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:

[Hammou et al., 2307.10370, JHEP]

[Costantini et al., 2402.03308]

[Hammou and Ubiali, 2410.00963]

[Hammou, Rojo and Ubiali, Forthcoming]

European Research Council

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PBSP

Funded by
the European Union

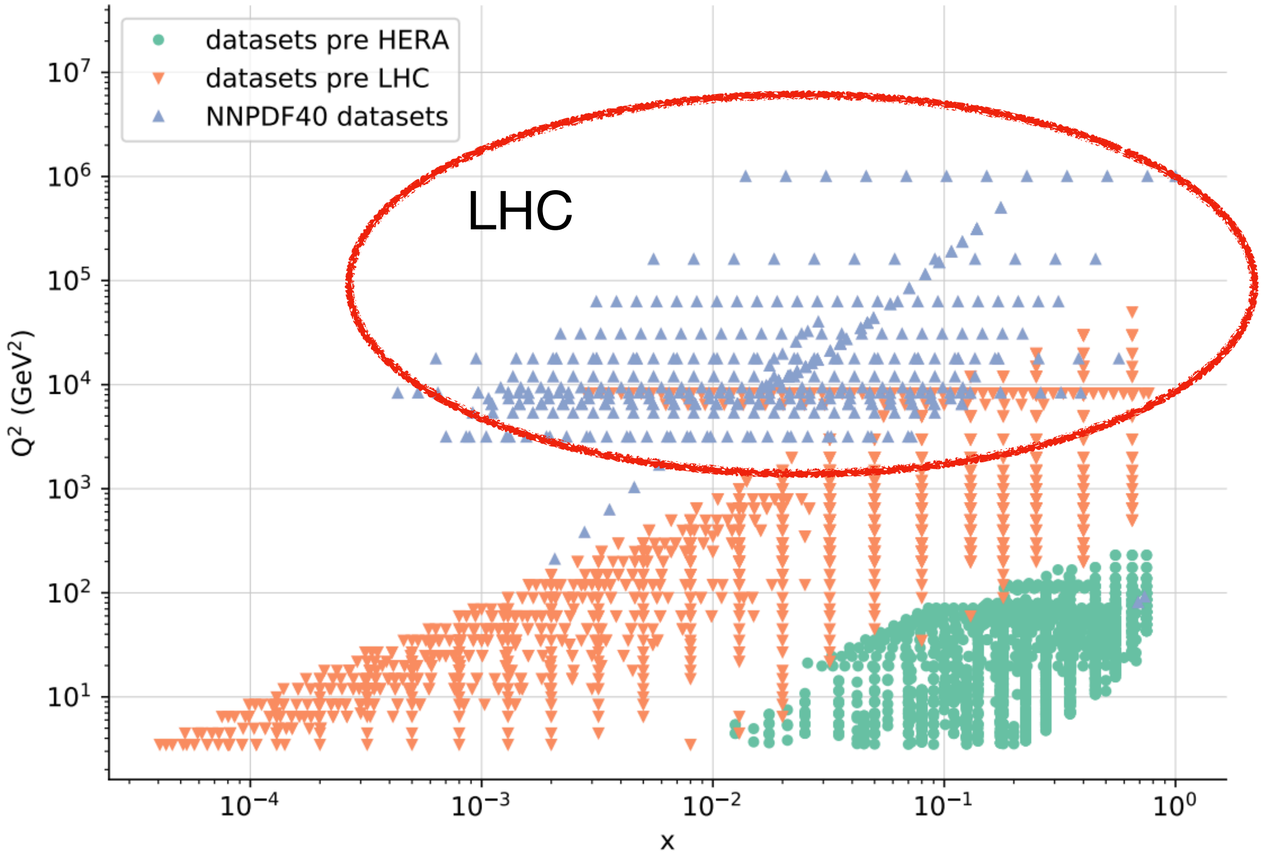
Elie Hammou, University of Cambridge

LHeC workshop, Nov 2024

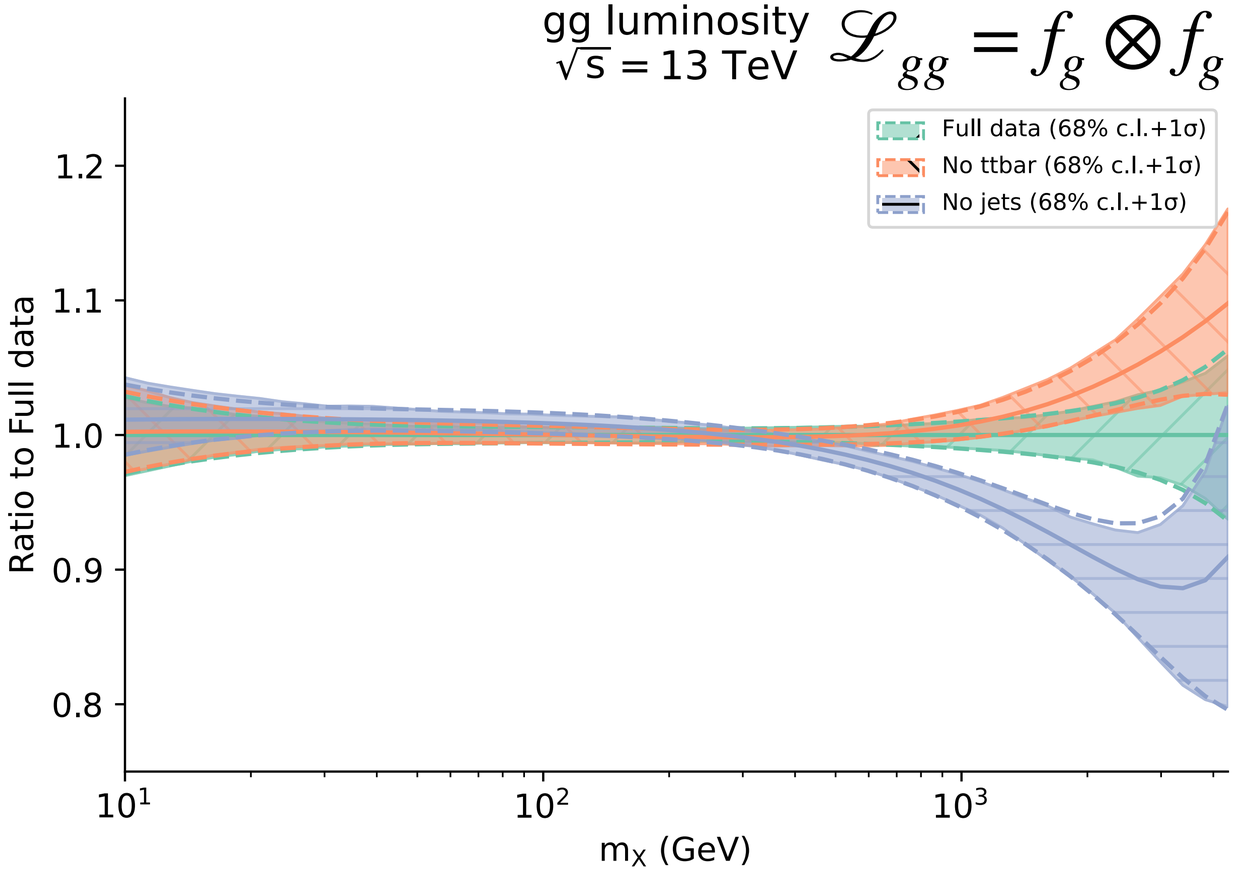
Tension between high energy data

Comparison of PDFs trained on different datasets

Full data kinematic coverage



PDFs' process dependance…



Impact on the PDFs

Comparison between SMEFT and SM PDFs

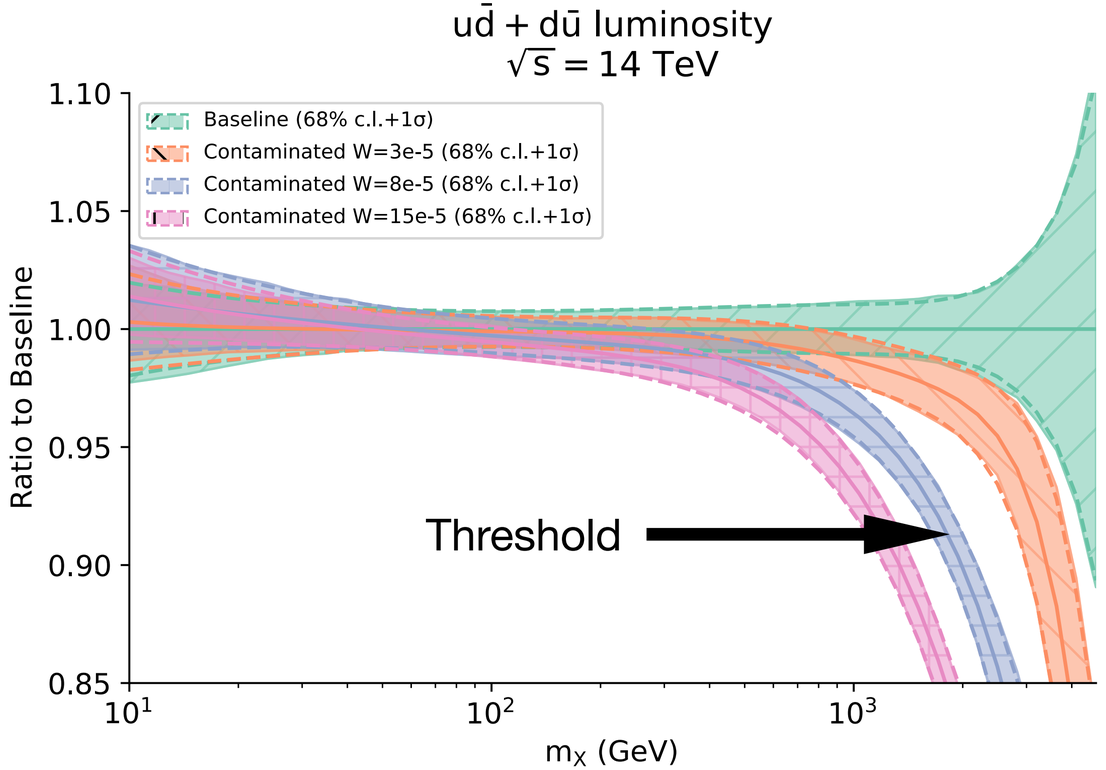
$M_{W'} = 13.8$ TeV

Risk assessment

- Toy model with pseudodata
- Inject BSM physics
- Use it for PDF fit
- Compare PDF with baseline
- Can we recover the new physics?

[Hammou et al., 2307.10370, JHEP]

