Measurements of rare top production and their BSM interpretations with CMS

Jiwon Park

DESY,
on behalf of the CMS Collaboration

EPS-HEP 2025, Marseille, France

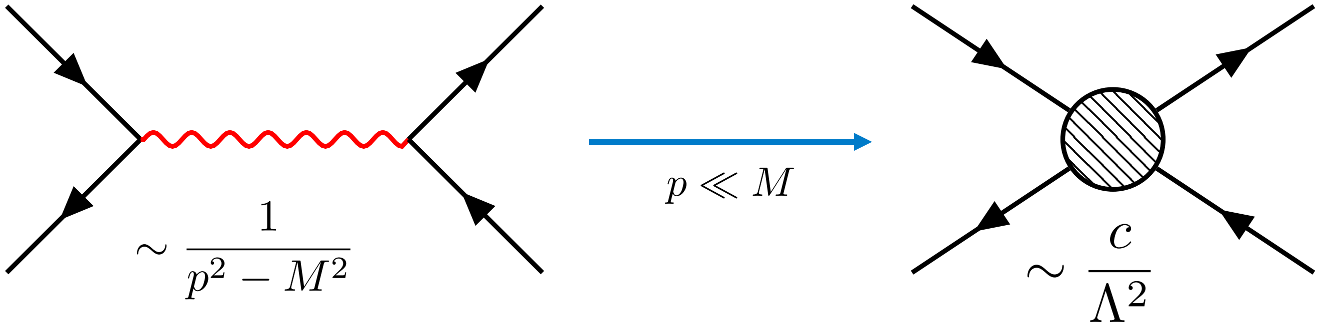
10 July, 2025

Effective field theory

Where is the new physics?

Standard model is known to be incomplete, new physics has to exist somewhere

- No clear guidance on where to explore
- EFT provides relatively model-independent and structured approach



$$\mathcal{L}_{\text{EFT}} = \mathcal{L}_{\text{SM}} + \sum_{d,i} \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

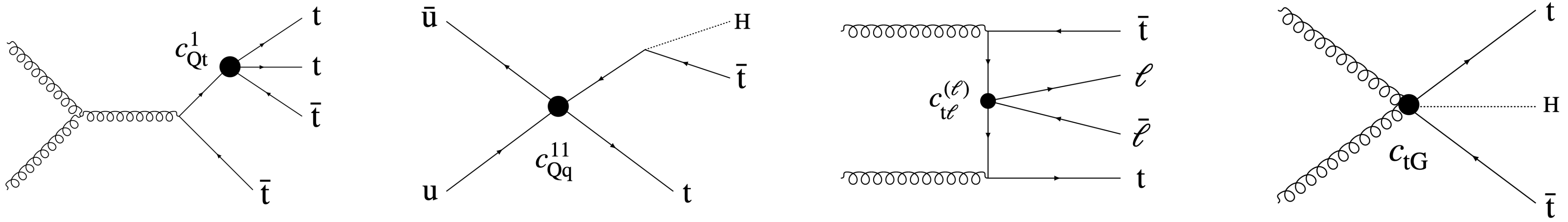
d: Dimension
c_i: Wilson coefficient
O: EFT operator
Λ: New physics scale (typically set to 1 TeV)

EFT allows to explore heavy new physics over the LHC limit on direct search

Recent top quark related EFT analyses in CMS

t($\bar{t}$) + X production — boosted $t\bar{t}Z/H$ (PRD 108 (2023) 032008), t($\bar{t}$)+leptons (JHEP 12 (2023) 068),

- 4 heavy quarks / 2 heavy quarks and 2 light quarks / 2 heavy quarks and 2 leptons / 2 heavy quarks and boson



Baryon number violations (Phys. Rev. Lett. 132, 241802)

Lepton flavor violations — trilepton (Phys. Rev. D 111, 012009) and $\mu\tau$ final states (arxiv:2504.08532)

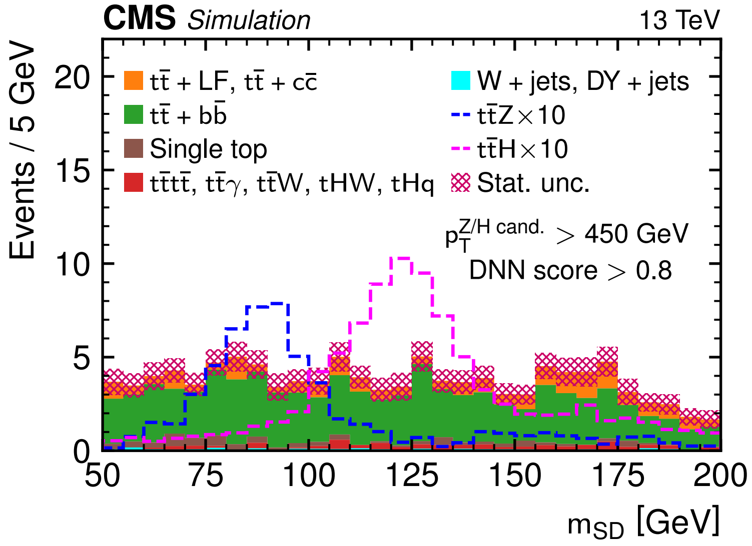
Flavor changing neutral current interactions — Hqt, H → WW/ZZ/$\tau\tau$ (arXiv:2407.15172)

Flavor structure (CMS-PAS-TOP-23-009) and CP violation (arXiv:2505.21206)
→ **Sergio's talk** later in this session

CMS collaboration has investigated a variety of EFT programs

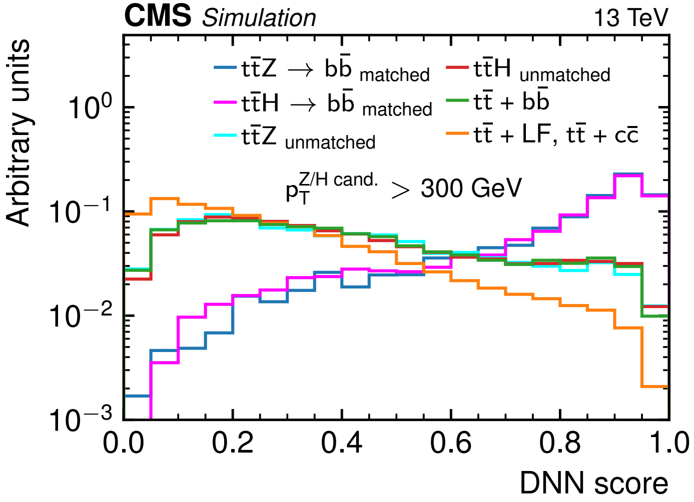
Search for new physics in $t\bar{t}$ + boosted Z/H

Phys. Rev. D 108, 032008

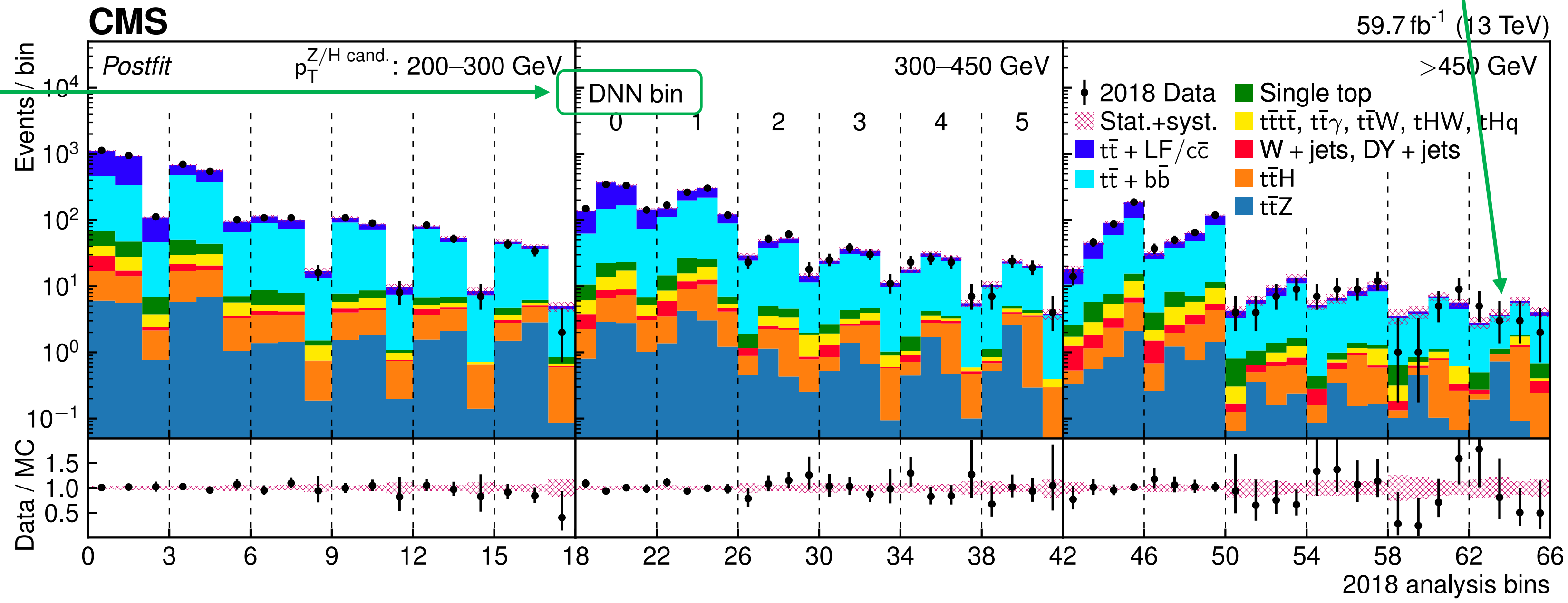


Several WCs strongly affect high p_T (Z/H) region

- Events with one isolated lepton and jets
  - AK8 jet for boostd Z/H → bb decay, identified with DeepAK8 bb-tagger
- Deep neural network (DNN) for boosted $t\bar{t}$Z/H vs backgrounds



