Opportunities for unpolarized TMDs in EIC early science conditions

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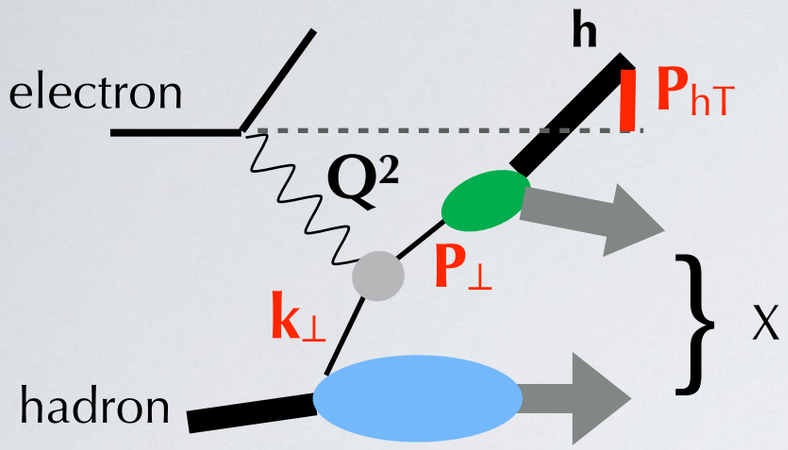
for the MAP Collaboration

SIDIS with unpolarized electron and proton



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

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

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

$$Y_+ = \left[1 + (1 - Q^2/xs)^2\right]$$

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

hard part | TMDPDF | TMDFF

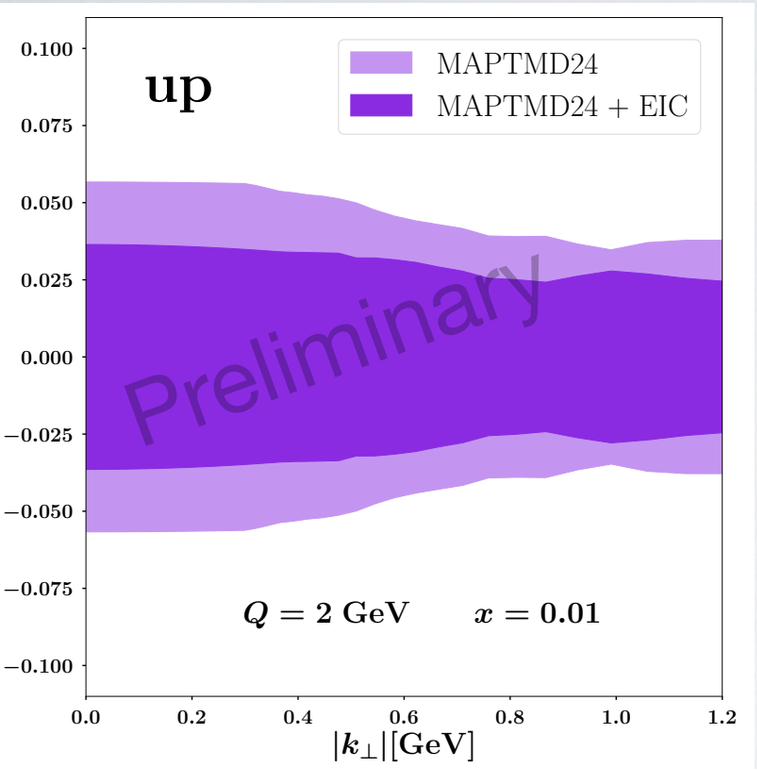
Baseline: MAPTMD24 extraction

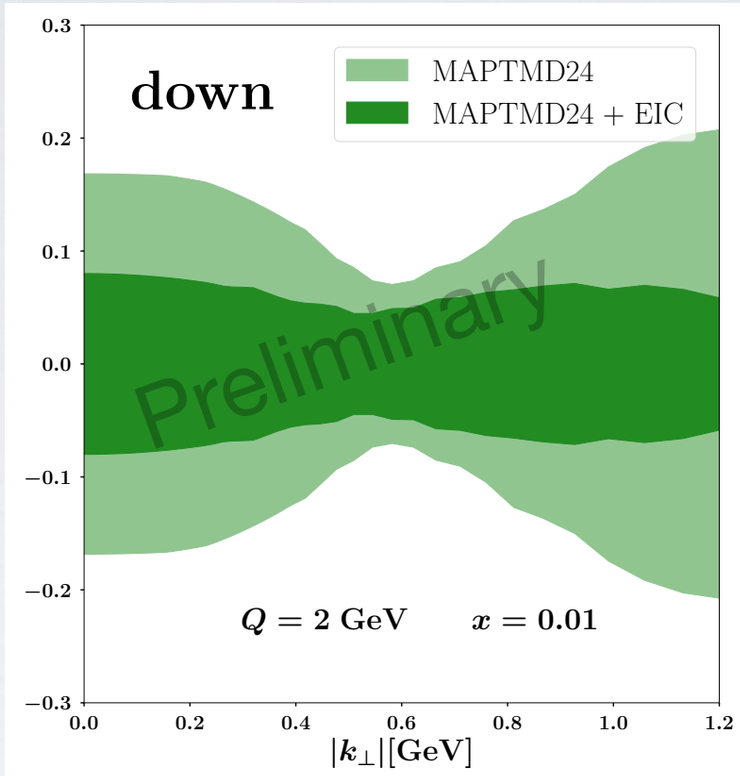
Bacchetta et al. (MAP Coll.),
*JHEP **08** (24) 232, arXiv:2405.13833*

global fit with N_{dat} = 2031

χ^2/N_{dat} =1.08, N^{3}LL accuracy

The EIC impact at x=0.01

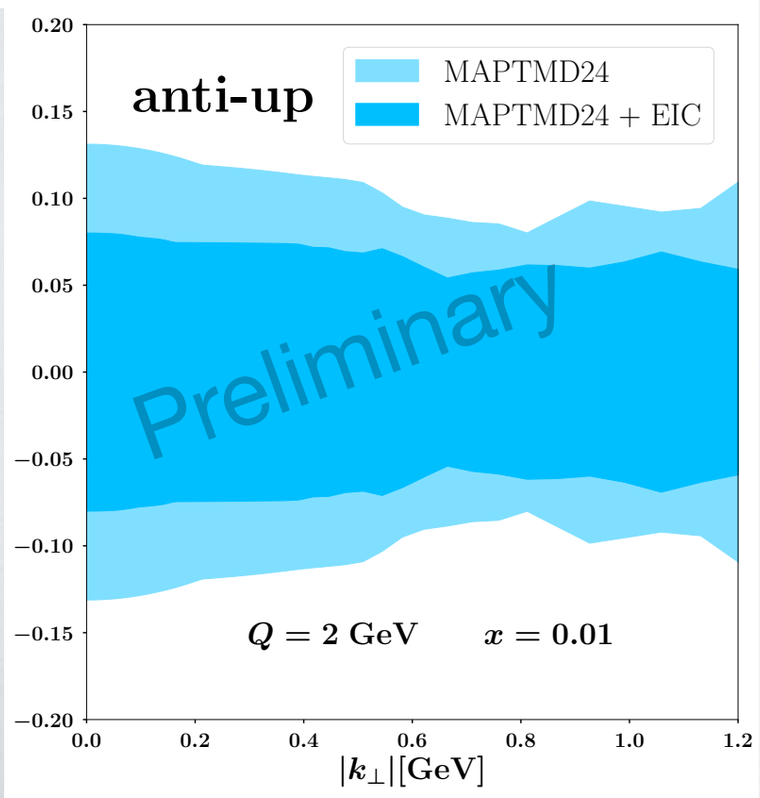


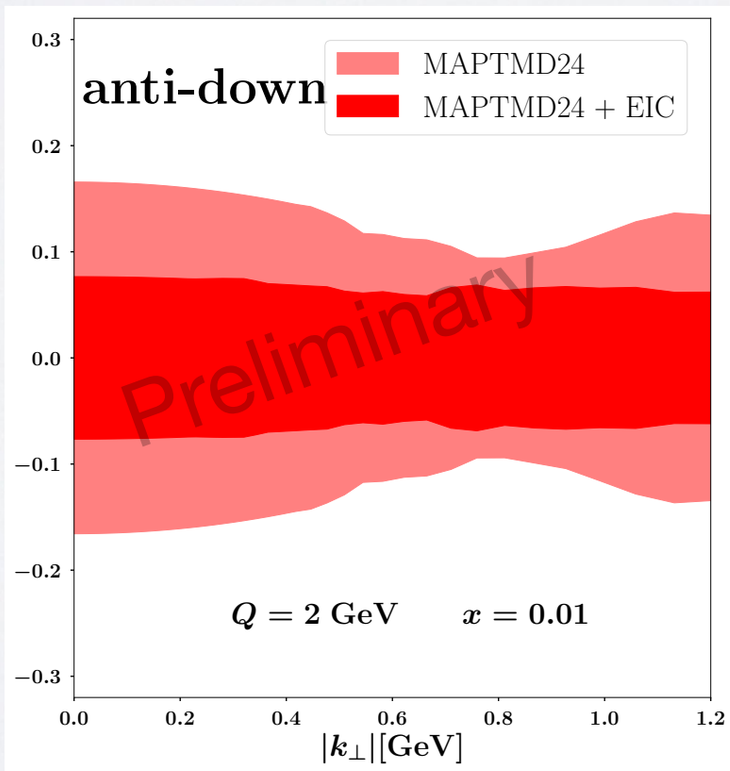


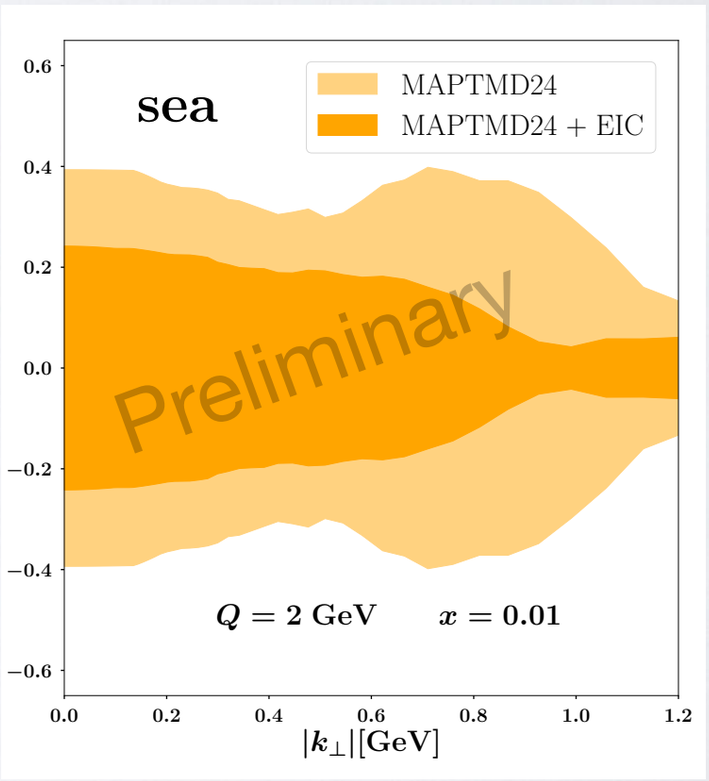
$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$ **x=0.01**

