PRECISION QCD PREDICTIONS IN EP PHYSICS AT EIC WORKSHOP

STONYBROOK UNIVERSITY

AUGUST 3, 2022

Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ DI PAVIA

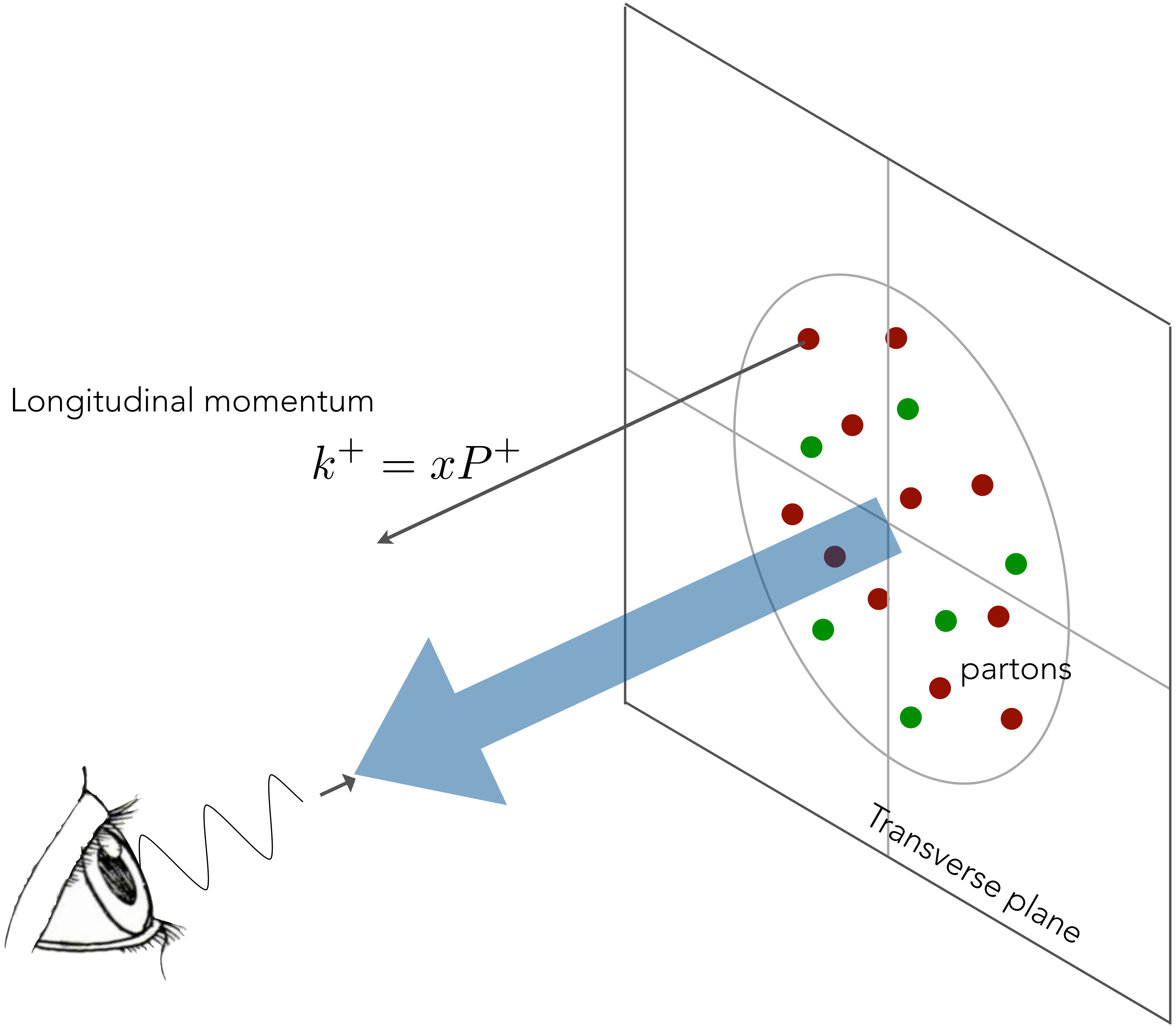
MAPTMD22

A new precise extraction of unpolarized TMDs

MATTEO CERUTTI

MAP COLLABORATION

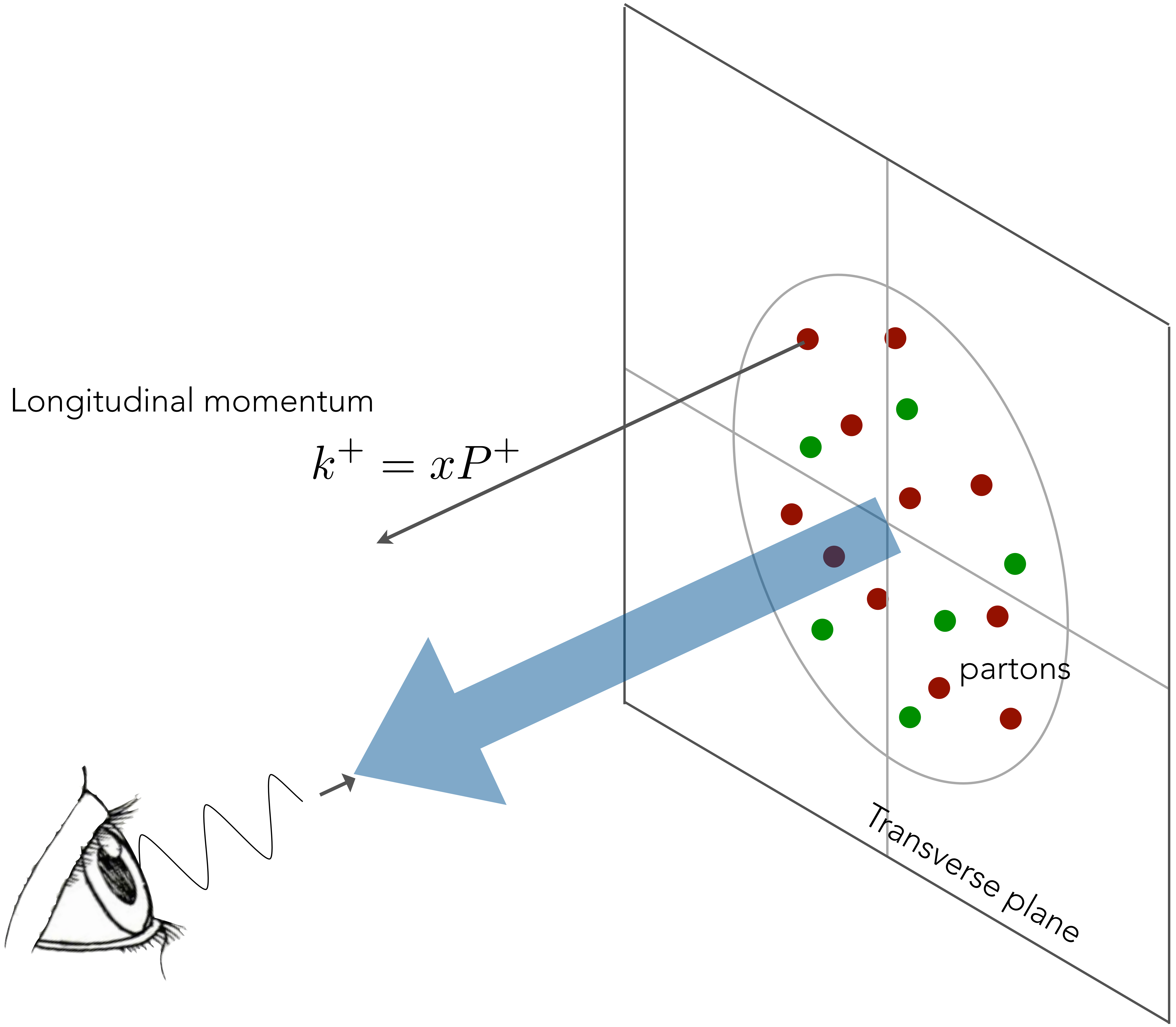
Parton Distribution Functions (PDFs)



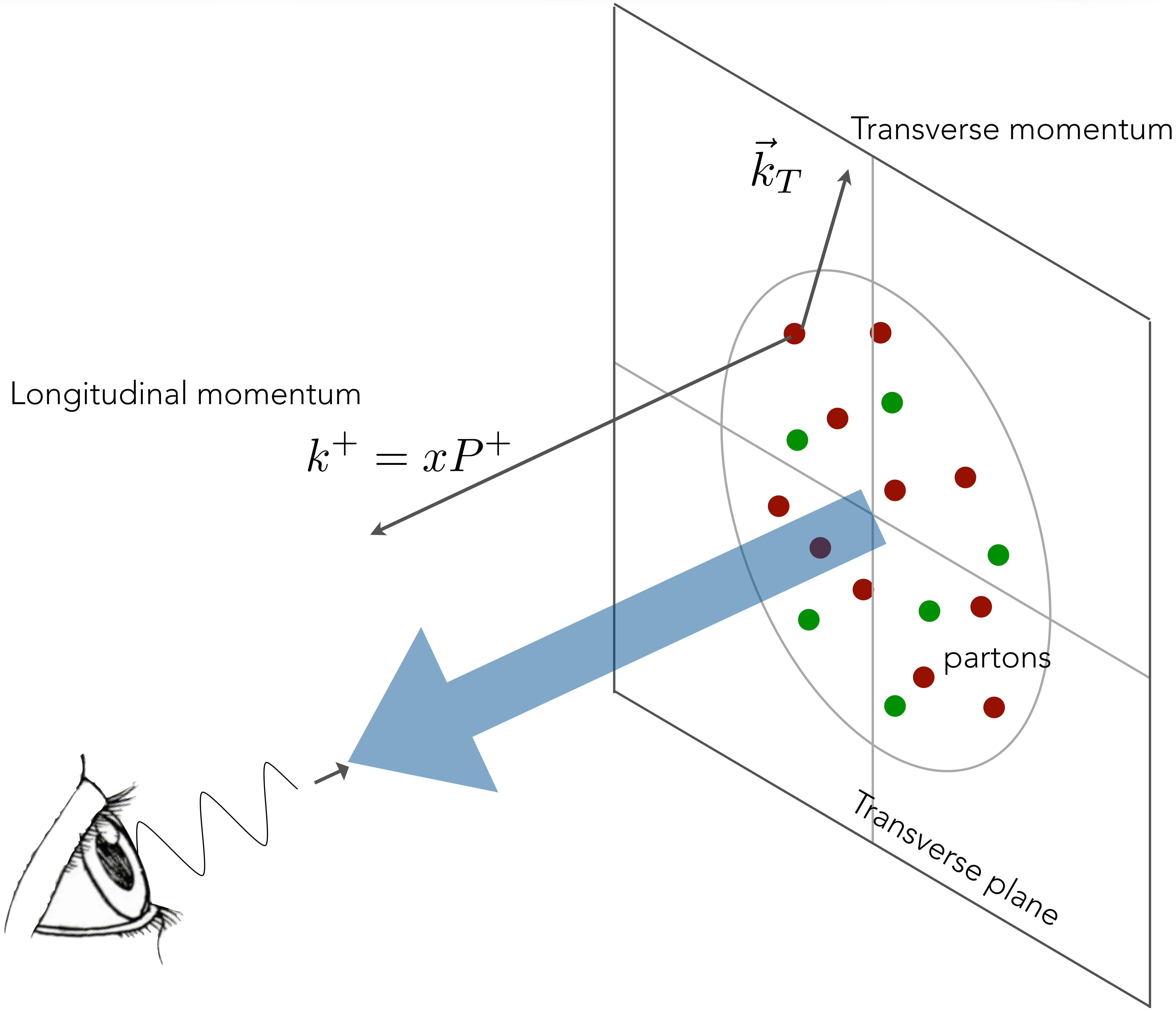
Parton Distribution Functions (PDFs)

1-D maps of the internal structure of the nucleon

$$f(x)$$



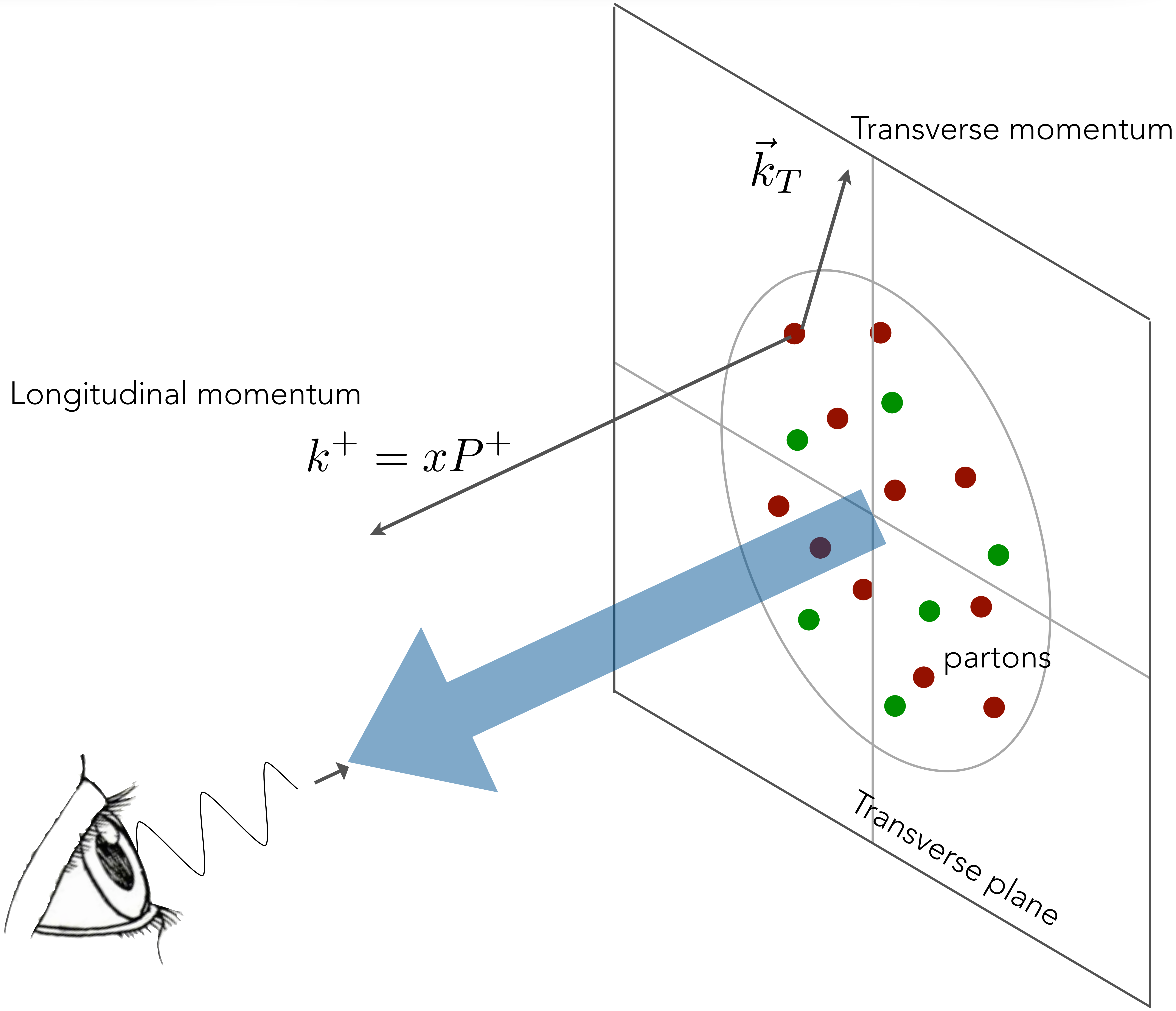
Transverse Momentum Distributions (TMDs)



Transverse Momentum Distributions (TMDs)

3-D maps of the internal structure of the nucleon

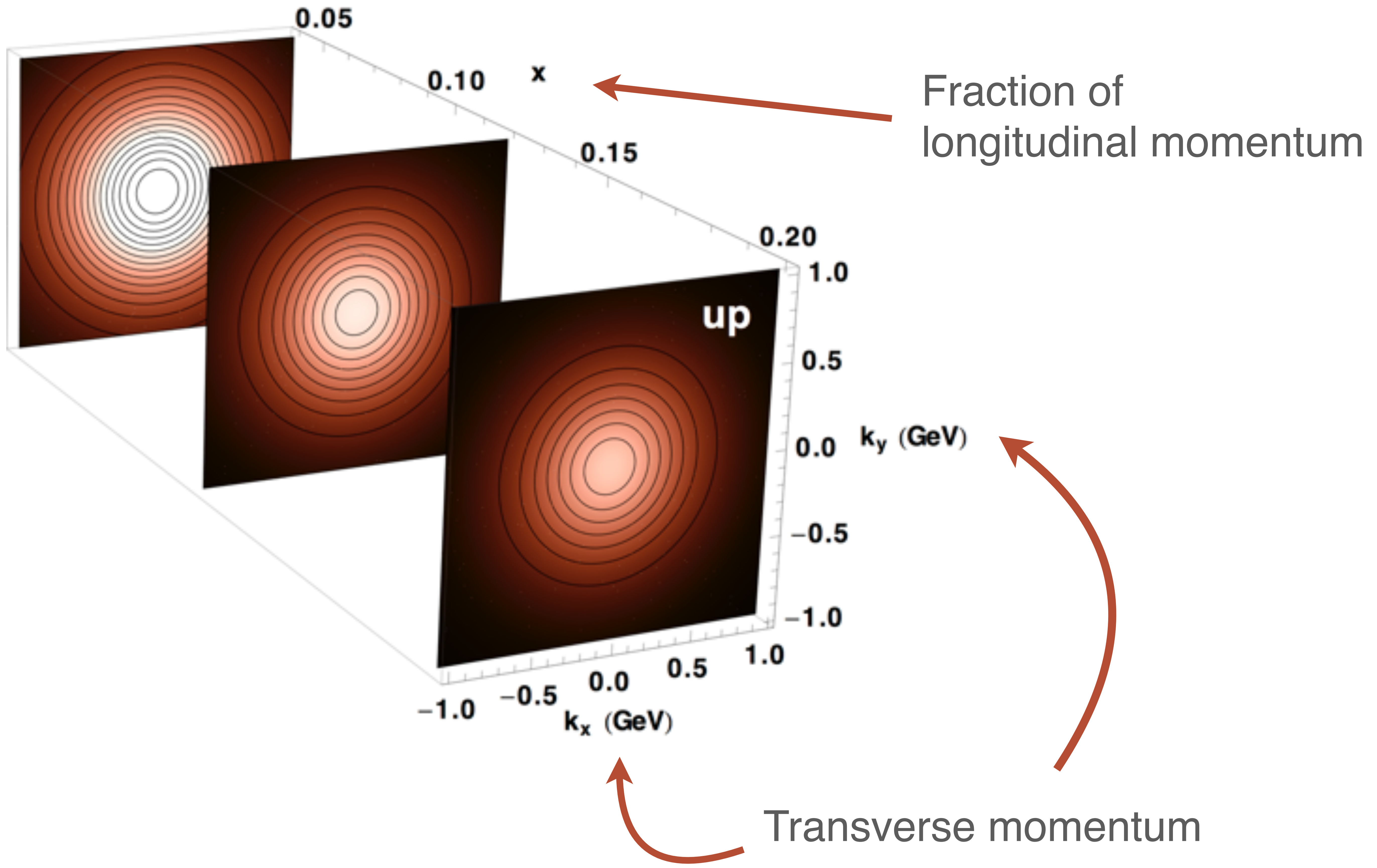
$$f(x, \vec{k}_T)$$



Transverse Momentum Distributions (TMDs)

TMDs describe the distribution of partons in three dimensions in momentum space

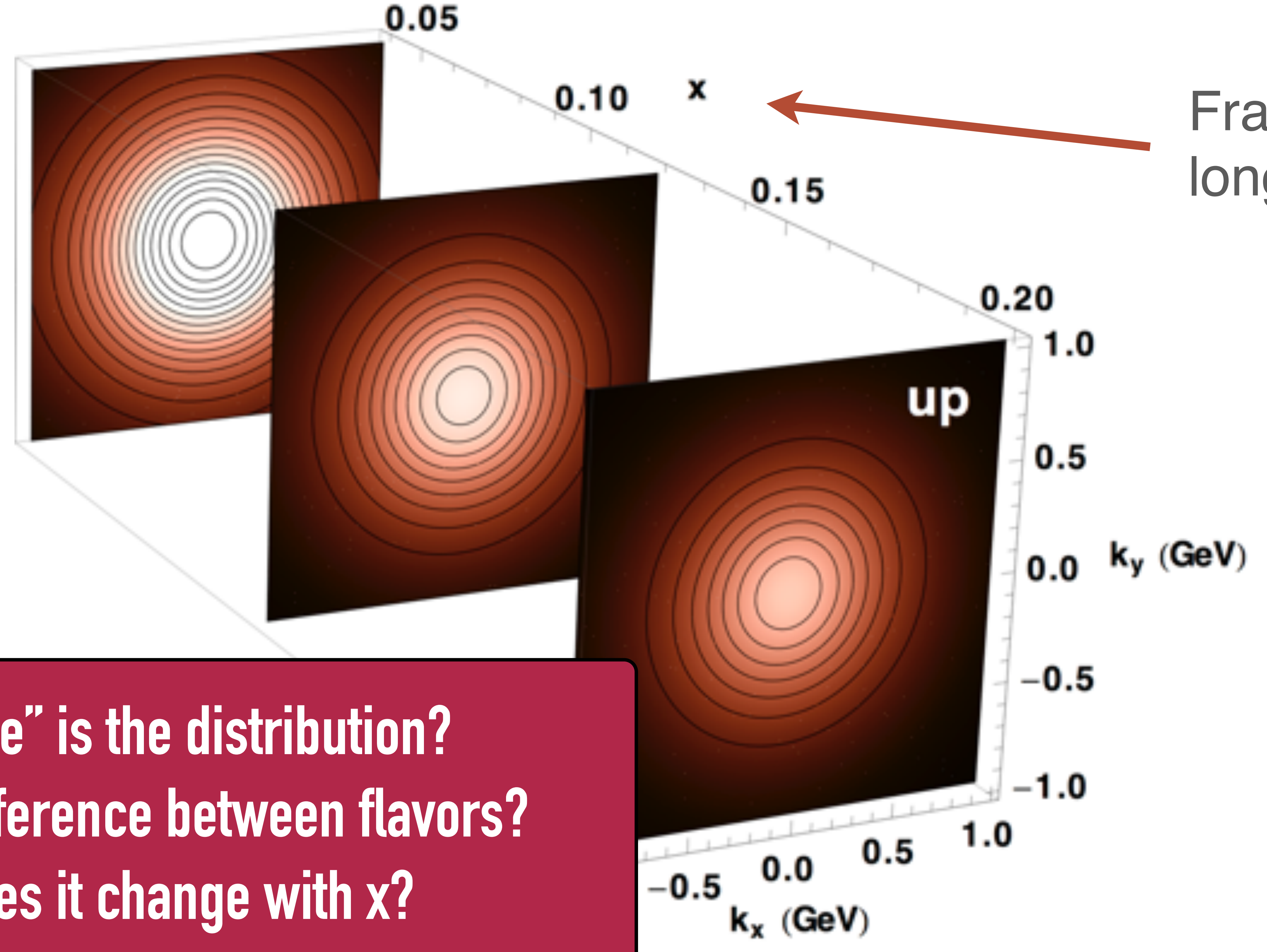
They can be extracted through global fits
There are attempts to calculate them in lattice QCD



Transverse Momentum Distributions (TMDs)

TMDs describe the distribution of partons in three dimensions in momentum space

They can be extracted through global fits
There are attempts to calculate them in lattice QCD



Fraction of longitudinal momentum

Transverse momentum

How "wide" is the distribution?
Is there a difference between flavors?
How does it change with x?

Table of TMD PDFs

Quark Polarization

Nucleon Pol.

	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

Survive upon integration over transverse momentum

Time-reversal odd

Time-reversal even

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

Table of TMD PDFs

Quark Polarization (columns); Nucleon Pol. (rows)

	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

Survive upon integration over transverse momentum

Time-reversal odd

Time-reversal even

On top of them, there are gluon-TMDs and twist-3 functions

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

Table of TMD PDFs

Quark Polarization

Nucleon Pol.	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

Main topic of this talk

Survive upon integration over transverse momentum

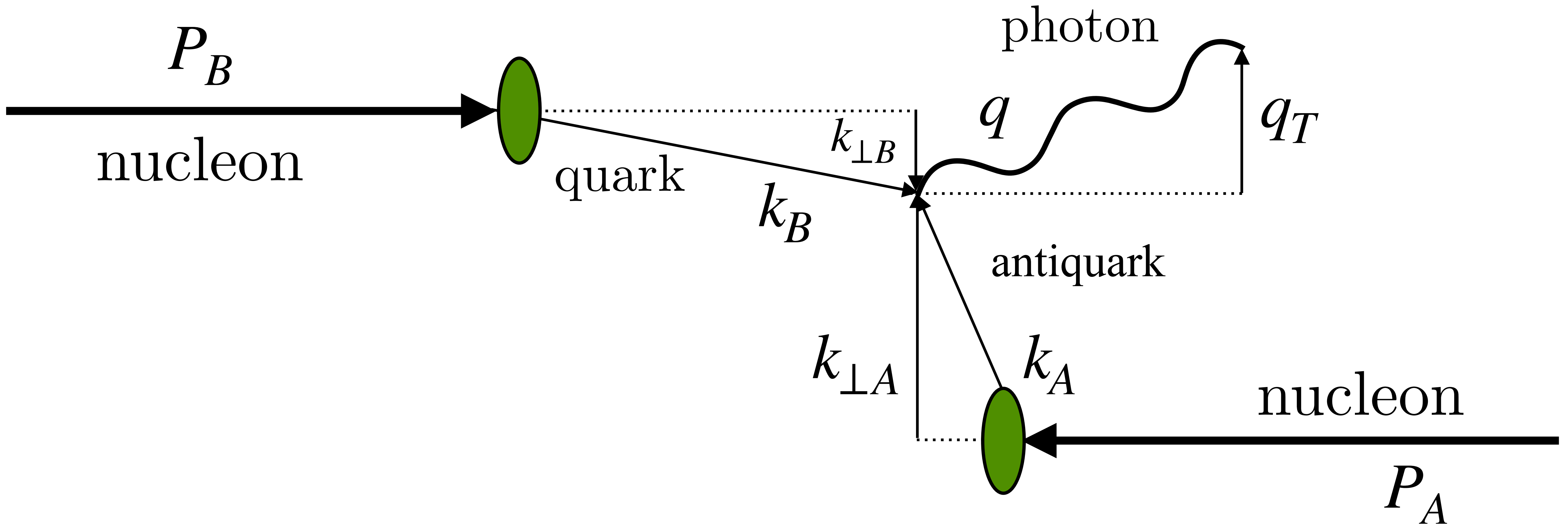
Time-reversal odd

Time-reversal even

On top of them, there are gluon-TMDs and twist-3 functions

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

TMD factorization — Drell-Yan process



W term

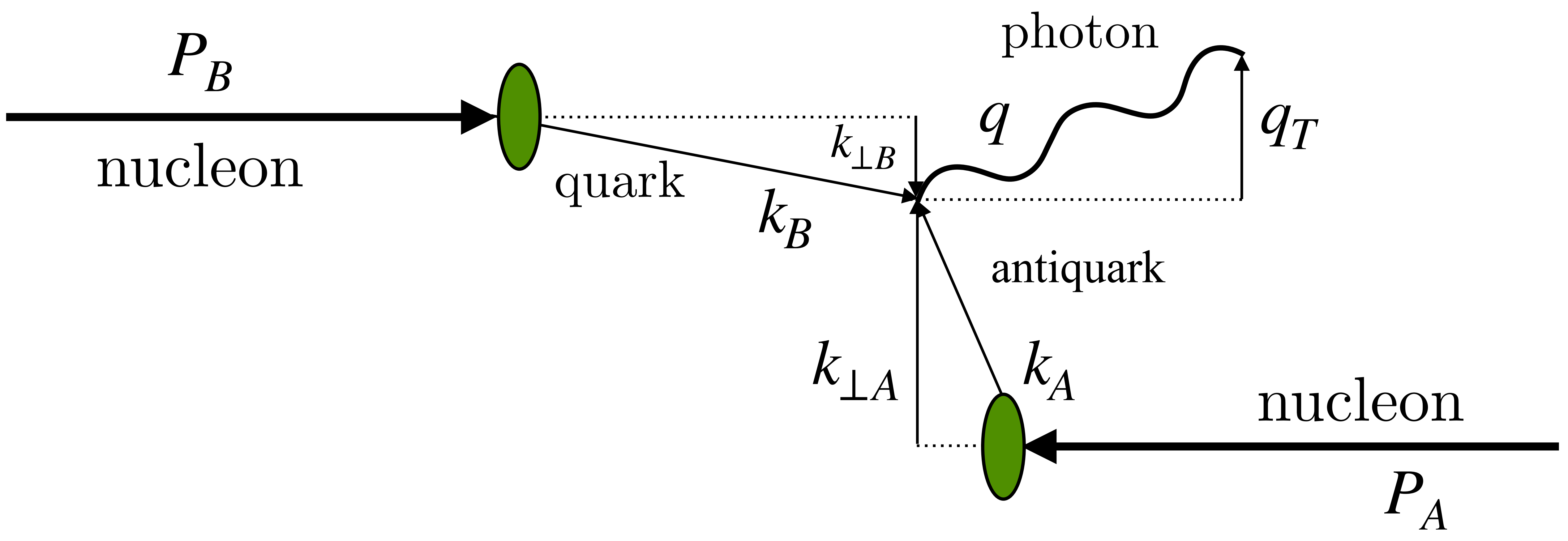
$$F_{UU}^{1}(x_A, x_B, \boldsymbol{q}_T^2, Q^2)$$

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

$$+ Y_{UU}^{1}\big(Q^2, \boldsymbol{q}_T^2\big) + \mathcal{O}\big(M^2/Q^2\big)$$

Arnold, Metz and Schlegel, Phys.Rev.D 79 (2009)

TMD factorization — Drell-Yan process



W term

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

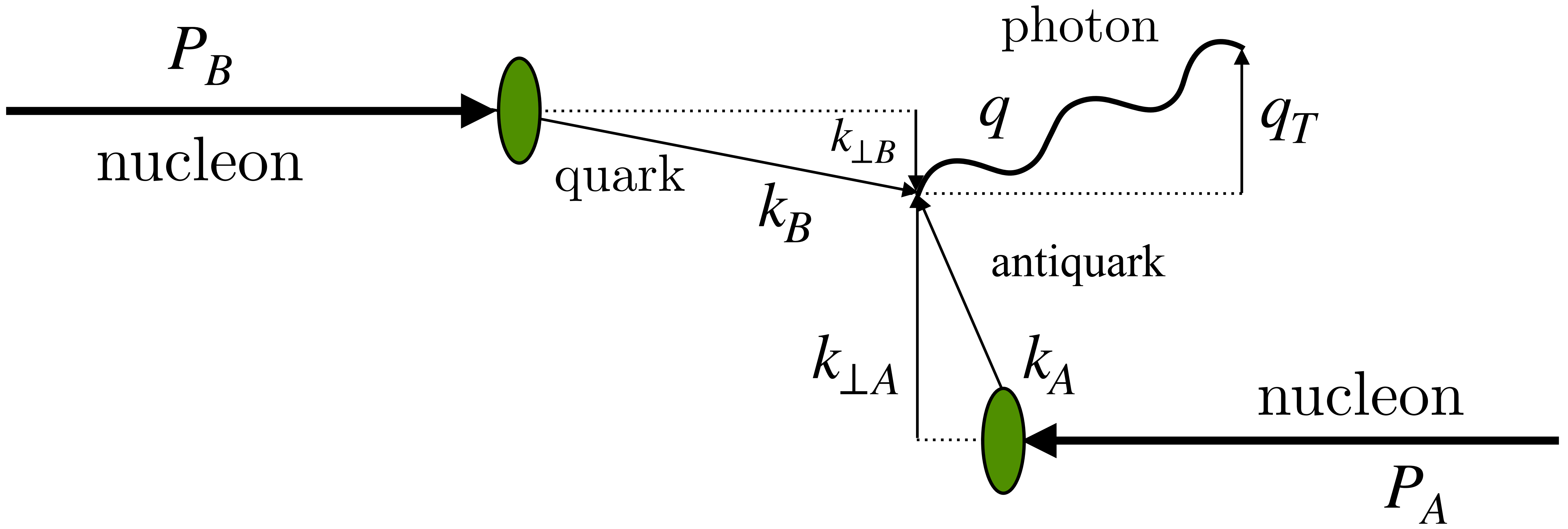
$$= \sum_a \mathcal{H}_{UU}^{1a}(Q^2, \mu^2) \int d^2\boldsymbol{k}_{\perp A}\, d^2\boldsymbol{k}_{\perp B}\, f_1^a(x_A, \boldsymbol{k}_{\perp A}^2; \mu^2)\, f_1^{\bar{a}}(x_B, \boldsymbol{k}_{\perp B}^2; \mu^2)\, \delta^{(2)}(\boldsymbol{k}_{\perp A} - \boldsymbol{q}_T + \boldsymbol{k}_{\perp B})$$

$$+ Y_{UU}^1(Q^2, \boldsymbol{q}_T^2) + \mathcal{O}(M^2/Q^2)$$

Arnold, Metz and Schlegel, Phys.Rev.D 79 (2009)

- The **W term** dominates in the region where $q_T \ll Q$

TMD factorization — Drell-Yan process



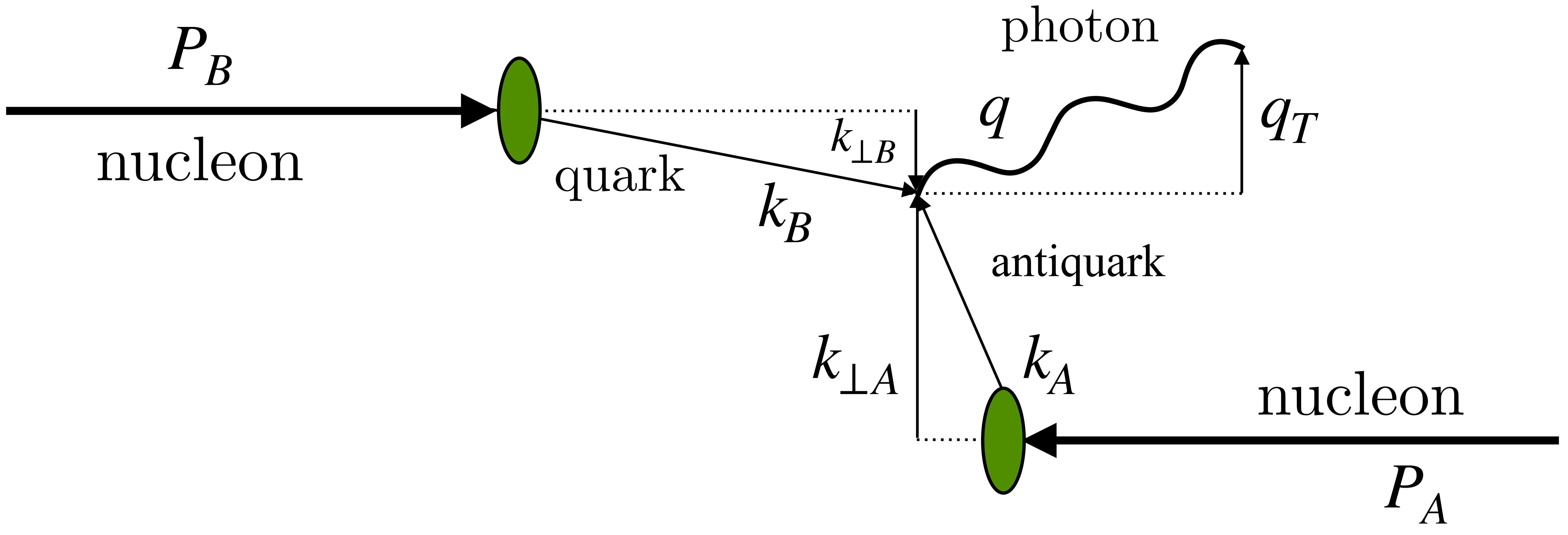
W term

$$F_{UU}^{1}(x_A, x_B, \boldsymbol{q}_T^2, Q^2) = \sum_a \mathcal{H}_{UU}^{1a}(Q^2,\mu^2) \int d^2\boldsymbol{k}_{\perp A}\, d^2\boldsymbol{k}_{\perp B}\, f_1^a(x_A, \boldsymbol{k}_{\perp A}^2;\mu^2)\, f_1^{\bar{a}}(x_B, \boldsymbol{k}_{\perp B}^2;\mu^2)\, \delta^{(2)}(\boldsymbol{k}_{\perp A} - \boldsymbol{q}_T + \boldsymbol{k}_{\perp B})$$
$$+ Y_{UU}^{1}(Q^2, \boldsymbol{q}_T^2) + \mathcal{O}(M^2/Q^2)$$

Arnold, Metz and Schlegel, Phys.Rev.D 79 (2009)

- The **W term** dominates in the region where **$q_T \ll Q$**
- Y term dominates in the complementary region

TMD factorization — Drell-Yan process



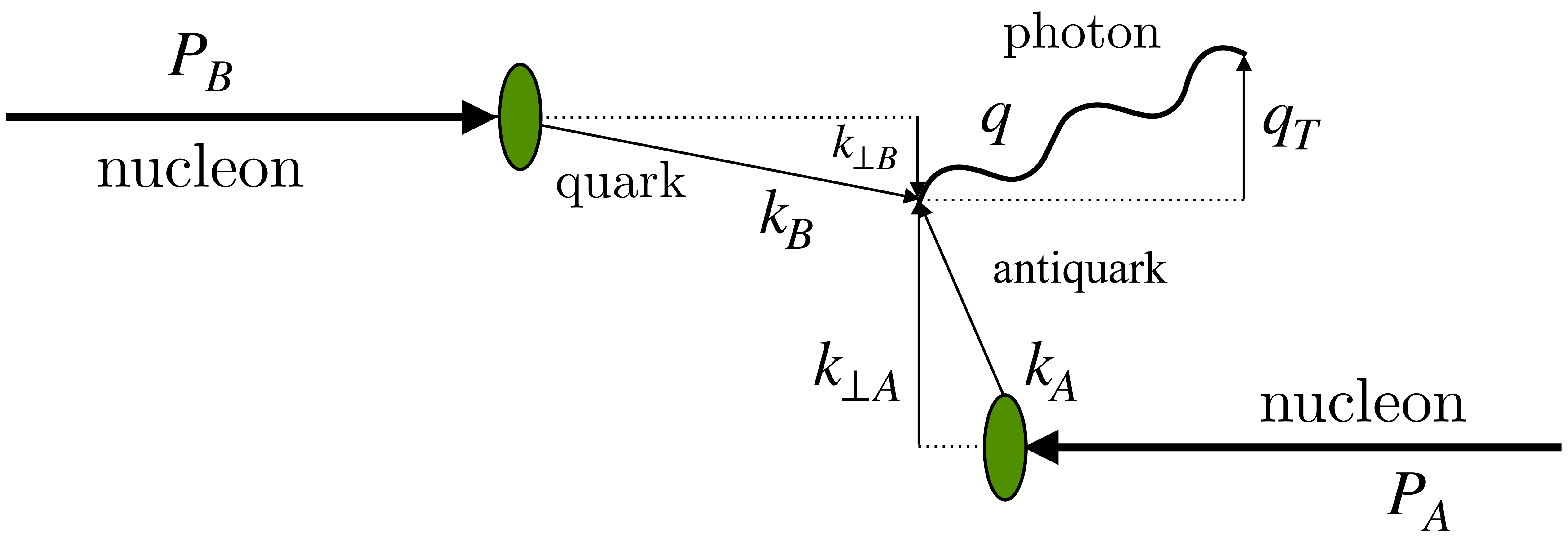
$$F^1_{UU}(x_A, x_B, \boldsymbol{q}_T^2, Q^2)$$

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

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

Arnold, Metz and Schlegel, Phys.Rev.D 79 (2009)

TMD factorization — Drell-Yan process



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

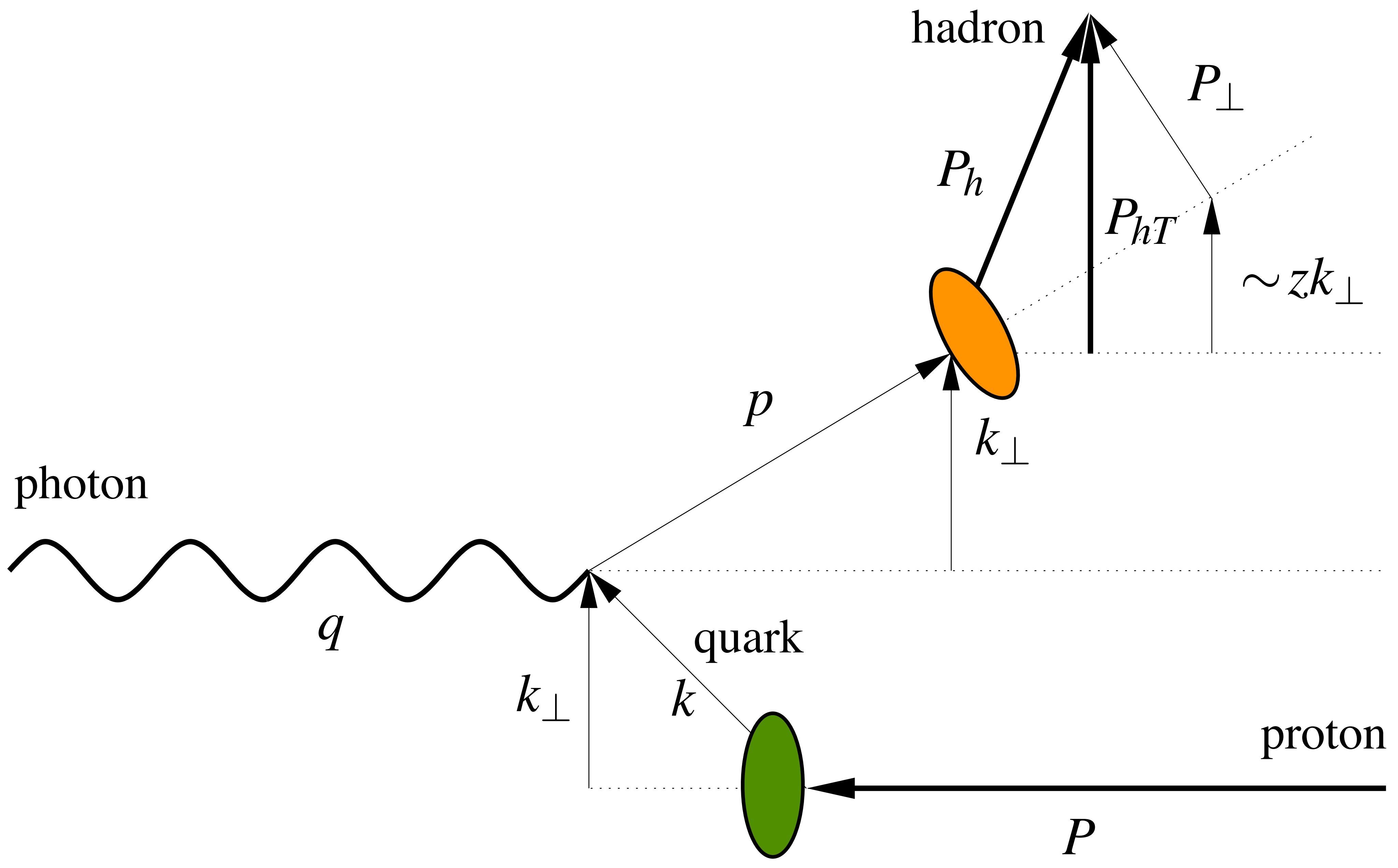
$$\approx \sum_q \mathcal{H}_{UU}^{1q}(Q^2,\mu^2) \int d^2\boldsymbol{k}_{\perp A}\, d^2\boldsymbol{k}_{\perp B}\, f_1^q(x_A, \boldsymbol{k}_{\perp A}^2;\mu^2)\, f_1^{\bar q}(x_B, \boldsymbol{k}_{\perp B}^2;\mu^2)\, \delta^{(2)}(\boldsymbol{k}_{\perp A} - \boldsymbol{q}_T + \boldsymbol{k}_{\perp B})$$

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

Arnold, Metz and Schlegel, Phys.Rev.D 79 (2009)

- Fourier-transformed space to avoid convolutions
- TMDs formally depend on two scales, but we set them equal $\hat{f}_1^q(x, b_T^2; \mu, \zeta)$

TMD factorization — SIDIS process



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

Bacchetta, Diehl, et al., JHEP 02 (2007)

Available codes — NangaParbat

https://github.com/MapCollaboration/NangaParbat

README.md

Nanga Parbat is a fitting framework aimed at the determination of the non-perturbative component of TMD distributions.

