A model calculation of the transverse-momentum-dependent gluon density in the proton

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in collaboration with
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HAS QCD
HADRONIC STRUCTURE AND QUANTUM CHROMODYNAMICS

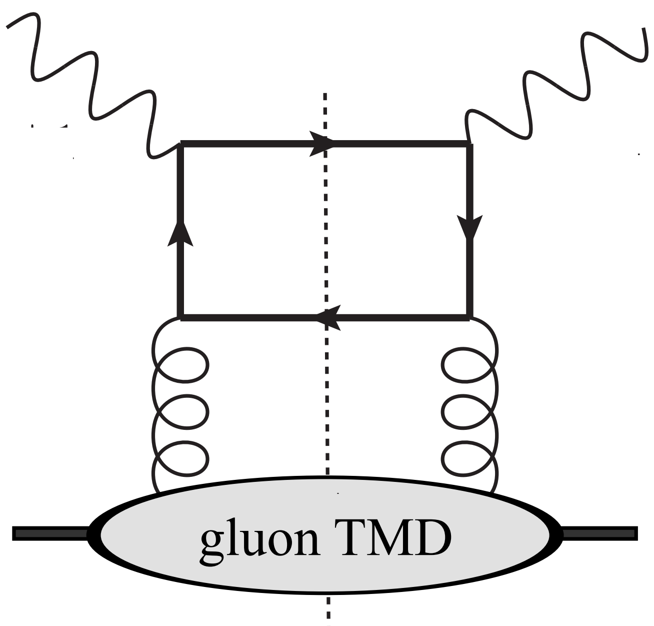
3DSPIN
MAPPING THE PROTON IN 3D

INFN
Istituto Nazionale di Fisica Nucleare
Sezione di Pavia

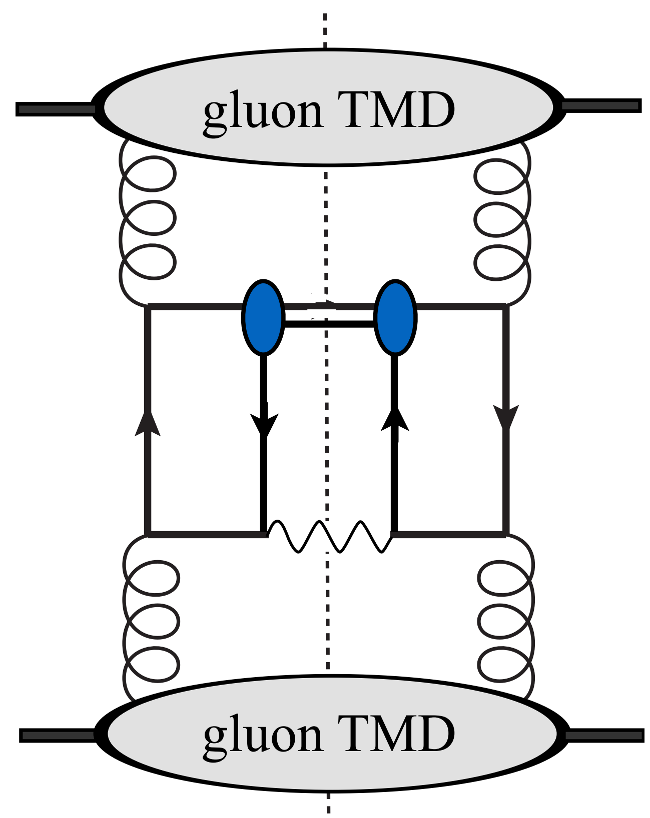
UNIVERSITÀ DI PAVIA

Gluon TMDs: a largely unexplored territory

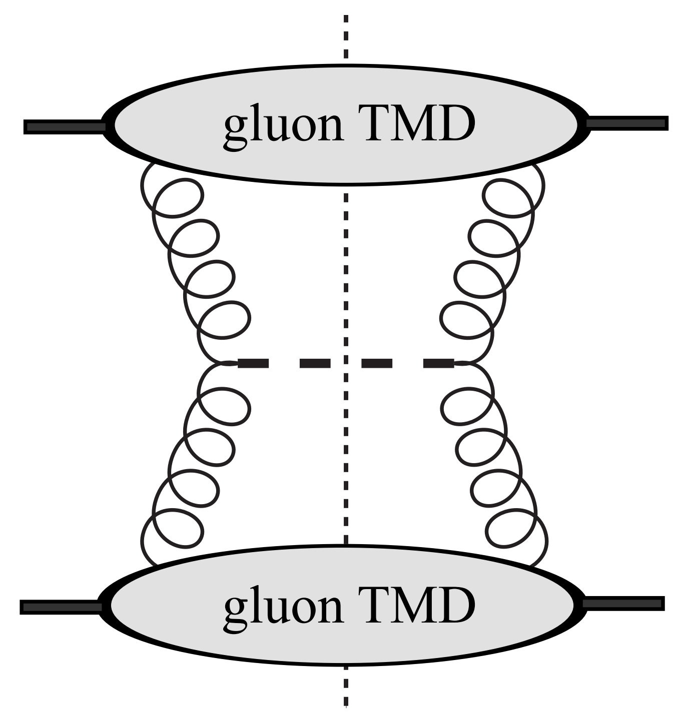
$ep \to e + \text{jet} + \text{jet} + X$



$pp \to J/\Psi + \gamma + X$



$pp \to H(\eta_c) + X$



[D. Boer, W.J. den Dunnen, C. Pisano, M. Schlegel, W. Vogelsang, *Phys. Rev. Lett.* **108** (2012) 032002]
[W.J. den Dunnen, J.P. Lansberg, C. Pisano, M. Schlegel, *Phys. Rev. Lett.* **112** (2014) 21200]
[J.P. Lansberg, C. Pisano, F. Scarpa, M. Schlegel, *Phys. Lett. B* **784** (2018) 217]
[A. Bacchetta, D. Boer, C. Pisano, P. Taels, arXiv:1809.02056 [hep-ph]]
[U. D'Alesio, C. Flore, F. Murgia, C. Pisano, P. Taels, arXiv:1811.02970 [hep-ph]]

Motivation

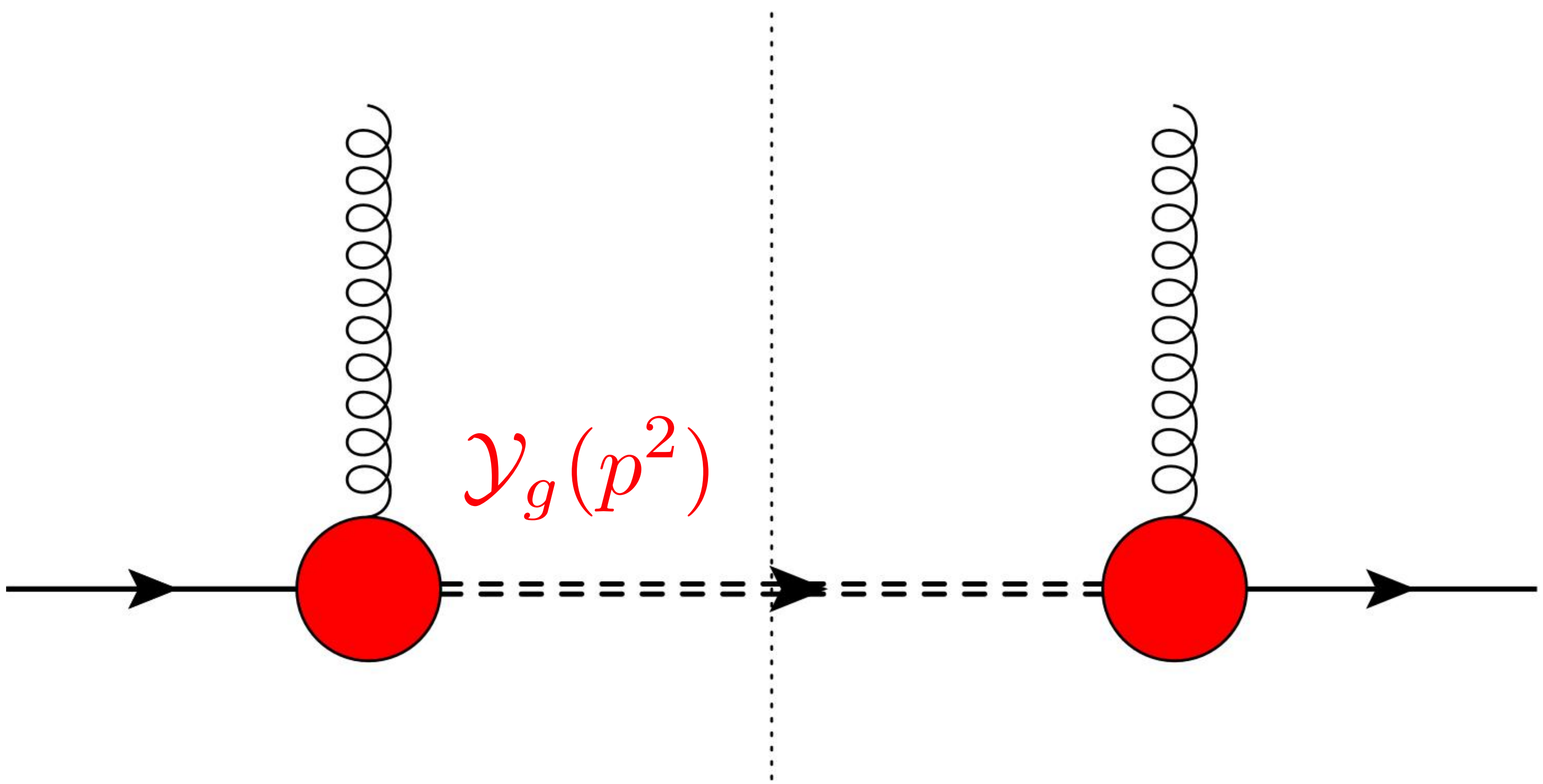
* Need for a flexible model, suited to phenomenology

* Correctly reproduces gluon collinear PDF…

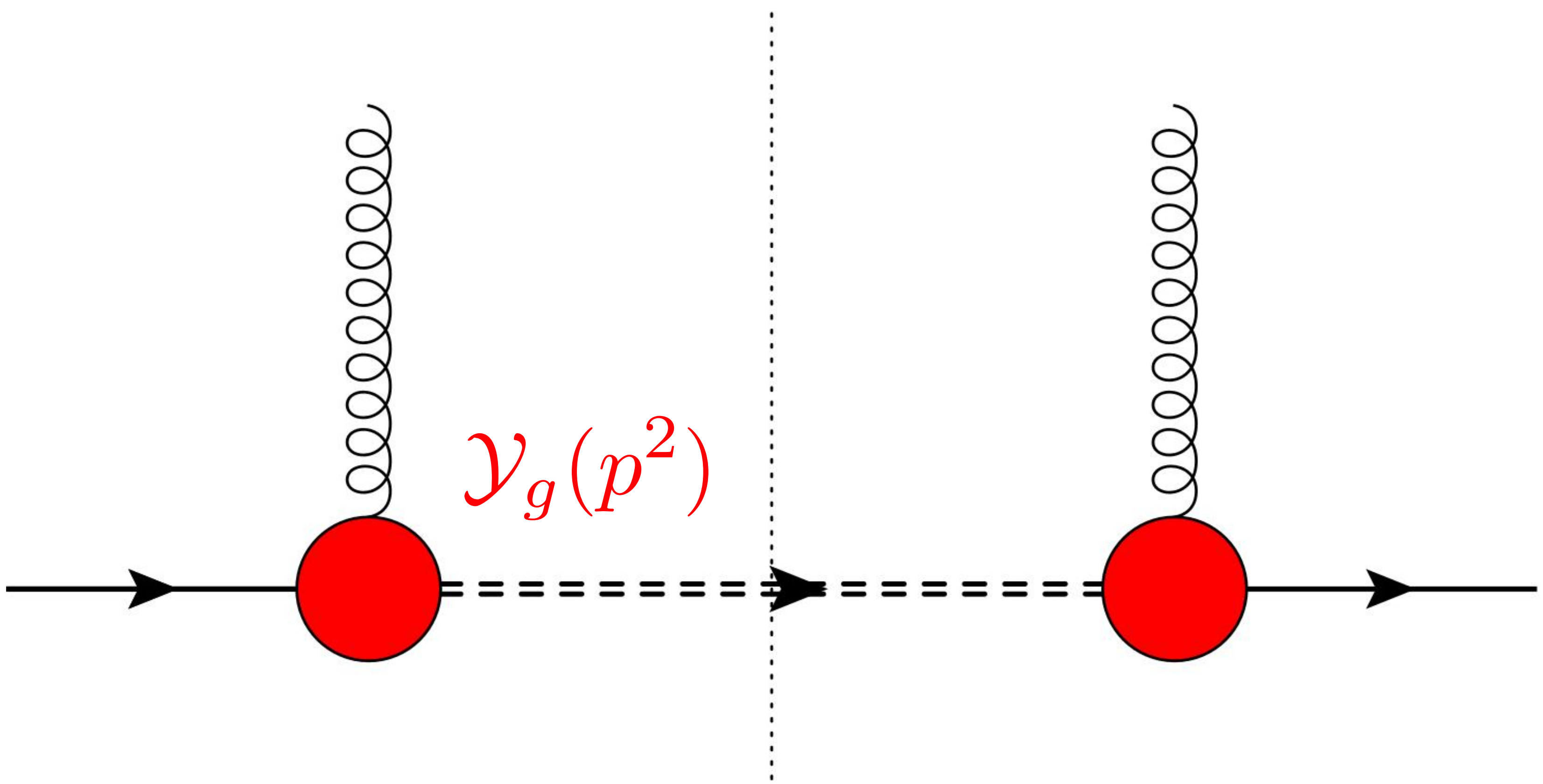
* …allows us to predict unpol. and pol. gluon TMDs

* Consistent framework for quark TMDs

Effective vertex and gluon correlator



Effective vertex and gluon correlator

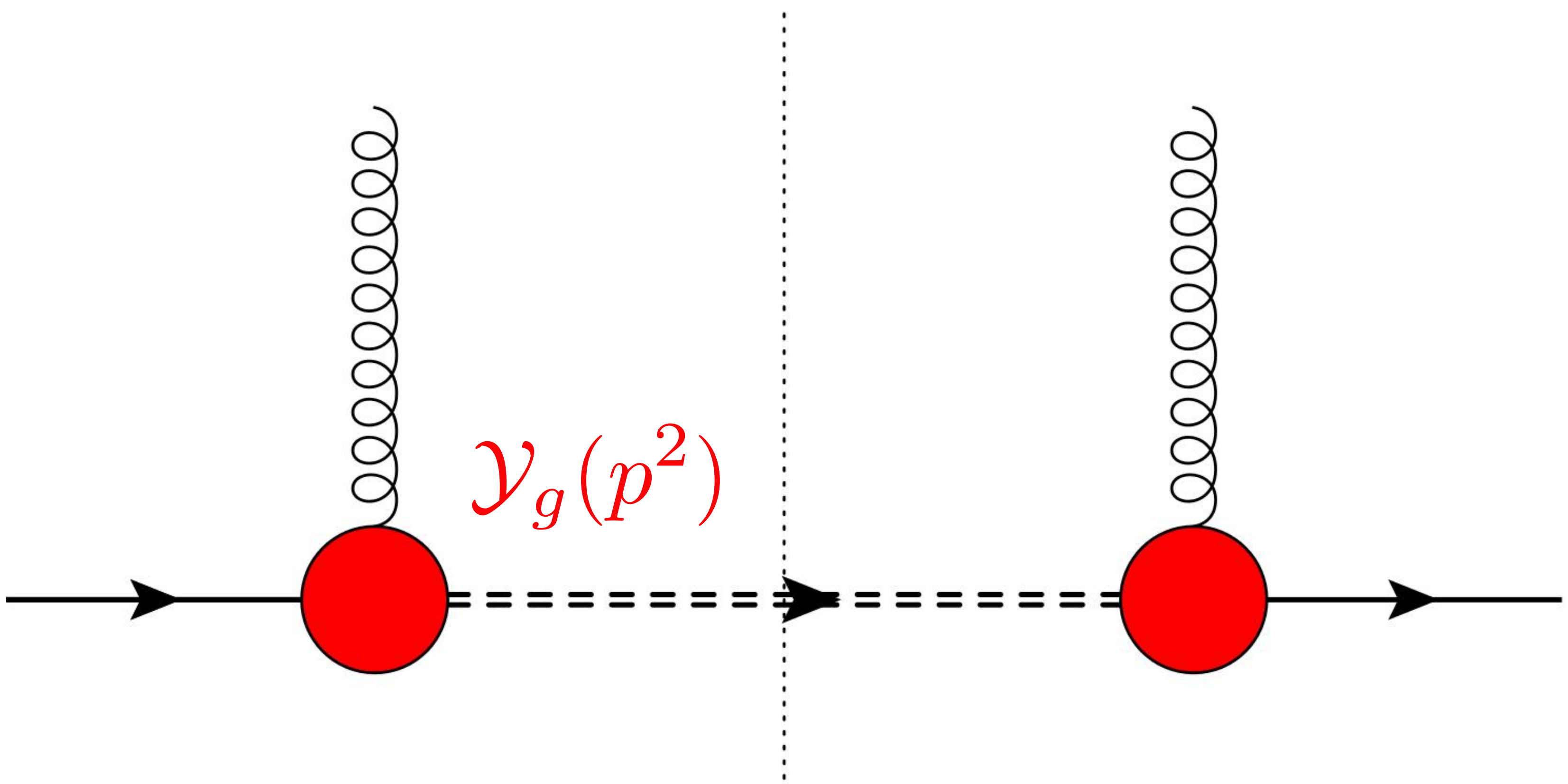


Spin-1/2 spectator (gluon)

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

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

Effective vertex and gluon correlator



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

Selection out of
12 Dirac structures

Gluon TMDs at twist-2

gluon pol.

nucleon pol.

	U	circ.	lin.
U	f_1^g		$h_1^{\perp g}$
L		g_1^g	$h_{1L}^{\perp g}$
T	$f_{1T}^{\perp g}$	g_{1T}^g	h_1^g, $h_{1T}^{\perp g}$

T-even

T-odd

Gluon TMDs at twist-2

unpolarized TMD

Boer-Mulders

gluon pol.

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T-even

T-odd

helicity TMD

worm-gear

State of the art

- First calculation of leading-twist T-even quark TMDs with scalar and axial-vector di-quarks

  [R. Jakob, P. J. Mulders, and J. Rodrigues, Nucl. Phys. **A626**, 937 (1997)]

- Gluon TMD PDFs and FFs

  [P.J. Mulders, J. Rodrigues, Phys. Rev. **D63** (2001) 094021]
  [J. Rodrigues, PhD thesis (2001)]

- Complete calculation of all the leading-twist TMDs with scalar di-quarks

  [S. Meissner, A. Metz, and K. Goeke, Phys. Rev. **D76**, 034002 (2007)]

- Inclusion of different axial-vector di-quark polarization states and nucleon-parton-spectator form factors

  (fit to PDF parametrizations) [A. Bacchetta, F. Conti, M. Radici, Phys. Rev. **D78** (2008) 074010]
  (application on azimuthal asymmetries) [A. Bacchetta, M. Radici, F. Conti, M. Guagnelli, Eur. Phys. J. **A45** (2010) 373-388]

How to improve the description?

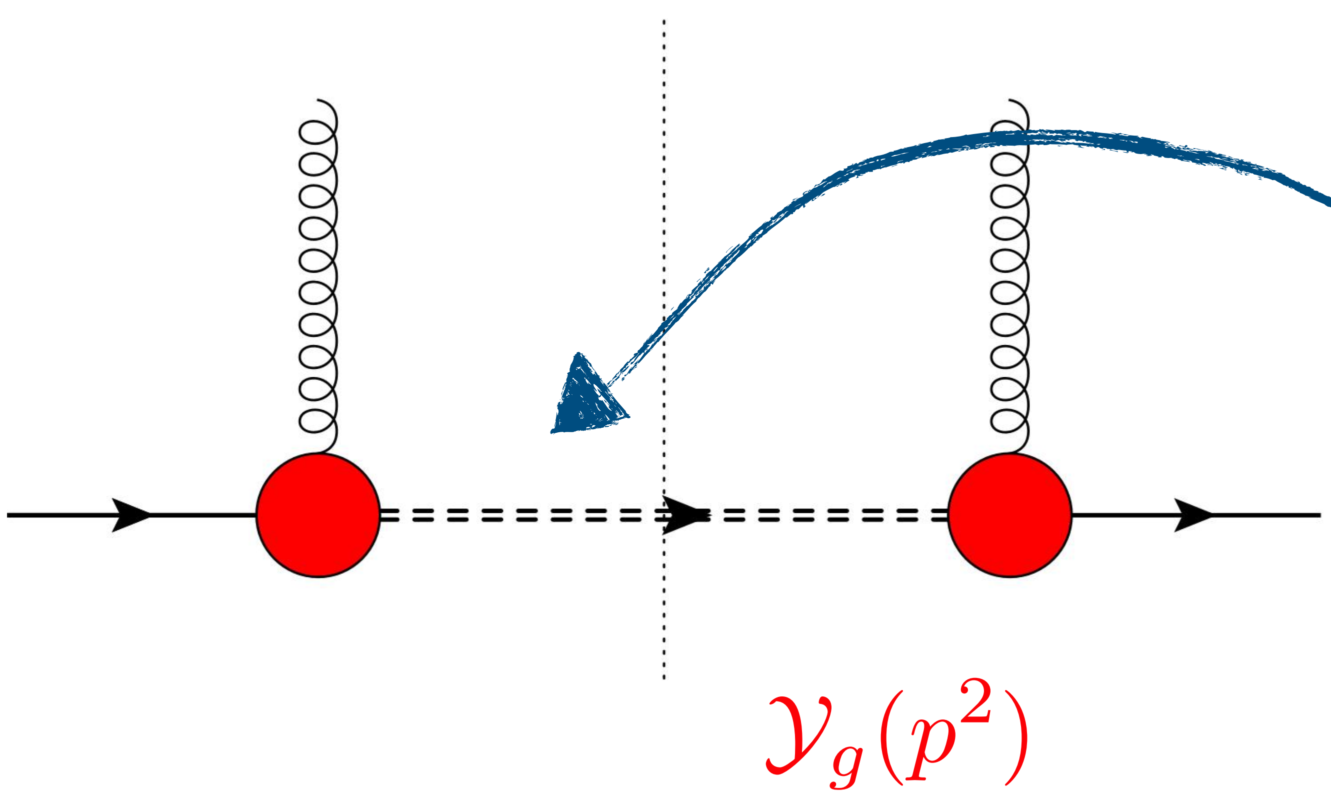
Spectator-system spectral-mass function

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

spectral-mass function

spectator-model TMD

[Inspired by G.R. Goldstein, J.O.G. Hernandez, S. Liuti, Phys.Rev. **D84** (2011) 034007]



