Lepton Flavor Violation searches in ATLAS, CMS (and LHCb)

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Theory Motivations

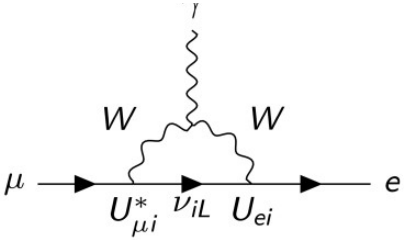
With **Mν>0**, neutrino oscillations could produce Lepton Flavor Violation → If the origin of LFV is **only** due to SM neutrinos oscillations, rate of LFV is extremely small at colliders (undetectable)

Lepton Flavor conservation is not related to a gauge symmetry=> why conserved?

→ Any observation of LFV at colliders **is a clear signal** of physics Beyond Standard Model

Lepton Flavor Violation **is a portal** to New Physics at colliders

$$Br(\mu \to e\gamma) \simeq G_F^2(\Delta m_\nu^2)^2 \sim 10^{-50}$$



Would have to take data at LHC for more than the remaining life of our solar system

Lepton Flavor Violation

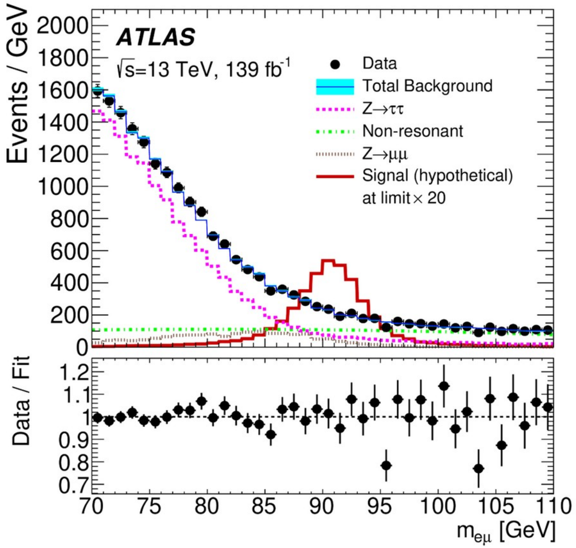
- Standard Model bosons LFV decays ($Z \to e\mu, e\tau, \mu\tau$; $H \to e\mu, e\tau, \mu\tau$)
- Beyond Standard Model bosons LFV decays ($Z' \to e\mu, e\tau, \mu\tau$)
- Lepton Flavor Violation in top sector ($\mu\tau$q top,eμq top)
- Lepton Flavor Violation in tau leptons ($\tau \to 3\mu$)

Important to search for LFV at different energy scales (from TeV to GeV)
Clean environment from theory

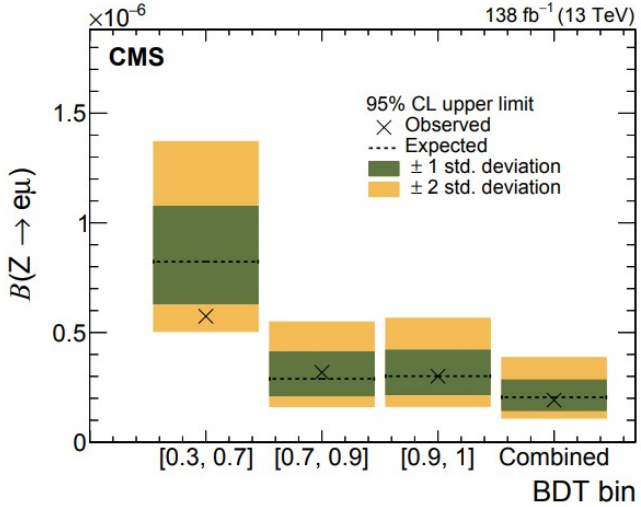
$Z \to e\mu$: ATLAS and CMS

Search for Lepton Flavor Violation in Z boson decays
BDT selection aiming at $e\mu$ signal
CR with same flavor events. Dominant backgrounds $Z \to \tau_{lep}\tau_{lep}$, $Z \to \mu\mu$

arXiv:2508.07512
accepted by PRD



Phys Rev. D 108 (2023) 032015



0.3 < BDT<0.7	5.7 (8.7) $\times 10^{-7}$
0.7<BDT<0.9	3.2 (2.9) $\times 10^{-7}$
0.9<BDT<1.0	3.0 (3.0) $\times 10^{-7}$
Combined	1.9 (2.0) $\times 10^{-7}$

B($Z \to e\mu$) excluded at
2.62 (2.37) $\times 10^{-7}$ at 95% CL

$Z \to (e/\mu)\tau$:CMS

Search for Lepton Flavor Violation in $Z \to \ell\tau$ (both hadronic and leptonic decays)
Embedding technique to evaluate $Z \to \tau\tau_\mu$ background from data $Z \to \mu\mu$ replacing one of the muons with simulated τ
Four BDT used to discriminate $Z \to e\tau_{had}$, $e\tau_\mu$, $\mu\tau_{had}$, $\mu\tau_e$ vs $Z \to \tau\tau$, jet $\to$ $tau_{Mis\text{-}ID}$

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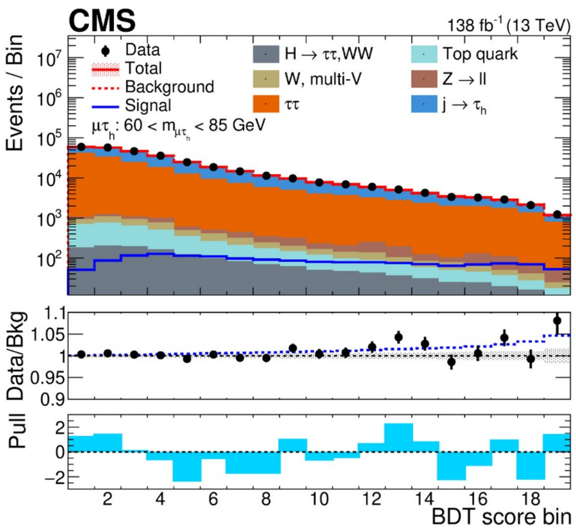
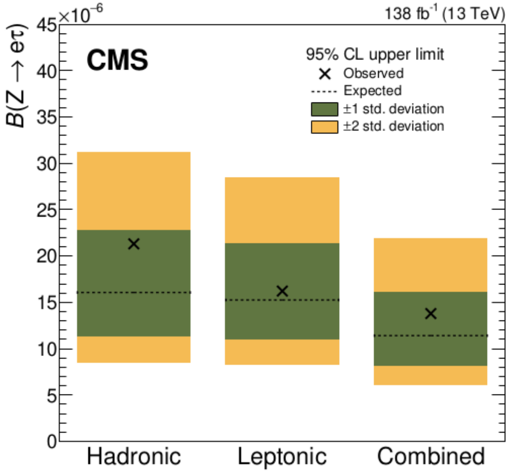
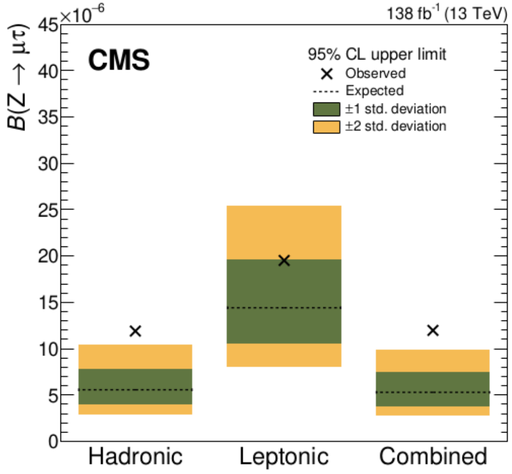


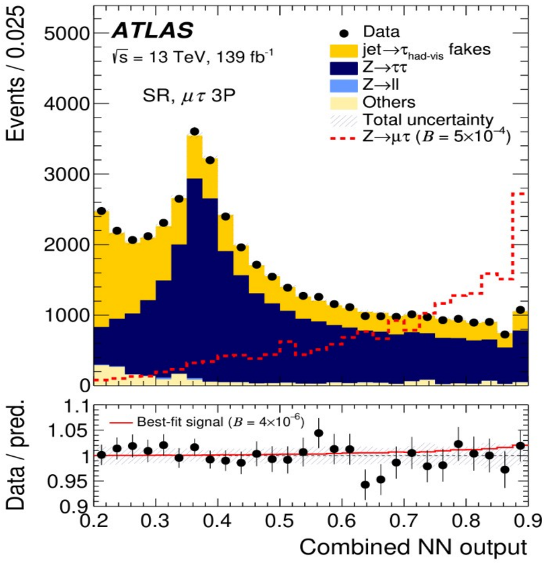


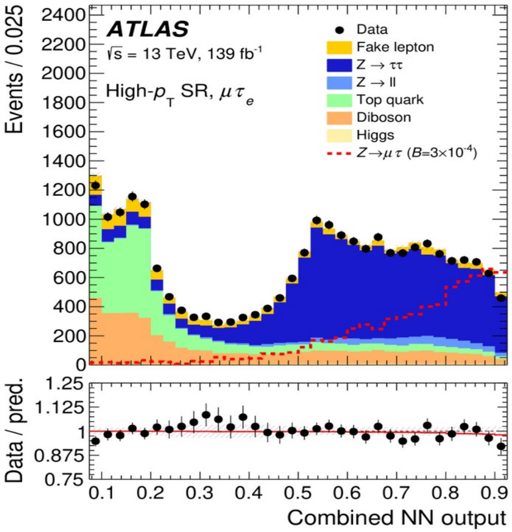


BR($Z \to \ell\tau$)<1.9 (2.0) x 10^{-7}

$Z\rightarrow(e/\mu)\tau_{\text{Had/Lep}}$: ATLAS

Search for Lepton Flavor Violation in $Z \rightarrow \ell\tau_{\text{Had/Lep}}$
Combined fit on SR using NN score and m_{coll} for $Z\rightarrow\tau\tau$ CR
Hadronic Channel: Separation 1 prong to 3 prong
NN discriminating signal vs W+jet, $Z\rightarrow\tau\tau$ $Z\rightarrow\ell\ell$
Leptonic Channel: NN trained signal vs $Z\rightarrow\tau\tau$, $t\bar{t}$, diboson
SR divided in a low-pt and high-pt with $P_T(\ell)$





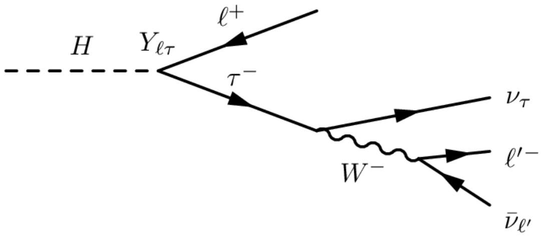
	eτ	μτ
$\ell\tau_{\text{Had}}$	$8.1(8.1)\text{x}10^{-6}$	$9.5(6.1)\text{x}10^{-6}$
$\ell\tau_{\text{Had}}$ Left H	$8.2(8.6)\text{x}10^{-6}$	$9.5(6.7)\text{x}10^{-6}$
$\ell\tau_{\text{Had}}$ Right H	$8.4(11)\text{x}10^{-6}$	$9.8\ (13)\text{x}10^{-6}$
$\ell\tau_{\text{Lep}}$	$7.0(8.9)\text{x}10^{-6}$	$7.2(10)\text{x}10^{-6}$
$\ell\tau_{\text{Lep}}$ Left H	$5.9(7.5)\text{x}10^{-6}$	$5.7(8.5)\text{x}10^{-6}$
$\ell\tau_{\text{Lep}}$ Right H	$8.4(11)\text{x}10^{-6}$	$9.8(13)\text{x}10^{-6}$
$\ell\tau$	$5.0(6.0)\text{x}10^{-6}$	$6.5(5.3)\text{x}10^{-6}$
$\ell\tau$ Left H	$4.5(5.7)\text{x}10^{-6}$	$5.6(5.3)\text{x}10^{-6}$
$\ell\tau$ Right H	$5.4(6.2)\text{x}10^{-6}$	$7.7(5.3)\text{x}10^{-6}$

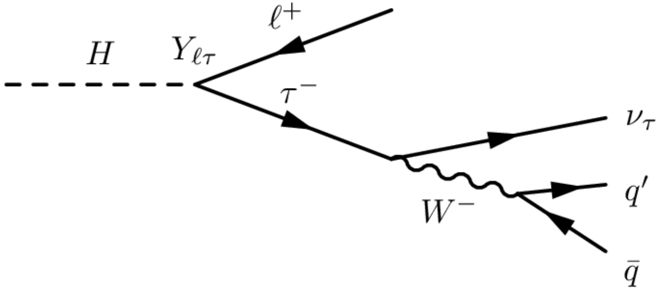
Hadronic: Nature Phys. 17 (2021) 819

Leptonic: Phys. Rev. Lett. 127 (2021) 271801

$H \to (e/\mu)\tau$: ATLAS

Three different analysis: one independent search for each of the $H \to e\tau$ and $H \to \mu\tau$ decays and one one simultaneous determination of the $H \to e\tau$ and $H \to \mu\tau$ signals.