Download

You can obtain NangaParbat directly from the github repository:

https://github.com/MapCollaboration/NangaParbat

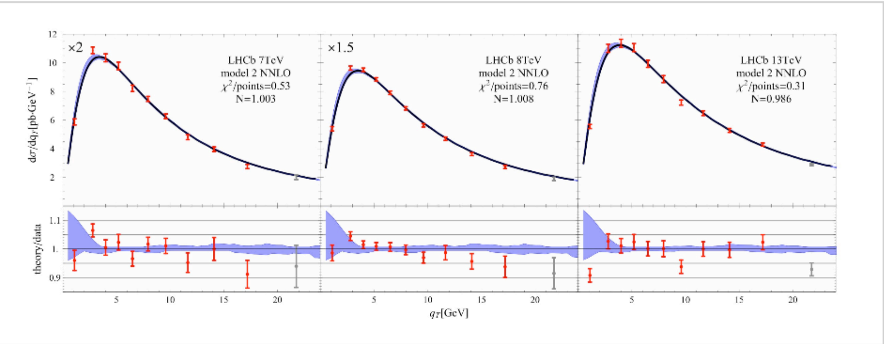
For the last development branch you can clone the master code:

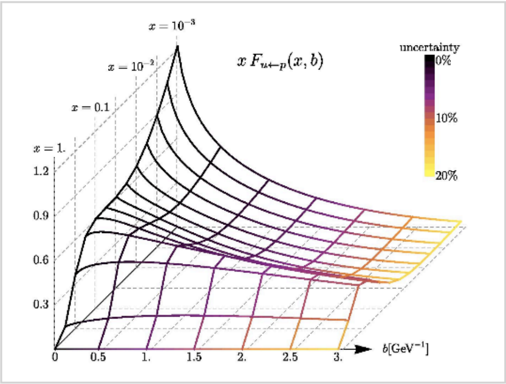
```
git clone git@github.com:MapCollaboration/NangaParbat.git
```

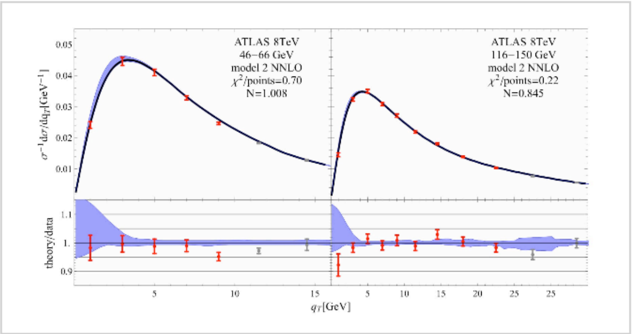
Available codes — NangaParbat

https://teorica.fis.ucm.es/artemide/

arTeMiDe







News

12 Dec 2019: Version 2.02 released (+manual update).

23 Feb 2019: Version 1.4 released (+manual update).

21 Jan 2019: Artemide now has a repository.

Archive of older links/news.

Articles, presentations & supplementary materials

Extra pictures for the paper arXiv:1902.08474

Seminar of A.Vladimirov in Pavia 2018 on TMD evolution.

Link to the text in Inspire.

Archive of older links/news.

Download

Recent version/release can be found in repository

About us & Contacts

If you have found mistakes, or have suggestions/questions, please, contact us.

Some extra materials can be found on Alexey's web-page

Alexey Vladimirov Alexey.Vladimirov@physik.uni-regensburg.de

Ignazio Scimemi ignazios@fis.ucm.es

TMD factorization — expression of a TMD

Structure of a TMD in b_T-space

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

$$\hat{f}_1^a(x, b_T^2; \mu_f, \zeta_f) = [C \otimes f_1](x, \mu_{b_*})\; e^{\int_{\mu_{b_*}}^{\mu_f} \frac{d\mu}{\mu} \left(\gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_f}}{\mu}\right)} \left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\text{resum}} + g_K} f_{1\,NP}(x, b_T^2; \zeta_f, Q_0)$$

Collins, "Foundations of Perturbative QCD"

TMD factorization — expression of a TMD

Structure of a TMD in b_T-space

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

$$\hat{f}_1^a(x, b_T^2; \mu_f, \zeta_f) = [C \otimes f_1](x, \mu_{b_*})\; e^{\int_{\mu_{b_*}}^{\mu_f} \frac{d\mu}{\mu}\left(\gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_f}}{\mu}\right)} \left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\mathrm{resum}}+g_K} f_{1\,NP}(x, b_T^2; \zeta_f, Q_0)$$

matching coefficients
(perturbative)

Collins, "Foundations of Perturbative QCD"

TMD factorization — expression of a TMD

Structure of a TMD in b_T-space

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

$$\hat{f}_1^a(x, b_T^2; \mu_f, \zeta_f) = [C \otimes f_1](x, \mu_{b_*})\; e^{\int_{\mu_{b_*}}^{\mu_f} \frac{d\mu}{\mu} \left(\gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_f}}{\mu}\right)} \left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\text{resum}} + g_K} f_{1\,NP}(x, b_T^2; \zeta_f, Q_0)$$

collinear PDF

matching coefficients
(perturbative)

Collins, "Foundations of Perturbative QCD"

TMD factorization — expression of a TMD

Structure of a TMD in b_T-space

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

perturbative Sudakov form factor

$$\hat{f}_1^a(x, b_T^2; \mu_f, \zeta_f) = [C \otimes f_1](x, \mu_{b_*})\; e^{\int_{\mu_{b_*}}^{\mu_f} \frac{d\mu}{\mu}\left(\gamma_F - \gamma_K \ln\frac{\sqrt{\zeta_f}}{\mu}\right)} \left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\rm resum}+g_K} f_{1\,NP}(x, b_T^2; \zeta_f, Q_0)$$

collinear PDF

matching coefficients (perturbative)

Collins, "Foundations of Perturbative QCD"

TMD factorization — expression of a TMD

Structure of a TMD in b_T-space

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

$$\hat{f}_1^a(x, b_T^2; \mu_f, \zeta_f) = [C \otimes f_1](x, \mu_{b_*}) \; e^{\int_{\mu_{b_*}}^{\mu_f} \frac{d\mu}{\mu} \left(\gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_f}}{\mu}\right)} \left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\mathrm{resum}} + g_K} f_{1\,NP}(x, b_T^2; \zeta_f, Q_0)$$

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

Collins, *"Foundations of Perturbative QCD"*

TMD factorization — expression of a TMD

Structure of a TMD in b_T-space

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

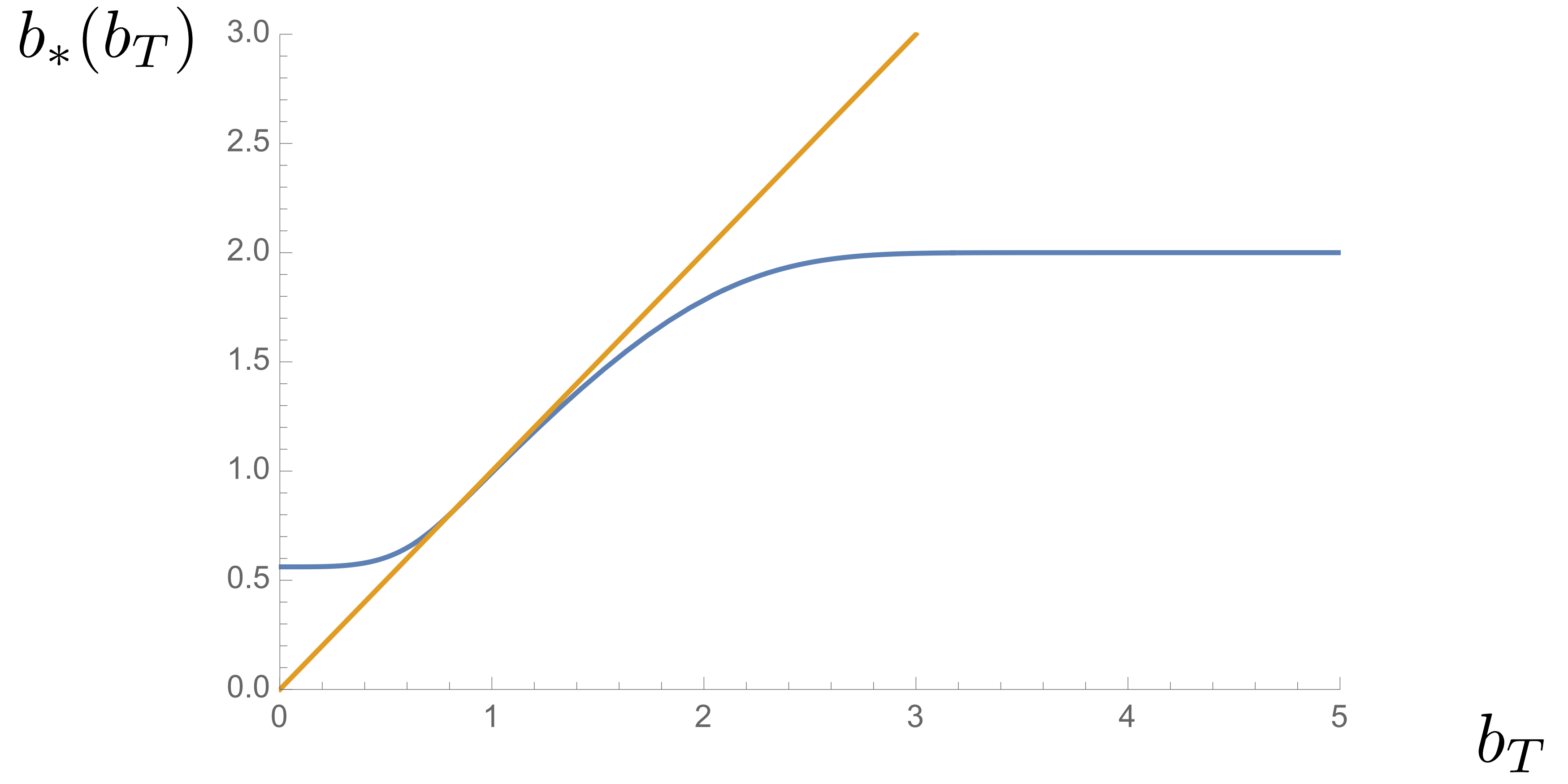
$$\hat{f}_1^a(x, b_T^2; \mu_f, \zeta_f) = [C \otimes f_1](x, \mu_{b_*}) \, e^{\int_{\mu_{b_*}}^{\mu_f} \frac{d\mu}{\mu} \left(\gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_f}}{\mu}\right)} \left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\text{resum}} + g_K} f_{1\,NP}(x, b_T^2; \zeta_f, Q_0)$$

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

$$b_*(b_T) = b_{\max}\left(\frac{1 - \exp\left(-\frac{b_T^4}{b_{\max}^4}\right)}{1 - \exp\left(-\frac{b_T^4}{b_{\min}^4}\right)}\right)^{\frac{1}{4}}$$

$$b_{\max} = 2e^{-\gamma_E}$$

$$b_{\min} = \frac{2e^{-\gamma_E}}{Q}$$



Collins, "Foundations of Perturbative QCD"

TMD factorization — expression of a TMD

Structure of a TMD in b_T-space

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

$$\hat{f}_1^a(x, b_T^2; \mu_f, \zeta_f) = [C \otimes f_1](x, \mu_{b_*})\ e^{\int_{\mu_{b_*}}^{\mu_f} \frac{d\mu}{\mu}\left(\gamma_F - \gamma_K\ \ln\frac{\sqrt{\zeta_f}}{\mu}\right)} \left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\rm resum}+g_K} f_{1\,NP}(x, b_T^2; \zeta_f, Q_0)$$

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

Collins, "Foundations of Perturbative QCD"

TMD factorization — expression of a TMD

Structure of a TMD in b_T-space

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

$$\hat{f}_1^a(x, b_T^2; \mu_f, \zeta_f) = [C \otimes f_1](x, \mu_{b_*})\, e^{\int_{\mu_{b_*}}^{\mu_f} \frac{d\mu}{\mu}\left(\gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_f}}{\mu}\right)} \left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\text{resum}} + g_K} f_{1\,NP}(x, b_T^2; \zeta_f, Q_0)$$

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

nonperturbative part of evolution

Collins, "Foundations of Perturbative QCD"

TMD factorization — expression of a TMD

Structure of a TMD in b_T-space

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

$$\hat{f}_1^a(x, b_T^2; \mu_f, \zeta_f) = [C \otimes f_1](x, \mu_{b_*})\, e^{\int_{\mu_{b_*}}^{\mu_f} \frac{d\mu}{\mu} \left(\gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_f}}{\mu}\right)} \left(\frac{\sqrt{\zeta_f}}{\mu_{b_*}}\right)^{K_{\mathrm{resum}} + g_K} f_{1\,NP}(x, b_T^2; \zeta_f, Q_0)$$

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

nonperturbative part of evolution

nonperturbative part of TMD

Collins, "Foundations of Perturbative QCD"

Perturbative accuracy

Orders in powers of α_S

Perturbative accuracy

Orders in powers of α_S

Hard factor and matching coefficient

Ingredients in perturbative Sudakov form factor

Accuracy	H and C	K and γ_F	γ_K	PDFs/FFs and α_S evol.
LL	0	-	1	-
NLL	0	1	2	LO
NLL'	1	1	2	NLO
NNLL	1	2	3	NLO
NNLL'	2	2	3	NNLO
N^3LL^-	2	3	4	NLO (FF only)
N^3LL	2	3	4	NNLO
N^3LL'	3	3	4	N^3LO

Perturbative accuracy

Orders in powers of α_S

Hard factor and matching coefficient → H and C

Ingredients in perturbative Sudakov form factor → K and γ_F, γ_K

Accuracy	H and C	K and γ_F	γ_K	PDFs/FFs and α_S evol.
LL	0	-	1	-
NLL	0	1	2	LO
NLL’	1	1	2	NLO
NNLL	1	2	3	NLO
NNLL’	2	2	3	NNLO
N^3LL^-	2	3	4	NLO (FF only)
N^3LL	2	3	4	NNLO
N^3LL'	3	3	4	N^3LO

Collinear fragmentation functions available beyond NLO only recently

Borsa et al., 2202.05060
Khalek et al., 2204.10331

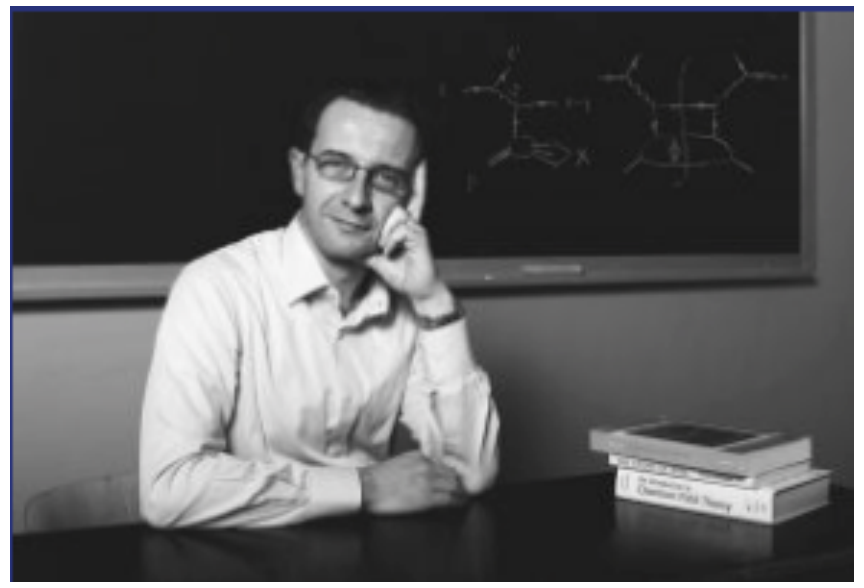
Available global fits

	Accuracy	SIDIS	DY	Z production	N of points	χ^2/N_{data}
Pavia 2017 arXiv:1703.10157	NLL	✔	✔	✔	8059	1.55
SV 2019 arXiv:1912.06532	N^3LL^-	✔	✔	✔	1039	1.06
MAPTMD22	***N^3LL^-***	✔	✔	✔	***2031***	***1.06***

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

A new extraction of unpolarized quark TMDs

Alessandro Bacchetta



Marco Radici

Andrea Signori

Valerio Bertone

Chiara Bissolotti

Giuseppe Bozzi

Fulvio Piacenza

A new extraction of unpolarized quark TMDs

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

A new extraction of unpolarized quark TMDs

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

A new extraction of unpolarized quark TMDs

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points
- Perturbative accuracy: $\boldsymbol{N^3LL^-}$

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

A new extraction of unpolarized quark TMDs

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points
- Perturbative accuracy: $\boldsymbol{N^3LL^-}$
- ***Normalization*** of SIDIS multiplicities beyond NLL

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

A new extraction of unpolarized quark TMDs

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points
- Perturbative accuracy: $\boldsymbol{N^3LL^-}$
- ***Normalization*** of SIDIS multiplicities beyond NLL
- Number of fitted parameters: ***21***

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

A new extraction of unpolarized quark TMDs

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points
- Perturbative accuracy: ***N³LL⁻***
- ***Normalization*** of SIDIS multiplicities beyond NLL
- Number of fitted parameters: ***21***
- Extremely good description: $\chi^2/N_{data} = 1.06$

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

Main differences with SV19

Main differences with SV19

- Different implementation of TMD evolution

Main differences with SV19

- Different implementation of TMD evolution

Collins-Soper-Sterman vs ***zeta-prescription***

Main differences with SV19

- Different implementation of TMD evolution

  Collins-Soper-Sterman vs ***zeta-prescription***

- Different criteria of data selection

Main differences with SV19

- Different implementation of TMD evolution

  Collins-Soper-Sterman vs ***zeta-prescription***

- Different criteria of data selection

- Different choice of nonperturbative functional form

MAPTMD22 — Datasets included

Drell-Yan

Fixed-target low-energy DY

RHIC data

LHC and Tevatron data

$9 \lesssim Q \lesssim 11$ GeV excluded (Υ resonance)

