Search for CLFV in the production and decay of top quarks using trilepton final states

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On behalf of the CMS Collaboration

Moriond EW, La Thuile, 18-25 March

CMS-PAS-TOP-22-005

Introduction

- **Charged lepton flavor violation (CLFV) is highly suppressed in the Standard Model (SM)**
- **CLFV provides a clear signature for new physics**
- **Top quarks are abundantly produced at the LHC**
  - They can be used as a good probe for CLFV searches

- **Existing searches involving eμtq interaction → compatible with the SM**
  - ATLAS[a]: 3ℓ channel, top decay mode only
  - CMS: 2ℓ channel, top production and decay mode

[CMS-PAS-TOP-22-005]

- **This talk presents results from a new CMS search that combines the advantages of both searches**
  - 3ℓ channel → lower background yield than 2ℓ channel
  - Top production mode → adds 10 × signal yield

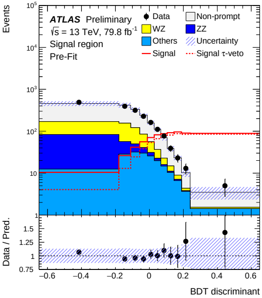

Figure 1: **ATLAS-CONF-2018-044**

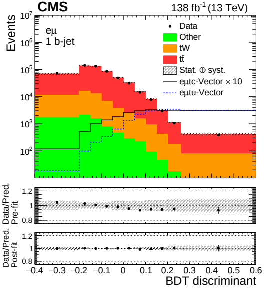

Figure 2: **arXiv:2201.07859**

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[a] **new results on μτtq interaction [ATLAS-CONF-2023-001] is also consistent with the SM**

Analysis overview

- **Data collected by CMS in 2016-2018: $\sqrt{s} = 13$ TeV, $\int \mathcal{L}dt = 138$ fb^{-1}**
- **Targeting top production and decay signals in 3ℓ (e or μ) final states**
  - eμtu and eμtc interactions are considered
- **Parameterising signals with Dimension-6 effective field theory (EFT) operators**
  - Eleni/Sergio's talk contains more materials on EFT

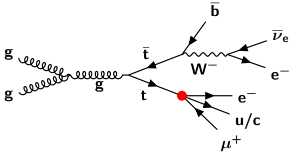


Figure 3: **Top decay**

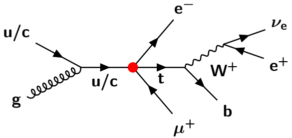


Figure 4: **Top production**

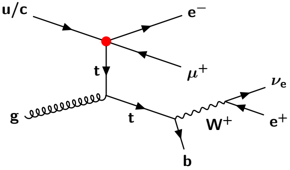


Figure 5: **Top production**

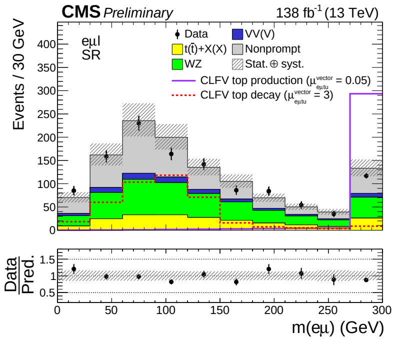
- **Nonprompt backgrounds → data-driven method**
- **Prompt backgrounds → MC simulation**

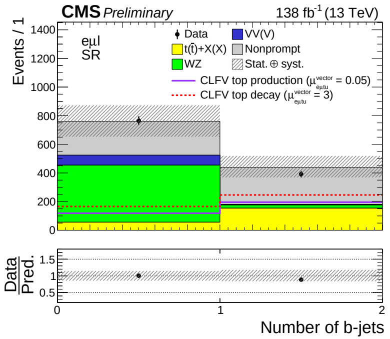
Signal region (prefit)

Signal region (SR) selection

One oppositely charged eμ pair + an extra ℓ, at least one jet, no more than one b-jet, $p_T^{miss} > 20$ GeV, Z mass veto (50-106 GeV)

Nonprompt backgrounds and WZ production → dominant background





- **SR is further subdivided to target different CLFV signal modes**
  - SR1: m(eμ) < 150 GeV → Top decay enriched
  - SR2: m(eμ) > 150 GeV → Top production enriched

