Search for L Violating and Lepton Flavor Violating Processes at the LHC

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On behalf of the ATLAS and CMS collaborations

Outline

- Introduction
- Lepton Flavor Universality Measurements
  - W Decays: $W \to \tau\nu, \mu\nu, R_{\tau/\mu}$
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  - Z Decays: $Z \to e\tau, \mu\tau$
  - Higgs Decays: $H \to e\mu, e\tau, \mu\tau$
  - $\tau \to 3\mu$
  - Top Quark Decays: $t \to \ell^+\ell^- q$, $t \to e\mu eq$
  - Dileptons + b-jets
  - High-mass dilepton pairs $R_{ee/\mu\mu}$
  - LFV Resonances: $Z' \to e\mu, \mu\tau, e\tau$
- RPV SUSY
  - Trilepton resonances
  - Final states containing leptons and many jets
- HL LHC projections

Introduction

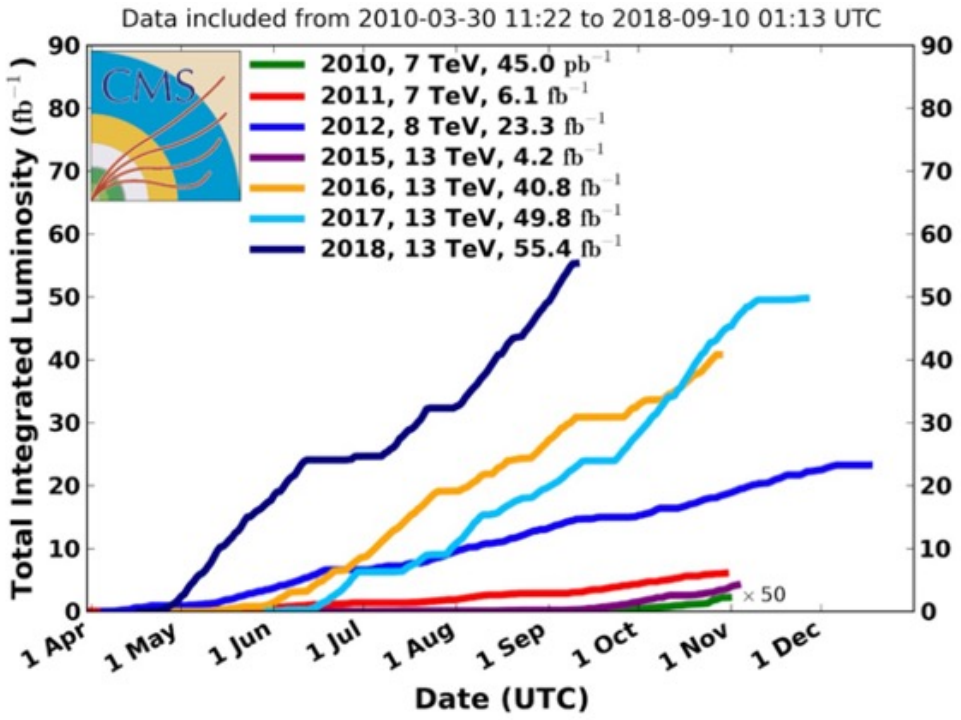
- All electroweak bosons are assumed to couple to all three lepton generations with the same strength, a property known as Lepton Flavor Universality (LFU).
  - Hence, charged-lepton flavor is basically conserved in the Standard Model.
  - There is no fundamental reason for this to happen (i.e., no fundamental symmetry preserving lepton numbers).
  - In many SM extensions LFV occurs and only more general symmetries, e.g., B - L are conserved.
  - An observation of LFV in charged-lepton interactions would be an unambiguous sign of new physics.
- Neutrino oscillations guarantee charged-lepton flavor violation via loops.
  - Extremely suppressed: $B(\mu \rightarrow e\gamma) \sim 10^{-55}$.
- However, couplings of the Higgs boson to leptons are not flavor-universal.
  - This was first shown via an evidence for $H \rightarrow \mu\mu$ decays (PLB 812 (2021) 135980).
  - The first clear sign of LFU violation.

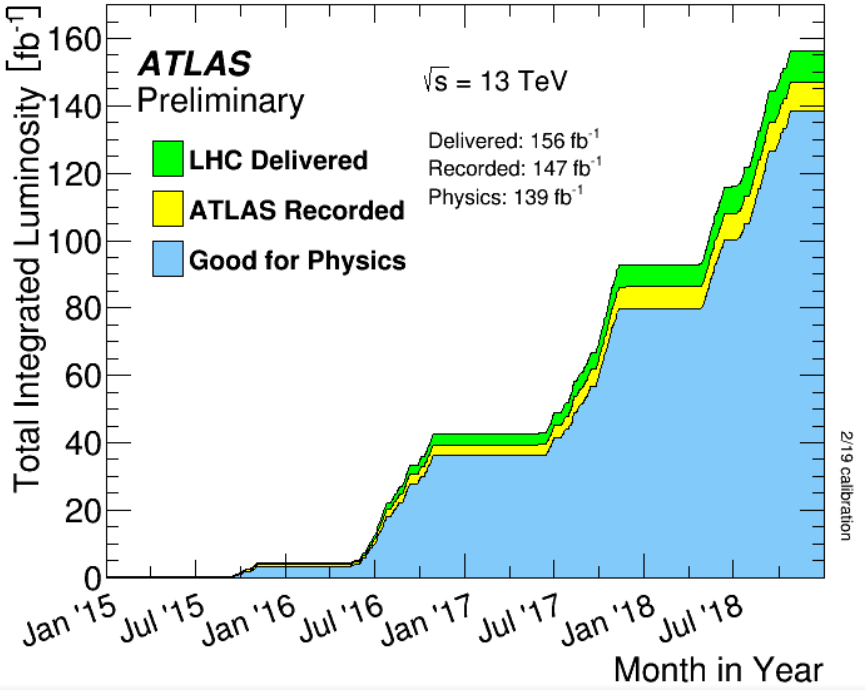
Motivation for LFV Searches

- Direct LFV processes are not allowed in the Standard Model, but are predicted in its many extensions.
  - e.g. models with heavy neutrinos, SUSY, extra U(1) symmetry, models with more Higgs doublets.
- Higgs coupling constants are so far in accordance with Standard Model predictions, nevertheless exotic decays are not yet excluded.
- In recent years, hints of potential LFV have been reported, e.g., in semileptonic decays of B mesons where the bottom quark converts into a strange quark through an intermediate W boson.
- In addition, other hints of LFU failure have been seen in rarer (electroweak, loop-induced) B-meson decays.
  - Possible flavor anomalies reported in the $b \to s\ell^+\ell^-$ and $b \to c\ell^-\nu$ transitions.
- The quest for LFV processes at the LHC is one of the key searches for new physics.

LHC Run 2

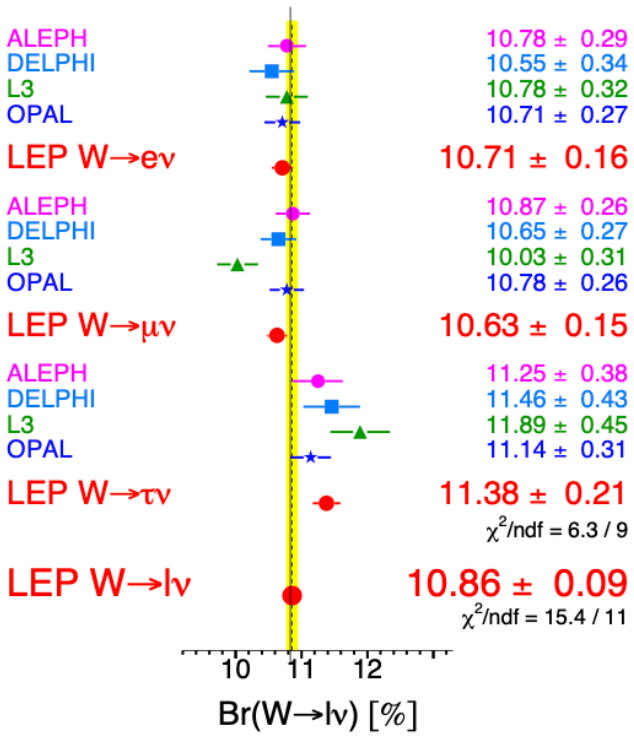
- The LHC has been operating at $\sqrt{s}$ = 13 TeV in 2015−2018 (Run 2).
- It delivered a dataset corresponding to about 160 fb^{-1}.
- About 140 fb^{-1} of physics-quality data recorded by each ATLAS & CMS.
- The ATLAS and CMS detectors has been working spectacularly with virtually no degradation in performance over the years.





Lepton Flavor Universality in W Decays

- The $W \to \tau\nu$ branching fraction is measured consistently higher w.r.t. the $W \to e\nu$ or $W \to \mu\nu$ branching fractions in all four LEP experiments.
  - Combined result: $R_{\tau/\mu} = 1.070 \pm 0.026$, 2.7σ from unity.
  - Possible hint of lepton non-universality or statistical fluctuation?

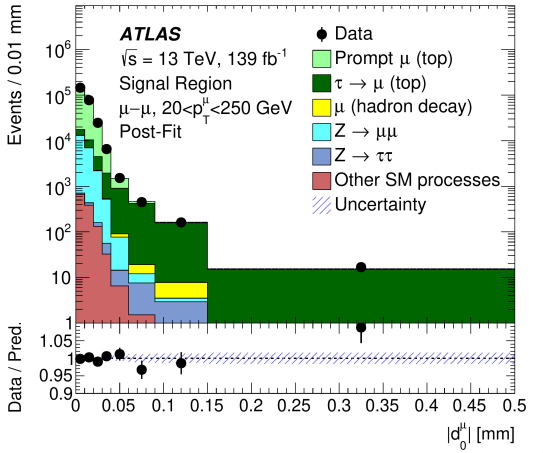


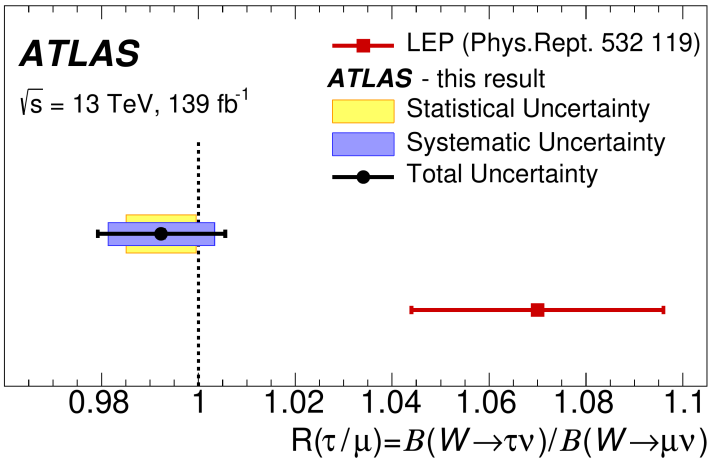
	Lepton non–universality			Lepton universality
Experiment	$\mathcal{B}(W \to e\bar{\nu}_e)$ [%]	$\mathcal{B}(W \to \mu\bar{\nu}_\mu)$ [%]	$\mathcal{B}(W \to \tau\bar{\nu}_\tau)$ [%]	$\mathcal{B}(W \to \text{hadrons})$ [%]
ALEPH	10.78 ± 0.29	10.87 ± 0.26	11.25 ± 0.38	67.13 ± 0.40
DELPHI	10.55 ± 0.34	10.65 ± 0.27	11.46 ± 0.43	67.45 ± 0.48
L3	10.78 ± 0.32	10.03 ± 0.31	11.89 ± 0.45	67.50 ± 0.52
OPAL	10.71 ± 0.27	10.78 ± 0.26	11.14 ± 0.31	67.41 ± 0.44
LEP	10.71 ± 0.16	10.63 ± 0.15	11.38 ± 0.21	67.41 ± 0.27
χ^2/dof	6.3/9			15.4/11

ADLO: Phys. Rep. 532 (2013) 119

Test of LFU in W Decays (ATLAS)

- Large samples of muonic W decays in $t\bar{t}$ events, either prompt or via a τ lepton, made it possible for a precision test of the LEP result.
- Measure $R_{\tau/\mu} = B(W\rightarrow\tau\nu_\tau)/B(W\rightarrow\mu\nu_\mu)$.
  - Tag one top quark leptonic (e/μ) decay and look on the other side, utilizing the probe muon p_T and impact parameter to distinguish prompt and non-prompt events.
  - Muons from W bosons are distinguished from those originating from an intermediate τ-lepton by using the lifetime of the τ-lepton, the muon transverse impact parameter, and differences in the muon transverse momentum spectra.
  - Main backgrounds $Z\rightarrow\mu\mu$ with lost μ and and non-W probe μ events.
  - Fit impact parameter spectra in different $p_T(\mu)$ bins.
- Result: $R_{\tau/\mu} = 0.992 \pm 0.013$, in good agreement with LFU.





