EIC impact study on unpolarized TMDs

EIC User Group & ePIC Joint Collaboration Meeting

Lorenzo Rossi

July 15th

Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ DEGLI STUDI DI MILANO


VS TERRARVM ORBIS GEOGRAPHICA AC HYDROGRAPHICA TABVLA

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From Bachelor to PhD
Under Supervision of
M. Radici and A. Bacchetta

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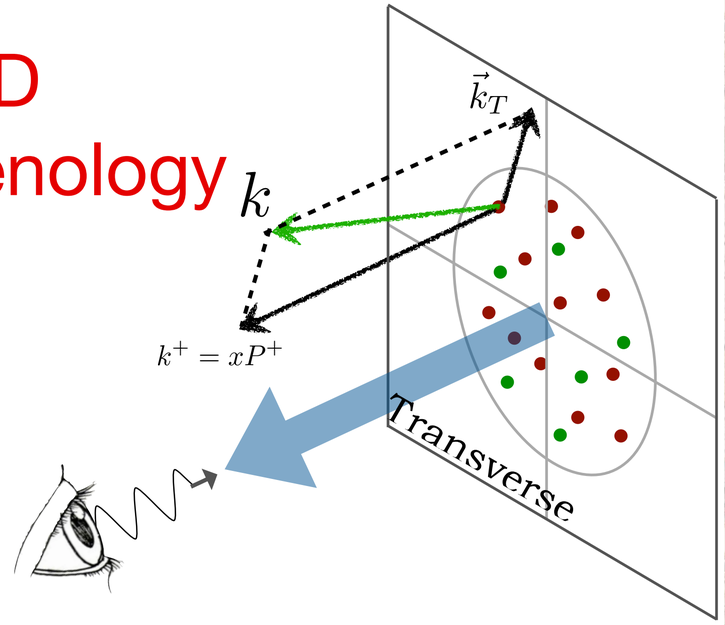
TMD
phenomenology



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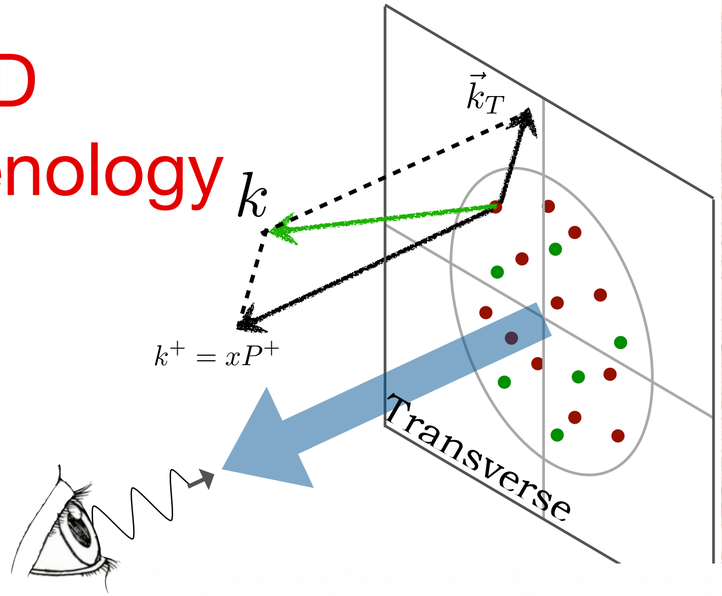

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Flavor dependence of unpolarized quark transverse momentum distributions from a global fit

The MAP collaboration[1]

Alessandro Bacchetta[a,b] Valerio Bertone[c] Chiara Bissolotti[d]
Giuseppe Bozzi[e,f] Matteo Cerutti[g,h] Filippo Delcarro[a,b] Marco Radici[b]
Lorenzo Rossi[a,b] and Andrea Signori[i,j]

PHYSICAL REVIEW LETTERS **134,** 121901 (2025)

PHYSICAL REVIEW LETTERS **135,** 021904 (2025)

Neural-Network Extraction of Unpolarized Transverse-Momentum-Dependent Distributions

Alessandro Bacchetta[1,2,*] Valerio Bertone[3,†] Chiara Bissolotti[4,‡] Matteo Cerutti[5,6,§] Marco Radici[2,‖]
Simone Rodini[7,¶] and Lorenzo Rossi[8,9,**]

MAP (Multi-dimensional Analyses of Partonic distributions) Collaboration

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Exploring the Three-Dimensional Momentum Distribution of Longitudinally Polarized Quarks in the Proton

Alessandro Bacchetta[1,2,*] Alessia Bongallino[3,†] Matteo Cerutti[4,5,‡] Marco Radici[2,§] and Lorenzo Rossi[1,2,‖]

PHYSICAL REVIEW D **107,** 014014 (2023)

Extraction of pion transverse momentum distributions from Drell-Yan data

Matteo Cerutti[1,2,*] Lorenzo Rossi[1,2,†] Simone Venturini[1,2,‡] Alessandro Bacchetta[1,2,§]
Valerio Bertone[3,‖] Chiara Bissolotti[4,¶] and Marco Radici[2,**]

MAPTMD24 extraction - starting points

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- Global analysis of Drell-Yan and Semi-Inclusive DIS data sets: ***2031*** data points (DY + SIDIS)

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Flavour dependence

JHEP 08 (2024) 232

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- Extremely good description: $\chi^2/\mathrm{N_{data}} = 1.08$

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Normalized extracted TMD PDFs

Normalized extracted TMD PDFs $\frac{f_1(x, k_\perp, Q)}{f_1(x,0,Q)}$

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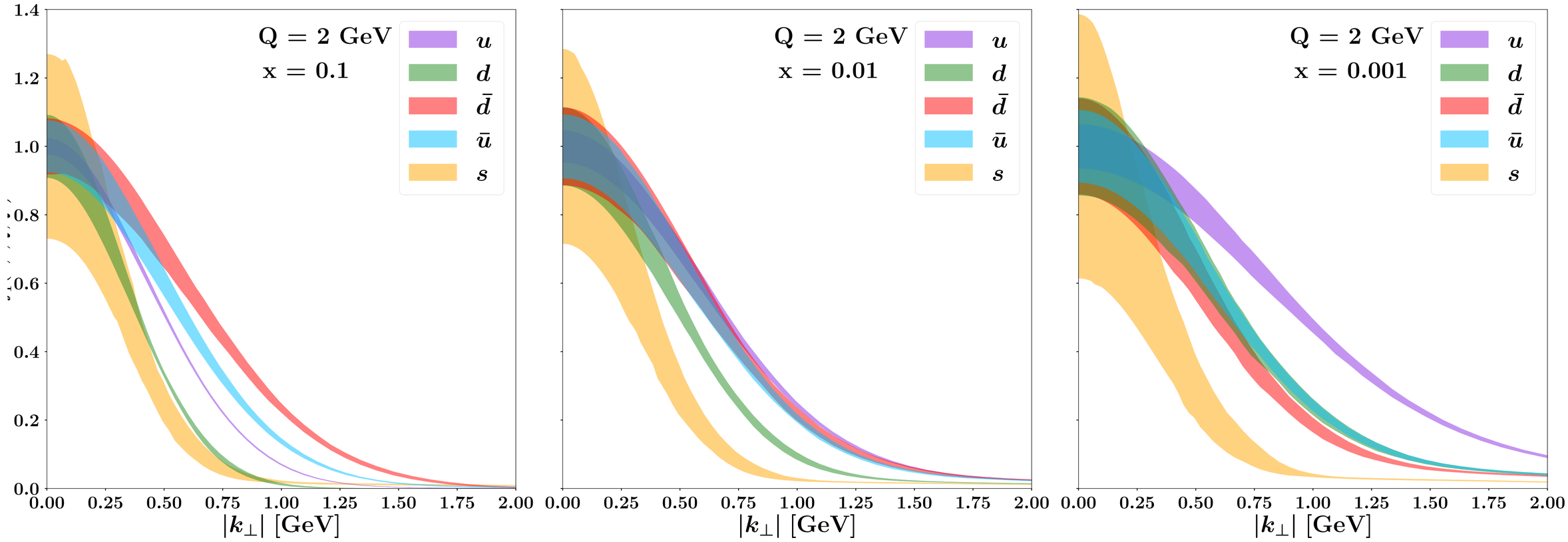

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Normalized extracted TMD PDFs

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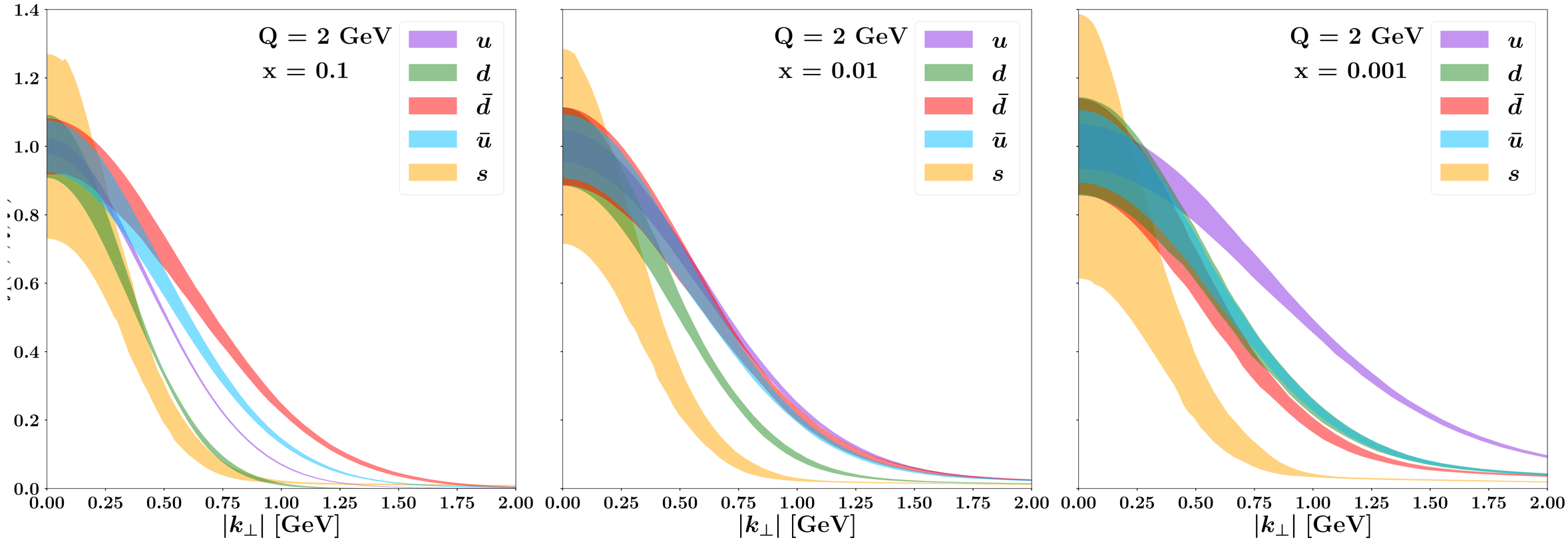

Very different $k_\perp$- behaviours!

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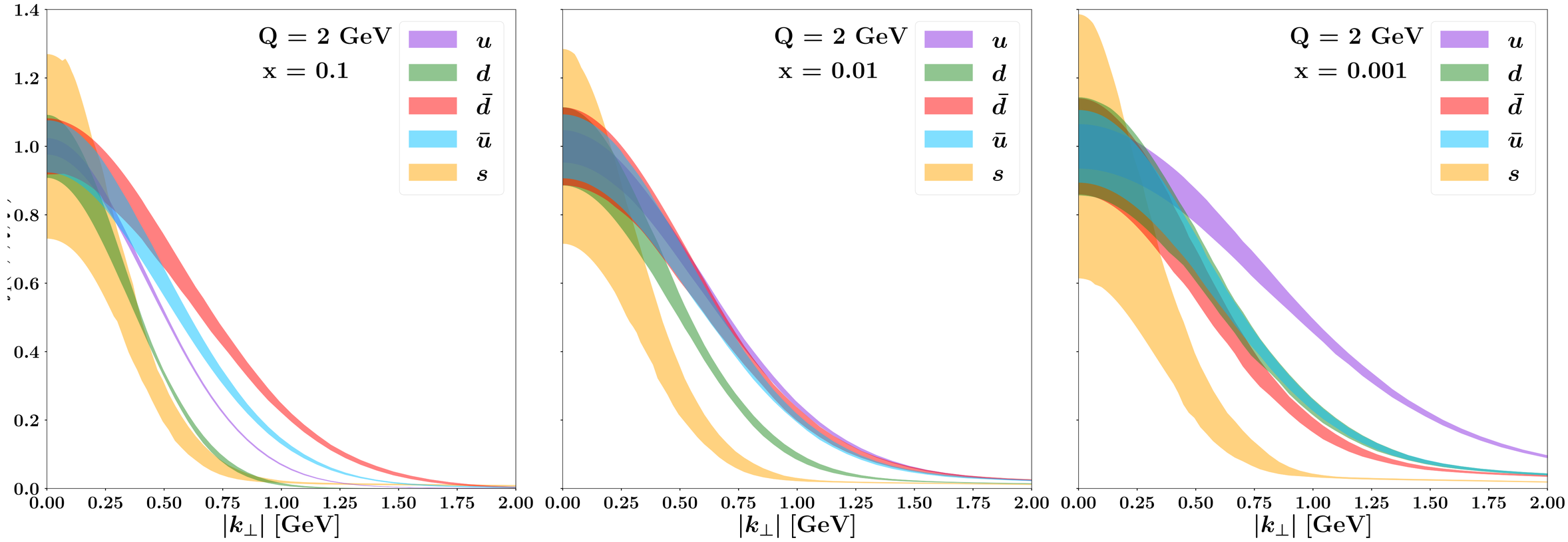

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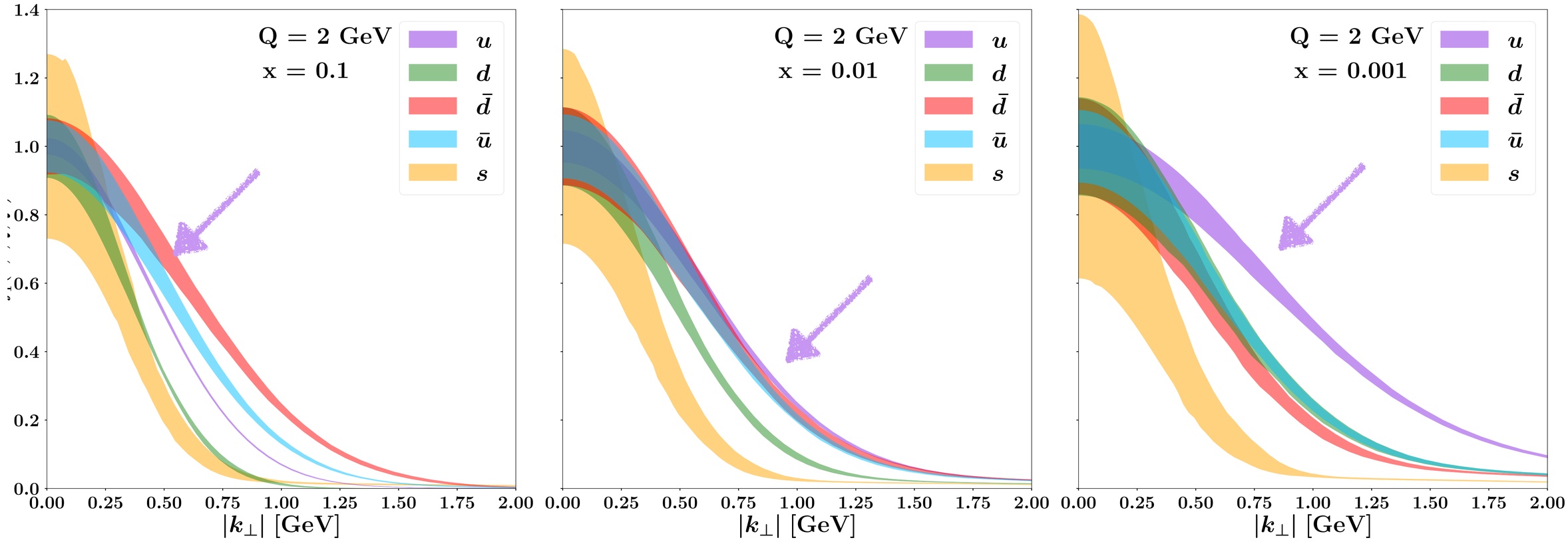

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EIC impact in Early Science conditions (SIDIS with only π^+)

ep Luminosity for Phase-1

High Divergence	Lumi per Fill (5 h)	Lumi per Year
5 GeV e x 250 GeV p	9.26 pb^{-1}	6.48 fb^{-1}
10 GeV e x 250 GeV p	13.12 pb^{-1}	9.18 fb^{-1}
5 GeV e x 130 GeV p	6.3 pb^{-1}	4.36 fb-1
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Low Divergence	Lumi per Fill (5 h)	Lumi per Year
5 GeV e x 250 GeV p	6.81 pb^{-1}	4.78 fb^{-1}
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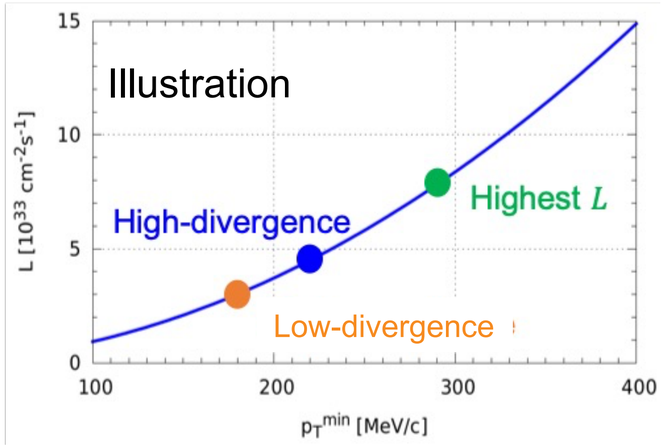
Compare to HERA integrated luminosity 1992 – 2007: 0.6 fb^{-1}

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



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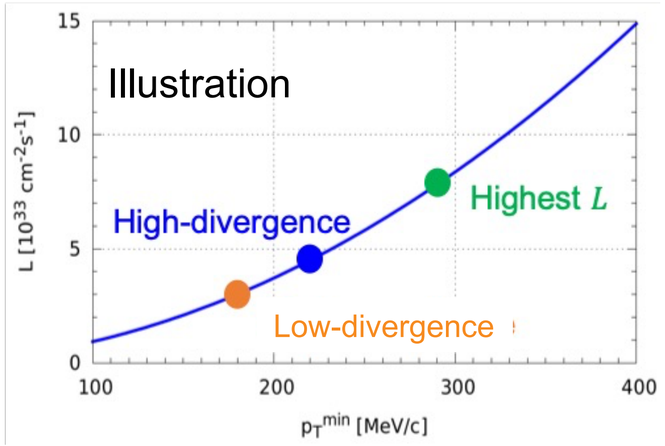

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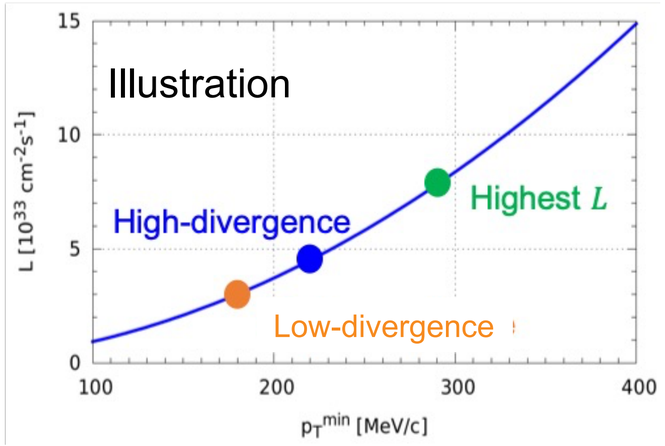

