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

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Introduction

- 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
- 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 a clear bump on-top of a SM background

Introduction

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

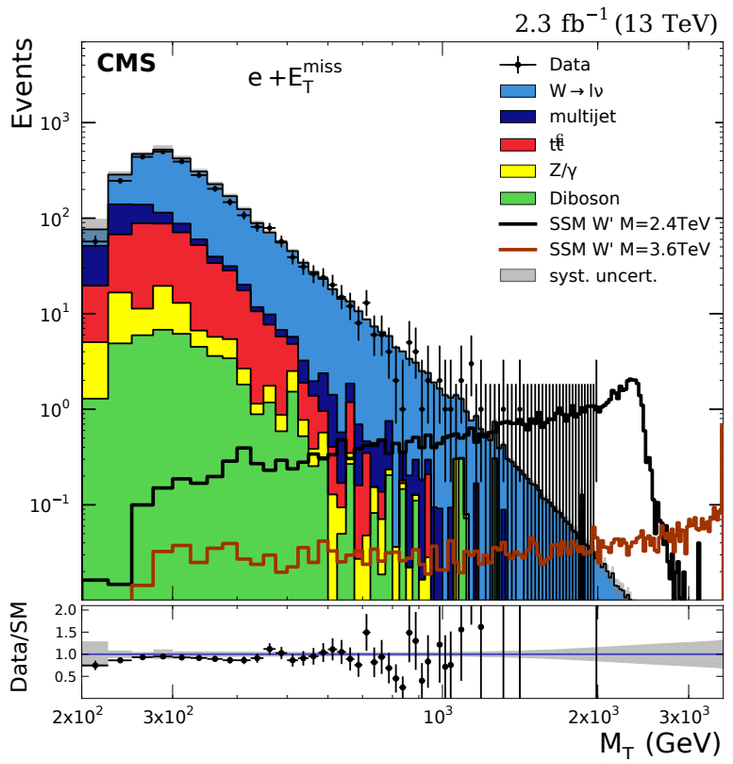
#	Analysis	Integrated Luminosity	Code
1	$W' \to \ell\nu$ (ℓ=e/μ)	2.3 fb^{-1} (2015)	EXO-15-006
2	$W' \to \ell\nu$ (ℓ=τ)	2.3 fb^{-1} (2015)	EXO-16-006
3	$Z' \to \ell\ell$ (ℓ=e/μ)	13 fb^{-1} **(2016)**	EXO-16-031
4	$Z' \to \ell\ell$ (ℓ=τ)	2.2 fb^{-1} (2015)	EXO-16-008
5	$X \to e\mu$	2.7 fb^{-1} **(2016)**	EXO-16-001
6	$X \to Z\gamma$	36 fb^{-1} **(2016)**	EXO-17-005
7	$X \to \gamma\gamma$	12.9 fb^{-1} **(2016)** + 3.3 fb^{-1} (2015) + 19.7 fb^{-1} (Run I)	EXO-16-027
	$q^* \to \gamma J$	See Giorgia's Talk	EXO-16-015

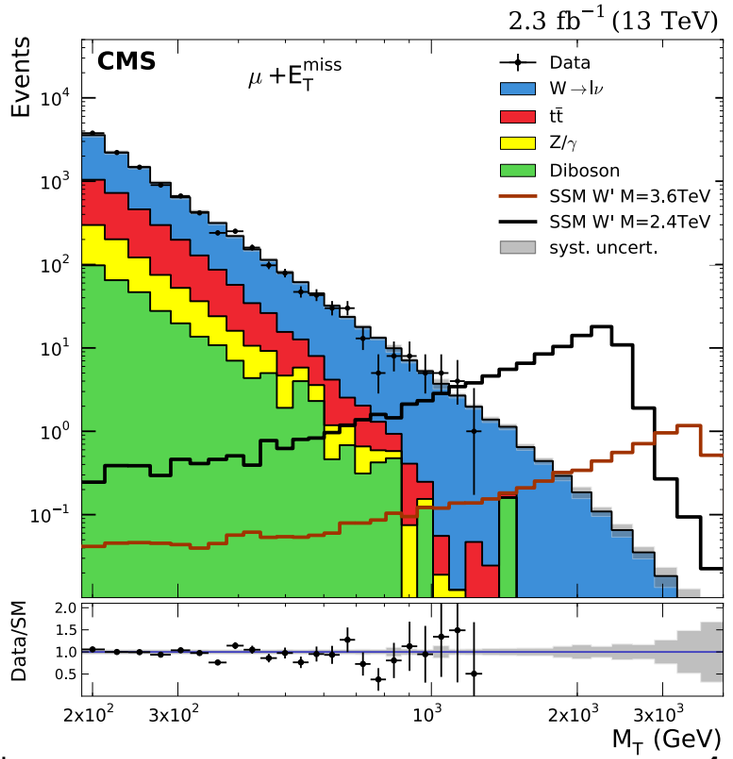
- Full list of CMS Exotica results are available here

1. $W' \rightarrow \ell\nu$ (ℓ=e/μ)

EXO-15-006

- Searching for a highly energetic electron or muon along with missing energy using 2.3 fb^{-1} (2015)
- Uses the discriminating variable: transverse mass, $M_T = \sqrt{2p_T^\ell E_T^{miss}(1-\cos[\Delta\phi(\vec{p}_T^{\,\ell}, \vec{p}_T^{\,miss})])}$
- Dominant and irreducible background is $W \rightarrow \ell\nu$
  - Pythia 8.2 MC generated at LO, LO→NNLO mass-dependant K factor used (FEWZ 3.1)
- pT>130 (53) GeV for electron (muon)
  - Events with additional electrons (muons) with pT> 35 (25) GeV are excluded

