# Search for high-mass resonances in the di-electron channel using the data collected by CMS in 2017


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- On behalf of CMS collaboration


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# Introduction

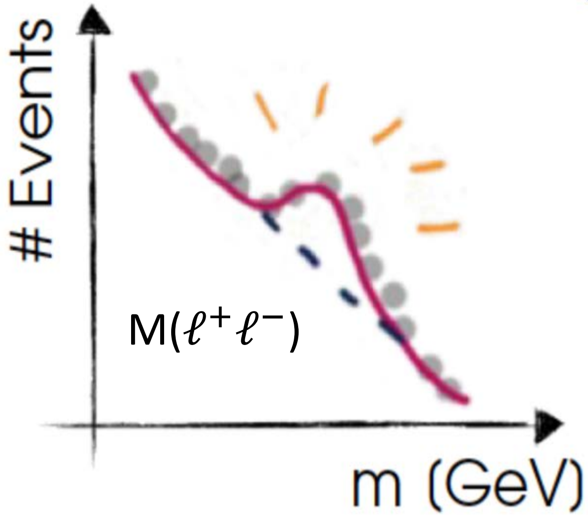


❑One of the most striking signatures of physics beyond the standard model (SM) would be the observation of a narrow resonance in the invariant mass spectrum of lepton pairs.

❑Many models designed to address the shortcomings of the SM predict such resonances at the TeV scale

- The sequential standard model $Z'_{SSM}$.
- The superstring mode $Z'_{\psi}$.

❑Strategy of the analysis: Looking for a "bump" in the $\ell^+\ell^-$ invariant mass distribution, particularly in the high mass tail.




❑Clean final state, with few background events.

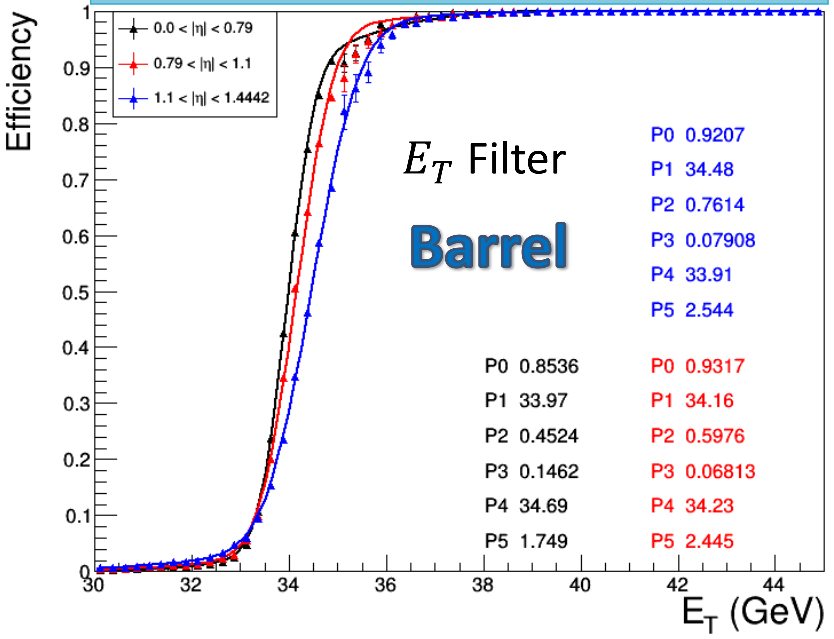
❖ It is a high priority analysis.

| Di-electron + di-muon 2016 data | $Z'_{SSM}$ (Obs / Exp) | $Z'_{\psi}$ (Obs / Exp) |
|---|---|---|
| CMS 2016 | 4.5 TeV / 4.5 TeV | 3.9 TeV / 3.9 TeV |
| ATLAS 2016 | 4.5 TeV / 4.5 TeV | 3.8 TeV / 3.7 TeV |

# Search strategy && Event selection

- Reconstructed electrons are required to pass the High-Energy-Electron-Pair (HEEP) selection, the official selection developed by CMS for high energy electron.
- Double electron trigger with lowest ET threshold is used.
- At least one electron should be in the barrel and no opposite charge requirement.

