Top EFT fit

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ATLAS

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Approaching EFT combination

An EFT analysis: **complex**!

◆ An EFT ATLAS+CMS combination: **complex**²!

→ Need to **start early** in order not to cut corners later

→ Internal **discussions** and common **tools** development is a key

How to combine?

Faster: Combined reinterpretation of ATLAS and CMS results **Better**: Use ATLAS and CMS results in a common EFT fit

• Use **Run 2 data** \rightarrow future baseline for Run 3

◆ Ultimately aim for a likelihood-based combination → in the meantime, various simplified approaches can be considered for existing results

• Benefit from **exploring both approaches** to agree on:

- common conventions
- systematics correlations
- fitting method
- publication format

LHCtopWG EFT combination

- Several discussions within LHCtopWG on how to perform an EFT combination (conventions, strategies, scope, etc.)
- Prepared a shortlist of candidates: focus on recent results (people are still active), look for overlap in EFT operators

Process	ATLAS	CMS	Possible strategy
Spin correlations	EPJC 80 (2020) 754	PRD 100 (2019) 072002	Differential, EFTfitter
ttZ/W	PRD 99 (2019) 072009	JHEP 03 (2020) 056, JHEP 08 (2018) 011	EFT/SM generator-level reweighting, full likelihood
ttγ	JHEP 09 (2020) 049	CMS-PAS-TOP-21-004, arXiv:2107.01508	EFT/SM generator-level reweighting, full likelihood
tZq	JHEP 07 (2020) 124	arXiv:2107.13896, arXiv:2111.02860	Differential + inclusive, EFTfitter
FCNC t-gluon	EPJC 76 (2016) 55	JHEP 02 (2017) 028	Inclusive, EFTfitter
FCNC t-Higgs	JHEP 05 (2019) 123	arXiv:2111.02219, CMS-PAS-TOP-19-002	Inclusive, EFTfitter
t(t)X	ttZ/W	JHEP 03 (2021) 095	Detector level, full likelihood

