Adrien AURIOL, adrien.auriol@cern.ch

April 30, 2025

EFT in Top Physics

From Single Analyses to Global Fits

Why EFT ..?

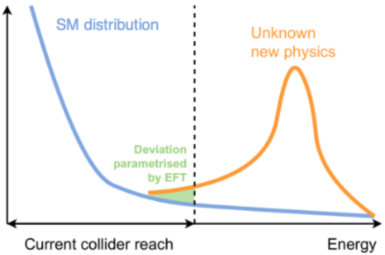
SM is incomplete!

Effective Field Theories (EFT) are parametrizations of the "low-energy" limit of a more fundamental theory :

- Model-independant approach
- Comes as a complement of direct searches
- Connects LHC data to UV theories

$$\mathcal{L}_{\text{eff.}} = \mathcal{L}_{\text{SM}} + \sum_{d=5}^{\infty} \sum_{i} \frac{c_{i,d}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

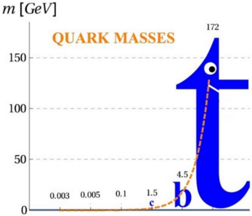
- Integrate out heavy degrees of freedom
- Only local operators from SM fields (exhaustive list)



... in Top Physics?

Top quark → unique EFT probe!

- Uniquely sensitive to Higgs sector being the largest Yukawa coupling : ($H - t$ coupling, H potential stability)
- Closest to (possible) NP sectors
- High production cross-section at LHC (stat. power) : $\sigma_{t\bar{t}} \sim 800$pb
- Decays before hadronization (direct access to spin and kinematics)



[Taken from [1]]

New physics can be found as a deviation in any of the EFT parameters!

SMEFT basics

Warsaw basis of dimension-6 operators : 59 indep. operators!

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar l_p e_r \varphi)$
$Q_{\widetilde G}$	$f^{ABC} \widetilde G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p u_r \widetilde\varphi)$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star \left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p d_r \varphi)$
$Q_{\widetilde W}$	$\varepsilon^{IJK} \widetilde W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar l_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar l_p \gamma^\mu l_r)$
$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\, \widetilde G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eB}	$(\bar l_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar l_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uG}	$(\bar q_p \sigma^{\mu\nu} T^A u_r)\widetilde\varphi\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar e_p \gamma^\mu e_r)$
$Q_{\varphi\widetilde W}$	$\varphi^\dagger\varphi\, \widetilde W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar q_p \sigma^{\mu\nu} u_r)\tau^I \widetilde\varphi\, W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar q_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar q_p \sigma^{\mu\nu} u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar q_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\, \widetilde B_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar q_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar u_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar q_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar d_p \gamma^\mu d_r)$
$Q_{\varphi\widetilde WB}$	$\varphi^\dagger\tau^I\varphi\, \widetilde W^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar q_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu\varphi)(\bar u_p \gamma^\mu d_r)$