Leptonic channel ($\ell\tau_{\ell'}$):

- Non-VBF channel: background estimated with **MC template** normalized to data
- VBF channel: background estimated using **Symmetry Method** between SM prompt lepton background

Hadronic channel ($\ell\tau_{had}$):
Background estimated with **MC template** normalized to data

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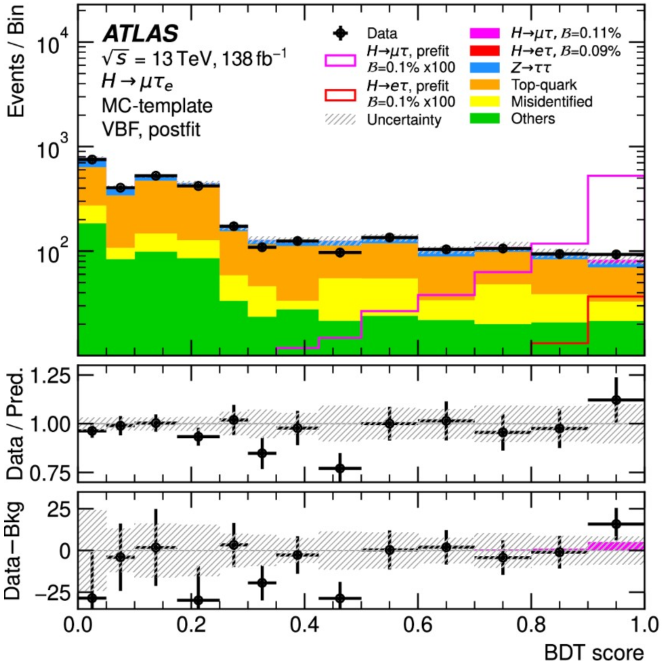
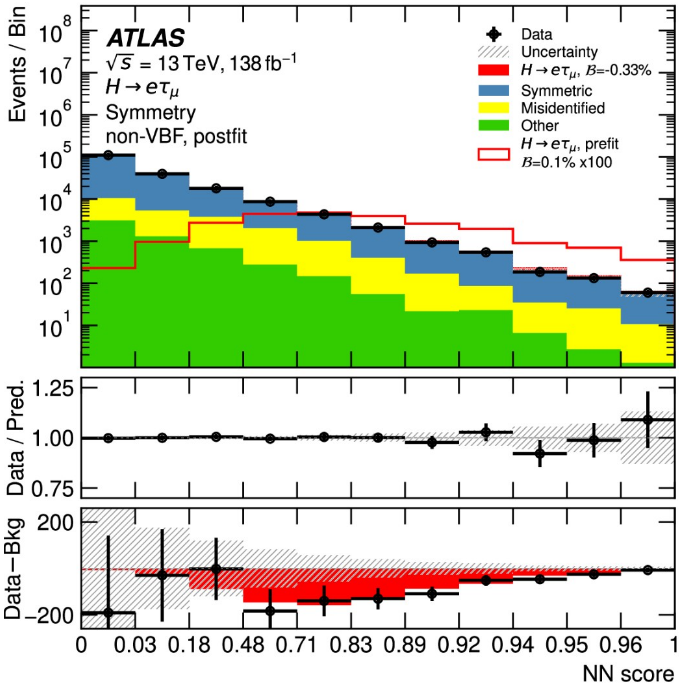
H→(e/μ)τ: ATLAS





Leptonic τ **non-VBF** & Hadronic τ channels: BDTs
Leptonic τ **VBF** channel: Deep neural network

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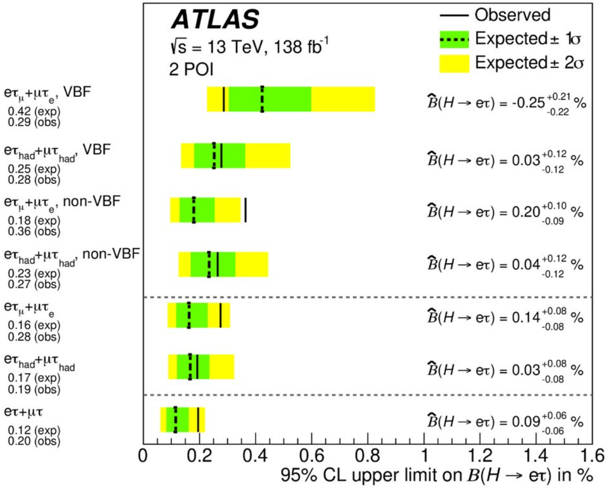
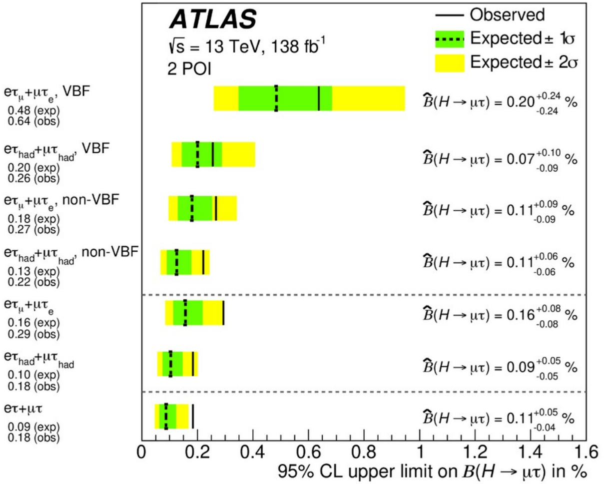
H→(e/μ)τ: ATLAS

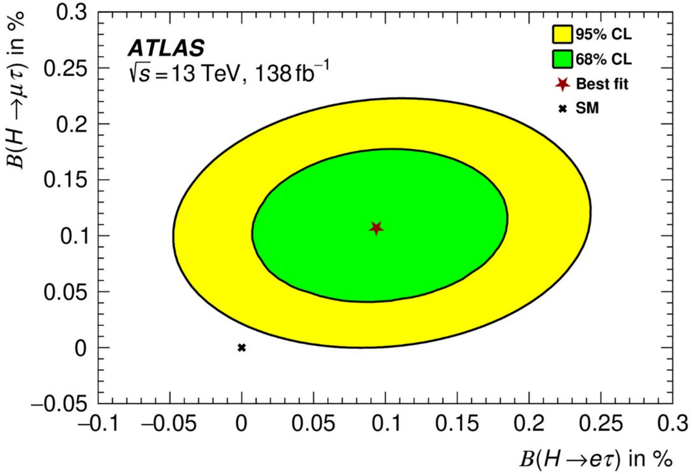
Simultaneous fit of B(H→ eτ) and B(H →μτ) (2 Parameter Of Interest)



BR(H→eτ)<0.2 %



BR(H→μτ)<0.18 %



SM expectation of (0, 0) slightly outside of 95% CL contour → 2.1σ "excess"

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H→(e/μ)τ: CMS

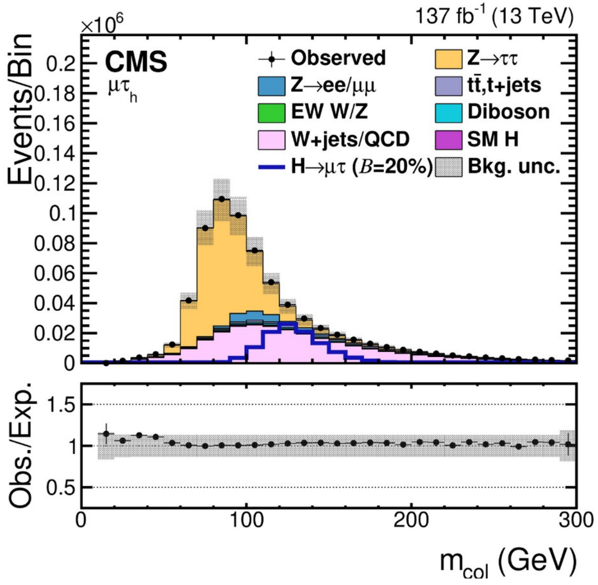
Addressing $e\tau_{Had}$, $e\tau_{\mu}$, $\mu\tau_{Had}$ and $\mu\tau_{e}$
8 categories in total:
($e\tau$, $\mu\tau$) x (0 jets, 1 jet, 2jets ggH, 2 jets VBF)
Signal selection using BDTs for each channel (background composed by Z→ ττ and same sign lepton) → Z Z→ ττ estimated with **embedding** technique

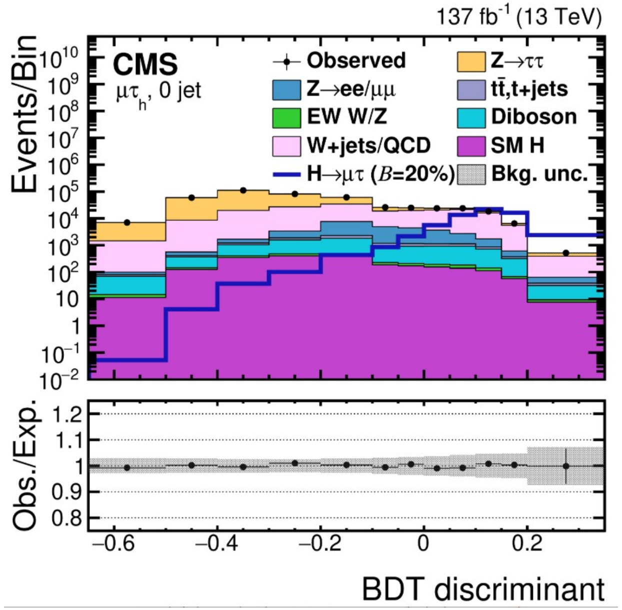
Colinear mass:

$$m_{\mathrm{col}} = m_{\mathrm{vis}} / \sqrt{x_{\tau}^{\mathrm{vis}}},$$

$$x_{\tau}^{\mathrm{vis}} = p_{\mathrm{T}}^{\vec{\tau}^{\mathrm{vis}}} / (p_{\mathrm{T}}^{\vec{\tau}^{\mathrm{vis}}} + p_{\mathrm{T}}^{\vec{\nu},\mathrm{est}})$$

$p_{\mathrm{T}}^{\vec{\nu},\mathrm{est}}$ $E_{T,Miss}$ proj. in τ direction

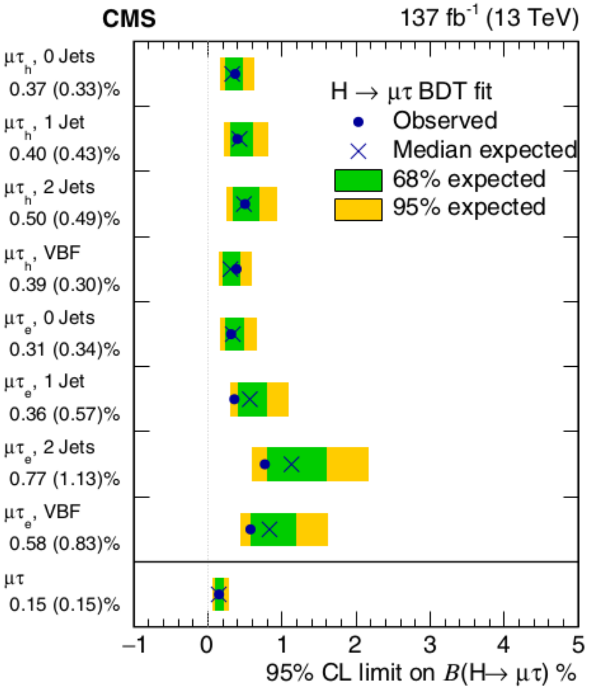


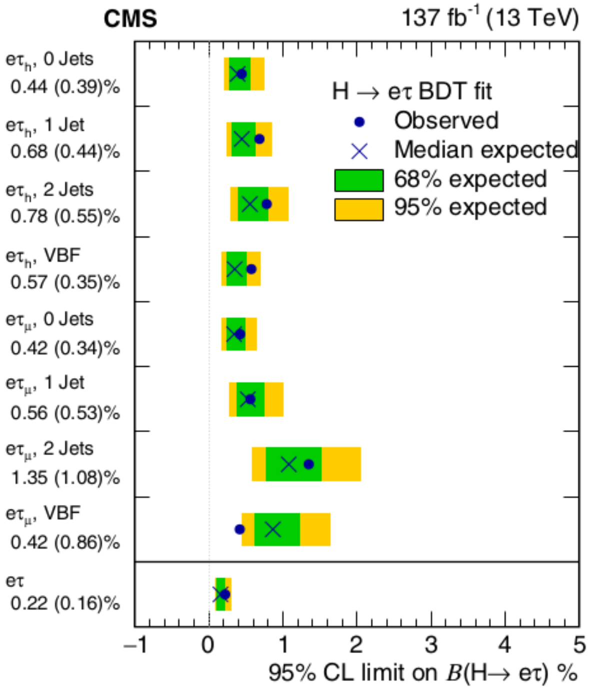


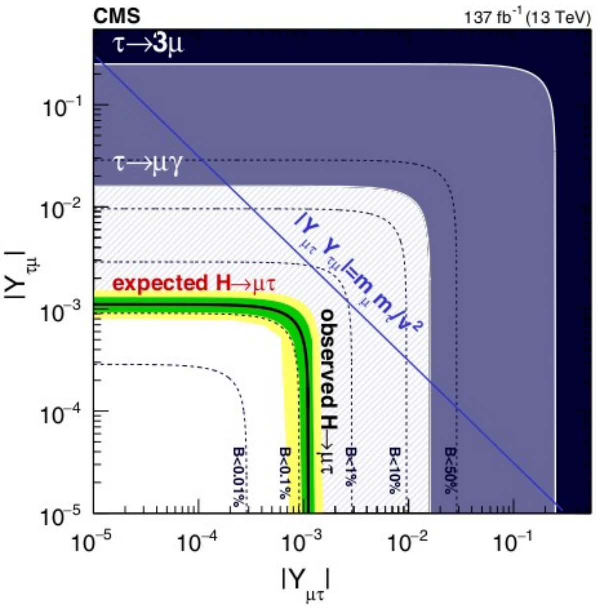
Phys.Rev.D (2021) 104, 032013

$H \to (e/\mu)\tau$: CMS

$$|Y_{\ell\tau}|^2 + |Y_{\tau\ell}|^2 = \frac{8\pi}{m_H} \frac{\mathcal{B}(H \to \ell\tau)}{1 - \mathcal{B}(H \to \ell\tau)} \Gamma_H(\mathrm{SM})$$







