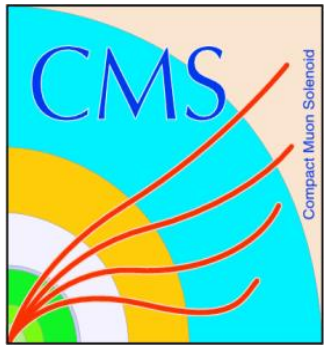

Search for new physics in dilepton final states with CMS run2 data

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Search for resonant and nonresonant new phenomena in high-mass dilepton final states

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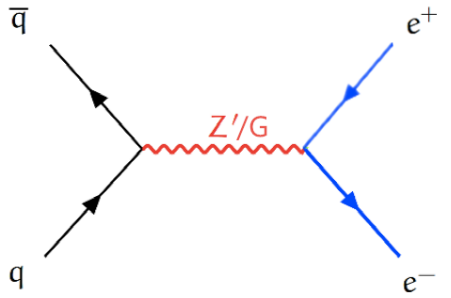
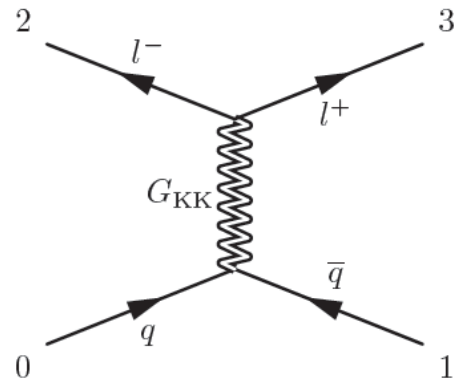
- Many models designed to address the shortcomings of the SM high-mass Z' Gauge bosons resonances at the TeV scale
  - The sequential standard model Z'_{SSM}.
  - The GUT mode Z'_{ψ}.



- The Randall-Sundrum (RS) model of extra spatial dimension predicts a spin-2 graviton candidate that can be searched for in this final state as well.

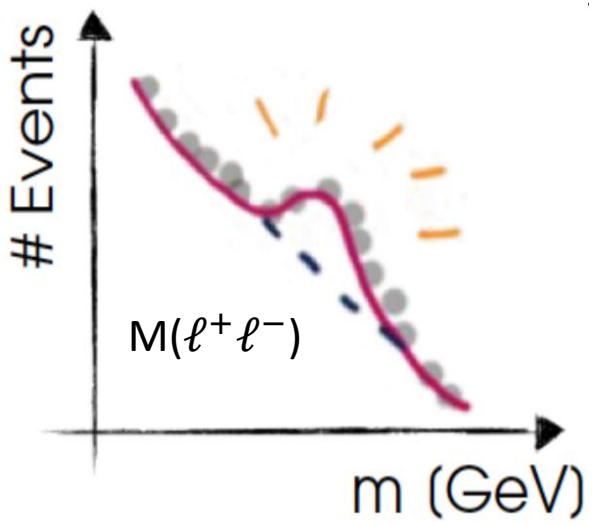


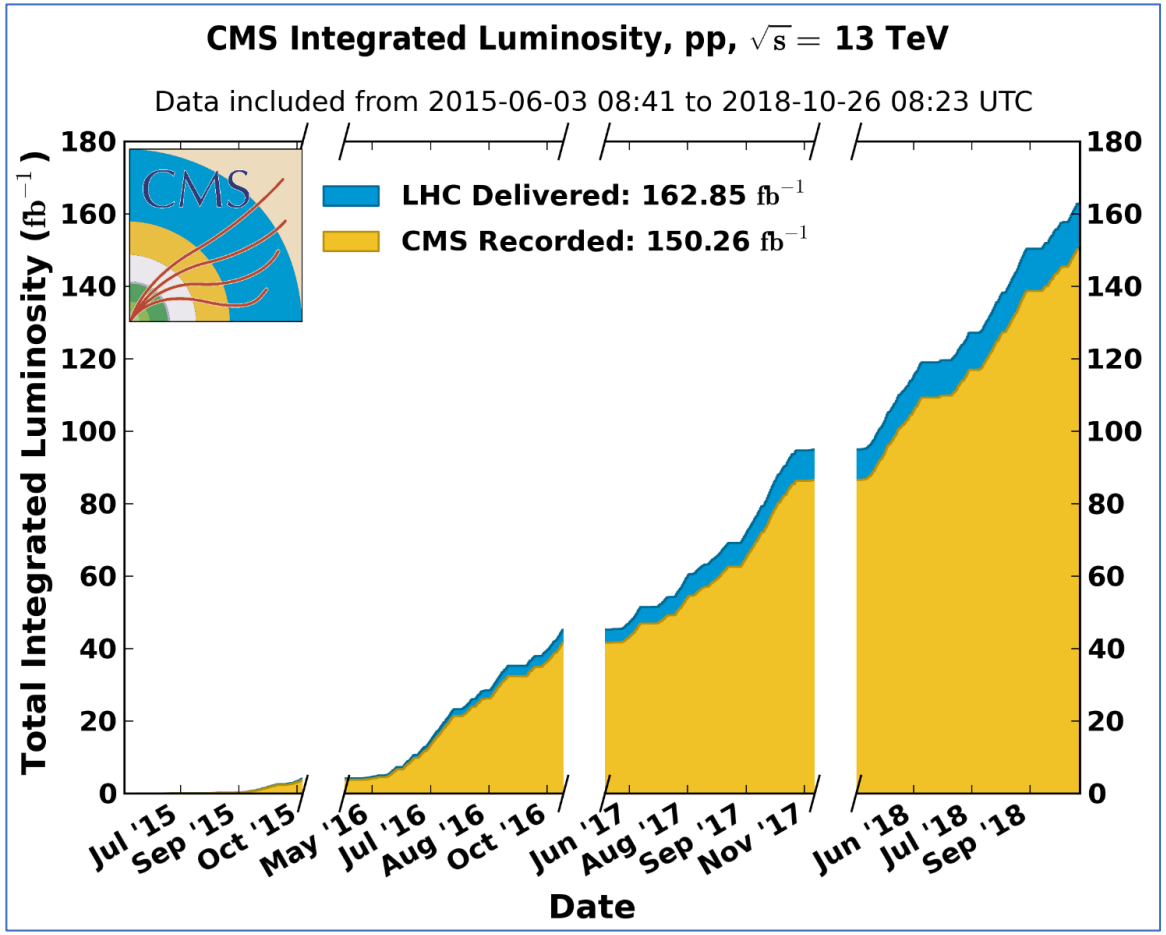
- Nonresonant analysis for Contact Interaction and Large Extra Dimensional.

