Tailored PDFs for new physics searches

2602.20235

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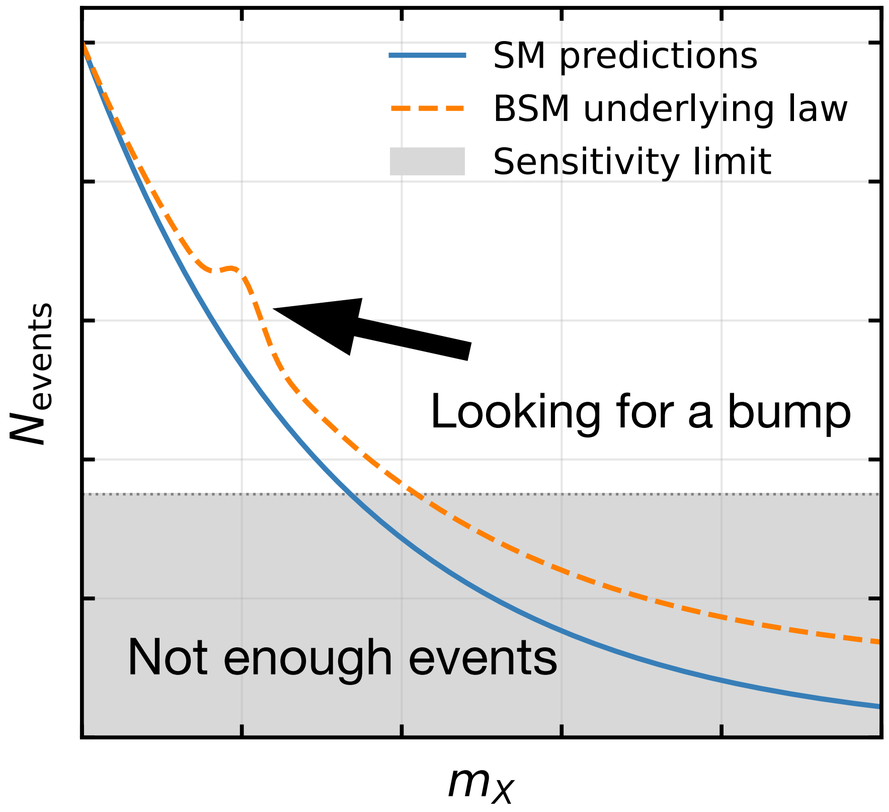
SM@LHC, Torino, Apr 2026

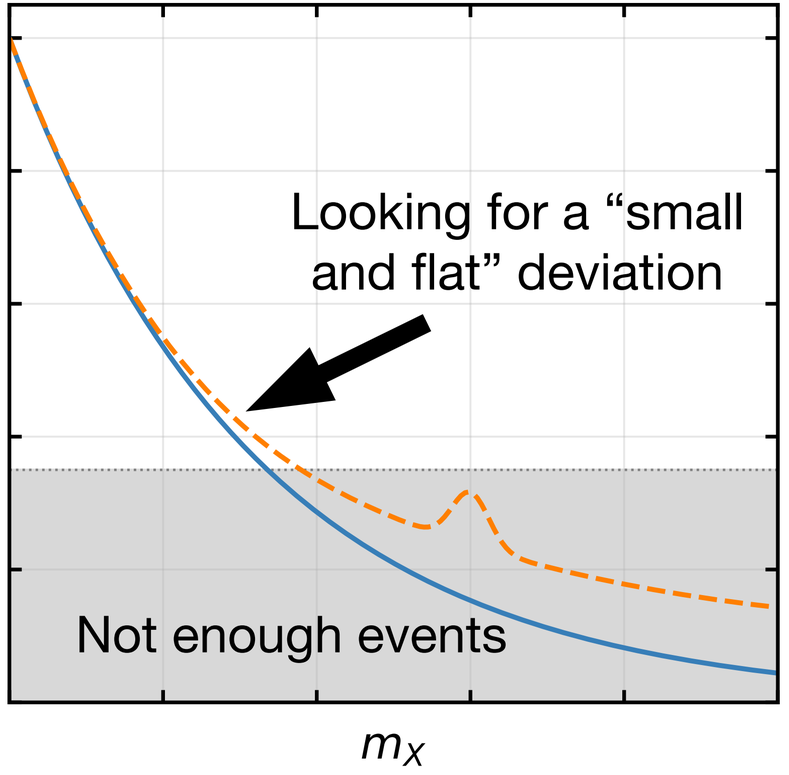
New physics searches

Direct versus indirect searches

Direct searches



Indirect searches

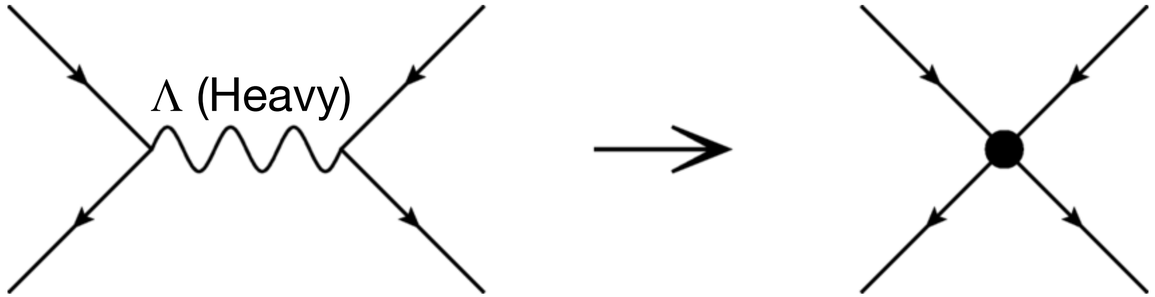


Indirect searches and Effective Field Theories

The Standard Model EFT (SMEFT)

Integrate heavy fields out:

UV Model



EFT Model

[10.1007/s10773-021-04723-1]

Obtain model independent Lagrangian:

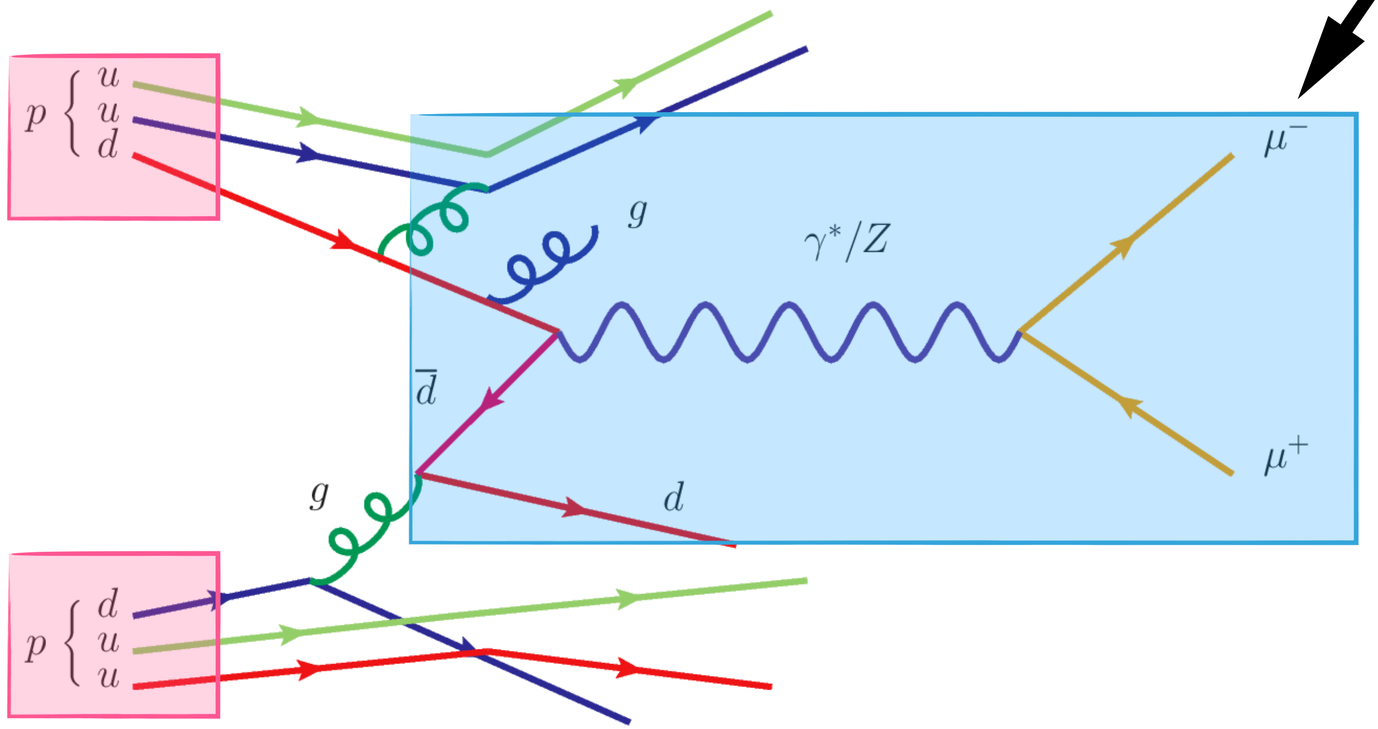
$$\mathscr{L}^{\text{UV}} = \mathscr{L}^{\text{SM}} + \mathscr{L}^{\text{Heavy}} \longrightarrow \mathscr{L}^{\text{SMEFT}} = \mathscr{L}^{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \dots$$

- Dim 6 EFT operators with SM fields: $\mathcal{O}_i^{(6)}$
- Wilson coefficients fittable from data: $\frac{c_i}{\Lambda^2}$