Impact on PDFs

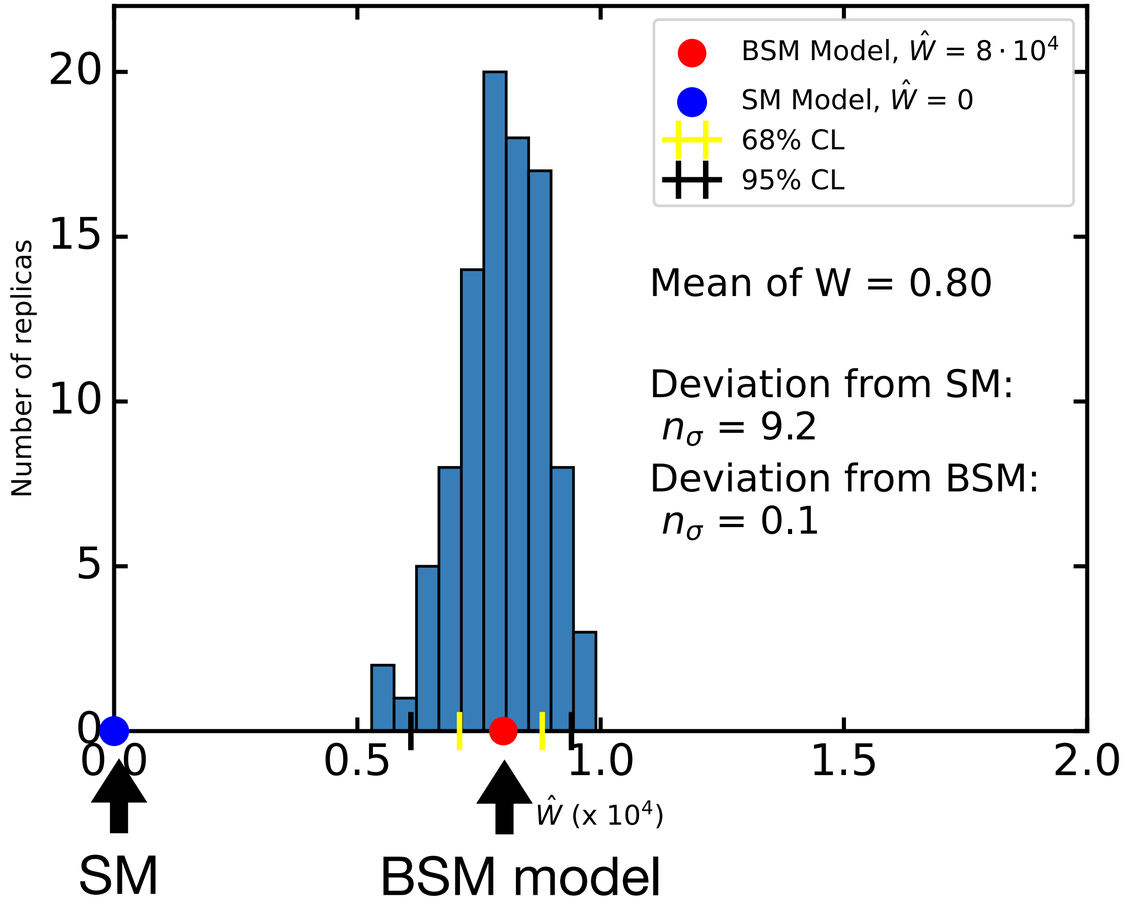


$$\sigma_{BSM}^{Data} \approx \hat{\sigma}_{SM} \otimes \mathscr{L}_{BSM}$$

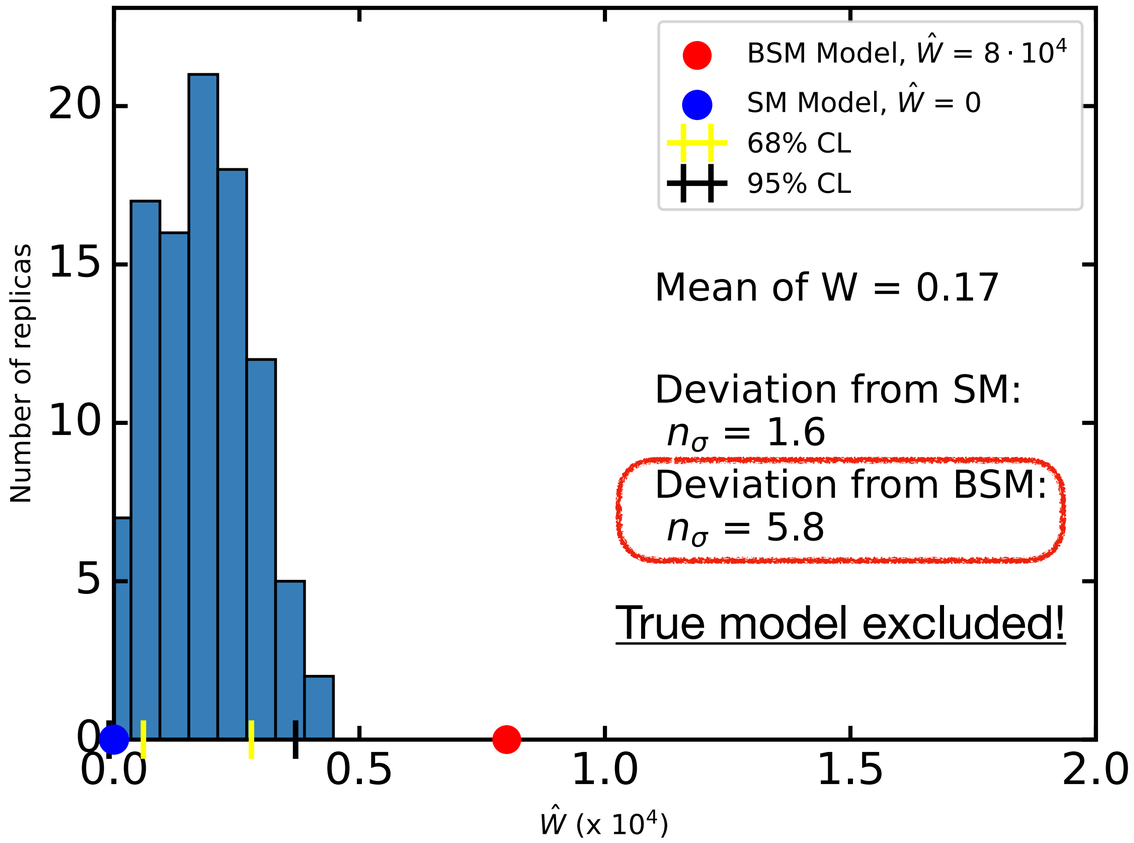
Missing new physics

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
- FASERν and SND@LHC already running
- Proposed expansion for HL-LHC run (FASERν2 , AdvSND, FLArE)
- Probes large-x, low-energy
- Constrain large-x antiquarks

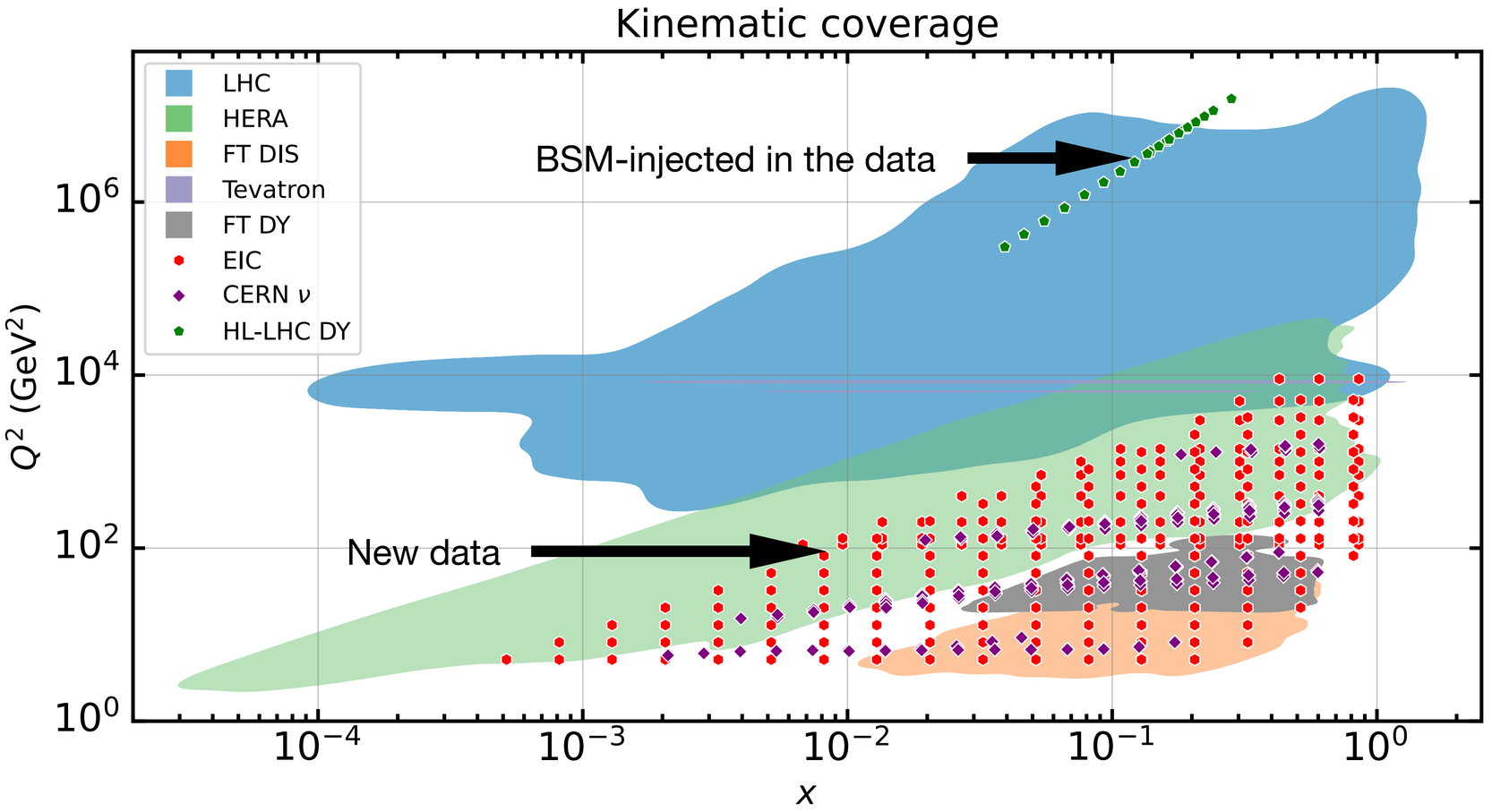
Future low energy data

Kinematic coverage

Projection data:

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

  (neutrino DIS)



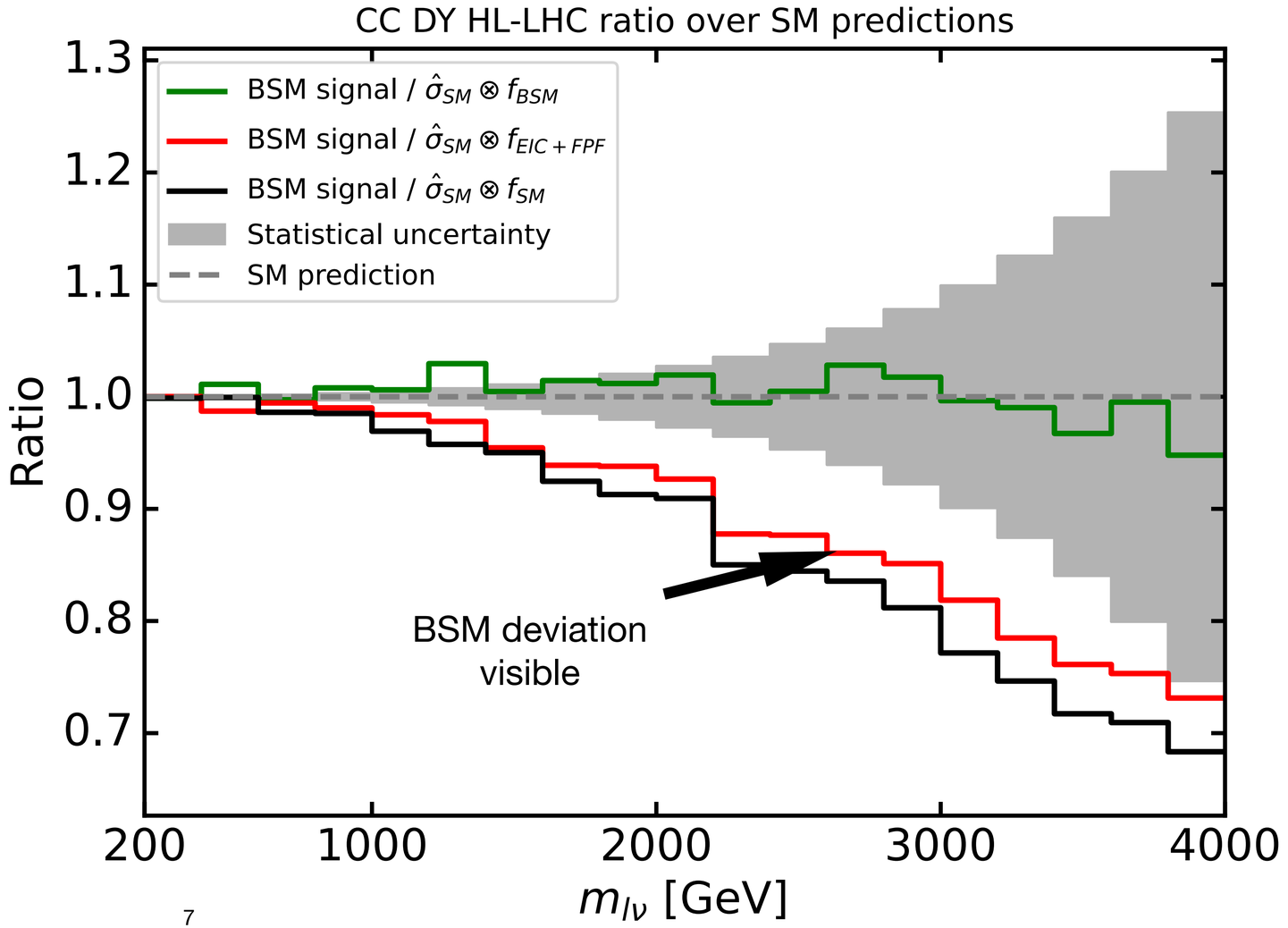
Recovering the signs of new physics

BSM data versus SM theory predictions

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

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

[Hammou and Ubiali, 2410.00963]



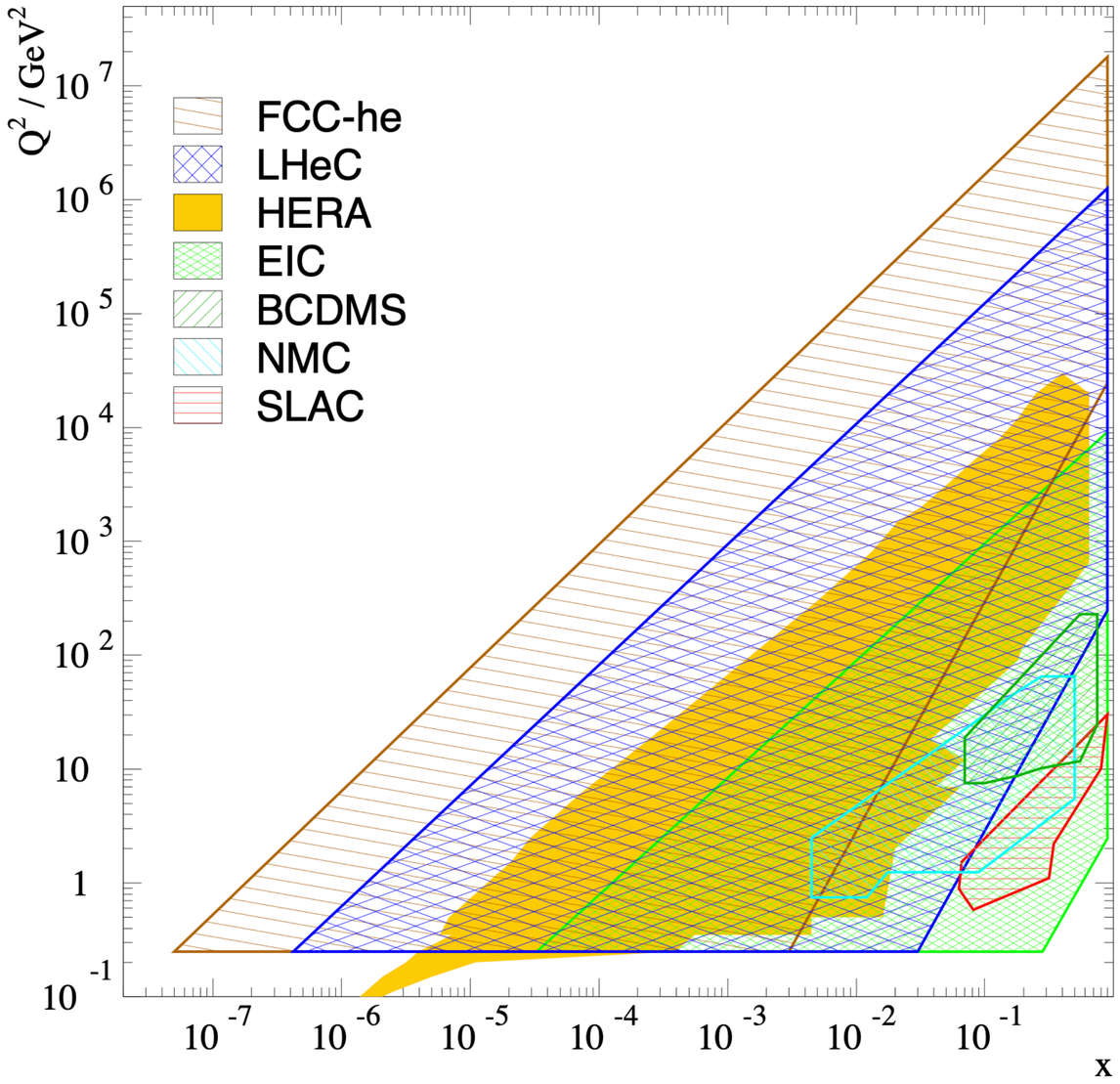
Kinematic coverage of LHeC

Projection data LHeC:

- Probes large-x
- Probes higher energies

➡ Bigger SMEFT corrections

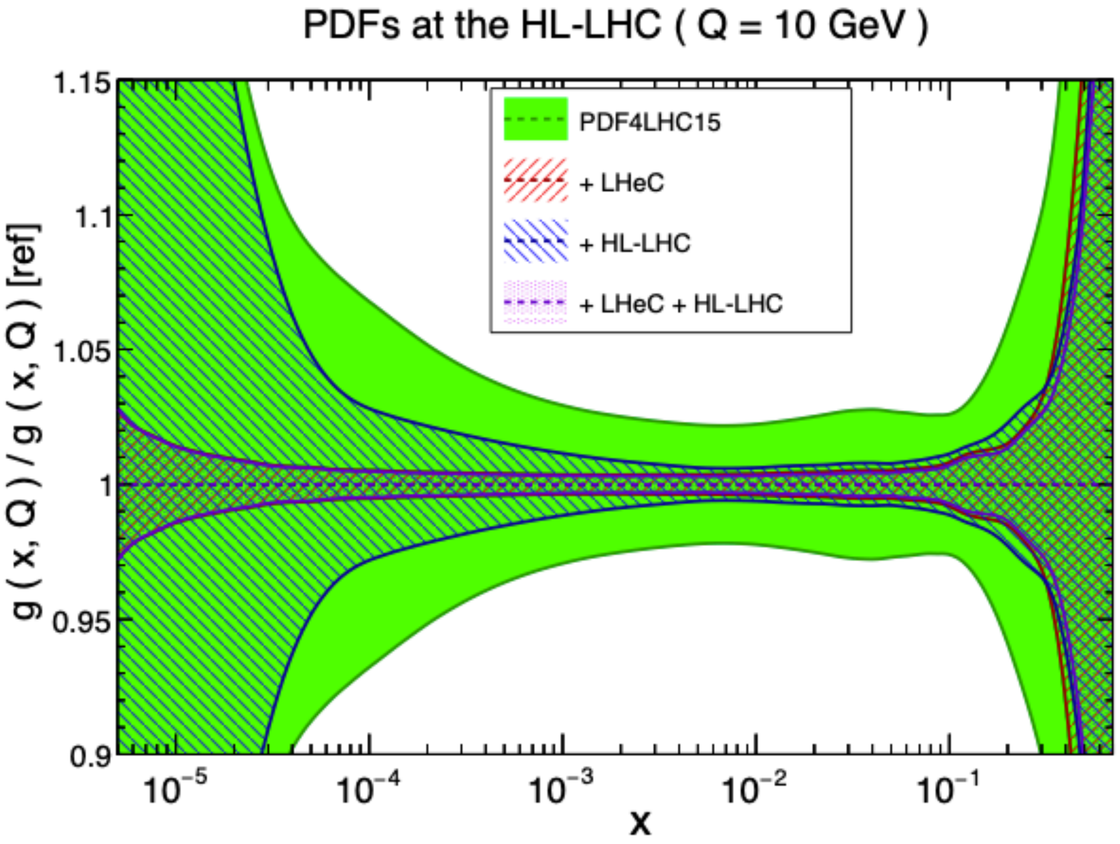
Same problem as with HL-LHC data



Constraining PDFs with LHeC data

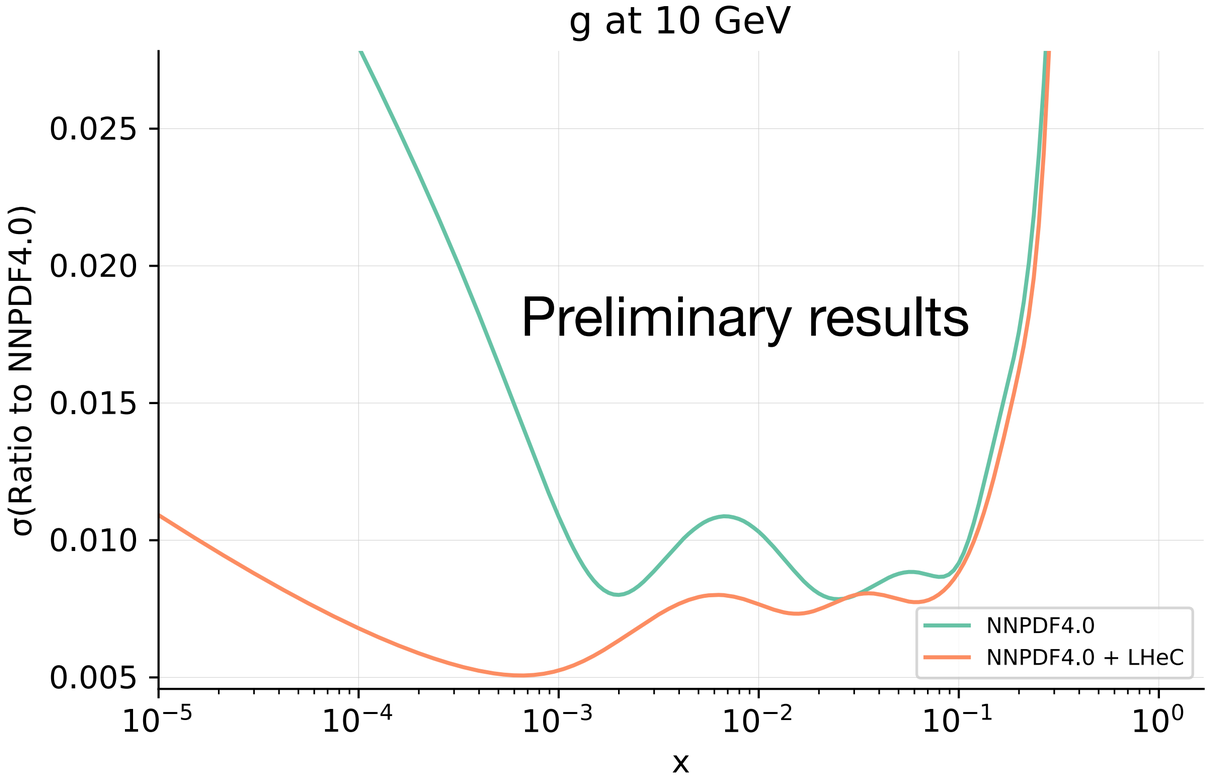
From literature

10.21468/SciPostPhys.7.4.051, Khalek, Bailey, Gao, Harland-Lang, Rojo



PDFs uncertainties

New fit based on NNPDF4.0



4-Fermion SMEFT corrections

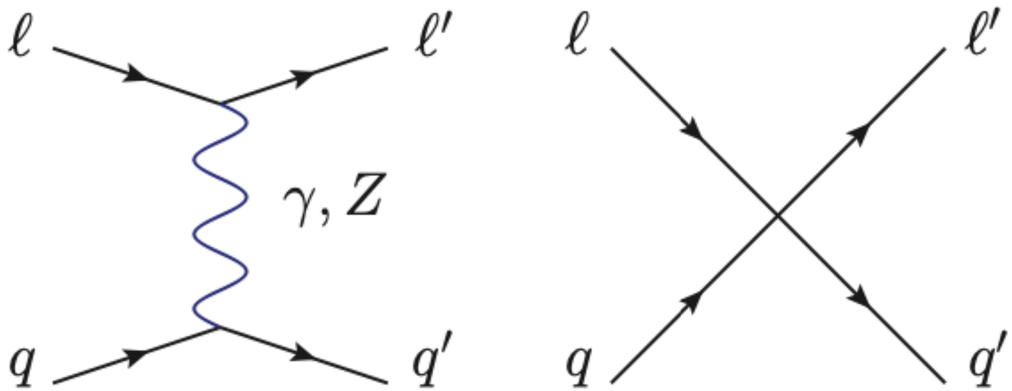
10.1103/PhysRevD.106.016006, Boughezal et al.
10.1103/PhysRevD.108.075007, Bissoloti, Boughezal and Simsek

Computes SMEFT projections:

- EIC
- LHeC
- FCC-eh

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

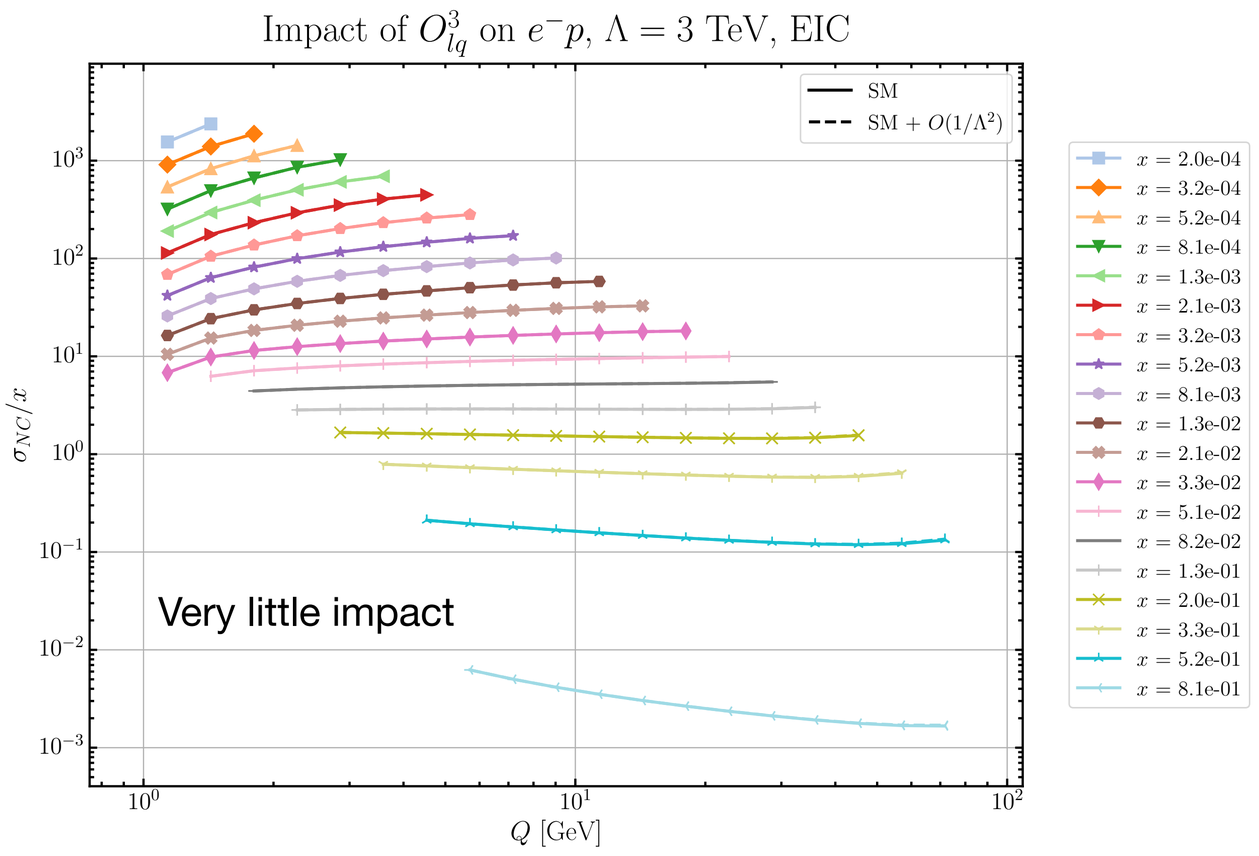
DIS Neutral-Current corrections



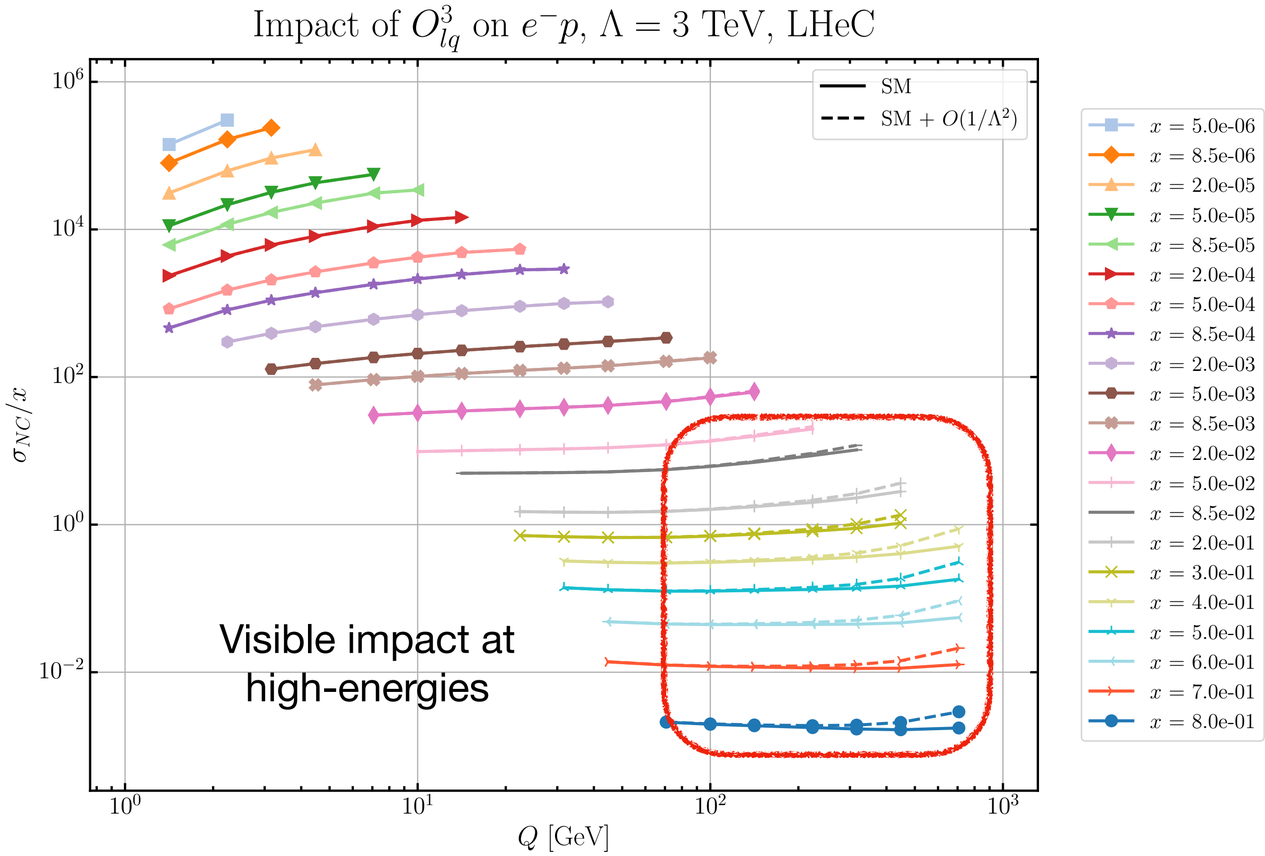
Charged-Current not yet computed

Impact of $\mathcal{O}^3_{lq}$ on EIC and LHeC projections

EIC projections



LHeC projections



Simultaneous fit of PDF and new physics

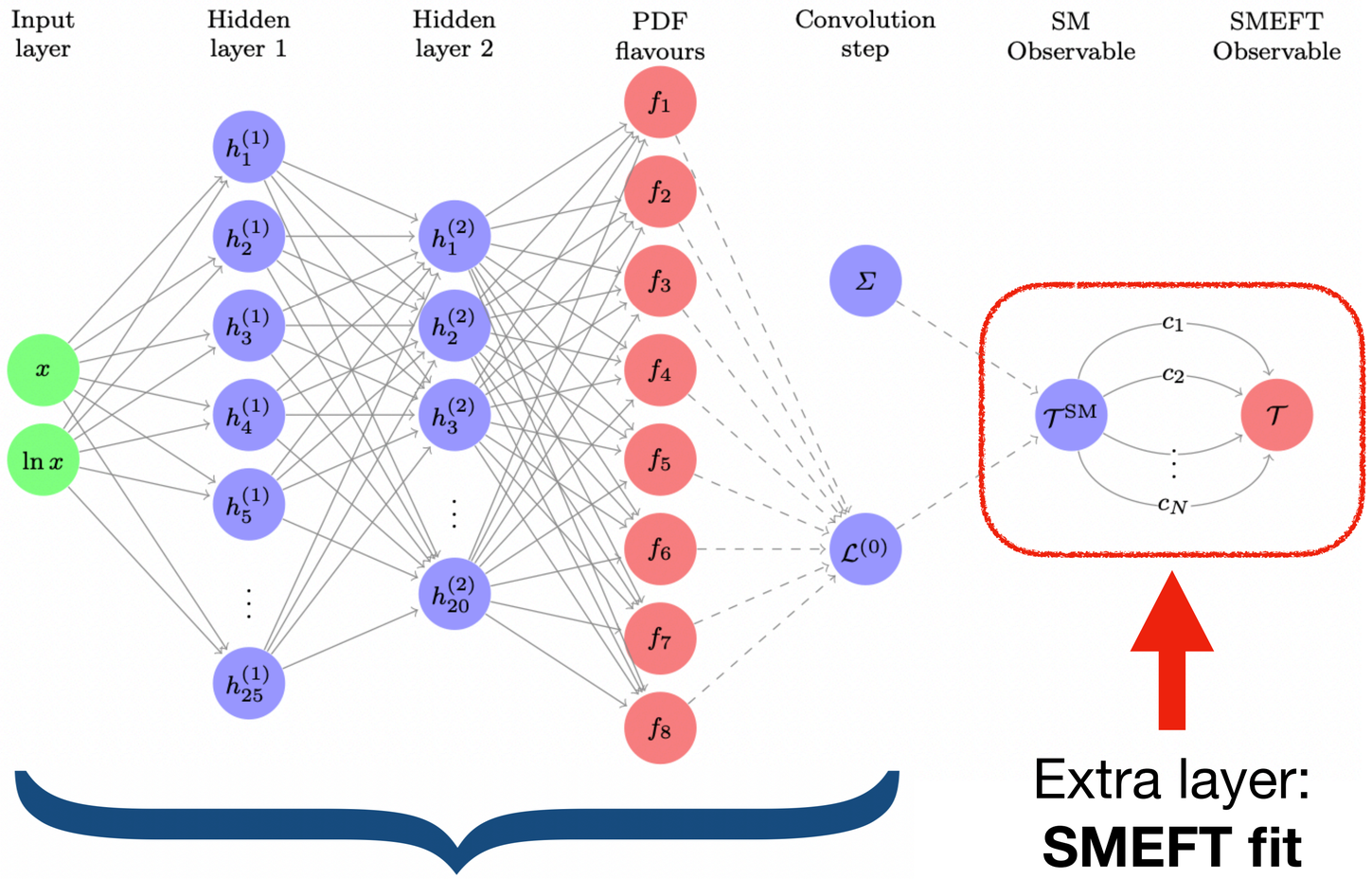
Presentation of the tool: SIMUnet

SIMUnet:

- Open-source tool: github.com/HEP-PBSP/SIMUnet

  [2402.03308]

- Fits PDFs and WC simultaneously



[Iranipour et Ubiali, 2201.07240]

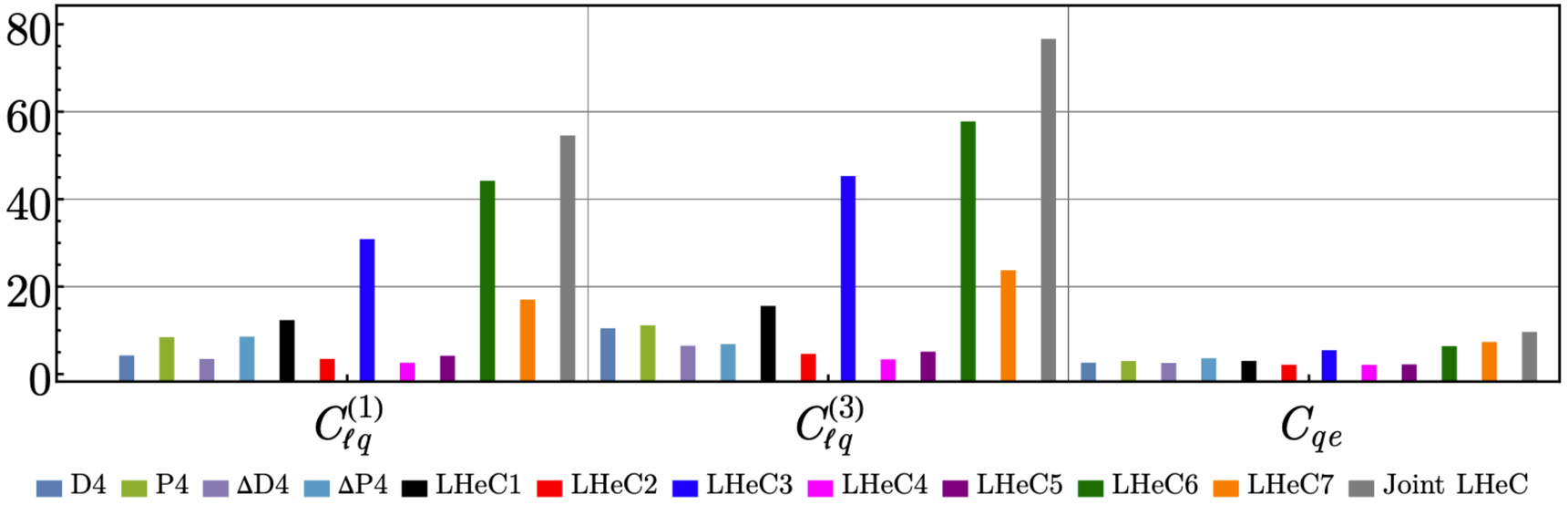
Bounds on $\mathcal{O}^3_{lq}$ from LHeC projections

Bounds from literature

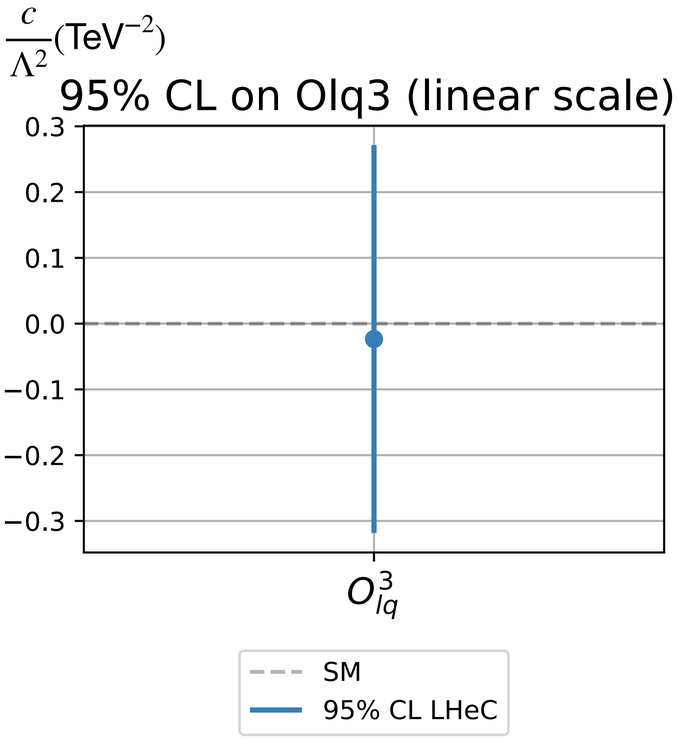
10.1103/PhysRevD.108.075007, Bissoloti, Boughezal and Simsek

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

$$P_\ell = -80\,\%,\ C_{eu} \approx -13\left(C^{(1)}_{\ell q} - C^{(3)}_{\ell q}\right),\ C_{\ell u} \approx -0.052\,C_{qe},\ C_{ed} \approx -22\left(C^{(1)}_{\ell q} + C^{(3)}_{\ell q}\right),\ C_{\ell d} \approx 0.12\,C_{qe}$$



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
- Adding low-energy large-x data
  - Reduce PDF uncertainty
  - Can prevent new physics absorption
- The LHeC study:
  - Reduces uncertainty in gluon PDF
  - SMEFT studies partially performed for Olq3
  - SMEFT-PDF interplay study necessary and ongoing

You can contact me at:
eh651@cam.ac.uk

Thank you for your attention!