**Double electron trigger**



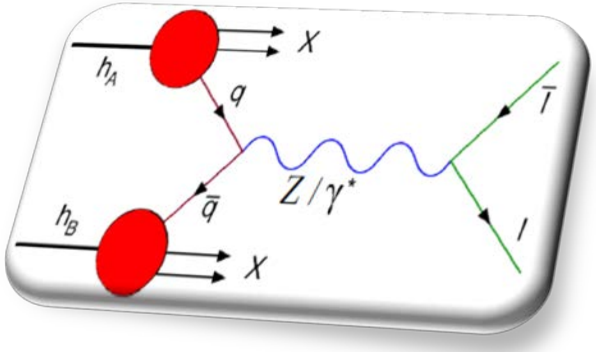

MC samples are normalized to data in the Z peak region

All $E_T$ **independent** effects are included in the normalization factor

All $E_T$ **dependent** effects are considered in the analysis

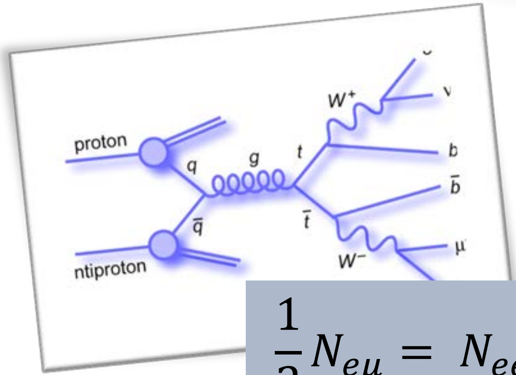
- Events are categorized to:
  - Barrel-Barrel events
    - Both electrons in the barrel part of the ECAL.
  - Barrel-Endcap events
    - One electron in the barrel part of the ECAL and another in the in the endcap part of the ECAL.

# Background




- The dominant and irreducible SM background arises from the Drell-Yan process. It is estimated with simulations.
- A cross check is performed by measuring the Drell-Yan cross section of the Z peak [60 GeV, 120 GeV].

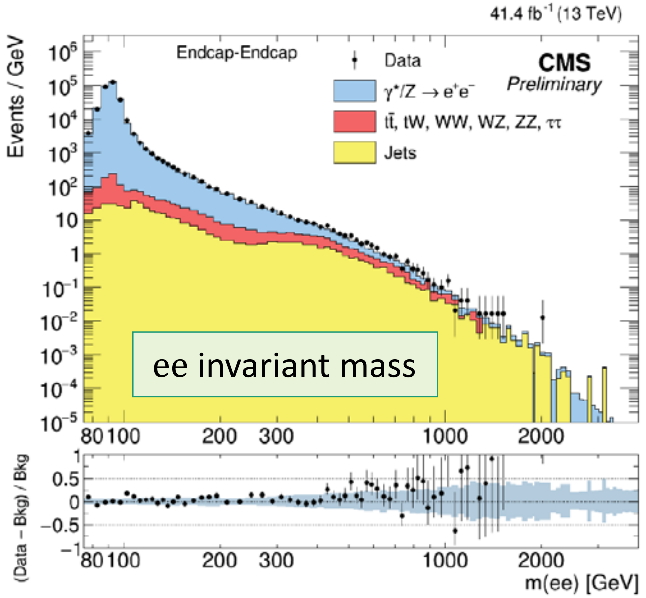
- Additional sources of background are processes which produce real prompt leptons where the two prompt leptons are from different particles. Includes $\mathrm{t\bar{t}, tW, WW, WZ, ZZ, Z \rightarrow \tau\tau}$ and it is predicted with simulations.



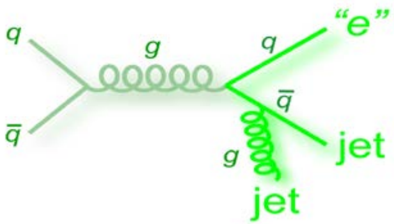

$$\frac{1}{2}N_{e\mu} = N_{ee} = N_{\mu\mu}$$

- The simulation predictions in these channels are compared to data in the $e\mu$ final state.

- Backgrounds arising from jets that are misidentified as electrons include W + jets and QCD processes are measured from data using the Fake Rate method.




- Validated in a control region enriched in jet background: when both leptons are **in the ECAL endcaps**.



