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

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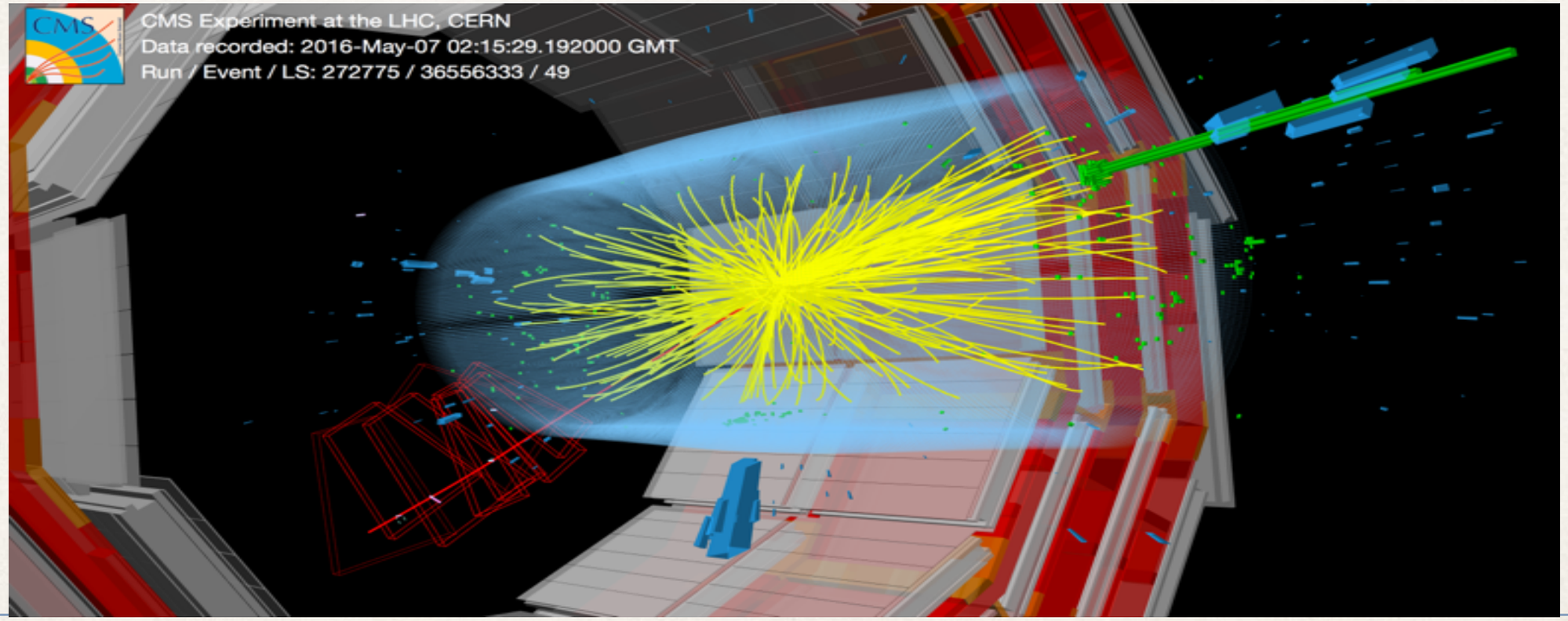
On behalf of the CMS collaboration



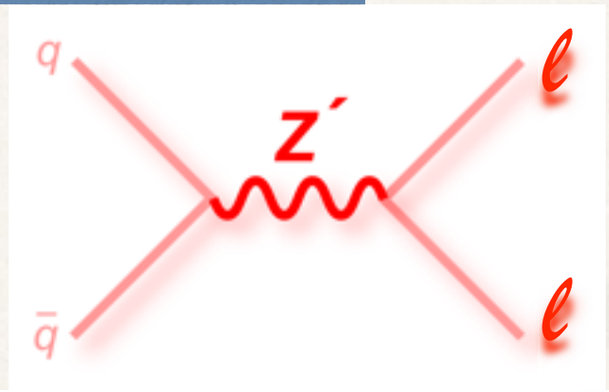
Date: 4th July, 2016

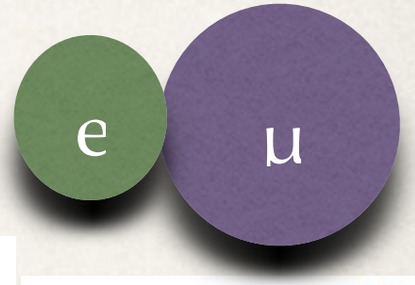
Search for new physics with leptons

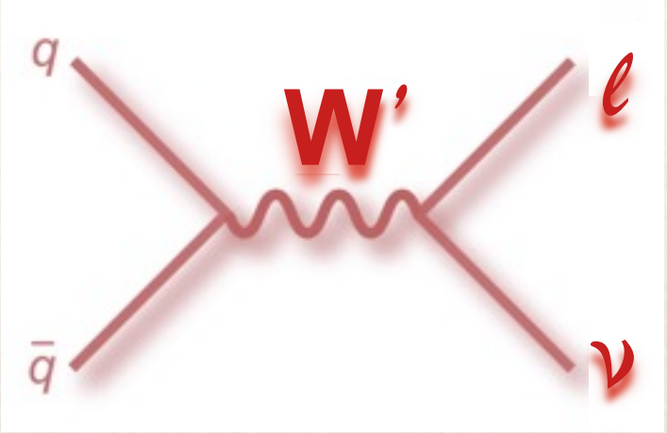
- Final states of leptons are clean probes of new physics in both SUSY and non-SUSY searches
- non-SUSY searches involving leptonic final states:
  - Search for Z' in dilepton events (EXO-15-005)
  - Search for W' in lepton+MET events (EXO-15-006)
  - Search for high-mass resonances and quantum black holes in the eμ final state (EXO-16-001)
  - Search for type-III seesaw mechanism in multilepton events (EXO-16-002)
  - Search for resonances in Z(ll)gamma events (EXO-16-019)
  - Search for pair production of second-generation scalar leptoquarks (EXO-16-007)
  - Search for heavy stable charged particles (EXO-15-010)