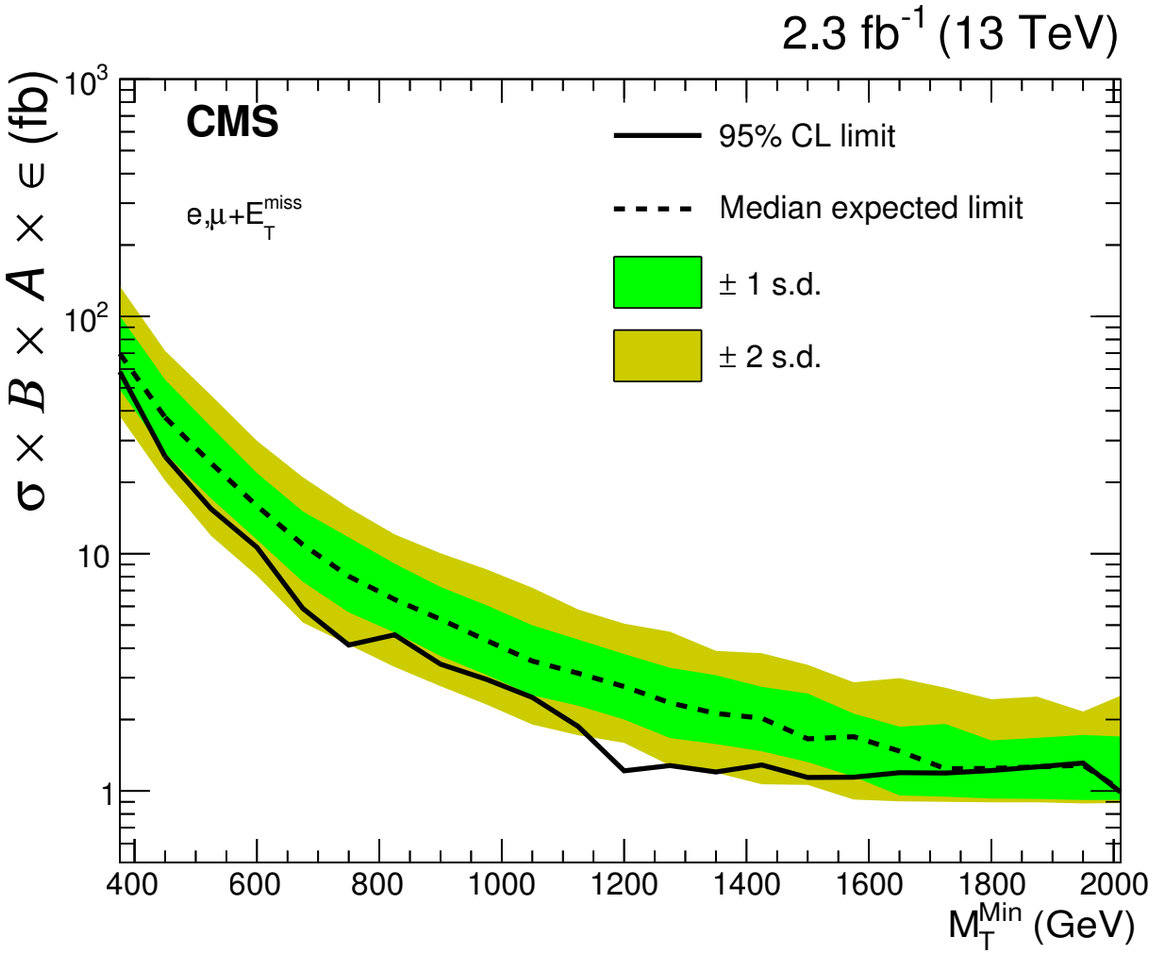




1. $W' \to \ell\nu$ (ℓ=e/μ)

EXO-15-006

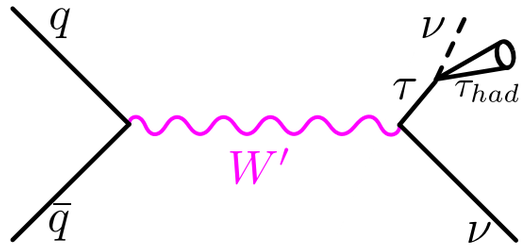
- With no observed excess with respect to the SM, lower limits can be placed on the mass of the W′
  - **$m(W'_{SSM})>4.1$ TeV**
  - **Model independent** cross section × branching fraction **limits** as a function of the lower M_T threshold are also produced



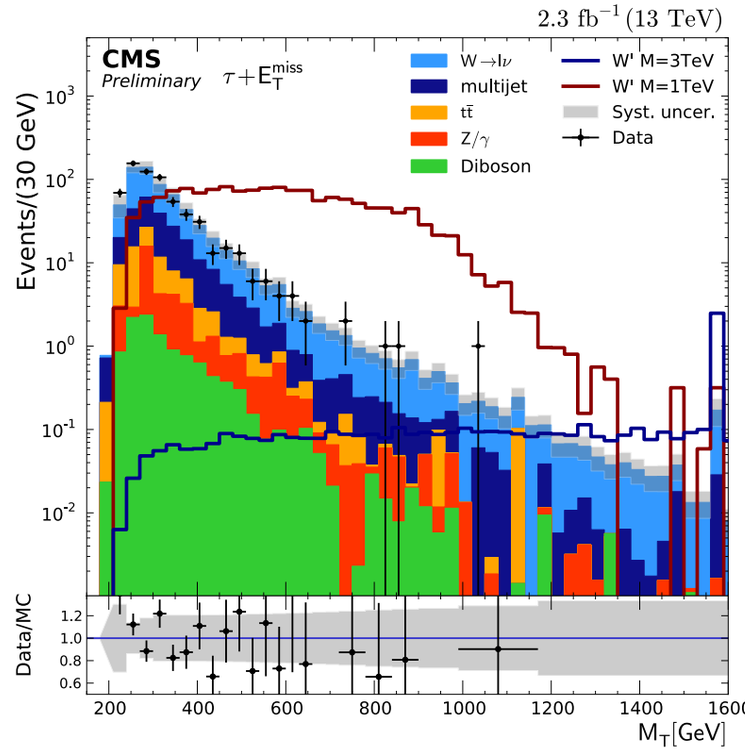
2. $W' \rightarrow \ell\nu$ ($\ell=\tau$)

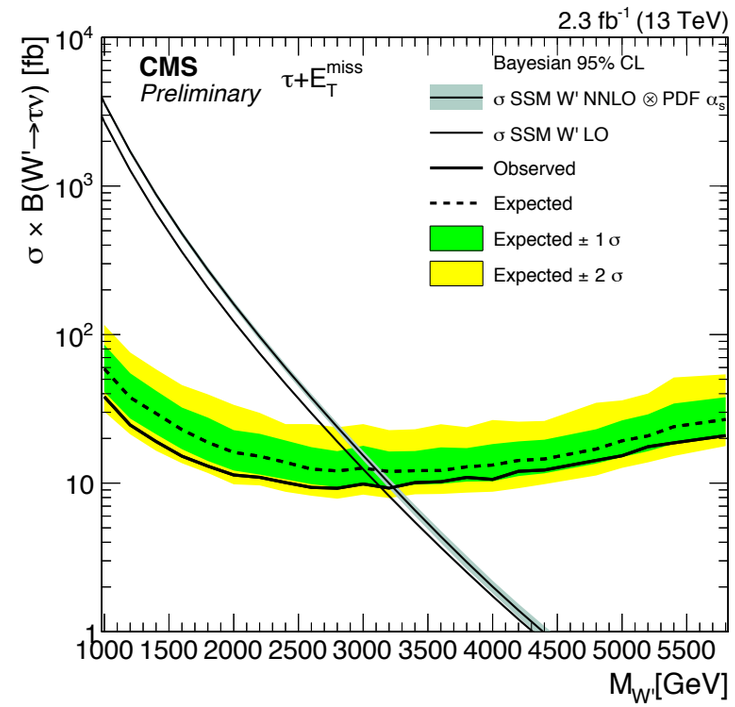
EXO-16-006

- Search for $W' \rightarrow \tau\nu$ using 2.3 fb^{-1} (2015)



  - Hadronic decays of the tau result in low charged hadron multiplicity
  - Leptonically decaying taus cannot be distinguished from $W' \rightarrow \ell\nu$ ($\ell=e/\mu$) and are covered by that analysis
  - M_T is again used as a discriminator variable
  - Similarly to $W' \rightarrow \ell\nu$ ($\ell=e/\mu$) limits are produced in a **model independent way**
    - **$m(W'_{SSM})>3.3$ TeV**

