

EFT interpretations in top quark events in CMS

On behalf of the CMS Collaboration



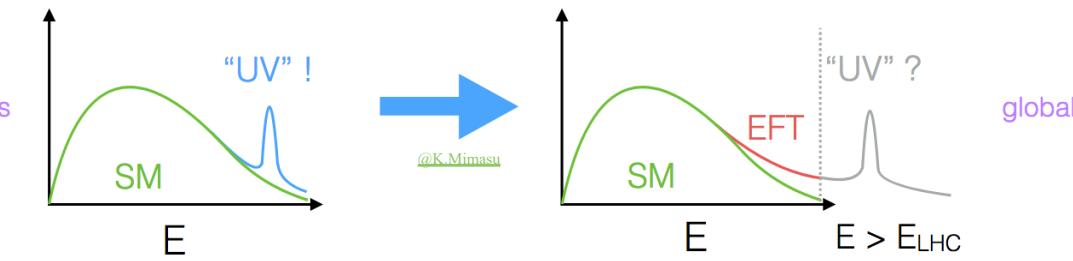
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TOP EFT

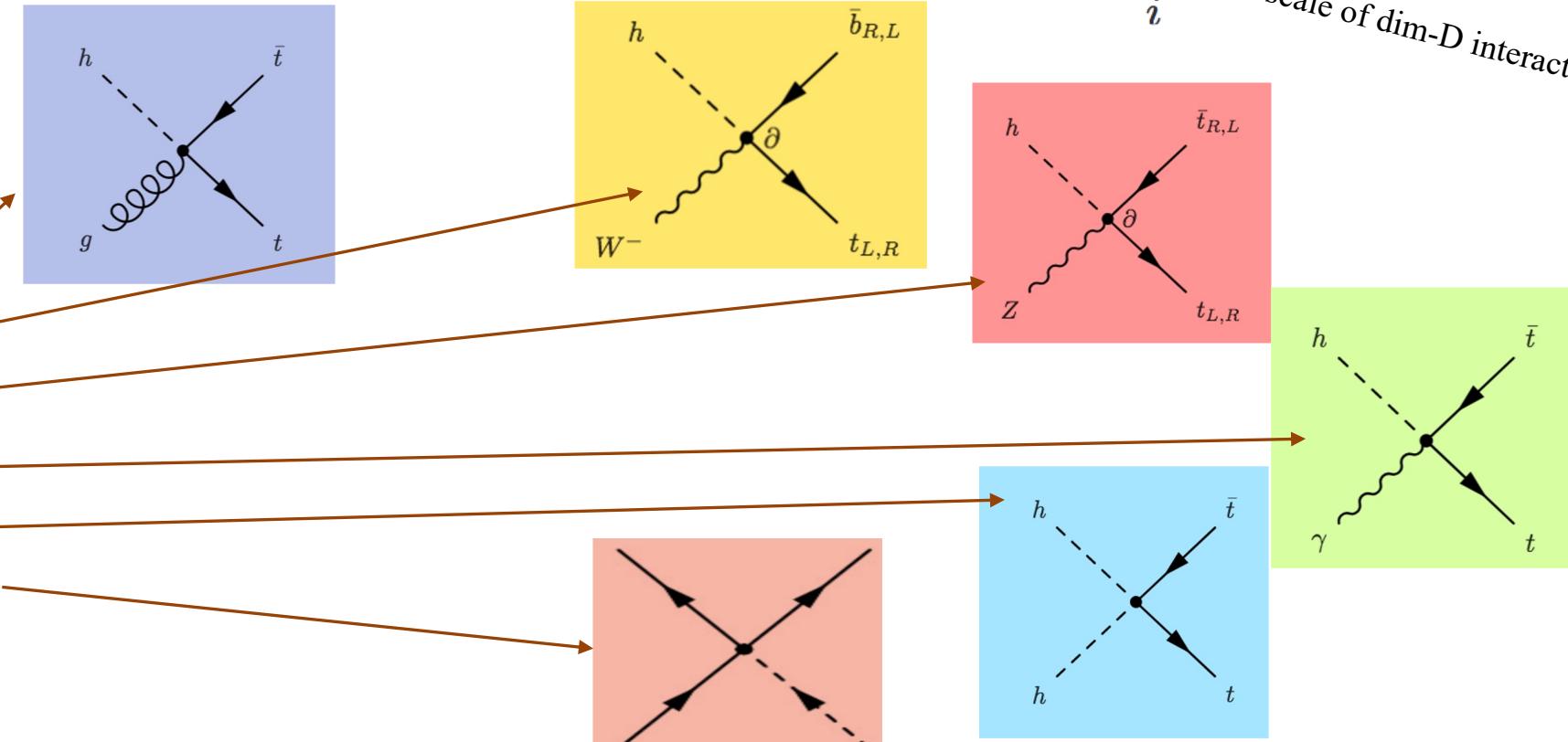
- Possibility that new states exist (just) beyond the energy reach of the LHC
- Framework: SM effective field theory (SMEFT)
 - Lagrangian is built from higher-dimensional operators with SM fields
 - SM is the leading term in a series expansion with new physics (NP) arising in higher order terms
 - Model independent
 - Theoretically consistent
- Top interactions
 - Gluon interactions
 - W interactions
 - Z interactions
 - Photon interactions
 - Higgs interactions
 - 4 Fermi interactions



$$\mathcal{L}_{\text{eff}} = \sum_i \frac{c_i \mathcal{O}_i^D}{\Lambda_{\text{scale of dim-}D \text{ interactions}}^{D-4}}$$

Wilson coefficients

dim- D operators



Theory base line

- Within CMS, we have followed the recommendations presented by the LHCTOPWG
 - Warsaw basis of dimension-six operators
 - Minimal flavour violation
 - ...
- We have used dim6 UFO Model for signal generation

four heavy quarks	11 + 2 CPV
two light and two heavy quarks	14
two heavy quarks and bosons	9 + 6 CPV
two heavy quarks and two leptons	(8 + 3 CPV) × 3 lepton flavours

Operator	Definition
$\not{O}_{u\varphi}^{(ij)}$	$\bar{q}_i u_j \tilde{\varphi} (\varphi^\dagger \varphi)$
$O_{\varphi q}^{1(ij)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi) (\bar{q}_i \gamma^\mu q_j)$
$O_{\varphi q}^{3(ij)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi) (\bar{q}_i \gamma^\mu \tau^I q_j)$
$O_{\varphi u}^{(ij)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi) (\bar{u}_i \gamma^\mu u_j)$
$\not{O}_{\varphi ud}^{(ij)}$	$(\varphi^\dagger i D_\mu \varphi) (\bar{u}_i \gamma^\mu d_j)$
$\not{O}_{uW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I u_j) \tilde{\varphi} W_{\mu\nu}^I$
$\not{O}_{dW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I d_j) \varphi W_{\mu\nu}^I$
$\not{O}_{uB}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} u_j) \tilde{\varphi} B_{\mu\nu}$
$\not{O}_{uG}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} T^A u_j) \tilde{\varphi} G_{\mu\nu}^A$