Instead of a single on-shell spectator, a continuum of spectators

Spectator-system spectral-mass function

spectral-mass function

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

spectator-model TMD

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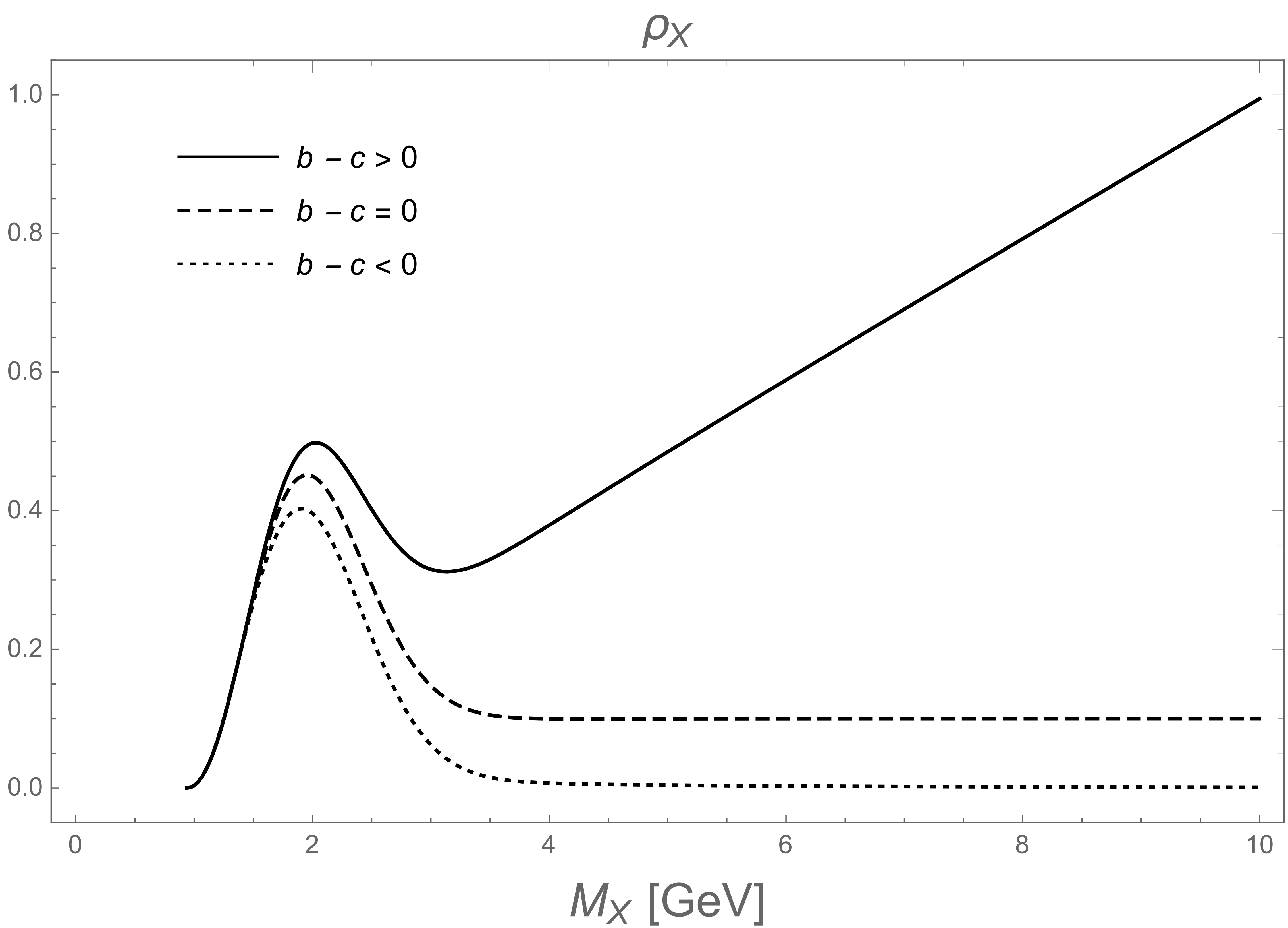
$$\rho_X\left(M_X;\{X^{(\mathrm{pars})}\} \equiv \{A,B,b,c,C,M_D,\sigma\}\right) = \mu^{2b}\left[\frac{A}{B+\mu^{2c}} + \frac{C}{\pi\sigma}e^{-\frac{(M_X-M_D)^2}{\sigma^2}}\right]$$

low-*x* (high-μ^2) tail $\propto$ *(b - c)*
2*N*-quark contribution

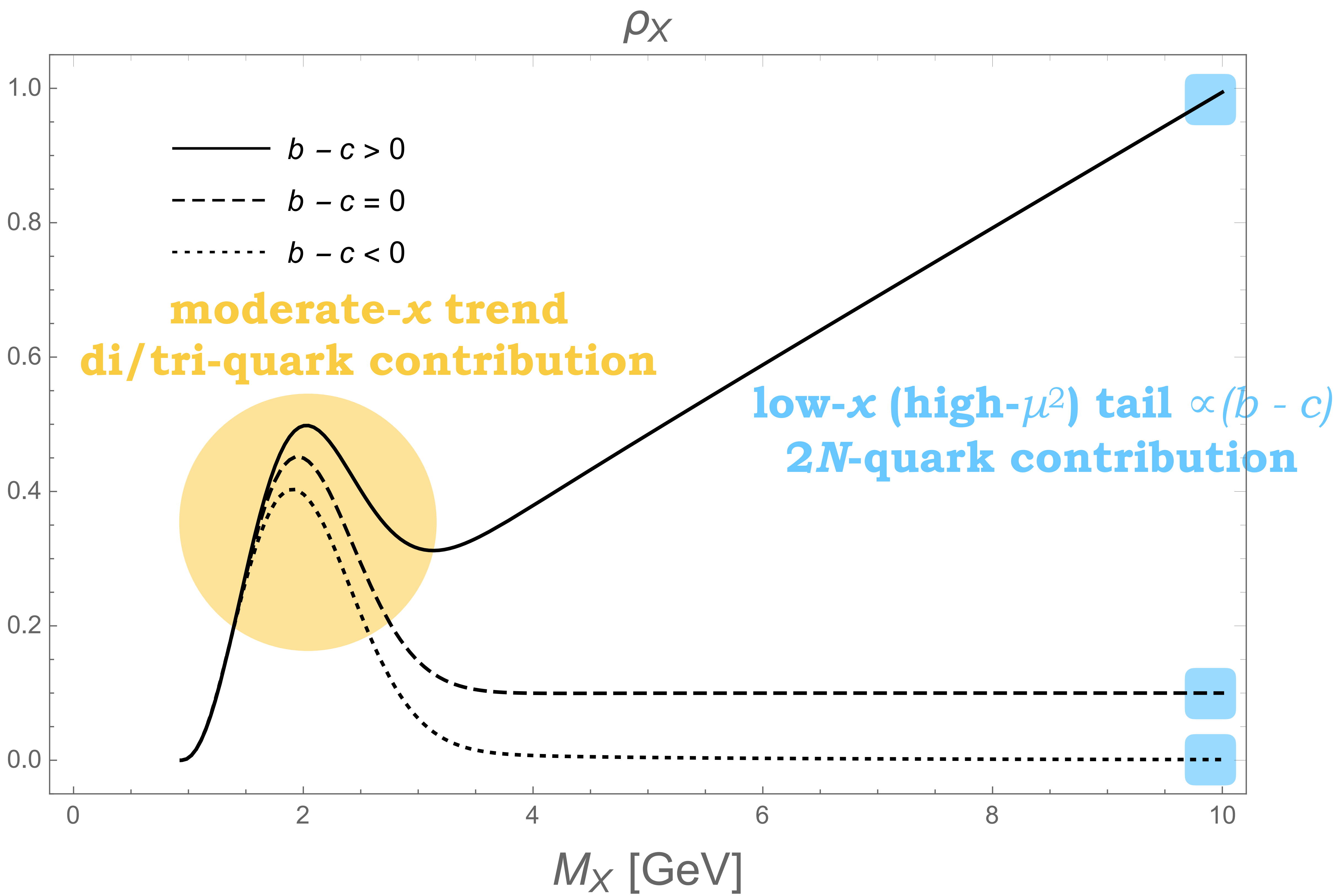
$$\mu^2 = M_X^2 - (M_H - m_{q/g})^2$$

moderate-*x* trend
tri-quark contribution

Spectral function vs *(b - c)*



Spectral function vs $(b - c)$



Metodology

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

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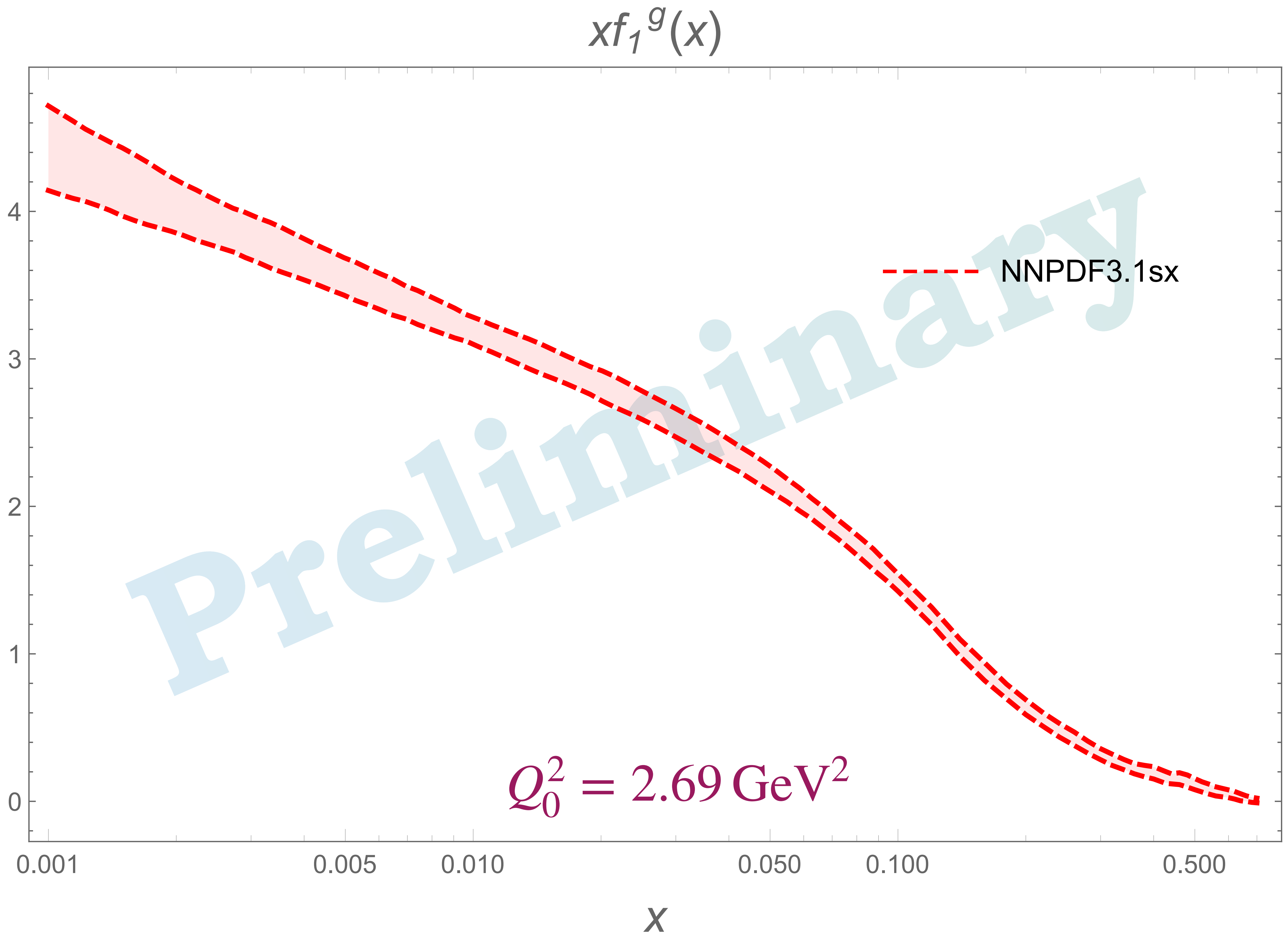
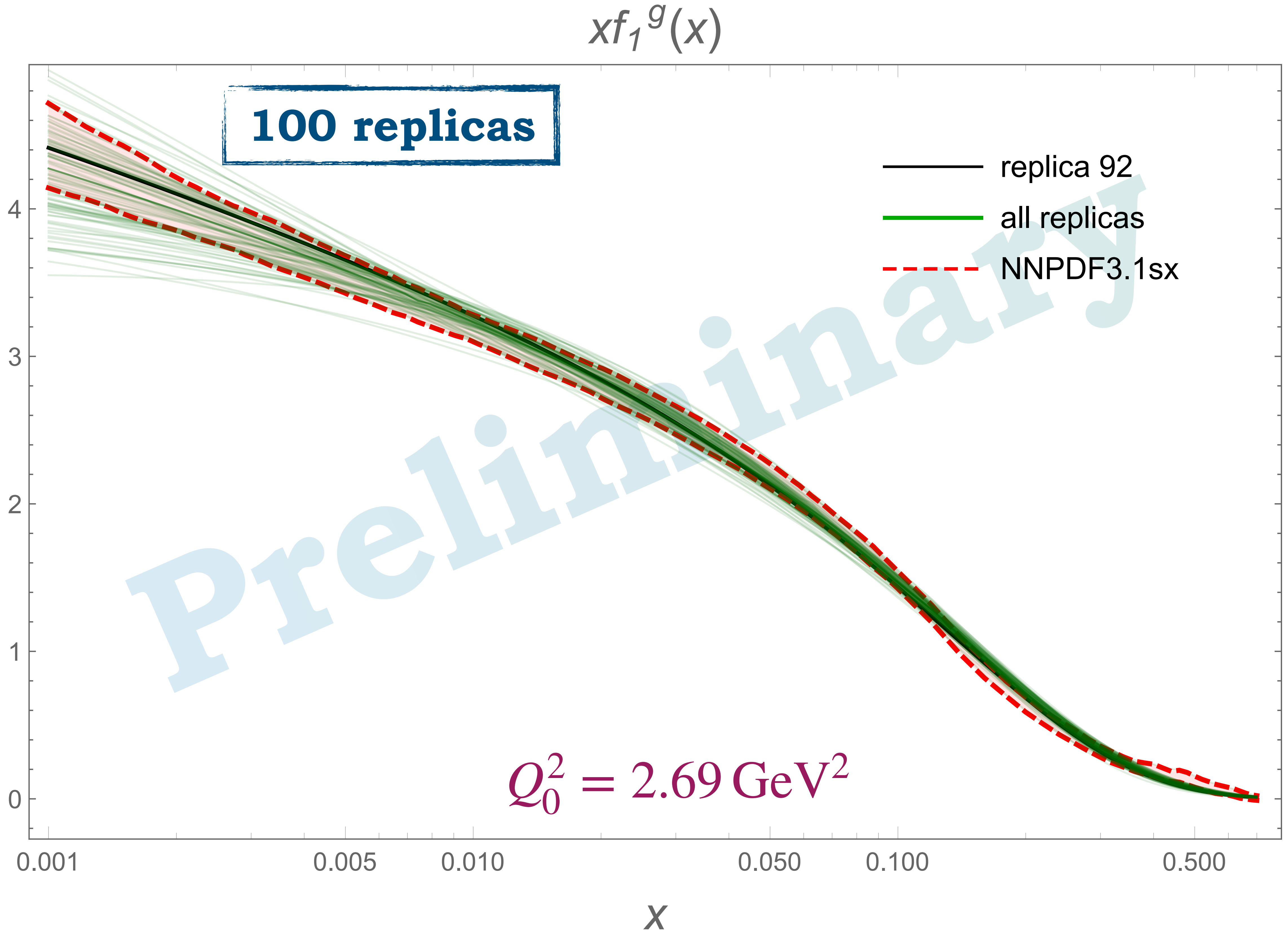
☑ **Fit** model parameters to reproduce f_1 and g_1 **collinear** PDFs

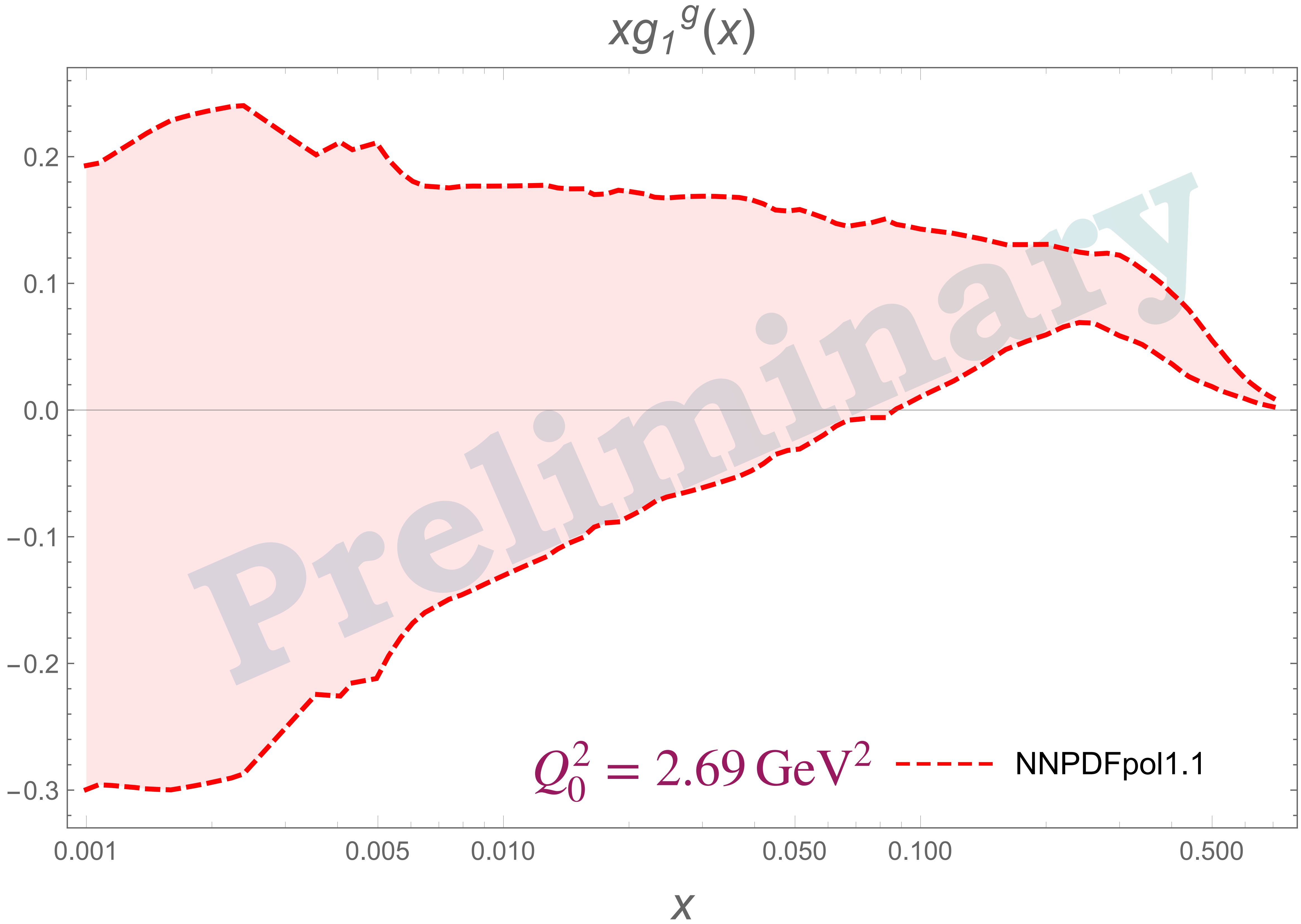
Unpolarized gluon PDF



Unpolarized gluon PDF



Helicity gluon PDF



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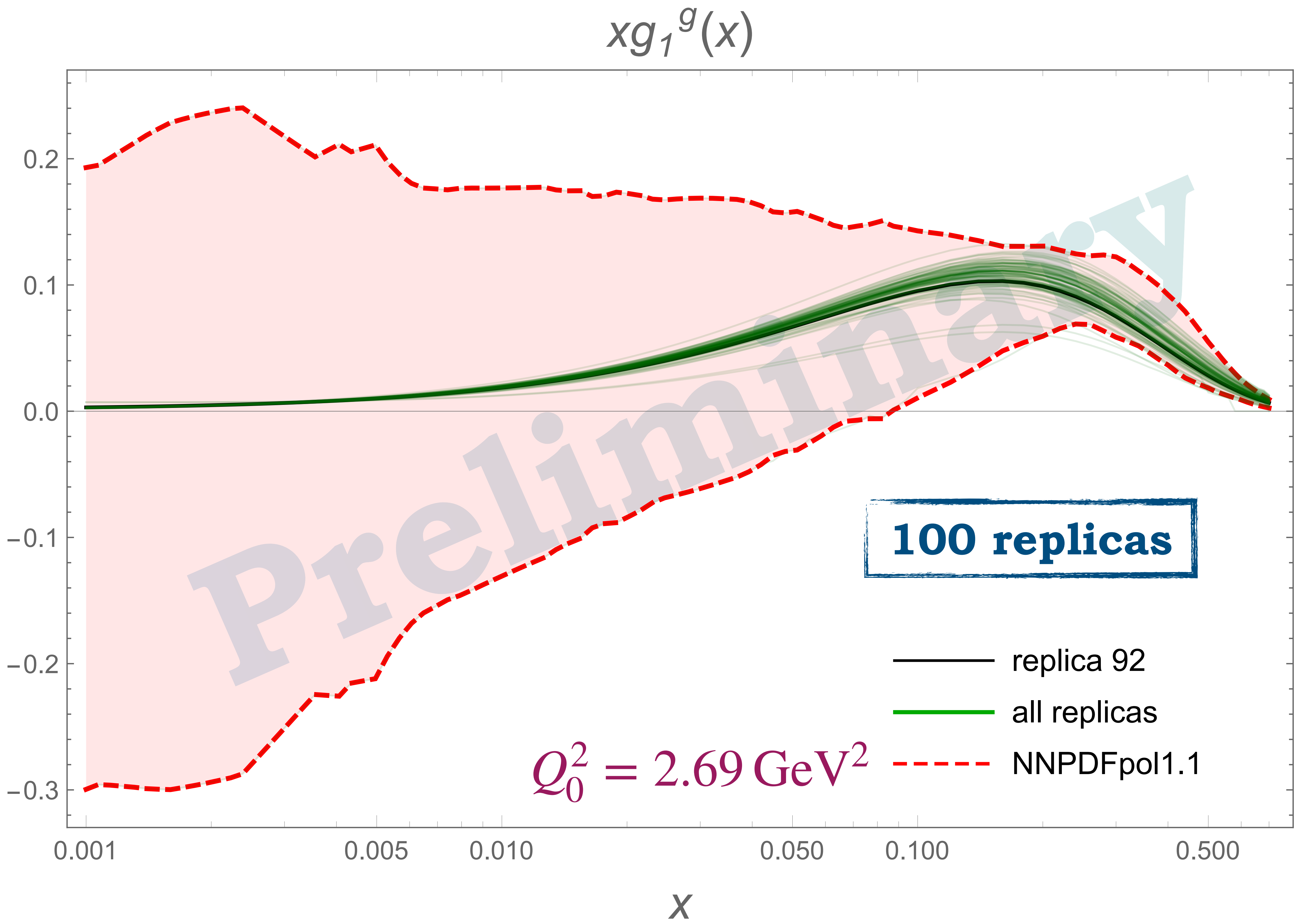
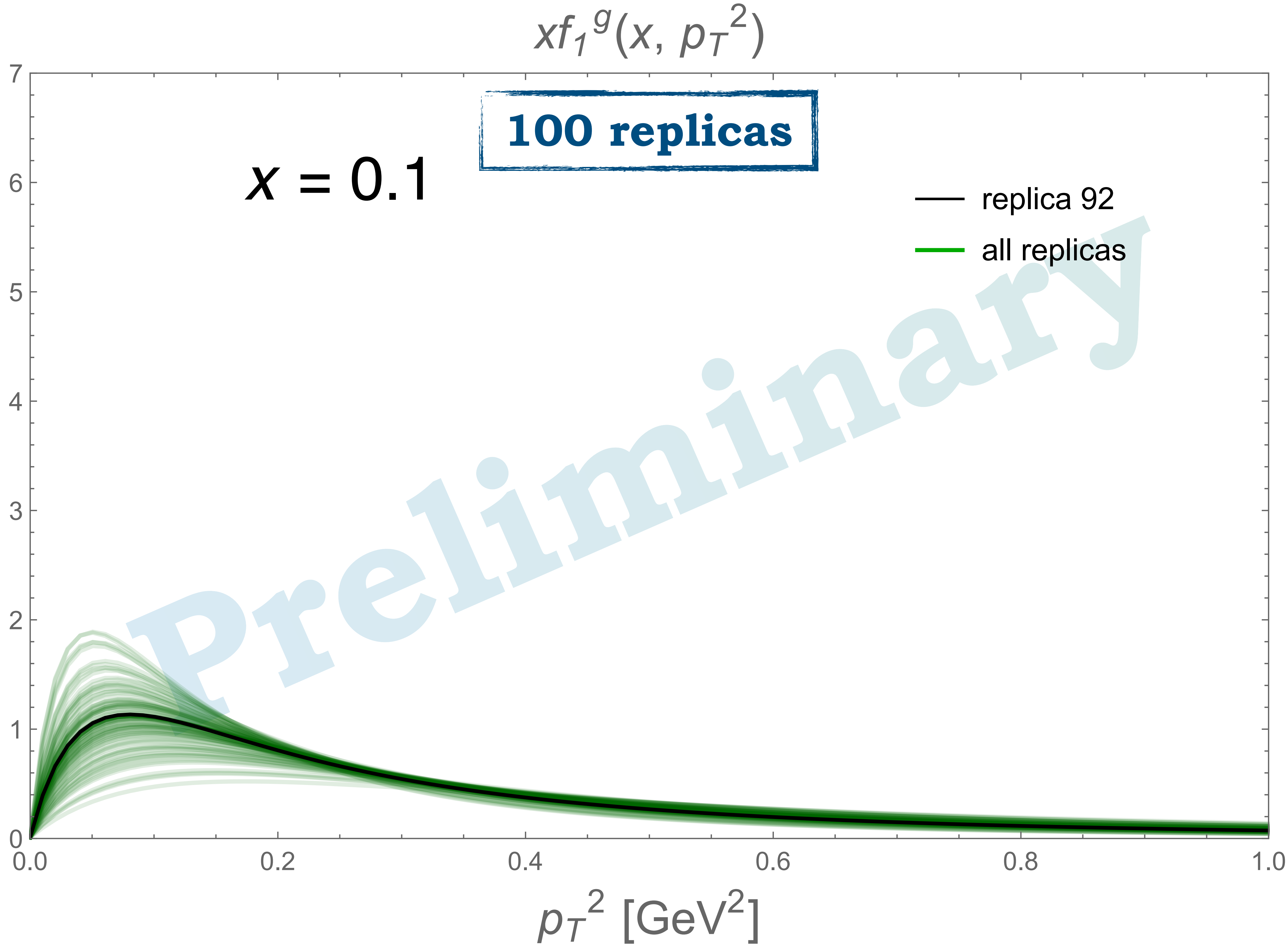


