ALESSANDRO BACCHETTA, PAVIA U. AND INFN

TMD OVERVIEW


slide from 2018 CPHI@Yerevan

slide from 2018 CPHI@Yerevan

It's the dawn of TMD global fits era


slide from 2018 CPHI@Yerevan
It's the dawn of TMD global fits era
...but there's still a lot of climbing to be done

In five to ten years

slide from 2018 CPHI@Yerevan

In five to ten years

- TMD multiplicities for pions and kaons, off protons and deuterons, from COMPASS and JLab

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- TMD multiplicities for pions and kaons, off protons and deuterons, from COMPASS and JLab
- Drell-Yan and Z measurements from CERN, RHIC, FermiLab (COMPASS with pions)

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- More flexible functional forms, flavour dependence, at least two or three alternative extractions

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- Use TMDs for something else (W mass… comparison with lattice… Wigner distributions…)

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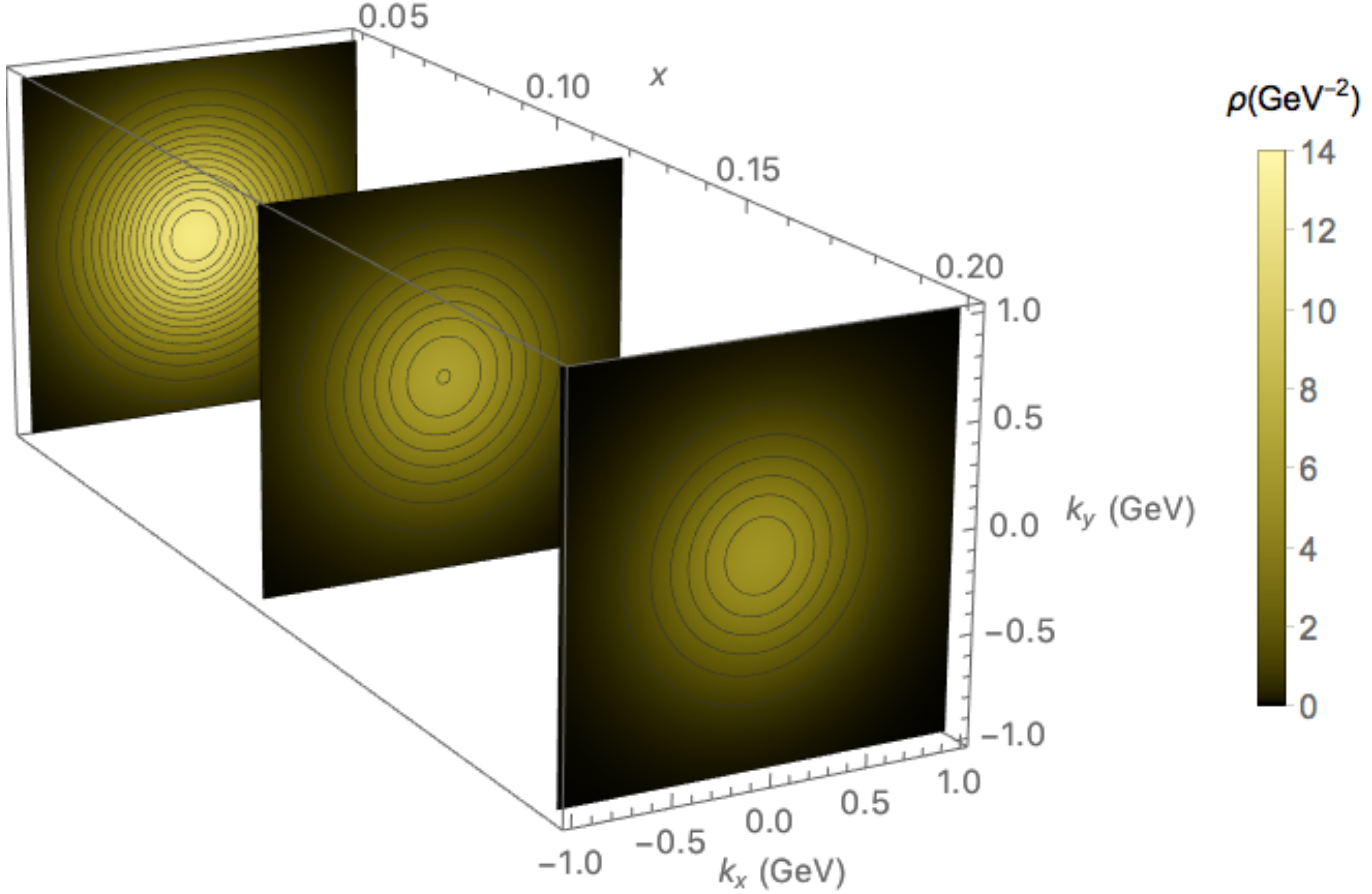
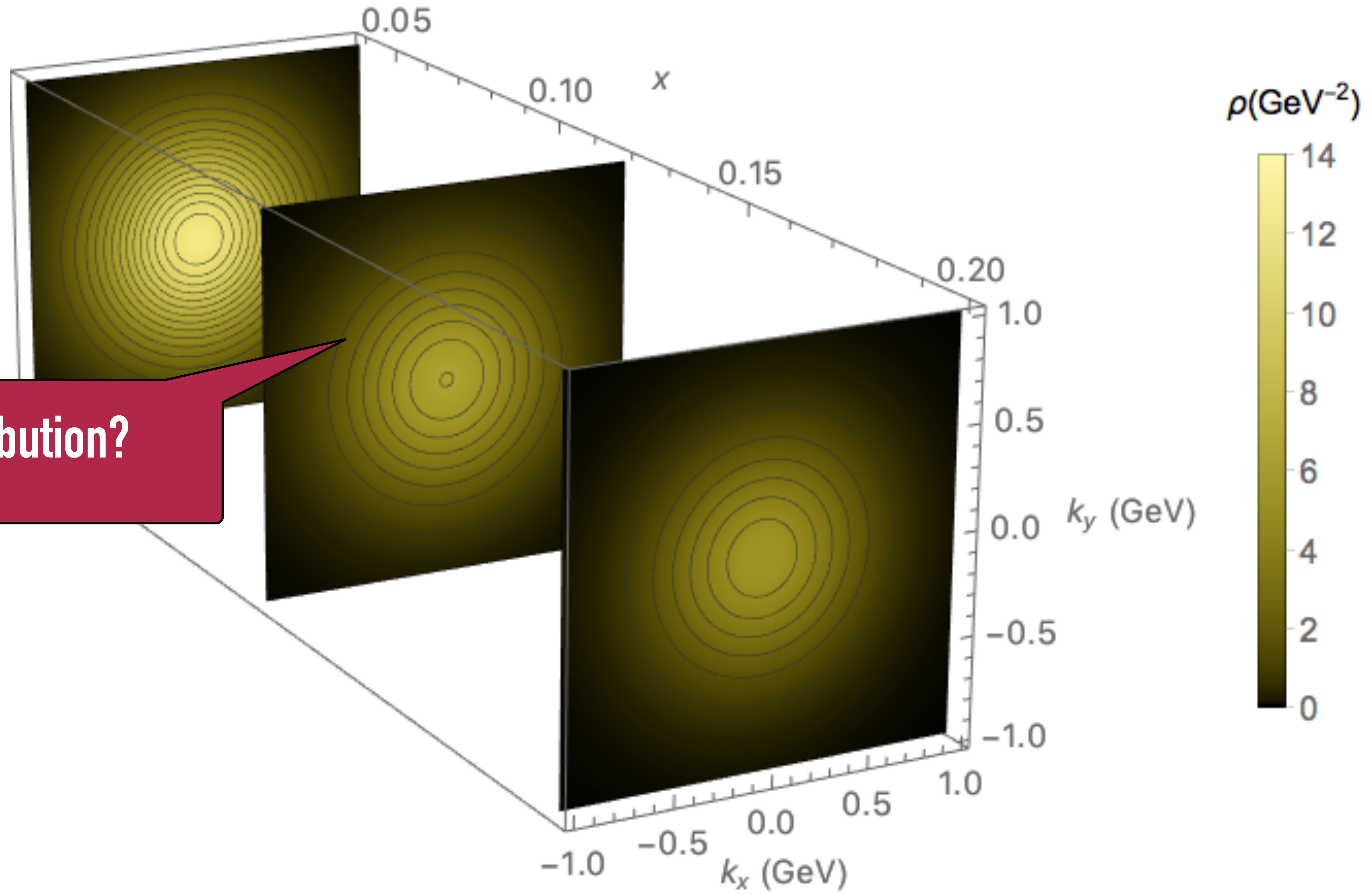
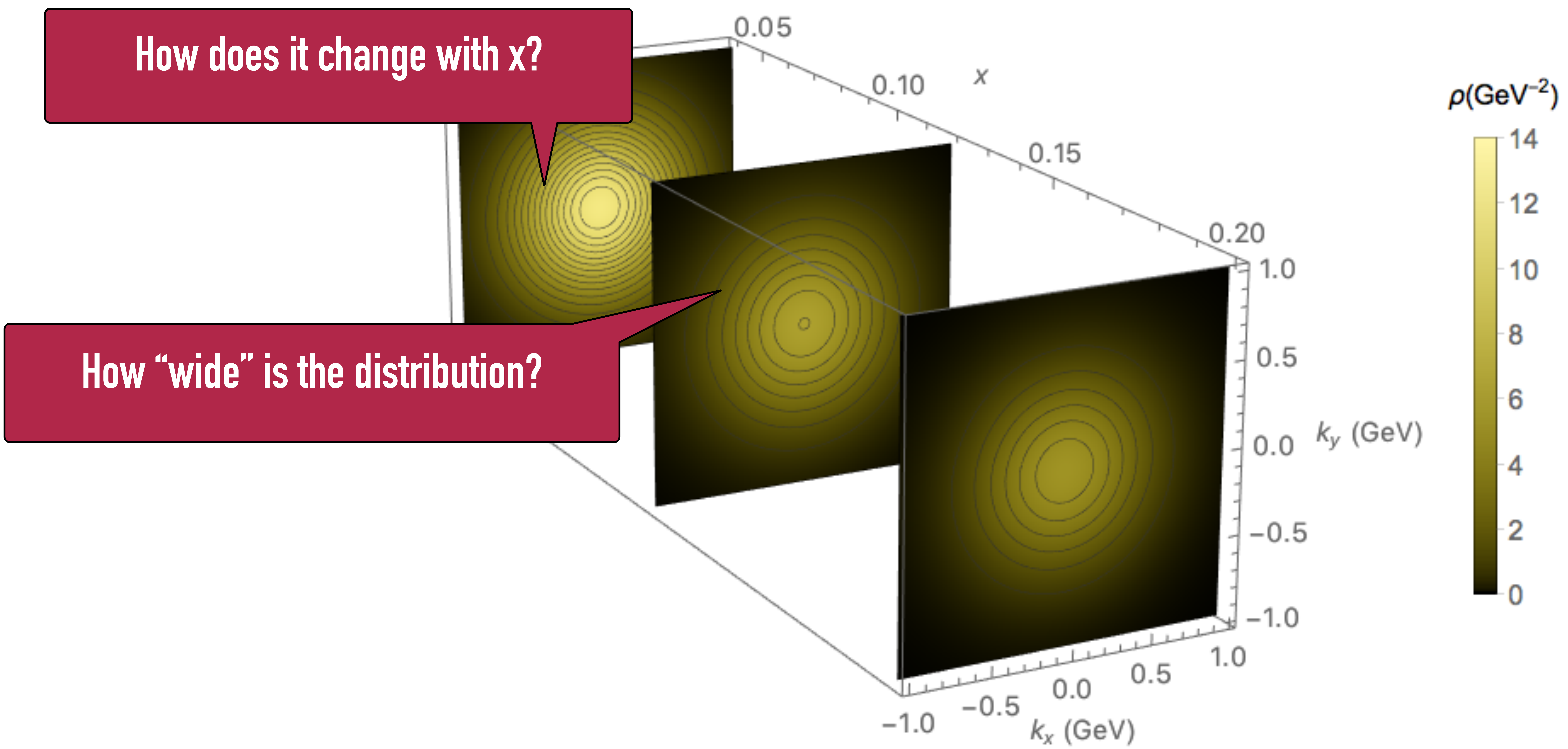
- Use TMDs for something else (W mass… comparison with lattice… Wigner distributions…)
- **READY TO USE EIC DATA**

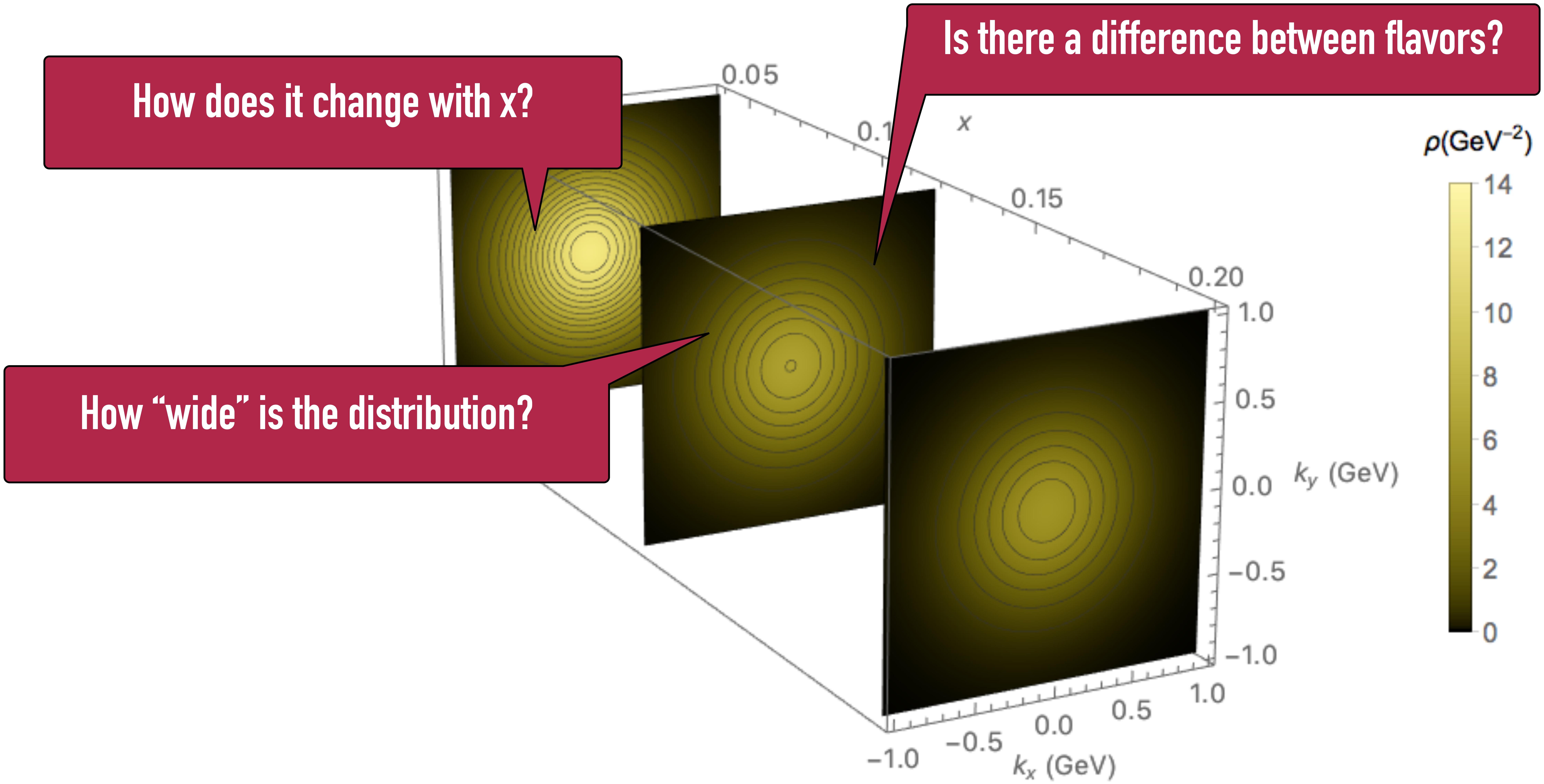


0.05
0.10
x
0.15
0.20
1.0
0.5
0.0
-0.5
-1.0
k_y (GeV)
-1.0
-0.5
0.0
0.5
1.0
k_x (GeV)
$\rho(\mathrm{GeV}^{-2})$
14
12
10
8
6
4
2
0

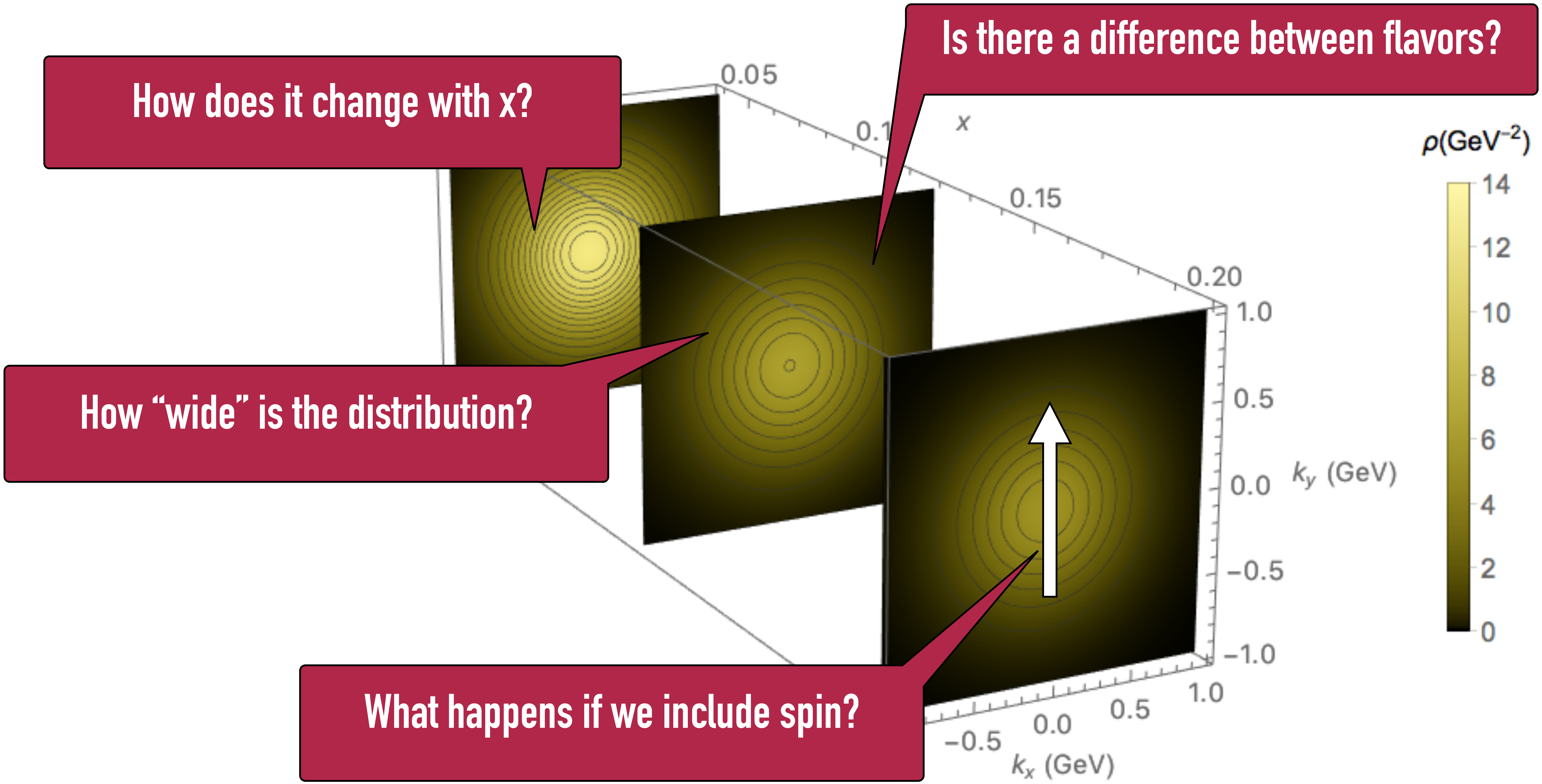


How “wide” is the distribution?


How does it change with x?
How “wide” is the distribution?
0.05
0.10
0.15
0.20
x
1.0
0.5
0.0
−0.5
−1.0
k_y (GeV)
−1.0
−0.5
0.0
0.5
1.0
k_x (GeV)
ρ(GeV^{-2})
14
12
10
8
6
4
2
0



How does it change with x?
Is there a difference between flavors?
How “wide” is the distribution?
x
0.05
0.15
0.20
k_y (GeV)
k_x (GeV)
1.0
0.5
0.0
−0.5
−1.0
$\rho(\mathrm{GeV}^{-2})$
14
12
10
8
6
4
2
0


How does it change with x?
Is there a difference between flavors?
How "wide" is the distribution?
What happens if we include spin?
0.05
0.1
0.15
0.20
x
1.0
0.5
0.0
−0.5
−1.0
k_y (GeV)
−0.5
0.0
0.5
1.0
k_x (GeV)
$\rho(\mathrm{GeV}^{-2})$
14
12
10
8
6
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2
0

TMD TABLES: QUARK, LEADING TWIST

Mulders-Tangerman, NPB 461 (96)
Boer-Mulders, PRD 57 (98)

quark pol. (columns) / nucleon pol. (rows)

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

TMDs in **black** survive integration over transverse momentum
TMDs in **red** are time-reversal odd

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Sivers

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Sivers

Transversity

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Sivers

Transversity

- Very good knowledge of x dependence of f_1 and g_{1L}

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Sivers ($f_{1T}^\perp$)

Transversity (h_1)

- Very good knowledge of x dependence of f_1 and g_{1L}
- Good knowledge of the k_T dependence of f_1 (also for pions)

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- Very good knowledge of x dependence of f_1 and g_{1L}
- Good knowledge of the k_T dependence of f_1 (also for pions)
- Fair knowledge of Sivers and transversity (mainly x dependence)
- Some hints about all others

AVAILABLE EXTRACTIONS (NEWEST ONLY)

Unpol. TMD	MAP 22 arXiv:2206.07598, ART23 2305.07473
Helicity	
Transversity	arXiv:1505.05589, arXiv:1612.06413, arXiv:2205.00999
Sivers	MAP20 arXiv:2004.14278, arXiv:2009.10710, arXiv:2103.03270, arXiv:2205.00999, arXiv:2304.14328
Boer-Mulders	arXiv:2004.02117,
Worm-gear g1T	arXiv:2110.10253, arXiv:2210.07268
Worm-gear h1L	
Pretzelosity	arXiv:1411.0580

AVAILABLE EXTRACTIONS (NEWEST ONLY)

NEW THIS YEAR

Unpol. TMD	MAP 22 arXiv:2206.07598, ART23 2305.07473, **MAP24 arXiv:2405.13833**
Helicity	**arXiv:2409.08110, MAP24, arXiv:2409.18078**
Transversity	arXiv:1505.05589, arXiv:1612.06413, arXiv:2205.00999
Sivers	MAP20 arXiv:2004.14278, arXiv:2009.10710, arXiv:2103.03270, arXiv:2205.00999, arXiv:2304.14328
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Not mentioned: pion TMDs, TMD fragmentation functions, nuclear TMDs

QUARK, SUBLEADING TWIST

Mulders-Tangerman, NPB 461 (96)
Boer-Mulders, PRD 57 (98)
Bacchetta, Mulders, Pijlman, hep-ph/0405154
Goeke, Metz, Schlegel, hep-ph/0504130

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- Lots of progress from the theory side
- Some knowledge of g_T x-dependence
- First hints about e x-dependence
- All others unknown

TMD TABLE: GLUONS, LEADING TWIST

Mulders, Rodrigues, PRD63, 2001

gluon pol.

nucleon pol.	U	circ	linear
U	f_1^g		$h_1^{\perp g}$
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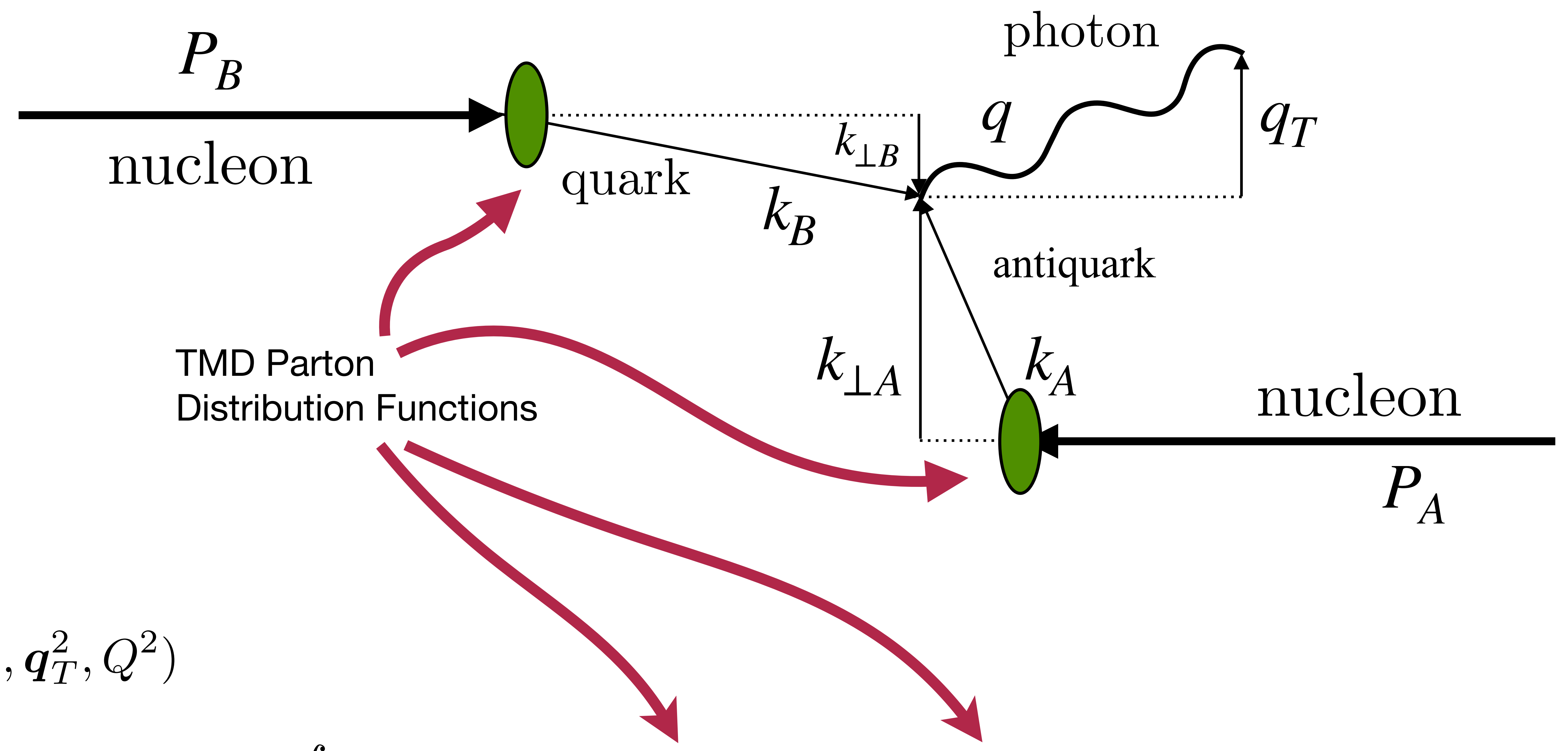
See talk by Cristian Pisano

UNPOLARIZED TMD

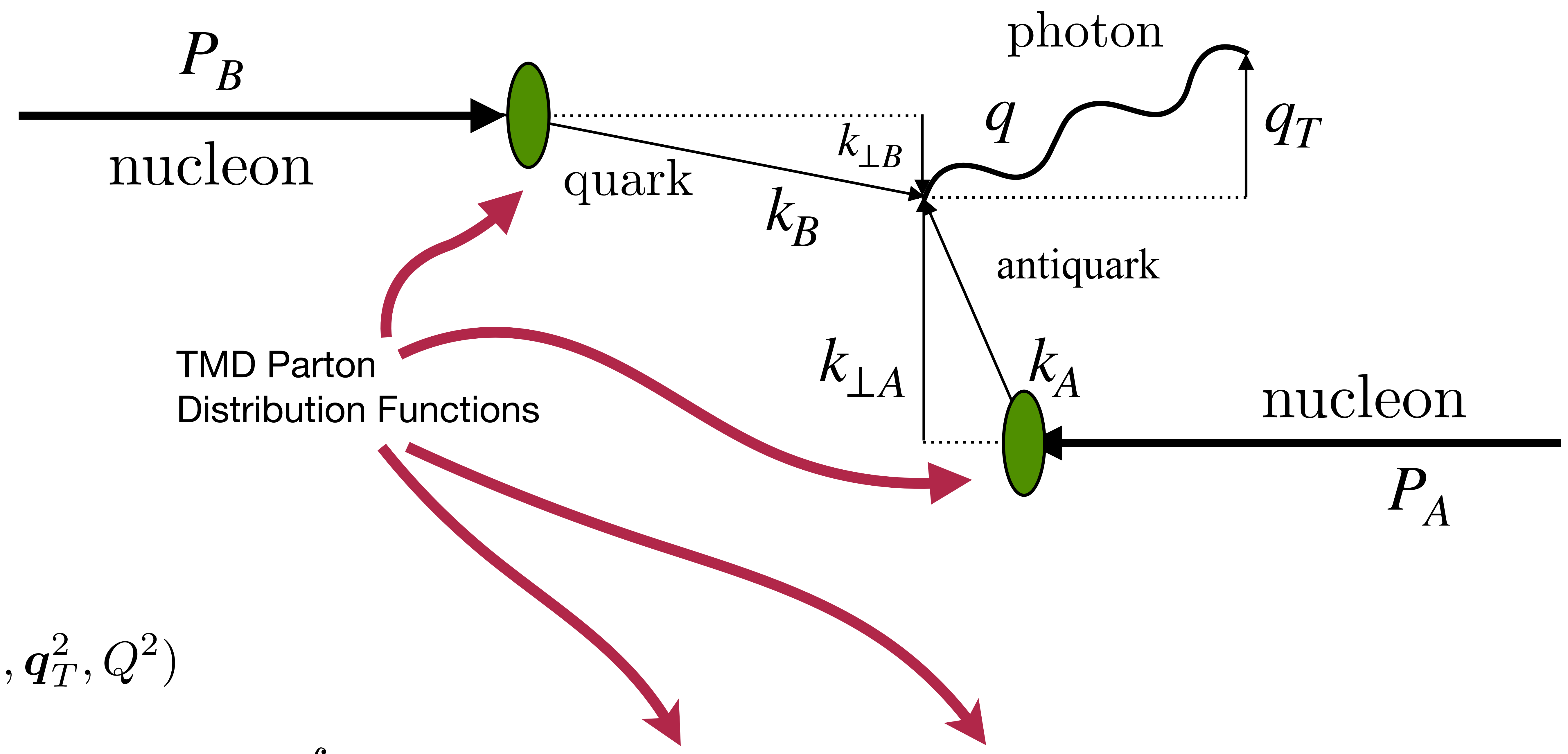
TMDS IN DRELL-YAN PROCESSES



$$F_{UU}^1(x_A, x_B, \boldsymbol{q}_T^2, Q^2)$$

$$\approx \sum_q \mathcal{H}_{UU}^{1q}(Q^2, \mu^2) \int d^2\boldsymbol{k}_{\perp A}\, d^2\boldsymbol{k}_{\perp B}\, f_1^q\big(x_A, \boldsymbol{k}_{\perp A}^2; \mu^2\big)\, f_1^{\bar{q}}\big(x_B, \boldsymbol{k}_{\perp B}^2; \mu^2\big)\, \delta^{(2)}\big(\boldsymbol{k}_{\perp A} - \boldsymbol{q}_T + \boldsymbol{k}_{\perp B}\big)$$

TMDS IN DRELL-YAN PROCESSES



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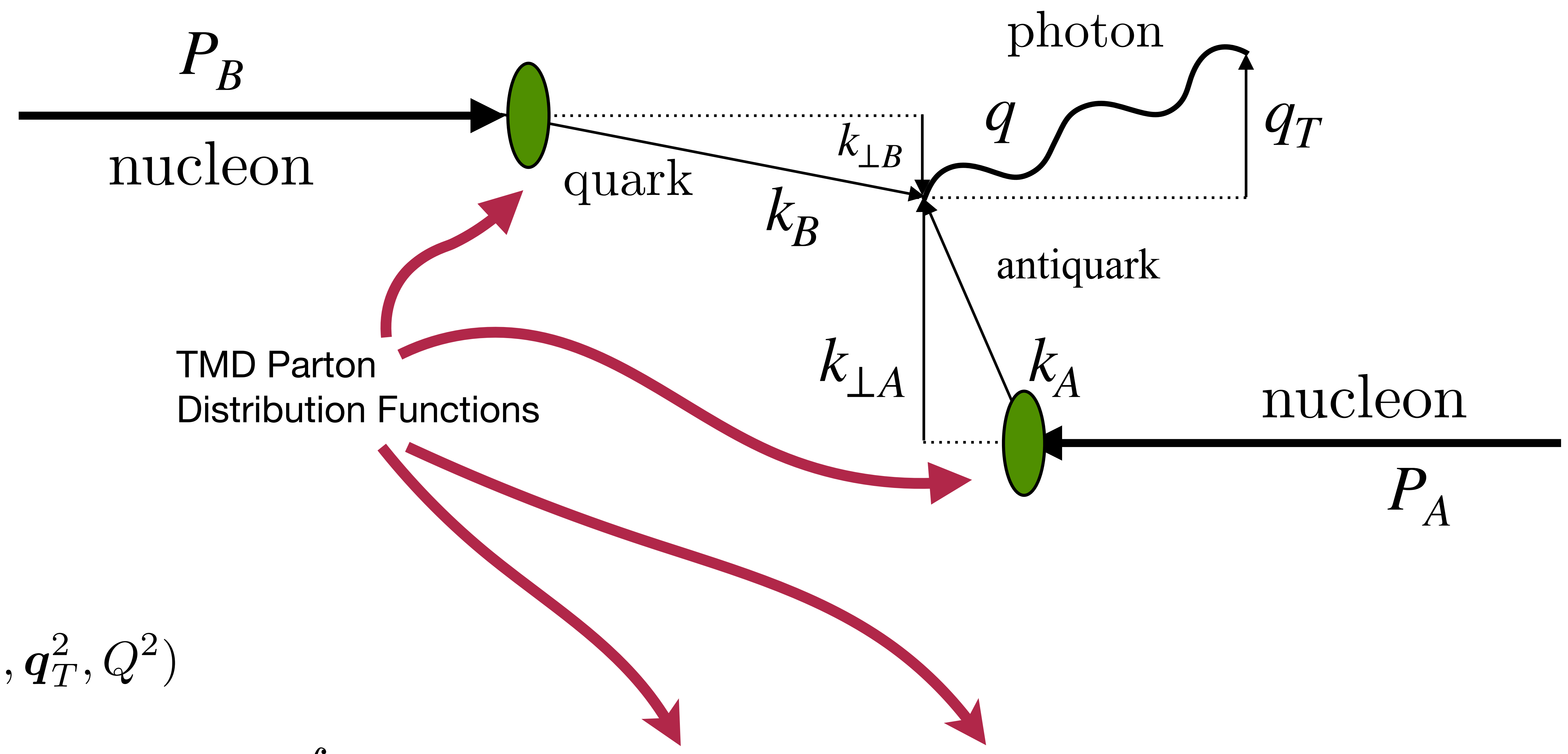
$$= \sum_q \mathcal{H}_{UU}^{1q}(Q^2,\mu^2) \int db_T b_T J_0(b_T|\boldsymbol{q}_T|)\hat{f}_1^q(x_A, b_T^2;\mu^2)\, \hat{f}_1^{\bar{q}}(x_B, b_T^2;\mu^2)$$

The analysis is usually done in Fourier-transformed space

TMDS IN DRELL-YAN PROCESSES



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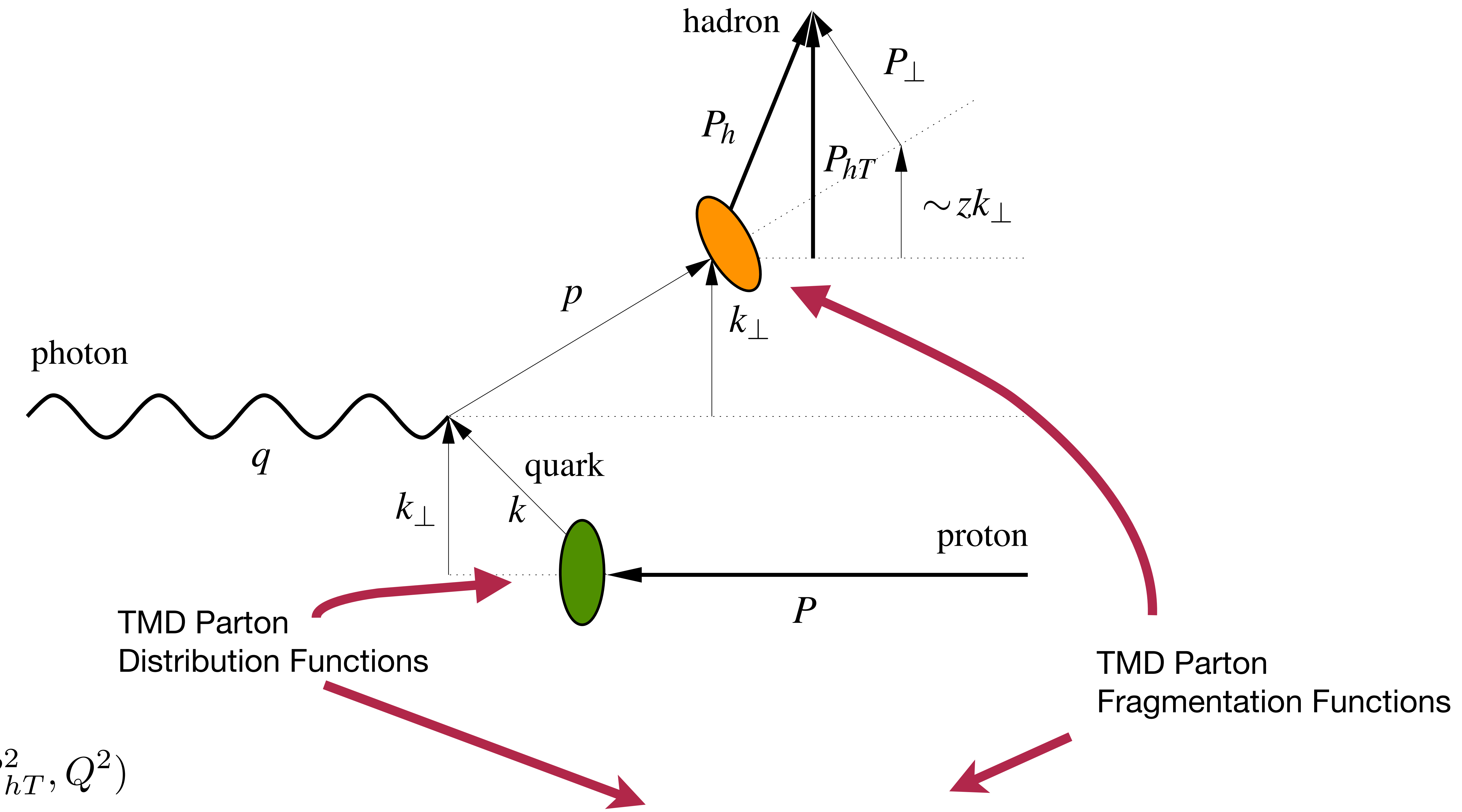
$$= \sum_q \mathcal{H}_{UU}^{1q}(Q^2, \mu^2) \int db_T b_T J_0(b_T |\boldsymbol{q}_T|) \hat{f}_1^q(x_A, b_T^2; \mu^2)\, \hat{f}_1^{\bar{q}}(x_B, b_T^2; \mu^2)$$

The analysis is usually done in Fourier-transformed space

TMDs formally depend on two scales, but we set them equal.

TMDS IN SEMI-INCLUSIVE DIS (SIDIS)



$$
\begin{aligned}
&F_{UU,T}(x, z, \boldsymbol{P}_{hT}^2, Q^2) \\
&= x \sum_q \mathcal{H}^q_{UU,T}(Q^2, \mu^2) \int d^2\boldsymbol{k}_\perp \, d^2\boldsymbol{P}_\perp \, f_1^a(x, \boldsymbol{k}_\perp^2; \mu^2) \, D_1^{a\to h}(z, \boldsymbol{P}_\perp^2; \mu^2) \, \delta(z\boldsymbol{k}_\perp - \boldsymbol{P}_{hT} + \boldsymbol{P}_\perp) \\
&= x \sum_a \mathcal{H}^q_{UU,T}(Q^2, \mu^2) \int db_T b_T J_0(b_T |\boldsymbol{P}_{h\perp}|) \hat{f}_1^q(x, z^2 b_\perp^2; \mu^2) \, \hat{D}_1^{a\to h}(z, b_\perp^2; \mu^2)
\end{aligned}
$$

TMD STRUCTURE

$$\hat{f}_1^a(x, |\boldsymbol{b}_T|; \mu, \zeta) = \int d^2\boldsymbol{k}_\perp \, e^{i\boldsymbol{b}_T\cdot\boldsymbol{k}_\perp} \, f_1^a(x, \boldsymbol{k}_\perp^2; \mu, \zeta)$$

see, e.g., Collins, "Foundations of Perturbative QCD" (11)
TMD collaboration, "TMD Handbook," arXiv:2304.03302

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$$\hat{f}_1^a(x, |\boldsymbol{b}_T|; \mu, \zeta) = \int d^2\boldsymbol{k}_\perp \, e^{i\boldsymbol{b}_T \cdot \boldsymbol{k}_\perp} \, f_1^a(x, \boldsymbol{k}_\perp^2; \mu, \zeta)$$

$$\hat{f}_1^a(x, b_T^2; \mu_f, \zeta_f) = [C \otimes f_1](x, \mu_{b_*}) \; e^{\int_{\mu_{b_*}}^{\mu_f} \frac{d\mu}{\mu} \left(\gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_f}}{\mu}\right)} \left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\mathrm{resum}} + g_K}$$

$$\mu_b = \frac{2e^{-\gamma_E}}{b_T}$$

see, e.g., Collins, "Foundations of Perturbative QCD" (11)
TMD collaboration, "TMD Handbook," arXiv:2304.03302

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perturbative Sudakov form factor

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collinear PDF

Collins-Soper kernel (perturbative and nonperturbative)

$$\mu_b = \frac{2e^{-\gamma_E}}{b_T}$$

matching coefficients (perturbative)

see, e.g., Collins, "Foundations of Perturbative QCD" (11)
TMD collaboration, "TMD Handbook," arXiv:2304.03302

TMD STRUCTURE

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matching coefficients (perturbative)

collinear PDF

Collins-Soper kernel (perturbative and nonperturbative)

nonperturbative part of TMD

$$\mu_b = \frac{2e^{-\gamma_E}}{b_T}$$

↓

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[see, e.g., Collins, "Foundations of Perturbative QCD" (11)](#)
[TMD collaboration, "TMD Handbook," arXiv:2304.03302](#)

UNPOLARIZED TMD GLOBAL FITS

	Accuracy	SIDIS HERMES	SIDIS COMPASS	DY fixed target	DY collider	N of points	χ^2/N_{points}
Pavia 2017 arXiv:1703.10157	NLL	✔	✔	✔	✔	8059	1.55
SV 2019 arXiv:1912.06532	N^3LL^-	✔	✔	✔	✔	1039	1.06
MAP22 arXiv:2206.07598	N^3LL^-	✔	✔	✔	✔	2031	1.06
ART23 arXiv:2305.07473	N^4LL	✘	✘	✔	✔	627	0.96
MAP24 arXiv:2405.13833	N^3LL	✔	✔	✔	✔	2031	1.08

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See talks by Filippo Delcarro and Valentin Moos

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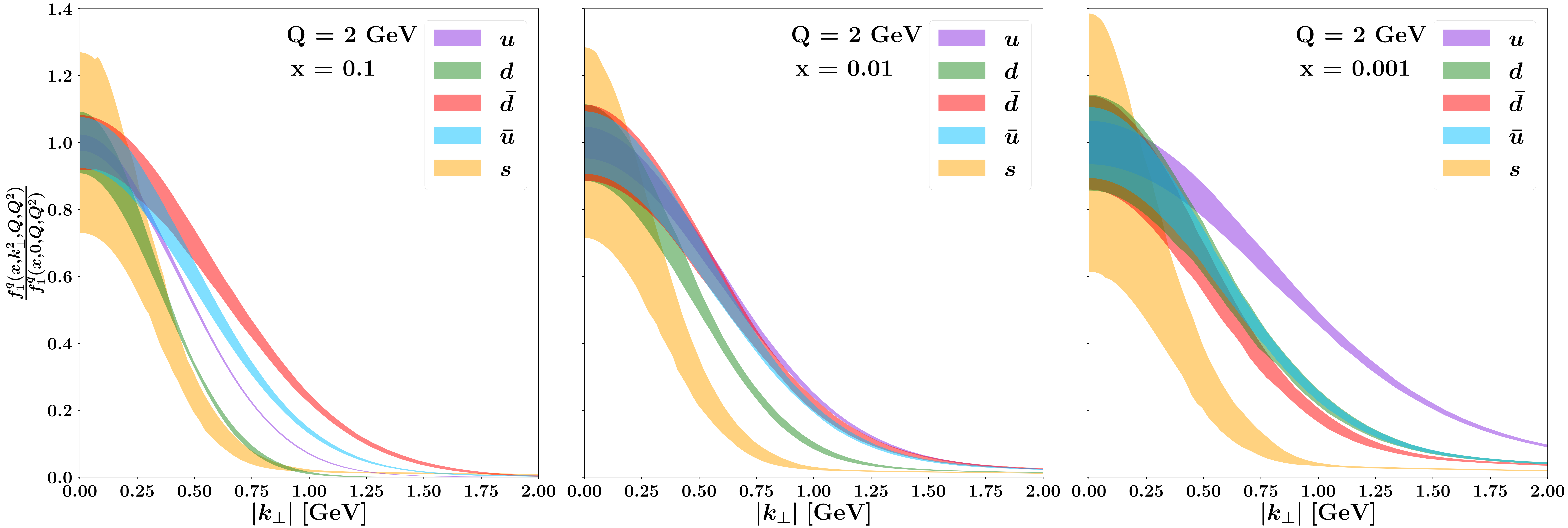
See talks by Filippo Delcarro and Valentin Moos

see also Parton Branching approach, talk by Louis Moureaux

FLAVOR-DEPENDENT UNPOLARIZED TMDS

MAP Collaboration, arXiv:2405.13833



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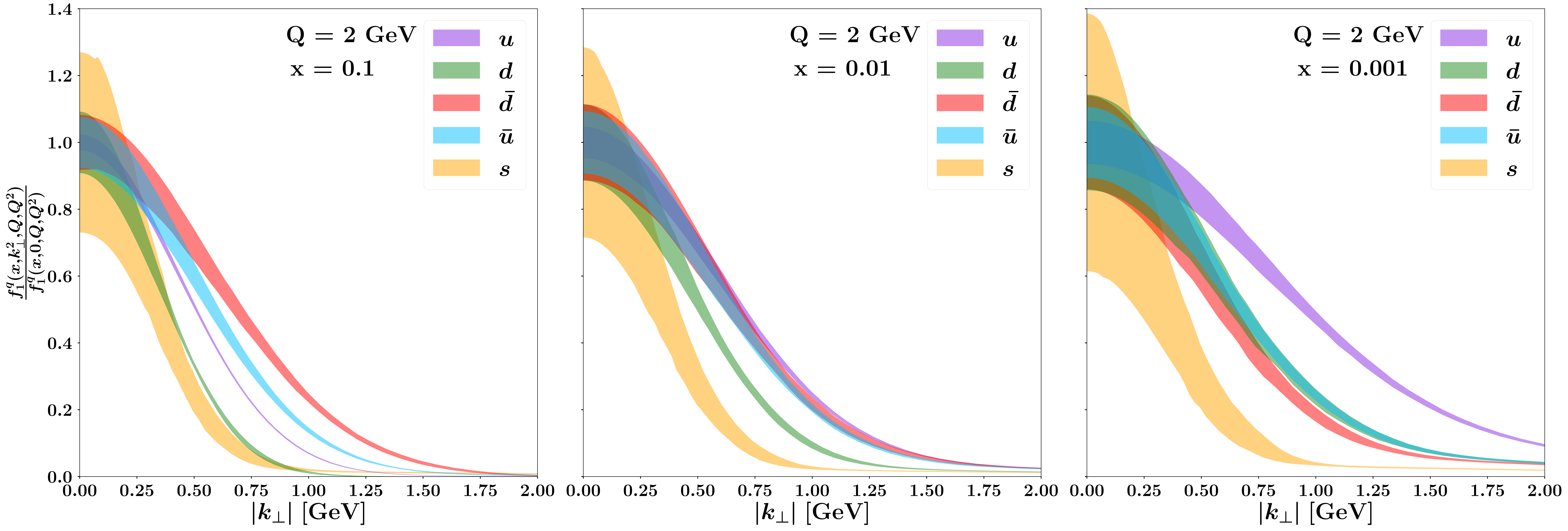
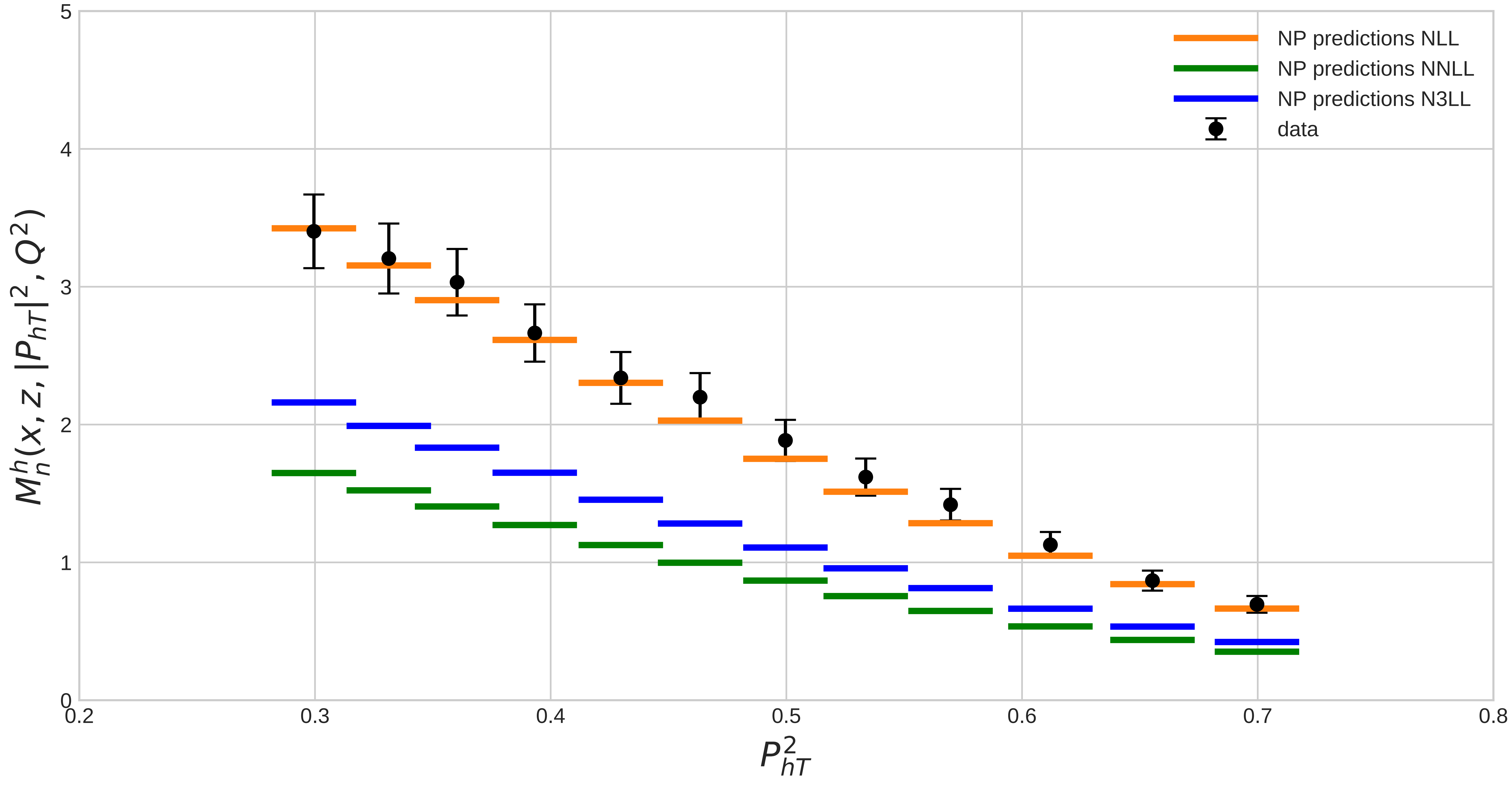


See talk by Filippo Delcarro

SOME OPEN ISSUES…

IMPROVED ACCURACY AND SIDIS

COMPASS multiplicities (one of many bins)



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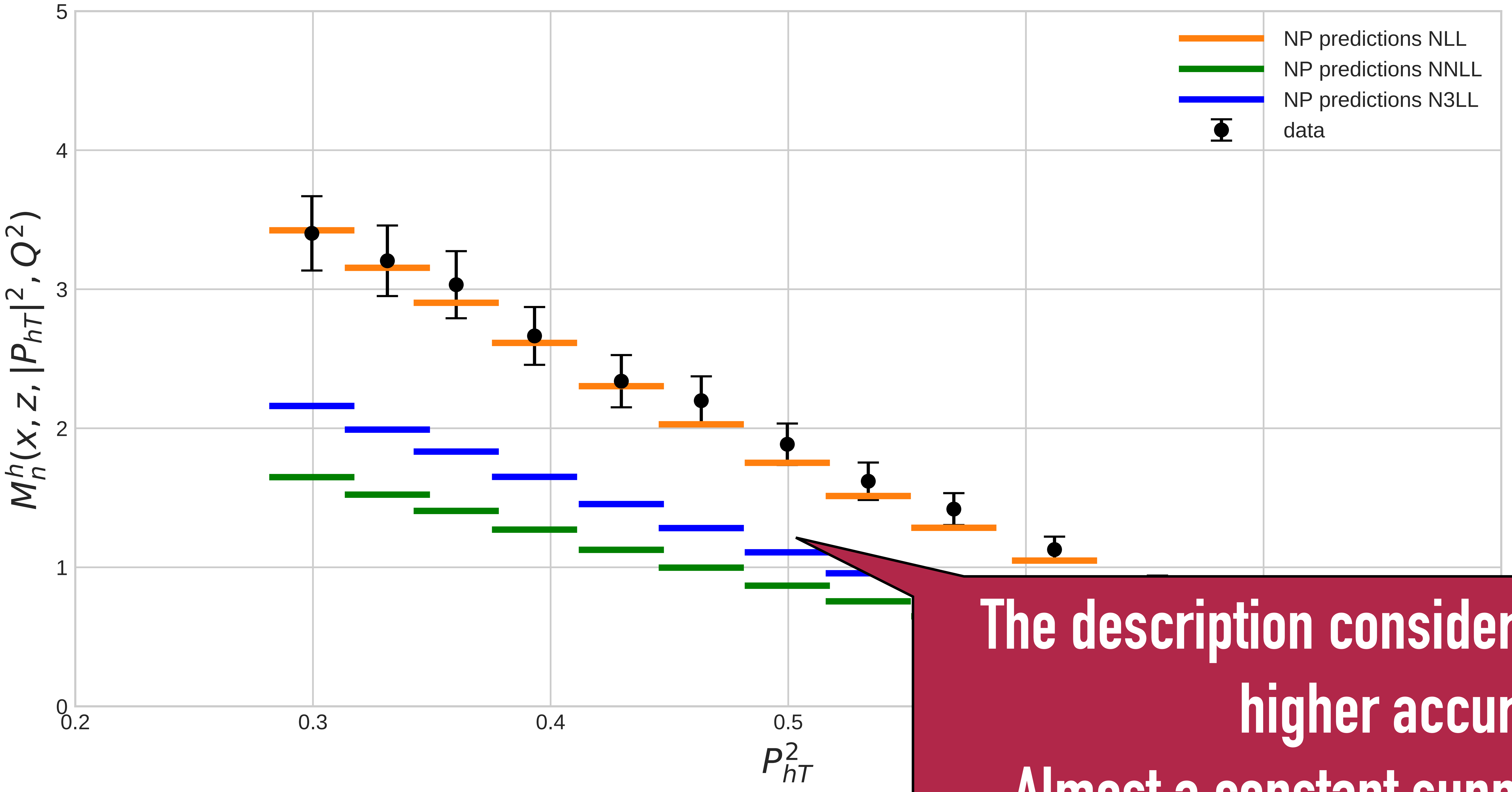
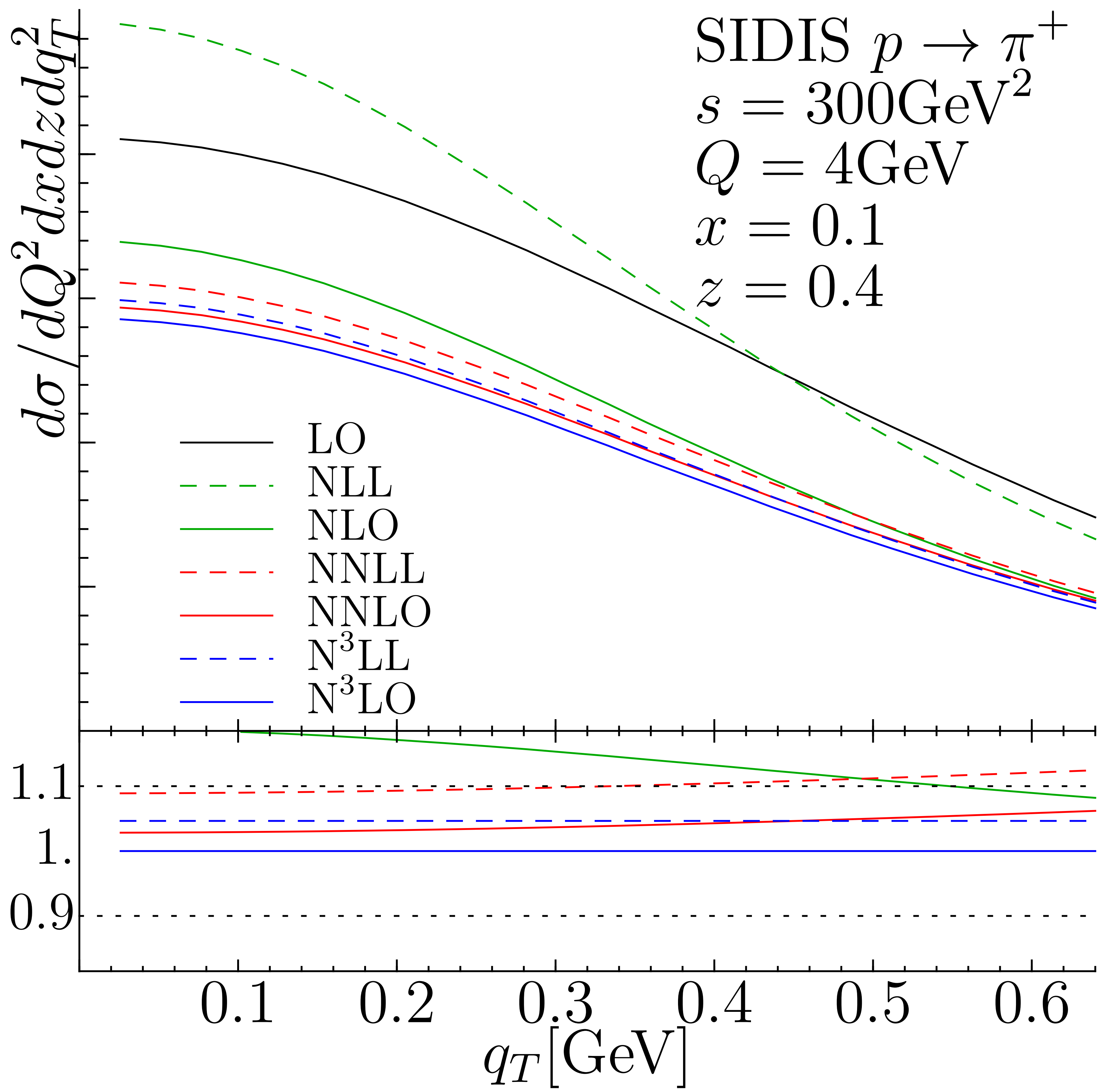


The description considerably worsens at higher accuracy.
Almost a constant suppression factor.