BDT discriminant (prefit)

- **One binary BDT is trained for each SR**
- **Different signal samples are combined in training**

Figure 6: **SR1: BDT targeting top decay**

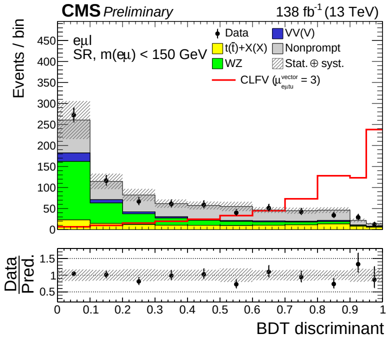
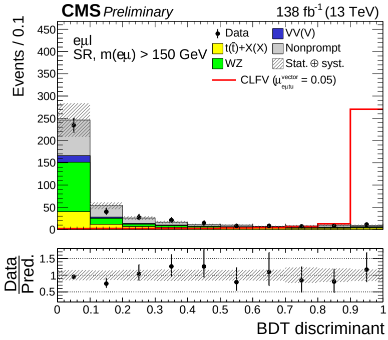


Figure 7: **SR2: BDT targeting top production**



- **No significant excess over SM expectations**
  - Full BDT distributions are used to set limits

Results

- **Observed upper limits @ 95% CL on branching fractions of t→eμq, q=u/c**

Int. type	$\mathcal{B}(t\to e\mu u)\times 10^{-7}$	$\mathcal{B}(t\to e\mu c)\times 10^{-7}$
Tensor	0.23	2.58
Vector	0.16	1.99
Scalar	0.09	1.05

Figure 8: **Upper limits on branching fractions**

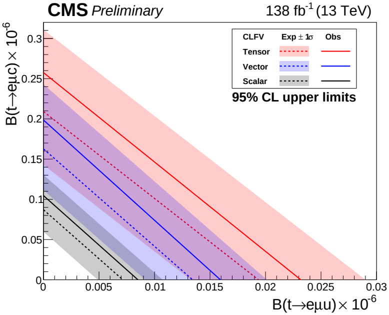
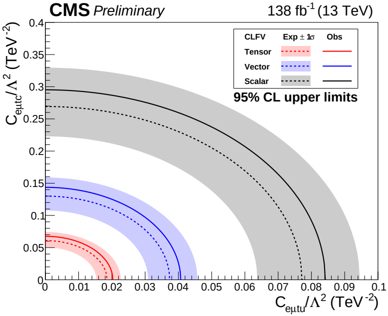


Figure 9: **Upper limits on Wilson coefficients**



- **Most stringent limits on $\mathcal{B}(t\to e\mu q)$ to date**
  - One (two) order(s) of magnitude improvement w.r.t. previous CMS (ATLAS) results

Summary

[CMS-PAS-TOP-22-005]

- **A new CMS search for charged lepton flavor violation is presented**
  - 3ℓ (e or μ) channel
  - Targeting top production and decay
- **No significant excess is observed over the prediction from the Standard Model**
- **Improving the existing upper limits on $\mathcal{B}(t \to e\mu q)$ by one order of magnitude**

Thank you for listening!

Back up

EFT operators and signal cross sections

- **Effective Lagrangian**: $\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}}^{(4)} + \frac{1}{\Lambda^2}\sum_a C_a^{(6)} O_a^{(6)} + O(\frac{1}{\Lambda^4})$
- **Vector-like operators are combined in this analysis**

Int. type	Operator
vector	$O_{lq}^{(1)ijkl} = (\bar{l}_i\gamma^\mu l_j)(\bar{q}_k\gamma^\mu q_l)$
	$O_{lu}^{ijkl} = (\bar{l}_i\gamma^\mu l_j)(\bar{u}_k\gamma^\mu u_l)$
	$O_{eq}^{ijkl} = (\bar{e}_i\gamma^\mu e_j)(\bar{q}_k\gamma^\mu q_l)$
	$O_{eu}^{ijkl} = (\bar{e}_i\gamma^\mu e_j)(\bar{u}_k\gamma^\mu u_l)$
scalar	$O_{lequ}^{(1)ijkl} = (\bar{l}_i e_j)\ \varepsilon\ (\bar{q}_k u_l)$
tensor	$O_{lequ}^{(3)ijkl} = (\bar{l}_i\sigma^{\mu\nu} e_j)\ \varepsilon\ (\bar{q}_k\sigma_{\mu\nu} u_l)$