All the analyses shown are with 2015 data

covered in today's talk



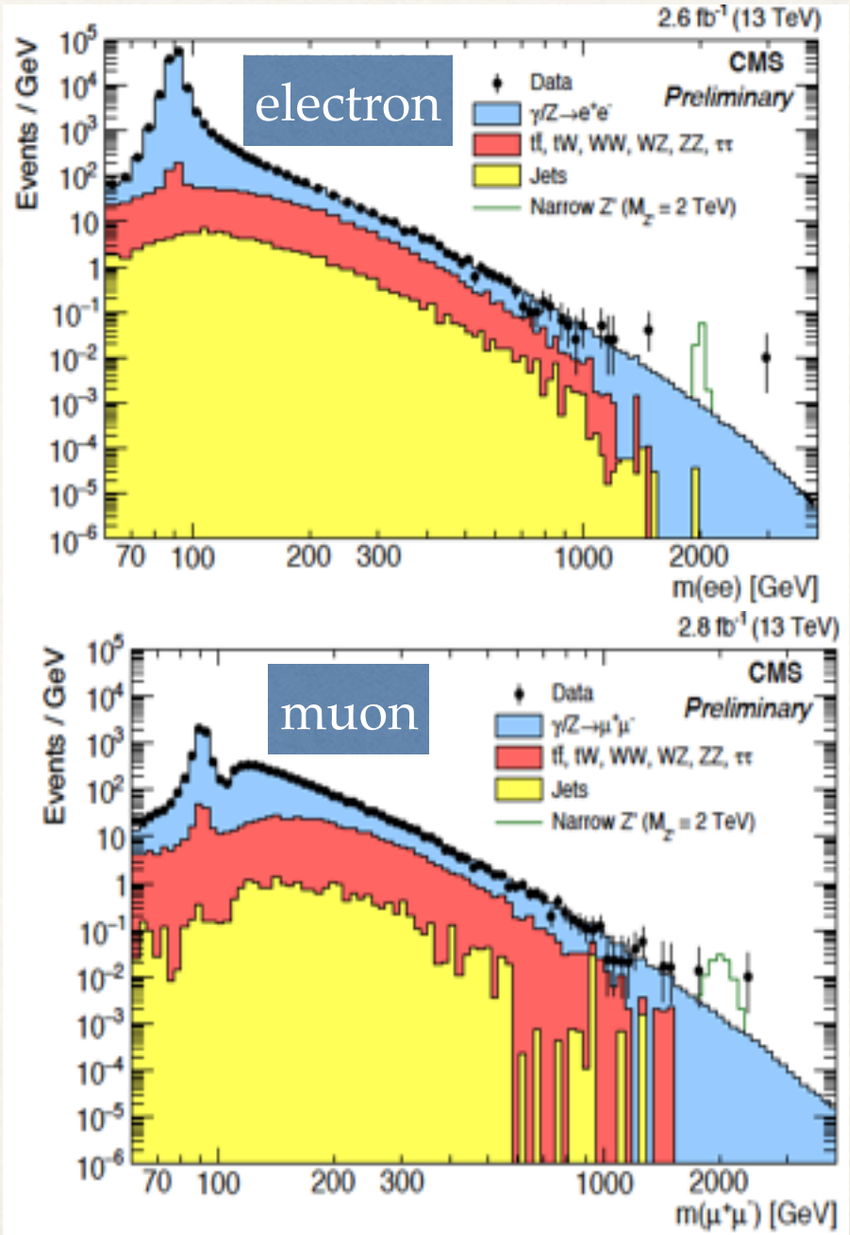




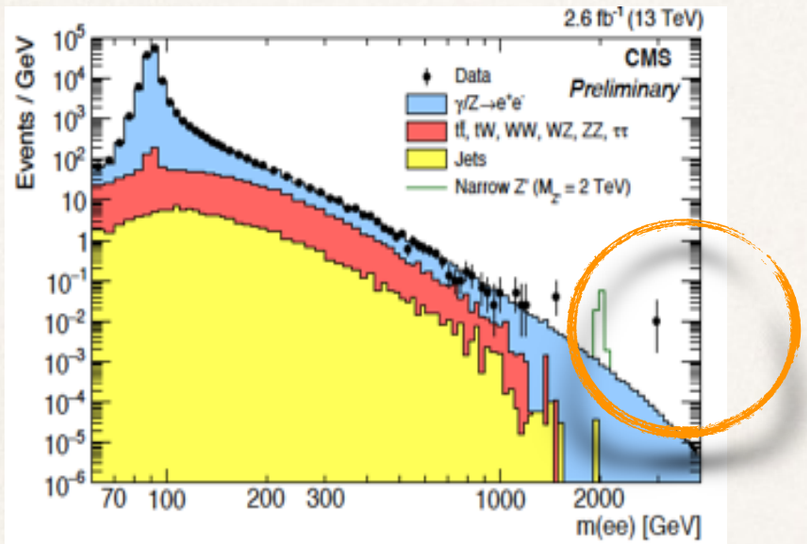
Narrow resonance → ee, μμ

PAS-EXO-15-005

- Models:
  - massive neutral spin 1:
    - Z'_{ψ} : width 0.6%
    - Z'_{SSM} : width 3%
- Experimental signature: **2 high pT leptons**:
  - pT > 35 GeV (53 GeV) for e (μ)
- Backgrounds:
  - Major background: **SM DY - estimated using MC**
  - **non-prompt leptons - estimated using data-driven** estimate by measuring the probability for a misidentified lepton passing a loose selection and then full selection
    - ~3% for electron channel and < 1% for muon channel



Significance at 2.9 TeV



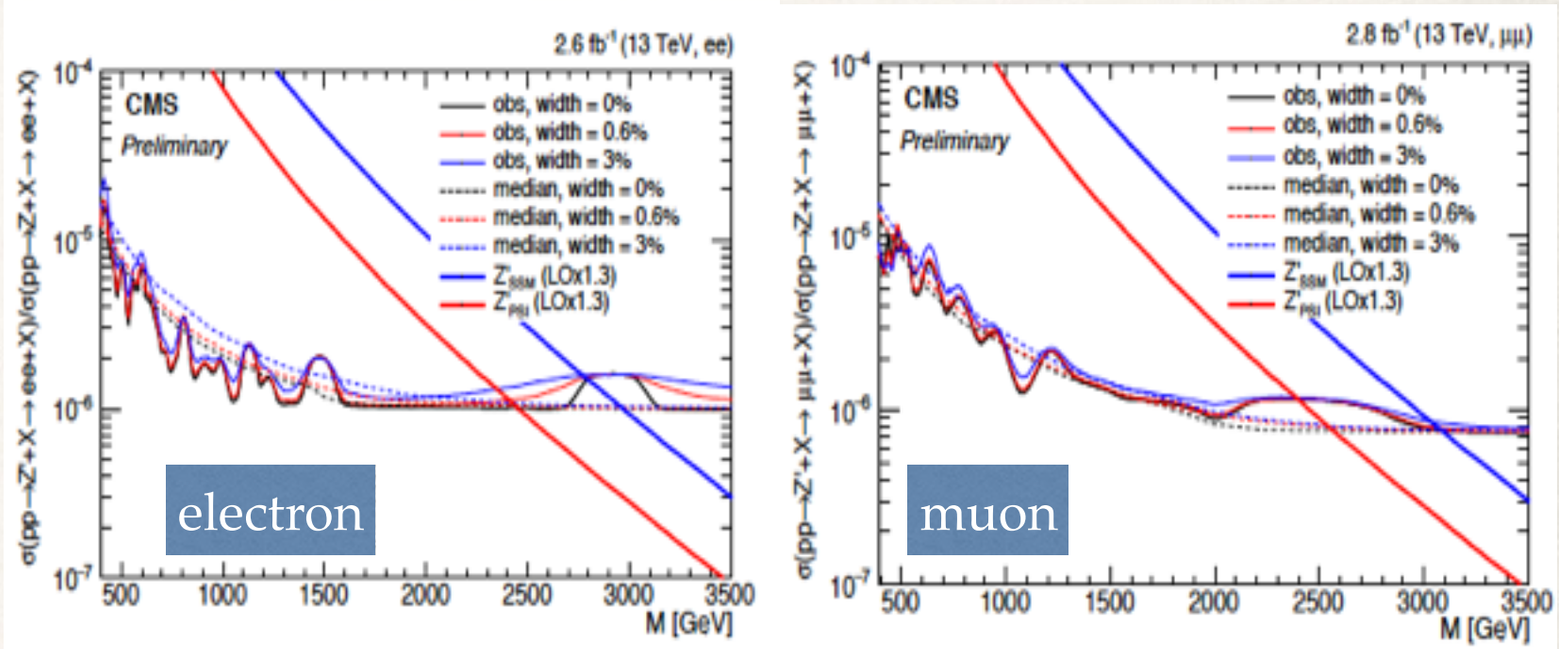
Mass range	background Expectation
> 2 TeV	0.31 +/- 0.05
> 2.5 TeV	0.080 +/- 0.016
> 2.8 TeV	0.036 +/- 0.009

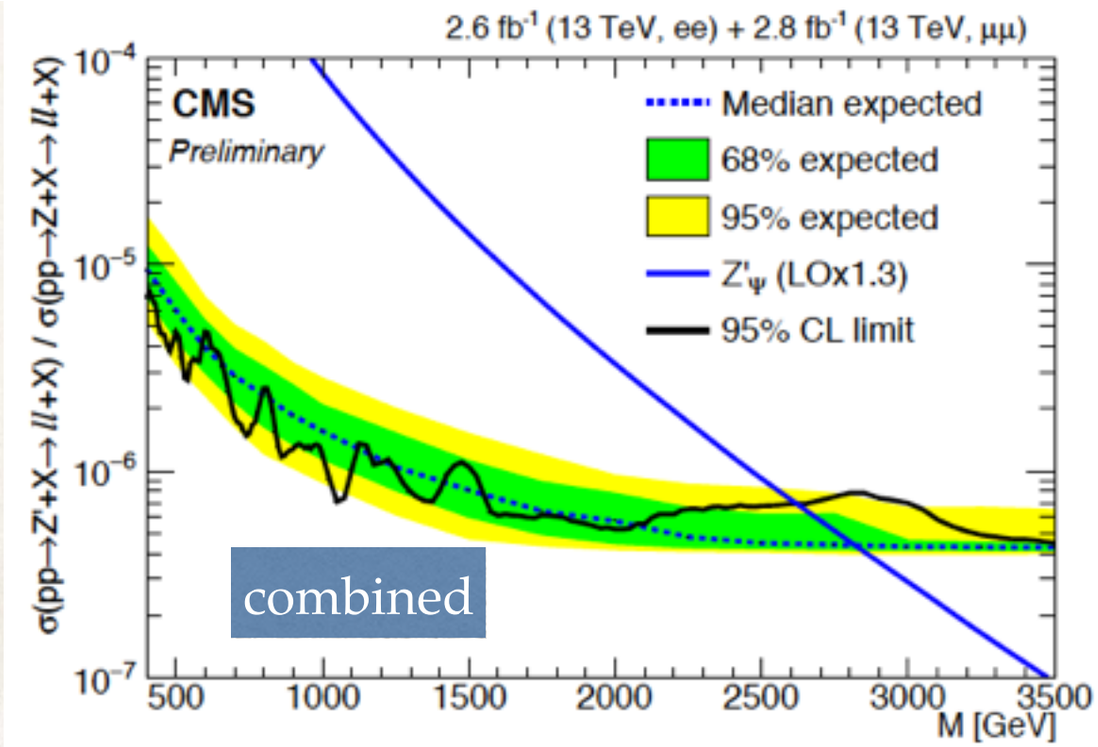
- Highest mass event observed in the electron channel at 2.9 TeV

- Local p-value for the null hypothesis to observe at least one event above 2.8 TeV is 0.036 - could be just a statistical fluctuation

Results

- Observed spectrum agrees well with the SM background
- Excludes:
  - $Z'_{SSM} < 3.15$ TeV and $Z'_{\psi} < 2.6$ TeV
  - compared to Run I: $Z'_{SSM} < 2.9$ TeV and $Z'_{\psi} < 2.57$ TeV