$$q_T|_{\max} = 0.2Q$$

484 experimental points

MAPTMD22 — Datasets included

Drell-Yan

Fixed-target low-energy DY

RHIC data

LHC and Tevatron data

$$9 \lesssim Q \lesssim 11 \text{ GeV excluded } (\Upsilon \text{ resonance})$$

$$q_T|_{\max} = 0.2Q$$

484 experimental points

SIDIS

HERMES data

COMPASS data

$$Q > 1.3 \text{ GeV}$$

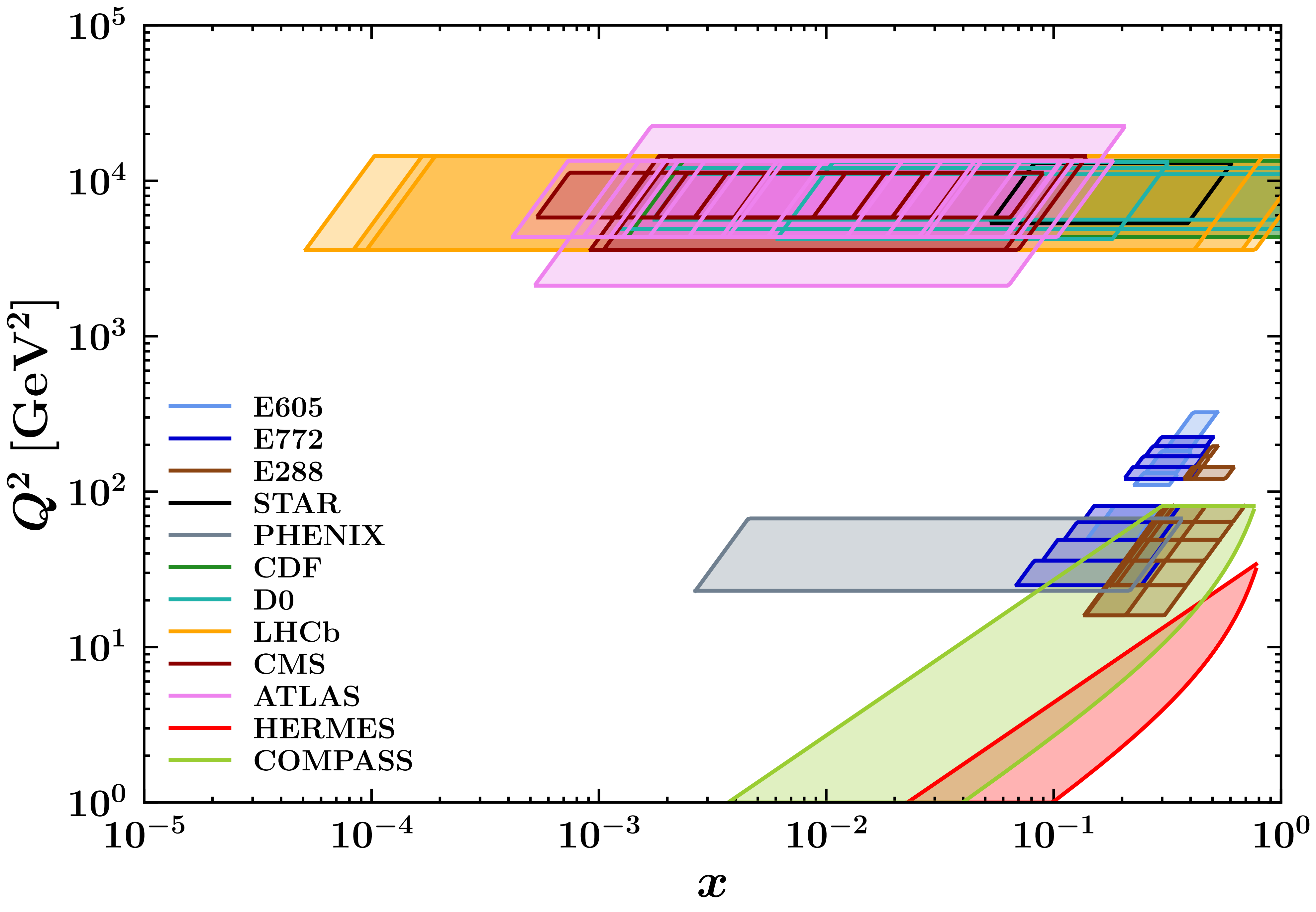
$$0.2 < z < 0.7$$

$$P_{hT}|_{\max} = \min[\min[0.2Q, 0.5zQ] + 0.3 \text{ GeV}, zQ]$$

1547 experimental points

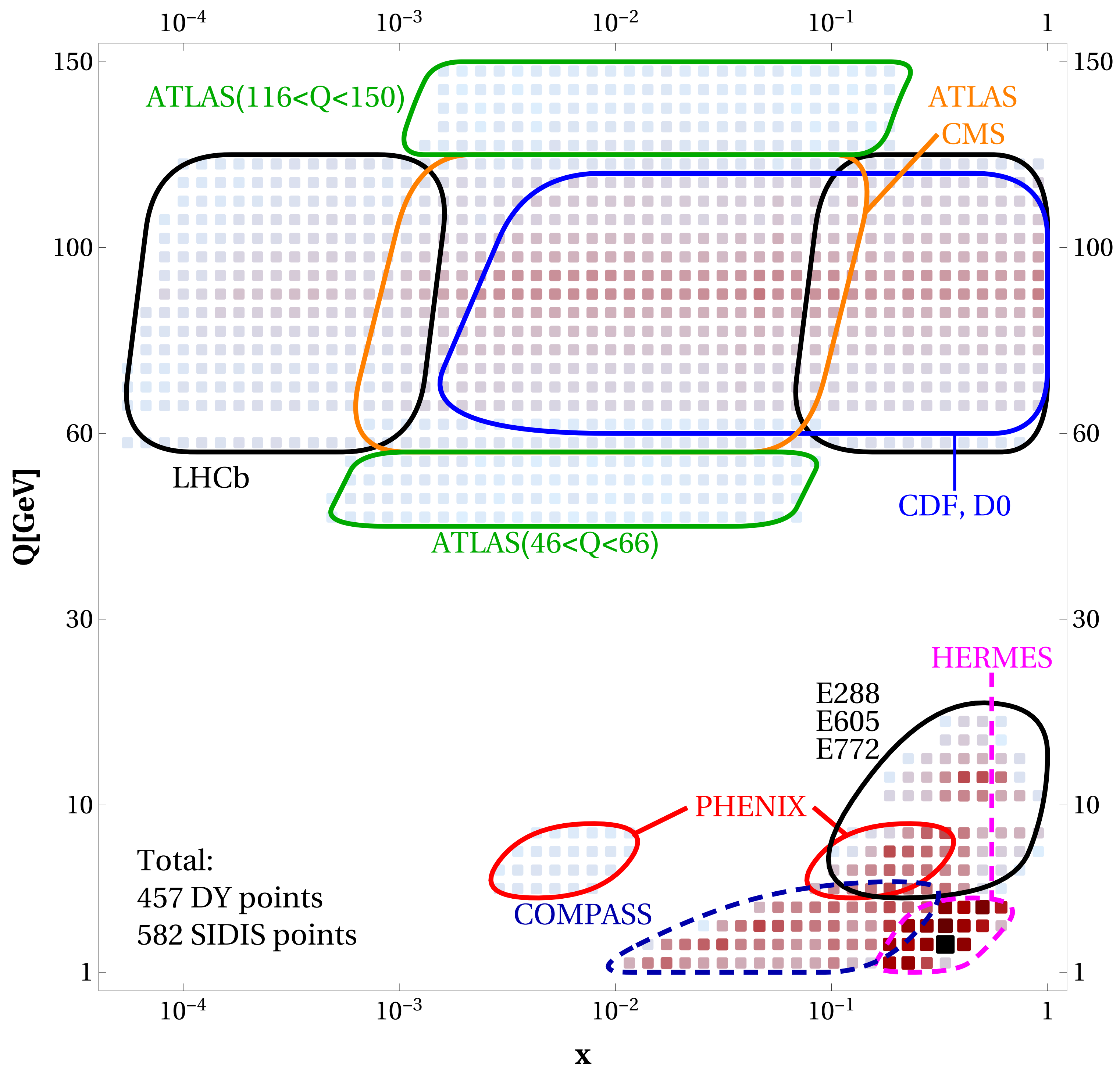
Comparison of datasets included

MAPTMD22



484(DY) + 1547(SIDIS) = 2031 fitted data

SV19

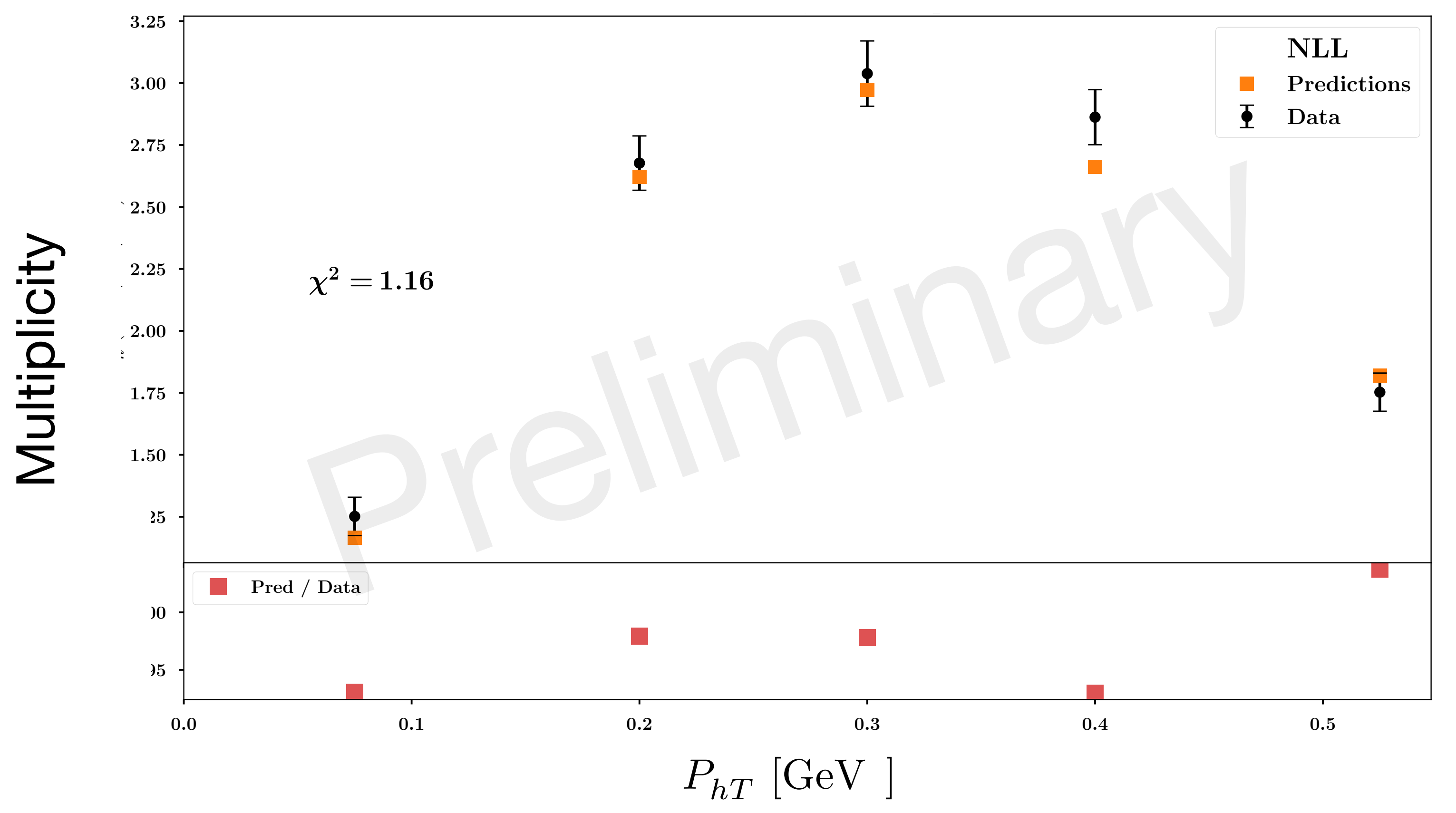


457(DY) + 582(SIDIS) = 1039 fitted data

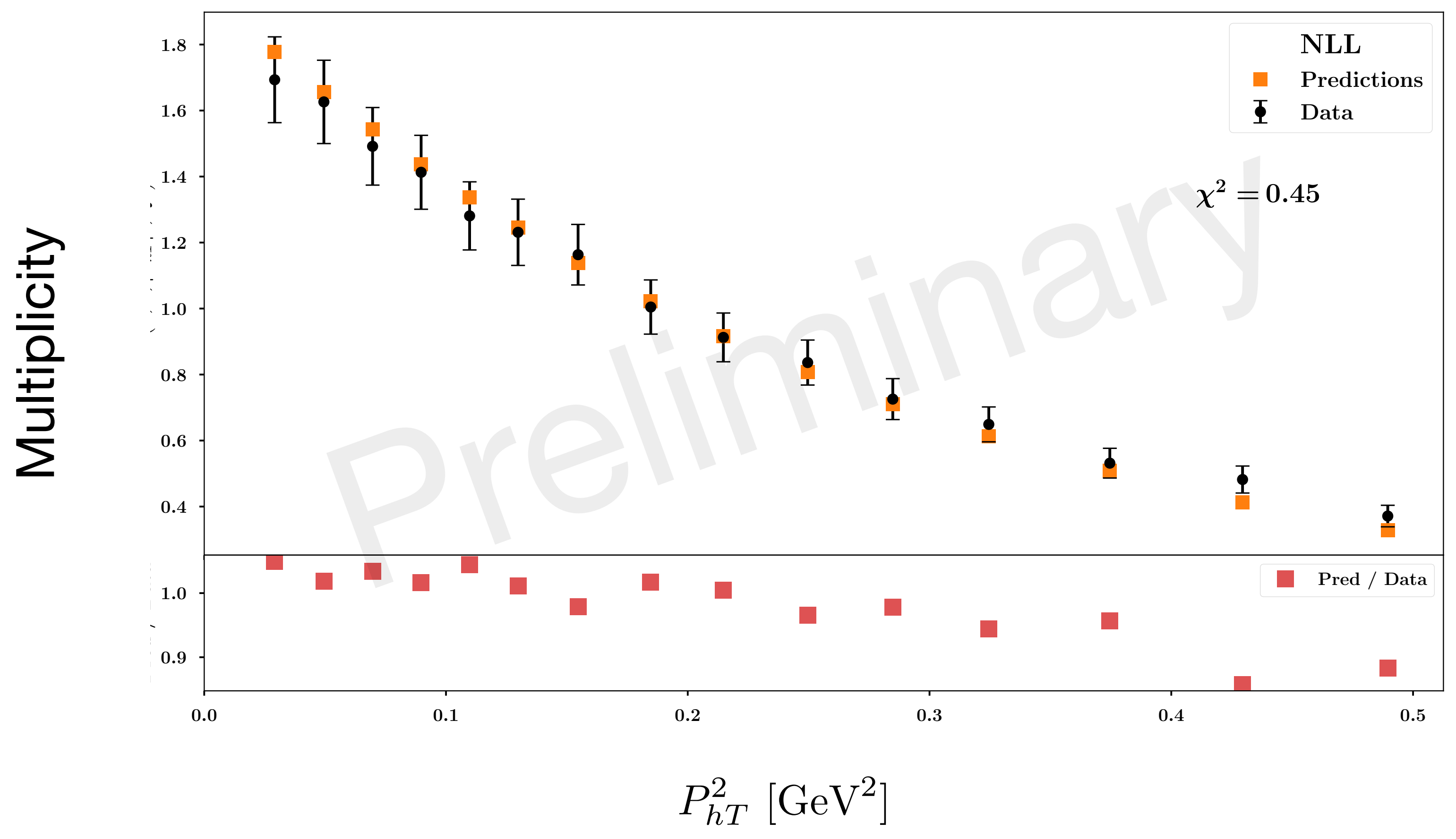
MAPTMD22 — Normalization of SIDIS

SIDIS multiplicities at NLL

HERMES



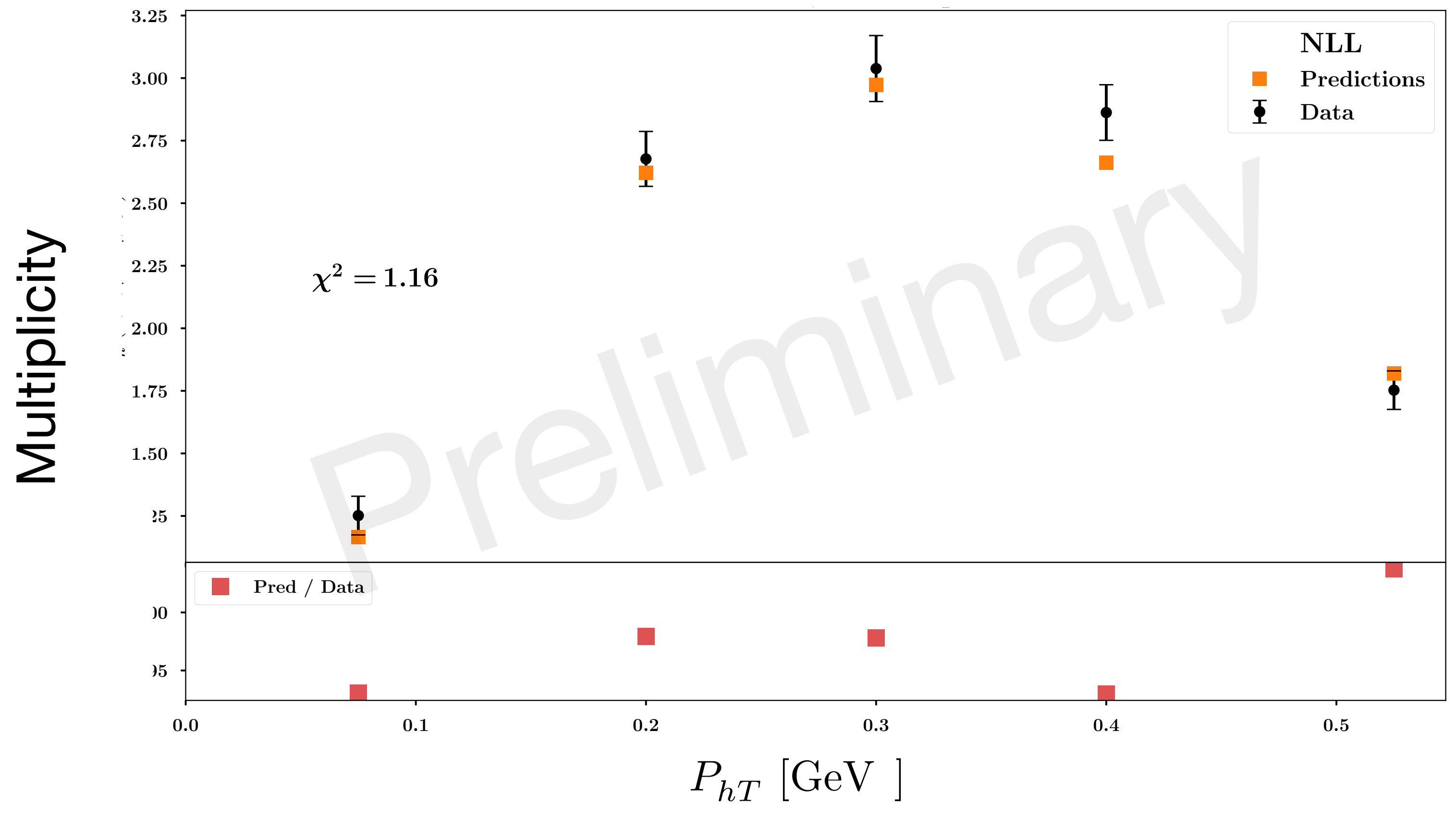
COMPASS



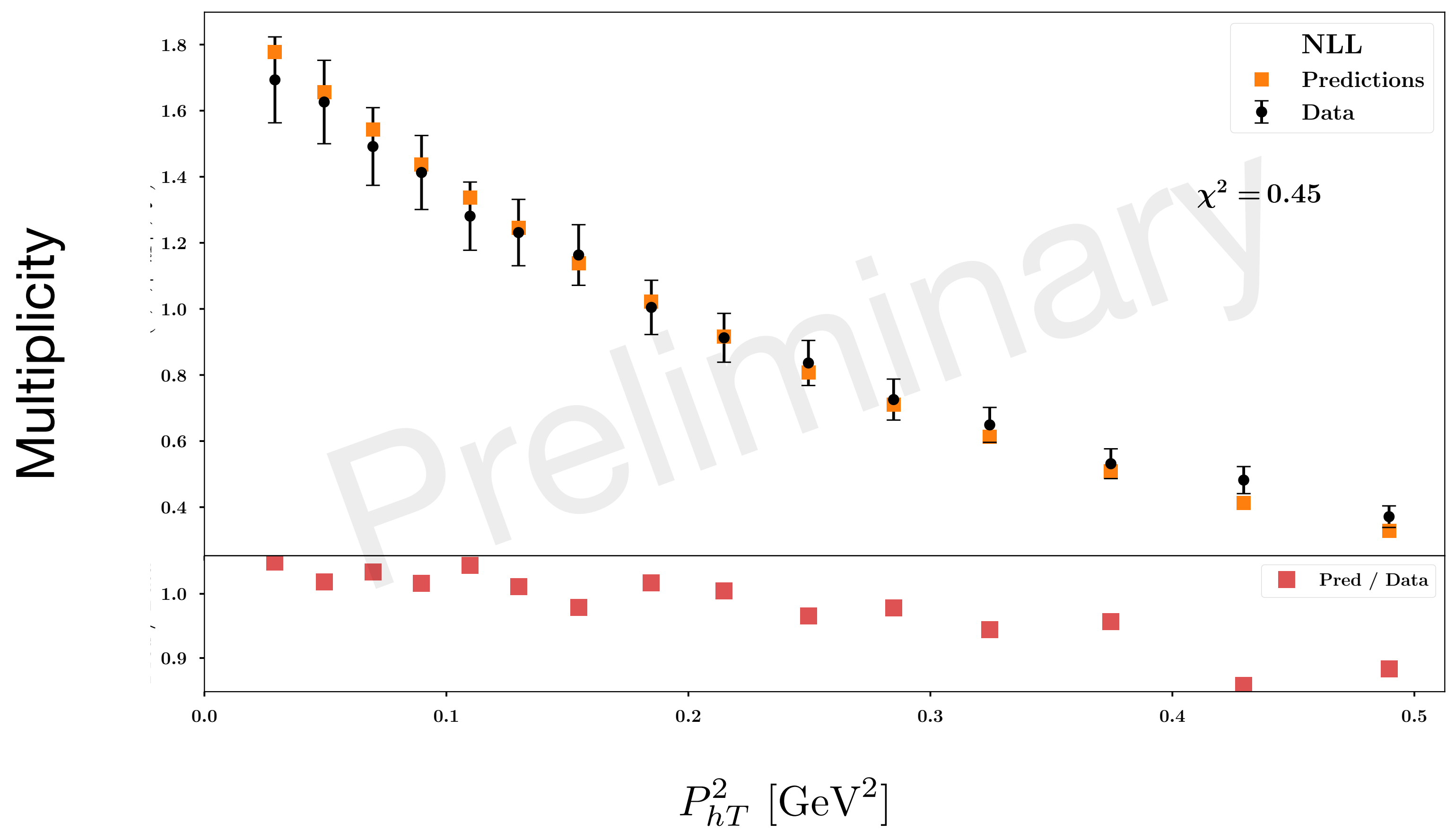
MAPTMD22 — Normalization of SIDIS

SIDIS multiplicities at NLL

HERMES

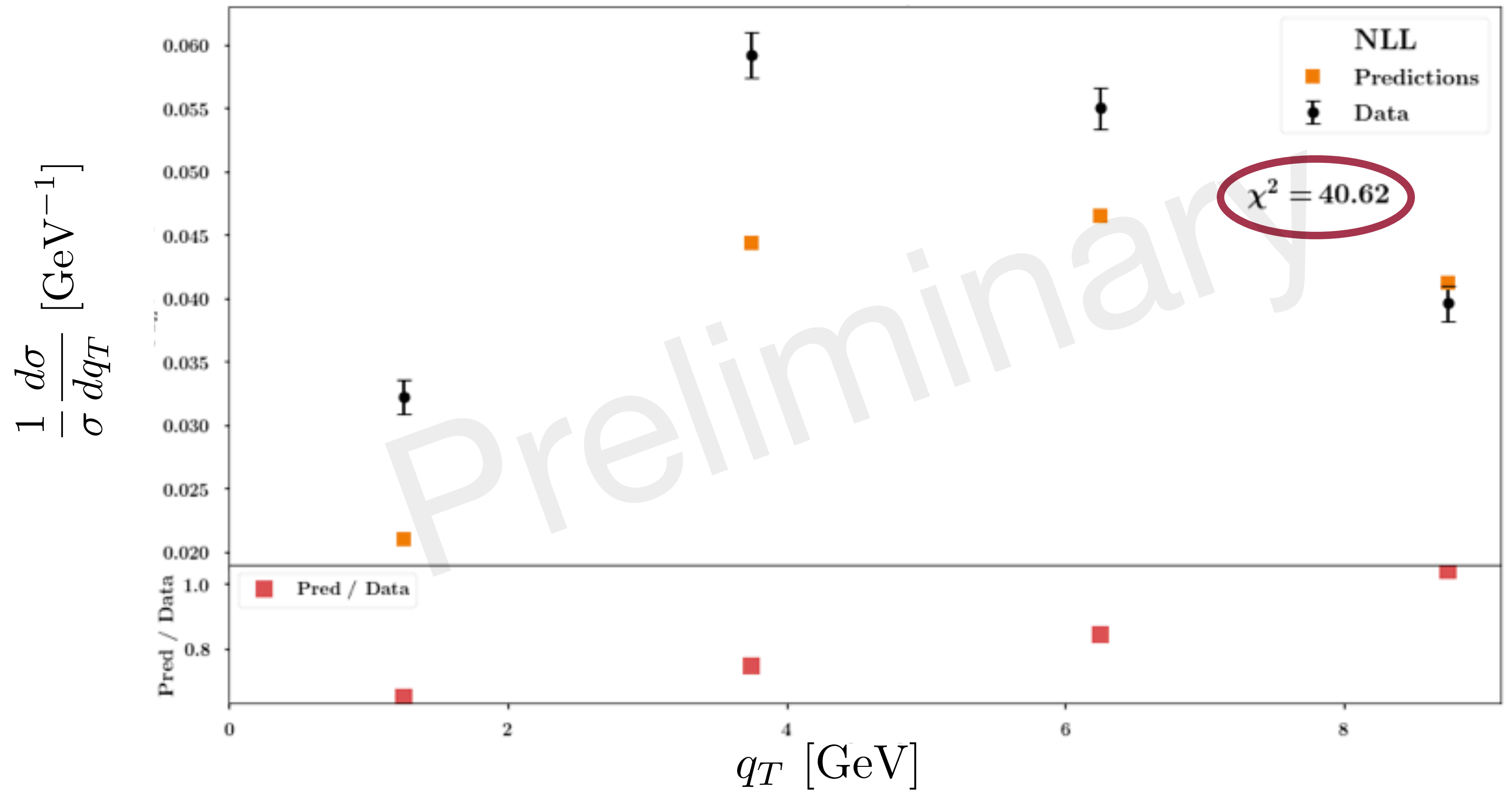


COMPASS

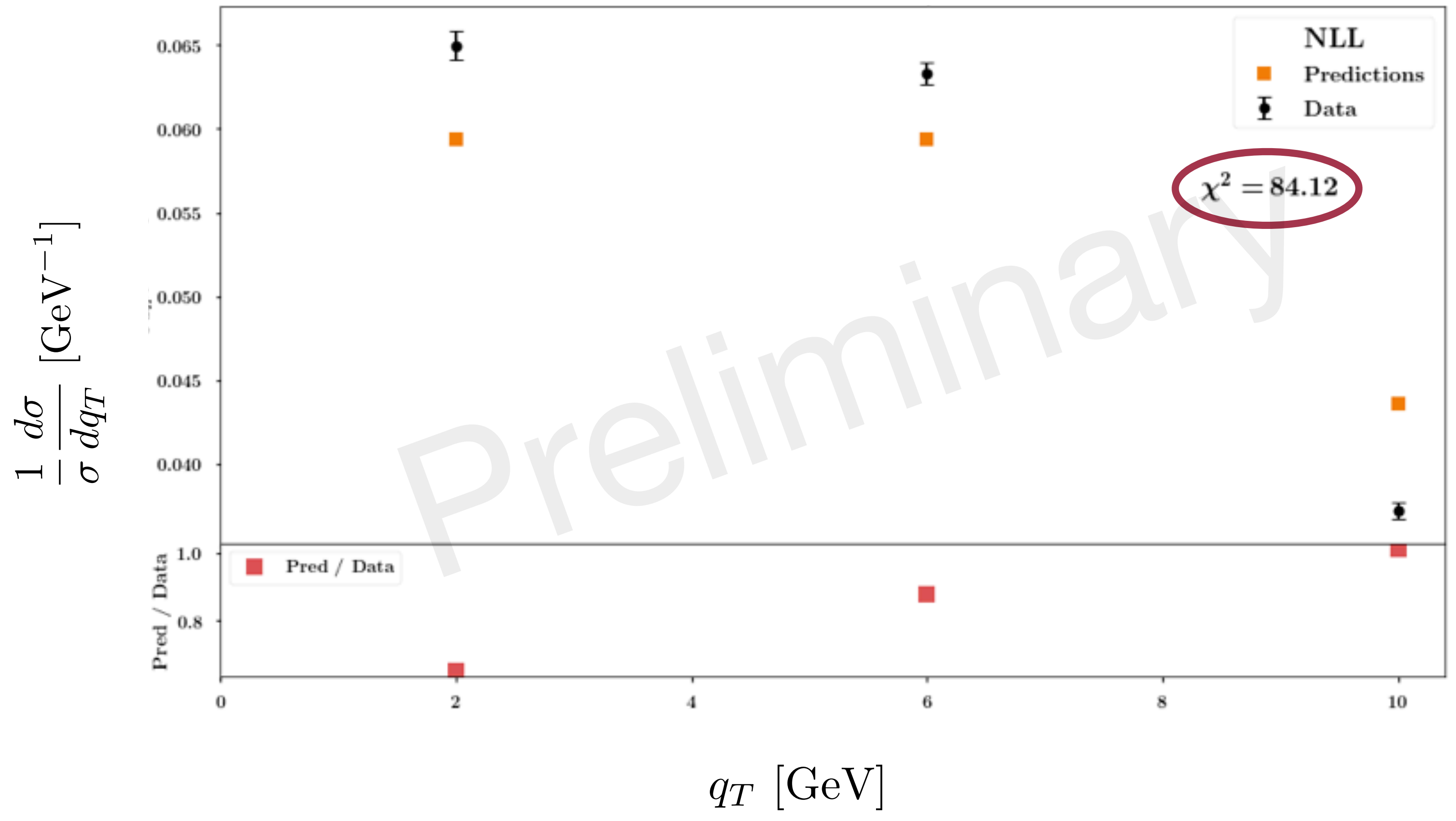


High-Energy Drell-Yan at NLL

CMS 7 TeV



D0 Run II muons

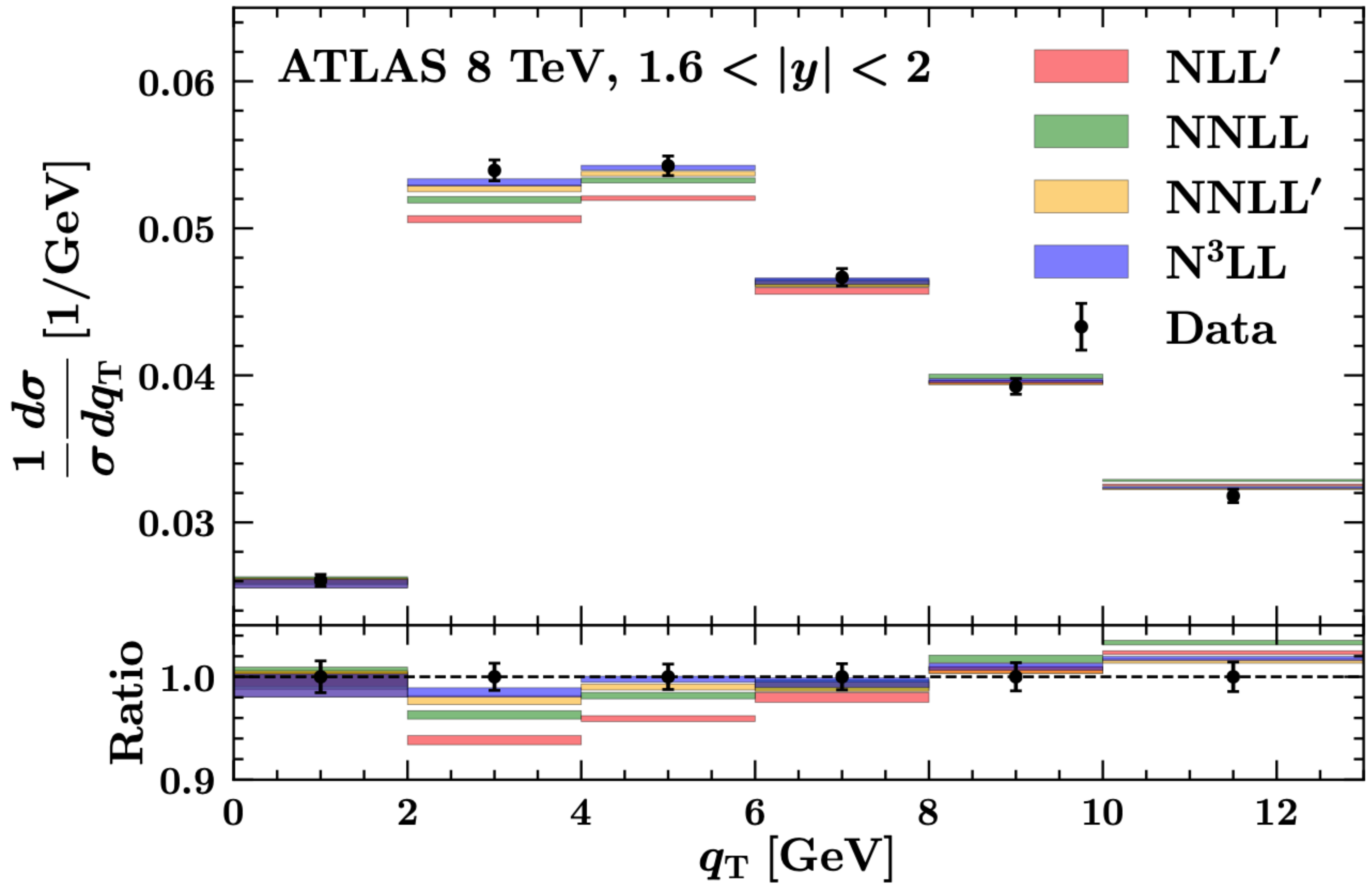


MAPTMD22 — Normalization of SIDIS

MAPTMD22 — Normalization of SIDIS

High-Energy Drell-Yan beyond NLL

$Q \sim 100$ GeV



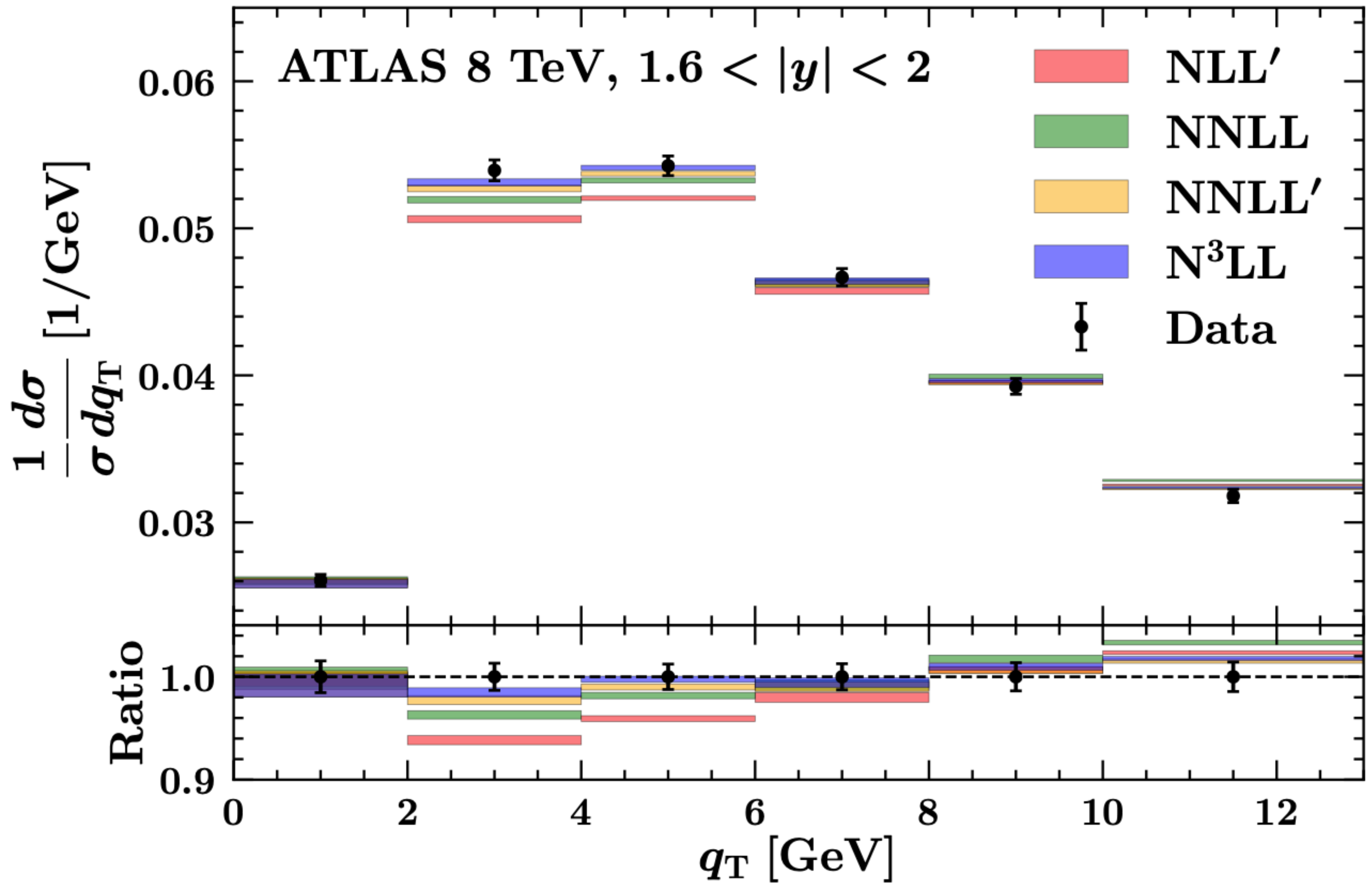
Bacchetta, Bertone, Bissolotti, Bozzi, Delcarro, Piacenza, Radici, arXiv:1912.07550

MAPTMD22 — Normalization of SIDIS

<u>SIDIS multiplicities beyond NLL</u>

<u>High-Energy Drell-Yan beyond NLL</u>

$Q \sim 100$ GeV



Bacchetta, Bertone, Bissolotti, Bozzi, Delcarro, Piacenza, Radici, arXiv:1912.07550

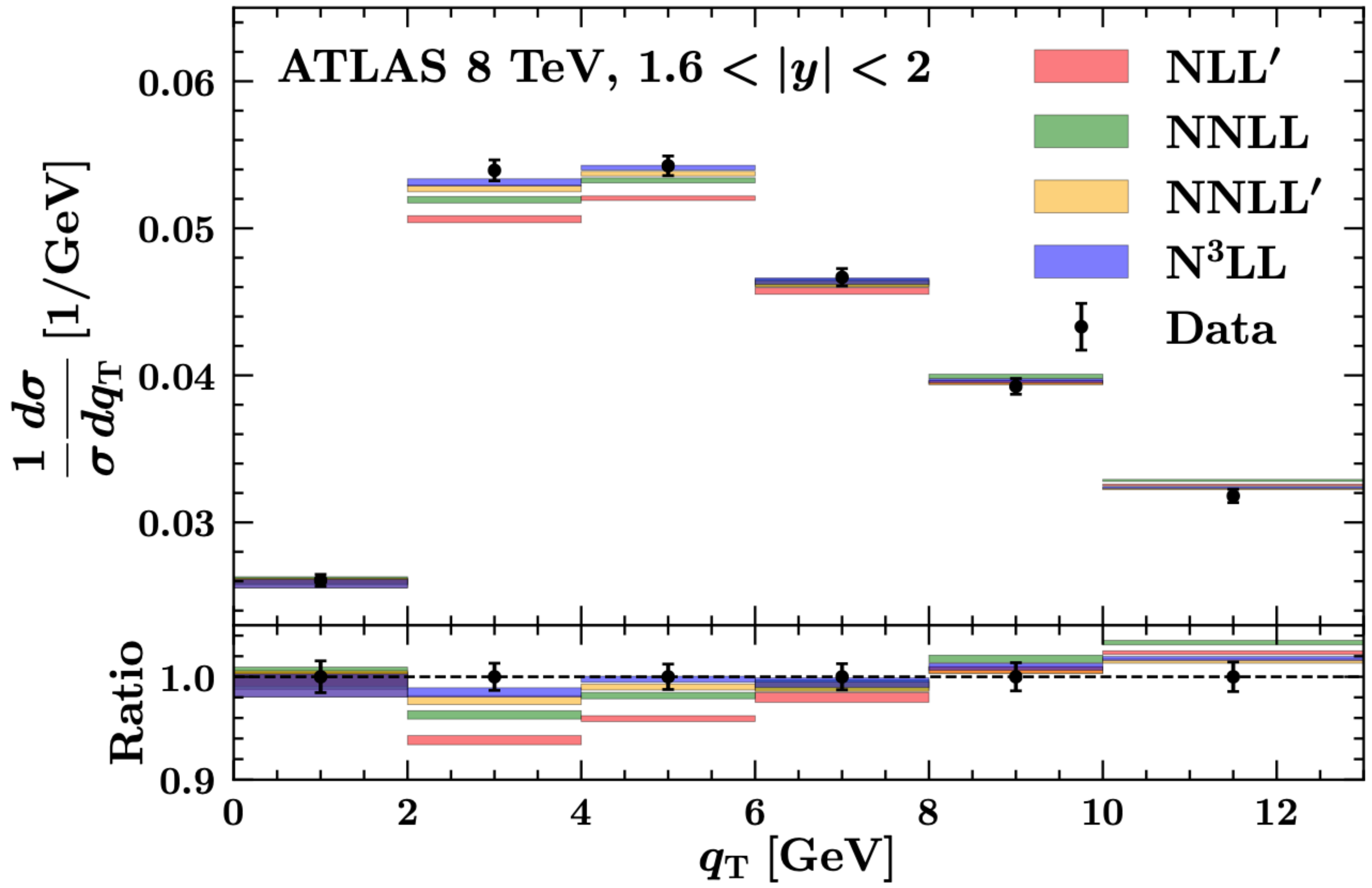
MAPTMD22 — Normalization of SIDIS

SIDIS multiplicities beyond NLL

$Q \sim 2$ GeV

High-Energy Drell-Yan beyond NLL

$Q \sim 100$ GeV

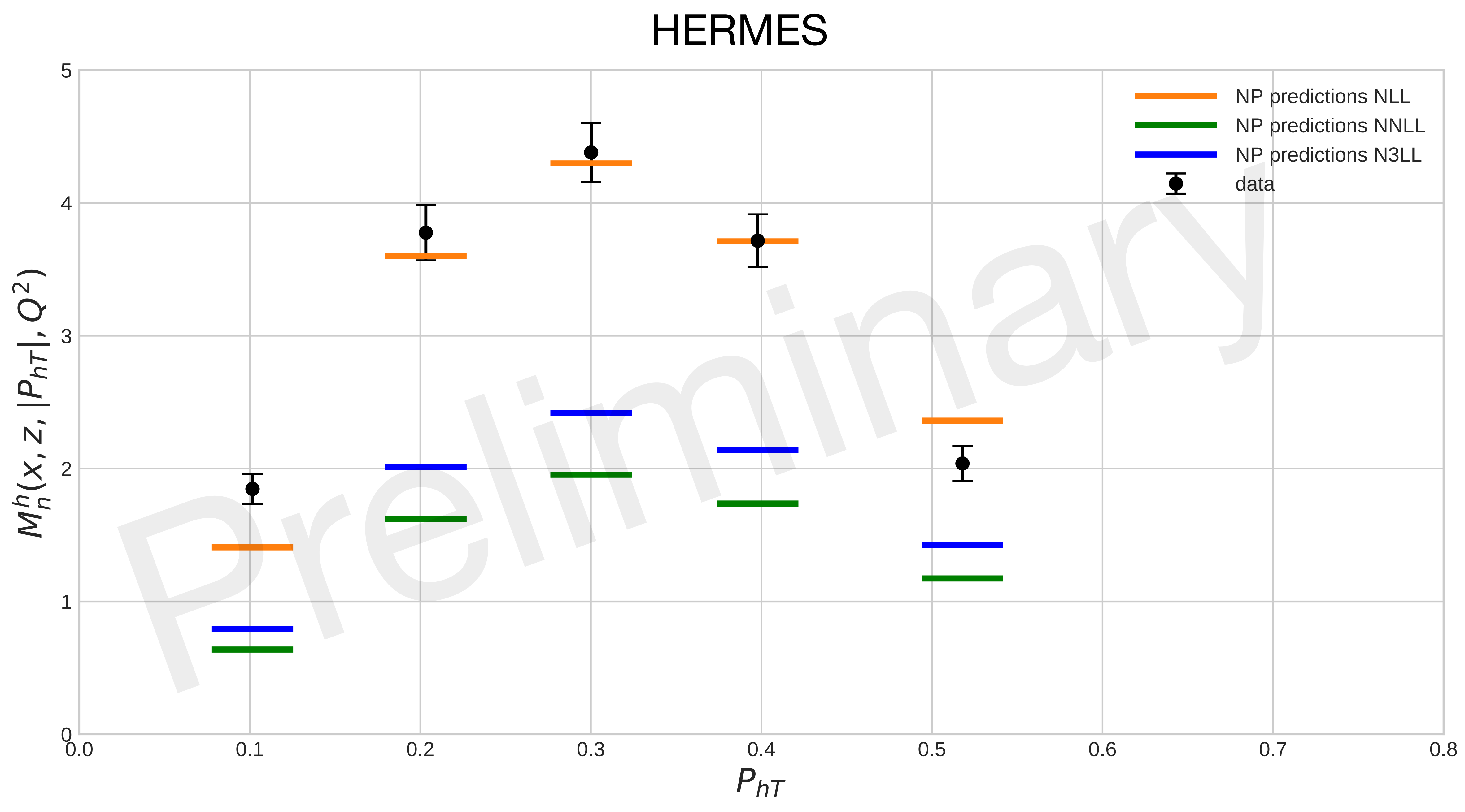


Bacchetta, Bertone, Bissolotti, Bozzi, Delcarro, Piacenza, Radici, arXiv:1912.07550

MAPTMD22 — Normalization of SIDIS

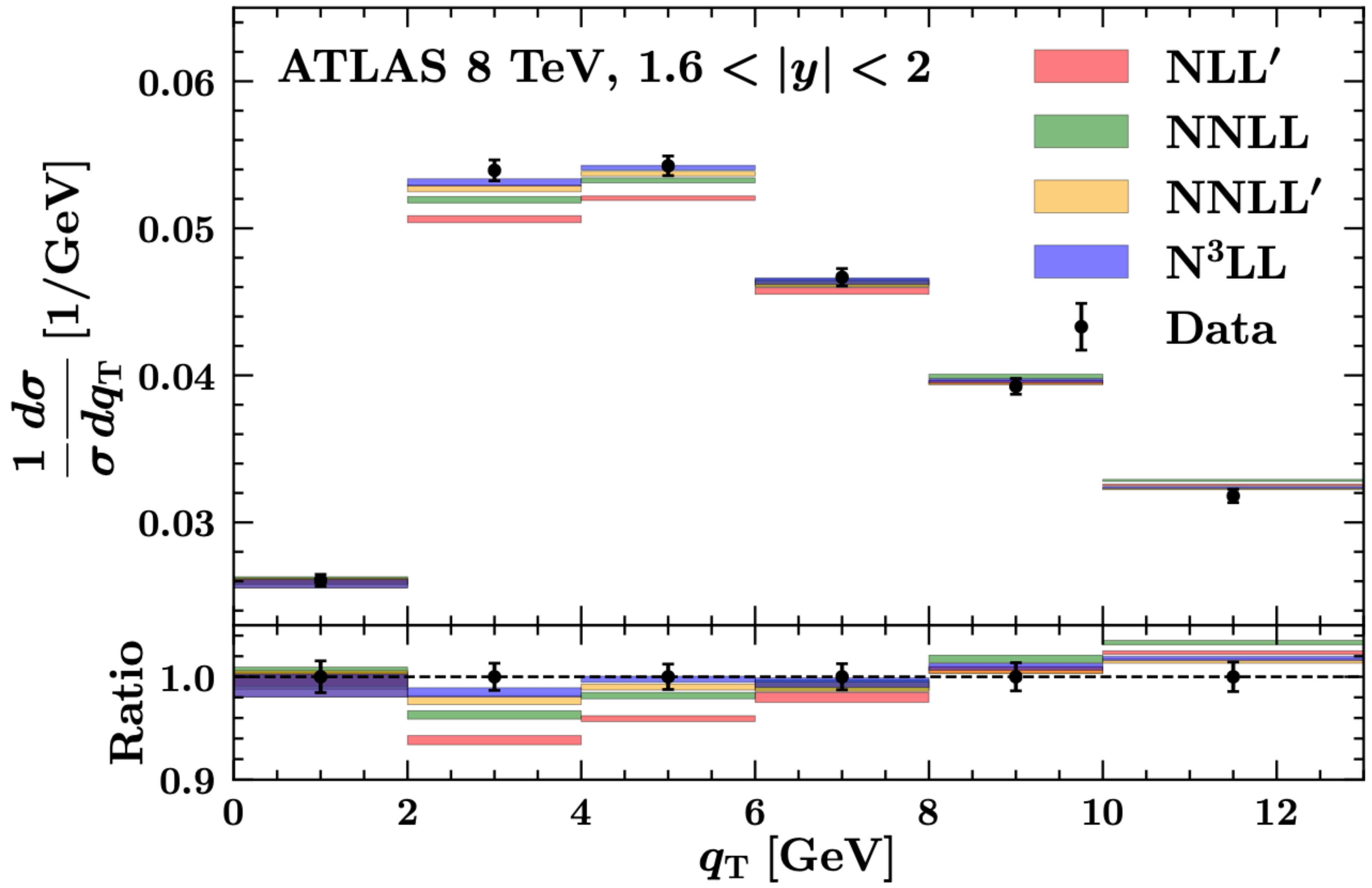
<u>SIDIS multiplicities beyond NLL</u>

$Q \sim 2$ GeV



<u>High-Energy Drell-Yan beyond NLL</u>

$Q \sim 100$ GeV

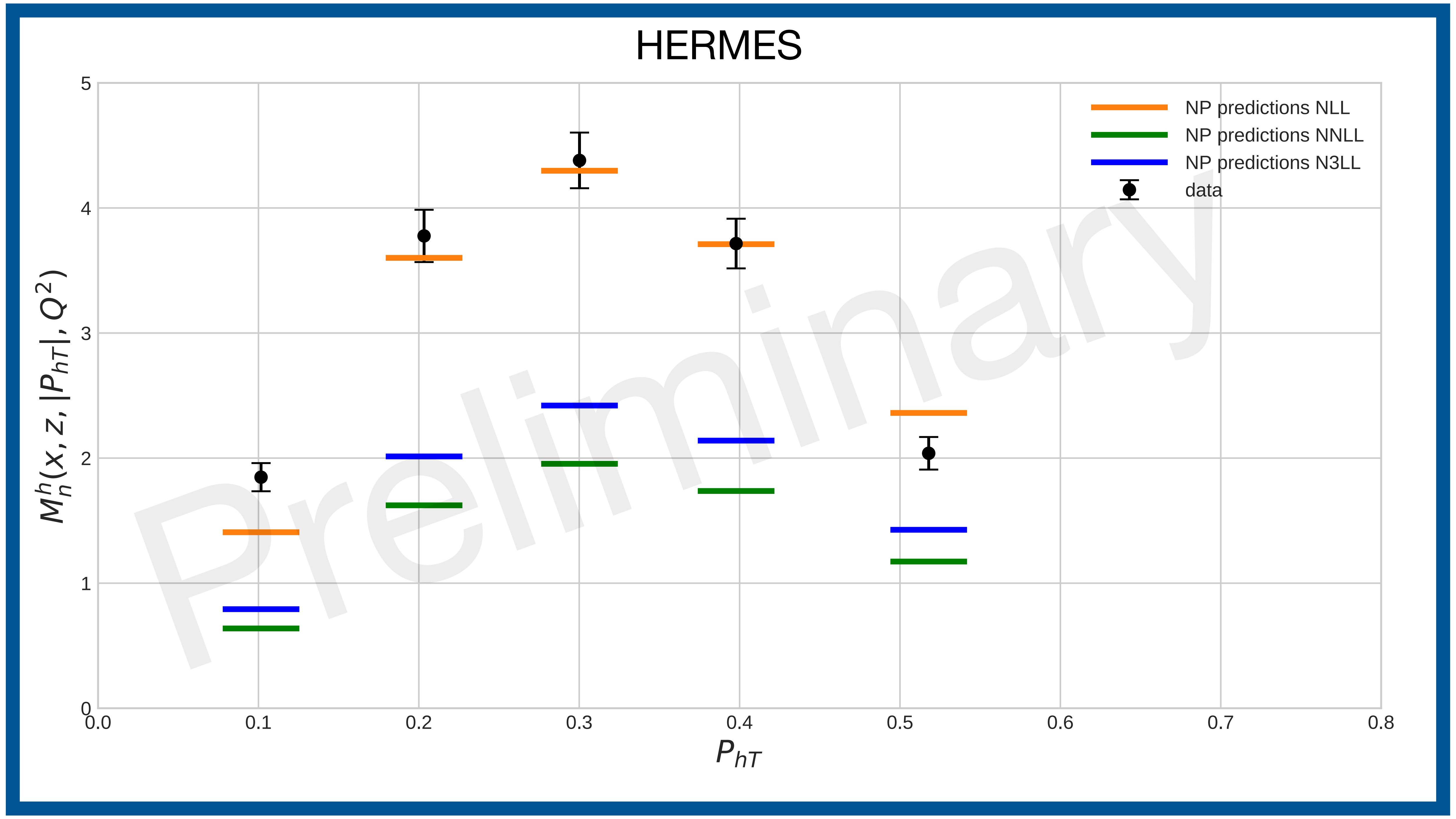


Bacchetta, Bertone, Bissolotti, Bozzi, Delcarro, Piacenza, Radici, arXiv:1912.07550

MAPTMD22 — Normalization of SIDIS

SIDIS multiplicities beyond NLL

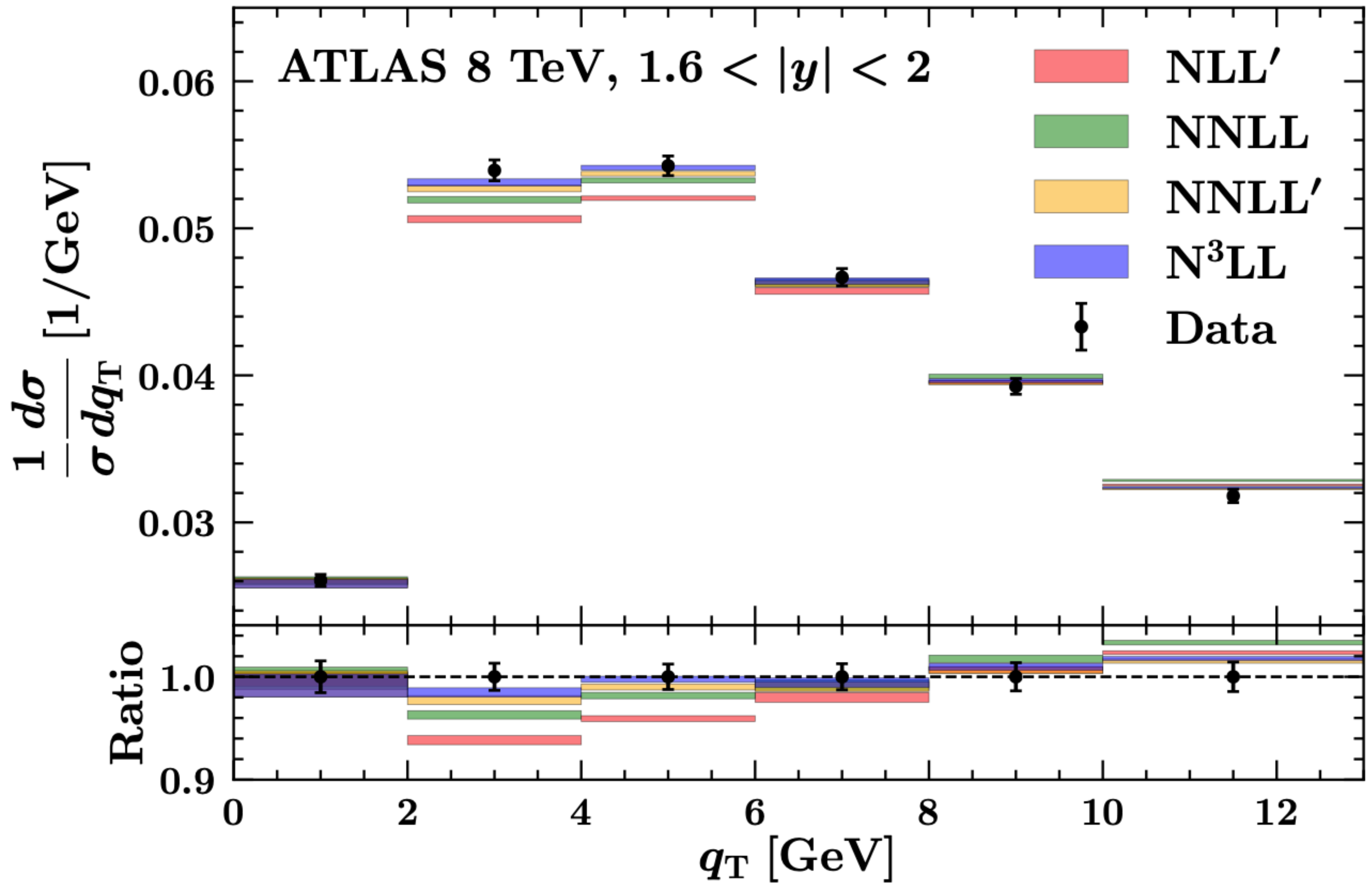
$Q \sim 2$ GeV



The description considerably worsens at higher orders!!

High-Energy Drell-Yan beyond NLL

$Q \sim 100$ GeV

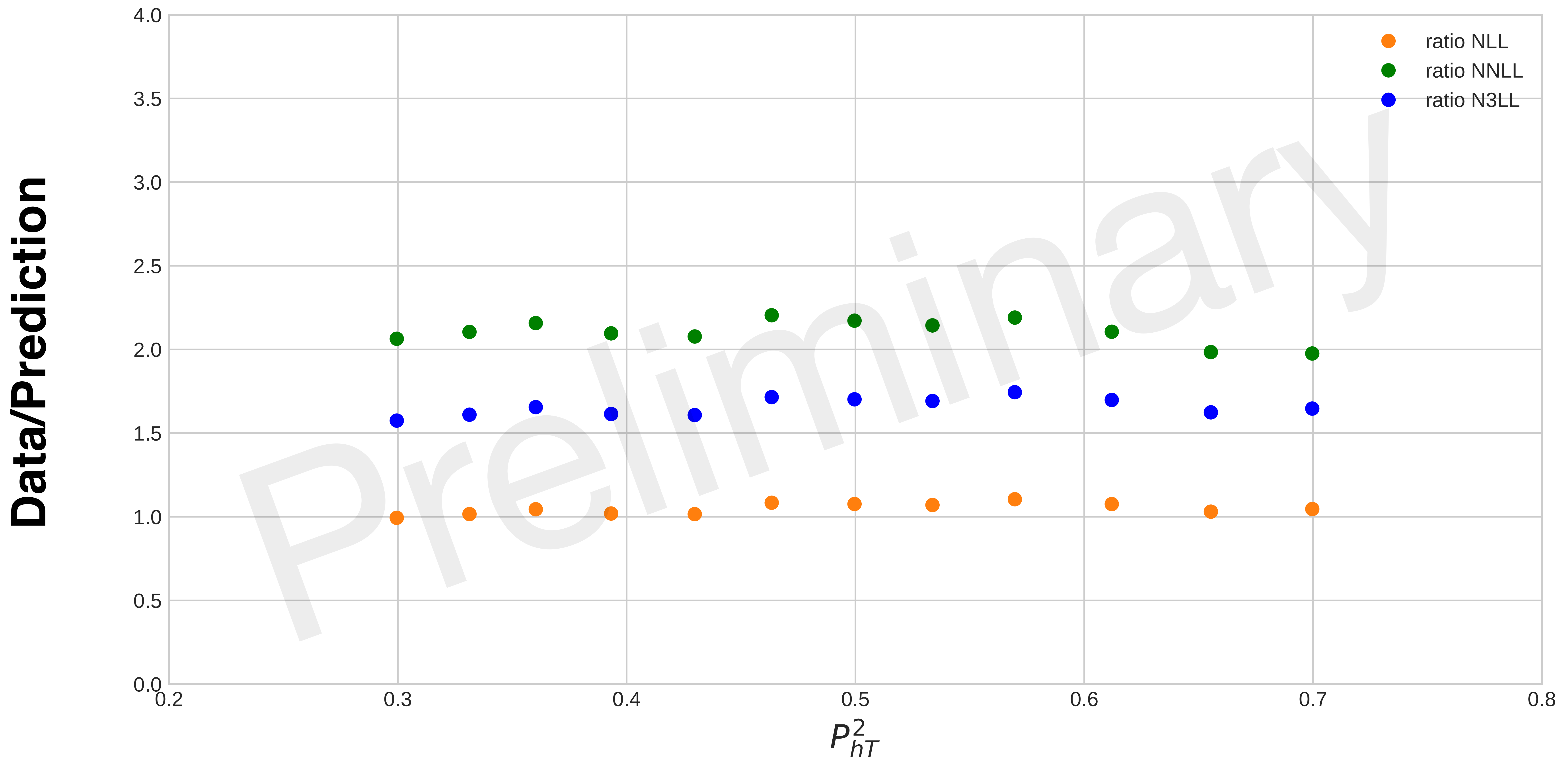


Bacchetta, Bertone, Bissolotti, Bozzi, Delcarro, Piacenza, Radici, arXiv:1912.07550

MAPTMD22 — Normalization of SIDIS

COMPASS multiplicities (one of many bins)

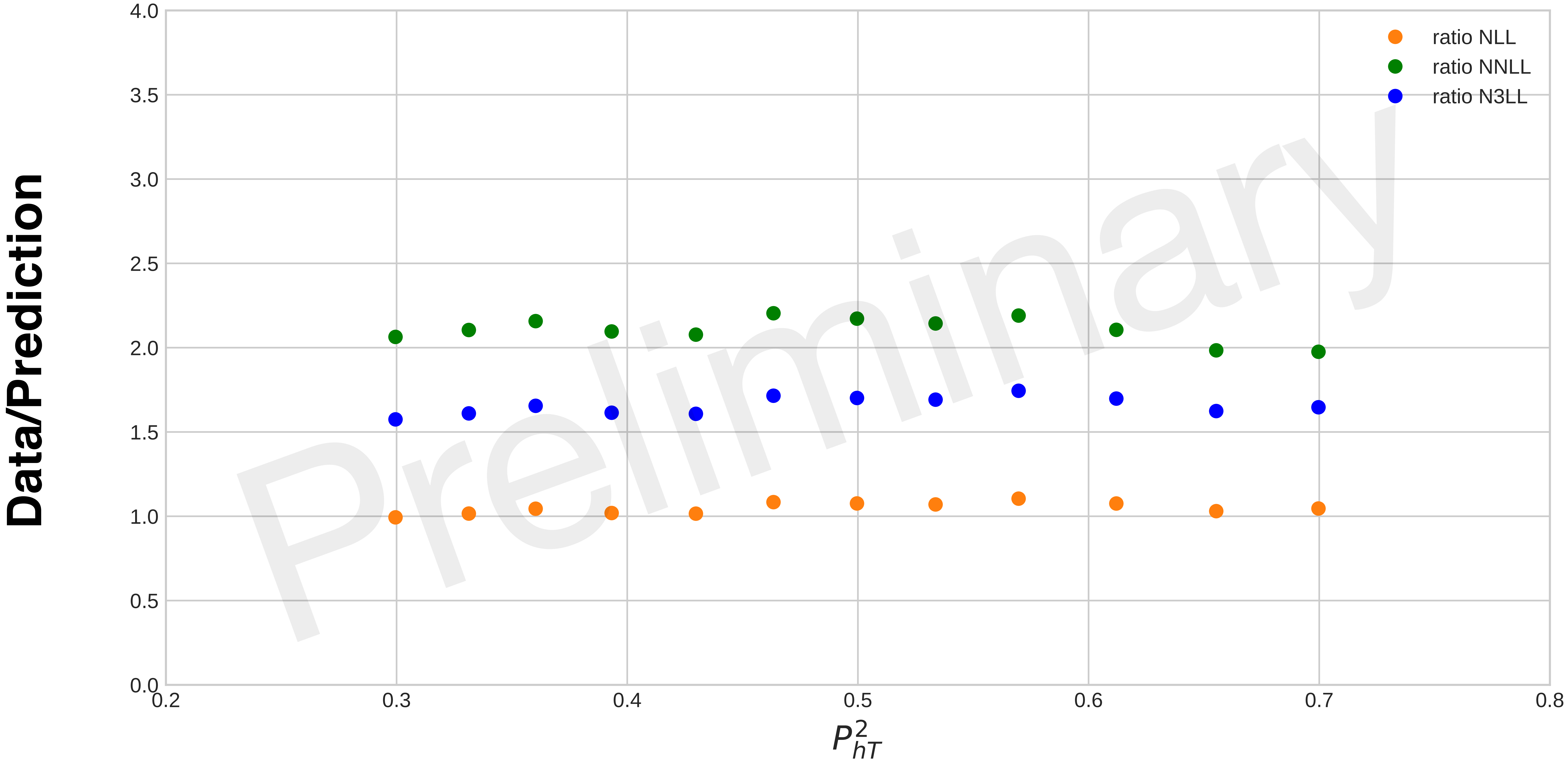
J.O. Gonzalez-Hernandez, PoS DIS2019 (2019) 176



MAPTMD22 — Normalization of SIDIS

COMPASS multiplicities (one of many bins)

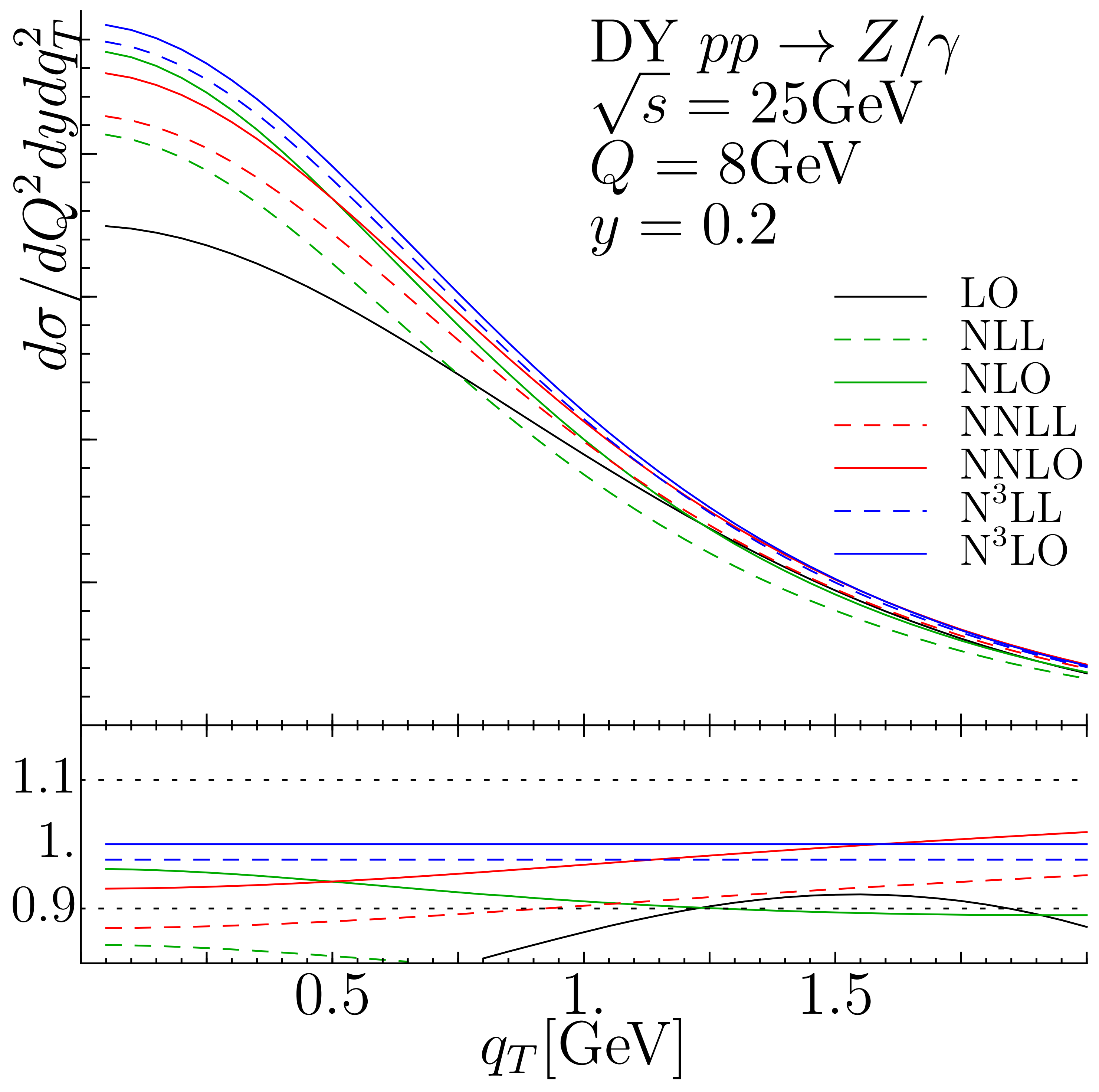
J.O. Gonzalez-Hernandez, PoS DIS2019 (2019) 176



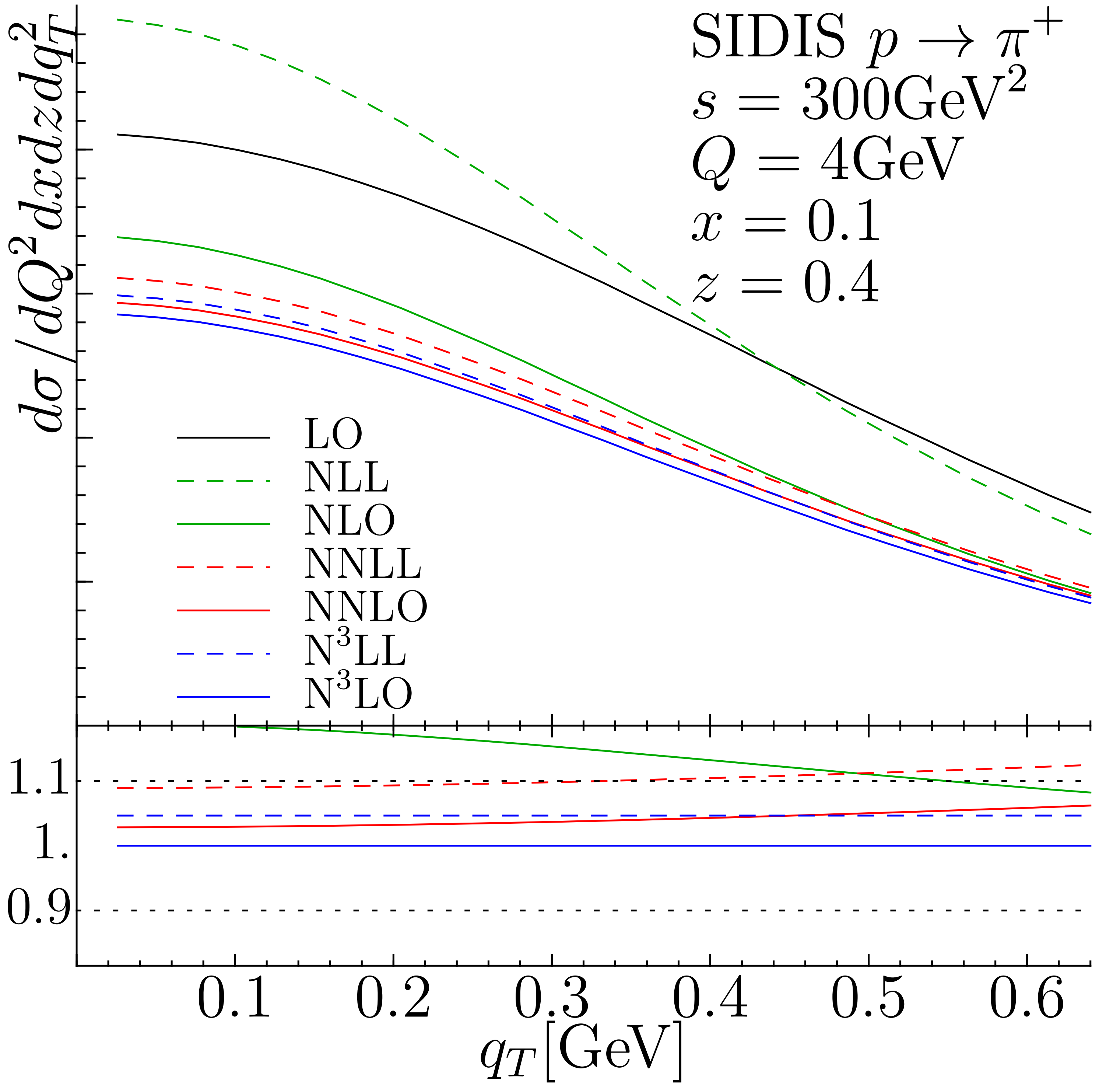
The discrepancy amounts to an almost <u>constant factor</u>!!

