Can Parton Distribution Functions Absorb New Physics?

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based on 2307.10370: E. Hammou, Z. Kassabov, MM, M. L. Mangano, L. Mantani, J. Moore, M. Morales Alvarado, M. Ubiali

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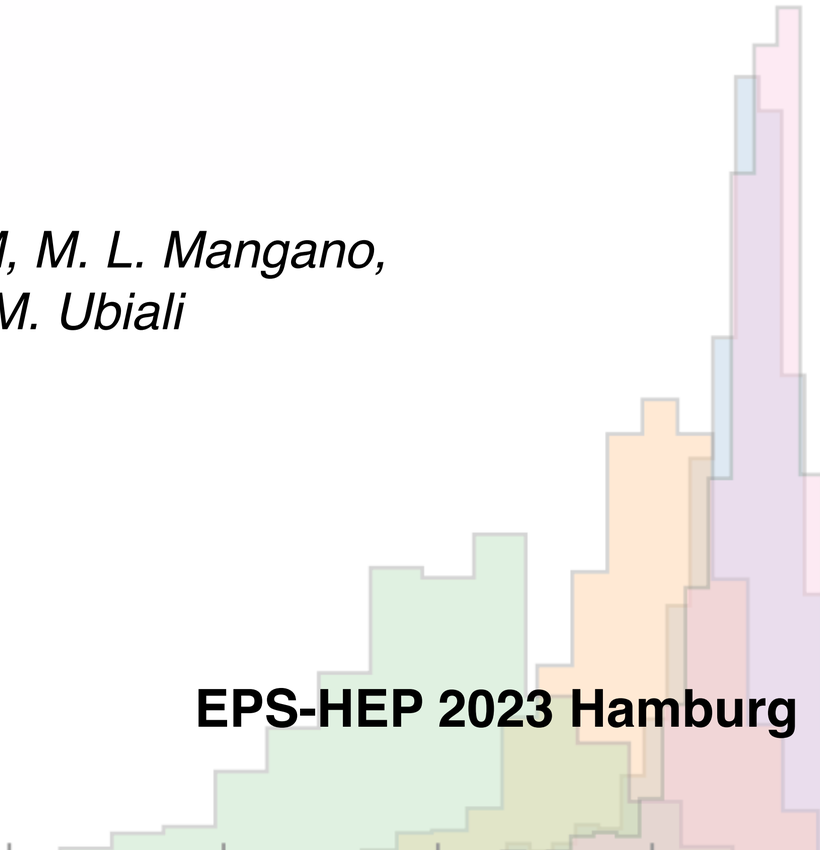
PBSP



EPS-HEP 2023 Hamburg

PDF-BSM Interplay

BSM parameters: c
PDF parameters: θ

PDF fits

BSM parameters are kept fixed:

$$\sigma(\bar{c}, \theta) = f_1(\theta) \otimes f_2(\theta) \otimes \hat{\sigma}(\bar{c})$$

SMEFT Fits and BSM searches

PDF parameters are fixed:

$$\sigma(c, \bar{\theta}) = f_1(\bar{\theta}) \otimes f_2(\bar{\theta}) \otimes \hat{\sigma}(c)$$

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Typically PDF fits assume the SM:
$\bar{c} = 0$

SMEFT Fits and BSM searches

PDF parameters are fixed:

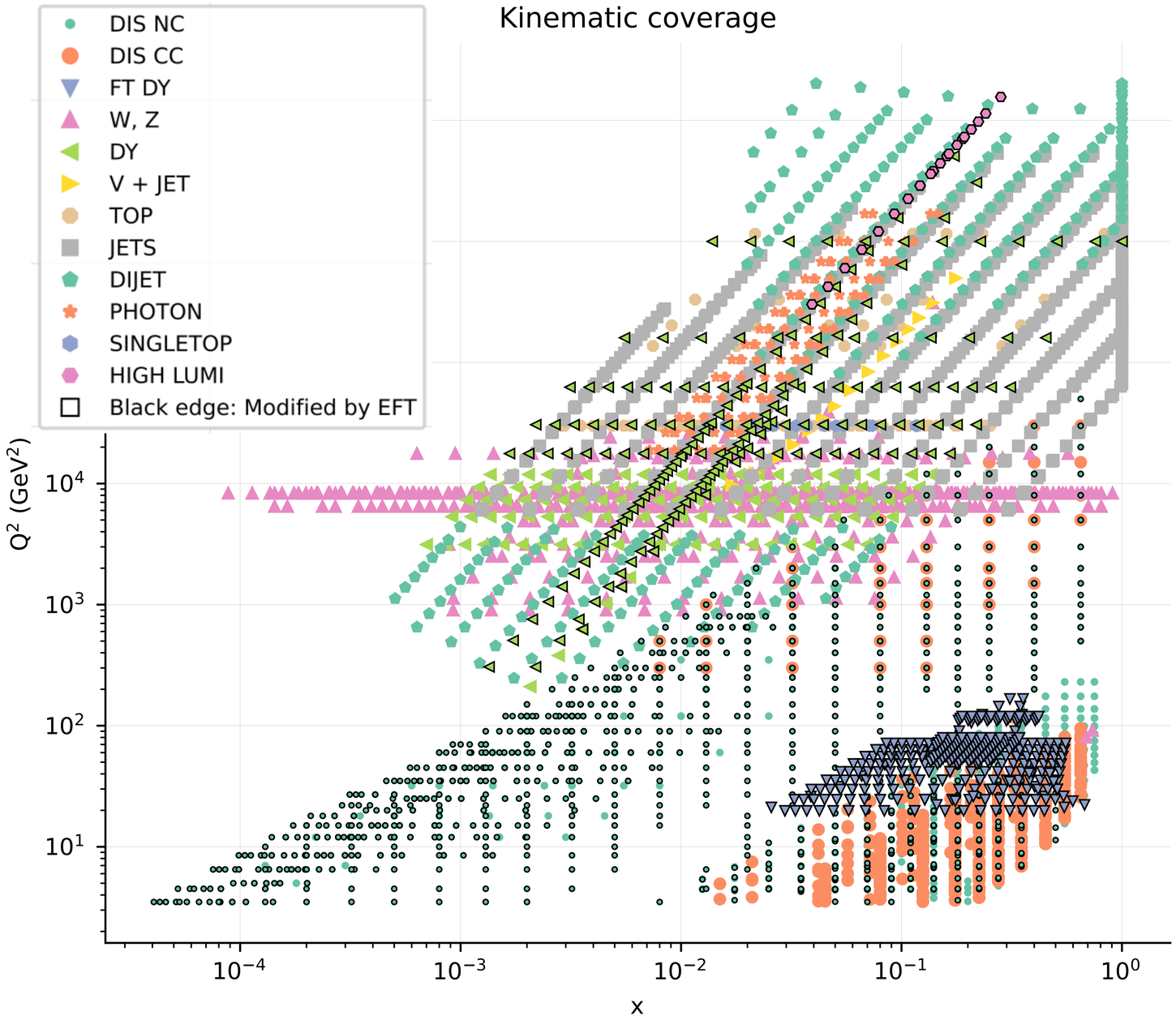
$$\sigma(c, \bar{\theta}) = f_1(\bar{\theta}) \otimes f_2(\bar{\theta}) \otimes \hat{\sigma}(c)$$

PDFs used in BSM searches rely on SM assumptions

Data overlap

Often the data used in PDF fits are also used in EFT fits.

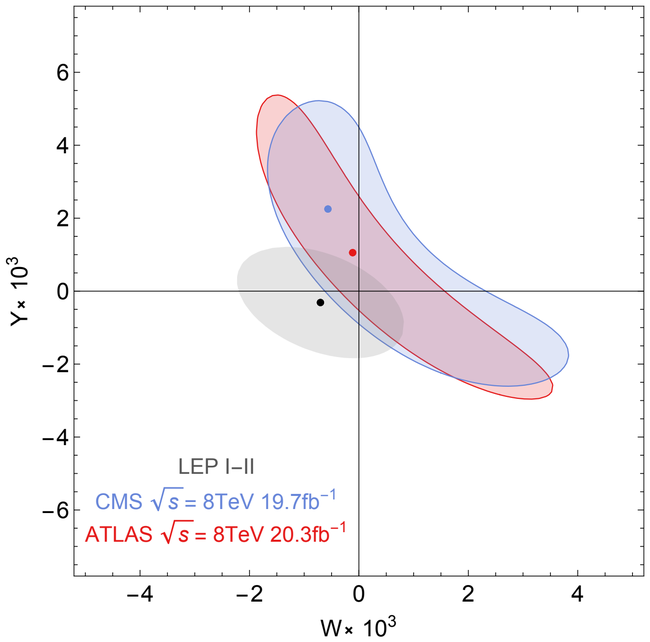
This overlap will grow as we continue to take a global approach to constraining the SMEFT.