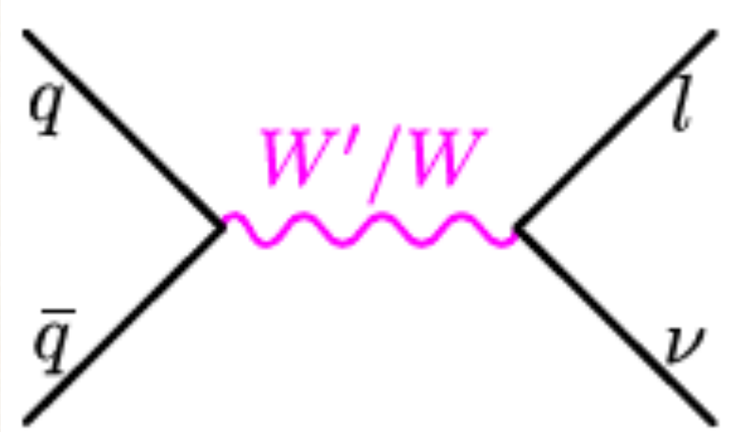


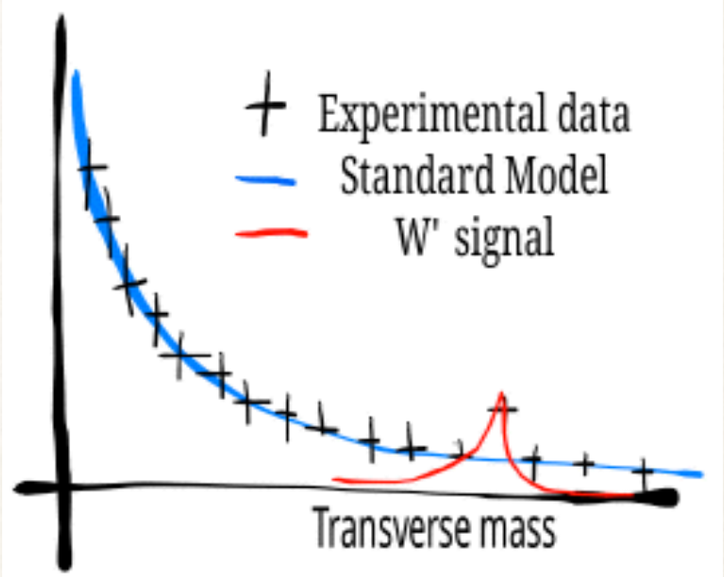
W'$_{SSM}$ ⟶ lepton + MET

PAS-EXO-15-006

Model:

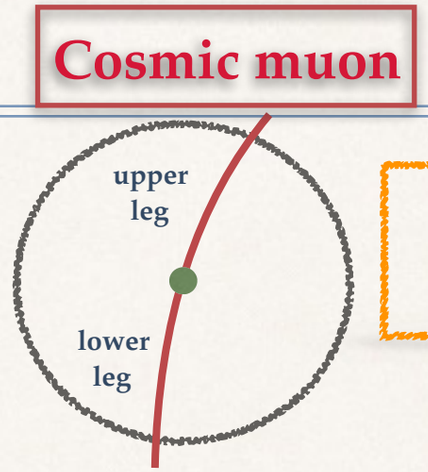
- TeV object W'—> ℓ+ν
- Experimental signature: high energy charged lepton + MET
- Dominant background: W—>ℓ+ν - estimated from MC
  - QCD mulitjet - data-driven
- Event selection includes:
  - MT > 120 GeV
  - second lepton veto
  - To ensure back to back pattern, apply:
    - $|\Delta\phi(\ell, \text{MET})| > 2.5$
    - $0.4 < pT_{\ell} / \text{MET} < 1.5$





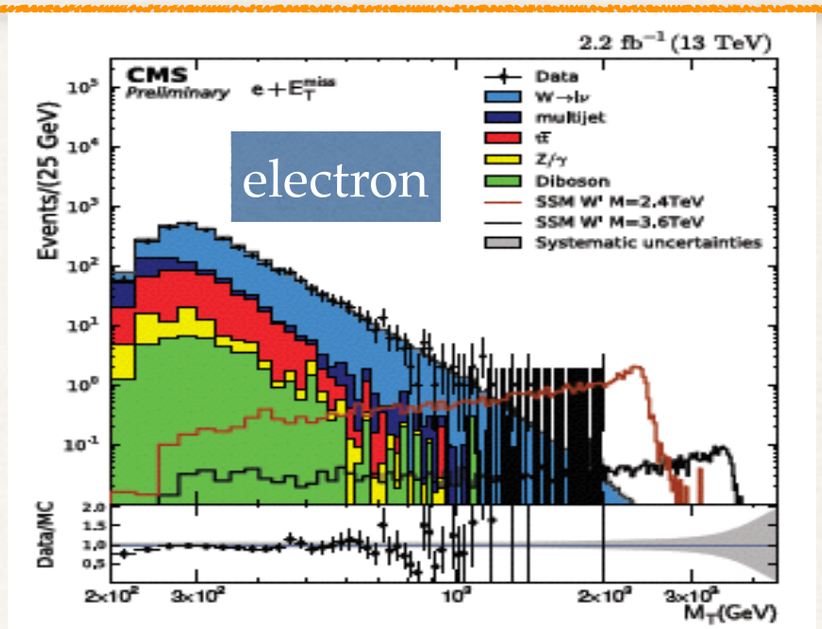
Main discriminant: M_T
Signal has high M_T, whereas, background appears as a tail

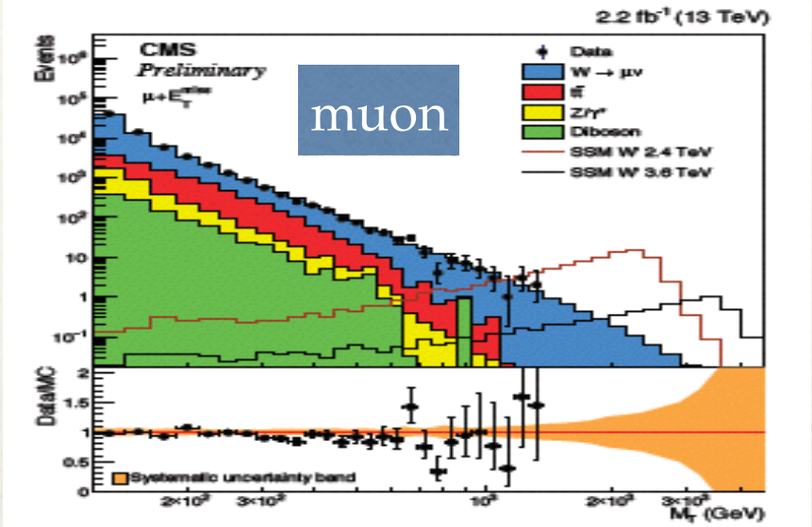
How well are the leptons understood?



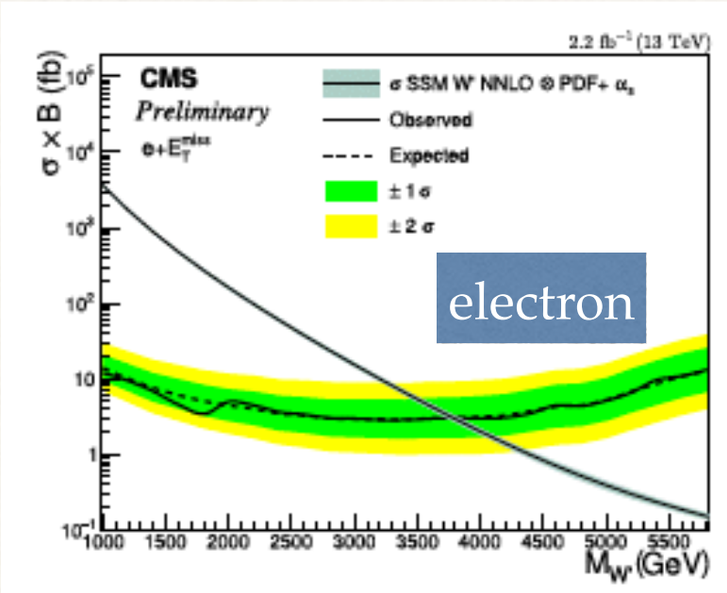
using the lower and upper "legs", resolution and scale is studied in the TeV region

