Recent CMS results on Top quark physics

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On behalf of CMS collaborations

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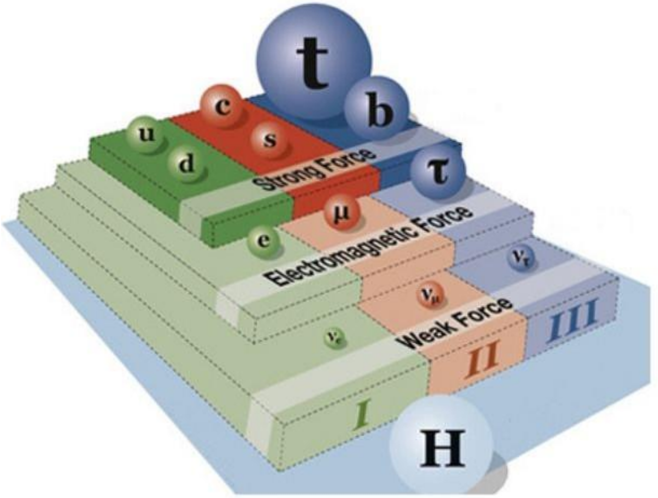
top-quark

The top has several features that make it a very interesting particle:



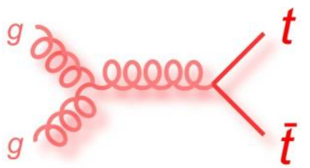
- ✓ Heaviest particle discovered till now
  - -- $m^t = 173.34 \pm 0.27(\text{stat}) \pm 0.71(\text{syst})$ GeV
- ✓ Decays before hadronization
  - -- Give access to the physics of a "free" quark
- ✓ Intensively couples to the Higgs boson

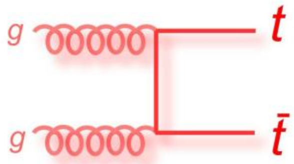
The LHC is a top factory and allows:

Over 200M top quark pairs in LHC Run II 13 TeV data

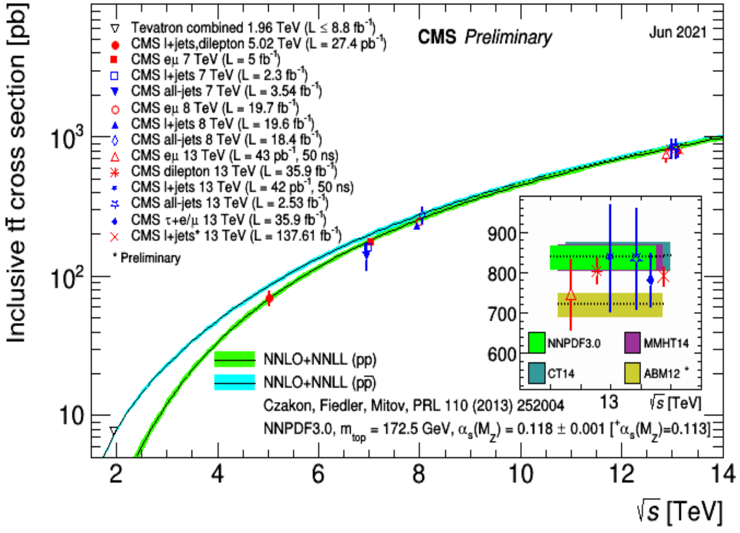
- ✓ Precise measurements of top pairs and single top production
- ✓ Observation of rare processes involving top
- ✓ Use the top quark as a "tool" to study the SM

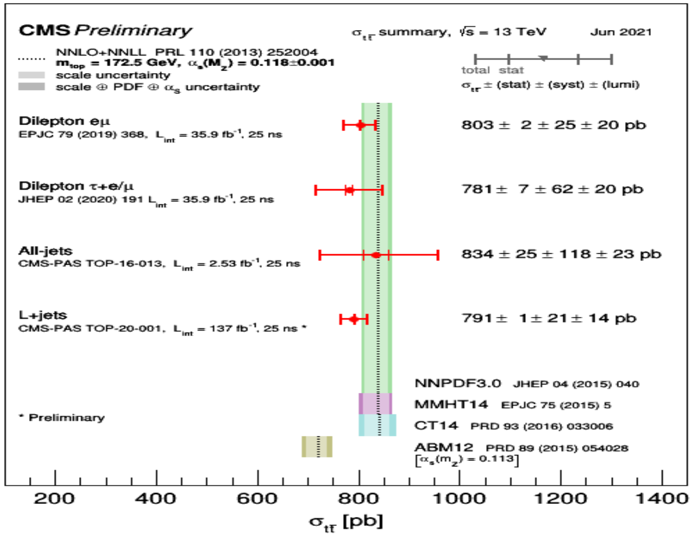
$t\bar{t}$ cross-section





- ✓ Provide a stringent test of our level of understanding of QCD
- ✓ Allow to extract several SM parameters: α_S, m^{top}
- ✓ Allow to improve the description of parton distribution functions

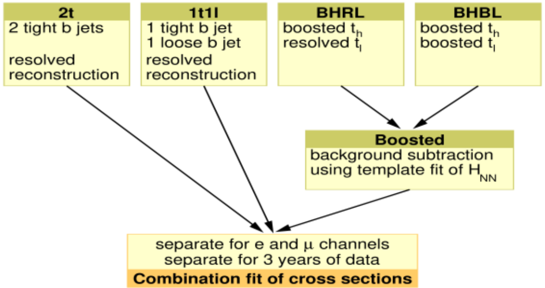


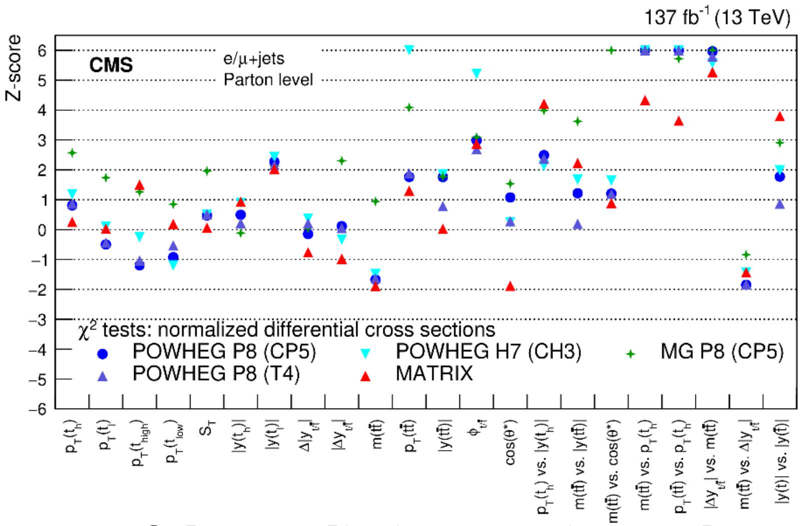


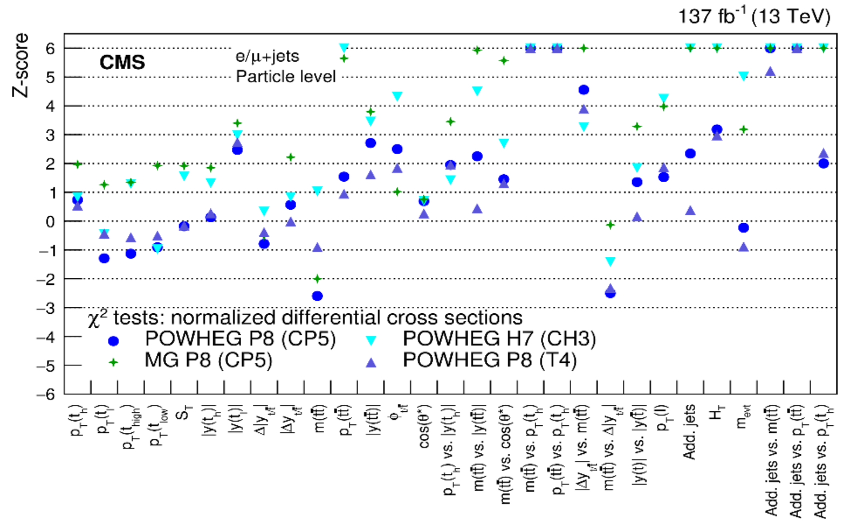
Differential and double-differential σ($t\bar{t}$) in lepton + jets   arXiv:2108.02803

- ✓ High precision measurement of differential and double-differential cross sections
- ✓ For the first time the full spectra of differential cross sections are determined

-- combine of resolved and boosted $t\bar{t}$ topologies







Most of the predictions are in good agreement with the measurement, except:

- ➢ M($t\bar{t}$) vs. pT(th) and pT($t\bar{t}$) vs. pT(th) shows largest disagreements.
- ➢ At particle level add. jets vs. kinematic observable are difficult to describe by NLO.

Inclusive cross section: **791 ± 1 (stat.) ± 21 (syst.) ± 14 (lumi.) pb**

- ✓ most precise measurement in lepton + jets channel
- ✓ Dominanted by: JES and b-tagging

$t\bar{t}c\bar{c}/b\bar{b}$ and $t\bar{t}jj$ production

PLB 820 (2021) 136565

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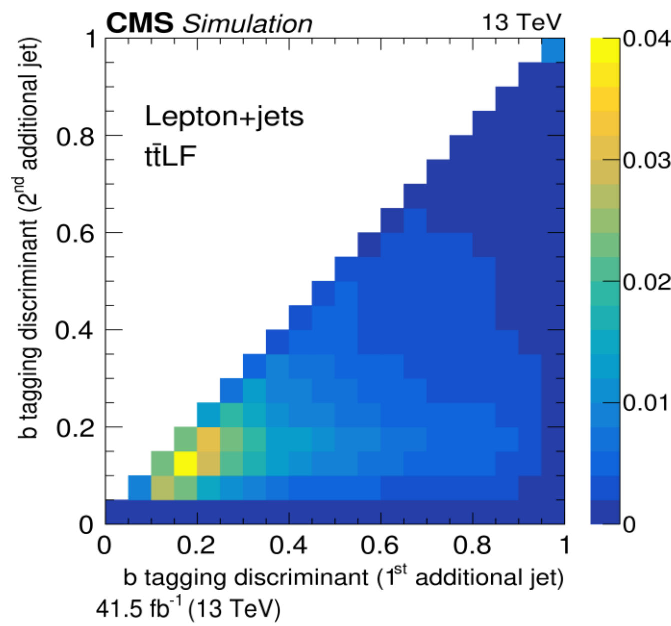
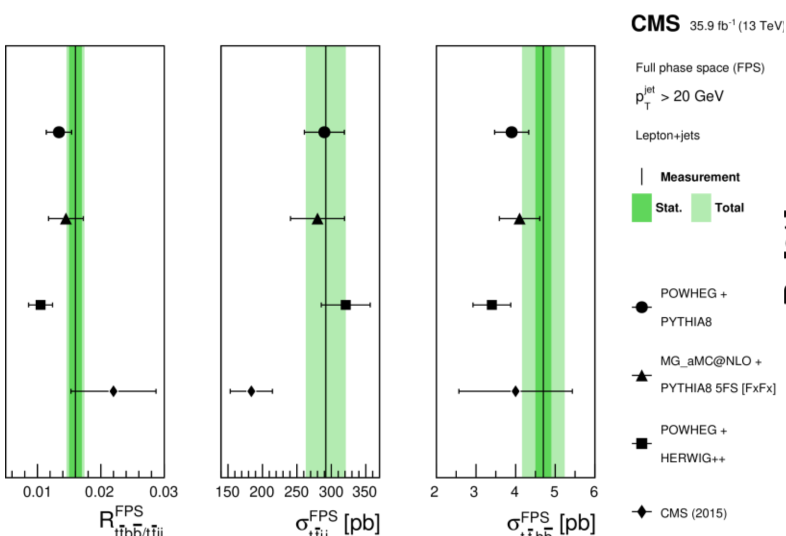
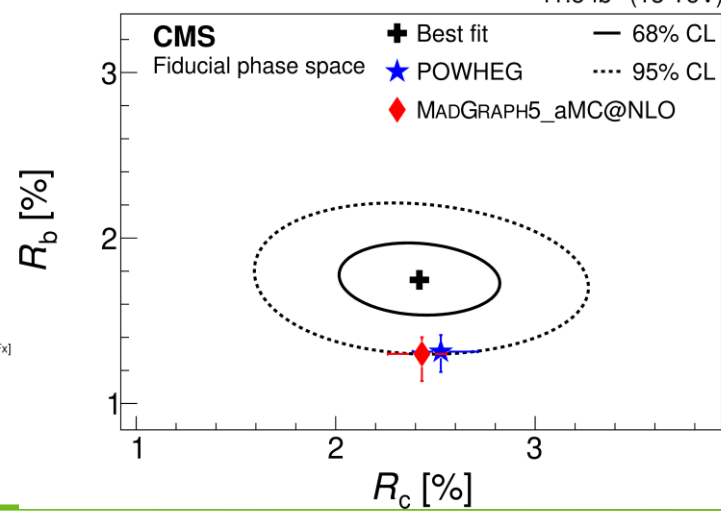
- Test the state-of-art predictions at NLO
- Irreducible background to ttH, $H \rightarrow bb$
- $\boldsymbol{ttb\bar{b}}$ and $\boldsymbol{ttj\bar{j}}$ measurement
  - $\sigma_{t\bar{t}bb}$ and $\sigma_{t\bar{t}bb}/\sigma_{t\bar{t}jj}$ extracted simultaneously from a 2D discriminant
  - PowhegPythia8 and MG_aMC@NLO+Pythia8 provide the best description