E. Aschenauer, ePIC general meeting Jan. 2025 (Villa Mondragone)

and $10\,fb^{-1}$

EIC impact in Early Science Conditions

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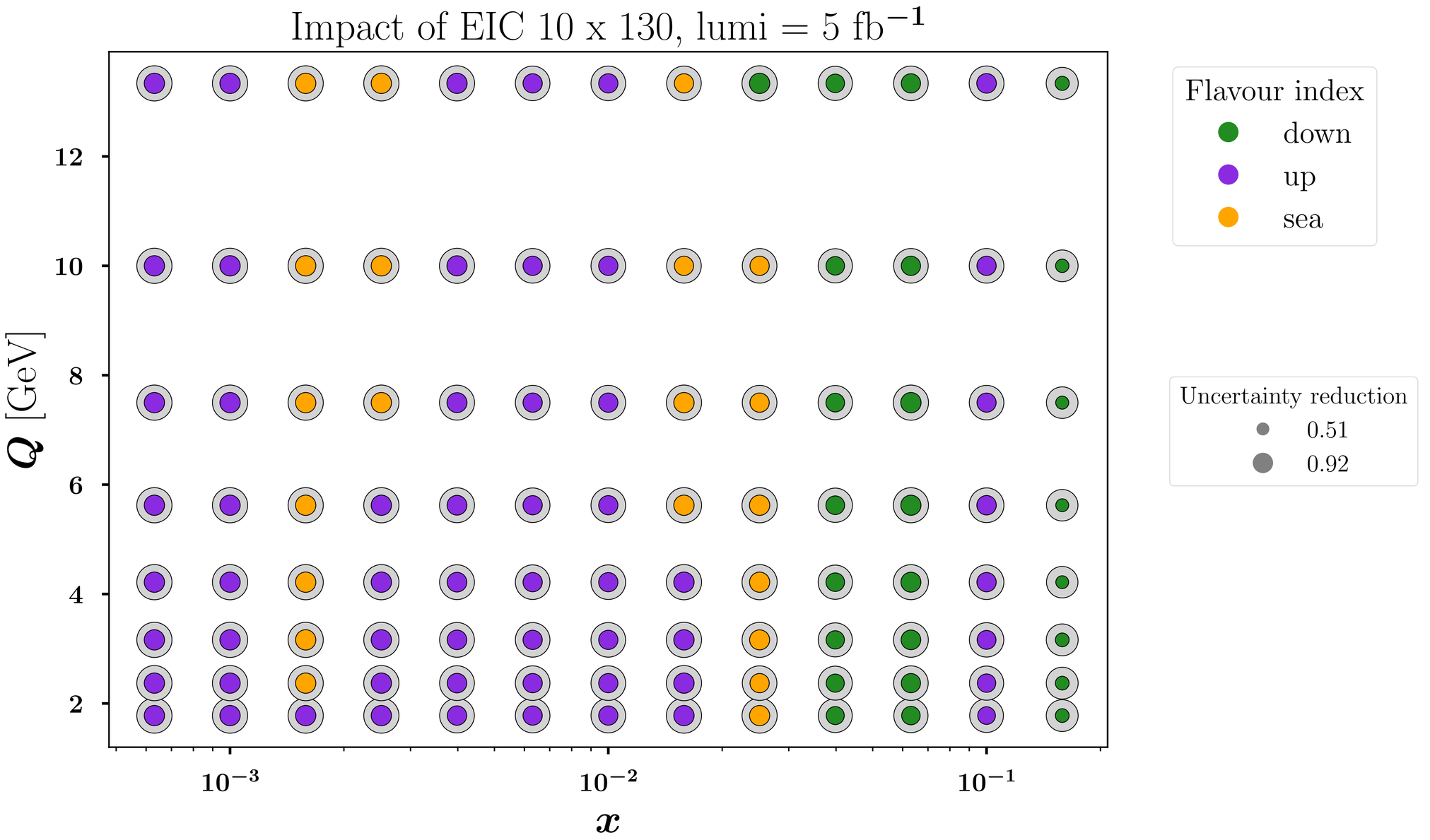

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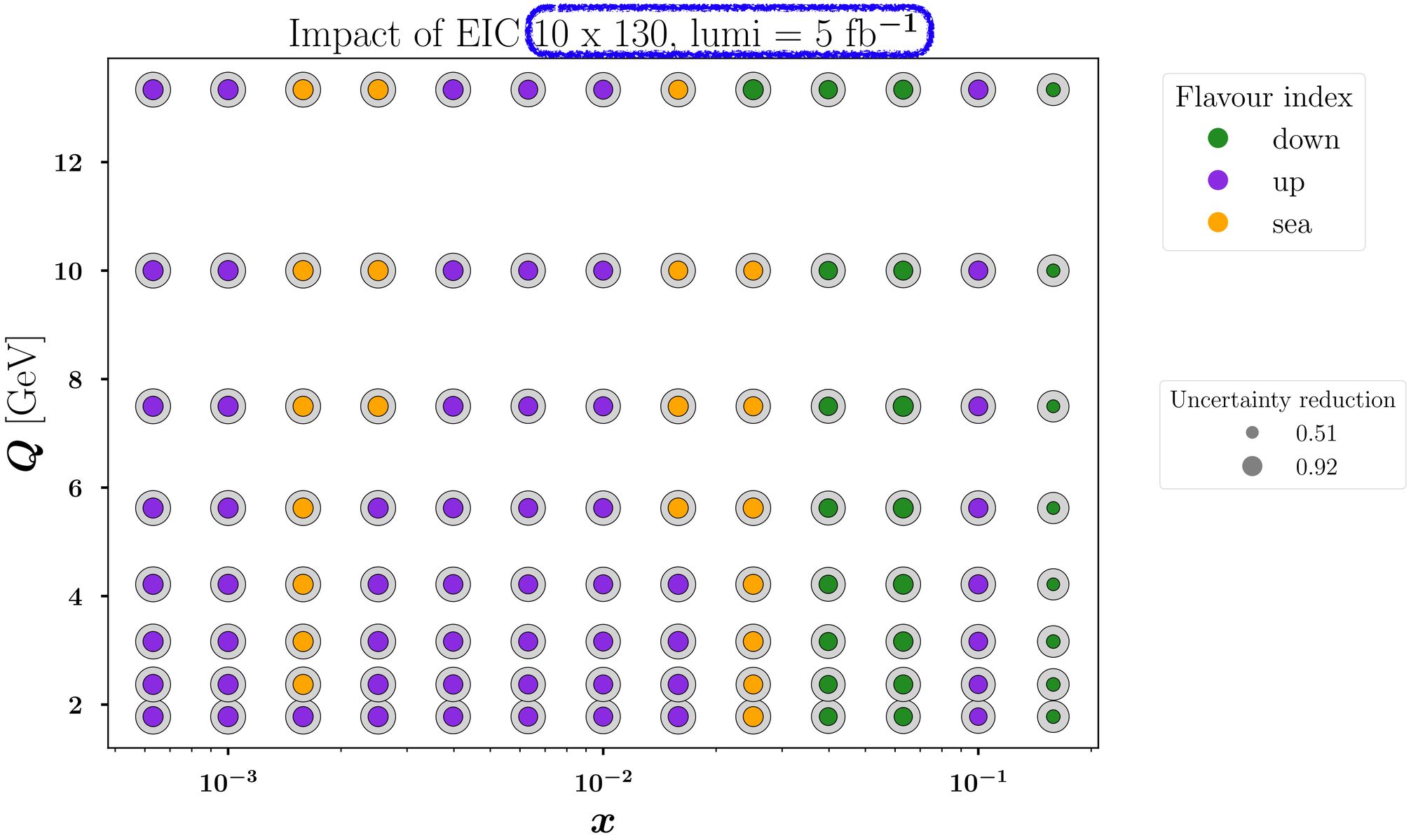

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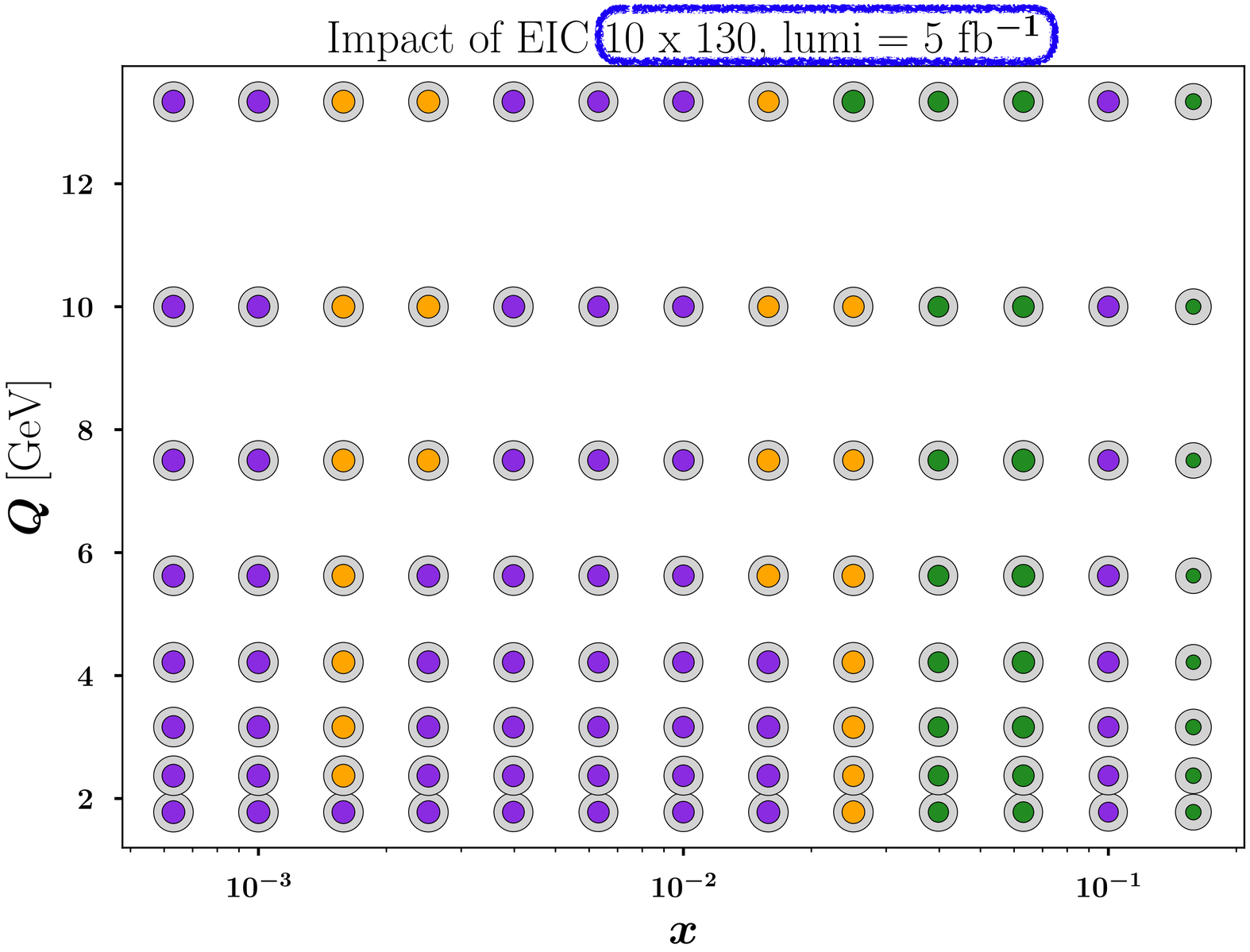

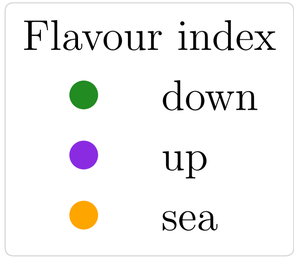

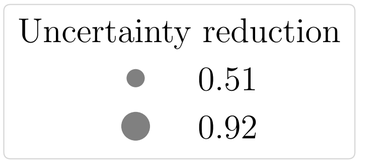

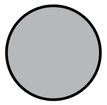

MAPTMD24 max. uncertainty of $f_1(x, k_\perp, Q)$ over all $k_\perp$

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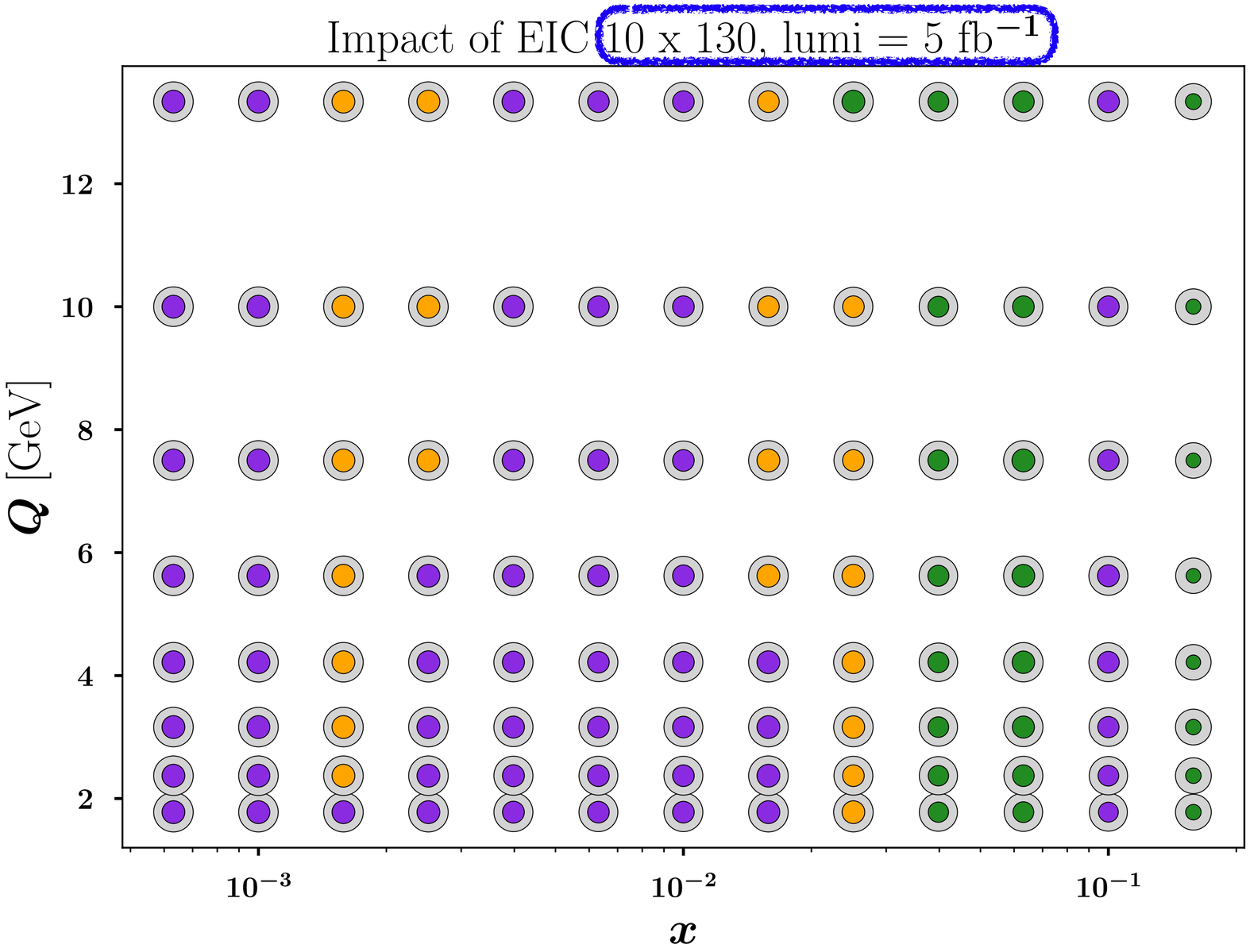

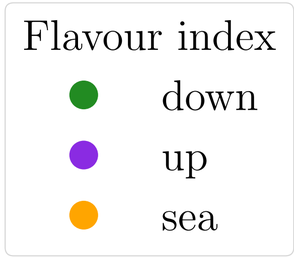

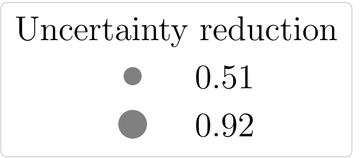

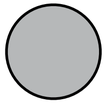

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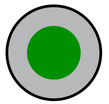

MAPTMD24 + EIC, color indicates the flavor with max. reduction over all $k_\perp$

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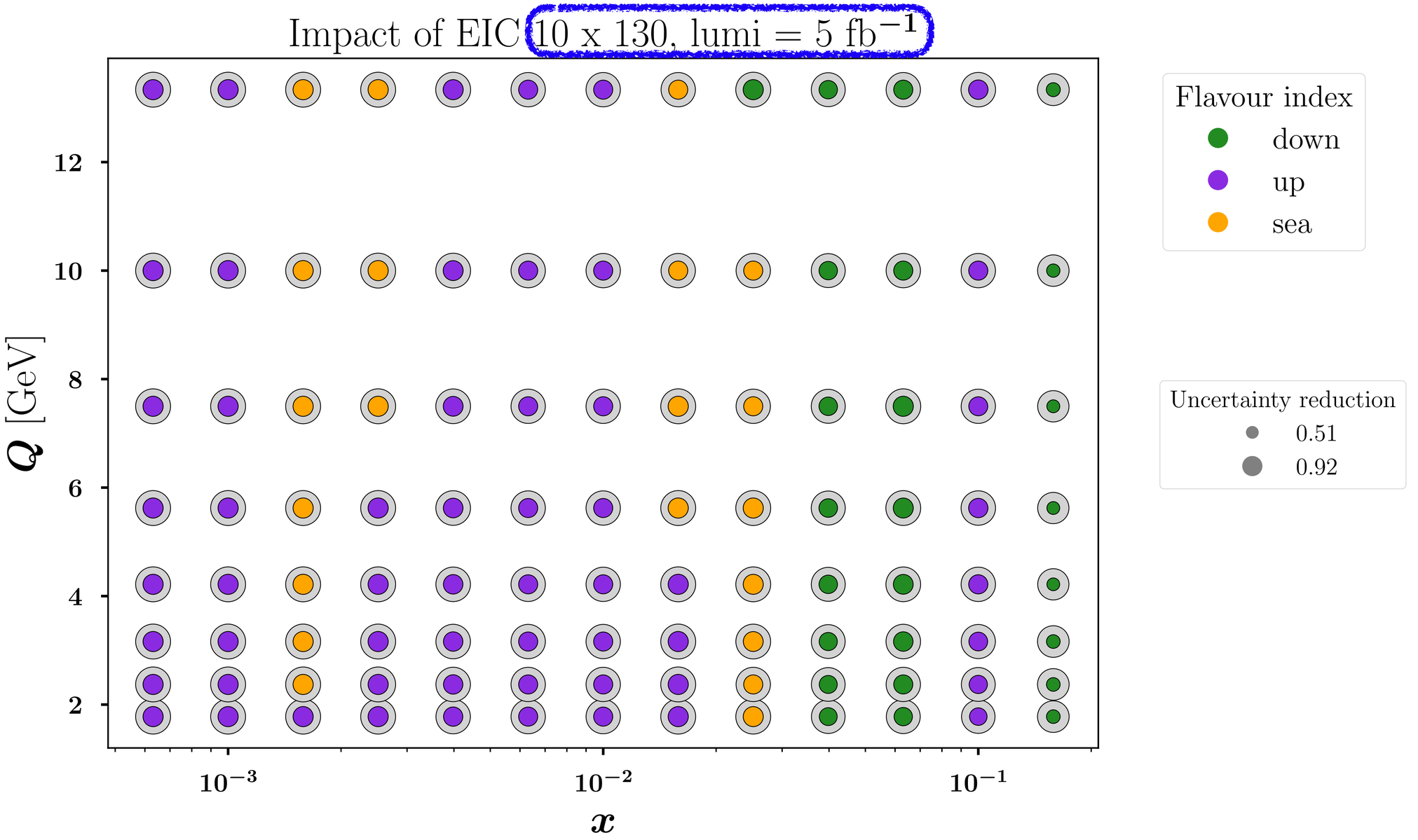