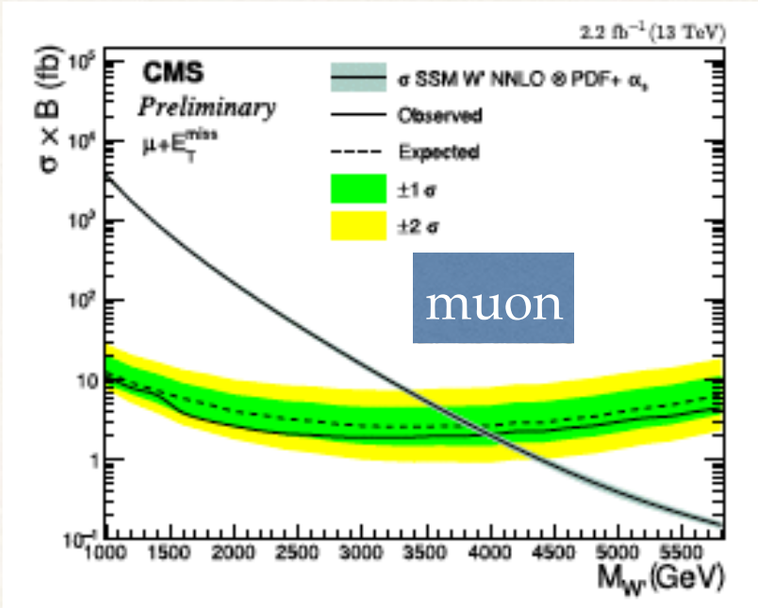
- Challenge:
  - Single high pT lepton signal
  - Understanding leptons in high pT regions is important
- Electrons:
  - constant resolution at high energy: O(2%)
  - saturation of ECAL crystals do not play a role yet at that energy
- Muons:
  - resolution decreases with pT
    - Look at cosmic to study resolution and scale- O(10%) at 1 TeV
  - alignment is also looked at using cosmics



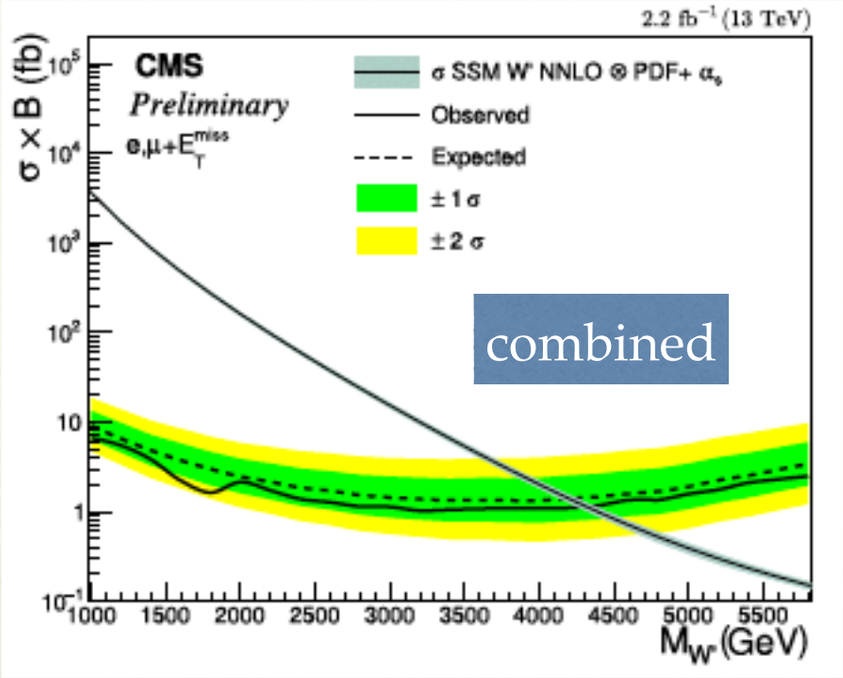


Results





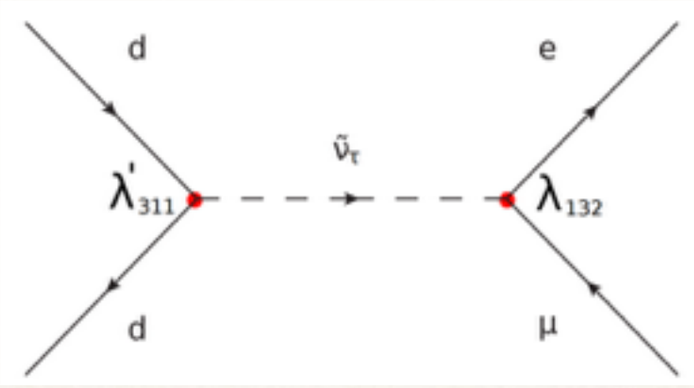
- MT > 1 TeV, Run II is expected to be more sensitive to new physics than Run I
  - signal cross-section depends on W′ mass
- No significant deviation seen - limits are set
- Combining both channels, W′ mass < 4.4 **TeV** is excluded
  - compared to Run I: W′ mass < 3.24 was excluded



e-μ resonance

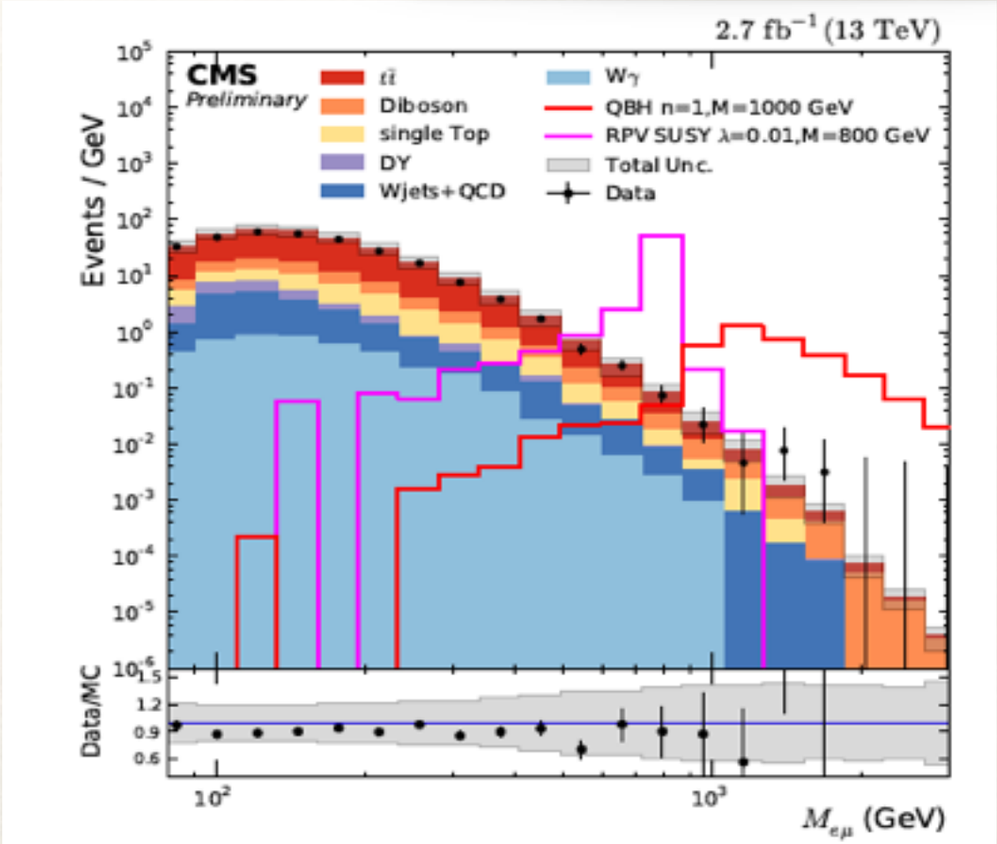
PAS-EXO-16-001

- Model: RPV SUSY with τ sneutrino as LSP and Quantum black holes (QBH)



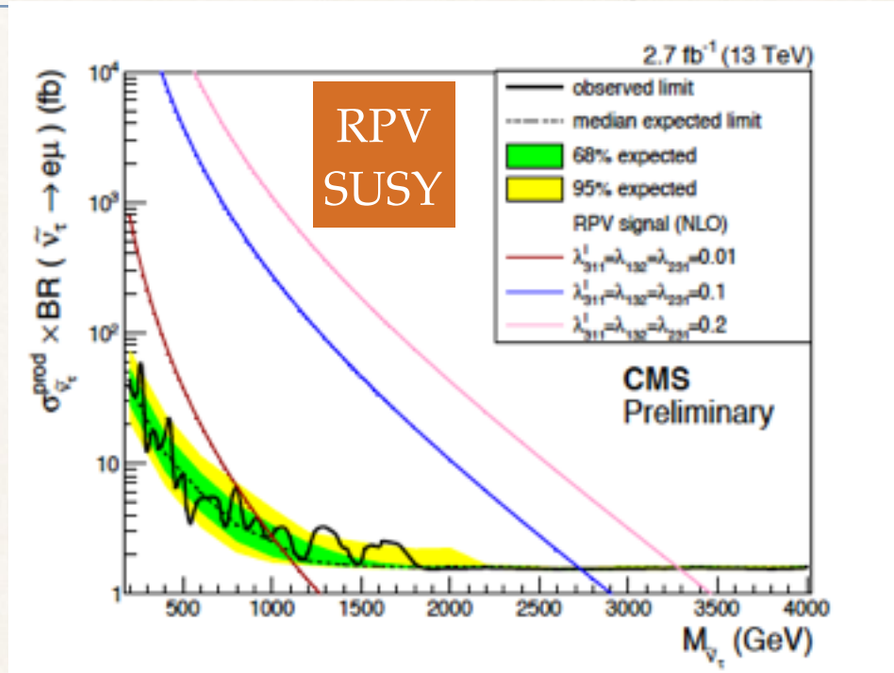
parameters of the theory:
SUSY: λ_{132}, λ_{231}, λ'_{311}
QBH: M_{th} (threshold mass for QBH production) and n (number of extra dimensions)

