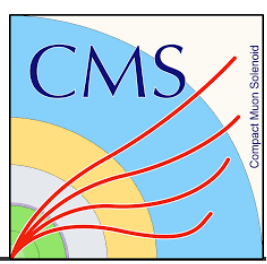
Searches for non-resonant new phenomena in final states with leptons and photons

Shubhanshu Chauhan (IISER Pune)
on behalf of CMS collaboration

SUSY 17,
TIFR, Mumbai, India
14/12/2017



Introduction

- Several possibilities for new physics to exist.
- Narrow or broad resonances decaying into various SM particles.
- We might also see new physics in the tails of various distributions or as a production of exotic particles.
- In today's talk:
  - Search for type-III seesaw mechanism with multileptons. $\geq 3\ell$
  - Search for excited leptons in $\ell\ell\gamma$ final states. $\ell\ell\gamma$
  - Search for new physics with $(Z \longrightarrow \ell^+\ell^-)$ + MET(p_T^{Miss}) $\ell^+\ell^- \; p_T^{Miss}$
  - Search for quantum black holes in e μ final state. e μ

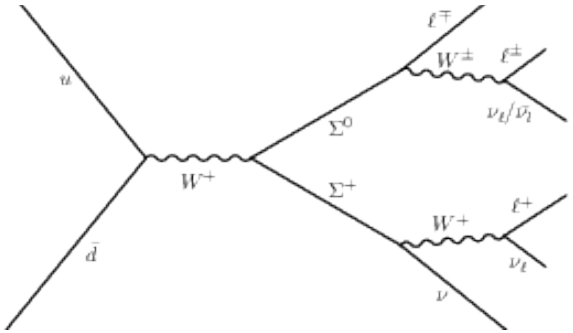
Type-III Seesaw with multileptons

35.9 fb^{-1} 2016 Data PhysRevLett.119.221802

- The type-III seesaw model: SU(2) triplets produced via EW interactions. ($\Sigma^+ \Sigma^-$, $\Sigma^+ \Sigma^0$,$\Sigma^- \Sigma^0$)
- Seesaw fermions decay via gauge bosons, resulting in multileptonic final states (≥3ℓ).

  $\Sigma^\pm \longrightarrow W^\pm \upsilon / Z\, \ell^\pm / h\, \ell^\pm$

  $\Sigma^0 \longrightarrow W^\pm \ell^\pm / Z\, \upsilon / h\, \upsilon$

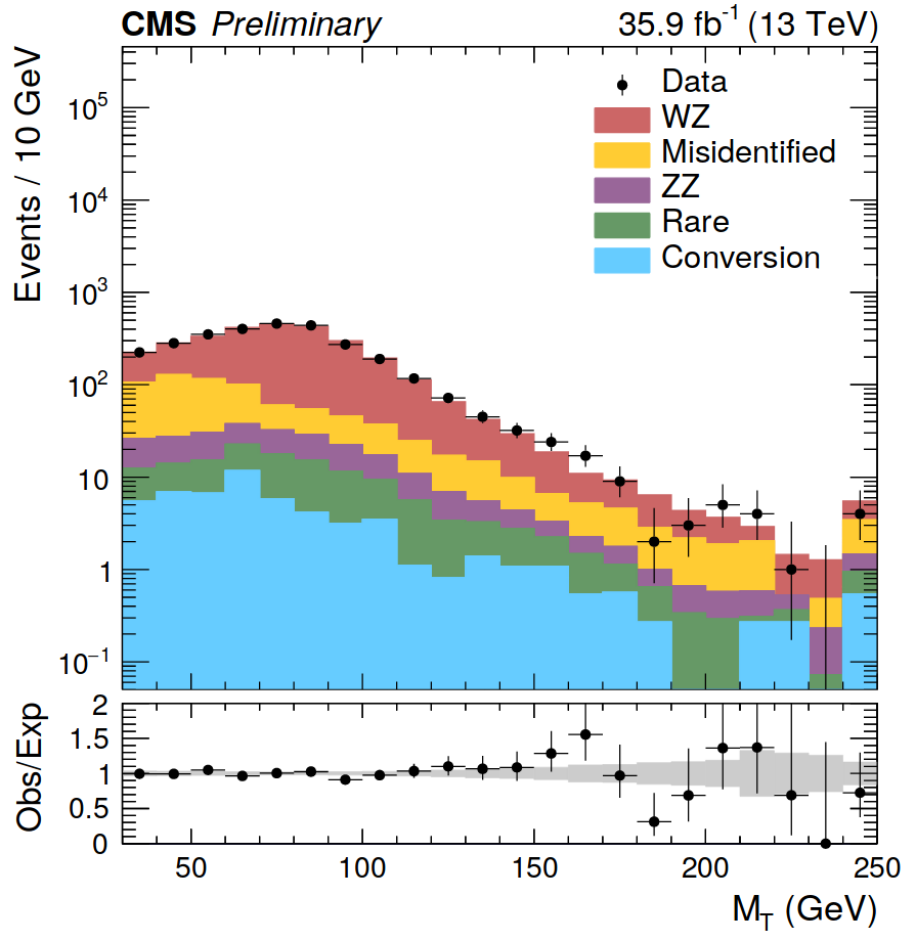


N_{leptons}	OSSF & mass	Variable	p_T^{miss} requirement
3	OSSF1, on-Z	M_T	$p_T^{\text{miss}} > 100$ GeV
3	OSSF1, above-Z	$L_T+p_T^{\text{miss}}$	—
	OSSF1, below-Z	$L_T+p_T^{\text{miss}}$	$p_T^{\text{miss}} > 50$ GeV
	OSSF0	$L_T+p_T^{\text{miss}}$	—
≥ 4	OSSF1	$L_T+p_T^{\text{miss}}$	—
	OSSF2	$L_T+p_T^{\text{miss}}$	$p_T^{\text{miss}} > 50$ GeV if on-Z

- Total 27 distinct productions and decay combinations.
- Lepton p_T >25/15/10 GeV.
- Search regions with OSSF pair mass, OnZ/belowZ/aboveZ, or no OSSF pair.
- Scalar sum of lepton p_T (L_T) + missing transverse energy (p_T^{Miss}) and transverse mass M_T used as discriminating variables.

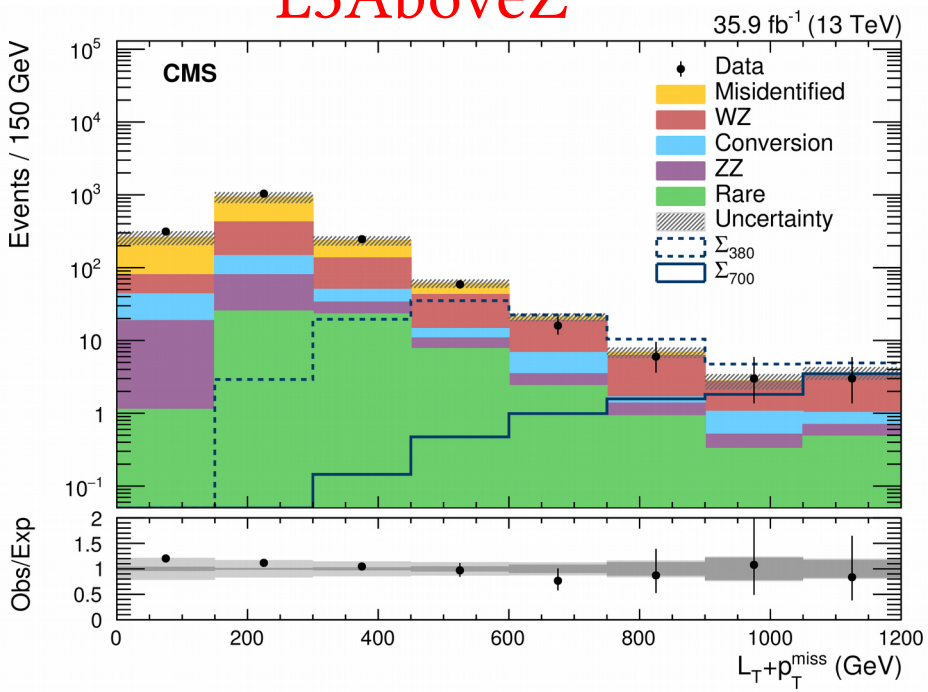
Backgrounds

- Irreducible backgrounds from leptonic decays of diboson (WZ, ZZ) productions.
  - Estimated using Monte-Carlo samples normalized in control samples.
- Irreducible backgrounds from rare VVV, ttV and higgs productions.
- Reducible background:
  - DY+jets, ttbar + jets , WW +jets. Estimated using a data driven matrix method.
  - Photon conversion background. Estimated using data driven photon proxy method.

