Searches for BSM physics in dilepton, multilepton and lepton + MET final states at CMS

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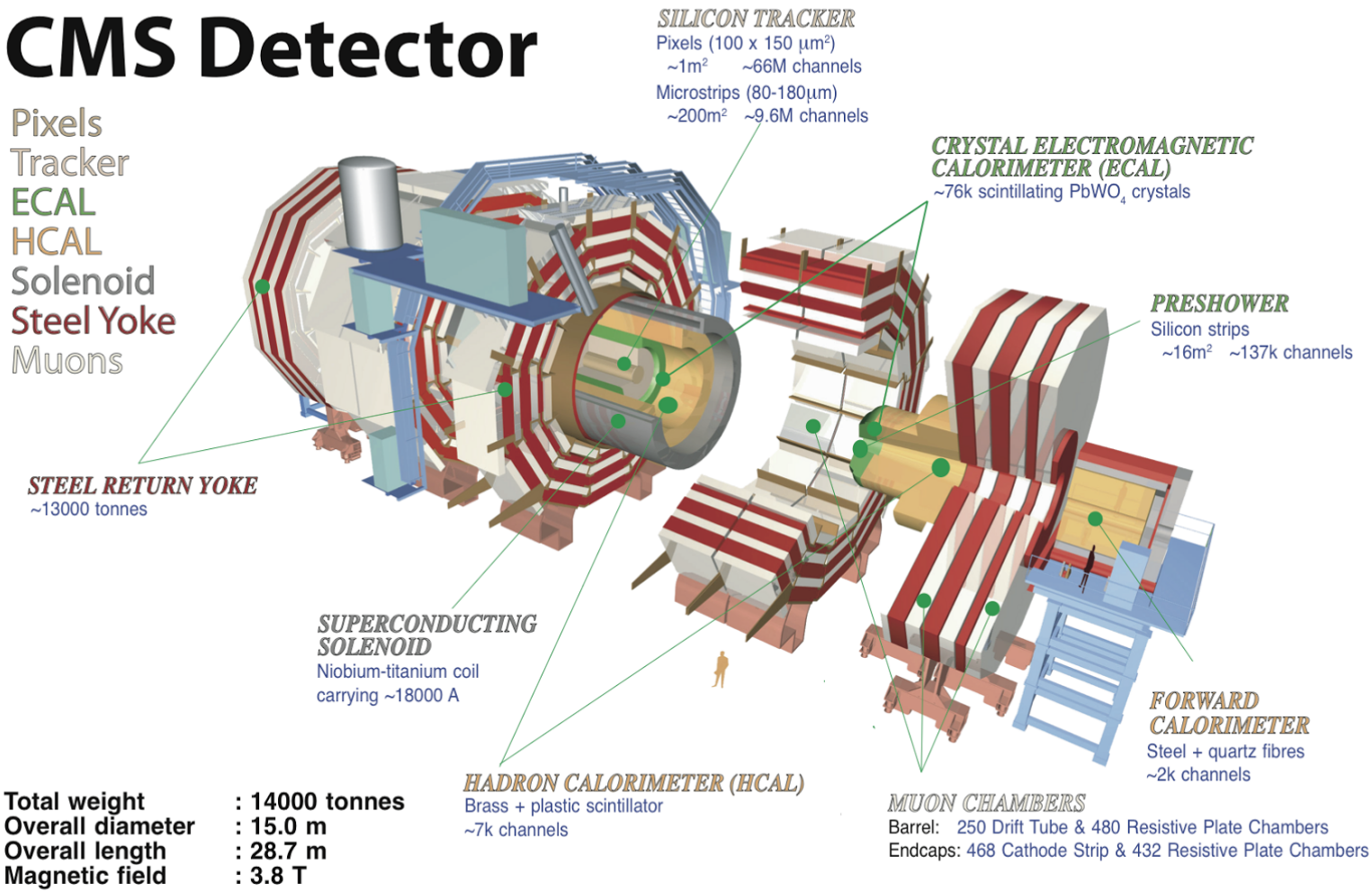
Lisa Benato on behalf of CMS collaboration

Summary

Outlook

- Many BSM physics models predict the existence of **new heavy particles** decaying into dilepton, multilepton and lepton + neutrino final states
  - **leptons** = e, μ
  - **neutrinos** = revealed as MET (missing transverse energy)
- The leptonic final states are historically channels of discovery and precision measurements: very clean signatures
- Dealing with **high energetic leptons** implies careful studies of the objects and their properties
- Models predict very **small branching ratio** for leptonic decays:
  - accurate evaluation of backgrounds
  - often statistical uncertainties dominate
- We present here the results obtained from the LHC Run 2 data collected in 2015 at CMS
  - going up to $\sqrt{s} = 13$ TeV makes the parton luminosities of processes $q\bar{q} \to X$ increase substantially, especially at high mass region

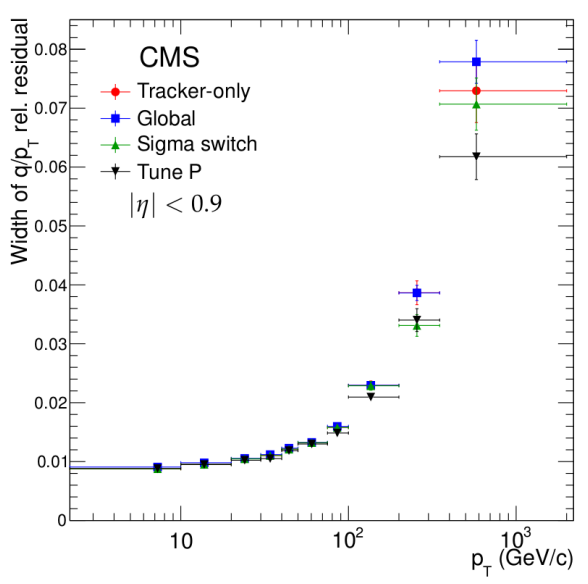
CMS experiment



High energy objects

Muons

- **High-p_T muon reconstruction algorithms** have been exploited: combine informations from outer muon chambers and inner tracker; improvement in muon identification efficiency
- Main issues: p_T measurement strongly influenced by **alignment** and **showering** inside the detector $\rightarrow$ p_T **resolution decreases** at higher values
- Many studies performed on cosmic muons:



Electrons

- Particle flow candidates: reconstructed using informations from all the sub-detectors
- Dedicated **selections for High-p_T electrons**
- **Energy and p_T resolution** approx. **constant** at increasing energy