IMPROVED ACCURACY AND SIDIS

Scimemi, Vladimirov, arXiv:1912.06532



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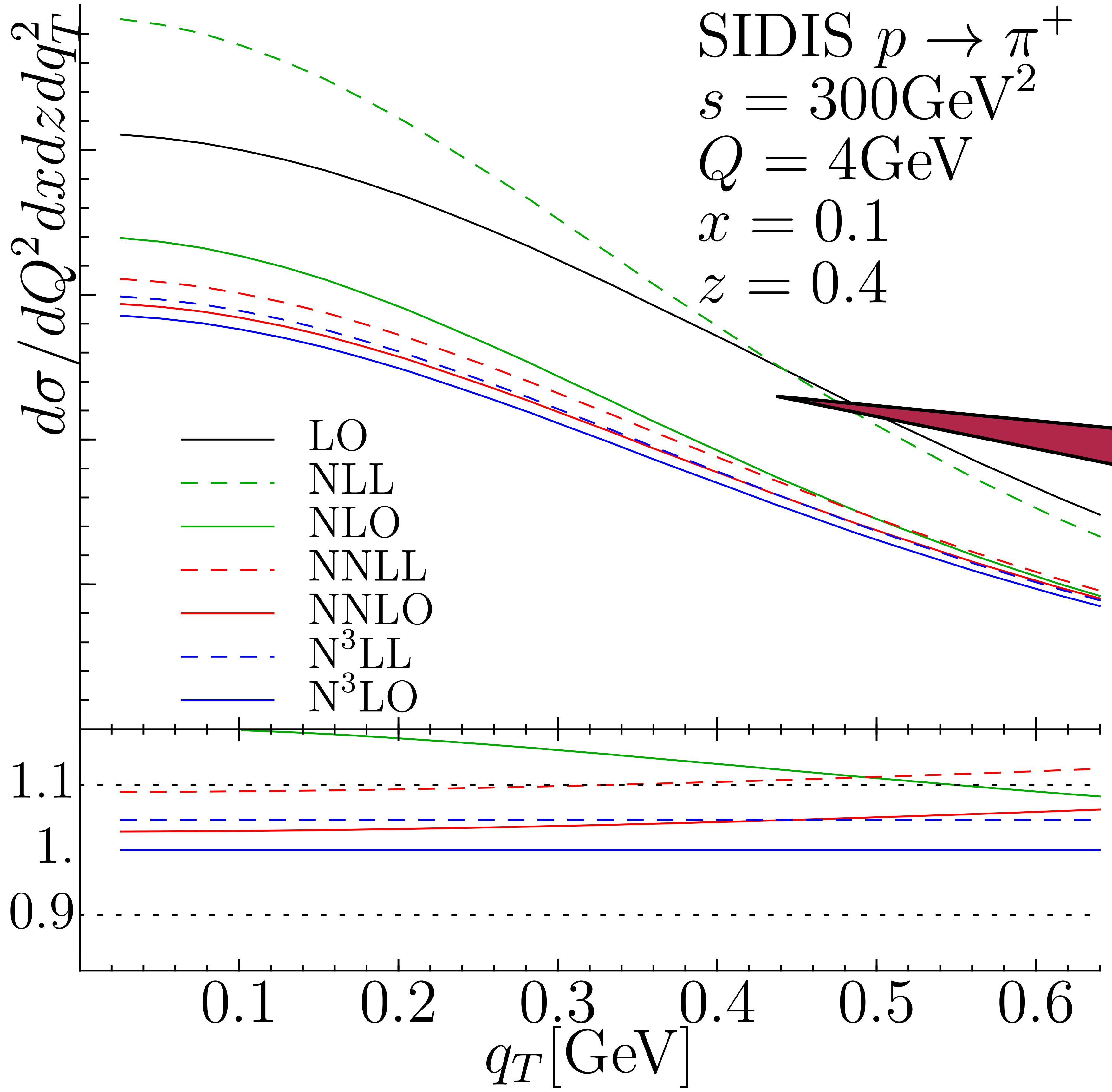

Also in the SV19 study, the overall decrease is evident

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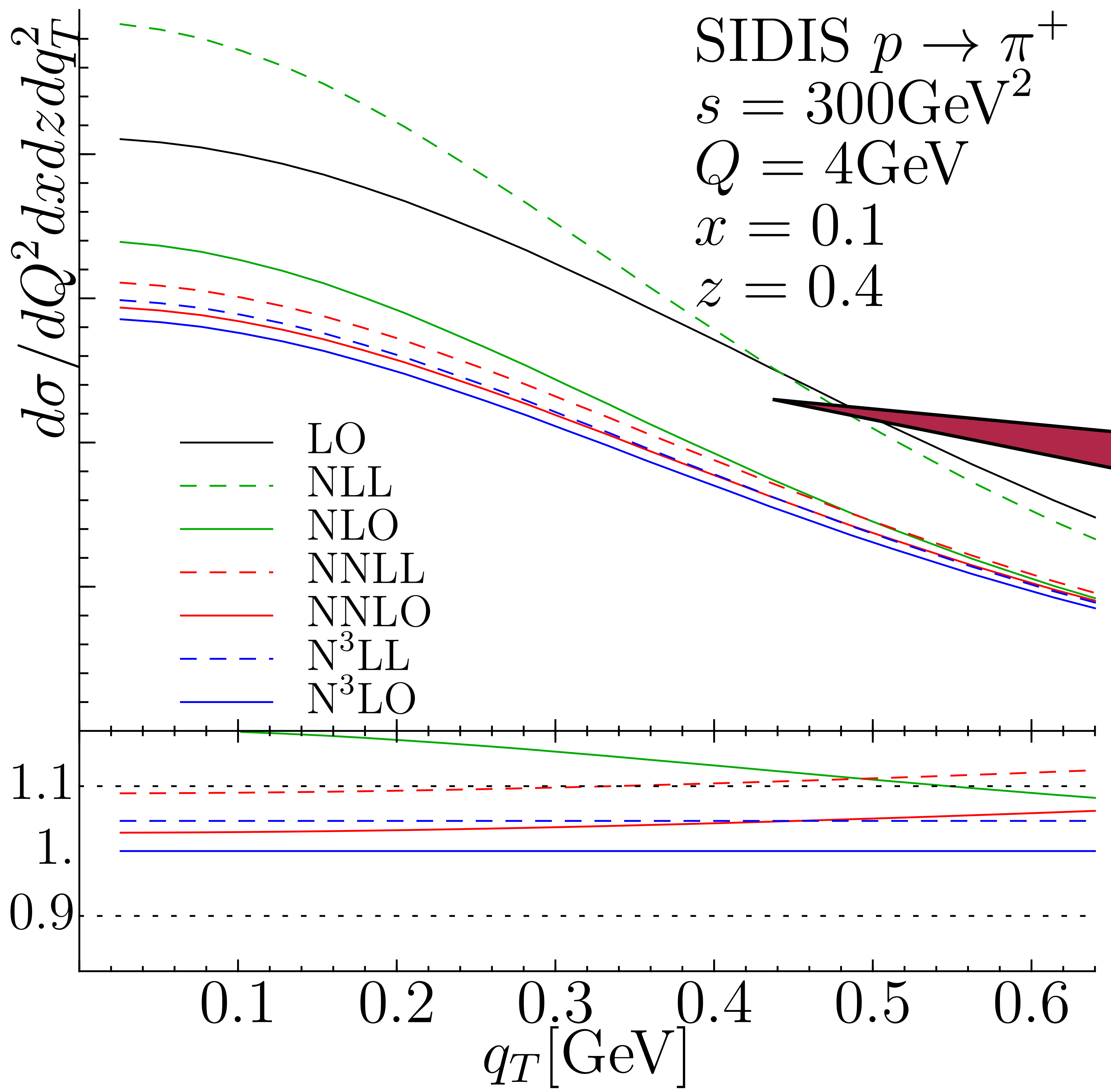

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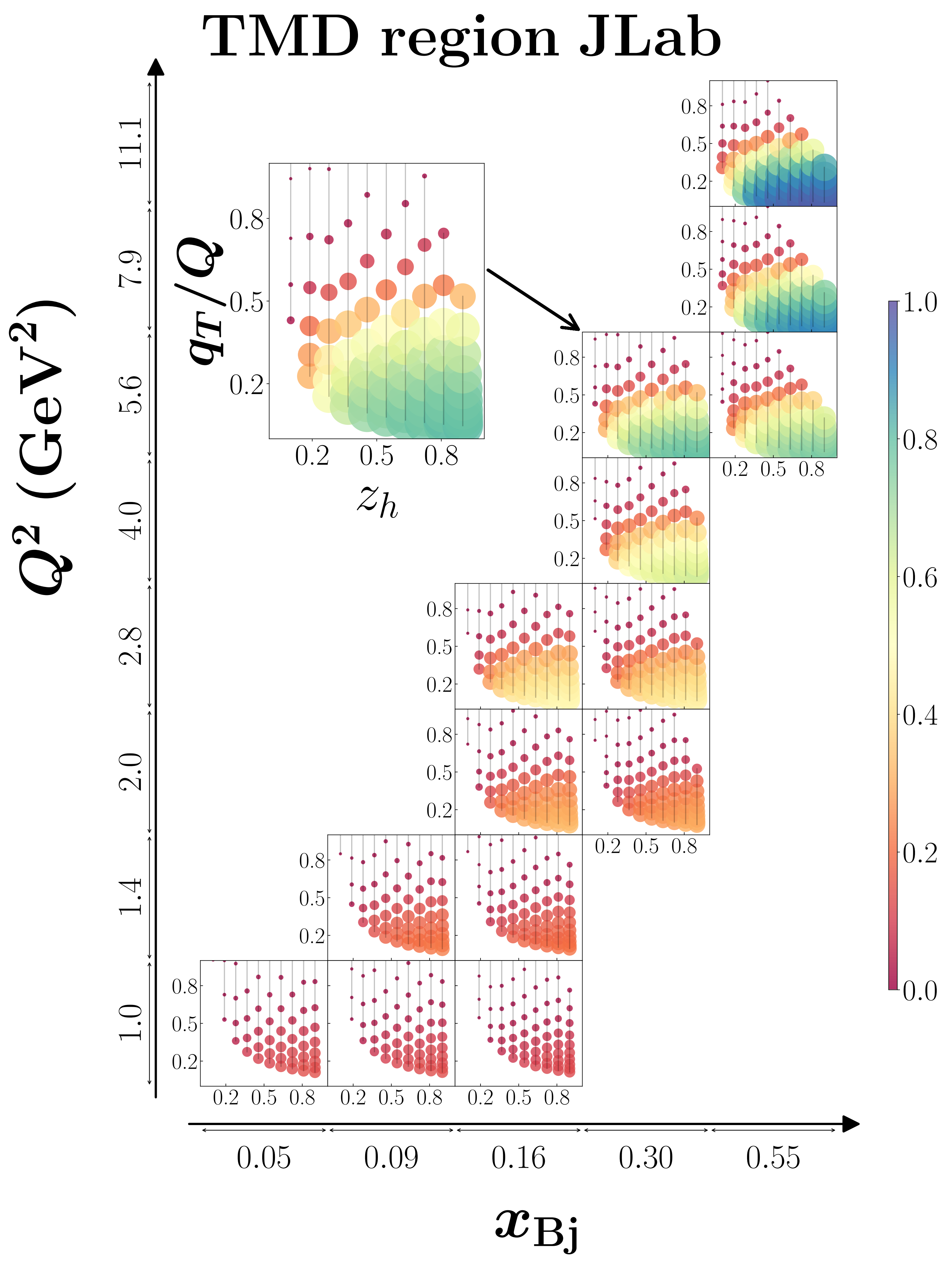
See talk by Valentin Moos

REGION OF VALIDITY OF TMD FORMALISM

[Boglione, Diefenthaler, Dolan, Gamberg, Melnitchouk, arXiv:2201.12197](https://arxiv.org/abs/2201.12197)

$$|q_T| = |P_{hT}|/z \ll Q$$



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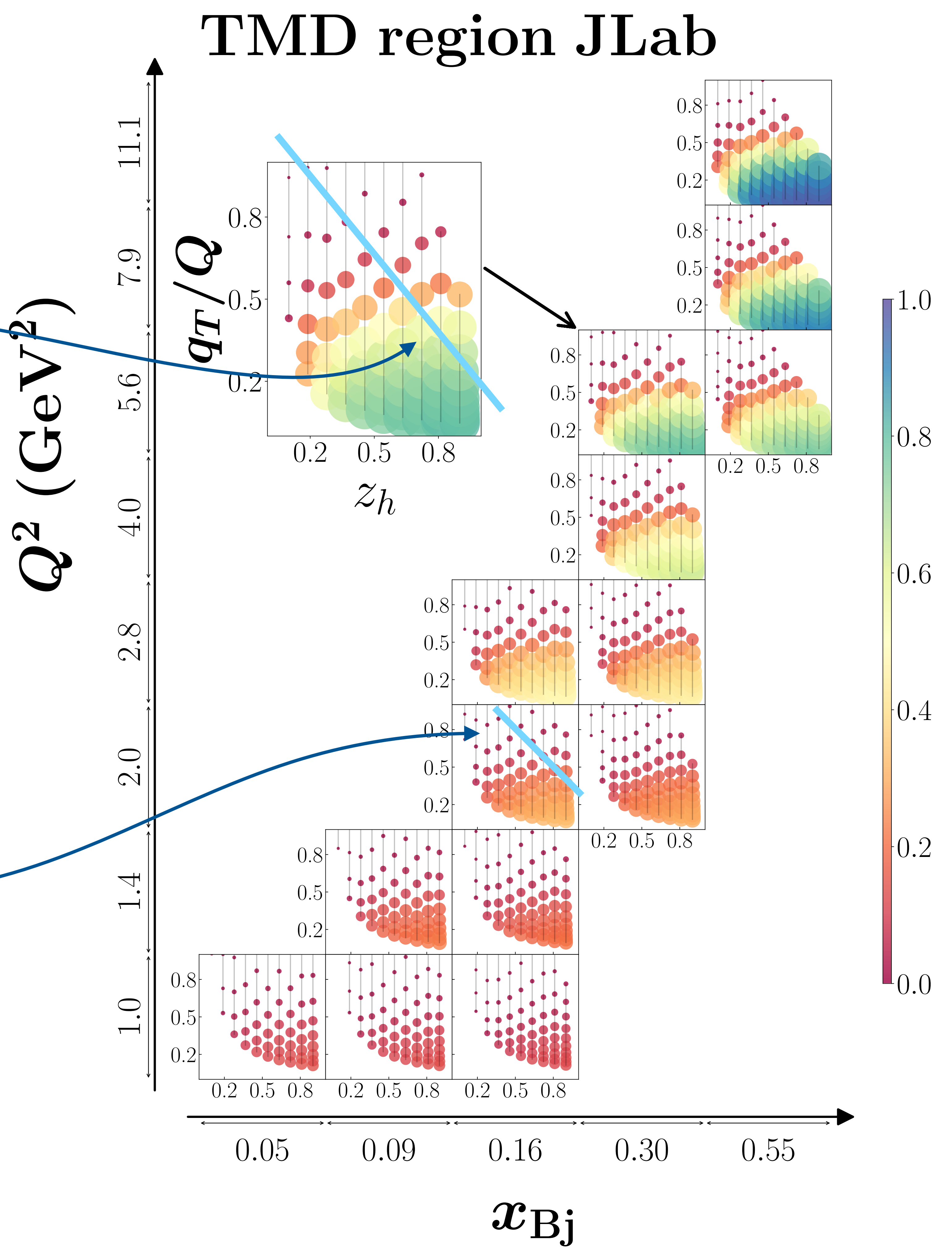
Approximate region corresponding to MAP22 cuts



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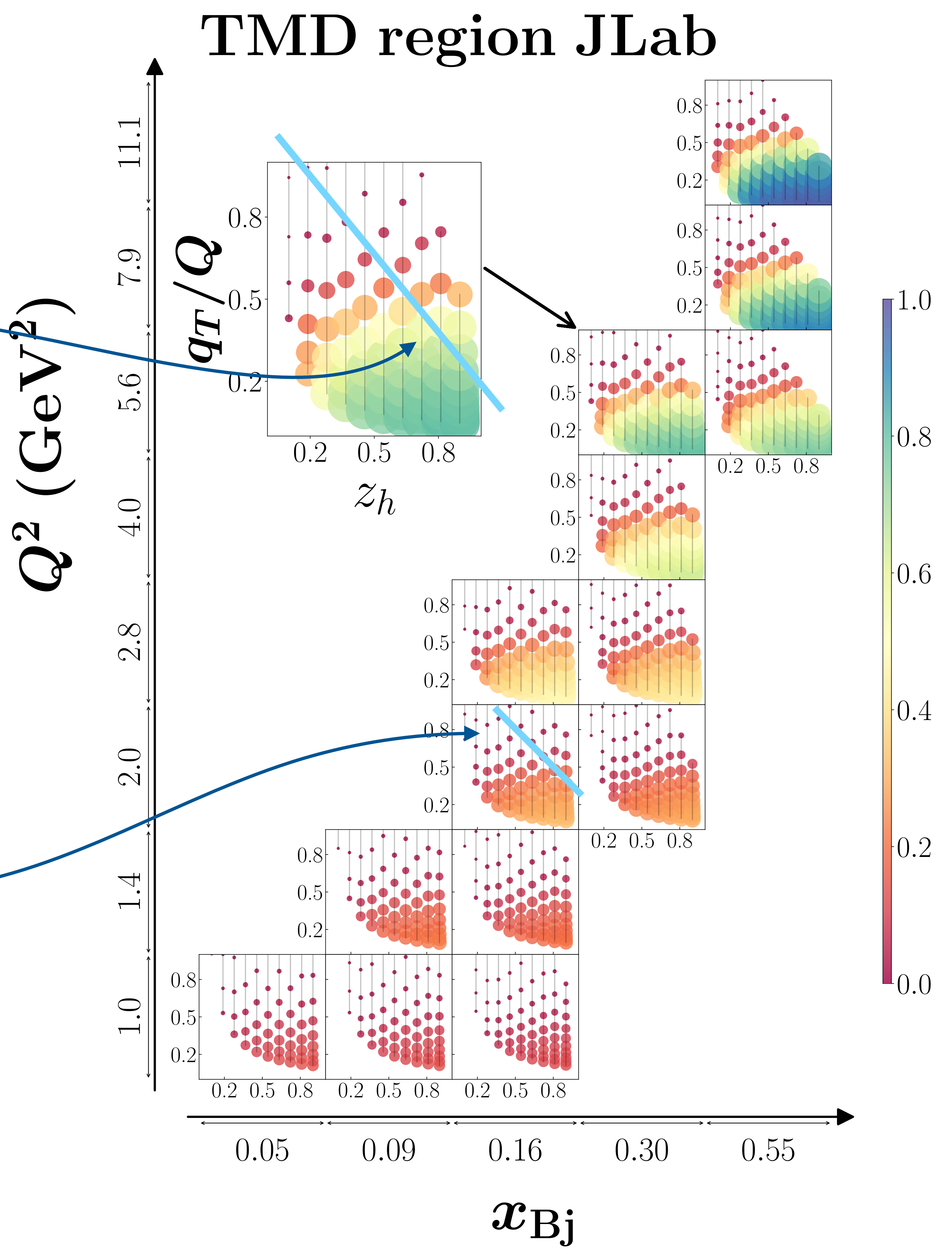

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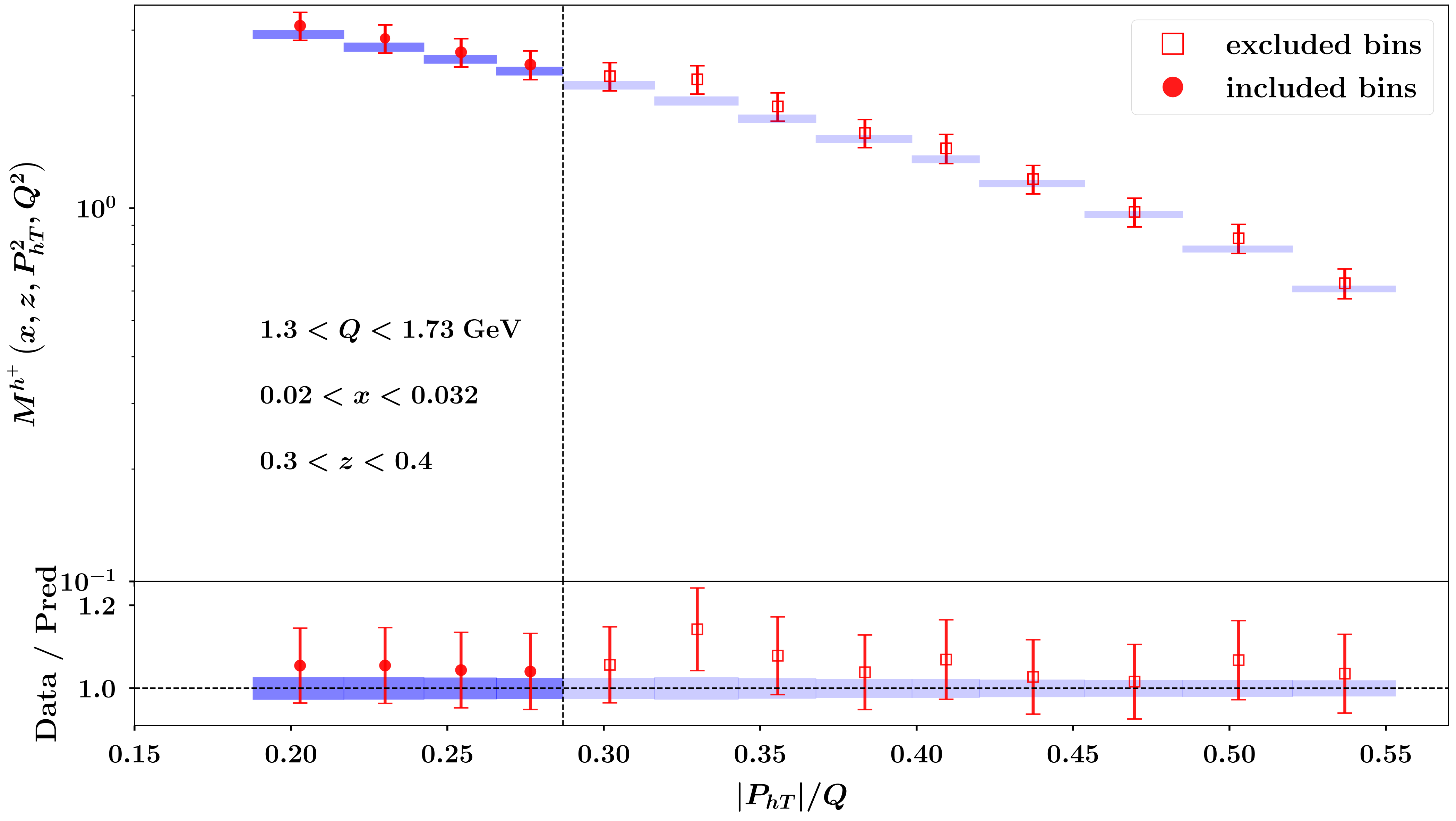

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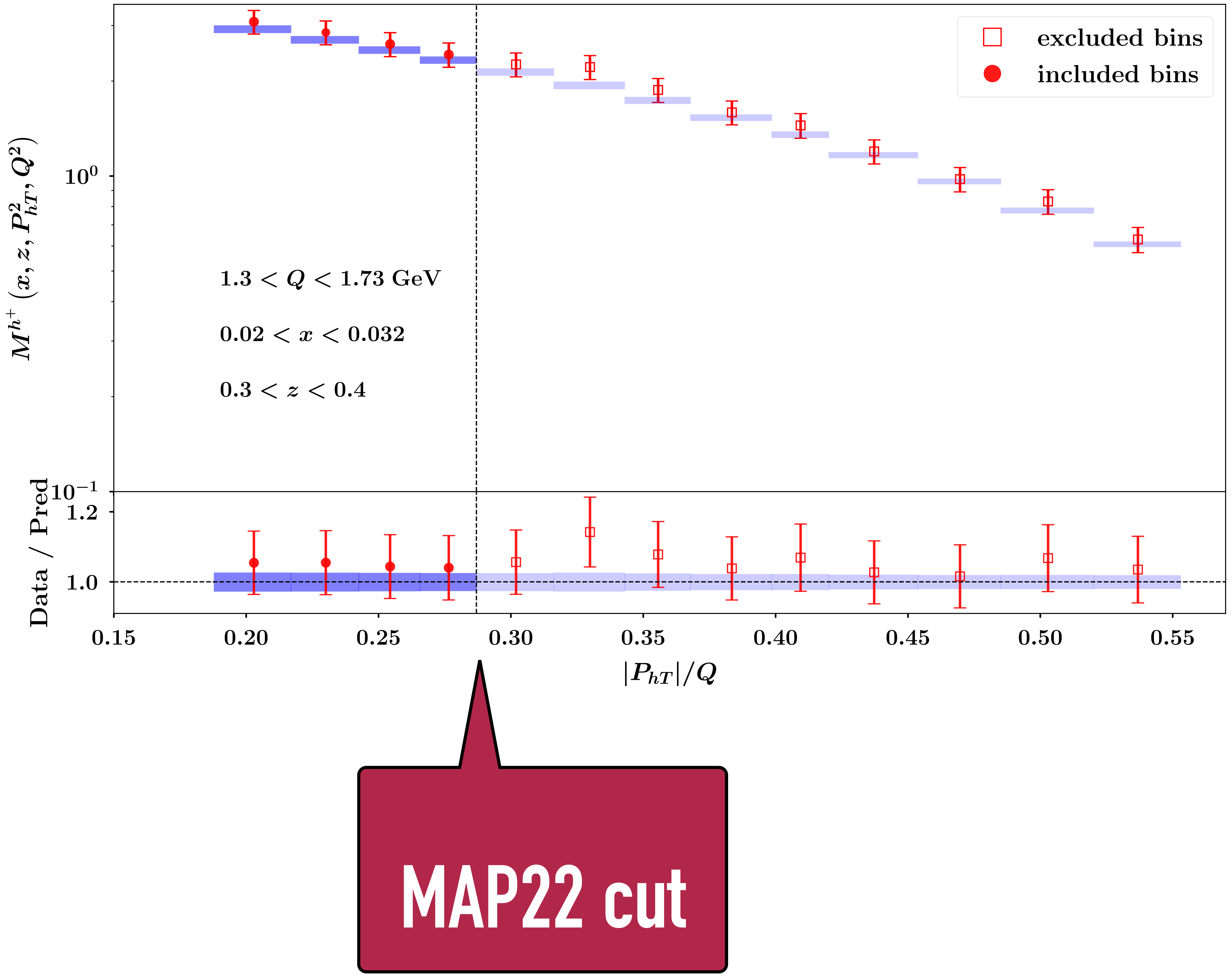

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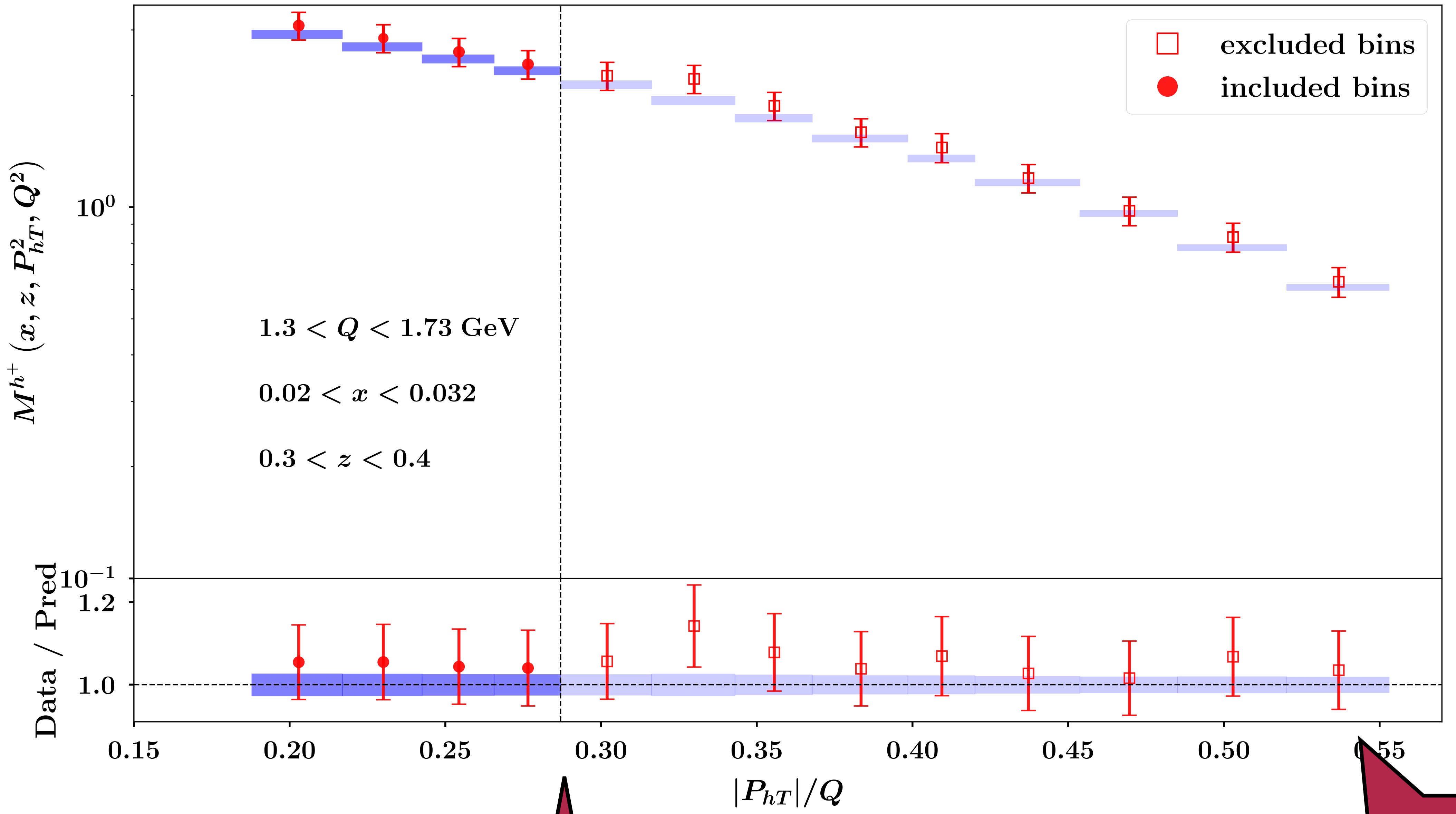

MAP22 cut

MAP22 extrapolation

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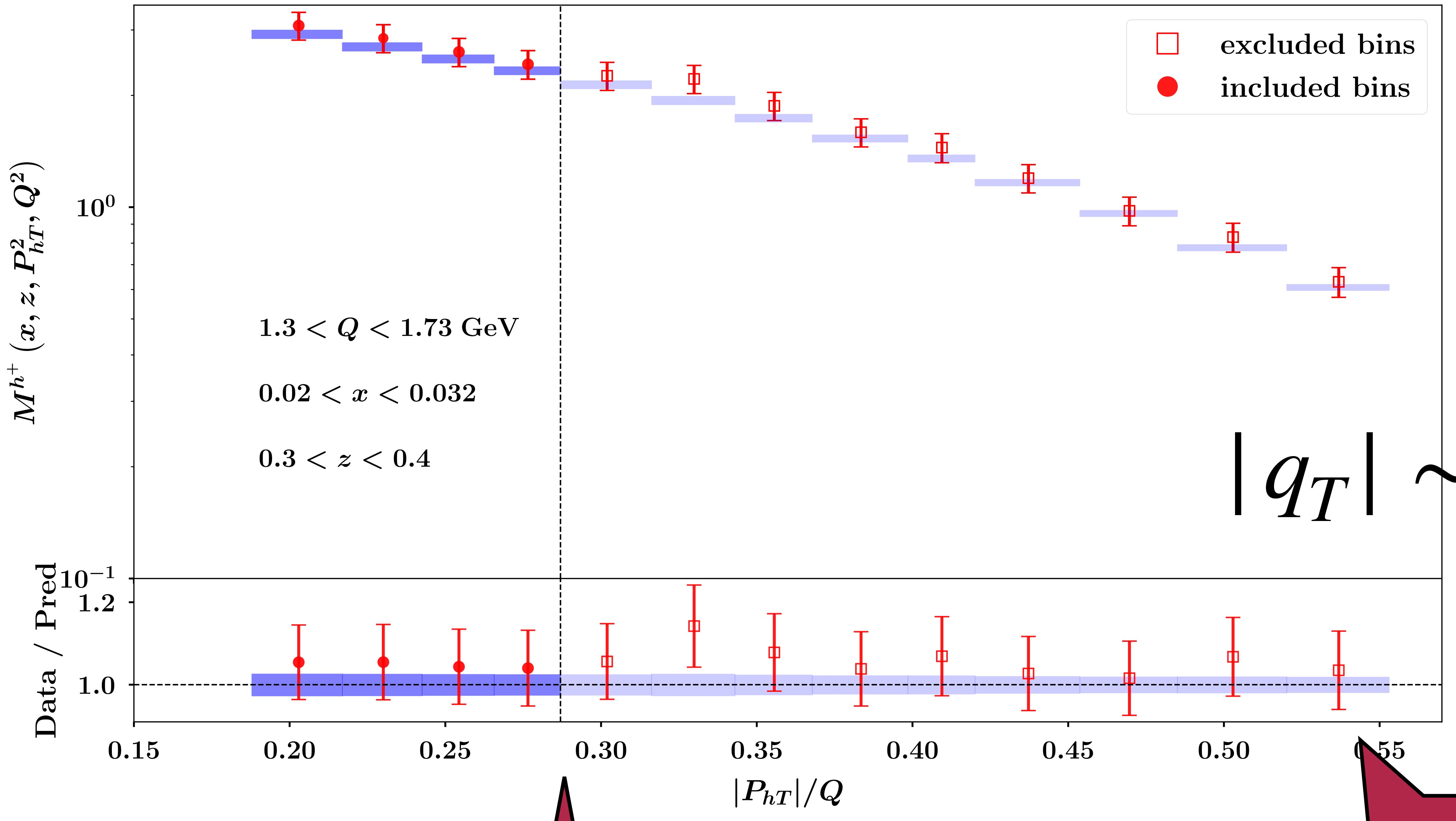

$$|q_T| \sim 1.5\ Q$$!

MAP22 cut

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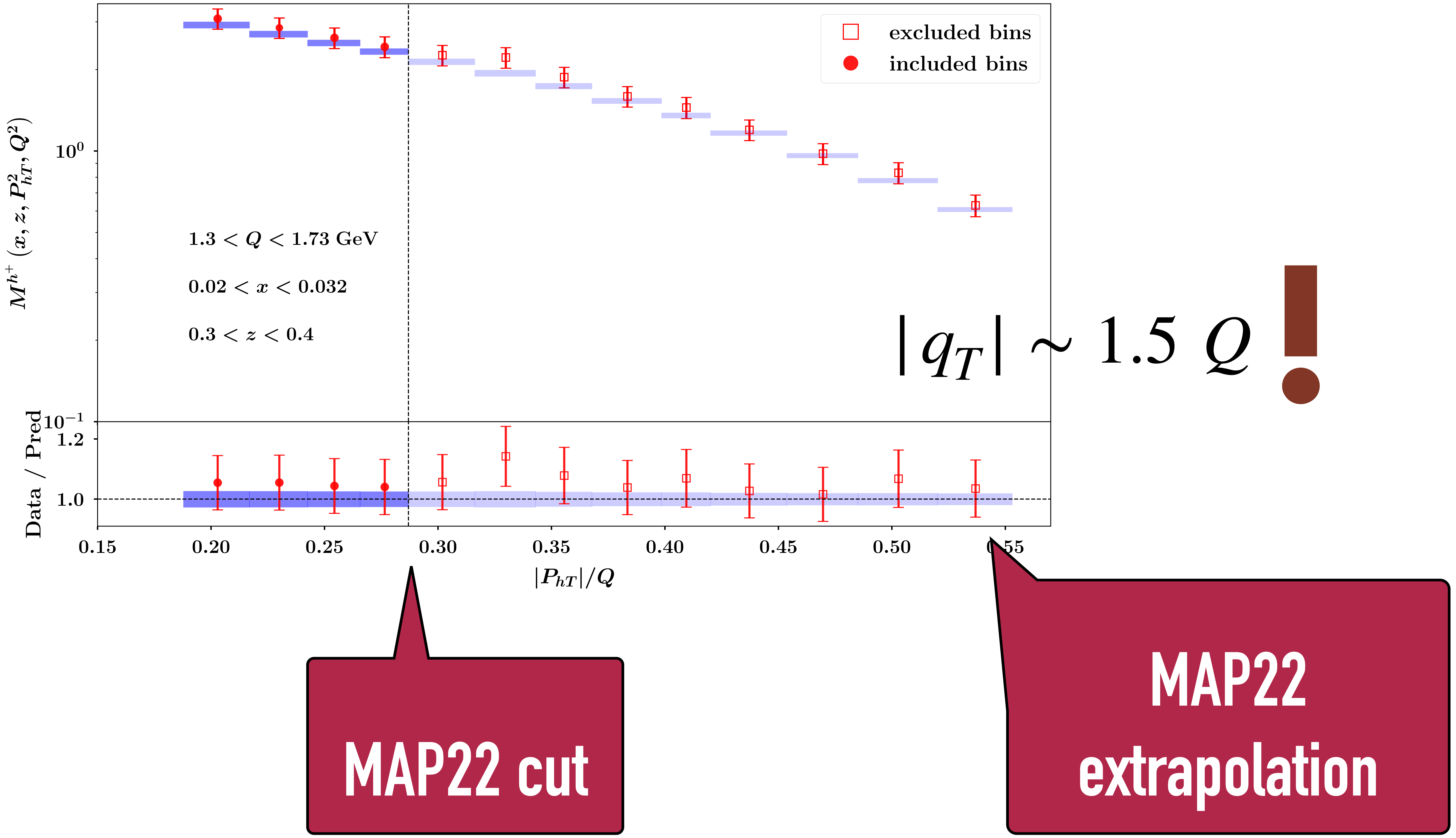

The MAP22 cut is already considered to be "generous",
but the physics seems to be the same for a much wider transverse momentum

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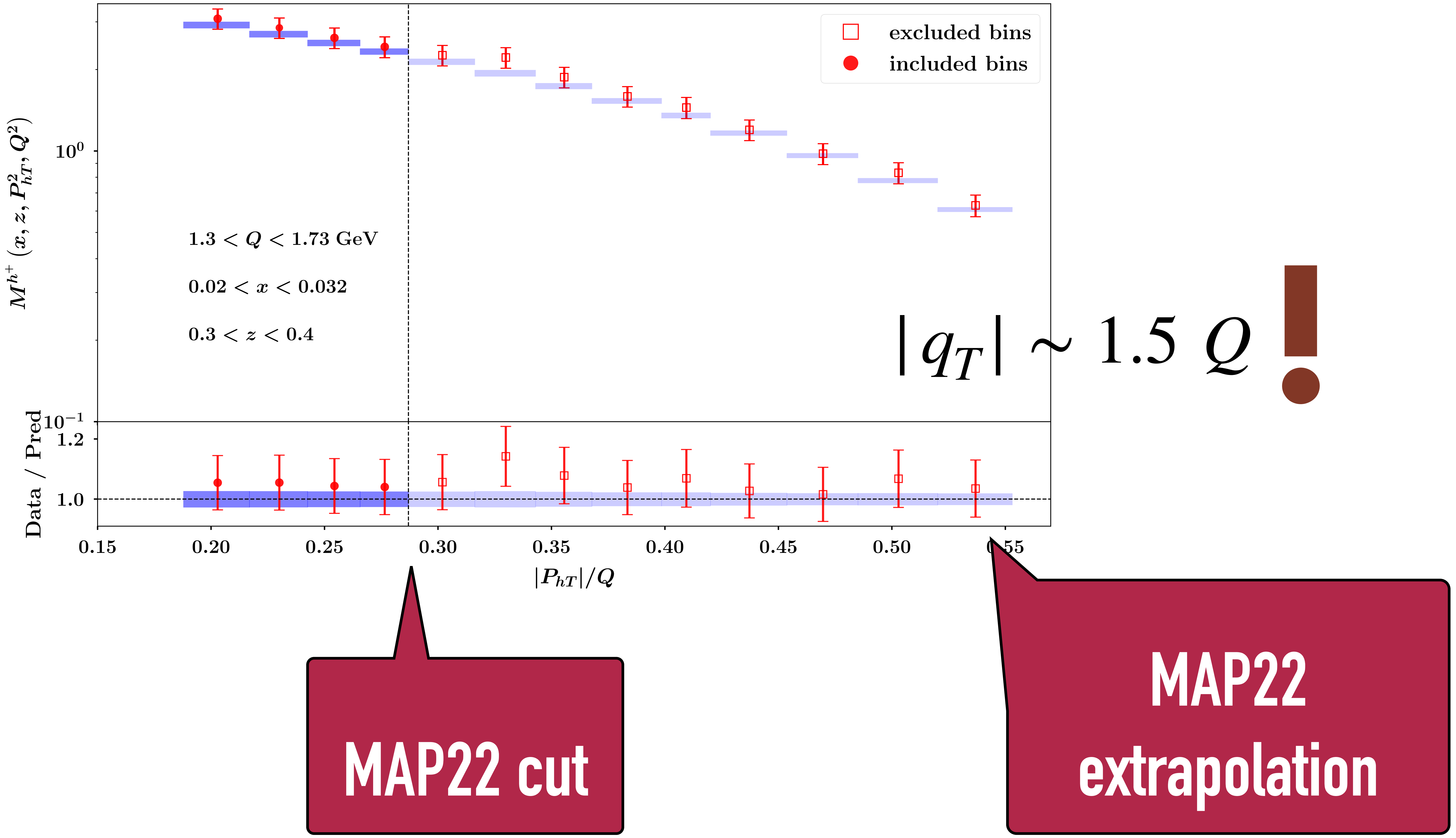

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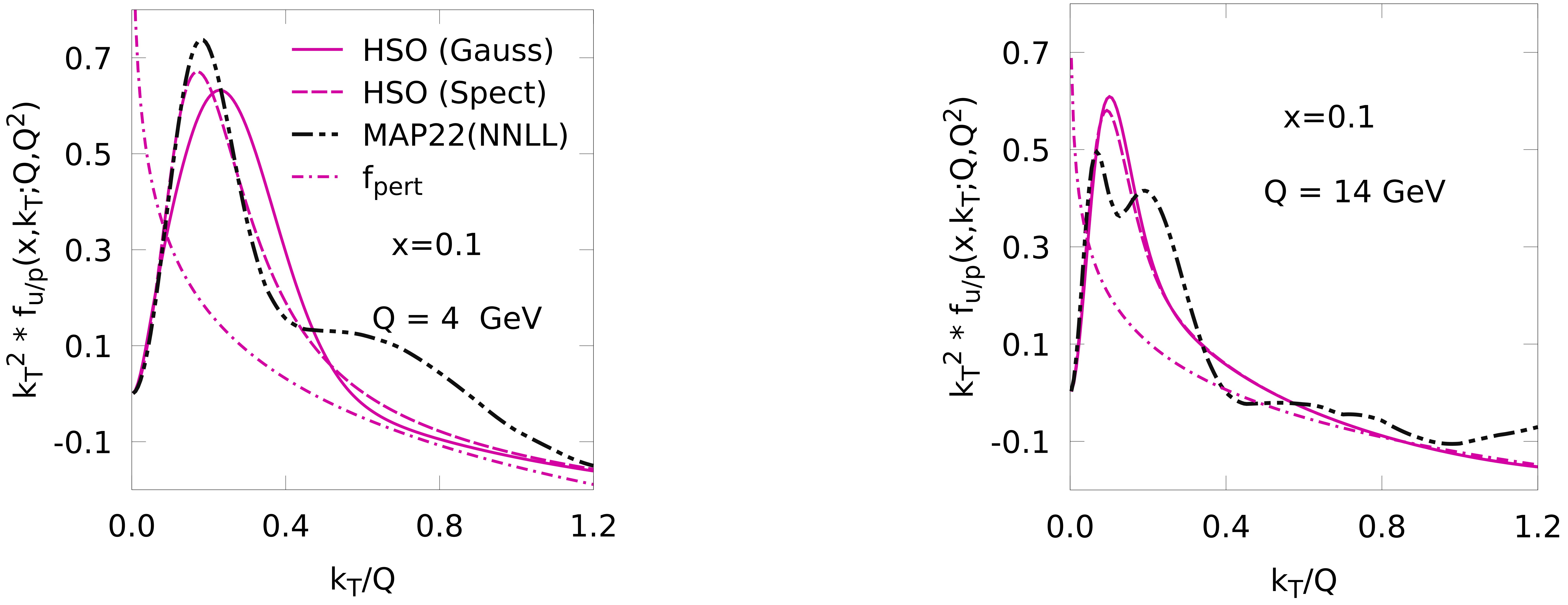
RECENT DISCUSSION ABOUT "HSO" APPROACH

Aslan, Boglione, Gonzalez-Hernandez, Rainaldi, Rogers, Simonelli, 2401.14266



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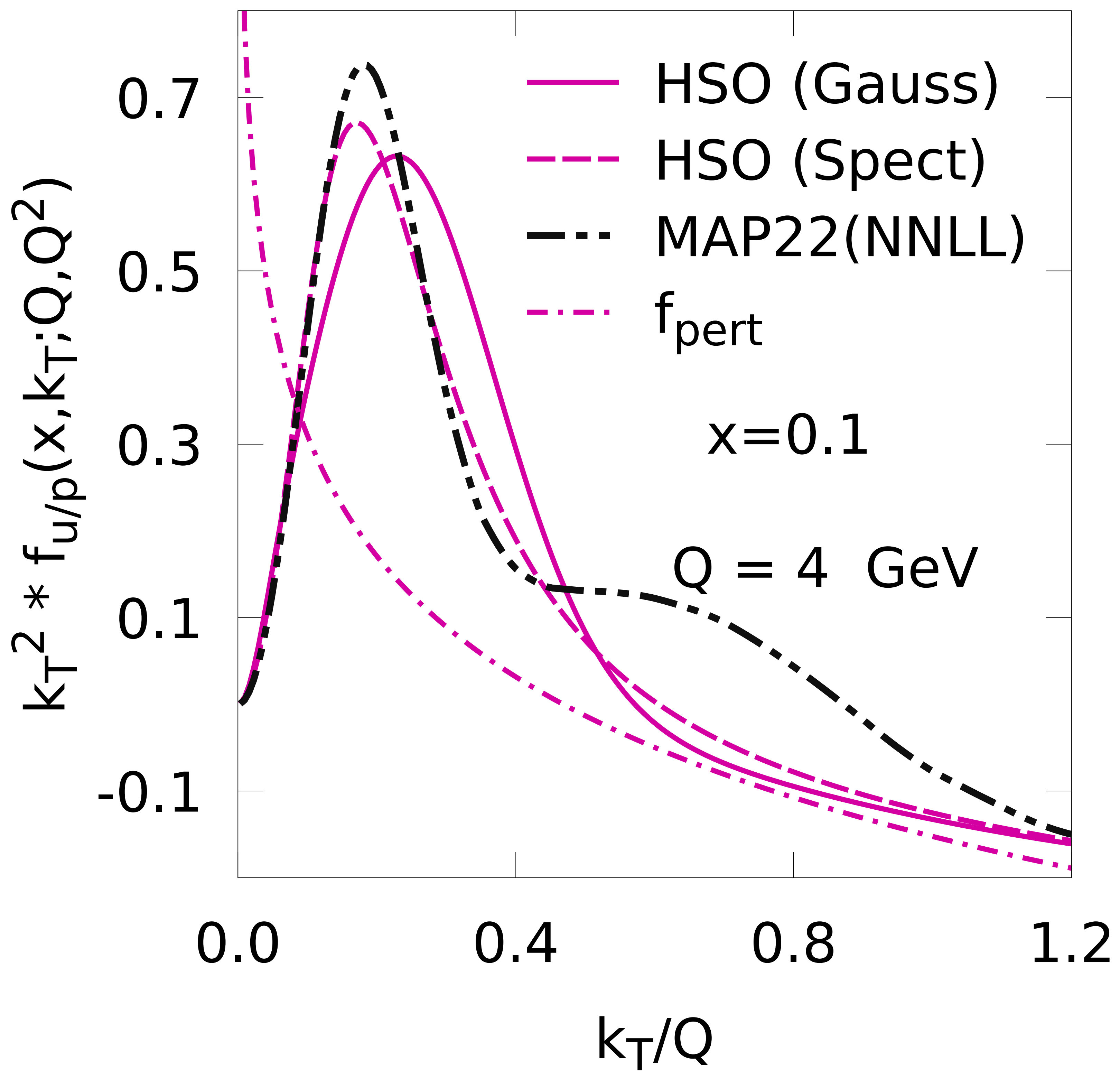

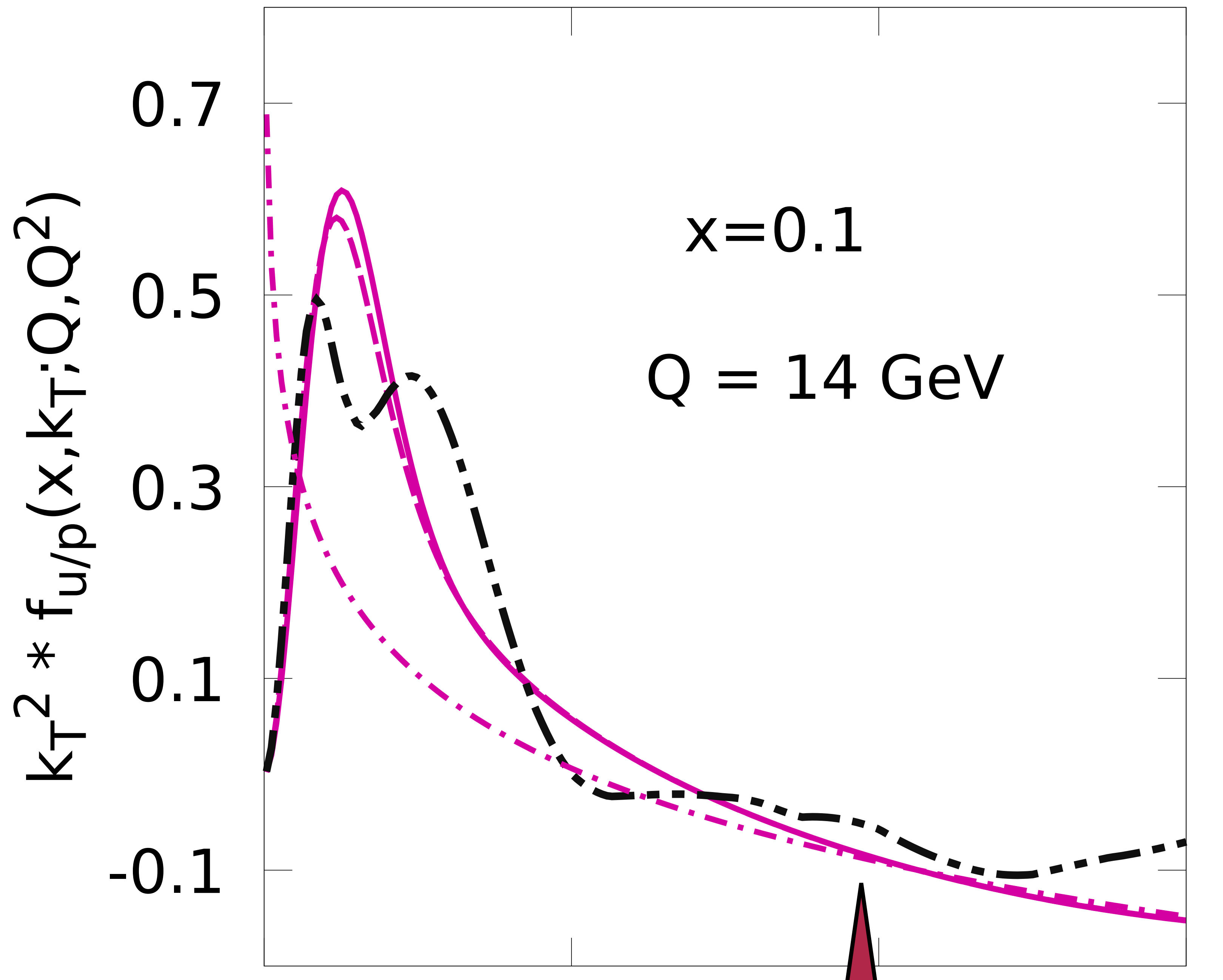

The k_T^2 weighing exposes the tails

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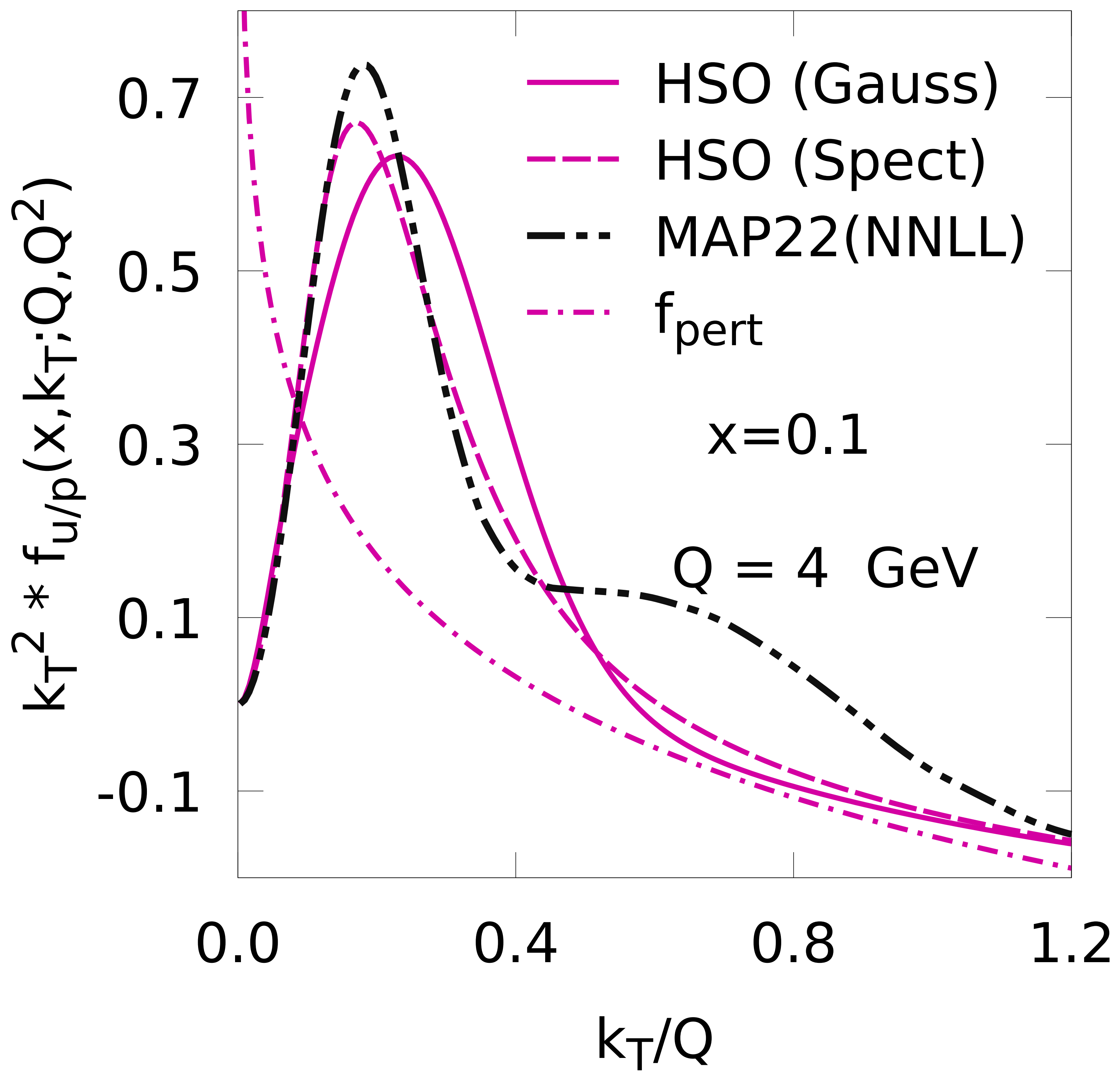
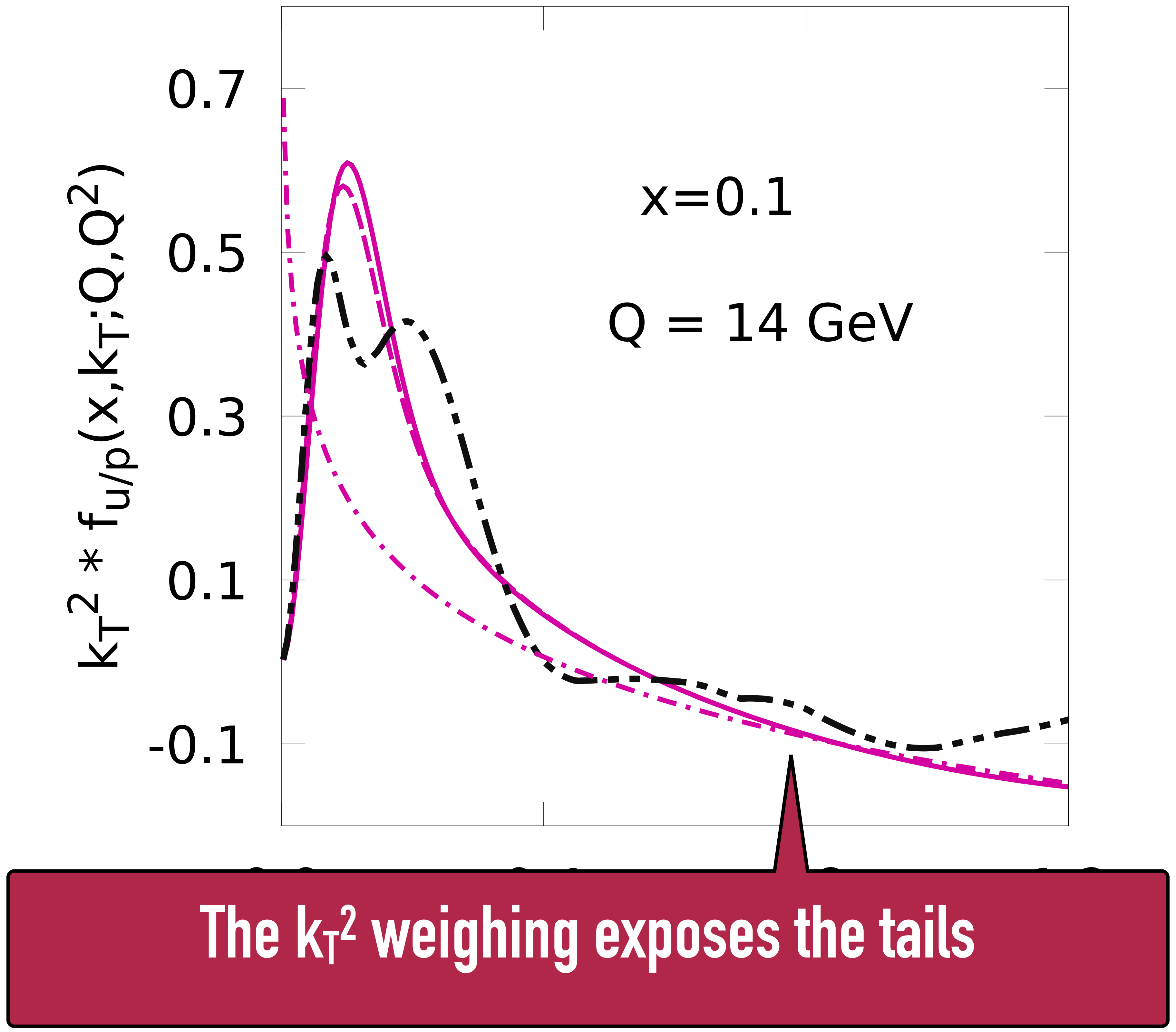
[Aslan, Boglione, Gonzalez-Hernandez, Rainaldi, Rogers, Simonelli, 2401.14266](https://arxiv.org/abs/2401.14266)





The paper emphasizes the relevance of prescription choices and simultaneous TMD-PDF fit, but does not provide a fit to extended data sets.