Unpolarized gluon TMD



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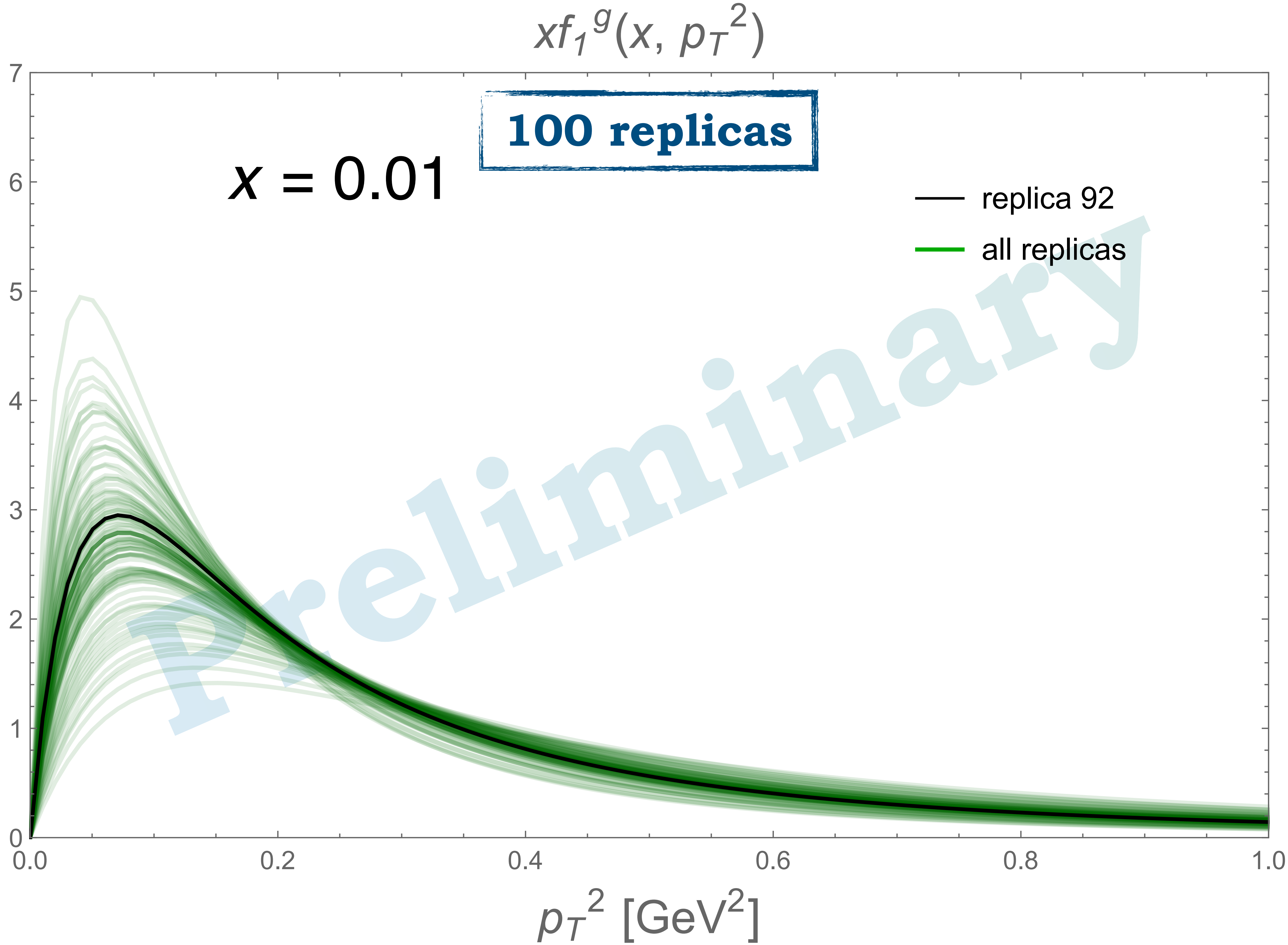

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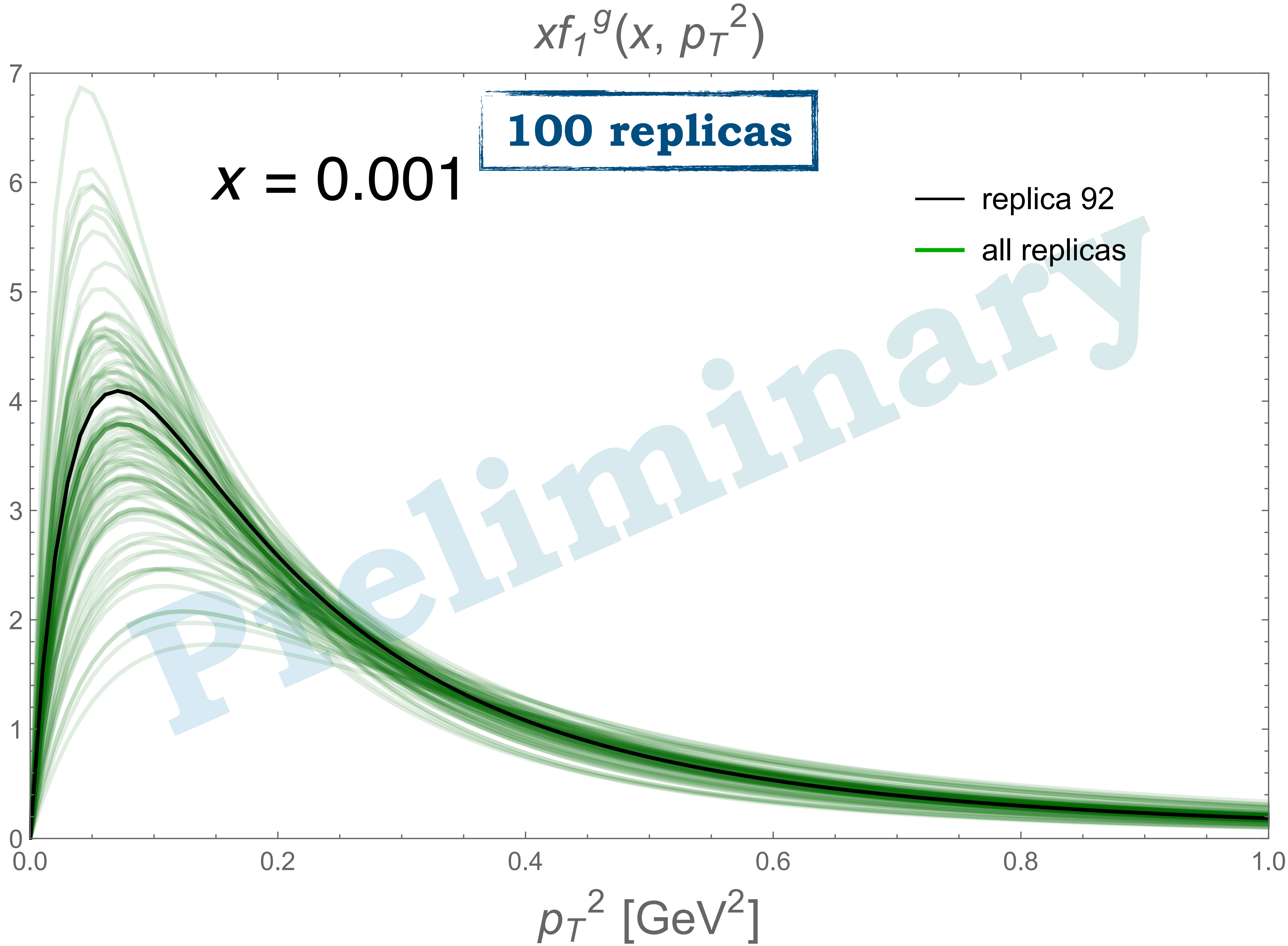

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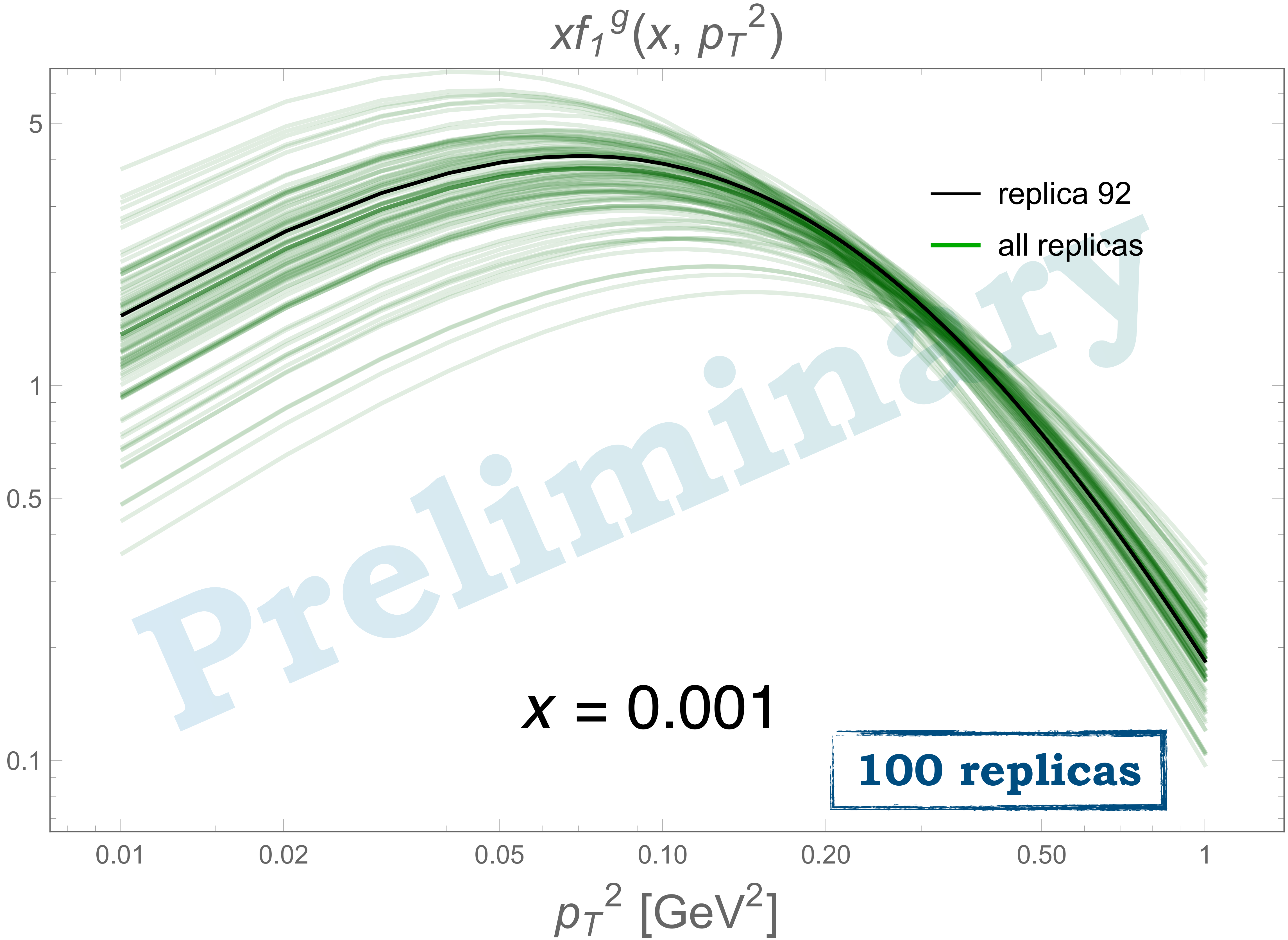

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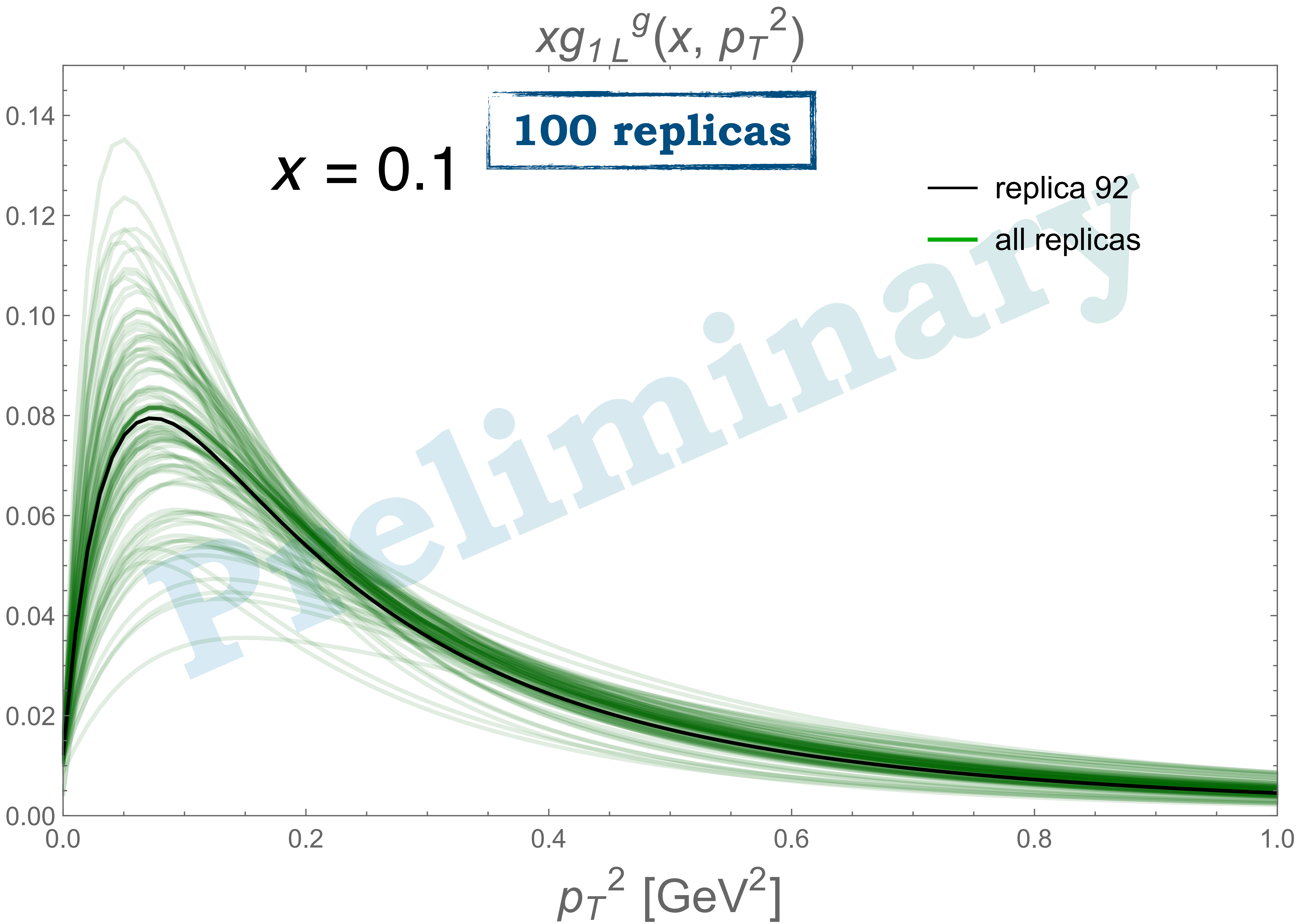

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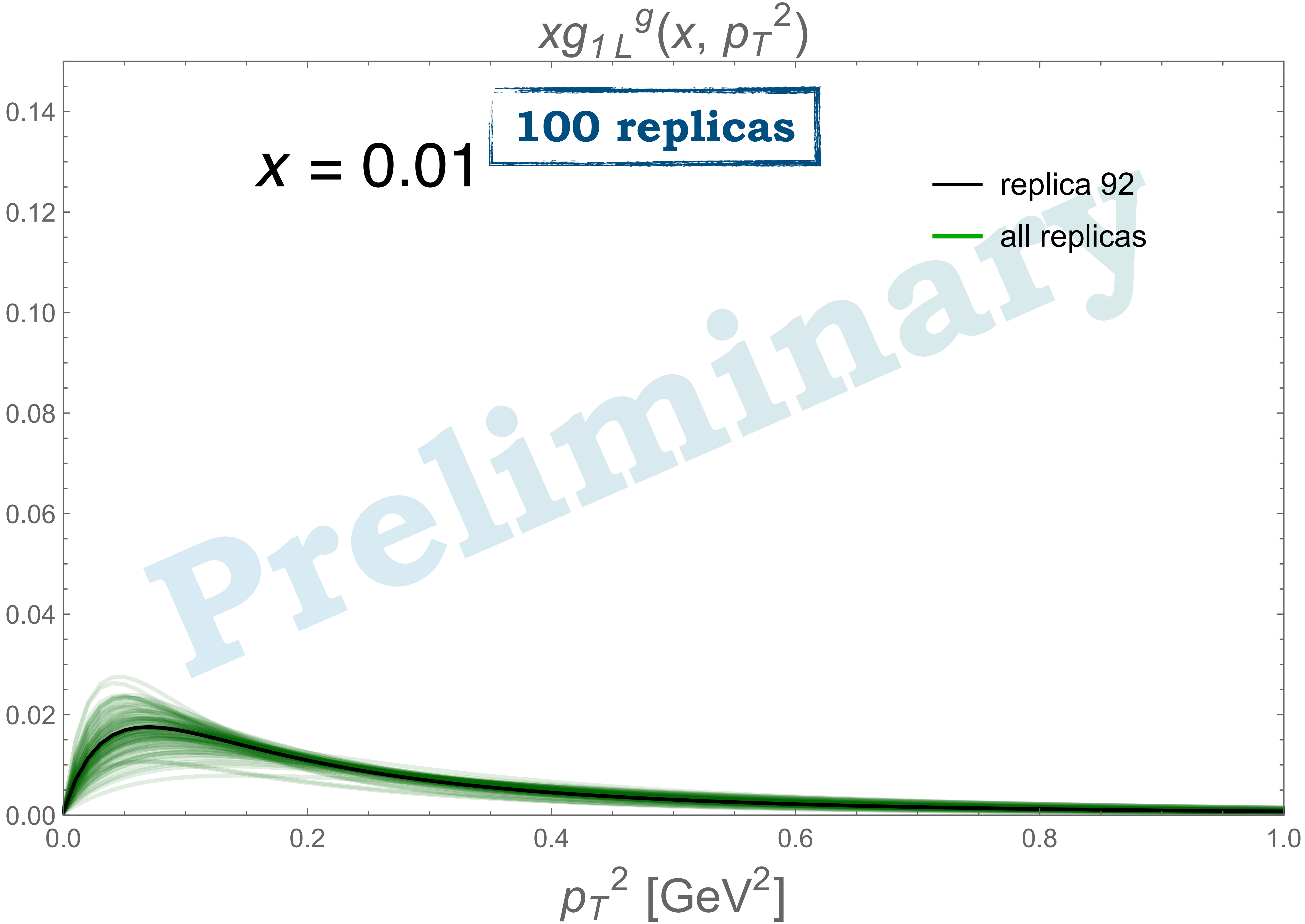

