Effective Field Theory interpretation of Higgs & weak boson measurements with ATLAS data & LEP precision observables

Heavy particles beyond direct reach subtly affect kinematics of current measurements
EFT provides a framework to probe for indirect signs of new phenomena by extending the SM

A common Lagrangian

SMEFT is a low-energy description of a fundamental theory at energy scale $\Lambda \gg \langle v \rangle, E$
Lagrangian consists of higher dimensional operators $\{\mathcal{O}_i^d(d>4)\}$ & captures all allowed local contact interactions with known symmetries

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(5)}}{\Lambda} O_i^{(5)} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \dots$$

$\propto \frac{1}{\Lambda^0}$

Weinberg operator violates Baryon & Lepton no. Λ ~ Majorana ν mass scale

2499 SMEFT operators at dimension 6 with $\Delta L, \Delta B = 0$

Wilson Coefficients *parameters of interest*

Operators defined in Warsaw basis (2499 operators) $\xrightarrow{\text{flavour symmetry}}$ (182 operators)

dedicated operators affecting t,b quarks, same effects for leptons & other quark generations

Allows to probe indirect signs of new physics in a model-agnostic manner

Operator impact on measurements

SMEFT parameterisation of kinematic bins given as polynomial in Wilson coefficients:

Matrix element relation

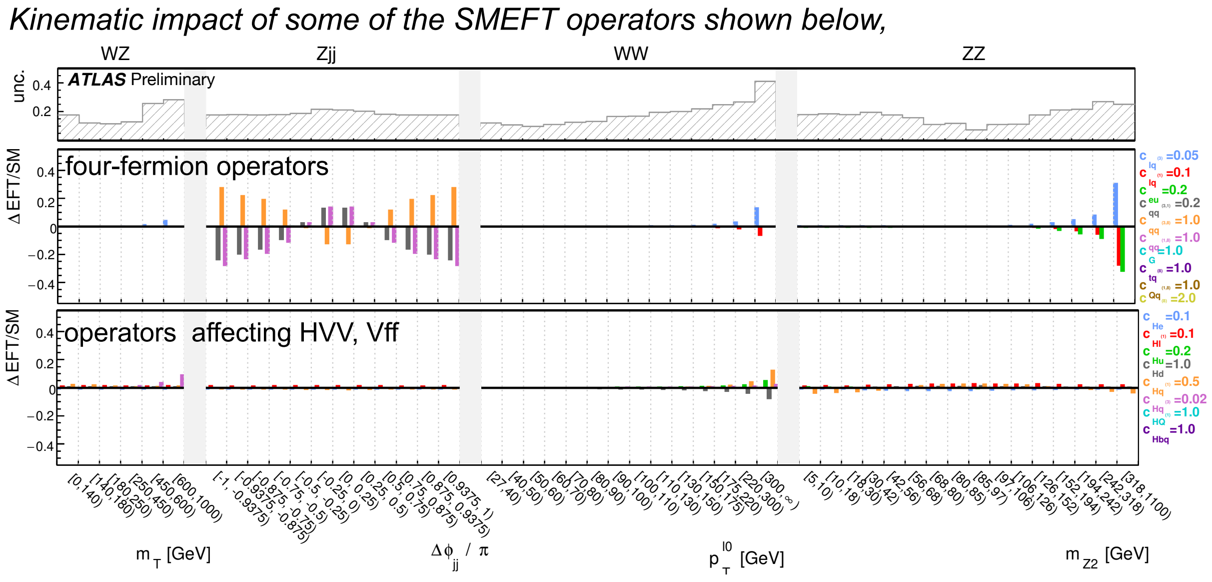
$$\sigma = |\mathcal{A}_{\text{SMEFT}}|^2$$
$$= |\mathcal{A}_{\text{SM}}|^2 + \sum_i \frac{c_i^{(6)}}{\Lambda^2} 2\text{Re}\left(\mathcal{A}_i^{(6)}\mathcal{A}_{\text{SM}}^*\right) + \sum_i \frac{\left(c_i^{(6)}\right)^2}{\Lambda^4}\left|\mathcal{A}_i^{(6)}\right|^2 + \sum_{i<j} \frac{c_i^{(6)}c_j^{(6)}}{\Lambda^4} 2\text{Re}\left(\mathcal{A}_i^{(6)}\mathcal{A}_j^{(6)*}\right) + \dots,$$

