# MAPTMD24: New insights on flavor dependence in TMD extractions

arXiv 2405.13833

Transversity Workshop

Lorenzo Rossi

MAP Collaboration

June 6th



UNIVERSITÀ DI PAVIA

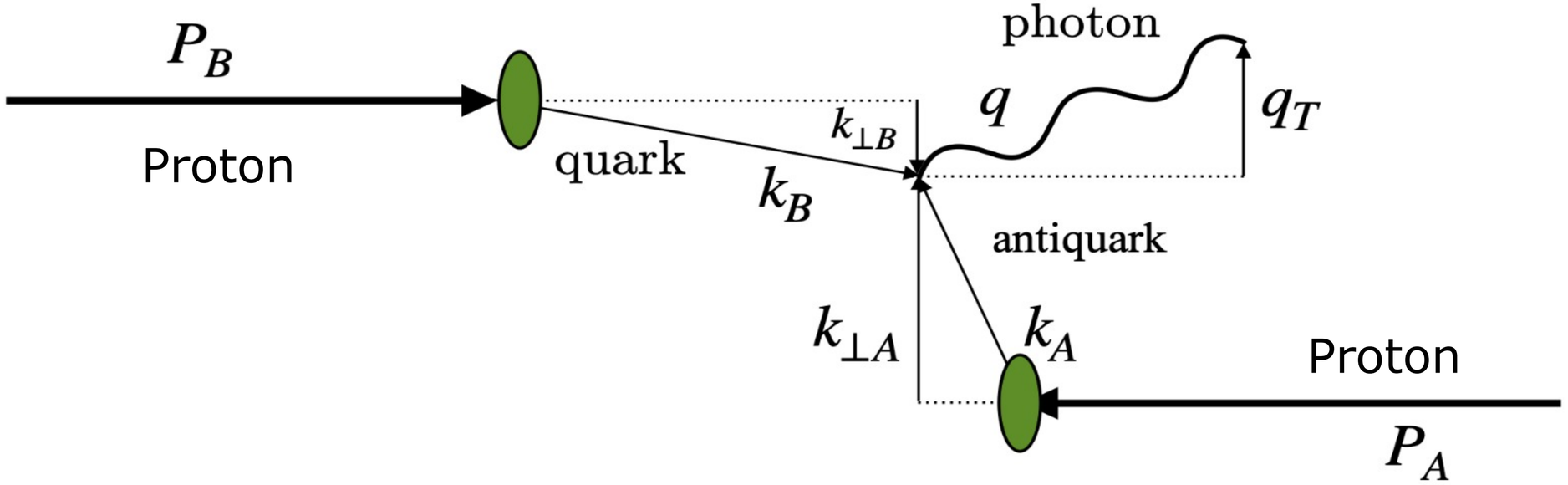

MAPTMD24
MAPTMD22
Theory recap


MAPTMD24
MAPTMD22
Theory recap

# TMD factorization — Drell-Yan process

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

# TMD factorization — Drell-Yan process

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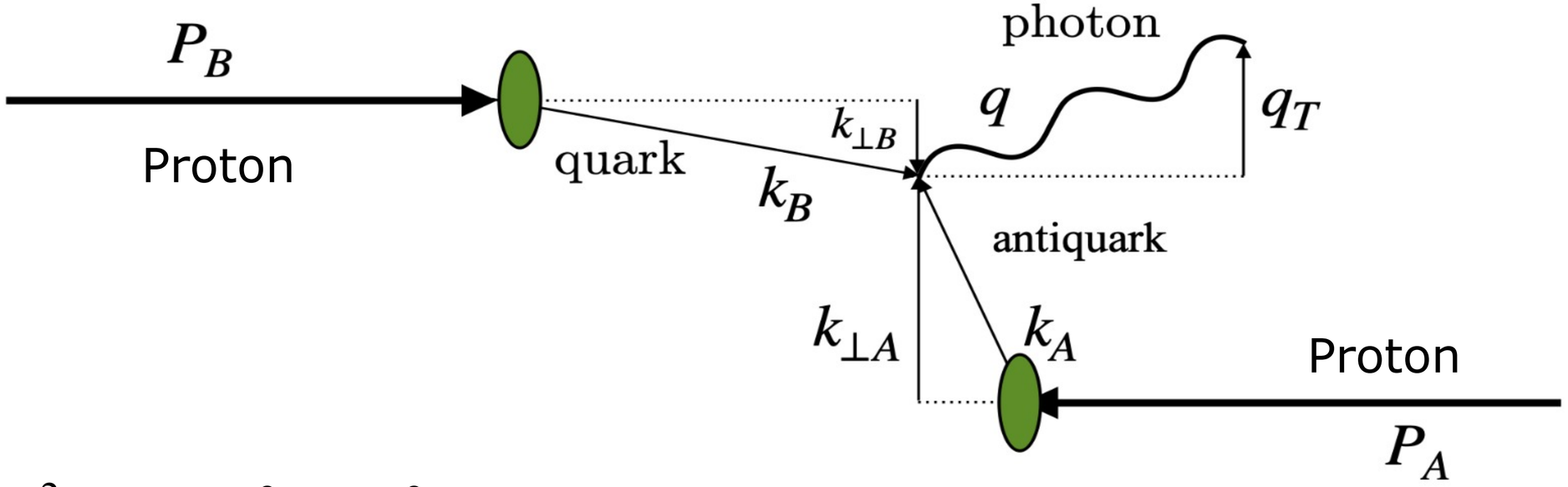


In $q_T^2 \ll Q^2$ and $M^2 \ll Q^2$ region:

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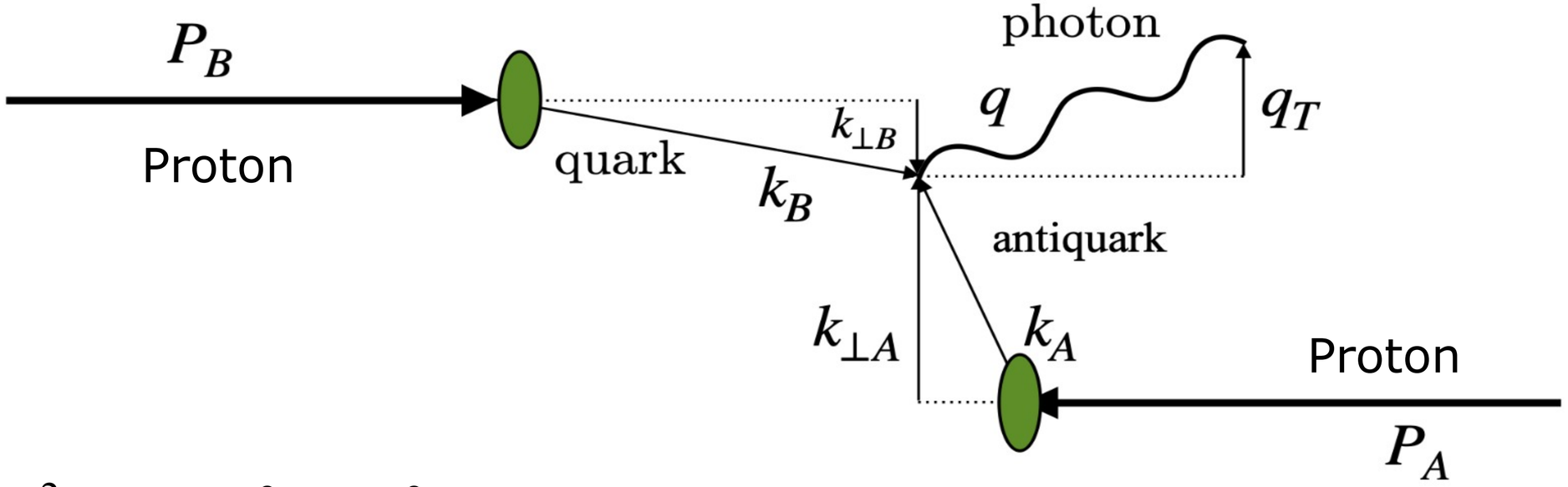


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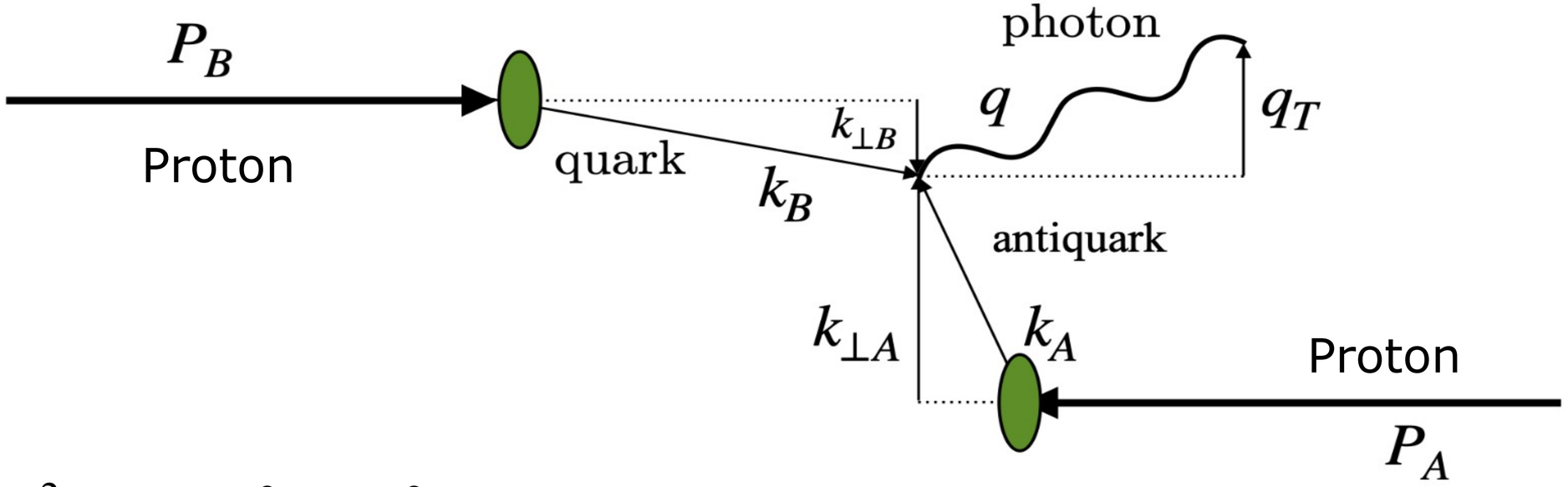


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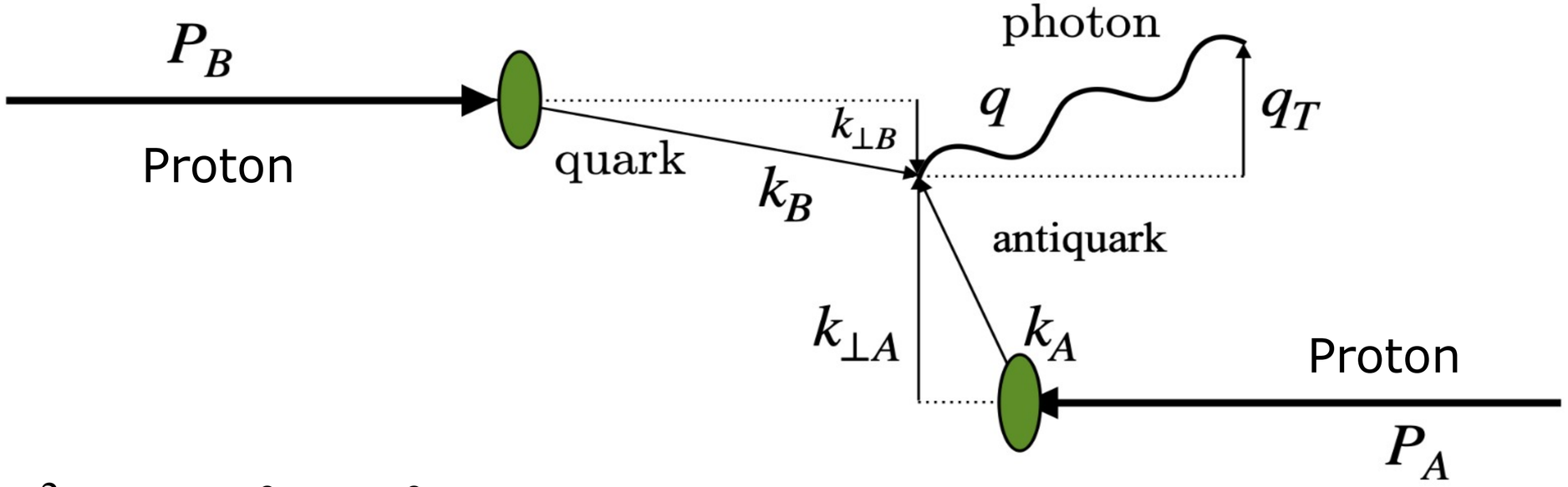


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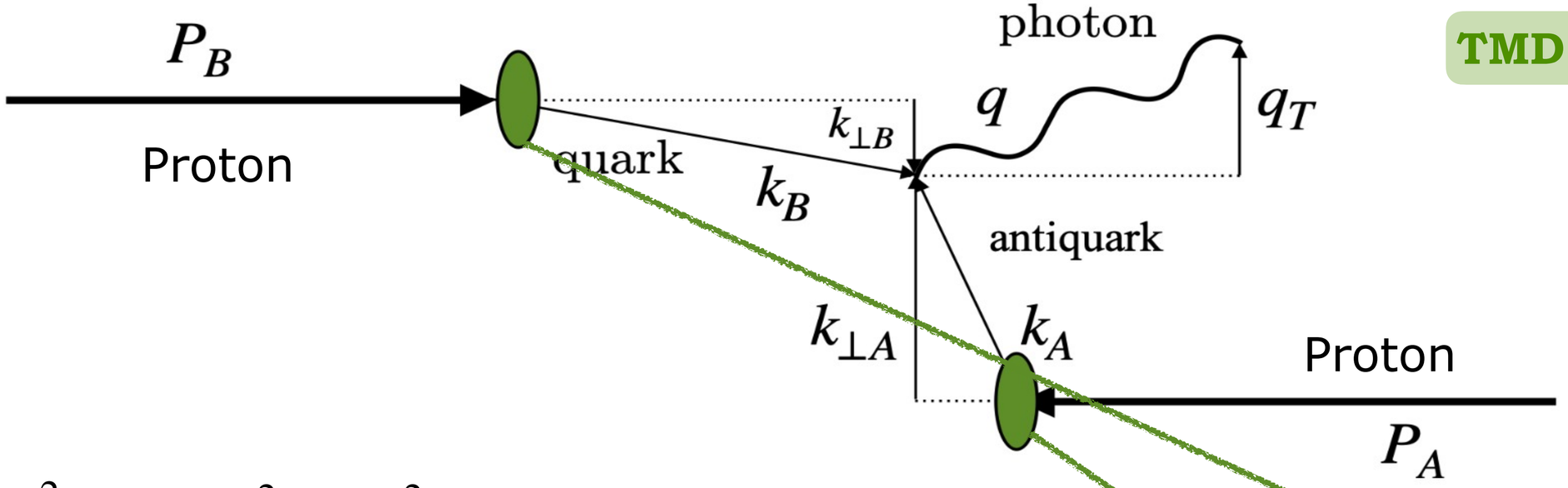


TMD PDFs

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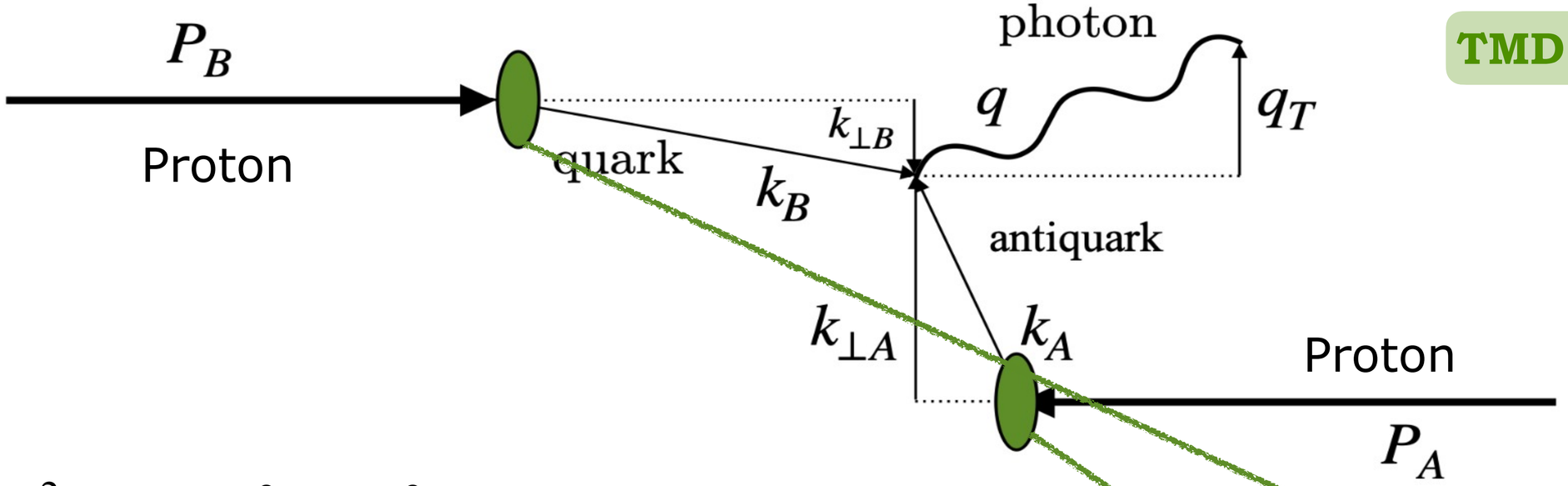


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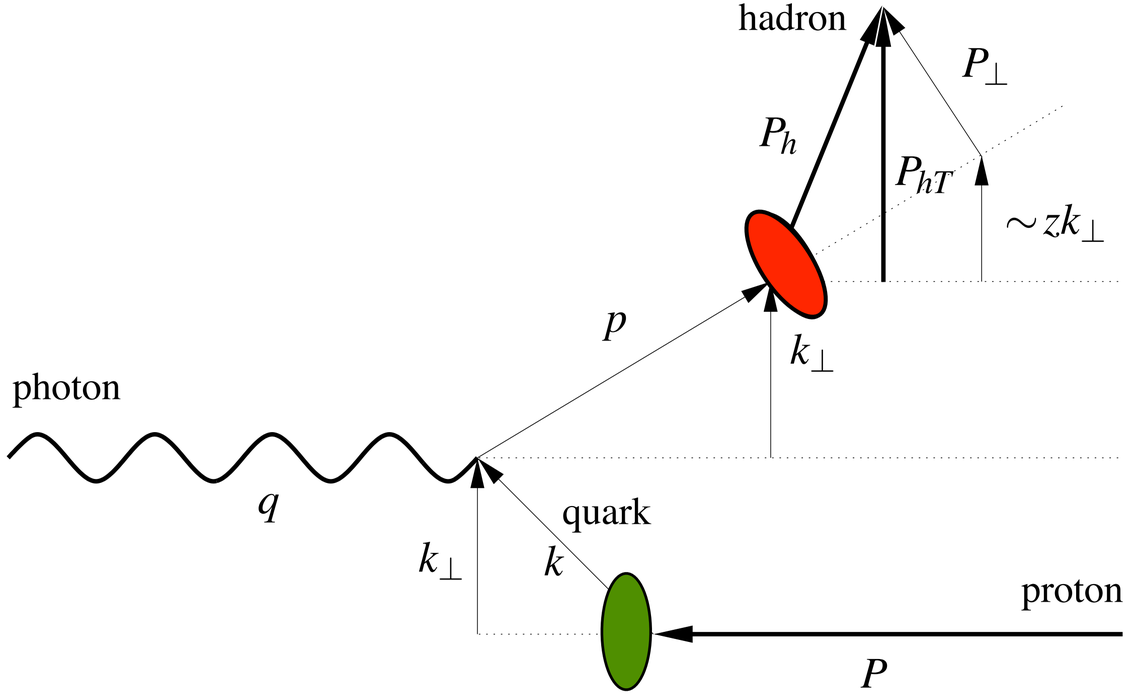
W term

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

# TMD Factorization - SIDIS process




$$F_{UU,T}(x\,.\,z;\mu_F,\mathbf{P}_{hT}^2,Q^2) = x\sum_a H^a_{UU,T}(Q^2,\mu^2)\int d^2\mathbf{k}_\perp \mathbf{d^2P}_\perp f_1^{\mathbf{a}}(x,\mathbf{k}_\perp^2;\mu^2) D_1^{\mathbf{a}\to\mathbf{h}}(z,\mathbf{P}_\perp^2;\mu^2)\delta^{(2)}(z\mathbf{k}_\perp - \mathbf{P}_{hT} + \mathbf{P}_\perp)$$

$$+ Y_{UU,T}(Q^2,\mathbf{P}_{hT}^2) + \mathcal{O}(M^2/Q^2)$$

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

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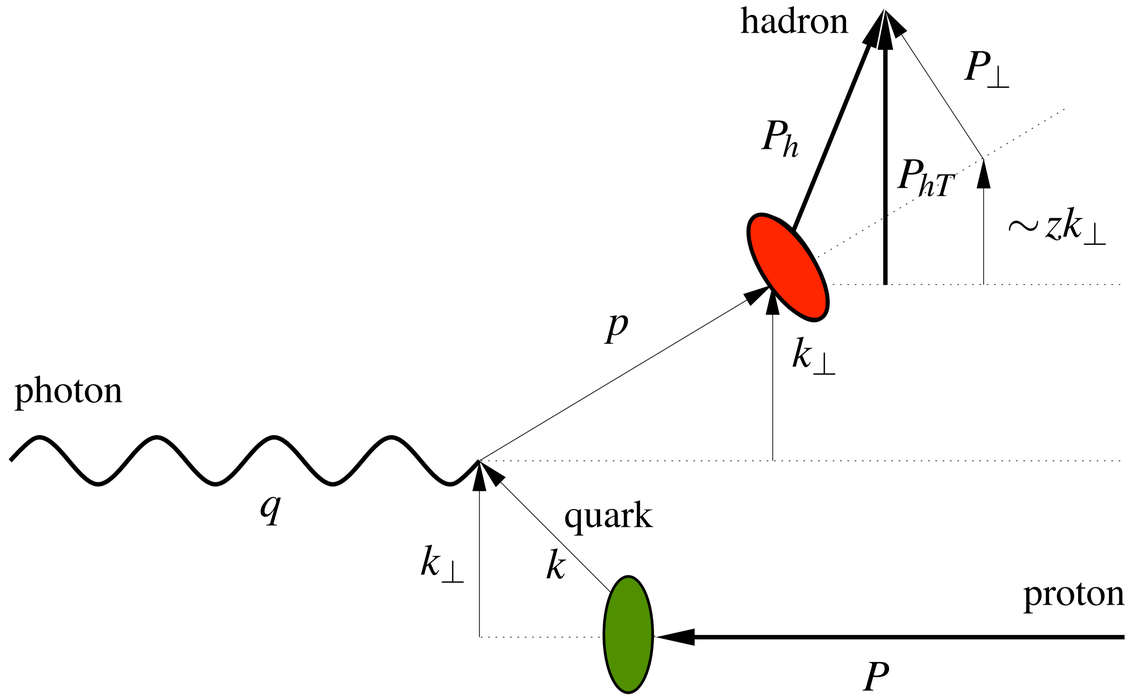


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**W Term**

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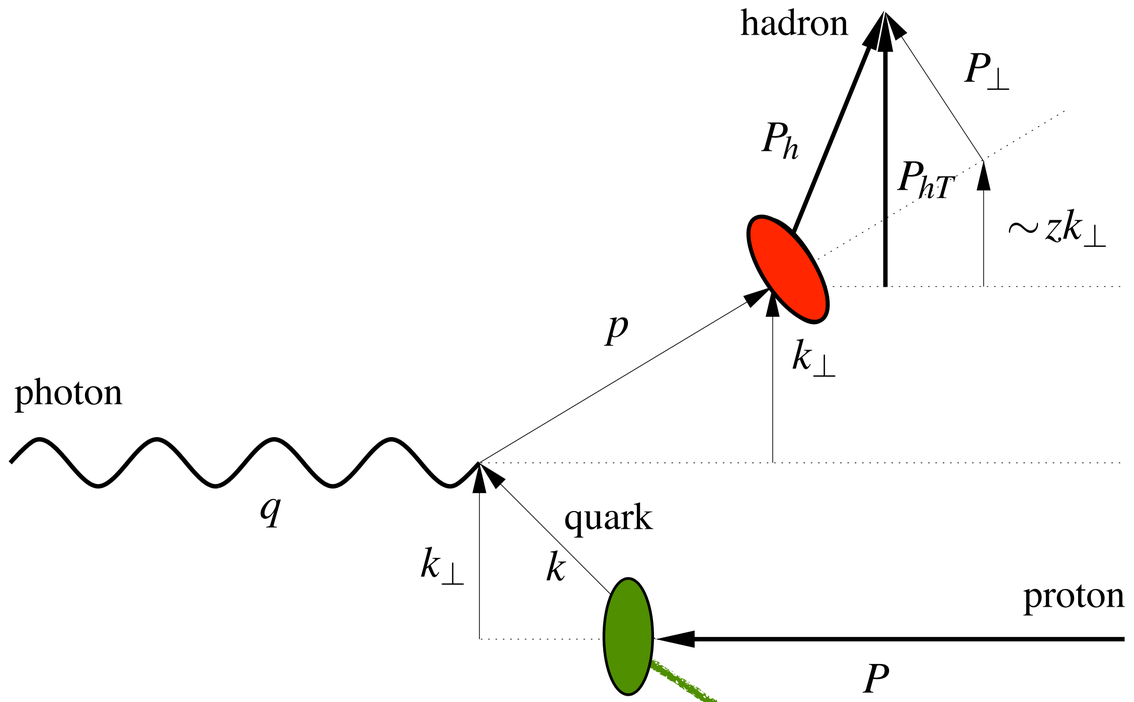


**TMD PDF**

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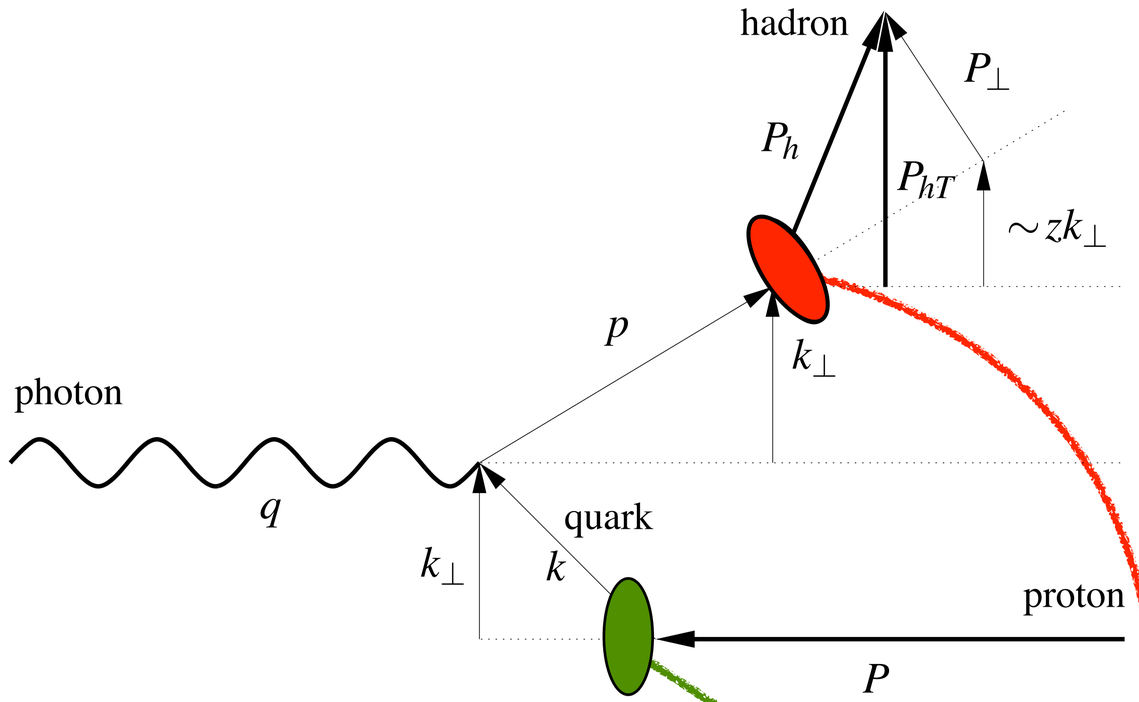


