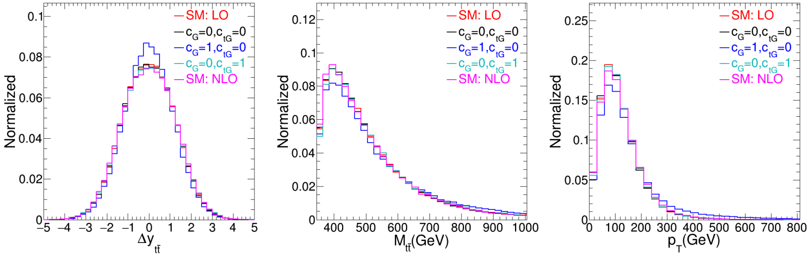
Top Quark Pairs Production



CMS Draft Analysis Note

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Archive Tag: trunk

Constraining the top quark Yukawa coupling from $\mathrm{t\bar{t}}$ differential cross sections in the lepton+jets final state at 13 TeV

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Abstract

A measurement of the top quark Yukawa coupling from the differential production cross sections in the semi-leptonic channel is presented. The production cross section is sensitive to the square of the Yukawa coupling via weak corrections that enter when Higgs-bosons are exchanged between the final state top and anti-top quarks. These weak corrections have a negligible effect in the inclusive production cross section, but they may lead to strong distortions of differential distributions near the threshold energy for pair-production (for low relative velocities of the top quarks). The differential distributions are therefore sensitive to anomalous values of the top Yukawa coupling and allow us to set an upper limit based on precision measurements. This analysis is based on data collected by the CMS experiment in the LHC at 13 TeV corresponding to an integrated luminosity of 35.8 fb^{-1}. In addition to a top reconstruction with at least four jets in the final state, a novel technique to reconstruct the $\mathrm{t\bar{t}}$ system with one missing jet is developed to enhance experimental resolutions in the low invariant mass region. We compare the data yields in $M_{t\bar{t}}$, the rapidity difference $|y_t - y_{\bar{t}}|$, and the number of reconstructed jets with templates of different Yukawa couplings and extract an upper limit on the top quark Yukawa coupling of XXXX at 95% CL.

Table 1: Simulation samples of RunIISummer16MiniAODv2-PUMoriond17i_80X_mcRun2_asymptotic_2016.

RunIISummer16	Evts.(weights) [$\times 10^6$]	σ[pb]
Signal		
TT_TuneCUETP8M2T4_13TeV-powheg-pythia8	154.64(154.64)	832
TT_TuneCUETP8M2T4_13TeV-powheg-fsrdown-pythia8	59.1(59.1)	
TT_TuneCUETP8M2T4_13TeV-powheg-fsrup-pythia8	59.2(59.2)	
TT_TuneCUETP8M2T4_13TeV-powheg-isrdown-pythia8	59.0(59.0)	
TT_TuneCUETP8M2T4_13TeV-powheg-isrup-pythia8	58.84(58.84)	
TT_TuneCUETP8M2T4_mtop1715_13TeV-powheg-pythia8	19.58(19.58)	
TT_TuneCUETP8M2T4_mtop1735_13TeV-powheg-pythia8	19.42(19.42)	
TT_TuneCUETP8M2T4down_13TeV-powheg-pythia8	58.34(58.34)	
TT_TuneCUETP8M2T4up_13TeV-powheg-pythia8	58.95(58.95)	
TT_hdampDOWN_TuneCUETP8M2T4_13TeV-powheg-pythia8	58.16(58.16)	
TT_hdampUP_TuneCUETP8M2T4_13TeV-powheg-pythia8	58.86(58.86)	
TT_TuneCUETP8M2T4_erdON_13TeV-powheg-pythia8	59.88(59.88)	
TT_TuneEE5C_13TeV-powheg-herwigpp	59.17(59.17)	
TTJets_TuneCUETP8M2T4_13TeV-amcatnloFXFX-pythia8	43.56(15.07)	
Backgrounds		
W1JetsToLNu_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	45.17(45.17)	11917.5
W2JetsToLNu_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	59.52(59.52)	3850.4
W3JetsToLNu_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	58.07(58.07)	1124
W4JetsToLNu_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	30.00(30.00)	579.3
DYJetsToLL_M-50_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	144.61(144.61)	5765
WW_TuneCUETP8M1_13TeV-pythia8	7.98(7.98)	118.7
WZ_TuneCUETP8M1_13TeV-pythia8	4.00(4.00)	47.13
ST_t-channel_antitop_4f_inclusiveDecays_13TeV-powhegV2-madspin-pythia8_TuneCUETP8M1	38.81(38.81)	81
ST_t-channel_top_4f_inclusiveDecays_13TeV-powhegV2-madspin-pythia8_TuneCUETP8M1	67.24(67.24)	136
ST_tW_antitop_5f_NoFullyHadronicDecays_13TeV-powheg_TuneCUETP8M1	5.43(5.43)	19.3
ST_tW_top_5f_NoFullyHadronicDecays_13TeV-powheg_TuneCUETP8M1	5.37(5.37)	19.3
ST_s-channel_4f_leptonDecays_13TeV-amcatnlo-pythia8_TuneCUETP8M1	1.0(0.62)	3.4
QCD_Pt-30to50_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8	29.56(29.56)	
QCD_Pt-50to80_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8	19.81(19.81)	
QCD_Pt-80to120_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8	23.18(23.18)	
QCD_Pt-120to170_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8	19.98(19.98)	
QCD_Pt-170to300_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8	36.96(36.96)	
QCD_Pt-300to470_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8	49.0(49.0)	
QCD_Pt-470to600_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8	19.36(19.36)	
QCD_Pt-600to800_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8	19.74(19.74)	
QCD_Pt-800to1000_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8	19.77(19.77)	
QCD_Pt-1000toInf_MuEnrichedPt5_TuneCUETP8M1_13TeV_pythia8	13.2(13.2)	
QCD_Pt-50to80_EMEnriched_TuneCUETP8M1_13TeV_pythia8	23.47(23.47)	
QCD_Pt-30to50_EMEnriched_TuneCUETP8M1_13TeV_pythia8	11.5(11.5)	
QCD_Pt-80to120_EMEnriched_TuneCUETP8M1_13TeV_pythia8	77.7(77.7)	
QCD_Pt-120to170_EMEnriched_TuneCUETP8M1_13TeV_pythia8	77.77(77.77)	
QCD_Pt-170to300_EMEnriched_TuneCUETP8M1_13TeV_pythia8	11.54(11.54)	
QCD_Pt-300toInf_EMEnriched_TuneCUETP8M1_13TeV_pythia8	7.37(7.37)	

