Opportunities for unpolarized TMDs in EIC early science conditions

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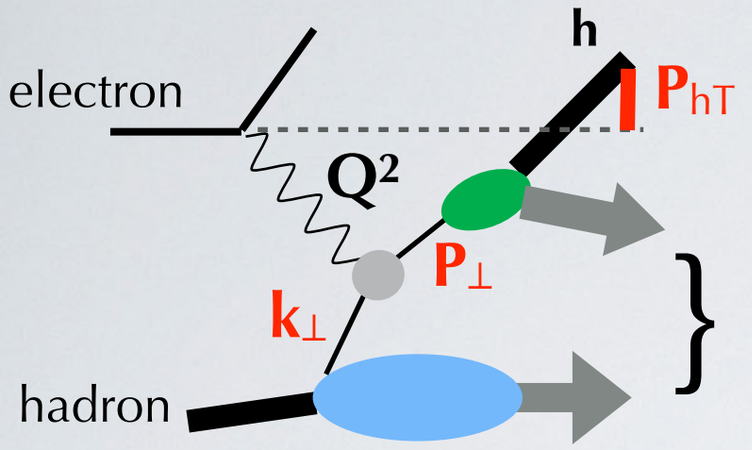
for the MAP Collaboration

SIDIS with unpolarized electron and proton



- TMD factorization $M^2 \ll Q^2 \quad q_T^2 = \dfrac{P_{hT}^2}{z^2} \ll Q^2$

- Neglect higher twists, mass corrections; Integrate $\int d\phi_h$

$$\frac{d\sigma}{dx dz dq_T dQ} = \frac{8\pi^2\alpha^2 z^2}{2xQ^3} Y_+ \left[F_{UU,T}(x,z,q_T^2,Q^2) + \ldots\right] \qquad Y_+ = \left[1 + (1 - Q^2/xs)^2\right]$$

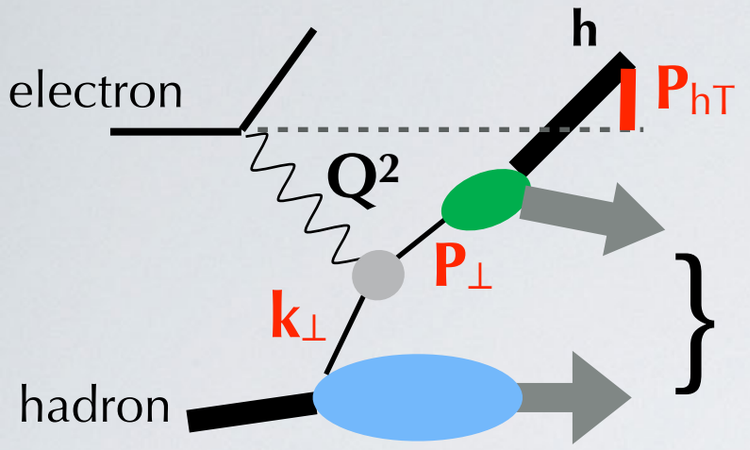
$$F_{UU,T} = x\,\mathscr{H}(Q^2) \sum_q e_q^2 \left[f_1^q \otimes_{\mathbf{k}_\perp,\mathbf{P}_\perp} D_1^{q\to h}\right] = \frac{x}{2\pi}\,\mathscr{H}(Q^2) \sum_q e_q^2 \int_0^\infty db_T\, b_T\, J_0(b_T, q_T)\, \tilde{f}_1^q(x, b_T^2; Q^2)\, \tilde{D}_1^{q\to h}(z, b_T^2; Q^2)$$

hard part

TMDPDF

TMDFF

SIDIS with unpolarized electron and proton



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hard part — TMDPDF — TMDFF

MAPTMD24 extraction

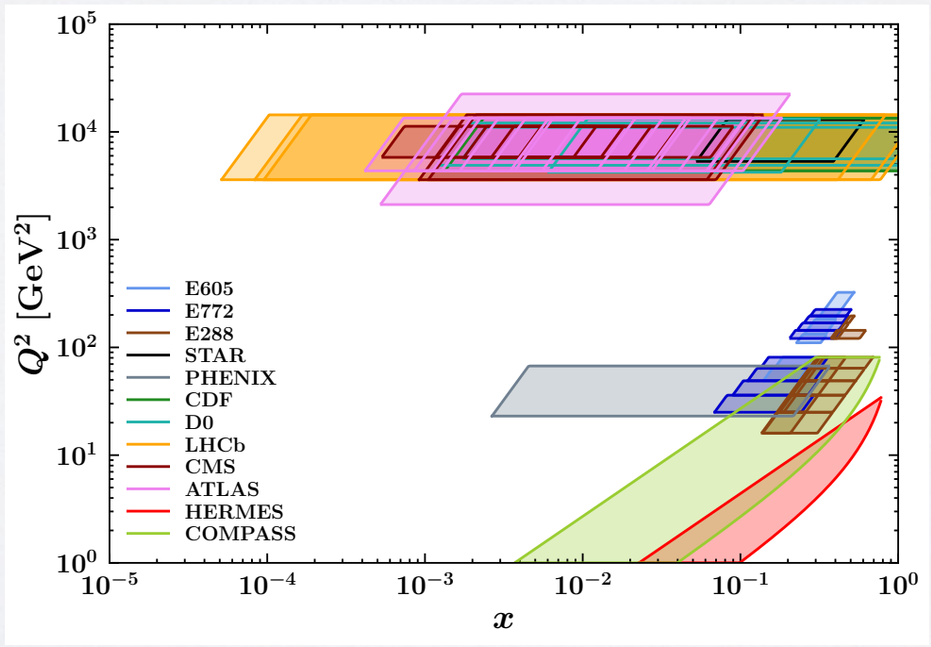
*Bacchetta et al. (MAP Coll.), JHEP **08** (24) 232, arXiv:2405.13833*

χ^2/N_{dat} =1.08, N^{3}LL accuracy

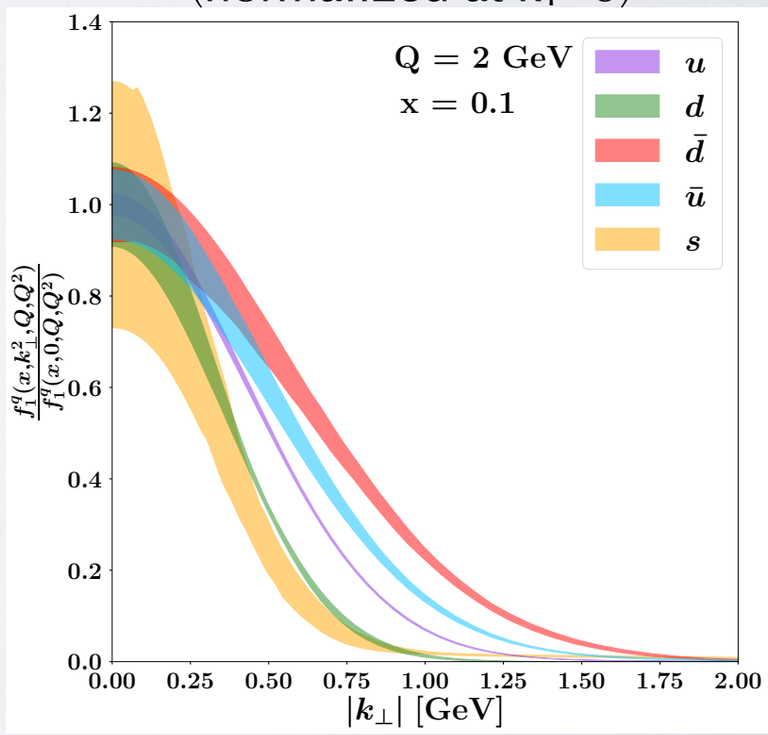
N_{dat} = 2031

484 DY

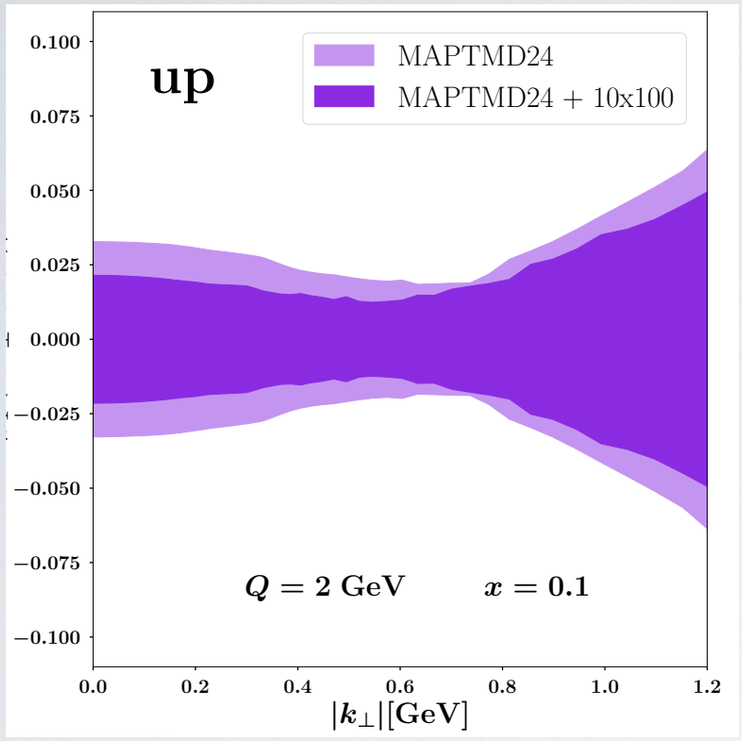
344 / 1203 — 1547 SIDIS

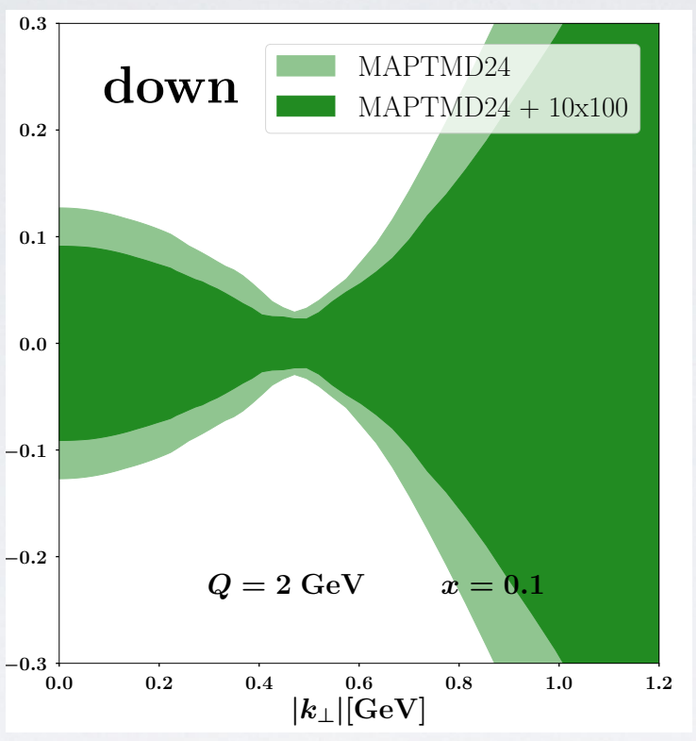


TMDPDF
(normalized at k_T=0)



The EIC impact with 10x100 at x=0.1



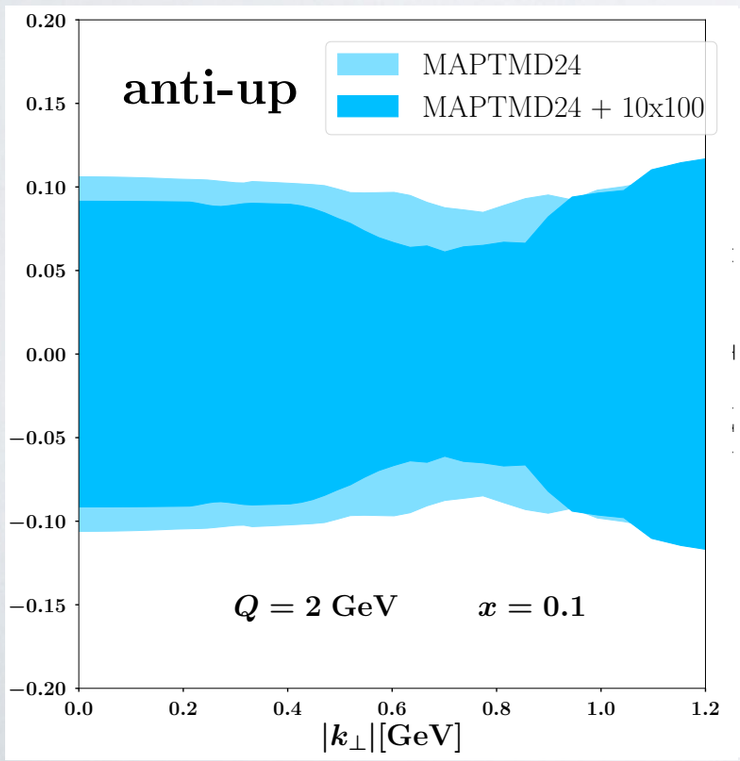


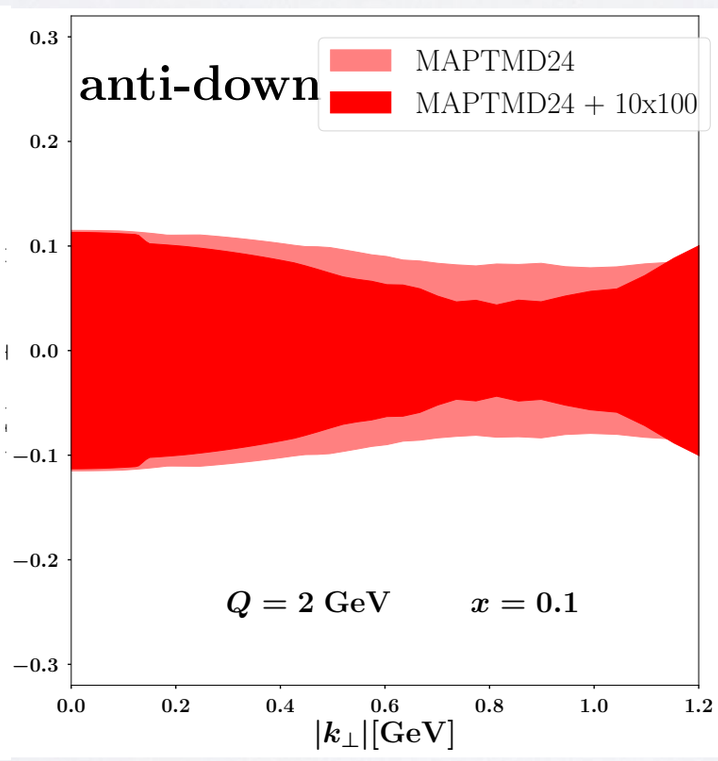
$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle} \qquad \textbf{x=0.1}$$

