

# PDFs and SMEFT

## A study of the interplay of Parton Distribution Functions (PDFs) and BSM signals in global fits

Work with Juan Rojo, Maria Ubiali and her group:

[2307.10370, JHEP]

[2402.03308]

[Forthcoming]



European Research Council  
Established by the European Commission



Elie Hammou, University of Cambridge  
LHeC workshop, Nov 2024

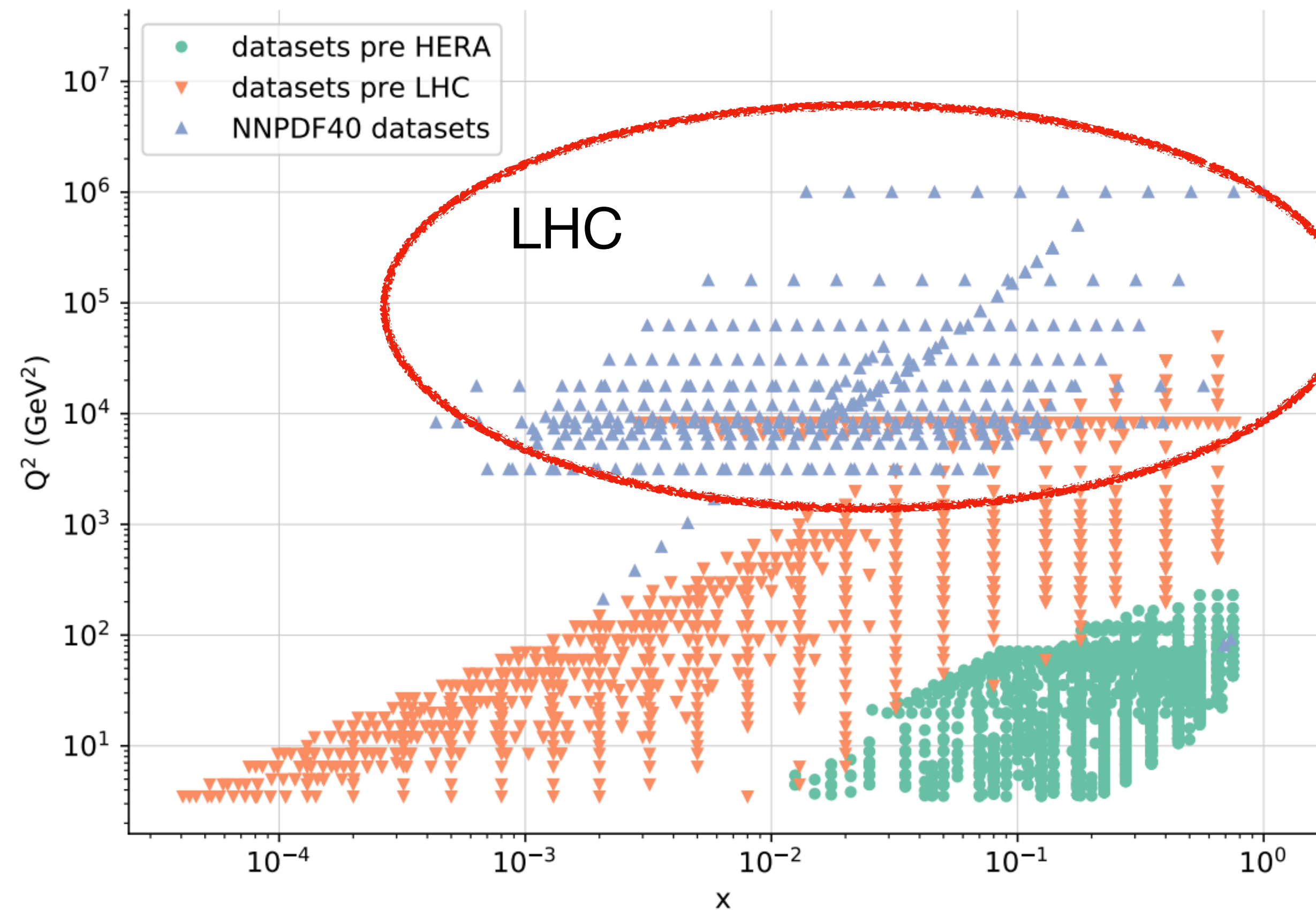


Funded by  
the European Union

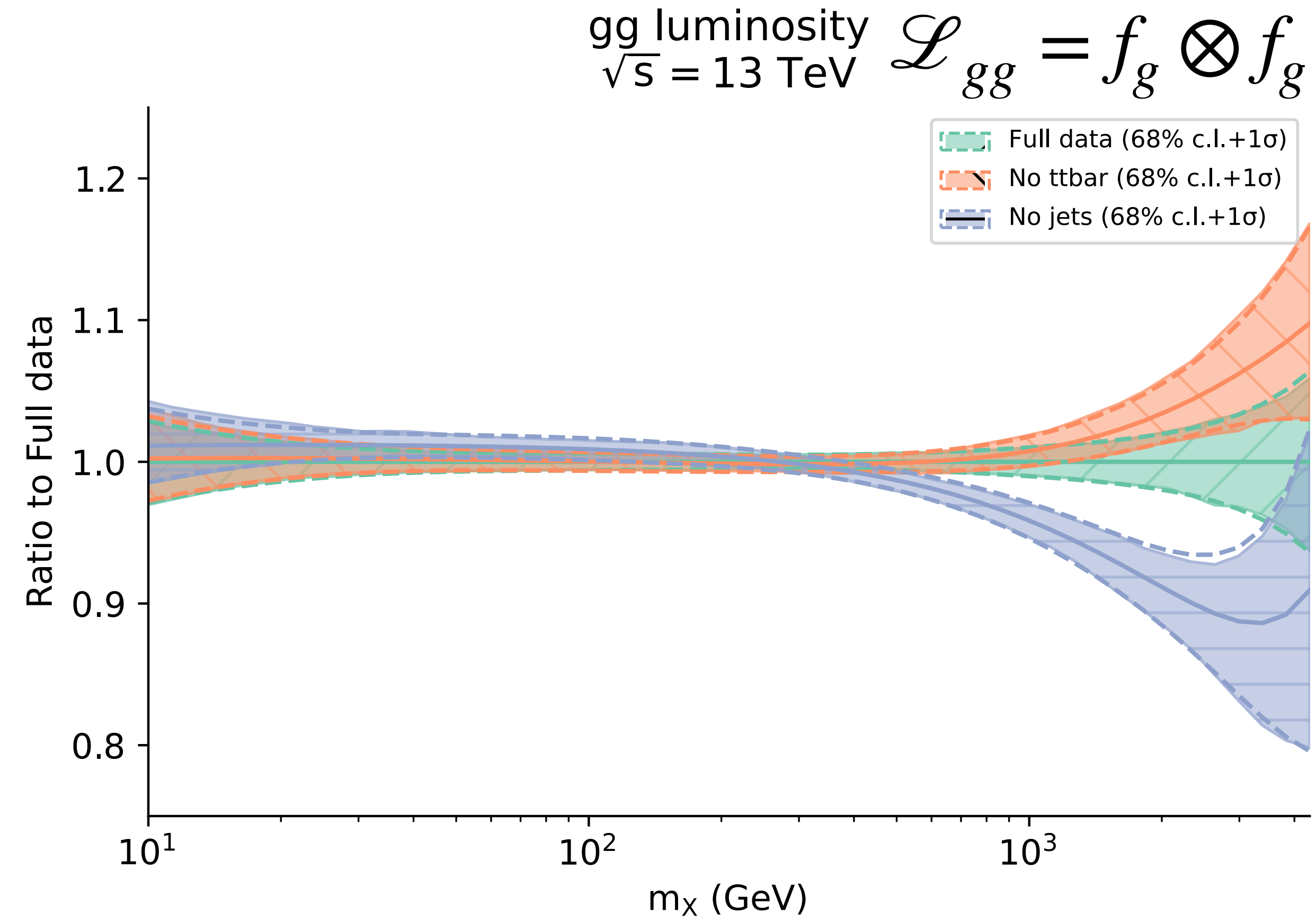
# Tension between high energy data

## Comparison of PDFs trained on different datasets

Full data kinematic coverage



PDFs' process dependance...



# New physics scenario: $W'$ $pp \rightarrow l^- \bar{\nu}$ $M_{W'} = 13.8 \text{ TeV}$

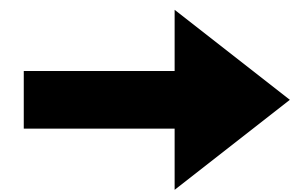
## Generation of the pseudodata

$$\mathcal{L}_{UV}^{W'} = \mathcal{L}_{SM} - \frac{1}{4} W_{\mu\nu}^{\prime a} W^{\prime a, \mu\nu} + \frac{1}{2} M_{W'}^2 W_{\mu}^{\prime a} W^{\prime a, \mu} - g_{W'} W^{\prime a, \mu} \sum_{f_L} \bar{f}_L T^a \gamma^\mu f_L$$



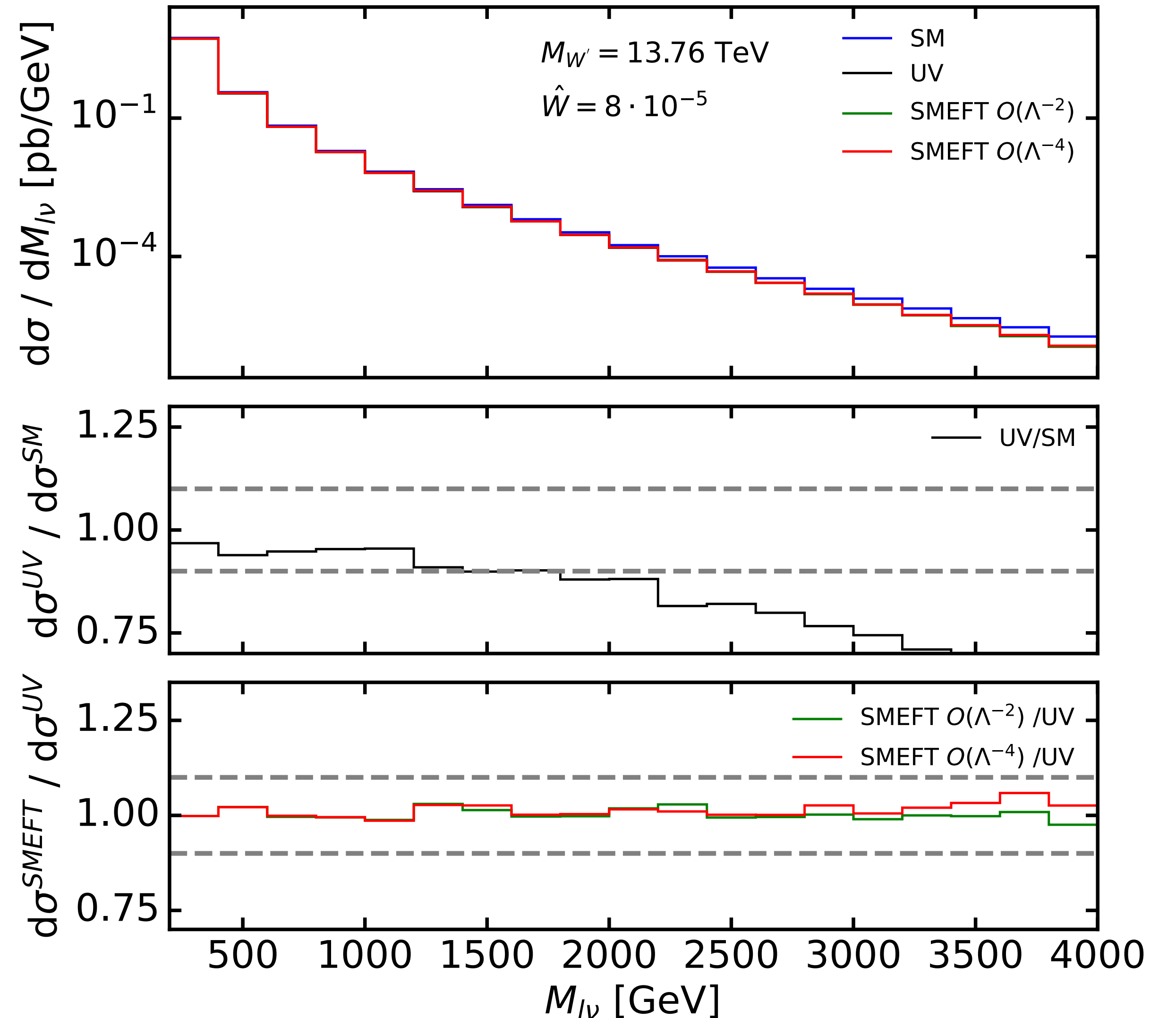
$$\mathcal{L}_{SMEFT}^{W'} = \mathcal{L}_{SM} - \frac{g_{W'}^2}{2M_{W'}^2} J_L^{a, \mu} J_{L, \mu}^a$$

