Searches for New Heavy Resonances in Final States with Leptons and Photons

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Introduction

- Many models beyond the Standard Model (BSM) predict resonances at the TeV energy scale
  - These include spin-0, spin-1 and spin-2 resonances produced in such models as the Sequential Standard Model (SSM) with SM-like couplings, Grand Unified Theories (GUT) with E_6 gauge group, Randall–Sundrum (RS) model of extra dimensions leading to Kaluza–Klein graviton (G_{KK}) excitations
    - We search for an excess on-top of a SM background
- The use of leptonic/photonic resonances has been a critical tool in searching for signatures of physics
  - The W&Z boson as well as Higgs boson were all discovered using these signatures

Importance of different final states

- Electrons provide an important tool for discoveries with their excellent energy resolution at higher energies
  - This leads to a better mass resolution compared to muons
- High momentum muons are reconstructed with higher efficiency than their electrons counterparts
  - This allows us to set stronger limits with muons compared to electrons
- Taus allow us to probe couplings to 3rd generation leptons
- Photons are sensitive to spin-0 resonances
- Only by utilising **all** these final states can we robustly search for heavy resonances

Analyses

- I will briefly present the following results which are based from different datasets collected by the CMS experiment including those from 2016 and 2017

#	Analysis	Integrated Luminosity	Code	
1	$Z' \to \ell\ell$ (ℓ=e/μ)	36 fb^{-1} **(2016)**	EXO-16-047	~New = released in 2018
2	$Z' \to ee$	41 fb^{-1} **(2017)**	EXO-18-006	~New = released in 2018
3	$W' \to \ell\nu$ (ℓ=e/μ)	36 fb^{-1} **(2016)**	EXO-16-033	~New = released in 2018
4	$W' \to \tau\nu$	36 fb^{-1} **(2016)**	EXO-17-008	~New = released in 2018
5	$X \to e\mu$	36 fb^{-1} **(2016)**	EXO-16-058	~New = released in 2018
6	$X \to \gamma\gamma$	36 fb^{-1} **(2016)**	EXO-17-017	~New = released in 2018

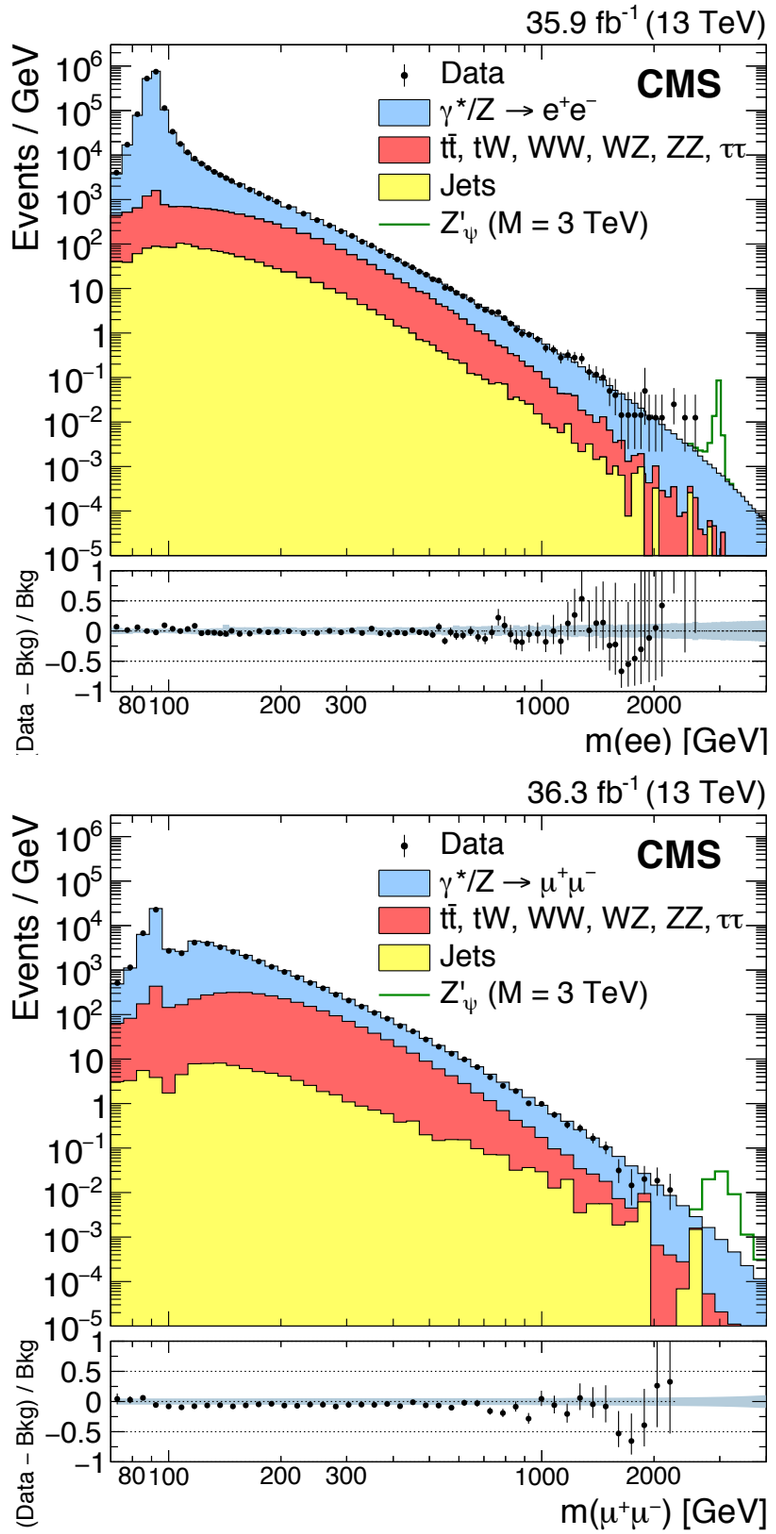
- Full list of CMS Exotica results are available here

1. $Z' \rightarrow \ell\ell$ (ℓ=e/μ)

~New

EXO-16-047

- An inclusive search for a new resonance using 36 fb^{-1} **(all 2016)**
  - The MC background is normalised to the Z peak
  - The amount of jet background is estimated from data
- Selection: Electrons (muons) are required to have p_T>35 (53) GeV and isolated
- Improvements in both the online and offline muon selection increased the efficiency above 1 TeV
- A deficit in muons ($|\eta|$<1.2, $M_{\mu\mu}$>1.6 TeV) leads to a local significance of 1.8σ when considering the entire pseudorapidity range
  - Significance is compatible with stat. fluctuation
  - Subsequent studies gave deepest understanding of high p_T muons at CMS