Operator	Definition
$O_{\ell q}^{1(ijkl)}$	$(\bar{\ell}_i \gamma^\mu \ell_j) (\bar{q}_k \gamma^\mu q_\ell)$
$O_{\ell q}^{3(ijkl)}$	$(\bar{\ell}_i \gamma^\mu \tau^I \ell_j) (\bar{q}_k \gamma^\mu \tau^I q_\ell)$
$O_{\ell u}^{(ijkl)}$	$(\bar{\ell}_i \gamma^\mu \ell_j) (\bar{u}_k \gamma^\mu u_\ell)$
$O_{e\bar{q}}^{(ijkl)}$	$(\bar{e}_i \gamma^\mu e_j) (\bar{q}_k \gamma^\mu q_\ell)$
$O_{eu}^{(ijkl)}$	$(\bar{e}_i \gamma^\mu e_j) (\bar{u}_k \gamma^\mu u_\ell)$
$\not{O}_{\ell equ}^{1(ijkl)}$	$(\bar{\ell}_i e_j) \epsilon (\bar{q}_k u_\ell)$
$\not{O}_{\ell equ}^{3(ijkl)}$	$(\bar{\ell}_i \sigma^{\mu\nu} e_j) \epsilon (\bar{q}_k \sigma_{\mu\nu} u_\ell)$

Interpreting top-quark LHC measurements
in the standard-model effective field theory

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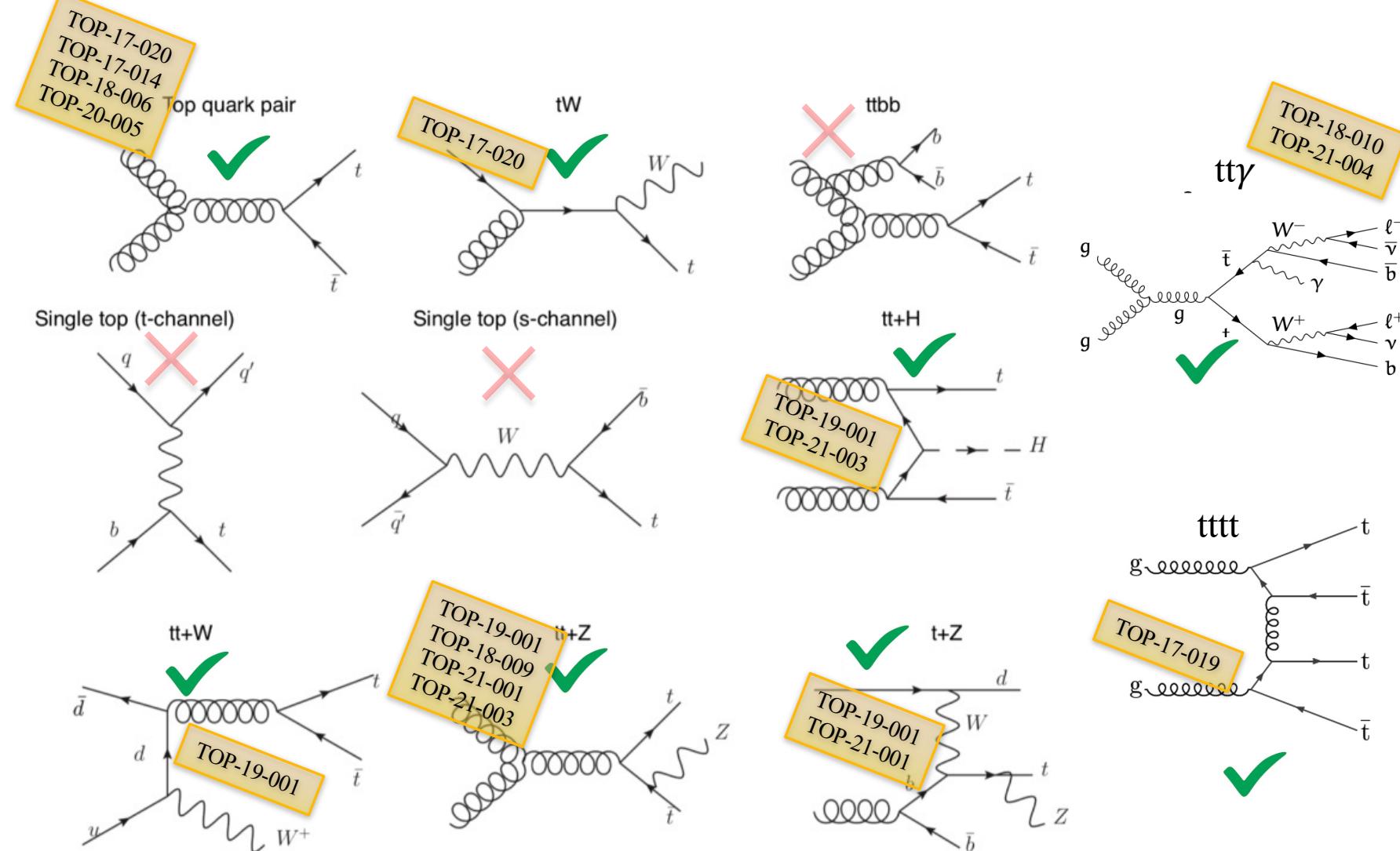
Abstract

This note proposes common standards and prescriptions for the effective-field-theory interpretation of top-quark measurements at the LHC.

The top quark EFT searches in CMS

@ J.Rojo

- A large number of different dimension-6 EFT operators modify top production at the LHC



Notation	Sensitivity at $\mathcal{O}(\Lambda^{-2})$ ($\mathcal{O}(\Lambda^{-4})$)							
	$t\bar{t}$	single-top	tW	tZ	$t\bar{t}W$	$t\bar{t}Z$	$t\bar{t}H$	$t\bar{t}t$
0QQ1								✓
0QQ8								✓
0Qt1								✓
0Qt8								✓
0Qb1							(✓)	✓
0Qb8							(✓)	✓
0tt1							✓	✓
0tb1							(✓)	✓
0tb8							✓	✓
0QtQb1							(✓)	✓
0QtQb8							✓	✓
081qq	✓					✓	✓	✓
011qq	✓					(✓)	(✓)	✓
083qq	✓		✓			(✓)	✓	✓
013qq	✓		✓			(✓)	(✓)	✓
08qt	✓					✓	✓	✓
01qt	✓					(✓)	(✓)	✓
08ut	✓					✓	✓	✓
01ut	✓					(✓)	(✓)	✓
08qu	✓					✓	✓	✓
01qu	✓					(✓)	(✓)	✓
08dt	✓					✓	✓	✓
01dt	✓					(✓)	(✓)	✓
08qd	✓					✓	✓	✓
01qd	✓					(✓)	(✓)	✓
0tG	✓						✓	✓
0tW		✓				✓	✓	✓
0bW		(✓)	(✓)					
0tZ				✓				
0ff		(✓)	(✓)	(✓)				
0fq3		✓	✓	✓			✓	
0pQM					✓	✓		
0pt					✓	✓	✓	
0tp						✓		

