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NNPDF

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For more information see arXiv: 2104.02723

Parton distributions in the SMEFT from high-energy Drell-Yan tails

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Background: PDFs

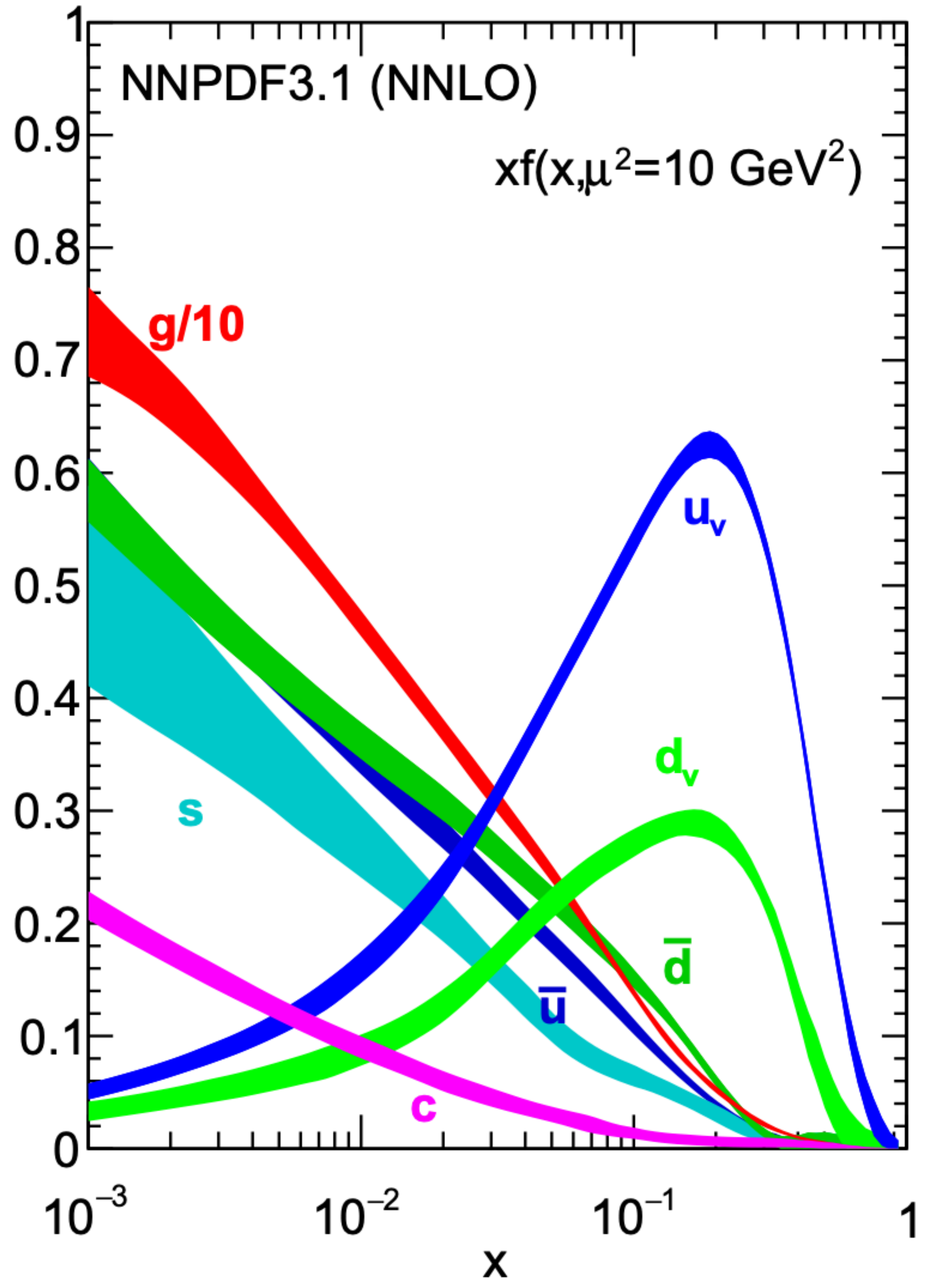
- Parton distribution functions (PDFs) describe **partonic content** of protons

- Depend on Bjorken-x (non-pert.) and energy scale (pert.). Extract via **fit**:

$$\sigma = f_1 \otimes f_2 \otimes \hat{\sigma}$$

$$\rightarrow f_i(x, Q^2) \pm \Delta_i(x, Q^2)$$

- Process-independent but **more data → higher precision**



The problem

1. **PDFs assume SM cross sections**

$$\sigma_{\text{meas.}} = \boxed{f_1 \otimes f_2} \otimes \hat{\sigma}_{\text{SM}}$$

2. **EFT analyses assume SM PDFs**

$$\sigma_{\text{BSM}} = \boxed{f_1 \otimes f_2} \otimes \hat{\sigma}_{\text{BSM}}$$

$$\boxed{f_i \equiv f_{i,\,\text{SM}}}$$

→ How valid is this assumption, especially when looking for subtle deviations?

Question raised

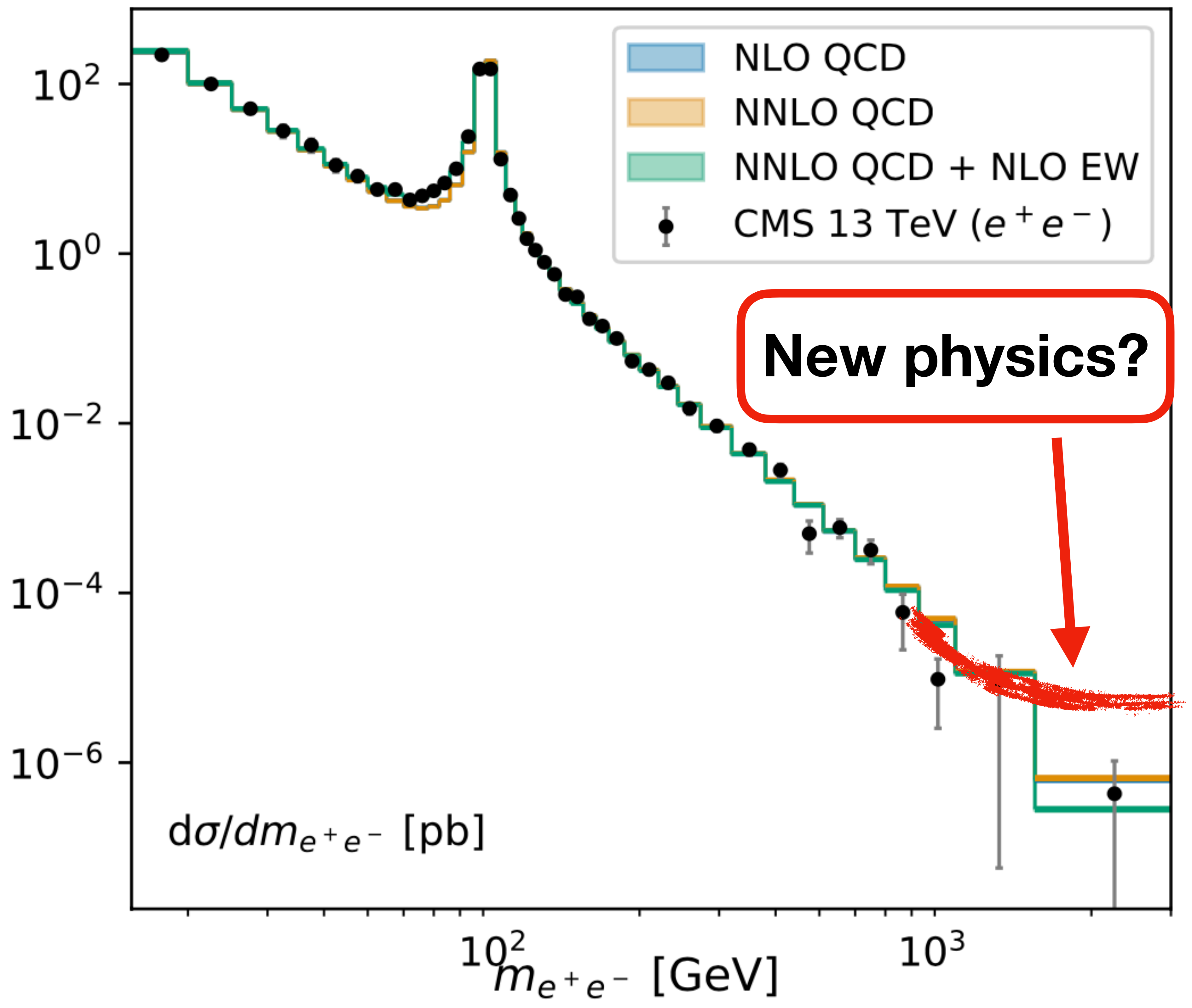
Can the SMEFT be **constrained correctly** using SM PDFs?