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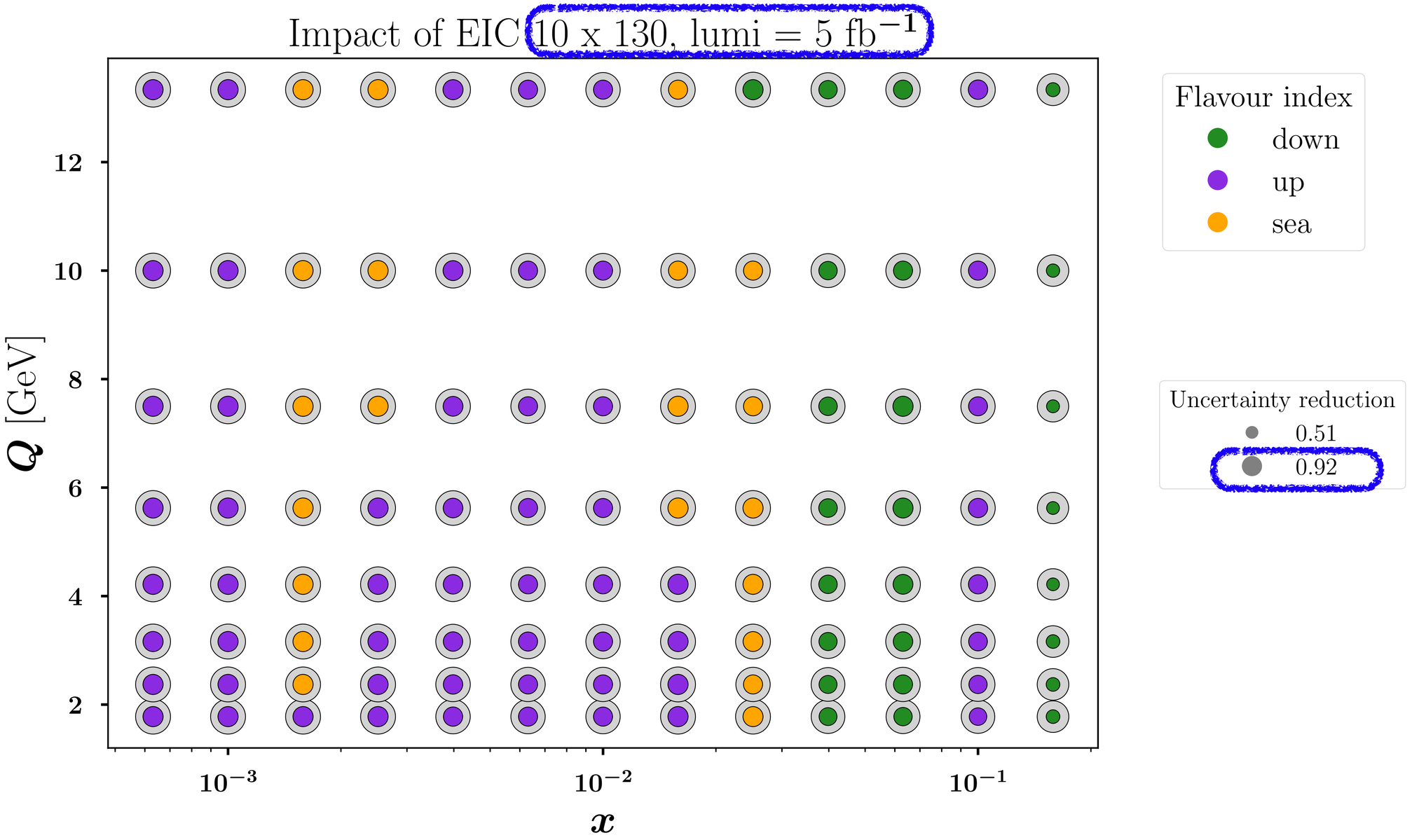

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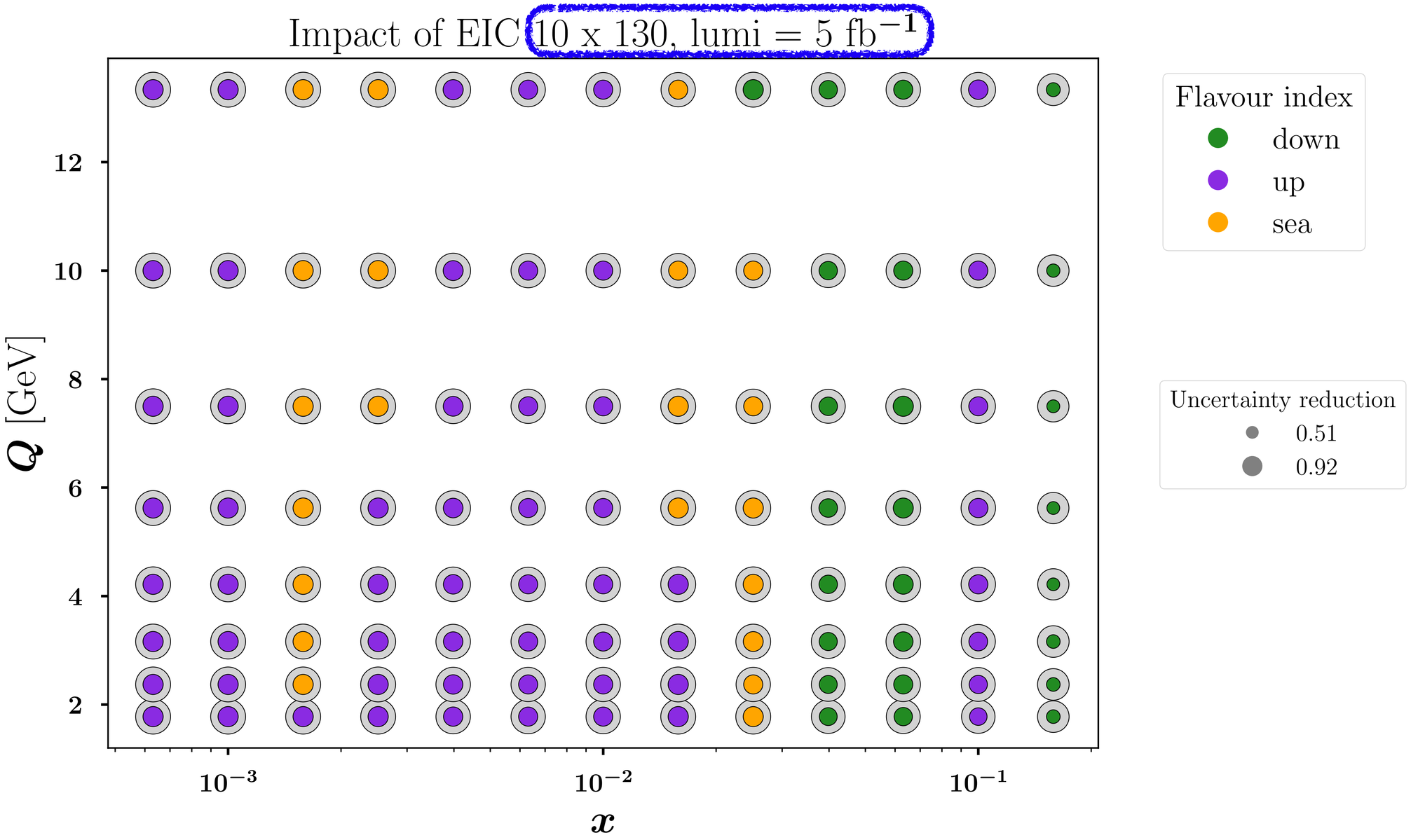

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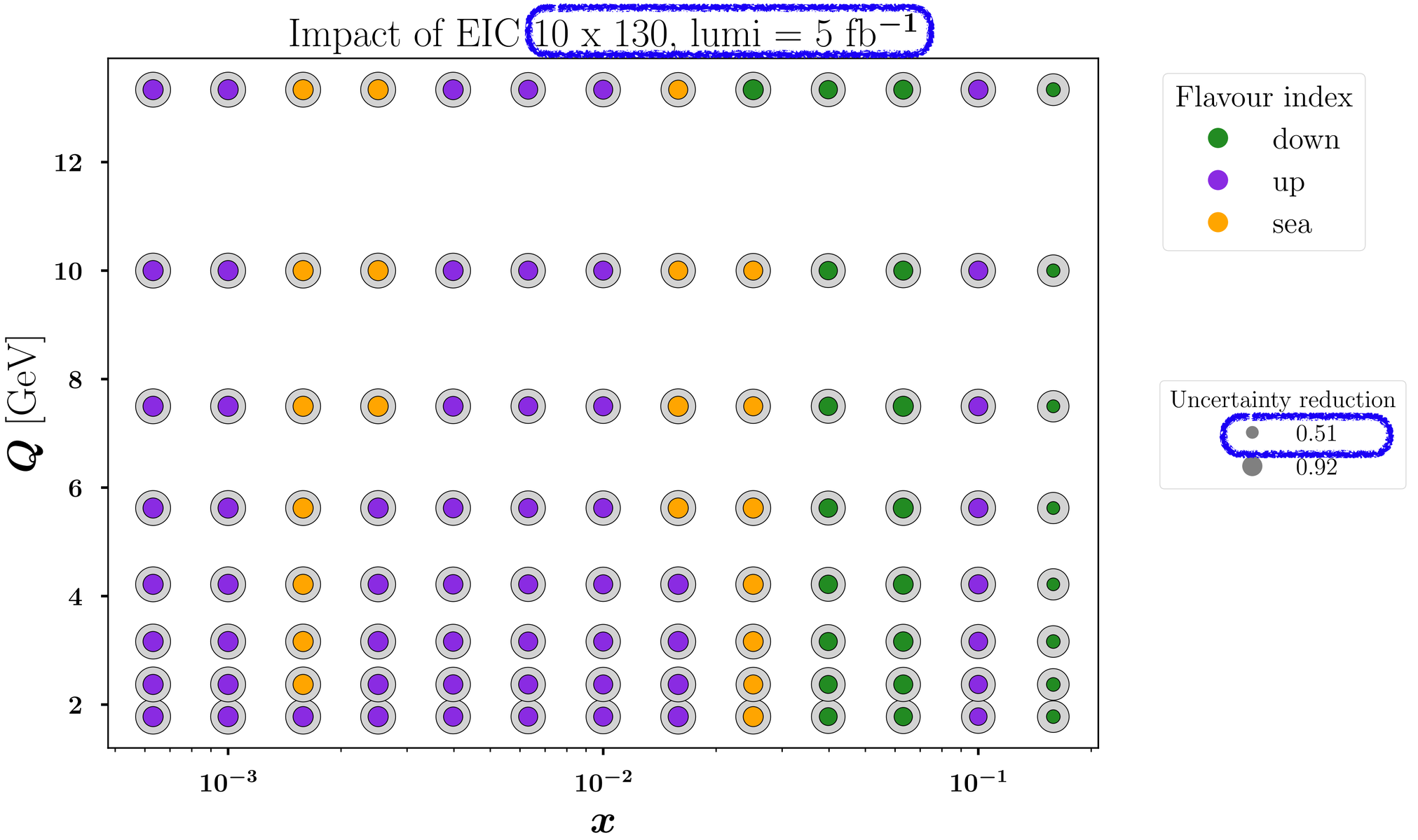

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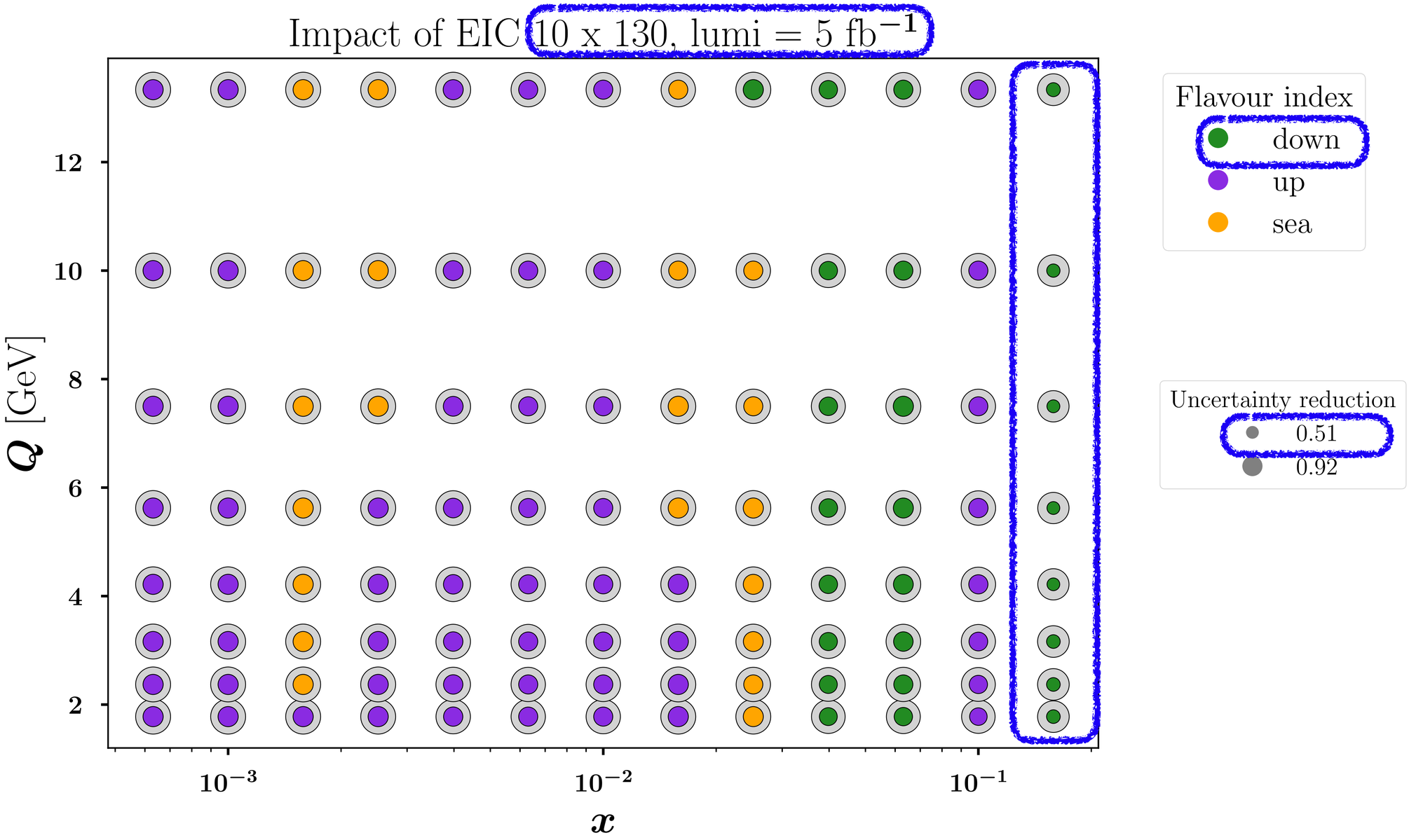

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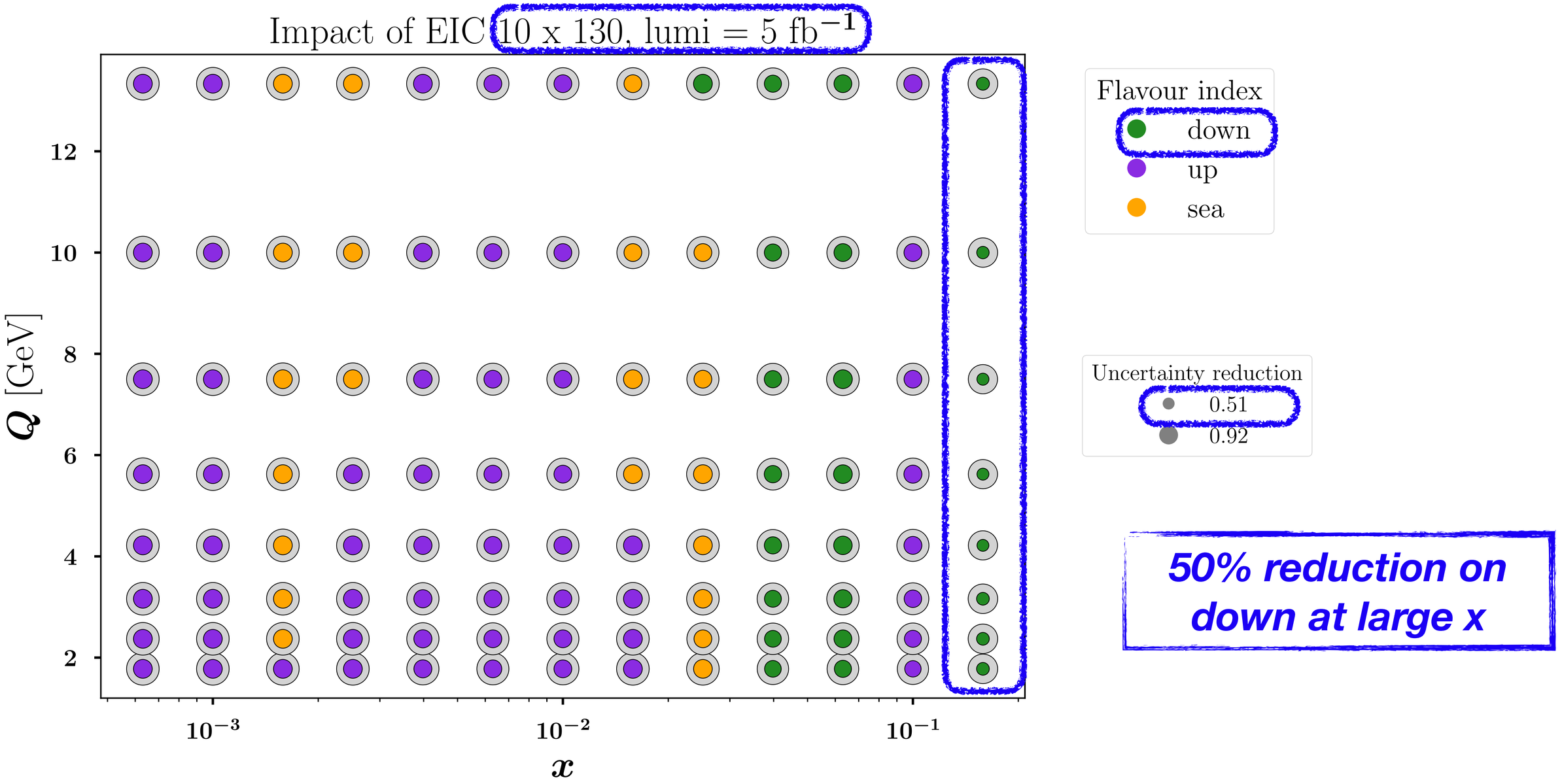

50% reduction on down at large x

EIC impact in Early Science Conditions

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MAPTMD24 2031

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10x130	~1620	5

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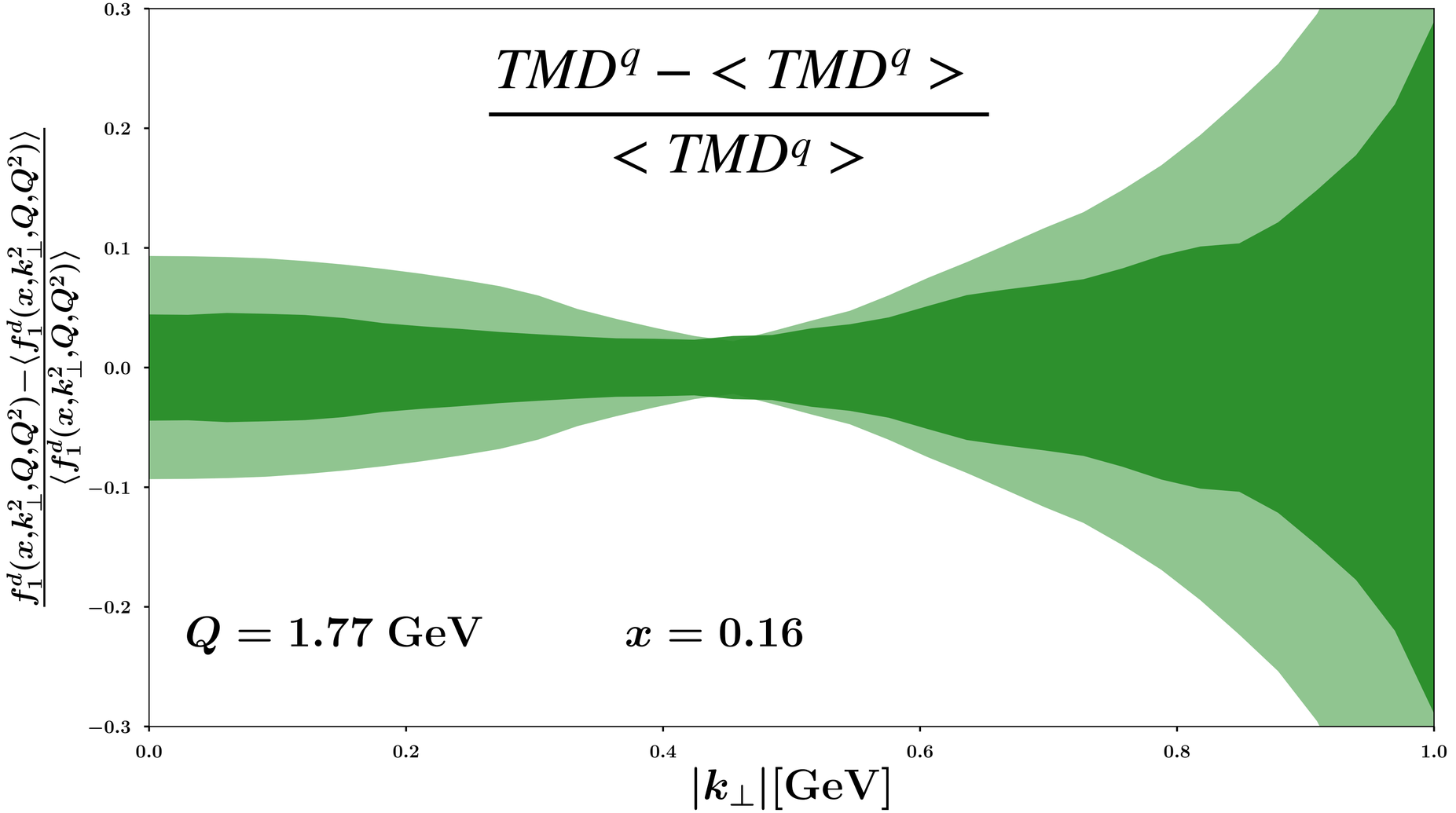