top quark associated production with a W boson (tW) and PYTHIA8 is used for multijet production. In all cases the parton shower and the hadronization are described by PYTHIA8 with tune CUETP8M1T4 [17]. The W boson and DY backgrounds are normalized to their NNLO cross sections [18]. The single top quark processes are normalized to NLO calculations [19, 20], and the multijet simulation is normalized to the LO calculation [12].

The detector response is simulated using GEANT4 [21]. The same reconstruction algorithms that are applied to the data are used.

3.1 Pile-up weighting

To correct the simulation to be in agreement with the pileup conditions during the data taking the average number of pileup events per bunch crossing μ is calculated from the measured instantaneous luminosity and a minimum bias cross section of 69 mb. Event weights are calcu-

Probing EFT operators in $t(\bar{t})Z$ production in multilepton final states.

TOP-21-001 approval

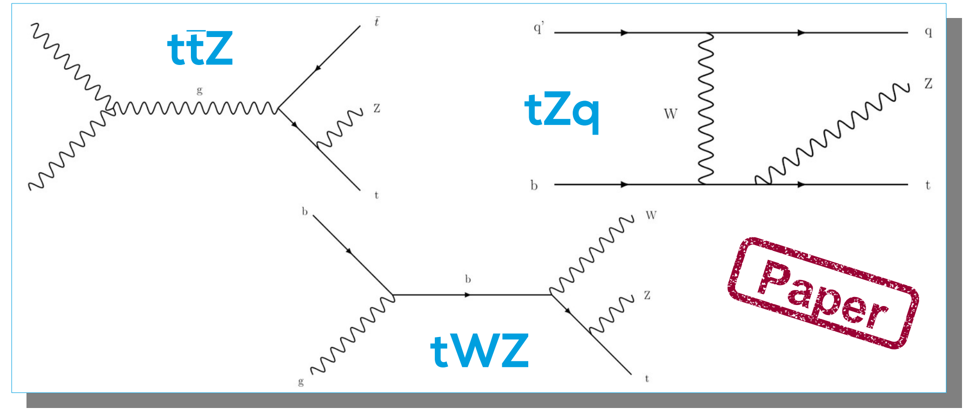
Nicolas Tonon, Abideh Jafari, David Walter (DESY)

Top PAG

11th May 2021

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

OVERVIEW



- Target 3 t-Z associated production modes
  - Complementary, probe similar EFT operators
- 3ℓ & 4ℓ final states, Run 2 dataset

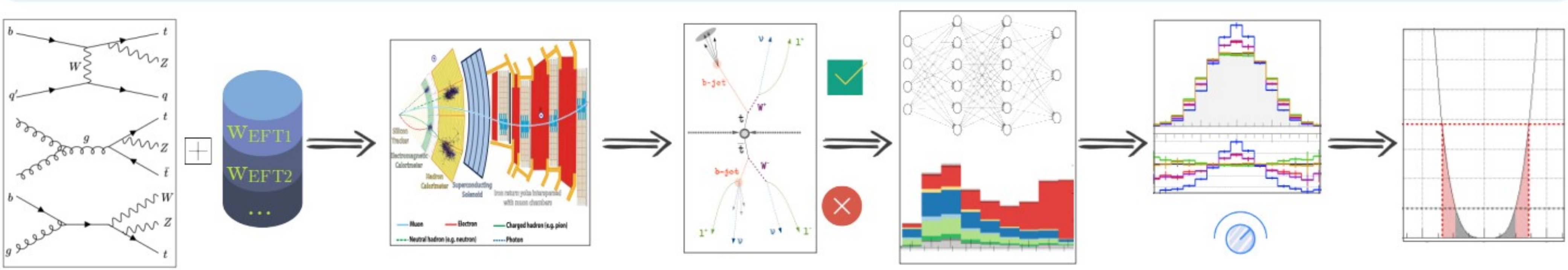
New **Use novel machine-learning techniques** to improve sensitivity to WCs

- Analysis strategy entirely optimized to search for EFT effects
  - Simulated at detector-level, without assumptions

MUCH OBLIGED

We thank TOP-19-001 authors for developing & sharing convenient EFT reweighting tools [1]

MC simulation	+ SMEFT reweighting	Full detector reconstruction	Object reco. & Event sel. & Bkg estim.	SR/CR observables optimized with MVA	Templates parameterized with WCs	Constrain WCs via MLE