LHCtopWG EFT Summary plots

ATLAS+CMS Preliminary June 2022 LHC <i>top</i> WG			ATLAS+CMS Preliminary June 2022					
(Top) quark - vector boson operators - Individual limits	Dimension 6 operators		Four formion operators Individual limite			Following arXiv:1802.07237	Following arXiv:1802.07237	
- ATLAS - CMS - ATLAS+CMS	$\tilde{C}_i \equiv C_i / \Lambda^2$ * Pre	liminary				Dimension 6 operators		
	CMS, tZq/ttZ [1]	138 fb ⁻¹	- ATLAS		- ATLAS+CMS	$C_i \equiv C_i / \Lambda^2$ * Pre	liminary	
Č _{1Z}	CMS, tīγ [2] CMS, tīZ [3] CMS, tī+Z/W/H, tZq,tHq [4]	137 fb ⁻¹ 78 fb ⁻¹ 42 fb ⁻¹				CMS, 4 top quarks [1]	36 fb ⁻¹	
č ⁱⁱ	CMS, ιτγ [2]	137 fb ⁻¹	C _{Qt}			CMS, 4 top quarks [1]	36 fb ⁻¹	
		26 fb ⁻¹				CMS, 4 top quarks [1]	36 fb ⁻¹	
	ATLAS, Top polarization [6]	139 fb ⁻¹	Ĉ,			CMS, 4 top quarks [1]	36 fb ⁻¹	
C _{tw}	ATLAS, tīZ [5] ATLAS+CMS, W helicity [7] CMS tZedīt [1]	36 fb ⁻¹ 20+20 fb ⁻¹	C _{OI}			CMS, tt+Z/W/H, tZq,tHq [2]	42 fb ⁻¹	
	CMS, t2q/t2 [1] CMS, tī and tW, BSM search [8] CMS, tī+Z/W/H, tZq,tHq [4]	138 fb ⁻¹ 36 fb ⁻¹	C _O			CMS, tt+Z/W/H, tZq,tHq [2]	42 fb ⁻¹	
č ¹⁰	ATLAS, Top polarization [6]	139 fb ⁻¹	Ĉ ^(I)			CMS, tt+Z/W/H, tZq,tHq [2]	42 fb ⁻¹	
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\tilde{C}_{tG}/g_{s}	ATLAS, tt l+jets boosted [9]	139 fb ⁻¹	Č.,			CMS, tt+Z/W/H, tZq,tHq [2]	42 fb ⁻¹	
Ũ _{tG}	CMS, tt and tW, BSM search [8] CMS, tt spin correlations [10] CMS, tt+Z/W/H, tZq,tHq [4]	36 fb ⁻¹ 36 fb ⁻¹ 42 fb ⁻¹				CMS, tī+Z/W/H, tZq,tHq [2]	42 fb ⁻¹	
č	CMS, tī spin correlations [10]	36 fb ⁻¹	$\tilde{C}_{t}^{T(l)}$		•	CMS, tt+Z/W/H, tZq,tHq [2]	42 fb ⁻¹	
$ \tilde{C}_{uW}^{(32)} + \tilde{C}_{uB}^{(32)} $	ATLAS, FCNC tqy [11]	139 fb ⁻¹	\tilde{C}_{Qq}^{11}	+		ATLAS, tt energy asymmetry [3]	139 fb ⁻¹	
$ \tilde{C}_{uW}^{(23)^*} + \tilde{C}_{uB}^{(23)^*} $	ATLAS, FCNC tqy [11]	139 fb ⁻¹	~ ¹⁸			ATLAS, tt all-hadronic boosted [4]	139 fb ⁻¹	
$ \widetilde{C}_{uW}^{(31)} + \widetilde{C}_{uB}^{(31)} $	ATLAS, FCNC tqy [11]	139 fb ⁻¹	U _{Qq}			ATLAS, tt energy asymmetry [3]	139 fb ⁻¹	
$ \tilde{C}_{uW}^{(13)^*} + \tilde{C}_{uB}^{(13)^*} $	ATLAS, FCNC tqy [11]	139 fb ⁻¹	Ĉ _{tq}			ATLAS, tt energy asymmetry [3]	139 fb ⁻¹	
	ATLAS, FCNC tZq [12]	139 fb ⁻¹	~8	-		ATLAS, tī l+jets boosted [5]	139 fb ⁻¹	
	ATLAS, FCNC tZq [12]	139 fb ⁻¹	C _{tq}		-	ATLAS, tt all-hadronic boosted [4] ATLAS, tt energy asymmetry [3]	139 fb ⁻¹ 139 fb ⁻¹	
	ATLAS, FCNC tZq [12]	139 fb ⁻¹	\tilde{c}^1			ATLAS, tt energy asymmetry [3]	139 fb ⁻¹	
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C _{uW} ≈ ³¹	ATLAS, FCNC (Zq [12]	139 fb ⁻¹	\widetilde{C}_{tu}^{8}		-	ATLAS, it an-nadronic boosted [4] ATLAS, it energy asymmetry [3]	139 fb ⁻¹	
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C _{uw} - č ¹³ *	ATLAS, FCNC tZq [12]	139 fb ⁻¹	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			ATLAS, tī all-hadronic boosted [4]	139 fb ⁻¹	
i⊂uβ i	ATLAS, FCNC tqg [13]	139 fb ⁻¹	Č ⁸			ATLAS, tr all-hadronic boosted [4]	139 fb ⁻¹	
	CMS, tt and tW, BSM search [8]	36 fb ⁻¹	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			ATLAS trall-hadronic boosted [4]	139 fb-	
ICC [1] JHEP 12 (2021) 083 [8] EPIC 79 (2019) 886 [2] JHEP 05 (2022) 091 [9] arXiv:2202.12134 * [3] JHEP 03 (2020) 056 [10] PRD 100 (2019) 072002 [4] JHEP 03 (2021) 095 [11] arXiv:2200.2537 * [5] PRD 99 (2019) 072009 [12] ATLAS-CONF-2021-049 * [6] arXiv:2202.11382 * [13] EPIC 82 (2022) 334	EFT formalism is employed at different experimental analyses	36 fb ⁻¹	- Oq (1) JHEP 11 (20 (2) JHEP 03 (20 (3) EPJC 82 (20) (4) arXiv:2205.0 (5) arXiv:2202.1 -10 -5	19) 082 21) 095 22) 374 2817 * 2134 *	5 1	EFT for containing bed at the for	vol-ee s	
-4 -2 0 2 4 95% CL limit [TeV ⁻²]				95% CL limi	t [TeV ⁻²]	U		