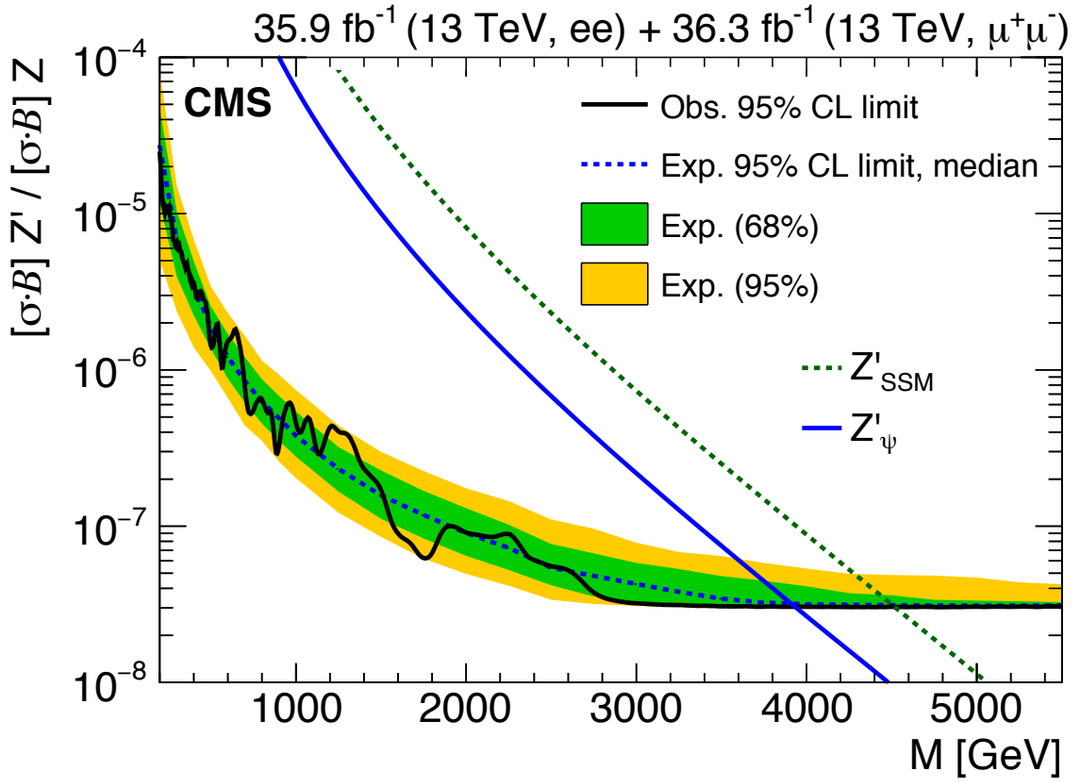


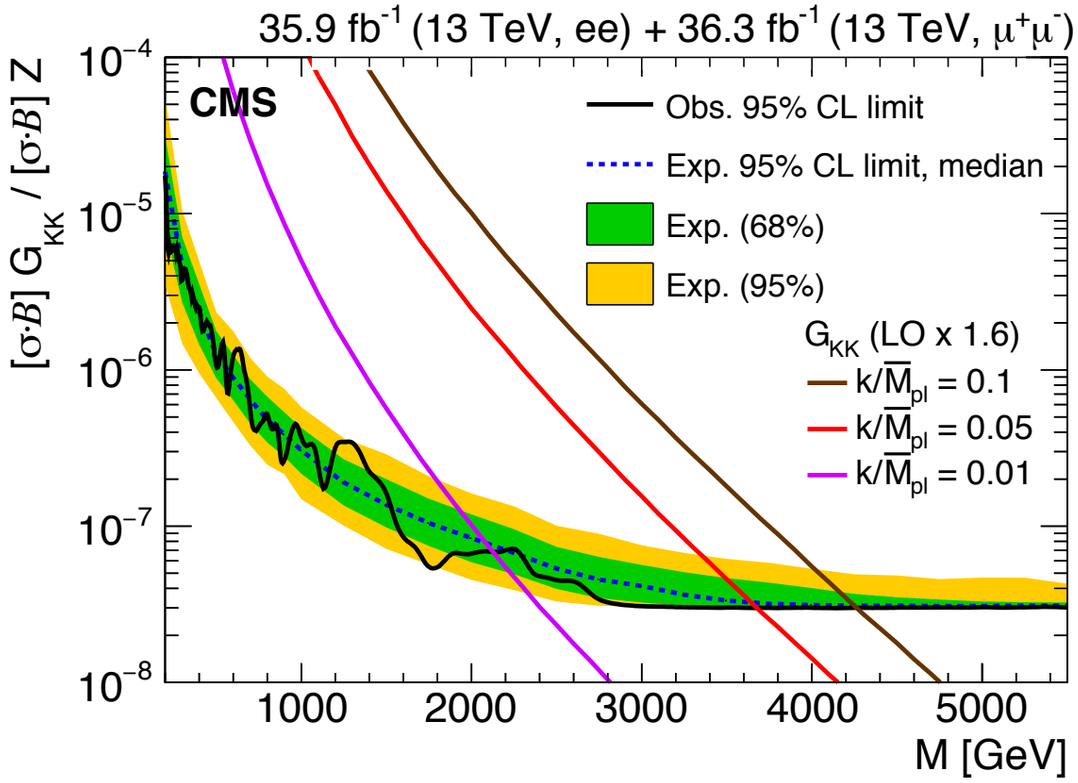
1. $Z' \rightarrow \ell\ell$ (ℓ=e/μ)

~New

EXO-16-047

- Results are interpreted in the ratio of the signal cross section/Z cross section so we are insensitive to the uncertainty on the luminosity
- The statistical analysis from the electron channel and muon channel are combined in order to place stronger limits on the lower bounds of the Z′ mass
- Limits are set on both spin-1 and spin-2 resonances
  - No significant deviations from the SM
  - Spin-1: **$m(Z'_{\psi})>3.9$ TeV**, **$m(Z'_{SSM})>4.5$ TeV**
  - Spin-2: **$k/\bar{M}_{Pl}=0.01$: $m>2.10$ TeV**, **$k/\bar{M}_{Pl}=0.05$: $m>3.65$ TeV**, **$k/\bar{M}_{Pl}=0.1$: $m>4.25$ TeV**