EFT Approaches

Unfolded data

Inclusive (fiducial)
cross section

Differential cross
section at parton
level

Differential cross
section at particle
level

detector-level data

JHEP 11 (2019) 082

Phys. Rev. D 100, 072002 (2019)

JHEP 02 (2019) 149

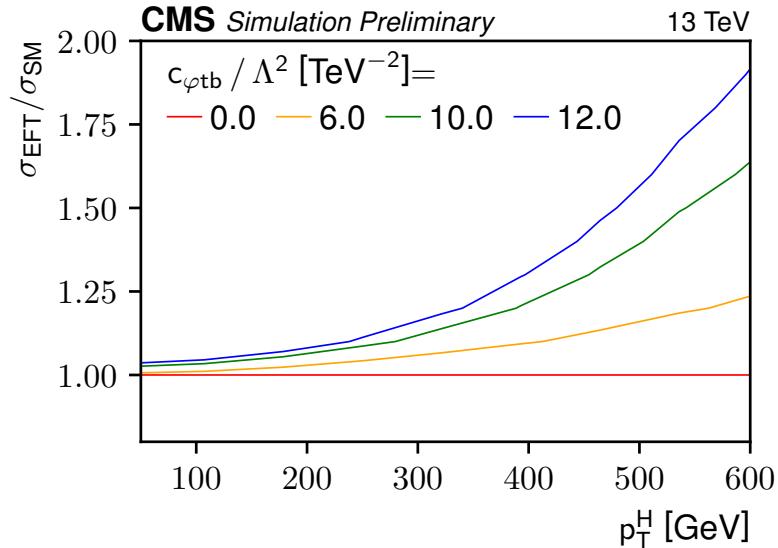
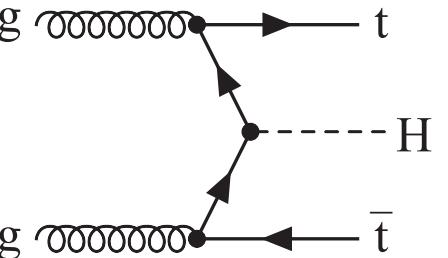
Eur. Phys. J. C 79 (2019) 886
JHEP 03 (2020) 056
JHEP 05 (2022) 091

JHEP 03 (2021) 095
JHEP 12 (2021) 083
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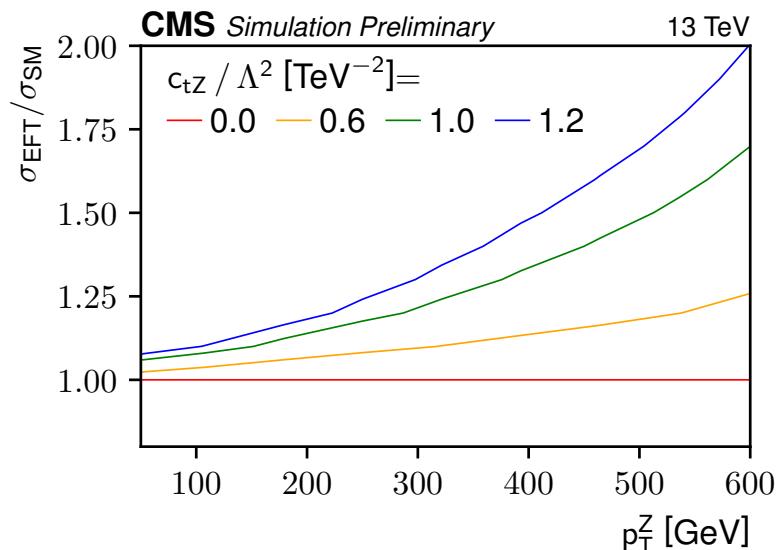
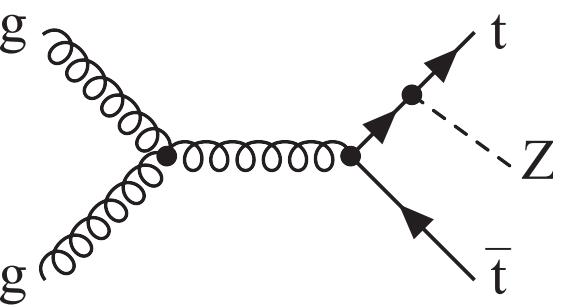
- Based on the probed processes, sensitive Wilson Coefficients, and accessible theory and experimental precisions, each analysis develops a dedicated approach
- Meanwhile make the best out of their access to data: global analysis, correlations, EFT effects on backgrounds, ...

Boosted ttH and ttZ

- Measurement of ttZ/ttH when $p_T(Z/H)$ is large
- EFT effects more pronounced at high $p_T(Z/H)$
- Select events with one charged lepton, missing p_T , and jets
- Reconstruct Z/H as single bb-tagged large-radius jet
 - Most important background is $t\bar{t} + bb$
 - 8 WCs