BR($H \to \mu\tau$)<0.22 (0.16) %

BR($H \to e\tau$)<0.15 (0.15) %

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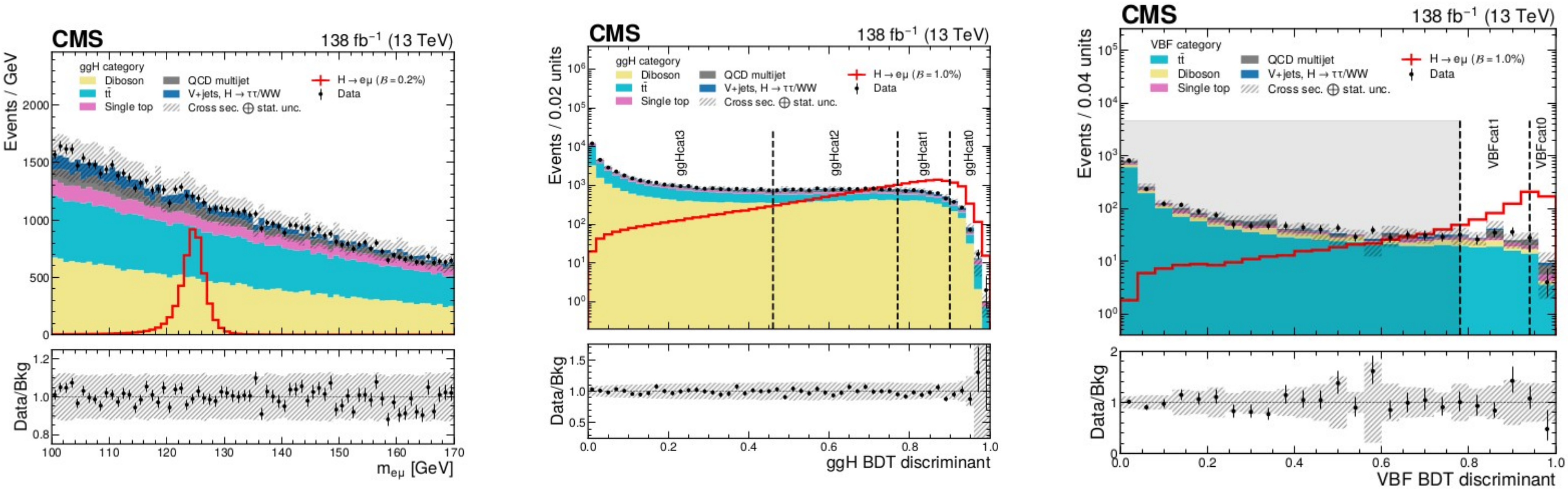
H → $e\mu$: CMS

Look for $e\mu$ pairs in [100-170] invariant mass interval
Selection in two categories: (VBF and non-VBF) x (categories based on BDT score)
Main background $t\bar{t}$ and WW events



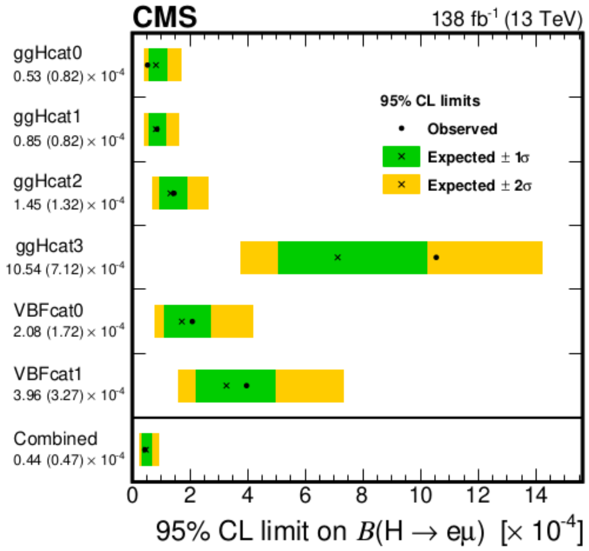
Before BDT categorization

PRD 108 (2023) 072004

H → $e\mu$: CMS

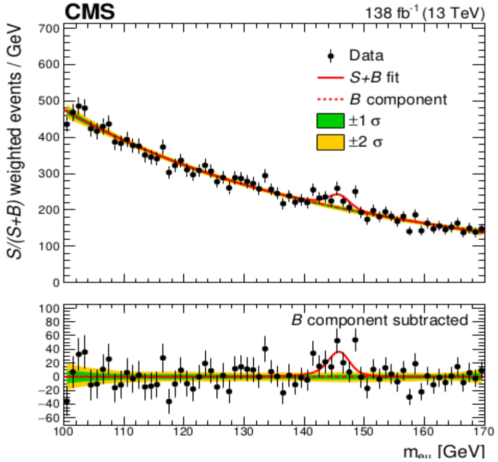
PRD 108 (2023) 072004

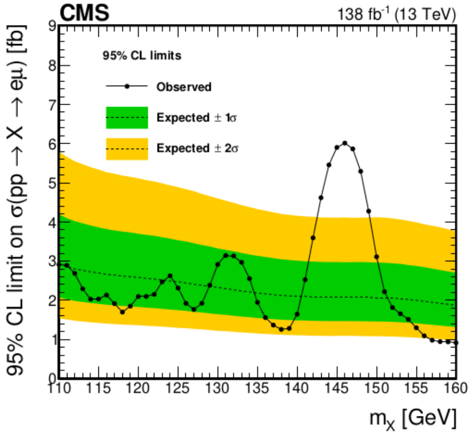
For M_{Higgs}=125 GeV



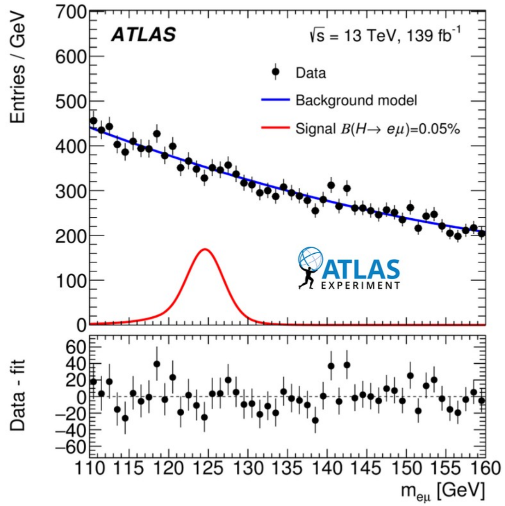
BR(H→eμ)<4.4 (4.7) 10^{-5}

Looking at the [100;170] GeV interval





Small excess 3.8 (2.8 global) at M_X=146 GeV mainly driven by ggH cat 0 and 2 and VBF cat 0



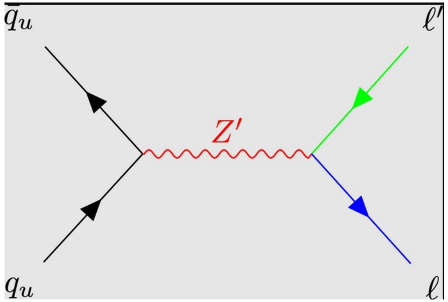
Phys. Lett. B 801 (2020) 135148

Lepton Flavor Violation

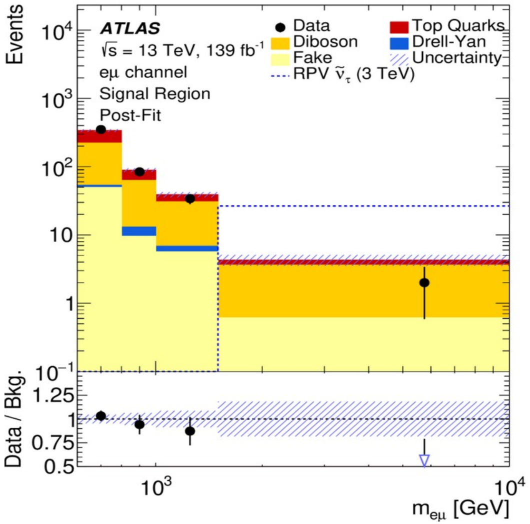
- Standard Model bosons LFV decays ($Z \rightarrow e\mu, e\tau, \mu\tau$; $H \rightarrow e\mu, e\tau, \mu\tau$)
- Beyond Standard Model bosons LFV decays ($Z' \rightarrow e\mu, e\tau, \mu\tau$)
- Lepton Flavor Violation in top sector ($\mu\tau q$ top,$e\mu q$ top)
- Lepton Flavor Violation in tau leptons ($\tau \rightarrow 3\mu$)

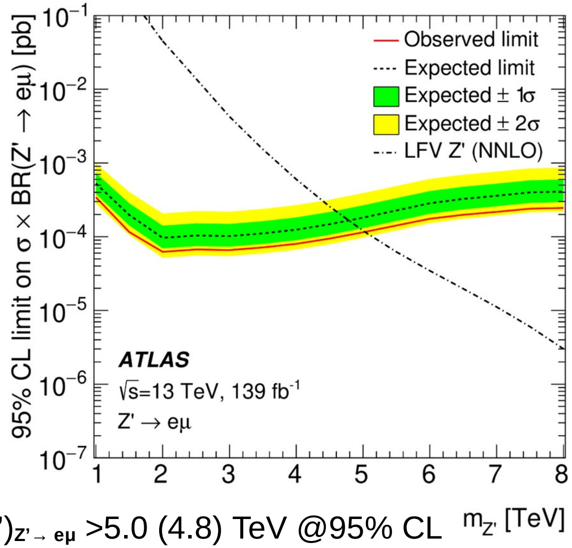
Z’ → ℓℓ’: ATLAS

- LFV might occur for BSM bosons decays: Z’, QBH, RPV SUSY
- $e\mu$,$e\tau$ and $\mu\tau$ channels
- Main background: $t\bar{t}$ and WW.
- Reducible background: W+jet and “QCD” using data driven methods

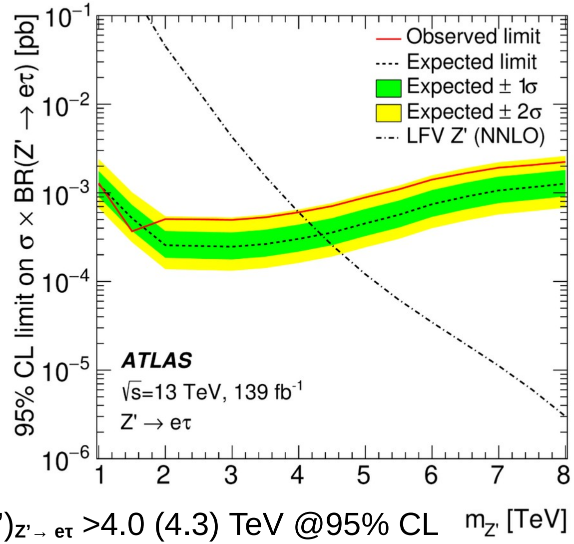


Z’ LFV BR modeled with the Sequential Standard Model





M(Z’)$_{Z’\rightarrow e\mu}$ >5.0 (4.8) TeV @95% CL



M(Z’)$_{Z’\rightarrow e\tau}$ >4.0 (4.3) TeV @95% CL
M(Z’)$_{Z’\rightarrow \mu\tau}$ >3.9 (4.2) TeV @95% CL

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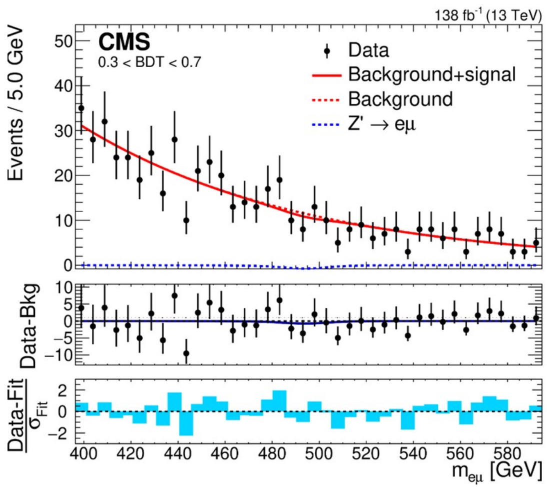
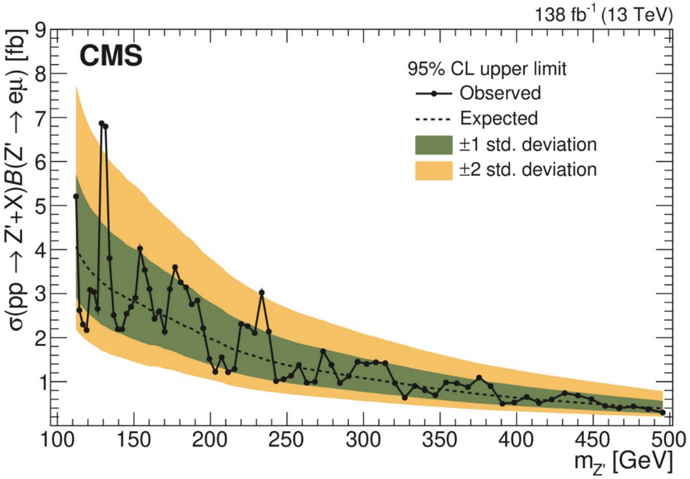
Z’ → ℓℓ’: CMS

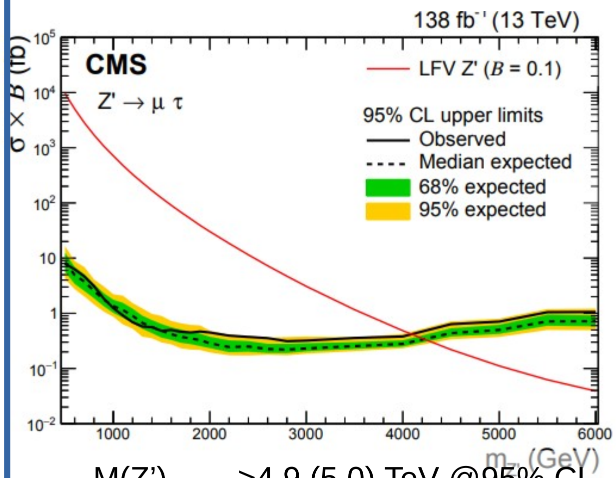
Scan for new neutral vector resonances Z’ → $e\mu$ in the [110,500] GeV mass ranges
Signal events are selected using their BDT score [0.3,0.7] and [0.7,1.0] and fit of $e\mu$ distribution using sliding windows
Look at larger masses with Z’ SSM ($\bar{B}$=0.1) and model independent search ($e\mu$, $e\tau$, $\mu\tau$)
Main background for both analysis: tt and WW.