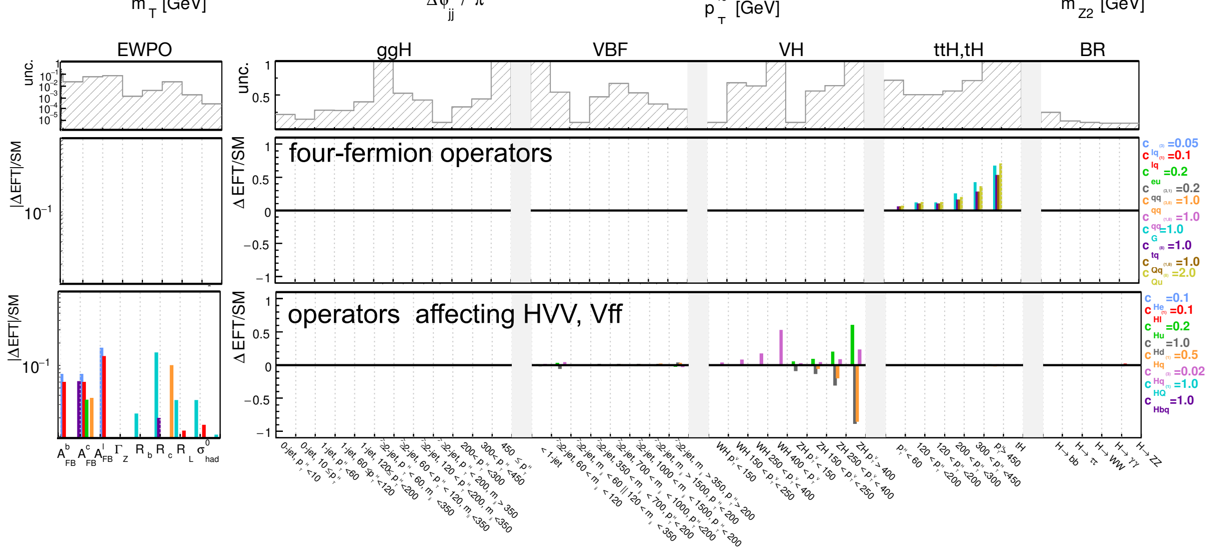
Linear — **Quadratic** — *+ missing interference of d=8 with SM*

Terms suppressed further in $1/\Lambda^{d>4}$

Parameterisation derived from both MC simulations and analytical predictions :
- Predictions for tree-level EFT insertion with SMEFTsim 3.0
- SMEFTatNLO to resolve important loop contribution ($gg \to ZH, gg \to H, H \to gg$)
- Analytical predictions for H $\to \gamma\gamma$ and EWPO observables

62 operators relevant for processes considered in this analysis
Kinematic impact of some of the SMEFT operators shown below,





Many operators affect measurements with similar impact, cannot distinguish individually

Inputs to the combination

Electroweak precision observables (EWPO) from Z-resonance data from LEP & SLC

Kinematic information of Higgs production from 5 decay channels, measured in the simplified cross-section framework

Unfolded differential measurements of di-boson (WW, WZ, ZZ) & Z-boson (Z+2jets)

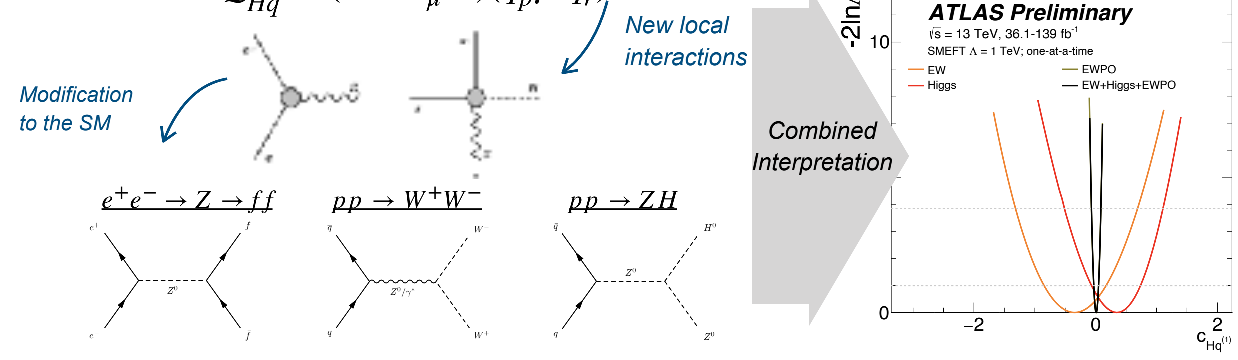
Remove categories with overlapping event selections across different analyses
Common treatment for systematics sources of uncertainties