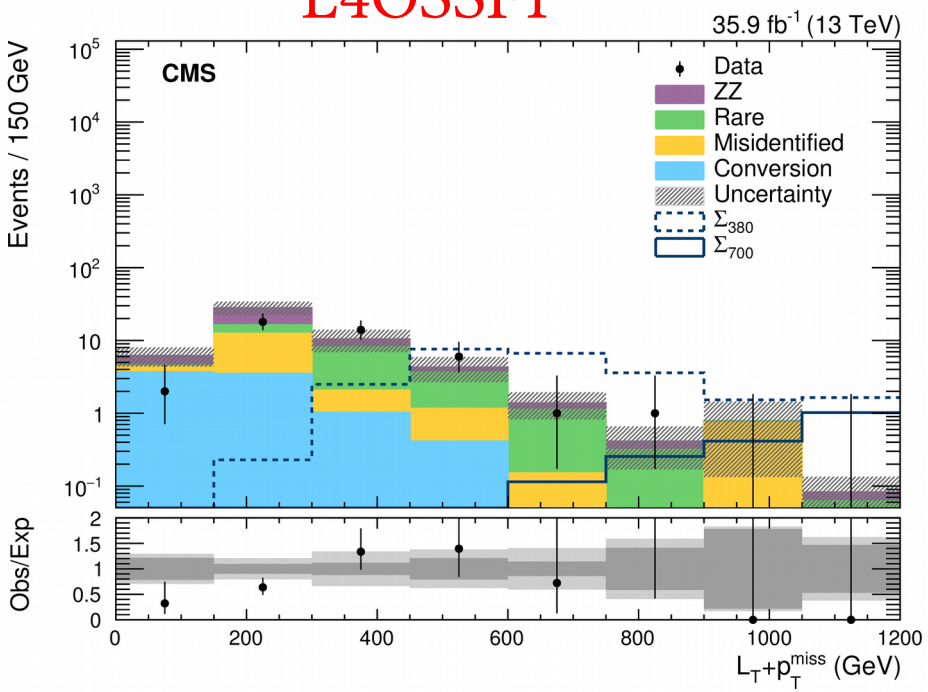


Results

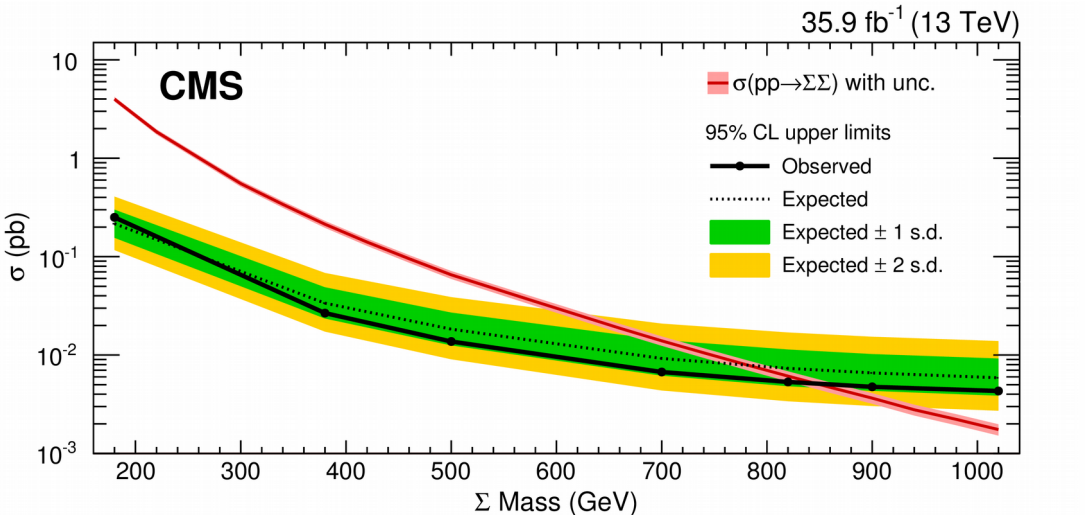
L3AboveZ

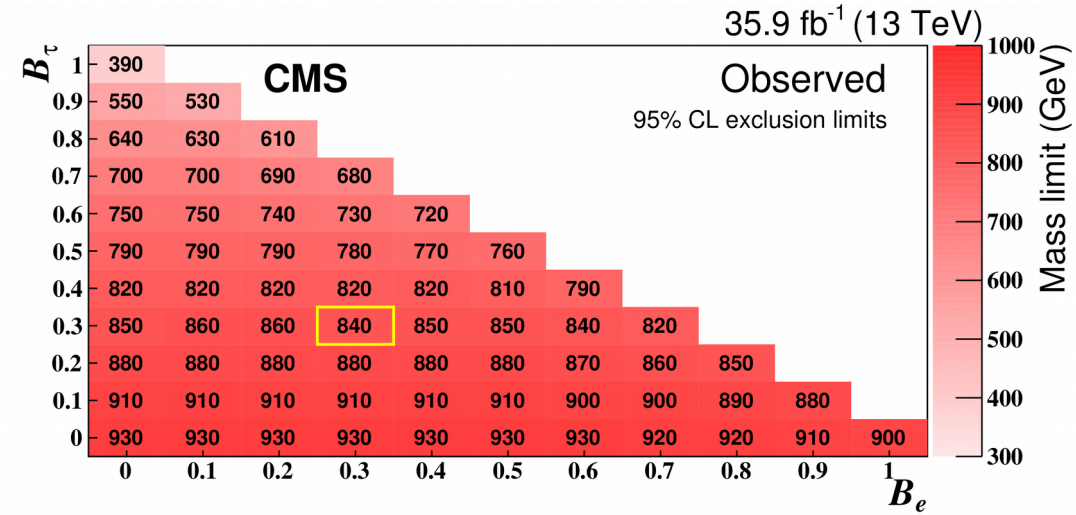


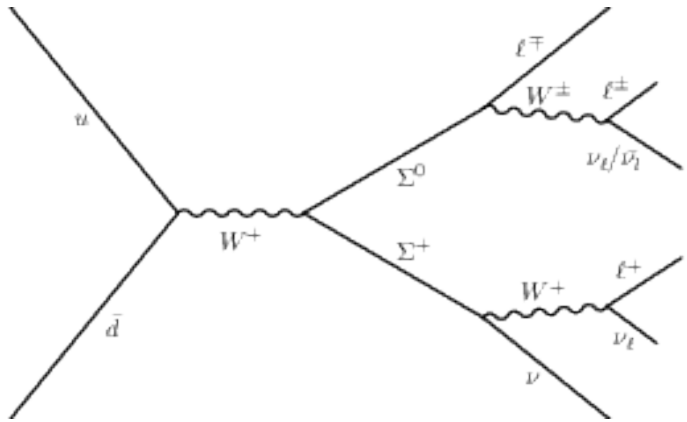
L4OSSF1



Interpretation





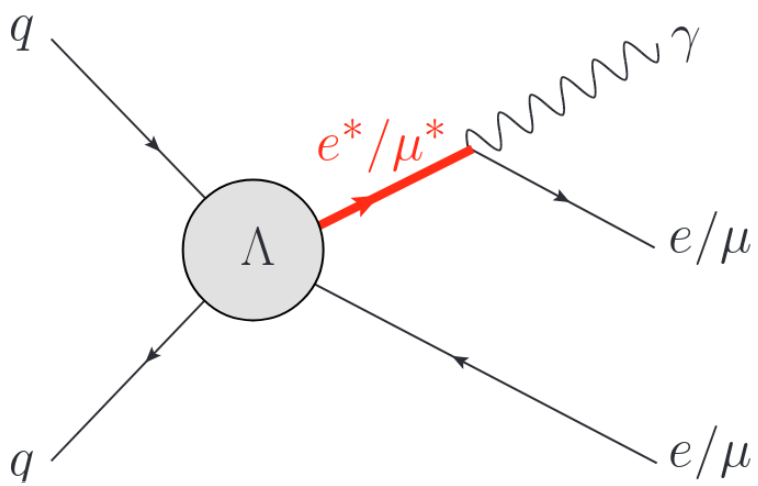


Heavy Seesaw fermions with mass below 840 GeV are excluded for democratic lepton couplings.