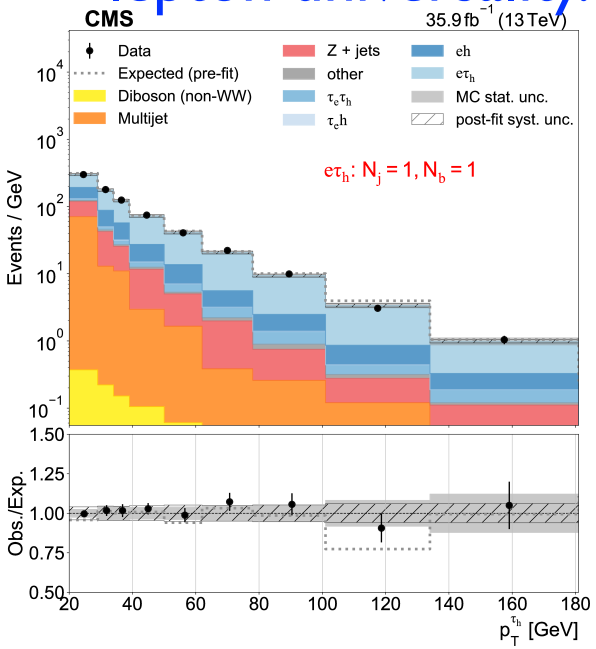
ATLAS: Nature Phys. 17 (2021) 813

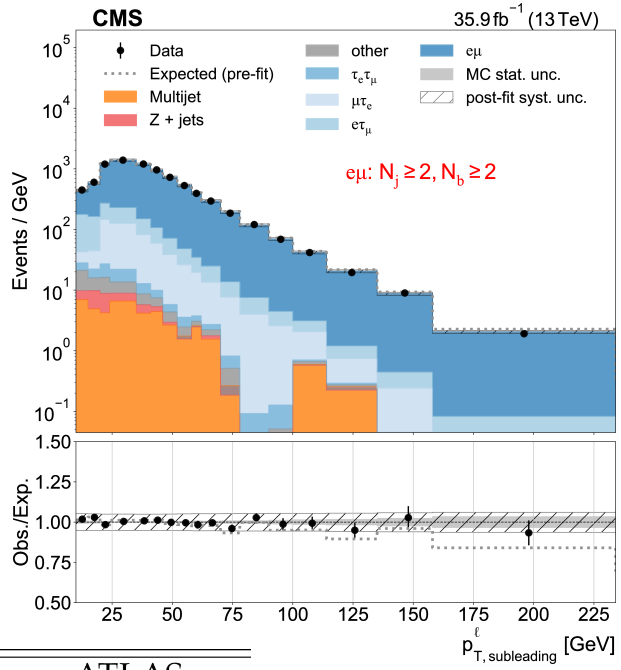
Test of LFU in W Decays (CMS)

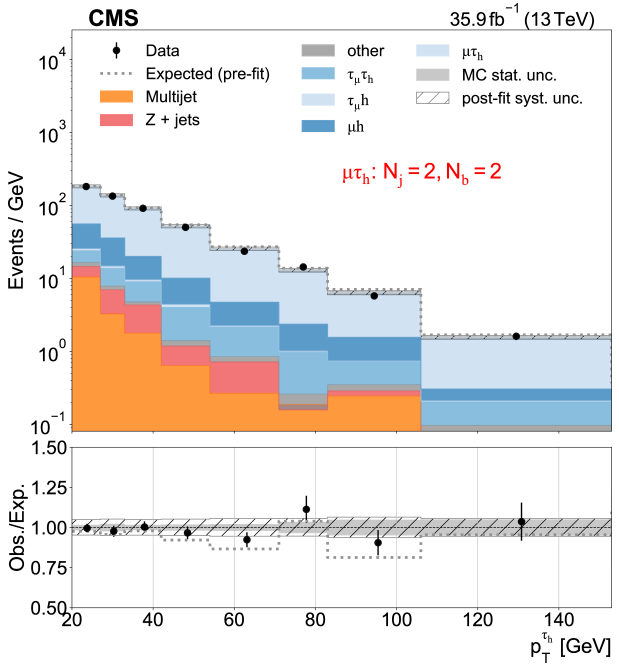
- Inclusive analysis targeting simultaneous extraction of $\beta = \{\beta_e, \beta_\mu, \beta_\tau, \beta_h\}$ W boson branching fractions, using both leptonic and hadronic τ lepton decays.
- Events with one or two W bosons produced are collected using single-charged-lepton triggers that require at least one prompt electron or muon with large transverse momentum.
  - Search includes WW, W+jets, tW, and $t\bar{t}$ production.
- W boson leptonic branching fractions are determined using a binned maximum likelihood fit of events in multiple categories.
  - Events categorized based on lepton flavor (muon, electron, or hadronic τ), jet multiplicity, and b-tagged jet multiplicity.
  - Simultaneous fit of all categories and the distribution of a single kinematic variable within each category.
- Uses kinematic information in dilepton events to separate leptons coming directly from the W boson decay from those coming from the intermediate τ lepton decays.

Test of LFU in W Decays (CMS)

- Fit of the $p_T(\tau)$ distribution in the $e\mu$, $e\tau_h$, and $\mu\tau_h$ categories.
- Both leptonic and hadronic branching fractions measured.
- Hadronic branching fractions reported with and without assuming lepton universality.





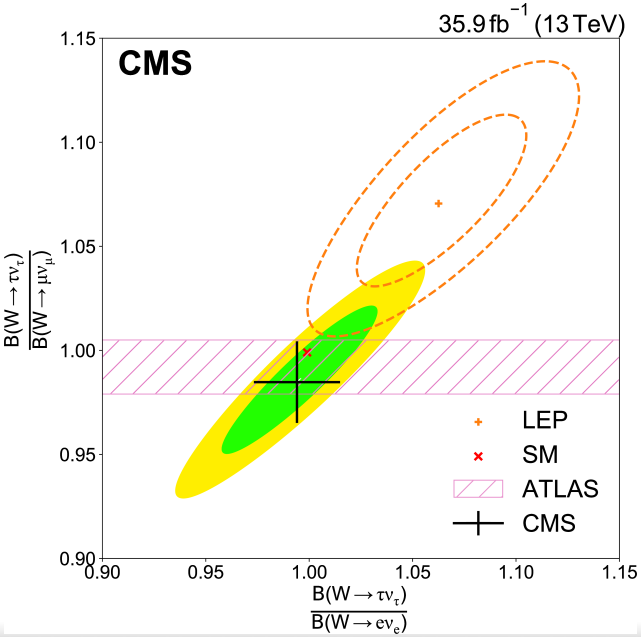


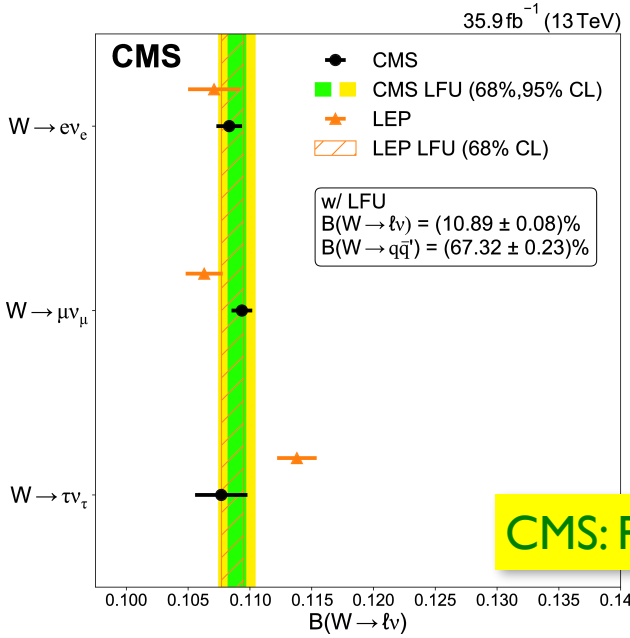
	CMS	LEP	ATLAS
$R_{\mu/e}$	1.009 ± 0.009	0.993 ± 0.019	1.003 ± 0.010
$R_{\tau/e}$	0.994 ± 0.021	1.063 ± 0.027	—
$R_{\tau/\mu}$	0.985 ± 0.020	1.070 ± 0.026	0.992 ± 0.013
$R_{\tau/\ell}$	1.002 ± 0.019	1.066 ± 0.025	—

CMS: Phys. Rev. D 105 (2022) 072008

Test of LFU in W Decays (CMS)

- Results are consistent with both LFU and ATLAS results, and are complementary to ATLAS via the inclusion of the electron channel.
- Uncertainties are comparable to or smaller than LEP.
- Sensitivity to hadronic decays allow to test the CKM matrix unitarity and extract the poorly measured $|V_{cs}|$ element with a precision rivaling the world average.
- Constrain the CKM matrix parameters and the strong coupling constant:





CKM matrix unitarity:

$$\sum_{ij} |V_{ij}|^2 = 1.984 \pm 0.021$$

Extraction of $|V_{cs}|$:

$$|V_{cs}| = 0.967 \pm 0.011$$

CMS: Phys. Rev. D 105 (2022) 072008

LFV Searches in Z Decays

- By now ATLAS and CMS each has collected 2.5 orders of magnitude more (~10^{10}) Z bosons than all four LEP experiments (~2×10^{7}).
  - Explore LFV in Z boson decays with unprecedented precision, particularly for the LFV couplings involving third-generation leptons.
  - Previous best direct limits on the μe decay were set by LEP at 1.7×10^{-6} @95% CL and the LHC at 7.5×10^{-7} @95% CL.
  - Previous best limits on the τe and τμ decays were set by LEP at 9.8×10^{-6} and 1.2×10^{-5} @95% CL, respectively.
- Challenging new ATLAS search for $Z \rightarrow \mu e$ and $Z \rightarrow \tau e$ and $\tau\mu$ using the hadronic τ decay channel.

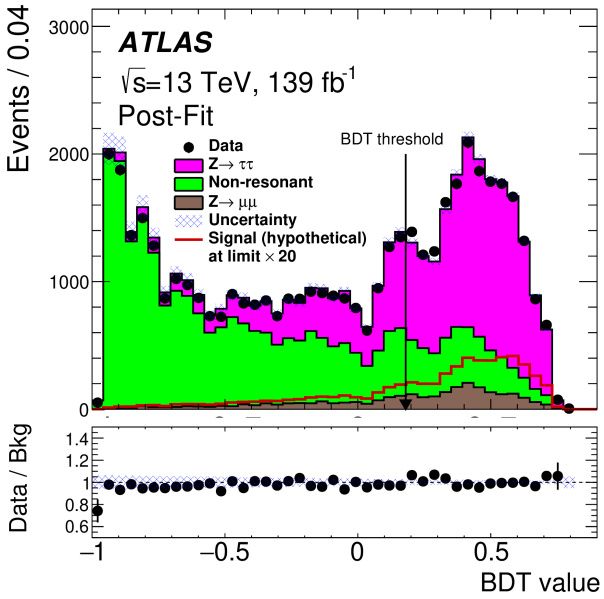
ATLAS: arXiv:2204.10783v1

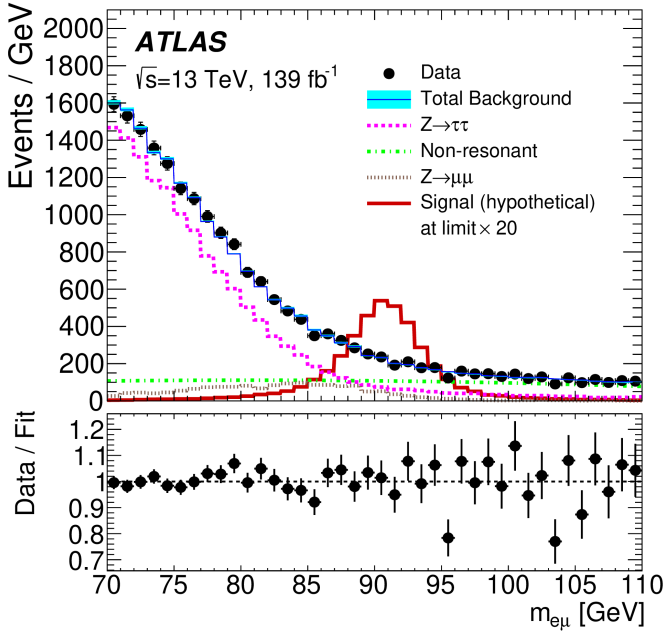
ATLAS: Nature Phys. 17 (2021) 819

ATLAS: PRL 127 (2021) 271801

LFV Searches in Z Decays (ATLAS)