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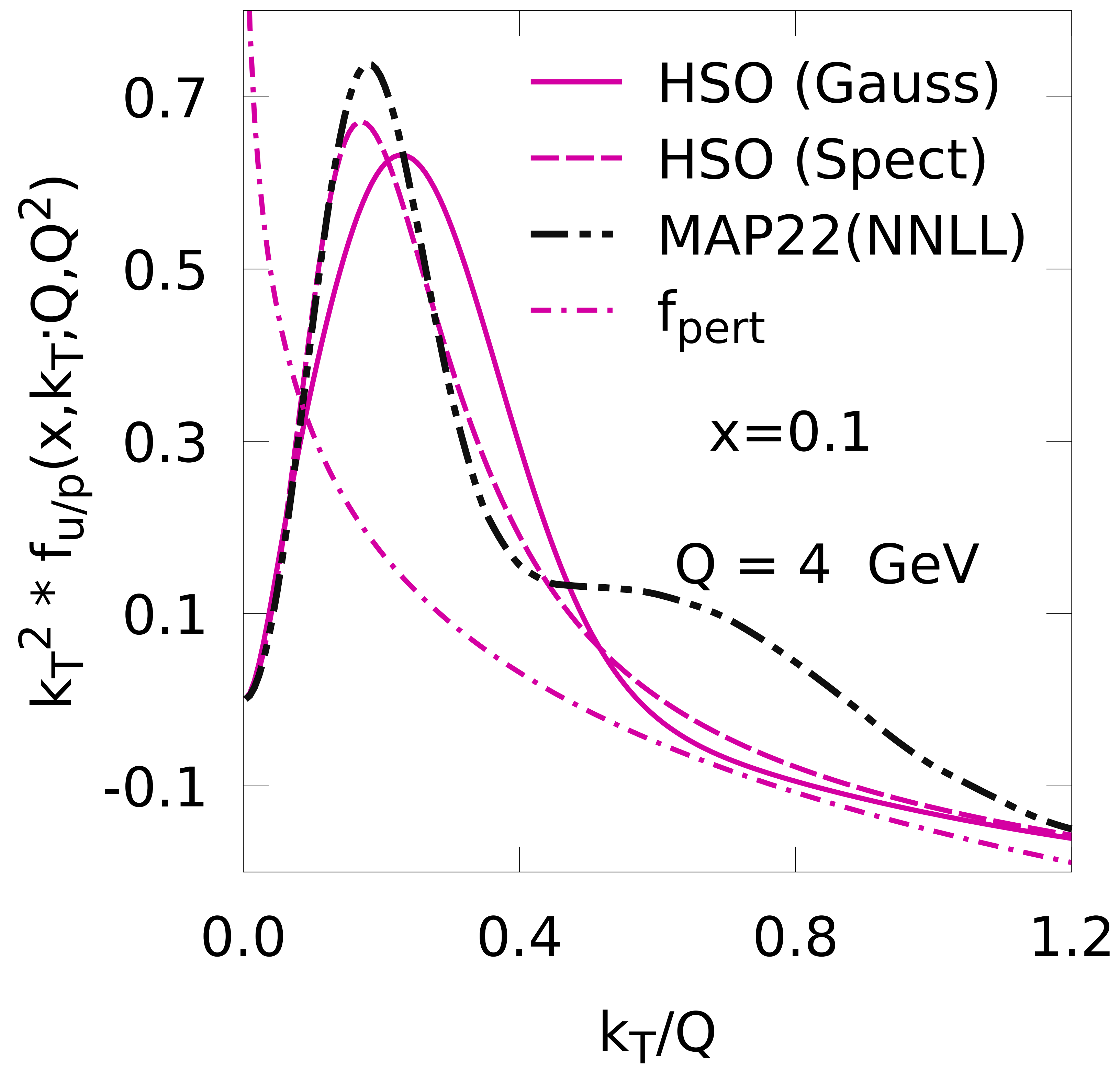

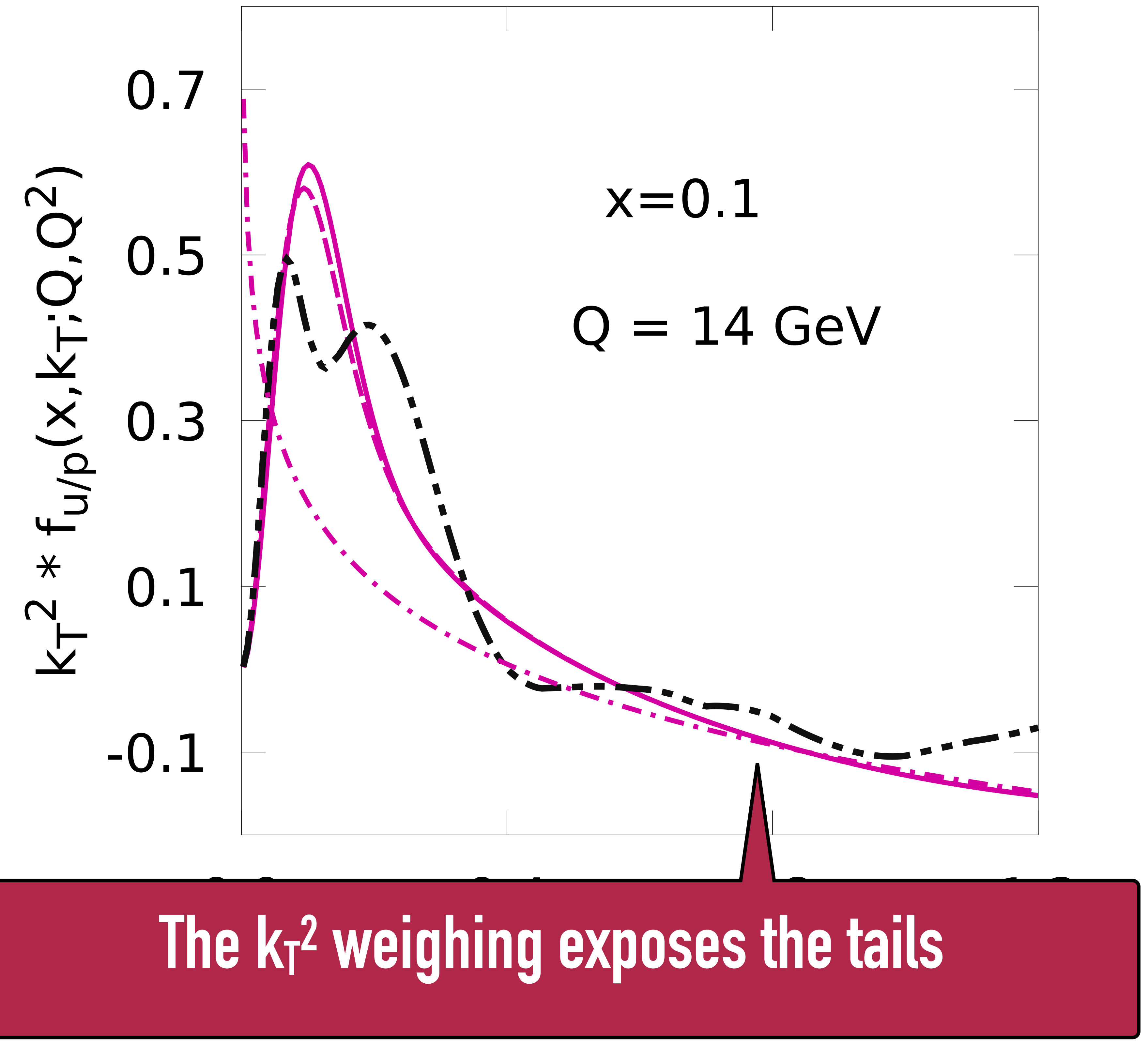

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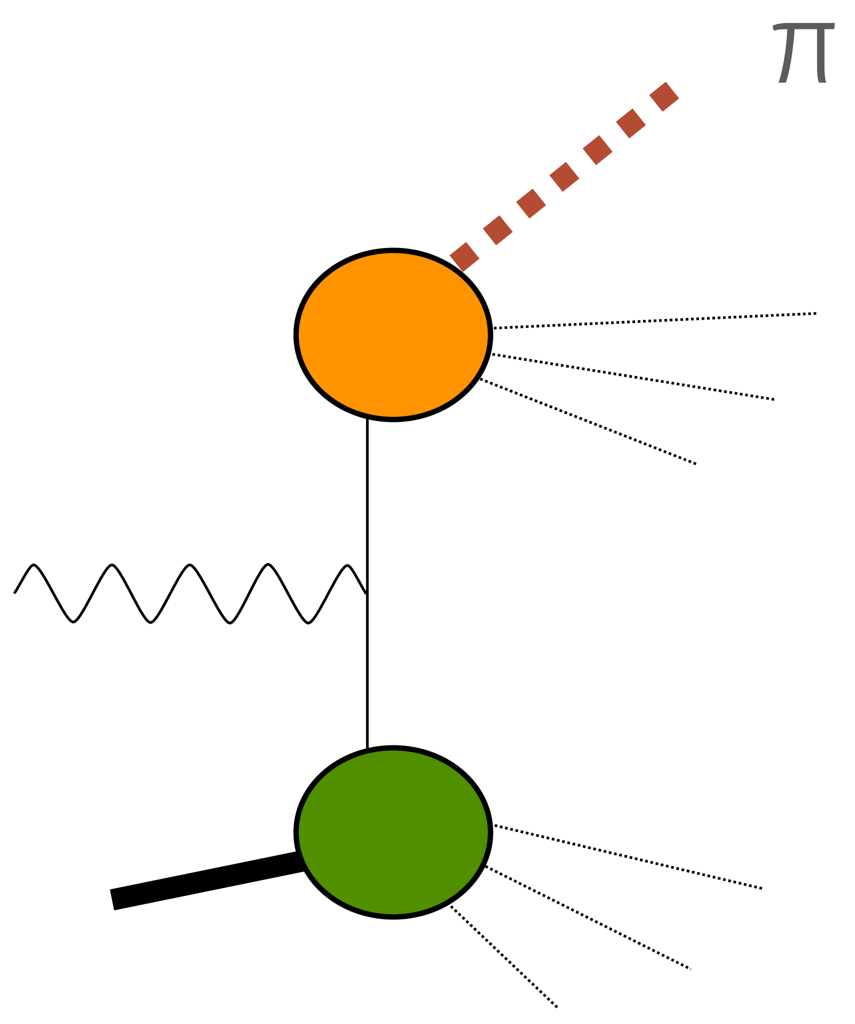
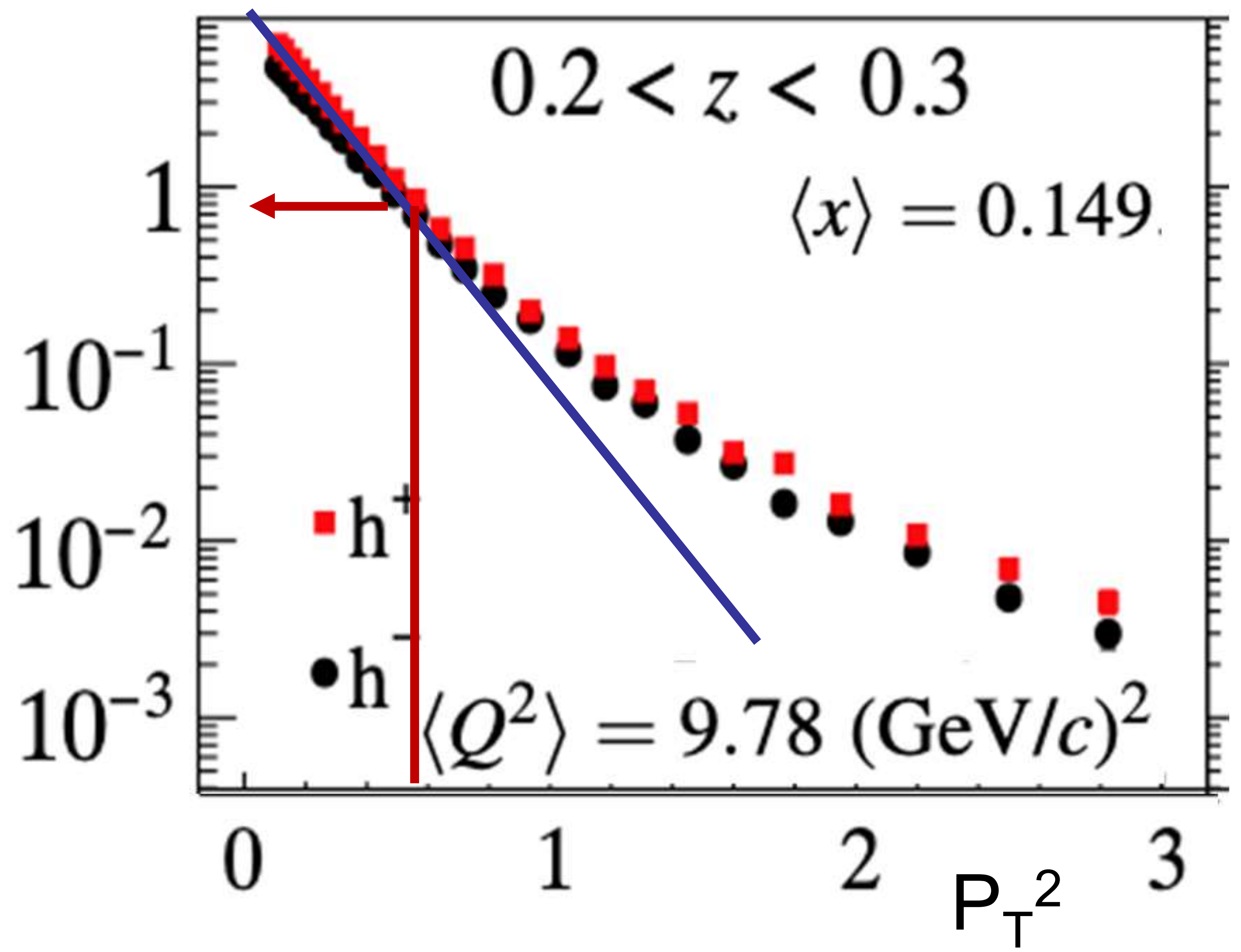
See talk by Tommaso Rainaldi

VECTOR MESON CONTAMINATIONS



Semi-inclusive



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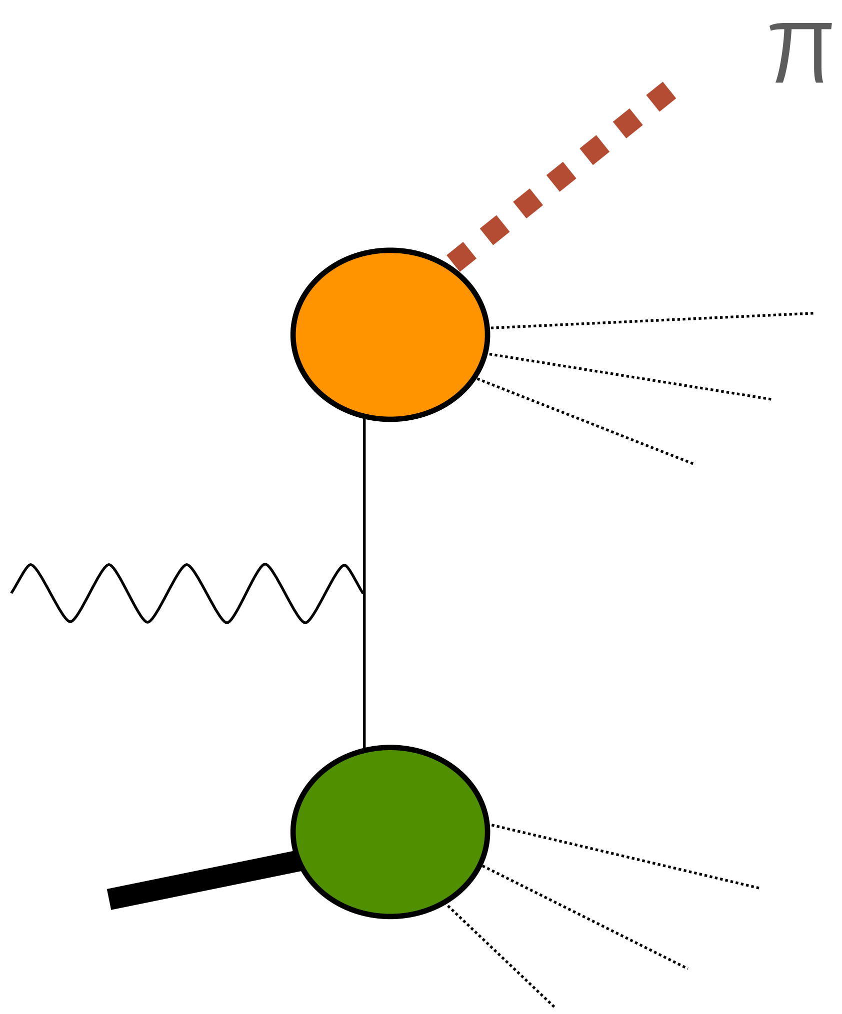

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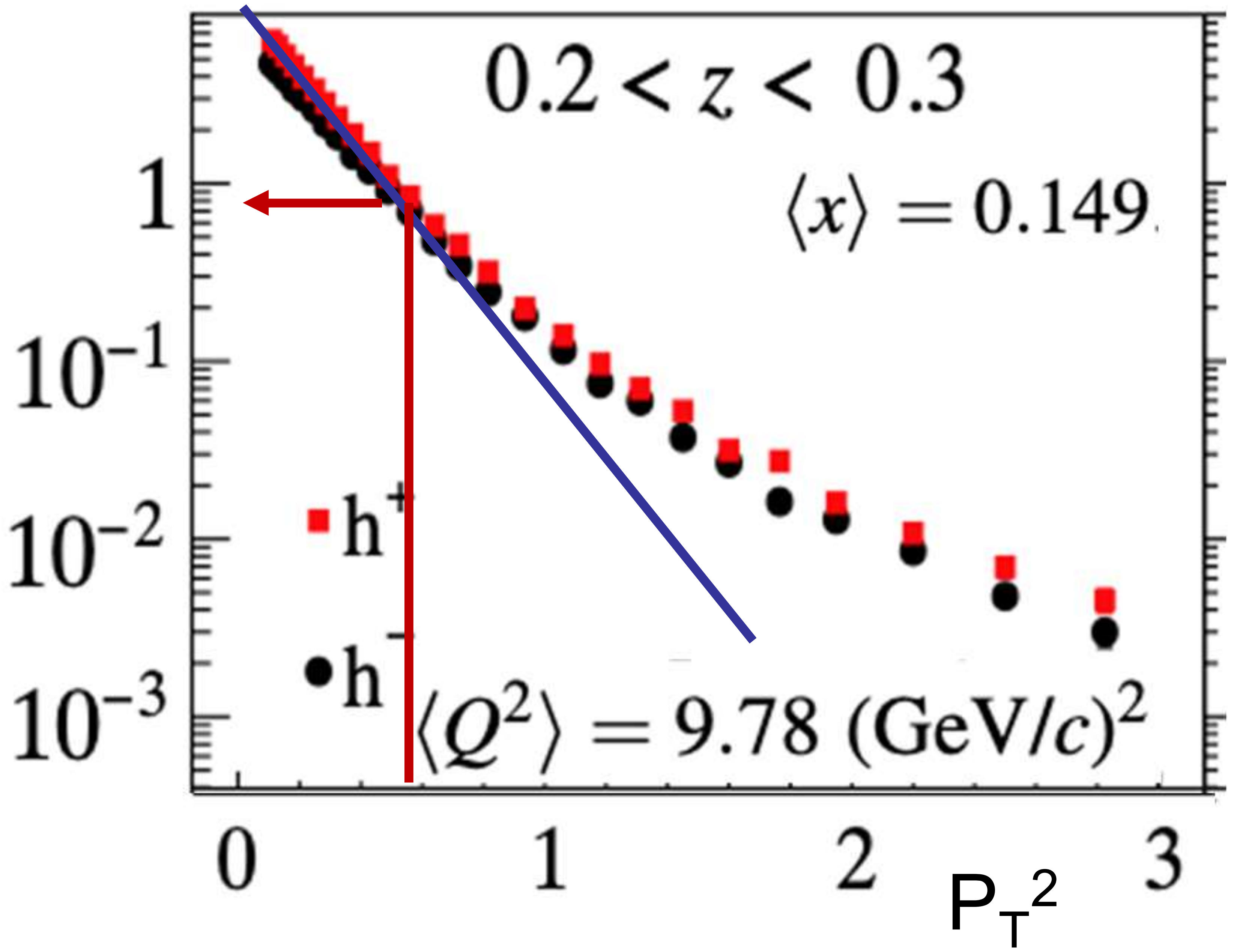

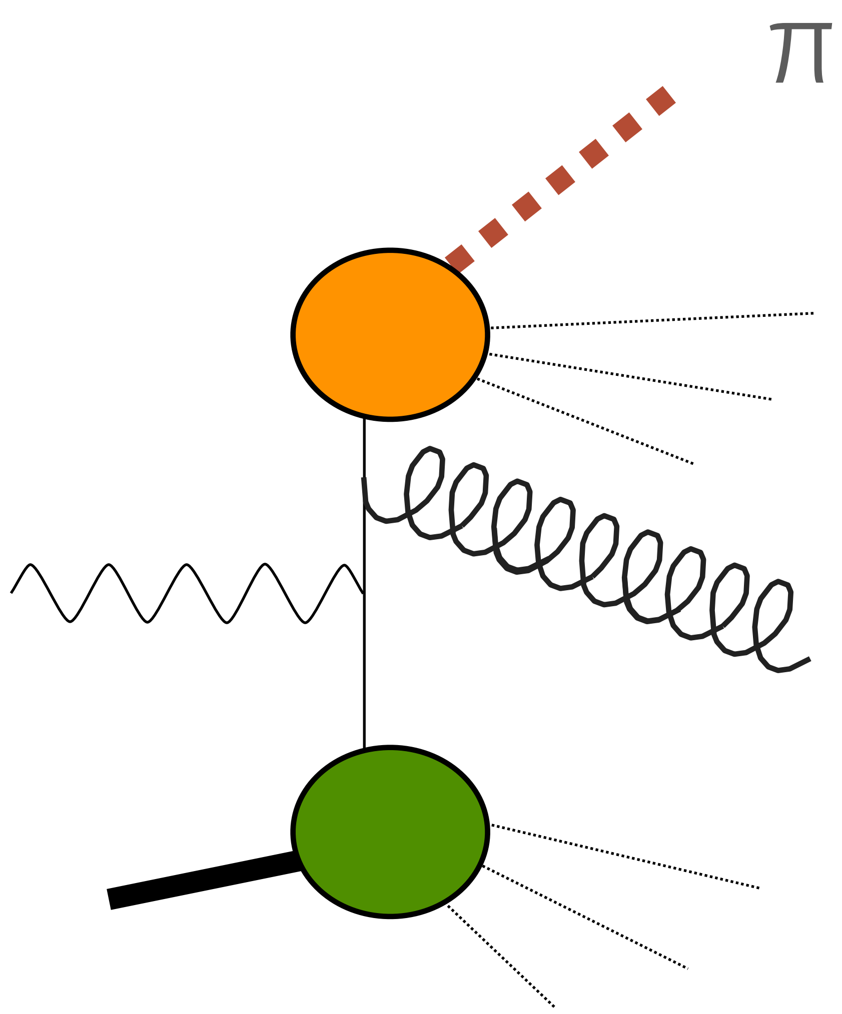

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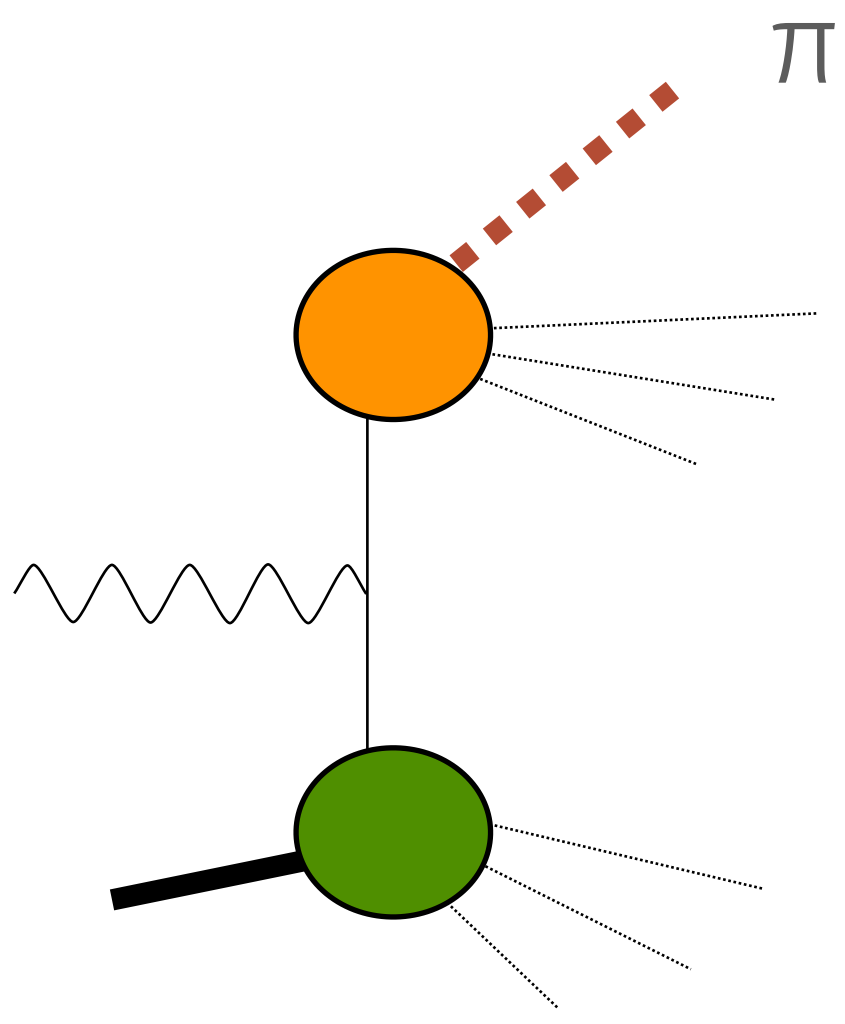
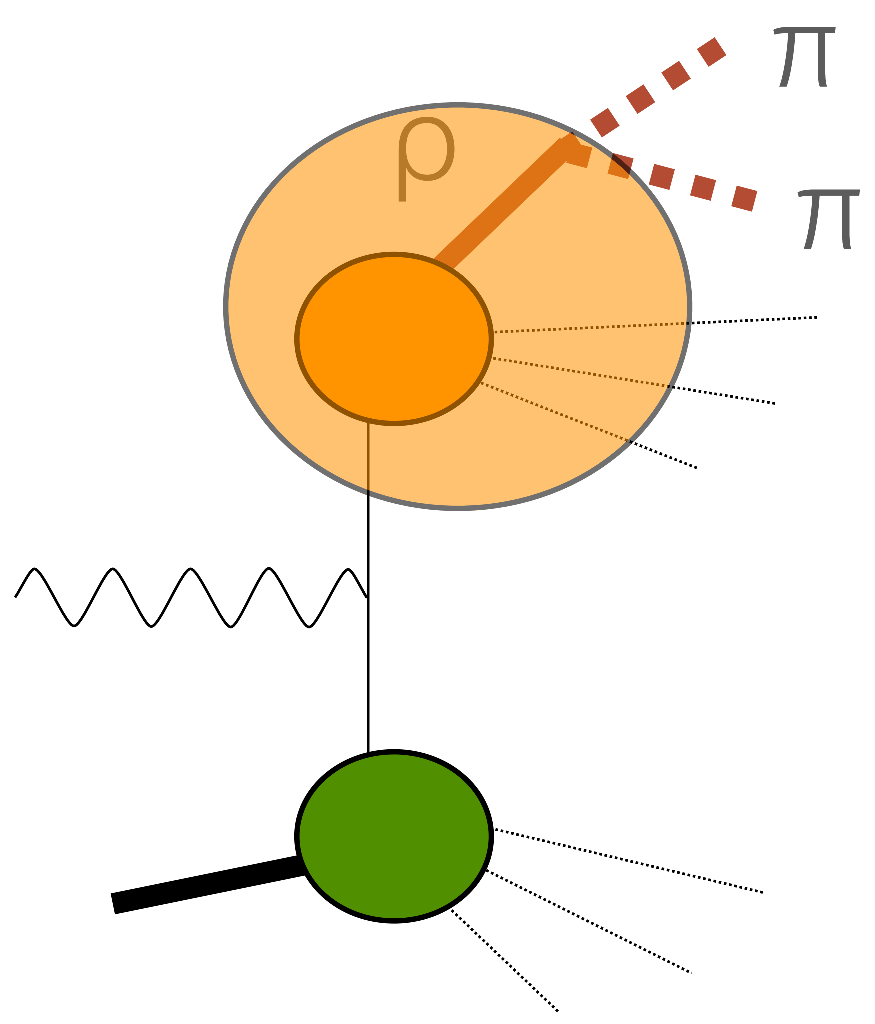
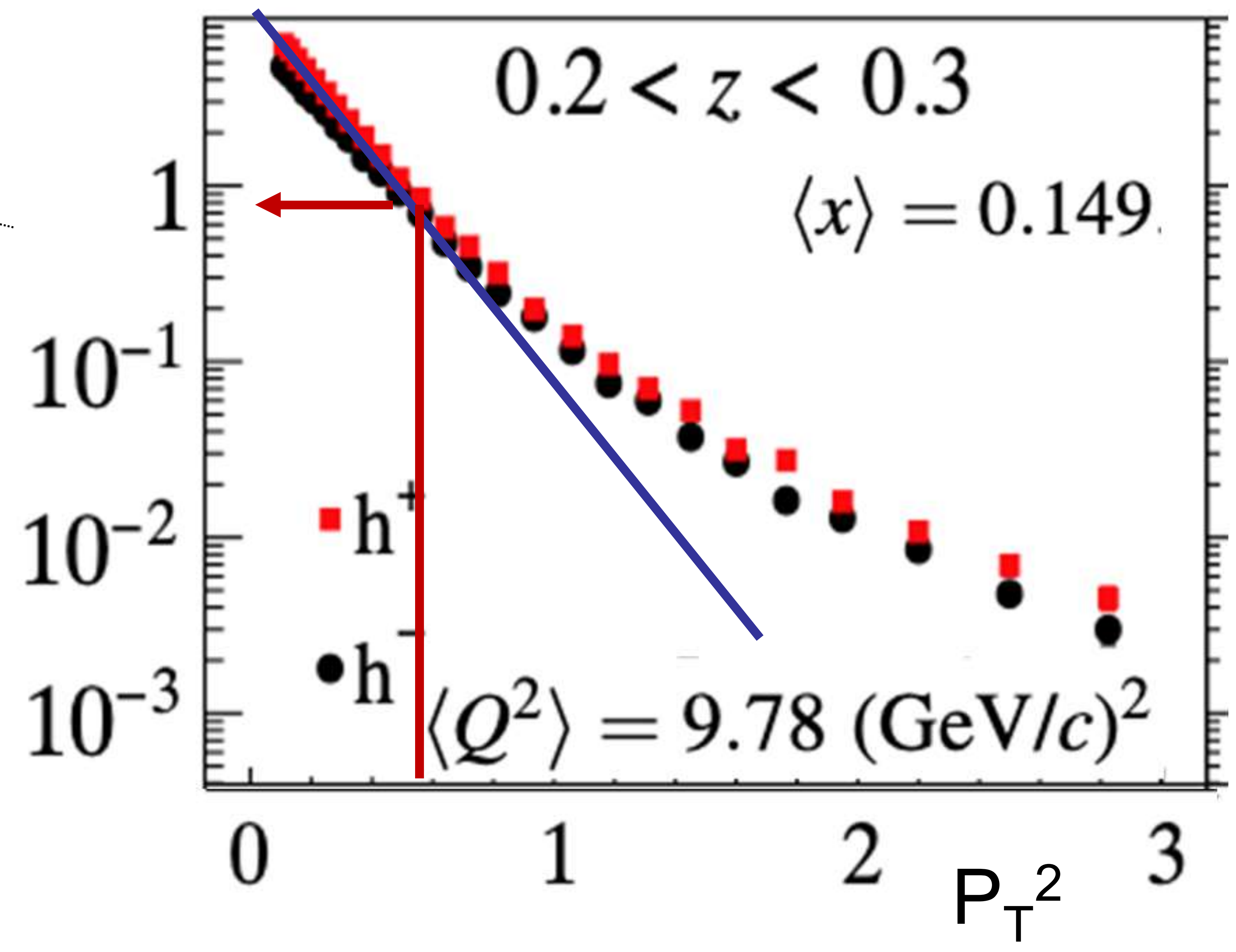
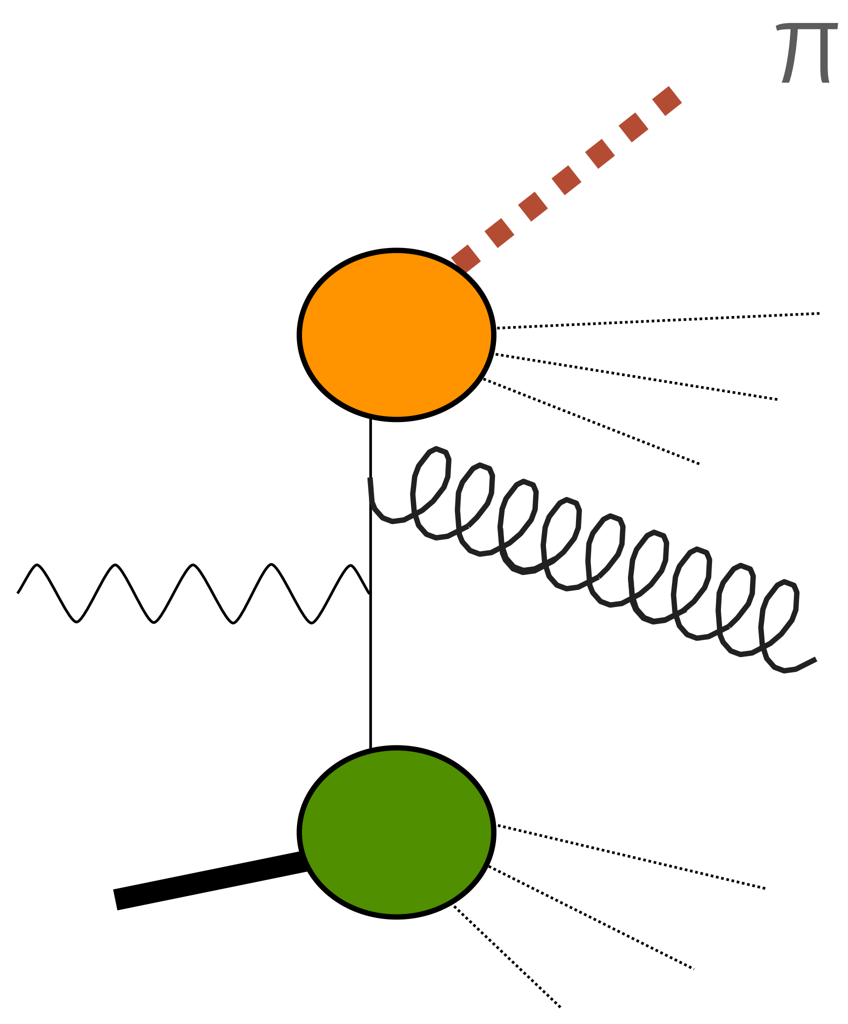


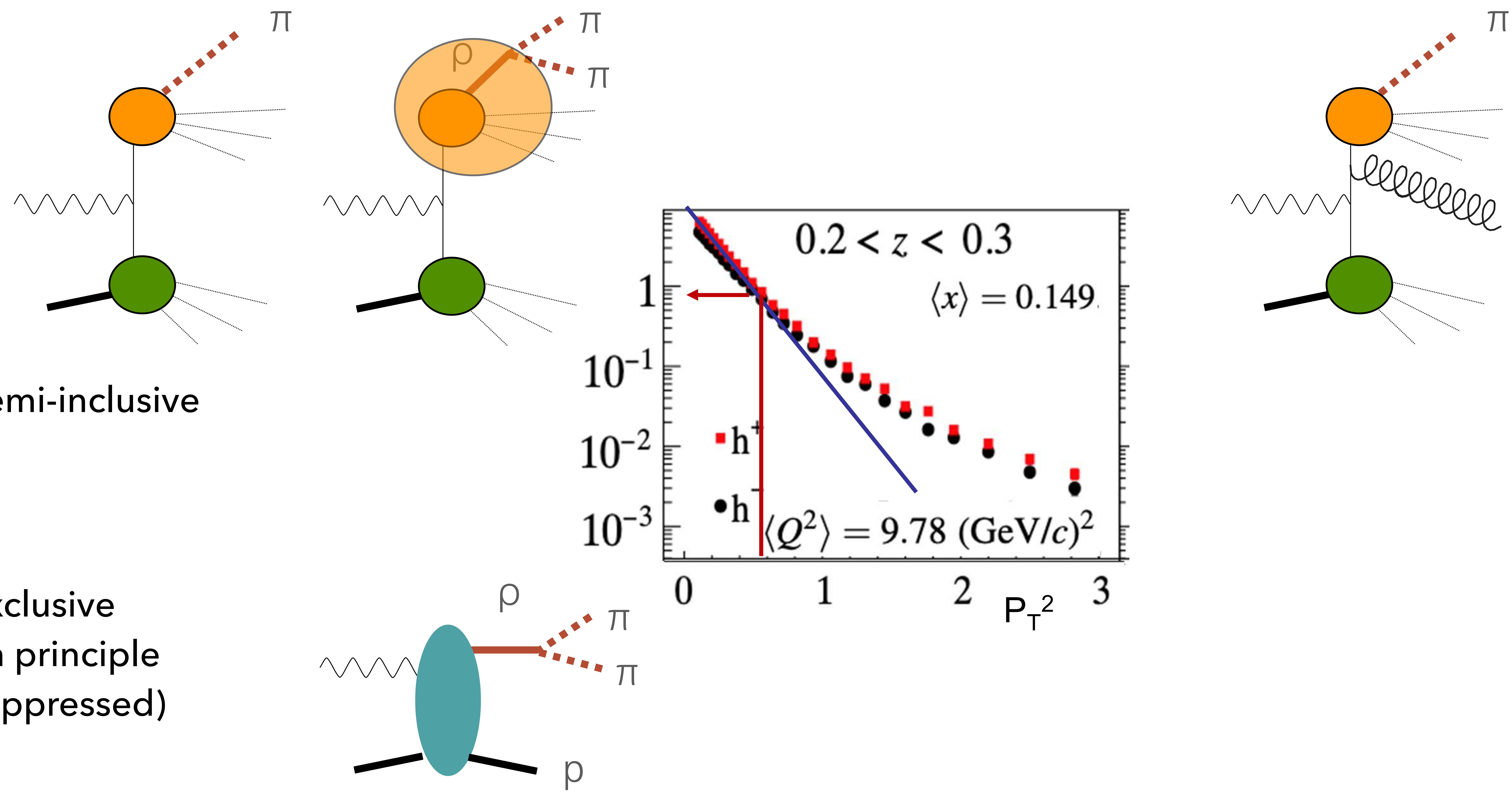






Semi-inclusive

VECTOR MESON CONTAMINATIONS

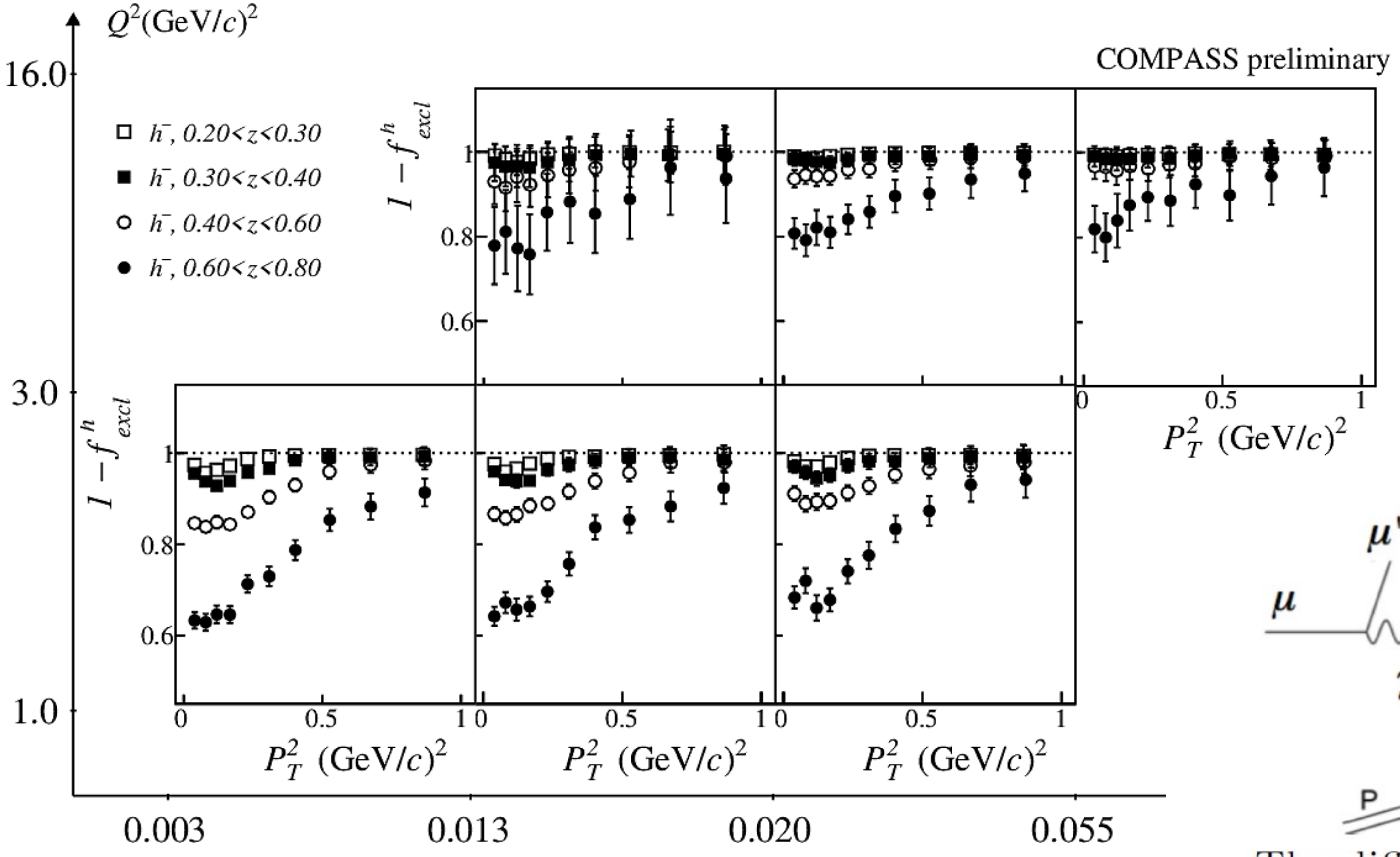


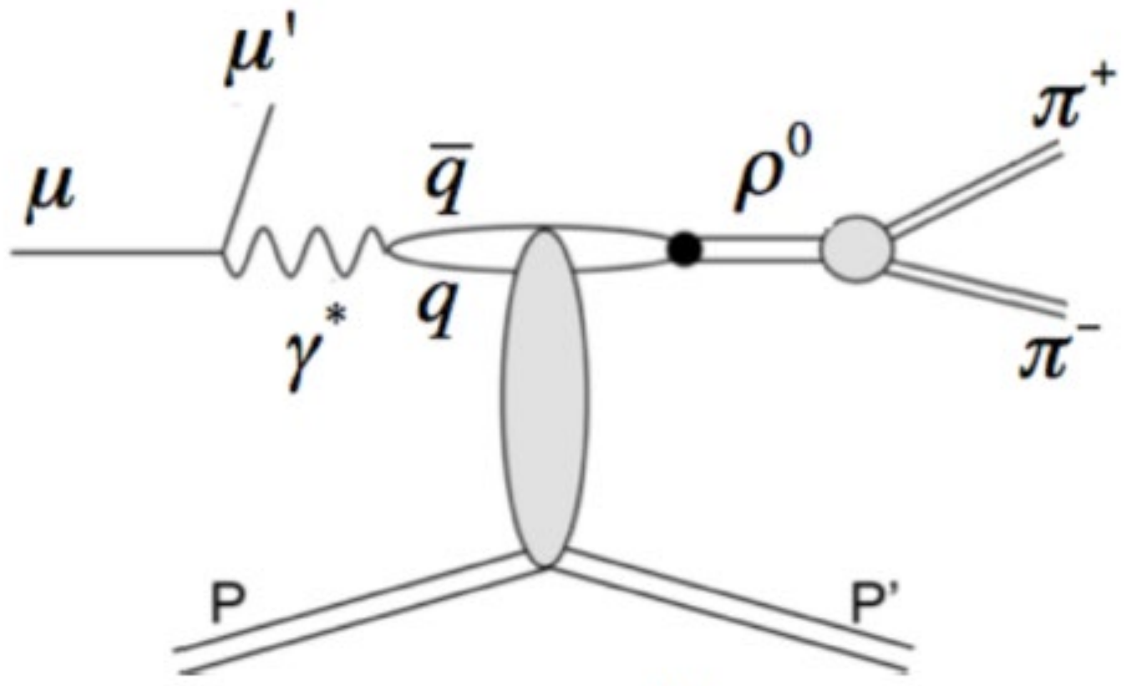
Semi-inclusive

Exclusive
(in principle
suppressed)

VECTOR MESON CONTAMINATIONS

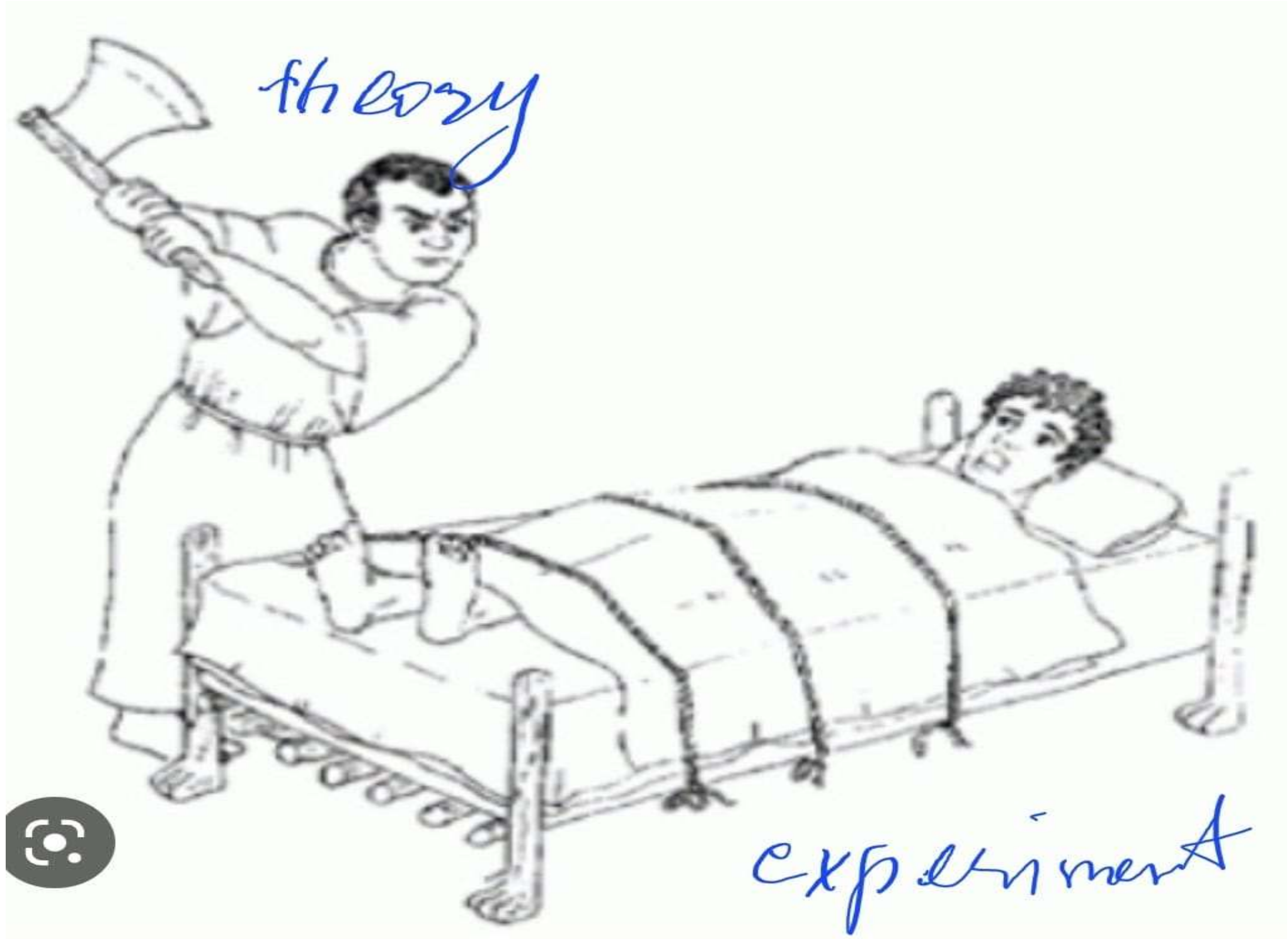
A. Bressan's talk at Transversity 2024





The diffractive ρ^0 production and decay.