Hadron colliders and PDFs

Collinear factorization theorem

SMEFT corrections



Parton Distribution Functions

Hard Scattering: Perturbative QCD + EW

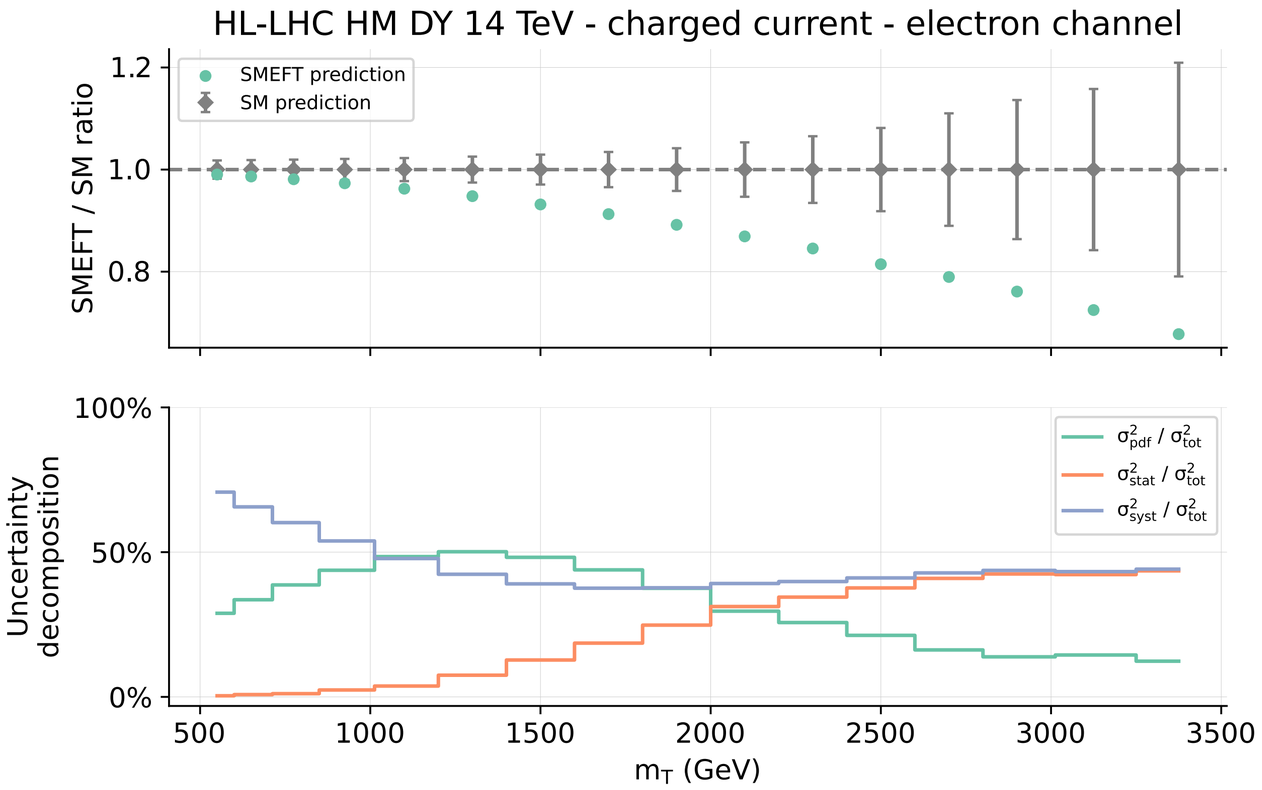
$$d\sigma^{pp\to ab} = \sum_{i,j} f_i \otimes f_j \otimes d\hat{\sigma}^{ij\to ab} + \ldots$$

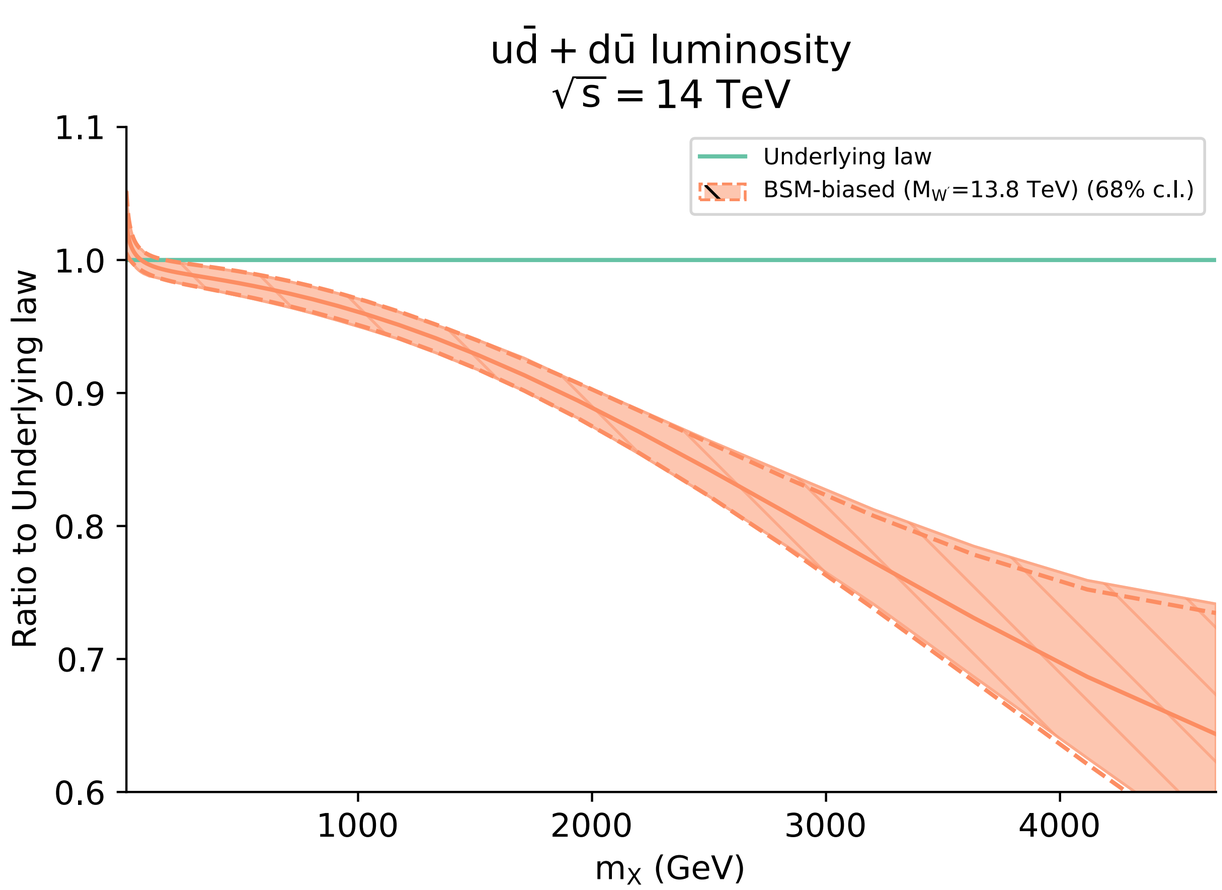
SMEFT-PDF degeneracy in HL-HMDY

PDFs can absorb/mimic the SMEFT effects

2307.10370

Charged current HMDY



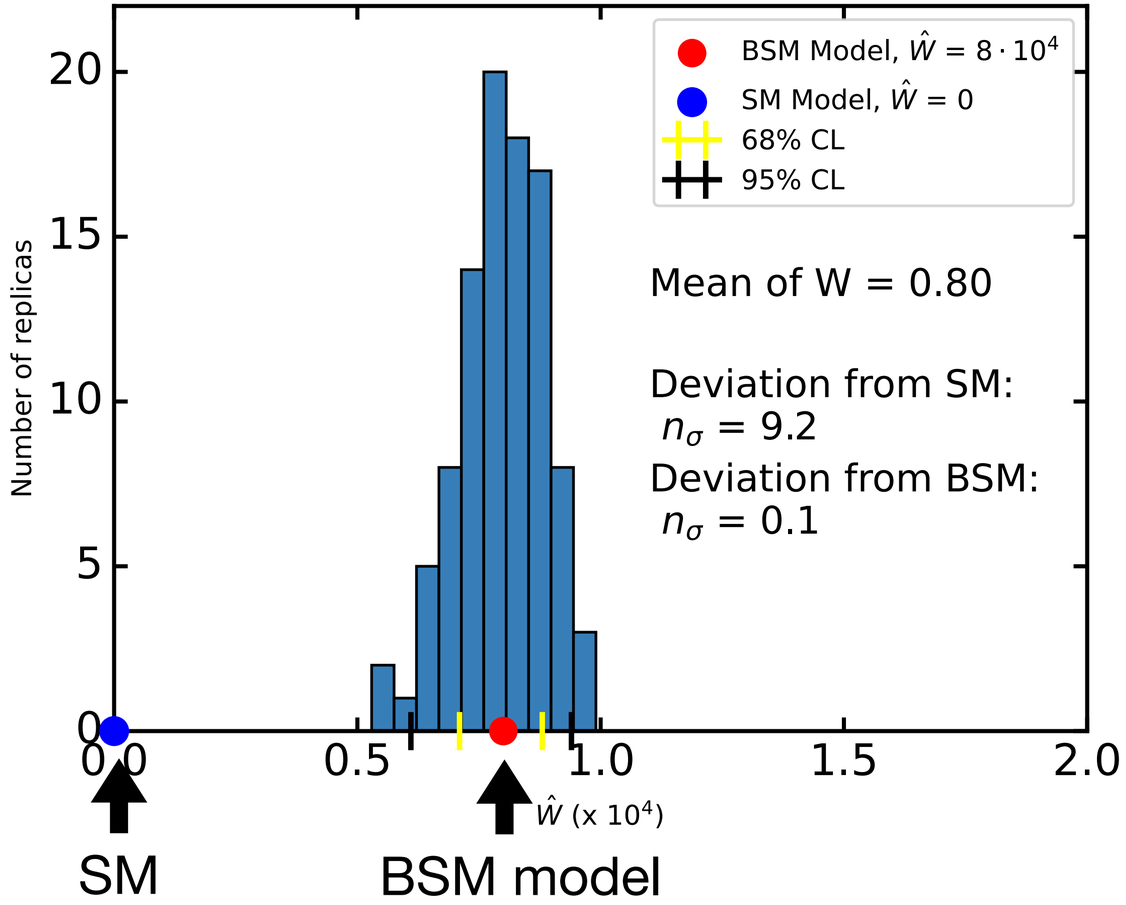


$$\mathscr{L}_{true} \otimes \hat{\sigma}_{BSM} \approx \mathscr{L}_{BSM-biased} \otimes \hat{\sigma}_{SM}$$

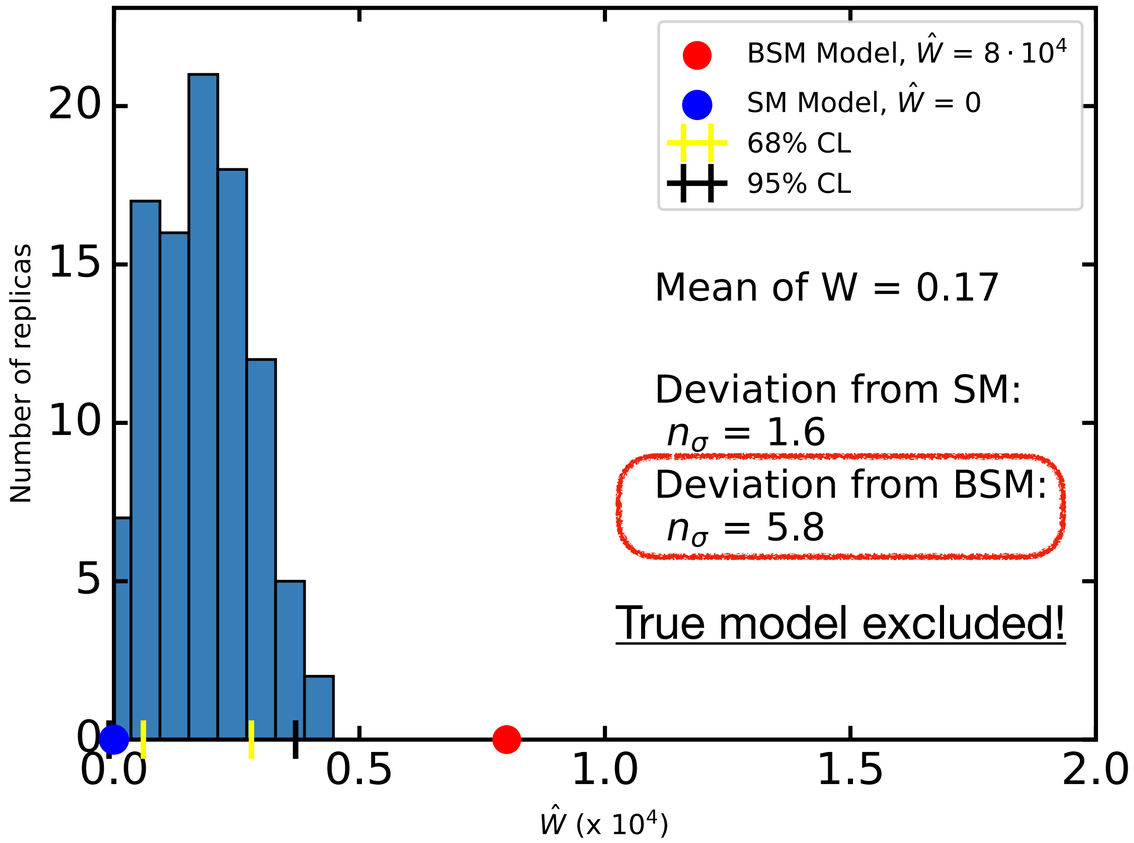
Missing new physics

Impact of the NP absorption in PDFs on SMEFT fits

SMEFT fit with true PDF



SMEFT fit with BSM-biased PDF



How do we fix this?

