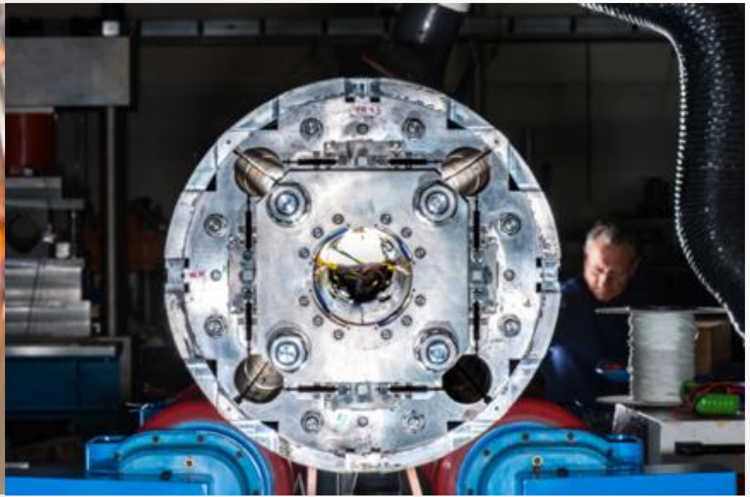
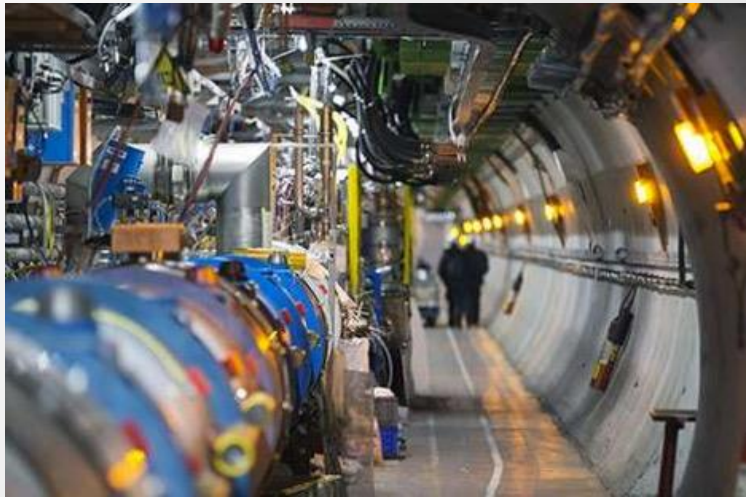
PROBING EFT TOP QUARK PRODUCTION

R. Schöfbeck, July 30th, 2021 on behalf of the CMS Collaboration



EPS

EUROPEAN PHYSICAL SOCIETY
HEP2021
VIRTUAL EDITION



TOP CROSS SECTION MEASUREMENTS AT CMS

Figure adapted by N. Tonon from this [link]

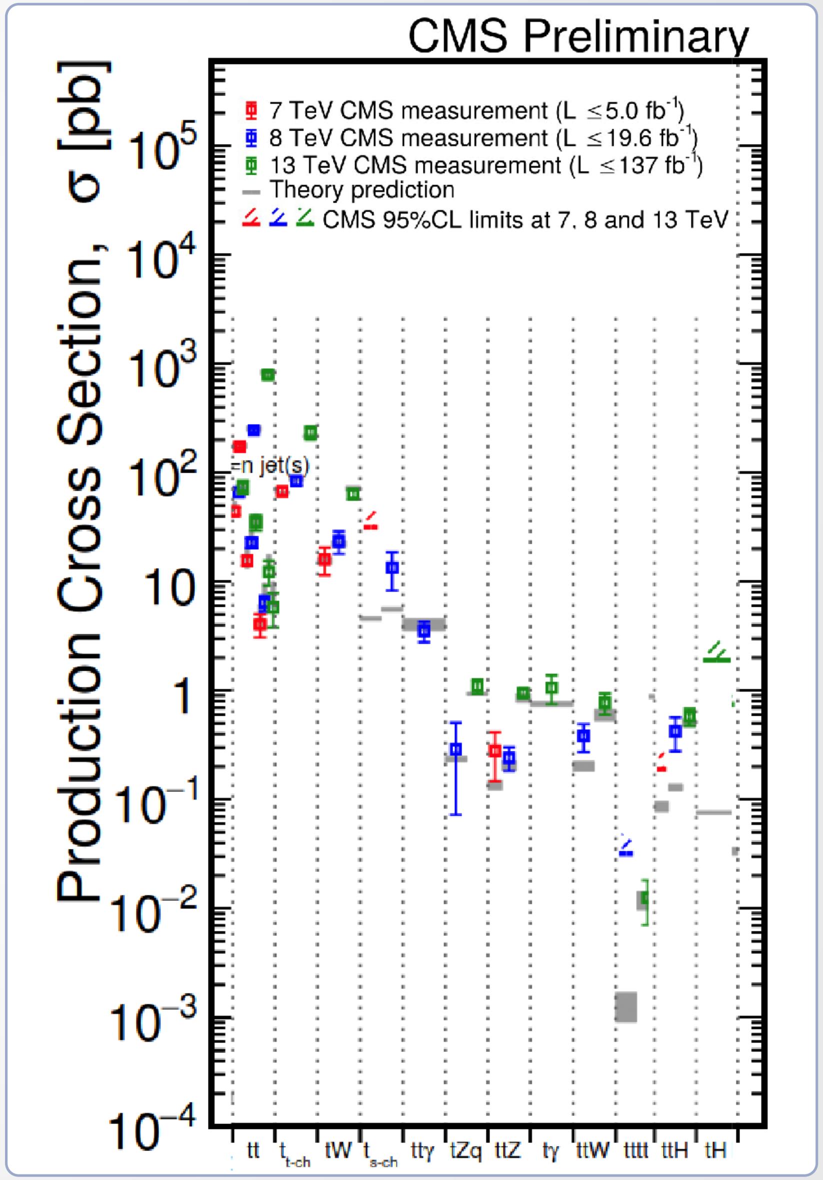
- No clear sign of new physics (BSM) at LHC so far…
- Future facilities increase ∫L , not √s
- top quark measurements are now systematics limited
- Many BSM theories predict deviations of top quark's couplings

Theme of EFT measurements:
Reveal indirect and widely dispersed hints of new physics in precision measurements

- Today: 3 new EFT results

top quarks with additional leptons [CMS-TOP-19-001]
t/tt+Z in 3l with ML [CMS-TOP-21-001]
ttɣ differential cross section [CMS-TOP-18-010]

- For the SM aspects, consider these talks:
  - [D. Walter: top EWK couplings] [L. Lambrecht: top EWK production at CMS]



OPERATORS AND PHYSICS IMPLICATIONS

SMEFT Lagrangian

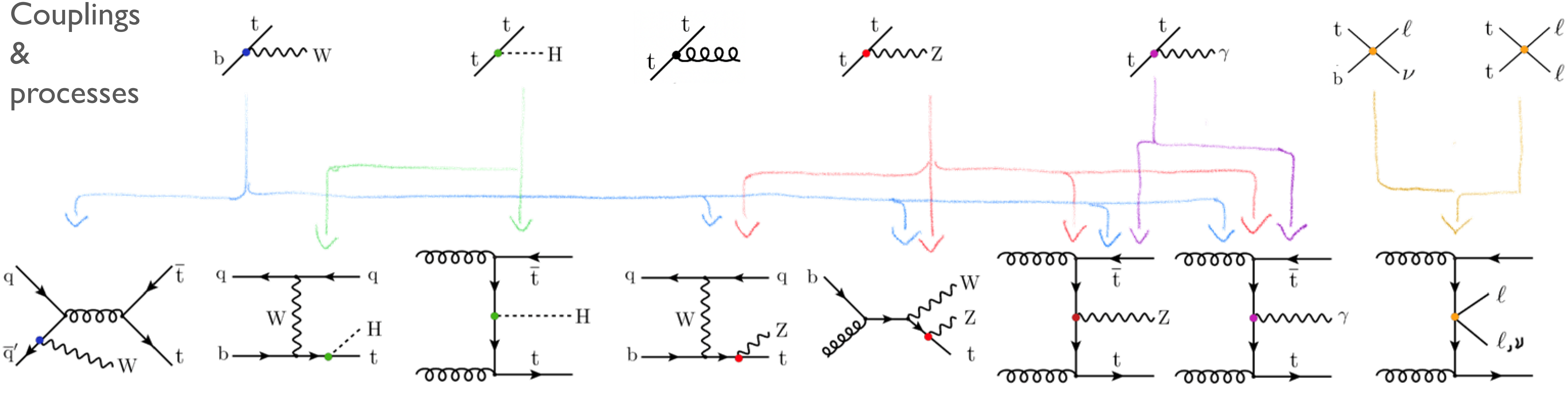
$$\mathcal{L} = \mathcal{L}_{4,\mathrm{SM}} + \frac{1}{\Lambda_{\delta L\neq 0}}\mathcal{L}_5 + \boxed{\frac{1}{\Lambda^2}\mathcal{L}_6} + \frac{1}{\Lambda^2_{\delta B\neq 0}}\mathcal{L}'_6 + \frac{1}{\Lambda^3_{\delta L\neq 0}}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \ldots$$

