

EFT results in the top sector with the ATLAS detector

Dr James Howarth On behalf of the ATLAS Collaboration





M A R S E I L L E







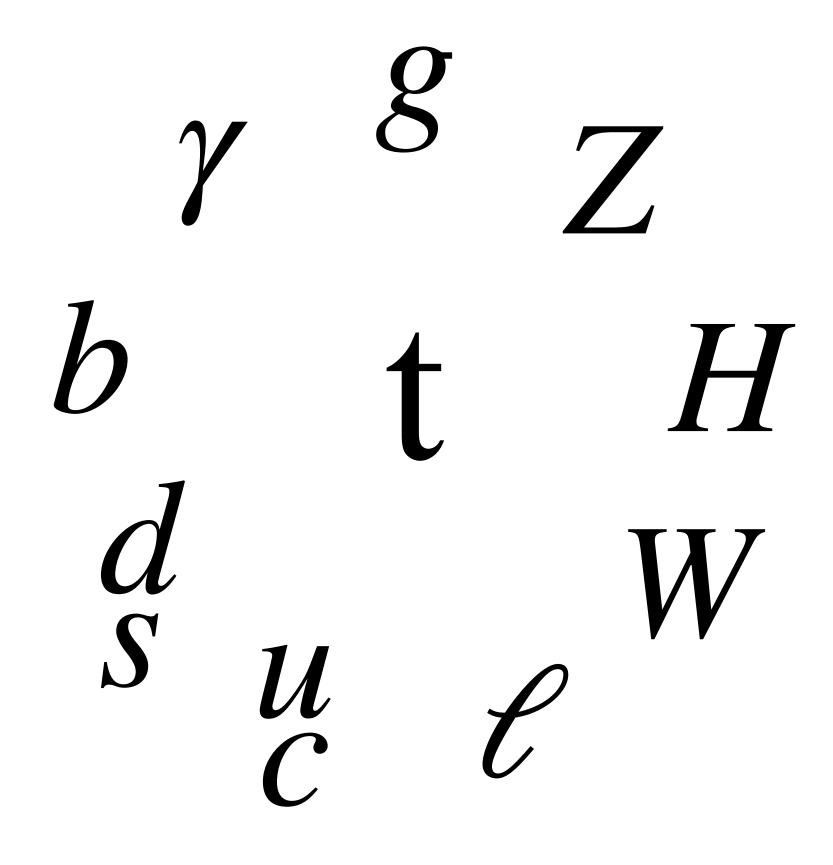




- Community currently focused on the next collider, to measure Higgs couplings with precision.
- Easy to forget that we haven't even done half of the top ones (and those we have still giving surprises)!







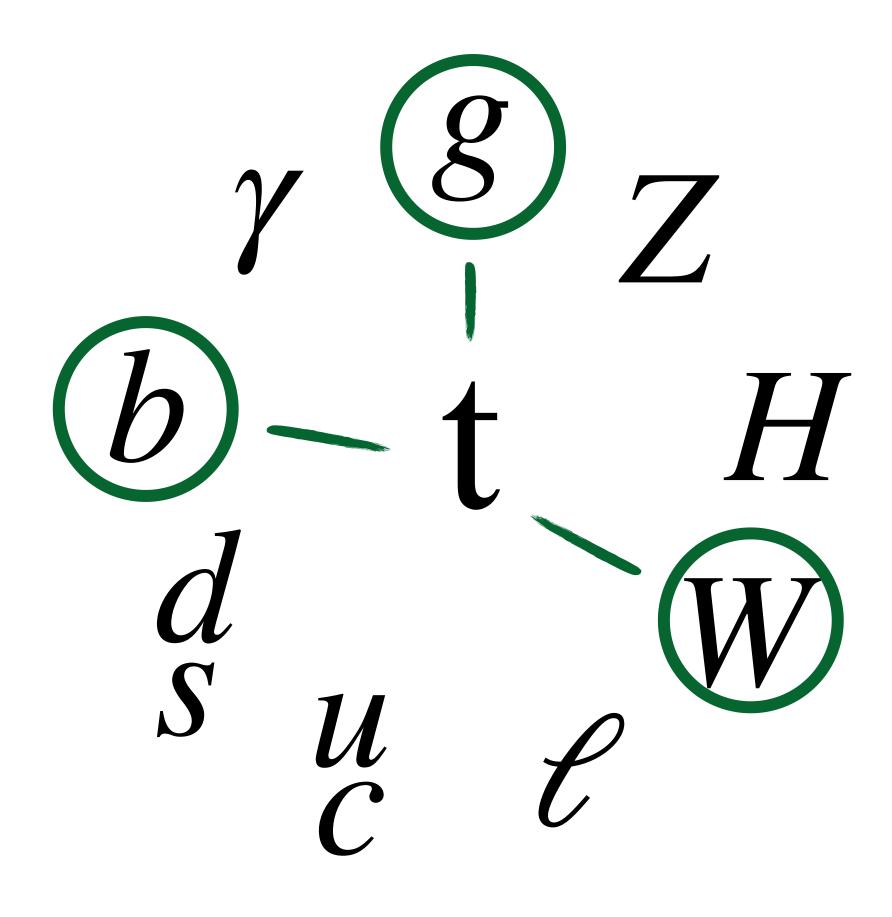




- We have probed the top's interactions with some particles in great detail.
- However, surprises still happen at high precision! (See topponium for a timely example of top-gluon surprises).





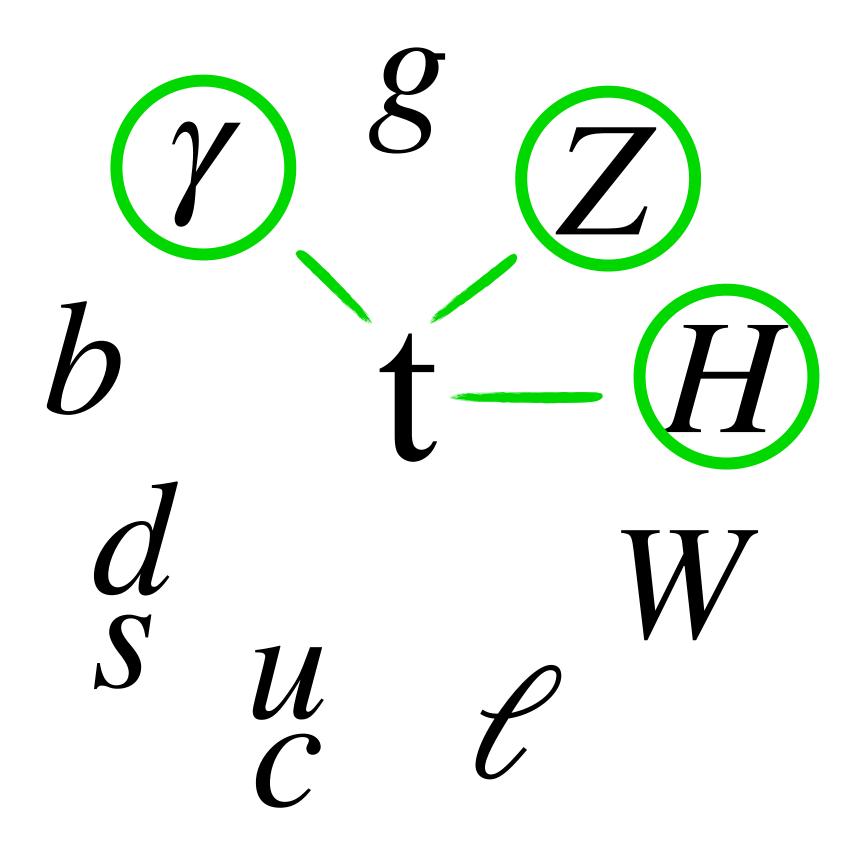




- Some couplings we have only just begun to access and understand relatively poorly.
- These are excellent avenues to probe for new Physics and exploring them will be a key exploit of the HL-LHC.







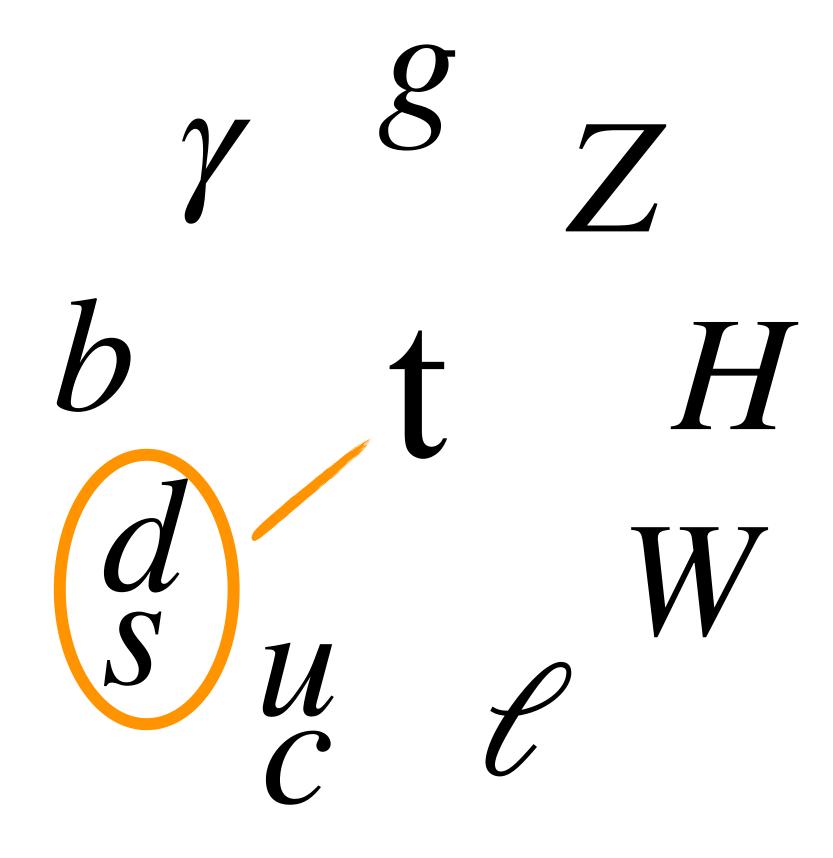




Even with the HL-LHC, some will test our experimental abilities to the limits to even observe!