Missing transverse energy

- E_T^{miss} magnitude is influenced by all the other objects, including jets, and their corrections

- **Isolation** requirements of the leptons, to reduce backgrounds coming from objects misidentified as ℓ

Main benchmark models explored

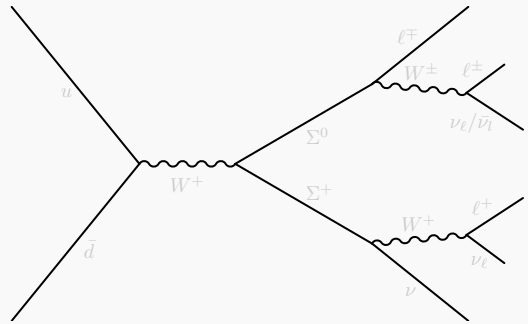
Sequential standard model and super string inspired models

- Enlarging SM gauge symmetry group → once broken, new residual groups → new spin-1 heavy bosons
- W'_{SSM} and Z'_{SSM}: heavy spin-1 W and Z (same couplings to leptons)
- Super string inspired Z'_{ψ} from $E(6)$ breaking

Seesaw type III mechanism

Heavy particles accounting for neutrino masses and their smallness

- Fermionic triplet (Σ^0, $\Sigma^{\pm}$) coupled to leptons and Higgs
- Multi-lepton final states (at least 3)
- Decay rate of Σ to $\ell \propto \frac{V_\ell}{\sqrt{|V_e|^2+|V_\mu|^2+|V_\tau|^2}}$
- Flavour democratic scenario same V_ℓ for e, μ, τ



Quantum black holes

Fundamental Planck scale at TeV: production of microscopic black holes decaying into couple of particles

- Spin-0, colourless, neutral QBH with lepton flavour violation (final state $e\mu$)
- Interpretation depending on extra-dimensions n ($n = 1$: Randall-Sundrum, $n \geq 2$ ADD) and QBH mass threshold M_{th}

$Z' \to \ell^+\ell^-$ (CMS PAS EXO-15-005)

Analysis strategy

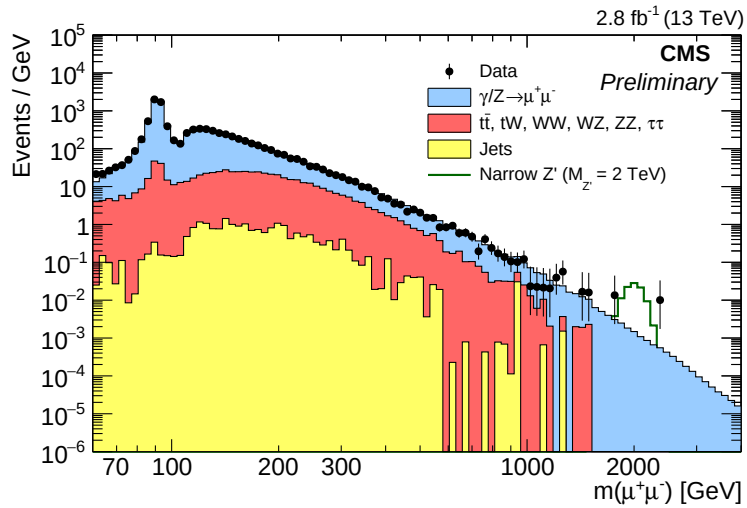
- Invariant mass of the heaviest $\ell^+\ell^-$ pair, after all ℓ selections

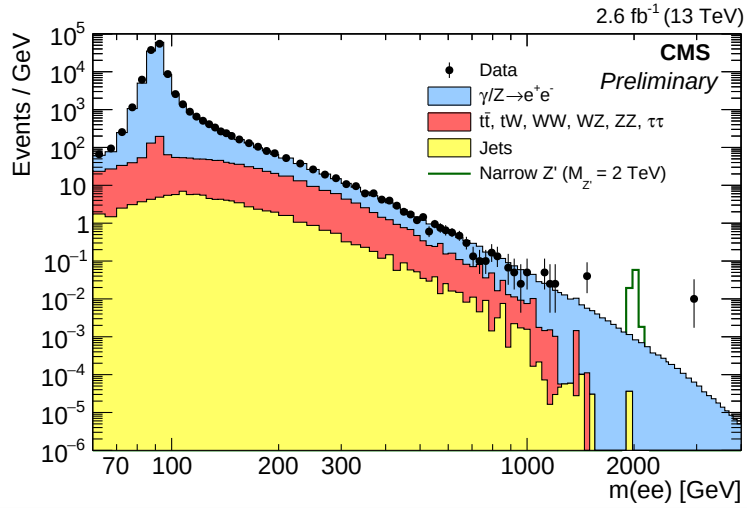
Background predictions

- Drell-Yan process $Z/\gamma^* \to \ell^+\ell^-$: predicted via MC samples
- Prompt leptons ($t\bar{t}$, tW, WW, WZ, ZZ): predicted via MC samples, validation on data in $e\mu$ region
- Non-prompt leptons (jets misidentified as leptons): predictions data-driven
- Cosmic muons: suppressed with cut on impact parameter w.r.t. primary vertex

- Highest mass event: 2.9 TeV in ee
- 0.036 ± 0.009 ee events expected above 2.8 TeV (1 seen): local p-value 0.036