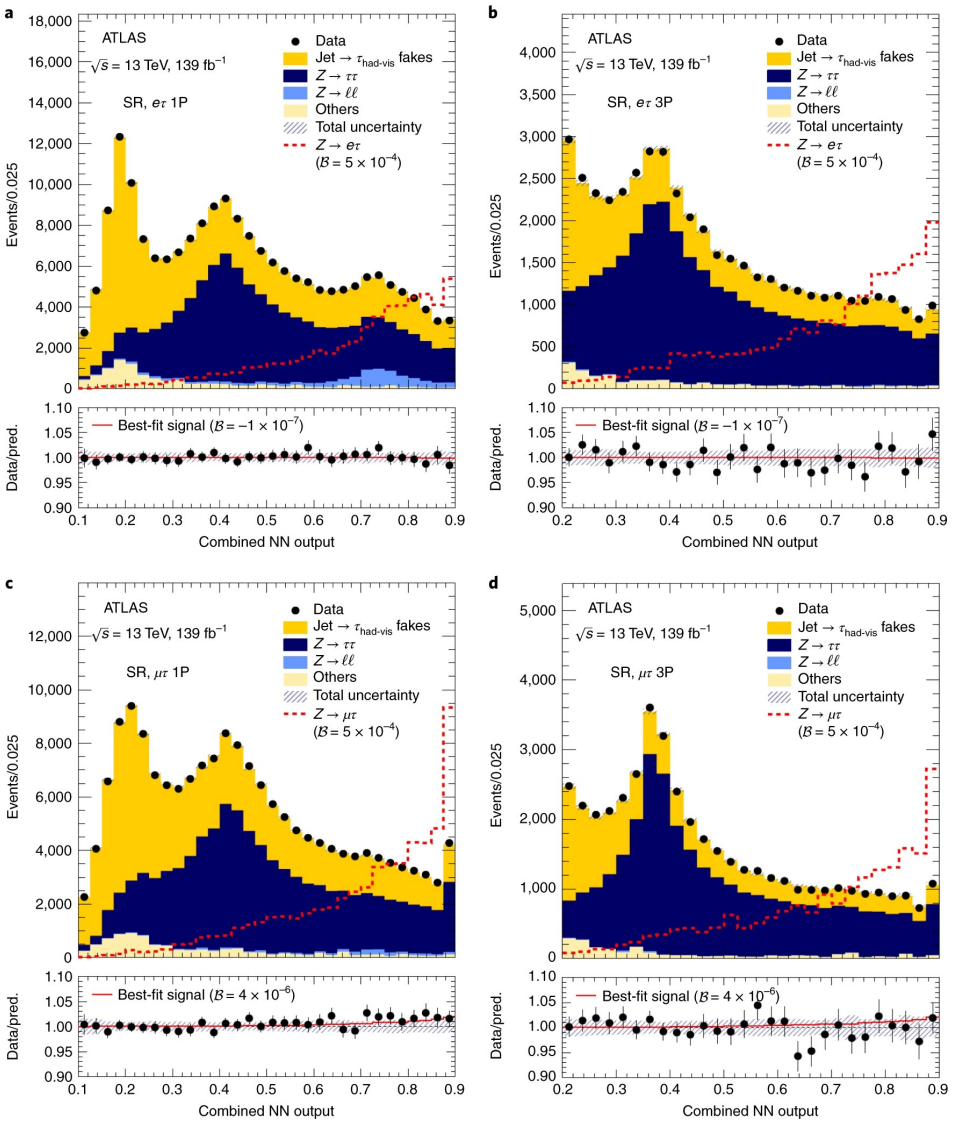
- ATLAS search for Z→ eμ uses a boosted decision tree (BDT) and a veto on b-quark-tagged jets to enhance the signal selection.
- B(Z→eμ) is extracted using a maximum-likelihood signal-plus-background fit.
- An upper limit of B(Z→eμ) < 2.62×10^{-7} is set at 95% CL.
  - a significant improvement on the previous LHC limit, and the most stringent direct result yet reported.





LFV Searches in Z Decays with τ Leptons

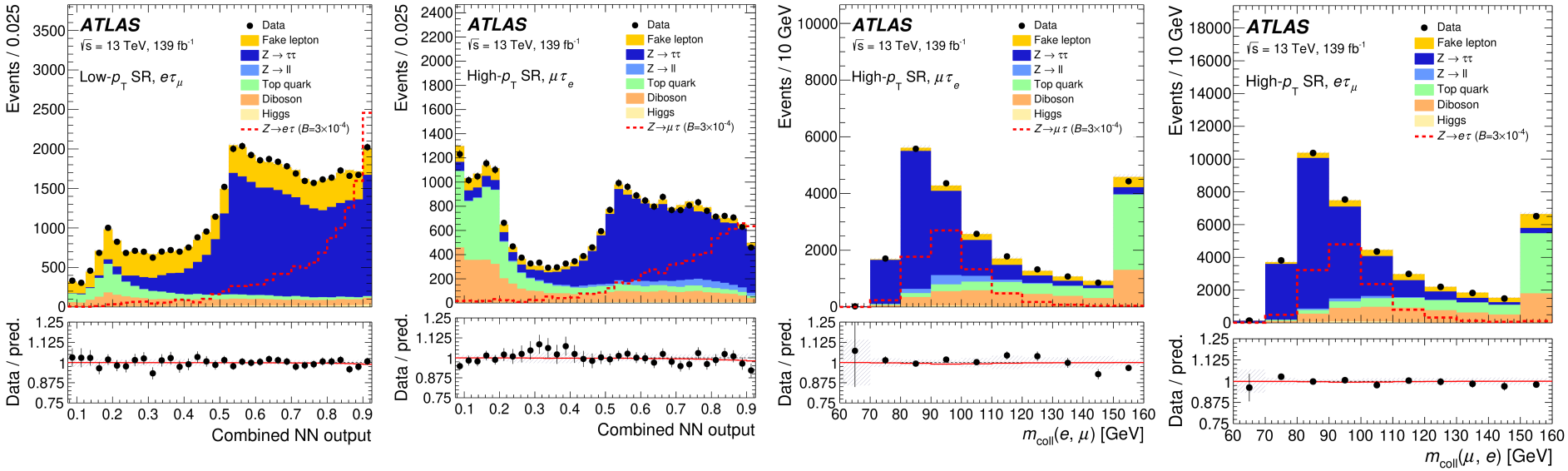
- Only events with a τ lepton that decays hadronically are considered.
- Main backgrounds come from $Z \to \tau_h \tau_\ell$ and $W \to \ell \nu$+jet.
  - Neural network (NN) classifiers are used for optimal discrimination of signal from background.
- $B(Z \to e\tau) < 8.1 \times 10^{-6}$ and $B(Z \to \mu\tau) < 9.5 \times 10^{-6}$.
  - These results supersede the most stringent ones set by the LEP experiments.
  - Limits and are statistics limited and will keep improving with increasing luminosity.



ATLAS: Nature Phys. 17 (2021) 819

LFV Searches in Z Decays with τ Leptons

- Adding leptonic tau decays.
- First search at the LHC for $Z \to \ell \tau_{\ell'}$ in the $e\tau_\mu$ and $\mu\tau_e$ channels.
  - Channels are further split into a high-and low-$p_T(\ell)$ signal regions.
  - The main irreducible $Z \to \tau_\ell \tau_\ell$ background is suppressed via a NN based on lepton kinematic variables.



ATLAS: PRL 127 (2021) 271801

LFV Searches in Z Decays with τ Leptons

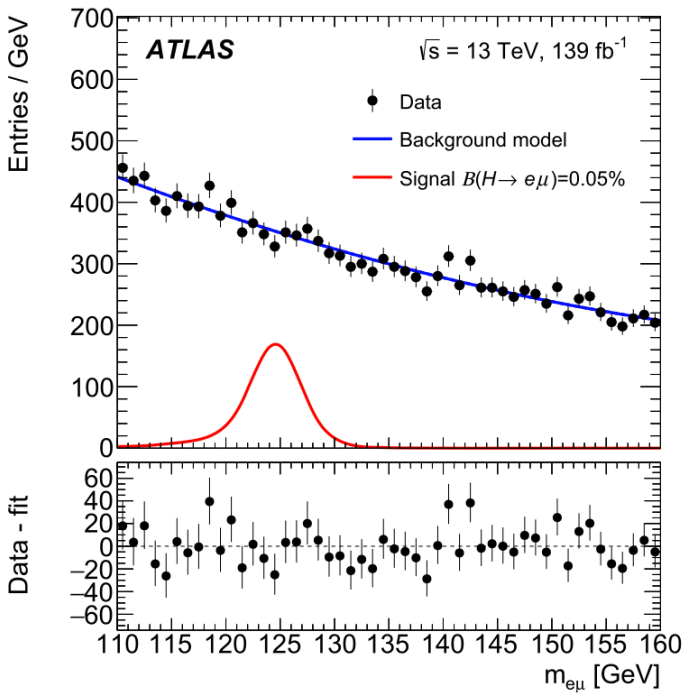
- The addition of leptonically decaying τ-leptons significantly improves the sensitivity reach for $Z \to \ell\tau$ decays.
- The $Z \to \ell\tau$ branching fractions are constrained in this analysis to $B(Z \to e\tau) < 7.0 \times 10^{-6}$ and $B(Z \to \mu\tau) < 7.2 \times 10^{-6}$ at 95% confidence level.
- The combination with previously published analyses provides the most stringent limits on these LFV Z boson decay to date:
  - $B(Z \to e\tau) < 5.0 \times 10^{-6}$ and $B(Z \to \mu\tau) < 6.5 \times 10^{-6}$ at 95% confidence level.

Final state, polarization assumption	Observed (expected) upper limit on $\mathcal{B}(Z \to \ell\tau)$ [$\times 10^{-6}$] $e\tau$	$\mu\tau$
$\ell\tau_{\text{had}}$ Run 1 + Run 2, unpolarized τ	8.1 (8.1)	9.5 (6.1)
$\ell\tau_{\text{had}}$ Run 2, left-handed τ	8.2 (8.6)	9.5 (6.7)
$\ell\tau_{\text{had}}$ Run 2, right-handed τ	7.8 (7.6)	10 (5.8)
$\ell\tau_{\ell'}$ Run 2, unpolarized τ	7.0 (8.9)	7.2 (10)
$\ell\tau_{\ell'}$ Run 2, left-handed τ	5.9 (7.5)	5.7 (8.5)
$\ell\tau_{\ell'}$ Run 2, right-handed τ	8.4 (11)	9.8 (13)
Combined $\ell\tau$ Run 1 + Run 2, unpolarized τ	5.0 (6.0)	6.5 (5.3)
Combined $\ell\tau$ Run 2, left-handed τ	4.5 (5.7)	5.6 (5.3)
Combined $\ell\tau$ Run 2, right-handed τ	5.4 (6.2)	7.7 (5.3)

ATLAS: PRL 127 (2021) 271801

LFV in Higgs Decays

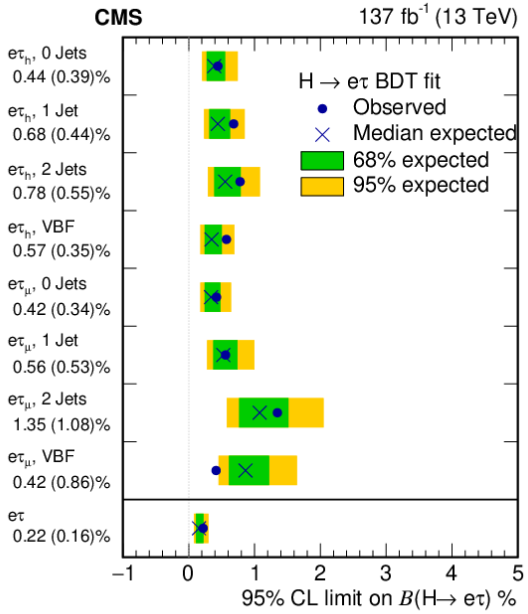
- The Higgs boson is the only known fundamental particle with non-universal lepton flavor couplings.
- The LFV decays $H \to e\mu$, $H \to e\tau$, or $H \to \mu\tau$ are forbidden in the SM, but take place through the LFV Yukawa couplings $Y_{e\mu}$, $Y_{e\tau}$ or $Y_{\mu\tau}$.
  - Interesting to look for LFV decays in this sector, which is predicted in a variety of new physics models.
- The latest searches from ATLAS and CMS are based on the entire Run 2 data set and look for $H \to e\mu$, $H \to e\tau$, and $H \to \mu\tau$ decays.
  - Both leptonic and hadronic τ-decay modes are explored.
  - $B(H \to e\mu)$ is constrained below ~10^{-8} from $\mu \to e\gamma$, while the other two decay modes are only constrained to <10% by rare decays.
- ATLAS: $B(H \to e\mu) < 6.2 \times 10^{-5}$ @ 95% CL.