$(\bar LL)(\bar LL)$		$(\bar RR)(\bar RR)$		$(\bar LL)(\bar RR)$	
Q_{ll}	$(\bar l_p \gamma_\mu l_r)(\bar l_s \gamma^\mu l_t)$	Q_{ee}	$(\bar e_p \gamma_\mu e_r)(\bar e_s \gamma^\mu e_t)$	Q_{le}	$(\bar l_p \gamma_\mu l_r)(\bar e_s \gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar q_s \gamma^\mu q_t)$	Q_{uu}	$(\bar u_p \gamma_\mu u_r)(\bar u_s \gamma^\mu u_t)$	Q_{lu}	$(\bar l_p \gamma_\mu l_r)(\bar u_s \gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar q_p \gamma_\mu \tau^I q_r)(\bar q_s \gamma^\mu \tau^I q_t)$	Q_{dd}	$(\bar d_p \gamma_\mu d_r)(\bar d_s \gamma^\mu d_t)$	Q_{ld}	$(\bar l_p \gamma_\mu l_r)(\bar d_s \gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar l_p \gamma_\mu l_r)(\bar q_s \gamma^\mu q_t)$	Q_{eu}	$(\bar e_p \gamma_\mu e_r)(\bar u_s \gamma^\mu u_t)$	Q_{qe}	$(\bar q_p \gamma_\mu q_r)(\bar e_s \gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar l_p \gamma_\mu \tau^I l_r)(\bar q_s \gamma^\mu \tau^I q_t)$	Q_{ed}	$(\bar e_p \gamma_\mu e_r)(\bar d_s \gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar u_s \gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar u_p \gamma_\mu u_r)(\bar d_s \gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar q_p \gamma_\mu T^A q_r)(\bar u_s \gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar u_p \gamma_\mu T^A u_r)(\bar d_s \gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar d_s \gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar q_p \gamma_\mu T^A q_r)(\bar d_s \gamma^\mu T^A d_t)$
$(\bar LR)(\bar RL)$ and $(\bar LR)(\bar LR)$		B-violating			
Q_{ledq}	$(\bar l_p^j e_r)(\bar d_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$		
$Q_{quqd}^{(1)}$	$(\bar q_p^j u_r)\varepsilon_{jk}(\bar q_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$		
$Q_{quqd}^{(8)}$	$(\bar q_p^j T^A u_r)\varepsilon_{jk}(\bar q_s^k T^A d_t)$	$Q_{qqq}^{(1)}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$		
$Q_{lequ}^{(1)}$	$(\bar l_p^j e_r)\varepsilon_{jk}(\bar q_s^k u_t)$	$Q_{qqq}^{(3)}$	$\varepsilon^{\alpha\beta\gamma}(\tau^I\varepsilon)_{jk}(\tau^I\varepsilon)_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$		
$Q_{lequ}^{(3)}$	$(\bar l_p^j \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar q_s^k \sigma^{\mu\nu} u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$		

[Taken from [2]]

Enters in many **top quark interactions** and therefore in many **final states**!

Top EFT Analysis Evolution

Growing complexity of the analyses and methods used to extract EFT information from LHC data.

Single-channel inclusive	**Differential distributions**	**Multi-channel combinations**	**Cross-domain global fits**
2016–2018	*2019–2022*	*2023–2024*	*2025+*
ATLAS ttX cross-sections [3]	*CMS ttZ p_T spectra* [4]	*ATLAS ttγ xsec EFT interpretation* [5]	*CMS Apr 2025 combination* [6]

This talk will focus on the 2 later stages of this evolution via one ATLAS and one CMS result.

ATLAS $t\bar{t}\gamma$ cross-section

Publication

JHEP

Published for SISSA by Springer

Received: *March 15, 2024*
Accepted: *September 16, 2024*
Published: *October 25, 2024*

Measurements of inclusive and differential cross-sections of $t\bar{t}\gamma$ production in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

ATLAS EXPERIMENT

The ATLAS collaboration

E-mail: atlas.publications@cern.ch

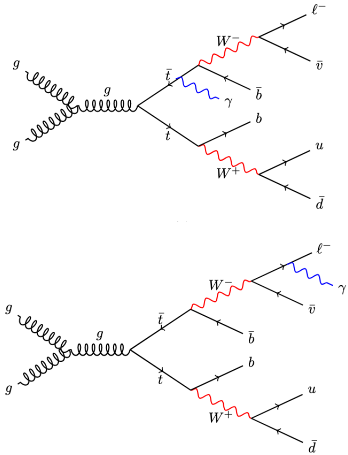
Abstract: Inclusive and differential cross-sections are measured at particle level for the associated production of a top quark pair and a photon ($t\bar{t}\gamma$). The analysis is performed using an integrated luminosity of 140 fb^{-1} of proton-proton collisions at a centre-of-mass energy of 13 TeV collected by the ATLAS detector. The measurements are performed in the single-lepton and dilepton top quark pair decay channels focusing on $t\bar{t}\gamma$ topologies where the photon is radiated from an initial-state parton or one of the top quarks. The absolute and normalised differential cross-sections are measured for several variables characterising the photon, lepton and jet kinematics as well as the angular separation between those objects. The observables are found to be in good agreement with the Monte Carlo predictions. The photon transverse momentum differential distribution is used to set limits on effective field theory parameters related to the electroweak dipole moments of the top quark. The combined limits using the photon and the Z boson transverse momentum measured in $t\bar{t}$ production in associations with a Z boson are also set.

