Effective field theory interpretation of CMS data

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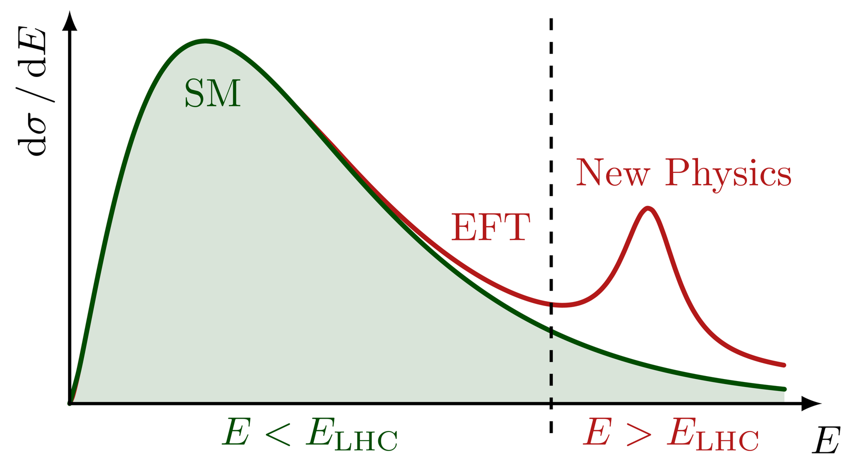
Indirect searches for physics beyond the Standard Model

- There are several phenomena the standard model of particle physics (SM) can not explain, such as gravity, dark matter, neutrino masses, ...

→ we know there must be *some* unknown theory beyond the standard model (BSM) that can explain these observations

- The LHC at CERN allows us to search for new particles with masses up to a few TeV, but none have been found so far
- Maybe BSM particles are just too heavy to be produced at the LHC? 🤔

→ look for indirect evidence of BSM physics via deviations in precision measurements of known SM processes



SM Effective Field Theory

One way to do this: The Standard Model Effective Field Theory (SMEFT)

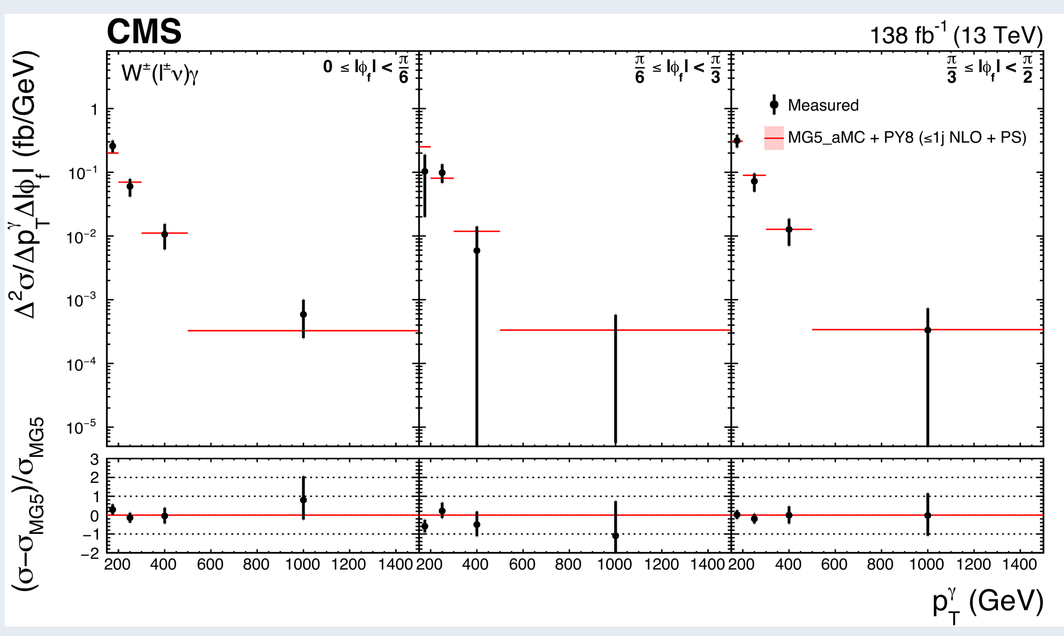
$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{d,i} \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{Q}_i^{(d)}$$