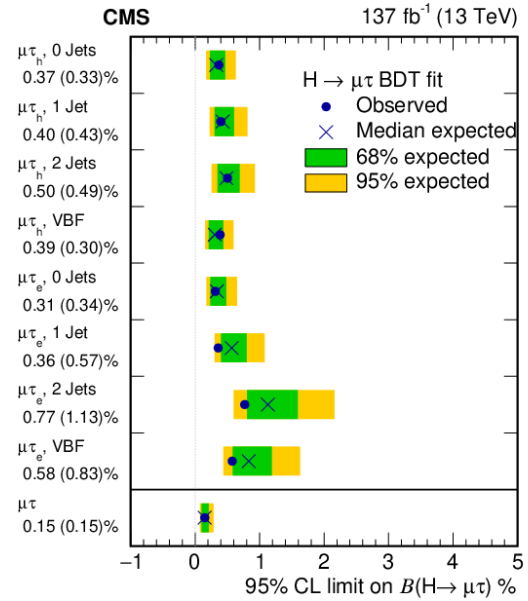


ATLAS: PLB 801 (2020) 1352148

LFV Search in Higgs Decays

- The CMS search proceeds in 6 different channels, depending on the τ lepton decay mode (τ_e, τ_μ, τ_h).
- Production mode is categorized according to the number of jets (0, 1, 2), and the 2-jet category is split into the VBF-like and the other.
- Signal is enhanced via a BDT that uses kinematic properties of the leptons and τ_h, the collinear, visible, and transverse masses.
- The dominant $Z \to \tau\tau$ background is estimated using the "embedding" technique based on $Z \to \mu\mu$ events in data with the muon footprints being replaced with simulated τ decays.

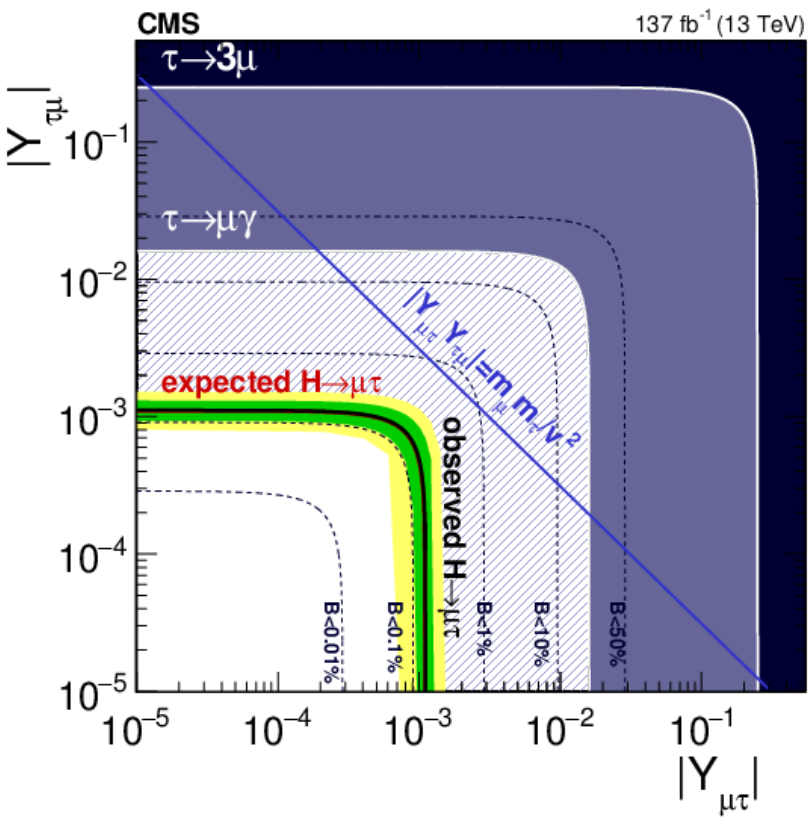


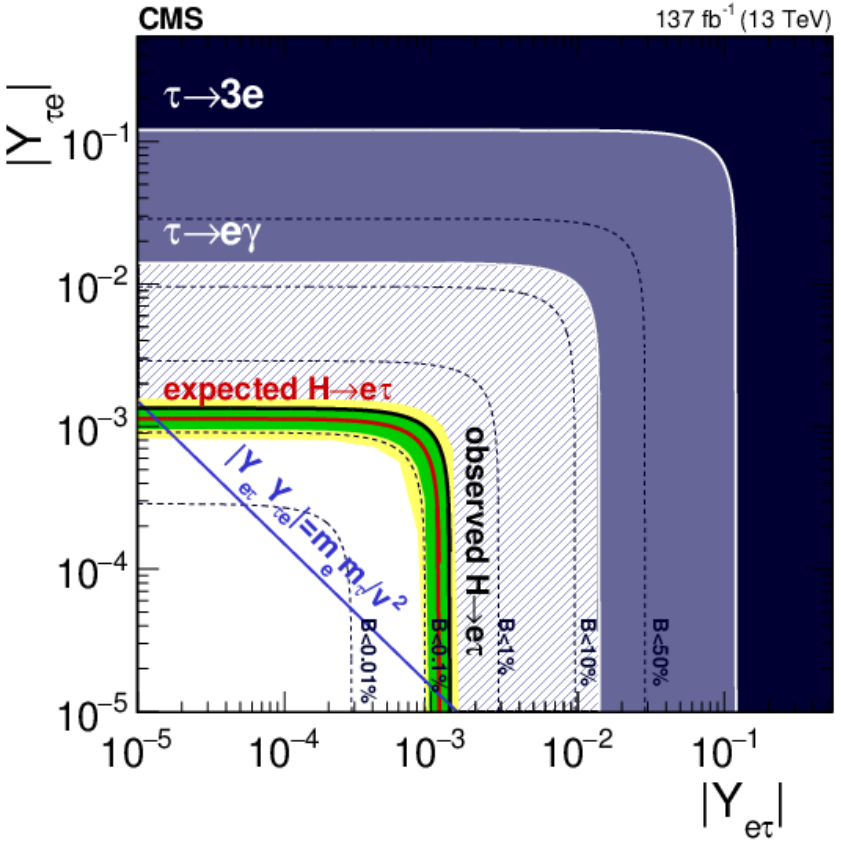


	Observed (expected) upper limits (%)	Best fit branching fractions (%)	Yukawa coupling constraints
$H \to \mu\tau$	<0.15 (0.15)	0.00 ± 0.07	$<1.11(1.10) \times 10^{-3}$
$H \to e\tau$	<0.22 (0.16)	0.08 ± 0.08	$<1.35(1.14) \times 10^{-3}$

LFV Search in Higgs Decays

- The results on LFV Higgs decays are interpreted in terms of non-diagonal Yukawa couplings and compared to other LFV searches ($\tau \to \ell\gamma, \tau \to 3\ell, \mu \to e\gamma, \mu \to 3e$).

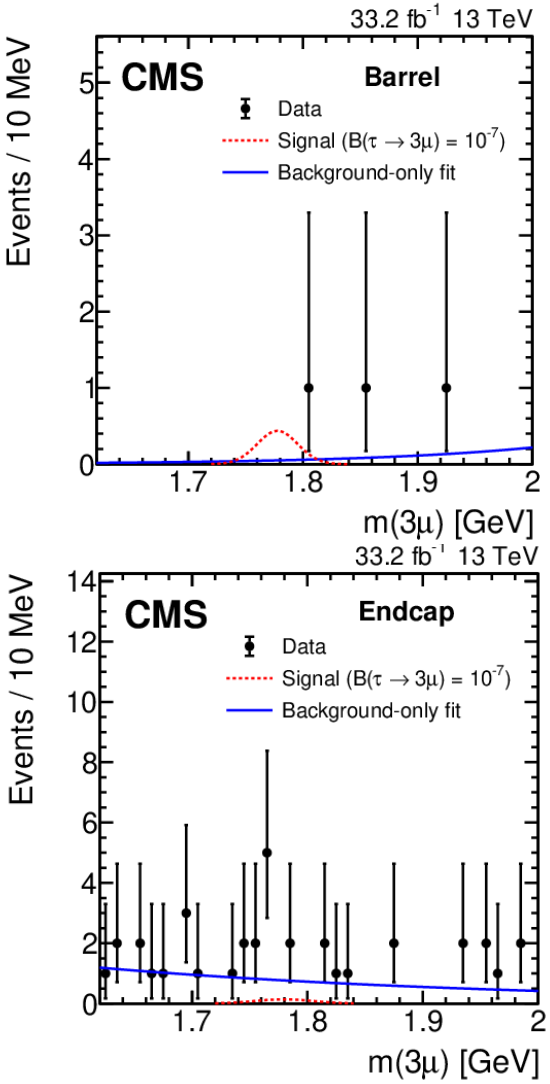




CMS: Phys. Rev. D 104 (2021) 032013

Search for LFV in $\tau \rightarrow 3\mu$ Decay

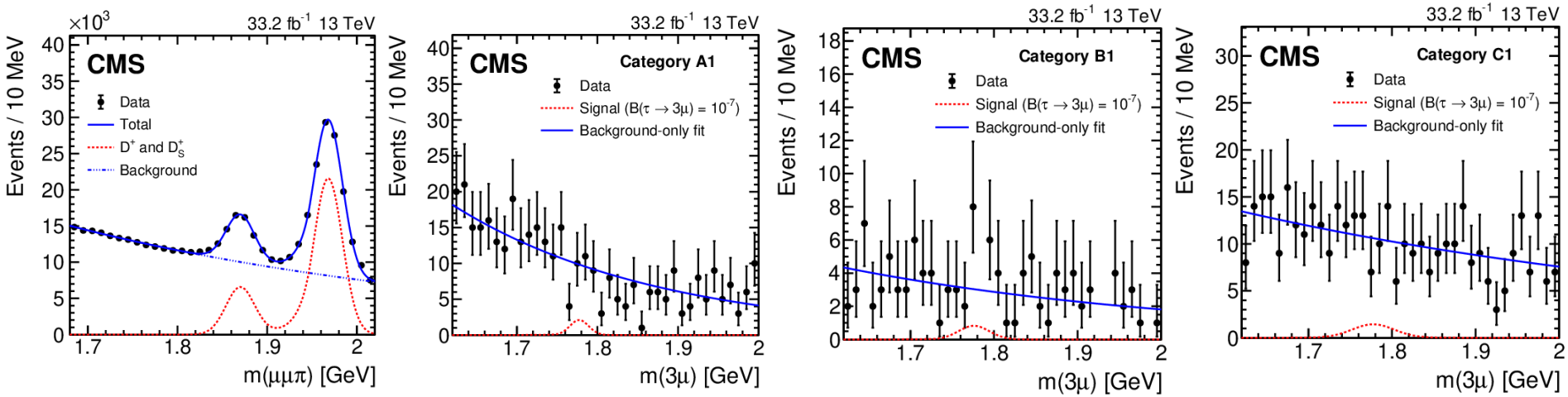
- The present best limit was obtained by the Belle experiment:
  $B(\tau \rightarrow 3\mu) < 2.1 \times 10^{-8}$ @90% CL.
  - At the LHC, LHCb set a limit of 4.6×10^{-8} using τ leptons from $B/D_{(s)}$ meson decays.
  - ATLAS set a limit of 38×10^{-8} using $W \rightarrow \tau\nu$ decays.
- A new analysis from CMS combines the W boson and heavy-flavor hadron decay channels to maximize the sensitivity.
- The analysis uses a boosted decision tree (BDT) to better separate signal from background.
- The W channel is normalized through the inclusive W cross section measurement.



