

EXPERIMENTAL EFT RESULTS

Nicolas Morange,
On behalf of the ATLAS and CMS collaborations
LHCP, 09/06/2021



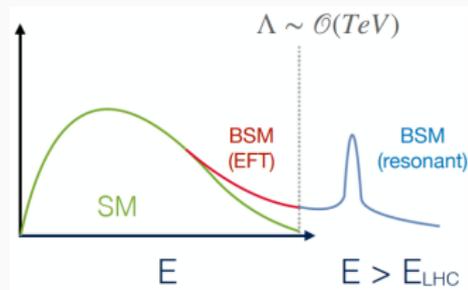
No direct evidence so far of any BSM physics at the LHC

- ⇒ View SM as low-energy approximation of a more fundamental theory
- ⇒ Search for BSM using precision measurements

Effective Field Theory Lagrangian

- Systematic way to parameterise deviations from SM in measurements
- Using higher-dim operators $\mathcal{O}_i^{(d)}$ suppressed by powers of Λ
- Constraints set on associated Wilson Coefficients $c_i^{(d)}$

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$



Effect on measured cross-sections ($\times \mathcal{B} \times \epsilon$ to be added on top)

$$\sigma = \sigma_{SM} + \sigma_{\text{int}} + \sigma_{\text{BSM}} = \sigma_{SM} \left(1 + \sum_i a_i^{(6)} \frac{c_i^{(6)}}{\Lambda^2} + \sum_{ij} b_{ij}^{(6)} \frac{c_i^{(6)} c_j^{(6)}}{\Lambda^4} + \dots \right)$$

Linear terms

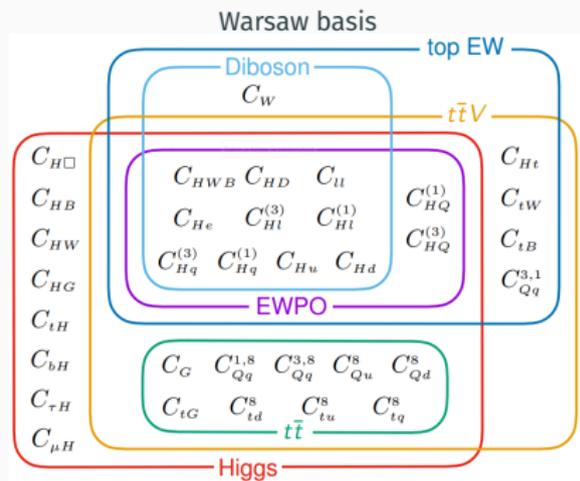
Quadratic terms

A gigantic task

- Even when rejecting Baryon/Lepton-number-violating dim. 5 and 7 operators
 - Dim-6: 2499 operators for $\Delta B = 0$ and $N_f = 3$
 - Reduced to $O(30)$ in flavour-universal scenarios
 - Main focus of current interpretations
 - Dim-8: 36971 operators...
- ⇒ Non unique choice of operators → different choices of bases
- ⇒ Each single measured observable depends on several coefficients

Fortunately

- Numerous measurements at our disposal
 - In particular, great interplay between Electroweak, Higgs boson and Top-quark measurements to probe the SMEFT
- ⇒ >20 ATLAS and CMS measurements in the past year!
- ⇒ See presentations of:
- Top session:** Laura Barranco Navarro, Juan Gonzalez
- Higgs session:** Haider Abidi
- Electroweak session:** Many talks !



J. Ellis et al, JHEP 04 (2021) 279

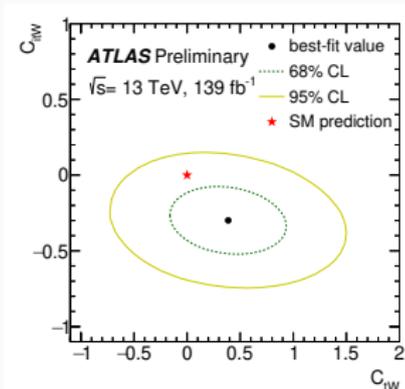
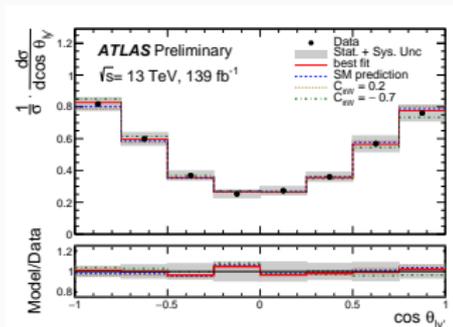
TOP-QUARK MEASUREMENTS

ATLAS-CONF-2021-027 (to appear), 139fb⁻¹

Top and anti-top polarization in t-channel

- Unfolded differential measurements of lepton decay angles in a top-quark reference frame
- Normalized distributions of $\cos\theta_{\ell x'}$ and $\cos\theta_{\ell y'}$ sensitive to c_{tW} and c_{itW} (Warsaw basis)
 - Insensitive to other SMEFT operators
 - Operators appearing in both production and decay \Rightarrow Impact up to quartic terms
- Results compatible with SM within 2σ
 - Very insensitive to quadratic / higher-order terms

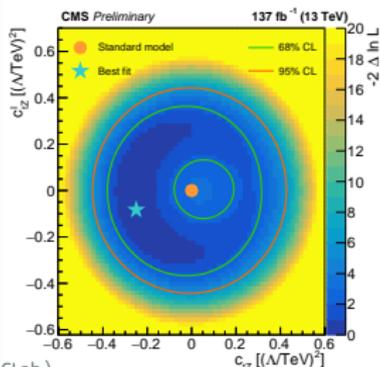
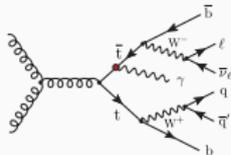
	C_{tW}		C_{itW}	
	68% CL	95% CL	68% CL	95% CL
All terms	[-0.2, 0.9]	[-0.7, 1.5]	[-0.5, -0.1]	[-0.7, 0.2]
Order $1/\Lambda^4$	[-0.2, 0.9]	[-0.7, 1.5]	[-0.5, -0.1]	[-0.7, 0.2]
Order $1/\Lambda^2$	[-0.2, 1.0]	[-0.7, 1.7]	[-0.5, -0.1]	[-0.8, 0.2]