Published in **JHEP** on **October 25, 2024**

JHEP, 191(2024)

[5]

Motivation and strategy



Photon can be radiated from production or decay

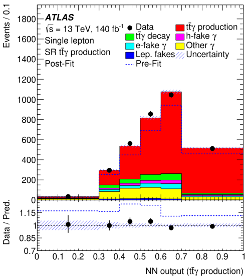
Motivation :

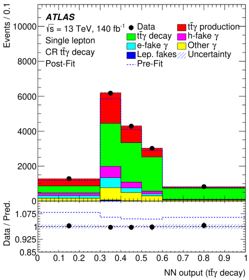
- Sensitive to $t-\gamma$ EWK coupling / NP via anomalous dipole moment of t
- Can be used to constrain C_{tB}, C_{tW} SMEFT parameters

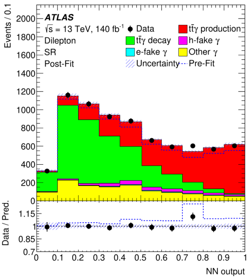
Strategy :

- 1L and 2L channels
- For production only and total
  - Prod. is most sensitive to the couplings
    $\rightarrow$ diff. xsec used for EFT
- NN for signal/background separation

Inclusive / differential xsec







Single lepton channel :

- 1 SR and 3 CR ($t\bar{t}\gamma$ decay, photon fake, other prompt γ) defined based on NN thresholds

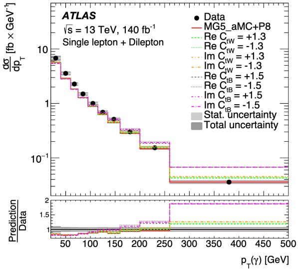
Dilepton channel :

- Binary classification ($t\bar{t}\gamma$ production vs. all backgrounds)
- NN output used for definition of 2 regions for the diff. xsec

EFT interpretation

C_{tB} and C_{tW} are 2 complex parameters in the SMEFT Lagrangian

- Anomalous dipole moment couplings can be expressed as function of them
- Modify both $t\bar{t}\gamma$ and $t\bar{t}Z$
- Photon p_T is the most sensitive variable



$$C^{Z}_{2,\mathrm{V}} = \frac{v^2 m_t}{\sqrt{2} c_w s_w m_Z \Lambda^2} \Re\,[C_{tZ}]\,, \quad C^{Z}_{2,\mathrm{A}} = \frac{v^2 m_t}{\sqrt{2} c_w s_w m_Z \Lambda^2} \Im\,[C_{tZ}]\,,$$

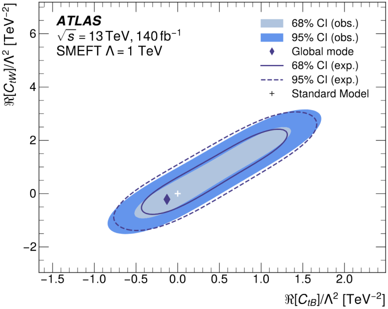
$$C^{\gamma}_{2,\mathrm{V}} = \frac{\sqrt{2} v m_t}{e \Lambda^2} \Re\,[C_{t\gamma}]\,, \quad C^{\gamma}_{2,\mathrm{A}} = \frac{\sqrt{2} v m_t}{e \Lambda^2} \Im\,[C_{t\gamma}]\,,$$