CMS: JHEP 01 (2021) 163

Search for LFV in $\tau \to 3\mu$ Decay

- The HF channel utilizes the decay $D_s \to \phi\pi \to \mu\mu\pi$ to normalize the signal yield.
- Set the limit at 8.0×10^{-8} @90% CL. in the combination of the two channels, dominated by the heavy-flavor channel (2:1).
- Finalizing the full Run 2 data analyses with an even more optimized selection, expected to approach Belle sensitivity.



CMS: JHEP 01 (2021) 163

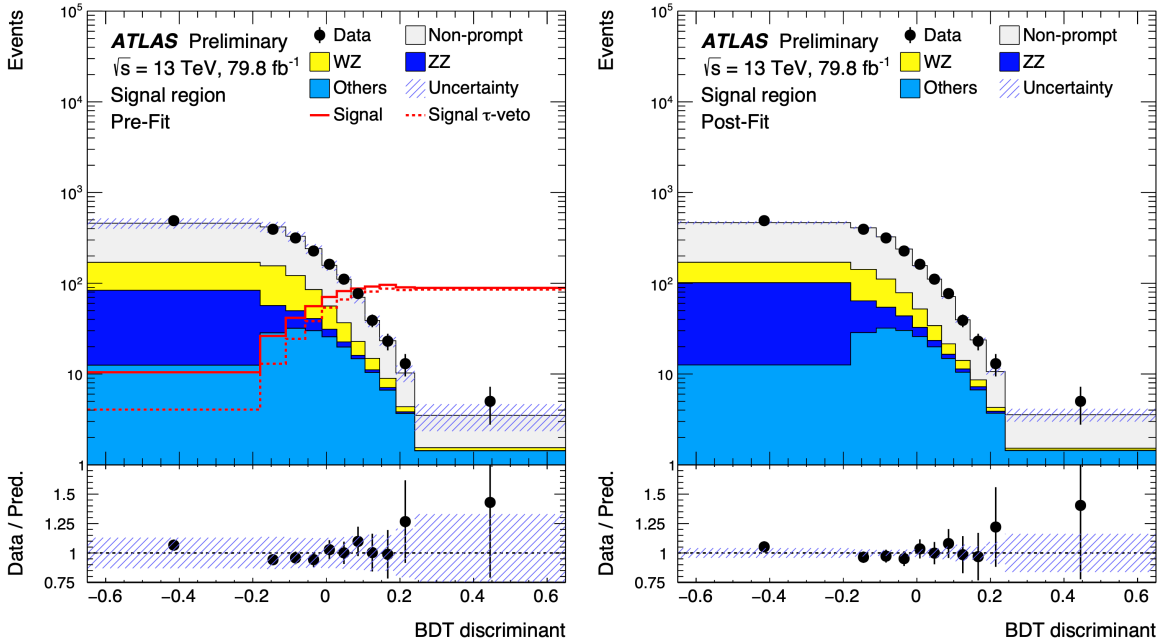
LFV in Top Quark Decays (ATLAS)

- Test of the universality of τ and μ lepton couplings in W-boson decays from $t\bar{t}$ events with the ATLAS detector.
- One could look for charged LFV in top quark decays $t \to \ell\ell' q$ (ℓ = e, μ, τ; q = u, c).
  - Can be described via dim-6 EFT
  - Indirect limits on $B(t \to e\mu u/c) \sim 4\times10^{-3}$
- Use top quark pair production with one top quark decaying into $bW \to b\ell\nu$ and the other via LFV, leading to a clean trilepton final state.
- Main backgrounds come from non-prompt leptons, WZ, and ZZ.
  - Use BDT built with a set of 13 input variables (the kinematic variables and various invariant masses) to suppress the background.

ATLAS-CONF-2018-044

LFV in Top Quark Decays (ATLAS)

- Results are the first direct limits on this decay, and improve by 3 orders of magnitude the indirect B(t →eμq) limit.



ATLAS-CONF-2018-044

$$\mathcal{B}(t \to \ell\ell' q) < 1.36^{+0.61}_{-0.37} \times 10^{-5} \quad \text{(expected)}$$

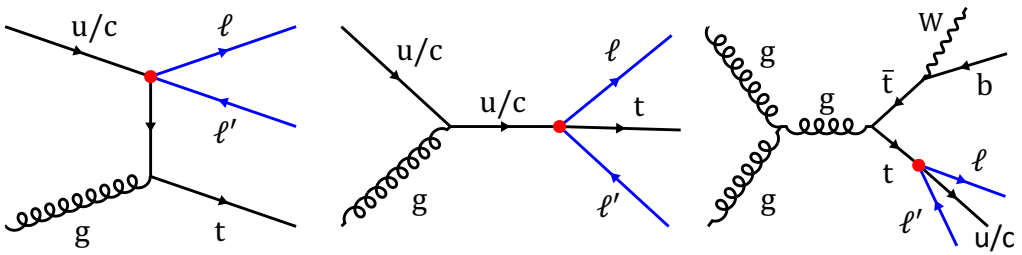
$$\mathcal{B}(t \to \ell\ell' q) < 1.86 \times 10^{-5} \quad \text{(observed)}$$

$$\mathcal{B}(t \to e\mu q) < 4.8^{+2.1}_{-1.4} \times 10^{-6} \quad (\text{no } \tau \text{ in cLFV vertex, expected}),$$

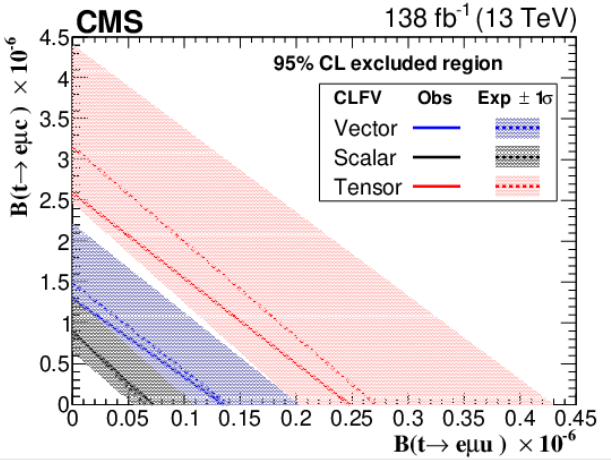
$$\mathcal{B}(t \to e\mu q) < 6.6 \times 10^{-6} \quad (\text{no } \tau \text{ in cLFV vertex, observed}).$$

LFV in Top Quark Decays (CMS)

- CMS has a recent result in the t→eμq (q=u/c) channel, using both the effects of this LFV vertex on production (q→eμt) and decay.
  - The search is performed in events with an oppositely charged electron-muon pair in the final state along with at least one jet identified as originating from a bottom quark.
  - Relies mainly on hadronic decays of the second top quark and on single t production.
  - Uses BDT and b-tag categories for optimal signal extraction.
  - Upper limits are set on the strength of the individual vector-, scalar-, and tensor-like four-fermion EFT operators and converted to limits on the branching fractions: $B(t \to e\mu q)$, q = u (c) $<0.13\times10^{-6}$ (1.31×10^{-6}), 0.07×10^{-6} (0.89×10^{-6}), and 0.25×10^{-6} (2.59×10^{-6}) for vector, scalar, and tensor CLFV interactions, respectively.
  - The resulting limits are the most restrictive bounds to date.



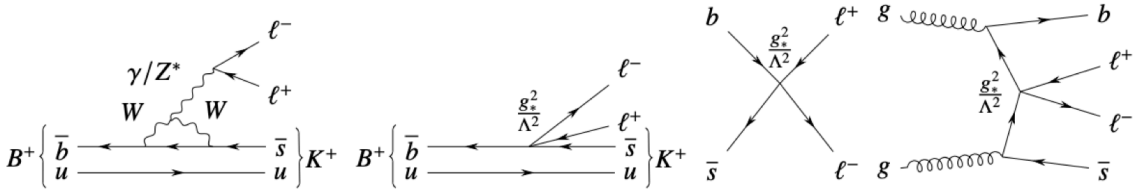
CMS: JHEP 06 (2022) 082



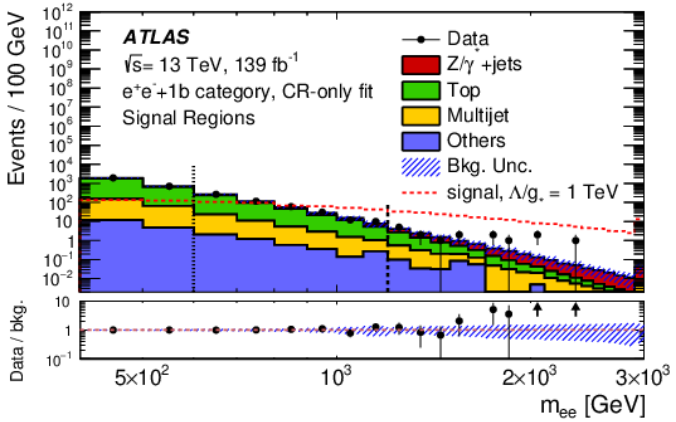
Dileptons+b-jets (ATLAS)

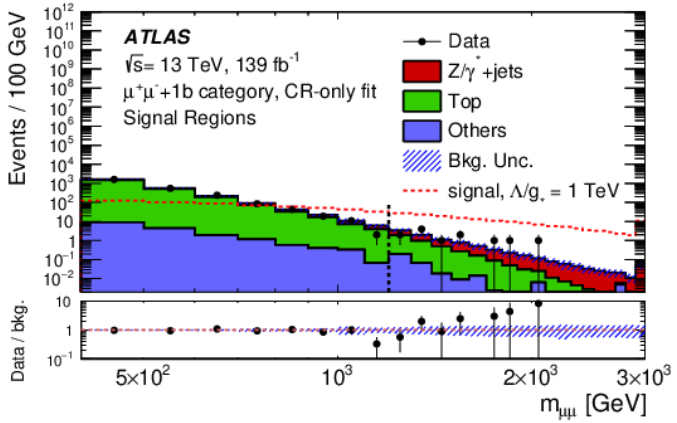
- Inspired by recent hints at a possible LFV in rare B-meson decays into a K meson and a pair of muons or electrons, a new ATLAS analysis is searching for BSM interactions between the initial (b quark) and final states (s quark and two charged electrons or muons).

ATLAS: PRL 127 (2021) 141801



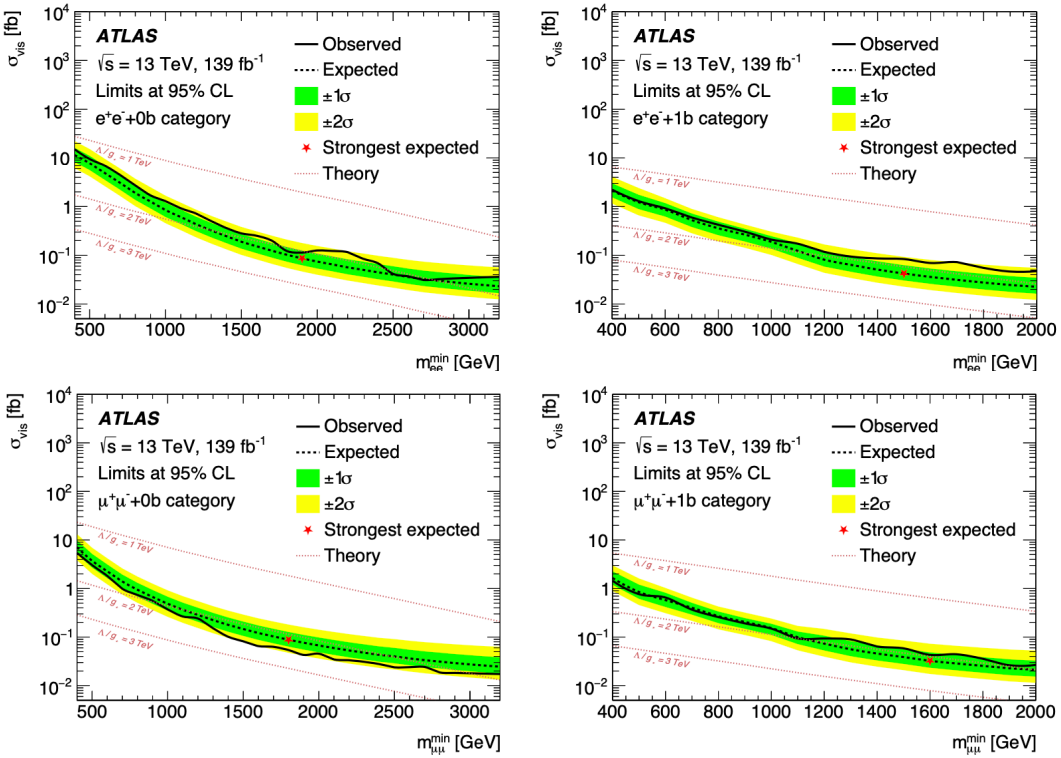
- A four-fermion contact interaction between two quarks (b, s) and two leptons (ee or μμ) is used as a benchmark signal model, which is characterized by the energy scale and coupling, Λ and g_*, respectively.
  - Same operators will give rise to signatures with dileptons and jets in the final state.