First studied in arXiv:1905.05215

The playground: Drell-Yan tails

- Drell-Yan (DY) tails, a.k.a. **high-mass DY**
- DY used in **both PDF and EFT determinations**:

  1. **Important constraints** on $q\bar{q}$
  2. New physics could **distort tails**



The models

$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{\text{SM}} + ?$$

Choose two benchmark scenarios, described via SMEFT:

1. **Flavour-universal electroweak oblique corrections:** $\hat{W}, \hat{Y}$

2. Flavour-specific 4-fermion operator coupling muons and b-quarks

The models: $\hat{W}, \hat{Y}$

$$\mathscr{L}_{\mathrm{SMEFT}} \supset -\frac{\hat{W}}{4m_W^2}(D_\rho W^a_{\mu\nu})^2 - \frac{\hat{Y}}{4m_W^2}(\partial_\rho B_{\mu\nu})^2$$

Studied in e.g. arXiv: 1609.08157, 2008.12978

- Electroweak (EW) oblique corrections: **parametrise self-energy of EW gauge bosons**
- Four operators that can be matched to dim-6 in SMEFT: $\hat{S}, \hat{T}, \hat{W}, \hat{Y}$
  - $\hat{S}, \hat{T}$ **well constrained**, **weaker q^2-dependence**

The methodology

Standard procedure: SM PDFs

1. Take data, make predictions accounting for operators with **fixed SM PDF set**

2. Compute χ^2 for set of Wilson coefficients (WCs)

$$\chi^2 = \frac{1}{n_{\rm dat}} \sum_{i,j=1}^{n_{\rm dat}} (D_i - T_i)\,({\rm cov}^{-1})_{ij}\,(D_j - T_j)$$

3. Fit function

$$T = f_{1,\rm SM} \otimes f_{2,\rm SM} \otimes \hat{\sigma}_{\rm BSM}$$

4. Extract bounds

The methodology

First studied in arXiv:1905.05215

Our procedure: SMEFT PDFs

- Same as previously, but…
- For each value of WC do a **consistent PDF fit** $\Rightarrow \mathbf{N}_{\mathrm{WCs}}$ **SMEFT PDF sets**

$$T = f_{1,\mathrm{BSM}} \otimes f_{2,\mathrm{BSM}} \otimes \hat{\sigma}_{\mathrm{BSM}}$$

Settings

Data

- **DIS & low-mass/on-shell DY** data from NNPDF3.1
- Plus **high-mass DY**:

  - **LHC NC data**: ATLAS 7, 8 TeV; CMS 7, 8, 13 TeV

  - **HL-LHC** projections (later)

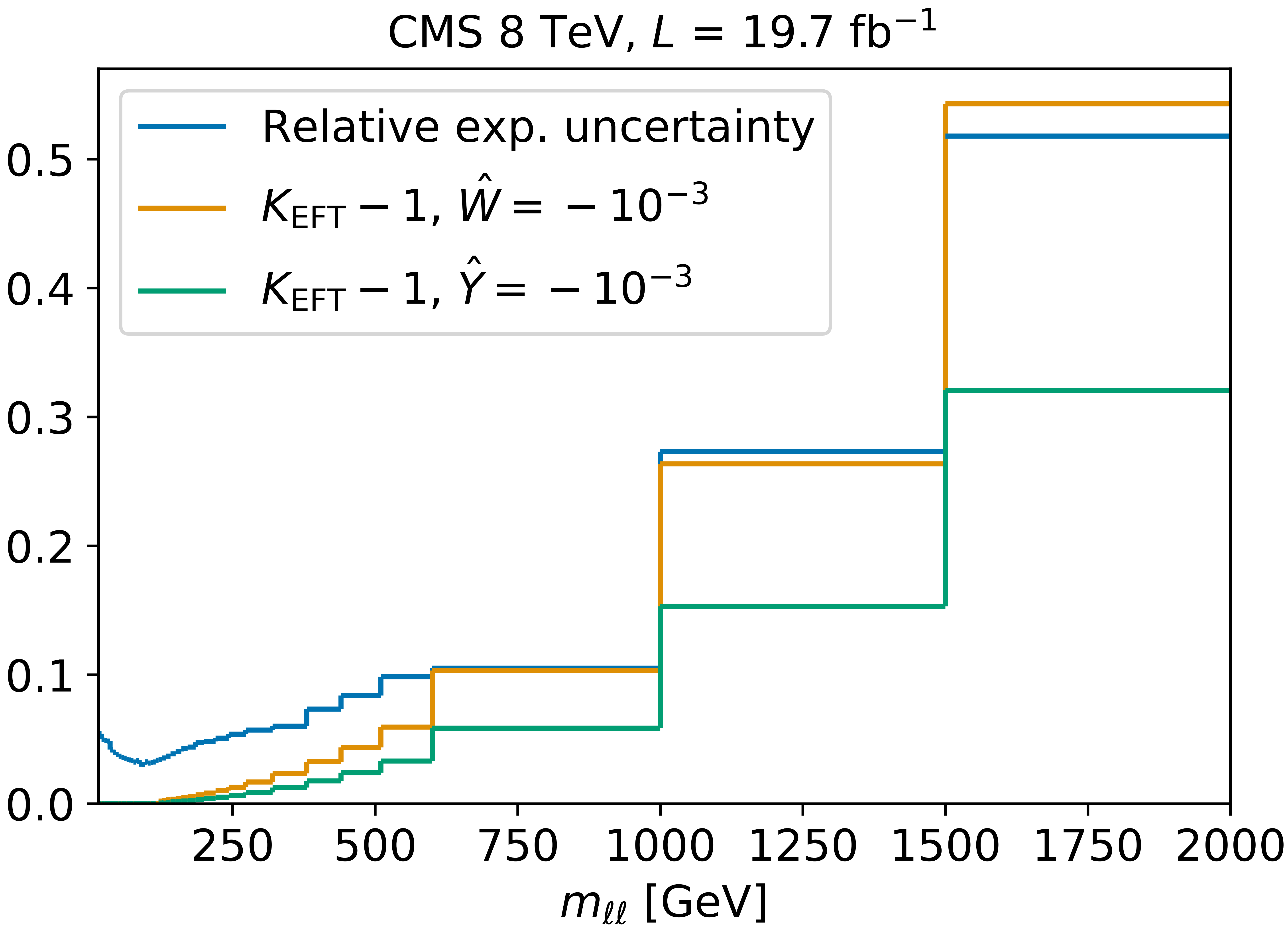
Theory: SM

- **NNLO QCD + NLO EW**

SMEFT

- **K-factor approach**, $d\sigma_{\text{SMEFT}} = d\sigma_{\text{SM}} \times K_{\text{EFT}}$
- **Linear (dim-6)** for $\hat{W}, \hat{Y}$
- Applied to **DIS & DY**