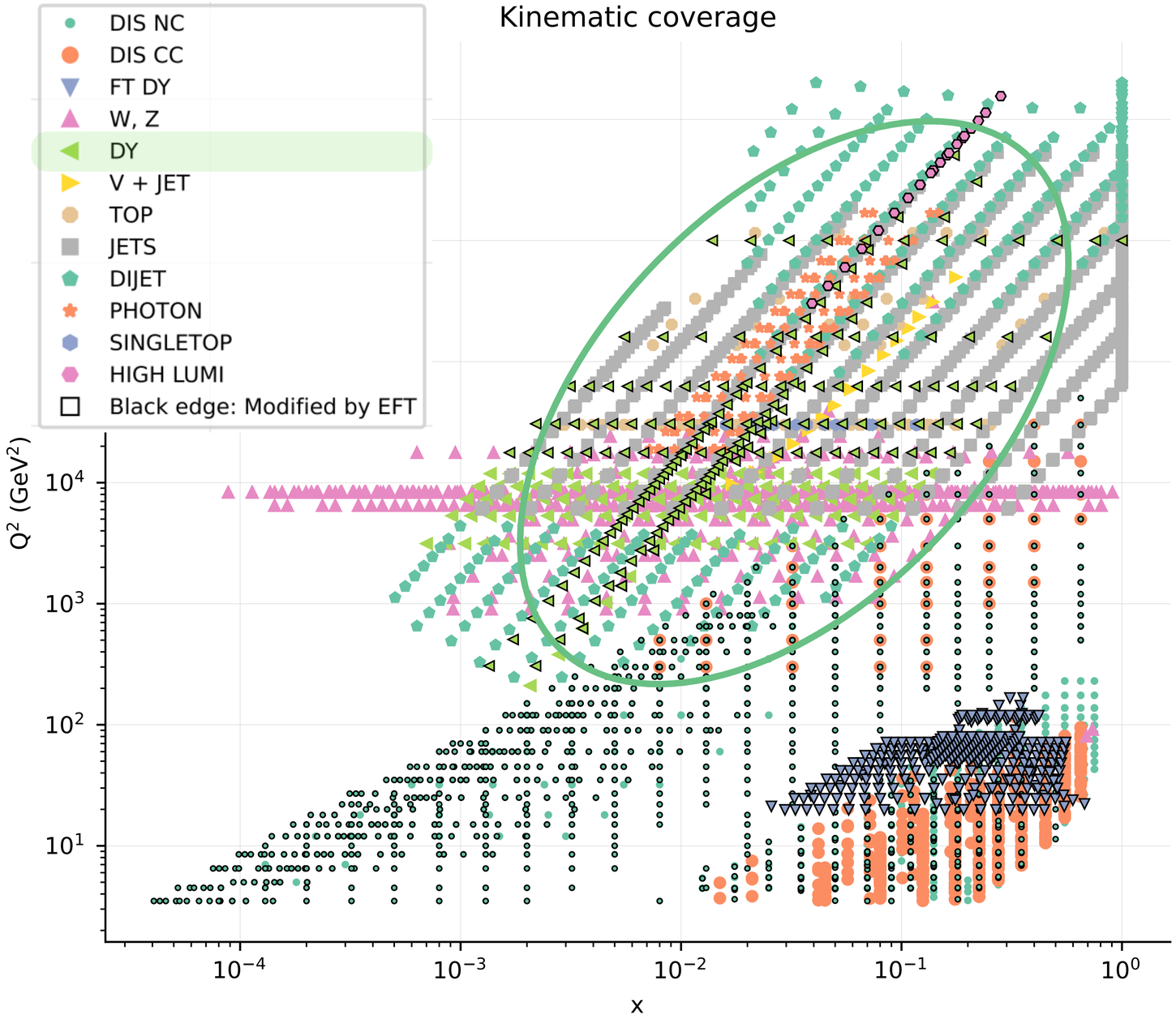
Data included in our study

Data overlap

- e.g. High-mass Drell-Yan data used to fit the SMEFT 4-fermion operators in *Farina et. al 1609.08157*



Kinematic coverage

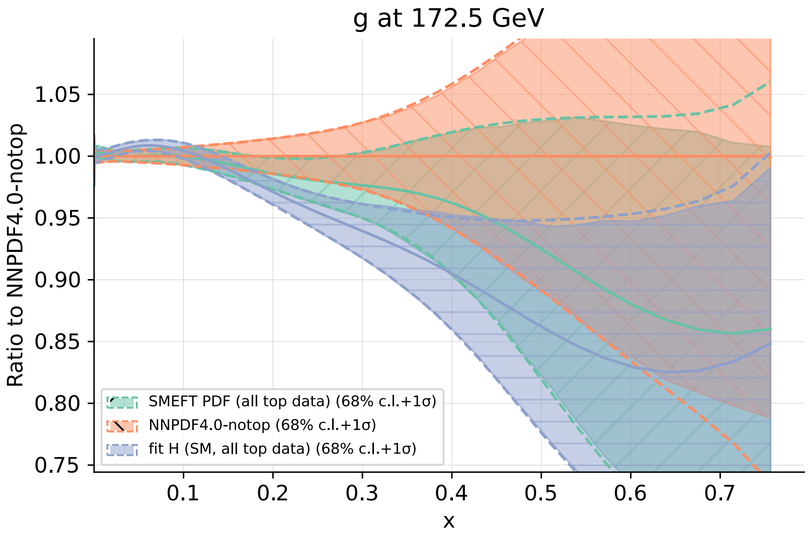


Data included in our study

Understanding PDF-BSM Interplay

Simultaneous PDF-EFT determinations:

- Deep Inelastic Scattering data
  Carrazza et al.: PRL 123 (2019) 13, 132001
- DIS + high-mass Drell-Yan tails
  Greljo et. al 2104.02723
- Top quark data
  Kassabov et. al: 2303.06159
  See also 2201.06586, 2211.01094



→ *See James Moore's talk on Thursday*

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HL-LHC projections: neglecting PDF-EFT interplay leads to a significant **underestimate** of PDF and SMEFT uncertainties

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Contaminated PDF fits:

What are the consequences of performing a SM PDF fit in the presence of new physics?

Contaminated PDFs

closely follows the *closure test methodology* developed by NNPDF, 1410.8849

Assume that we know the **true underlying law of nature**: SM + UV model

$$T = T(\theta_{\rm SM}, \theta_{\rm NP})$$

PDF parameters

Parameters of the BSM model

Contaminated PDFs

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Assume that we know the true underlying law of nature: SM + UV model

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Generate Monte Carlo pseudodata according to this underlying law:

$$D \sim \mathcal{N}(T(\theta_{\rm SM}, \theta_{\rm NP}), \Sigma)$$

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Perform a PDF fit: **fit only the SM parameters** $\theta_{\rm SM}$ using the NNPDF4.0 methodology *2109.02653*

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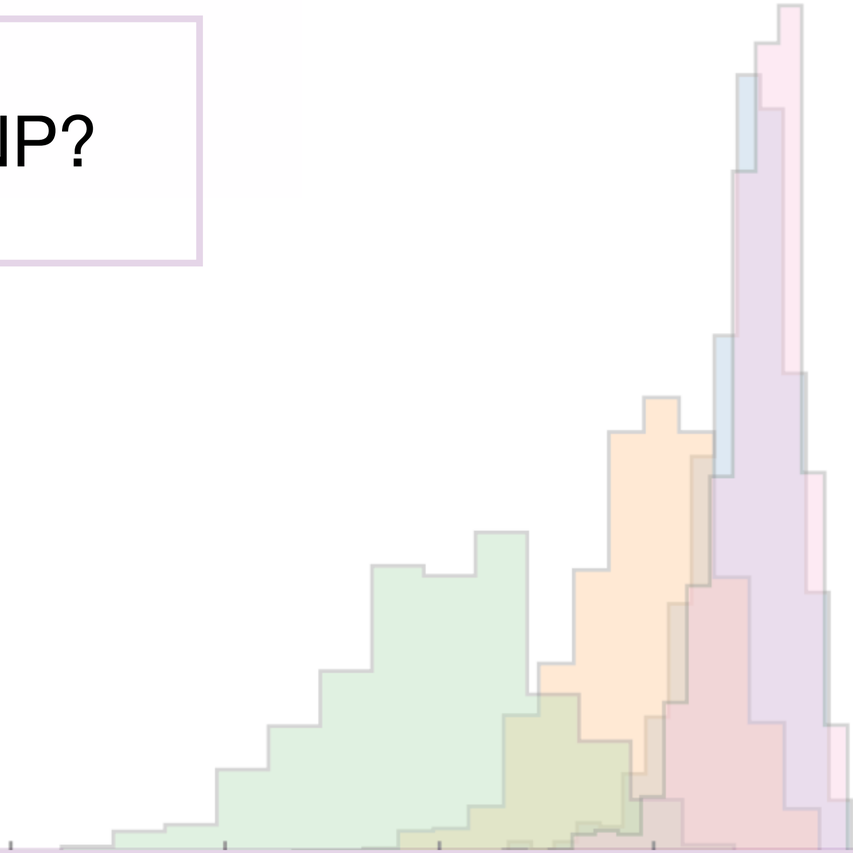
PDF has **absorbed new physics** if the fit quality is good $n_\sigma = \dfrac{\chi^2 - 1}{\sigma_{\chi^2}} < 2$

Can PDFs be contaminated by NP?