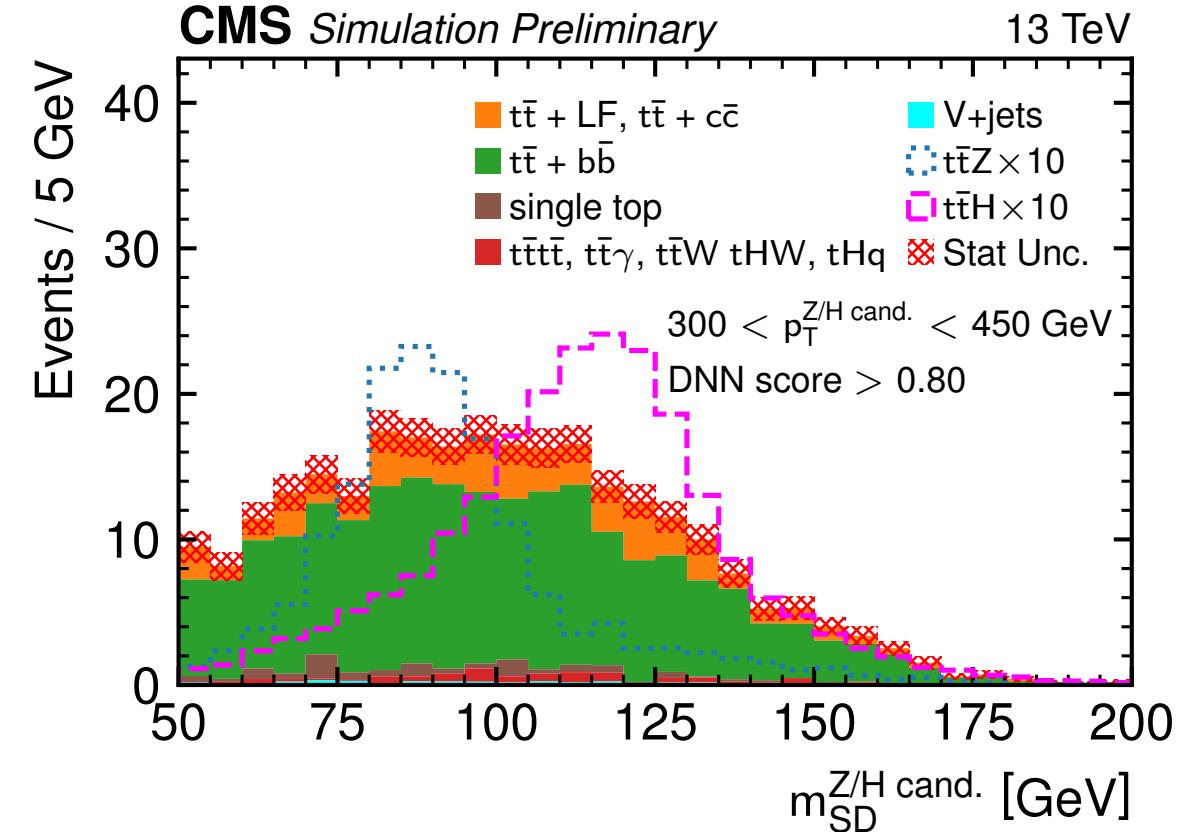
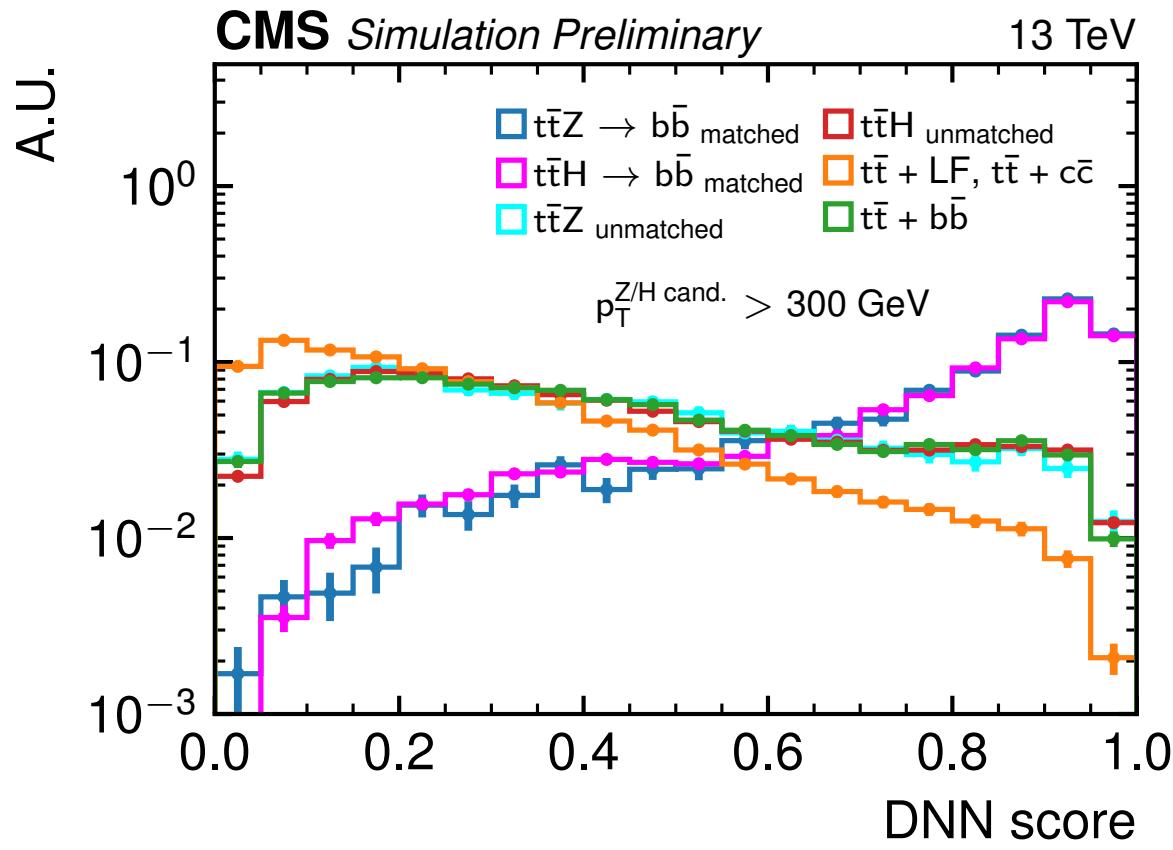


Operator	Definition	WC
$\frac{1}{2} O_{u\varphi}^{(ij)}$	$\bar{q}_i u_j \tilde{\varphi} (\varphi^\dagger \varphi)$	$c_{t\varphi} + i c_{t\varphi}^I$
$O_{\varphi q}^{1(ij)}$	$(\varphi^\dagger i D_\mu \varphi)(\bar{q}_i \gamma^\mu q_j)$	$c_{\varphi Q}^- + c_{\varphi Q}^3$
$O_{\varphi q}^{3(ij)}$	$(\varphi^\dagger i D_\mu^I \varphi)(\bar{q}_i \gamma^\mu \tau^I q_j)$	$c_{\varphi Q}^3$
$O_{\varphi u}^{(ij)}$	$(\varphi^\dagger i D_\mu \varphi)(\bar{u}_i \gamma^\mu u_j)$	$c_{\varphi t}$
$\frac{1}{2} O_{\varphi ud}^{(ij)}$	$(\tilde{\varphi}^\dagger i D_\mu \varphi)(\bar{u}_i \gamma^\mu d_j)$	$c_{\varphi tb} + i c_{\varphi tb}^I$
$\frac{1}{2} O_{uW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I u_j) \tilde{\varphi} W_{\mu\nu}^I$	$c_{tW} + i c_{tW}^I$
$\frac{1}{2} O_{dW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I d_j) \varphi W_{\mu\nu}^I$	$c_{bW} + i c_{bW}^I$
$\frac{1}{2} O_{uB}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} u_j) \tilde{\varphi} B_{\mu\nu}$	$(\mathcal{C}_W c_{tW} - c_{tZ})/\mathcal{S}_W + i(\mathcal{C}_W c_{tW}^I - c_{tZ}^I)/\mathcal{S}_W$