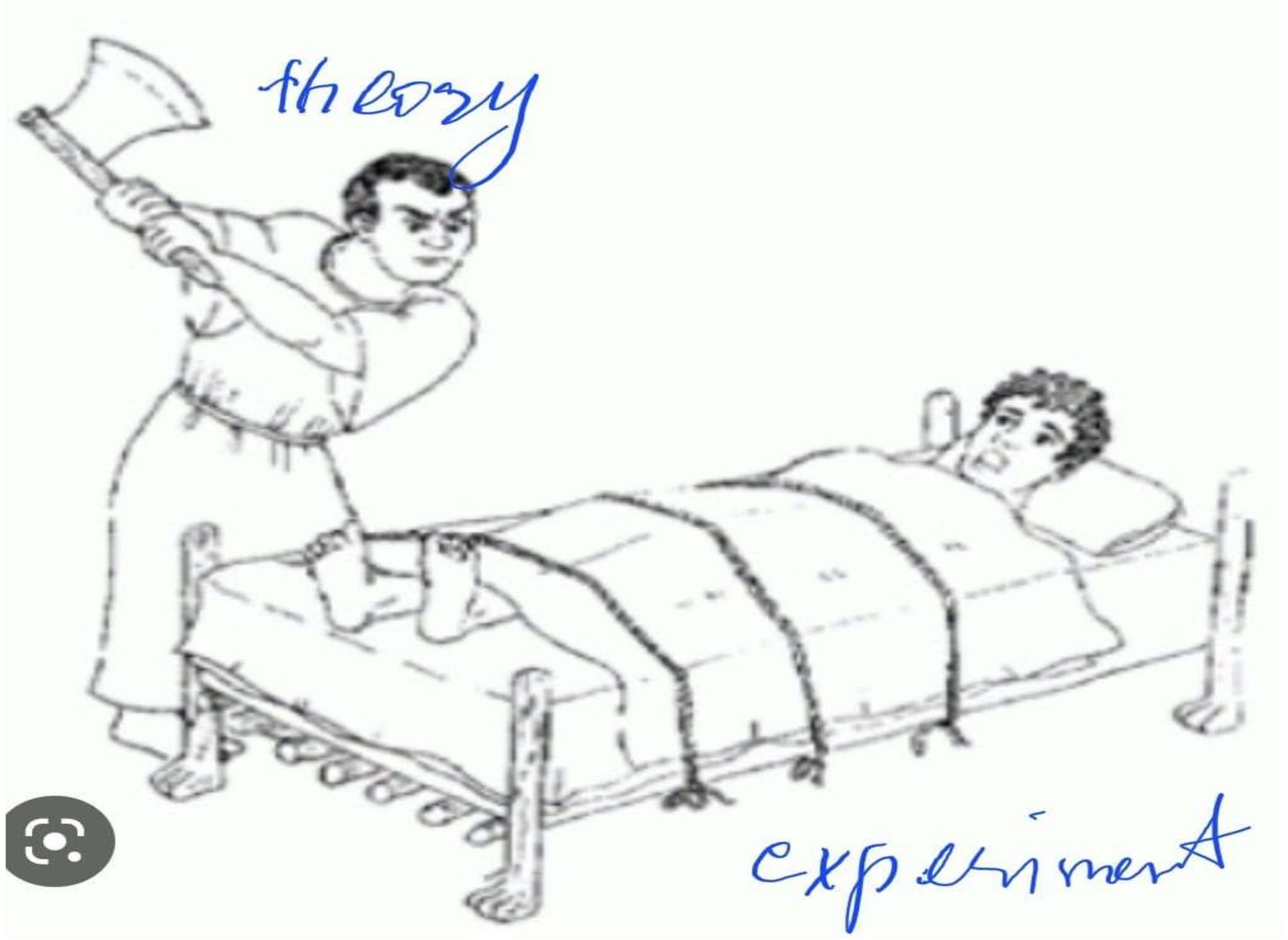
HARUT'S CARTOON AT TRANSVERSITY 2024



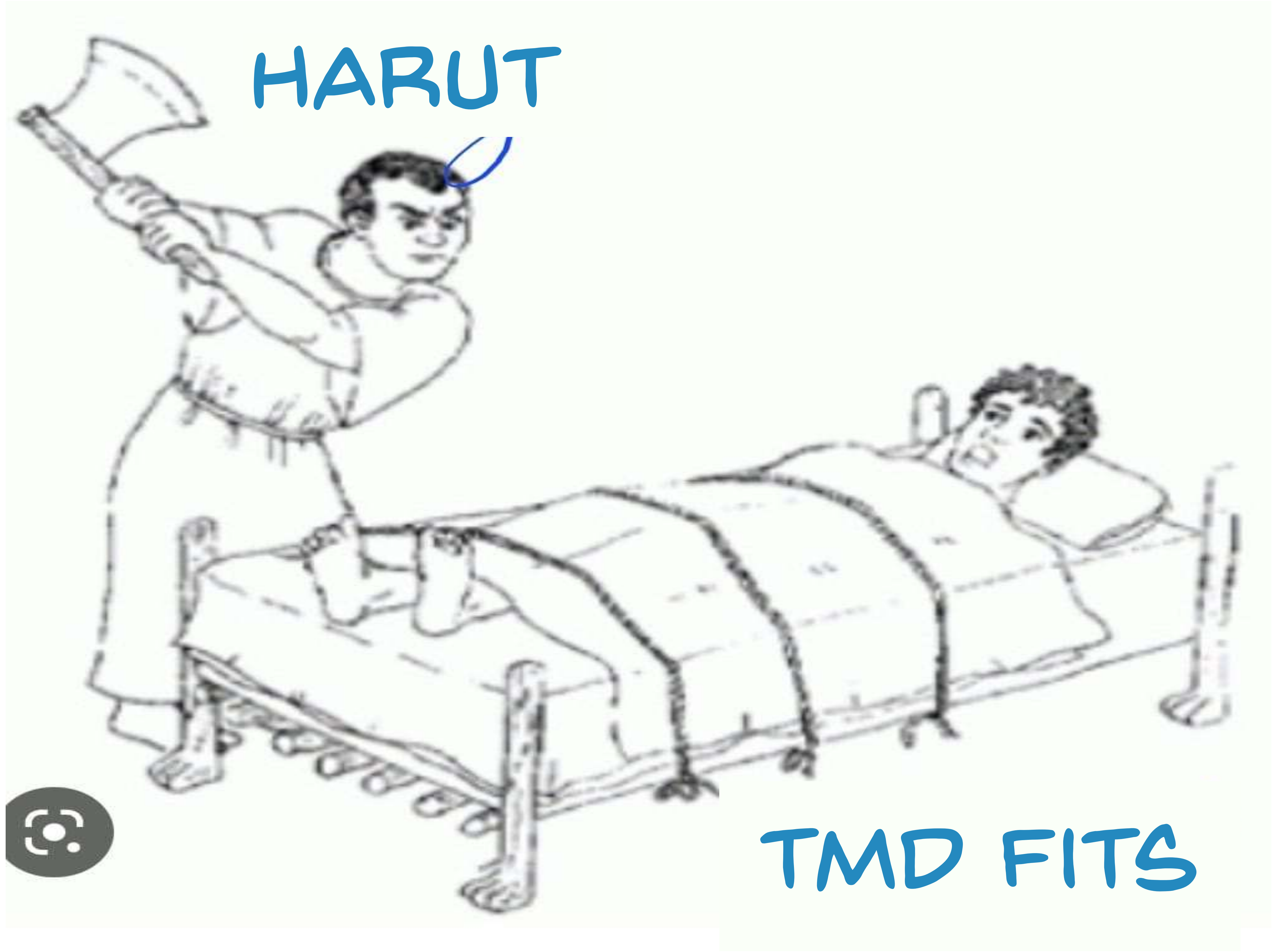
Procrustes - Greek Mythology

HARUT'S CARTOON AT TRANSVERSITY 2024

Modified version



Procrustes - Greek Mythology

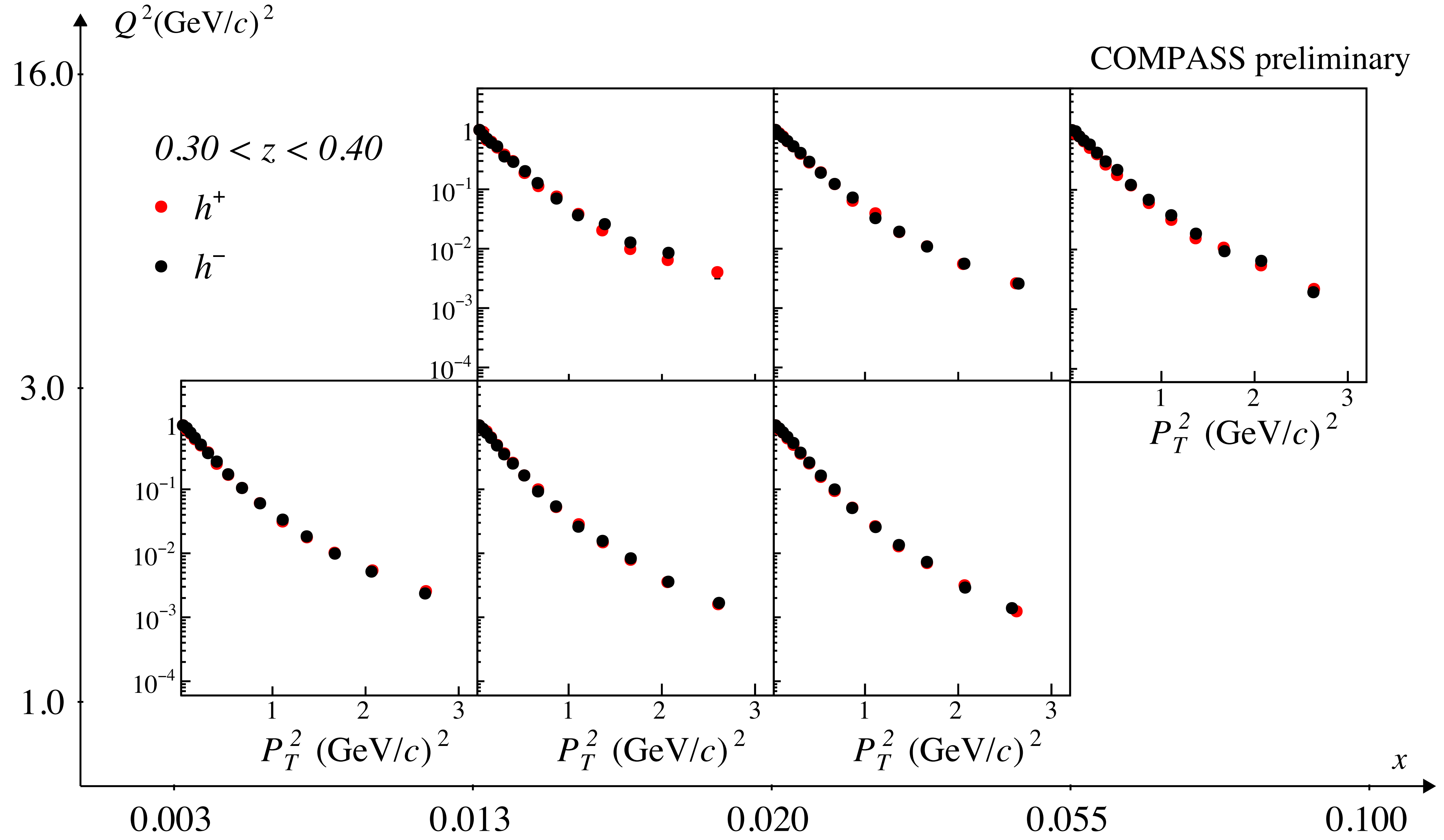


Procrustes - Greek Mythology

Let’s hope that both data and fits can lie in comfortable beds

EXPECTED DATA

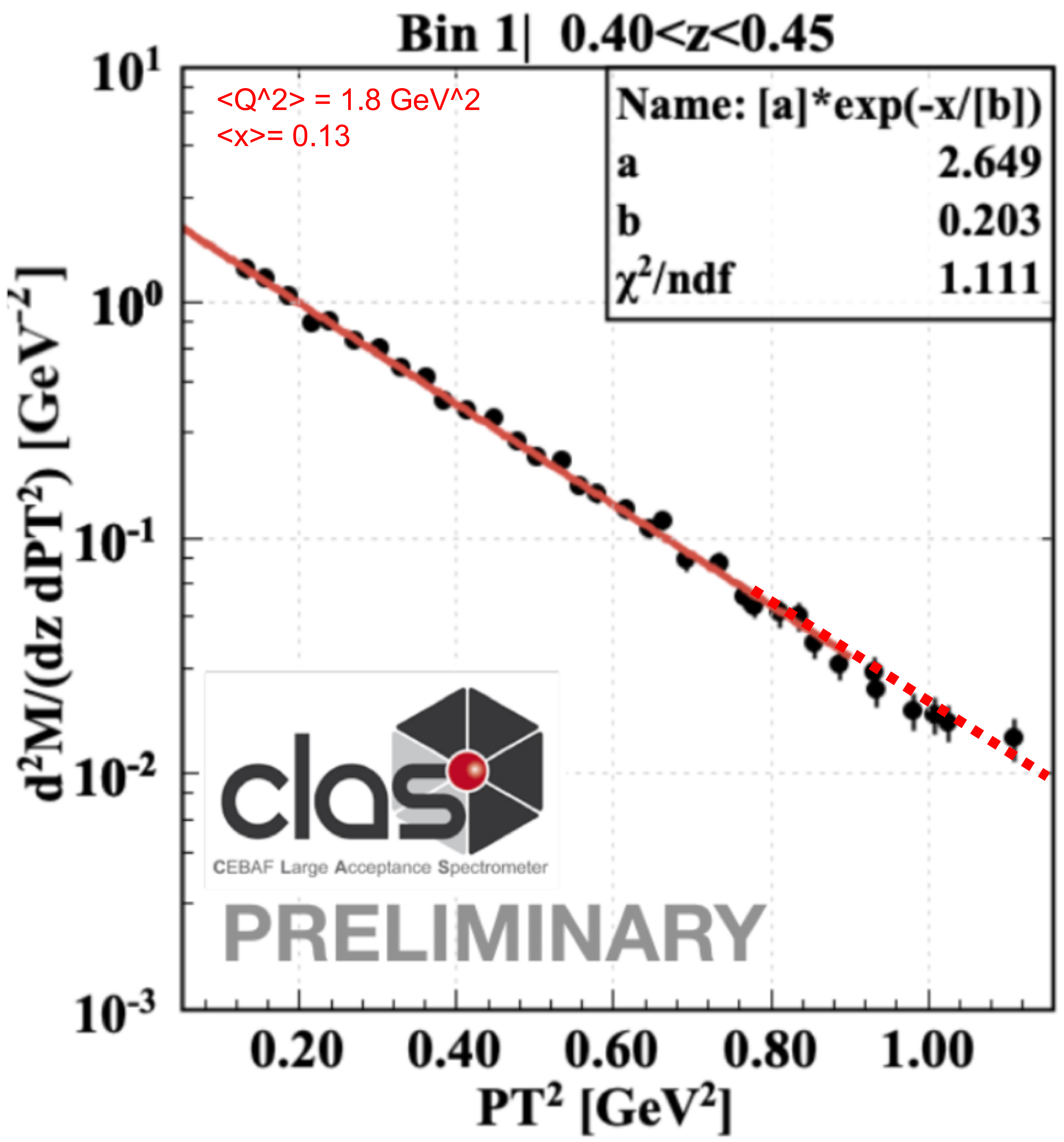
Compass multiplicities
off protons



h$^{\pm}$ distributions in $x : Q^2 : z : P_T^2$ (2nd z bin)

[A. Moretti (COMPASS), Proc. of ICNFP 2020]

G. Angelini's talk at SarWors2021



SOME LESSONS LEARNED

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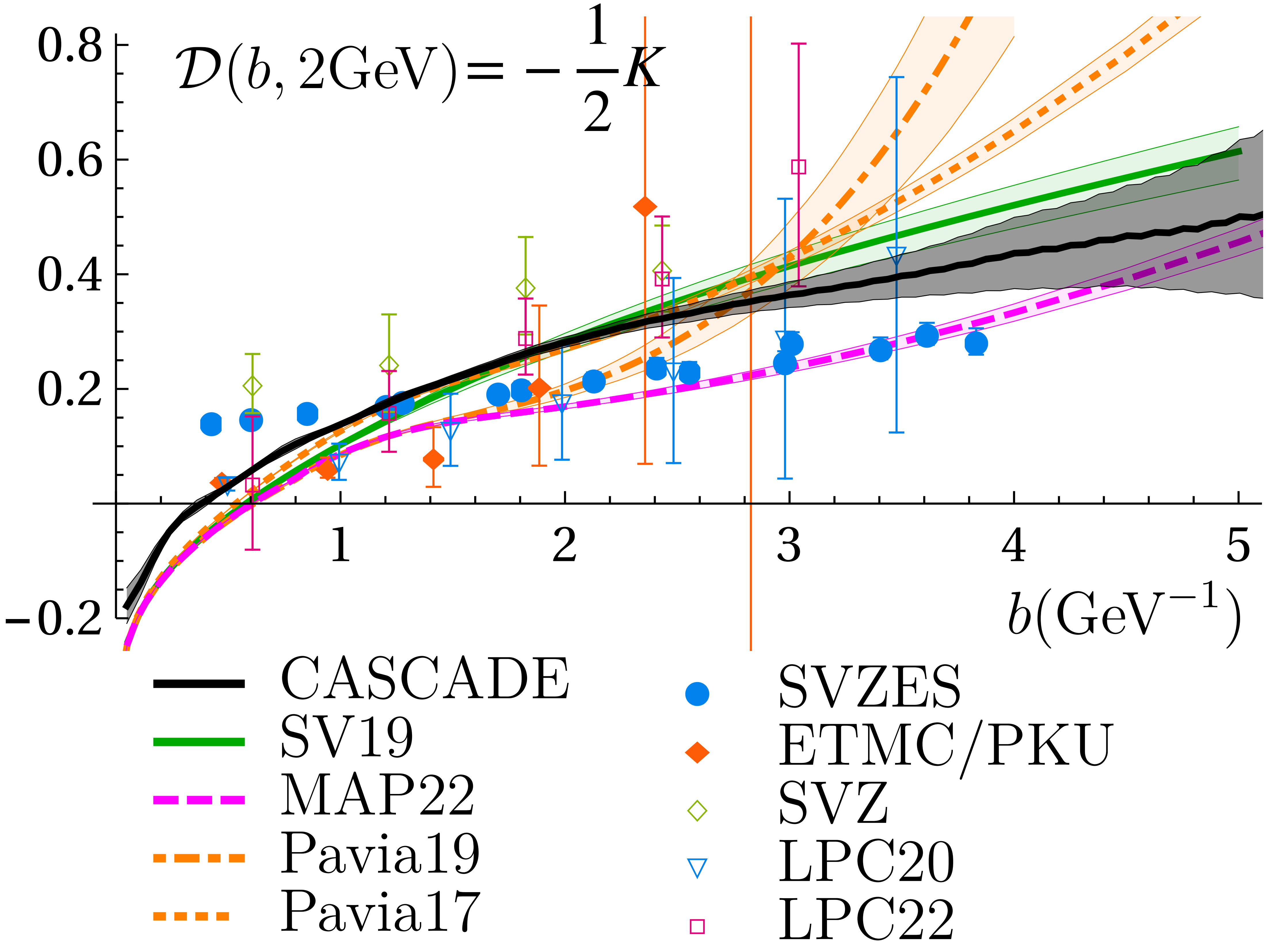
- Simple Guassians or bell-like shapes are not sufficient to describe data
- The TMD shape must be x-dependent
- The TMD frag. functions are probably different for different final-state hadrons
- The TMDs are probably different for different quark flavors

CONNECTIONS WITH OTHER FIELDS

CONNECTIONS WITH LATTICE QCD: COLLINS-SOPER KERNEL

Bermudez Martinez, Vladimirov, arXiv:2206.01105



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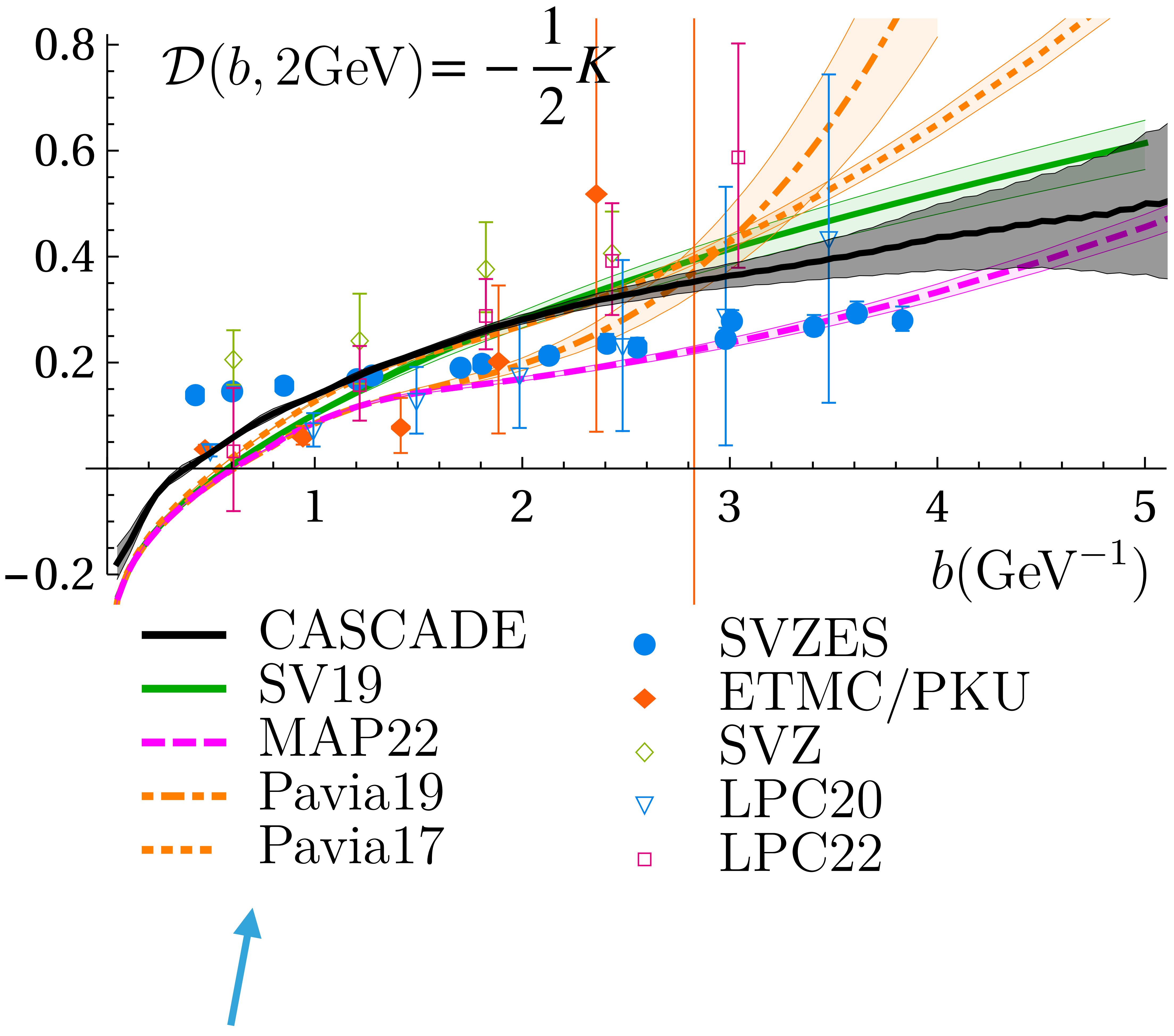
[Bermudez Martinez, Vladimirov, arXiv:2206.01105](#)



TMD phenomenology

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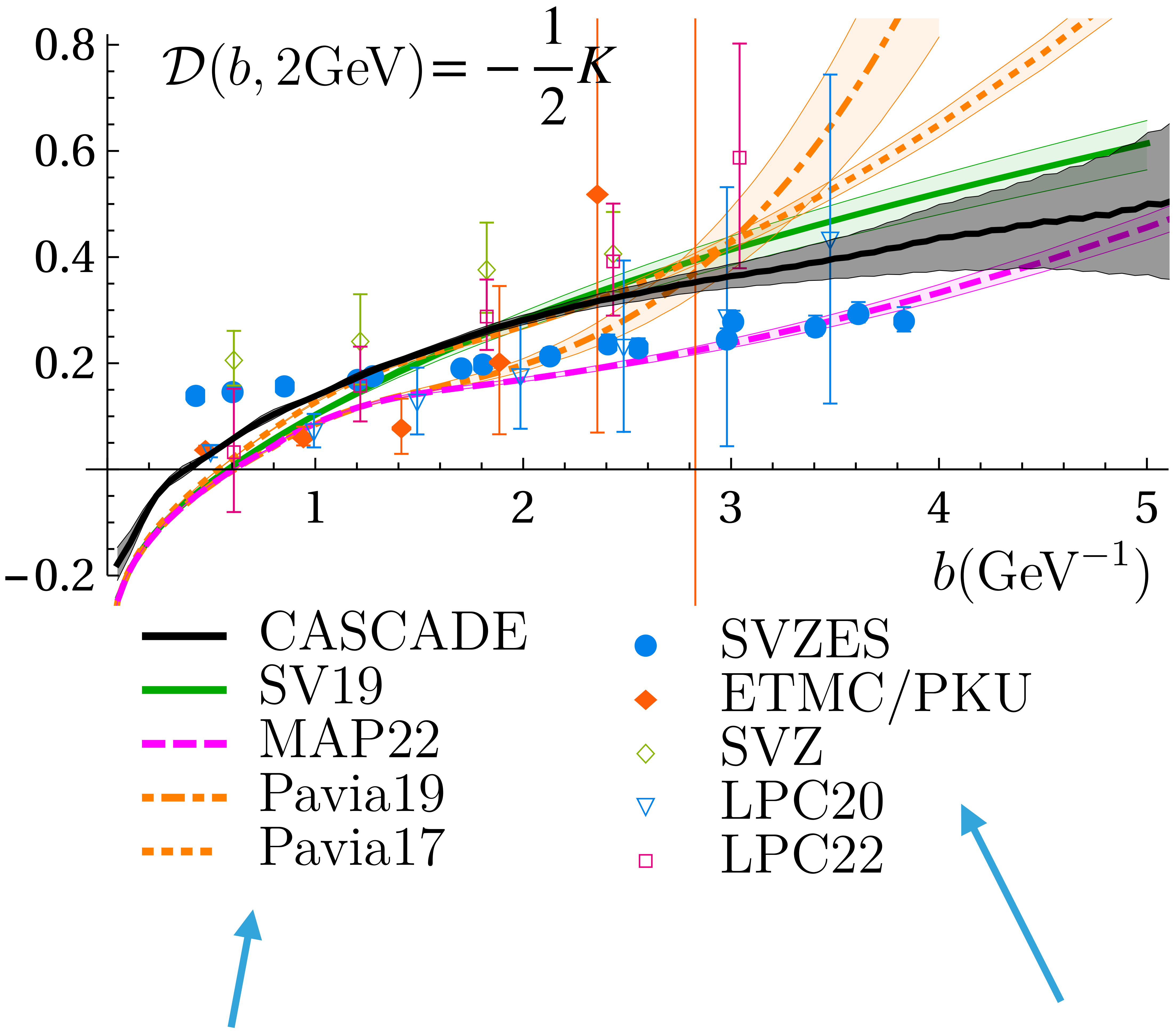


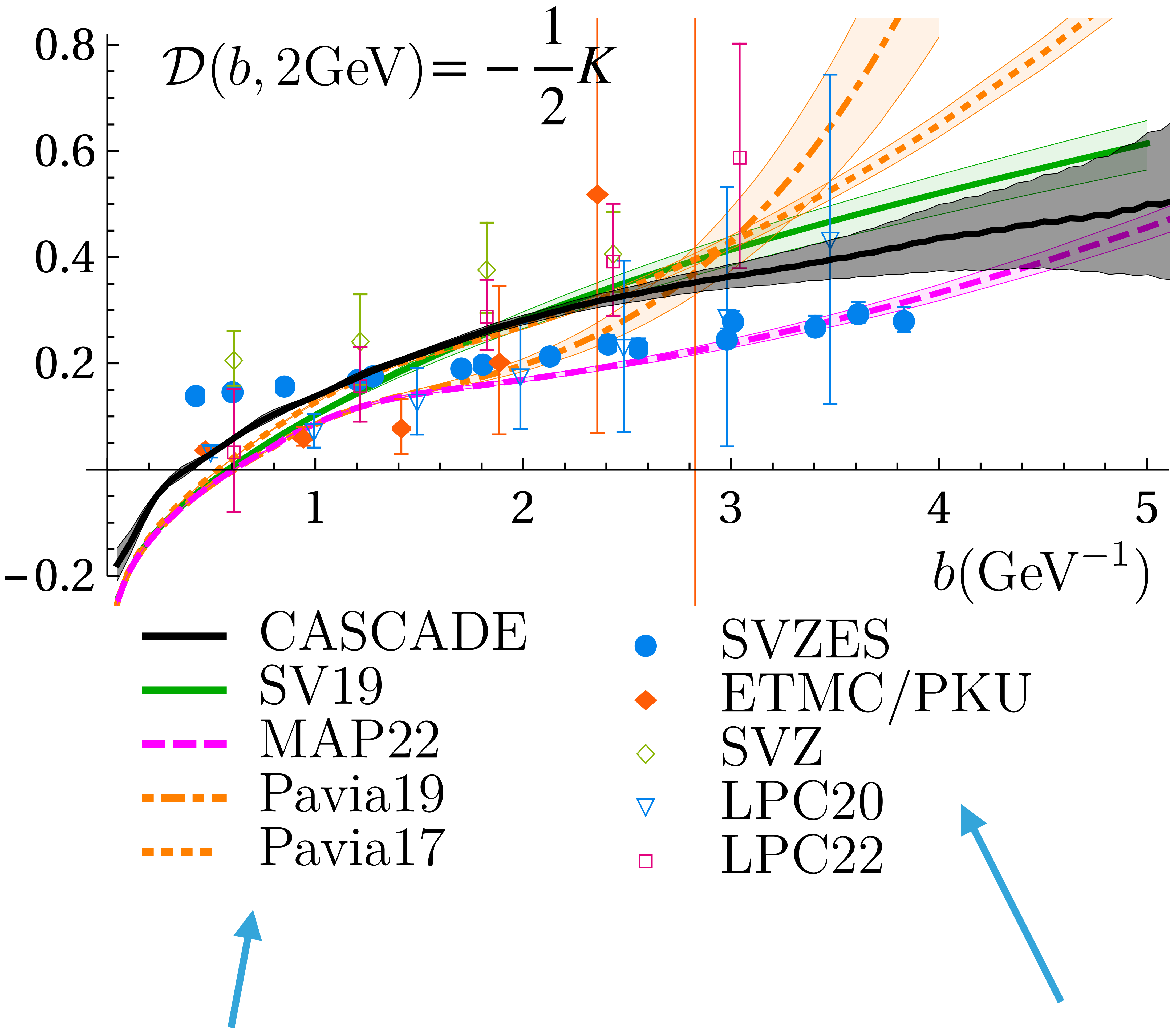
TMD phenomenology

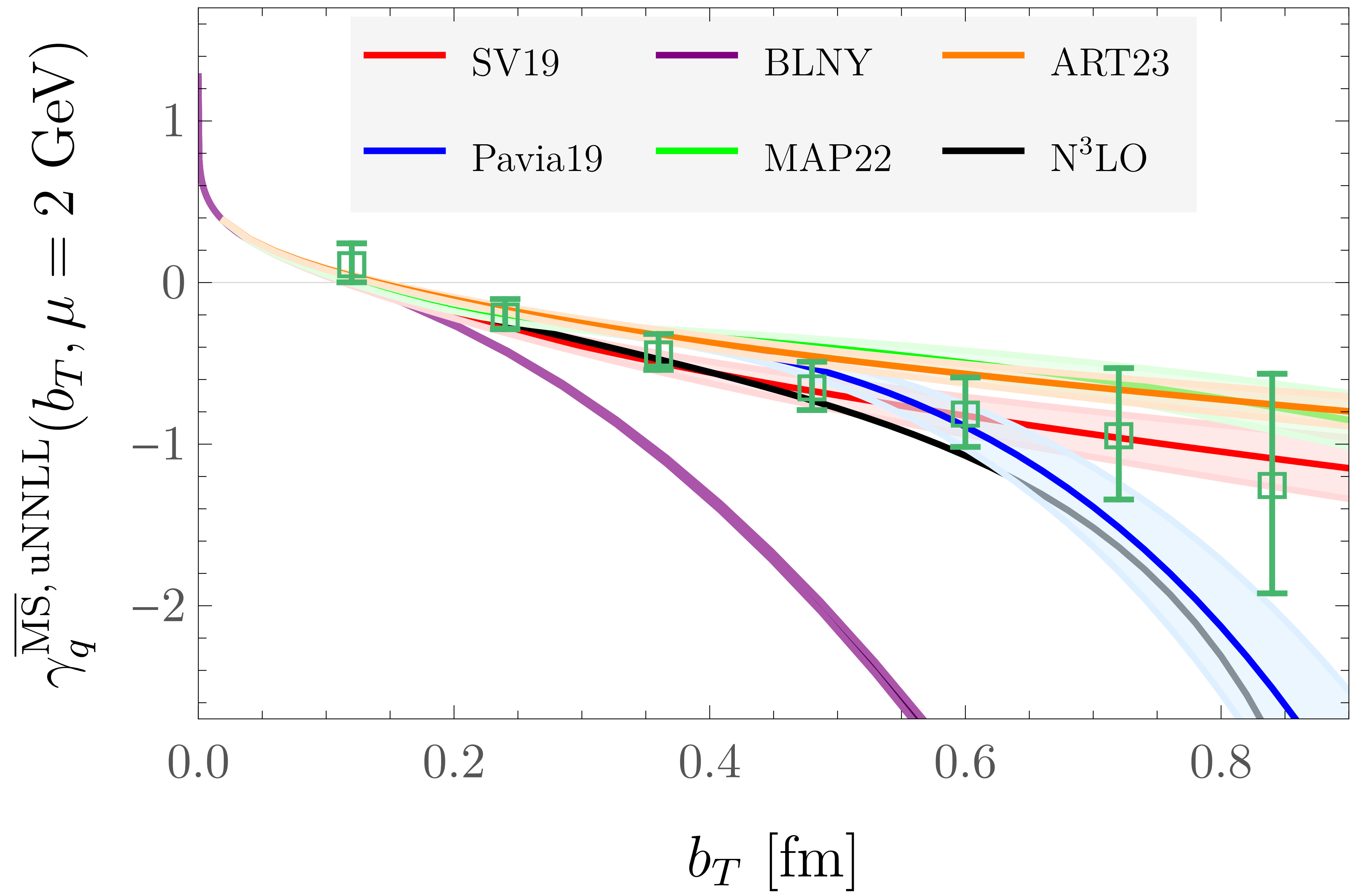
Lattice QCD

CONNECTIONS WITH LATTICE QCD: COLLINS-SOPER KERNEL

Bermudez Martinez, Vladimirov, arXiv:2206.01105

Avkhadiev, Shanahan, Wagman, Zhao, arXiv:2307.12359





TMD phenomenology

Lattice QCD

CONNECTIONS WITH LATTICE QCD: COLLINS-SOPER KERNEL

Bermudez Martinez, Vladimirov, arXiv:2206.01105

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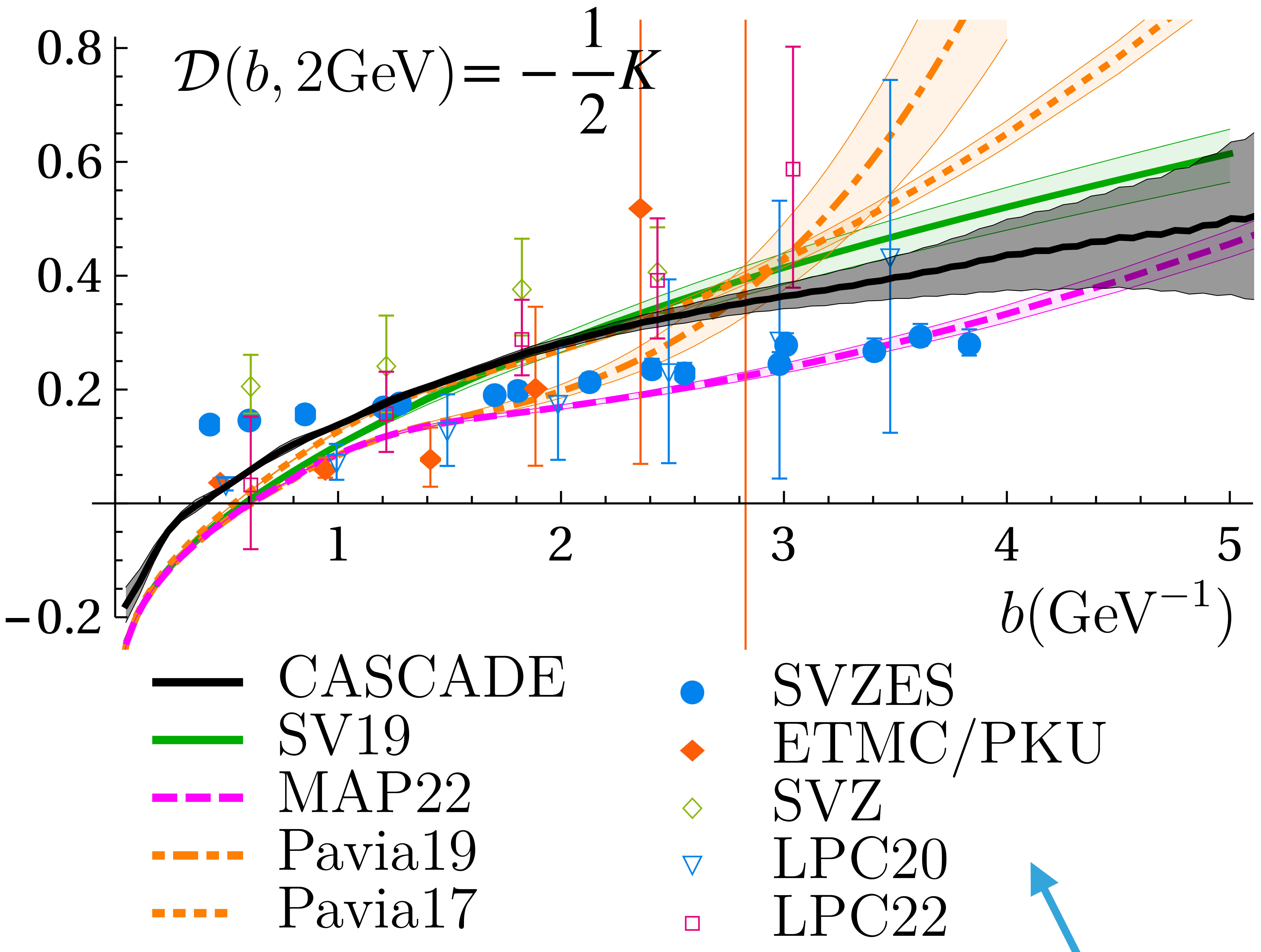

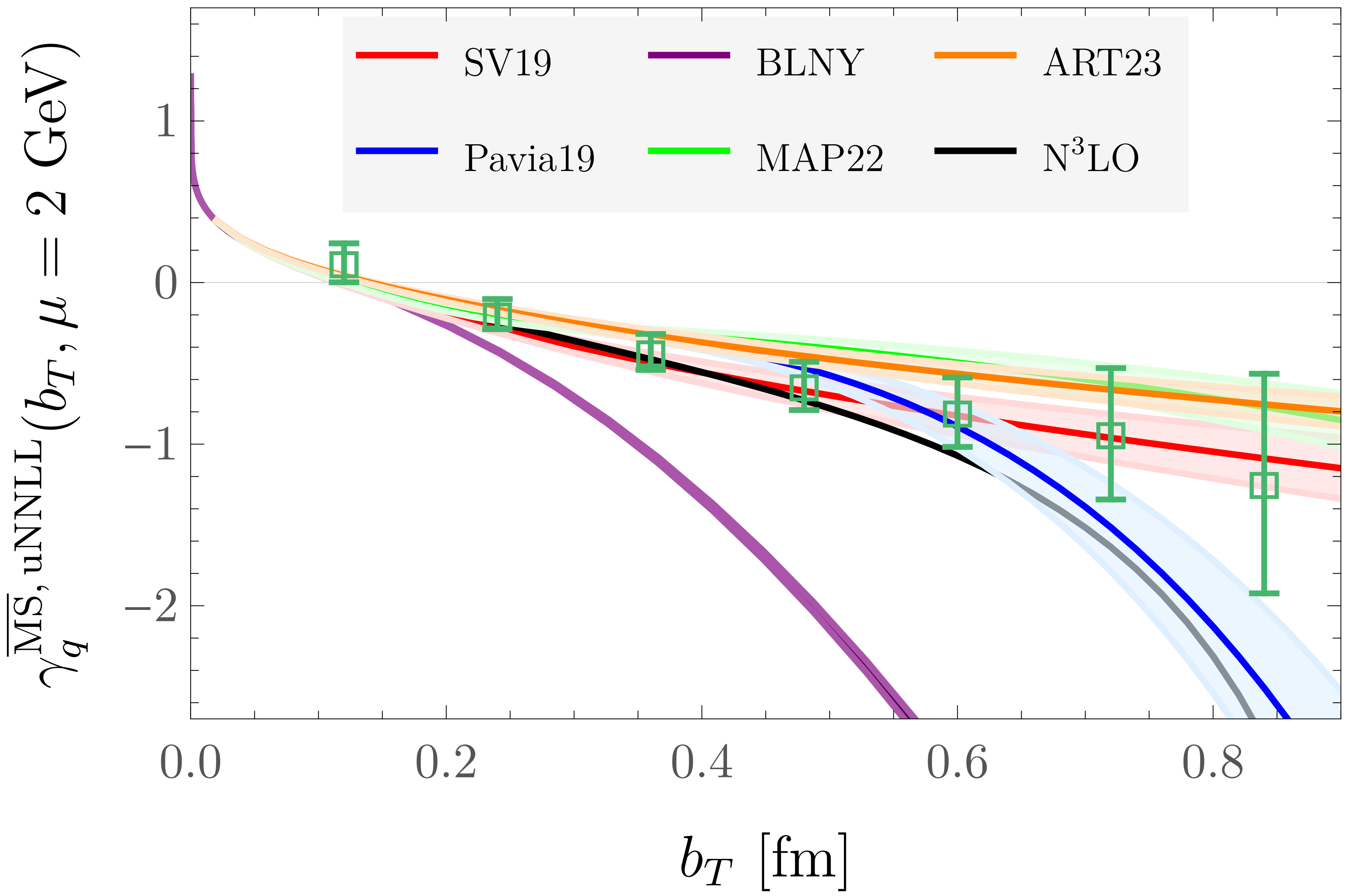

TMD phenomenology

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See talk by Patrizio Pucci

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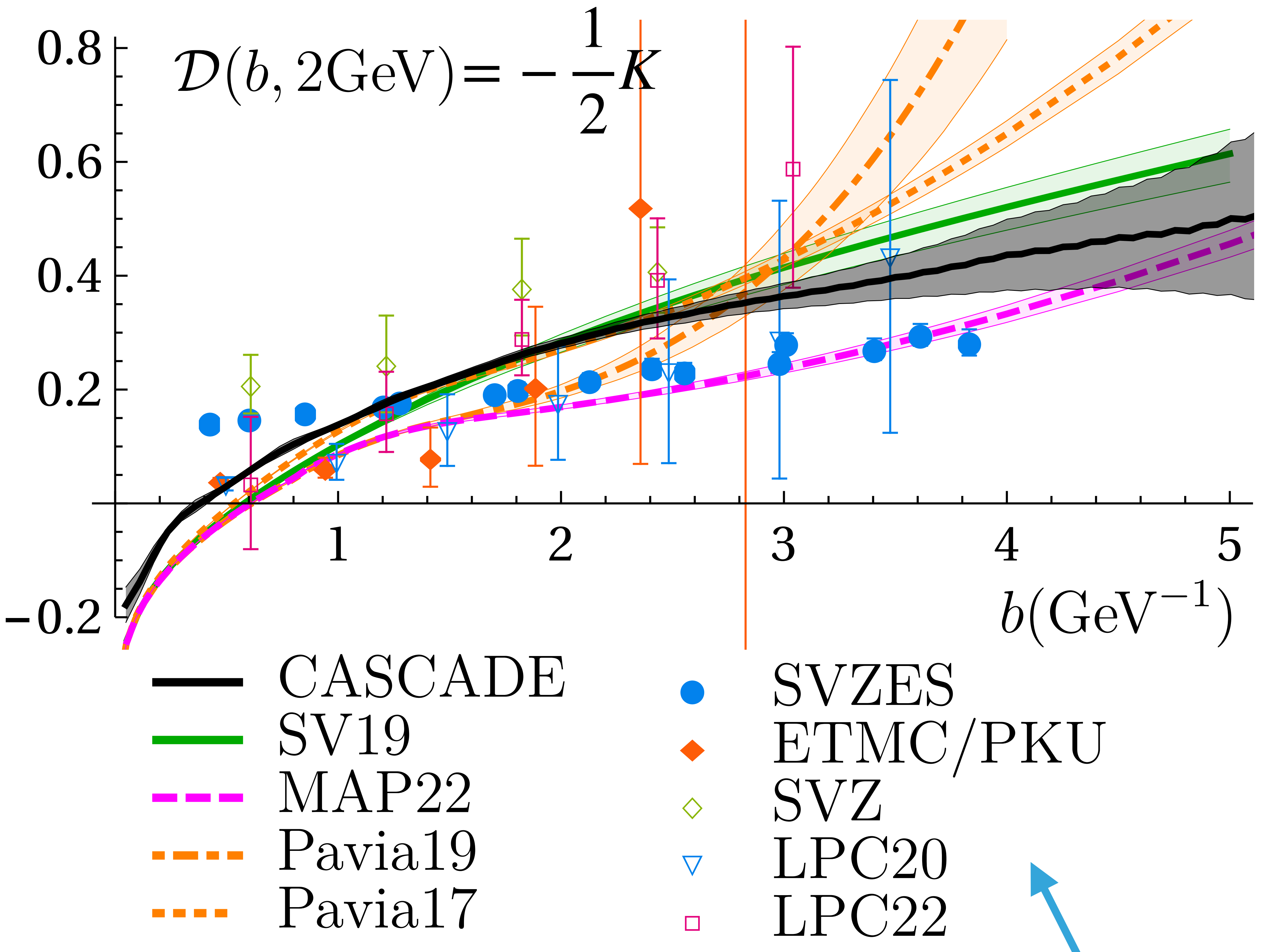

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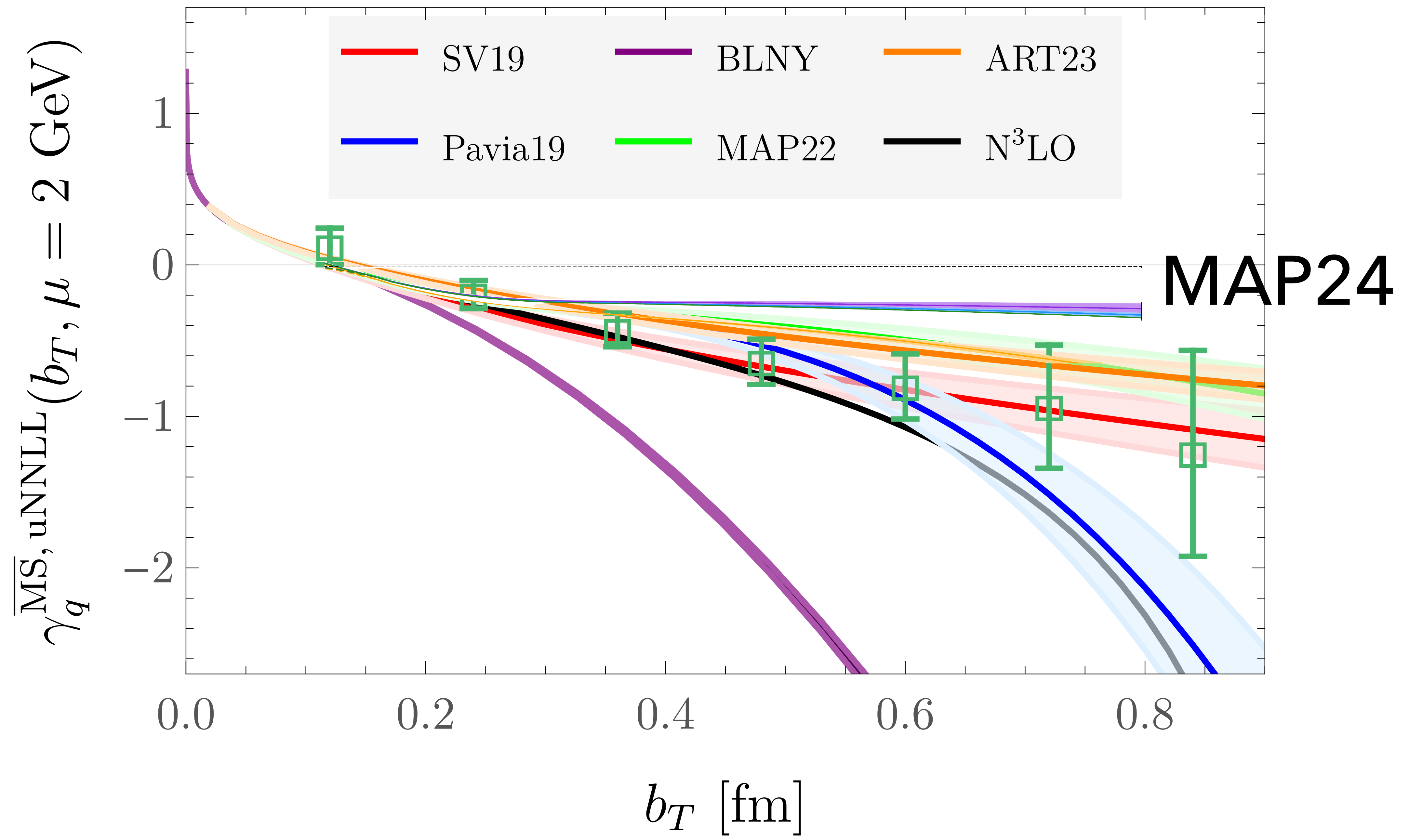
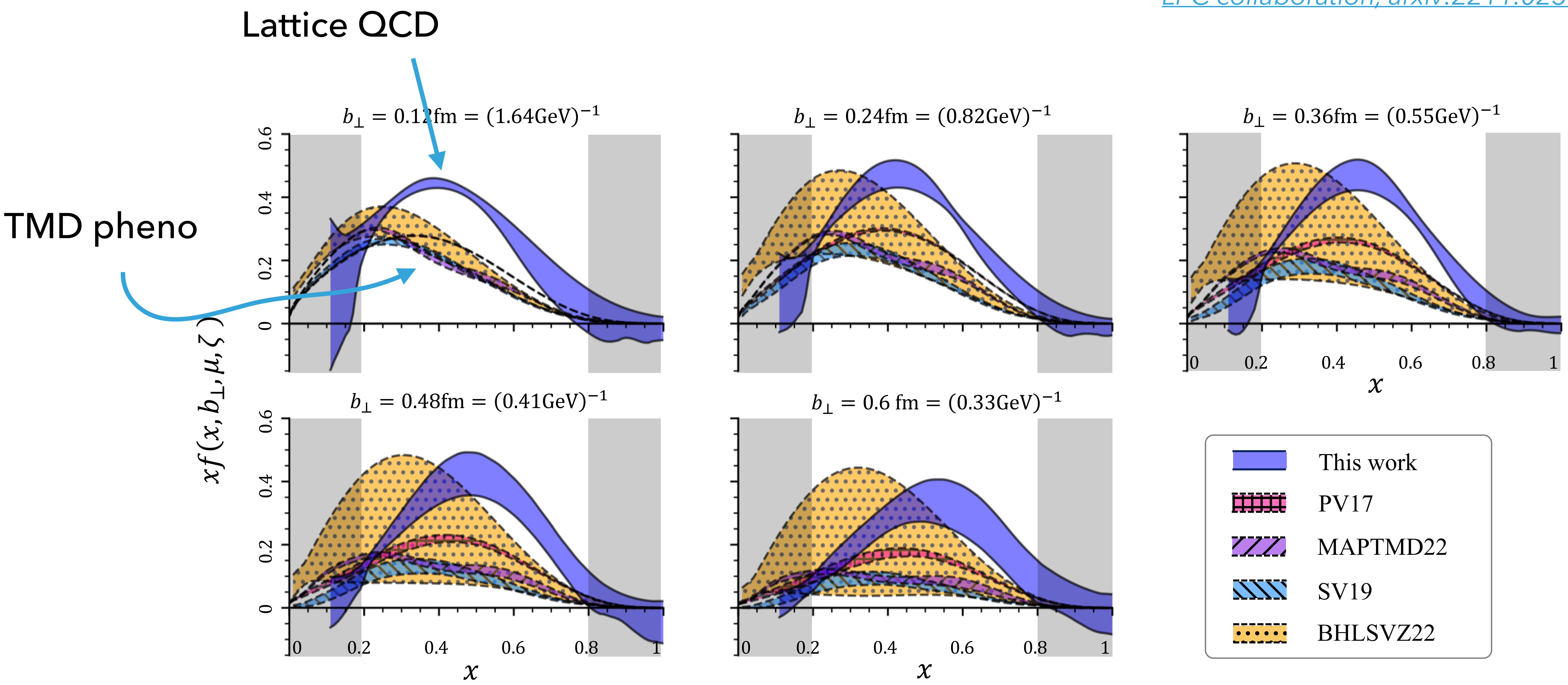


See talk by Patrizio Pucci

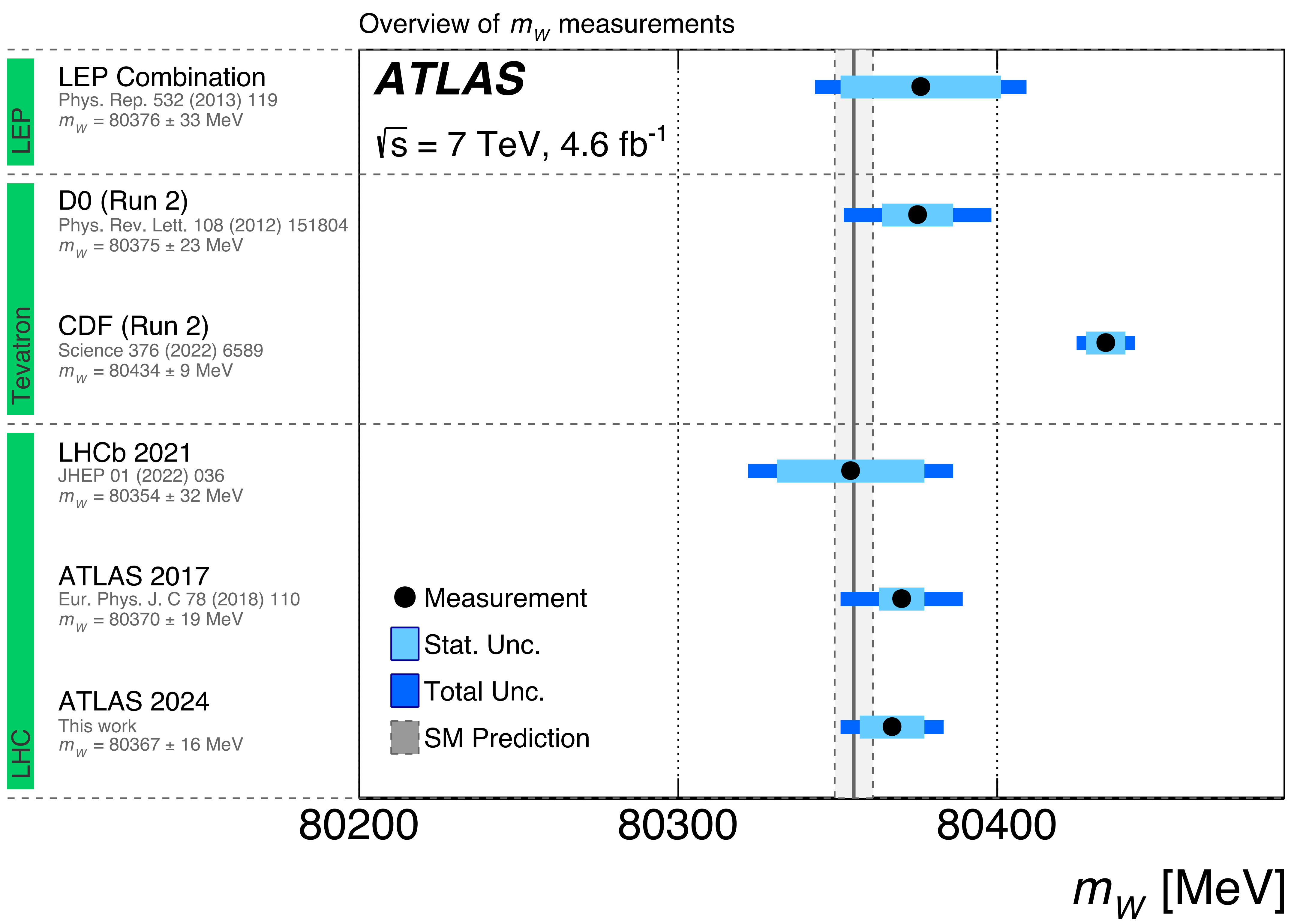
CONNECTION WITH LATTICE QCD: TMDS

LPC collaboration, arxiv:2211.02340



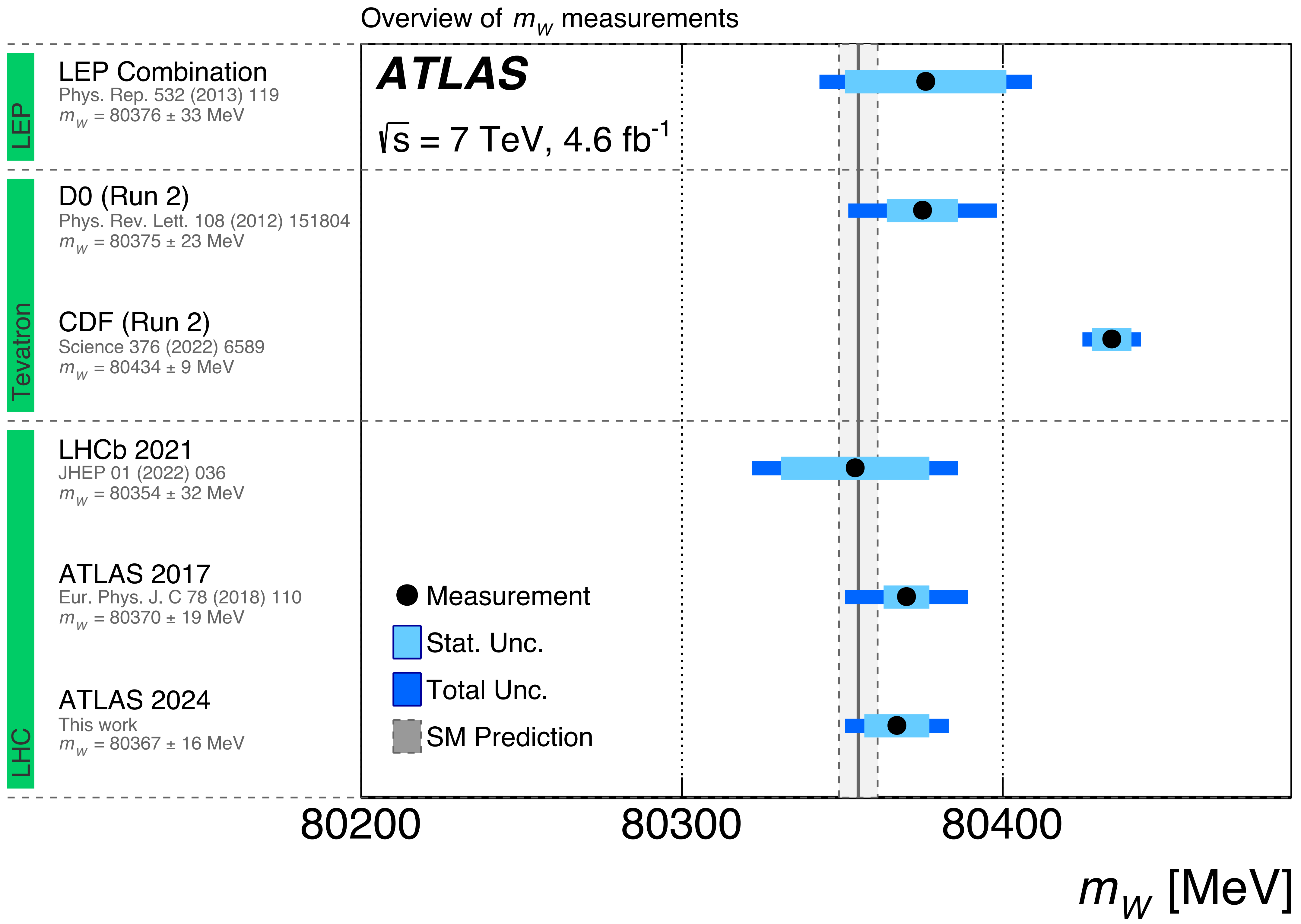
CONNECTION WITH LHC PHYSICS: M_W

ATLAS Collab. arXiv:2403.15085



Unc. [MeV]	Total	Stat.	Syst.	PDF	A_i	Backg.	EW	e	μ	u_T	Lumi	Γ_W	PS
p_T^ℓ	16.2	11.1	11.8	4.9	3.5	1.7	5.6	5.9	5.4	0.9	1.1	0.1	1.5
m_T	24.4	11.4	21.6	11.7	4.7	4.1	4.9	6.7	6.0	11.4	2.5	0.2	7.0
Combined	15.9	9.8	12.5	5.7	3.7	2.0	5.4	6.0	5.4	2.3	1.3	0.1	2.3

CONNECTION WITH LHC PHYSICS: M_W



ATLAS Collab. arXiv:2403.15085

Not taking into account the flavor dependence of TMDs can lead to errors in the determination of the W mass, of the order of a few MeVs

Bacchetta, Bozzi, Radici, Ritzmann, Signori, arXiv:1807.02101

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CONNECTION WITH LHC PHYSICS: α_S

[ATLAS coll., arXiv:2309.12986](https://arxiv.org/abs/2309.12986)

The coupling constant of the strong force is determined from the transverse-momentum distribution of Z bosons produced in 8 TeV proton–proton collisions at the LHC and recorded by the ATLAS experiment.

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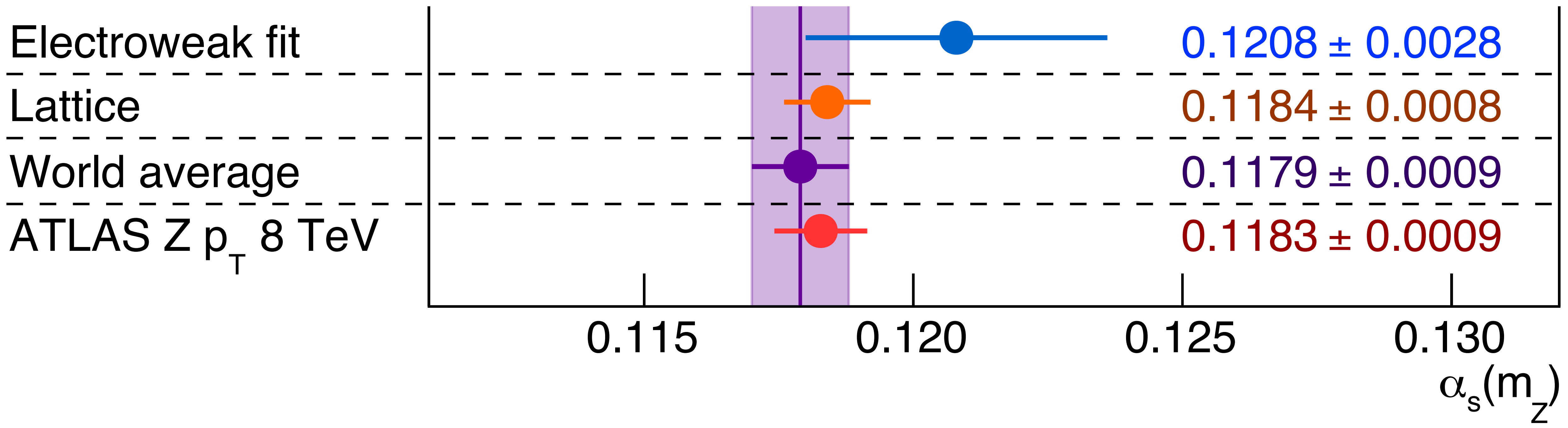

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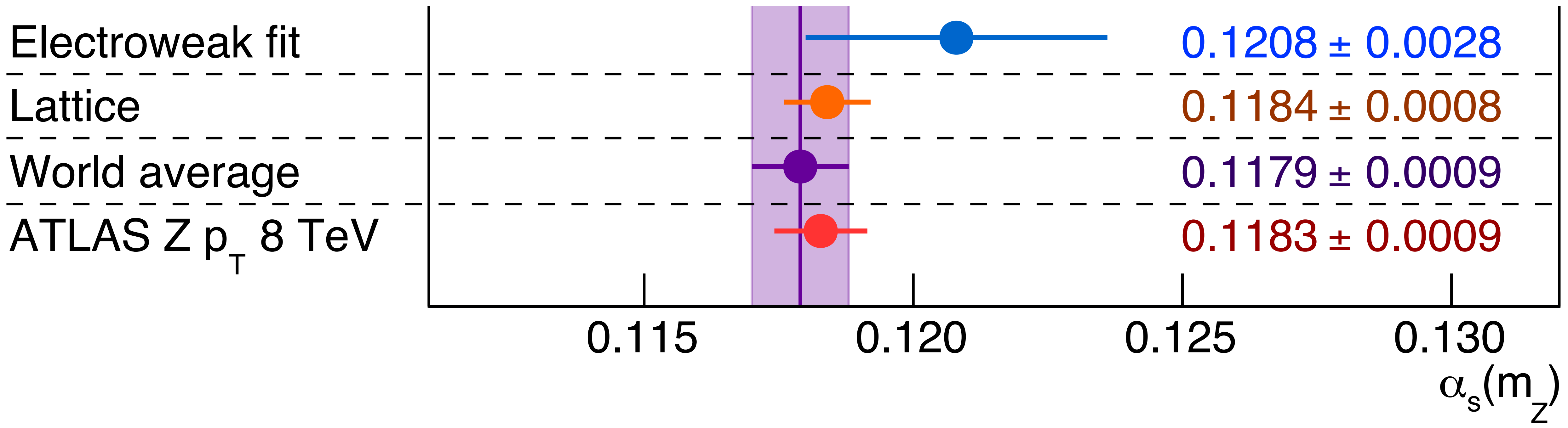

Table 1: Summary of the uncertainties in the determination of $\alpha_s(m_Z)$, in units of 10^{-3}.