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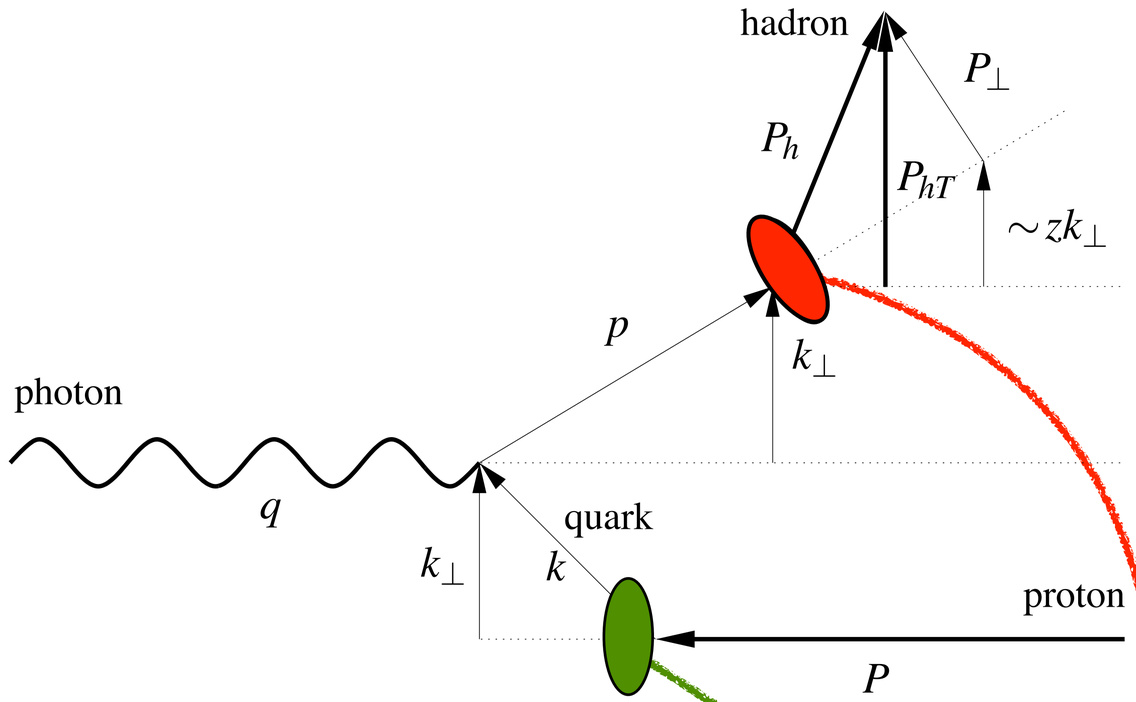


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W Term

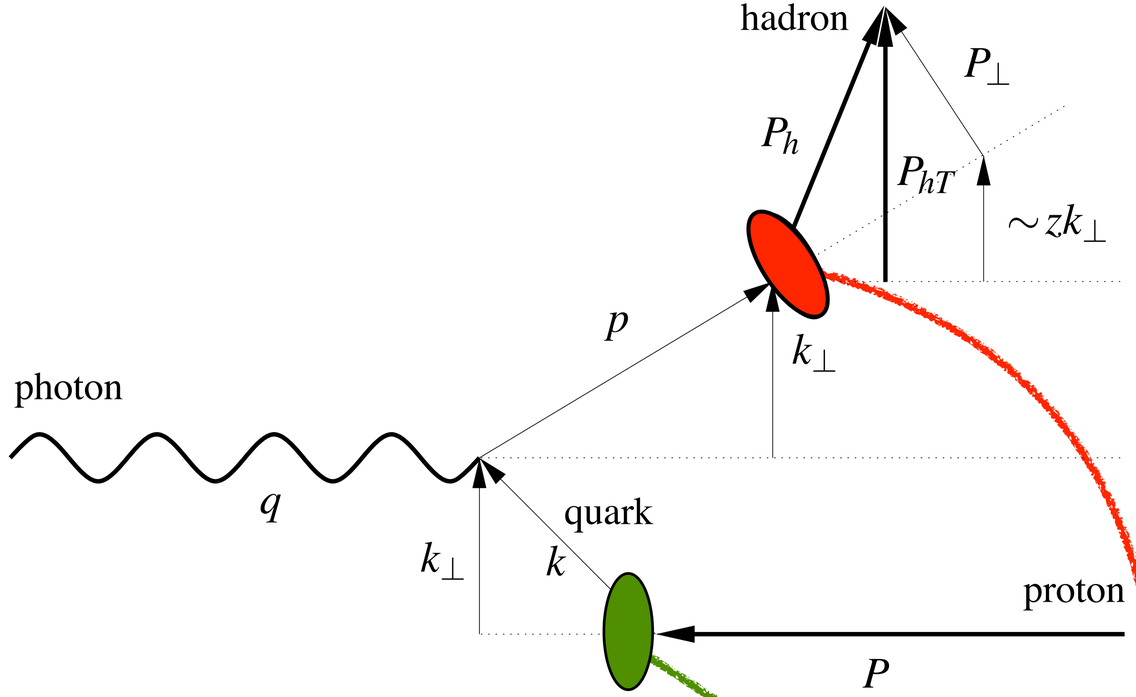
- The W term dominates in the region where $q_T \ll Q$

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

# TMD Factorization - SIDIS process

**TMD FF**

**TMD PDF**

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**W Term**

- The **W term** dominates in the region where $q_T \ll Q$
- The Y term has been excluded in the MAP analysis

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

# TMD Factorization - structure of TMDs

$$\hat{f}_1^q(x_B, \mathbf{b}_T; \mu_F, \zeta_F) = [C \otimes f_1](x_B, b_\star; \mu_{b_\star}, \mu_{b_\star}^2) \exp\left\{ \int_{\mu_{b_\star}}^{\mu_F} \frac{d\mu'}{\mu'} \gamma(\mu', \zeta_F) \right\}$$

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*Collins, "Foundations of Perturbative QCD"*

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(perturbative calculable)

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**Fit extraction**

*Collins, "Foundations of Perturbative QCD"*


MAPTMD22
MAPTMD24
Theory recap

# MAPTMD22 extraction — starting point

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

*MAP Collaboration, JHEP 10 (2022)*

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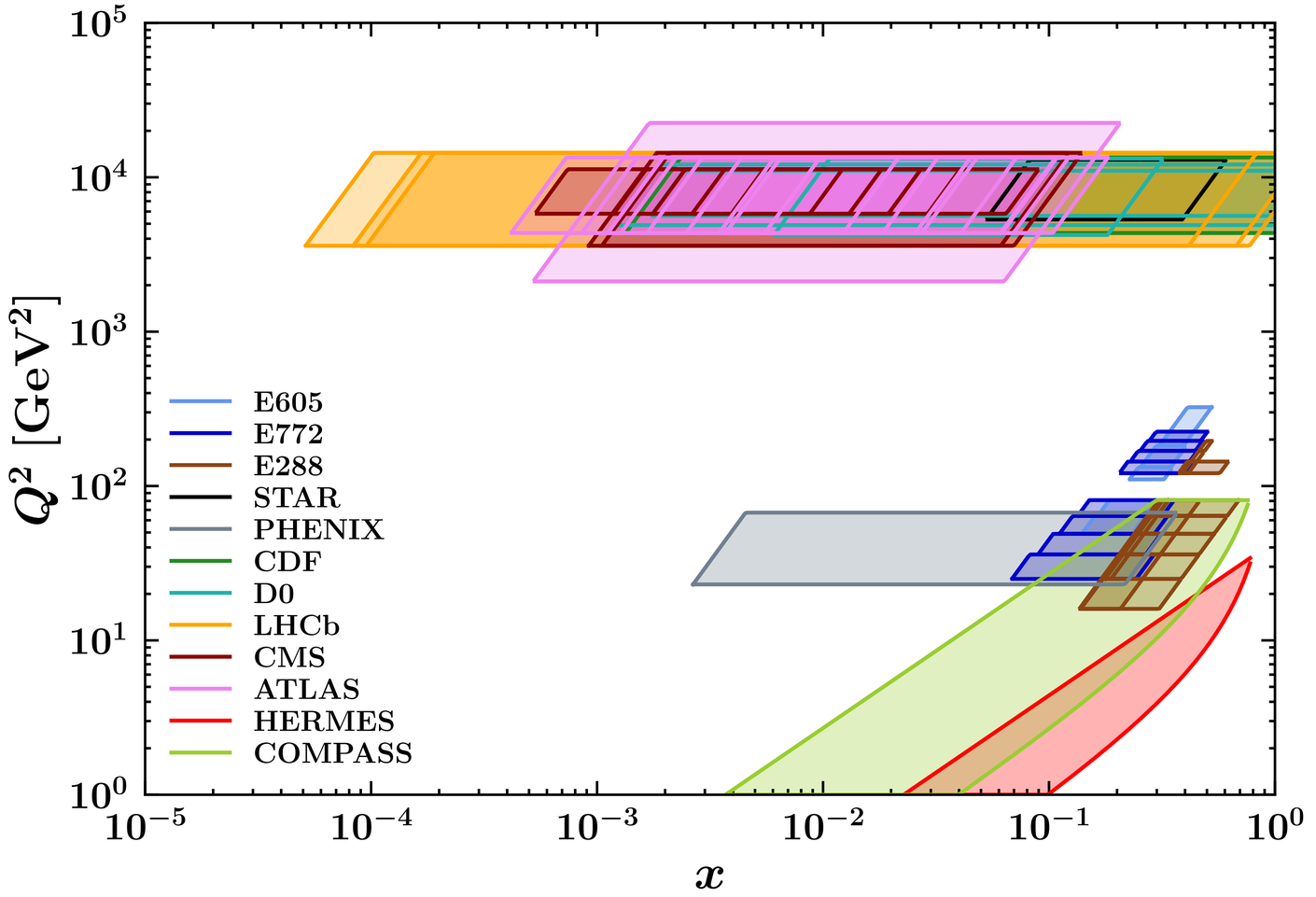


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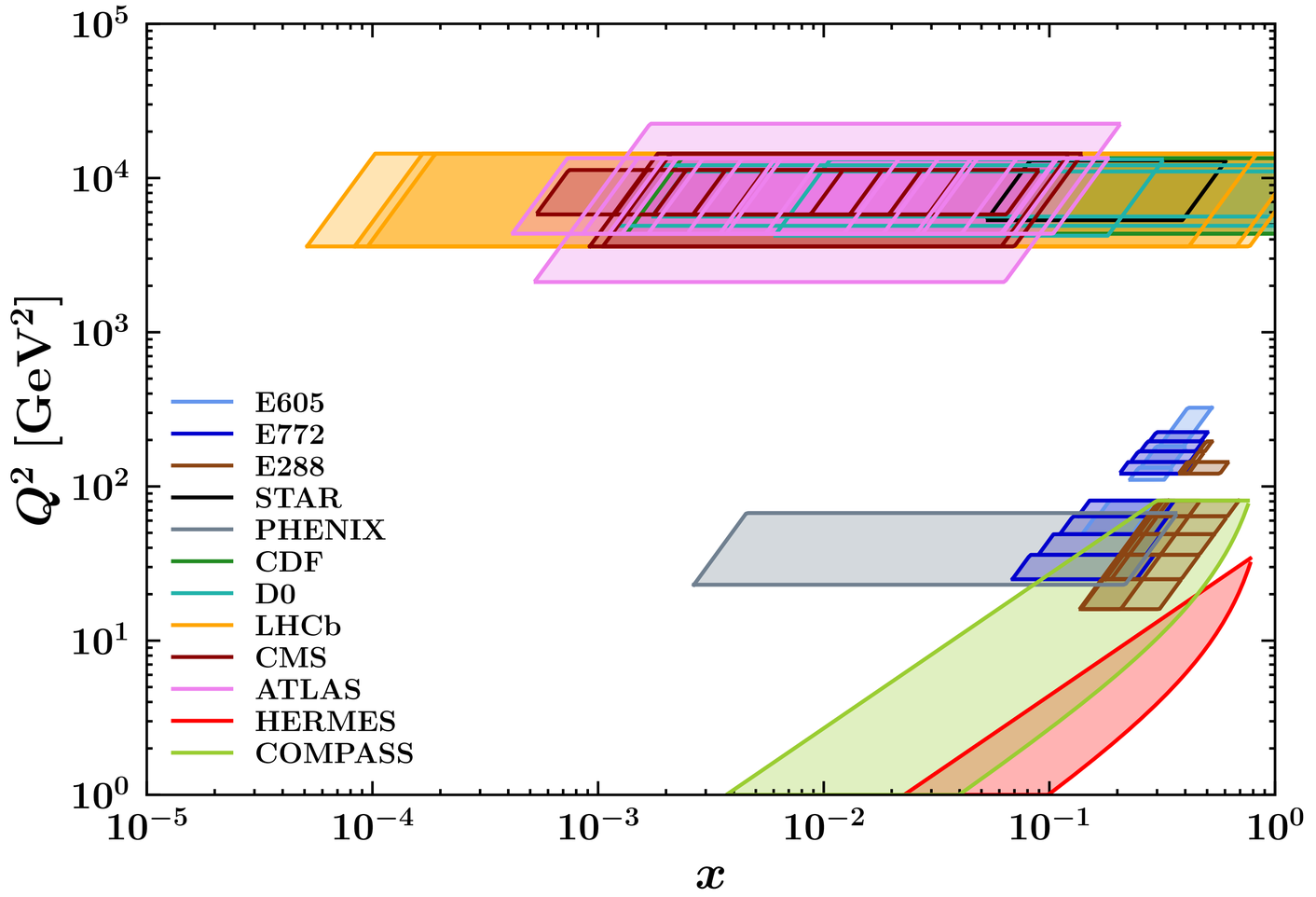
**Drell-Yan data**
**484**

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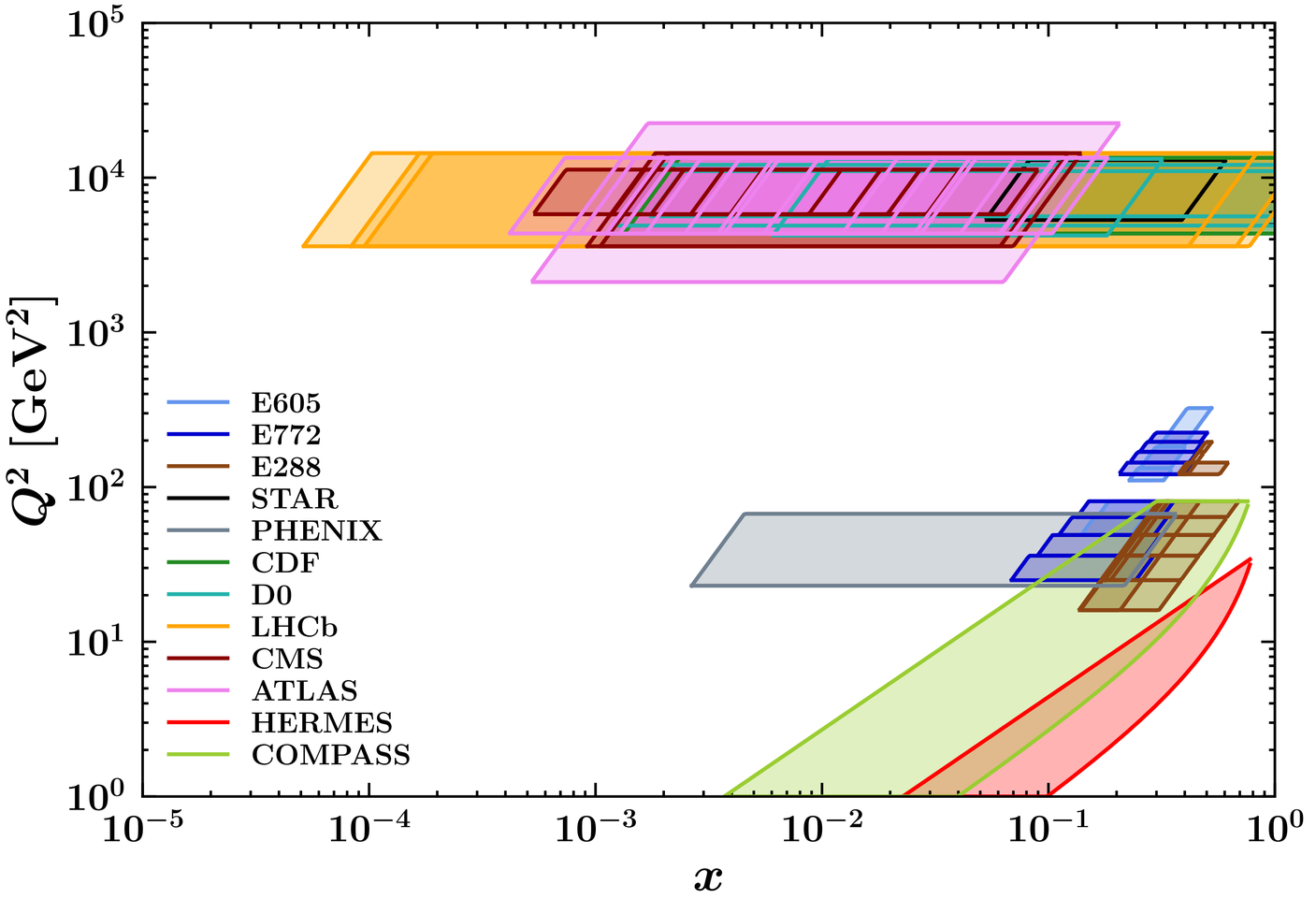
**Drell-Yan data**

**484**

**SIDIS data**

**1547**

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# MAPTMD22 extraction — starting point

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

*MAP Collaboration, JHEP 10 (2022)*

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| Accuracy | $H$ and $C$ | $K$ and $\gamma_F$ | $\gamma_K$ | PDFs/FFs and $\alpha_S$ 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 | NNLO + NLO |
| $N^3LL$ | 2 | 3 | 4 | NNLO |
| $N^3LL'$ | 3 | 3 | 4 | $N^3LO$ |

*MAP Collaboration, JHEP 10 (2022)*

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| $N^3LL$ | 2 | 3 | 4 | NNLO |
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| $N^3LL’$ | 3 | 3 | 4 | $N^3LO$ |

MMHT2014nnlo
DSS14-17 NLO

*MAP Collaboration, JHEP 10 (2022)*

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- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points
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*MAP Collaboration, JHEP 10 (2022)*

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- Number of fitted parameters: ***21***

*MAP Collaboration, JHEP 10 (2022)*

# MAPTMD22 extraction — starting point

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

$$f_{1\mathrm{NP}}(x, b_T^2) \propto \text{F.T. of } \left( e^{-\frac{k_\perp^2}{g_{1A}}} + \lambda_B k_\perp^2 e^{-\frac{k_\perp^2}{g_{1B}}} + \lambda_C e^{-\frac{k_\perp^2}{g_{1C}}} \right) \qquad g_1(x) = N_1 \frac{(1-x)^\alpha \; x^\sigma}{(1-\hat{x})^\alpha \; \hat{x}^\sigma}$$

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**11 parameters for TMD PDF + 1 for NP evolution + 9 for TMD FF**

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*MAP Collaboration, JHEP 10 (2022)*


MAPTMD24
MAPTMD22
Theory recap

# MAPTMD22 → MAPTMD24

- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points
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*2405.13833*

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

  **Same global data set**

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- Perturbative accuracy: $N^3LL$ ***MMHT2014nnlo***
  ***DSS14-17 NLO***

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

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- Perturbative accuracy: $N^3LL$ ***MMHT2014nnlo*** → ***NNPDF31NNLO***
  ***DSS14-17 NLO*** → ***MAPFF10NNLO***

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***Why does the $\chi^2$ get worse?***

*2405.13833*

# MAPTMD24 extraction

| | Data set $\chi^2_0/N_{dat}$ | | |
|---|---|---|---|
| Collinear sets | DY total | SIDIS total | **Total** |
| MMHT + DSS (MAP22) | 1.66 | 0.87 | **1.06** |
| NNPDF + MAPFF (MAP24 FI) | 1.58 | 1.34 | **1.40** |

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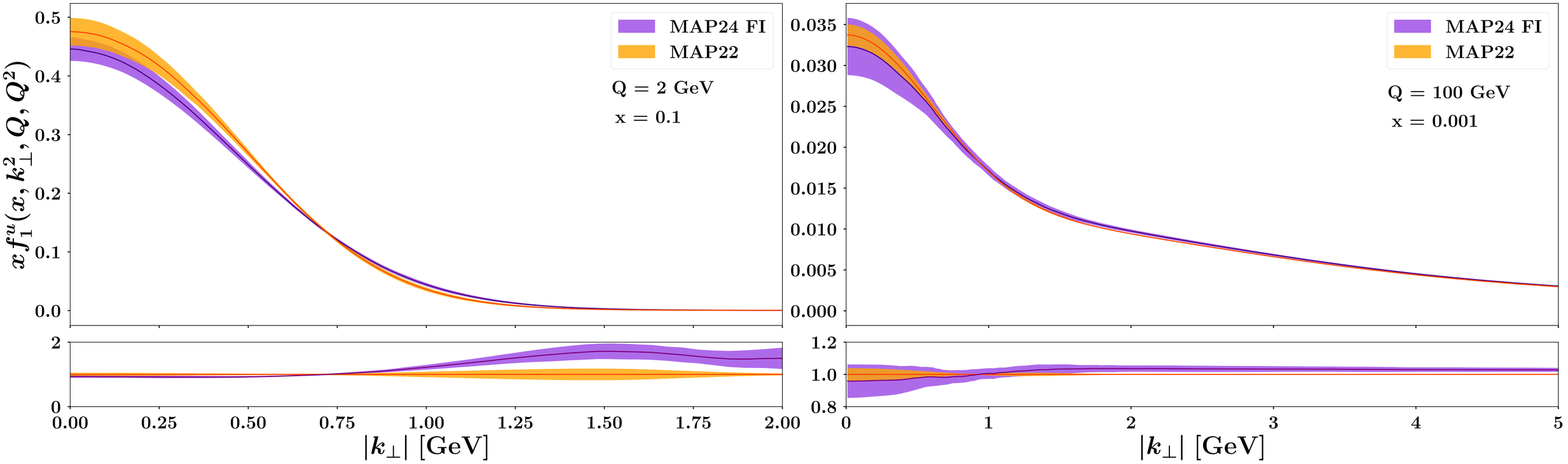


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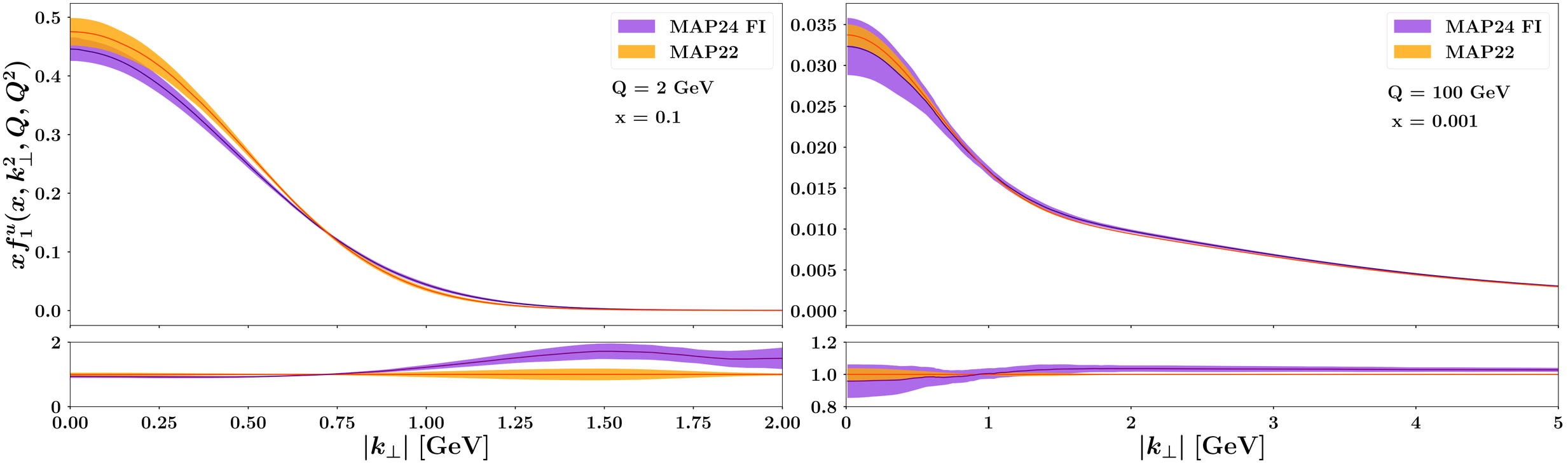


**TMD PDFs are compatible with MAP22**

*2405.13833*

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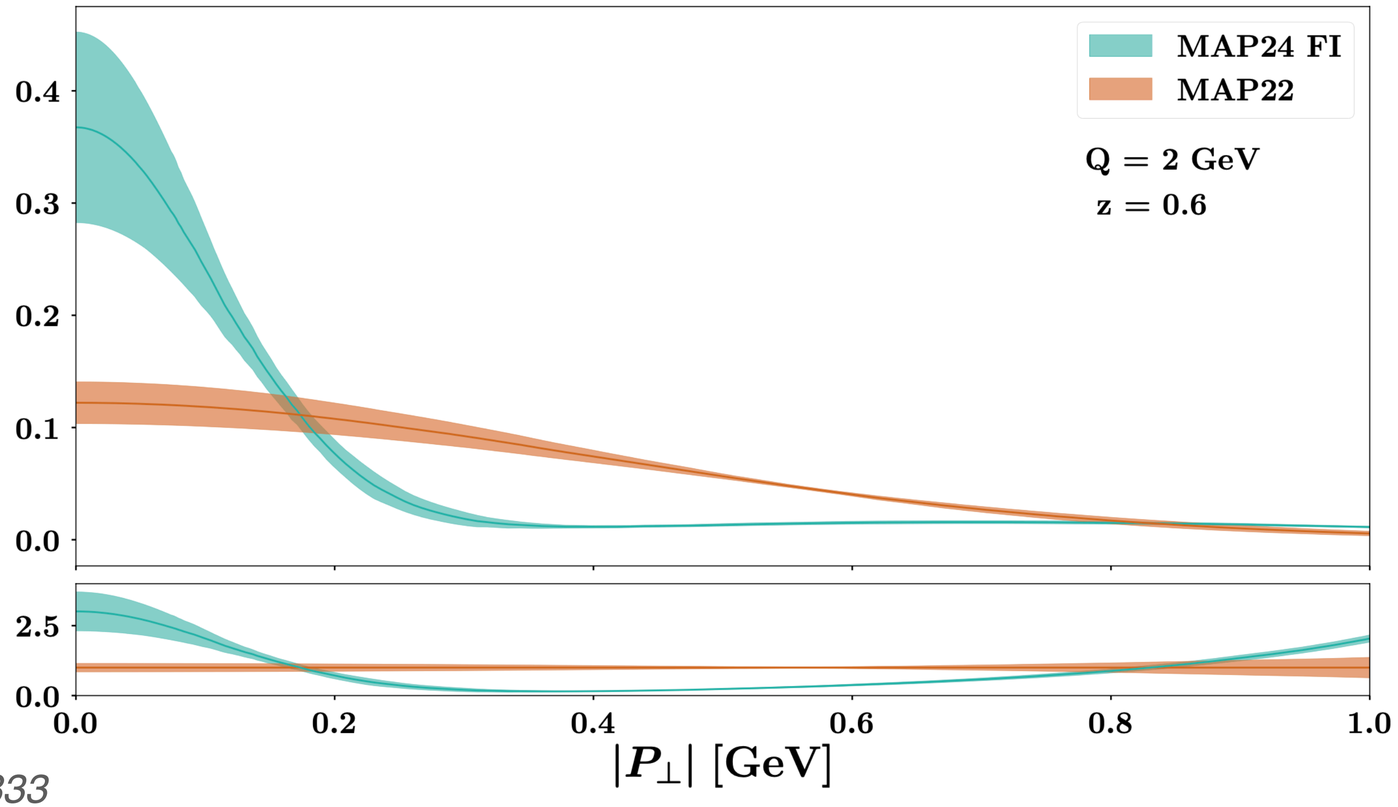