Z’ → $e\mu$

arXiv:2508.07512
Accepted by PRD



M(Z’)$_{Z' \to e\mu}$ >4.9 (5.0) TeV @95% CL
M(Z’)$_{Z' \to e\tau}$ >4.3 (4.3) TeV @95% CL
M(Z’)$_{Z' \to \mu\tau}$ >4.1 (4.2) TeV @95% CL

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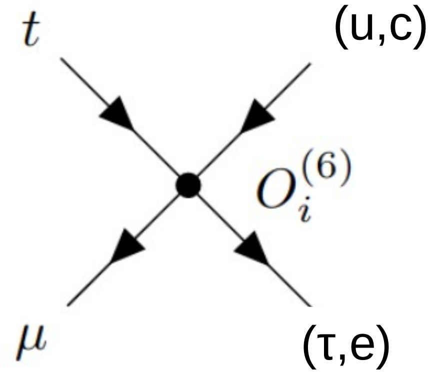
Lepton Flavor Violation

- Standard Model bosons LFV decays (Z $\rightarrow$ eμ, eτ, μτ; H$\rightarrow$eμ, eτ, μτ)
- Beyond Standard Model bosons LFV decays (Z’ $\rightarrow$ eμ, eτ, μτ)
- Lepton Flavor Violation in top sector (μτq top,eμq top)
- Lepton Flavor Violation in tau leptons (τ$\rightarrow$ 3μ)

LFV in top sector

In Effective Field Theory LFV related to dim-6 (n=6) operators. Vertices could be diagonal $t\bar{t}ll$, semidiagonal tqll and CLFV (fully off diagonal) **tqℓℓ’**
→ Looking at **tqℓℓ’** vertices



Operator	Interaction	Lorentz Structure
$O_{\mathrm{lq}}^{1(ijkl)}$	$(\bar{\mathrm{l}}_i\gamma^\mu \mathrm{l}_j)(\bar{\mathrm{q}}_k\gamma_\mu \mathrm{q}_l)$	Vector
$O_{\mathrm{lq}}^{3(ijkl)}$	$(\bar{\mathrm{l}}_i\gamma^\mu\sigma^I \mathrm{l}_j)(\bar{\mathrm{q}}_k\gamma_\mu\sigma_I \mathrm{q}_l)$	Vector
$O_{\mathrm{eq}}^{(ijkl)}$	$(\bar{\mathrm{e}}_i\gamma^\mu \mathrm{e}_j)(\bar{\mathrm{q}}_k\gamma_\mu \mathrm{q}_l)$	Vector
$O_{\mathrm{lu}}^{(ijkl)}$	$(\bar{\mathrm{l}}_i\gamma^\mu \mathrm{l}_j)(\bar{\mathrm{u}}_k\gamma_\mu \mathrm{u}_l)$	Vector
$O_{\mathrm{eu}}^{(ijkl)}$	$(\bar{\mathrm{e}}_i\gamma^\mu \mathrm{e}_j)(\bar{\mathrm{u}}_k\gamma_\mu \mathrm{u}_l)$	Vector
$O_{\mathrm{lequ}}^{1(ijkl)}$	$(\bar{\mathrm{l}}_i \mathrm{e}_j)\varepsilon(\bar{\mathrm{q}}_k \mathrm{u}_l)$	Scalar
$O_{\mathrm{lequ}}^{3(ijkl)}$	$(\bar{\mathrm{l}}_i\sigma^{\mu\nu} \mathrm{e}_j)\varepsilon(\bar{\mathrm{q}}_k\sigma_{\mu\nu} \mathrm{u}_l)$	Tensor

i,j → lepton generations
k,l → quark generations

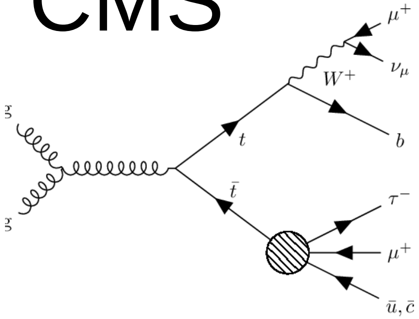
$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{i,n} \frac{c_i^{(n)}}{\Lambda^{n-4}} \mathcal{O}_i^{(n)}$$

Standard Model

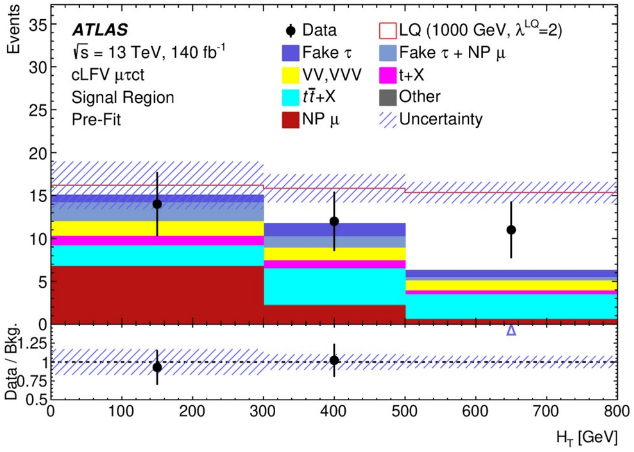
Coupling Strength

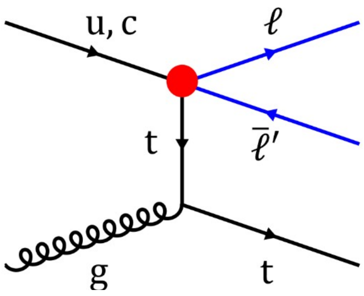
Operators introducing new interactions

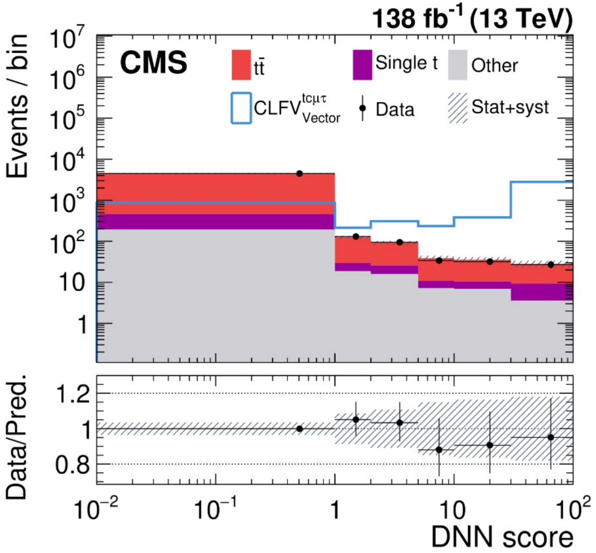
τq top: ATLAS and CMS



Addressing both top u**τμ** and top c**τμ** vertices
Event selection **τ** had, two muons (Same Sign)>=1 jet & 1-bjet (exactly)
Main background from ttbar(+X) and diboson events
ATLAS: Uses H_T as discriminating variable
CMS: DNN to discriminate LFV signal from background







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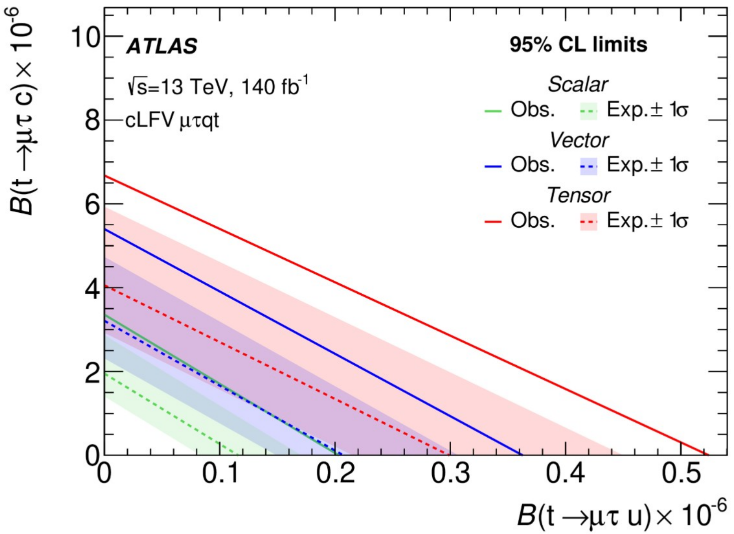
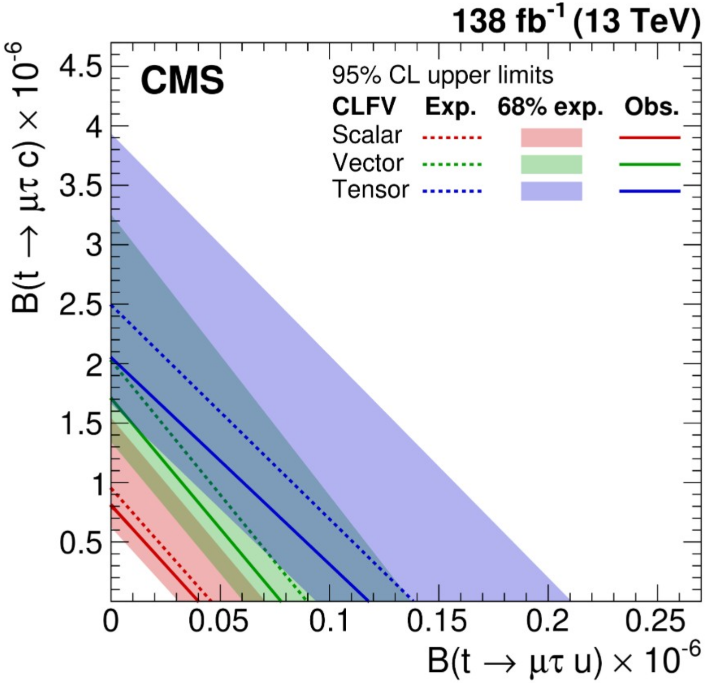
arXiv:2504.0853
accepted by JHEP

$\mu\tau$q top: ATLAS and CMS





Better limits on BR(t→**τμu**) than BR(t→**τμc**) because u production favored over c production

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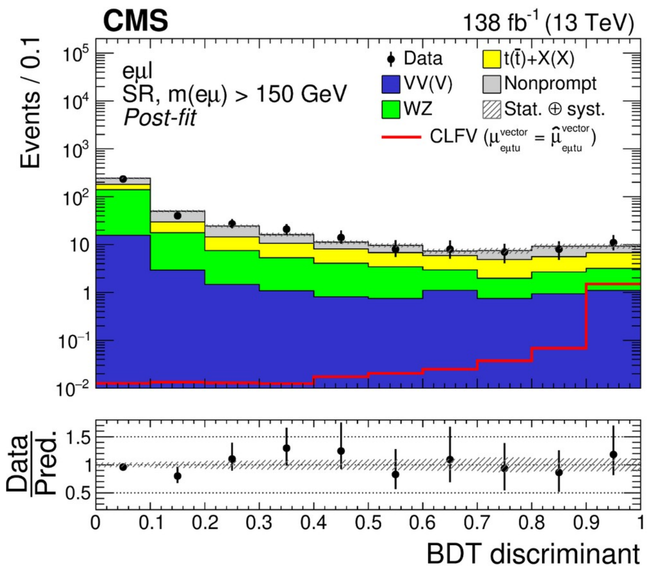
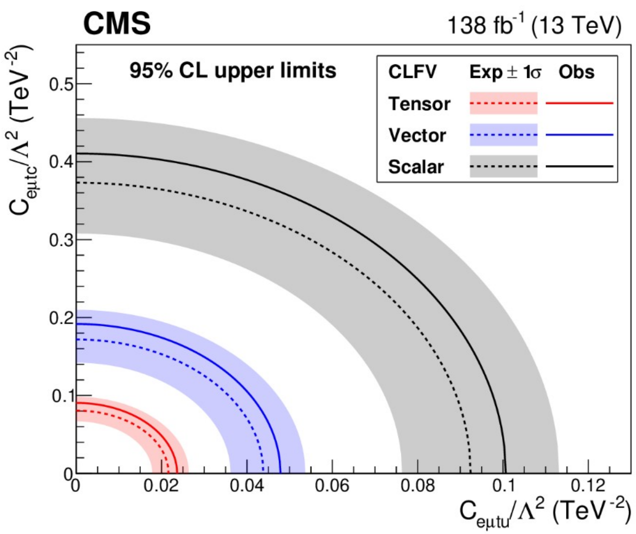
arXiv:2504.0853
accepted by JHEP