Dileptons+b-jets (ATLAS)

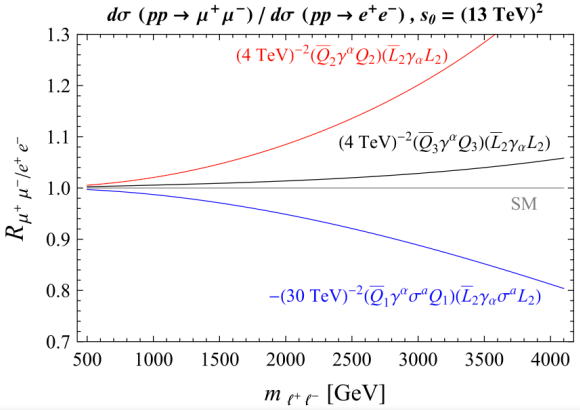
- The event selection requires two OS leptons of the same flavor (electrons or muons) with a large invariant mass and either 0 or 1 b-tagged jet.
- The dilepton mass distribution is then analyzed in the EFT or model-independent context.
- Model-independent limits are set as a function of the minimum dilepton invariant mass, which allow the results to be reinterpreted in various signal scenarios.



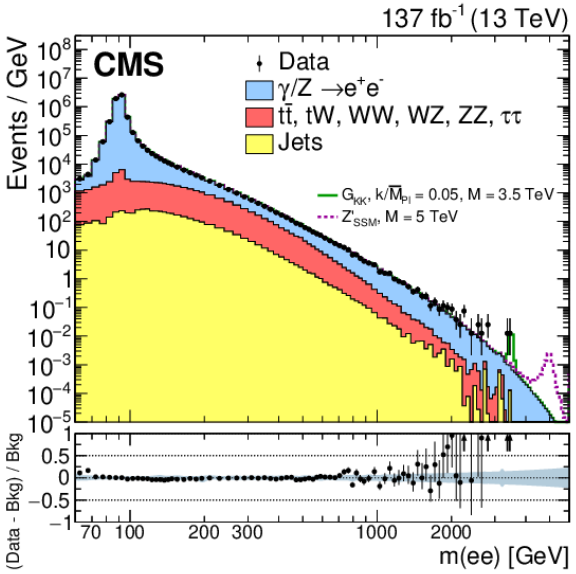
ATLAS: PRL 127 (2021) 141801

High-Mass Dilepton Analysis (CMS)

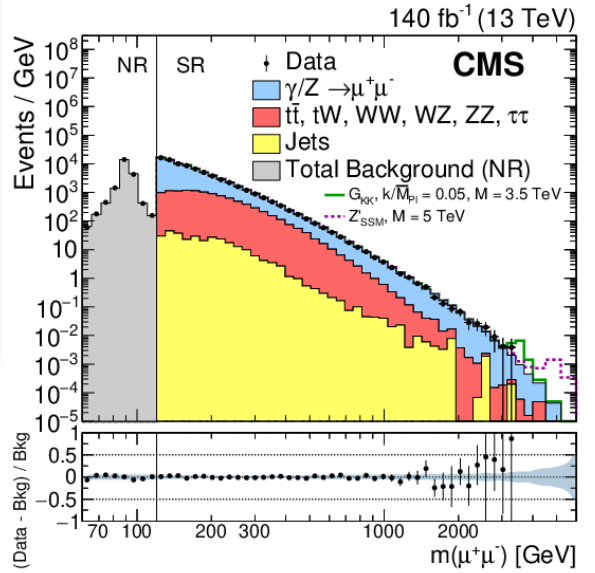
- New heavy neutral bosons or leptoquarks coupling to the different generations of quarks and leptons with different strengths could explain the observed flavor anomalies.
- If the mass of these particles is outside the kinematic reach of the LHC, their impact on the tail of the dilepton mass distribution can be described as a contact interaction in an EFT with dimension-6 operators.
- CMS analysis compares the dielection and dimuon mass spectra are as a function of mass.



A. Greljo and D. Marzocca, Eur. Phys. J. C77 (2017) 548



CMS: JHEP **07** (2021) 208

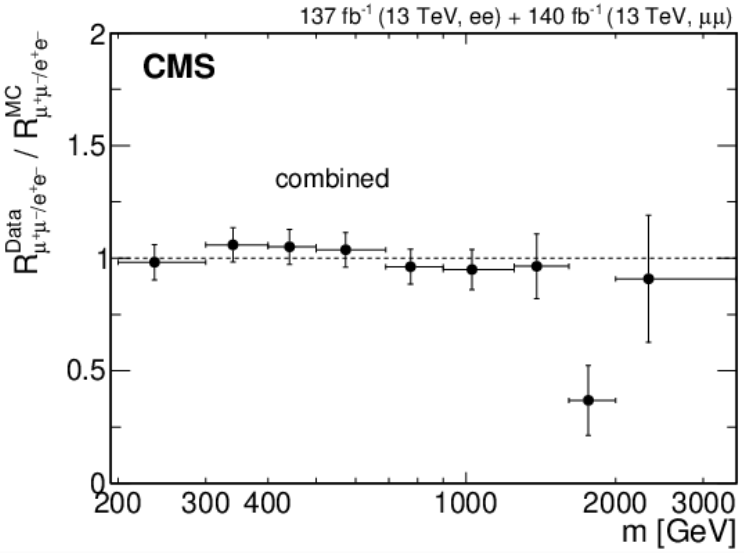


High-Mass Dilepton Analysis (CMS)

- Measure the ratio of the differential dilepton production cross section in the dimuon and dielectron channels:

$$R_{\mu^+\mu^-/e^+e^-} = \frac{d\sigma(q\bar{q} \to \mu^+\mu^-)/dm_{\ell\ell}}{d\sigma(q\bar{q} \to e^+e^-)/dm_{\ell\ell}}$$

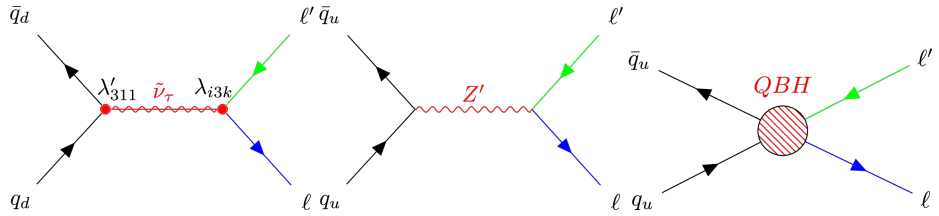
- Spectra are unfolded to particle level and corrected for different acceptance and efficiency in the two channels.
- Some moderate deviations from unity at high mass, from excess events in the dielectron channel, but no smoking gun for LFU violation.



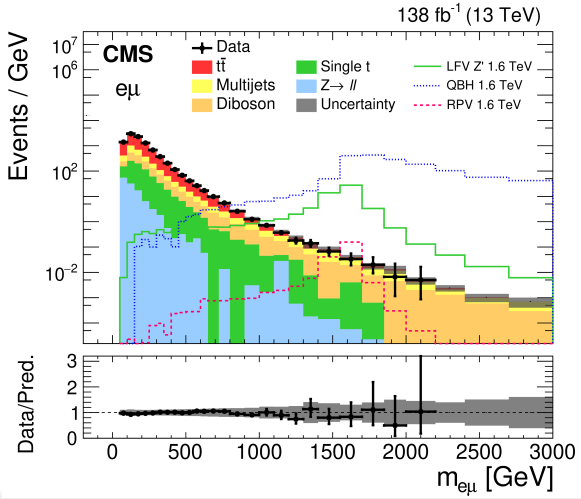
CMS: JHEP **07** (2021) 208

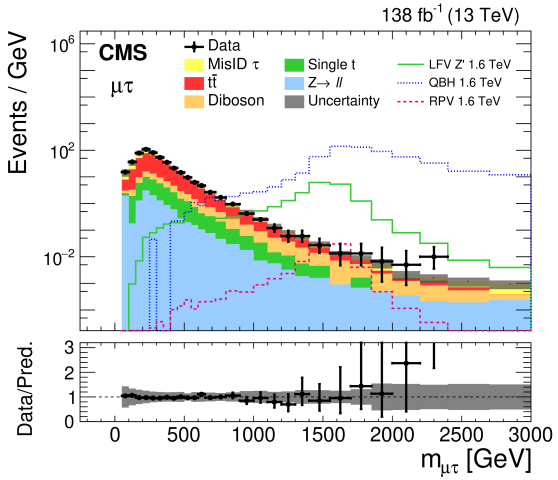
Search for LFV Resonances (CMS)

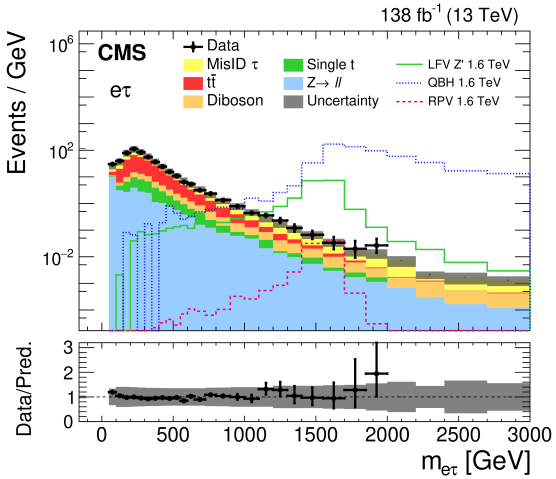
- One could look for generic high-mass objects decaying via LFV channels: eμ, μτ, eτ.
- Classical examples are R-parity violating SUSY, LFV Z', quantum black holes.



- Recent CMS analysis based full Run 2 data.
- Standard background estimation techniques: irreducible from MC simulation, reducible from control data samples.



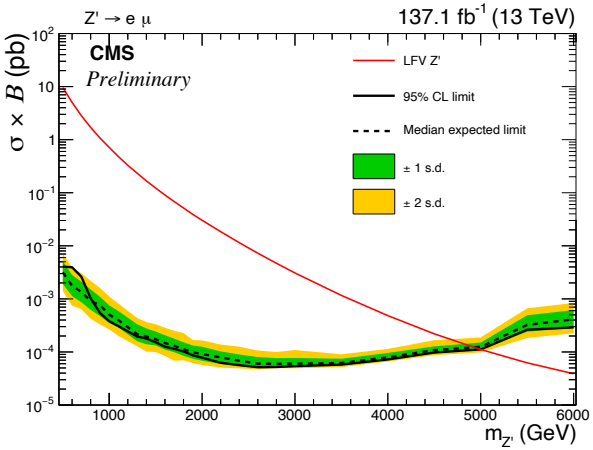


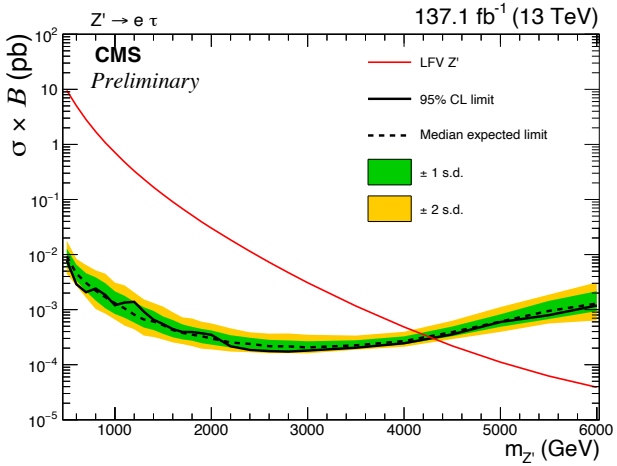


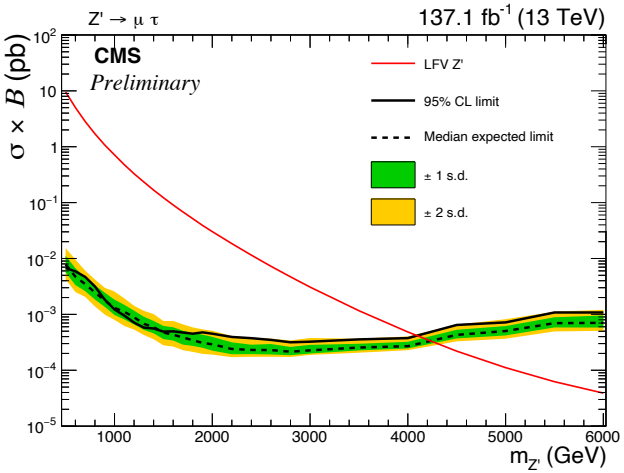
CMS: PAS EXO-19-014

Search for LFV Resonances (CMS)

- Limits are set on resonant τ sneutrino production in RPV SUSY models, heavy LFV Z' gauge bosons, and non-resonant QBH.
- A LFV Z' boson is excluded up to a mass of 5.0 TeV in the eμ channel, up to 4.3 TeV in the eτ channel, and up to 4.1 TeV in the μτ channel.
- The results of these searches provide the most stringent limits available from collider experiments for heavy particles that undergo lepton flavor violating decays.



