Fudan CMS status report

Institute of modern physics, Fudan University

Xuyang Gao

2022-07-15

Fudan University CMS group (2019-2022)

- 2 faculty (Chengping Shen, Hideki Okawa)
- 3 post doc (Xuyang Gao, Yu Zhang (former) , Duncan (former))

- Focusing on Standard Model rare decays and new physics in at TeV scale and in top sector

- Contribute to HLT validation, Jet/MET algorithms improvement, HGCAL reconstruction & steering (Hideki: HGCAL Conference Committee Chair).

In this presentation

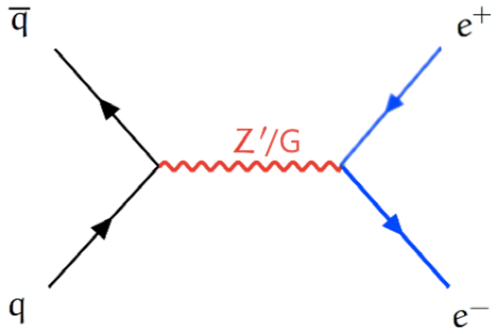
- Search for high mass resonance in di-lepton final states
- Search for high-mass LFV in $e\mu$, $e\tau$, and $\mu\tau$ final states
- Search for new physics in top quark sector

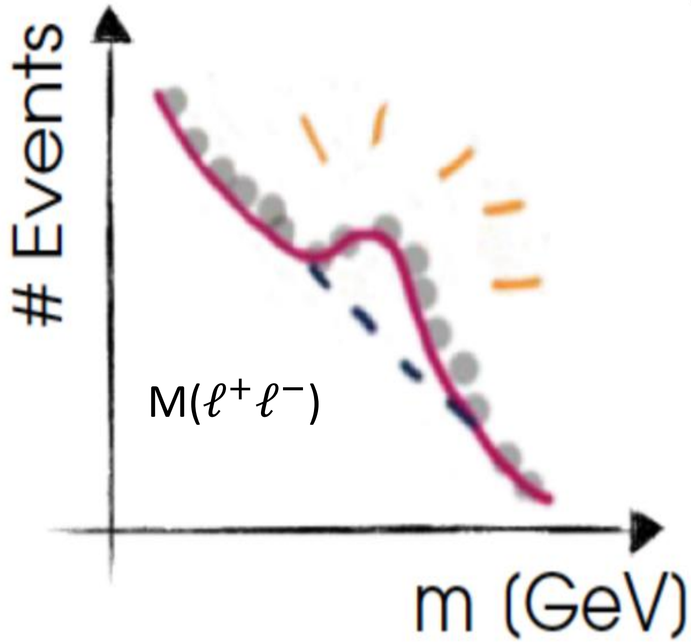
lepton final state:

- Clean signal, high efficiency
- Well-understanded background
- Precise theoretical calculation

Search for high mass resonance in di-lepton final states

- Searches for high-mass Z' Gauge bosons have a long history, golden channel for BSM
  - The sequential standard model $\mathrm{Z}'_{\mathrm{SSM}}$.
  - The GUT mode Z'_{ψ}.
- Many BSM models predict other resonances at the TeV scale
  - DM intermediator
  - Spin-2 graviton

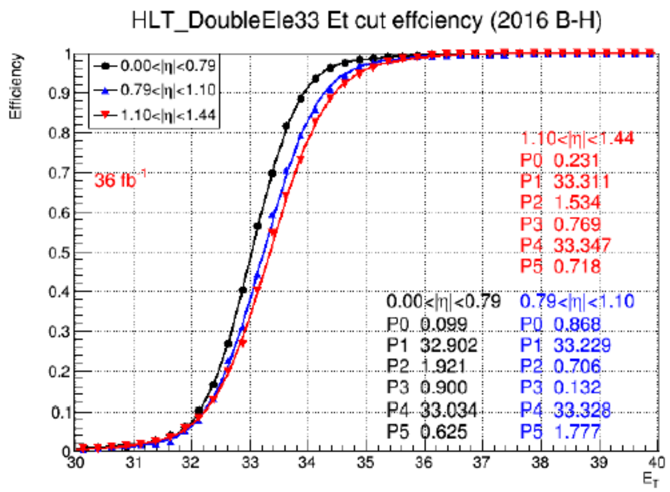


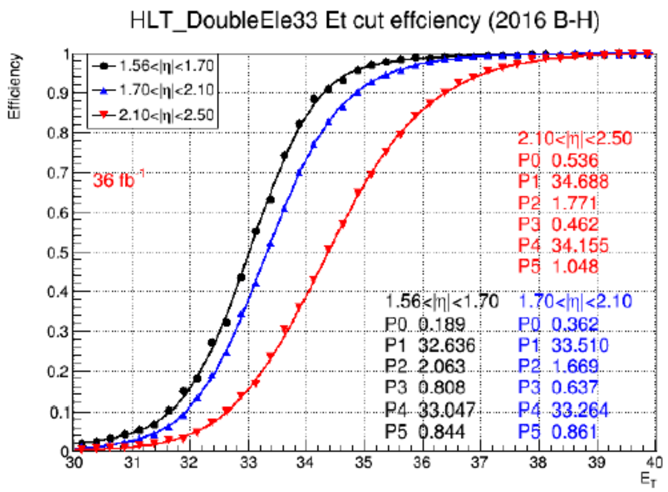


MC samples are normalized to data in the Z peak region

All E_T **independent** effects are included in the normalization factor

All E_T **dependent** effects are considered in the analysis

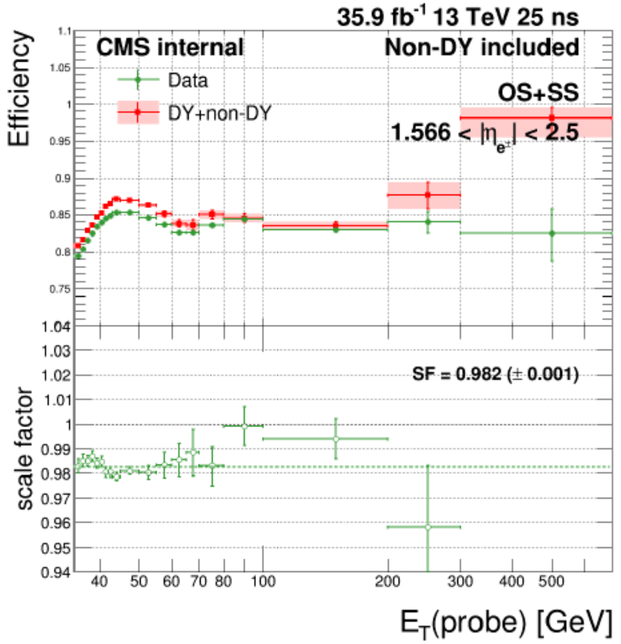




- Reconstructed electrons are required to pass the official High-Energy-Electron-Pair (HEEP) selection.