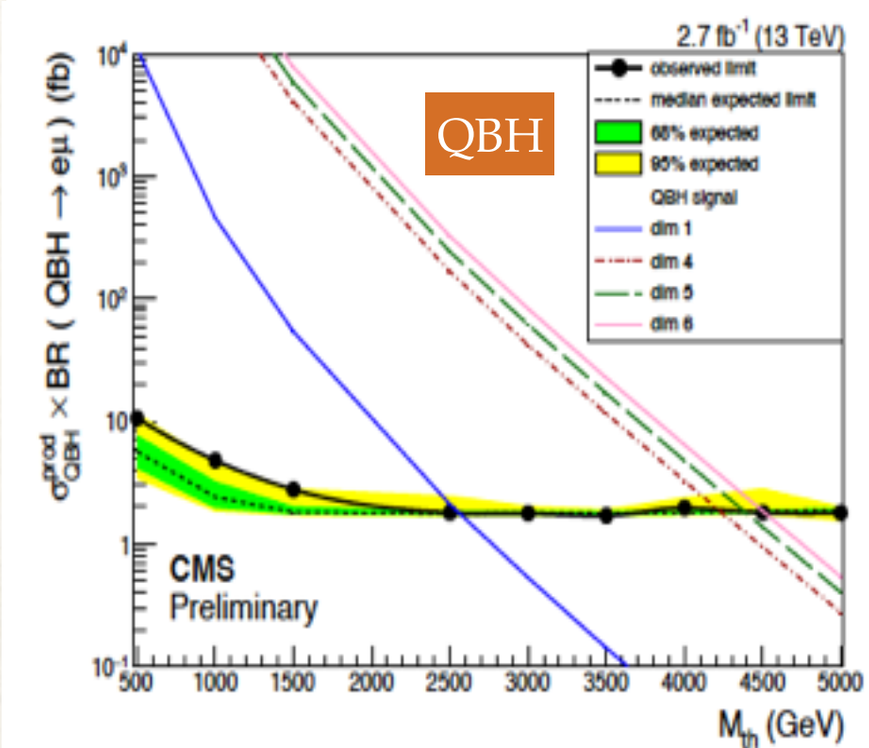
- Event selection:
  - pT > 35 GeV (53 GeV) for e (μ)
  - High energetic muons can produce bremsstrahlung and can thus be mis-identified as electrons
    - reject electron candidate if $dR_{e\text{-}\mu} < 0.1$ and pT of μ > 5 GeV
  - eμ pair with highest invariant mass is selected
- Backgrounds:
  - prompt leptons: tt, diboson - estimated from MC
  - W+jets and QCD: data-driven



Results

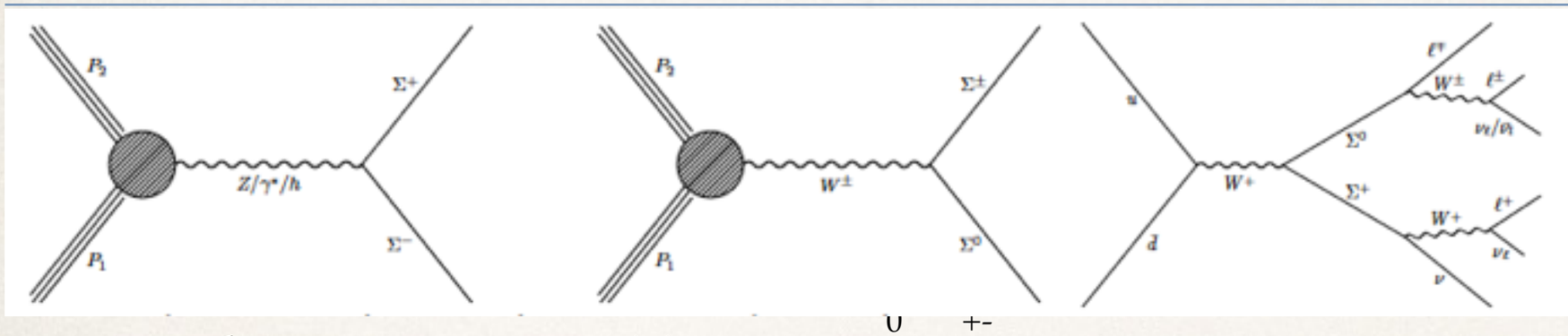
- Shape based limits:
  - RPV SUSY: narrow signal - shapes obtained by fitting MC sample with Gaussian
  - QBH: shapes directly from MC sample
- Background: all shapes from MC except for jet->electron which is taken from data
- RPV SUSY: For λ_{132}, λ_{231}, $\lambda_{311}' = 0.2$, mass below 3.3 TeV is excluded
- QBH: For n = 6, $M_{th} < 4.5$ TeV is excluded





Multileptons: Type III see-saw

PAS-EXO-16-002



- Predicts the existence of SU(2) triplet: Σ^0, Σ^{+-} to explain smallness of neutrino masses
- Channels: $\Sigma^+ \rightarrow W^+\nu$, $\Sigma^+ \rightarrow Z\,(H)\ell^+$, $\Sigma^0 \rightarrow W^{+(-)}\ell^{-(+)}$, $\Sigma^0 \rightarrow Z\,(H)\,\nu$
  - These give rise to 27 different final states with multi-leptons
- Final state: >= 3 leptons (each lepton could be e or μ)
- Decay rate is proportional to: →

$$v_{\ell N} = \frac{V_\ell}{\sqrt{|V_e|^2+|V_\mu|^2+|V_\tau|^2}}$$

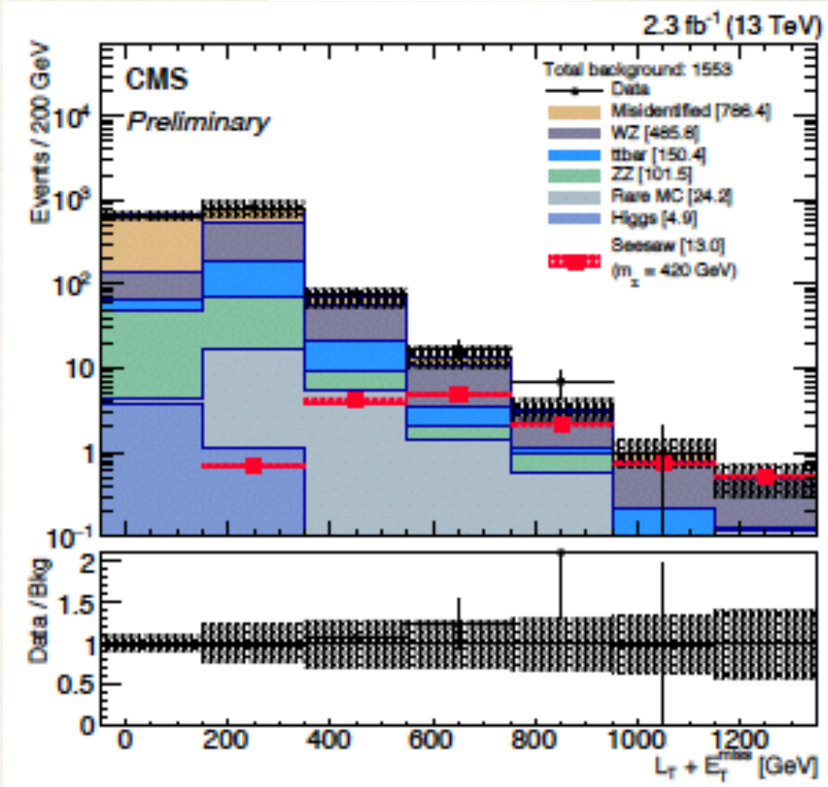
- Sensitive variable: $\mathbf{L_T + E_T^{miss}}$ (L_T is scalar lepton pT sum)
  - maintains efficiency for signal topology like: $\Sigma^{+-} \rightarrow Z\ell^{+/-}$ (LT is high) and $\Sigma^0 \rightarrow H\nu \rightarrow WW\nu$ (high $E_T$miss) at the same time

Democratic scenario: mixing parameters, V_ℓ are all the same

Search strategy and backgrounds

- Event classification:
  - based on maximum number of Opposite Sign Same Flavour (OSSF) leptons (4 categories)
    - further categorized in bins of $\mathbf{L_T + E_T^{miss}}$ variable (5 bins)
  - in all 20 signal bins (4x5)
- Backgrounds:
  - WZ: 51%. Estimated using MC
  - ttbar: 21%. Kinematics from MC and rate using data-driven
  - Z+jets: 17%. Data-driven
  - ZZ: 3%. Estimated using MC
  - remaining: ttbar W, ttbar Z, H—>2l: MC