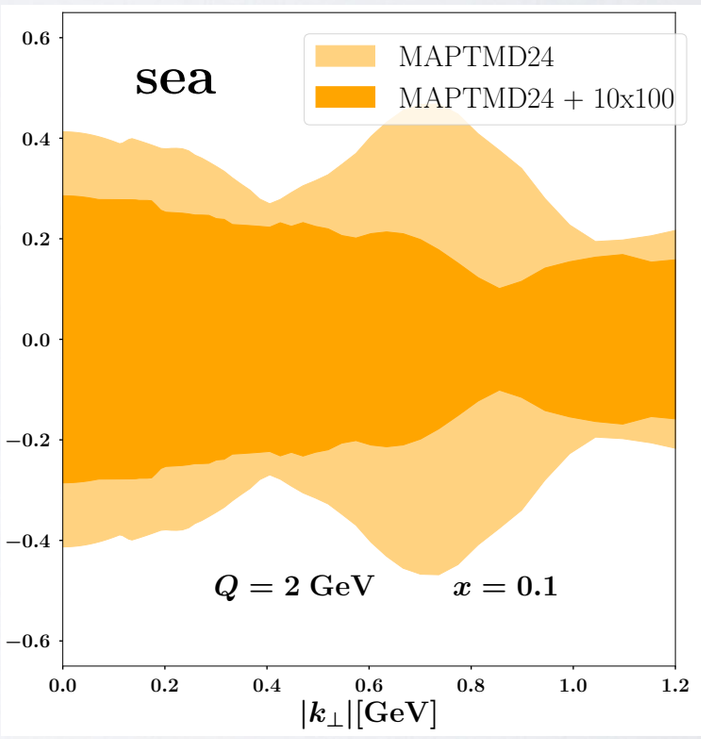
MAPTMD24 2031

EIC	# pts.	lumi [fb^{-1}]
10x100	1611	51.3

(simulation campaign of May 2024)

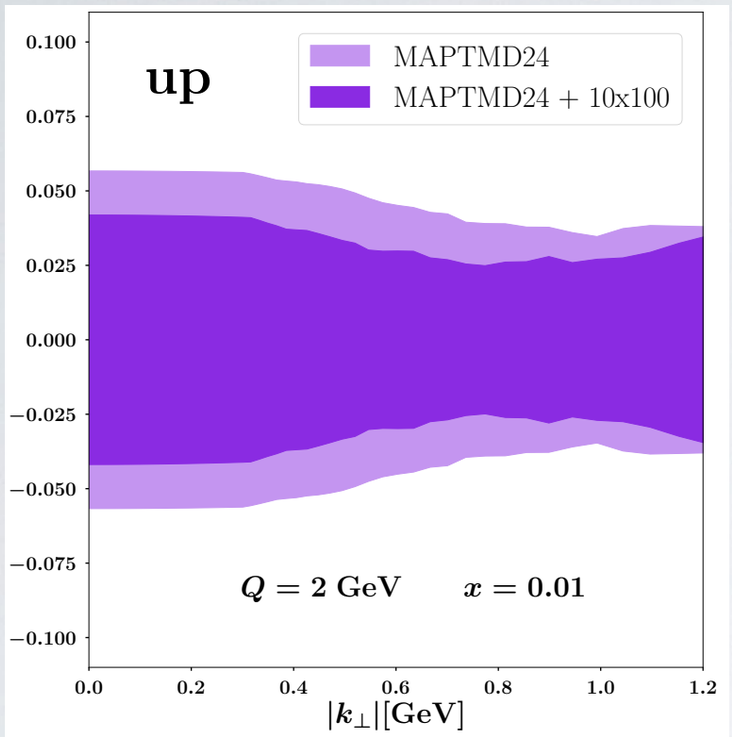


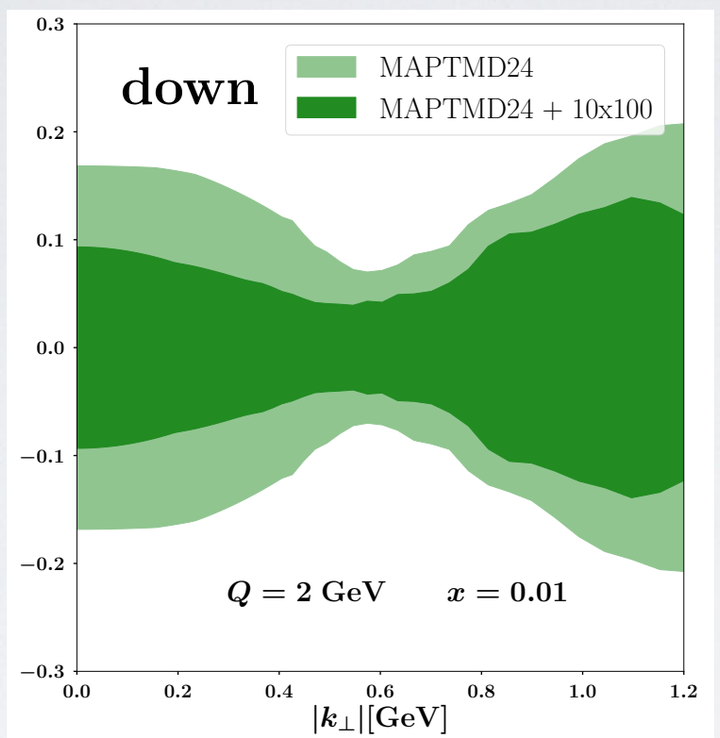




L. Rossi, Ph.D. Thesis, in preparation

The EIC impact with 10x100 at x=0.01





$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$ **x=0.01**

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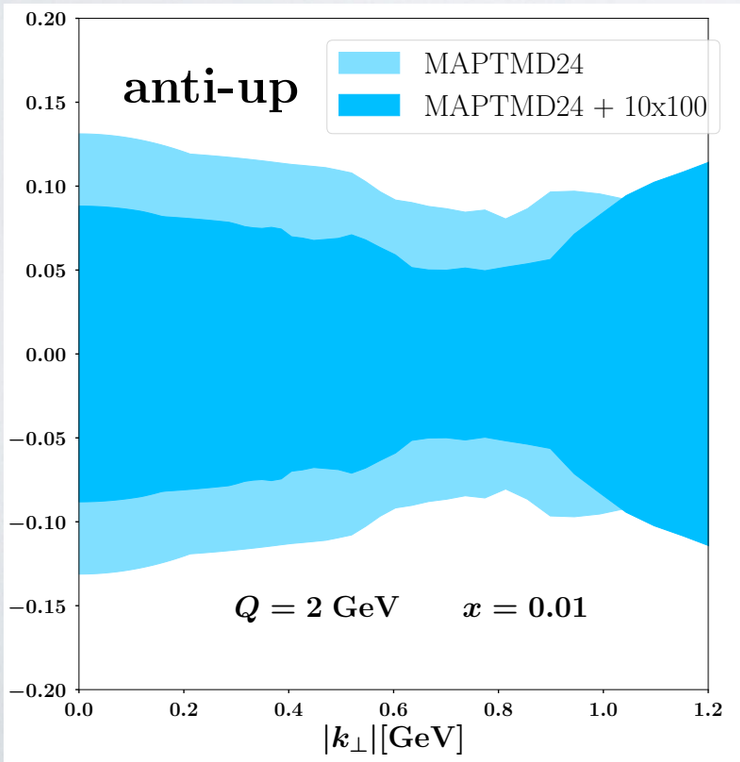

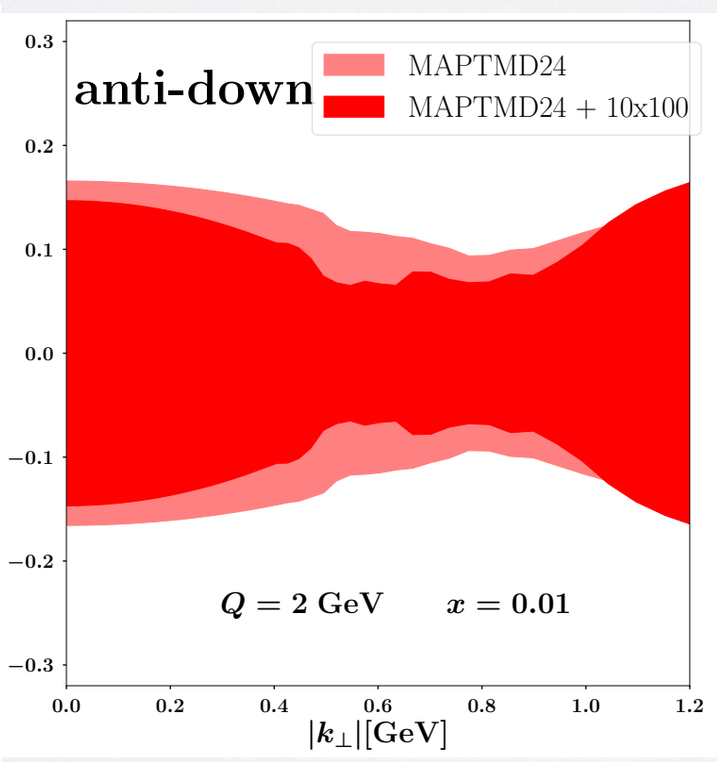

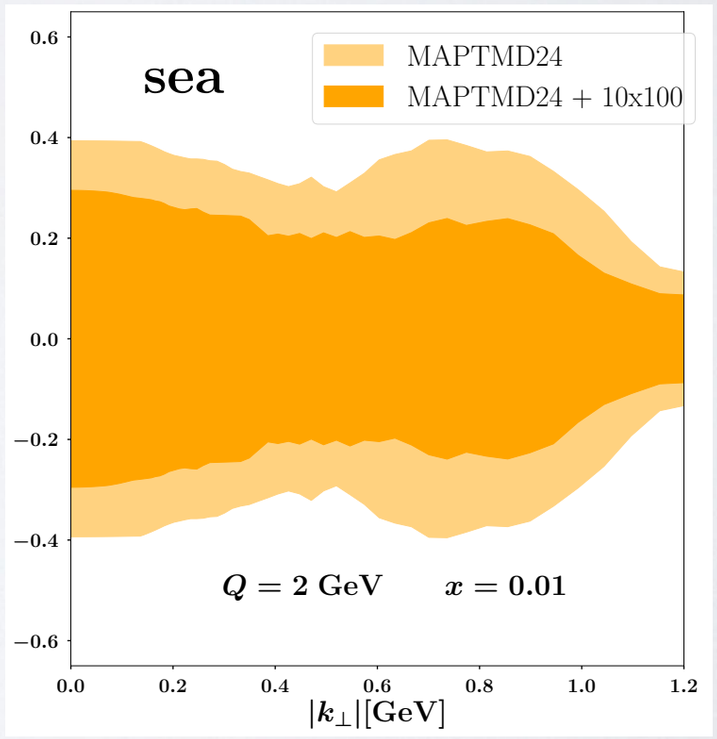

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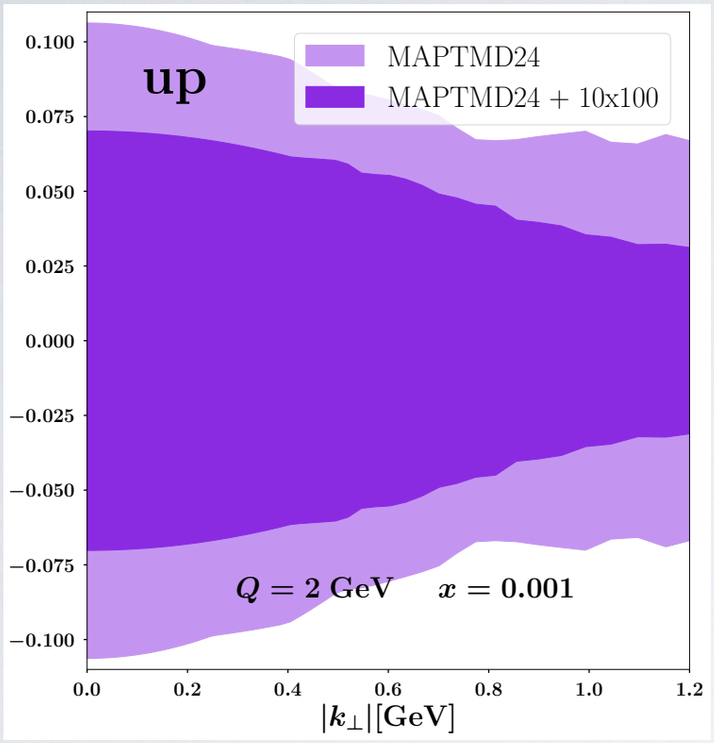
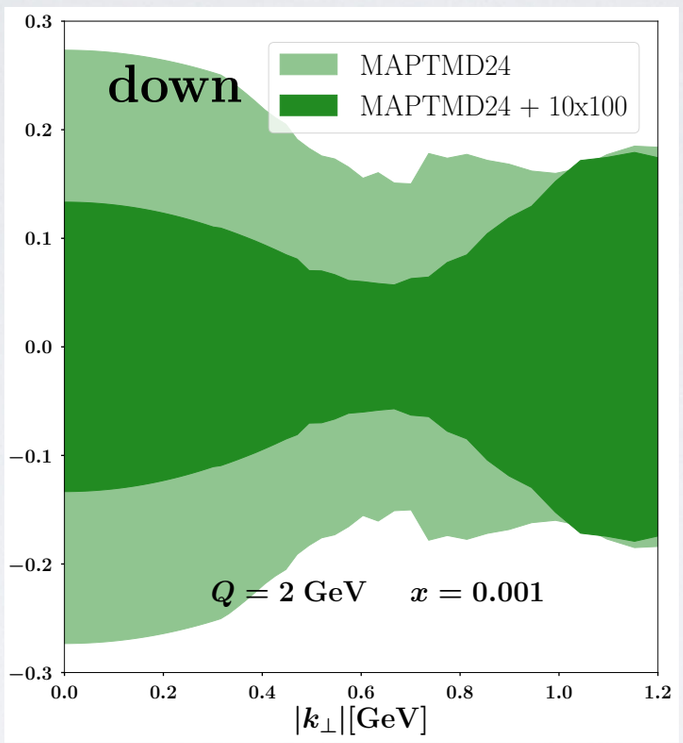
The EIC impact with 10x100 at x=0.001