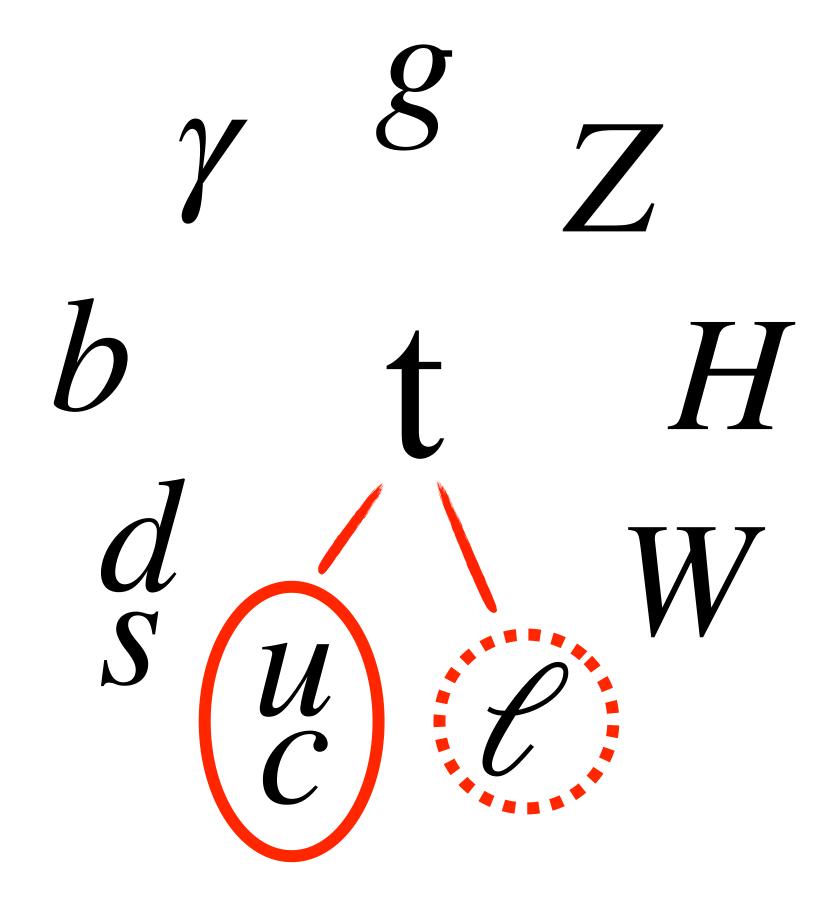




And some can only exist with FCNC (loop, CKM, and GIM suppressed, unless BSM) or more exotic signatures (making them excellent avenues to probe for BSM)





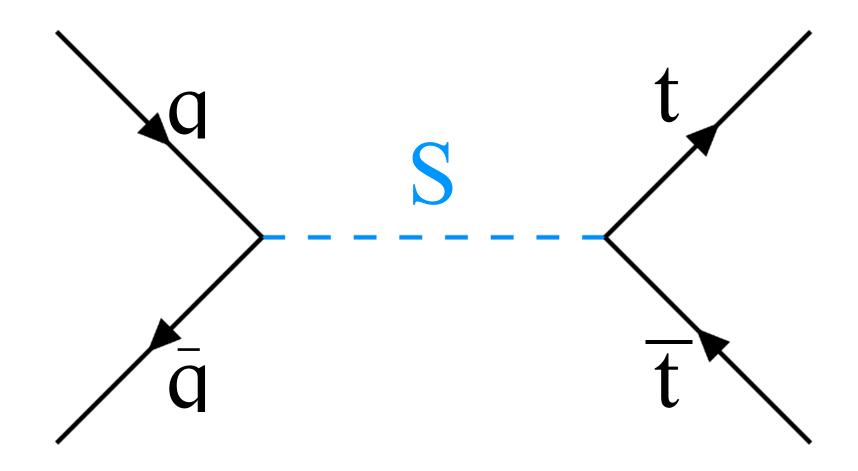






EFT vs UV Complete

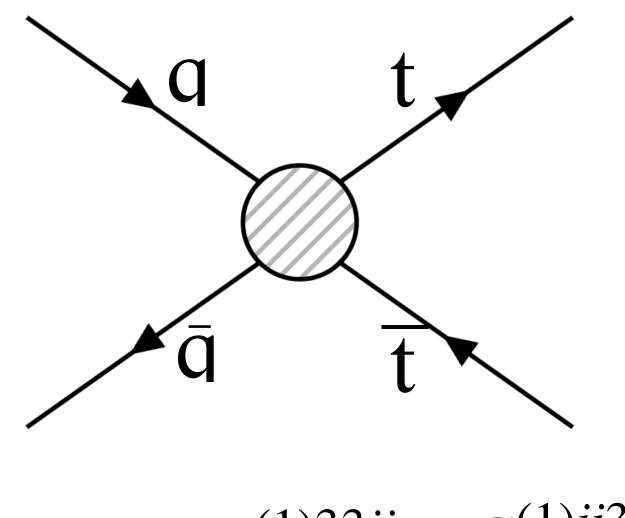
EFT's are a convenient way to describe deviations and probe sensitivity (but are not BSM models).

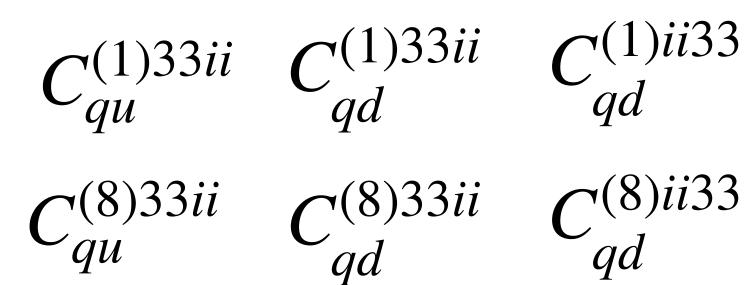


$m(S), \Gamma(S), \alpha_S$

UV complete models described by multiple EFT operators.













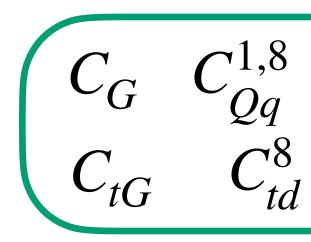








tī is the most prevalent form of top production at the LHC. Operators are related to the gluon or quark initiated production.



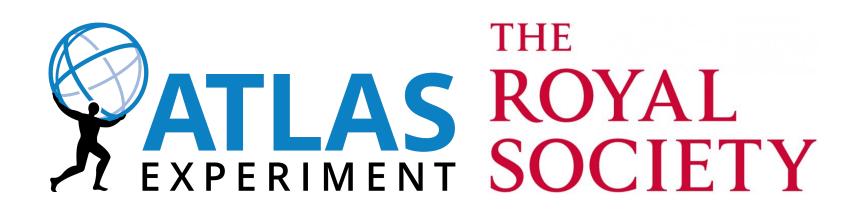


 $C_{Qq}^{3,8} C_{Qu}$ C_{Qd} C^8





$$C_{HWB} C_{HD} C_{ll} C_{ll} C_{HQ} C_{HQ}^{(1)} C_{He} C_{Hl}^{(3)} C_{Hl}^{(1)} C_{Hl} C_{Hl}^{(3)} C_{Hq}^{(3)} C_{Hq}^{(1)} C_{Hu} C_{Hd} C_{Hd}^{(3)} C_{Hq}^{(3)} C_{H$$



EWPO observations also appear, mostly in the decays of the top.



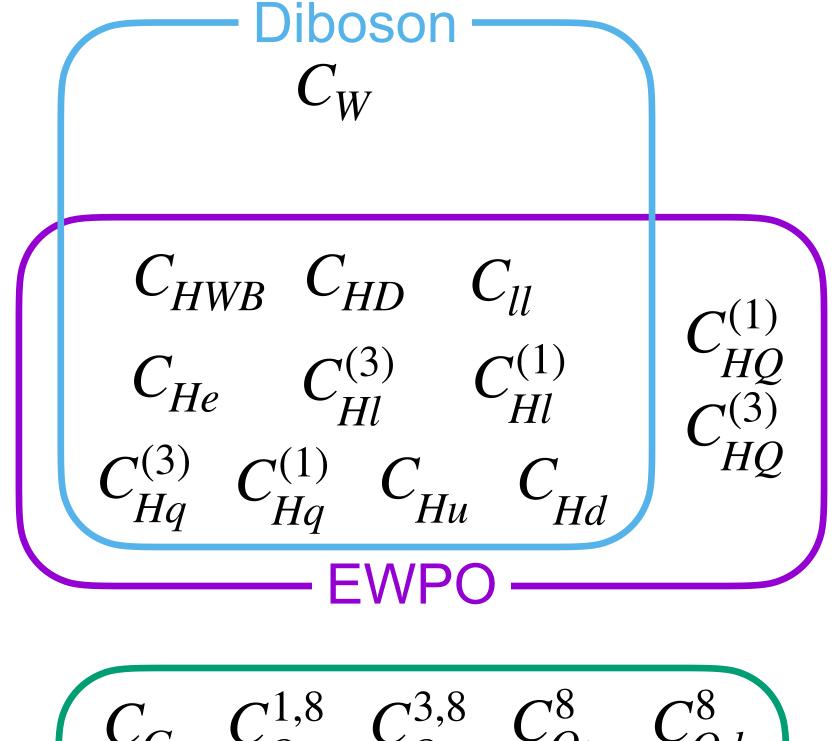


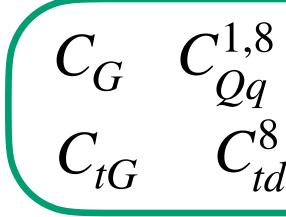






As well as some operators seen more commonly in Diboson signatures





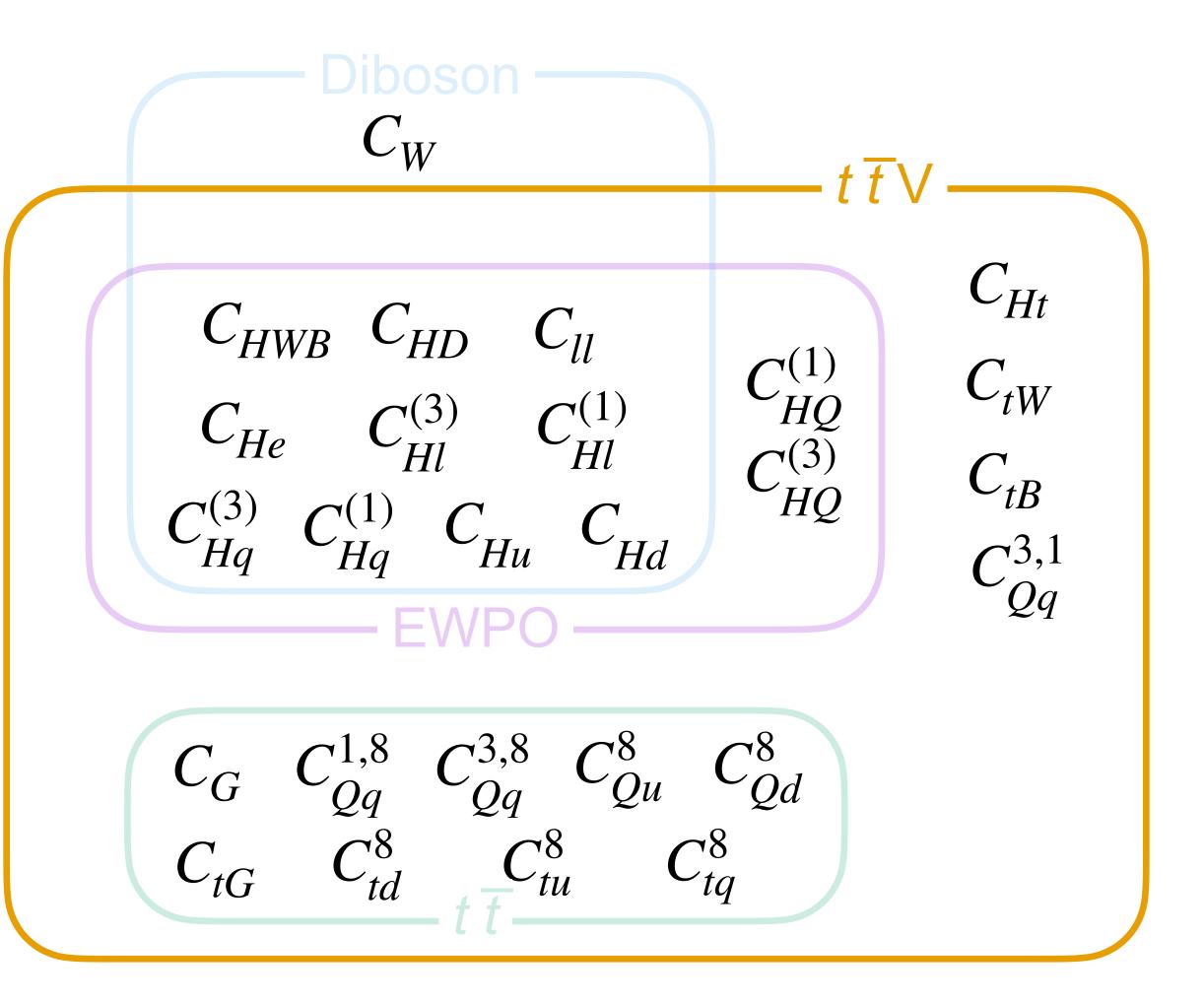


$$\begin{array}{cccc}
C_{Qq}^{3,8} & C_{Qu}^{6} & C_{Qd}^{6} \\
C_{Qq}^{8} & C_{Qd}^{8} \\
\frac{C_{tu}^{8} & C_{tq}^{8}}{t & t_{q}^{8}}
\end{array}$$