Differential $t\bar{t} + \gamma$ cross-section

CMS-PAS-TOP-18-010, 137fb^{-1}

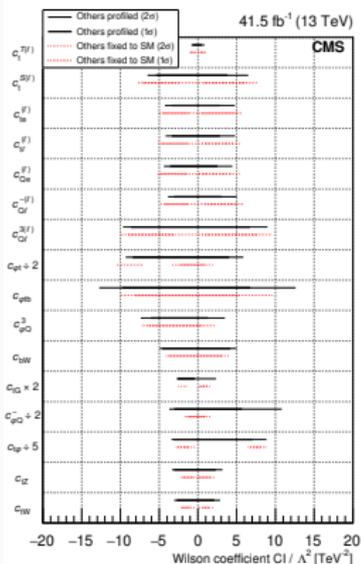
- Unfolded $p_T(\gamma)$ distributions in single-lepton events with 3 or ≥ 4 jets
- Interpretation: SMEFT, operators c_{tZ} and c_{tZ}^{\prime} sensitive to anomalous $t\gamma$ vertex
 - Induce top quark EW dipole moments
- Results consistent with SM within 2σ



Top quark + leptons

CMS-TOP-19-001, 41.5fb^{-1}

- Probes $t\bar{t}H$, $t\bar{t}\ell\bar{\ell}$, $t\bar{t}\ell\nu$, $t\bar{t}\ell q$ and tHq topologies
- Direct SMEFT fit to event yields in 35 signal regions
- Simultaneous measurement of 16 Wilson Coefs
 - Simulated events weighted by $w_i \left(\frac{c_i}{\Lambda^2}\right)$
- Results consistent with SM within 2σ

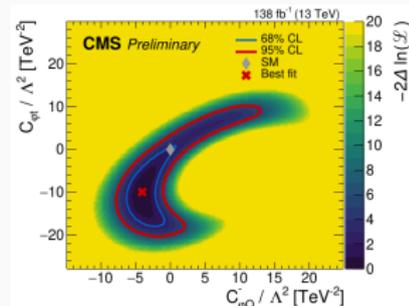
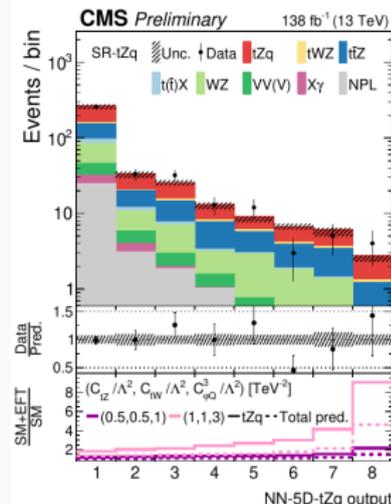


CMS-PAS-TOP-21-001, 138fb^{-1}

Dedicated EFT analysis

- Analysis optimised to probe 5 coefficients
 - Signal regions with 3 or 4 leptons
 - Multiclass NN classifiers to enhance sensitivity to SMEFT operators
 - Either for 1-D constraints or for 5-D constraints
- Includes linear + quadratic terms through MC weights
- All results compatible with SM
 - c_{tZ} and c_{tW} limited by stat uncertainties
 - $c_{\phi Q}^3$, $c_{\phi Q}^-$ and $c_{\phi t}$ limited by syst uncertainties
- Use of NN provides 20% to 75% improvement wrt counting experiments

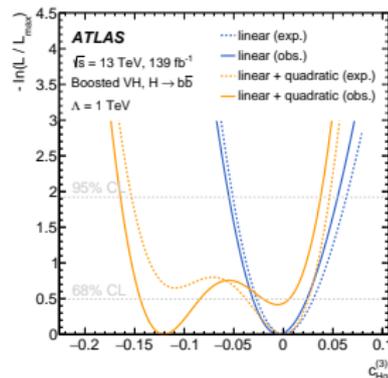
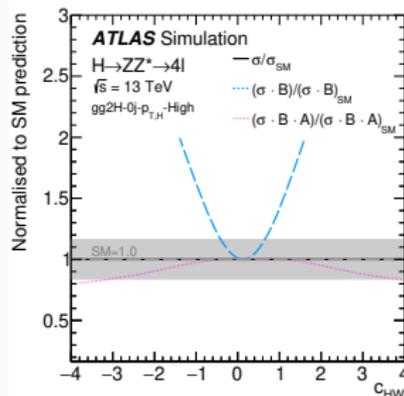
WC / Λ^2 [TeV $^{-2}$]	Other WCs fixed to SM		5D fit	
	Expected	Observed	Expected	Observed
	95% CL confidence intervals			
c_{tZ}	[-0.97, 0.96]	[-0.76, 0.71]	[-1.24, 1.17]	[-0.85, 0.76]
c_{tW}	[-0.76, 0.74]	[-0.52, 0.52]	[-0.96, 0.93]	[-0.69, 0.70]
$c_{\phi Q}^3$	[-1.39, 1.25]	[-1.10, 1.41]	[-1.91, 1.36]	[-1.26, 1.43]
$c_{\phi Q}^-$	[-2.86, 2.33]	[-3.00, 2.29]	[-6.06, 14.09]	[-7.09, 14.76]
$c_{\phi t}$	[-3.70, 3.71]	[-21.65, -14.61] U[-2.06, 2.69]	[-16.18, 10.46]	[-19.15, 10.34]