66 analysis bins using p_T(Z/H), NN score, and m_{SD}

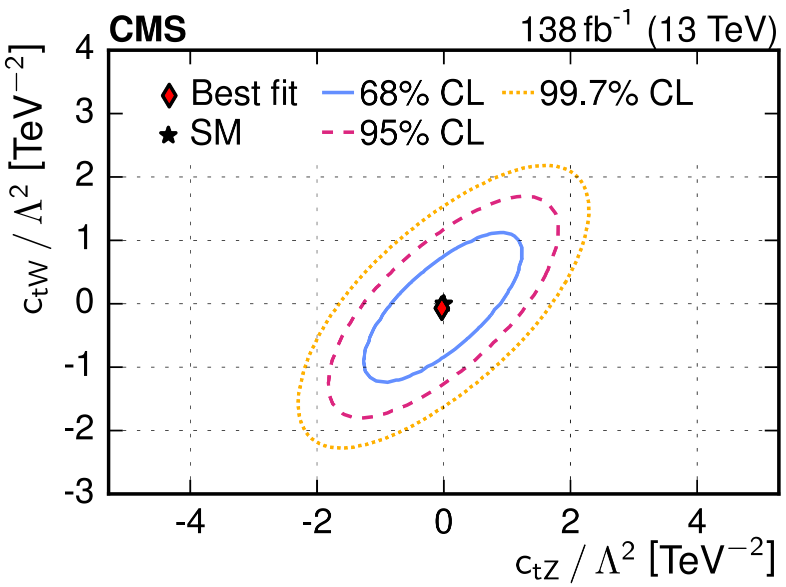


Search for new physics in $t\bar{t}$ + boosted Z/H

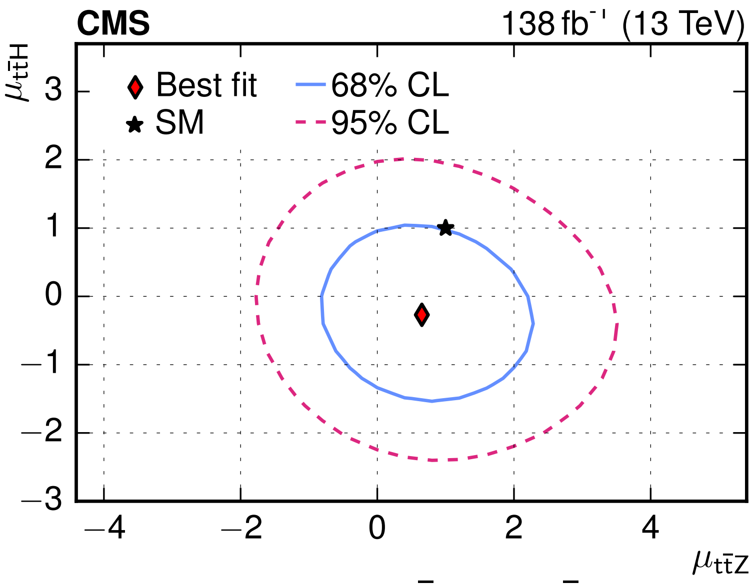
Phys. Rev. D 108, 032008

Profiled likelihood fit and set EFT constraints

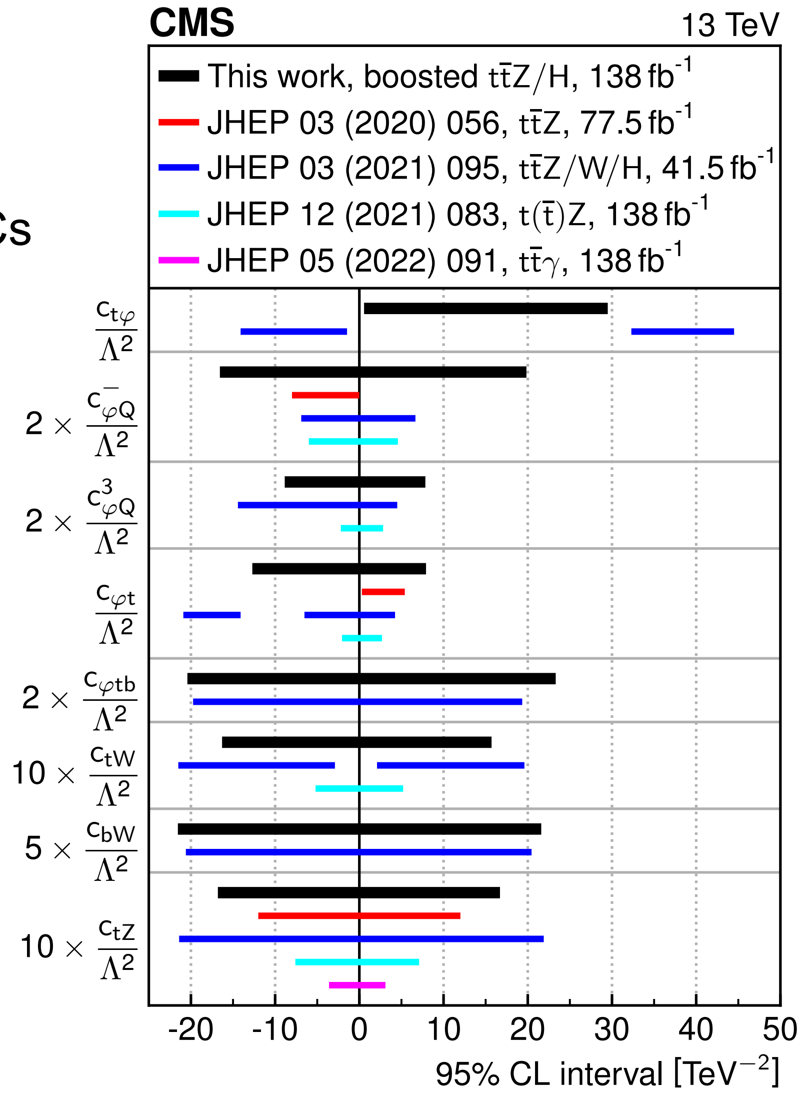
- Vary the $t\bar{t}Z/H$ signal and $t\bar{t}$+bb background as functions of the WCs
- 2D / 1D likelihood scans are performed to check correlations between WCs
- Consistent with SM at 95% CL



correlation between C_{tW} and C_{tZ}



observed $t\bar{t}Z$ and $t\bar{t}H$ signal strengths



Search for new physics in $t(\bar{t})$ + additional leptons

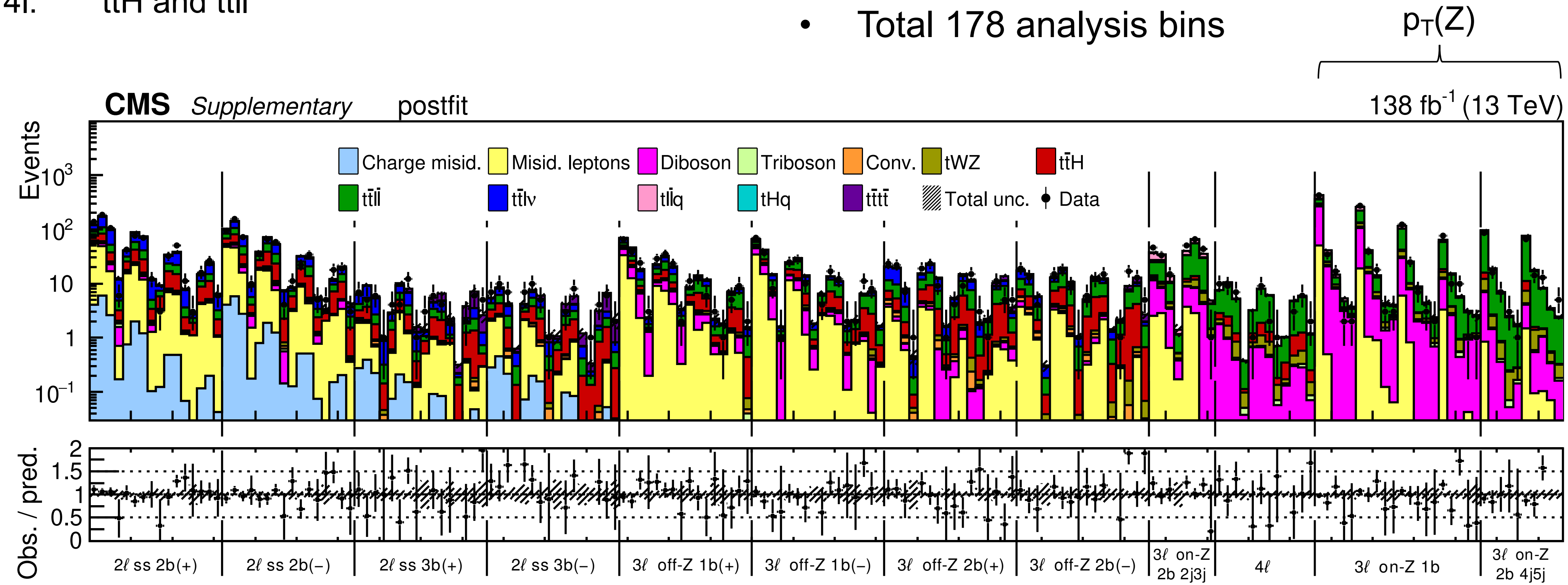
JHEP 12 (2023) 068

Explore leptonic final states including top quarks

- Event categories for $t\bar{t}t\bar{t}$, $t\bar{t}W$, $t\bar{t}X$, and tXq (X=Z,H)
  - 2lss: ttH and ttW
  - 3l on Z: ttll (2b), tllq (1b)
  - 3l off Z: non-resonant ttll and tllq
  - ≥ 4l: ttH and ttll