$L_T+E_T^{miss}$

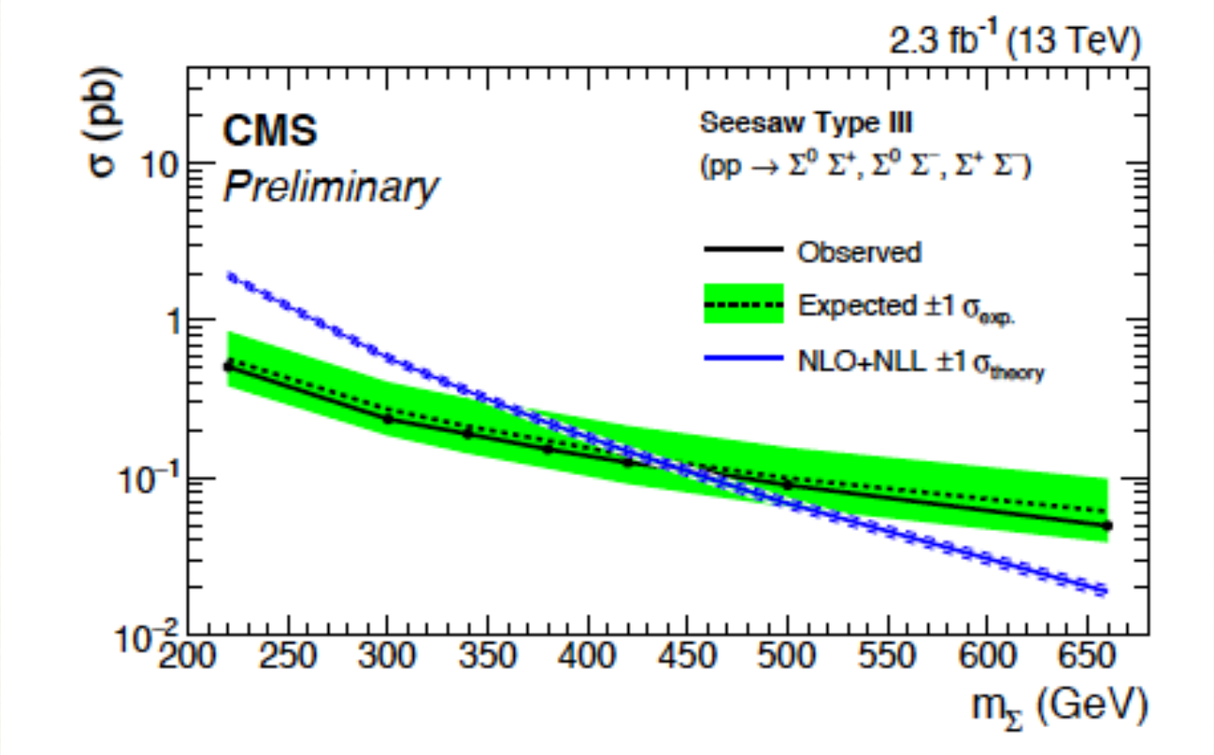


Final selection:

$L_T + E_T^{miss} > 350$ GeV

Results

- No significant excess
- Put limits assuming flavour-democratic scenario and $M_{\Sigma^-} = M_{\Sigma^+} = M_{\Sigma^0}$
- $M_\Sigma < 440$ GeV excluded (expected 430 GeV)
  - In Run I $M_\Sigma < 278$ GeV (expected 250 GeV) was excluded



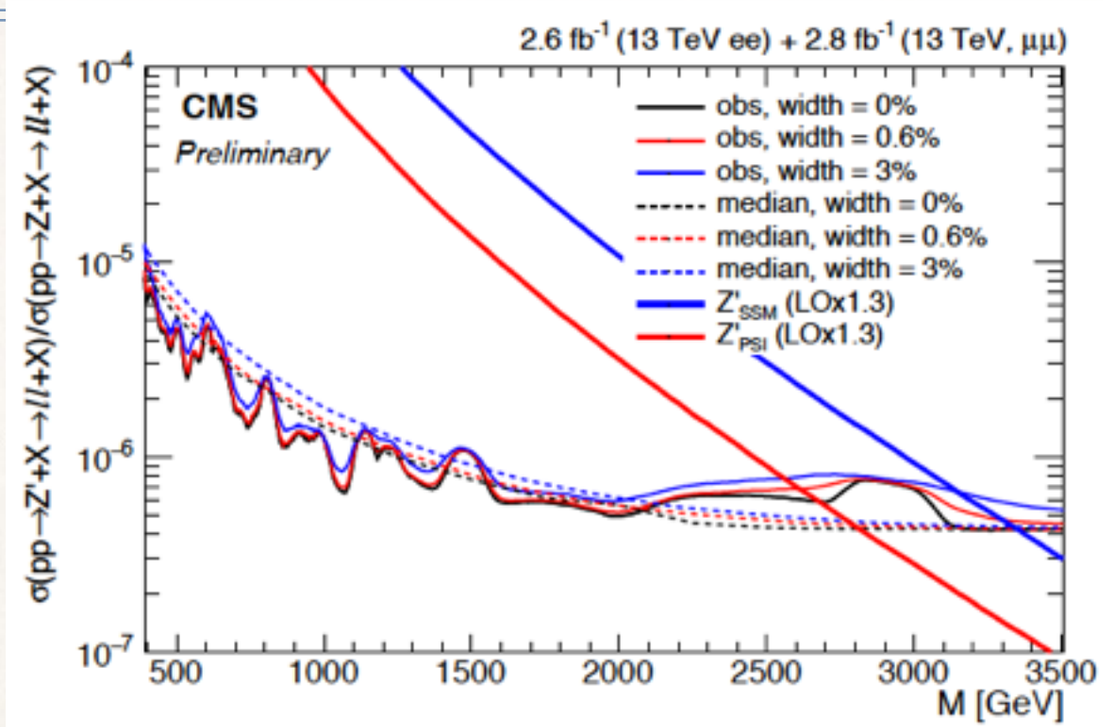
Summary

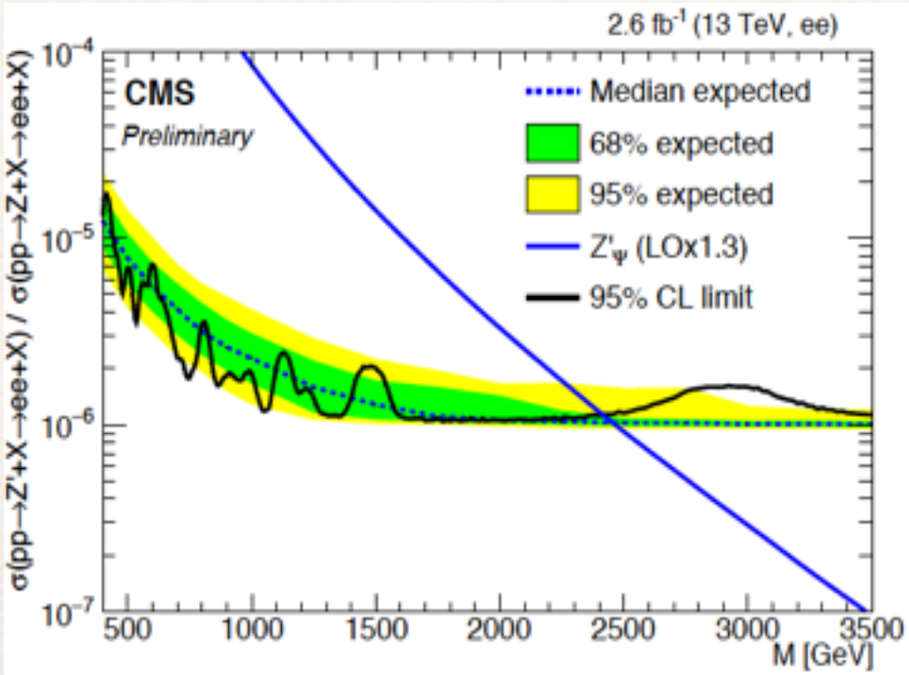
- Many new searches for BSM physics have been performed in leptonic final state
  - Most recent have been presented today
  - More can be found here:
    - http://cms-results.web.cern.ch/cms-results/public-results/publications/
- Improved limits on the dilepton, multilepton and lepton+MET final states compared to Run I
  - $Z'_{SSM} >$ 3.15 TeV and $Z'_{\psi} >$2.6 TeV
  - W' mass > 4.4 TeV
  - RPV SUSY: sτ neutrino mass > 3.3 TeV; QBH: $M_{th} >$ 4.5 GeV
  - $M_{\Sigma} >$ 440 GeV
- Exciting times ahead for the search of new physics with the new energy frontier at the LHC