Event yield



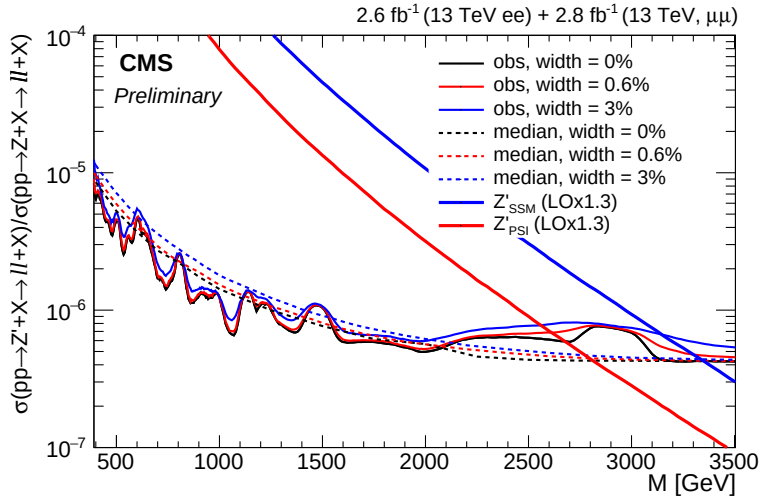


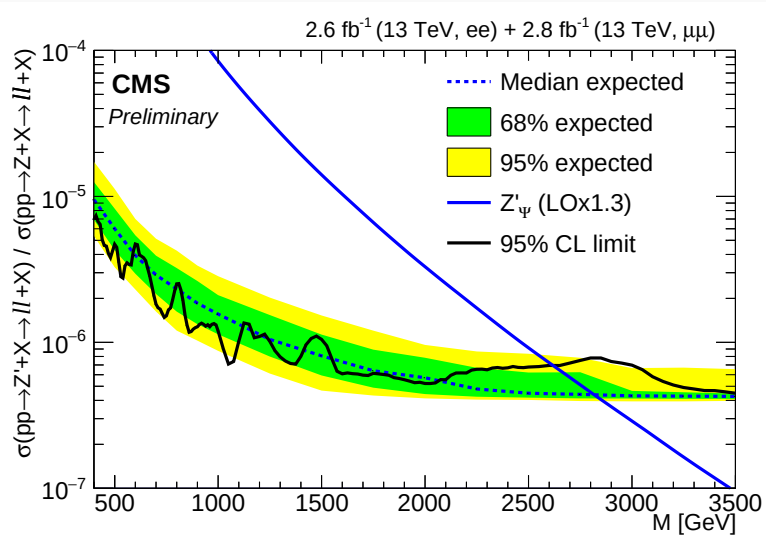
$Z' \to \ell^+\ell^-$ (CMS PAS EXO-15-005)

Limits extraction and interpretations

- Limits at 95% CL on $\frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z/\gamma^* + X \to \ell\ell + X)}$, Bayesian unbinned likelihood
- Main uncertainties:
  - Signal: lepton identification (e 6%, μ 7%)
  - Background: PDF uncertainties (20% at 3 TeV)
  - Mass scale uncertainty (e 1%, μ 3%)
- Signal modelled as convolution Breit-Wigner and Gaussian, narrow width approximation explored ($\Gamma_{Z'_\Psi} = 0.6\%, \Gamma_{Z'_{SSM}} = 3\%$)
  - only on-shell region of the resonance is considered, interference is strongly model-dependent
- Observed limits (final $\Gamma = 0.6\%$):

Channel	Z'_Ψ	Z'_{SSM}
ee	2.40 TeV	2.75 TeV
$\mu\mu$	2.40 TeV	3.00 TeV
comb.	2.60 TeV	3.15 TeV





$W' \to \ell\nu$ (CMS PAS EXO-15-006)

Analysis strategy

- Discriminant variable is the transverse invariant mass:

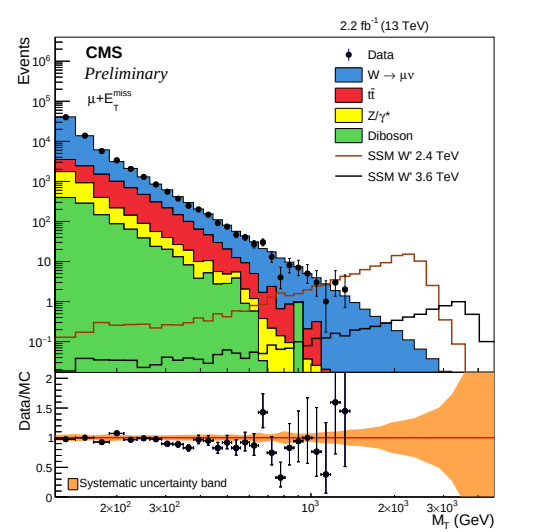
$$M_T = \sqrt{2p_T^{\ell} E_T^{miss} \left(1 - \cos\left[\Delta\phi(\vec{p_T^{\ell}}, \vec{p_T^{miss}})\right]\right)}$$

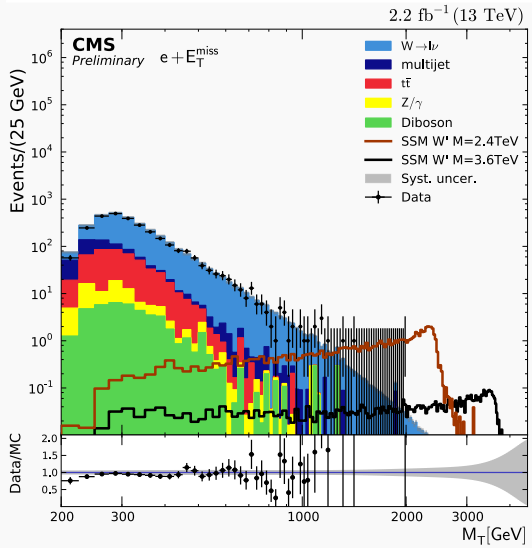
- Back-to-back topology:
  - $|\Delta\phi(\vec{p_T^{\ell}}, \vec{p_T^{miss}})| > 2.5$
  - $0.4 < p_T/E_T^{miss} < 1.5$

Background predictions

- $W \to \ell\nu$: predicted from MC
- Secondary: Drell-Yan, $t\bar{t}$, single t, WW, WZ, ZZ from simulation
- QCD multijet: estimated from data
- Cosmic muons: suppressed with cut on impact parameter w.r.t. primary vertex

Event yield



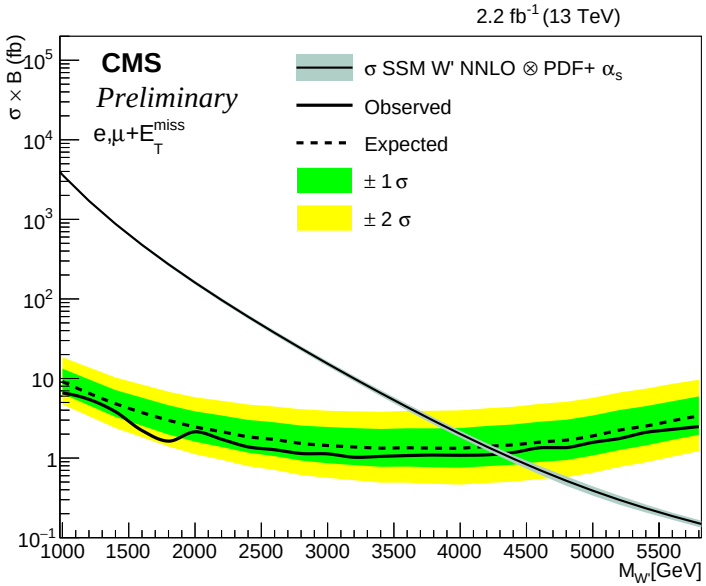


$W' \to \ell\nu$ (CMS PAS EXO-15-006)