- **First** measurement of $\boldsymbol{tt\bar{c}c}$ production
  - Simultaneous extraction of $\sigma_{t\bar{t}bb}$, $\sigma_{tt\bar{c}c}$ and $\sigma_{tt\bar{L}L}$ using a template fit procedure



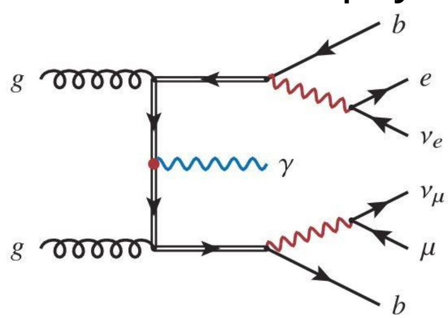


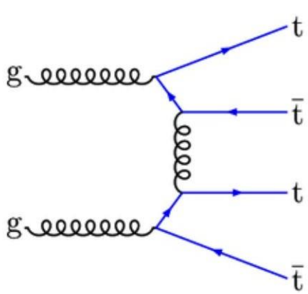
Precision dominated by : MC modelling, JES, c-tagging

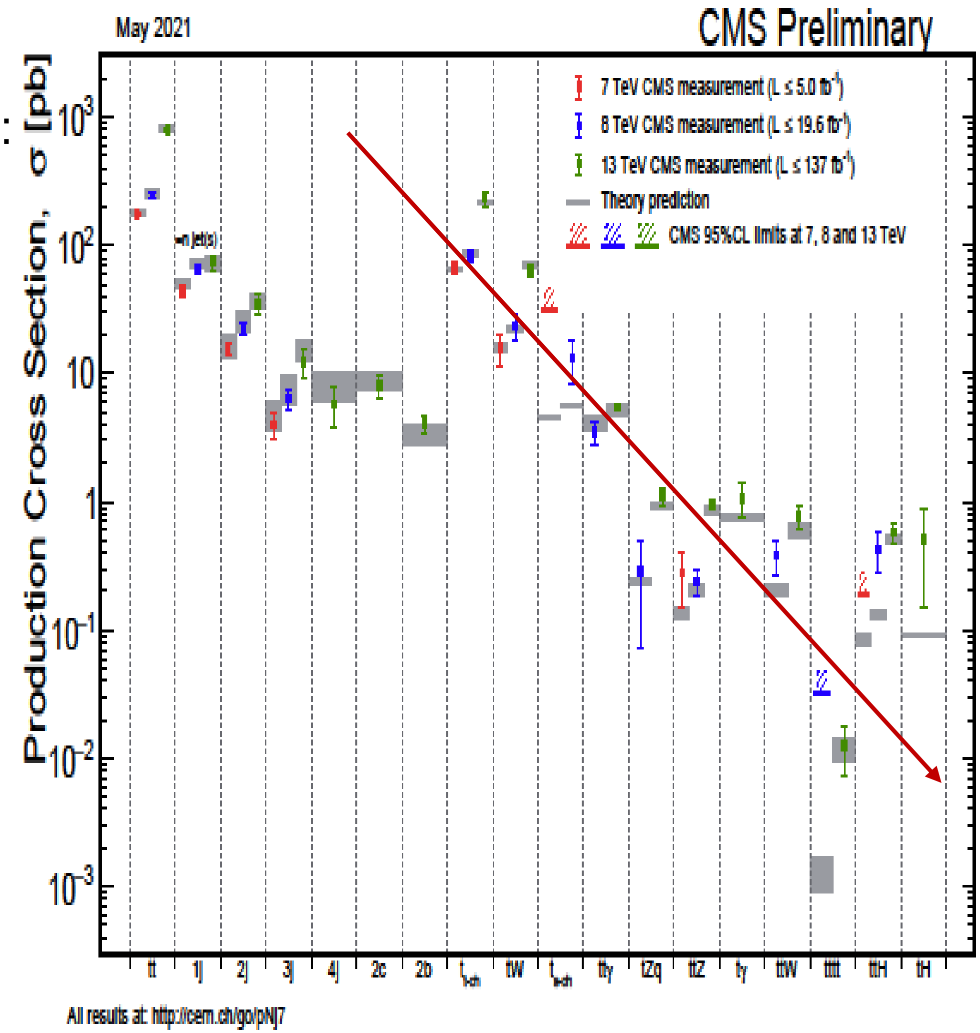
Rare processes

Precise measurement of t($\bar{t}$)+X production:

- ✓ Provide a stringent test also of electroweak processes
- ✓ Access to several coupling (tγ,tW,tH) sensitive to new physics effects

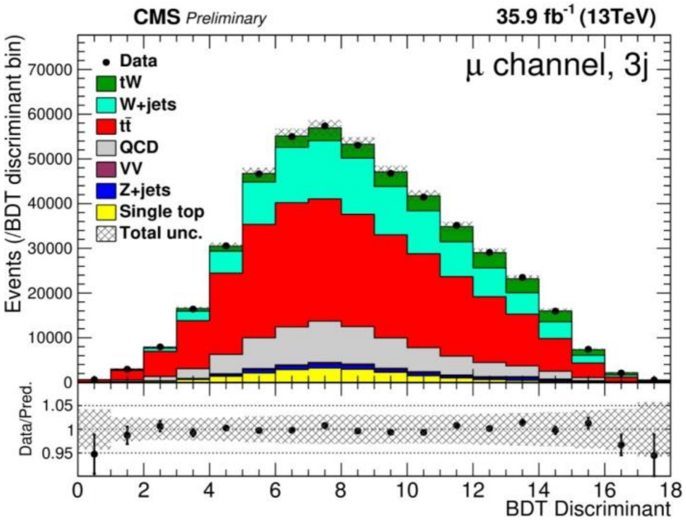






tW production in ℓ+jets

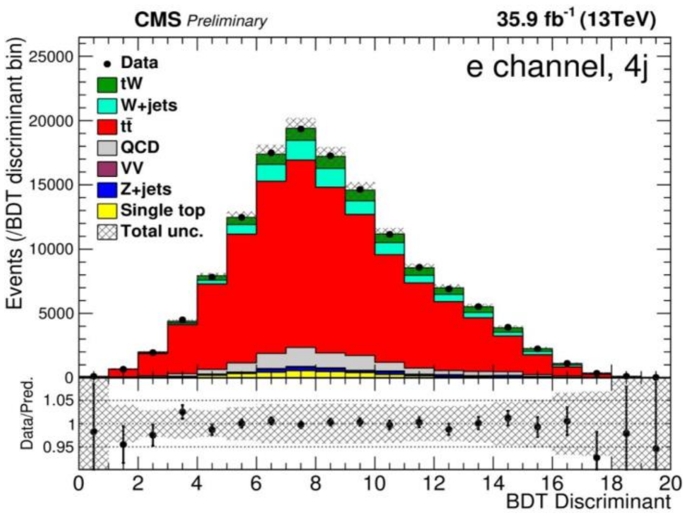
- Categories based on jet multiplicity and 1 b-tagged jet: 2J1T (W+Jets). **3J1T** (tw Signal region) and 4J1T (ttbar)
- Data-driven background



- ✓ One BDT is trained per lepton flavor in signal (3J1T) region and evaluation in all regions
- ✓ Simultaneous ML fit performed in all categories using BDT discriminants
- ✓ Dominant uncertainty: Background estimation, JES and modeling

Measured (expected) signal strength:

μ = 1.24 ± 0.18 (1.00 ± 0.17)



Cross section:

σ_{tW} = 89 ± 4 (stat.) ± 12 (syst.) pb

$\sigma_{SM} = 72 \pm 4$ pb

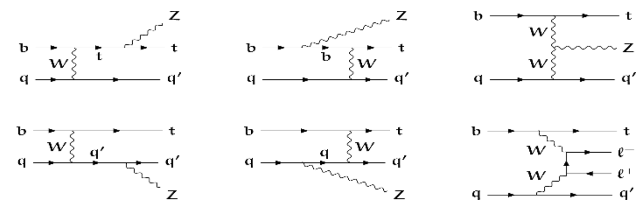
- ✓ Observed (expected) significance is 7.4 (6.8) standard deviations

First observation of tW production in ℓ+jets

Inclusive and differential tZq

CMS-PAS-TOP-20-010

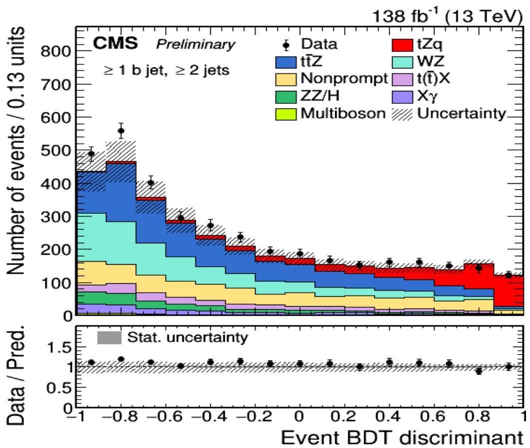
- ✓ Full run2 dataset
- ✓ 3 leptons with improved lepton MVA
- ✓ constraining nonprompt background
- ✓ multiclass NN or BDT



Inclusive tZq cross-section:

$$\sigma_{tZq} = 87.9\ ^{+7.5}_{-7.3}\ (\text{stat})\ ^{+7.3}_{-6.0}\ (\text{syst})\ \text{fb}\ .$$