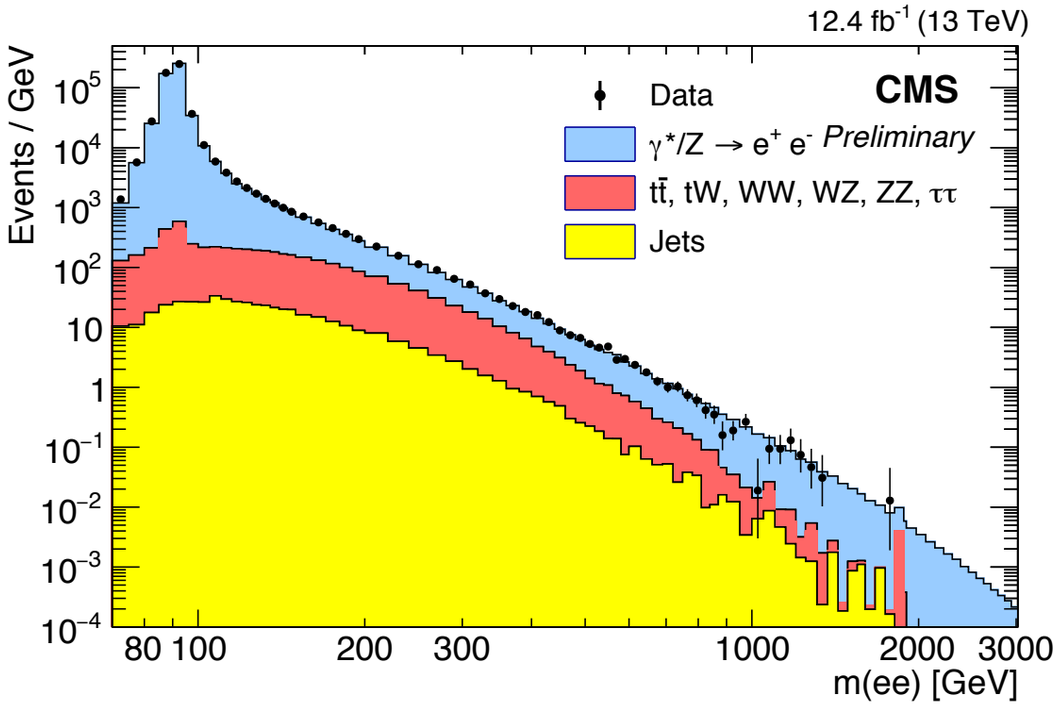


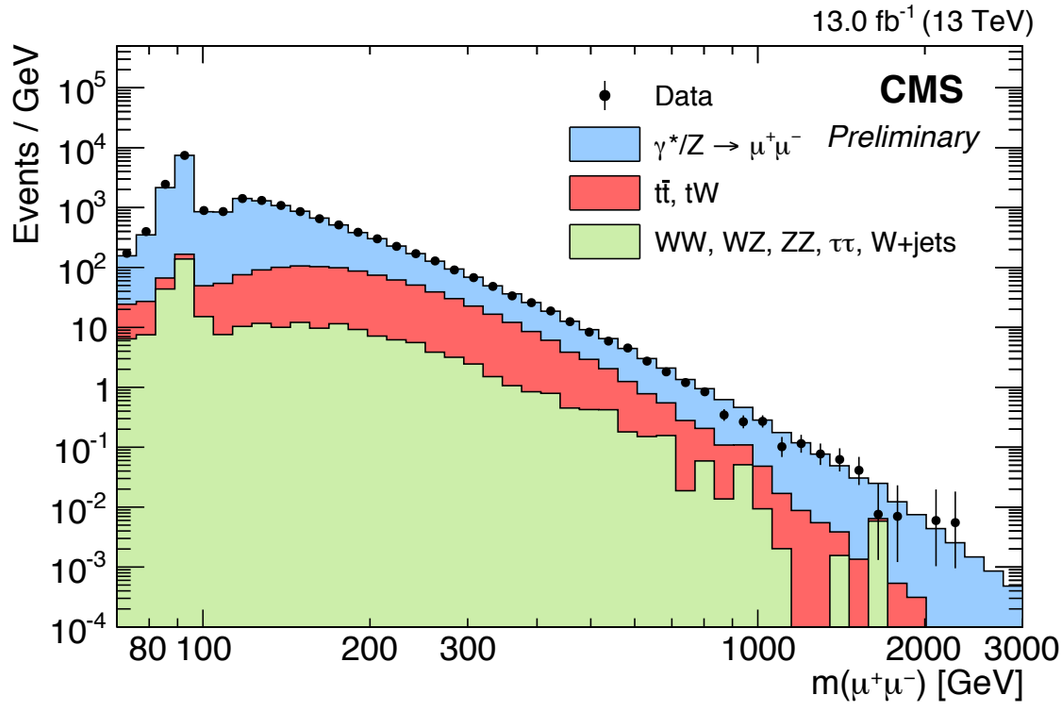


3. $Z' \rightarrow \ell\ell$ (ℓ=e/μ)

EXO-16-031

- An inclusive search for a new resonance using 13 fb^{-1} **(2016)**
  - The MC background is normalised to the Z peak
  - The amount of jet background is estimated from data
- Muons are efficiently reconstructed, which leads to placing stronger limits on production
- Electrons provide extremely good resolution at high p_T which is useful for discoveries





3. $Z' \rightarrow \ell\ell$ (ℓ=e/μ)

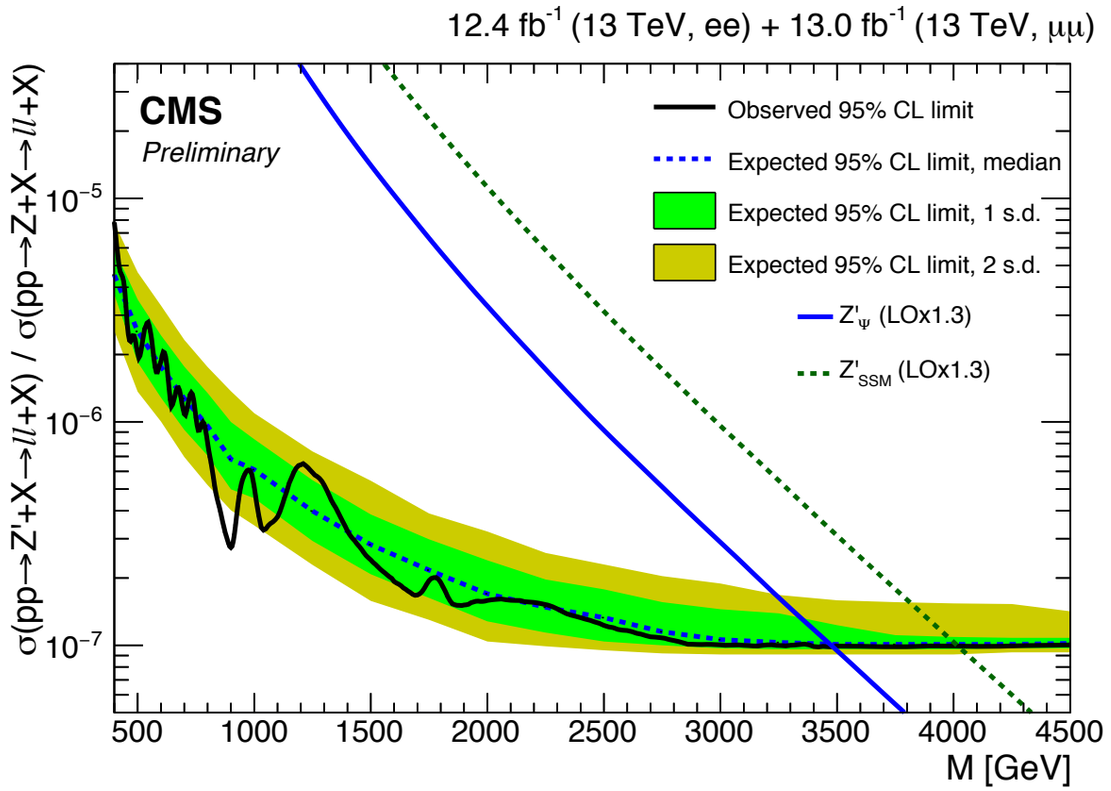
EXO-16-031

- 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

- No significant deviations from the SM
  - Limit on **$m(Z'_{\psi})$>3.5 TeV**
  - Limit on **$m(Z'_{SSM})$>4.0 TeV**