Operators

$\mathcal{O}_{\phi\mathrm{tb}}$	$i(\tilde{\phi}\, D_\mu\, \phi)(\bar{t}_R\,\gamma^\mu\, b_R) + \mathrm{h.c.}$	$\mathcal{O}_{\mathrm{tB}}$	$i(\bar{q}_L\sigma^{\mu\nu}\, t_R)\,\tilde{\phi}\, B_{\mu\nu} + \mathrm{h.c.}$	$\mathcal{O}^{(3)}_{\phi q_L}$	$i(\phi^\dagger \overleftrightarrow{D}_\mu\, \tau_I \phi)(\bar{q}_L\,\gamma^\mu\, \tau^I q_L)$	$\mathcal{O}^1_{qq}$	$(\bar{q}_L\,\gamma_\mu\, q_L)(\bar{q}_L\,\gamma^\mu q_L)$
$\mathcal{O}_{\mathrm{t}\phi}$	$(\phi^\dagger\phi)\,\bar{q}_L\, t_R\,\tilde{\phi} + \mathrm{h.c.}$	$\mathcal{O}_{\mathrm{tG}}$	$i(\bar{q}_L\sigma^{\mu\nu}\lambda^a\, t_R)\,\tilde{\phi}\, G^a_{\mu\nu} + \mathrm{h.c.}$	$\mathcal{O}^{(1)}_{\phi q_L}$	$i(\phi^\dagger \overleftrightarrow{D}_\mu\, \phi)(\bar{q}_L\,\gamma^\mu\, q_L)$	$\mathcal{O}^8_{qq}$	$(\bar{q}_L\,\gamma_\mu T^A\, q_L)(\bar{q}_L\,\gamma^\mu T^A\, q_L)$

…

Couplings & processes



Parametrized predictions

$$N\left(\frac{\vec{c}}{\Lambda^2}\right) = S_0 + \sum_j S_{1j}\frac{c_j}{\Lambda^2} + \sum_j S_{2j}\frac{c_j^2}{\Lambda^4} + \sum_{j,k} S_{3jk}\frac{c_j}{\Lambda^2}\frac{c_k}{\Lambda^2}$$

TOP QUARKS WITH ADDITIONAL LEPTONS

[CMS-TOP-19-001]

- Data set: 41.5 fb^{-1} from 2017

- Testing 16 operators; two groups
  - ttV(V): affecting: ttH, tHq, ttZ, ttW
  - with 7 four-fermion operators : ttll, ttlν

- 35 signal regions in total
  - lepton channels split further in jet and b-tag multiplicities
    - "inclusive approach"
  - 2l (same-sign): ttW and ttH processes
  - 3l (with and w/o Z candidate): ttZ(3l), tZq (ttll, tllq, ttlν)
  - 4l (no further binning): ttZ(4l)

2 quarks + bosons

Operator	Definition	Lead processes affected
$^{\ddagger}O_{u\varphi}^{(ij)}$	$\bar{q}_i u_j \tilde{\varphi}\, (\varphi^{\dagger}\varphi)$	$t\bar{t}H$, tHq
$O_{\varphi q}^{1(ij)}$	$(\varphi^{\dagger} i\overleftrightarrow{D}_{\mu}\varphi)(\bar{q}_i\gamma^{\mu}q_j)$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$O_{\varphi q}^{3(ij)}$	$(\varphi^{\dagger} i\overleftrightarrow{D}^{I}_{\mu}\varphi)(\bar{q}_i\gamma^{\mu}\tau^{I}q_j)$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$O_{\varphi u}^{(ij)}$	$(\varphi^{\dagger} i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_i\gamma^{\mu}u_j)$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$^{\ddagger}O_{\varphi ud}^{(ij)}$	$(\tilde{\varphi}^{\dagger} iD_{\mu}\varphi)(\bar{u}_i\gamma^{\mu}d_j)$	$t\bar{t}H$, $tl\bar{l}q$, tHq
$^{\ddagger}O_{uW}^{(ij)}$	$(\bar{q}_i\sigma^{\mu\nu}\tau^{I}u_j)\,\tilde{\varphi}W^{I}_{\mu\nu}$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$^{\ddagger}O_{dW}^{(ij)}$	$(\bar{q}_i\sigma^{\mu\nu}\tau^{I}d_j)\,\varphi W^{I}_{\mu\nu}$	$t\bar{t}H$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$^{\ddagger}O_{uB}^{(ij)}$	$(\bar{q}_i\sigma^{\mu\nu}u_j)\,\tilde{\varphi}B_{\mu\nu}$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$^{\ddagger}O_{uG}^{(ij)}$	$(\bar{q}_i\sigma^{\mu\nu}T^{A}u_j)\,\tilde{\varphi}G^{A}_{\mu\nu}$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$

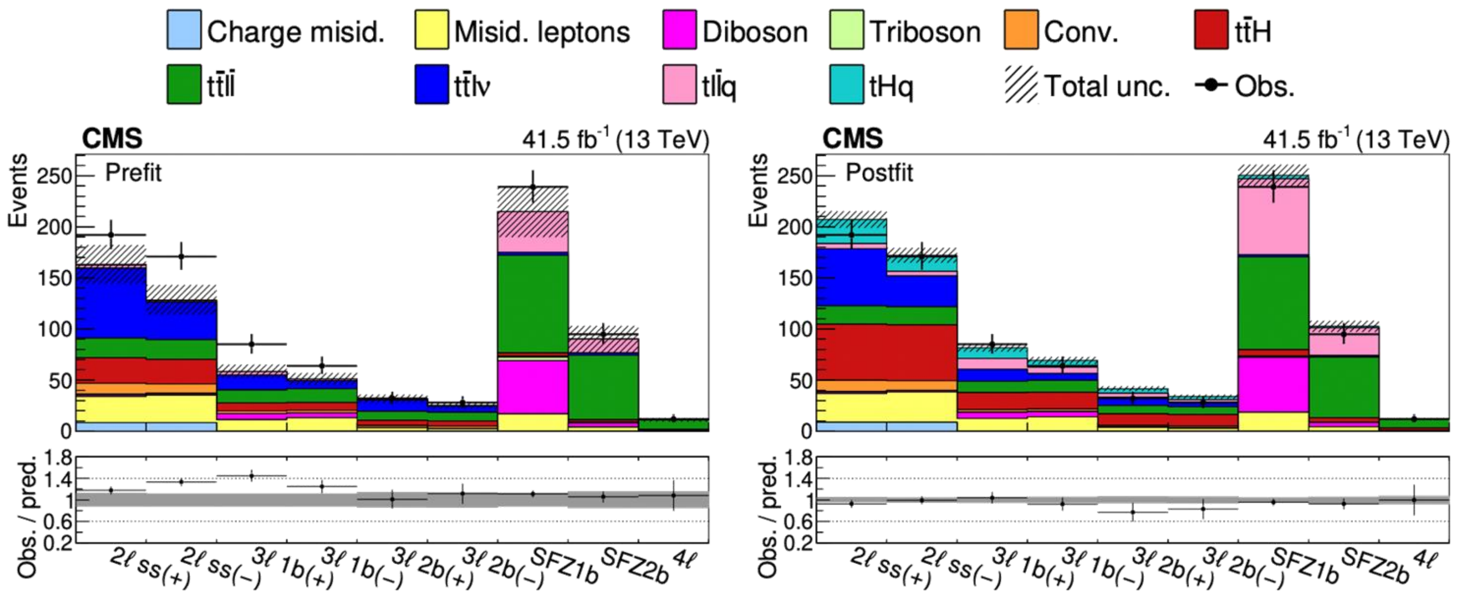
2 quarks + 2 leptons

Operator	Definition	Lead processes affected
$O_{\ell q}^{1(ijkl)}$	$(\bar{\ell}_i\gamma^{\mu}\ell_j)(\bar{q}_k\gamma^{\mu}q_{\ell})$	$t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$O_{\ell q}^{3(ijkl)}$	$(\bar{\ell}_i\gamma^{\mu}\tau^{I}\ell_j)(\bar{q}_k\gamma^{\mu}\tau^{I}q_{\ell})$	$t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$O_{\ell u}^{(ijkl)}$	$(\bar{\ell}_i\gamma^{\mu}\ell_j)(\bar{u}_k\gamma^{\mu}u_{\ell})$	$t\bar{t}l\bar{l}$
$O_{eq}^{(ijkl)}$	$(\bar{e}_i\gamma^{\mu}e_j)(\bar{q}_k\gamma^{\mu}q_{\ell})$	$t\bar{t}l\bar{l}$, $tl\bar{l}q$
$O_{eu}^{(ijkl)}$	$(\bar{e}_i\gamma^{\mu}e_j)(\bar{u}_k\gamma^{\mu}u_{\ell})$	$t\bar{t}l\bar{l}$
$^{\ddagger}O_{\ell equ}^{1(ijkl)}$	$(\bar{\ell}_i e_j)\,\varepsilon\,(\bar{q}_k u_{\ell})$	$t\bar{t}l\bar{l}$, $tl\bar{l}q$
$^{\ddagger}O_{\ell equ}^{3(ijkl)}$	$(\bar{\ell}_i\sigma^{\mu\nu}e_j)\,\varepsilon\,(\bar{q}_k\sigma_{\mu\nu}u_{\ell})$	$t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$

TOP QUARKS WITH ADDITIONAL LEPTONS

[CMS-TOP-19-001]

- Backgrounds for 2lss
  - Non-prompt lep & charge mis-id
  - Estimated in tt and DY CR
  - FR/misid measurements
- 3l/4l signal regions:
  - dominant diboson background