Comparison of different orders — SV19

Scimemi, Vladimirov, arXiv:1912.06532



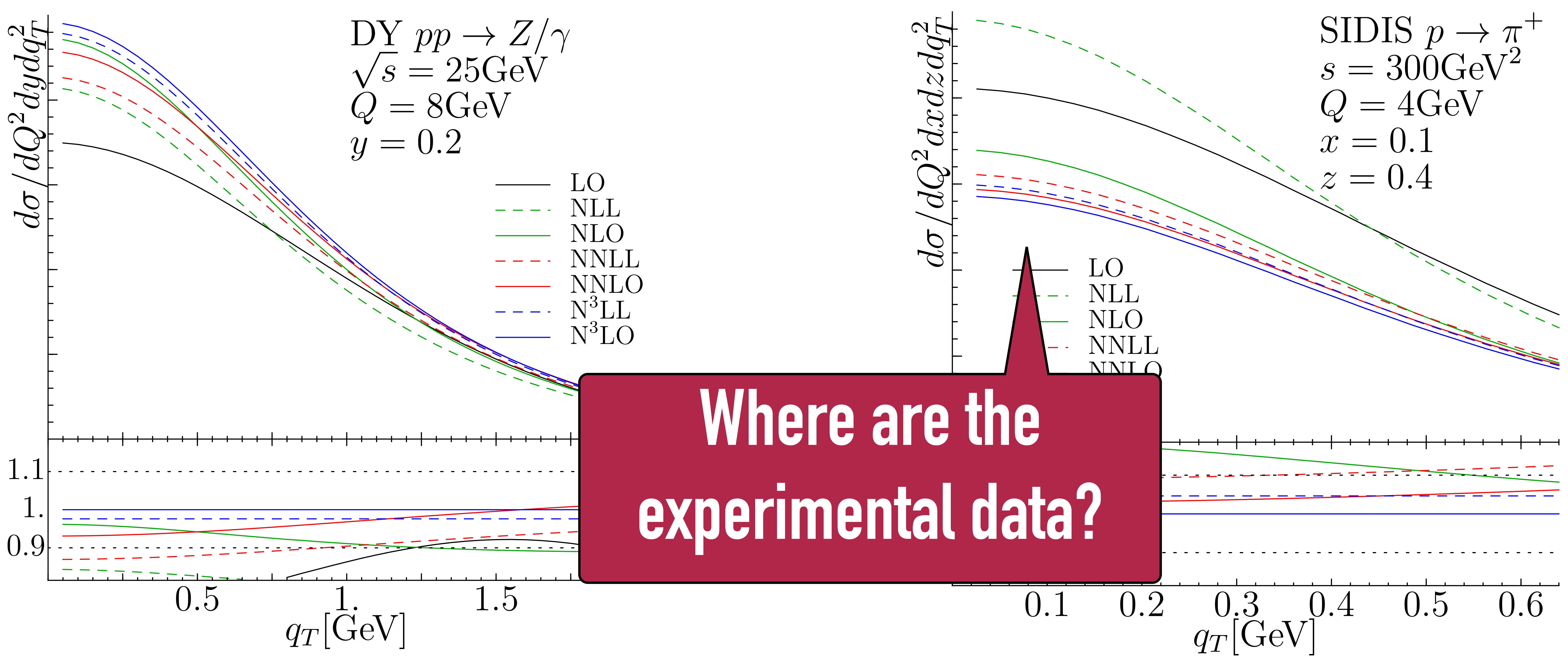
Drell-Yan



SIDIS

Comparison of different orders — SV19

Scimemi, Vladimirov, arXiv:1912.06532

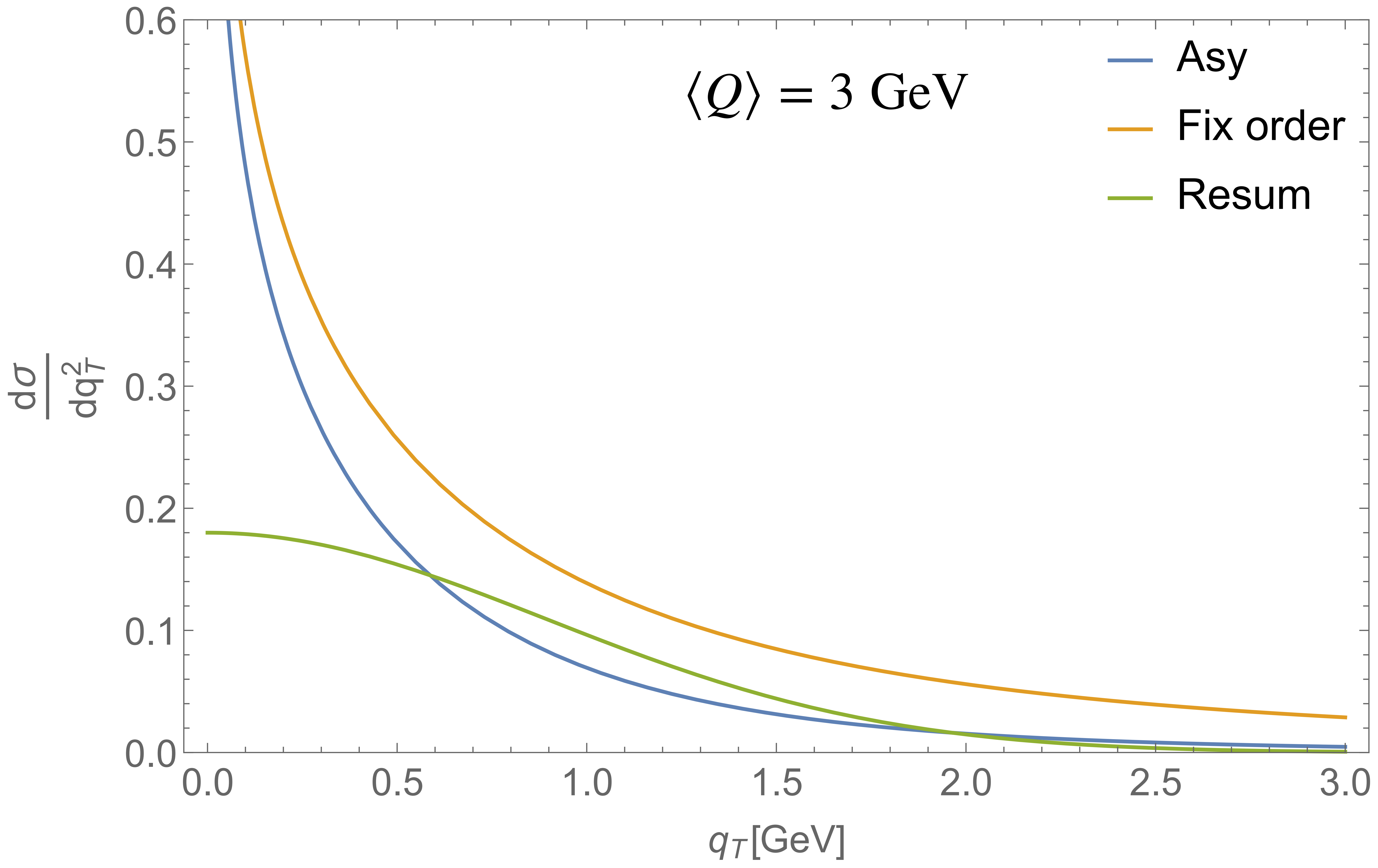


Drell-Yan

SIDIS

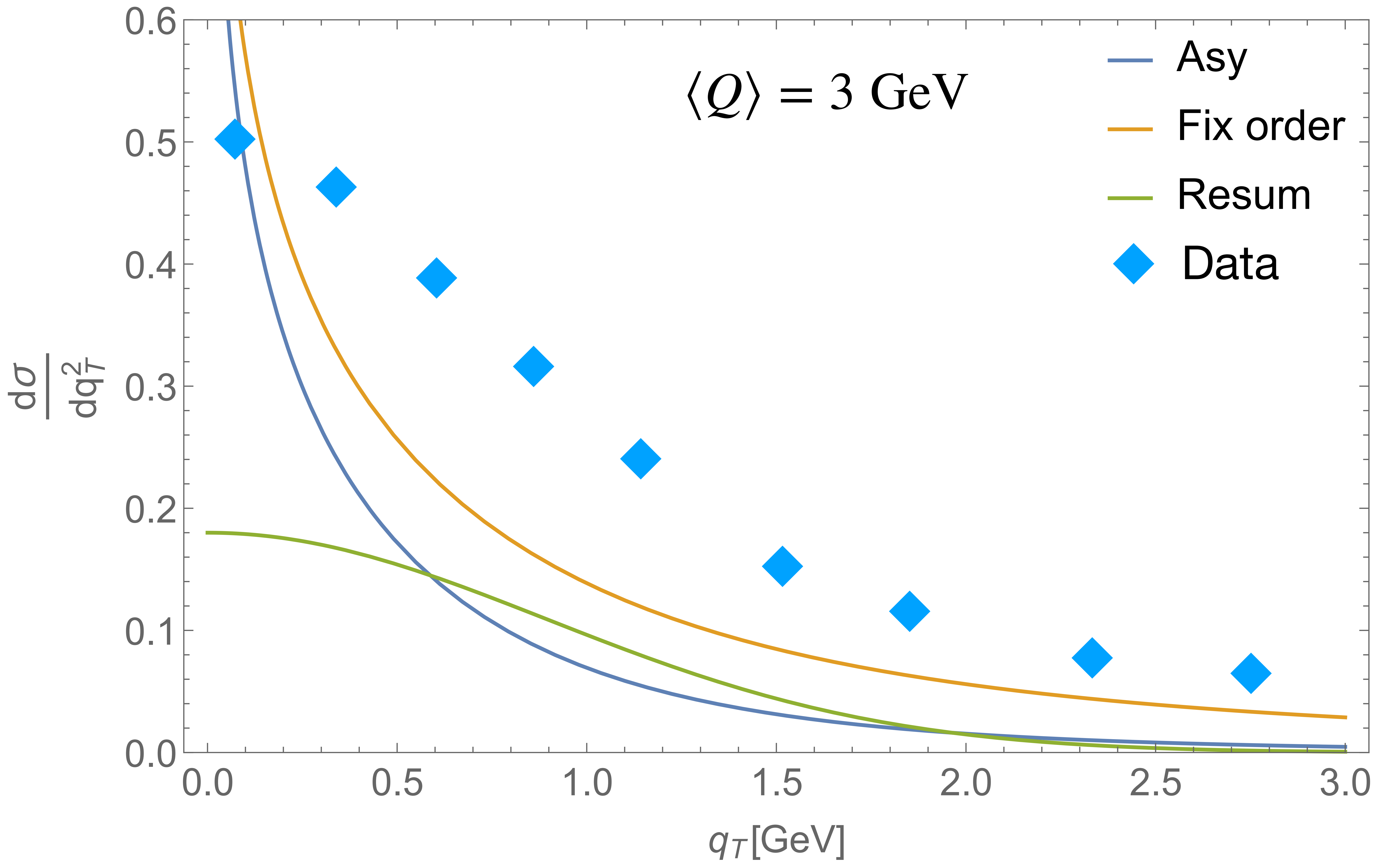
MAPTMD22 — Normalization of SIDIS

According to our formalism



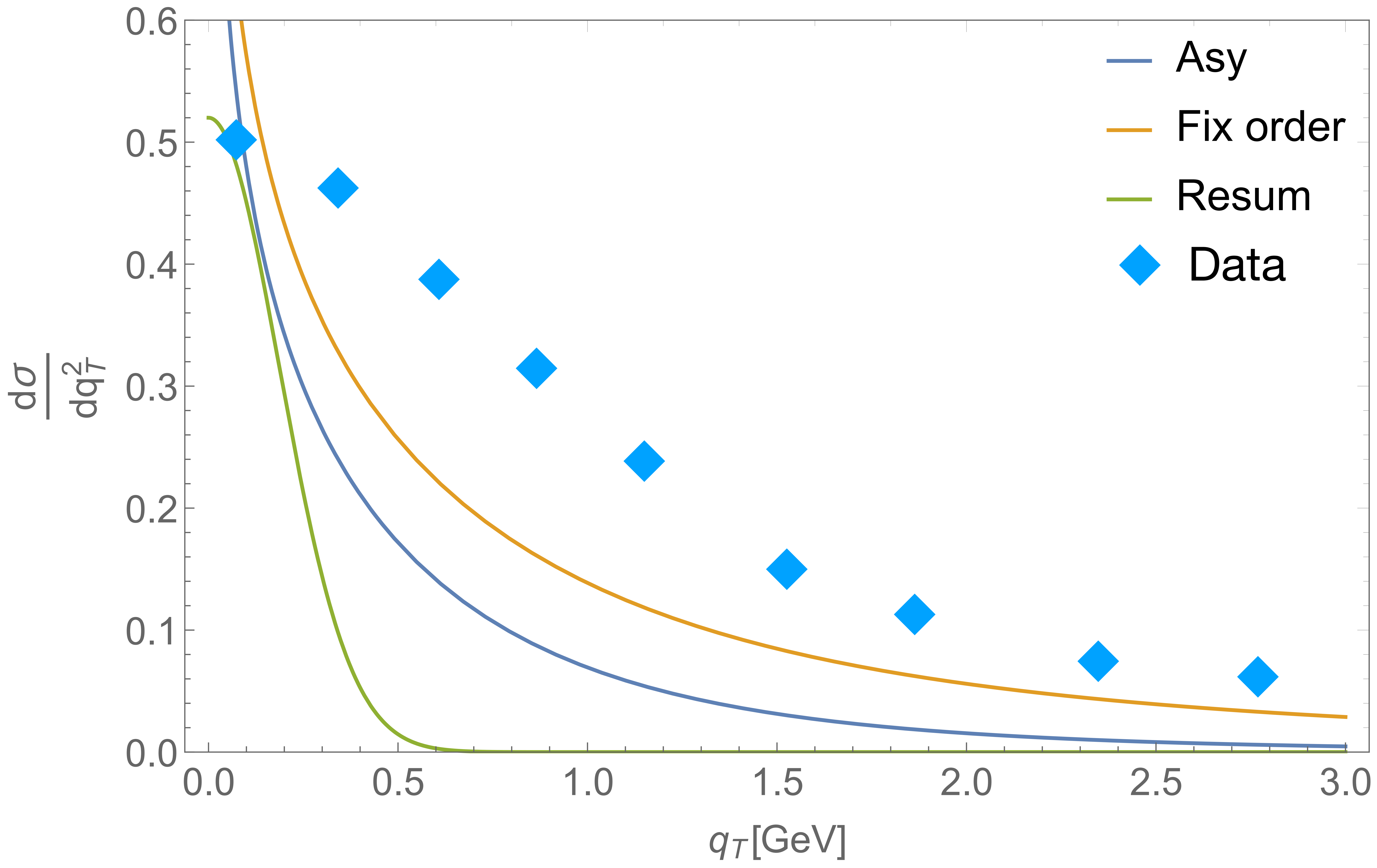
MAPTMD22 — Normalization of SIDIS

According to our formalism



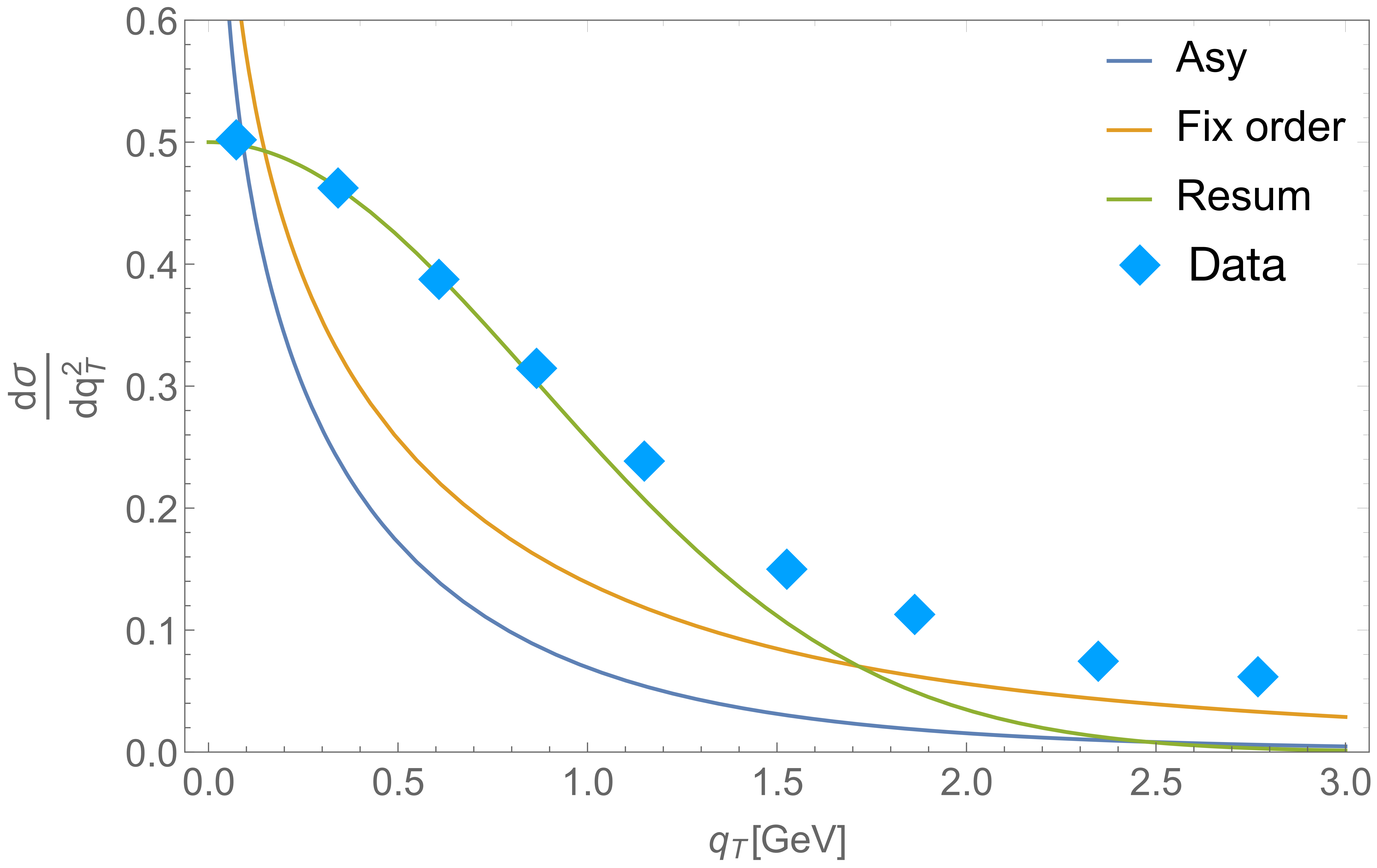
MAPTMD22 — Normalization of SIDIS

<u>Solution1</u>: restrict the TMD region



MAPTMD22 — Normalization of SIDIS

Solution2: enhance TMD contributions



MAPTMD22 — Normalization of SIDIS

MAPTMD22 — Normalization of SIDIS

SIDIS multiplicity

$$M(x, z, P_{hT}, Q) = \frac{d\sigma}{dx dQ dz dP_{hT}} \Bigg/ \frac{d\sigma}{dx dQ}$$

MAPTMD22 — Normalization of SIDIS

SIDIS multiplicity $$M(x, z, P_{hT}, Q) = \frac{d\sigma}{dx dQ dz dP_{hT}} \Bigg/ \frac{d\sigma}{dx dQ}$$

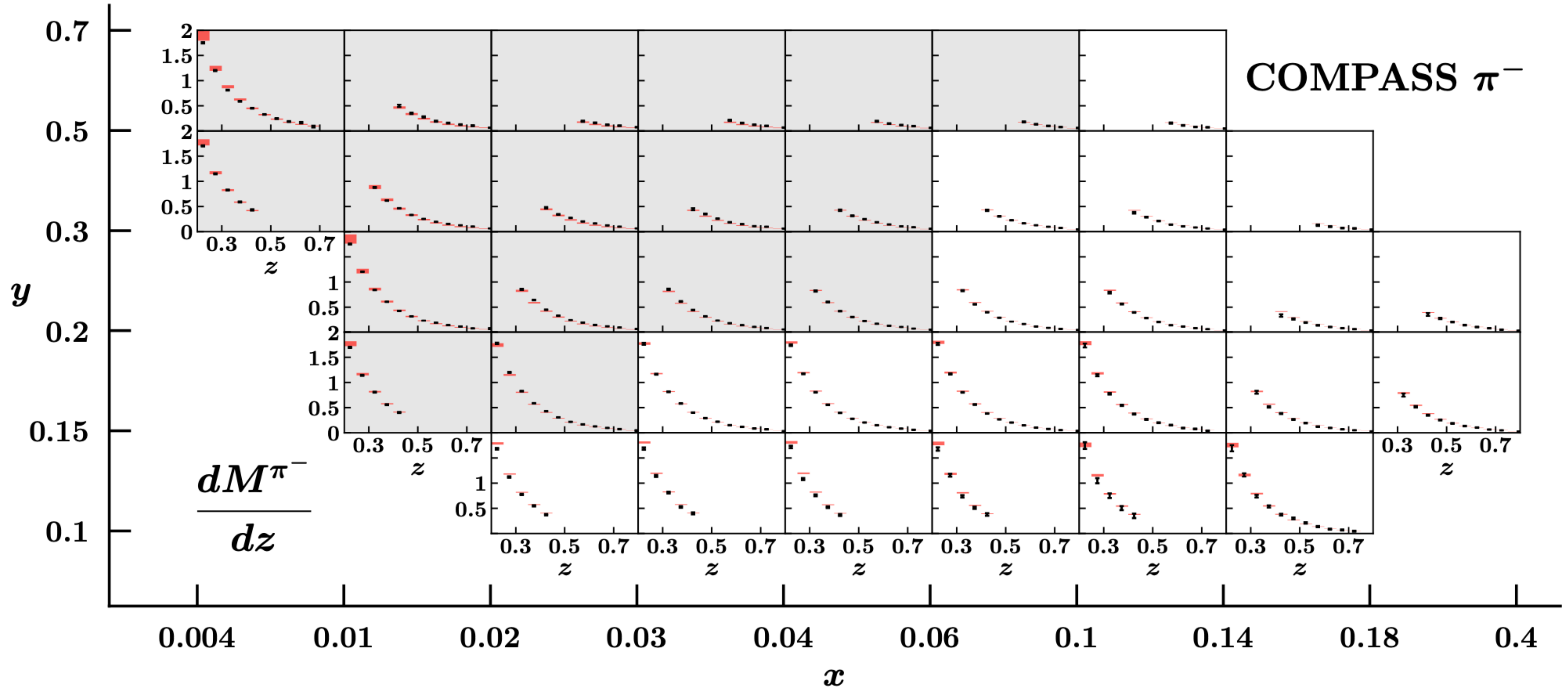
Collinear SIDIS cross section $$\frac{d\sigma}{dx dQ dz}$$

MAPTMD22 — Normalization of SIDIS

SIDIS multiplicity $$M(x, z, P_{hT}, Q) = \frac{d\sigma}{dx dQ dz dP_{hT}} \Big/ \frac{d\sigma}{dx dQ}$$

Collinear SIDIS cross section $$\frac{d\sigma}{dx dQ dz}$$

No problems of normalization!!



Khalek, Bertone, Nocera, arXiv: 2105.08725

MAPTMD22 — Normalization of SIDIS

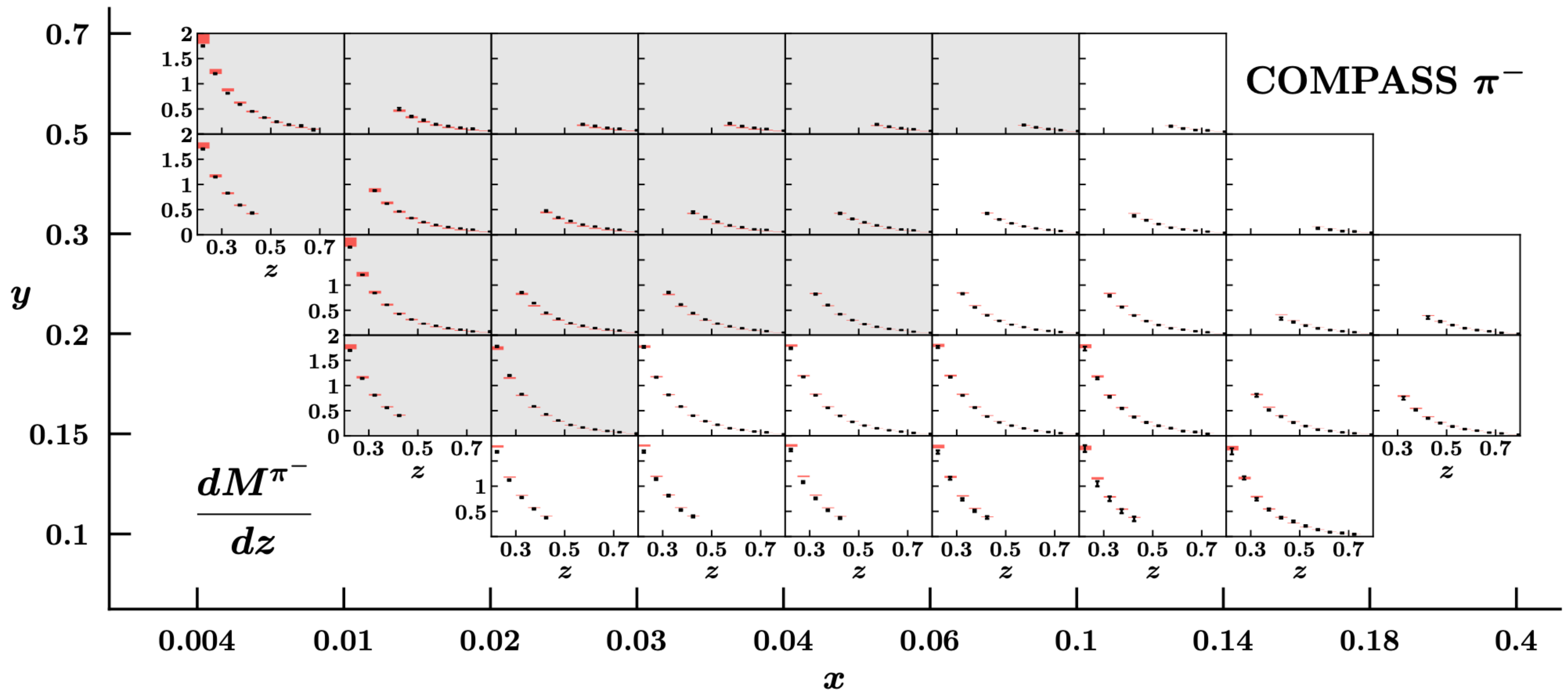
SIDIS multiplicity $$M(x,z,P_{hT},Q) = \frac{d\sigma}{dx dQ dz dP_{hT}} \Bigg/ \frac{d\sigma}{dx dQ}$$

Collinear SIDIS cross section $$\frac{d\sigma}{dx dQ dz}$$

No problems of normalization!!

Normalization of prediction such that

$$\int dP_{hT} \frac{d\sigma}{dx dQ dz dP_{hT}} = \frac{d\sigma}{dx dQ dz}$$



Khalek, Bertone, Nocera, arXiv: 2105.08725

MAPTMD22 — Normalization of SIDIS

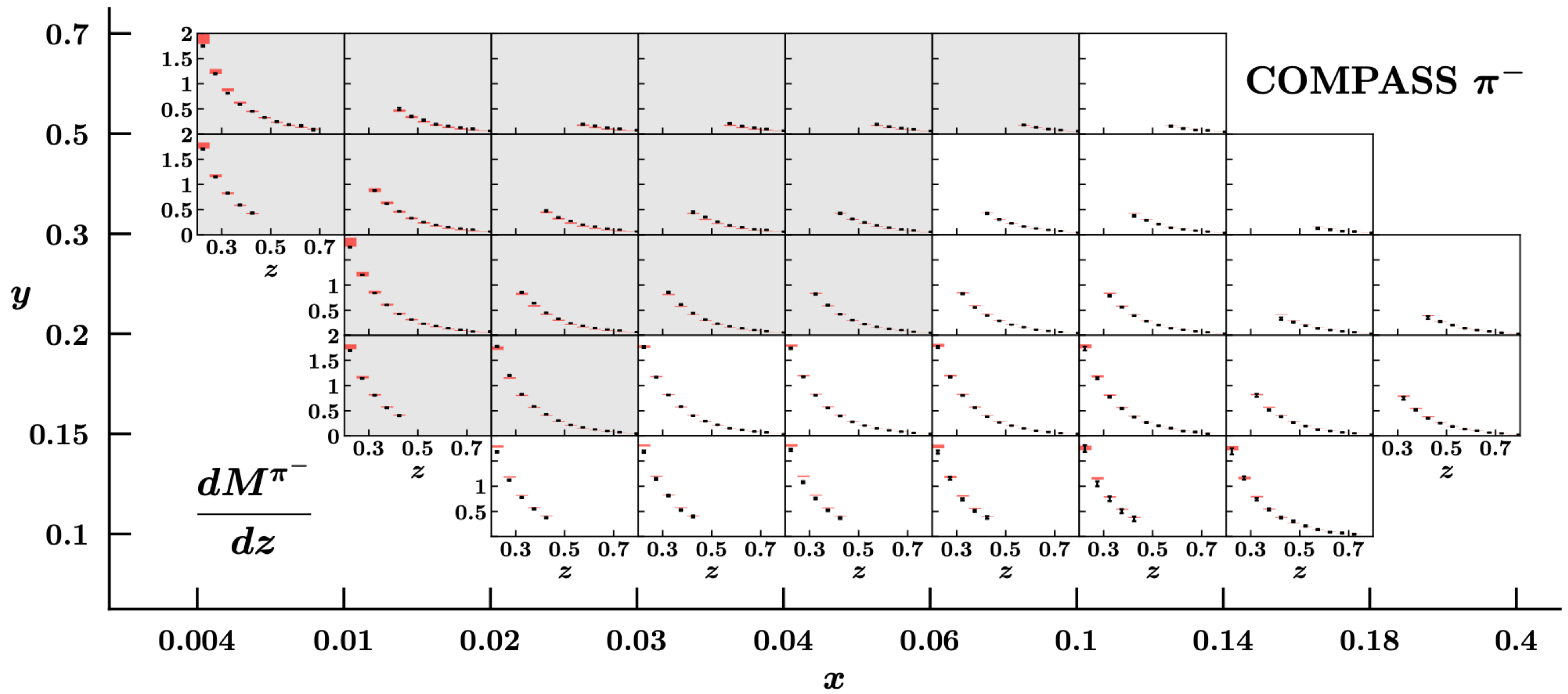
SIDIS multiplicity
$$M(x,z,P_{hT},Q) = \frac{d\sigma}{dxdQdzdP_{hT}} \Big/ \frac{d\sigma}{dxdQ}$$

Collinear SIDIS cross section
$$\frac{d\sigma}{dxdQdz}$$

No problems of normalization!!

Normalization of prediction such that

$$w(x,z,Q) = \frac{d\sigma}{dxdQdz} \Big/ \int dP_{hT} \frac{d\sigma}{dxdQdzdP_{hT}}$$



Khalek, Bertone, Nocera, arXiv: 2105.08725

MAPTMD22 — Normalization of SIDIS

SIDIS multiplicity $$M(x, z, P_{hT}, Q) = \frac{d\sigma}{dx dQ dz dP_{hT}} \Big/ \frac{d\sigma}{dx dQ}$$

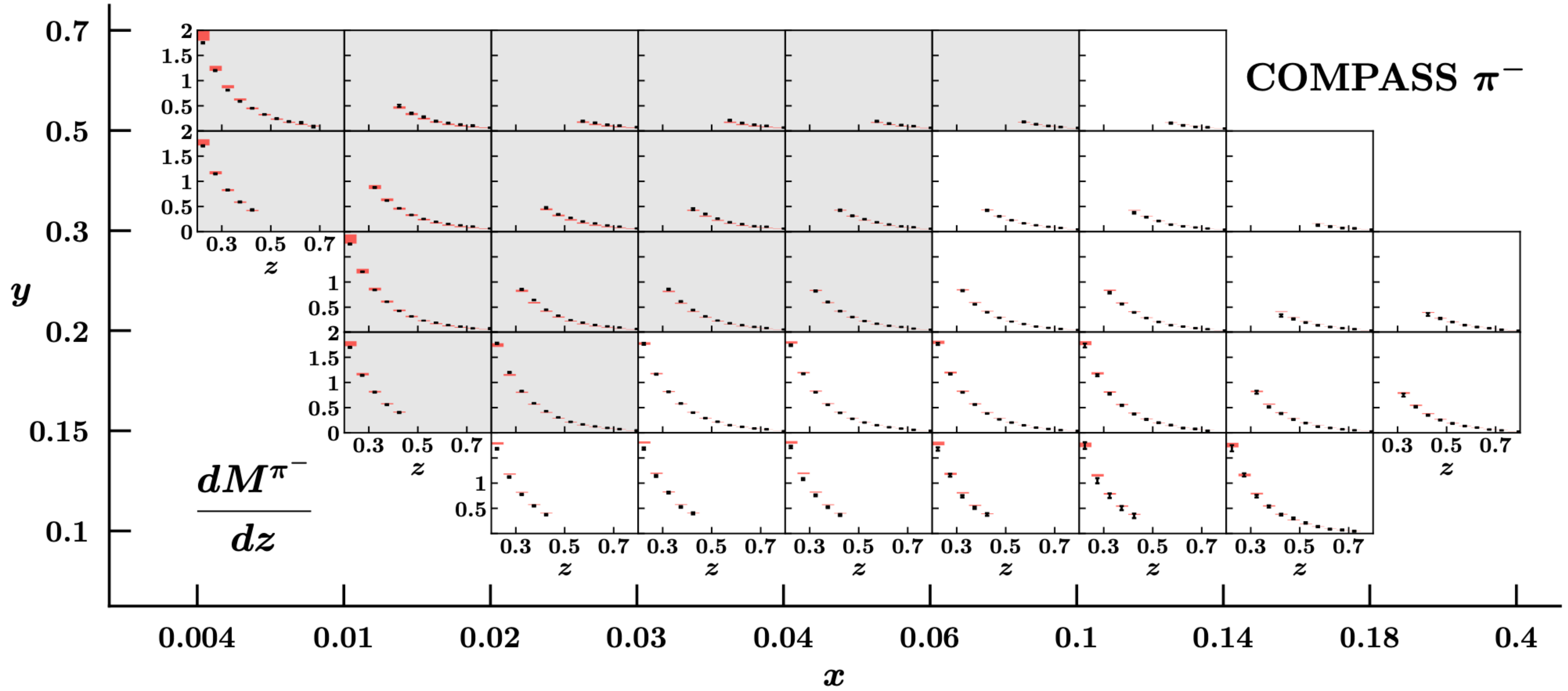
Collinear SIDIS cross section $$\frac{d\sigma}{dx dQ dz}$$

No problems of normalization!!

Normalization of prediction such that

$$w(x, z, Q) = \frac{d\sigma}{dx dQ dz} \Big/ \int dP_{hT} \frac{d\sigma}{dx dQ dz dP_{hT}}$$

$$M(x, z, P_{hT}, Q) = w(x, z, Q) \frac{d\sigma}{dx dQ dz dP_{hT}} \Big/ \frac{d\sigma}{dx dQ}$$



Khalek, Bertone, Nocera, arXiv: 2105.08725

MAPTMD22 — Normalization of SIDIS

SIDIS multiplicity $$M(x,z,P_{hT},Q) = \frac{d\sigma}{dxdQdzdP_{hT}} \Big/ \frac{d\sigma}{dxdQ}$$

Collinear SIDIS cross section $$\frac{d\sigma}{dxdQdz}$$

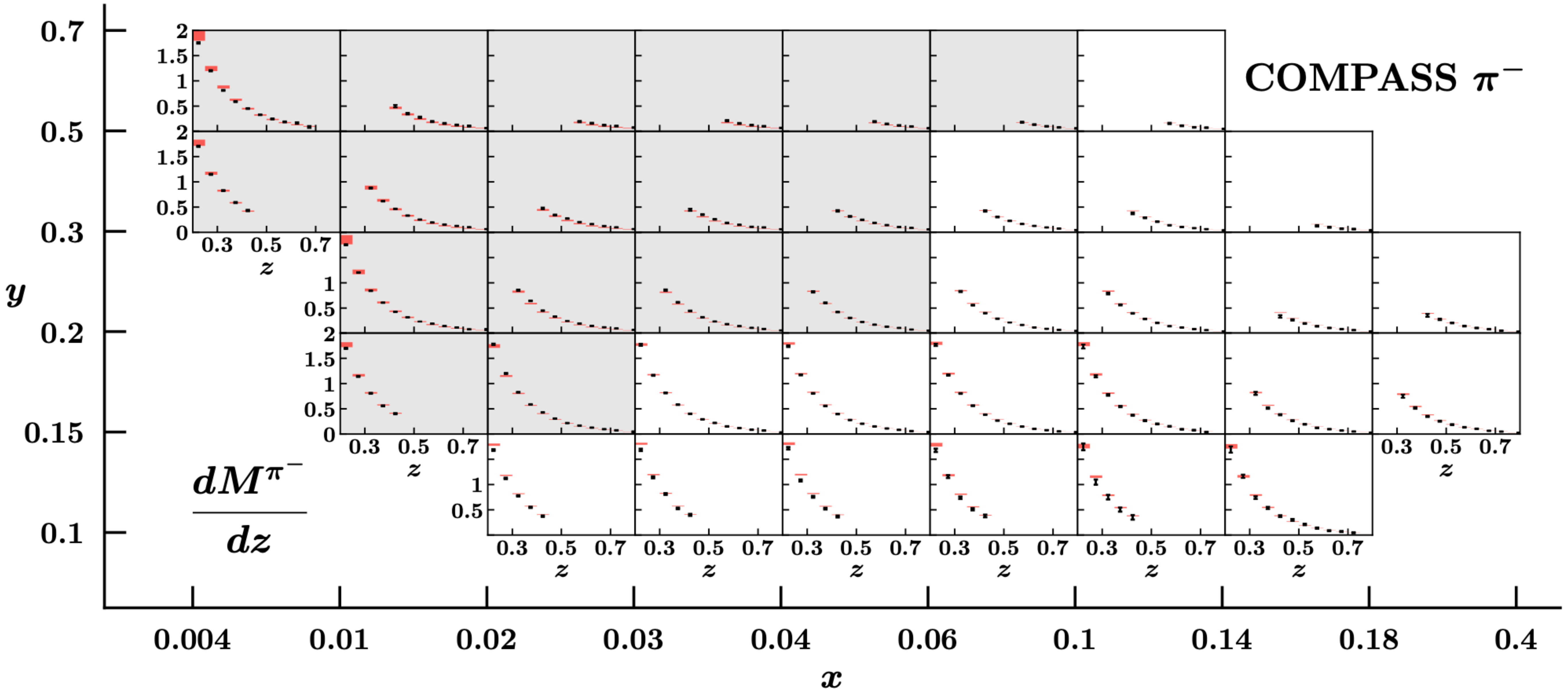
No problems of normalization!!

Normalization of prediction such that

$$w(x,z,Q) = \frac{d\sigma}{dxdQdz} \Big/ \int dP_{hT} \frac{d\sigma}{dxdQdzdP_{hT}}$$

$$M(x,z,P_{hT},Q) = w(x,z,Q) \frac{d\sigma}{dxdQdzdP_{hT}} \Big/ \frac{d\sigma}{dxdQ}$$

Independent of the fitting parameters!!