Extra slides

New physics scenario: W'

$pp \to l^- \bar{\nu}$ $M_{W'} = 13.8$ TeV

Generation of the pseudodata

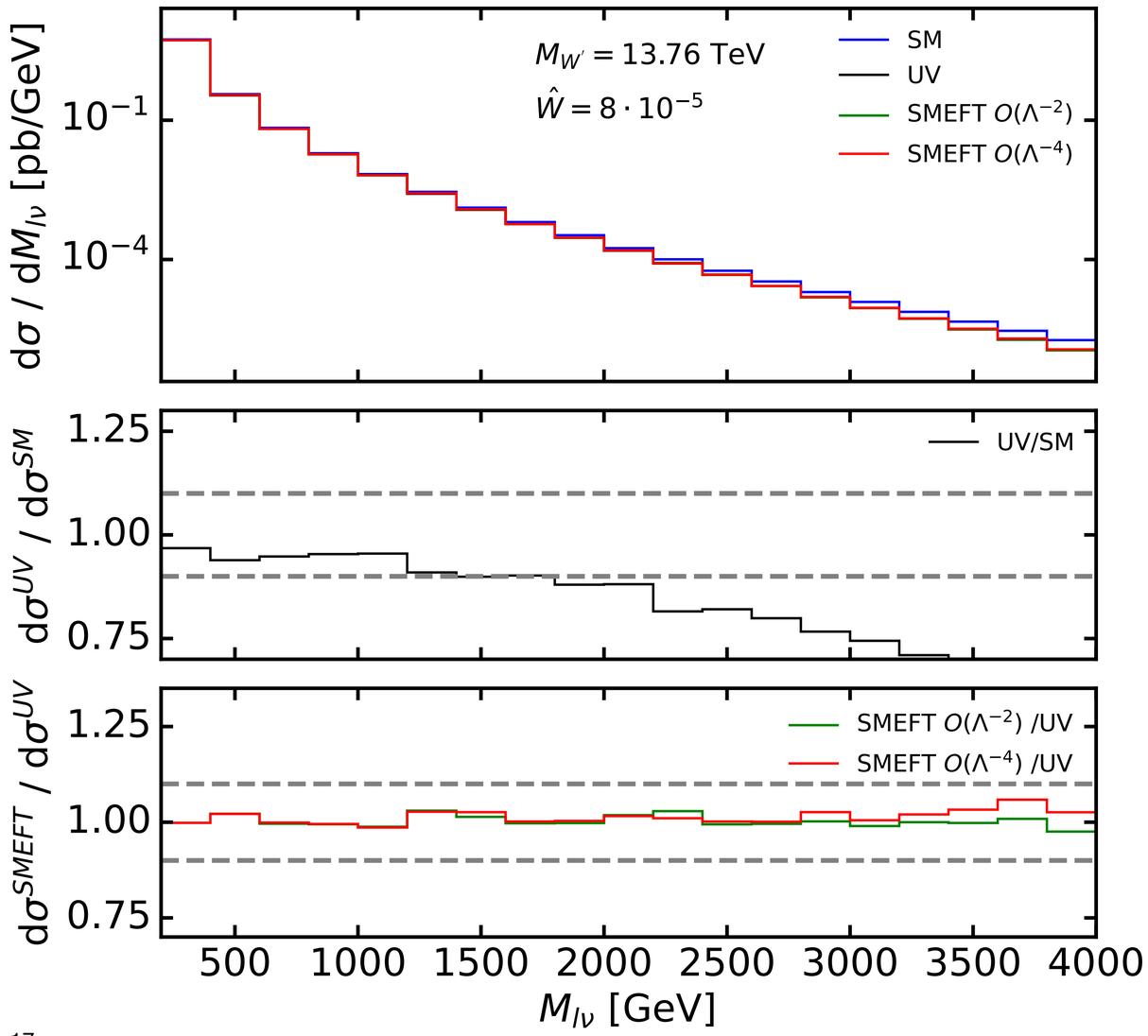
$$\mathscr{L}_{UV}^{W'} = \mathscr{L}_{SM} - \frac{1}{4} W'^{a}_{\mu\nu} W'^{a,\mu\nu} + \frac{1}{2} M_{W'}^2 W'^{a}_{\mu} W'^{a,\mu} - g_{W'} W'^{a,\mu} \sum_{f_L} \bar{f}_L T^a \gamma^\mu f_L$$

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

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

→ Impacts Drell-Yan

HL-LHC Projections

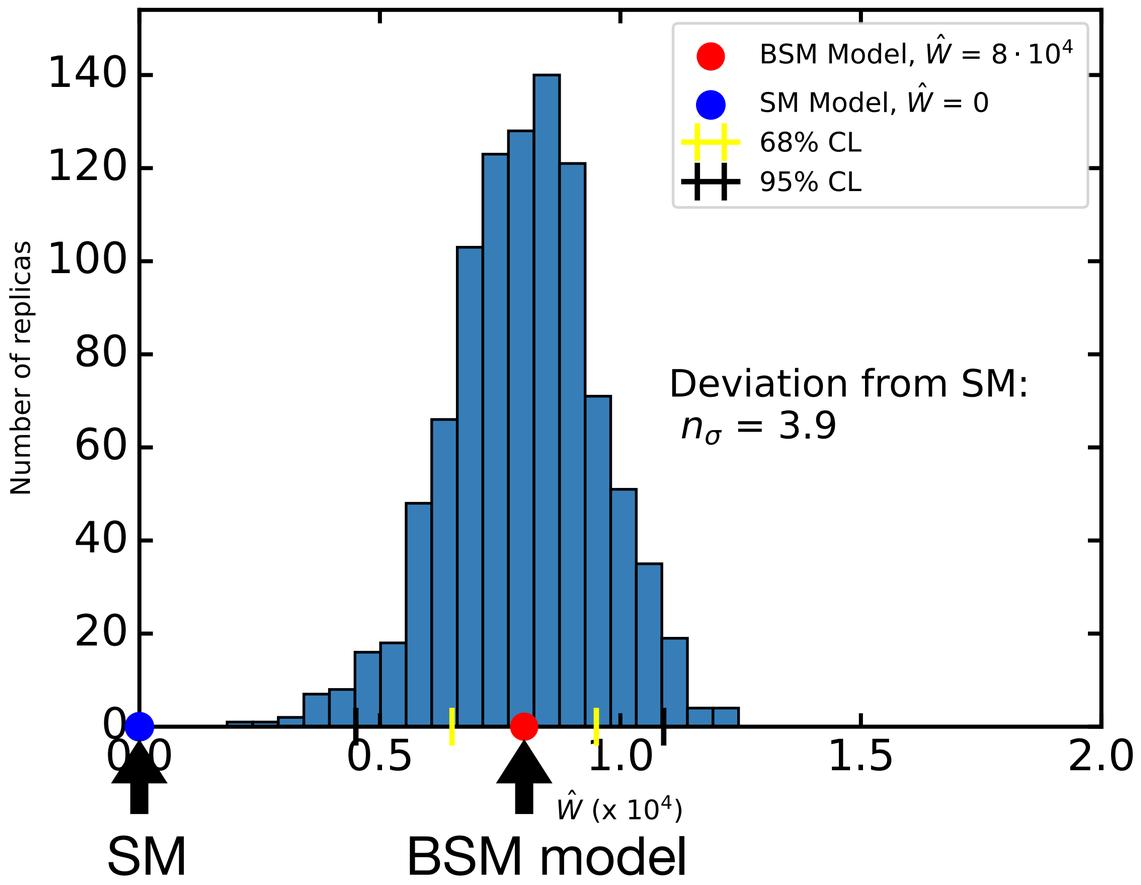


Application to the Drell-Yan sector

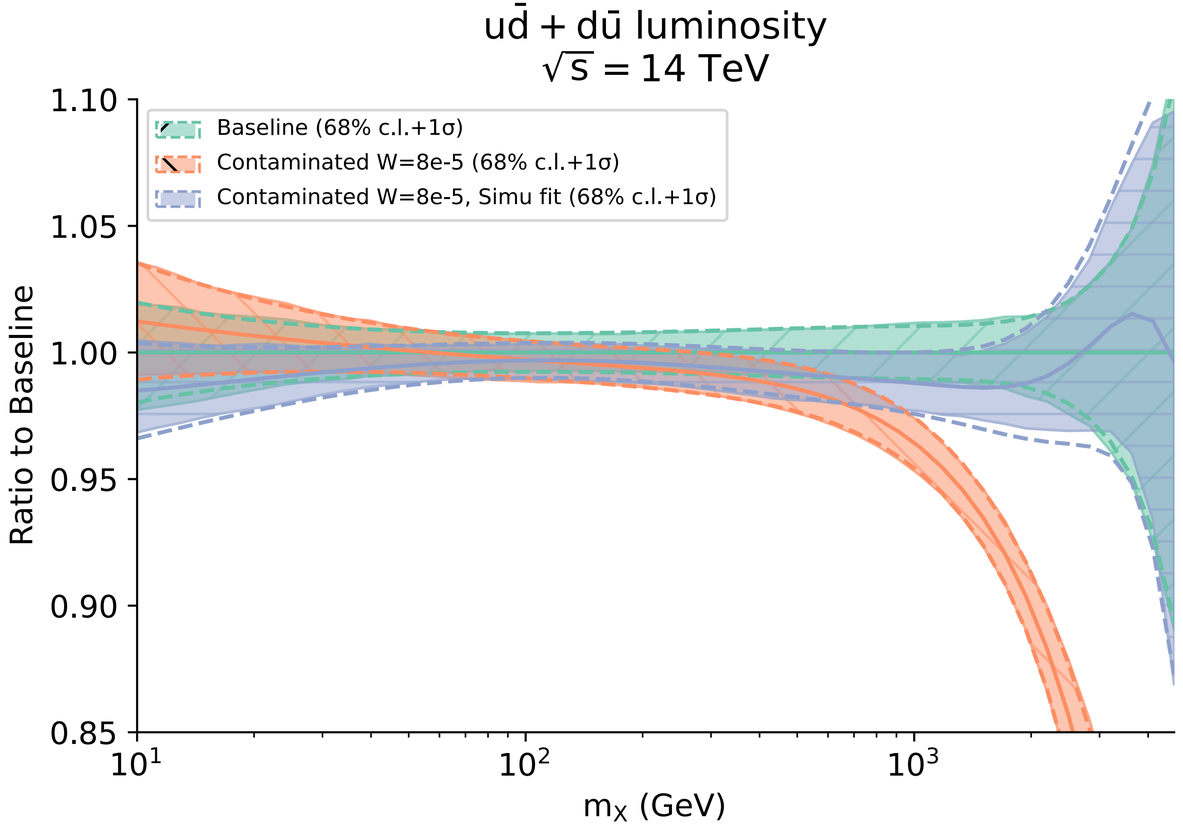
Disentangling PDF contamination

[PBSP, forthcoming]

SMEFT Fit



PDF Fit



Constraining PDFs with LHeC data

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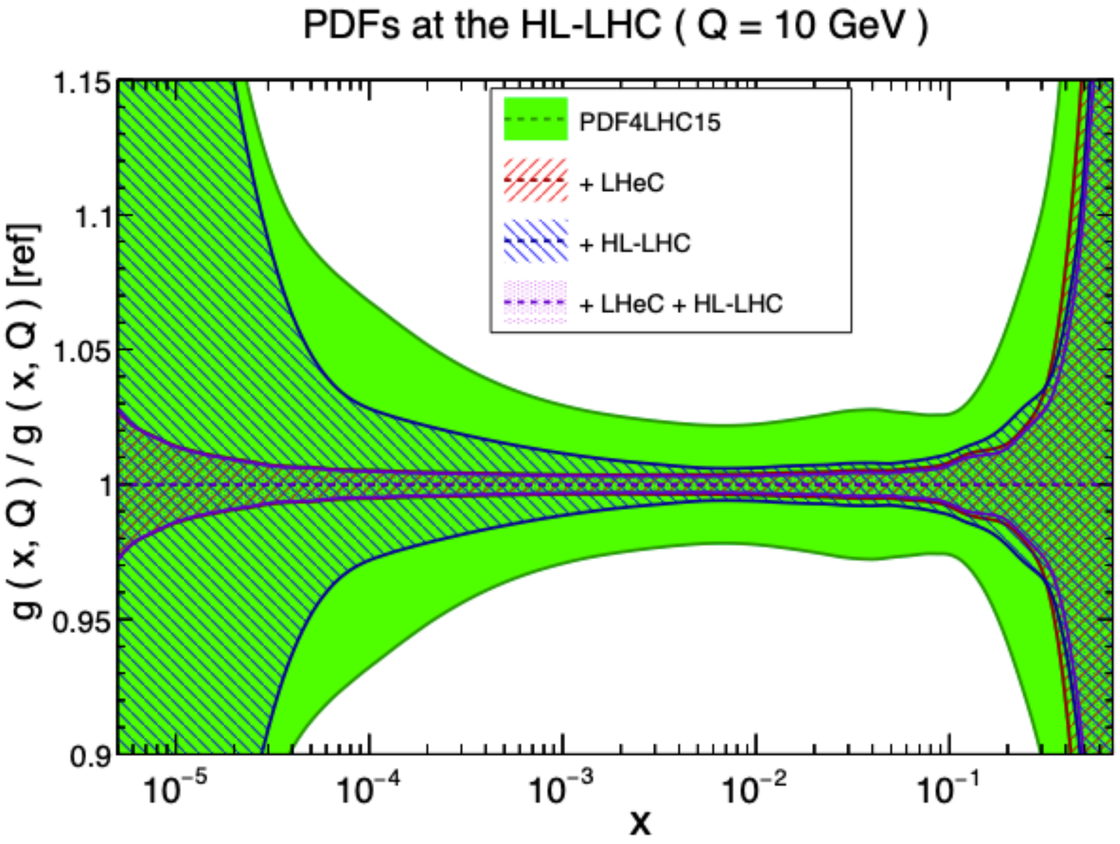
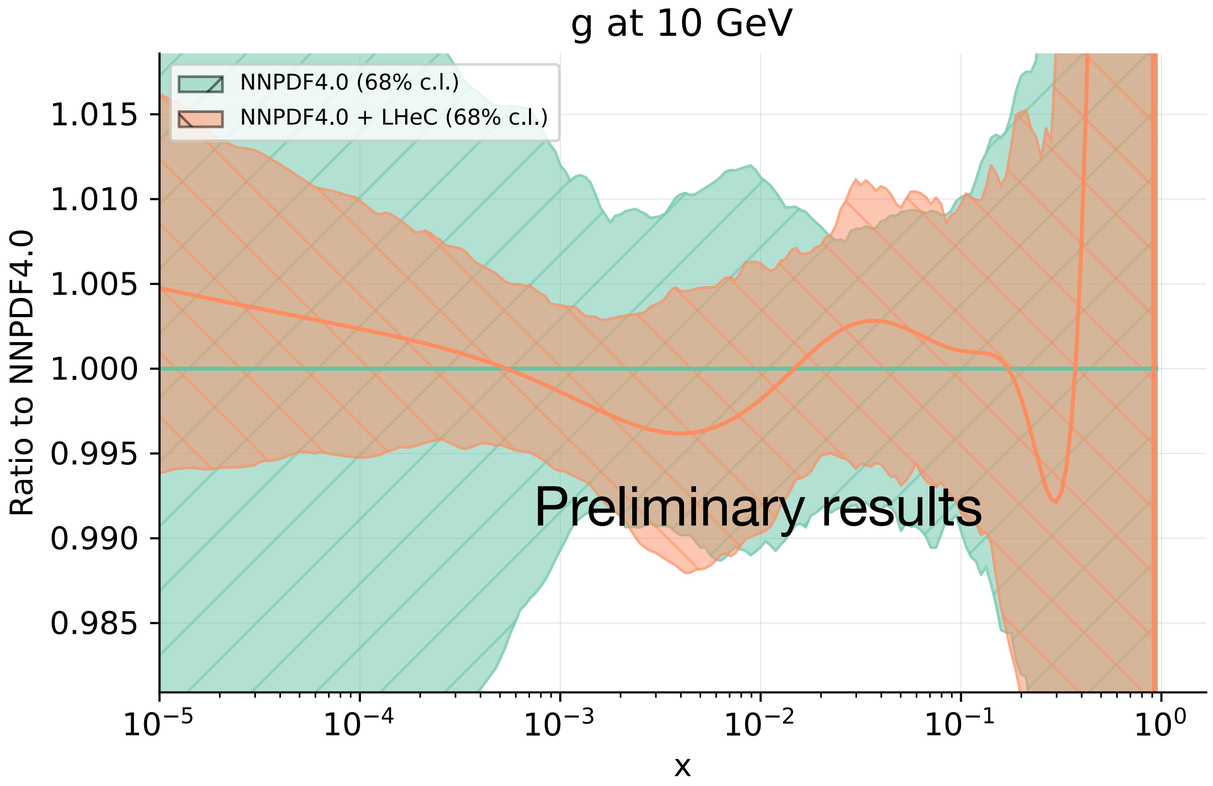