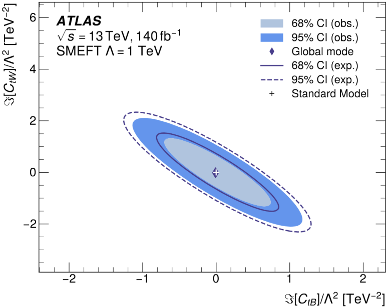
$$C_{tZ} = c_w \cdot C_{tW} - s_w \cdot C_{tB},$$

$$C_{t\gamma} = s_w \cdot C_{tW} + c_w \cdot C_{tB}.$$

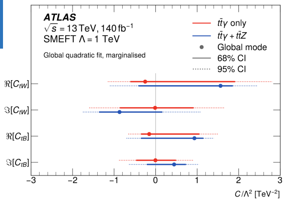
Limits from $t\bar{t}\gamma$ production

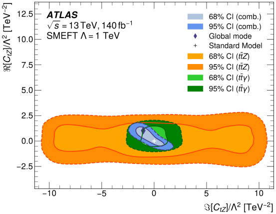
- Linear and quadratic terms included
- Simultaneous fit of real and imaginary parts of C_{tB} and C_{tW} in both channels
- **Good agreement with SM is observed**

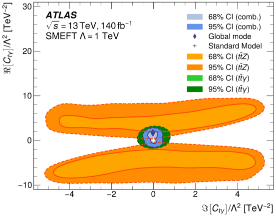




Combination with $t\bar{t}Z$ results



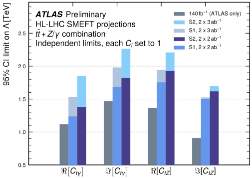


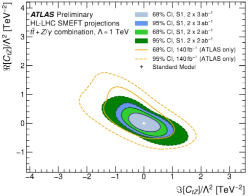


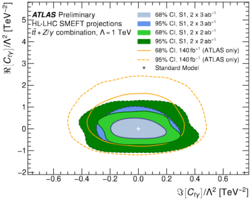
- Simultaneous measure of unfolded γ and Z p_T
  - Object selection and unc. were homogenised
  - Correctly account for all correlations
- Combining with $t\bar{t}Z$ gives tighter limits
- Same contour shape alone, different structure when combined
- $t\bar{t}\gamma$ measurement resolves degeneracies from $t\bar{t}Z$ alone
- **Good agreement with SM is observed**

HL-LHC projection [7]

Extrapolated for ATLAS + CMS at HL-LHC with 2 or 3 ab^{-1} of data each in two different systematics scenarios:

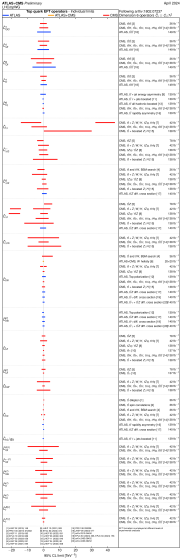






Demonstrates that BSM physics in the sector of t anomalous electroweak dipole moments can be **excluded** up to mass scales of **2.2 TeV**

LHC Top Working Group



Summary plots from the LHC Top WG [8] $\rightarrow$ comprehensive **overview** of the current status of the top quark sector in both **ATLAS and CMS**

Combined EFT interpretation

Publication

CERN-EP-2025-035
2025/04/07

CMS-SMP-24-003

Combined effective field theory interpretation of Higgs boson, electroweak vector boson, top quark, and multijet measurements

The CMS Collaboration*

Abstract

Constraints on Wilson coefficients (WCs) corresponding to dimension-6 operators of the standard model effective field theory (SMEFT) are determined from a simultaneous fit to seven sets of CMS measurements probing Higgs boson, electroweak vector boson, top quark, and multijet production. Measurements of electroweak precision observables at LEP and SLC are also included and provide complementary constraints to those from the CMS experiment. The CMS measurements, using LHC proton-proton collision data at $\sqrt{s} = 13\,\text{TeV}$, corresponding to integrated luminosities of 36.3 or 138 fb^{-1}, are chosen to provide sensitivity to a broad set of operators, for which consistent SMEFT predictions can be derived. These are primarily measurements of differential cross sections which are parameterized as functions of the WCs. Measurements targeting $t(\bar{t})X$ production directly incorporate the SMEFT effects through event weights that are applied to the simulated signal samples, which enables detector-level predictions. Individual constraints on 64 WCs, and constraints on 42 linear combinations of WCs, are obtained.