$$J_L^{a, \mu} = \sum_{f_L} \bar{f}_L T^a \gamma^\mu f_L$$



Impacts Drell-Yan

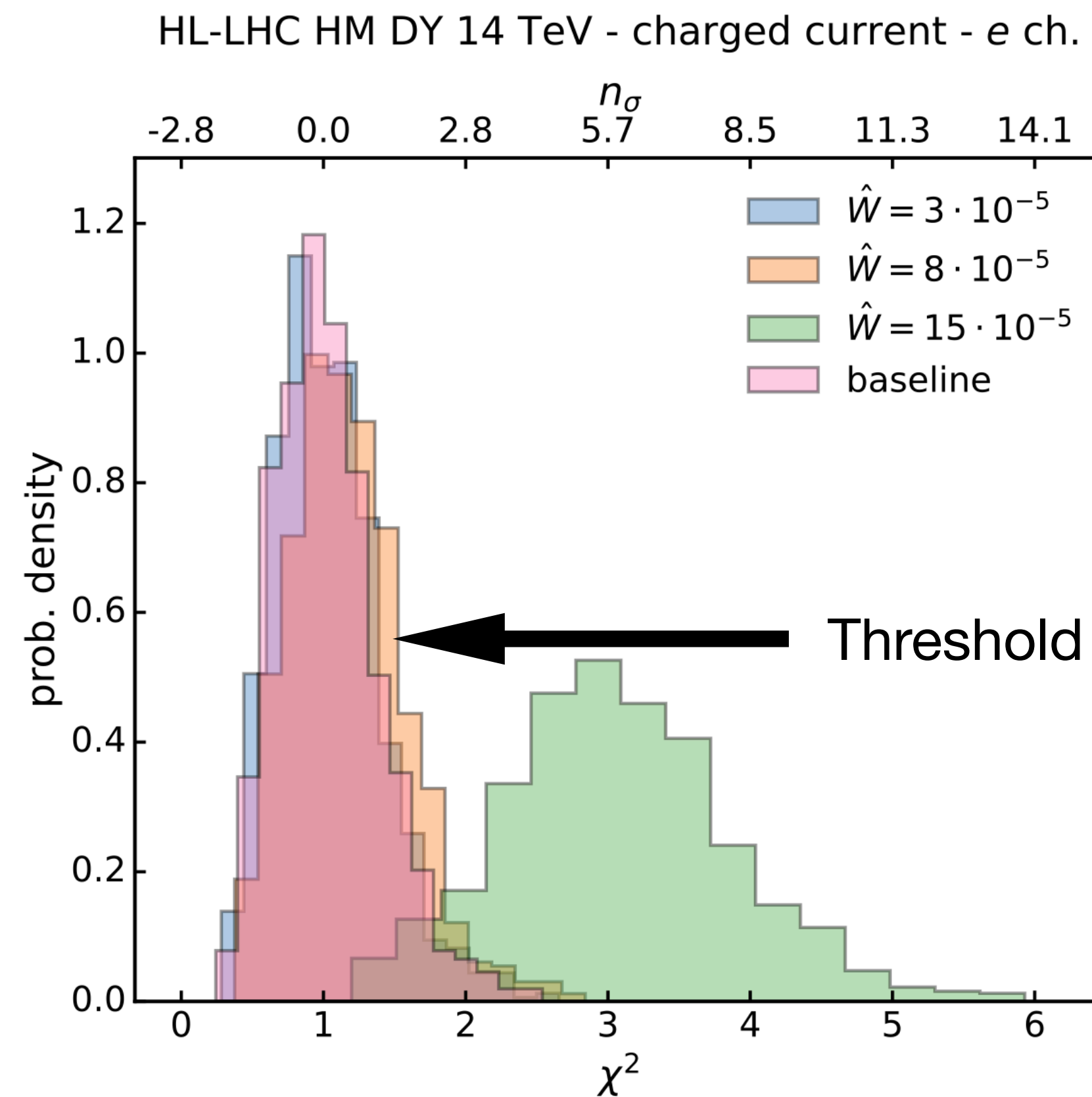
HL-LHC Projections



# Impact on the PDFs

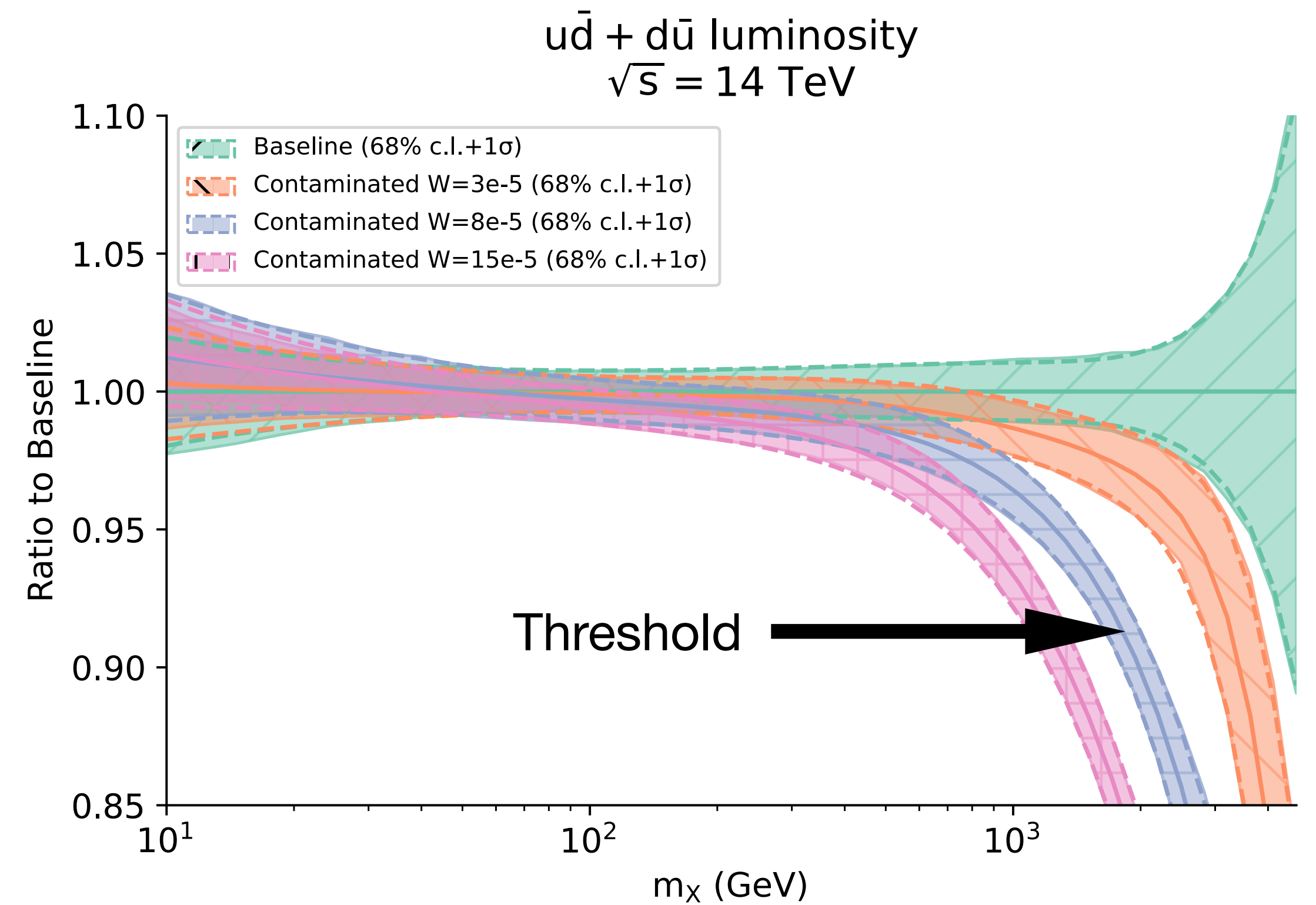
## Comparison between SMEFT and SM PDFs

Fit quality



$$M_{W'} = 13.8 \text{ TeV}$$

Impact on PDFs

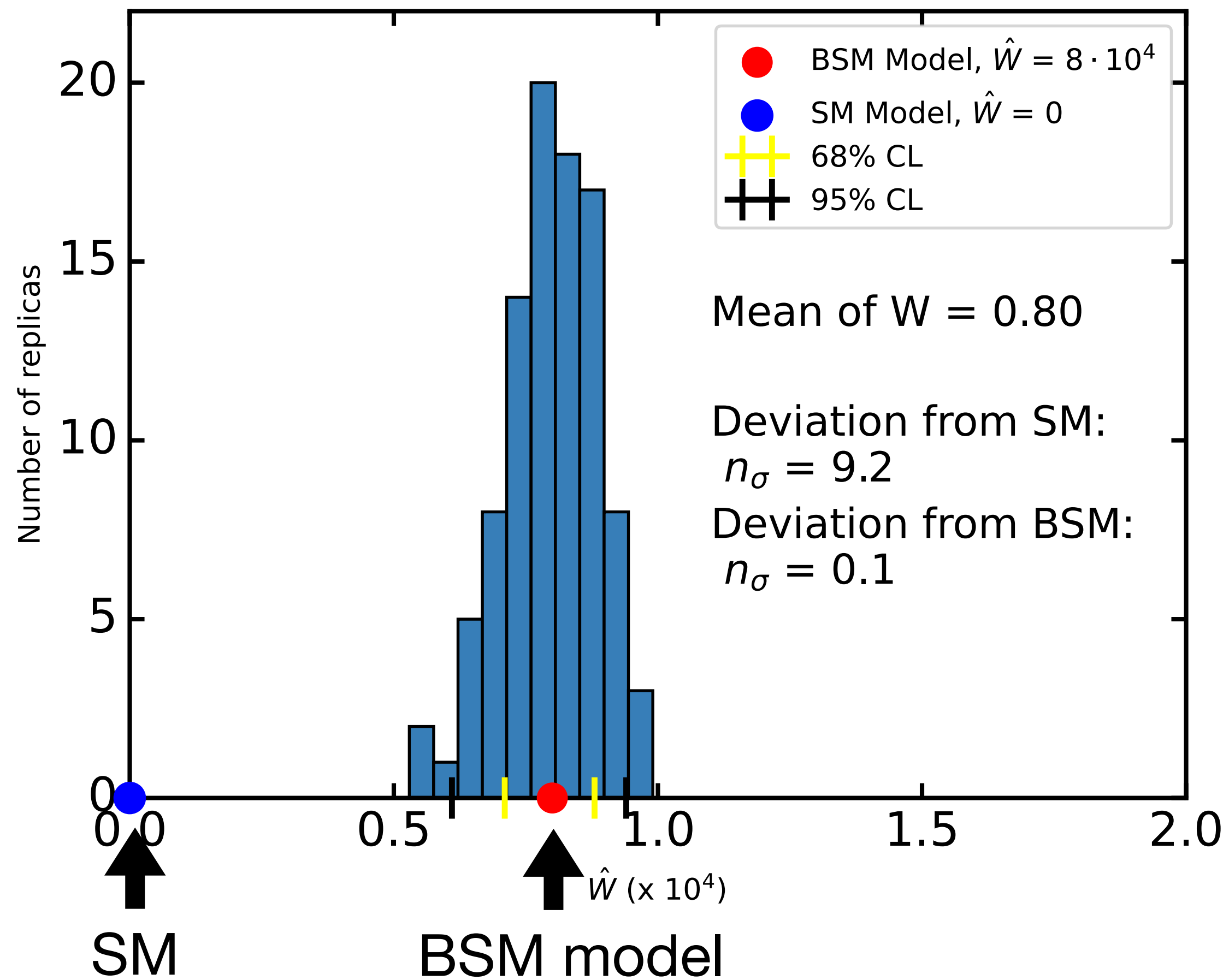


$$\sigma_{BSM}^{Data} \approx \hat{\sigma}_{SM} \otimes \mathcal{L}_{cont}$$

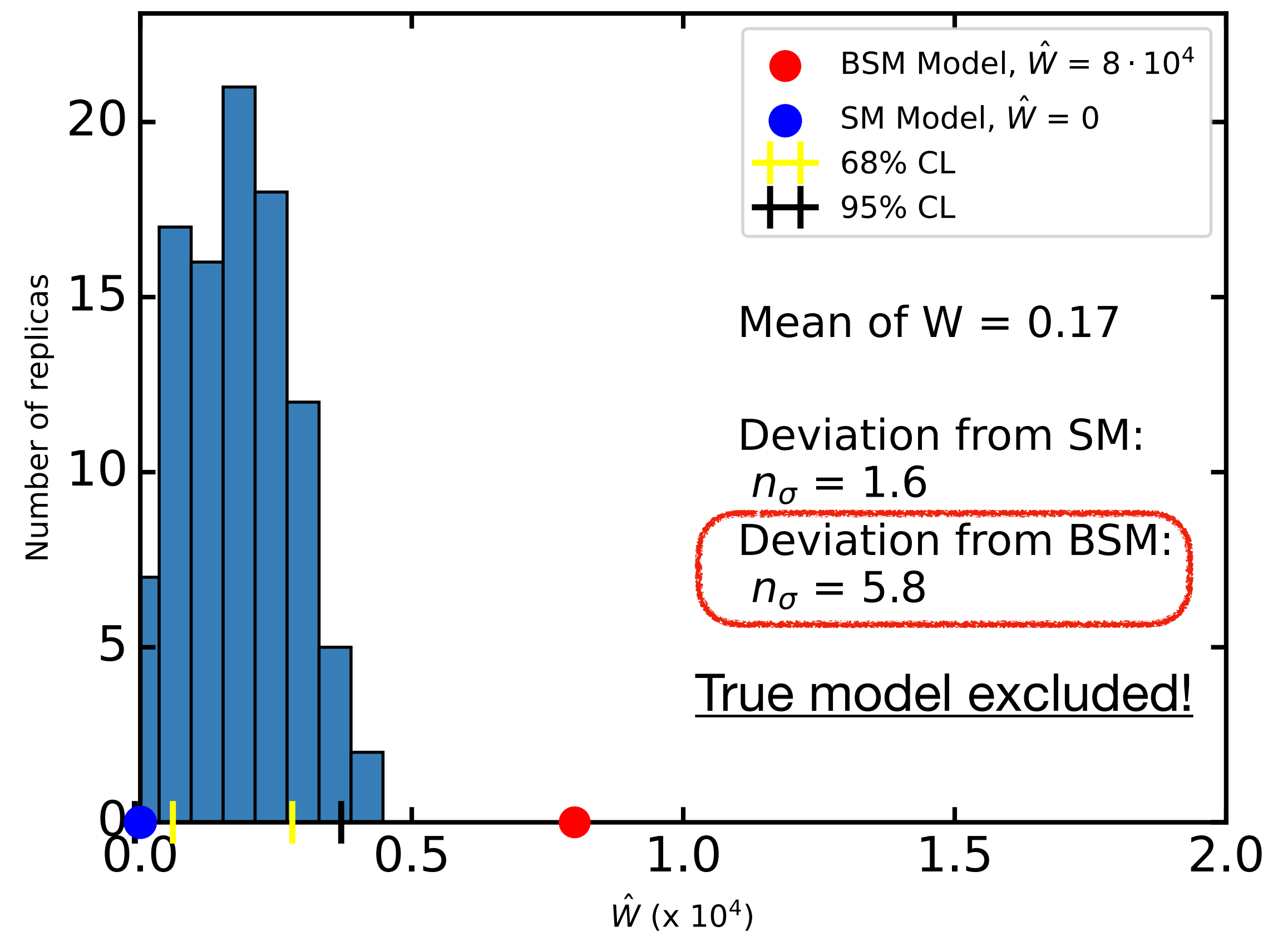
# Missing new physics

## Impact of the choice of PDF on SMEFT fits

SMEFT Fit with true PDF



SMEFT Fit with SMEFT PDF



# Future low energy data

## Presentation of the future DIS programmes

### Electron Ion Collider

- $e^+/e^-$  projectiles
- proton, deuteron and heavy ions targets
- Hosted in Brookhaven
- Planned for 2030s
- Probes large-x, low-energy

### Forward Physics Facility

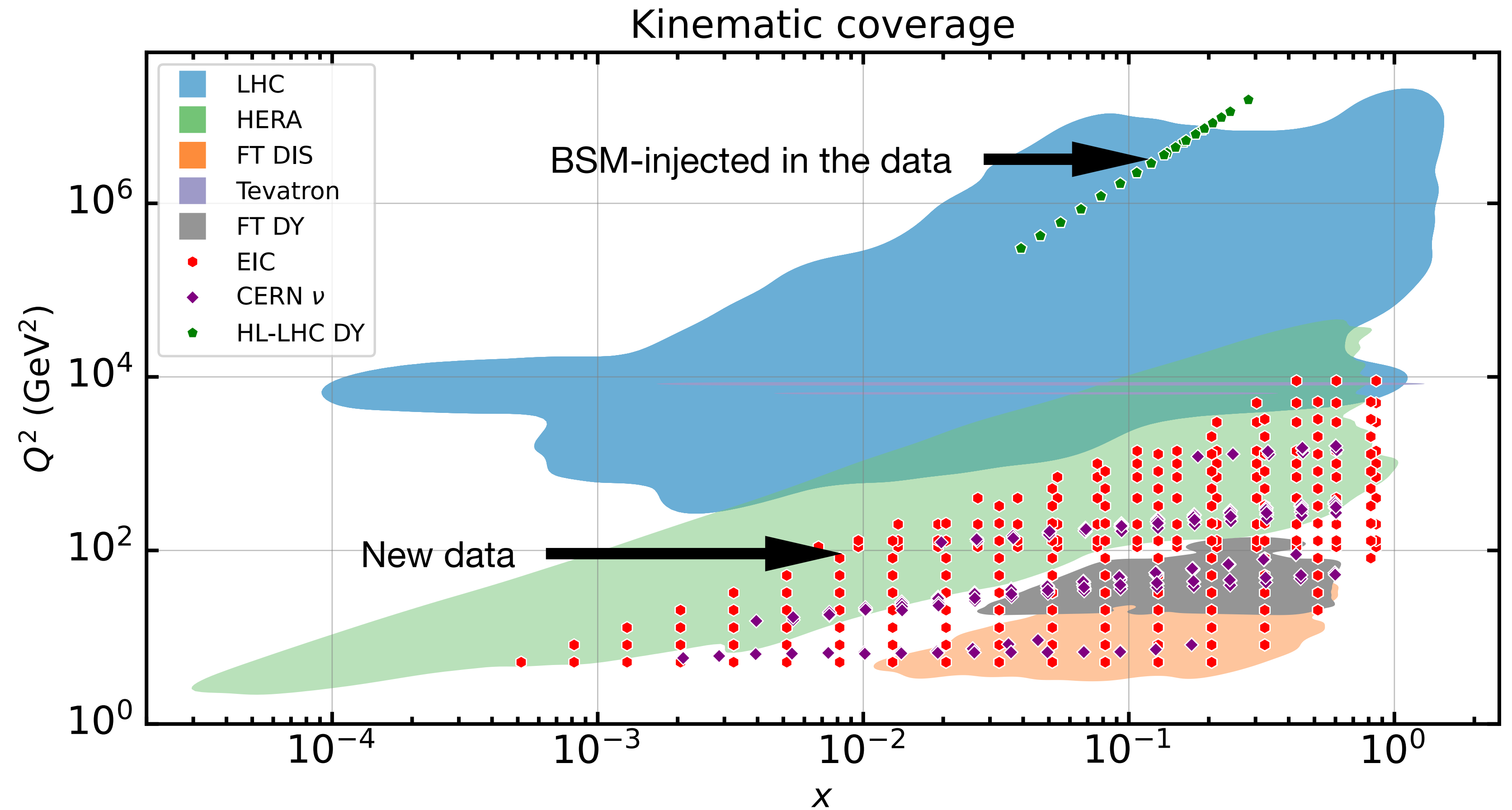
- “Neutrino Ion collider” at the LHC
- $\nu/\bar{\nu}$  projectiles from proton beam
- proton, neutron and other nuclear targets
- FASER $\nu$  and SND@LHC already running
- Proposed expansion for HL-LHC run (FASER $\nu$ 2 , AdvSND, FLArE)
- Probes large-x, low-energy
- Constrain large-x antiquarks