Event selection (ee channel)

CMS run2 dataset, ~137/fb

- Looking for a "bump" particularly in the high mass tail.
- Measure the corss section for hints of higher energy scale BSM.
- Clean final state, with few background events.





Event selection (ee channel)

- Reconstructed electrons are required to pass the official High-Energy-Electron-Pair (HEEP) selection.
- Double electron unprescaled trigger with lowest ET threshold is used.

Variable	Barrel	Endcap
	Acceptance selections	
E_T	$E_T > 35$ GeV	$E_T > 35$ GeV
η	$\lvert\eta_{SC}\rvert < 1.4442$	$1.566 < \lvert\eta_{SC}\rvert < 2.5$
	Identification selections	
isEcalDriven	true	true
$\Delta\eta_{in}^{seed}$	$\lvert\Delta\eta_{in}^{seed}\rvert < 0.004$	$\lvert\Delta\eta_{in}^{seed}\rvert < 0.006$
$\Delta\phi_{in}$	$\lvert\Delta\phi_{in}\rvert < 0.06$	$\lvert\Delta\phi_{in}\rvert < 0.06$
H/E	$H/E < 1/E + 0.05$	$H/E < 5/E + 0.05$
$\sigma_{i\eta i\eta}$	-	$\sigma_{i\eta i\eta} < 0.03$
$\frac{E_{1\times5}}{E_{5\times5}}$, $\frac{E_{2\times5}}{E_{5\times5}}$	$\frac{E_{1\times5}}{E_{5\times5}} > 0.83$ or $\frac{E_{2\times5}}{E_{5\times5}} > 0.94$	-
Inner lost layer hits	lost hits ≤ 1	lost hits ≤ 1
Impact parameter, d_{xy}	$\lvert d_{xy}\rvert < 0.02$	$\lvert d_{xy}\rvert < 0.05$
	Isolation selections	
EM + had depth 1 isolation, iso	$iso < 2 + 0.03E_T + 0.28\rho$	$iso < 2.5 + 0.28\rho$ ($E_T < 50$ GeV) else $iso < 2.5 + 0.03(E_T - 50\text{ GeV}) + 0.28\rho$
p_T isolation (V7), isopt	isopt < 5 GeV	isopt < 5 GeV

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

- At least one electron should be in the barrel and no opposite charge requirement.
- Events are categorized to:
  - Barrel-Barrel events
  - Barrel-Endcap events

Event selection ($\mu\mu$ channel)

CMS run2 dataset, ~137/fb

- Reconstructed muons are selected via High p_T Muon ID.
- Main trigger is Mu50 in OR with two backup triggers at 100 GeV.

We do not touch the 2016 result, and only add it at the statistical analysis level to the 2017+2018 results

Selection optimized for high p_T muons
Updated ID recovering 2-3% efficiency at high momenta

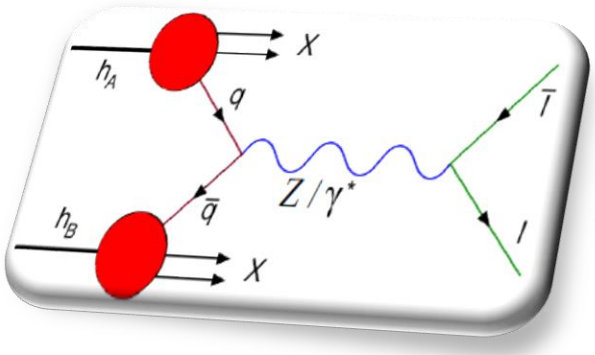
- Global muon reconstruction
- At least one muon chamber hit
- Muon segments present in at least one muon station other than the first one
- Relative error on muon best track $p_T < 30\%$
- $d_{xy} < 2$ mm, $d_z < 5$ mm
- At least one hit in the pixel tracker
- Number of tracker layers with hits > 5

To increase the yield of Z bosons we use a prescaled trigger which has the same performance as our signal trigger in the plateau

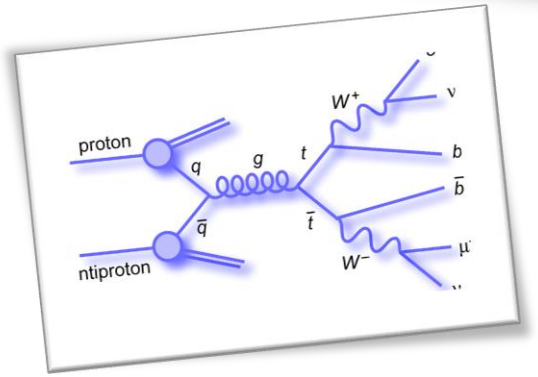
- Events are categorized to:
  - Barrel-Barrel (BB) events
  - non-BB events

Background study (ee channel)

- 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].



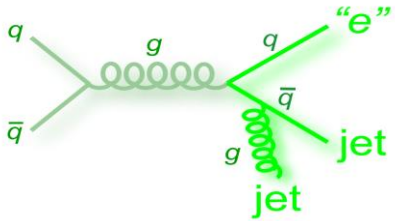
- Additional sources of background are processes which produce real prompt leptons where the two prompt leptons are from different particles, $t\bar{t}$, tW, WW, WZ, ZZ, $Z \rightarrow \tau\tau$.
- **Validated** in the eμ final state.

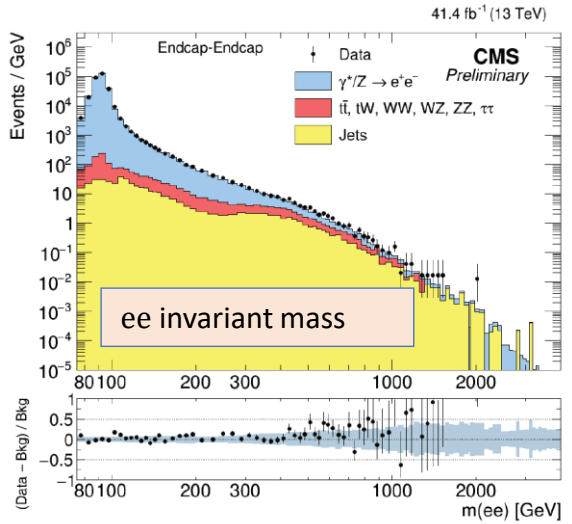


$$\frac{1}{2}N_{e\mu} = N_{ee} = N_{\mu\mu}$$

- 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**.