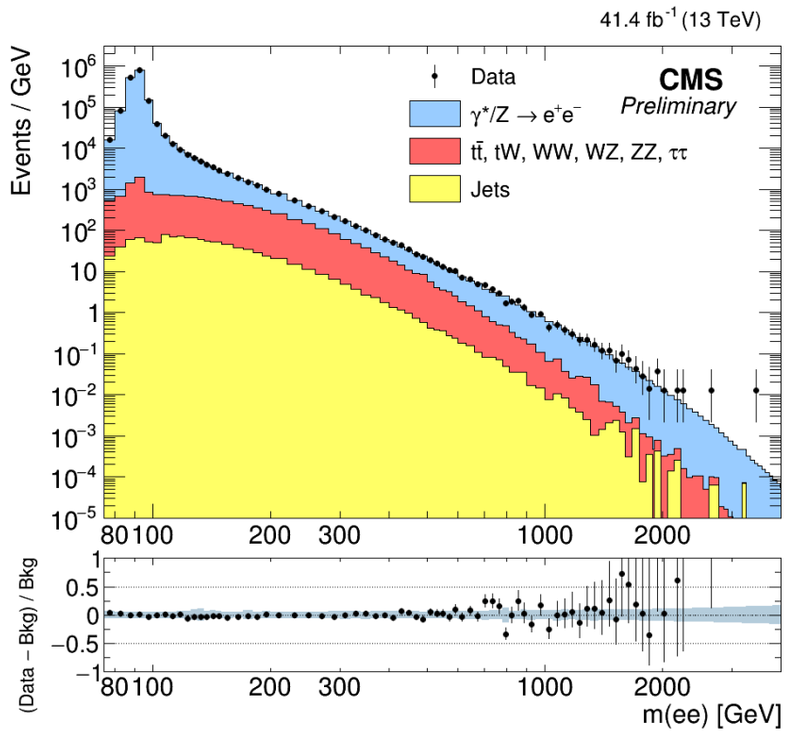


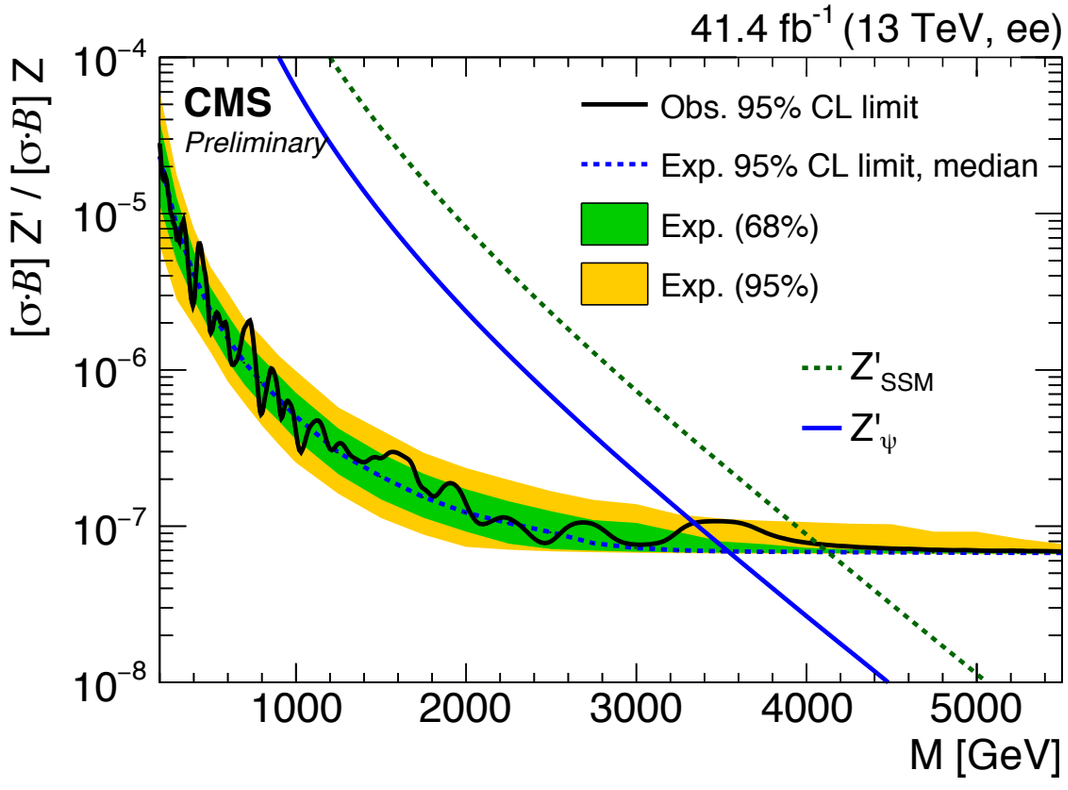
2. $Z' \rightarrow ee$

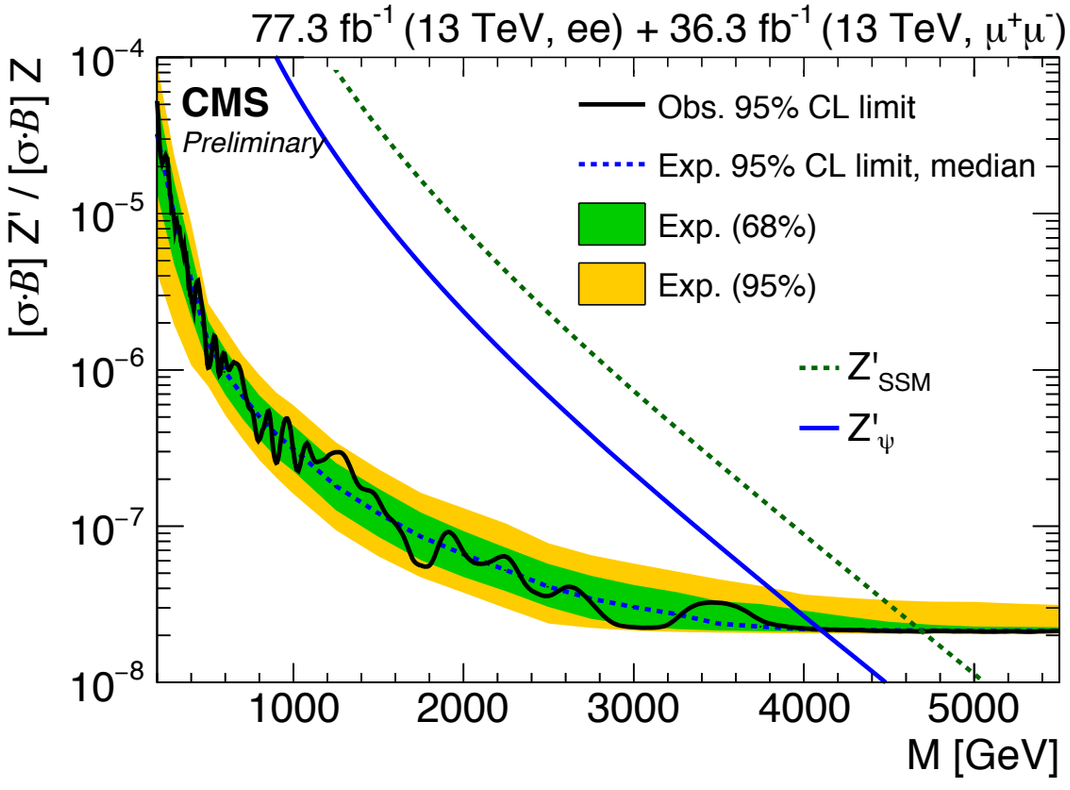
~New

EXO-18-006

- An inclusive search for a new resonance using 41 fb^{-1} **(all 2017)** in the electron channel
- The statistical analysis from the electron channel are combined with **2016** analysis in order to place stronger limits on the lower bounds of the Z′ mass
  - Spin-1: **$m(Z'_{\psi})$>4.1 TeV**, **$m(Z'_{SSM})$>4.7 TeV**





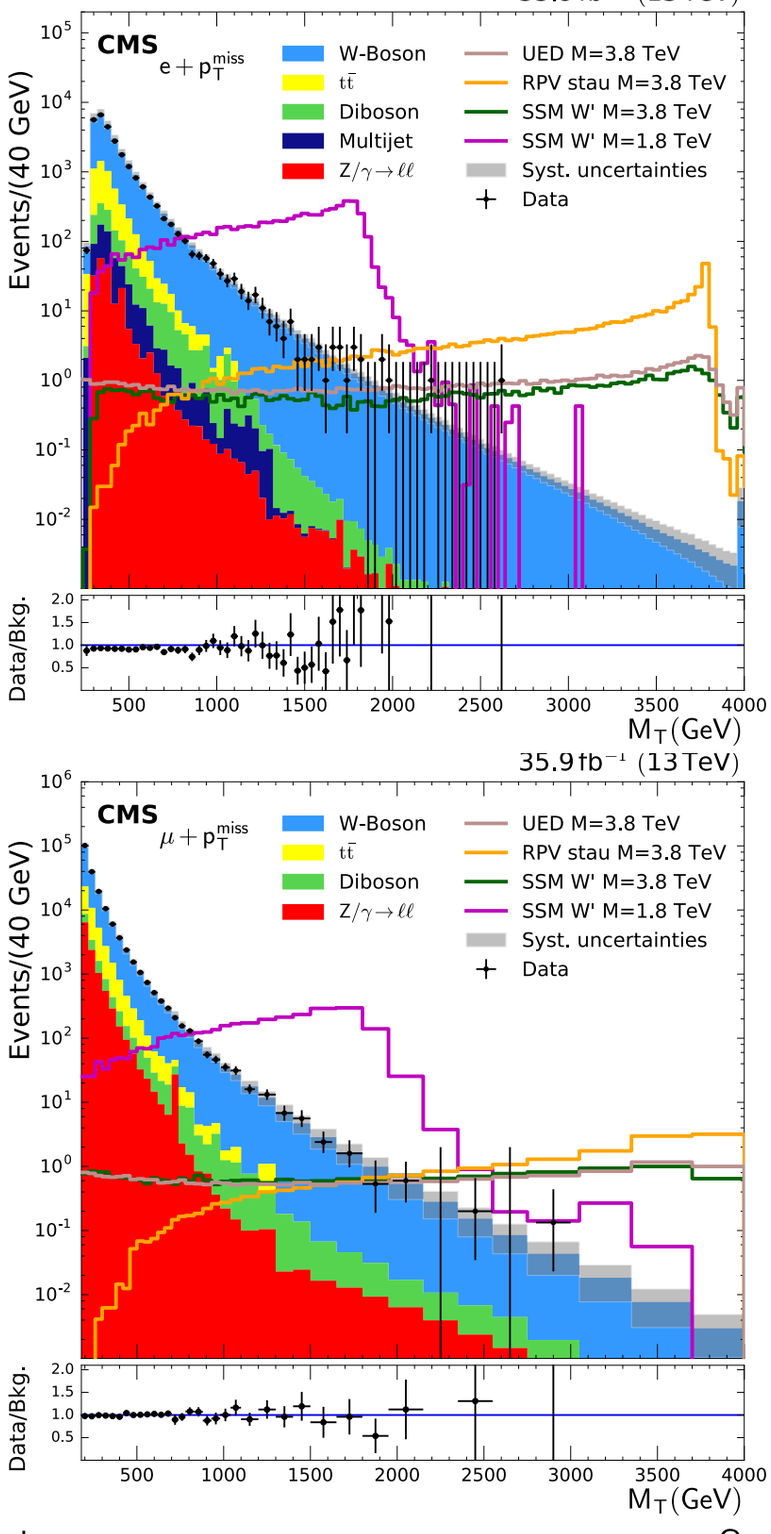


3. $W' \rightarrow \ell\nu$ (ℓ=e/μ)

~New

EXO-16-033

- Searching for a highly energetic electron or muon along with missing energy using 36 fb^{-1} **(all 2016)**
- Uses the discriminating variable: transverse mass, $M_T = \sqrt{2p_T^{\ell}\ p_T^{miss}(1-\cos[\Delta\phi(\ell,\vec{p}_T^{miss})])}$
- Dominant and irreducible background is $W \rightarrow \ell\nu$
  - Different MC generated at both LO and NLO, with higher order EW and QCD effects are evaluated and a suitable K factor used (FEWZ 3.1)
- Selection:
  - p_T>130 (53) GeV for electron (muon)
  - Events with additional leptons with p_T>25 GeV are excluded
  - In the electron channel the p_T^{miss}>150 GeV