- The limits are produced using only the Z′ peak which allows for **easy reinterpretation,** such as within Dark Matter models



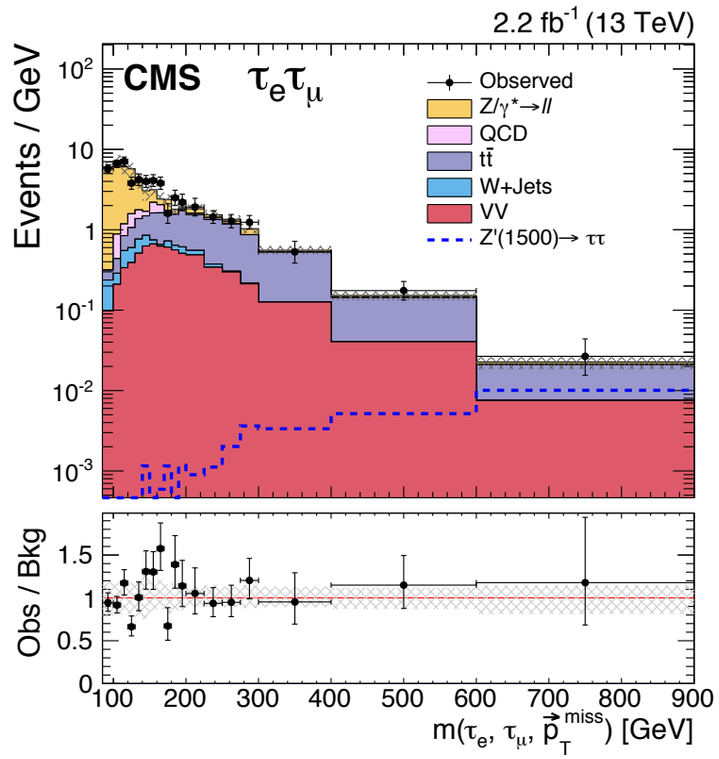
4. $Z' \rightarrow \ell\ell$ ($\ell = \tau$)

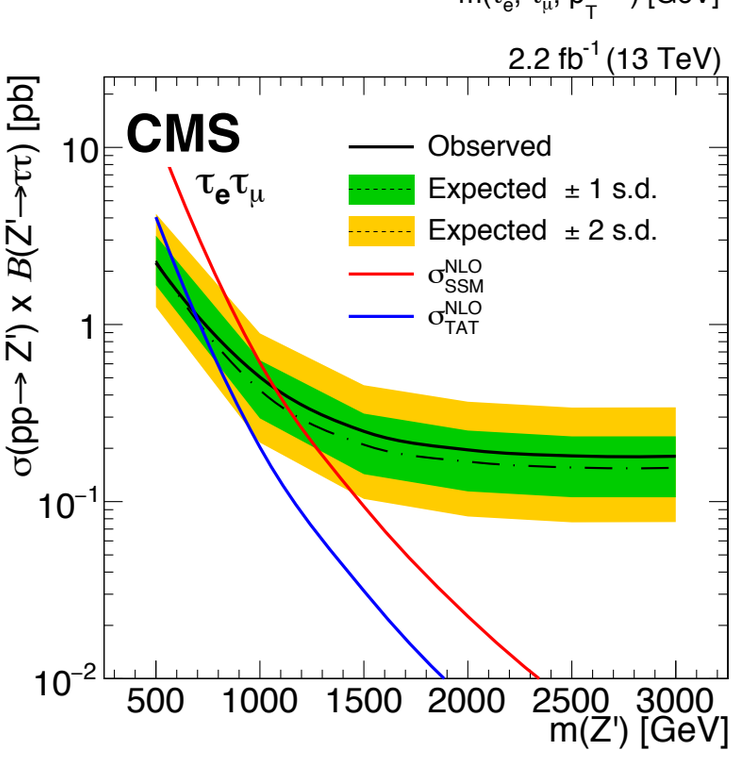
EXO-16-008

- Searching for a heavy resonance decaying into two taus using 2.2 fb^{-1} (2015)
  - Probing connections to the **third generation**
- Offline p_T cut of 35 (40) GeV for electrons (muons) and 20 (60) GeV for τ_h in $\tau_\ell\tau_h$ ($\tau_h\tau_h$) channel
  - Taus are required to be back to back
- Mass value is reconstructed using taus and missing transverse momentum vector

$$m(\tau_1, \tau_2, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}) = \sqrt{(E_{\tau_1} + E_{\tau_2} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})^2}.$$

- Also set limits on models in which the resonance preferentially decays to taus such as the topcolor-assisted technicolor (TAT)
  - Limit on **$m(Z'_{SSM})>2.1$ TeV**
  - Limit on **$m(Z'_{TAT})>1.7$ TeV**





5. X→eμ

EXO-16-001

- Searching for heavy resonances decaying into eμ using 2.7 fb^{-1} **(2016)**

- **Lepton Flavour Violation** may occur in models including τ sneutrino production in R-parity violating (RPV) supersymmetry (SUSY)

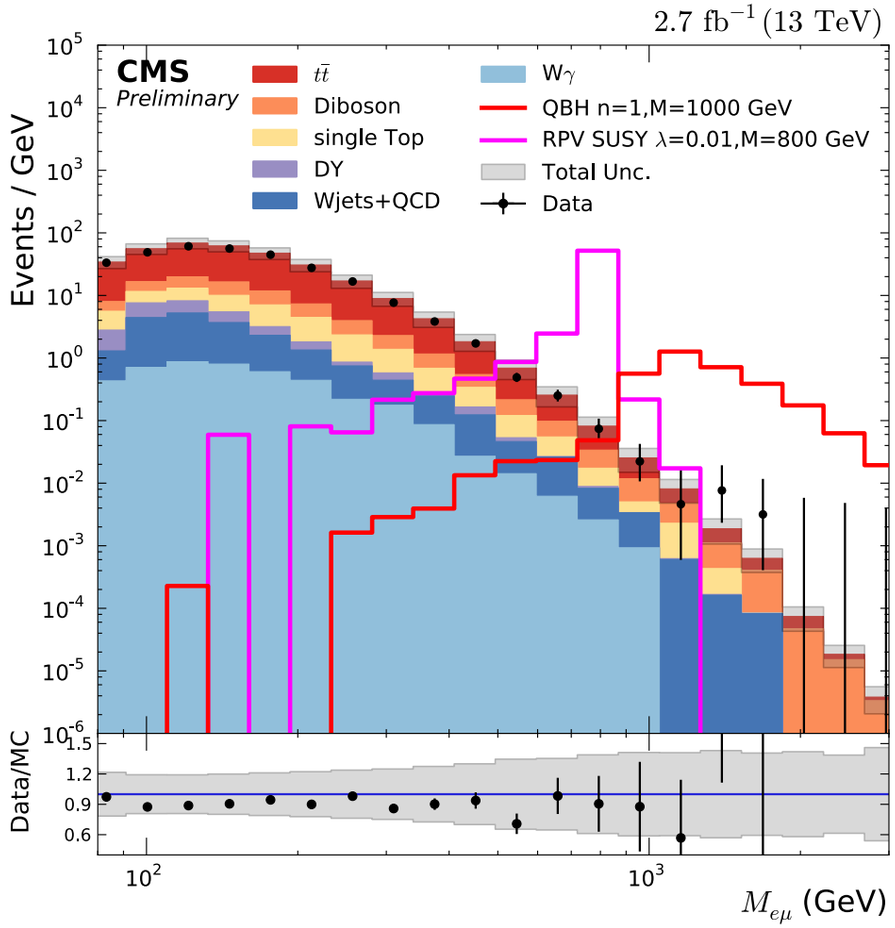
  - RPV SUSY also **naturally generate non-zero neutrino masses**