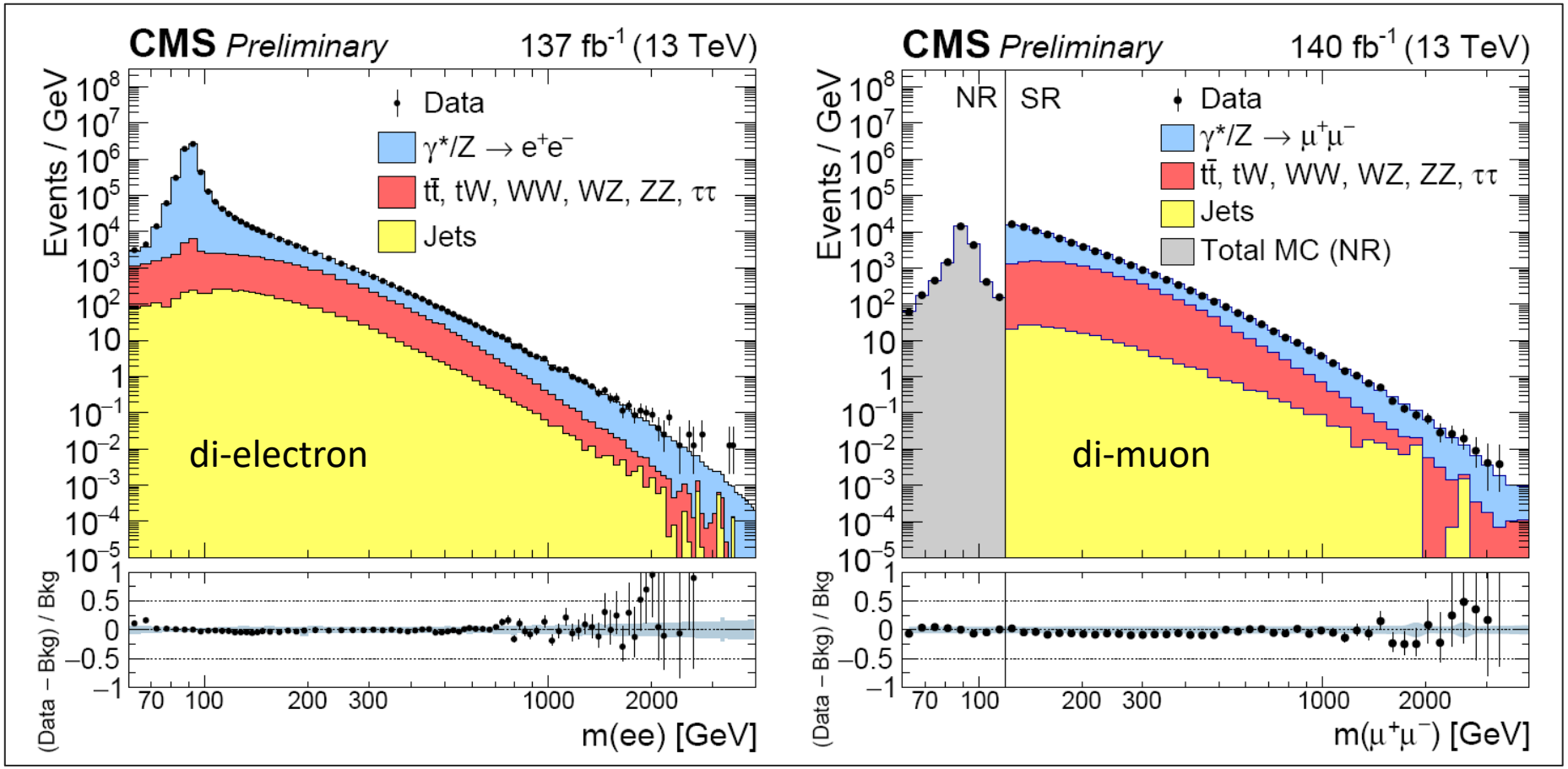


Invariant mass distribution

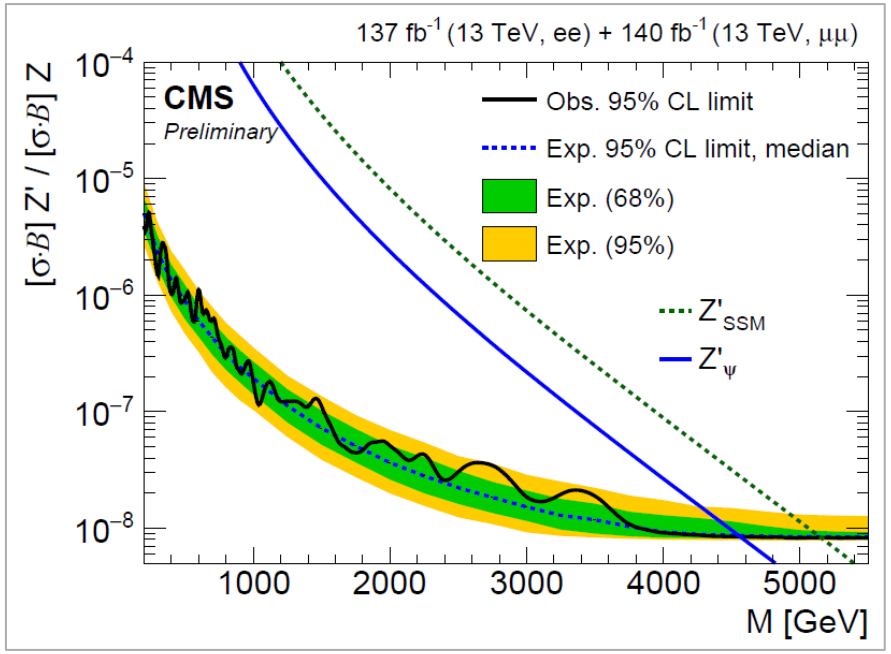
No hints for any BSM excesses.