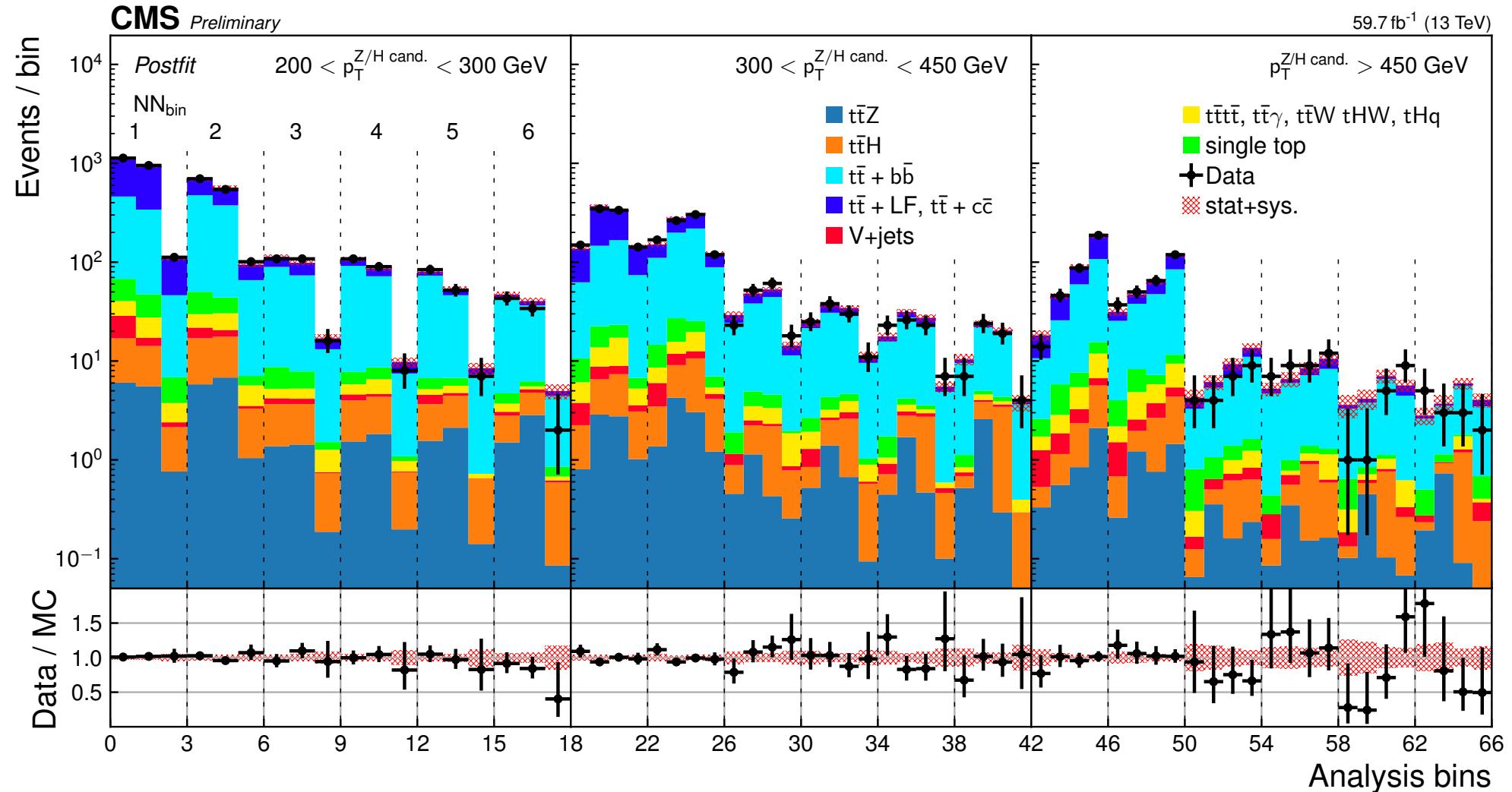
Boosted ttH and ttZ

- NN trained to distinguish ttZ /H from backgrounds
- NN score provides a high-purity region
- Z/H jet mass provides sidebands to help control backgrounds



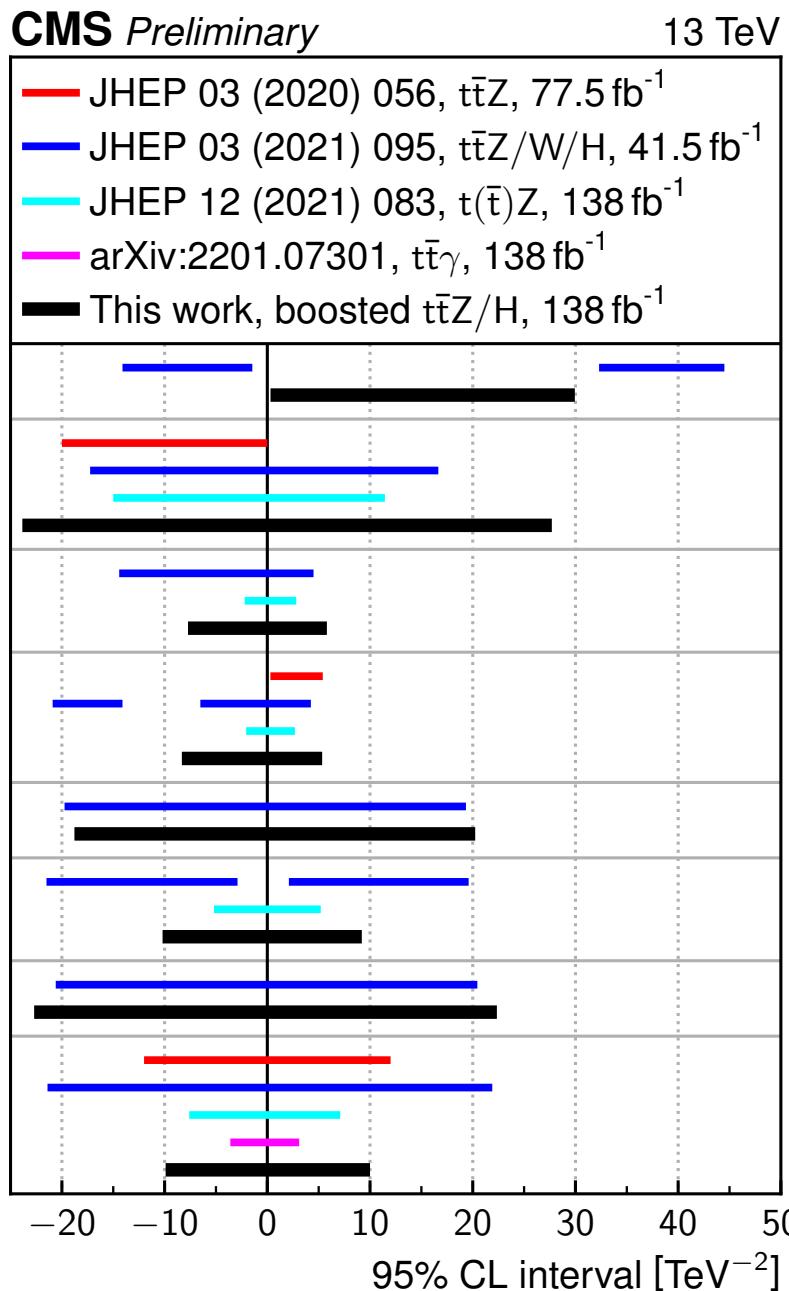
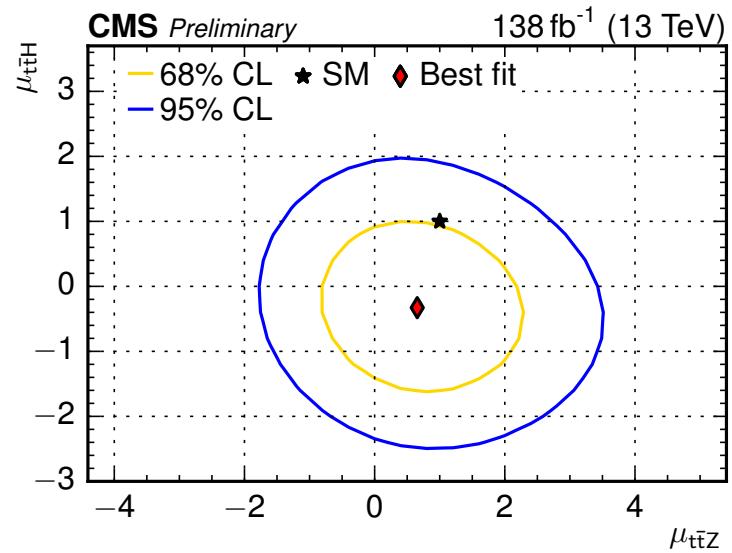
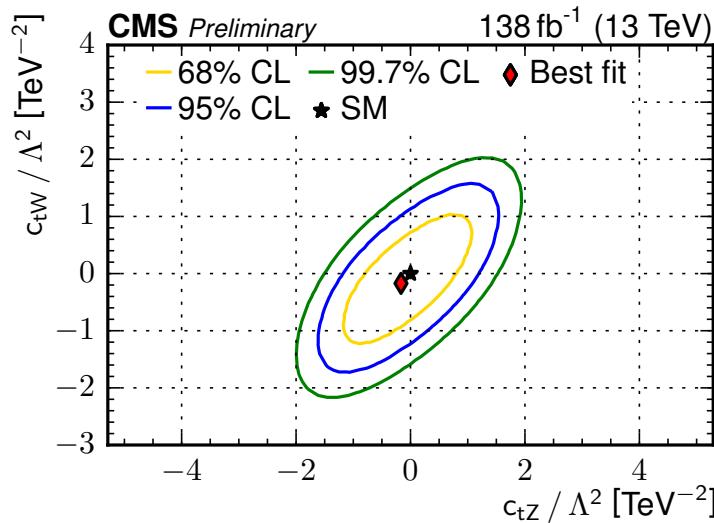
Boosted ttH and ttZ