- A consistent and model independent way to parametrise deviations in all SM processes
- Constraints on Wilson coefficients c_i can then be matched to limits on parameters in BSM theories

1) Measurement

- Measure differential cross section of a process that is potentially sensitive to BSM effects
- Compare the measurement to theoretical predictions (assuming the SM)

For example, pp → Wγ (sensitive to modified triple gauge coupling: $\mathcal{Q}_W = \varepsilon^{ijk} W_\mu^{i\nu} W_\nu^{j\rho} W_\rho^{k\mu}$)

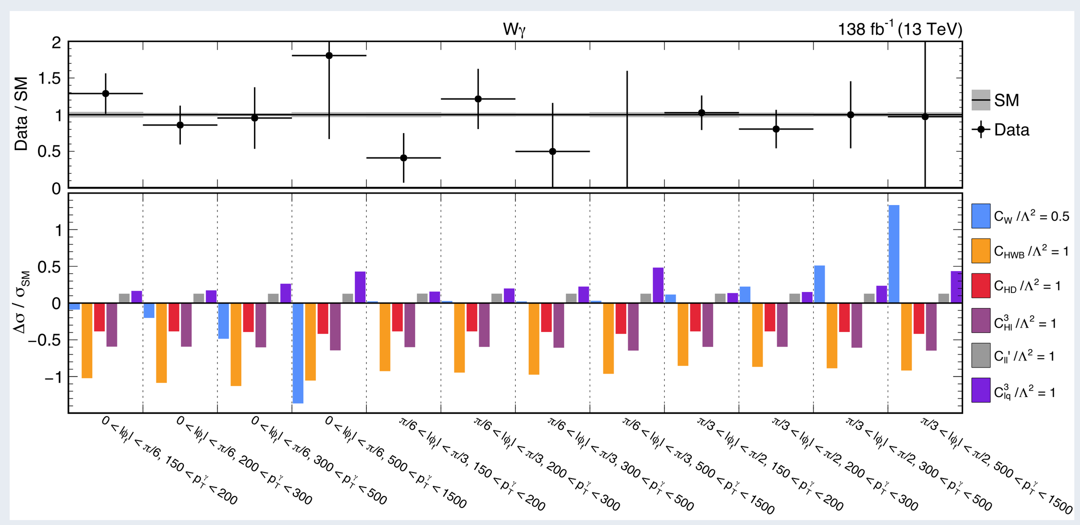


2) Parameterization

- SMEFT operators modify the SM cross section

$$\sigma_{\text{total}} = \sigma_{\text{SM}} + \sum_j \frac{c_j}{\Lambda^2} \sigma_j^{\text{int.}} + \sum_{j,k} \frac{c_j c_k}{\Lambda^4} \sigma_{jk}^{\text{BSM}}$$

- The terms $\sigma_j^{\text{int.}}$ and σ_{jk}^{BSM} are computed using simulated data (`MG5_aMC@NLO` + `SMEFTsim3`)



3) Fit

- Construct a likelihood model based on the number of observed and predicted events in each bin (1), their uncertainties, and the SMEFT parameterization (2)

$$L = \prod_i \text{Pois}\big(n_i \big| s_i(\vec{c}, \vec{\nu}) + b_i(\vec{\nu})\big) \prod_k p_k(\hat{\nu}_k | \nu_k)$$

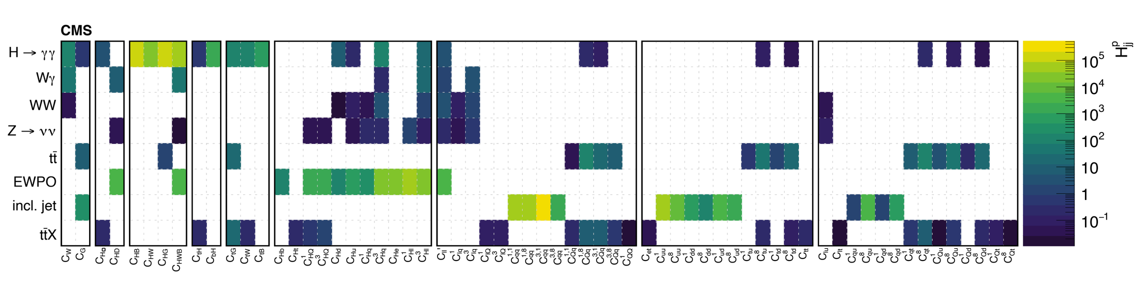
– $\vec{c}$: Wilson coefficients; $\vec{\nu}$: nuisance parameters corresponding to systematic uncertainties
– n_i: observed number events in bin i
– s_i, b_i: predicted number of signal and background events in bin i, for given values of $\vec{c}$ and $\vec{\nu}$