The limits are expressed as function of R_σ

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

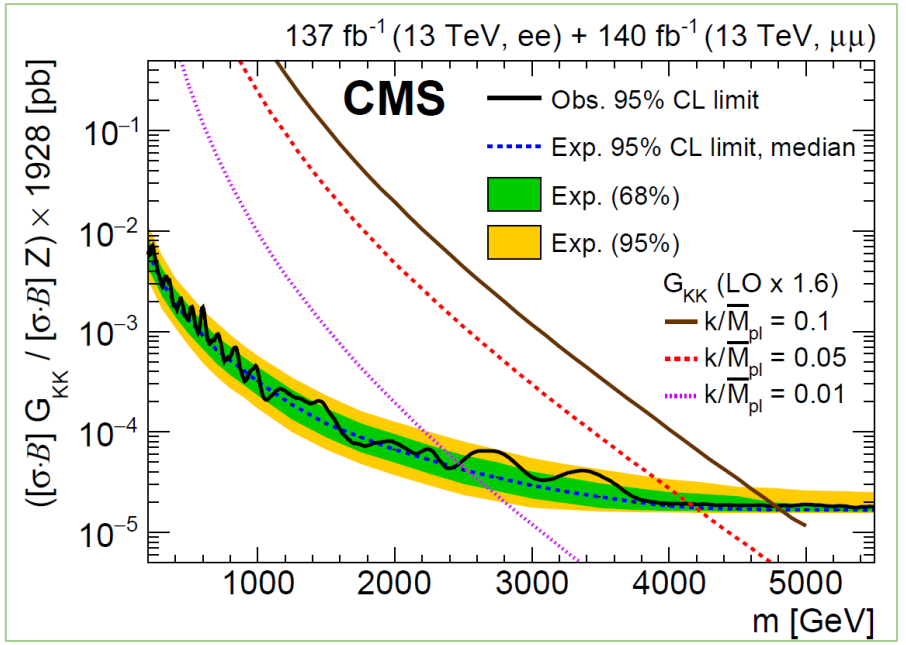


Upper limits



Z'

Spin-2 graviton



Channel	Z'_{SSM}		Z'_{ψ}	
	Obs. [TeV]	Exp. [TeV]	Obs. [TeV]	Exp. [TeV]
e e	4.72	4.72	4.11	4.13
$\mu^+\mu^-$	4.89	4.90	4.29	4.30
e e + $\mu^+\mu^-$	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
$\mu\mu$	2.34	2.32	3.96	3.96	4.59	4.59
ee + $\mu\mu$	2.47	2.53	4.16	4.19	4.78	4.81

ATLAS result with 139 fb^{-1}:

exclude Z'_{SSM} at 5.1 TeV and Z'_{ψ} at 4.5 TeV.

Non-resonant interpretation of the high mass dilepton search

- Event selection, background estimation, and systematic uncertainties are identical to the search for resonant phenomena in the same final state but focus on the specific non-resonant signal models.

- The event sample is divided into several bins in invariant mass and the scattering angle $\cos(\theta^*)$ in the Collins-Soper frame.

Four fermion Contact Interaction (CI)

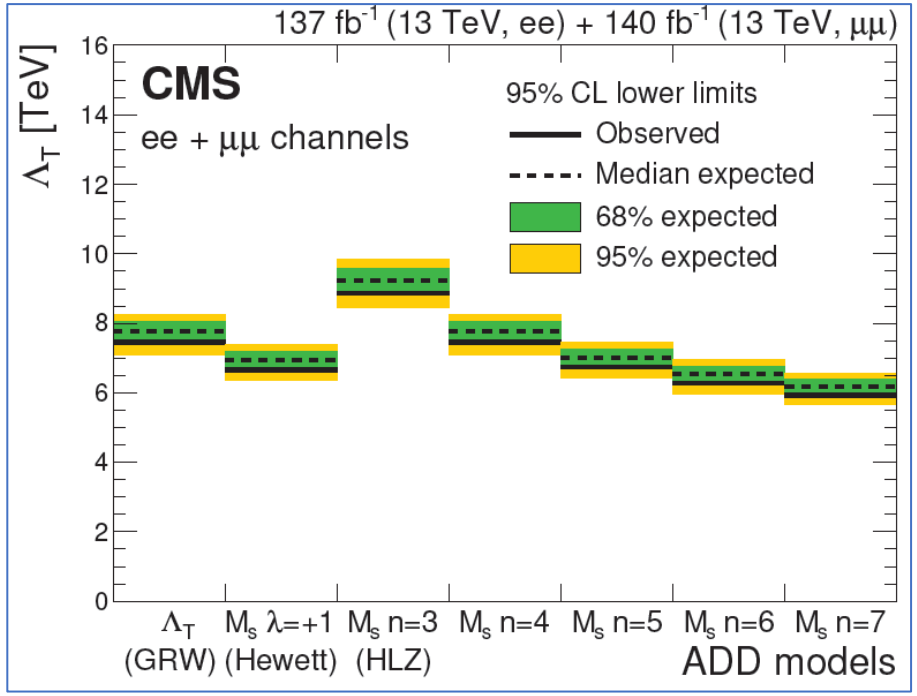
- Caused by fermion substructure
- Consider constructive and destructive interference with DY
- 4 helicity models (LL, LR, RL, RR)
- Signal parameter: Energy scale Lambda