Differential analysis

- Bins in lepton charge sum, jet and b-jet multiplicities
- Kinematic variable in each bin
  - $p_T(lj)_{max}$: p_T of leading lepton + jet pairs
  - $p_T(Z)$: where Z kinematics are sensitive
- Total 178 analysis bins

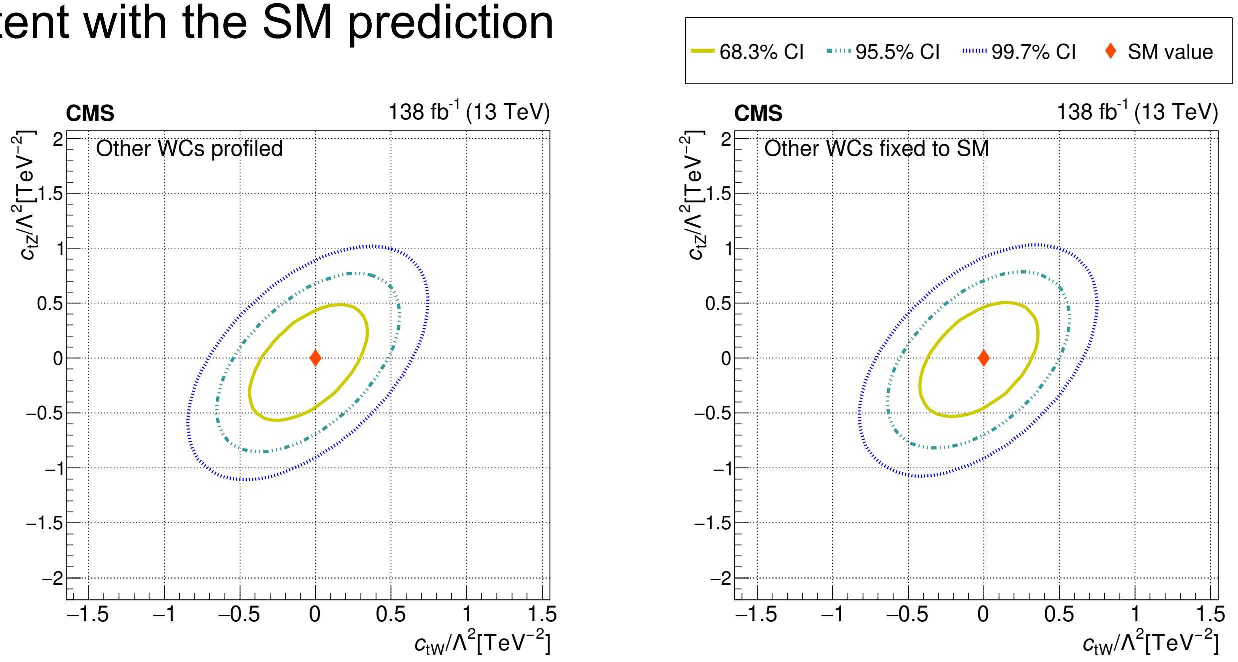


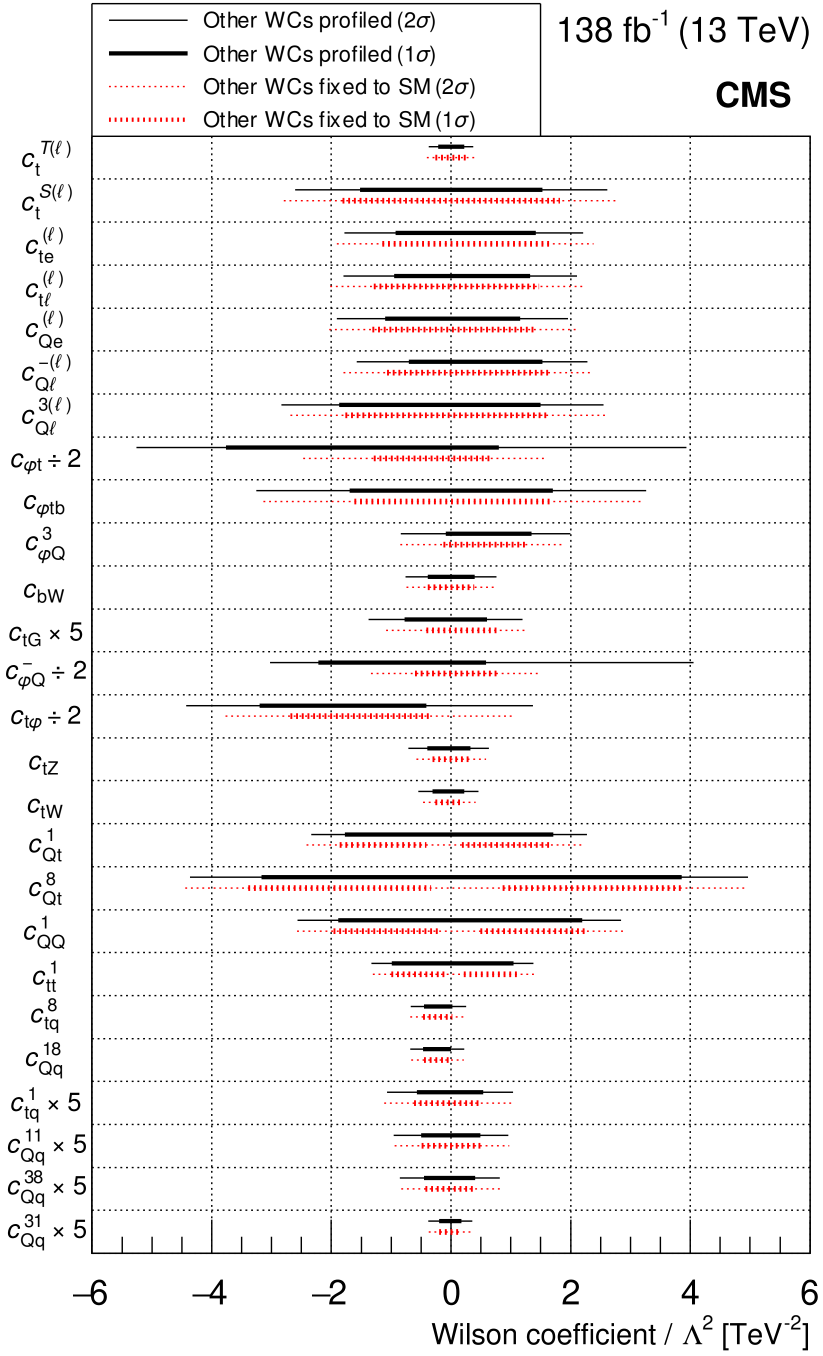
Search for new physics in $t(\bar{t})$ + leptons

JHEP 12 (2023) 068

Profiled likelihood fit and set EFT constraints

- Fit with all 26 WCs on / fits with only one WC
- Additional fits are performed to identify
  - sensitive analysis bins to WCs
  - correlations between WCs
- Results dominated by statistical uncertainties
- Consistent with the SM prediction



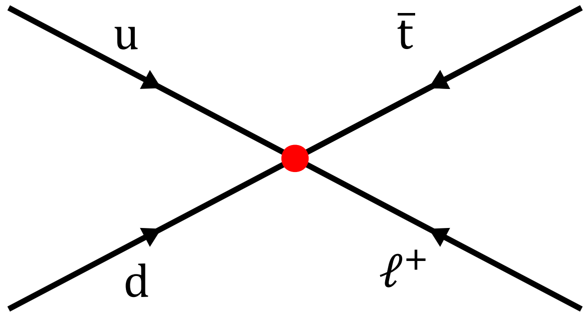


Search for baryon number violation

Phys. Rev. Lett. 132, 241802

High sensitivity for potential high-energy BNV processes involving the top quark at LHC

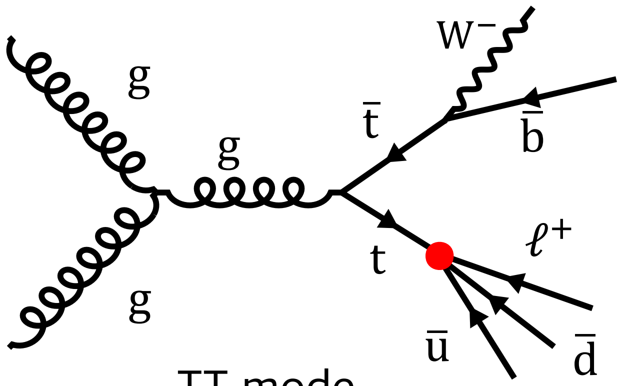
- General effective Lagrangian for BNV: $\mathcal{L}_{\text{eff}} = \frac{C_s}{\Lambda^2}\epsilon^{\alpha\beta\gamma}[\overline{t^c_\alpha} d_\gamma][\overline{u^c_\beta}\ell] + \frac{C_t}{\Lambda^2}\epsilon^{\alpha\beta\gamma}[\overline{t^c_\alpha}\ell][\overline{u^c_\beta} d_\gamma] + \text{H.c.}$
- Total 2 * 6 * 2 = 24 couplings
  - C_s, C_t : s and t channel couplings (2)
  - Quarks: (u, c) ⊗ (d, s, b) (6)
  - Leptons: e or μ (2)
- ST modes are the leading BNV processes