In top-pair + Boson signatures we pick up sensitivity to top-EW-Boson couplings







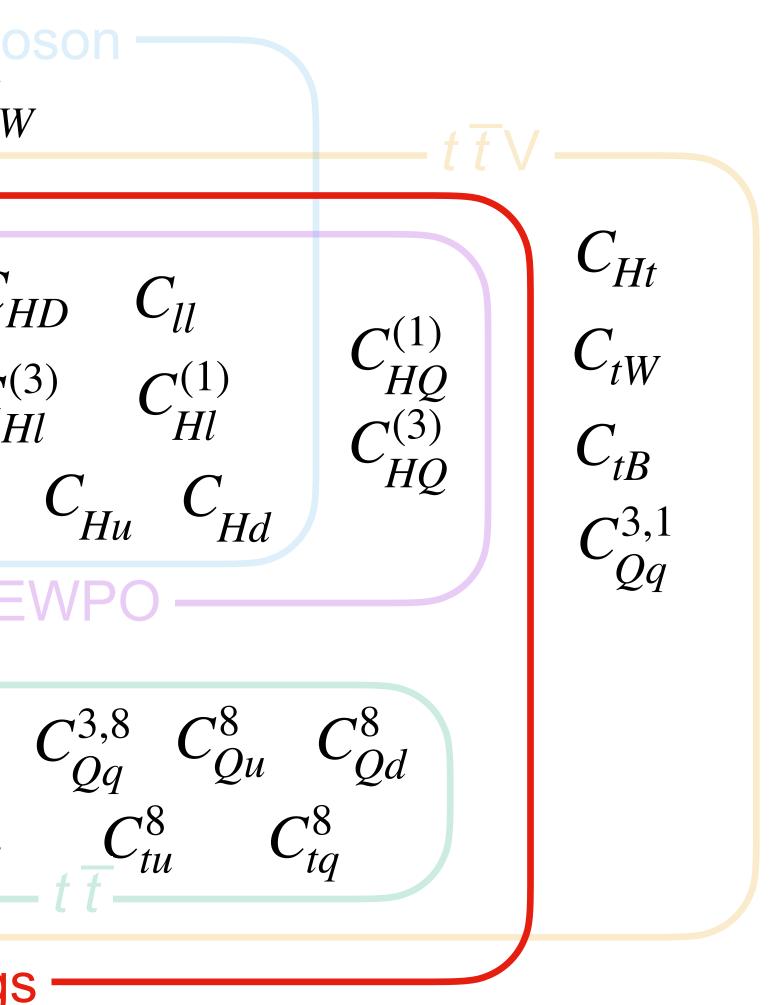




And finally, we get some Higgs sensitivity as well

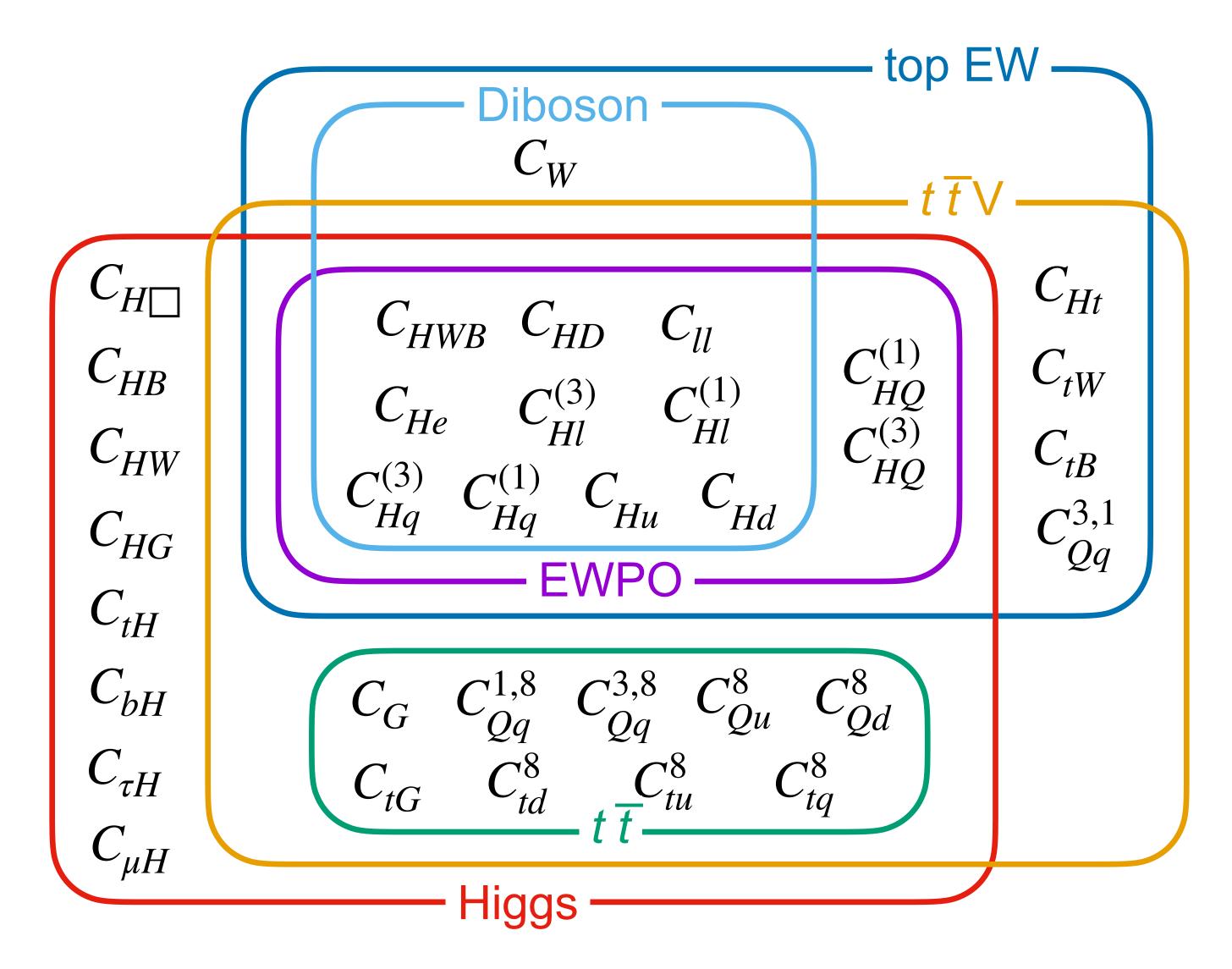
 C_W $C_{H\square}$ $egin{array}{ll} C_{HWB} & C_{HD} \ C_{He} & C_{Hl}^{(3)} \ Hl \end{array}$ C_{HB} C_{HW} $C_{Hq}^{(3)}$ $\mathcal{T}^{(1)}_{Hq}$ C_{HG} C_{tH} $\begin{array}{ccc} C_G & C_{Qq}^{1,8} \\ C_{Qq} & C_{Qq}^8 \\ C_{tG} & C_{td}^8 \end{array}$ C_{bH} $C_{\tau H}$ $C_{\mu H}$ Higgs











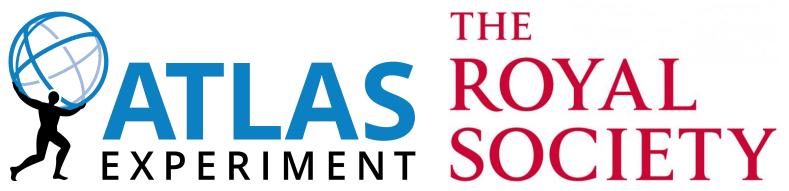


Figure from Ellist, Madigan, Mimasu, Sanz, You, JHEP 04 (2021) 279





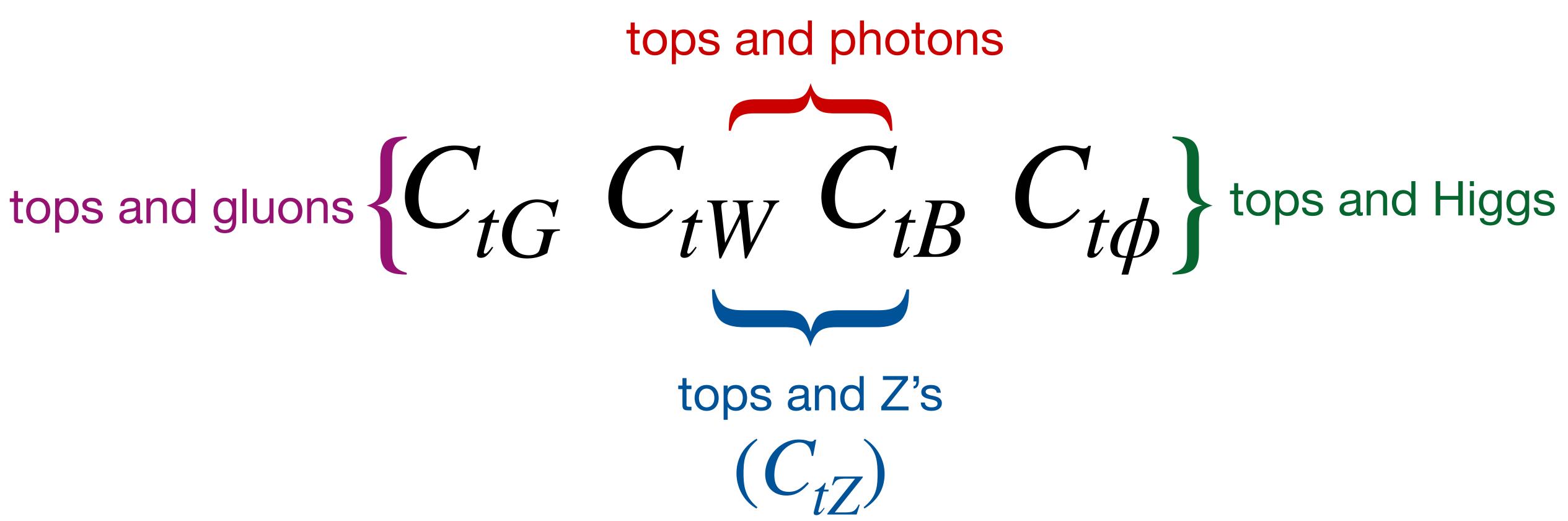


tops and bosons

As some of the heaviest processes at the LHC, top + Boson signatures are ideal places to search for BSM.







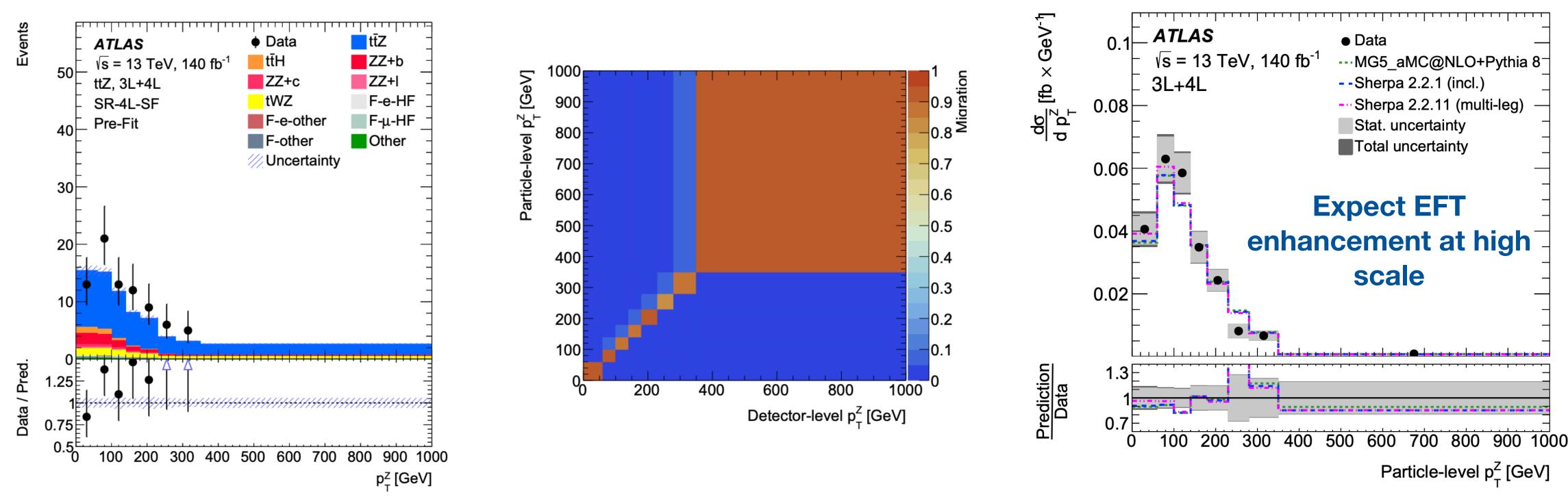






Detector Level

ttZ



unfolding on full Run2 data (on multiple observables).