MadGraph | GEANT4 | ROOT | K + TensorFlow | TH1EFT | Combine

MVA

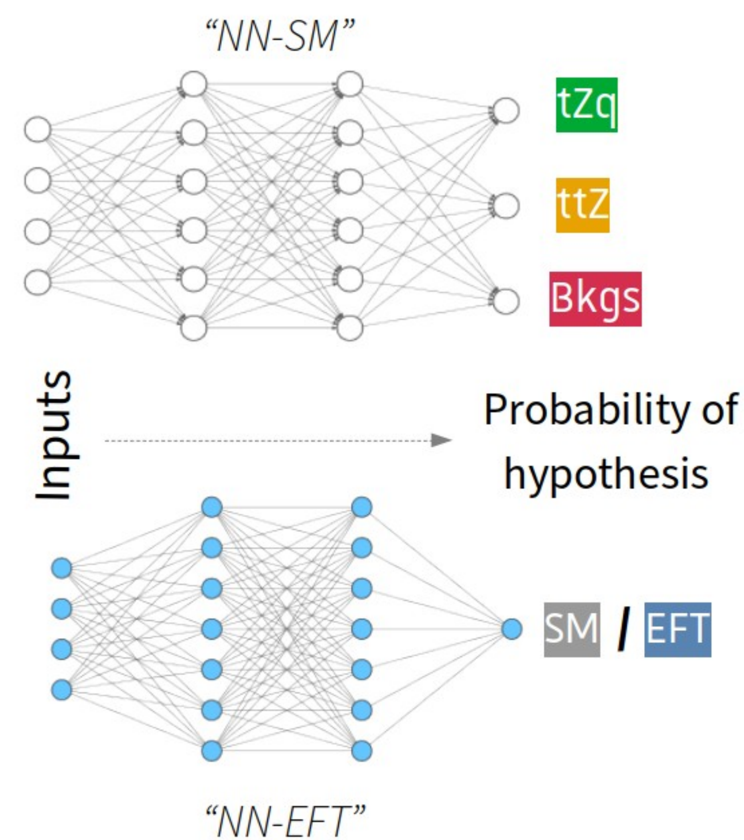
- Most EFT operators modify the final state kinematics non-trivially
  → Use multivariate analysis (MVA) to optimize the sensitivity to EFT

- Design MVA in SR-3ℓ only (other regions are enriched w/ single process, or insensitive to top-EFT)

- Train neural networks (NNs) for two purposes :

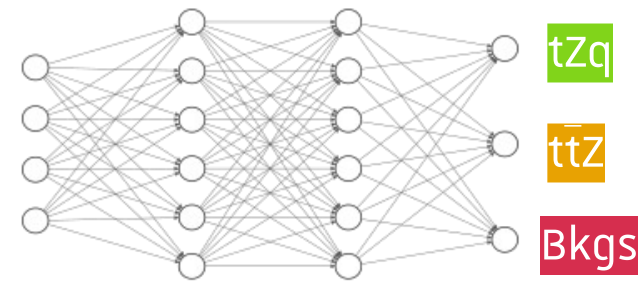
1) Separate physics processes
↔ Enrich SR with processes most sensitive to our operators

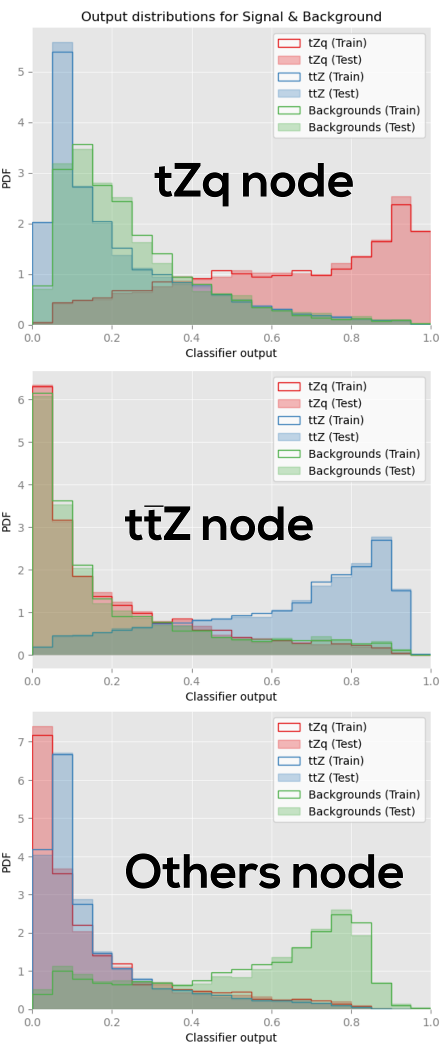
2) Separate SM / EFT scenarios
↔ Learn characteristic features of new physics events

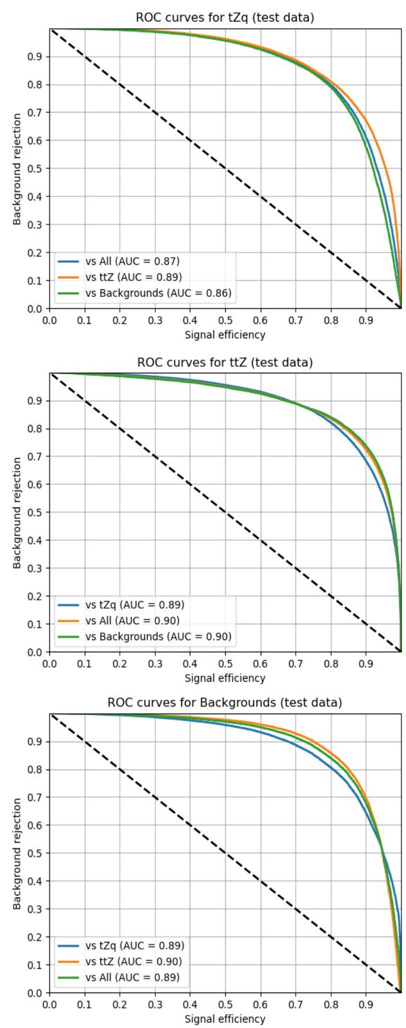


1) SM VS SM

- ‘NN-SM’ multiclass classifier trained to separate tZq/tt̄Z/others







- Trained on central CMS signal samples (NLO, high-statistics, not used for signal extraction)
- List of high- and low-level variables