Experimental uncertainty	±0.44	
PDF uncertainty	±0.51	
Scale variation uncertainties	±0.42	
Matching to fixed order	0	−0.08
Non-perturbative model	+0.12	−0.20
Flavour model	+0.40	−0.29
QED ISR	±0.14	
N^4LL approximation	±0.04	
Total	+0.91	−0.88

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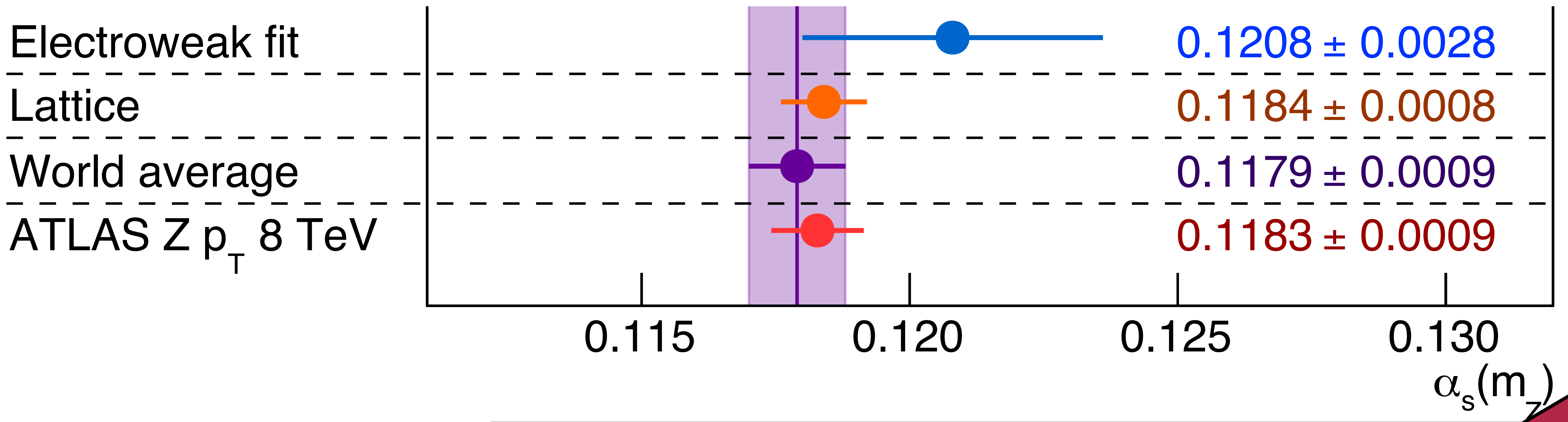

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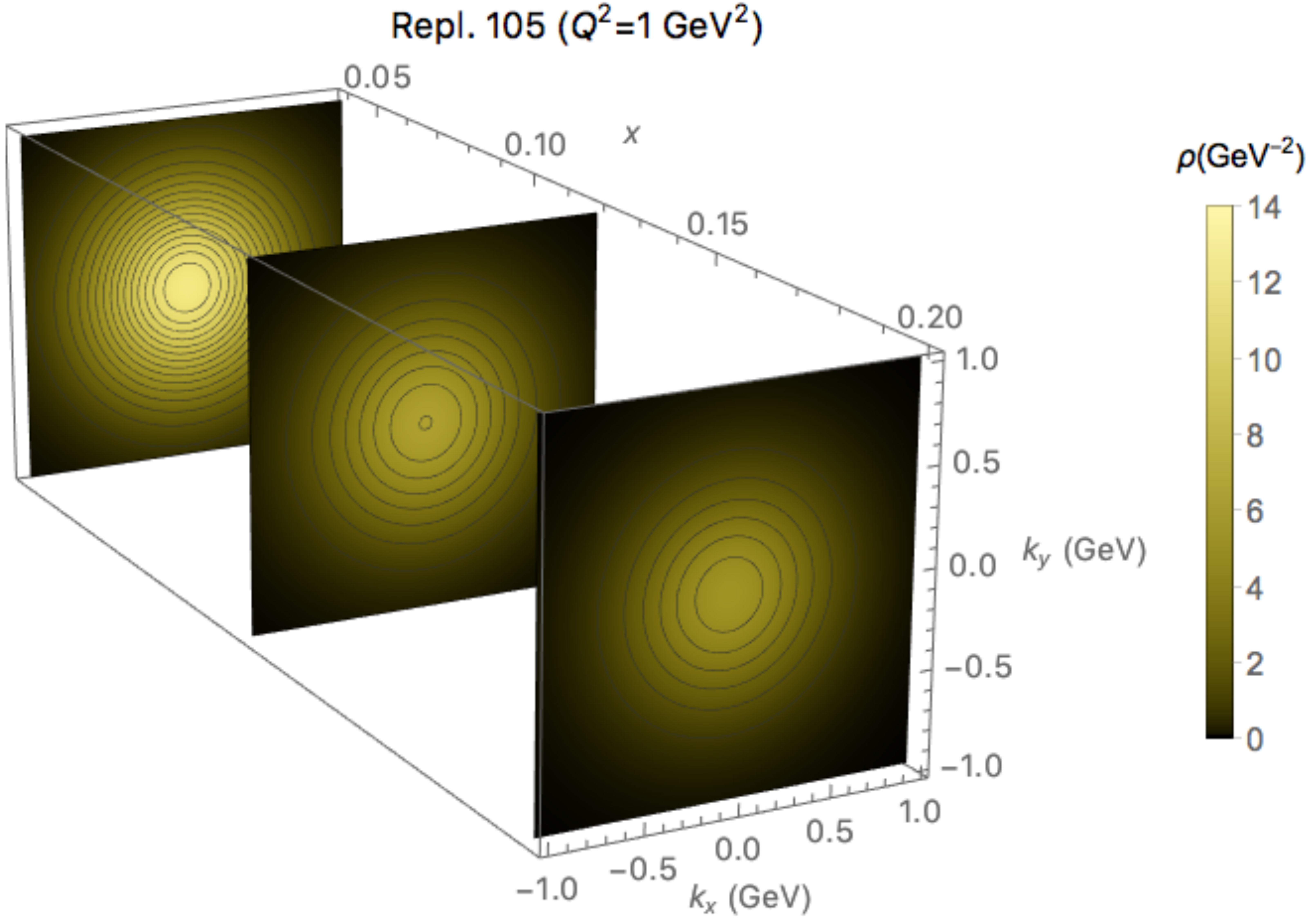
Estimate that does not take into account recent TMD results

HELICITY TMD



Repl. 105 (Q^2=1 GeV^2)
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0.10
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−0.5
−1.0
k_y (GeV)
−1.0
−0.5
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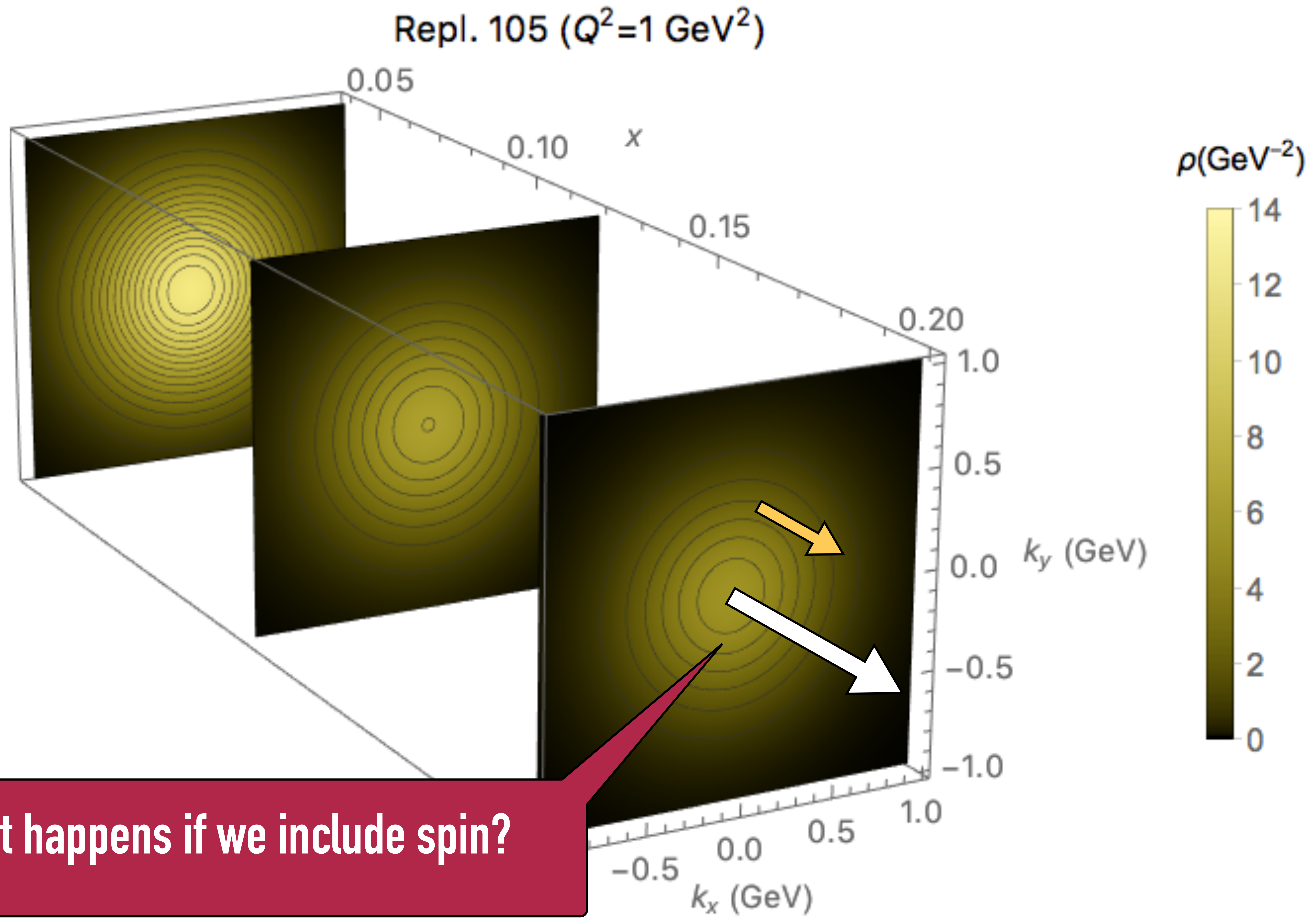
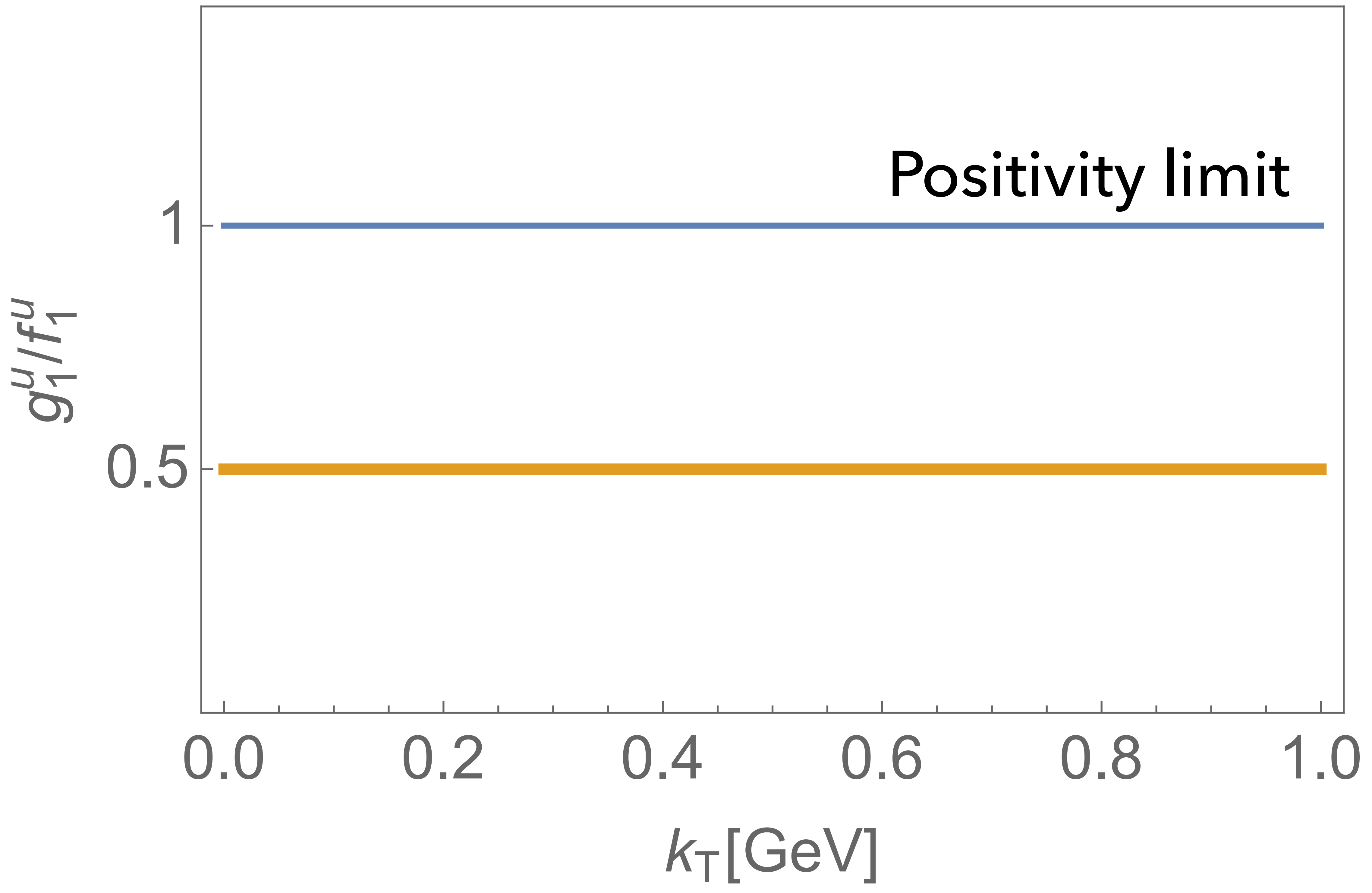
0.5
1.0
k_x (GeV)
ρ(GeV^{-2})
14
12
10
8
6
4
2
0

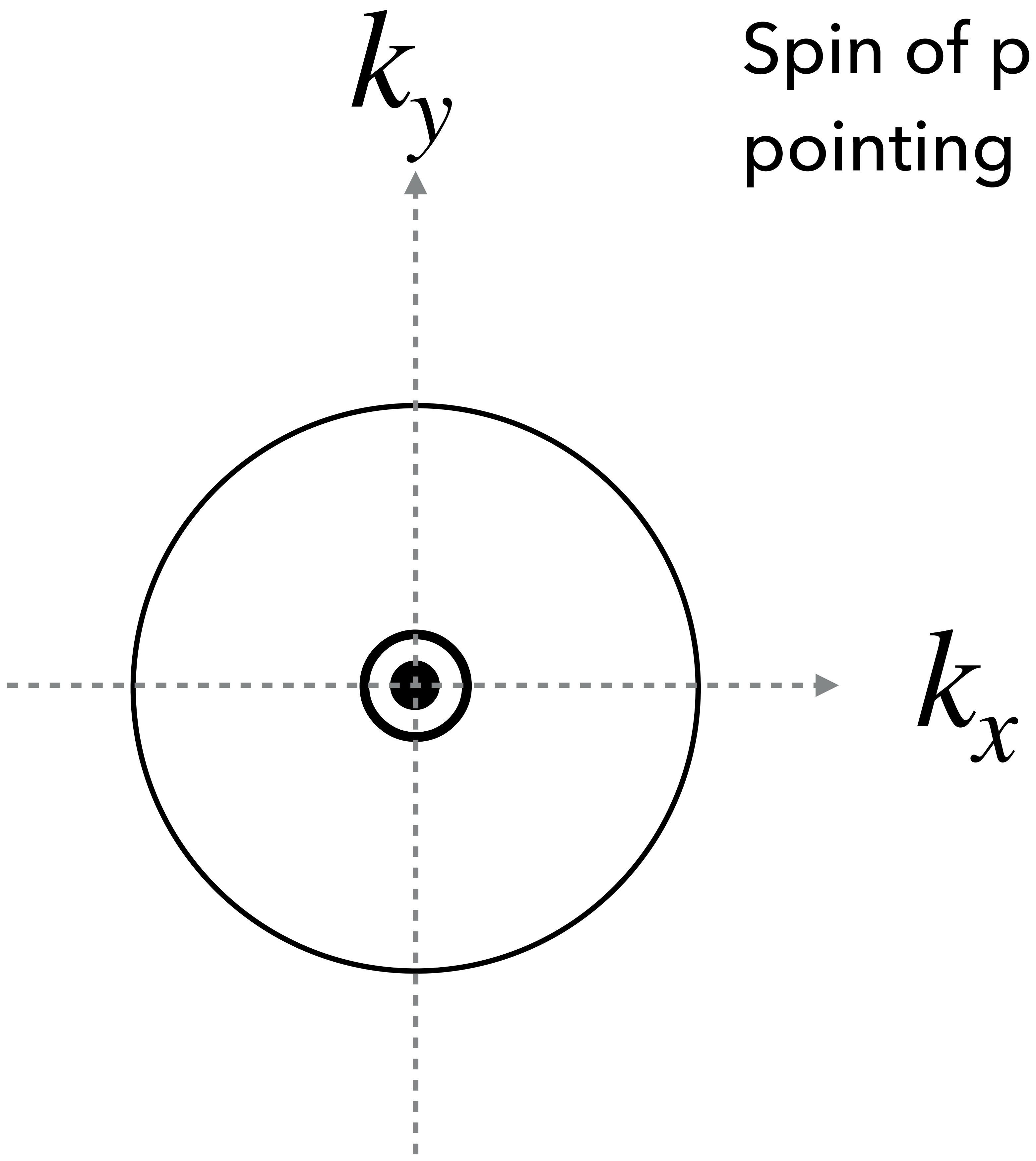


What happens if we include spin?

HELICITY TMD INTERPRETATION

At a certain value of x





Spin of proton pointing out

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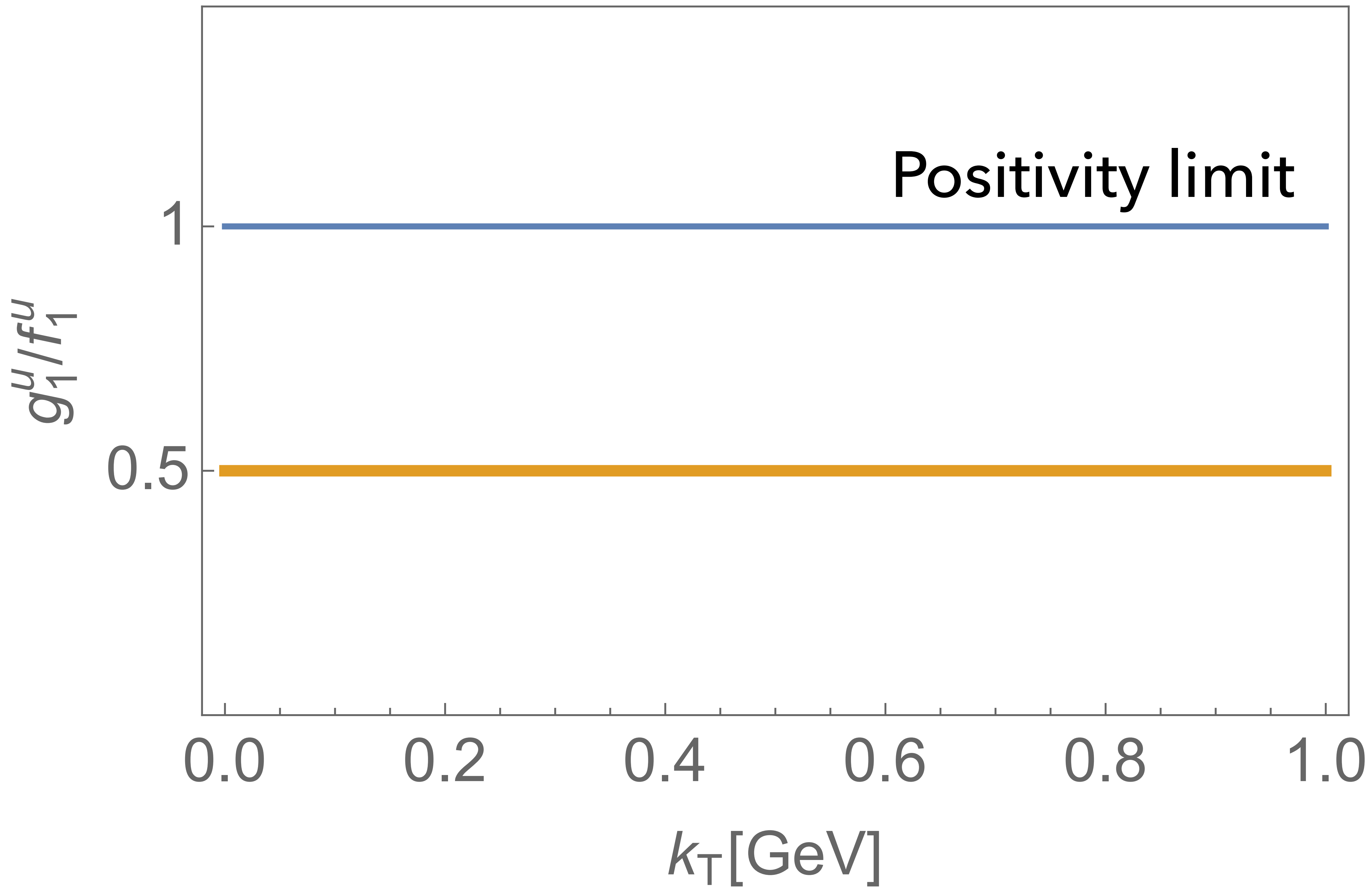
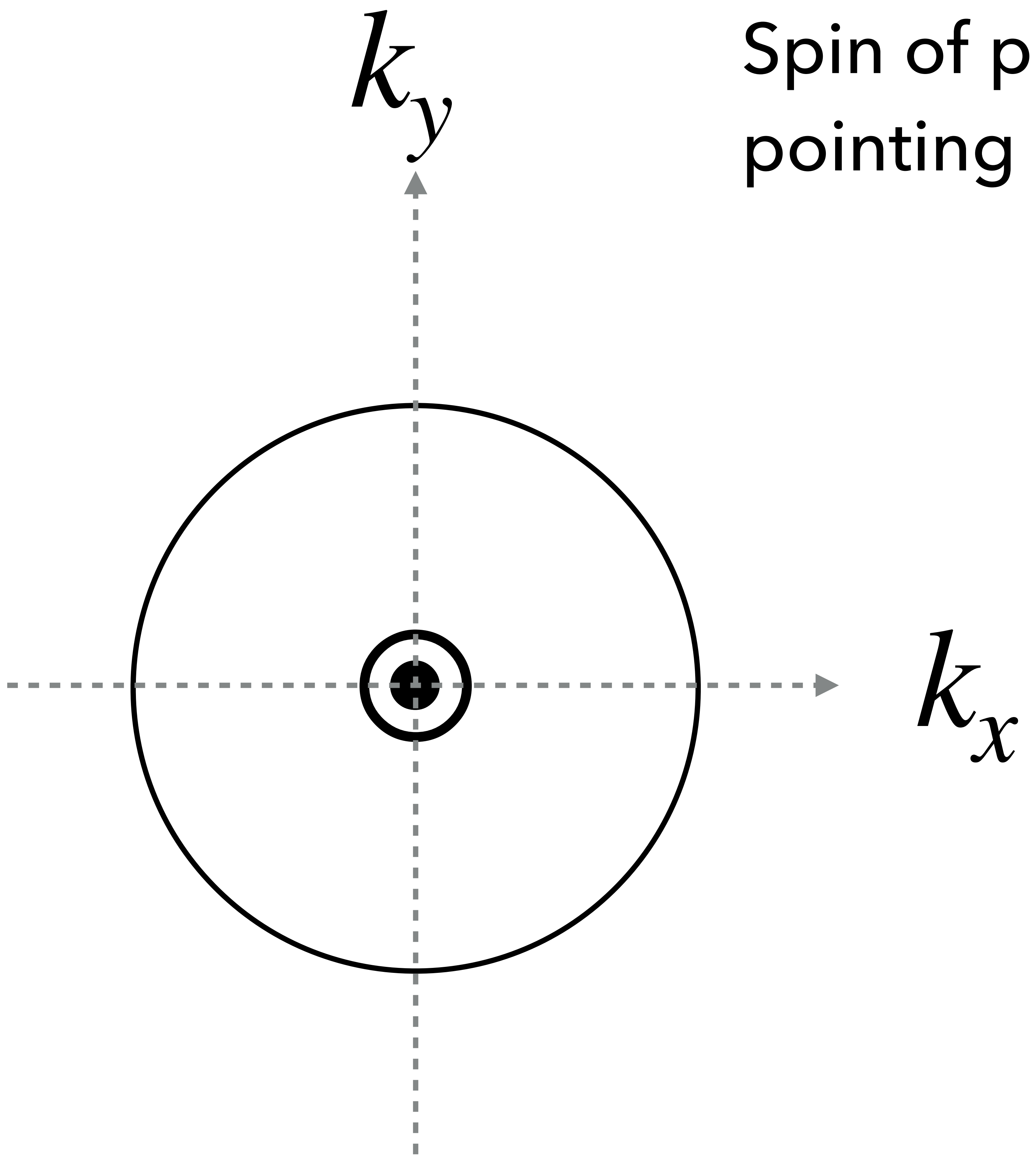
At a certain value of x





Spin of proton pointing out

We try to always impose positivity limits. We prefer rigid and physical to flexible and unphysical

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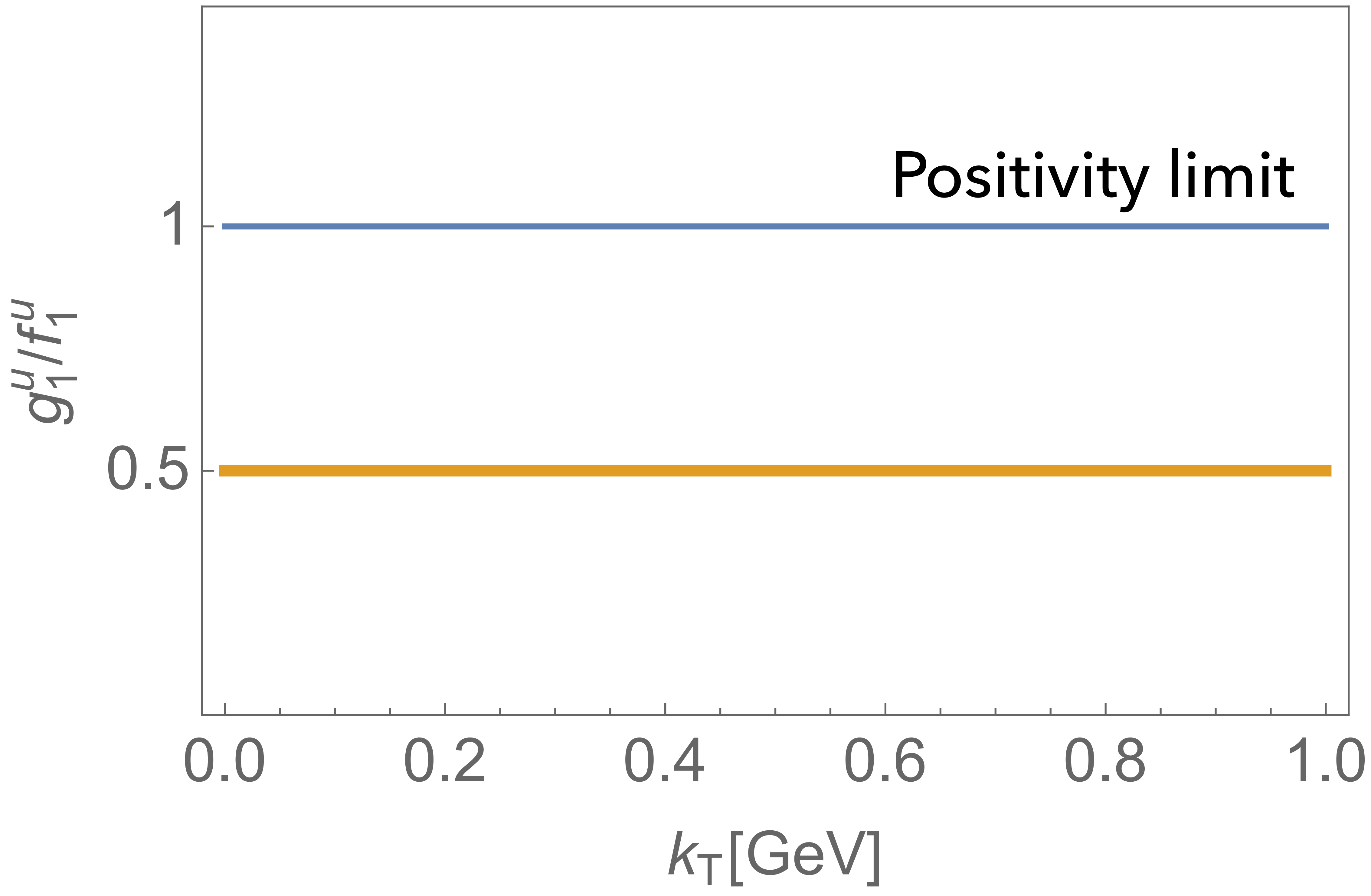

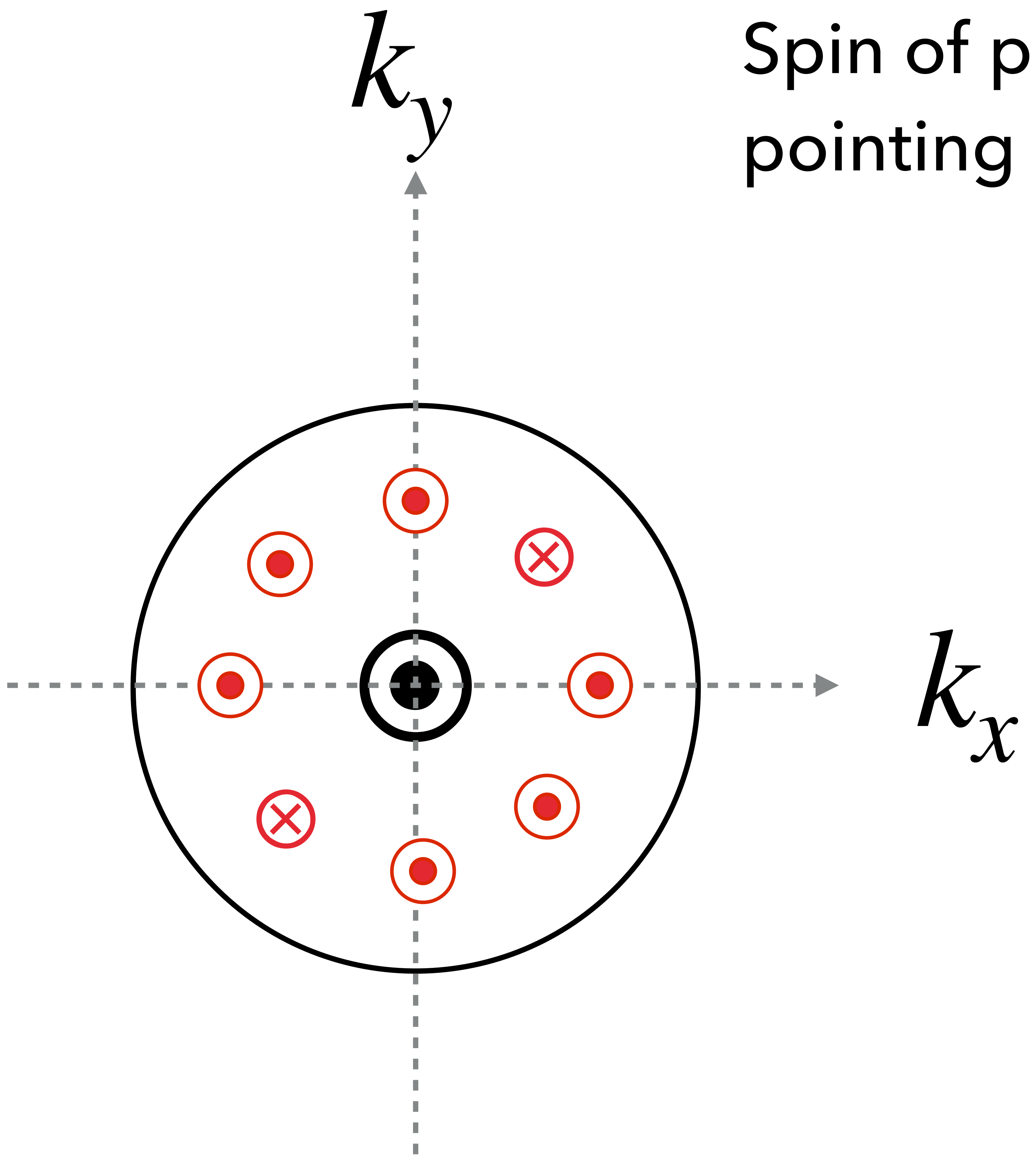

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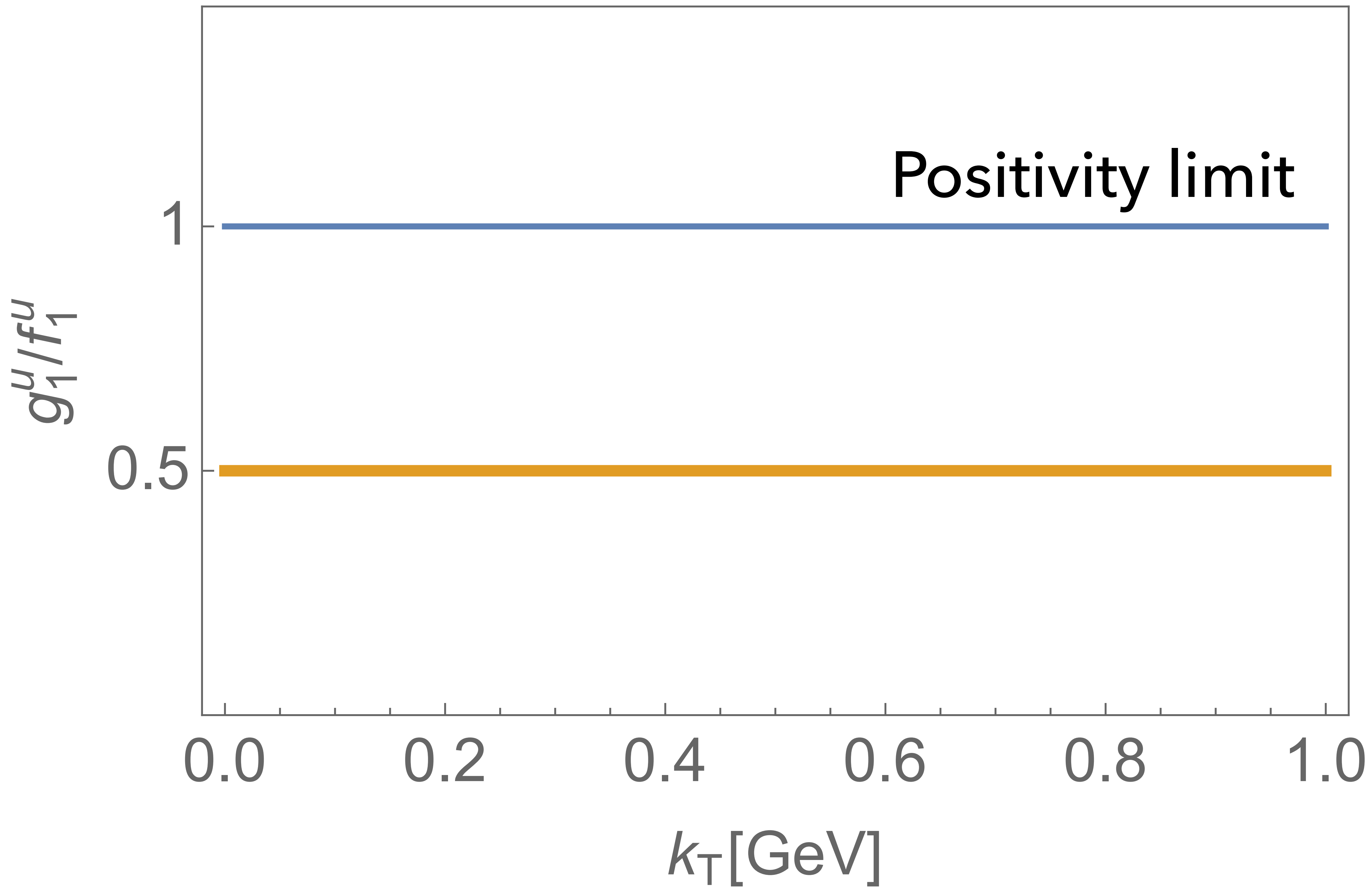

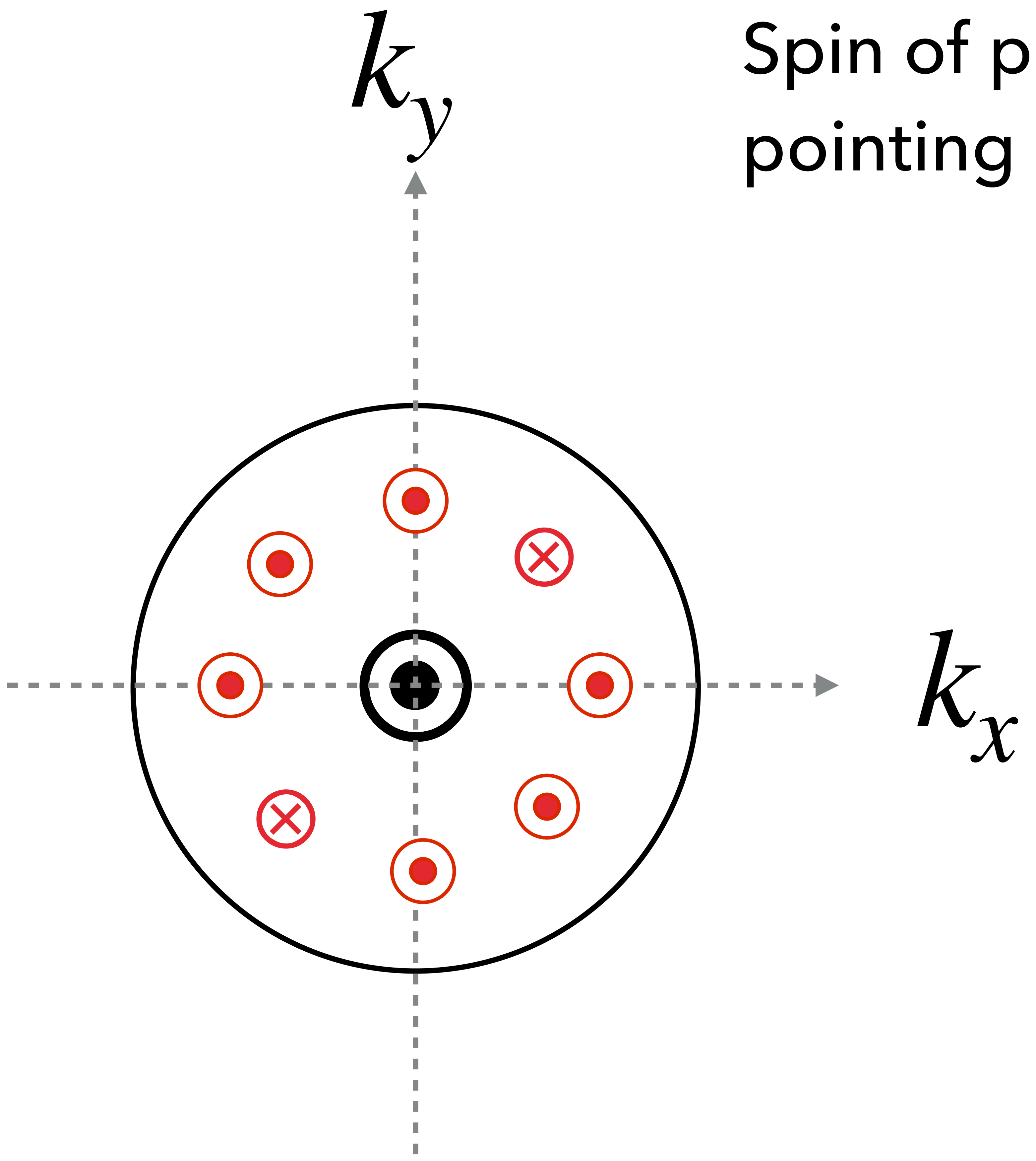

Spin of proton pointing out

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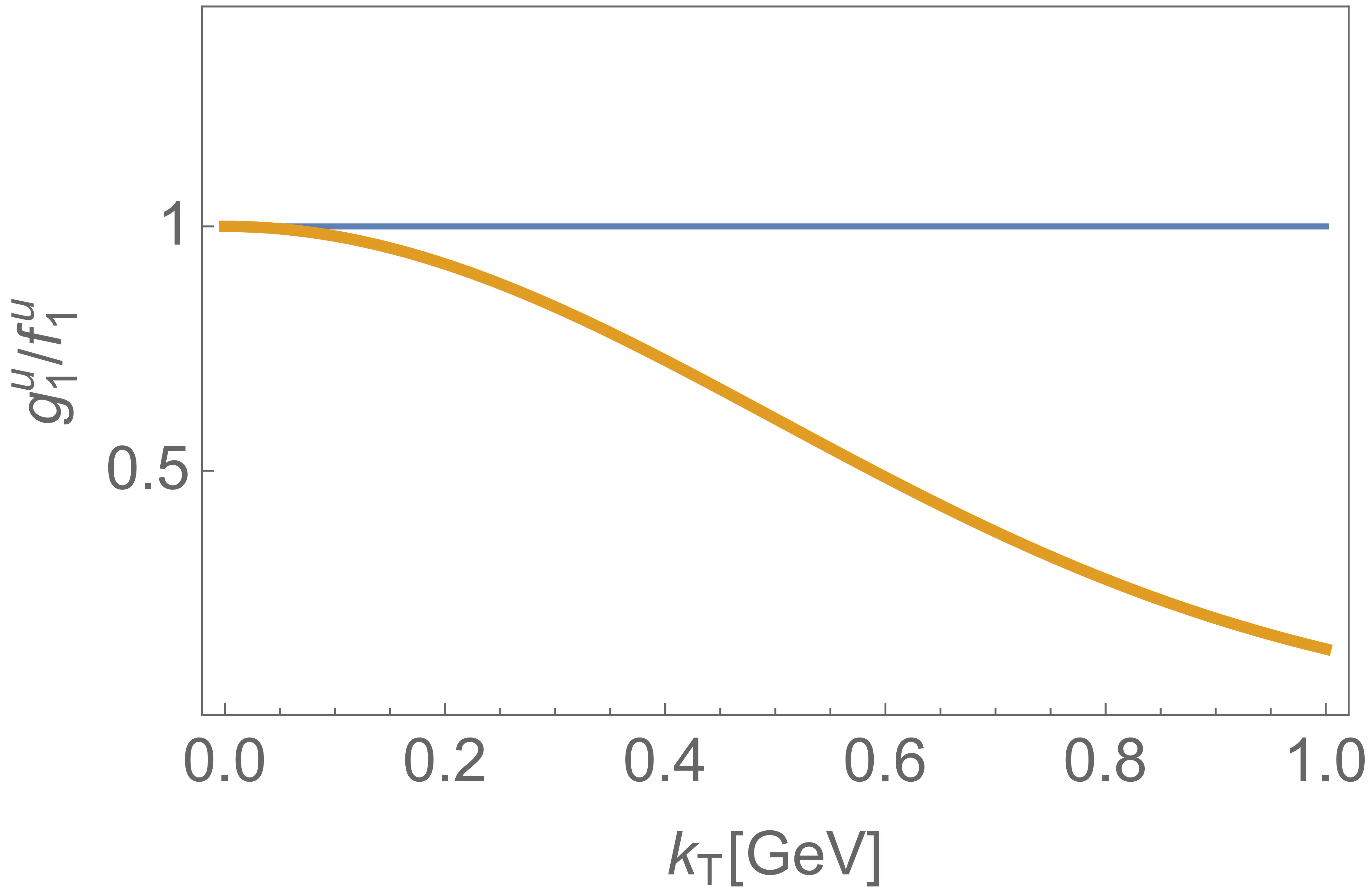
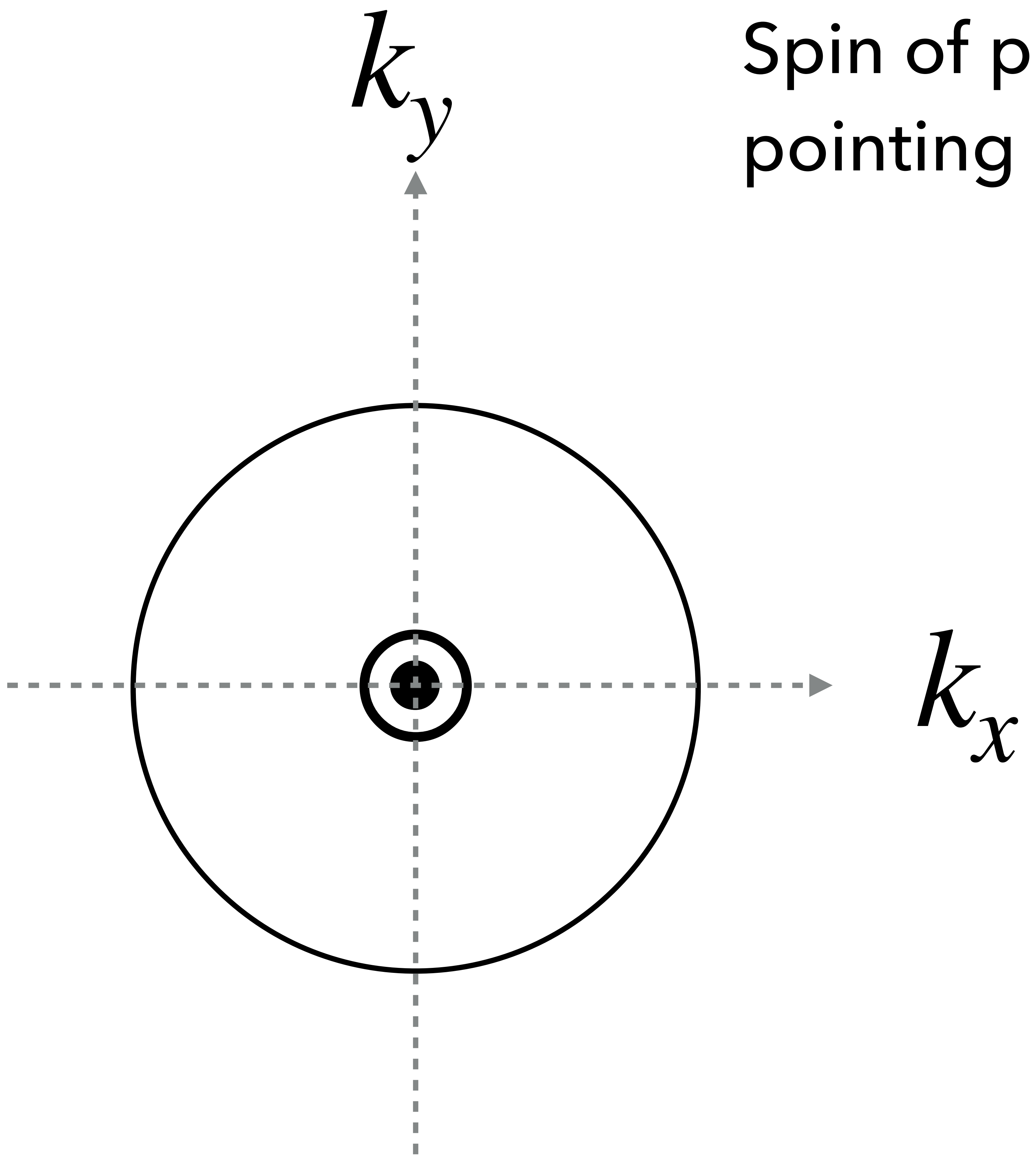
The fraction of same/opposite helicities is the same at any transverse momentum

HELICITY TMD INTERPRETATION

At a certain value of x





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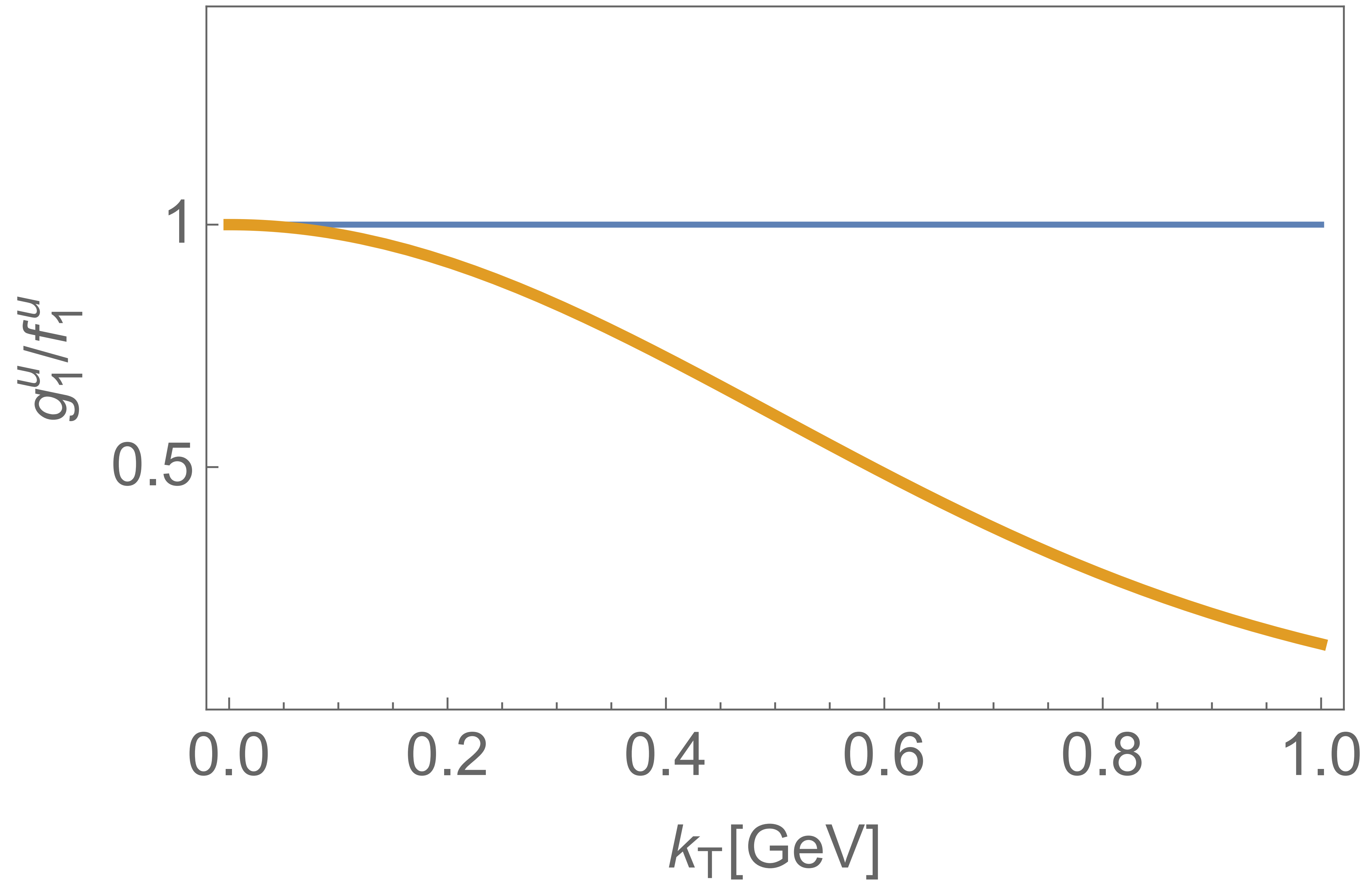

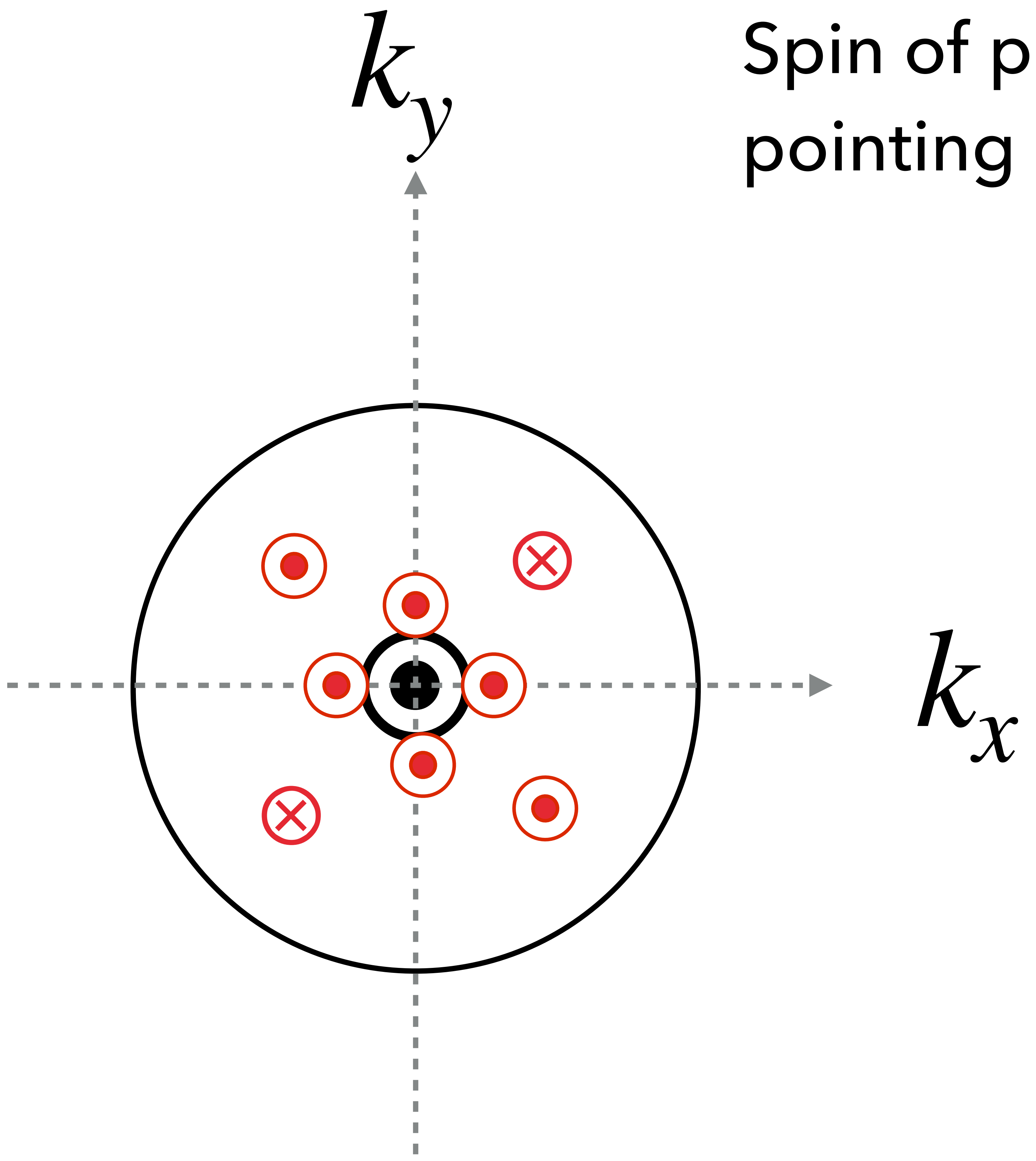

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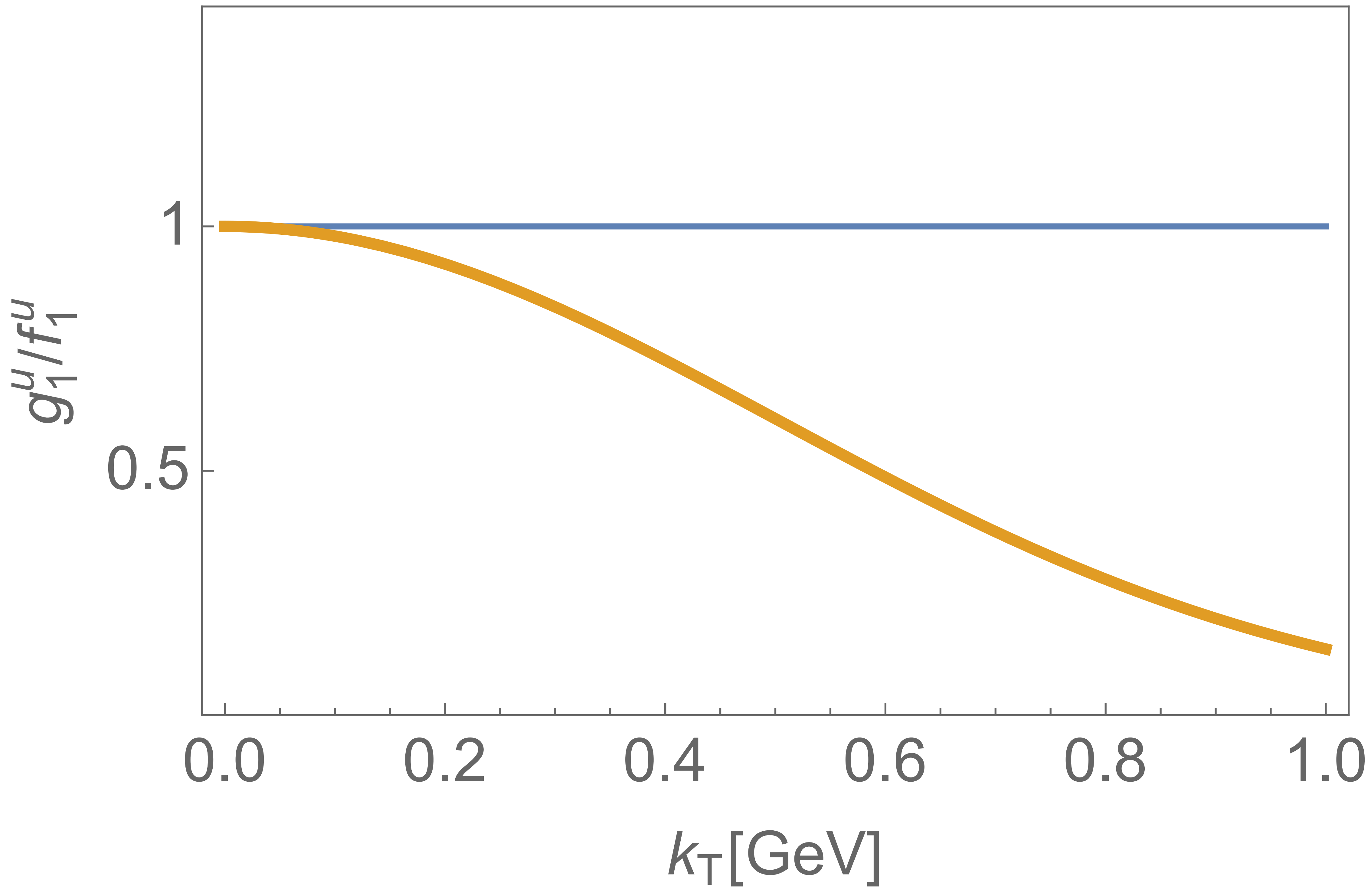