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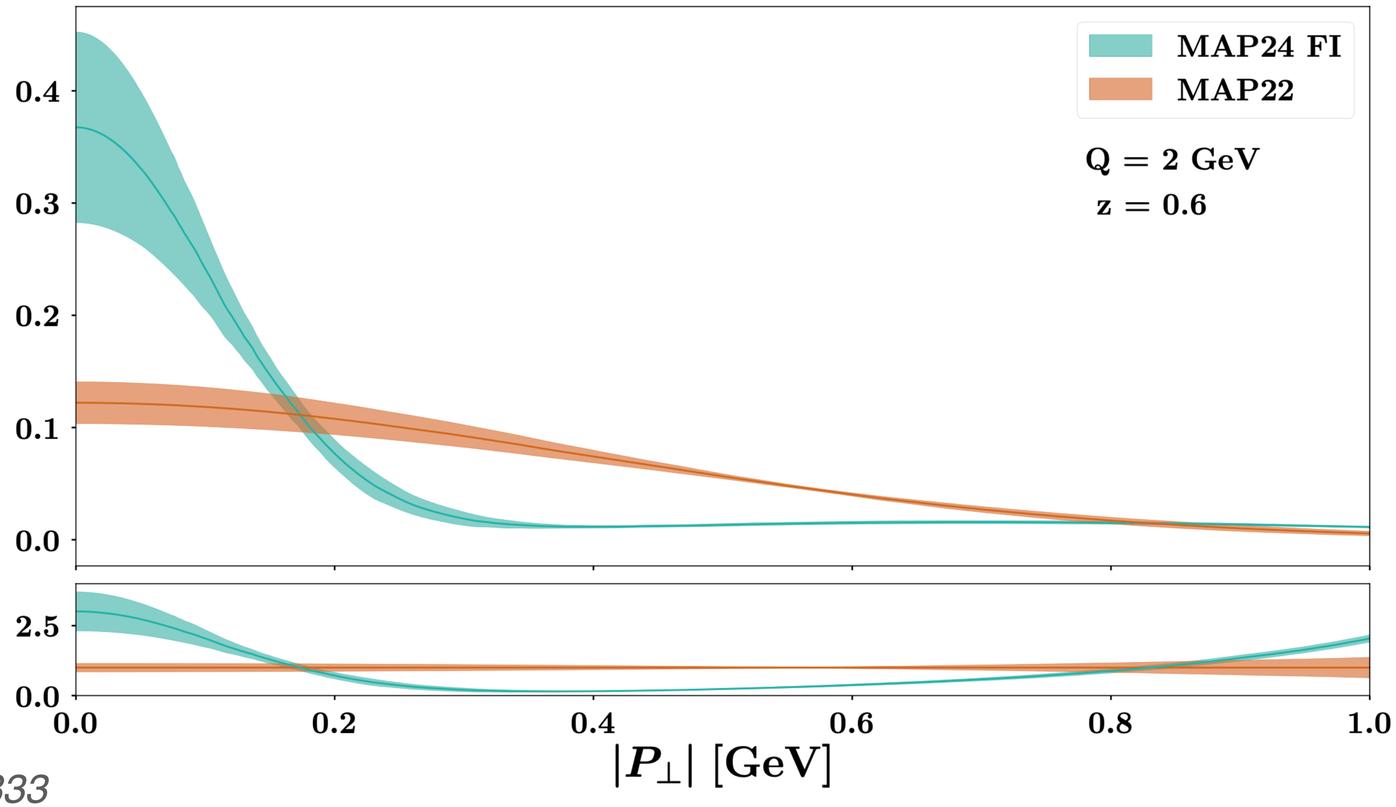


## MAPFF1.0nnlo

- Approx NNLO
- NN approach
- New behaviors
- Smaller uncertainties

*2405.13833*

# MAPTMD24 extraction

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider total | 251 | 2.14 |
| Dy fixed target total | 233 | 0.68 |
| HERMES total | 344 | 2.72 |
| COMPASS total | 1203 | 0.99 |
| SIDIS total | 1547 | 1.38 |
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NNPDF + MAPFF

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MMHT + MAPFF

Agreement

Similar worsening

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| Total | 2031 | 1.07 |

NNPDF + DSS

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider total | 251 | 2.06 |
| Dy fixed target total | 233 | 1.24 |
| HERMES total | 344 | 0.71 |
| COMPASS total | 1203 | 0.92 |
| SIDIS total | 1547 | 0.87 |
| Total | 2031 | 1.06 |

MMHT + DSS (MAP22)

*2405.13833*

# MAPTMD24 extraction

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider total | 251 | 2.14 |
| Dy fixed target total | 233 | 0.68 |
| HERMES total | 344 | 2.72 |
| COMPASS total | 1203 | 0.99 |
| SIDIS total | 1547 | 1.38 |
| Total | 2031 | 1.40 |

NNPDF + MAPFF

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider total | 251 | 2.01 |
| Dy fixed target total | 233 | 1.11 |
| HERMES total | 344 | 2.51 |
| COMPASS total | 1203 | 0.99 |
| SIDIS total | 1547 | 1.33 |
| Total | 2031 | 1.39 |

MMHT + MAPFF

Similar worsening

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider total | 251 | 2.43 |
| Dy fixed target total | 233 | 0.75 |
| HERMES total | 344 | 0.95 |
| COMPASS total | 1203 | 0.88 |
| SIDIS total | 1547 | 0.90 |
| Total | 2031 | 1.07 |

NNPDF + DSS

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider total | 251 | 2.06 |
| Dy fixed target total | 233 | 1.24 |
| HERMES total | 344 | 0.71 |
| COMPASS total | 1203 | 0.92 |
| SIDIS total | 1547 | 0.87 |
| Total | 2031 | 1.06 |

MMHT + DSS (MAP22)

*2405.13833*

# MAPTMD24 extraction

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider total | 251 | 2.14 |
| Dy fixed target total | 233 | 0.68 |
| HERMES total | 344 | 2.72 |
| COMPASS total | 1203 | 0.99 |
| SIDIS total | 1547 | 1.38 |
| Total | 2031 | 1.40 |

NNPDF + MAPFF

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider total | 251 | 2.01 |
| Dy fixed target total | 233 | 1.11 |
| HERMES total | 344 | 2.51 |
| COMPASS total | 1203 | 0.99 |
| SIDIS total | 1547 | 1.33 |
| Total | 2031 | 1.39 |

MMHT + MAPFF

Similar worsening

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider total | 251 | 2.43 |
| Dy fixed target total | 233 | 0.75 |
| HERMES total | 344 | 0.95 |
| COMPASS total | 1203 | 0.88 |
| SIDIS total | 1547 | 0.90 |
| Total | 2031 | 1.07 |

NNPDF + DSS

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider total | 251 | 2.06 |
| Dy fixed target total | 233 | 1.24 |
| HERMES total | 344 | 0.71 |
| COMPASS total | 1203 | 0.92 |
| SIDIS total | 1547 | 0.87 |
| Total | 2031 | 1.06 |

MMHT + DSS (MAP22)

*2405.13833*

# MAPTMD24 extraction

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider t | 251 | 2.01 |
| Dy fixed targ | 233 | 1.11 |
| HERMES tot | 344 | 2.51 |
| COMPASS t | 1203 | 0.99 |
| SIDIS total | 1547 | 1.33 |
| Total | 2031 | 1.39 |

NNF

Why us?

APFF

| Data set | $N_{\rm dat}$ | $\chi^2_0/N_{\rm dat}$ |
|---|---|---|
| DY collider t | 251 | 2.06 |
| Dy fixed targ | 233 | 1.24 |
| HERMES tot | 344 | 0.71 |
| COMPASS t | 1203 | 0.92 |
| SIDIS total | 1547 | 0.87 |
| Total | 2031 | 1.07 |

NNPDF + DSS

| Total | 2031 | 1.06 |
|---|---|---|

MMHT + DSS (MAP22)

2405.13833

# MAPTMD24 extraction

# MAPTMD24 extraction

***Solution:***

*2405.13833*

# MAPTMD24 extraction

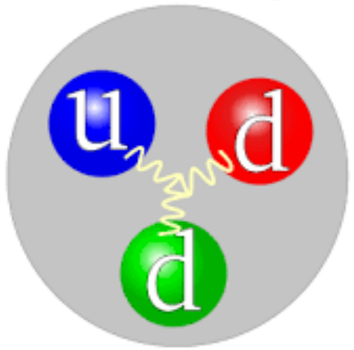
***Solution*:** ***Flavour dependence***

*2405.13833*

# MAPTMD24 extraction

***Solution:*** ***Flavour dependence***

$p$




$u, d$

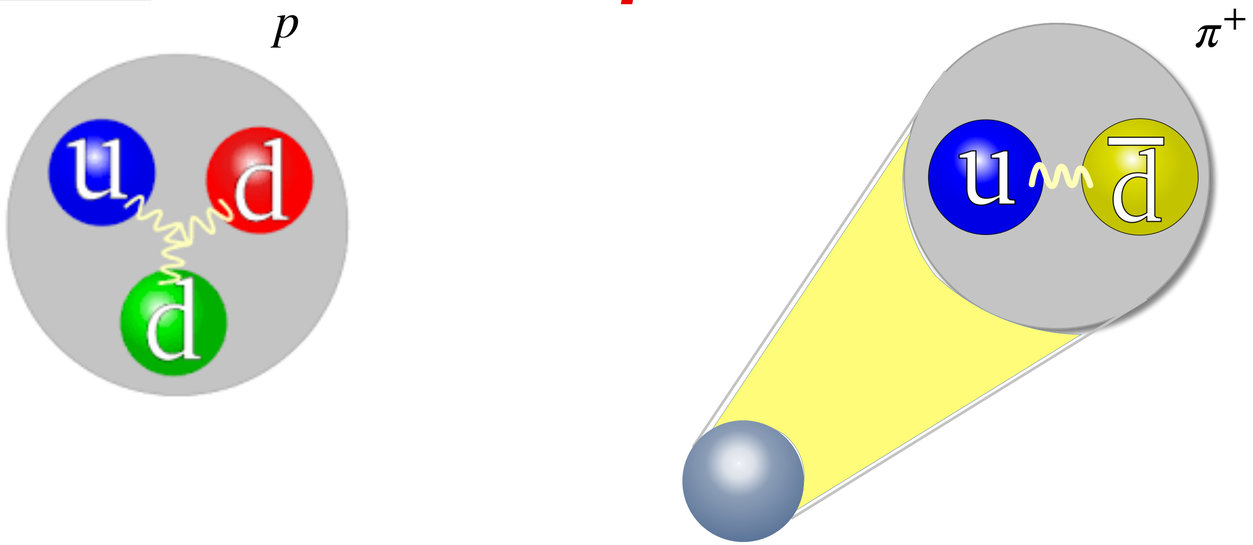
$\bar{u}, \bar{d}$

$s\ (sea)$

*2405.13833*

# MAPTMD24 extraction

***Solution:*** ***Flavour dependence***




$u, d$

$\bar{u}, \bar{d}$

$s\ (sea)$

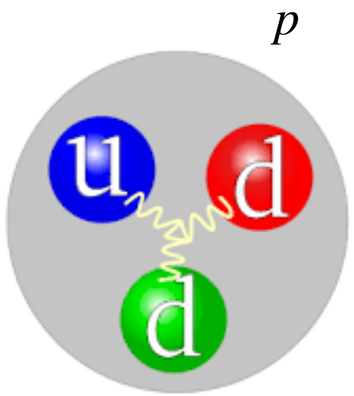
$u \to \pi^+, \ldots$

$d \to \pi^+, \ldots$

*2405.13833*

# MAPTMD24 extraction

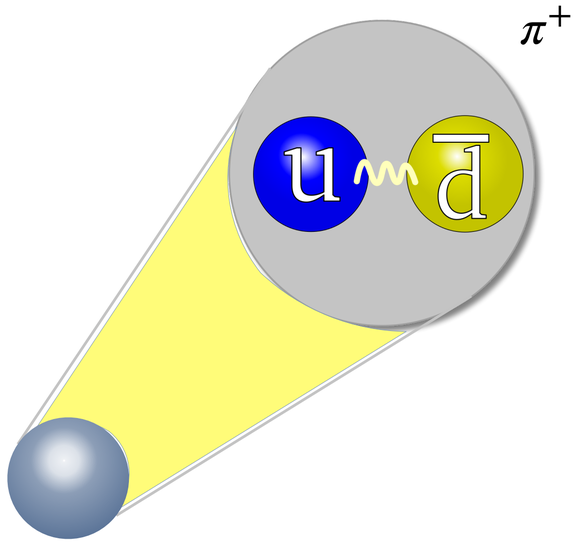
***Solution:*** ***Flavour dependence***




$u, d$

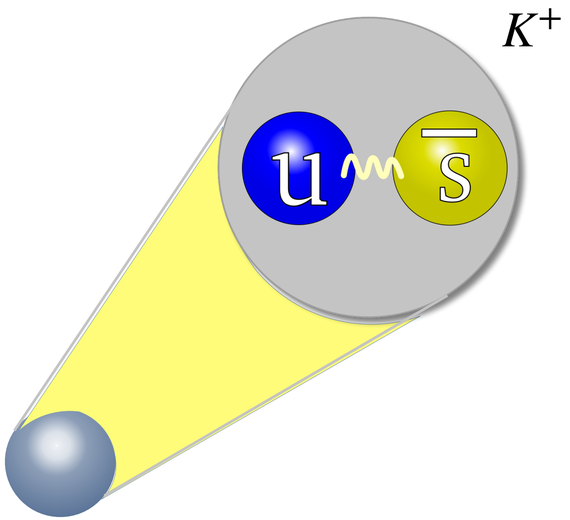
$\bar{u}, \bar{d}$

$s\ (sea)$




$u \to \pi^+, \ldots$

$d \to \pi^+, \ldots$



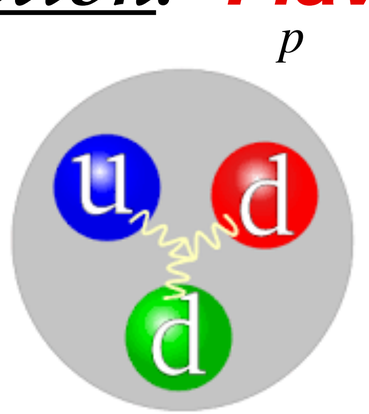

$u \to K^+, \ldots$

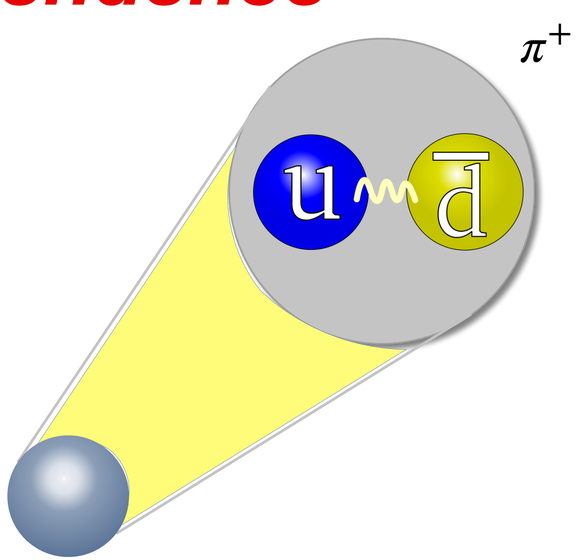
$\bar{s} \to K^+, \ldots$

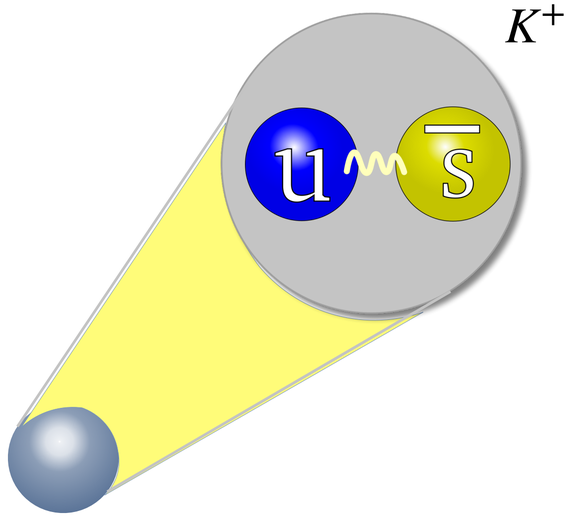
$d \to K^+, \ldots$

# MAPTMD24 extraction

***Solution*: Flavour dependence**




$u, d$

$\bar{u}, \bar{d}$

$s\ (sea)$

$u \to \pi^+, \ldots$

$d \to \pi^+, \ldots$

$u \to K^+, \ldots$

$\bar{s} \to K^+, \ldots$

$d \to K^+, \ldots$

**Negative fragmenting mesons: charge conjugation**

*2405.13833*

# MAPTMD24 extraction

*2405.13833*

# MAPTMD24 extraction

**HERMES**

$$e + p \to e' + \pi^+ + X$$
$$e + p \to e' + \pi^- + X$$
$$e + p \to e' + K^+ + X$$
$$e + p \to e' + K^- + X$$

+ deuteron target

*2405.13833*

# MAPTMD24 extraction

**HERMES**

$$e + p \to e' + \pi^+ + X$$
$$e + p \to e' + \pi^- + X$$
$$e + p \to e' + K^+ + X$$
$$e + p \to e' + K^- + X$$

+ deuteron target

**high sensitivity to flavour dependence**

*2405.13833*

# MAPTMD24 extraction

**HERMES**

$$e + p \to e' + \pi^+ + X$$
$$e + p \to e' + \pi^- + X$$
$$e + p \to e' + K^+ + X$$
$$e + p \to e' + K^- + X$$

+ deuteron target

**high sensitivity to flavour dependence**

**COMPASS** deuteron target & unidentified final state hadron

*2405.13833*

# MAPTMD24 extraction

**HERMES**

$$e + p \to e' + \pi^+ + X$$
$$e + p \to e' + \pi^- + X$$
$$e + p \to e' + K^+ + X$$
$$e + p \to e' + K^- + X$$

+ deuteron target

**high sensitivity to flavour dependence**

**COMPASS** deuteron target & unidentified final state hadron

low sensitivity to flavour dependence

*2405.13833*

# MAPTMD24 extraction

**HERMES**

$$e + p \to e' + \pi^+ + X$$
$$e + p \to e' + \pi^- + X$$
$$e + p \to e' + K^+ + X$$
$$e + p \to e' + K^- + X$$

+ deuteron target

**high sensitivity to flavour dependence**

**COMPASS** deuteron target & unidentified final state hadron

low sensitivity to flavour dependence

**Drell-Yan** $q\bar{q}$ in the initial state

*2405.13833*

# MAPTMD24 extraction

**HERMES**

$$e + p \to e' + \pi^+ + X$$
$$e + p \to e' + \pi^- + X$$
$$e + p \to e' + K^+ + X$$
$$e + p \to e' + K^- + X$$

+ deuteron target

**high sensitivity to flavour dependence**

**COMPASS** deuteron target & unidentified final state hadron

low sensitivity to flavour dependence

**Drell-Yan** $q\bar{q}$ in the initial state

lowest sensitivity to flavour dependence

*2405.13833*

# MAPTMD24 extraction - Results $\chi^2/N_{data} = 1.08$

| | $\mathrm{N^3LL}$ | | | |
|---|---|---|---|---|
| Data set | $N_{\mathrm{dat}}$ | $\chi^2_D$ | $\chi^2_\lambda$ | $\chi^2_0$ |
| DY collider total | 251 | 1.37 | 0.28 | 1.65 |
| DY fixed-target total | 233 | 0.63 | 0.31 | 0.94 |
| *HERMES total* | 344 | 0.81 | 0.24 | 1.05 |
| *COMPASS total* | 1203 | 0.67 | 0.27 | 0.94 |
| SIDIS total | 1547 | 0.70 | 0.26 | 0.96 |
| **Total** | **2031** | **0.81** | **0.27** | **1.08** |

*2405.13833*

# MAPTMD24 extraction - Results $\chi^2/N_{data} = 1.08$

| | N$^3$LL | | | |
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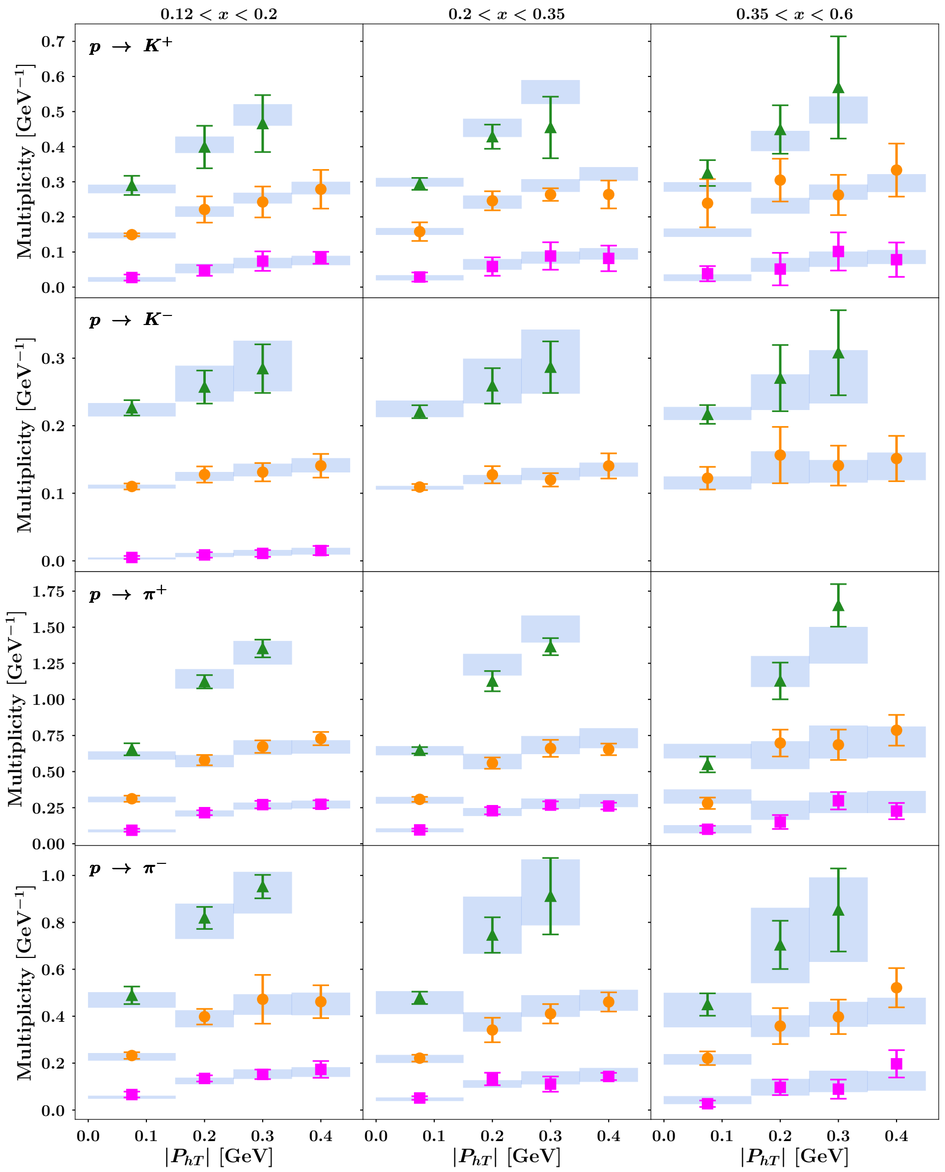
| **Total** | **2031** | **0.81** | **0.27** | **1.08** |




*2405.13833*

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|---|---|---|---|---|
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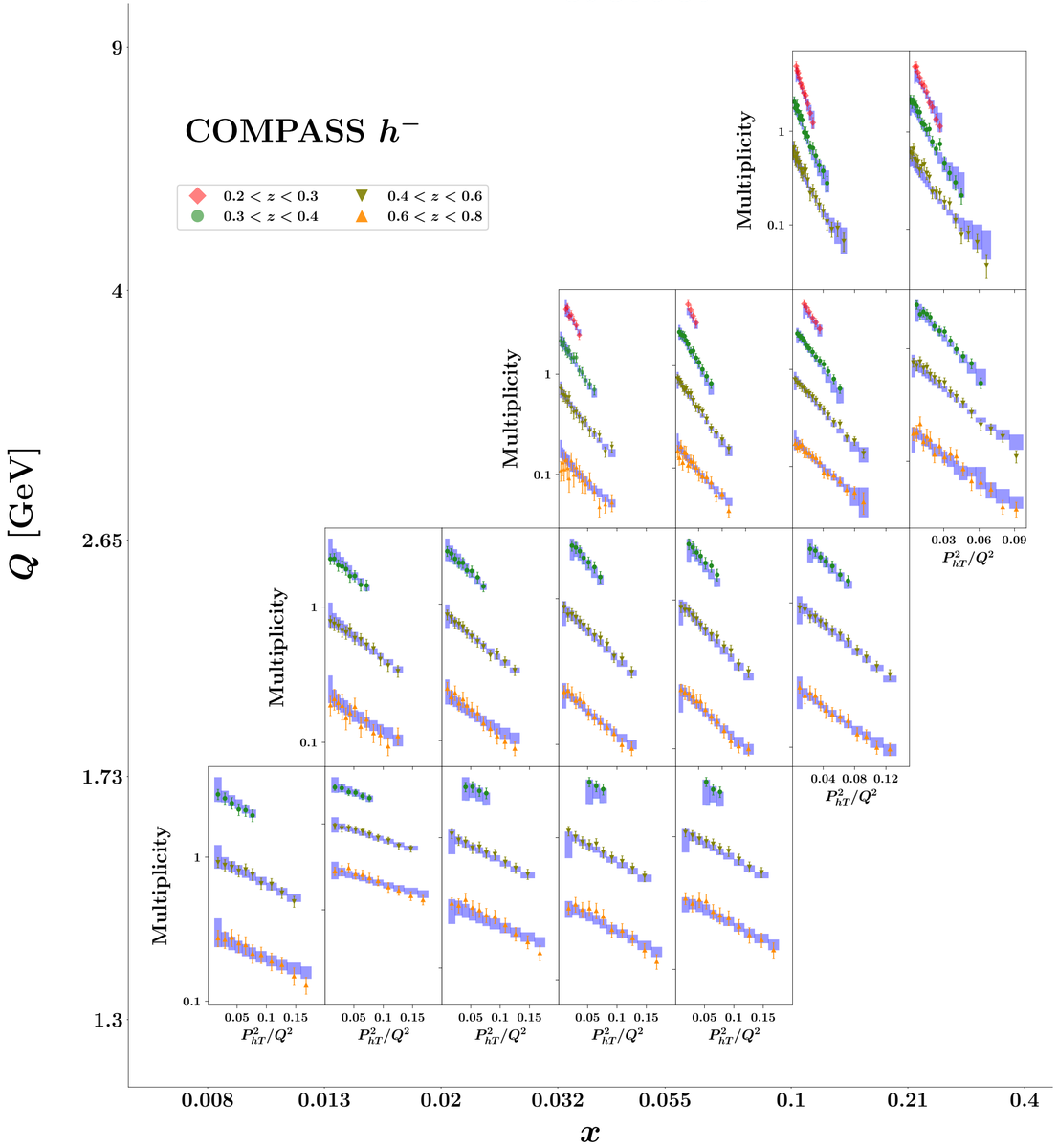


*2405.13833*

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|---|---|---|---|---|
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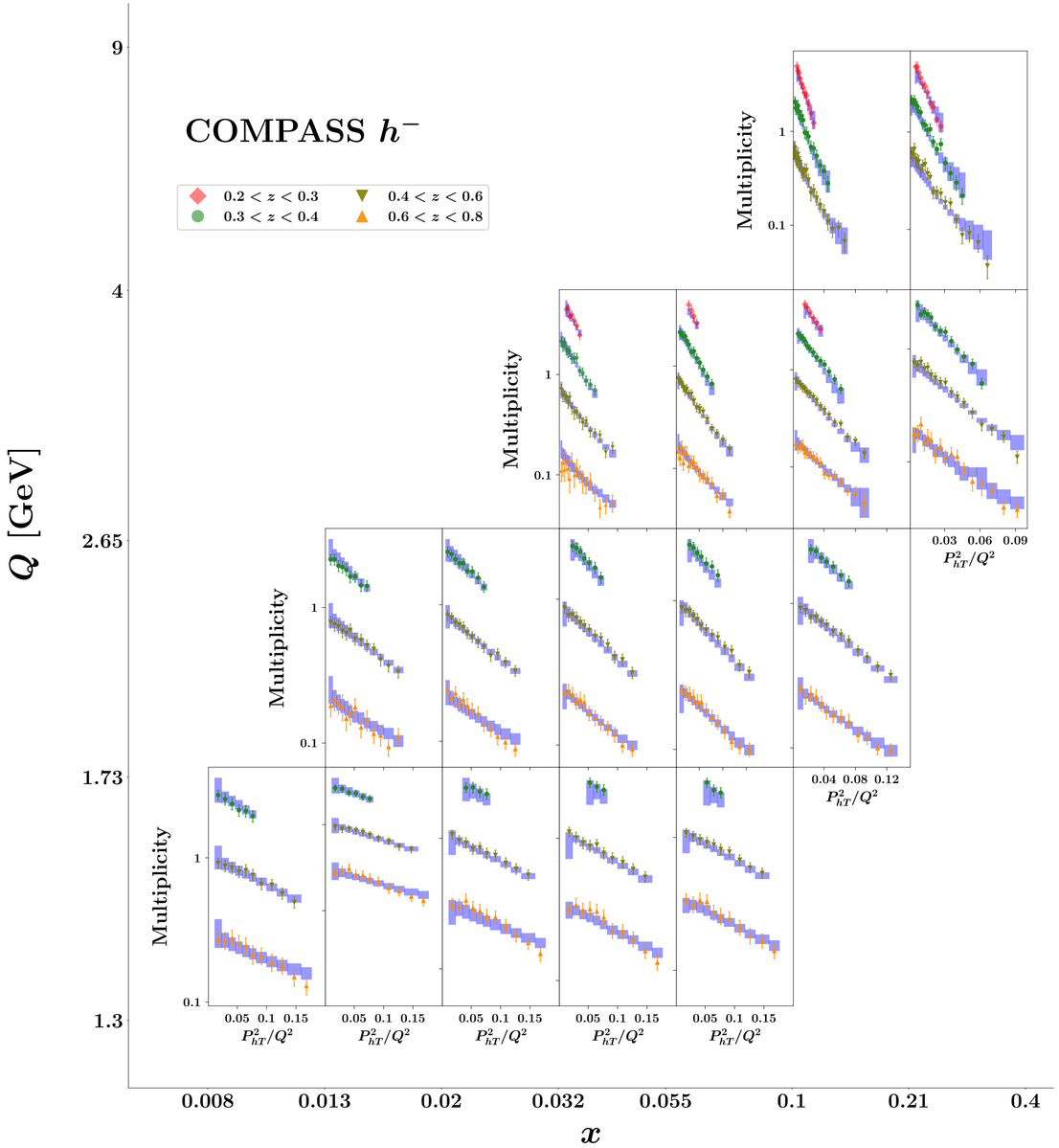
*Very good agreement*