Separate versus simultaneous fits

Separate fits

PDF fit:

$$T(\{\theta\}, \{c = 0\}) = \text{PDF}(\{\theta\}) \otimes \hat{\sigma}(\{c = 0\})$$

➡ $\bar{\theta}$

Assumes SM: source of bias

SMEFT fit:

$$T(\{\theta = \bar{\theta}\}, \{c\}) = \text{PDF}(\{\theta = \bar{\theta}\}) \otimes \hat{\sigma}(\{c\})$$

➡ $\bar{c}$

Simultaneous fits

$$T(\{\theta\}, \{c\}) = \text{PDF}(\{\theta\}) \otimes \hat{\sigma}(\{c\})$$

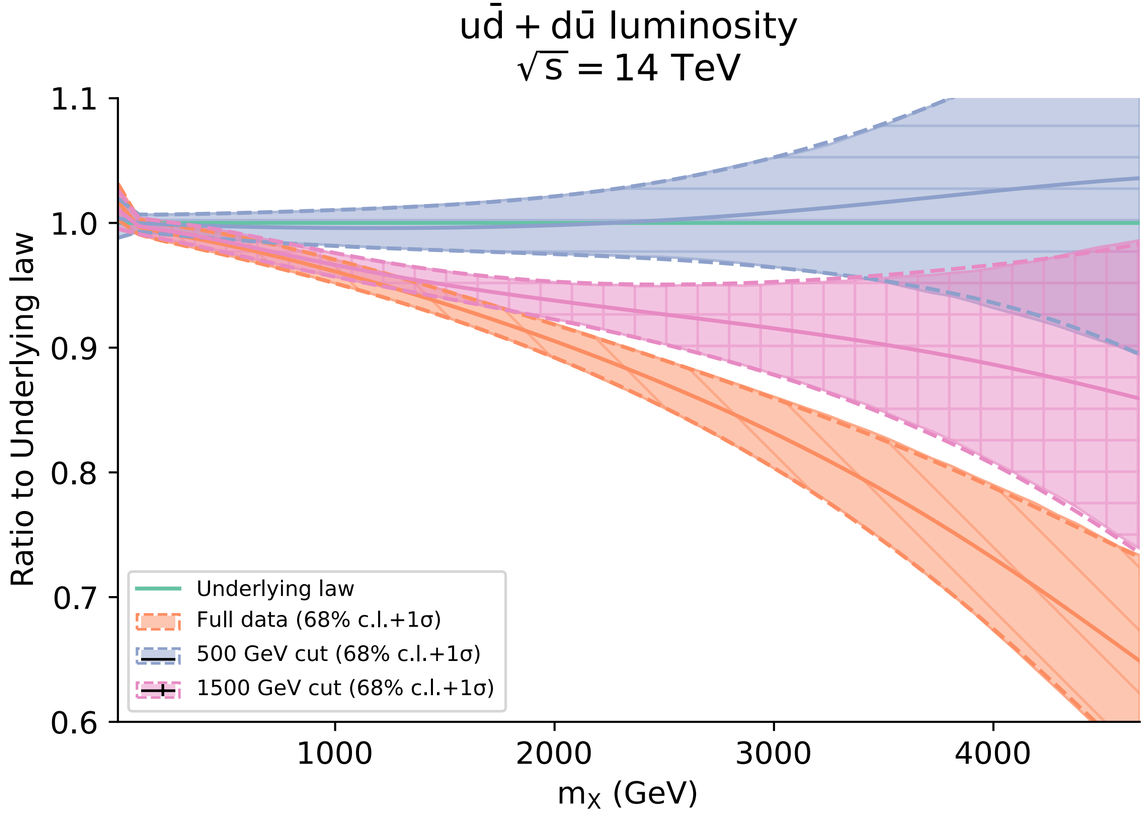
➡ $\{\bar{\theta}, \bar{c}\}$

Removes assumption-based bias

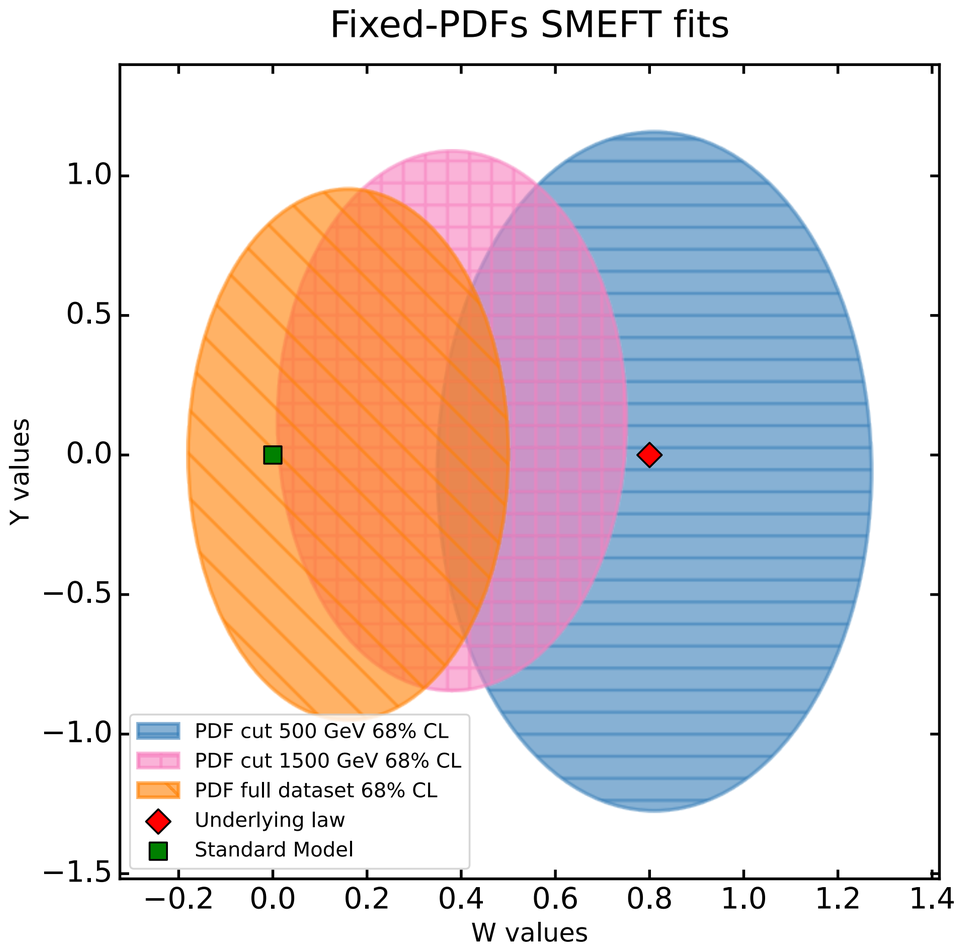
Performing “conservative” separate fits

Implementing varying energy cuts on PDF dataset

PDF luminosity



SMEFT bounds



Simultaneous fit of PDF and SMEFT

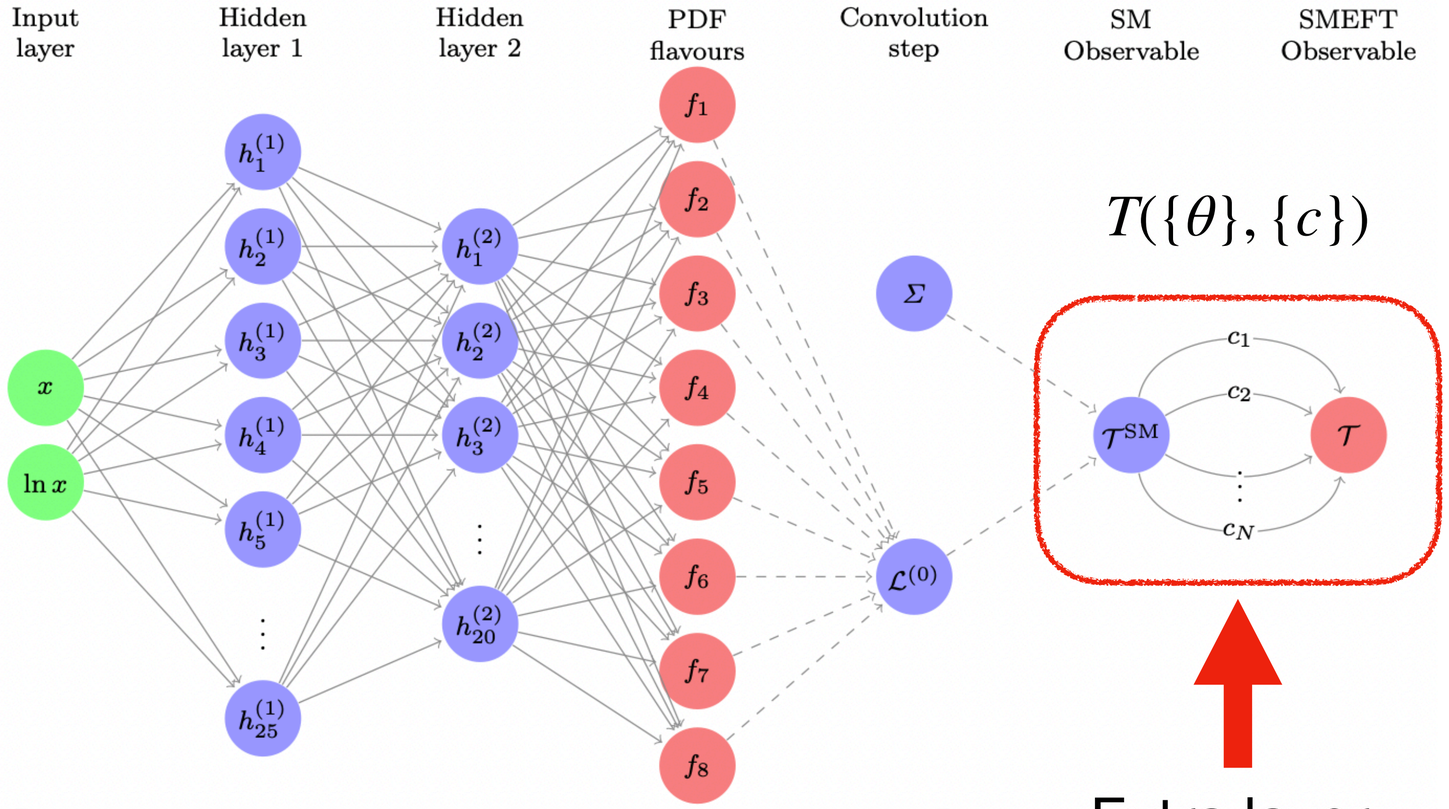
Presentation of the tool: SIMUnet

SIMUnet:

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

  [PBSP, 2402.03308]

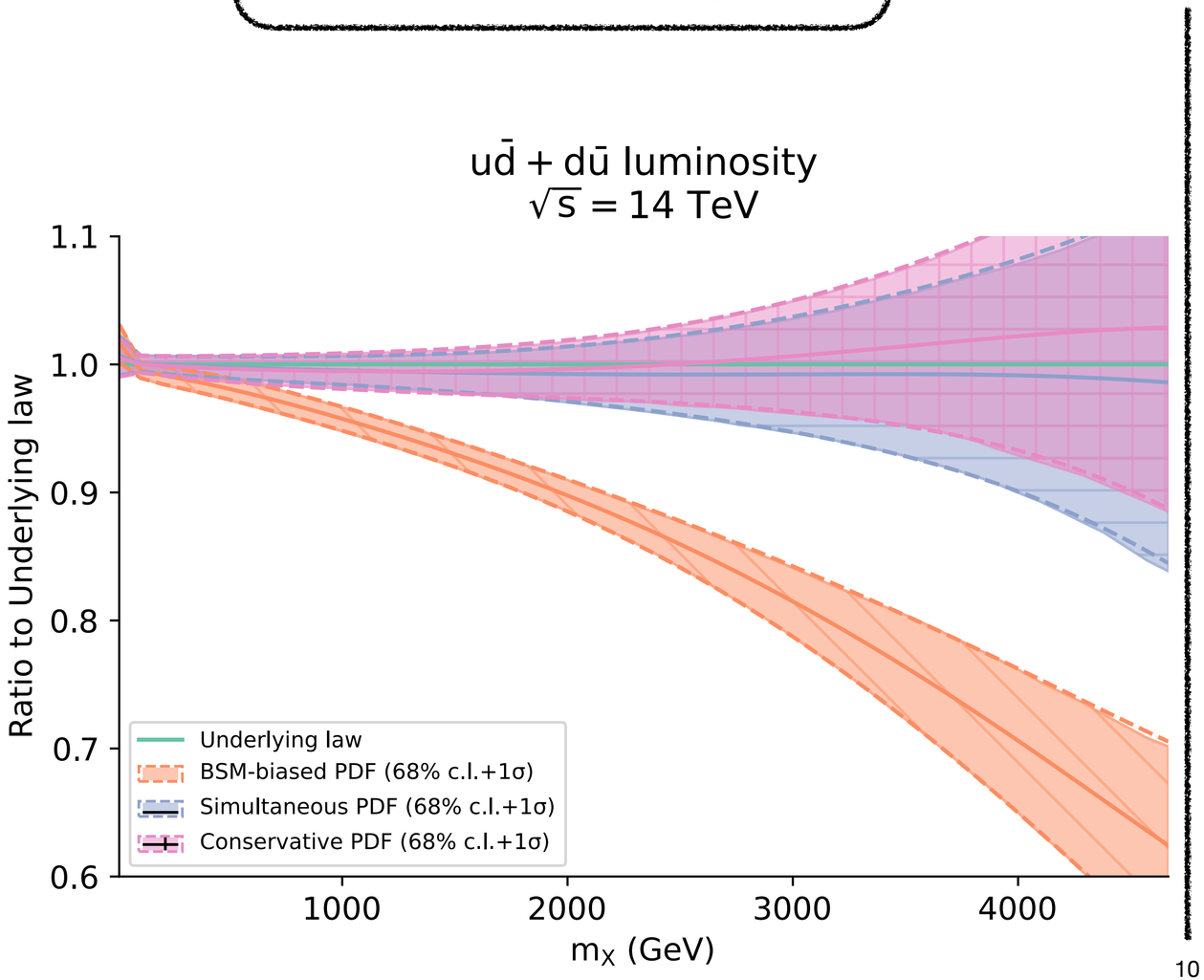
- Fits PDFs and WC simultaneously
- Performs contaminated PDF fits



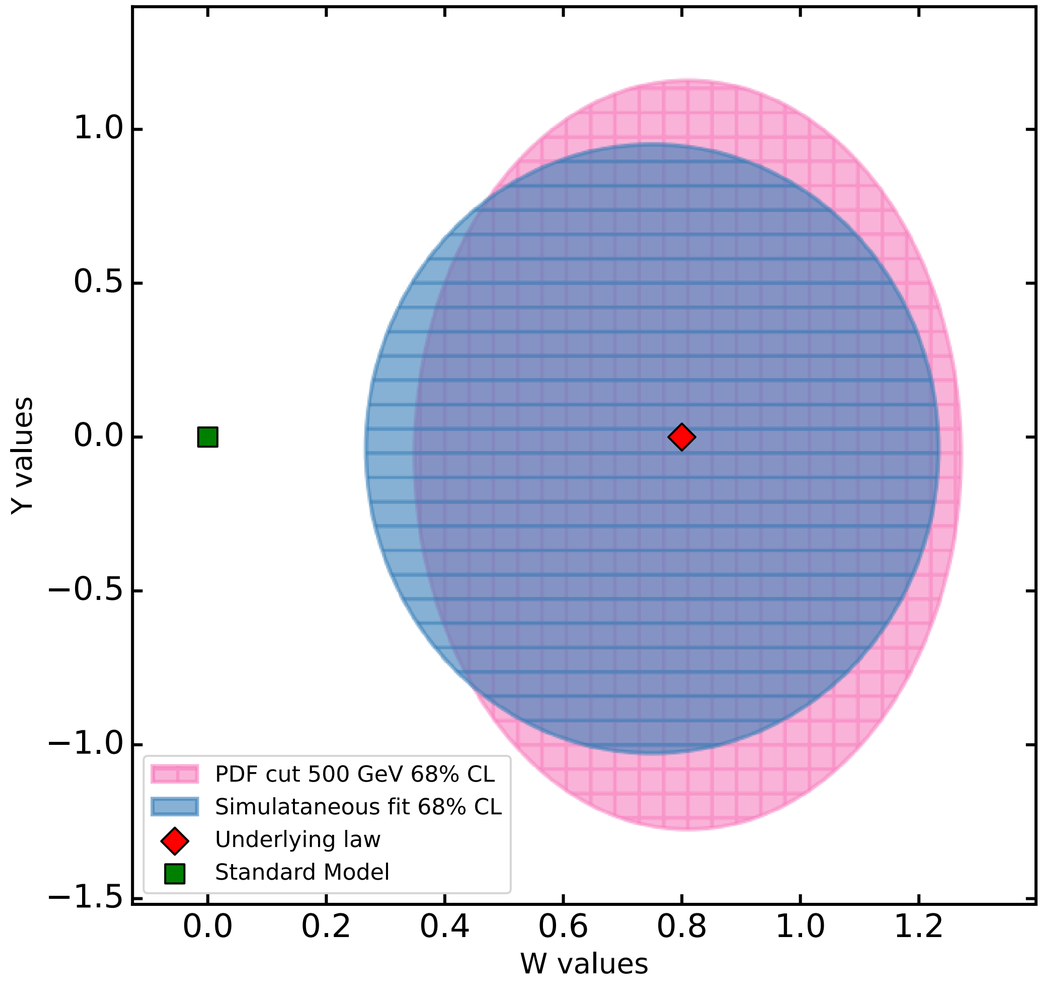
[Iranipour et Ubiali, 2201.07240]

Performing simultaneous fits

PDF luminosity



SMEFT bounds



Comparing conservative and simultaneous fits

Conservative separate fits

Pros:

- Easier
- Less parameters per fit

Cons:

- Difficult to figure out optimal cutoff (manageable)
- **Cannot use precise high-energy observables to constrain PDFs**

Simultaneous fits

Pros:

- Entire dataset constrains PDF and SMEFT
- High-energy observables constrain PDF

Cons:

- More parameters -> more uncertainty (manageable)
- **Risk to absorb SM error as SMEFT signal**

BSM-biased PDF and centre-of-mass

Collinear factorisation

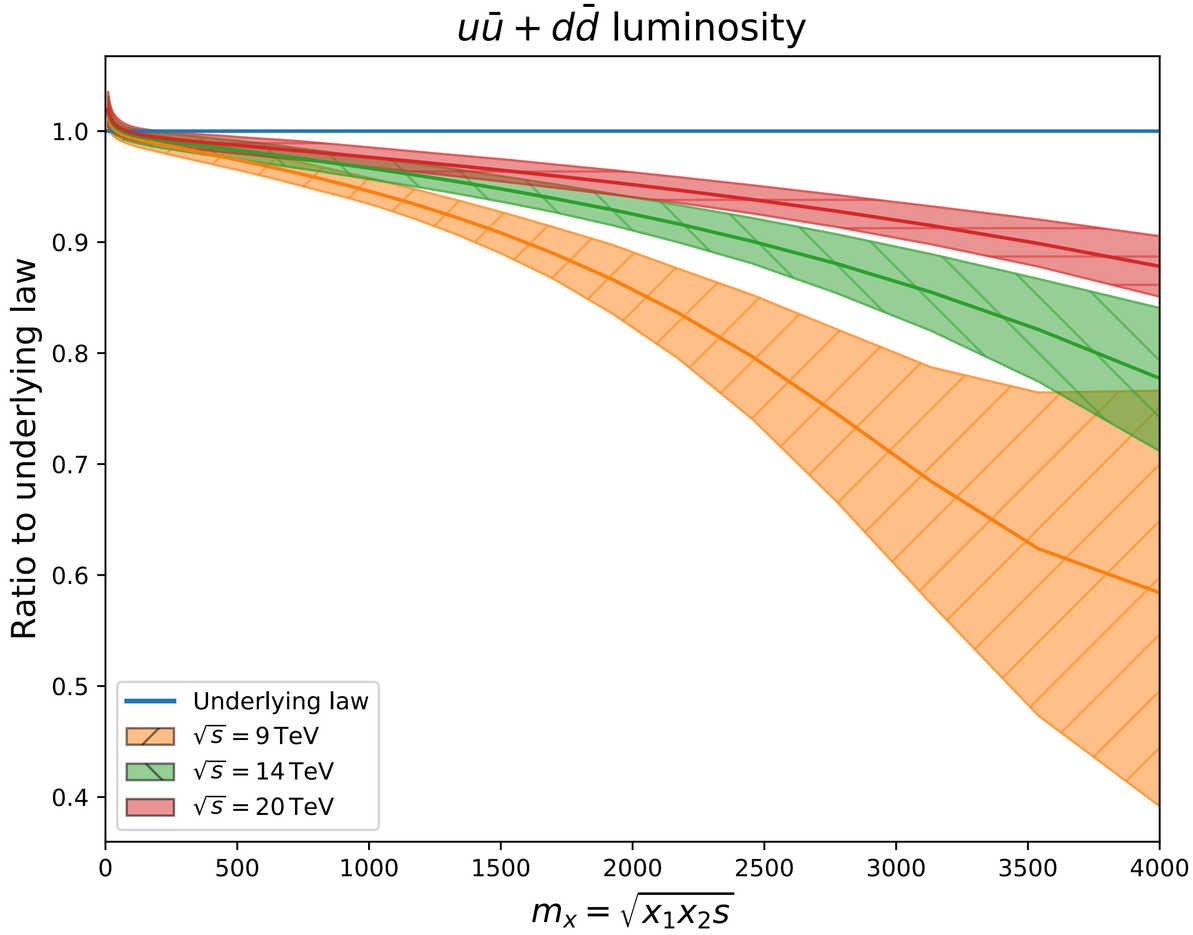
$$\sigma_{\mathrm{pp}\to\mathrm{A}}(M^2) = \sum_{ij} \int dx_1\, dx_2\, f_i^{(1)}(x_1,\mu) f_j^{(2)}(x_2,\mu) \hat{\sigma}_{ij\to A}(M^2,\mu)$$