Example: SMEFT corrections

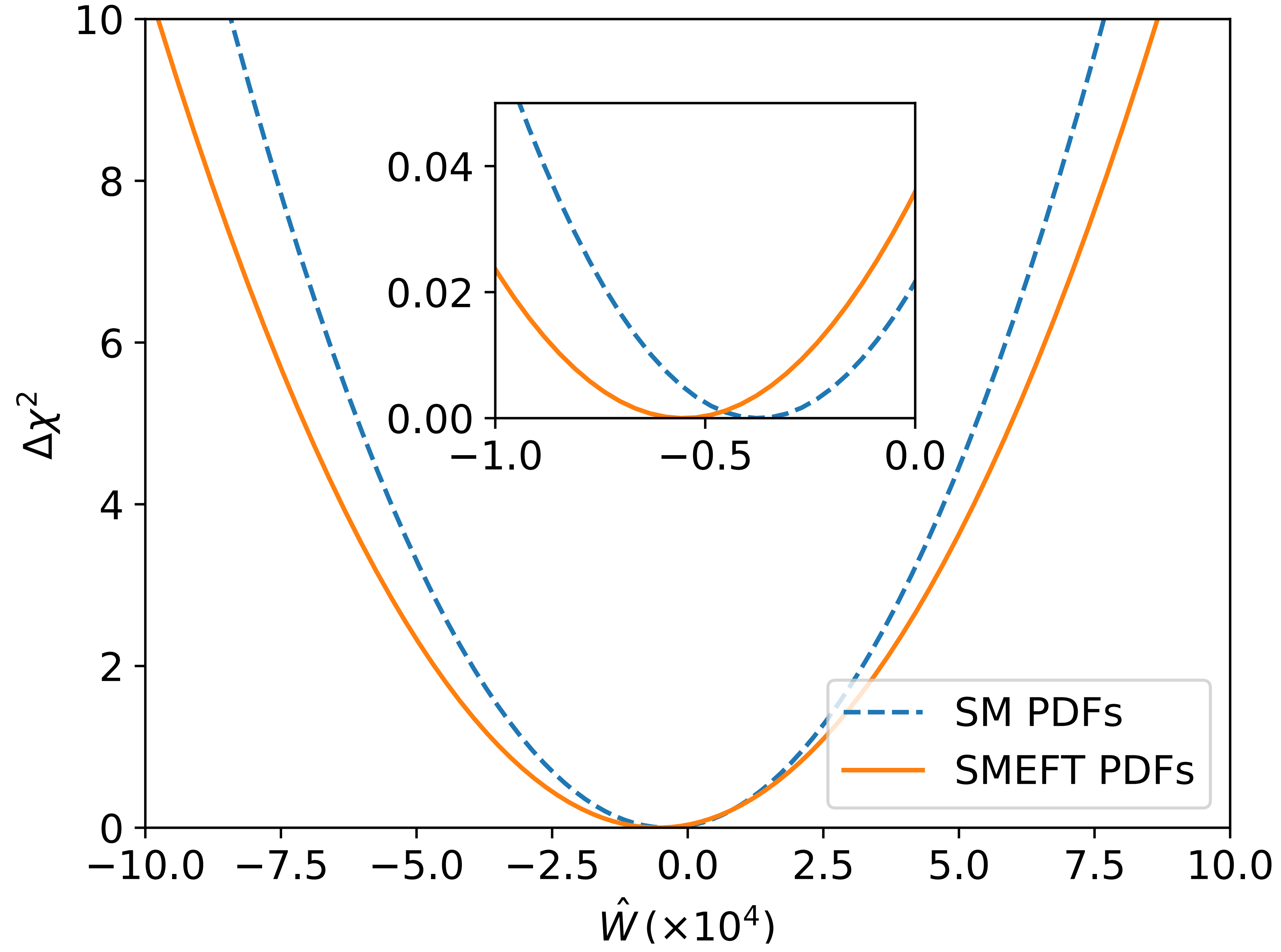


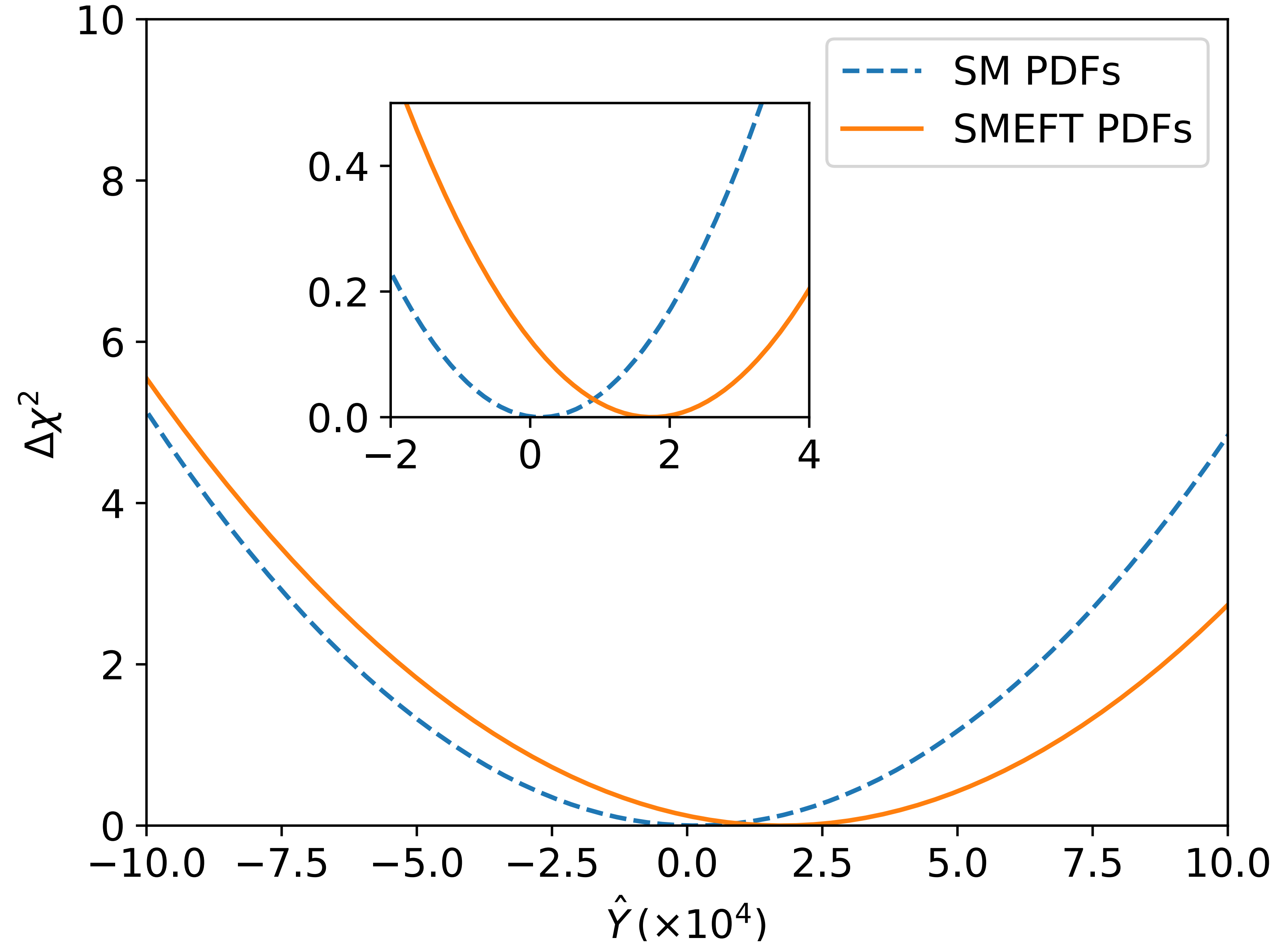
Question raised

Can the SMEFT be **constrained correctly** using SM PDFs?

$\rightarrow$ **Current data**

Results: current data





- 95% CL bounds:

  - **broaden** by **15% ($\hat{W}$), 12% ($\hat{Y}$)**

- PDF unc. included:

  - becomes **shrinking** by **11% ($\hat{W}$), 13% ($\hat{Y}$)**

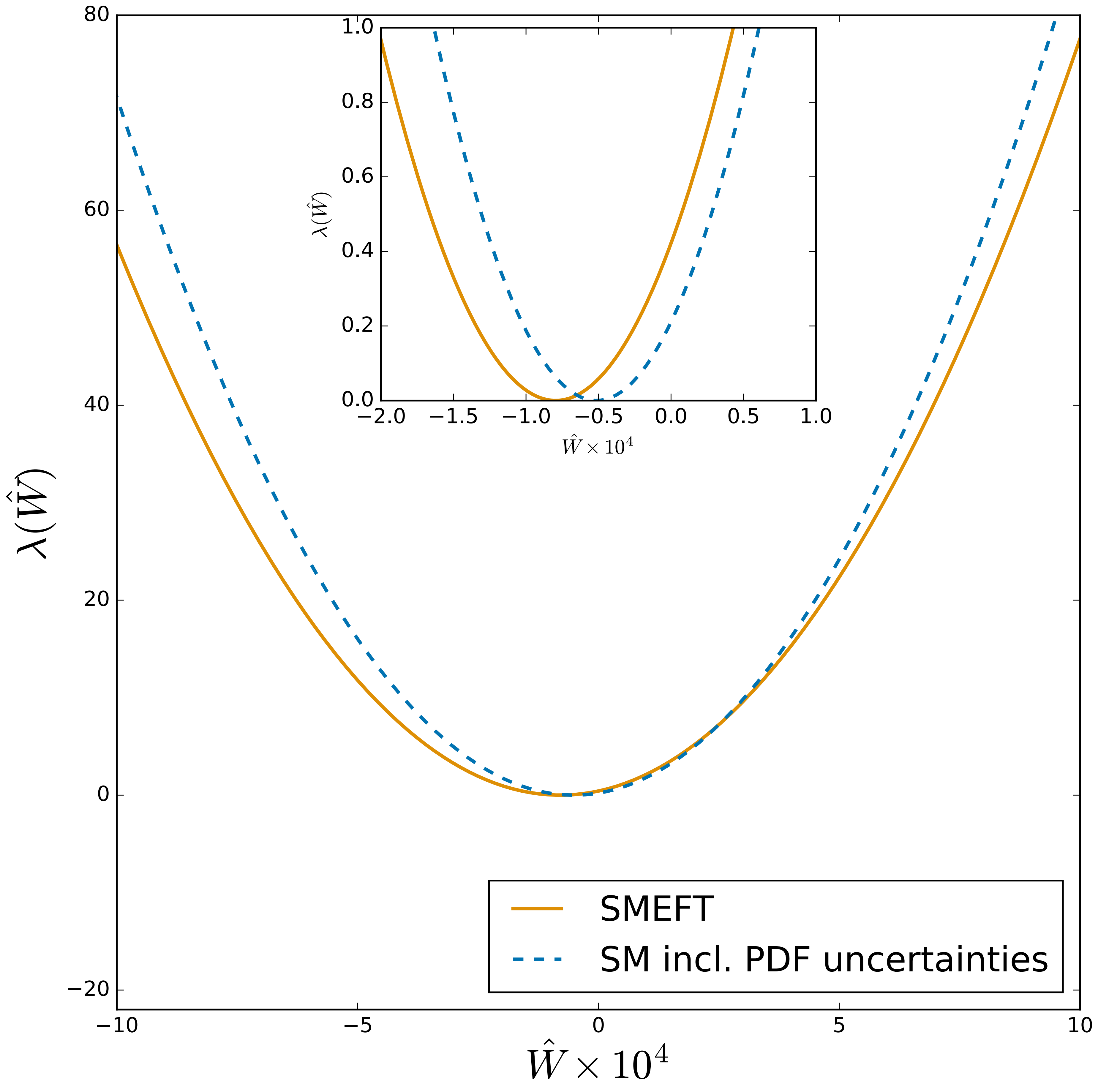
Results: current data

- Complementary investigation with **search data** (not included in PDF fits!)