# Future low energy data

## Kinematic coverage

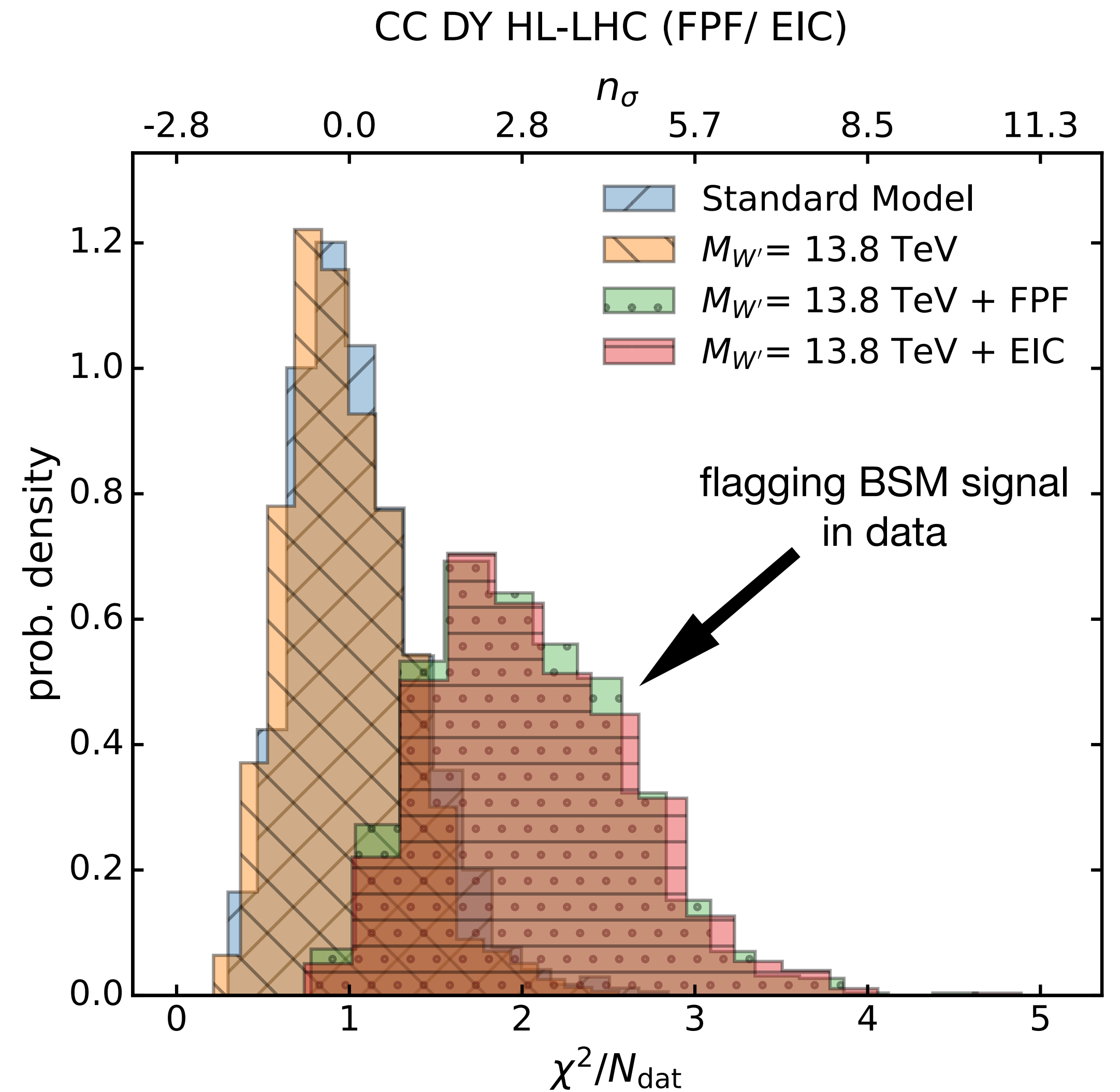
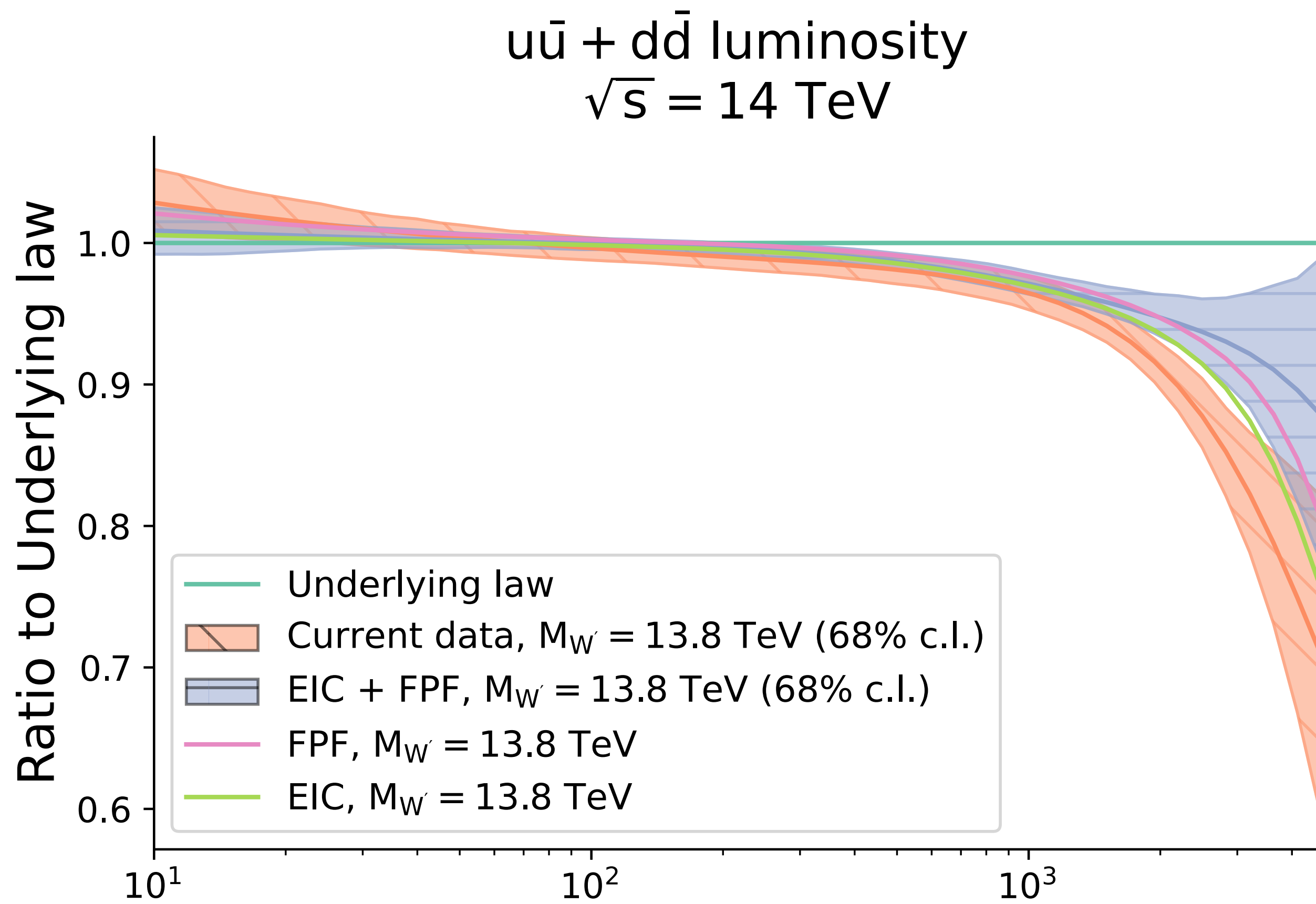
### Projection data:

- Electron Ion Collider (EIC)
- Forward Physics Facility (FPF)  
(neutrino DIS)



# Impact on the PDF contamination

## Flagging the BSM data



# Recovering the signs of new physics

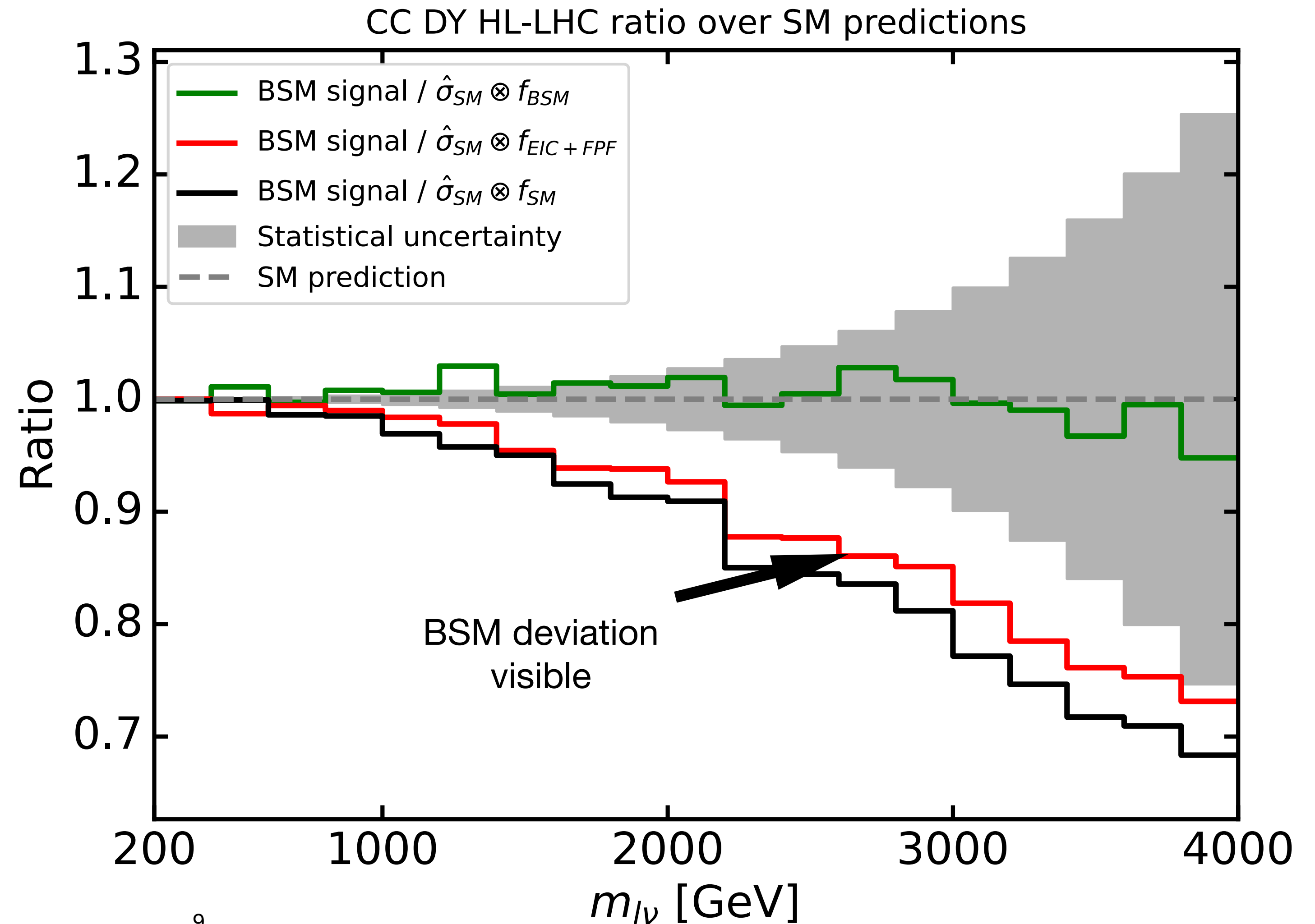
## BSM data versus SM theory predictions

$$\hat{\sigma}_{BSM} \otimes \mathcal{L}_{SM} \approx \hat{\sigma}_{SM} \otimes \mathcal{L}_{cont}$$



$$\hat{\sigma}_{BSM} \otimes \mathcal{L}_{SM} \neq \hat{\sigma}_{SM} \otimes \mathcal{L}_{EIC+FPF}$$