Improvement 30% w.r.t.earlier measurements



Partial tZq cross-sections:

$$\sigma_{tZq(\ell_t^+)} = 62.2\ ^{+5.9}_{-5.7}\ (\text{stat})\ ^{+4.4}_{-3.7}\ (\text{syst})\ \text{fb}\ ,$$

$$\sigma_{\bar{t}Zq(\ell_t^-)} = 26.1\ ^{+4.8}_{-4.6}\ (\text{stat})\ ^{+3.0}_{-2.8}\ (\text{syst})\ \text{fb}\ ,$$

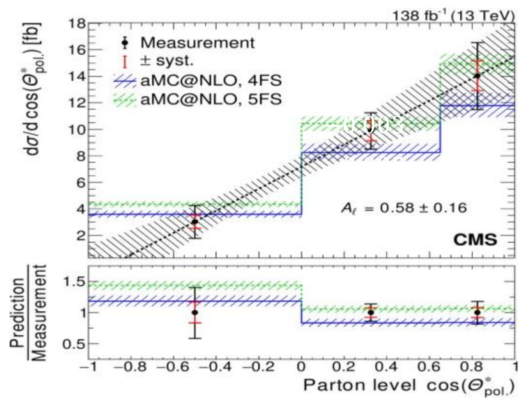
$$R = 2.37\ ^{+0.56}_{-0.42}\ (\text{stat})\ ^{+0.27}_{-0.13}\ (\text{syst})\ .$$

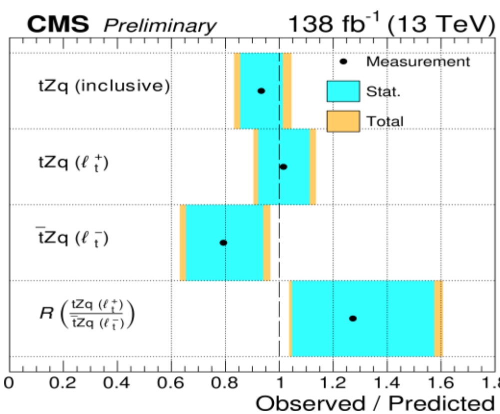
First time!

Spin asymmetry:

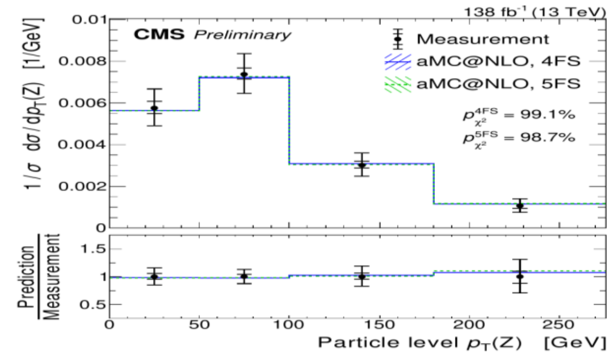
$$A_\ell = 0.58\ ^{+0.15}_{-0.16}\ (\text{stat})\ \pm 0.06\ (\text{syst})\ .$$

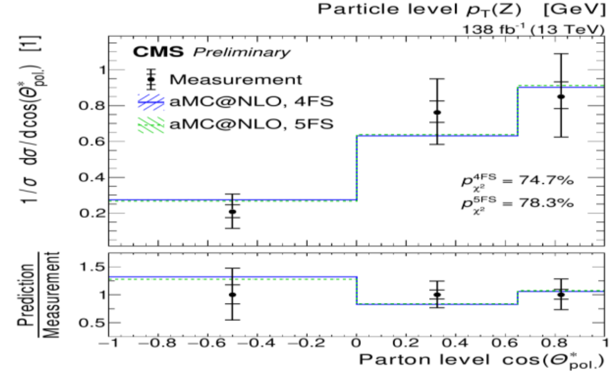
Agreement with SM prediction:





Differential tZq cross-section:





In general, observe good agreement between measurement and prediction.

Rare top production: $t\bar{t}V$

arXiv: 2107.01508

$t\bar{t}Z$ production

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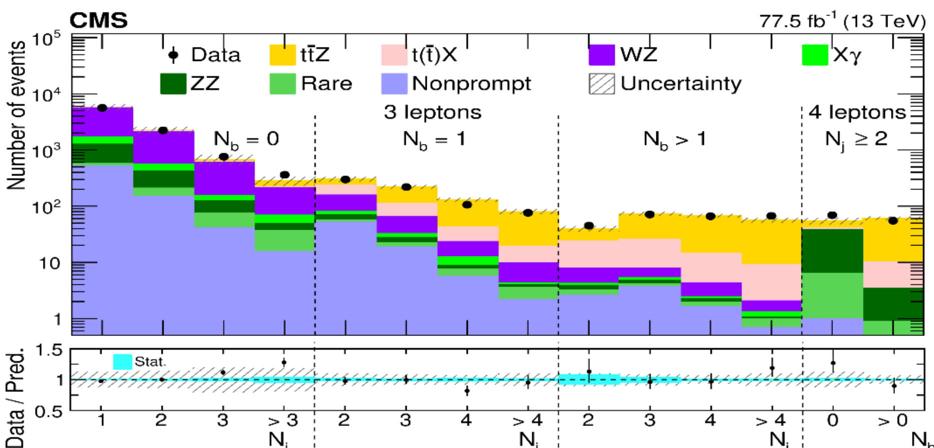
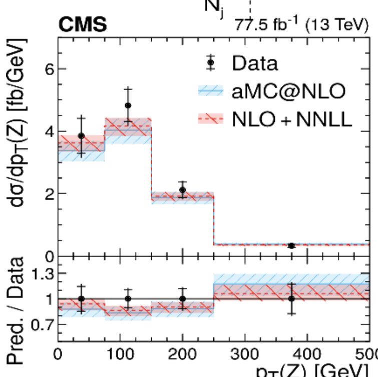
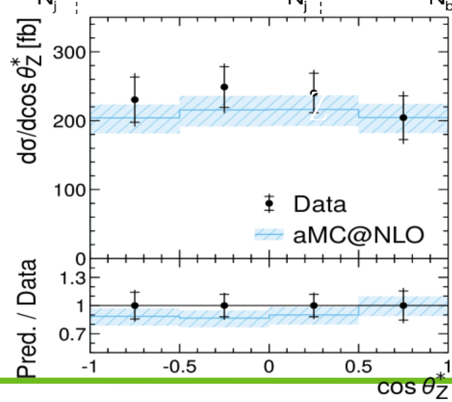
- Targets 3 or 4 isolated lepton channel with Z to l^+l^-
- Inclusive cross section already systematic limited

$$\sigma(t\bar{t}Z) = 0.95 \pm 0.05\ (\text{stat}) \pm 0.06\ (\text{syst})\ \text{pb}$$

- Dominated by signal/background MC modelling
- Differential cross sections are measured fist time

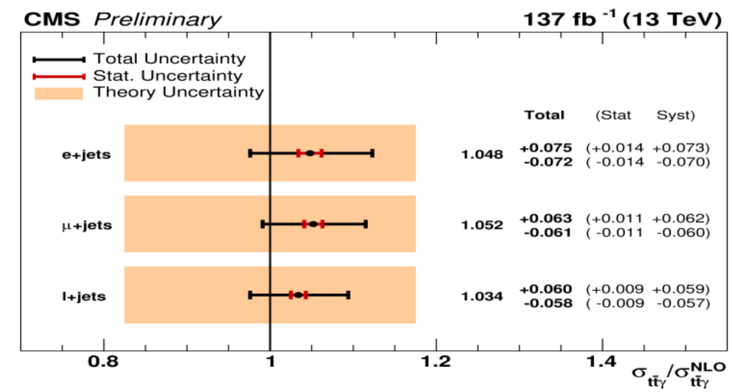


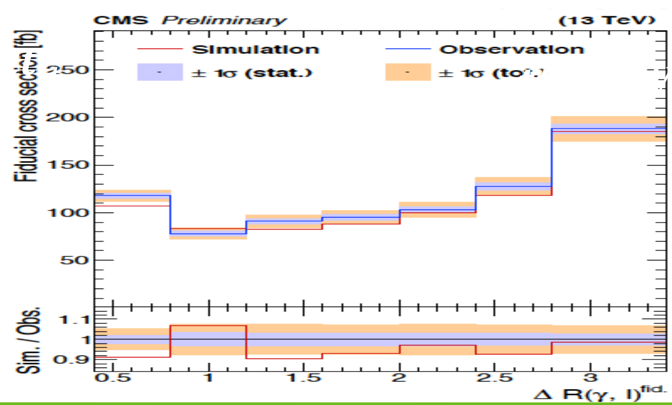




$t\bar{t}\gamma$ production

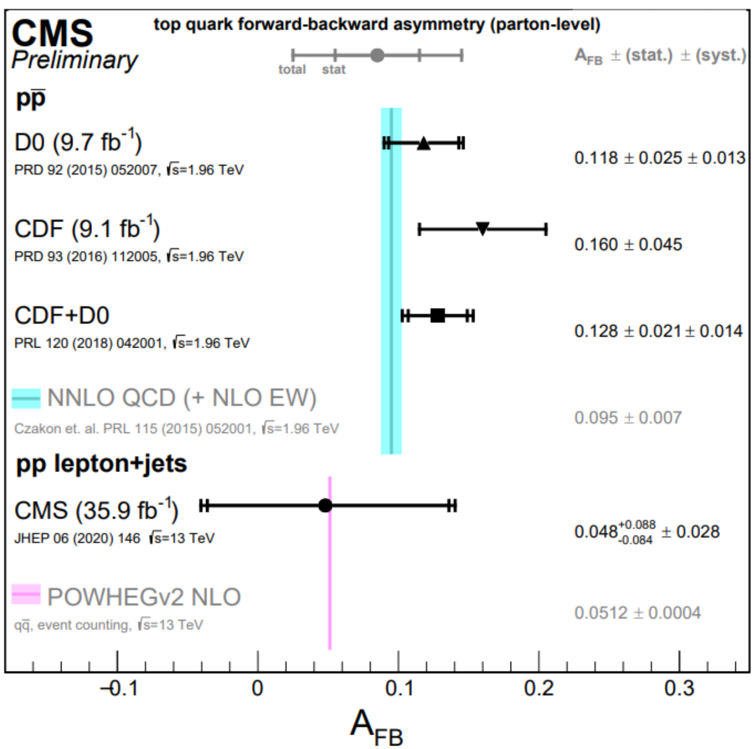
- ✓ Measured in lepton+jets channel
  800 ± 46 (syst) ± 7 (stat) fb,
- ✓ Precision limited by MC modelling
- ✓ Differential cross sections measured in several kinematic observables
- ✓ Good agreement with SM prediction

