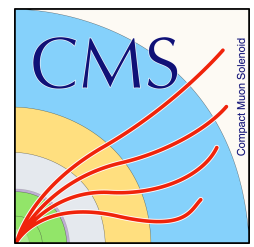
Search for new physics in the top quark sector using effective field theory

Jack Li (Northeastern University)

On behalf of the CMS Collaboration



Large Hadron Collider Physics Conference
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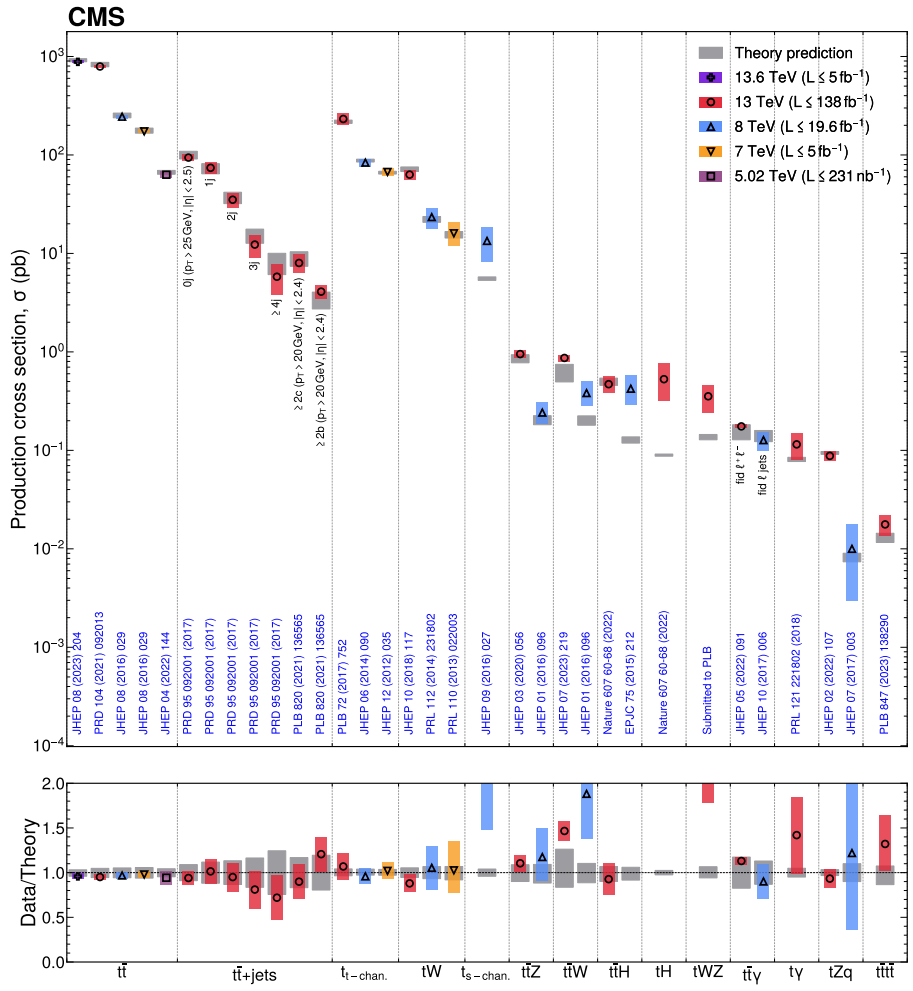
Top quark as a probe

- **No clear signs of New Physics (heavy?) at the LHC**
  - Indirect searches may provide insights
- **Top quark provides a clear signature and is abundantly produced**
  - Ideal probe in indirect searches
- **Effective field theory (EFT) assumes the scale of New Physics is above current measurements**
  - The most relevant EFT in top quark physics is the Standard Model EFT (SMEFT)



$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \frac{C_i}{\Lambda^2}\mathcal{O}_i^{(6)} + O(\frac{1}{\Lambda^4})$$

Detector-level EFT analyses

- All three analyses use data collected by CMS in 2016-2018 (138 fb^{-1})
- Dimension-six operators involving at least one top quark