$M_{W'}$  : 13.8 TeV



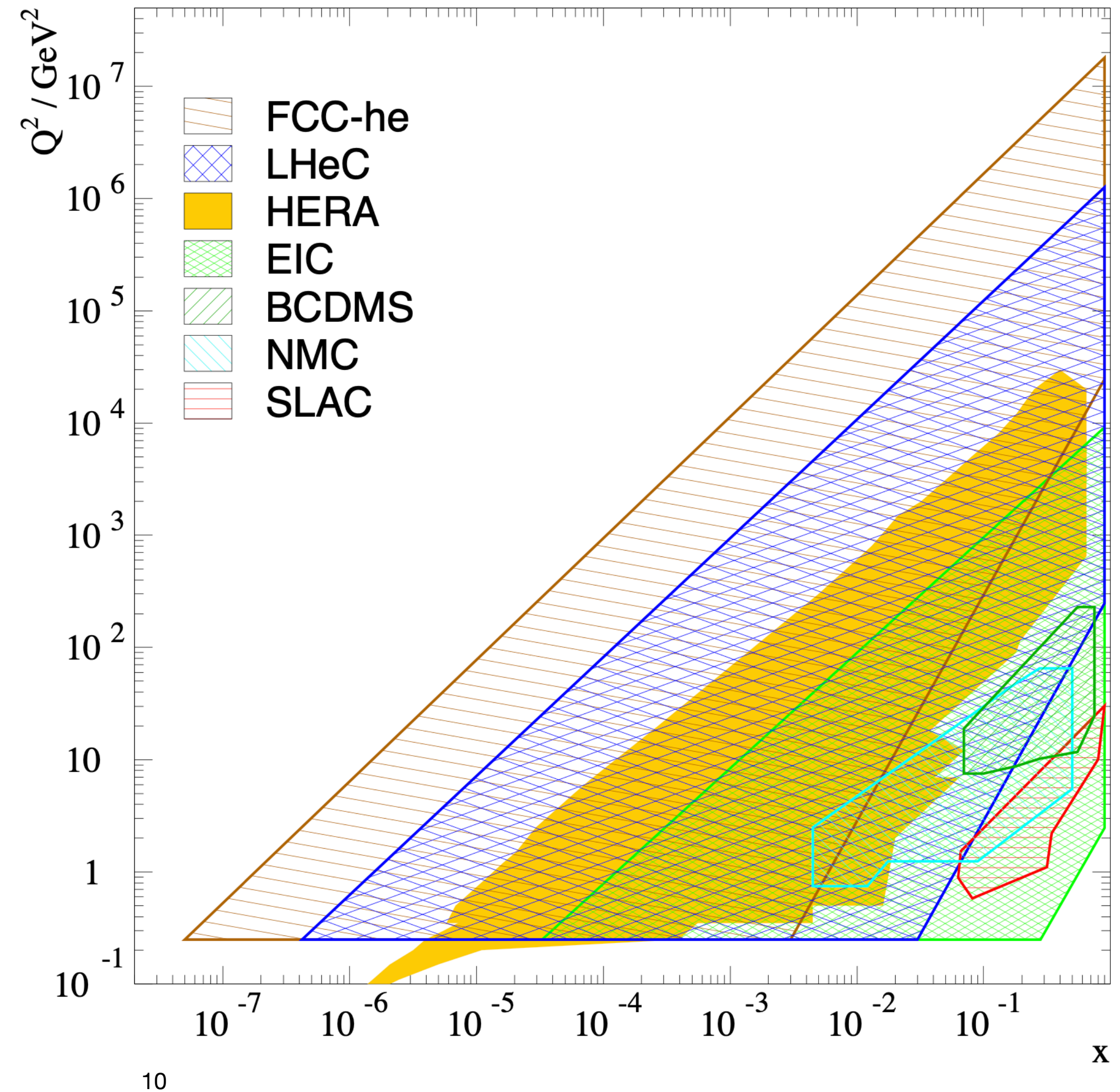
# Kinematic coverage of DIS programmes

## Projection data LHeC:

- Probes large- $x$
- Probes higher energies

➔ Bigger SMEFT corrections

Same problem as with HL-LHC data

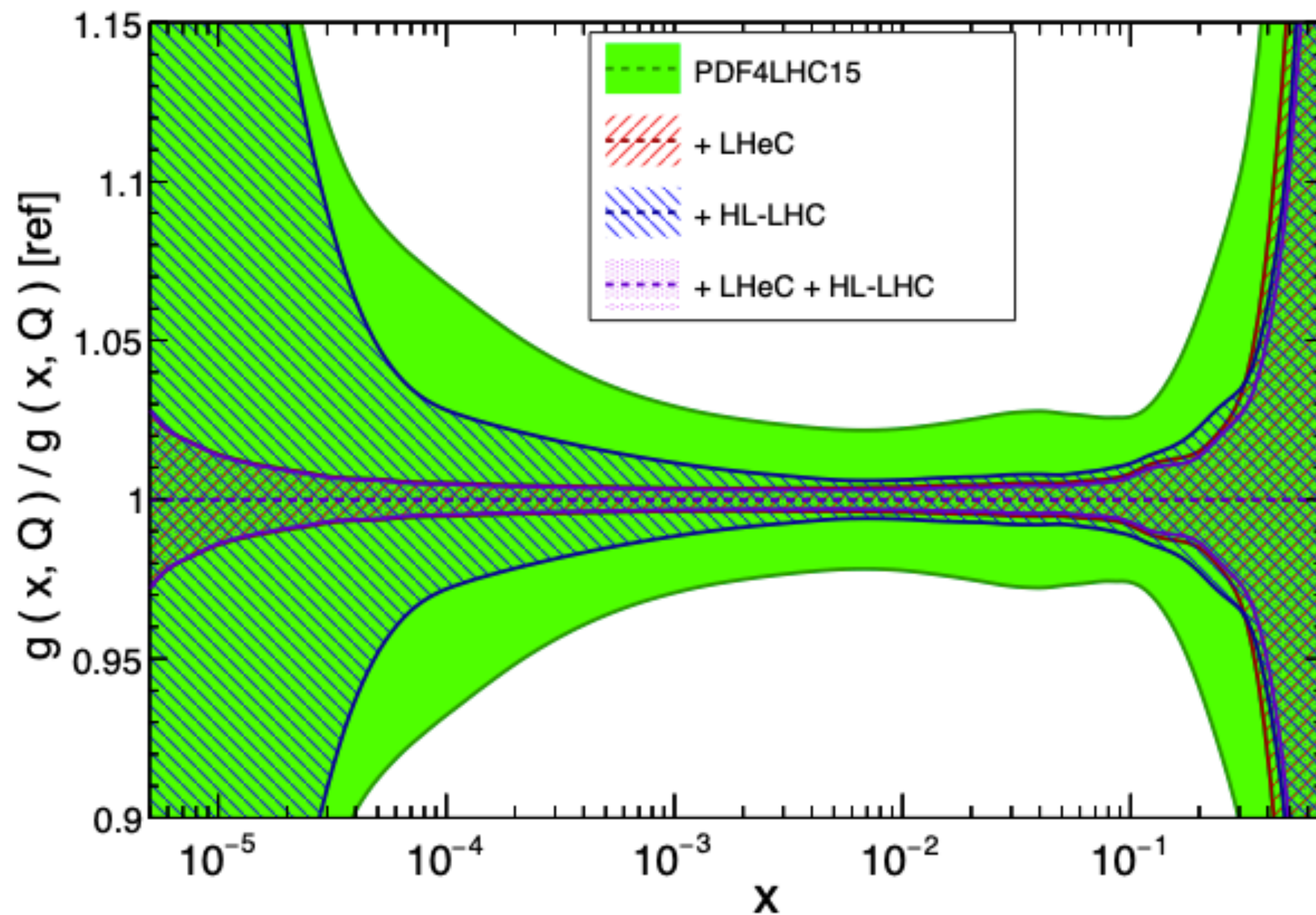


# Constraining PDFs with LHeC data

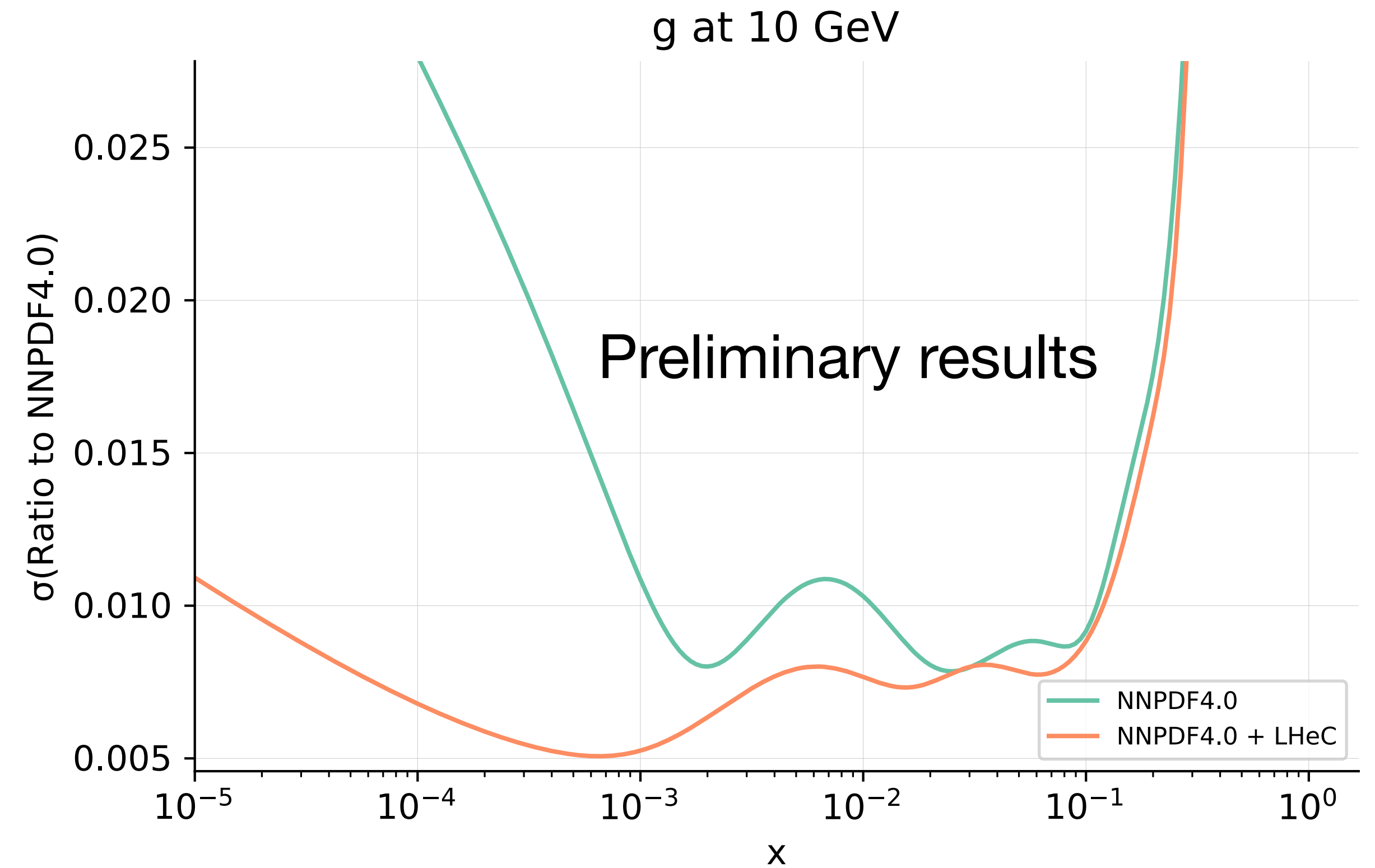
From literature

[10.21468/SciPostPhys.7.4.051](https://arxiv.org/abs/10.21468/SciPostPhys.7.4.051), Khalek, Bailey, Gao, Harland-Lang, Rojo

PDFs at the HL-LHC (  $Q = 10$  GeV )



PDFs uncertainties



# 4-Fermion SMEFT corrections

10.1103/PhysRevD.106.016006, Boughezal et al.

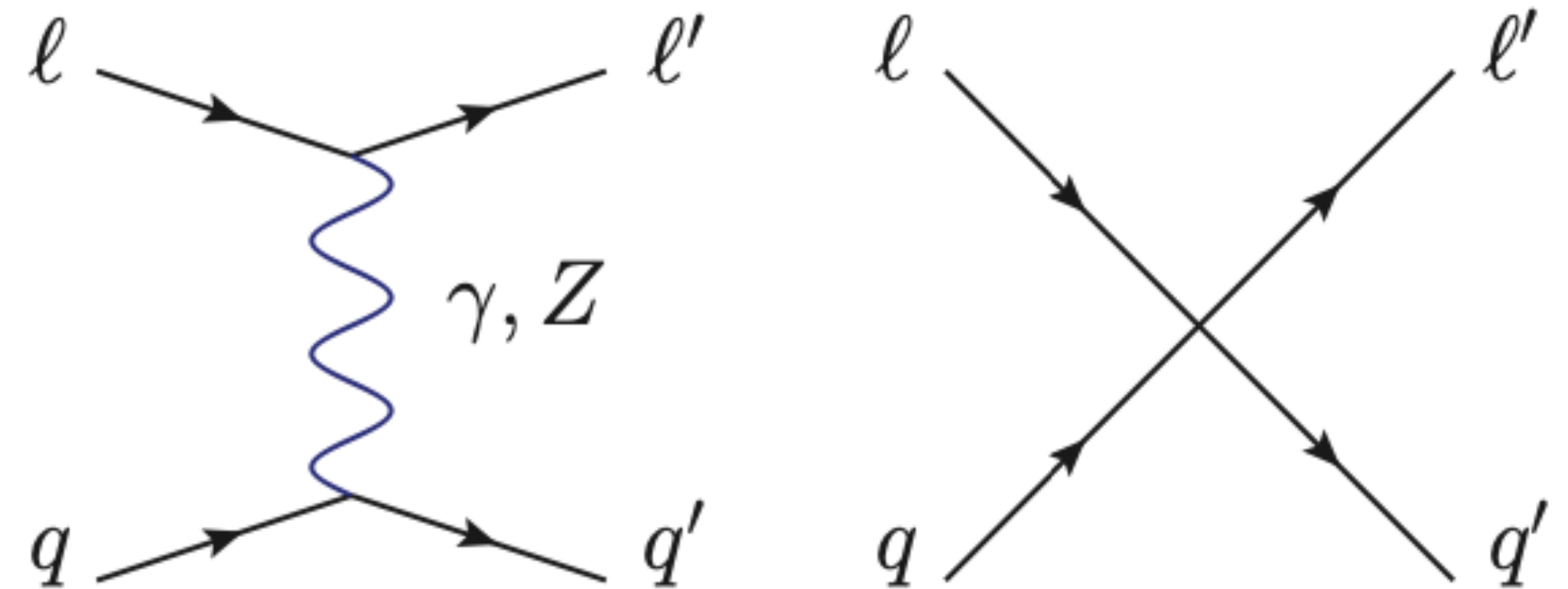
10.1103/PhysRevD.108.075007, Bissoloti, Boughezal and Simsek

Computes SMEFT projections:

- EIC
- LHeC
- FCC-eh

$C_r$	$\mathcal{O}_r$
$C_{lq}^{(1)}$	$\mathcal{O}_{lq}^{(1)} = (\bar{L}_L \gamma^\mu L_L)(\bar{Q}_L \gamma_\mu Q_L)$
$C_{lq}^{(3)}$	$\mathcal{O}_{lq}^{(3)} = (\bar{L}_L \gamma^\mu \tau^I L_L)(\bar{Q}_L \gamma_\mu \tau^I Q_L)$
$C_{eu}$	$\mathcal{O}_{eu} = (\bar{e}_R \gamma^\mu e_R)(\bar{u}_R \gamma_\mu u_R)$
$C_{ed}$	$\mathcal{O}_{ed} = (\bar{e}_R \gamma^\mu e_R)(\bar{d}_R \gamma_\mu d_R)$
$C_{lu}$	$\mathcal{O}_{lu} = (\bar{L}_L \gamma^\mu L_L)(\bar{u}_R \gamma_\mu u_R)$
$C_{ld}$	$\mathcal{O}_{ld} = (\bar{L}_L \gamma^\mu L_L)(\bar{d}_R \gamma_\mu d_R)$
$C_{qe}$	$\mathcal{O}_{qe} = (\bar{Q}_L \gamma^\mu Q_L)(\bar{e}_R \gamma_\mu e_R)$