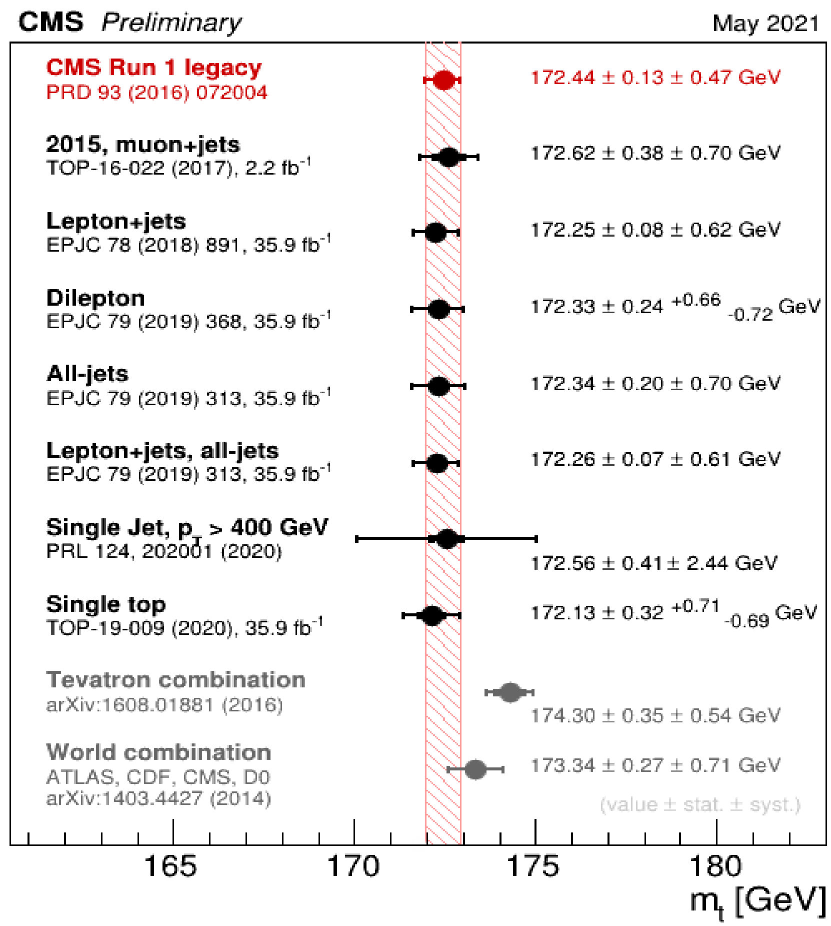




top properties

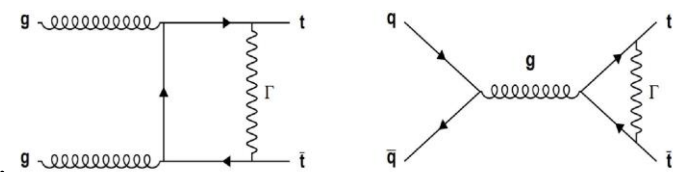
Now at LHC is possible to reach un-precedent precisions for the property measurements





Measurement of the y^t

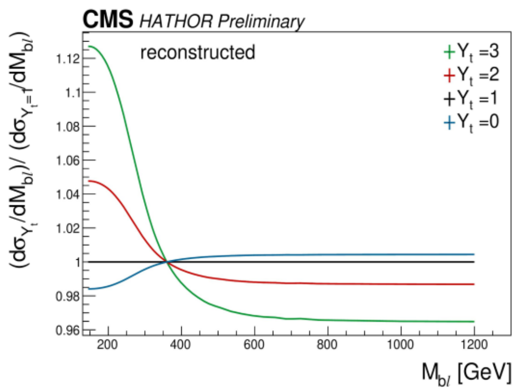
- ✓ Measure the Yukawa (y^t) coupling in $t\bar{t}$ production.
  - ✓ Exploit the large effect that the radiation of a virtual H boson has on $t\bar{t}$ differential distributions

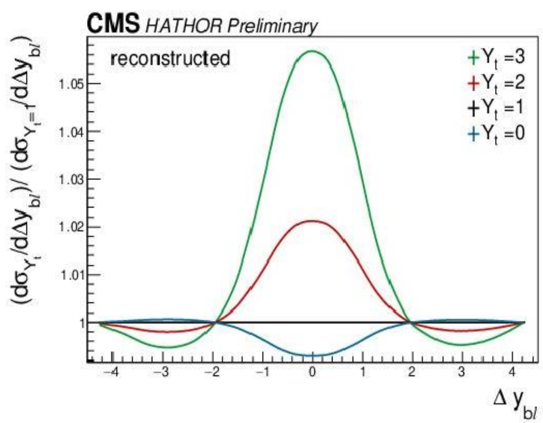


- ✓ $t\bar{t}$ predictions for different values of y^t obtained as event-based multiplicative corrections using HATHOR:
  - ✓ Applied on POWHEG predictions

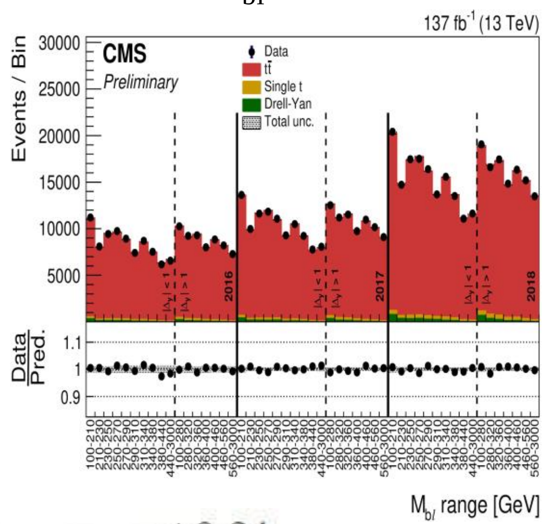
$$R_{\mathrm{EW}}(M_{t\bar{t}}, \Delta y_{t\bar{t}}) = \frac{d^2\sigma_{\mathrm{HATHOR}}}{dM_{t\bar{t}}\, d\Delta y_{t\bar{t}}} \Big/ \frac{d^2\sigma_{\mathrm{LO\ QCD}}}{dM_{t\bar{t}}\, d\Delta y_{t\bar{t}}}$$

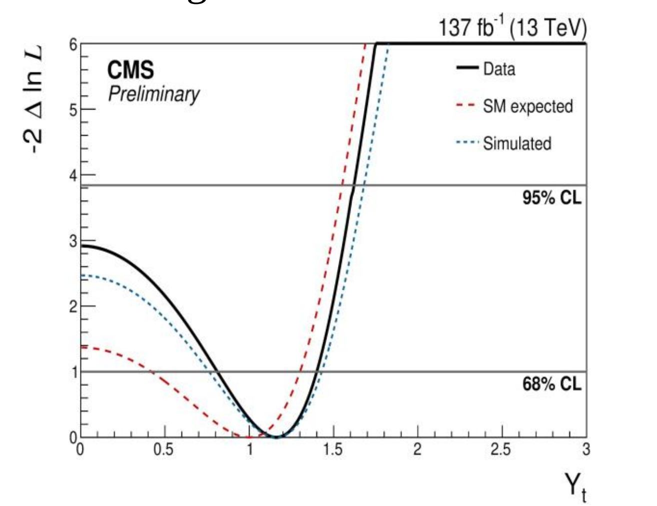
- ✓ The comparison with an additive approach is taken as uncertainty





- ✓ Event collected in the diletopn channel, >=2bjets
- ✓ Variables used based on partial system reconstruction: $M(l^+ + l^- + 2$ b-jets) and Δy_{bl} : requires the correct matching of b and l





$Y_t = 1.16^{+0.24}_{-0.36}$ Compatible with the result in l+jets $Y_t = 1.07^{+0.34}_{-0.43}$

PRD 102 (2020) 092013 PRD 100 (2019) 072002

$t\bar{t}$ forward-backward asymmetry

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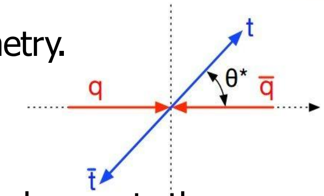
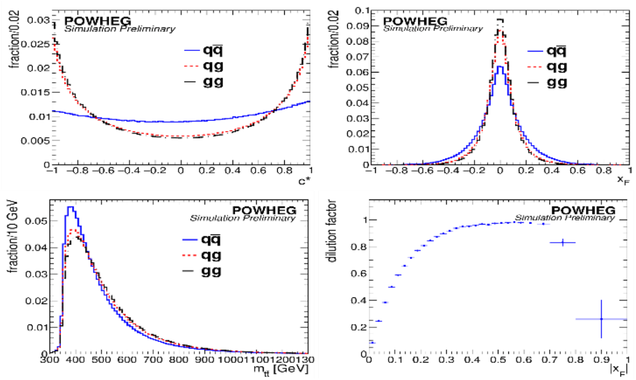


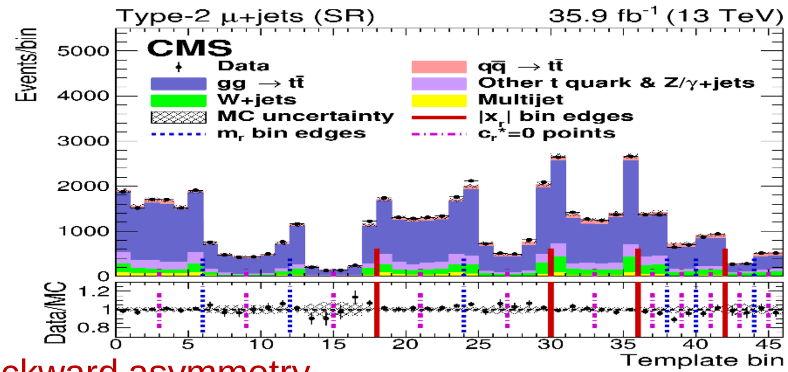
- ✓ NLO interference terms in $t\bar{t}$ production from qq initial state creates a forward-backward asymmetry.

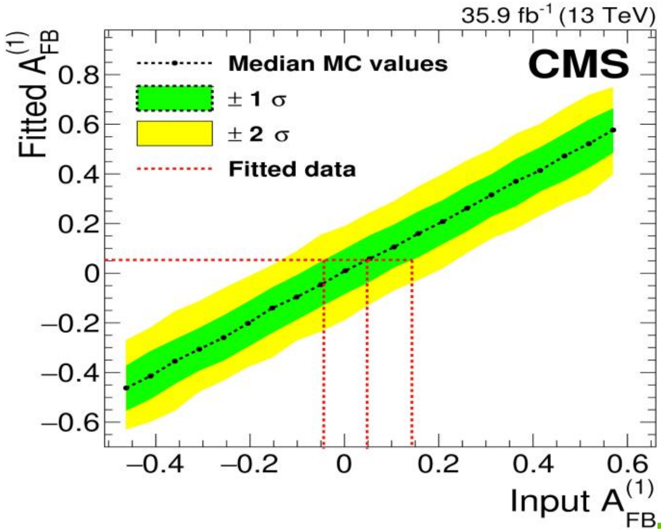
$$A_{\mathrm{FB}} = \frac{\sigma(c^* > 0) - \sigma(c^* < 0)}{\sigma(c^* > 0) + \sigma(c^* < 0)}$$

- ✓ Quantity never measured before @LHC, where the charge asymmetry is measured as a proxy
- ✓ Use variables sensitive to the difference between qq, qg and gg initial state to build templates and separate the qq
- ✓ Extract A_{FB} and anomalous chromoelectric and chromomagnetic dipole moments