t(t̄)X global fit
JHEP 12 (2023) 068

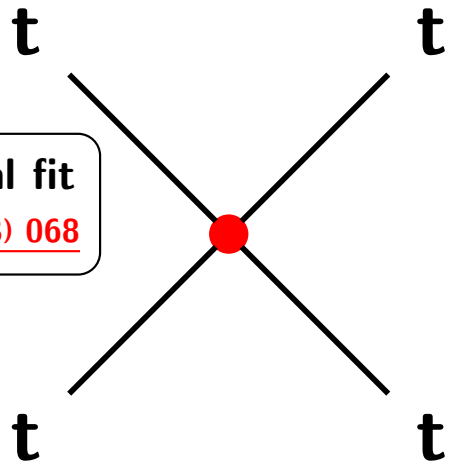


Figure 1: 4 heavy quarks

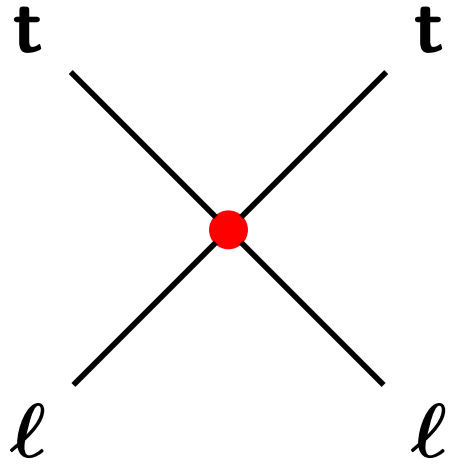


Figure 3: 2 heavy quarks + 2 leptons

LFV trilepton
arXiv:2312.03199

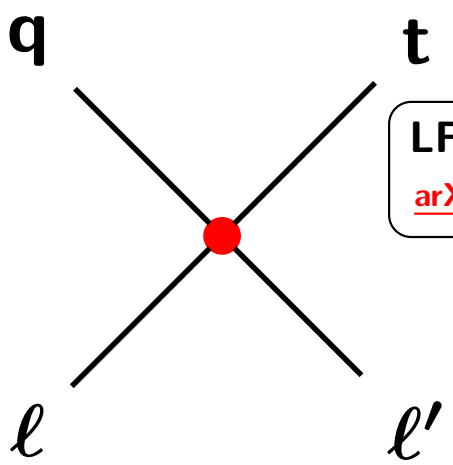


Figure 5: Lepton flavor violation

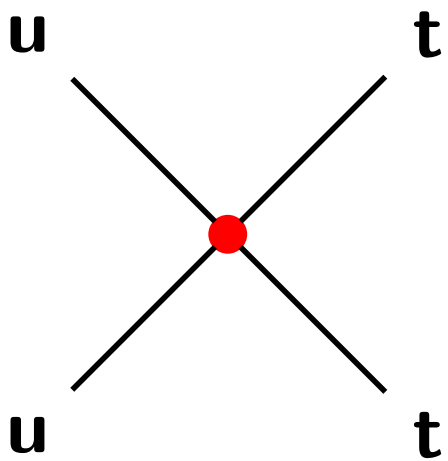


Figure 2: 2 heavy 2 light quarks

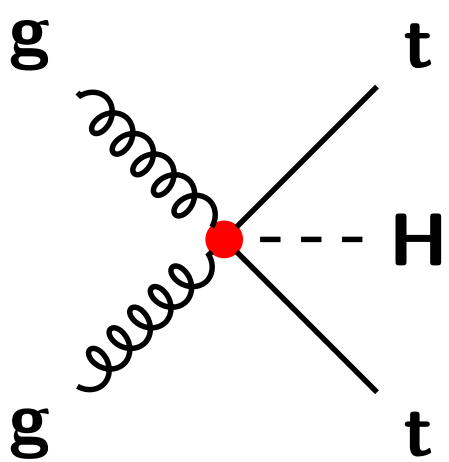


Figure 4: 2 heavy quarks + bosons

BNV dilepton
arXiv:2402.18461

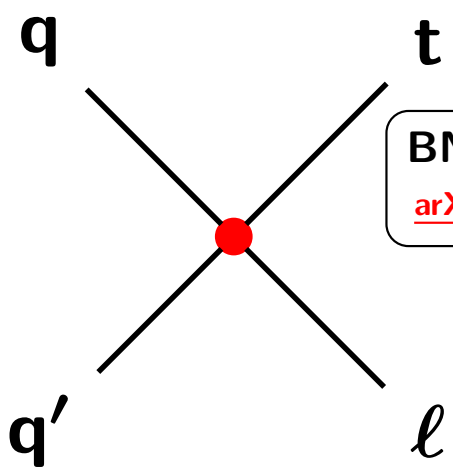
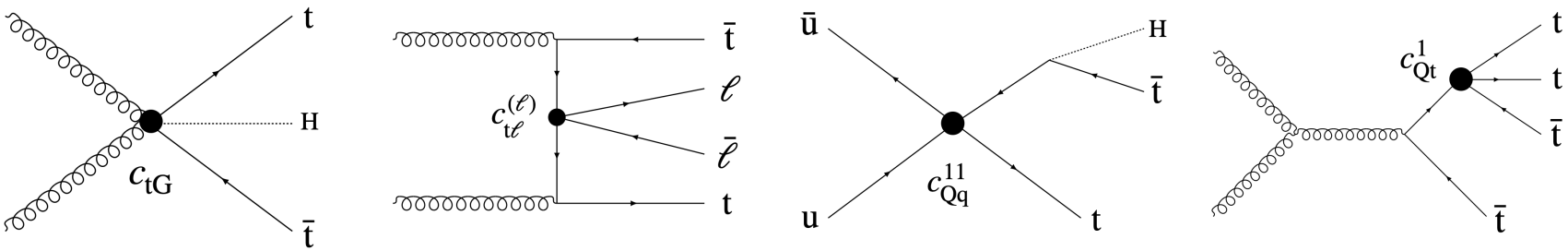


Figure 6: Baryon number violation

EFT search in t($\bar{t}$)X [JHEP 12 (2023) 068]

- **Signal processes: tt$\ell\nu$, tt$\ell\ell$, ttH, tZq, tHq, tttt**
  - Fully simulated to detector level
- **Global approach: 26 dimension-six operators considered simultaneously**
  - Grouped into four categories: 2 heavy quarks with bosons, 2 quarks 2 leptons, 2 heavy 2 light quarks, and 4 heavy quarks.