Excited Leptons with ℓℓγ

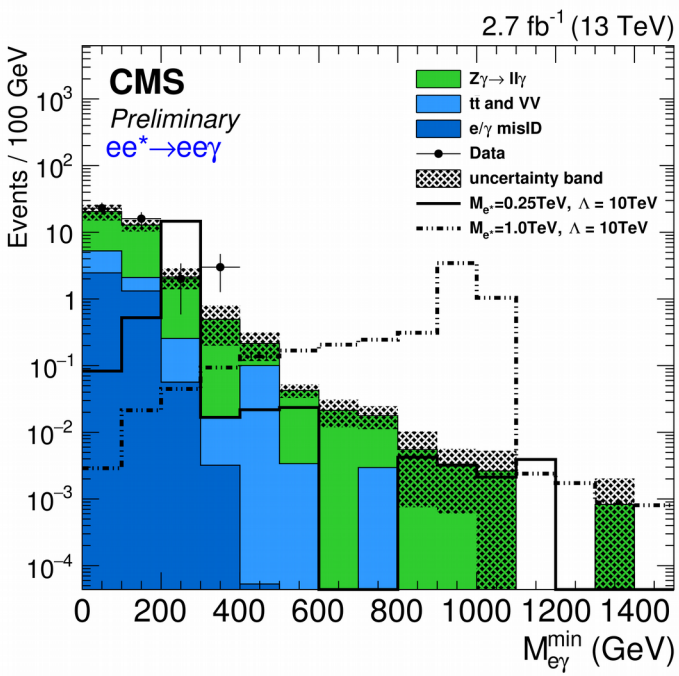
- Looking for heavy excited leptons decaying to e/μ and a photon.
- Select events with 2 same flavor lepton with (p_T> 35 GeV) and a photon in the barrel (p_T>35 GeV).
- Backgrounds:
  - Prompt lepton and photon backgrounds Zγ, ttbar γ, VVγ , estimated using MC samples.
  - Fake e or γ backgrounds, estimated using data driven techniques.

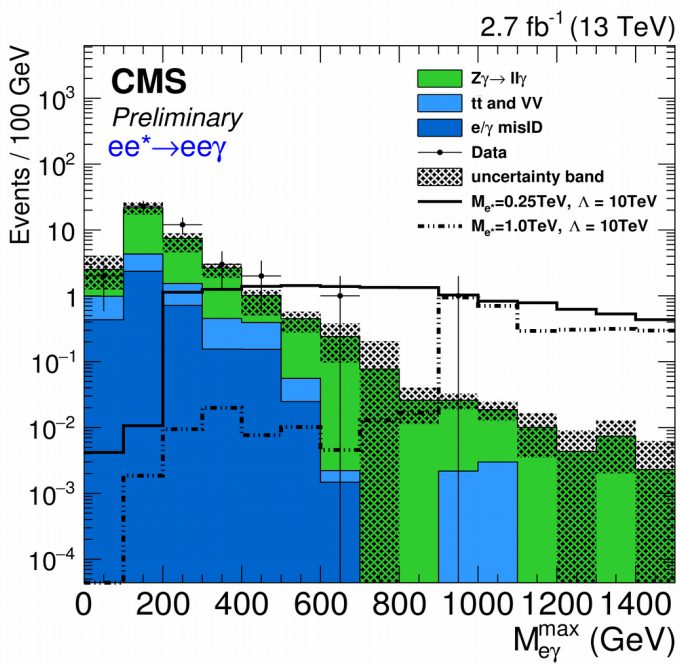
2.7 fb^{-1} 2015 Data
CMS-PAS-EXO-16-009

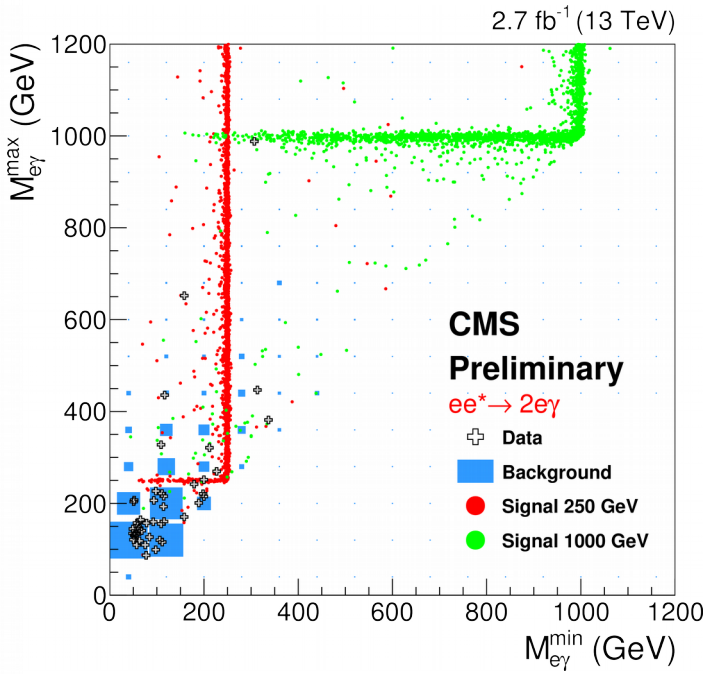


Strategy

- Two invariant mass are formed using each leptons once with photon.
- Excited lepton signal is expected to be at high mass values.
- Select ℓ^* mass dependent, L shaped window on max and min mass.