Khalek, Bertone, Nocera, arXiv: 2105.08725

MAPTMD22 — Parameterization of TMDs

$$f_{1\mathrm{NP}}(x, b_T^2) \propto \text{F.T. of} \left(e^{-\frac{k_\perp^2}{g_{1A}}} + \lambda_B k_\perp^2 e^{-\frac{k_\perp^2}{g_{1B}}} + \lambda_C e^{-\frac{k_\perp^2}{g_{1C}}} \right)$$

MAPTMD22 — Parameterization of TMDs

$$f_{1\mathrm{NP}}(x, b_T^2) \propto \text{F.T. of} \left(e^{-\frac{k_\perp^2}{g_{1A}}} + \lambda_B k_\perp^2 e^{-\frac{k_\perp^2}{g_{1B}}} + \lambda_C e^{-\frac{k_\perp^2}{g_{1C}}} \right)$$

$$g_1(x) = N_1 \frac{(1-x)^\alpha \; x^\sigma}{(1-\hat{x})^\alpha \; \hat{x}^\sigma}$$

MAPTMD22 — Parameterization of TMDs

$$f_{1\mathrm{NP}}(x, b_T^2) \propto \text{F.T. of } \left(e^{-\frac{k_\perp^2}{g_{1A}}} + \lambda_B k_\perp^2 e^{-\frac{k_\perp^2}{g_{1B}}} + \lambda_C e^{-\frac{k_\perp^2}{g_{1C}}} \right)$$

$$D_{1\mathrm{NP}}(x, b_T^2) \propto \text{F.T. of } \left(e^{-\frac{P_\perp^2}{g_{3A}}} + \lambda_{FB} k_\perp^2 e^{-\frac{P_\perp^2}{g_{3B}}} \right)$$

$$g_1(x) = N_1 \frac{(1-x)^\alpha \; x^\sigma}{(1-\hat{x})^\alpha \; \hat{x}^\sigma}$$

MAPTMD22 — Parameterization of TMDs

$$f_{1\mathrm{NP}}(x, b_T^2) \propto \text{F.T. of } \left(e^{-\frac{k_\perp^2}{g_{1A}}} + \lambda_B k_\perp^2 e^{-\frac{k_\perp^2}{g_{1B}}} + \lambda_C e^{-\frac{k_\perp^2}{g_{1C}}} \right)$$

$$g_1(x) = N_1 \frac{(1-x)^\alpha \; x^\sigma}{(1-\hat{x})^\alpha \; \hat{x}^\sigma}$$

$$D_{1\mathrm{NP}}(x, b_T^2) \propto \text{F.T. of } \left(e^{-\frac{P_\perp^2}{g_{3A}}} + \lambda_{FB} k_\perp^2 e^{-\frac{P_\perp^2}{g_{3B}}} \right)$$

$$g_3(z) = N_3 \frac{(z^\beta + \delta)(1-z)^\gamma}{(\hat{z}^\beta + \delta)(1-\hat{z})^\gamma}$$

MAPTMD22 — Parameterization of TMDs

$$f_{1NP}(x, b_T^2) \propto \text{F.T. of } \left(e^{-\frac{k_\perp^2}{g_{1A}}} + \lambda_B k_\perp^2 e^{-\frac{k_\perp^2}{g_{1B}}} + \lambda_C e^{-\frac{k_\perp^2}{g_{1C}}} \right)$$

$$g_1(x) = N_1 \frac{(1-x)^\alpha \; x^\sigma}{(1-\hat{x})^\alpha \; \hat{x}^\sigma}$$

$$D_{1NP}(x, b_T^2) \propto \text{F.T. of } \left(e^{-\frac{P_\perp^2}{g_{3A}}} + \lambda_{FB} k_\perp^2 e^{-\frac{P_\perp^2}{g_{3B}}} \right)$$

$$g_3(z) = N_3 \frac{(z^\beta + \delta)(1-z)^\gamma}{(\hat{z}^\beta + \delta)(1-\hat{z})^\gamma}$$

$$g_K(b_T^2) = -g_2^2 \frac{b_T^2}{4}$$

MAPTMD22 — Parameterization of TMDs

$$f_{1\mathrm{NP}}(x, b_T^2) \propto \text{F.T. of} \left(e^{-\frac{k_\perp^2}{g_{1A}}} + \lambda_B k_\perp^2 e^{-\frac{k_\perp^2}{g_{1B}}} + \lambda_C e^{-\frac{k_\perp^2}{g_{1C}}} \right)$$

$$g_1(x) = N_1 \frac{(1-x)^\alpha \; x^\sigma}{(1-\hat{x})^\alpha \; \hat{x}^\sigma}$$

$$D_{1\mathrm{NP}}(x, b_T^2) \propto \text{F.T. of} \left(e^{-\frac{P_\perp^2}{g_{3A}}} + \lambda_{FB} k_\perp^2 e^{-\frac{P_\perp^2}{g_{3B}}} \right)$$

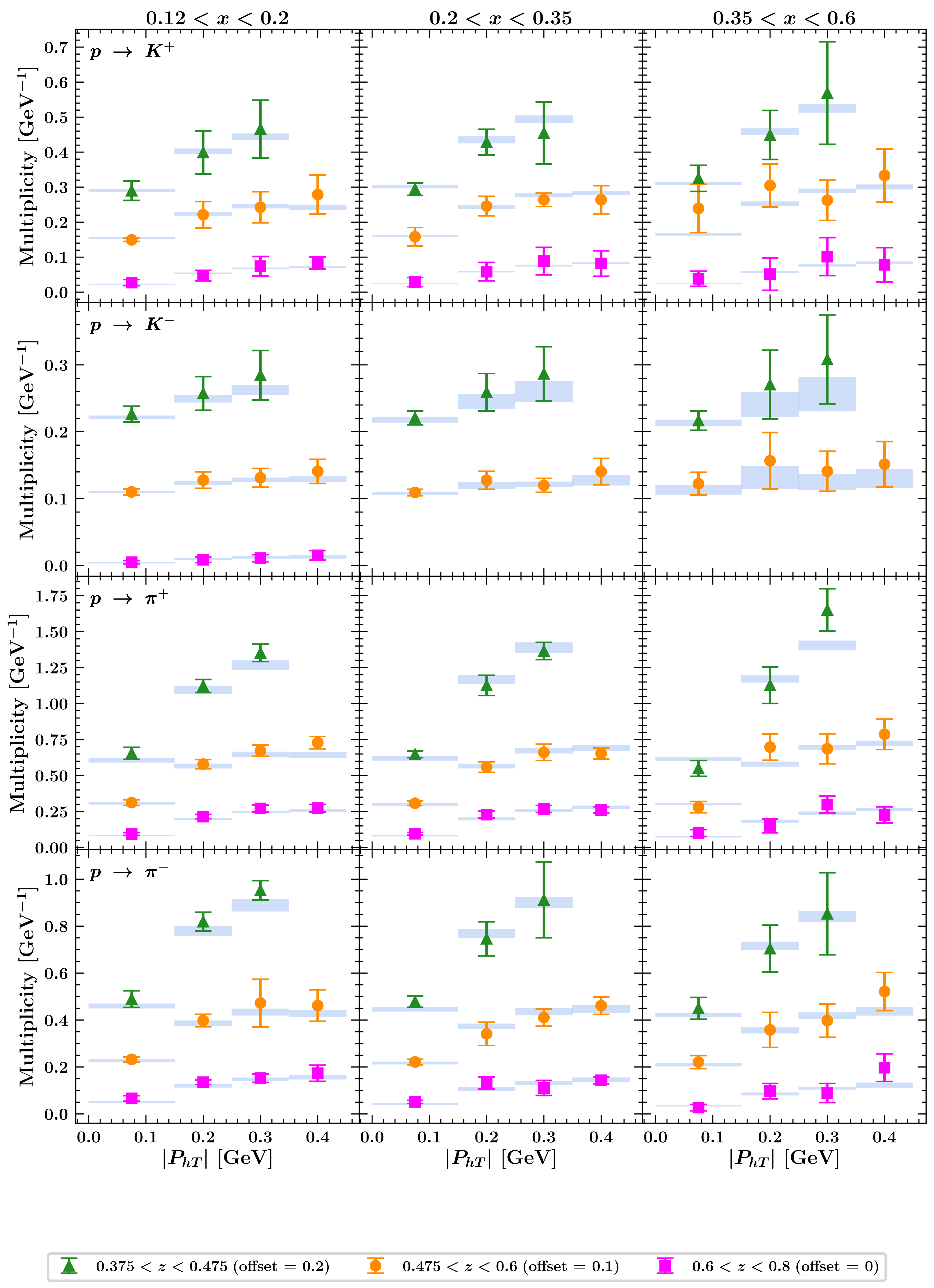
$$g_3(z) = N_3 \frac{(z^\beta + \delta)(1-z)^\gamma}{(\hat{z}^\beta + \delta)(1-\hat{z})^\gamma}$$

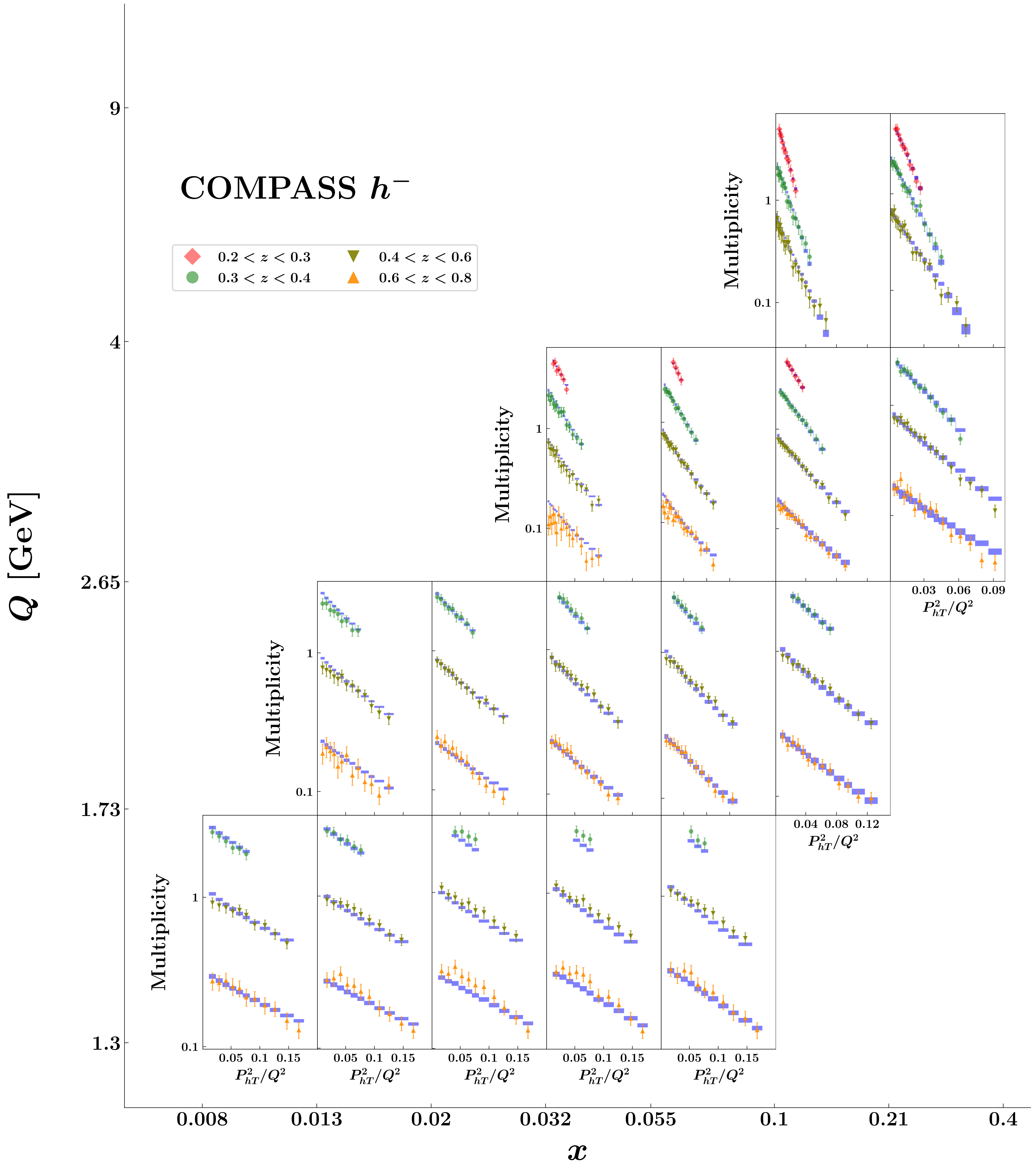
$$g_K(b_T^2) = -g_2^2 \frac{b_T^2}{4}$$

11 parameters for TMD PDF
+ 1 for NP evolution + 9 for TMD FF
= 21 free parameters

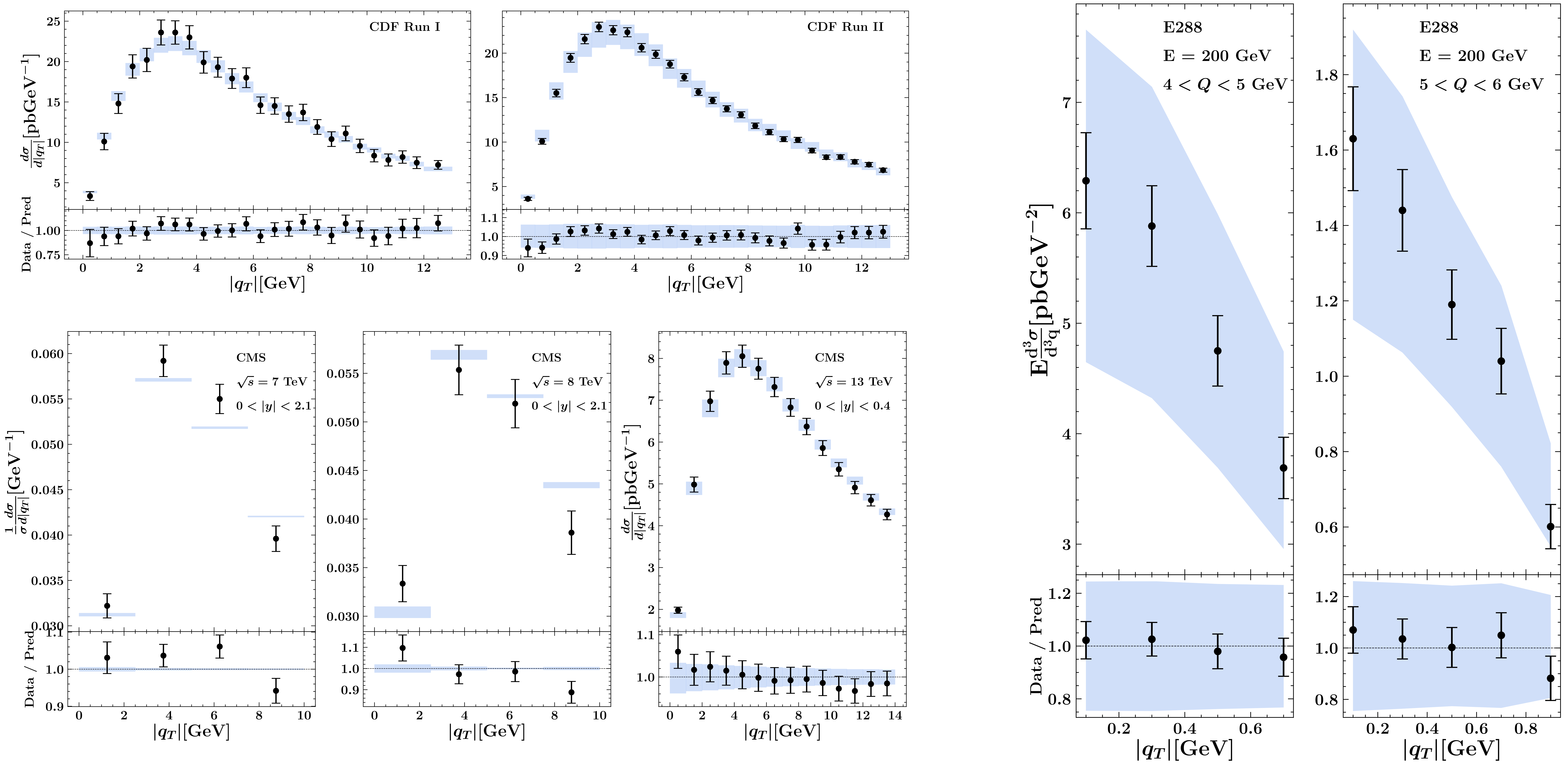
MAPTMD22 — Results of the fit $\chi^2/N_{data} = 1.06$

HERMES

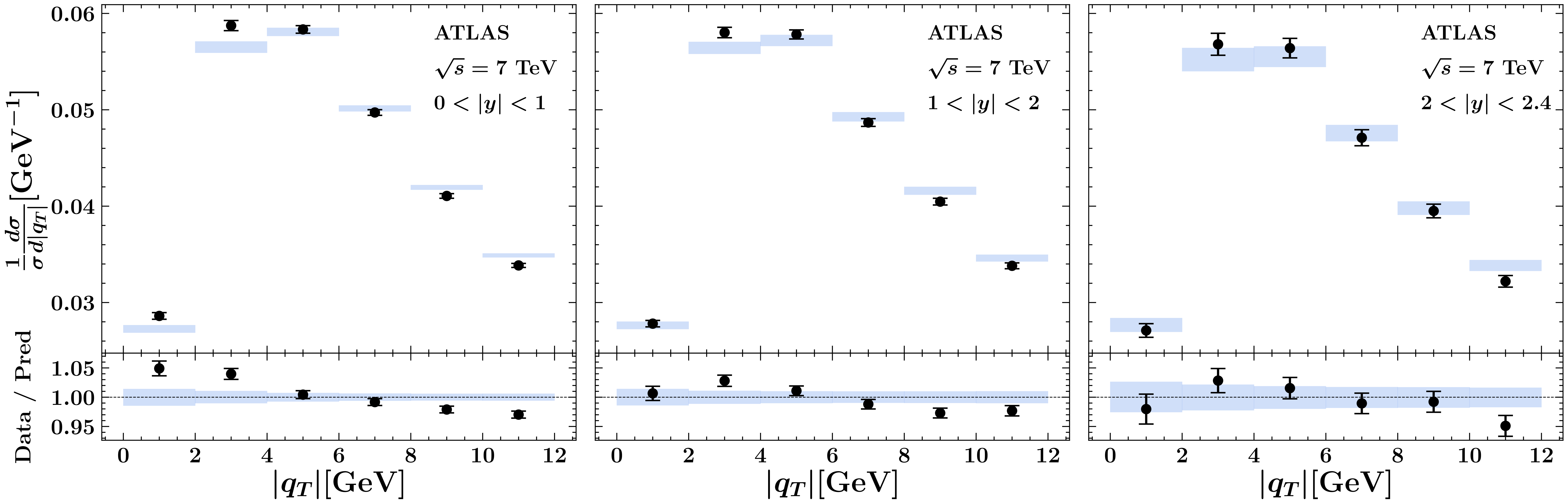




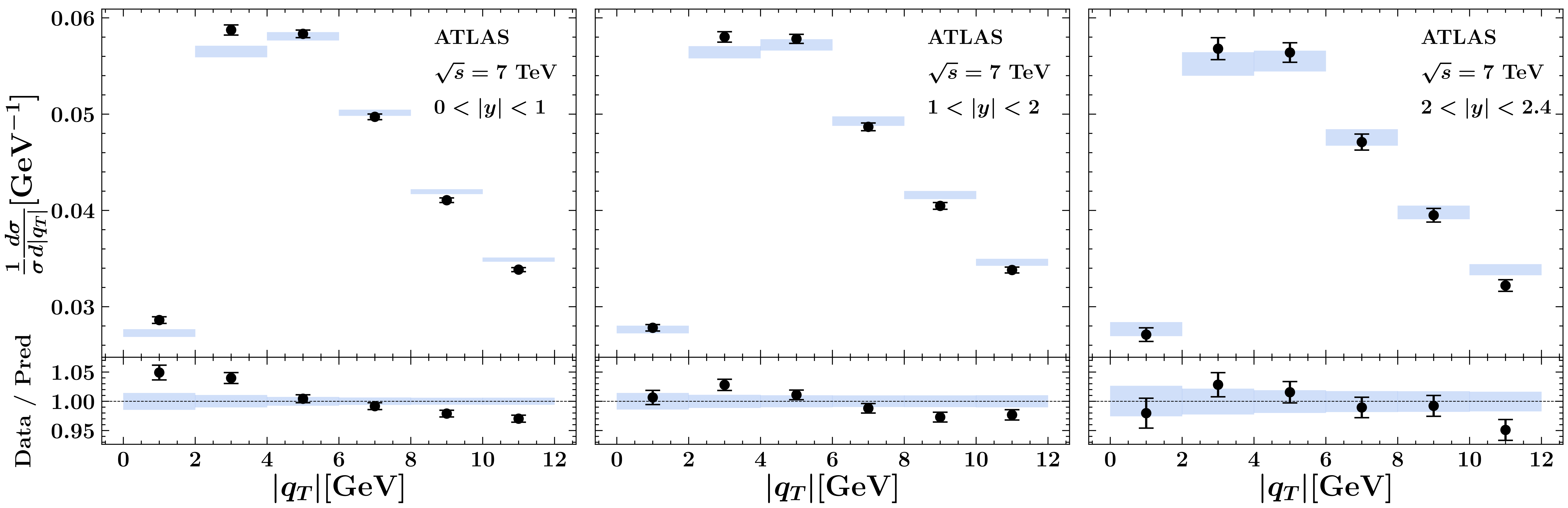
MAPTMD22 — Results of the fit $\chi^2/N_{data} = 1.06$



MAPTMD22 — Results of the fit $\chi^2/N_{data} = 1.06$

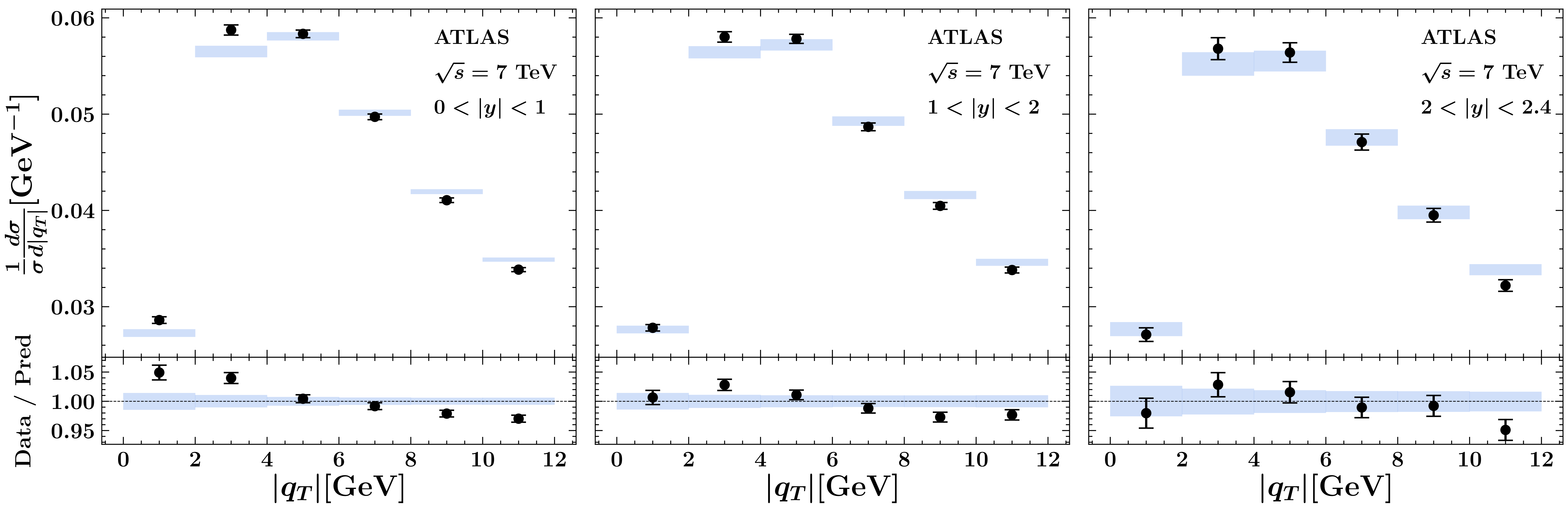


MAPTMD22 — Results of the fit $\chi^2/N_{data} = 1.06$



<u>Possible justifications:</u>

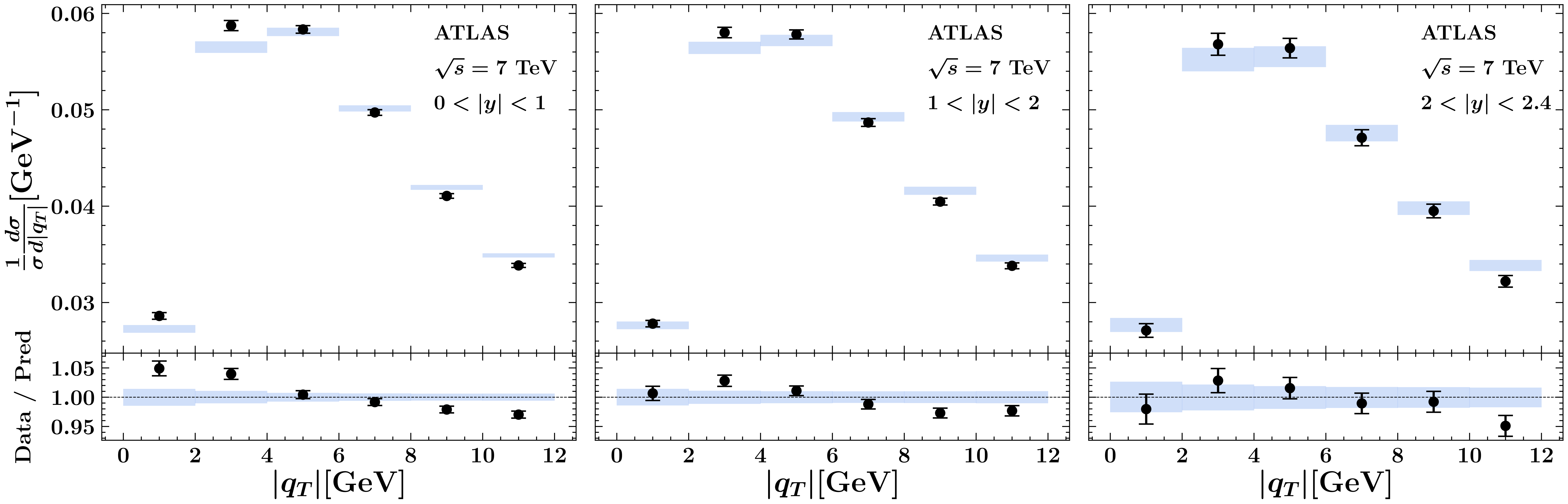
MAPTMD22 — Results of the fit $\chi^2/N_{data} = 1.06$



<u>Possible justifications:</u>

Small experimental uncertainties

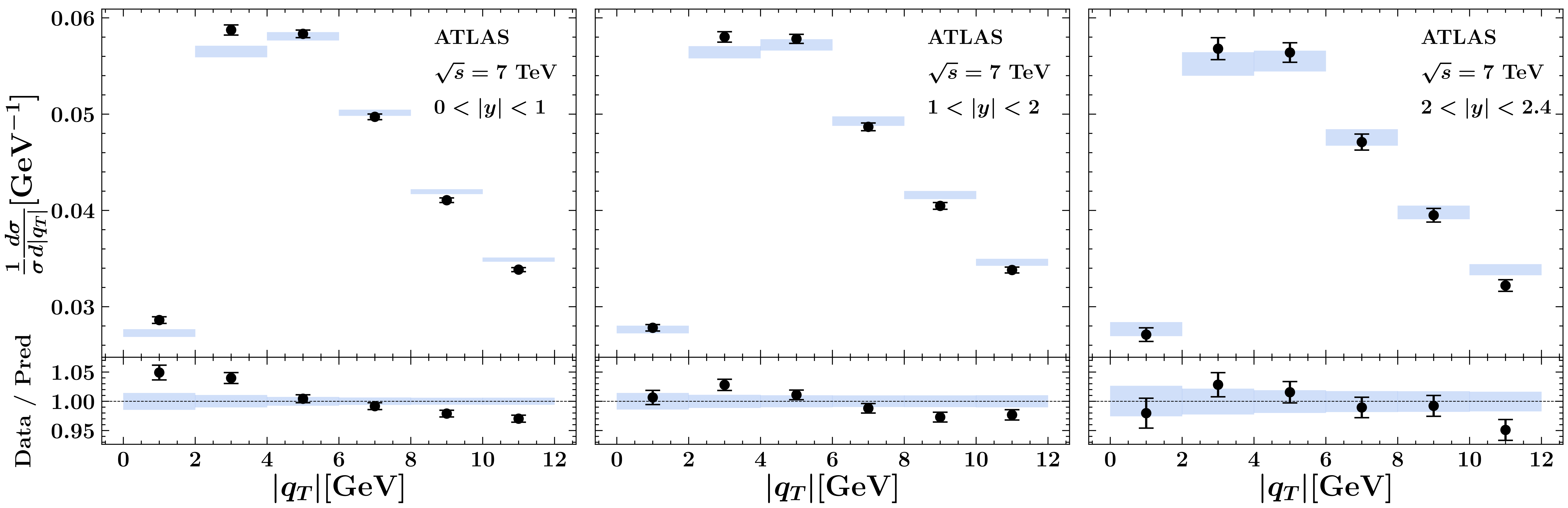
MAPTMD22 — Results of the fit $\chi^2/N_{data} = 1.06$



<u>Possible justifications:</u>

- Small experimental uncertainties
- Implementation of lepton cuts

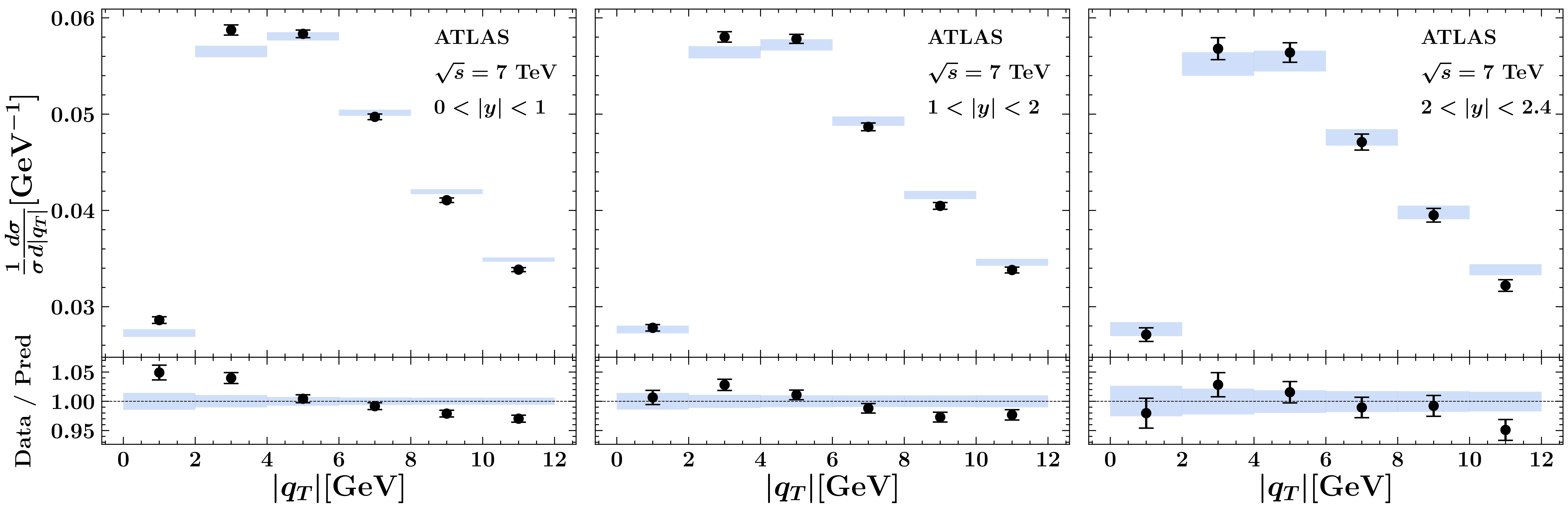
MAPTMD22 — Results of the fit $\chi^2/N_{data} = 1.06$



Possible justifications:

- Small experimental uncertainties
- Effects of power corrections
- Implementation of lepton cuts

MAPTMD22 — Results of the fit $\chi^2/N_{data} = 1.06$

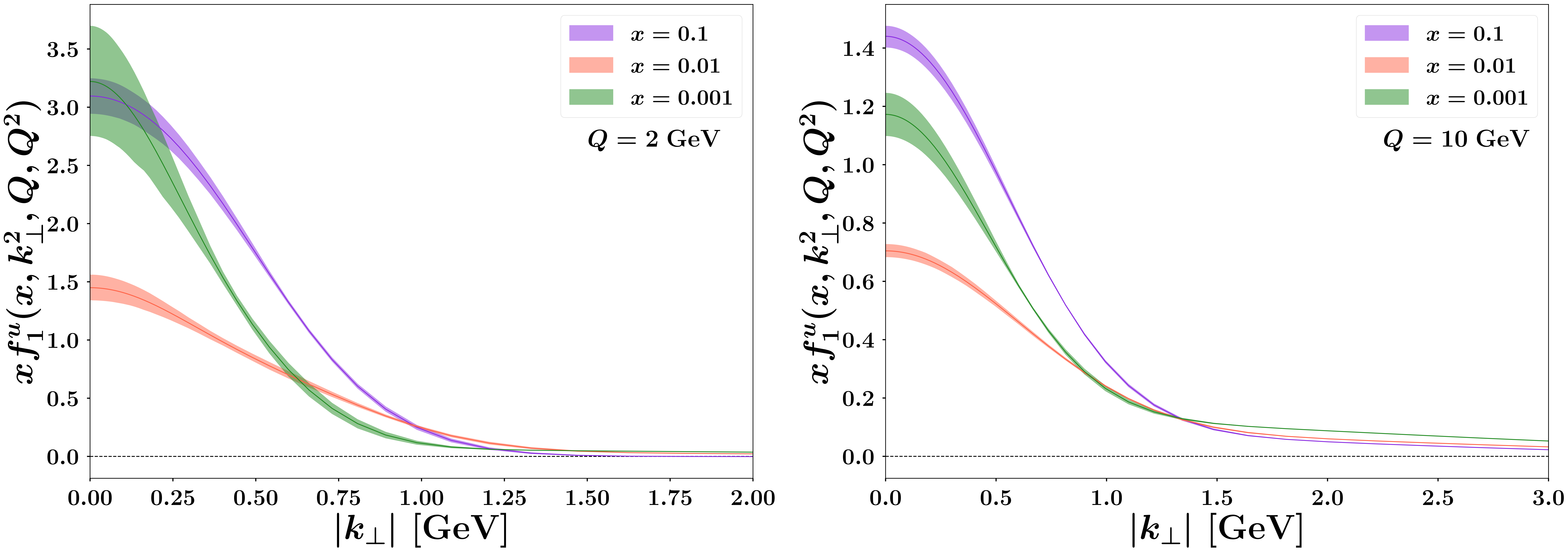


<u>Possible justifications:</u>

- Small experimental uncertainties
- Implementation of lepton cuts
- Effects of power corrections
- Effects of the matching between perturbative and non-perturbative physics

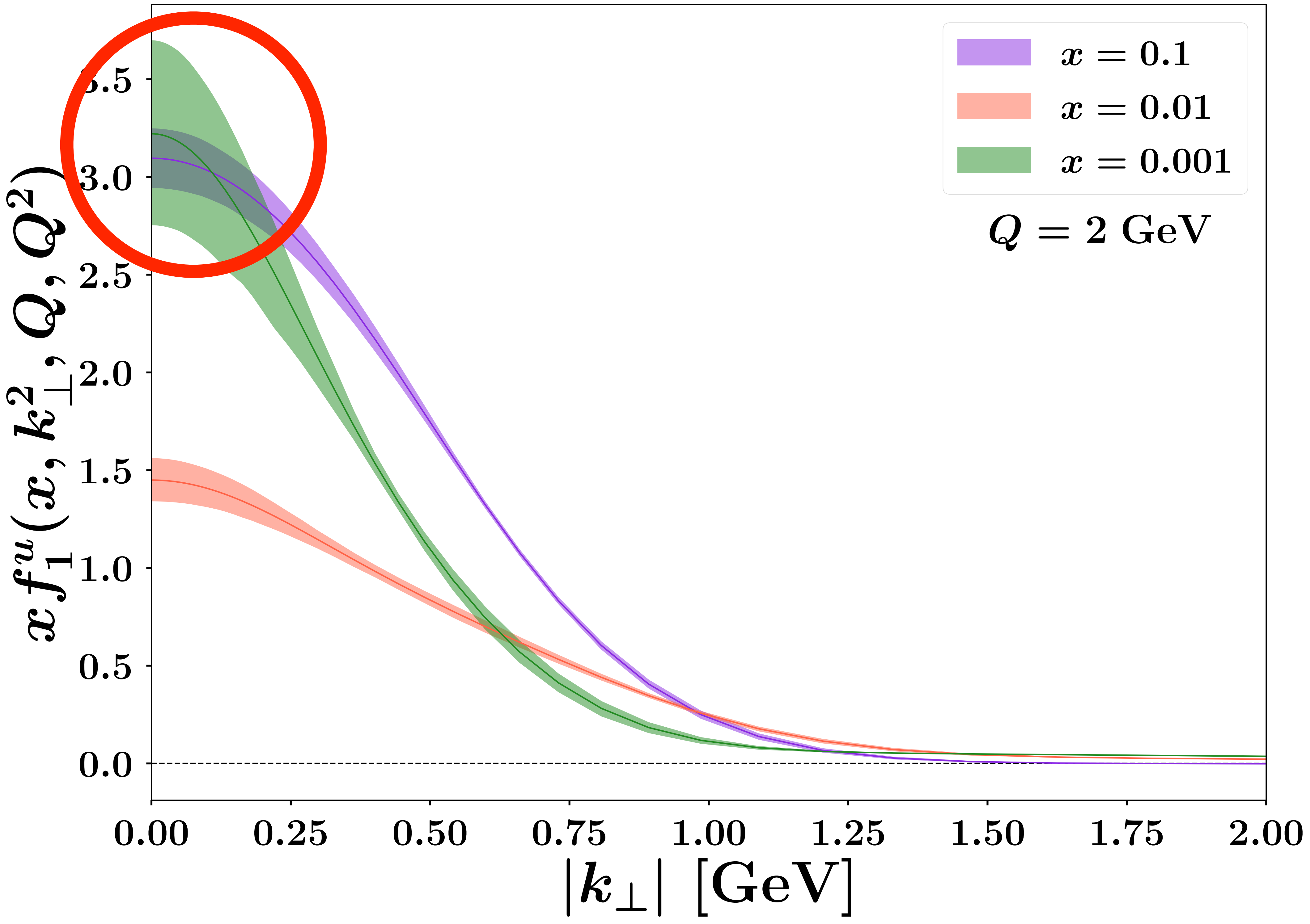
MAPTMD22 — Output of the fit

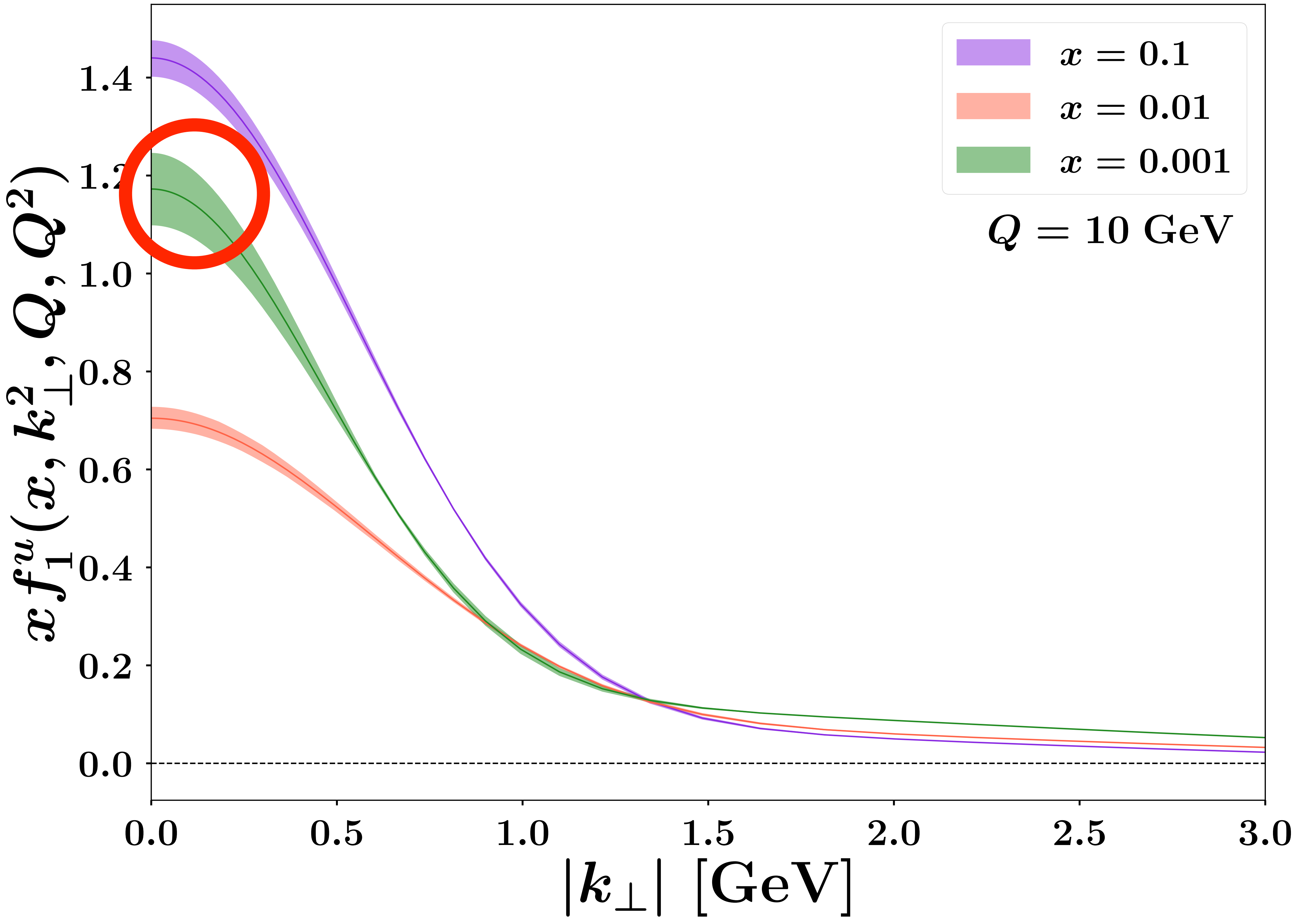
Visualisation of TMD PDFs



MAPTMD22 — Output of the fit

Visualisation of TMD PDFs





MAPTMD22 — Output of the fit

Collins-Soper kernel

MAPTMD22 — Output of the fit

Collins-Soper kernel

Kernel of the rapidity evolution equation

$$\frac{\partial \ln \hat{f}_1(x, b_T; \mu, \zeta)}{\partial \ln \sqrt{\zeta}} = K(b_T, \mu)$$

$$K(b_T, \mu_{b_*}) = K(b_*, \mu_{b_*}) + g_K(b_T)$$

MAPTMD22 — Output of the fit

Collins-Soper kernel

Kernel of the rapidity evolution equation

$$\frac{\partial \ln \hat{f}_1(x, b_T; \mu, \zeta)}{\partial \ln \sqrt{\zeta}} = K(b_T, \mu)$$

$$K(b_T, \mu_{b_*}) = K(b_*, \mu_{b_*}) + g_K(b_T)$$

↓

perturbatively calculable

MAPTMD22 — Output of the fit

Collins-Soper kernel

Kernel of the rapidity evolution equation

$$\frac{\partial \ln \hat{f}_1(x, b_T; \mu, \zeta)}{\partial \ln \sqrt{\zeta}} = K(b_T, \mu)$$

$$K(b_T, \mu_{b_*}) = K(b_*, \mu_{b_*}) + g_K(b_T)$$

to be fitted

perturbatively calculable

MAPTMD22 — Output of the fit

Collins-Soper kernel

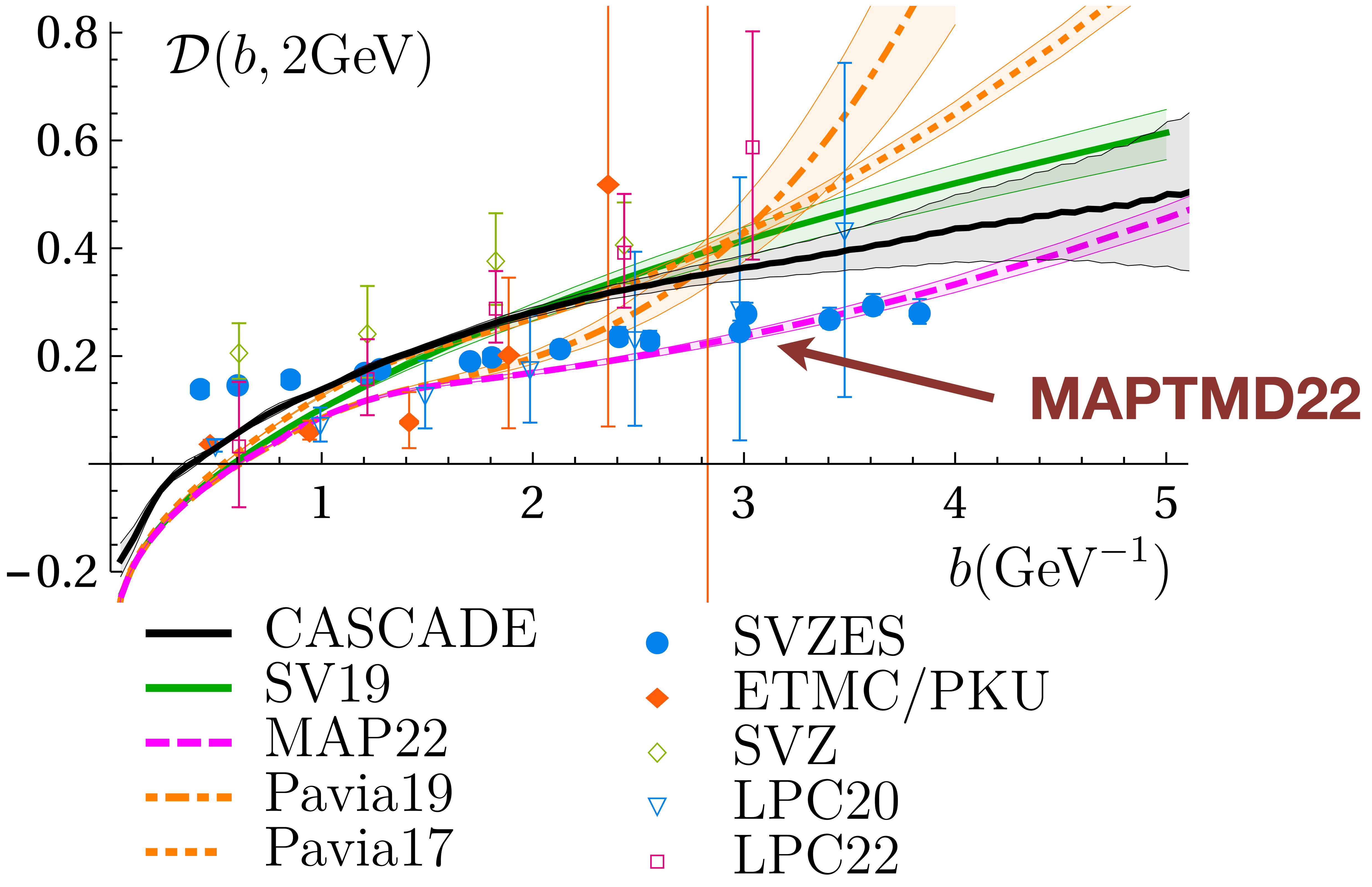
Kernel of the rapidity evolution equation

$$\frac{\partial \ln \hat{f}_1(x, b_T; \mu, \zeta)}{\partial \ln \sqrt{\zeta}} = K(b_T, \mu)$$

$$K(b_T, \mu_{b_*}) = K(b_*, \mu_{b_*}) + g_K(b_T)$$

$K(b_*, \mu_{b_*})$ → perturbatively calculable

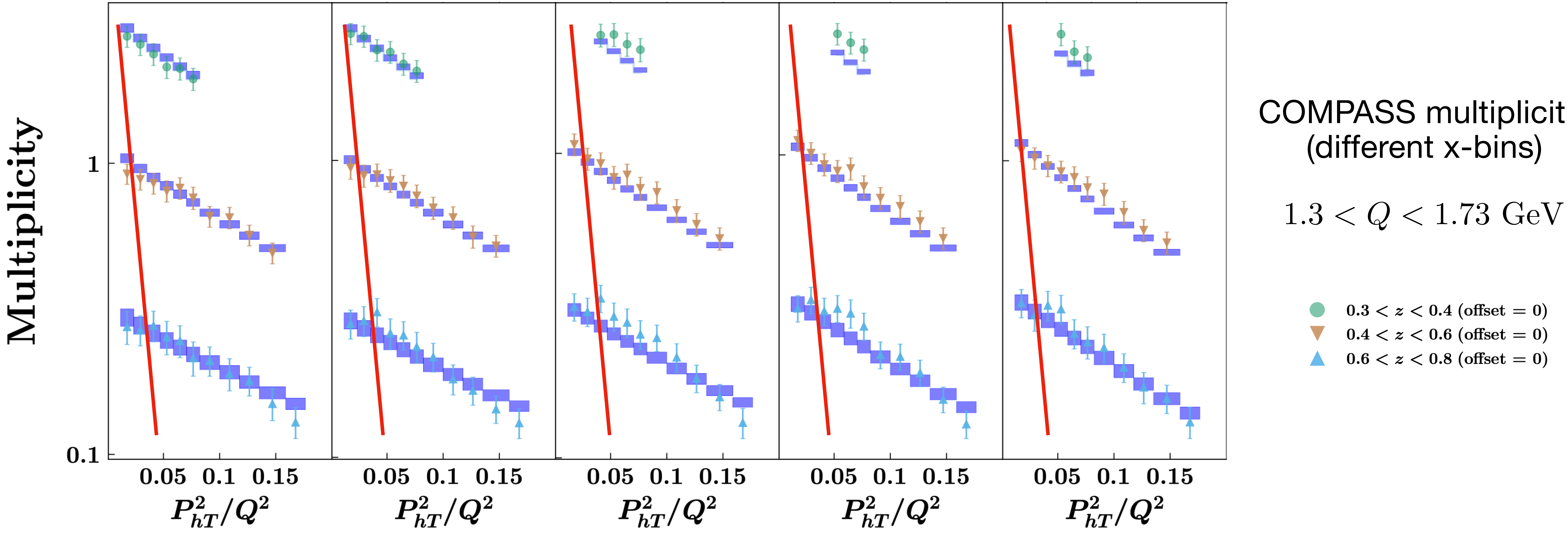
$g_K(b_T)$ → to be fitted



Martinez, Vladimirov, arXiv:2206.01105

SIDIS data selection

$$\left.\frac{P_{hT}}{zQ}\right|_{\max} = 0.25$$

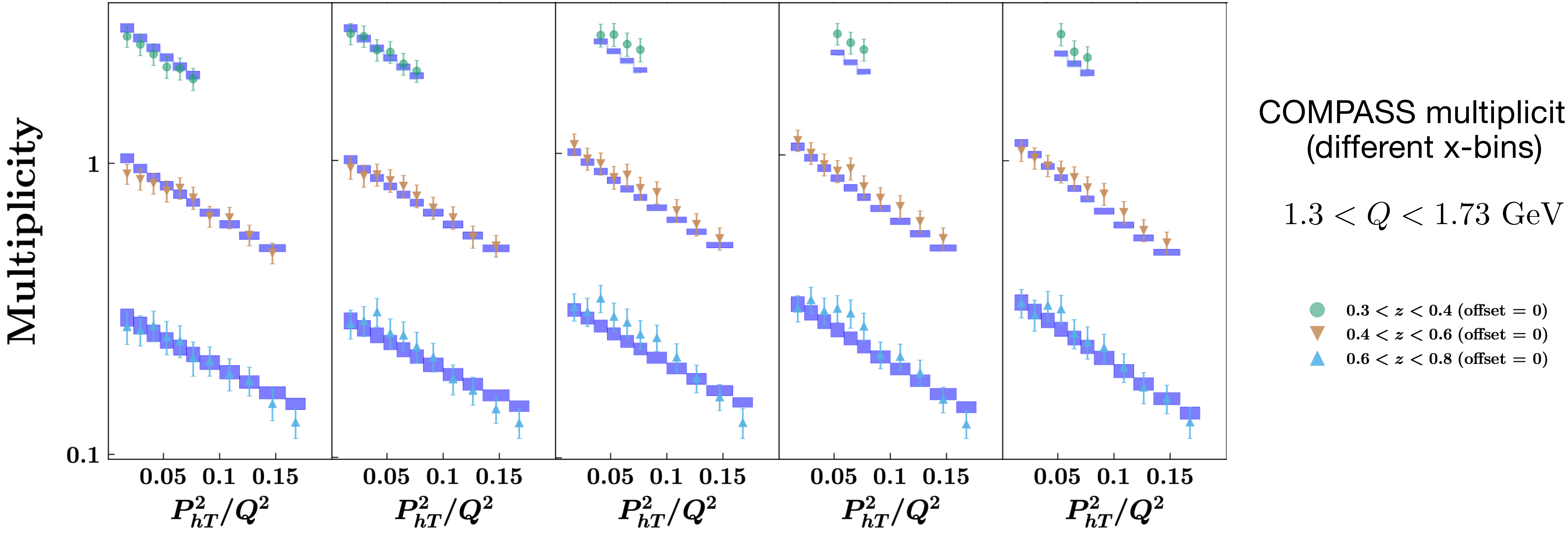


COMPASS multiplicities (different x-bins)

