SMEFT ANALYSIS OF LHC DATA

ICFA Seminar 2026

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3 November 2026

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JG|U

Different Scales – Different Degrees of Freedom

Example nucleus

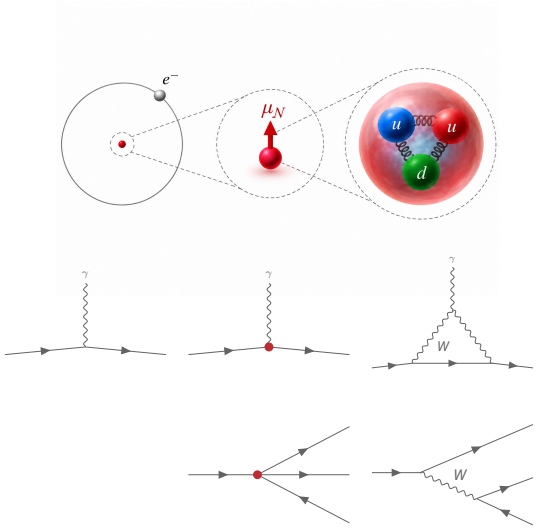
- $R \gg r_N$: point charge
- $R > r_N$: dipole, multipoles
- $R \sim r_N$: new degrees of freedom

Example electroweak interaction

- Low energies: QED + effective *weak* interactions
- Higher energies: resolve SM

How far can we zoom in at the LHC?

- SM + new particles? $\rightarrow$ best case
- SM + anomalous interactions? $\rightarrow$ SMEFT case



The Standard Model Effective Field Theory

SMEFT: SM as *effective* theory at the EW scale

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(5)}}{\Lambda} \mathcal{O}_i^{(5)} + \sum_j \frac{c_j^{(6)}}{\Lambda^2} \mathcal{O}_j^{(6)} + \cdots \text{(often truncate at dim. 6)}$$

Simplifies description: BSM as anomalous interactions of SM particles

- $\mathcal{O}^{(n)}$: Dim.-*n* operators of SM fields
- c_i: Wilson coefficients (interaction strengths)
- Impact suppressed by Λ^{n-4}

A general framework

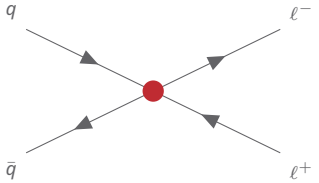
- Few assumptions: heavy BSM particles, SM gauge symmetries
- Predicts patterns of deviations we should look for

Our task at the LHC (in the absence of new particles)

- Constrain 59 $\otimes$ flavour (baryon-conserving) dim.-6 operators
- BSM theories can be *matched* to SMEFT: constrain SMEFT $\Rightarrow$ constrain UV physics

CMS High-Mass Drell–Yan | EFT Analysis

arXiv:2610.04782

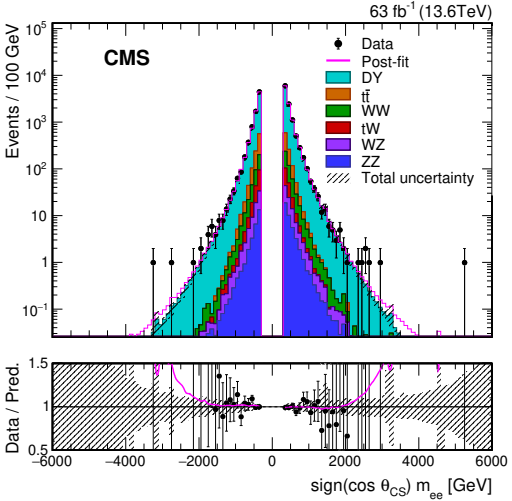


SMEFT analyses at the LHC:

- Constrain general models
- Search for subtle signatures

Example: CMS dilepton EFT search

- Partition $m_{\ell\ell}$ by $\mathrm{sign}(\cos\theta_{\mathrm{CS}})$ $\rightarrow$ chiral coupling sensitivity
- Search for smooth deviation