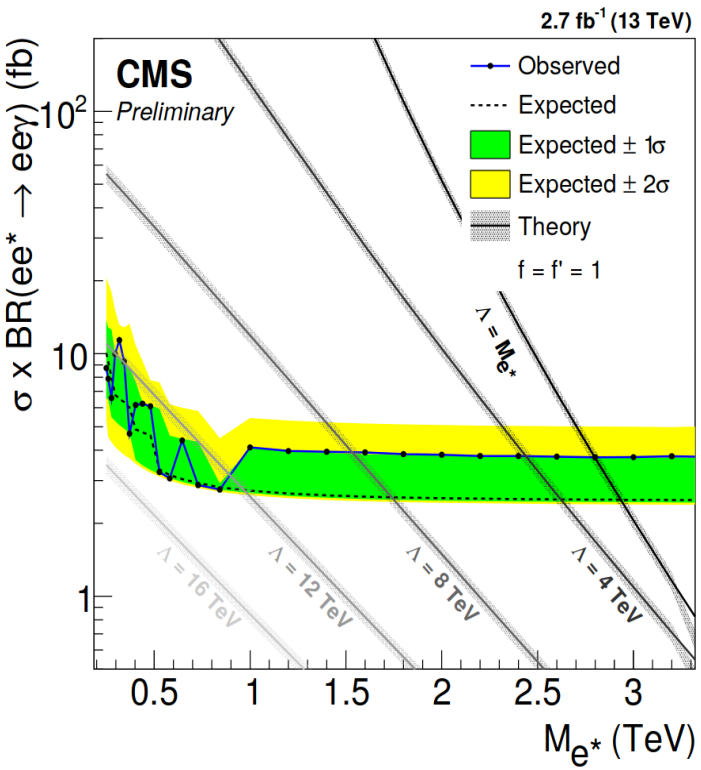


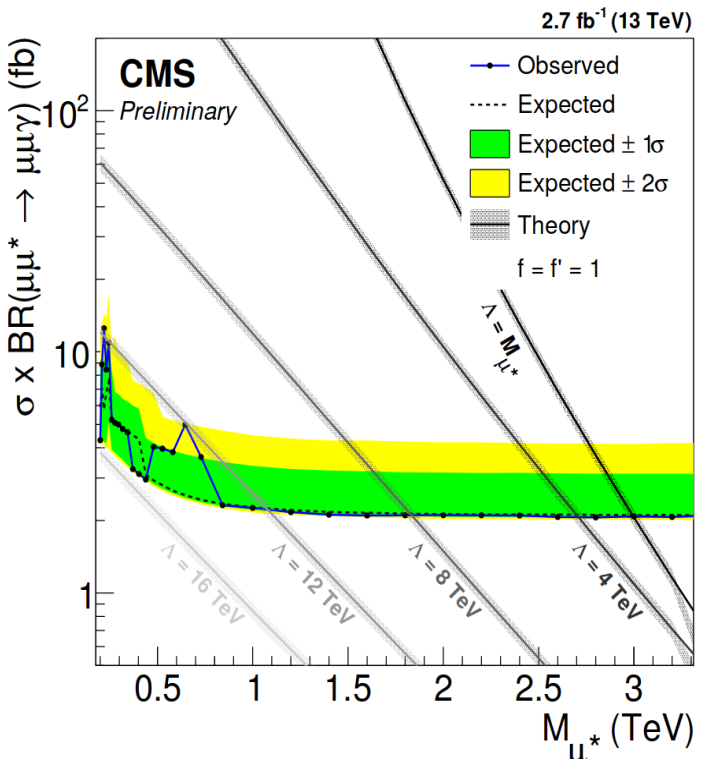


Interpretation

- No significant excess is seen.
- Interpret results as limits on excited lepton mass and compositeness scale.

Λ (TeV)	e* mass (TeV)	μ* mass (TeV)
e*/μ*	2.8	3

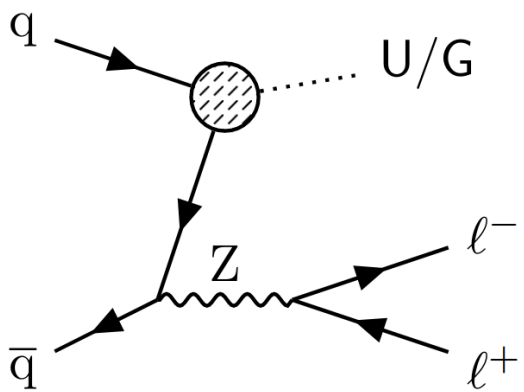




New physics with ($Z \rightarrow \ell^+\ell^-$) + MET($p_T^{Miss}$)

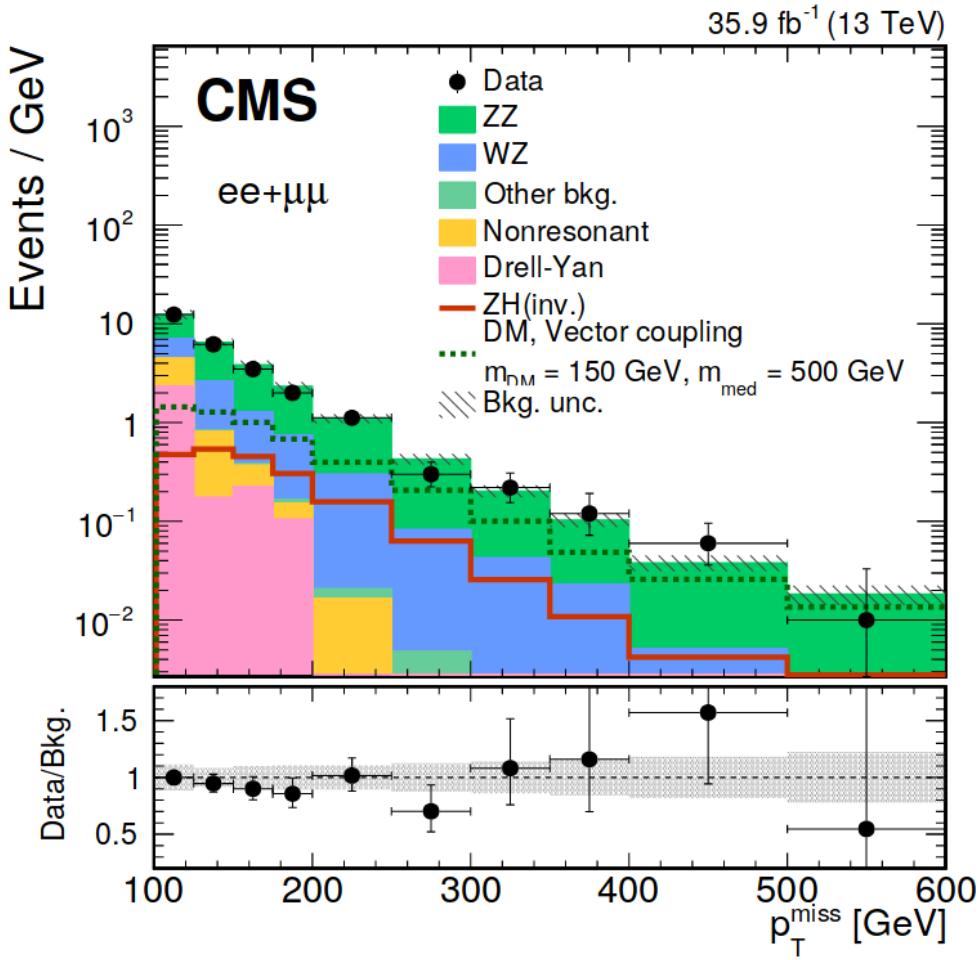
- Signature: 2 OSSF electrons or muons + missing transverse energy.
- Electron(Muon) p_T> 25/20(20/20) GeV, p_T^{Miss}>100 GeV
- Could be used to probe a variety of BSM physics
  - Large extra dimensions. (ADD)
  - Dark matter models.
  - BSM higgs coupling through ZH associate production.
- Backgrounds:
  - ZZ(2ℓ2υ), WZ(3ℓυ) when W lepton is lost.
  - Non resonant backgrounds from WW(ℓυℓυ), or top production.
  - Drell-Yan + mis-measured p_T^{Miss}.