$1.3 < Q < 1.73$ GeV

SIDIS data selection

$$P_{hT}|_{\max} = \min[\min[0.2Q, 0.5zQ] + 0.3\ \text{GeV}, zQ]$$



COMPASS multiplicities (different x-bins)

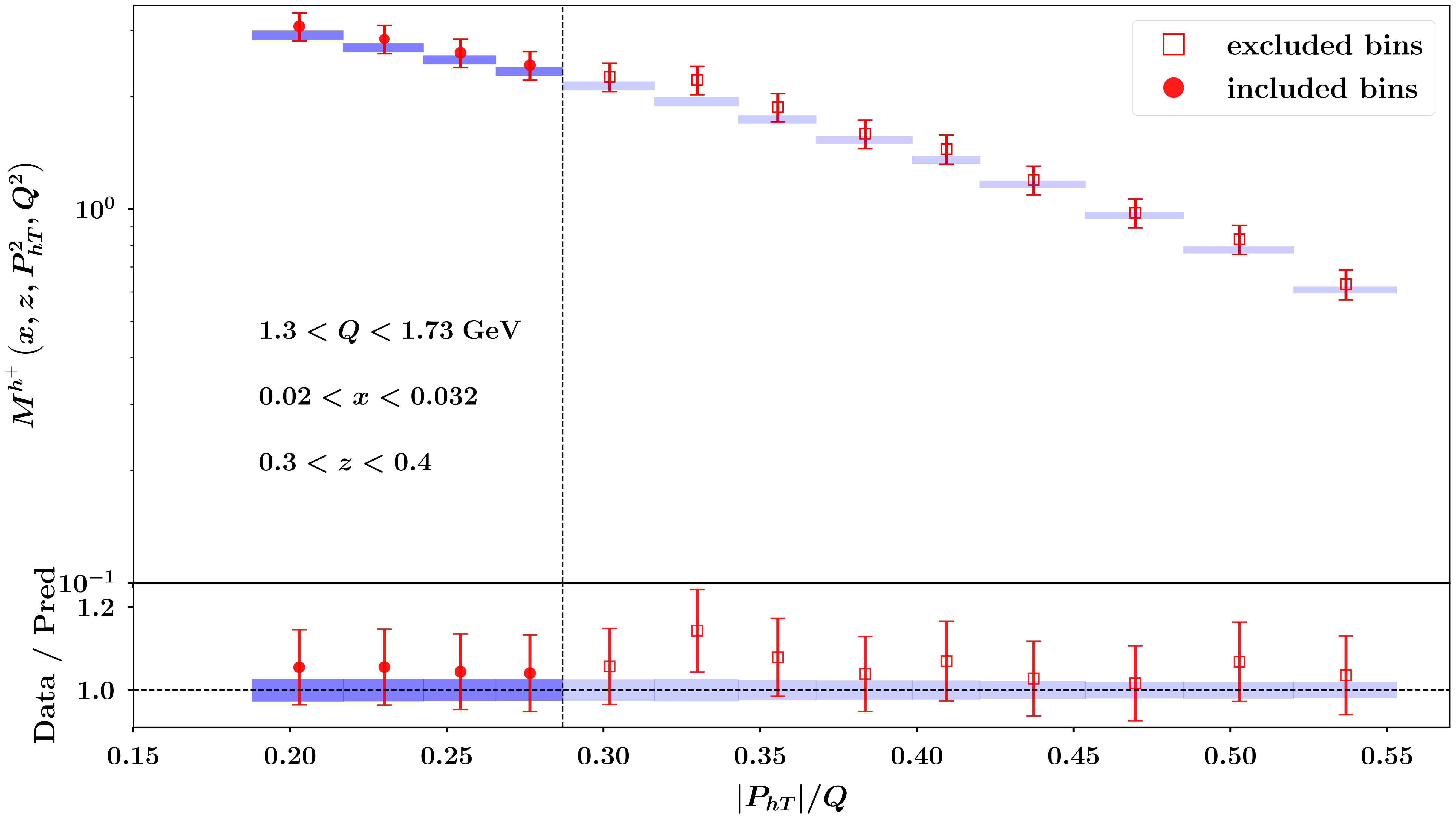
$1.3 < Q < 1.73$ GeV

MAPTMD22 — SIDIS data selection

COMPASS multiplicities (one of many bins)

$$P_{hT}|_{\max} = \min[\min[0.2Q, 0.5zQ] + 0.3 \text{ GeV}, zQ]$$

$$P_{hT}|_{\max} = \min[0.2Q, 0.7zQ] + 0.5 \text{ GeV}$$

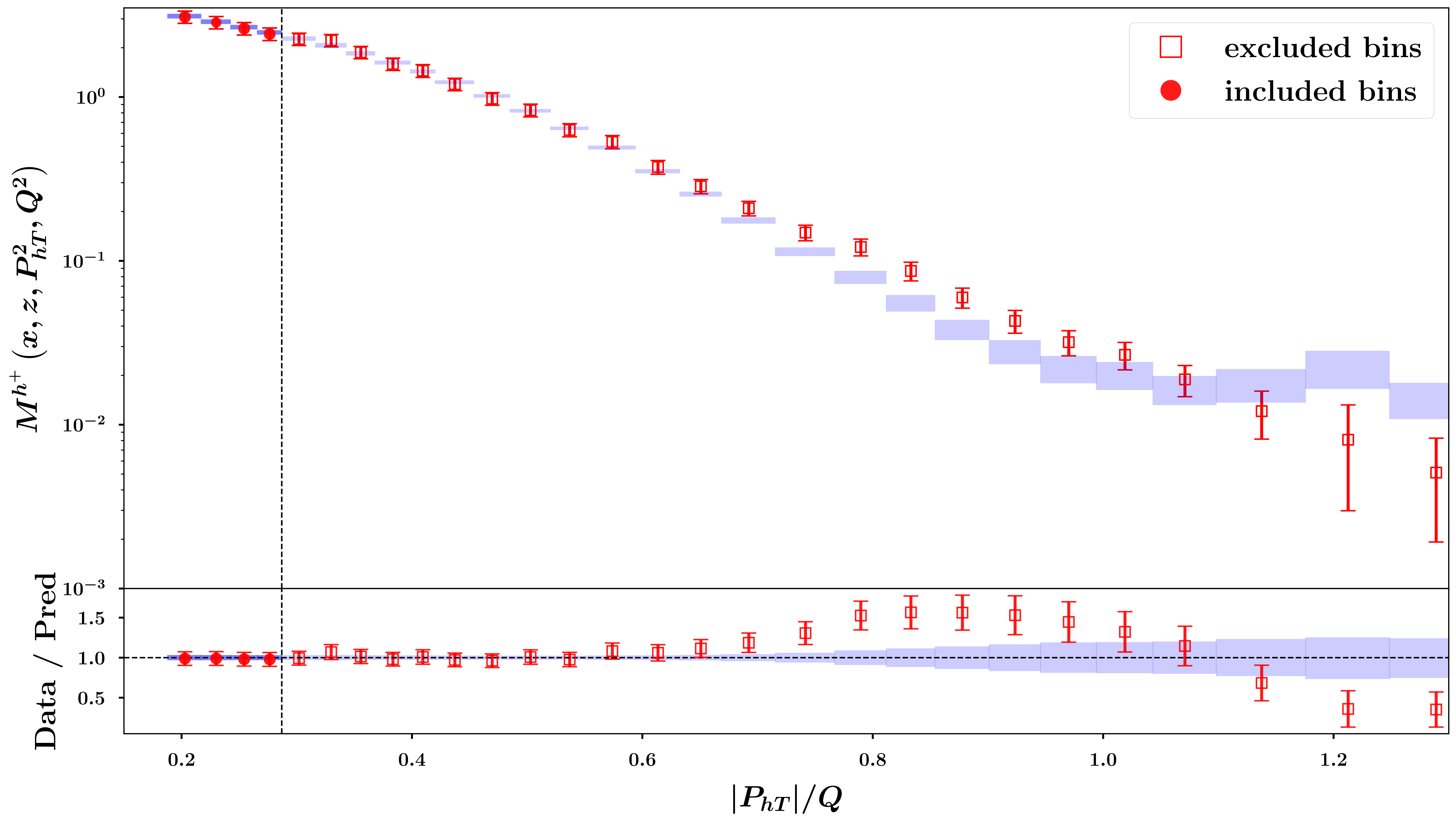


MAPTMD22 — SIDIS data selection

COMPASS multiplicities (one of many bins)

$$P_{hT}|_{\max} = \min[\min[0.2Q, 0.5zQ] + 0.3 \text{ GeV}, zQ]$$

Total number of points



Impact of power corrections

Results obtained with the arTeMiDe framework

include (m/Q)
include (M/Q)
include (q_T/Q) in kinematics
include (q_T/Q) in x_S, z_S

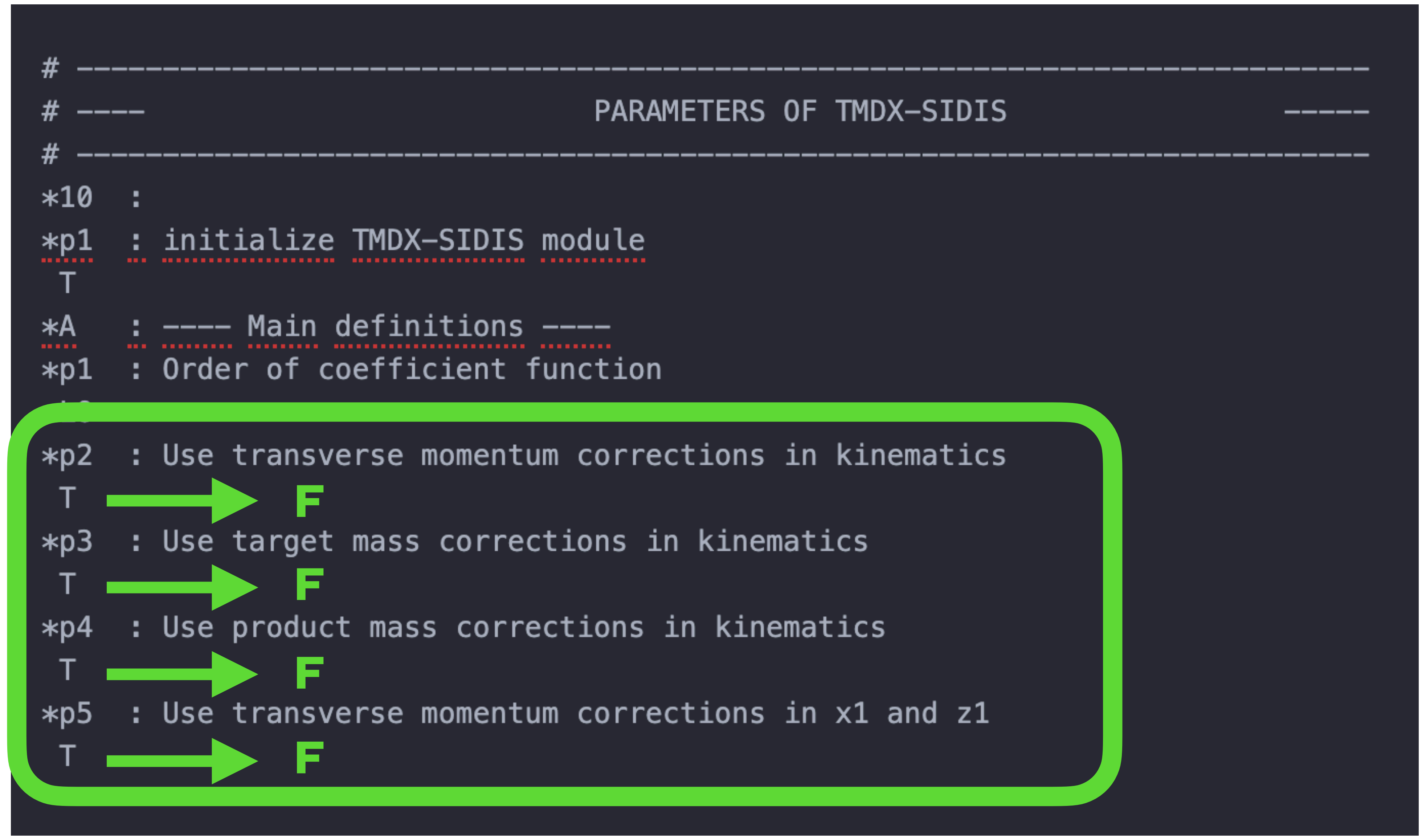
Impact of power corrections

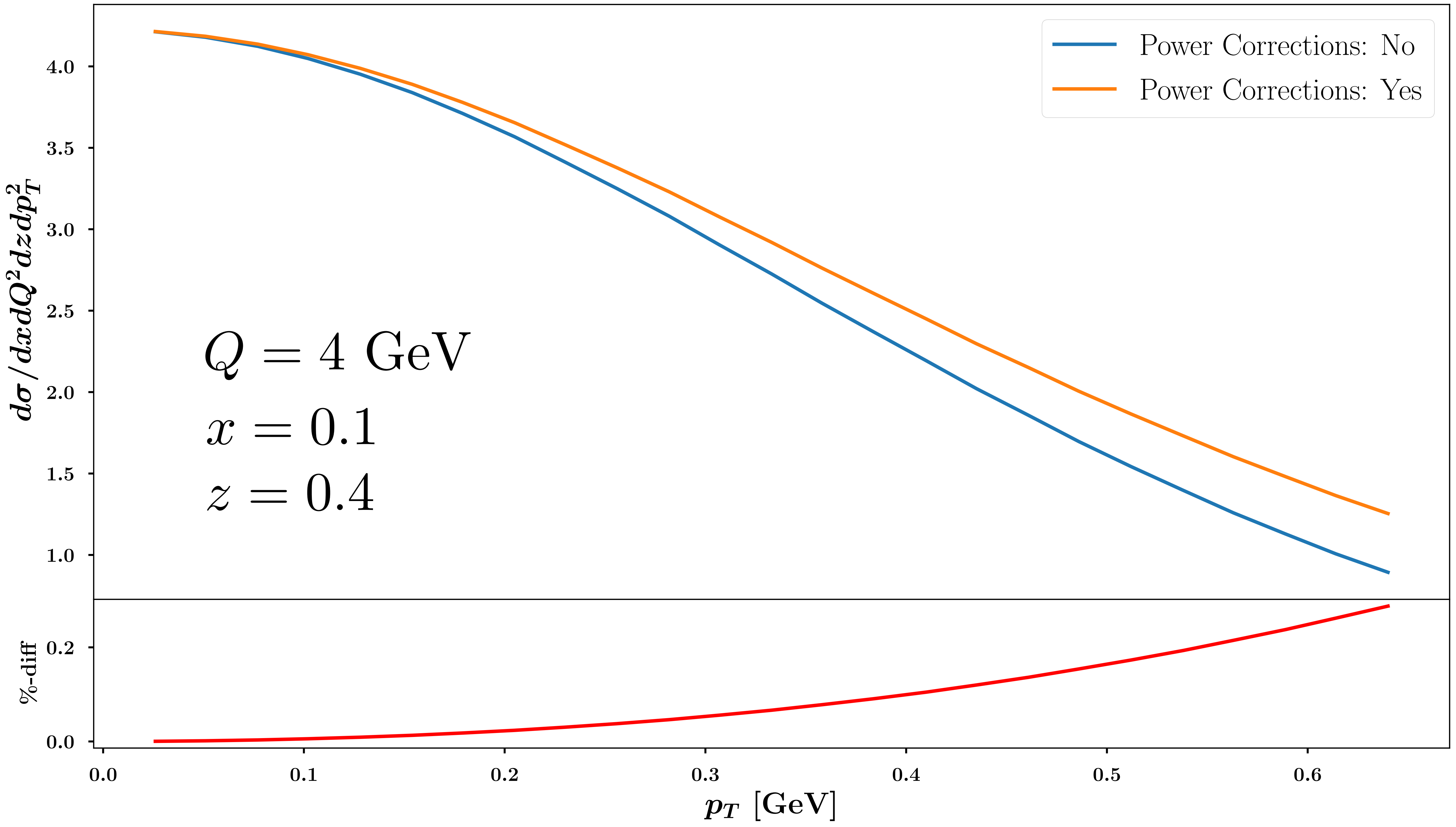
Results obtained with the arTeMiDe framework

```
# ----------------------------------------------------------------------------
# ----                      PARAMETERS OF TMDX-SIDIS                     -----
# ----------------------------------------------------------------------------
*10  :
*p1  : initialize TMDX-SIDIS module
 T
*A   : ---- Main definitions ----
*p1  : Order of coefficient function
*p2  : Use transverse momentum corrections in kinematics
 T  →  F
*p3  : Use target mass corrections in kinematics
 T  →  F
*p4  : Use product mass corrections in kinematics
 T  →  F
*p5  : Use transverse momentum corrections in x1 and z1
 T  →  F
```

Impact of power corrections

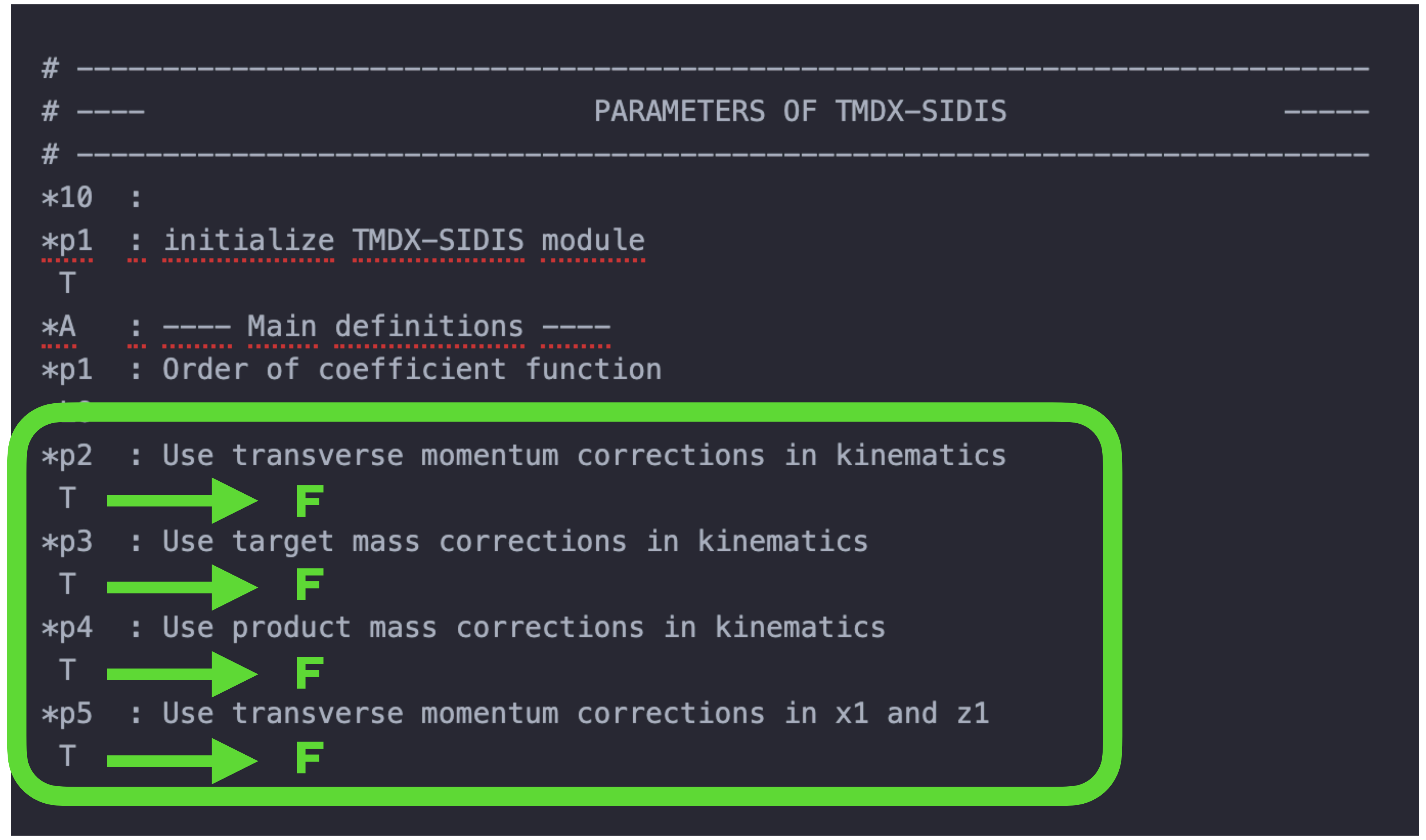
Results obtained with the arTeMiDe framework

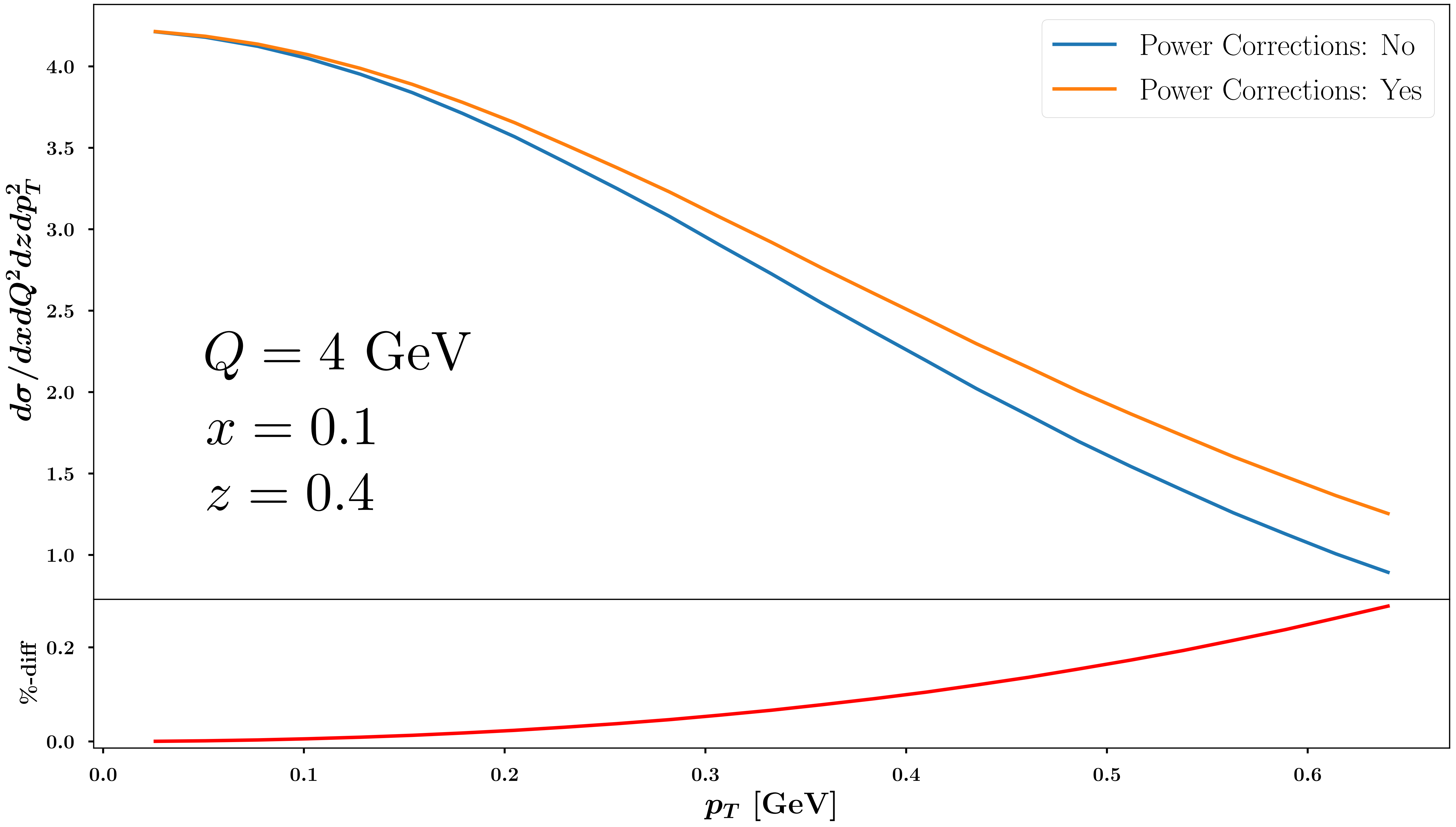




Impact of power corrections

Results obtained with the arTeMiDe framework





This is NOT a constant factor

Summary

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

Summary

MAPTMD22 GLOBAL FIT - A new precise extraction of unpol TMDs

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

Summary

MAPTMD22 GLOBAL FIT - A new precise extraction of unpol TMDs

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

Summary

MAPTMD22 GLOBAL FIT - A new precise extraction of unpol TMDs

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points

- Perturbative accuracy: N^3LL^-

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

Summary

MAPTMD22 GLOBAL FIT - A new precise extraction of unpol TMDs

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points
- Perturbative accuracy: N^3LL^-
- ***Normalization*** of SIDIS multiplicities beyond NLL

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

Summary

MAPTMD22 GLOBAL FIT - A new precise extraction of unpol TMDs

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points
- Perturbative accuracy: N^3LL^-
- ***Normalization*** of SIDIS multiplicities beyond NLL
- Number of fitted parameters: ***21***

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

Summary

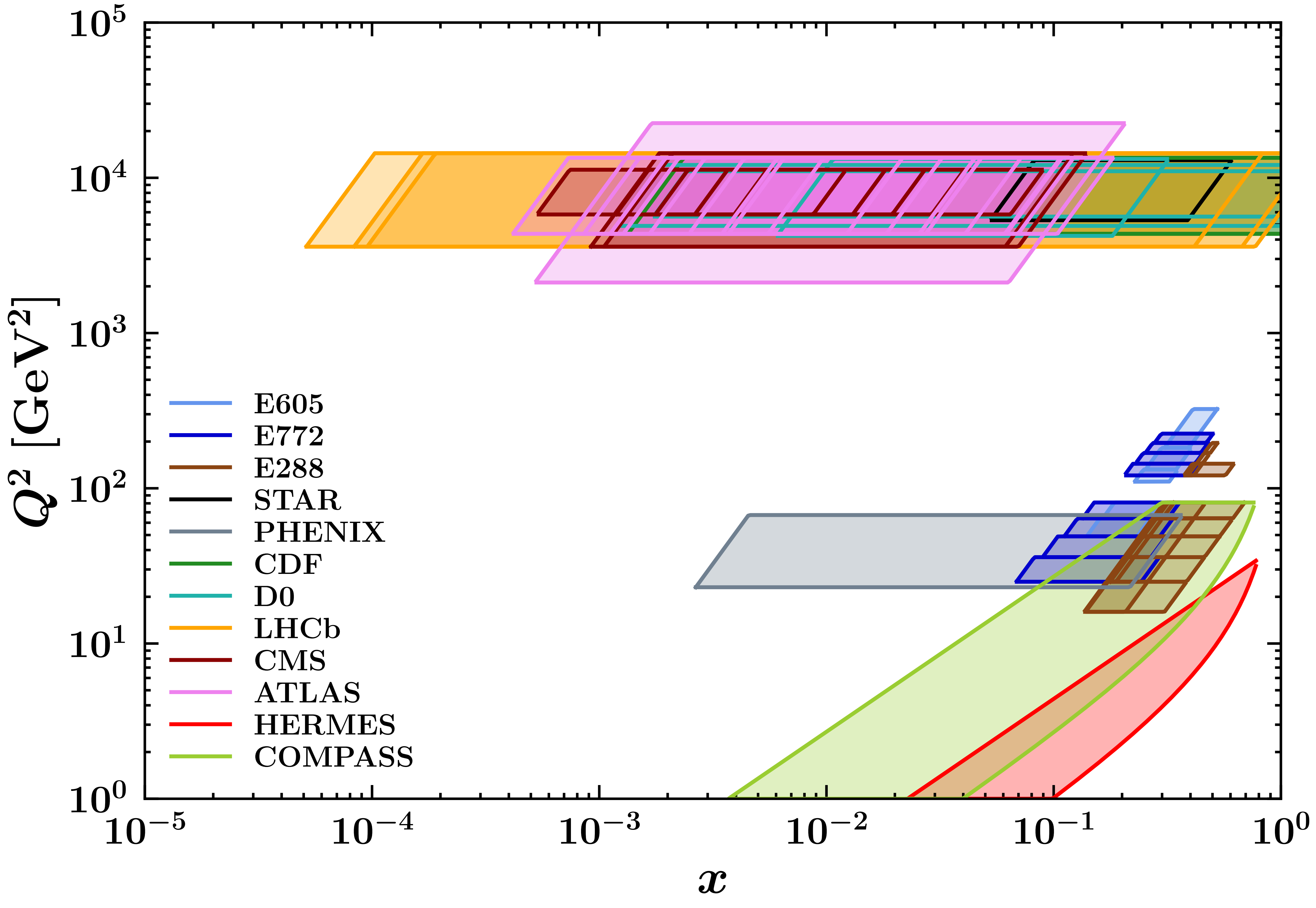
MAPTMD22 GLOBAL FIT - A new precise extraction of unpol TMDs

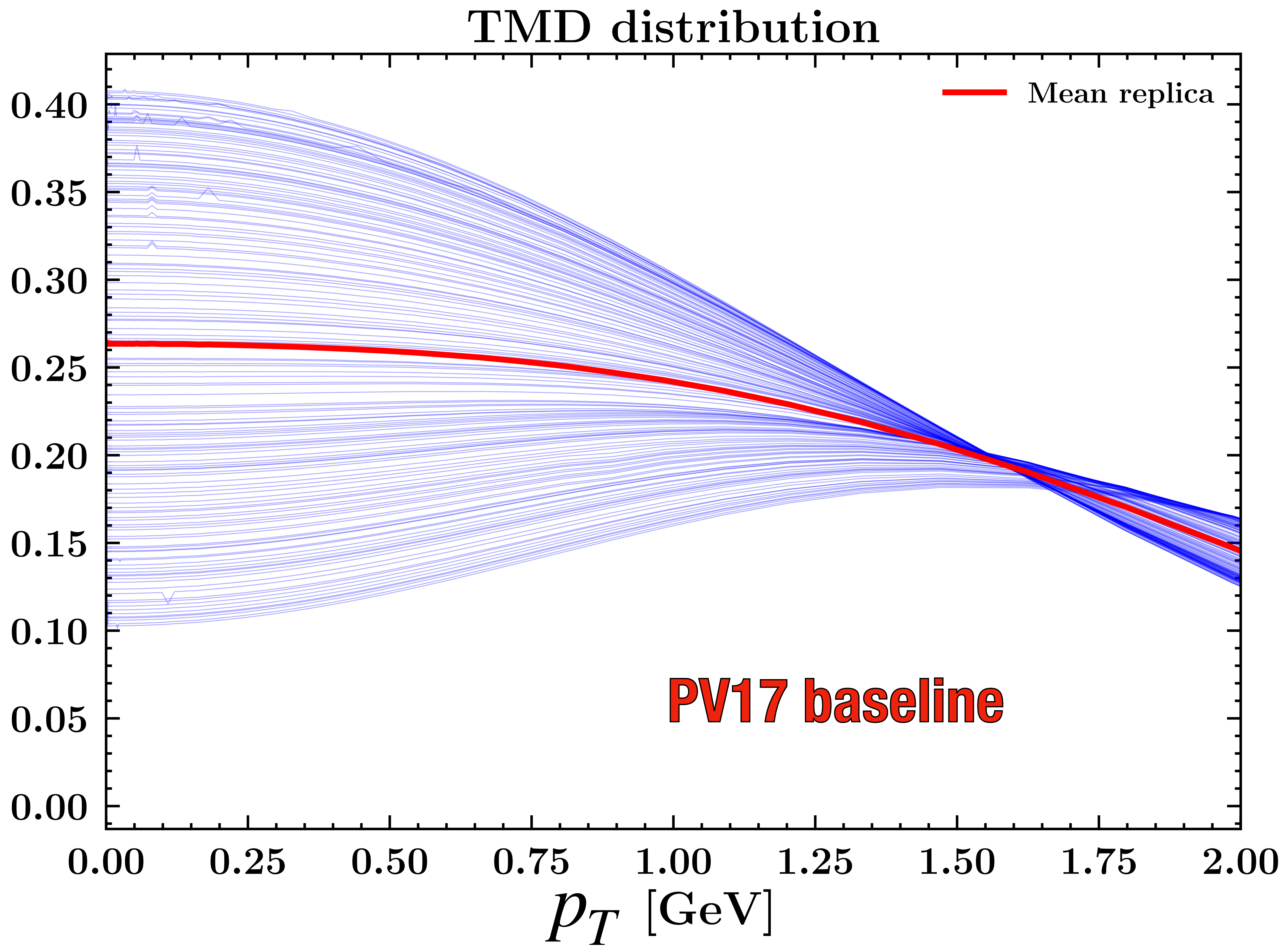
- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points
- Perturbative accuracy: N^3LL^-
- ***Normalization*** of SIDIS multiplicities beyond NLL
- Number of fitted parameters: ***21***
- Extremely good description: $\chi^2/N_{data} = 1.06$

Bacchetta, Bertone, Bissolotti, Bozzi, MC, Piacenza, Radici, Signori arXiv: 2206.07598

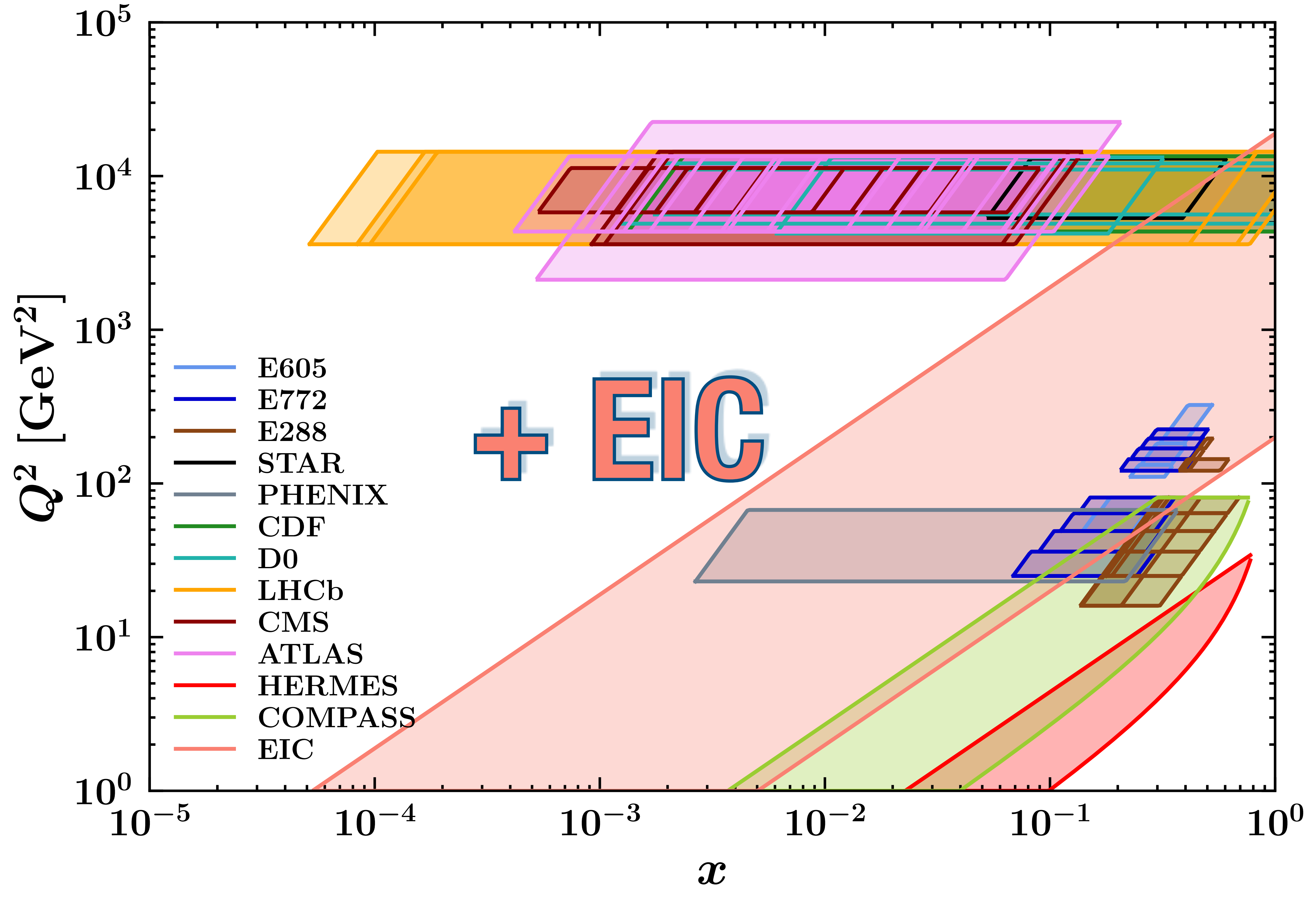
What is the role of the EIC?