MAPTMD24 2031

EIC	# pts.	lumi [fb^{-1}]
5x41	1273	2.85
10x100	1611	51.3
18x275	1648	10

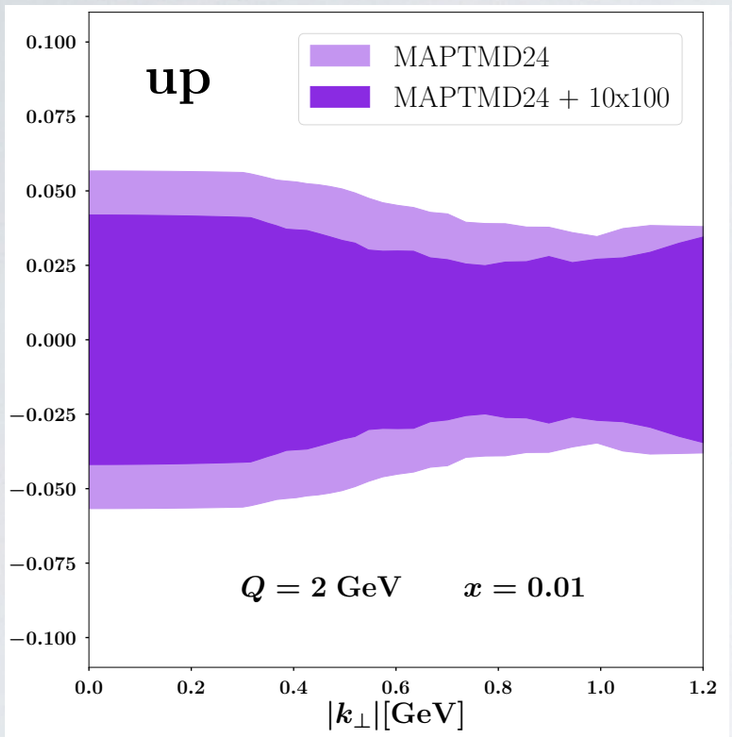


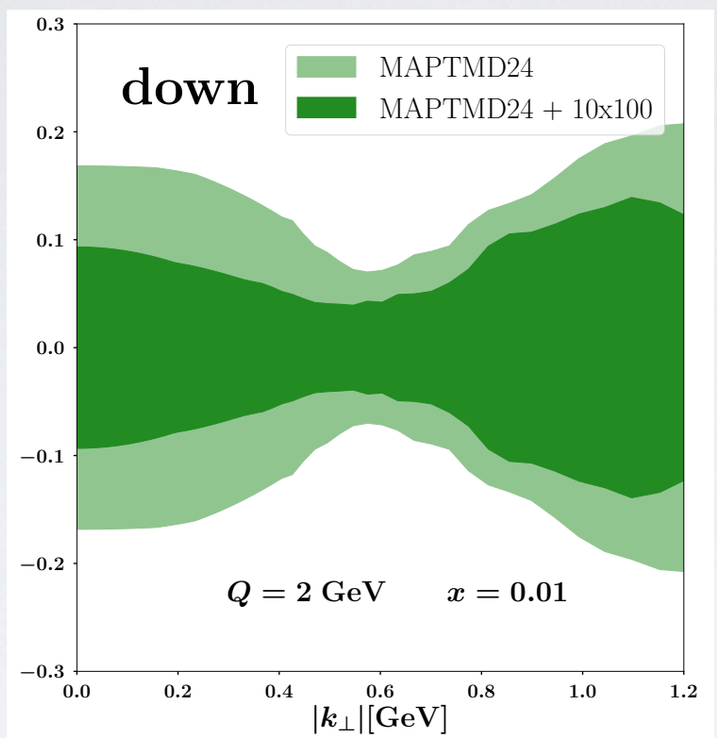




L. Rossi, Ph.D. Thesis

The EIC impact with 10x100 at x=0.01





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MAPTMD24 2031

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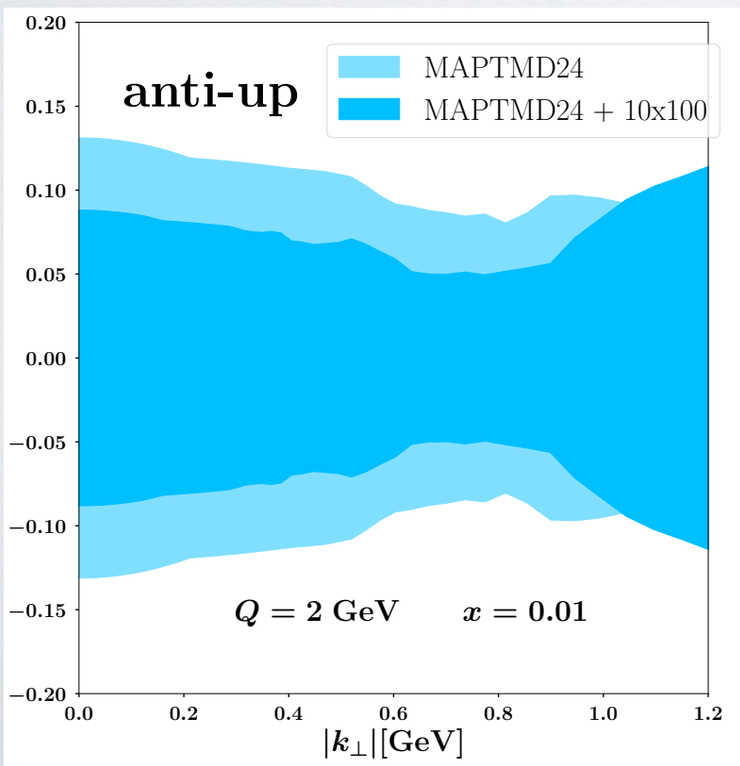
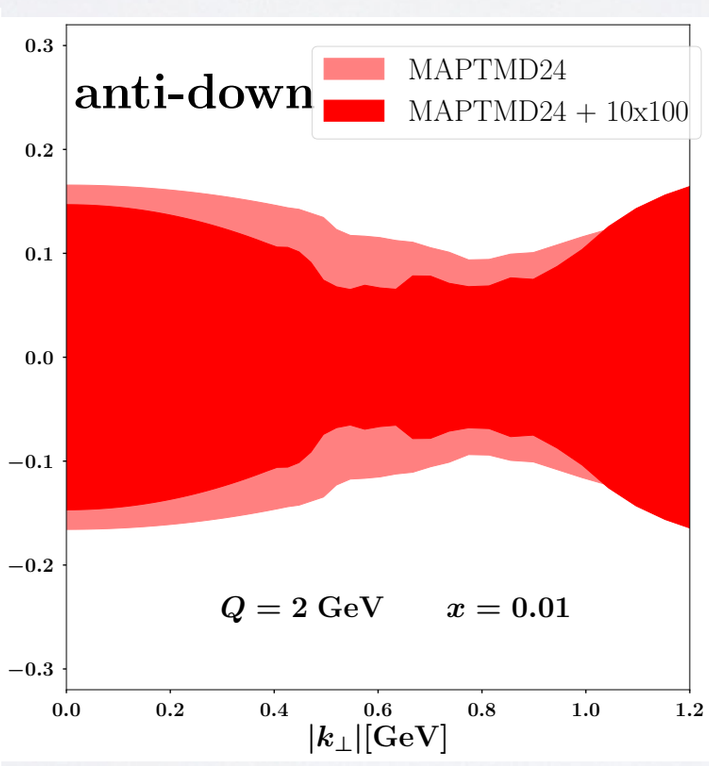
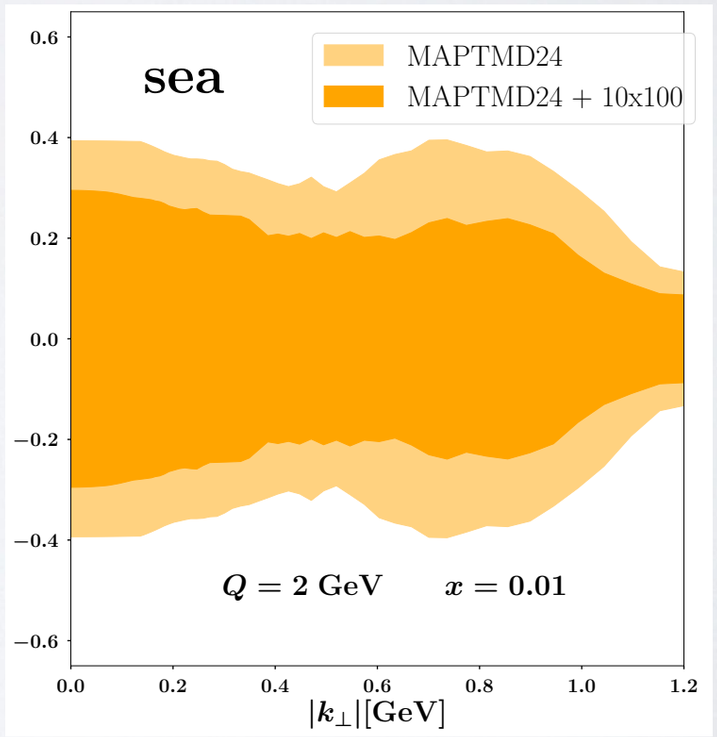
(simulation campaign of May 2024)







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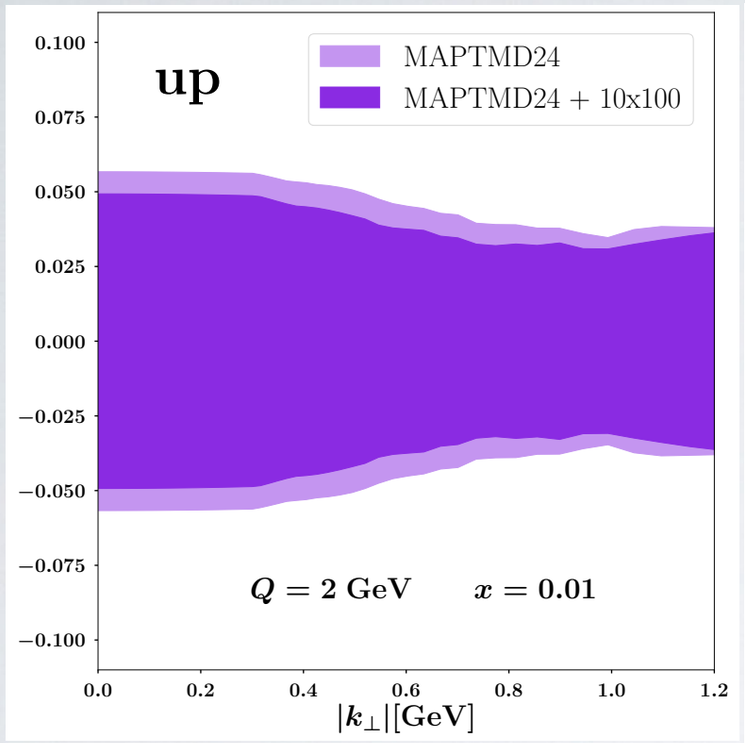
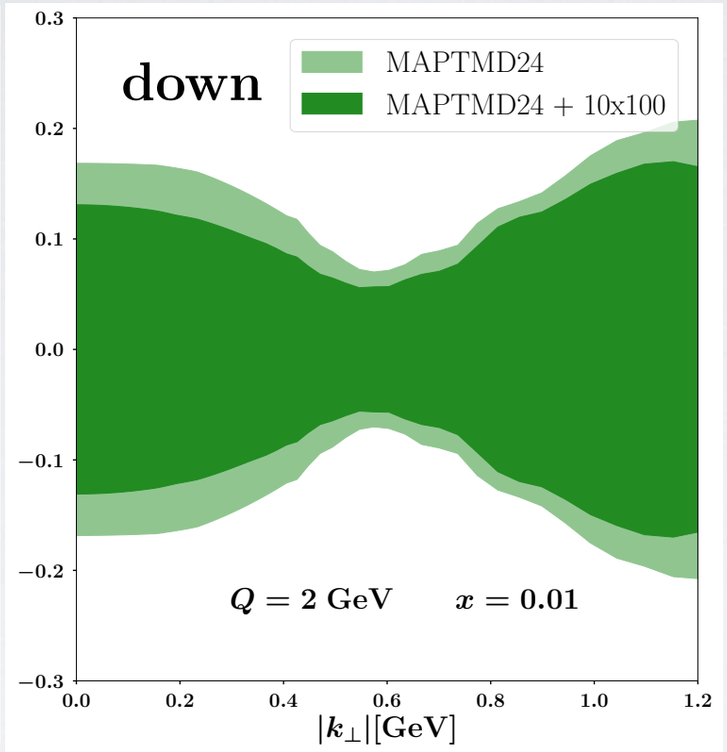


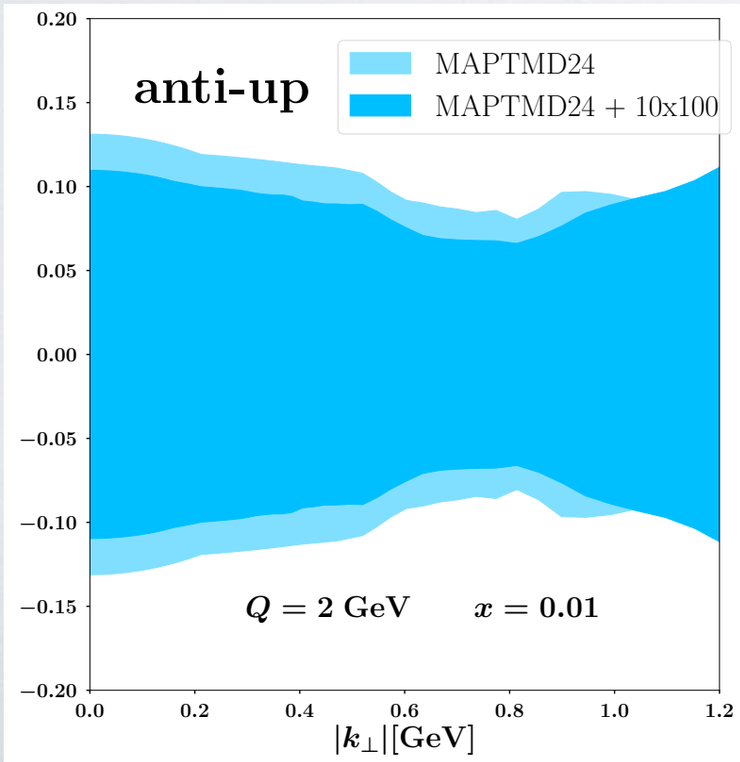


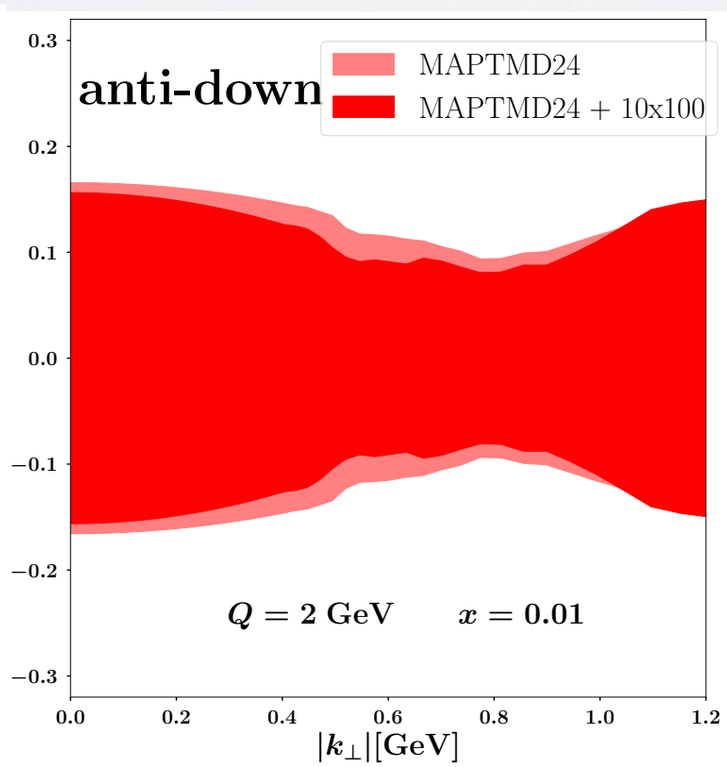
$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$ **x=0.01**

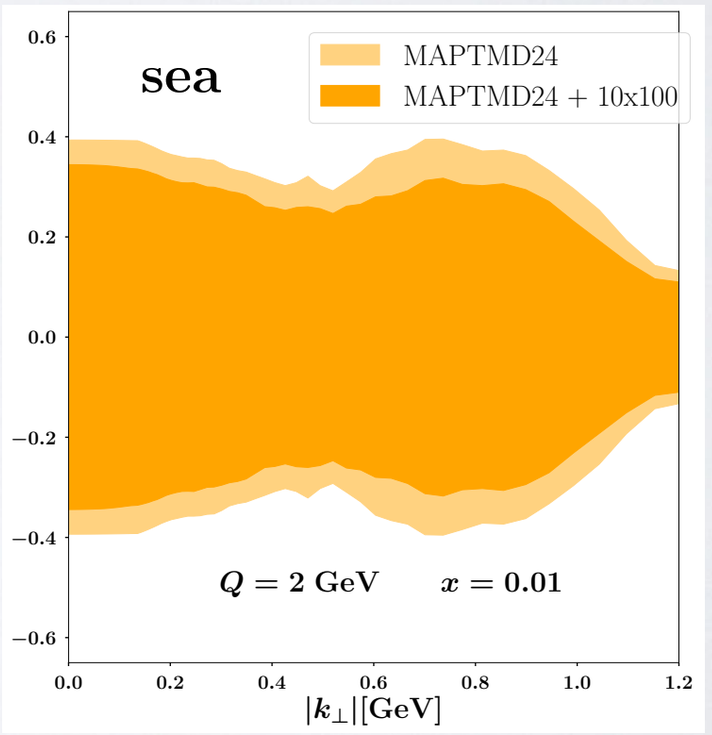
MAPTMD24 2031

EIC	**# pts.**	**lumi [fb^{-1}]**
10x100	1611	5

(early Science conditions)







courtesy L. Rossi

Early Science Conditions

Proposal for EIC Science Program in the First Years

Year - 1

Start with Phase 1 EIC
New Capability:
Commission electron polarization in parallel
Run:
10 GeV electrons on 115 GeV/u heavy ion beams (Ru or Cu)
Physics:
Add your preferred science topic

Year - 2

Phase 1 EIC
+ electron polarization
New Capability:
Commission proton polarization in parallel
Run:
10 GeV polarized electrons on 130 GeV/u Deuterium
Physics:
Add your preferred science topic

Run:
Last weeks 10 GeV electrons and 130 GeV polarized protons
Physics:
Add your preferred science topic

Year - 3

Phase 1 EIC
+ electron polarization
+ proton polarization
New Capability:
Commission running with hadron spin rotators
Run:
10 GeV polarized electrons on 130 GeV transverse polarized protons
Physics:
Add your preferred science topic

Run:
Last weeks switch to longitudinal proton polarization
Physics:
Add your preferred science topic

Year - 4

Phase 1 EIC
+ electron polarization
+ proton polarization
+ operation of hadron spin rotators
New Capability:
Commission hadron accelerator to operate with not centered orbits
Run:
10 GeV polarized electrons on 100 GeV Au
Physics:
Add your preferred science topic

Run:
10 GeV electrons on 250 GeV transverse and longitudinal polarized protons
Physics:
Add your preferred science topic

Year - 5

Phase 1 EIC
+ electron polarization
+ proton polarization
+ operation of hadron spin rotators
+ operation of hadron beams with not centered orbits
Run:
10 GeV polarized electrons on 100 GeV Au
Physics:
Add your preferred science topic

Run:
10 GeV electrons on 166 GeV transverse and longitudinal polarized He-3
Physics:
Add your preferred science topic

Time to install additional ESR RF and HSR PS to reach design Current and max. Energies

Early Science Conditions

ep Luminosity for Phase-1

High Divergence	Lumi per Fill (5 h)	Lumi per Year	Low Divergence	Lumi per Fill (5 h)	Lumi per Year
5 GeV e x 250 GeV p	9.26 pb^{-1}	6.48 fb^{-1}	5 GeV e x 250 GeV p	6.81 pb^{-1}	4.78 fb^{-1}
10 GeV e x 250 GeV p	13.12 pb^{-1}	9.18 fb^{-1}	10 GeV e x 250 GeV p	8.8 pb^{-1}	6.19 fb^{-1}
5 GeV e x 130 GeV p	6.3 pb^{-1}	4.36 fb-1	5 GeV e x 130 GeV p	5.8 pb^{-1}	4.1 fb^{-1}
10 GeV e x 130 GeV p	7.6 pb^{-1}	5.33 fb^{-1}	10 GeV e x 130 GeV p	7.1 pb^{-1}	4.95 fb^{-1}

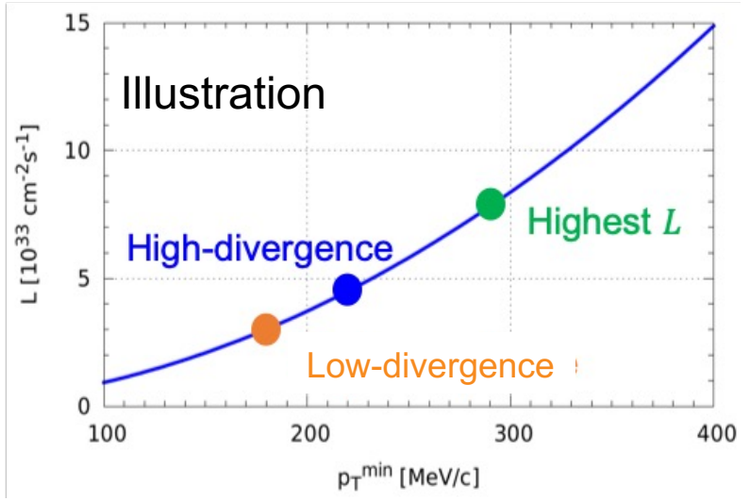
Compare to HERA integrated luminosity 1992 – 2007: 0.6 fb^{-1}

Remember:

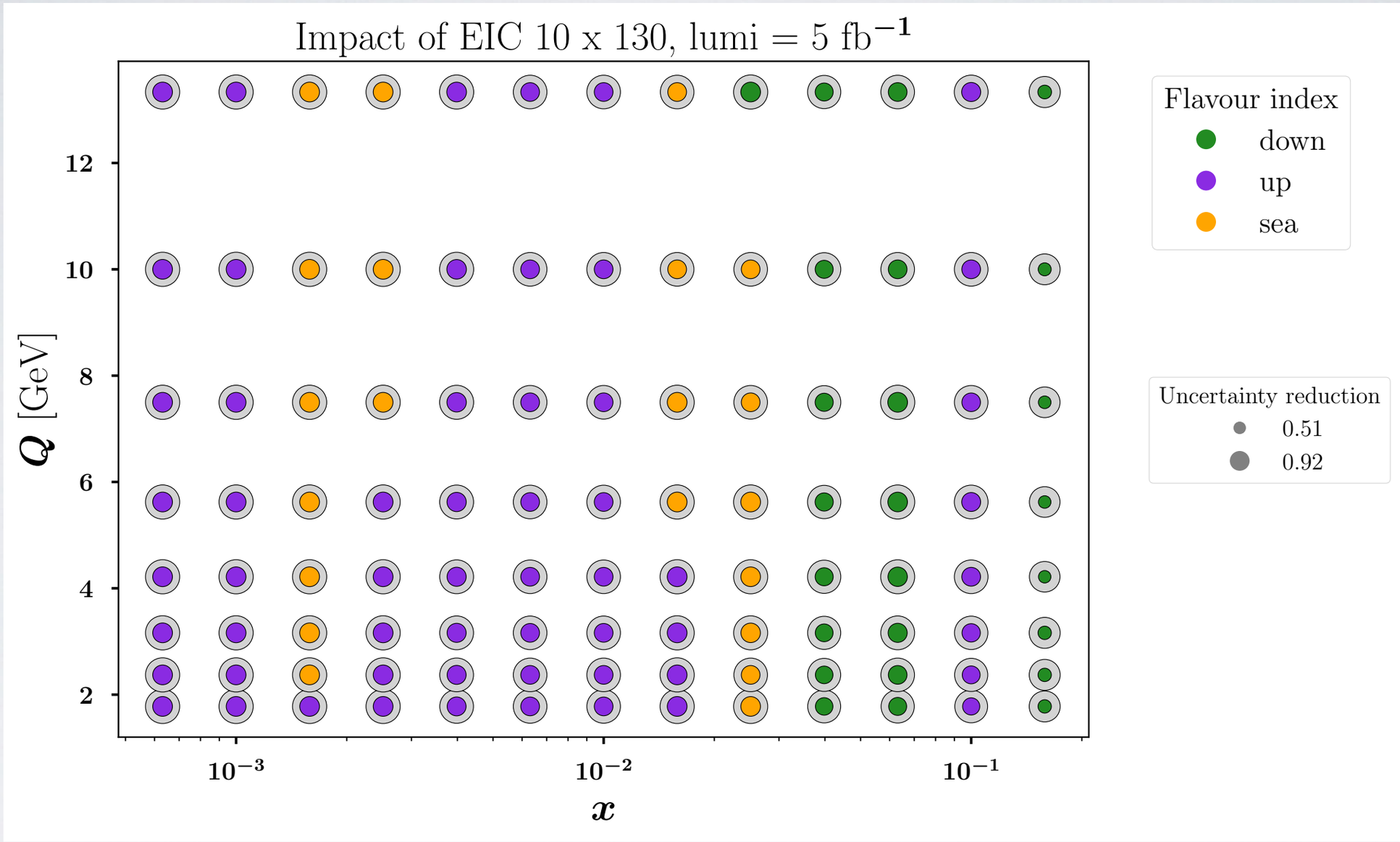
high divergence: higher lumi, but reduced acceptance for low forward particle p_T^{min}

low divergence: lower lumi, but increased acceptance for low forward particle p_T^{min}

→ important for exclusive processes



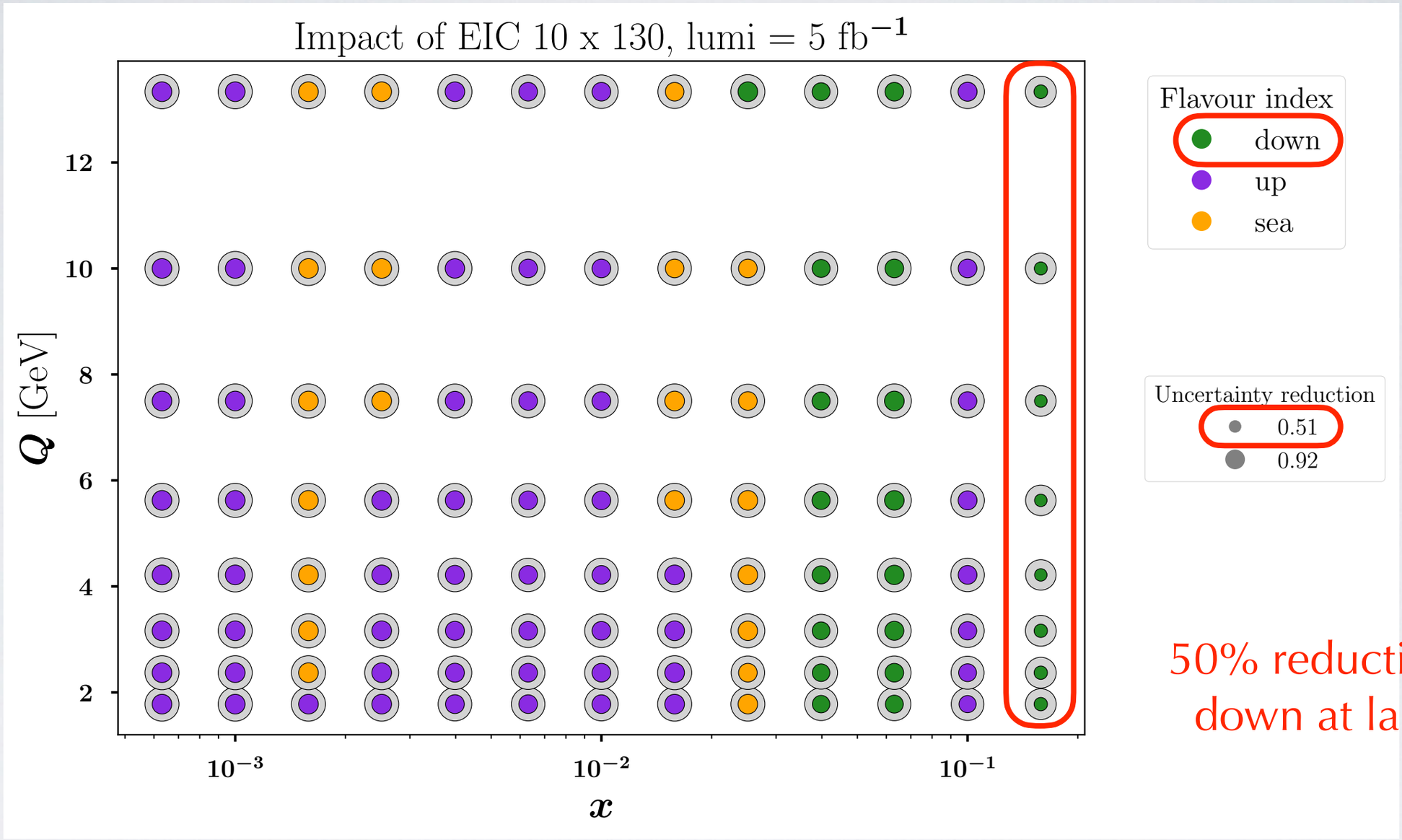
EIC impact in Early Science Conditions



For each (x,Q^2) bin:

- from MAPTMD24, max. uncertainty of $f_1^q(x,k_T;Q)$ over all k_T and all flavors q
- including EIC pseudodata, color code indicates the flavor with max. reduction in uncertainty over all k_T

EIC impact in Early Science Conditions



50% reduction on down at large x

For each (x,Q^2) bin:

- from MAPTMD24, max. uncertainty of $f_1^q(x,k_T;Q)$ over all k_T and all flavors q
- including EIC pseudodata, color code indicates the flavor with max. reduction in uncertainty over all k_T

The EIC impact with 10x130 at x=0.16

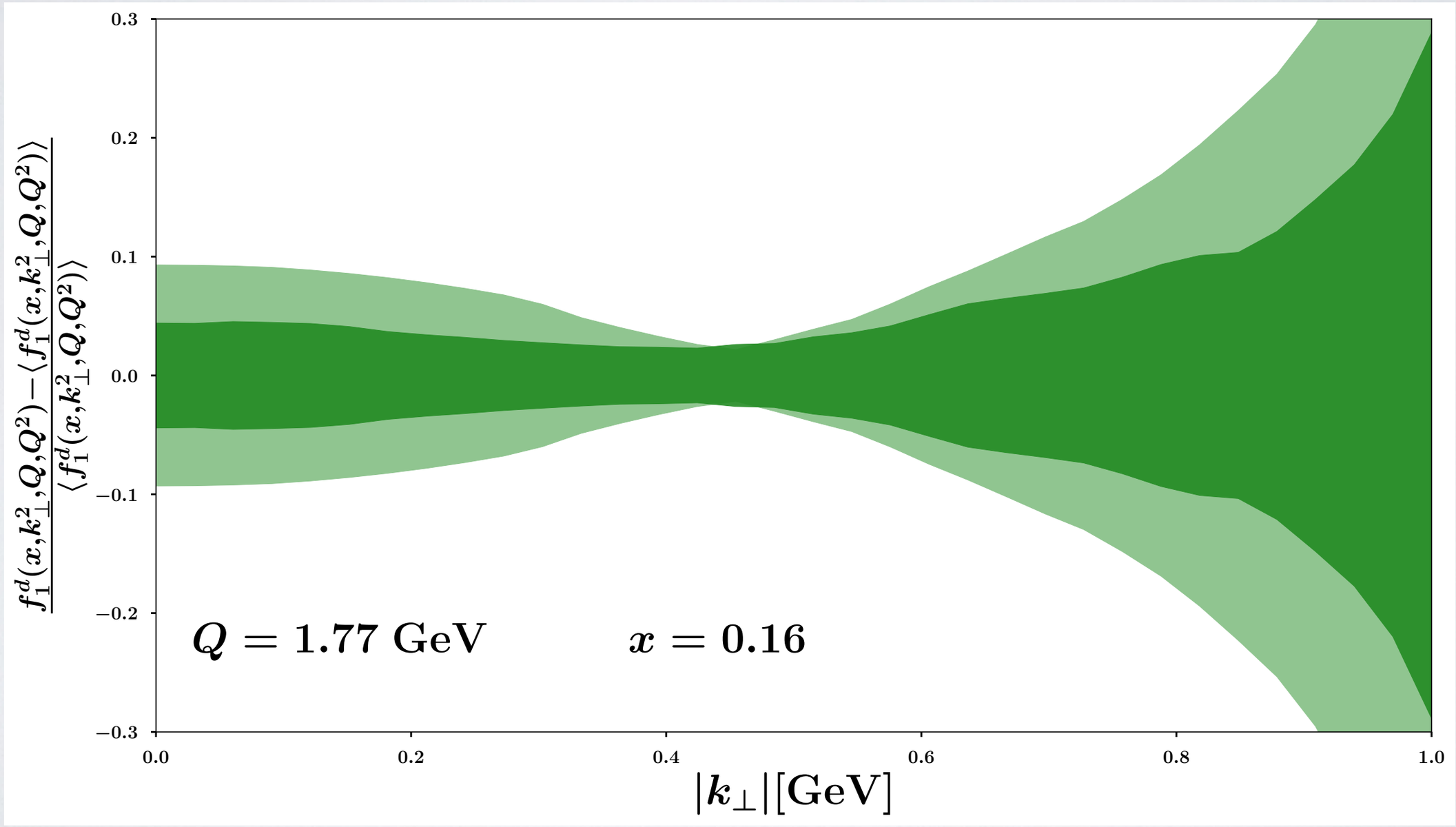
MAPTMD24 2031

EIC	**# pts.**	**lumi [fb^{-1}]**
10x130	~1620	5

(early Science conditions)