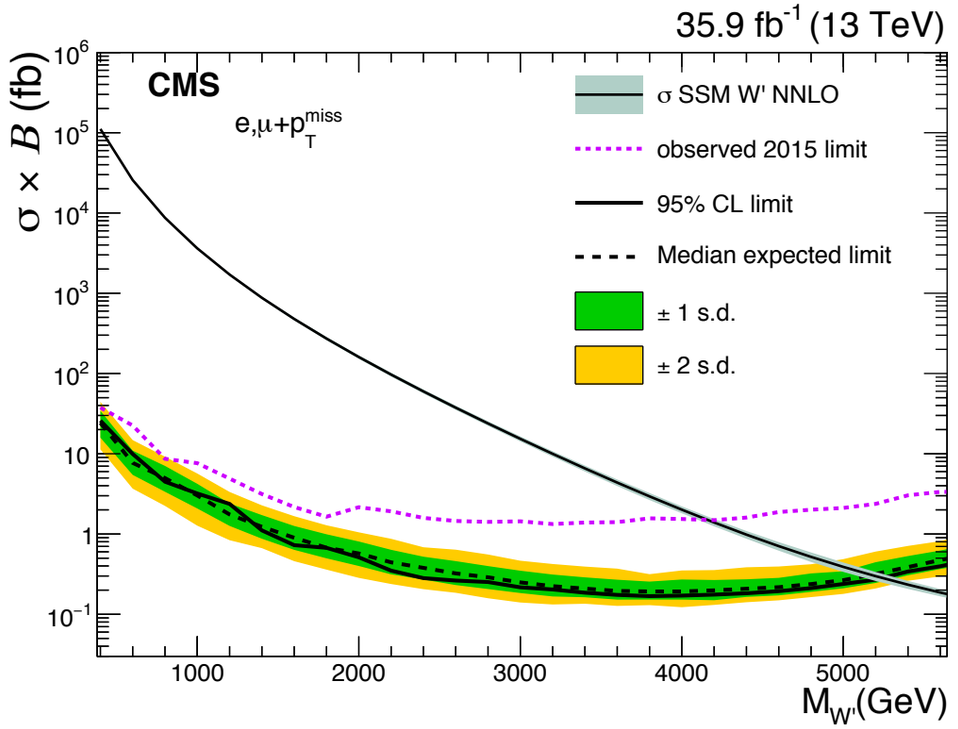


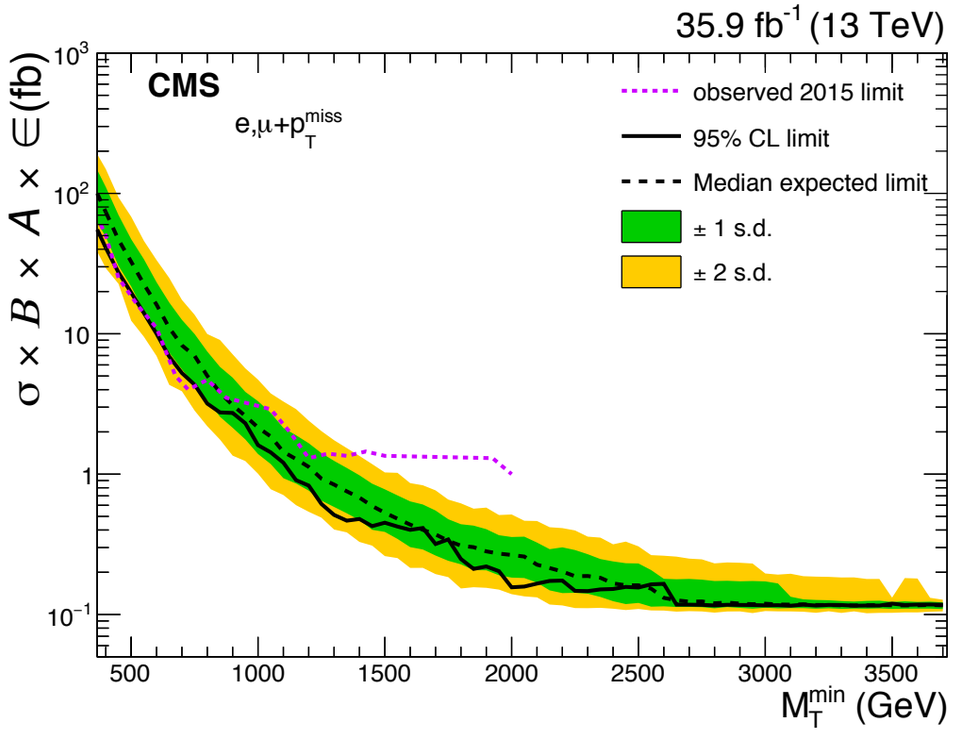
3. $W' \rightarrow \ell\nu$ (ℓ=e/μ)

~New

EXO-16-033

- With no observed excess with respect to the SM, lower limits can be placed on the mass of the W′
  - **$m(W'_{SSM})>5.2$ TeV**
- Model independent cross section × branching fraction limits as a function of the lower M_T threshold are also produced
- Reinterpreted in split-UED and R-parity violating (RPV) supersymmetry (SUSY) models
  - RPV SUSY naturally generates non-zero neutrino masses



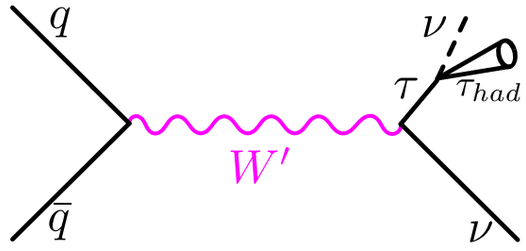


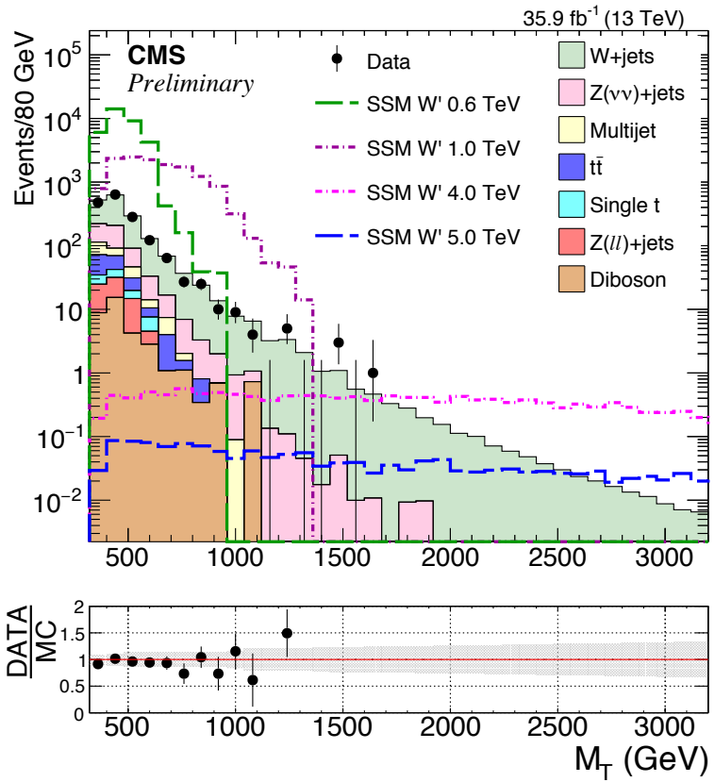
4. W′→τν

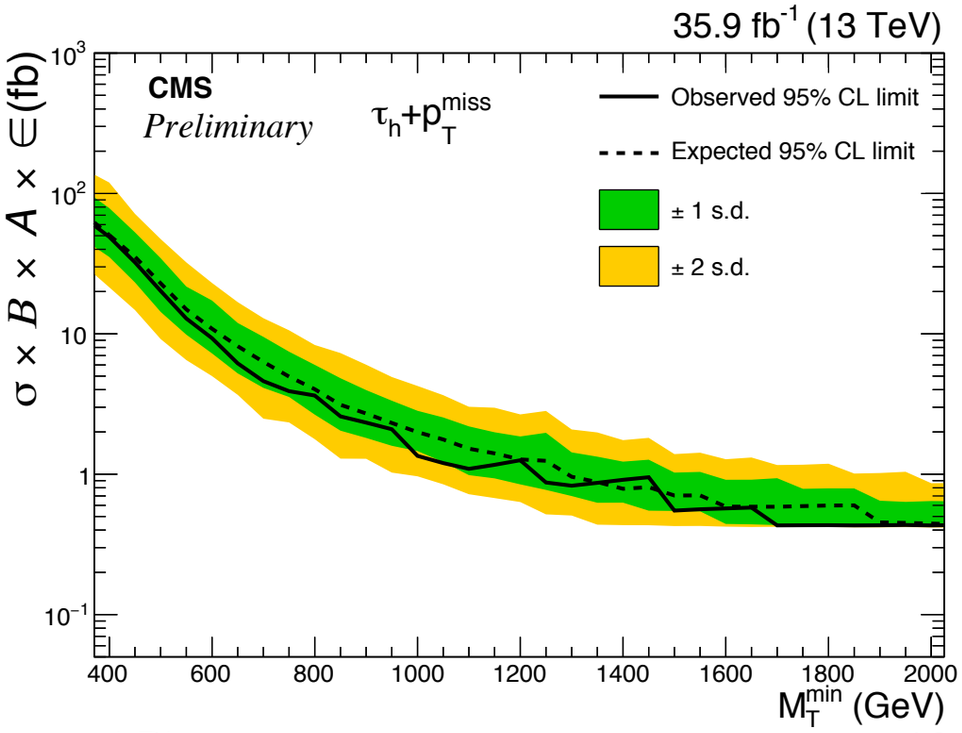
~New

EXO-17-008

- Search for W′→τν
  - Using 36 fb^{-1} **(all 2016)**
  - Hadronic decays of the tau which result in low charged hadron multiplicity
  - Leptonically decaying taus cannot be distinguished from W′→ℓν (ℓ=e/μ) and are covered by that analysis
  - M_T is used as a discriminator variable
  - Selection:
    - τ p_T>50 GeV and p_T^{miss}>90 GeV
    - Events with additional leptons with p_T>20 GeV are excluded
  - Limits are set on the lower mass for a W′
  - **m(W′$_{SSM}$)>4.0 TeV**
  - Similarly to W′→ℓν (ℓ=e/μ) limits are produced in a model independent way
    - Allowing for further reinterpretations