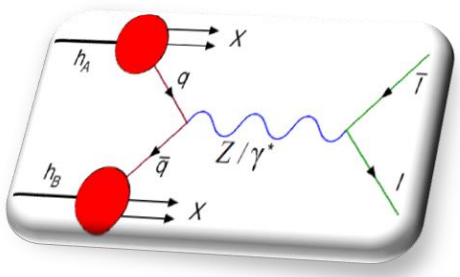
- Double electron unprescaled trigger with lowest ET threshold is used.

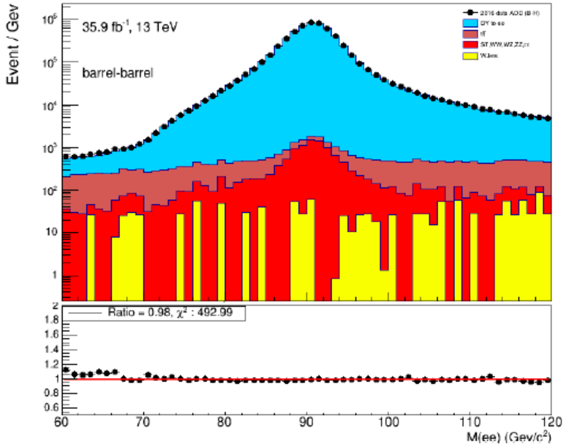
- At least one electron should be in the barrel and no opposite charge requirement.



Analysis

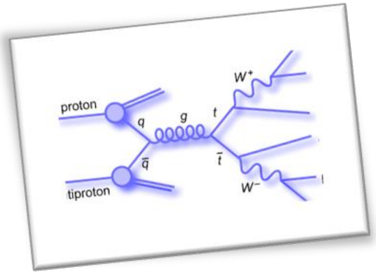
- The dominant and irreducible SM background arises from the Drell-Yan process.
- **Validated** by measuring the Drell-Yan cross section of the Z peak [60 GeV, 120 GeV].



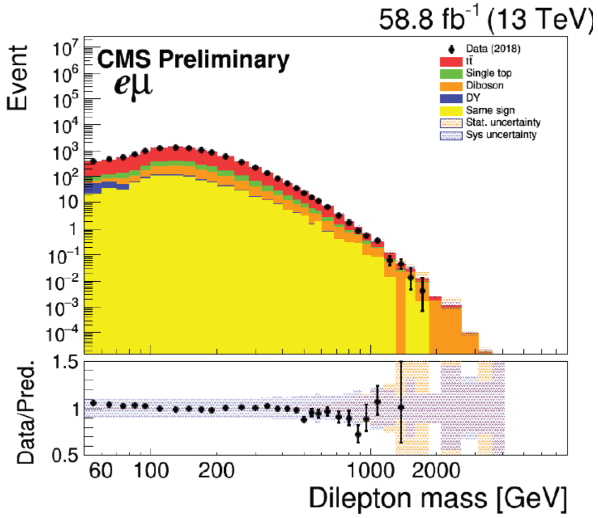


- Additional sources of background are processes which produce real prompt leptons where the two prompt leptons are from different particles, $t\bar{t}$, tW, WW, WZ, ZZ, $Z \rightarrow \tau\tau$.
- **Validated** in the eμ final state.

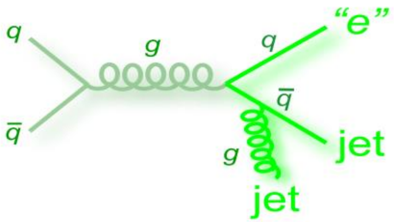
$$\frac{1}{2} N_{e\mu} = N_{ee} = N_{\mu\mu}$$



- Backgrounds arising from jets that are misidentified as electrons include W + jets and QCD processes are measured from data using the Fake Rate method.



- **Validated** in a control region : where both leptons are **in the ECAL endcaps**.