Submitted to the European Physical Journal C

Submitted to **Eur. Phys. J. C** on **April 3, 2025**
arXiv:2504.02958

[6]

Context

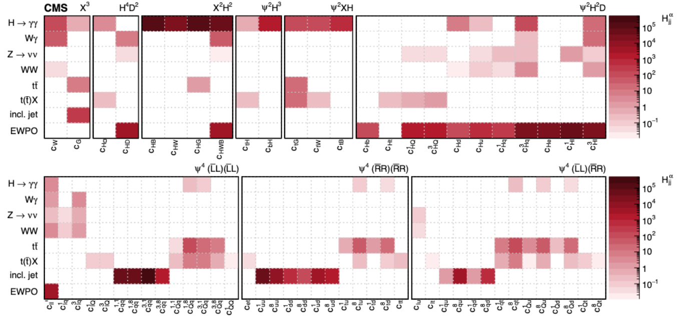
Multi-sector combined EFT interpretation from :
EWPO (LEP+SLC), **Higgs**, **Electroweak**, **Top**, **Multi-jet** (CMS)

Analysis	Type of measurement	Observables used	Experimental likelihood
$H \to \gamma\gamma$	Differential cross sections	STXS bins [54]	✓
$W\gamma$	Fiducial differential cross sections	$p_T^{\gamma} \times \|\phi_f\|$ [33]	✓
$Z \to \nu\nu$	Fiducial differential cross sections	p_T^{Z}	✓
WW	Fiducial differential cross sections	$m_{\ell\ell}$	✓
$t\bar{t}$	Fiducial differential cross sections	$m_{t\bar{t}}$	×
$t(\bar{t})X$	Direct EFT	Yields in regions of interest	✓
Inclusive jet	Fiducial differential cross sections	$p_T^{jet} \times \|y^{jet}\|$	×
EWPO	Pseudo-observables	Γ_Z, σ^0_{had}, R_ℓ, R_c, R_b, $A_{FB}^{0,\ell}$, $A_{FB}^{0,c}$, $A_{FB}^{0,b}$ [36]	×

- Input analysis chosen to provide sensitivity in 64 SMEFT operators
- Negligible overlap
- Small backgrounds

Sensitity

Diagonal entries of the Hessian matrix ($H_{jk} = \frac{\partial^2 \ln \mathcal{L}}{\partial c_j \partial c_k}$) evaluated for each input channel :

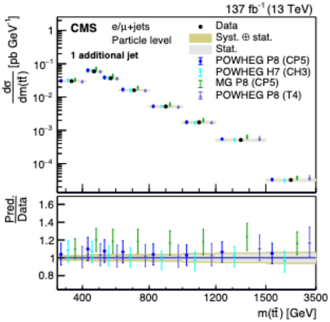


⇒ Indicates which analysis is expected to be the most sensitive to any given operator

Top input channels (1)

Measurement of $t\bar{t}$ [9]

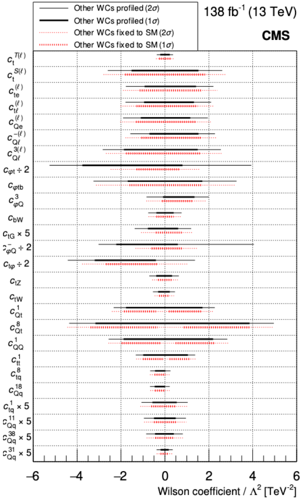
- 138 fb^{-1} of data (2016-18)
- Single-lepton plus jets channel
- Differential and double-differential cross-sections
- $m_{t\bar{t}}$ is chosen as it is one of the most sensitive variable and well modelled
- No EFT interpretation



Top input channels (2)

Measurement of $t(\bar{t})X$ [10]