Architecture :

- Independent train/test samples
- 3 hidden layers * 100 neurons
- reLu activation function
- Adam optimizer
- Cross-entropy loss function
- Dropout, batch norm., L2 regularization, early-stopping

SIGNAL EXTRACTION

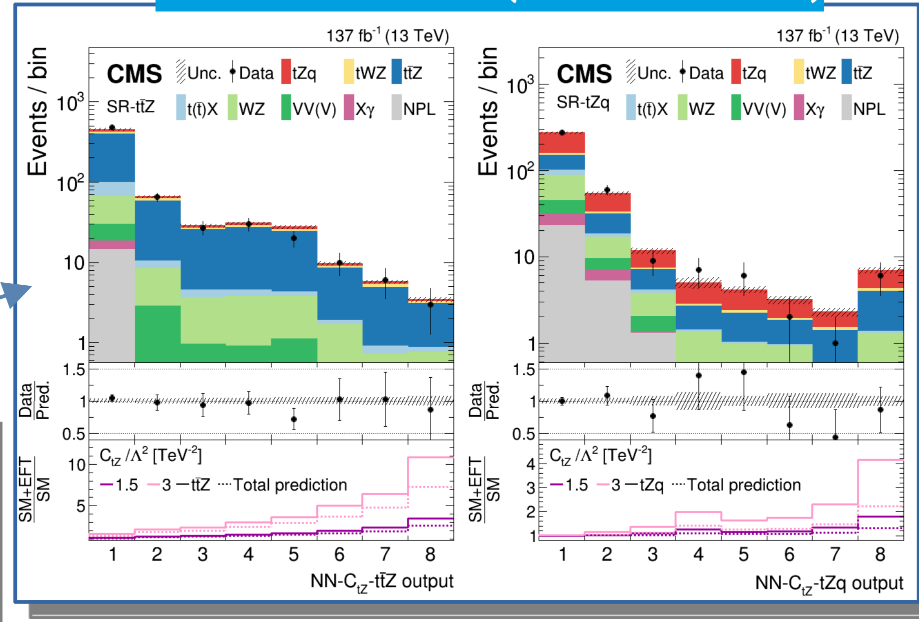
Paper

- Simultaneous template fits in [6 regions * 3 years]
  - 1D, 2D, or 5D
- NN distributions used in SRtZq & SRttZ are fit-dependent

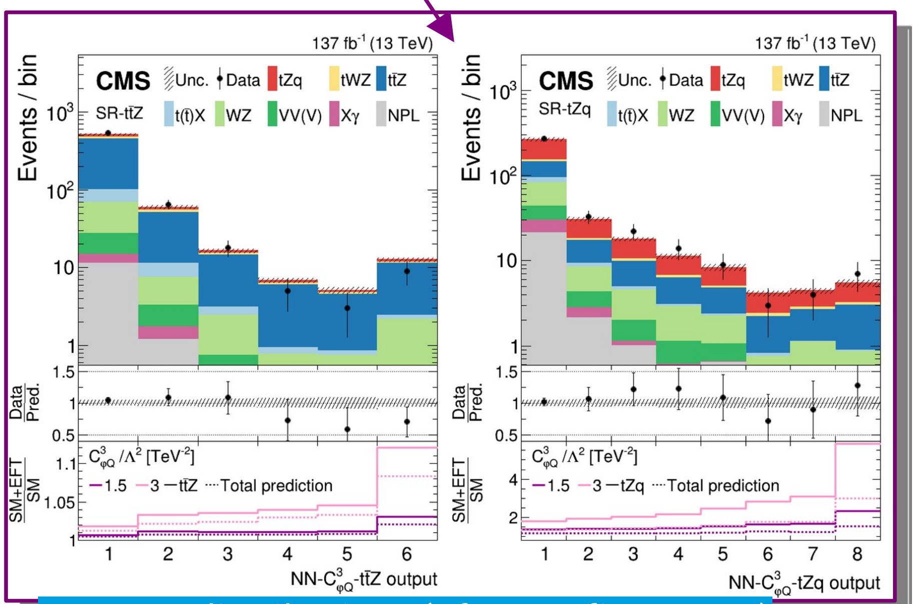
Observables used in the different regions and fits

	Region					
Fit configuration	SR-tZq	SR-$t\bar{t}$Z	SR-Others	SR-$t\bar{t}$Z-4ℓ	CR WZ	CR ZZ
1D c_{tZ}	NN-c_{tZ}-tZq	NN-c_{tZ}-$t\bar{t}$Z				
1D c_{tW}	NN-c_{tW}-tZq	NN-c_{tW}-$t\bar{t}$Z				
1D $c^{3}_{\varphi Q}$	NN-$c^{3}_{\varphi Q}$-tZq	NN-$c^{3}_{\varphi Q}$-$t\bar{t}$Z	m_{T}^{W}	Counting experiments		
1D $c^{-}_{\varphi Q}$	NN-SM (tZq node)	NN-SM ($t\bar{t}$Z node)				
1D $c_{\varphi t}$	NN-SM (tZq node)	NN-SM ($t\bar{t}$Z node)				
2D and 5D	NN-5D-tZq	NN-5D-$t\bar{t}$Z				