HIGGS BOSON MEASUREMENTS

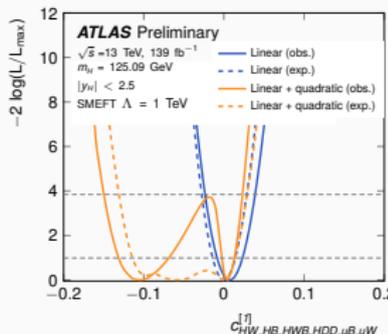
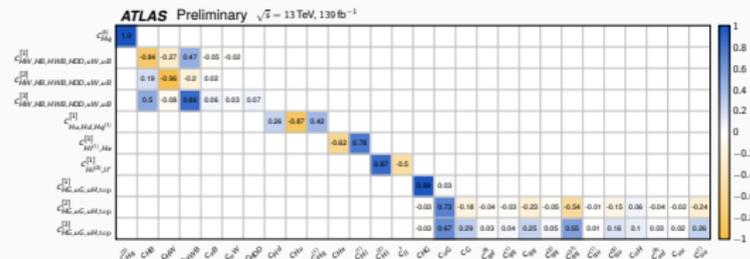
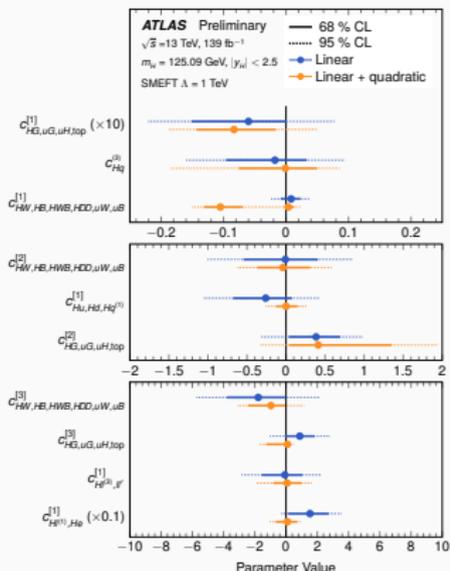
SMEFT interpretations of STXS measurements

- Included in 139fb^{-1} Higgs analyses
 - $H \rightarrow 4\ell$: [ATL-HIGG-2018-28](#)
 - $VH H \rightarrow b\bar{b}$: [ATL-HIGG-2018-51](#)
 - $VH H \rightarrow b\bar{b}$ in boosted topology: [ATL-HIGG-2018-52](#)
- σ and \mathcal{B} parameterised as function of SMEFT Wilson Coefficients; acceptance effects included for $H \rightarrow ZZ^* \rightarrow 4\ell$
- Using subset of relevant SMEFT operators
- $VH H \rightarrow b\bar{b}$ in boosted topology: lower sensitivity to inclusive WH and ZH measurements, but **similar constraints to SMEFT operators**
- SMEFT interpretations also possible from unfolded differential cross-section measurements: $H \rightarrow \gamma\gamma$ [ATLAS-CONF-2019-029](#)



ATLAS-CONF-2020-053, 139fb^{-1}

- Combine STXS (1.2) measurements of $H \rightarrow \gamma\gamma$, $H \rightarrow 4\ell$ and $VH H \rightarrow b\bar{b}$
 - σ and \mathcal{B} parameterised as function of SMEFT Wilson Coefficients
 - Acceptance effects included as additional corrections in HZZ
- Impacted by 32 operators
 - Cannot probe them all simultaneously
 - Rotate into basis of physics-guided eigenvectors
 - Simplify to 10 sensitive directions. No sensitivity to other directions, coefficients can be set to 0.
- Results consistent with the SM
 - Some differences when including the quadratic terms



CMS-HIG-19-009, 137fb^{-1}

Dedicated EFT measurement in $H \rightarrow ZZ \rightarrow 4\ell$ channel

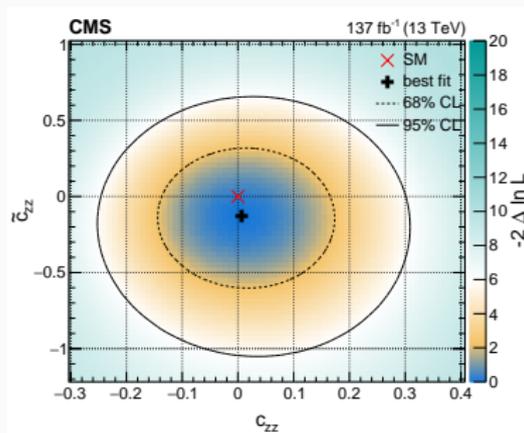
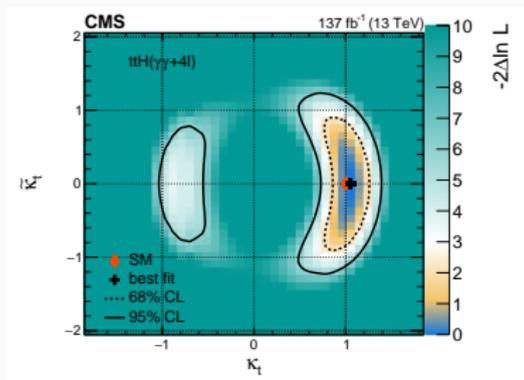
- Analysis optimised in each category using matrix element method
- Production and decay amplitudes parameterised including anomalous effects
 - Closely related to SMEFT in the Higgs basis under $SU(2) \times U(1)$ assumption
 - Results then translated into Warsaw basis

Study of $Hg\bar{g}$ and Htt couplings

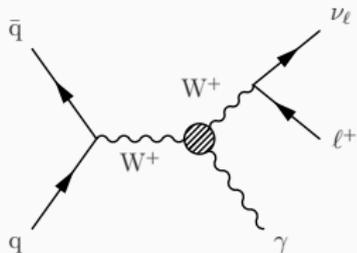
- In combination with $t\bar{t}H$ results in $H \rightarrow \gamma\gamma$ decay
- Complementary information in $t\bar{t}H$ and ggH productions for κ_t , point-like c_{gg} and CP-odd counterparts

Study of HVV couplings

- Probes 4 couplings in Higgs basis, including CP-odd term \tilde{c}_{ZZ}
- Translated into linear combination of 9 terms in Warsaw basis



ELECTROWEAK MEASUREMENTS



Fiducial $W\gamma$ cross-section

CMS-SMP-19-002, 137fb^{-1}

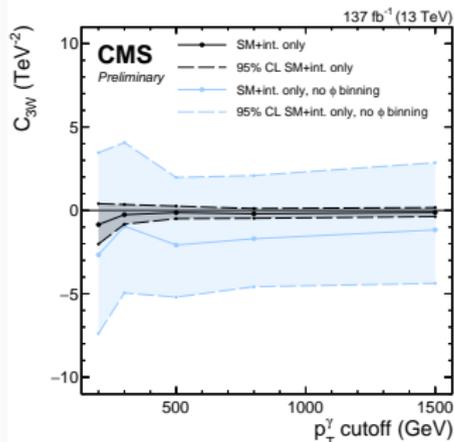
- Cross-section from $m_{\ell\gamma}$ fit
- High tail of $p_T(\gamma)$ used to set limit on 4 SMEFT coefficients (HISZ basis)