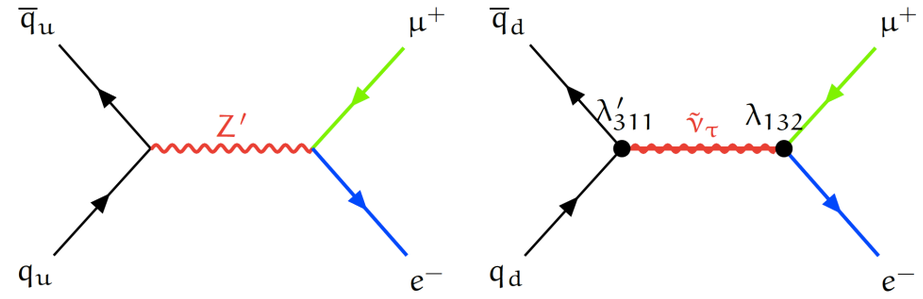


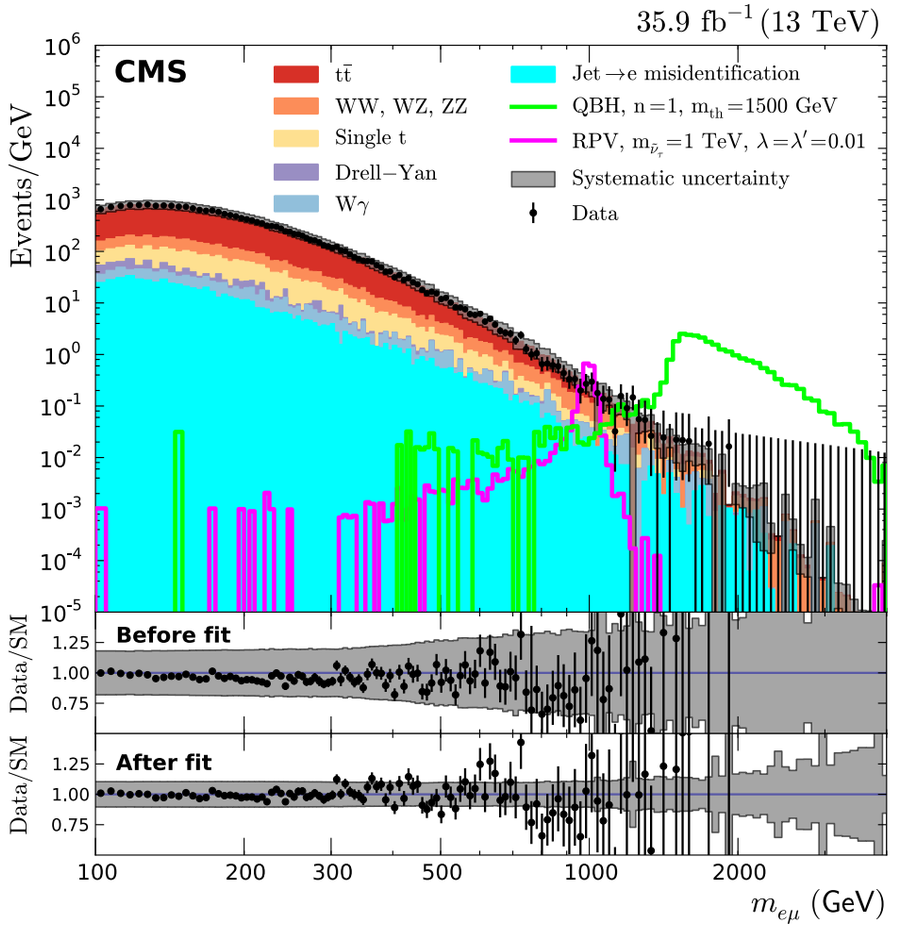
5. X→eμ

~New

EXO-16-058

- Model independent search for heavy resonances decaying into eμ using 36 fb^{-1} **(all 2016)**
- Selection:
  - p_T>35 (53) GeV for electron (muon)
  - A minimum transverse momentum requirement of p_T>50 GeV is also required online
  - The electron and muon are not required to have opposite charge (to avoid loss through charge mis-ID)
  - $M_{e\mu}$≥200 GeV
- SM background from processes with two prompt leptons as well as Wγ is obtained from MC while W+Jets and QCD multijet backgrounds are calculated using fake rate studies in data