PDFs uncertainties



Apparition of fake deviations

Impact on predictions for other sectors

Theory predictions (red band):

- SMEFT PDFs + SM

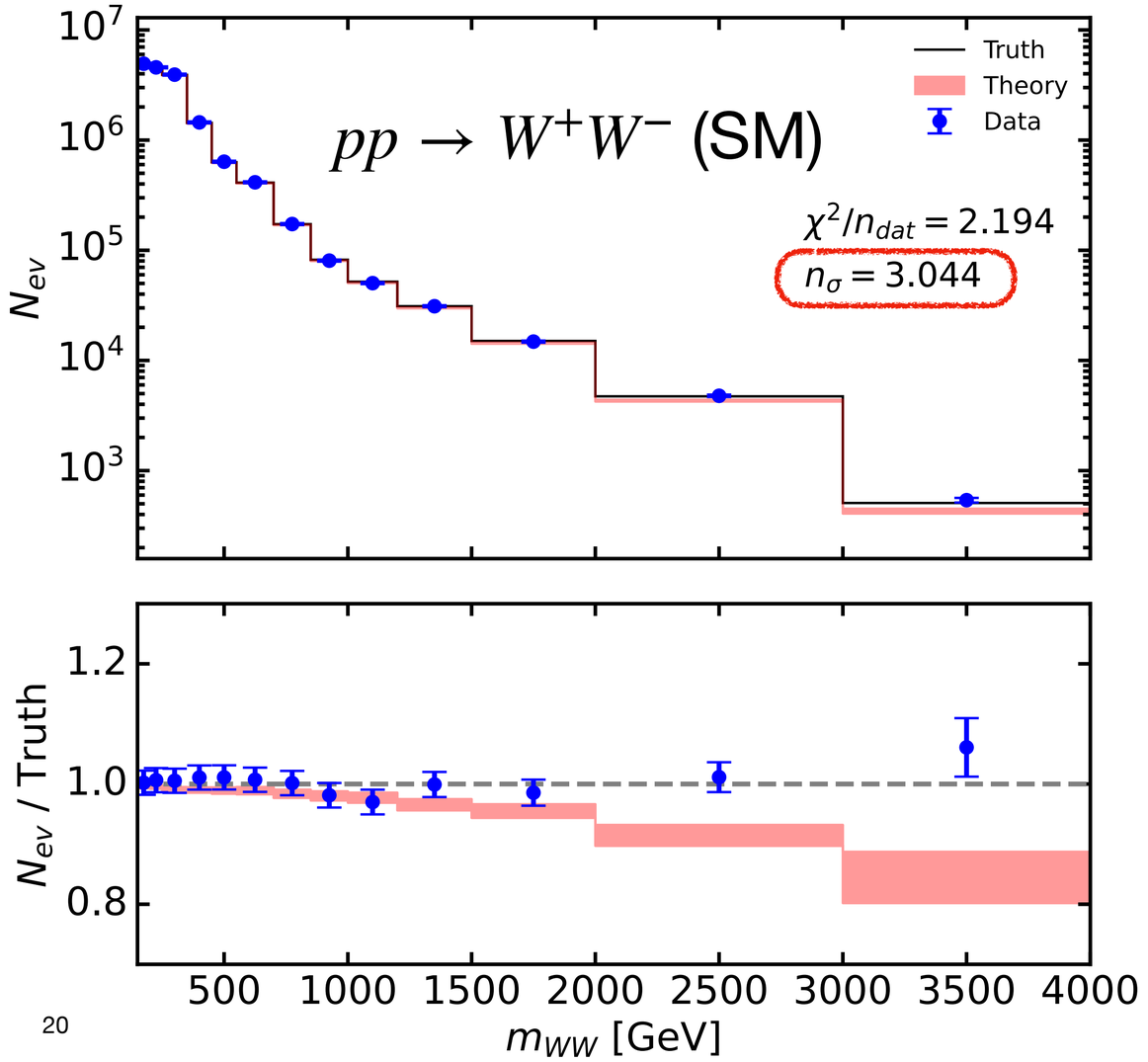
Data (blue dots):

- True PDFs + SM

➡ Fake deviation from SM

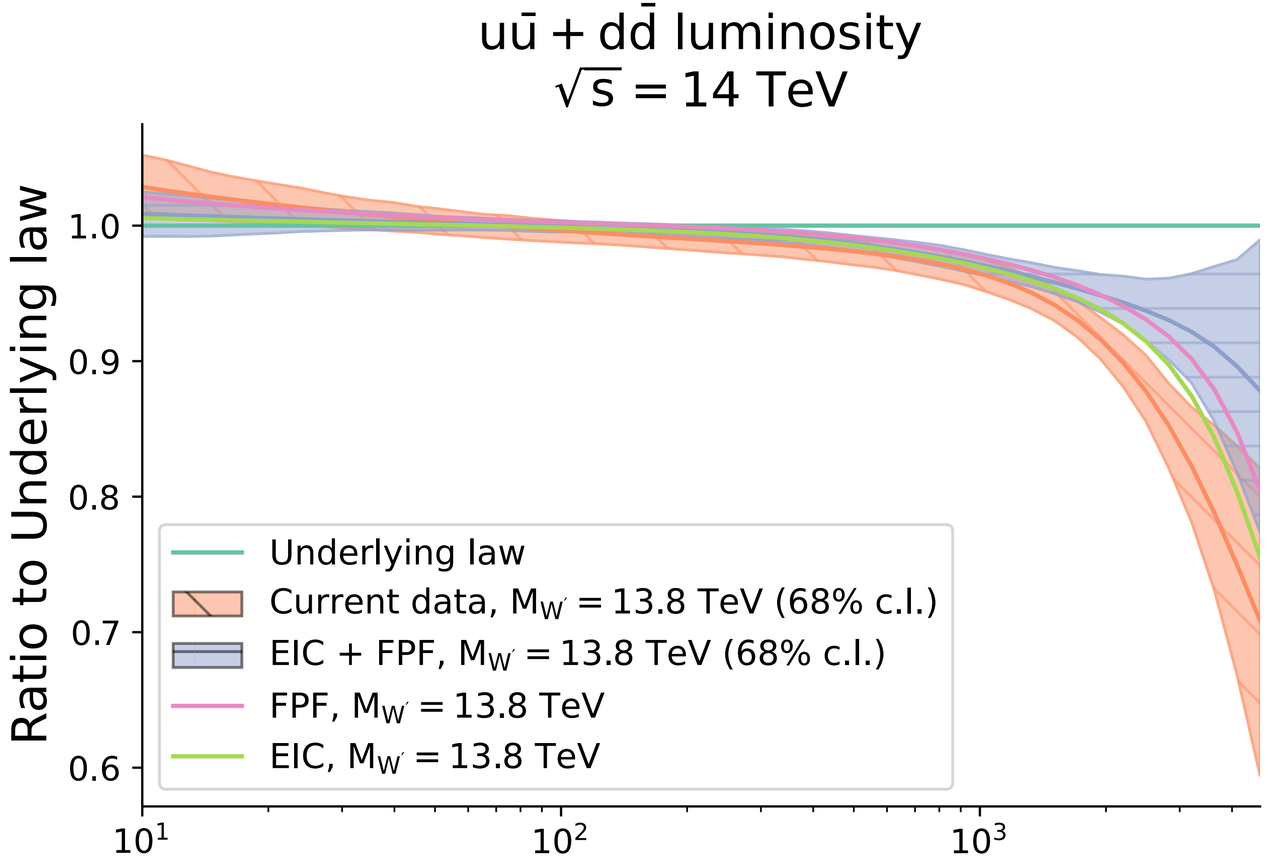
Also seen in WH, WZ, ZH production

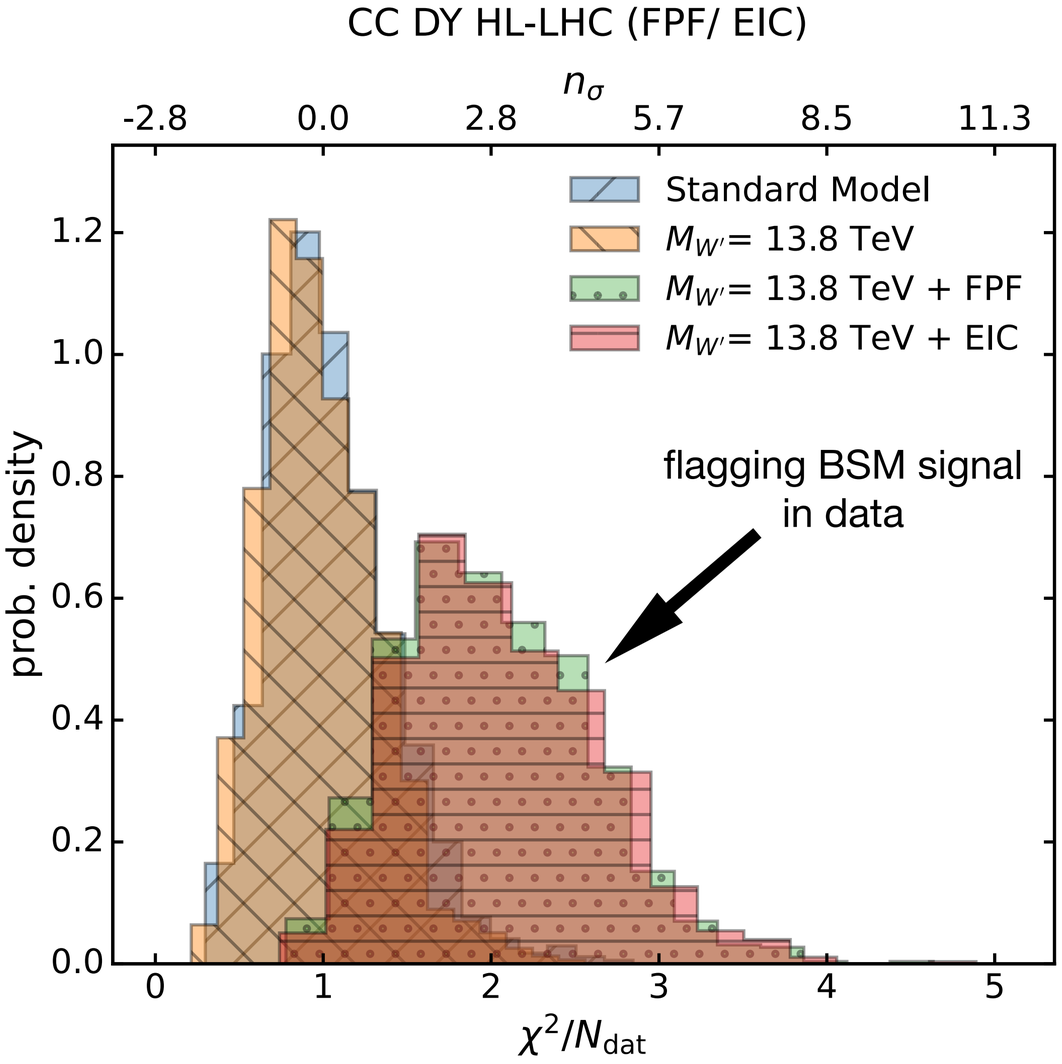
HL-LHC Projections



Impact on the PDF contamination

Flagging the BSM data





List of deviations

	HL-LHC		Stat. improved	
Dataset	$\chi^2/n_{\rm dat}$	n_σ	$\chi^2/n_{\rm dat}$	n_σ
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