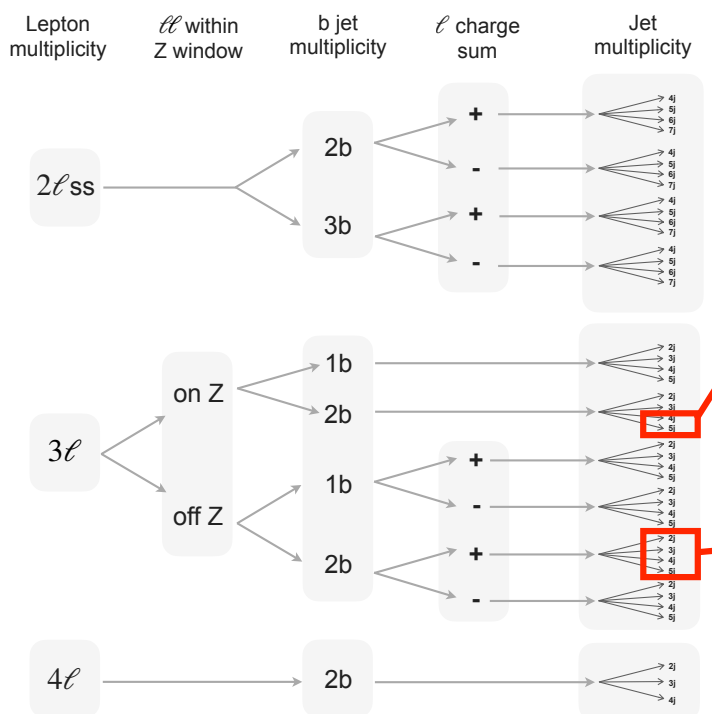


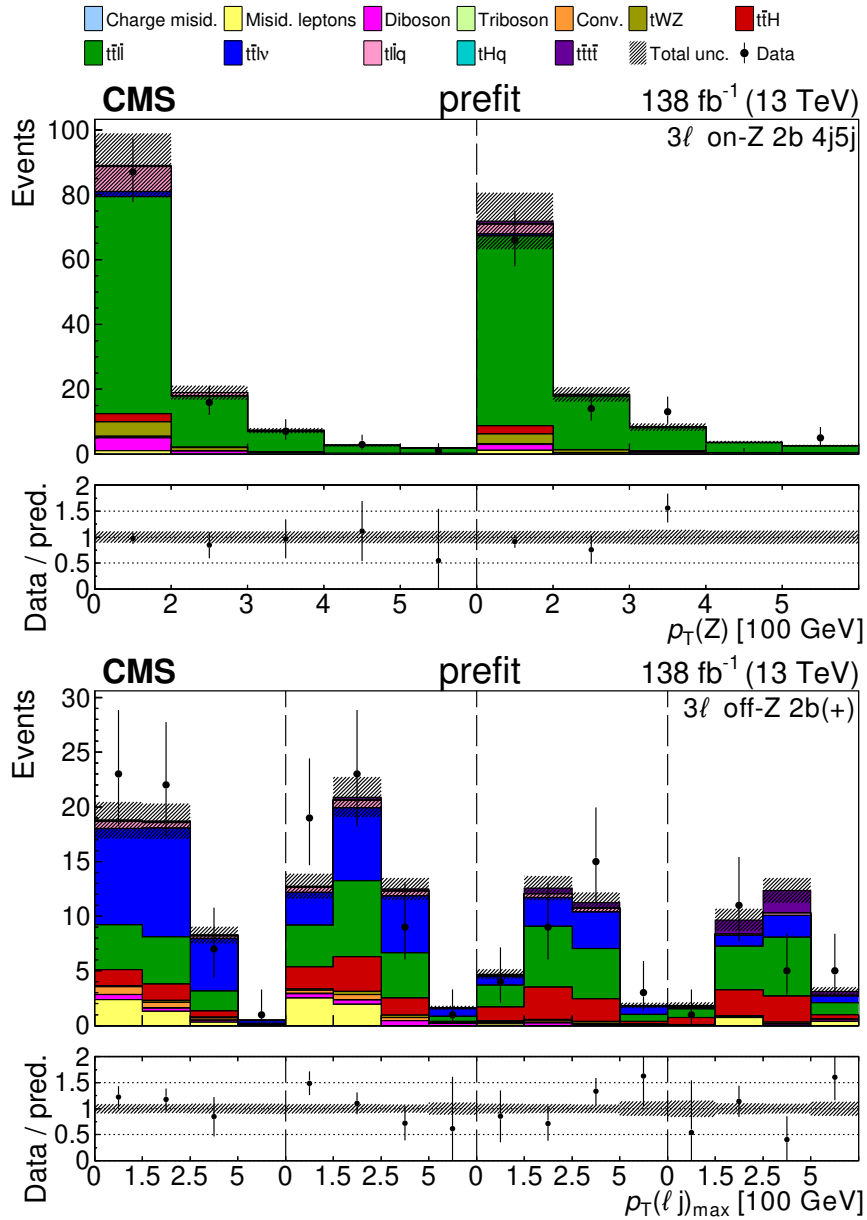
- **Signal yields ($\mathcal{N}$) are parametrised as a 26-dimensional quadratic function**
  - Including SM-EFT interference and EFT-EFT interference
- **Structure constants s_0, s_1, and s_2 obtained using MadGraph reweighting**

$$\mathcal{N}(\vec{C}/\Lambda^2) \propto \underbrace{s_0}_{\text{SM}} + \underbrace{(s_1)_i \frac{C_i}{\Lambda^2}}_{\text{Int. with SM}} + \underbrace{(s_2)_{ij} \frac{C_i C_j}{\Lambda^4}}_{\text{Pure EFT}}$$