- ATLAS 13 TeV Z' search with full Run II luminosity

- 95% CL bounds (PDF unc. inc. or not):

  - **broaden** by **7% ($\hat{W}$ & $\hat{Y}$)**



Summary: current data

Unfolded data (inc. in fits)

- Effects **visible** but **within uncertainties** (when PDF unc. inc.)

Search data (not inc. in fits)

- Bounds **widen beyond uncertainties** (when PDF unc. inc.)
- Even at this luminosity & $\sqrt{s}$ we **start to see impact**

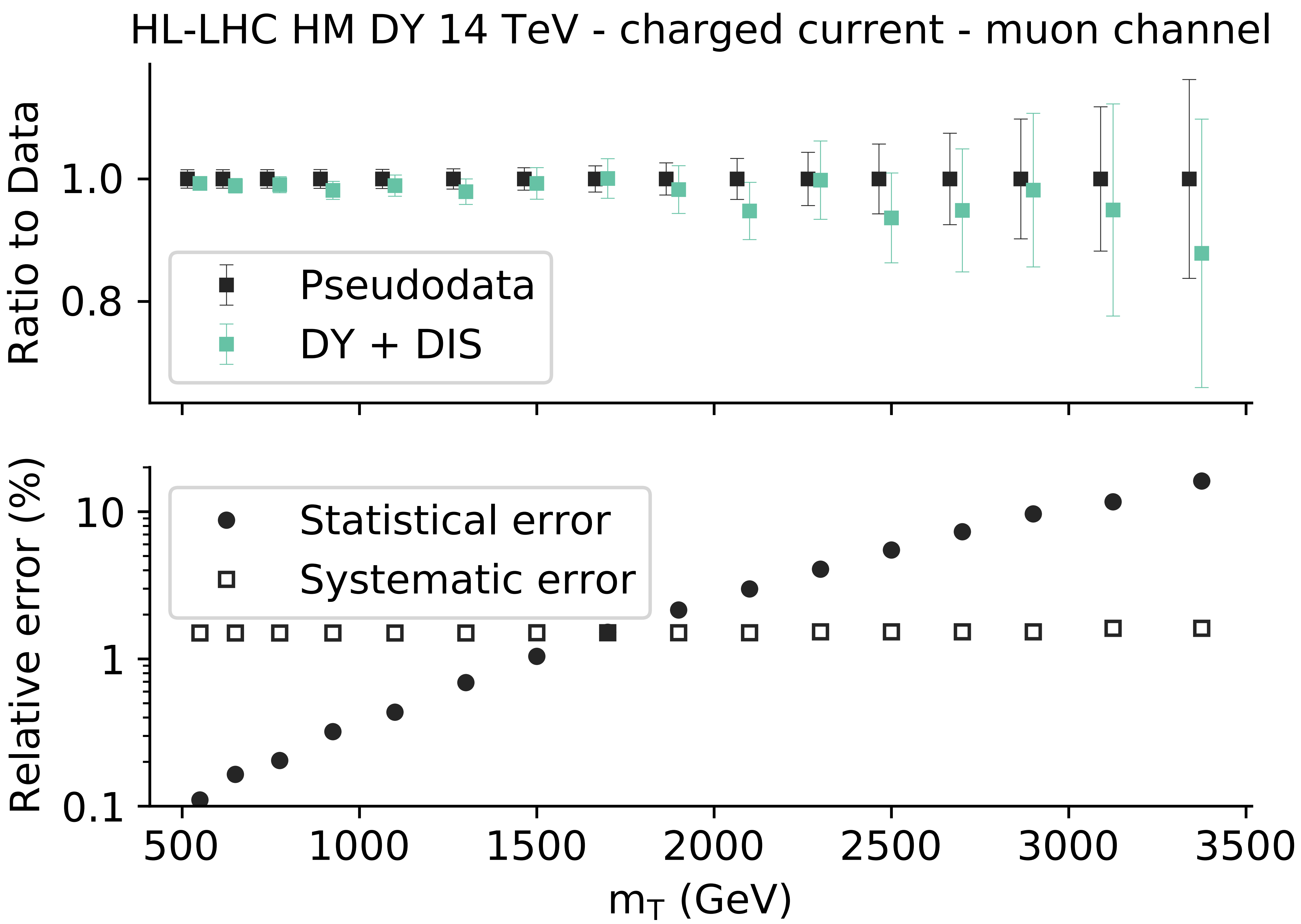
Question raised

Can the SMEFT be **constrained correctly** using SM PDFs?

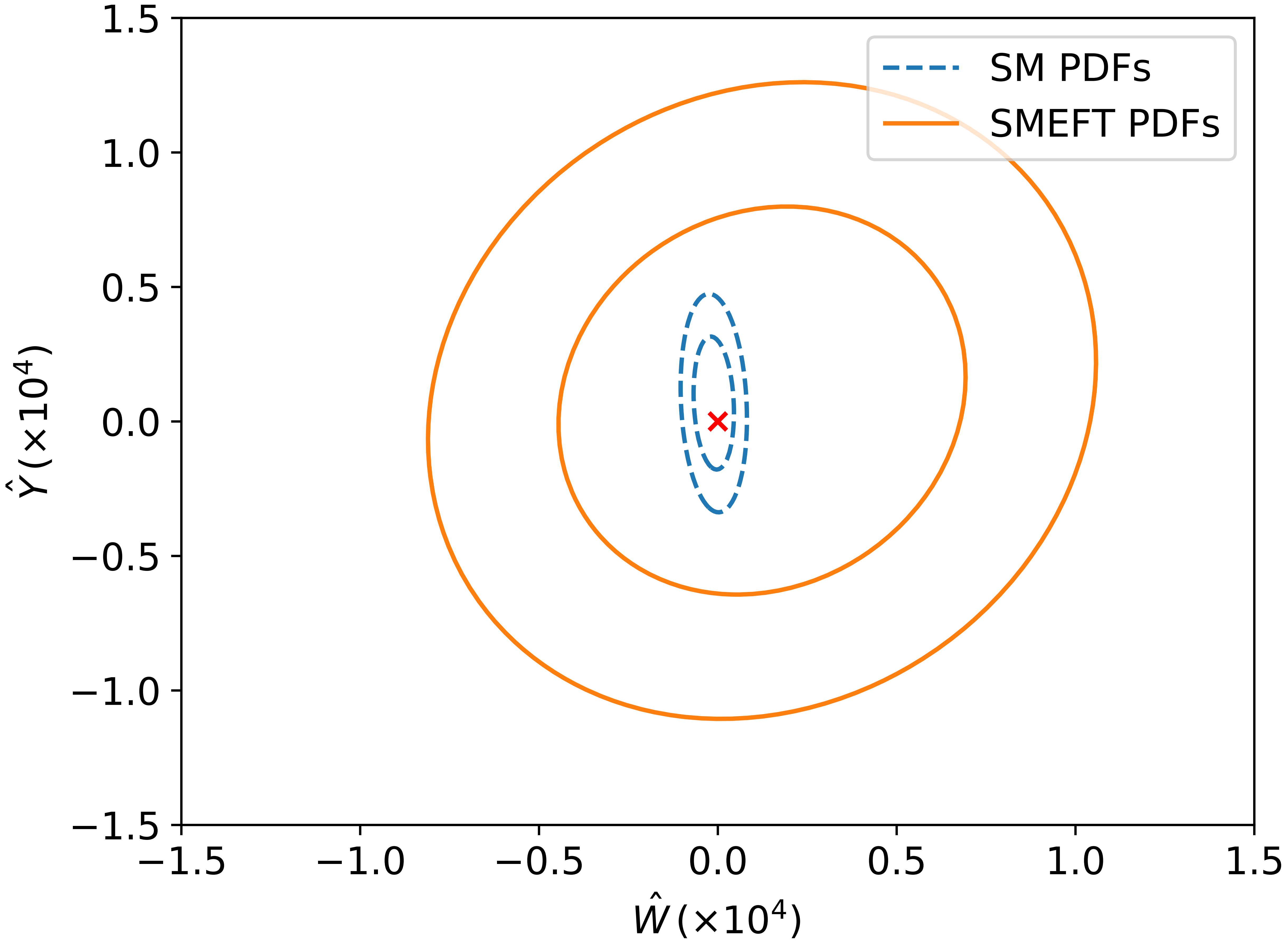
$\rightarrow$ **Future data**

HL-LHC projections

- Consider an **optimistic** scenario
- $\sqrt{s}$ = 14 TeV, $\mathscr{L}$ = 6 ab^{-1}
  $f_{\text{red,sys}}$ = 0.2 (arXiv:1810.03639)
- Data generated via **fluctuating theory**



Results: future data



- 95% CL bounds:

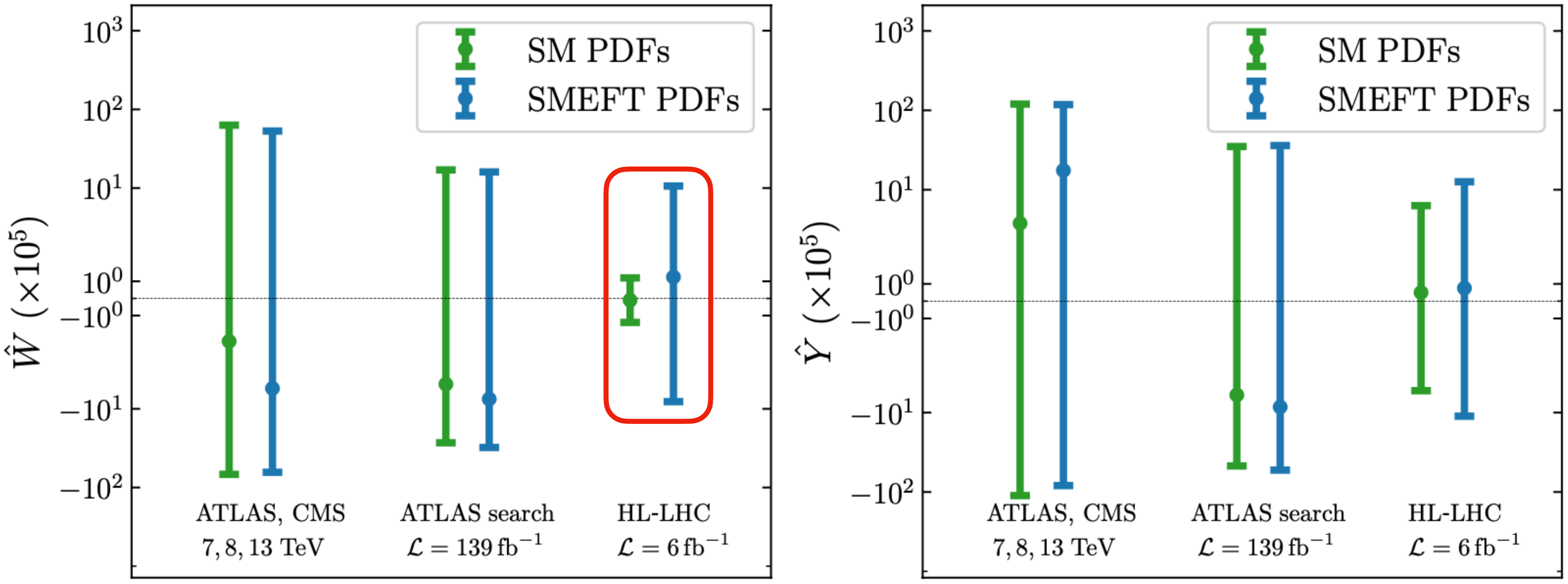
  - **broaden** by **940%** $(\hat{W})$, **190%** $(\hat{Y})$

- PDF unc. included:

  - **broaden** by **620%** $(\hat{W})$, **110%** $(\hat{Y})$

- **Neglecting PDF-EFT interplay** would lead to **significant underestimate** of uncertainty on EFT parameters

Summary



Using **SM PDFs** to find optimal reach leads to **significant underestimate of uncertainties** — **consistent treatment** suggests only **mild improvement versus current bounds**!

Conclusions

Can the SMEFT be **constrained correctly** using SM PDFs?

- **Care must be taken!** Inconsistent use of PDFs can lead to **artificially precise bounds**
- **Ideal** solution is **simultaneous fit of WCs & PDFs**

Next steps

- **Generalise** — e.g. more general EFT scenarios + other processes
- Build **more powerful methodology** — goal: truly simultaneous fit

Thank you for listening!

Backup

Unfolded high-mass Drell-Yan data

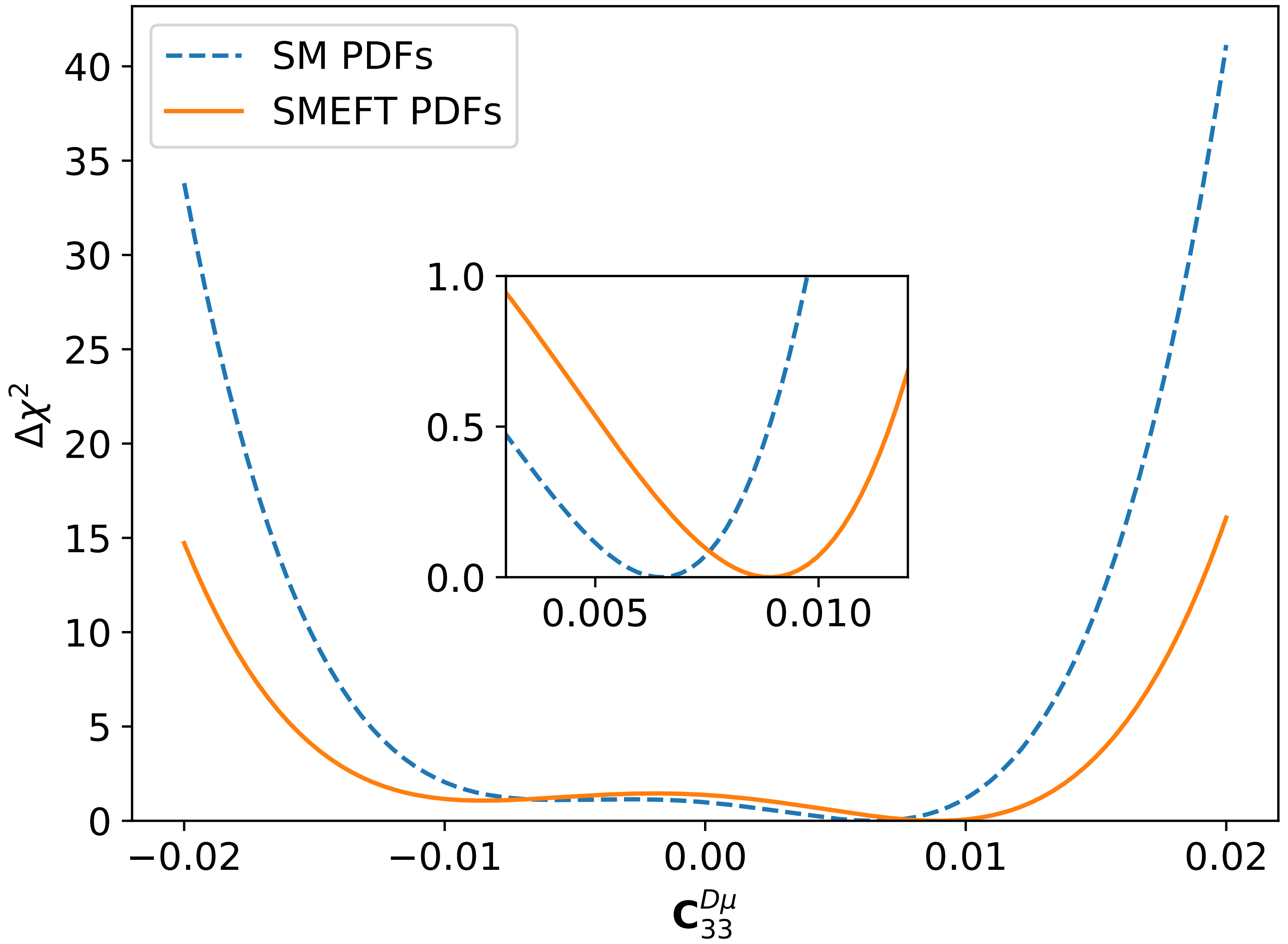
Exp.	$\sqrt{s}$ (TeV)	Ref.	$\mathcal{L}$ (fb^{-1})	Channel	1D/2D	$n_{\rm dat}$	$m_{\ell\ell}^{\rm max}$ (TeV)
ATLAS	7	[118]	4.9	e^-e^+	1D	13	[1.0, 1.5]
ATLAS (*)	8	[84]	20.3	$\ell^-\ell^+$	2D	46	[0.5, 1.5]
CMS	7	[119]	9.3	$\mu^-\mu^+$	2D	127	[0.2, 1.5]
CMS (*)	8	[85]	19.7	$\ell^-\ell^+$	1D	41	[1.5, 2.0]
CMS (*)	13	[120]	5.1	e^-e^+, $\mu^-\mu^+$ $\ell^-\ell^+$	1D	43, 43 43	[1.5, 3.0]
Total						**270 (313)**	