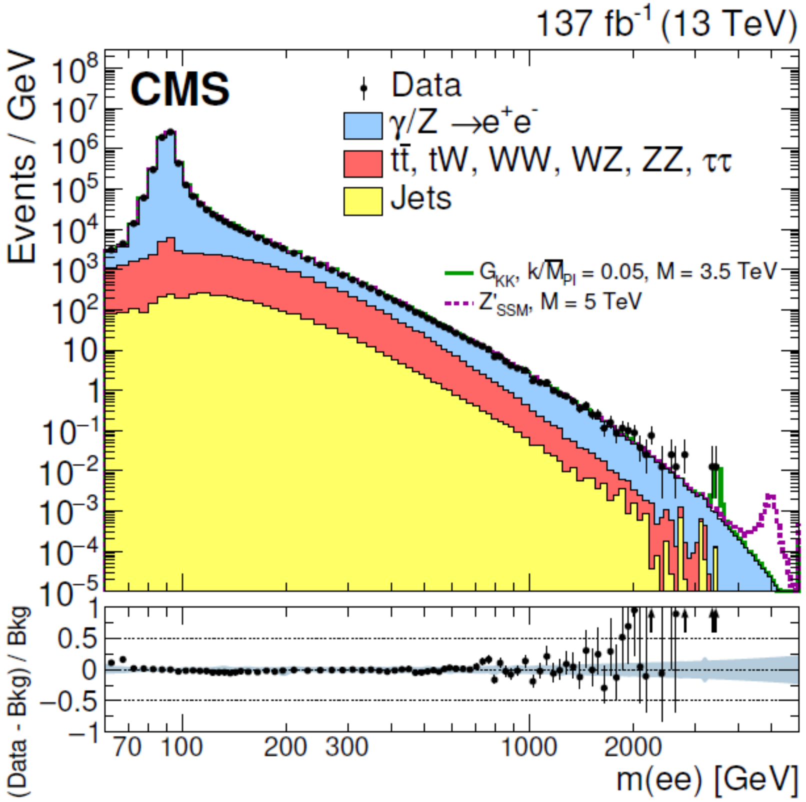
Analysis

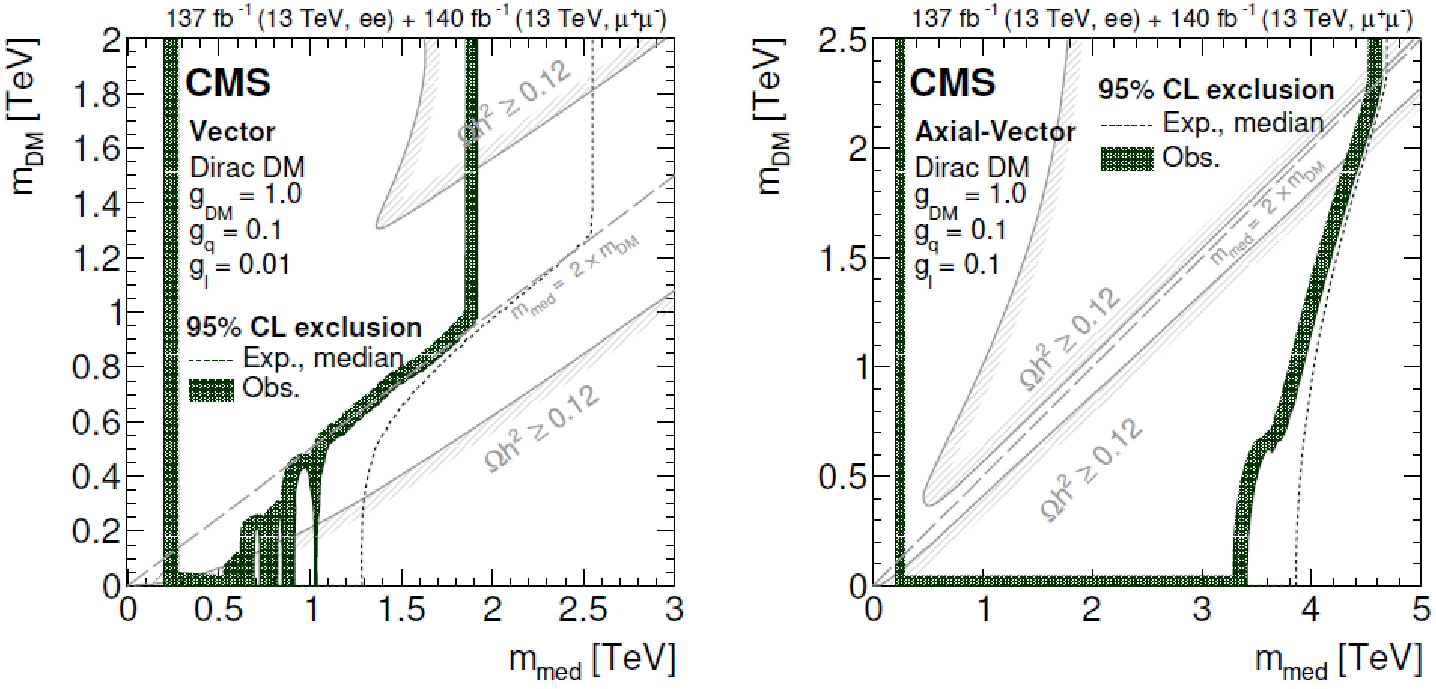
Systematic uncertainty

- Normalization to Z peak: **1-4%**
- Pile-up reweighting: **4.6%**.
- DY PDF: **7%**
- Jets: **50%**
- Electron energy scale: **2%** in BB and **1%** in BE.
- HEEP ID scale factor: **1-5%** linearly increase as function of $\mathrm{E_T}$.

Data-MC in consistence, upper limit on ratio of branching fractions are set and interpretated to different models.