• EFT limits set using unfolded results.



Migration Matrix



Unfolded Particle Level

Measurement uses 3L + 4L final states and a profile-likelihood based





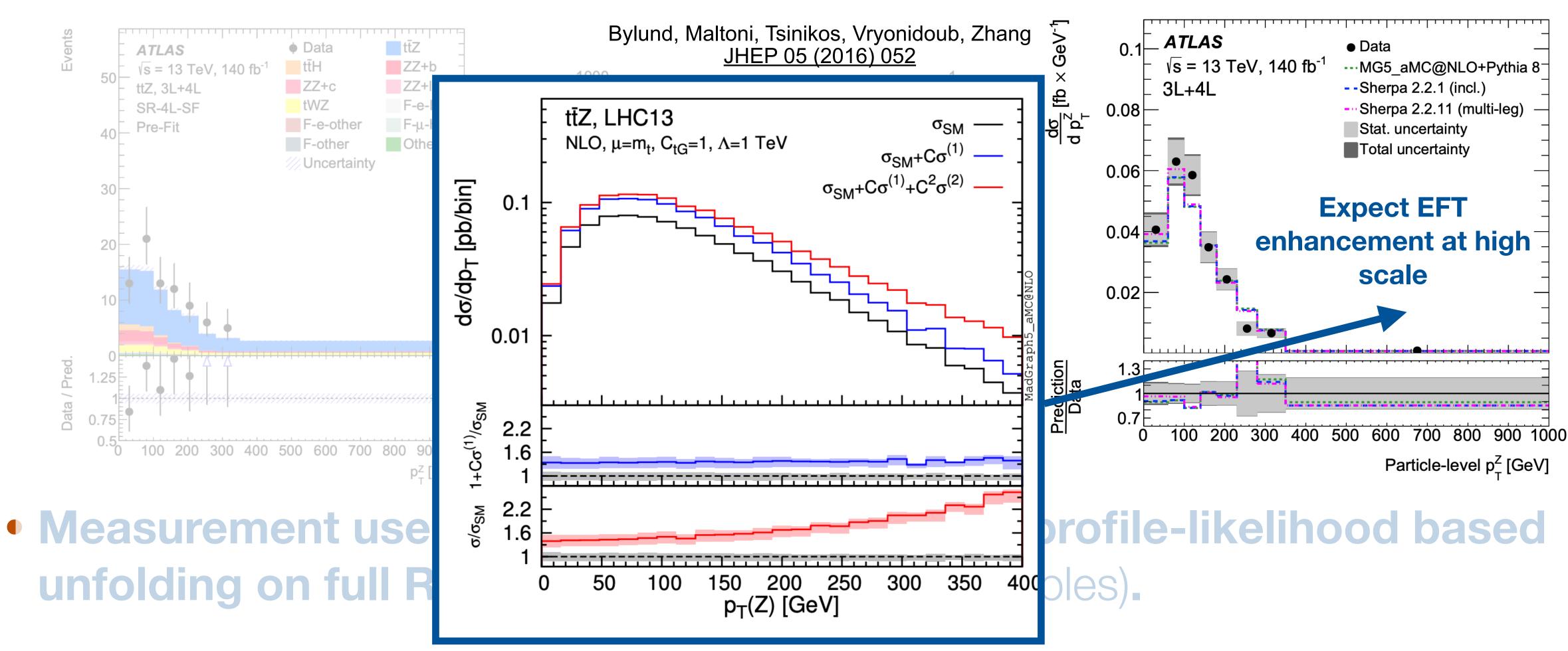




Detector Level

ttZ





• EFT limits set using unfolded results.

JHEP 07 (2024) 163

Migration Matrix



Unfolded Particle Level





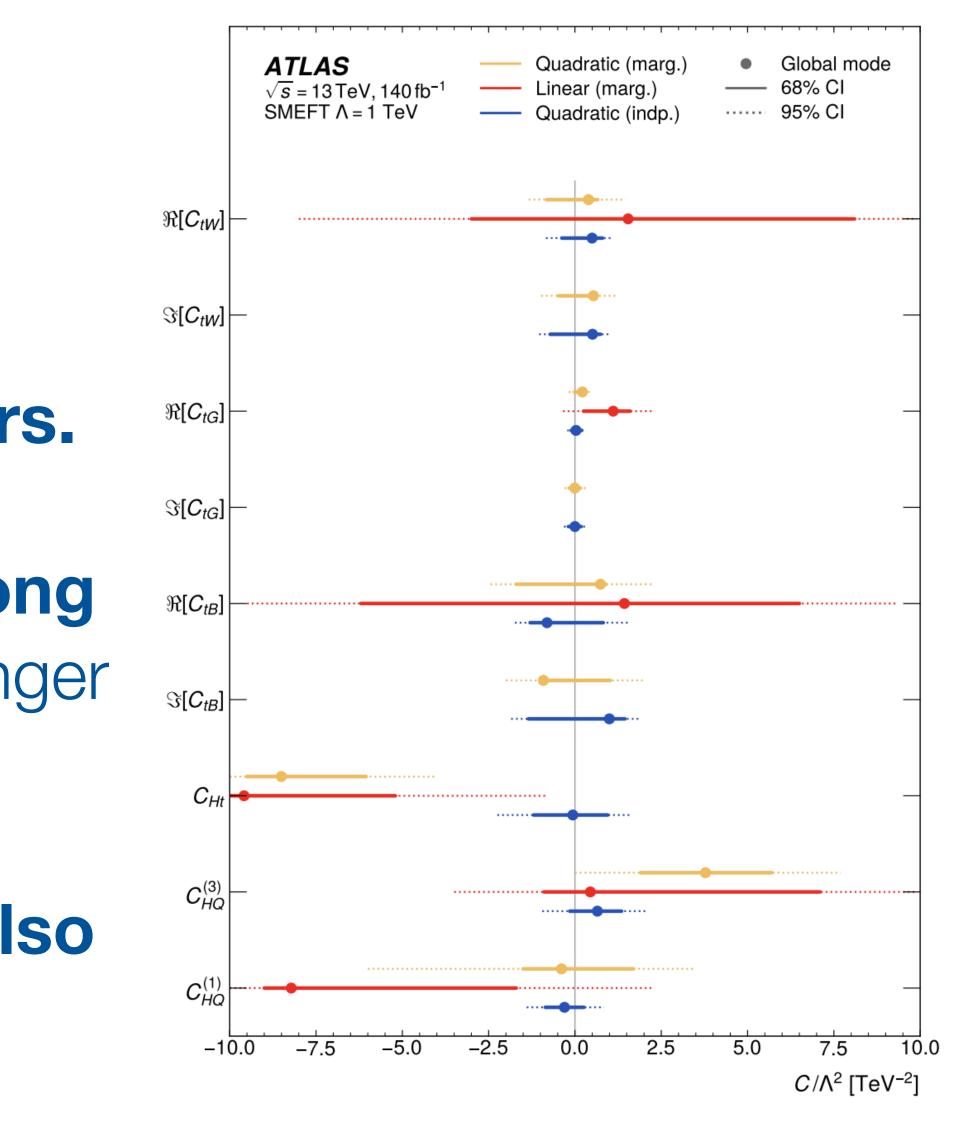




- Limits set on top-boson and 4fermion operators.
- EFT fit to both linear and linear+quadratic dim. 6 operators.
- Many of the operators have strong quadratic effects (leading to stronger constraints on operators in the fit)
 - But that means dim. 8 may also need to be considered.