ADD model of large extra dimensions

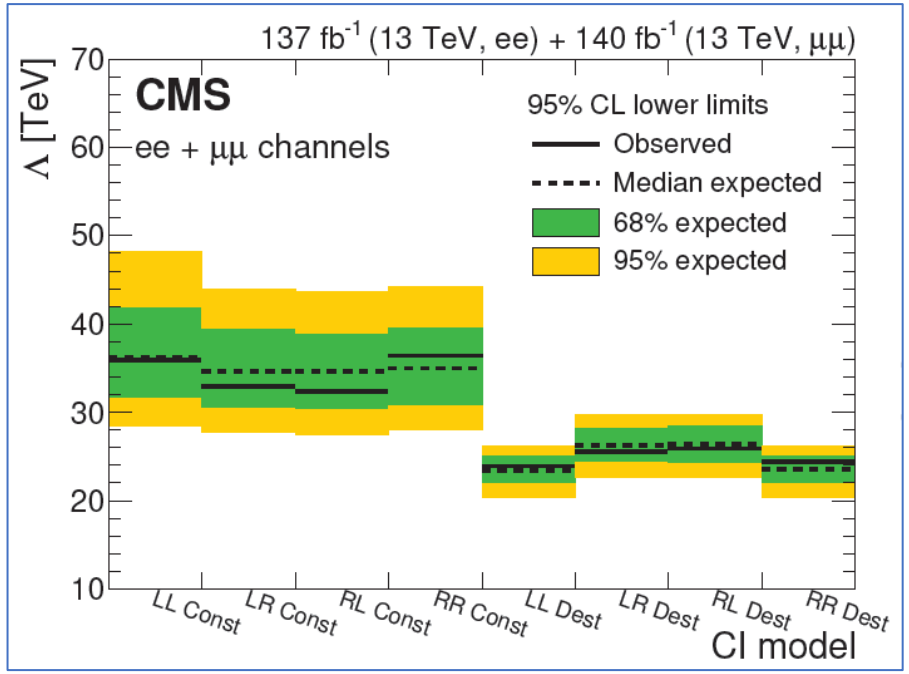
- Spin-2 graviton excitations in the ADD model of large extra dimensions lead to non-resonant signal
- Serval parameter conventions: GRW, LHZ, Hewitt
- Signal Parameter: UV cutoff Lambda_T

$$\frac{\mathrm{d}\sigma_{\mathrm{X}\to\ell\ell}}{\mathrm{d}m_{\ell\ell}} = \frac{\mathrm{d}\sigma_{\mathrm{DY}}}{\mathrm{d}m_{\ell\ell}} + \eta_{\mathrm{X}}\mathcal{I}(m_{\ell\ell}) + \eta_{\mathrm{X}}^2\mathcal{S}(m_{\ell\ell}),$$

Upper limits



Non-resnant



Order	GRW Λ_T [TeV]	Hewett M_S [TeV] $\lambda = +1$	HLZ M_S [TeV] $n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$
			ee				
LO	6.7 (6.9)	5.9 (6.2)	7.9 (8.2)	6.7 (6.9)	6.0 (6.3)	5.6 (5.8)	5.3 (5.5)
LO ×1.3	6.9 (7.2)	6.1 (6.4)	8.2 (8.5)	6.9 (7.2)	6.2 (6.5)	5.8 (6.0)	5.5 (5.7)
			$\mu\mu$				
LO	7.0 (7.1)	6.2 (6.4)	8.3 (8.5)	7.0 (7.1)	6.3 (6.4)	5.9 (6.0)	5.6 (5.7)
LO ×1.3	7.2 (7.4)	6.5 (6.6)	8.6 (8.8)	7.2 (7.4)	6.5 (6.7)	6.1 (6.2)	5.8 (5.9)
			Combined ee and $\mu\mu$				
LO	7.3 (7.5)	6.5 (6.7)	8.6 (8.9)	7.3 (7.5)	6.6 (6.8)	6.1 (6.3)	5.8 (6.0)
LO ×1.3	7.5 (7.8)	6.7 (6.9)	8.9 (9.2)	7.5 (7.8)	6.7 (7.0)	6.3 (6.5)	5.9 (6.2)

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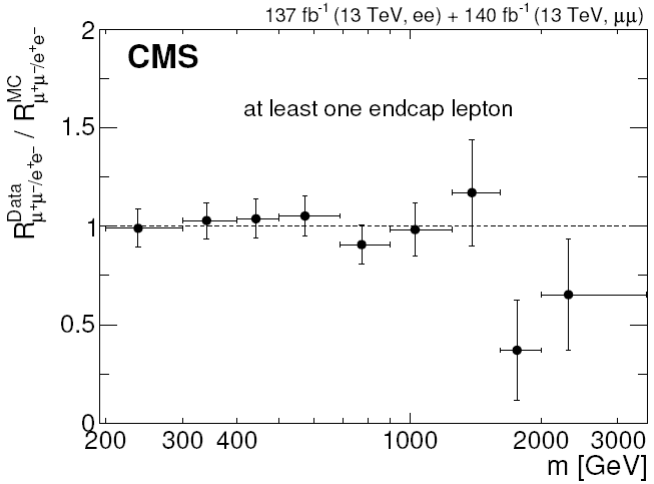
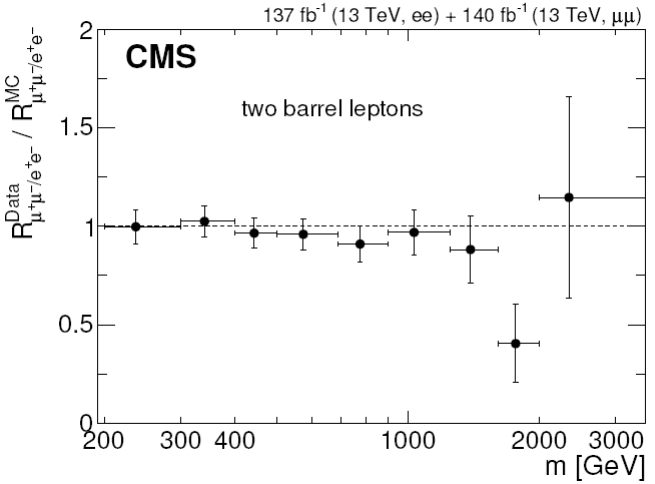
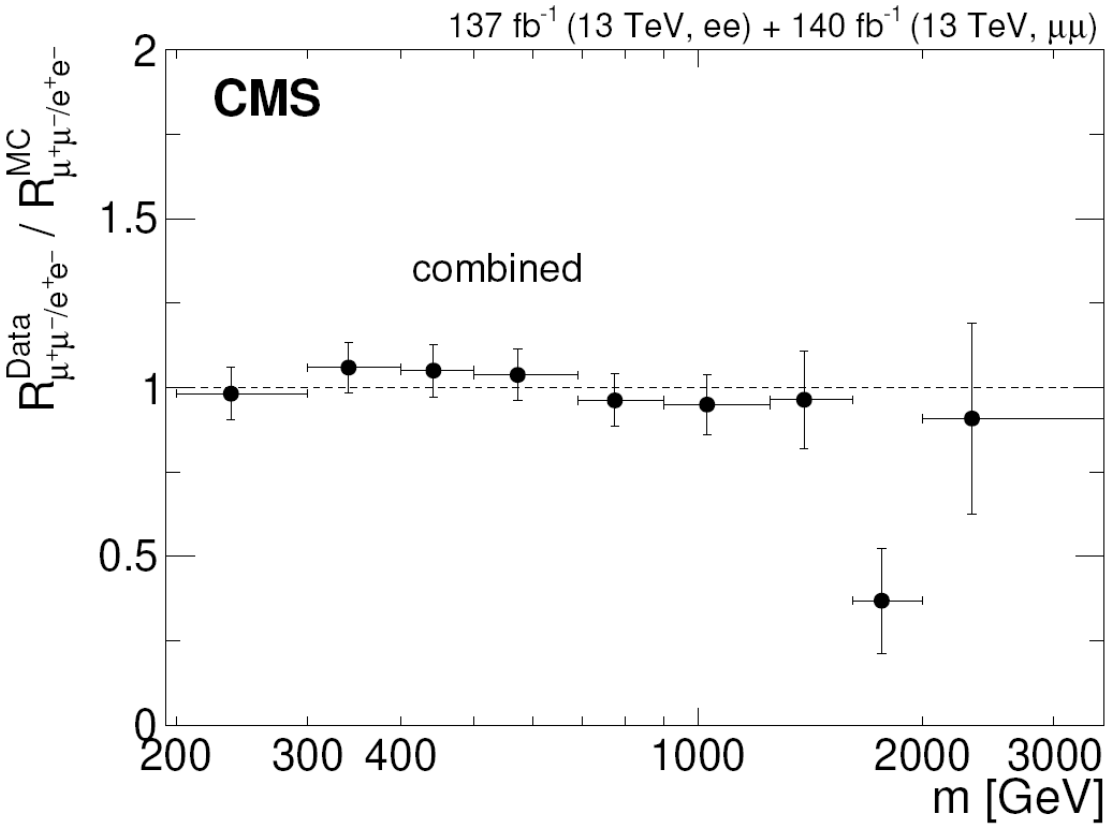
Lepton flavor universality





