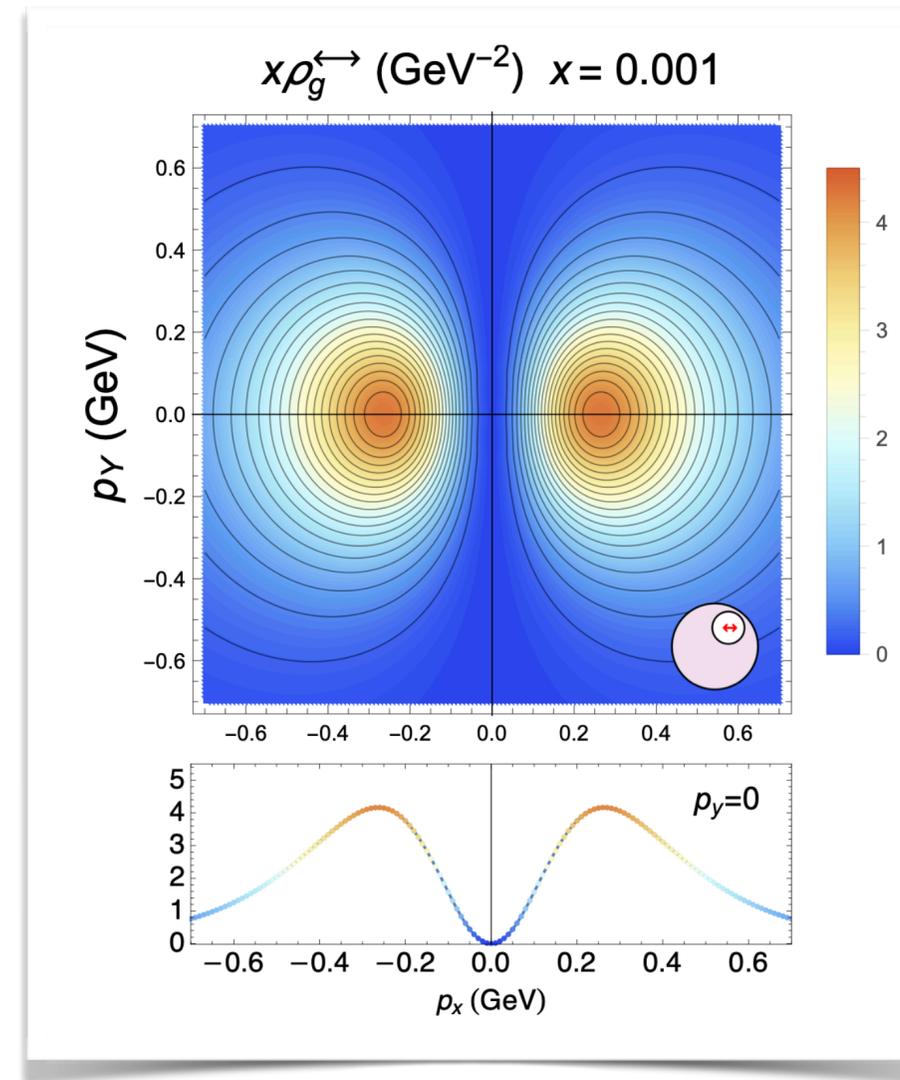
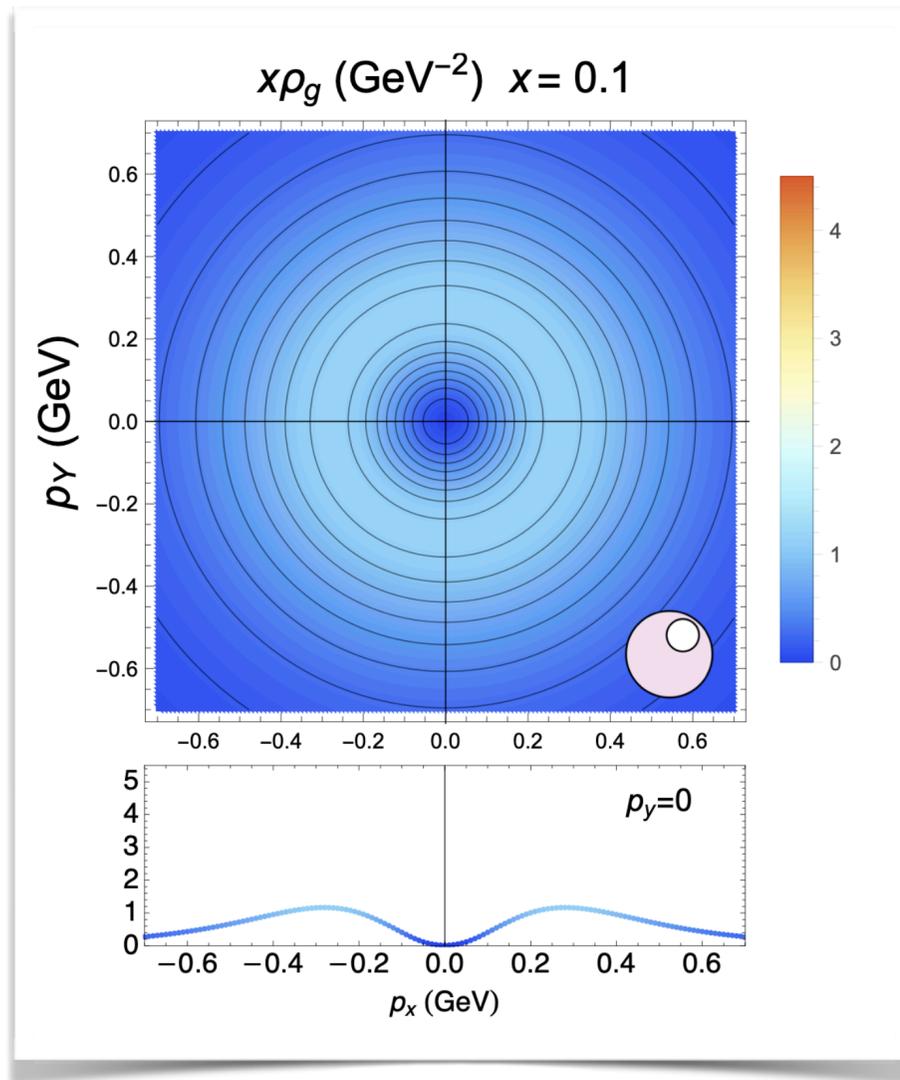
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3D tomography: the gluon content in the proton

unpolarized TMD

Boer-Mulders

worm-gear



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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**

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**
- Twist-2 T -odd TMDs (**Sivers**, etc.) soon available!
- Phenomenological** studies in progresss
- Extension to quark TMDs in the same framework

Thanks for your attention!