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

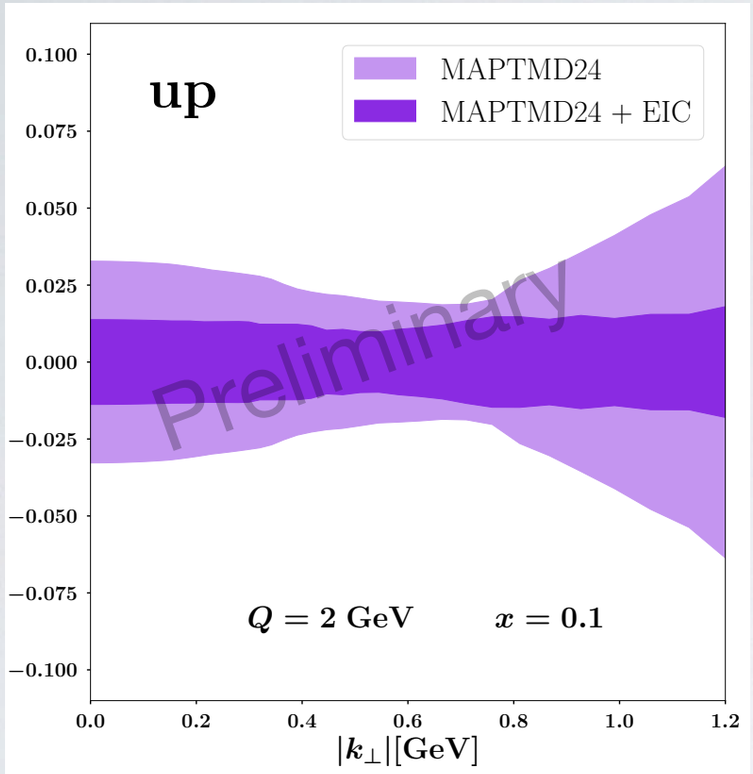
x=0.16, Q=1.77 GeV

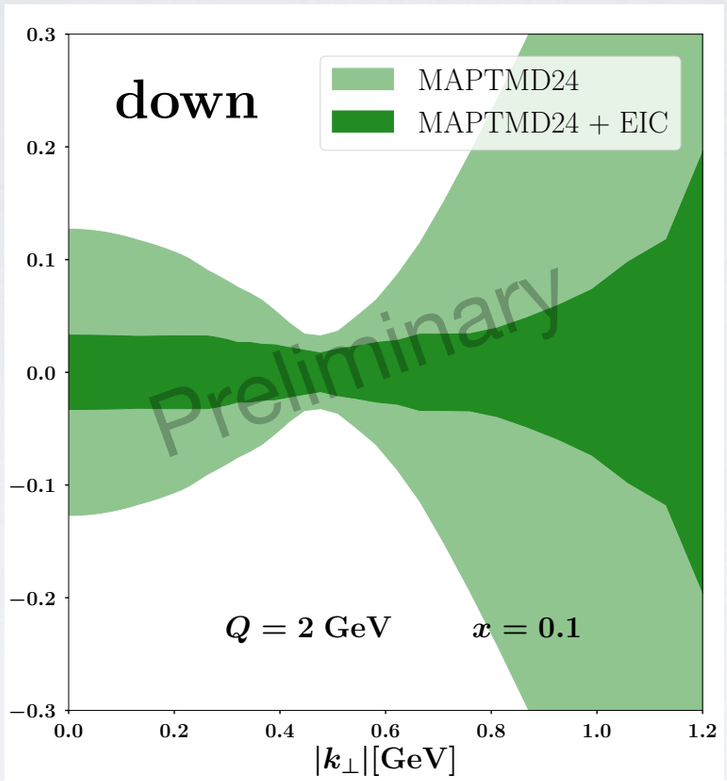


courtesy L. Rossi

Backup

The EIC impact with MAPTMD24



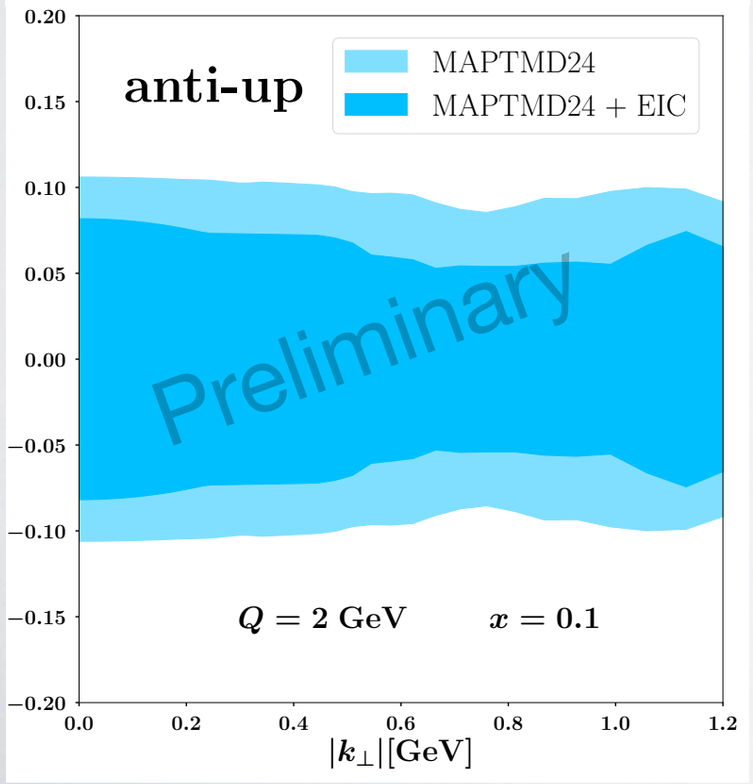


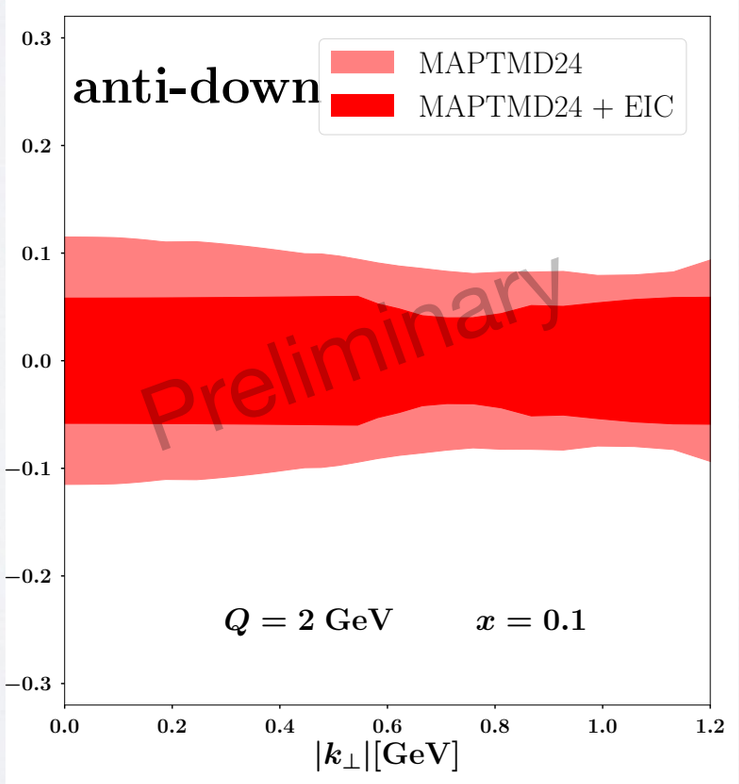
$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$ **x=0.1**

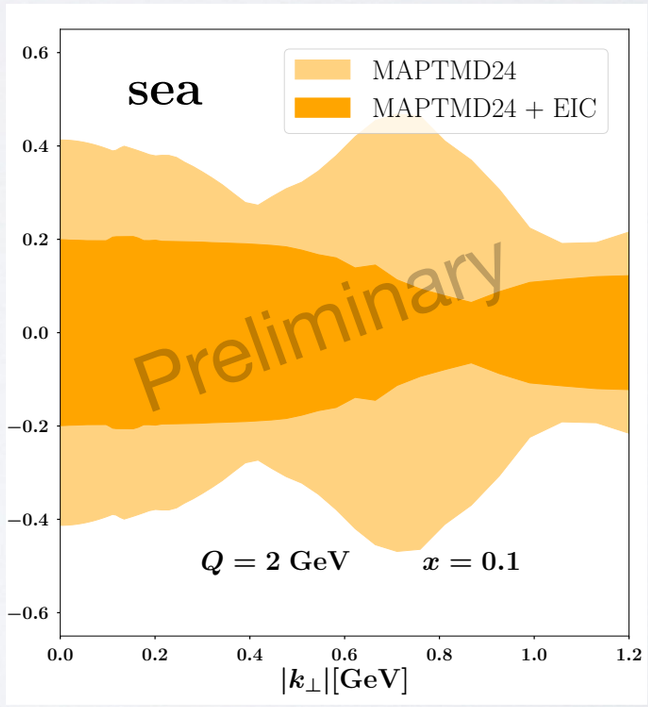
MAPTMD24 2031

EIC	**# pts.**	**lumi [fb^{-1}]**
5x41	1273	2.85
10x100	1611	51.3
18x275	1648	10

(conditions as May simulation campaign)







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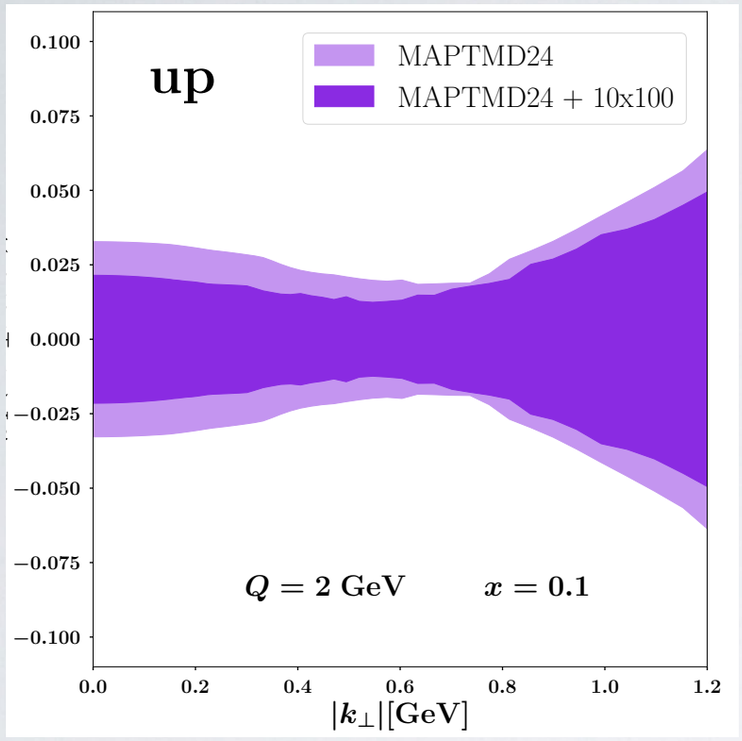
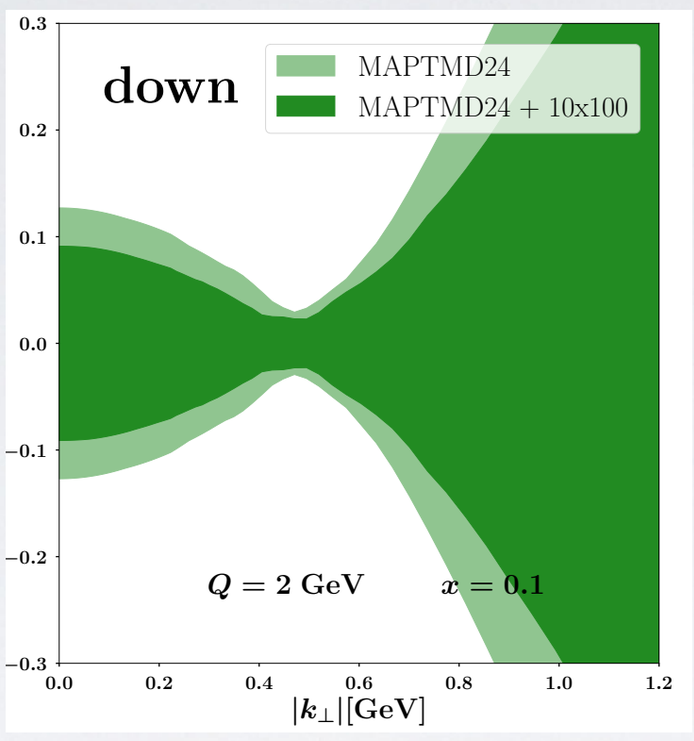
The EIC impact with 10x100 at x=0.1





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

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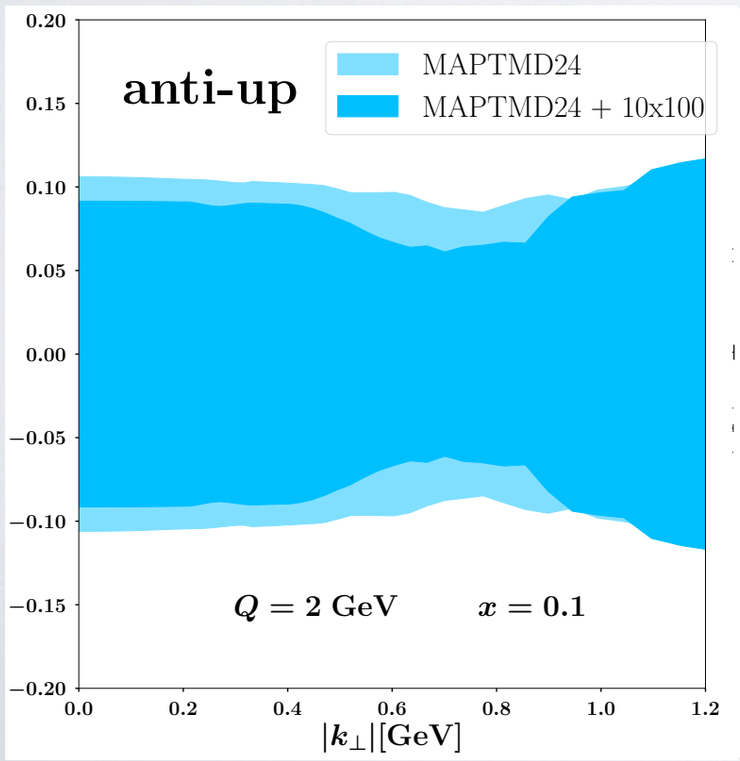
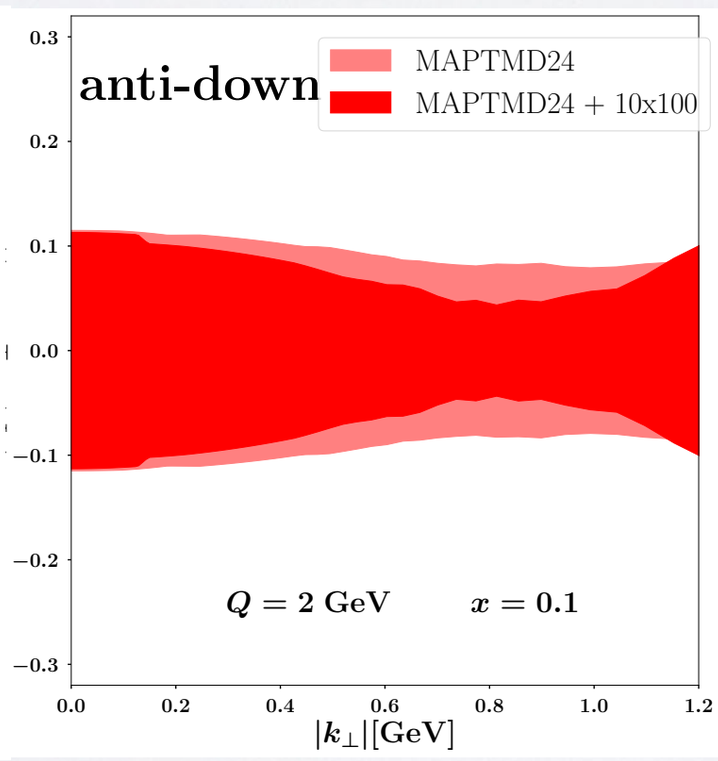
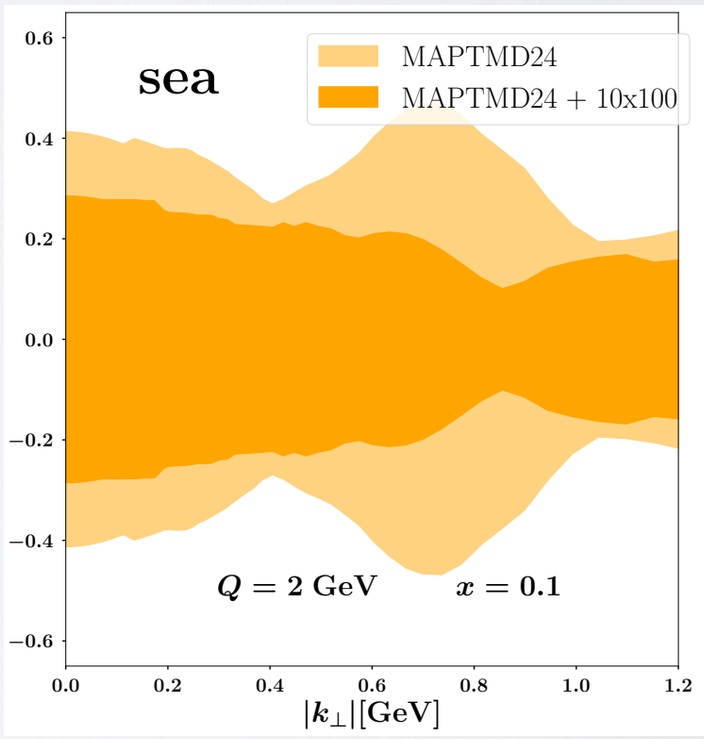
(simulation campaign of May 2024)







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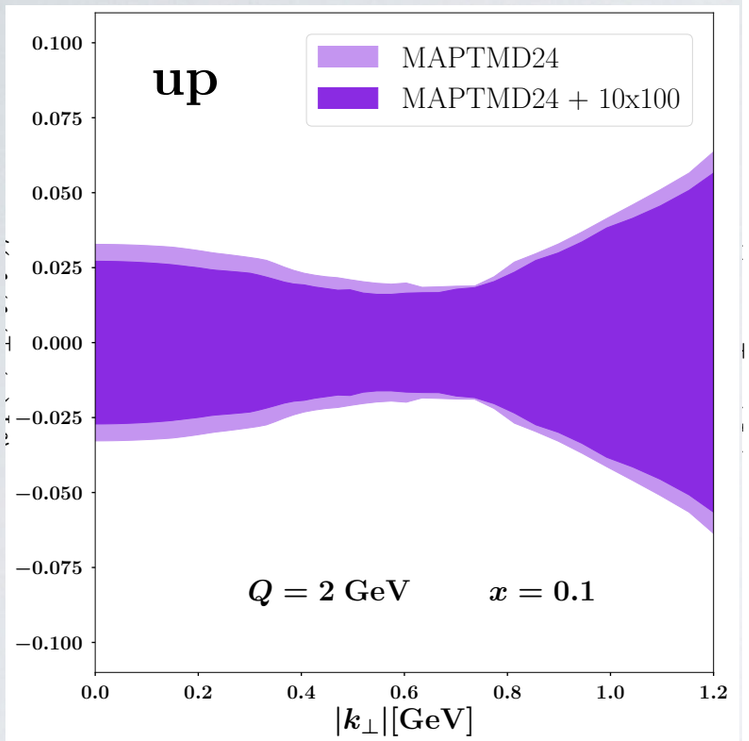