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



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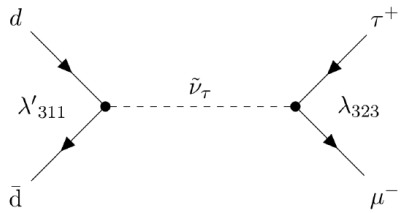
Search for heavy resonances and quantum black holes in $e\mu$, $e\tau$ and $\mu\tau$ final states in proton-proton collisions at $\sqrt{s}$ = 13 TeV

PAS-EXO-19-019

- Charged lepton flavor is conserved in SM but can be violated in some BSM models, including R-parity violating (RPV) supersymmetry (SUSY) models, Microscopic quantum black holes (QBHs), and Gauge boson Z'.

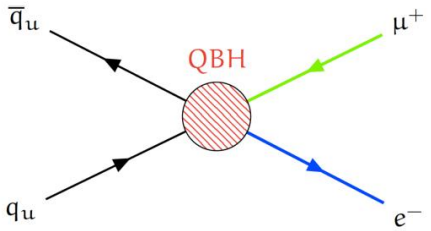
R-Parity Violating SUSY

- $\widetilde{\nu_\tau}$ resonance: lightest SUSY particle
- All RPV couplings = 0 except those allowing for LFV decay to a specific final state



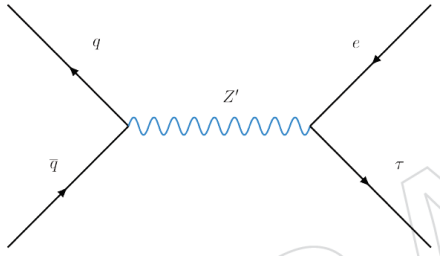
Quantum black hole (QBH)

- Extra dimensions → TeV scale QBH
- Spin 0, colorless, neutral
- n=4 extra dimensions (ADD)



SSM-like LFV Z'

- Z-like couplings in quark sector
- LFV-only decays in lepton sector



- We present this search in $e\mu$ $e\tau$ $\mu\tau$ final states with the full CMS run2 data.

Event selection

CMS run2 dataset, ~137/fb

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{l} p_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \Delta\phi(\vec{p}_{\mathrm{T}}^{\,l}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}}))},$$

- $e\mu$: Single Muon, Single Photon
- $e\tau$: Single Electron, Single Photon (EGamma in 2018)
- $\mu\tau$: Single Muon

- The lepton candidates pair with highest mass is chosen.

Considering the τ candidate in this analysis has high momentum, collinear mass is used as final discriminating variable in τ channels.

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

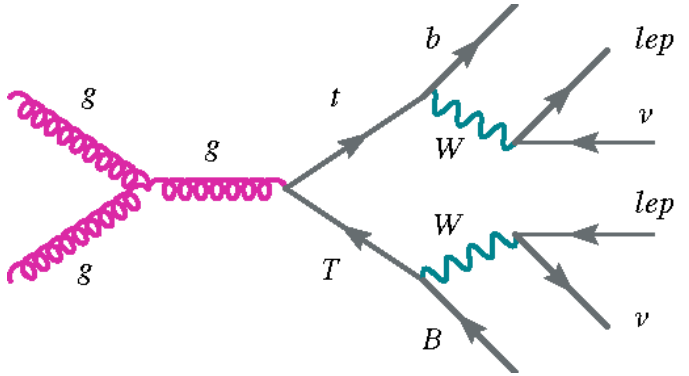
$$x = \frac{p_T(\tau)}{p_T(\tau) + p_T^{miss}{}_{coll}}$$

$e\mu$	$e\tau$	$\mu\tau$
Trigger: 2016: Mu50 or TkMu50 or Photon175 2017: Mu50 or TkMu100 or OldMu100 or Photon175 2018: Mu50 or TkMu100 or OldMu100 or Photon200	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	Trigger: 2016: Mu50 or TkMu50 2017-18: Mu50 or TkMu100 or OldMu100
MET filters	MET filters	MET filters
e: $p_T > 35$ GeV, HEEP ID (V7.0-2018Prompt for 2018), $\Delta R > 0.1$ with any muon	e: $p_T > 50$ GeV, HEEP ID (V7.0-2018Prompt for 2018)	μ: $p_T > 53$ GeV, $\lvert\eta\rvert < 2.4$, HighPt ID, tracker iso < 0.1
μ: $p_T > 53$ GeV, $\lvert\eta\rvert < 2.4$, HighPt ID, tracker iso < 0.1	τ: $p_T > 50$ GeV, $\lvert\eta\rvert < 2.3$, new DM finding (DM5,6 veto), DeepTau tight anti-jet, loose anti-e and tight anti-μ	τ: $p_T > 50$ GeV, $\lvert\eta\rvert < 2.3$, new DM finding (DM5,6 veto), DeepTau tight anti-jet, loose anti-e and tight anti-μ
$\Delta R(e, \mu) > 0.1$	$m_T(\mathrm{e}, \mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}) > 120$ GeV Extra lepton veto $\Delta R(e, \tau) > 0.5$	$m_T(\mu, \mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}) > 120$ GeV Extra lepton veto $\Delta R(\mu, \tau) > 0.5$

