Tailored PDFs for new physics searches

Based on:

- [Hammou et al., 2307.10370, JHEP]
- [Cole et al., forthcoming]

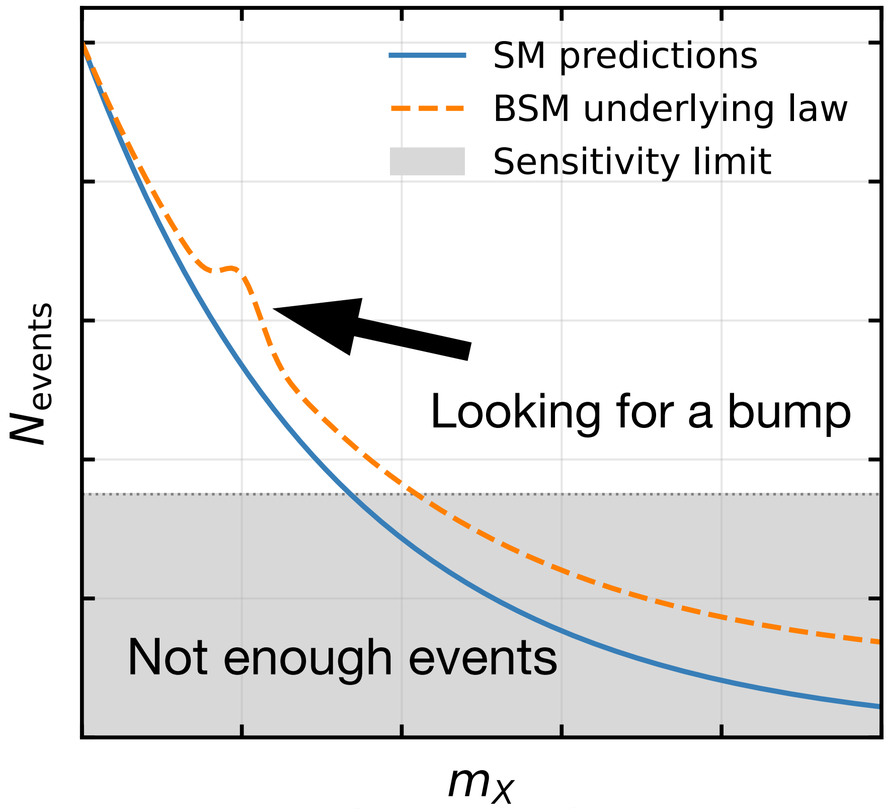
Elie Hammou

NWO Physics, Eindhoven, Jan 2026

New physics searches

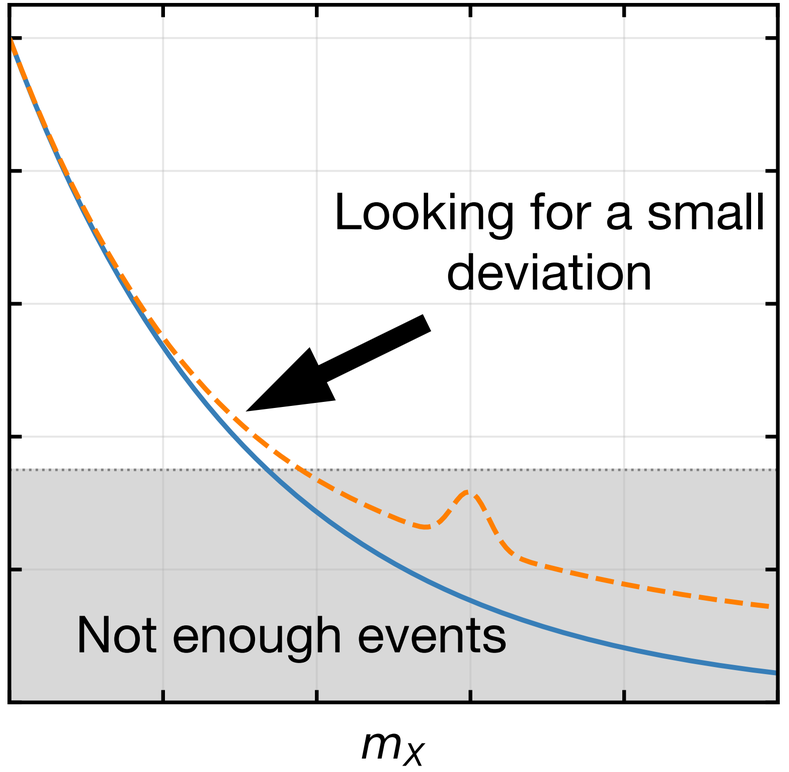
Looking toward higher energy scales and indirect searches

Direct searches



No luck so far…

Indirect searches



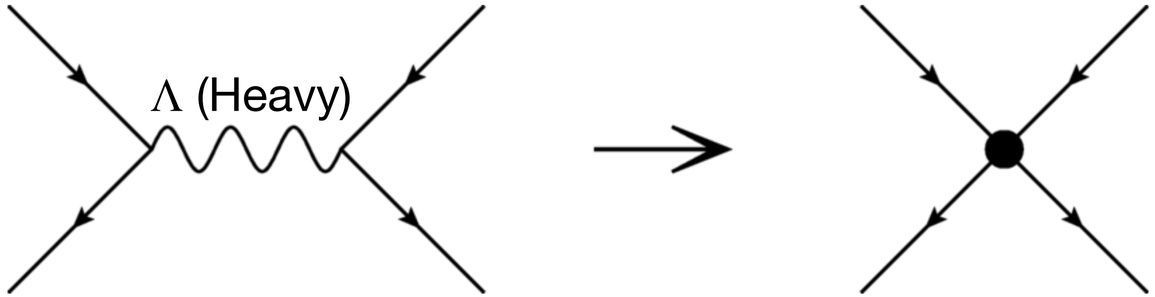
Requires precision

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:

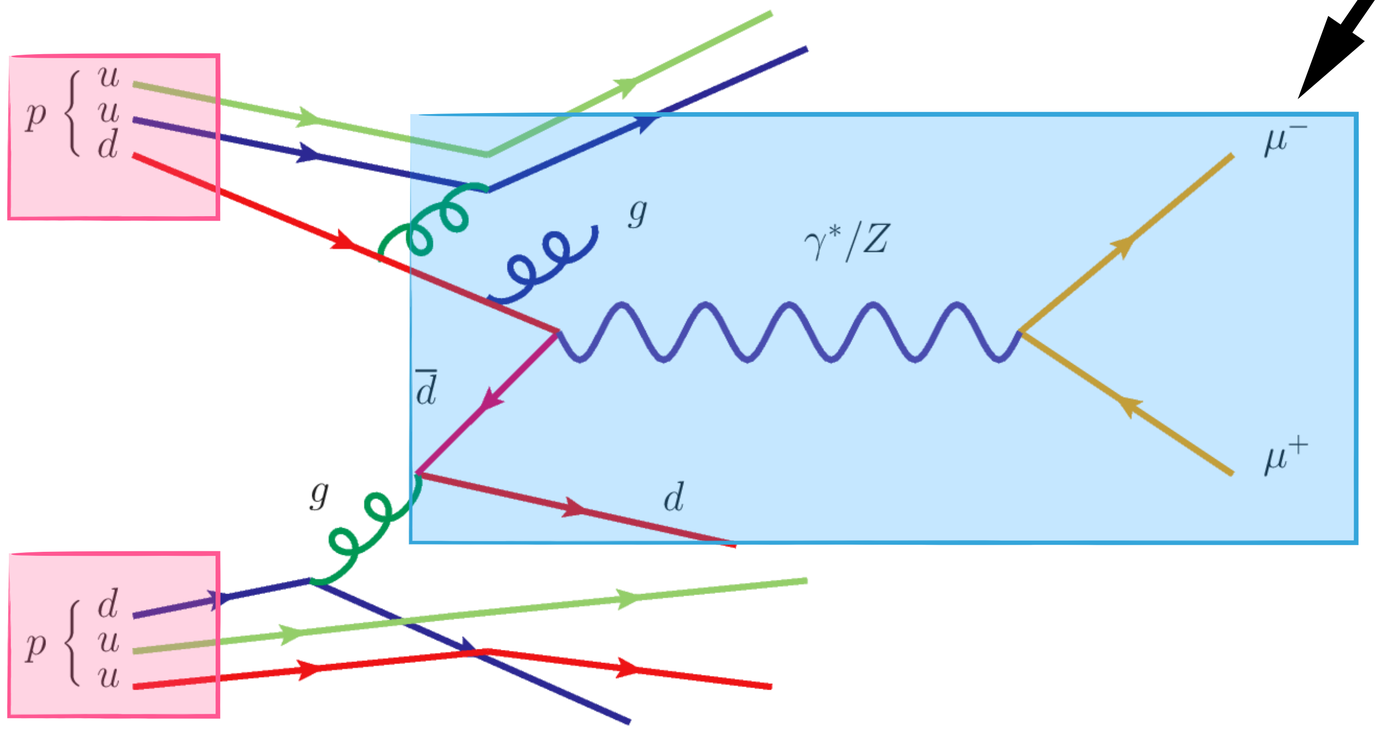
$$\mathscr{L}^{\text{UV}} = \mathscr{L}^{\text{SM}} + \mathscr{L}^{\text{Heavy}} \longrightarrow \mathscr{L}^{\text{SMEFT}} = \mathscr{L}^{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \dots$$