Limits extraction and interpretations

- Limits at 95% CL on $\sigma(pp \to W' + X \to \ell\nu + X)$, CL_s method
- Limits provided in region > 1 TeV, where Run 2 data are more sensitive due to the increased $\sqrt{s}$ and cross section
- Main uncertainties:
  - Muon channel: muon momentum scale and p_T resolution, that propagate to E_T^{miss}
  - Electron channel: mainly affected by PDF uncertainties at high M_T
- Observed limits:

Channel	W'_{SSM}
e	3.8 TeV
μ	4.0 TeV
comb.	4.4 TeV



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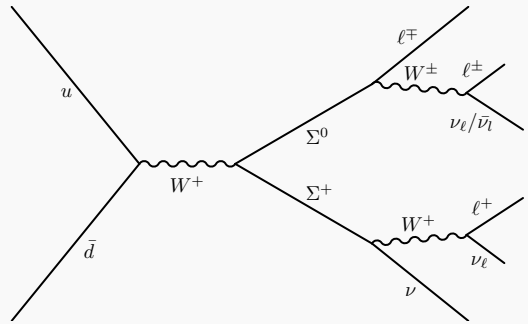
- Enlarging SM gauge symmetry group $\rightarrow$ once broken, new residual groups $\rightarrow$ new spin-1 heavy bosons
- W'_{SSM} and Z'_{SSM}: heavy spin-1 W and Z (same couplings to leptons)
- Super string inspired Z'_{ψ} from $E(6)$ breaking

Seesaw type III mechanism

Heavy particles accounting for neutrino masses and their smallness

- Fermionic triplet (Σ^0, $\Sigma^{\pm}$) coupled to leptons and Higgs
- Multi-lepton final states (at least 3)
- Decay rate of Σ to $\ell \propto \frac{V_\ell}{\sqrt{|V_e|^2+|V_\mu|^2+|V_\tau|^2}}$
- Flavour democratic scenario same V_ℓ for e, μ, τ



Quantum black holes

Fundamental Planck scale at TeV: production of microscopic black holes decaying into couple of particles

- Spin-0, colourless, neutral QBH with lepton flavour violation (final state $e\mu$)
- Interpretation depending on extra-dimensions n ($n = 1$: Randall-Sundrum, $n \geq 2$ ADD) and QBH mass threshold M_{th}

Seesaw type III (CMS PAS EXO-16-002)

Analysis strategy

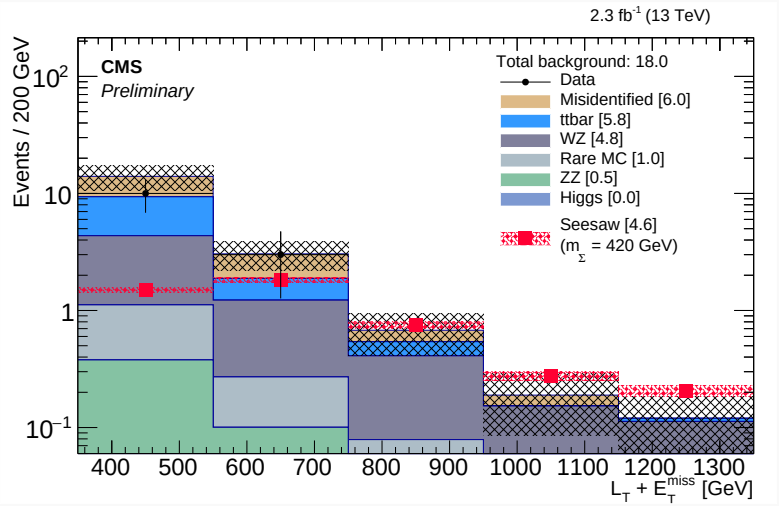
- 27 signal channels grouped in categories depending on the number of OSSF pairs (0,1,2) and the $m_{\ell^+\ell^-}$ (on-above m_Z)
- Efficient cut to reject backgrounds: $L_T + E_T^{miss} > 350$ GeV, scalar sum of lepton p_T

Background predictions

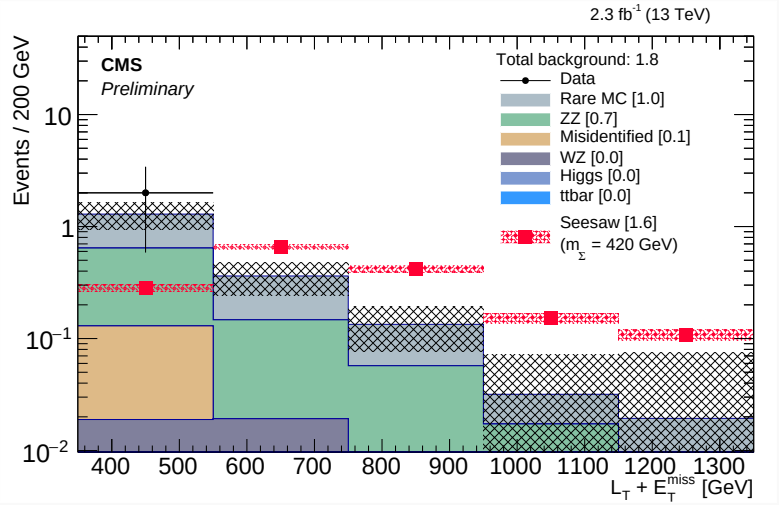
- $WZ \to \ell\ell\ell$: on MC, validated on data
- Leptonic $t\bar{t}$ + misidentified lepton: kinematics from MC, misidentification rates measured in data control region
- $Z \to \ell\ell$ + misidentified lepton in jet: data-driven prediction
- $ZZ \to 4\ell$: on MC, validated on data
- Rare processes ($t\bar{t}Z$, $t\bar{t}W$) and Higgs ($H \to 4\ell$): on MC

Event yield

1 OSSF pair, 3 leptons, $m_{\ell^+\ell^-}$ above-Z:



At least 1 OSSF pairs, 4 leptons:

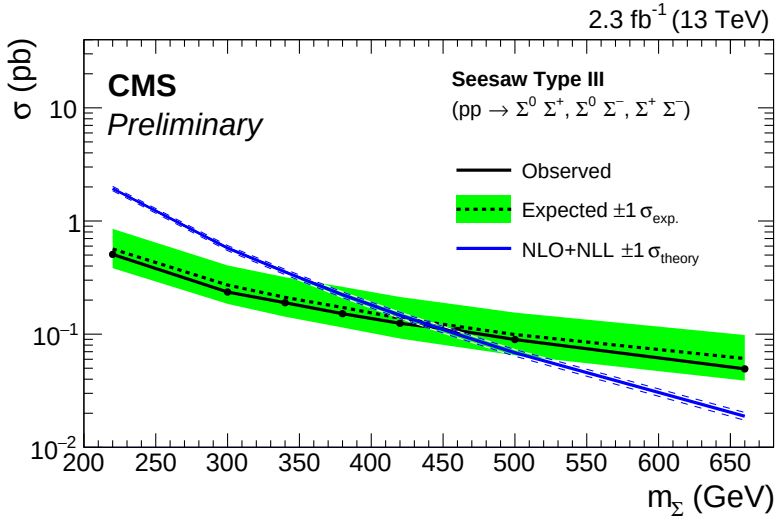


Seesaw type III (CMS PAS EXO-16-002)

Limits extraction and interpretations

- Limits at 95% CL on $\sigma(pp \to (\Sigma^0\Sigma^+, \Sigma^0\Sigma^-, \Sigma^+\Sigma^-) + X)$, CL_s method
- Assumptions: degenerate m_Σ, flavour democratic scenario $V_e = V_\mu = V_\tau = 10^{-6}$
- p-value for all channels is 0.93
- Uncertainties dominated by statistics
  - Systematics small, due to PDF, renormalization and factorization uncertainties related to E_T^{miss} range in dominant WZ background
- Observed limit:

Channel	m_Σ
comb.	440 GeV



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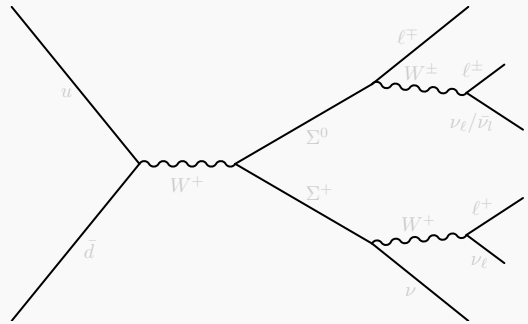

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- Interpretation depending on extra-dimensions n ($n = 1$: Randall-Sundrum, $n \geq 2$ ADD) and QBH mass threshold M_{th}

Quantum black holes: $e\mu$ resonances (CMS PAS EXO-16-001)

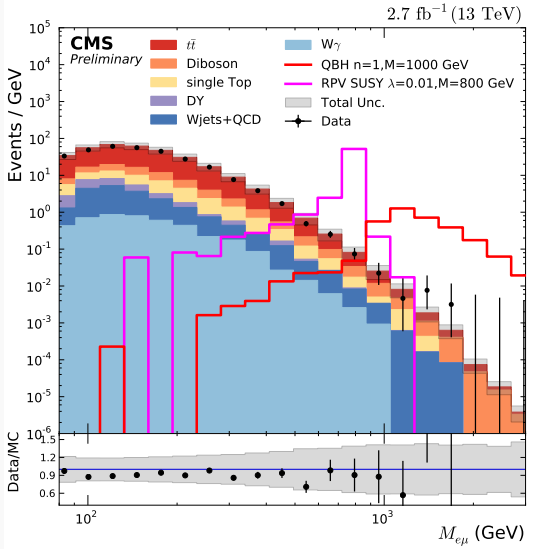
Analysis strategy

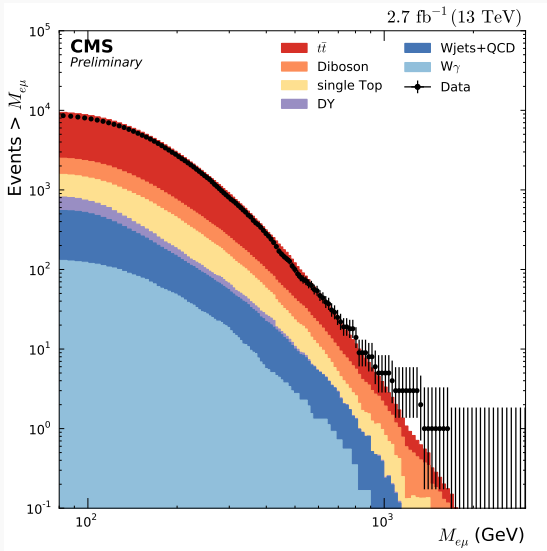
- Invariant mass $e\mu$ distribution
- Most energetic $e\mu$ pair not required to be OS
- Electrons close ($\Delta R < 0.1$) to muons producing bremsstrahlung are rejected (avoid misidentification)

Background predictions

- Prompt isolated leptons: $t\bar{t}$, WW, WZ, ZZ, single t, DY estimated from MC samples
- Non prompt backgrounds (misidentified jets, mainly in W+jets process): data-driven prediction

Event yield



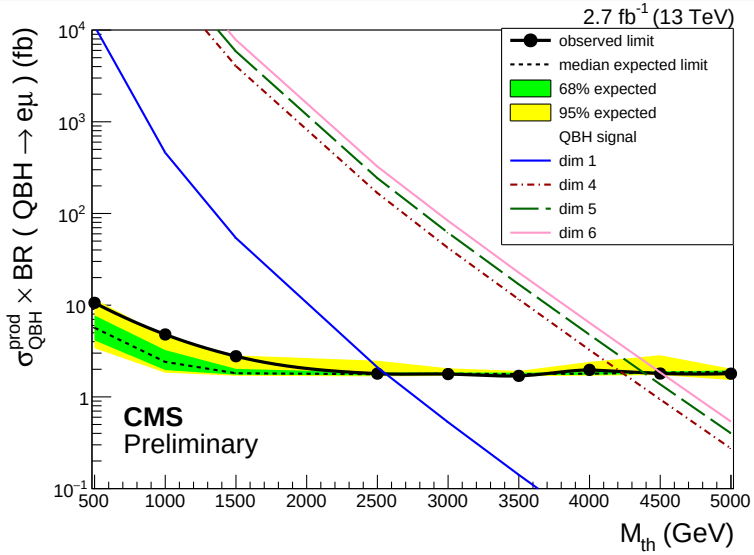


Quantum black holes: $e\mu$ resonances (CMS PAS EXO-16-001)