*2405.13833*

# MAPTMD24 extraction - Results $\chi^2/N_{data} = 1.08$

| | N$^3$LL | | | |
|---|---|---|---|---|
| Data set | $N_{\rm dat}$ | $\chi^2_D$ | $\chi^2_\lambda$ | $\chi^2_0$ |
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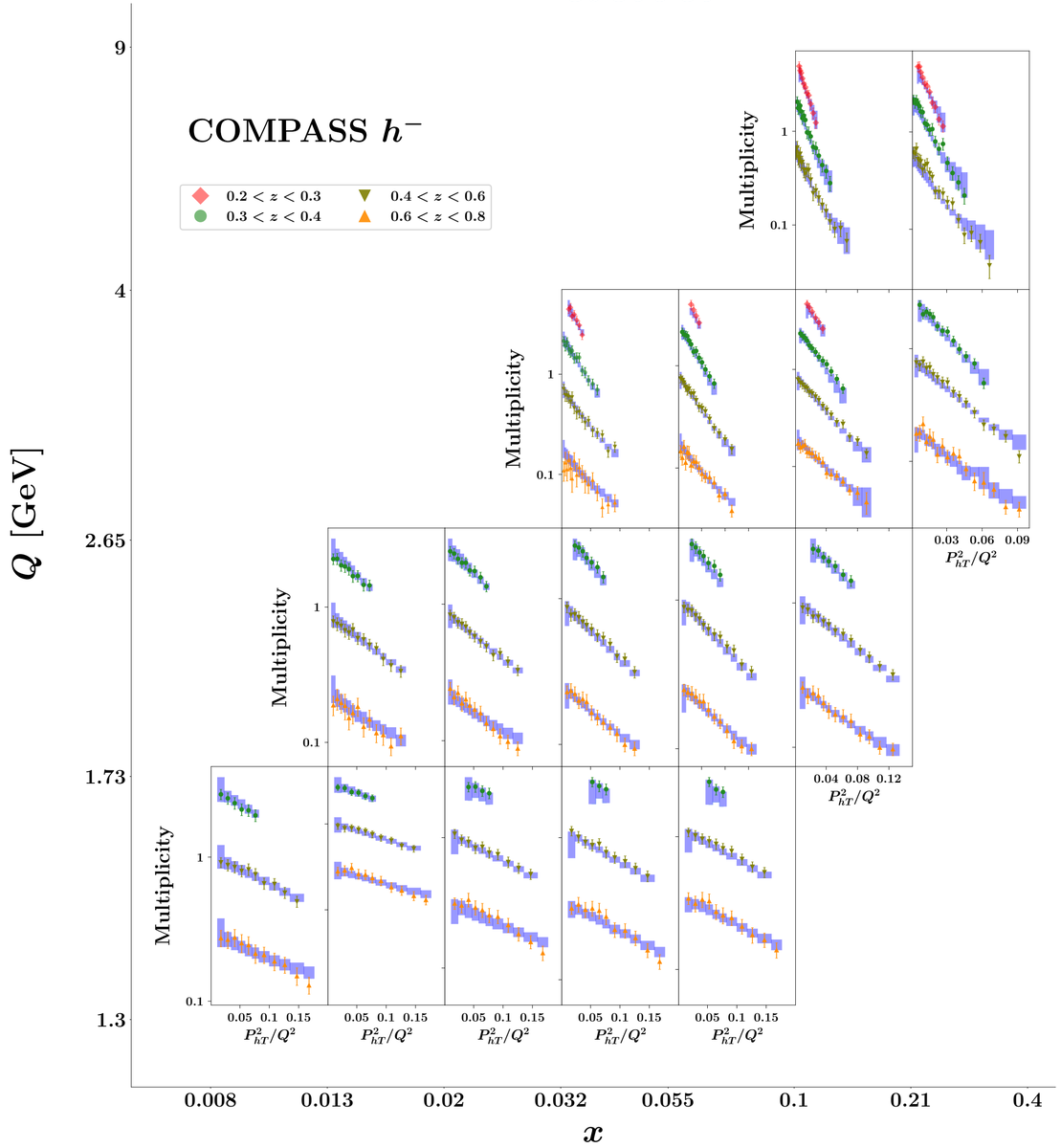


*2405.13833*

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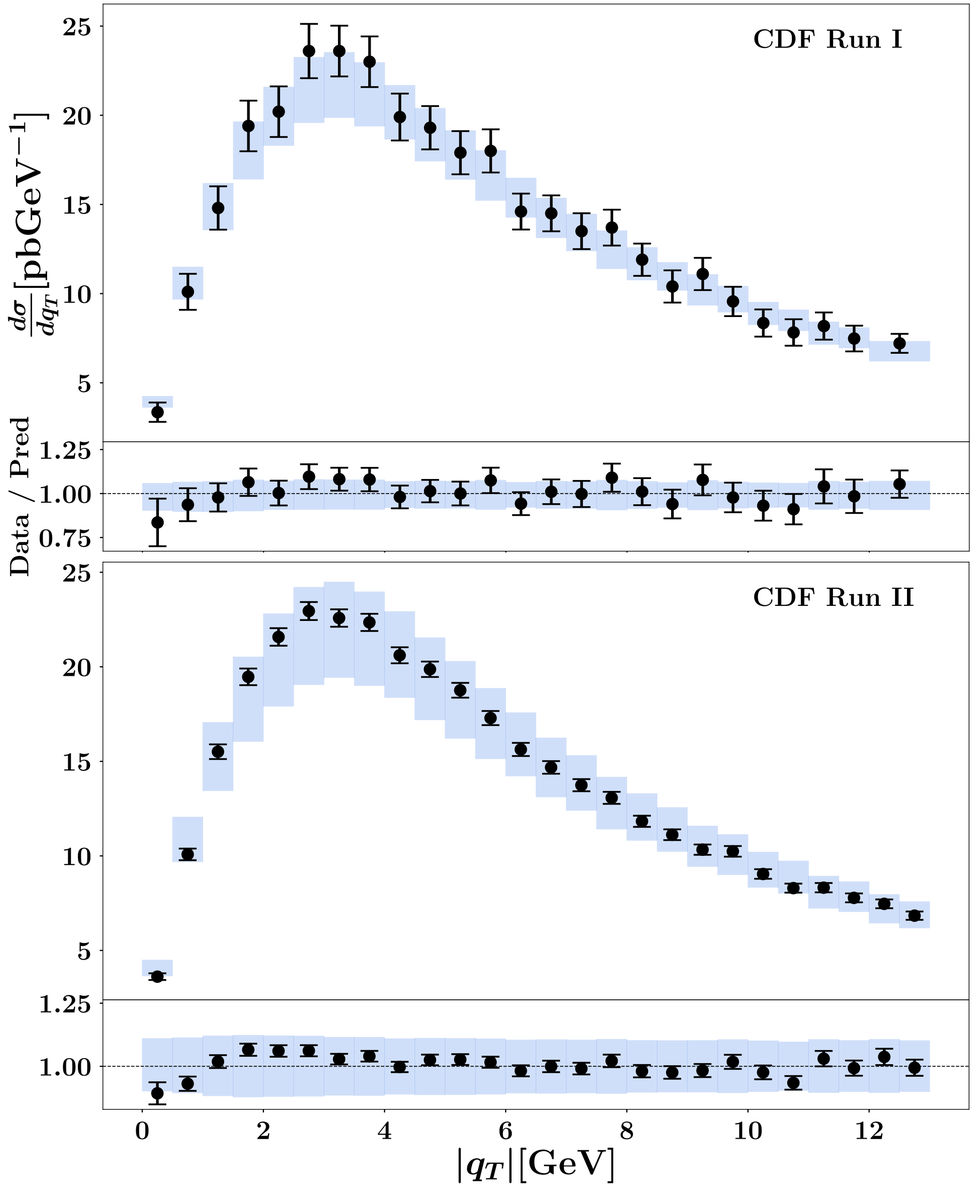


2405.13833

# MAPTMD24 extraction - Results $\chi^2/N_{data} = 1.08$

| | N$^3$LL | | | |
|---|---|---|---|---|
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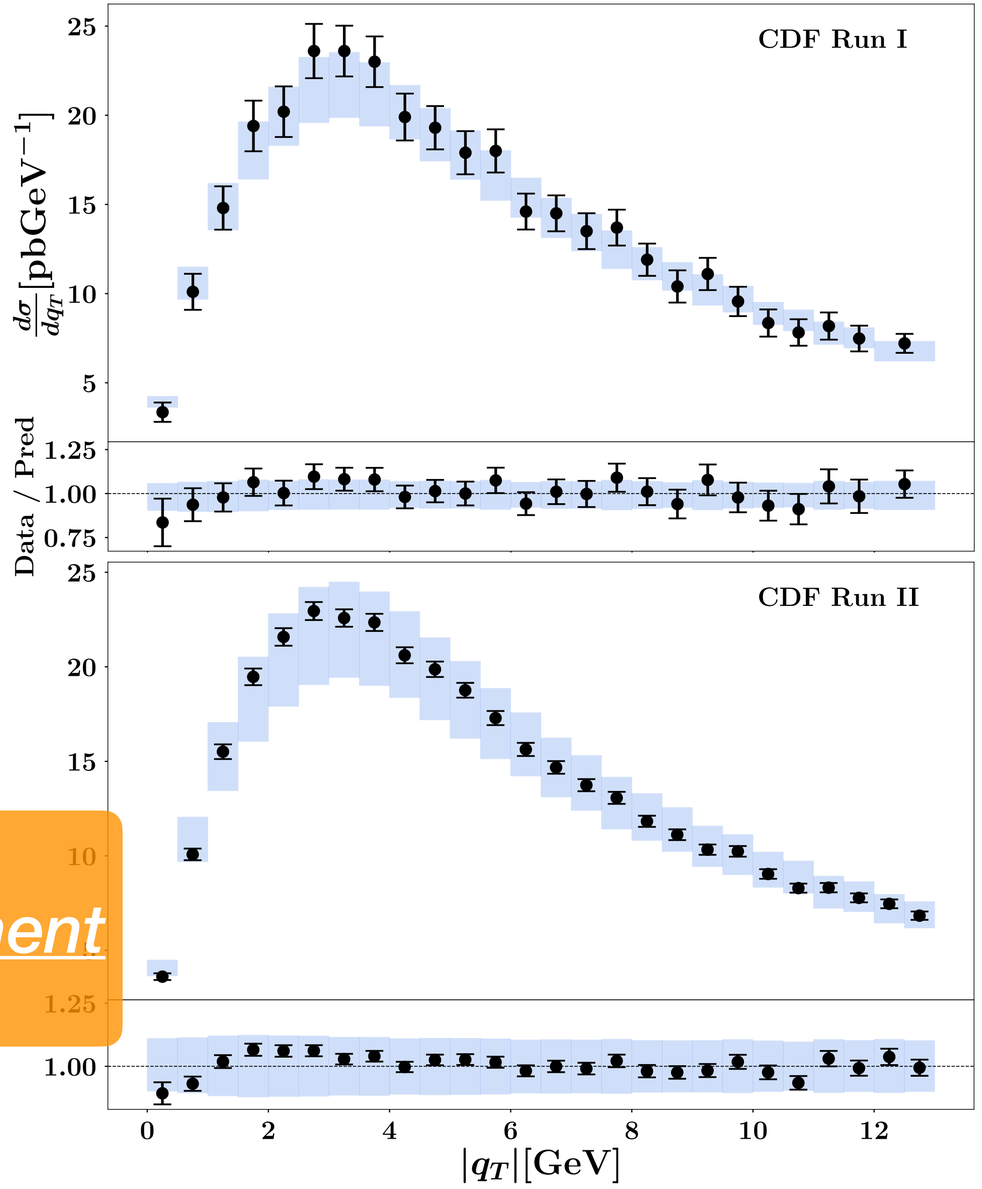


*Very good agreement*

*Quite good agreement*

*2405.13833*

# MAPTMD24 extraction - Results $\chi^2/N_{data} = 1.08$

| | N$^3$LL | | | |
|---|---|---|---|---|
| Data set | $N_{\rm dat}$ | $\chi^2_D$ | $\chi^2_\lambda$ | $\chi^2_0$ |
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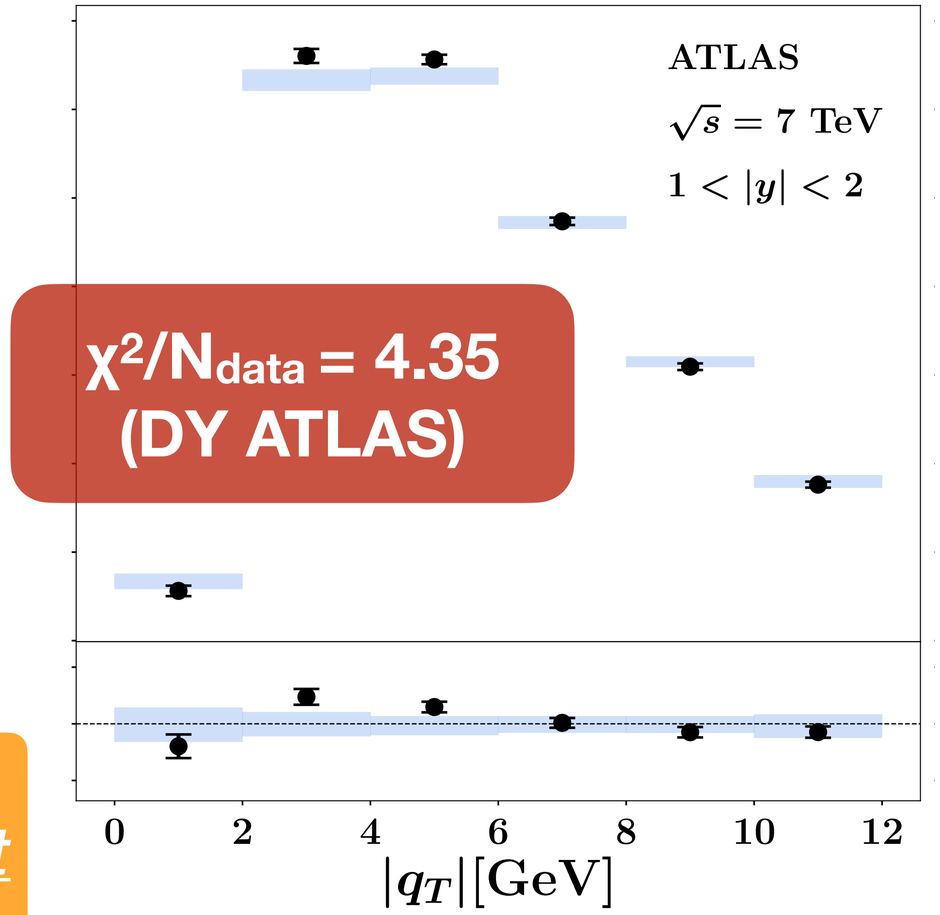
| **Total** | **2031** | **0.81** | **0.27** | **1.08** |



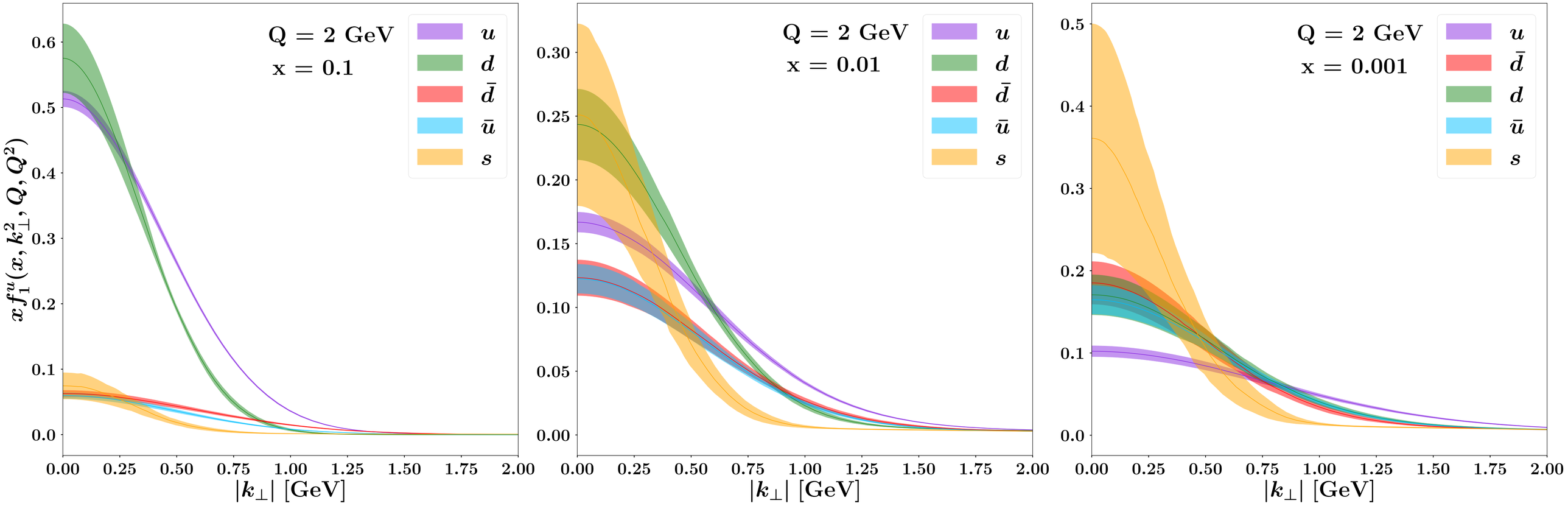

$\chi^2/N_{data} = 4.35$ (DY ATLAS)