CMS High-Mass Drell–Yan | EFT Results

arXiv:2610.04782

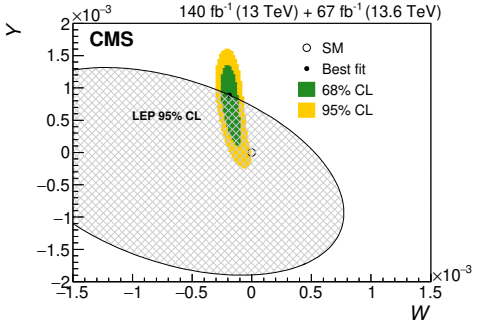
LHC energy can beat LEP precision

- CMS strongly constrains oblique parameters $\mathcal{Y}$ and $\mathcal{W}$
- Map to SMEFT: e.g. $\frac{c_{\ell q}^{(3)}}{\Lambda^2} = -\frac{\mathcal{W}}{v^2}$

Constraints on c/Λ^2, not both c and Λ
May report:

- Limits on c for fixed Λ
- Lower bounds on Λ for fixed c

BSM mass reach depends on coupling strength *and* SMEFT direction



Includes high-mass $\ell\nu$ constraint JHEP 07 (2022) 067

Implied lower bounds on Λ for fixed $|c|$

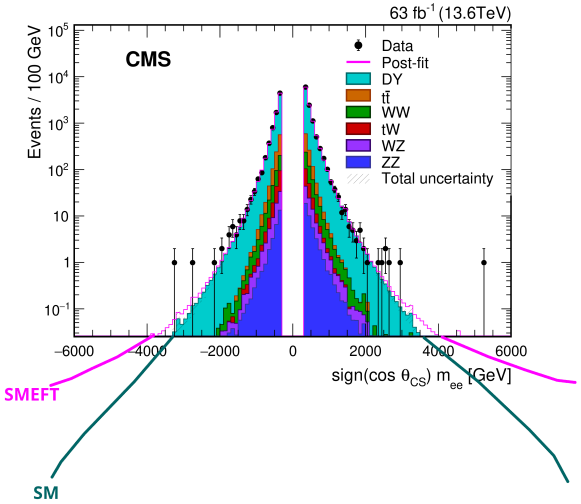
$\lvert c\rvert$	1	0.1	0.01
$\Lambda_{\min}$	~ 20 TeV	~ 6 TeV	~ 2 TeV

CMS High-Mass Drell–Yan | EFT Validity

arXiv:2610.04782

Energy and validity

- High-energy regions improve SMEFT constraints

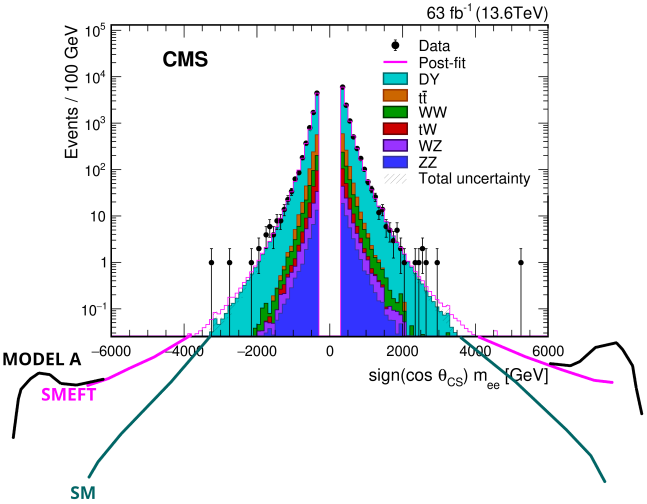


CMS High-Mass Drell–Yan | EFT Validity

arXiv:2610.04782

Energy and validity

- High-energy regions improve SMEFT constraints
- SMEFT can be a good approximation