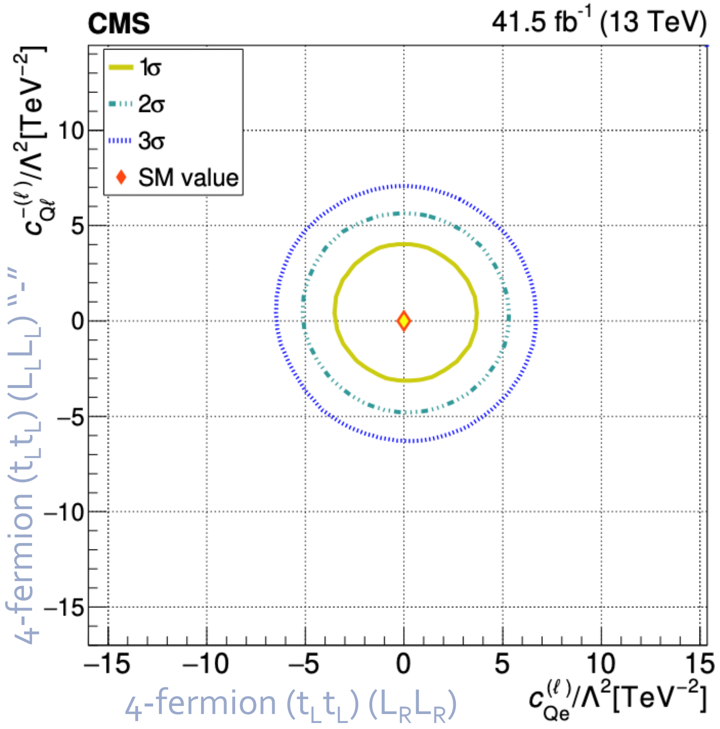
prefit postfit

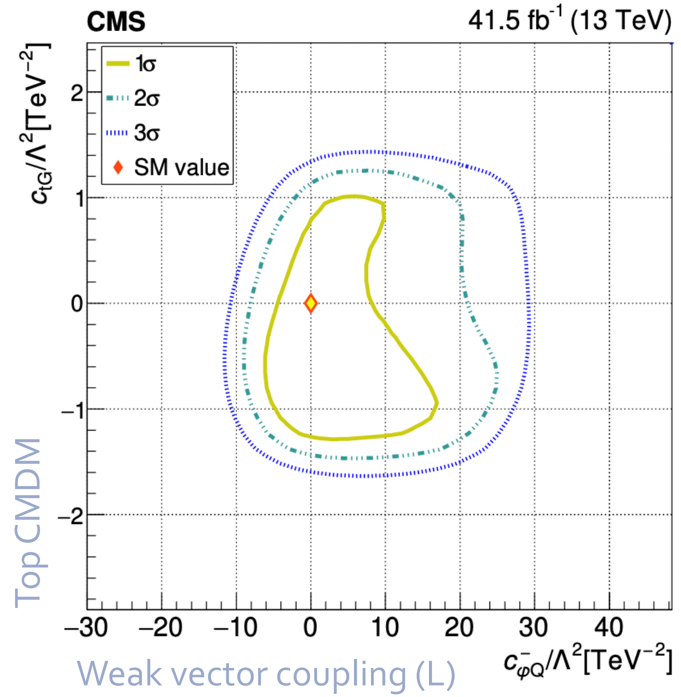
- Main systematics:
  - Theory ($\mu_{R,F}$) and modelling
  - Experimental: Jet energy scale, lepton identification and isolation, luminosity
- Obtain 1D and 2D profiled and individual limits from likelihood fit

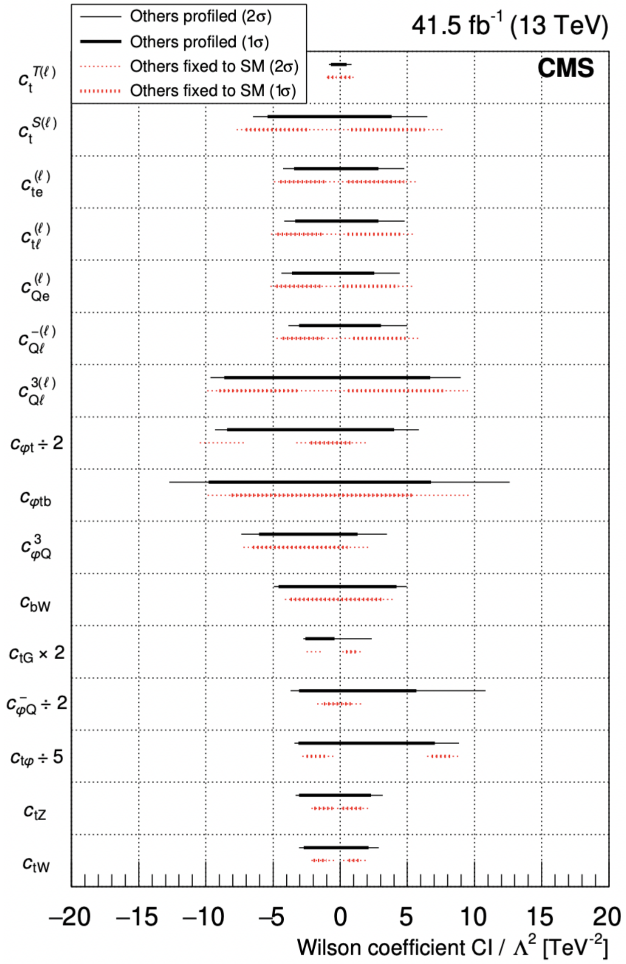
TOP QUARKS WITH ADDITIONAL LEPTONS

[CMS-TOP-19-001]

- Good agreement of all WCs with the SM prediction
  - c_{tW}, $c_{t\phi}$, c_{tG} just outside the 2σ when all other WC are zero





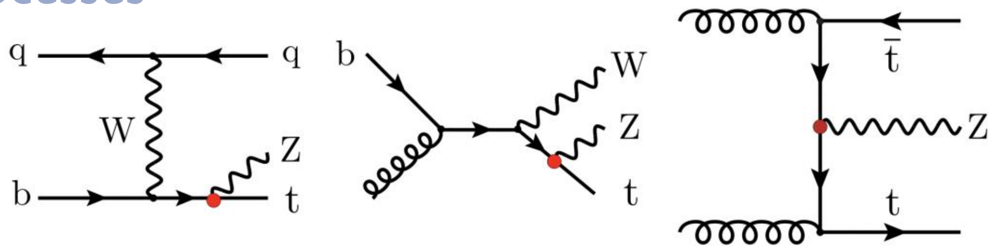


MVA-EFT SEARCH IN ≥3L FINAL STATES

[CMS-TOP-21-001]

- Full Run II Luminosity 138/fb
- Main processes: tZq/ttZ/tWZ
  - Leptonically decaying top + Z boson candidate
- 5 operators: weak dipole moment interactions, left- and right-handed top quark vector couplings
- Main sensitivity: from SR-3l
- Extensive use of MVAs
  - Multiclassifier "NN-SM" in SR-3l to discriminate between several SM processes : tZq / ttZ / (bkg.)
    - 33 (mostly kinematic) event properties
  - 8 neural network binary classifiers to separate SM-events from BSM events

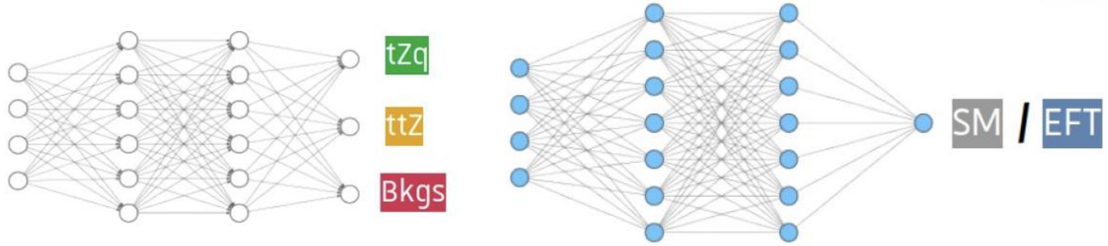
Processes



Operators

Weak top dipole interactions	$\mathcal{O}_{tZ}$	$\mathrm{Re}\{-s_W c_{uB}^{(33)} + c_W c_{uW}^{(33)}\}$
	$\mathcal{O}_{tW}$	$\mathrm{Re}\{c_{uW}^{(33)}\}$
LH vector couplings	$\mathcal{O}_{\varphi Q}^{3}$	$c_{\varphi q}^{3(33)}$
	$\mathcal{O}_{\varphi Q}^{-}$	$c_{\varphi q}^{1(33)} - c_{\varphi q}^{3(33)}$
RH vector couplings	$\mathcal{O}_{\varphi t}$	$c_{\varphi u}^{(33)}$