Coefficient	Exp. lower	Exp. upper	Obs. lower	Obs. upper
c_{WWW}/Λ^2	-0.85	0.87	-0.90	0.91
c_B/Λ^2	-46	45	-40	41
$c_{\overline{W}W}/\Lambda^2$	-0.43	0.43	-0.45	0.45
$c_{\overline{W}}/\Lambda^2$	-23	22	-20	20

Differential $W\gamma$ cross-section

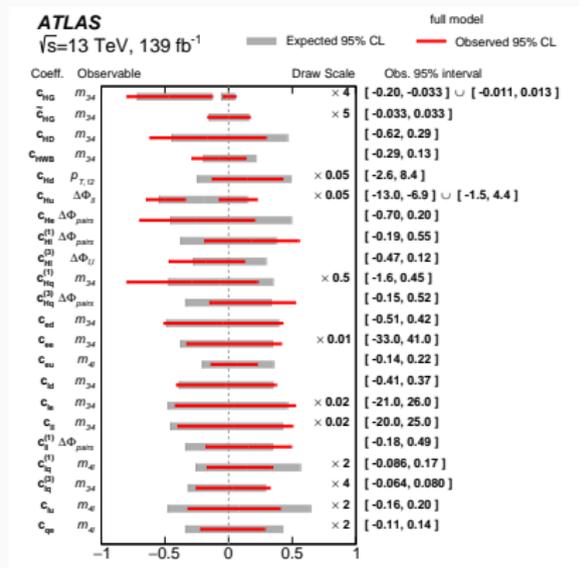
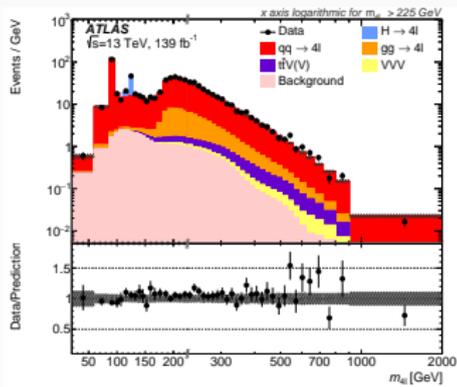
CMS-SMP-20-005, 137fb^{-1}

- 2D differential cross-section in $p_T(\gamma)$ and in the azimuthal angle of the lepton in a center-of-mass frame of the $W\gamma$ system
- Sensitivity to the \mathcal{O}_{WWW} operator
 - Importance of the large γ boost
 - Significant enhancement from the ϕ measurement: overcomes helicity suppression of interference term



Inclusive $pp \rightarrow 4\ell$ ATL-STD-2018-30, 139fb^{-1}

- Inclusive selection $pp \rightarrow 4\ell$ to probe $Z \rightarrow 4\ell$, $H \rightarrow 4\ell$ and ZZ
- Doubly differential cross-sections in $m_{4\ell}$ vs other variables
- Individual constraints to 22 coefficients in Warsaw basis
 - Most sensitive distribution chosen for each one
 - Significant impact of quadratic terms for 4-fermion operators



On-shell $pp \rightarrow ZZ$ CMS-SMP-19-001, 137fb^{-1}

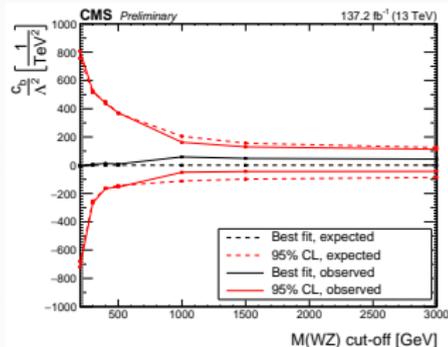
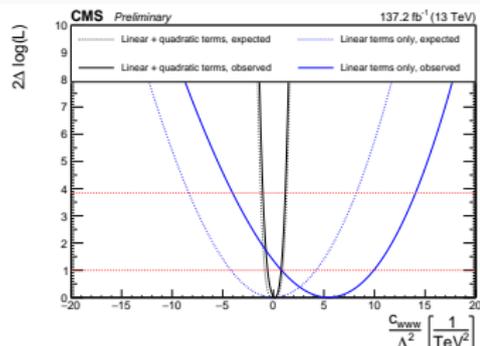
- See backup

WZ Differential cross-sections and polarization angles

CMS-PAS-SMP-20-014, 137fb^{-1}

- Study of leptonic decays of WZ events
- Measurements of kinematic distributions, of charge asymmetry and of polarization coefficients
- SMEFT interpretation uses m_{WZ} observed distributions
 - Simultaneous fit to c_W , c_{WWW} and c_b
 - Simultaneous fit to CP-violating \tilde{c}_W and \tilde{c}_{WWW}
 - Large impact of quadratic terms on c_b and c_{WWW}
 - Sensitivity coming from high- m_{WZ} regions

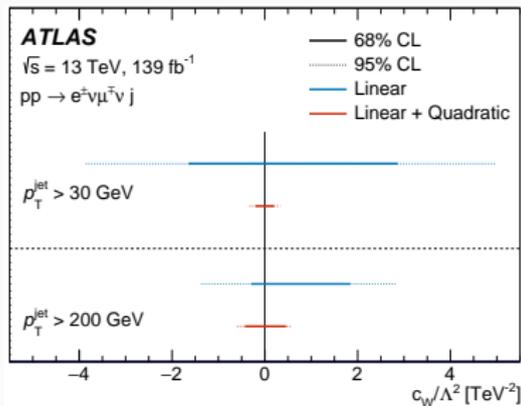
Parameter	95% CI, Exp. (TeV^{-2})	95% CI, Obs. (TeV^{-2})	Best fit, Obs. (TeV^{-2})
c_W/Λ^2	$[-2.05, 1.27]$	$[-2.52, 0.33]$	-1.34
c_{WWW}/Λ^2	$[-1.27, 1.33]$	$[-1.04, 1.19]$	0.15
c_b/Λ^2	$[-86.0, 125.0]$	$[-42.7, 113.0]$	43.6
$\tilde{c}_{WWW}/\Lambda^2$	$[-0.76, 0.65]$	$[-0.62, 0.53]$	-0.03
\tilde{c}_W/Λ^2	$[-46.1, 46.1]$	$[-45.9, 45.9]$	0.0