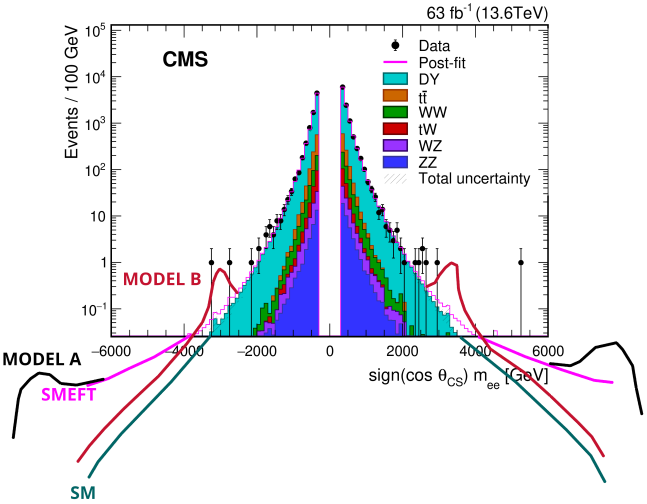
CMS High-Mass Drell–Yan | EFT Validity

arXiv:2610.04782

Energy and validity

- High-energy regions improve SMEFT constraints
- SMEFT can be a good approximation
- But not if $m_{\ell\ell} \sim M_{\text{BSM}}$

SMEFT validity depends on probed energy *and* UV model



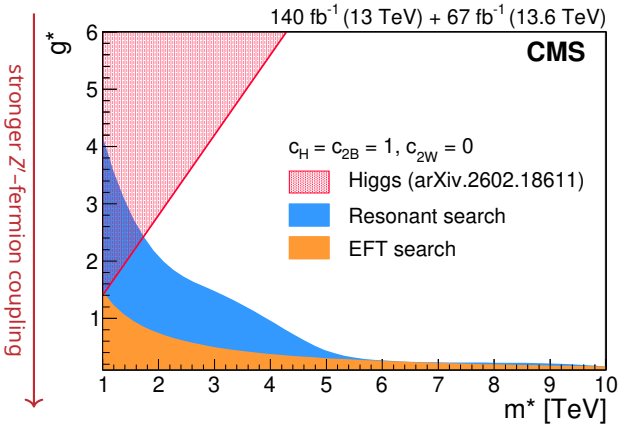
CMS High-Mass Drell–Yan | UV Models

arXiv:2610.04782

Directly comparing models to data remains important

- CMS tests a composite Higgs model with Z'
- SMEFT agrees with model for $M_{Z'} \gtrsim 6\ \mathrm{TeV}$

Higgs combination arXiv:2602.18611 provides complementary SMEFT constraints



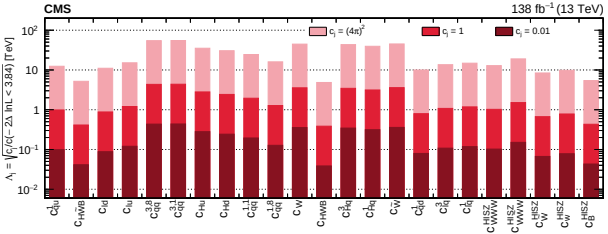
CMS High-Mass Dibosons

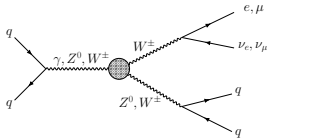
arXiv:2608.18245

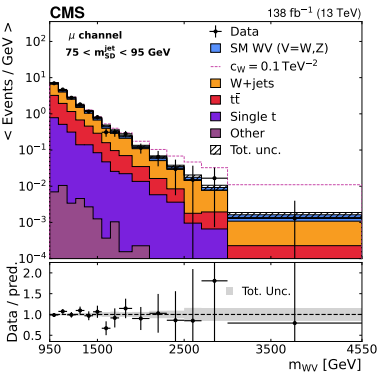
CMS semileptonic diboson measurement

- Offers stringent constraints on anomalous triple gauge, Vqq, and $4f$ couplings
- Limits up to 2–3 TeV scale for $|C| \sim 1$