Shift of the contamination threshold

From the fit quality

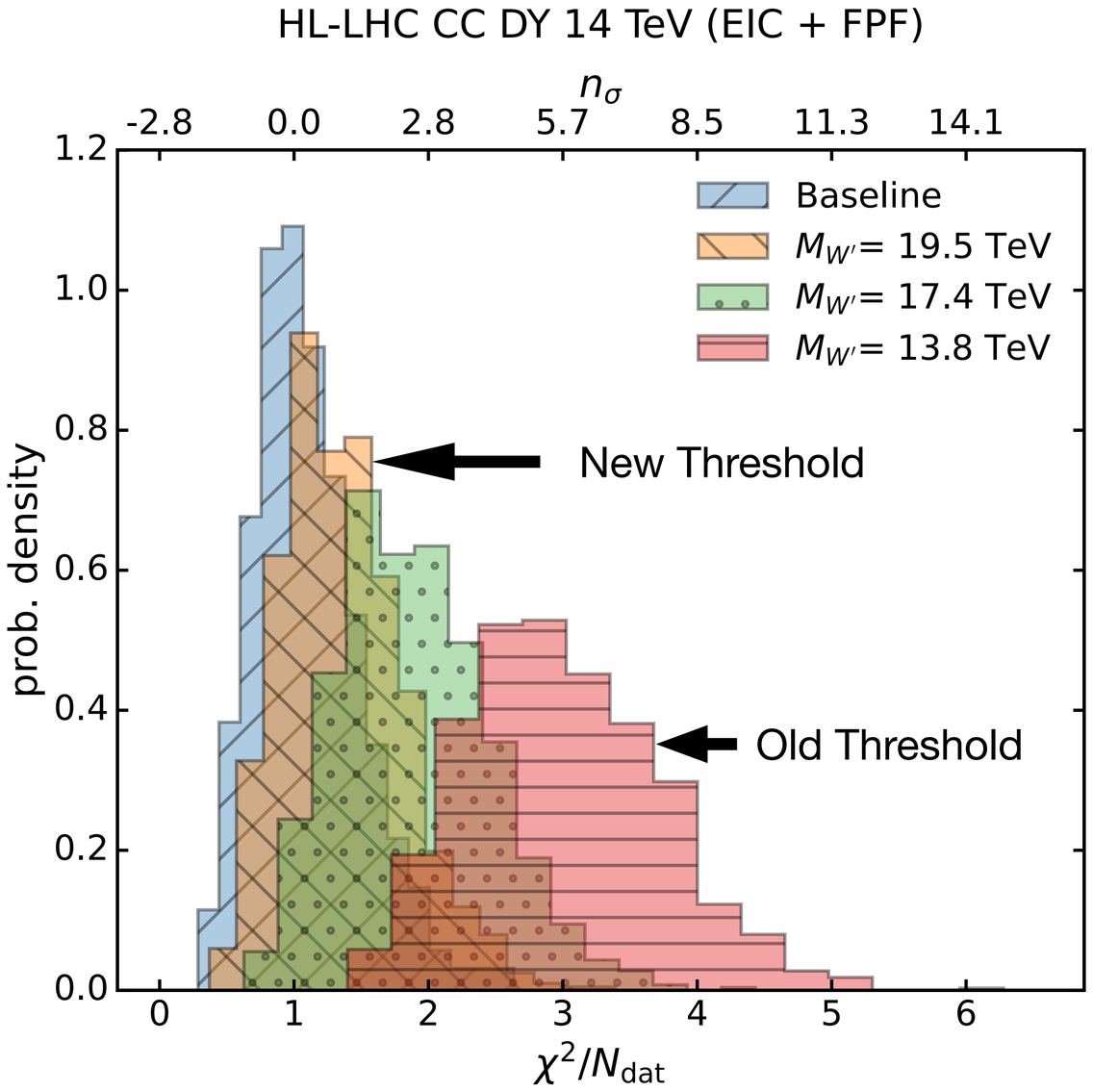
Not a complete solution:

Smaller deviations can still be absorbed

➡ risk at higher BSM mass

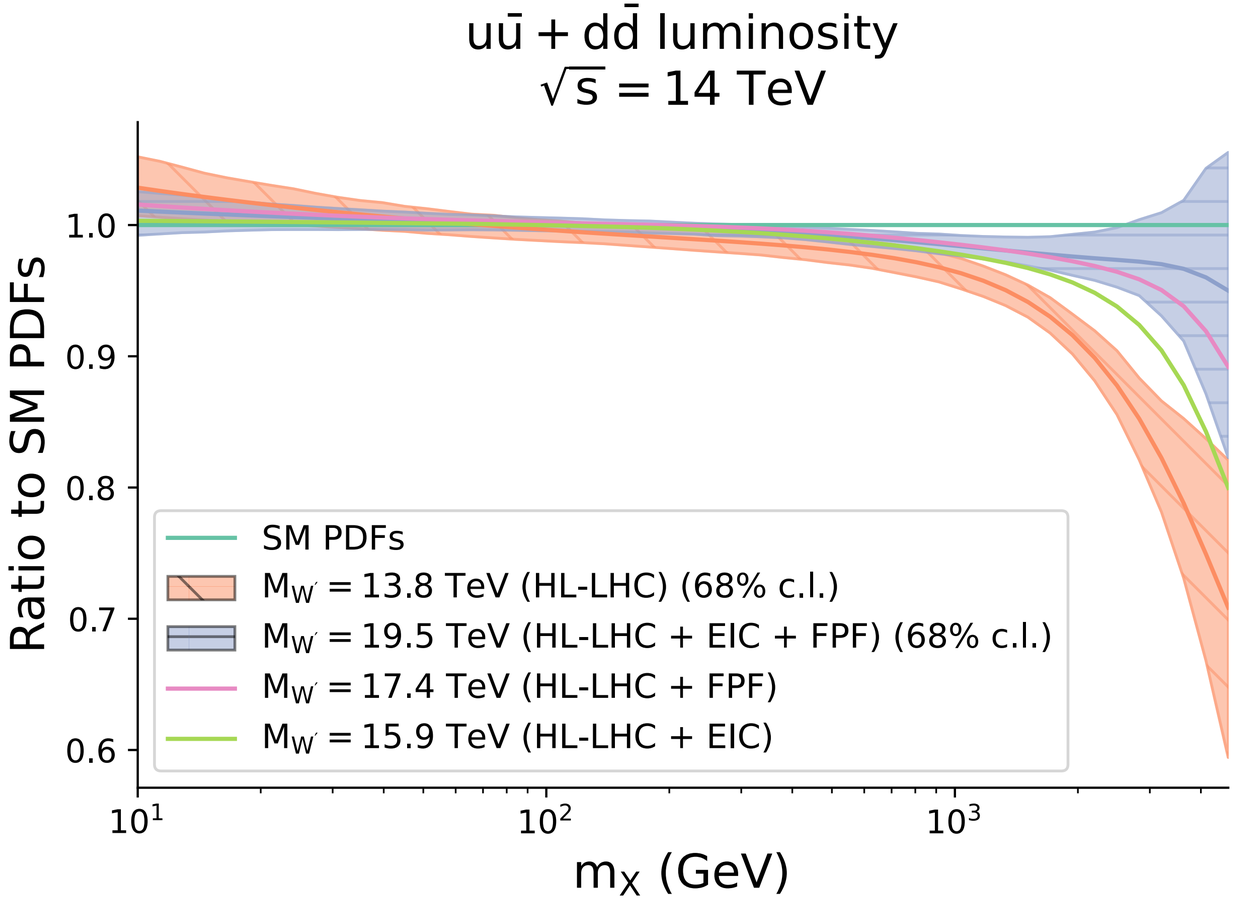
Reduction of the “blindspot”:

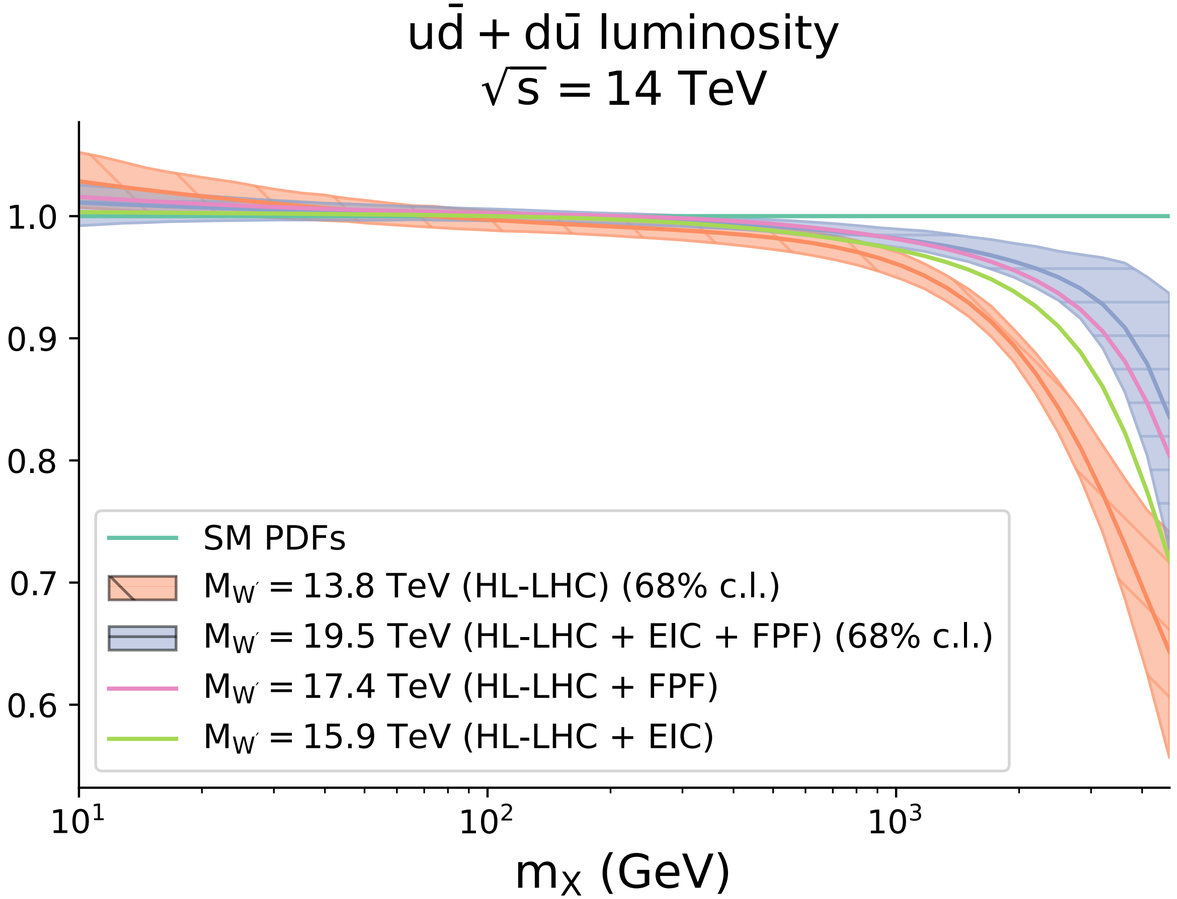
$$M_{W'} : 13.8 \rightarrow 19.5 \text{ TeV}$$



Shift of the contamination threshold

Impact on PDF luminosities





New physics scenarios: Z'

Generation of the pseudodata

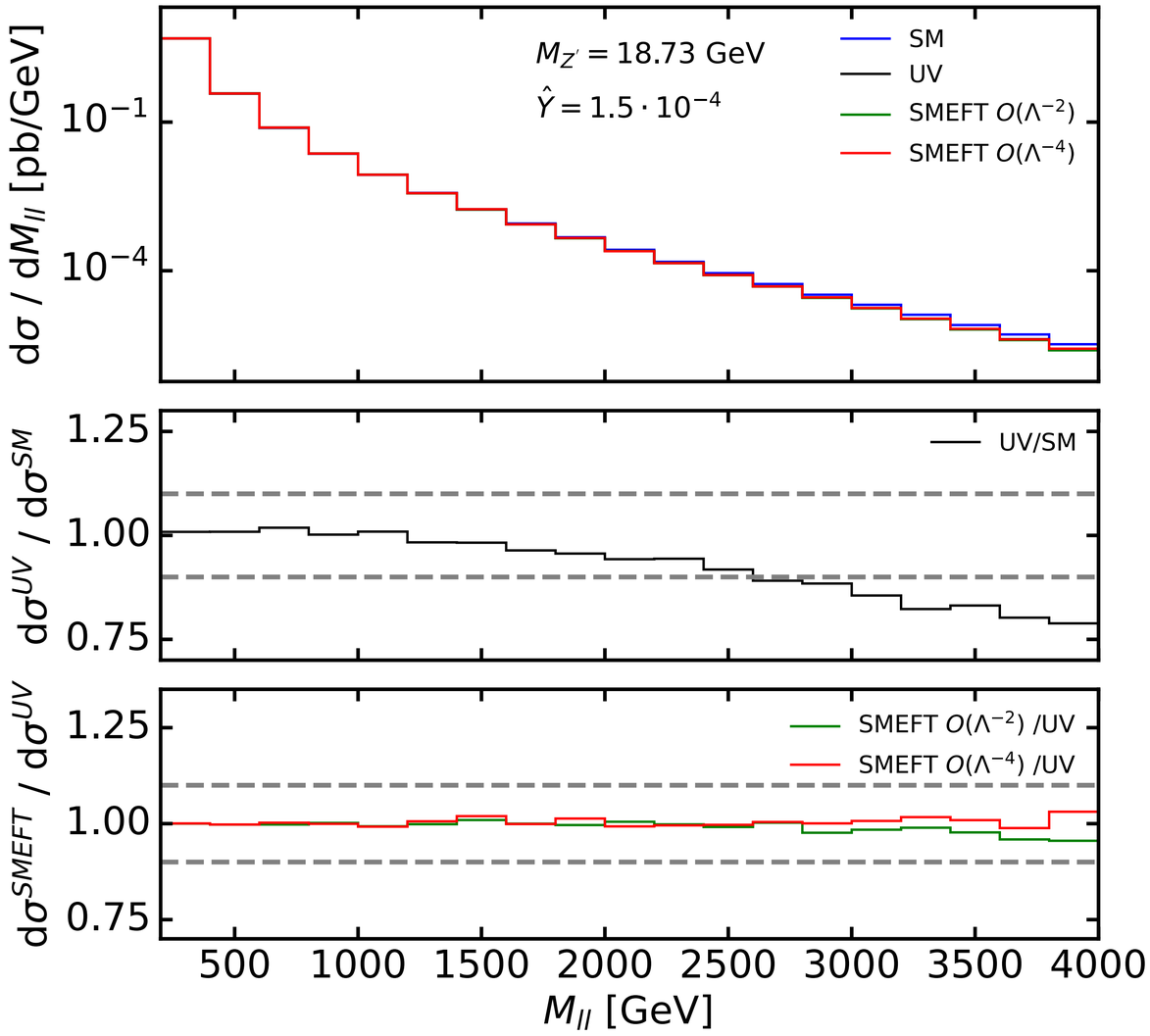
$$\mathscr{L}^{Z'}_{SMEFT} = \mathscr{L}_{SM} - \frac{g^2_{Z'}}{2M^2_{Z'}} J^{\mu}_{Y} J_{Y,\mu}$$