$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$

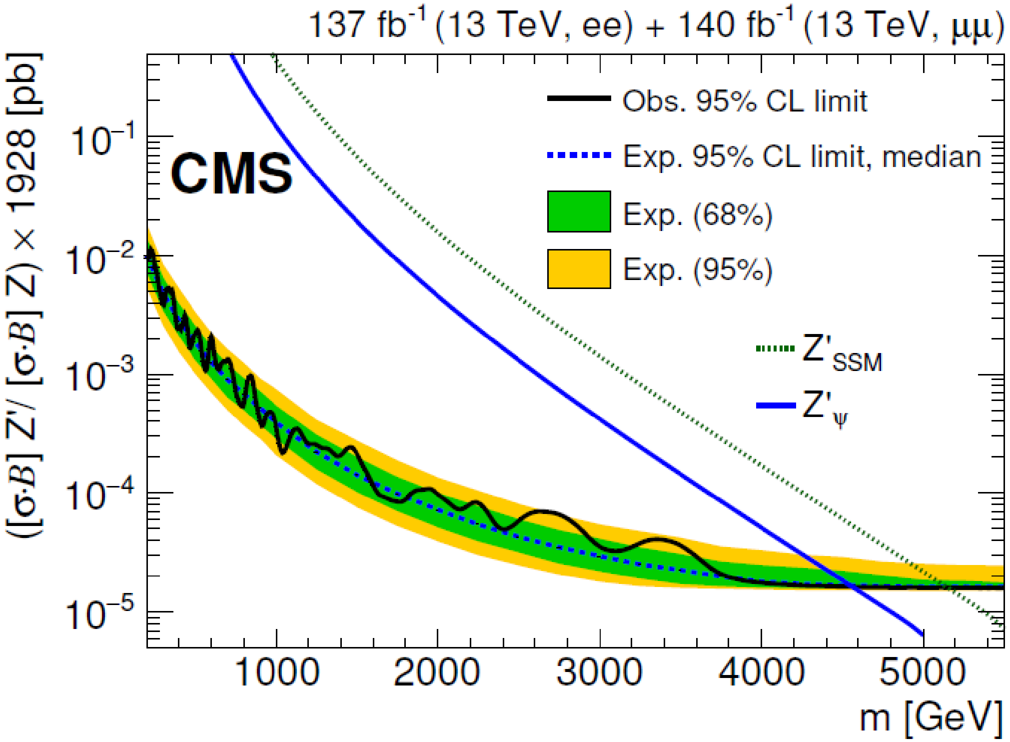


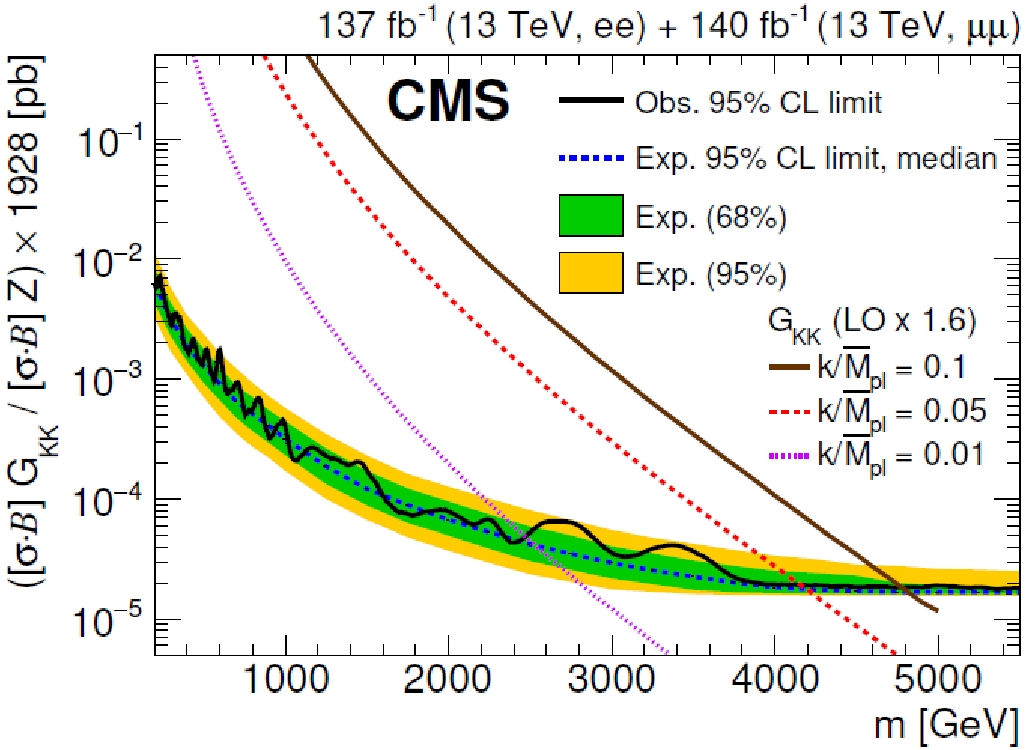


Upper limits on DM

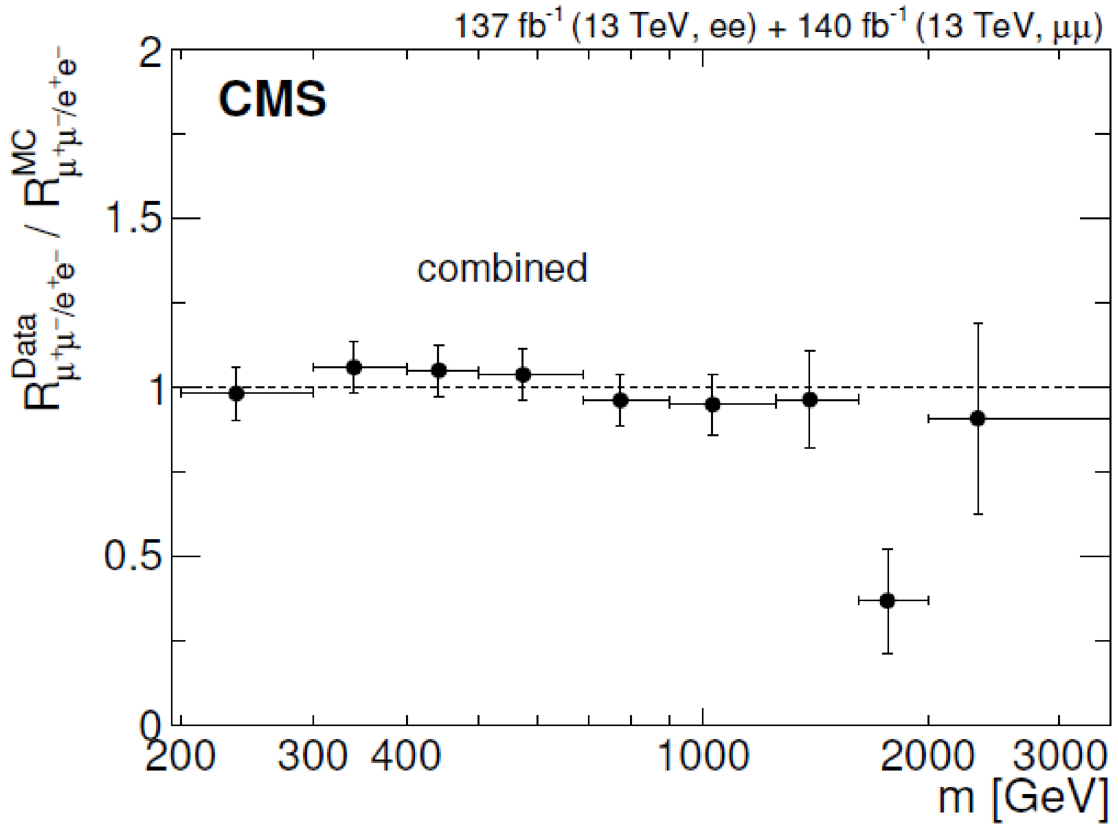
Channel	Z'_{SSM}		Z'_{ψ}	
	Obs. [TeV]	Exp. [TeV]	Obs. [TeV]	Exp. [TeV]
ee	4.72	4.72	4.11	4.13
μμ	4.89	4.90	4.29	4.30
ee + μμ	5.15	5.14	4.56	4.55

Channel	$k/\overline{M}_{Pl} = 0.01$		$k/\overline{M}_{Pl} = 0.05$		$k/\overline{M}_{Pl} = 0.1$	
	Obs. [TeV]	Exp. [TeV]	Obs. [TeV]	Exp. [TeV]	Obs. [TeV]	Exp. [TeV]
ee	2.16	2.29	3.70	3.83	4.42	4.43
μμ	2.34	2.32	3.96	3.96	4.59	4.59
ee + μμ	2.47	2.53	4.16	4.19	4.78	4.81





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



X. Gao contributed to trigger efficiency measurement, background study, event selection, acceptance and efficiency.

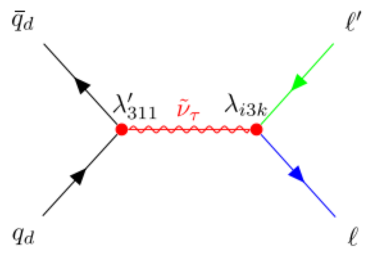
approval report for ee 2017 (belong this analysis)

J. High Energy Phys 06, 120 2018

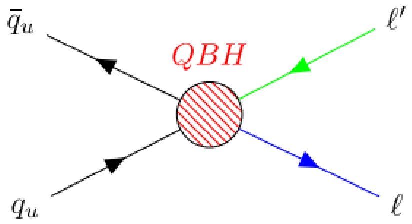
J. High Energy Phys 07, 208 2021

Search for high-mass LFV in $e\mu$, $e\tau$, and $\mu\tau$ final states.