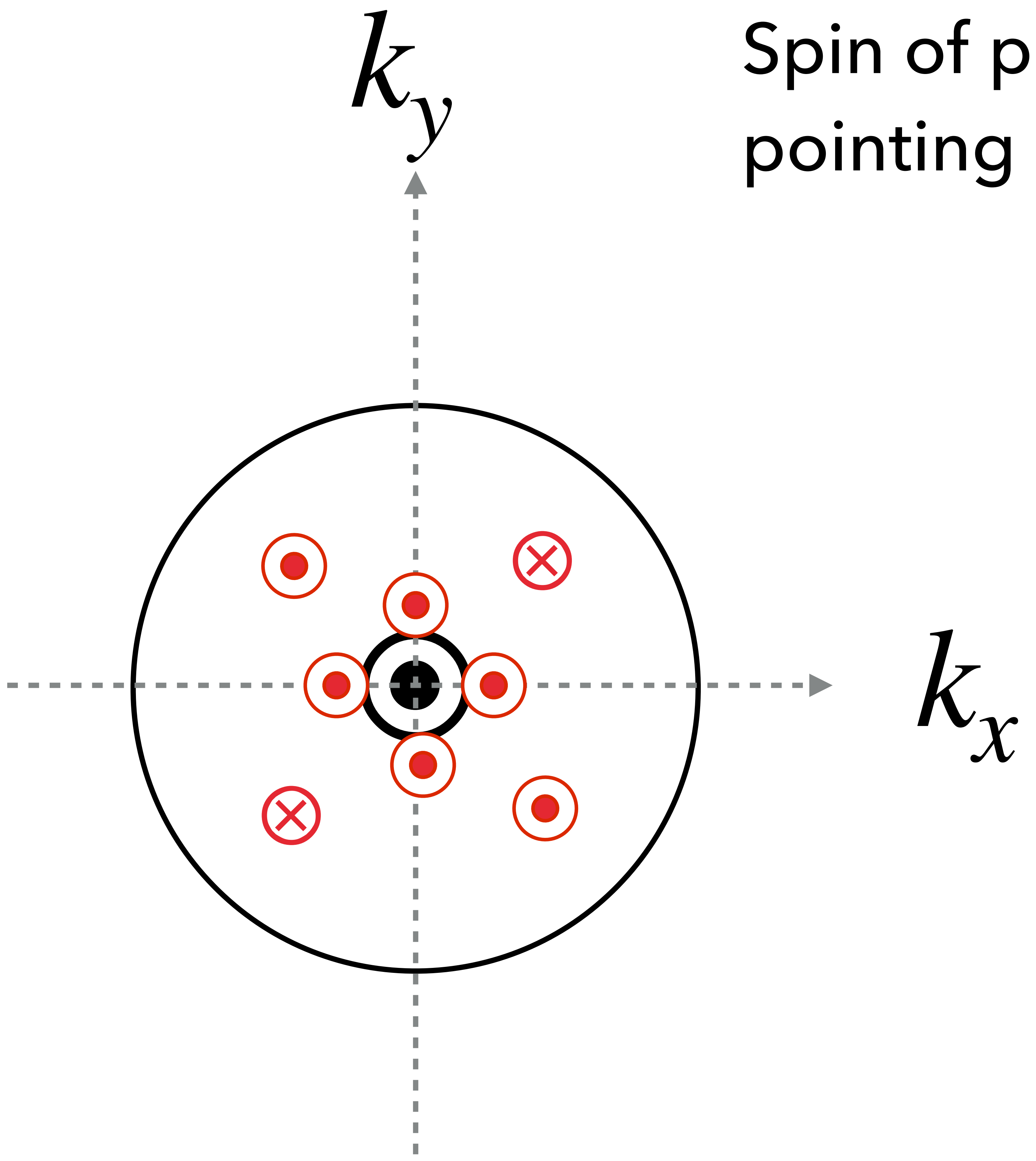

Spin of proton pointing out

The quarks with the same helicity as the proton's have less transverse momentum

HELICITY TMD INTERPRETATION

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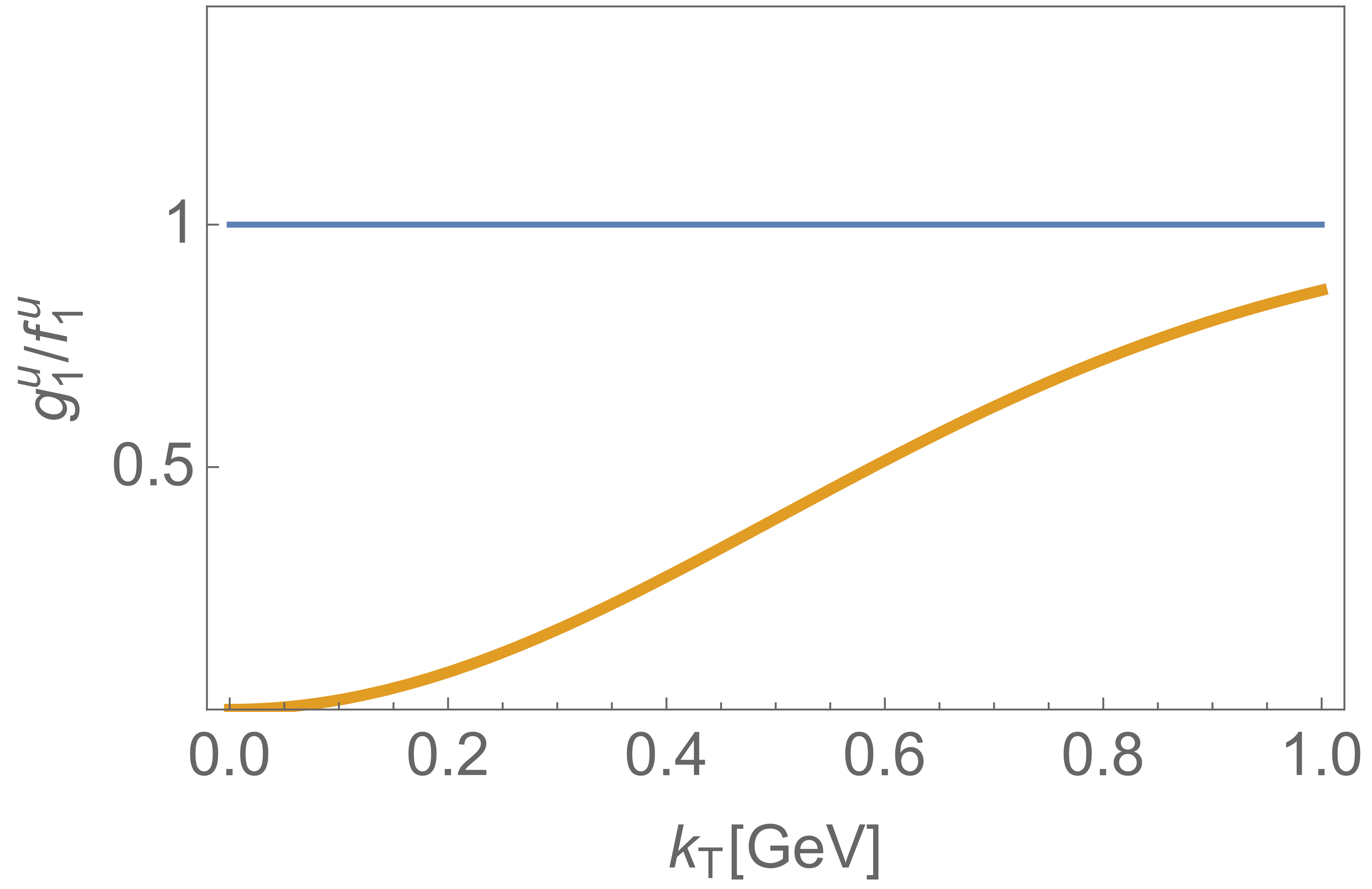

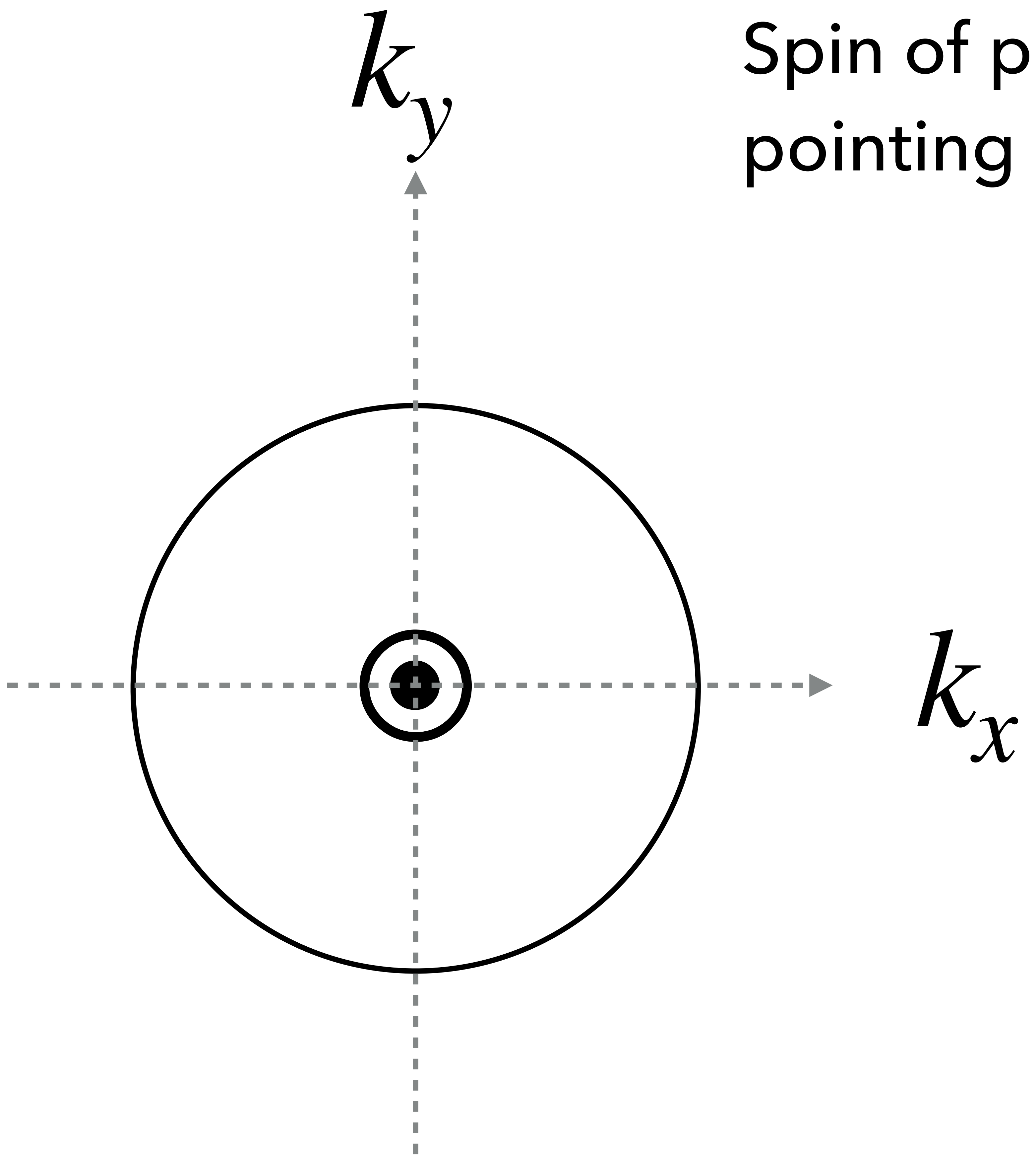

Spin of proton pointing out

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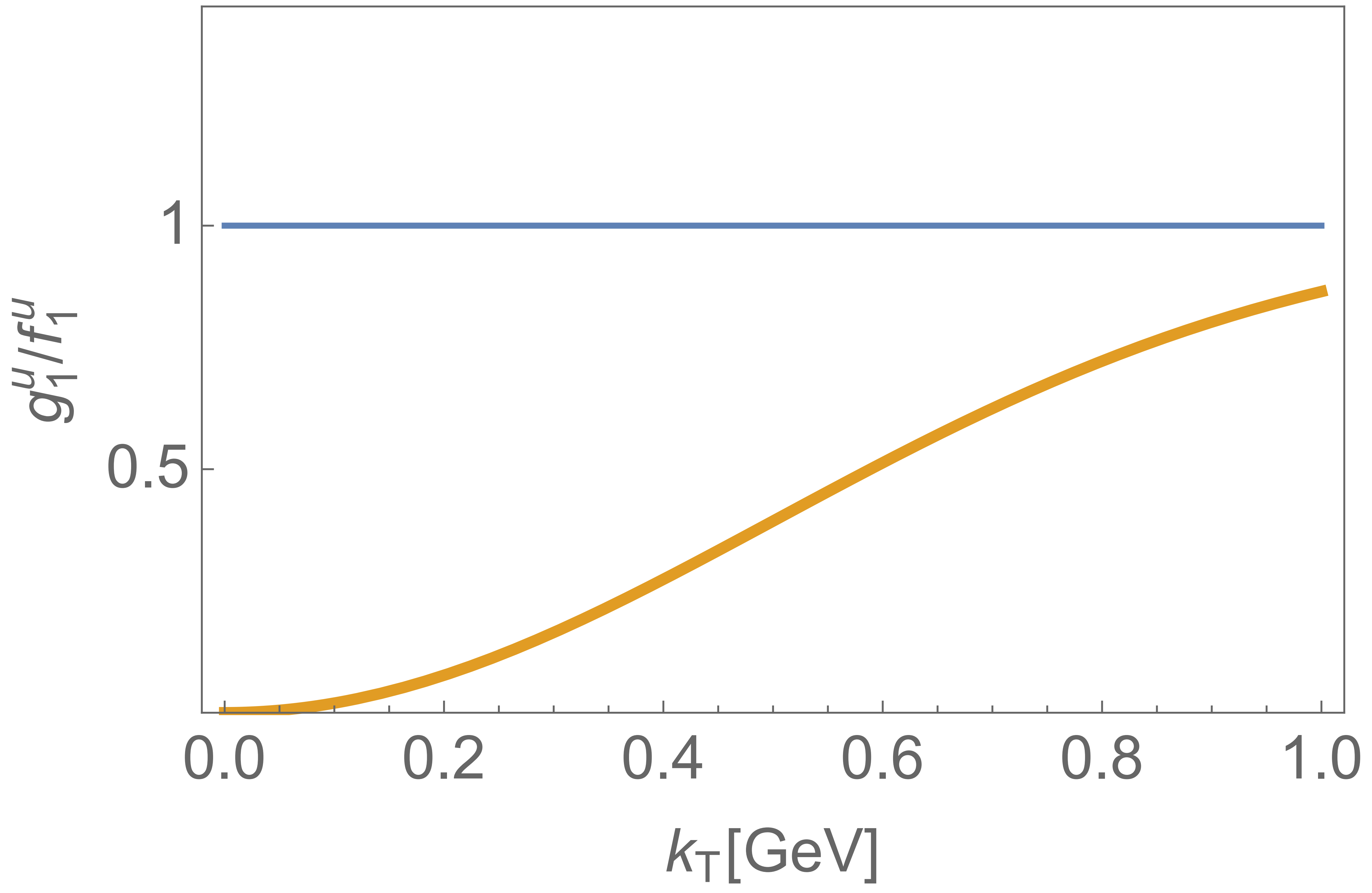

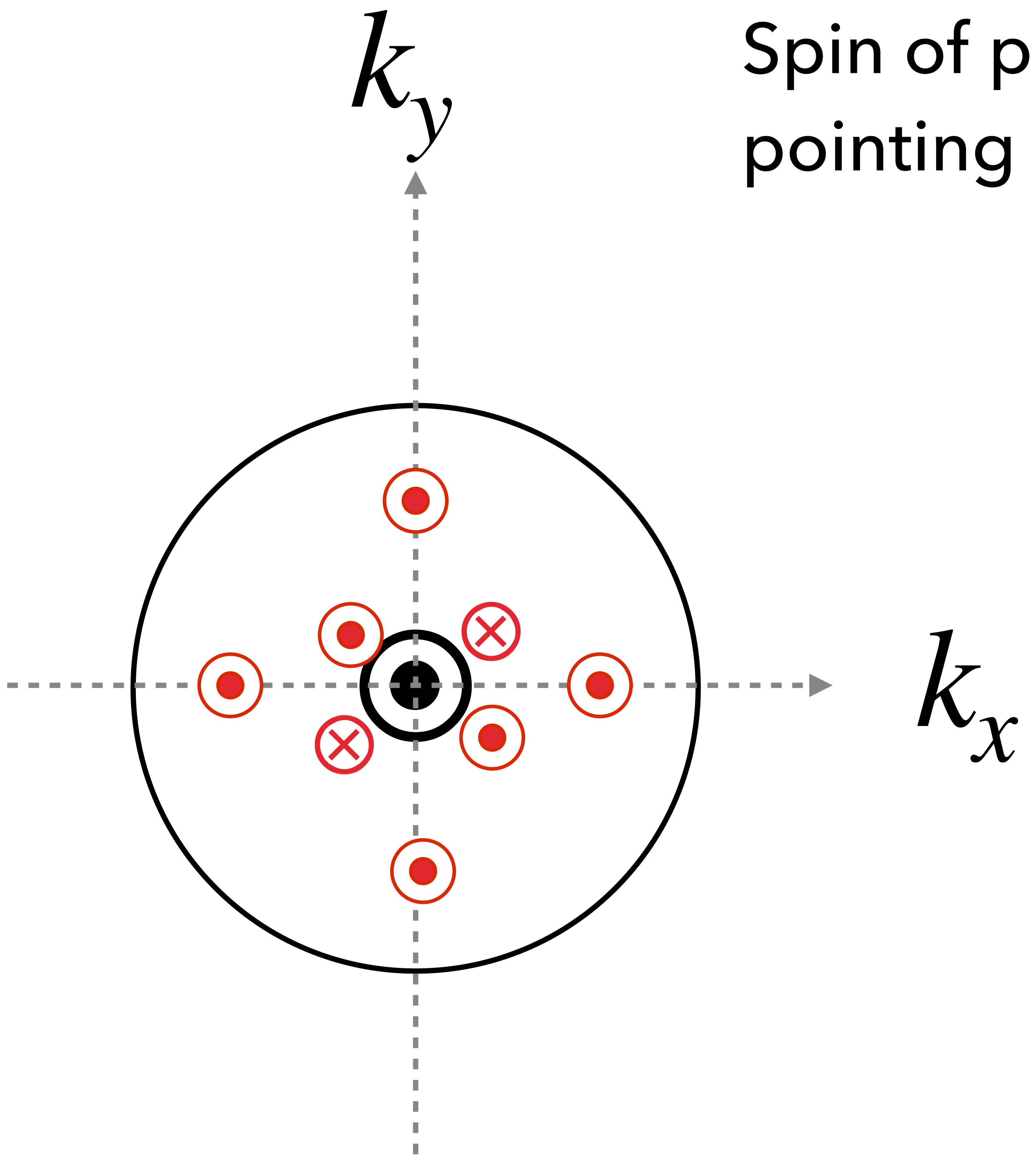

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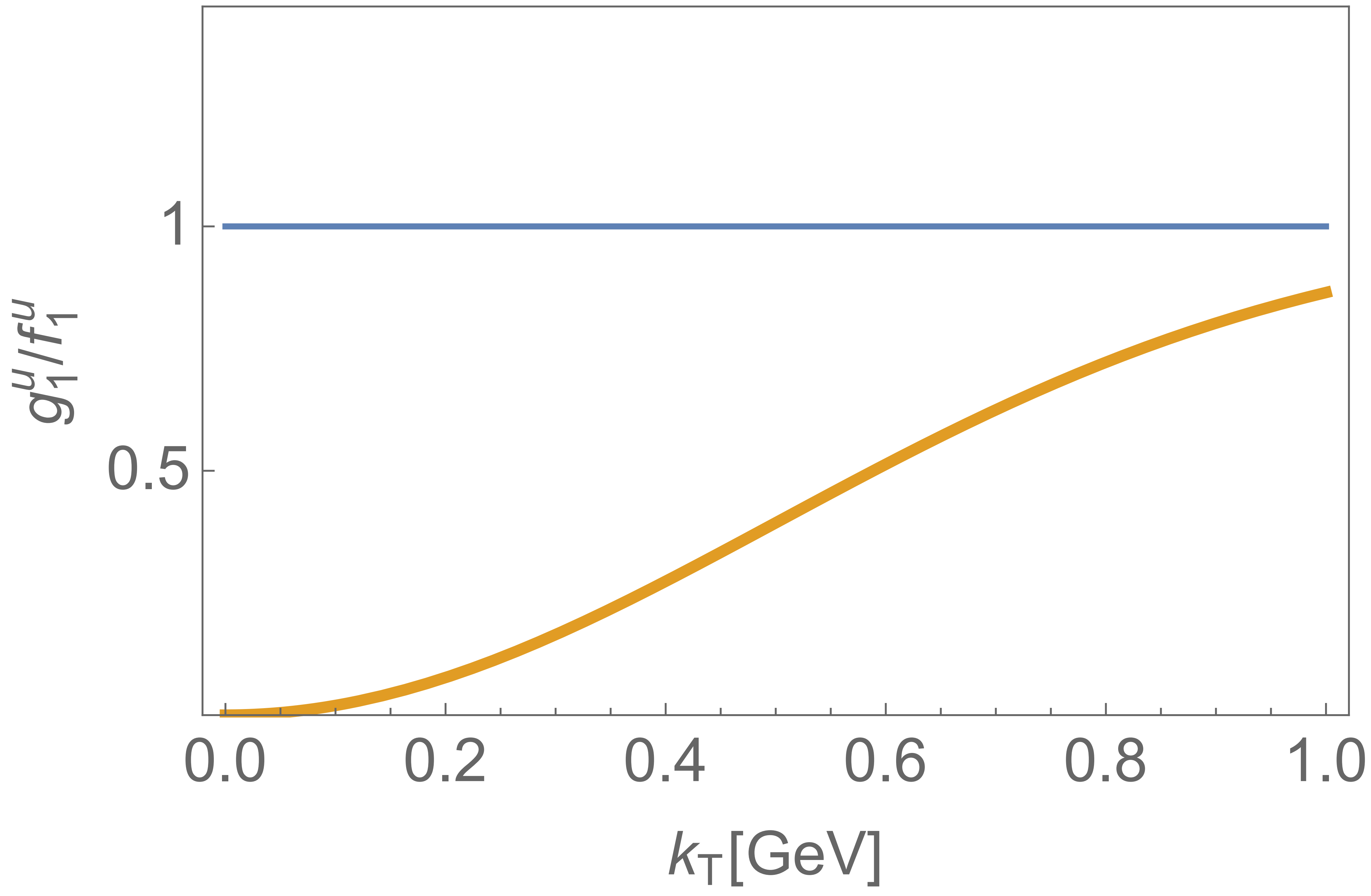

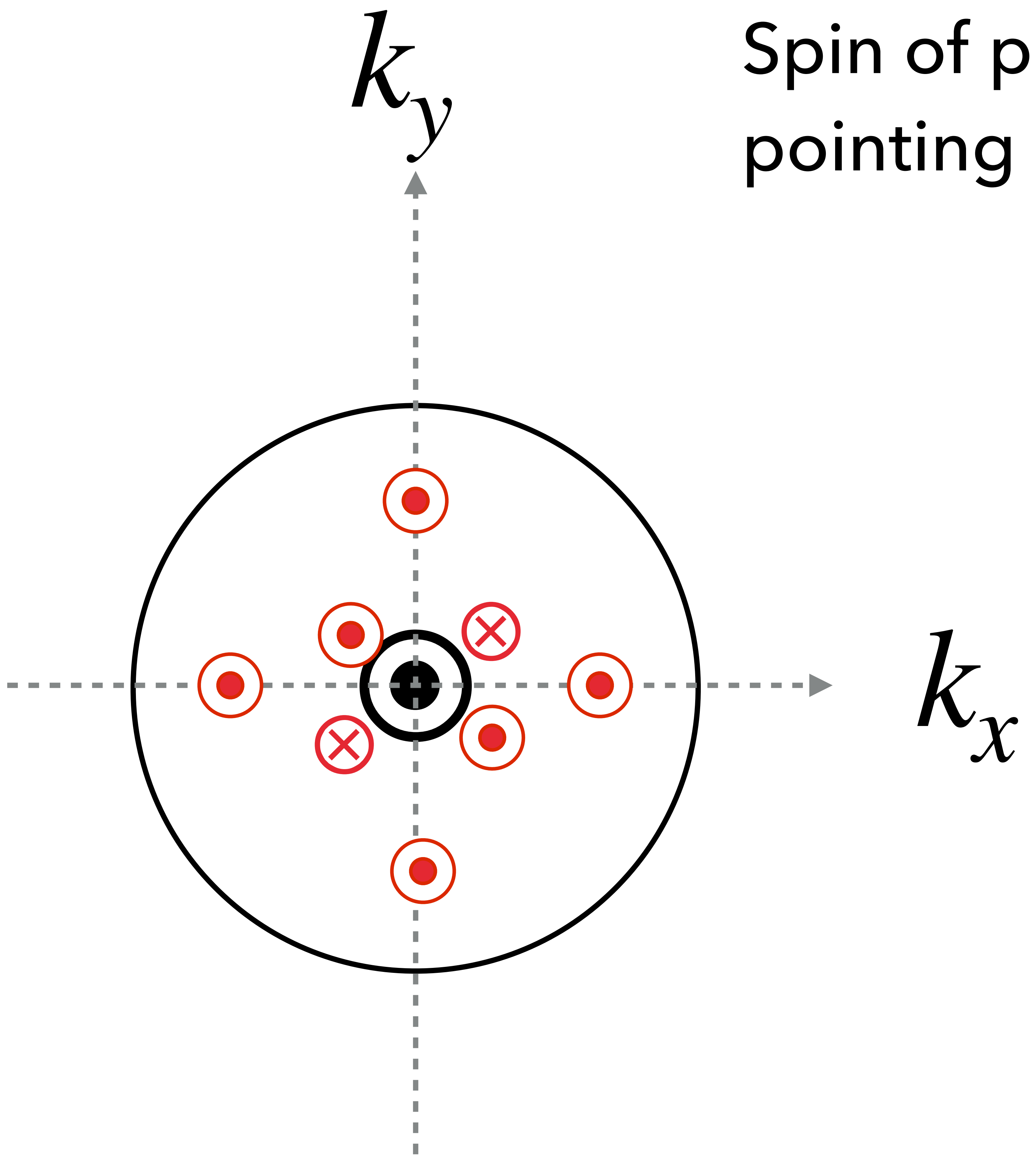

Spin of proton pointing out

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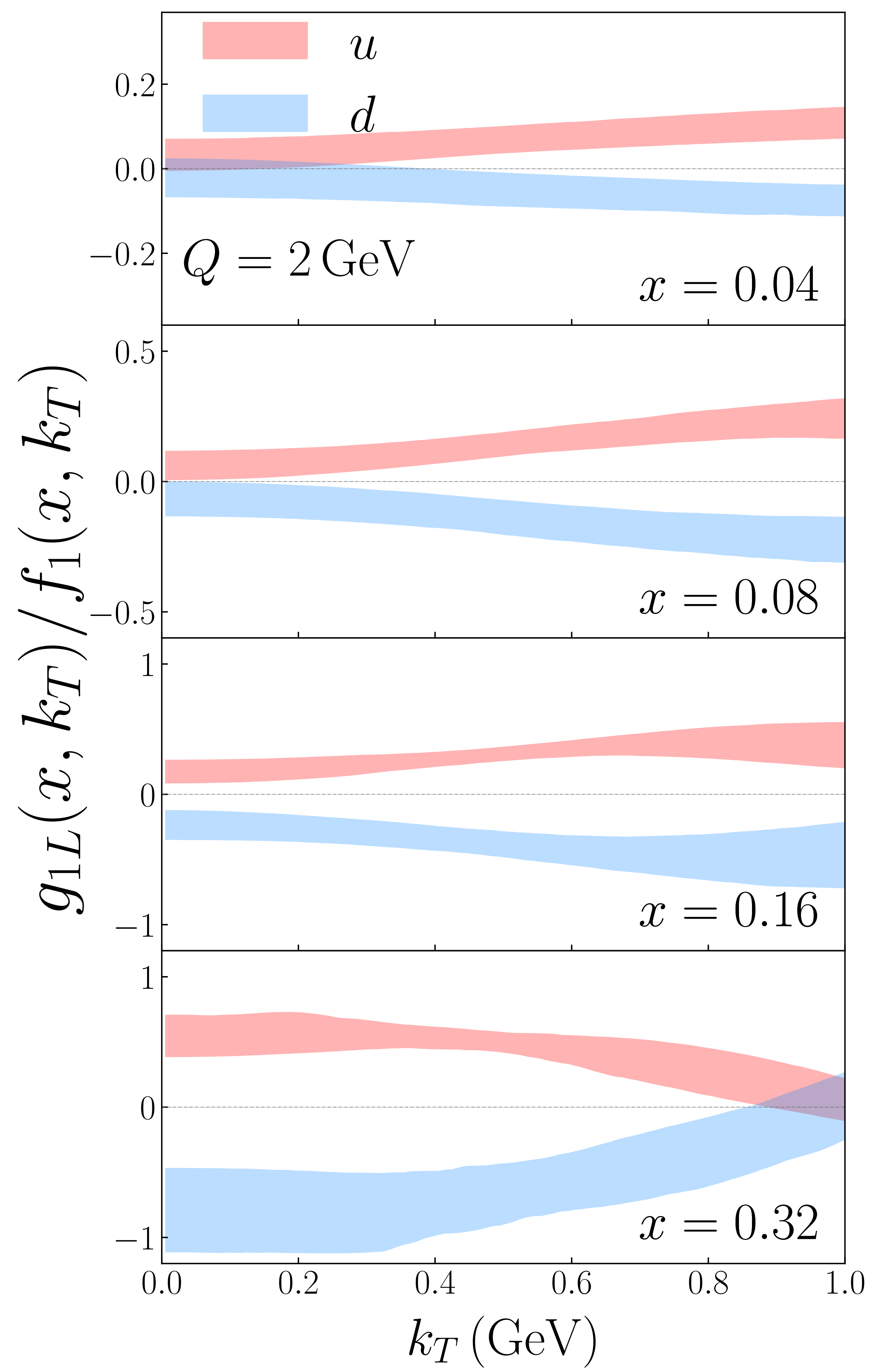
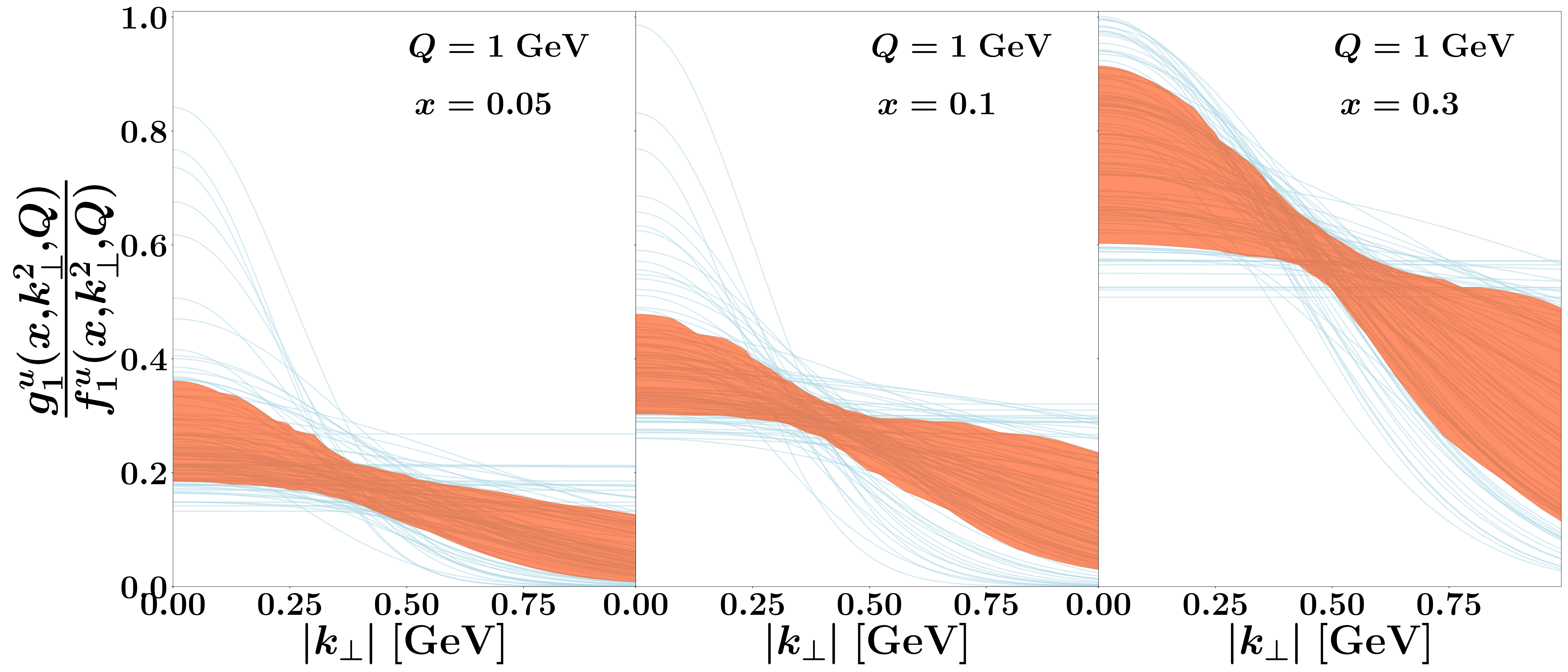
TWO (EXTREMELY) RECENT EXTRACTIONS

Yang, Liu, Sun, Zhao, Ma, arXiv:2409.08110



MAP collaboration, arXiv:2409.18078



USED DATASETS

Yang, Liu, Sun, Zhao, Ma, arXiv:2409.08110

Experiment	Process	Data points	χ^2/N
HERMES[82]	$e^{\pm}p \to e^{\pm}hX$	84 (160)	0.72
HERMES[82]	$e^{\pm}d \to e^{\pm}hX$	160 (317)	0.71
CLAS[83]	$e^{-}p \to e^{-}\pi^{0}X$	9 (21)	1.43
Total		253 (498)	0.74

MAP collaboration, arXiv:2409.18078

Experiment	$N_{\rm dat}$	$\chi^2_{\rm NLL}/N_{\rm dat}$	$\chi^2_{\rm NNLL}/N_{\rm dat}$
HERMES $(d \to \pi^+)$	47	1.34	1.30
HERMES $(d \to \pi^-)$	47	1.10	1.08
HERMES $(d \to K^+)$	46	1.26	1.25
HERMES $(d \to K^-)$	45	0.93	0.89
HERMES $(p \to \pi^+)$	53	1.17	1.21
HERMES $(p \to \pi^-)$	53	0.86	0.86
Total	291	1.11	1.09

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Yang, Liu, Sun, Zhao, Ma, arXiv:2409.08110

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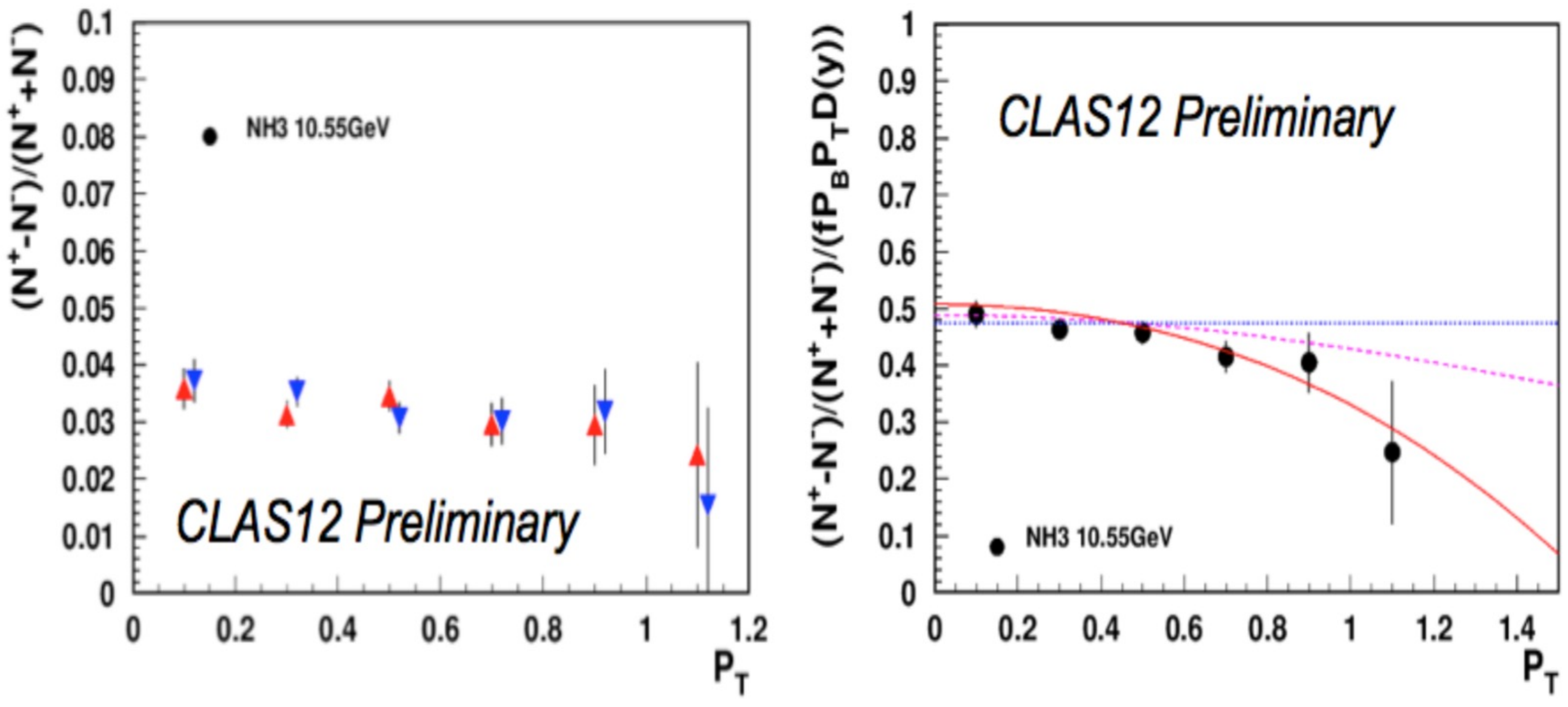
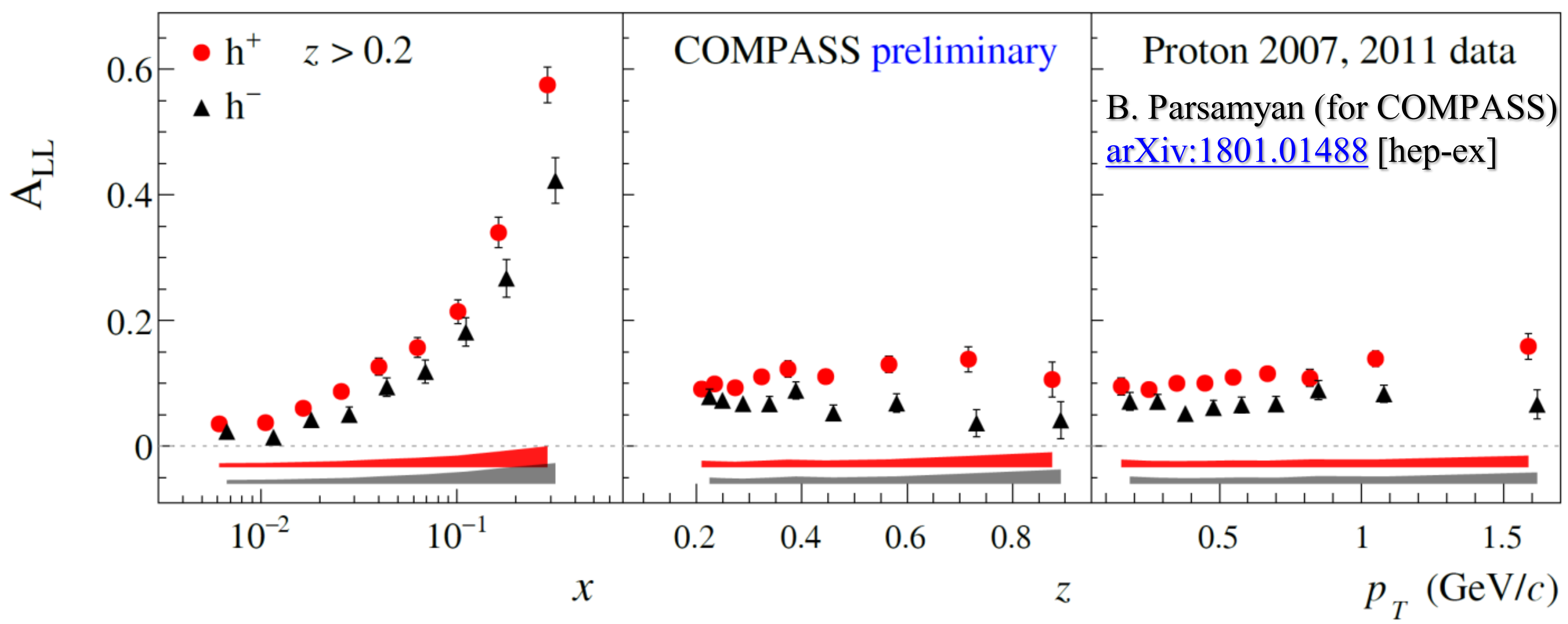
More data needed

EXPECTED DATA

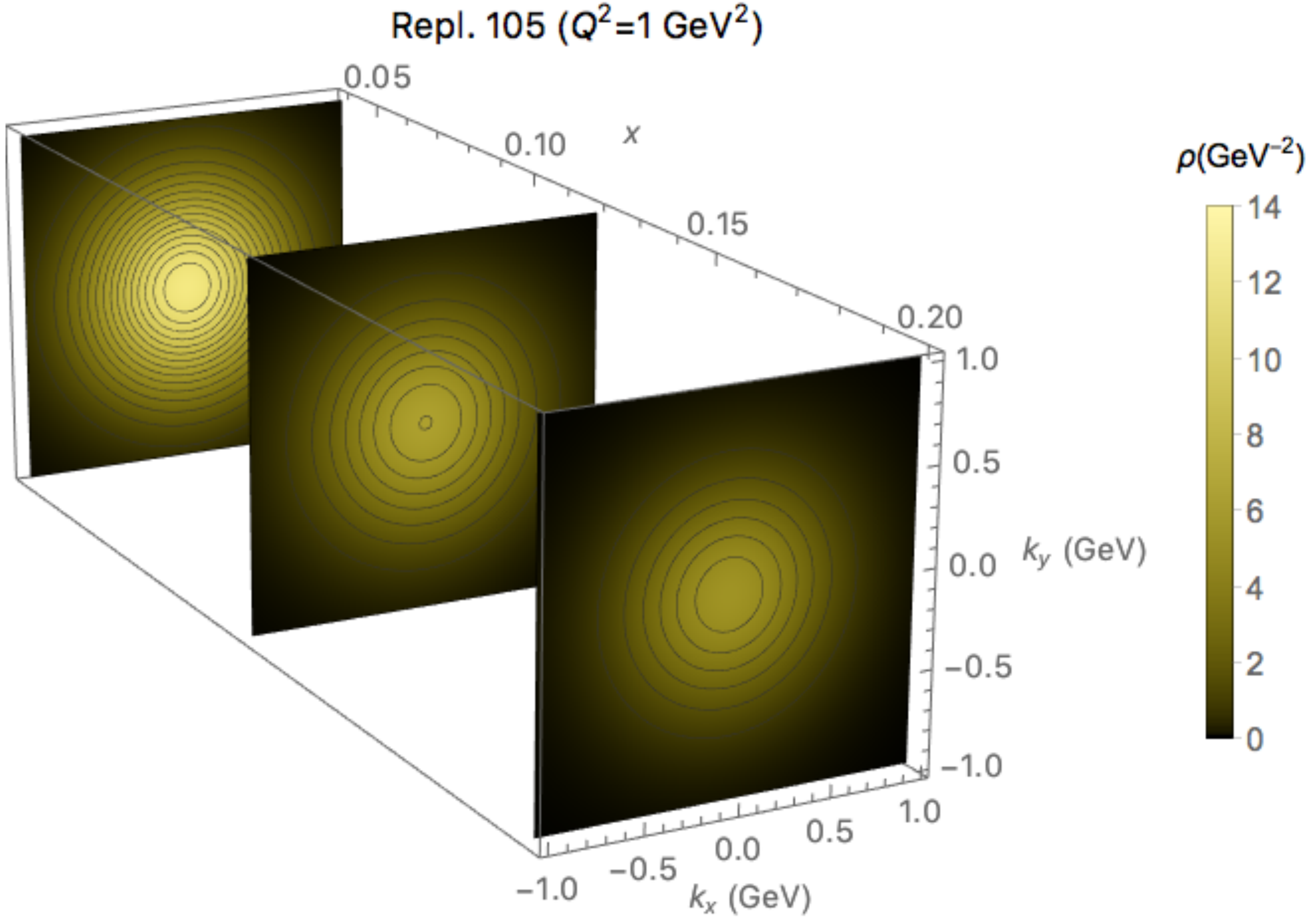
Multidimensional binning needed





See talks by Tim Hayward, Bakur Parsamyan

SIVERS TMD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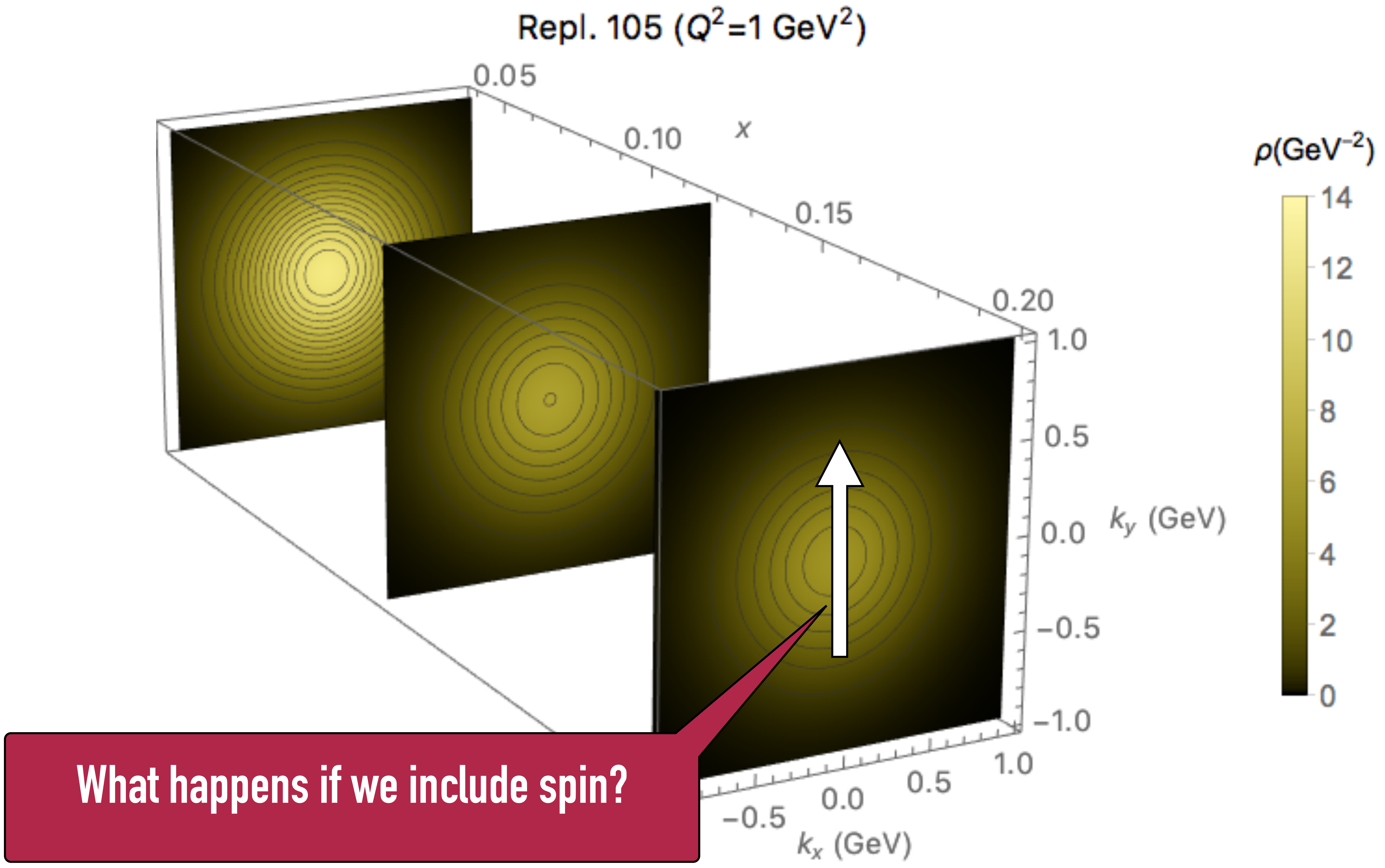
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What happens if we include spin?

SIVERS FUNCTION

$$\rho^{q}_{N\uparrow}(x, k_x, k_y; Q^2) = f^{q}_{1}(x, k_T^2; Q^2) - \frac{k_x}{M} f^{\perp q}_{1T}(x, k_T^2; Q^2)$$

In a nucleon polarized in the +y direction,
the distribution of quarks can be distorted in the x direction

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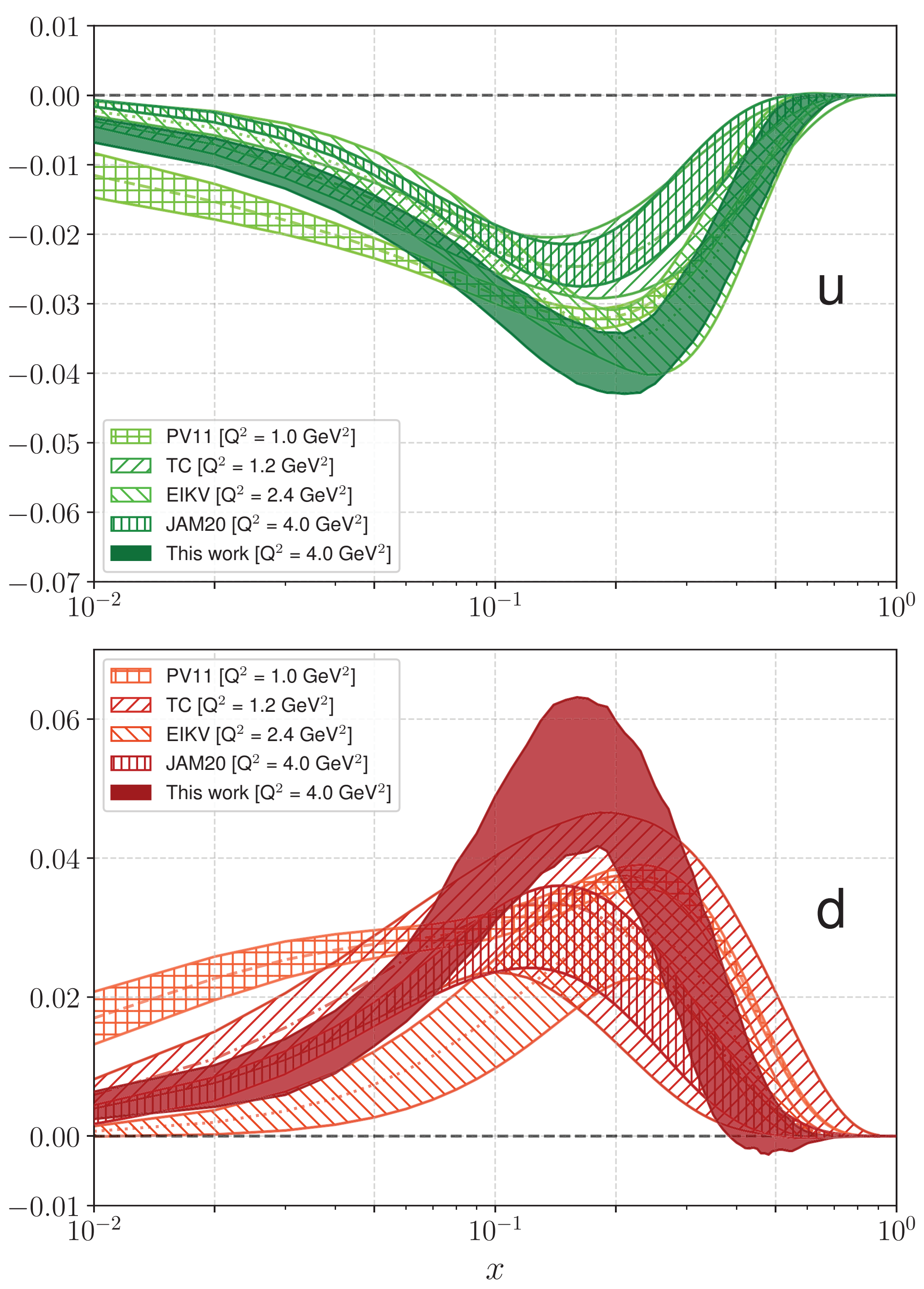
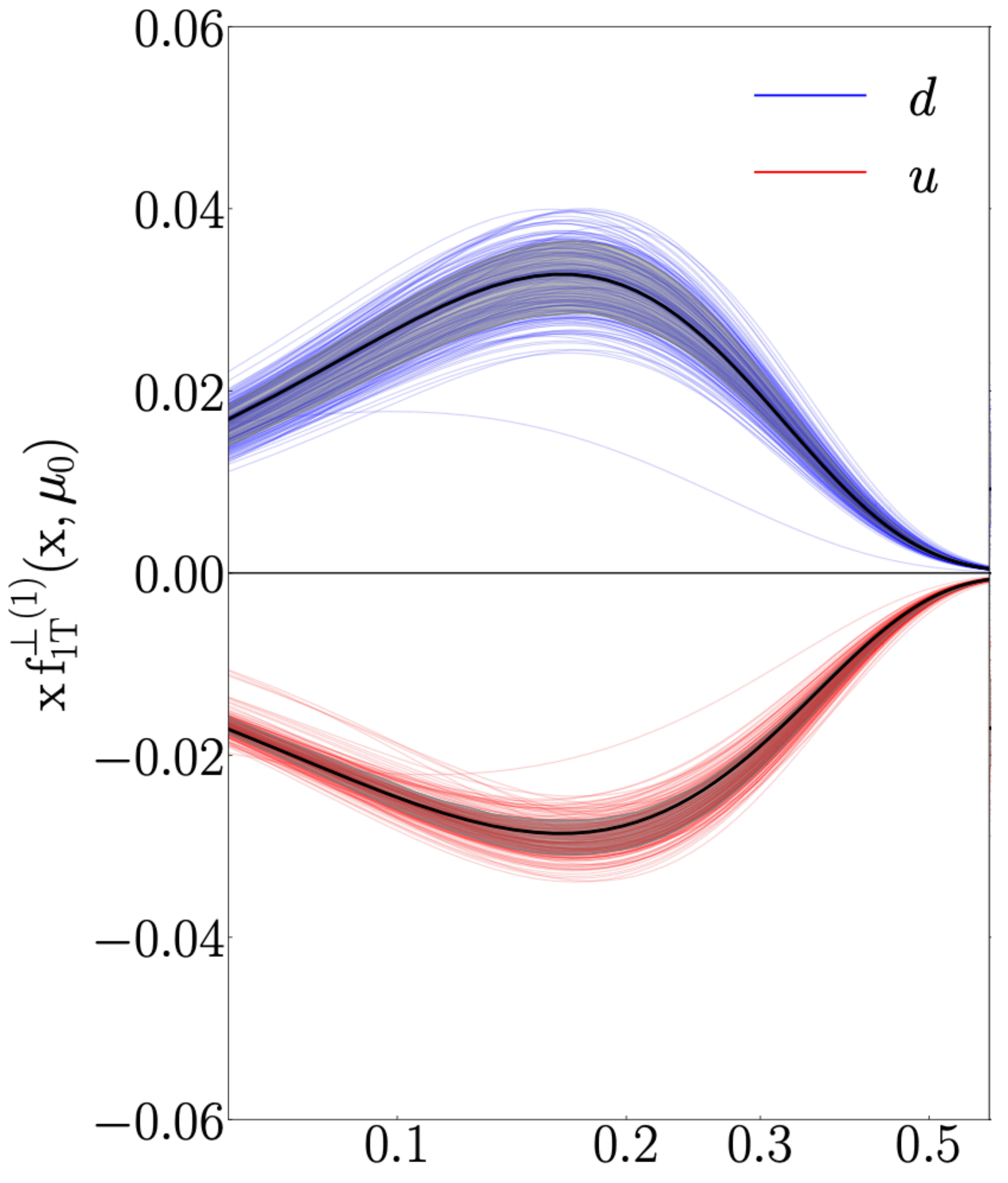
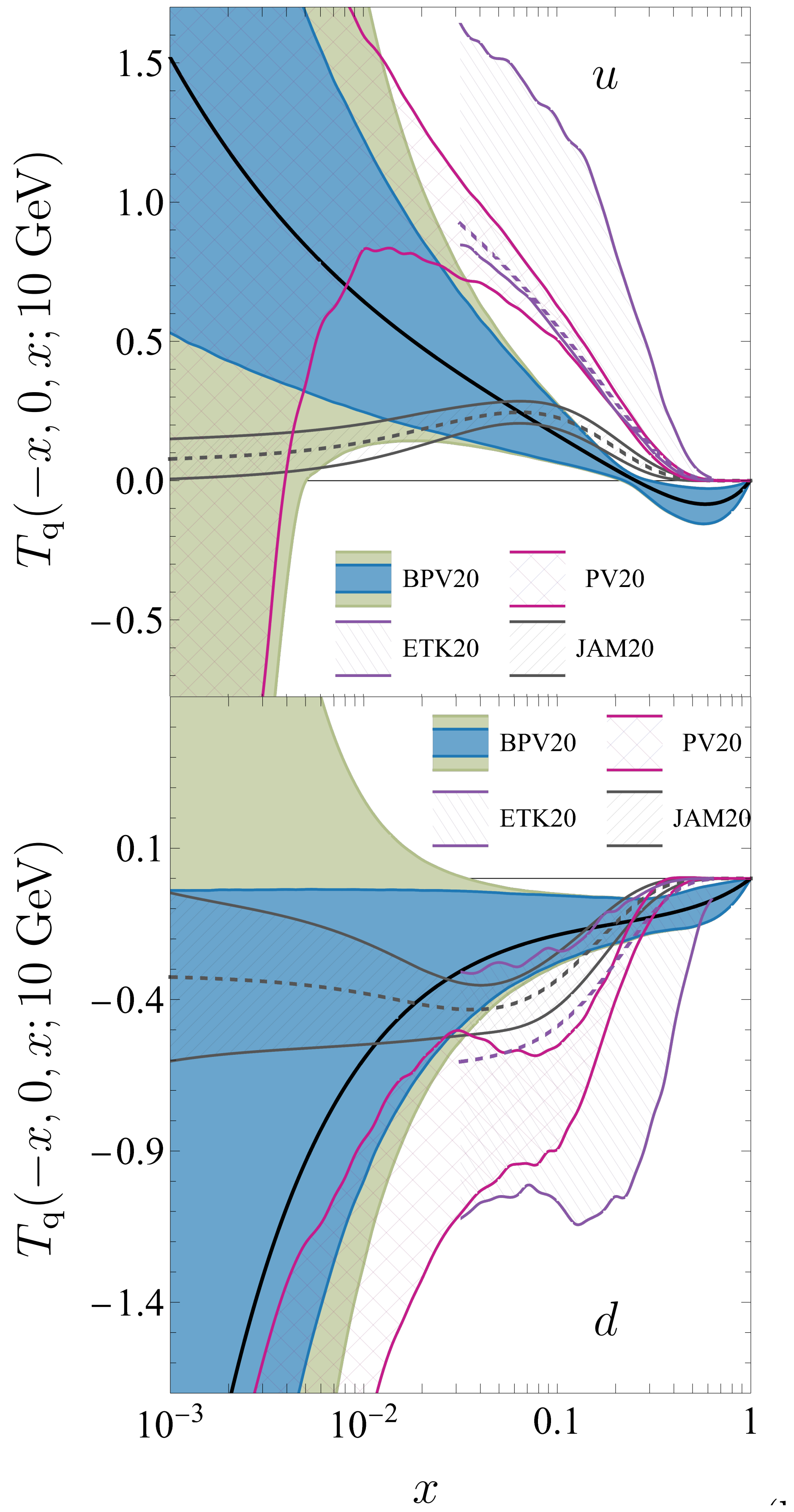