ST mode

Search strategy

- Leptonic final state of SM top quark
- Events with OS lepton pair, one b-jet, and p_T^{miss}
- Signal discrimination in each lepton channel (ee, $e\mu$, $\mu\mu$)
- Perform fit for individual coupling



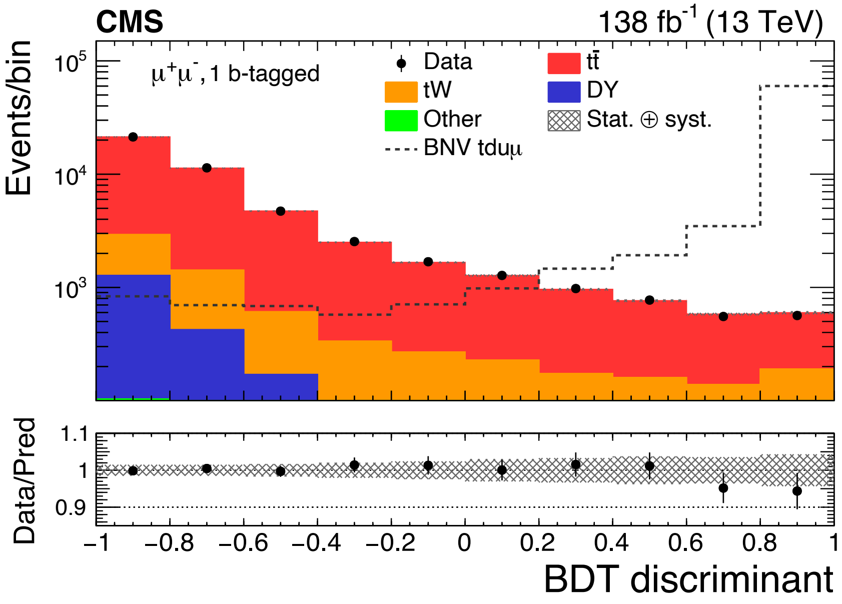
TT mode

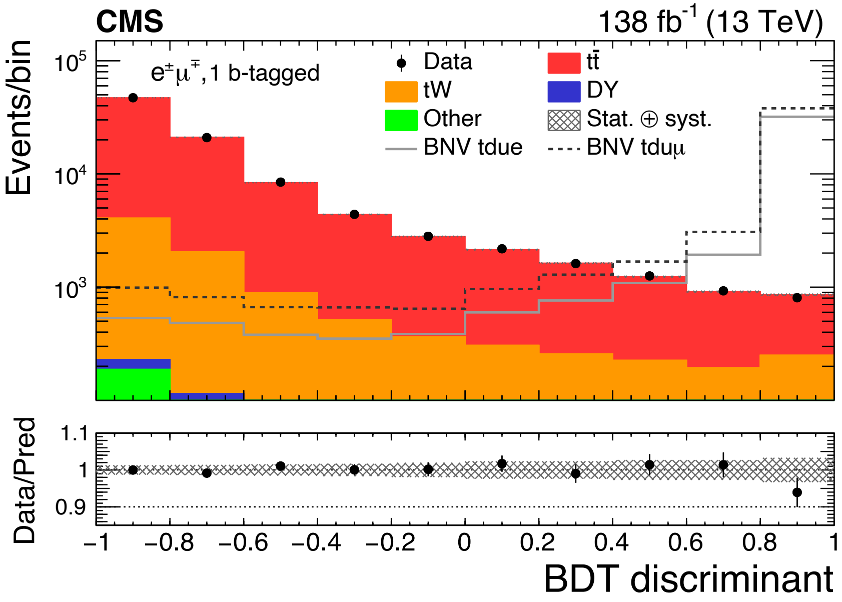
Search for baryon number violation

Phys. Rev. Lett. 132, 241802

Signal discrimination with BDT

- Top quark reconstruction
  - Leading lepton is directly produced from the vertex in the ST mode
  - Use subleading lepton, neutrino, and b-jet for top quark
- Train boosted decision trees (BDTs) for signals vs background ($t\bar{t}$, tW and Z+jets)
  - Inputs: Kinematic properties of leptons, top quark candidate, and dilepton system
- Postfit distributions of SM prediction and of BNV signals
  - Signals are normalized to $C_s = C_t = 1$
  - teud (solid gray line) and $t\mu$ud (dashed black line) are shown



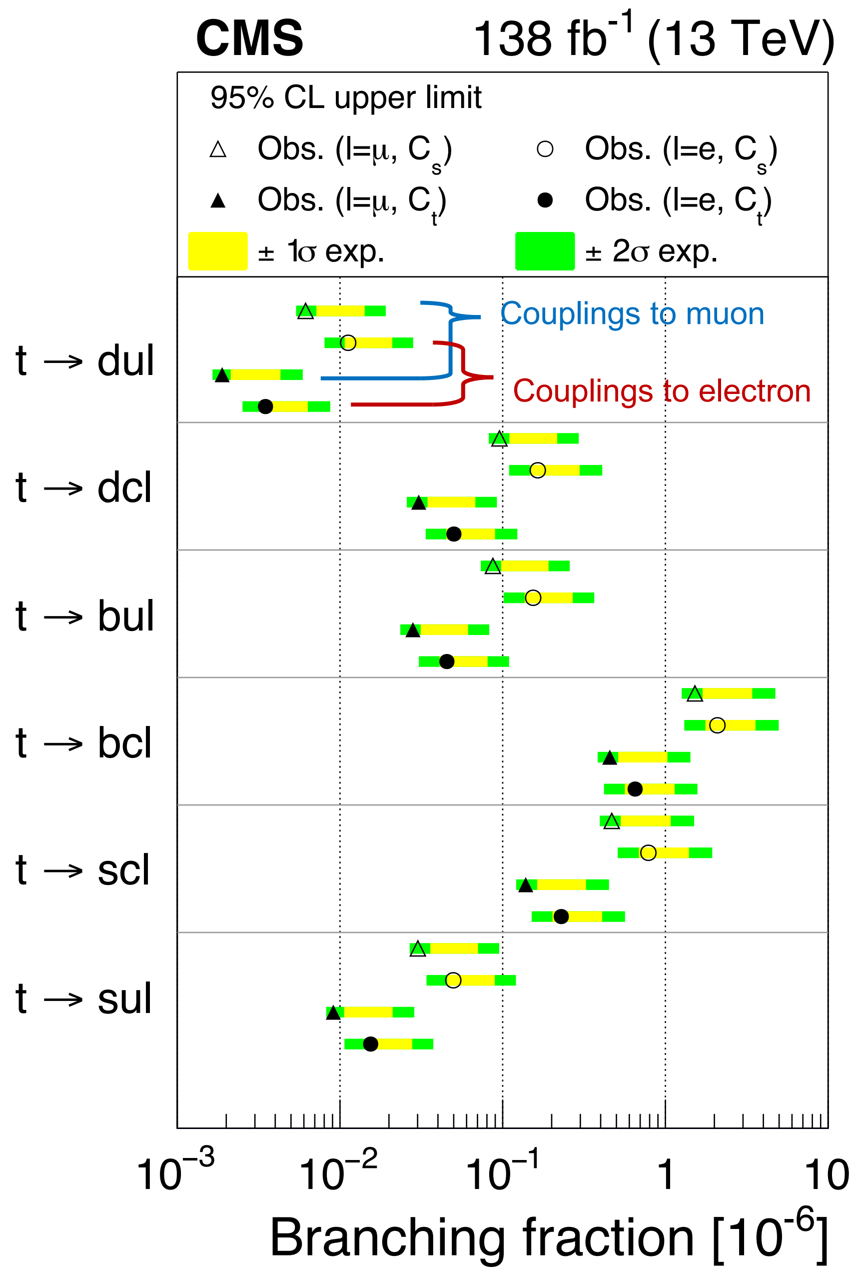


Search for baryon number violation

Phys. Rev. Lett. 132, 241802

Results

- Simultaneous binned maximum-likelihood fit on BDT distributions
- No significant deviation from the SM prediction
- Upper limits on the BNV couplings and branching fractions for the BNV top quark decays are set
- Limits on branching fractions range from 10^{-6} to 10^{-8}
- Improved limits on branching fractions of $O(10^{-3})$ from 8 TeV results by multiple orders of magnitude (Phys.Lett.B 731 (2014) 173)

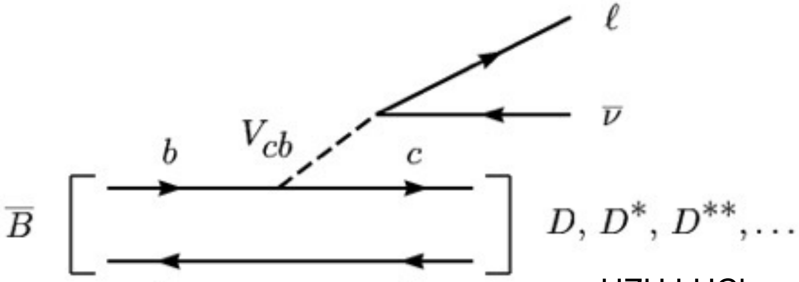


Search for charged-lepton flavor violation in tq$\mu\tau$ interaction

arXiv:2504.08532 (submitted to JHEP)

Inspired by excessive τ decays observed in B physics results (HFLAV 2025)