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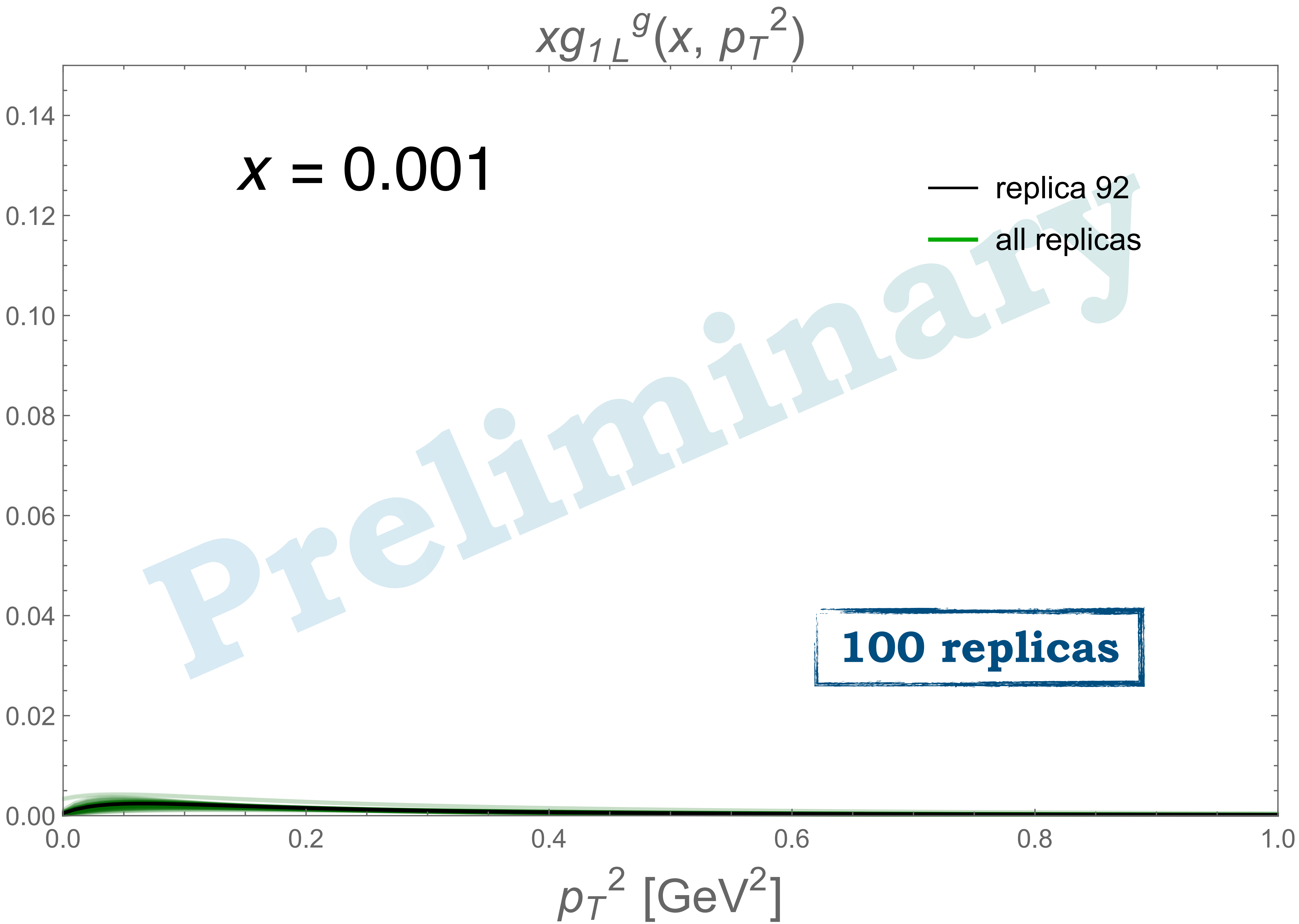
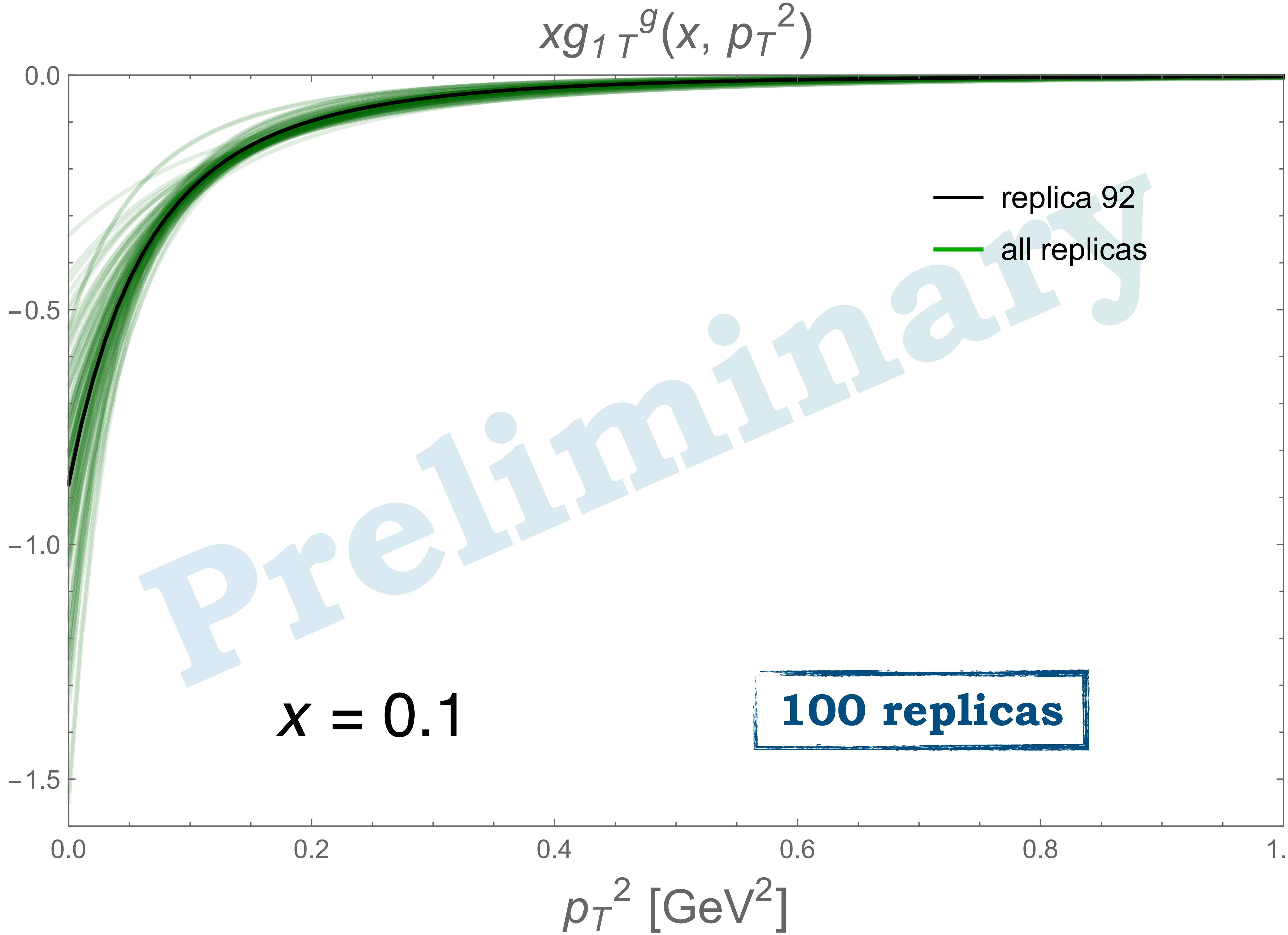


Worm-gear gluon TMD



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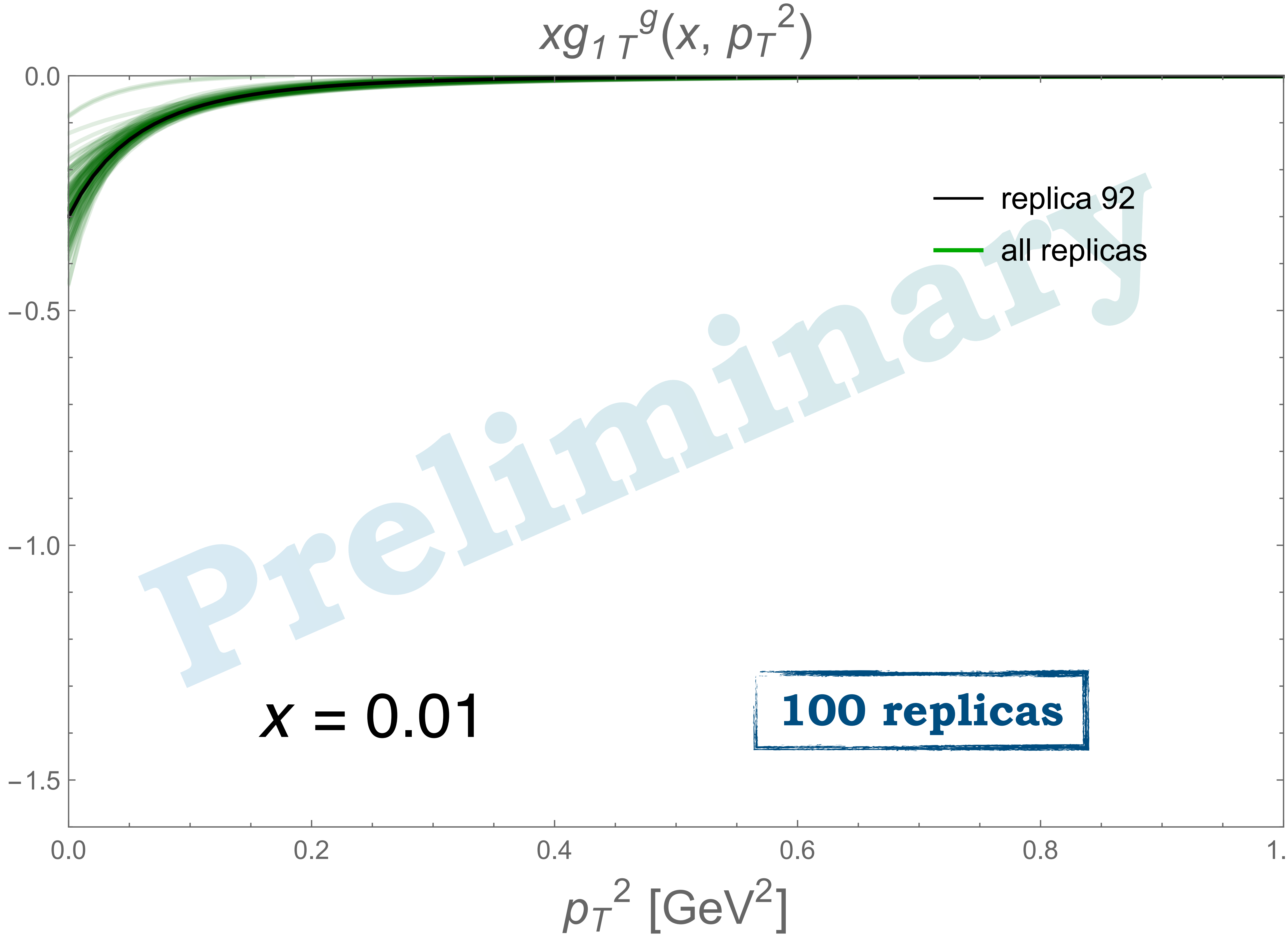

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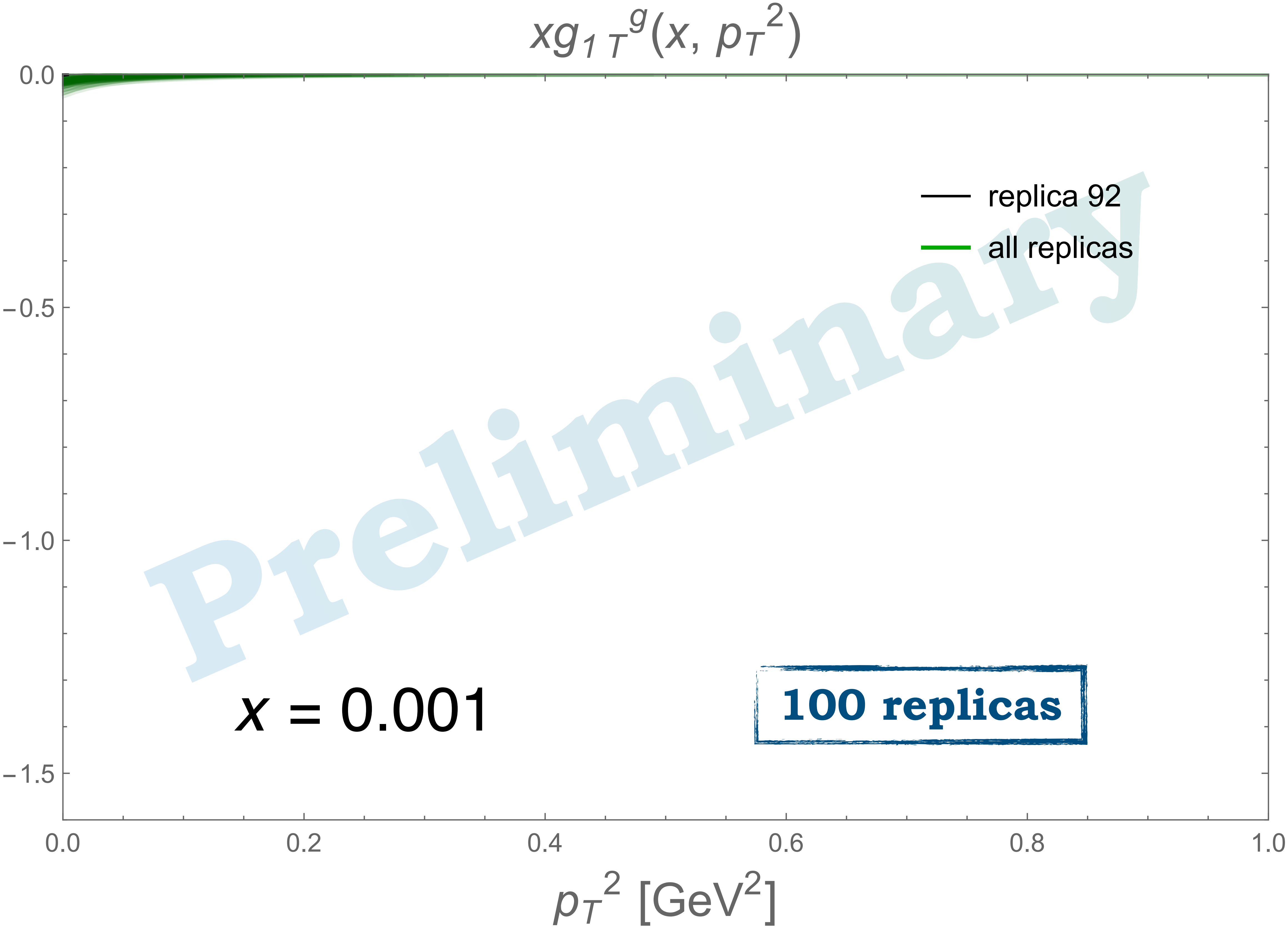
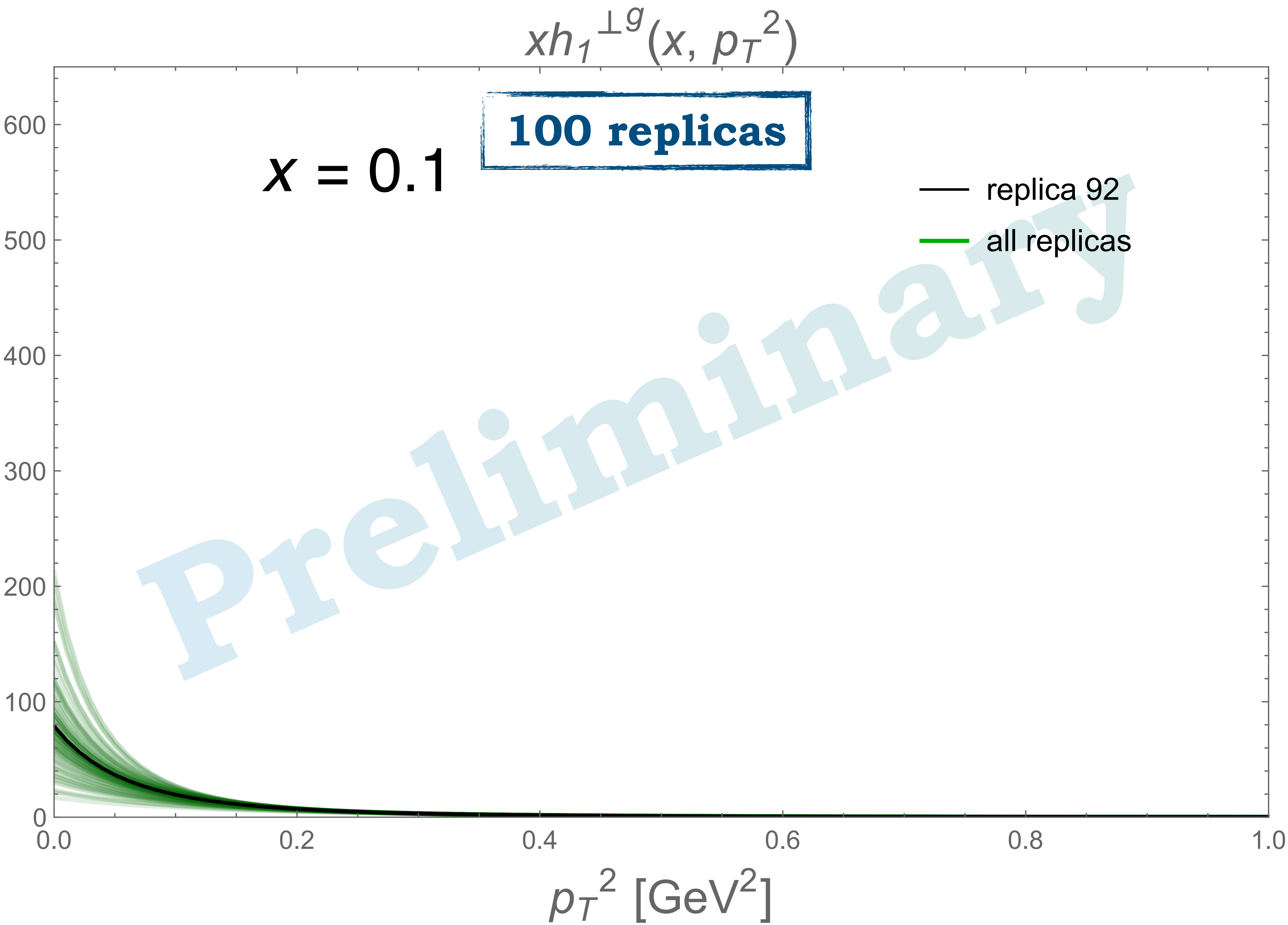


Boer-Mulders gluon TMD



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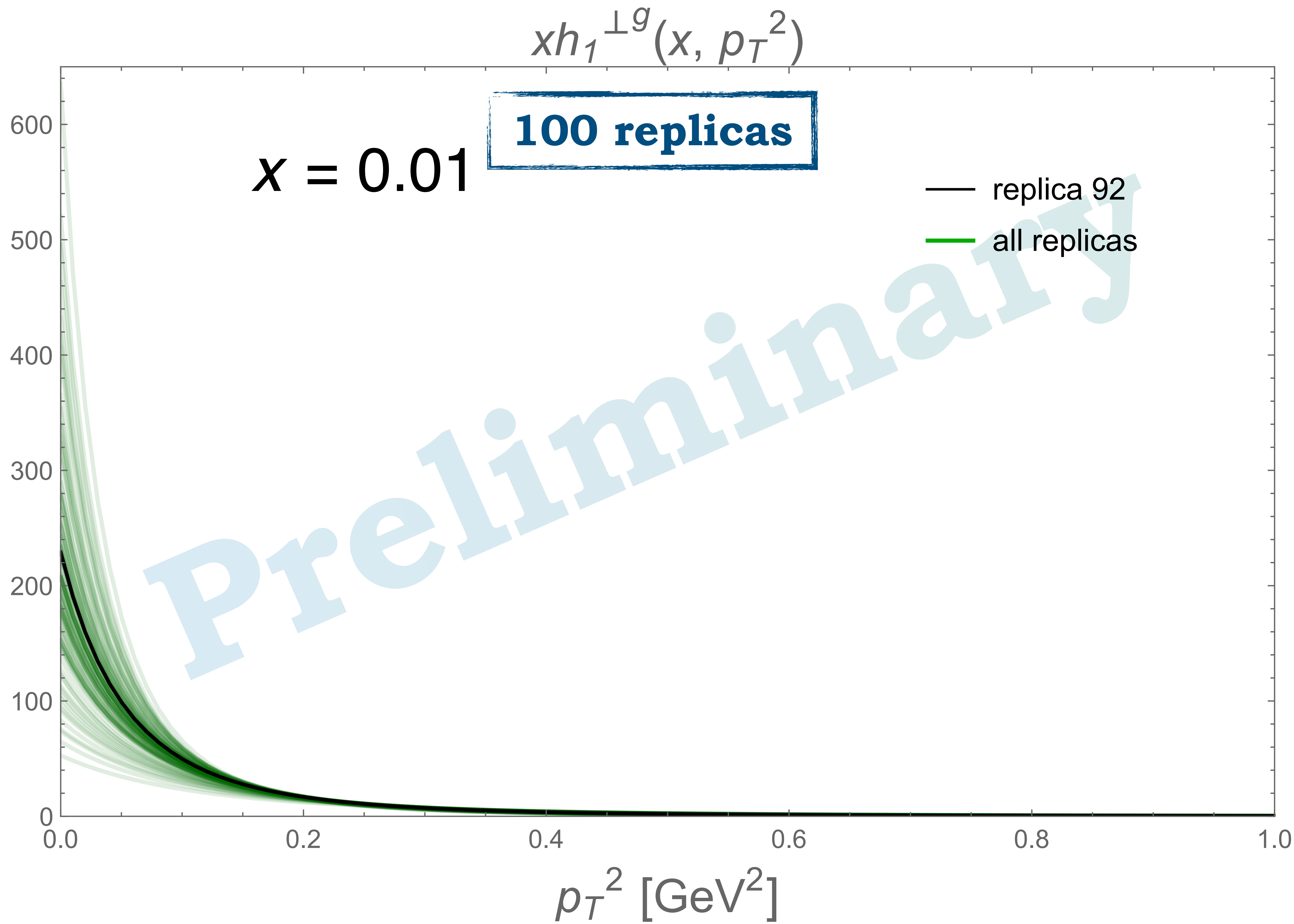

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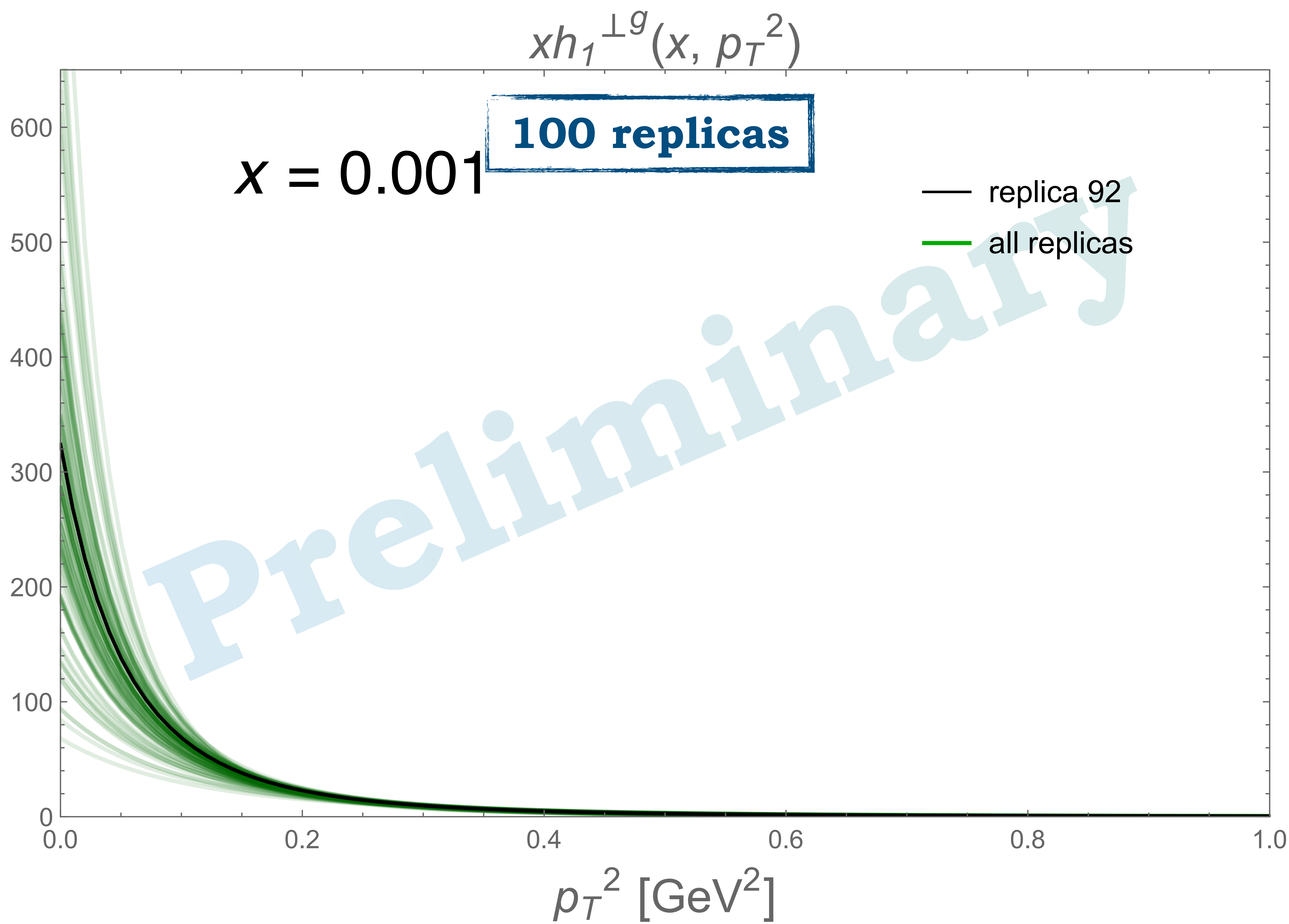
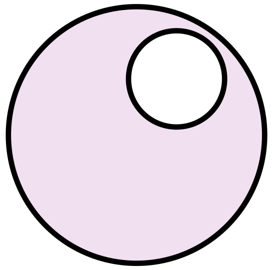