Limits extraction and interpretations

- Limits at 95% CL on $\sigma(pp \to QBH + X \to e\mu + X)$, Bayesian binned likelihood
- Non-resonant signal: broad shape smeared by detector resolution and sharper edge at M_{th}
- Main uncertainties:
  - muon momentum scale uncertainties (30% at 3 TeV)
  - $t\bar{t}$ cross section (5%) and $e\mu$ shape modelling (affects the background yield of up to 26% at $M_{e\mu} = 1$ TeV; 30% at $M_{e\mu} = 3$ TeV)
- Observed limit:

n	M_{th}
1 (RS)	2.5 TeV
4 (ADD)	4.2 TeV
5 (ADD)	4.3 TeV
6 (ADD)	4.5 TeV



Conclusions

We are in the "search era" of LHC, a unique once-in-a-lifetime chance!

- BSM models predict the existence of new heavy particles decaying into leptons and MET
- Many searches have been performed during 2015 LHC Run 2 at CMS detector
- The increased $\sqrt{s}$ allows improvements w.r.t. Run 1, pushing the exclusion limits to higher masses of the resonances
- These searches are being repeated in 2016 data: more luminosity is expected and more interesting results are coming soon

Thanks for your attention!

Backup slides

Limits from Run 1

$Z' \to \ell^+\ell^-$

Model	mass
Z'_{SSM}	2.90 TeV
Z'_{ψ}	2.57 TeV

Quantum black holes: $e\mu$ resonances

Model	mass
QBH n=0	1.99 TeV
QBH n=1 (RS)	2.36 TeV
QBH n=2	3.15 TeV
QBH n=3	3.34 TeV
QBH n=4	3.46 TeV

$W' \to \ell\nu$

Model	mass
W'_{SSM}	3.28 TeV

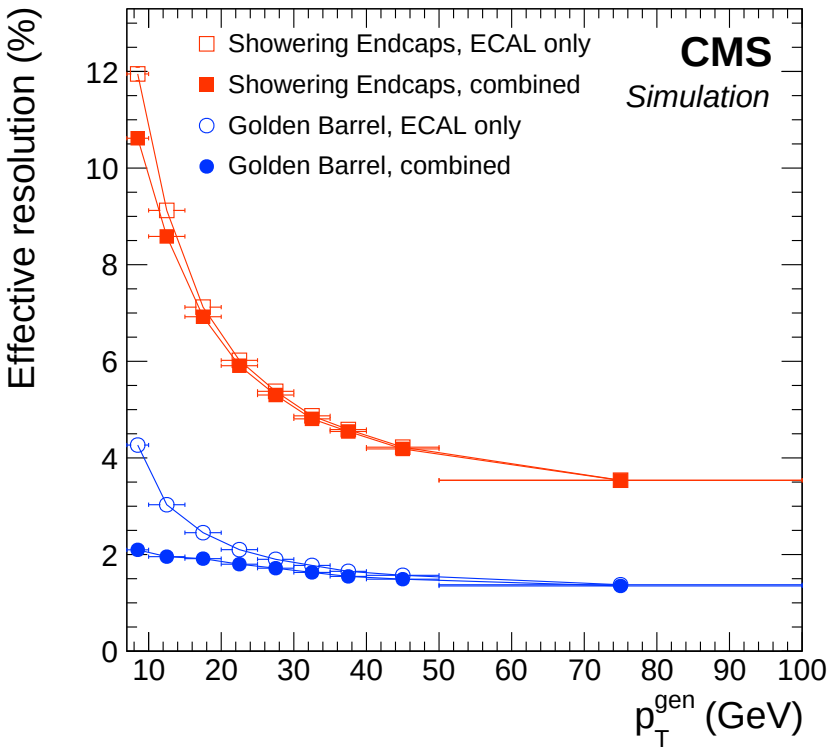
Seesaw type III mechanism

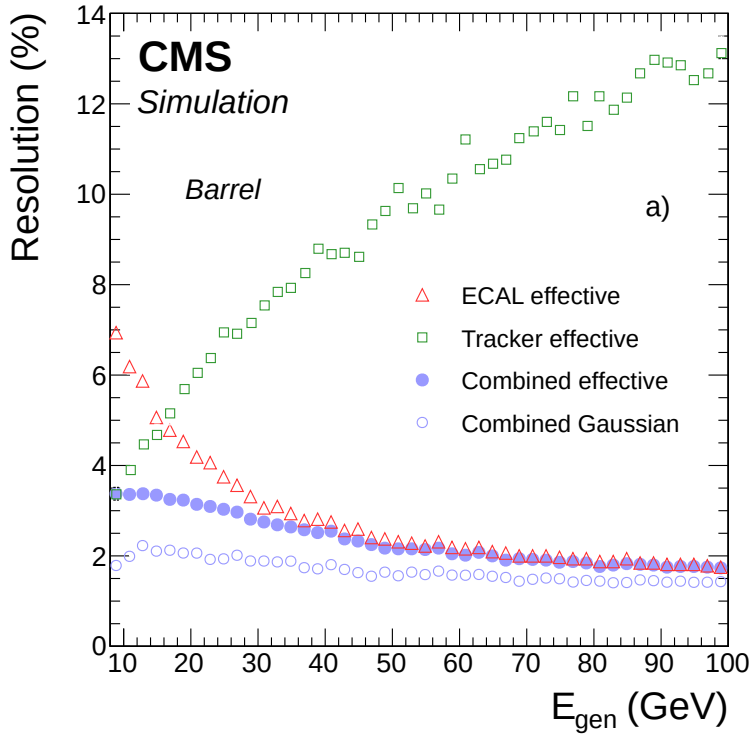
Important remarks on Run 1 analysis:

- the search was performed only in the 3ℓ final states
- every pair of OSSF leptons whose $m_{\ell^+\ell^-} \approx m_Z$ was vetoed
- decay channel via Higgs boson not considered
- different selections and different background evaluation strategy