$$J^{\mu}_{Y} = \sum_{f} Y_f \bar{f} \gamma^{\mu} f$$

Impacts neutral current Drell-Yan processes

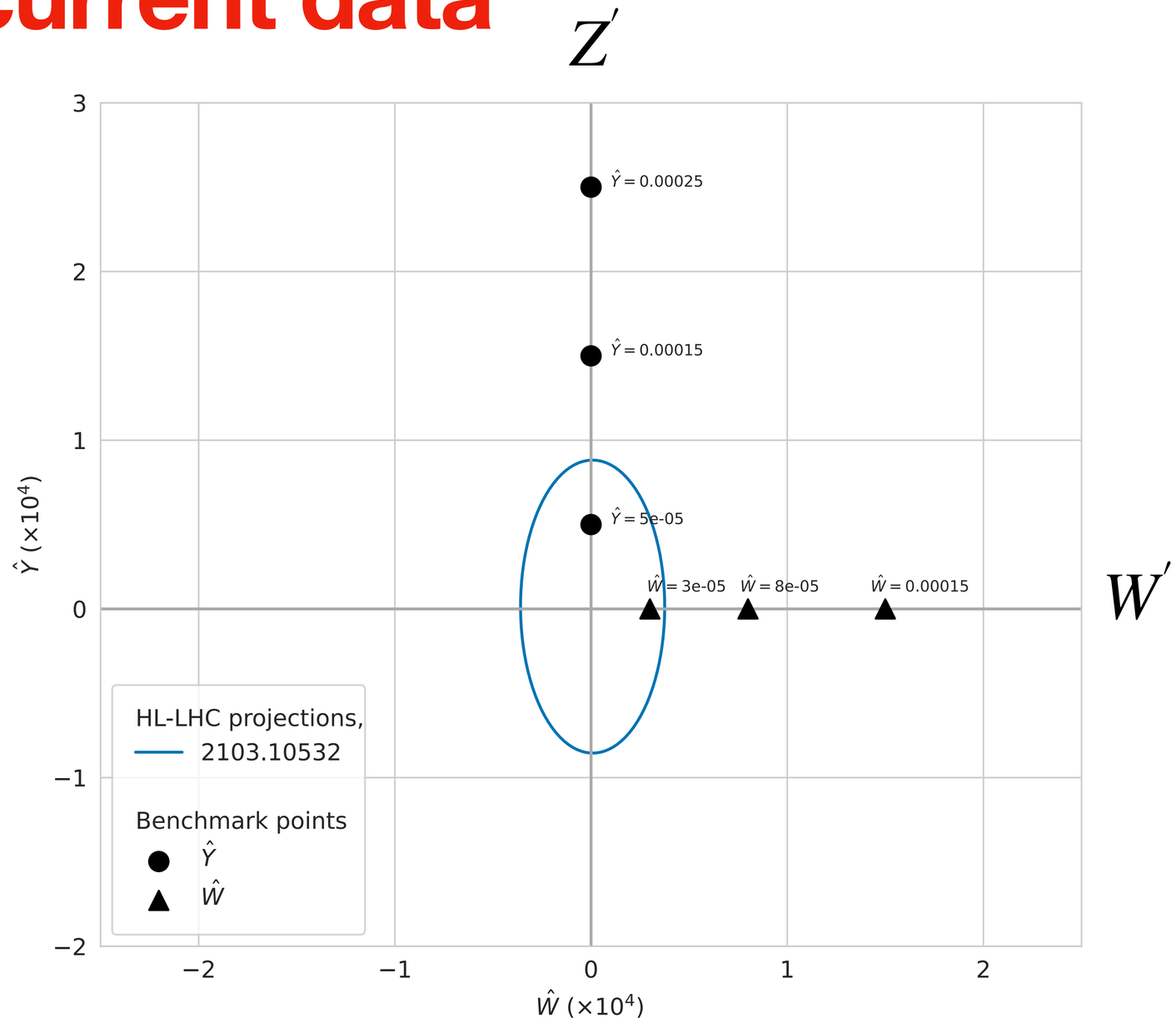
$$p\bar{p} \to l^+ l^-$$

$M_{Z'} = 18.7$ TeV



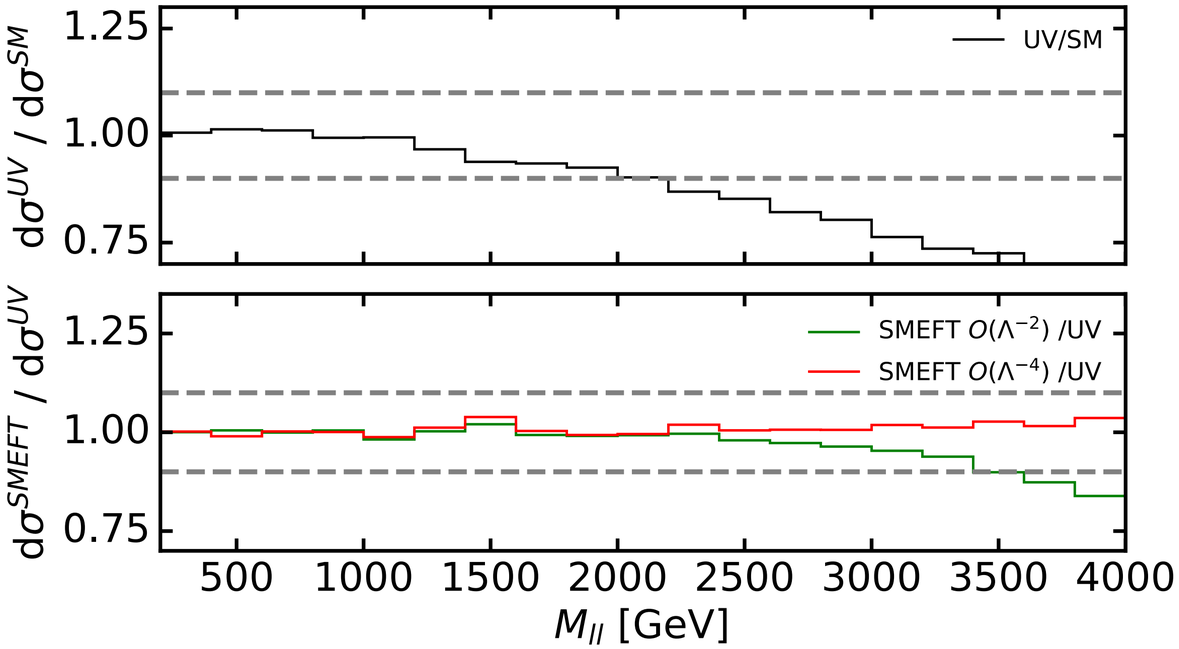
Constraints from current data

- New physics scenarios compared to constraints at 95% CL

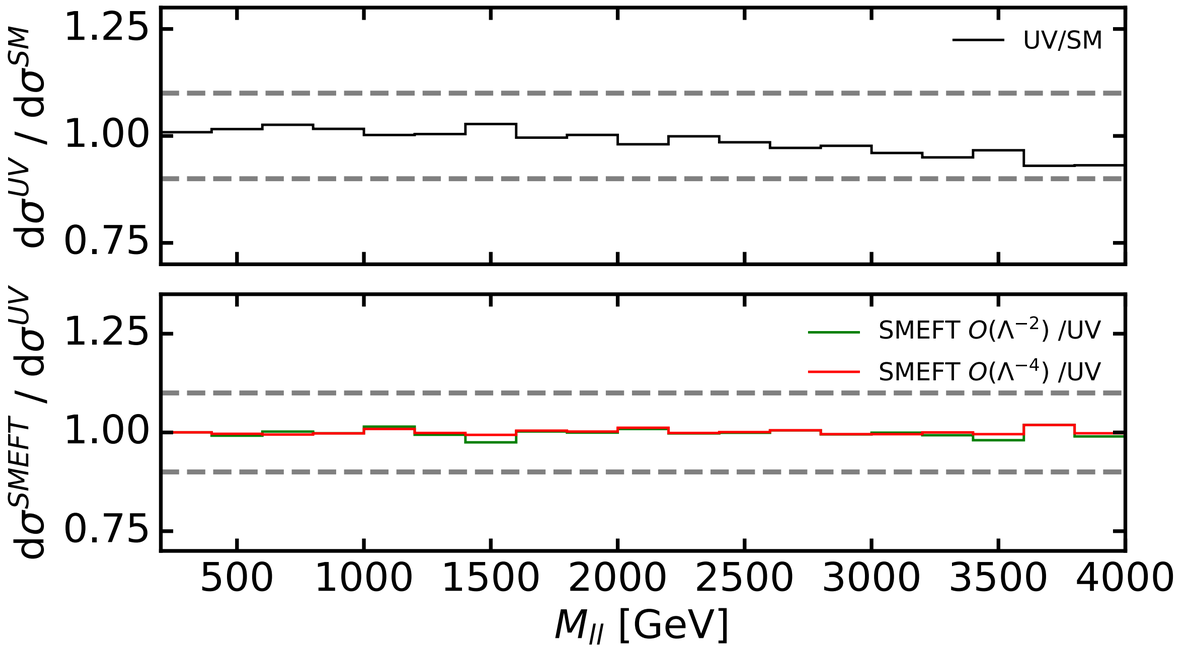


New physics scenarios: Z'

$M_{Z'} = 14.5$ TeV

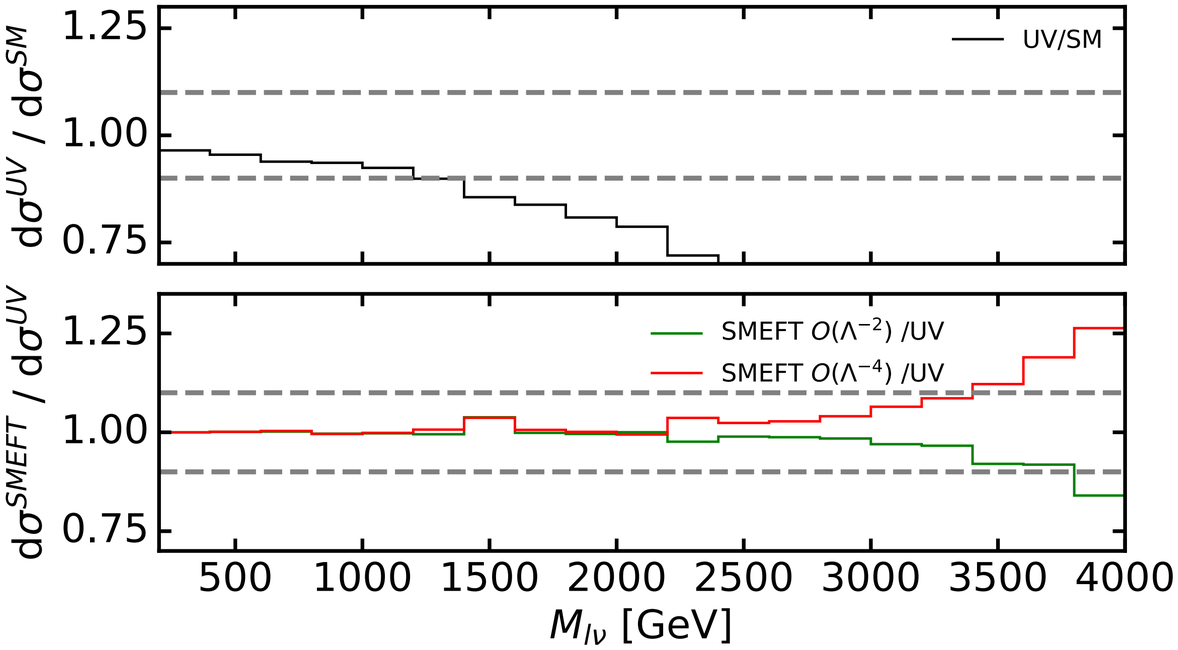


$M_{Z'} = 32.5$ TeV



New physics scenarios: W'

$M_{W'} = 10$ TeV



$M_{W'} = 22.5$ TeV