Production of $WW + \geq 1$ jet

ATL-STD-2018-34, 139fb^{-1}

- Differential cross-sections measured for several kinematic variables
- Unfolded $m_{e\mu}$ used to set constraints on c_W coefficient
 - Linked to aTGC
 - Effect suppressed at interference-level
 - Hard jet requirement reduces the suppression
 - Still dominated by quadratic term

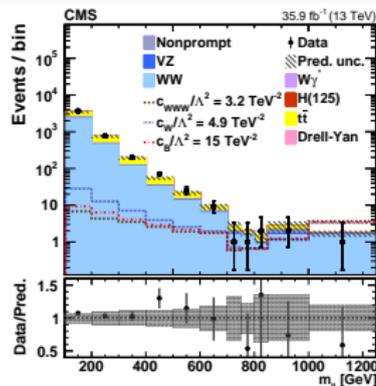


WW measurements

CMS-SMP-18-004, 36fb^{-1}

- Fiducial and differential measurements of kinematic variables
- SMEFT constraints from fit to observed $m_{e\mu}$ distribution in 0- and 1-jet categories
 - Constraints on c_{WWW} , c_W and c_B
 - Fitted individually or two at a time

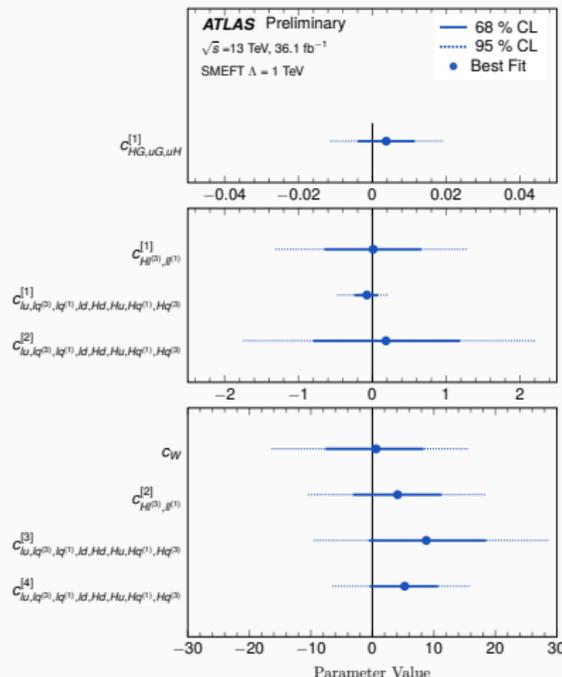
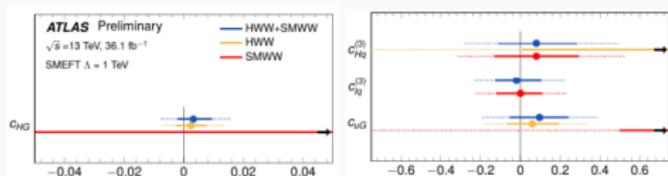
Coefficients (TeV^{-2})	68% confidence interval		95% confidence interval	
	expected	observed	expected	observed
c_{WWW}/Λ^2	$[-1.8, 1.8]$	$[-0.93, 0.99]$	$[-2.7, 2.7]$	$[-1.8, 1.8]$
c_W/Λ^2	$[-3.7, 2.7]$	$[-2.0, 1.3]$	$[-5.3, 4.2]$	$[-3.6, 2.8]$
c_B/Λ^2	$[-9.4, 8.4]$	$[-5.1, 4.3]$	$[-14, 13]$	$[-9.4, 8.5]$



Combination of WW and $H \rightarrow WW^*$ measurements

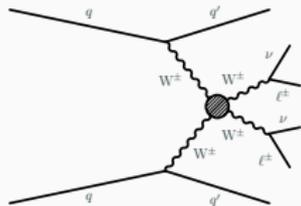
ATL-PHYS-PUB-2021-010, 36fb^{-1}

- Combined fit of signal strengths of ggH and VBF in $H \rightarrow WW^*$ and of unfolded differential cross-sections of $\rho_{\text{T}}^{\text{lead,lep.}}$ in WW events in the 0-jet channel.
 - WW CR in HWW analysis removed (orthogonality)
- SMEFT measurement in Warsaw basis
 - Many operators affecting the measurements
 - Parameterise the signal strengths as function of EFT coefficients
 - Acceptance effects included when needed
 - Complementary sensitivity of WW and $H \rightarrow WW^*$
 - Rotation to physics-guided eigenbasis to probe 8 sensitive directions
- Stepping stone for more global EFT combinations



Common approach for EW production of diboson + dijets

- Analyses sensitive to (anomalous) quartic gauge couplings
- Probe dimension-8 effective operators S_x (derivative of the Higgs field), T_x (constructed from $SU_L(2)$ gauge fields) and M_x (involving both Higgs and $SU_L(2)$ gauge fields)



Measurements in many final states by CMS

$WZjj$ and $WWjj$: CMS-SMP-19-012, 137fb^{-1}

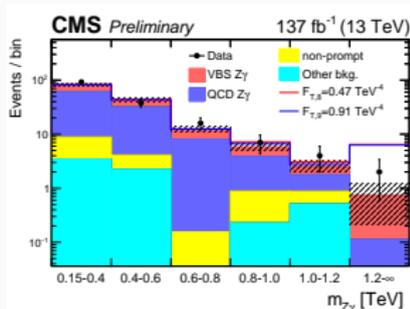
$W\gamma jj$: CMS-SMP-19-008, 36fb^{-1}

$ZZjj$: CMS-SMP-20-001, 137fb^{-1}

$Z\gamma jj$: CMS-PAS-SMP-20-016, 137fb^{-1}

- Fits to m_{VV} distributions (sometimes 2-D with m_{jj})
- Limits usually with/without cut-off at unitarity limit of 1.5 TeV
- Different final states probe complementary operators