- 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) and $M_{e\mu} \geq 200$ GeV

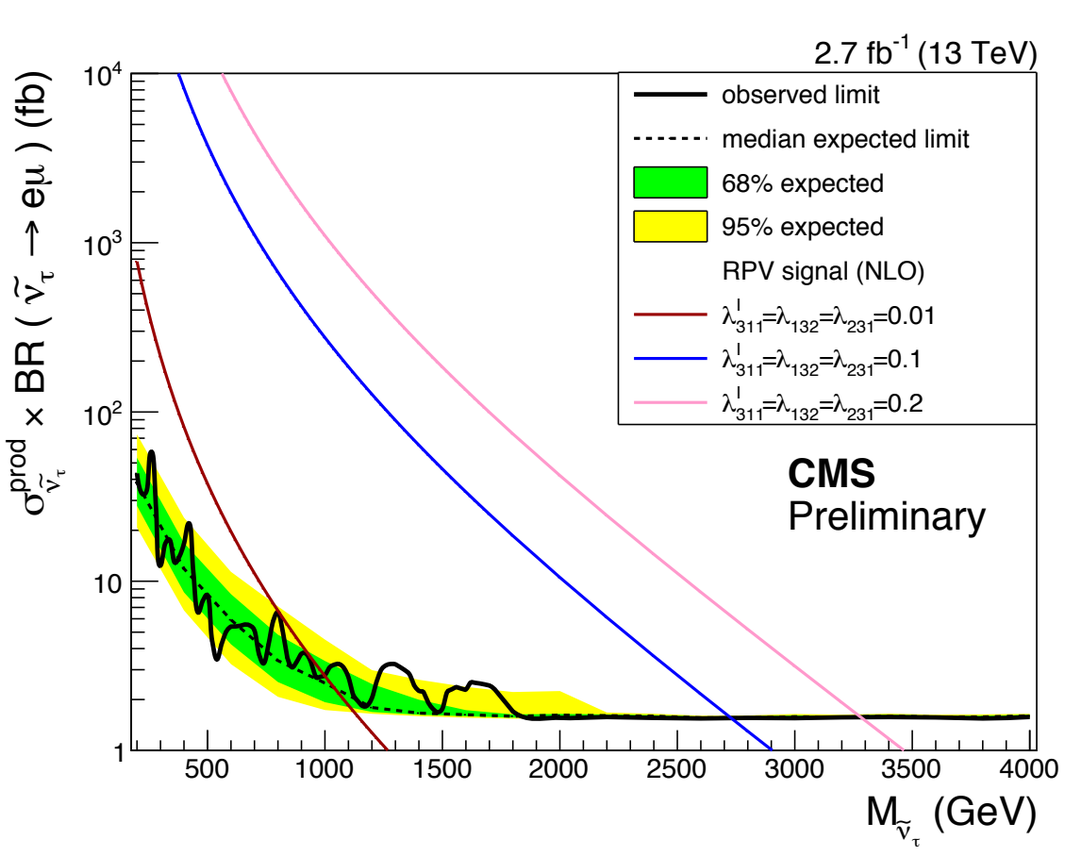
- SM background from processes with two prompt leptons as well as Wγ is obtained from MC while W+Jets and QCD multijet backgrounds are calculated using fake rate studies in data

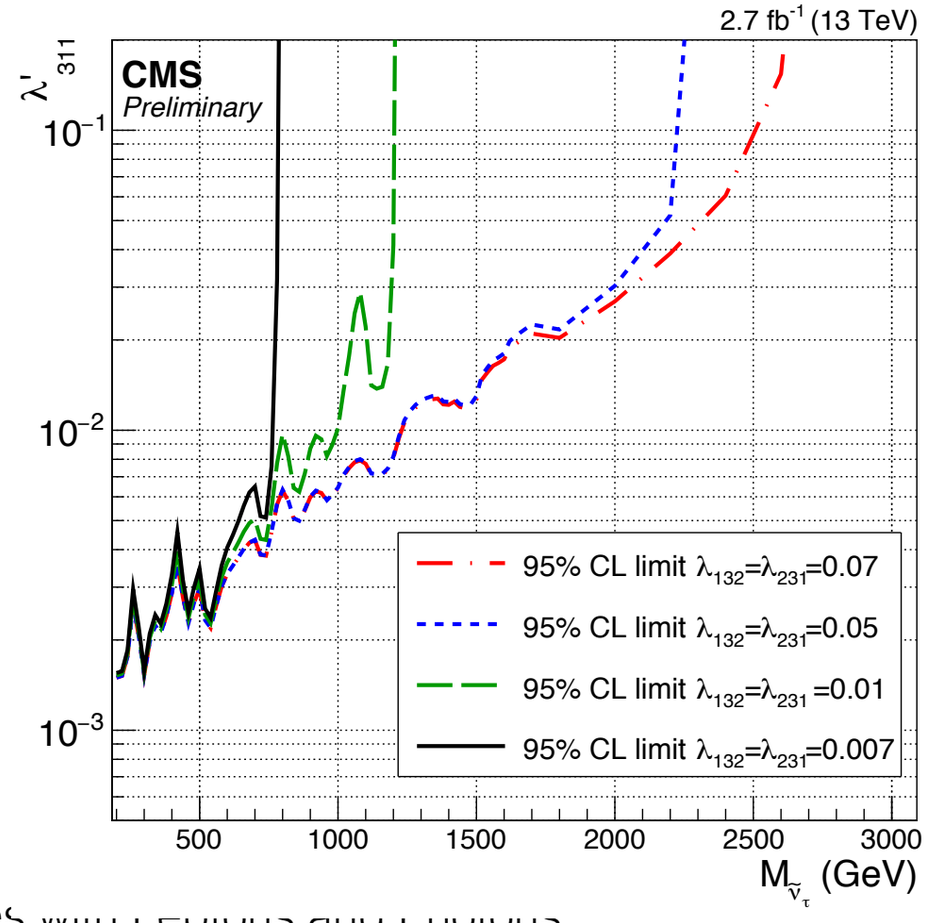


5. X→eμ

EXO-16-001

- **m(X) > 1.0, 2.7, 3.3 TeV** for RPV couplings $\lambda_{132}=\lambda_{231}=\lambda'_{311}=0.01$, 0.1, 0.2
- Also interpreted in 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 $\lambda_{132}=\lambda_{231}$