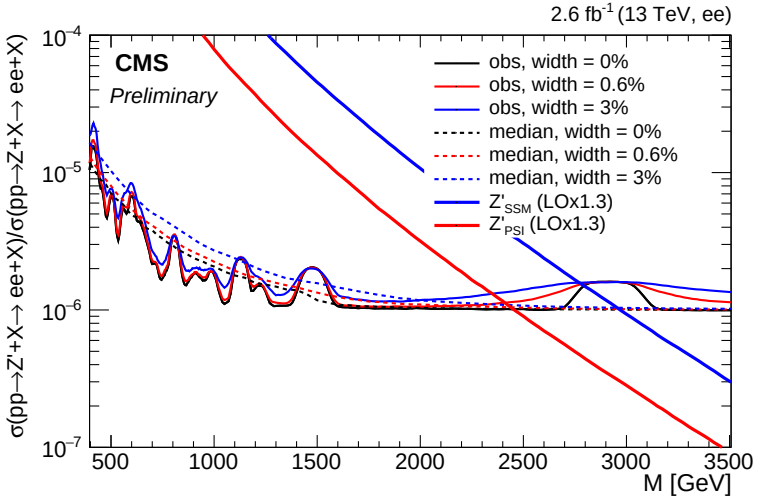
Model	mass
$(\Sigma^0, \Sigma^+, \Sigma^-)$	278 GeV

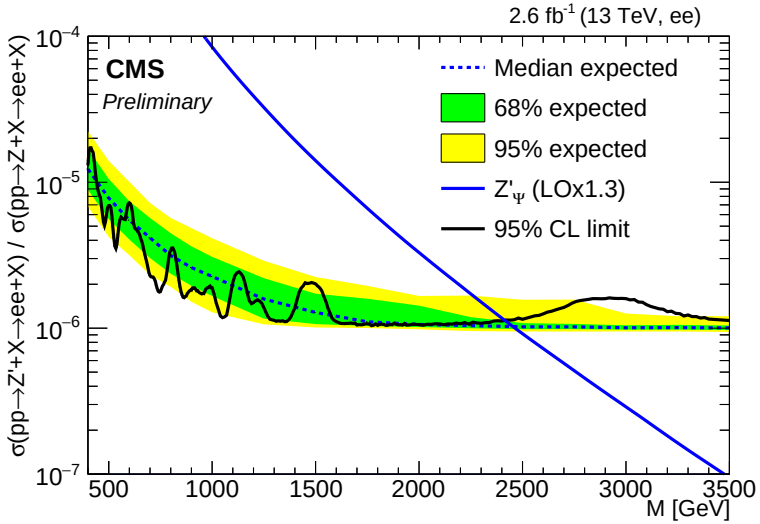
Electron p_T and energy resolution

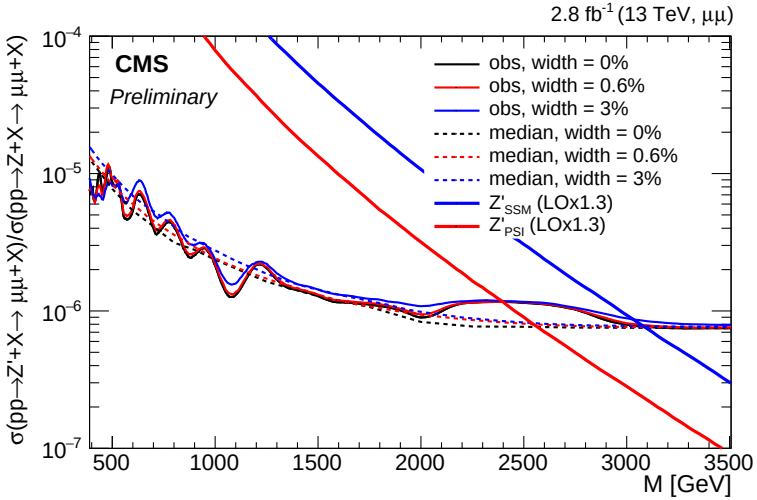


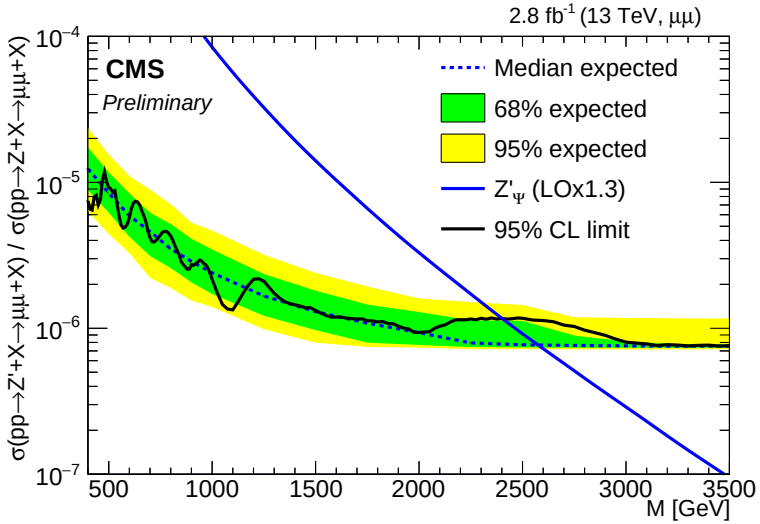


$Z' \to \ell^+\ell^-$

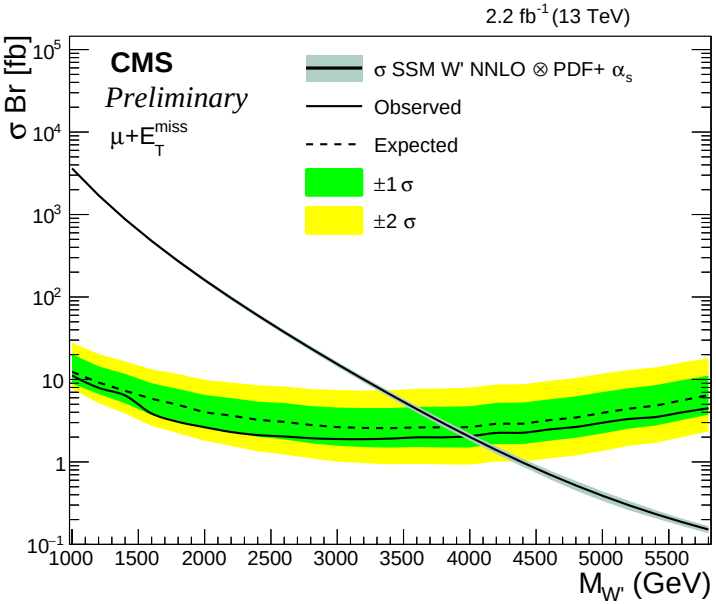

2.6 fb-1 (13 TeV, ee)
CMS
Preliminary
obs, width = 0%
obs, width = 0.6%
obs, width = 3%
median, width = 0%
median, width = 0.6%
median, width = 3%
Z'SSM (LOx1.3)
Z'PSI (LOx1.3)
σ(pp→Z'+X→ ee+X)/σ(pp→Z+X→ ee+X)
M [GeV]