ATLAS Run-2 measurements

One model to interpret them all

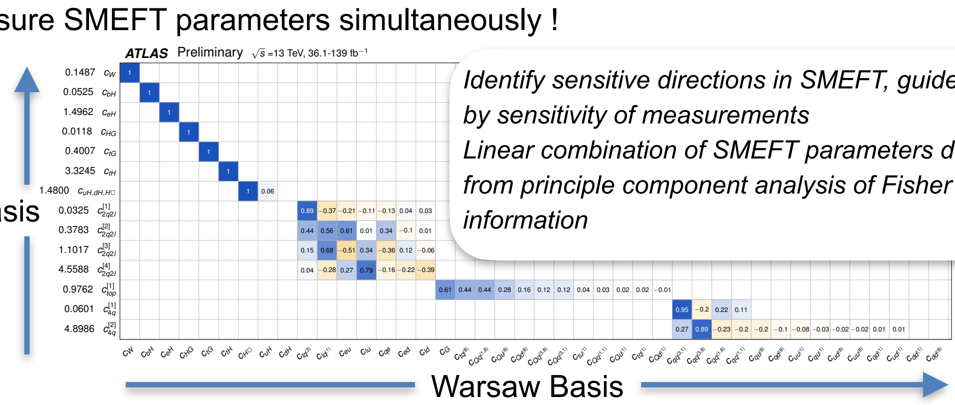
SMEFT framework allows to probe deviations across different measurements

For instance, $Q_{Hq}^{(1)} = (H^\dagger i\overleftrightarrow{D}_\mu^i H)(\bar{q}_p\gamma^\mu q_r)$



Measurement-inspired SMEFT

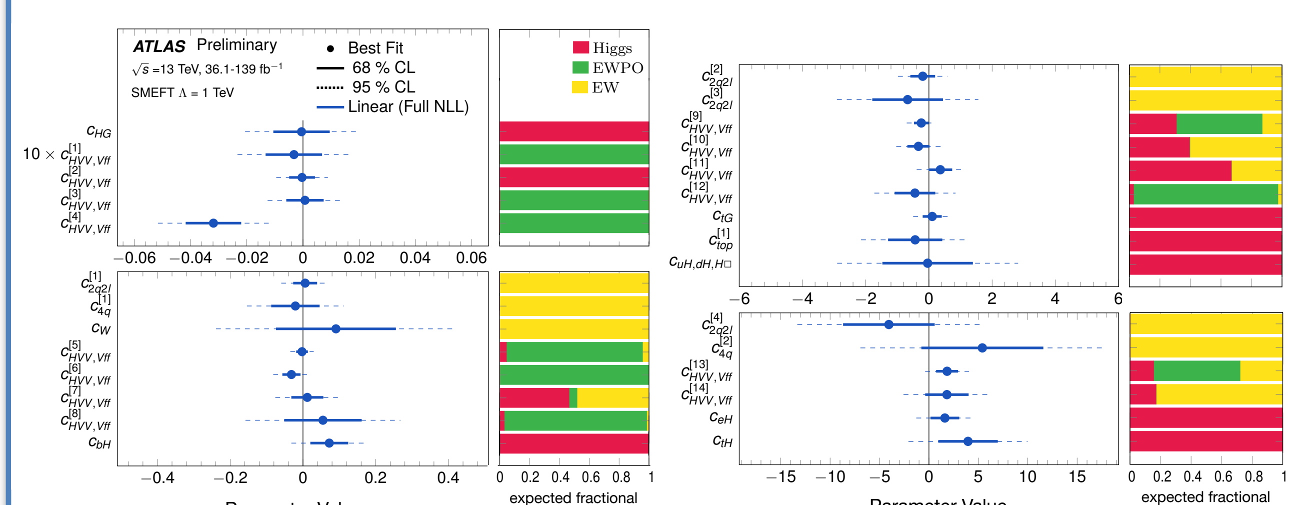
Wilson coefficients might not always be *"physical"* - parameters of a Lagrangian may not map one-to-one to observables
Dedicated BSM models map usually map to a set of Wilson coefficients, important to measure SMEFT parameters simultaneously !



Identify sensitive directions in SMEFT, guided by sensitivity of measurements
Linear combination of SMEFT parameters defined from principle component analysis of Fisher information

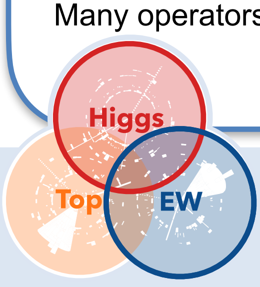
SMEFT constraints

Out of 62 operators, sensitive to 28 parameters in total !
6 correspond to Warsaw basis operators, rest are linear combination



$c \sim O(0.01 - 0.1)$	$\leftarrow$ Limits on SMEFT parameters $\rightarrow$	$c \sim O(1 - 10)$
$\Lambda \sim O(3 - 10\ \text{TeV})$	$\leftarrow$ probe energy scales upto $\rightarrow$	$\Lambda \sim O(0.3 - 1\ \text{TeV})$

Simplified likelihood model based on multi-variate Gaussian is also available,
light-weight matter to reproduce SMEFT constraints



First ATLAS global SMEFT fit, including eight EWPO → Grow into more global combination inc. top, Drell-Yan & many more

Reference :
- ATL-PHYS-PUB-2022-037

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ATLAS EXPERIMENT