- 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

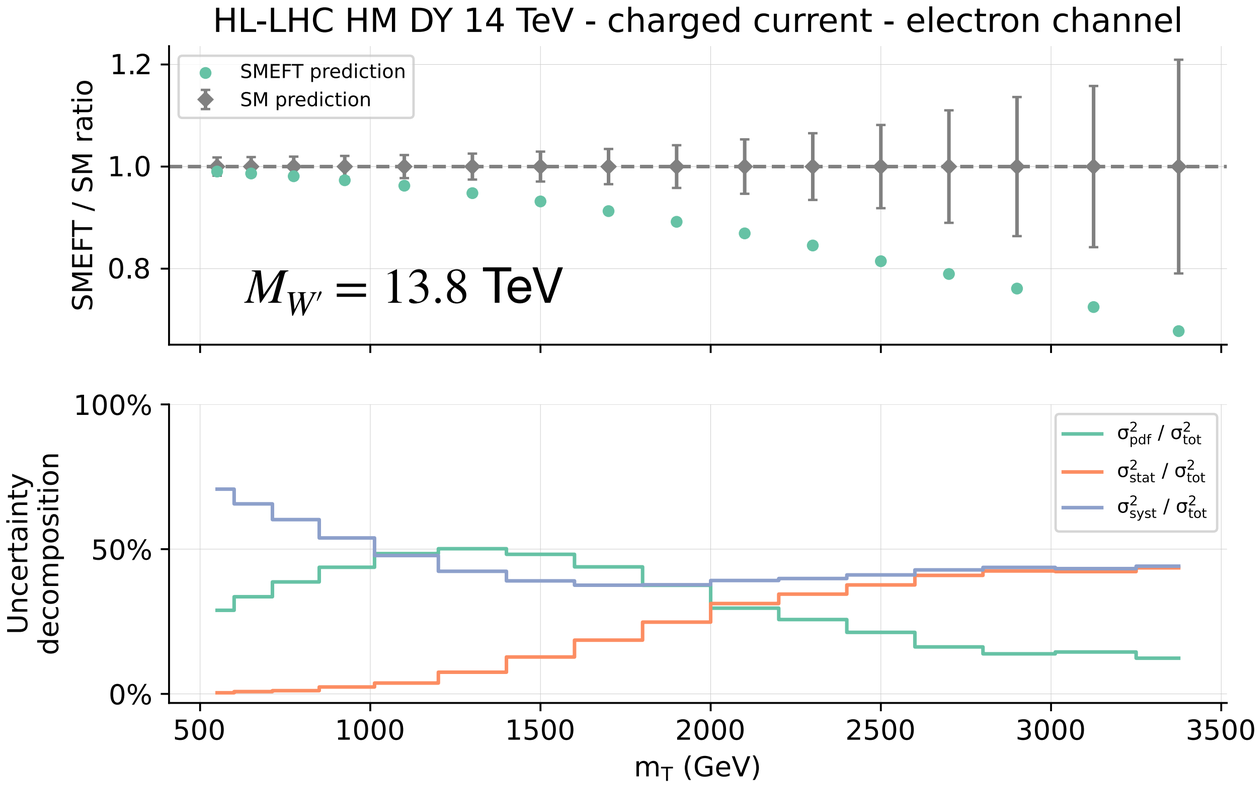
Hard Scattering: Perturbative QCD + EW

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

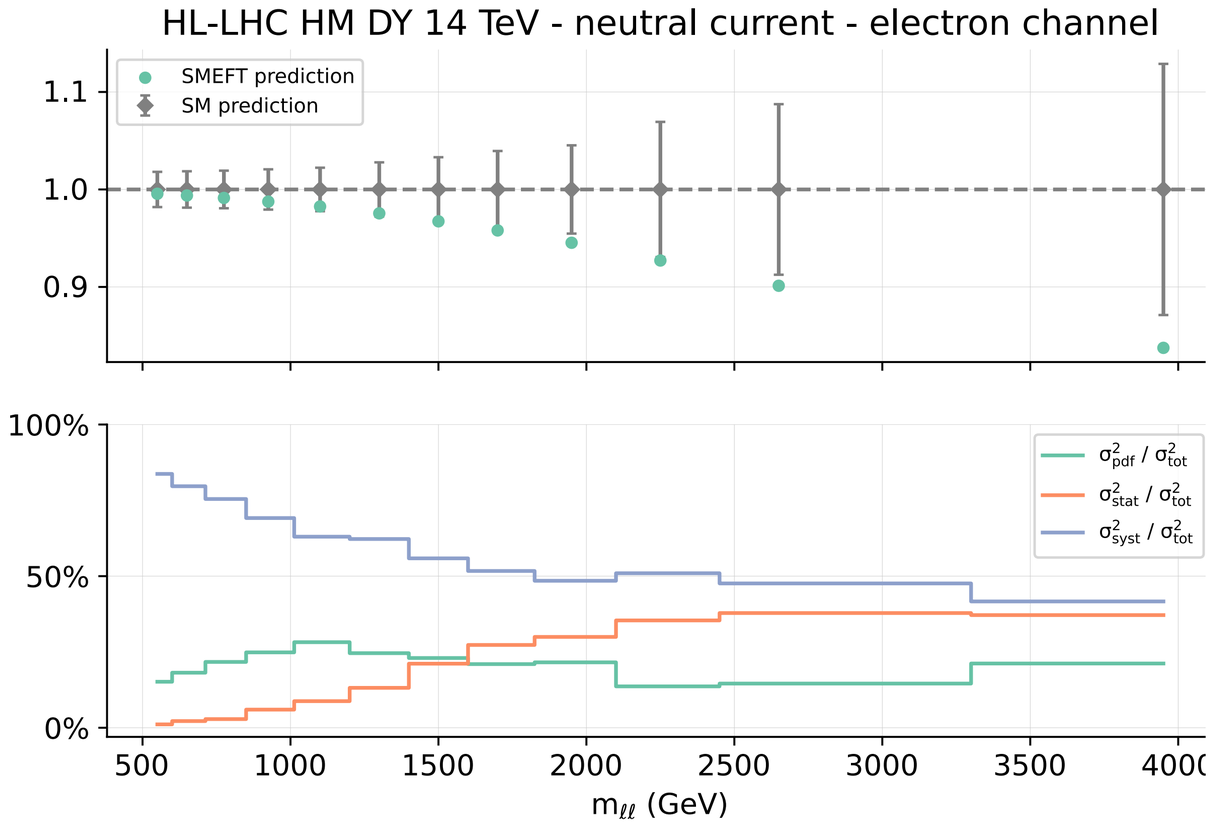
Injecting new physics in HL-LHC projections (DY)