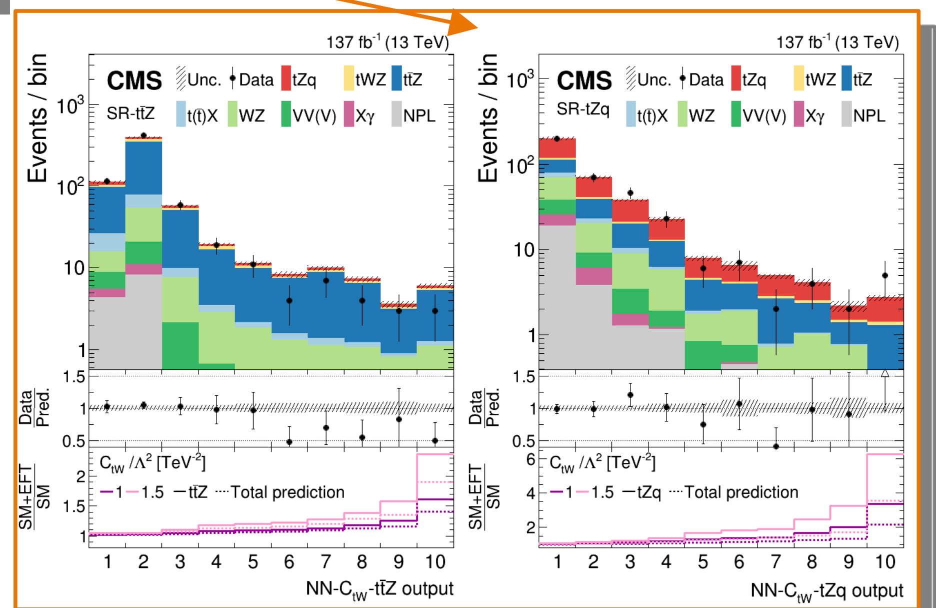
NN-ctz distributions (after 1D fit to ctz)



NN-cpq3 distributions (after 1D fit to cpq3)

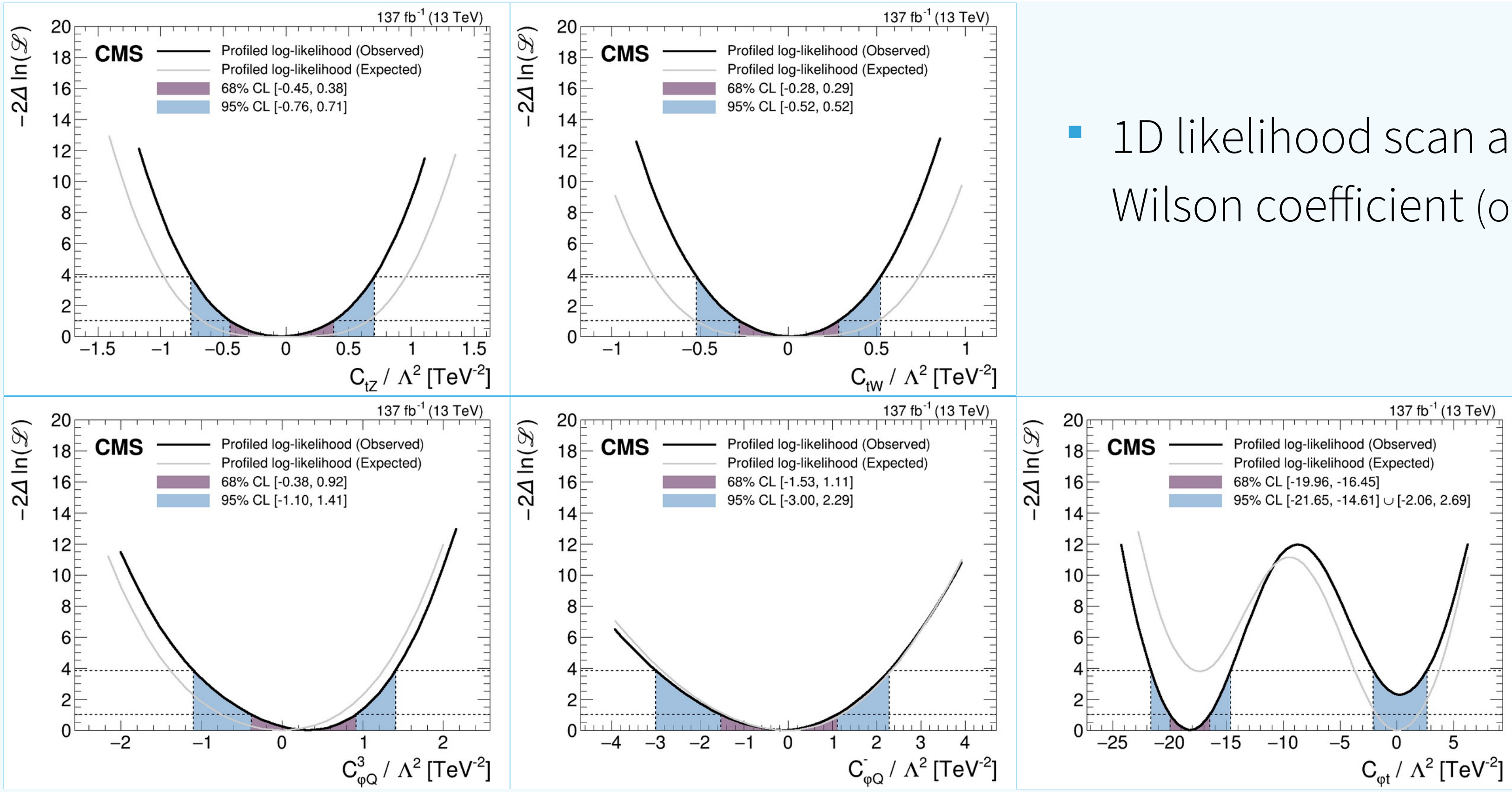


NN-ctw distributions (after 1D fit to ctw)