# HEEP ID efficiency && Mass scale and resolution

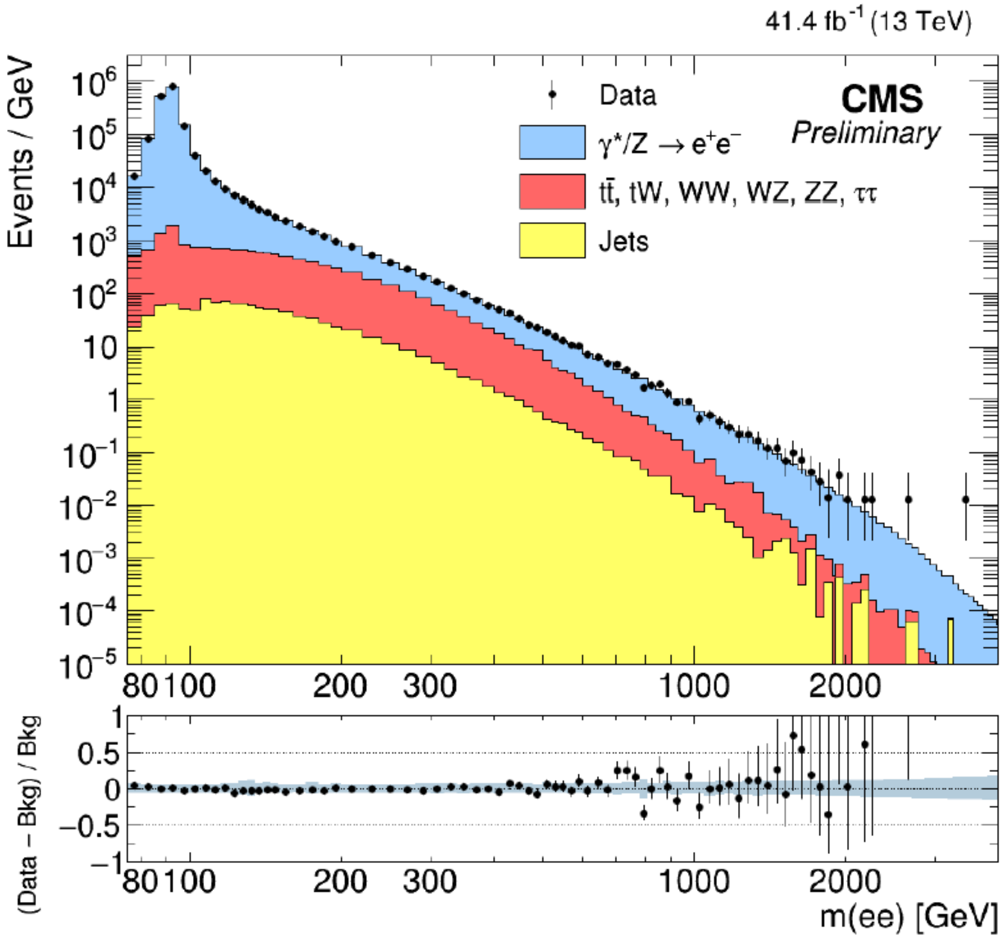
- HEEP ID is calculated with tag & probe method. The scale factor is calculated but not used in the main analysis ($E_T$ independent).

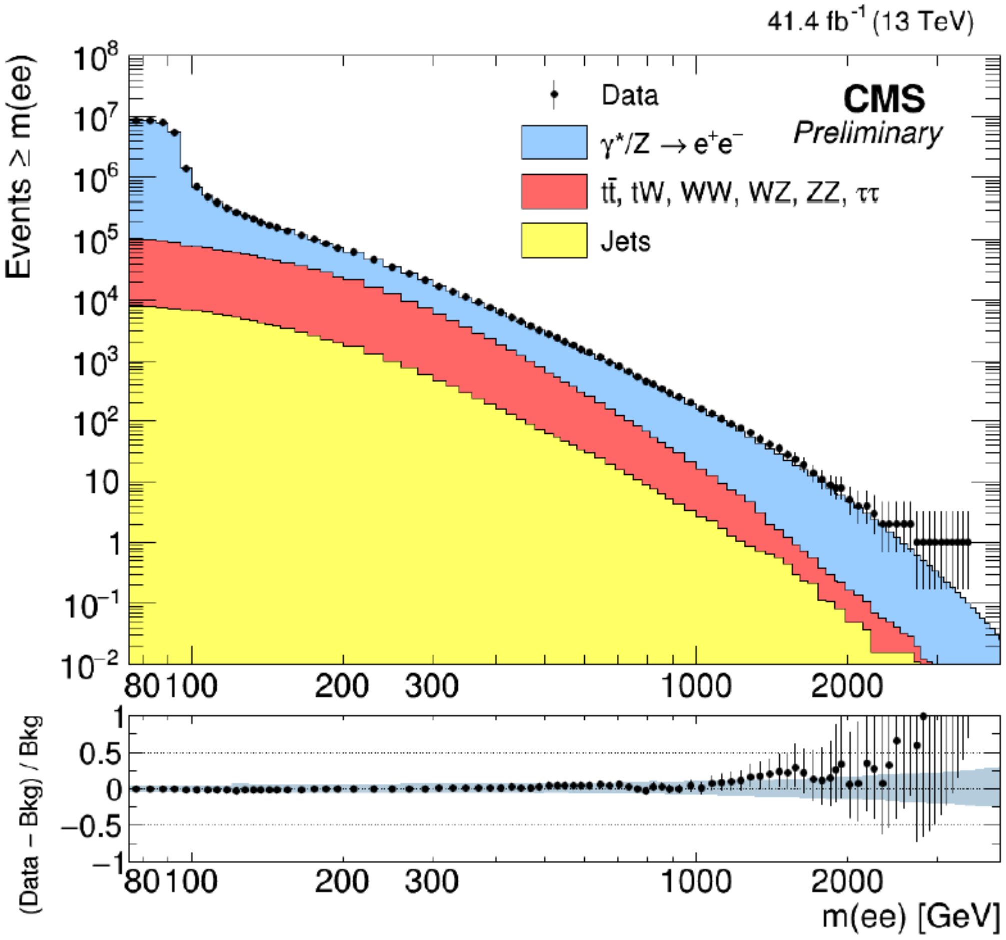
- We estimate mass scale and resolution in two steps:
  - 1- using data and MC at Z peak (80-100 GeV) .
    - Distributions are fitted with Breit-Wigner convoluted with double-sided Crystal Ball (dCB).
  - 2- using MC only for  high masses.
    - Distributions are fitted with double-sided Crystal Ball (dCB).