35.9 fb^{-1} 2016 Data
arXiv:1711.00431

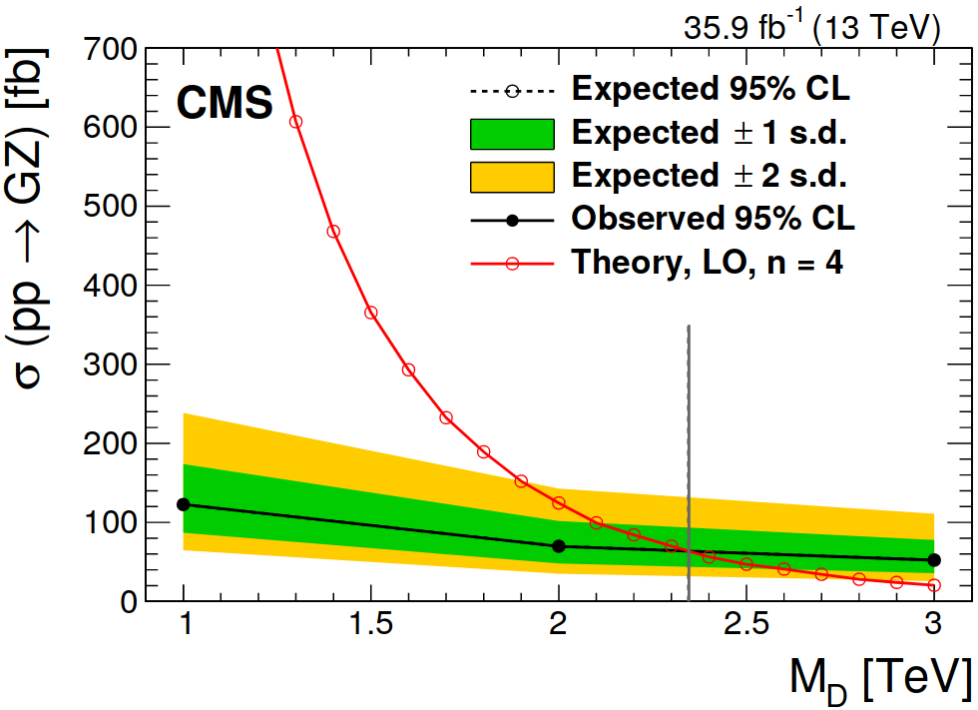


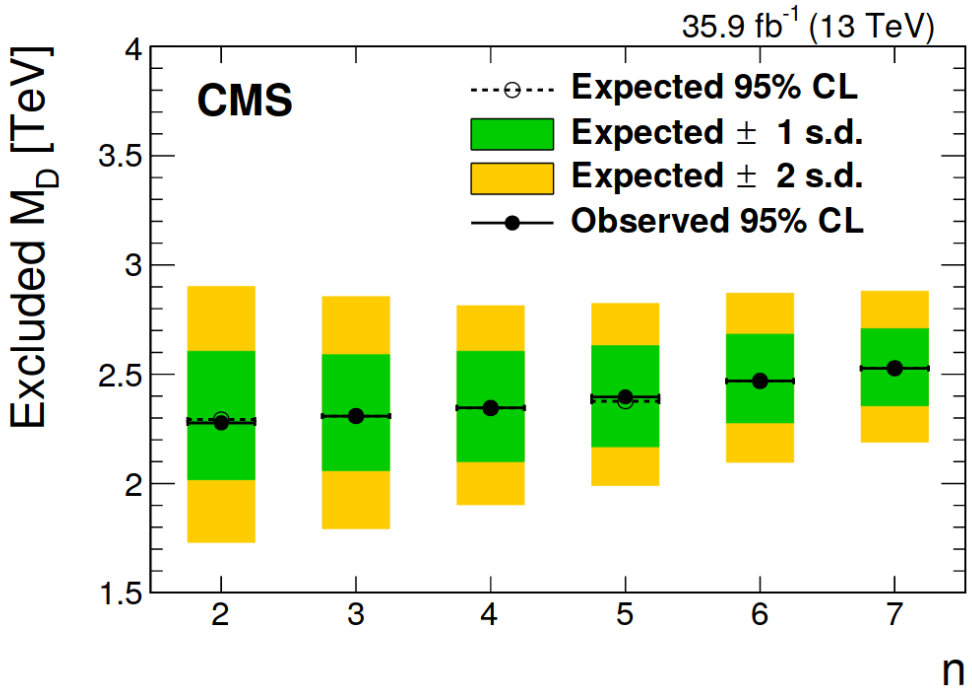
Strategy

- Looking for an excess of events in the missing transverse energy distribution.
- No significant excess over backgrounds predictions from SM.
- Results are used to constrain BSM physics.



Interpretation



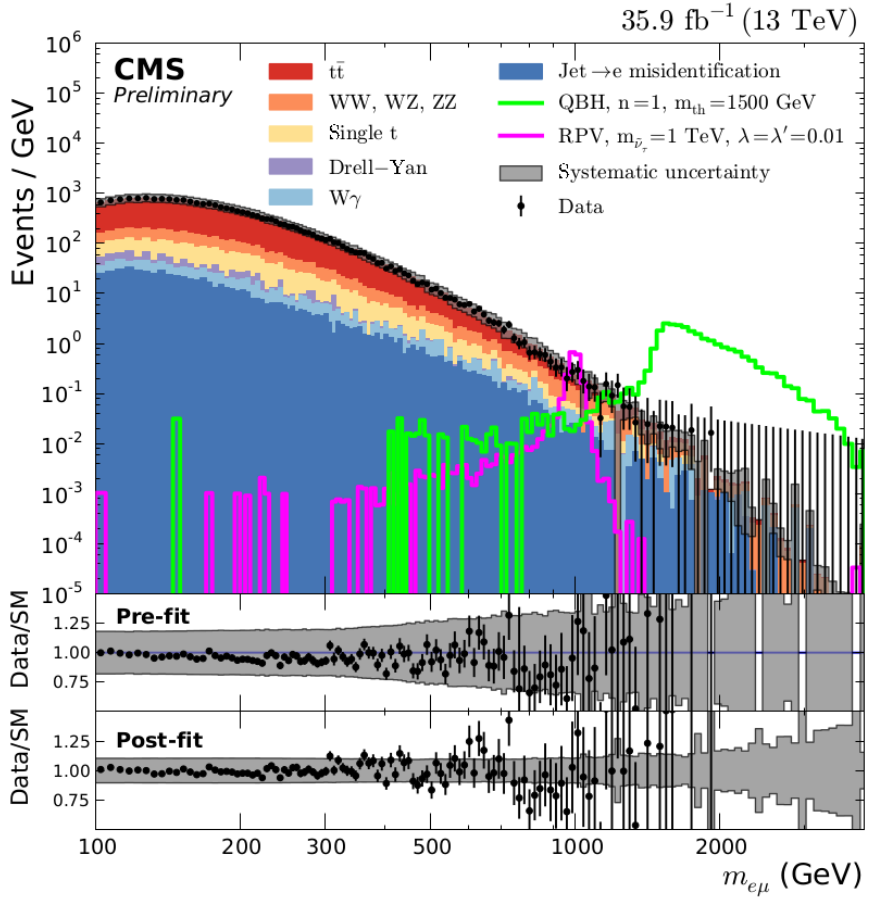


The exclusion of M_D ranges between 2.3 and 2.5 TeV for n between 2 and 7.

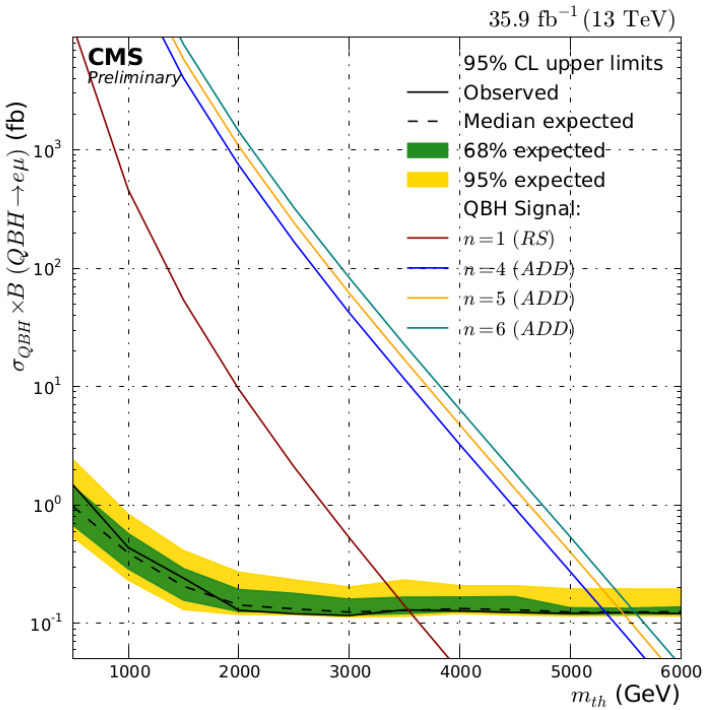
Quantum Black holes in e μ final state.

35.9 fb^{-1} 2016 Data
EXO-16-058

- Looking for excess of events in the e μ invariant mass distribution.
- No significant excess; interpreted as limits on M_{th} for the number of extra dimensions.