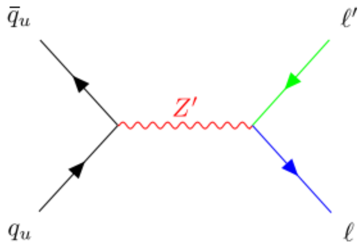
- Extensions of the SM can accommodate heavy particles that undergo lepton flavor violating decays.
- Clear signal for new physics since it is not allowed in SM.
- Model independent search and interpretated to different theoretical models.



A τ sneutrino ($\tilde{\upsilon}_\tau$) in R-parity violating (RPV) supersymmetry (SUSY) models



Spin-0, colorless, neutral Microscopic quantum black holes (QBHs)



Z' has the probability of LFV decay assuming branching fraction ~10%

- Select events include at least a pair of passed leptons, highest mass candidate is kept
- Remove other flavor leptons avoiding possible overlap
- Considering the τ candidate in this analysis has high momentum, collinear mass is used as final discriminating variable in τ channels.

$$\tau_{coll} = \frac{\tau_{vis}}{x}$$

$$x = \frac{p_T(\tau)}{p_T(\tau) + p_{T\ \ coll}^{miss}}$$

$e\mu$

Trigger:

2016: Mu50 or TkMu50 or Photon175

2017: Mu50 or TkMu100 or OldMu100 or Photon175

2018: Mu50 or TkMu100 or OldMu100 or Photon200

MET filters

e: $p_T > 35$ GeV, HEEP ID (V7.0-2018Prompt for 2018), $\Delta R > 0.1$ with any muon

μ: $p_T > 53$ GeV, $|\eta| < 2.4$, HighPt ID, tracker iso < 0.1

$\Delta R(e, \mu) > 0.1$

$e\tau$

Trigger:

2016: Ele27_WPTight_Gsf or Photon175 or Ele115_CaloIdVT_GsfTrkIdT

2017: Ele35_WPTight_Gsf or Photon200 or Ele115_CaloIdVT_GsfTrkIdT

2018: Ele32_WPTight_Gsf or Photon200 or Ele115_CaloIdVT_GsfTrkIdT

MET filters

e: $p_T > 50$ GeV, HEEP ID (V7.0-2018Prompt for 2018)

τ: $p_T > 50$ GeV, $|\eta| < 2.3$, new DM finding (DM5,6 veto), DeepTau tight anti-jet, loose anti-e and tight anti-μ

$m_T(\mathrm{e}, \mathrm{E}_\mathrm{T}^\mathrm{miss}) > 120$ GeV

Extra lepton veto

$\Delta R(e, \tau) > 0.5$

$\mu\tau$

Trigger:

2016: Mu50 or TkMu50

2017-18: Mu50 or TkMu100 or OldMu100

MET filters

μ: $p_T > 53$ GeV, $|\eta| < 2.4$, HighPt ID, tracker iso < 0.1

τ: $p_T > 50$ GeV, $|\eta| < 2.3$, new DM finding (DM5,6 veto), DeepTau tight anti-jet, loose anti-e and tight anti-μ

$m_T(\mu, \mathrm{E}_\mathrm{T}^\mathrm{miss}) > 120$ GeV

Extra lepton veto

$\Delta R(\mu, \tau) > 0.5$

Background

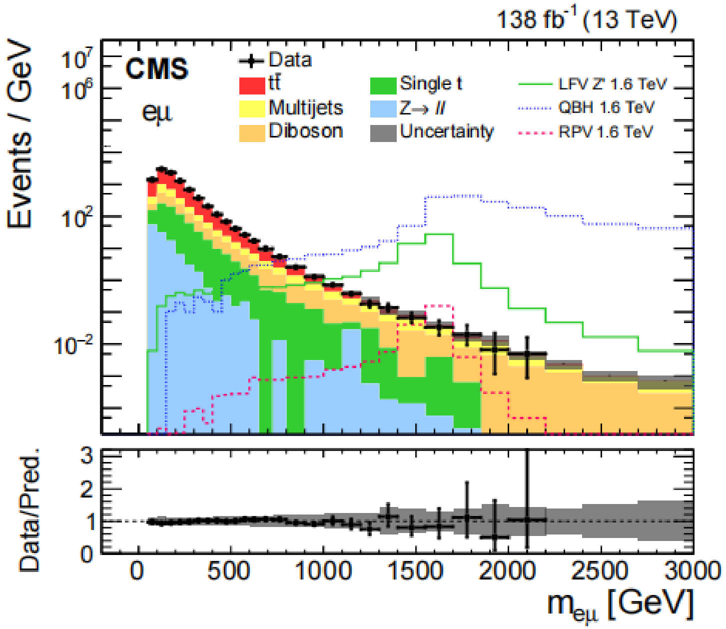
- $t\bar{t}(-like)$: Simulation for $t\bar{t}$, tW, VV, DY processes
- multi-jet: data-driven method
    - fake-rate for $e\mu$
    - fake-rage/shape for tau