- Divide events among bins as functions of NN score, Z /H jet mass, and pT (Z /H)



Boosted ttH and ttZ

- Vary the ttZ /H signal and tt + bb background as functions of the WCs
- Perform 1-D and 2-D likelihood scans for each WC and pair of WCs
- Consistent with SM (all WCs zero) at 95% CL
- Novel phase space with highly-boosted Z /H
- Complementary to other analyses with comparable sensitivity



t_tγ (dileptonic)

JHEP 05 (2022) 091

- t_tγ in dileptonic final state
- Measure differential cross section as function of pT (γ)
- Non-prompt photon background estimated from data in a sideband region
- Other backgrounds estimated from MC and validated in a separate control region
- Sensitivity to the electroweak dipole moments of the top quark
- Complimentary to ttZ production

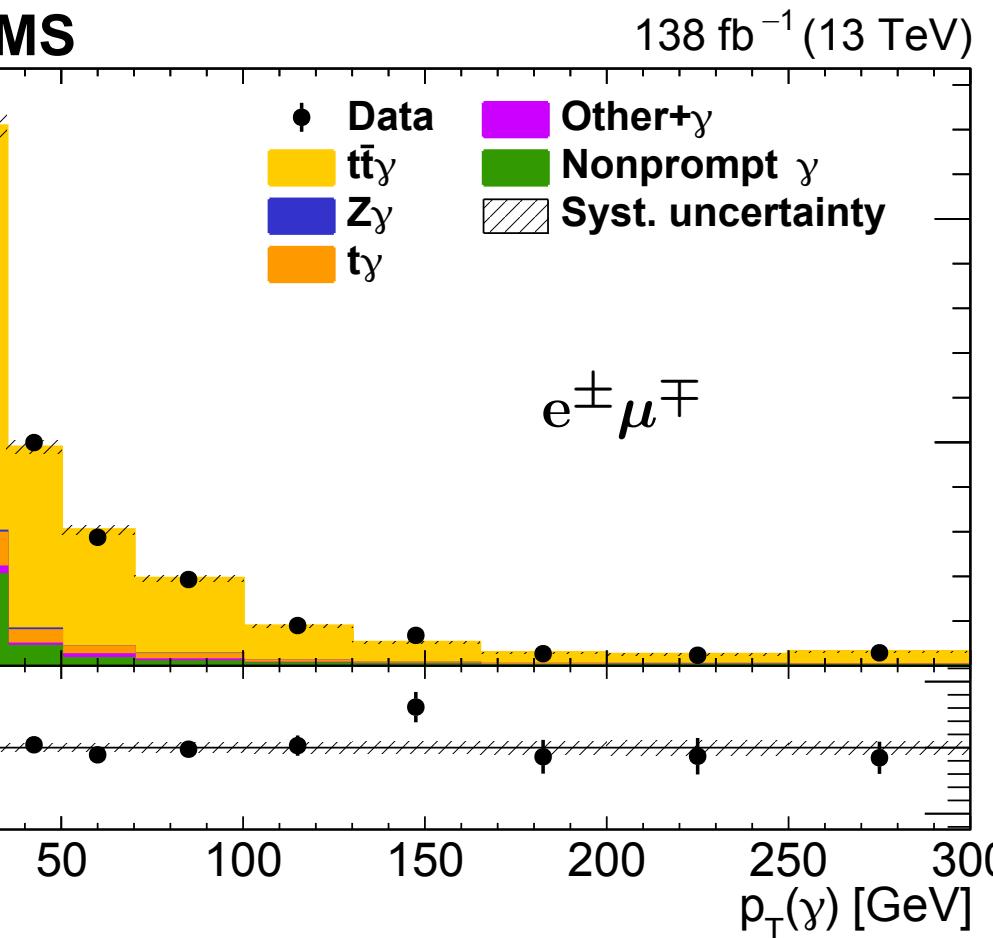
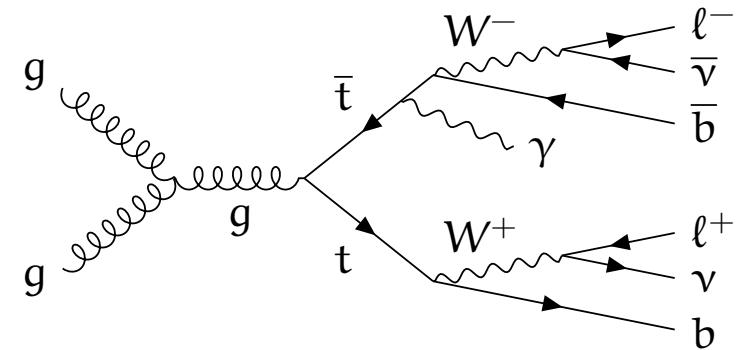
$$c_{tZ} = \text{Re} \left(-\sin \theta_W c_{uB}^{(33)} + \cos \theta_W c_{uW}^{(33)} \right),$$

$$c_{tZ}^I = \text{Im} \left(-\sin \theta_W c_{uB}^{(33)} + \cos \theta_W c_{uW}^{(33)} \right),$$