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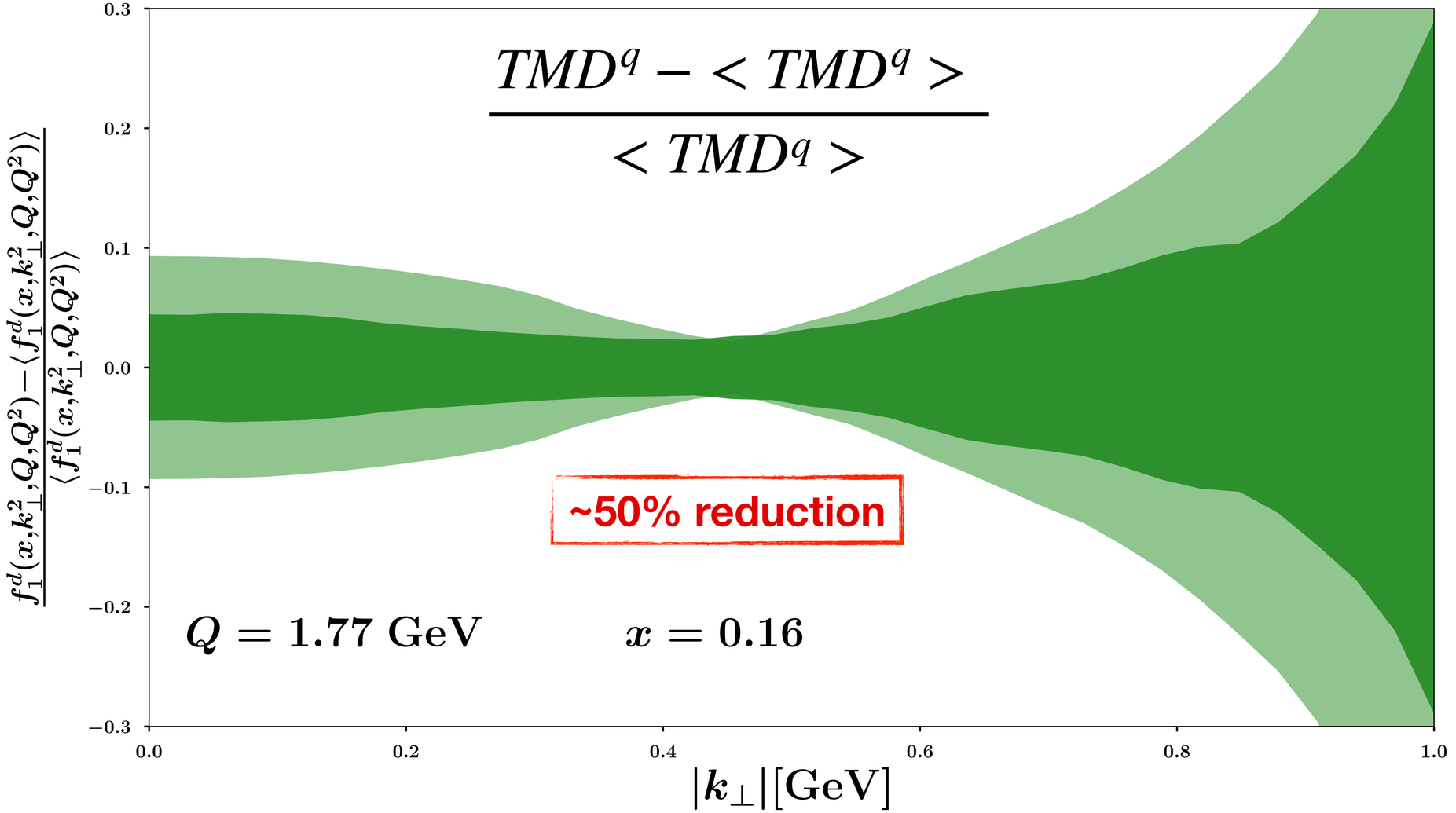

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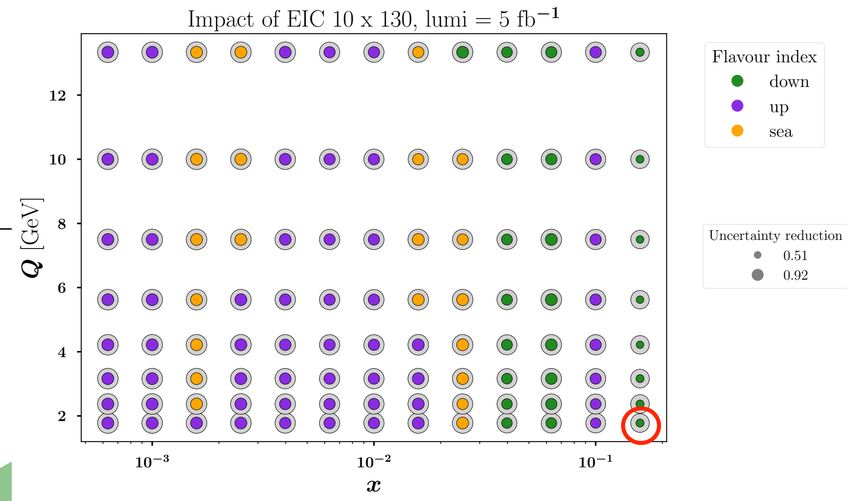

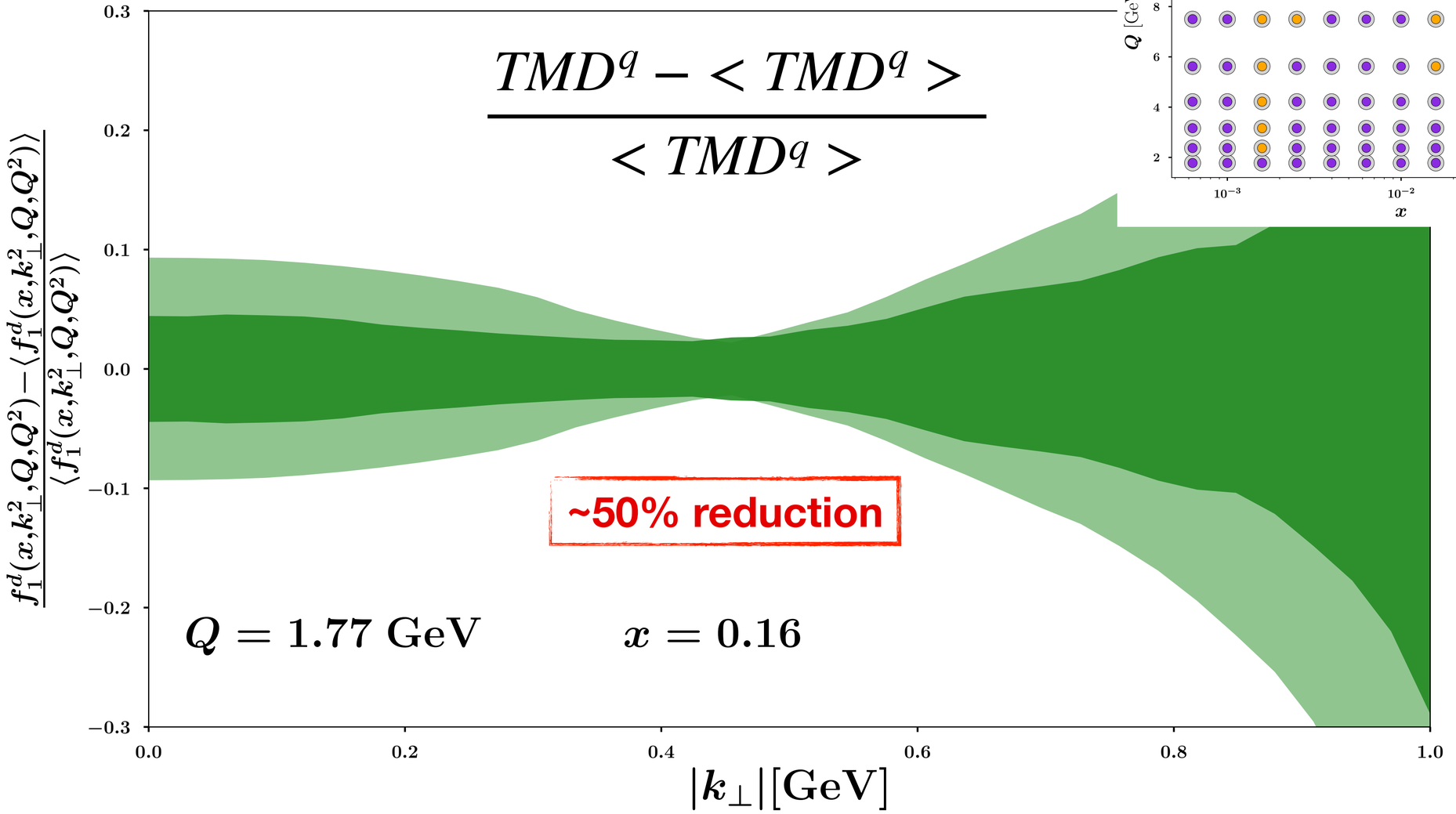

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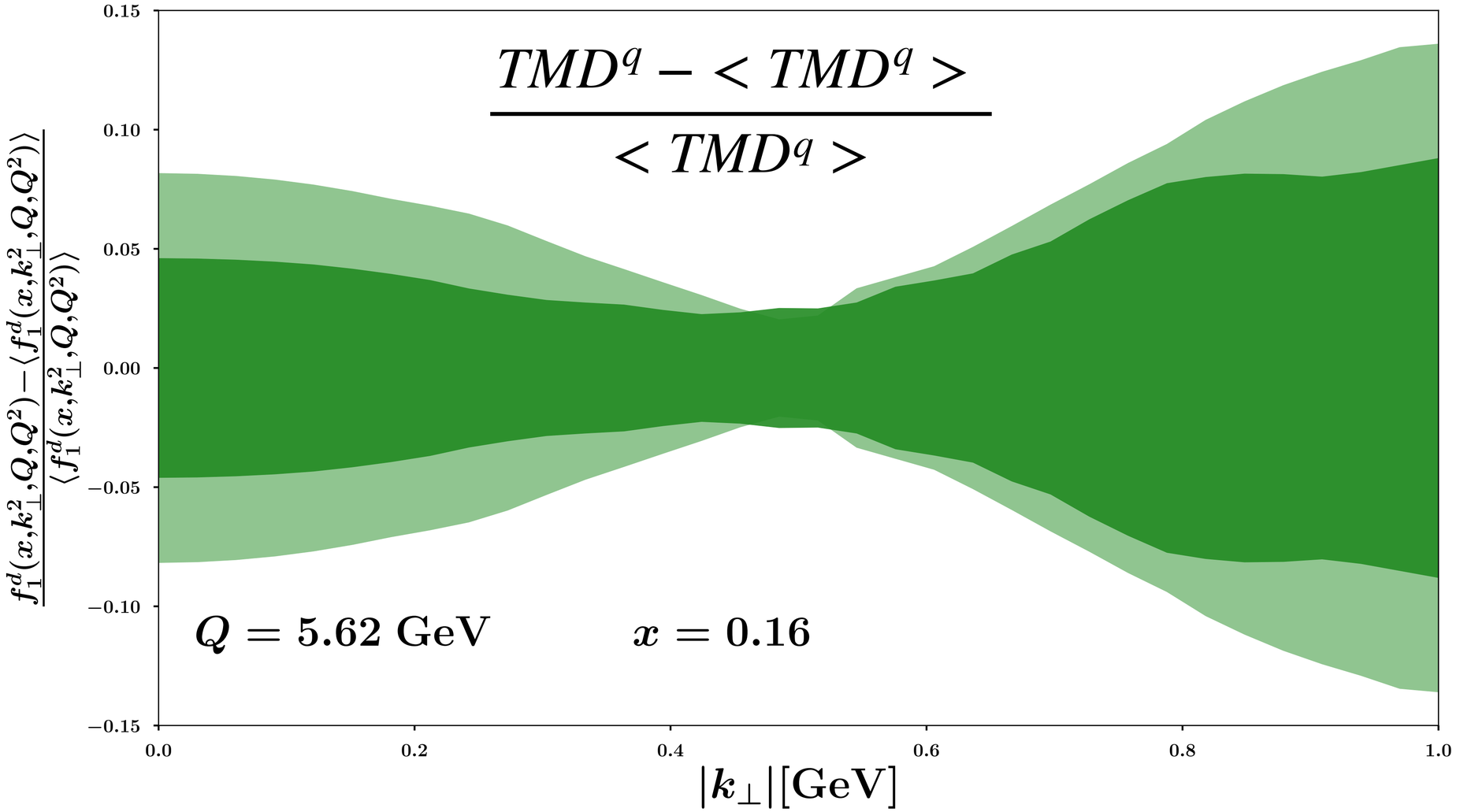

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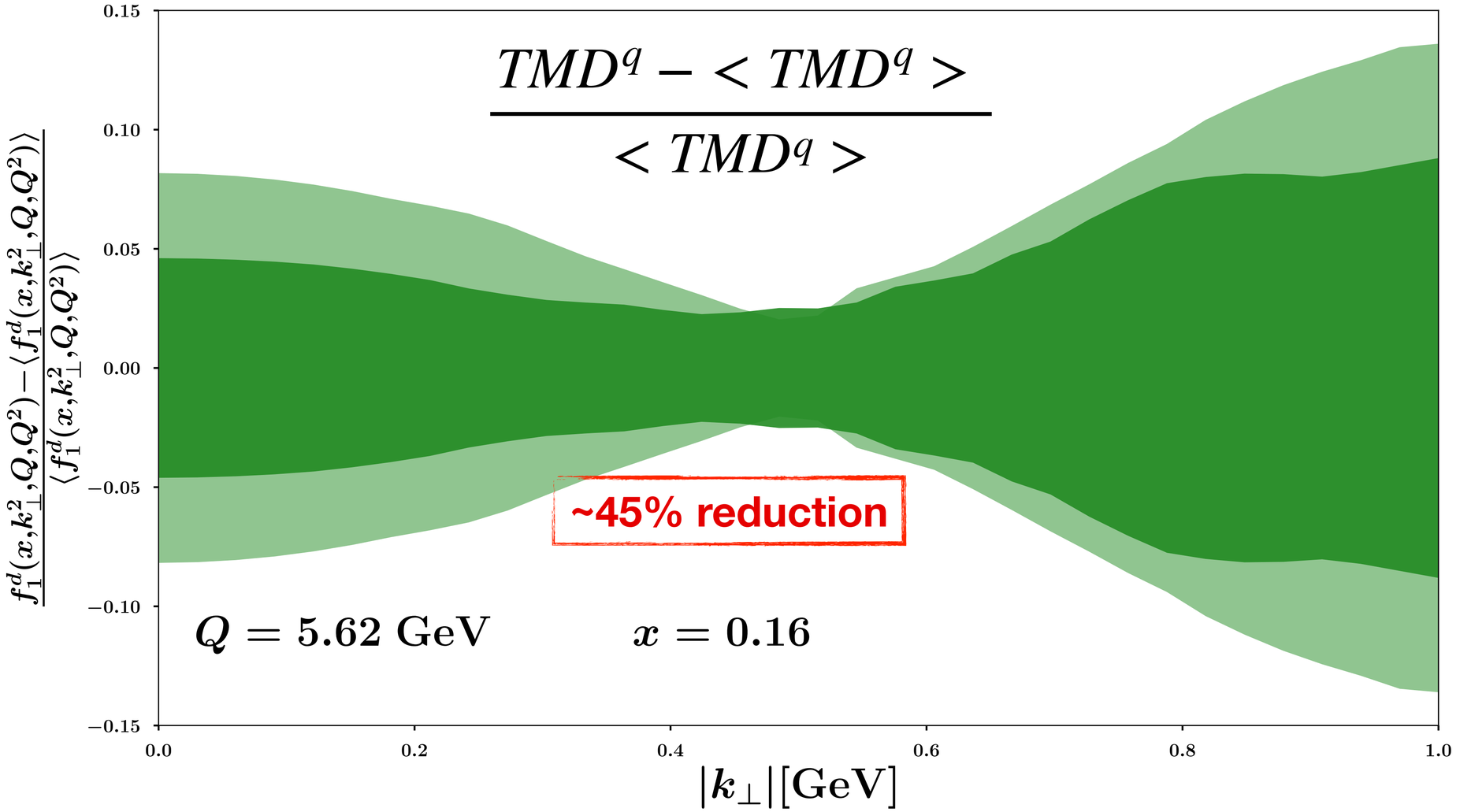

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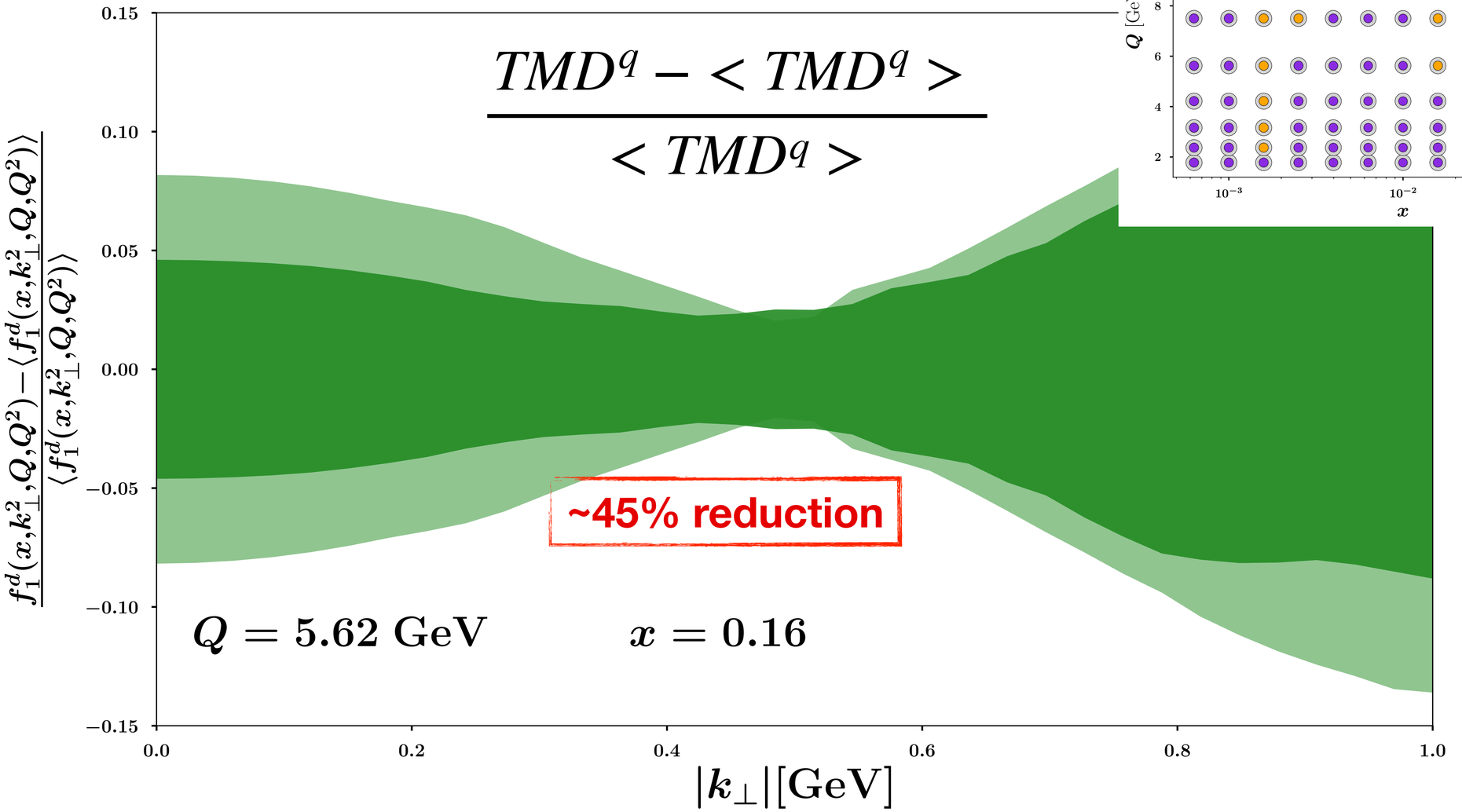