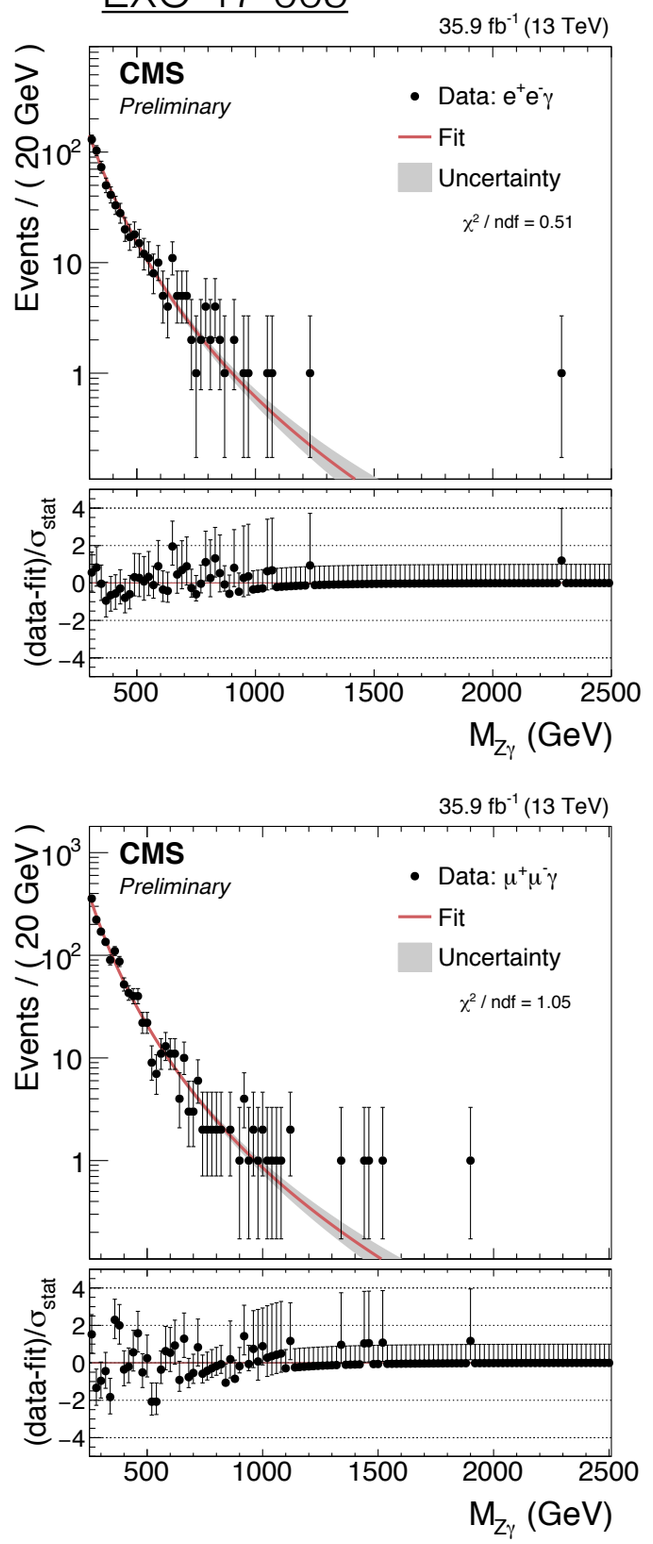




6. X→Zγ

- Searching for a high mass resonance decaying to a Z boson and a photon using 36 fb^{-1} **(2016)**
  - **Sensitive to spin-1 resonances**
- The search is performed in **both** the **leptonic** and **hadronic** decay channels (where hadronic decays dominate sensitivity above 2 TeV)
- Leading electron (muon) should have pT > 65 (52) GeV; subleading electron (muon) pT > 10 (10) GeV
- All jets are required to have pT > 200 GeV and |η| < 2.0
- The photon is required to satisfy pT > 65 (40) GeV in dielectron (dimuon) channels
- Leptonic channels are dominant at low mass