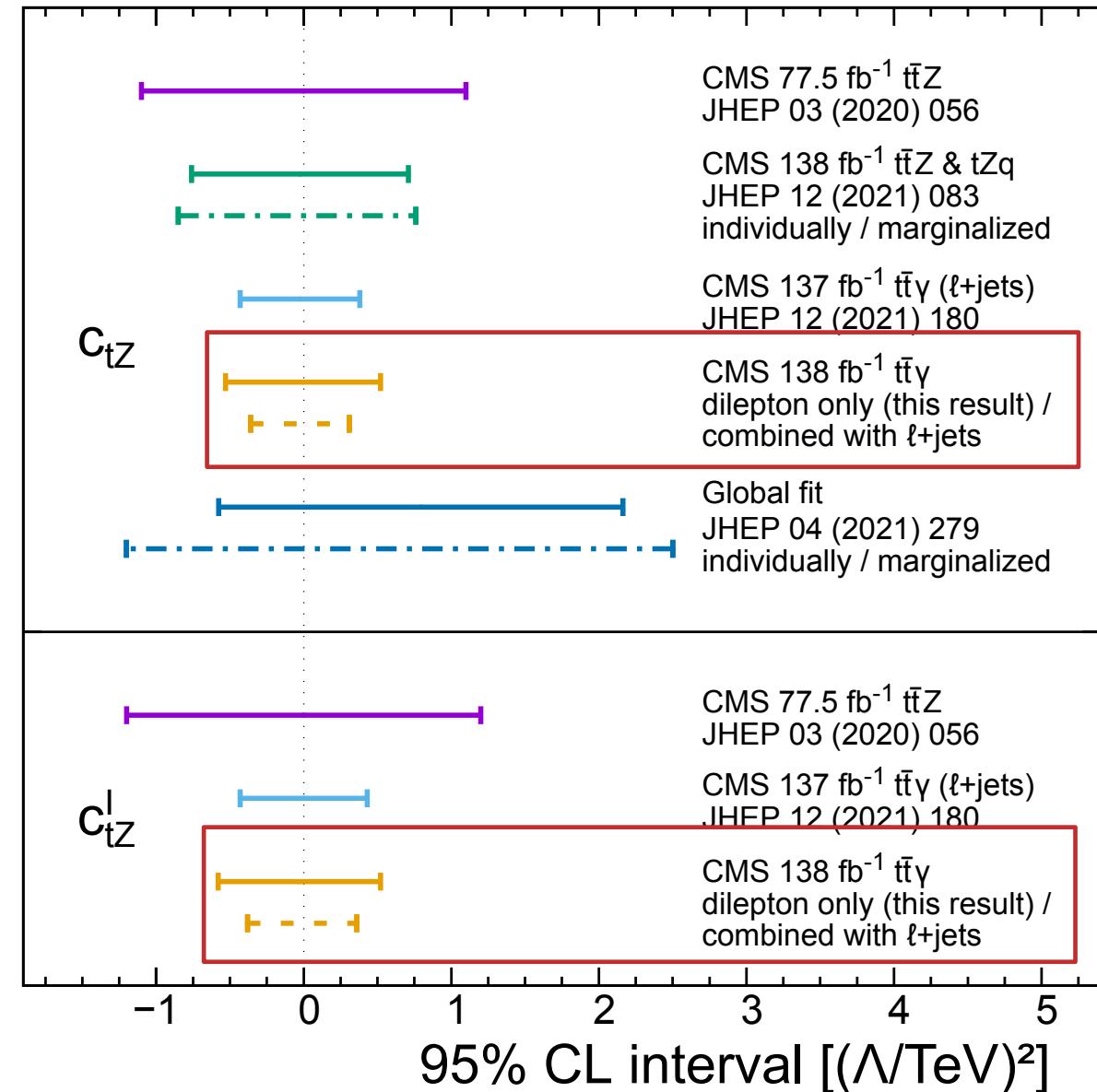
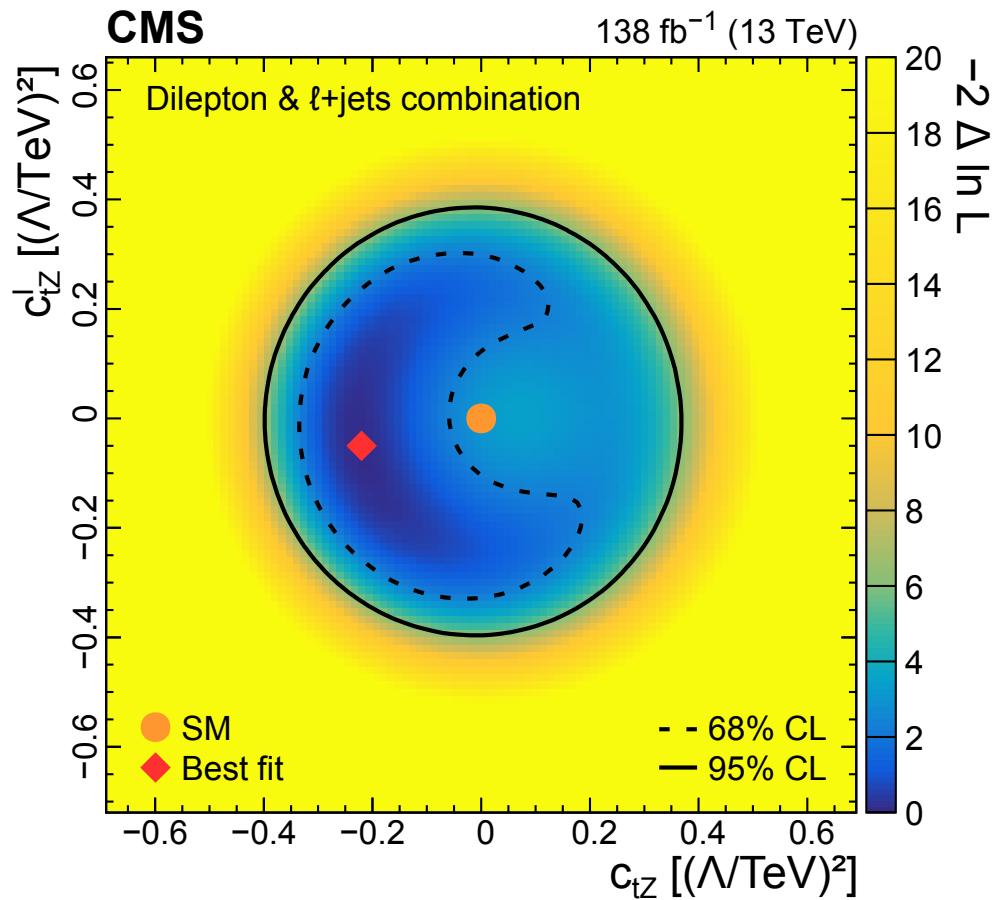
$$c_{t\gamma} = \text{Re} \left(\cos \theta_W c_{uB}^{(33)} - \sin \theta_W c_{uW}^{(33)} \right),$$

$$c_{t\gamma}^I = \text{Im} \left(\cos \theta_W c_{uB}^{(33)} - \sin \theta_W c_{uW}^{(33)} \right).$$