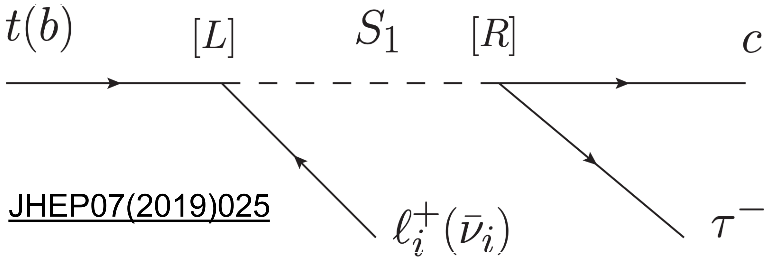
- Can be explained by CLFV with τ lepton (e.g. leptoquark)
- It might be visible in top quark interactions
  → Use EFT for generalized approach



UZH LHCb

Semileptonic B decay in SM

Scalar leptonquark S_1



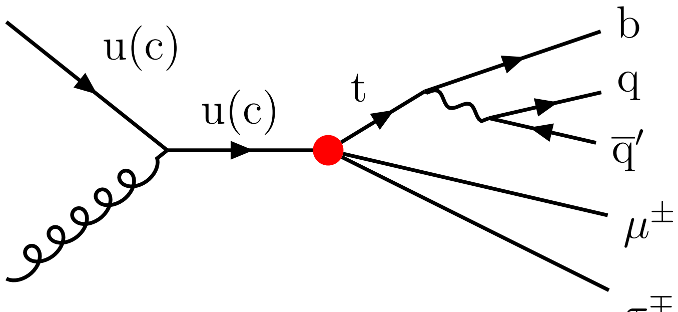
JHEP07(2019)025

Signals are categorized by Lorentz structure of EFT operators

- Scalar / vector / tensor types in tq$\mu\tau$ interactions
- ST CLFVs are the leading contribution
  - Highly energetic μ and τ
  - Larger production rate in u-channel

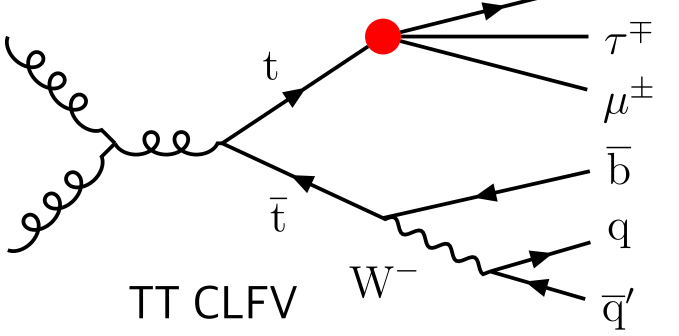
Search strategy

- Select events with OS $\mu\tau$ + jets
- Signal discrimination using DNN
- Perform fit for individual WC



ST CLFV

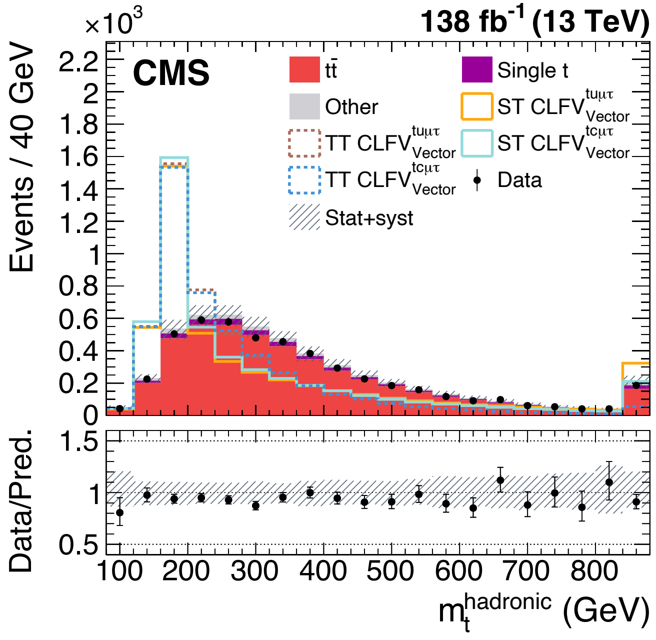
This analysis: dim-6 EFT



TT CLFV

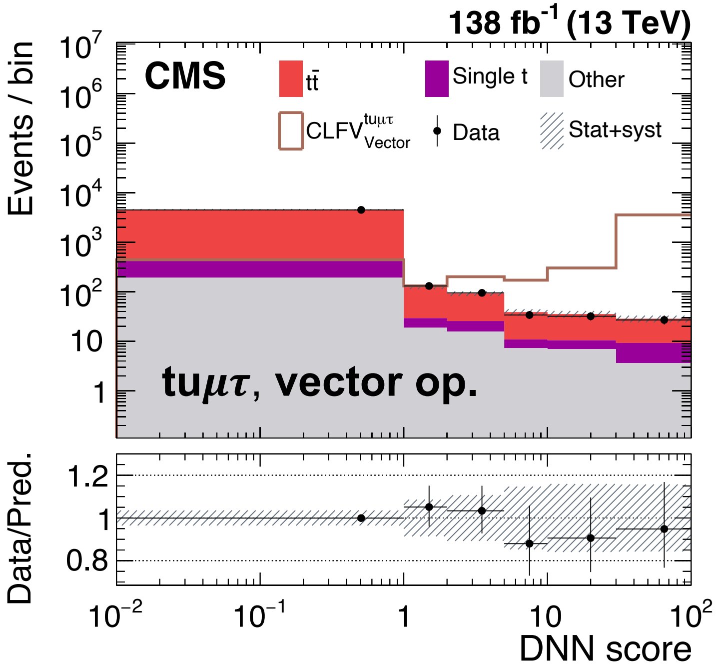
Search for charged-lepton flavor violation in tq$\mu\tau$ interaction

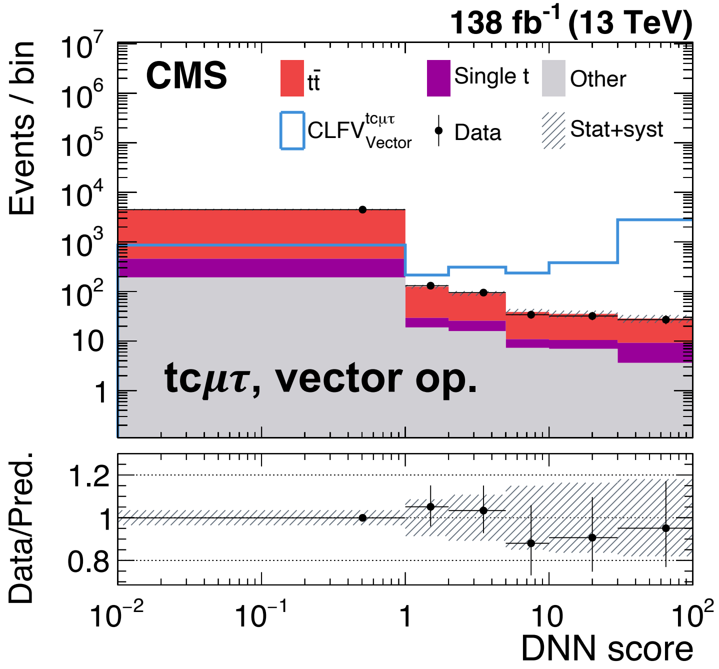
arXiv:2504.08532 (submitted to JHEP)



Signal discrimination with multiclass DNN

- Hadronic top quark is reconstructed targeting signals
- Multiclass DNN for ST CLFV / TT CLFV / backgrounds
  - Inputs: Kinematic variables of μ, τ, jets, MET, reconstructed top quark
  - Final distribution: $\mathrm{DNN\,score} = \dfrac{0.1p(\mathrm{TT\ CLFV}) + 0.9p(\mathrm{ST\ CLFV})}{p(\mathrm{background})}$





Postfit distribution for the vector operators

Signal yields are normalized to data

Search for charged-lepton flavor violation in tq$\mu\tau$ interaction

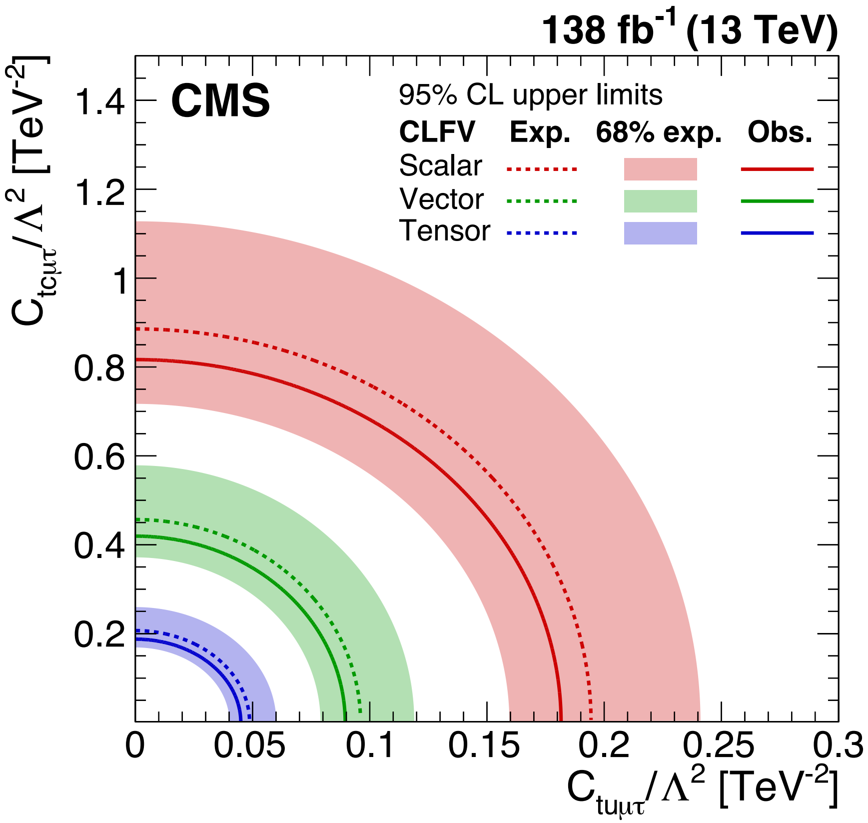
arXiv:2504.08532 (submitted to JHEP)