Goal: recover it with a SMEFT fit

Charged current HMDY



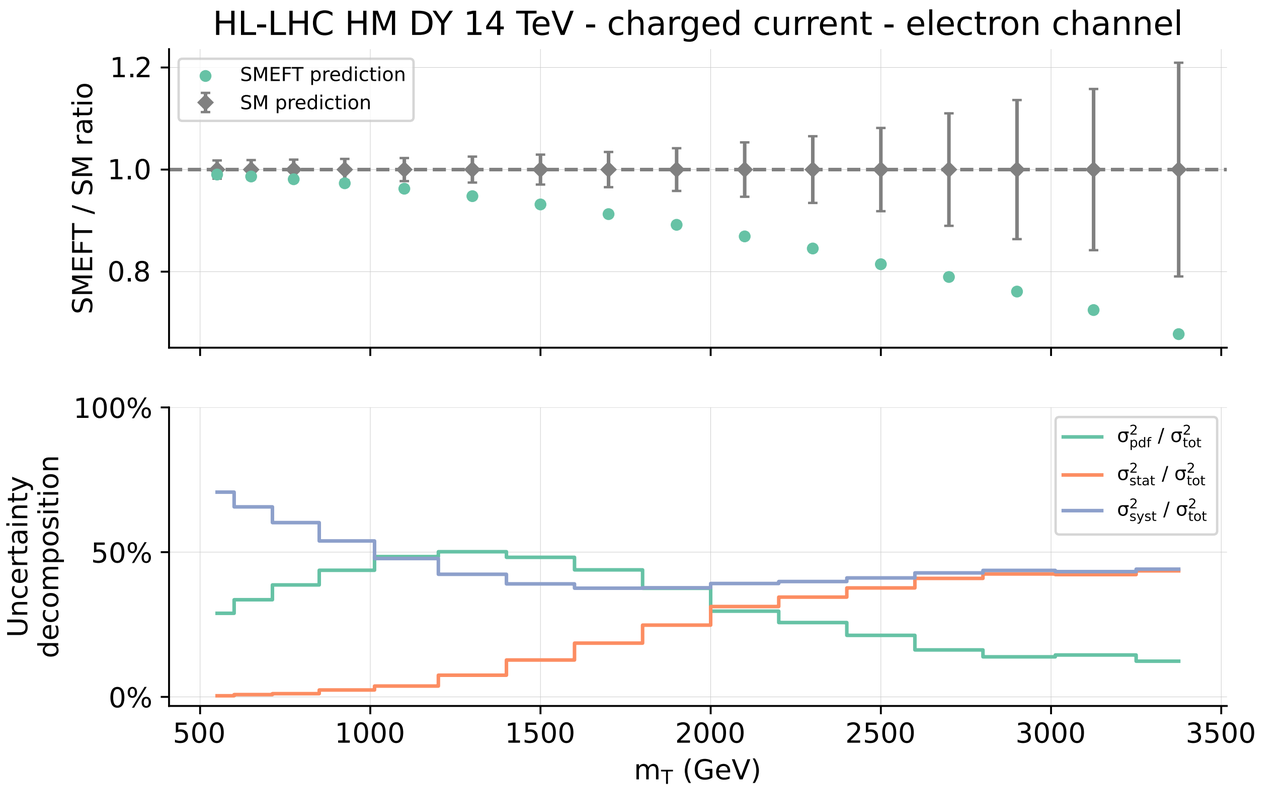
Neutral current HMDY

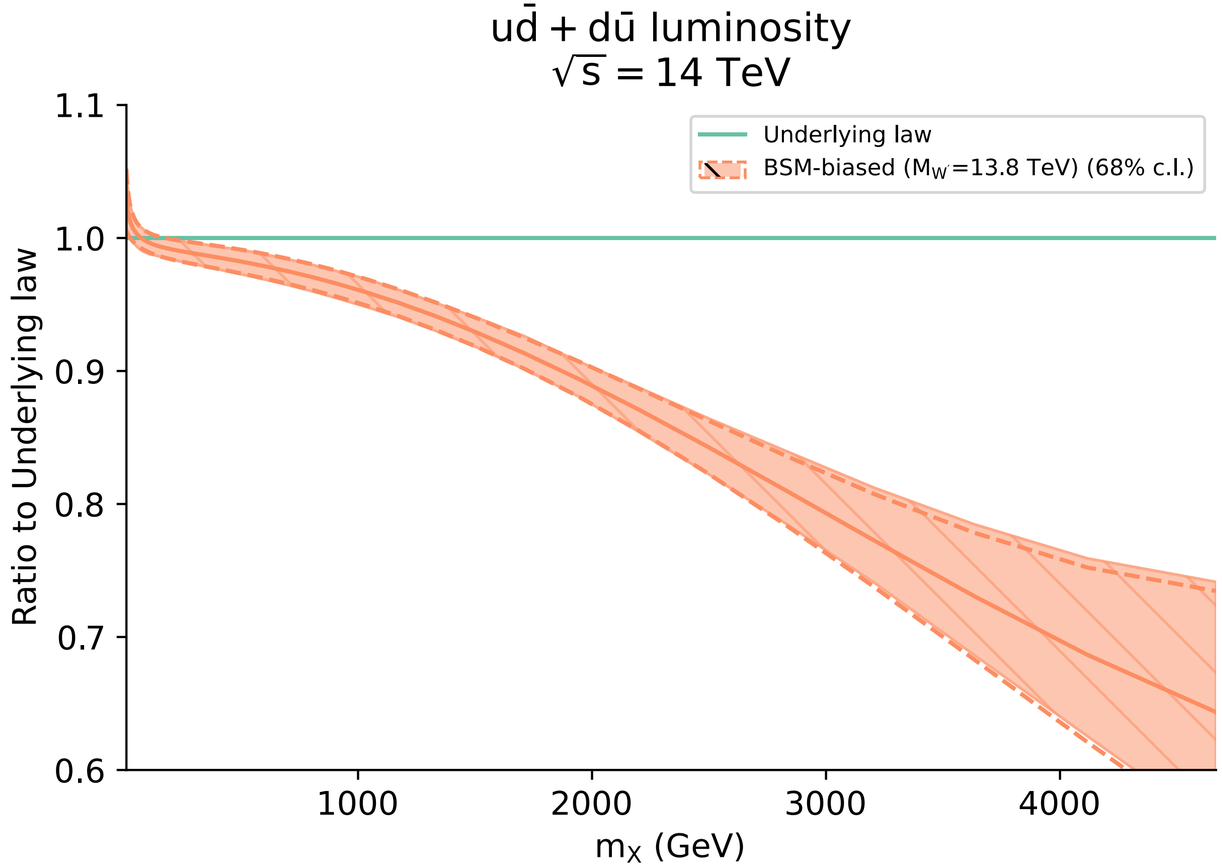


“BSM-biased” PDF in HMDY

PDFs are mimicking the SMEFT corrections

Charged current HMDY



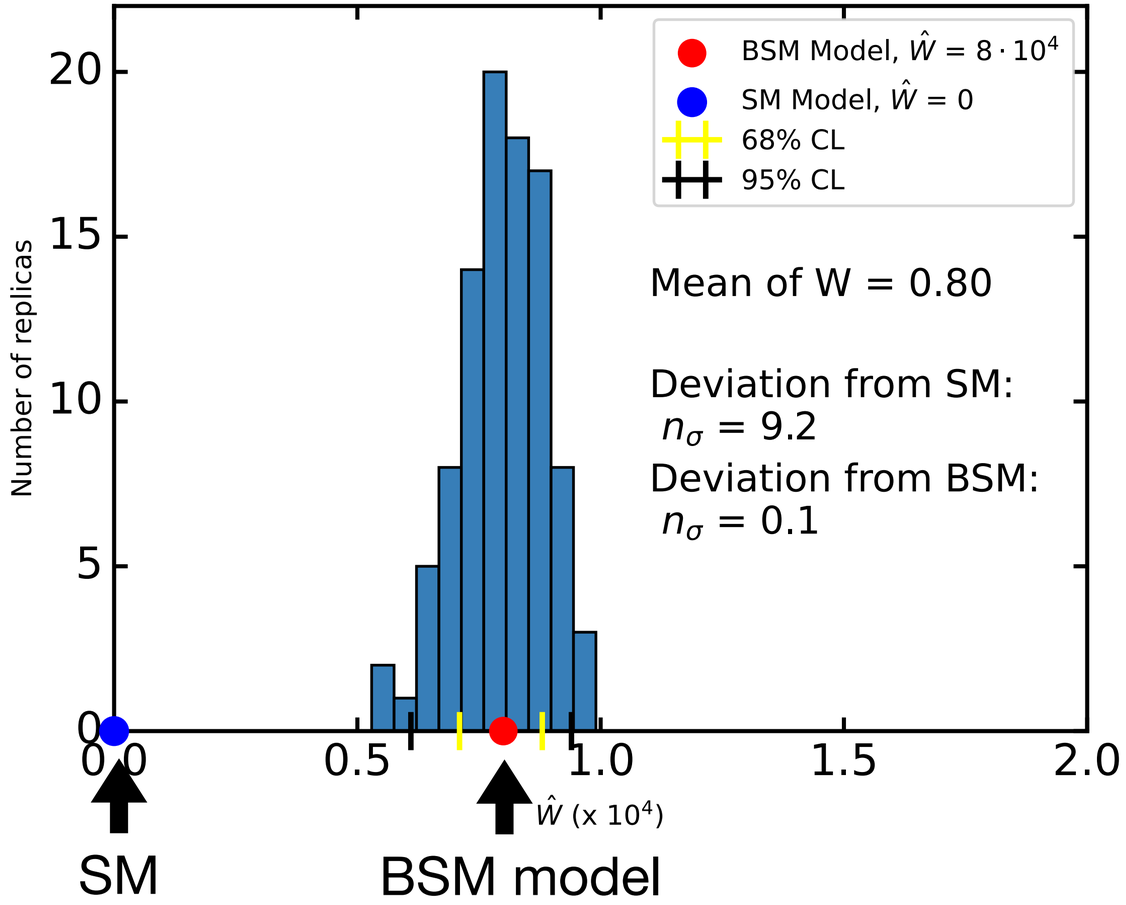


$$\mathscr{L}_{true} \otimes \hat{\sigma}_{BSM} \approx \mathscr{L}_{BSM-biased} \otimes \hat{\sigma}_{SM}$$

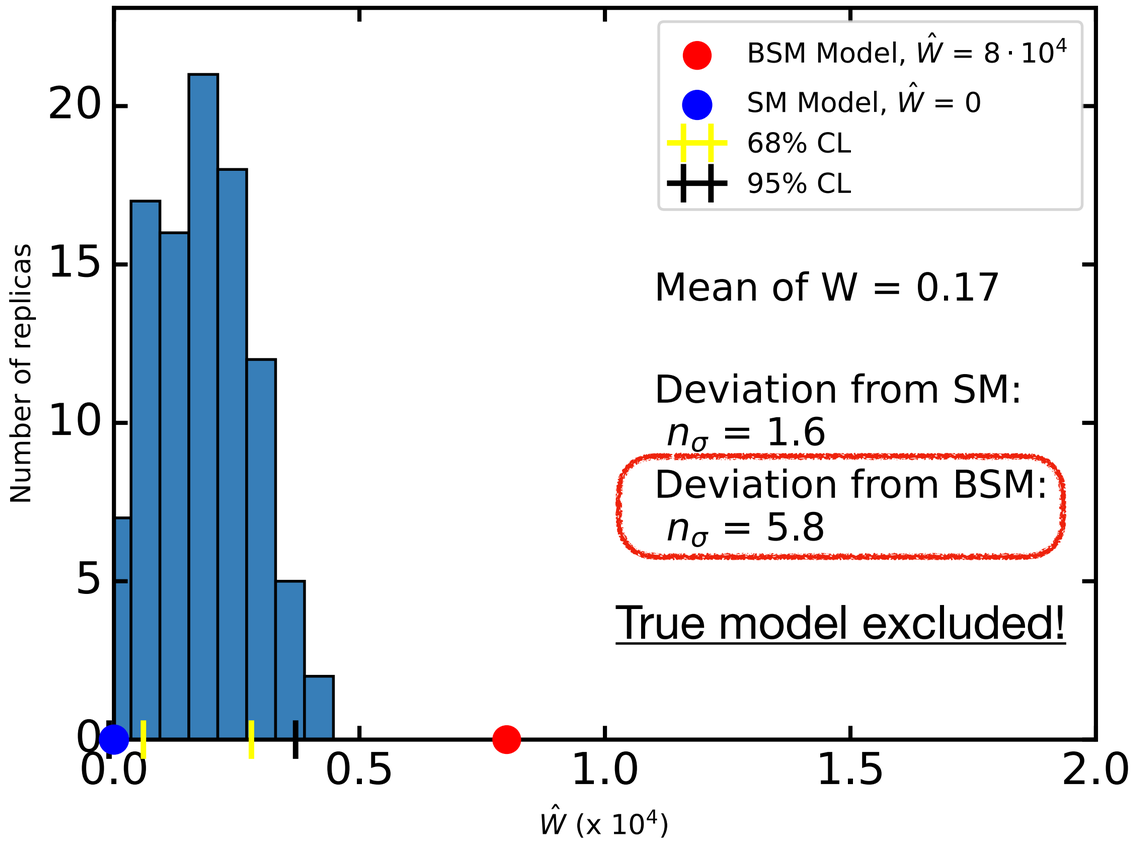
Missing new physics

Impact of the NP absorption in PDFs on SMEFT fits

SMEFT fit with true PDF



SMEFT fit with BSM-biased PDF



Solutions?