Table 1: **Relevant Dimension-6 EFT operators**

Int. type	samples	xsection(fb)	precision
vector	top production via u quark	$634^{+113}_{-90} \pm 8$	LO
	top production via c quark	$58^{+9}_{-7} \pm 8$	LO
	top decay via u/c quark	$32^{+0.8}_{-1.1} \pm 1.3$	NNLO
scalar	top production via u quark	$139^{+26}_{-20} \pm 2$	LO
	top production via c quark	$12.1^{+2.0}_{-1.6} \pm 1.8$	LO
	top decay via u/c quark	$4^{+0.1}_{-0.1} \pm 0.2$	NNLO
tensor	top production via u quark	$2908^{+503}_{-401} \pm 37$	LO
	top production via c quark	$292^{+42}_{-35} \pm 37$	LO
	top decay via u/c quark	$187^{+5}_{-6} \pm 8$	NNLO

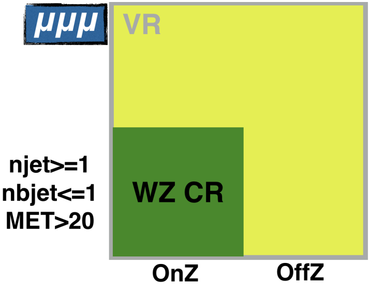
Table 2: **Signal cross sections given by arXiv:2201.07859**

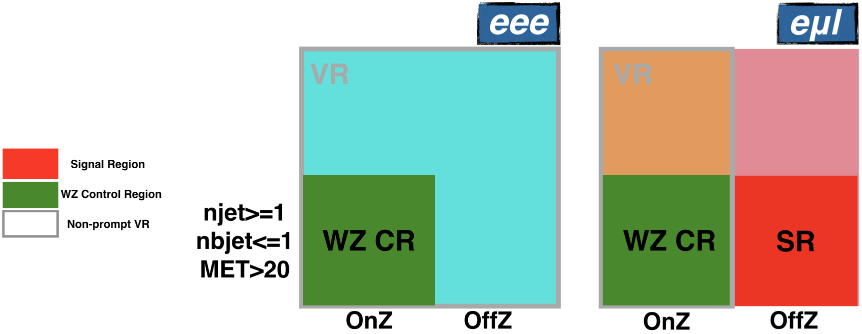
Event regions

- Events are required to contain exactly three leptons and $|\Sigma_i q_{e_i}| = 1$
- Events are further categorized based on lepton flavor-composite
- OnZ: 50 GeV $< m_{\ell\bar{\ell}} <$ 106 GeV

Table 3: **Definitions of different event regions**

Channel	Region	OnZ	OffZ	$p_T^{miss} > 20$ GeV	# jets ≥ 1	# b jets ≤ 1
eee/μμμ	VR	-	-	-	-	-
	WZ CR	✓	-	✓	✓	✓
eμℓ	SR	-	✓	✓	✓	✓
	VR	✓	-	-	-	-
	WZ CR	✓	-	✓	✓	✓





Validation of the data-driven method (prefit)

[arXiv:1407.5624]

- We use the **"matrix method"** to estimate nonprompt backgrounds
- Three validation regions (VR) are used to validate this method

Figure 10: **eee-VR: leading lepton η**

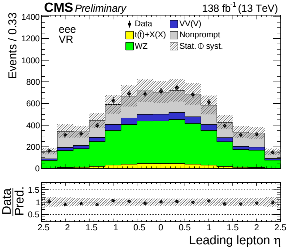


Figure 11: **e$\mu\ell$-VR: leading lepton η**

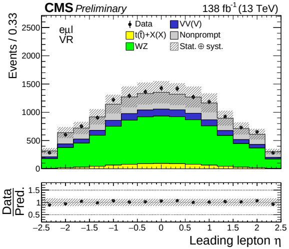
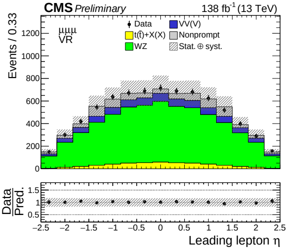