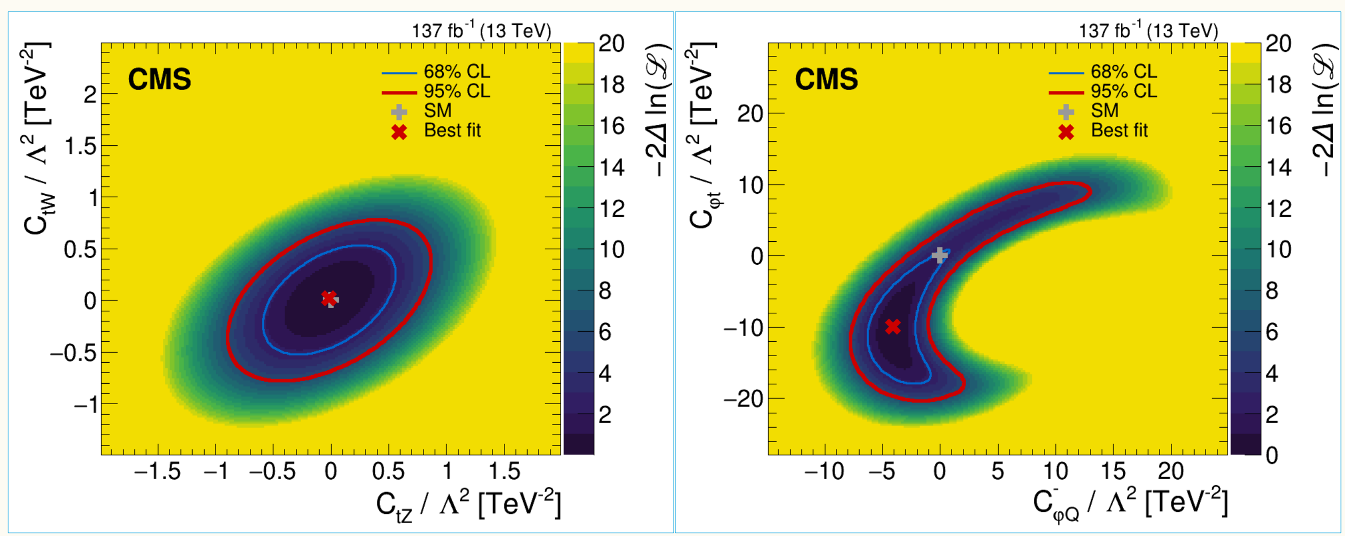
LIKELIHOOD SCANS

Paper



- 1D likelihood scan as a function of each Wilson coefficient (other WCs fixed to 0)

- 2D likelihood scans illustrate correlations of pairs of WCs (other WCs fixed to 0)



Probing EFT using $t\bar{t}$ associated with a boosted Z or Higgs boson

Bryan Caraway ,
Andrew Brinkerhoff, Kenichi Hatakeyama, Joe Pastika,
Jon Wilson (Baylor University)

TOP-21-003 Pre-approval

TOP PAG
May 31st, 2021

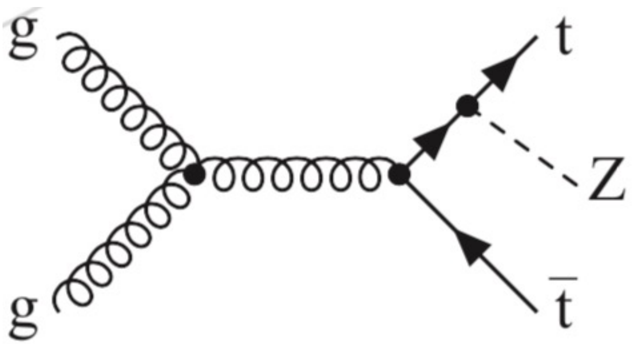
Introduction

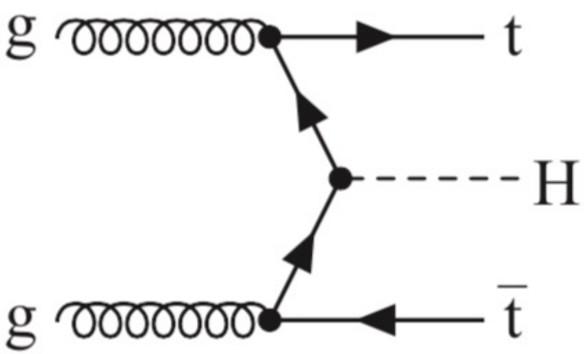
Effective field theory

- The Standard Model is incomplete: hierarchy problem, dark matter, etc.
- To this date, no BSM discoveries have been made at CMS. New physics may exist beyond the LHC energy spectrum
- **Effective field theory (EFT)**: model independent way to probe deviations from the SM, that exists at higher energies