*Very good agreement*

*Quite good agreement*

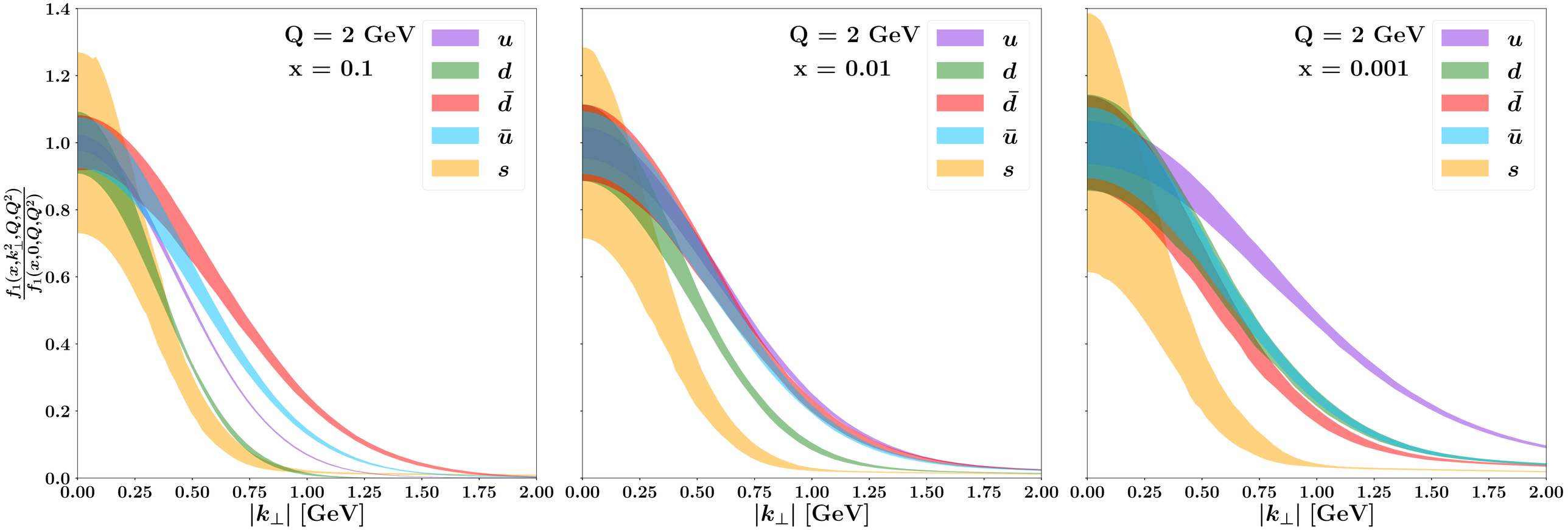
*2405.13833*

# MAPTMD24 extraction - TMD PDFs



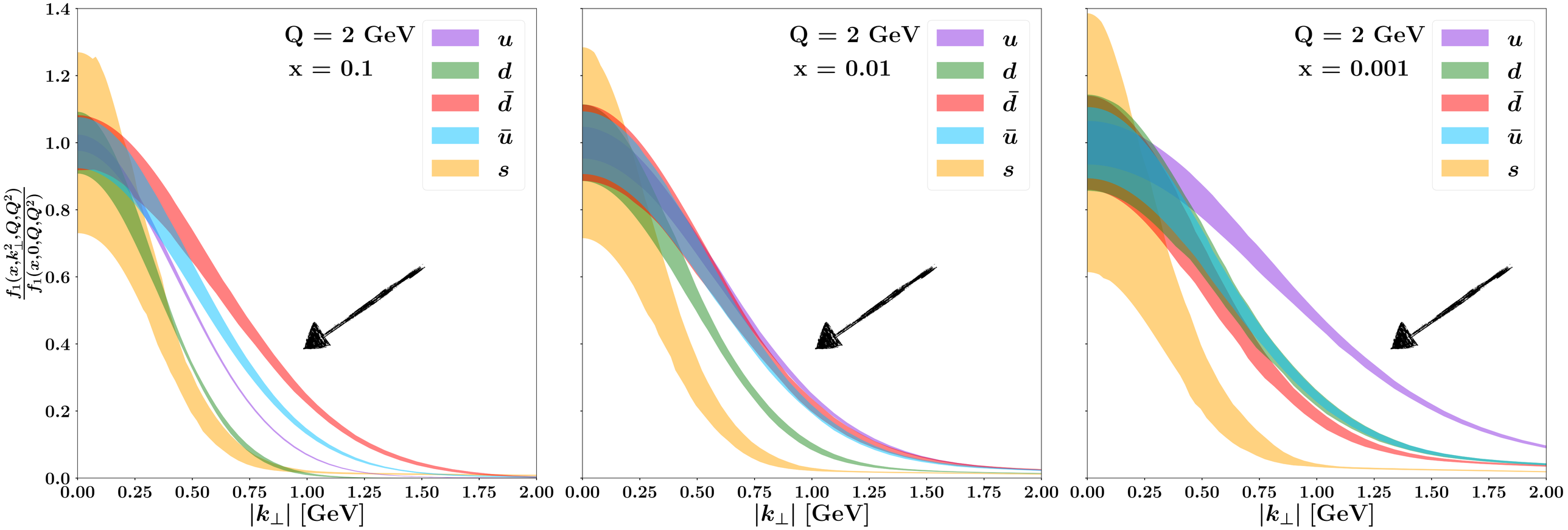

*2405.13833*

# MAPTMD24 extraction - TMD PDFs



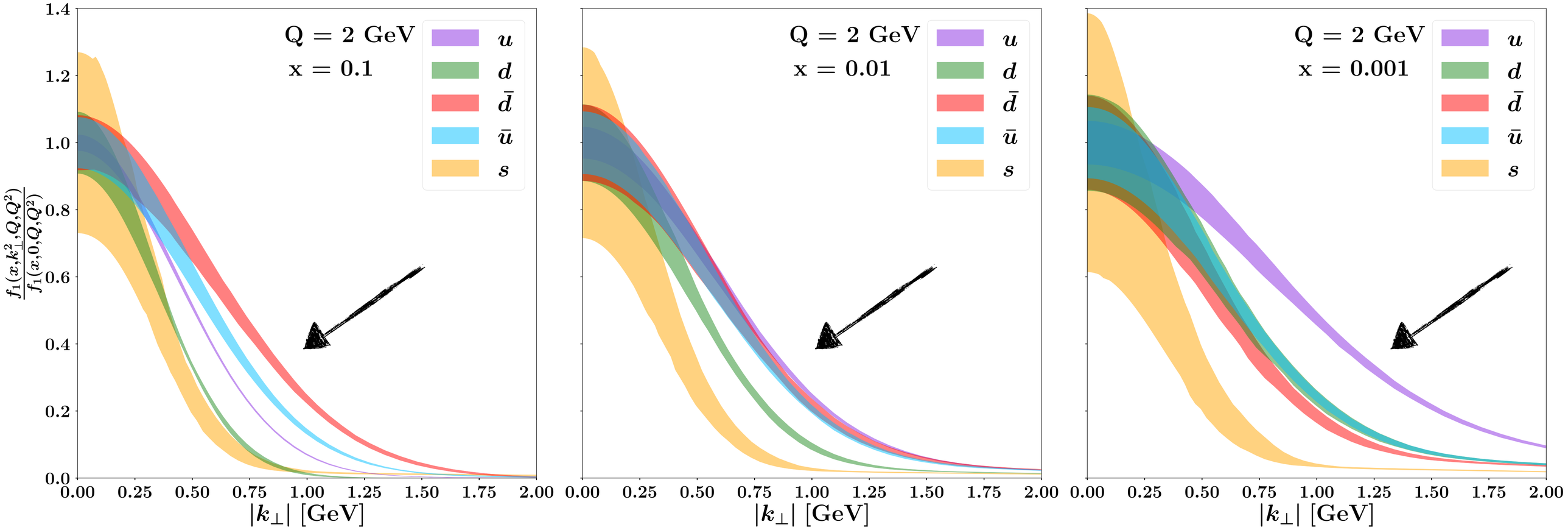

*2405.13833*

# MAPTMD24 extraction - TMD PDFs




*2405.13833*

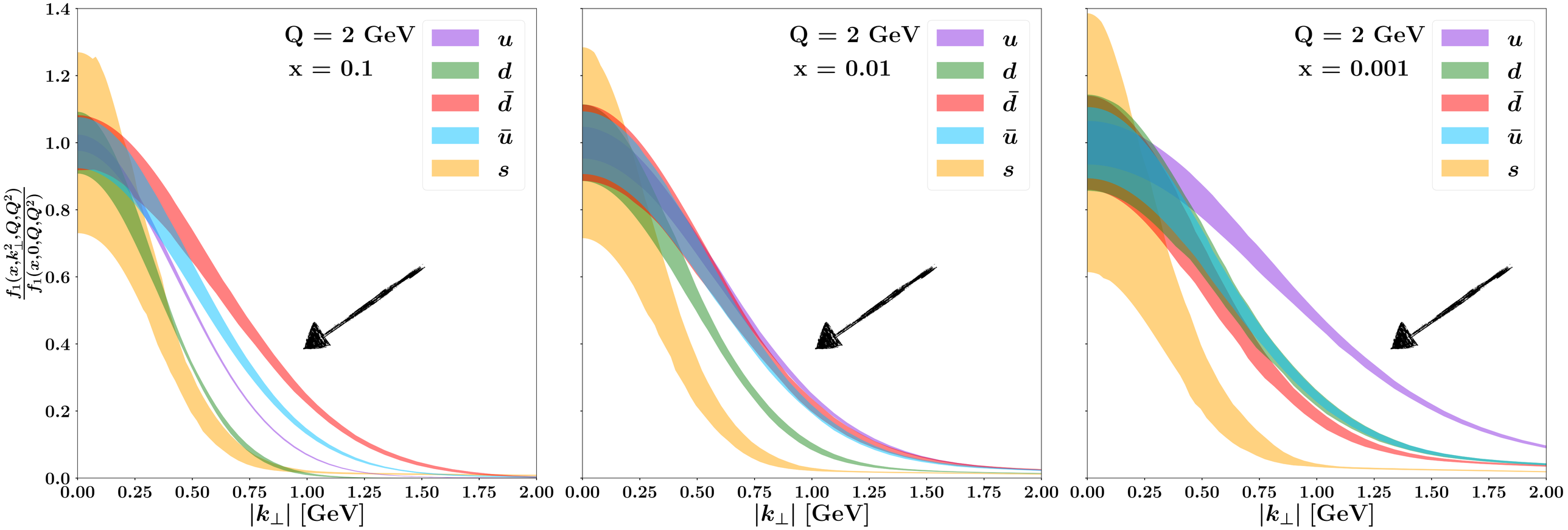
# MAPTMD24 extraction - TMD PDFs




***Very different $k_\perp$- behaviours!***

*2405.13833*

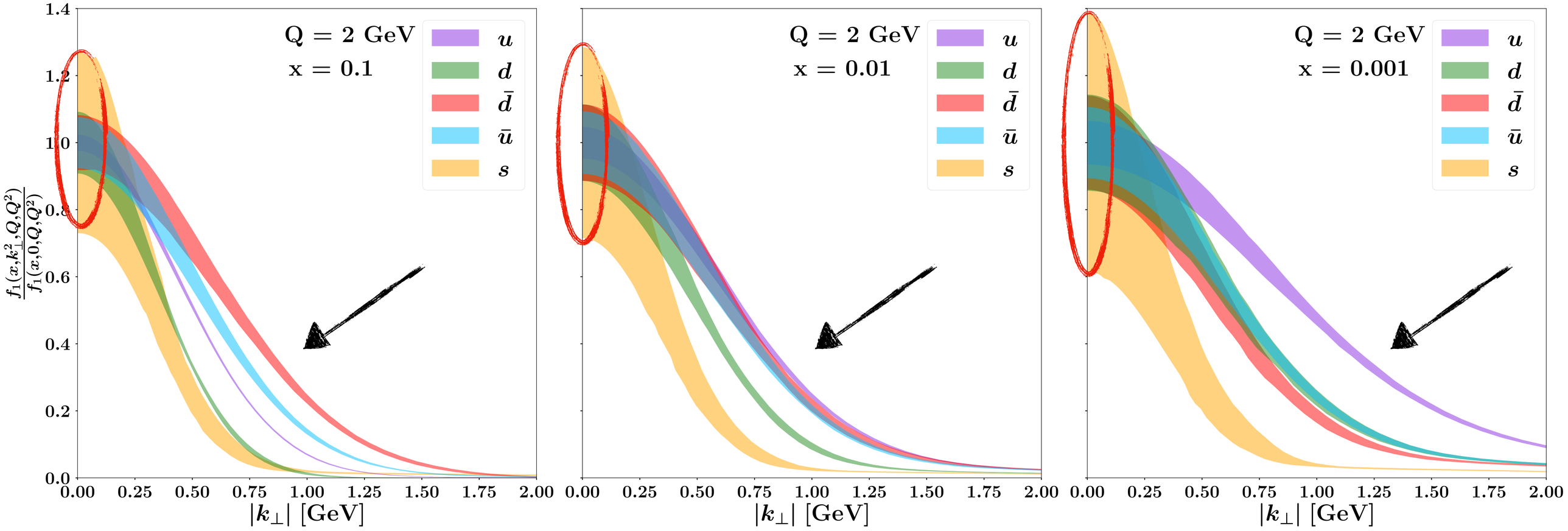
# MAPTMD24 extraction - TMD PDFs




***Very different $k_\perp$- behaviours!*** → ***It changes also by varying $x$***

*2405.13833*

# MAPTMD24 extraction - TMD PDFs

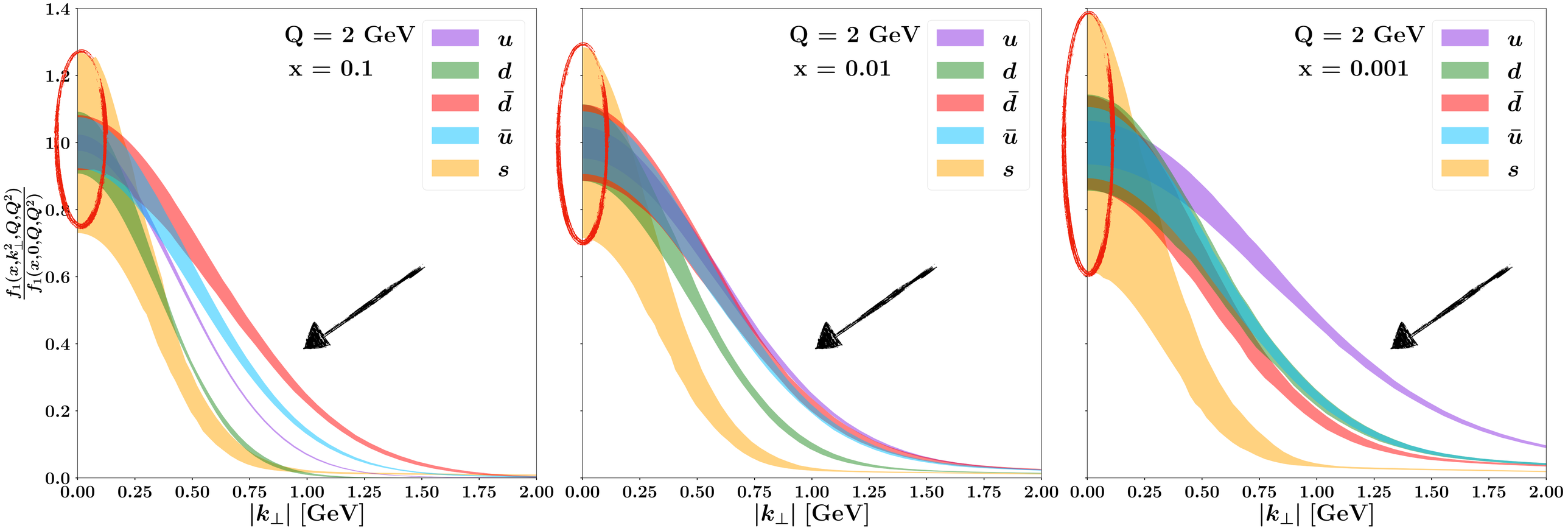



***Very different $k_\perp$- behaviours!*** → ***It changes also by varying $x$***

*2405.13833*

# MAPTMD24 extraction - TMD PDFs

***The sea is the least constrained***

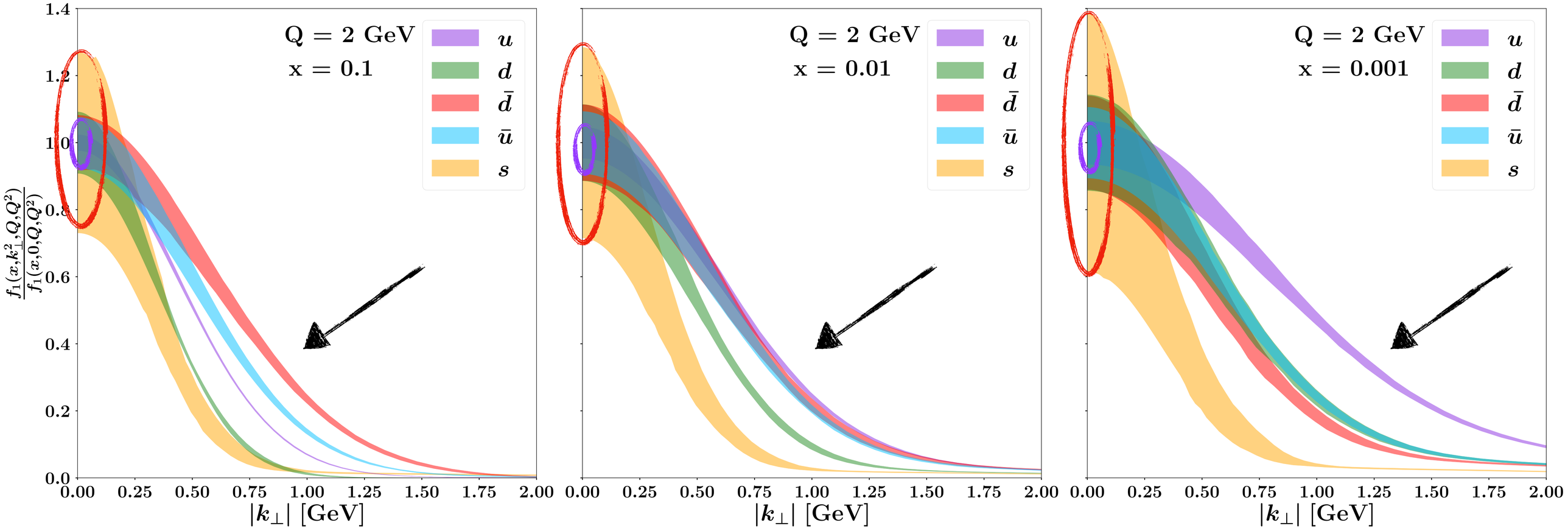



***Very different $k_\perp$- behaviours!*** → ***It changes also by varying $x$***

2405.13833

# MAPTMD24 extraction - TMD PDFs

***The sea is the least constrained***

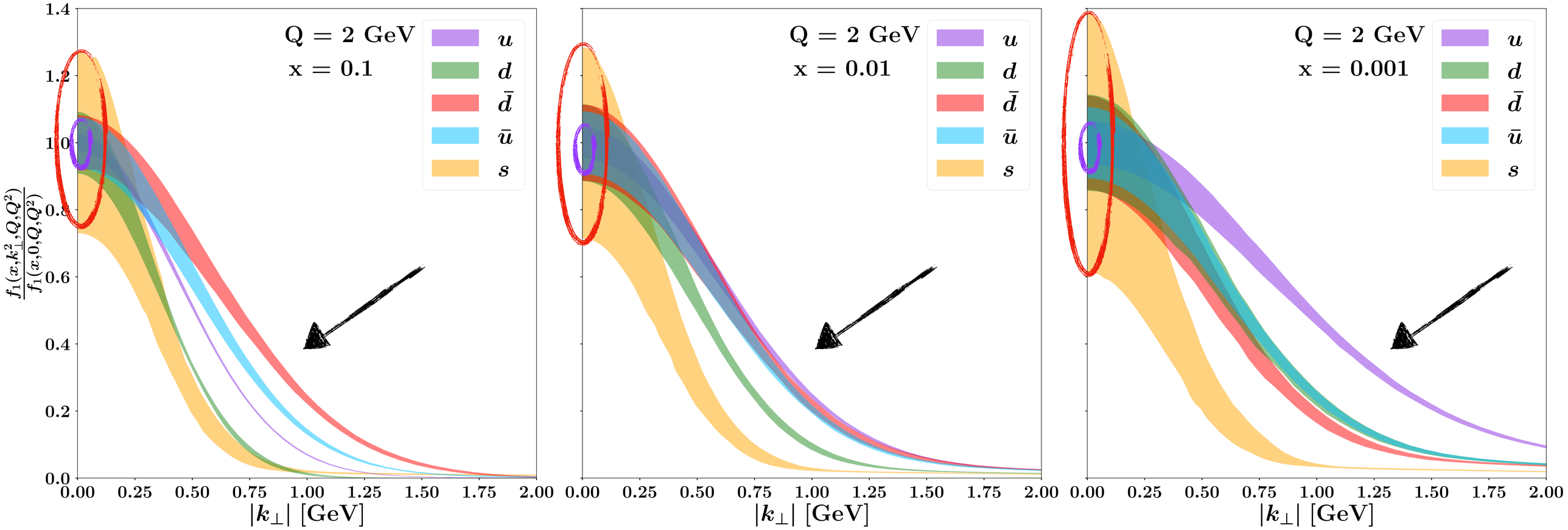



***Very different $k_\perp$- behaviours!*** → ***It changes also by varying $x$***

2405.13833

# MAPTMD24 extraction - TMD PDFs

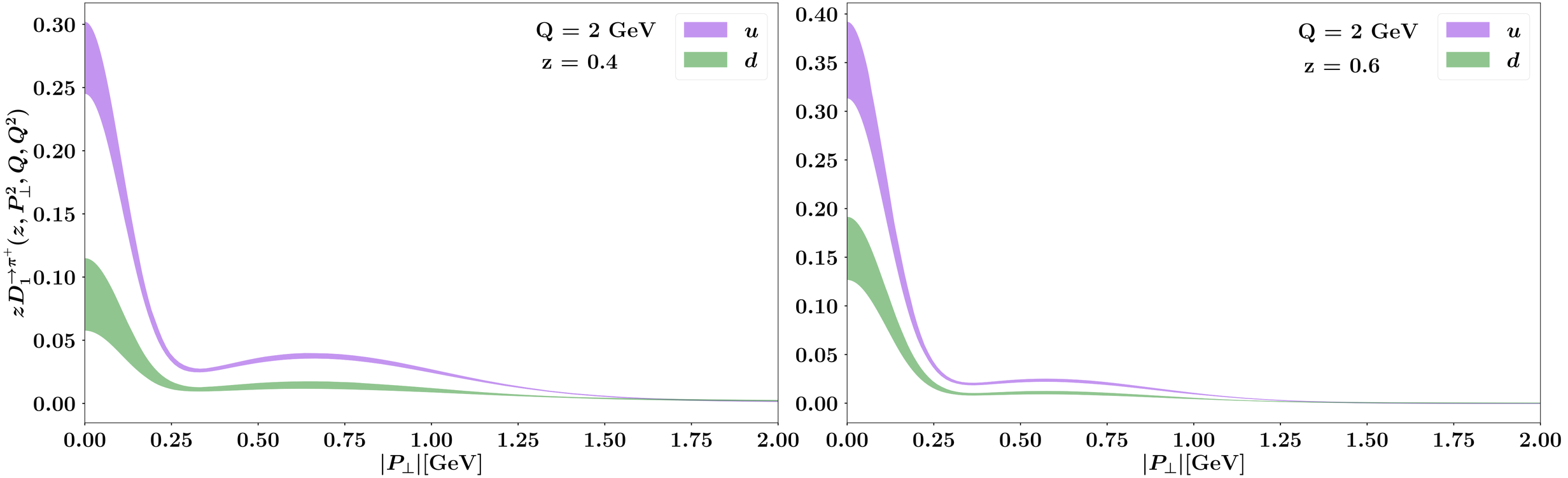
***The sea is the least constrained*** ⟷ ***The up quark is the most one***




***Very different $k_\perp$- behaviours!*** → ***It changes also by varying $x$***

*2405.13833*

# MAPTMD24 extraction - TMD FFs




*2405.13833*

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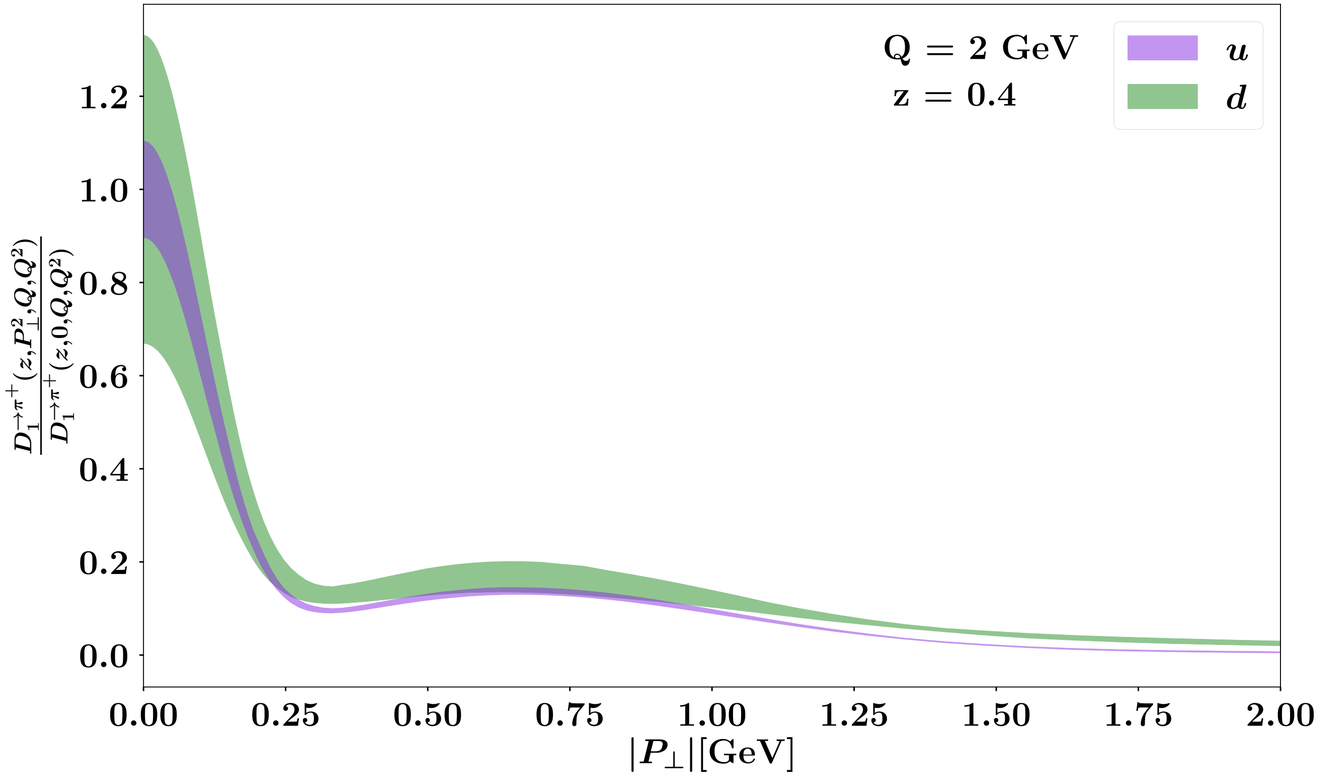


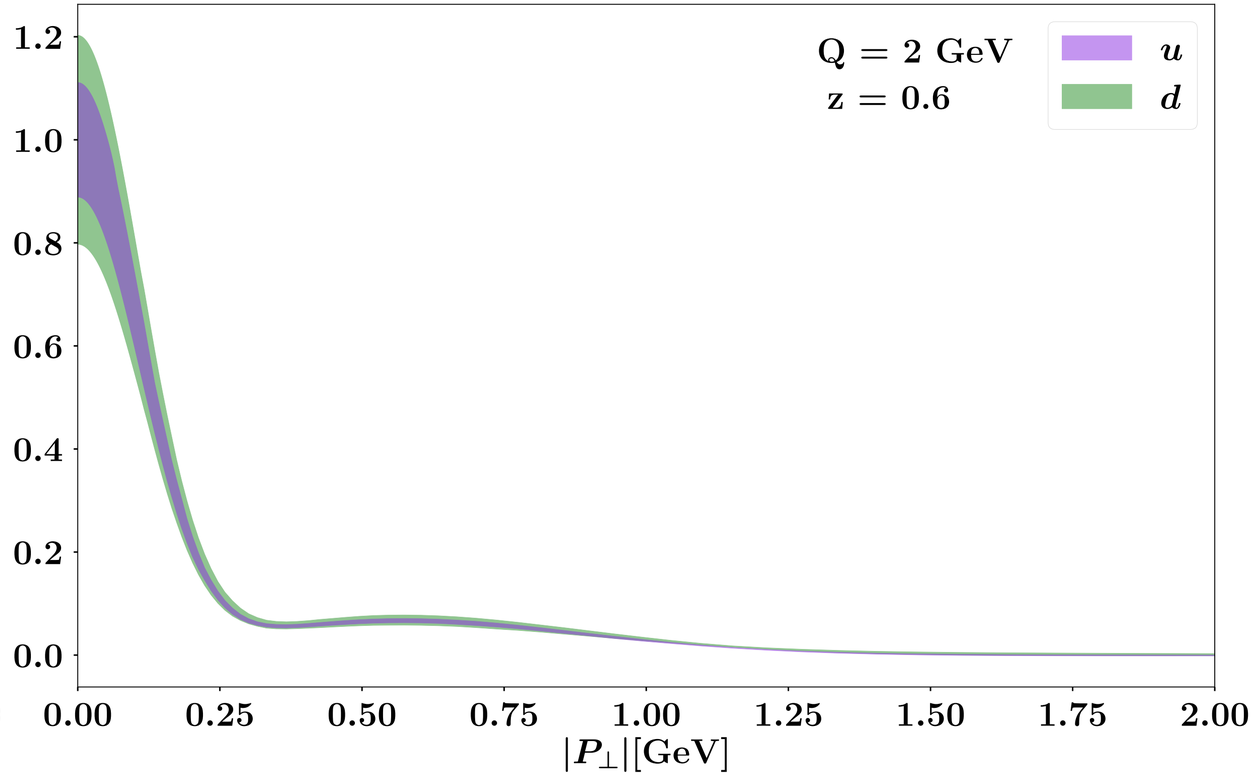


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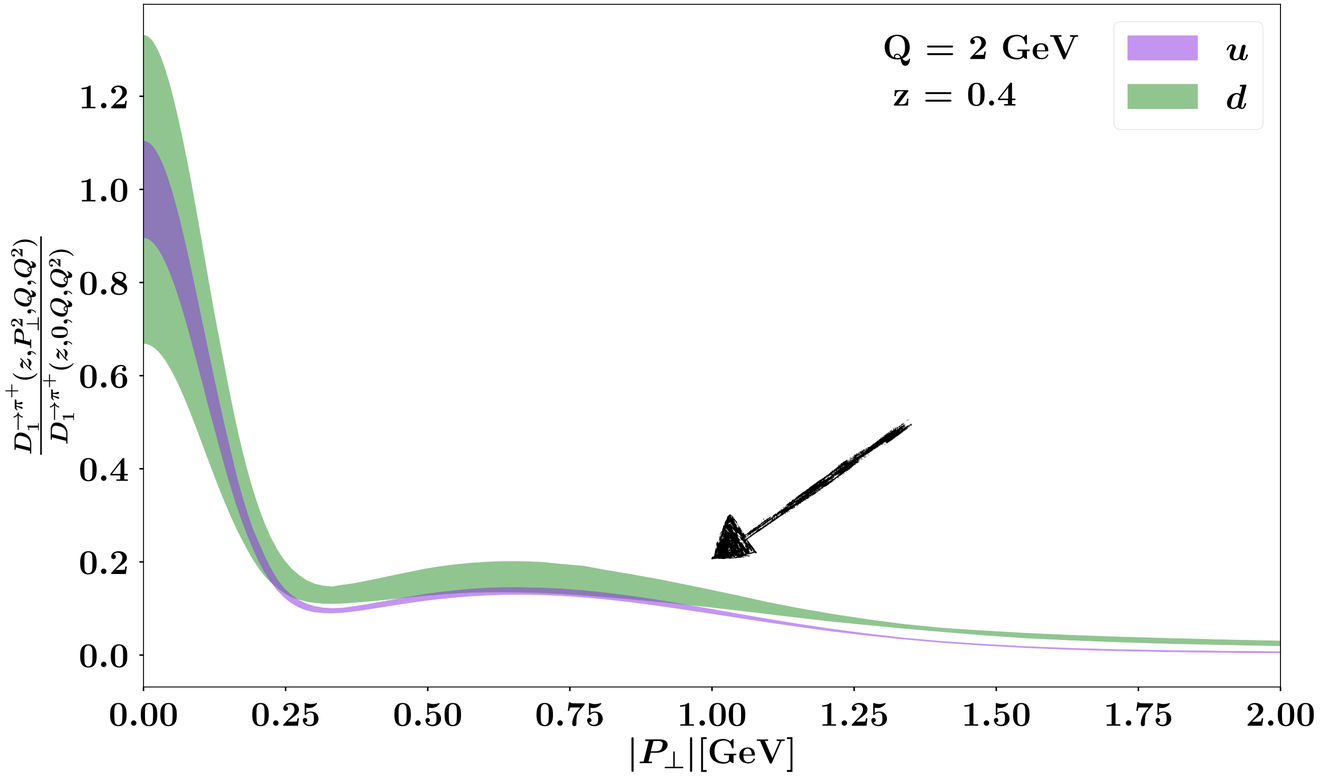


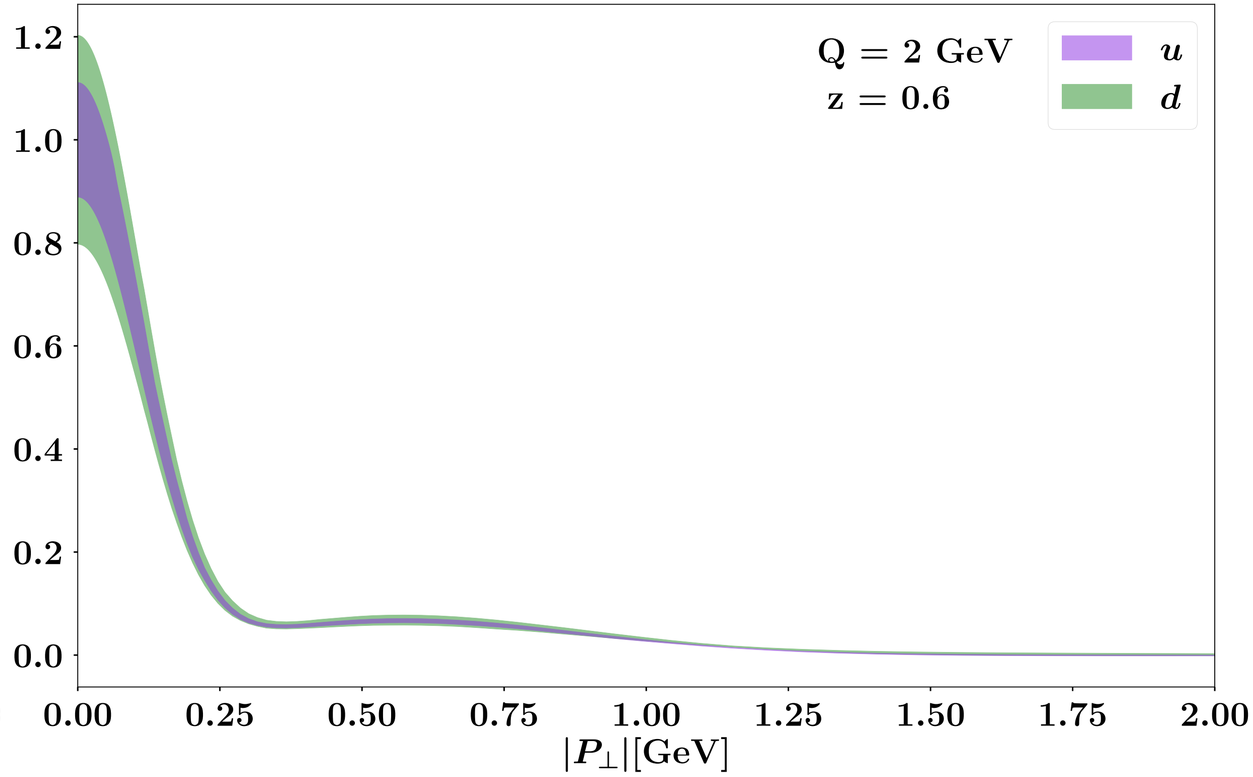


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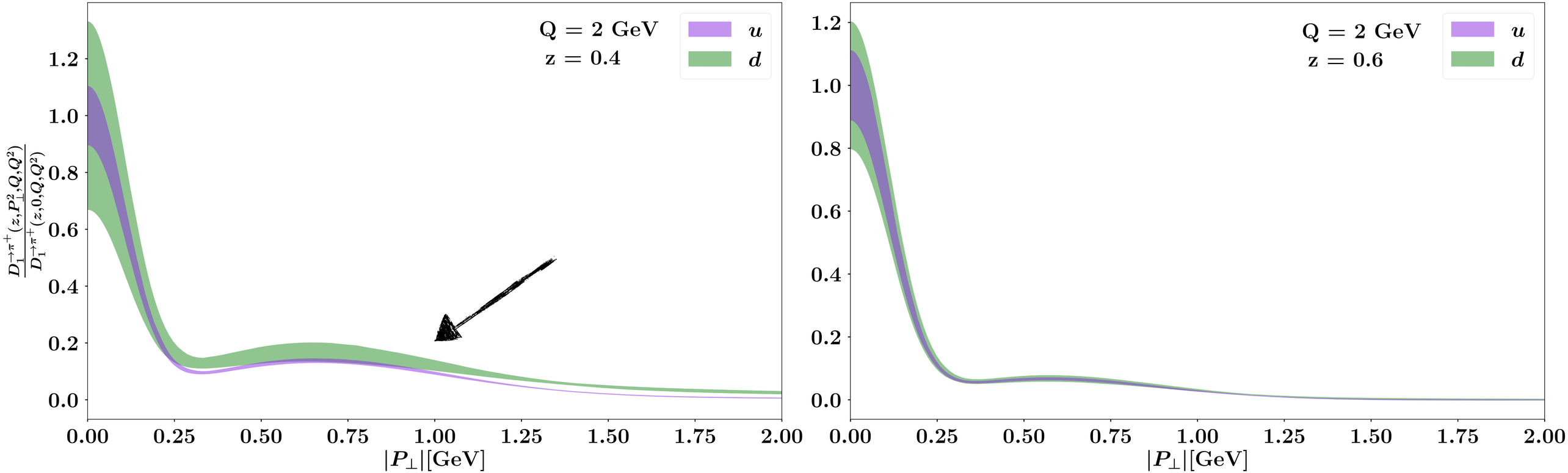
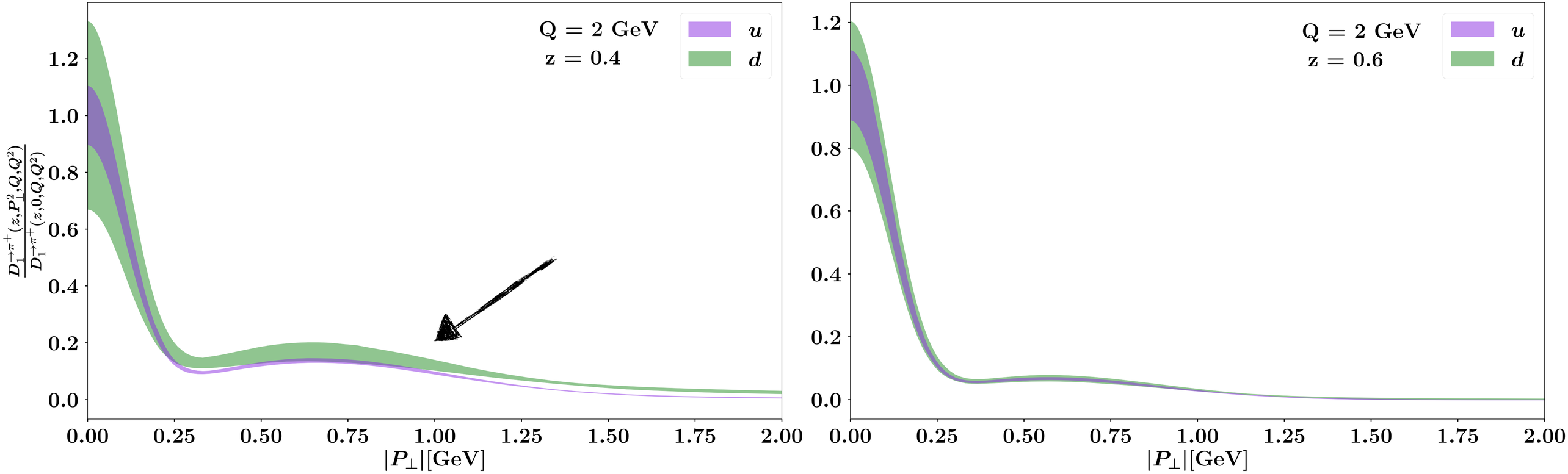