LHCtopWG EFT Summary plots







UnfoldEFT

- EFT reinterpretation of experimental results using Unfolded differential cross sections
- ◆ Backgrounds subtracted → information on EFT dependence of backgrounds is lost
- ◆ Typically, only total statistical and systematic uncertainties (split in signal and background) are available → **impossible** to properly correlate systematics
- ◆ Publishing unfolded cross sections in HEPData became a standard
 → many suitable results available for reinterpretation
- Exercise: start by combining ttZ unfolded results at parton level (taken from HEPData); then extend to other processes

UnfoldEFT: Inputs



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(2021)

EPJC 81



HEP 03 (2020) 056

UnfoldEFT: Event generation

- Agreed on a common set of MG5 parameters and the EFT model (SMEFTsim, topU3I)
- Generated MC events with EFT weights
- Include: cHQ3, cHQ1, cHt, CtBRe, CtBIm, CtWRe, CtWIm, CtGRe, CtGIm
- Derived EFT parametrization as a function of kinematic variable (p_T of Z boson)





UnfoldEFT: Results

Perform 1D and 2D fits to extract credible intervals



UnfoldEFT: Results



bin4

UnfoldEFT: Add more processes

d م_{ff} / d p_Tth [pb/GeV] 01 04

arXiv:2202.12134

√s = 13 TeV, 139 fb⁻¹

Data

 Λ^{-4} model (C_{tG}=-0.11, C_{tg}⁽⁸⁾=-0.43)

2000

12

PWG+PY8 (NNLO rw.)

Prediction uncertainty

ATLAS

- Include boosted I+jets ttbar results (ATLAS) in combination with ATLAS+CMS ttZ differential cross sections
- Improve CtG limits by 20x



UnfoldEFT: Results



ATLAS+CMS ttZ

ATLAS+CMS ttZ +ATLAS boosted ttbar

RecoEFT: Strategy

- Use full Recostruction-level likelihoods from both experiments
- The EFT reinterpretation becomes the direct EFT measurement
- Full information on signal and background processes with an extensive systematics breakdown \rightarrow **preserve** experimental results
- **Reweight** generator-level SM predictions to EFT in a single observable easier to agree on a common generation procedure; consider full MC simulation for (much) later time



RecoEFT

RecoEFT: Inputs

- Only a few detector-level likelihood are publicly available
- ◆ First published by ATLAS in the ttZ cross section measurement
- Need to agree on the data format, statistical model and tools



RecoEFT: ttZ (ATLAS)



- EPJC 81 (2021) 737, published detector-level likelihood (pyhf)
- No EFT results included
- ◆ Fit the number of reconstructed jets and b-tagged jets (bins = 8)
- Total number of bins = 8
- Total number of nuisances = 223 (syst) + 8 (stat) = 231

Preservation of likelihoods



- The methodology described in <u>ATL-PHYS-PUB-2019-029</u>
- Introduces a JSON schema for the HistFactory statistical model
- The mathematical model and fitting procedure implemented in pyhf
- ATLAS uses this approach to publish likelihoods in HEPData