Bottom line

- Each TMD shows a distinctive x- and p_T-behavior

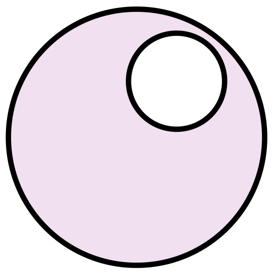
- Data on gluon TMDs will exclude many replicas and constrain parameters not yet so well constrained by collinear PDFs

ρ-densities



[unpol/unpol] $f_1(x, p_x, p_y)$

ρ-densities



[unpol/unpol]

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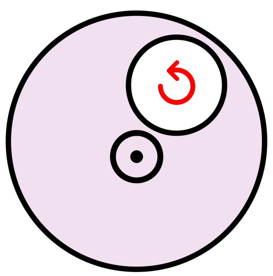
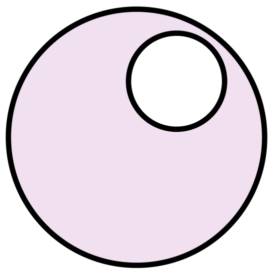


[↺/+]

$$\frac{1}{2}\left[f_1(x, p_x, p_y) + g_{1L}(x, p_x, p_y)\right]$$

ρ-densities



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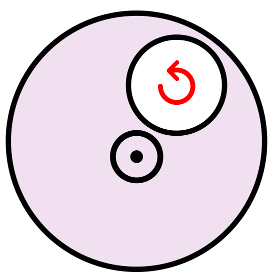

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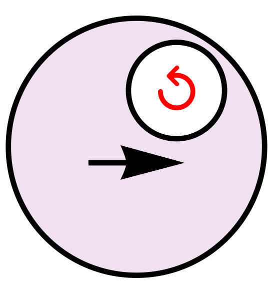
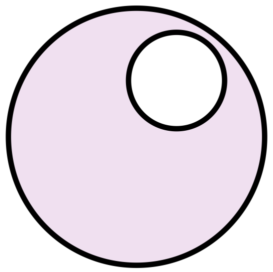


[↺/→]

$$\frac{1}{2}\left[f_1(x, p_x, p_y) - \frac{p_x}{M_H} g_{1T}(x, p_x, p_y)\right]$$

ρ-densities



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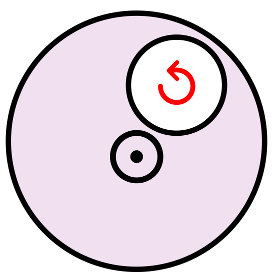
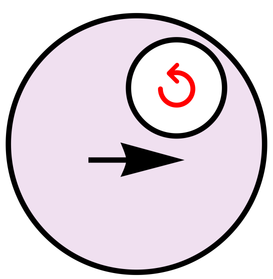


[↺/+] $\frac{1}{2}\left[f_1(x, p_x, p_y) + g_{1L}(x, p_x, p_y)\right]$



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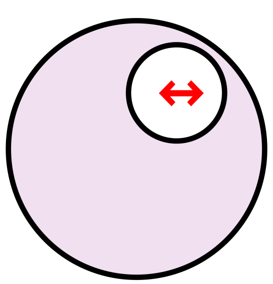
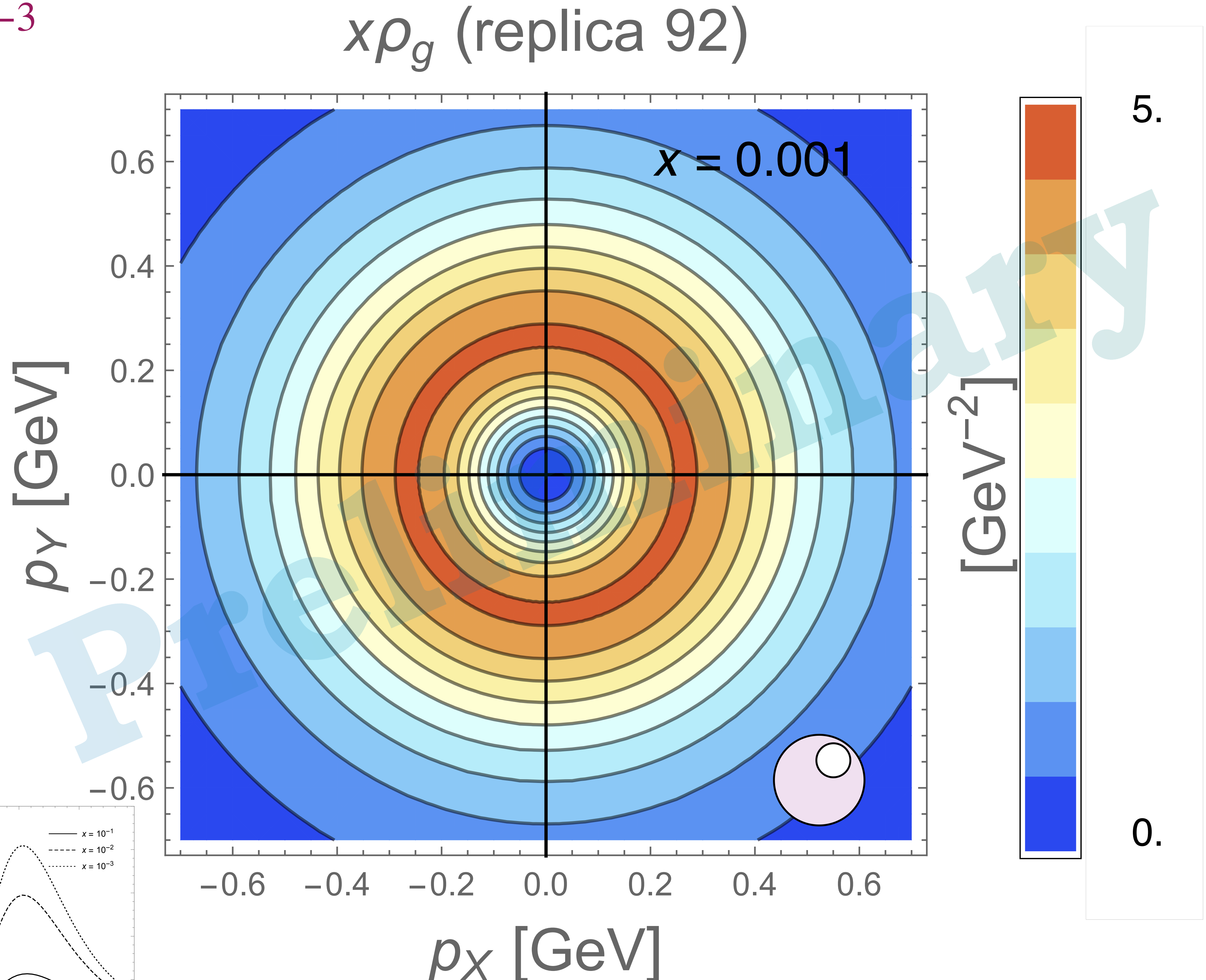
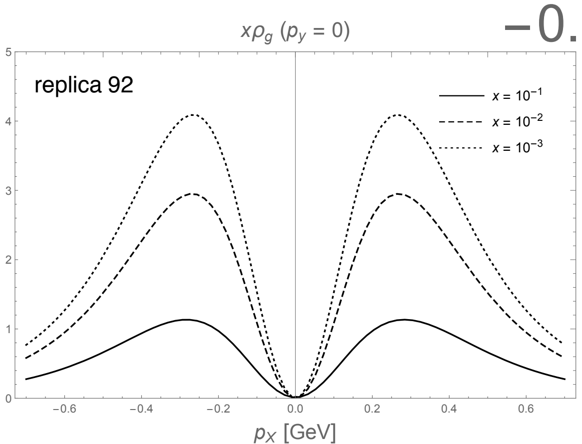


[↔/unpol] $\frac{1}{2}\left[f_1(x, p_x, p_y) + \frac{p_x^2 - p_y^2}{2M_H^2} h_1^{\perp}(x, p_x, p_y)\right]$

[unpol/unpol] ρ-density

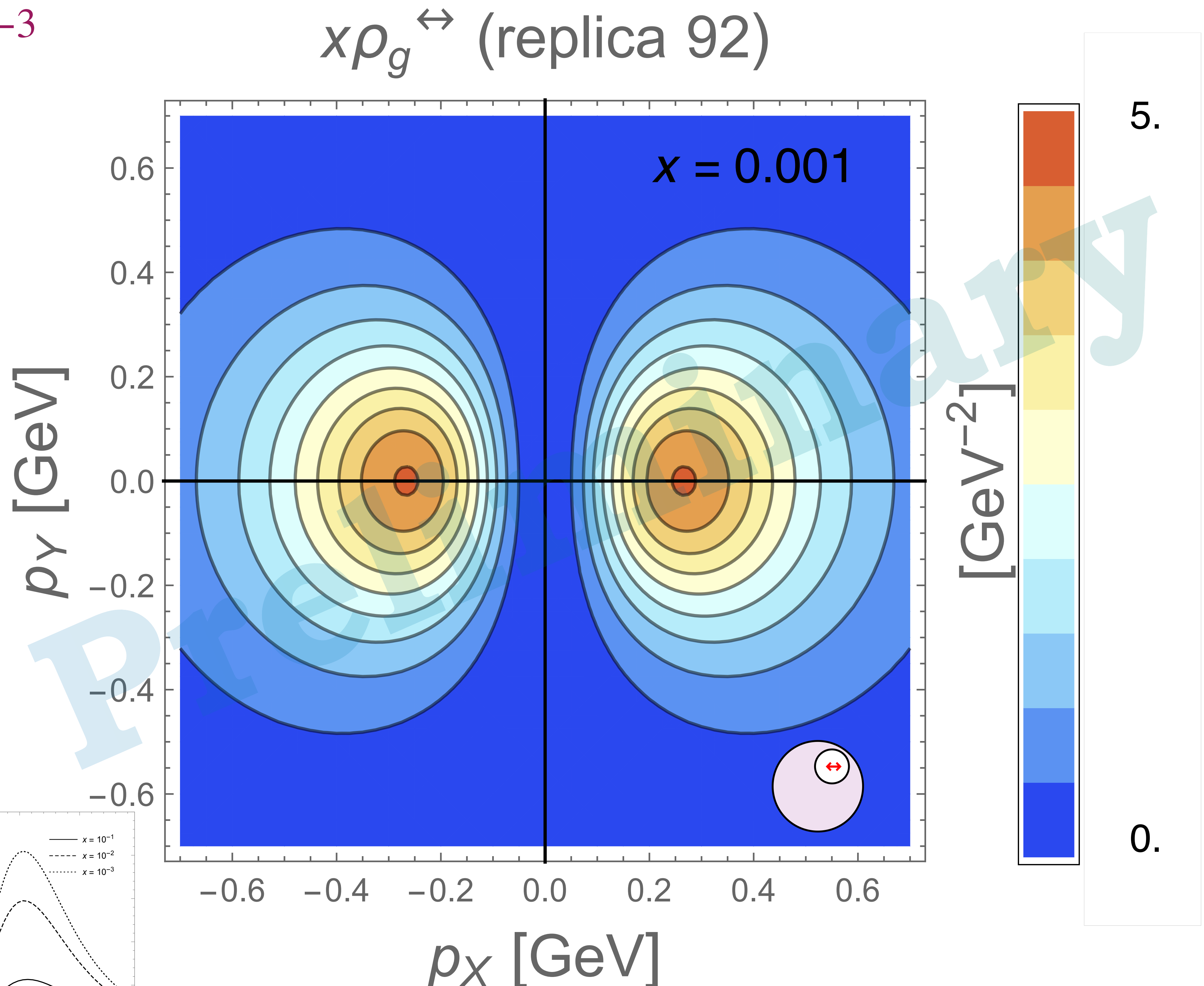
$x = 10^{-3}$

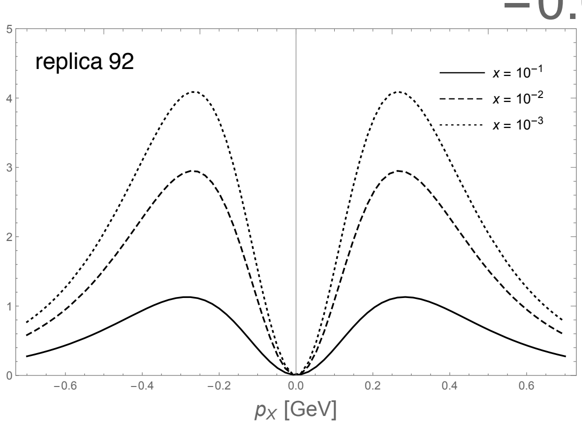




[↔/unpol] ρ-density (BM)

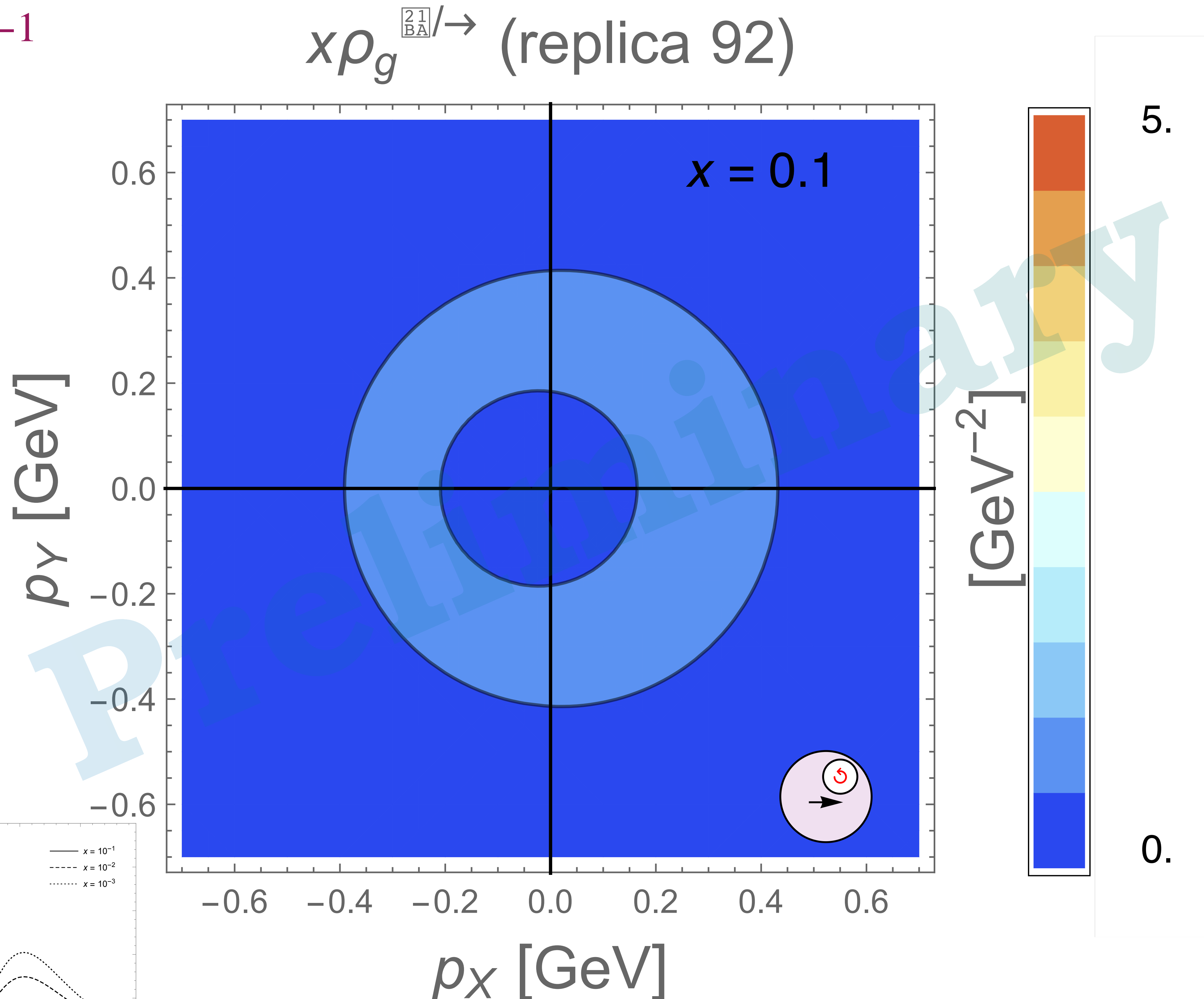
$x = 10^{-3}$

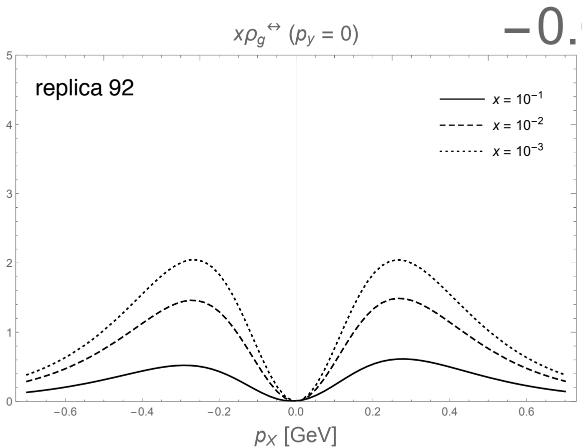




[↺/→] ρ-density (WG)

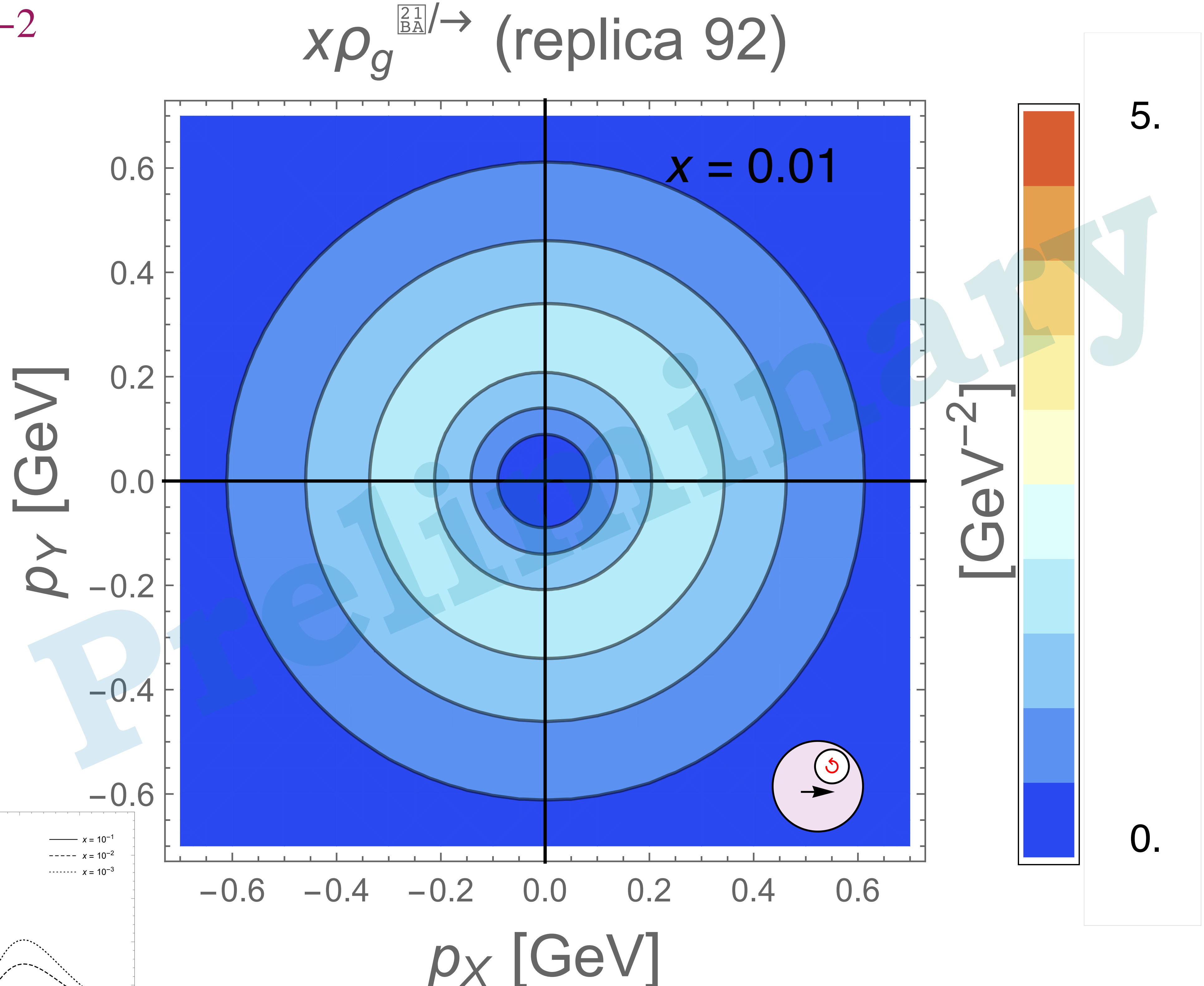
$x = 10^{-1}$

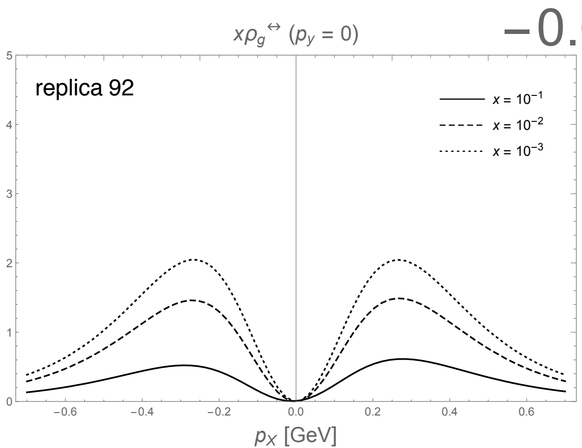




[↺/→] ρ-density (WG)