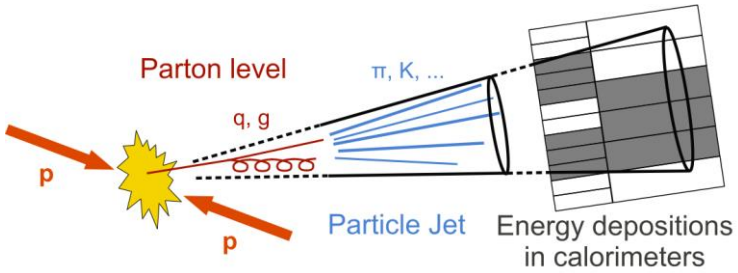
Background study

CMS run2 dataset, ~137/fb

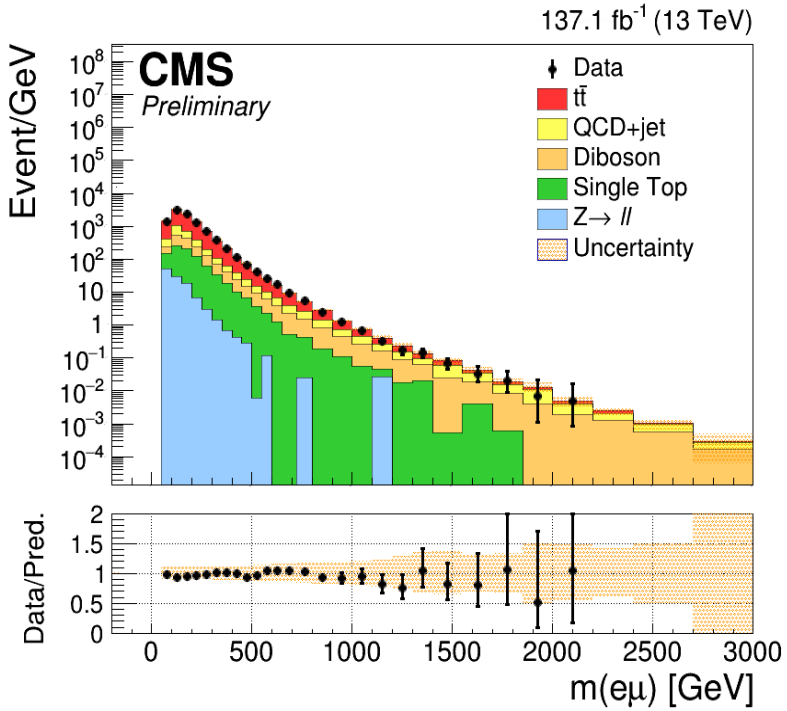
- One background is the processes which produces the leptons and is called “prompt background”. [Monte Carlo]
  - $t\bar{t} \rightarrow 2l2\nu$: POWHEG binned M_{ll}
  - $WW \rightarrow 2l2\nu$: POWHEG binned in M_{ll}
  - WZ, ZZ: POWHEG and amc@NLO binned in decay mode
  - $DY \rightarrow ll$: amc@NLO binned in M_{ll}
  - Single Top : POWHEG, tW channel