- ✓ Events collected in the l+jets channel
- ✓ Both resolved and boosted topologies.
- ✓ Profile likelihood-fit to the 3D template to extract AFB and the anomalous moments separately





forward-backward asymmetry

$$A_{\mathrm{FB}}^{(1)} = 0.048\,^{+0.095}_{-0.087}\,(\mathrm{stat})\,^{+0.020}_{-0.029}\,(\mathrm{syst}),$$

chromomagnetic moments

$$\hat{\mu}_t = -0.024^{+0.013}_{-0.009}\,(\mathrm{stat})\,^{+0.016}_{-0.011}\,(\mathrm{syst}),$$

anomalous chromoelectric

$$|\hat{d}_t| < 0.03 \text{ at 95\% confidence level.}$$

Consistent with the SM and previous CMS results

W polarization in ATLAS and CMS

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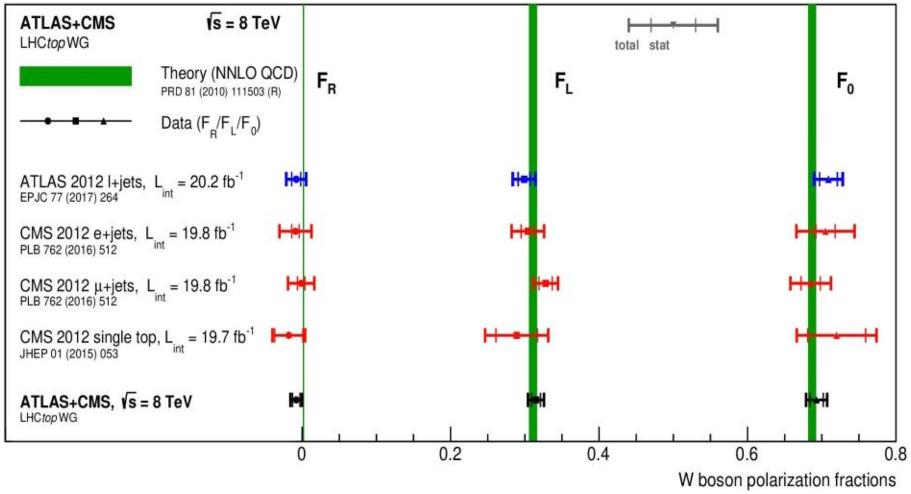
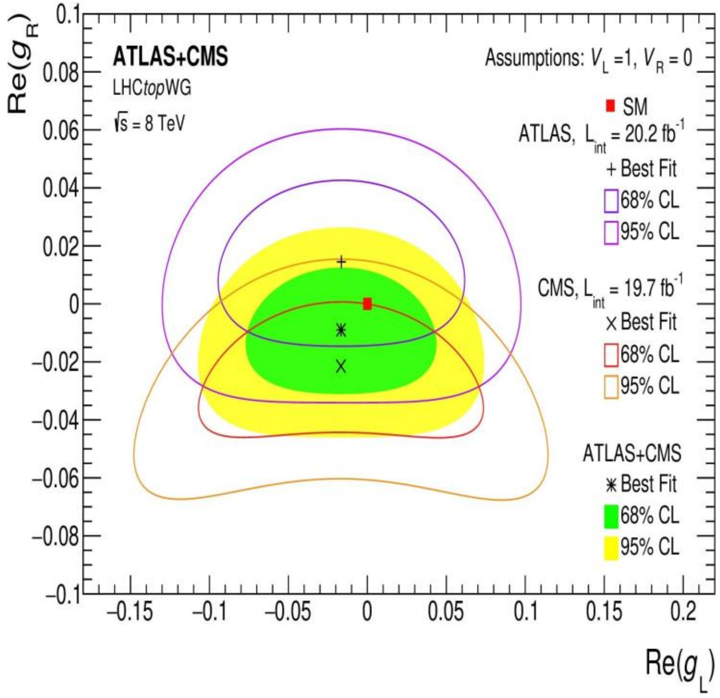
- ✓ Combination of the W boson polarization in top quark decays, on Run1 (8 TeV, 20 fb^{-1}) data.
  - ✓ W boson polarization determined by the V-A structure of the tWb vertex

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{4}\left(1-\cos^2\theta^*\right) F_0 + \frac{3}{8}\left(1-\cos\theta^*\right)^2 F_L + \frac{3}{8}\left(1+\cos\theta^*\right)^2 F_R$$



➢ Combination of the polarization fractions from 4 measurements



- ✓ Combination Improvement > 20% wrt the most precise measurement
- ✓ Measurement used to set limits on the anomalous coupling in the tWb vertex

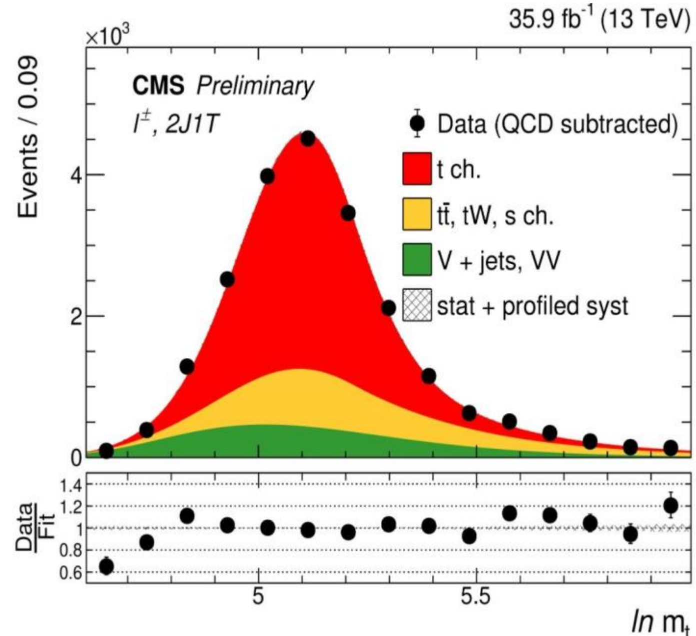
	95% CL interval		
Coupling	ATLAS	CMS	ATLAS+CMS combination
$\mathrm{Re}(V_R)$	$[-0.17, 0.25]$	$[-0.12, 0.16]$	$[-0.11, 0.16]$
$\mathrm{Re}(g_L)$	$[-0.11, 0.08]$	$[-0.09, 0.06]$	$[-0.08, 0.05]$
$\mathrm{Re}(g_R)$	$[-0.03, 0.06]$	$[-0.06, 0.01]$	$[-0.04, 0.02]$

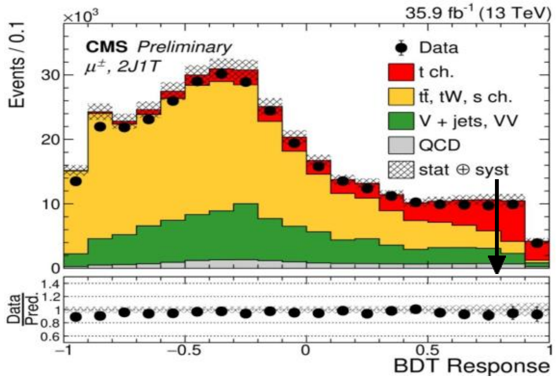
Mass measurement in single top events

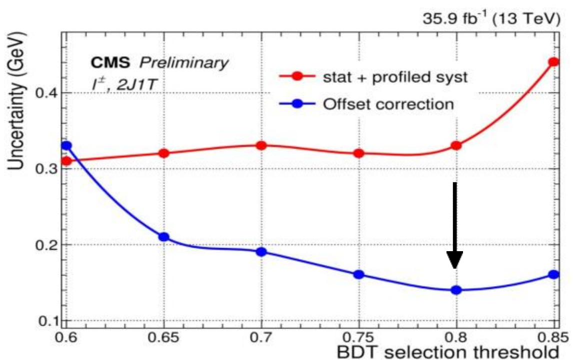
- ✓ BDT discriminator and cut optimization
- ✓ Data-driven QCD is subtracted from the data
- ✓ Simultaneous ML fit using $y = ln(m_t)$ distributions in μ and e final states, validated in control region

$$F(y) = f_{t-ch} F_{t-ch}(y\,;y_0) + f_{Top} F_{Top}(y\,;y_0) + f_{EWK} F_{EWK}(y)$$

- ✓ y_0, f_{t-ch}, f_{Top} and f_{EWK} are allowed to float during the fit







mass results:

Sub GeV precision

$$m_t = 172.13 \pm 0.32\,(\text{stat}+\text{prof})\,^{+0.69}_{-0.70}\,(\text{syst})\ \text{GeV} = 172.13^{+0.76}_{-0.77}\ \text{GeV}$$

$$m_t = 172.62 \pm 0.37\,(\text{stat}+\text{prof})\,^{+0.97}_{-0.65}\,(\text{syst})\ \text{GeV} = 172.62^{+1.04}_{-0.75}\ \text{GeV},$$

$$m_{\bar{t}} = 171.79 \pm 0.58\,(\text{stat}+\text{prof})\,^{+1.32}_{-1.39}\,(\text{syst})\ \text{GeV} = 171.79^{+1.44}_{-1.51}\ \text{GeV}.$$

Masses ratio and difference (a check for CPT Invariance)

$$R_{m_t} = \frac{m_{\bar{t}}}{m_t} = 0.995 \pm 0.004\,(\text{stat}+\text{prof})\,^{+0.002}_{-0.004}\,(\text{syst}) = 0.995^{+0.005}_{-0.006}$$

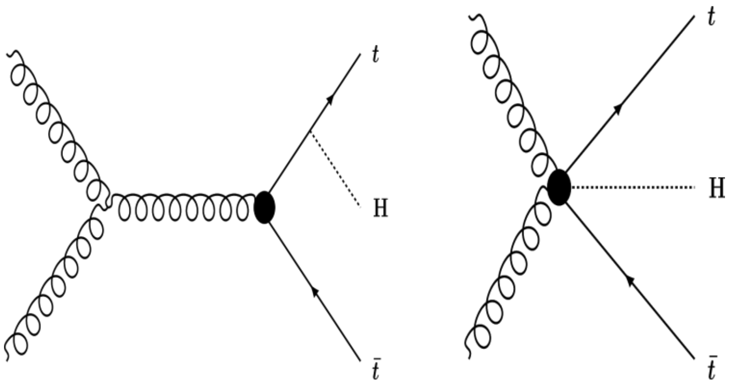
$$\Delta m_t = m_t - m_{\bar{t}} = 0.83 \pm 0.69\,(\text{stat}+\text{prof})\,^{+0.35}_{-0.74}\,(\text{syst})\ \text{GeV} = 0.83^{+0.77}_{-1.01}\ \text{GeV}$$

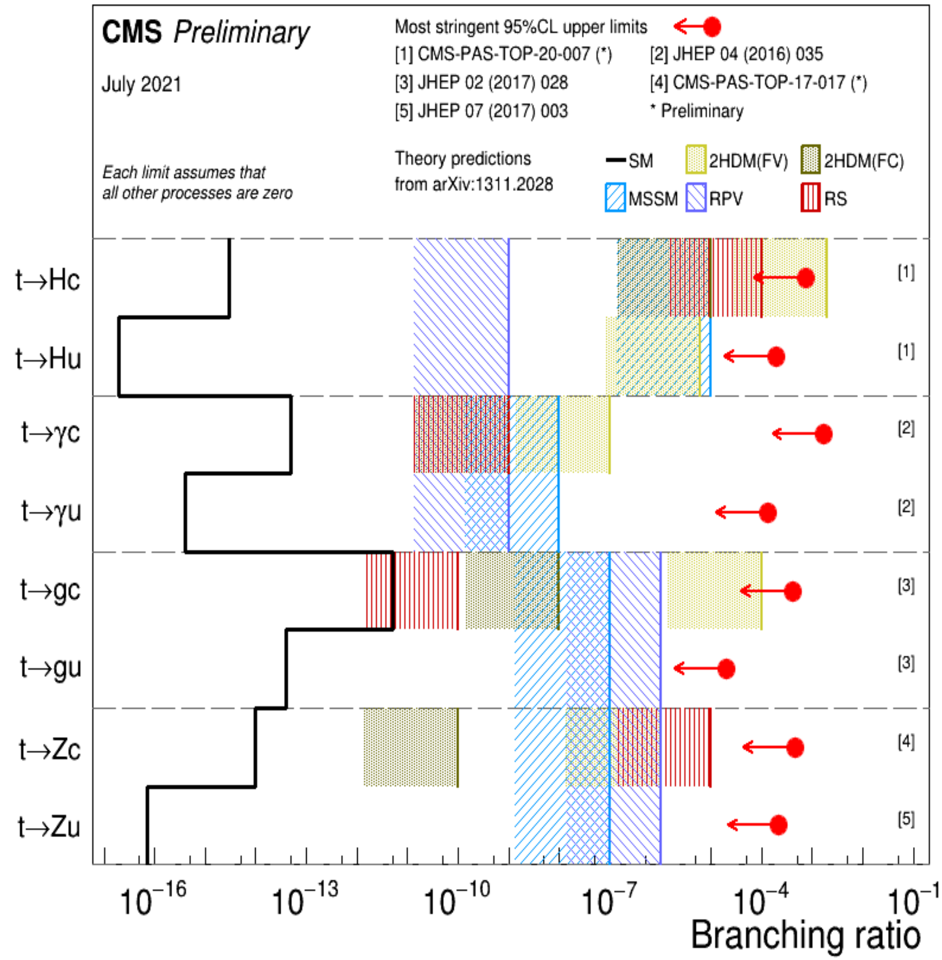
Precision limited by : JES and modelling