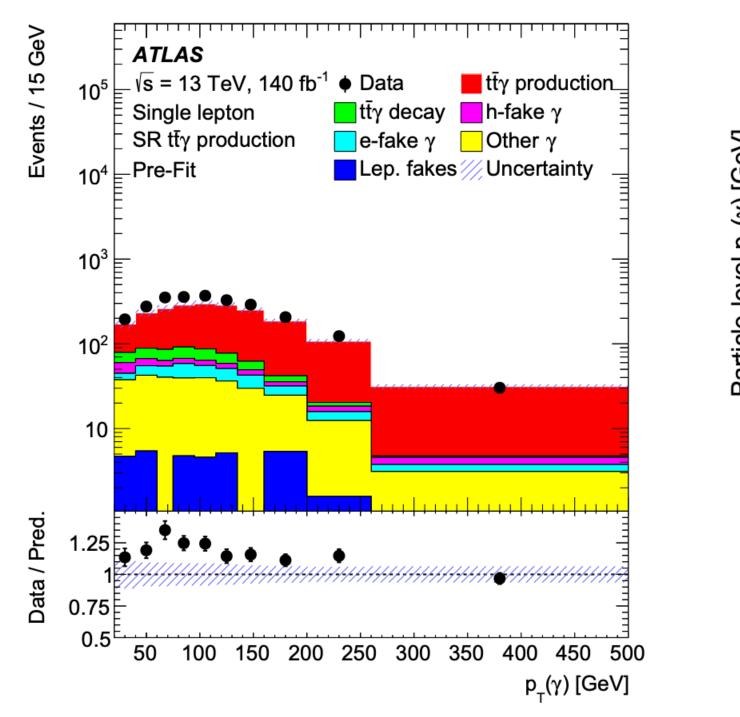




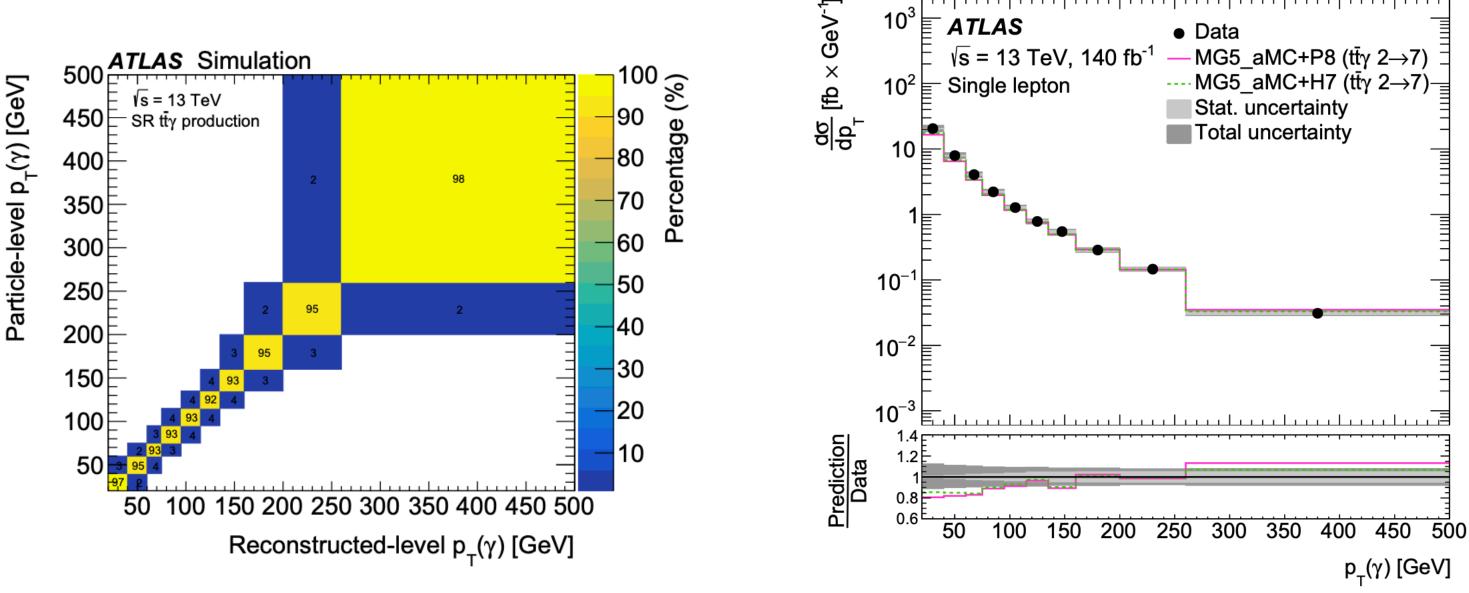


Detector Level

ttv





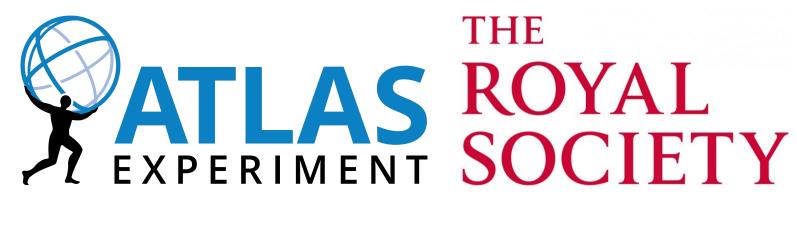


• Very similar procedure for tty (now using 1L and 2L channels).

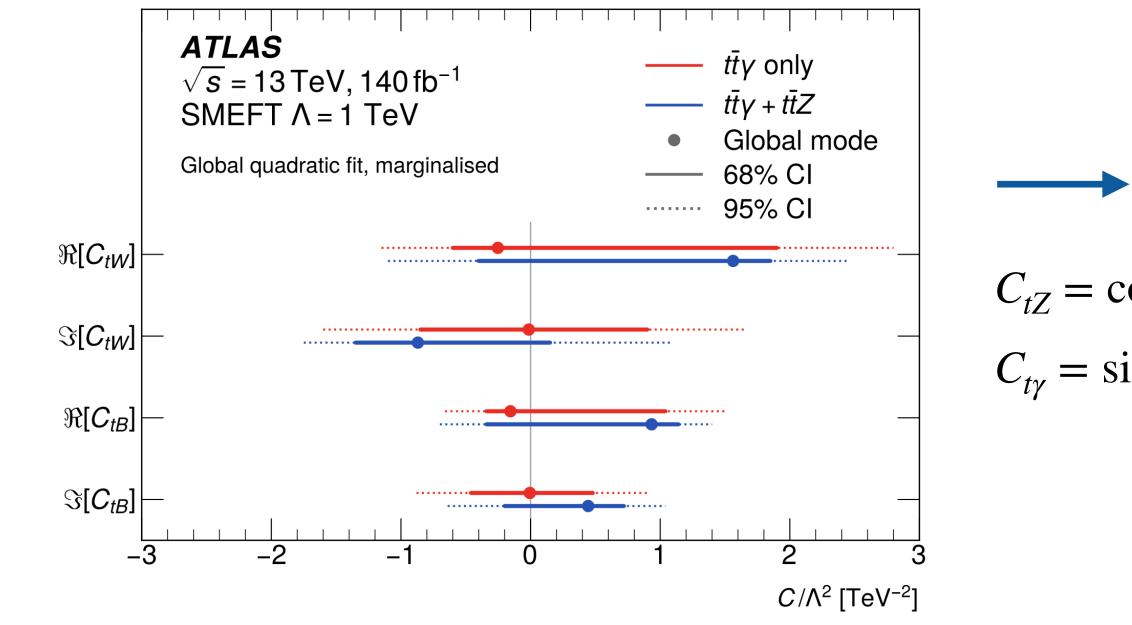
Again, multiple top and y-related observables fit simultaneously in **EFT** interpretation.



Migration Matrix



Unfolded Particle Level



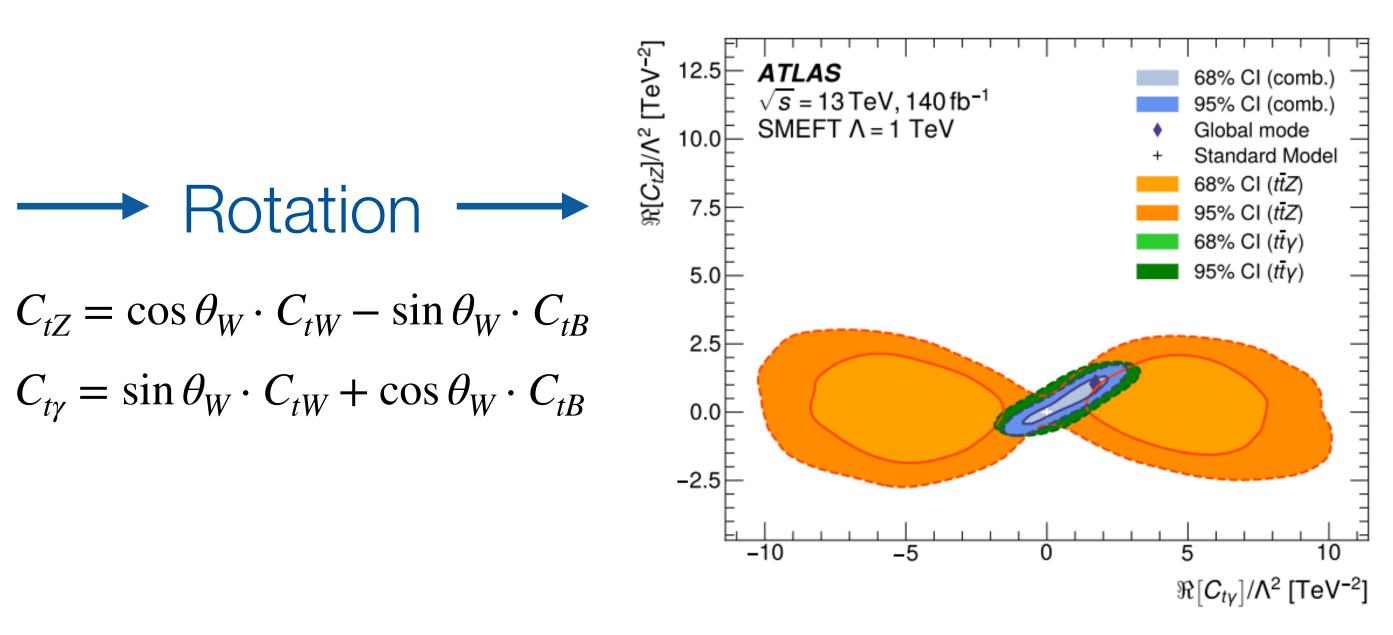
ttZ + tty

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Glasgow

- dataset to constrain operators.
- All results compatible with no deviation and set limits on scale of **BSM allowed in these processes.**





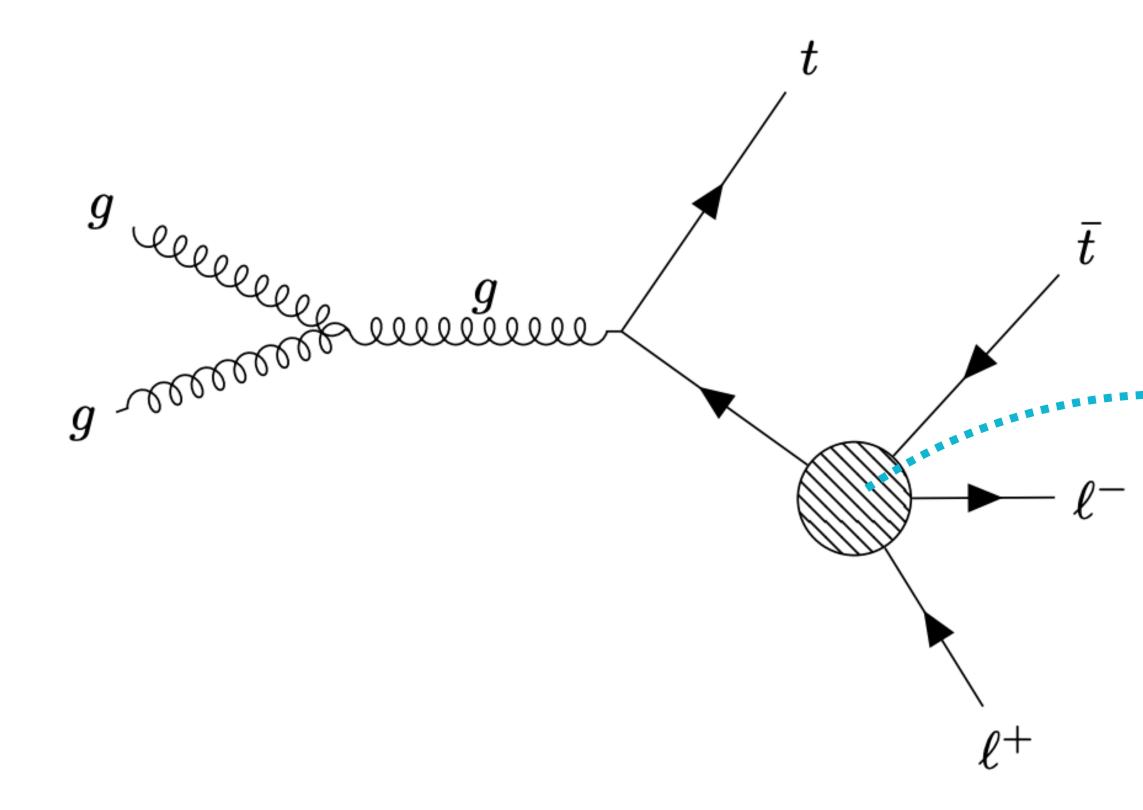
• Combining the two results helps to maximise the power of the Run2







off-shell till production ($|m(\ell \ell) - m(Z)| > 10 \ GeV$).





Searching for lepton flavour violation and focusing on 4-fermion operators in

• Unlike the other measurements, here a profile likelihood fit at detector level is performed to test six fourfermion operators:

 $C_{tl}, C_{te}, C_{Qe}, C_{Ql}^{-}, (C_{Ol}^{1} - C_{Ol}^{3}) C_{leOt}^{1} C_{leOt}^{3}$

 Also considering flavour split scenario (i.e. ee and µµ separately).