Measurement scale $\sim \Lambda$-constraint:
lower precision $\Rightarrow$ narrower EFT validity







ATLAS Single-Top | Four-Angle Analysis

JHEP 07 (2026) 107

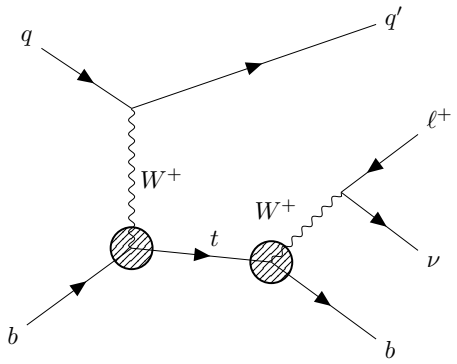
Use more than just high-energy tails:

- High precision
- Novel kinematic features

SMEFT guides construction of BSM-sensitive observables

Example:
ATLAS single-top four-angle analysis

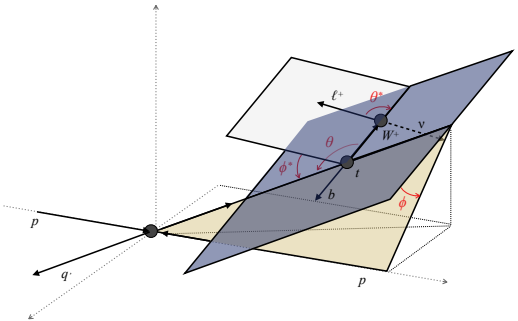
- Precision study of *W-tb* vertex
- Sensitive to top-specific and mass-enhanced operators



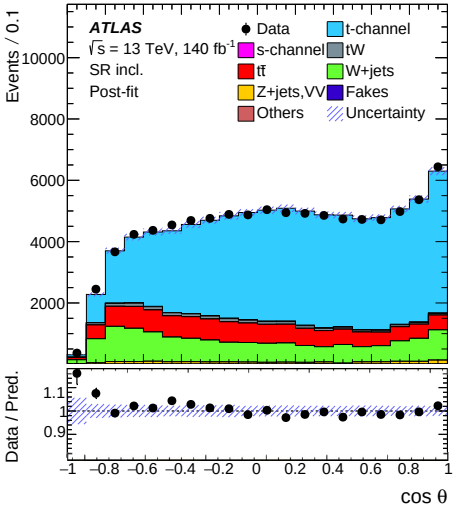
$\mathcal{O}_{tW}, \mathcal{O}_{bW}, \mathcal{O}_{\varphi tb}, \mathcal{O}^{(3)}_{\varphi Q}$

ATLAS Single-Top | Angular Observables

JHEP 07 (2026) 107



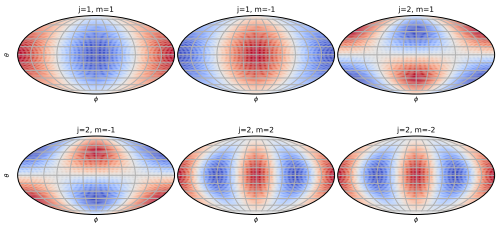
- Simultaneous analysis of four top-quark decay angles

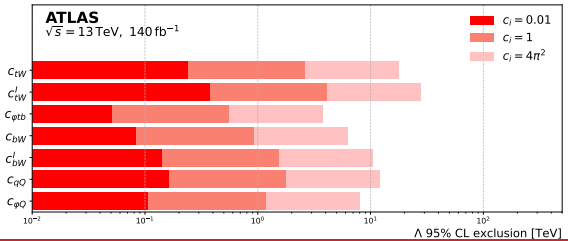


ATLAS Single-Top | Results

JHEP 07 (2026) 107

- 4D angular distribution projected onto orthogonal angular functions
- 23 angular coefficients measured in 4 SRs
- Constrains 7 SMEFT parameters
- Sensitivity up to $\Lambda \sim 3$ TeV – with EW-scale energies
- Overall SM-compatible