***Some signals of differences between favoured and unfavoured channels***

*2405.13833*

# MAPTMD24 extraction - TMD FFs

***The favoured is better constrained than the unfavoured one***

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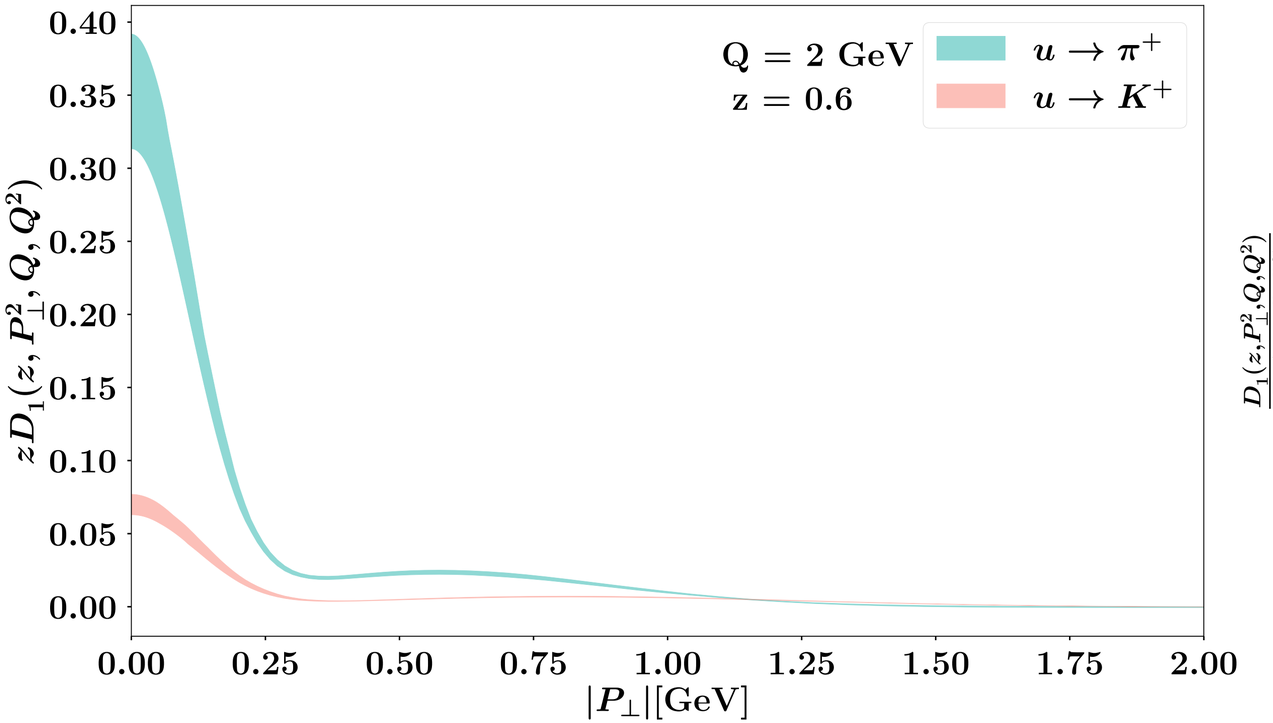


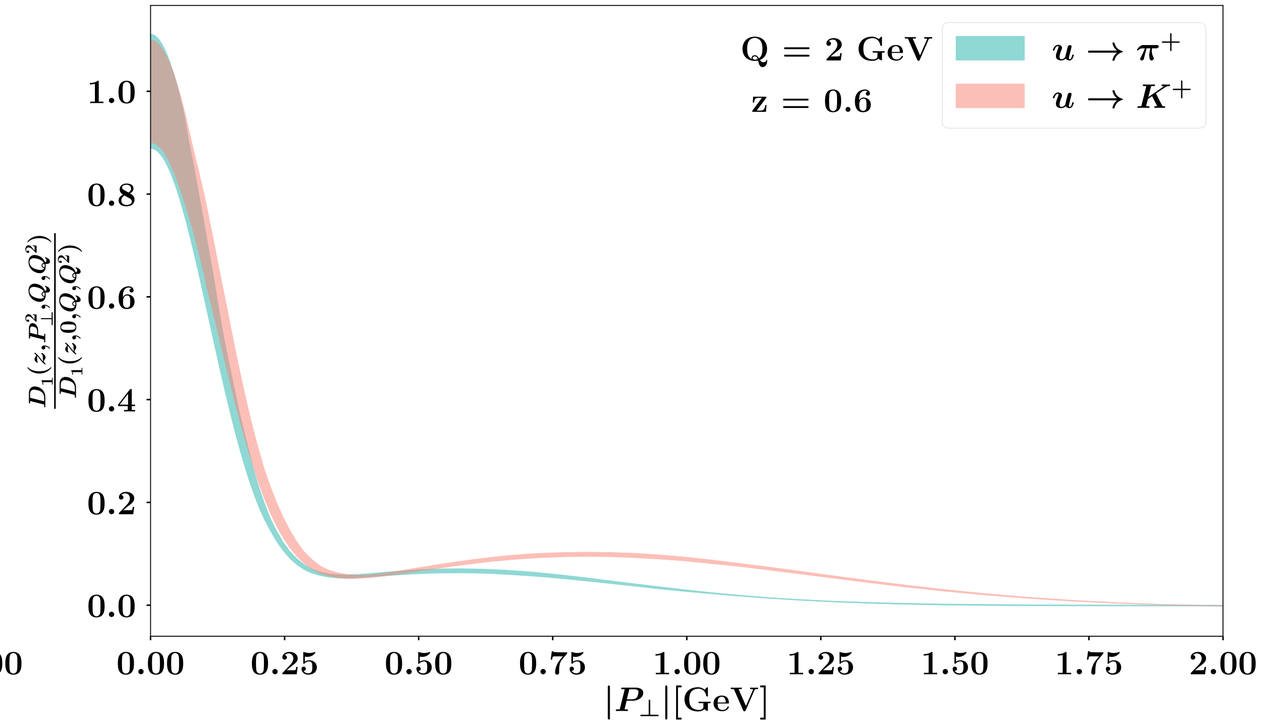


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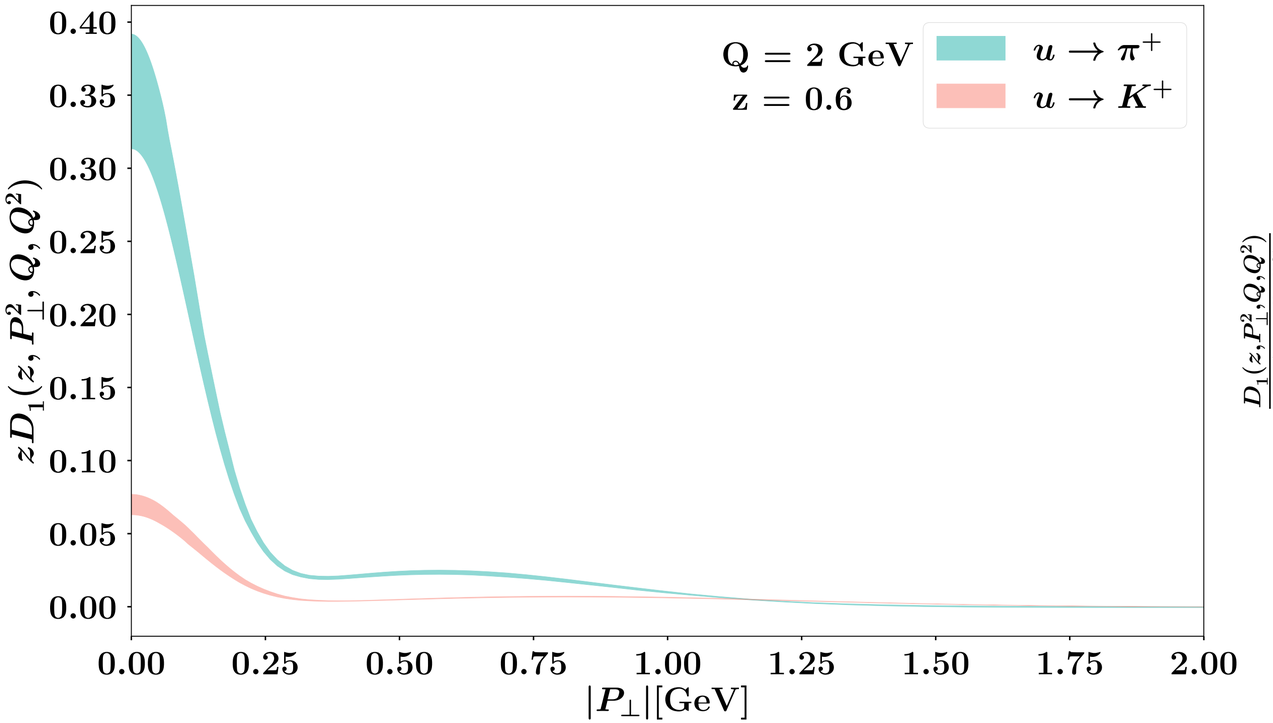


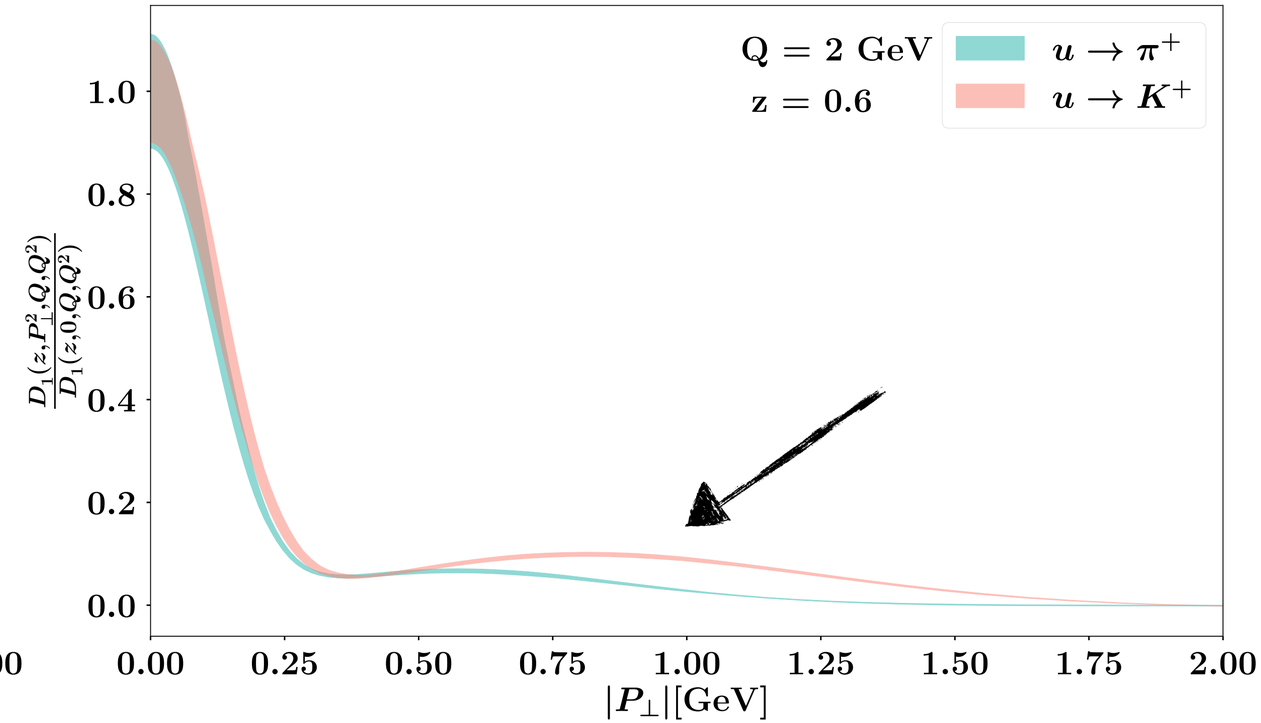


*2405.13833*

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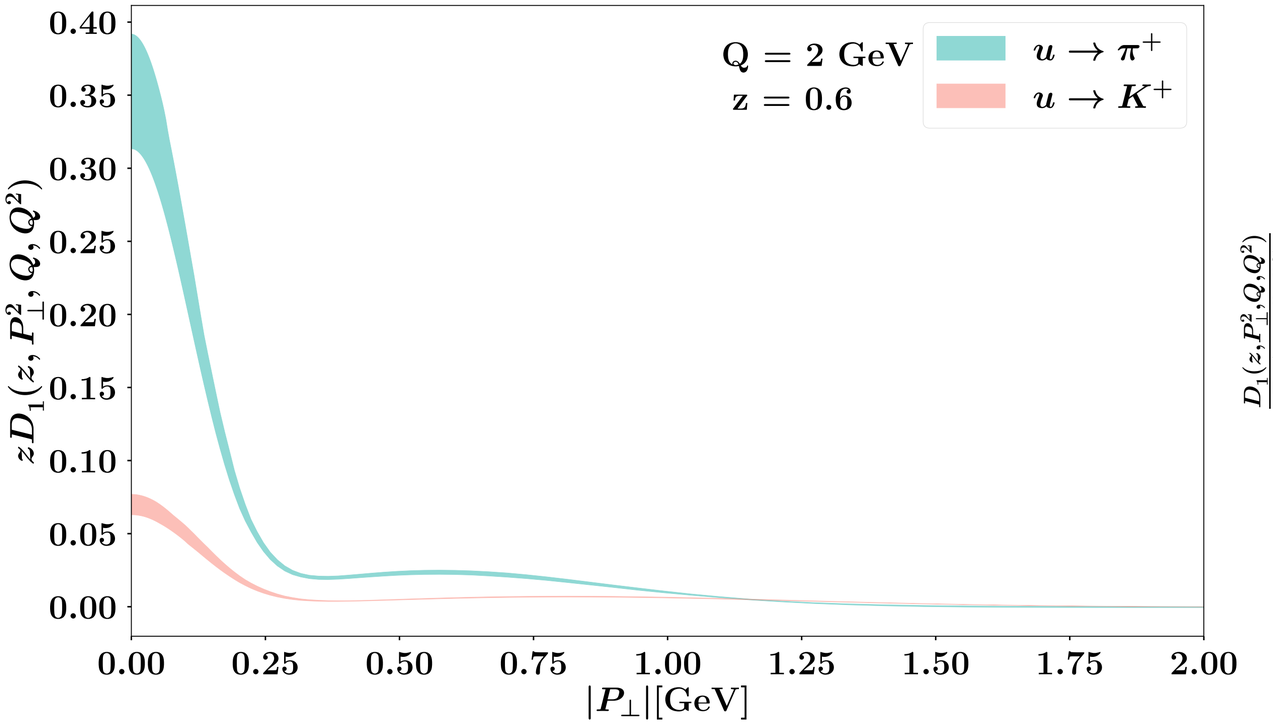
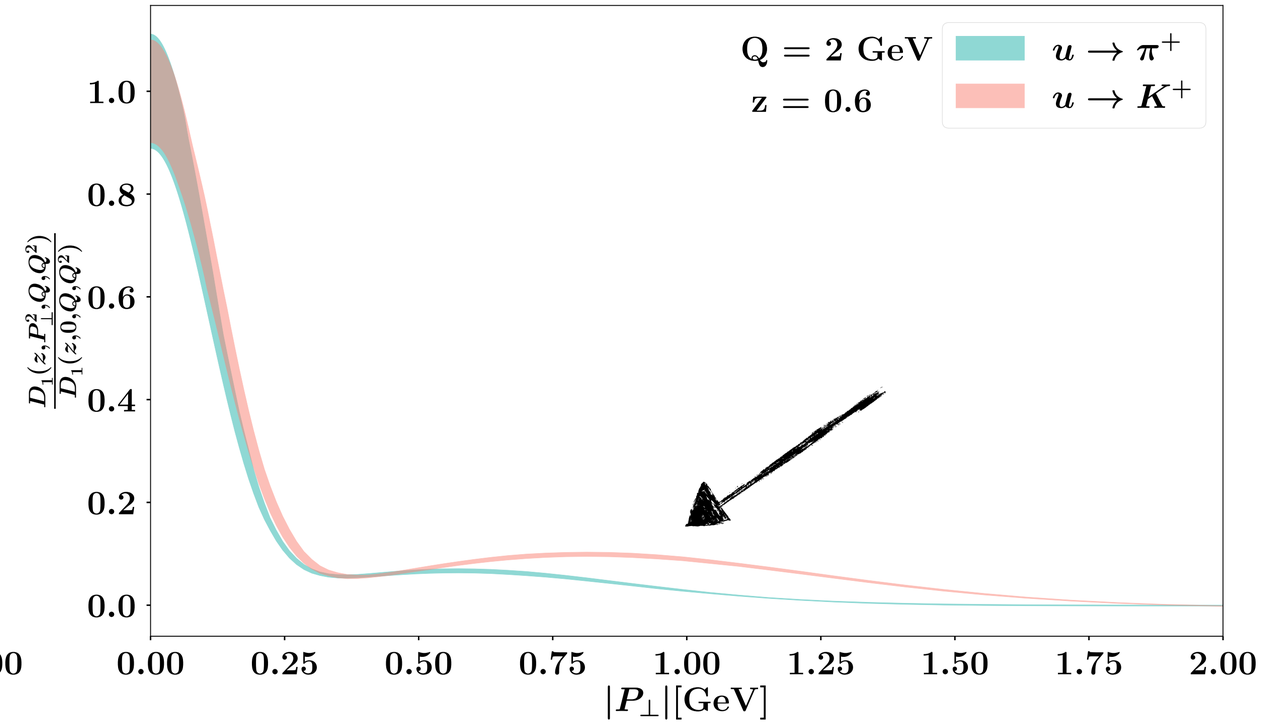
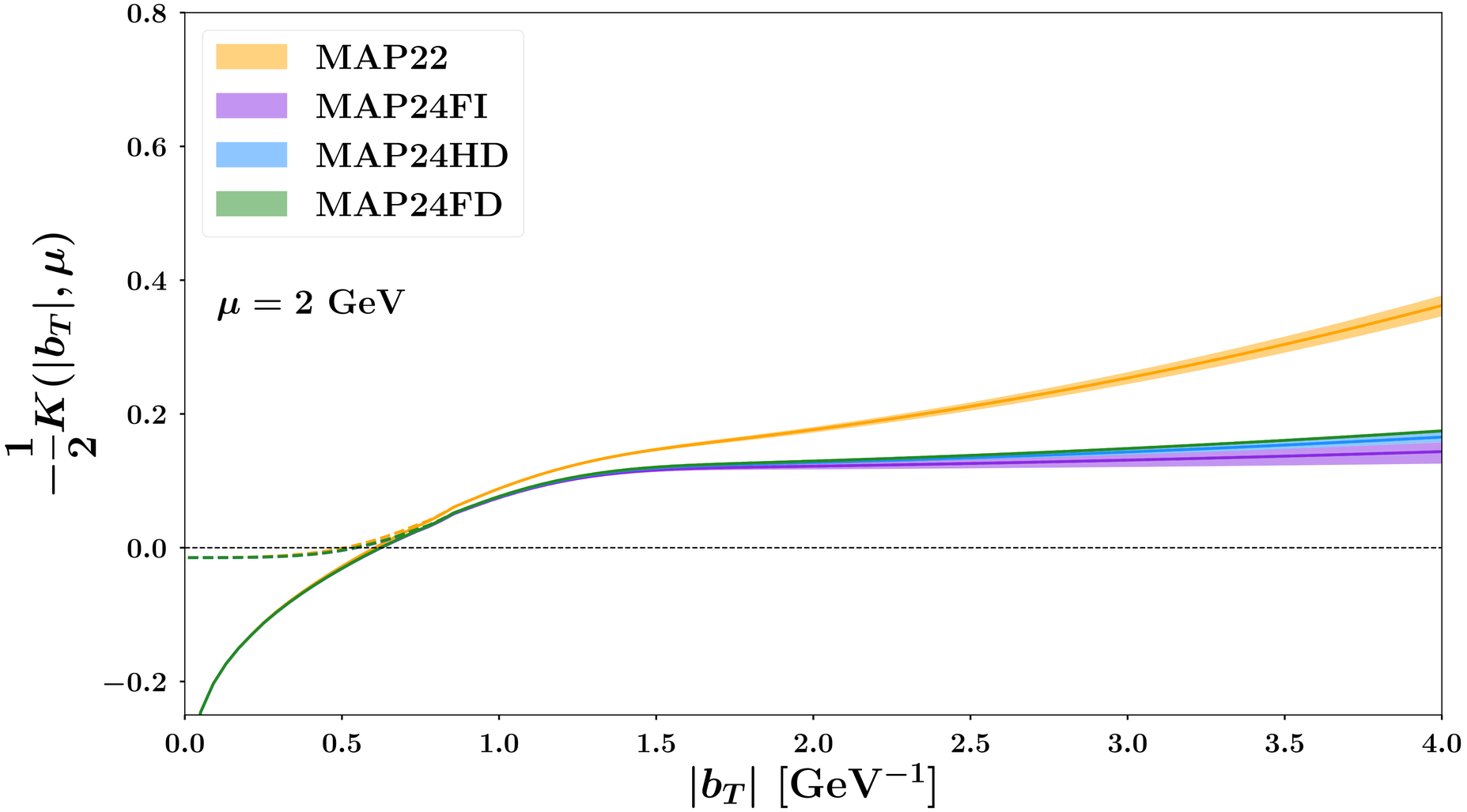



***Strong differences between different hadron fragmentations!***

*2405.13833*

# MAPTMD24 extraction - Collins Soper Kernel




*2405.13833*

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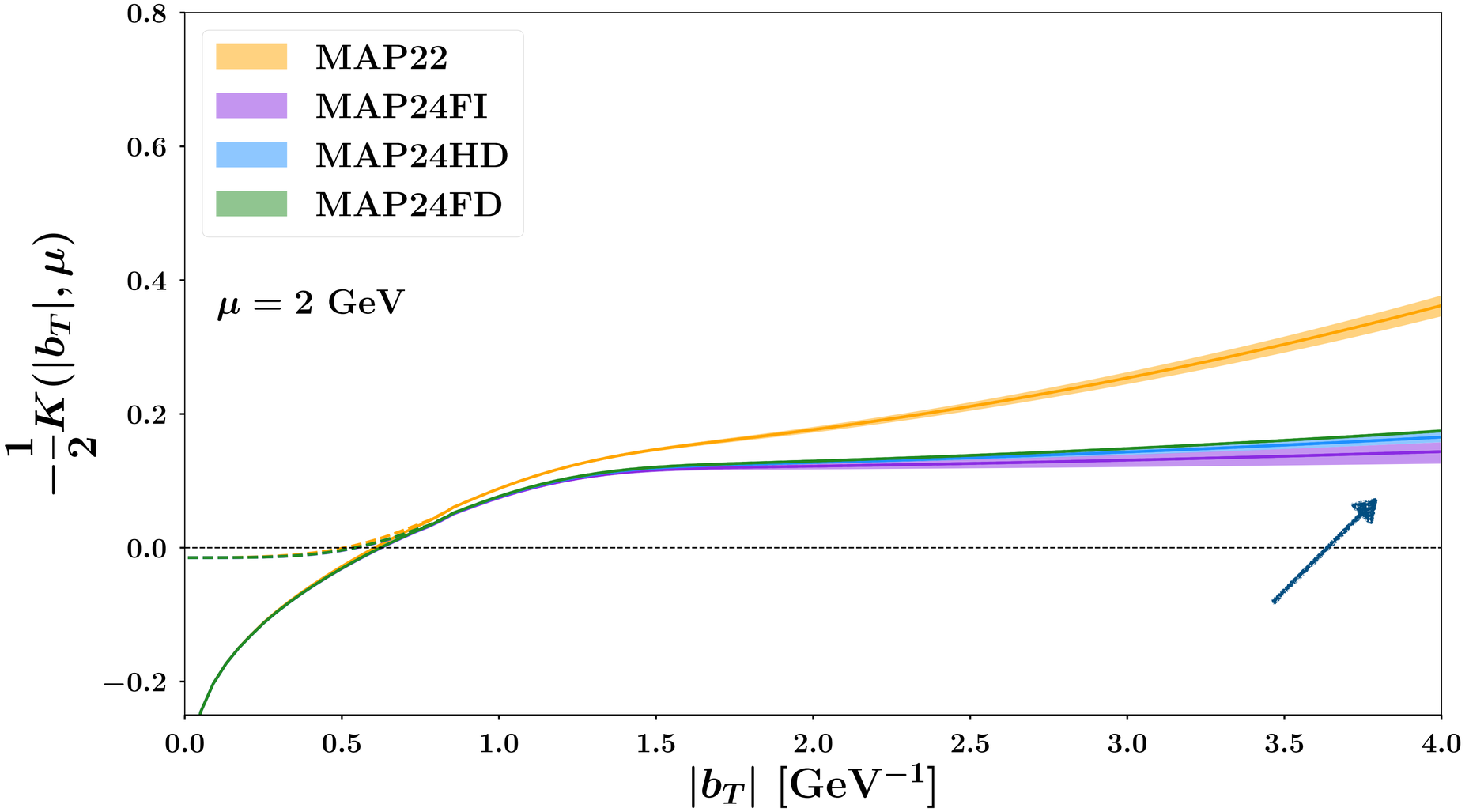