Figure 12: **$\mu\mu\mu$-VR: leading lepton η**



- Good agreement between observed data and prediction in all three VRs

More SR observables (prefit)

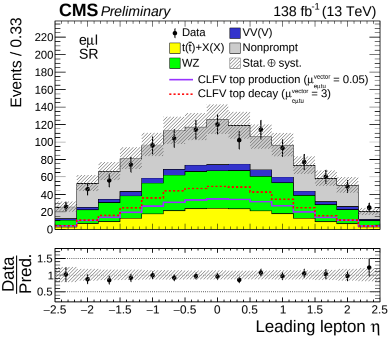


Figure 13: **SR: leading lepton η**

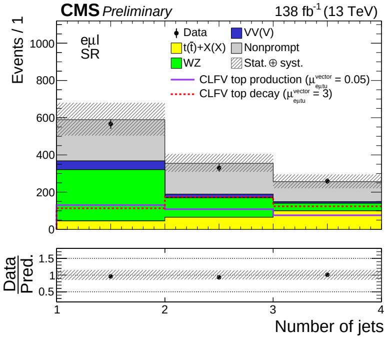


Figure 14: **SR: number of jets**

- **Good agreement between observed data and prediction in the SR**

BDT discriminant (postfit)

- **A profile likelihood function $\mathcal{L}(\mu,\theta)$ is constructed using full BDT distributions**
- **A maximum likelihood fit is performed by maximalizing $\mathcal{L}(\mu,\theta)$**

Figure 15: **SR1: BDT targeting top decay**

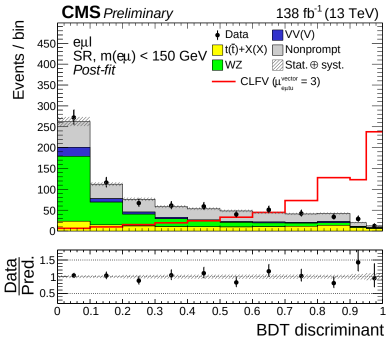
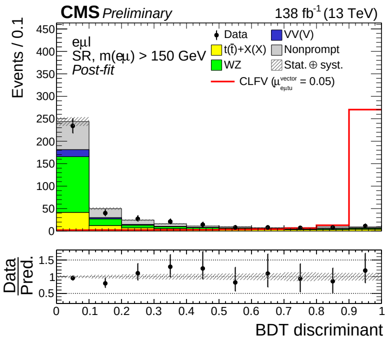


Figure 16: **SR2: BDT targeting top production**



Upper limits

[arXiv:1007.1727]

- **Upper limit on individual Wilson coefficient is obtained using asymptotic formula**
  - Other Wilson coefficients set to zero
- **Upper limits on Wilson coefficients are converted to upper limits on $\mathcal{B}(t \to e\mu q)$**

Table 4: **Upper limits at the 95% CL on the different CLFV signals**

CLFV coupling	Interaction type	$C_{e\mu tq}/\Lambda^2$ (TeV^{-2}) Exp (68% range)	**Obs**	$\mathcal{B}(t \to e\mu q) \times 10^{-6}$ Exp (68% range)	**Obs**
eμtu	tensor	0.019 (0.015-0.023)	**0.020**	0.019 (0.013-0.029)	**0.023**
	vector	0.037 (0.031-0.046)	**0.041**	0.013 (0.009-0.020)	**0.016**
	scalar	0.077 (0.064-0.095)	**0.084**	0.007 (0.005-0.011)	**0.009**
eμtc	tensor	0.061 (0.050-0.074)	**0.068**	0.209 (0.143-0.311)	**0.258**
	vector	0.130 (0.108-0.159)	**0.144**	0.163 (0.111-0.243)	**0.199**
	scalar	0.269 (0.223-0.330)	**0.295**	0.087 (0.060-0.130)	**0.105**