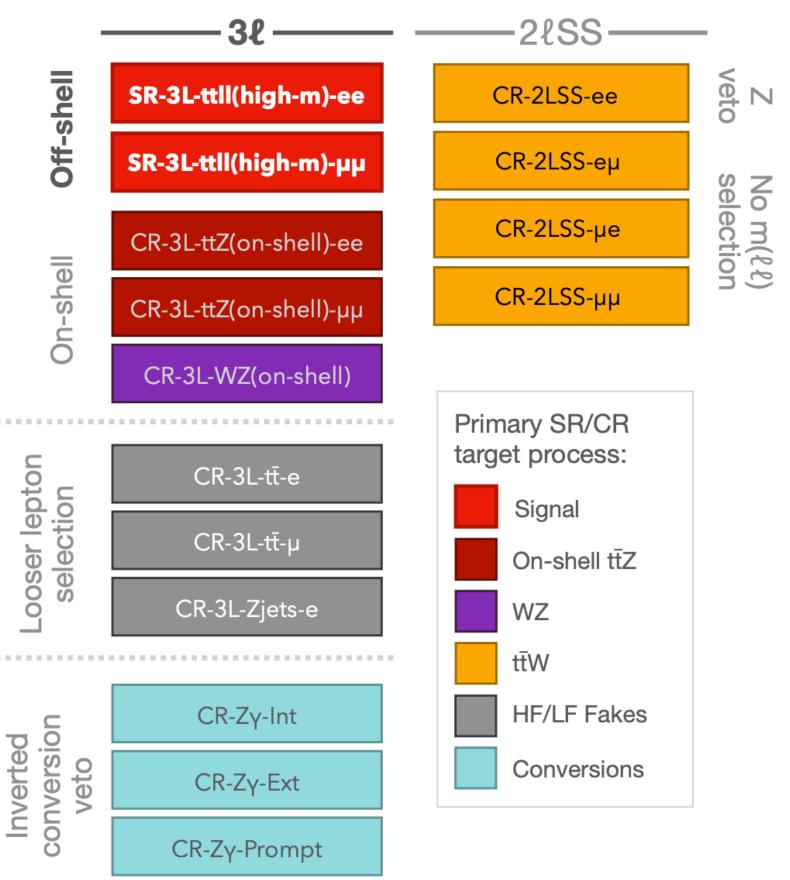








Signal region focuses on the 3-lepton high m(II) region as this is the highest purity phase-space that can be accessed.



Signal Region is the off-shell Z/γ^* region

> on-shell ttZ 3L used as control region

Submitted to EPJC



- Main sources of background come from SM processes with same or similar final state, and from misidentified leptons.
- Complex selection to isolate control regions to control these backgrounds (very good control of backgrounds post-fit).





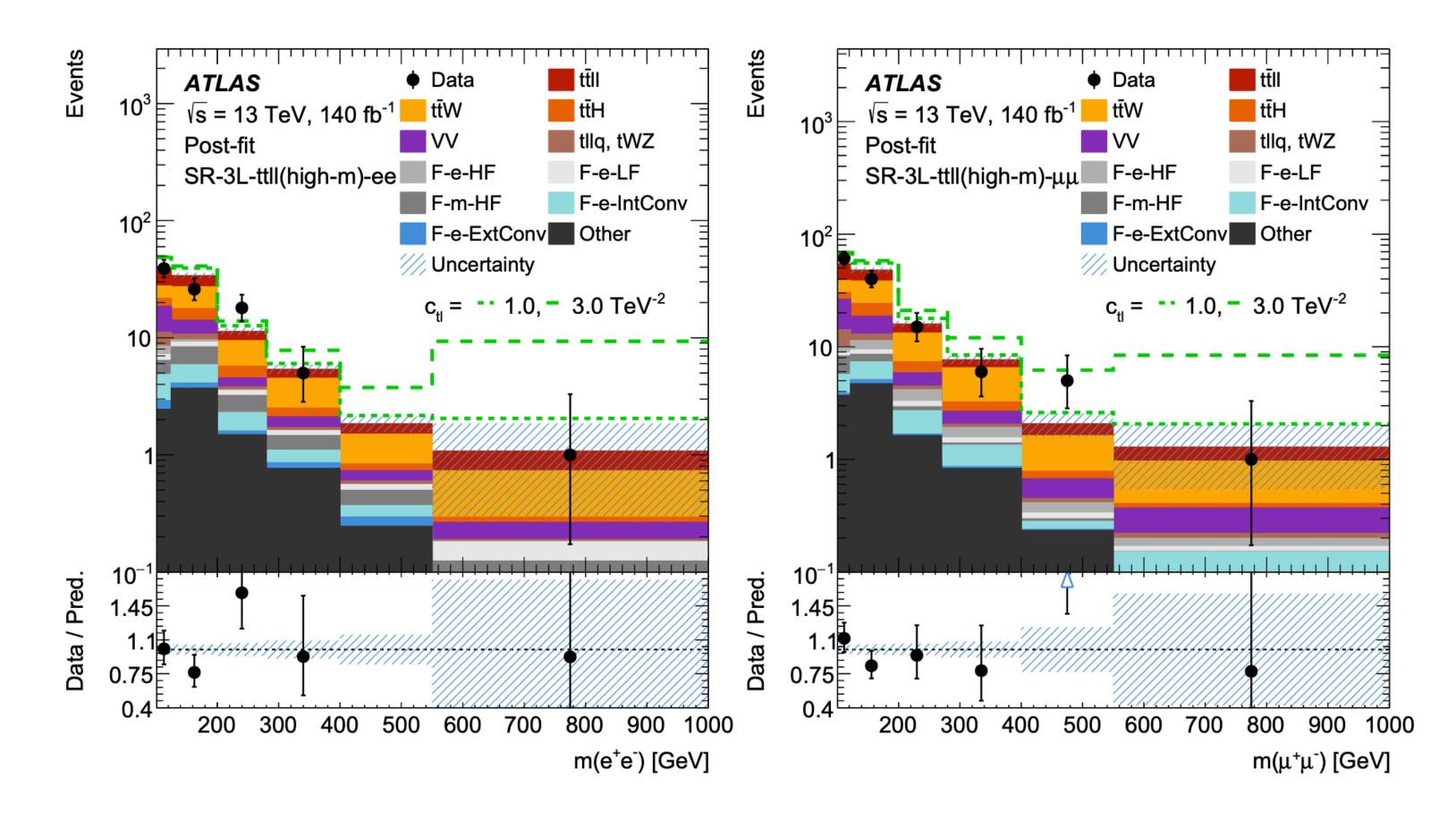












 EFT effects are expected to be strongest a high m(II) but also induce a general cross-section enhancement across the phase-space. Evidence for off-shell till production at significance of 2.9σ .

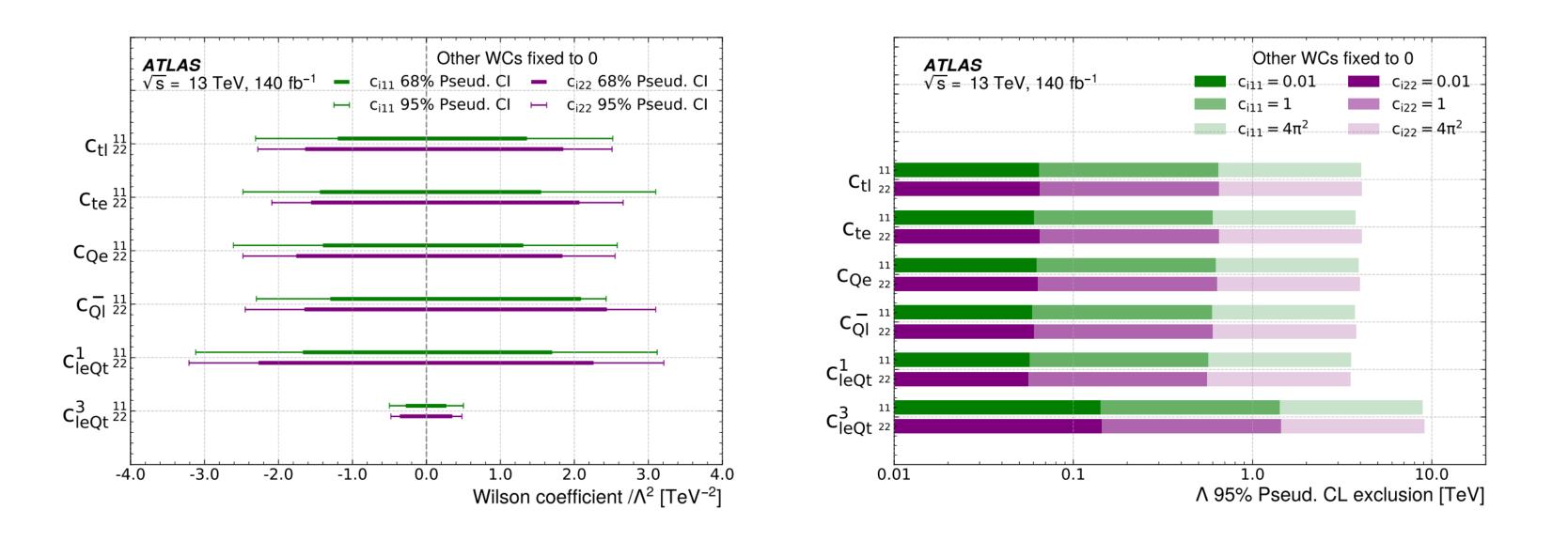
Submitted to EPJC







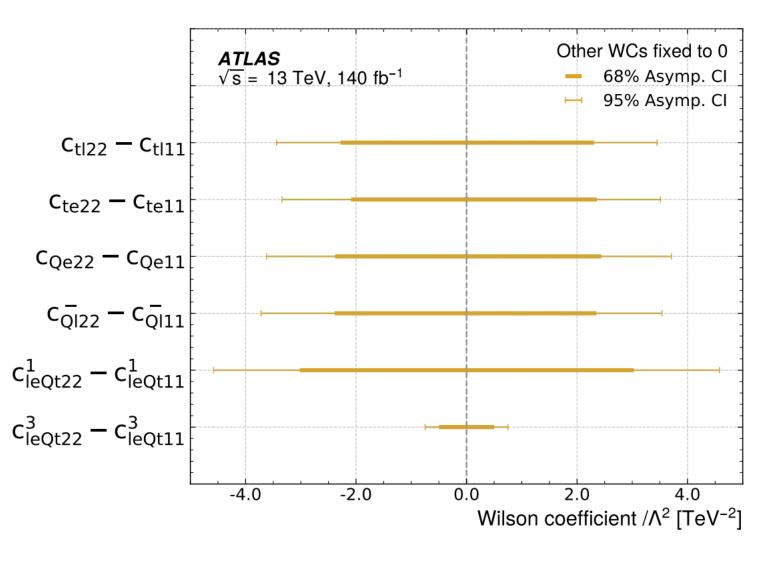




- (Run3 data will bring significant improvements).
- Fits use pseudo-data to address possible loss of coverage due to dominant quadratic effects in EFT parameterisation.
- Results show no evidence of lepton flavour violating effects.

Submitted to EPJC





Limits improve upon previous searches but are still statistically limited







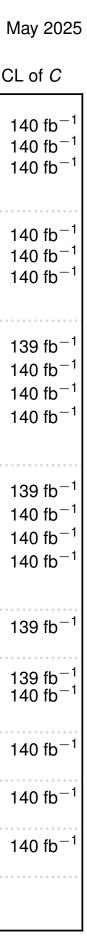
ATLAS Preliminary **ATLAS** asymptotic $C_i = 0.01, 1, 4\pi^2$ [1] JHEP 06 (2022) 063 [2] JHEP 11 (2022) 040

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(Top) quark - boson operators - Individual limits		Following arXiv:1802.07237 Dimension 6 operators $\tilde{C} \equiv C/\Lambda^2$, using 9	5% CL
	$\sqrt{C_i/\tilde{C}_{tB}}$	ATLAS, $t\bar{t}Z$ diff. cross section [4] ATLAS, $t\bar{t}\gamma$ diff. cross section [5] ATLAS, $t\bar{t}\gamma$ + $t\bar{t}Z$ diff. cross section [6]	14 14 14
	$\sqrt{C_i/ ilde{C}_{tB}^{[I]}}$	ATLAS, $t\bar{t}Z$ diff. cross section [4] ATLAS, $t\bar{t}\gamma$ diff. cross section [5] ATLAS, $t\bar{t}\gamma$ + $t\bar{t}Z$ diff. cross section [6]	14 14 14
	$\sqrt{C_i/\tilde{C}_{tW}}$	ATLAS, Top polarization [2] ATLAS, $t\bar{t}Z$ diff. cross section [4] ATLAS, $t\bar{t}\gamma$ diff. cross section [5] ATLAS, $t\bar{t}\gamma + t\bar{t}Z$ diff. cross section [6]	13 14 14 14
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	$\sqrt{\mathcal{C}_i/(ilde{\mathcal{C}}_{tG}/g_S)}$	ATLAS, $t\bar{t} \ell$ + jets boosted [1]	13
	$\sqrt{C_i/ ilde{C}_{tG}}$	ATLAS, <i>tt</i> rapidity asymmetry [3] ATLAS, <i>ttZ</i> diff. cross section [4]	13 14
	$\sqrt{C_i/ ilde{C}_{\phi t}}$	ATLAS, $t\bar{t}Z$ diff. cross section [4]	14
	$\sqrt{C_i/ ilde{C}_{\phi Q}^1}$		14
	$\sqrt{C_i/ ilde{C}_{\phi Q}^3}$	ATLAS, $t\bar{t}Z$ diff. cross section [4]	14
[3] JHEP 08 (2023) 077 [4] JHEP 07 (2024) 163	[5] JHEP 10 (2024) 191 [6] JHEP 10 (2024) 191	EFT formalism is employed at different levels of experimental analyses	
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A 95% CL exclusion [TeV]