EFT search in t($\bar{t}$)X [JHEP 12 (2023) 068]

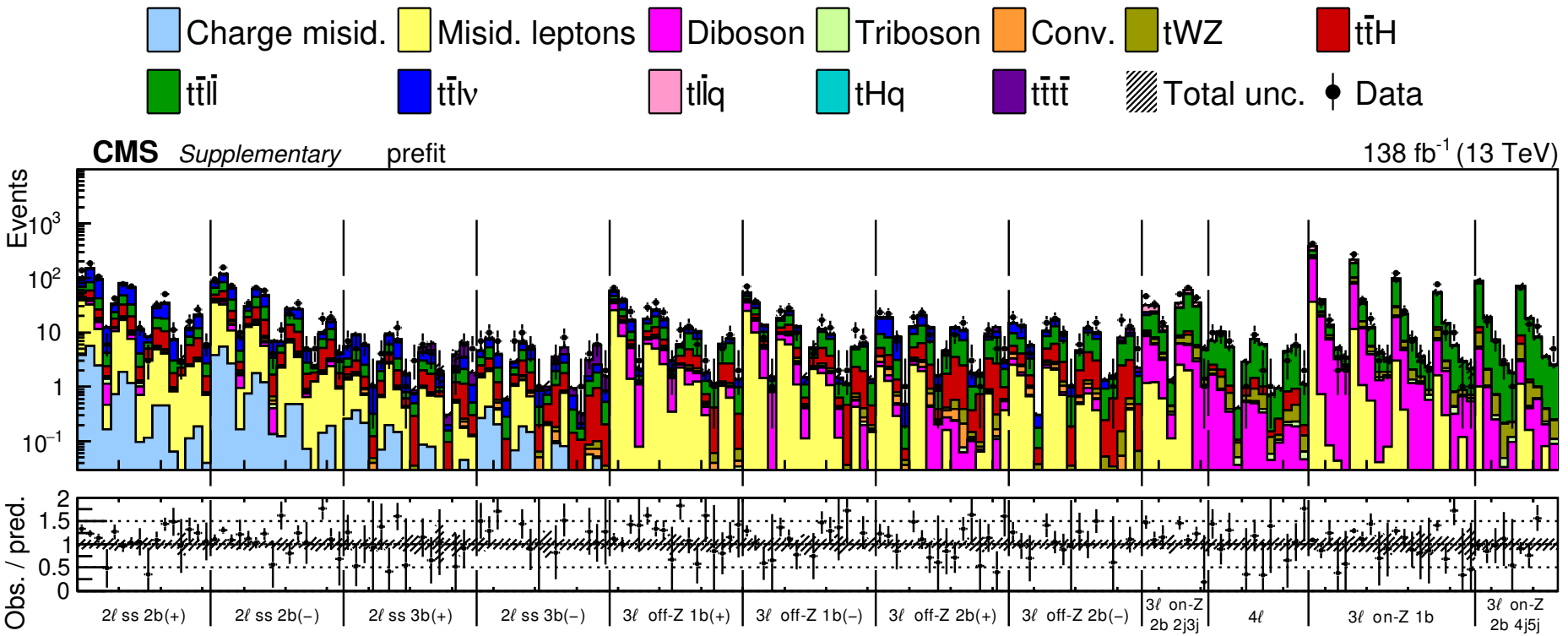
- **Events contain 2 same-sign (ss), 3 or 4 leptons**
  - Further divided into 43 categories
- **Kinematic variables are used to bin events in each category**
  - p_T of the most energetic pair of leptons and jets
  - Or p_T of the Z boson candidate





EFT search in t($\bar{t}$)X [JHEP 12 (2023) 068]

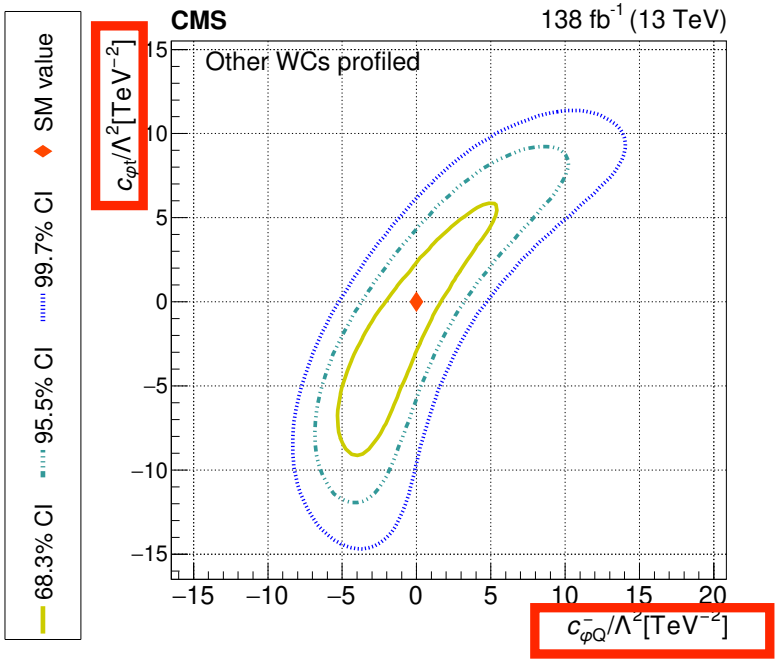
- **A total of 178 analysis bins**
  - 26-dimensional quadratic parameterization for each bin
- **Binned maximum likelihood fit**
  - 26 Wilson Coefficients (WCs) fitted together