Results

- Perform a profile likelihood fit for each WC
- Limits on branching fractions range from 10^{-6} to 10^{-8}
- Set the most stringent limits on the tq$\mu\tau$ CLFV interactions

Observed (expected) limits and 68% interval containing expected limits

Interaction	Type	σ [fb]	$C_{tq\mu\tau}/\Lambda^2$ [TeV^{-2}]	$\mathcal{B}(t \to \mu\tau q)$ [10^{-6}]
tu$\mu\tau$	Scalar	2.039 (2.337)	0.182 (0.194)	0.040 (0.046)
		[1.574, 3.594]	[0.160, 0.241]	[0.031, 0.071]
	Vector	2.384 (2.746)	0.090 (0.096)	0.078 (0.090)
		[1.857, 4.213]	[0.079, 0.119]	[0.061, 0.138]
	Tensor	2.834 (3.326)	0.045 (0.049)	0.118 (0.138)
		[2.257, 5.063]	[0.040, 0.060]	[0.094, 0.211]
tc$\mu\tau$	Scalar	4.269 (5.020)	0.817 (0.886)	0.810 (0.953)
		[3.291, 8.142]	[0.717, 1.128]	[0.625, 1.545]
	Vector	7.213 (8.552)	0.419 (0.457)	1.710 (2.027)
		[5.663, 13.734]	[0.372, 0.579]	[1.342, 3.255]
	Tensor	7.927 (9.633)	0.188 (0.207)	2.052 (2.494)
		[6.427, 15.200]	[0.169, 0.260]	[1.664, 3.936]



Outlook

EFT approaches are widely used in CMS to search for new physics in the TOP sector

Results remain consistent with Standard Model predictions

- Global EFT analyses simultaneously constrain multiple Wilson coefficients and probe their correlations
- Searches targeting final states from new physics set stringent limits on interaction couplings

Many EFT analyses on rare top quark processes are still limited by data statistics

CMS collaboration is analyzing data from the ongoing Run 3 (2022 - 2026) data-taking period

Exciting updates coming soon — stay tuned!

Thank you

Contact

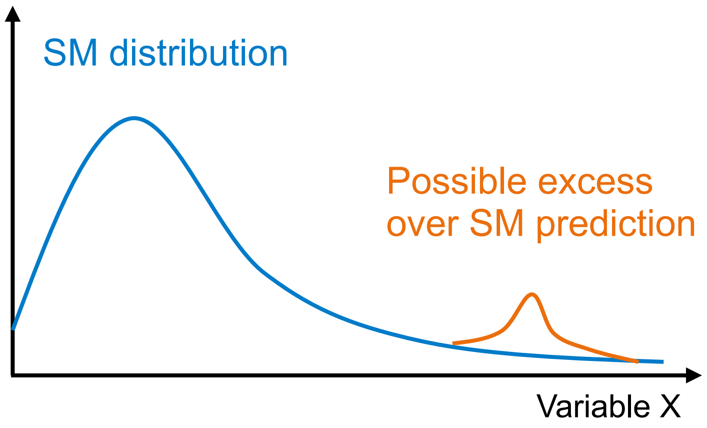
Deutsches Elektronen-
Synchrotron DESY

www.desy.de

Jiwon Park
CMS
jiwon.park@cern.ch

Overview

EFT measurements, searches, and their fits by the CMS collaboration



Effective field theory (EFT) in top quark physics

- What is EFT?
- Why are EFT approaches important?

Global EFT analysis with rare top quark processes

- Focus on the top quark production + other particles
- Probe discrepancies between data and the standard model with multiple EFT operators
- $t\bar{t}$ + boosted Z/H (PhysRevD.108.032008) and $t(\bar{t})$ + additional leptons (JHEP12(2023)068)

Searches for beyond-the-SM with EFT

- Directly model BSM event signatures and search for new physics
- Use multivariate techniques to maximize signal sensitivity
- Baryon number violation (PhysRevLett.132.241802) and charged lepton flavor violation (arXiv:2504.08532)

Searches for new physics in $t\bar{t}$ + boosted Z/H

PhysRevD.108.032008

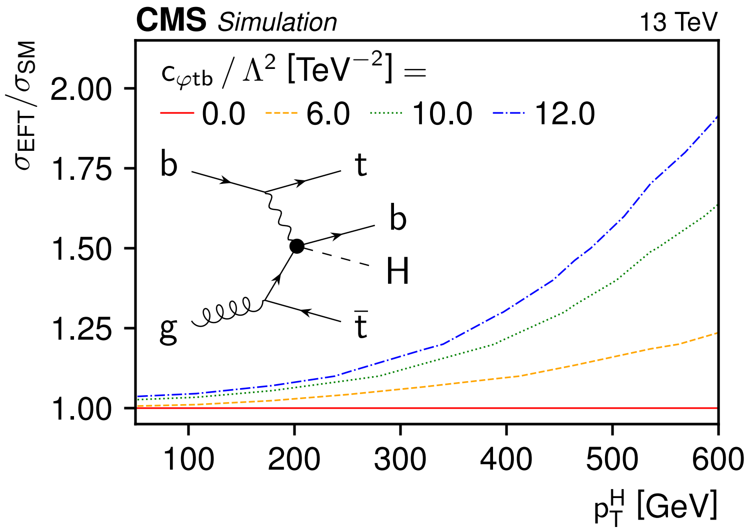
List of EFT operators and corresponding WCs

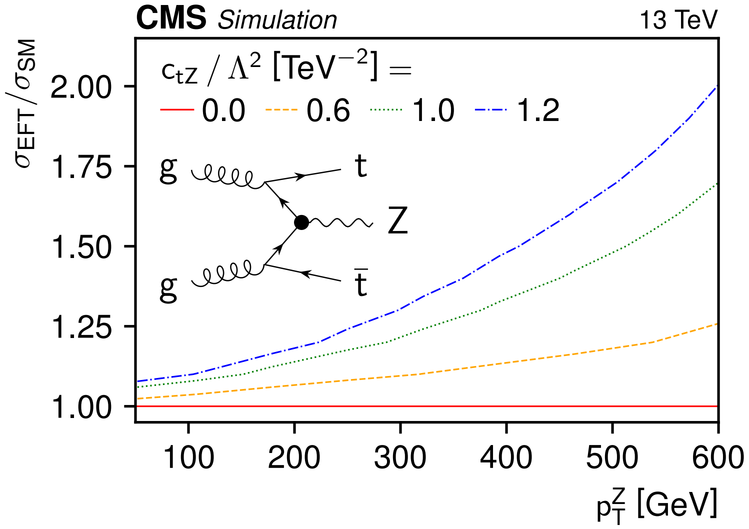
Operator	Definition	WC
$^{\ddagger}O^{(ij)}_{u\varphi}$	$\bar{q}_i u_j \tilde{\varphi}\,(\varphi^\dagger\varphi)$	$c_{t\varphi} + i c^{I}_{t\varphi}$
$O^{(ij)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{q}_i\gamma^\mu q_j)$	$c^{-}_{\varphi Q} + c^{3}_{\varphi Q}$
$O^{3(ij)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}^{I}_\mu\varphi)(\bar{q}_i\gamma^\mu\tau^I q_j)$	$c^{3}_{\varphi Q}$
$O^{(ij)}_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_i\gamma^\mu u_j)$	$c_{\varphi t}$
$^{\ddagger}O^{(ij)}_{\varphi ud}$	$(\tilde{\varphi}^\dagger iD_\mu\varphi)(\bar{u}_i\gamma^\mu d_j)$	$c_{\varphi tb} + i c^{I}_{\varphi tb}$
$^{\ddagger}O^{(ij)}_{uW}$	$(\bar{q}_i\sigma^{\mu\nu}\tau^I u_j)\,\tilde{\varphi}W^{I}_{\mu\nu}$	$c_{tW} + i c^{I}_{tW}$
$^{\ddagger}O^{(ij)}_{dW}$	$(\bar{q}_i\sigma^{\mu\nu}\tau^I d_j)\,\varphi W^{I}_{\mu\nu}$	$c_{bW} + i c^{I}_{bW}$
$^{\ddagger}O^{(ij)}_{uB}$	$(\bar{q}_i\sigma^{\mu\nu}u_j)\,\tilde{\varphi}B_{\mu\nu}$	$\frac{c_W}{s_W}(c_{tW} + i c^{I}_{tW}) - \frac{1}{s_W}(c_{tZ} + i c^{I}_{tZ})$

Results in table

WC/Λ^2	95% CL interval [TeV^{-2}]	
	(Others profiled)	(Others fixed to SM)
$c_{t\varphi}/\Lambda^2$	[0.56, 30]	[0.20, 30]
$c^{-}_{\varphi Q}/\Lambda^2$	[−8.3, 9.9]	[−6.6, 8.7]
$c^{3}_{\varphi Q}/\Lambda^2$	[−4.4, 3.9]	[−4.1, 3.0]
$c_{\varphi t}/\Lambda^2$	[−13, 7.9]	[−12, 6.3]
$c_{\varphi tb}/\Lambda^2$	[−10, 12]	[−9.9, 11]
c_{tW}/Λ^2	[−1.6, 1.6]	[−1.0, 0.96]
c_{bW}/Λ^2	[−4.3, 4.3]	[−4.2, 4.2]
c_{tZ}/Λ^2	[−1.7, 1.7]	[−1.0, 1.1]