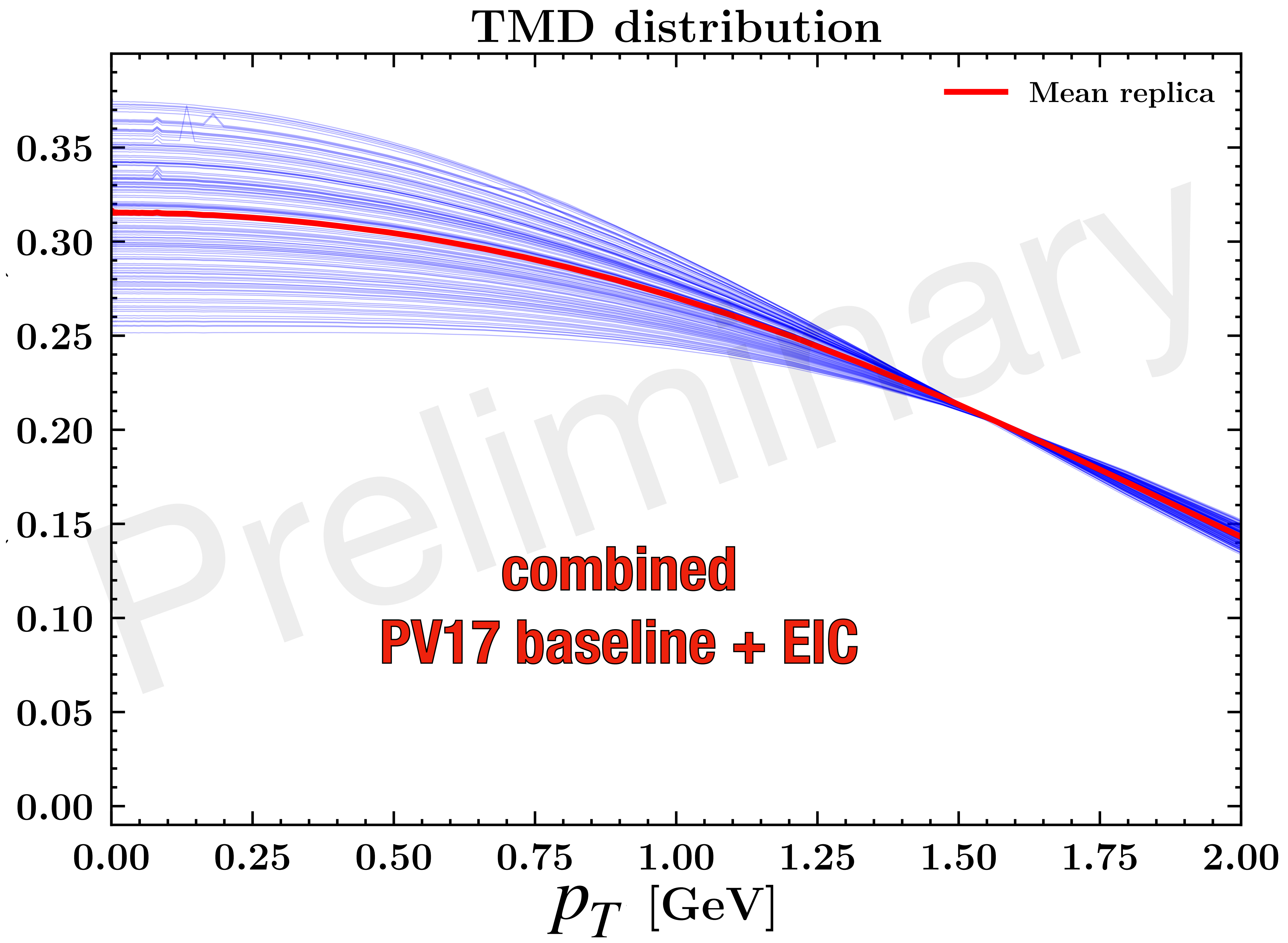
Impact of EIC pseudodata on TMDs





Impact of EIC pseudodata on TMDs

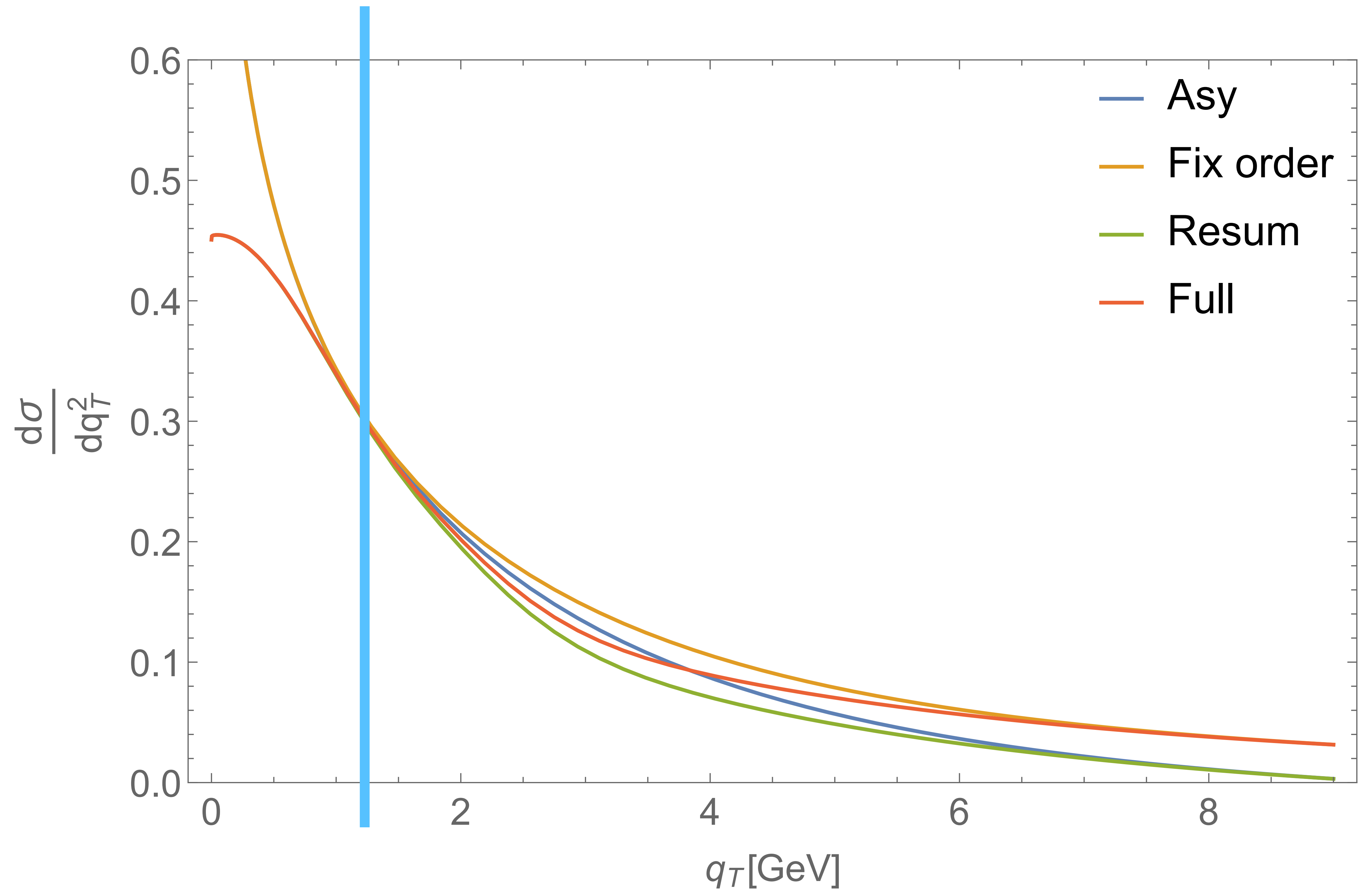




BACKUP SLIDES

Source of W-term suppression

Ideal situation at high Q

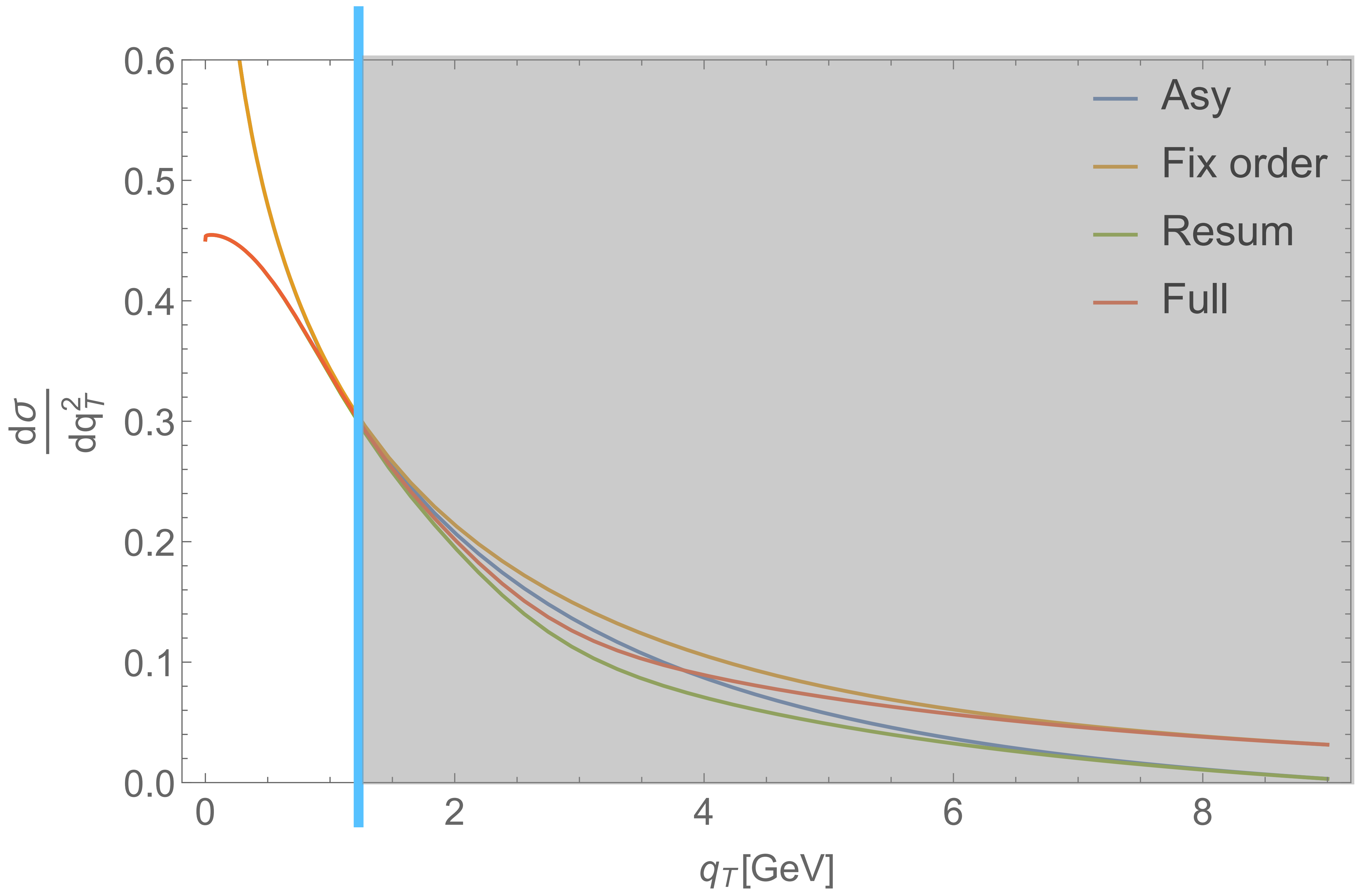


Standard approach

- Resummed contribution is dominant where the Asymptotic term is close to the Fixed Order

Source of W-term suppression

Ideal situation at high Q

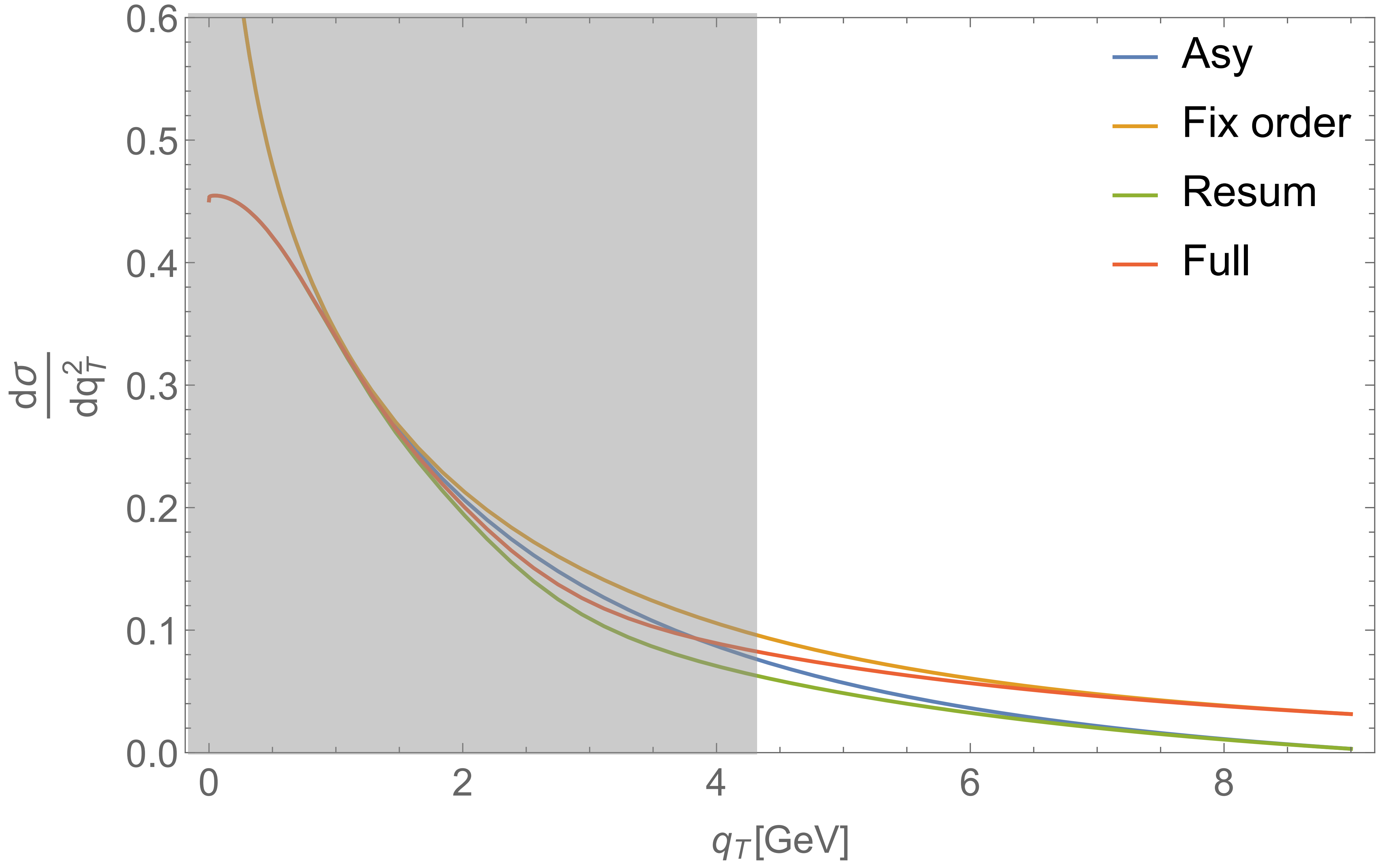


Standard approach

- Resummed contribution is dominant where the Asymptotic term is close to the Fixed Order ⟶ **TMD Region**

Source of W-term suppression

Ideal situation at high Q

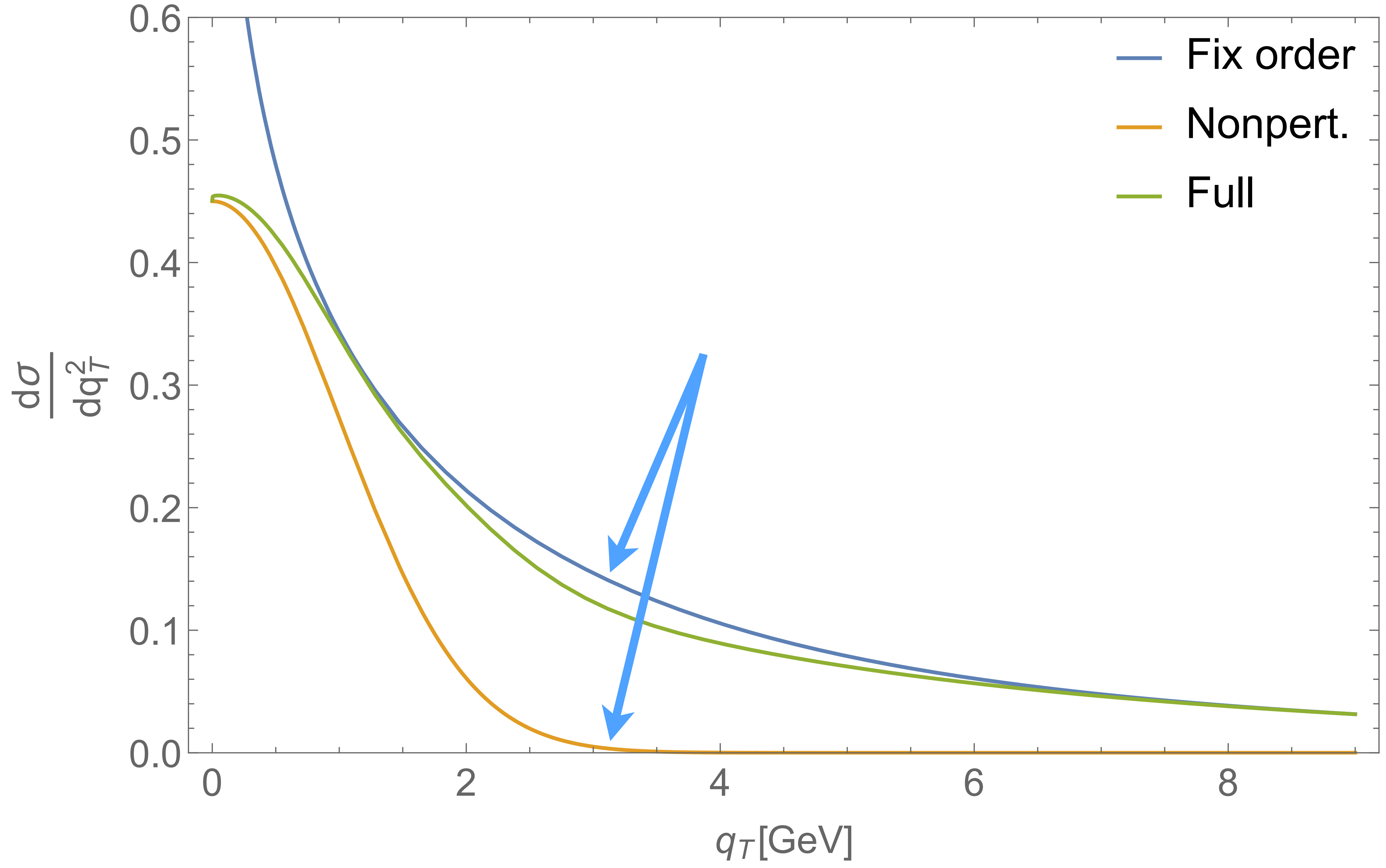


Standard approach

- Resummed contribution is dominant where the Asymptotic term is close to the Fixed Order
- From a certain value of qT the total cross section follows the Fixed Order term

Source of W-term suppression

Ideal situation at high Q

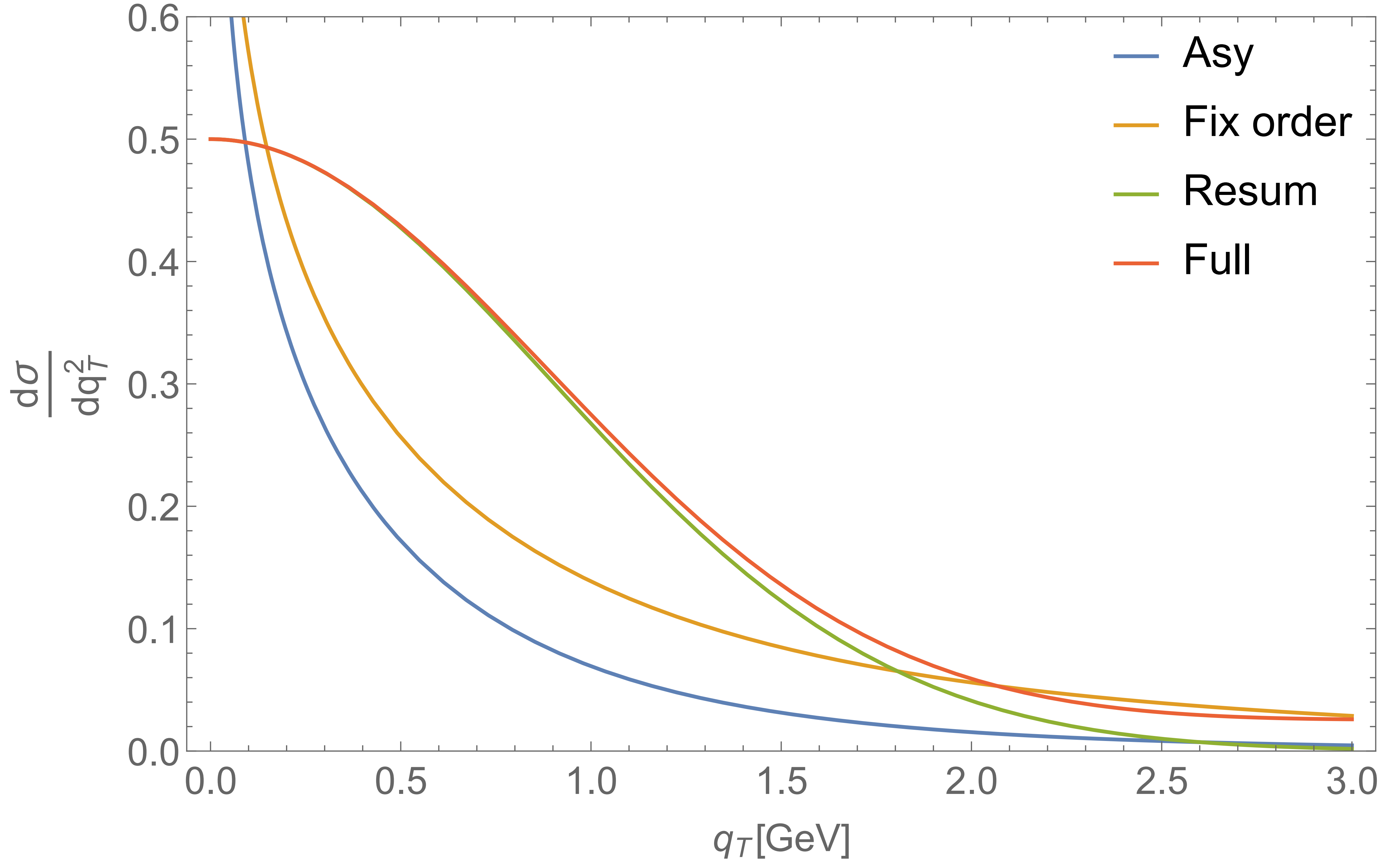


Standard approach

- Collinear result is mostly given by the integral of the Fixed Order
- The Non-Perturbative term is only a small correction

Source of W-term suppression

Ideal situation at low Q

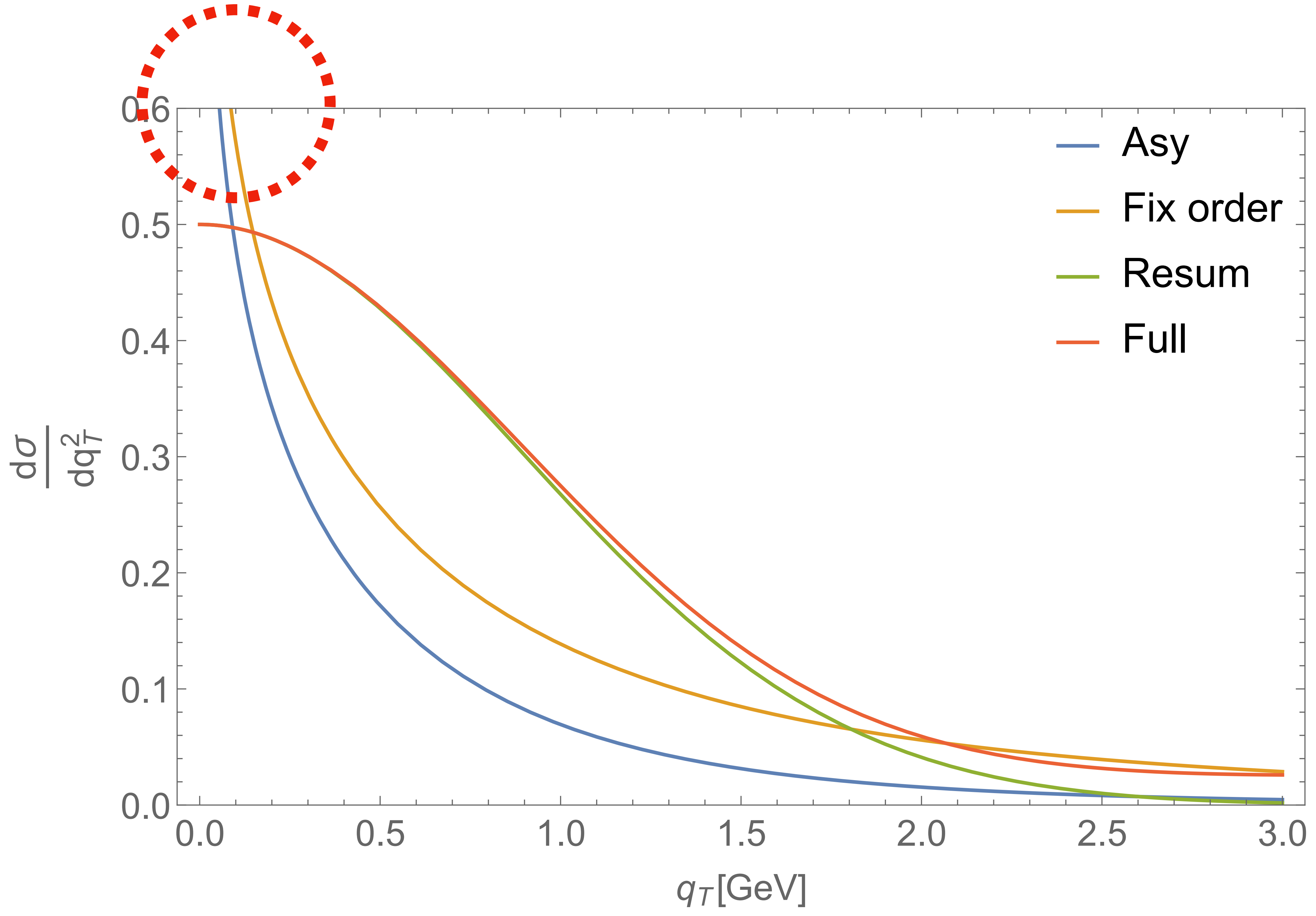


Standard approach

- Resummed contribution is dominant where the Asymptotic term is close to the Fixed Order

Source of W-term suppression

Ideal situation at low Q

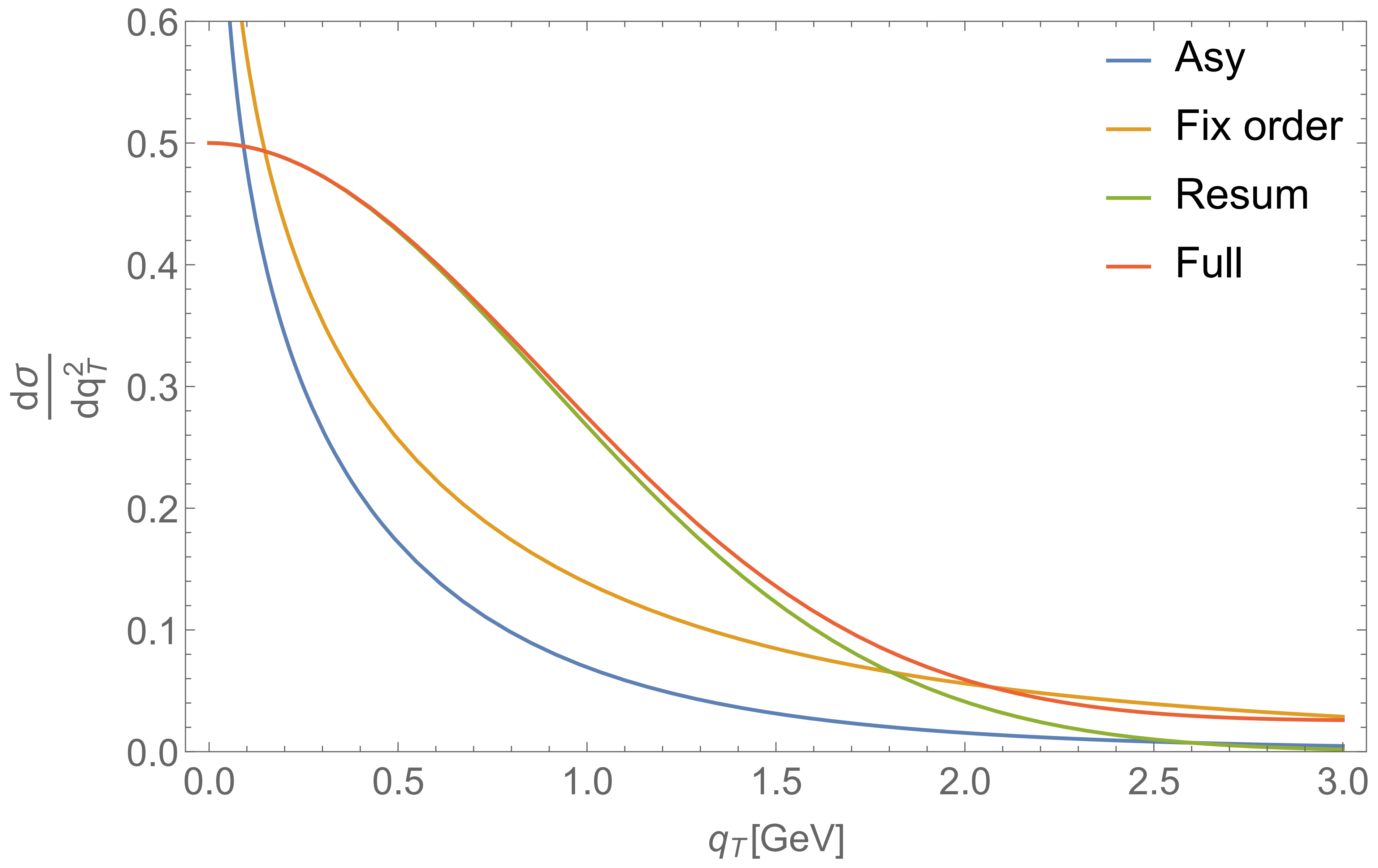


Standard approach

- Resummed contribution is dominant where the Asymptotic term is close to the Fixed Order ⟶ **TMD Region?**

Source of W-term suppression

Ideal situation at low Q

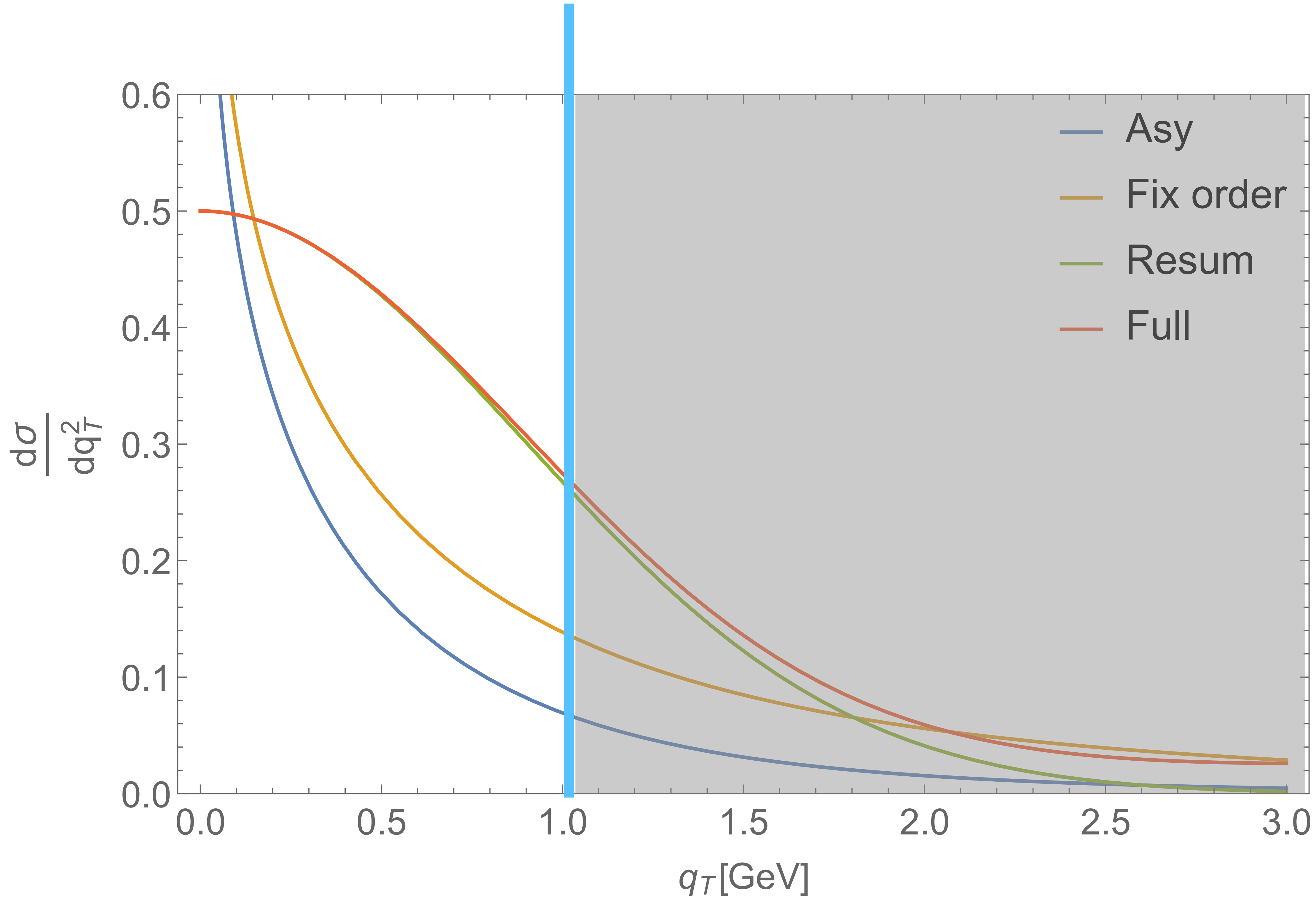


Non-Perturbative approach

- Resummed contribution is dominant where the Asymptotic term is close to the Fixed Order OR the Non-Perturbative contributions dominates

Source of W-term suppression

Ideal situation at low Q



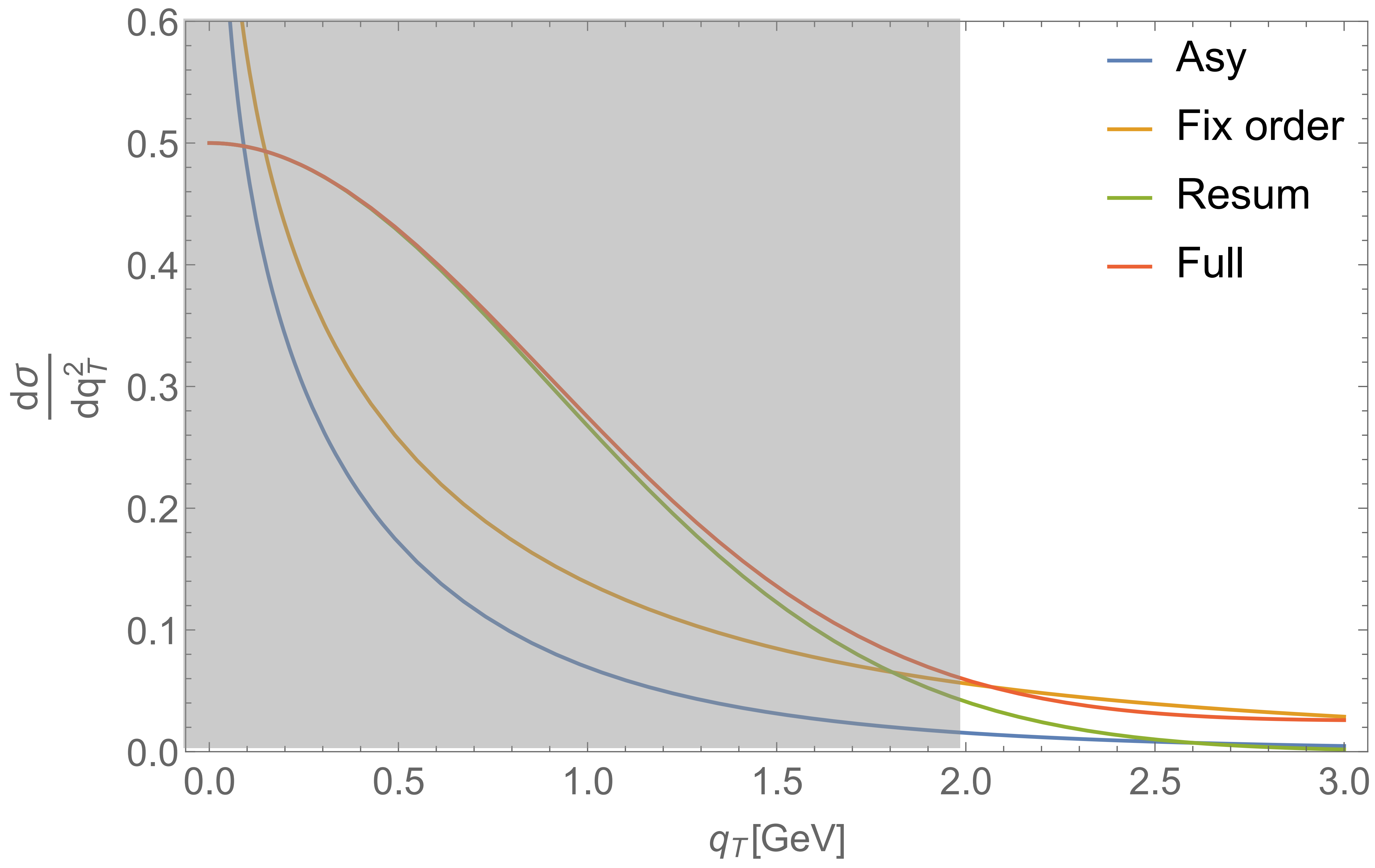
Non-Perturbative approach

- Resummed contribution is dominant where the Asymptotic term is close to the Fixed Order OR the Non-Perturbative contributions dominates

→ **TMD Region**

Source of W-term suppression

Ideal situation at low Q



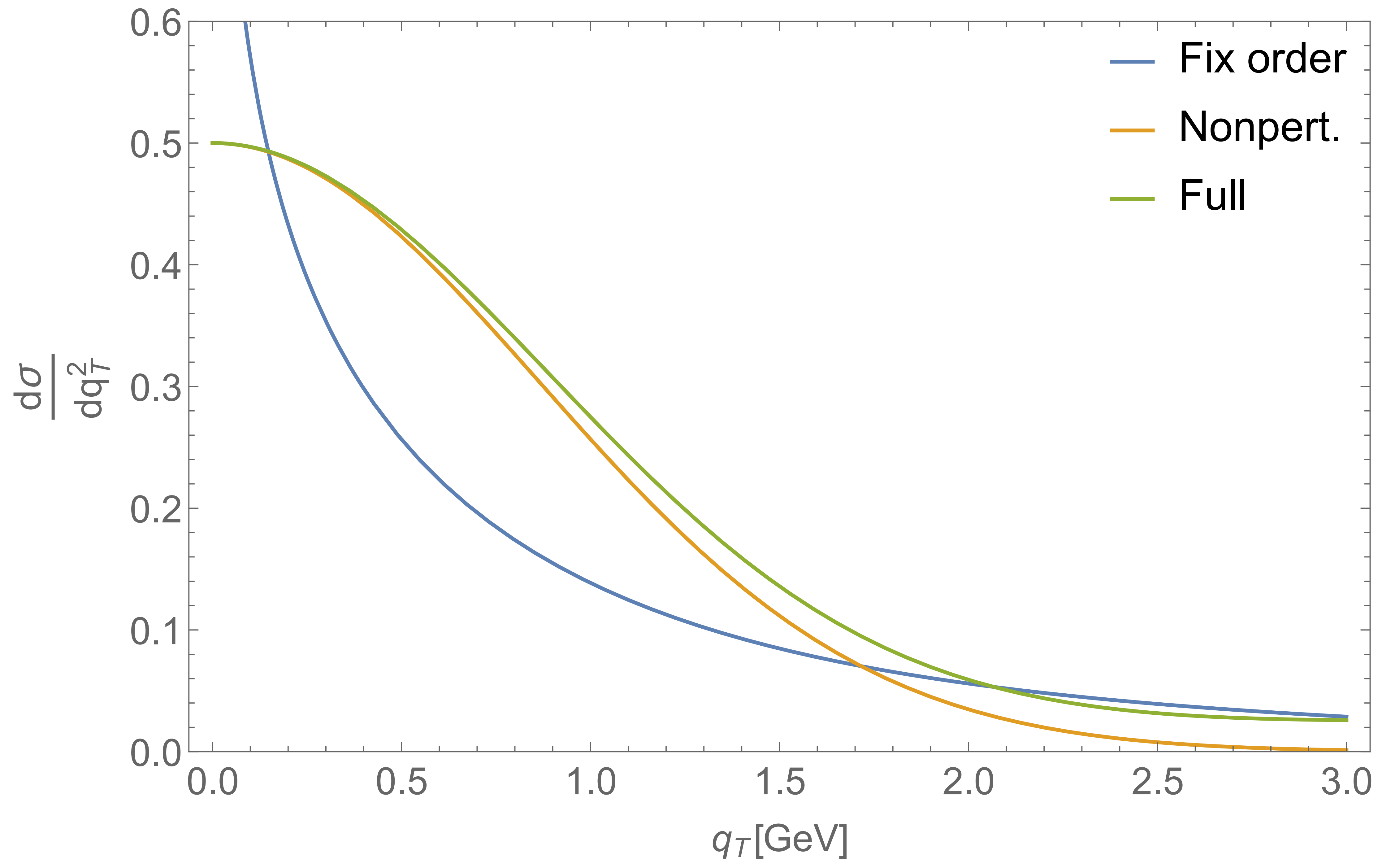
Non-Perturbative approach

- Resummed contribution is dominant where the Asymptotic term is close to the Fixed Order OR the Non-Perturbative contributions dominates

- From a certain value of qT the cross section follows the Fixed Order term

Source of W-term suppression

Ideal situation at low Q



Non-Perturbative approach

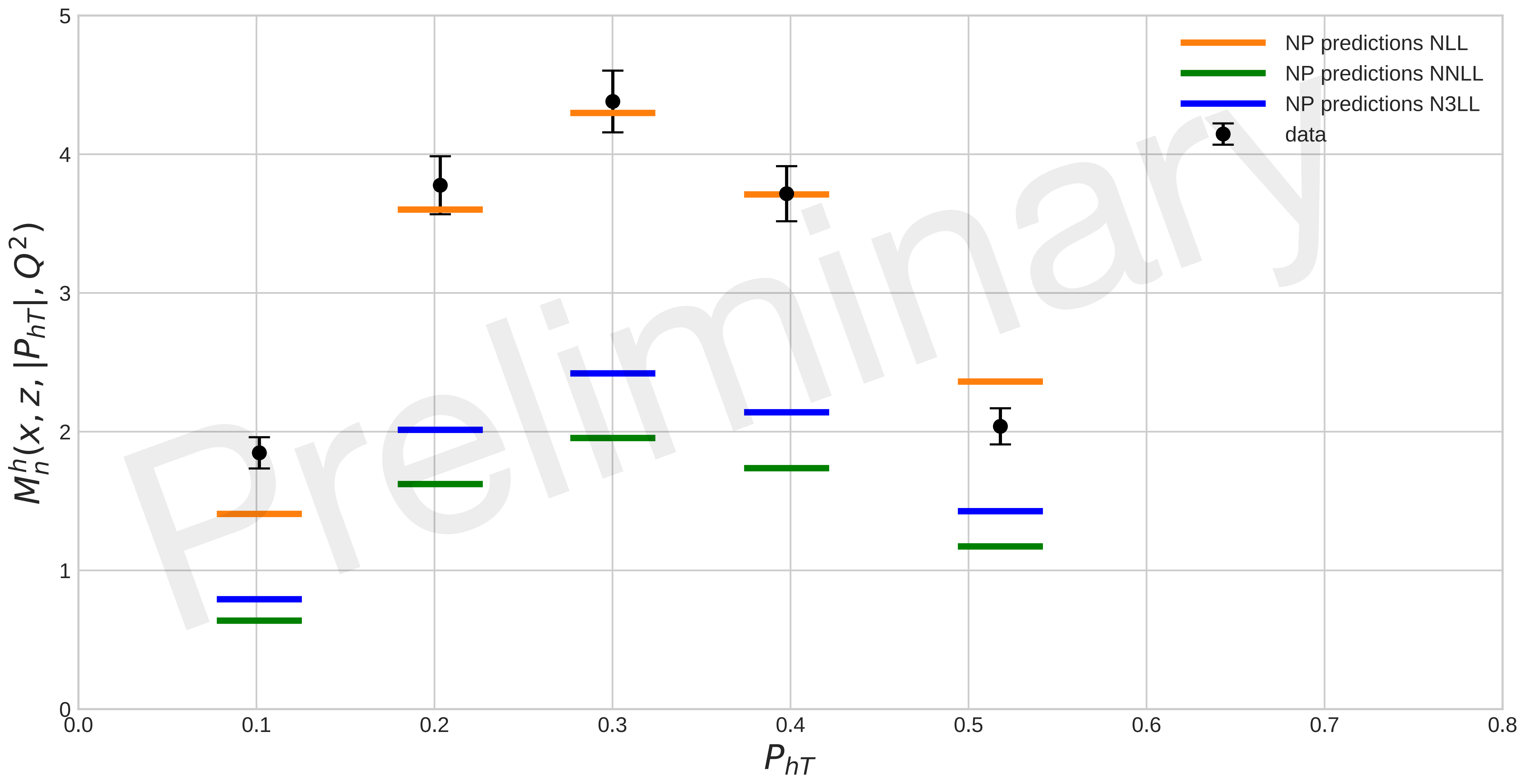
- Collinear result is <u>no more</u> mostly given by the integral of the Fixed Order
- The Non-Perturbative term is <u>not</u> only a small correction, but is even larger than the Fixed Order contribution