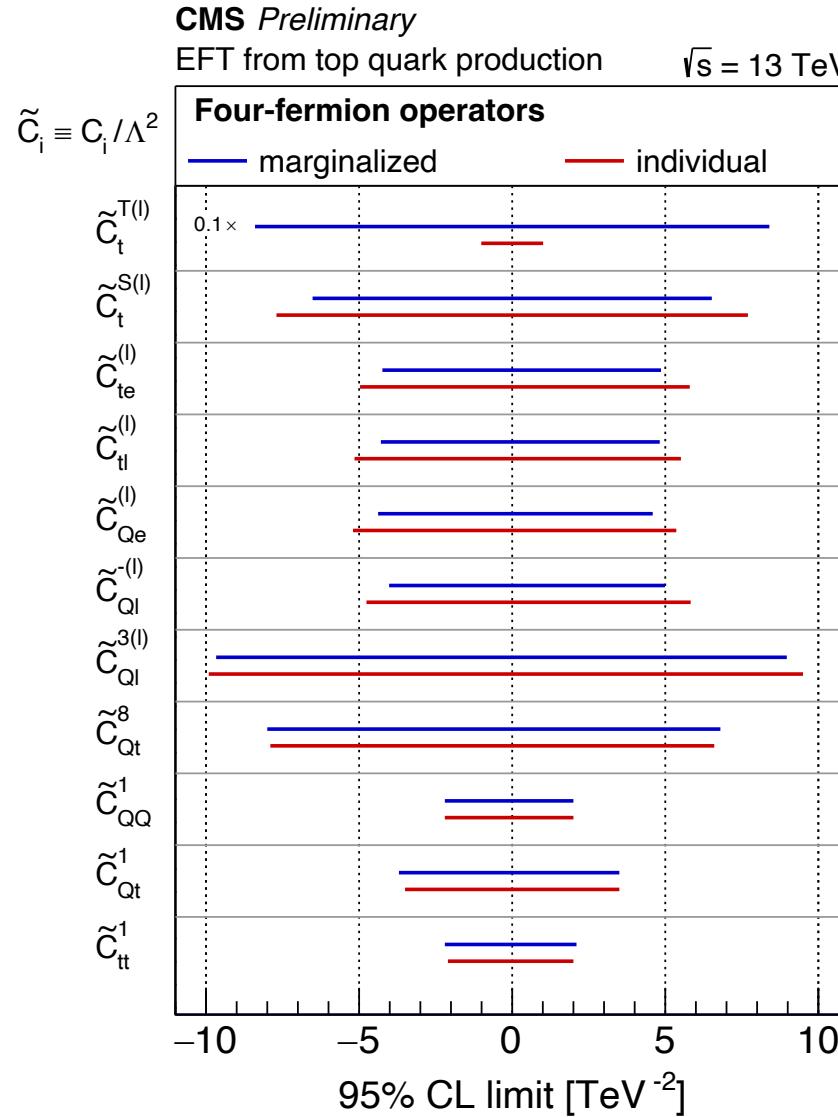
- c_{tZ} and c_{tZ}^I couplings are preferred



- The effect of the EFT operators is probed in the measured distribution of the photon pT at the reconstructed level
- Results are combined with the lepton+jets channel



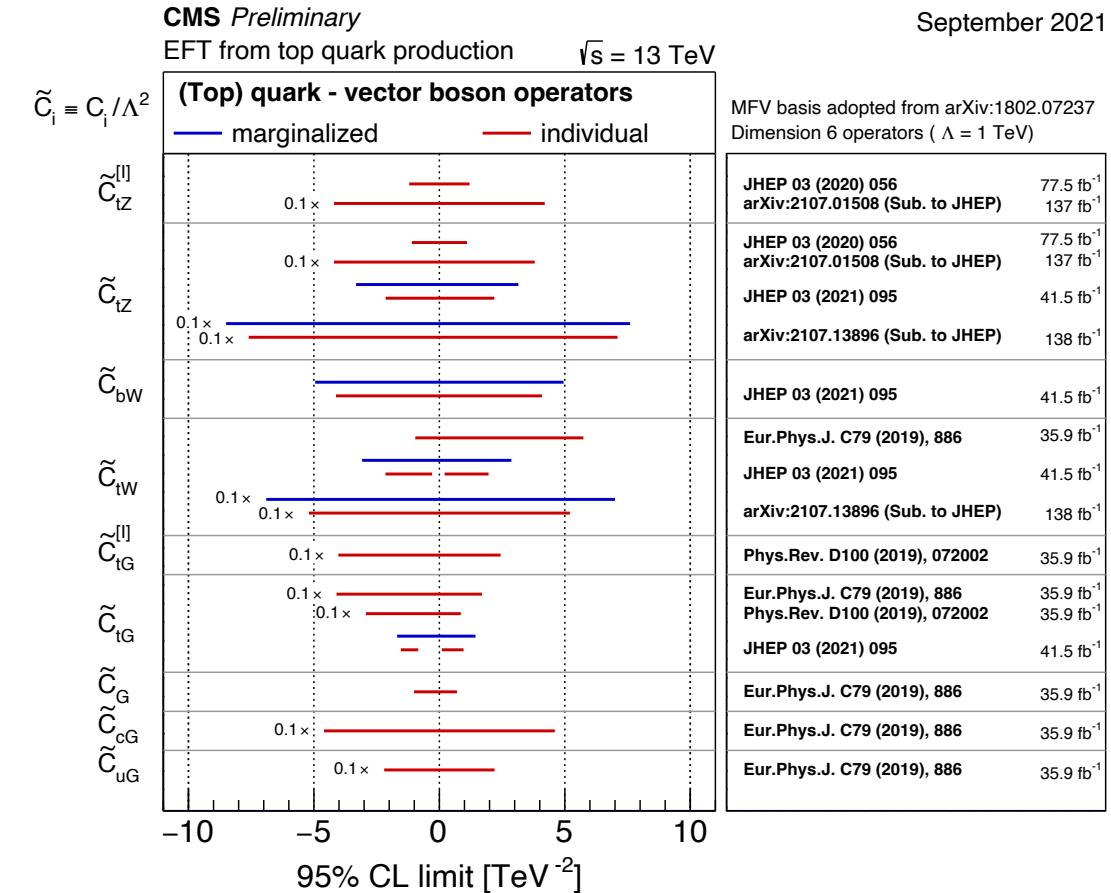
Summary of constraints



September 2021

MFV basis adopted from arXiv:1802.07237
Dimension 6 operators ($\Lambda = 1 \text{ TeV}$)

JHEP 03 (2021) 095	41.5 fb^{-1}
JHEP 03 (2021) 095	41.5 fb^{-1}
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JHEP 1911 (2019) 082	35.9 fb^{-1}
JHEP 1911 (2019) 082	35.9 fb^{-1}
JHEP 1911 (2019) 082	35.9 fb^{-1}



Summary

- Top quark is still a prime target to probe BSM
- The CMS Top group continues to pursue the full spectrum of approaches for EFT analysis
 - From measuring unfolded differential cross sections to dedicated detector-level analyses

- For a dataset with contributions from multiple physics processes impacted by a range of EFT operators, simultaneously fits are performed
 - On a good track towards a global experimental analysis of EFT operators
- There remain challenges to overcome, but there are also potential improvements to pursue. Stay tuned!