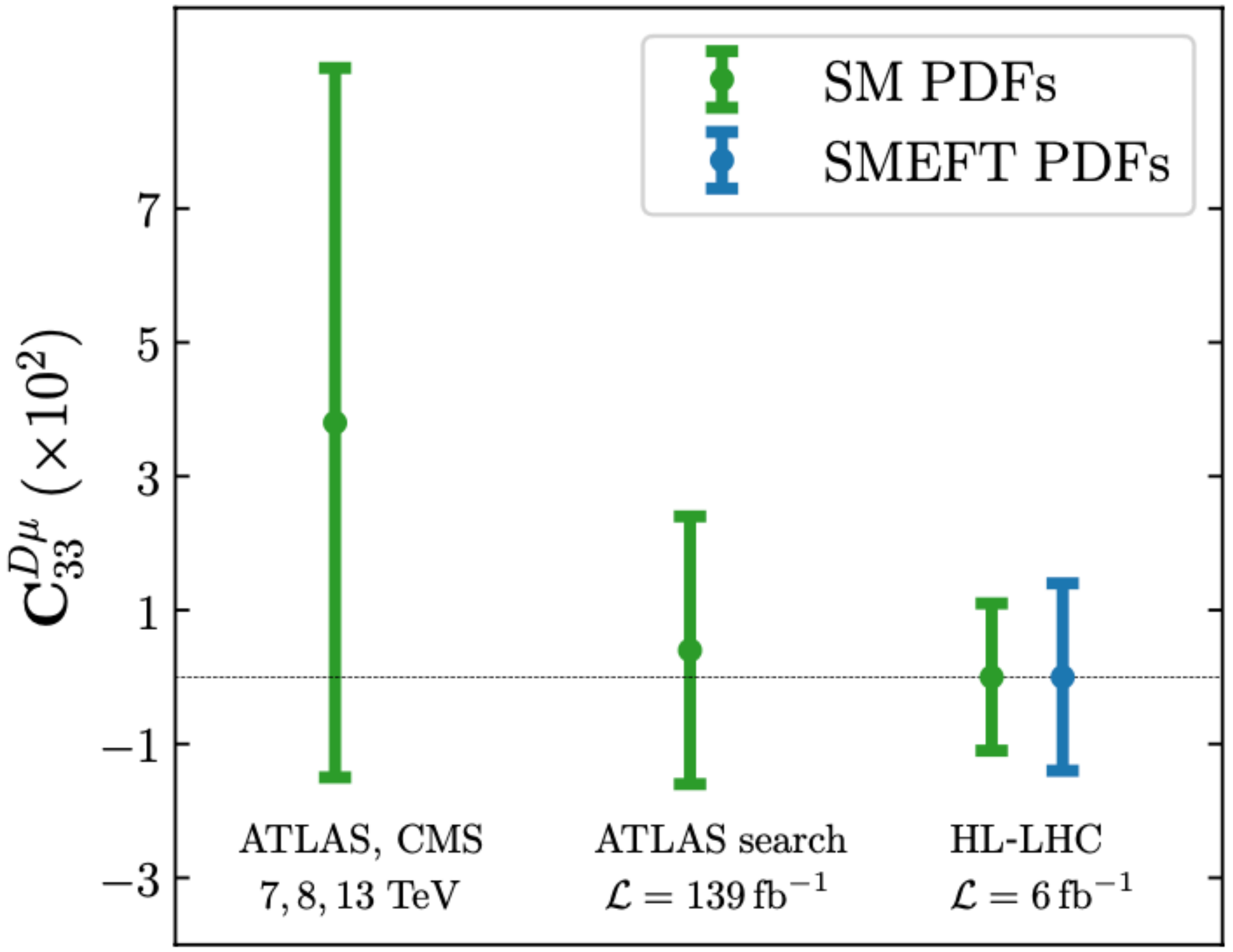
The models: $\text{C}_{33}^{D\mu}$

$$\mathscr{L}_{\text{SMEFT}} \supset \frac{\text{C}_{33}^{D\mu}}{v^2}(\bar{d}_L\gamma_\mu d_L)(\bar{\mu}_L\gamma^\mu\mu_L)$$

- **Left-handed muon-philic lepton-quark interactions**
- Motivated by $R(K^{(*)})$ anomaly