EFT effects on p_T(Z/H)





Searches for new physics in $t\bar{t}$ + boosted Z/H

PhysRevD.108.032008

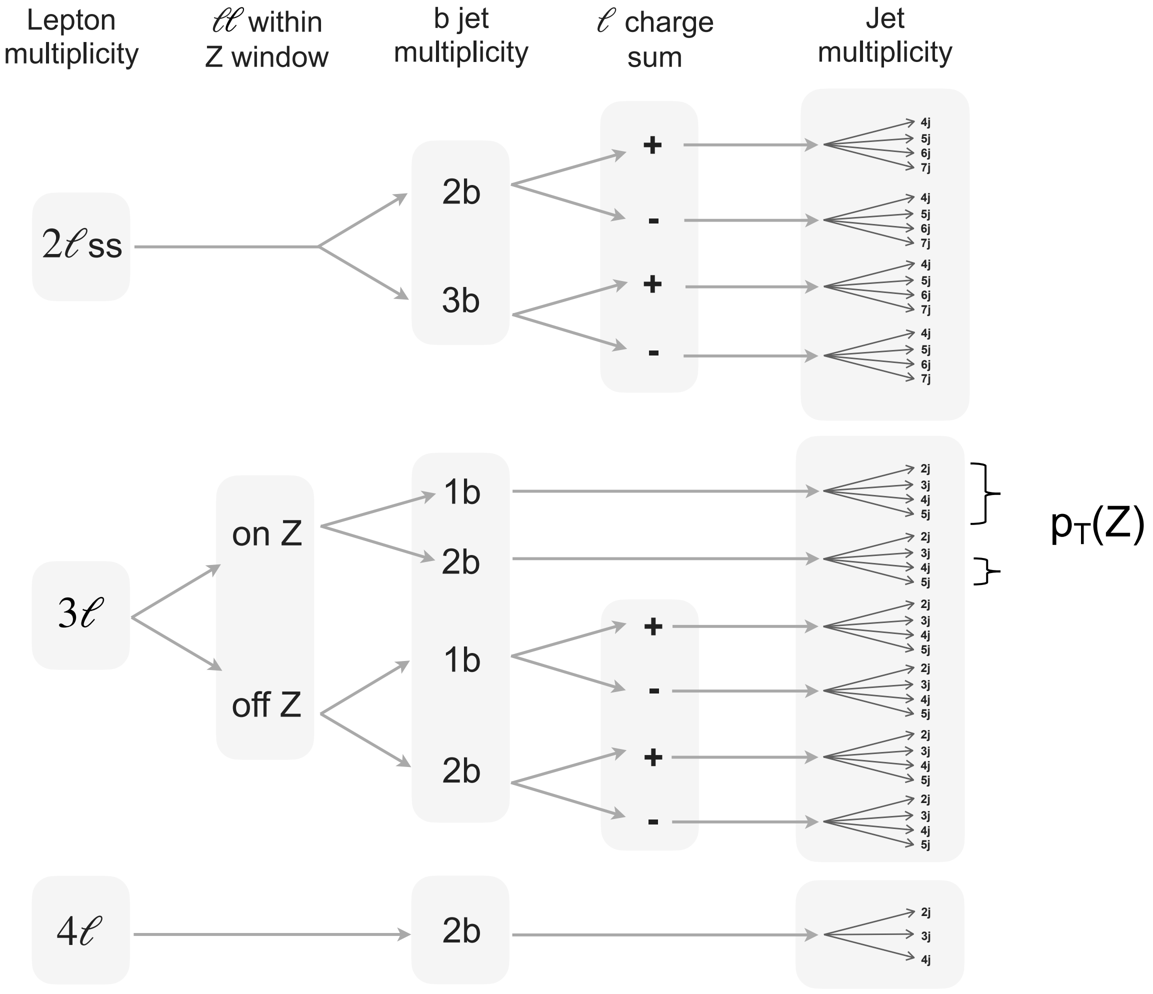
List input variable for DNN

Name	Description
$t\bar{t}$ system	
b p_T	p_T of the leading (subleading) b jet
b score	DeepCSV score of the leading (subleading) b jet
q p_T	p_T of the leading (subleading) non-b jet
q score	DeepCSV score of the leading (subleading) non-b jet
$\Delta R(\mathrm{b},\mathrm{q})$	minimum ΔR between the leading (subleading) b jet and any non-b jet
$\Delta R(\mathrm{q},\mathrm{q})$	ΔR between the two non-b jets closest to the leading (subleading) b jet
$m(\mathrm{q}+\mathrm{q})$	invariant mass of the two non-b jets closest to the leading (subleading) b jet
$\Delta R(\mathrm{b},\mathrm{q}+\mathrm{q})$	ΔR between the leading (subleading) b jet and the sum of the nearest two non-b jets
$m(\mathrm{b}+\mathrm{q}+\mathrm{q})$	invariant mass of the leading (subleading) b jet and the nearest two non-b jets
$\Delta R(\mathrm{Z/H},\mathrm{b}+\mathrm{q}+\mathrm{q})$	ΔR between the Z or Higgs boson candidate and the sum of the leading (subleading) b jet and the two non-b jets nearest to the leading (subleading) b jet
$\Delta R(\mathrm{Z/H},\mathrm{b}+\mathrm{b}+\mathrm{q}+\mathrm{q}+\ell)$	ΔR between the Z or Higgs boson candidate and the sum of the leading and subleading b jets, the two non-b jets nearest to the leading (subleading) b jet, and the lepton
$m_T(\mathrm{b}+\ell,\vec{p}_T^{\,\mathrm{miss}})$	transverse mass of the subleading b jet and the lepton
$m(\mathrm{Z/H}+\mathrm{b})$	invariant mass of the Z or Higgs boson candidate and the nearest b jet
$m(\mathrm{b}+\mathrm{b})$	invariant mass of the leading and subleading b jets
$\Delta R(\mathrm{b},\mathrm{b})$	ΔR between the leading and subleading b jets
$\Delta R(\mathrm{Z/H},\mathrm{q})$	ΔR between the Z or Higgs boson candidate and the leading non-b jet
$\Delta R(\mathrm{Z/H},\mathrm{b})$	ΔR between the Z or Higgs boson candidate and the leading b jet
$\Delta R(\mathrm{Z/H},\ell)$	ΔR between the Z or Higgs boson candidate and the lepton
$m(\mathrm{Z/H}+\ell)$	invariant mass of the Z or Higgs boson candidate and the lepton
$\Delta R(\mathrm{b},\ell)$	ΔR between the leading (subleading) b jet and the lepton
$m(\mathrm{b}+\ell)$	invariant mass of the leading (subleading) b jet and the lepton
$N(\mathrm{b_{out}})$	number of b jets outside the Z or Higgs boson candidate cone ($\Delta R > 0.8$)
$N(\mathrm{q_{out}})$	number of non-b jets outside the Z or Higgs boson candidate cone ($\Delta R > 0.8$)
Event topology	
N(AK8 jets)	number of AK8 jets, including the Z or Higgs boson candidate
N(AK4 jets)	number of AK4 jets
$N(\mathrm{Z/H})$	number of AK8 jets with a minimum AK8 $\mathrm{b\bar{b}}$ tagger score of 0.8
AK8 m_{SD}	maximum m_{SD} of AK8 jets, excluding the Z or Higgs boson candidate
$H_T(\mathrm{b_{out}})$	H_T of the b jets outside the Z or Higgs boson candidate cone ($\Delta R > 0.8$)
$H_T(\mathrm{b_{out}},\mathrm{q_{out}},\ell)$	H_T of all AK4 jets outside the Z or Higgs boson candidate cone ($\Delta R > 0.8$) and the lepton
sphericity	sphericity calculated from the AK4 jets and the lepton [89]
aplanarity	aplanarity calculated from the AK4 jets and the lepton [89]
Z or Higgs boson candidate substructure	
$\mathrm{b_{in}}$ score	maximum (minimum) DeepCSV score of AK4 jets within the Z or Higgs boson candidate cone ($\Delta R < 0.8$)
$\Delta R(\mathrm{b_{in}},\mathrm{b_{out}})$	ΔR between one b jet within the Z or Higgs boson candidate cone ($\Delta R < 0.8$) and the leading b jet outside of the Z or Higgs boson candidate cone
$N(\mathrm{b_{in}})$	number of b jets within the Z or Higgs boson candidate cone ($\Delta R < 0.8$)
$N(\mathrm{q_{in}})$	number of non-b jets within the Z or Higgs boson candidate cone ($\Delta R < 0.8$)
Z/H $\mathrm{b\bar{b}}$ score	AK8 $\mathrm{b\bar{b}}$ tagger score of the Z or Higgs boson candidate

Search for new physics in $t(\bar{t})$ + additional leptons

JHEP 12 (2023) 068

Event categorization



WC and their categories

Operator category	Wilson coefficients
Two-heavy (2hqV)	$c_{t\varphi}$, $c^{-}_{\varphi Q}$, $c^{3}_{\varphi Q}$, $c_{\varphi t}$, $c_{\varphi tb}$, c_{tW}, c_{tZ}, c_{bW}, c_{tG}
Two-heavy-two-lepton (2hq2ℓ)	$c^{3(\ell)}_{Q\ell}$, $c^{-(\ell)}_{Q\ell}$, $c^{(\ell)}_{Qe}$, $c^{(\ell)}_{t\ell}$, $c^{(\ell)}_{te}$, $c^{S(\ell)}_{t}$, $c^{T(\ell)}_{t}$
Two-heavy-two-light (2hq2lq)	c^{31}_{Qq}, c^{38}_{Qq}, c^{11}_{Qq}, c^{18}_{Qq}, c^{1}_{tq}, c^{8}_{tq}
Four-heavy (4hq)	c^{1}_{QQ}, c^{1}_{Qt}, c^{8}_{Qt}, c^{1}_{tt}