Parameters	Obs. limit	Exp. limit	U_{bound}
$f_{M,0}/\Lambda^4$	[-8.1, 8.0]	[-7.7, 7.6]	1.0
$f_{M,1}/\Lambda^4$	[-12, 12]	[-11, 11]	1.2
$f_{M,2}/\Lambda^4$	[-2.8, 2.8]	[-2.7, 2.7]	1.3
$f_{M,3}/\Lambda^4$	[-4.4, 4.4]	[-4.0, 4.1]	1.5
$f_{M,4}/\Lambda^4$	[-5.0, 5.0]	[-4.7, 4.7]	1.5
$f_{M,5}/\Lambda^4$	[-8.3, 8.3]	[-7.9, 7.7]	1.8
$f_{M,6}/\Lambda^4$	[-16, 16]	[-15, 15]	1.0
$f_{M,7}/\Lambda^4$	[-21, 20]	[-19, 19]	1.3
$f_{T,0}/\Lambda^4$	[-0.6, 0.6]	[-0.6, 0.6]	1.4
$f_{T,1}/\Lambda^4$	[-0.4, 0.4]	[-0.3, 0.4]	1.5
$f_{T,2}/\Lambda^4$	[-1.0, 1.2]	[-1.0, 1.2]	1.5
$f_{T,5}/\Lambda^4$	[-0.5, 0.5]	[-0.4, 0.4]	1.8
$f_{T,6}/\Lambda^4$	[-0.4, 0.4]	[-0.3, 0.4]	1.7
$f_{T,7}/\Lambda^4$	[-0.9, 0.9]	[-0.8, 0.9]	1.8

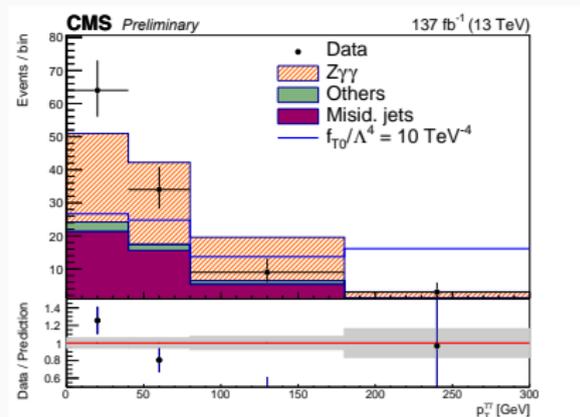


Measurements of $W\gamma\gamma$ and $Z\gamma\gamma$ processesCMS-PAS-SMP-19-013, 137fb^{-1}

- Measurements of fiducial cross-sections
- Observed $p_T^{\gamma\gamma}$ distributions fitted to extract aQGC constraints

Constraints on aQGC

- Nice complementarity of all EW $VWjj$ and of triple gauge boson measurements
- All results consistent with SM



Parameter	$W\gamma\gamma$ (TeV^{-4})		$Z\gamma\gamma$ (TeV^{-4})	
	Expected	Observed	Expected	Observed
f_{M2}/Λ^4	[-57.3, 57.1]	[-39.9, 39.5]	-	-
f_{M3}/Λ^4	[-91.8, 92.6]	[-63.8, 65.0]	-	-
f_{T0}/Λ^4	[-1.86, 1.86]	[-1.30, 1.30]	[-4.86, 4.66]	[-5.70, 5.46]
f_{T1}/Λ^4	[-2.38, 2.38]	[-1.70, 1.66]	[-4.86, 4.66]	[-5.70, 5.46]
f_{T2}/Λ^4	[-5.16, 5.16]	[-3.64, 3.64]	[-9.72, 9.32]	[-11.4, 10.9]
f_{T3}/Λ^4	[-0.76, 0.84]	[-0.52, 0.60]	[-2.44, 2.52]	[-2.92, 2.92]
f_{T6}/Λ^4	[-0.92, 1.00]	[-0.60, 0.68]	[-3.24, 3.24]	[-3.80, 3.88]
f_{T7}/Λ^4	[-1.64, 1.72]	[-1.16, 1.16]	[-6.68, 6.60]	[-7.88, 7.72]
f_{T8}/Λ^4	-	-	[-0.90, 0.94]	[-1.06, 1.10]
f_{T9}/Λ^4	-	-	[-1.54, 1.54]	[-1.82, 1.82]

EFT measurements are becoming more and more common in Electroweak, Higgs boson and Top-quark analyses

- Wealth of measurements, complementary to probe subtle effects of higher-energy BSM physics
 - All results compatible with the SM so far
 - Getting a more complete picture would involve interpreting all these measurement simultaneously
 - Not a small task !
 - Diversity of SMEFT measurements: unfolded distributions vs Higgs STXS vs reconstructed distributions
 - Diversity of interpretation frameworks, of EFT basis, methodologies, profiled vs constrained parameters
 - Treatment of higher-order effects (quadratic terms) ? Dimension-8 operators ?
- ⇒ Hot topics for LHC EFT WG !

SUPPLEMENTARY MATERIAL

Differential measurements of $t\bar{t}$ charge asymmetry

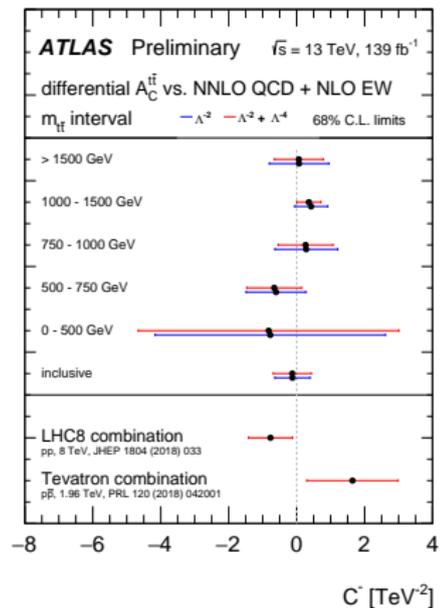
ATLAS-CONF-2019-026, 139fb^{-1}

- Unfolded $t\bar{t}$ central-forward charge asymmetry A_C in single-lepton channel:

$$A_C = \frac{N(|\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

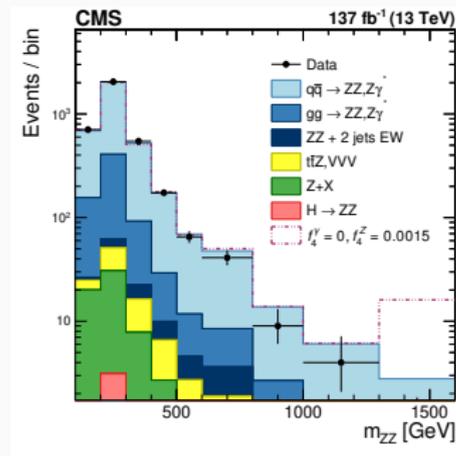
with $\Delta|y| = |y_t| - |y_{\bar{t}}|$

- Interpretation: SMEFT, difference between octet and singlet 4-fermion operators $C^- = C^1 - C^2$ (assuming equal couplings to up- and down-type quarks)
- Strong constraints from high- $m_{t\bar{t}}$ bins
- Results consistent with SM



On-shell $pp \rightarrow ZZ$ CMS-SMP-19-001, 137fb⁻¹

- $pp \rightarrow ZZ \rightarrow 4\ell$ analysis with on-shell Zs
- Differential m_{ZZ} distribution used to set limits on aTGC parameters
- Results also expressed in terms of SMEFT parameters



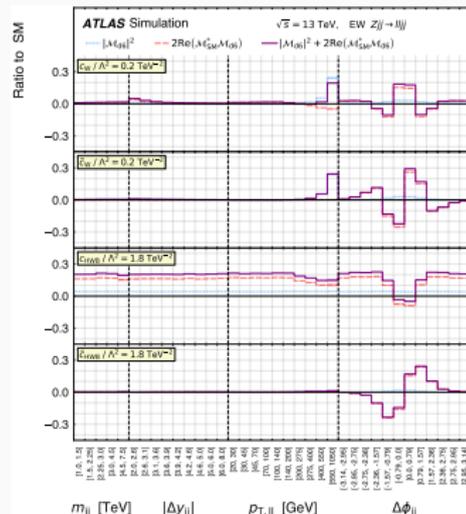
	Expected 95% CL	Observed 95% CL
aTGC parameter	$\times 10^{-4}$	$\times 10^{-4}$
f_4^Z	-8.8 ; 8.3	-6.6 ; 6.0
f_5^Z	-8.0 ; 9.9	-5.5 ; 7.5
f_4^{γ}	-9.9 ; 9.5	-7.8 ; 7.1
f_5^{γ}	-9.2 ; 9.8	-6.8 ; 7.5
EFT parameter	TeV ⁻⁴	TeV ⁻⁴
C_{BW}/Λ^4	-3.1 ; 3.3	-2.3 ; 2.5
C_{WW}/Λ^4	-1.7 ; 1.6	-1.4 ; 1.2
C_{BW}/Λ^4	-1.8 ; 1.9	-1.4 ; 1.3
C_{BB}/Λ^4	-1.6 ; 1.6	-1.2 ; 1.2

Electroweak Zjj analysis

ATL-STD-2017-27, 139fb^{-1}

- Topology with central $Z \rightarrow \ell\ell$ and forward jets
- Unfolded 1D differential measurements in kinematic variables
- SMEFT Interpretation: Warsaw basis
 - Large sensitivity of c_W , \tilde{c}_W , c_{HWB} and \tilde{c}_{HWB} to $\Delta\phi_{jj}$ distribution
 - Test of CP invariance of gauge boson self-interaction
 - Lower sensitivity to c_{WWW} (in HISZ basis) than other analyses, but very small impact of quadratic terms

Wilson coefficient	Includes $ \mathcal{M}_{d6} ^2$	95% confidence interval [TeV^{-2}]		p -value (SM)
		Expected	Observed	
c_W/Λ^2	no	$[-0.30, 0.30]$	$[-0.19, 0.41]$	45.9%
	yes	$[-0.31, 0.29]$	$[-0.19, 0.41]$	43.2%
\tilde{c}_W/Λ^2	no	$[-0.12, 0.12]$	$[-0.11, 0.14]$	82.0%
	yes	$[-0.12, 0.12]$	$[-0.11, 0.14]$	81.8%
c_{HWB}/Λ^2	no	$[-2.45, 2.45]$	$[-3.78, 1.13]$	29.0%
	yes	$[-3.11, 2.10]$	$[-6.31, 1.01]$	25.0%
$\tilde{c}_{HWB}/\Lambda^2$	no	$[-1.06, 1.06]$	$[0.23, 2.34]$	1.7%
	yes	$[-1.06, 1.06]$	$[0.23, 2.35]$	1.6%



Measurement of $WZjj$ and same-sign $WWjj$ CMS-SMP-19-012, 137fb^{-1}

- Fits to 2-D distributions of $m_T(VV)$ and m_{jj}
- Limits with/without cut-off at unitarity limit of 1.5 TeV

	Observed (W^+W^+) (TeV^{-4})	Expected (W^+W^+) (TeV^{-4})	Observed (WZ) (TeV^{-4})	Expected (WZ) (TeV^{-4})	Observed (W^+W^+) (TeV^{-4})	Expected (W^+W^+) (TeV^{-4})
$f_{M,0}/\Lambda^4$	[-1.5, 2.3]	[-2.1, 2.7]	[-1.6, 1.9]	[-2.0, 2.2]	[-1.1, 1.6]	[-1.6, 2.0]
$f_{M,1}/\Lambda^4$	[-0.81, 1.2]	[-0.98, 1.4]	[-1.3, 1.5]	[-1.6, 1.8]	[-0.69, 0.97]	[-0.94, 1.3]
$f_{M,2}/\Lambda^4$	[-2.1, 4.4]	[-2.7, 5.3]	[-2.7, 3.4]	[-4.4, 5.5]	[-1.6, 3.1]	[-2.3, 3.8]
$f_{M,3}/\Lambda^4$	[-13, 16]	[-19, 18]	[-16, 16]	[-19, 19]	[-11, 12]	[-15, 15]
$f_{M,4}/\Lambda^4$	[-20, 19]	[-22, 25]	[-19, 20]	[-23, 24]	[-15, 14]	[-18, 20]
$f_{M,5}/\Lambda^4$	[-27, 32]	[-37, 37]	[-34, 33]	[-39, 39]	[-22, 25]	[-31, 30]
$f_{M,6}/\Lambda^4$	[-22, 24]	[-27, 25]	[-22, 22]	[-28, 28]	[-16, 18]	[-22, 21]
$f_{M,7}/\Lambda^4$	[-35, 36]	[-31, 31]	[-83, 85]	[-88, 91]	[-34, 35]	[-31, 31]
f_{SI}/Λ^4	[-100, 120]	[-100, 110]	[-110, 110]	[-120, 130]	[-86, 99]	[-91, 97]