Search for new physics

Tool to search for new physics:

- ✓ Many BSM models are expected to involve top quark
  - ➢ Possible to perform direct searches for new resonances and FCNC
- ✓ Use the precise measurements to set a limit on new operators in an EFT framework





Search for FCNC in the top sector

- Flavor changing neutral currents (FCNC) allow for transitions between quarks of different flavor but same electric charge
- FCNC processes are highly suppressed in the SM due to the GIM mechanism
  - Small contributions appear at one loop level
- Many extensions of the SM predict the presence of FCNC and give rise to detectable FCNC amplitude

Any evidence of FCNC will indicate the existence of new physics

	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY
$t \to uZ$	8×10^{-17}	1.1×10^{-4}	–	–	2×10^{-6}	3×10^{-5}
$t \to u\gamma$	3.7×10^{-16}	7.5×10^{-9}	–	–	2×10^{-6}	1×10^{-6}
$t \to ug$	3.7×10^{-14}	1.5×10^{-7}	–	–	8×10^{-5}	2×10^{-4}
$t \to uH$	2×10^{-17}	4.1×10^{-5}	5.5×10^{-6}	–	10^{-5}	$\sim 10^{-6}$
$t \to cZ$	1×10^{-14}	1.1×10^{-4}	$\sim 10^{-7}$	$\sim 10^{-10}$	2×10^{-6}	3×10^{-5}
$t \to c\gamma$	4.6×10^{-14}	7.5×10^{-9}	$\sim 10^{-6}$	$\sim 10^{-9}$	2×10^{-6}	1×10^{-6}
$t \to cg$	4.6×10^{-12}	1.5×10^{-7}	$\sim 10^{-4}$	$\sim 10^{-8}$	8×10^{-5}	2×10^{-4}
$t \to cH$	3×10^{-15}	4.1×10^{-5}	1.5×10^{-3}	$\sim 10^{-5}$	10^{-5}	$\sim 10^{-6}$

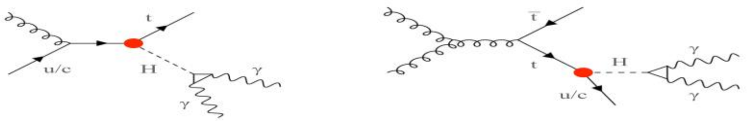
Branching ratios for top FCN decays in the SM, models with $Q = 2/3$ quark singlets (QS), a general 2HDM, a flavour-conserving (FC) 2HDM, in the MSSM and with R parity violating SUSY.

Search for FCNC tHq interaction by H→γγ

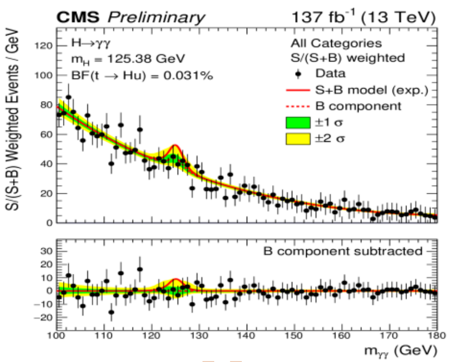
CMS-PAS-TOP-20-007

- Signal modeling: effective Lagrangian

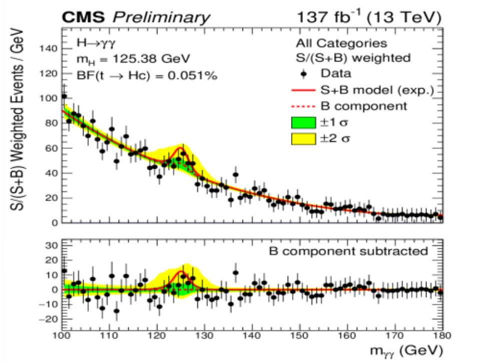
$$\mathcal{L} = \sum_{q=u,c} \frac{g}{\sqrt{2}} \bar{t}\kappa_{Hqt}\left(F^{L}_{Hq}P_L + F^{R}_{Hq}P_R\right)qH + h.c.,$$



- Production & decay
- Signal regions: 2 photons, 100 < $m_{\gamma\gamma}$ < 180 GeV
  - leptonic: ≥1 jet, ≥1ℓ
  - hadronic: ≥3 jet, ≥1 b-jet

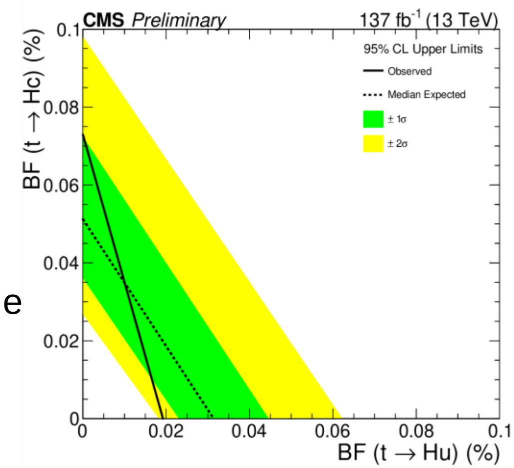


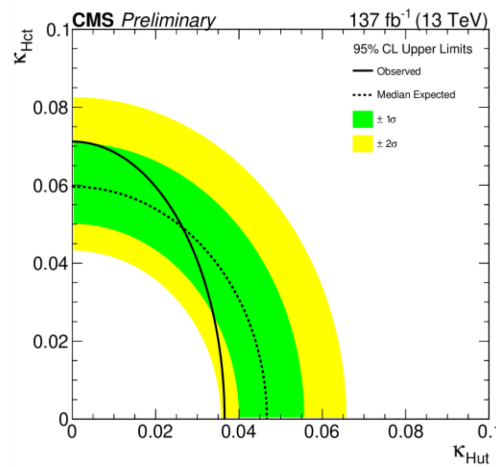
tHu



tHc

- Strategy
  - 8 BDTs: (u, c) × (lep, had) × (res, non-res bkg)
  - 7 categories defined by BDT score
  - 14 $m_{\gamma\gamma}$ distributions to fit





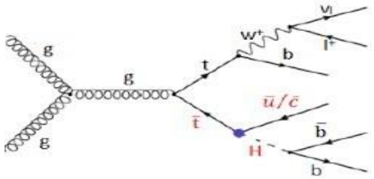
- Dominant uncertainties:

  b-tagging and γ identification
- Data compatible with absence of signal
- Upper limits on the signal cross sections are translated to the strength of the tqH anomalous couplings and related branching fractions

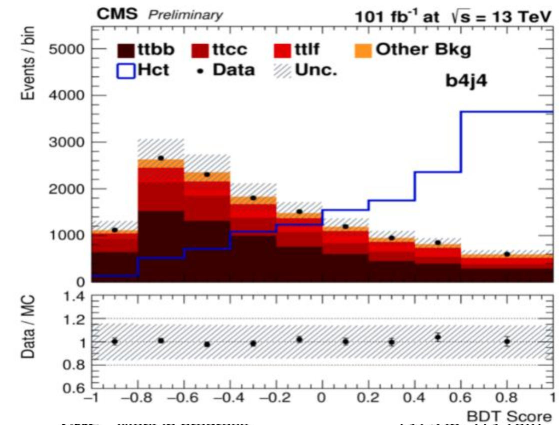
- **Upper limits**
  - B(t→Hu) < 1.9×10⁻⁴ (exp. 3.1×10⁻⁴)
  - B(t→Hc) < 7.3×10⁻⁴ (exp. 5.1×10⁻⁴)

Search for FCNC tHq interaction by H→bb CMS-PAS-TOP-19-002

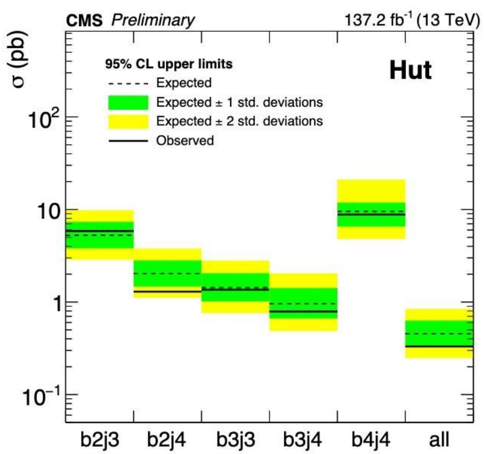
- Production & decay

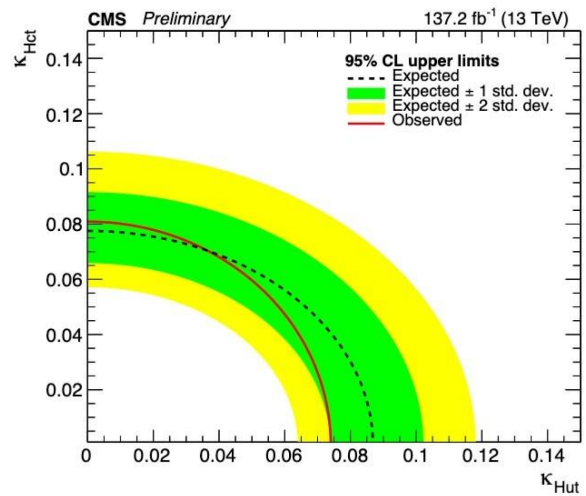


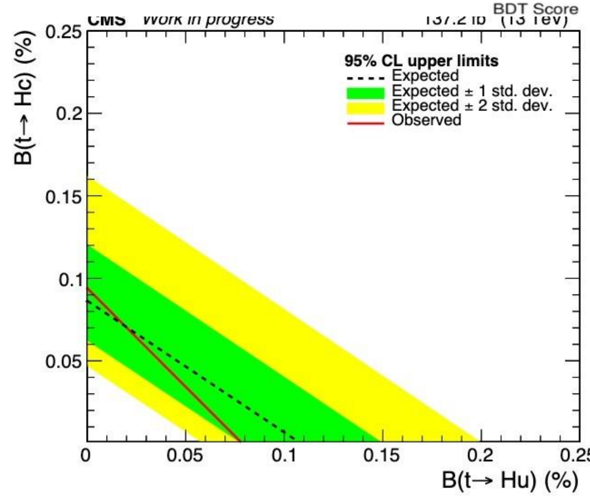
- Signal region: 1ℓ, ≥3 jet, ≥2 b-jet
- A deep neural network is used to associate the reconstructed objects to the matrix-element partonic final state