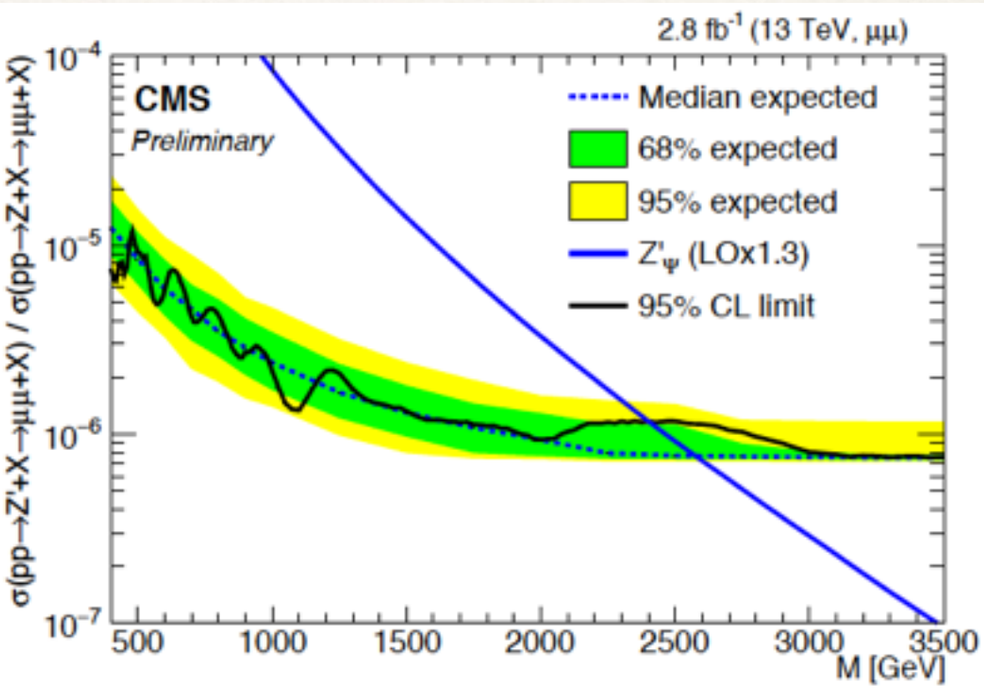
We continue to dig further LHC data in 2016 … we may be just a few fb^{-1} away from new physics. So stay tuned!

Backup

Z'


2.6 fb^{-1} (13 TeV ee) + 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→ll+X)/σ(pp→Z+X→ll+X)
M [GeV]


2.6 fb^{-1} (13 TeV, ee)
CMS
Preliminary
Median expected
68% expected
95% expected
Z'$_{\psi}$ (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
Median expected
68% expected
95% expected
Z'$_{\psi}$ (LOx1.3)
95% CL limit
σ(pp→Z'+X→μμ+X) / σ(pp→Z+X→μμ+X)
M [GeV]

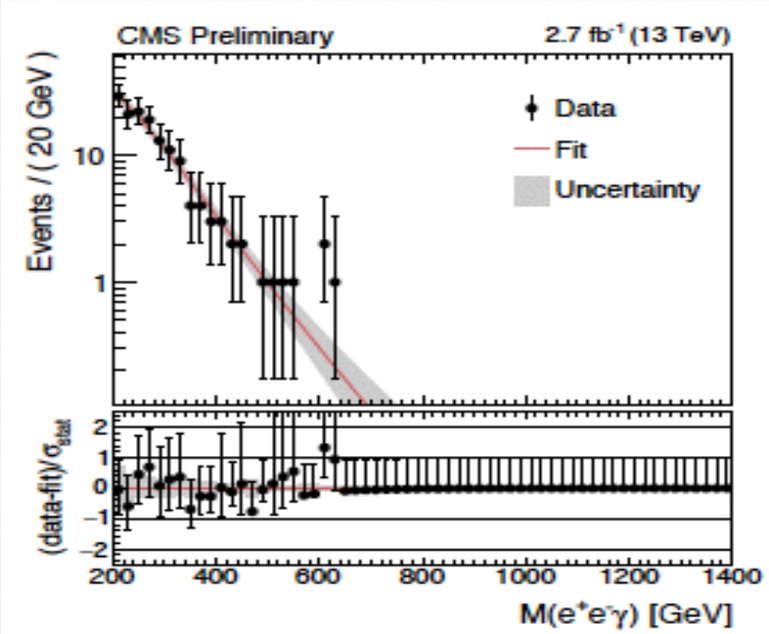
Categories in Type III see-saw

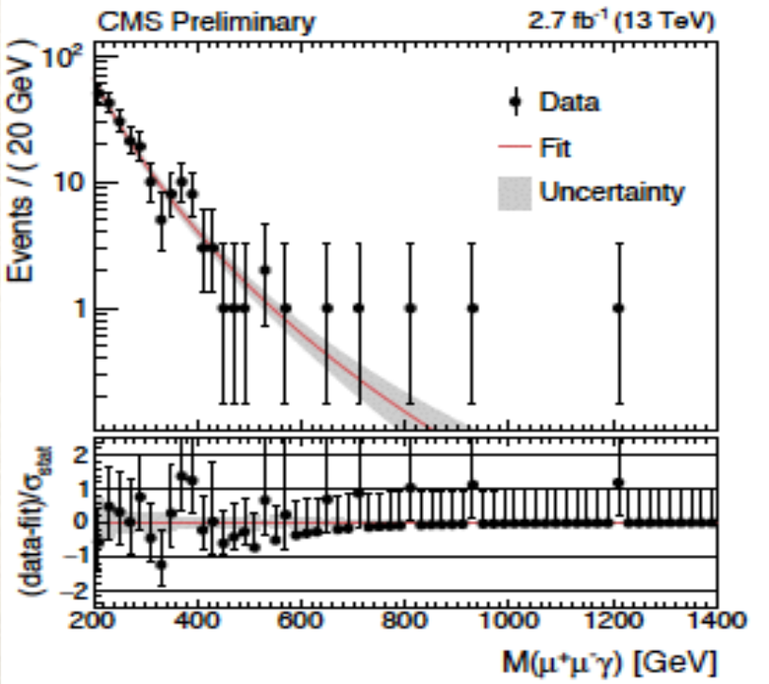
- 3 leptons without OSSF pair
- 3 leptons with one OSSF pair on-Z
- 3 leptons with one OSSF pair above-Z
- 4 leptons with at least one OSSF pair
- Distribution starts from 350 GeV and goes beyond 1150 in bins of 200 GeV

High mass $X \rightarrow \ell\ell\gamma$

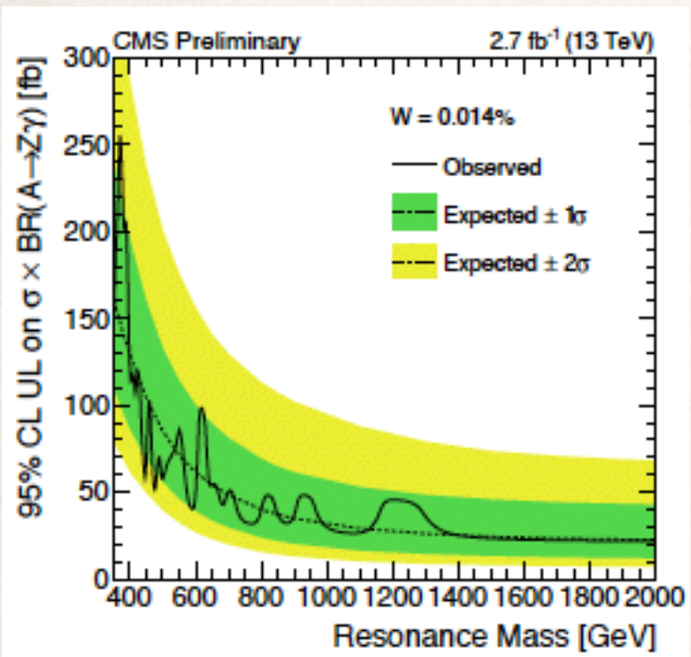
- Model: scalar resonance (X) decaying to Z(—>$\ell\ell$)γ
- Experimental signature: 2 leptons (e,μ) and a high pT γ
- Selection:
  - pT of leptons > 25 (20 GeV)
  - pT of γ > 40 GeV
  - Mll > 50 GeV
  - pTγ/Mllγ > 40./150.
- Background estimation: Fit function to data

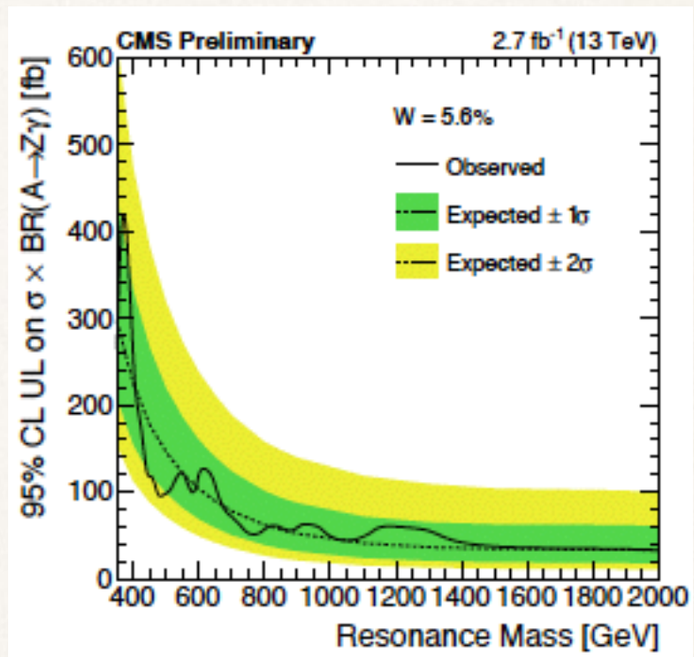
$$f(m_{Z\gamma}) = m_{Z\gamma}^{a+b\log m_{Z\gamma}}$$