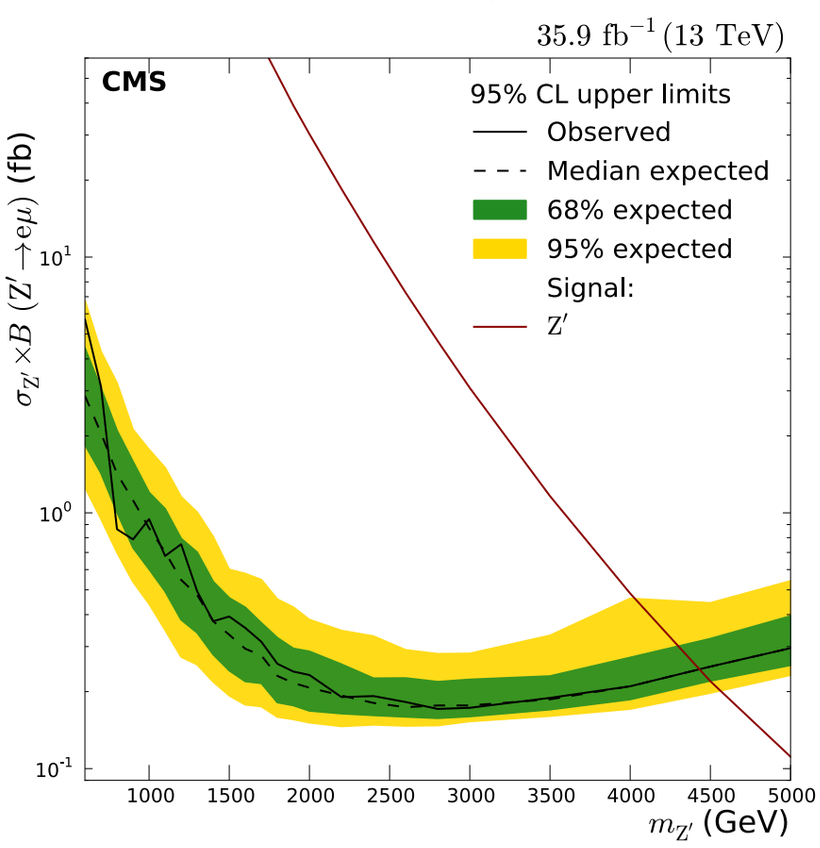


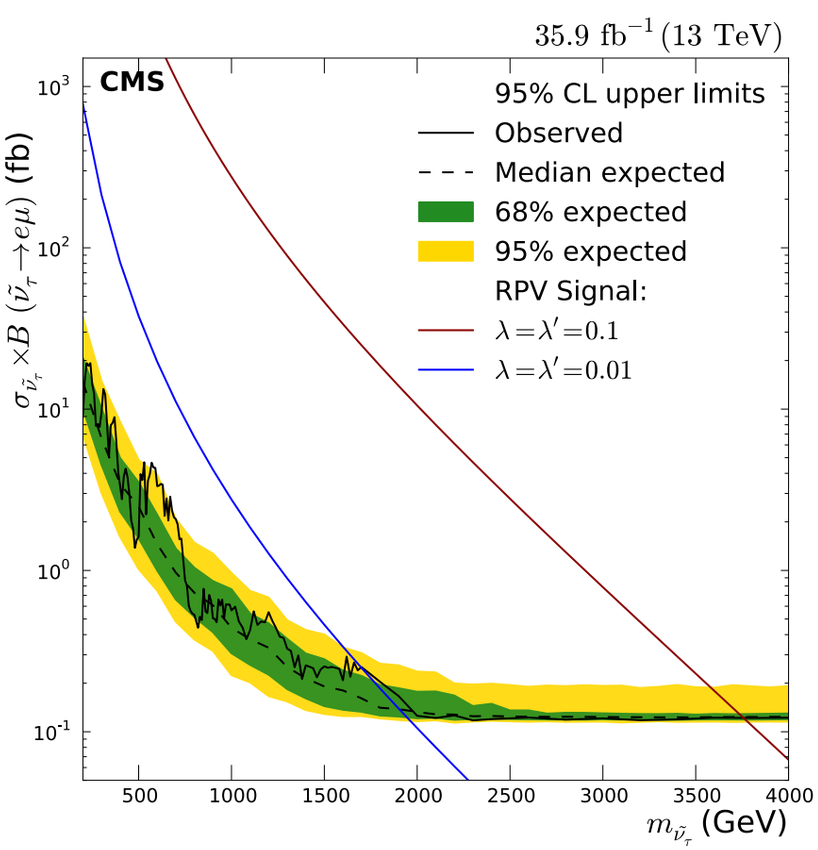
5. X→eμ

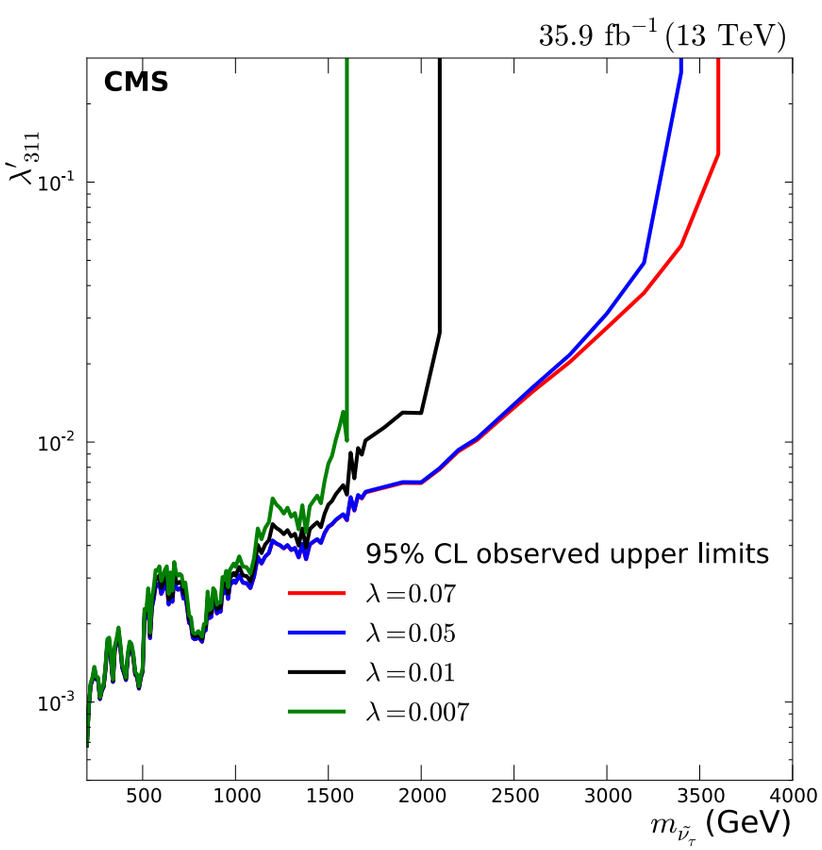
~New

EXO-16-058

- Results are interpreted in models with Lepton Flavour Violation
  - A heavy Z′ with LFV: **m(Z′)>4.4 TeV** where $\mathcal{B}(Z' \to e\mu)=10\%$
  - τ sneutrino in RPV SUSY: **m(X) > 1.7, 3.8 TeV** for RPV couplings $\lambda_{132}=\lambda_{231}=\lambda'_{311}=0.01$, 0.1
  - Non-resonant QBH (not shown here)
- In narrow width approximation the σ×BR scales with the RPV coupling
  - Using this information and observed bounds, limit contours in the $(M(\tilde{\nu}_\tau),\lambda'_{311})$ plane can be produced as a function of a fixed value of $\lambda_{132}=\lambda_{231}$





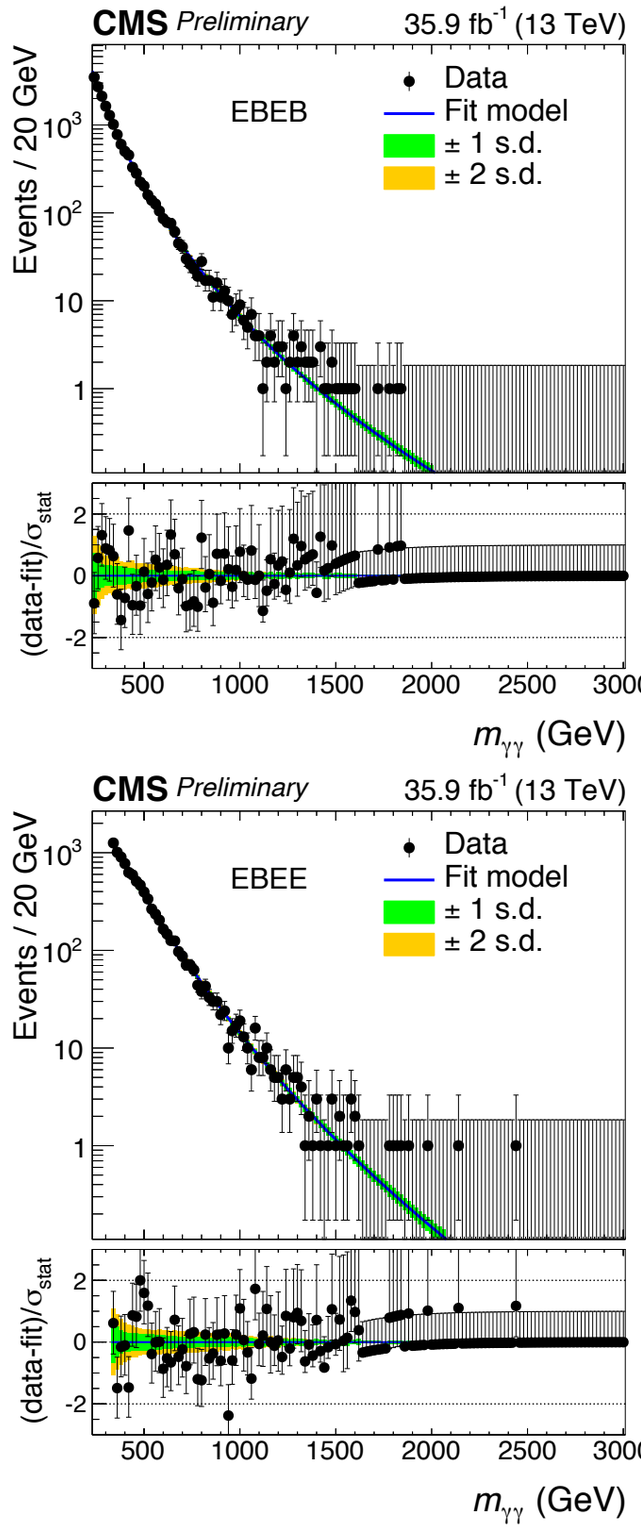


6. $X \rightarrow \gamma\gamma$

~New

EXO-17-017

- Search for resonant production of photon pairs using 36 fb^{-1} **(all 2016)**
  - A very clean final state without additional activity in the direction of the two photons
- Three values of the relative width Γ_X/m_X are used as benchmarks: 1.4×10^{-4}, 1.4×10^{-2}, and 5.6×10^{-2}
- Selection:
  - Photons are required to have $p_T>75$ GeV
  - At least one photon in the barrel
- Events are categorised depending on the location of the two photons
- A fit is performed to the invariant mass spectra to determine the compatibility of the data with the background-only and the signal+background hypotheses
- Results are interpreted in terms of a spin-2 RS graviton and spin-0 heavy Higgs resonance