DIS Neutral-Current corrections

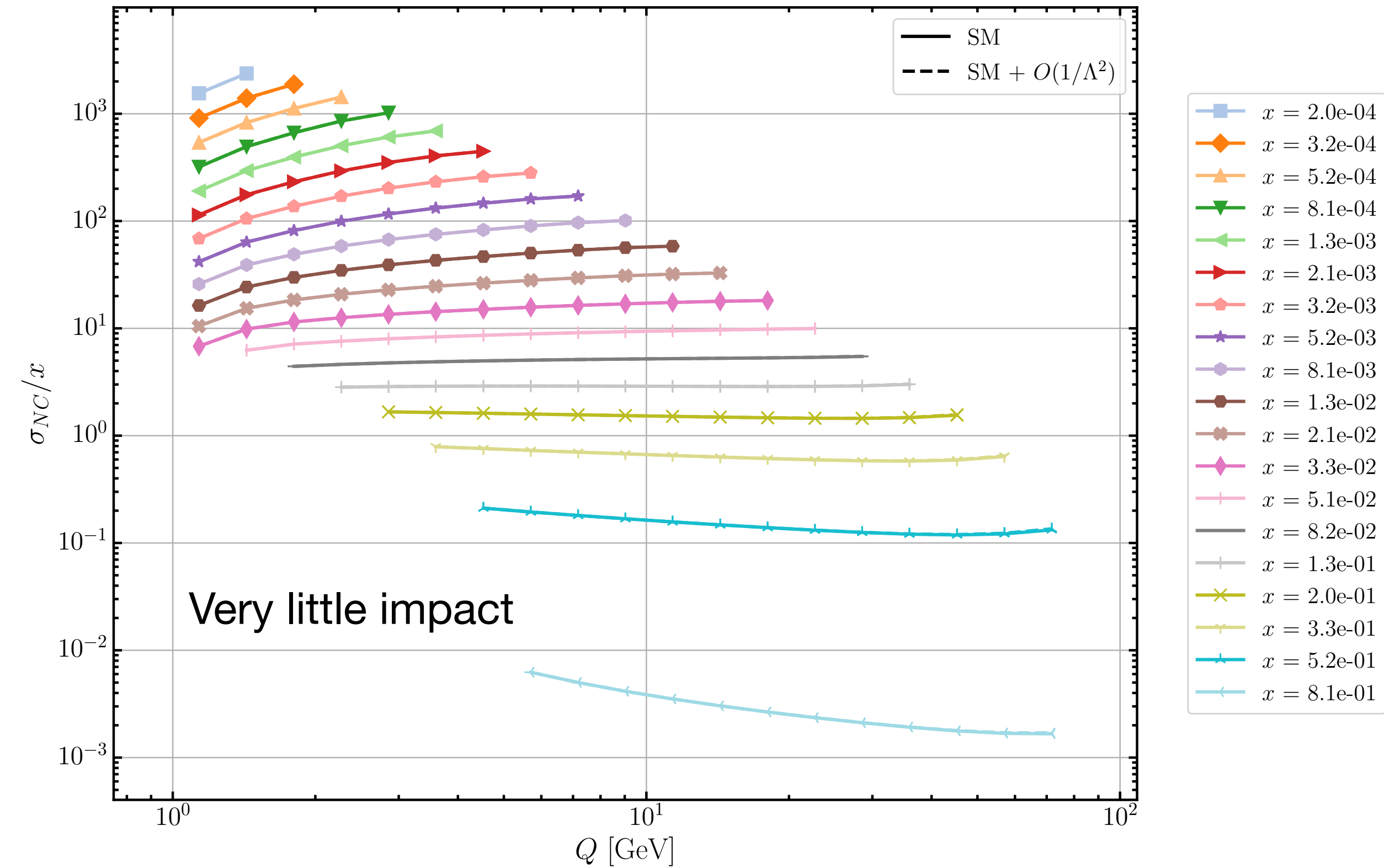


Charged-Current not yet computed

# Impact of $O_{lq}^3$ on EIC and LHeC projections

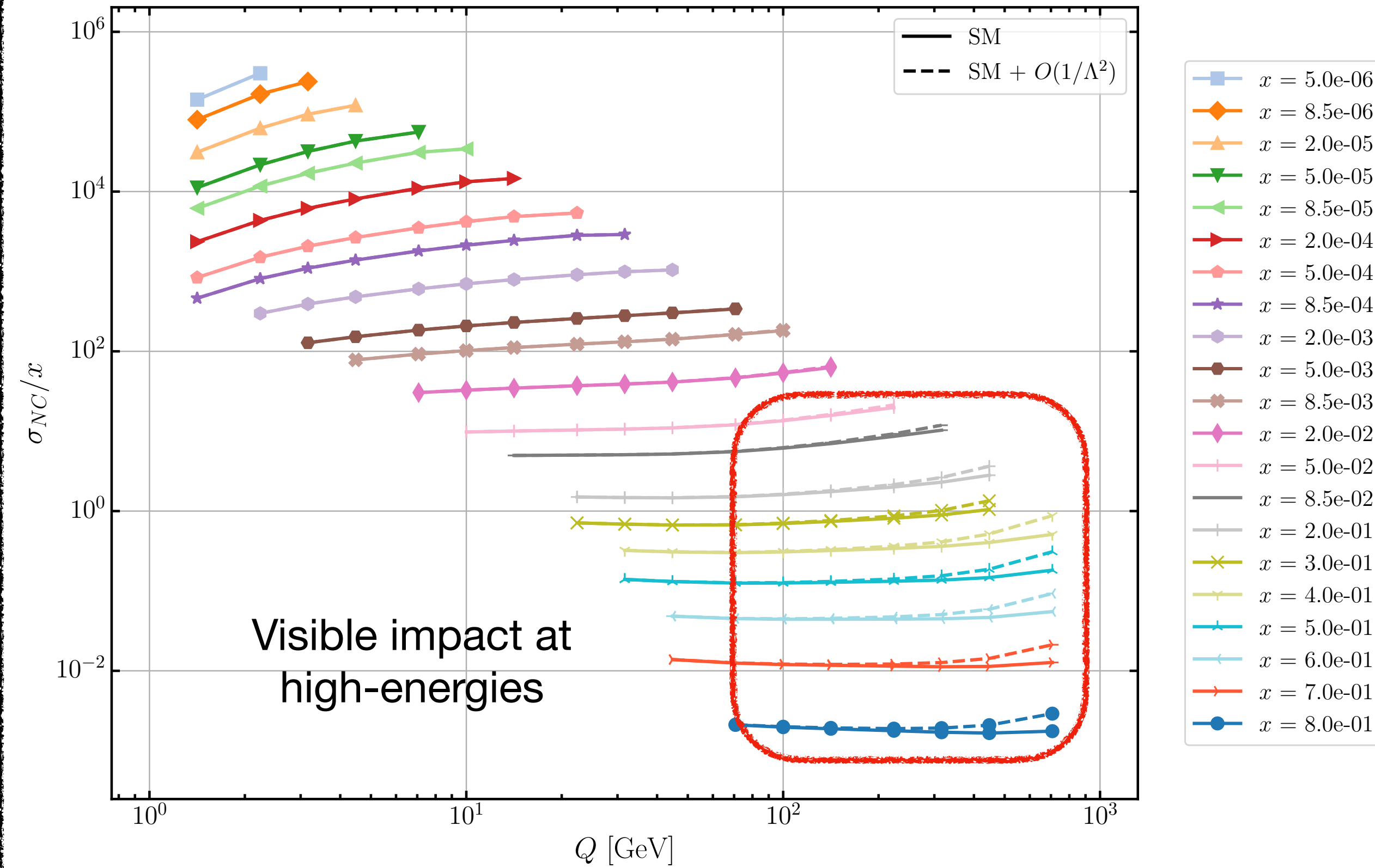
EIC projections

Impact of  $O_{lq}^3$  on  $e^-p$ ,  $\Lambda = 3$  TeV, EIC



LHeC projections

Impact of  $O_{lq}^3$  on  $e^-p$ ,  $\Lambda = 3$  TeV, LHeC

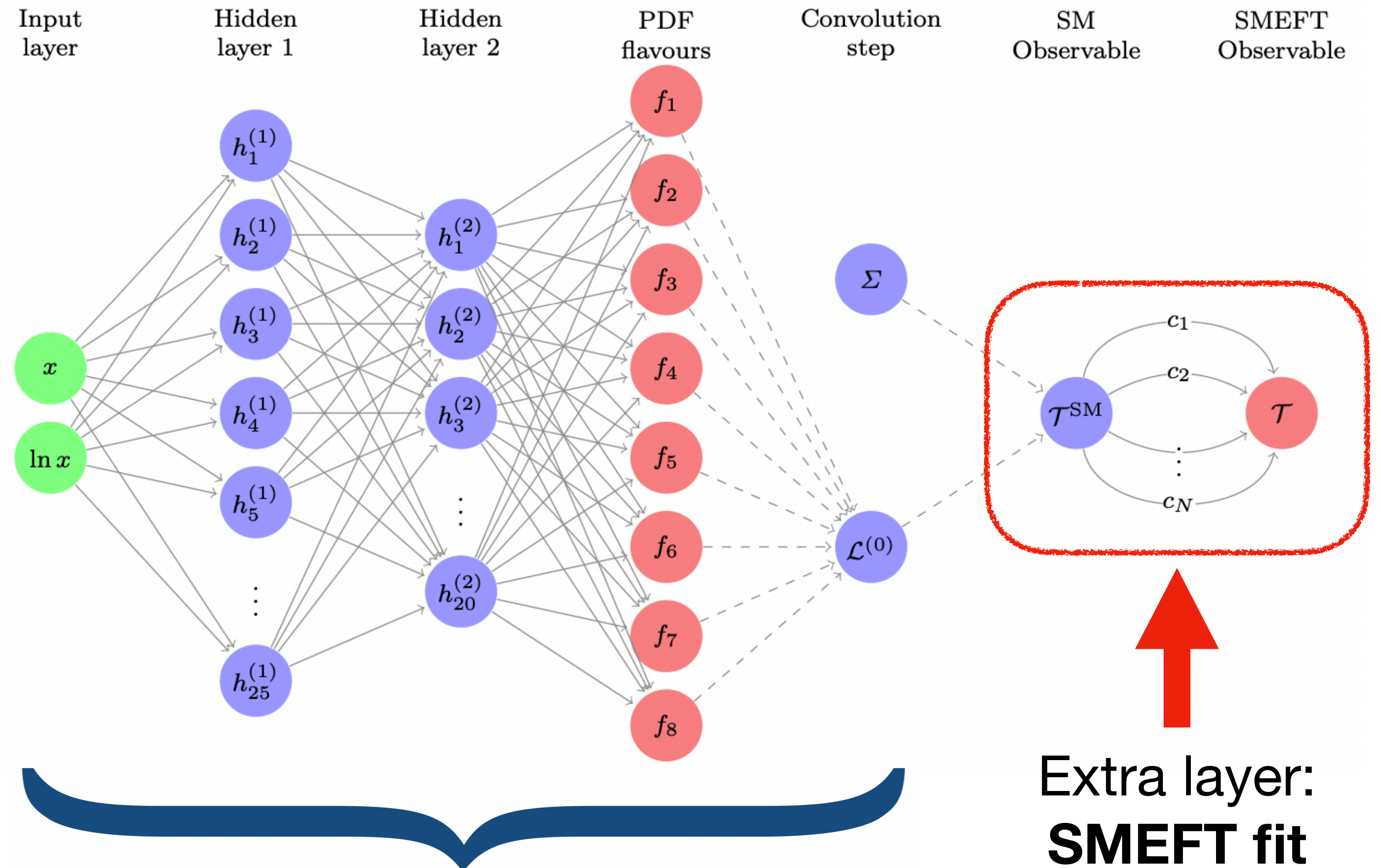


# Simultaneous fit of PDF and new physics

## Presentation of the tool: SIMUnet

### SIMUnet:

- Open-source tool:  
[github.com/HEP-PBSP/SIMUnet](https://github.com/HEP-PBSP/SIMUnet)  
[2402.03308]
- Fits PDFs and WC simultaneously



NNPDF

[Iranipour et Ubiali, 2201.07240]

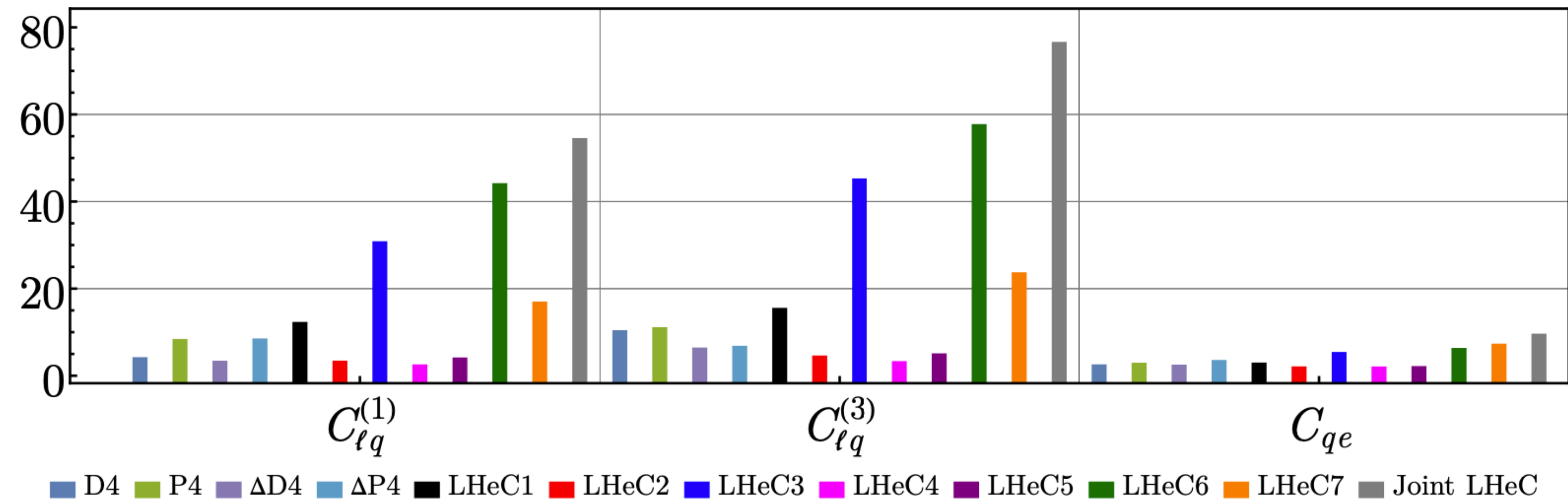
# Bounds on $\mathcal{O}_{lq}^3$ from LHeC projections

Bounds from literature

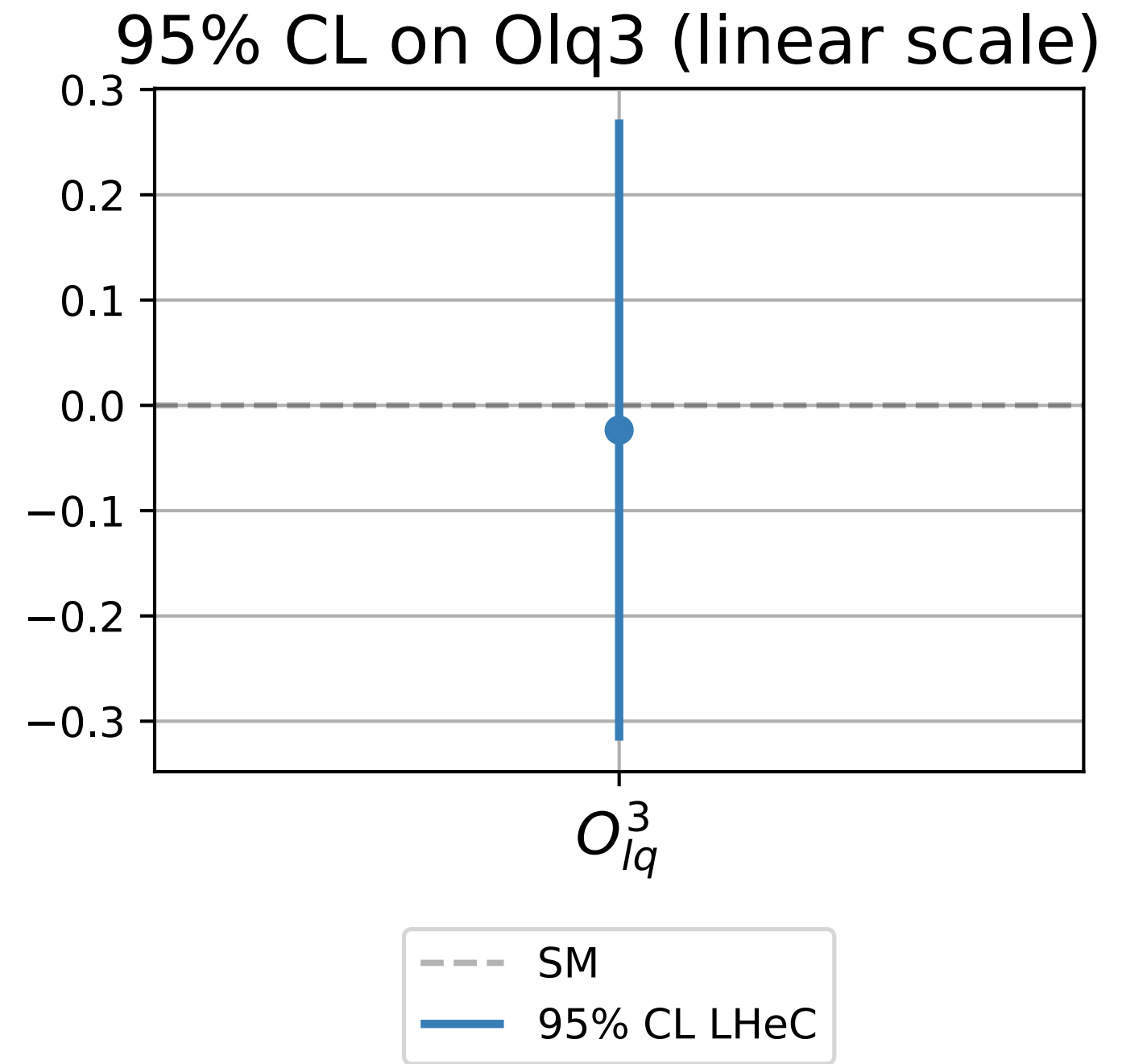
10.1103/PhysRevD.108.075007, Bissoloti, Boughezal and Simsek

$\Lambda/\sqrt{C_k}$  [TeV] at 95% CL, 3d fit

$$P_\ell = -80\%, C_{eu} \approx -13(C_{lq}^{(1)} - C_{lq}^{(3)}), C_{lu} \approx -0.052 C_{qe}, C_{ed} \approx -22(C_{lq}^{(1)} + C_{lq}^{(3)}), C_{ld} \approx 0.12 C_{qe}$$



Preliminary results



# Plan for the study

- Implement all NC SMEFT operators
- Compare SMEFT bounds with literature
- Add CC SMEFT corrections
- Fit simultaneously SMEFT and PDF
  - Assess impact on SMEFT bounds
  - Study PDF constraining potential
  - Assess BSM and PDF interplay at LHeC and FCC-eh