Results: $C_{33}^{D\mu}$

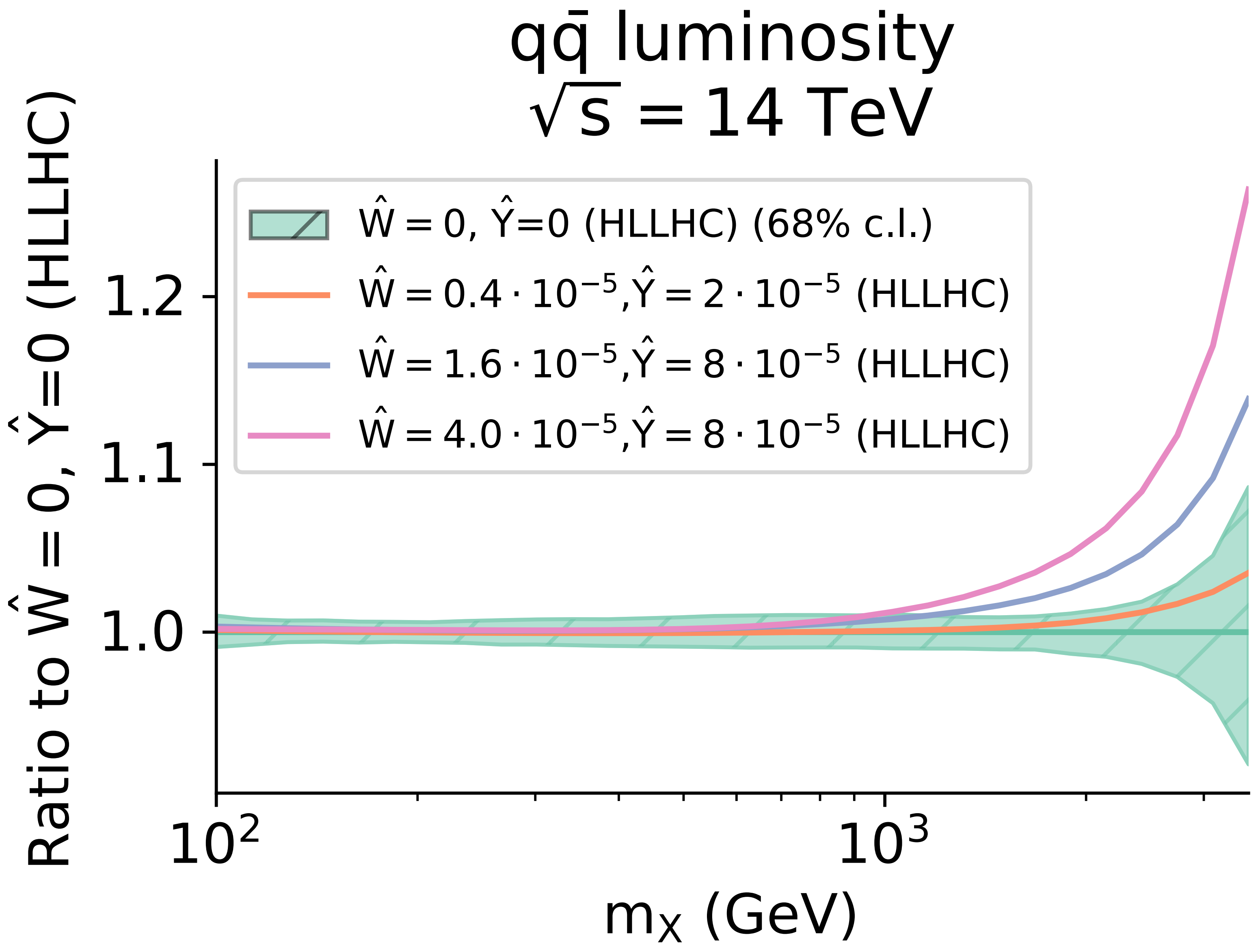


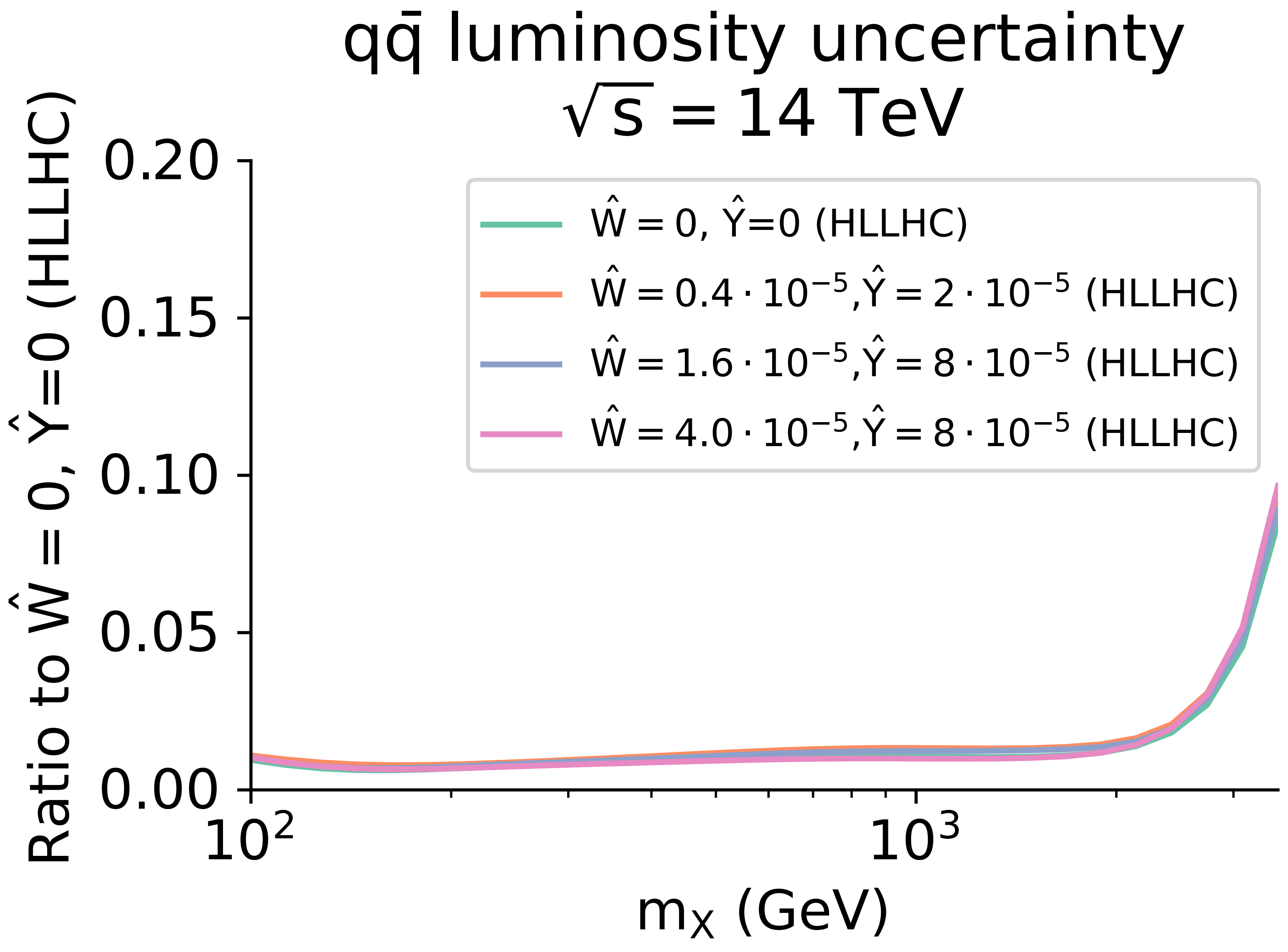


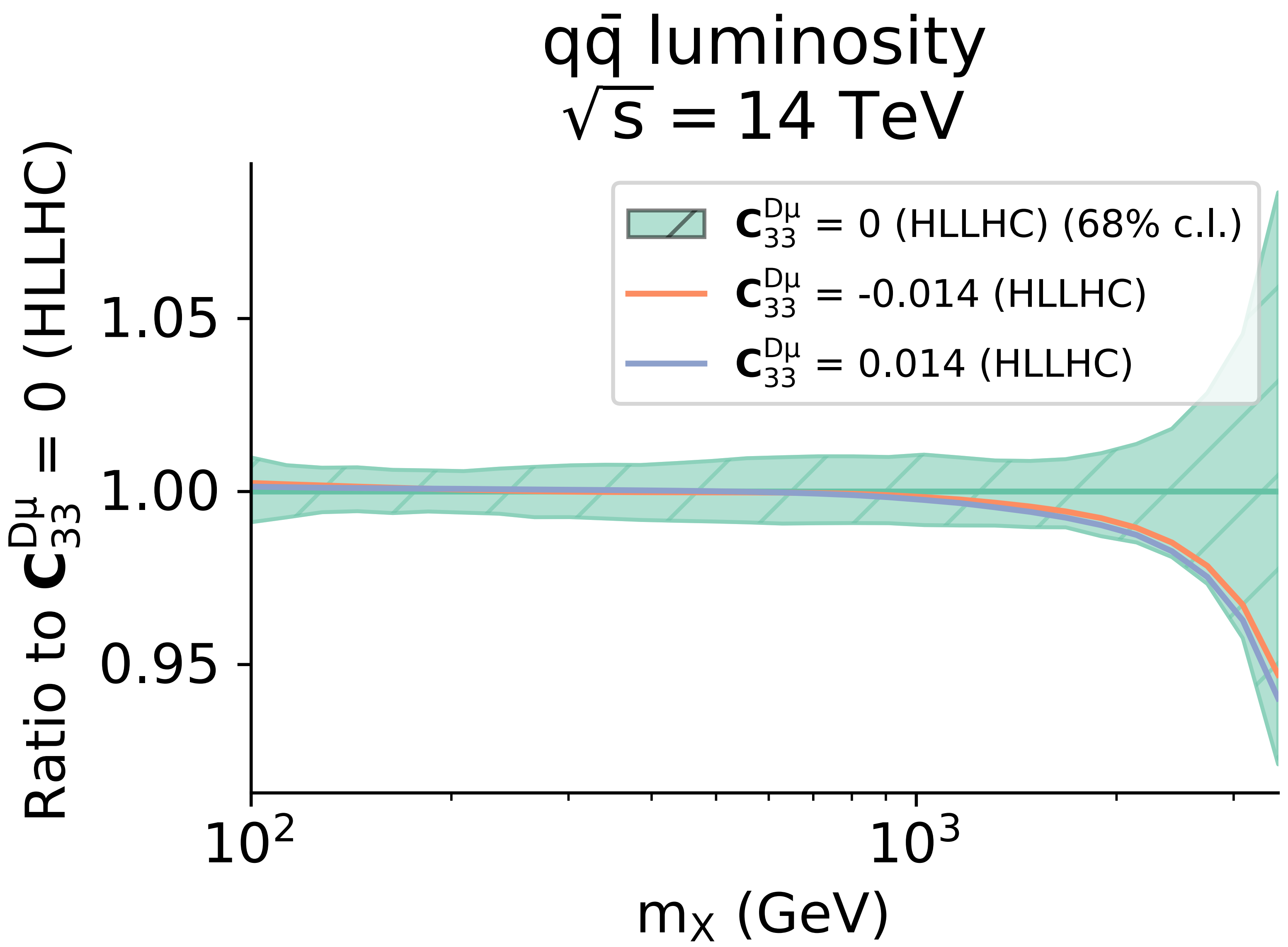
- Little current high-mass muon-only data → look at **projections only**
- 95% CL bounds **broaden** by **27%**
- **Smaller shift** than with $\hat{W}$, $\hat{Y}$

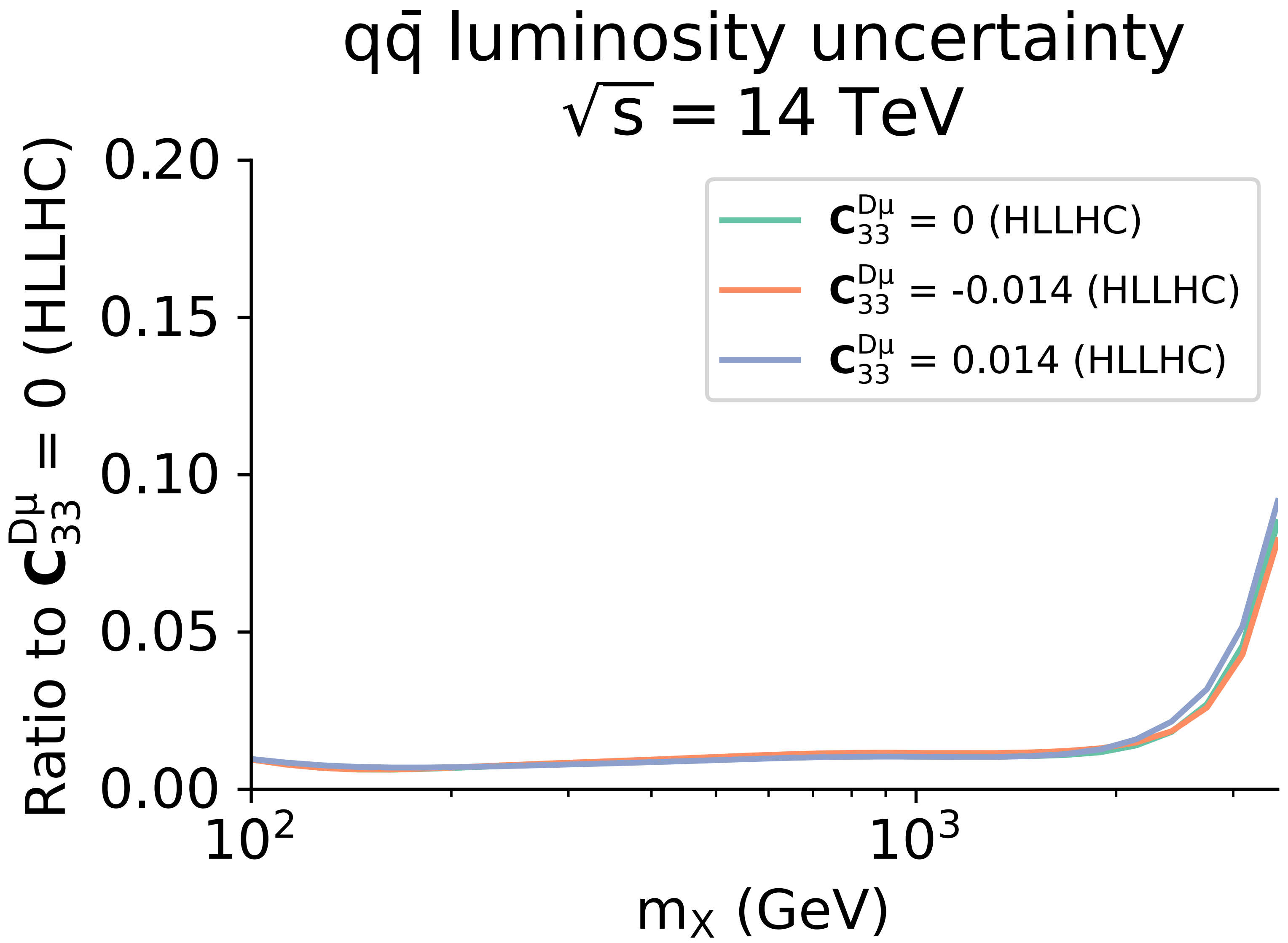
Luminosities (current data)