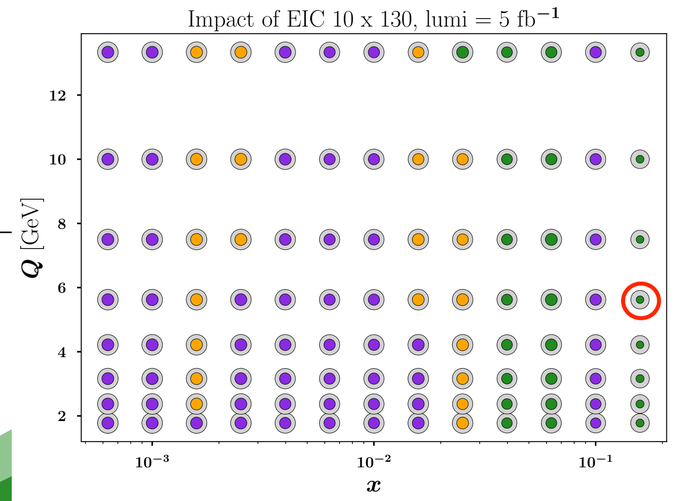

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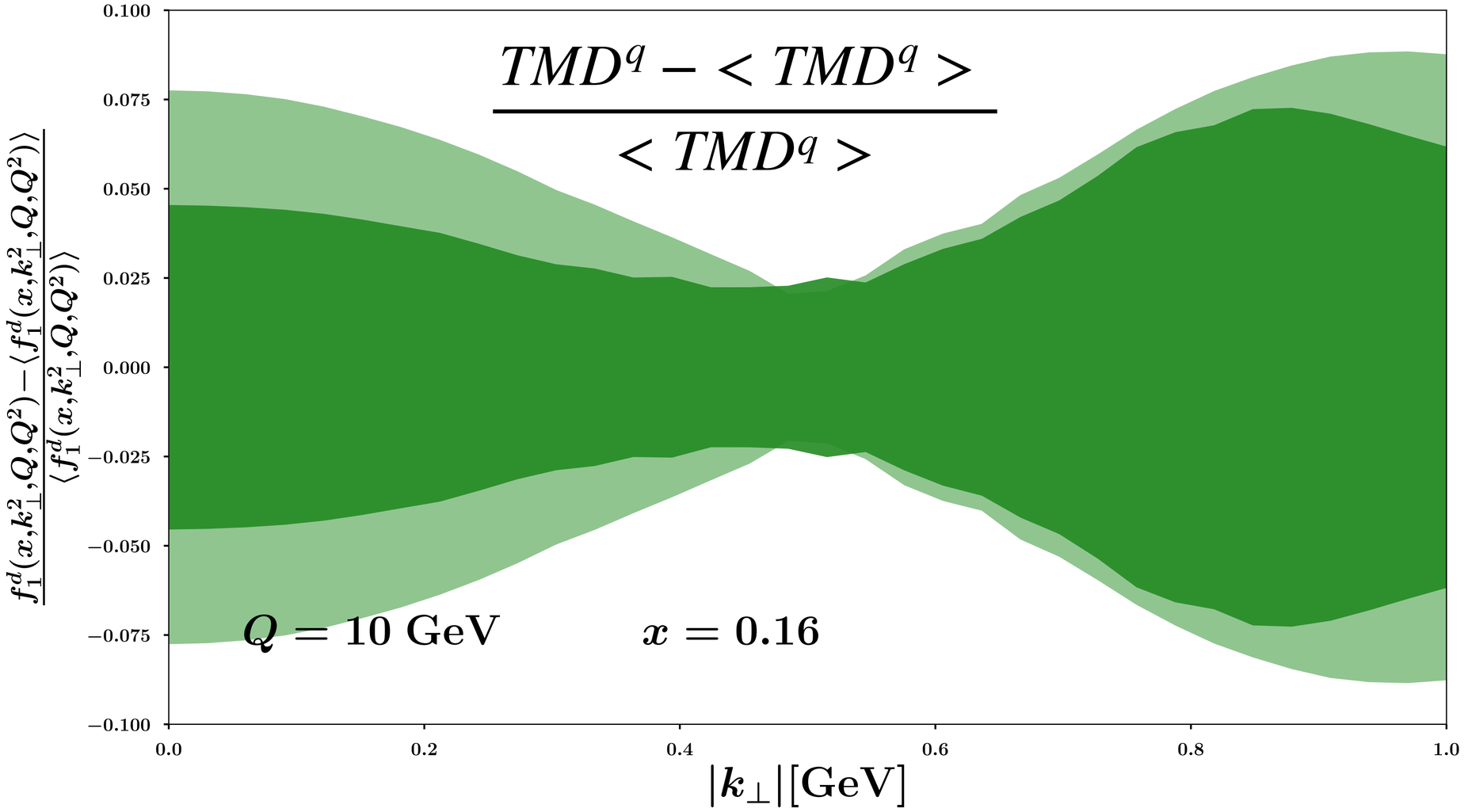

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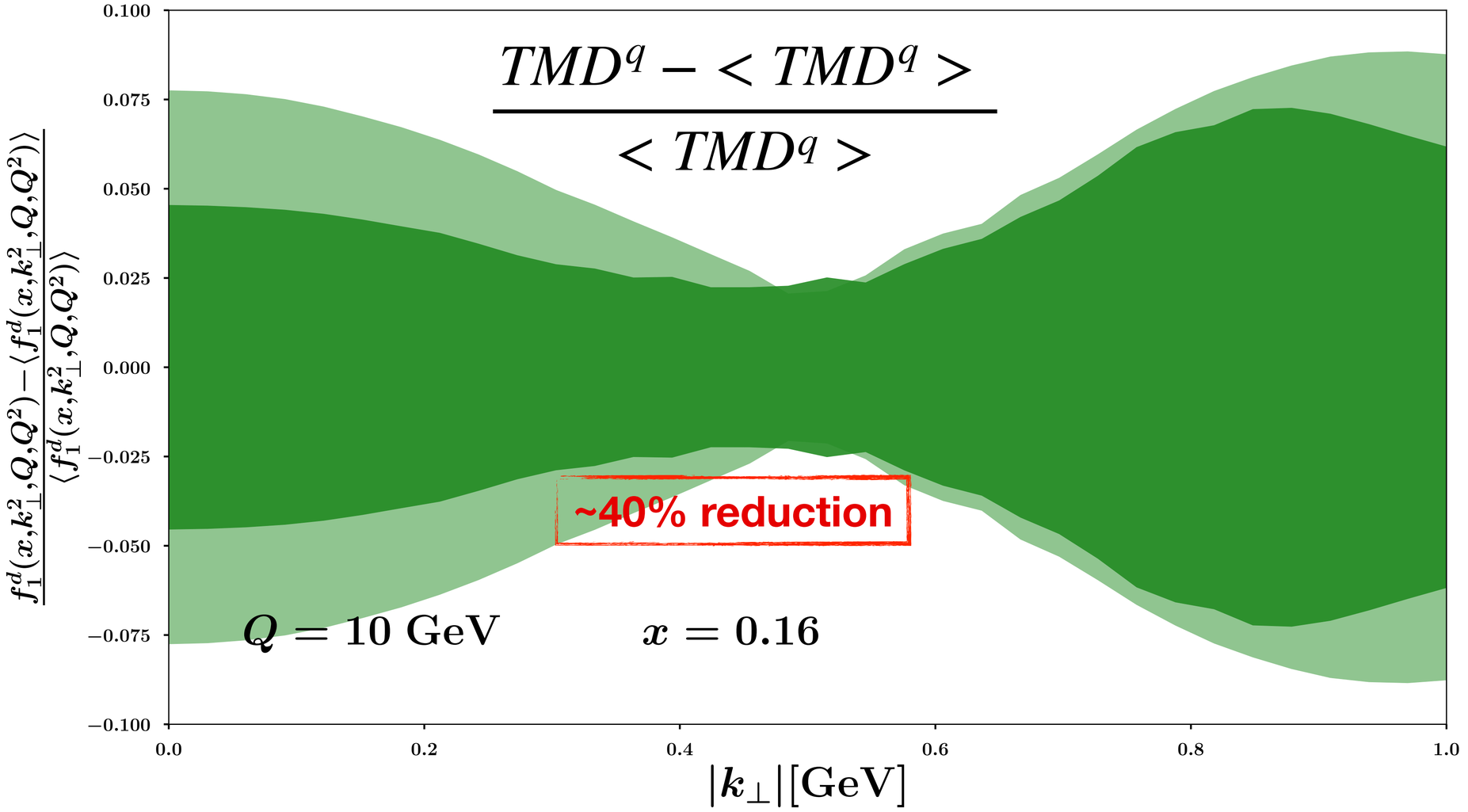
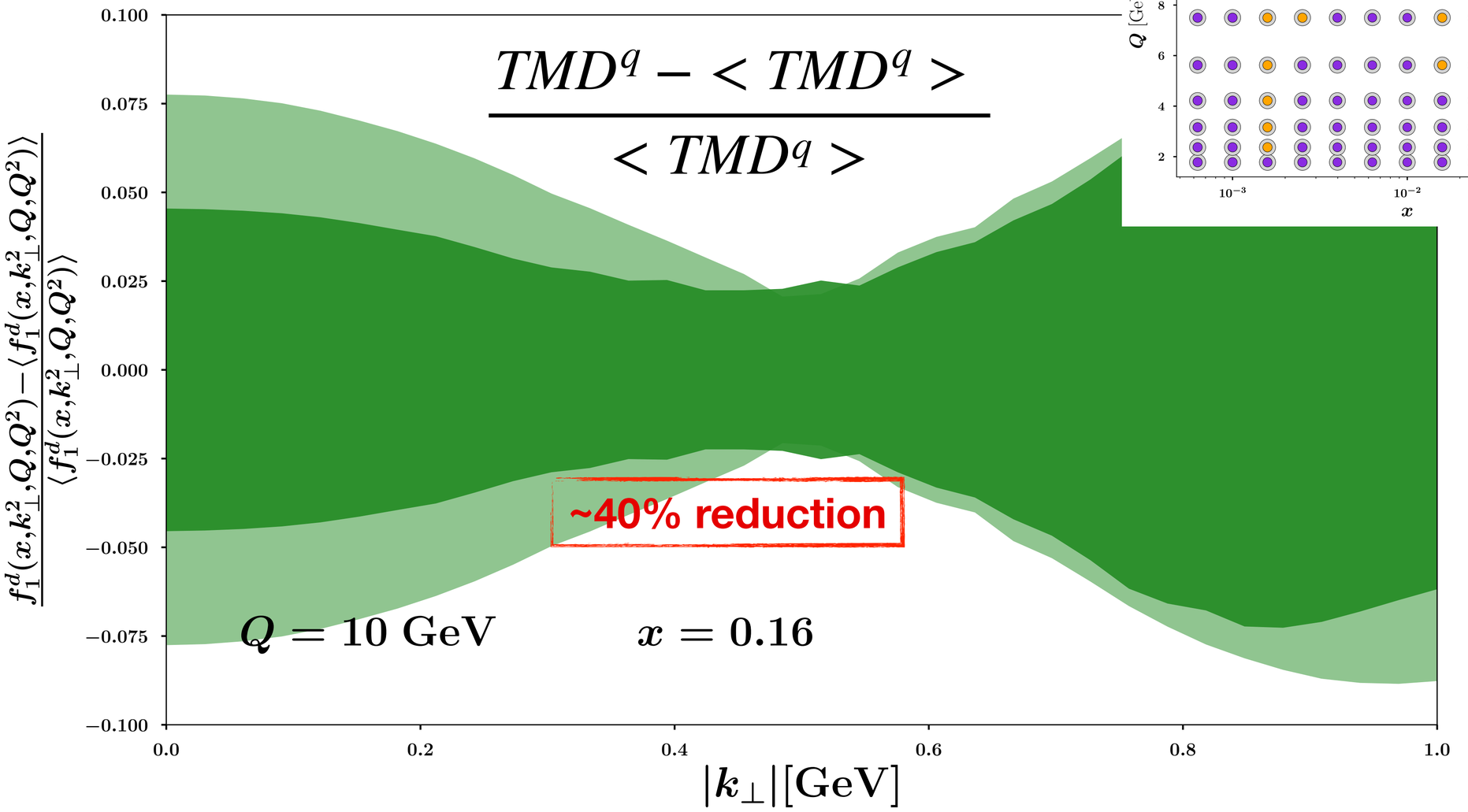
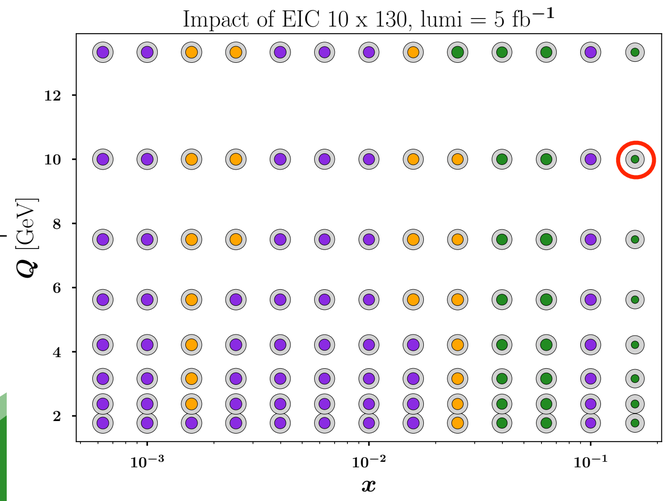


EIC impact in Early Science Conditions

MAPTMD24 2031

EIC	# pts.	lumi [fb-1]
10x130	~1620	5





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MAPTMD24 2031

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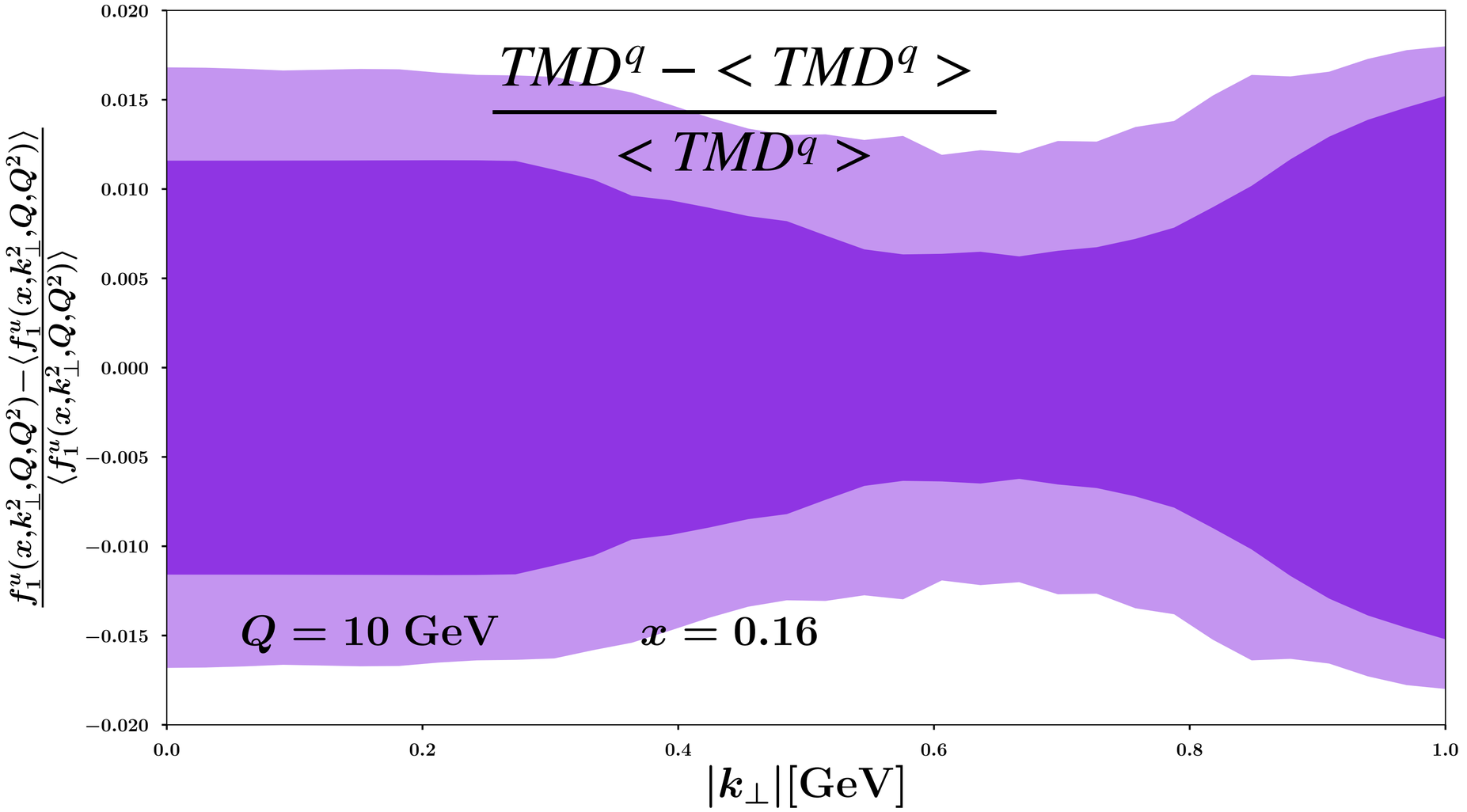

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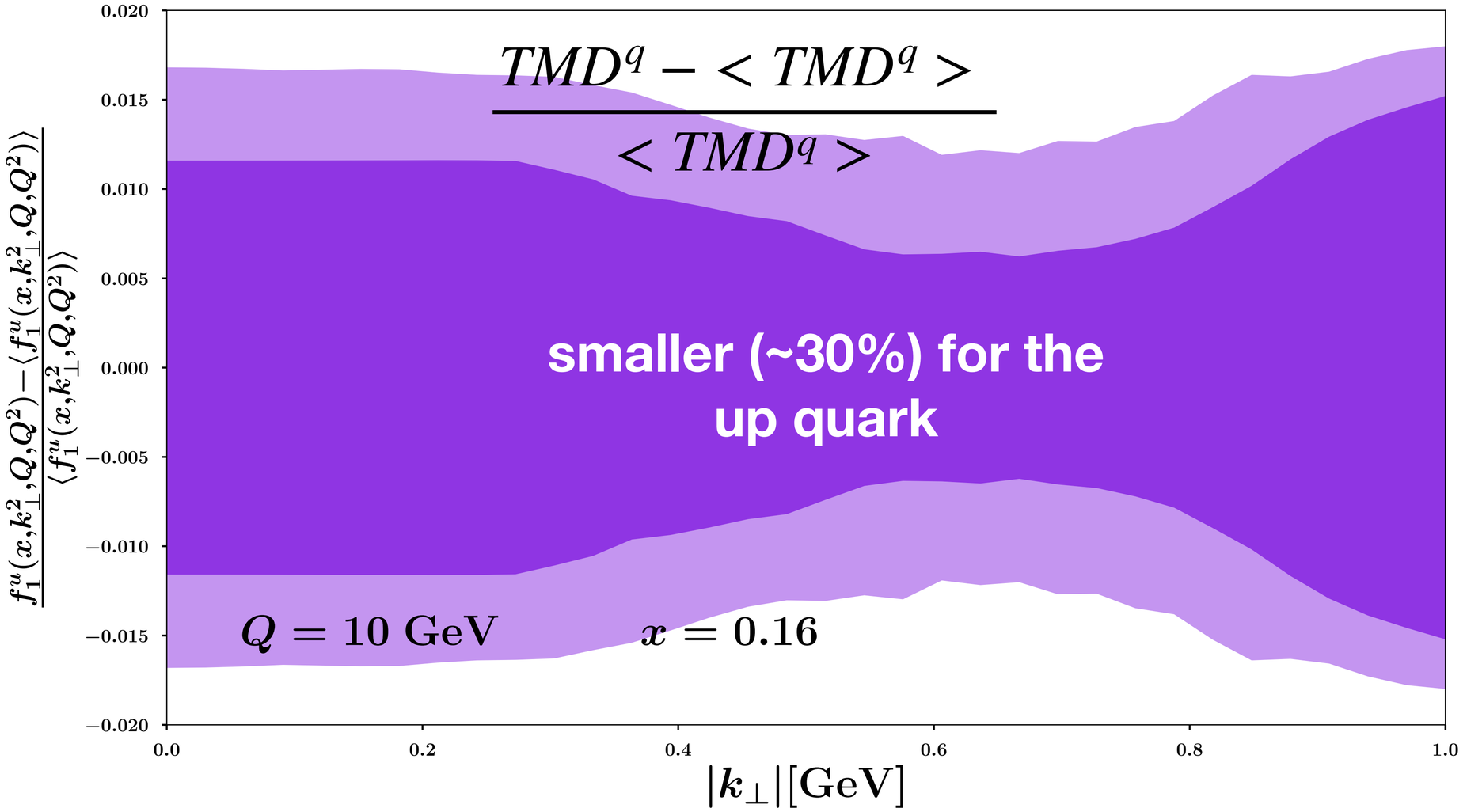