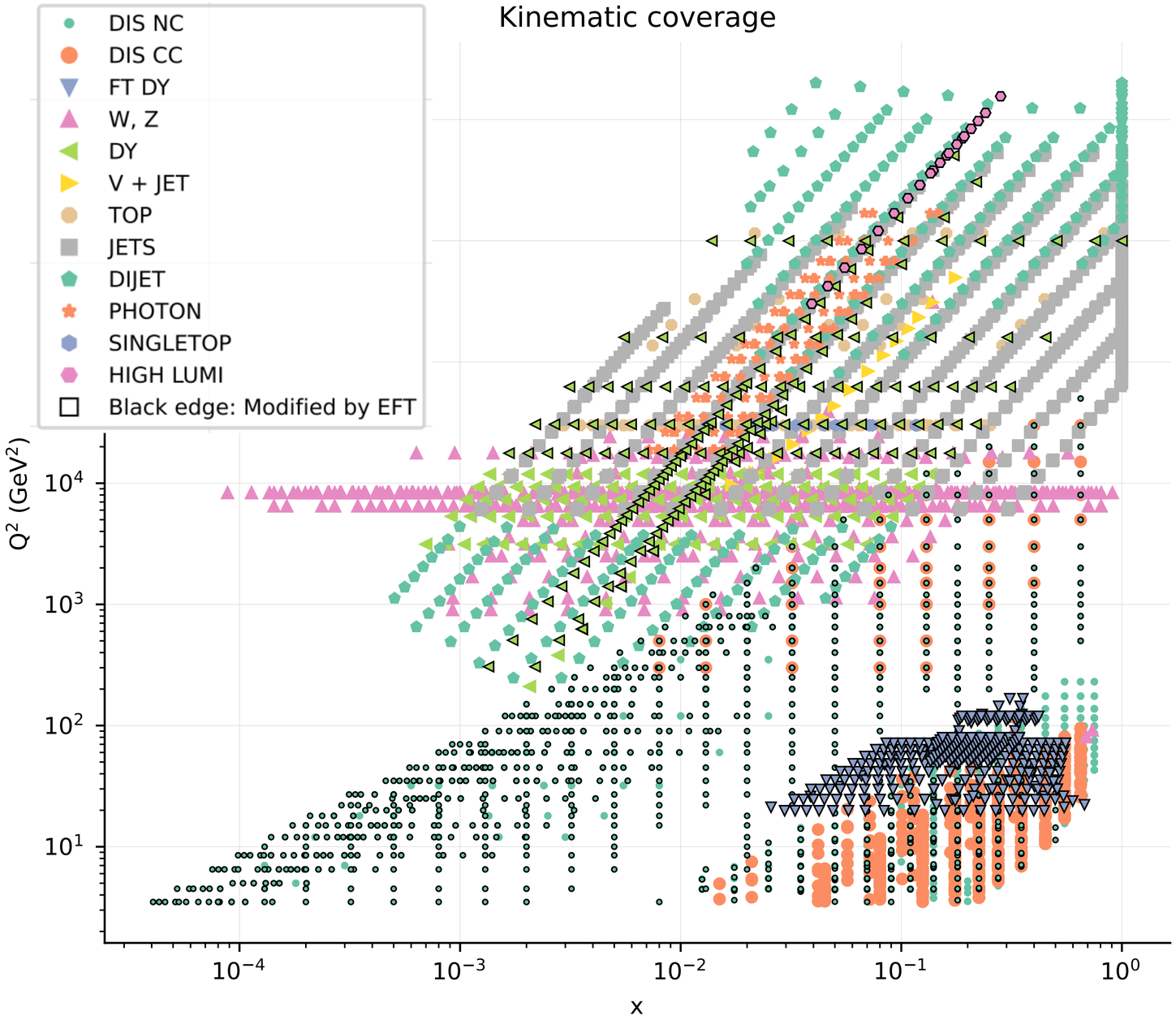
Data

- We generate MC pseudodata for all datasets included in NNPDF 4.0

2109.02653

- Additionally, we include **HL-LHC** projections for neutral current and charged current DY

as in Greljo et. al 2104.02723



BSM scenario

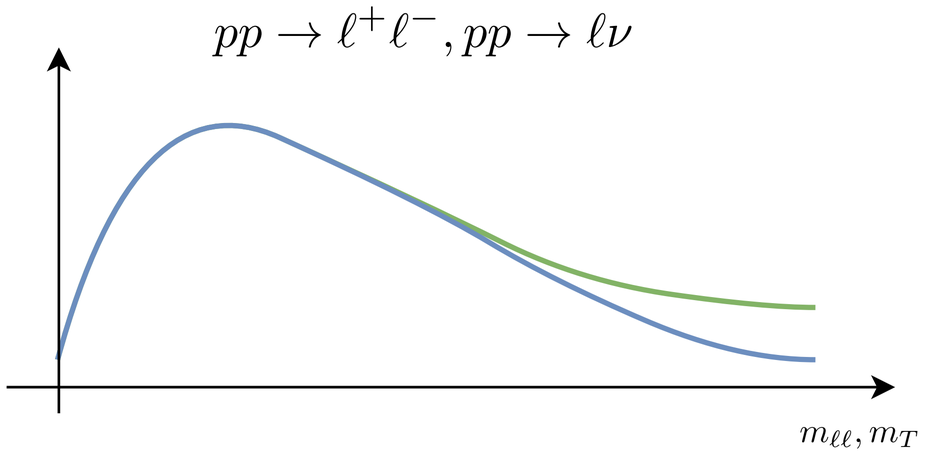
W’

See 2307.10370 for a flavour universal Z’ scenario

- Flavour universal W’

$$\mathcal{L}^{W'}_{\rm SMEFT} = \mathcal{L}_{\rm SM} - \frac{g^2 \hat{W}}{2m_W^2} J_L^\mu J_{L,\mu} \qquad J_L^\mu = \sum_{f_L} \bar{f}_L T^a \gamma^\mu f_L$$