M and x connected by s

$$M^2 = x_1 x_2 s$$

$s_1 \neq s_2 \Rightarrow$ **M and x misaligned**

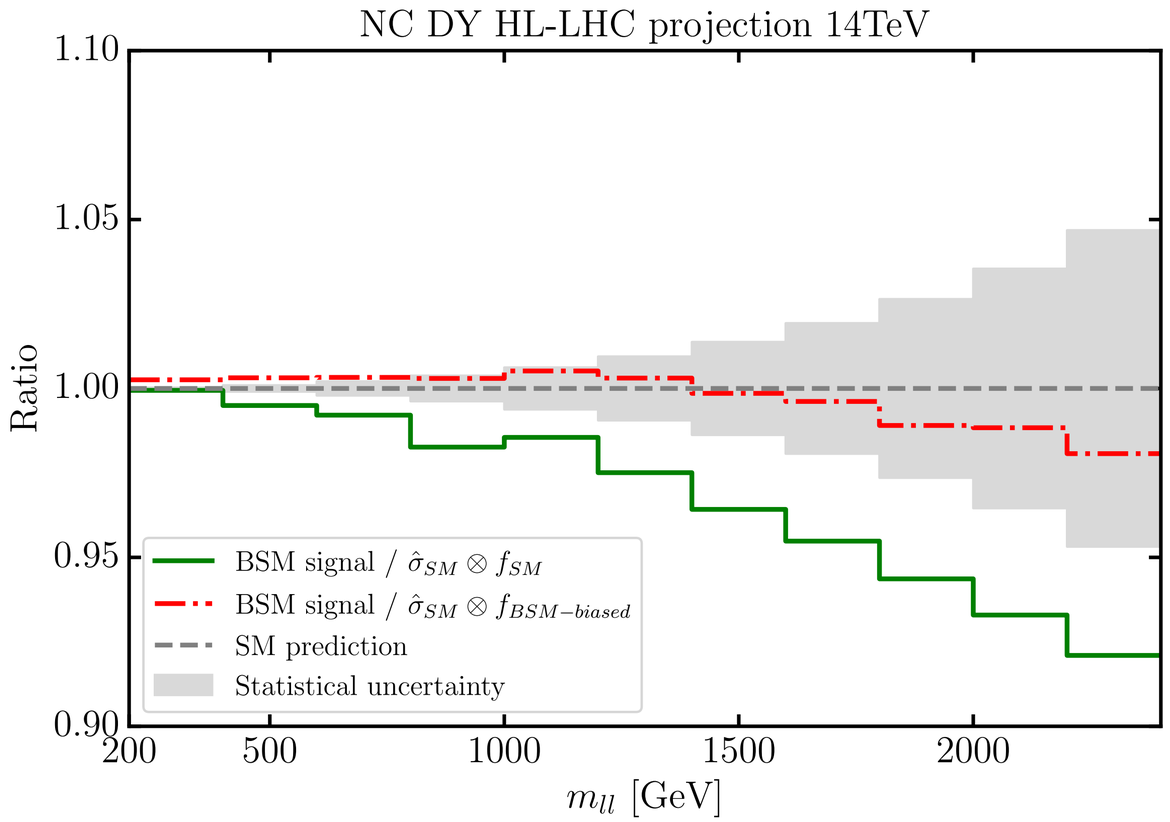
BSM-biased PDF luminosity



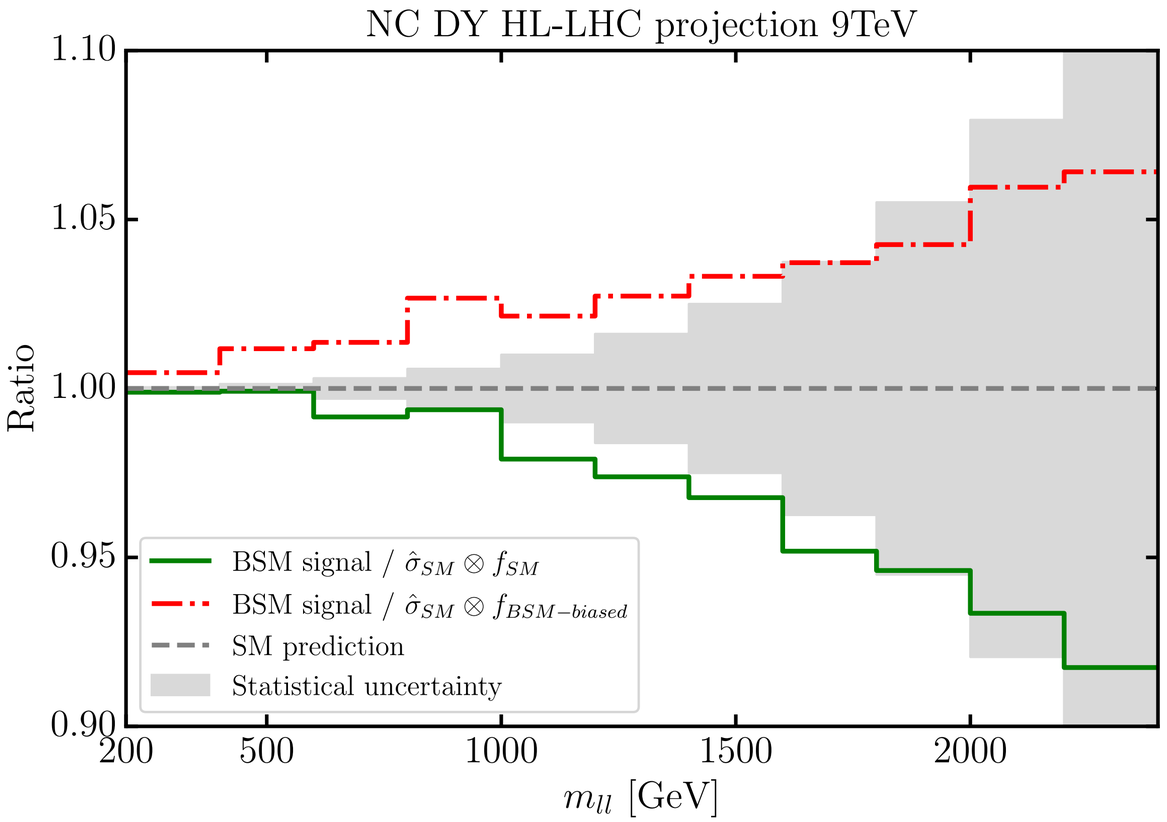
Test observables a different CoM

Breaking degeneracy between x and M_{ll}

Vanilla HL-LHC projection



9TeV HL-LHC projection



Summary and outlook

- Signs of new physics fitted away in PDF
  - Missed new physics
  - Exclude true underlying law
- Possible solutions
  - “Conservative” separate fits
  - Simultaneous fits (SIMUnet)
  - Combination of different centre-of-mass
- Future directions:
  - Real data study in the jet sector [Greljo, Hammou, Merlotti, Smolkovic, Ubiali, forthcoming]
  - Development of a Bayesian framework (Colibri) [Costantini, Moore, Mantani, Schutze, Ubiali, forthcoming (PDF)] [Cole, Hammou, ter Hoeve in progress (SMEFT)]

You can contact me at:
ehammou@nikhef.nl

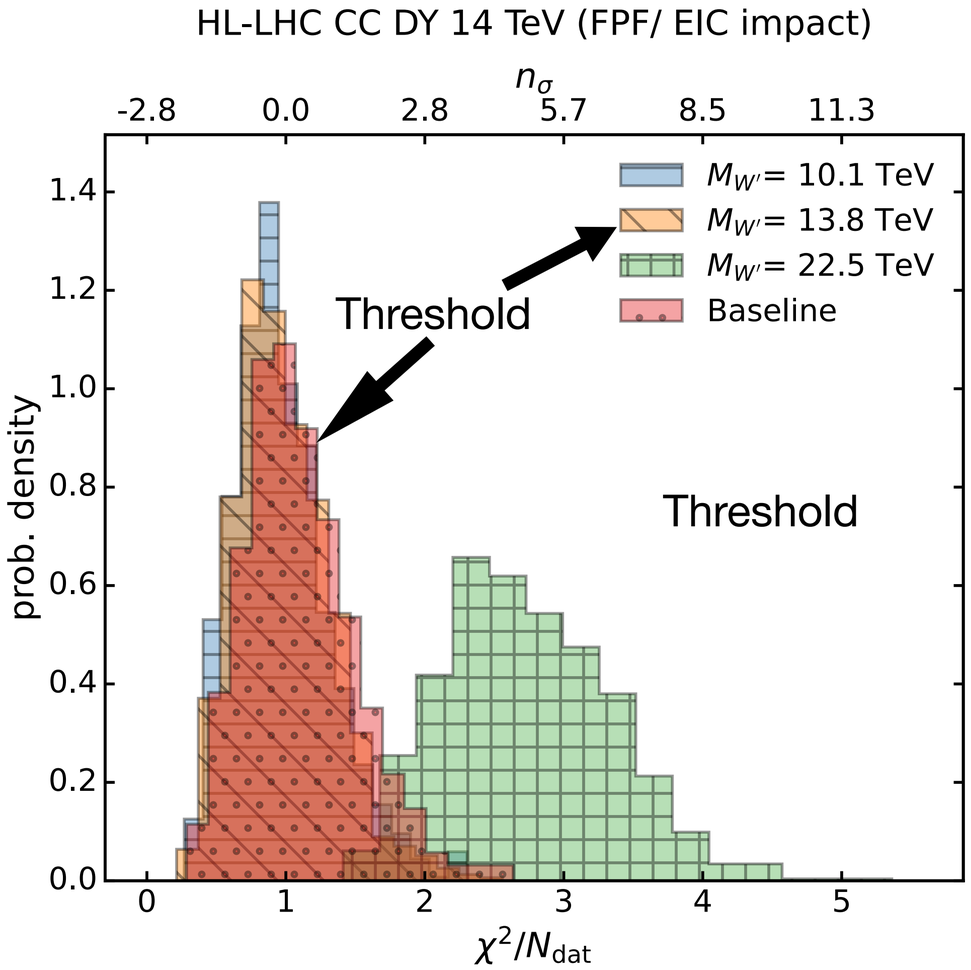
Thank you for your attention!