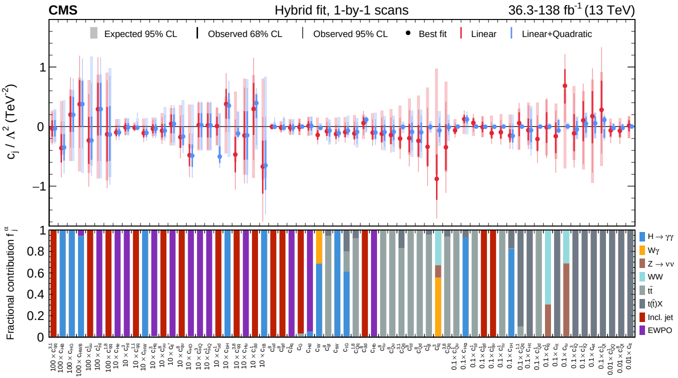
- 138 fb^{-1} of data (2016-18)
- Search for new physics in multi-leptonic final states
- 26 EFT operators considered
- Indep. measurement exist, but cannot be easily interpreted in terms of SMEFT constraints (overlap)
- # of events in different regions defined by the multiplicity of final state objects and kin. variables



Strategy

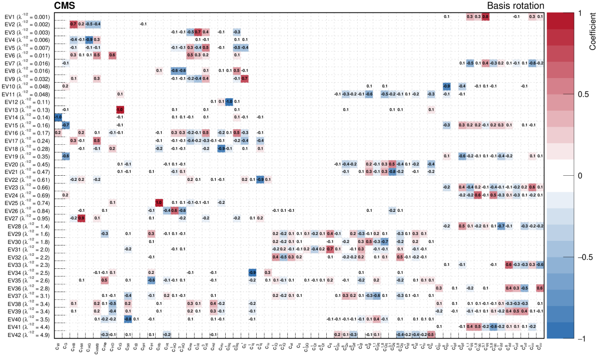
- Using a combined likelihood model :
  $\mathcal{L}(\text{data}; \vec{c}, \vec{\nu}) = \mathcal{L}^{\text{expt}}(\text{data}; \vec{c}, \vec{\nu})\mathcal{L}^{\text{simpl}}(\text{data}; \vec{c})$
  - $\vec{c}$ represents the POIs (WC or their combinations)
  - $\vec{\nu}$ represents nuisance parameters (theoretical and experimental)
  - $\mathcal{L}^{\text{expt}}(\vec{c}, \vec{\nu})$ covers measurements for which an experimental likelihood is available
  - $\mathcal{L}^{\text{simpl}}(\vec{c})$ covers the other measurements, for which the unc. are included in the covariance matrix
- Minor modifications to input measurements
  - New PDF set for some of the measurements
  - PDF and lumi. uncertainties correlated between inputs
  - Basis rotation for $t(\bar{t})X$ and added operators

Individual constraints



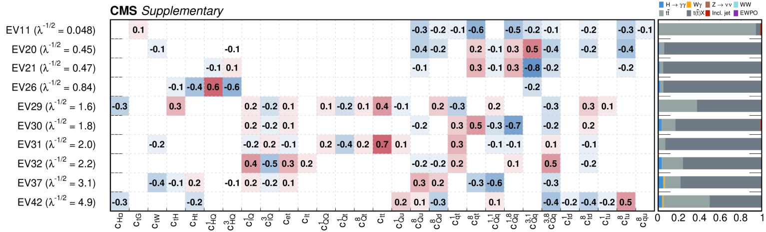
- Setting constraints by fixing all others to 0
- Fractional contributions calculated as $f_j^p = \frac{H_{jj}^p}{H_{jj}^{\text{comb.}}}$
- Top sector operators are among the most constrained

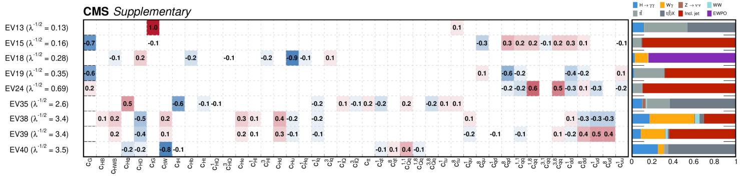
Combined constraints



- PCA (principal component analysis) used to extract the most sensitive directions in the parameter space
  - 42 linear combinations are retained ($1/\sqrt{\lambda} < 5$ cutoff, with λ an estimate of half the 68% CL interval)
  - 22 are set to their SM value (not sensitive enough) - flat directions