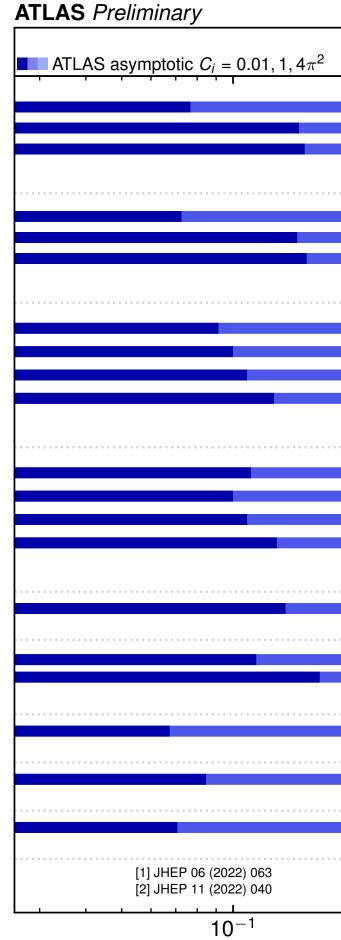






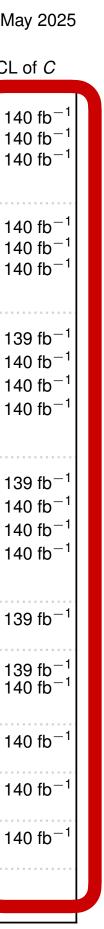


- ATLAS has fully exploited the Run2 data for EFT interpretations!
- Novel analyses in ultra rare processes (all of them looking at more than just EFT).





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(Top) quark - boson operators - Individual limits		Following arXiv:1802.07237 Dimension 6 operators $\tilde{C} \equiv C/\Lambda^2$, using 95°	% CL o
	$\sqrt{C_i/\tilde{C}_{tB}}$	ATLAS, $t\bar{t}Z$ diff. cross section [4] ATLAS, $t\bar{t}\gamma$ diff. cross section [5] ATLAS, $t\bar{t}\gamma$ + $t\bar{t}Z$ diff. cross section [6]	140 140 140
	$\sqrt{C_i/ ilde{C}_{tB}^{[I]}}$	ATLAS, $t\bar{t}Z$ diff. cross section [4] ATLAS, $t\bar{t}\gamma$ diff. cross section [5] ATLAS, $t\bar{t}\gamma$ + $t\bar{t}Z$ diff. cross section [6]	140 140 140
	$\sqrt{C_i/ ilde{C}_{tW}}$	ATLAS, Top polarization [2] ATLAS, $t\bar{t}Z$ diff. cross section [4] ATLAS, $t\bar{t}\gamma$ diff. cross section [5] ATLAS, $t\bar{t}\gamma + t\bar{t}Z$ diff. cross section [6]	139 140 140 140
	$\sqrt{C_i/ ilde{C}_{tW}^{[I]}}$	ATLAS, Top polarization [2] ATLAS, $t\bar{t}Z$ diff. cross section [4] ATLAS, $t\bar{t}\gamma$ diff. cross section [5] ATLAS, $t\bar{t}\gamma + t\bar{t}Z$ diff. cross section [6]	139 140 140 140
	$\sqrt{C_i/(ilde{C}_{tG}/g_S)}$	ATLAS, $t\bar{t} \ell$ + jets boosted [1]	139
		ATLAS, <i>tī</i> rapidity asymmetry [3] ATLAS, <i>tīZ</i> diff. cross section [4]	139 140
	$\sqrt{m{\mathcal{C}}_i/ ilde{m{\mathcal{C}}}_{\phi t}}$	ATLAS, $t\bar{t}Z$ diff. cross section [4]	140
	$\sqrt{C_i/ ilde{C}_{\phi Q}^1}$	ATLAS, $t\bar{t}Z$ diff. cross section [4]	140
	$\sqrt{m{C}_i/ ilde{m{C}}_{\phim{Q}}^3}$	ATLAS, $t\bar{t}Z$ diff. cross section [4]	140
[3] JHEP 08 (2023) 077 [4] JHEP 07 (2024) 163	[5] JHEP 10 (2024) 191 [6] JHEP 10 (2024) 191	EFT formalism is employed at different levels of experimental analyses	
10 ⁰ Λ 95% CL exclusion [TeV]	10 ¹	<u>.u</u>	



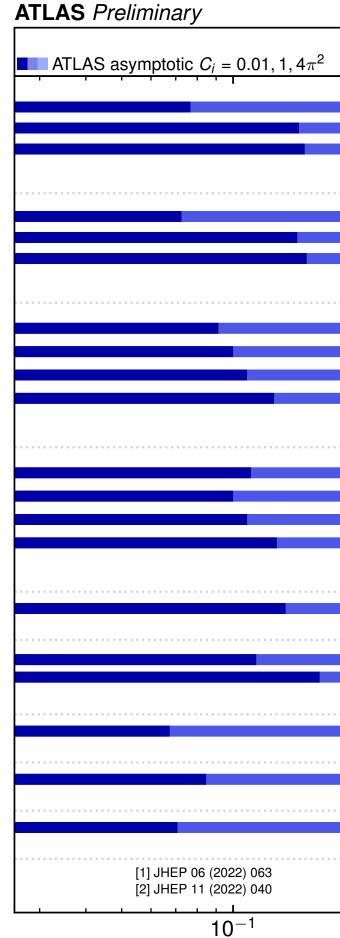








- Very strong BSM effects can be excluded into the many-TeV range, even up to 10 TeV.
- Safe to say that strongly coupling, multi-TeV new bosons or loop modifications not favoured by data.

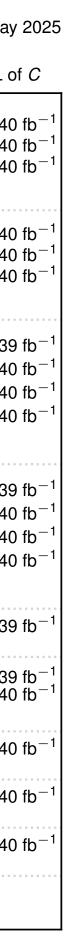


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(Top) quark - boson operators - Individual limits			Following arXiv:1802.07237 Dimension 6 operators $\tilde{C} \equiv C/\Lambda^2$, using 95	5% CL
		$\sqrt{C_i/ ilde{C}_{tB}}$	ATLAS, $t\bar{t}Z$ diff. cross section [4] ATLAS, $t\bar{t}\gamma$ diff. cross section [5] ATLAS, $t\bar{t}\gamma$ + $t\bar{t}Z$ diff. cross section [6]	14 14 14
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		$\sqrt{C_i/(ilde{C}_{tG}/g_S)}$	ATLAS, $t\bar{t} \ell$ + jets boosted [1]	13
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	JHEP 10 (20 JHEP 10 (20		EFT formalism is employed at different levels of experimental analyses	
10 ⁰ Λ 95% CL exclusion [TeV]	10	1	1	

< 8-9 TeV









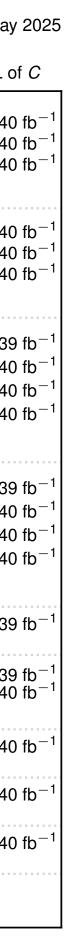
Even moderately strong BSM effects are excluded at the TeV level by multiple different analyses.

ATLAS asymptotic $C_i = 0.01, 1, 4\pi^2$ [1] JHEP 06 (2022) 063 [2] JHEP 11 (2022) 040 10^{-1}

ATLAS Preliminary

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	$\sqrt{C_i/ ilde{C}_{tB}}$	ATLAS, $t\bar{t}\gamma$ + $t\bar{t}Z$ diff. cross section [6]	14
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		ATLAS, Top polarization [2]	13
	$\sqrt{C_i/\tilde{C}_{tM}^{[l]}}$	ATLAS, $t\bar{t}Z$ diff. cross section [4] ATLAS, $t\bar{t}\gamma$ diff. cross section [5]	14 14
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	EP 10 (2024) 191 EP 10 (2024) 191 I I I I I I I I I I I I I I I I I I I	EFT formalism is employed at different levels of experimental analyses	
Λ 95% CL exclusion [TeV]			
< 1.5 TeV < 8-	9 TeV		



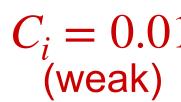




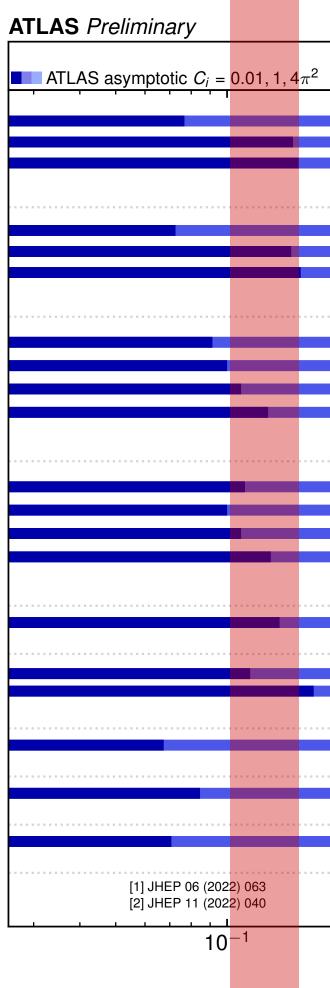








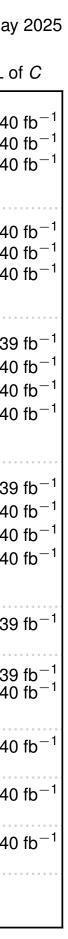
• The subtlest physics would struggle to hide at the EW scale, highlighting the impressive power of these measurements.



< 200 Ge

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1 $C_i = 1$ (medium)	$P = 4\pi^2$ (strong)	IMENT SOCI
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	$\sqrt{C_i/ ilde{C}_{tW}^{[I]}}$	ATLAS, Top polarization [2]13ATLAS, $t\bar{t}Z$ diff. cross section [4]14ATLAS, $t\bar{t}\gamma$ diff. cross section [5]14ATLAS, $t\bar{t}\gamma$ + $t\bar{t}Z$ diff. cross section [6]14
	·····	ATLAS, $t\bar{t} \ \ell$ + jets boosted [1]13ATLAS, $t\bar{t}$ rapidity asymmetry [3]13ATLAS, $t\bar{t}Z$ diff. cross section [4]14
	$\sqrt{C_i/ ilde{C}_{\phi t}}$	ATLAS, $t\bar{t}Z$ diff. cross section [4] 14 ATLAS, $t\bar{t}Z$ diff. cross section [4] 14
[3] JHEP 08 (20 <mark>23) 077</mark> [4] JHEP 07 (20 <mark>24) 163</mark>	$\frac{\sqrt{C_i/\tilde{C}_{\phi Q}^1}}{\sqrt{C_i/\tilde{C}_{\phi Q}^3}}$ [5] JHEP 10 (2024) 191 [6] JHEP 10 (2024) 191	ATLAS, $t\bar{t}Z$ diff. cross section [4] 14 ATLAS, $t\bar{t}Z$ diff. cross section [4] 14 EFT formalism is employed at different levels of experimental analyses
10 ⁰ Λ 95% CL exclusion [TeV] < 1.5 TeV <	^{10¹} 8-9 TeV	











- No time to talk about the other types of operators, but the story is similar (constraints a little weaker in places).
- So, is there no new physics in the top sector?
 - Not necessarily, but it is clear that it is well hidden.
 - EFT is a guide, and it is telling us to look more closely and carefully. BSM isn't going to make itself easy to find.
- Next generation of Run3 measurements will start to appear soon, looking in more places, with more observables, to leave nowhere for BSM to hide!