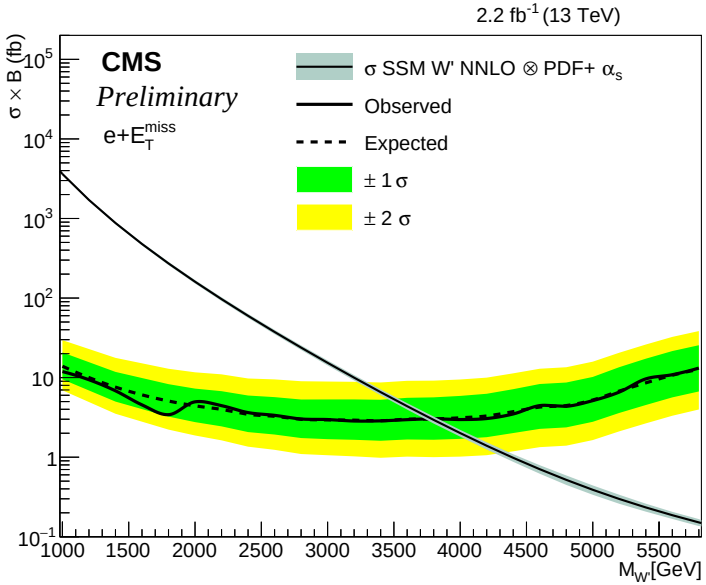

2.6 fb-1 (13 TeV, ee)
CMS
Preliminary
Median expected
68% expected
95% expected
Z'Ψ (LOx1.3)
95% CL limit
σ(pp→Z'+X→ee+X) / σ(pp→Z+X→ee+X)
M [GeV]


2.8 fb-1 (13 TeV, μμ)
CMS
Preliminary
obs, width = 0%
obs, width = 0.6%
obs, width = 3%
median, width = 0%
median, width = 0.6%
median, width = 3%
Z'SSM (LOx1.3)
Z'PSI (LOx1.3)
σ(pp→Z'+X→ μμ+X)/σ(pp→Z+X→ μμ+X)
M [GeV]


2.8 fb-1 (13 TeV, μμ)
CMS
Preliminary
Median expected
68% expected
95% expected
Z'Ψ (LOx1.3)
95% CL limit
σ(pp→Z'+X→μμ+X) / σ(pp→Z+X→μμ+X)
M [GeV]

$W' \to \ell\nu$

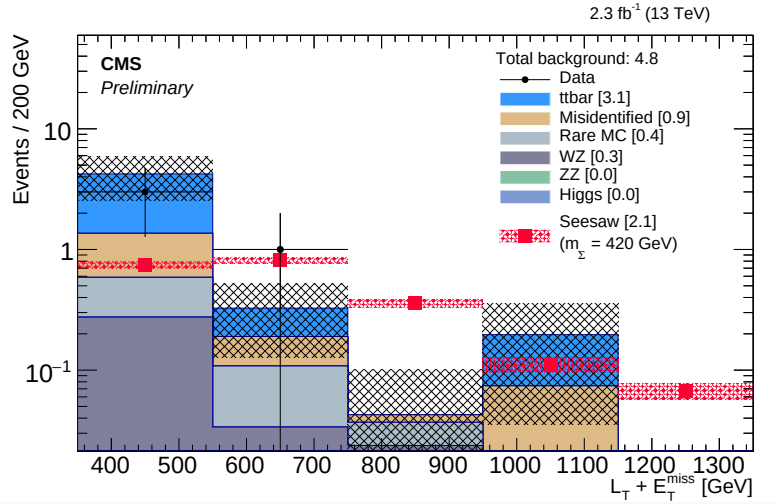

2.2 fb^{-1} (13 TeV)
CMS
Preliminary
μ+E$_T^{miss}$
σ SSM W' NNLO ⊗ PDF+ α$_s$
Observed
Expected
±1 σ
±2 σ
σ Br [fb]
M$_{W'}$ (GeV)


2.2 fb^{-1} (13 TeV)
CMS
Preliminary
e+E$_T^{miss}$
σ SSM W' NNLO ⊗ PDF+ α$_s$
Observed
Expected
± 1 σ
± 2 σ
σ × B (fb)
M$_{W'}$[GeV]

Seesaw type III mechanism

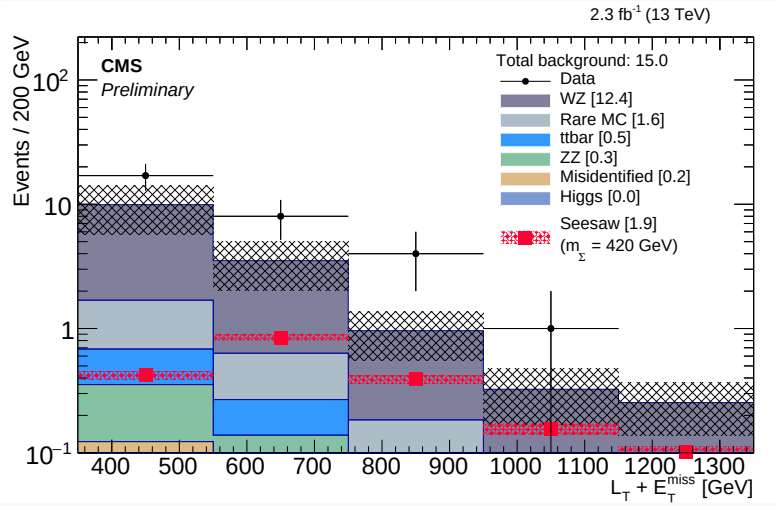
Event yield

0 OSSF pair, 3 leptons:



Event yield

1 OSSF pair, 3 leptons, $m_{\ell^+\ell^-}$ on-Z:



Quantum black holes: $e\mu$ resonances

Alternative R-parity violating SUSY interpretation: τ sneutrino