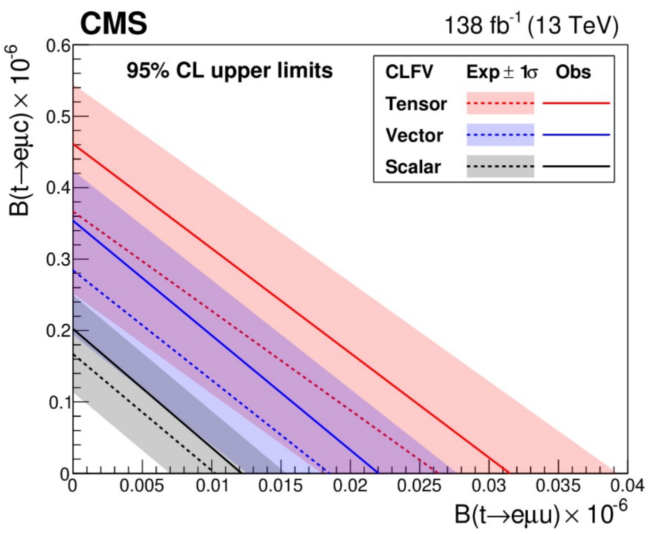
eμq top: CMS

Looking for eμtop(u/c) vertex
Trilepton events: e$\mu\ell$ signal. 3e or 3μ for background studies
Main background: tt SM with non prompt lepton, diboson
Two BDTs used to discriminate LFV events from background m(eμ)<150 GeV and m(eμ)>150 GeV

Phys. Rev. D 111 (2025) 012009







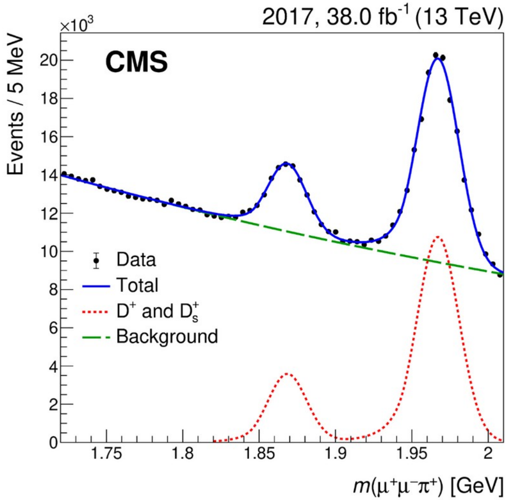
Lepton Flavor Violation

- Standard Model bosons LFV decays ($Z \rightarrow e\mu, e\tau, \mu\tau$; $H \rightarrow e\mu, e\tau, \mu\tau$)
- Beyond Standard Model bosons LFV decays ($Z' \rightarrow e\mu, e\tau, \mu\tau$)
- Lepton Flavor Violation in top sector ($\mu\tau q$ top, $e\mu q$ top)
- Lepton Flavor Violation in tau leptons ($\tau \rightarrow 3\mu$)

$\tau \rightarrow 3\mu$ search: CMS

Tau leptons produced at LHC mainly by:
- D mesons decays (~10^{11} per fb^{-1}) (low pt)
- $W \rightarrow \tau\nu$ decays (~10^{7} per fb^{-1}) (high pt, isolated and large MET)

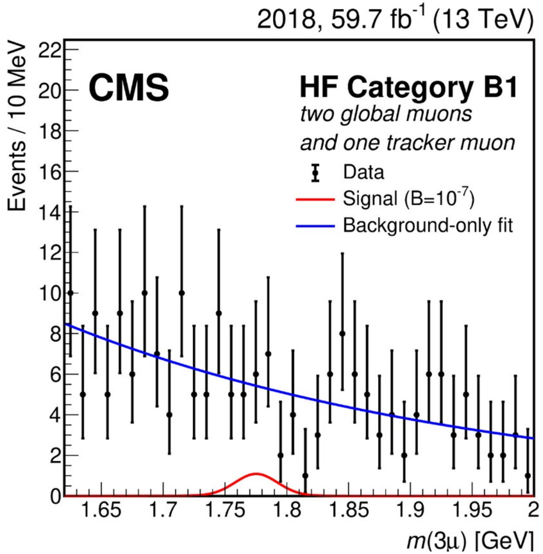
2 main analysis regions **HF** (Heavy Flavor) and **W**.
Further categorization in terms of expected resolution of 3μ system (3 intervals)
BDT used to discriminate signal from background (trained with sidebands events)
Three further regions based on BDT score

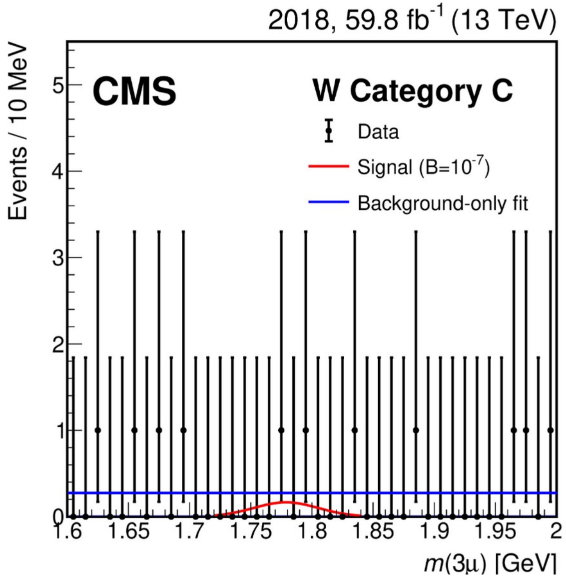


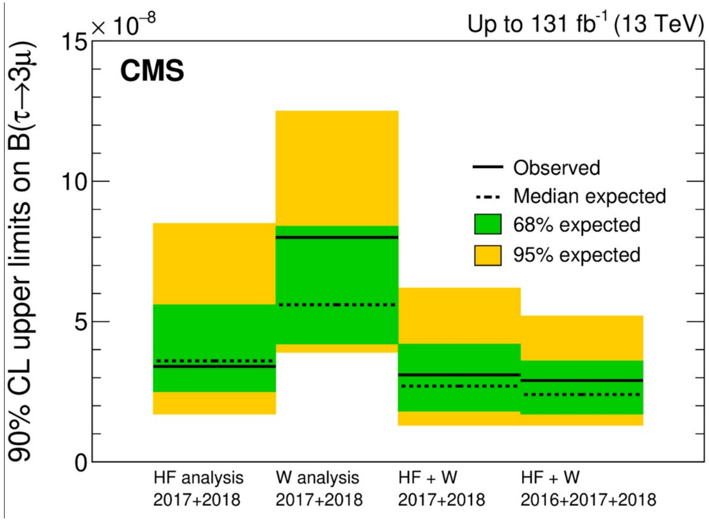
In **HF**, yields normalized to $D_s \rightarrow \phi\,\pi^+ \rightarrow \mu^+\mu^-\pi^+$

PLB 853 (2024) 138633

$\tau \rightarrow 3\mu$ search: CMS







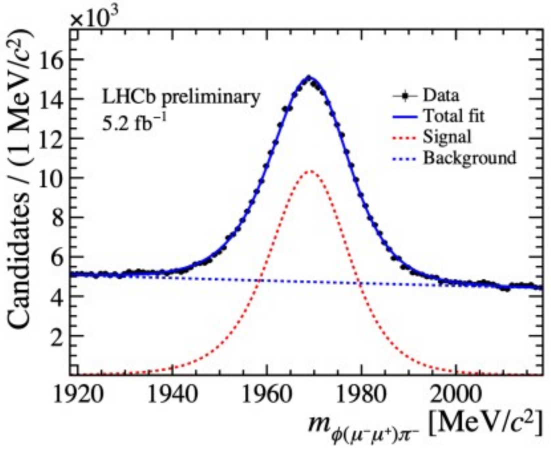
BR($\tau^- \rightarrow \mu^-\mu^+\mu^-$)<2.9 (3.6) x 10^{-8} at 90% (95%) CL

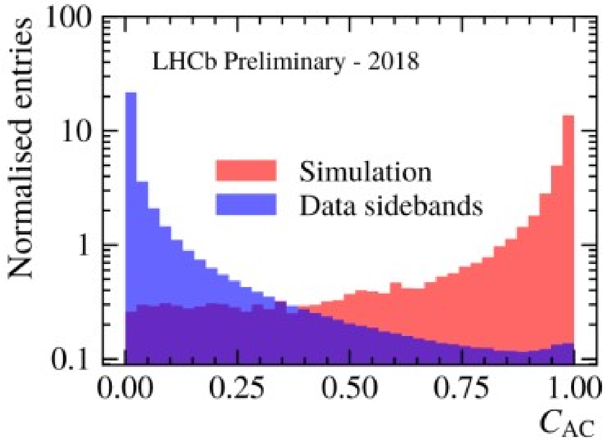
PLB 853 (2024) 138633

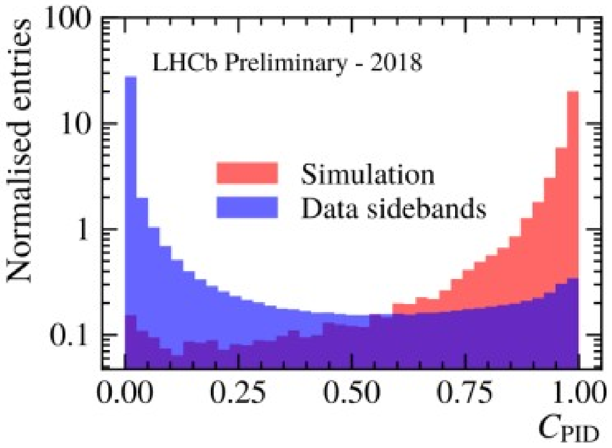
$\tau \to 3\mu$ search: LHCb

Only tau leptons from heavy flavor decays
Yields normalized to $D_s \to \phi \pi^+ \to \mu^+\mu^-\pi^+$
Main background:

- Combinatorial → BDT trained on kinematics + isolation variables (C_{AC})
- Hadron misID → BDT trained on PID and kinematics (C_{PID})
- 3μ background from D_s^-



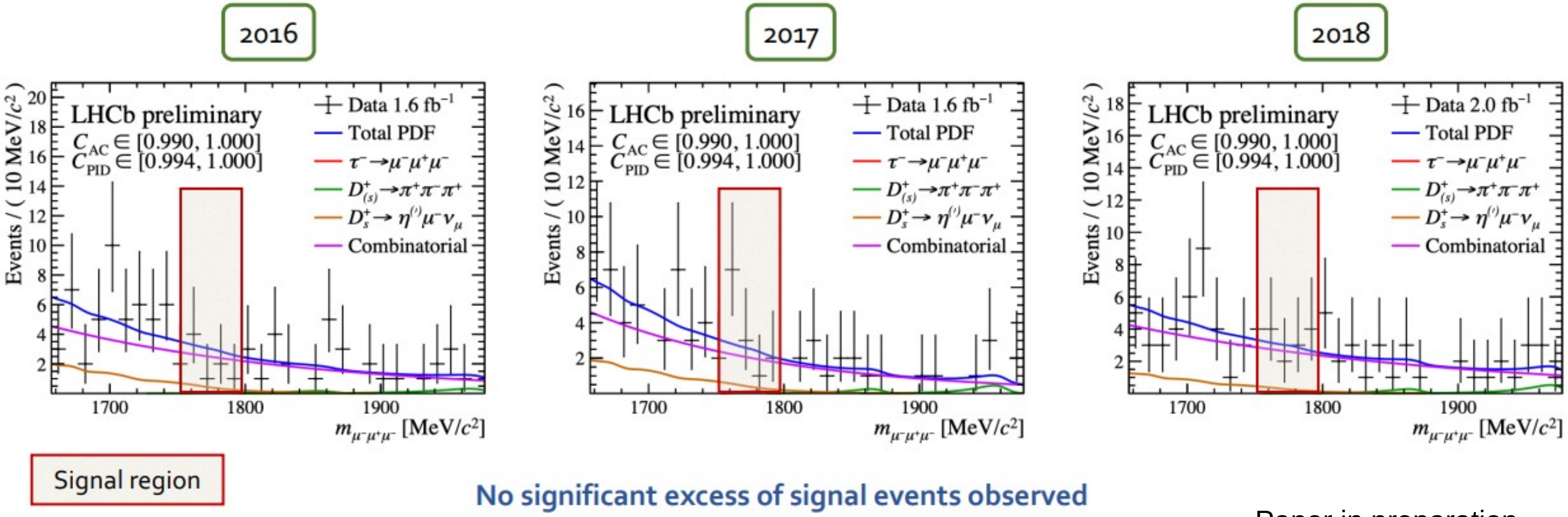




Paper in preparation

$\tau \rightarrow 3\mu$ search: LHCb

Unbinned maximum likelihood fit to the 3μ system mass performed simultaneously in the 15 ***CAC*** and ***CPID*** regions

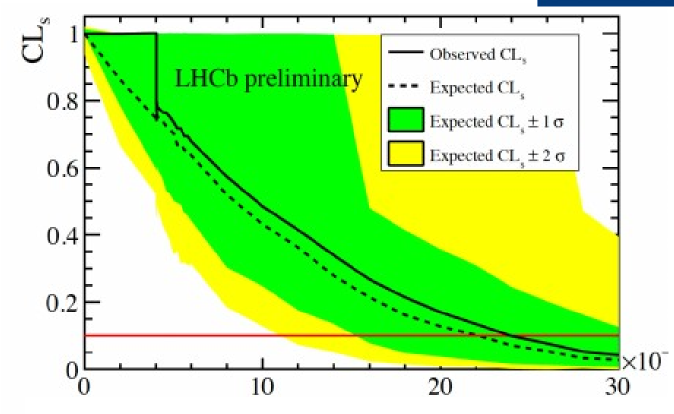


Paper in preparation

$\tau \rightarrow 3\mu$ search: LHCb

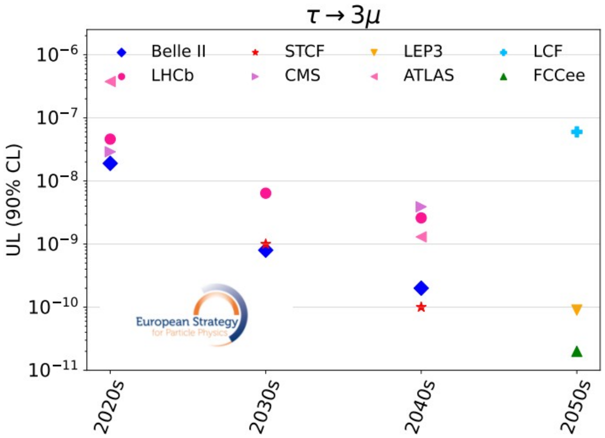
Expected limit:
$\mathcal{B}(\tau^- \rightarrow \mu^-\mu^+\mu^-)$ < 2.2(2.6)×10^{-8} at 90%(95%) CL