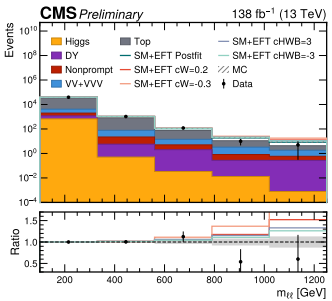


CMS Gauge-Coupling Combination | Inputs

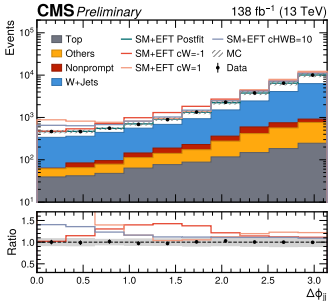
CMS-PAS-SMP-25-002

Combinations also improve sensitivity

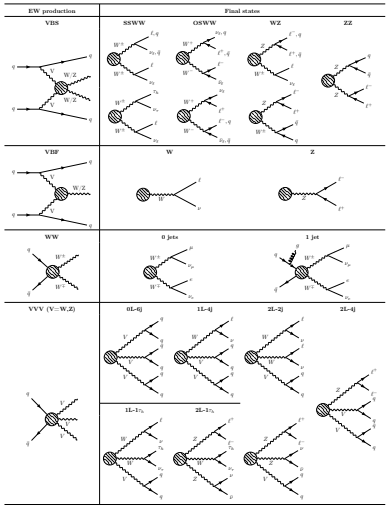
- Small deviations across observables may combine into a significant excess
- Example: CMS gauge-coupling combination of 10 VBS, VBF, *W* and *WW* measurements



$m_{\ell\ell}$ in *WW* SR

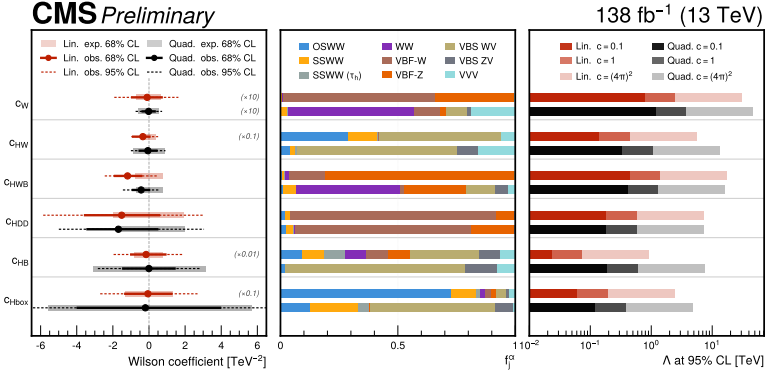


$\Delta\phi_{jj}$ in VBF *W* SR



CMS Gauge-Coupling Combination | Results

CMS-PAS-SMP-25-002



- Measurements compatible with SM
- All processes contribute to constraints
- Combined sensitivity competitive with semileptonic high-energy search