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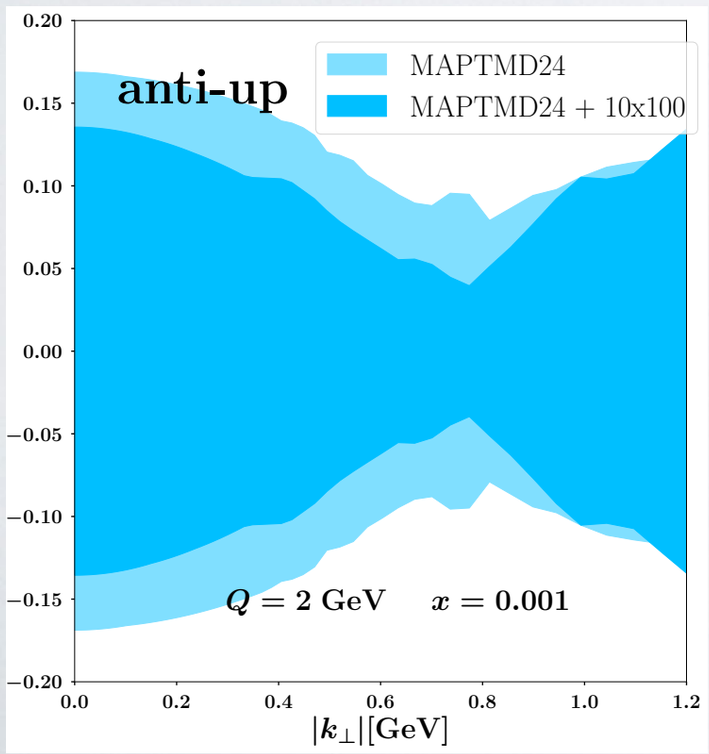

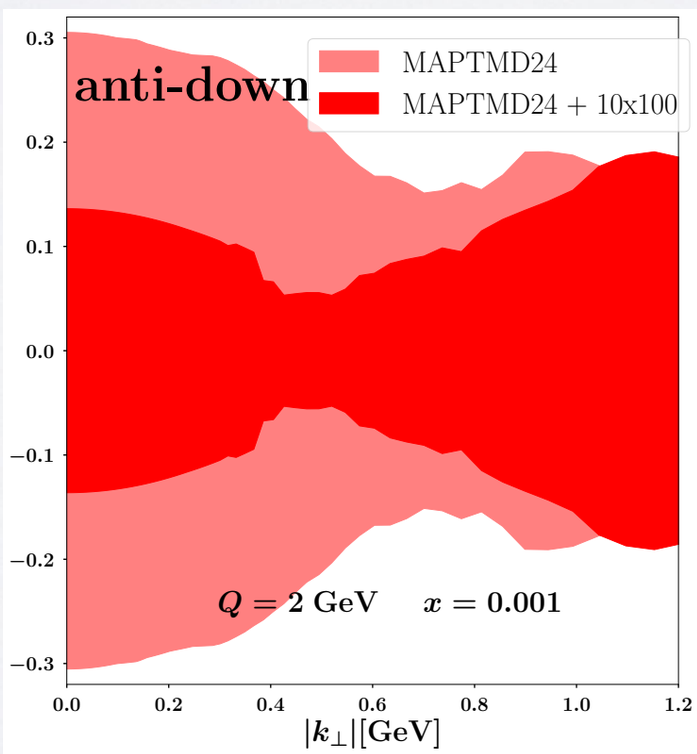

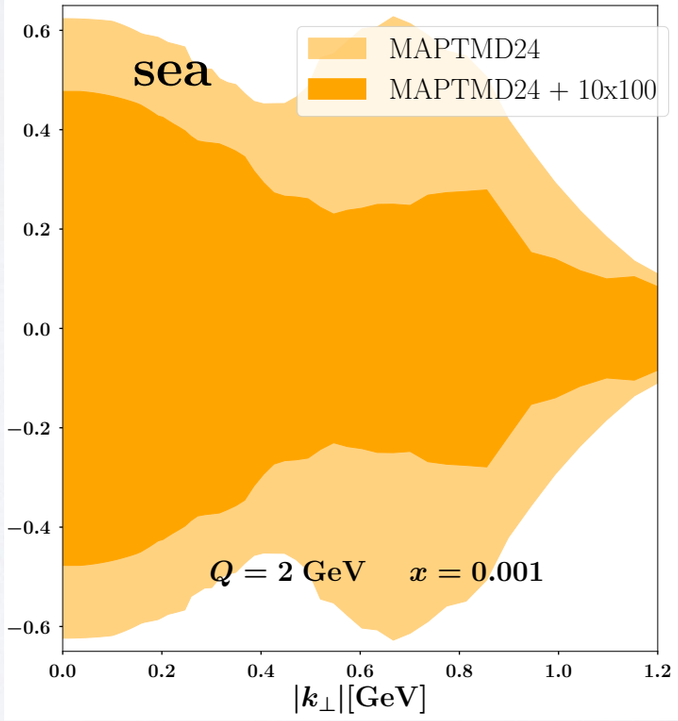

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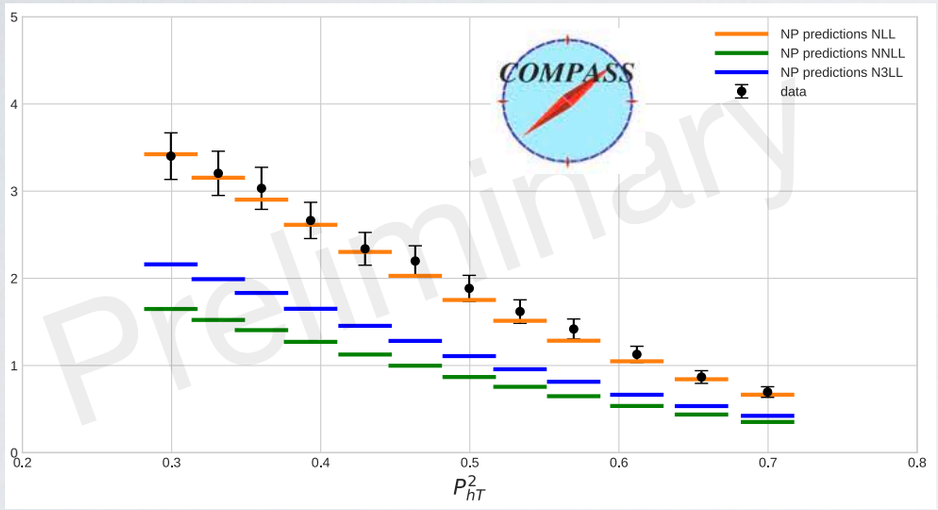
Normalization issue in SIDIS

increasing perturbative accuracy

$M^h(\bar{x}, \bar{z}, \bar{Q}, q_T)$ NLL NNLL N³LL



worsens agreement with SIDIS !

(but not in Drell-Yan!)

multiplicities $M(x, z, q_T, Q) = \dfrac{d\sigma^{\text{SIDIS}}}{dx dz dq_T dQ} \Big/ \dfrac{d\sigma^{\text{DIS}}}{dx dQ}$

discrepancy is P_{hT}-independent: $M_{\text{NLL}}/M_{\text{NNLL}} \sim 2$

$M_{\text{NLL}}/M_{\text{N}^3\text{LL}} \sim 1.5$

Bacchetta et al., JHEP **10** (22) 127, arXiv:2206.07598

$$\int dq_T \left[\frac{d\sigma}{dx dz dq_T dQ} \sim \mathscr{H} \left[\text{TMDPDF} \otimes \text{TMDFF}\right] \right] \overset{?}{=} \frac{d\sigma}{dx dz dQ}\Big|_X$$

NLL $\mathscr{H}^{\text{SIDIS}} \approx 1$ YES X = LO ~ PDF x FF

reasonably describes data

De Florian et al., P.R. D**75** (07) 114010

NNLL $\mathscr{H}^{\text{SIDIS}} < 1$ **NO** X = NLO

N³LL .....

Better use cross sections, not multiplicities !

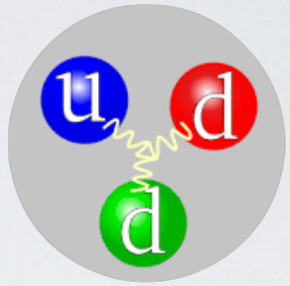
Backup

MAPTMD24 flavor channels

TMD PDF

$f^q_{\rm NP}(x, b_T; Q_0)$ = F.T.(combination of Gaussians)

5 channels: $q = u\,,\ \bar{u}\,,\ d\,,\ \bar{d}\,,\ sea\ (\text{“}s\text{”})$



sensitivity

TMD FF

$D^q_{\rm NP}(z, b_T; Q_0)$ = F.T.(combination of Gaussians)

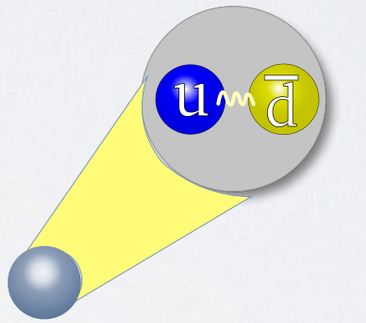
5 channels: favored pion $u \to \pi^+, \ldots$

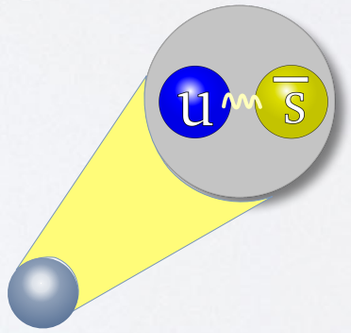
unfavored pion $d \to \pi^+, \ldots$

favored Kaon $u \to K^+, \ldots$

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

unfavored Kaon $d, s \to K^+, \ldots$





hermes Hermes

target: p, D

final: $\pi^\pm$, $K^\pm$

COMPASS Compass

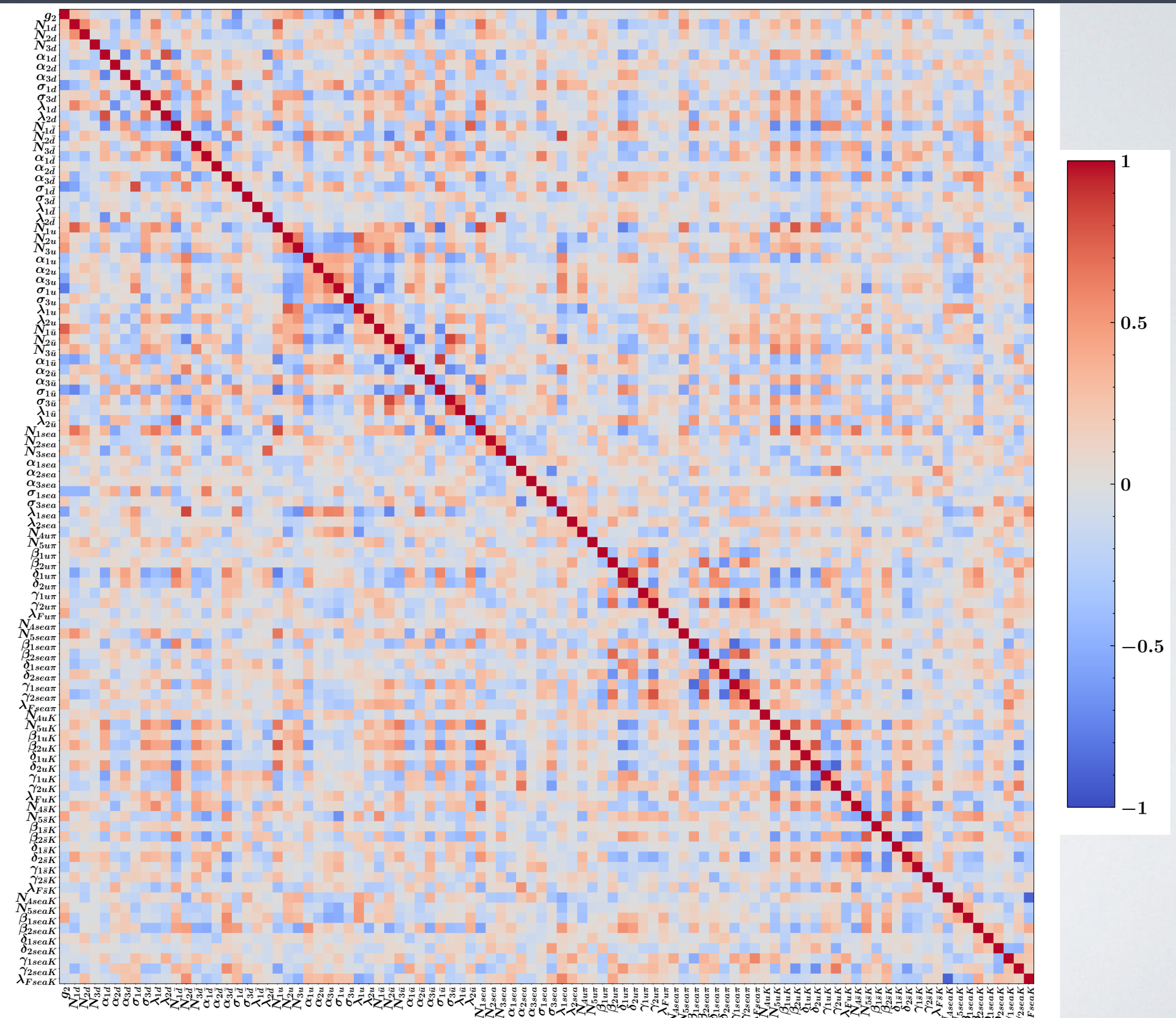
target: D

final: $h^\pm$

Drell-Yan

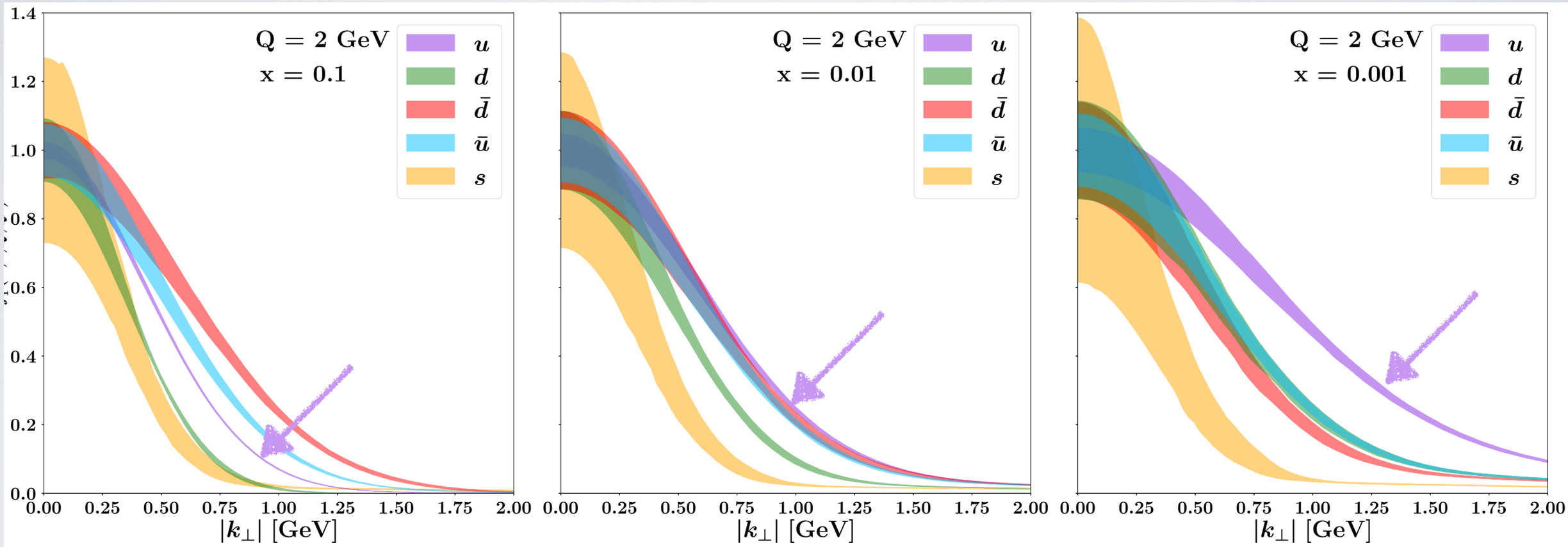
total of 96 parameters but with ~diagonal correlation matrix