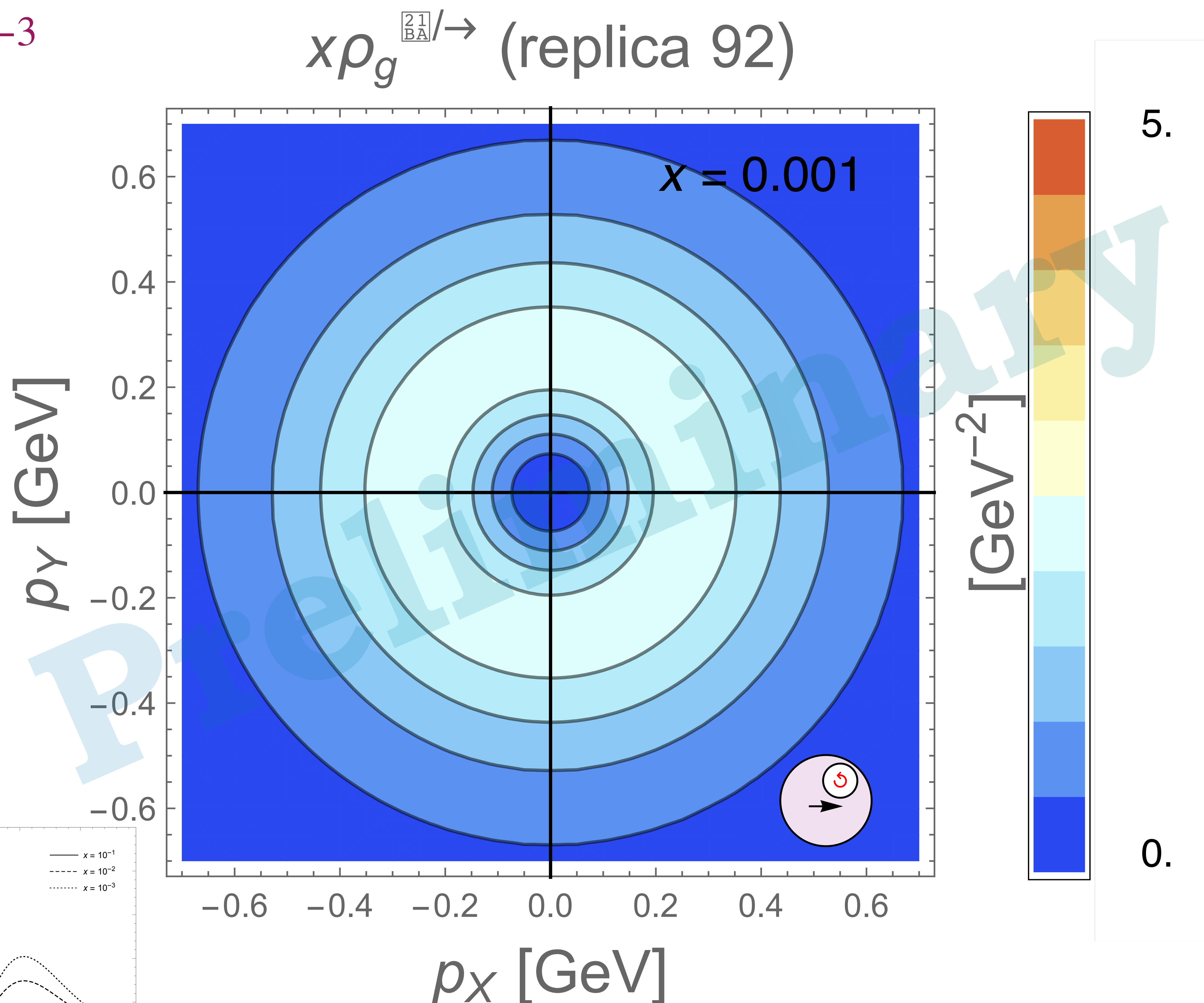
$x = 10^{-2}$

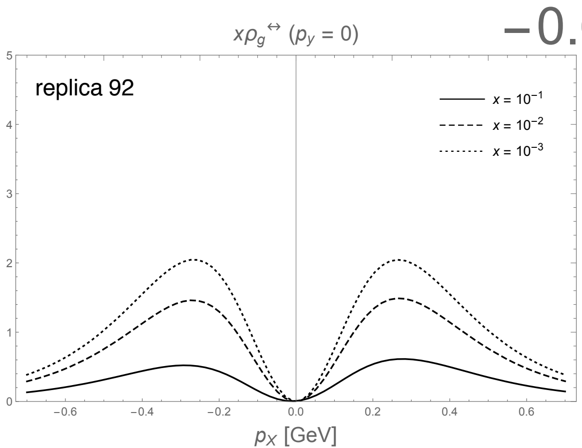




[↺/→] ρ-density (WG)

$x = 10^{-3}$





Conclusions & Outlook

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- ☐ Extension to quark TMDs in the same framework

Conclusions & Outlook

- ☑ 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
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Conclusions & Outlook

- [x] Systematic calculation of all twist-2 T-even gluon TMDs
- [x] Spectral mass to catch small- and moderate-x effects
- [x] **Simultaneous fit** of f_1 and g_1 PDFs
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- [ ] Inclusion of **BFKL** input on small-x tail
- [ ] Extension to quark TMDs in the same framework
- [ ] T-odd TMDs with one-gluon exchange in eikonal approximation
- [ ] Use of models to estimate impact of new data

Backup slides

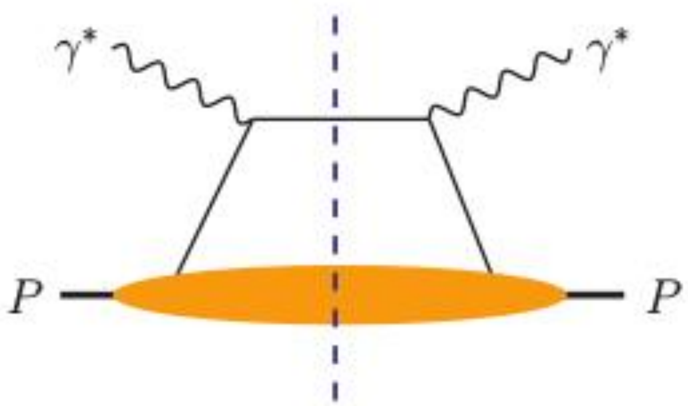
Parton densities: an overview

p_T - integrated

p_T - unintegrated

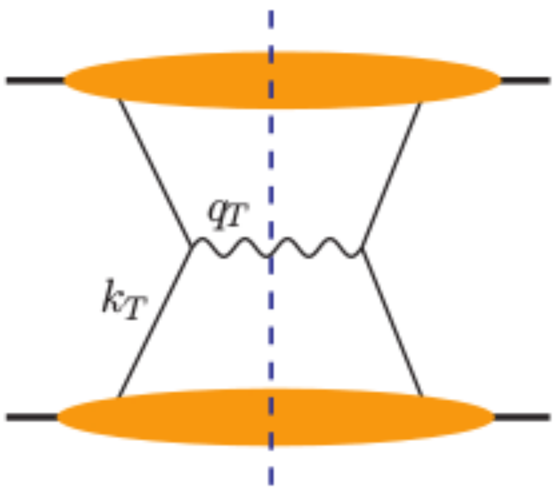
Collinear PDFs

- Inclusive processes
- p_T ~ hardest scale



TMDs

- (Semi-)inclusive processes
- p_T << hardest scale

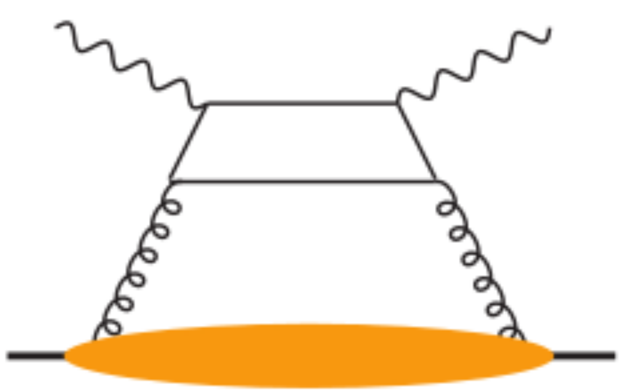


GPDs

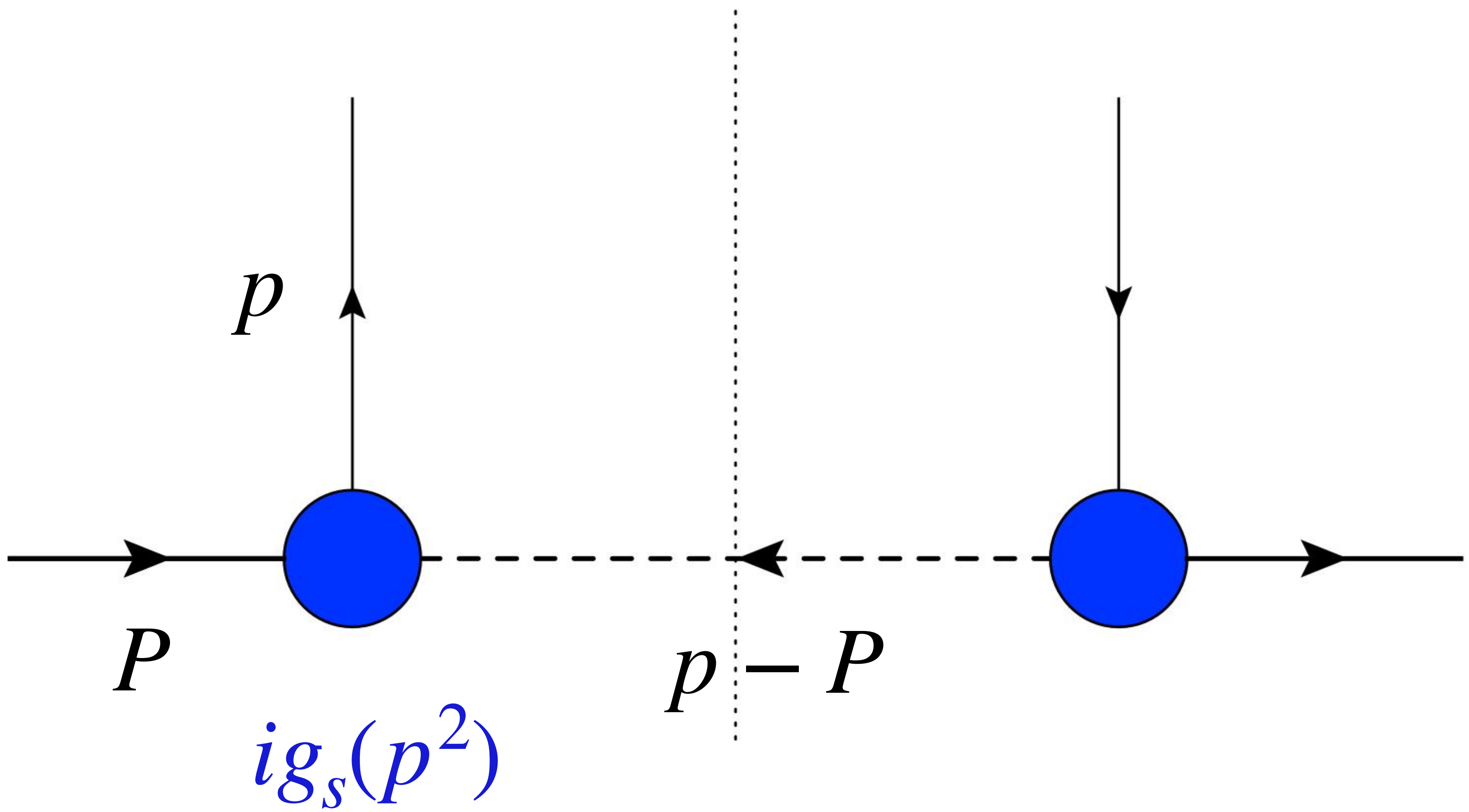
- Exclusive processes
- *Skewness* effects

UGDs

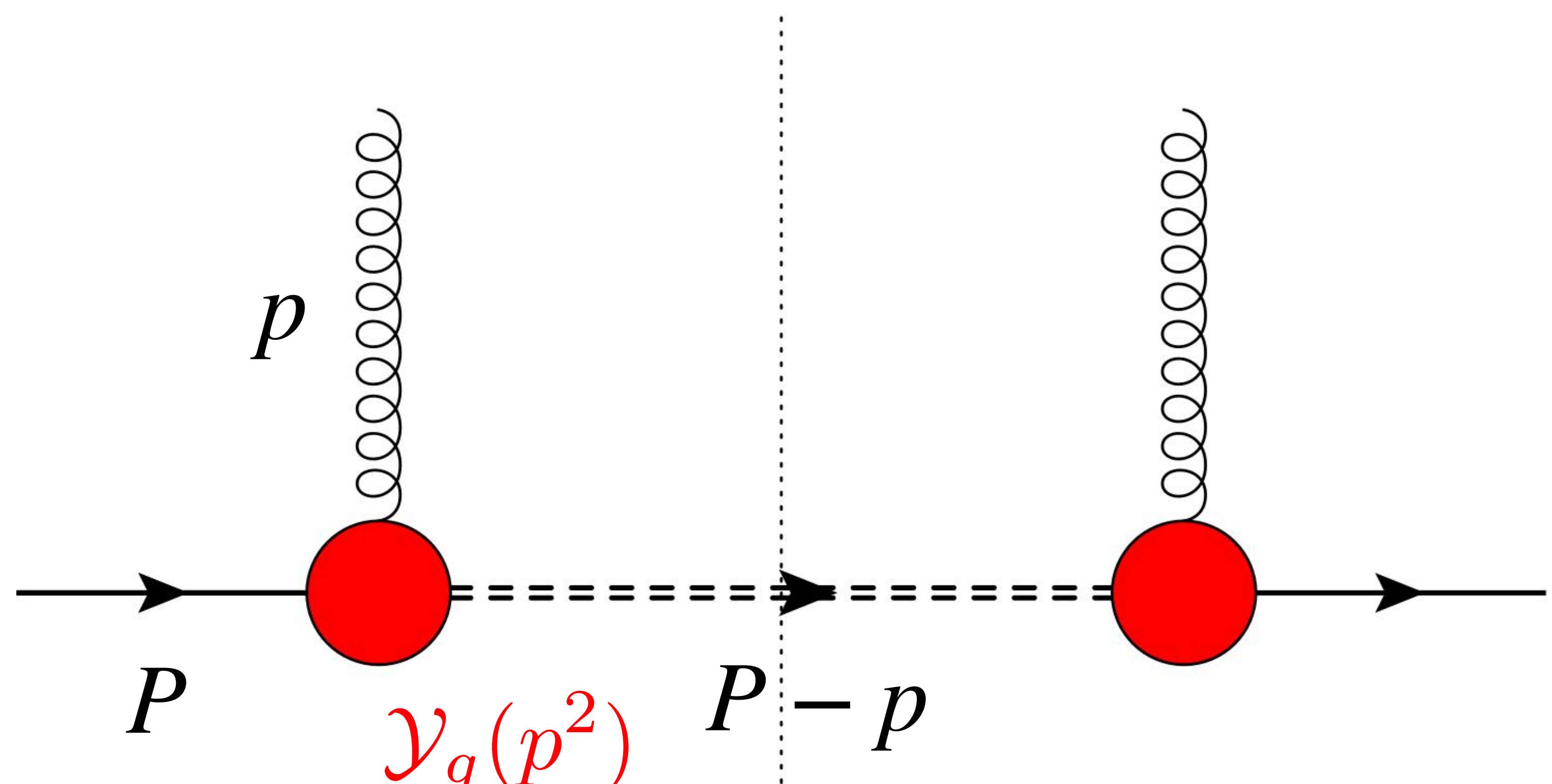
- *High-energy factorization* (**BFKL**)
- Small x, large p_T



Effective vertices



$$i\frac{g_a(p^2)}{\sqrt{2}}\gamma^\mu\gamma^5$$



Quark and gluon correlators

Scalar-diquark spectator

$$\Phi_s = \frac{1}{2(2\pi)^3(1-x)P^+}\frac{g_s^2}{(p^2-m_q^2)^2}(\not{p}+m_q)\frac{1+\gamma^5\not{S}}{2}(\not{P}+M_H)(\not{p}+m_q)$$

Axial-vector-diquark spectator

$$\Phi_a = \frac{1}{2(2\pi)^3(1-x)P^+}\frac{g_a^2}{(p^2-m_q^2)^2}(\not{p}+m_q)\frac{\gamma^5\gamma_\mu}{\sqrt{2}}\frac{1+\gamma^5\not{S}}{2}(\not{P}+M_H)\frac{\gamma^5\gamma_\nu}{\sqrt{2}}(\not{p}+m_q)d_T^{\mu\nu}(P-p)$$

Spin-1/2 spectator (gluon)

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

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

Quark and gluon correlators

Scalar-diquark spectator

$$\Phi_s = \frac{1}{2(2\pi)^3(1-x)P^+} \frac{g_s^2}{(p^2-m_q^2)^2} (\not{p}+m_q) \frac{1+\gamma^5 \not{S}}{2} (\not{P}+M_H)(\not{p}+m_q)$$

Axial-vector-diquark spectator

$$\Phi_a = \frac{1}{2(2\pi)^3(1-x)P^+} \frac{g_a^2}{(p^2-m_q^2)^2} (\not{p}+m_q) \frac{\gamma^5\gamma_\mu}{\sqrt{2}} \frac{1+\gamma^5 \not{S}}{2} (\not{P}+M_H) \frac{\gamma^5\gamma_\nu}{\sqrt{2}} (\not{p}+m_q) d_T^{\mu\nu}(P-p)$$

Spin-1/2 spectator (gluon)

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

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

Selection out of 12 Dirac structures

Spectator-model gluon TMDs (1)

$$\begin{aligned}\hat{f}_1^g(x, \boldsymbol{p}_T^2) = &\big[4g_1^2 M_H^2 (x^2 (M_X - M_H(1-x))^2 + \boldsymbol{p}_T^2((x-2)x+2)) \\ &- 4g_1 g_2 M_H x^2 (M_H + M_X)((M_X - M_H(1-x))^2 + \boldsymbol{p}_T^2) \\ &+ g_2^2(\boldsymbol{p}_T^2 x(M_H^2(3x-2) + 2M_H M_X x + M_X^2(x+2)) \\ &+ x^2(M_H+M_X)^2(M_X - M_H(1-x))^2 + 2(\boldsymbol{p}_T^2)^2)\big] \\ &/4(2\pi)^3 M_H^2 x (L_g^2(m_g^2) + \boldsymbol{p}_T^2)^2\end{aligned}$$

$$\begin{aligned}\hat{g}_{1L}^g(x, \boldsymbol{p}_T^2) = &\big[(2g_1 M_H - g_2(M_H + M_X))(2g_1 M_H (x(M_X - M_H(1-x))^2 - \boldsymbol{p}_T^2(x-2)) \\ &+ g_2(-M_H^2 x^3 (M_H + M_X) + \boldsymbol{p}_T^2 x(M_X - 3M_H) + 2\boldsymbol{p}_T^2(M_H - M_X) \\ &+ 2M_H x^2 (M_H - M_X)(M_H + M_X) - x(M_H - M_X)^2(M_H + M_X)))\big] \\ &/4(2\pi)^3 M_H^2 (L_g^2(m_g^2) + \boldsymbol{p}_T^2)^2\end{aligned}$$

$$L_X^2(m^2) = x M_X^2 + (1-x)m^2 - x(1-x)M_H^2$$

Spectator-model gluon TMDs (2)

$$g_{1T}^{g}(x,\boldsymbol{p}_T^2) = \big[((2g_1 M_H - g_2(M_H + M_X))((M_X - M_H(1-x))$$
$$(-2g_1 M_H(1-x) - g_2 M_X x) - g_2 \boldsymbol{p}_T^2))\big]$$
$$/(2(2\pi)^3 M_H (L_X^2(m_g^2) + \boldsymbol{p}_T^2)^2)$$

$$h_1^{\perp g}(x,\boldsymbol{p}_T^2) = \big[(4g_1^2 M_H^2(1-x) + g_2^2(x(M_X^2 - M_H^2(1-x)) + \boldsymbol{p}_T^2))\big]$$
$$/((2\pi)^3 x (L_X^2(m_g^2) + \boldsymbol{p}_T^2)^2)$$

$$L_X^2(m^2) = xM_X^2 + (1-x)m^2 - x(1-x)M_H^2$$

Spectator-model quark TMDs scalar di-quark (1)

$$f_1^{q(s)}(x,\boldsymbol{p}_T^2) = \frac{g_s^2}{(2\pi)^3}\,\frac{\left[(m+xM)^2+\boldsymbol{p}_T^2\right](1-x)}{2\left[\boldsymbol{p}_T^2+L_s^2(m^2)\right]^2}$$

$$g_{1L}^{q(s)}(x,\boldsymbol{p}_T^2) = \frac{g_s^2}{(2\pi)^3}\,\frac{\left[(m+xM)^2-\boldsymbol{p}_T^2\right](1-x)}{2\left[\boldsymbol{p}_T^2+L_s^2(m^2)\right]^2}$$

$$g_{1T}^{q(s)}(x,\boldsymbol{p}_T^2) = \frac{g_s^2}{(2\pi)^3}\,\frac{M\,(m+xM)\,(1-x)}{\left[\boldsymbol{p}_T^2+L_s^2(m^2)\right]^2}$$

$$h_{1L}^{\perp\,q(s)}(x,\boldsymbol{p}_T^2) = -g_{1T}^{q(s)}(x,\boldsymbol{p}_T^2)$$

$$L_X^2(m^2) = xM_X^2+(1-x)m^2-x(1-x)M_H^2$$

Spectator-model quark TMDs scalar di-quark (2)

$$h_{1T}^{q(s)}(x, \boldsymbol{p}_T^2) = f_1^{q(s)}(x, \boldsymbol{p}_T^2)$$

$$h_{1T}^{\perp\, q(s)}(x, \boldsymbol{p}_T^2) = -\frac{g_s^2}{(2\pi)^3} \frac{M^2\,(1-x)}{[\boldsymbol{p}_T^2 + L_s^2(m^2)]^2}$$

$$\begin{aligned} h_1^{q(s)}(x, \boldsymbol{p}_T^2) &= h_{1T}^{q(s)}(x, \boldsymbol{p}_T^2) + \frac{\boldsymbol{p}_T^2}{2M^2}\, h_{1T}^{\perp\, q(s)}(x, \boldsymbol{p}_T^2) \\ &= \frac{g_s^2}{(2\pi)^3} \frac{(m + xM)^2\,(1-x)}{2\,[\boldsymbol{p}_T^2 + L_s^2(m^2)]^2} = \frac{1}{2}\,\left(f_1^{q(s)}(x, \boldsymbol{p}_T^2) + g_1^{q(s)}(x, \boldsymbol{p}_T^2)\right) \end{aligned}$$

$$L_X^2(m^2) = xM_X^2 + (1-x)m^2 - x(1-x)M_H^2$$

Spectator-model quark TMDs axial-vector di-quark (1)

$$f_1^{q(a)}(x, \boldsymbol{p}_T^2) = \frac{g_a^2}{(2\pi)^3} \frac{\boldsymbol{p}_T^2\,(1+x^2) + (m+xM)^2\,(1-x)^2}{2\,[\boldsymbol{p}_T^2 + L_a^2(m^2)]^2\,(1-x)}$$

$$g_{1L}^{q(a)}(x, \boldsymbol{p}_T^2) = \frac{g_a^2}{(2\pi)^3} \frac{\boldsymbol{p}_T^2\,(1+x^2) - (m+xM)^2\,(1-x)^2}{2\,[\boldsymbol{p}_T^2 + L_a^2(m^2)]^2\,(1-x)}$$

$$g_{1T}^{q(a)}(x, \boldsymbol{p}_T^2) = \frac{g_a^2}{(2\pi)^3} \frac{M\,x\,(m+xM)}{[\boldsymbol{p}_T^2 + L_a^2(m^2)]^2}$$

$$L_X^2(m^2) = xM_X^2 + (1-x)m^2 - x(1-x)M_H^2$$

Spectator-model quark TMDs axial-vector di-quark (2)

$$h_{1L}^{\perp\, q(a)}(x, \boldsymbol{p}_T^2) = g_{1T}^{q(a)}(x, \boldsymbol{p}_T^2)/x \ ,$$

$$h_{1T}^{q(a)}(x, \boldsymbol{p}_T^2) = -\frac{g_a^2}{(2\pi)^3} \frac{x\, \boldsymbol{p}_T^2}{[\boldsymbol{p}_T^2 + L_a^2(m^2)]^2\,(1-x)}$$

$$h_{1T}^{\perp\, q(a)}(x, \boldsymbol{p}_T^2) = 0$$

$$h_1^{q(a)}(x, \boldsymbol{p}_T^2) = h_{1T}^{q(a)}(x, \boldsymbol{p}_T^2)$$

$$L_X^2(m^2) = x M_X^2 + (1-x)m^2 - x(1-x)M_H^2$$

Nucleon-parton-spectator effective vertex

$$
g_X(p^2) = \begin{cases} g_X^{p.l.} & \textbf{pointlike} \\ g_X^{dip} \dfrac{p^2 - m^2}{|p^2 - \Lambda_X^2|^2} & \textbf{dipolar} \\ g_X^{exp}\, e^{(p^2 - m^2)/\Lambda_X^2} & \textbf{exponential} \end{cases}
$$