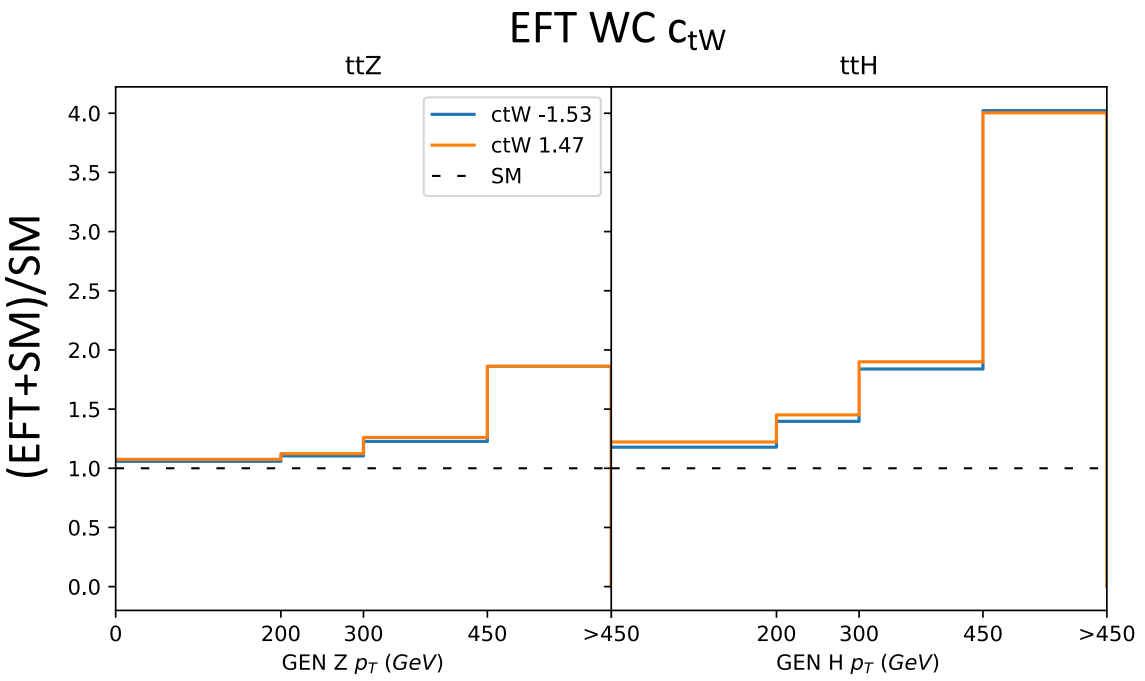
Analysis strategy

- Reconstruct Z/H as a single object and utilize machine learning techniques to maximize signal sensitivity
- Constrain top + electroweak EFT operators in boosted ttZ and ttH events, single-lepton tt, with Z/H decaying to bb.
- Perform cross section measurement of ttZ and ttH in the boosted regime.





Effective Field Theory - Implementation



ttZ and ttH provide complementary constraints

WCs allows morphing of SM distributions.
Interpret any data distribution as a constraint on possible WC values

"Dim6Top" is used to produce many event reweighting, based on WC settings, corresponding to points in EFT space.

Per event, we derive a quadratic fit of this space, to obtain a parameterization that allows us to model any "scenario" in EFT.

$$w\left(\frac{\vec{c}}{\Lambda^2}\right) = s_0 + \sum_j s_{1j}\frac{c_j}{\Lambda^2} + \sum_{j,k} s_{2jk}\frac{c_j}{\Lambda^2}\frac{c_k}{\Lambda^2},$$

SM

SM-EFT Interference

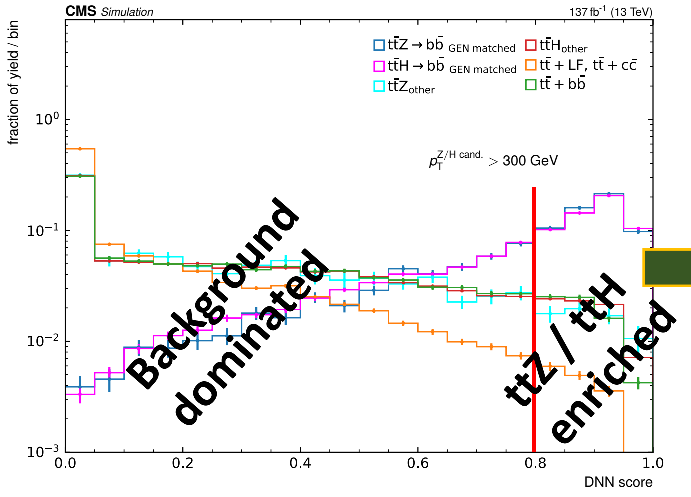
EFT-EFT Interference (j≠k)

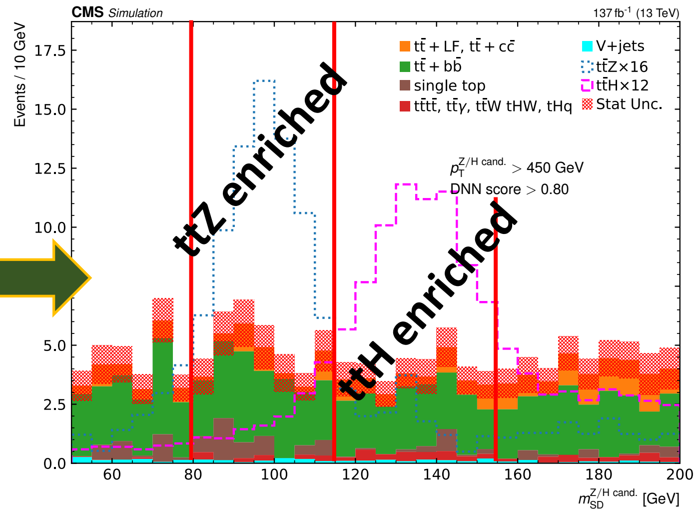
EFT Quadratic (j=k)