# Summary

- Fitting PDFs in the presence of new physics
  - Risk of absorbing it (BSM contamination)
- Adding low-energy large-x data
  - Reduce PDF uncertainty
  - Can prevent new physics absorption
- The LHeC study:
  - SMEFT studies partially performed
  - SMEFT-PDF interplay study necessary and ongoing

You can contact me at:  
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**Thank you for your  
attention!**

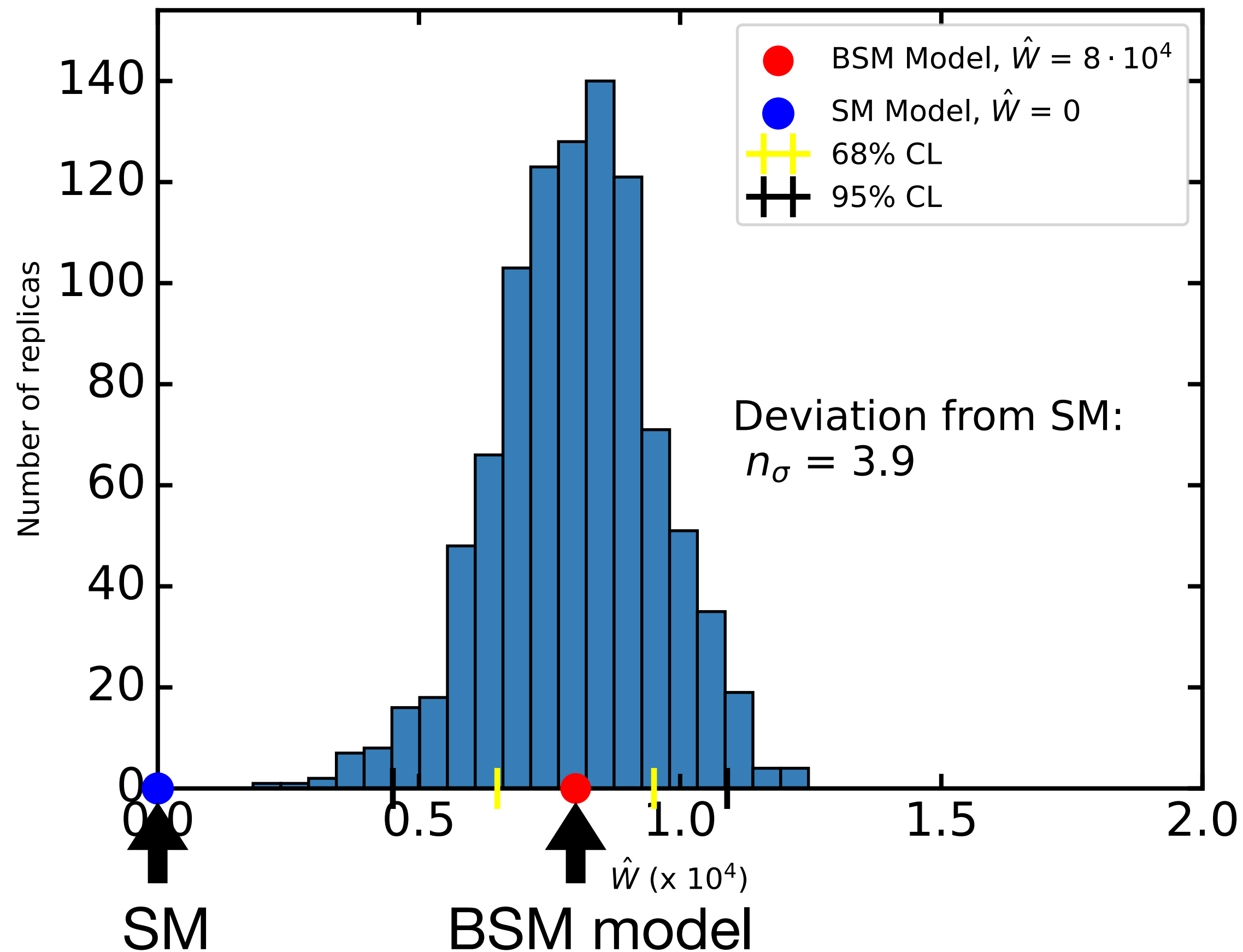
# Extra slides

# Application to the Drell-Yan sector

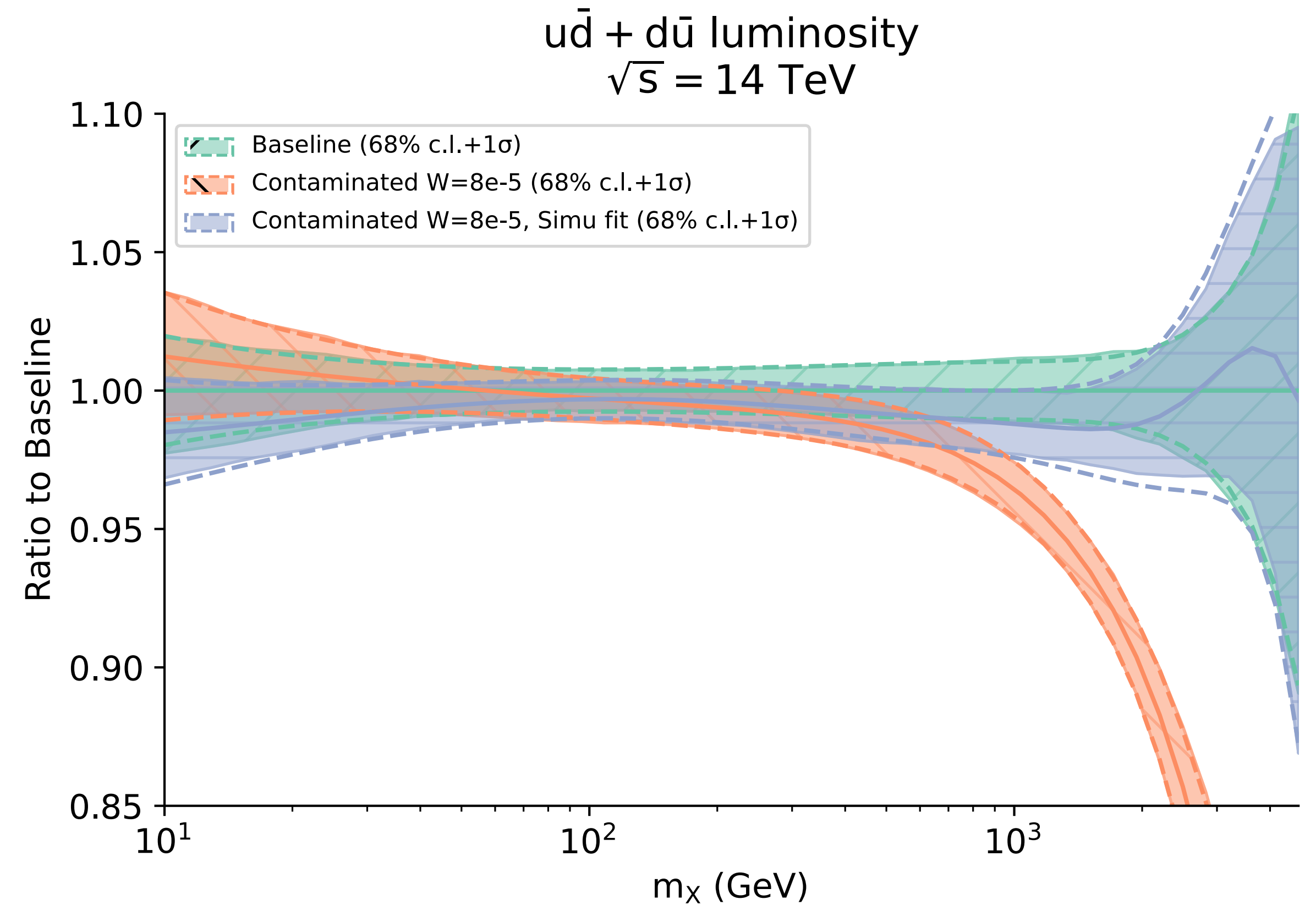
## Disentangling PDF contamination

[PBSP, forthcoming]

SMEFT Fit



PDF Fit

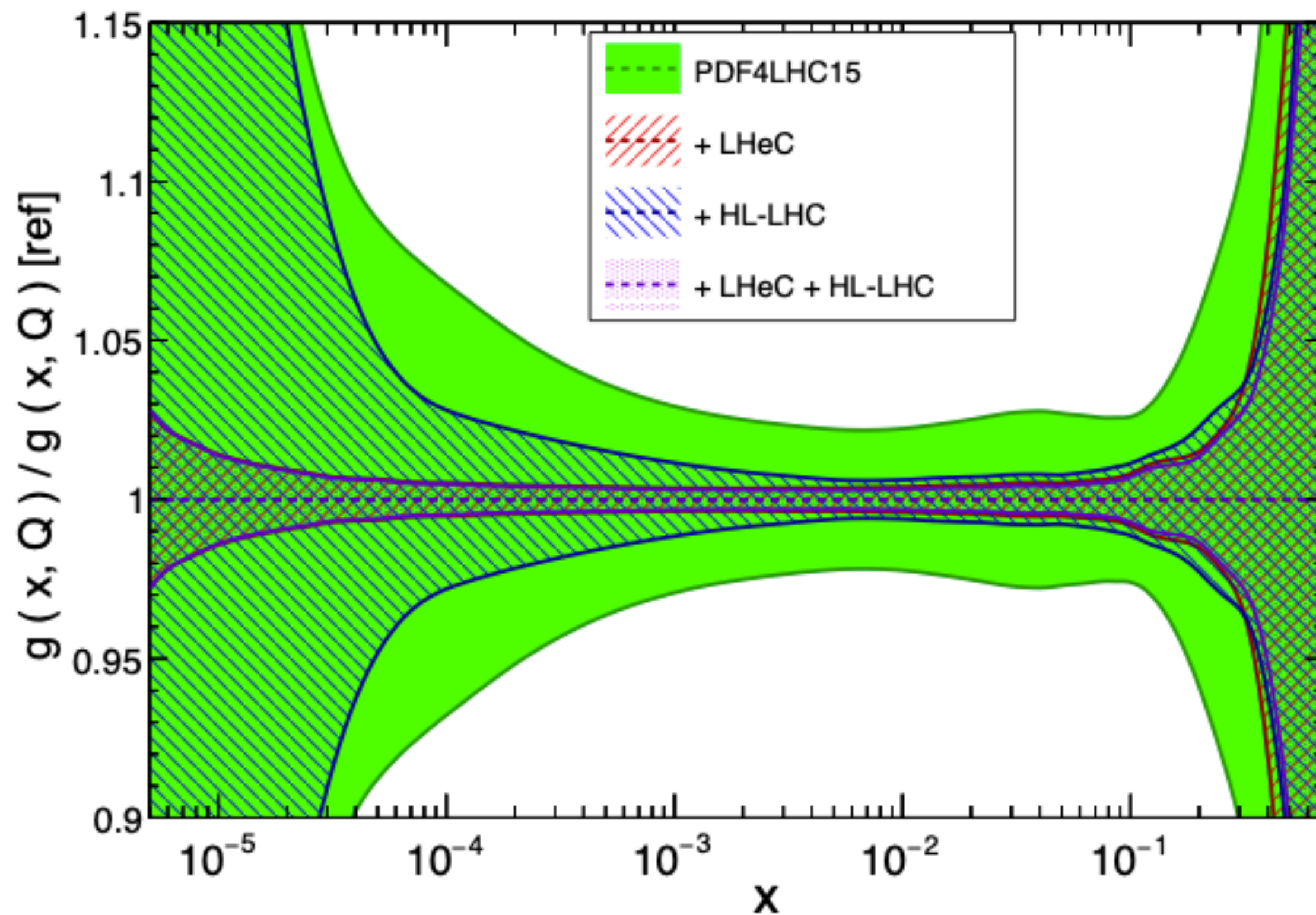


# Constraining PDFs with LHeC data

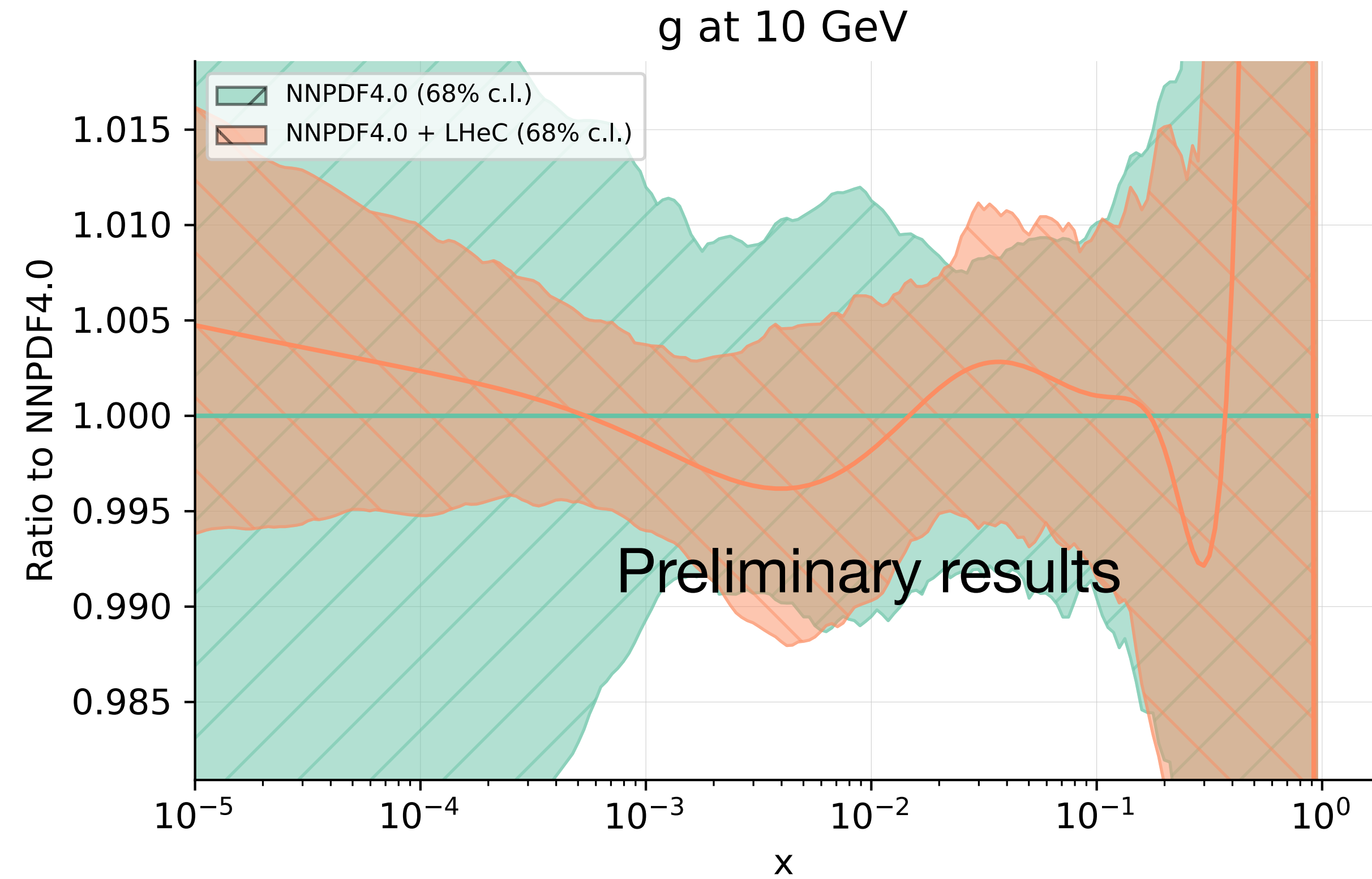
From literature

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PDFs at the HL-LHC (  $Q = 10$  GeV )



PDFs uncertainties



# Apparition of fake deviations

## Impact on predictions for other sectors

Theory predictions (red band):