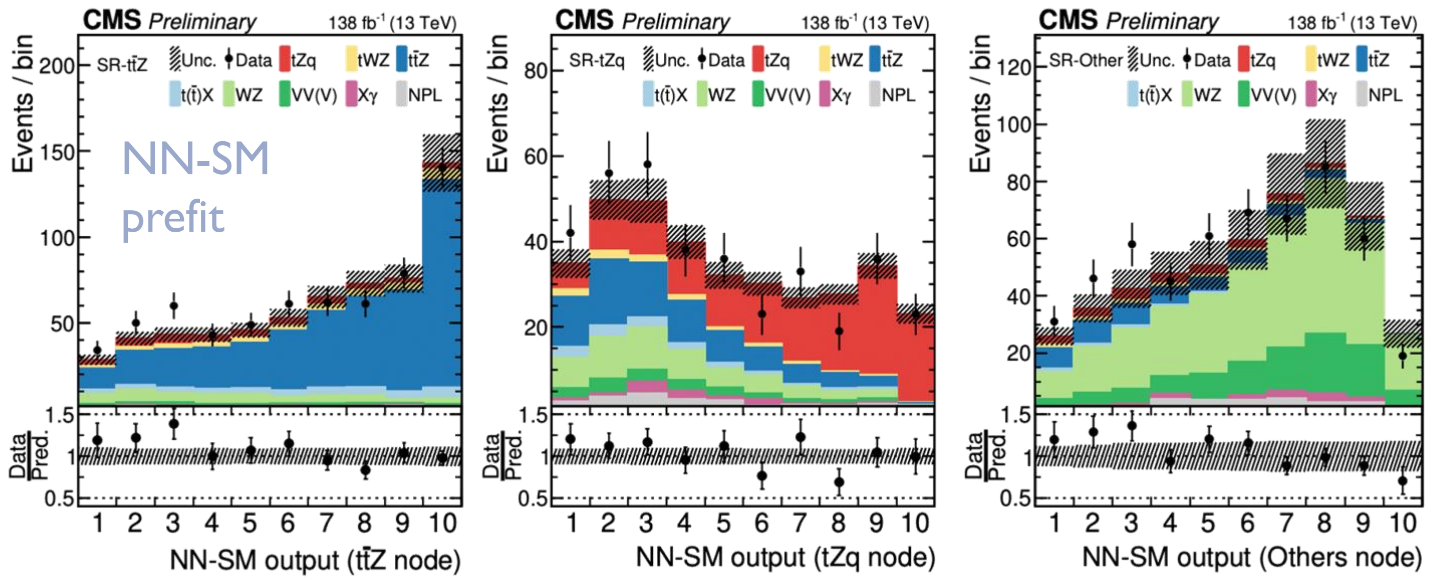
MVA topologies



MVA-EFT SEARCH IN ≥3L FINAL STATES

[CMS-TOP-21-001]

- Plots: Split according to max. value in the output node
  - Very good control of in SR-3l
- 5 MVAs for single-op inference
- Train separate SM vs. EFT MVAs
  - Trainings for tZq and ttZ
  - Single operator O_{tZ}, O_{tW}, $O^3_{\phi Q}$
    - Use for 1D limits
  - NN-5D training with all operators
  - Total of 8 MVAs for SM vs. EFT
- signal extraction with 1D, 2D, and 5D likelihood fit
- Systematics:
  - theory uncertainty and NP lepton systematics dominate



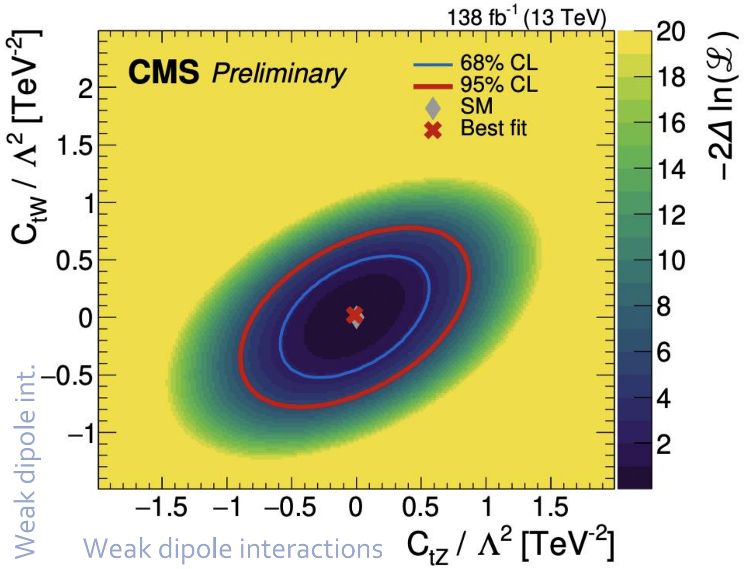
Fit configuration	SR-$t\bar{t}Z$	SR-tZq
1D c_{tZ}	NN-c_{tZ}-$t\bar{t}Z$	NN-c_{tZ}-tZq
1D c_{tW}	NN-c_{tW}-$t\bar{t}Z$	NN-c_{tW}-tZq
1D $c^3_{\varphi Q}$	NN-$c^3_{\varphi Q}$-$t\bar{t}Z$	NN-$c^3_{\varphi Q}$-tZq
1D $c^-_{\varphi Q}$	NN-SM ($t\bar{t}Z$ node)	NN-SM (tZq node)
1D $c_{\varphi t}$	NN-SM ($t\bar{t}Z$ node)	NN-SM (tZq node)
2D and 5D	NN-5D-$t\bar{t}Z$	NN-5D-tZq

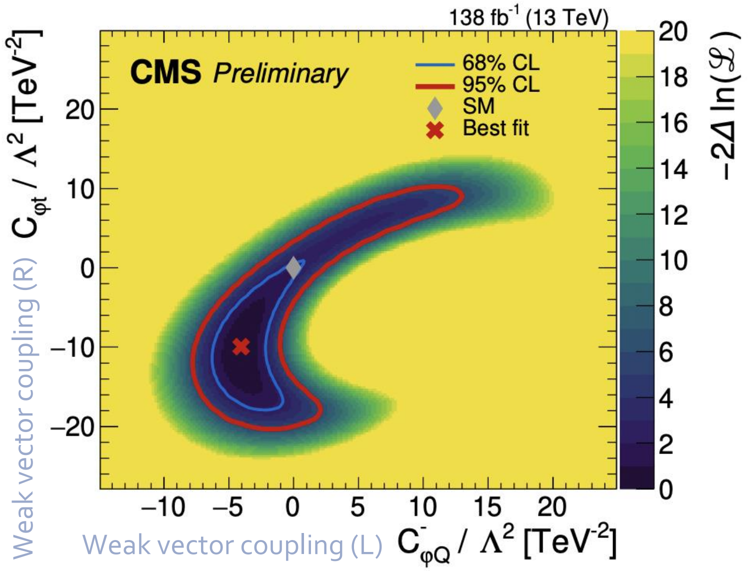
- Include M_T distribution in background node
- SR-ttZ-4l and WZ/ZZ CR as single-bin measurements

MVA-EFT SEARCH IN ≥3L FINAL STATES

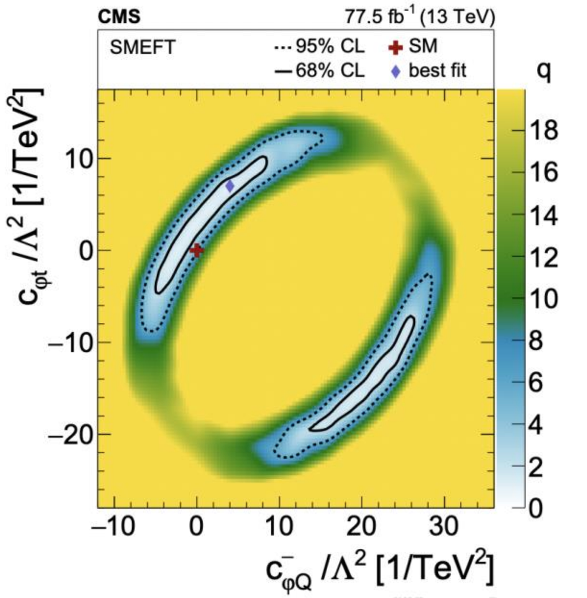
[CMS-TOP-21-001]

[CMS-TOP-18-009]





Compare to differential $p_T(Z)$ measurement with 77.5fb-1

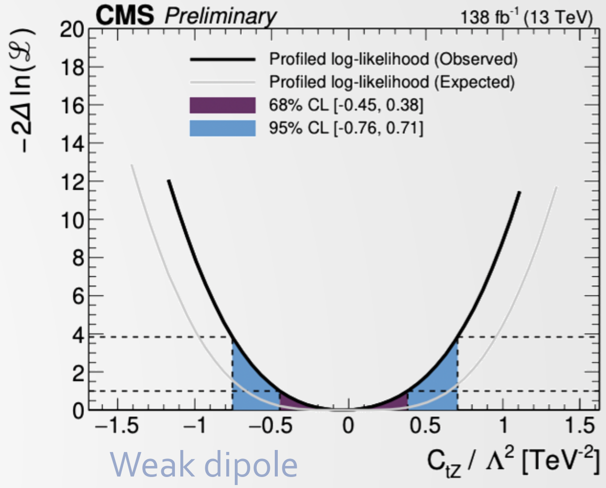


- Better limits than eariler results from the ttZ cross section measurement
- Agreement within 2σ in general

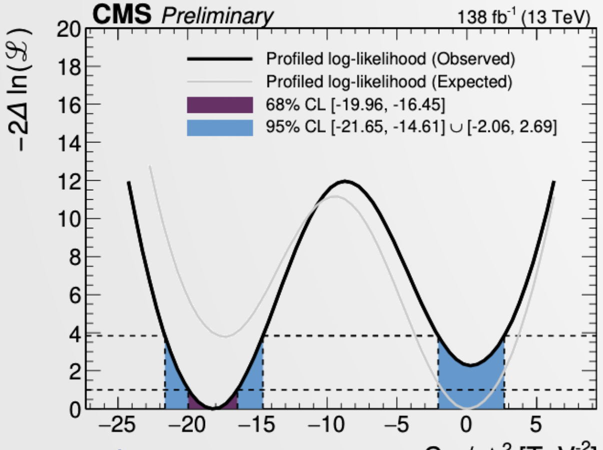
MVA-EFT SEARCH IN ≥3L FINAL STATES

[CMS-TOP-21-001]