Extra slides

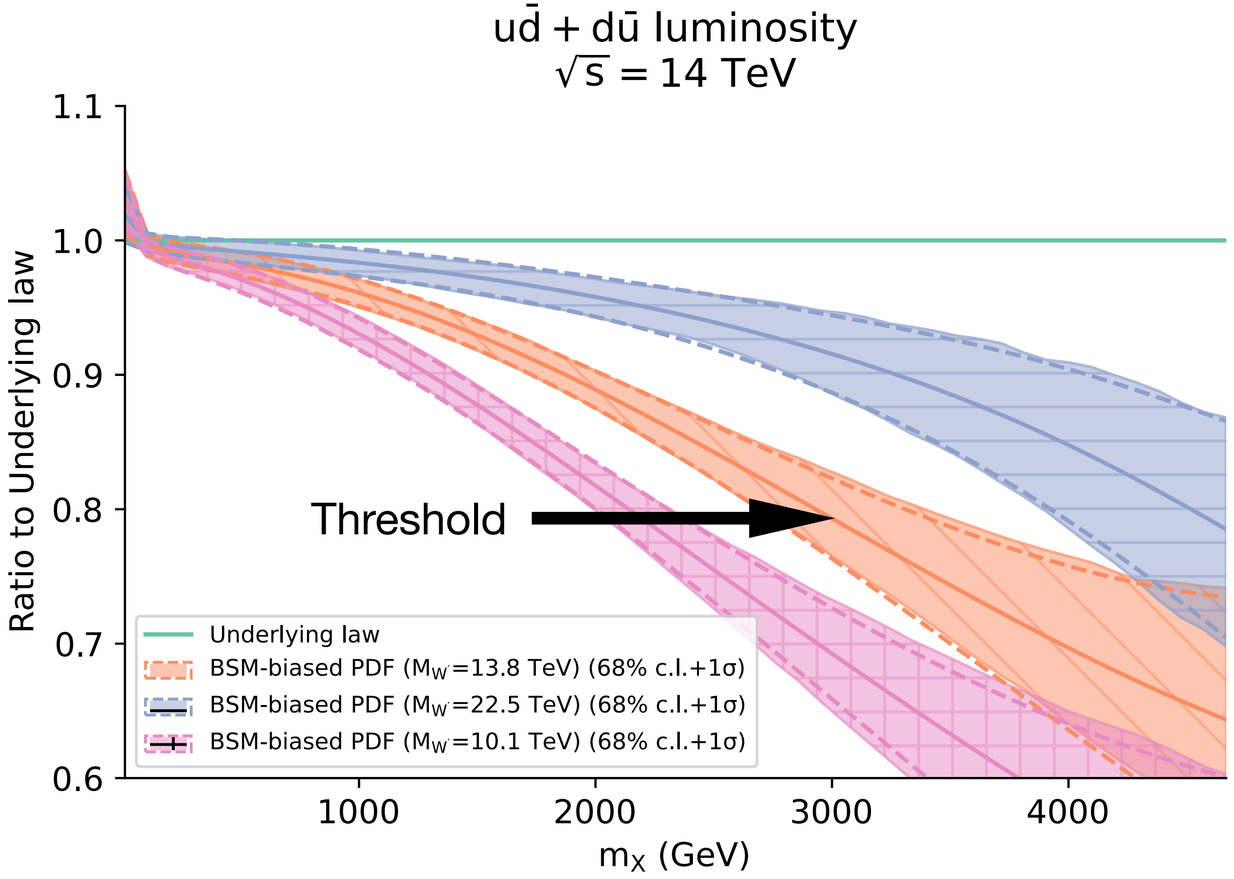
Maximal new physics absorption

Comparison between BSM and baseline fit qualities

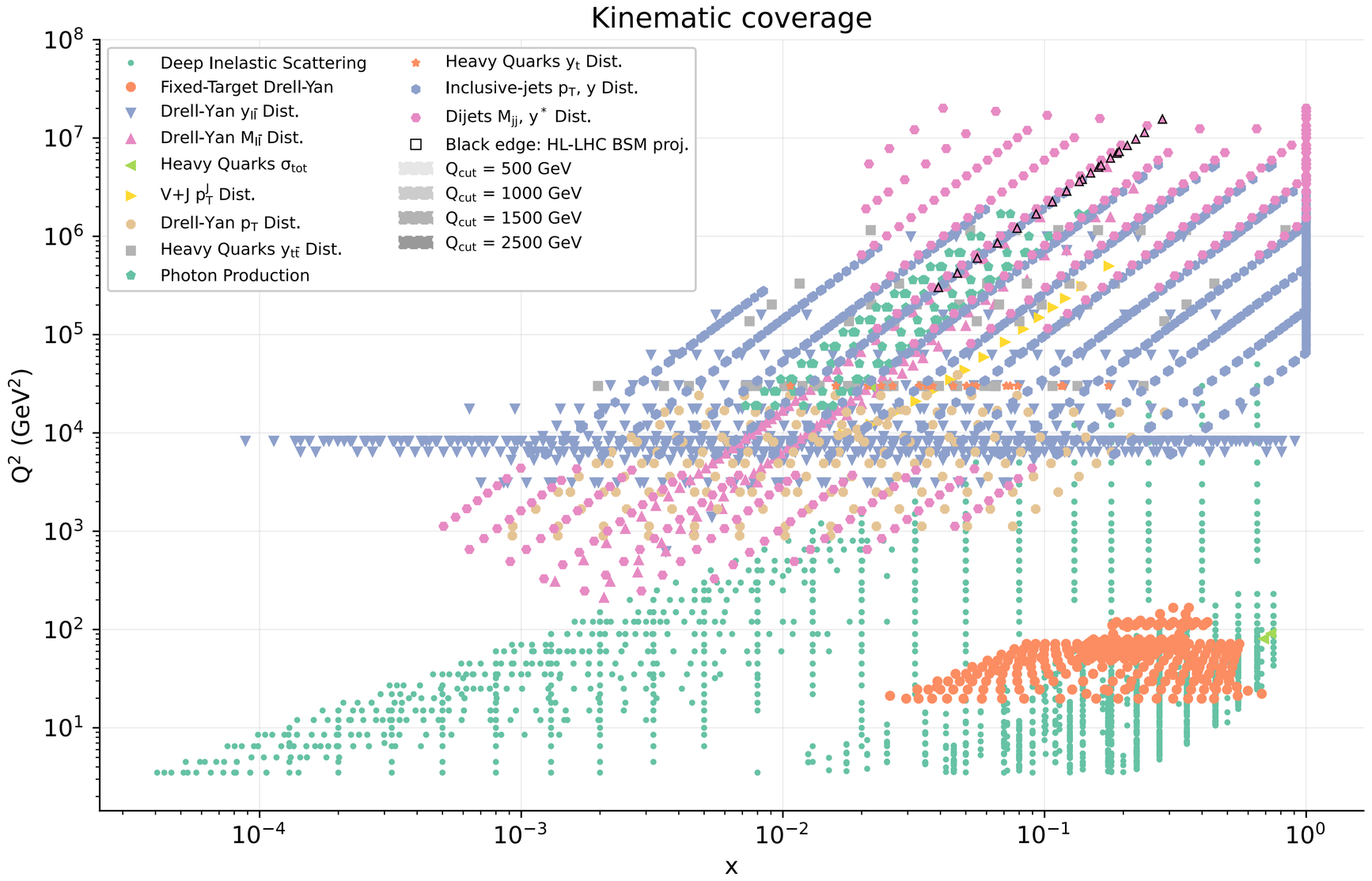
Fit quality



Impact on PDFs



Safe separate fits: “conservative” PDFs



Agnostic energy cuts

Impact of contamination: fake deviations

SM predictions with:

- Contaminated PDFs (red)
- True PDFs (black)

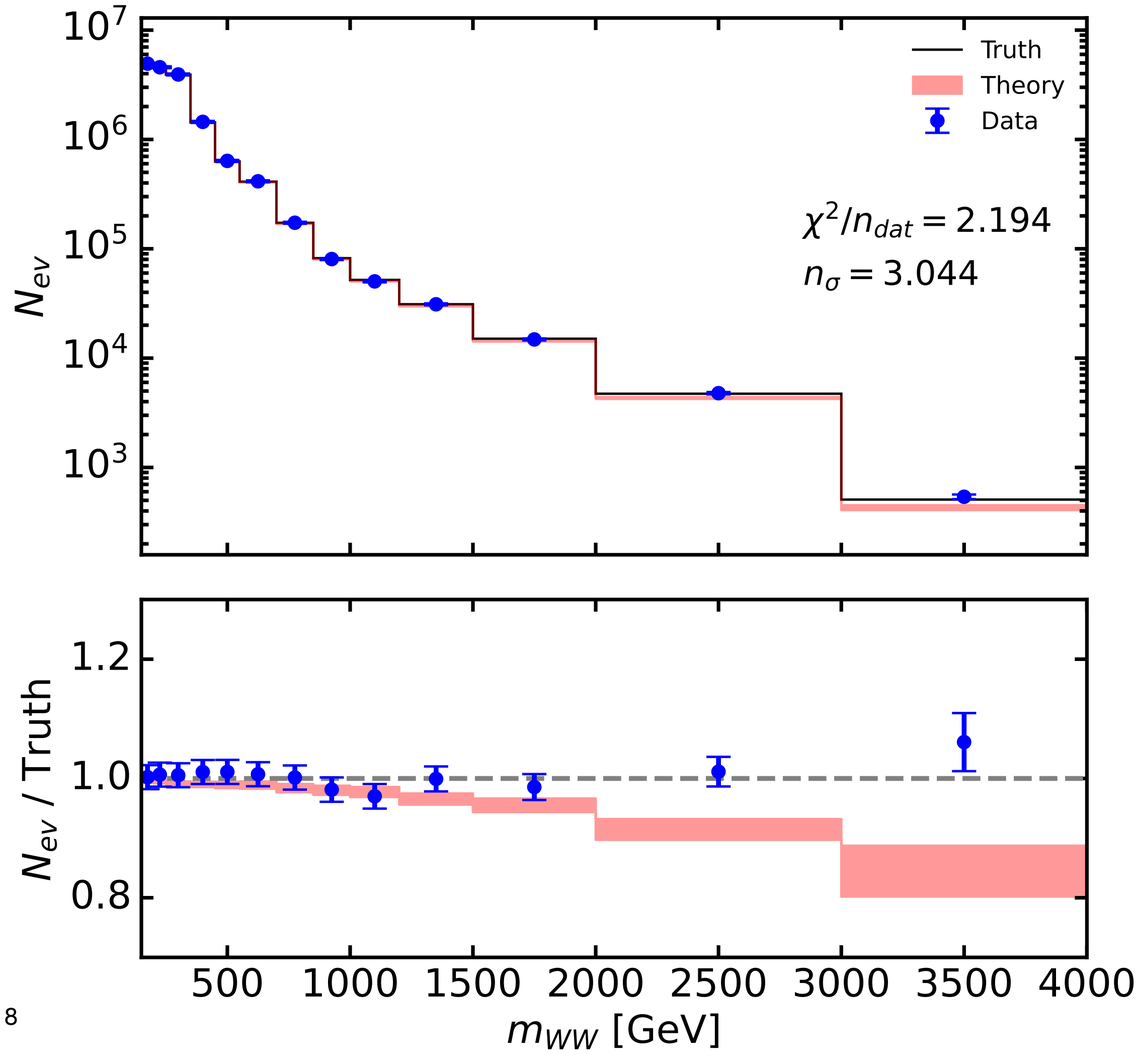
➡ Fake deviation in other sectors

Also seen in:

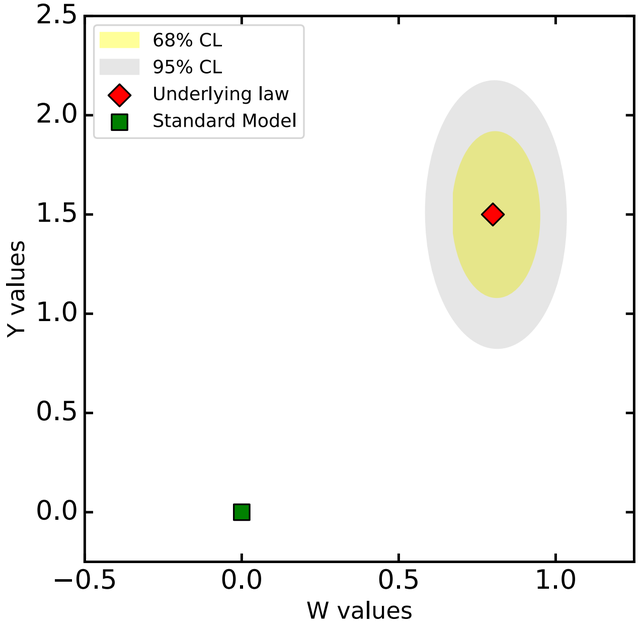
WH, WZ, ZH production

HL-LHC Projections

$pp \to W^+W^-$ (SM)



PDFs for new physics searches in HMDY

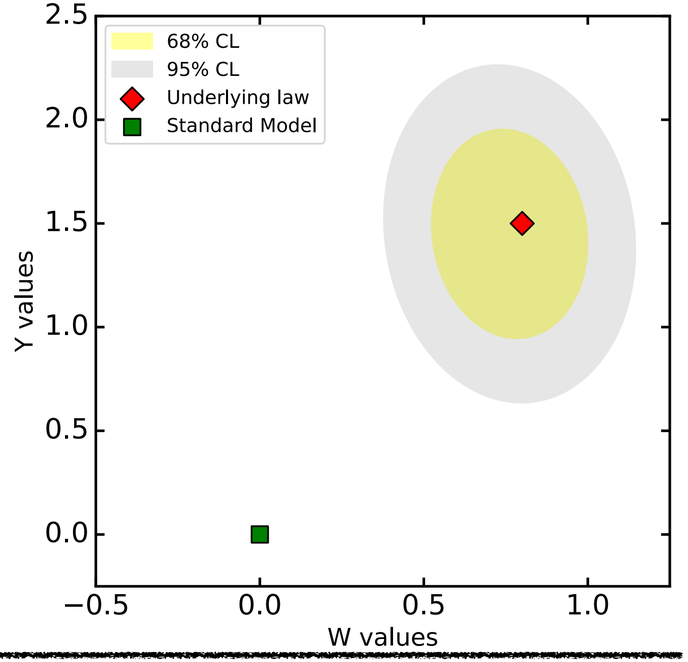


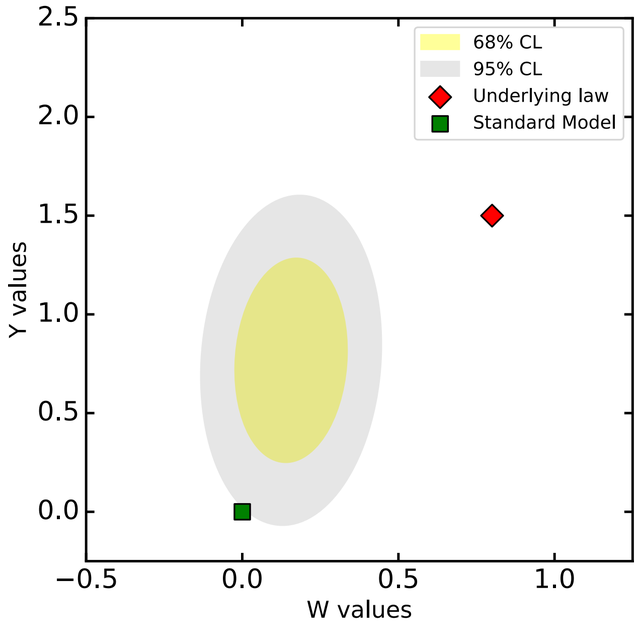
SMEFT only fit
(True PDF)

✗ Impossible

Simultaneous fit
(no PDF assumption)

✓ Doable



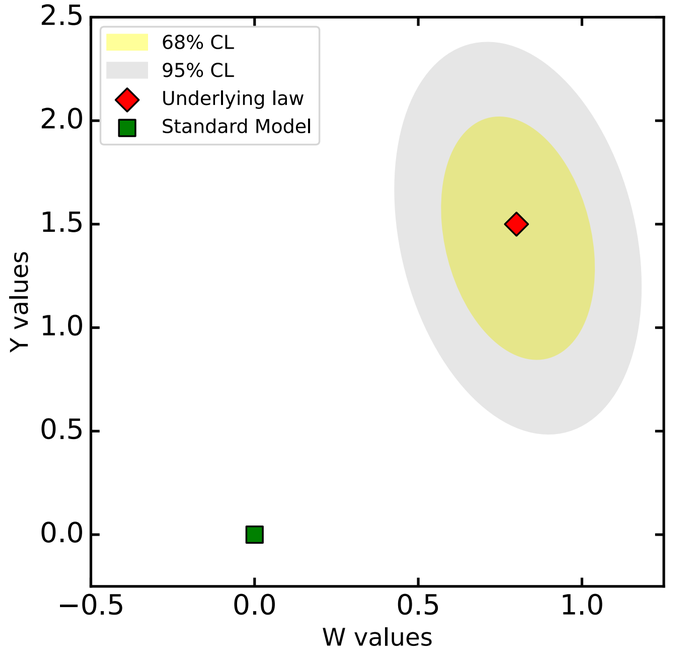


SMEFT only fit
(BSM-biased PDF)

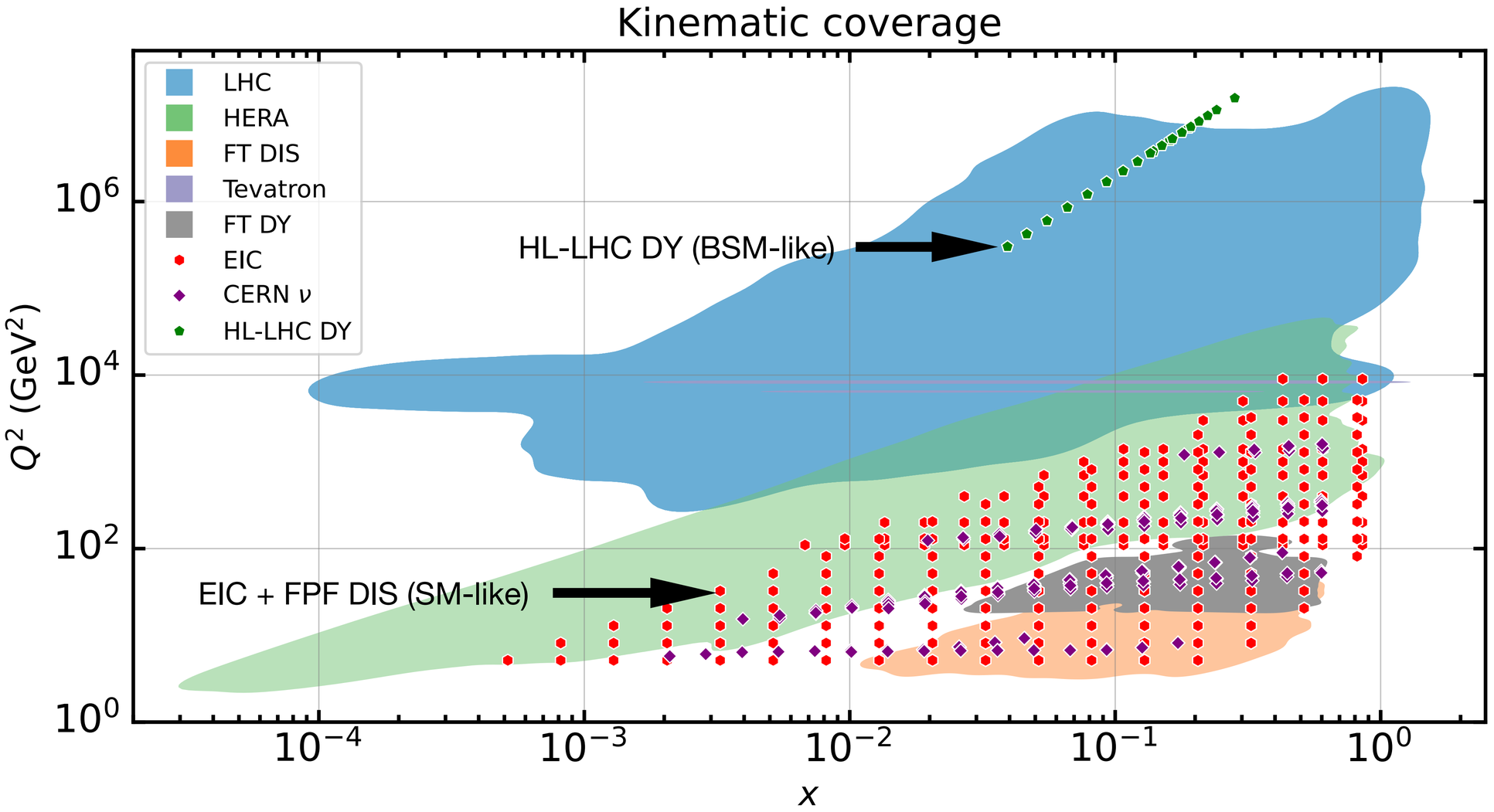
✗ Wrong

SMEFT only fit
(Conservative PDF)