2405.13833

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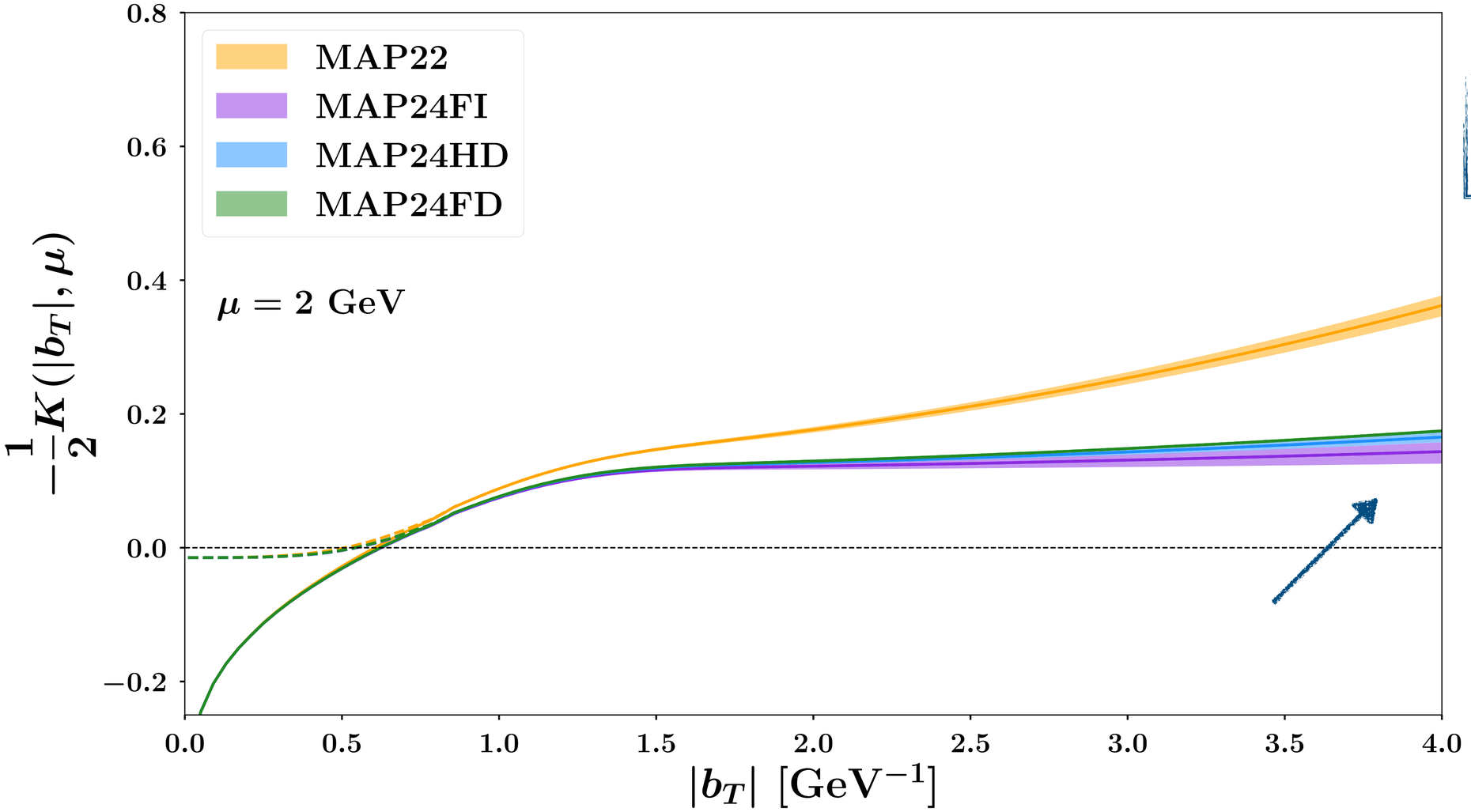
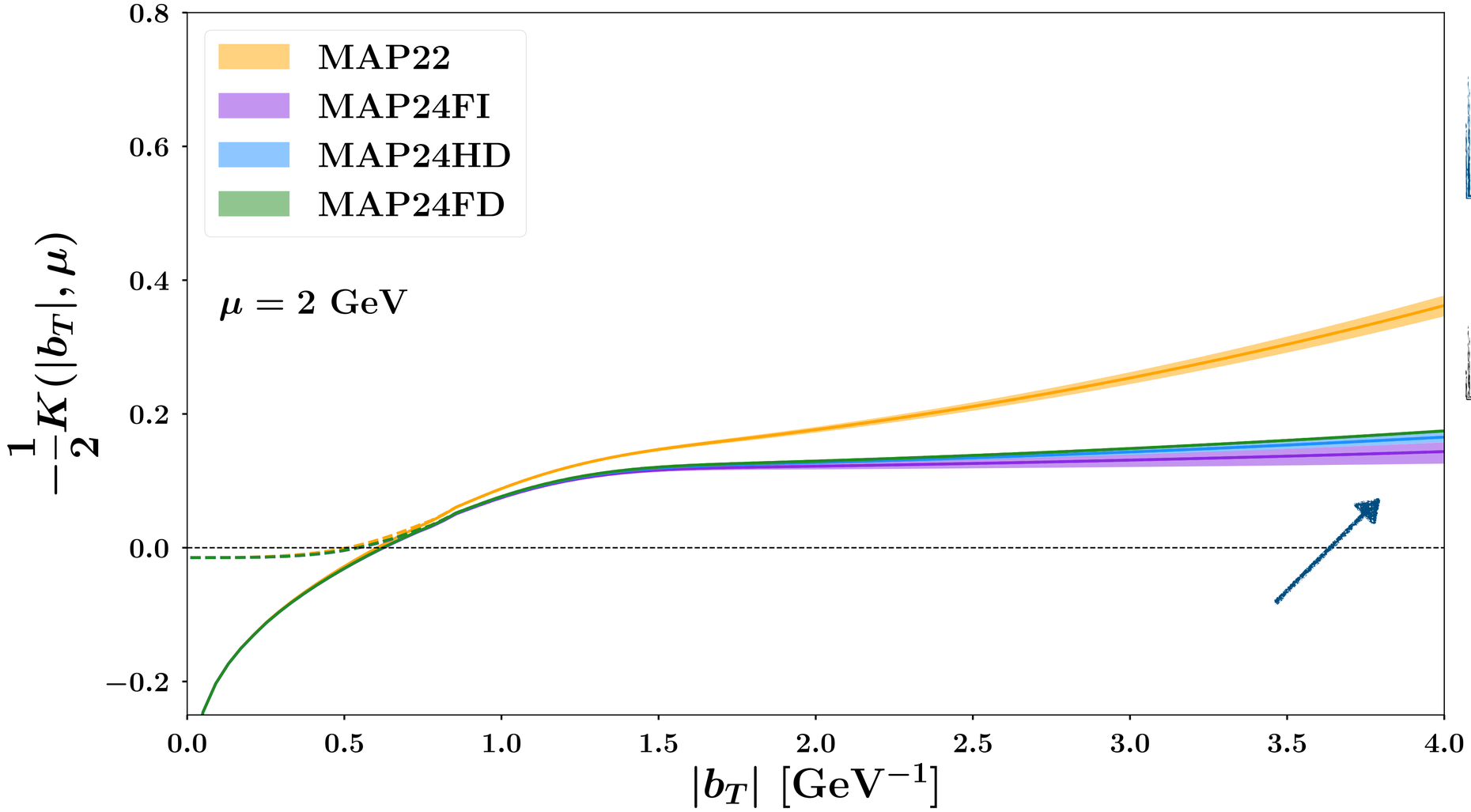



***Independent of our non perturbative choices***

*2405.13833*

# MAPTMD24 extraction - Collins Soper Kernel

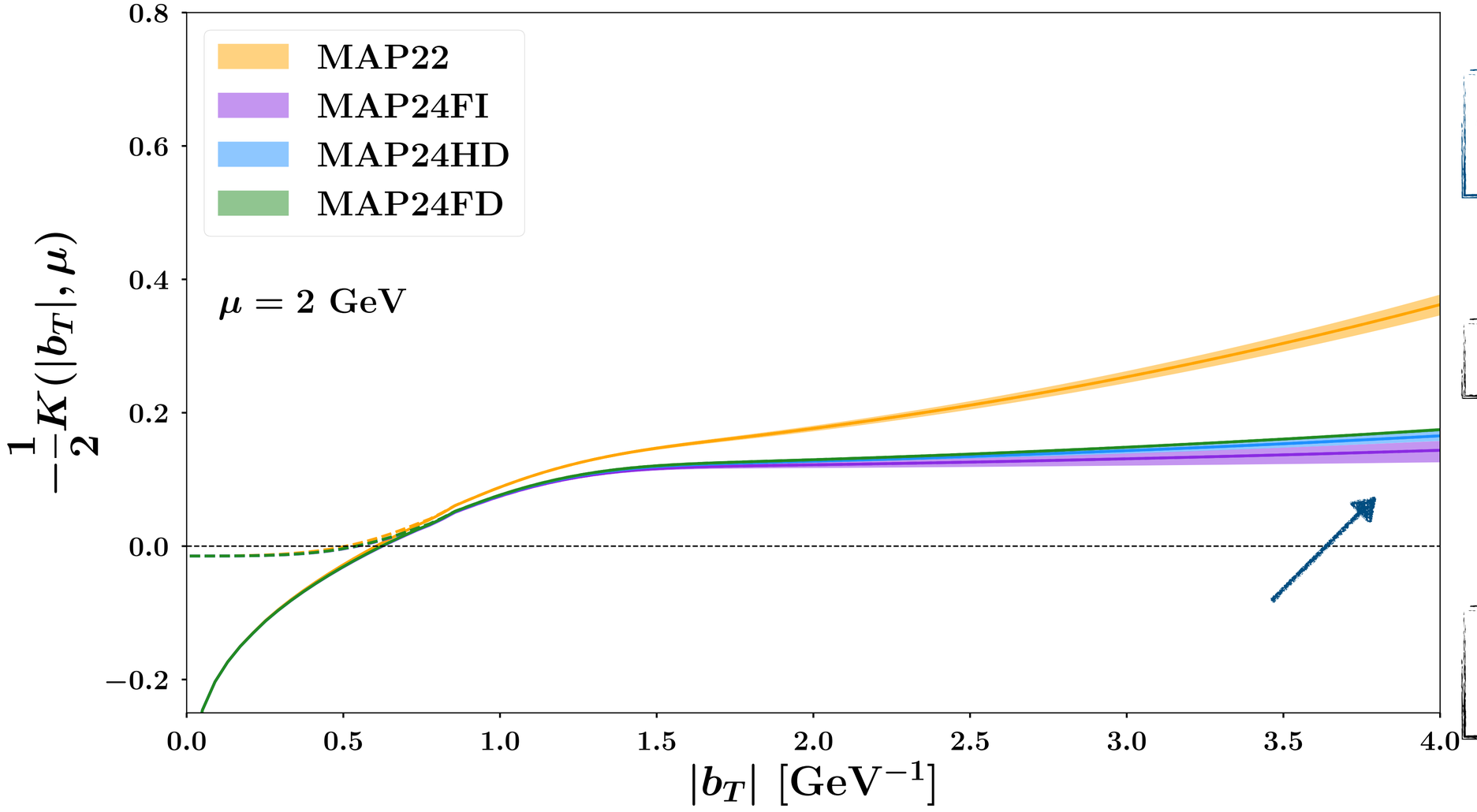



***Independent of our non perturbative choices***

***Quite flat behaviour***

*2405.13833*

# MAPTMD24 extraction - Collins Soper Kernel




***Independent of our non perturbative choices***

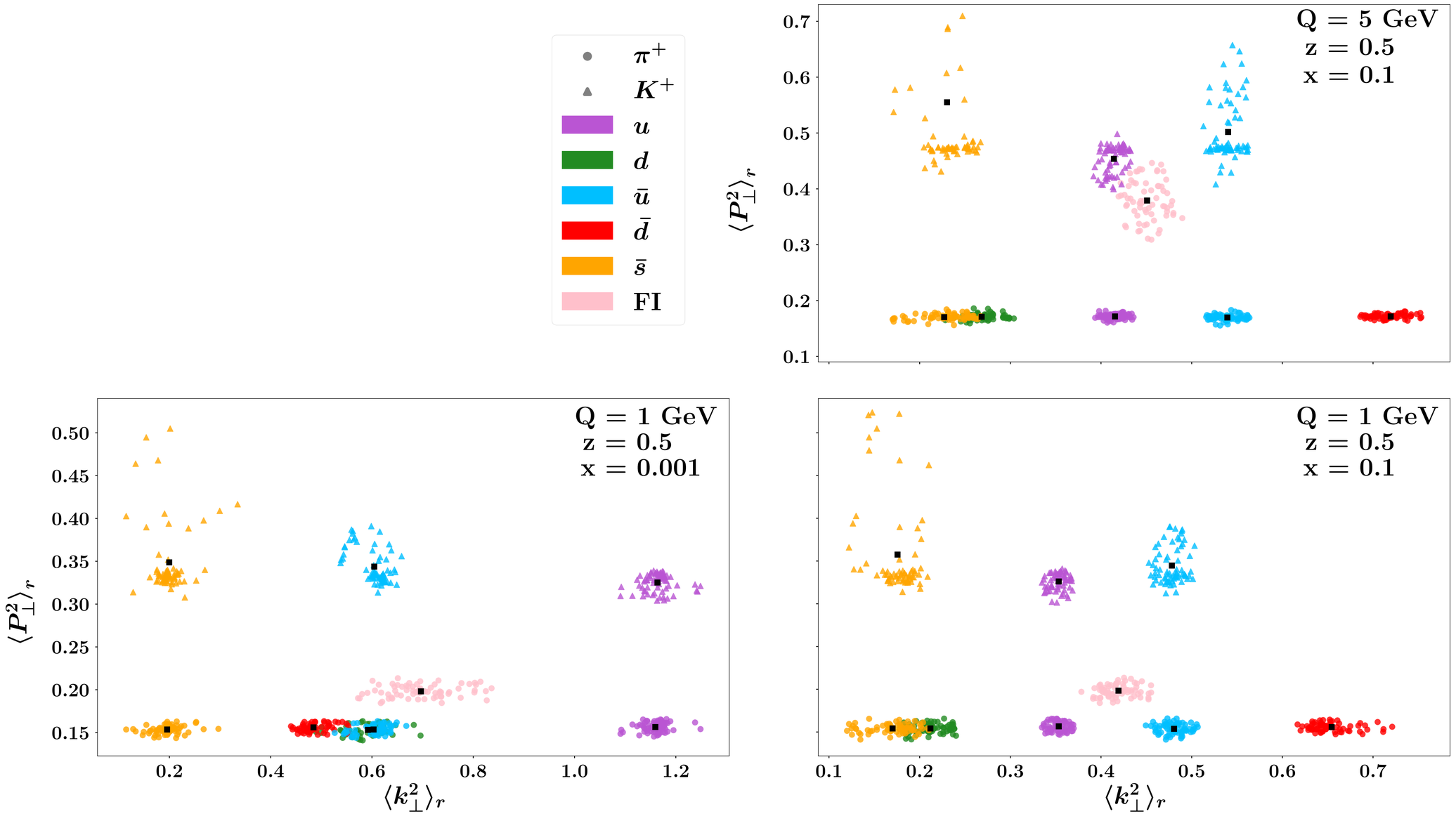
***Quite flat behaviour***

***Compatible with latest lattice calculation***

PLB 852 (2024) 138617

*2405.13833*

# MAPTMD24 extraction - Scatter plots



# Conclusions and outlook

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# Conclusions and outlook

- ***MAPTMD24*** will be the ***first flavour dependent*** extraction of unpolarized quarks TMDs in the proton from a ***global*** fit

  - We are finding ***significant*** differences between the flavors in the ***TMD PDFs***.

  - We are finding ***significant*** differences between different final hadrons in the ***TMD FFs***.

  - We are finding a weak signal between different flavors in the same final hadron.

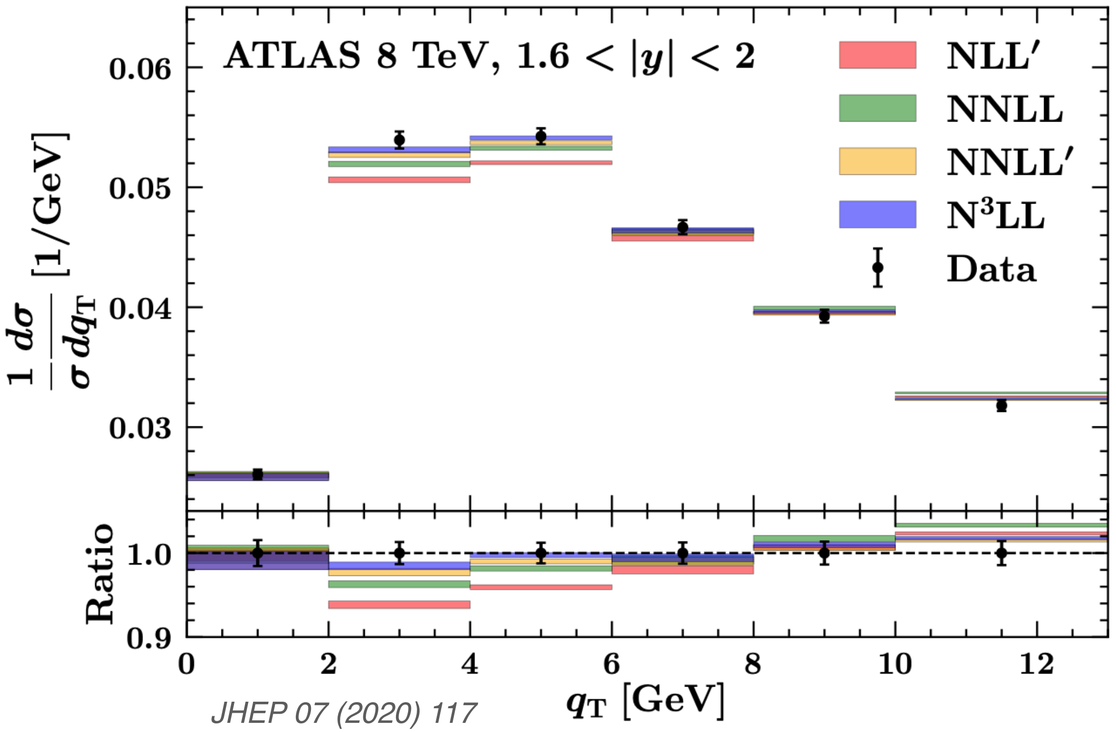
# BACKUP

# MAPTMD22: Normalization of SIDIS

*MAP Collaboration, JHEP 10 (2022)*

# MAPTMD22: Normalization of SIDIS

High Energy Drell-Yan




*JHEP 07 (2020) 117*

*MAP Collaboration, JHEP 10 (2022)*

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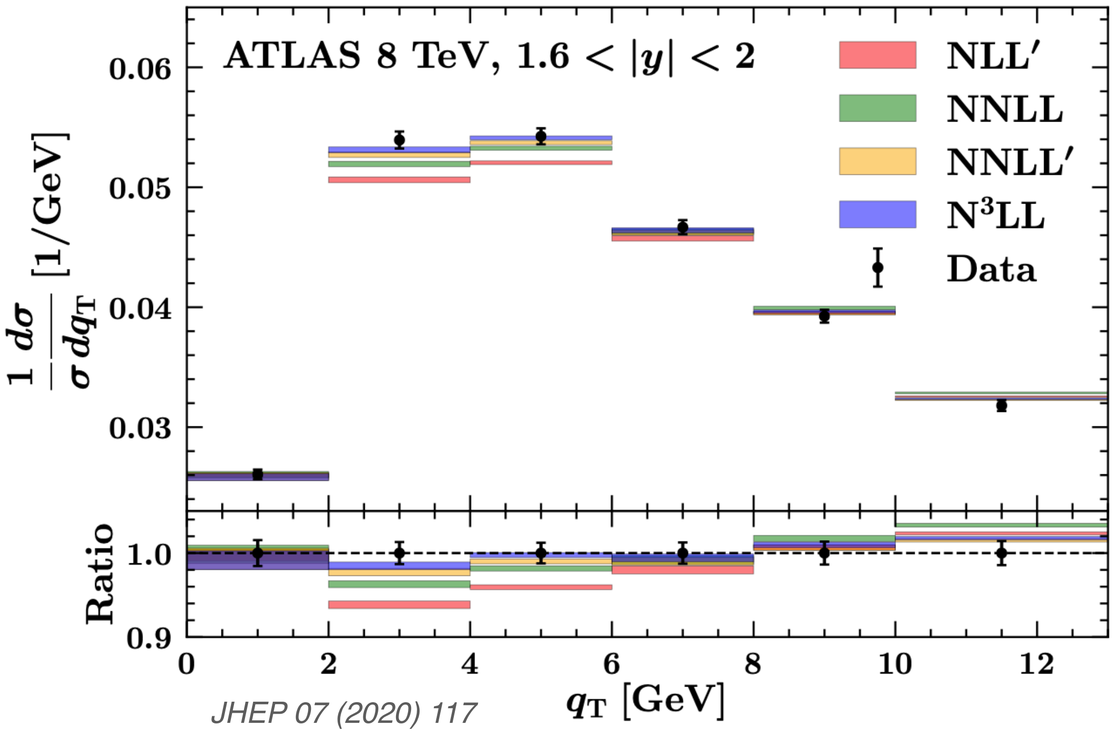
High Energy Drell-Yan



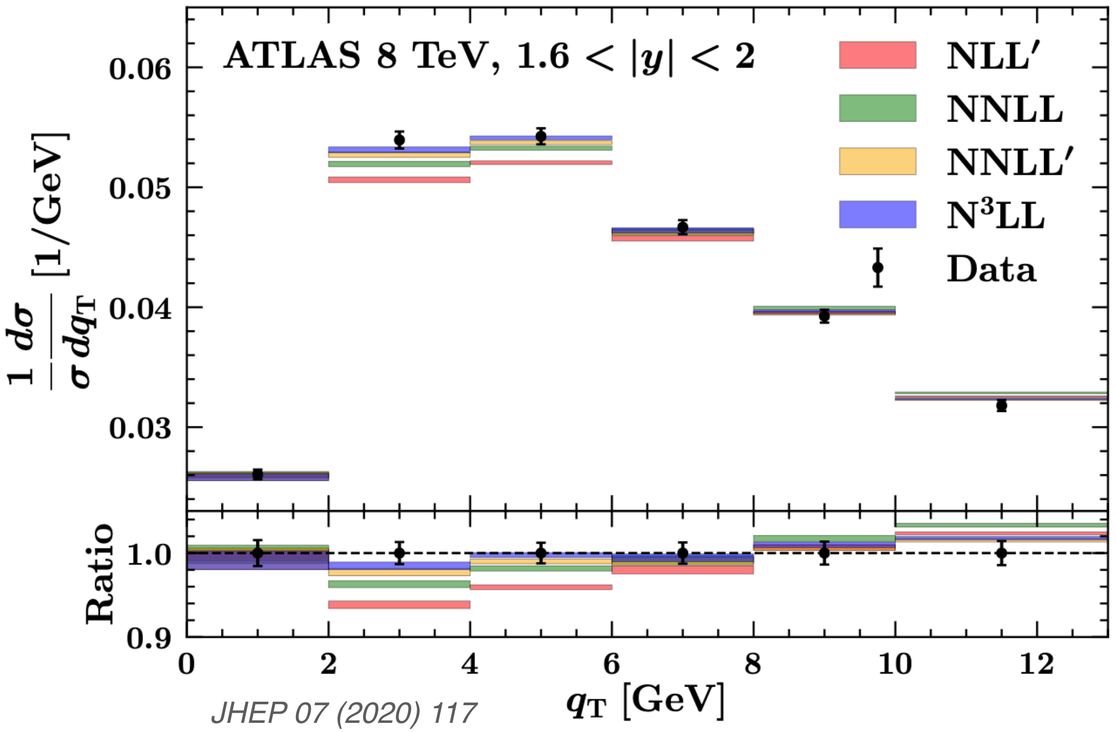

*JHEP 07 (2020) 117*

**The description improves at high orders**

*MAP Collaboration, JHEP 10 (2022)*

# MAPTMD22: Normalization of SIDIS

## High Energy Drell-Yan




*JHEP 07 (2020) 117*

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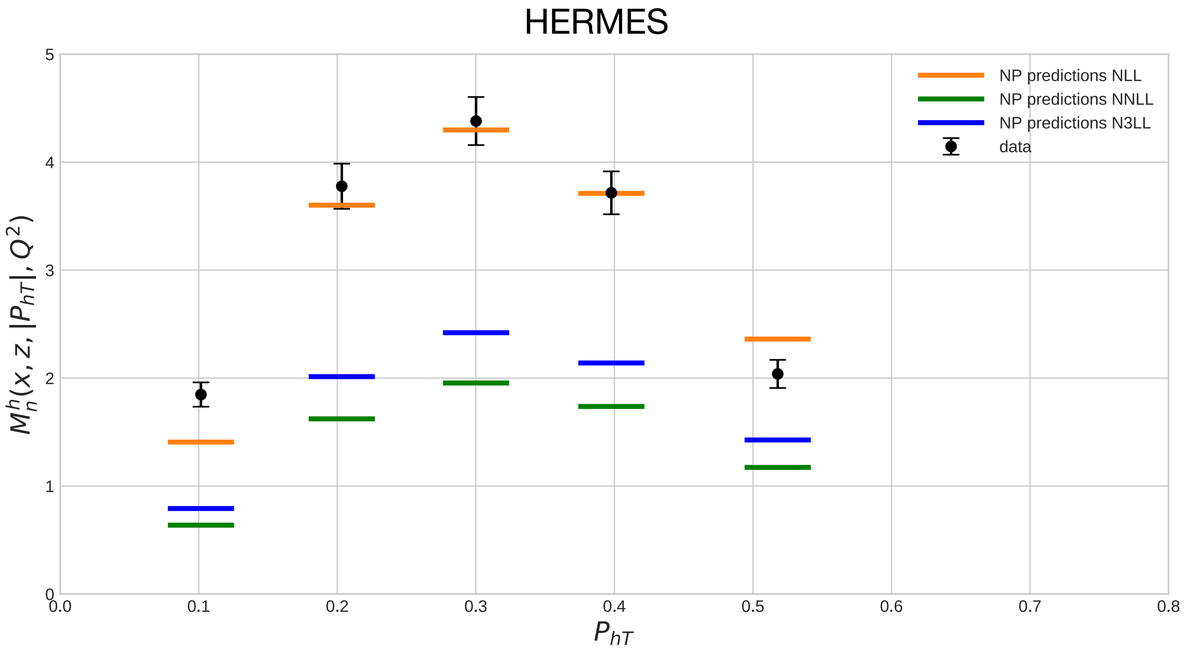
## SIDIS

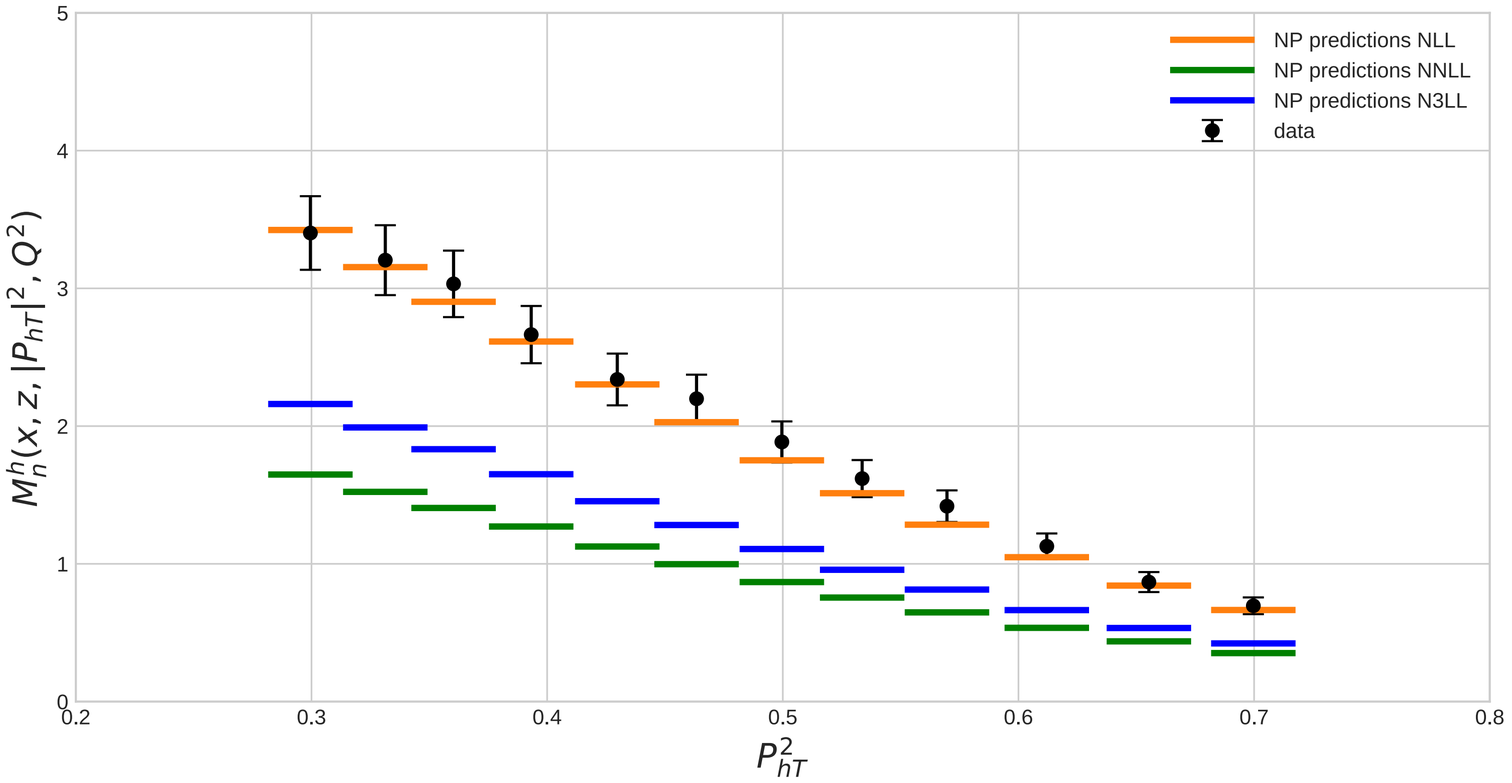



**Strange behaviors at higher orders**

*MAP Collaboration, JHEP 10 (2022)*

# MAPTMD22: Normalization of SIDIS

COMPASS multiplicities (one of many bins)