Correlation matrix



"Normalized" MAPTMD24 TMD PDF

$$\frac{f_1(x,k_T;Q)}{f_1(x,0;Q)}$$

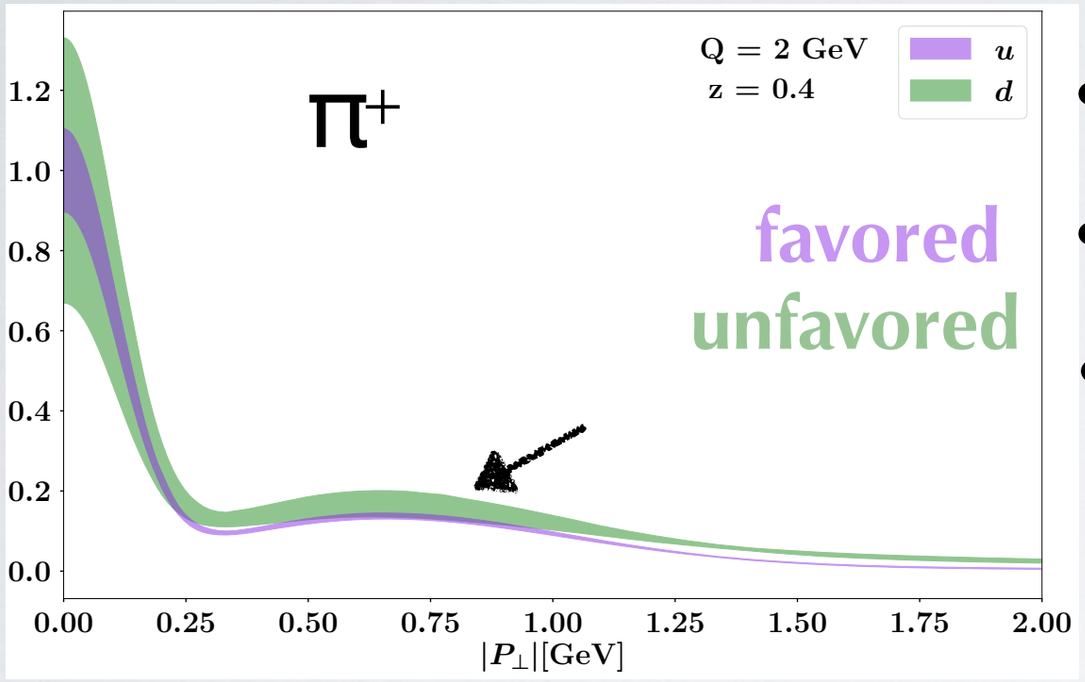


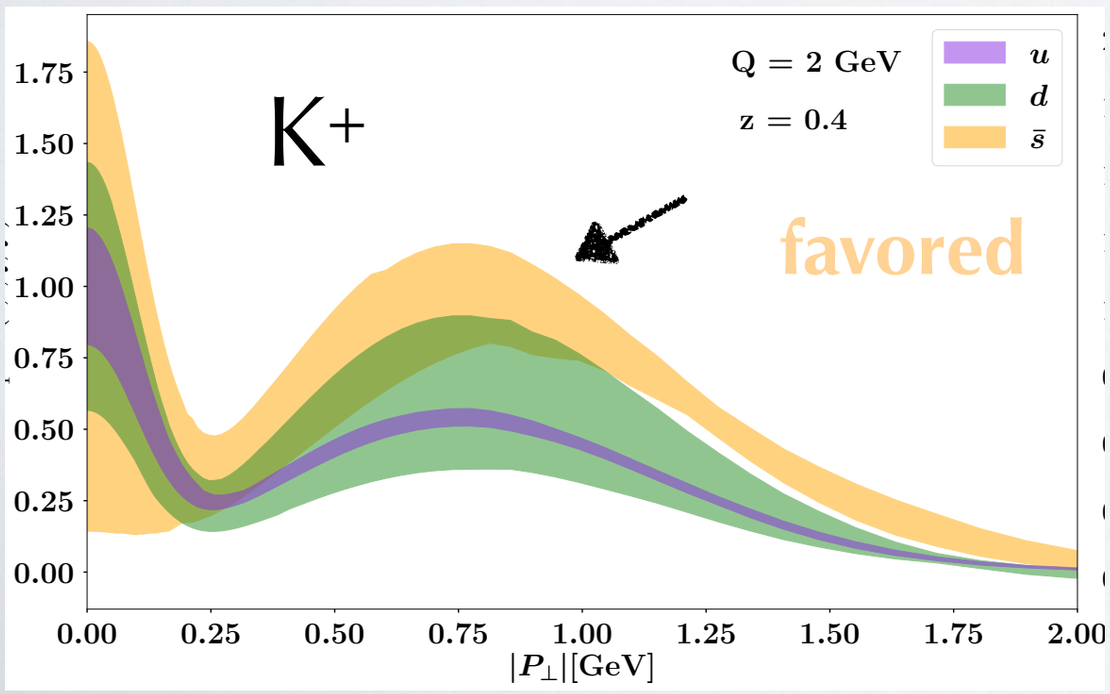
th. error band =
68% of all replicas

- very different k_T behavior
- it changes with x

“Normalized” MAPTMD24 TMD FF

$$\frac{D_1(z,P_T;Q)}{D_1(z,0;Q)}$$





- favored better constrained than unfavored
- signs of favored ≠ unfavored
- structure from nonperturbative parametrization
- evidence of final-hadron dependence

“Normalized” MAPTMD24 TMD FF

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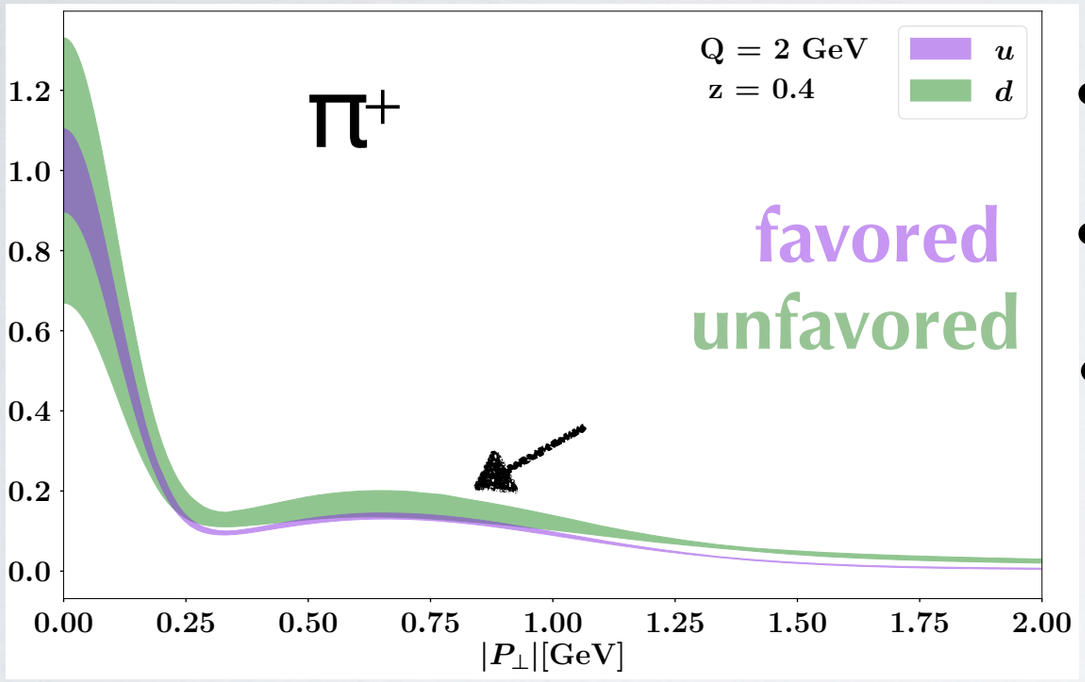