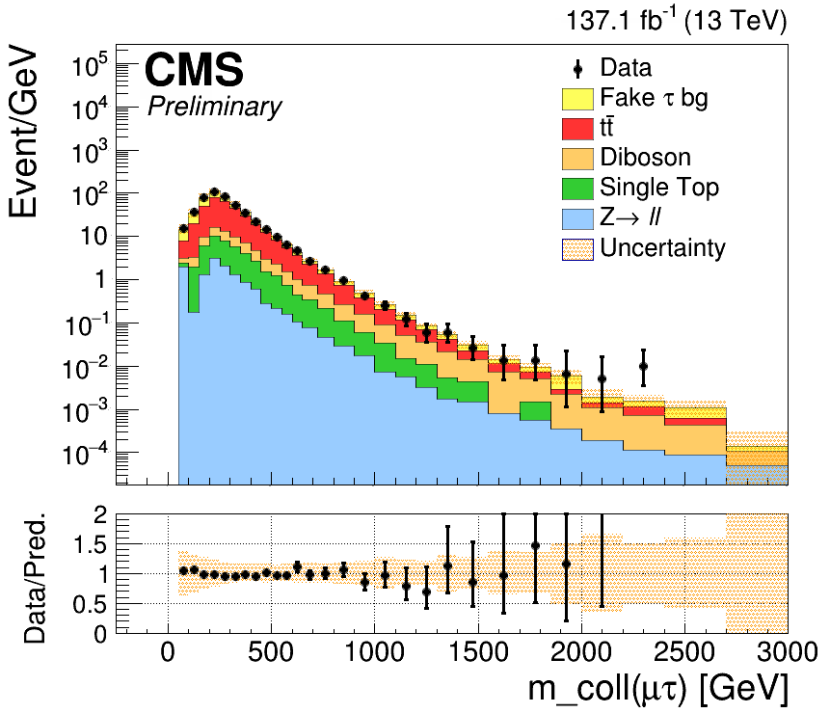


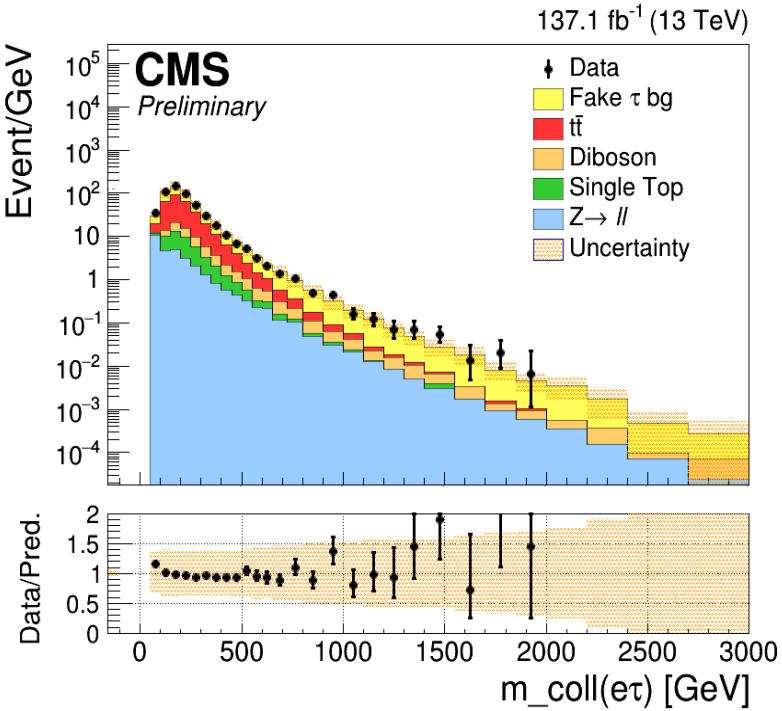
- The other one is called the “jet background” in which a jet is misidentified as an electron (a muon or a tau). [fake rate]



Invariant mass distribution







Upper limits

Lower limits at 95% C.L. [TeV]			
	Z′ LFV	RPV	QBH
$e\mu$	5.0	4.2	5.7
$e\tau$	4.2	3.7	5.3
$\mu\tau$	4.1	3.7	5.1

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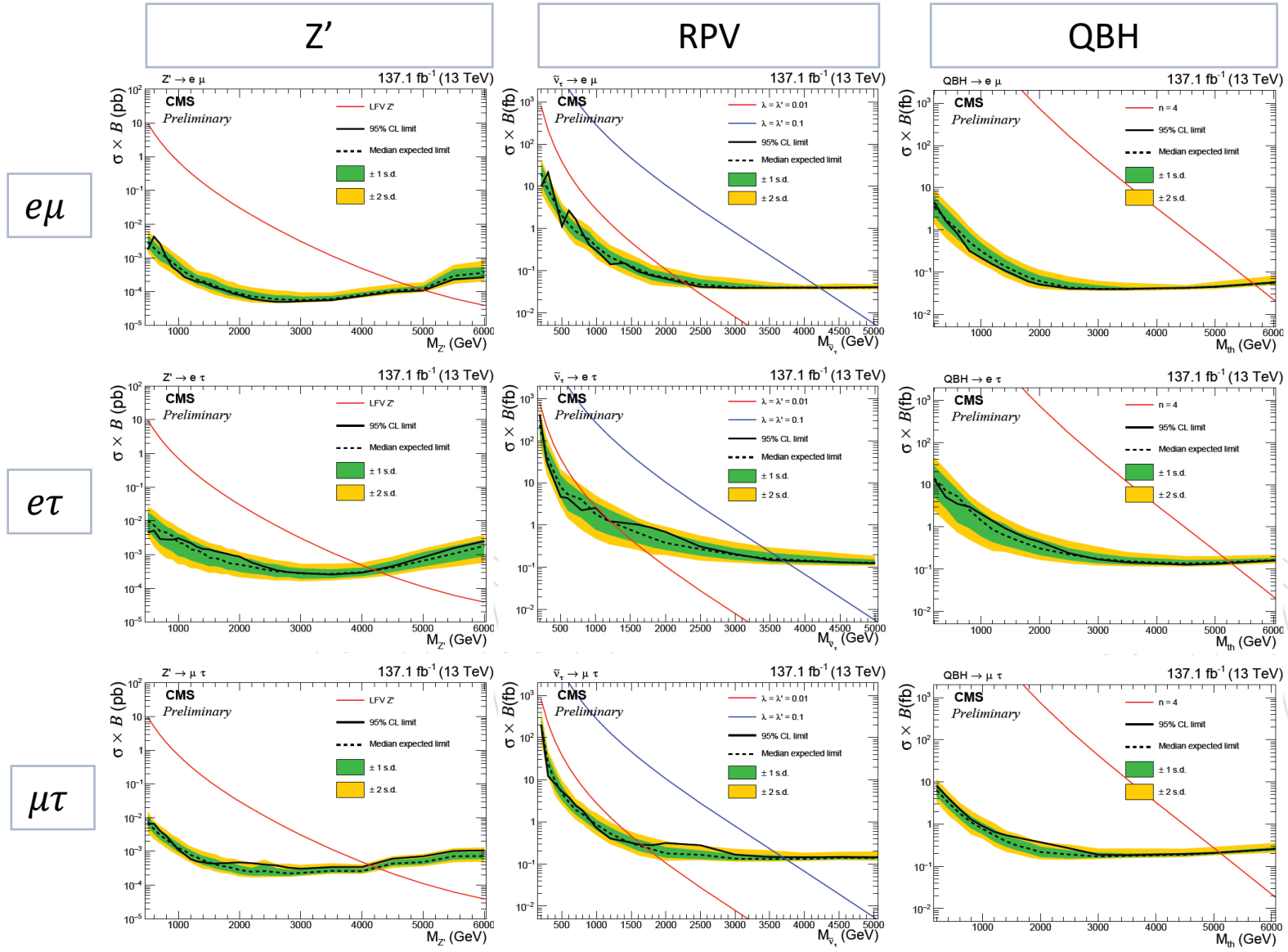

Summary

- Search for high mass BSM are performed in dilepton final states using the proton-proton collision dataset at a center-of-mass energy of 13 TeV collected by CMS in 2016, 2017, and 2018, corresponding to integrated luminosities up to ~140 fb^{-1}.
- The observations are consistent with the expectations of the standard model in all searched channels.
- Upper limits on the cross sections are calculated and lower mass limits are set for various BSM models.

"Search for resonant and nonresonant new phenomena in high-mass dilepton final states $\sqrt{s}$ = 13 TeV"
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"Search for heavy resonances and quantum black holes in $e\mu$, $e\tau$ and $\mu\tau$ final states in proton-proton collisions at $\sqrt{s}$ = 13 TeV"
PAS-EXO-19-019