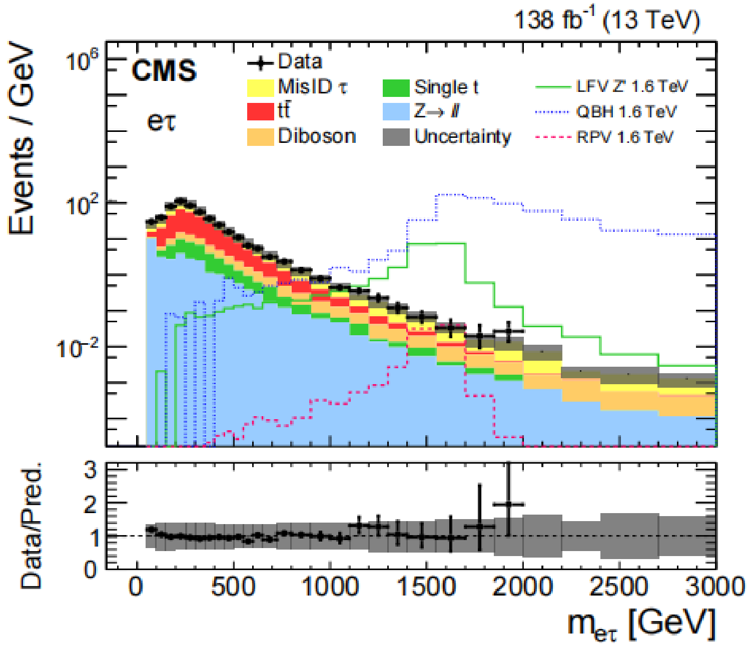
Correction

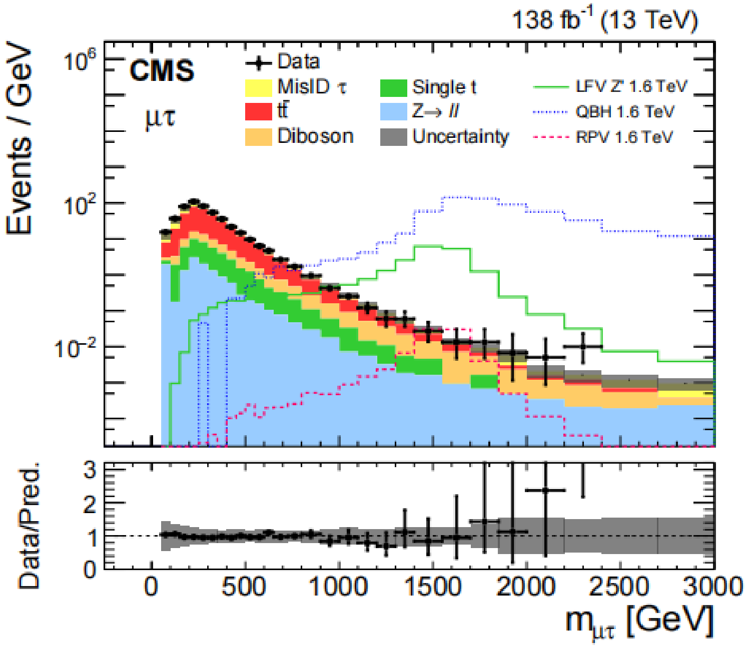
- object energy scale/smear
- Trigger/ID scale factor
- PU & prefiring reweighting

Systematic uncertainties

- PU & lumi & prefiring
- Normalization (50% for data-driven)
- Object p_T and ID scale factors
- Top & WW shape
- PDF







138/fb	SUSY RPV $\tilde{\upsilon}_\tau$ ($\lambda = \lambda' = 0.1$)	QBH (ADD, n=4)	Z' (Br = 10%)
$e\mu$	4.2 TeV	5.6 TeV	5.0 TeV
$e\tau$	3.7 TeV	5.2 TeV	4.3 TeV
$\mu\tau$	3.6 TeV	5.0 TeV	4.1 TeV

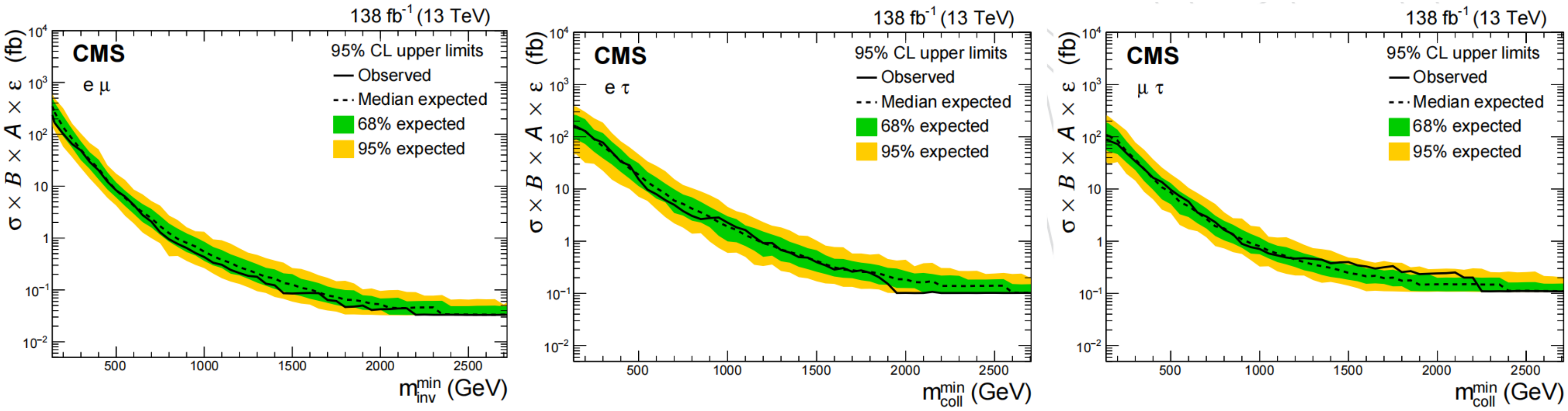
- Data in agreement with SM expectations
- Set limit on model (in)dependent cases
- First high mass LFV search in τ channel.
- Highest exclude mass.

J. High Energy Phys 04, 073 2018

arXiv: 2205.06709, to be accepted by JHEP

Model-independent limit:
No signal shape to consider, event counting above a mass threshold.

X. Gao contributed in $e\mu$ channel: trigger efficiency, background study, event selection, systematic



Search for charged-lepton flavor violation in top quark production and decay

top quark

- The heaviest Standard Model (SM) particle
- Close to the electroweak symmetry breaking scale
- Expected to play an important role in several new physics scenarios
- Large Sample in LHC

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_{\mathrm{eff}} = \mathcal{L}_{\mathrm{SM}} + \sum_x \frac{C_x}{\Lambda^2} O_x + \cdots$$

where C_x is a Wilson coefficient,
O_x is a renormalizable operator

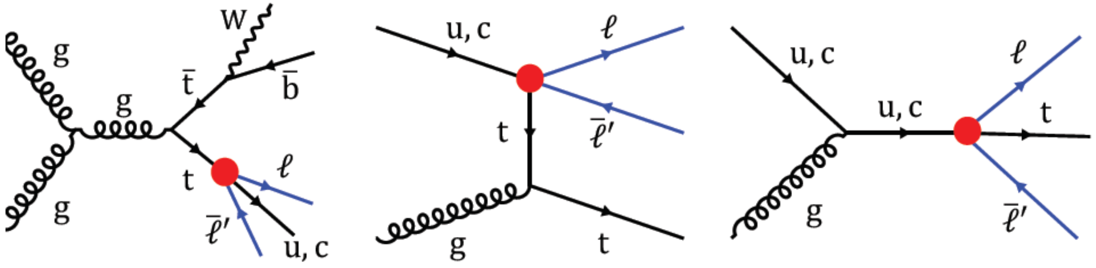
Effective Field Theory

- If new physics is too heavy to appear directly in the available energy, it could affect SM interactions indirectly, through modifications of SM couplings or enhancements of rare SM processes.