Bacchetta, Delcarro, Pisano, Radici, arXiv:2004.14278

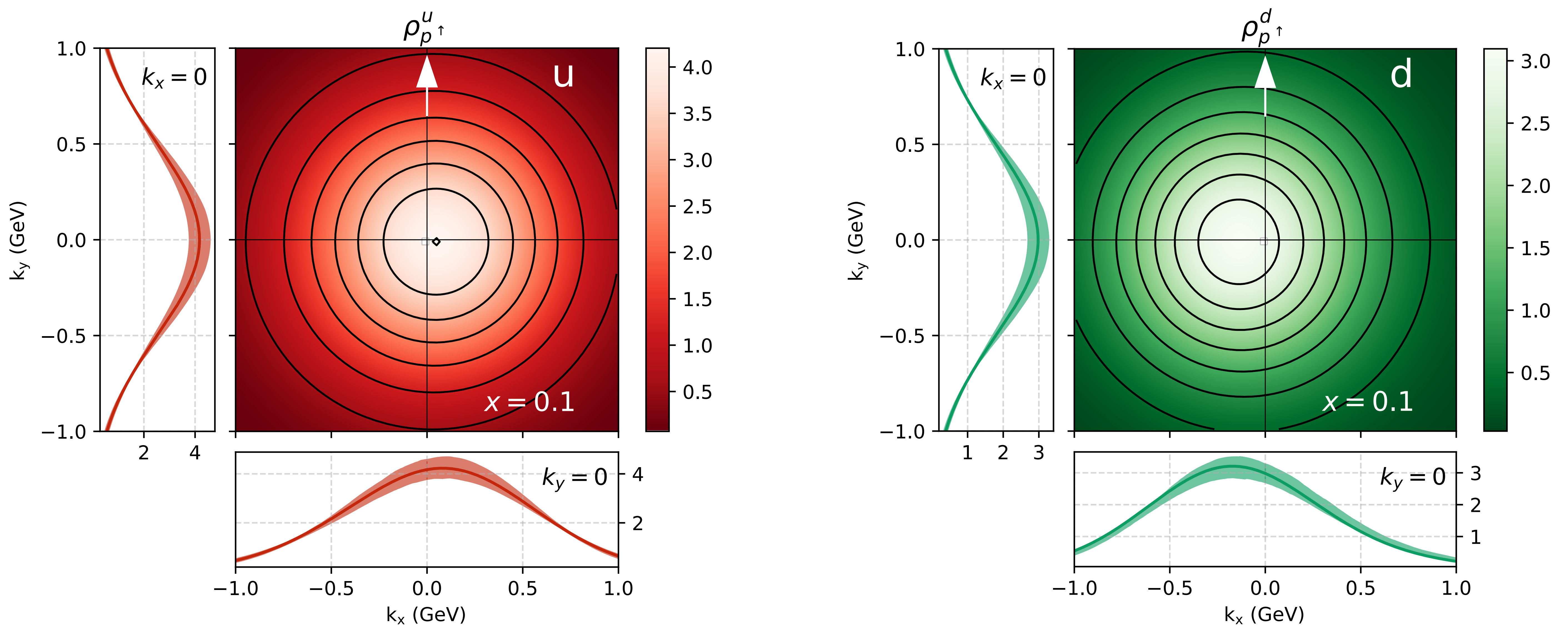


Echevarria, Kang, Terry, arXiv:2009.10710



Bury, Prokudin, Vladimirov, arXiv:2103.03270

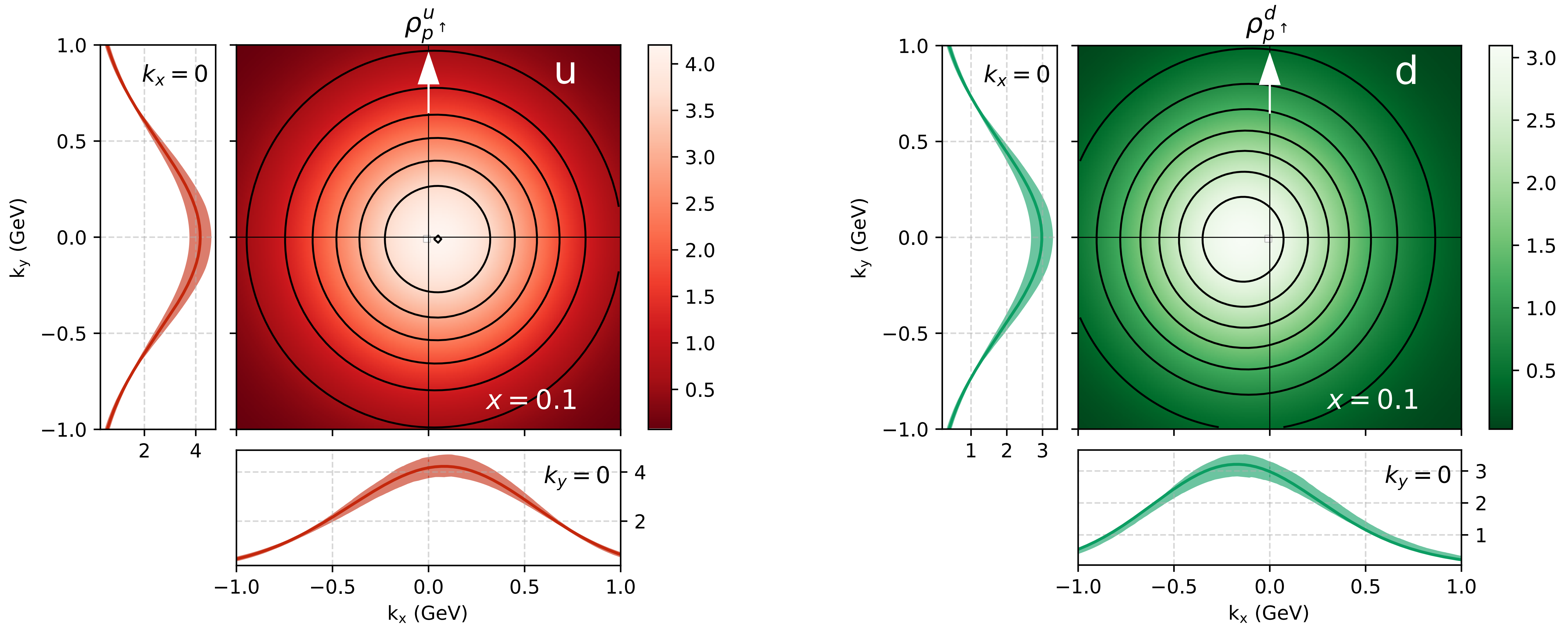
3D STRUCTURE IN MOMENTUM SPACE



Q= 2GeV

[Bacchetta, Delcarro, Pisano, Radici, arXiv:2004.14278]

3D STRUCTURE IN MOMENTUM SPACE



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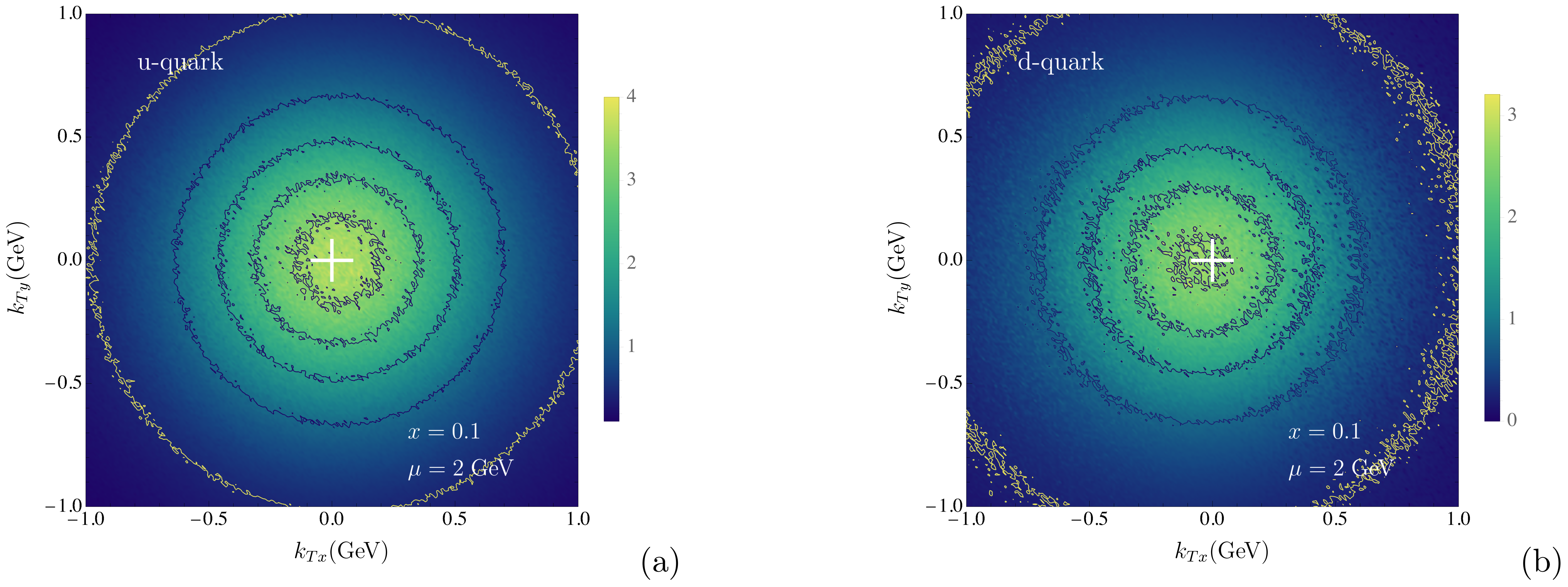
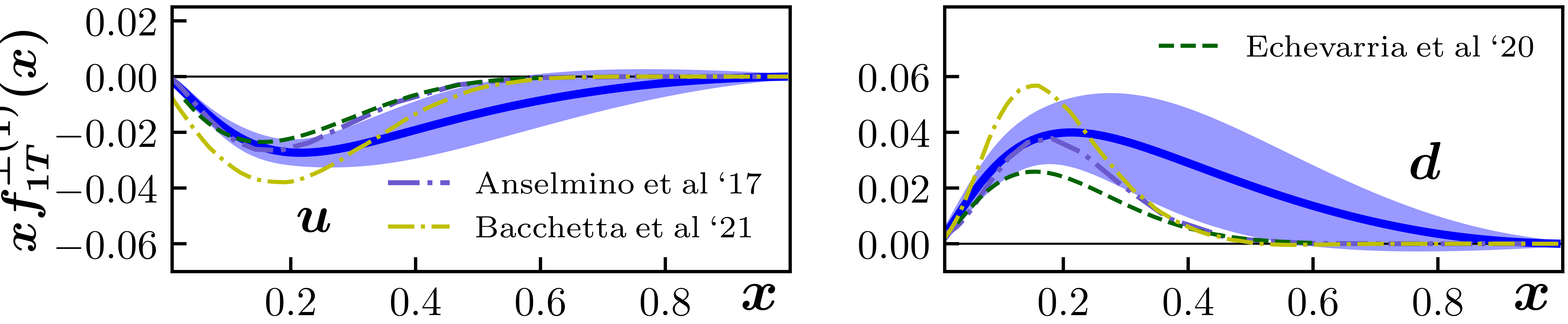


Bury, Prokudin, Vladimirov, arXiv:2103.03270

SIMULTANEOUS FIT OF SINGLE TRANSVERSE-SPIN ASY

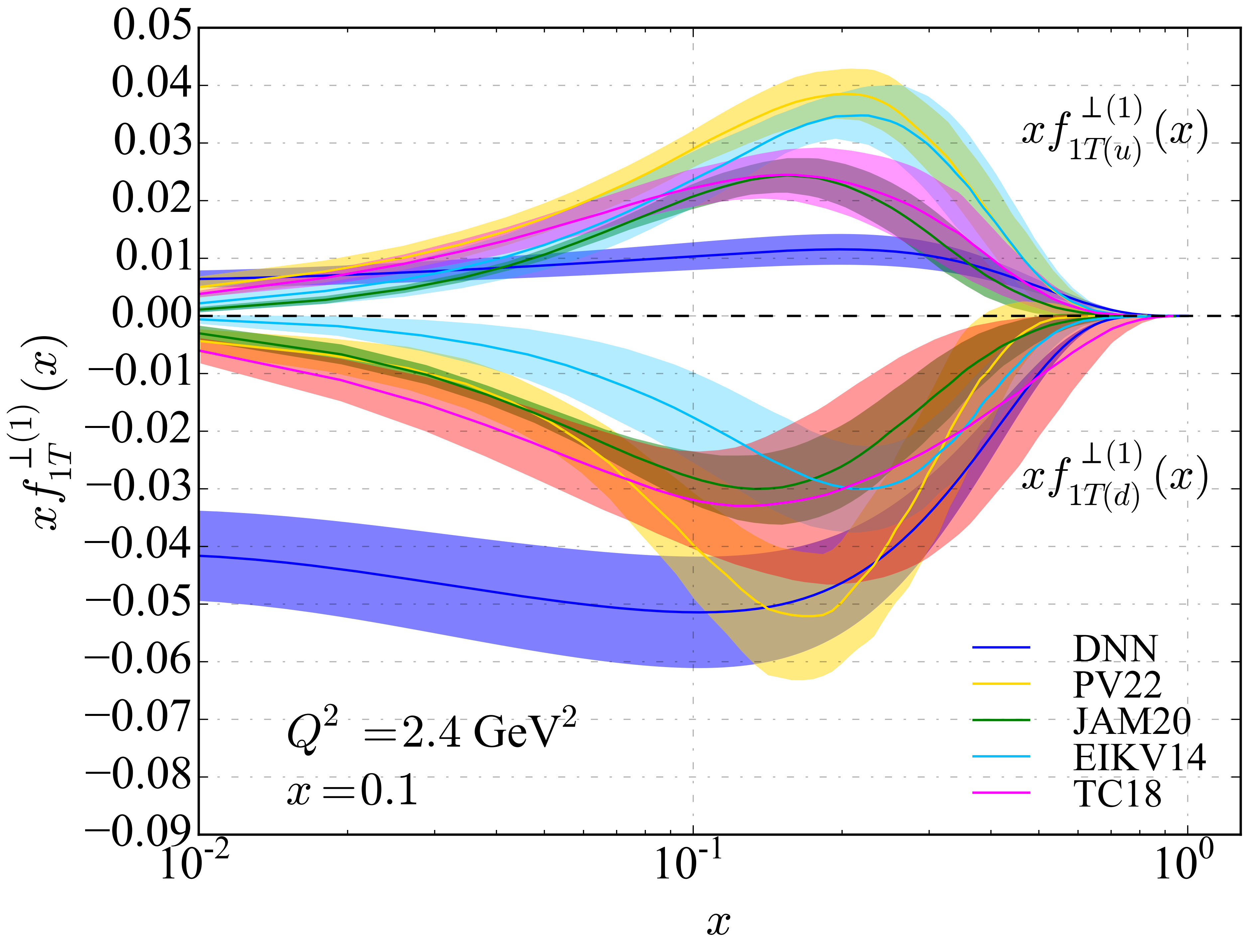
JAM, arXiv:2205.00999

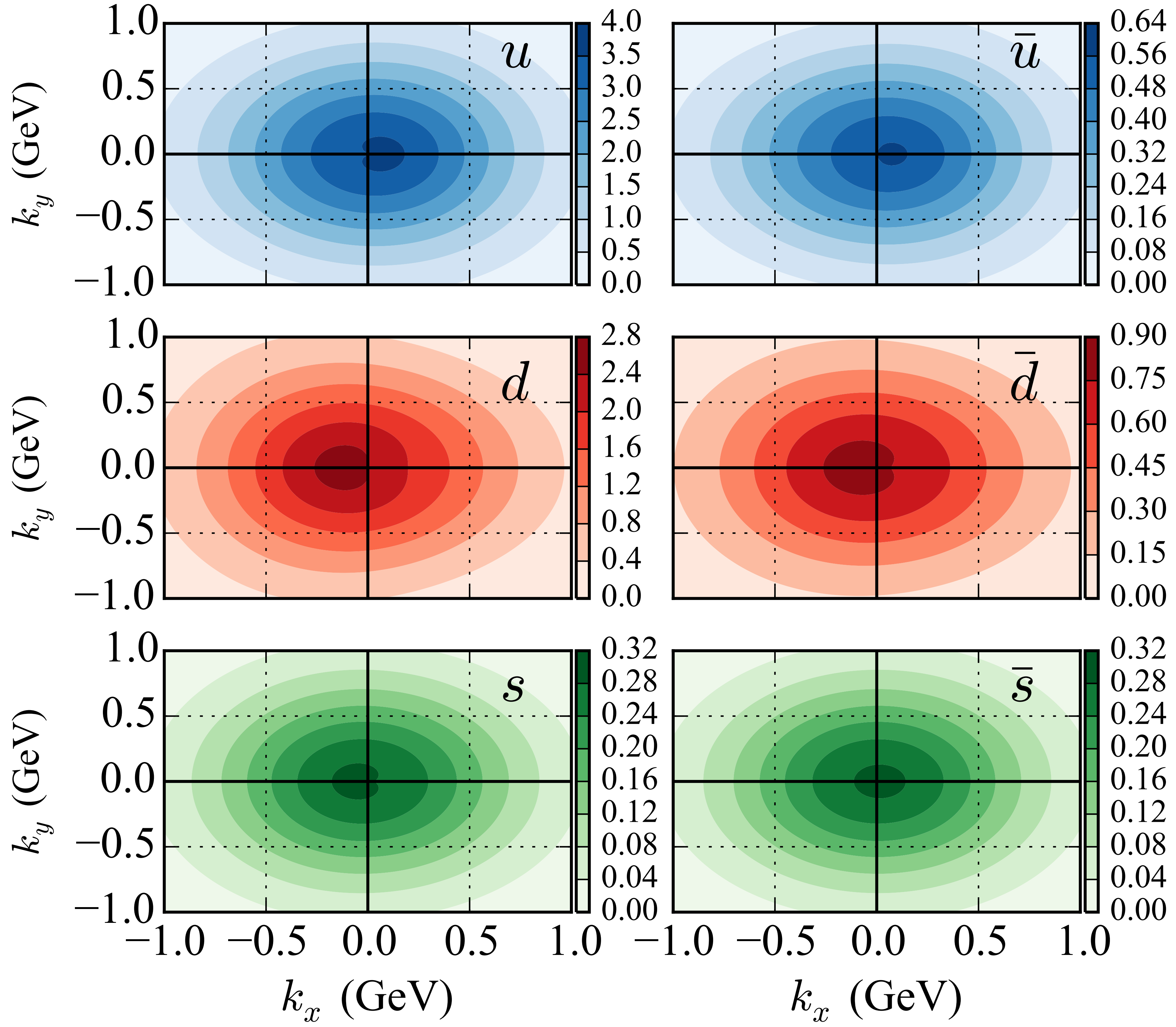


Interesting work from the point of view of simultaneous use of several measurements, but still limited from other perspectives (lack of TMD evolution and knowledge of the unpolarized function)

SIVERS FUNCTION WITH NEURAL NETWORKS

[Fernando, Keller, arXiv:2304.14328](https://arxiv.org/abs/2304.14328)





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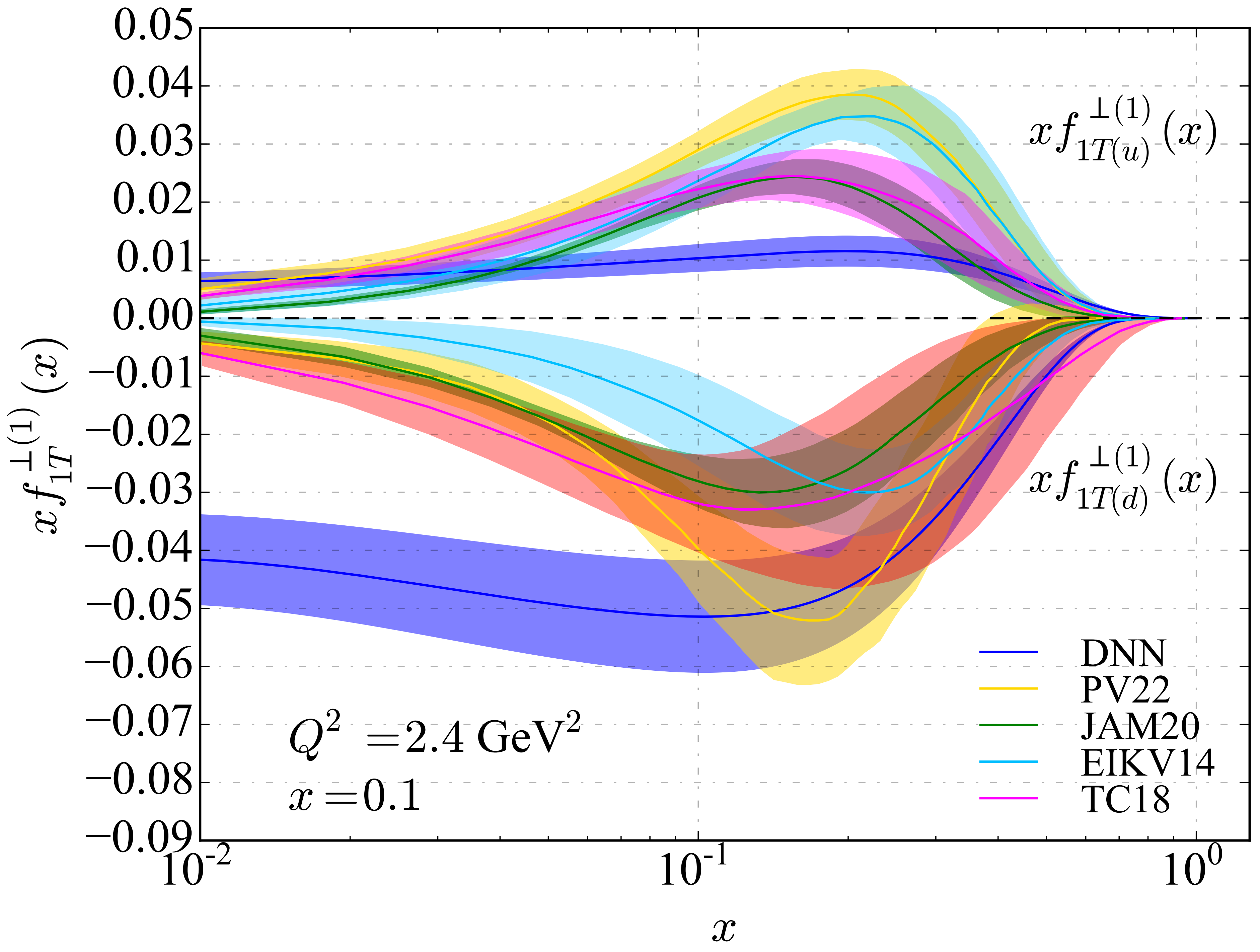

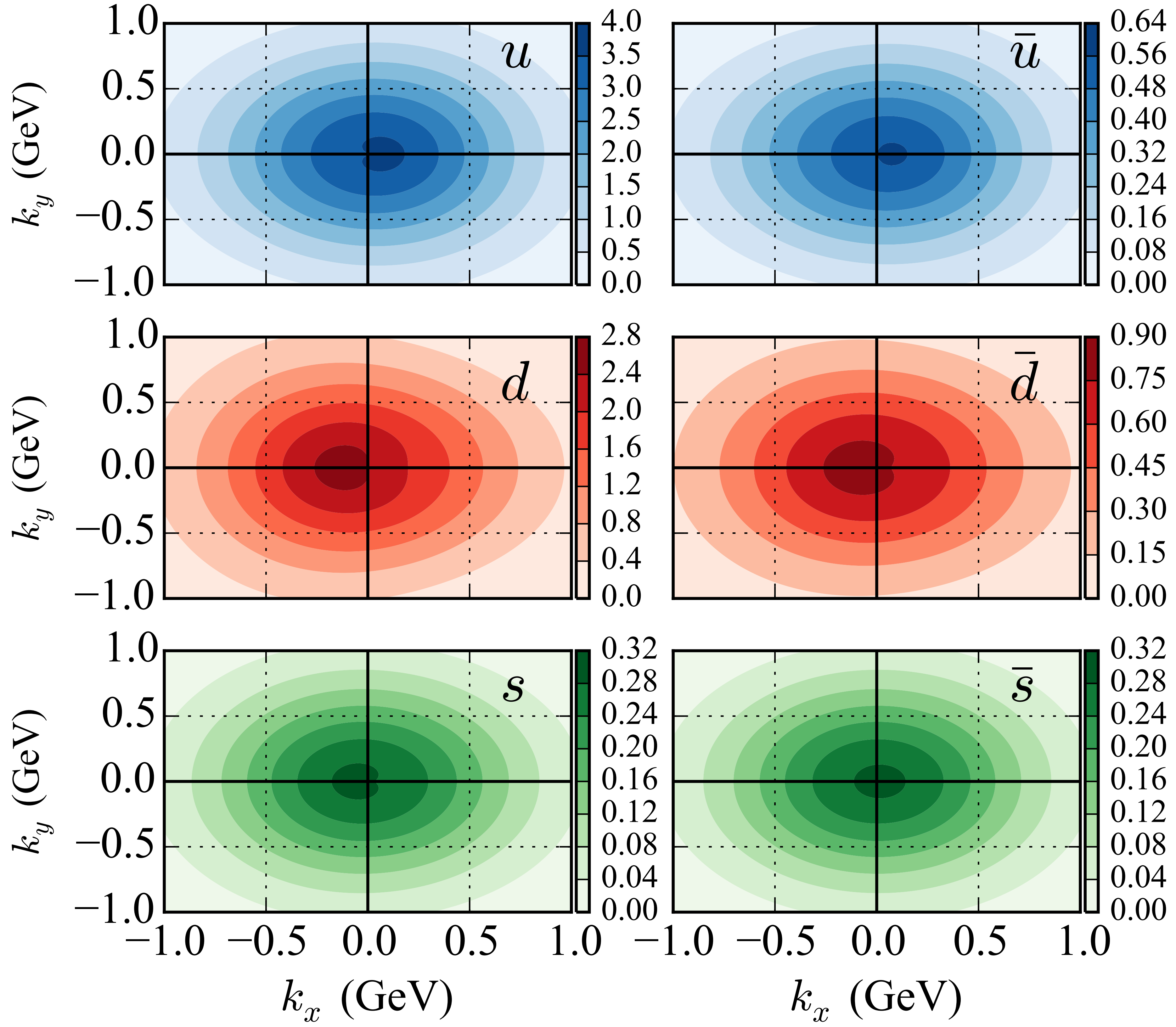

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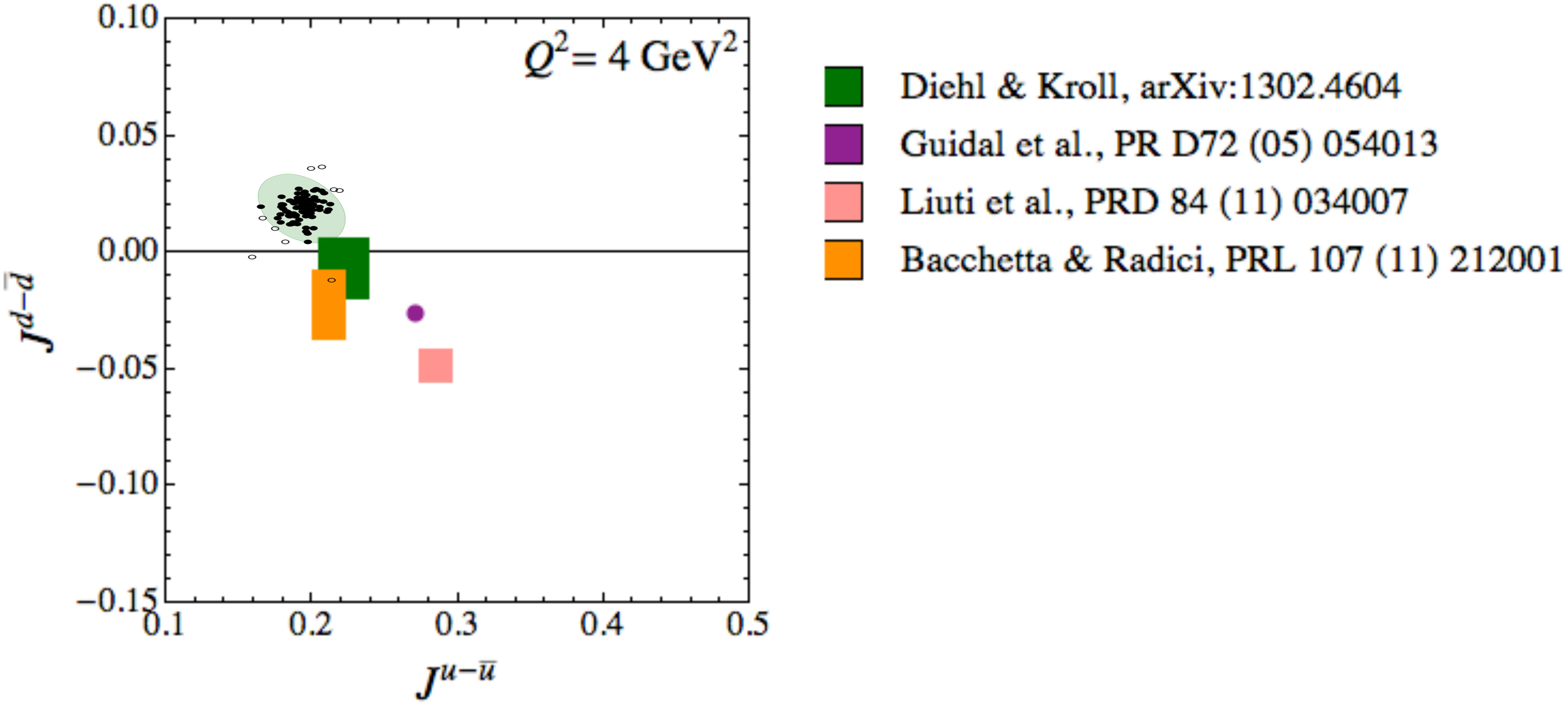
See talks by Ishara Fernando

CONNECTION WITH ANGULAR MOMENTUM?



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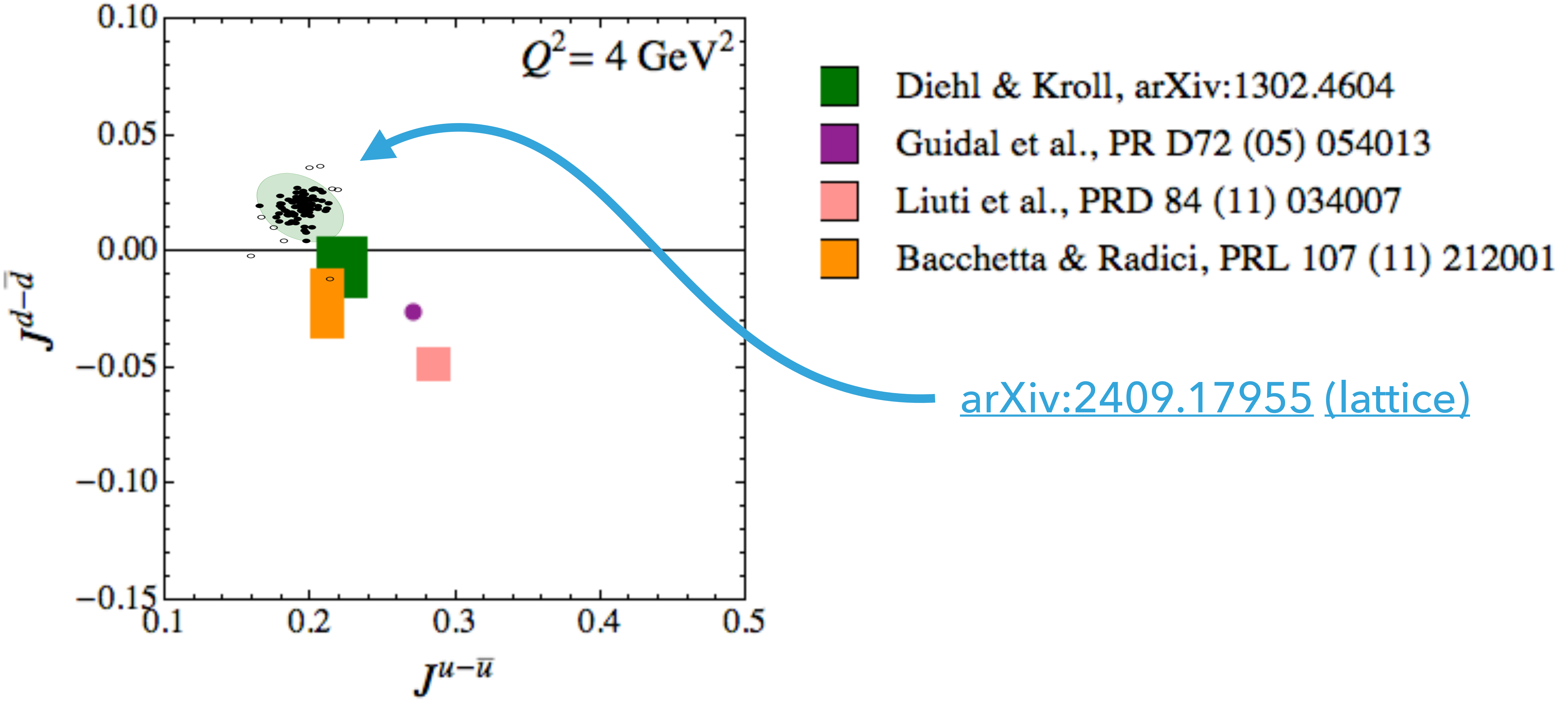

arXiv:2409.17955 (lattice)

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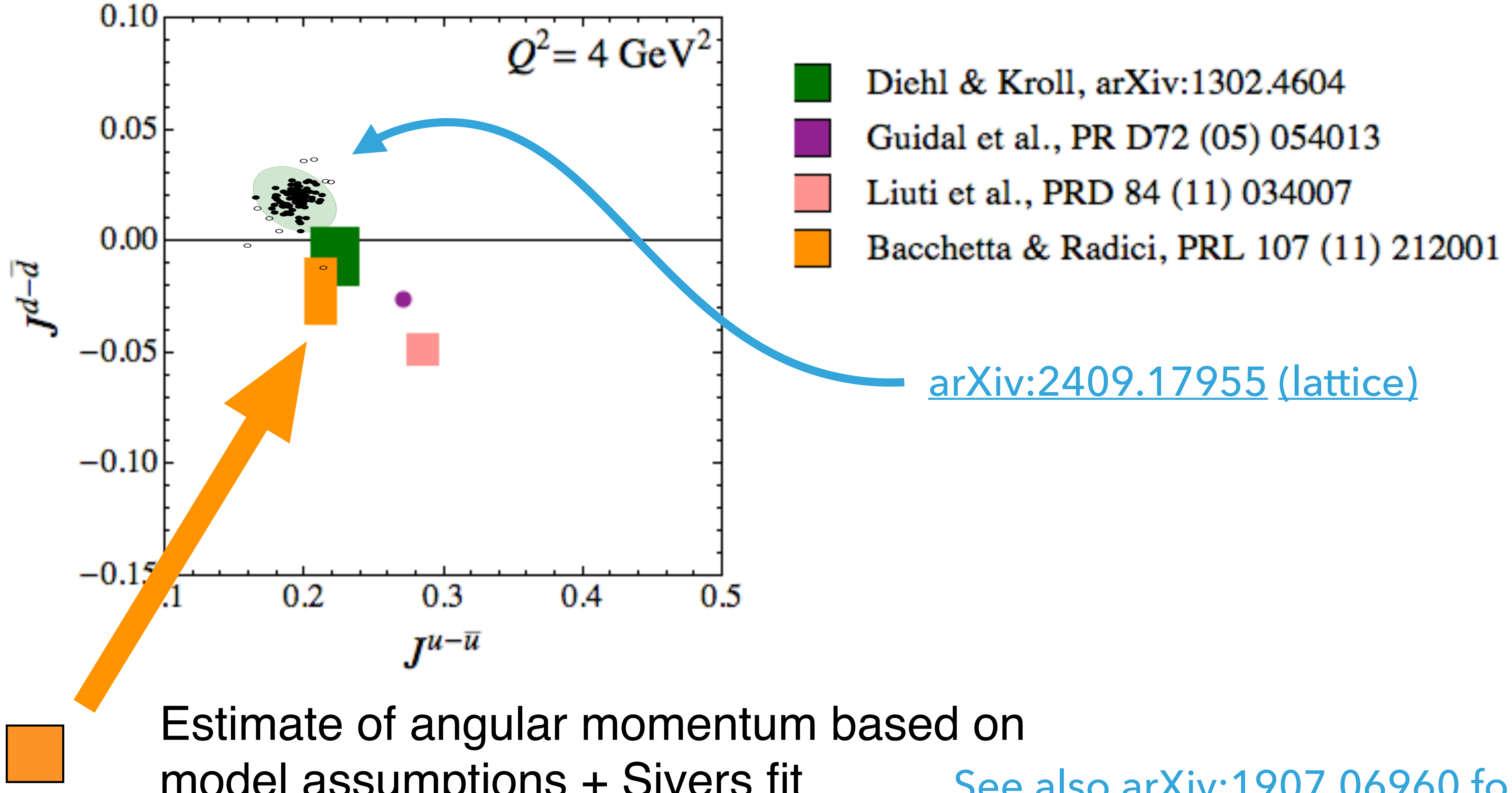
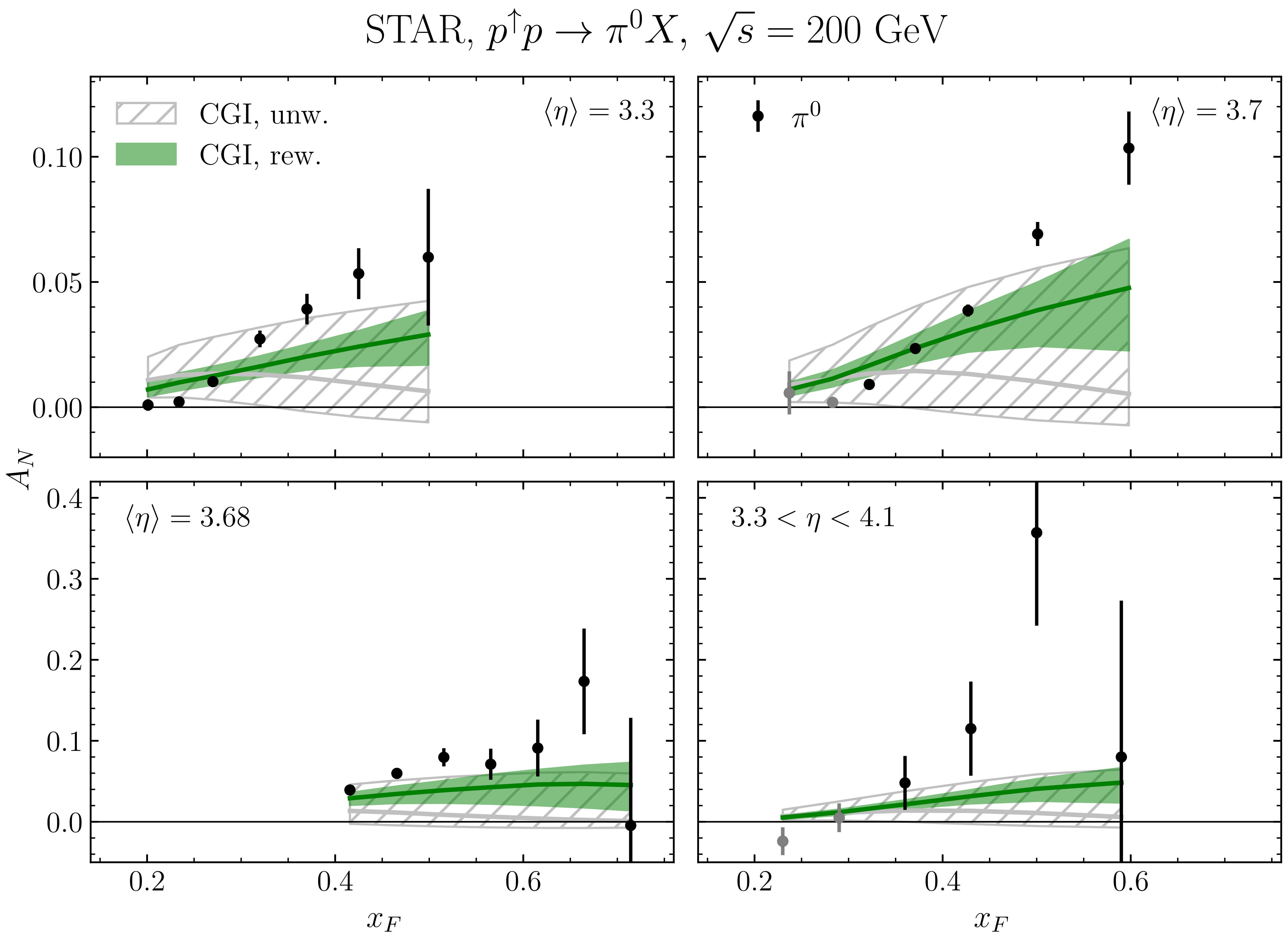


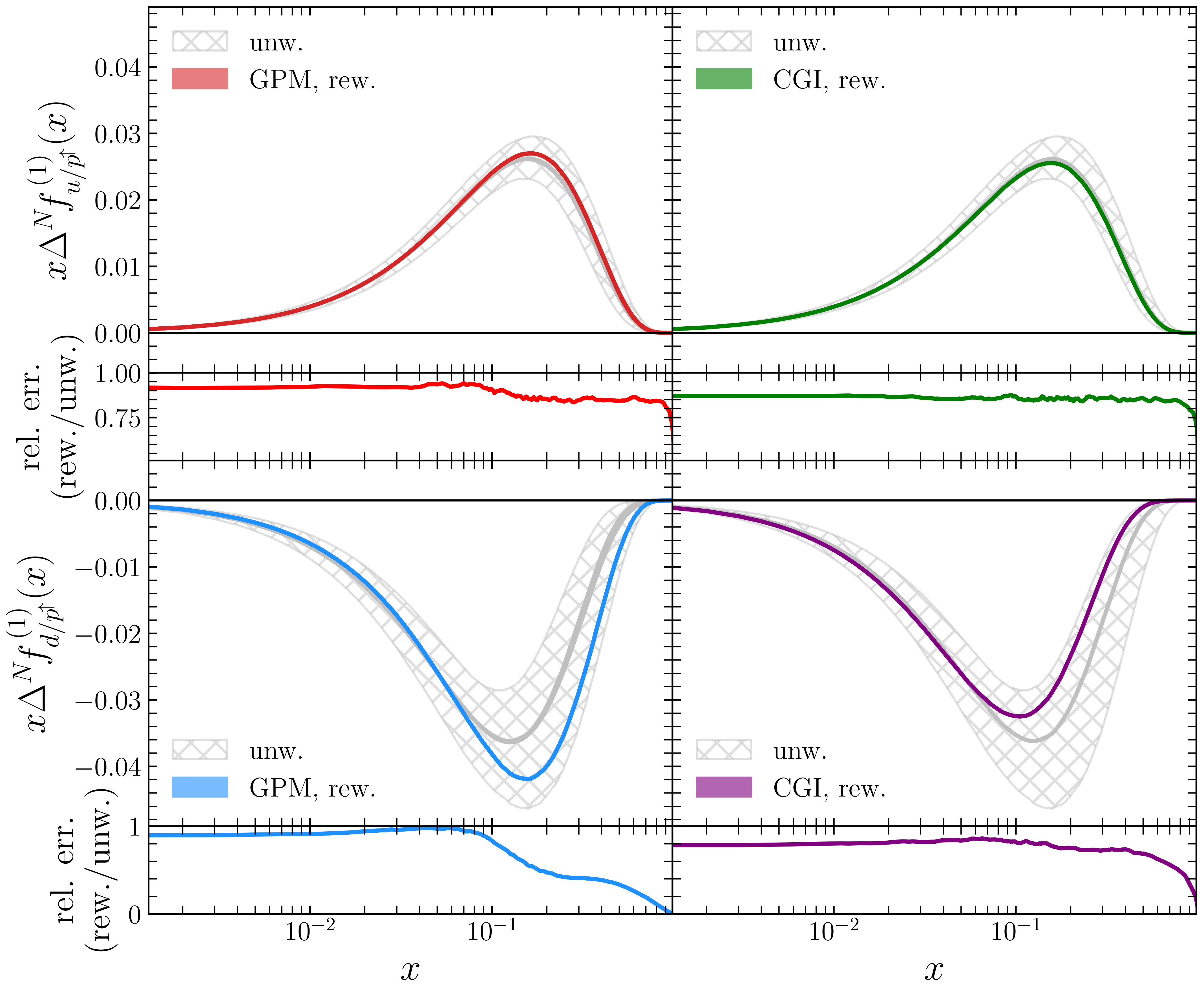
Estimate of angular momentum based on model assumptions + Sivers fit

See also arXiv:1907.06960 for a critique

IMPACT OF RICH DATA?

Boglione, D'Alesio, Flore, Gonzalez-Hernandez, Murgia, Prokudin, arXiv:2402.12322

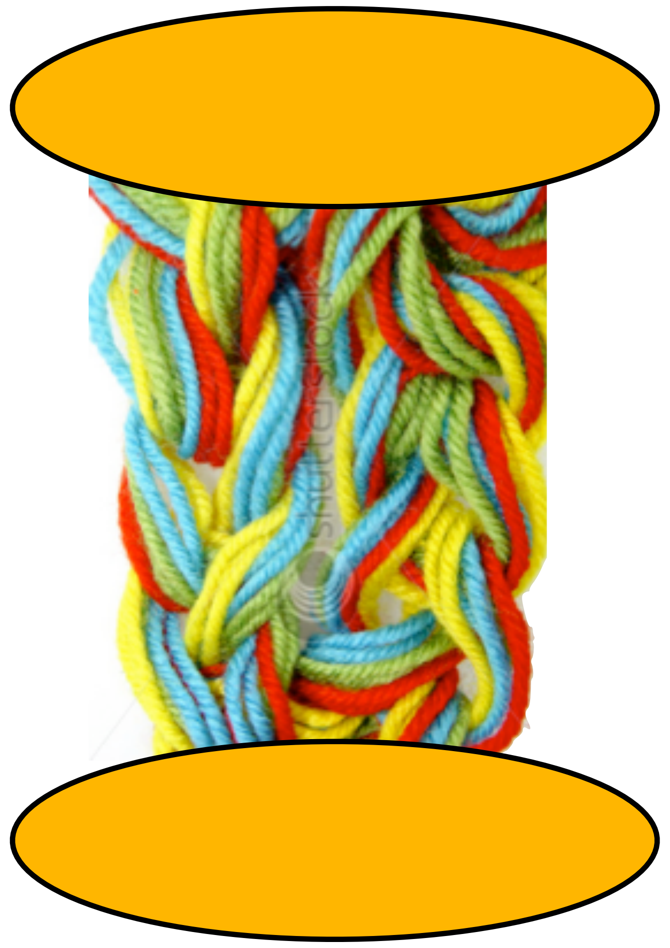




WHAT ABOUT PP →HADRONS DATA?

Artistic view of factorization

Mulders, Rogers, arXiv:1001.2977



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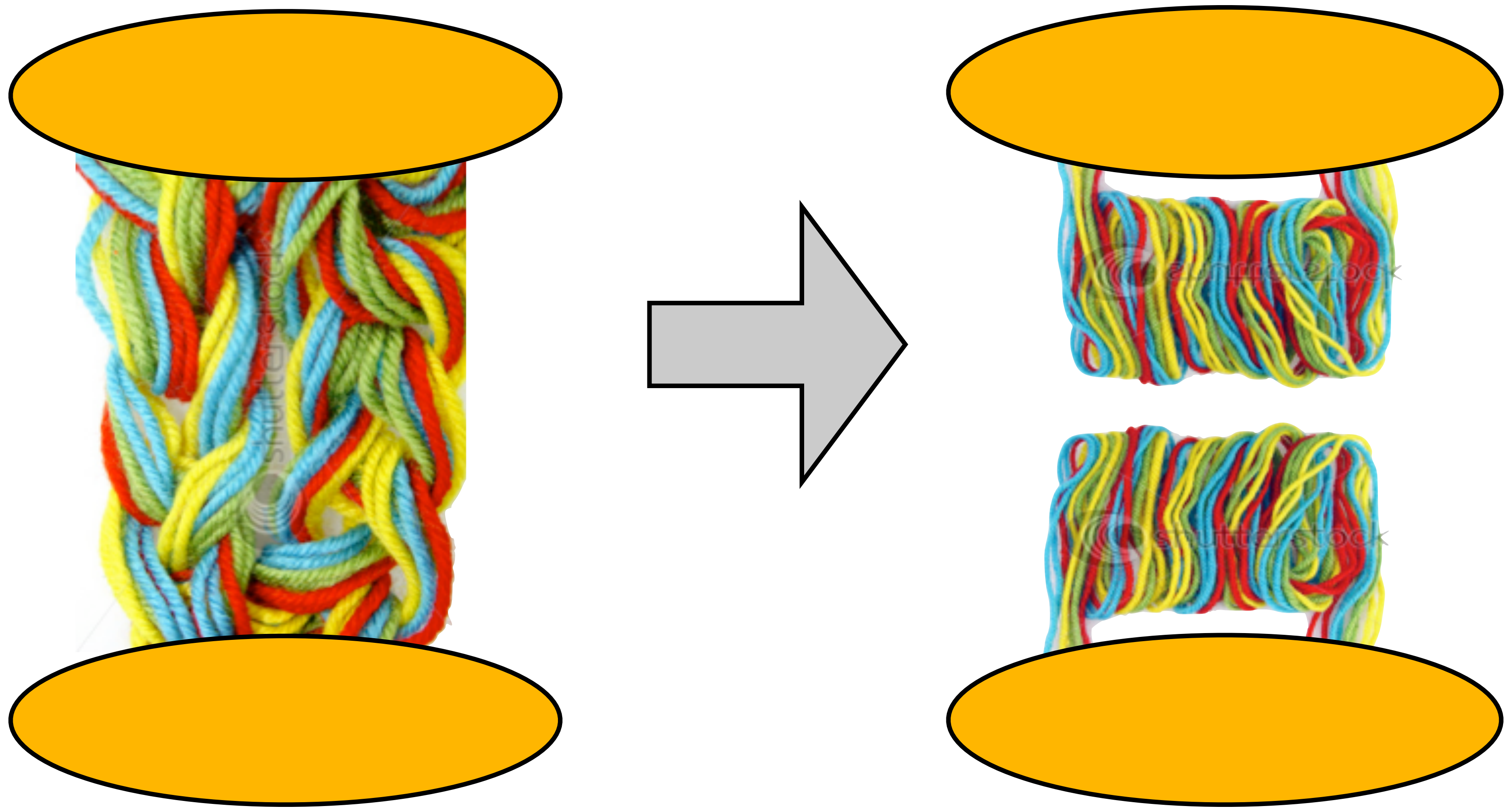

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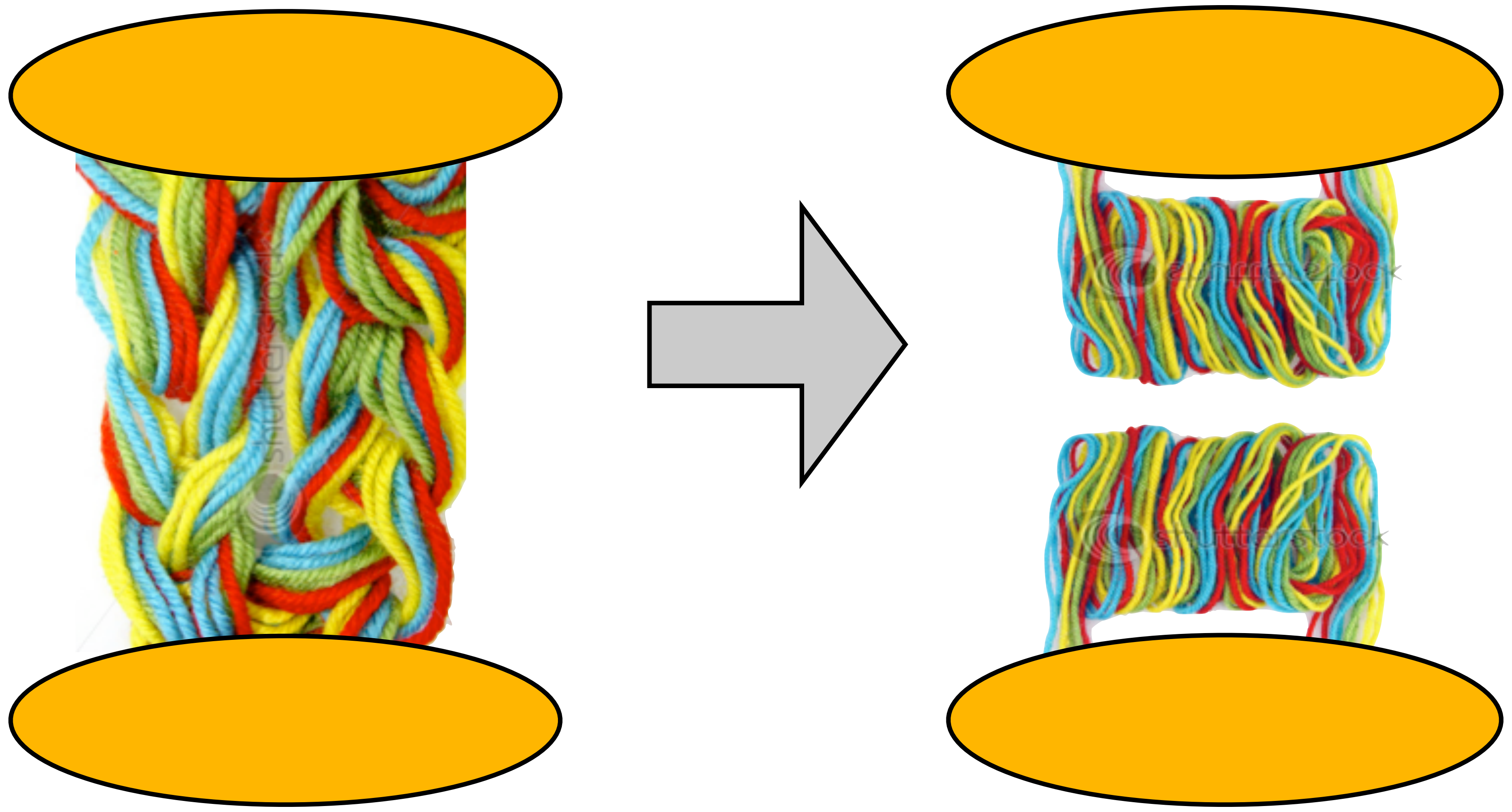

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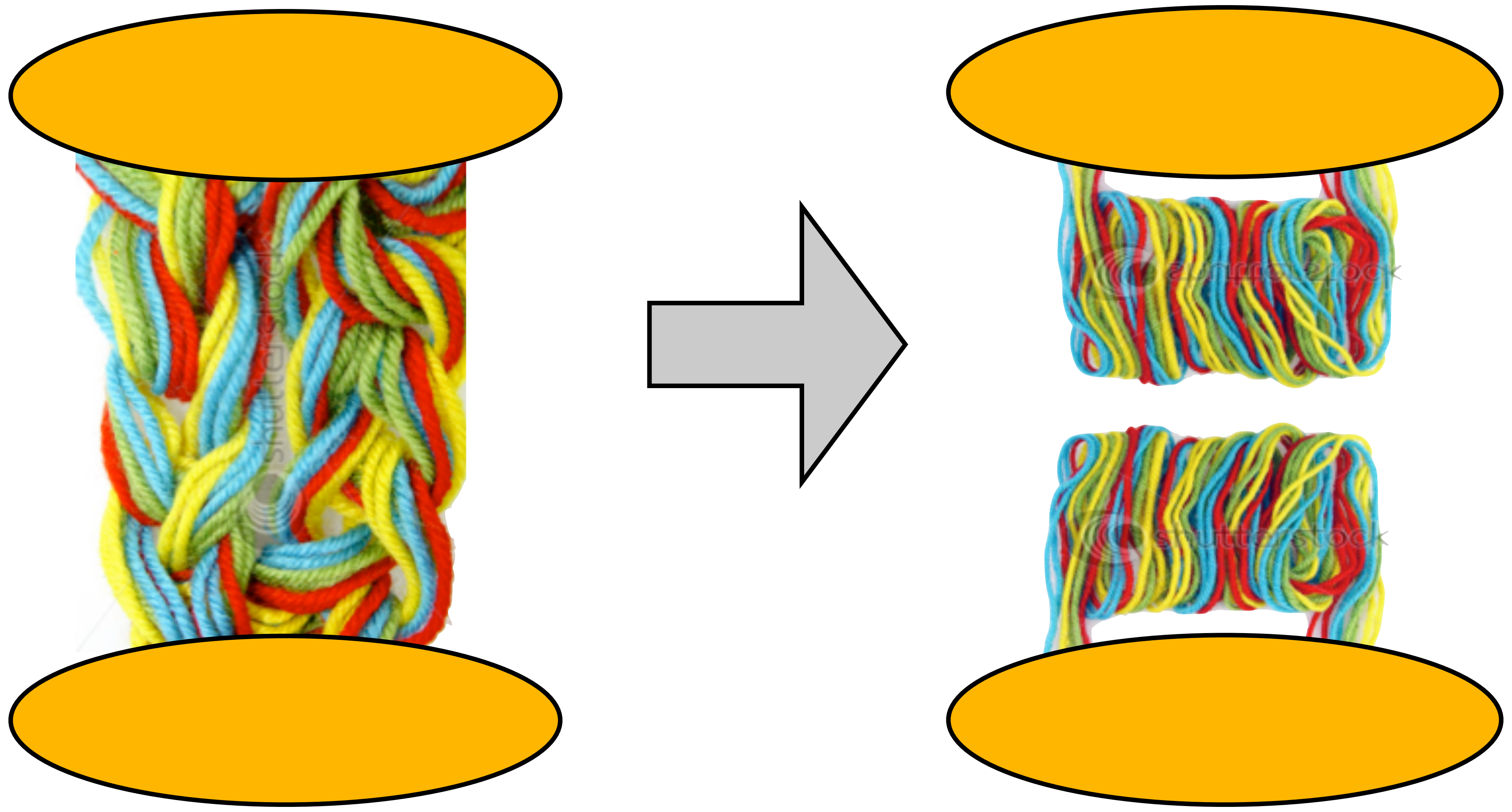