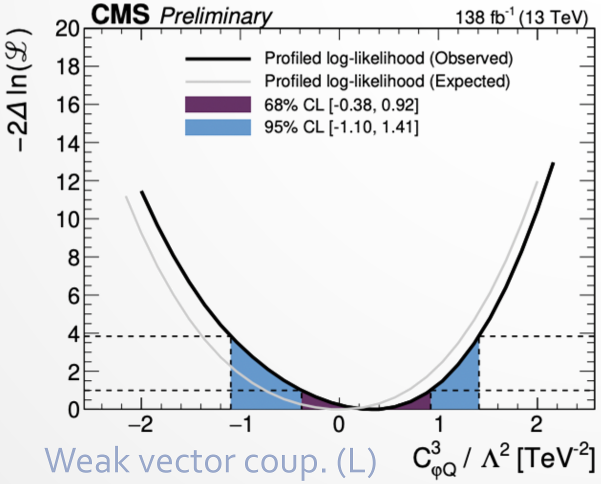
	Other WCs fixed to SM		5D fit	
	Expected	Observed	Expected	Observed
WC / Λ^2 [TeV^{-2}]	95% CL confidence intervals			
c_{tZ}	$[-0.97, 0.96]$	$[-0.76, 0.71]$	$[-1.24, 1.17]$	$[-0.85, 0.76]$
c_{tW}	$[-0.76, 0.74]$	$[-0.52, 0.52]$	$[-0.96, 0.93]$	$[-0.69, 0.70]$
$c^{3}_{\varphi Q}$	$[-1.39, 1.25]$	$[-1.10, 1.41]$	$[-1.91, 1.36]$	$[-1.26, 1.43]$
$c^{-}_{\varphi Q}$	$[-2.86, 2.33]$	$[-3.00, 2.29]$	$[-6.06, 14.09]$	$[-7.09, 14.76]$
$c_{\varphi t}$	$[-3.70, 3.71]$	$[-21.65, -14.61] \cup [-2.06, 2.69]$	$[-16.18, 10.46]$	$[-19.15, 10.34]$



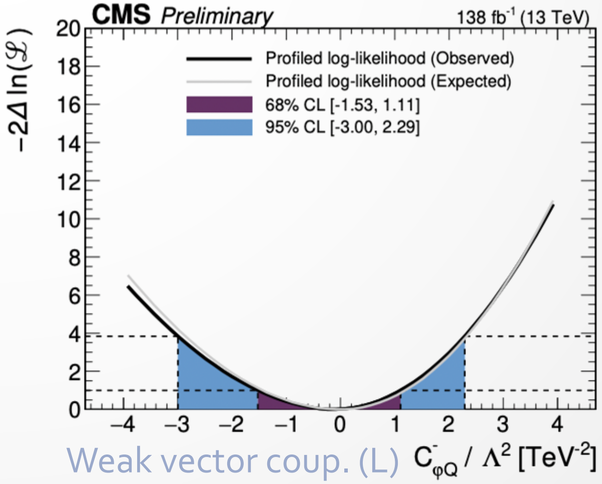
Weak dipole



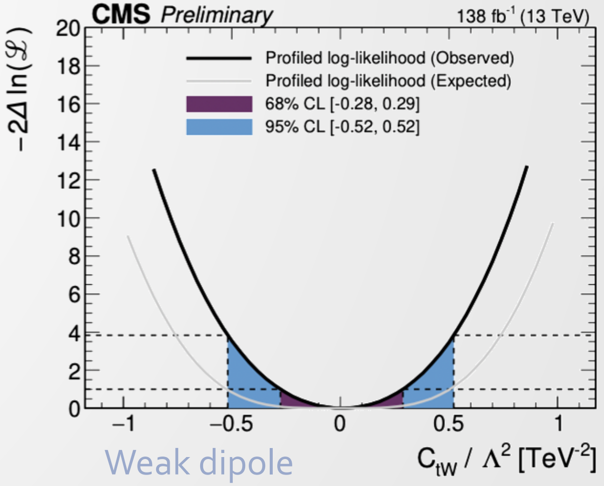
Weak vector coup. (R)



Weak vector coup. (L)



Weak vector coup. (L)

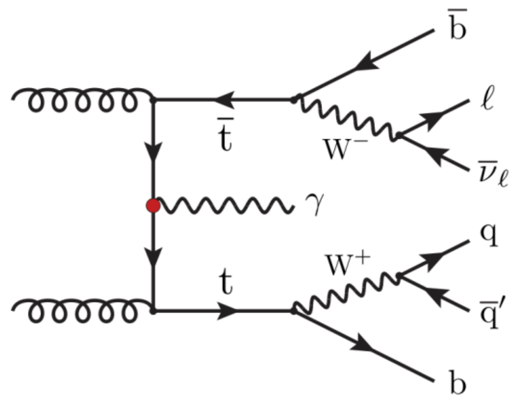


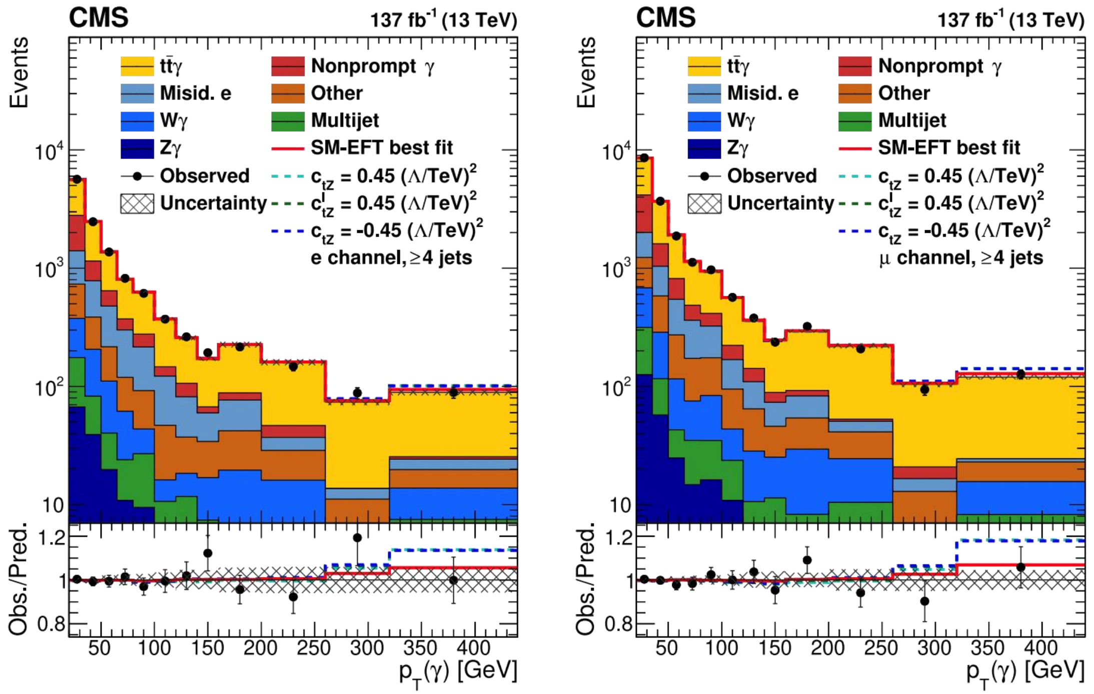
Weak dipole

TOP QUARK PAIRS WITH A PHOTON

[CMS-TOP-18-010]

- First CMS ttγ differential cross section measurement in th 1l channel
  - $N_b \geq 1$, $N_j = 3$, $N_j \geq 4$, Binned in lepton flavor
- Full Run II luminosity 137 fb^{-1}
- Details of the 112 CR: [D. Walter: top EWK couplings]
- Interpretation in c_{tZ} (weak dipole moment)
- SM gauge symmetry → linear relations among anomalous interactions