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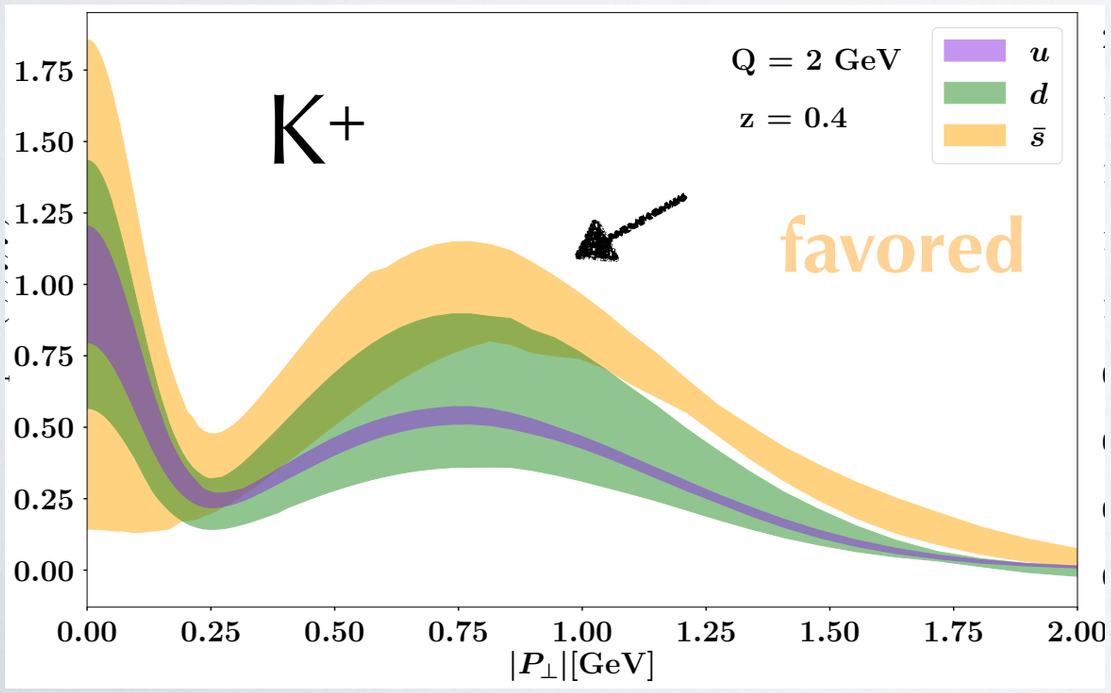
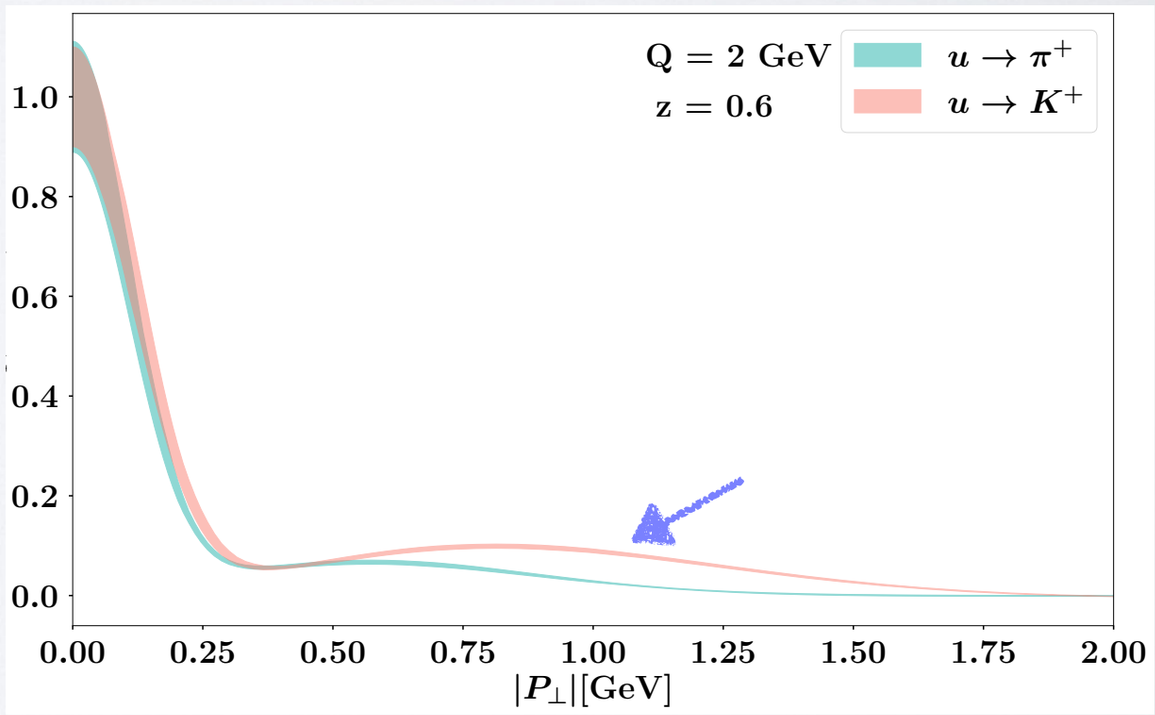
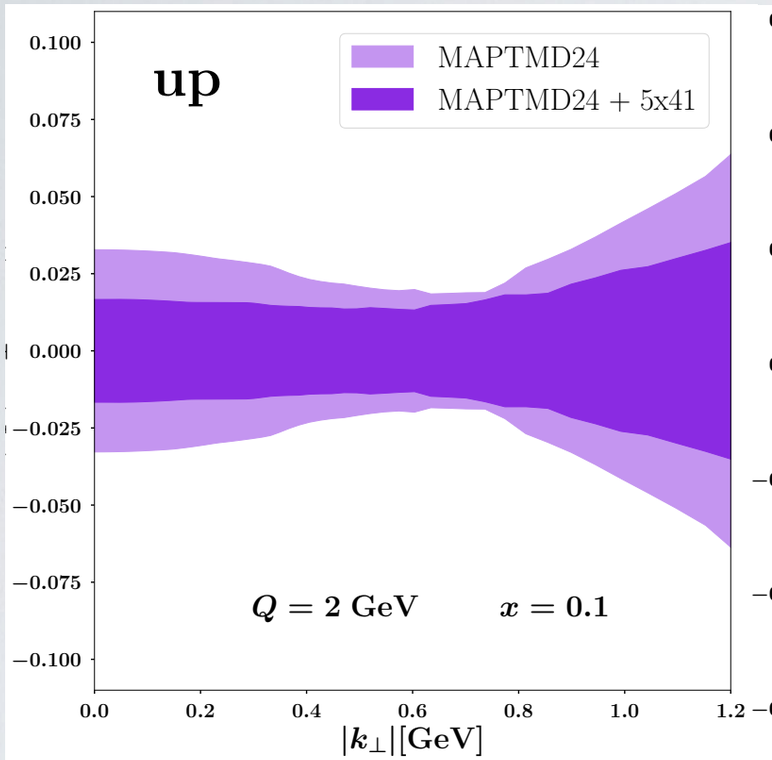
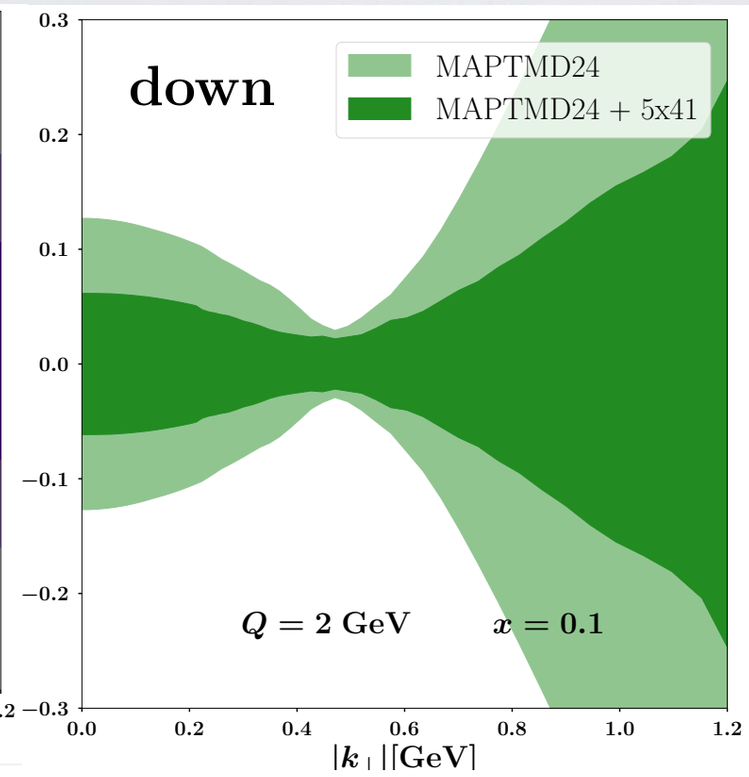
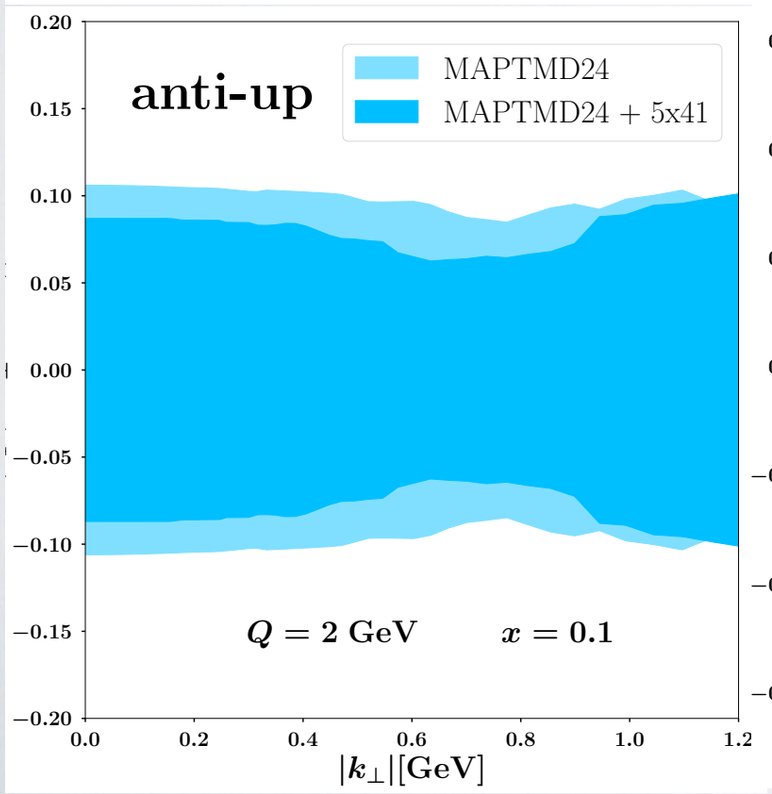


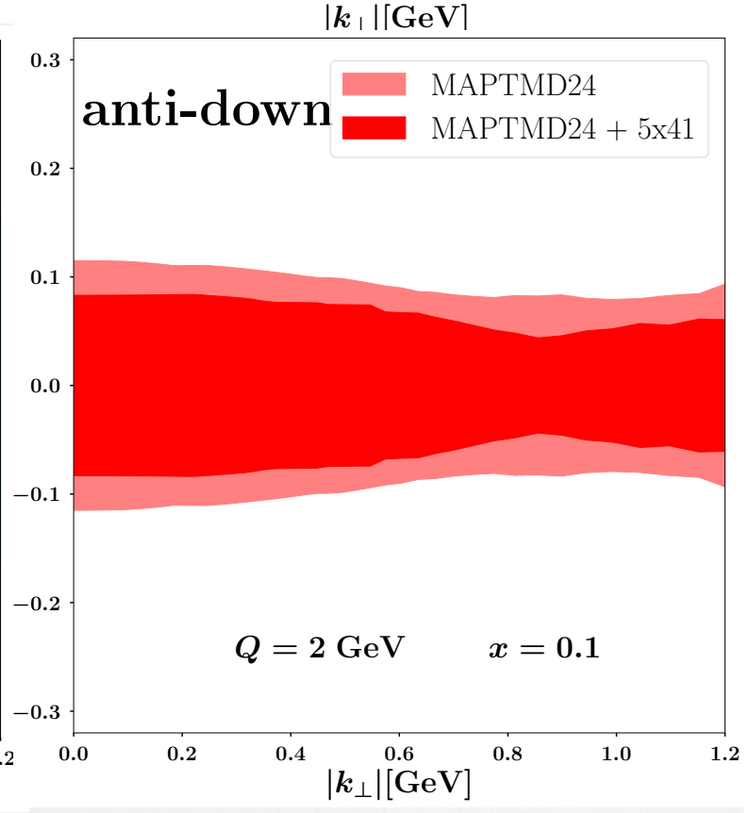


The EIC impact with MAPTMD24









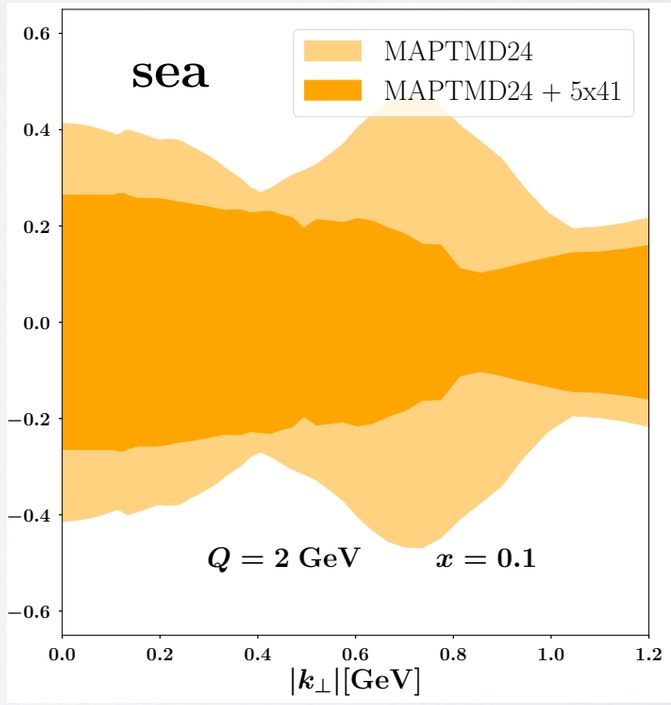
$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$

x=0.1

MAPTMD24 2031

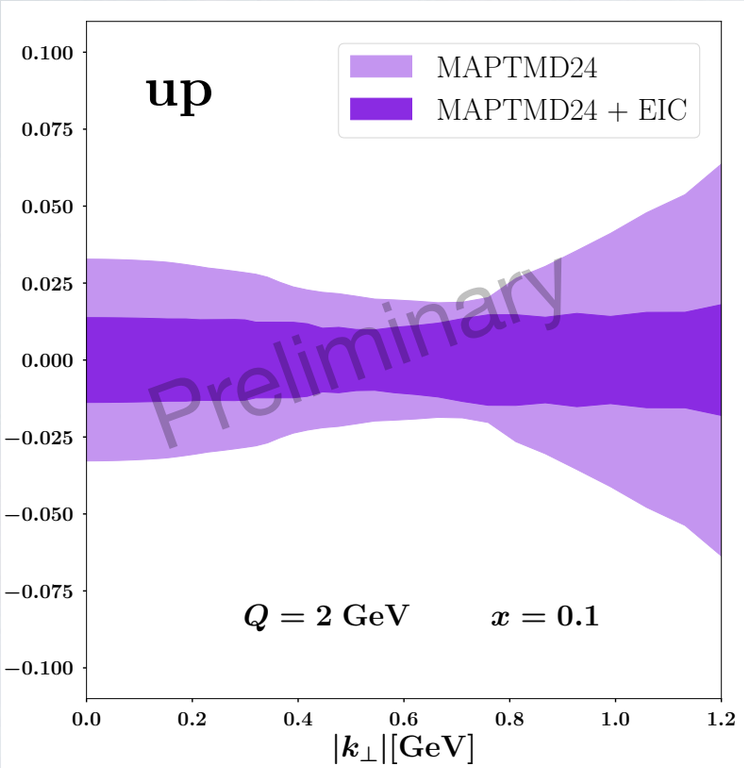
EIC	**# pts.**	**lumi [fb^{-1}]**
5x41	1273	2.85

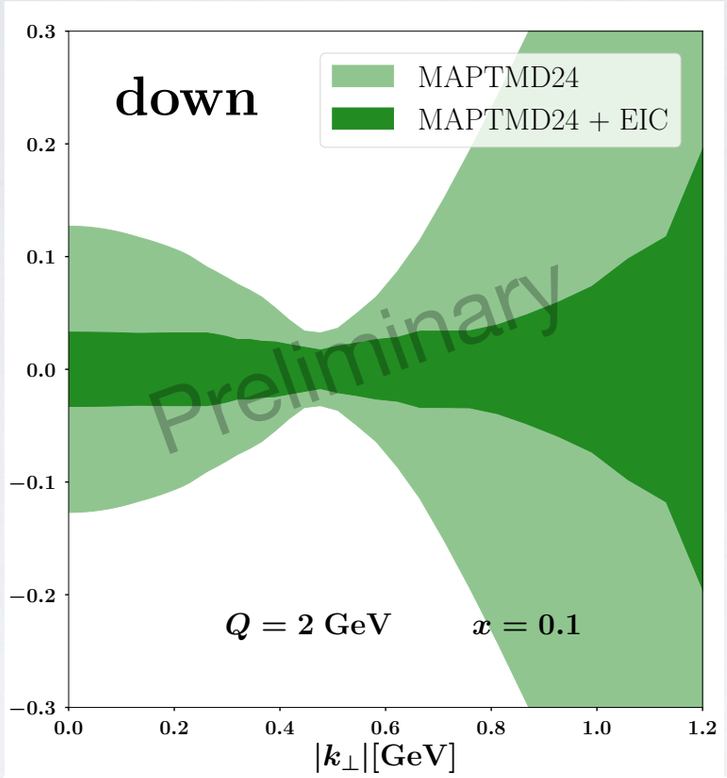
(conditions as May simulation campaign)