Grouping of WCs	WCs	Lead categories
2hq2ℓ	$c^{3(\ell)}_{Q\ell}$, $c^{-(\ell)}_{Q\ell}$, $c^{(\ell)}_{Qe}$, $c^{(\ell)}_{t\ell}$, $c^{(\ell)}_{te}$, $c^{S(\ell)}_{t}$, $c^{T(\ell)}_{t}$	3ℓ off-Z
4hq	c^{1}_{QQ}, c^{1}_{Qt}, c^{8}_{Qt}, c^{1}_{tt}	2ℓss
2hq2lq "$t\bar{t}\ell\nu$-like"	c^{11}_{Qq}, c^{18}_{Qq}, c^{1}_{tq}, c^{8}_{tq}	2ℓss
2hq2lq "$t\ell\bar{\ell}q$-like"	c^{31}_{Qq}, c^{38}_{Qq}	3ℓ on-Z
2hqV "$t\bar{t}\ell\bar{\ell}$-like"	c_{tZ}, $c_{\varphi t}$, $c^{-}_{\varphi Q}$	3ℓ on-Z and 2ℓss
2hqV "tXq-like"	$c^{3}_{\varphi Q}$, $c_{\varphi tb}$, c_{bW}	3ℓ on-Z
2hqV (significant impacts on many processes)	c_{tG}, $c_{t\varphi}$, c_{tW}	3ℓ and 2ℓss

Search for baryon number violation

PhysRevLett.132.241802

Effective Lagrangian and operators (PhysRevD.85.016006)

$$\mathcal{L}_{\rm BNV}^{\rm dim=6} = \frac{1}{\Lambda^2}\sum_{i=1}^{5} c_i\, O^{(i)}$$

$$O^{(s)} \equiv \epsilon^{\alpha\beta\gamma}[\overline{t^c_\alpha}(aP_L + bP_R)D_\beta][\overline{U^c_\gamma}(cP_L + dP_R)E],$$

$$O^{(t)} \equiv \epsilon^{\alpha\beta\gamma}[\overline{t^c_\alpha}(a'P_L + b'P_R)E][\overline{U^c_\beta}(c'P_L + d'P_R)D_\gamma]$$

Process	$\sigma(C_t = 1)$ [pb]	$\sigma(C_s = 1)$ [pb]
ST ($t\ell ud$)	$31.5 \pm 2.1 \pm 1.0$	$10.7 \pm 0.7 \pm 0.4$
ST ($t\ell us$)	$8.1 \pm 0.3 \pm 0.5$	$2.8 \pm 0.1 \pm 0.2$
ST ($t\ell ub$)	$3.31 \pm 0.13 \pm 0.06$	$1.14 \pm 0.05 \pm 0.02$
ST ($t\ell cd$)	$2.77 \pm 0.22 \pm 0.01$	$0.96 \pm 0.01 \pm 0.07$
ST ($t\ell cs$)	$0.79 \pm 0.02 \pm 0.11$	$0.27 \pm 0.01 \pm 0.04$
ST ($t\ell cb$)	$0.28 \pm 0.03 \pm 0.04$	$0.10 \pm 0.01 \pm 0.01$
TT	$0.007 \pm 0.002 \pm 0.001$	$0.007 \pm 0.002 \pm 0.001$

The (s), (t) labeling reminds that the scale Λ maybe linked to the mass of a heavy mediator (with electric charge 1/3) exchanged in s or t channels, respectively

Search for baryon number violation

PhysRevLett.132.241802

Result (table)

Vertex	C_x	C_x/Λ^2 [TeV^{-2}] Exp.	C_x/Λ^2 [TeV^{-2}] Obs.	$\mathcal{B}_x$ [10^{-6}] Exp.	$\mathcal{B}_x$ [10^{-6}] Obs.
teud	s	0.055	0.048	0.015	0.011
	t	0.031	0.027	0.005	0.003
tμud	s	0.046	0.036	0.010	0.006
	t	0.025	0.020	0.003	0.002
tecd	s	0.207	0.184	0.208	0.164
	t	0.114	0.102	0.063	0.050
tμcd	s	0.178	0.141	0.153	0.095
	t	0.100	0.080	0.048	0.030
teus	s	0.115	0.101	0.063	0.050
	t	0.064	0.056	0.019	0.015
tμus	s	0.102	0.079	0.050	0.030
	t	0.056	0.043	0.015	0.009
tecs	s	0.448	0.403	0.973	0.786
	t	0.243	0.218	0.286	0.229
tμcs	s	0.394	0.311	0.752	0.468
	t	0.217	0.169	0.228	0.138
teub	s	0.199	0.178	0.191	0.154
	t	0.109	0.097	0.057	0.045
tμub	s	0.168	0.134	0.136	0.087
	t	0.095	0.076	0.044	0.028
tecb	s	0.718	0.657	2.503	2.090
	t	0.405	0.367	0.795	0.652
tμcb	s	0.703	0.564	2.393	1.521
	t	0.386	0.307	0.722	0.455

Search for charged-lepton flavor violation in tq$\mu\tau$ interaction

arXiv:2504.08532 (submitted to JHEP)

Signal cross sections (with scale uncertainties)

Process	Lorentz structure	Cross section [fb]
ST CLFV tu$\mu\tau$	Scalar	$59.1^{+11.1}_{-8.7}$
	Vector	276^{+50}_{-39}
	Tensor	1272^{+220}_{-180}
ST CLFV tc$\mu\tau$	Scalar	$3.74^{+0.63}_{-0.54}$
	Vector	$19.5^{+3.1}_{-2.6}$
	Tensor	96^{+14}_{-12}
TT CLFV tq$\mu\tau$	Scalar	$2.69^{+0.71}_{-0.53}$
	Vector	$21.5^{+5.7}_{-4.2}$
	Tensor	129^{+34}_{-25}

Predicted event yields

Process	Event yield
ST CLFV tu$\mu\tau$ Scalar	535 ± 1
ST CLFV tu$\mu\tau$ Vector	2327 ± 3
ST CLFV tu$\mu\tau$ Tensor	9909 ± 13
ST CLFV tc$\mu\tau$ Scalar	$32 \pm <1$
ST CLFV tc$\mu\tau$ Vector	$129 \pm <1$
ST CLFV tc$\mu\tau$ Tensor	701 ± 1
TT CLFV tu$\mu\tau$ Scalar	$1.1 \pm <0.1$
TT CLFV tu$\mu\tau$ Vector	$8.2 \pm <0.1$
TT CLFV tu$\mu\tau$ Tensor	$48 \pm <1$
TT CLFV tc$\mu\tau$ Scalar	$1.1 \pm <0.1$
TT CLFV tc$\mu\tau$ Vector	$7.9 \pm <0.1$
TT CLFV tc$\mu\tau$ Tensor	$45 \pm <1$
$\mathrm{t\bar{t}}$	4573 ± 13
Single t	306 ± 9
Other	258 ± 5
Total	5136 ± 17
Data	4810

DNN input variables

Group	Variables	Description
Muon (μ)	$p_{\mathrm{T}\mu}$, η_μ	p_T and η of selected muon
Tau (τ_h)	$p_{\mathrm{T}\tau_\mathrm{h}}$, η_{τ_h}, m_{τ_h}	p_T, η, and mass of selected τ_h
Muon+Tau ($\mu\tau_\mathrm{h}$)	$m_{\mu\tau_\mathrm{h}}$, $\Delta\eta_{\mu\tau_\mathrm{h}}$, $\Delta\phi_{\mu\tau_\mathrm{h}}$, $\Delta R_{\mu\tau_\mathrm{h}}$	Mass and angular differences of $\mu\tau_\mathrm{h}$ system
Jets	$p_{\mathrm{T}1}$, $p_{\mathrm{T}2}$, $p_{\mathrm{T}3}$	p_T of jets ordered in decreasing p_T
	η_1, η_2, η_3	η of jets ordered in decreasing p_T
	m_1, m_2, m_3	Mass of jets ordered in decreasing p_T
	b_1, b_2, b_3	b tagging discriminant of jets ordered in decreasing p_T
Event	$p_\mathrm{T}^\mathrm{miss}$	Missing transverse momentum
t and W reco.	χ^2, $m_{\mathrm{bjj'}}$, $m_{\mathrm{jj'}}$	Minimum χ^2 and reconstructed t and W masses
	$\Delta\eta_{\mathrm{jj'}}$, $\Delta\phi_{\mathrm{jj'}}$, $\Delta R_{\mathrm{jj'}}$	Angular differences of jets used in W reco.

Search for charged-lepton flavor violation in tq$\mu\tau$ interaction

arXiv:2504.08532 (submitted to JHEP)

- Rate of jet -> τ_h misidentified events is non-negligible
- Normalizations of such backgrounds are calculated using a data-driven method
  - ABCD method is utilized by inverting τ_h ID and $\mu\tau$ charge, for each year and tau decay mode

$$\mathrm{SF} = \frac{N^D_{\text{mis-ID}}}{N^D_{\text{tot. bkg.}} - N^D_{\text{genuine}}}$$

where $N^i = N^i_{\text{obs}} - N^i_{\text{genuine}}$, and

$$N^{\mathrm{D}}_{\text{mis-ID}} = N^{\mathrm{C}} \frac{N^{\mathrm{B}}}{N^{\mathrm{A}}} = N(\text{OS looseID}) \times \frac{N(\text{SS tight ID})}{N(\text{SS looseID})}$$