- Impacts NC and CC DY



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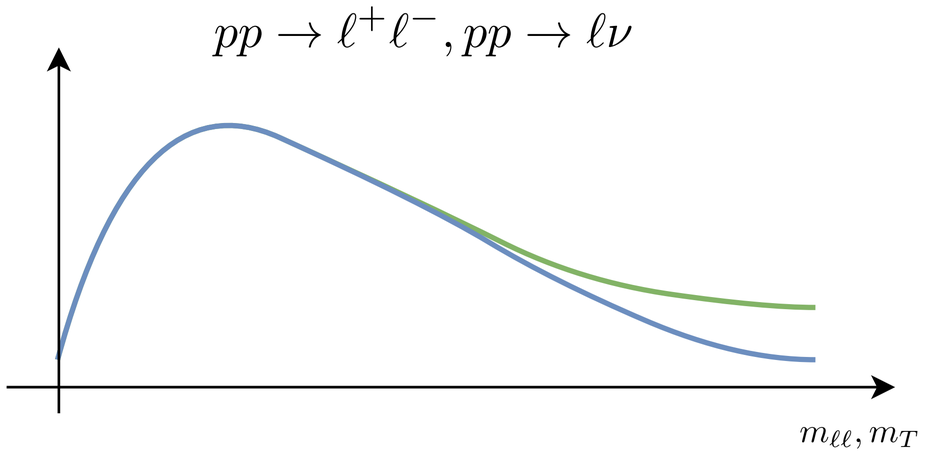
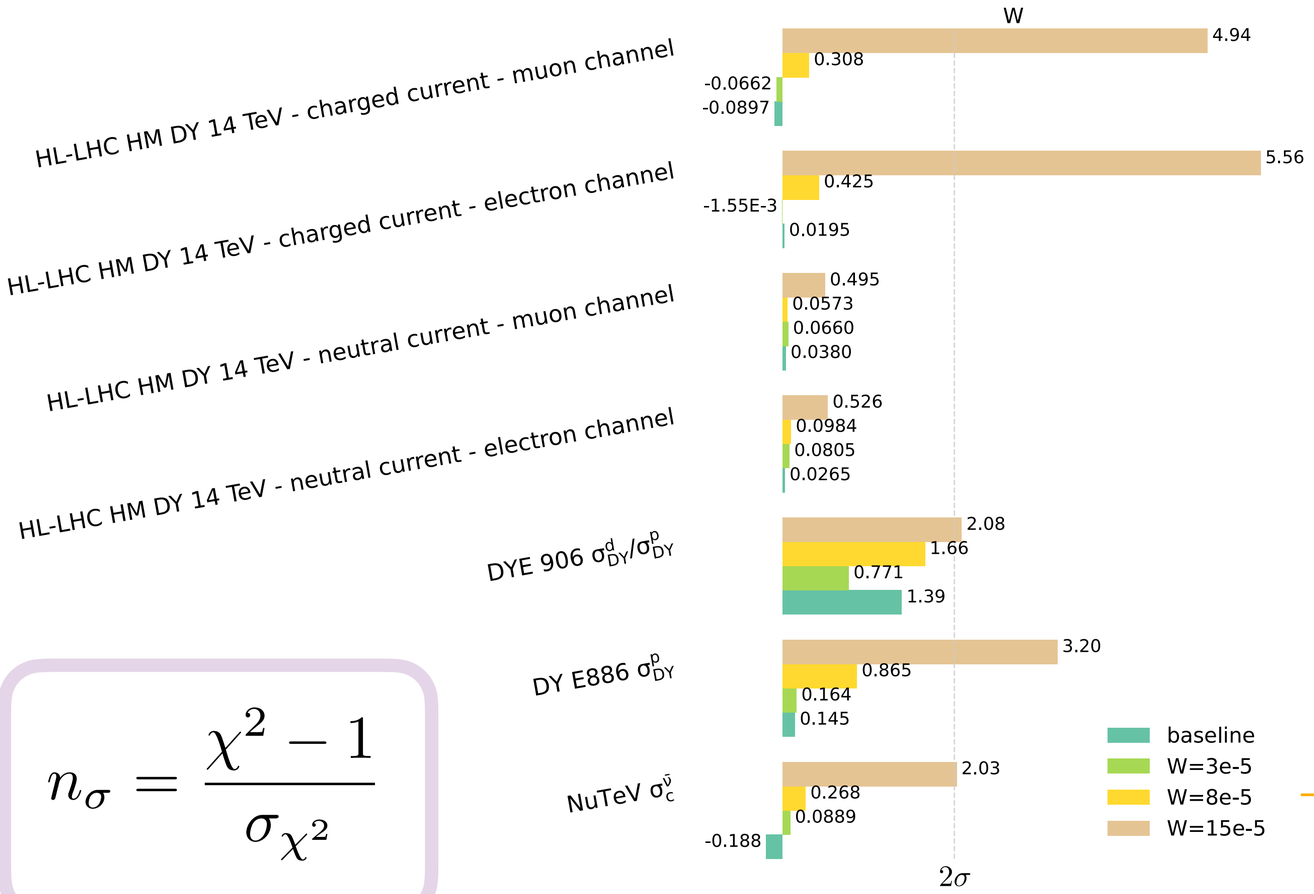
EFT approximation



Do our contaminated fits pass the selection criteria?



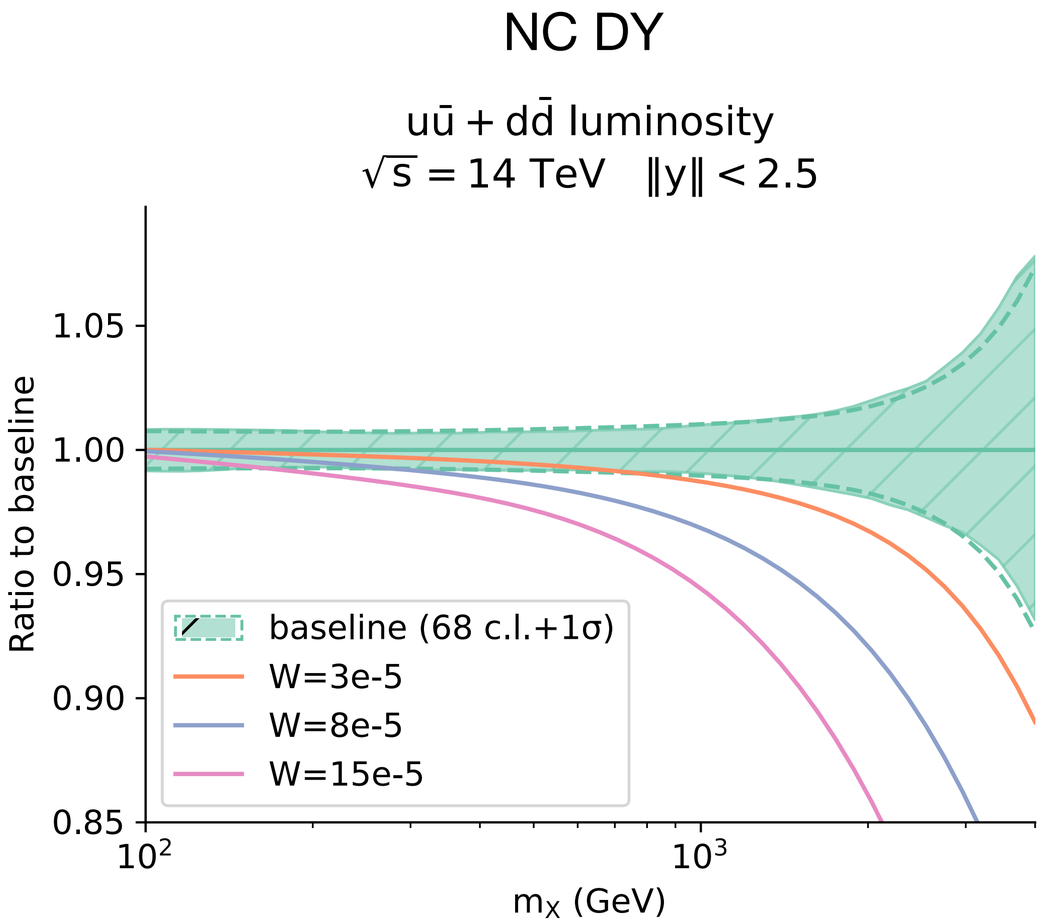
$$n_\sigma = \frac{\chi^2 - 1}{\sigma_{\chi^2}}$$

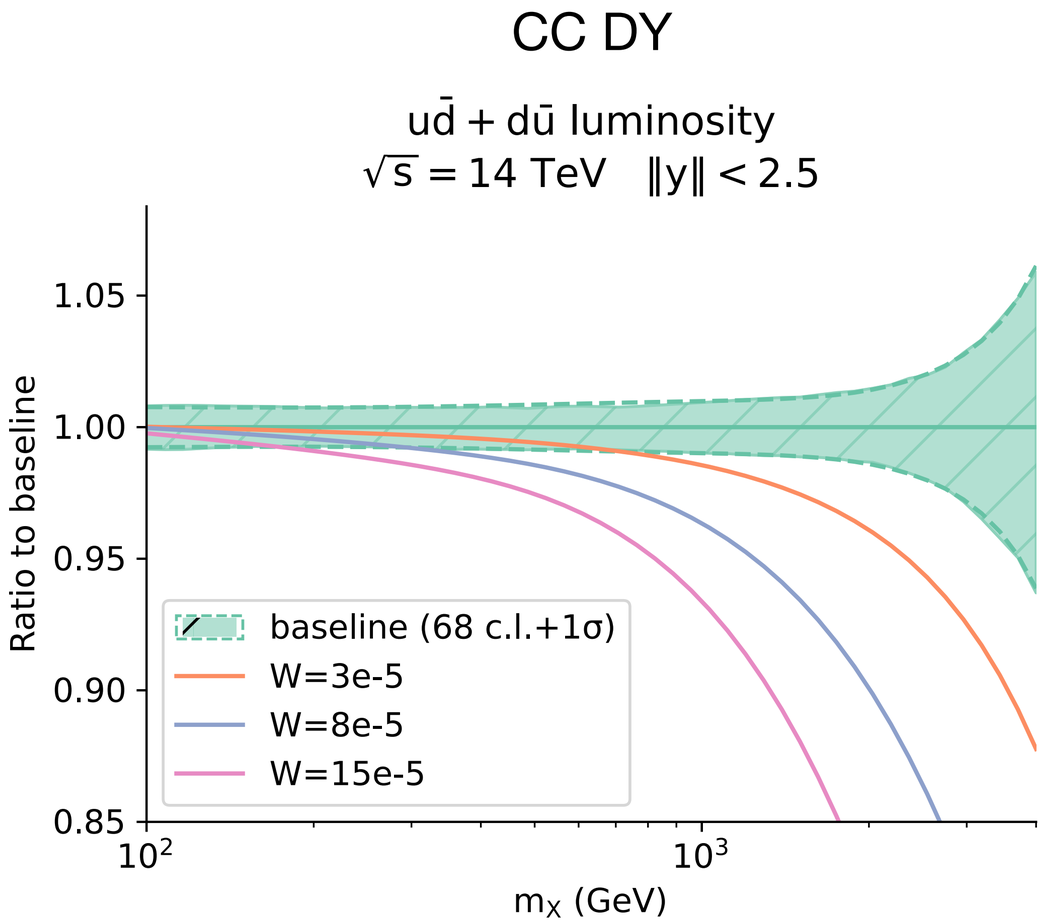
✓ ***Yes: PDFs absorb new physics***

$$\hat{W} = 8 \cdot 10^{-5}, \quad M_{W'} \approx 14 \text{ TeV}$$

W'-contaminated PDFs

Data: 'true' PDF ⊗ SM + W'
Theory: contaminated PDF ⊗ SM





Fewer constraints on the **large-x antiquark PDFs** allow freedom to shift away from the baseline