Luminosities (projections)



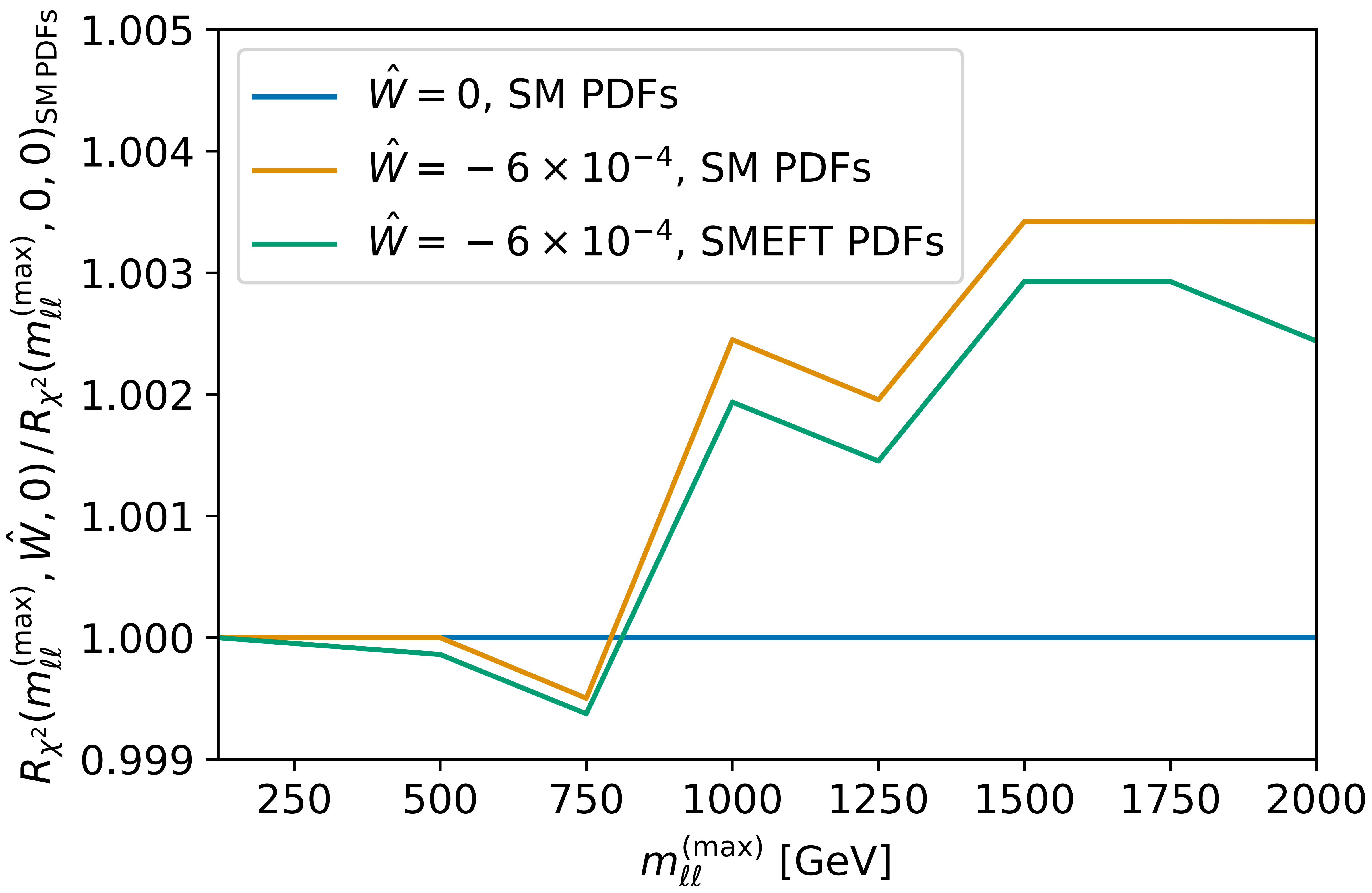


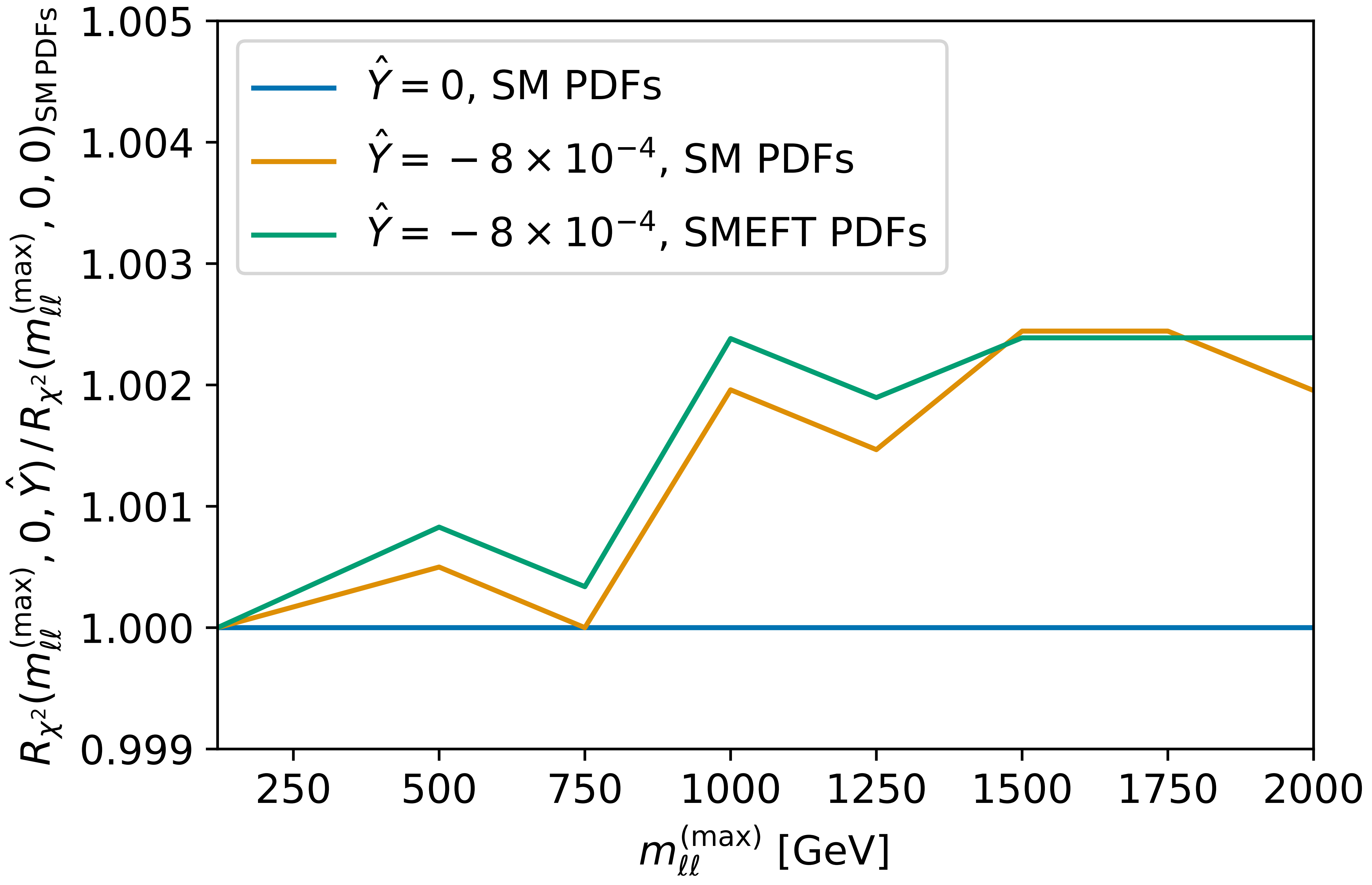




Absorption of new physics effects

$$R_{\chi^2}(m_{\ell\ell}^{(\max)}, \hat{W}, \hat{Y}) \equiv \frac{\chi^2(m_{\ell\ell}^{(\max)}, \hat{W}, \hat{Y})}{\chi^2(120\ \text{GeV}, \hat{W}, \hat{Y})}$$





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