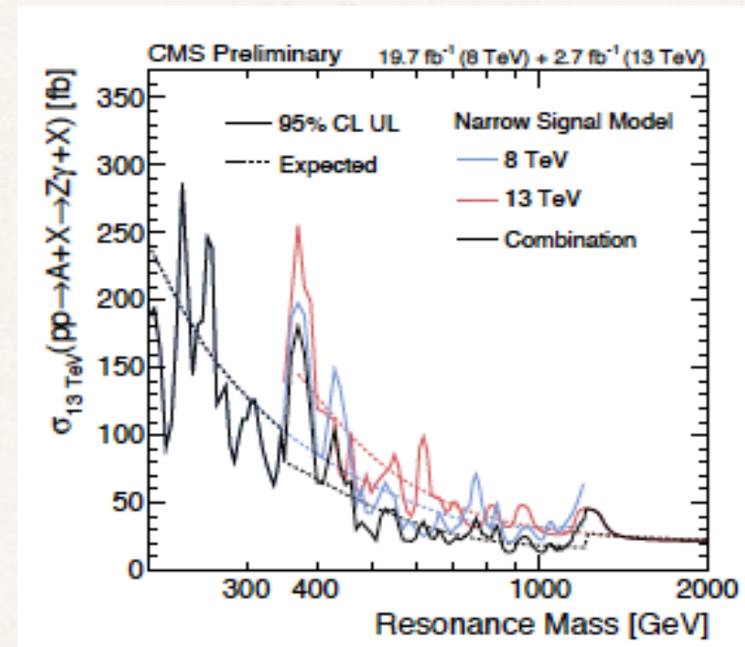




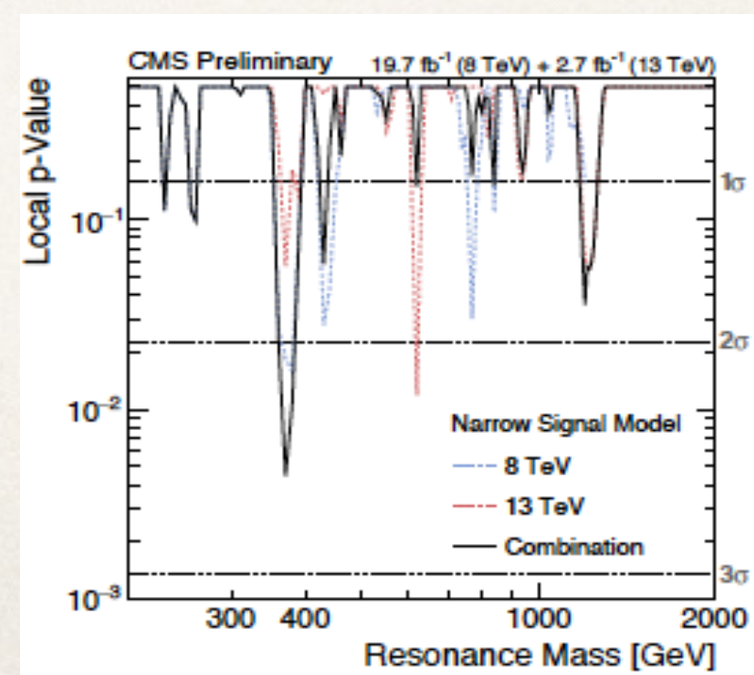
Results: High mass $X \rightarrow \ell\ell\gamma$







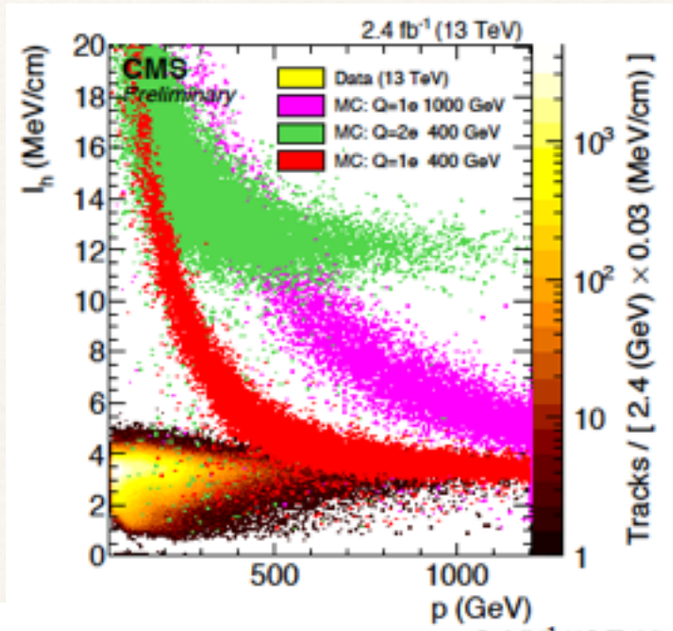
- Local significance around 370 GeV is 2.6σ and global is < 1σ

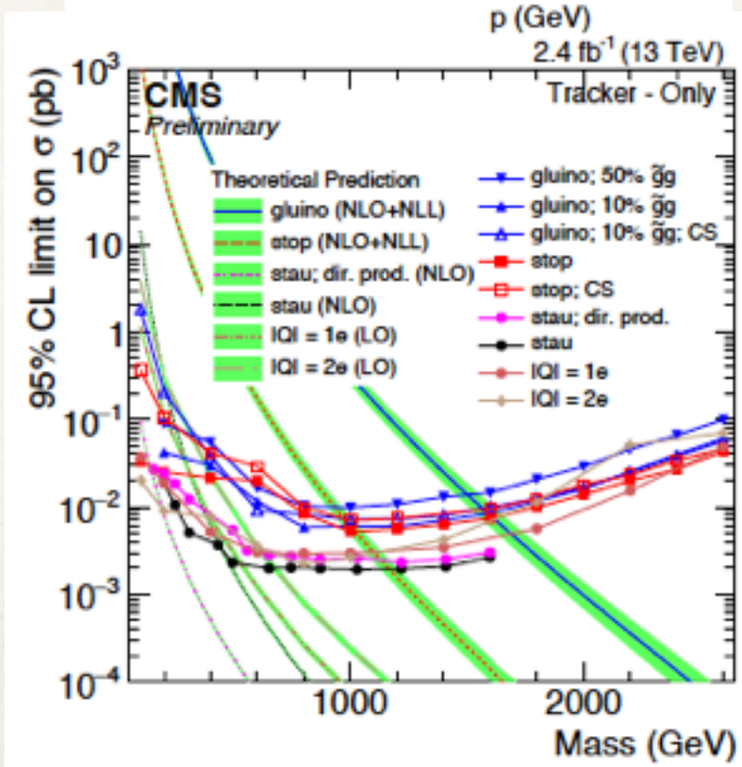


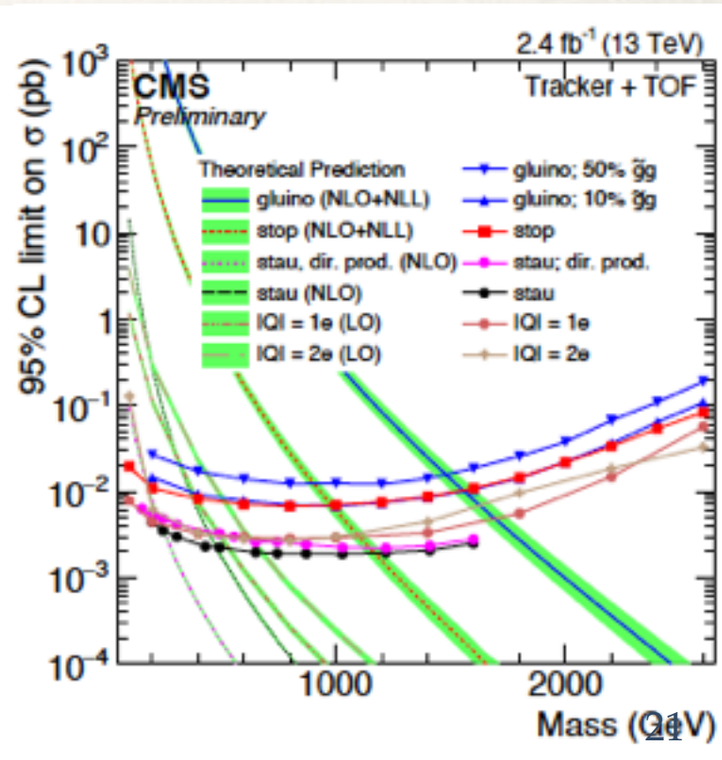
Search for long-lived charged particles

PAS-EXO-15-010

- Signature: Large energy deposition in silicon tracker and long-time-of flight to muon detectors
- Exclude masses < 1590 GeV







Comparison with ATLAS

- Z′:
  - SSM: M > 3.4 TeV excluded
  - Z' psi > 2.79 TeV
- W′: M > 4.04 TeV
- e-μ:
  - QBH > 4.54 TeV for ADD model (n=6)
  - QBH > 2.54 TeV for RS (n=1)
  - no RPV