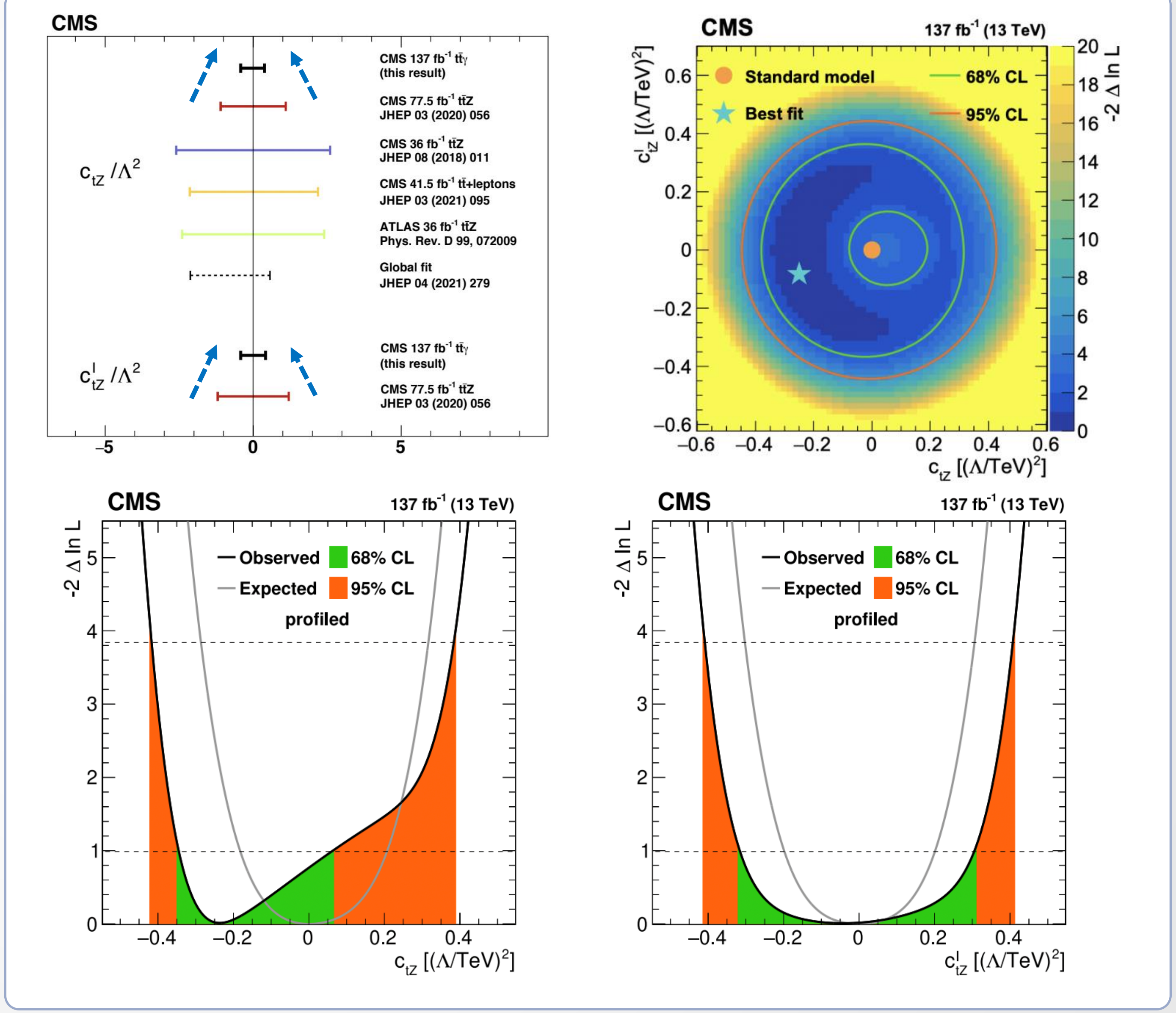


TT+ɣ DIFFERENTIAL CROSS SECTION

[CMS-TOP-18-010]

- Top dipole moments effect ttɣ stronger than ttZ (provided c_{tW} is small)
- Best current limits
- Measure real and imaginary part

		Wilson coefficient	68% CL interval $(\Lambda/\text{TeV})^2$	95% CL interval $(\Lambda/\text{TeV})^2$
Expected	c_{tZ}	$c^I_{tZ}=0$	$[-0.19, 0.21]$	$[-0.29, 0.32]$
		profiled	$[-0.19, 0.21]$	$[-0.29, 0.32]$
	c^I_{tZ}	$c_{tZ}=0$	$[-0.20, 0.20]$	$[-0.30, 0.31]$
		profiled	$[-0.20, 0.20]$	$[-0.30, 0.31]$
Observed	c_{tZ}	$c^I_{tZ}=0$	$[-0.35, -0.16]$	$[-0.42, 0.38]$
		profiled	$[-0.35, 0.07]$	$[-0.42, 0.39]$
	c^I_{tZ}	$c_{tZ}=0$	$[-0.35, -0.16], [0.17, 0.35]$	$[-0.42, 0.42]$
		profiled	$[-0.32, 0.31]$	$[-0.41, 0.41]$



SUMMARY

- Top quark final states have the power to constrain many SM-EFT effects, never tested before
- SM-EFT has become the leading theoretical toolkit for interpreting anomalous signals in precision experiments
- The sound theoretical footing allows for a globally consistent interpretation, with the prospect of benefitting from closely related fields

top quarks with additional leptons [CMS-TOP-19-001]
t/tt+Z in 3l with ML [CMS-TOP-21-001]
ttX differential cross section [CMS-TOP-18-010]

BACKUP

TOP QUARKS WITH ADDITIONAL LEPTONS

[CMS-TOP-19-001]

Operators involving two quarks and one or more bosons			
Operator	Definition	WC	Lead processes affected
$^{\ddagger}O_{u\varphi}^{(ij)}$	$\bar{q}_i u_j \tilde{\varphi}\,(\varphi^\dagger \varphi)$	$c_{t\varphi} + ic^I_{t\varphi}$	$t\bar{t}H$, tHq
$O_{\varphi q}^{1(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{q}_i \gamma^\mu q_j)$	$c^-_{\varphi Q} + c^3_{\varphi Q}$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$O_{\varphi q}^{3(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar{q}_i \gamma^\mu \tau^I q_j)$	$c^3_{\varphi Q}$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$O_{\varphi u}^{(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{u}_i \gamma^\mu u_j)$	$c_{\varphi t}$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$^{\ddagger}O_{\varphi ud}^{(ij)}$	$(\tilde{\varphi}^\dagger iD_\mu \varphi)(\bar{u}_i \gamma^\mu d_j)$	$c_{\varphi tb} + ic^I_{\varphi tb}$	$t\bar{t}H$, $tl\bar{l}q$, tHq
$^{\ddagger}O_{uW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I u_j)\,\tilde{\varphi} W^I_{\mu\nu}$	$c_{tW} + ic^I_{tW}$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$^{\ddagger}O_{dW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I d_j)\,\varphi W^I_{\mu\nu}$	$c_{bW} + ic^I_{bW}$	$t\bar{t}H$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$^{\ddagger}O_{uB}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} u_j)\,\tilde{\varphi} B_{\mu\nu}$	$(c_W c_{tW} - c_{tZ})/s_W +$ $i(c_W c^I_{tW} - c^I_{tZ})/s_W$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$
$^{\ddagger}O_{uG}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} T^A u_j)\,\tilde{\varphi} G^A_{\mu\nu}$	$g_s(c_{tG} + ic^I_{tG})$	$t\bar{t}H$, $t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, tHq, $tl\bar{l}q$

Operators involving two quarks and two leptons			
Operator	Definition	WC	Lead processes affected
$O_{\ell q}^{1(ijkl)}$	$(\bar{\ell}_i \gamma^\mu \ell_j)(\bar{q}_k \gamma^\mu q_\ell)$	$c^{-(\ell)}_{Q\ell} + c^{3(\ell)}_{Q\ell}$	$t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$O_{\ell q}^{3(ijkl)}$	$(\bar{\ell}_i \gamma^\mu \tau^I \ell_j)(\bar{q}_k \gamma^\mu \tau^I q_\ell)$	$c^{3(\ell)}_{Q\ell}$	$t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$
$O_{\ell u}^{(ijkl)}$	$(\bar{\ell}_i \gamma^\mu \ell_j)(\bar{u}_k \gamma^\mu u_\ell)$	$c^{(\ell)}_{t\ell}$	$t\bar{t}l\bar{l}$
$O_{eq}^{(ijkl)}$	$(\bar{e}_i \gamma^\mu e_j)(\bar{q}_k \gamma^\mu q_\ell)$	$c^{(\ell)}_{Qe}$	$t\bar{t}l\bar{l}$, $tl\bar{l}q$
$O_{eu}^{(ijkl)}$	$(\bar{e}_i \gamma^\mu e_j)(\bar{u}_k \gamma^\mu u_\ell)$	$c^{(\ell)}_{te}$	$t\bar{t}l\bar{l}$
$^{\ddagger}O_{\ell equ}^{1(ijkl)}$	$(\bar{\ell}_i e_j)\,\varepsilon\,(\bar{q}_k u_\ell)$	$c^{S(\ell)}_t + ic^{SI(\ell)}_t$	$t\bar{t}l\bar{l}$, $tl\bar{l}q$
$^{\ddagger}O_{\ell equ}^{3(ijkl)}$	$(\bar{\ell}_i \sigma^{\mu\nu} e_j)\,\varepsilon\,(\bar{q}_k \sigma_{\mu\nu} u_\ell)$	$c^{T(\ell)}_t + ic^{TI(\ell)}_t$	$t\bar{t}l\nu$, $t\bar{t}l\bar{l}$, $tl\bar{l}q$

EFT SEARCH IN MULTILEPTON FINAL STATES

[CMS-TOP-21-001]

Variable	NN-SM	NN-c_{tZ}-tZq	NN-c_{tZ}-t$\bar{t}$Z	NN-c_{tW}-tZq	NN-c_{tW}-t$\bar{t}$Z	NN-$c^{3}_{\varphi Q}$-tZq	NN-$c^{3}_{\varphi Q}$-t$\bar{t}$Z	NN-5D-tZq	NN-5D-t$\bar{t}$Z
p_{T}^{Z}	—	✓	✓	✓	✓	✓	✓	✓	✓
$\eta(Z)$	✓	✓	✓	—	—	✓	—	—	✓
$\Delta\phi(\ell_1^Z \ell_2^Z)$	✓	✓	✓	✓	✓	✓	✓	✓	✓
$p_T(t)$	✓	✓	✓	—	✓	✓	—	✓	✓
$\eta(t)$	—	✓	✓	✓	✓	✓	—	—	✓
$m(t, Z)$	—	—	—	—	—	—	—	—	—
$\lvert\eta(j')\rvert$	✓	—	—	—	—	—	—	✓	—
$p_T(j')$	✓	✓	—	✓	—	—	—	—	—
$\Delta R(b, \ell_t)$	—	✓	—	✓	—	—	—	—	—
$\Delta R(j', \ell_t)$	✓	—	—	—	—	—	—	—	—
$\Delta R(t, Z)$	—	✓	✓	✓	—	✓	—	—	✓
$\Delta\eta(Z, j')$	—	✓	—	—	—	—	—	✓	—
ΔR between t and the closest lepton	—	✓	—	✓	—	—	—	—	—
ΔR between j' and the closest lepton	—	—	—	—	—	—	—	✓	—
$m_{3\ell}$	✓	—	—	—	✓	—	✓	—	✓
m_T^W	✓	✓	✓	—	—	—	—	—	✓
p_T^{miss}	✓	—	—	—	—	—	—	—	—
Lepton asymmetry	✓	—	—	✓	✓	—	—	✓	—
$\cos\theta^{\star}_{Z}$	—	—	✓	—	—	✓	—	—	✓
Max. p_T among jet pairs	—	—	—	—	—	—	✓	—	✓
Max. DEEPJET discriminant	✓	—	—	—	—	—	—	—	—
b jet multiplicity	✓	—	—	—	—	—	—	—	—
Three-momenta of the three leading leptons	✓	—	—	—	—	—	—	—	—
Three-momenta of the three leading jets	✓	—	—	—	—	—	—	—	—
DEEPJET discriminants of the three leading jets	✓	—	—	—	—	—	—	—	—
Number of variables	33	11	8	8	6	7	4	7	10