Our parametrization

$$F^{u_v}(x,\boldsymbol{p}_T^2) = \int \mathrm{d}M_s^{u_v}\,\rho_s\,(M_s^{u_v})\,\hat{F}_s^{u_v}(x,\boldsymbol{p}_T^2) + \int \mathrm{d}M_a^{u_v}\,\rho_a\,(M_a^{u_v})\,\hat{F}_a^{u_v}(x,\boldsymbol{p}_T^2)$$

$$F^{d_v}(x,\boldsymbol{p}_T^2) = \int \mathrm{d}M_a^{d_v}\,\rho_a\left(M_a^{d_v}\right)\hat{F}_a^{d_v}(x,\boldsymbol{p}_T^2)$$

$$F^{\,\mathrm{sea}}(x,\boldsymbol{p}_T^2) = \int \mathrm{d}M_s^{\mathrm{sea}}\,\rho_s\,(M_s^{\mathrm{sea}})\,\hat{F}_s^{\,\mathrm{sea}}(x,\boldsymbol{p}_T^2)$$

$$F^{g}(x,\boldsymbol{p}_T^2) = \int \mathrm{d}M^{g}\,\rho_g\,(M^{g})\,\hat{F}^{g}(x,\boldsymbol{p}_T^2)$$

Our parametrization

$$F^{u_v}(x, \boldsymbol{p}_T^2) = \int dM_s^{u_v} \rho_s(M_s^{u_v}) \boxed{\hat{F}_s^{u_v}}(x, \boldsymbol{p}_T^2) + \int dM_a^{u_v} \rho_a(M_a^{u_v}) \boxed{\hat{F}_a^{u_v}}(x, \boldsymbol{p}_T^2)$$

$$F^{d_v}(x, \boldsymbol{p}_T^2) = \int dM_a^{d_v} \rho_a\left(M_a^{d_v}\right) \boxed{\hat{F}_a^{d_v}}(x, \boldsymbol{p}_T^2)$$

$$F^{\,\mathrm{sea}}(x, \boldsymbol{p}_T^2) = \int dM_s^{\mathrm{sea}} \rho_s(M_s^{\mathrm{sea}}) \boxed{\hat{F}_s^{\,\mathrm{sea}}}(x, \boldsymbol{p}_T^2)$$

$$F^{g}(x, \boldsymbol{p}_T^2) = \int dM^{g} \rho_g(M^{g}) \boxed{\hat{F}^{g}}(x, \boldsymbol{p}_T^2)$$

scalar di-quark **axial-vector di-quark**

spin-1/2

Our parametrization

$$F^{u_v}(x,\boldsymbol{p}_T^2) = \int \mathrm{d}M_s^{u_v}\rho_s\left(M_s^{u_v}\right)\hat{F}_s^{u_v}(x,\boldsymbol{p}_T^2) + \int \mathrm{d}M_a^{u_v}\rho_a\left(M_a^{u_v}\right)\hat{F}_a^{u_v}(x,\boldsymbol{p}_T^2)$$

$$F^{d_v}(x,\boldsymbol{p}_T^2) = \int \mathrm{d}M_a^{d_v}\rho_a\left(M_a^{d_v}\right)\hat{F}_a^{d_v}(x,\boldsymbol{p}_T^2)$$

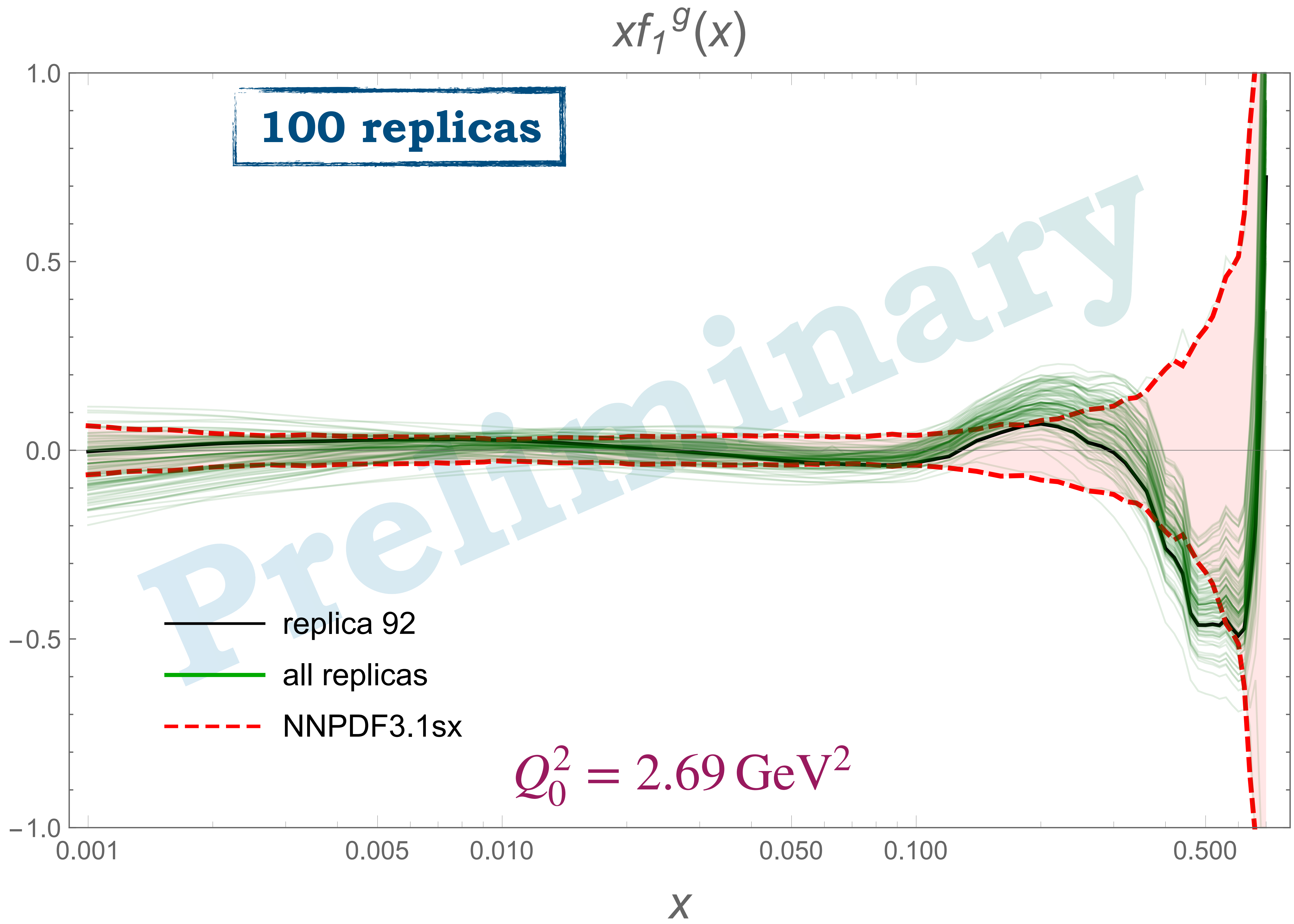
$$F^{\,\mathrm{sea}}(x,\boldsymbol{p}_T^2) = \int \mathrm{d}M_s^{\mathrm{sea}}\rho_s\left(M_s^{\mathrm{sea}}\right)\hat{F}_s^{\,\mathrm{sea}}(x,\boldsymbol{p}_T^2)$$

$$F^{g}(x,\boldsymbol{p}_T^2) = \int \mathrm{d}M^{g}\rho_g\left(M^{g}\right)\hat{F}^{g}(x,\boldsymbol{p}_T^2)$$