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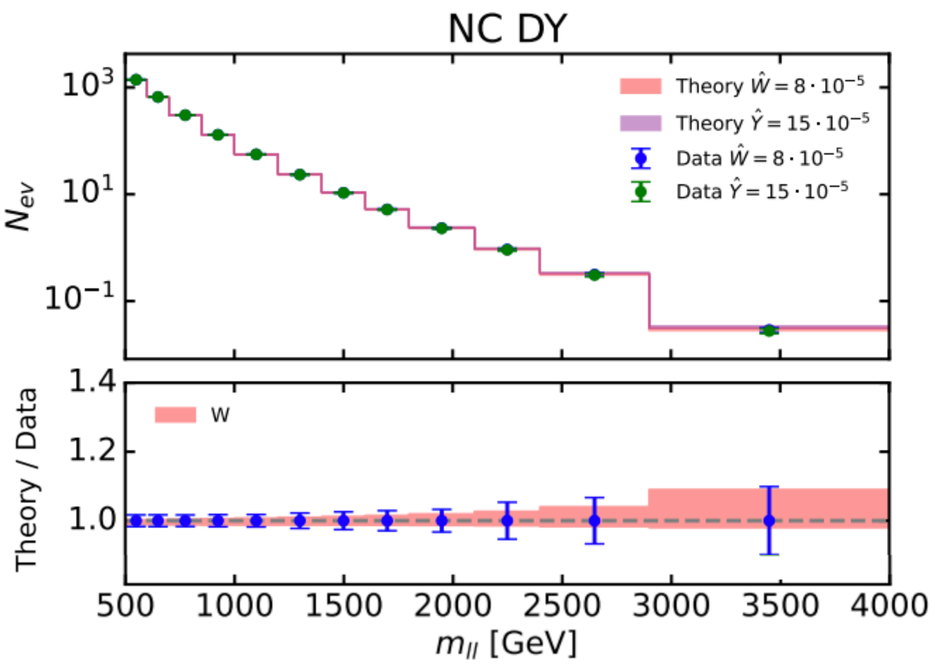
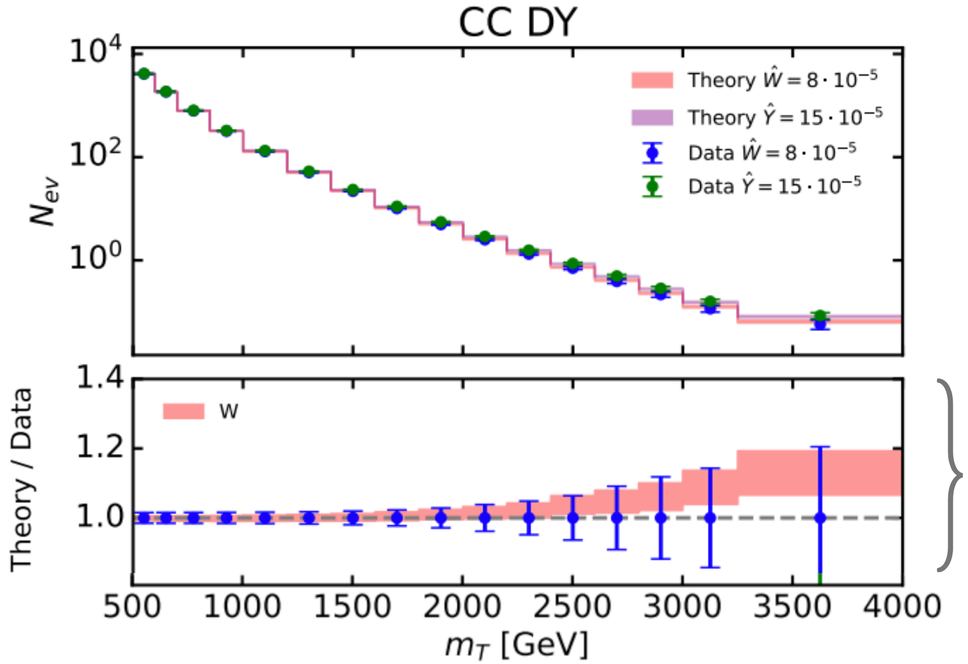




Excellent data-theory agreement

- The data appears to agree well with the SM
- **The shift in the PDFs compensates the NP effects**
- The effects of NP are completely missed

Impact on EW processes

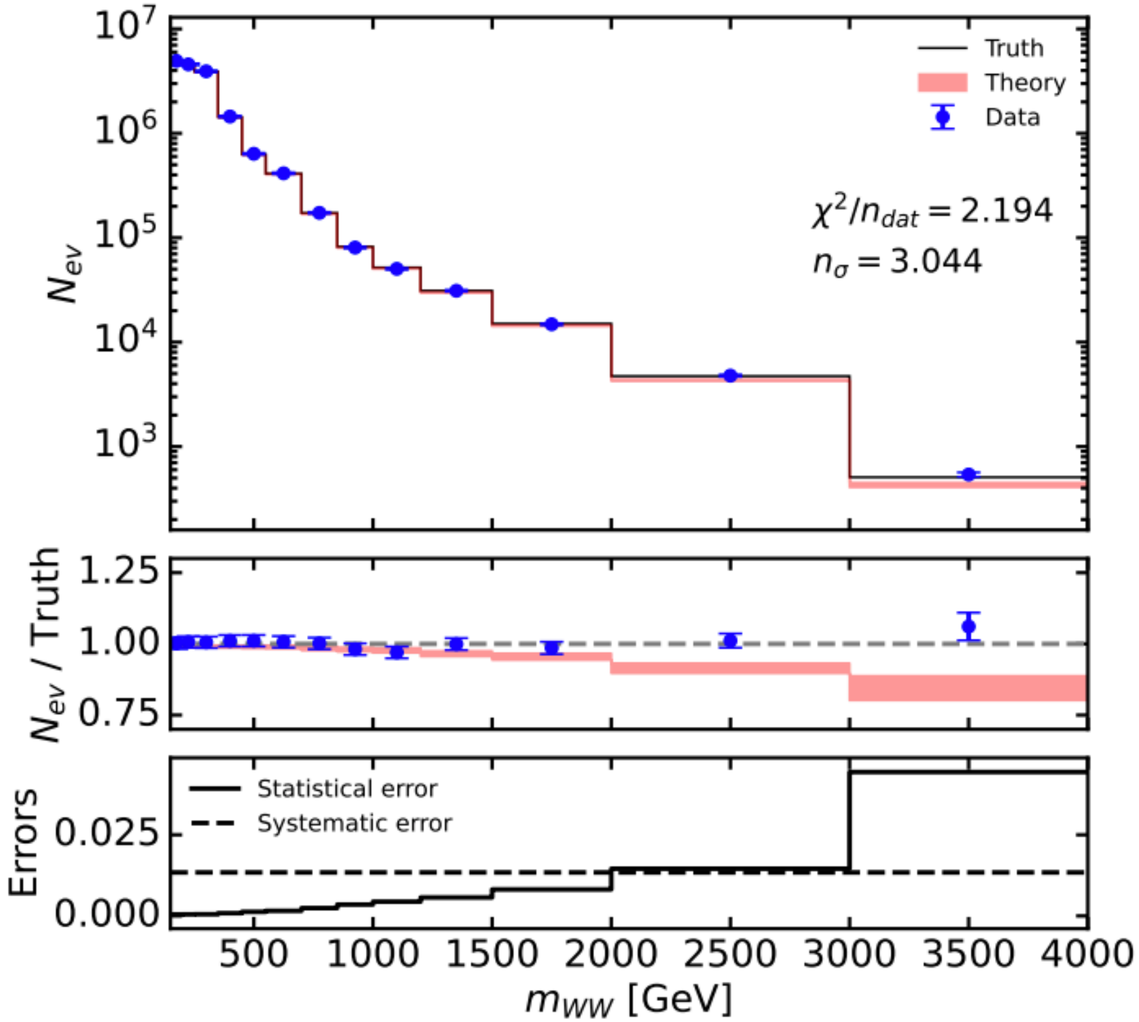
Data: ‘true’ PDF ⊗ SM
Theory: contaminated PDF ⊗ SM