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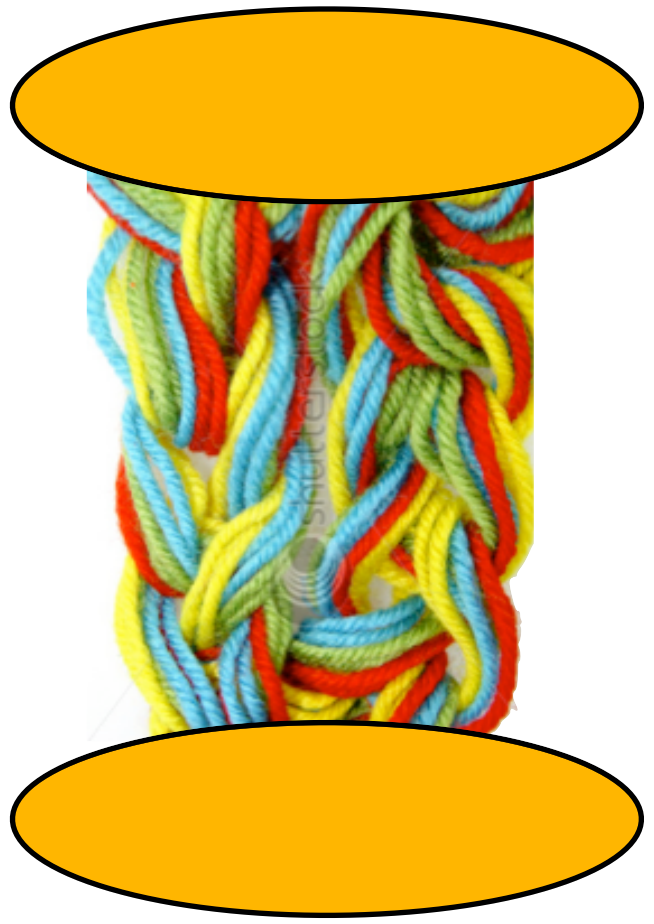

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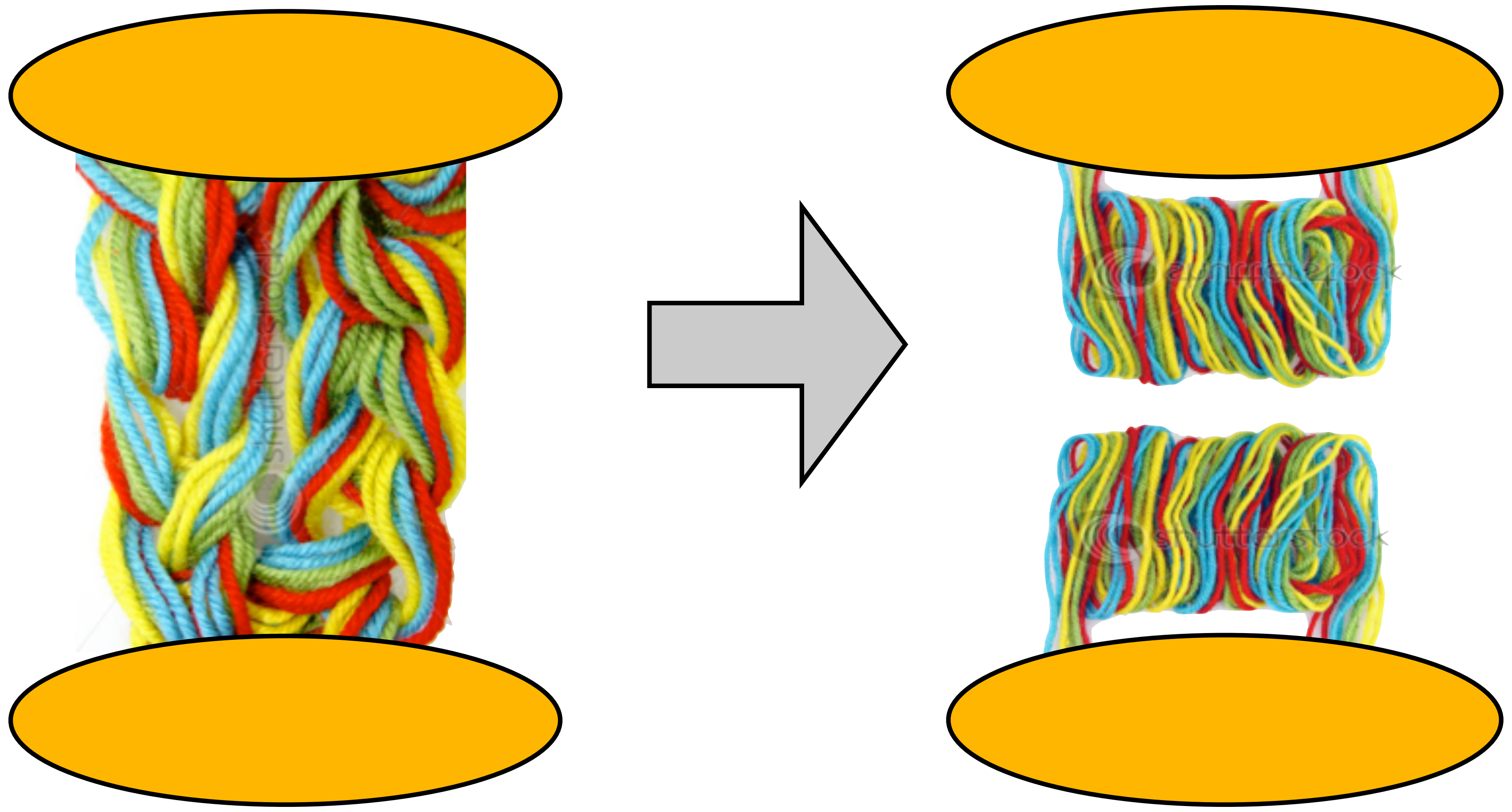

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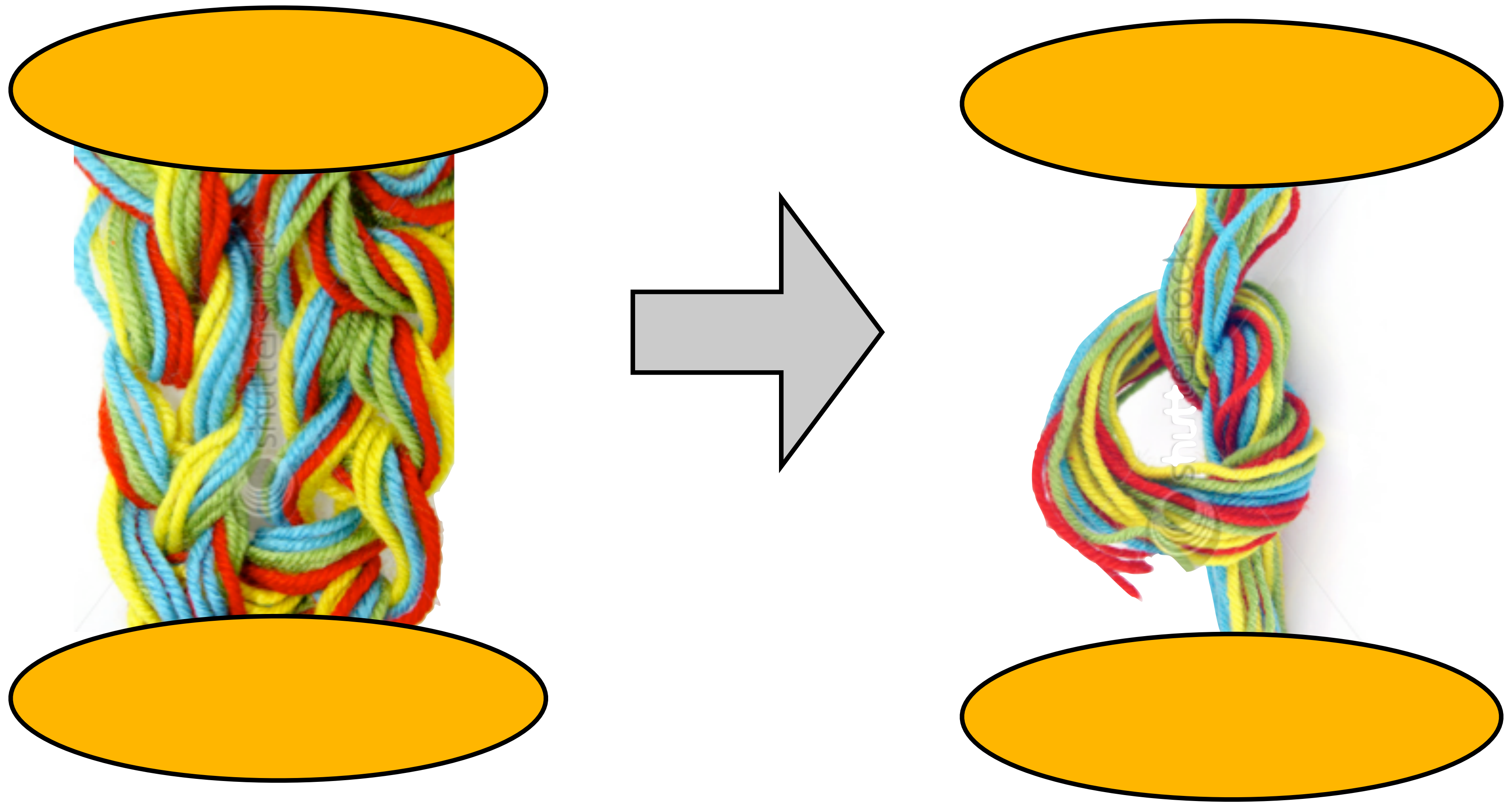

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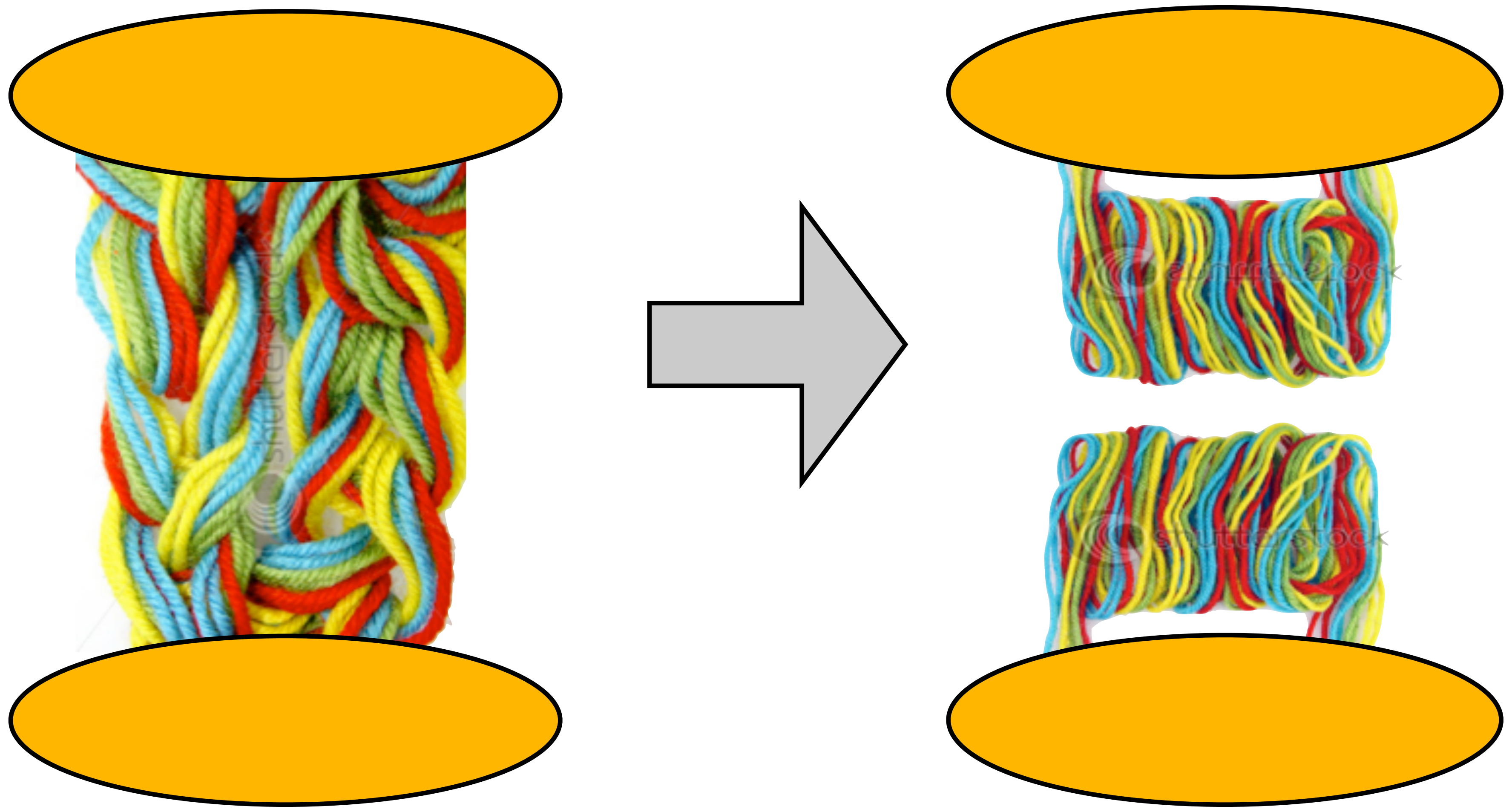

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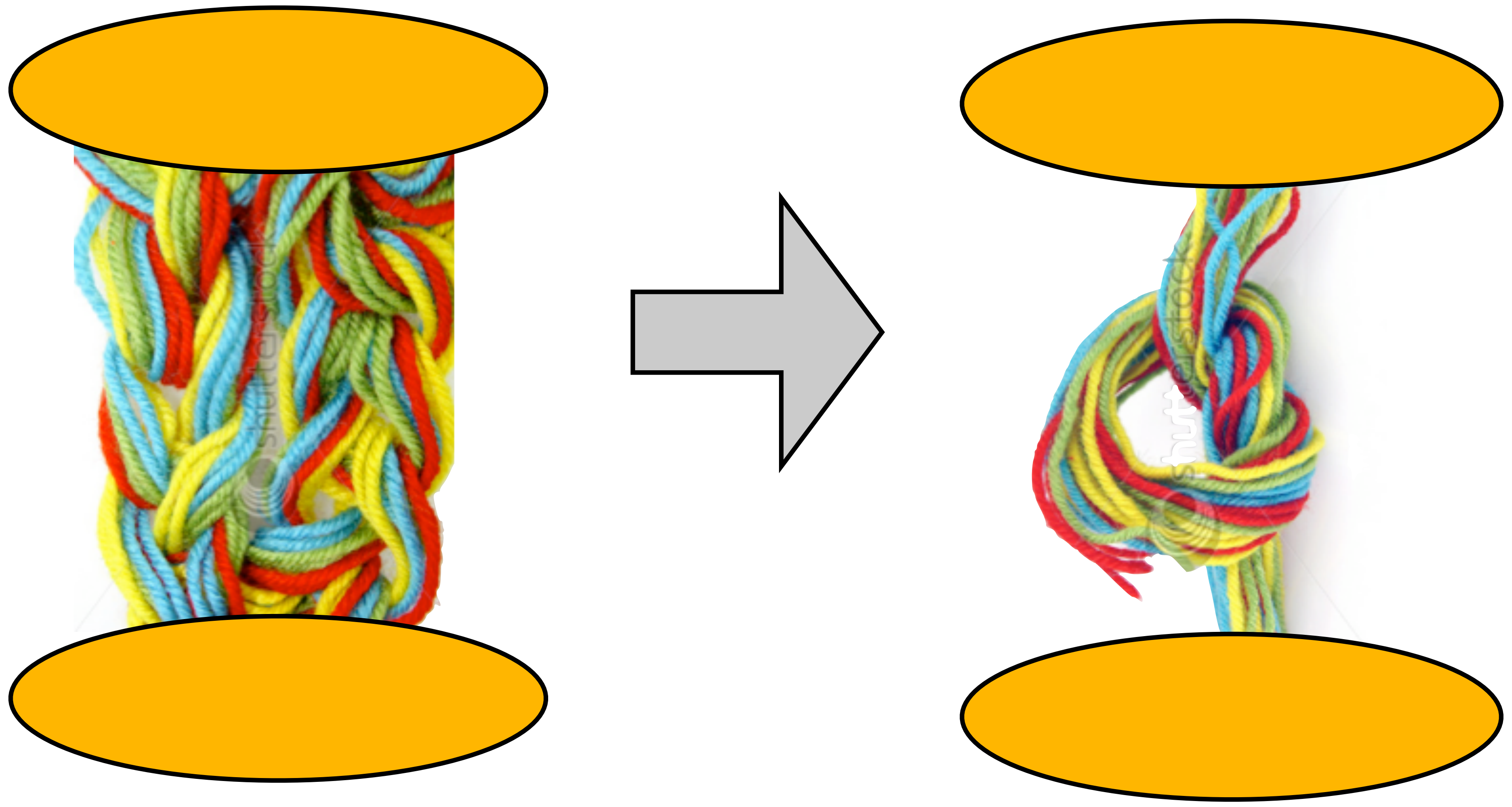

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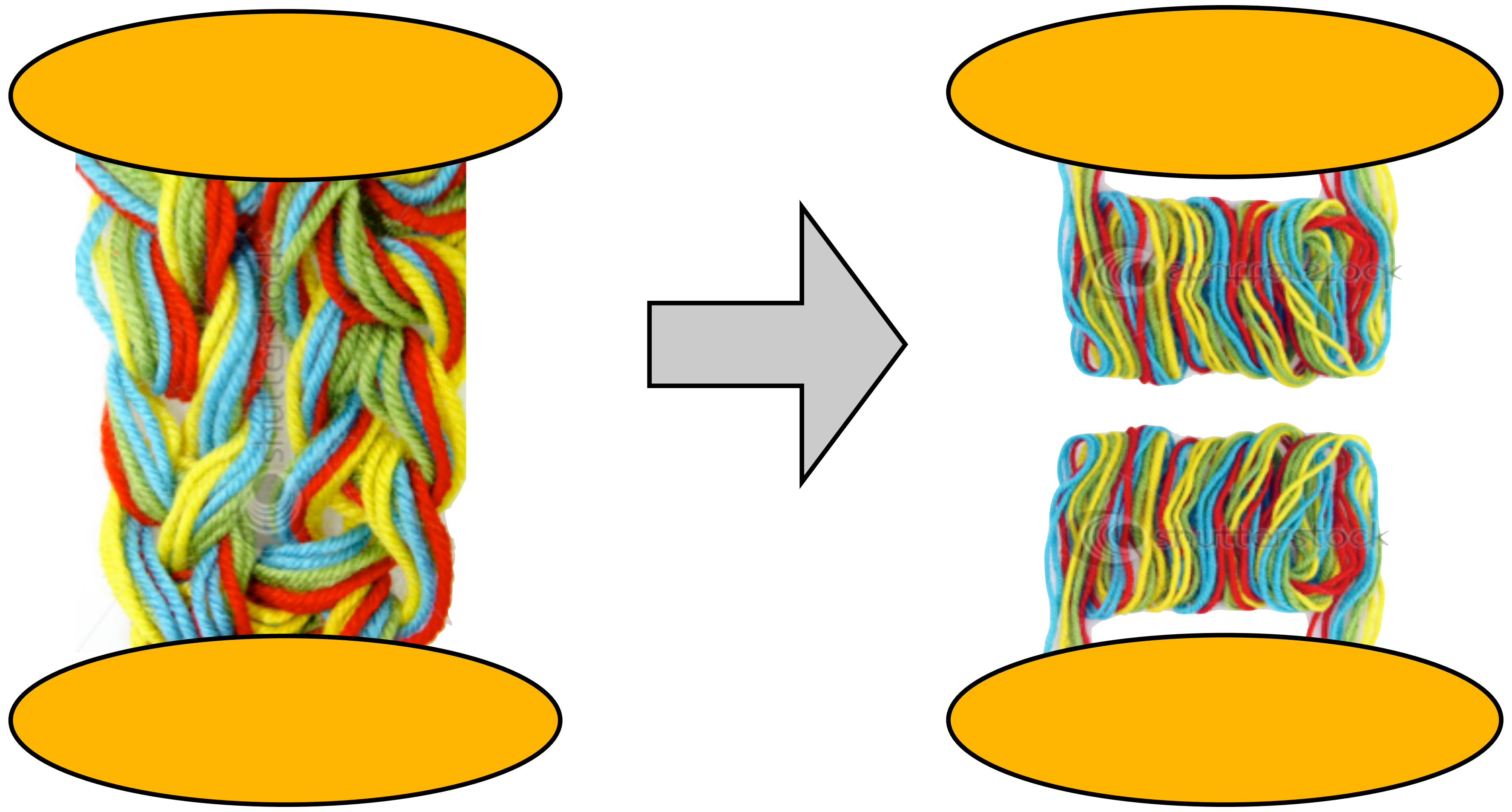

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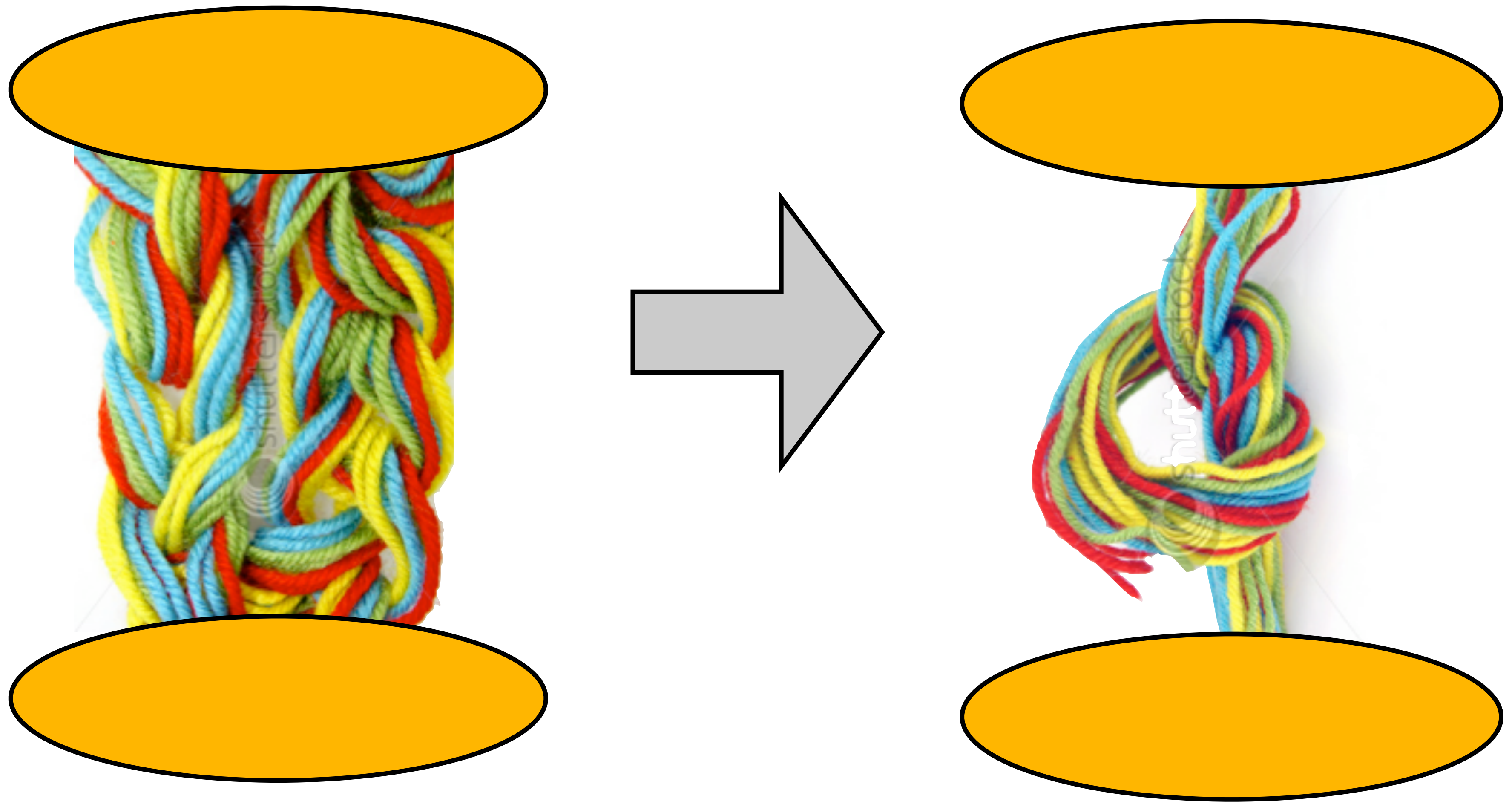

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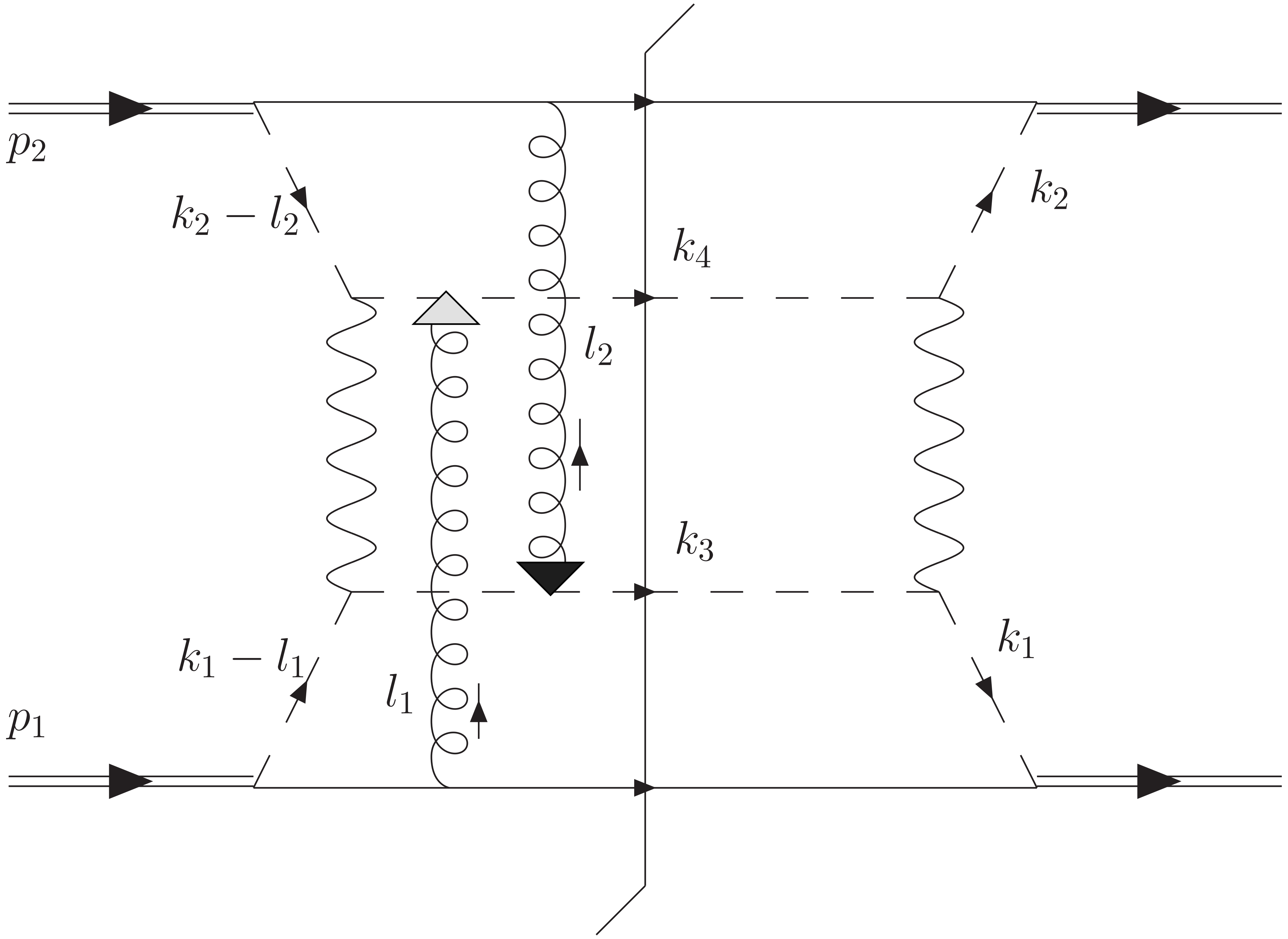

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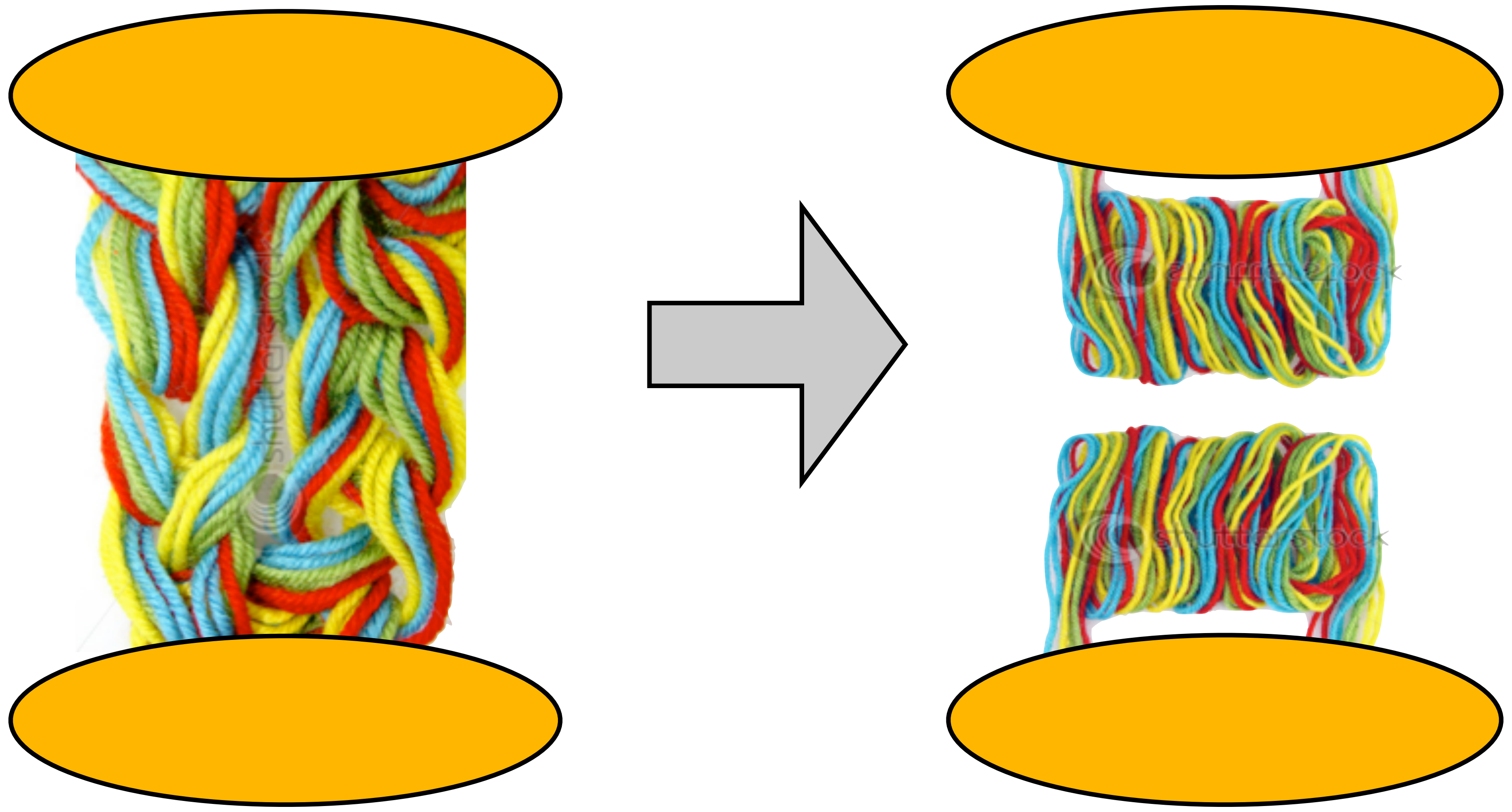

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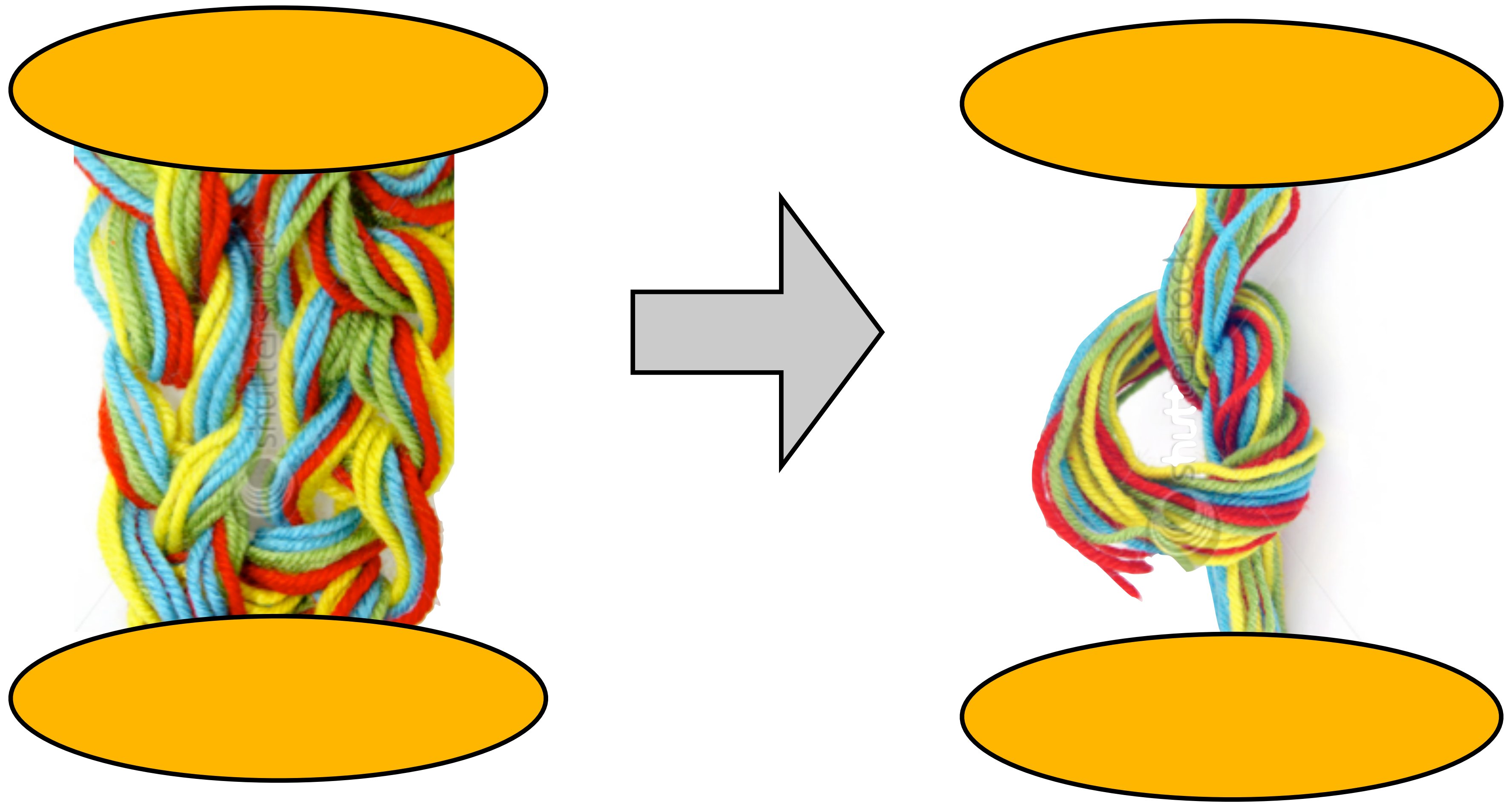

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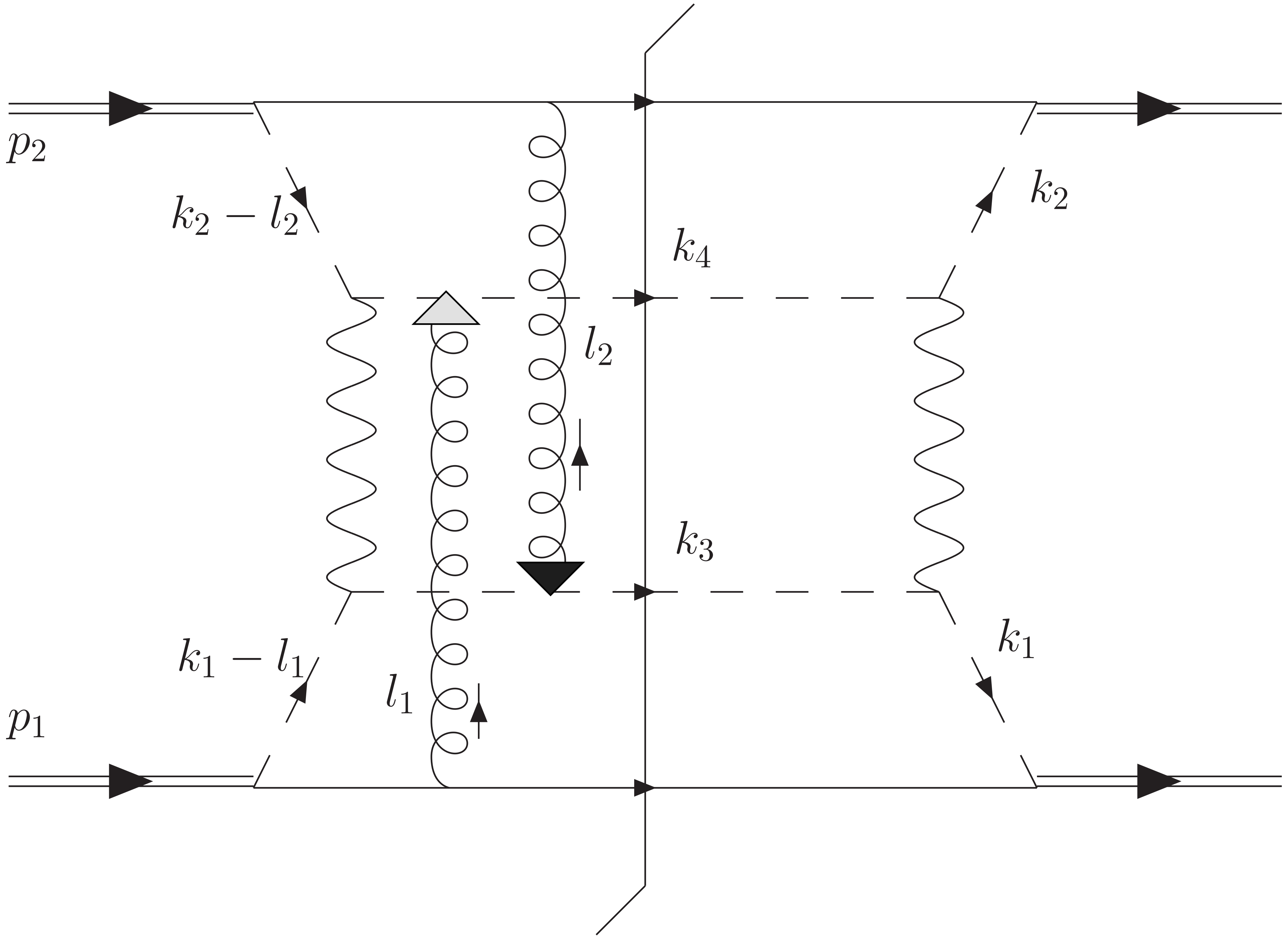
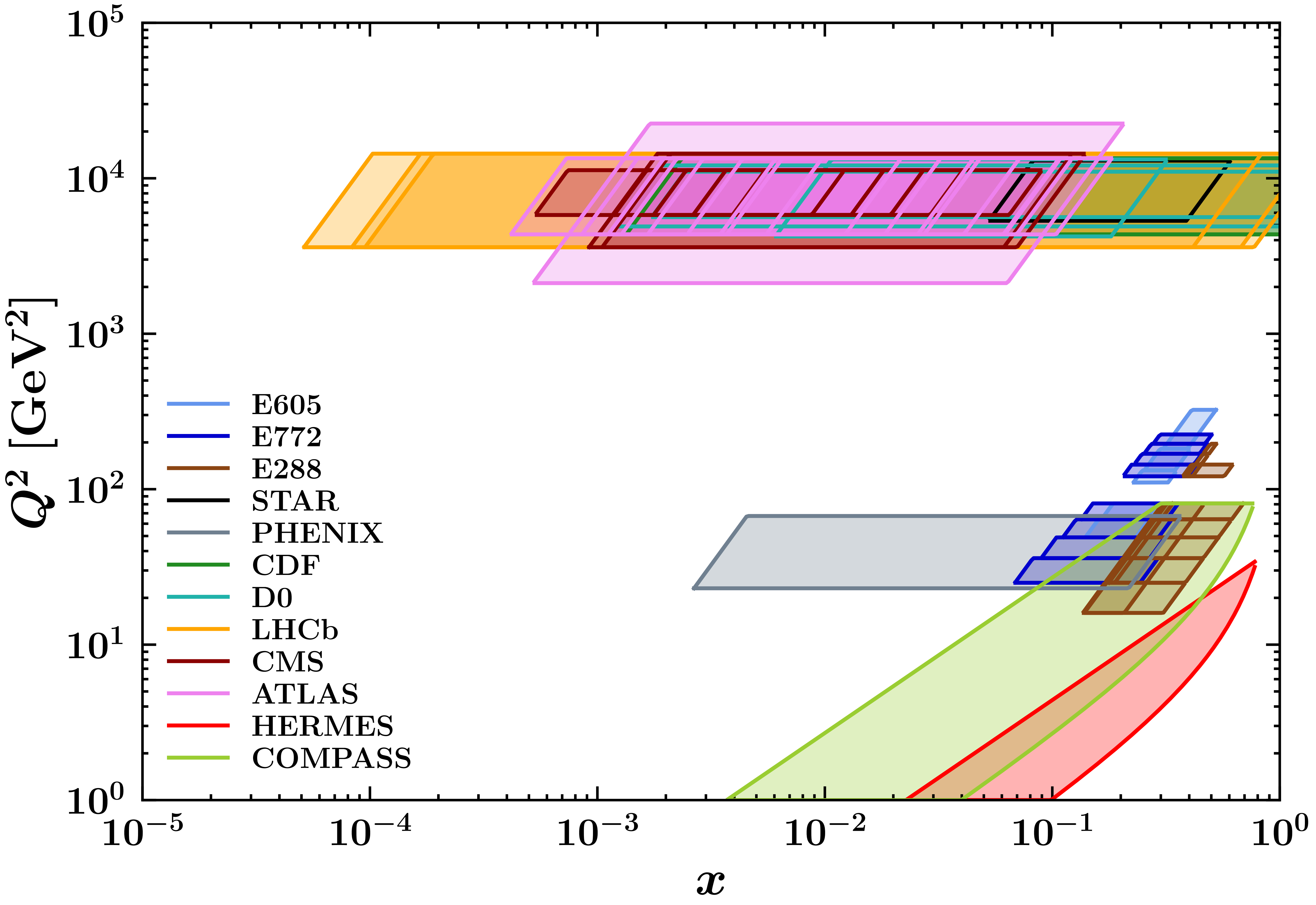


See talk by Oleg Eyser

WE'LL LOVE TO HAVE MORE DATA



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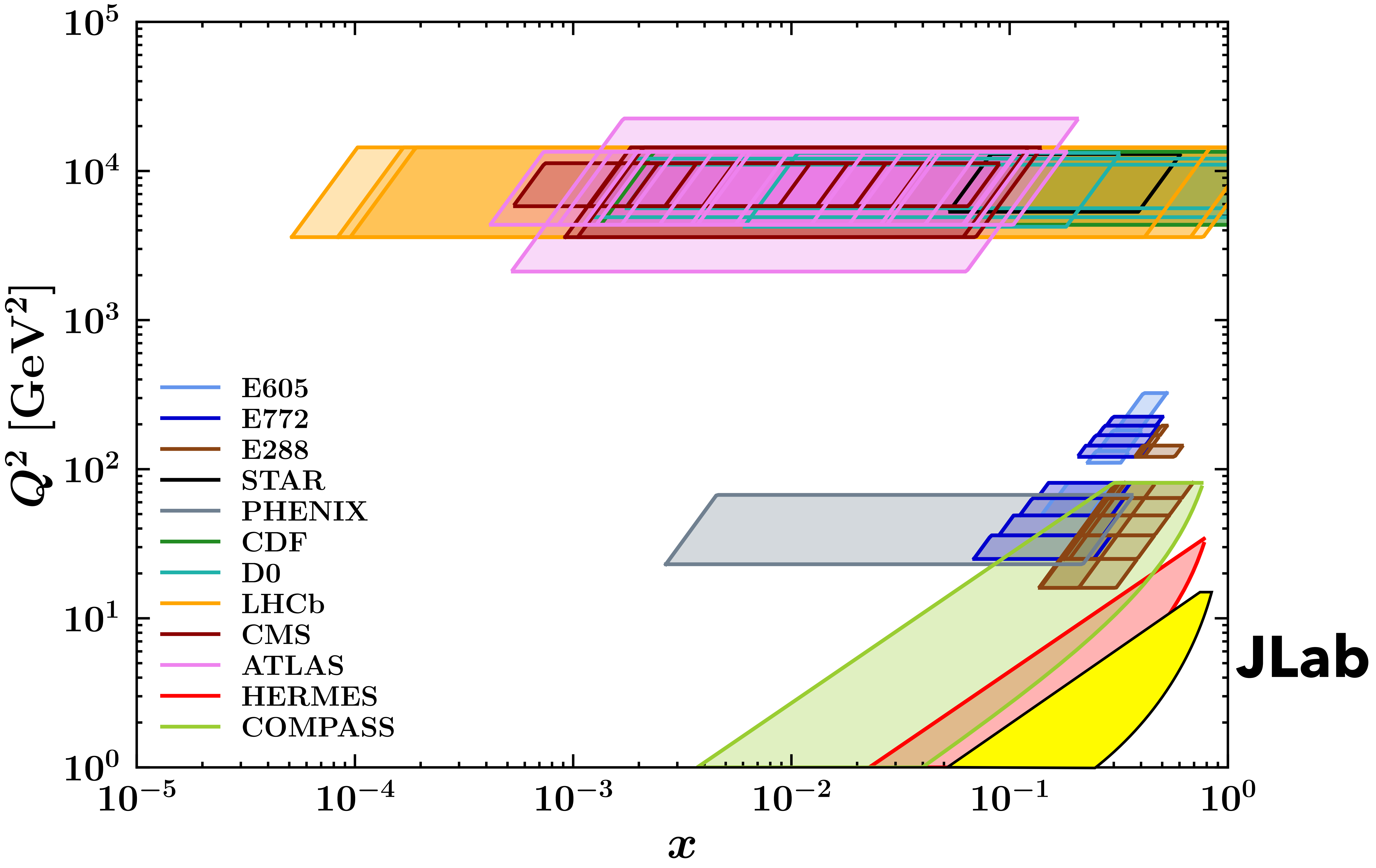

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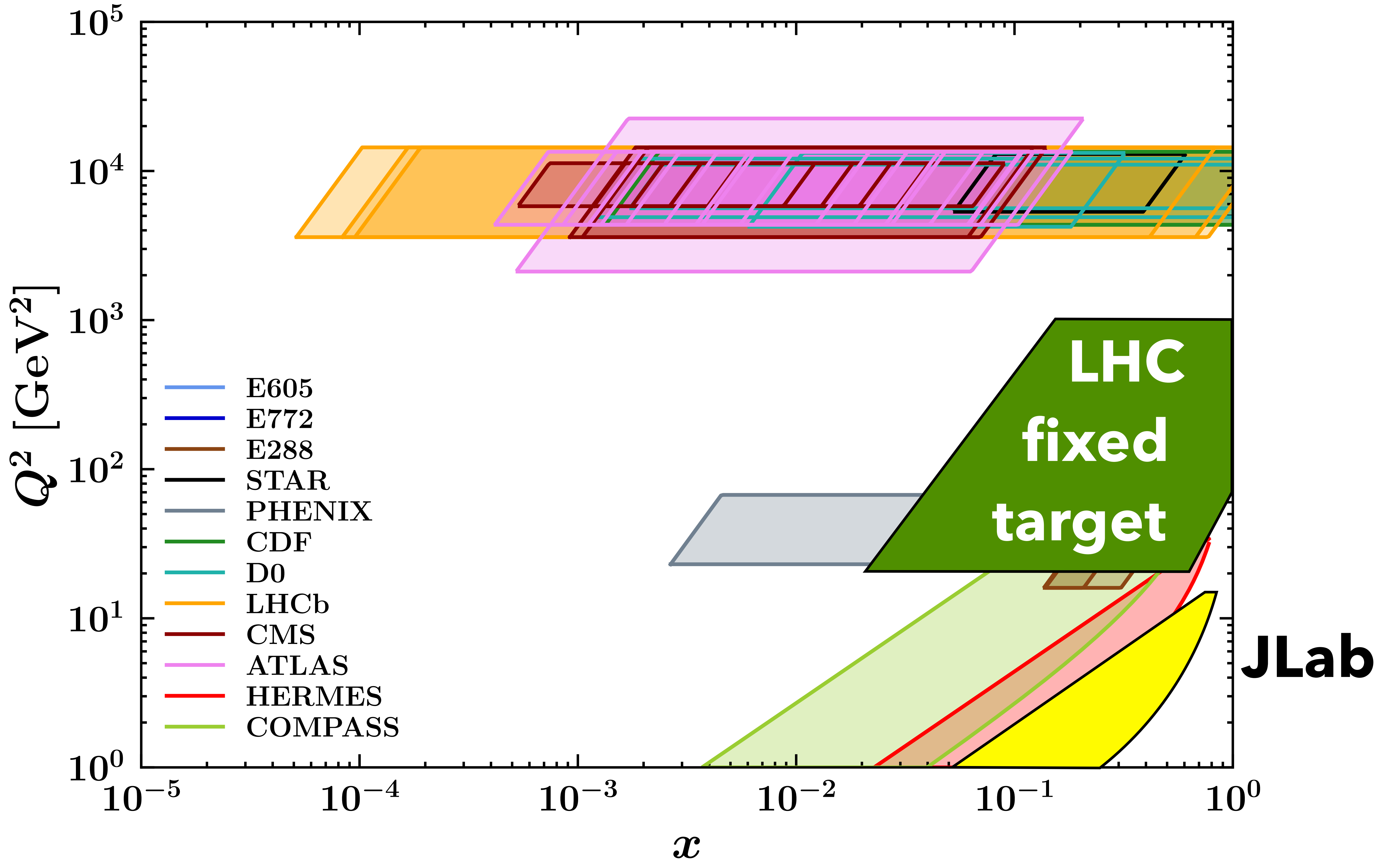

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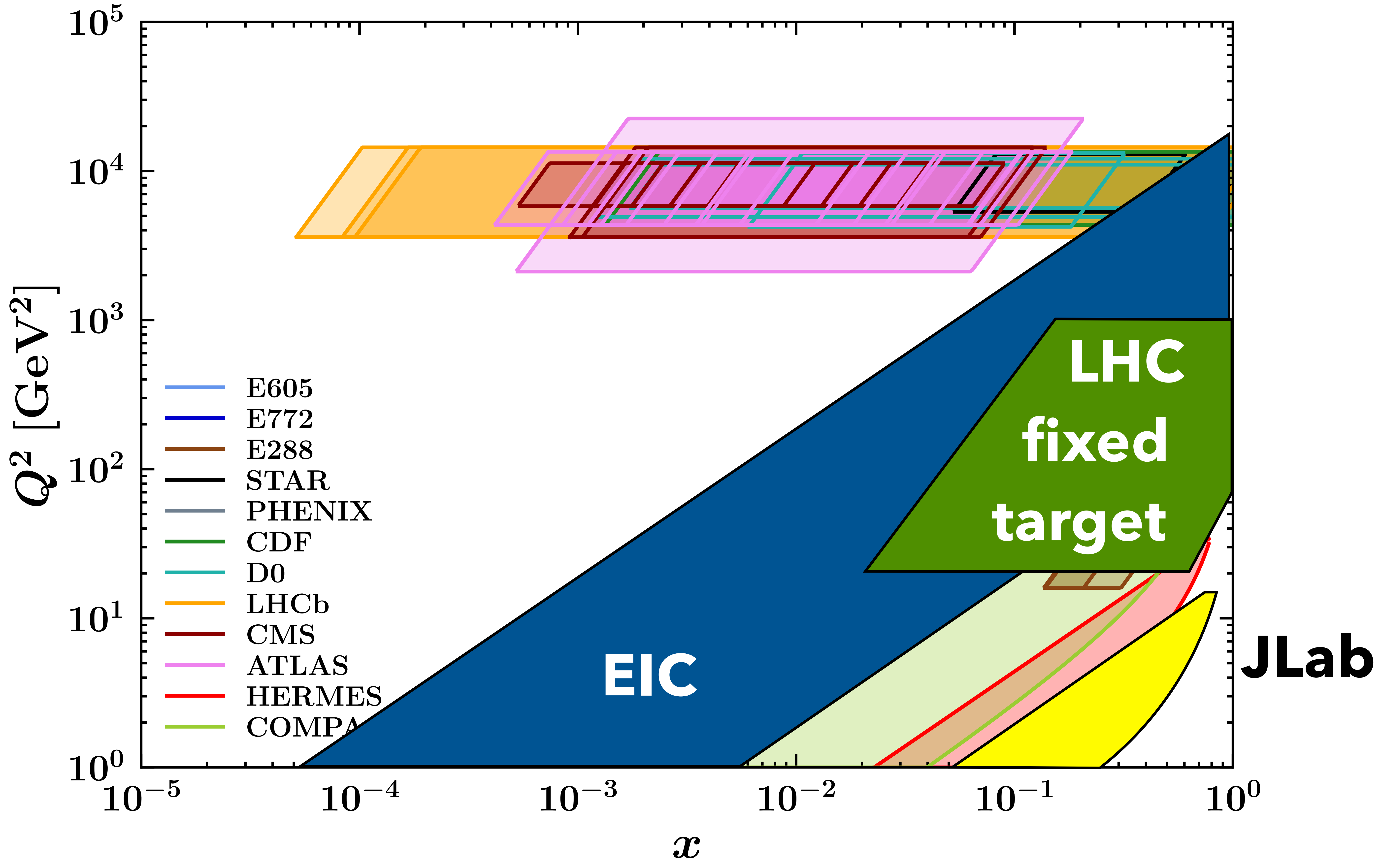

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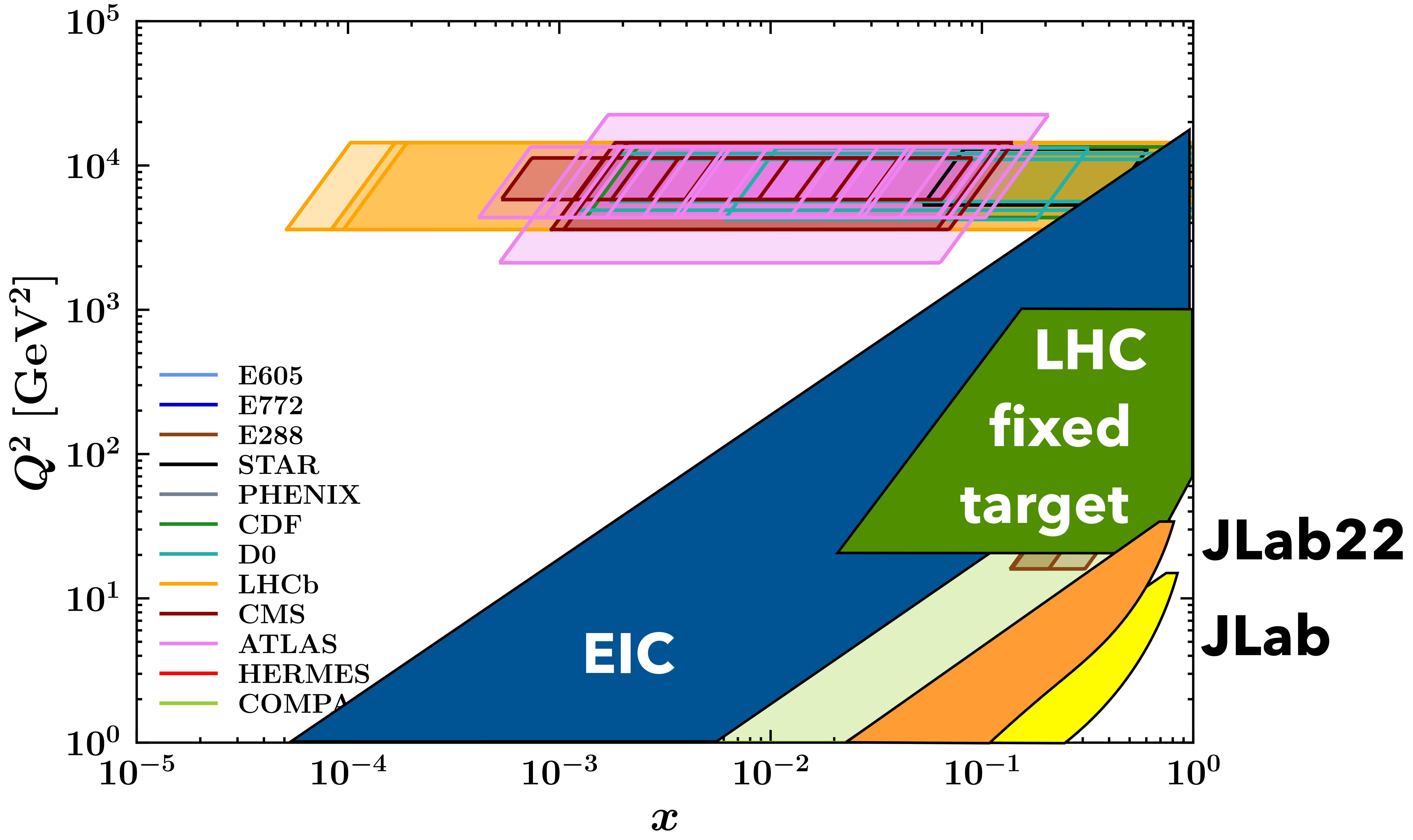

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In five to ten years

slide from 2018 CPHI@Yerevan

- TMD multiplicities for pions and kaons, off protons and deuterons, from COMPASS and JLab
- Drell-Yan and Z measurements from CERN, RHIC, FermiLab (COMPASS with pions)
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- Better understanding and control of higher-order QCD corrections
- More flexible functional forms, flavour dependence, at least two or three alternative extractions
- Use TMDs for something else (W mass… comparison with lattice… Wigner distributions…)
- **READY TO USE EIC DATA**

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- For other TMDs, the study has started and there is an increasing number of new results, but more data are needed