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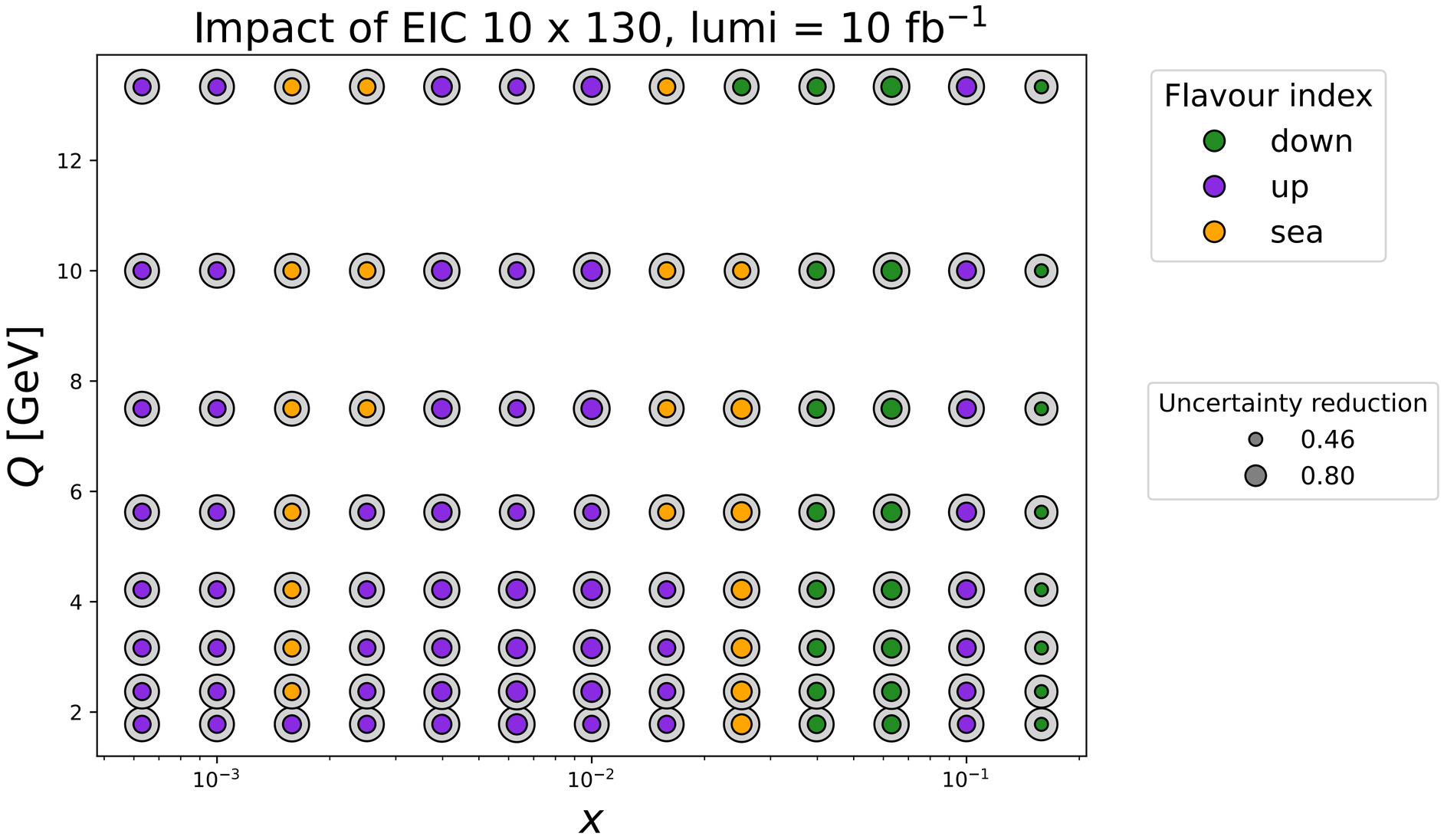

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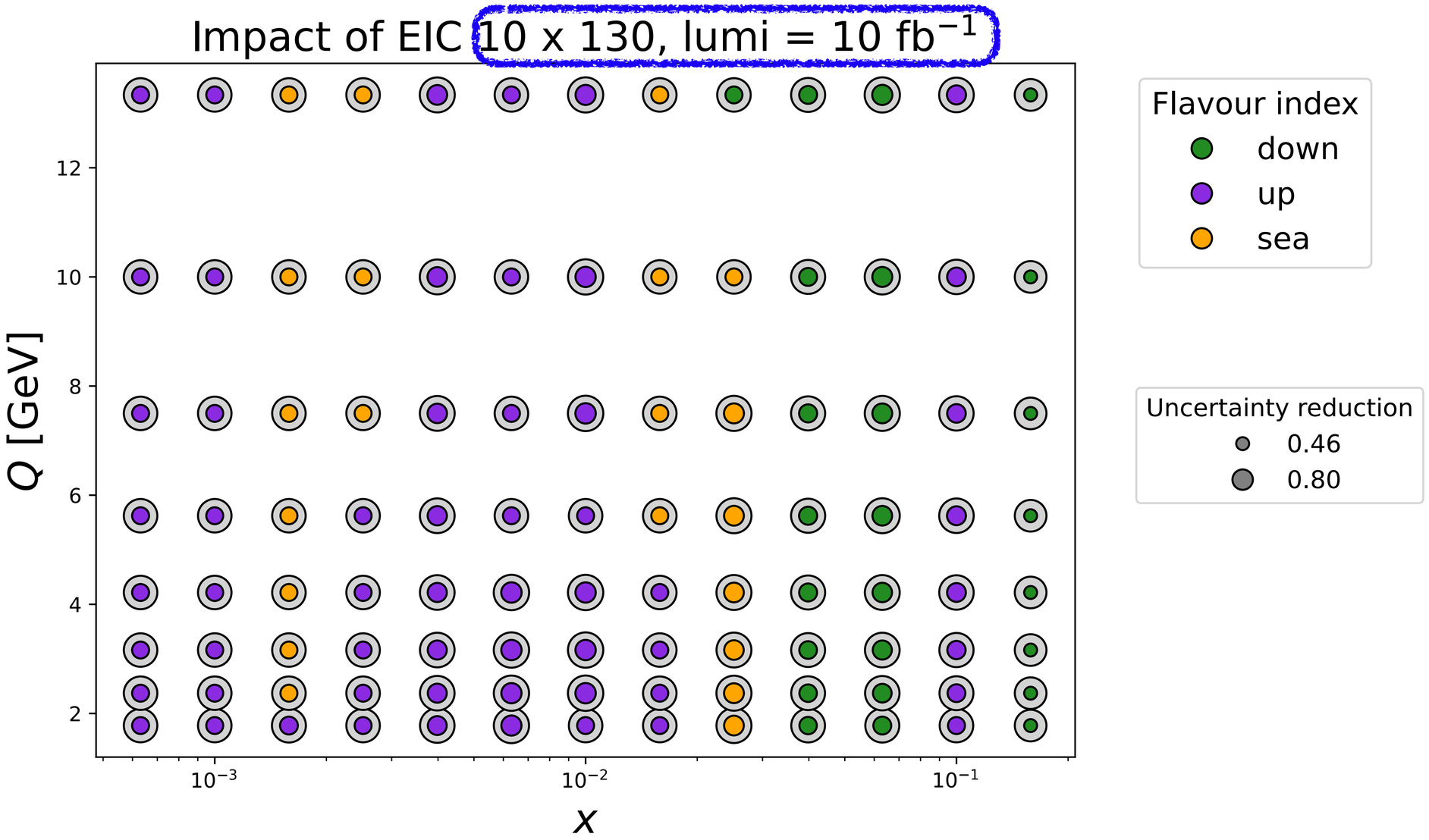
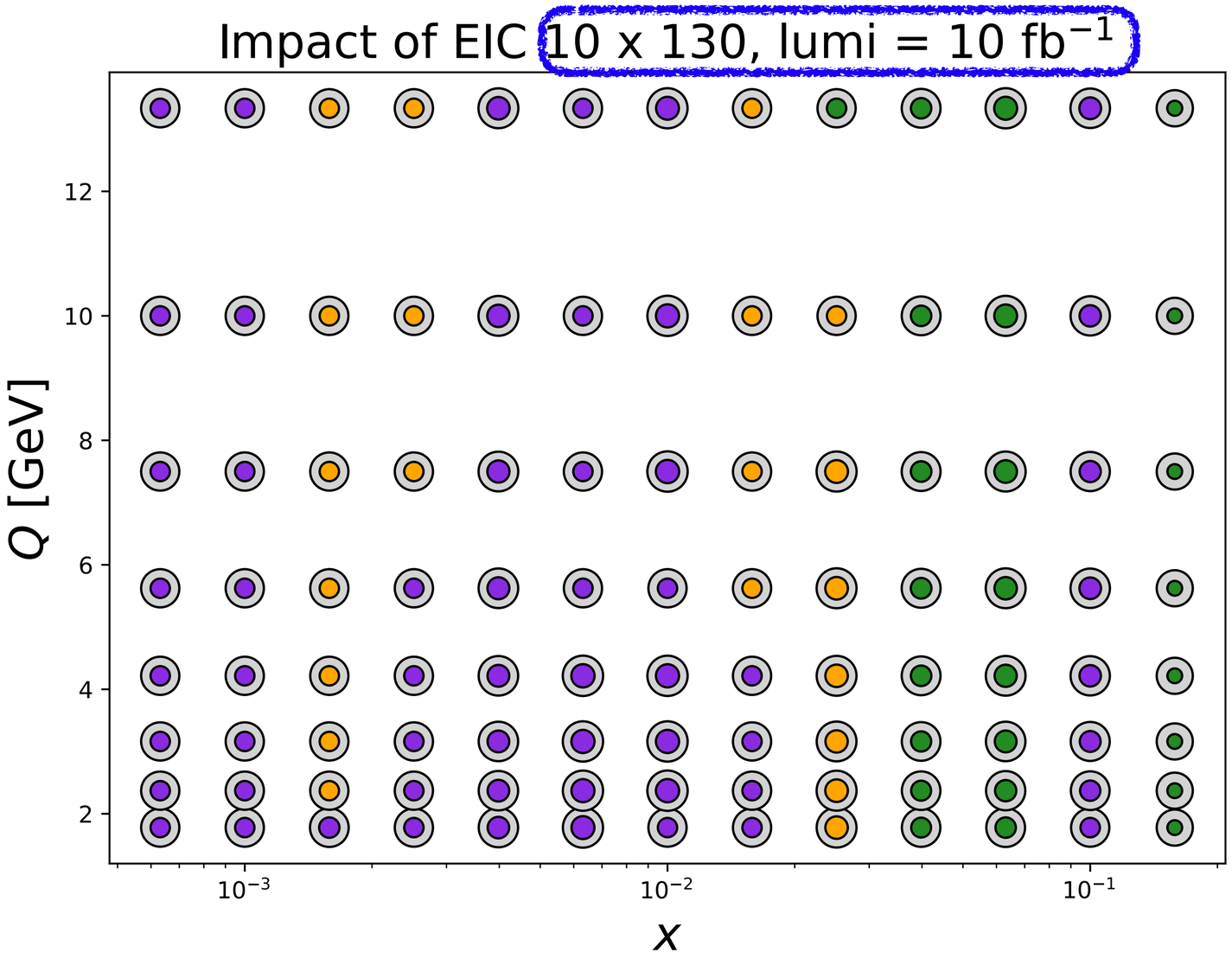


EIC impact in Early Science Conditions



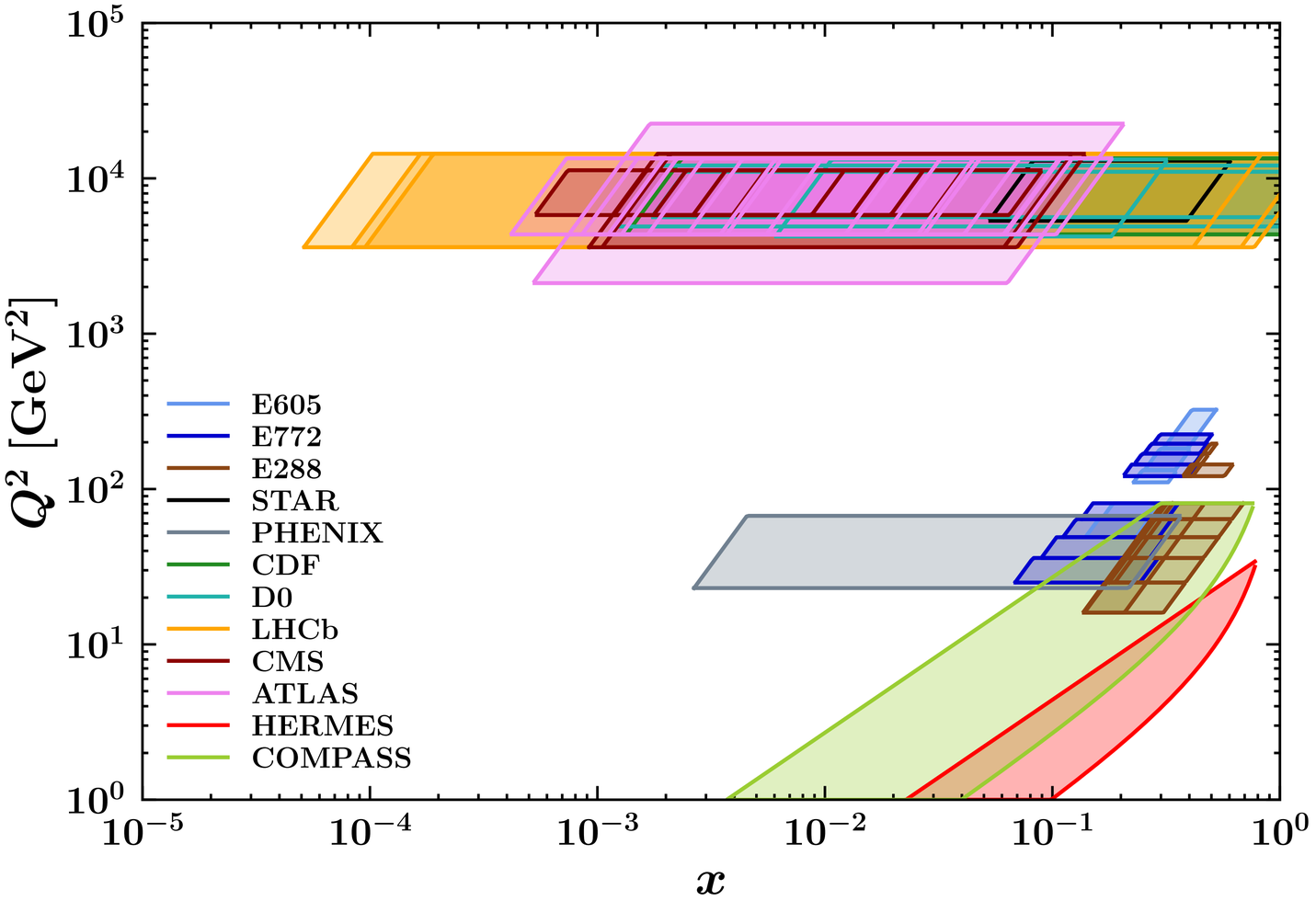
Flavour index
- down
- up
- sea

Uncertainty reduction
- 0.46
- 0.80

confirmed down at high x
slightly larger at other bins

EIC impact in "full glory"

EIC impact in "full glory"



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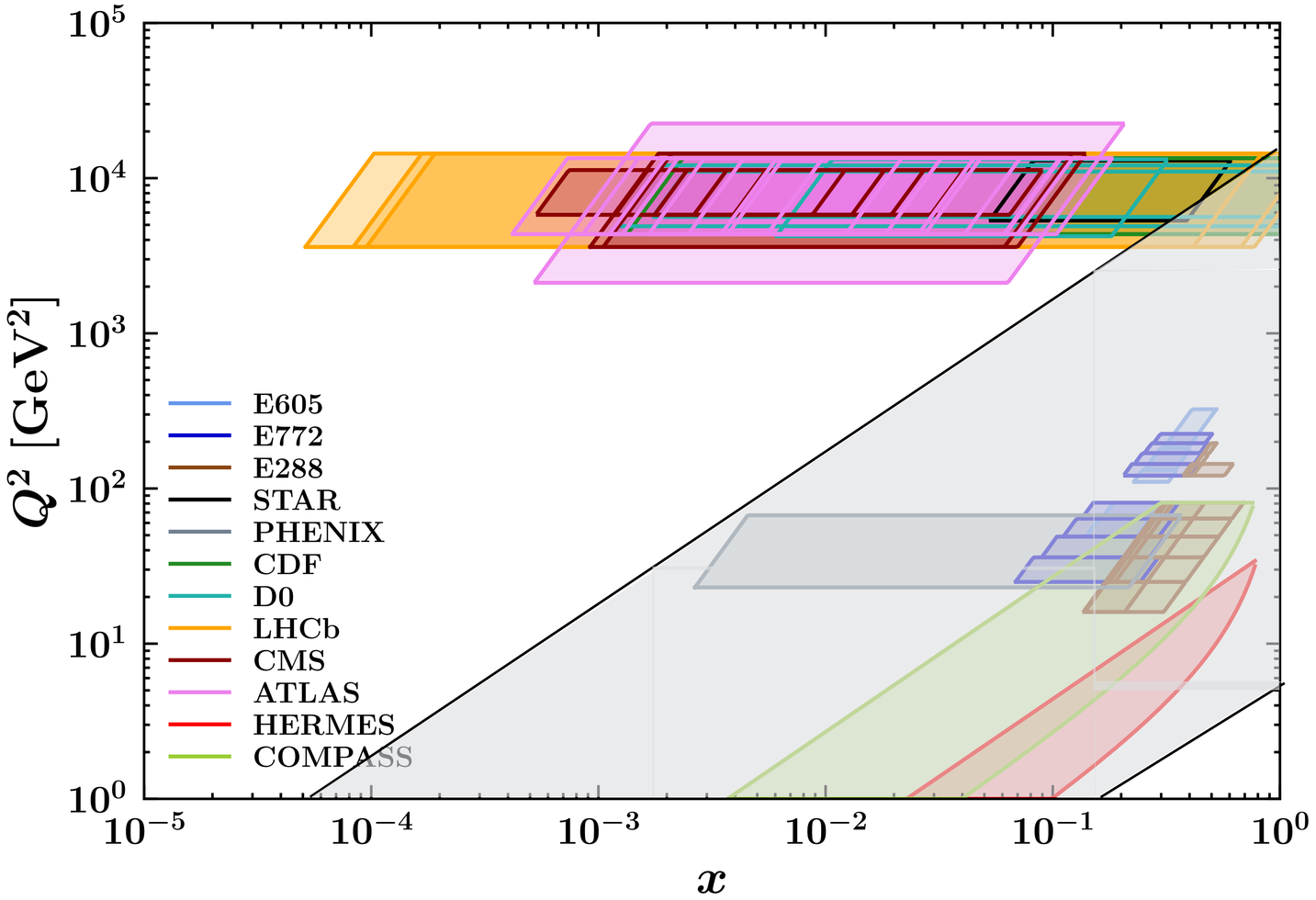


EIC impact in "full glory"