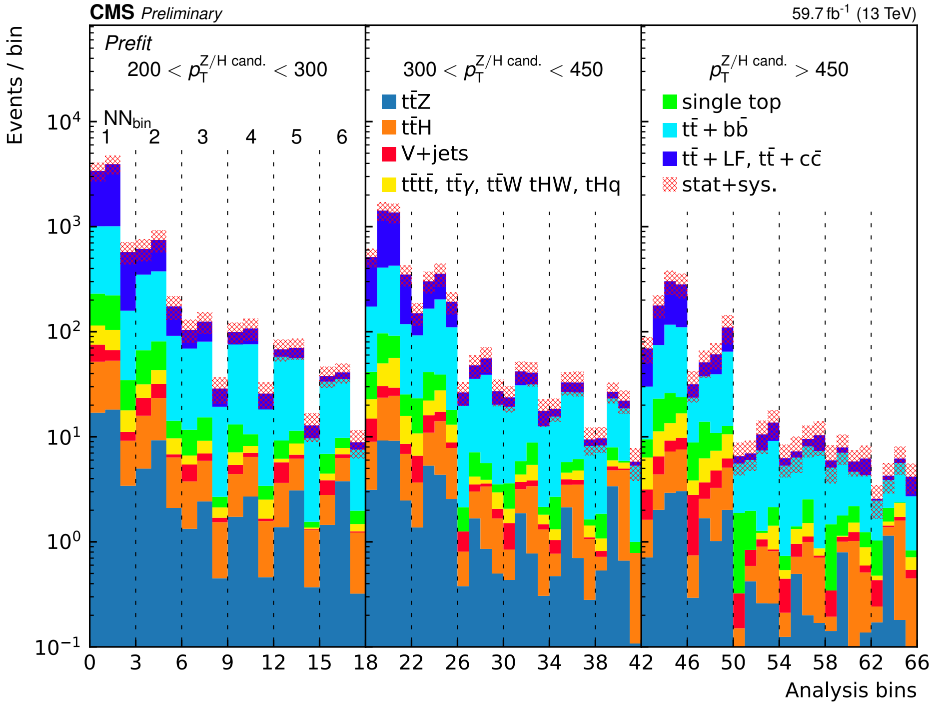
Signal Extraction - Strategy

We use the output **MVA score**, Z/H cand. **softdrop mass**, and Z/H **pT**
to construct signal sensitive analysis bins

Background dominated bins are used to constrain nuisance parameters in the fit







Fit templates to data and extract best-fit values for ttH/ttZ signal strength modifiers

Comparison with other CMS expected limits:
*(*TOP-21-001 in CWR)*

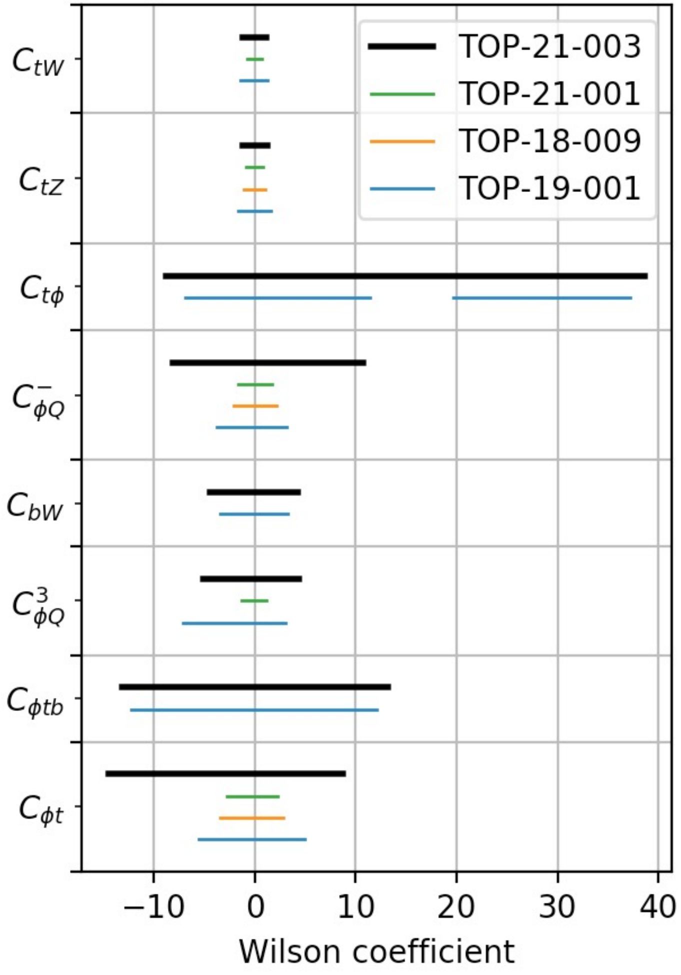
Results (expected) - EFT

CMS result – other WCs fixed to SM (95% CL Interval)

TOP-19-001
ttv – multilepton
(2017 data)

TOP-18-009
ttZ – differential meas. with lepton final states
(16/17 data)

TOP-21-001
ttZ, tZq – multilepton
(run 2 data)



WC/Λ^2[TeV^{-2}]	95% CL interval (others profiled)	95% CL interval (others fixed to SM)
c_{tW}	[−1.89, 1.87]	[−1.21, 1.15]
c_{tZ}	[−1.91, 1.89]	[−1.23, 1.27]
$c_{t\varphi}$	[−8.92, 38.91]	[−8.76, 38.58]
$c_{\varphi Q}^{-}$	[−10.79, 13.28]	[−8.12, 10.72]
c_{bW}	[−4.58, 4.55]	[−4.37, 4.33]
$c_{\varphi Q}^{3}$	[−5.99, 5.60]	[−5.07, 4.44]
$c_{\varphi tb}$	[−14.78, 14.77]	[−13.14, 13.18]
$c_{\varphi t}$	[−16.52, 11.87]	[−14.42, 8.76]

Analysis results have comparable strengths to EFT limits from other analyses in CMS, and compatible with statistical combination (**orthogonal phase space**)