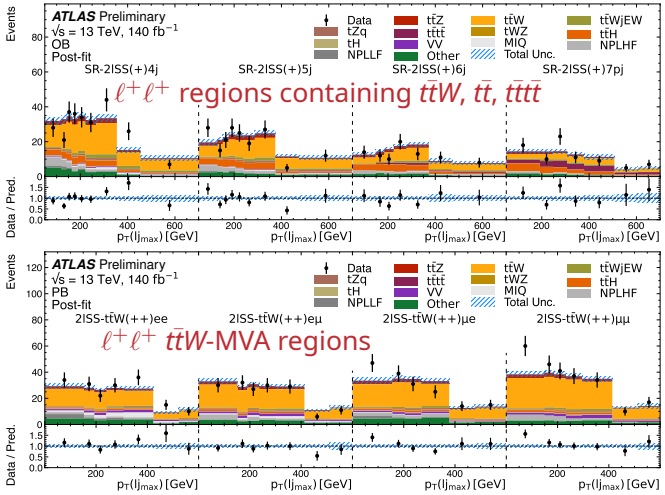
ATLAS Top+X Combination

To Appear

Overlapping signals require careful combination

- Signal in one measurement can be background in another
- Example: ATLAS top+X analysis performs coherent measurement of $t(t) + X$ processes
- Compares strategies: object based selection vs. MVA-based SRs

Similar CMS result: JHEP 12 (2023) 068

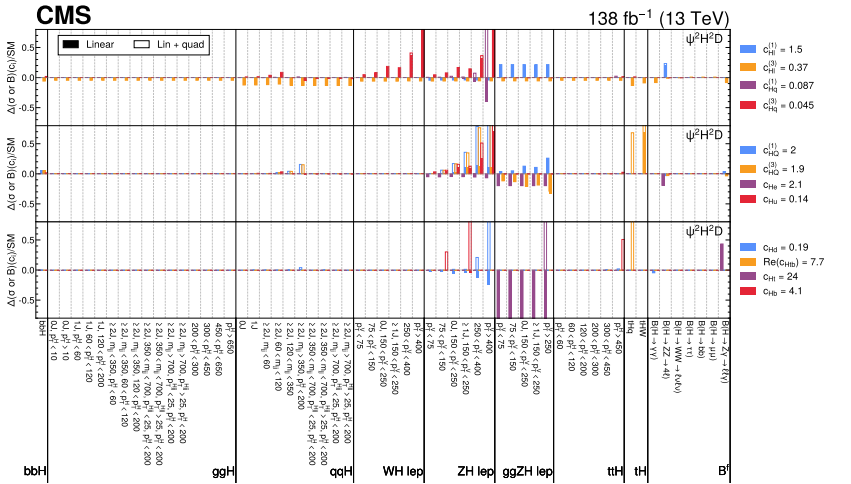


CMS Higgs Combination | SMEFT and STXS

Rep. Prog. Phys. 89 (2026) 087801

Higgs boson demands comprehensive combinations

- CMS Higgs combination considers 43 WCs (only 12 shown)
- Impact production and decay
- Effects kinematics-dependent



CMS Higgs Combination | Results

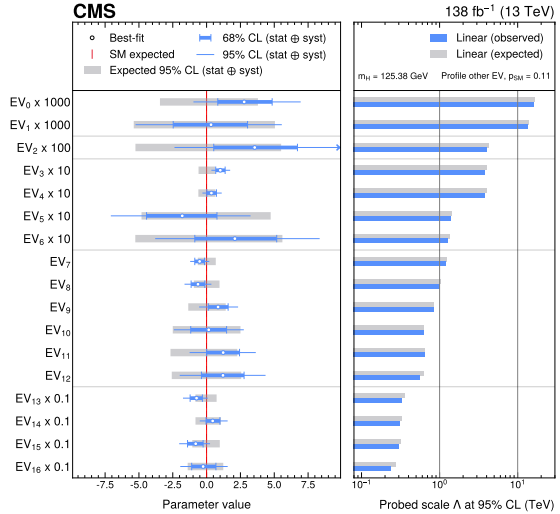
Rep. Prog. Phys. 89 (2026) 087801

Not all 43 SMEFT directions can be constrained independently:

- PCA identifies measurable combinations
- CMS constrains 17 directions
- All compatible with SM
- Strongest directions driven by $gg \to H \to \gamma\gamma$ constrain $\Lambda \sim 10\,\mathrm{TeV}$