The PDF then causes **spurious NP effects** in other observables e.g.

$$q\bar{q} \to W^+W^-$$

- Data appears to disagree with SM at 3σ
- However, W^+W^- is unaffected by W’ model:

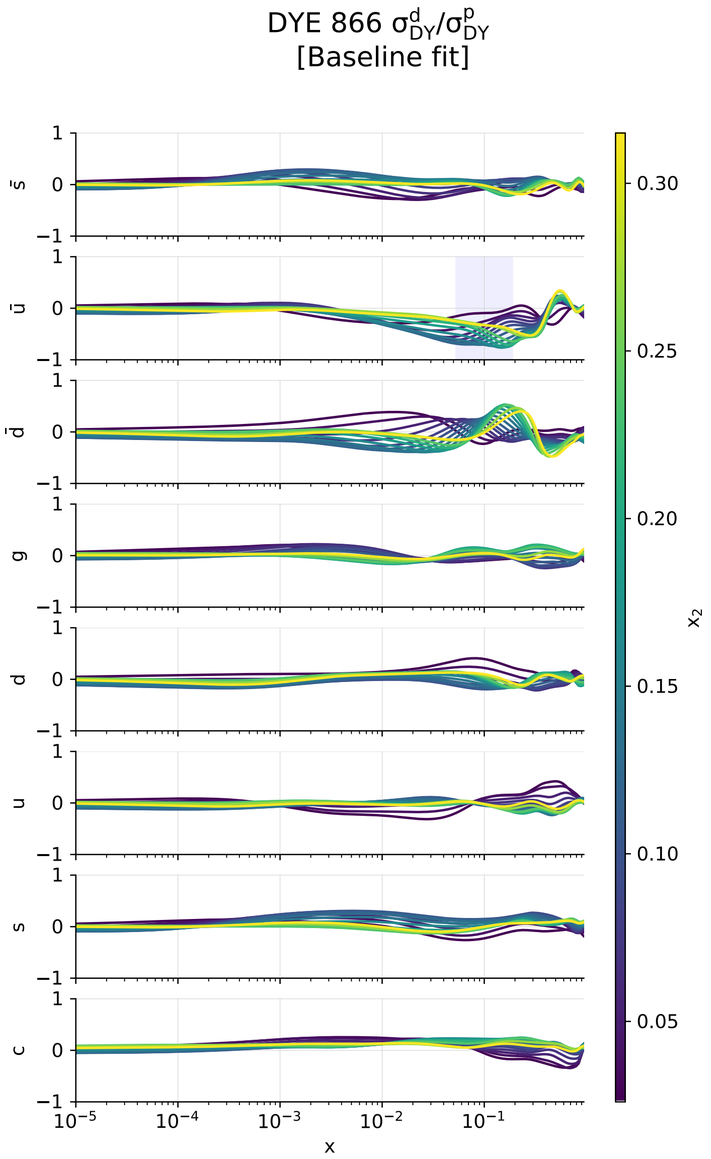
the deviation is in the PDF



Can we disentangle the effect of NP from PDFs?

Disentangling new physics effects post-fit

see 2307.10370 for other disentangling strategies



Fewer constraints on the **large-x antiquark PDFs** allow freedom to shift away from the baseline

Low-Q^2 measurements sensitive to large-*x* antiquarks may help

➡independent of NP effects

e.g.NuSea collaboration fixed target DY [hep-ex/0103030]

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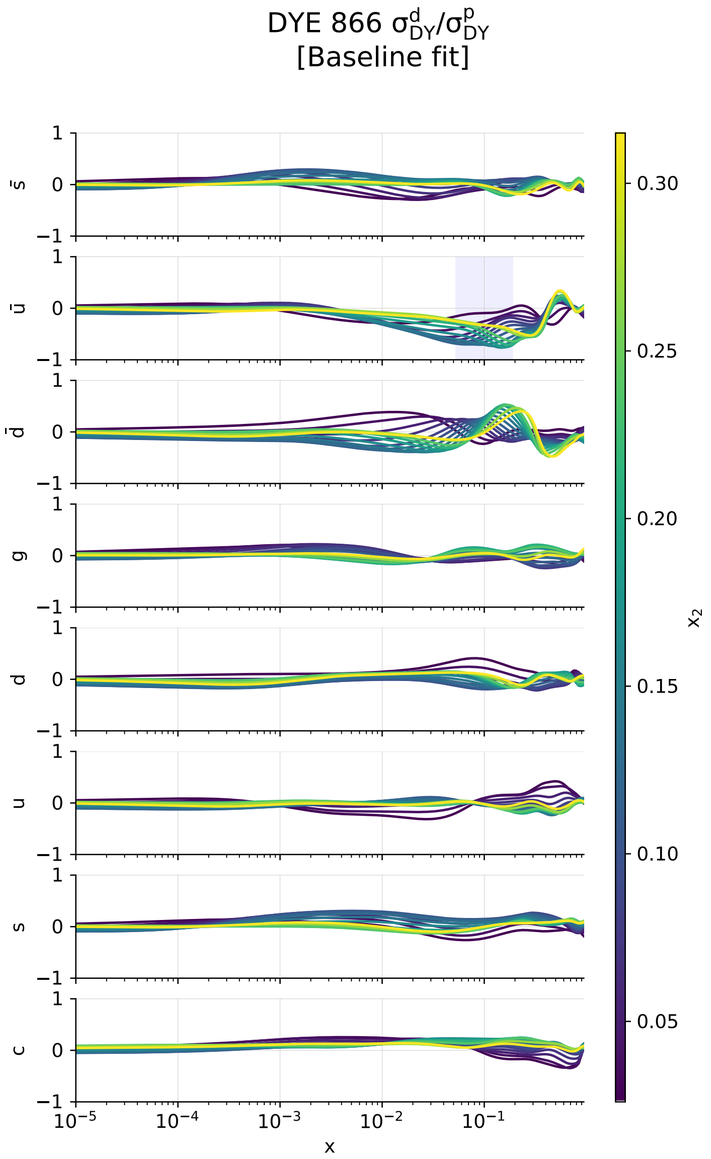

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However:

- data currently included in the fit is not precise enough to disentangle this effect
- Future low-energy measurements, e.g. the EIC programme, will provide crucial inputs to PDF fits

Conclusions

✓ PDFs can absorb new physics

- Effect of NP on **HL-LHC high-mass DY tails** in a realistic *W'* scenario can be absorbed by PDFs
- This cannot be disentangled post-fit
- Significant impact on DY and EW processes

- Future low-energy precision measurements of high-*x* antiquark PDFs will provide crucial inputs to PDF fits to disentangle these effects

- Tools to investigate contaminated PDF fits in other BSM scenarios are publicly available:
  https://www.pbsp.org.uk/contamination/

Conclusions

Thank you for listening!