Observed limit:
$\mathcal{B}(\tau^- \rightarrow \mu^-\mu^+\mu^-)$ < 2.4(2.8)×10^{-8} at 90%(95%) CL



Almost 30% improvement w.r.t extrapolated limit from Run 1 (based on increasing luminosity and cross section of Run 2)

Best current limit from Belle
$\mathcal{B}(\tau^- \rightarrow \mu^-\mu^+\mu^-)$ < 1.9×10^{-8} at 90% CL



From Physics Briefing Book (2025) European Strategy

Summary

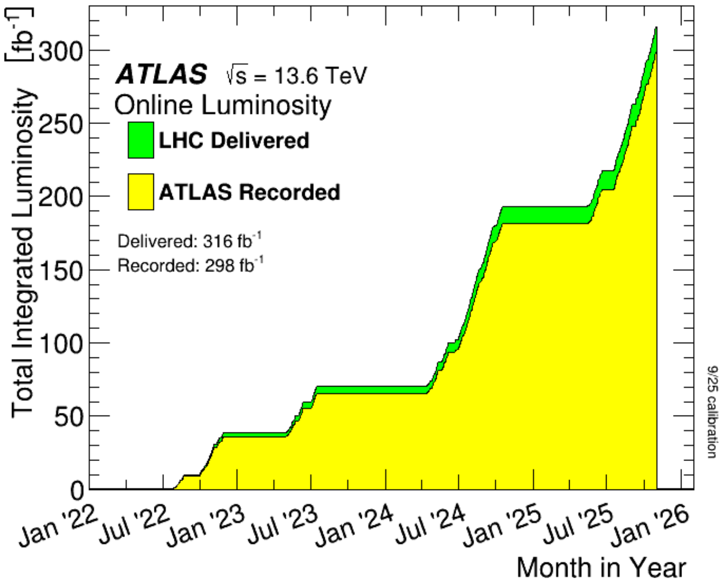
LFV searches can provide unambiguous signature for new Physics

→ Possibility to probe physics scales much larger than O(1 TeV) with EFT framework

ATLAS, CMS and LhCb could probe $\mathcal{B}$(LFV) down to 10^{-8}

Up to now, results based on Run2 → Run3 will add a factor 3 of dataset → up to now **300fb^{-1}** (**25fb^{-1}**) collected in Run3 for **ATLAS/CMS** (**LHCb**))

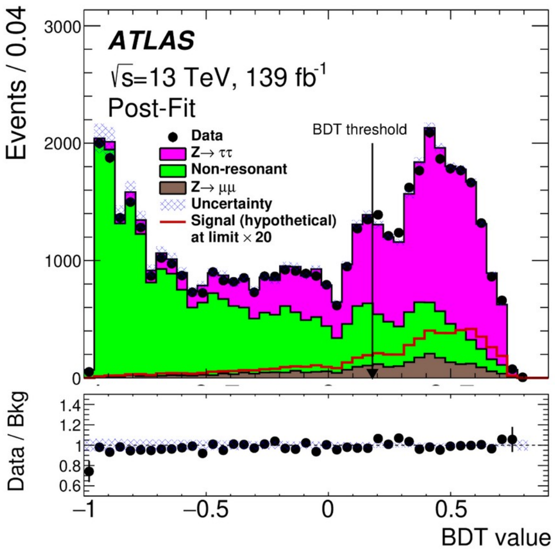
→ Also improvement expected from enhanced trigger and reconstruction strategies

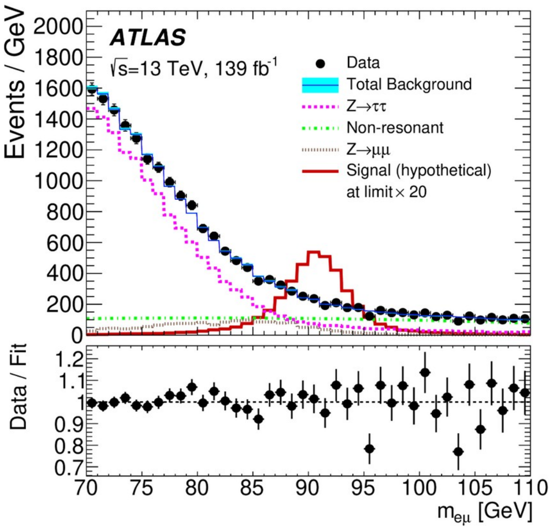



Backup
ctrl
alt

$Z \to e\mu$: ATLAS

Search for Lepton Flavor Violation in Z boson decays
BDT selection aiming at $e\mu$ signal
CR with same flavor events. Dominant backgrounds $Z \to \tau_{lep}\tau_{lep}$, $Z \to \mu\mu$





$B(Z \to e\mu)$ excluded at
$2.62\ (2.37) \times 10^{-7}$ at 95% CL

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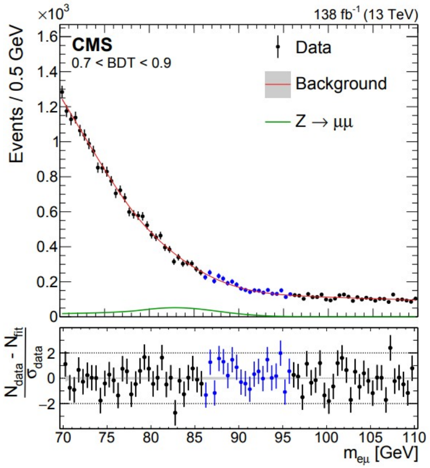
$Z \to e\mu$: CMS

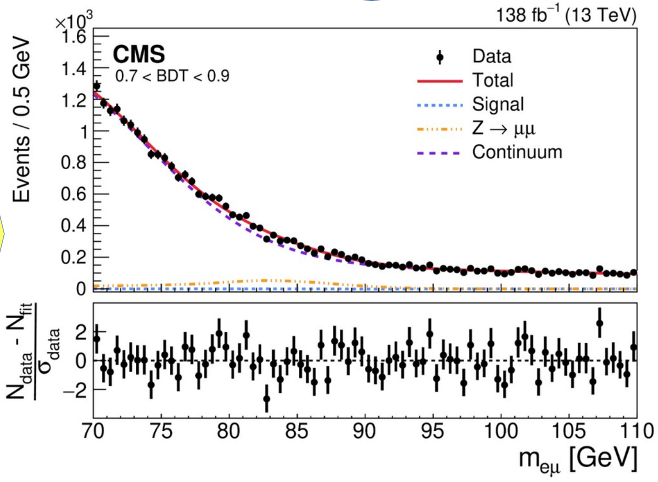
arXiv:2508.07512
accepted by PRD

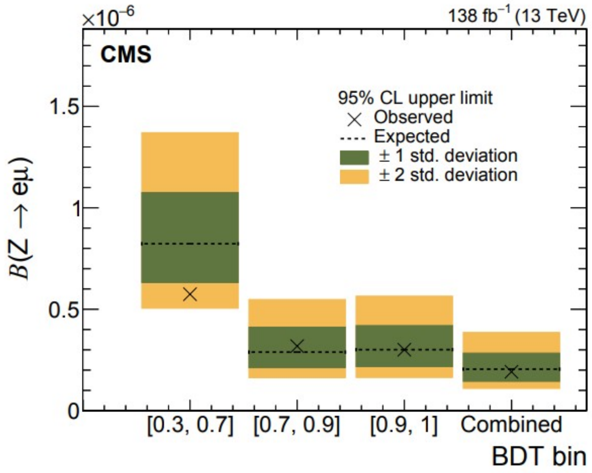
Search for Lepton Flavor Violation in Z boson decays
BDT to distinguish $Z \to e\mu$ signal from WW background → 3 classes according to BDT score
$Z \to e\mu$ signal modeled by a double Crystal ball function
Non resonant background modeled with an envelope of analytical function
$Z \to \mu\mu\gamma$ extracted from fit for each BDT score region

Background from sidebands



Signal from fit



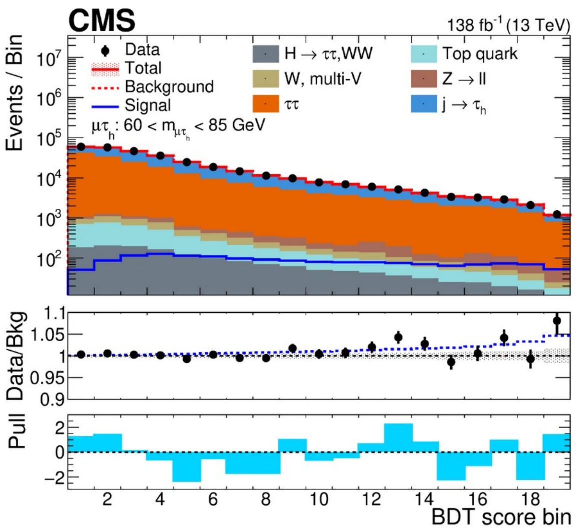


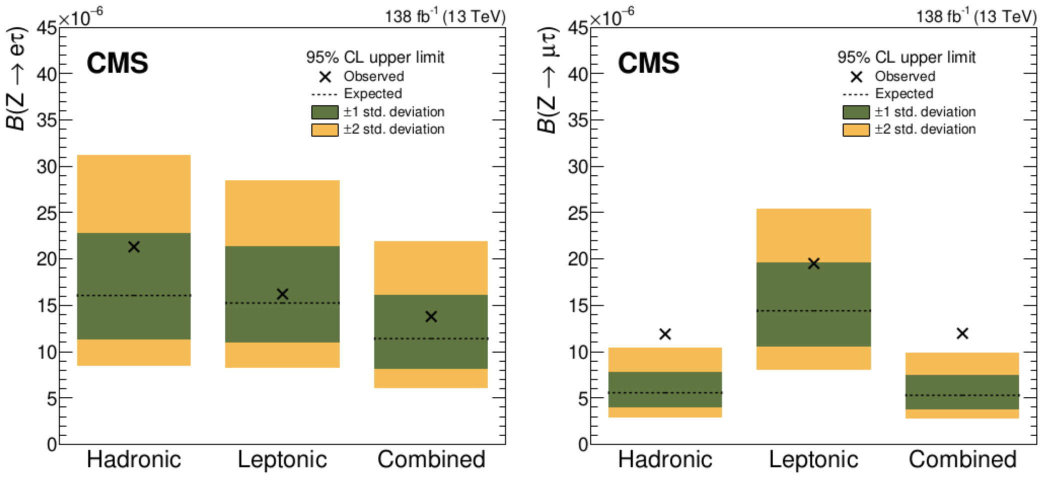
0.3 < BDT<0.7	5.7 (8.7) x10^{-7}
0.7<BDT<0.9	3.2 (2.9) x10^{-7}
0.9<BDT<1.0	3.0 (3.0) x10^{-7}
Combined	1.9 (2.0) x 10^{-7}

$Z \to (e/\mu)\tau$:CMS

Search for Lepton Flavor Violation in $Z \to \ell\tau$ (both hadronic and leptonic dcays)
Embedding technique to evaluate $Z \to \tau\tau_\mu$ background from data $Z \to \mu\mu$ replacing one of the muons with simulated τ
Four BDT used to discriminate $Z \to e\tau_{had}$, $e\tau_\mu$, $\mu\tau_{had}$, $\mu\tau_e$ vs $Z \to \tau\tau$ jet $\to$ $tau_{Mis\text{-}ID}$

arXiv:2508.07512
accepted by PRD

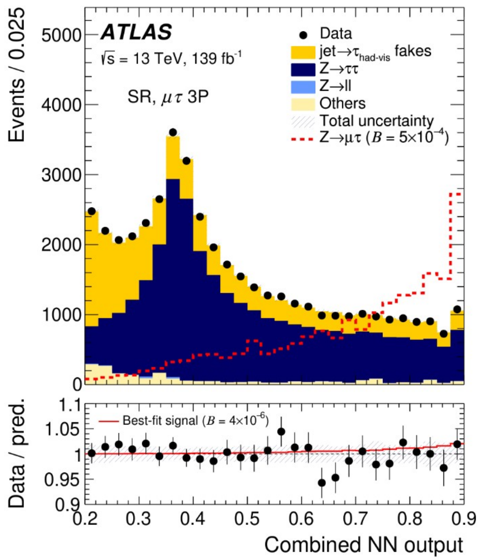


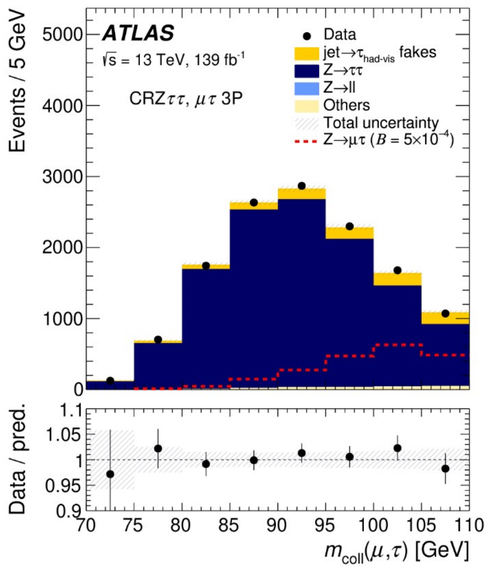


BR($Z \to \ell\tau$)<1.9 (2.0) x 10^{-7}

$Z \rightarrow (e/\mu)\tau_{\mathbf{Had}}$: ATLAS

Search for Lepton Flavor Violation in $Z \rightarrow \ell\tau_{\mathbf{Had}}$
NN discriminating signal vs W+jet, $Z \rightarrow \tau\tau$ $Z \rightarrow \ell\ell$
Separation 1 prong to 3 prong
Combined fit on SR using NN score and m_{coll} for $Z \rightarrow \tau\tau$ CR