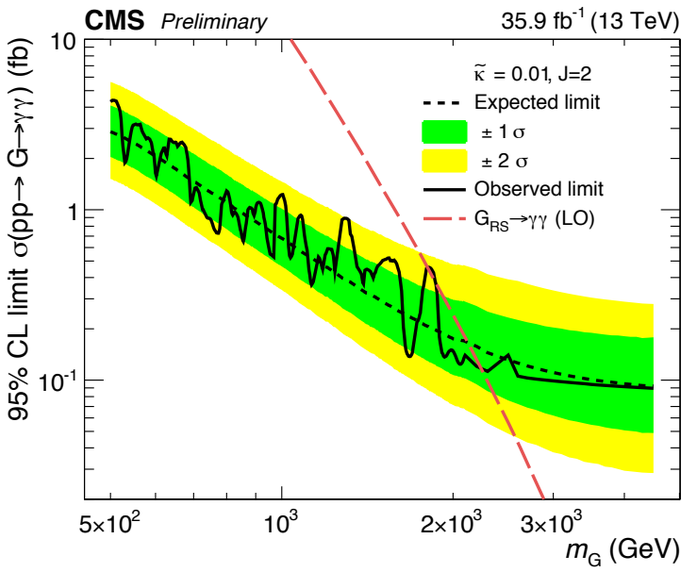


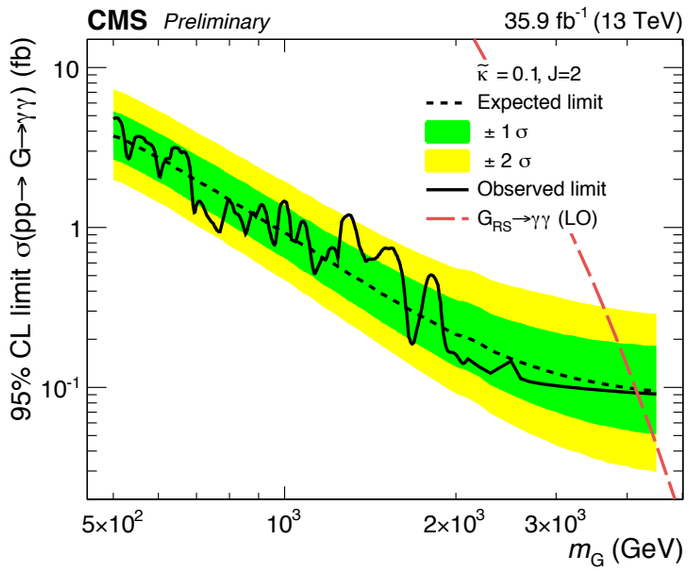
6. X→γγ

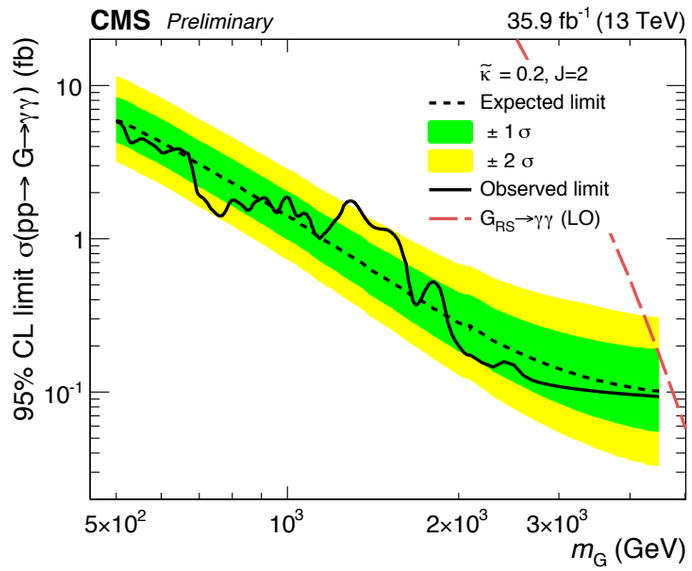
~New

EXO-17-017

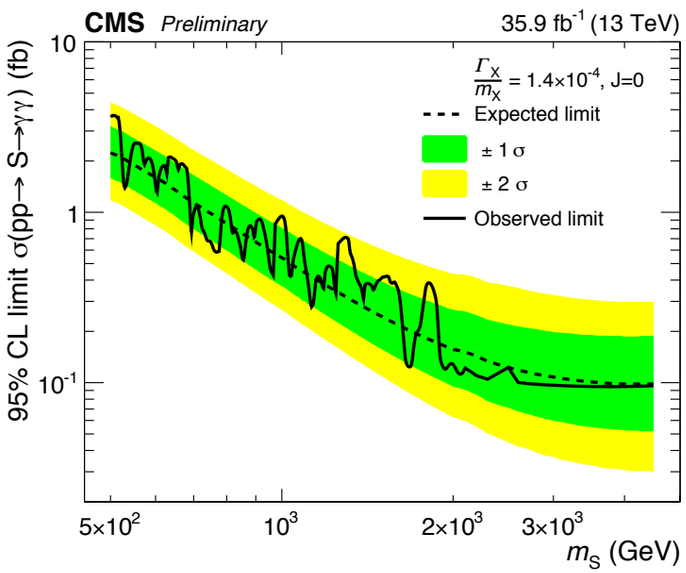
- Lower limits on the mass of the RS graviton are set as:
  - **$m(RS_G)$>2.1, 4.1, 4.6 TeV for $\tilde{k}$=0.01, 0.1, 0.2**

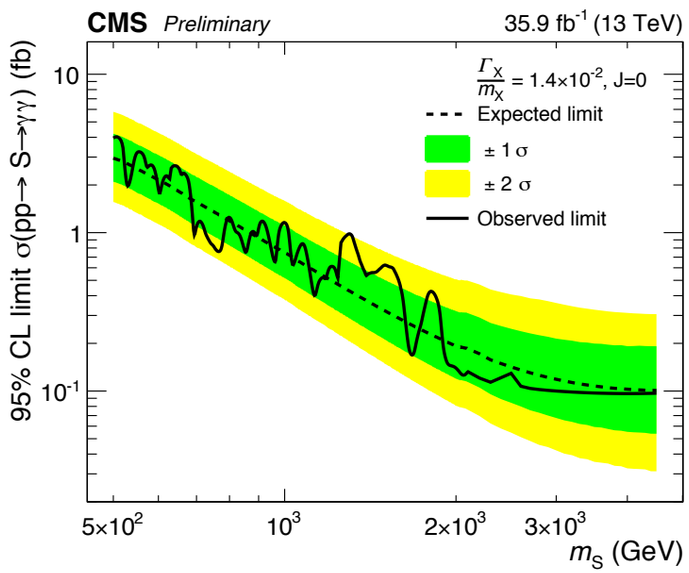


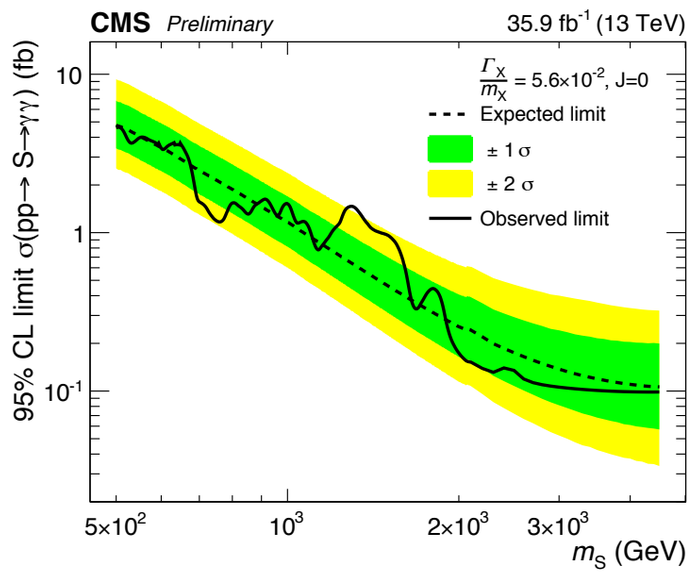




- Limits are also set for spin-0 resonances which differ due to detector acceptance and production mechanism