EXO-17-005

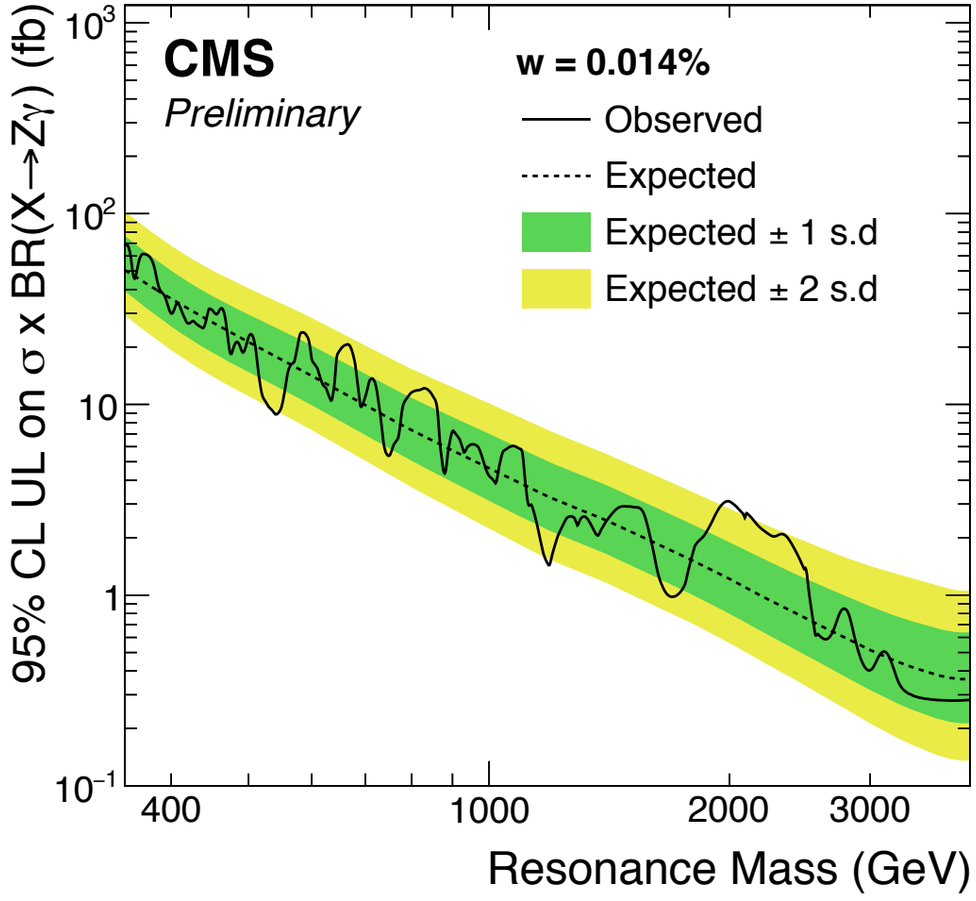


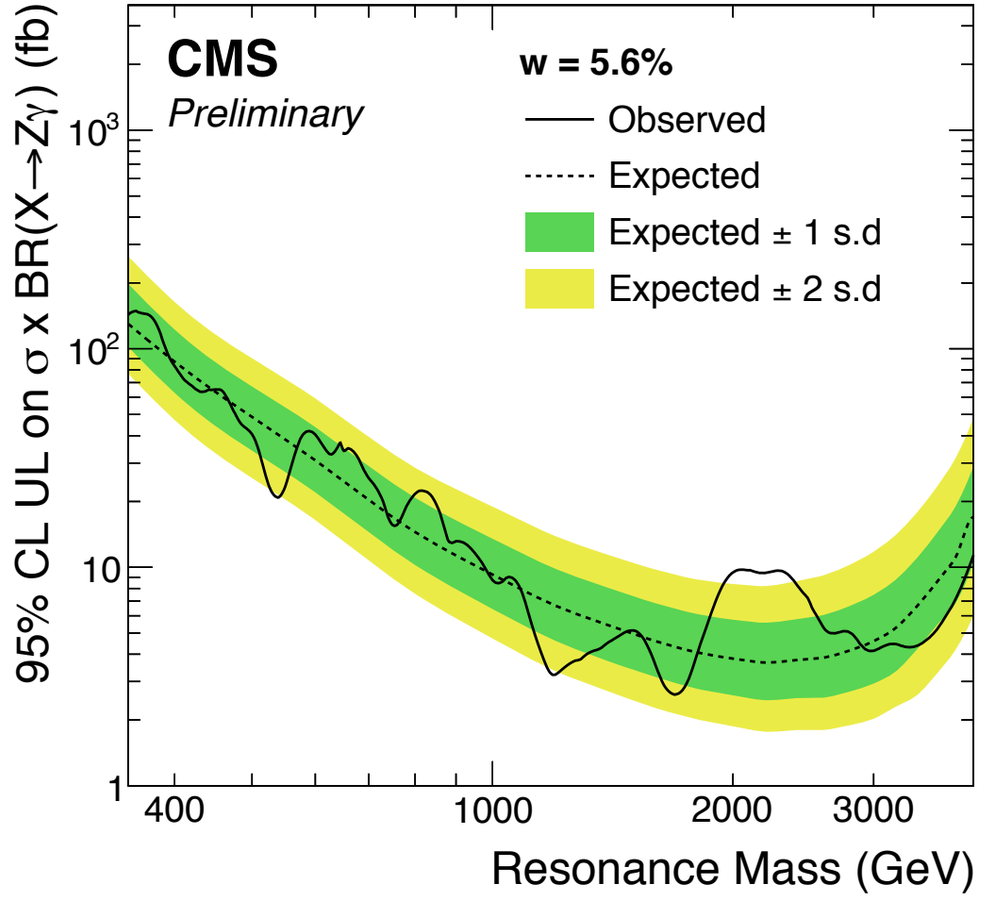
6. X→Zγ

EXO-17-005

- The leptonic and hadronic channels are combined during the statistical analysis

- Limits are set on both narrow spin-0 resonances and wide spin-0 resonances up to **m(X) > 4 TeV**

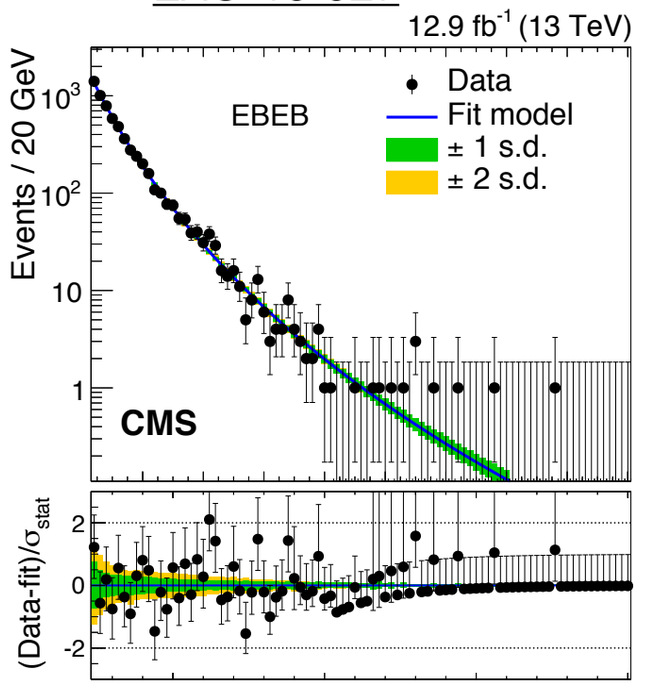




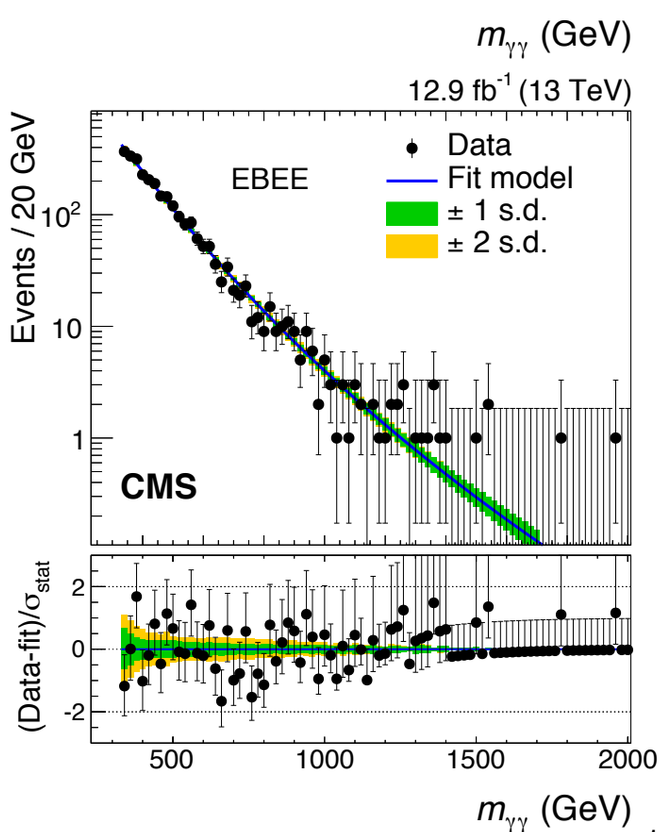
7. $X \rightarrow \gamma\gamma$

EXO-16-027

- Search for resonant production of photon pairs using 12.9 fb^{-1} **(2016)** + 3.3 fb^{-1} (2015) + 19.7 fb^{-1} (Run I)
  - A **very clean 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}; with $0.5<m_X<4.5$ TeV