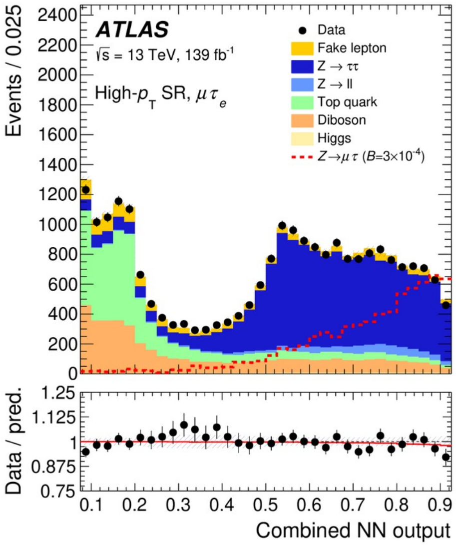
Experiment, polarization assumption	Observed (expected) upper limit on $\mathcal{B}(Z \rightarrow \ell\tau)$ [$\times 10^{-6}$] $e\tau$	$\mu\tau$
ATLAS Run 2, unpolarized τ	8.1 (8.1)	9.9 (6.3)
ATLAS Run 2, left-handed τ	8.2 (8.6)	9.5 (6.7)
ATLAS Run 2, right-handed τ	7.8 (7.6)	10 (5.8)

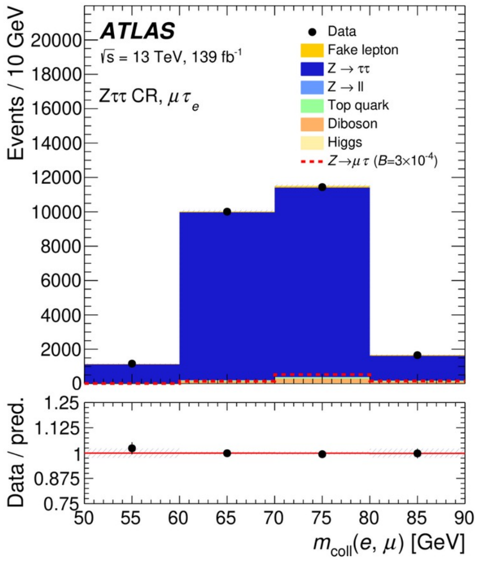
Nature Phys. 17 (2021) 819

$Z \to (e/\mu)\tau_{Lep}$: ATLAS

ATLAS EXPERIMENT

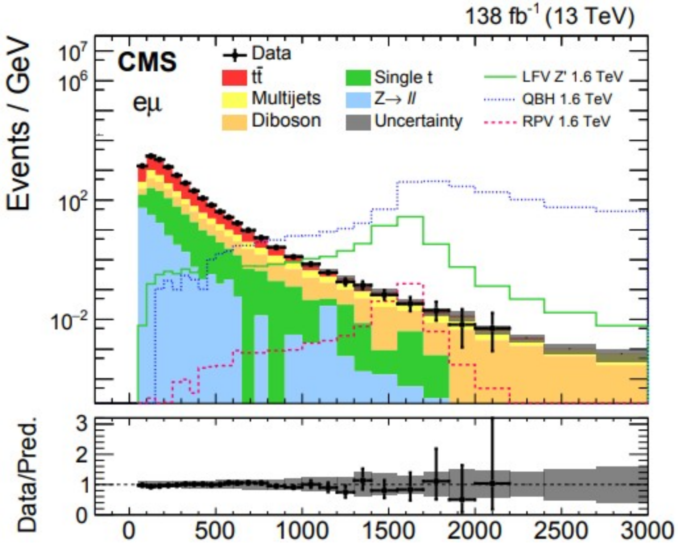
Search for Lepton Flavor Violation in $Z \to \ell\tau_{Lep}$
Dominant background $Z \to \tau\tau \to \ell\ell' + 4\nu$
3 NN trained signal vs $Z \to \tau\tau$, $t\bar{t}$, diboson
Combined fit for signal using NN score and m_{coll} for $Z \to \tau\tau$ CR
SR divided in a low-pt and high-pt with $P_T(\ell)$

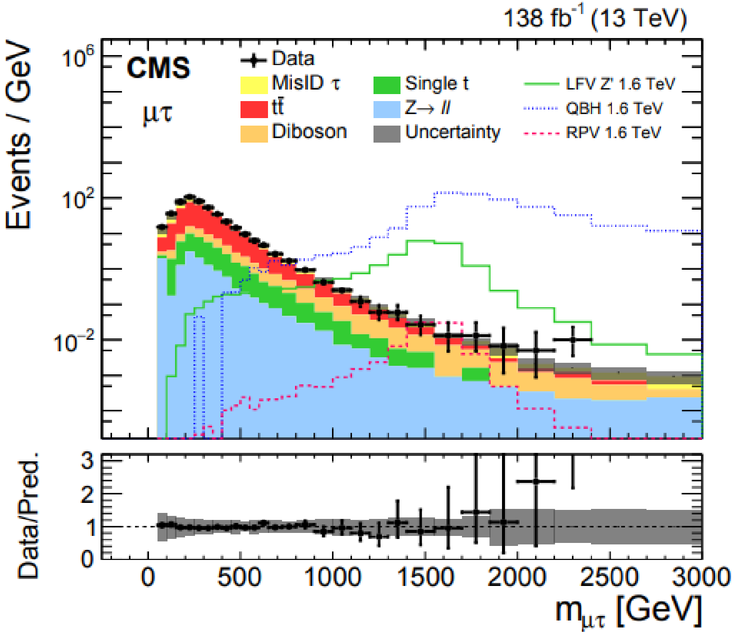


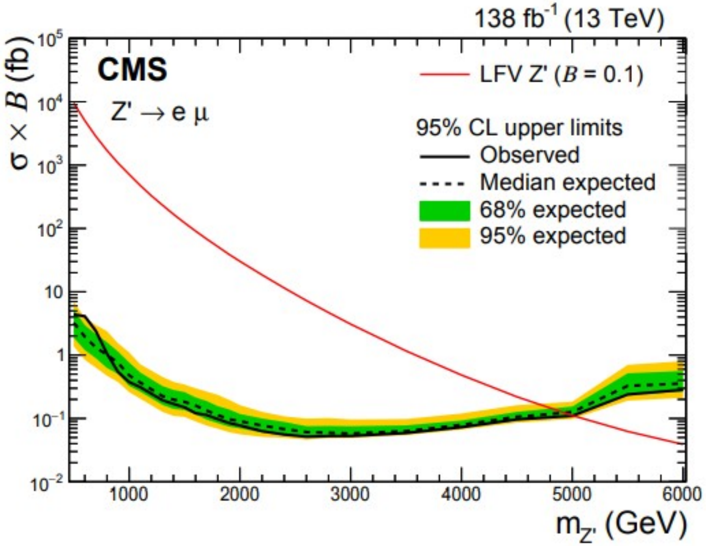


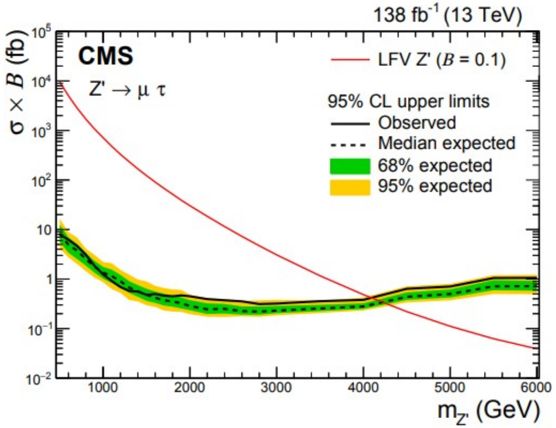
	eτ	μτ
τ unpol	$7.0\ (8.9) \times 10^{-6}$	$7.2\ (10) \times 10^{-6}$
τ Left Handed	$8.2\ (8.6) \times 10^{-6}$	$9.5\ (6.7) \times 10^{-6}$
τ Right Handed	$8.4\ (11) \times 10^{-6}$	$9.8\ (13) \times 10^{-6}$

Phys. Rev. Lett. 127 (2021) 271801


138 fb^{-1} (13 TeV)
CMS
eμ
Data
$t\bar{t}$
Multijets
Diboson
Single t
Z→ ll
Uncertainty
LFV Z' 1.6 TeV
QBH 1.6 TeV
RPV 1.6 TeV
Events / GeV
Data/Pred.


138 fb^{-1} (13 TeV)
CMS
μτ
Data
MisID τ
$t\bar{t}$
Diboson
Single t
Z→ ll
Uncertainty
LFV Z' 1.6 TeV
QBH 1.6 TeV
RPV 1.6 TeV
Events / GeV
Data/Pred.
$m_{\mu\tau}$ [GeV]


138 fb^{-1} (13 TeV)
CMS
Z' → e μ
LFV Z' (B = 0.1)
95% CL upper limits
Observed
Median expected
68% expected
95% expected
σ × B (fb)
$m_{Z'}$ (GeV)


138 fb^{-1} (13 TeV)
CMS
Z' → μ τ
LFV Z' (B = 0.1)
95% CL upper limits
Observed
Median expected
68% expected
95% expected
σ × B (fb)
$m_{Z'}$ (GeV)

Previous ATLAS results comes from t→ Zq channel

	95% CL upper limits on $|c|/\Lambda^2$ [TeV^{-2}]					
	$c_{\mathrm{lq}}^{-(ijk3)}$	$c_{\mathrm{eq}}^{(ijk3)}$	$c_{\mathrm{lu}}^{(ijk3)}$	$c_{\mathrm{eu}}^{(ijk3)}$	$c_{\mathrm{lequ}}^{1(ijk3)}$	$c_{\mathrm{lequ}}^{3(ijk3)}$
Previous (u) [34]	12	12	12	12	18	2.4
Expected (u)	0.33	0.31	0.3	0.32	0.33	0.08
Observed (u)	0.43	0.41	0.4	0.42	0.44	0.10
Previous (c) [34]	14	14	14	14	21	2.6
Expected (c)	1.3	1.2	1.2	1.2	1.4	0.28
Observed (c)	1.6	1.6	1.6	1.6	1.8	0.36

Limits from Wilson coeffiient → limits on BR

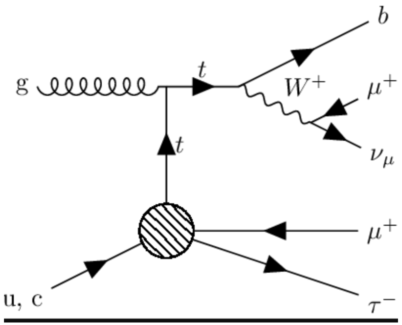
$$\Gamma(t \to \ell_i^+ \ell_j^- q_k) = \frac{m_t}{6144\pi^3}\left(\frac{m_t}{\Lambda}\right)^4 \Big\{4|c_{\mathrm{lq}}^{-(ijk3)}|^2 + 4|c_{\mathrm{eq}}^{(ijk3)}|^2 + 4|c_{\mathrm{lu}}^{(ijk3)}|^2 + 4|c_{\mathrm{eu}}^{(ijk3)}|^2 + 2|c_{\mathrm{lequ}}^{1(ijk3)}|^2 + 96|c_{\mathrm{lequ}}^{3(ijk3)}|^2\Big\} ,$$

ι and τ (where $\iota \neq \jmath$) and the quark generations are denoted by $k = 1, 2$ for u and c, respecti

	95% CL upper limits on $\mathcal{B}(t \to \mu\tau q)$ $(\times 10^{-7})$					
	$c_{\mathrm{lq}}^{-(ijk3)}$	$c_{\mathrm{eq}}^{(ijk3)}$	$c_{\mathrm{lu}}^{(ijk3)}$	$c_{\mathrm{eu}}^{(ijk3)}$	$c_{\mathrm{lequ}}^{1(ijk3)}$	$c_{\mathrm{lequ}}^{3(ijk3)}$
Expected (u)	2.3	2.0	1.9	2.2	1.2	3.0
Observed (u)	4.0	3.6	3.3	3.8	2.0	5.2
Expected (c)	33	32	32	33	20	41
Observed (c)	56	54	53	54	34	67

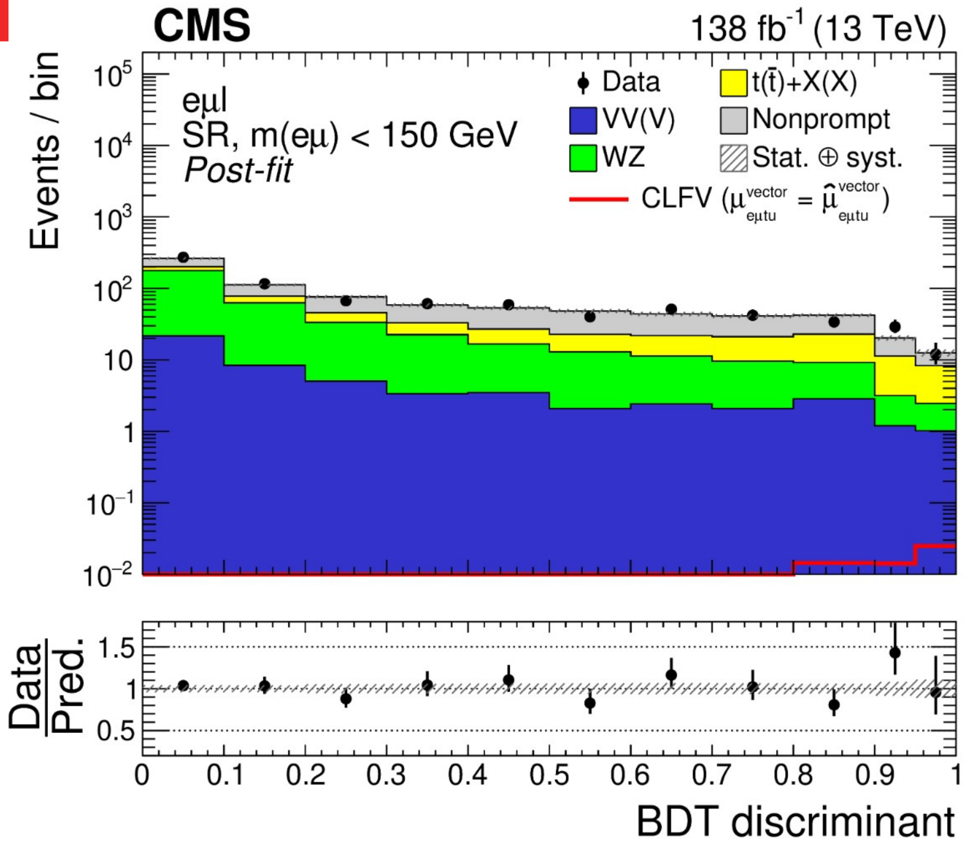
: full set of statistical and systematic uncertainties.