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:

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

➡ $\bar{c}$

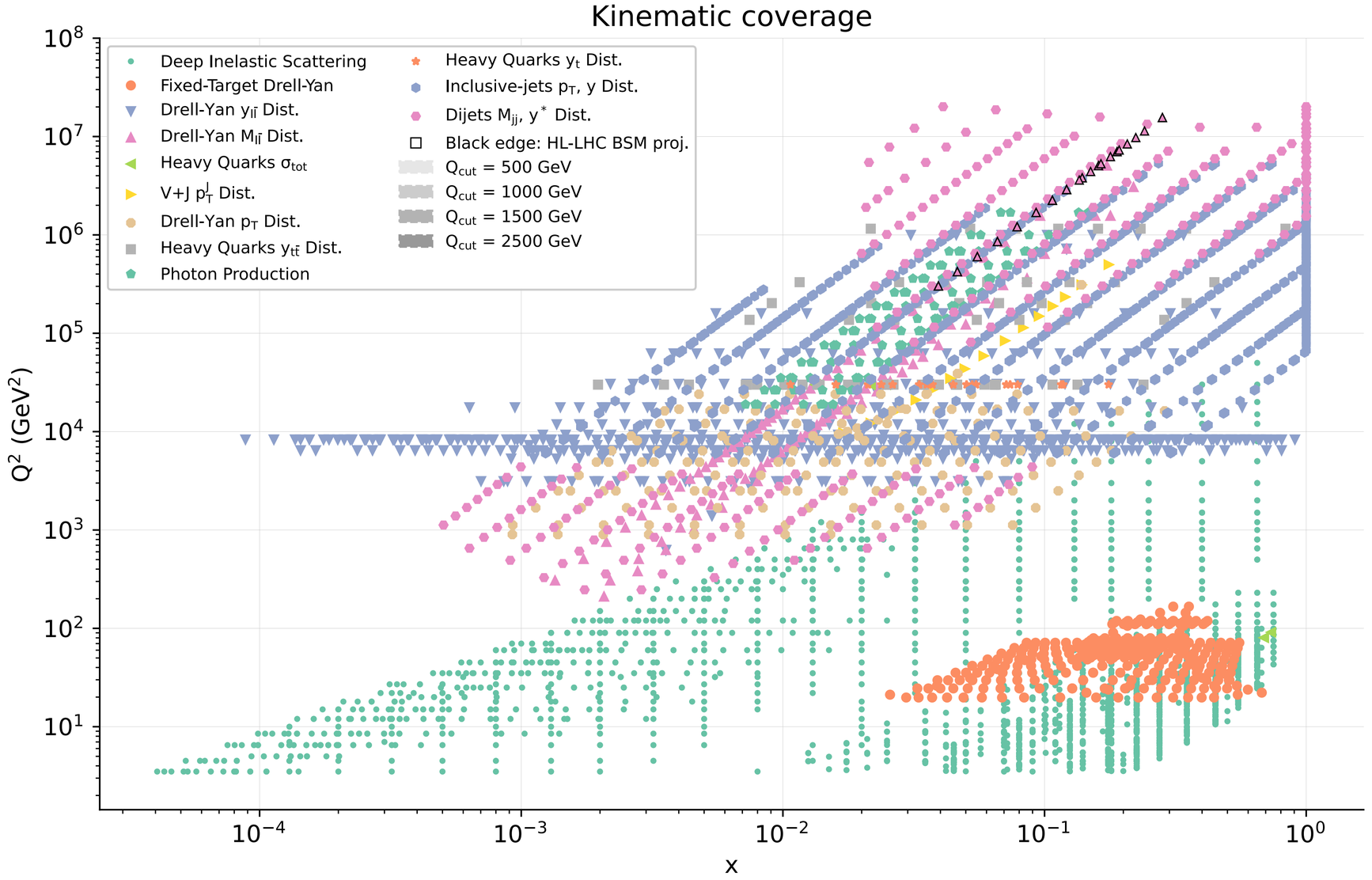
Simultaneous fits

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

➡ $\{\bar{\theta}, \bar{c}\}$

Removes assumption-based bias

Safe separate fits: “conservative” PDFs



Agnostic energy cuts

Simultaneous fit of PDF and new physics

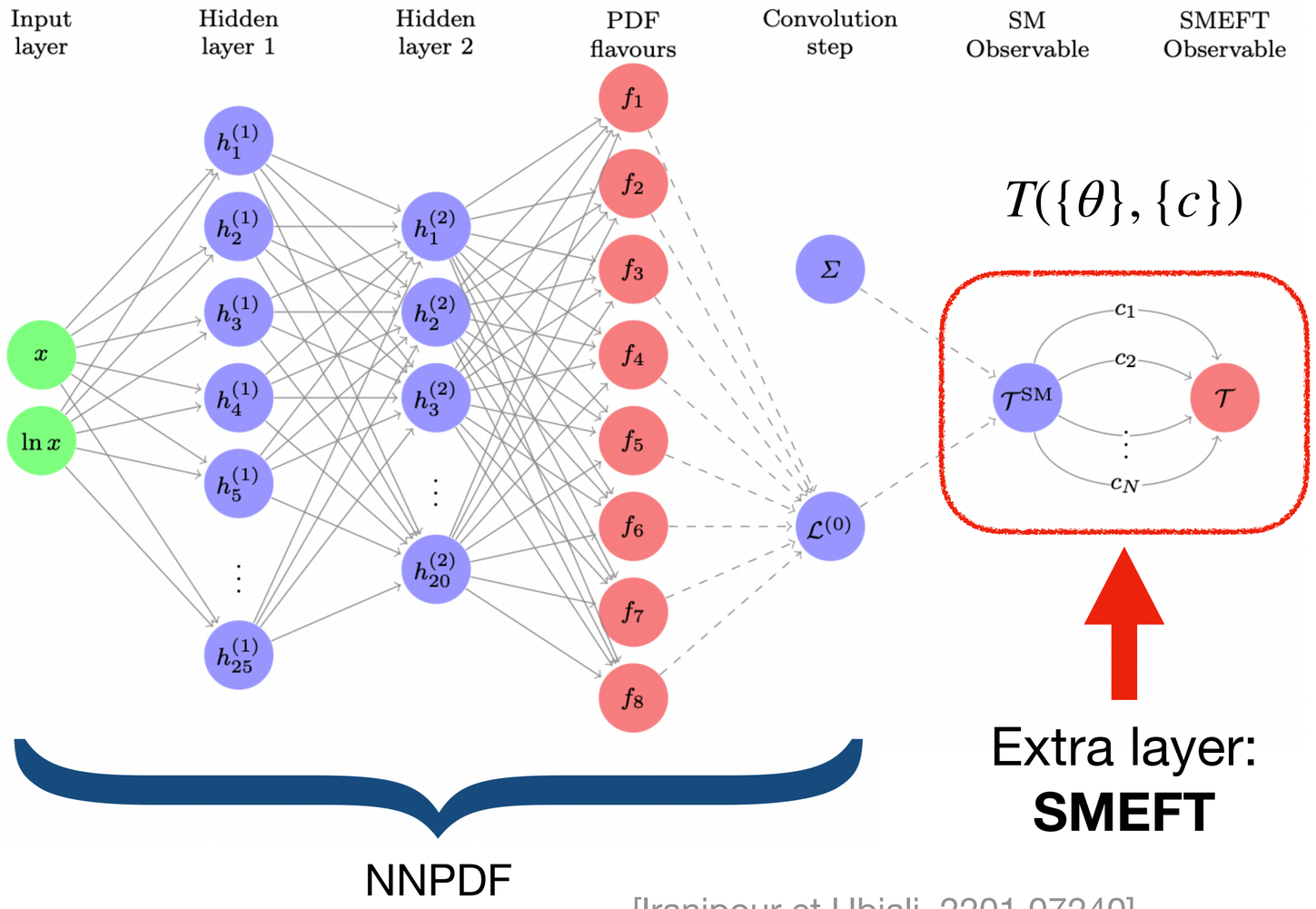
Presentation of the tool: SIMUnet

SIMUnet:

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

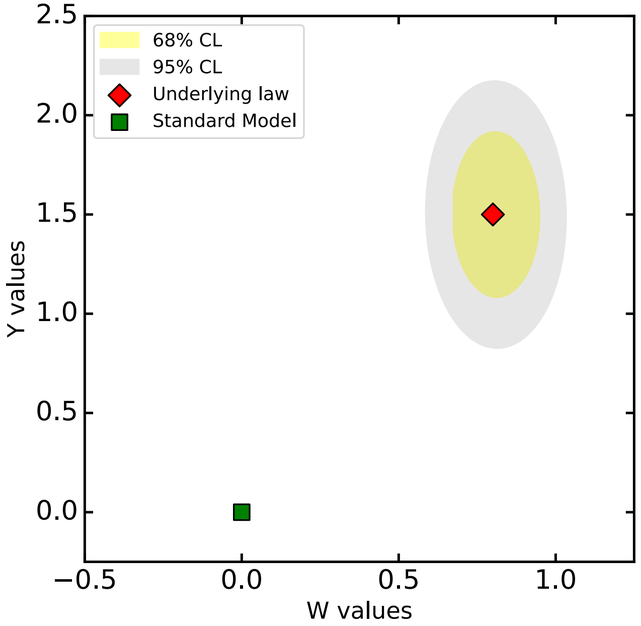
  [PBSP, 2402.03308]

- Fits PDFs and WC simultaneously
- Performs contaminated PDF fits



[Iranipour et Ubiali, 2201.07240]

PDFs for new physics searches in HMDY

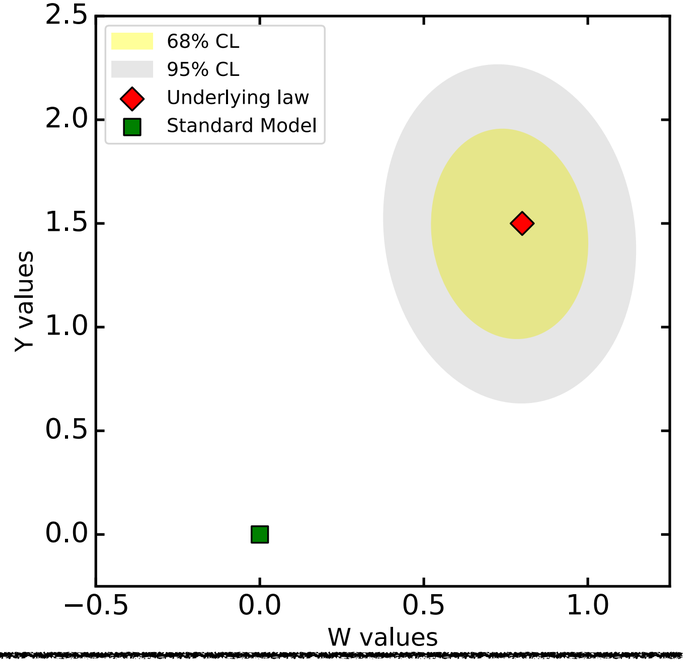


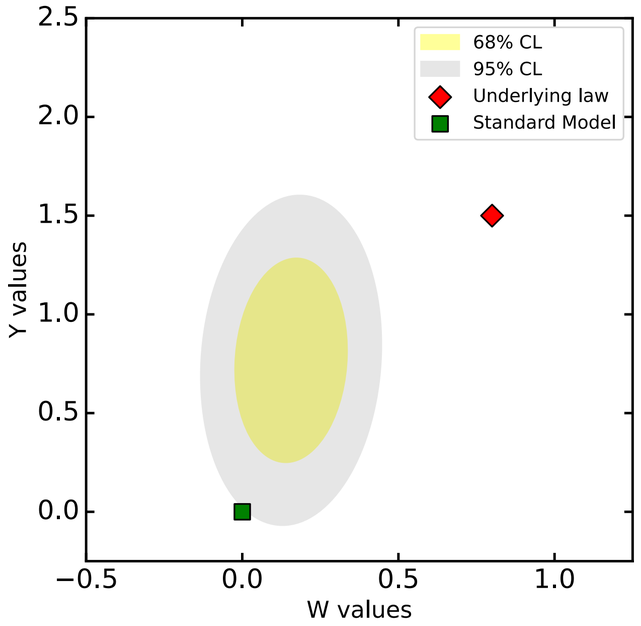
SMEFT only fit
(True PDF)

✗ Impossible

Simultaneous fit
(no PDF assumption)

✓ Doable



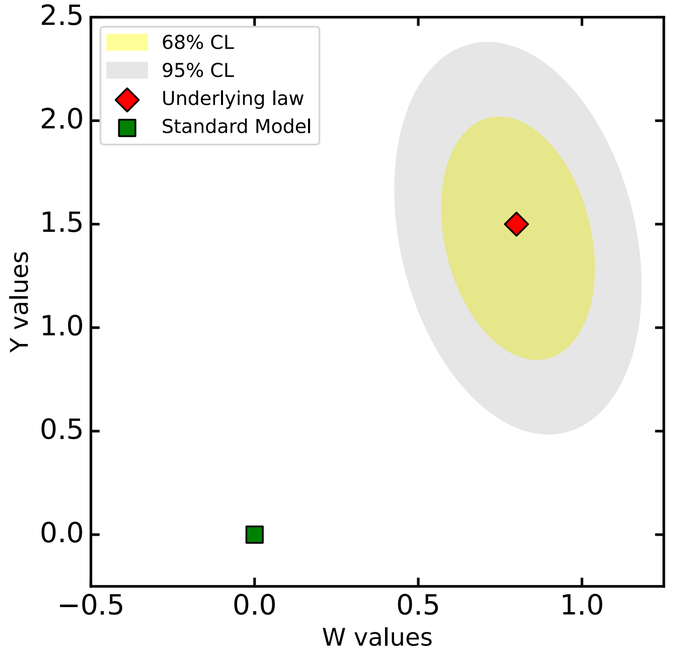


SMEFT only fit
(BSM-biased PDF)

✗ Wrong

SMEFT only fit
(Conservative PDF)

✓ Doable



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**

Summary and outlook

- Signs of new physics fitted away in PDF
  - Missed new physics
  - Exclude true underlying law

- Simultaneous fits of PDFs and SMEFT:
  - Fitting simultaneously PDF and new physics: **SIMUnet** tool already available
  - Ongoing study on real jet data [Greljo, Hammou, Merlotti, Smolkovic, Ubiali, forthcoming]
  - Developing a bayesian framework [Costantini, Moore, Mantani, Schutze, Ubiali, forthcoming (PDF)] [Hammou, ter Hoeve, Shutze, in progress (SMEFT)]

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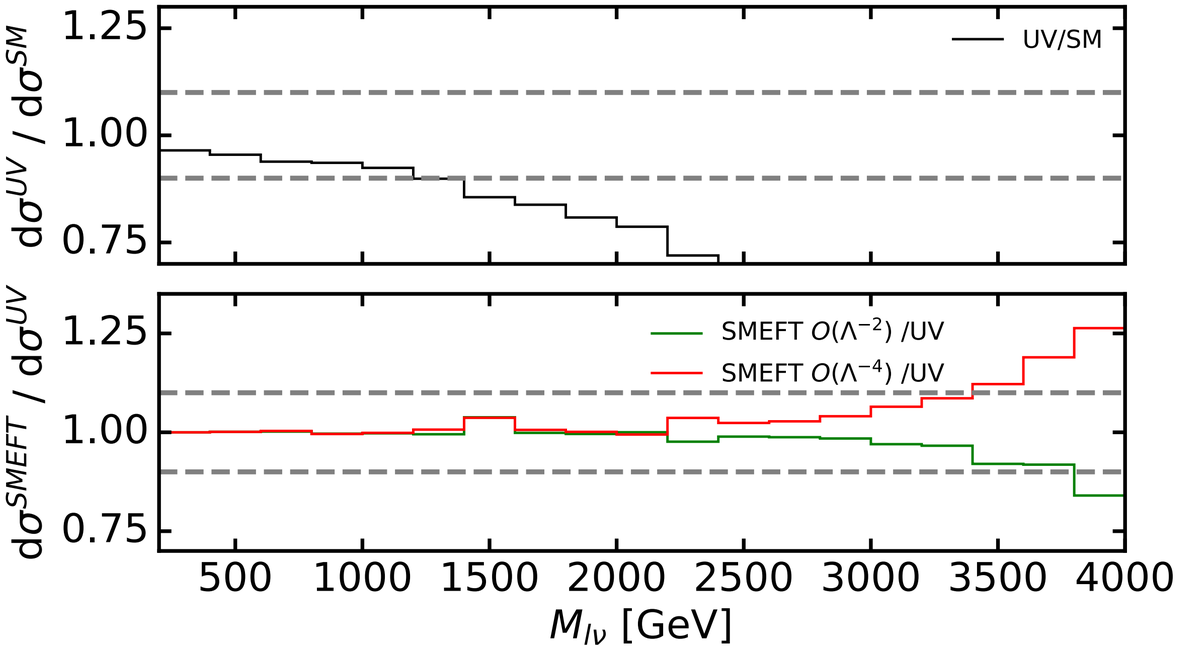
Thank you for your attention!