- SMEFT PDFs + SM

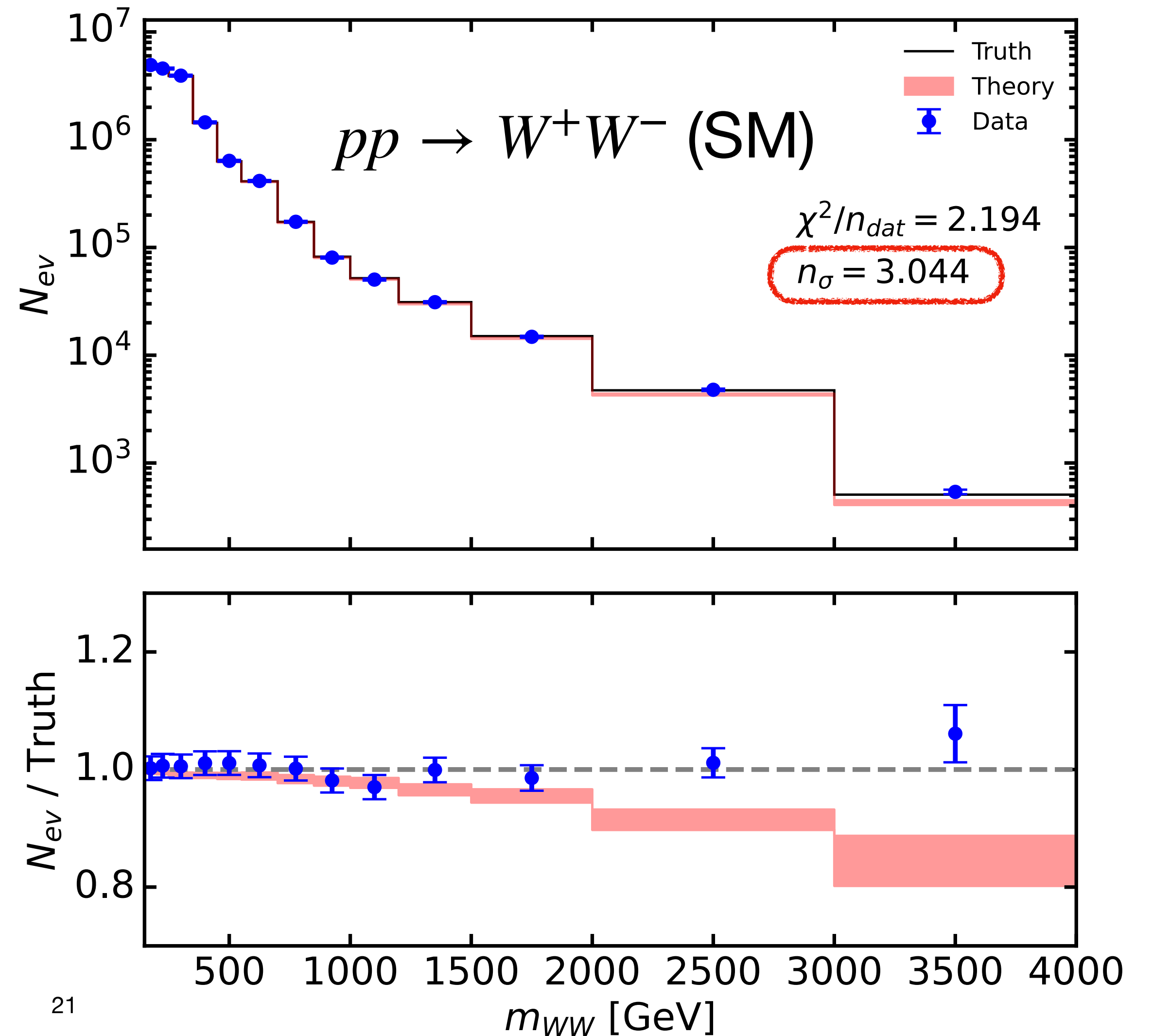
Data (blue dots):

- True PDFs + SM

➔ Fake deviation from SM

Also seen in WH, WZ, ZH production

HL-LHC Projections



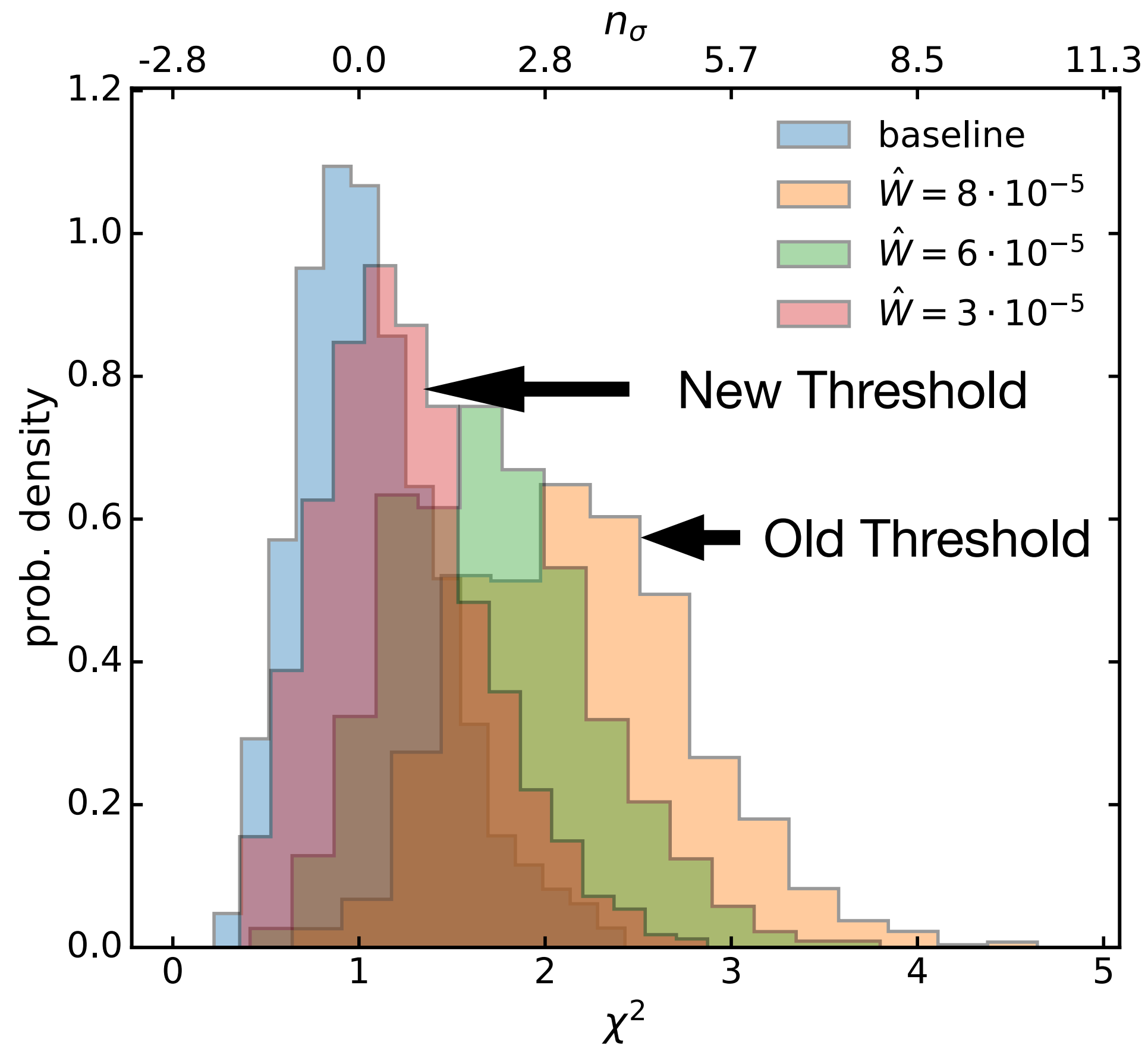
# List of deviations

	HL-LHC		Stat. improved	
Dataset	$\chi^2/n_{\text{dat}}$	$n_\sigma$	$\chi^2/n_{\text{dat}}$	$n_\sigma$
$W^+H$	1.17	0.41	1.77	1.97
$W^-H$	1.08	0.19	1.08	0.19
$W^+Z$	1.08	0.19	1.49	1.20
$W^-Z$	0.99	-0.03	1.02	0.05
$ZH$	1.19	0.44	1.67	1.58
$W^+W^-$	2.19	3.04	2.69	4.31
VBF $\rightarrow$ H	0.70	-0.74	0.62	-0.90

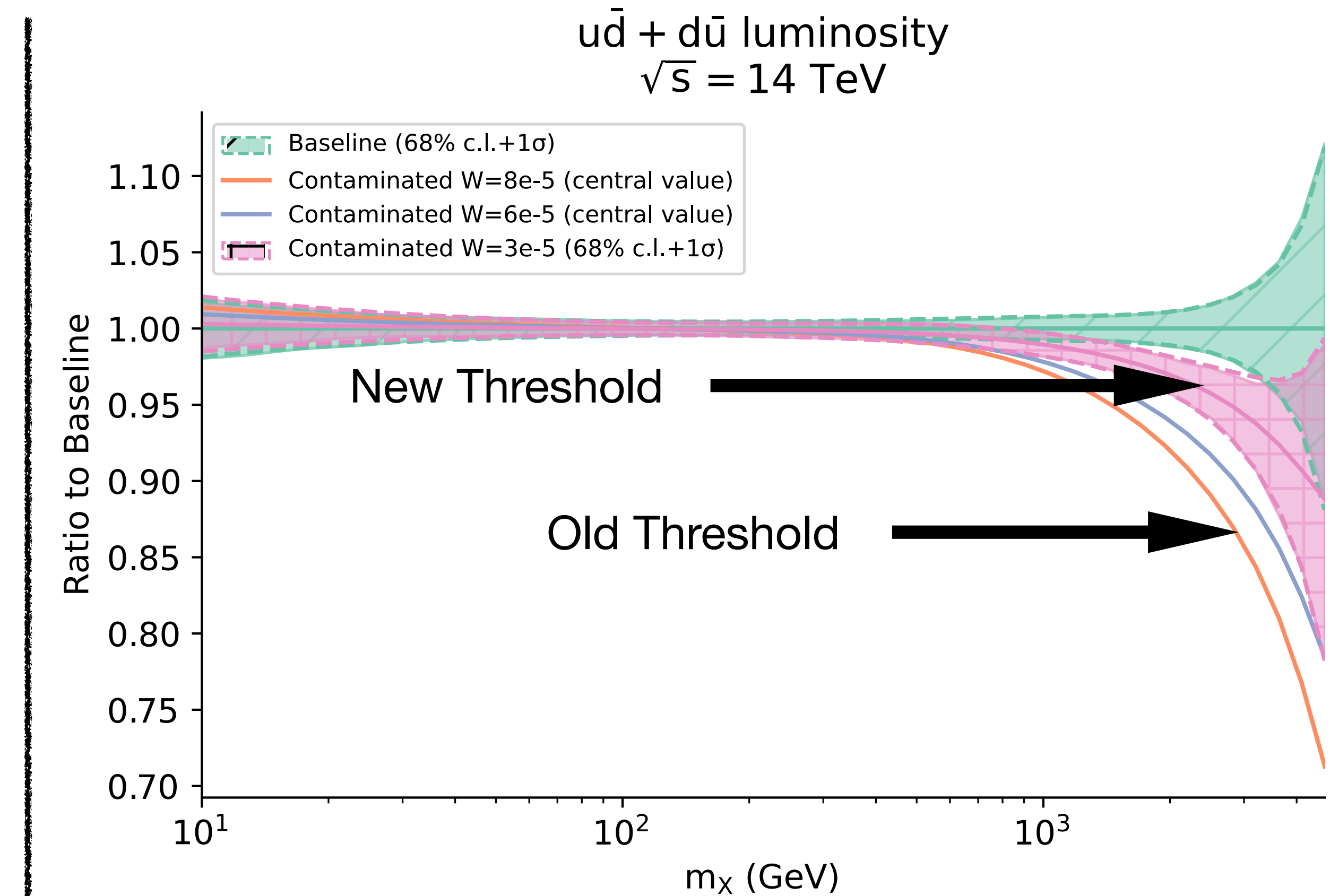
# Impact of FPF data on PDF contamination

## Projection data from neutrino DIS at the LHC

HL-LHC HM DY 14 TeV - charged current - electron channel



$M_{W'} : 13.8 \rightarrow 22.5 \text{ TeV}$



Reduces fake deviations

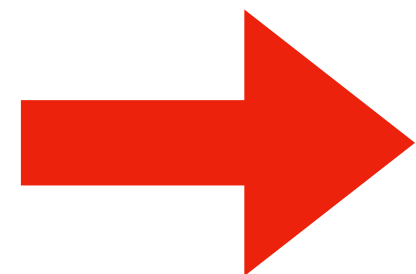
# New physics scenarios: $Z'$

$$M_{Z'} = 18.7 \text{ TeV}$$

## Generation of the pseudodata

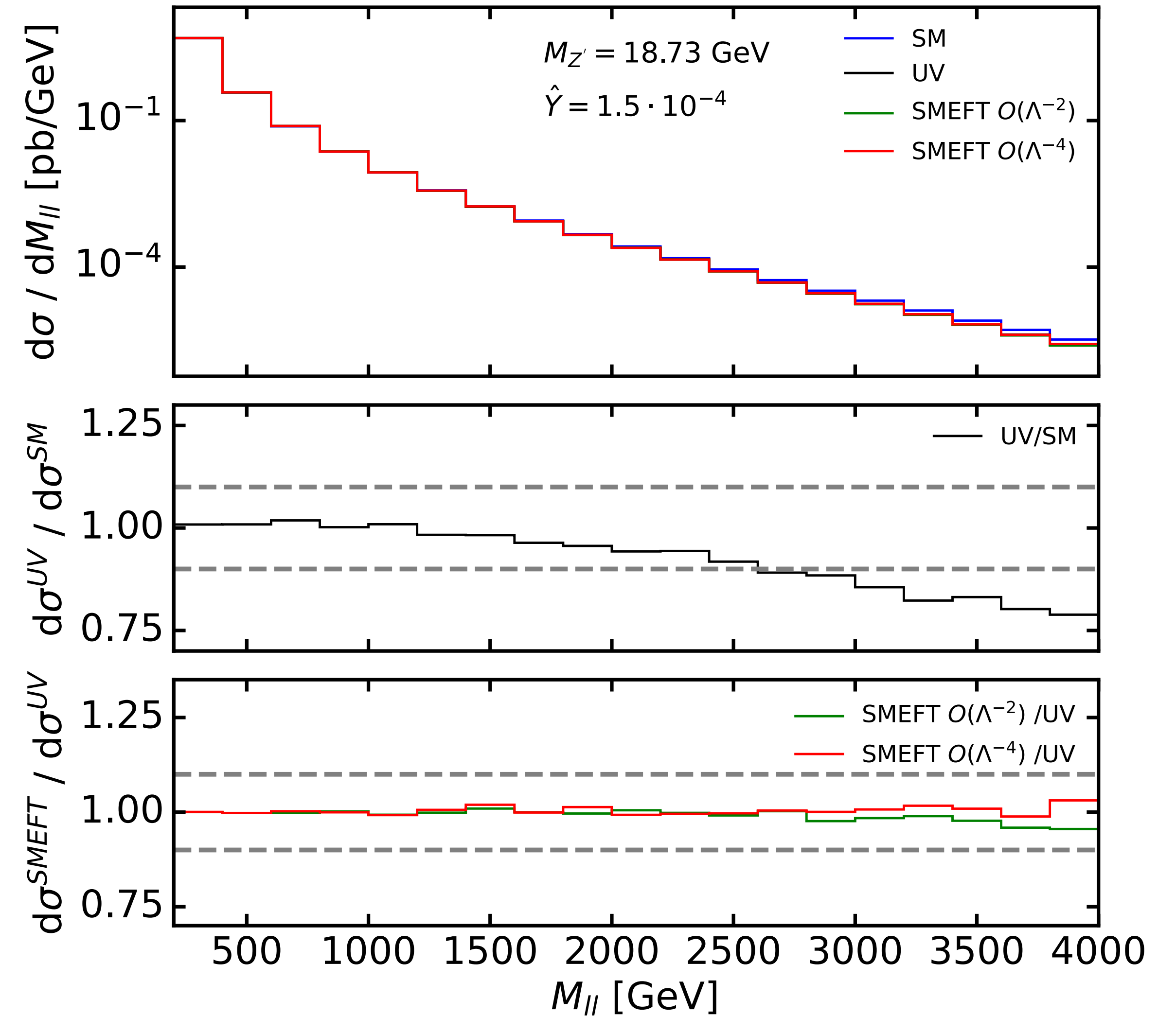
$$\mathcal{L}_{SMEFT}^{Z'} = \mathcal{L}_{SM} - \frac{g_{Z'}^2}{2M_{Z'}^2} J_Y^\mu J_{Y,\mu}$$