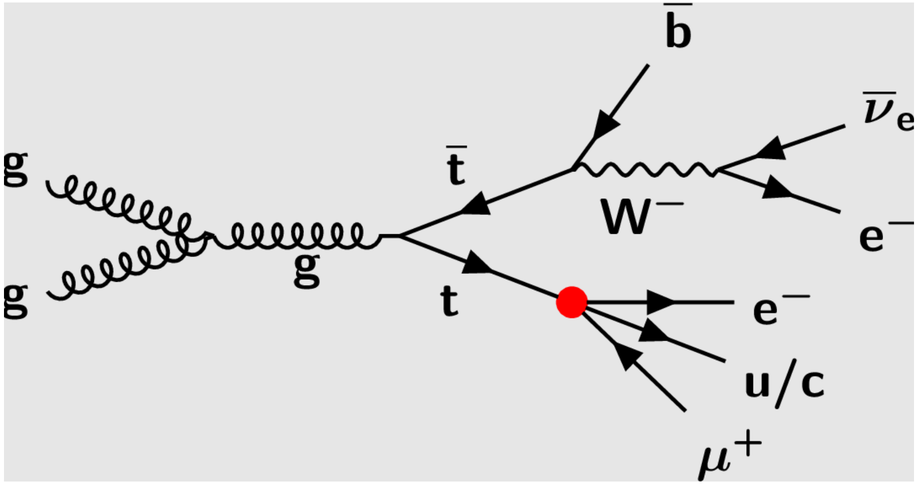
	95% CL upper limits on $\mathcal{B}(t \to \mu\tau q)$	
	Stat. uncertainty	**Stat.+syst. uncertainties**
Expected	4.6×10^{-7}	5.0×10^{-7}
Observed	8.2×10^{-7}	8.7×10^{-7}



1.0 for the calculation of the cross-section, with an energy scale of $\Lambda = 1$ TeV.

	Cross-section $\sigma^{+\text{scale}}_{-\text{scale}} \pm$ PDF [fb]		
	$c_{\text{vector}}^{(ijk3)}$	$c_{\text{lequ}}^{1(ijk3)}$	$c_{\text{lequ}}^{3(ijk3)}$
Production $\ell\ell' ut$	$118^{+24}_{-19} \pm 1$	$101^{+21}_{-16} \pm 1$	$2150^{+410}_{-320} \pm 20$
Production $\ell\ell' ct$	$7.9^{+1.2}_{-1.0} \pm 1.6$	$6.1^{+1.0}_{-0.8} \pm 1.5$	$153^{+21}_{-18} \pm 29$
Decay $\ell\ell' q_k t$	$6.9^{+1.8}_{-1.3} \pm 0.1$	$3.46^{+0.90}_{-0.66} \pm 0.03$	$166^{+43}_{-32} \pm 2$

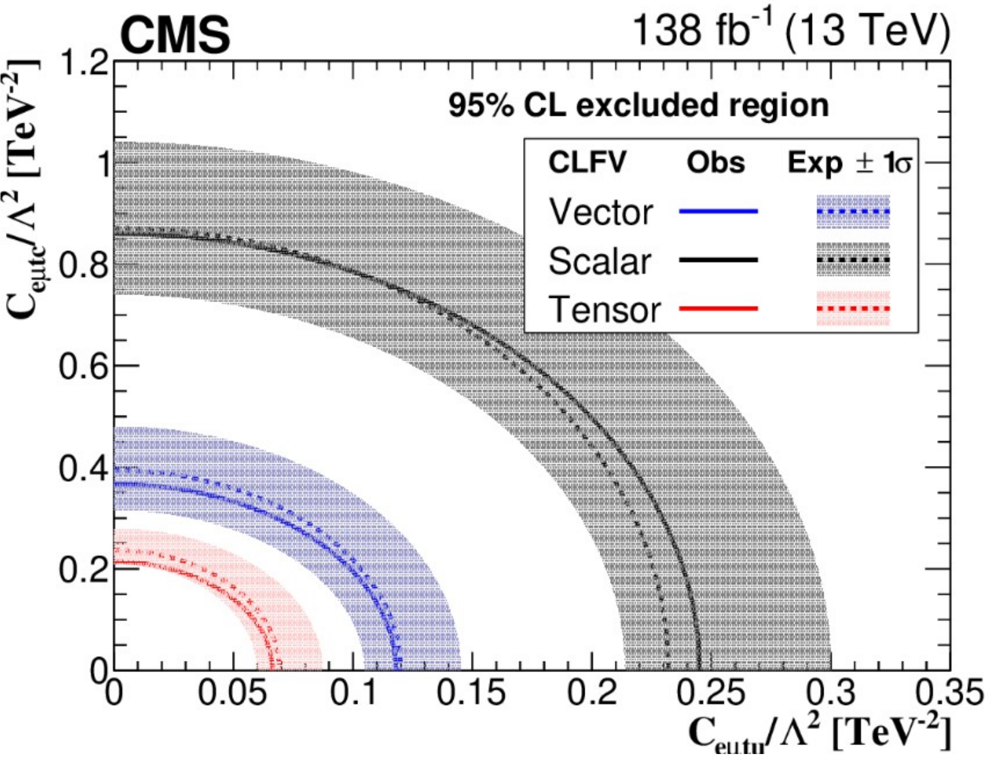


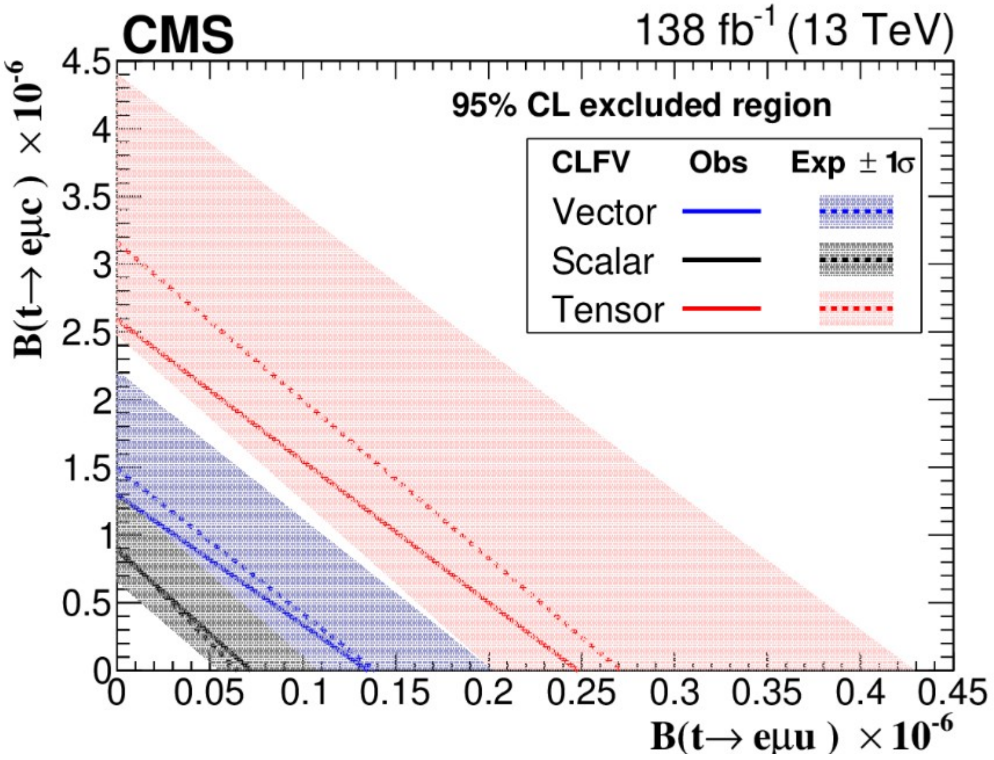


Category	Region	OnZ	OffZ	p_T^{miss}	# jets	# b jets
3ℓ	jet modeling VR	✓	—	>85 GeV	—	=0
$eee/\mu\mu\mu$	nonprompt VR	—	—	—	—	—
	WZ VR	✓	—	>20 GeV	≥1	≤1
$e\mu\ell$	SR	—	✓	>20 GeV	≥1	≤1
	nonprompt VR	✓	—	—	—	—
	WZ VR	✓	—	>20 GeV	≥1	≤1

Table 6: Expected and observed upper limits at 95% CL on Wilson coefficients and the branching fractions for tensor-, vector-, and scalar-like CLFV interactions. The intervals that contain 68% of the distribution of the expected upper limits are shown in parentheses.

CLFV coupling	Lorentz structure	$C_{e\mu tq}/\Lambda^2$ (TeV^{-2}) Exp. (68% CL range)	Obs.	$\mathcal{B}(t \to e\mu q) \times 10^{-6}$ Exp. (68% CL range)	Obs.
$e\mu tu$	Tensor	0.022 (0.018–0.026)	0.024	0.027 (0.018–0.040)	0.032
	Vector	0.044 (0.036–0.054)	0.048	0.019 (0.013–0.028)	0.022
	Scalar	0.093 (0.077–0.114)	0.101	0.010 (0.007–0.016)	0.012
$e\mu tc$	Tensor	0.084 (0.069–0.102)	0.094	0.396 (0.272–0.585)	0.498
	Vector	0.175 (0.145–0.214)	0.196	0.296 (0.203–0.440)	0.369
	Scalar	0.385 (0.318–0.471)	0.424	0.178 (0.122–0.266)	0.216



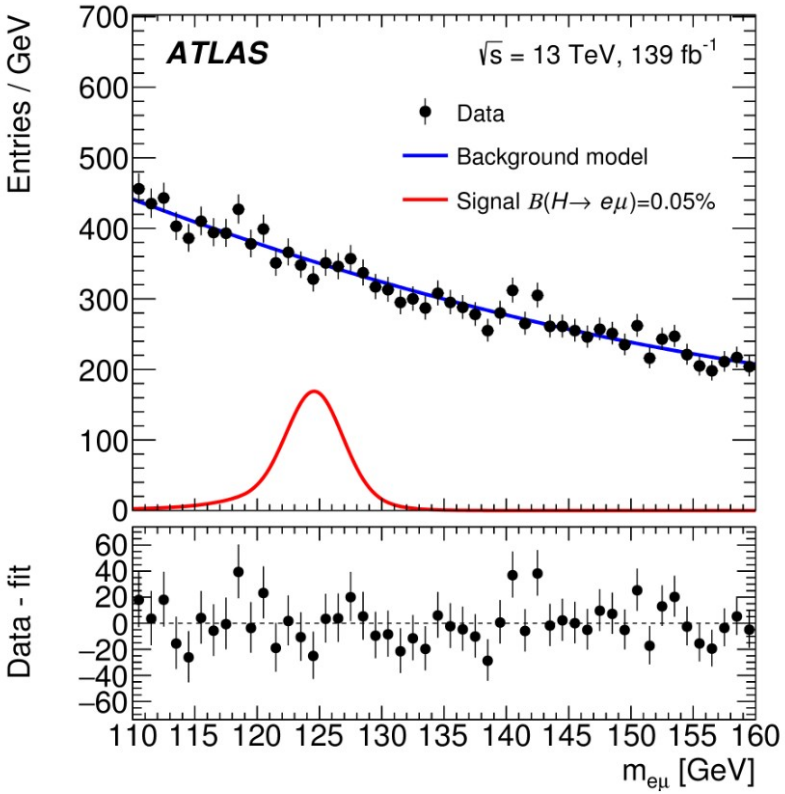


Old result

JHEP 06 (2022) 082

Method	Channel	Category	Region	1 POI fit	2 POI fit
MC-template	$\ell\tau_{\ell'}$	*non-VBF*	SR	✓	✓
			$Z \to \tau\tau$ CR	✓	✓
			Top-quark CR	✓	✓
		VBF	SR		✓
			$Z \to \tau\tau$ CR		✓
			Top-quark CR		✓
MC-template	$\ell\tau_{\text{had}}$	*non-VBF*	SR	✓	✓
		VBF	SR	✓	✓
Symmetry	$\ell\tau_{\ell'}$	*non-VBF*	SR		
		VBF	SR	✓	

H → emu



Phys. Lett. B 801 (2020) 135148