Extra slides

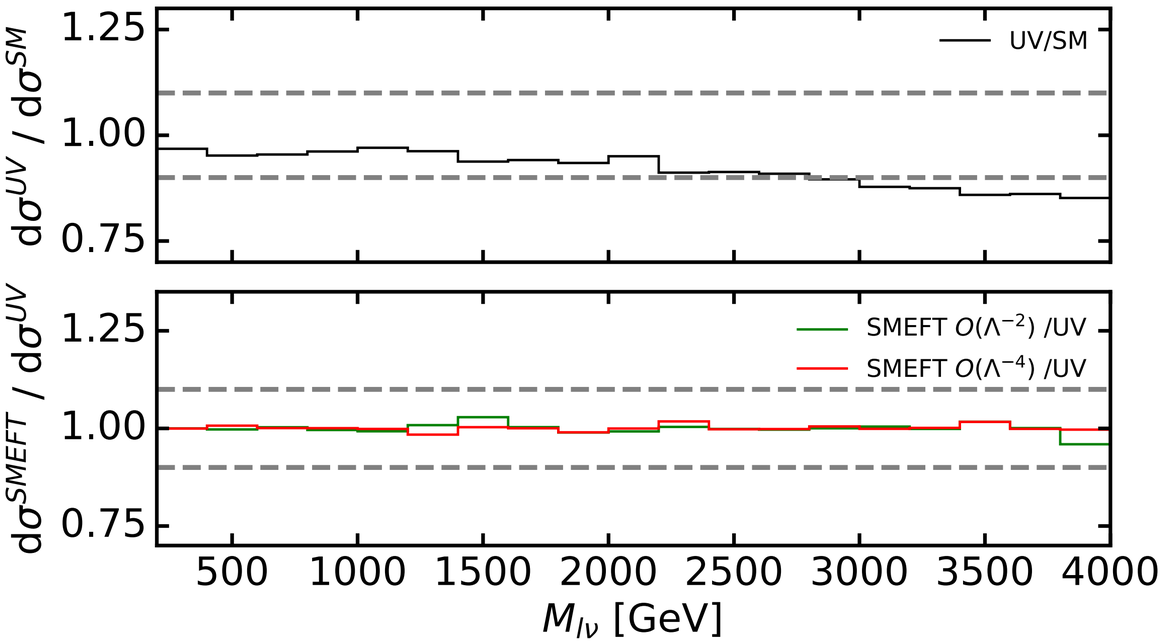
New physics scenarios: W'