Λ (TeV)	m_{th} (TeV)
1	3.6
4	5.4



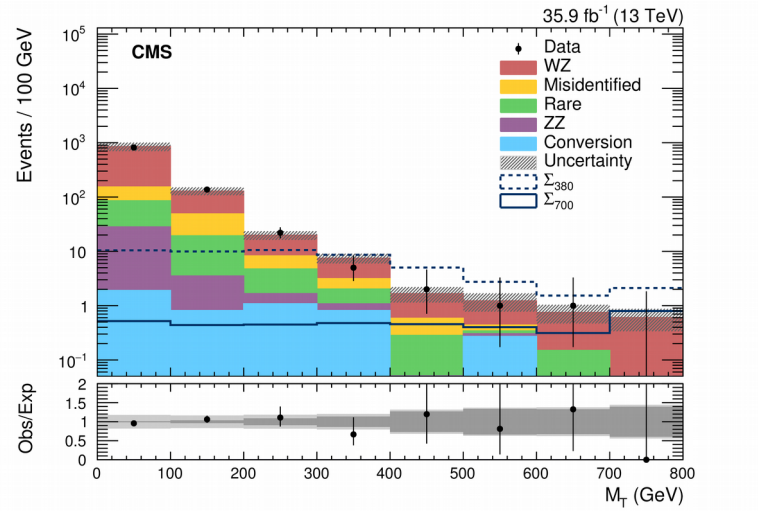
Summary & Outlook

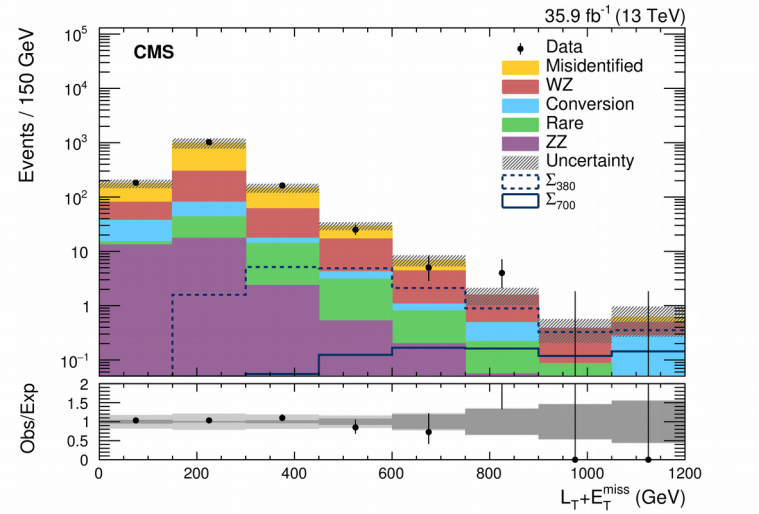
- Searches for non-resonant new physics in final states with leptons and photons are presented.
  - Heavy type-III Seesaw fermions.
  - Excited leptons.
  - Large extra dimensions.
  - Quantum black holes.
- No significant excess is observed.
  - Stringent limits are set on varity of BSM models.
- http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html
- Lot more data to come from LHC.

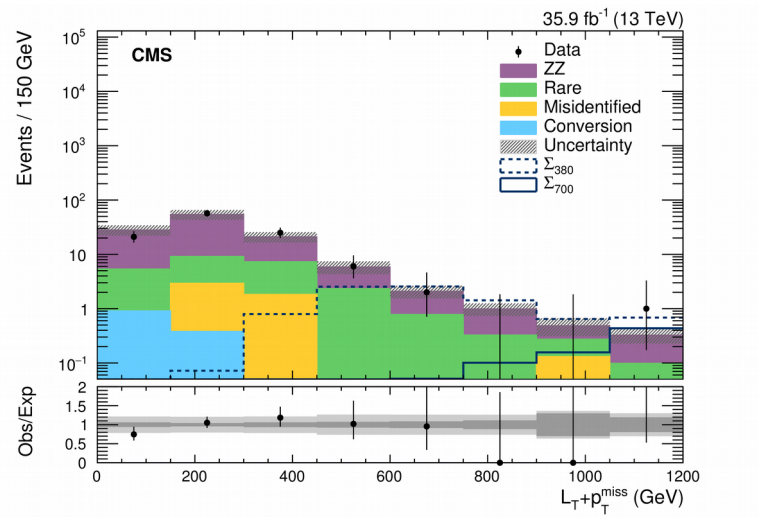
Future data may hold surprises !!!