$$J_Y^\mu = \sum_f Y_f \bar{f} \gamma^\mu f$$



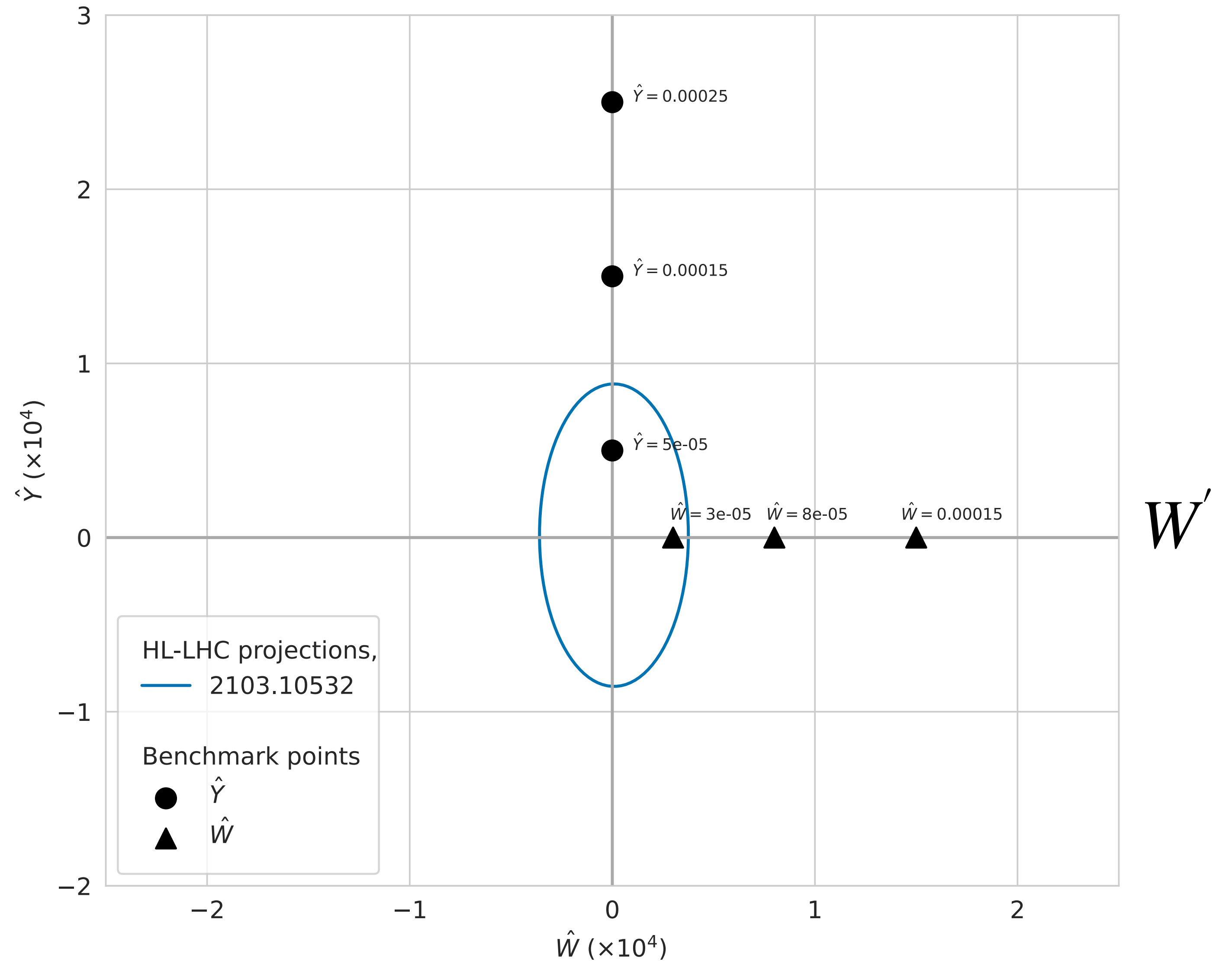
Impacts neutral current Drell-Yan processes

$$p\bar{p} \rightarrow l^+ l^-$$



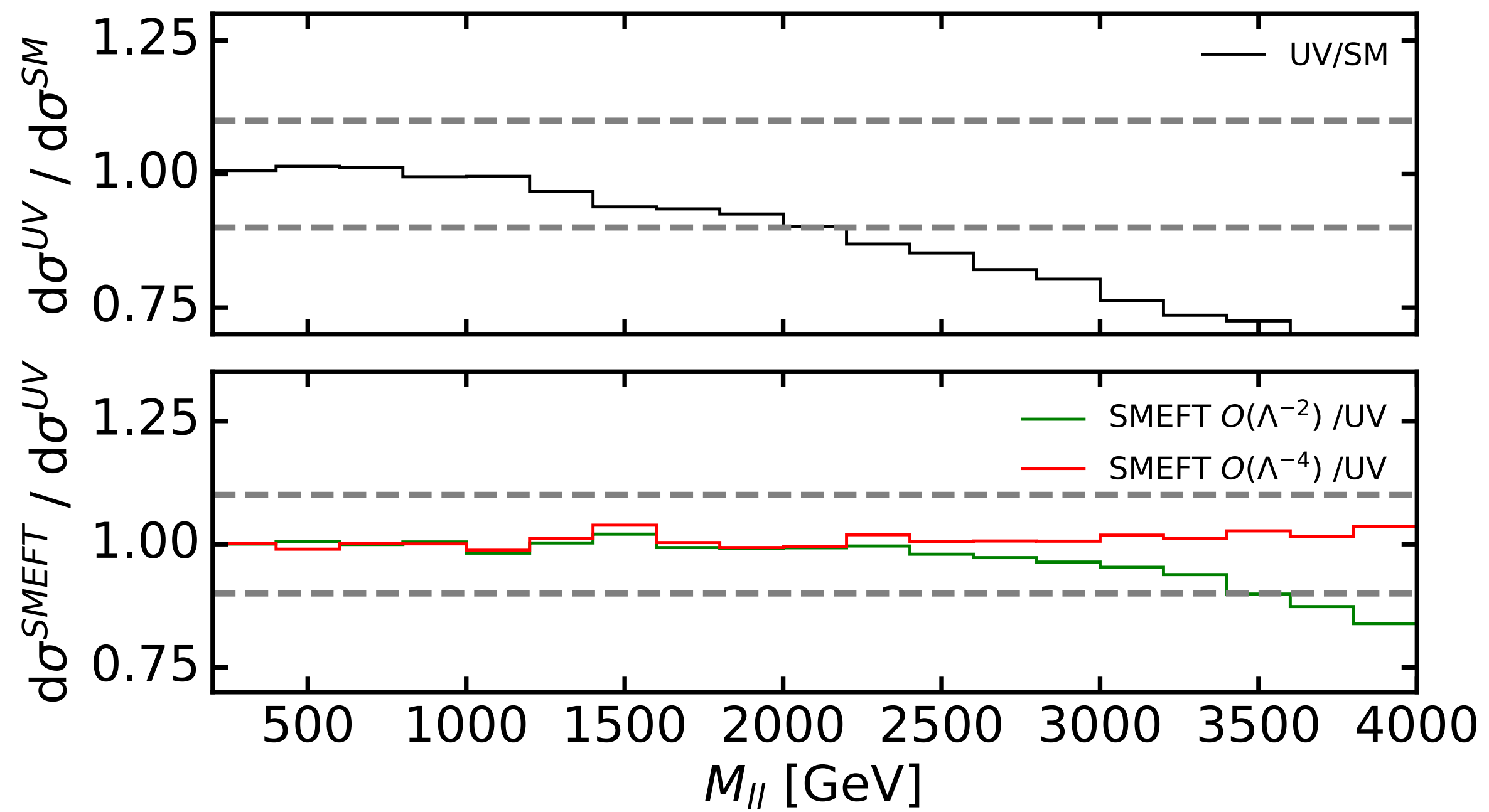
# Constraints from current data

- New physics scenarios compared to constraints at 95% CL

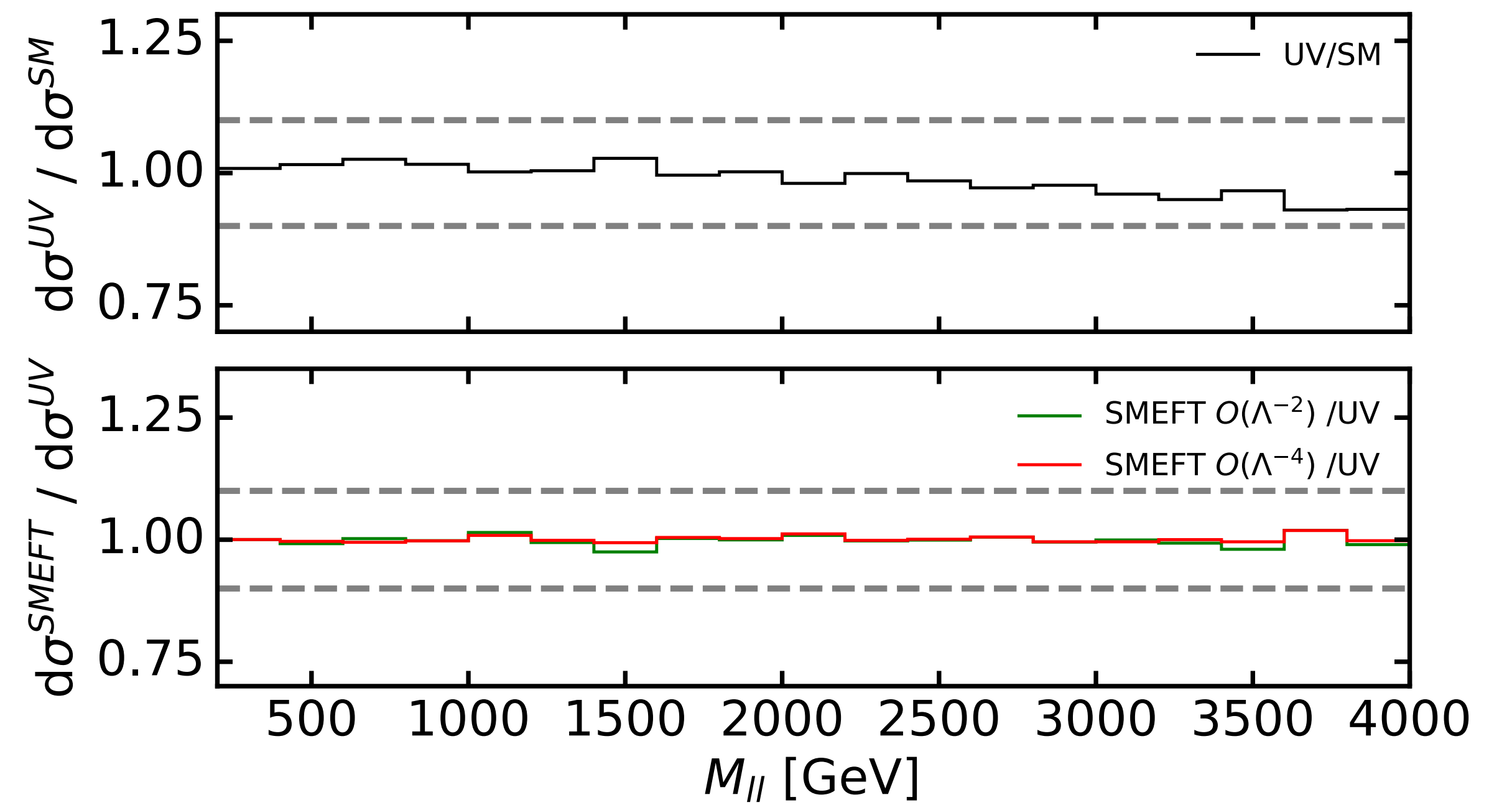


# New physics scenarios: $Z'$

$M_{Z'} = 14.5 \text{ TeV}$

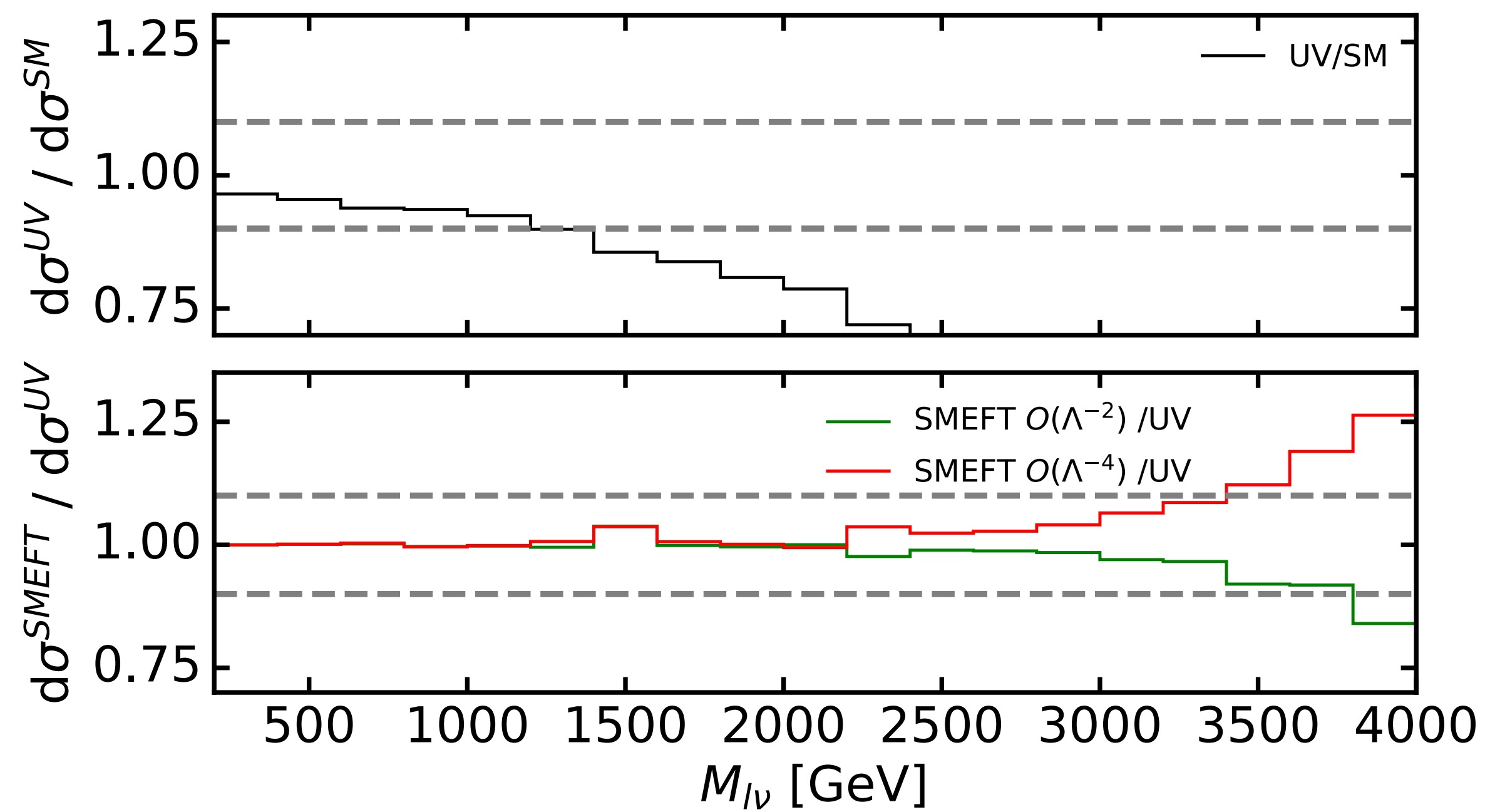


$M_{Z'} = 32.5 \text{ TeV}$



# New physics scenarios: $W'$

$M_{W'} = 10 \text{ TeV}$



$M_{W'} = 22.5 \text{ TeV}$