Consideration of different masses

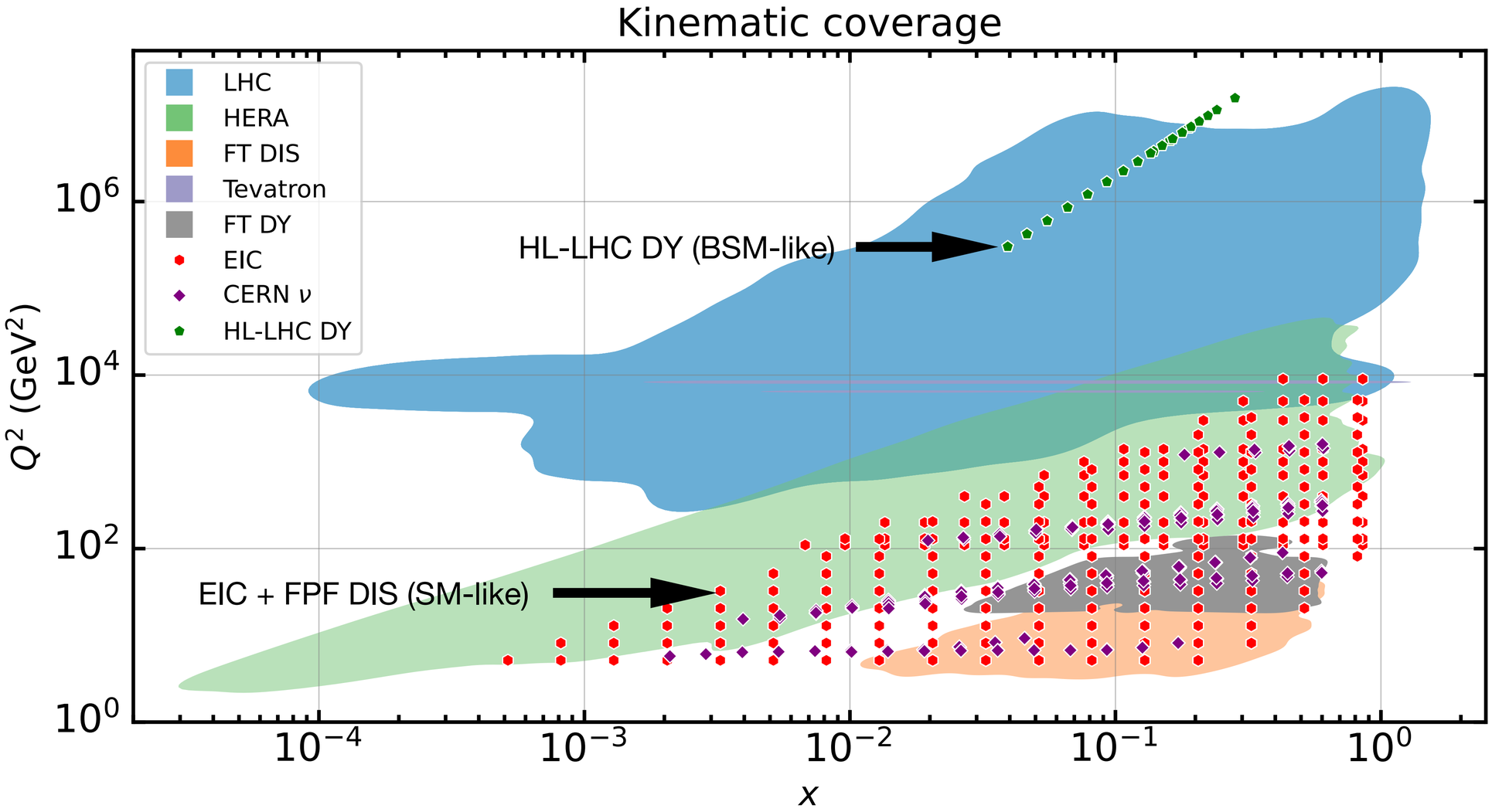
$M_{W'} = 10$ TeV



$M_{W'} = 22.5$ TeV



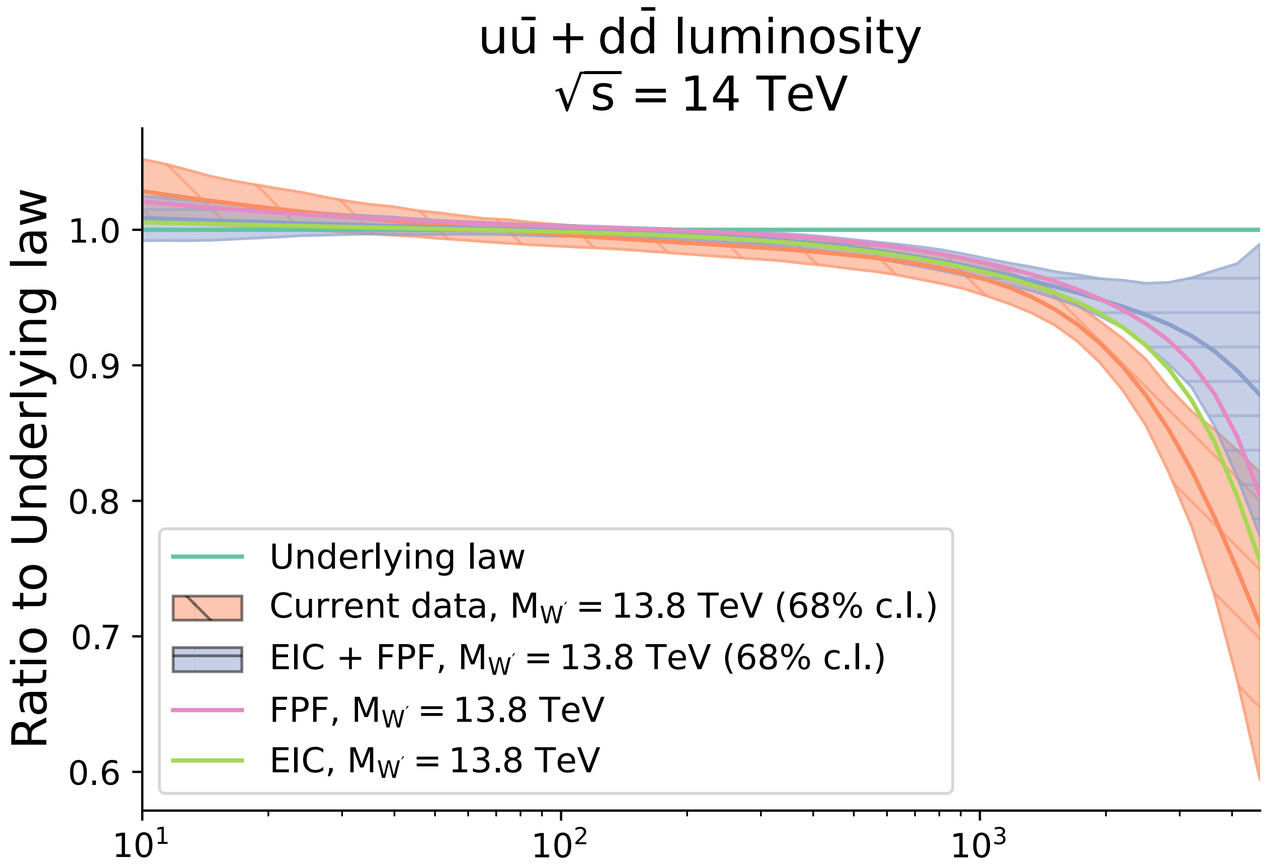
EIC, FPF and HL-LHC kinematics



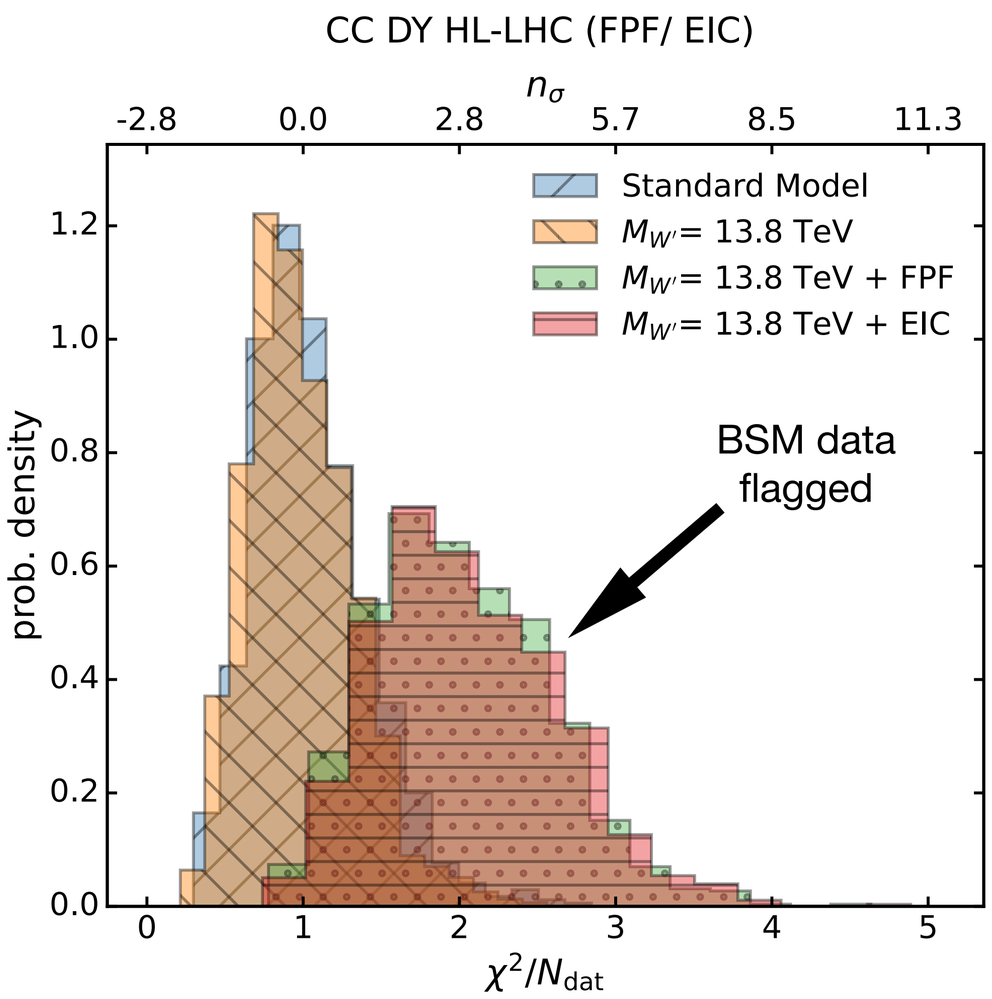
Impact on the PDF contamination

Flagging the BSM data

Pull on PDFs



Impact on fit quality



PDF fitting: selection criteria

Exclusion of incompatible datasets (NNPDF criteria)

Two criteria:

$$\chi^2 = (D - T_{SM})^T \cdot V_{cov}^{-1} \cdot (D - T_{SM})$$

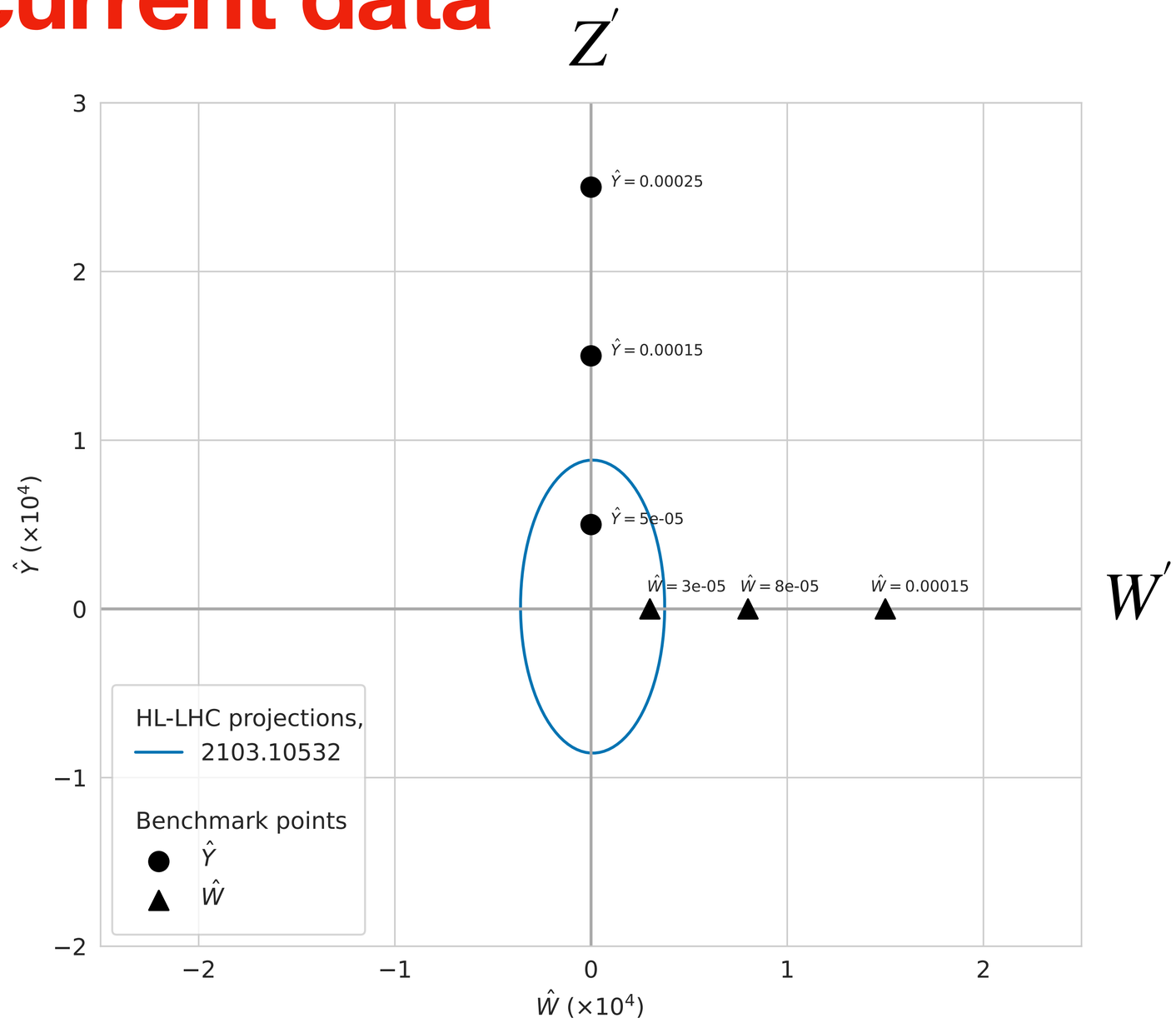
- χ^2-statistics:
  - $\frac{\chi^2}{n_{dat}} > 1.5$ → excluded

- n_σ standard deviation:
  - $n_\sigma > 2$ → excluded

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

Constraints from current data

- New physics scenarios compared to constraints at 95% CL



Impact of contamination: fake deviations

SM predictions with:

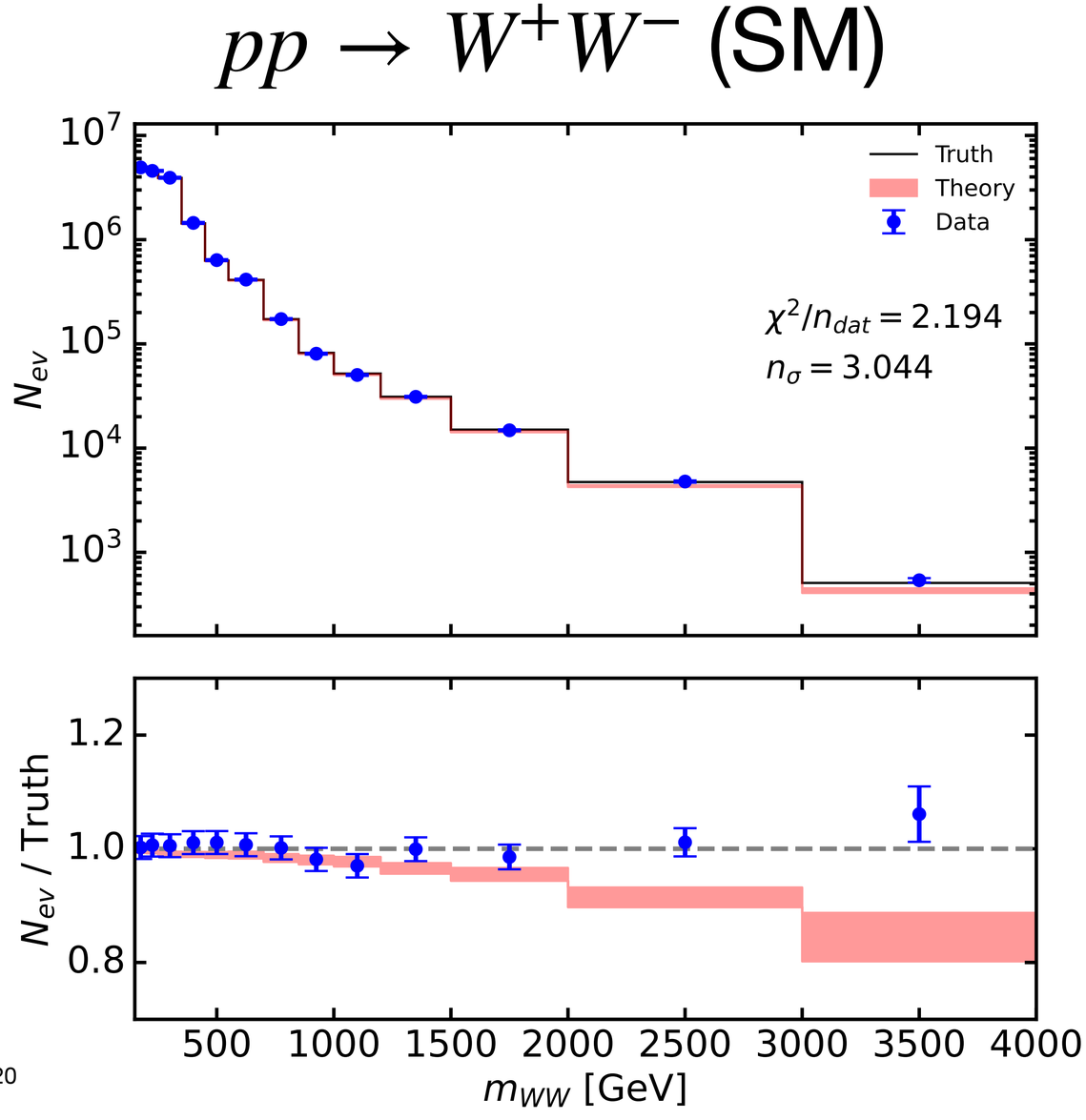
- Contaminated PDFs (red)
- True PDFs (black)

➡ Fake deviation in other sectors

Also seen in:

WH, WZ, ZH production

HL-LHC Projections

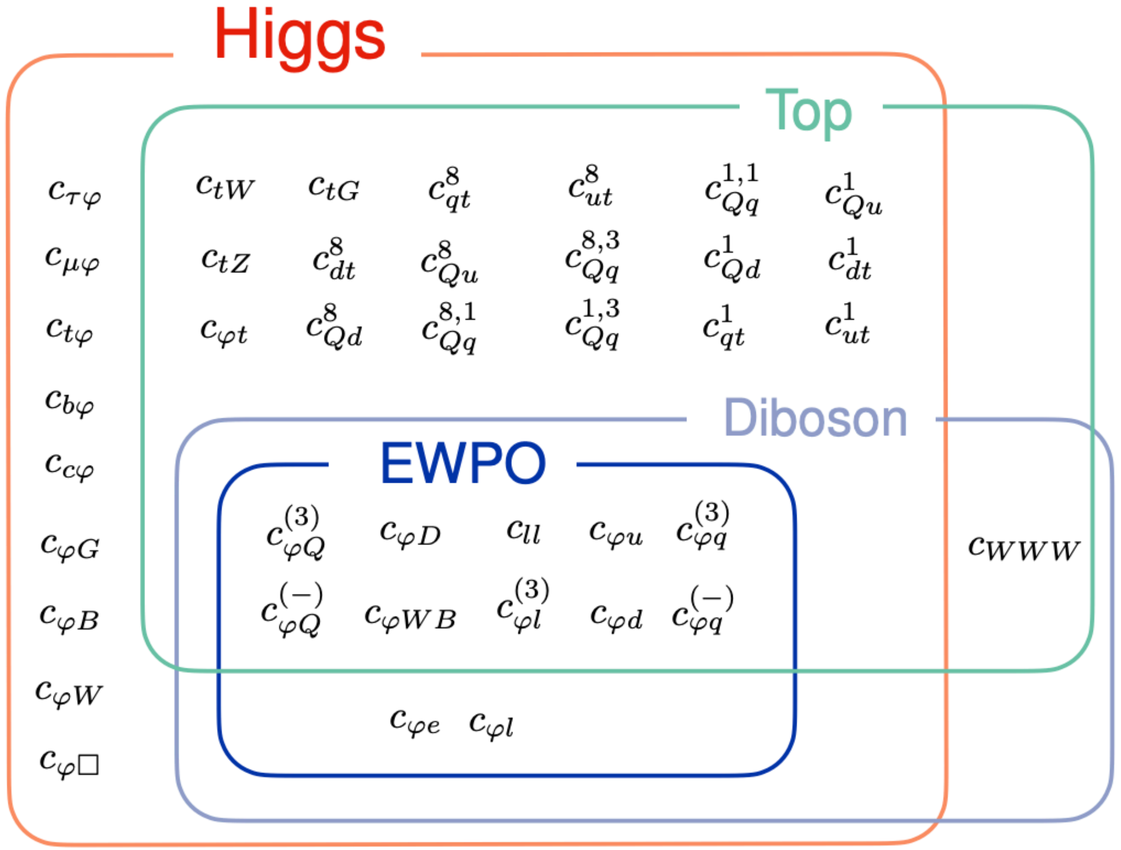


Simultaneous fit of PDF and new physics

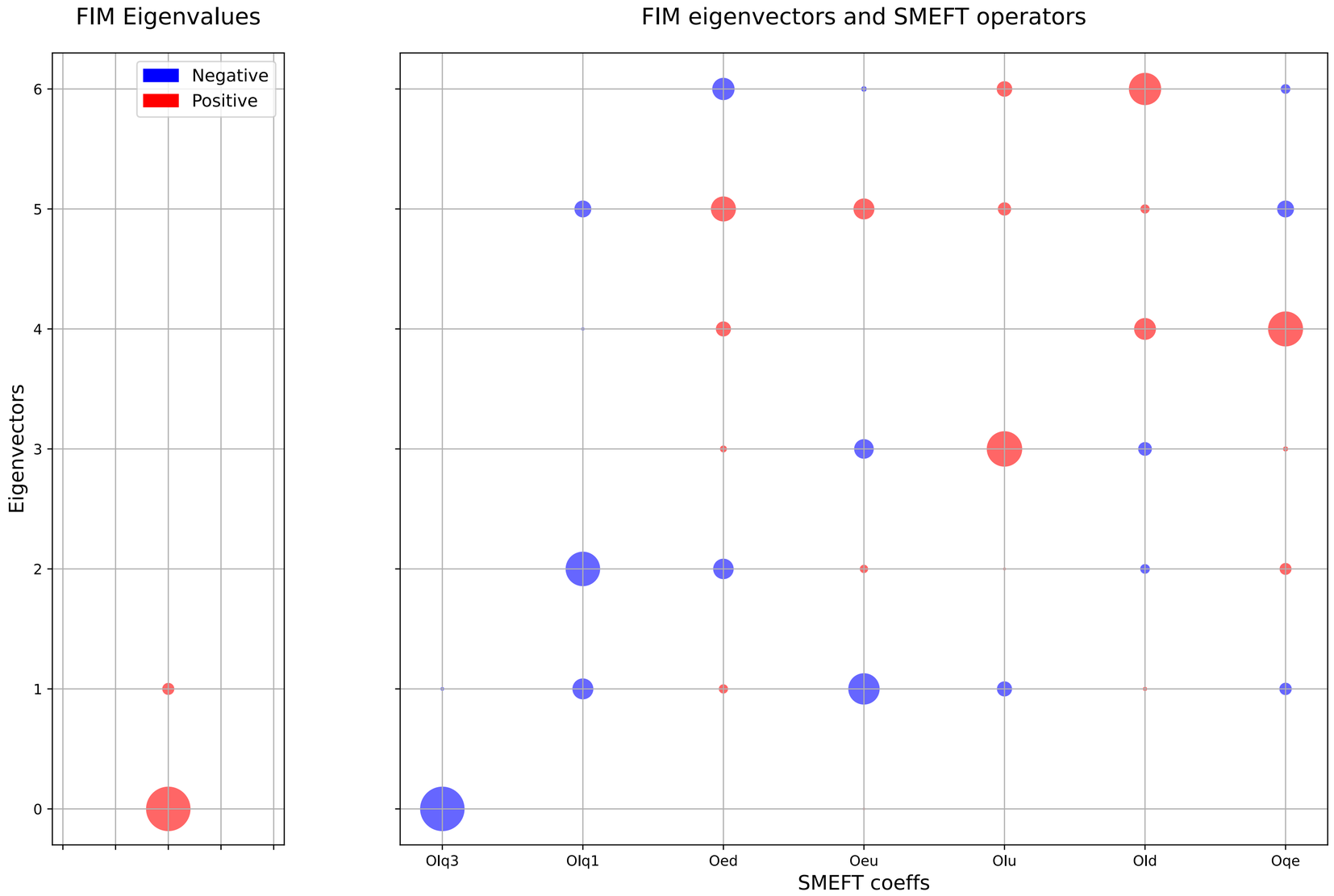
SMEFT operators implemented

- 40 operators implemented

- Observables:
  - top sector
  - diboson
  - Higgs
  - Drell-Yan
  - EW Precision Observables



SMEFT PCA results



Centre-of-mass comparison