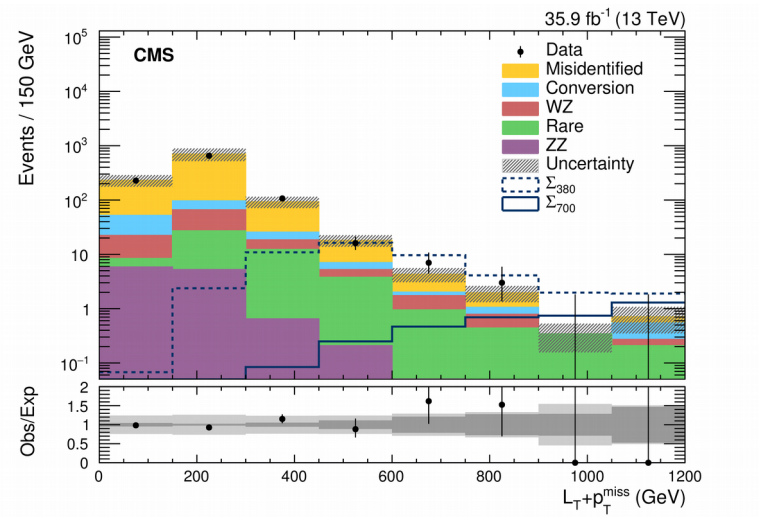
Additional Material

Type-III seesaw





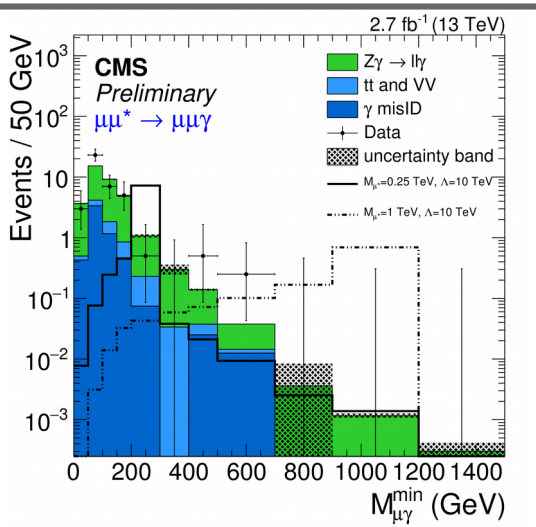


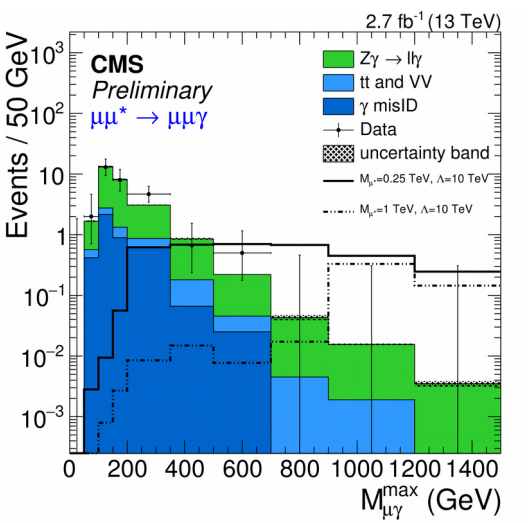


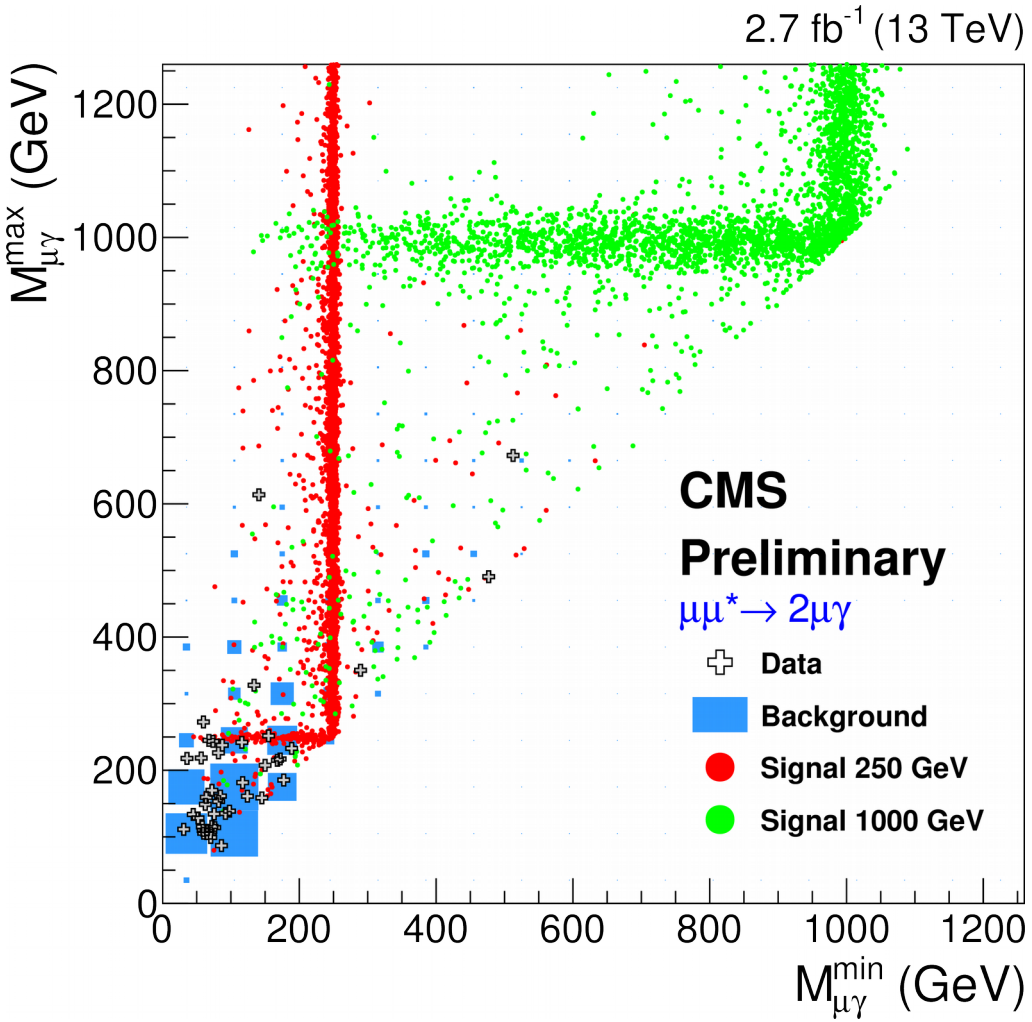
Type-III seesaw

Signal Region	Discriminating variable							
	$L_T + p_T^{miss}$ (0-150 GeV)		$L_T + p_T^{miss}$ (150-300 GeV)		$L_T + p_T^{miss}$ (300-450 GeV)		$L_T + p_T^{miss}$ (450-600 GeV)	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
L3BelowZ	183	177±32	1022	990±210	163	148±28	25	29.4±4.9
L3AboveZ	313	260±56	1038	930±160	246	235±34	59	60.8±8.1
L3OSSF0	228	232±56	654	710±180	107	93±22	16	18.1±4.4
L4OSSF1	2	6.2±1.8	18	28.2±5.5	14	10.5±3.5	6	4.3±1.6
L4OSSF2	21	28.2±6.1	57	54±11	25	21.1±4.6	6	5.9±1.5
	$L_T + p_T^{miss}$ (600-750 GeV)		$L_T + p_T^{miss}$ (750-900 GeV)		$L_T + p_T^{miss}$ (900-1050 GeV)		$L_T + p_T^{miss}$ ($>$ 1050 GeV)	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
L3BelowZ	5	6.9±1.6	4	1.57±0.50	0	0.38±0.17	0	0.61±0.34
L3AboveZ	16	20.9±2.7	6	6.88±1.17	3	2.78±0.65	3	3.58±0.73
L3OSSF0	7	4.3±1.2	3	1.97±0.65	0	0.34±0.18	0	0.71±0.36
L4OSSF1	1	1.39±0.55	1	0.41±0.24	0	0.78±0.65	0	0.08±0.05
L4OSSF2	2	2.09±0.56	0	0.99±0.27	0	0.48±0.18	1	0.32±0.10
	M_T (0-100 GeV)		M_T (100-200 GeV)		M_T (200-300 GeV)		M_T (300-400 GeV)	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
L3OnZ	816	840±150	137	115±20	22	19.1±3.4	5	7.2±1.5
	M_T (400-500 GeV)		M_T (500-600 GeV)		M_T (600-700 GeV)		M_T ($>$ 700 GeV)	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
L3OnZ	2	1.67±0.51	1	1.24±0.44	1	0.77±0.28	0	0.63±0.27

Excited leptons







Mono Z + MET

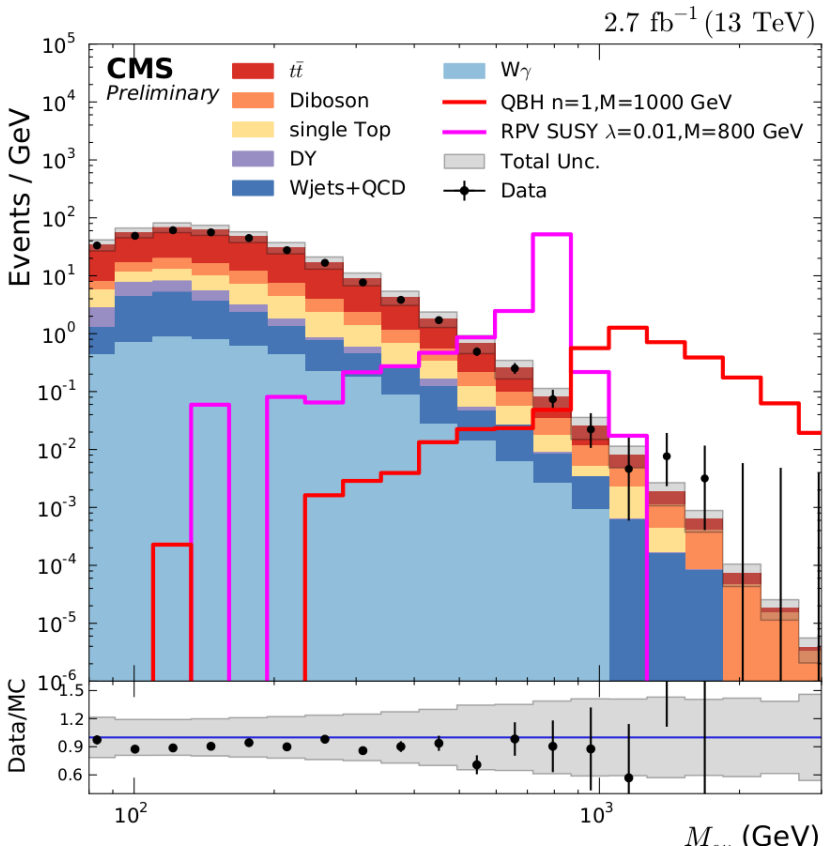
Selection	Requirement	Reject
N_ℓ	$=2$	WZ, VVV
p_{T}^{ℓ}	$>25/20$ GeV for electrons >20 GeV for muons	QCD
Z boson mass requirement	$\lvert m_{\ell\ell} - m_{\mathrm{Z}} \rvert < 15\ (30)$ GeV	WW, top quark
Jet counting	≤ 1 jet with $p_{\mathrm{T}}^{j} > 30$ GeV	$\mathrm{Z}/\gamma^* \to \ell\ell$, top quark, VVV
$p_{\mathrm{T}}^{\ell\ell}$	>60 GeV	$\mathrm{Z}/\gamma^* \to \ell\ell$
b tagging veto	CSVv2 < 0.8484	Top quark, VVV
τ lepton veto	0 τ_{h} cand. with $p_{\mathrm{T}}^{\tau} > 18$ GeV	WZ
$p_{\mathrm{T}}^{\mathrm{miss}}$	>100 GeV (130 GeV, training only)	$\mathrm{Z}/\gamma^* \to \ell\ell$, WW, top quark
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\,j}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})$	>0.5 rad	$\mathrm{Z}/\gamma^* \to \ell\ell$, WZ
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\,\ell\ell}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})$	>2.6 rad (omitted)	$\mathrm{Z}/\gamma^* \to \ell\ell$
$\lvert p_{\mathrm{T}}^{\mathrm{miss}} - p_{\mathrm{T}}^{\ell\ell} \rvert / p_{\mathrm{T}}^{\ell\ell}$	<0.4 (omitted)	$\mathrm{Z}/\gamma^* \to \ell\ell$
$\Delta R_{\ell\ell}$	<1.8 (omitted)	WW, top quark