Source of W-term suppression

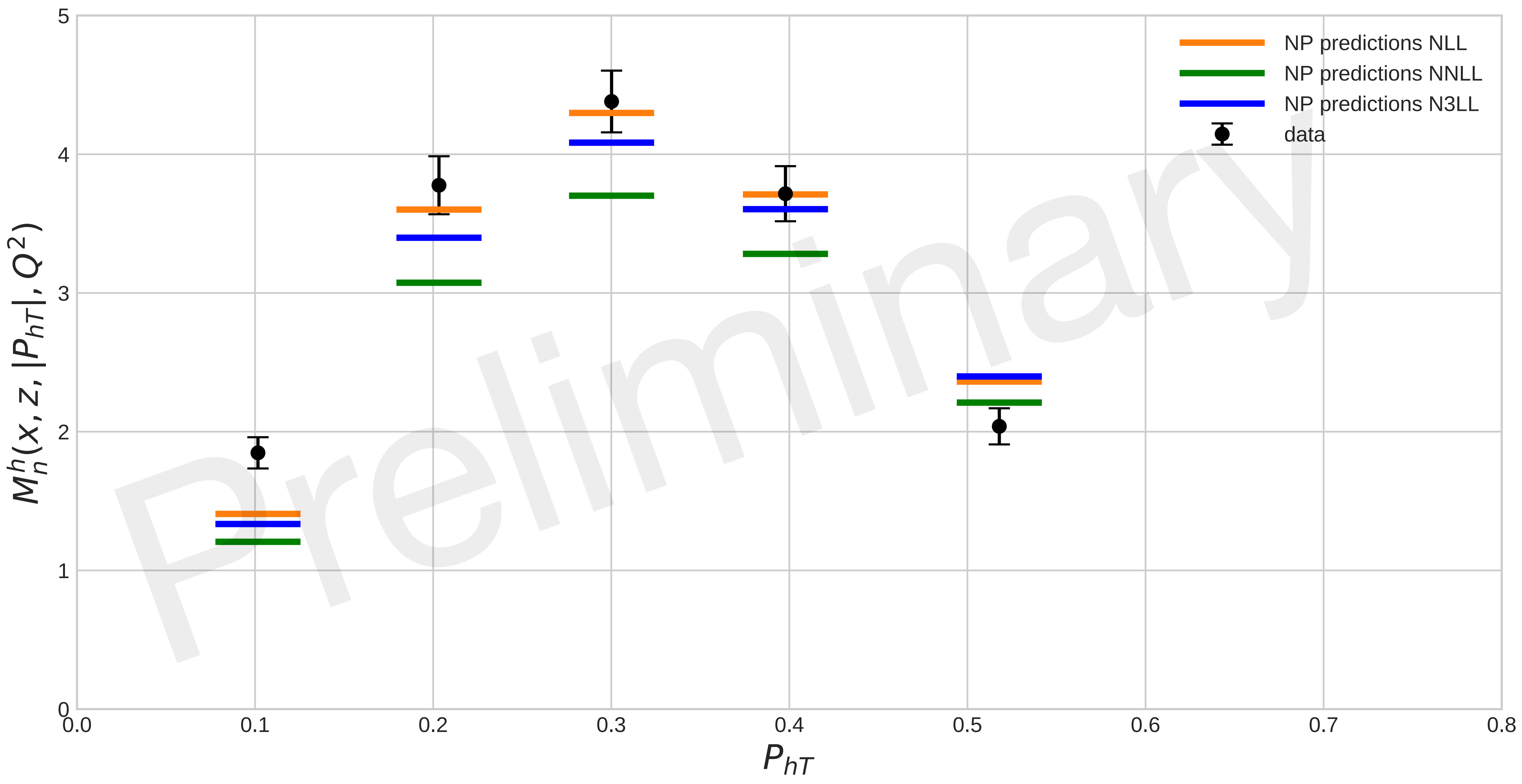
Present situation at low Q

HERMES multiplicity

Full Hard Factor



Hard Factor = 1

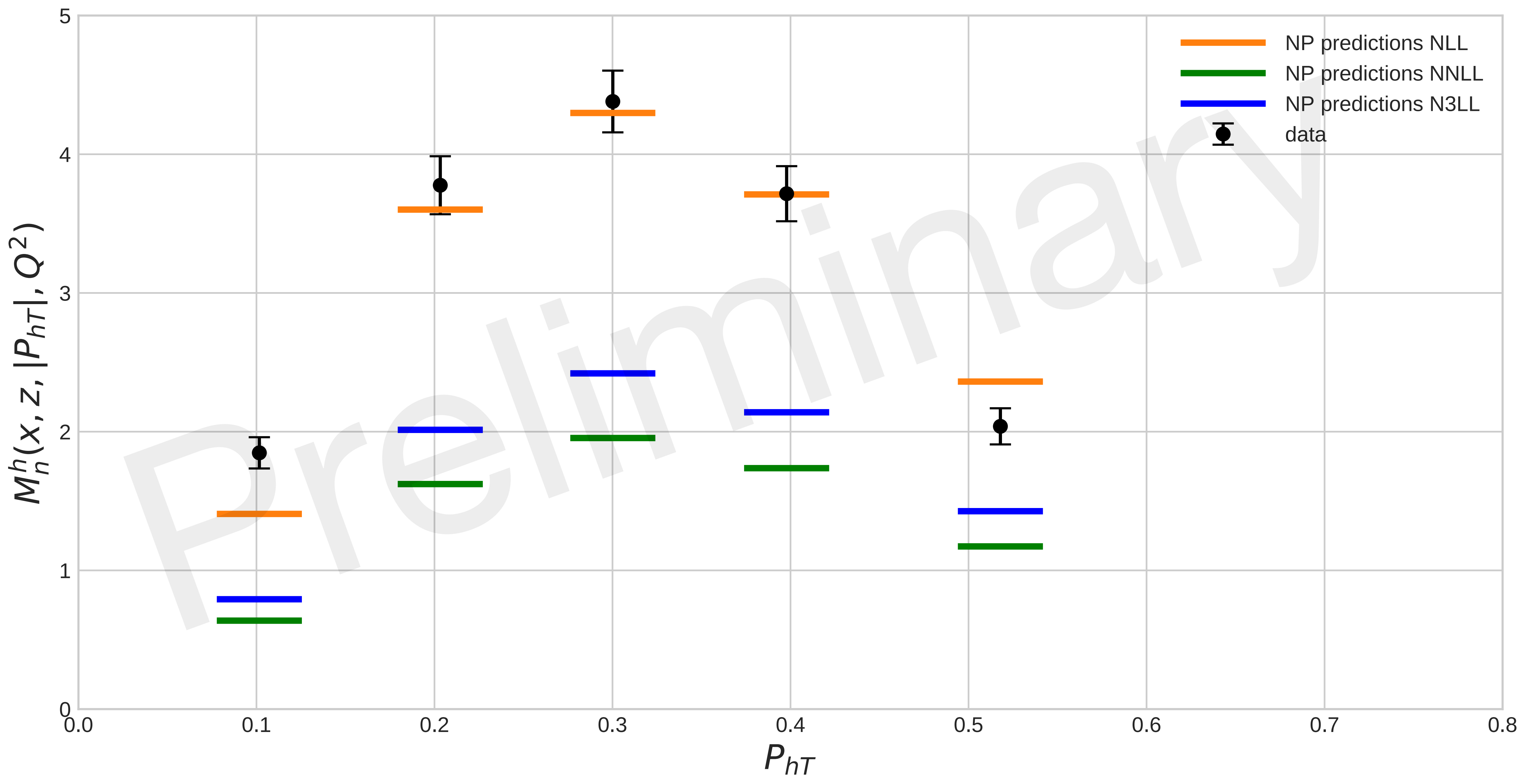


Source of W-term suppression

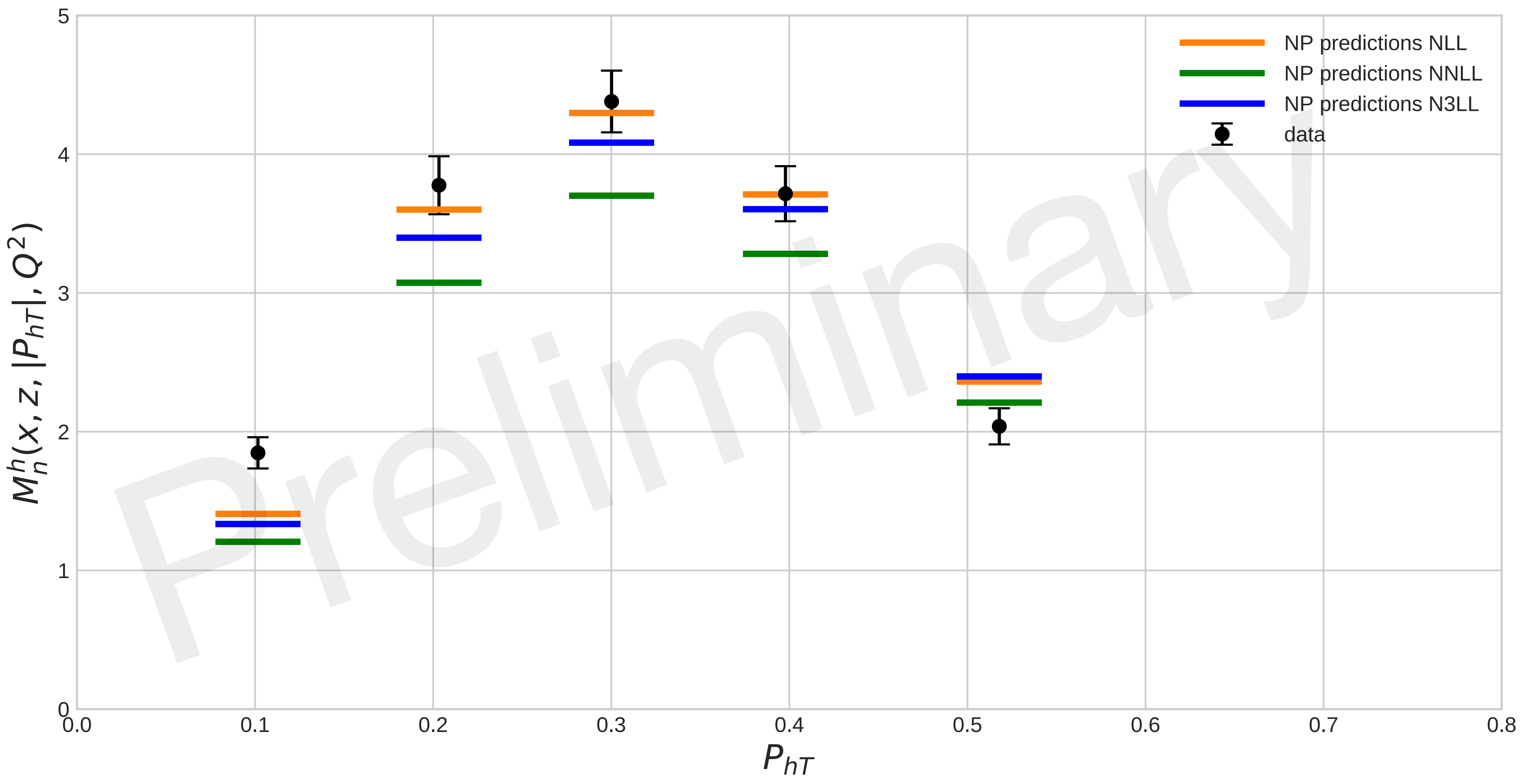
Present situation at low Q

HERMES multiplicity

Full Hard Factor



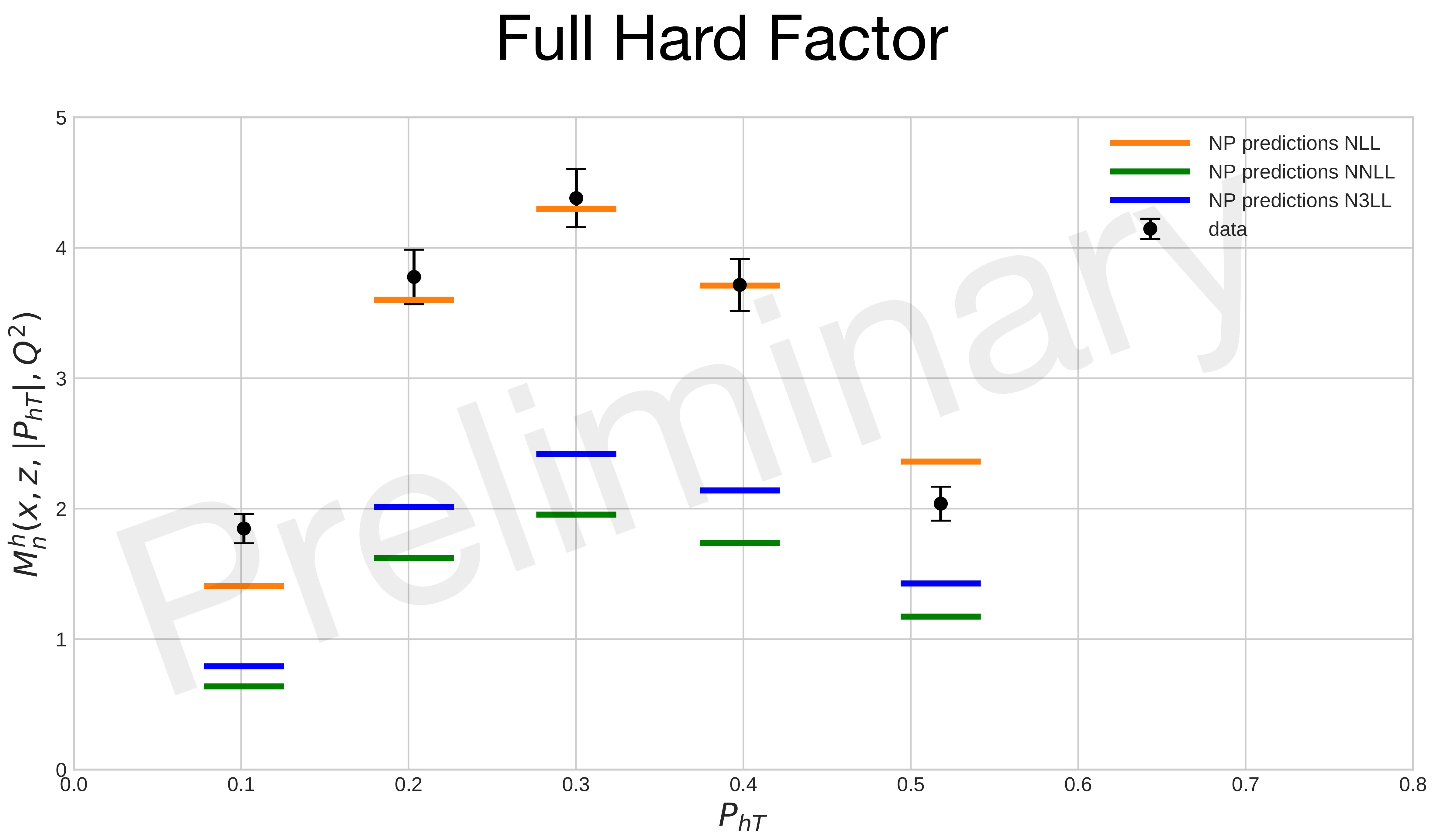
Hard Factor = 1

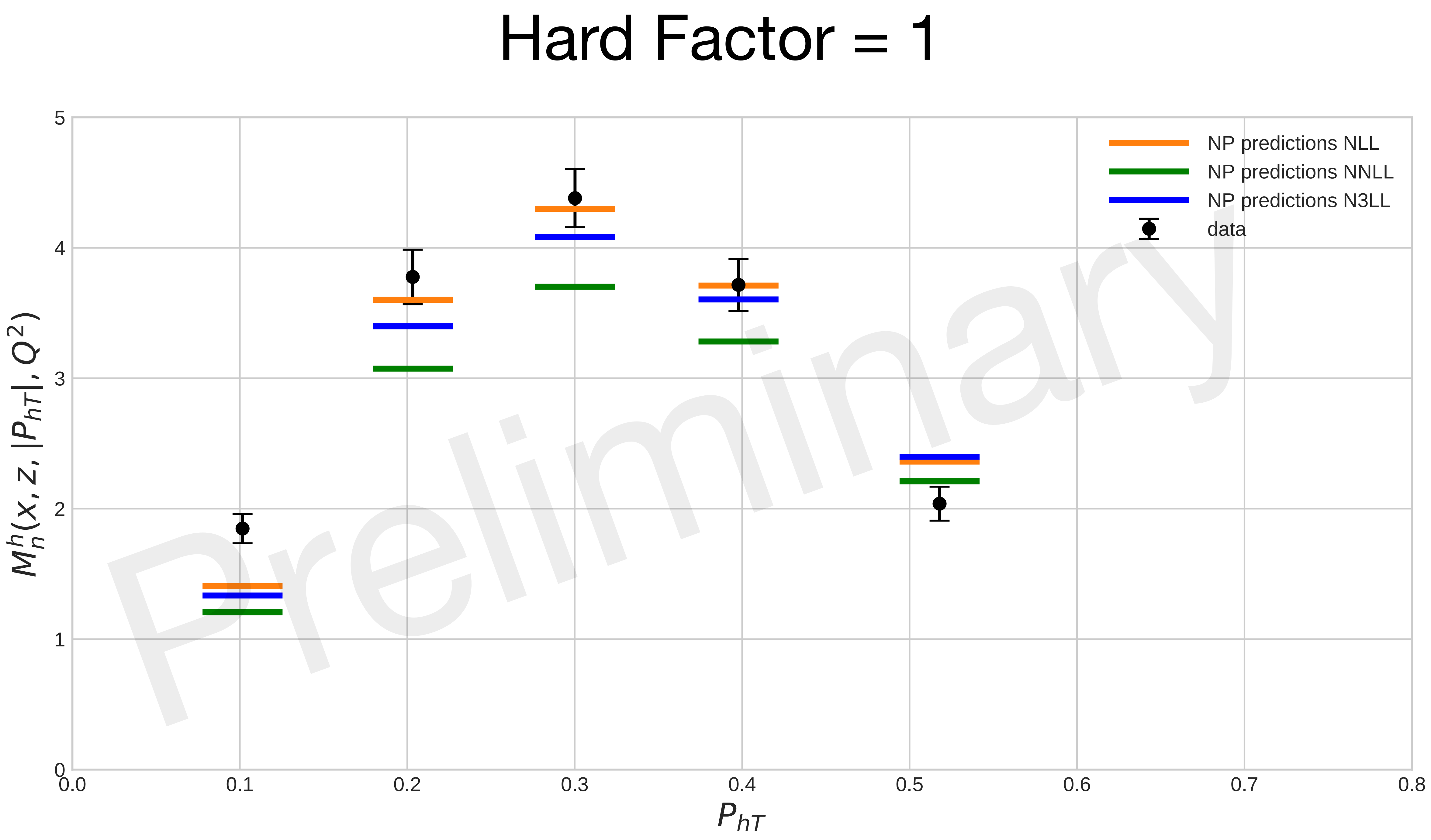


Source of W-term suppression

Present situation at low Q

HERMES multiplicity



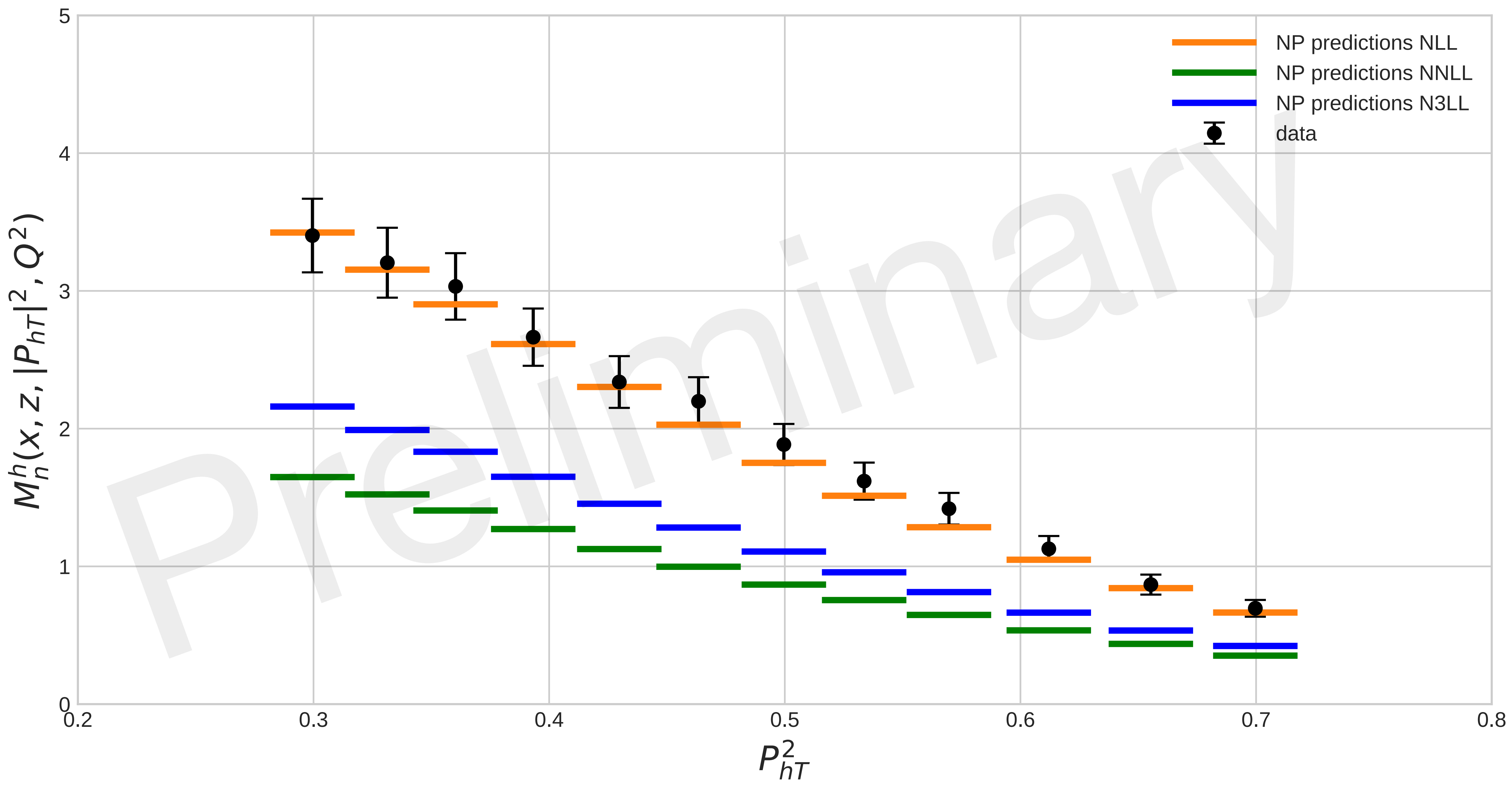


Source of W-term suppression

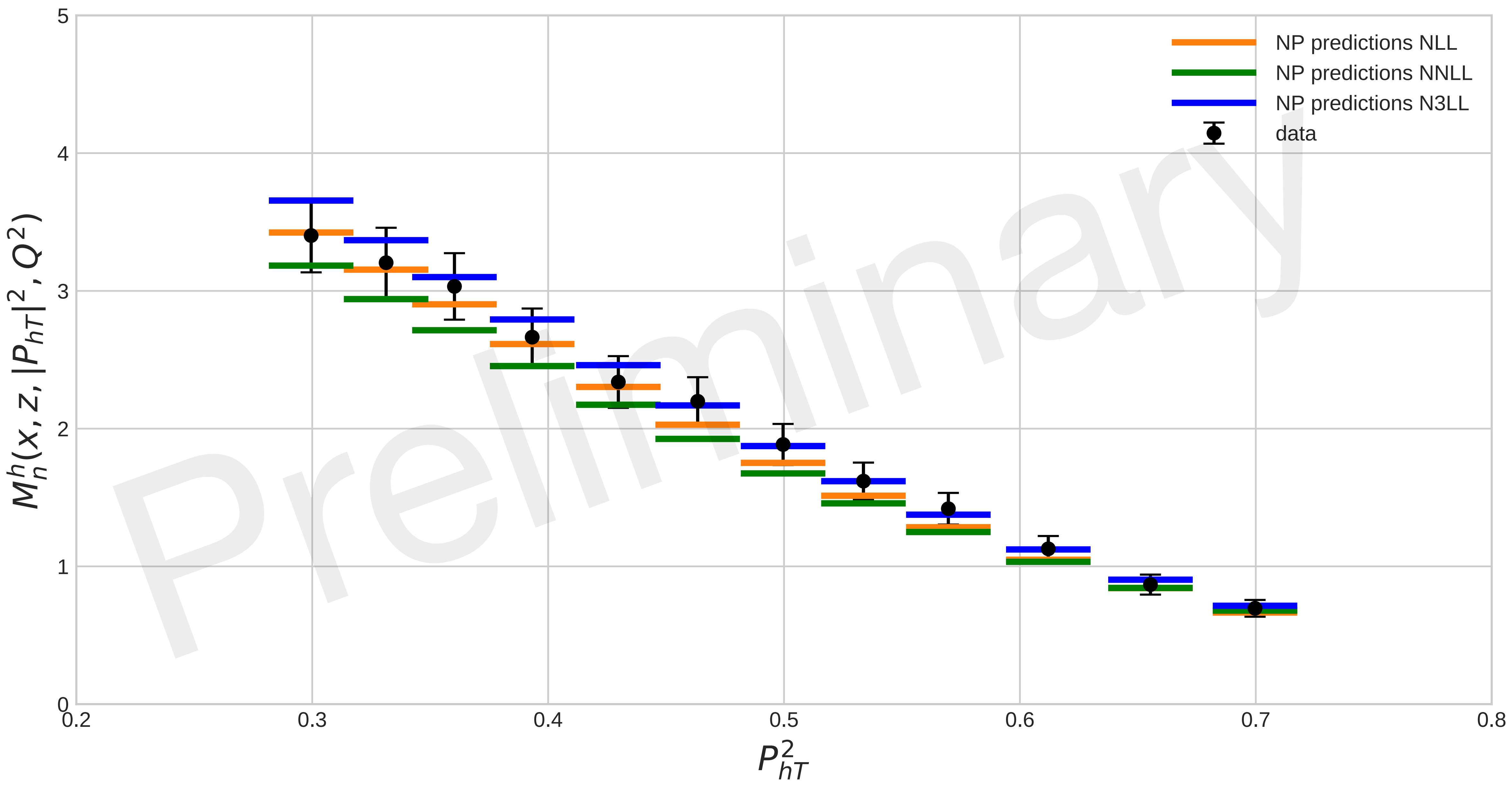
Present situation at low Q

COMPASS multiplicity

Full Hard Factor



Hard Factor = 1



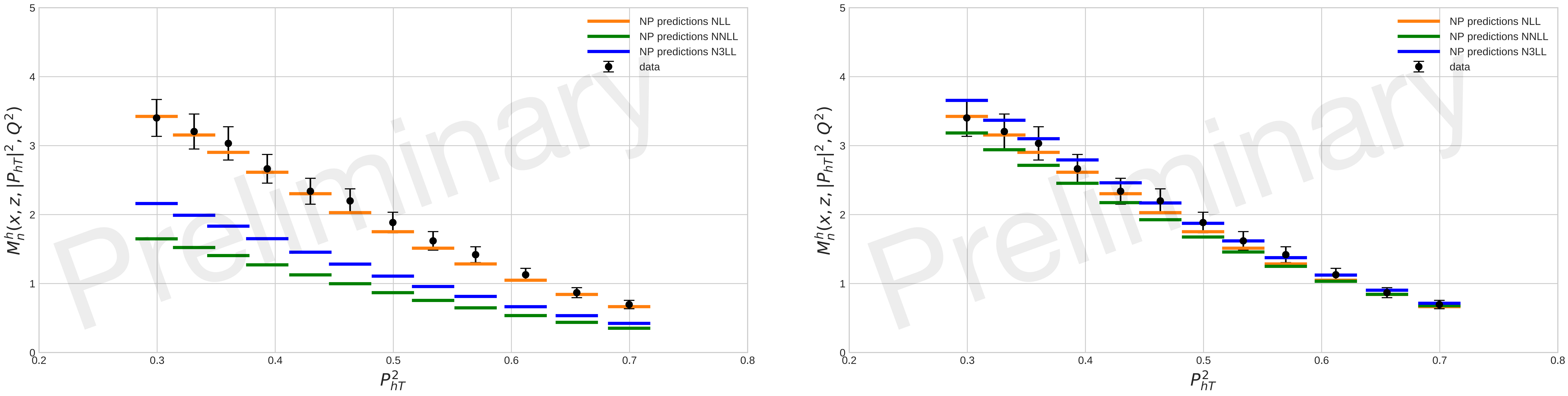
Source of W-term suppression

Present situation at low Q

COMPASS multiplicity

Full Hard Factor

Hard Factor = 1

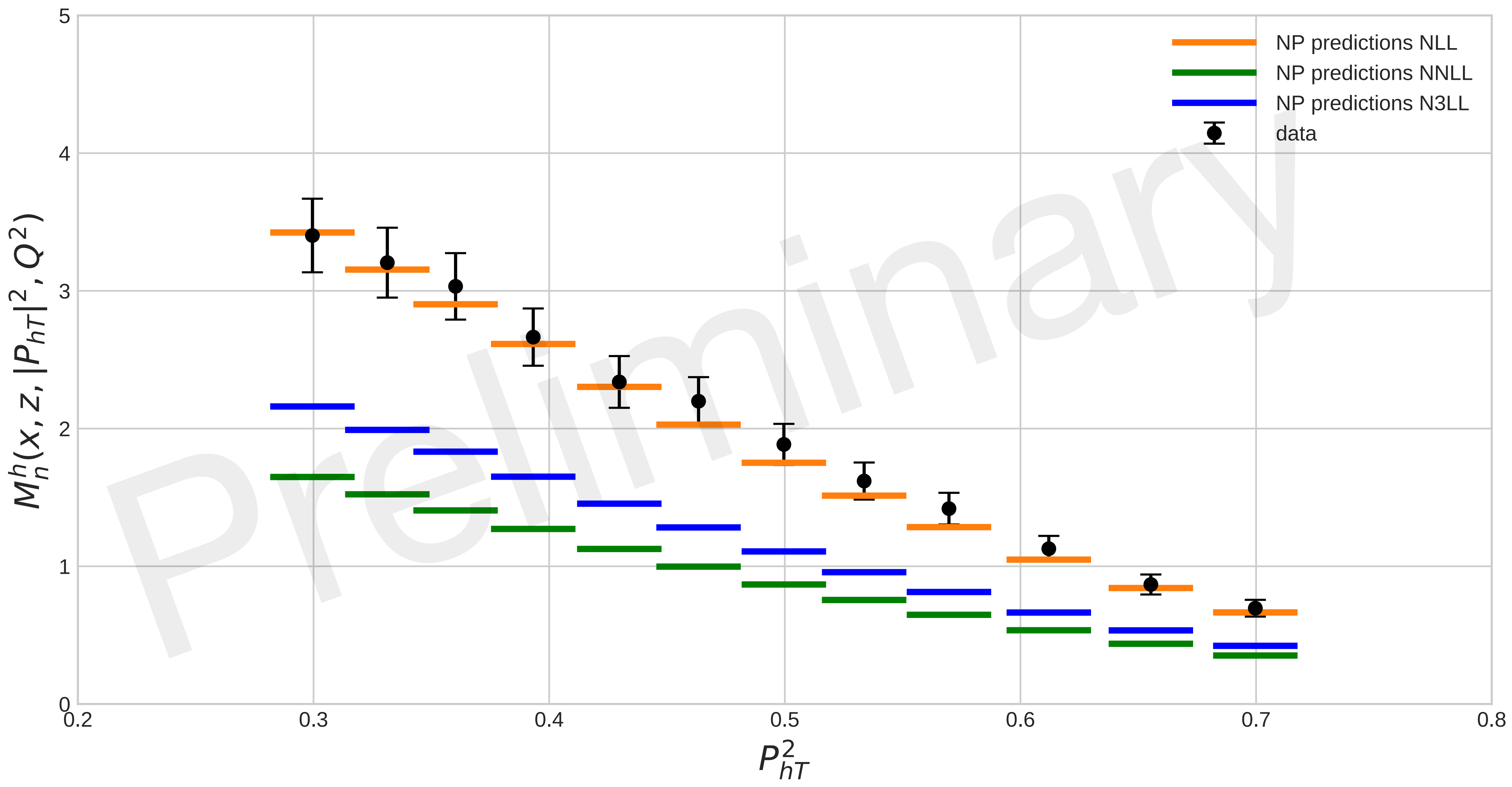


Source of W-term suppression

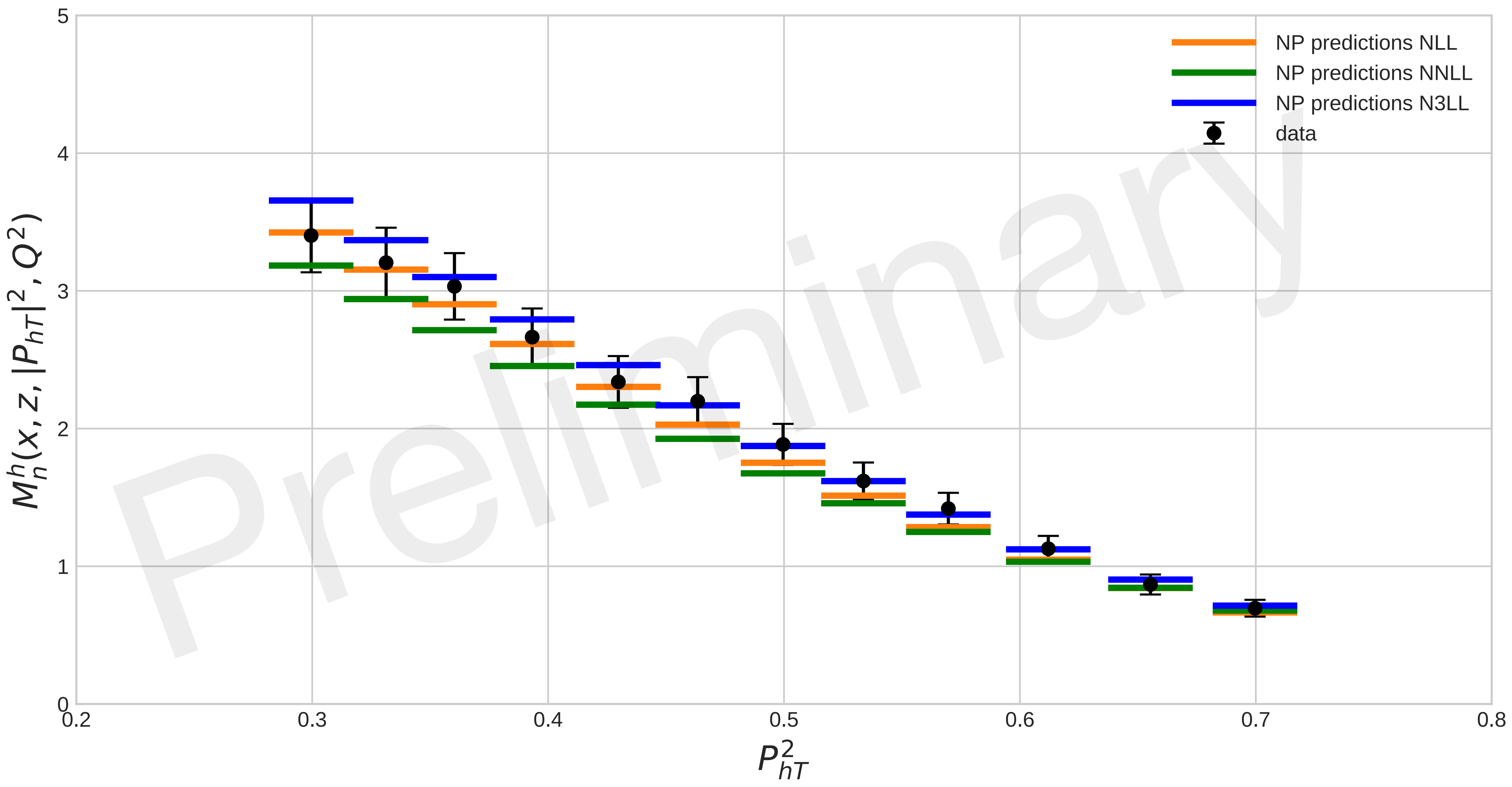
Present situation at low Q

COMPASS multiplicity

Full Hard Factor



Hard Factor = 1



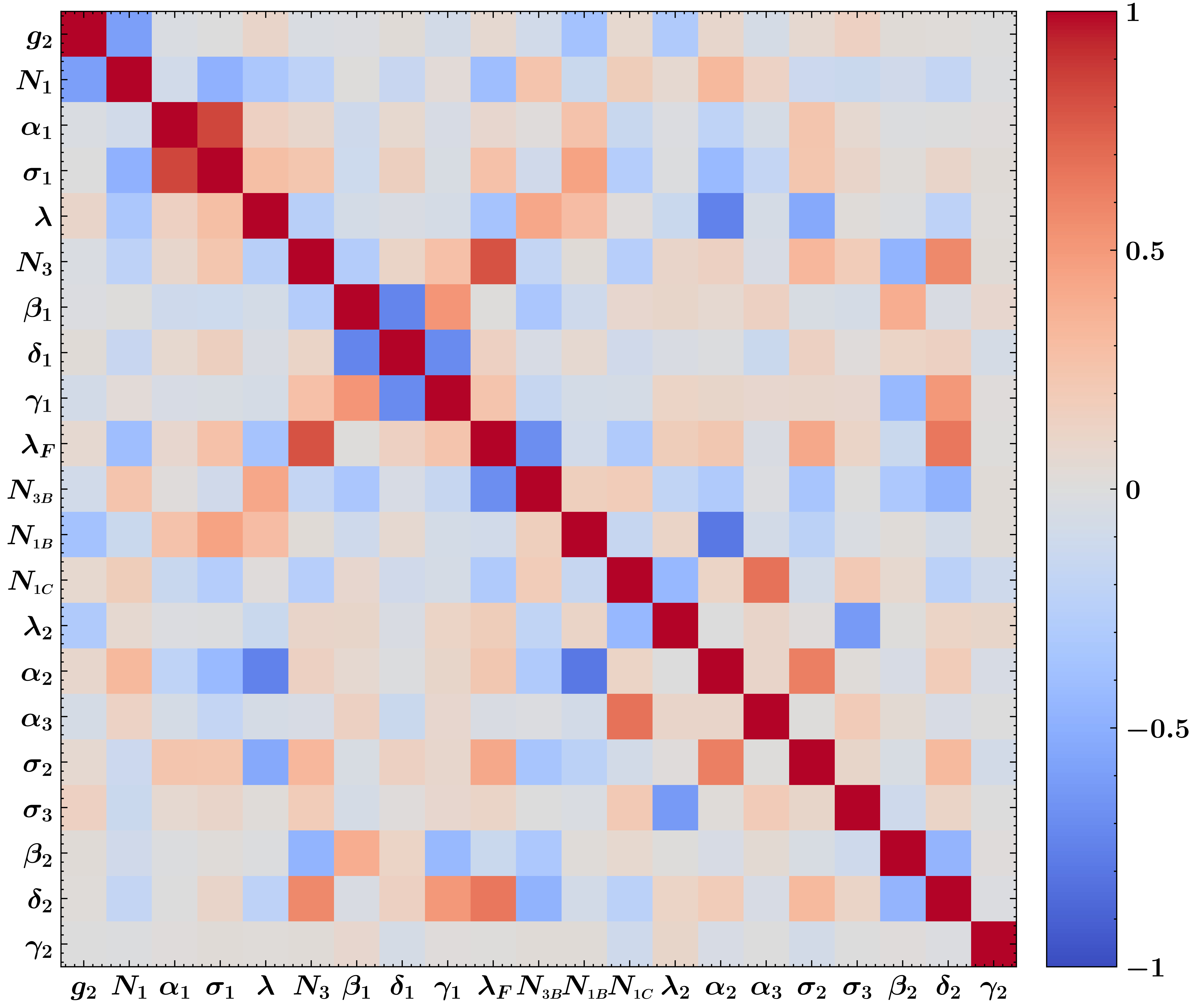
	Framework	HERMES	COMPASS	DY	Z production	N of points
Pavia 2013 arXiv:1309.3507	parton model	✔	✘	✘	✘	1538
Torino 2014 arXiv:1312.6261	parton model	✔ (separately)	✔ (separately)	✘	✘	576 (H) 6284 (C)
DEMS 2014 arXiv:1407.3311	NNLL	✘	✘	✔	✔	223
EIKV 2014 arXiv:1401.5078	NLL	1 (x,Q^2) bin	1 (x,Q^2) bin	✔	✔	500 (?)
SIYY 2014 arXiv:1406.3073	NLL′	✘	✔	✔	✔	200 (?)
Pavia 2017 arXiv:1703.10157	NLL	✔	✔	✔	✔	8059
SV 2017 arXiv:1706.01473	NNLL′	✘	✘	✔	✔	309
BSV 2019 arXiv:1902.08474	NNLL′	✘	✘	✔	✔	457
SV 2019 arXiv:1912.06532	N^3LL^-	✔	✔	✔	✔	1039
Pavia 2019 arXiv:1912.07550	N^3LL	✘	✘	✔	✔	353
MAP22 arXiv:2206.07598	N^3LL^-	✔	✔	✔	✔	2031

Results of the baseline fit

Error propagation

↓

250 Montecarlo replicas



Results of the baseline fit

Error propagation

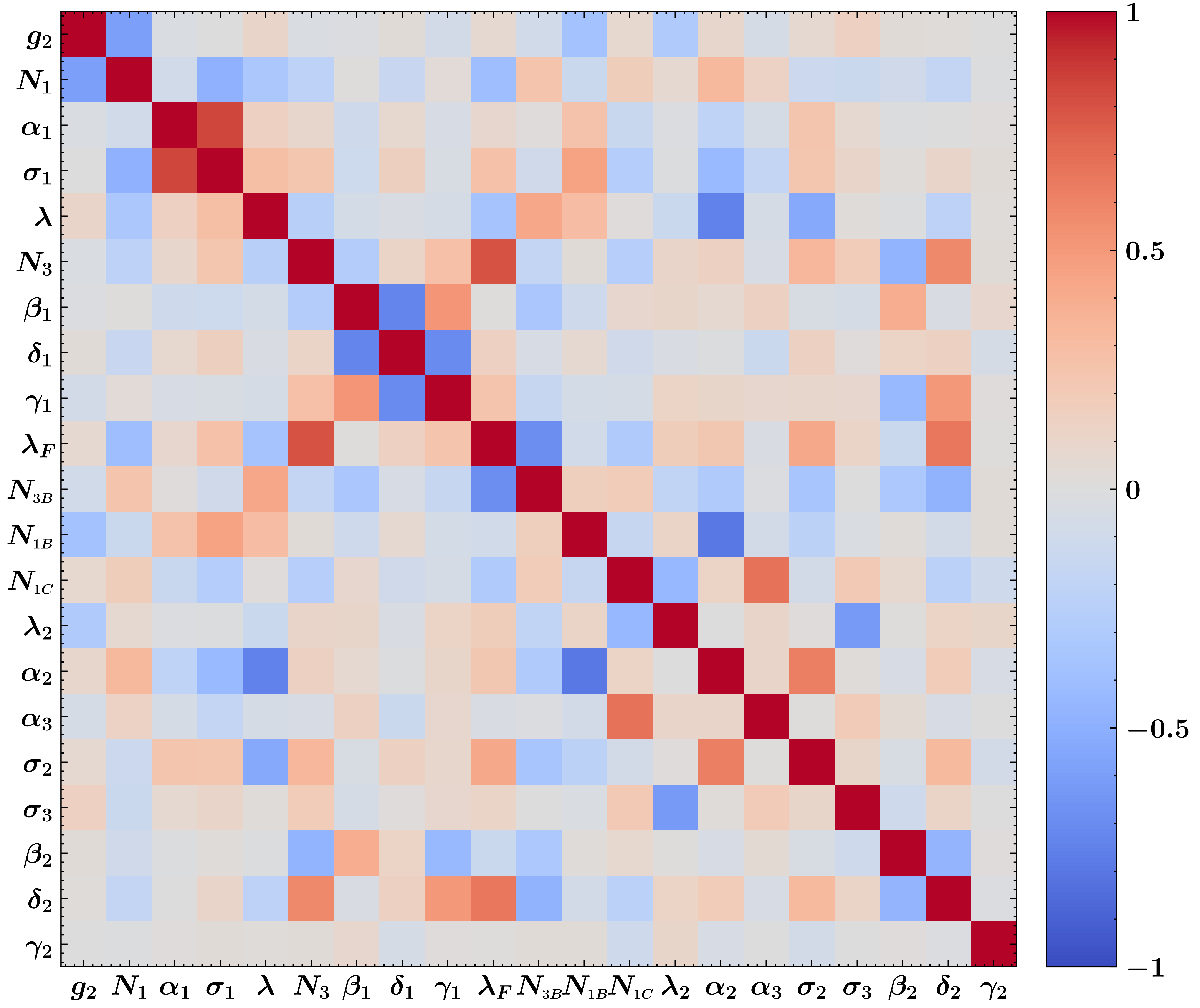
↓

250 Montecarlo replicas

Correlation matrix

↓

Hints of the appropriateness of the chosen functional form



Cut qT/Q for SIDIS dataset

$$P_{hT}|_{\max} = \min[\min[c_1 Q, c_2 z Q] + c_3 \text{ GeV}, c_4 z Q]$$

baseline (c)
$$\begin{cases} c_1 = 0.2 \\ c_2 = 0.5 \\ c_3 = 0.3 \\ c_4 = 1 \end{cases}$$

qT/Q = 0.4 (a)
$$\begin{cases} c_1 = 0.2 \\ c_2 = 0.5 \\ c_3 = 0.3 \\ c_4 = 0.4 \end{cases}$$

< baseline (b)
$$\begin{cases} c_1 = 0.15 \\ c_2 = 0.4 \\ c_3 = 0.2 \\ c_4 = 1 \end{cases}$$

> baseline (d)
$$\begin{cases} c_1 = 0.2 \\ c_2 = 0.6 \\ c_3 = 0.4 \\ c_4 = \infty \end{cases}$$

PV17 (e)
$$\begin{cases} c_1 = 0.2 \\ c_2 = 0.7 \\ c_3 = 0.5 \\ c_4 = \infty \end{cases}$$