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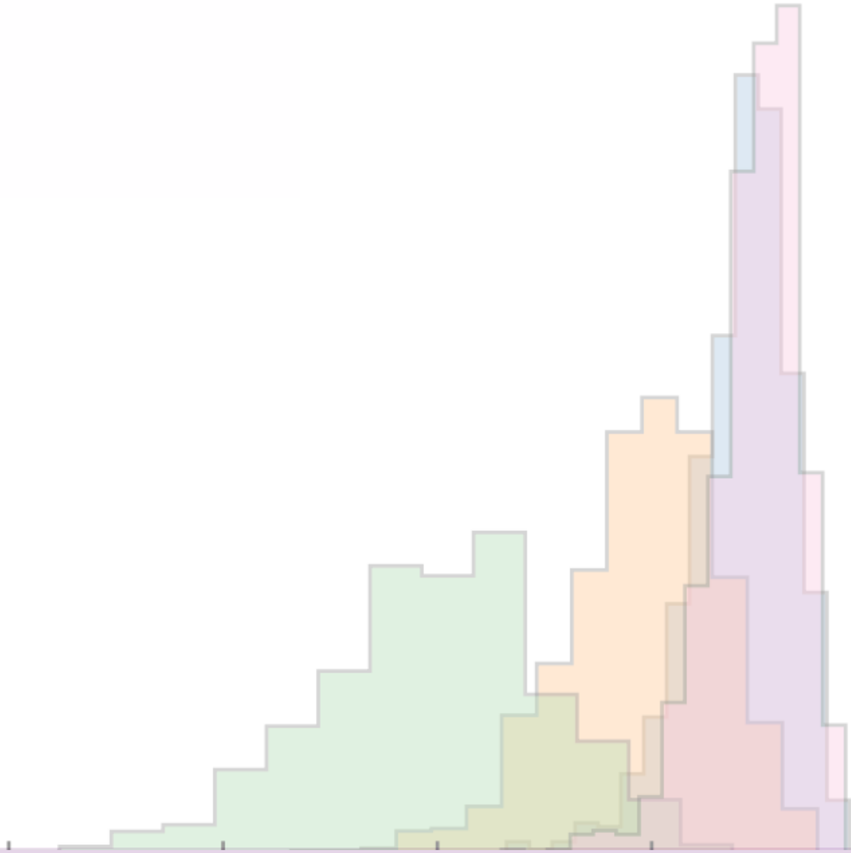
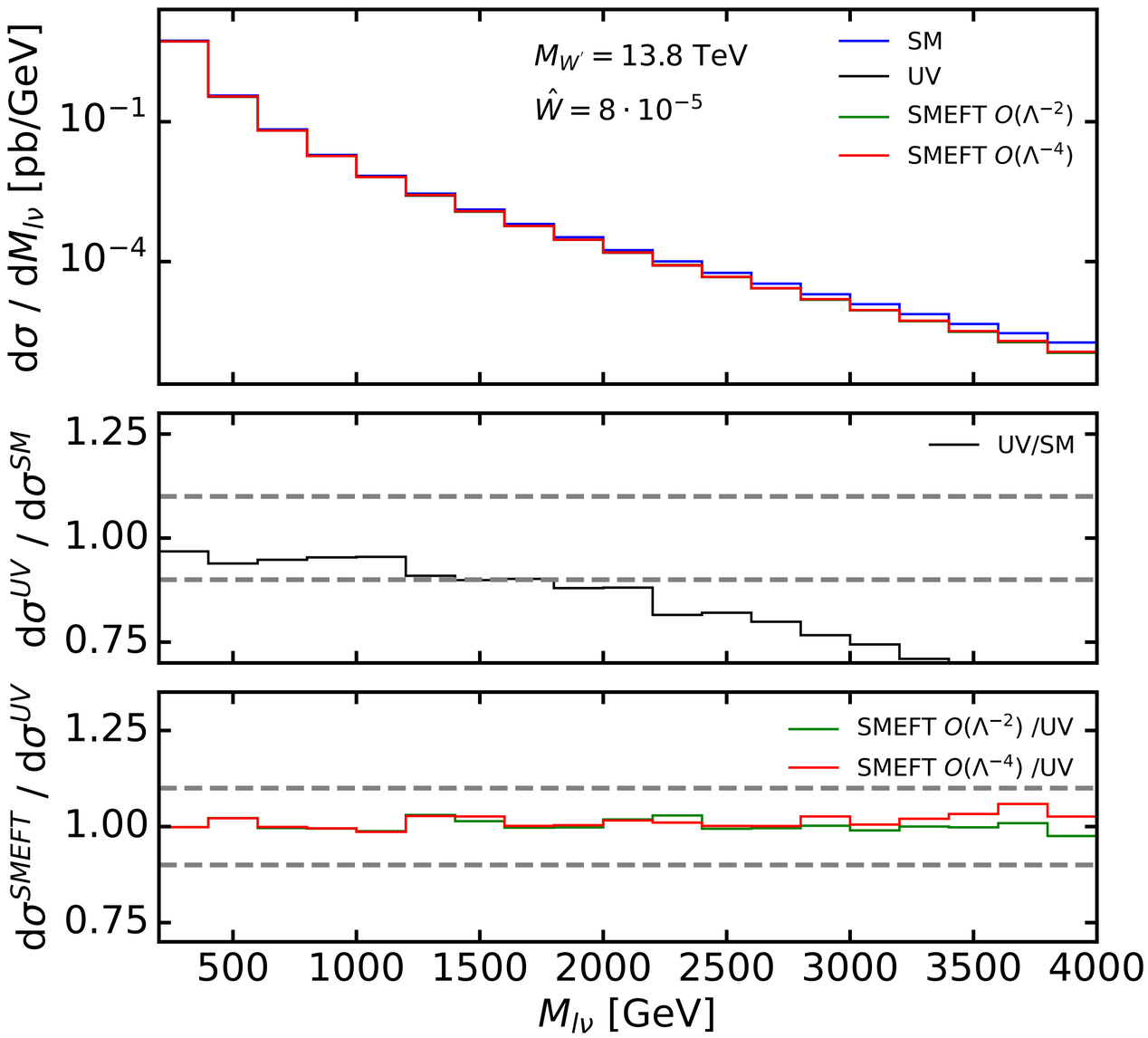
Backup