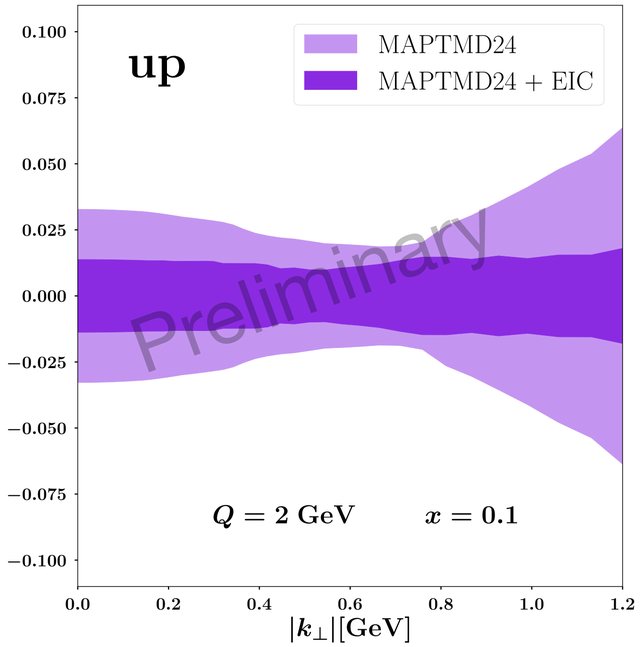
EIC impact in "full glory"

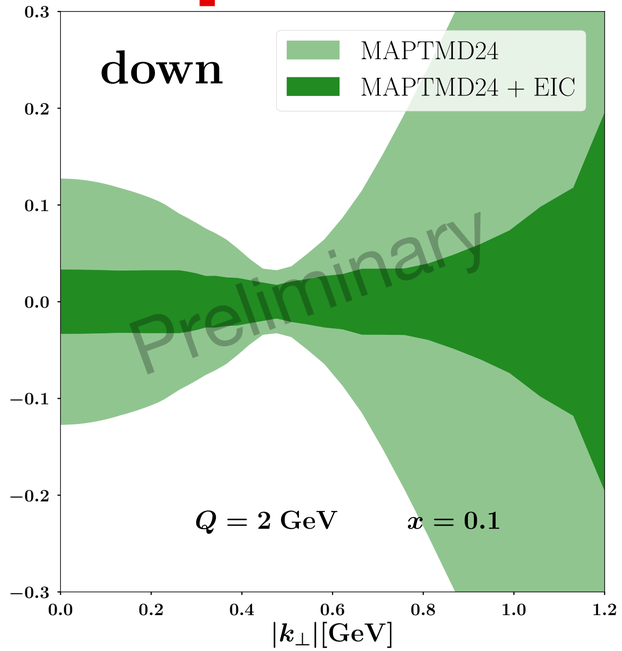
MAPTMD24 2031

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

(simulation May ’24, **only π+ production**)

EIC impact in "full glory"





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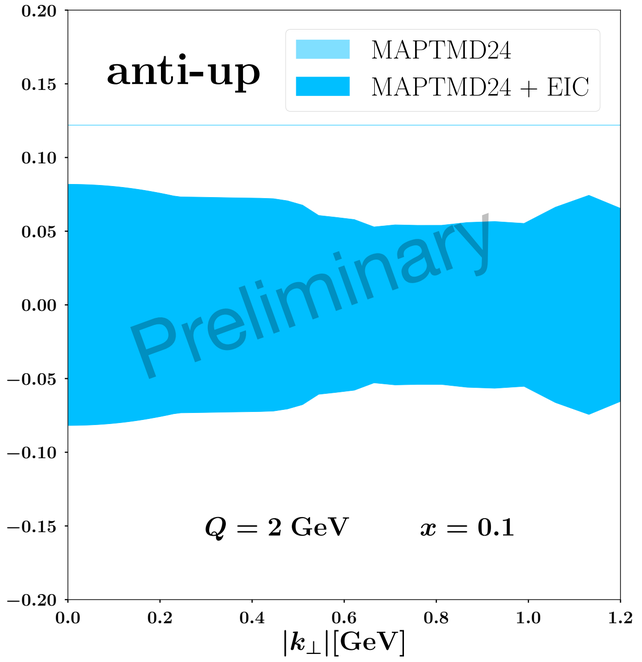

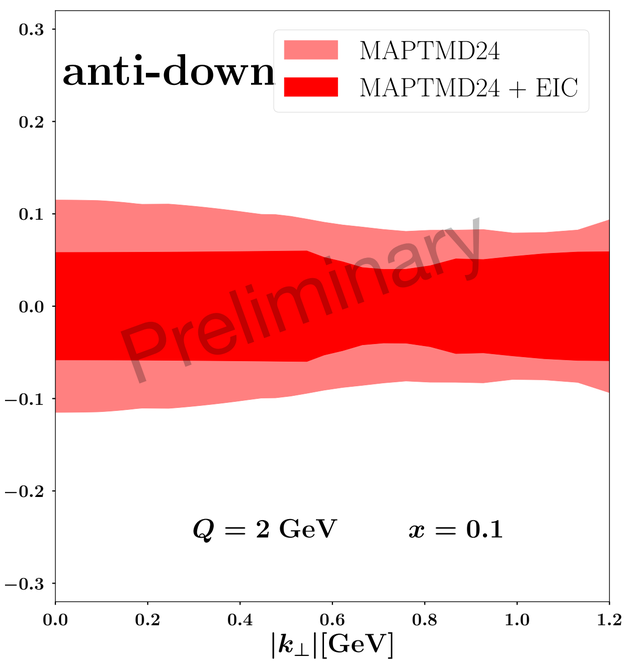

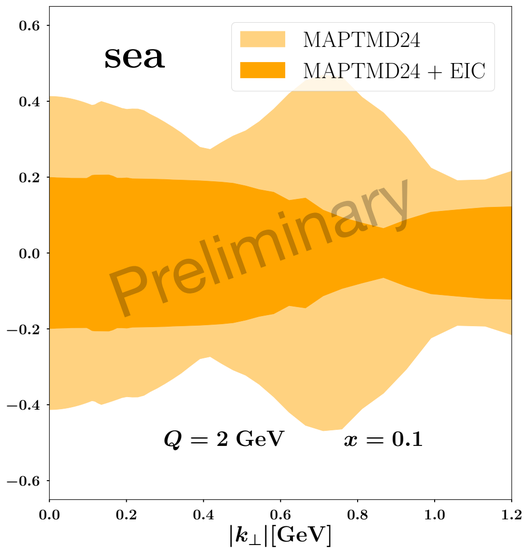

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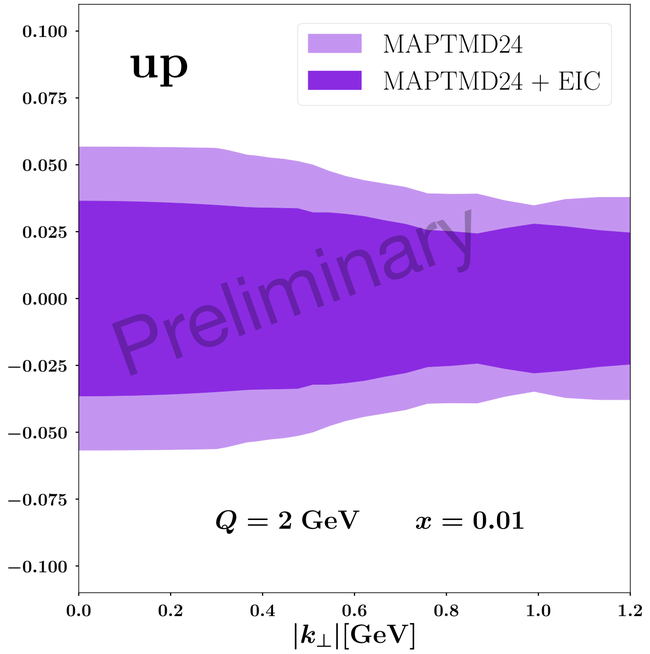

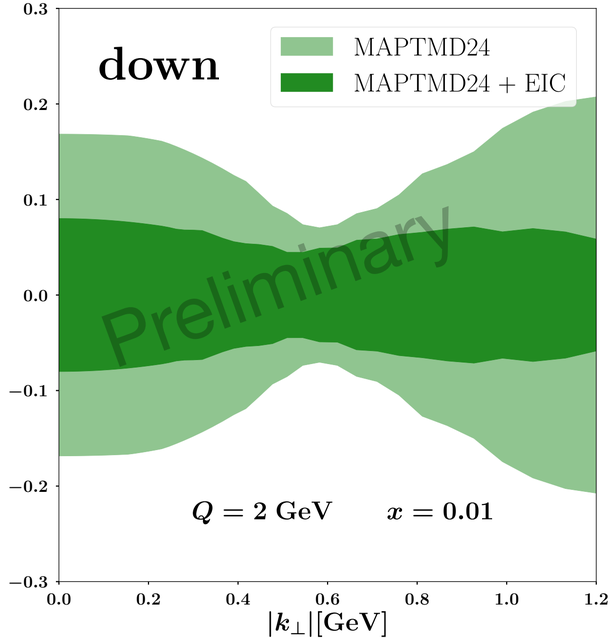

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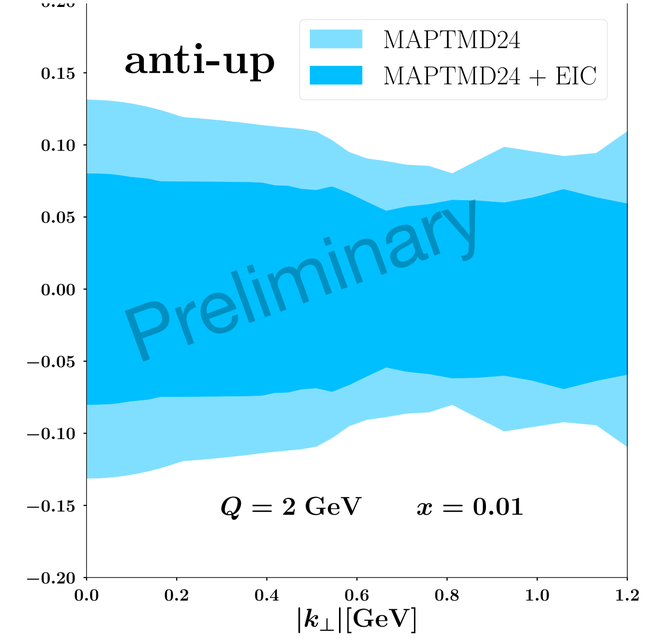
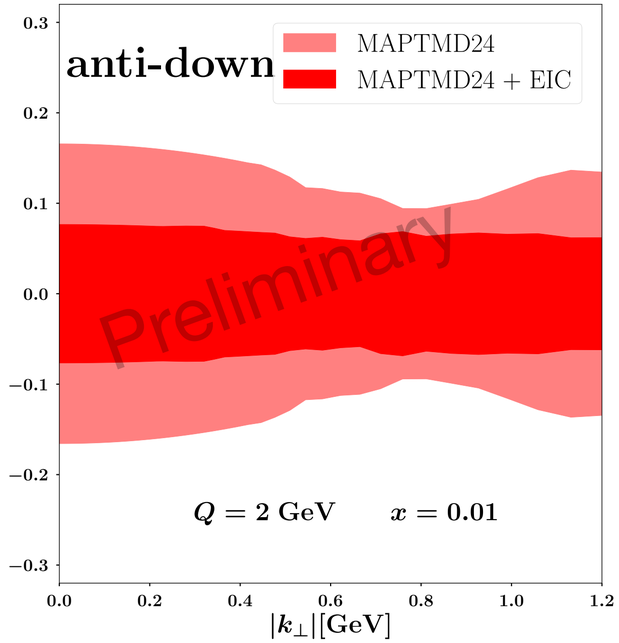
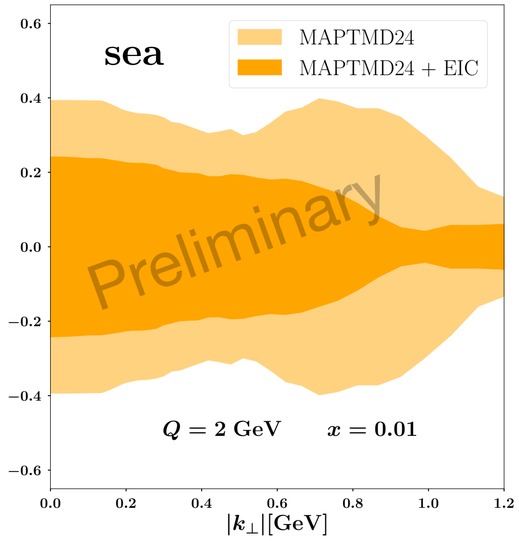
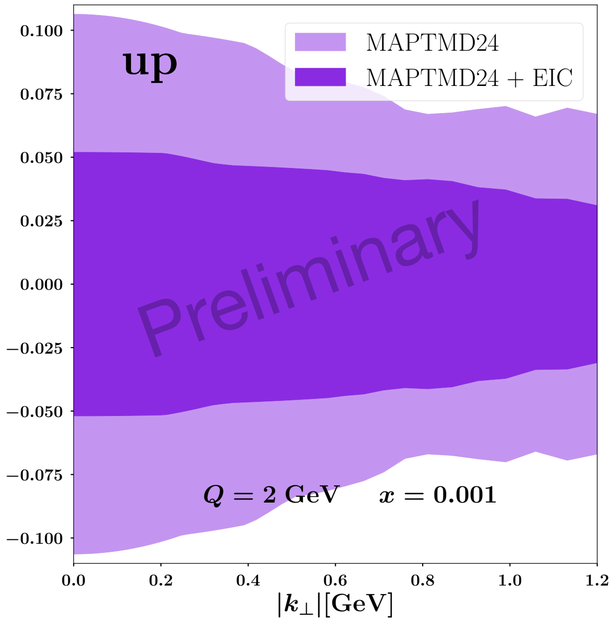
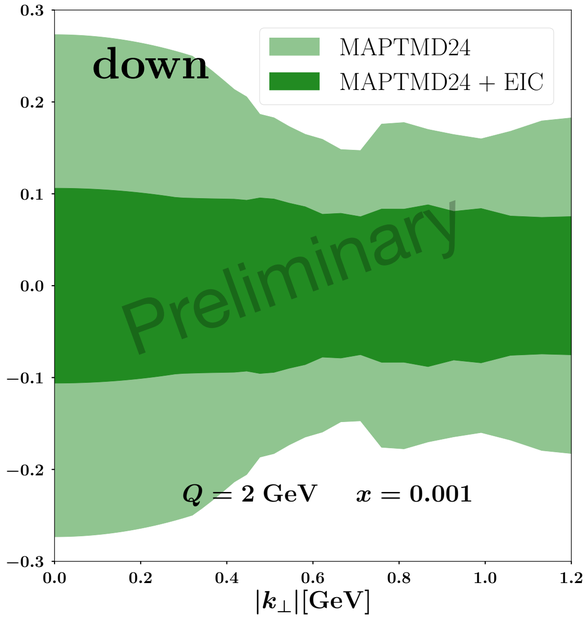






EIC impact in "full glory"





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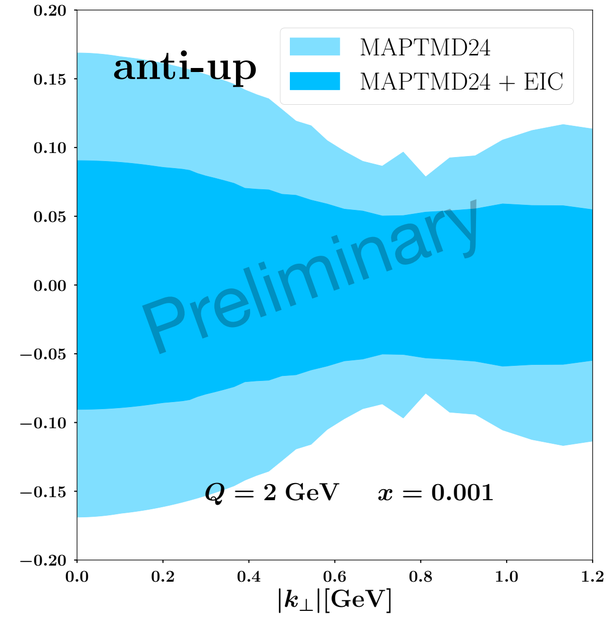

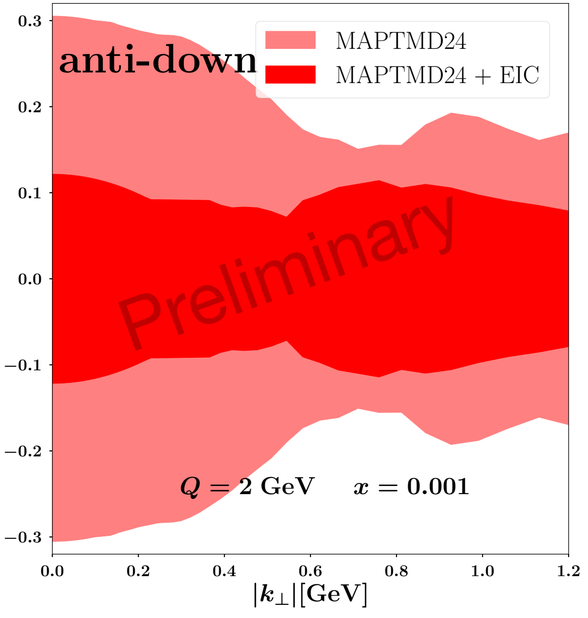

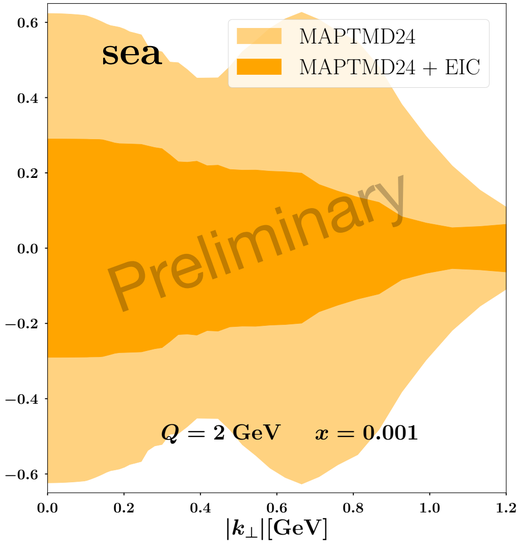

Conclusions and outlook

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- ***MAPTMD24*** provides new insights into the intrisic transverse momentum for different flavours
- ***EIC in early science condition*** would be valuable for better constraining the valence TMD PDFs at large x
- ***EIC in “full glory***" would help constrain all TMD PDFs across the full x region