- Run a maximum likelihood fit and determine the best fit values of the Wilson coefficients and their confidence intervals

CMS SMEFT Combination

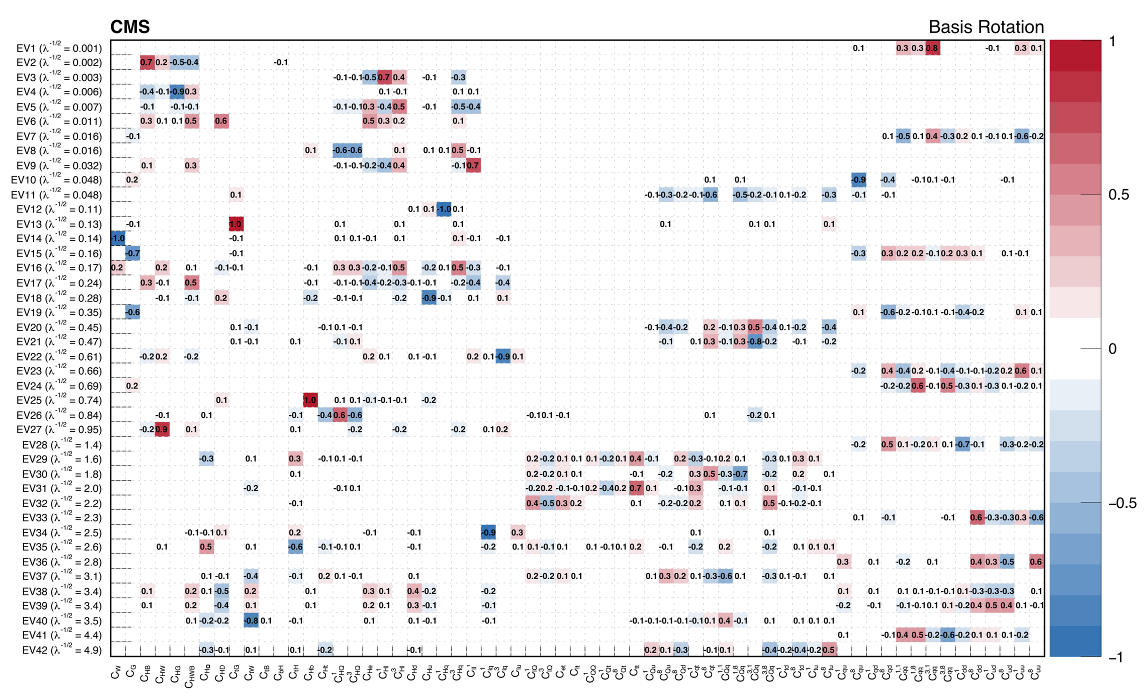
- We combine seven sets of CMS measurements and electroweak precision observables (EWPO) measured at LEP and SLC
  – Higgs sector: H → $\gamma\gamma$
  – Top sector: $t\bar{t}$, $t\bar{t}X$
  – Electroweak sector: Wγ, WW, Z → $\nu\nu$, EWPO
  – Strong sector: inclusive jet
- Inputs were selected to provide sensitivity to a broad set of SMEFT operators (64 in total), have negligible overlap in event selections, and small background contributions

Which input channel is sensitive to which operators:



Basis rotation

- Not enough data to constrain all 64 Wilson coefficients in a simultaneous fit (many are strongly correlated)
- Use Principal Component Analysis (PCA) to identify linear combinations of Wilson coefficients that can be constrained simultaneously



Future plans

- Add more existing measurements to combination (e.g. other Higgs decay modes, B-physics, ...)
- Dedicated analyses that target specific operators

→ we recently started work on a triple-differential Drell-Yan analysis targetting 2-quark-2-lepton SMEFT operators (indirect sensitivity to Z' models)

Reference: CMS Collaboration, *Combined effective field theory interpretation of Higgs boson, electroweak vector boson, top quark, and multi-jet measurements*

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