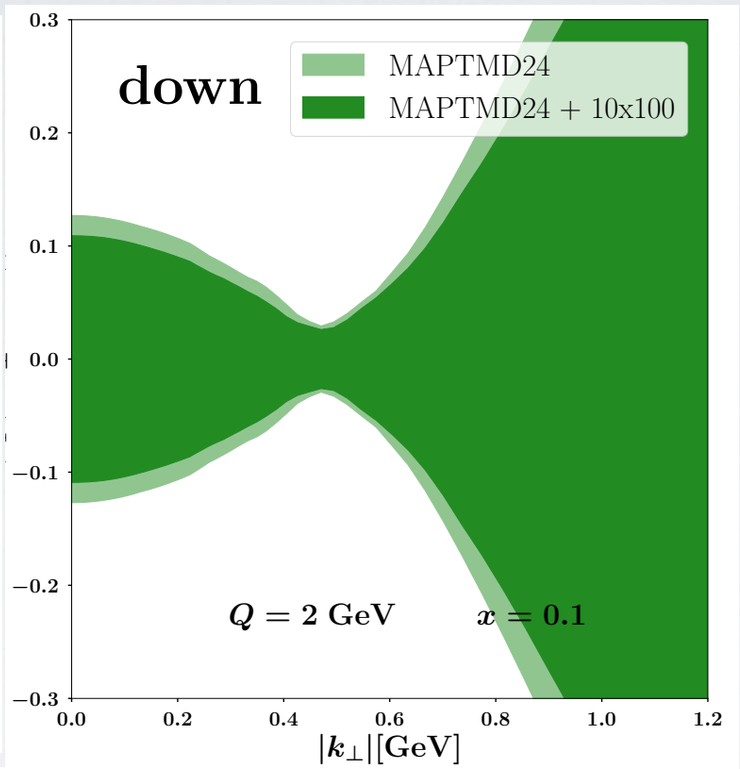

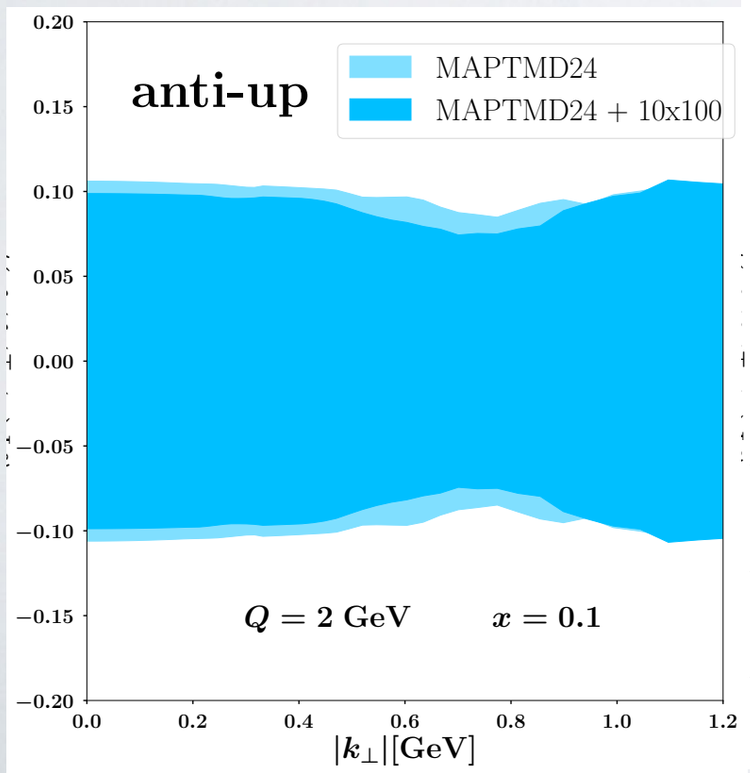

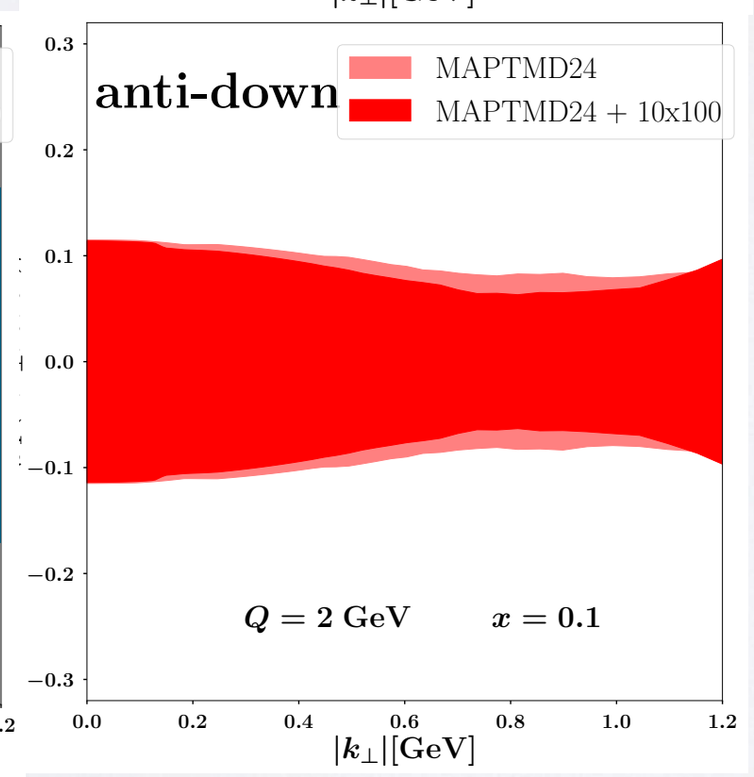

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MAPTMD24 2031

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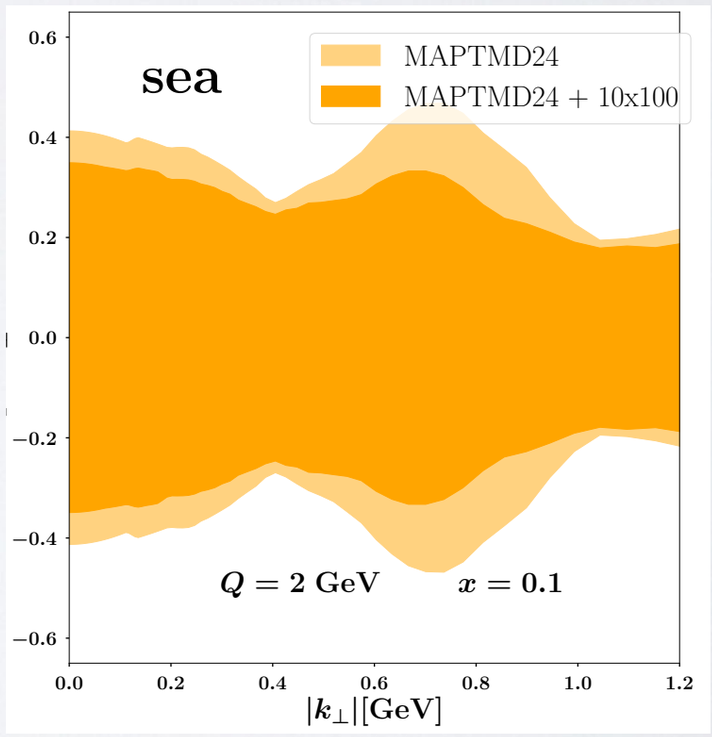
(early Science conditions)

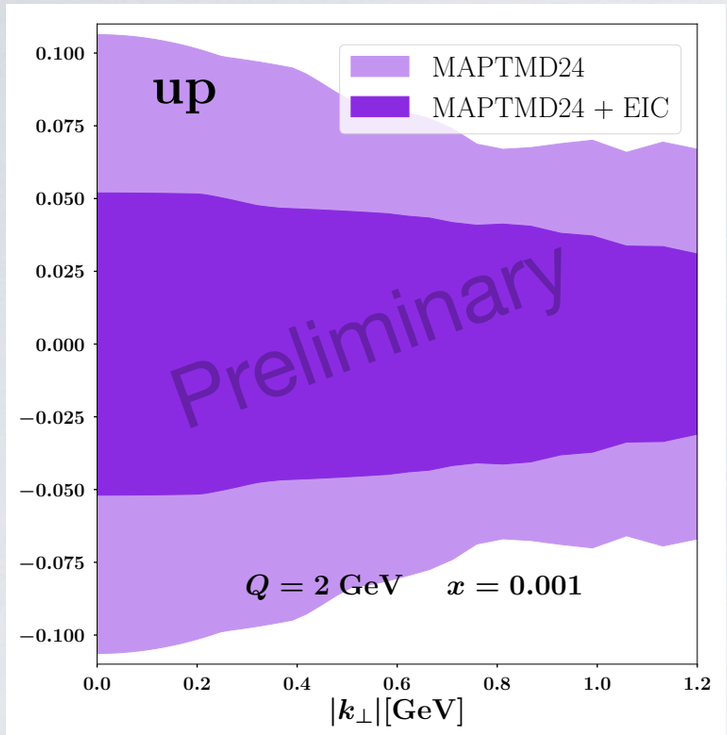


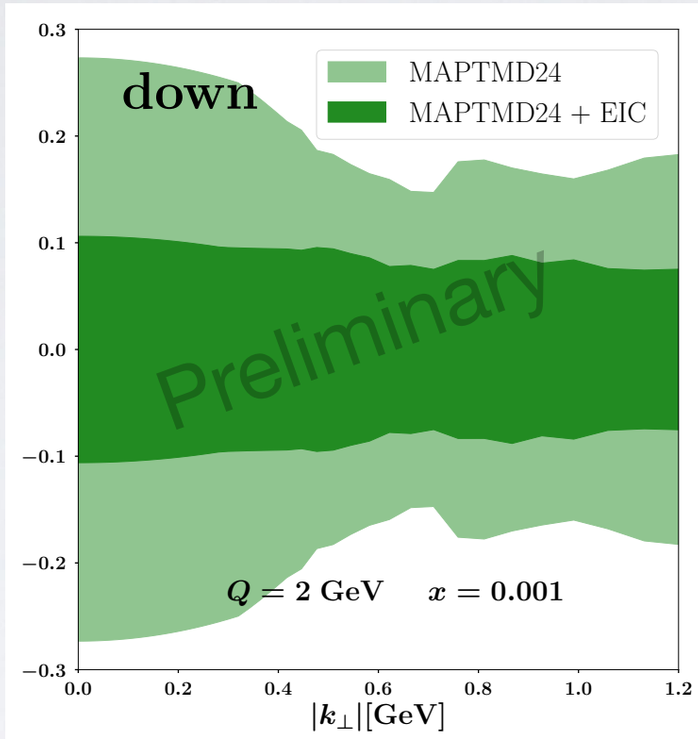
courtesy L. Rossi

The EIC impact

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

x=0.001





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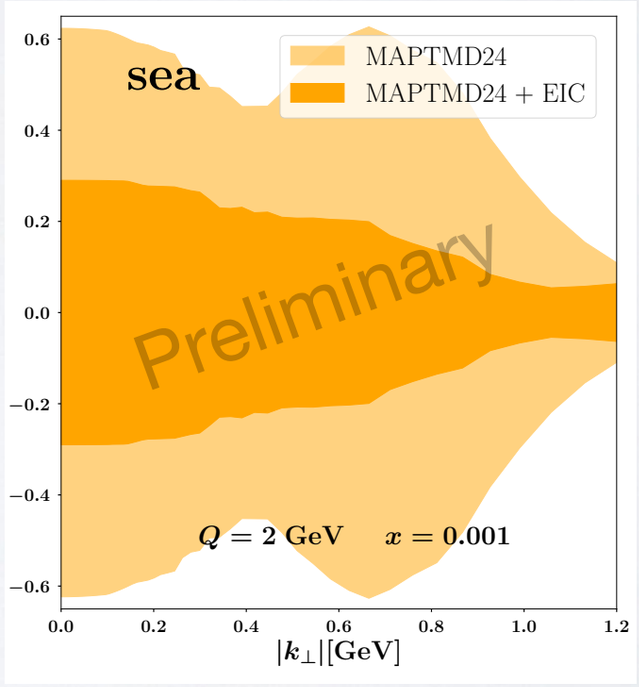

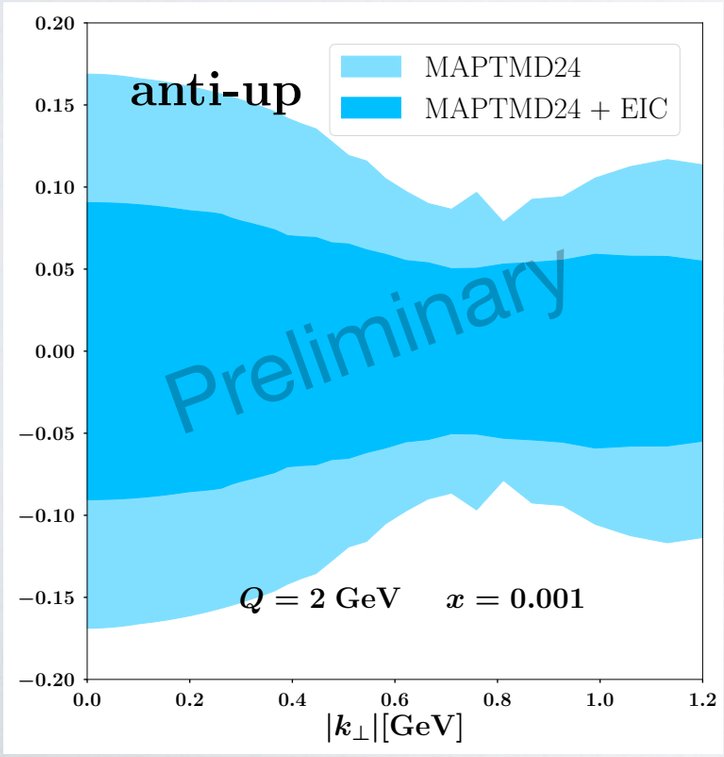

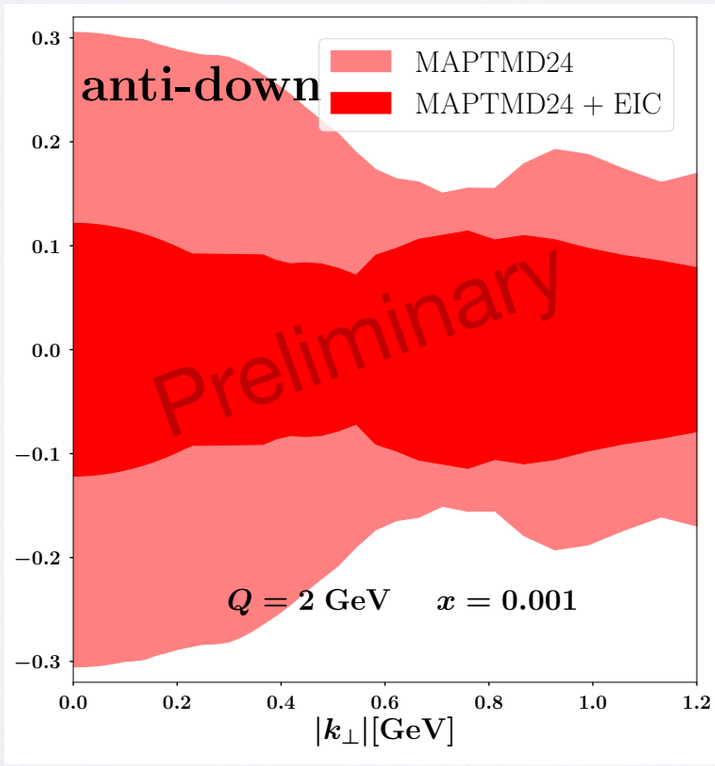

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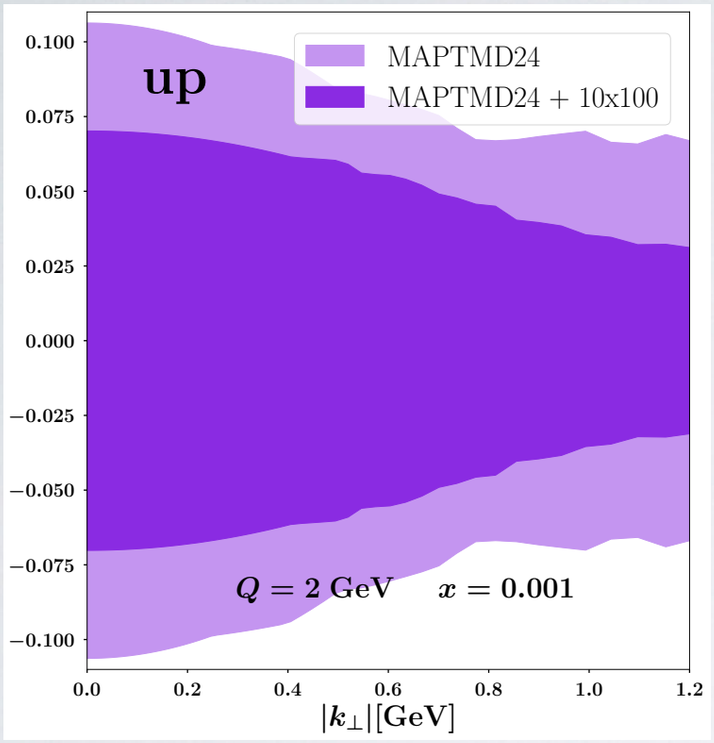