*MAP Collaboration, JHEP 10 (2022)*

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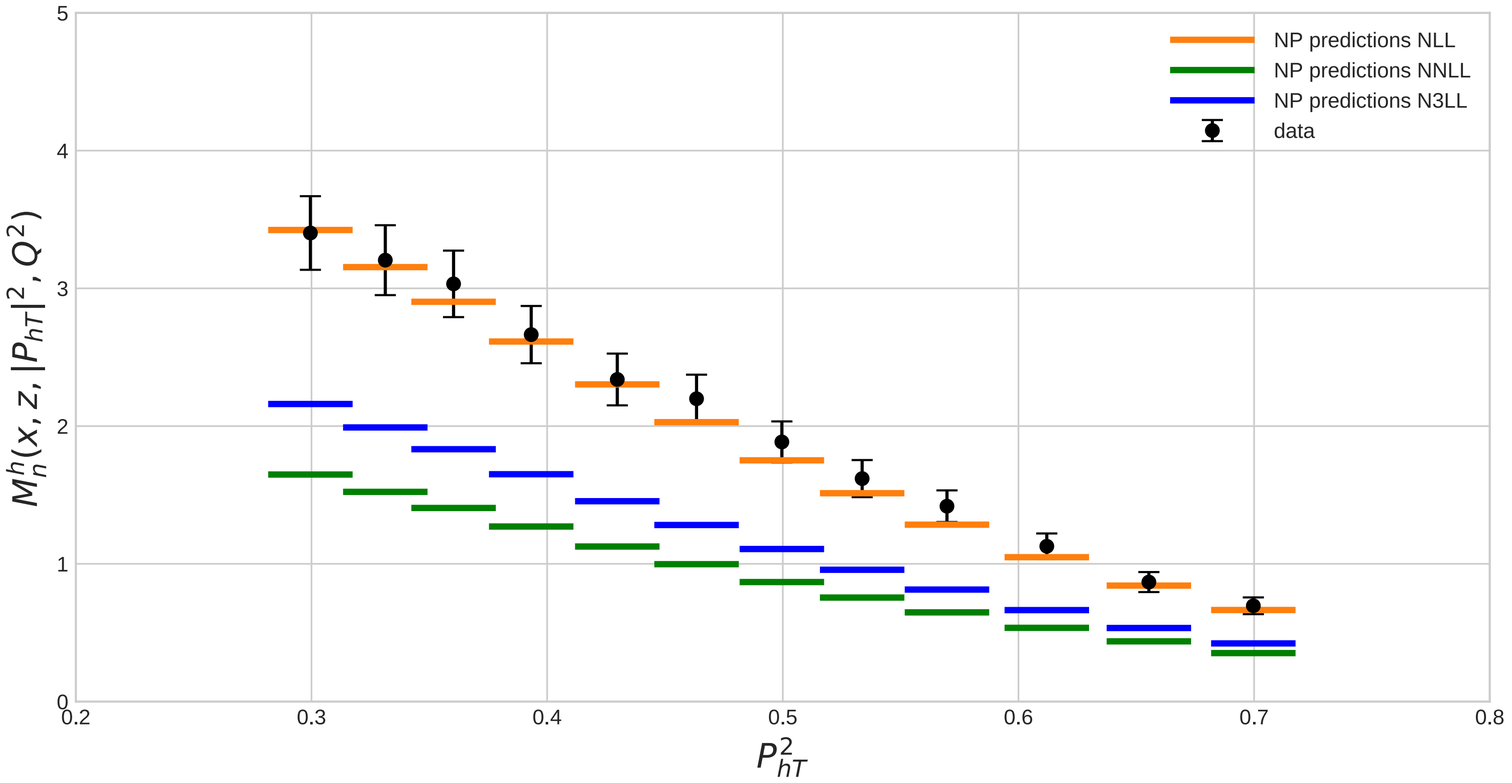


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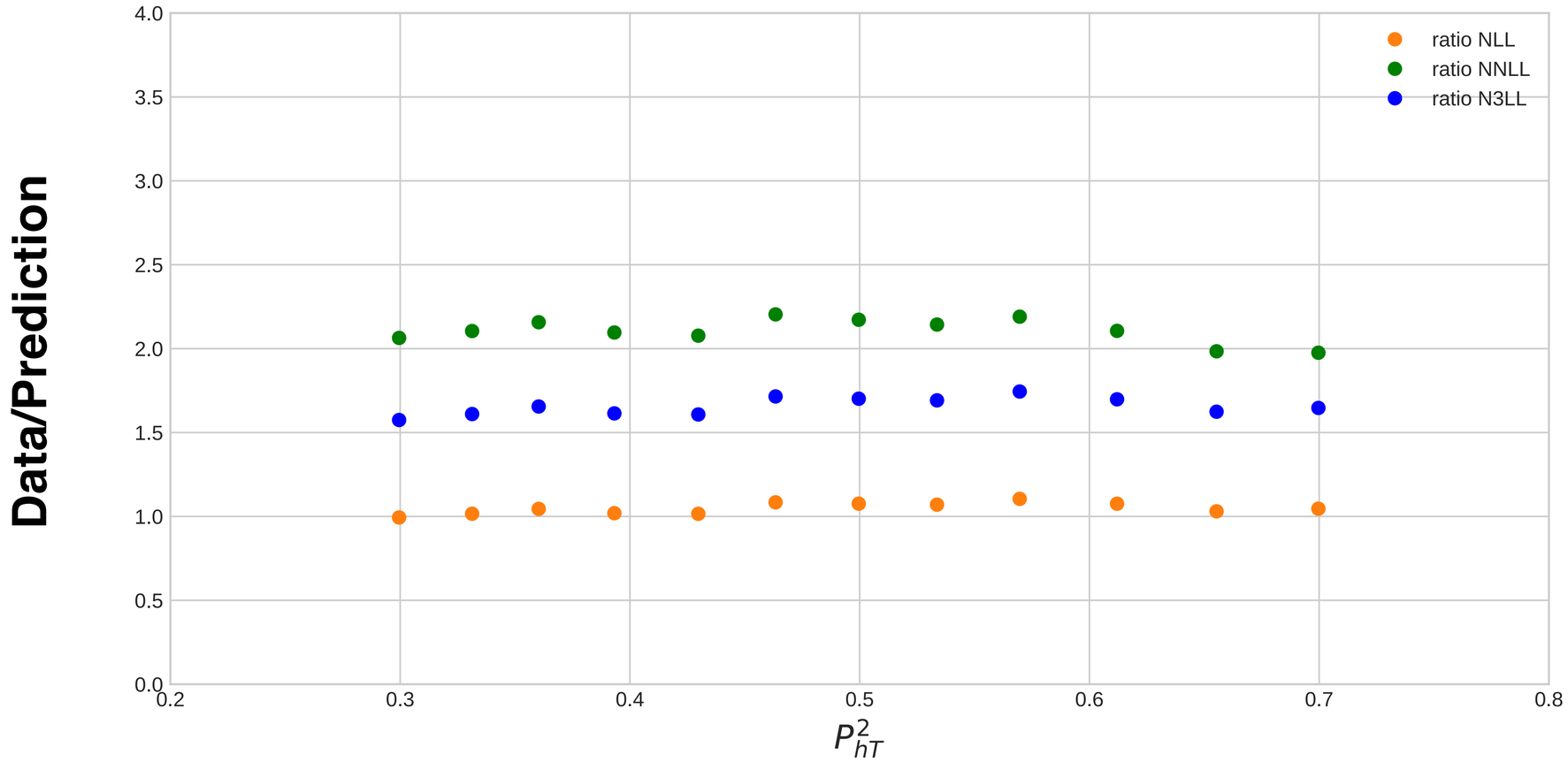


*MAP Collaboration, JHEP 10 (2022)*

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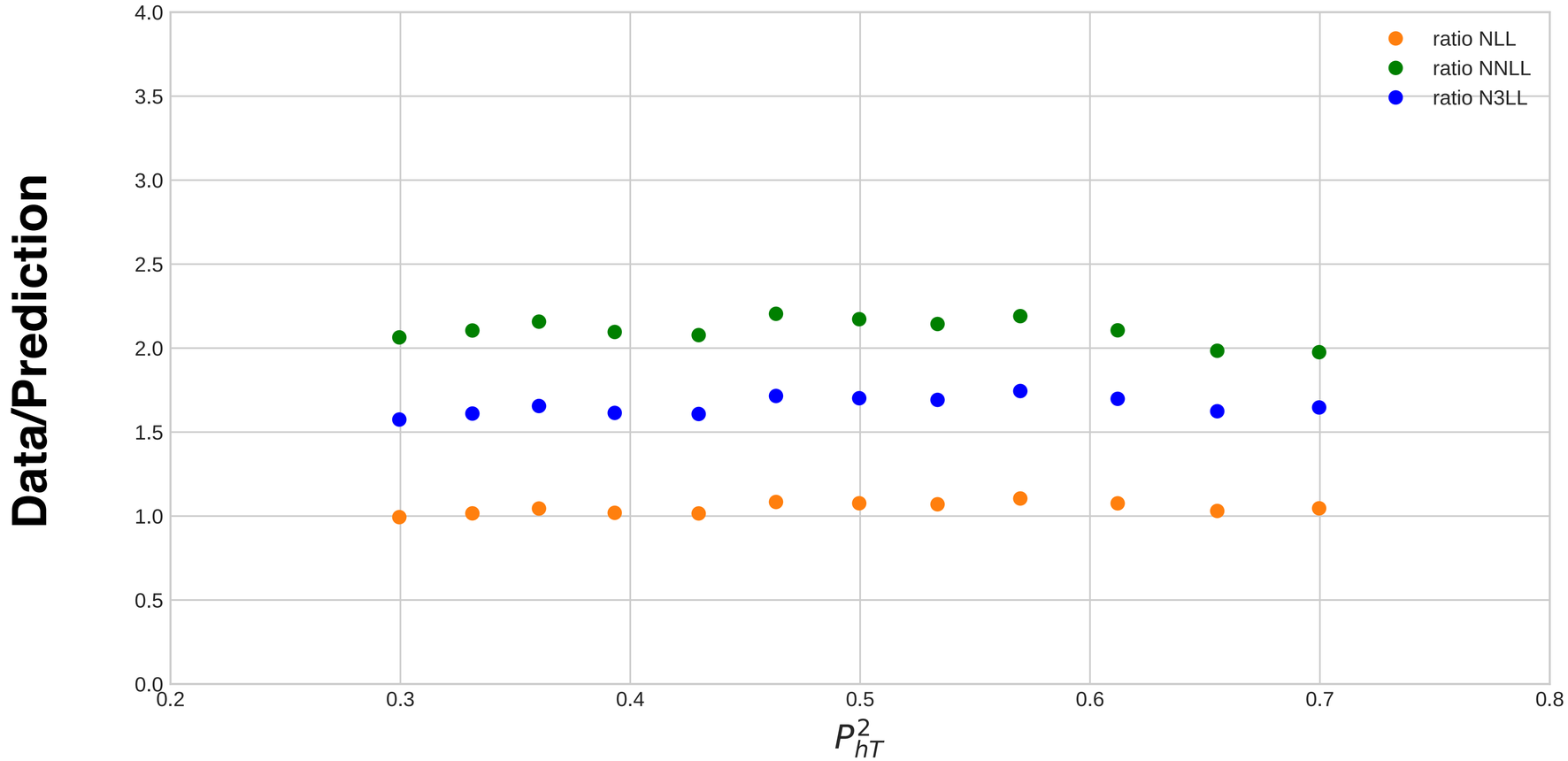


***For different orders the discrepancy amounts to a nearly constant factor***

*MAP Collaboration, JHEP 10 (2022)*

# MAPTMD22: Normalization of SIDIS

*MAP Collaboration, JHEP 10 (2022)*

# MAPTMD22: Normalization of SIDIS

SIDIS multiplicity

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

*MAP Collaboration, JHEP 10 (2022)*

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Collinear SIDIS cross section

$$\frac{d\sigma}{dxdQdz}$$

*MAP Collaboration, JHEP 10 (2022)*

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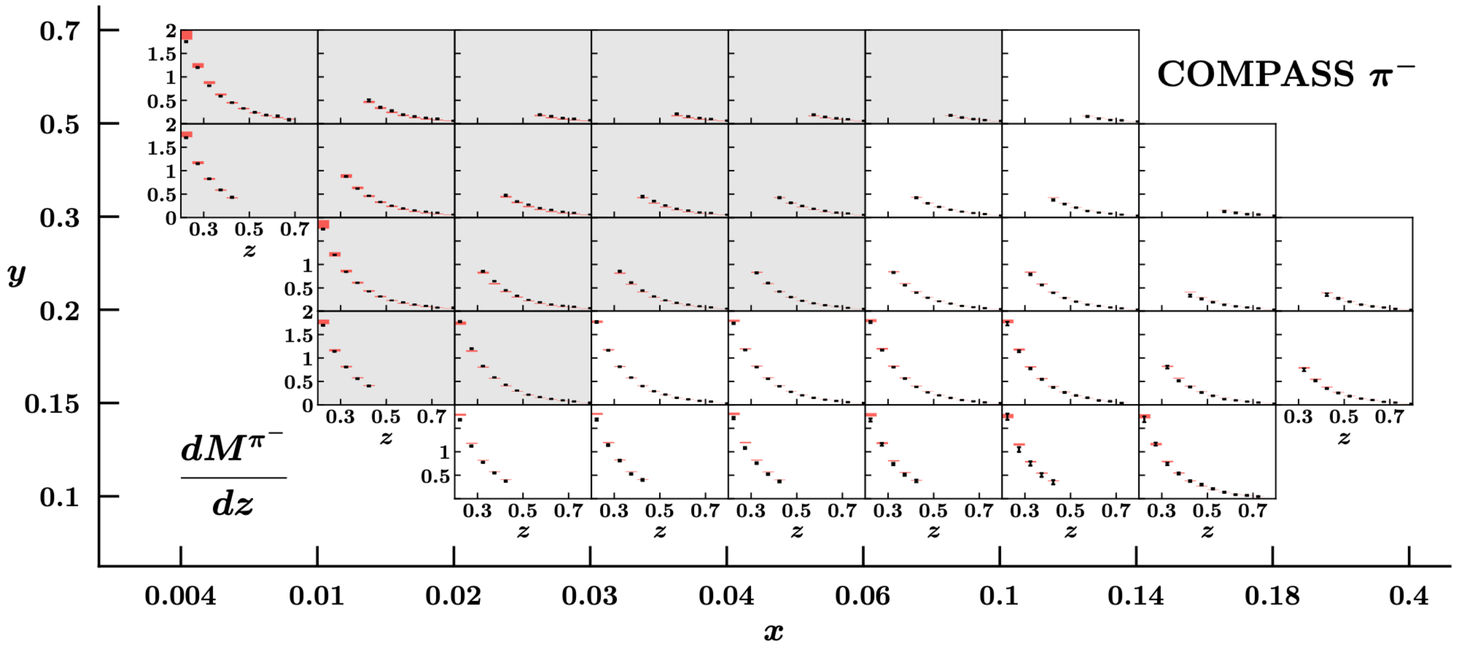


*MAP Collaboration, PRD 104 (2021) 3, 034007*

*MAP Collaboration, JHEP 10 (2022)*

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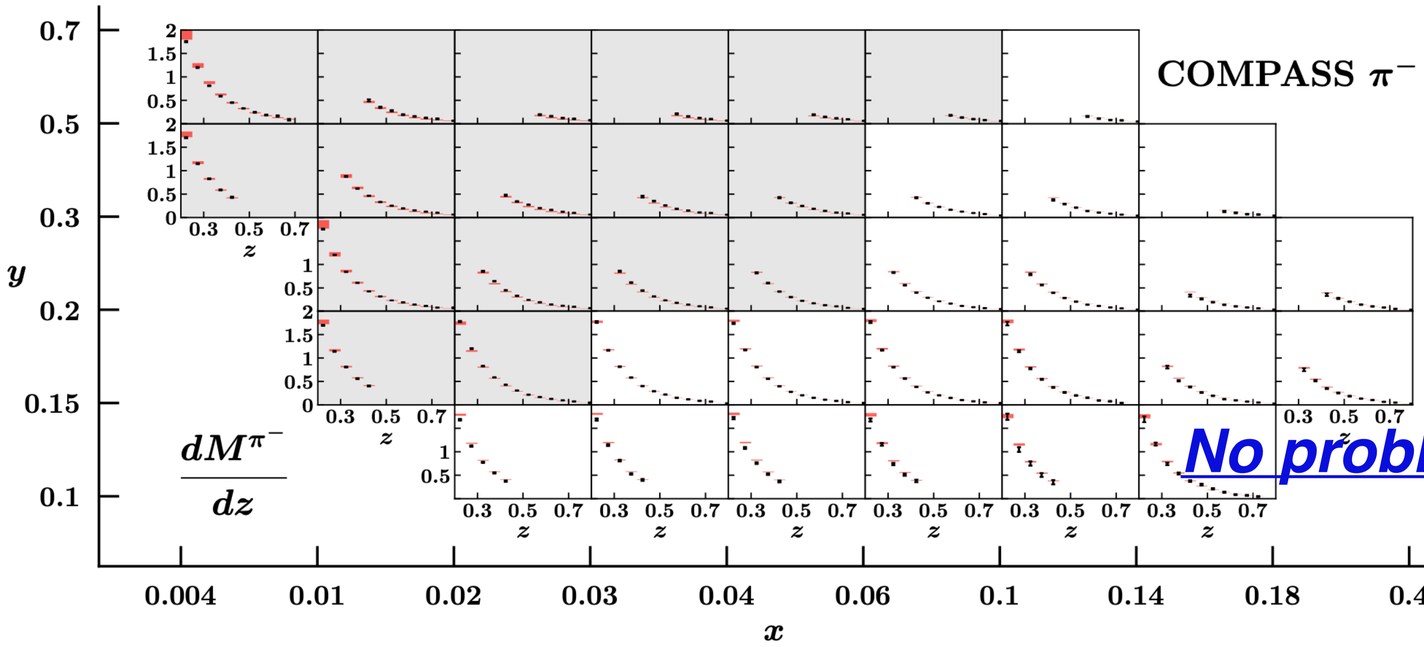


MAP Collaboration, PRD 104 (2021) 3, 034007

***No problems of normalization***

MAP Collaboration, JHEP 10 (2022)

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Collinear SIDIS cross section

$$\frac{d\sigma}{dxdQdz}$$

$$\frac{d\sigma}{dxdQdz} = \int dP_{hT} \frac{d\sigma}{dxdQdzdP_{hT}}$$

*MAP Collaboration, JHEP 10 (2022)*

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$$\frac{d\sigma}{dxdQdz}=\int dP_{hT}\frac{d\sigma}{dxdQdzdP_{hT}}\stackrel{?}{=}\int dP_{hT}\quad W\text{-term}$$

MAP Collaboration, JHEP 10 (2022)

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

Collinear SIDIS cross section

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$$\frac{d\sigma}{dxdQdz} = \int dP_{hT} \frac{d\sigma}{dxdQdzdP_{hT}} \stackrel{?}{=} \int dP_{hT} \quad \textit{W-term}$$

$$\frac{d\sigma}{dxdzdQ}\Big|_{\rm LO} = \simeq \int dq_T\, W\Big|_{\rm NLL} \propto f_1^q(x,Q)\, D_1^{q\to h}(z,Q)$$

*MAP Collaboration, JHEP 10 (2022)*

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$$\int dq_T\,W\Big|_{\rm NNLL}\neq\frac{d\sigma}{dxdzdQ}\Big|_{\rm NLO}$$

*MAP Collaboration, JHEP 10 (2022)*

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$$\frac{d\sigma}{dxdzdQ}\Big|_{\rm LO}=\ \simeq\int dq_T\,W\Big|_{\rm NLL}\propto f_1^q(x,Q)\,D_1^{q\to h}(z,Q)$$

At higher orders
something is missing
(Y-term? Power corrections?)

$$\int dq_T\,W\Big|_{\rm NNLL}\neq\frac{d\sigma}{dxdzdQ}\Big|_{\rm NLO}$$

*MAP Collaboration, JHEP 10 (2022)*

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*MAP Collaboration, JHEP 10 (2022)*

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Collinear SIDIS cross section

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$$\int dP_{hT}\frac{d\sigma}{dxdQdzdP_{hT}}=\frac{d\sigma}{dxdQdz}$$



MAP Collaboration, JHEP 10 (2022)

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Collinear SIDIS cross section

$$\frac{d\sigma}{dxdQdz}$$

$$\int dP_{hT}\frac{d\sigma}{dxdQdzdP_{hT}}=\frac{d\sigma}{dxdQdz}$$

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



*MAP Collaboration, JHEP 10 (2022)*

# MAPTMD22: Normalization of SIDIS

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



MAP Collaboration, JHEP 10 (2022)

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$$\int dP_{hT}\frac{d\sigma}{dxdQdzdP_{hT}}=\frac{d\sigma}{dxdQdz}$$

***Fitting parameters independent***

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

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



*MAP Collaboration, JHEP 10 (2022)*

# BACKUP

| | N$^3$LL | | | |
|---|---|---|---|---|
| Data set | $N_{\rm dat}$ | $\chi^2_D$ | $\chi^2_\lambda$ | $\chi^2_0$ |
| *Tevatron total* | 71 | 1.10 | 0.07 | 1.17 |
| *LHCb total* | 21 | 3.56 | 0.96 | 4.52 |
| *ATLAS total* | 72 | 3.54 | 0.82 | 4.36 |
| *CMS total* | 78 | 0.38 | 0.05 | 0.43 |
| PHENIX 200 | 2 | 2.76 | 1.04 | 3.80 |
| STAR 510 | 7 | 1.12 | 0.26 | 1.38 |
| DY collider total | 251 | 1.37 | 0.28 | 1.65 |
| E288 200 GeV | 30 | 0.13 | 0.40 | 0.53 |
| E288 300 GeV | 39 | 0.16 | 0.26 | 0.42 |
| E288 400 GeV | 61 | 0.11 | 0.08 | 0.19 |
| E772 | 53 | 0.88 | 0.20 | 1.08 |
| E605 | 50 | 0.70 | 0.22 | 0.92 |
| DY fixed-target total | 233 | 0.63 | 0.31 | 0.94 |
| *HERMES total* | 344 | 0.81 | 0.24 | 1.05 |
| *COMPASS total* | 1203 | 0.67 | 0.27 | 0.94 |
| SIDIS total | 1547 | 0.70 | 0.26 | 0.96 |
| **Total** | **2031** | **0.81** | **0.27** | **1.08** |

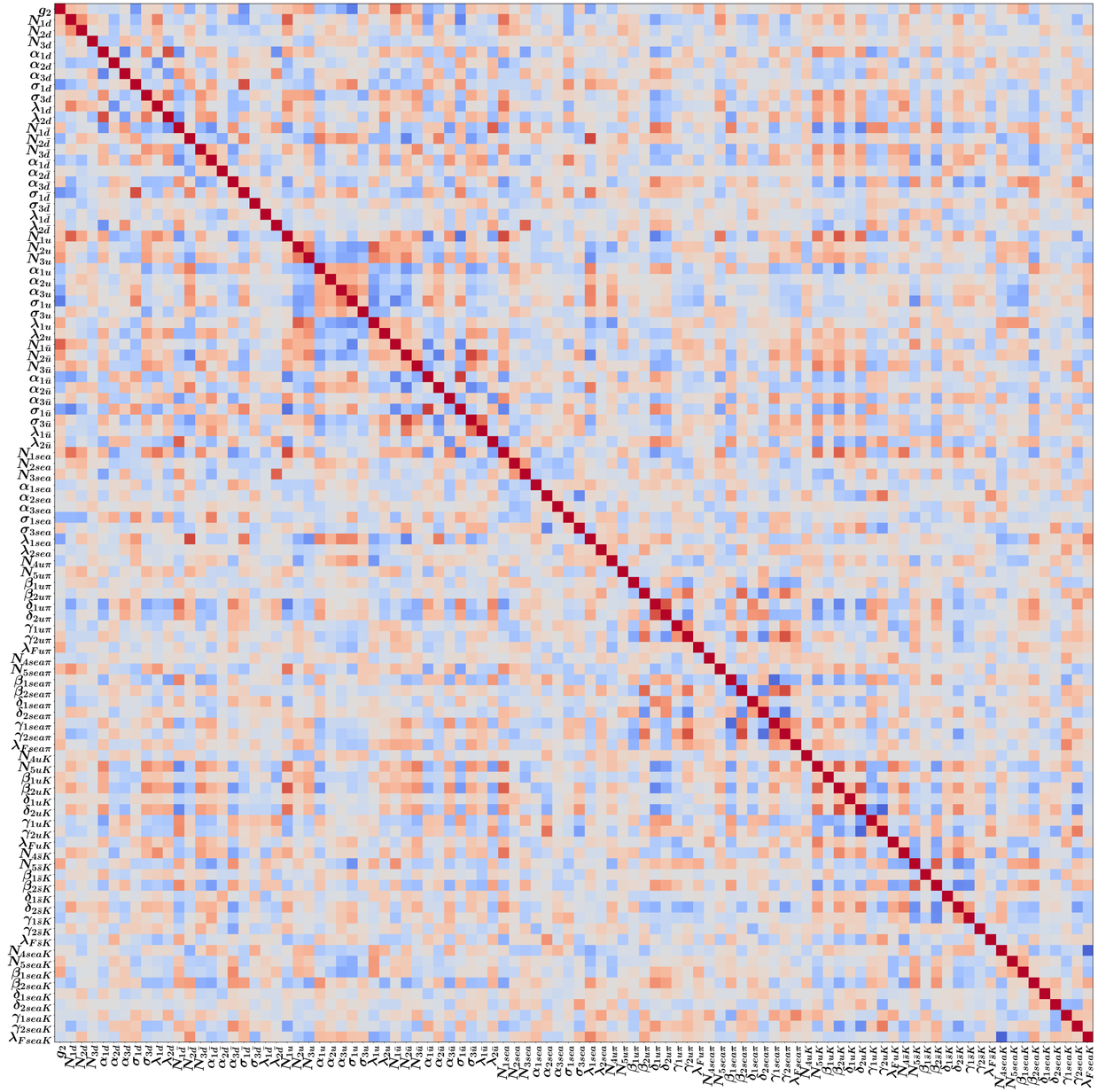
# BACKUP

Error propagation

**100 Monte Carlo replicas of data**

100 Monte Carlo replicas of PDFs

100 Monte Carlo replicas of FFs



# BACKUP

## Kinematic power corrections in TMD factorization theorem

#3

Alexey Vladimirov (Madrid U.) (Jul 24, 2023)

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Estimations made in sec. 5.3 demonstrate that including KPCs results in an almost constant increment of the cross-section. The magnitude of this correction depends on $Q$ and $x$. For typical LHC kinematics, the correction is around 1%, while at $Q \sim 4 - 5$ GeV, the correction can reach 100%. Interestingly, the deficiency in normalization for the TMD factorization at low energies has been reported by multiple groups. One could expect that these problems will be resolved with the inclusion of KPCs.