We probe different SMEFT directions with vastly different sensitivity

Similar ATLAS result arXiv:2608.07332



ATLAS Global Combination | Inputs

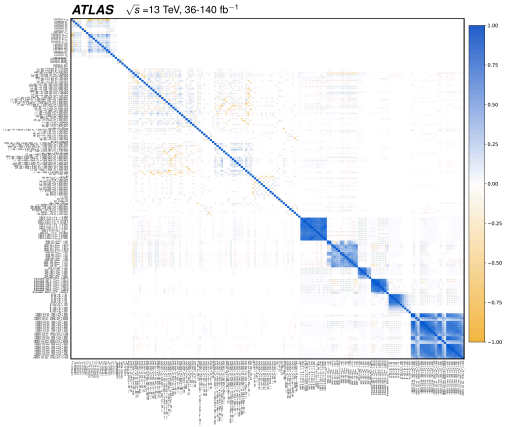
JHEP 07 (2026) 238

SMEFT connects measurements across different physics sectors

ATLAS global fit includes

- Higgs production (STXS) and decays
- Di-Higgs: $HH \to b\bar{b}\gamma\gamma,\ b\bar{b}\tau\tau$
- WW, WZ, electroweak Zjj
- High-mass Drell–Yan ($\ell\nu$, $\tau\tau$)
- $t\bar{t}$ (resolved and boosted)
- LEP/SLD and ATLAS precision observables

Similar CMS combination EPJC 86 (2026) 331



Correlations among ~ 180 signal strengths

ATLAS Global Combination | Results

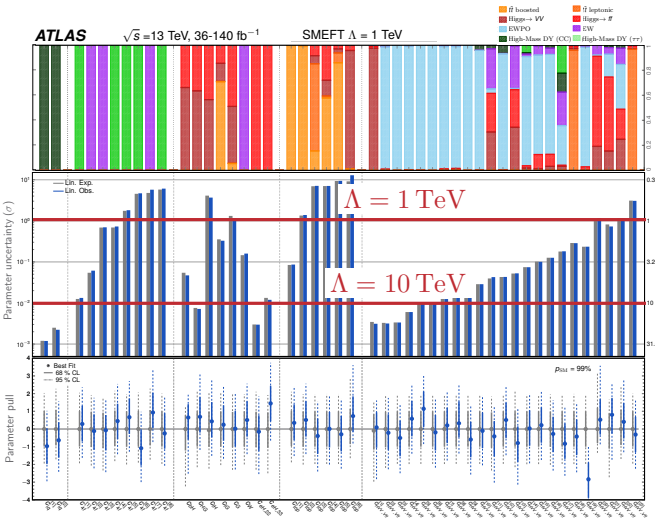
JHEP 07 (2026) 238

43 directions probed; highest sensitivity ($\Lambda_{\text{min}} > 10\,\text{TeV}$):

- High-mass DY
- $gg \to H$
- $H \to \mu\mu, \gamma\gamma$
- Precision observables: $M_Z, M_W, G_\mu, \Delta\alpha, \Gamma_Z, A_\ell$, ...

SMEFT also connects colliders – and beyond
$\to$ LEP/SLD precision remains important

SM-compatible: $p_{\text{SM}} = 99\%$



Similar Analyses from the Last 12 Months

Showed only a few recent examples from wealth of recent measurements!