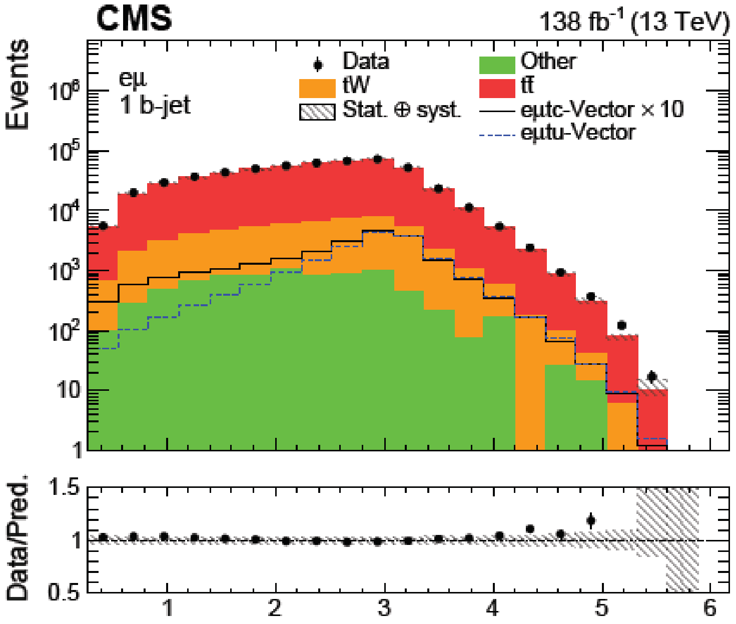
➢ An effective field theory (EFT) approach is followed to **search for new physics in the top quark sector in the di-lepton final states**.

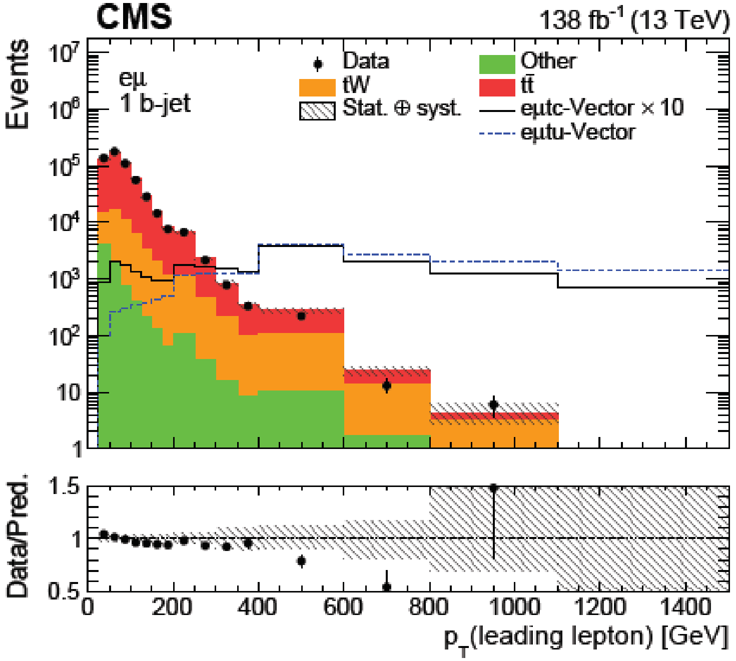
Analysis

- Search for charged lepton flavor violation with top
- Forbidden in SM, so no EFT-SM interference
- $e\mu tq$ vertex in production or decay
- Sensitive to WCs $C_{e\mu tc}$ and $C_{e\mu tu}$



- Select events with opposite-charged $e\mu$ and b-tagged jets
- All corrections applied: object energy, scale factor, top shape
- All background are estimated by MC simulated events
  - ttbar process contributes ~90%
- Events are categorized by number of b-jet