BACKUP

EIC impact: 10x130 lumi=10 fb^{-1} at x=0.16

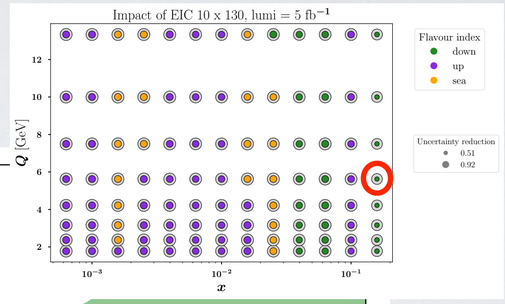
MAPTMD24 2031

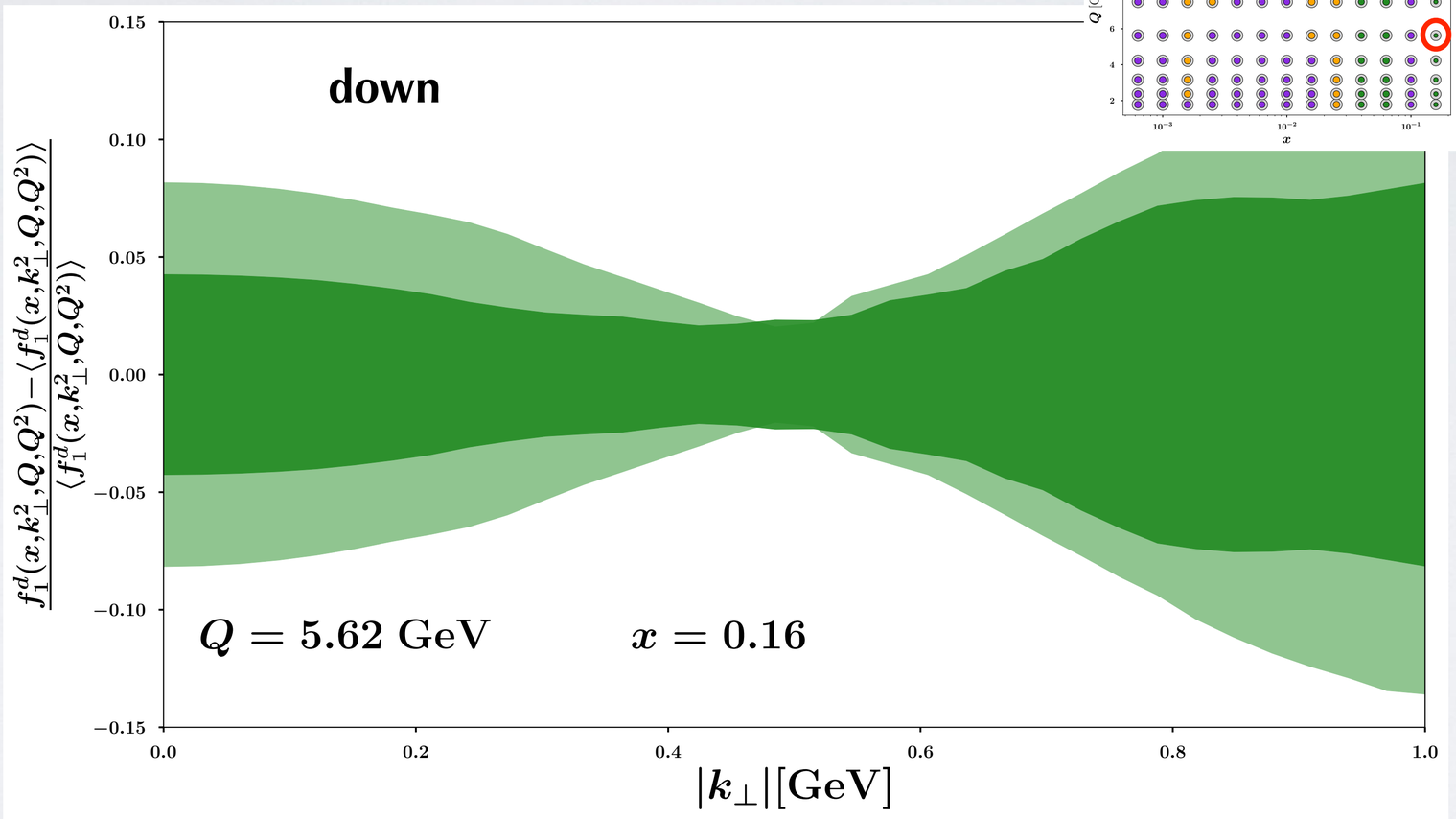
EIC	**# pts.**	**lumi [fb^{-1}]**
10x130	~1700	**10**

(early Science conditions, **only π+ production**)

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

x=0.16, Q=5.62 GeV





practically same result (~50%) as with 5 fb^{-1} (~44%)

courtesy L. Rossi

EIC impact: 10x130 lumi=5 fb^{-1} at x=0.16

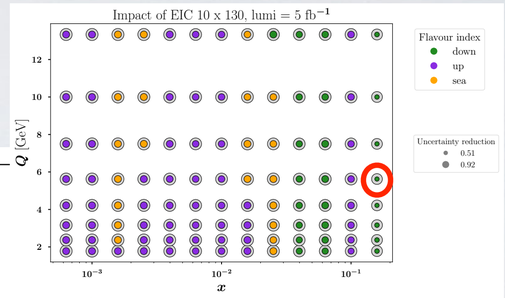
MAPTMD24 2031

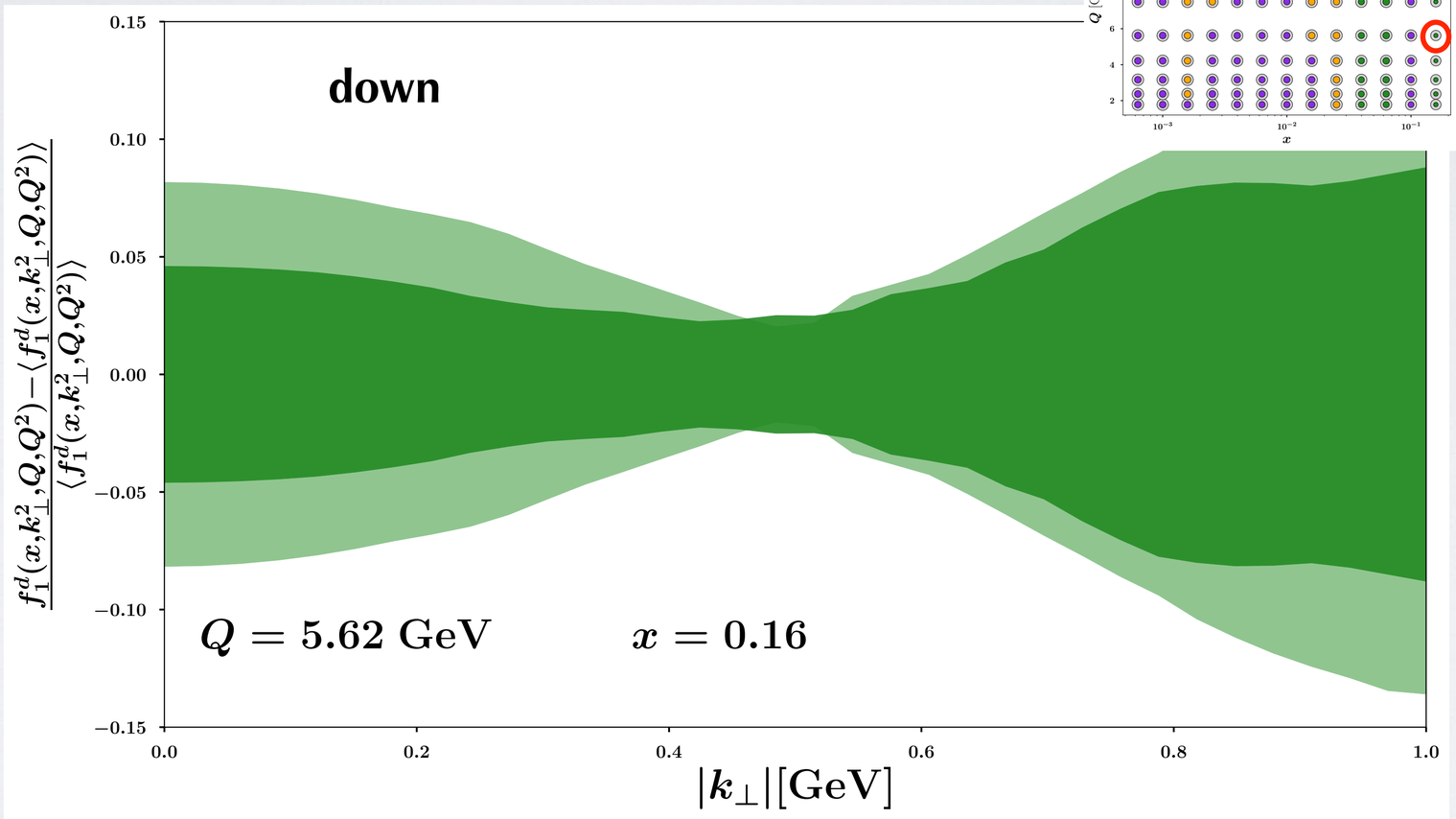
EIC	**# pts.**	**lumi [fb^{-1}]**
10x130	~1620	**5**

(early Science conditions, **only π+ production**)

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

x=0.16, Q=5.62 GeV





slightly decreasing (~44%) at larger Q²

courtesy L. Rossi

EIC impact: 10x130 lumi=10 fb^{-1} at x=0.04

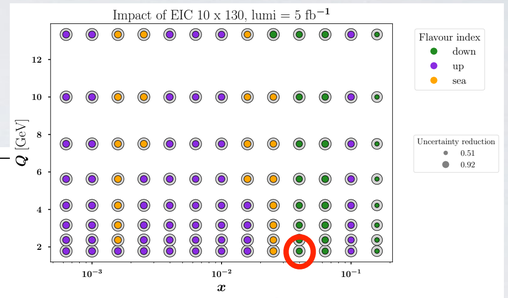
MAPTMD24 2031

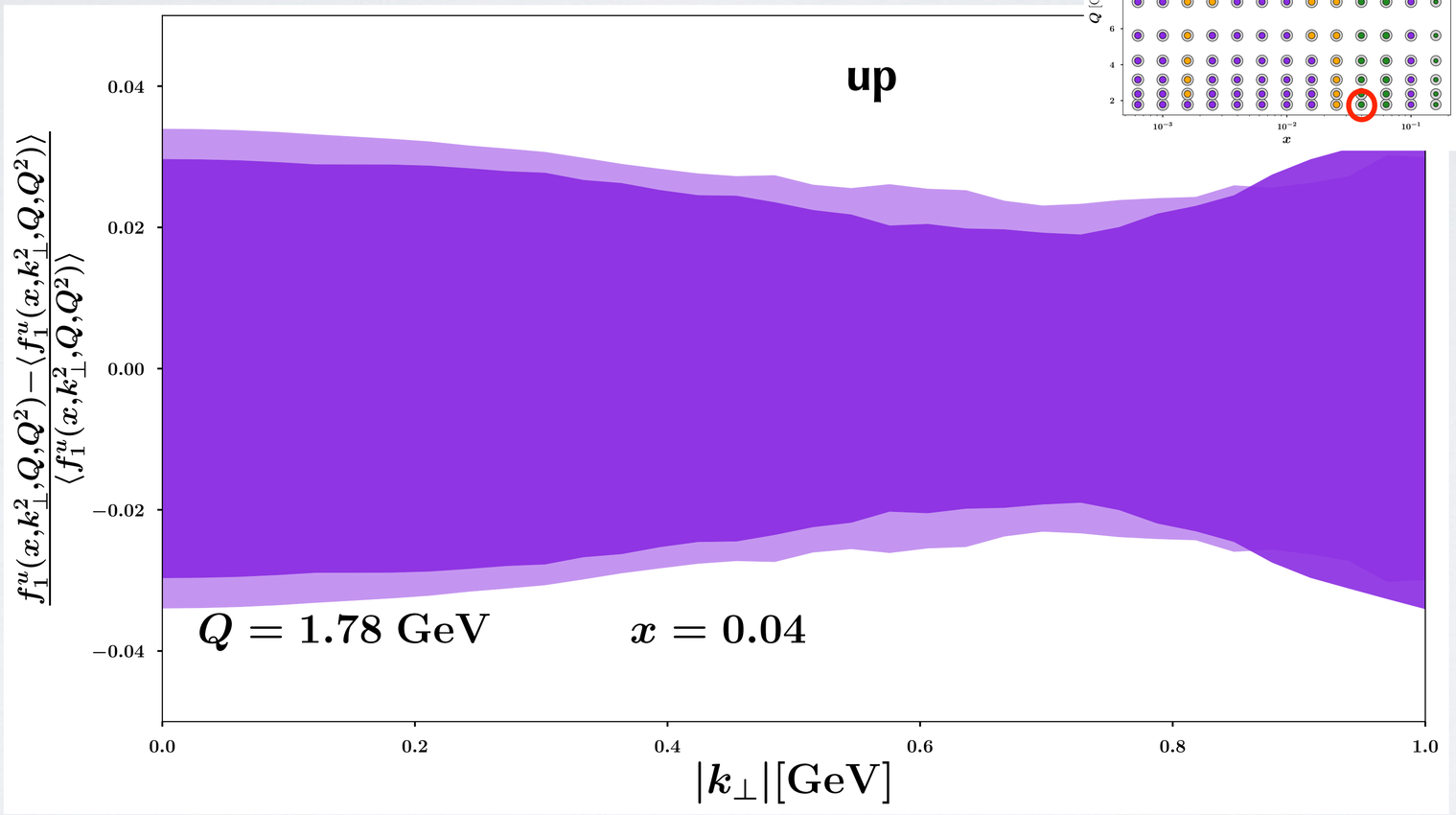
EIC	**# pts.**	**lumi [fb^{-1}]**
10x130	~1700	**10**

(early Science conditions, **only π+ production**)

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

x=0.04, Q=1.78 GeV





gain slightly larger (~12%) than with 5 fb^{-1}

courtesy L. Rossi

Baseline: MAPTMD24 fit

Bacchetta et al. (MAP), JHEP **08** (24) 232

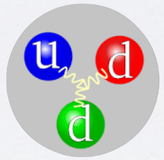
first global fit of SIDIS and Drell-Yan data
with flavor sensitivity of intrinsic quark k_T

nonperturbative input total of **96 parameters**

TMD PDF

F.T. of combination of 2 Gaussians
and 1 weighted Gaussian

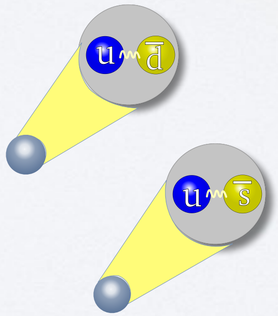
5 channels: $q = u\,,\ \bar{u}\,,\ d\,,\ \bar{d}\,,\ sea$ ("s")



TMD FF

F.T. of combination of 2 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 $d, s \to K^+, \ldots$



sensitivity

Hermes

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

Compass

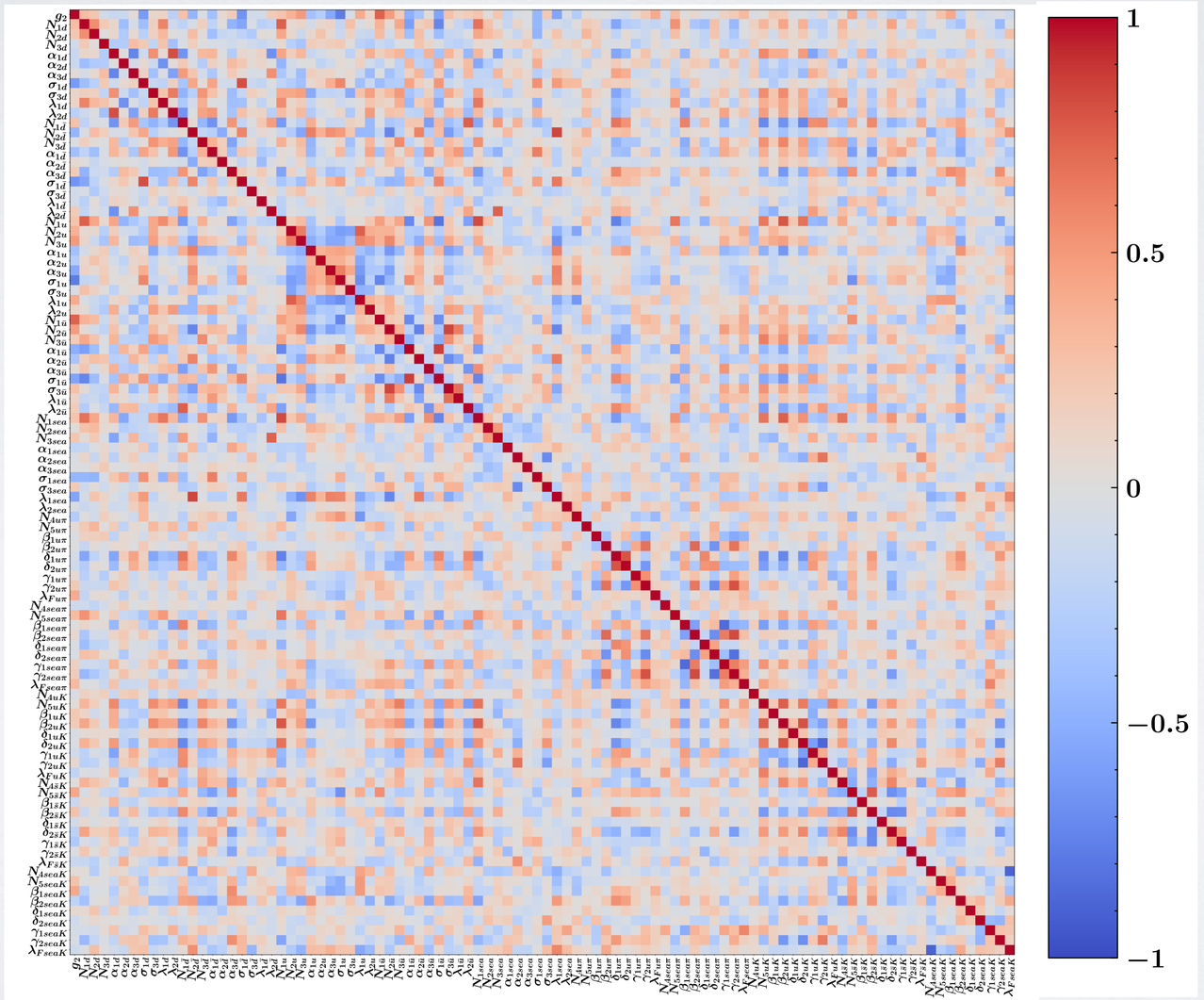
target: D
final: $h^\pm$

Drell-Yan

correlation matrix

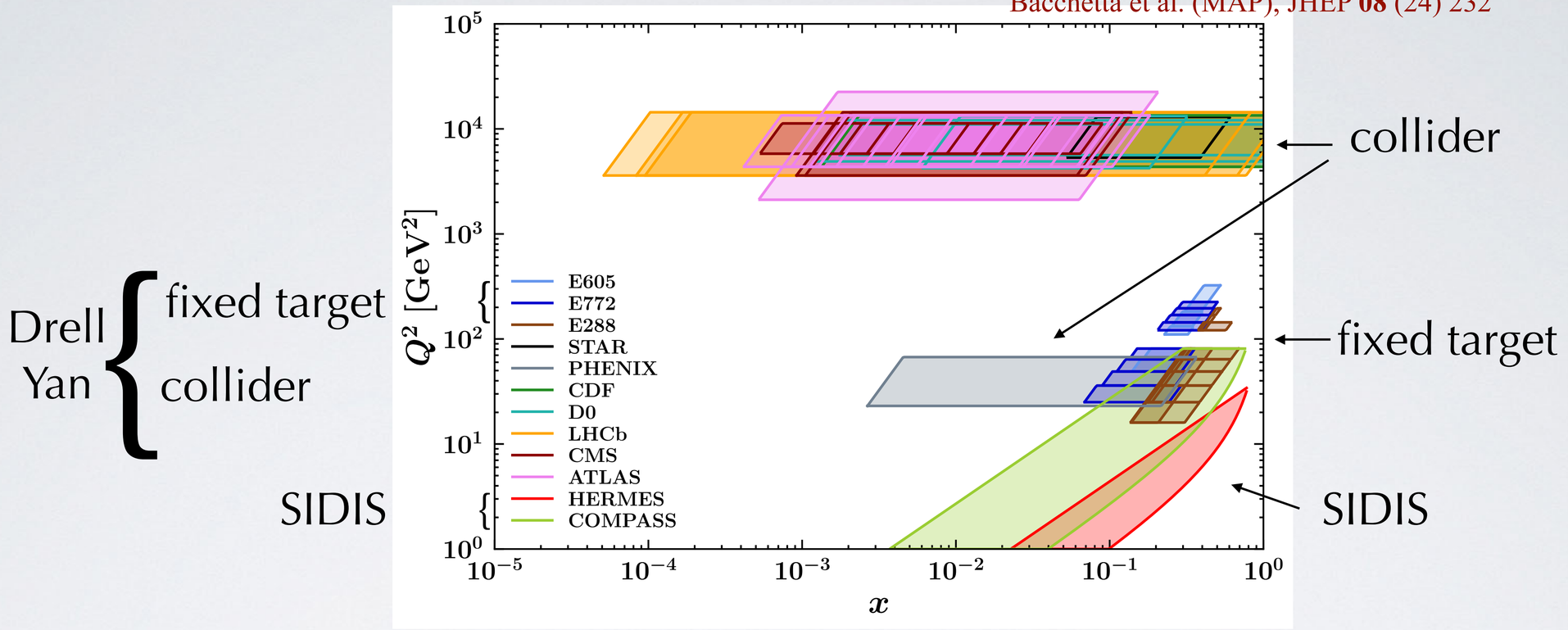
Bacchetta et al. (MAP), JHEP **08** (24) 232

MAPTMD24 total of 96 parameters



Phase space covered by data

Bacchetta et al. (MAP), JHEP **08** (24) 232



kin. cuts ⟶ **N = 2031 data pts. (with 96 params)**

$\langle Q \rangle > 1.4$ GeV $\qquad 0.2 < z < 0.7$

Drell-Yan $q_T < 0.2\,Q$

SIDIS

$$P_{hT} < \min\left[\min\left[0.2\,Q,\, 0.5\,Qz\right] + 0.3\,\text{GeV},\, zQ\right]$$

nonperturbative precision $\chi^2/N = 1.08$

perturbative accuracy N^{3}LL