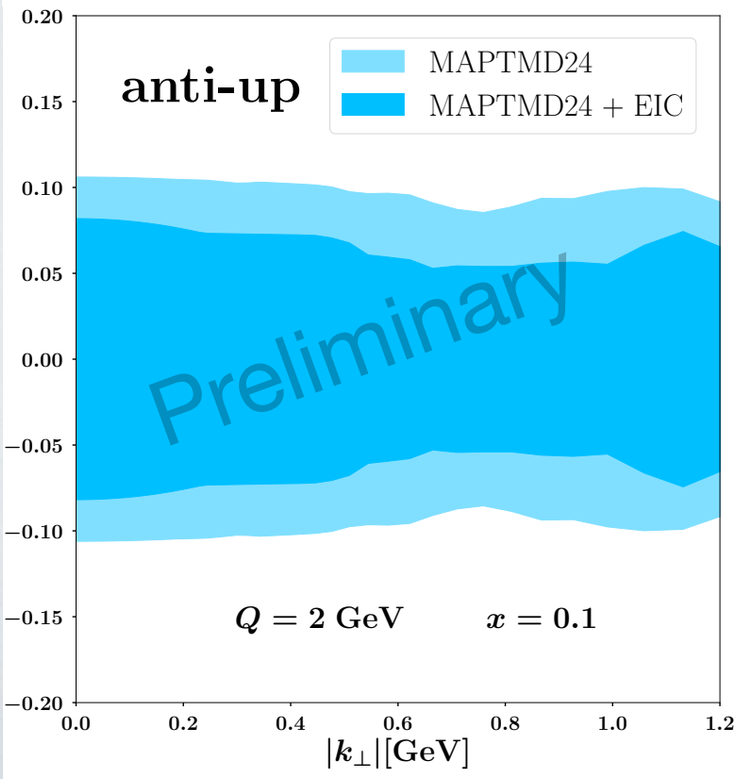


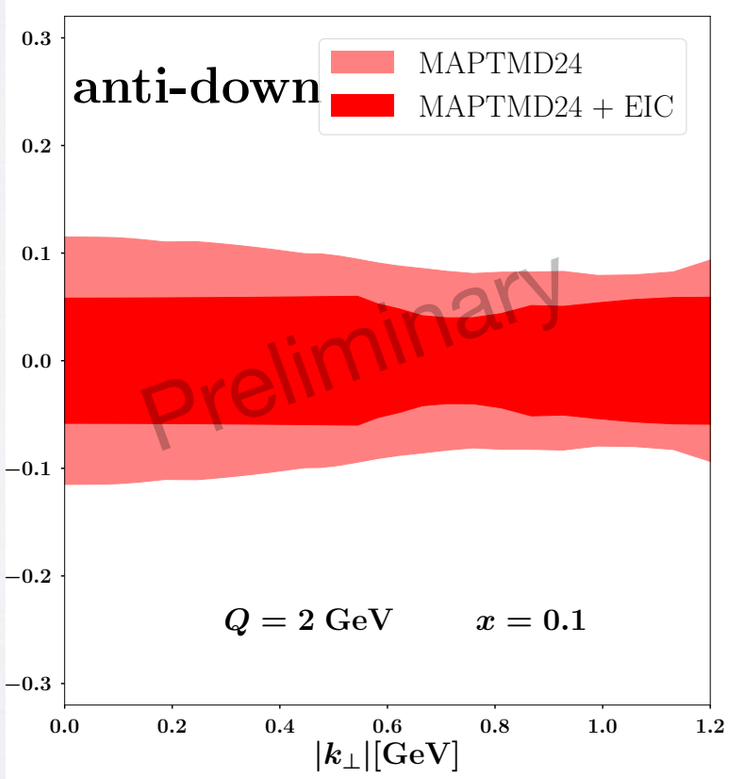
L. Rossi, Ph.D. Thesis, in preparation

The EIC impact with MAPTMD24









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x=0.1

MAPTMD24 2031

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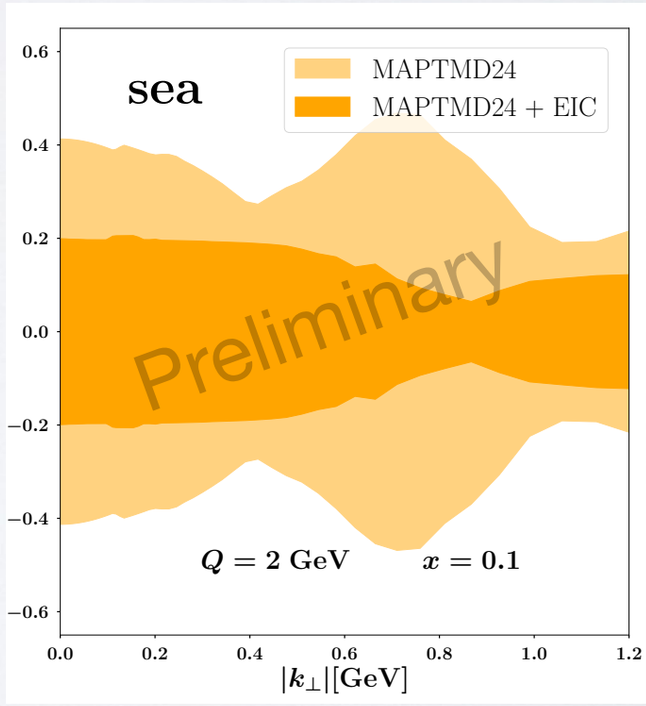
10x100	1611	51.3
18x275	1648	10

(conditions as May simulation campaign)



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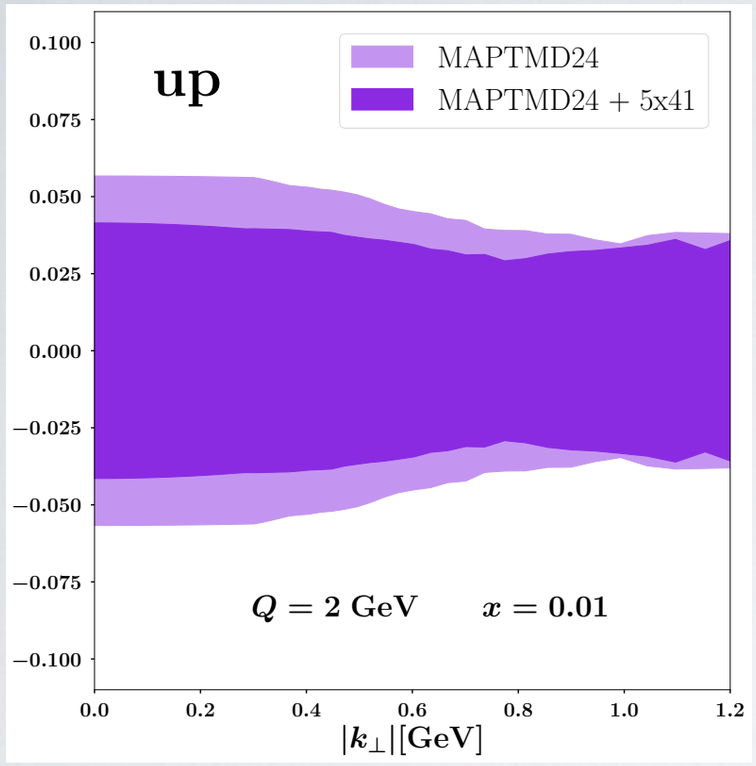
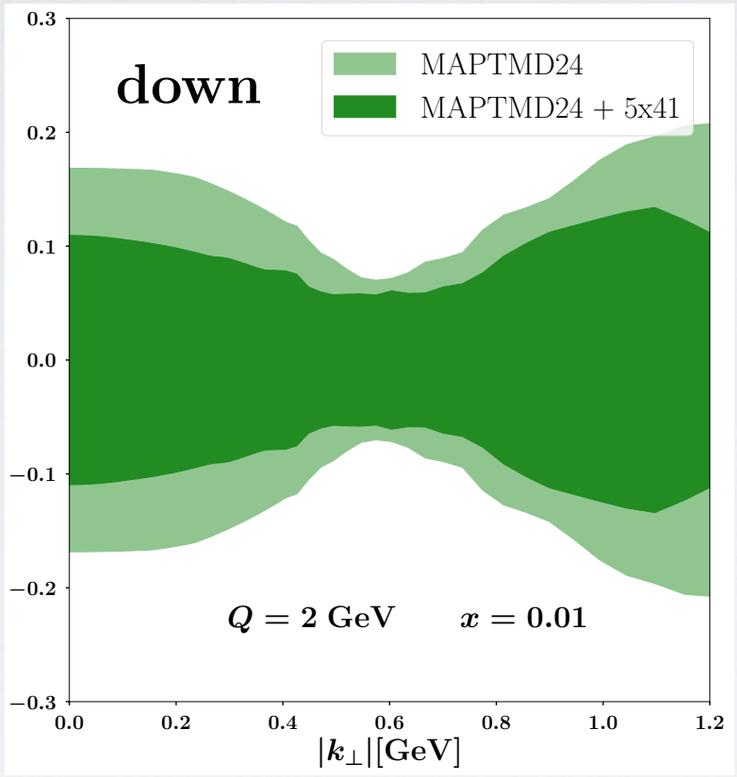
The EIC impact with MAPTMD24



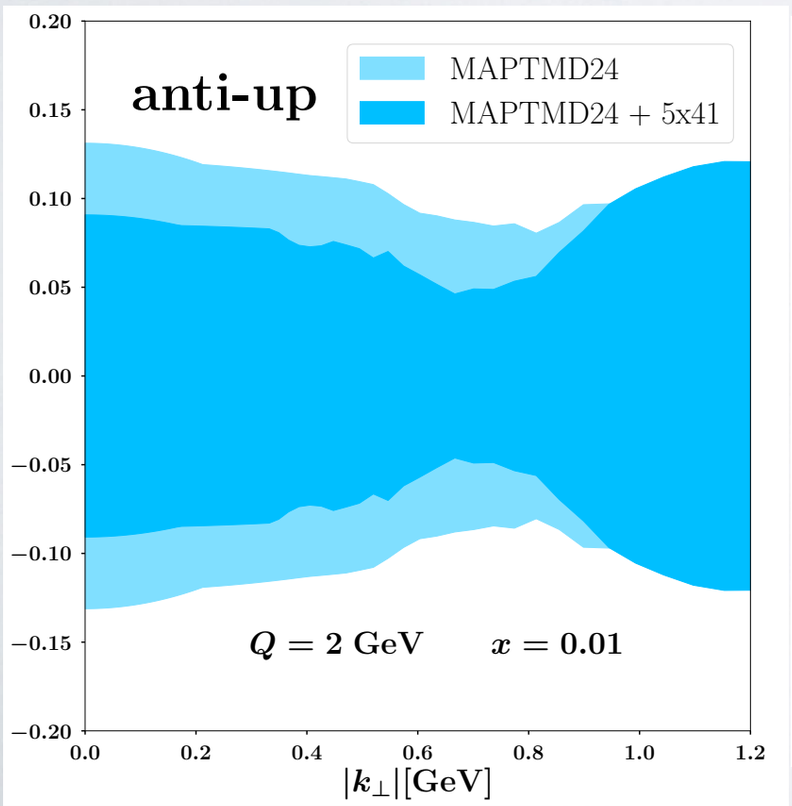


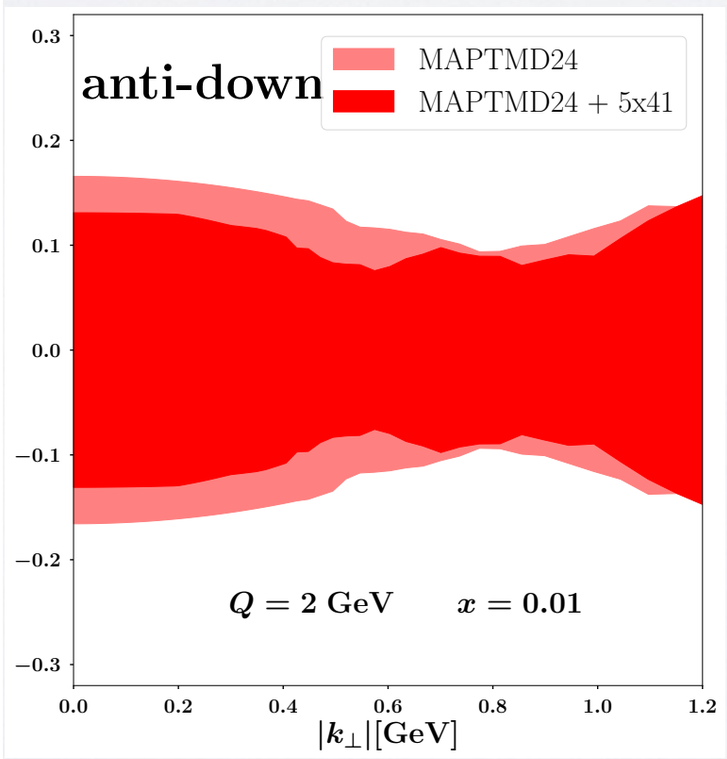
$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$