ATL-PHYS-PUB-2025-028



ATLAS asymptotic $C_i = 0.01, 1, 4\pi^2$	Four-fermion operators - Individu	ATLAS pseudodata $C_i = 0.01, 1, 4\pi$	² Dimension 6 operators $\tilde{C} \equiv C/\Lambda^2$, using 9	95% CL of C
		$\sqrt{C_i/\tilde{C}_{tt}^1}$	ATLAS, <i>tītī</i> [6]	140 fb
		$\sqrt{C_i/\tilde{C}_{Qt}^1}$	ATLAS, tĪtĪ [6]	140 fb
		$\sqrt{C_i/\tilde{C}_{QQ}^1}$	ATLAS, tĪtĪ [6]	140 fb
		$\sqrt{C_i/ ilde{C}_{Qt}^8}$	ATLAS, tĪtĪ [6]	140 fb
_			ATLAS, $t\bar{t}\ell\ell$ high mass [7]	140 fb
		$\sqrt{C_i/ ilde{C}_{Qe}^{(\ell)}}$	ATLAS, <i>tīℓℓ</i> high mass [7]	140 fb
		$\sqrt{rac{2}{C_i/ ilde{C}_{tl}^{(\ell)}}}$	ATLAS, $t\bar{t}\ell\ell$ high mass [7]	140 fb
		$\sqrt{C_i/ ilde{C}_{te}^{(\ell)}}$	ATLAS, $t\bar{t}\ell\ell$ high mass [7]	140 fb
		•••••••••••••••••••••••••••••••••••••••	ATLAS, $t\bar{t}$ + jet energy asymmetry [1]	139 fb
		$\sqrt{C_i/ ilde{C}_{Qq}^{11}}$	ATLAS, $t\bar{t}$ + jet energy asymmetry [1] ATLAS, $t\bar{t}$ rapidity asymmetry [4] ATLAS, $t\bar{t}Z$ diff. cross section [5]	139 fb 140 fb
			ATLAS, $t\bar{t}$ + jet energy asymmetry [1]	139 fb
		$\sqrt{C_i/ ilde{C}_{Qq}^{18}}$	ATLAS, $t\bar{t}$ all-hadronic boosted [3] ATLAS, $t\bar{t}$ rapidity asymmetry [4]	139 fb 139 fb
		$\sqrt{\mathcal{O}_{II}\mathcal{O}_{Qq}}$	ATLAS, $t\bar{t}Z$ diff. cross section [5]	140 ft
		$\sqrt{C_i/ ilde{C}_{Qq}^{31}}$	ATLAS, $t\bar{t}Z$ diff. cross section [5]	140 ft
			ATLAS, <i>tī</i> + jet energy asymmetry [1] ATLAS, <i>tī</i> rapidity asymmetry [4]	139 ft 139 ft
		$\sqrt{C_i/ ilde{C}_{tq}^1}$	ATLAS, <i>tt</i> rapidity asymmetry [4]	139 fl
			ATLAS, $t\bar{t}$ + jet energy asymmetry [1] ATLAS, $t\bar{t}$ ℓ + jets boosted [2]	139 f 139 f
		$\sqrt{C_i/ ilde{C}_{tq}^8}$	ATLAS, $t\bar{t}$ all-hadronic boosted [3] ATLAS, $t\bar{t}$ rapidity asymmetry [4]	139 f 139 f
		$\sqrt{C_i/ ilde{C}_{iu}^1}$	ATLAS, $t\bar{t}$ + jet energy asymmetry [1] ATLAS, $t\bar{t}$ rapidity asymmetry [4]	139 fl 139 fl
		$\sqrt{O_{I/}O_{tu}}$	ATLAS, <i>tT</i> Z diff. cross section [5]	140 ft
		$\sqrt{C_i/\tilde{C}_{id}^1}$	ATLAS, $t\bar{t}$ rapidity asymmetry [4] ATLAS, $t\bar{t}Z$ diff. cross section [5]	139 fl 140 fl
		ý , io		400 8
			ATLAS, $t\bar{t}$ + jet energy asymmetry [1] ATLAS, $t\bar{t}$ all-hadronic boosted [3]	139 f 139 f
		$\sqrt{\mathcal{C}_i/ ilde{C}^8_{tu}}$	ATLAS, <i>tī</i> rapidity asymmetry [4] ATLAS, <i>tīZ</i> diff. cross section [5]	139 f 140 f
			ATLAS, <i>tī</i> all-hadronic boosted [3]	139 fl
		$\sqrt{C_i/ ilde{C}^8_{td}}$	ATLAS, $t\bar{t}$ rapidity asymmetry [4] ATLAS, $t\bar{t}Z$ diff. cross section [5]	139 f 139 f
		•	-,	
		$\sqrt{C_i/ ilde{C}_{Qd}^8}$	ATLAS, $t\bar{t}$ all-hadronic boosted [3] ATLAS, $t\bar{t}$ rapidity asymmetry [4]	139 f 139 f
		$\sqrt{O_{i}/O_{Qd}}$	ATLAS, <i>tT</i> Z diff. cross section [5]	140 f
			ATLAS, $t\bar{t}$ all-hadronic boosted [3]	139 f 139 f
		$\sqrt{C_i/ ilde{C}_{Qu}^8}$	ATLAS, $t\bar{t}$ rapidity asymmetry [4] ATLAS, $t\bar{t}Z$ diff. cross section [5]	139 li 140 fi
			ATLAS, <i>t</i> ¹ / _t rapidity asymmetry [4] ATLAS, <i>t</i> ¹ / _Z diff. cross section [5]	139 fi 140 fi
		$\sqrt{C_i/\tilde{C}_{Qu}^1}$	AILAS, IIZ ant. cross section [5]	
		$\sqrt{C_i/ ilde{C}_{Qd}^1}$	ATLAS, $t\bar{t}$ rapidity asymmetry [4] ATLAS, $t\bar{t}Z$ diff. cross section [5]	139 fl 140 fl
			ATLAS, $t\bar{t}$ all-hadronic boosted [3]	139 f
		$\sqrt{C_i/ ilde{C}_{Qq}^{38}}$	ATLAS, $t\bar{t}$ rapidity asymmetry [4] ATLAS, $t\bar{t}Z$ diff. cross section [5]	139 fl 140 fl
[1] EPJC 82 (2022) 374 [2] JHEP 06 (2022) 063 [3] JHEP 04 (2023) 80	[4] JHEP 08 (2023) 077 [5] JHEP 07 (2024) 163	[6] EPJC 83 (2023) 496, EPJC 84 (2024) 156 [7] arXiv:2504.05919	EFT formalism is employed at different levels of experimental analyses	







Backup





 There are two ways to use EFT results to make statements about where BSM could be hiding based on E and C_i .

Limits on Energy Scale (E)(for various coefficient values)

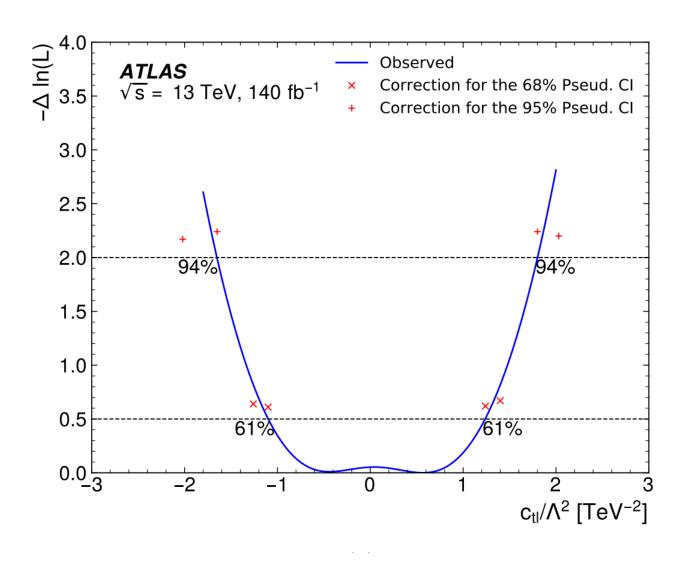
- C = 0.01 ('weak'), BSM excluded below X GeV
- C = 1.00 ('strong'), BSM excluded below Y GeV
- $C = 4\pi^2$ (' very '), BSM excluded below Z GeV strong

We usually present results both ways.





Limits on Coefficients (C_i) (at fixed scale, usually $\Lambda^2 = 1$ TeV)









Operator	Definition	Description
Ote	$(\bar{e}_p \gamma_\mu e_r)(\bar{t}\gamma^\mu t)$	R-handed leptons and
O_{Qe}	$(\bar{Q}\gamma_{\mu}Q)(\bar{e}_{p}\gamma^{\mu}e_{r})$	R-handed leptons and
O_{tl}	$(\bar{l}_p \gamma_\mu l_r)(\bar{t} \gamma^\mu t)$	L-handed leptons and
O^1_{Ql}	$(\bar{l}_p \gamma_\mu l_r) (\bar{Q} \gamma^\mu Q)$	L-handed leptons and
O_{Ql}^3	$(\bar{l}_p\sigma^i\gamma_\mu l_r)(\bar{Q}\sigma^i\gamma^\mu Q)$	L-handed leptons and
O^1_{leQt}	$(\bar{l}_p^j e_r) \epsilon_{jk} (\bar{Q}^k t)$	Mixed L-/R-handed qu
	$(\bar{l}_p^j\sigma_{\mu\nu}e_r)\epsilon_{jk}(\bar{Q}^k\sigma^{\mu\nu}t)$	Mixed L-/R-handed qu



- l R-handed quarks in the $t\bar{t}\ell^+\ell^-$ vertex
- d L-handed quarks in the $t\bar{t}\ell^+\ell^-$ and $b\bar{b}\ell^+\ell^-$ vertices
- d R-handed quarks in the $t\bar{t}\ell^+\ell^-$ vertex
- d L-handed quarks in the $t\bar{t}\ell^+\ell^-$ and $b\bar{b}\ell^+\ell^-$ vertices, weak-singlet
- d L-handed quarks in the $t\bar{t}\ell^+\ell^-$ and $b\bar{b}\ell^+\ell^-$ vertices, weak-triplet
- quarks and leptons in the $t\bar{t}\ell^+\ell^-$, $t\bar{b}\ell^+\ell^-$ and $b\bar{b}\ell^+\ell^-$ vertices, scalar
- quarks and leptons in the $t\bar{t}\ell^+\ell^-$, $t\bar{b}\ell\nu$, $\bar{t}b\ell\nu$ and $b\bar{b}\ell^+\ell^-$ vertices, tensor



Process $t\bar{t}\ell^+\ell^$ tŦW tĪH WZZZ $t\ell^+\ell^-q, tWZ$ F-e-ExtConv F-e-IntConv F-e-HF F-e-LF F-m-HF Other (fakes) Other (non-fakes) Total



SR-3L-ttll(high-m)			
ee	$\mu\mu$		
19.4 ± 1.4	27.4 ± 1.2		
19.9 ± 1.9	27.5 ± 3.5		
8.6 ± 0.8	11.9 ± 1.1		
12 ± 5	20 ± 8		
1.4 ± 0.6	2.4 ± 1.0		
4.2 ± 0.8	6.5 ± 1.2		
1.2 ± 1.1	0.67 ± 0.04		
4.9 ± 1.1	6.2 ± 2.6		
2.1 ± 1.5	4.5 ± 0.7		
2.4 ± 0.7	2.0 ± 0.5		
5.8 ± 1.5	4.2 ± 0.5		
4.4 ± 2.1	6 ± 4		
4.6 ± 1.6	5.7 ± 1.9		
91 ± 7	124 ± 9		