- *CMS dijets:* triple-gluon O_G from dijet angles [PLB 882 (2026) 140964]
- *CMS boosted VVV:* dim.-6 and dim.-8 EFT [arXiv:2605.15023]
- *ATLAS $W\gamma$:* NN-enhanced CP-odd sensitivity [arXiv:2603.22478]
- *ATLAS EW Wjj:* Strong linear aTGC EFT [arXiv:2607.21531]
- *CMS EW ZZjj:* dim.-8 aQGC limits [arXiv:2606.20558]
- *CMS top FCNC:* 24 coefficients in joint fit [arXiv:2608.19547]
- *CMS 3-/4-top:* four-heavy-quark and top–Higgs SMEFT [arXiv:2606.30862]
- *ATLAS tZq:* differential observables and polarization [arXiv:2608.25476]
- *ATLAS EW $t\bar{t}Wj$: tW*-scattering search [PRD 114 (2026) 012001]
- *ATLAS t-channel top:* differential, one four-quark coefficient [JHEP 05 (2026) 174]
- *ATLAS $t\bar{t}H + tH$:* top-Yukawa CP mixing (not Warsaw SMEFT) [arXiv:2606.04855]
- *CMS $H \to 4\ell$:* eight anomalous *HVV* couplings, spin [CMS-PAS-HIG-25-011]
- *CMS off-shell $H \to ZZ$:* gluon-fusion SMEFT, compositeness [arXiv:2607.23352]
- *CMS $H \to \gamma\gamma$:* anomalous HVV/Hgg tensors and CP [arXiv:2605.14245]
- *CMS $H \to \tau\tau$:* Yukawa CP mixing (not Warsaw EFT) [JHEP 10 (2026) 084]
- *ATLAS $HH \to b\bar{b}\gamma\gamma$:* SMEFT and HEFT [ATL-PHYS-PUB-2025-034]
- *ATLAS Run-3 $H \to ZZ^*$:* differential/STXS; SMEFT [JHEP 08 (2026) 052]
- *ATLAS Higgs CP:* three CP-odd *HVV* Warsaw coefficients [PRL 137 (2026) 021801]
- *ATLAS VBS + triboson:* quartic-gauge dim.-8, validity [PLB 879 (2026) 140683]
- *ATLAS Higgs STXS:* 20 sensitive SMEFT directions [arXiv:2608.07332]

Conclusion

SMEFT: model-independent framework for indirect BSM searches

- Multi-TeV sensitivity from high energy, precision, and tailored observables
- High LHC energies can challenge EFT validity

SMEFT connects sectors and colliders

- Combinations improve sensitivity and lift degeneracies; correlations matter
- LEP/SLD precision remains important; flavour physics provides further constraints

No compelling BSM signal so far

- Run 3 and HL-LHC: higher precision, new observables $\Rightarrow$ probe deeper and wider
- Global SMEFT constraints may become a lasting LHC legacy

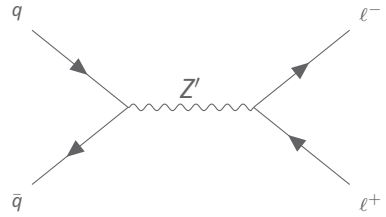
New experiments can extend mass reach and coverage

- SMEFT provides framework for benchmarks
- Includes not only collider experiments (e.g. proton decay)

BACKUP

CMS High-Mass Drell–Yan | Direct Search

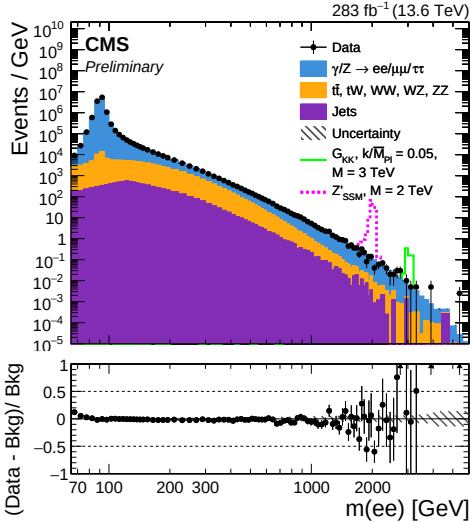
CMS-PAS-EXO-25-021



For comparison: direct search for heavy BSM

- Concrete simple models
- Clear signature

Example: CMS dilepton resonance search
→ discussed by Seema



Principal Component Analysis