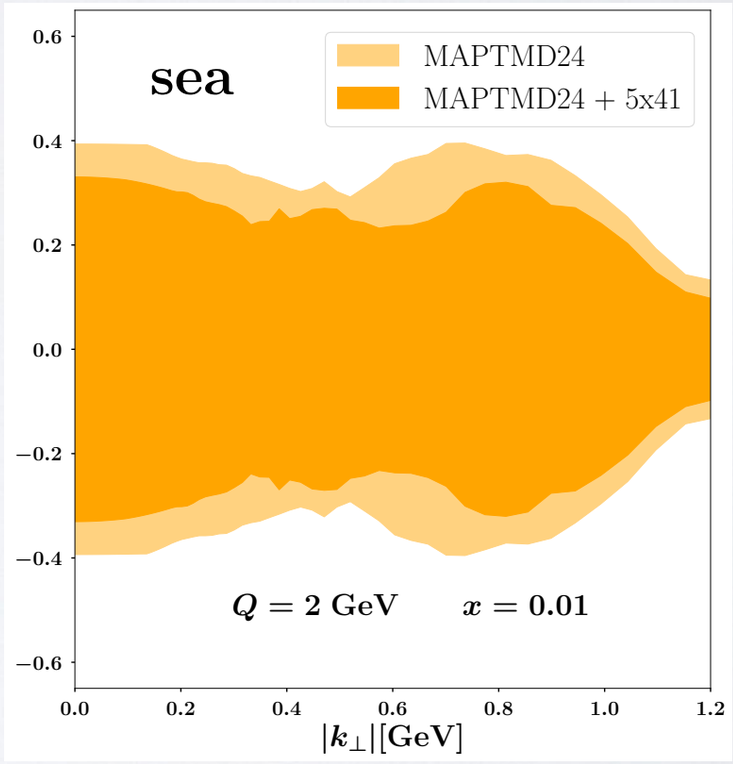
x=0.01

MAPTMD24 2031

EIC	# pts.	lumi [fb^{-1}]
5x41	1273	2.85







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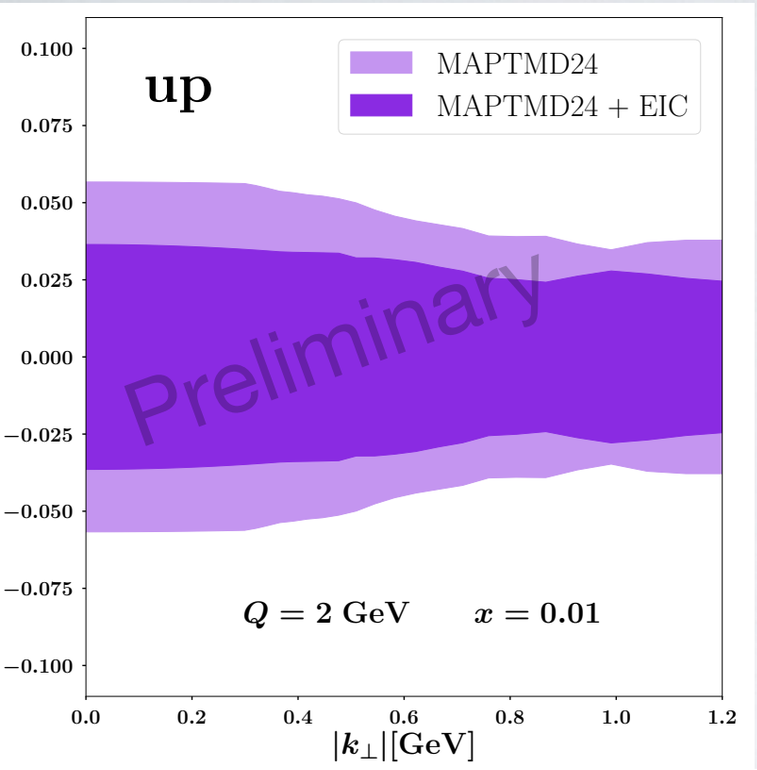
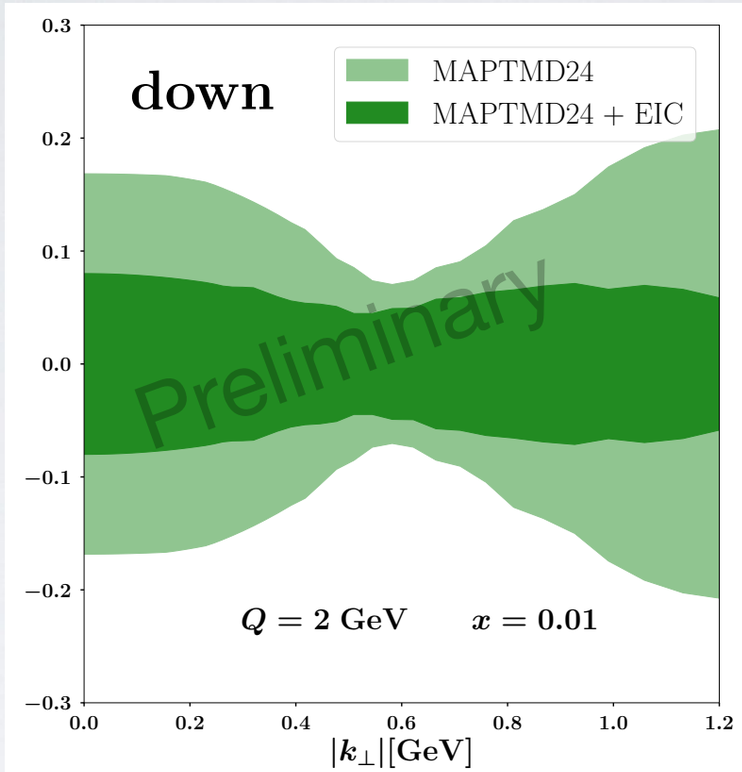
The EIC impact with MAPTMD24





$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$ **x=0.01**

MAPTMD24 2031

EIC	# pts.	lumi [fb^{-1}]
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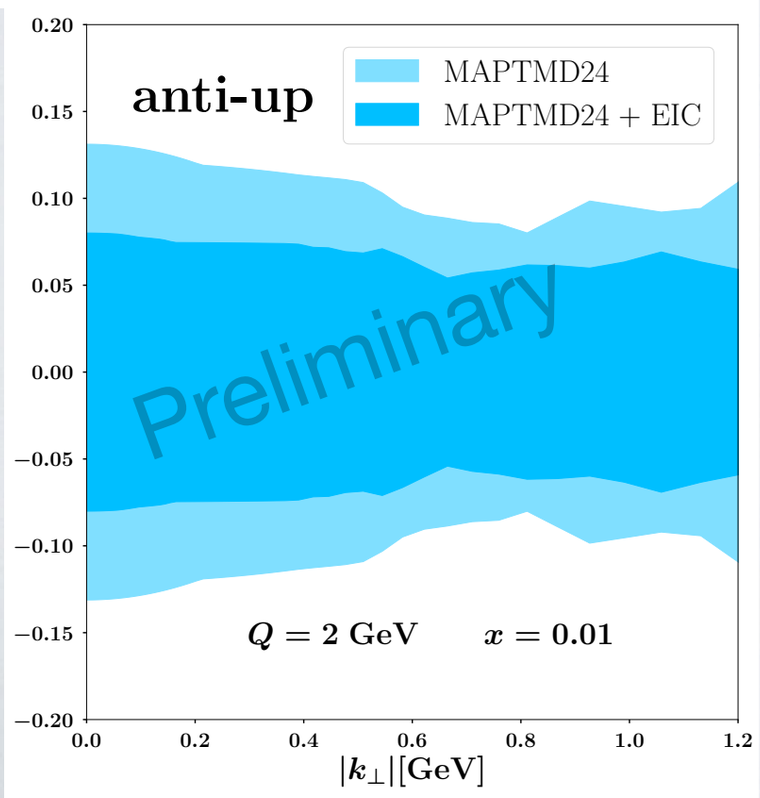
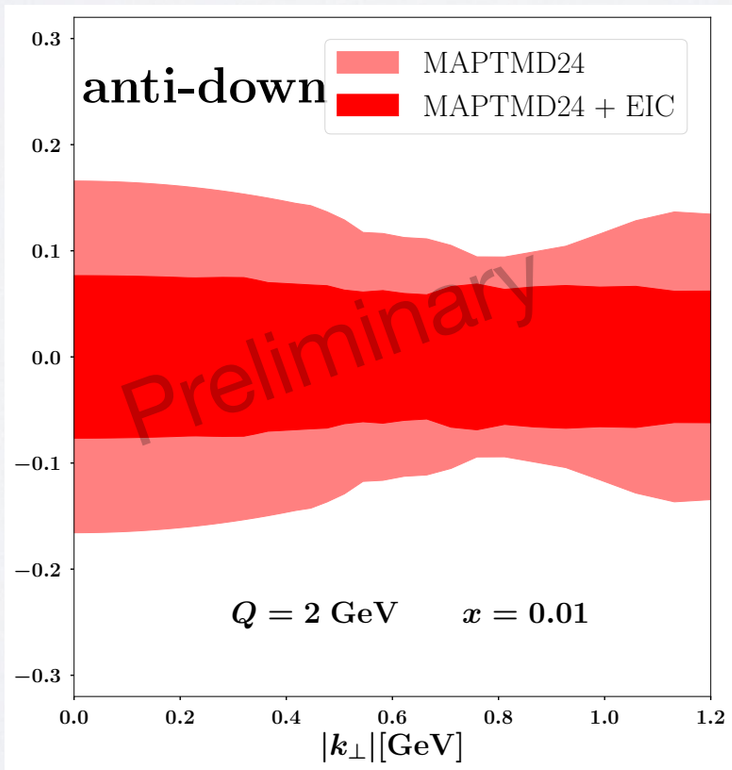
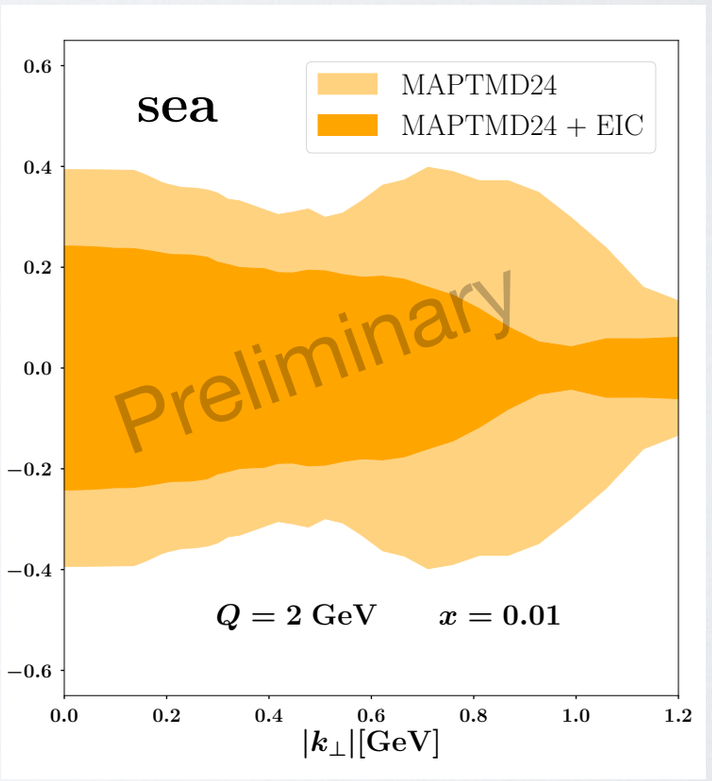
18x275	1648	10







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The EIC impact

$$\frac{\mathrm{TMD}^q - \langle \mathrm{TMD}^q \rangle}{\langle \mathrm{TMD}^q \rangle}$$

x=0.001

MAPTMD24 2031

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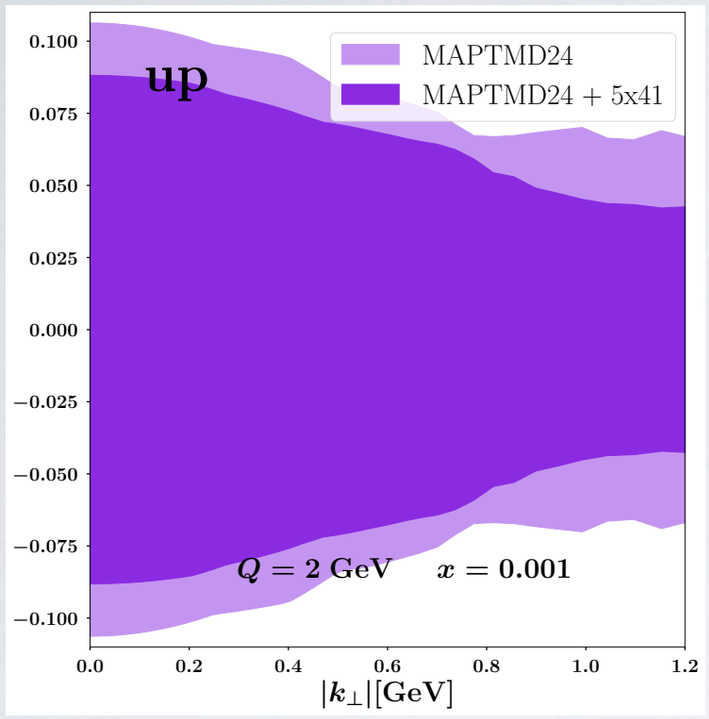