Combined constraints

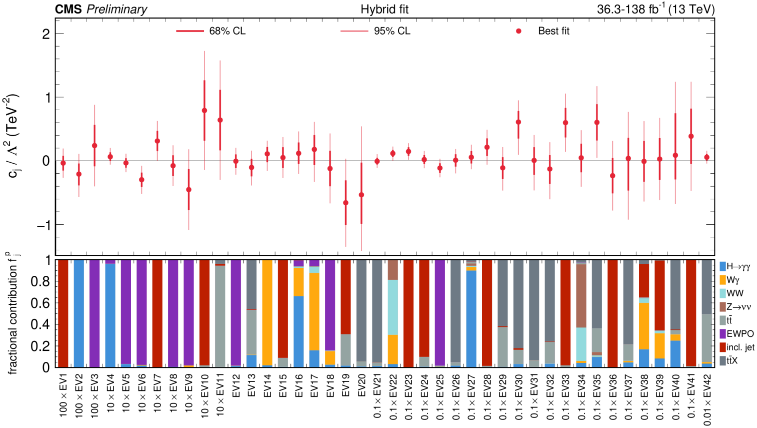




- 10 lin. comb. constrained by top measurements
- 6 by a mixture (top + Higgs and top + multijet)

Combin.

Results



⇒ Majority receive significant contribution by multiple channels

Conclusion

Conclusion and outlook

- EFT interpretation are a powerful tool, complementary to direct searches
- The SMEFT formalism is a good framework for the LHC
- Many interesting measurements have been performed in the top sector, many not covered in this talk
- Combined analysis significantly improve the sensitivity and can even resolve degeneracies

The future of EFT analyses ...

- EFT analysis are mainly focussed on interpretation rather than designing and optimising EFT exclusion limits
- Ability to re-interpret existing EFT measurements open the door to new possibilities
- Towards a combination from both experiments?

Thank you!

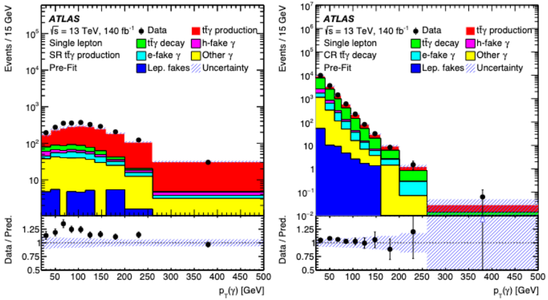
Thank you for your attention !

Special thanks to F. Stager [11], D. Kim [12], C. Diez Pardos
and to the **ATLAS** and **CMS** collaborations for their amazing work !

Backup

ATLAS $t\bar{t}\gamma$ - Event selection

- $t\bar{t}$ pair in 1L or 2L + exactly 1 photon
- Signal : $t\bar{t}\gamma$ production
- Background :
  - $t\bar{t}\gamma$ decay
  - Prompt photon background ($W\gamma$, $Z\gamma$, $t\bar{t}+V$ w/ γ from shower, single top, diboson)
  - Fake photon (electronic ($e \to \gamma$) or hadronic ($h \to \gamma$))
  - Fake leptons



ATLAS $t\bar{t}\gamma$ - Inclusive xsec

Channel	Production (fb)	Production + Decay (fb)
1L	$288 \pm 5(\text{stat})^{+20}_{-19}(\text{syst})$	$704 \pm 5(\text{stat})^{+49}_{-46}(\text{syst})$
2L	$45.7^{+1.4}_{-1.3}(\text{stat})^{+3.0}_{-2.8}(\text{syst})$	$116.1 \pm 1.7(\text{stat})^{+8.0}_{-7.6}(\text{syst})$
Comb.	$319 \pm 4(\text{stat})^{+15}_{-14}(\text{syst})$	$788 \pm 5(\text{stat})^{+38}_{-37}(\text{syst})$
NLO MC	$296^{+29}_{-30}(\text{scale})^{+6}_{-4}(\text{PDF})$	-