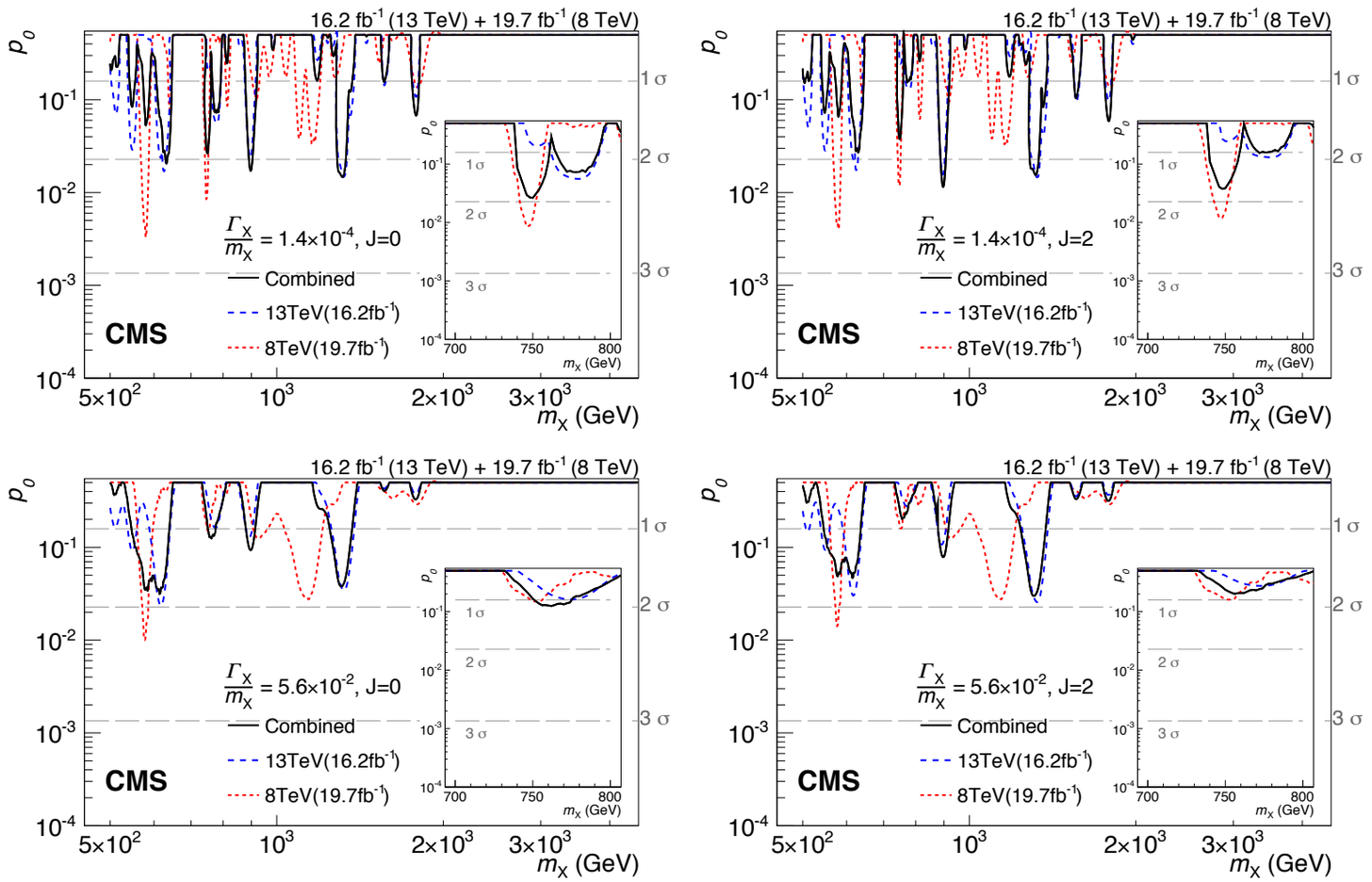
- Photons are required to have pT > 75 GeV
- Events are categorised depending on the location of the two photons
- A fit is performed to the invariant mass spectra to determine the compatibility of the data with the background-only and the signal+background hypotheses

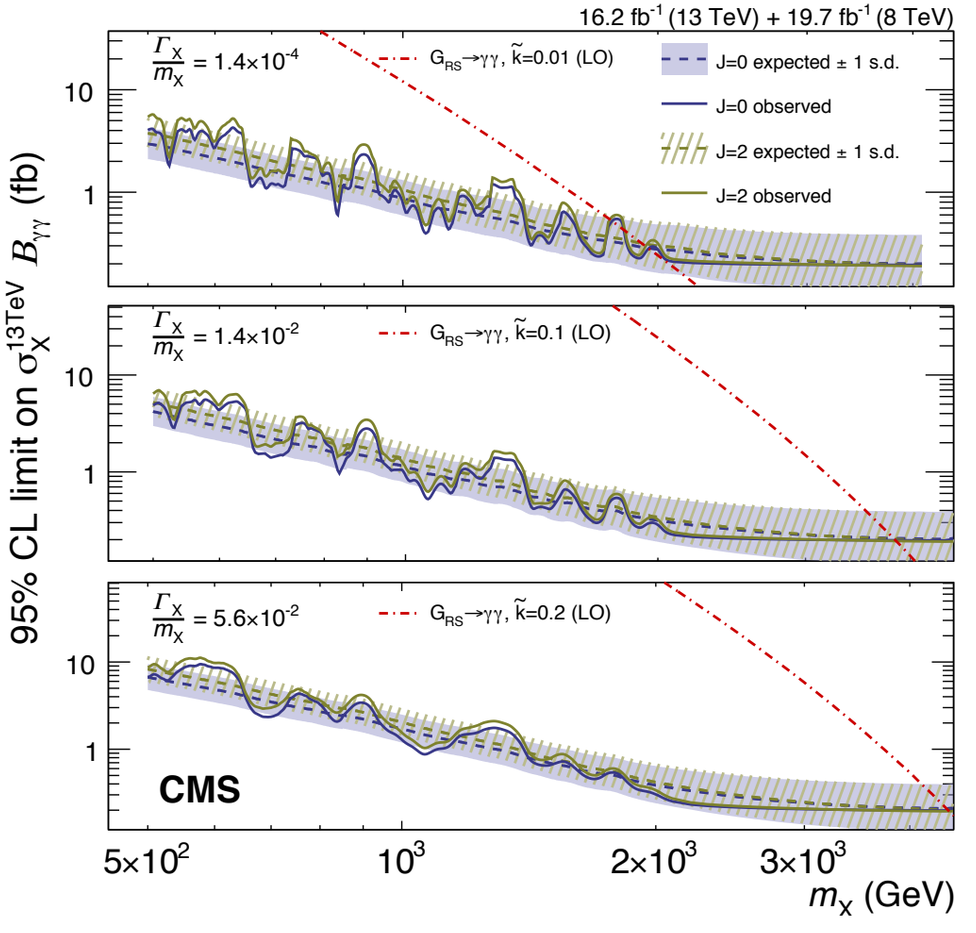


7. $X \rightarrow \gamma\gamma$

EXO-16-027

- Compatibility of the observation with the background-only hypothesis is evaluated by computing the background-only p-value
- Lower limits on the mass of the RS graviton are set as:
  - **$m(RS_G)>3.85$ (4.45) TeV for $\tilde{k}=0.1$ (0.2)**
  - **$m(RS_G)>1.95$ TeV except for $1.75 < m(RS_G) < 1.85$ TeV for $\tilde{k}=0.01$**





Summary

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

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

#	Analysis	Model	Mass (TeV)
1	$W' \to \ell\nu$ (ℓ=e/μ)	SSM	4.1
2	$W' \to \ell\nu$ (ℓ=τ)	SSM	3.3
3	$Z' \to \ell\ell$ (ℓ=e/μ)	SSM (Ψ)	4.0 (3.5)
4	$Z' \to \ell\ell$ (ℓ=τ)	SSM (TAT)	2.1 (1.7)
5	$X \to e\mu$	RPV SUSY	1.0-3.3
6	$X \to Z\gamma$	Spin0	4.0
7	$X \to \gamma\gamma$	RS_G	1.95-4.45*

*Entire mass range not ruled out

Thanks!