✓ Doable



EIC, FPF and HL-LHC kinematics

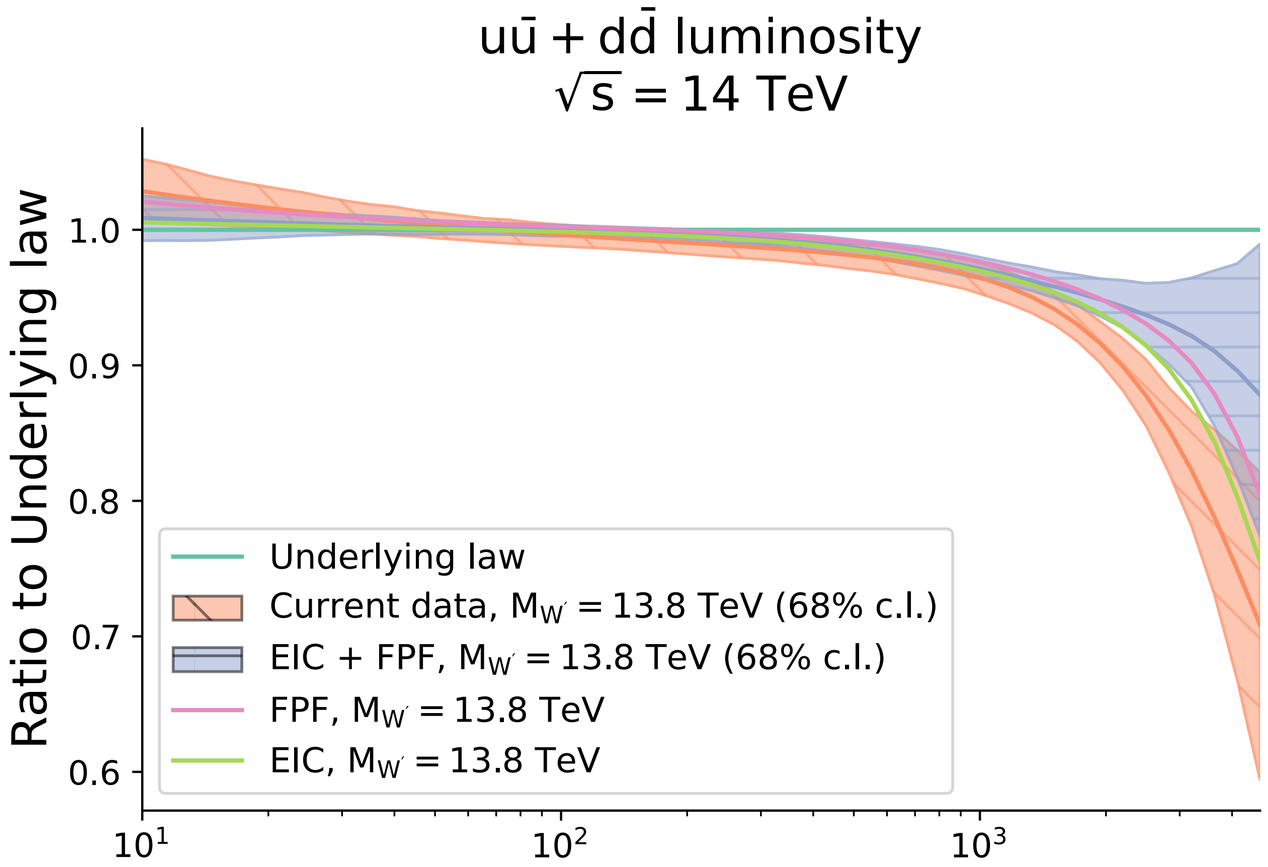


Impact on the PDF contamination

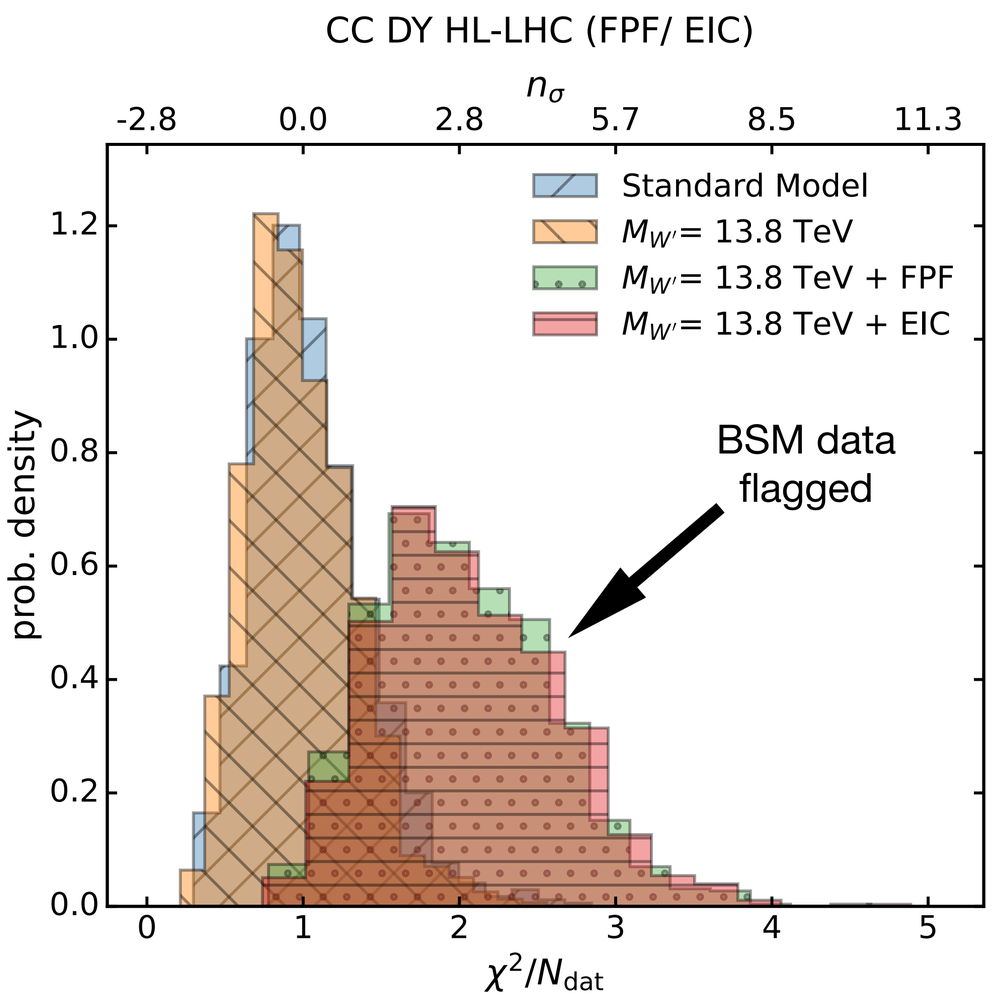
Flagging the BSM data

2410.00963

Pull on PDFs

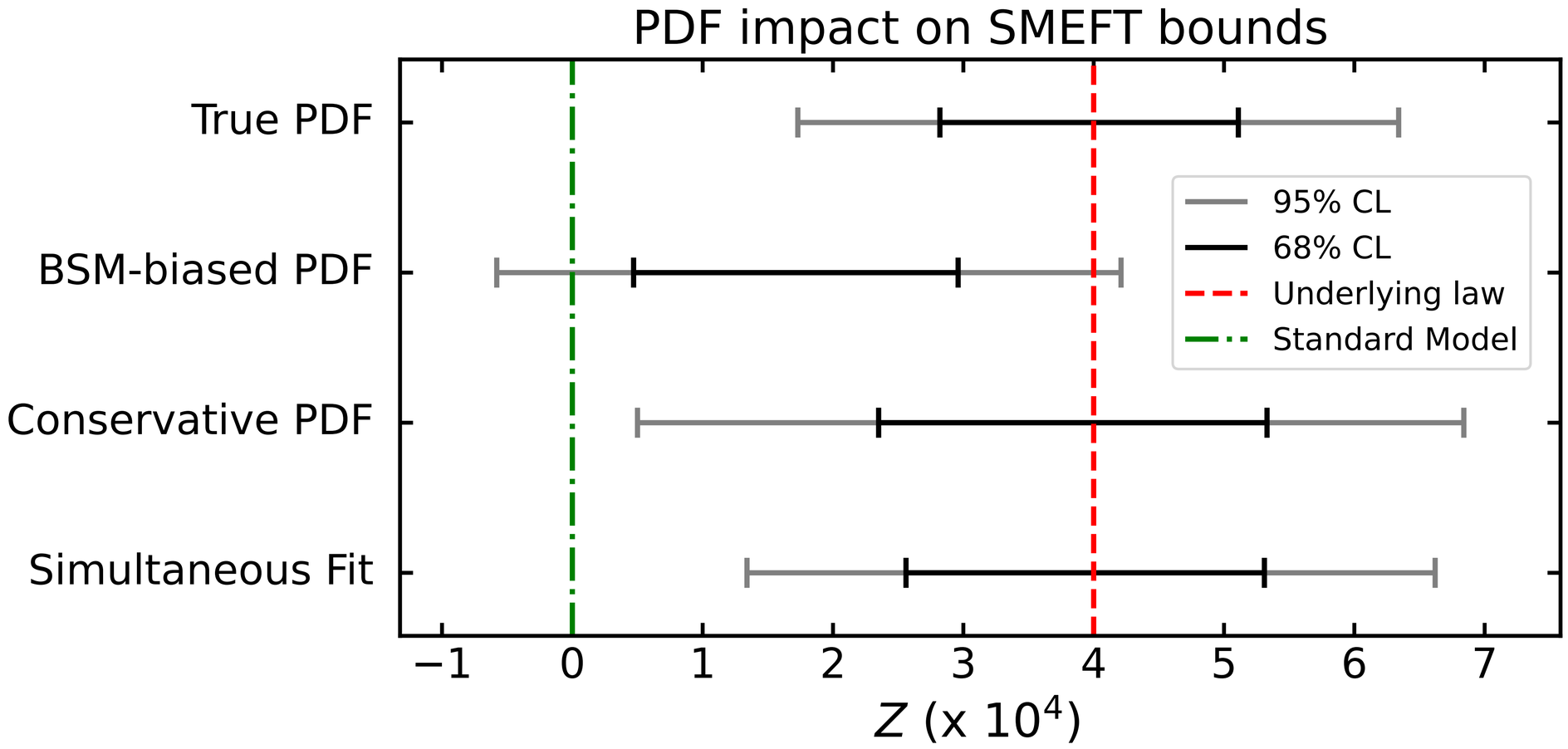


Impact on fit quality



PDFs for new physics searches in $t\bar{t}$

Same exercise with heavy gluon in ttbar at HL-LHC

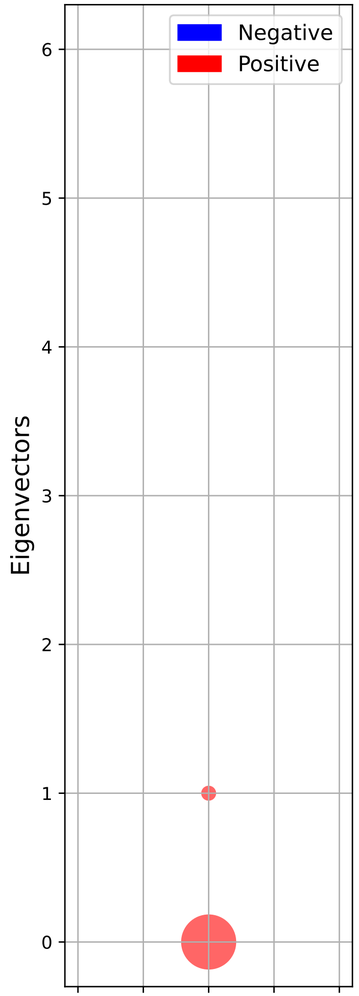


Fit quality comparison DY

Fit	$\hat{W} \times 10^4$	$\hat{Y} \times 10^4$	$\Delta\chi^2$
True PDF	[0.64, 0.98]	[0.99, 2.03]	-
BSM-biased PDF	[-0.08, 0.39]	[0.11, 1.44]	+32 (+48)
Conservative PDF	[0.50, 1.10]	[0.68, 2.22]	-0.1 (+0.0)
Simultaneous fit	[0.44, 1.05]	[0.79, 2.09]	-0.7 (-1.0)

SMEFT PCA results

FIM Eigenvalues



FIM eigenvectors and SMEFT operators