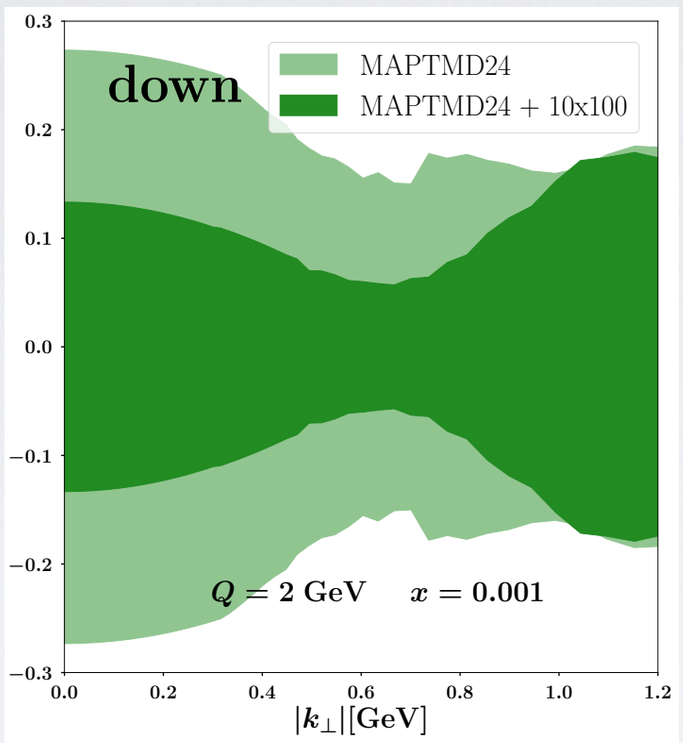

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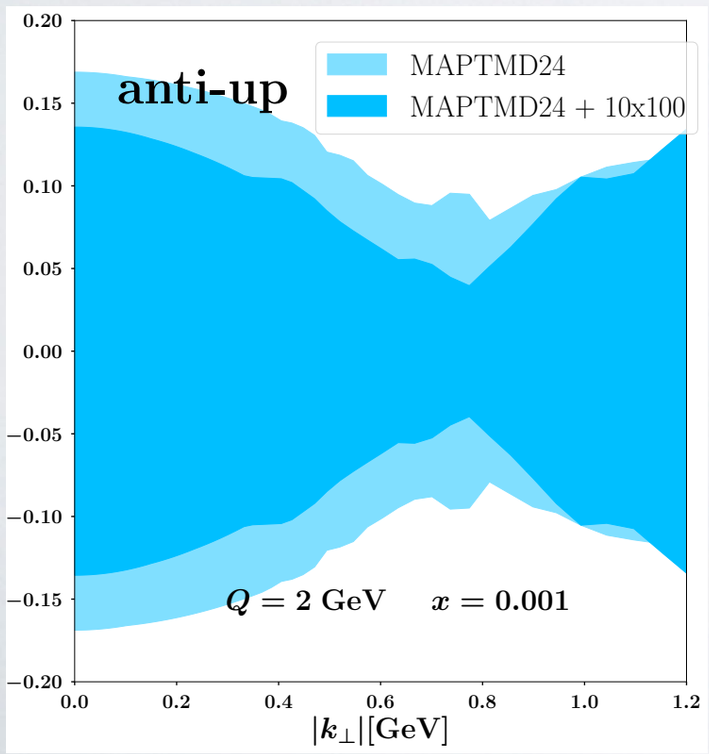
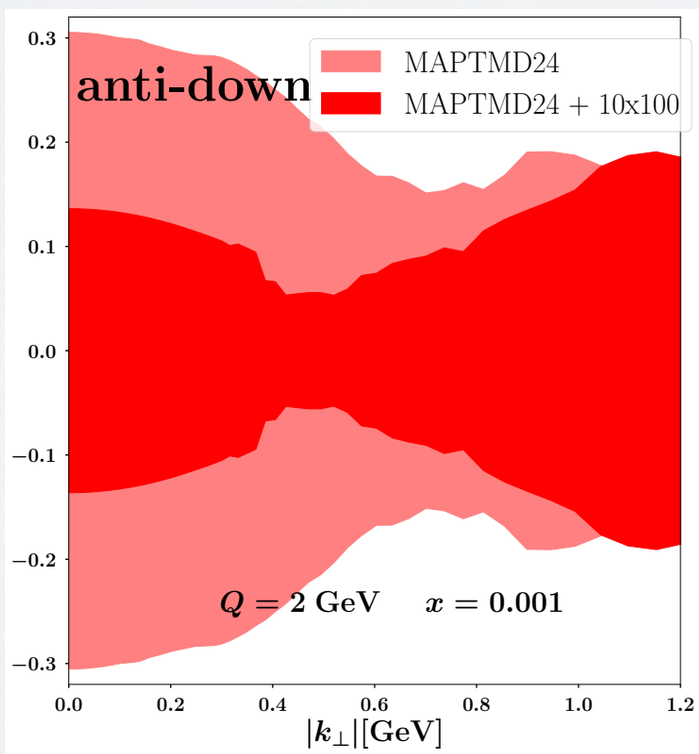
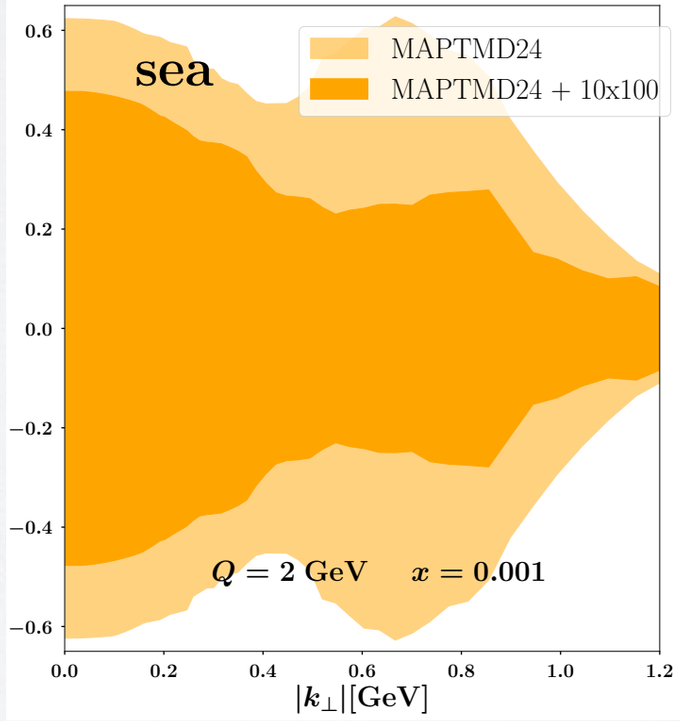
(simulation campaign of May 2024)







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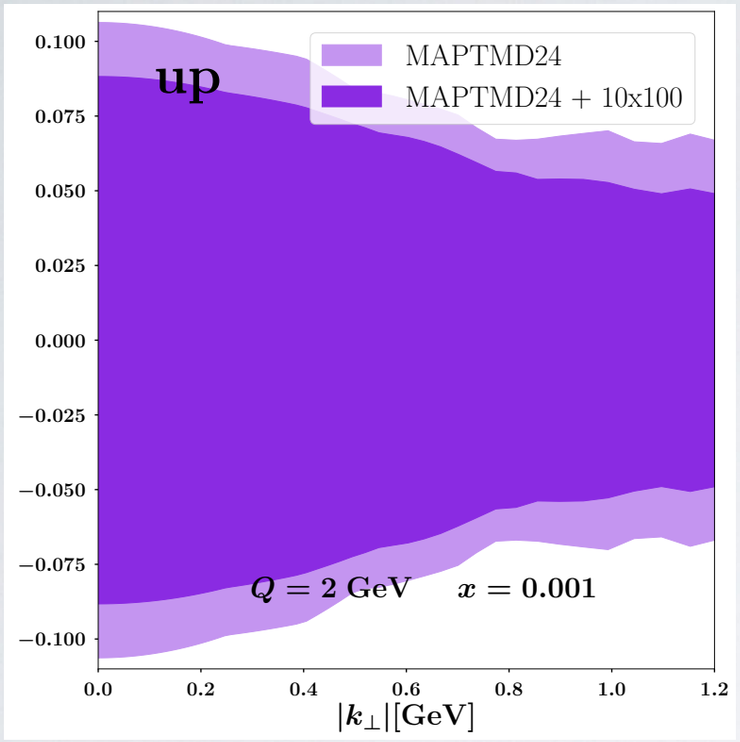
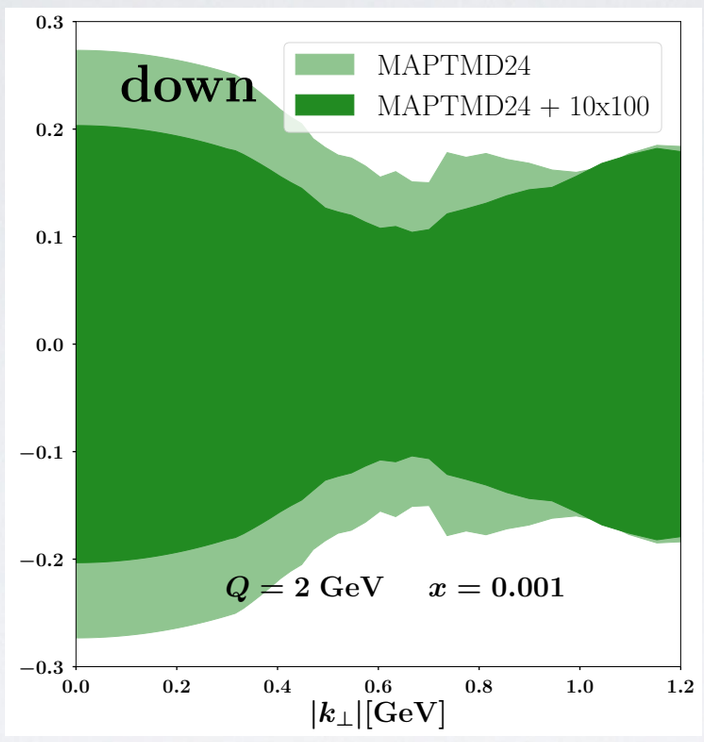
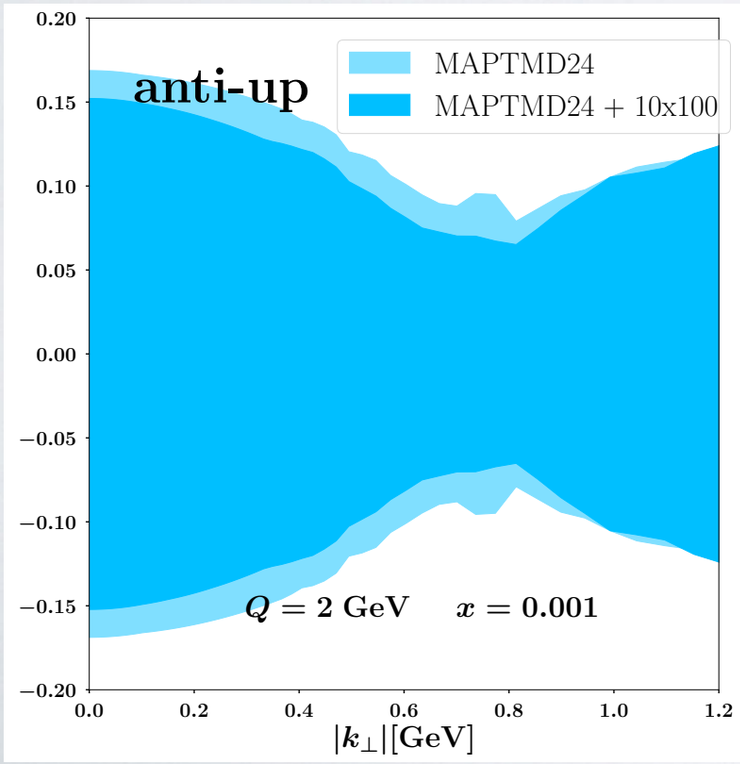
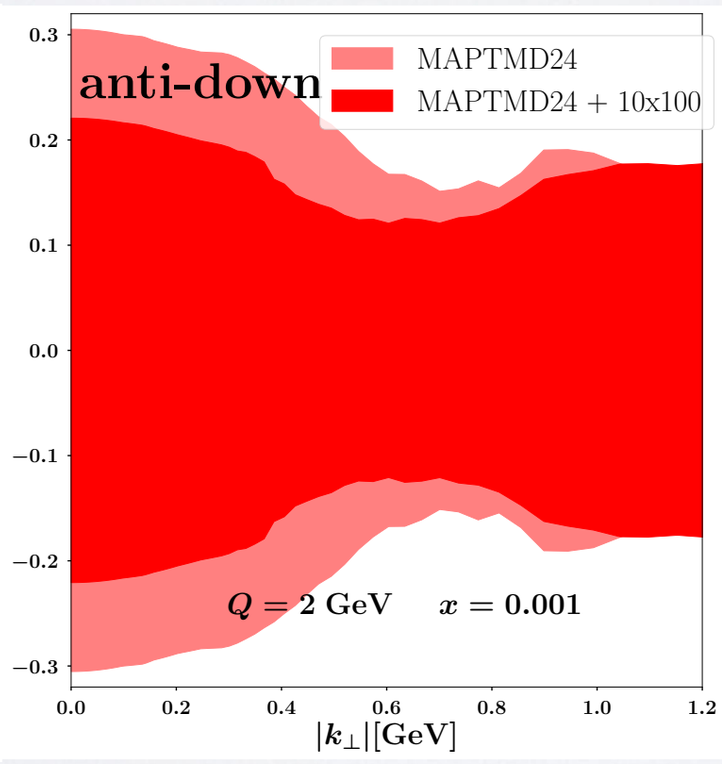
The EIC impact with 10x100 at x=0.001







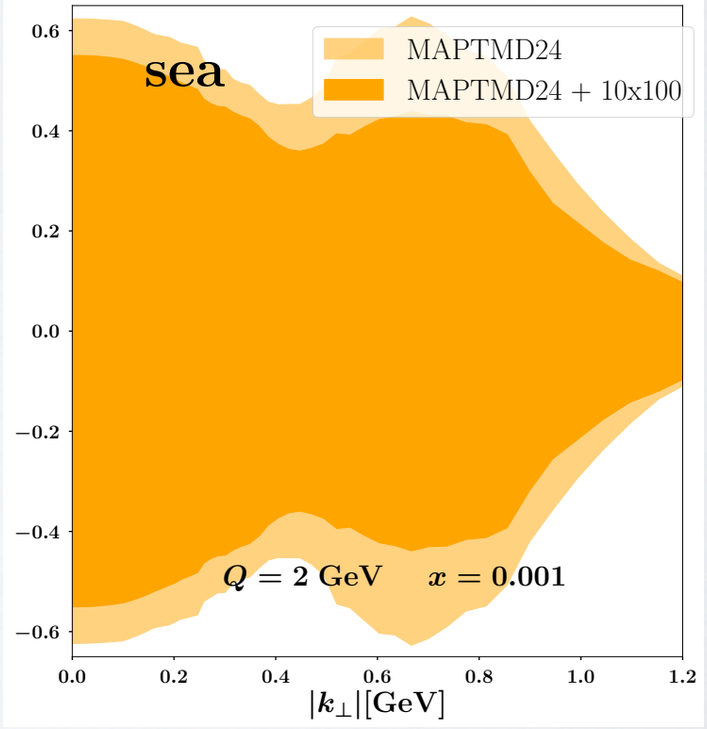


$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$ **x=0.001**

MAPTMD24 2031

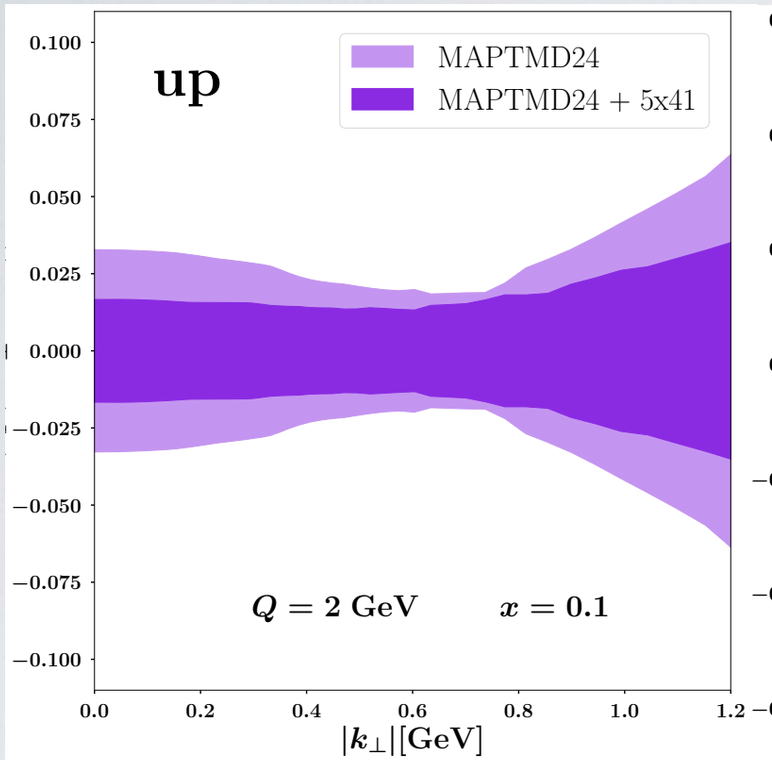
EIC	**# pts.**	**lumi [fb^{-1}]**
10x100	1611	5