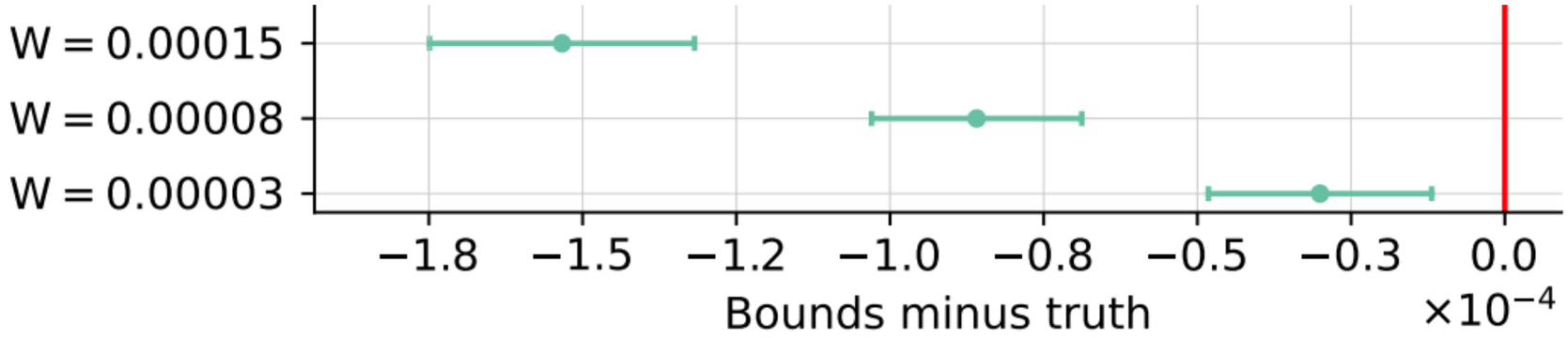
Impact of W’ model



Impact on DY of W’-contaminated PDFs

The high-mass DY data **appears** to agree well with the SM

This leads to constraints on the W’ which **miss the truth:**



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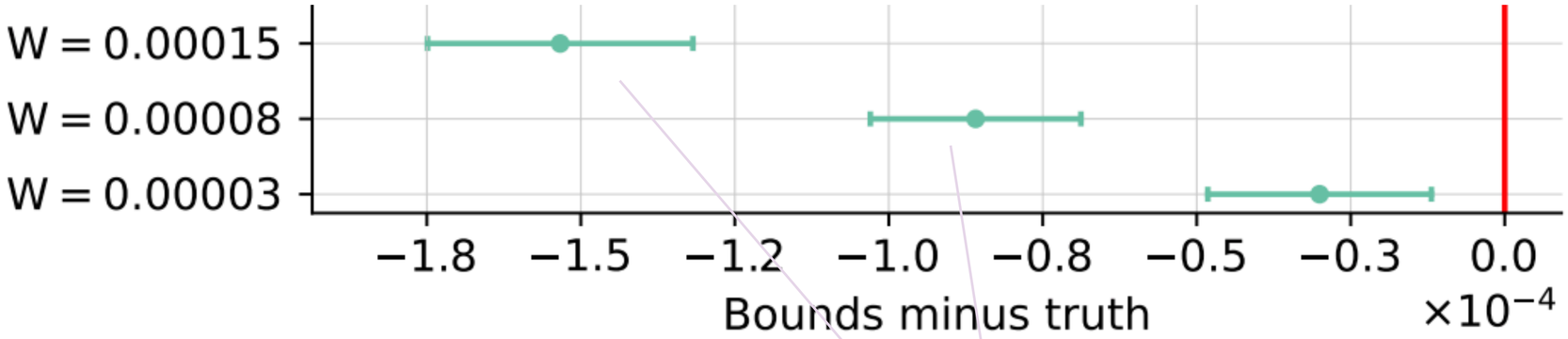
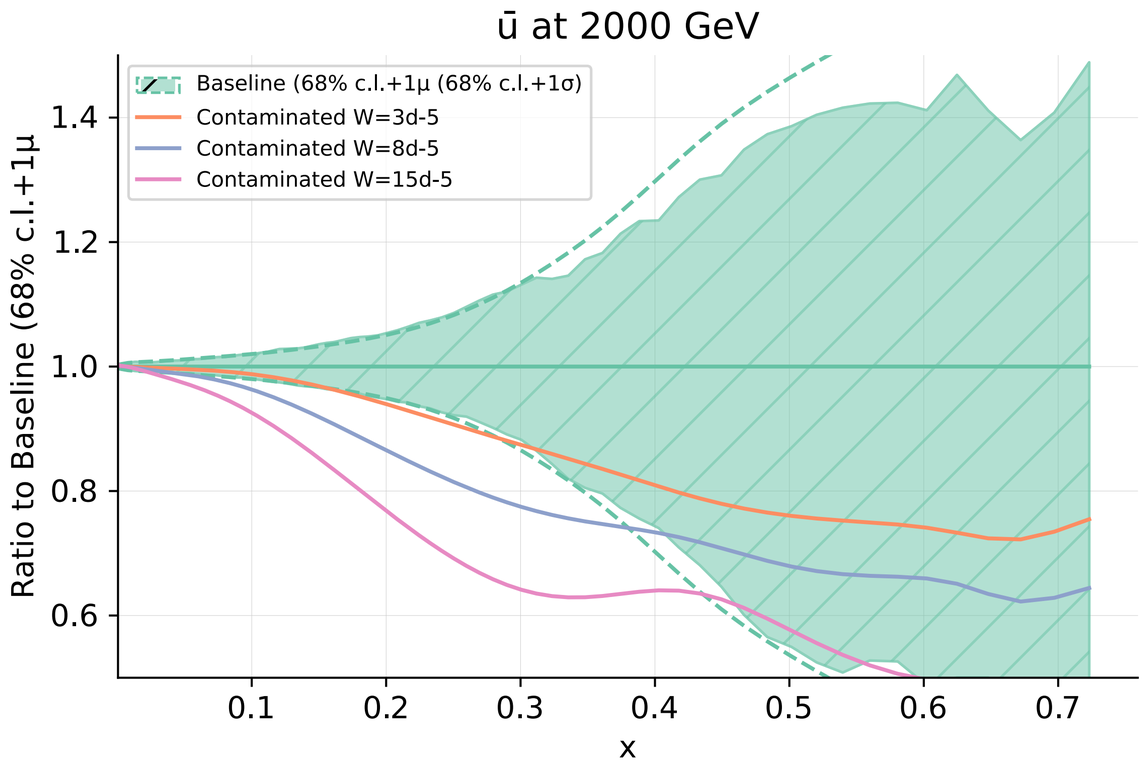
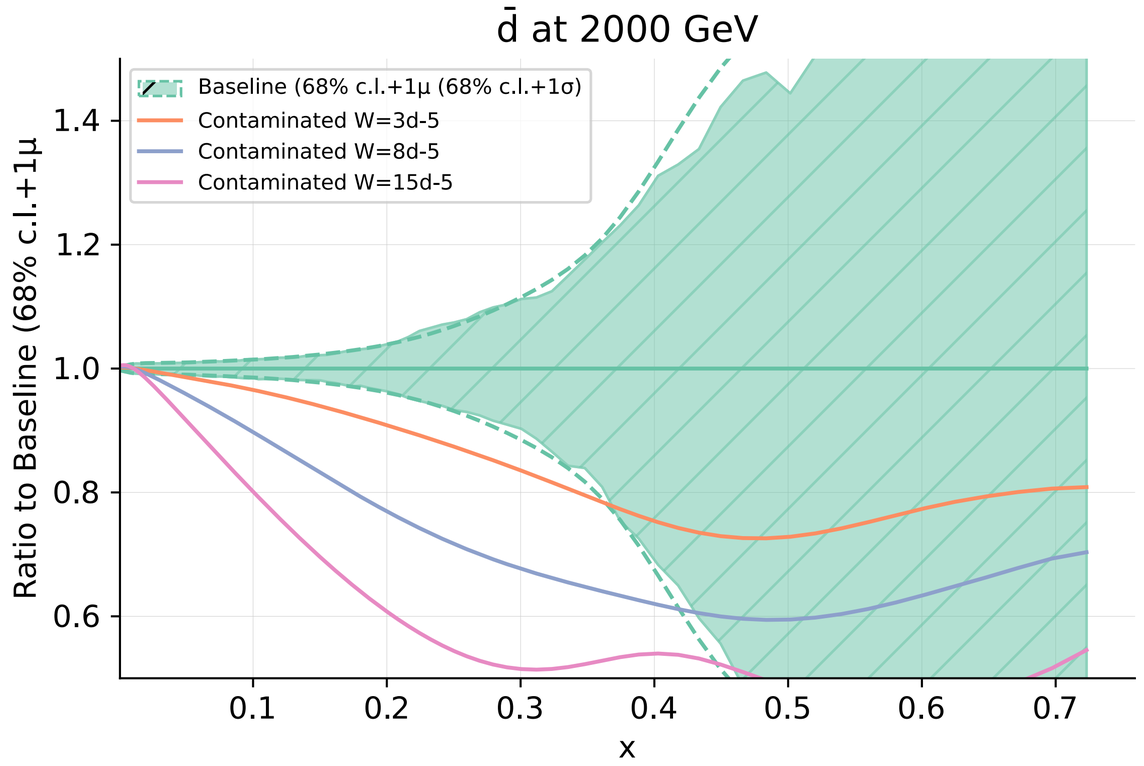


constraints miss the truth by $> 2\sigma$

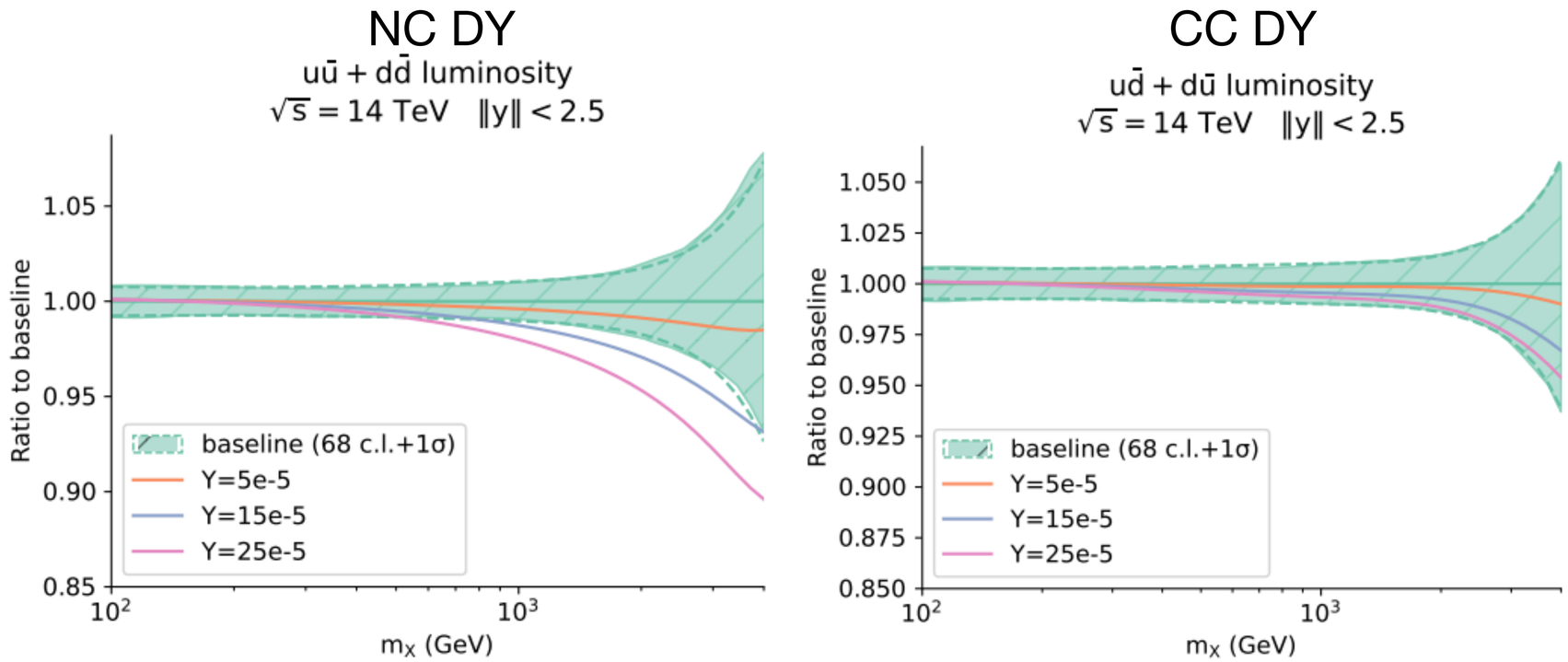
W’-contaminated PDFs





Z’-contaminated PDFs

Data: ‘true’ PDF ⊗ SM + Z’
Theory: contaminated PDF ⊗ SM



Charged current DY is not impacted by the Z’ model

➡ CC DY data constrains the large-x quark and antiquark PDFs to be SM-like

➡ PDFs cannot shift enough to absorb NP effects in neutral current DY

Z’-contaminated PDFs

Data: ‘true’ PDF ⊗ SM + Z’
Theory: contaminated PDF ⊗ SM