SYSTEMATICS – 3L ML

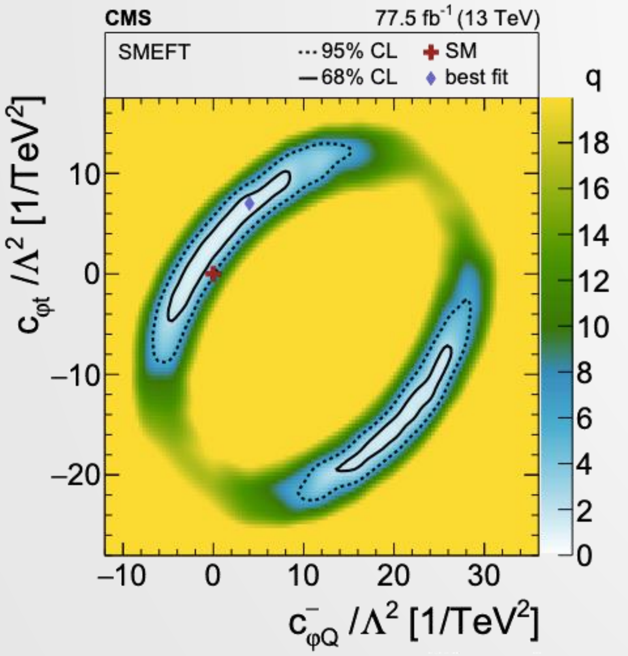
[CMS-TOP-21-001]

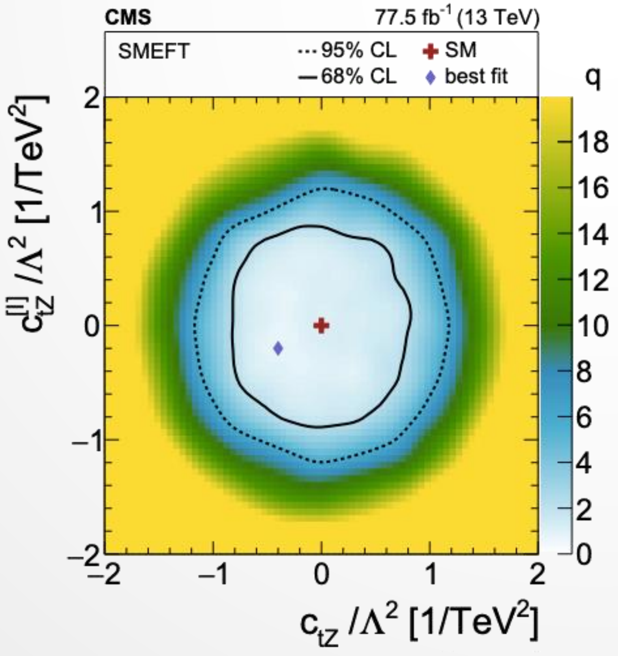
Source	c_{tZ}	c_{tW}	$c^{3}_{\varphi Q}$	$c^{-}_{\varphi Q}$	$c_{\varphi t}$
tZq normalization	<0.1	<0.1	1.2	0.1	0.8
$t\bar{t}Z$ normalization	0.6	<0.1	0.4	37.2	38
tWZ normalization	0.1	0.1	<0.1	0.7	2.1
Background normalizations	<0.1	<0.1	6.9	3.6	6.8
NPL background estimation	1.4	0.2	5.6	0.3	3.8
Jet energy scale	<0.1	<0.1	0.8	0.7	2.3
Jet energy resolution	<0.1	<0.1	<0.1	<0.1	1.4
p_{T}^{miss}	<0.1	<0.1	<0.1	<0.1	0.2
b tagging	<0.1	<0.1	0.9	2.0	0.3
Other (experimental)	<0.1	<0.1	1.6	0.8	0.6
Lepton identification and isolation	0.4	0.4	1.2	2.2	0.8
Theory	2.1	1.1	0.4	0.9	0.9

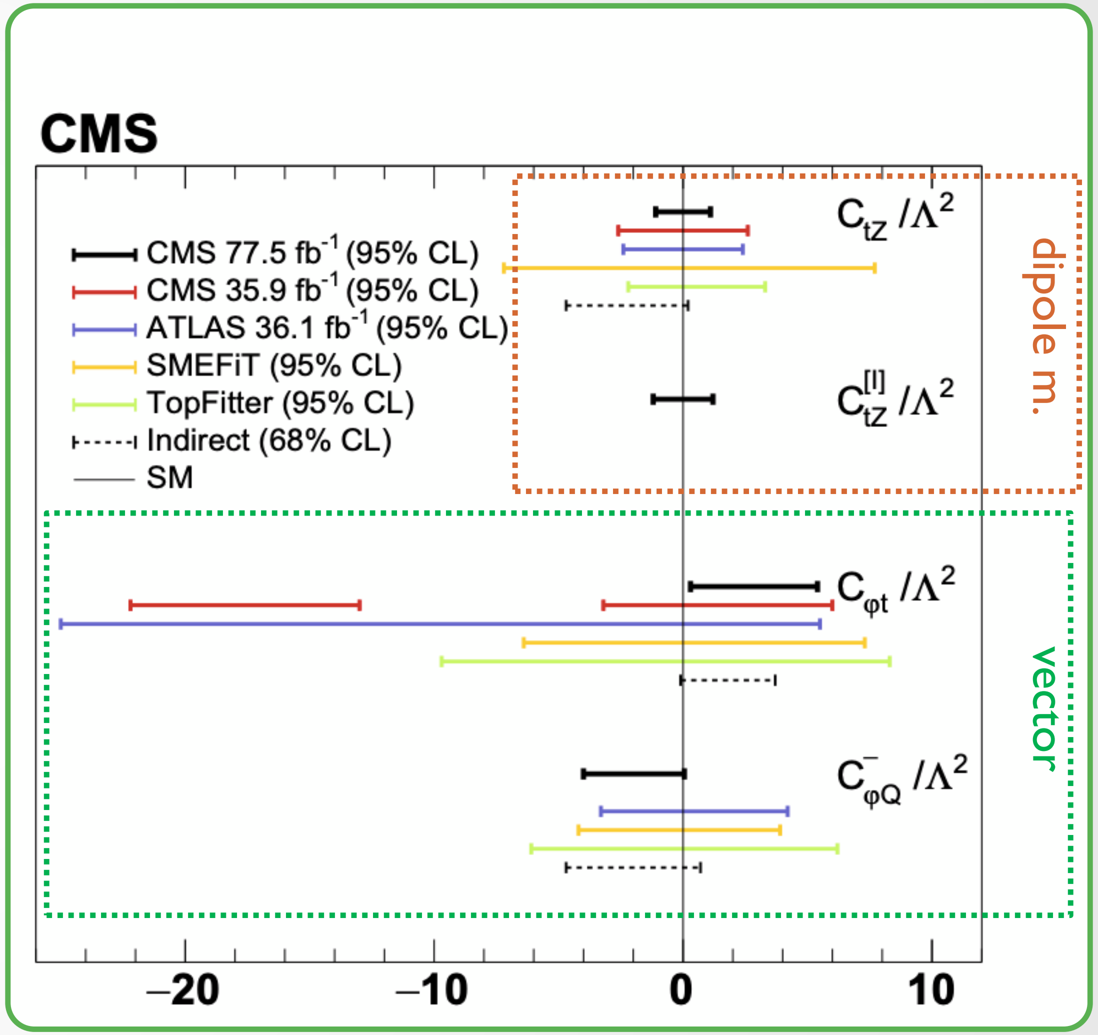
ELECTROWEAK TOP QUARK COUPLINGS

JHEP 03 (2020) 056

- vector-type couplings have large SM interference
- EFT tensor structure induces EWK dipole moments (quadratic)
- ~~most~~ stringent direct constraints on the top-Z vector coupling and the EWK dipole moments
  - differential measurement improves sensitivity by factor ~5