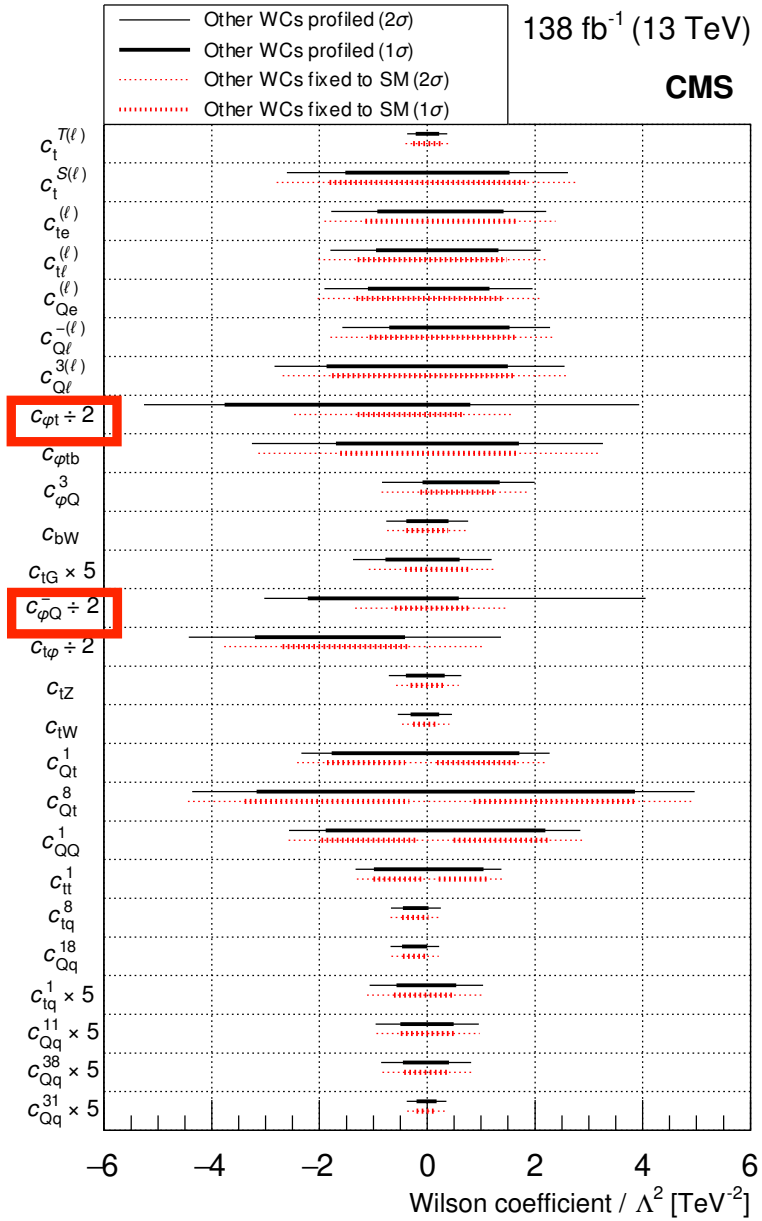


- **Nonprompt background and diboson production → dominate background**

EFT search in t($\bar{t}$)X [JHEP 12 (2023) 068]

- **Results compatible with the SM**
- **Confidence intervals for each WC are extracted by**
  - Fixing other WCs to zero
  - Or profiling other WCs
- **Improving previous constraints[a] by factors of 2 to 6**
  - 10 additional operators





[a] [JHEP 03 (2021) 095]

Lepton flavor violation [arXiv:2312.03199]

- **Lepton flavor is an accidental symmetry**
- **Search for LFV in 3ℓ (e or μ) final states**
  - Three leptons selected with custom (BDT) IDs
- **Probing 6 WCs individually**
  - 3 different Lorentz structure $\times$ 2 choices of light quark flavor