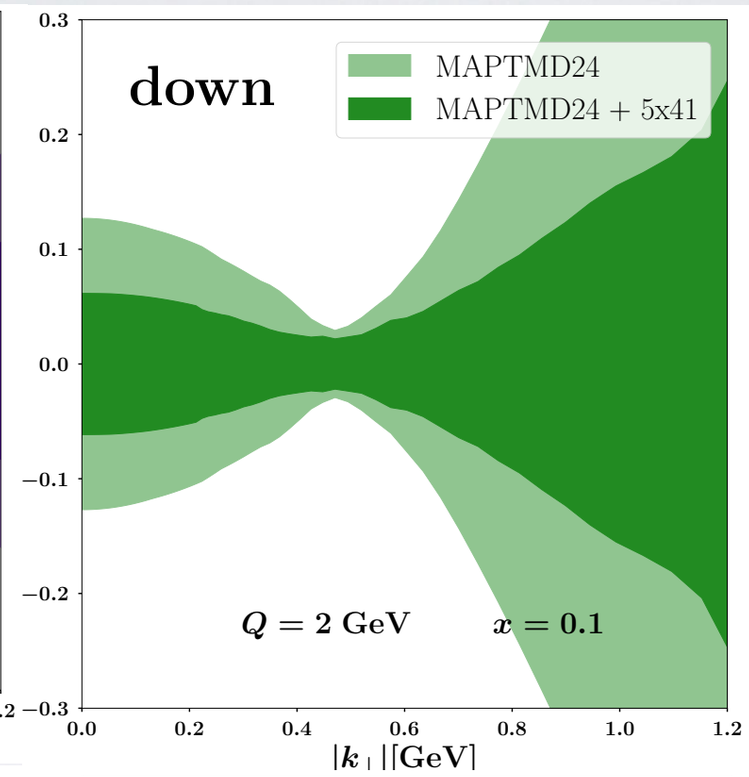
(early Science conditions)

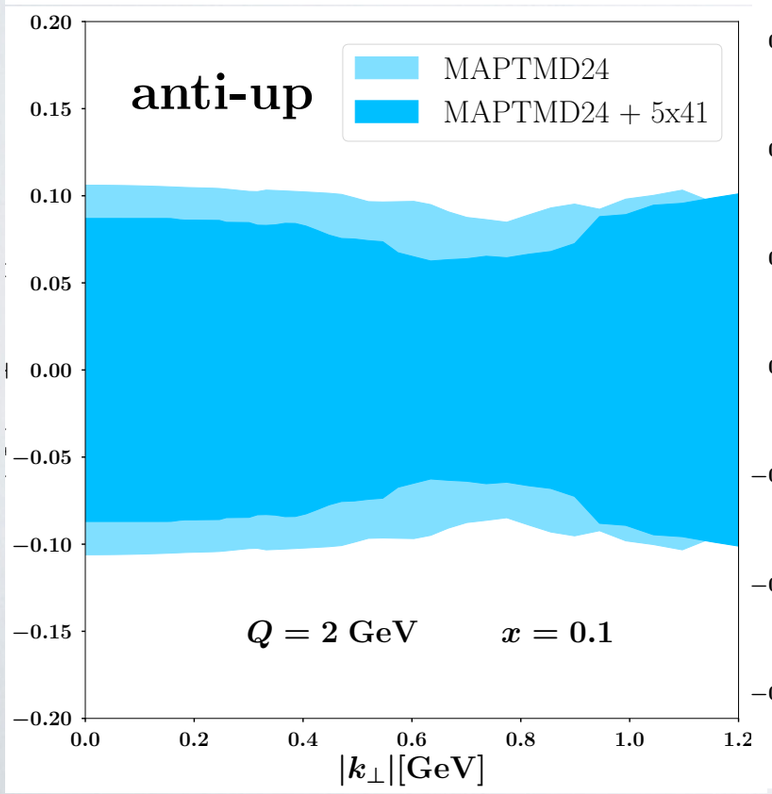


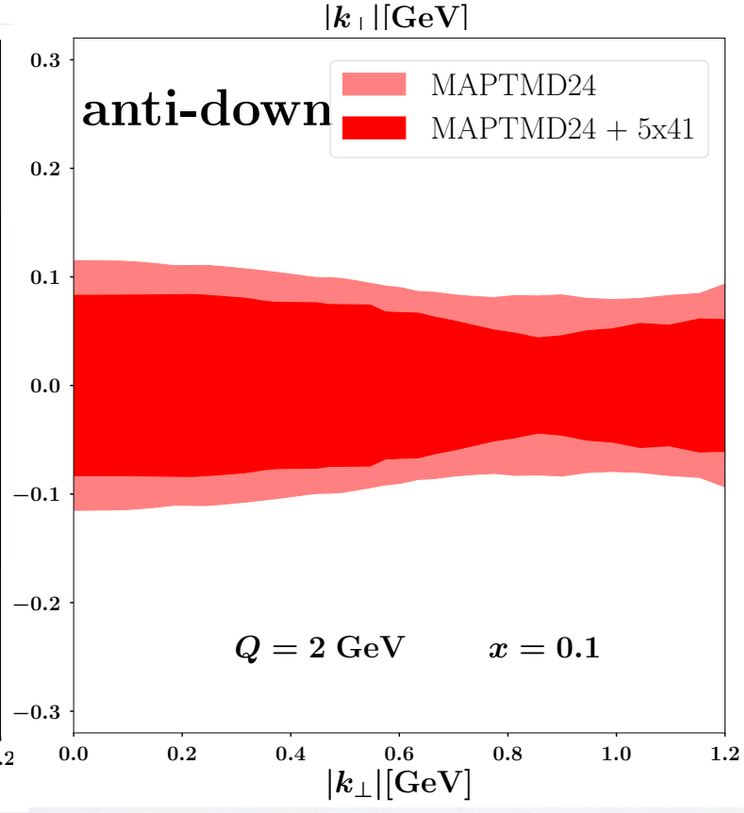
courtesy L. Rossi

The EIC impact with MAPTMD24









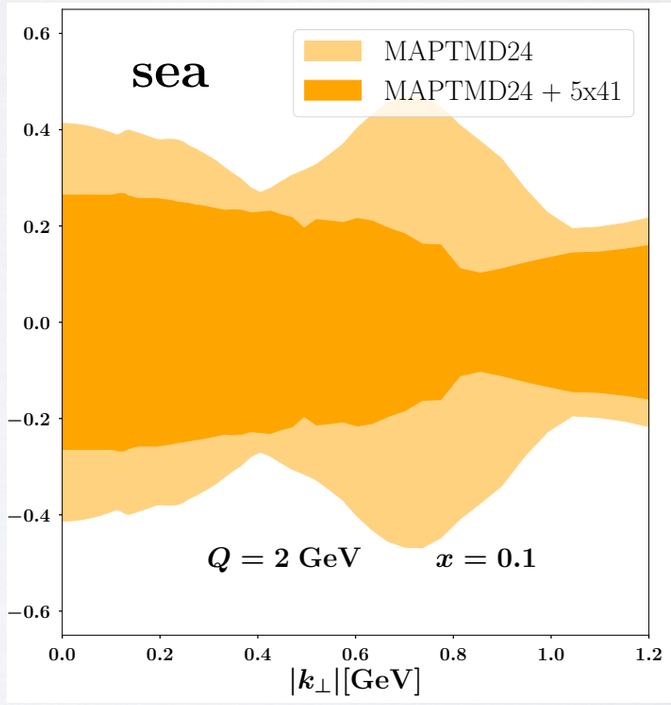
$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$

x=0.1

MAPTMD24 2031

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

(conditions as May simulation campaign)



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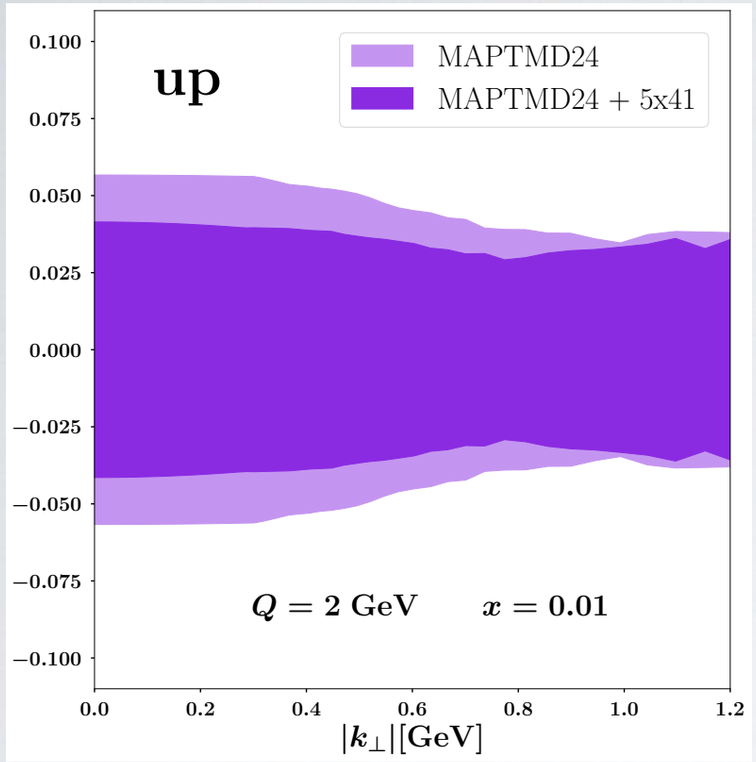
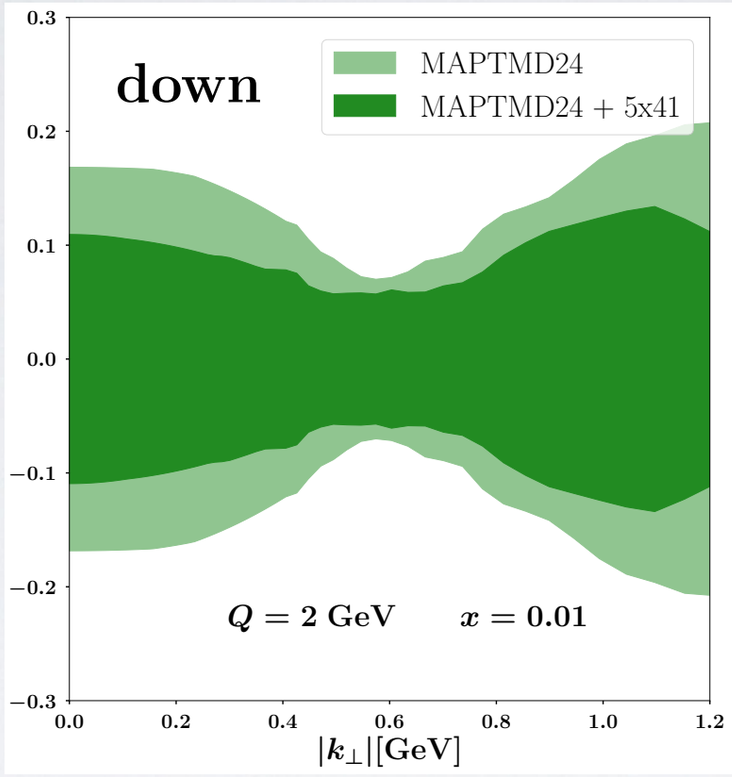
The EIC impact with MAPTMD24

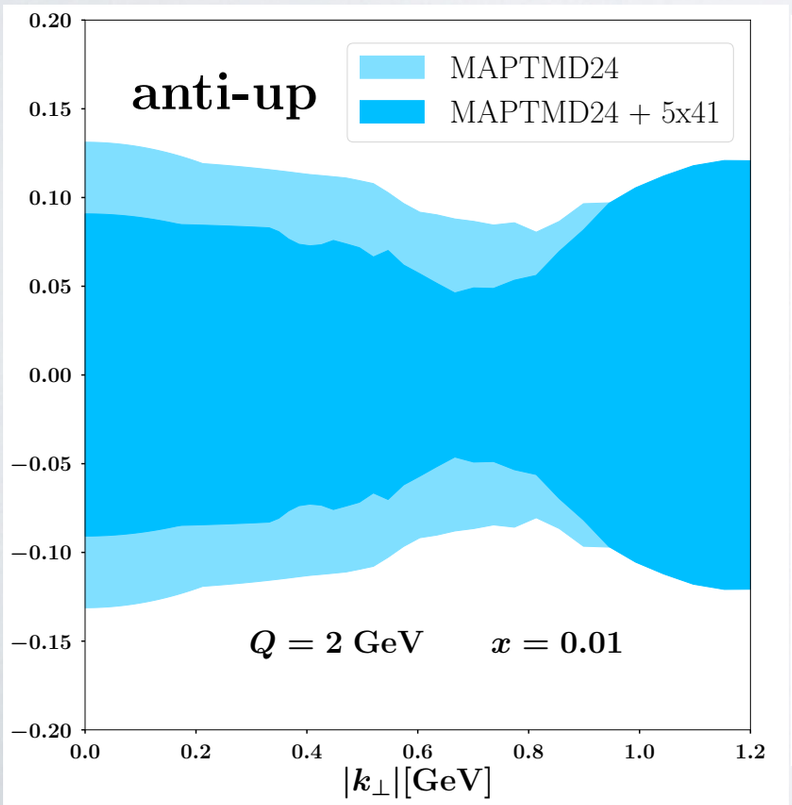


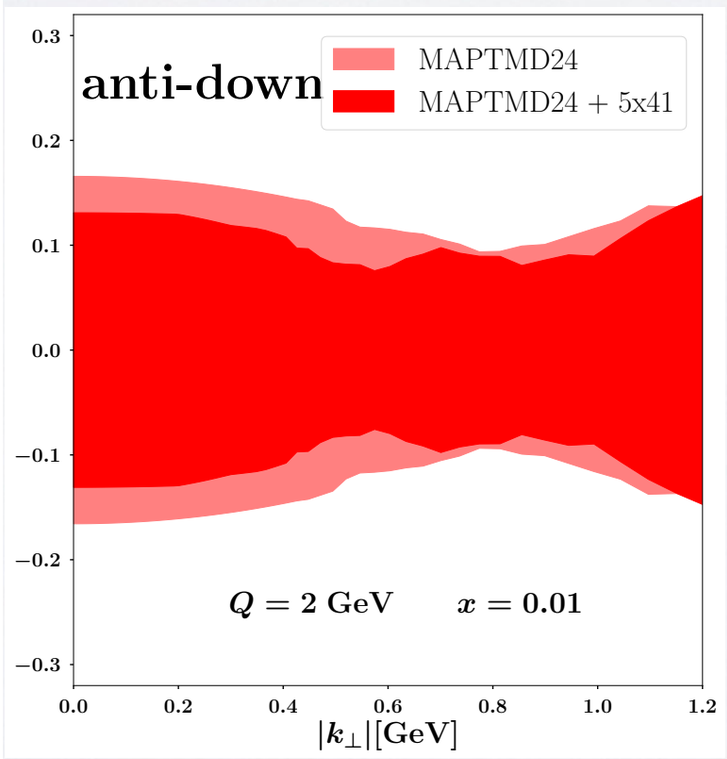


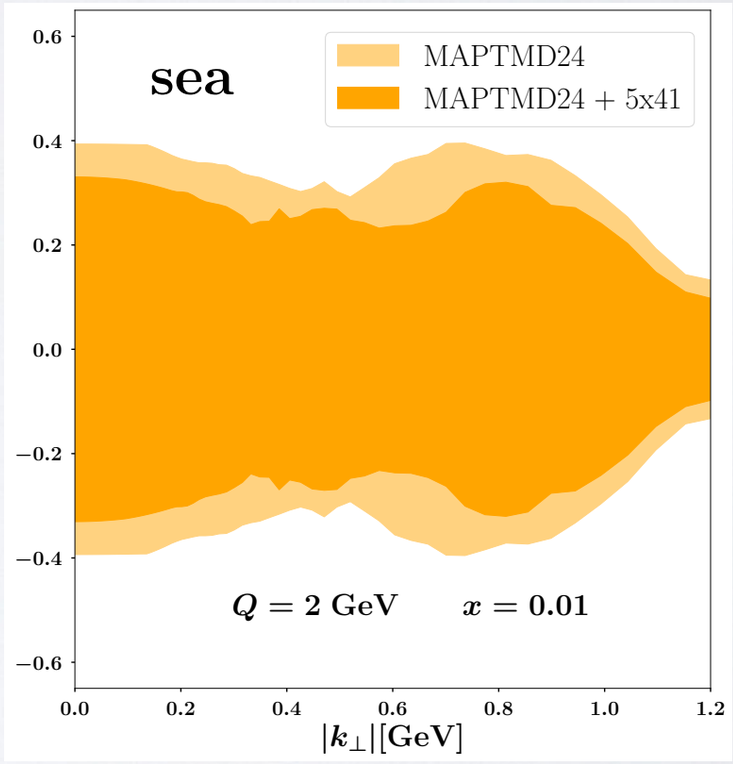
$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$ **x=0.01**