- BDTs are used to distinguish the signal from the background event
- All bjet-jet categories are combined
- No significant excess with respect to the SM background expectations: 95% CL limits are set on the xs, couplings and BRs
- Significant improve with respect to the early run-2 search







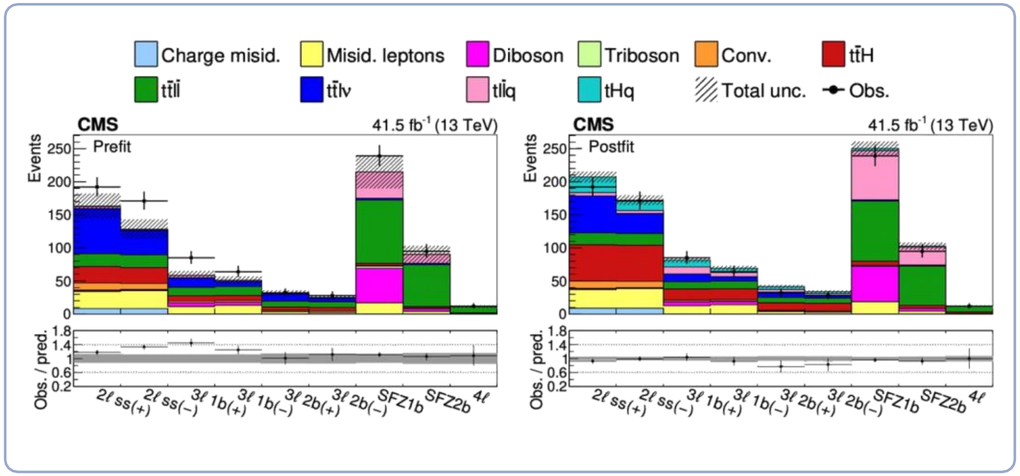
Upper limits:

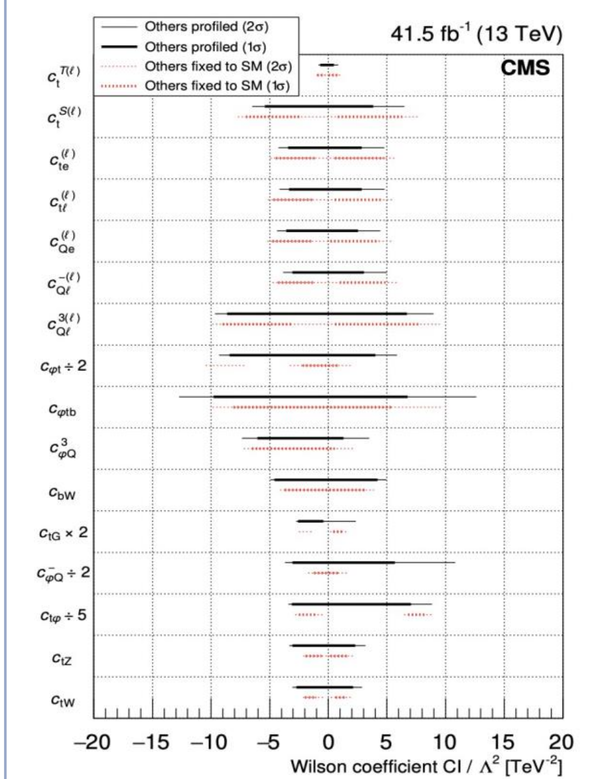
- $B(t\to Hu) < 7.9\times10^{-4}$ (exp: 11×10^{-4})
- $B(t\to Hc) < 9.4\times10^{-4}$ (exp: 8.6×10^{-4})

EFT interpretation of $t/t\bar{t}$ +leptons

JHEP 03 (2021) 095

- ✓ Considering at the same time the yields from several signals: $t\bar{t}$H,$t\bar{t}$Z(ll),$t\bar{t}$W(lnu),tZq,tHq
  - ➢ Divide the event collected in regions categorized on jets and b-jets multiplicity and lepton flavour and charge
  - ➢ Obtained a total of 35 independent regions used to constraint the EFT operators
- ✓ Investigate 16 EFT operators simultaneously
  - ➢ Only dimension 6 operators: 4 fermion operators, boson-quark and quark gluon operators included
  - ➢ Interference among operators and with the SM considered



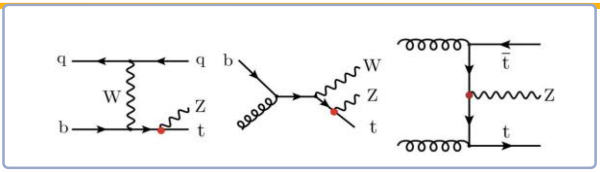


- ✓ Obtain 1D and 2D profiled and individual limits from likelihood fit
- ✓ Main systematics: Theory ($\mu_{R,F}$), modelling, JES, lepton ID and isolation

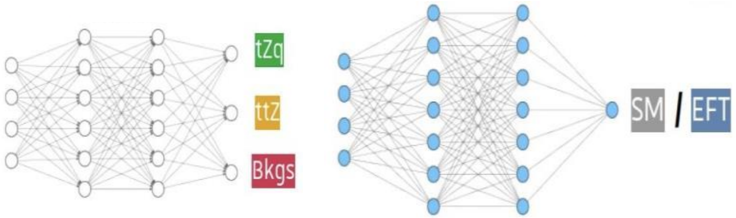
Good agreement of all WCs with the SM prediction

EFT search in ≥3L final states

CMS-PAS-TOP-21-001



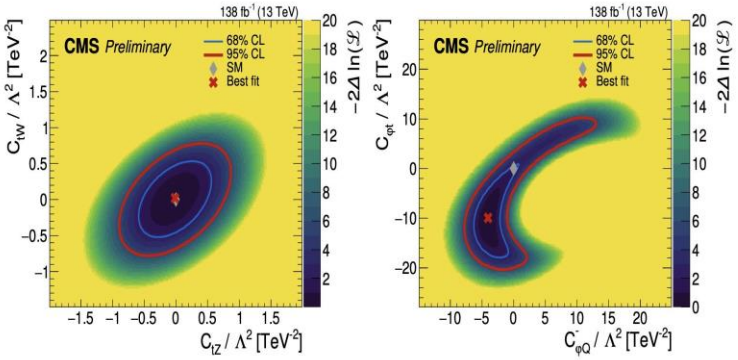
- Full Run II Luminosity 138/fb with main processes: tZq/ttZ/tWZ
  - Leptonically decaying top + Z boson candidate
- 5 operators: weak dipole moment interactions, left- and right-handed top quark vector couplings
- Extensive use of MVAs
  - -- discriminate SM processes :
  - -- separate SM/BSM events



$\mathcal{O}_{tZ}$	$\mathrm{Re}\{-s_W c_{uB}^{(33)} + c_W c_{uW}^{(33)}\}$
$\mathcal{O}_{tW}$	$\mathrm{Re}\{c_{uW}^{(33)}\}$
$\mathcal{O}_{\varphi Q}^{3}$	$c_{\varphi q}^{3(33)}$
$\mathcal{O}_{\varphi Q}^{-}$	$c_{\varphi q}^{1(33)} - c_{\varphi q}^{3(33)}$
$\mathcal{O}_{\varphi t}$	$c_{\varphi u}^{(33)}$

- signal extraction with 1D, 2D, and 5D likelihood fit
- Systematics: theory and NP lepton dominate

	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}	$[-0.76, 0.74]$	$[-0.52, 0.52]$	$[-0.96, 0.93]$	$[-0.69, 0.70]$
$c_{\varphi Q}^{3}$	$[-1.39, 1.25]$	$[-1.10, 1.41]$	$[-1.91, 1.36]$	$[-1.26, 1.43]$
$c_{\varphi Q}^{-}$	$[-2.86, 2.33]$	$[-3.00, 2.29]$	$[-6.06, 14.09]$	$[-7.09, 14.76]$
$c_{\varphi t}$	$[-3.70, 3.71]$	$[-21.65, -14.61] \cup [-2.06, 2.69]$	$[-16.18, 10.46]$	$[-19.15, 10.34]$

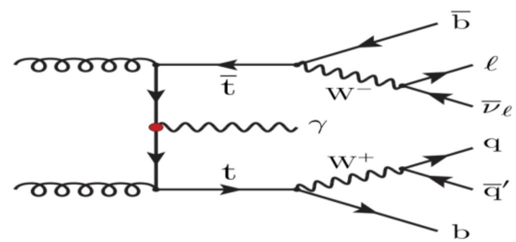


- Better limits than eariler results from the ttZ cross section measurement
- Agreement within 2σ in general

EFT search in $t\bar{t}\gamma$

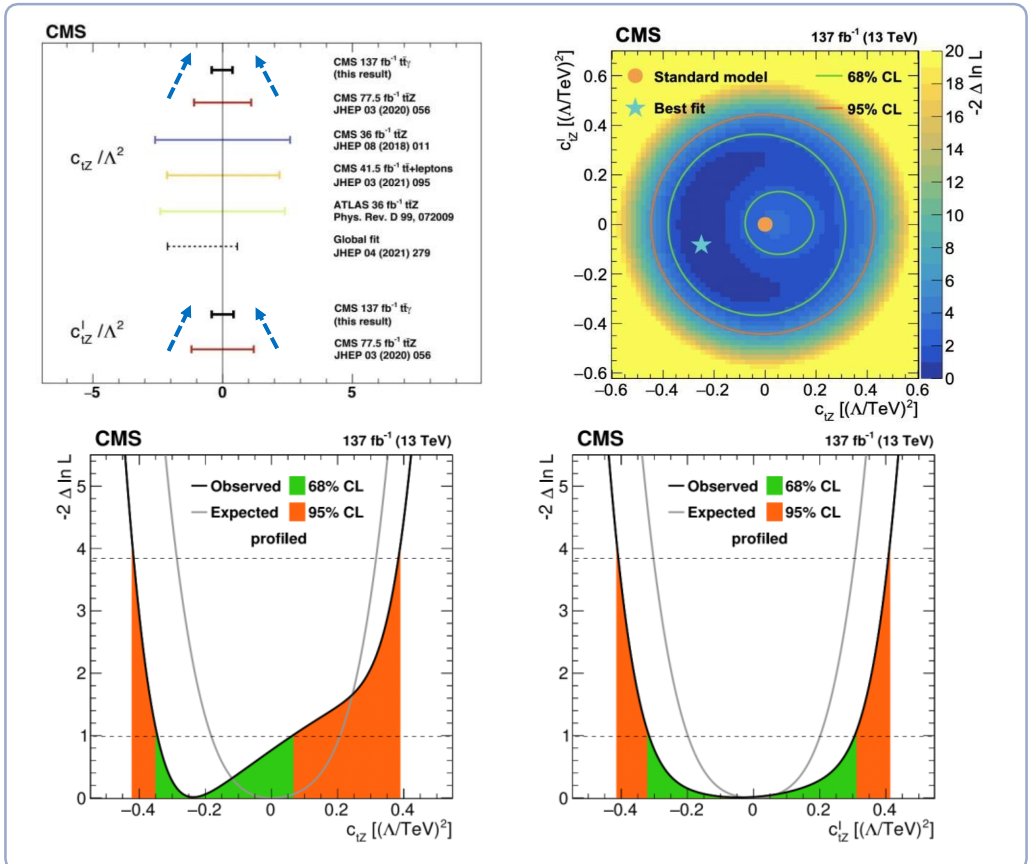
arXiv: 2107.01508

- Full Run II luminosity 137 fb^{-1}
  - 1lepton channel, binned in lepton flavor
- Interpretation in c_{tZ} (weak dipole moment)



✓ Best current limits.