- Dominant uncertainties from $t\bar{t}\gamma$ modelling and background normalisation
- **Good agreement** between measurement and NLO MC prediction

ATLAS $t\bar{t}\gamma$ - Diff. xsec

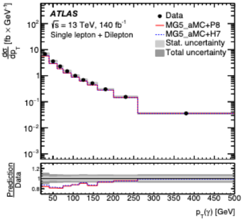
Differential xsec measurement in both channels for :

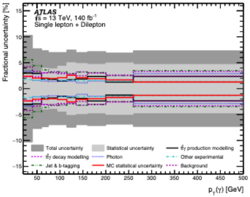
- Photon kinematics
- Angular distances between photon and other reco. objects

Differential xsec measurement in 2L channel only for :

- Sum of lepton p_T
- $\Delta\eta$ and $\Delta\phi$ between leptons

Dominant uncertainties from jets, b-tagging and stat. uncertainties (8-10% absolute, 5-7% normalised)





Good agreement with SM predictions!

References

References (1)

[1] Florian Goertz. All Scalars from one Source: Axiflavon-Higgs Unification. URL: https://moriond.in2p3.fr/2019/EW/slides/2_Monday/2_afternoon/2_Goertz_AxiflavonHiggs.pdf. Mar. 2019.

[2] B. Grzadkowski et al. "Dimension-six terms in the Standard Model Lagrangian". In: Journal of High Energy Physics 2010.10 (Oct. 2010).

[3] ATLAS Collaboration. "Measurement of the $t\bar{t}Z$ and $t\bar{t}W$ cross sections in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector". In: Physical Review D 99.7 (Apr. 2019).

References (2)

[4] CMS Collaboration. "Search for new physics in top quark production with additional leptons in proton-proton collisions at $\sqrt{s} = 13$ TeV using effective field theory". In: Journal of High Energy Physics 2021.3 (Mar. 2021).

[5] ATLAS collaboration. "Measurements of inclusive and differential cross-sections of $t\bar{t}\gamma$ production in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector". In: Journal of High Energy Physics 2024.10 (Oct. 2024).

[6] CMS Collaboration. "Combined effective field theory interpretation of Higgs boson, electroweak vector boson, top quark, and multi-jet measurements". In: (2025). arXiv: 2504.02958 [hep-ex].

References (3)

[7] ATLAS collaboration. Projected Sensitivity to Top-Quark Couplings in $t\bar{t}\gamma$ and $t\bar{t}Z$ Produc
Tech. rep. All figures including auxiliary figures are available at
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/A
PHYS-PUB-2025-015. Geneva: CERN, 2025.

[8] Top EFT summary plots April 2024. Tech. rep. All figures including auxiliary figures are available at
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/A
PHYS-PUB-2024-004. Geneva: CERN, 2024.

[9] CMS Collaboration. "Measurement of differential $t\bar{t}$ production cross sections in the full kinematic range using leptons+jets events from proton-proton collisions at $\sqrt{s} = 13$ TeV". In: Physical Review D 104.9 (Nov. 2021).

References (4)

[10] CMS Collaboration. "Search for physics beyond the standard model in top quark production with additional leptons in the context of effective field theory". In: Journal of High Energy Physics 2023.12 (Dec. 2023).

[11] Fabian Stager. Combined EFT fits in ATLAS and CMS. URL: https://indico.cern.ch/event/1383159/contributions/5970427/attachments/2935550/5156320/combined_eft_mbi24.pdf. Sept. 2024.

[12] Dongwon Kim. ATLAS EFT Results in the Top Quark Sector. URL: https://cds.cern.ch/record/2915336/files/ATL-PHYS-SLIDE-2024-489.pdf. Sept. 2024.