Observation of $W\gamma jj$ CMS-SMP-19-008, 36fb^{-1}

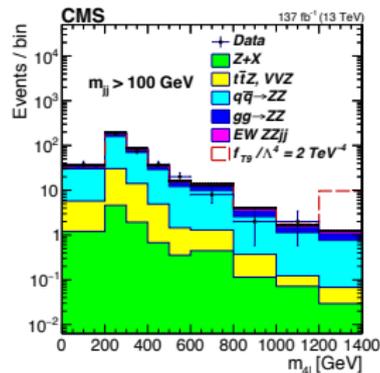
- Stricter selections compared to the measurement to enhance aQGC contributions
- Fit of the $m_{W\gamma}$ distribution to constrain the coefficients

Parameters	Exp. limit	Obs. limit	U_{bound}
$f_{M,0}/\Lambda^4$	[-8.1, 8.0]	[-7.7, 7.6]	1.0
$f_{M,1}/\Lambda^4$	[-12, 12]	[-11, 11]	1.2
$f_{M,2}/\Lambda^4$	[-2.8, 2.8]	[-2.7, 2.7]	1.3
$f_{M,3}/\Lambda^4$	[-4.4, 4.4]	[-4.0, 4.1]	1.5
$f_{M,4}/\Lambda^4$	[-5.0, 5.0]	[-4.7, 4.7]	1.5
$f_{M,5}/\Lambda^4$	[-8.3, 8.3]	[-7.9, 7.7]	1.8
$f_{M,6}/\Lambda^4$	[-16, 16]	[-15, 15]	1.0
$f_{M,7}/\Lambda^4$	[-21, 20]	[-19, 19]	1.3
$f_{M,0}/\Lambda^4$	[-0.6, 0.6]	[-0.6, 0.6]	1.4
$f_{M,1}/\Lambda^4$	[-0.4, 0.4]	[-0.3, 0.4]	1.5
$f_{M,2}/\Lambda^4$	[-1.0, 1.2]	[-1.0, 1.2]	1.5
$f_{M,5}/\Lambda^4$	[-0.5, 0.5]	[-0.4, 0.4]	1.8
$f_{M,6}/\Lambda^4$	[-0.4, 0.4]	[-0.3, 0.4]	1.7
$f_{M,7}/\Lambda^4$	[-0.9, 0.9]	[-0.8, 0.9]	1.8

Evidence for $ZZjj$ CMS-SMP-20-001, 137fb^{-1}

- Use matrix element method to separate from QCD production
- Fit to the m_{ZZ} distribution. Yield dependence quadratic in anomalous couplings

Coupling	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity bound
f_{10}/Λ^4	-0.37	0.35	-0.24	0.22	2.4
f_{11}/Λ^4	-0.49	0.49	-0.31	0.31	2.6
f_{12}/Λ^4	-0.98	0.95	-0.63	0.59	2.5
f_{18}/Λ^4	-0.68	0.68	-0.43	0.43	1.8
f_{19}/Λ^4	-1.5	1.5	-0.92	0.92	1.8

Measurement of EW $Z\gamma jj$ CMS-PAS-SMP-20-016, 137fb^{-1}

- Unfolded distributions of kinematic variables
- Constraints from fit to $m_{Z\gamma}$ distribution in phase space with higher p_T^γ requirement

Operator coefficients	Expected [TeV ⁻⁴]	Observed [TeV ⁻⁴]	Freeze all syst. [TeV ⁻⁴]	Unitarity bound [TeV]
F_{00}/Λ^4	-12.5, 12.8	-15.8, 16.0	-15.2, 15.4	1.1
F_{01}/Λ^4	-28.1, 27.0	-35.0, 34.7	-33.6, 33.3	1.2
F_{02}/Λ^4	-5.21, 5.12	-6.55, 6.49	-6.32, 6.23	1.4
F_{03}/Λ^4	-10.2, 10.3	-13.0, 13.0	-12.4, 12.5	1.6
F_{04}/Λ^4	-10.2, 10.2	-13.0, 12.7	-12.5, 12.3	1.4
F_{05}/Λ^4	-17.6, 16.8	-22.2, 21.3	-21.4, 20.4	1.8
F_{06}/Λ^4	-25.0, 25.6	-31.7, 32.0	-30.4, 30.8	1.1
F_{07}/Λ^4	-44.7, 45.0	-56.6, 55.9	-54.3, 53.8	1.3
F_{10}/Λ^4	-0.52, 0.44	-0.64, 0.57	-0.62, 0.55	1.4
F_{11}/Λ^4	-0.65, 0.63	-0.81, 0.90	-0.78, 0.77	1.5
F_{12}/Λ^4	-1.36, 1.21	-1.68, 1.54	-1.63, 1.48	1.4
F_{13}/Λ^4	-0.45, 0.52	-0.58, 0.64	-0.55, 0.62	1.8
F_{14}/Λ^4	-1.02, 1.07	-1.30, 1.33	-1.25, 1.29	1.7
F_{17}/Λ^4	-1.67, 1.97	-2.15, 2.43	-2.06, 2.36	1.8
F_{19}/Λ^4	-0.36, 0.36	-0.47, 0.47	-0.46, 0.46	1.5
F_{19}/Λ^4	-0.72, 0.72	-0.91, 0.91	-0.88, 0.88	1.6