	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	$[-0.32, 0.31]$	$[-0.41, 0.41]$



Search for CLFV interactions

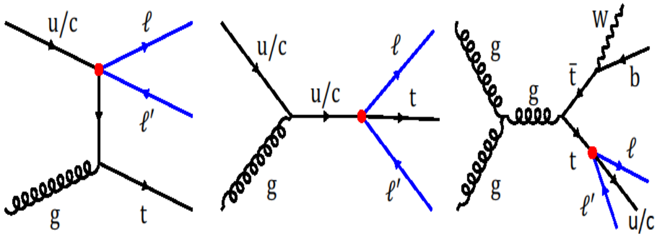
CMS-PAS-TOP-19-006

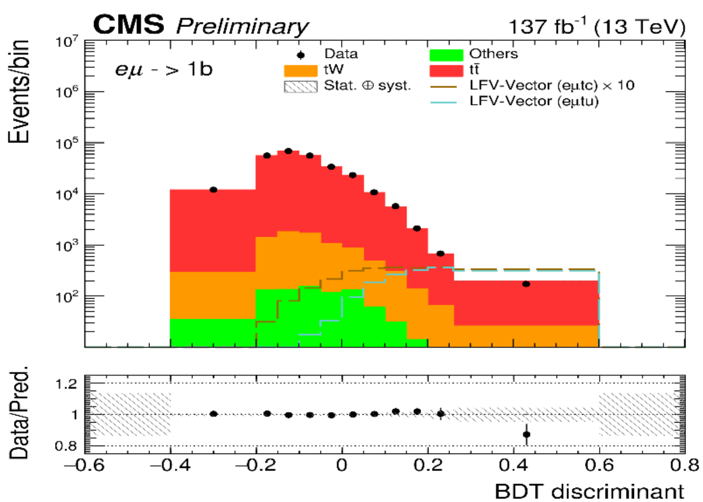
- In the SM, lepton flavor is conserved in all interactions
- Many new physics models predict sizable CLFV (neutrino mass, multi-Higgs doublet models,...)
- If the new physics responsible for the CLFV is at scales beyond what the LHC can directly probe, the SM Lagrangian can be extended by dimension-6 operators

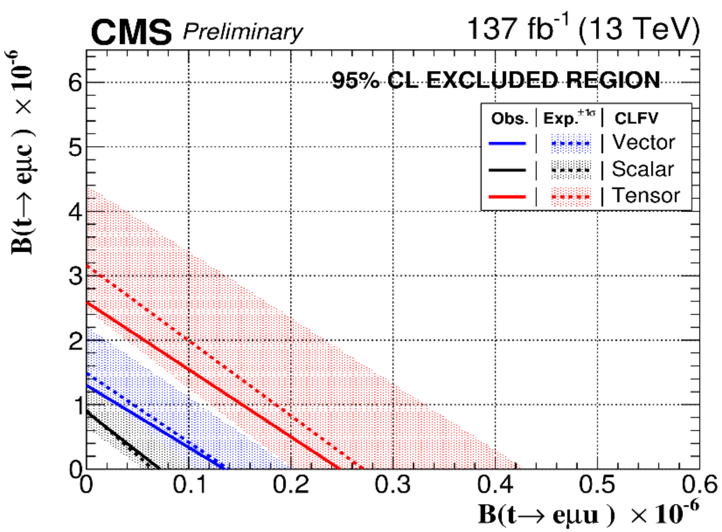
$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_{\mathrm{eff}} = \mathcal{L}_{\mathrm{SM}} + \sum_x \frac{C_x}{\Lambda^2} O_x + \ldots ,$$

- ✓ Search for CLFV in $e\mu$ final state [137 fb^{-1}]
- ✓ Production & decay
- ✓ Signal: CLFV vector, scalar and tensor
- ✓ BDT is used to discriminate signal from BG events
- ✓ Data consistent with SM expectation
  - ✓ Upper limits are set at 95%CL

Production Decay







Search for CP Violation

CMS-PAS-TOP-20-005

- CP violation in SM is insufficient to describe the matter-antimatter asymmetry of the universe
- In the SM, CPV in the production and decay of top quark pairs is predicted to be very small
- Simple CP odd observables

$$A_i = \frac{N(\mathcal{O}_i > 0) - N(\mathcal{O}_i < 0)}{N(\mathcal{O}_i > 0) + N(\mathcal{O}_i < 0)}.$$

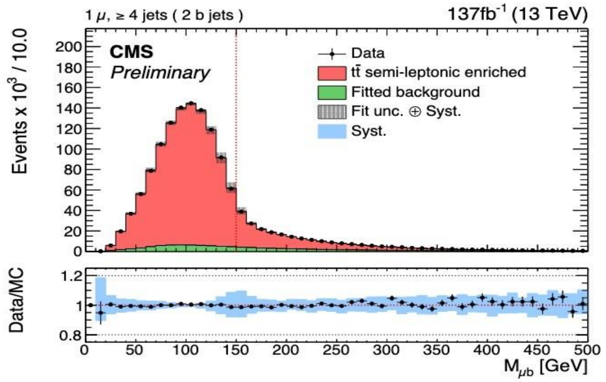
- chromo-electric dipole moment (CEDM) of top quark in top pair production induces CPV

✓ Lepton+jets final states [137 fb^{-1}]

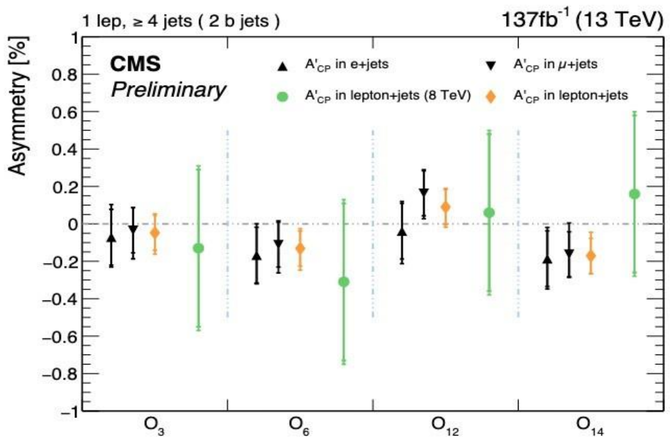
✓ Observables; O_3, O_6, O_{12} and O_{14}

✓ Top quark and antiquark candidates are reconstructed using a χ^2 sorting algorithm

✓ The background contribution in the signal region is estimated from a fit to the mass distribution



- There is no significant evidence of CPV in each observable
  - Consistent with the SM prediction



	$A'_{CP}(\%)$ $e+jets$	$\mu+jets$	Combined
O_3	$-0.071 \pm 0.149(\text{stat.})^{+0.092}_{-0.058}(\text{syst.})$	$-0.035 \pm 0.120(\text{stat.})^{+0.022}_{-0.094}(\text{syst.})$	$-0.048 \pm 0.094(\text{stat.})^{+0.041}_{-0.065}(\text{syst.})$
O_6	$-0.167 \pm 0.149(\text{stat.})^{+0.077}_{-0.038}(\text{syst.})$	$-0.111 \pm 0.120(\text{stat.})^{+0.042}_{-0.093}(\text{syst.})$	$-0.131 \pm 0.094(\text{stat.})^{+0.049}_{-0.068}(\text{syst.})$
O_{12}	$-0.039 \pm 0.149(\text{stat.})^{+0.056}_{-0.090}(\text{syst.})$	$+0.163 \pm 0.120(\text{stat.})^{+0.038}_{-0.065}(\text{syst.})$	$+0.090 \pm 0.094(\text{stat.})^{+0.034}_{-0.053}(\text{syst.})$
O_{14}	$-0.186 \pm 0.149(\text{stat.})^{+0.075}_{-0.065}(\text{syst.})$	$-0.162 \pm 0.120(\text{stat.})^{+0.117}_{-0.032}(\text{syst.})$	$-0.171 \pm 0.094(\text{stat.})^{+0.085}_{-0.023}(\text{syst.})$

Summary

LHC is a top factory and CMS is exploiting the large sample collected maximally:

- ✓ **Reducing the uncertainties on inclusive measurements**
- ✓ **Performing differential measurements**
  - – in challenging phase-space and channels and as a function of several variables
  - -- providing a complete description of the $t\bar{t}$ kinematic
  - – providing stringent test of QCD and electroweak predictions
- ✓ **Searching for very rare processes**
  - ➢ Measuring with increasing precision $t(\bar{t})$+X and including differential distributions
  - ➢ First observation of tW production in ℓ+jets
- ✓ **Measuring the top properties and couplings with innovative techniques**
  - ➢ Use top events to test the fundamental bases of the SM
- ✓ **Setting constraints to the existence of new physics:** FCNC, EFT, CLFV, CPV…

Several exciting new measurements have been presented, but stay tuned since more results are coming…..

Thanks for your attention!!!

References

- ✧ LHCTopWG https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWG
- ✧ ATLAS: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
- ✧ CMS: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Backup

OPERATORS AND PHYSICS IMPLICATIONS

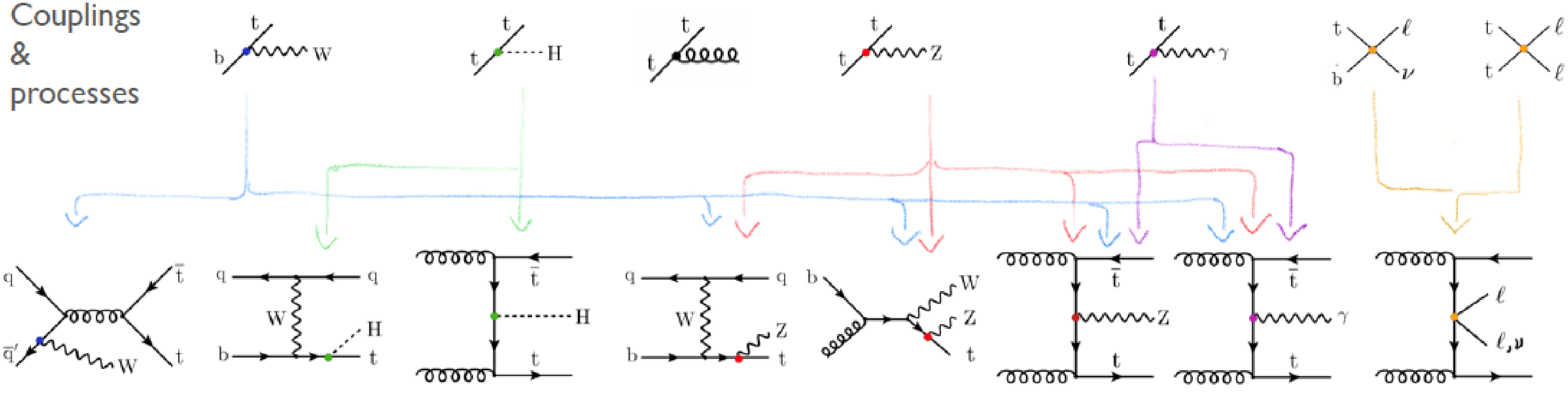
SMEFT Lagrangian

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

Operators

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

Couplings & processes



Parametrized predictions

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