MAPTMD24 2031

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







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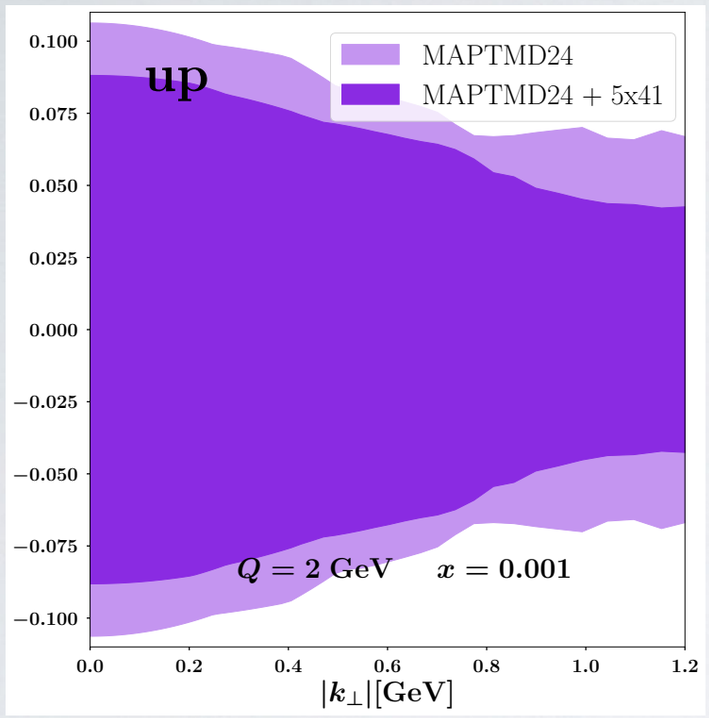
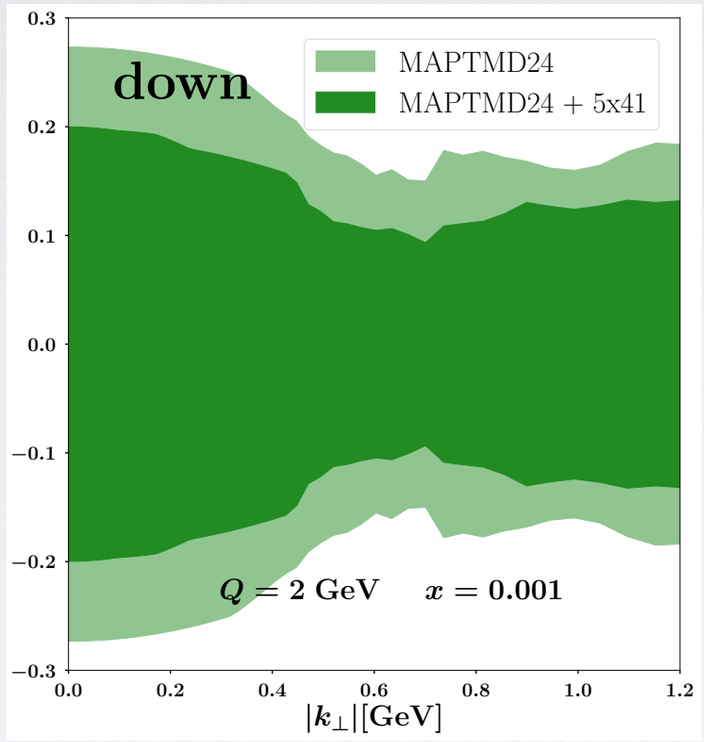
The EIC impact

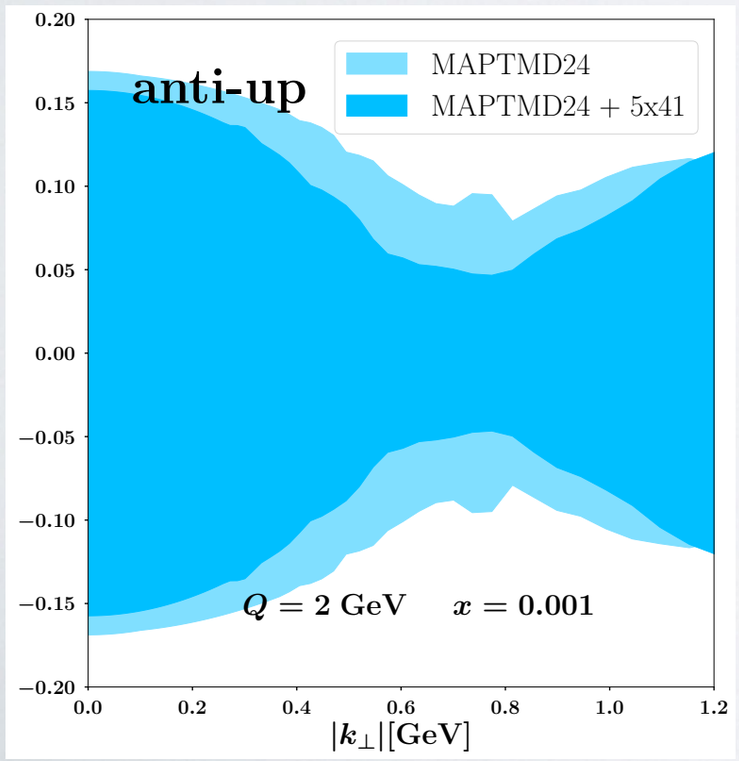
$$\frac{\text{TMD}^q - \langle\text{TMD}^q\rangle}{\langle\text{TMD}^q\rangle}$$ **x=0.001**

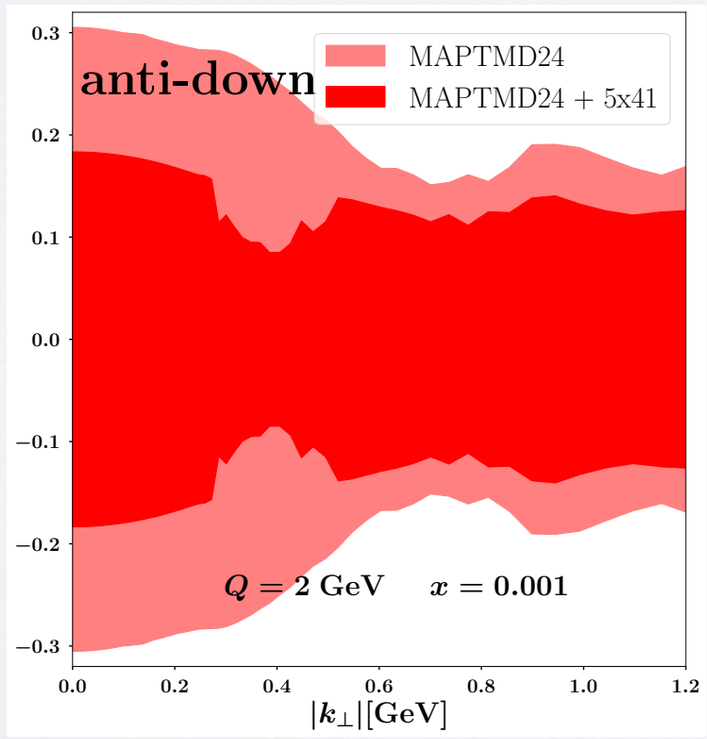
MAPTMD24 2031

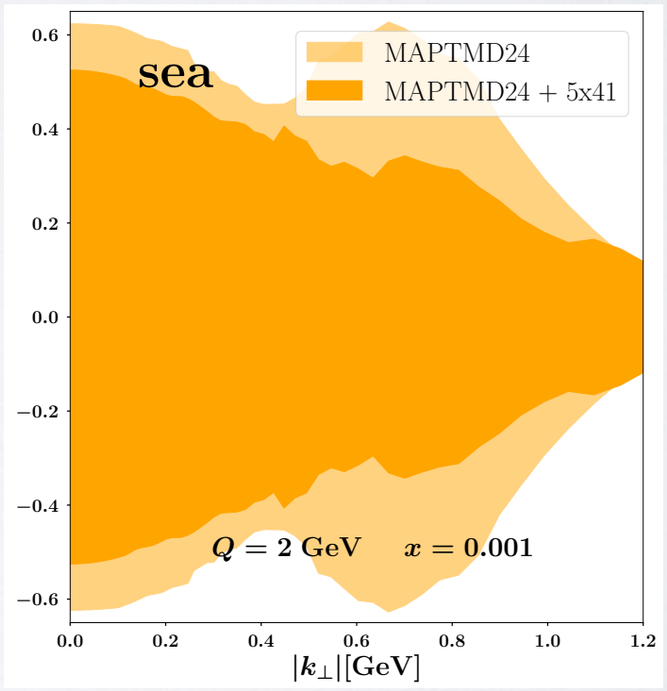
EIC	# pts.	lumi [fb^{-1}]
5x41	1273	2.85











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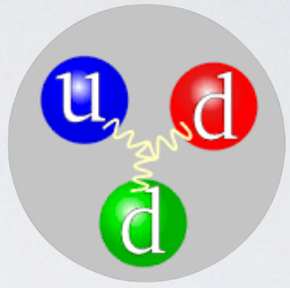
MAPTMD24 flavor channels

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

hermes Hermes

target: p, D
final: $\pi^{\pm}$, $K^{\pm}$

TMD FF

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

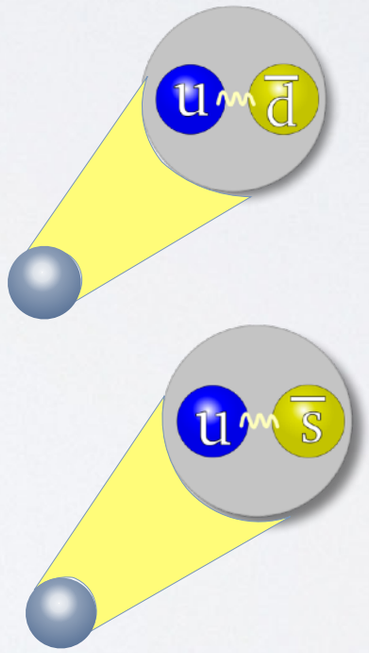
5 channels: favored pion $u \to \pi^+, \ldots$

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

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

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

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



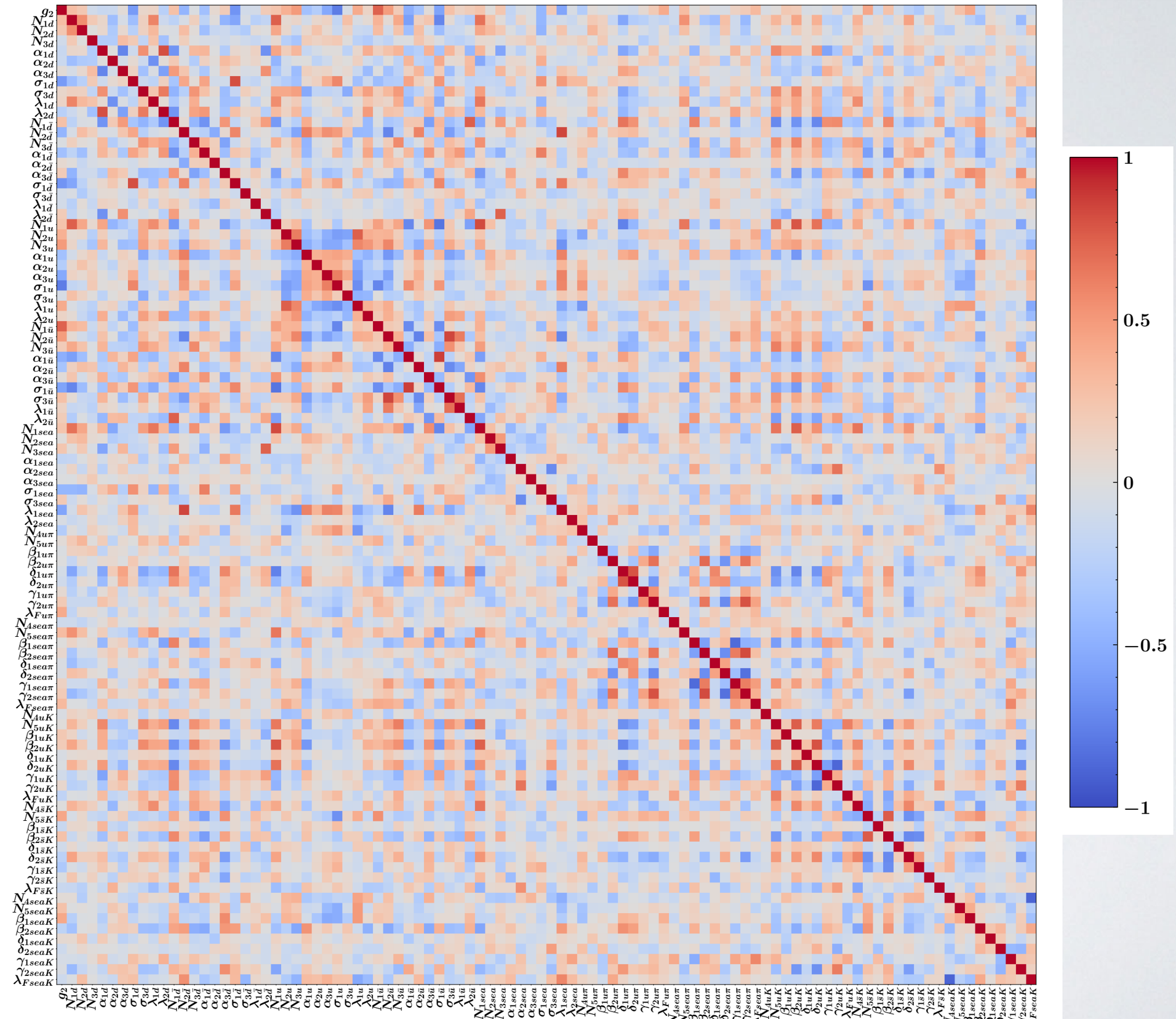
COMPASS Compass

target: D
final: $h^{\pm}$

Drell-Yan

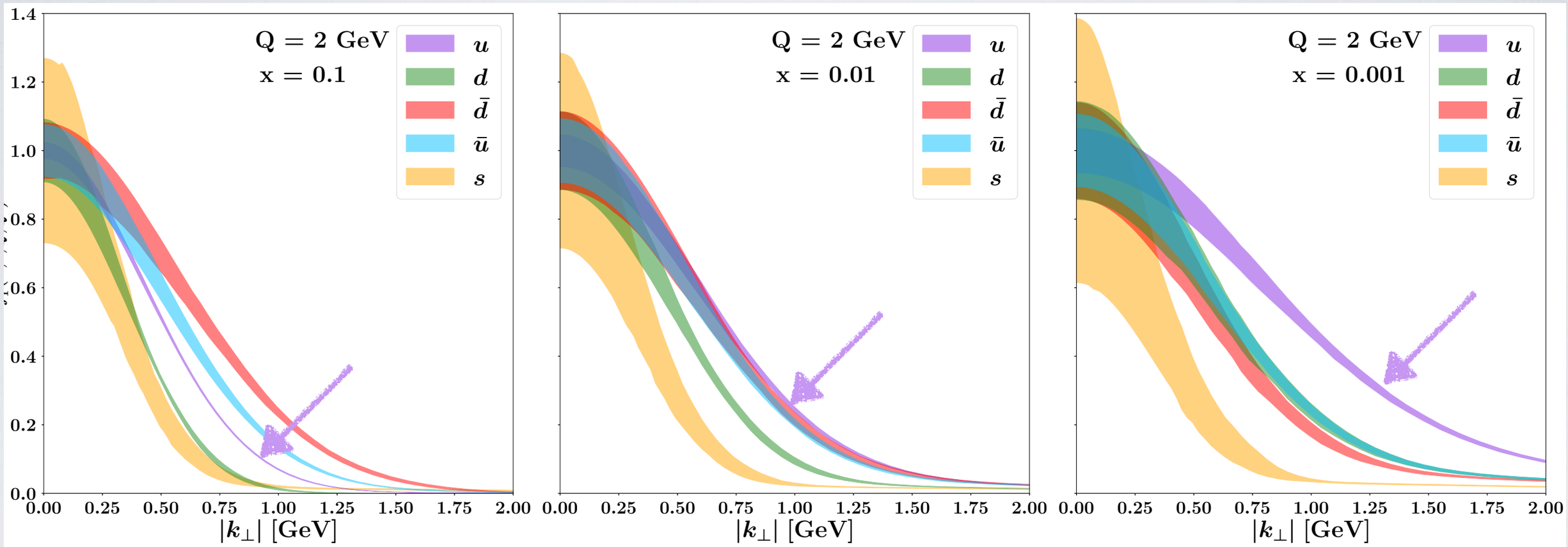
total of 96 parameters but with ~diagonal correlation matrix

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