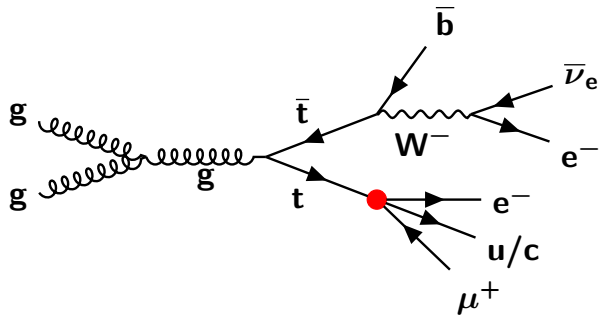


Figure 7: **LFV top decay**

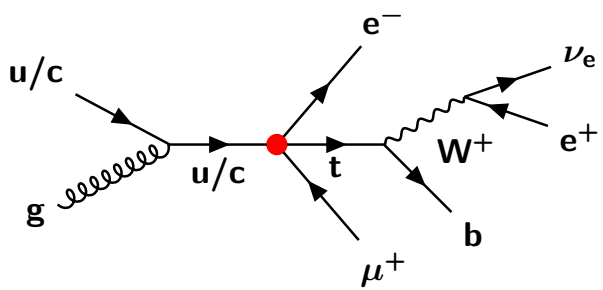


Figure 8: **LFV top production**

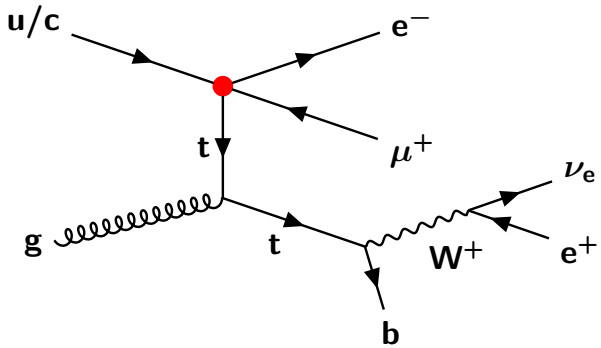


Figure 9: **LFV top production**

- **No SM-EFT or EFT-EFT interference considered**

$$\mathcal{N}(C_i/\Lambda^2) \propto \underbrace{[\frac{C_i}{\Lambda^2}]^2}_{\text{Pure EFT}}$$

Lepton flavor violation [arXiv:2312.03199]

- **Separate Signal Regions (SRs) to target top decay and production signals**
- **One binary Boosted Decision Tree (BDT) is trained for each SR**

Figure 10: **SR1: BDT targeting top decay**

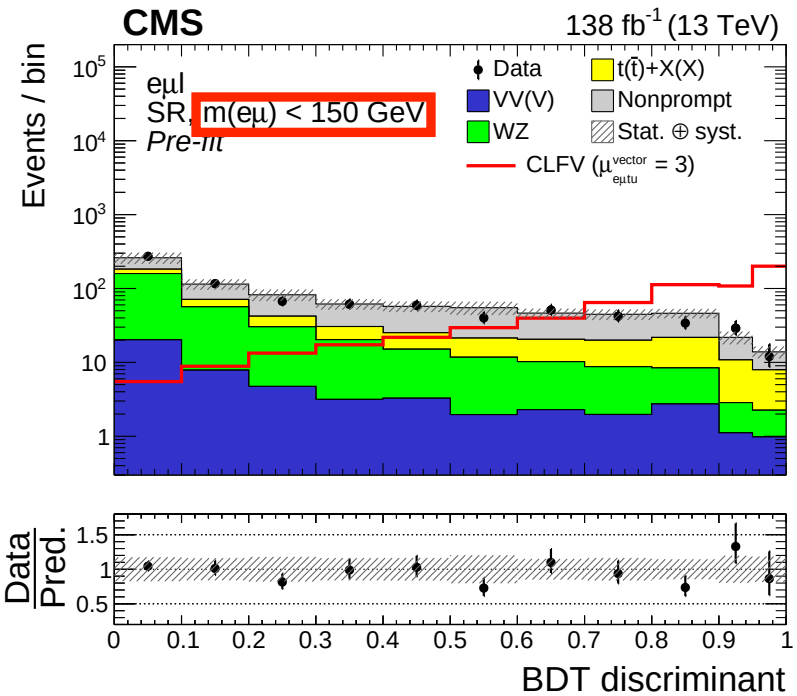
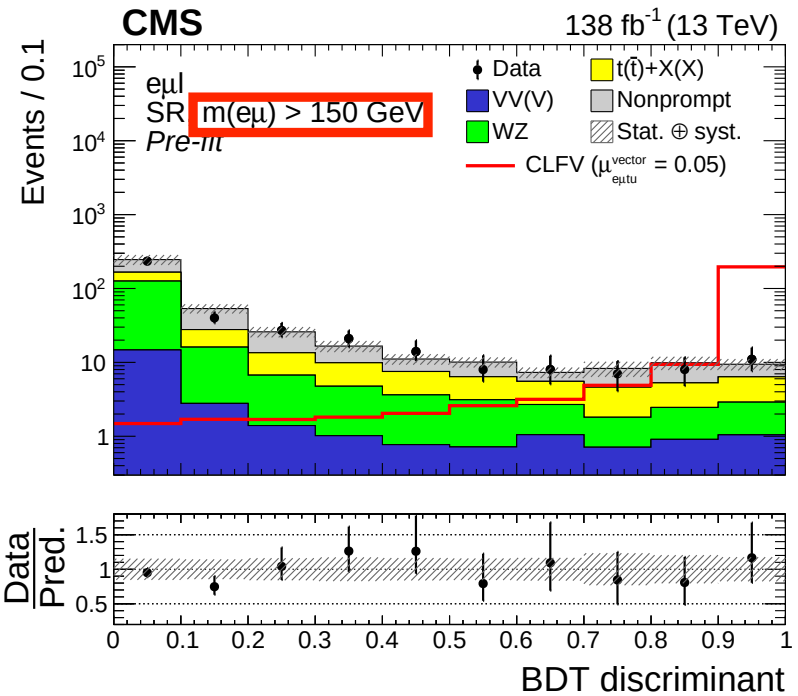


Figure 11: **SR2: BDT targeting top production**



- **No significant excess over SM expectations**
  - BDT output distributions used to set limits on WCs
- **Limits on WCs converted to limits on branching fractions of LFV top decay**

Lepton flavor violation [arXiv:2312.03199]

- **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	0.32	4.98
Vector	0.22	3.69
Scalar	0.12	2.16