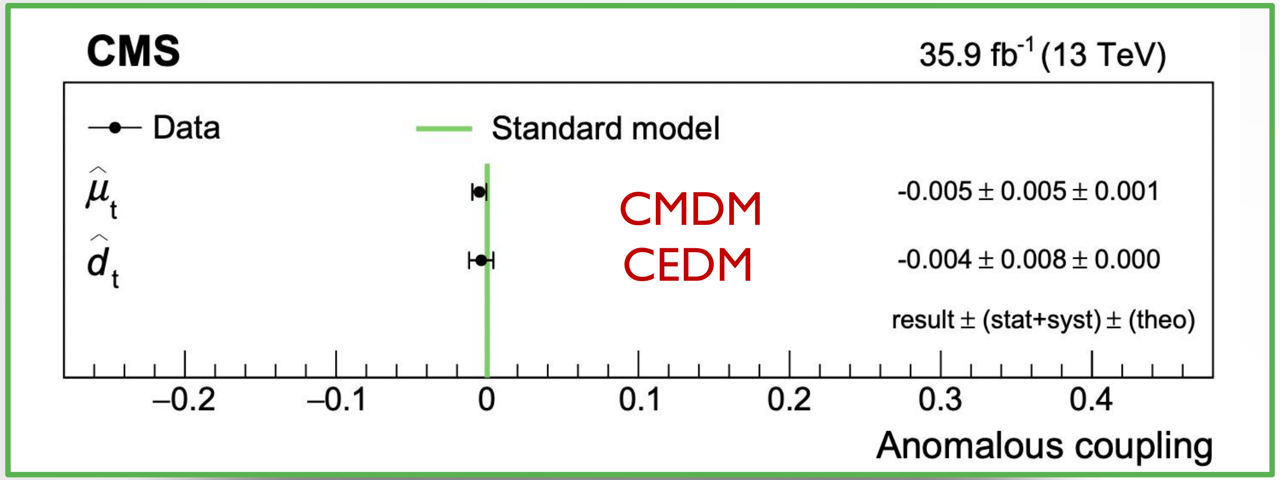


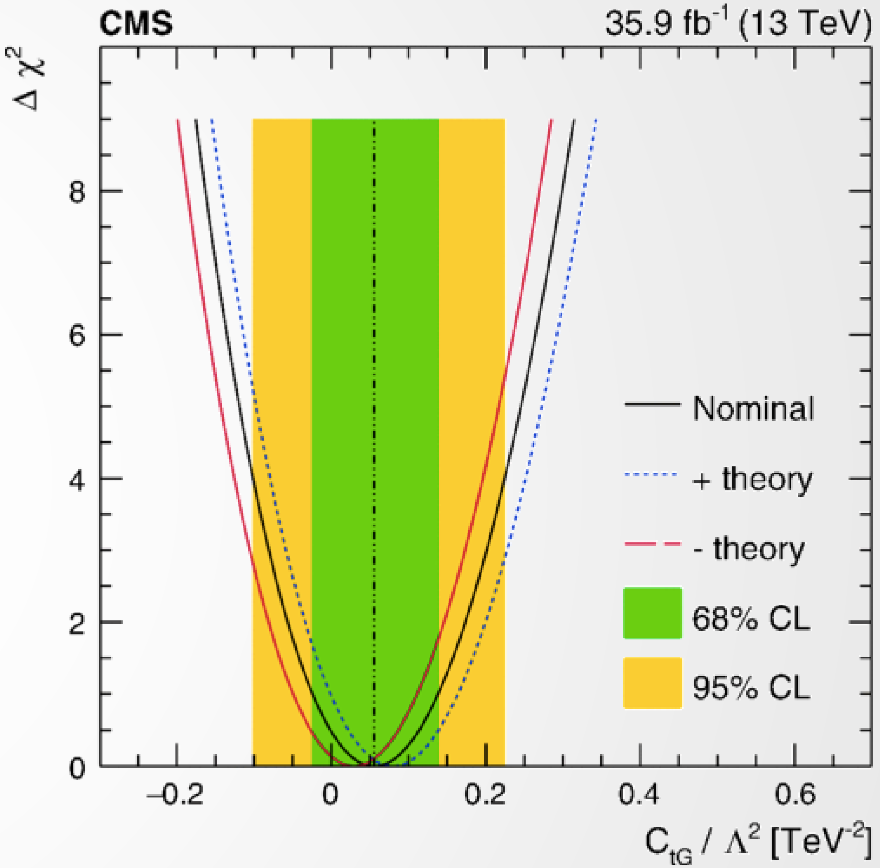
- Indirect limits: LEP Z pole, $B \to X_s \gamma$
- Z and γ coupling related by gauge symmetry

CHROMOMAGNETIC DIPOLE MOMENT

Phys. Rev. D 100, 072002 (2019)

EPJC 80(2020)754





- Constrain the top chromo-magnetic & electric dipole moment

$$\mathcal{O}_{tG} = i(\bar{q}_L \sigma^{\mu\nu} \lambda^a t_R)\tilde{\phi} G^a_{\mu\nu} + \text{h.c.}$$

  - 2HDM, SUSY, technicolor, compositeness $C_{tG}/\Lambda^2 = \mu_t/(2m_t^2)$
  - currently best limit: $-0.10 < C_{tG}/\Lambda^2 < 0.22$ TeV^{-2}

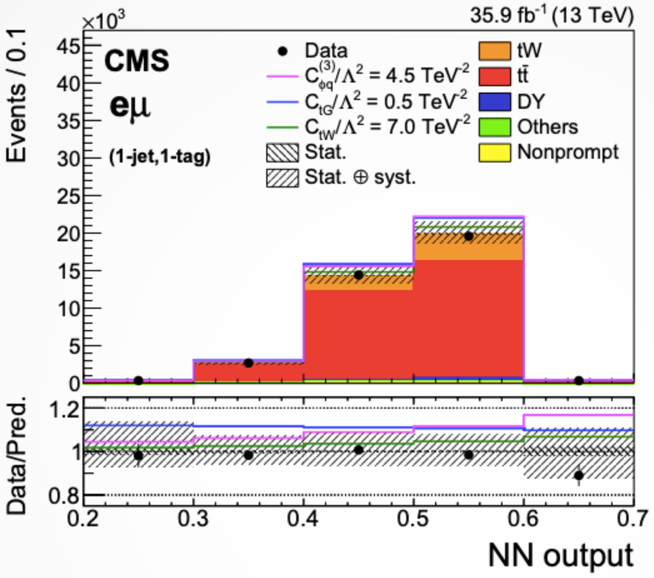
CONSTRAINING SM-EFT WITH TTBAR

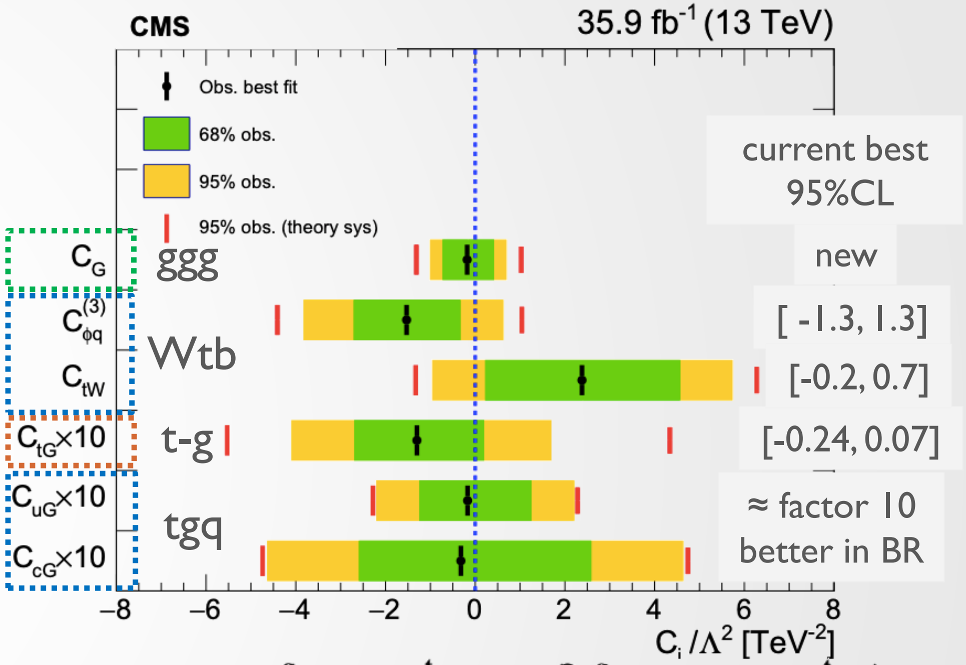
Eur. Phys. J. C 79 (2019) 886

- using the dilepton channel, directly constrain EFT with tW and tt̄ final states

Single Top (tW)	tt̄
Single Top (tW) + tt̄	

- split in e/**μ** lepton flavor
  - tt̄ ≥ 2 jets (≥ 2 b jets)
  - tW: 1-2 jets (0-1 b jet).





- test separately 6 Wilson coeff:
  - Wtb vertex, top-gluon coupling, 3g vertex, FCNC couplings

$$O^{(3)}_{\phi q} = (\phi^+\tau^I D_\mu \phi)(\bar{q}\gamma^\mu \tau^I q),$$

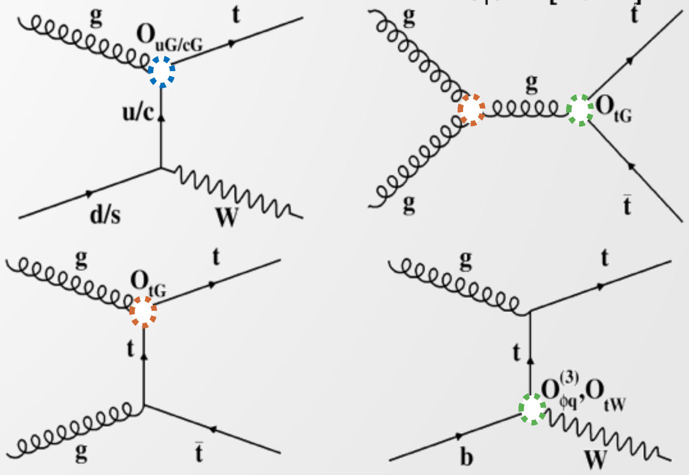
$$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W^I_{\mu\nu},$$

$$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi}G^A_{\mu\nu},$$

$$O_G = f_{ABC}G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho,$$

$$O_{u(c)G} = (\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi}G^A_{\mu\nu},$$

- Signal extraction via per-channel neural networks
- first attempt of a global analysis at CMS



TOP QUARKS WITH ADDITIONAL LEPTONS

[CMS-TOP-19-001]