Mono Z + MET

p_T^{miss} bin (GeV)	Observed events	Total background prediction SR+CR fit	Total background prediction CR-only fit
$100 \leq p_T^{miss} < 125$	311	300 ± 18	256 ± 32
$125 \leq p_T^{miss} < 150$	155	155.0 ± 7.0	150 ± 12
$150 \leq p_T^{miss} < 175$	87	90.8 ± 4.6	86.9 ± 8.4
$175 \leq p_T^{miss} < 200$	50	54.7 ± 3.1	52.7 ± 5.3
$200 \leq p_T^{miss} < 250$	56	51.3 ± 2.9	50.2 ± 4.9
$250 \leq p_T^{miss} < 300$	15	19.7 ± 1.4	19.4 ± 2.2
$300 \leq p_T^{miss} < 350$	11	9.64 ± 0.80	9.4 ± 1.2
$350 \leq p_T^{miss} < 400$	6	4.73 ± 0.47	4.58 ± 0.66
$400 \leq p_T^{miss} < 500$	6	3.44 ± 0.39	3.31 ± 0.54
$p_T^{miss} \geq 500$	1	1.63 ± 0.24	1.57 ± 0.33

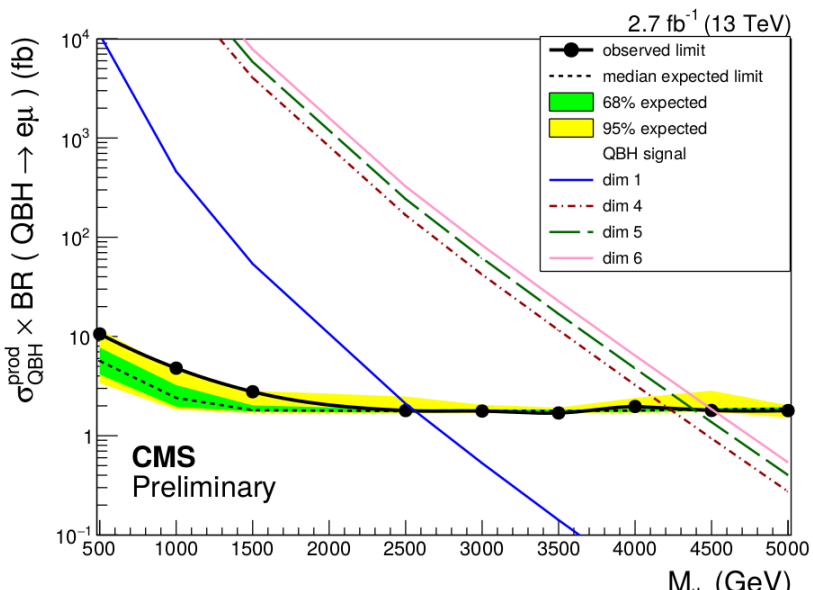
Quantum Black holes in e μ final state.

2.7 fb^{-1} 2015 data
CMS-PAS-EXO-16-001

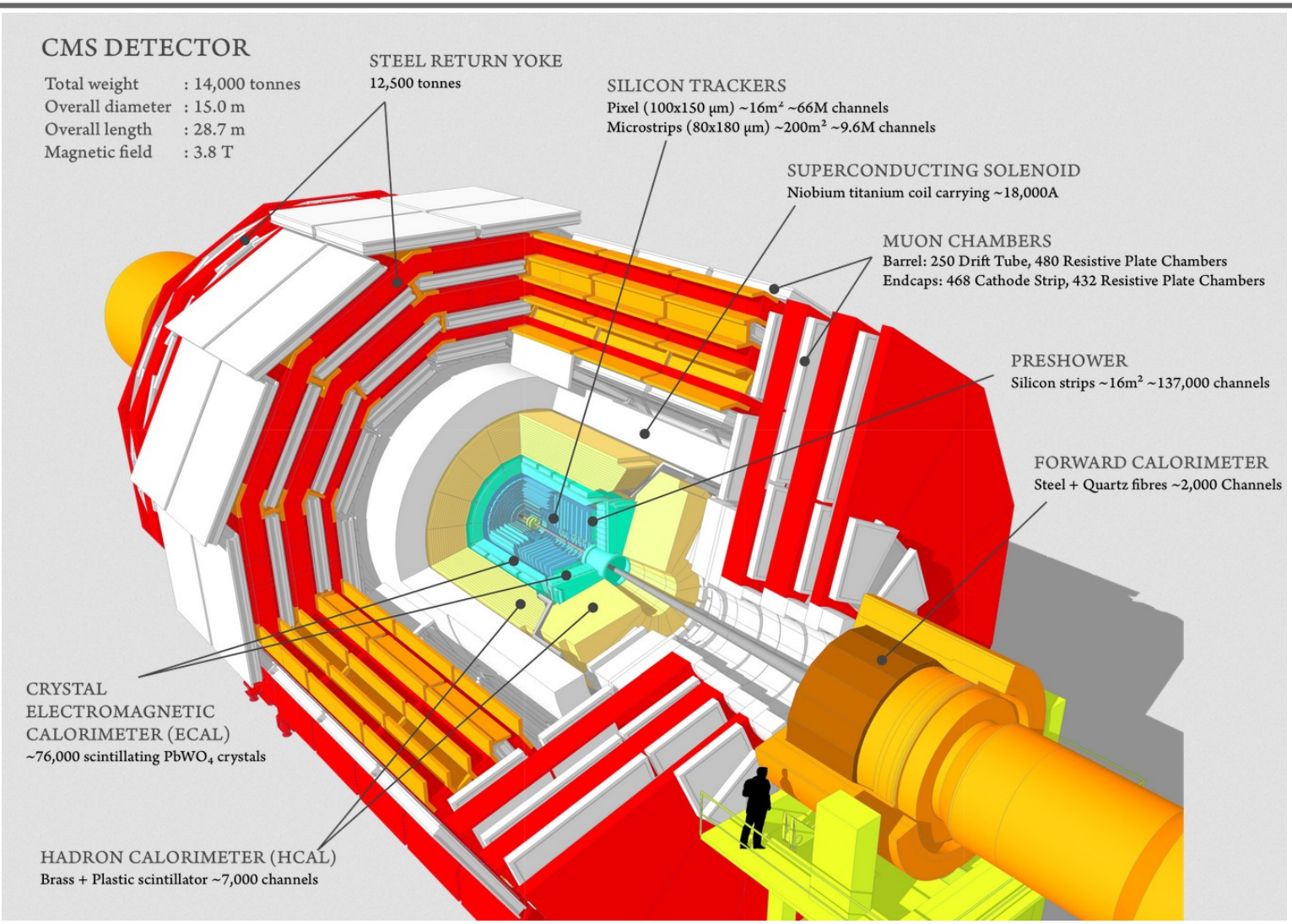


- Looking for excess of events in the e/μ invariant mass distribution.
- No significant excess; interpreted as limits on M_{th} for the number of extra dimensions.

Λ (TeV)	m_{th}
1	2.5
4	4.2



CMS Detector Overview



Multi-purpose detector:

- Charged particle tracker
- ECAL
- HCAL
- Magnet
- Muon Chambers

Use information from all detector components to reconstruct particles passing through.