Figure 12: **Upper limits on branching fractions**

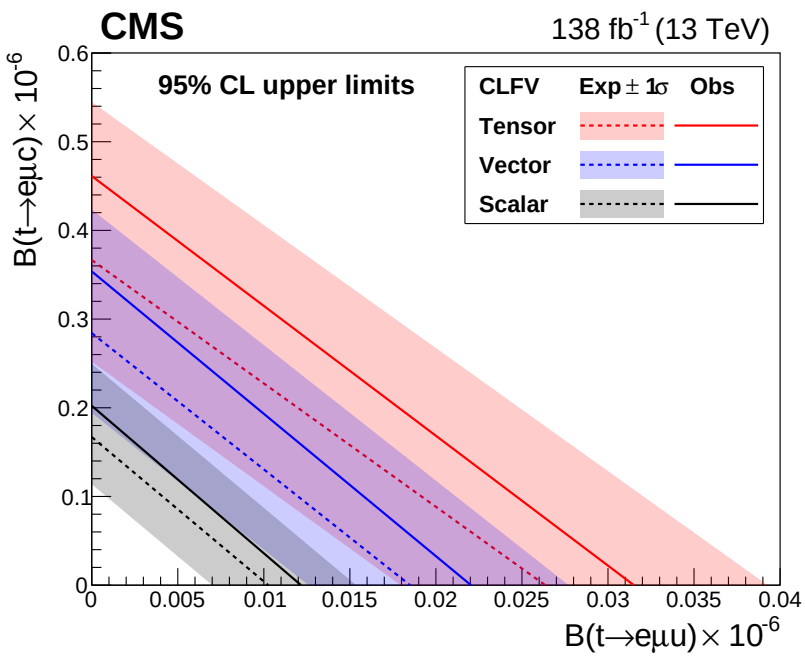
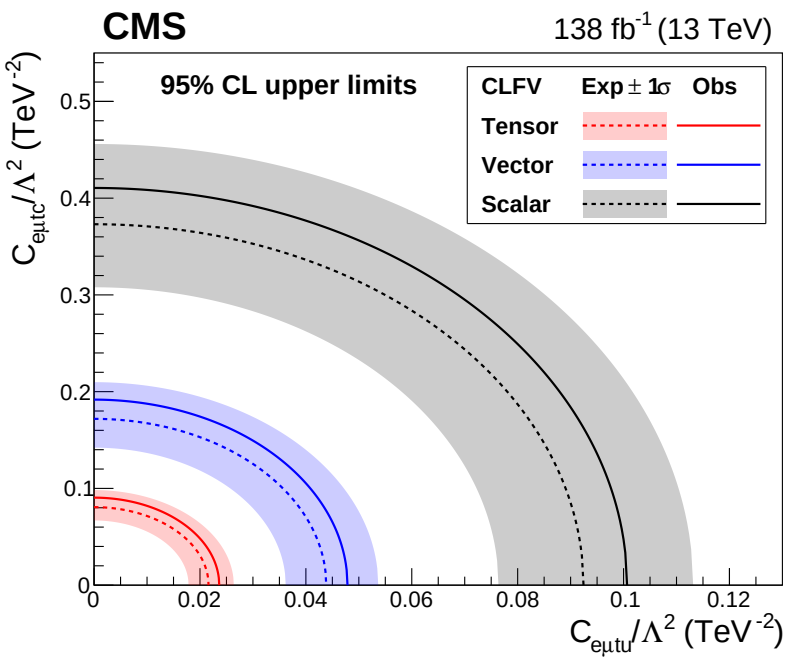


Figure 13: **Upper limits on Wilson coefficients**



- **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[b] (ATLAS[c]) results

[b] [arXiv:2201.07859] [c] [ATLAS-CONF-2018-044]

Baryon number violation [arXiv:2402.18461]

- **Baryon number is also an accidental symmetry**
- **Search for BNV in 2ℓ (e or μ) final states**
- **BNV (single) top production included for the first time**
  - Driving analysis sensitivity
- **A total of 24 WCs probed individually**
  - 6 quark-flavor combinations $\times$ *s vs. t* channel $\times$ 2 choices of lepton flavor