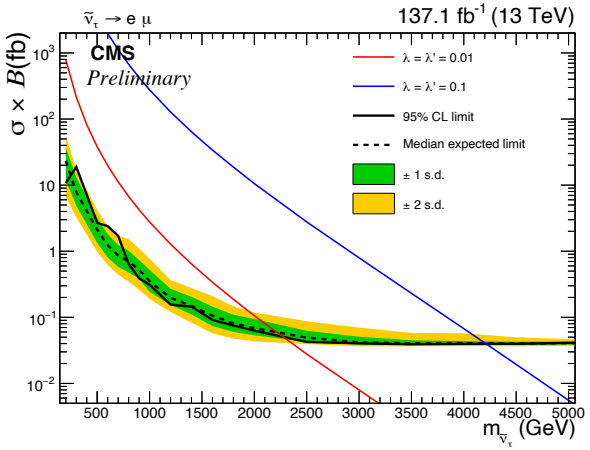


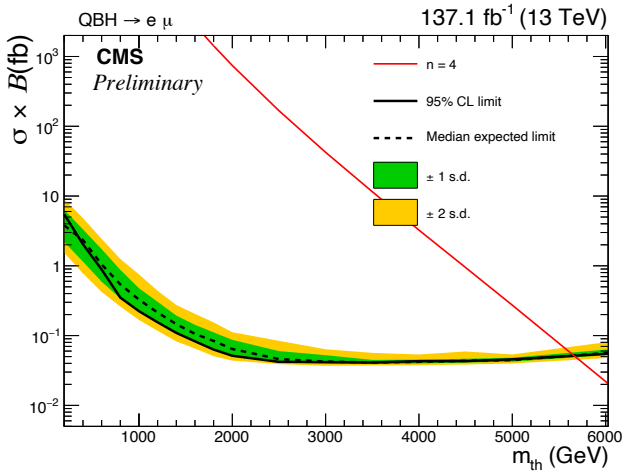


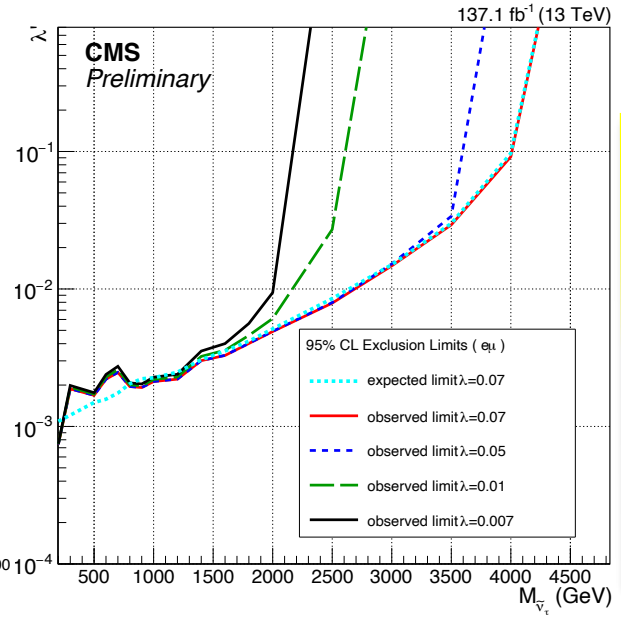
CMS: PAS EXO-19-014

Search for LFV Resonances (CMS)

- Resonant τ sneutrinos are excluded for masses up to 4.2 TeV in the eμ channel, 3.7 TeV in the eτ channel, and 3.6 TeV in the μτ channel.
- Quantum black holes in the benchmark model are excluded up to the threshold mass of 5.6 TeV in the eμ channel, 5.2 TeV in the eτ channel, and 5.0 TeV in the μτ channel.
- In addition, model-independent limits are extracted to allow comparisons with other models for the same final states and similar event selection requirements.





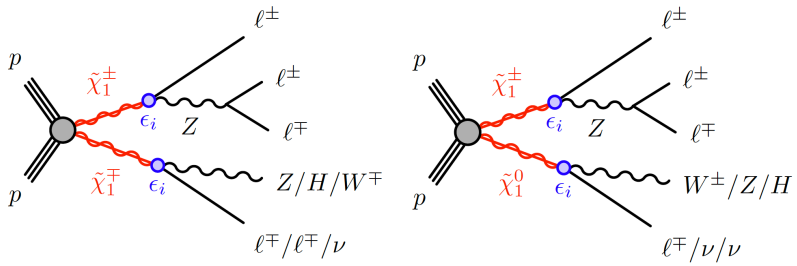


CMS: PAS EXO-19-014

RPV SUSY (ATLAS)

- SUSY can introduce processes that violate baryon number (B) and lepton number (L) conservation.
  - As such processes have not been observed, it is common to introduce an ad hoc requirement to conserve R-parity, where the R-parity of a particle is defined as $R = (-1)^{3(B-L)+2s}$.
  - Theories predicting R-parity violation (RPV) are viable if the interactions that violate B - L conservation have small couplings and violate only one of B or L at tree level, thus preventing rapid proton decay.
- The B - L RPV model allows for many different decay modes of $\tilde{\chi}_1^{\pm}/\tilde{\chi}_1^0$ and therefore many possible final states.
  - Look for decays $\tilde{\chi}_1^{\pm} \to Z\ell \to \ell\ell\ell$ because of the large number of leptons produced from a single resonance.

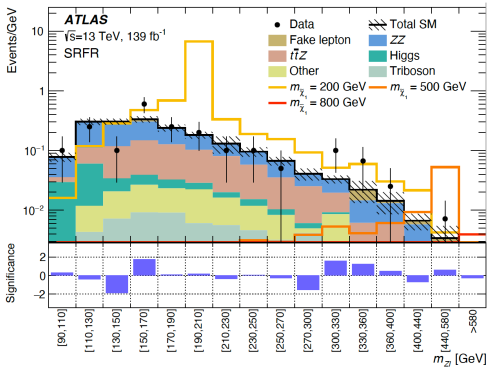
ATLAS: Phys. Rev. D 103 (2021) 112003

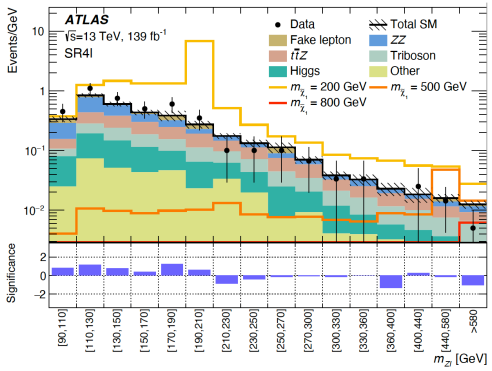


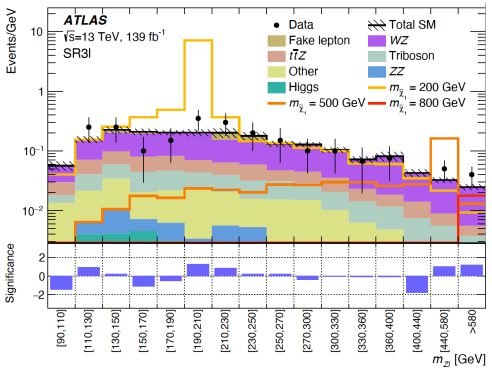
  - The invariant-mass distribution of the trilepton resonance ($mZ\ell$) is narrow due to the excellent momentum resolution of reconstructed electrons and muons.
  - No SM process naturally produces a three-lepton resonance, leading to a smooth combinatorial background distribution in which a resonance would be distinguishable.
  - Three orthogonal signal regions are used.

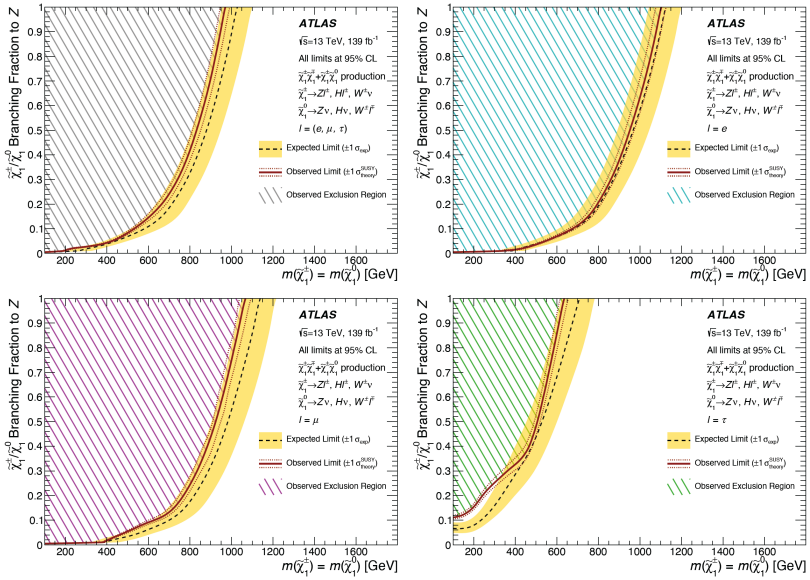
RPV SUSY (ATLAS)

- Model-independent limits are set at a 95% confidence level for each $m_{Z\ell}$ bin in each signal region.
- The largest excess of data over the expectation in the 48 model-independent regions is found to be 2.1σ.