scalar di-quark **axial-vector di-quark**

spin-1/2

Unpolarized gluon PDF



Fit specifics

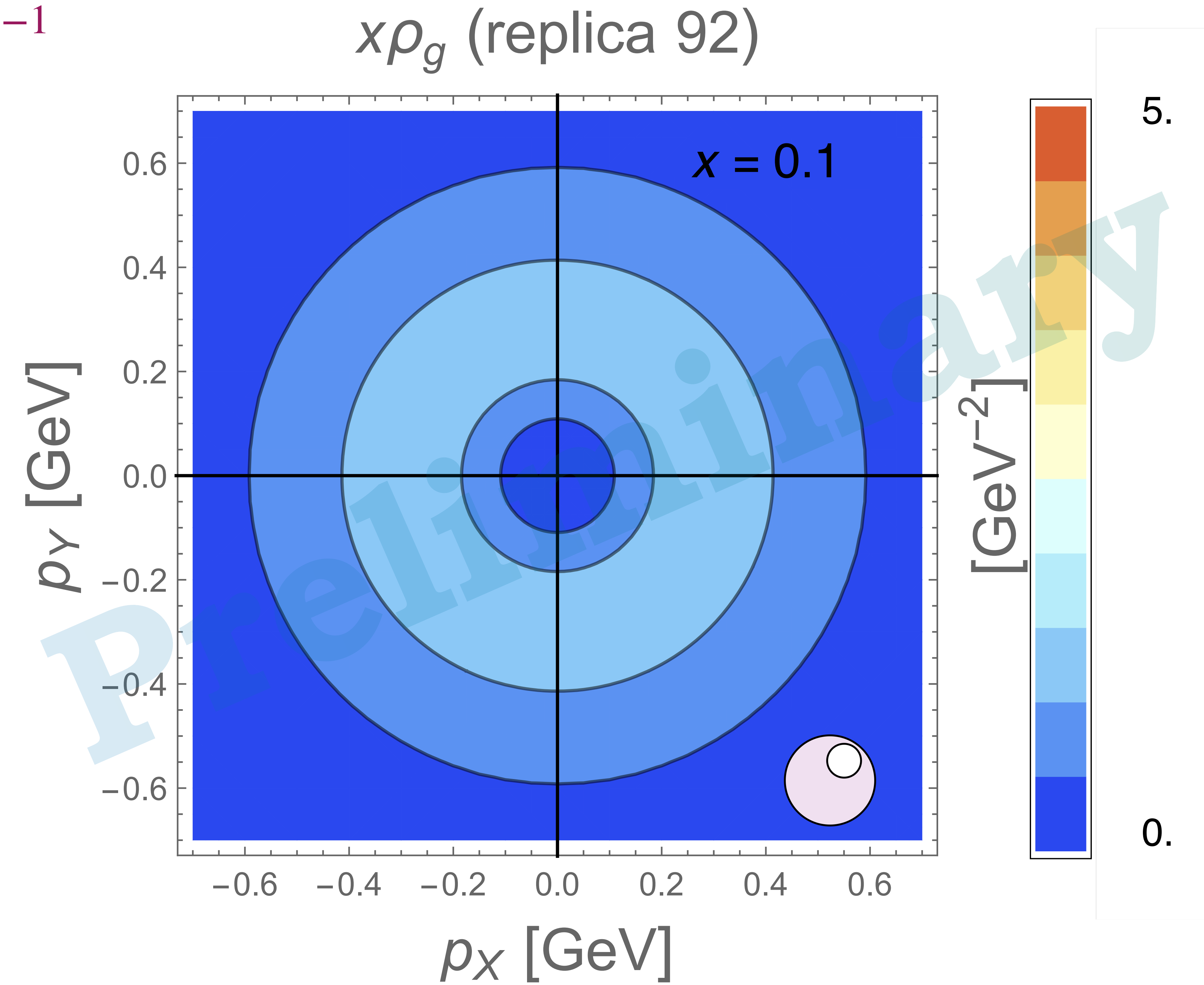
$$\boxed{\chi^2 = 0.51}$$

$$\boxed{x_{\mathrm{TOT}} = 0.42358\ [x > 10^{-5}] + 0.00006\ [x < 10^{-5}]}$$

$$\boxed{S_{\mathrm{TOT}} = 0.339\ [x > 10^{-5}] + 0.014\ [x < 10^{-5}]}$$

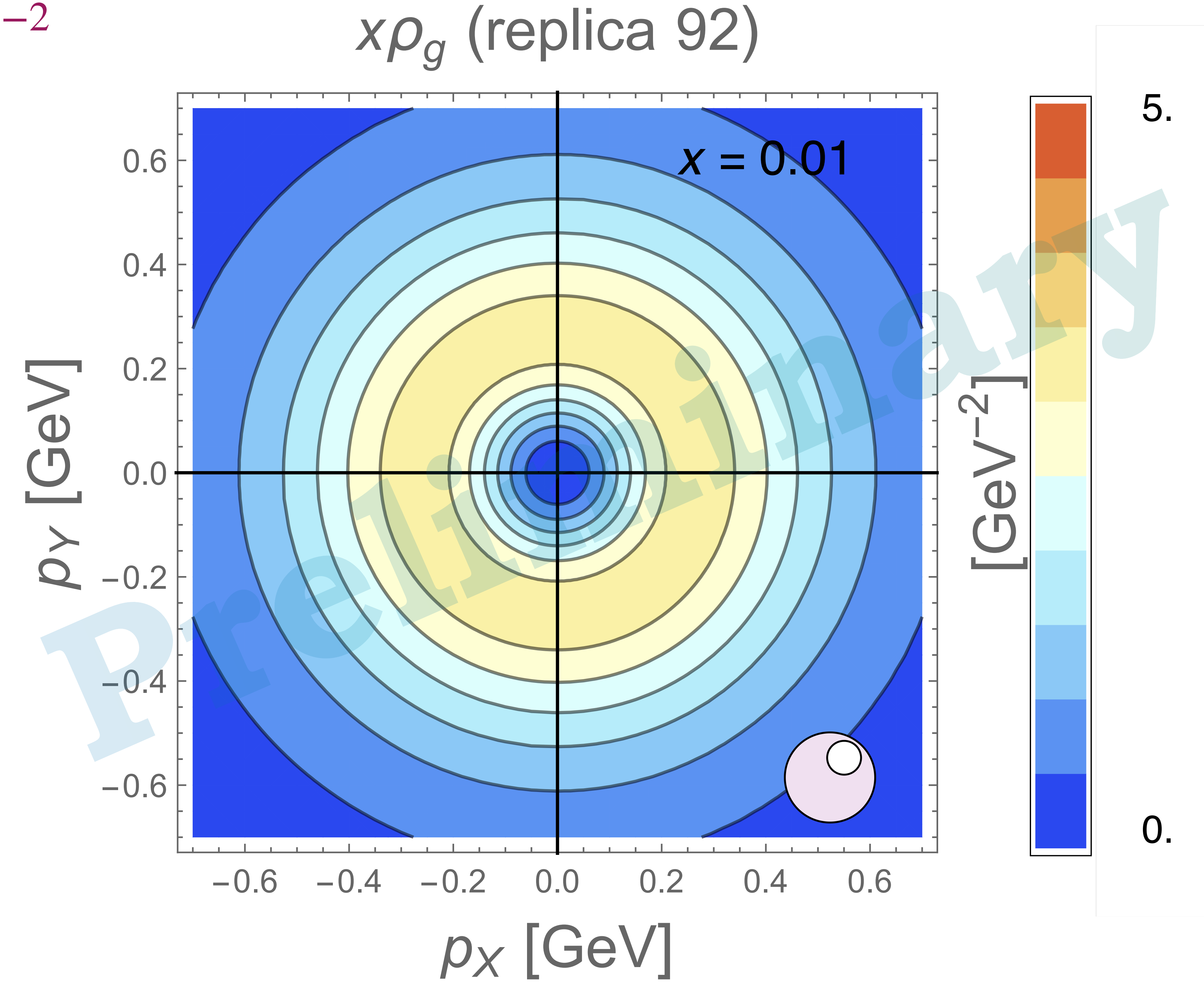
[unpol/unpol] ρ-density

$x = 10^{-1}$



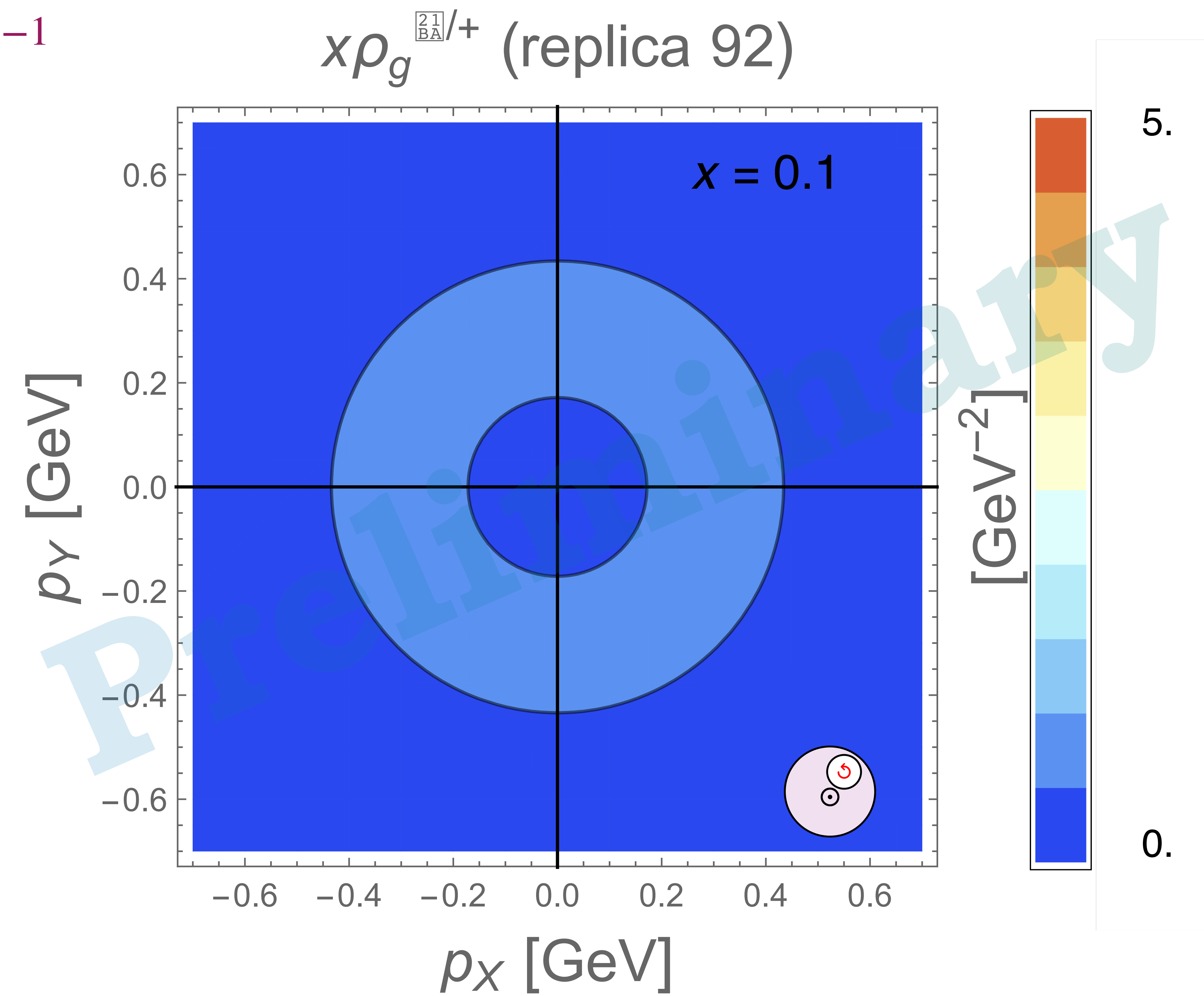
[unpol/unpol] ρ-density

$x = 10^{-2}$



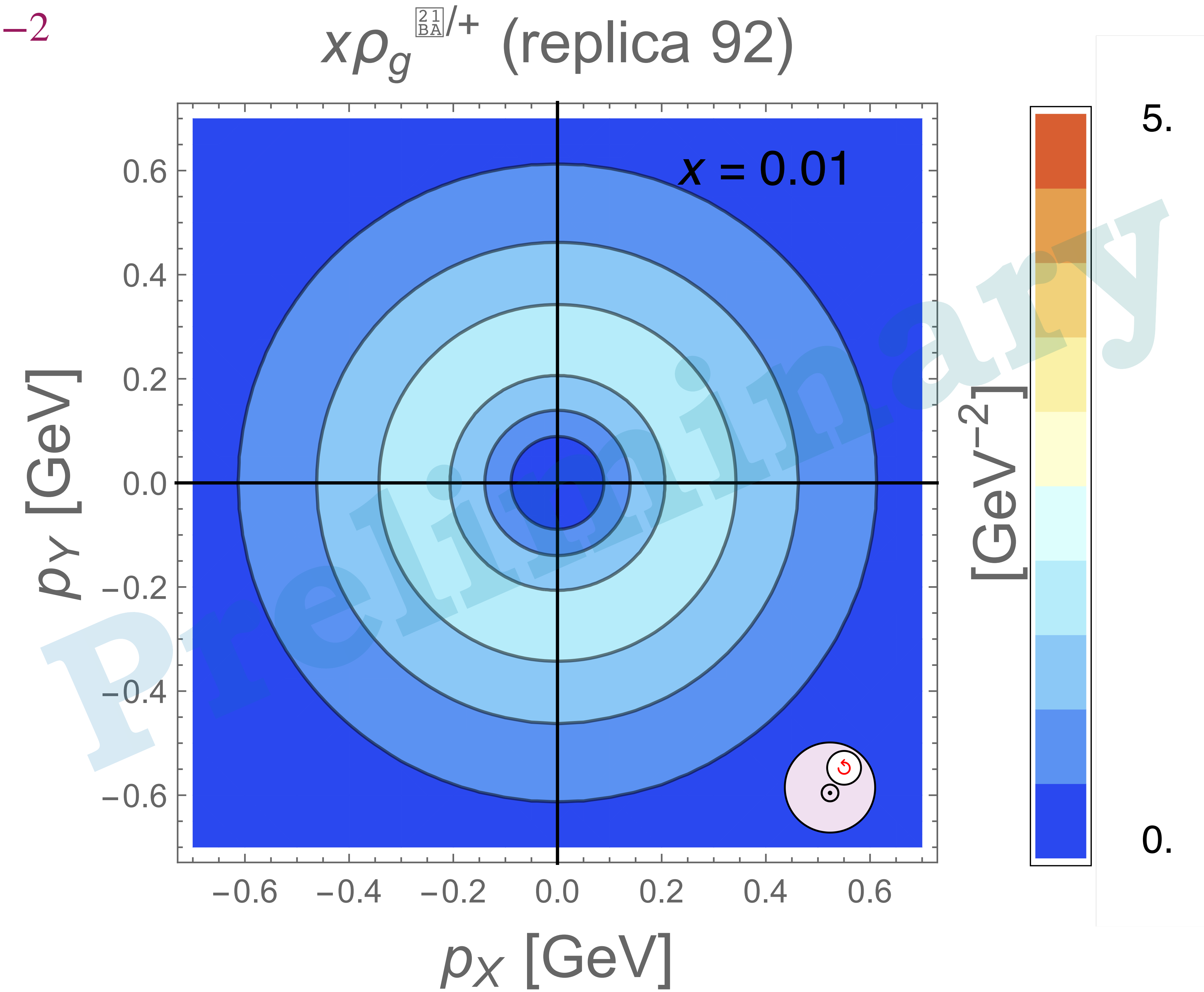
[↺/+] ρ-density

$x = 10^{-1}$



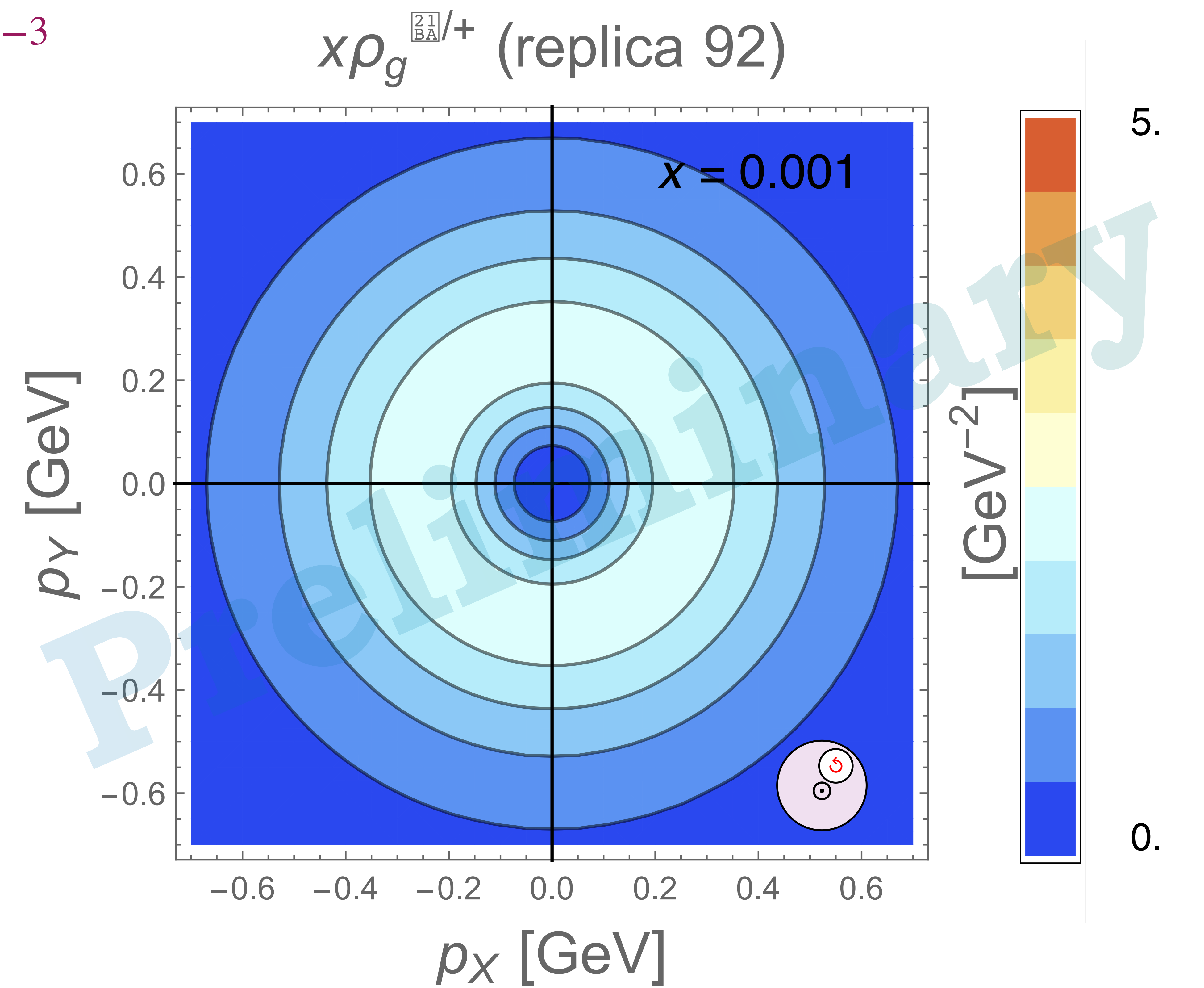
[↺/+] ρ-density

$x = 10^{-2}$



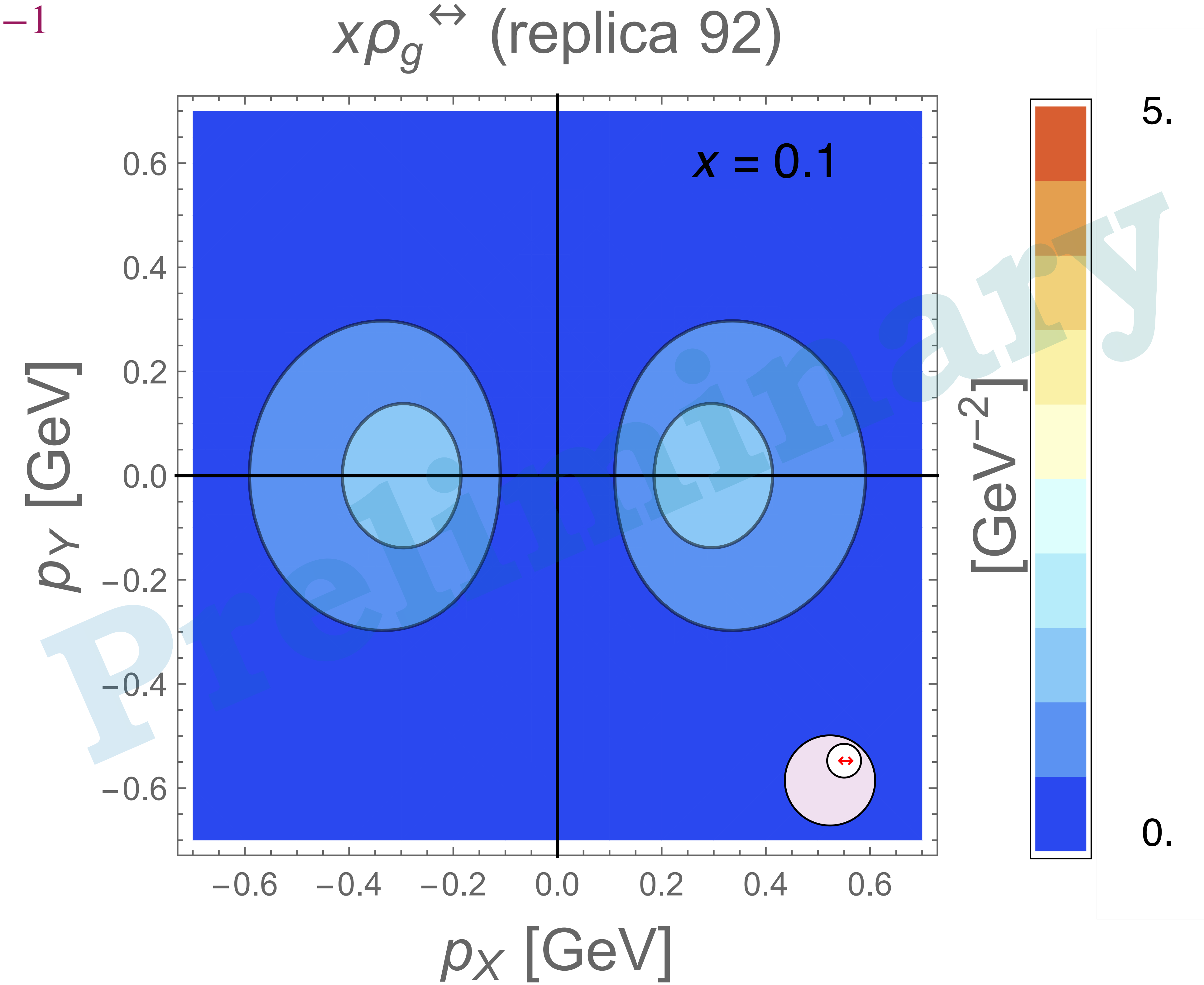
[↺/+] ρ-density

$x = 10^{-3}$



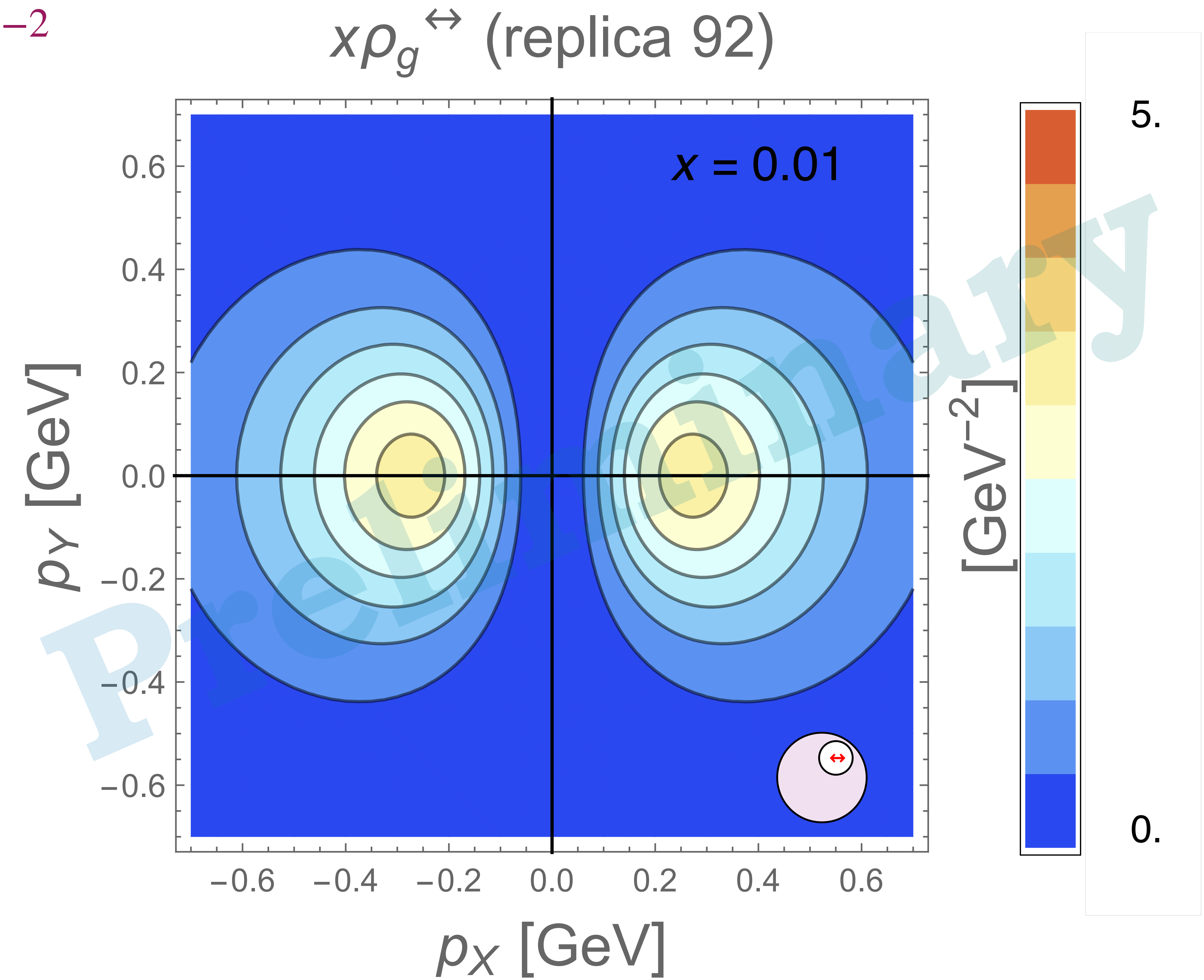
[↔/unpol] ρ-density (BM)

$x = 10^{-1}$

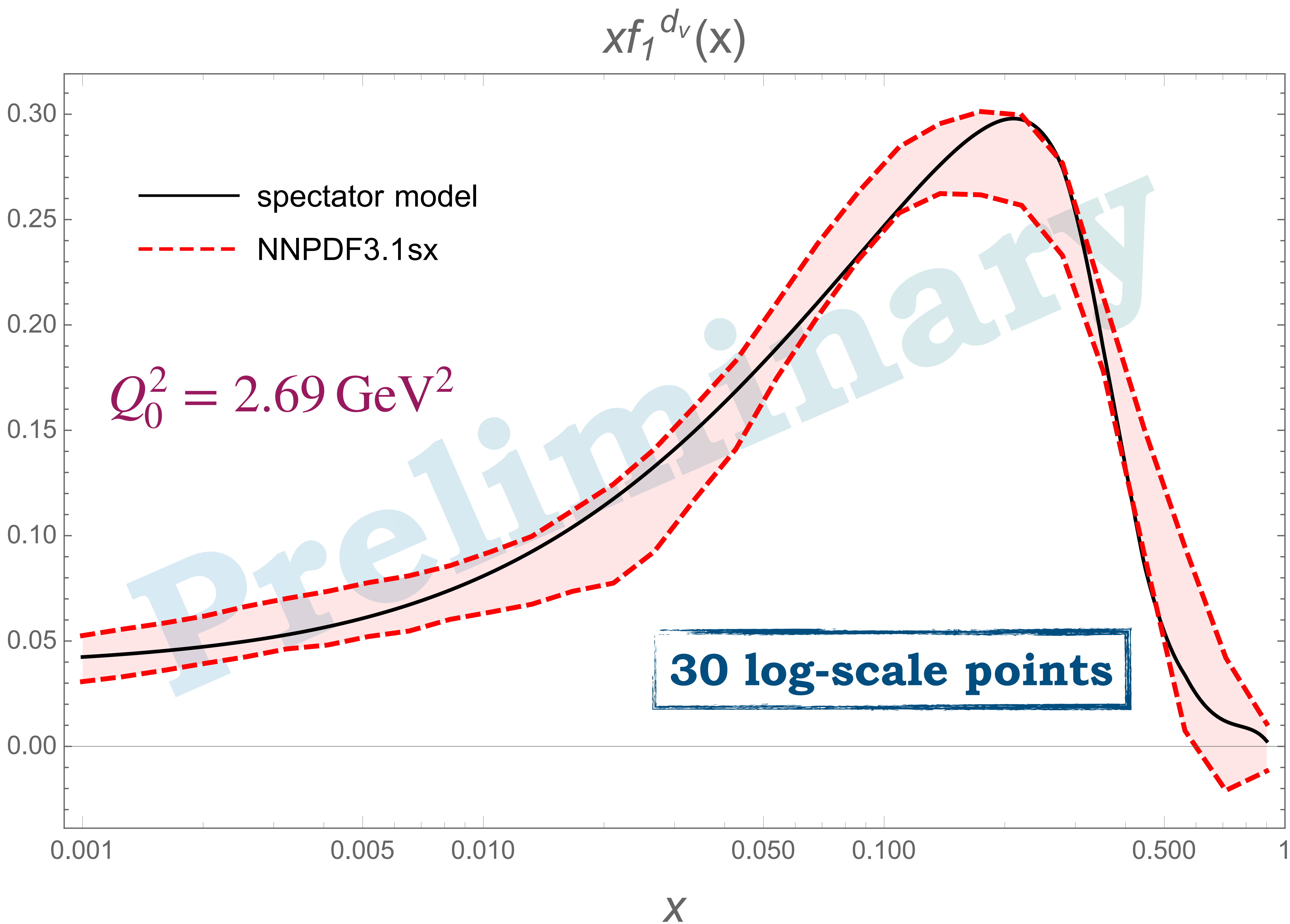


[↔/unpol] ρ-density (BM)

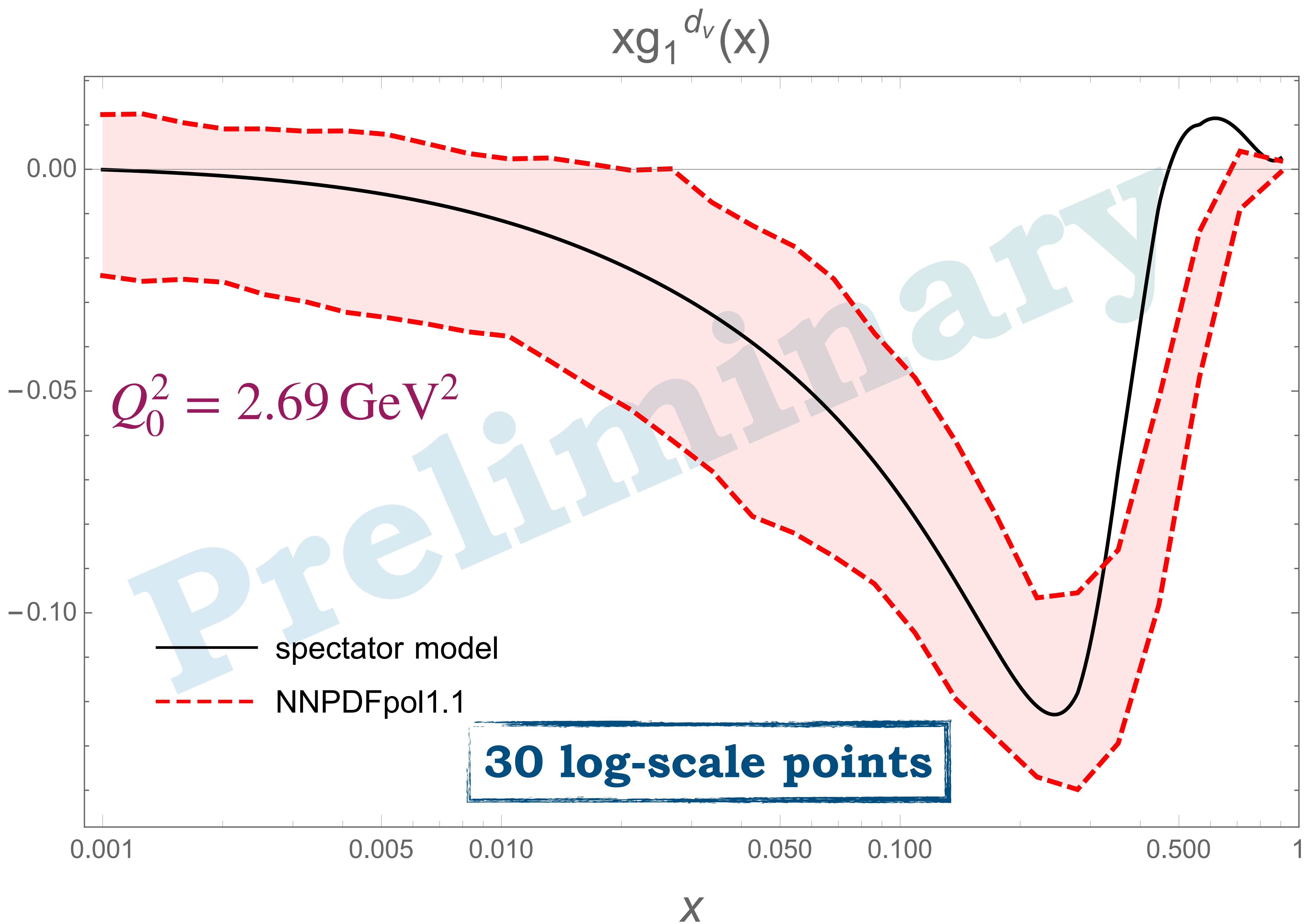
$x = 10^{-2}$



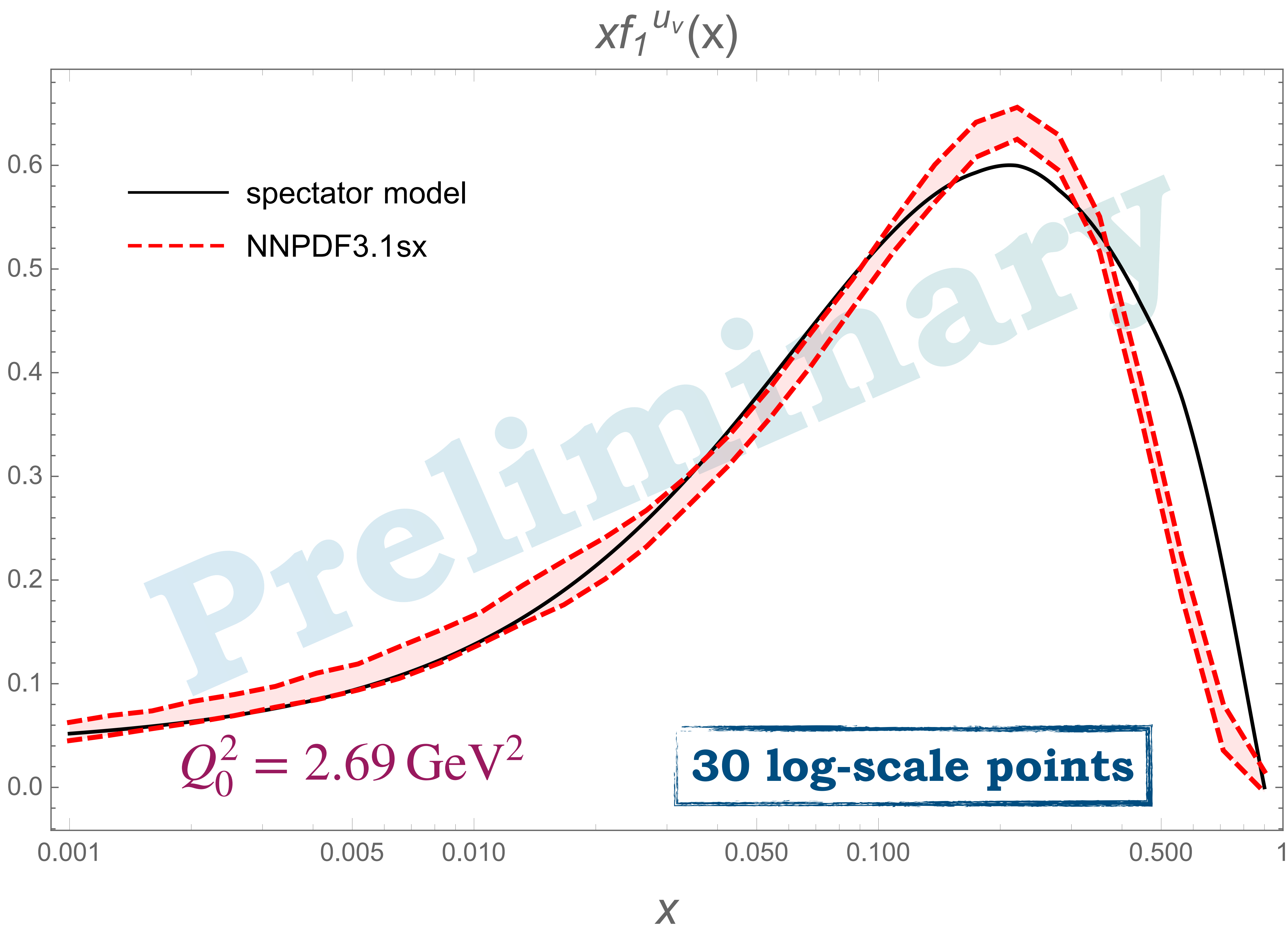
Unpolarized valence-down PDF



Helicity valence-down PDF



Unpolarized valence-up PDF



Helicity valence-up PDF