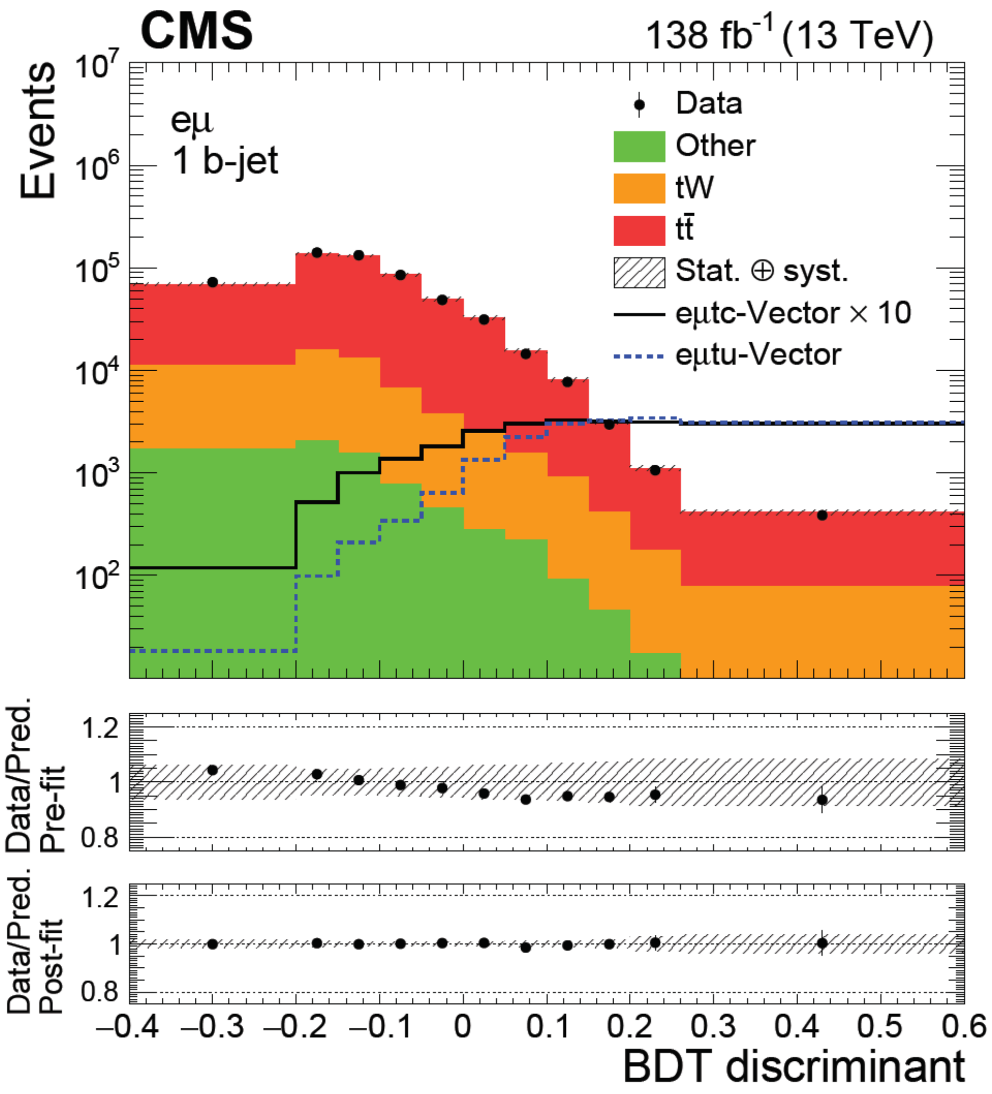


Systematic

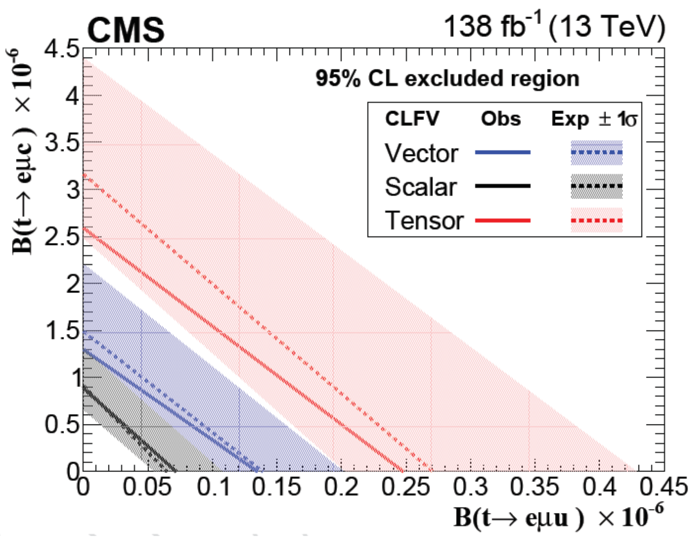
- PU & lumi & MET & trigger
- Object energy and ID scale factors
- $t\bar{t}$ modeling: hdamp, PDF, …
- Signal modeling
- Normalization (30% for other BGs)

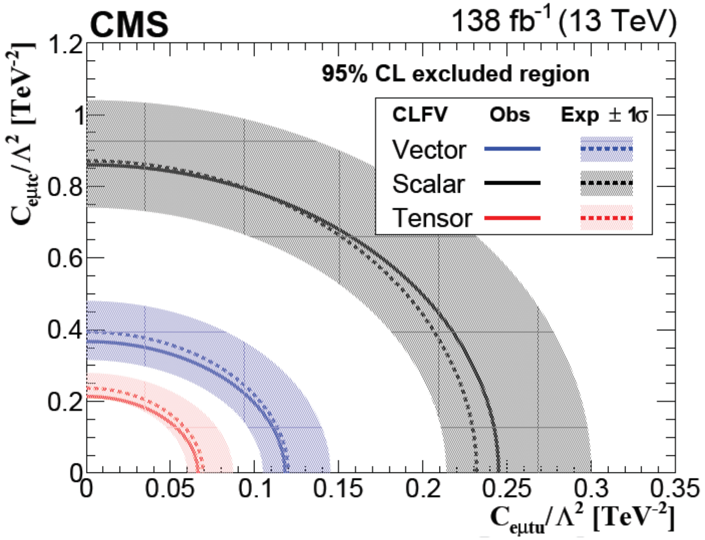
Use a BDT to separate signal from background

- Leptons do not originate from W decays
- No genuine MET
- Higher number of light jets

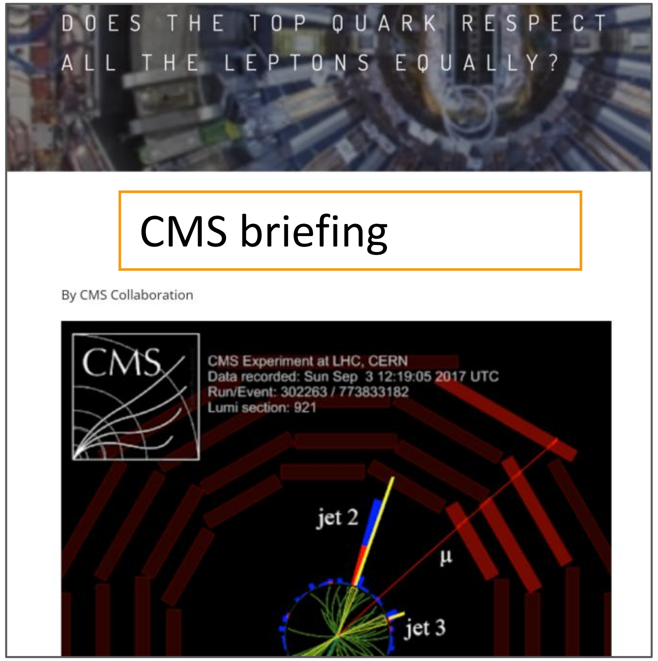


- Set limits on cross section and translate limit to branching fraction and $C_{e\mu tc} - C_{e\mu tu}$ exclusions
- Scalar, vector, tensor contribute differently, the scalar limits strongest while tensor weakest
- World's strongest limits on CLFV in top sector





X. Gao contributed in $e\mu$ channel: trigger efficiency, background study, event selection, signal extraction, systematic, final plot



https://cms.cern/news/does-top-quark-respect-all-leptons-equally

J. High Energy Phys 06, 082 (2022)

Summary

- Search for new physics beyond the standard model is a hot topic, and the LHC provides a unique opportunity to extern our horizon to high energy scale.
- Focus on TeV and top physics in BSM and SM rare processes.
- Publications contribute strongest limits on CLFV at TeV scale and in top sector.
- Continue contributing to HGCAL.

Thanks!