	Description	Modification	Constraint Term c_{χ}	Input
constrained	Uncorrelated Shape Correlated Shape Normalisation Unc. MC Stat. Uncertainty Luminosity	$\kappa_{scb}(\gamma_b) = \gamma_b$ $\Delta_{scb}(\alpha) = f_p \left(\alpha \middle \Delta_{scb,\alpha=-1}, \Delta_{scb,\alpha=1} \right)$ $\kappa_{scb}(\alpha) = g_p \left(\alpha \middle \kappa_{scb,\alpha=-1}, \kappa_{scb,\alpha=1} \right)$ $\kappa_{scb}(\gamma_b) = \gamma_b$ $\kappa_{scb}(\lambda) = \lambda$	$ \prod_{b} \operatorname{Pois} \left(r_{b} = \sigma_{b}^{-2} \middle \rho_{b} = \sigma_{b}^{-2} \gamma_{b} \right) $ $ \operatorname{Gaus} \left(a = 0 \middle \alpha, \sigma = 1 \right) $ $ \operatorname{Gaus} \left(a = 0 \middle \alpha, \sigma = 1 \right) $ $ \prod_{b} \operatorname{Gaus} \left(a_{\gamma_{b}} = 1 \middle \gamma_{b}, \delta_{b} \right) $ $ \operatorname{Gaus} \left(l = \lambda_{0} \middle \lambda, \sigma_{\lambda} \right) $	σ_{b} $\Delta_{scb,\alpha=\pm 1}$ $\kappa_{scb,\alpha=\pm 1}$ $\delta_{b}^{2} = \sum_{s} \delta_{sb}^{2}$ $\lambda_{0}, \sigma_{\lambda}$
free	Normalisation Data-driven Shape	$\kappa_{scb}(\mu_b) = \mu_b$ $\kappa_{scb}(\gamma_b) = \gamma_b$		

RecoEFT: tty, 11 (CMS)



- ◆ JHEP 12 (2021) 180, internal detector-level likelihood
- Includes reco-level EFT results (dim6top)
- Fit reconstructed photon p_T distributions (bins = 41)
- ◆ Per single-lepton channel (x2) and data-taking year (x3)
- ◆ Total number of bins = **246**
- Total number of nuisances = 105 (syst) + 246 (stat) = 351

RecoEFT: tty, 21 (CMS)





- <u>arXiv:2201.07301</u> (Accepted by JHEP), internal detector-level likelihood
- Includes reco-level EFT results (dim6top)
- Fit reconstructed **photon p**_T distributions
 (bins = 9)
- Per dilepton channel (x3) and datataking year (x3)
- Total number of bins = 81
- Total number of nuisances = 80 (syst) +
 81 (stat) = 161

RecoEFT: Parametrization



- Parametrize EFT effects based on the total cross section
- ATLAS likelihood is available in JSON
- Created a script to translate Combine datacard (CMS) to a common JSON format
- This translation procedure would need a dedicated validation
- First step: perform a global EFT fit of ttZ and tt γ results without uncertainties

RecoEFT: Results



RecoEFT: Including uncertainties

- Statistical uncertainties (335)
- Statistical + systematic uncertainties (743)
- Very computationally intensive: include only **dominant** systematic uncertainties for now
- Proper correlation of experimental uncertainties is critical
- Hitting fit convergence & memory issues for complex models already at inclusion of statistical uncertainties
- In the process of validating implementation of shape uncertainties and the fitting model



ndividual Asimov fits

Summary

- Active effort in LHCtopWG to perform an ATLAS-CMS EFT combination in the top quark sector
- Approaching EFT combinations using individual inputs from both experiments at unfolded and reconstruction levels
- **Complementary** ways of combining experimental results
- **First** (very preliminary) results obtained in both approaches
- Working on providing an UnfoldEFT input to LHC EFT combination (in EFT2Obs-compatible format)
- Exploring various options to further **optimize** the RecoEFT fits
- ◆ In the process of finalizing the Combine → pyhf **converter**
- **First** ATLAS-CMS EFT summary plots are also available