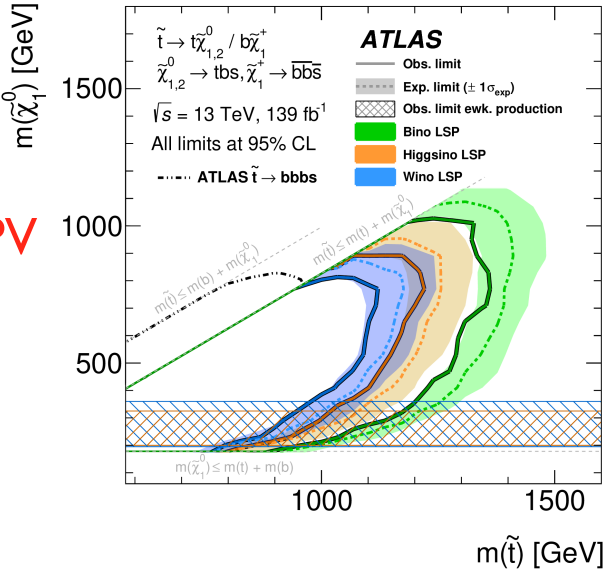


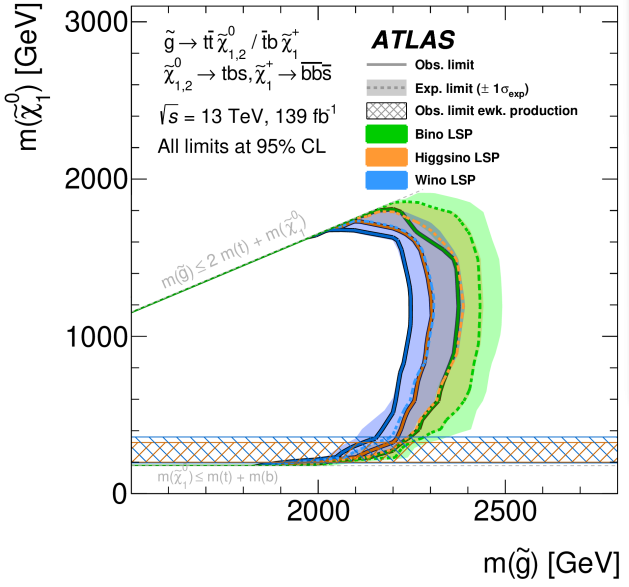


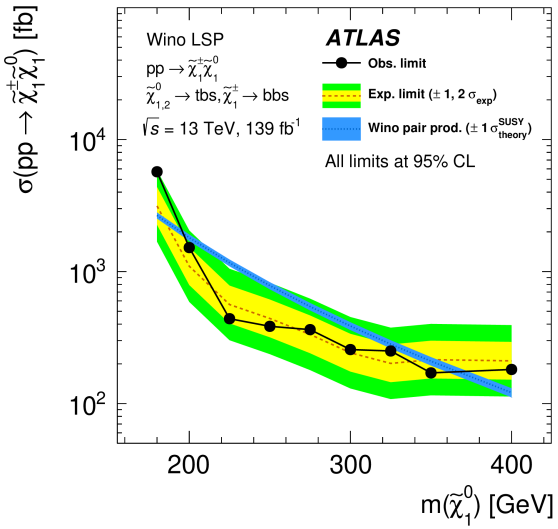
ATLAS: Phys. Rev. D 103 (2021) 112003

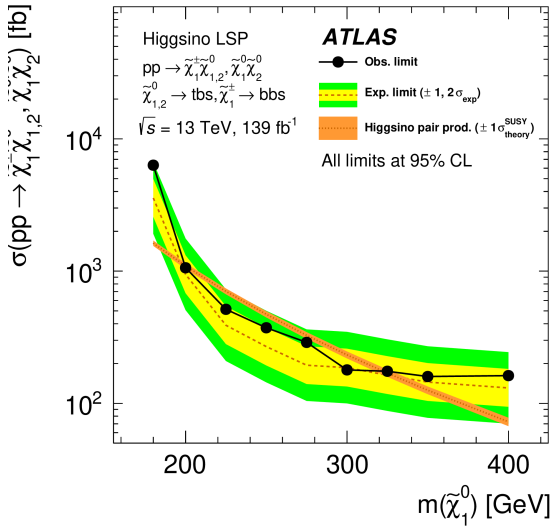
RPV SUSY (ATLAS)

- Search for RPV SUSY in final states with high jet multiplicity, at least one isolated light lepton and either zero or at least three *b*-tagged jets.
  - Such final states are commonly predicted in RPV models with either B or L violating couplings.
- The results are interpreted in the context of RPV supersymmetry models that feature gluino production, top-squark production, or electroweakino production.









ATLAS: Eur. Phys. J. C 81 (2021) 1023

What's Next

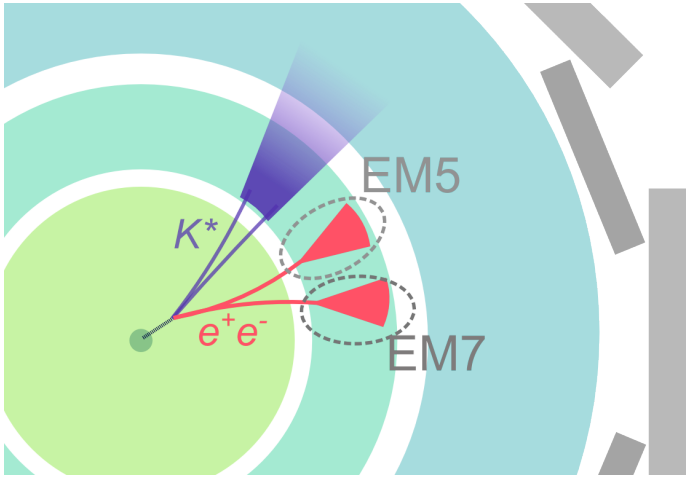
- Both ATLAS and CMS have dedicated analyses probing flavor anomalies ongoing.
  - R(K), R(K*), R(D), R(D*), R(J/ψ), ...
- Unfortunately, we don't have approved results on these topics yet, but they will become public very soon.
- In CMS, much of this program was made available through the 2018 data parking campaign.
- In ATLAS this is achieved by special triggering.
- We also plan to enhance our flavor analysis capabilities in Run 3 via dedicated triggers and data streams.

ATLAS Run 3

- Special triggers for R(K*) measurements were active in 2018.
- The triggers have been improved for Run 3 data taking.
- Measurements of R(K*) with Run 2 and Run 3 can be expected.
- New triggers for R(D*) and R(D) measurements have been activated for Run 3 data taking.

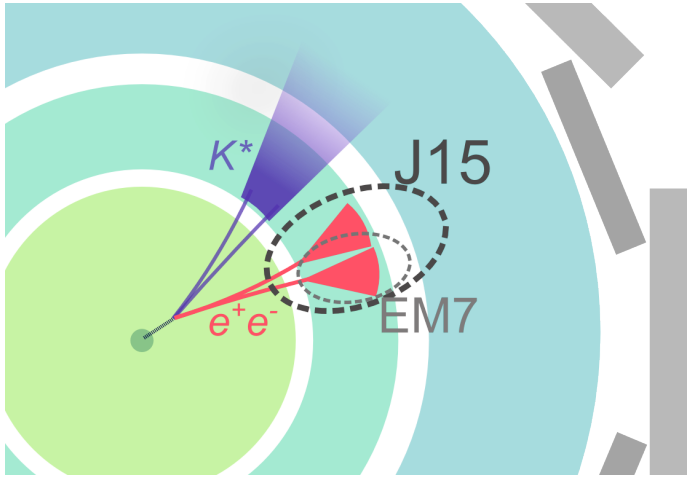
B→ K* e^+e^- decay

with two well-separated electrons



B→ K* e^+e^- decay

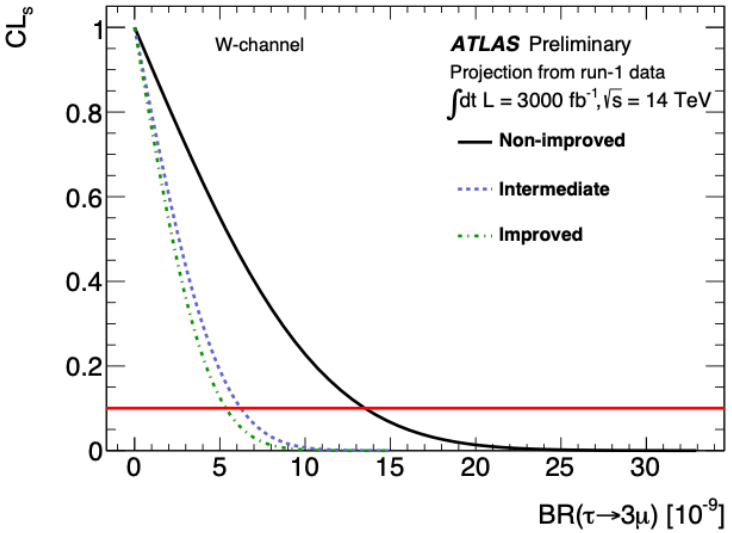
with two overlapping electrons

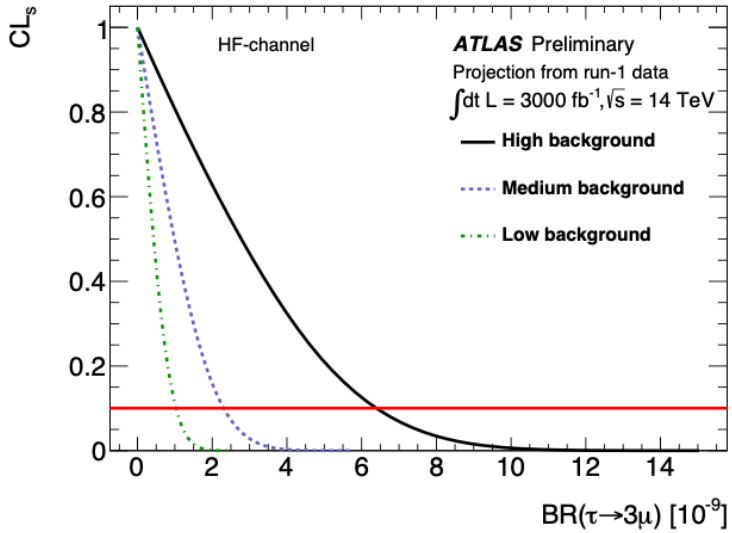


ATLAS: ATL-DAQ-PUB-2019-001

HL LHC Projections

- ATLAS projections for $\tau \rightarrow 3\mu$
  - Sensitivity ~10^{-9} @ 90% CL is likely to be achieved



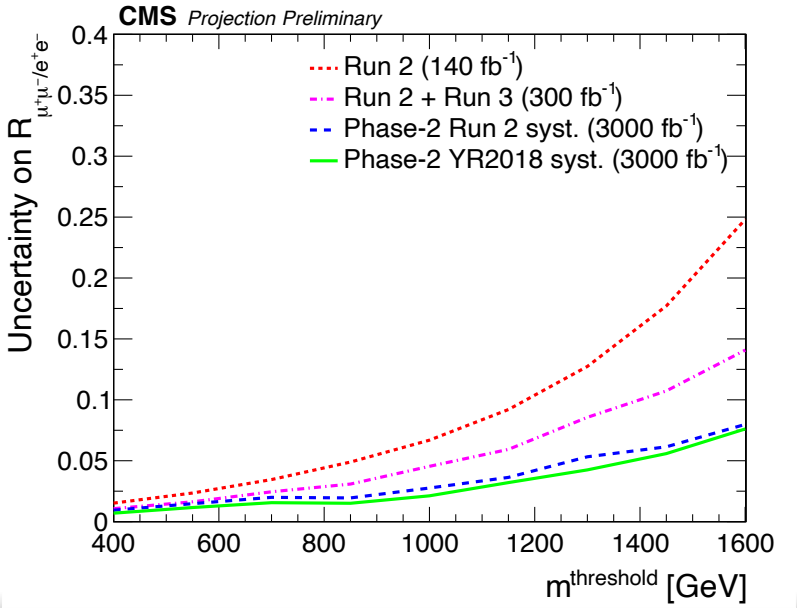


Scenario	$\mathcal{A} \times \epsilon$ [%]	$N_{\text{bkg}}^{\text{exp}}$	90% CL UL on BR($\tau \rightarrow 3\mu$) [10^{-9}]
Run 1 result	2.31	0.19	276
Non-improved	2.31	50.71	13.52
Intermediate	5.01	50.71	6.23
Improved	5.01	40.06	5.36

ATLAS-PHYS-PUB-2018-032

HL LHC Projections

- A projection study of the sensitivity for a search for new physics with two energetic leptons, e or μ in the final state has been performed by CMS.
- Two datasets are considered:
  - a combination of the Run 2 dataset with the expected Run 3 dataset.
  - the dataset expected from the high-luminosity LHC (HL-LHC) corresponding to 3000 fb^{-1}.
- The expected sensitivity for testing LFU by measuring the dimuon-to-dielectron ratio at high mass with these two datasets is shown.



$$R_{\mu^+\mu^-/e^+e^-} = \frac{d\sigma(q\bar{q} \to \mu^+\mu^-)/dm_{\ell\ell}}{d\sigma(q\bar{q} \to e^+e^-)/dm_{\ell\ell}}$$

CMS: PAS-FTR-21-005

Summary

- The ATLAS and CMS collaborations performed several searches for lepton flavor violating processes.
- No evidence for such process was observed so far, limits are set on LFV branching fractions (Z, H, τ) or cross-section × branching fraction and the masses of new particles.
- Several analyses with the full Run 2 dataset are still ongoing, stay tuned for new results.
  - So far no significant hint for the existence of new physics.
  - Results for dedicated analyses probing flavor anomalies R(K), R(D*), etc will become public soon.
- Looking forward to even more exciting Run 3.
  - Stay tuned!