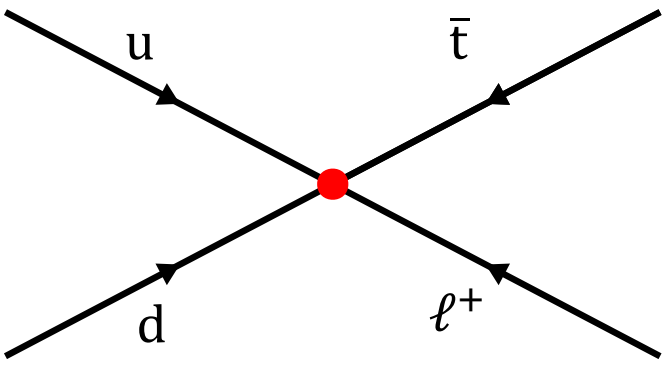


Figure 14: **BNV top production**

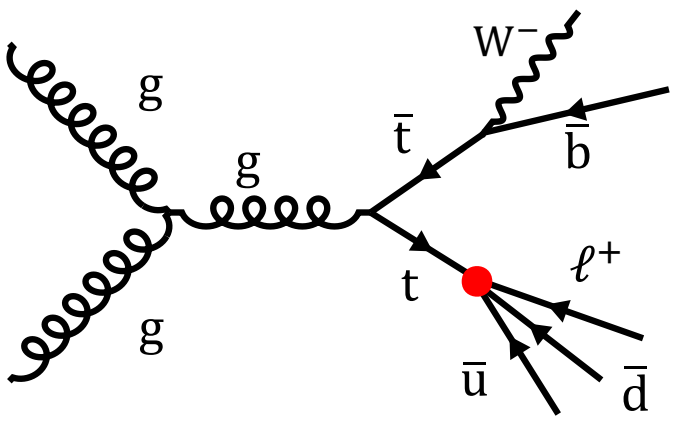
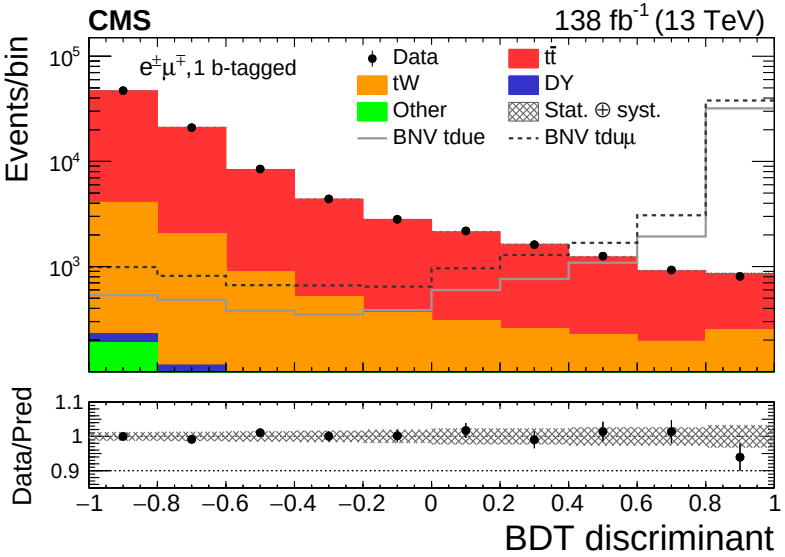


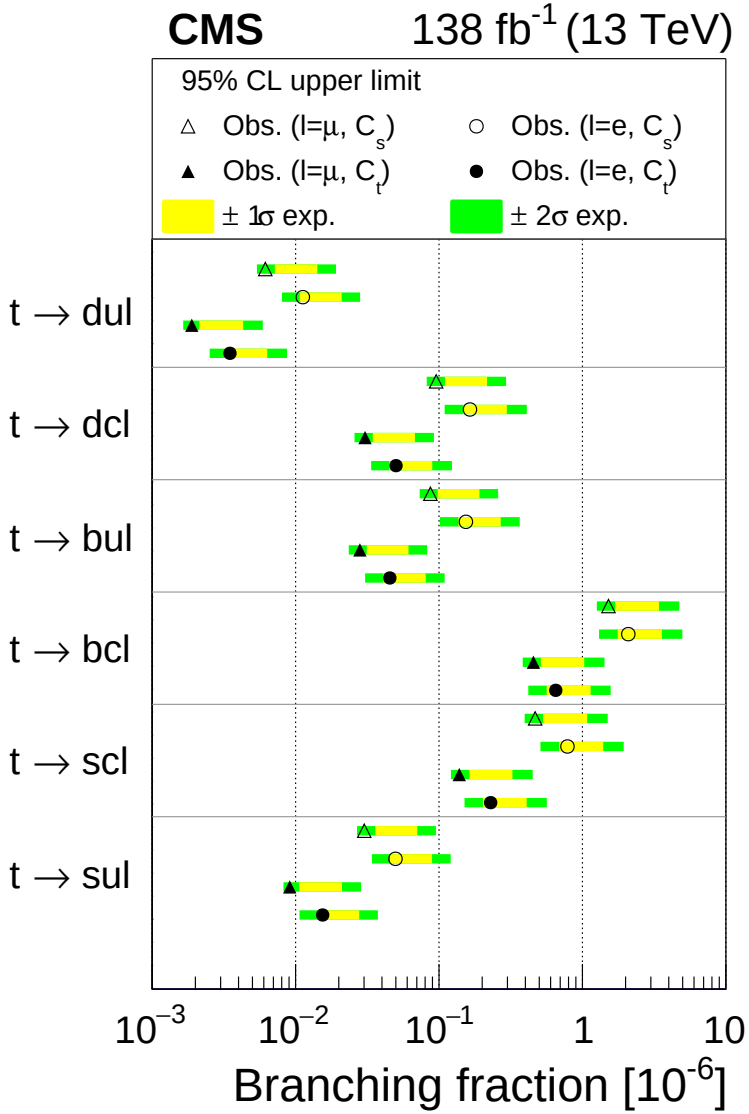
Figure 15: **BNV top decay**

- **Similar to the LFV analysis, no interferences are considered in this analysis**

Baryon number violation [arXiv:2402.18461]

- **BDT trained to distinguish signal from background**
- **No significant excess over SM expectations**
  - BDT output used to set limits on WCs, and converted to limits on BNV branching fractions
- **Improving previous limits[d] by multiple orders of magnitude**





[d] [PLB 731 (2014) 173]

Summary

- **EFT is a powerful tool to test the SM and search for New Physics**
- **Active and rich program of CMS EFT analyses in the top quark sector**
  - Measurements of rare SM processes, e.g. ttH, ttW, etc
  - Searches for BSM processes, e.g. LFV, BNV
- **All results compatible with the SM**

Thank you for listening!