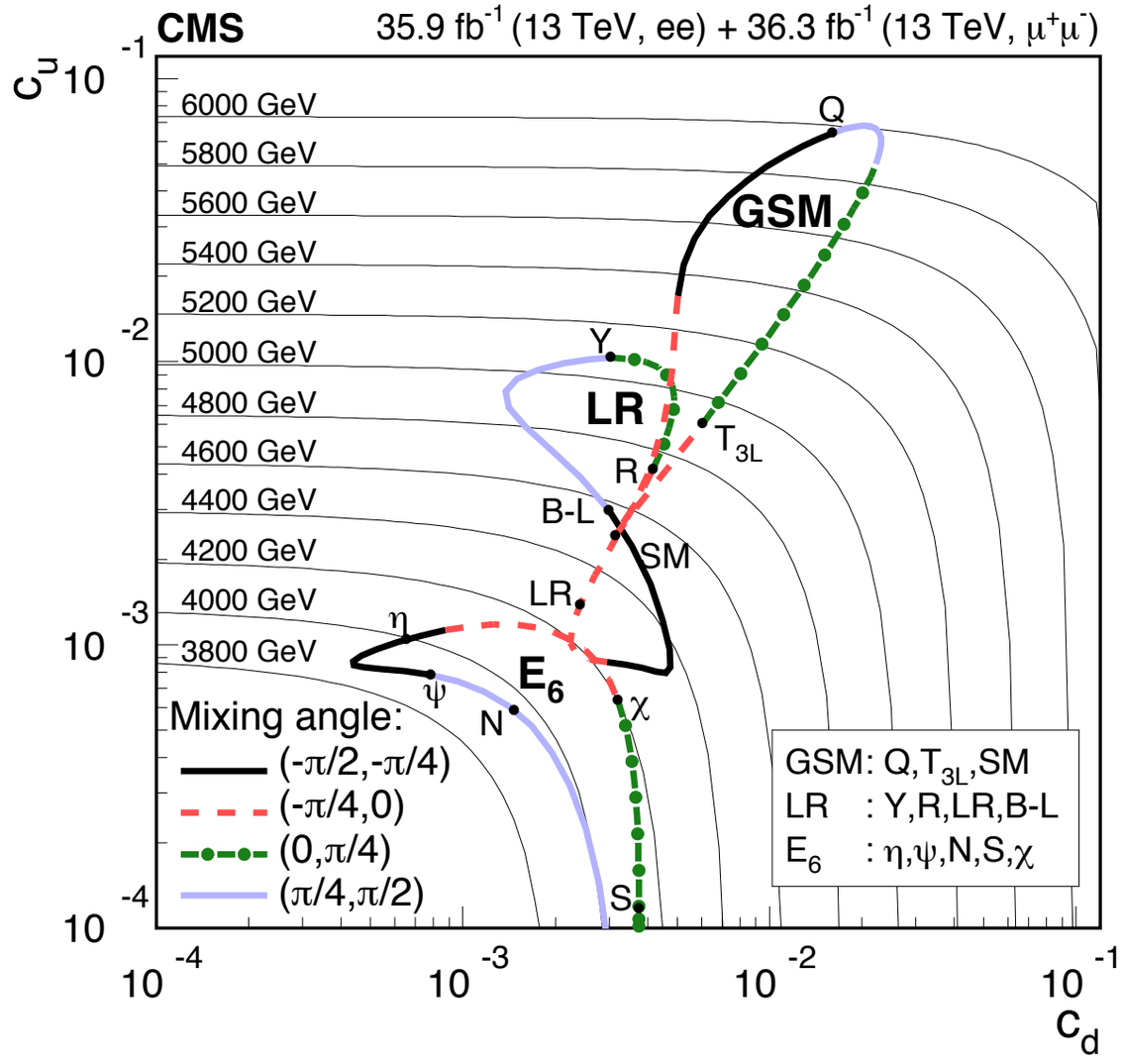






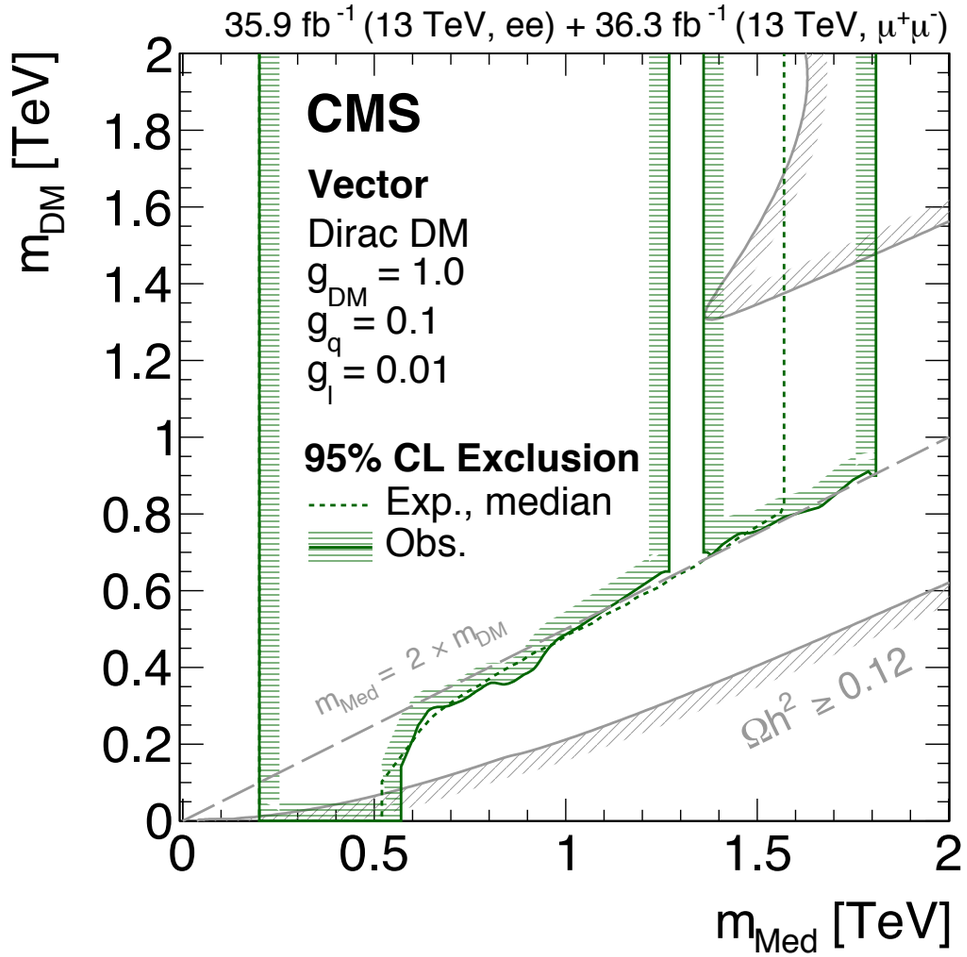
Reinterpretations

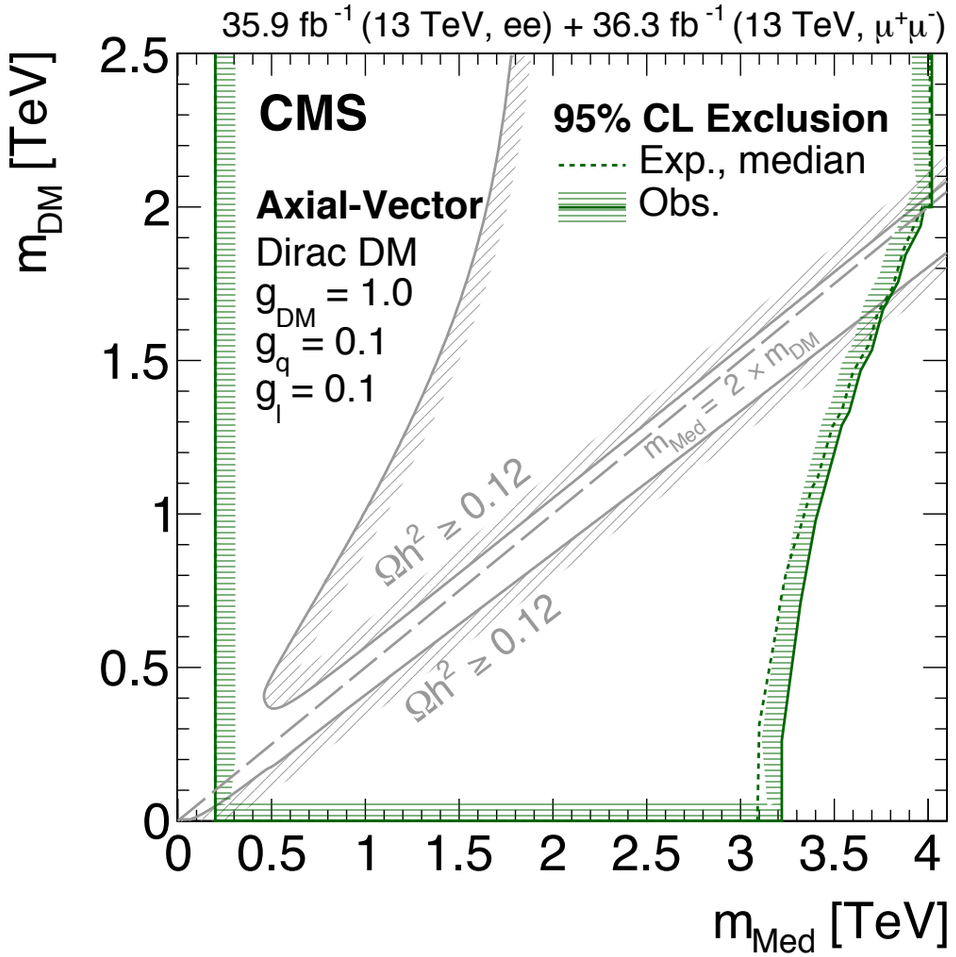
- Many of the results from these analyses are performed in a manner to allow reinterpretation
- e.g. 1. $Z' \rightarrow \ell\ell$ (ℓ=e/μ):
  - The limits are produced using only the Z′ peak allowing for easy reinterpretation
  - Limits are recast on the coupling parameters



Reinterpretations

- e.g. 1. $Z' \rightarrow \ell\ell$ (ℓ=e/μ):
  - Easy reinterpretation is then possible such as within a simplified Dark Matter (DM) model
  - Here we assume the DM particle is a Dirac fermion and its associated mediator is either vector or axial vector





Summary

- A summary of several analysis from CMS searching for new resonances with leptonic/photonic final states was presented using data collected from **2016** and **2017**

- No excesses above the SM have been observed and lower limits have be placed on the mass of resonances from various theoretical models

- Many results were produced in way to allow for easy reinterpretation

#	Analysis	Model	Mass (TeV)
1	$Z' \to \ell\ell$ (ℓ=e/μ)	SSM (Ψ)	4.5 (3.9)
2	$Z' \to ee$	SSM (Ψ)	4.7 (4.1)
3	$W' \to \ell\nu$ (ℓ=e/μ)	SSM	5.2
4	$W' \to \tau\nu$	SSM	4.0
5	$X \to e\mu$	RPV SUSY	1.7-3.8
6	$X \to \gamma\gamma$	RS_G	2.1-4.6