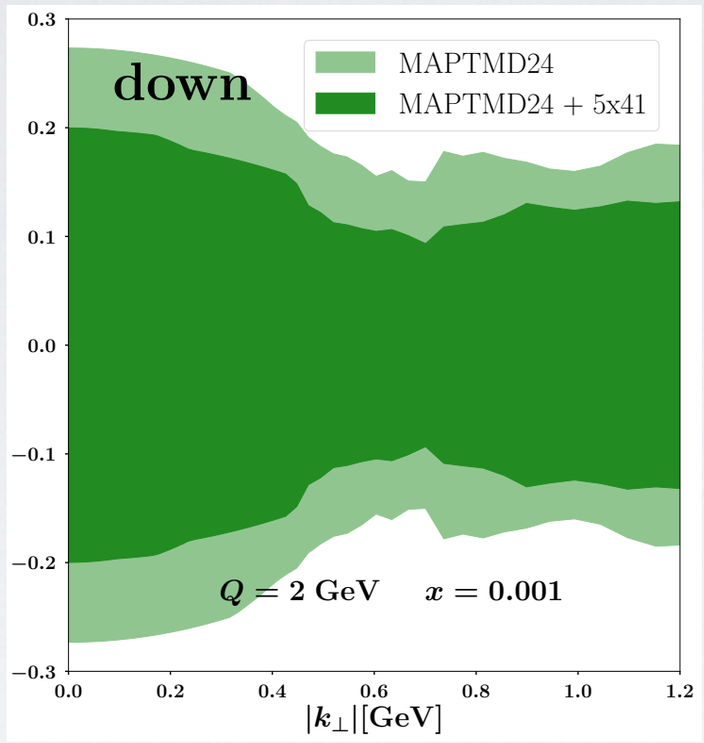

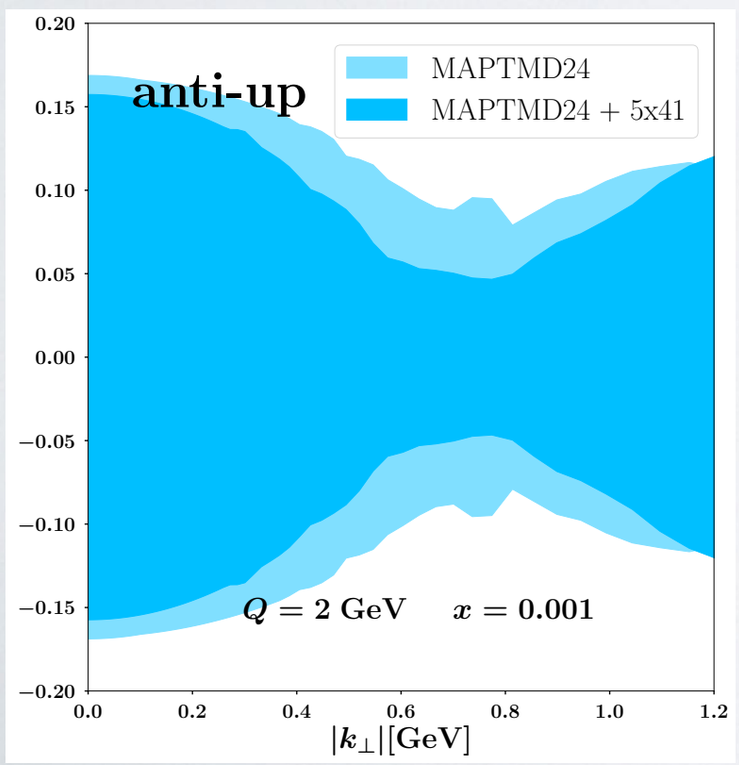

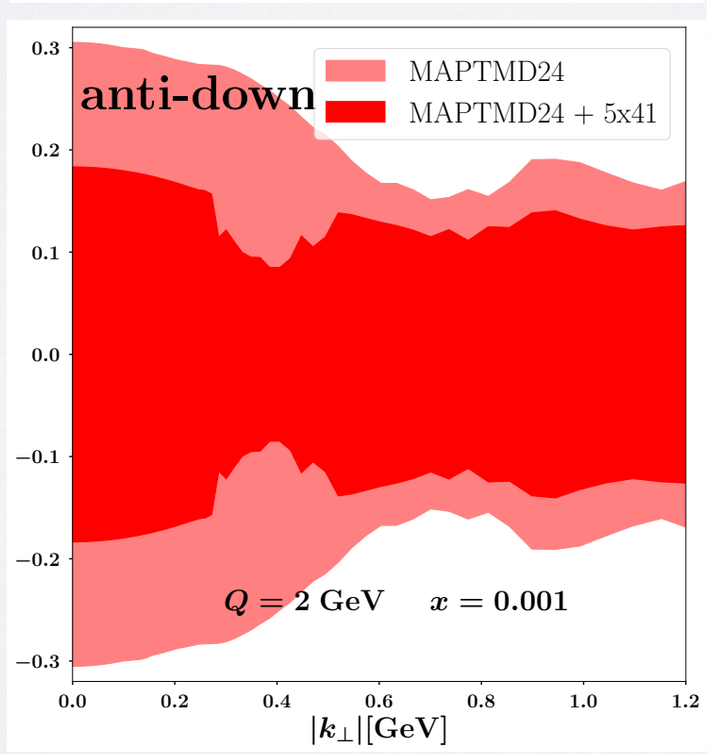

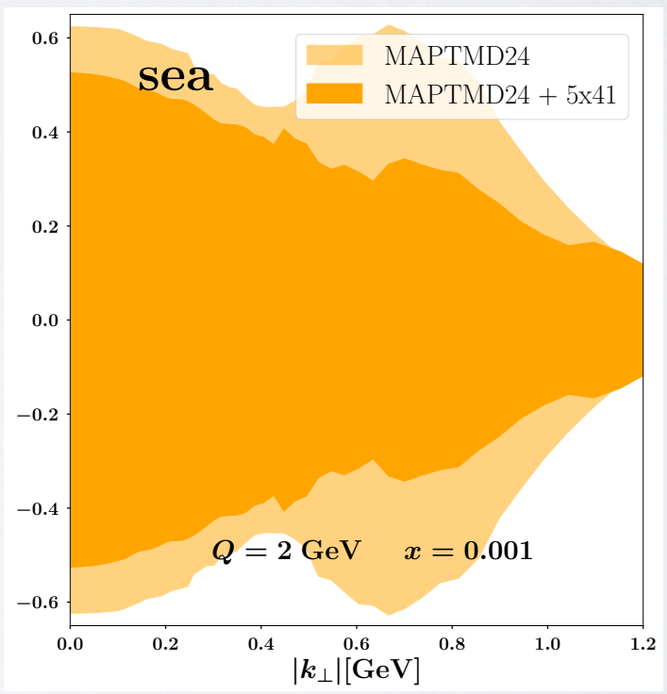

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The EIC impact

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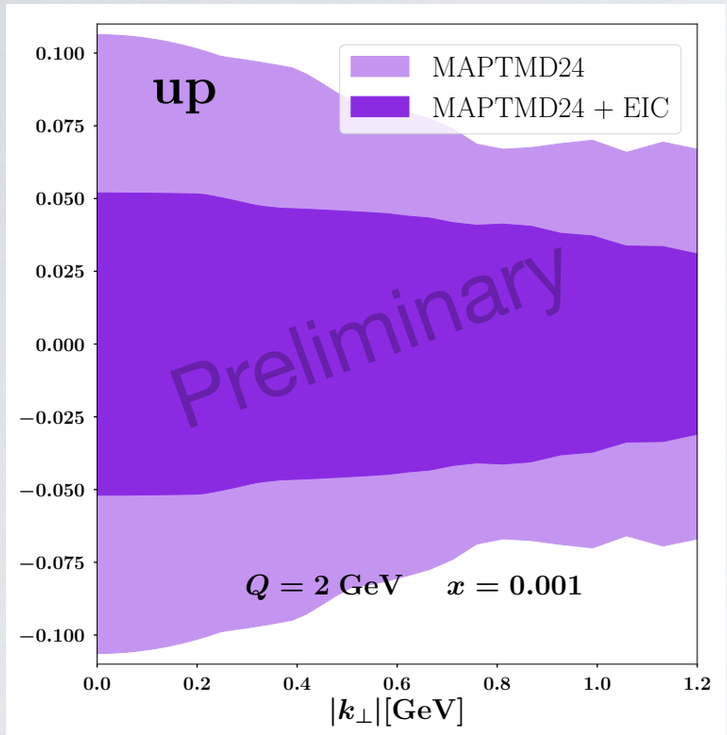

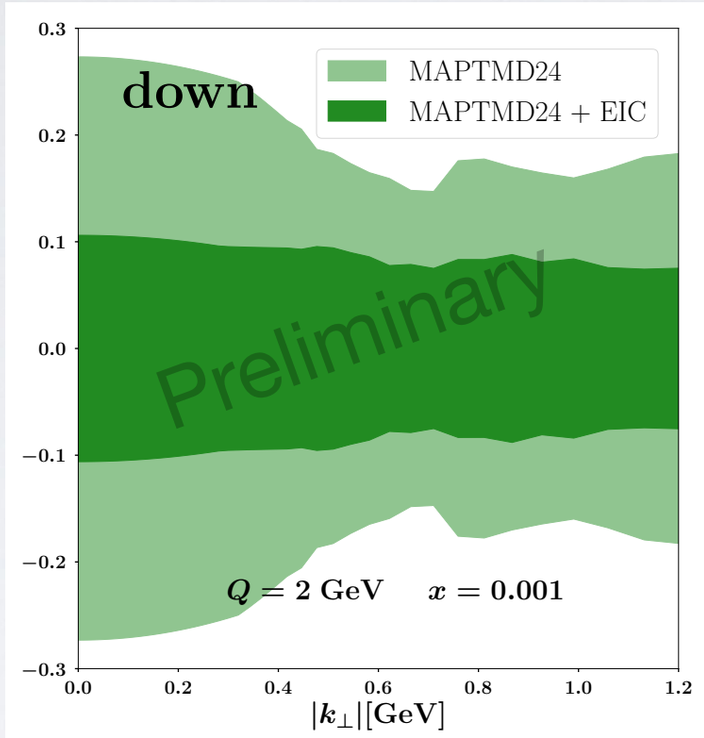

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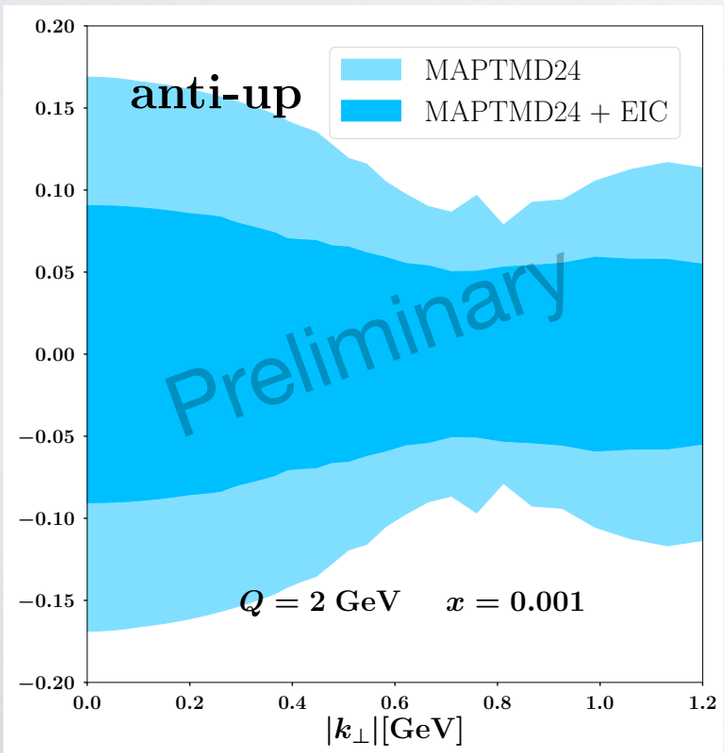

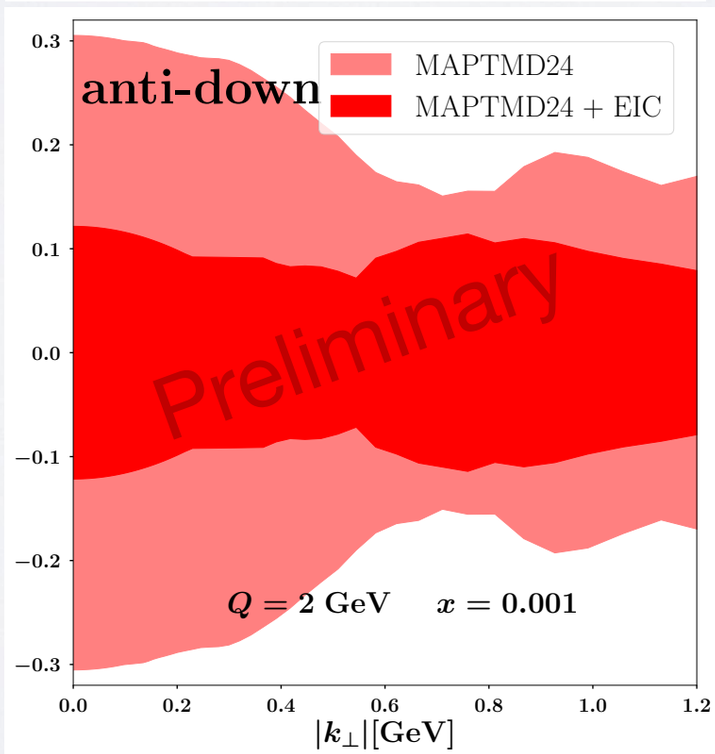

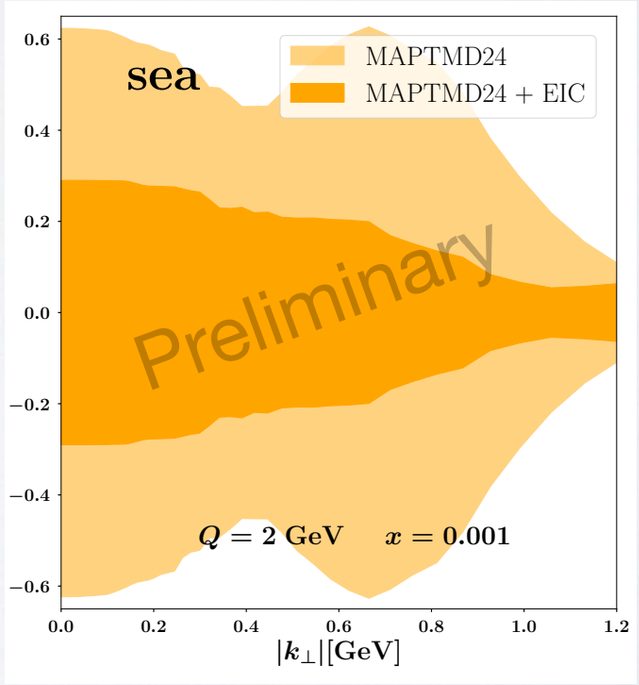

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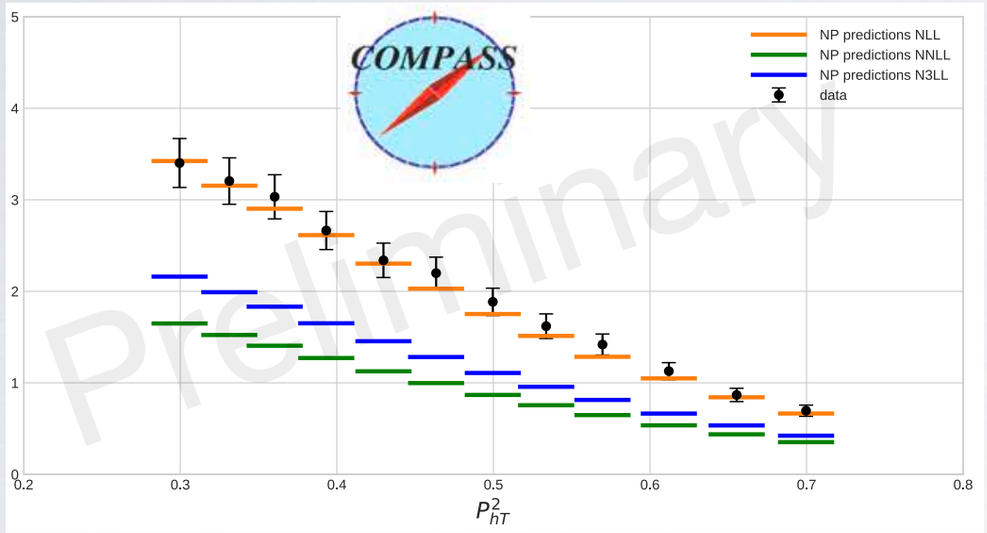
Normalization issue in SIDIS

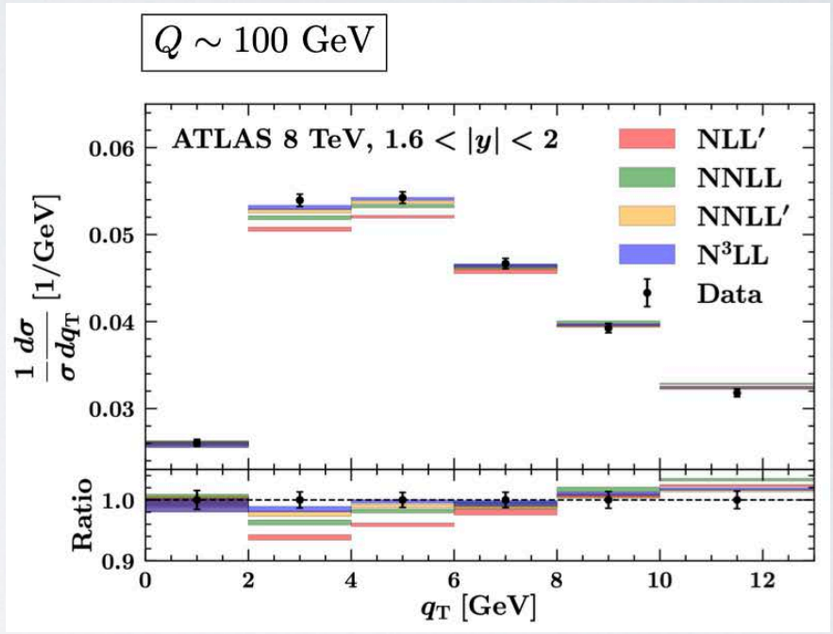
increasing perturbative accuracy

worsens agreement with SIDIS !

increases agreement with Drell-Yan

$M^h(\bar{x}, \bar{z}, \bar{Q}, q_T)$ NLL NNLL N³LL





discrepancy is P_{hT}-independent: $M_{\mathrm{NLL}}/M_{\mathrm{NNLL}} \sim 2$ $M_{\mathrm{NLL}}/M_{\mathrm{N^3LL}} \sim 1.5$

tensions observed also at larger q_T
and also in Drell-Yan at low Q
and also in e+e- annihilations

Gonzalez et al., P.R. D**98** (18) 114005
Bacchetta et al., P.R. D**100** (19) 014018
Moffat et al., P.R. D**100** (19) 094014

but not in SV 2019 fit

Scimemi & Vladimirov, arXiv:1912.06532

No normalization problems for collinear SIDIS $d\sigma/dxdzdQ$:

MAPFF1.0 (Map Collaboration)

Abdul Khalek et al., arXiv:2105.08725