# Invariant mass distributions



- Data is consistent with backgrounds and no evidence for a significant deviation is observed.

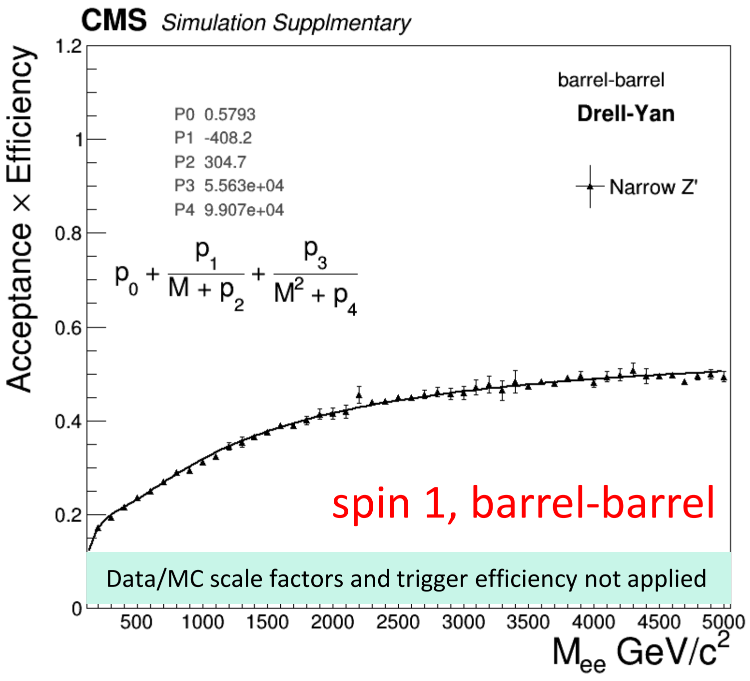


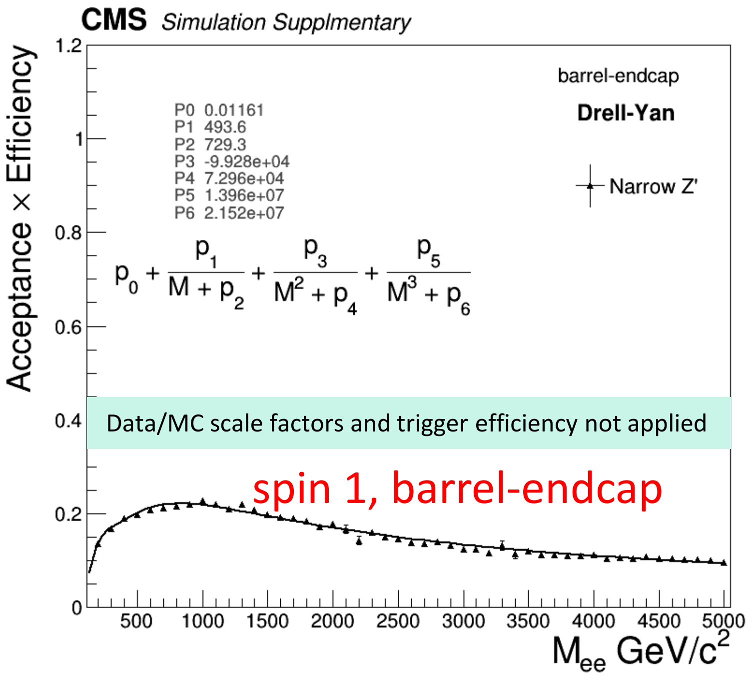



# Background and acc*eff parametrization

- The acceptance times efficiency curves for a spin-1 particle to be selected by the analysis in the barrel-barrel region and barrel-endcap region are shown.
- Background shape is parameterized from a fit to the SM expectation.

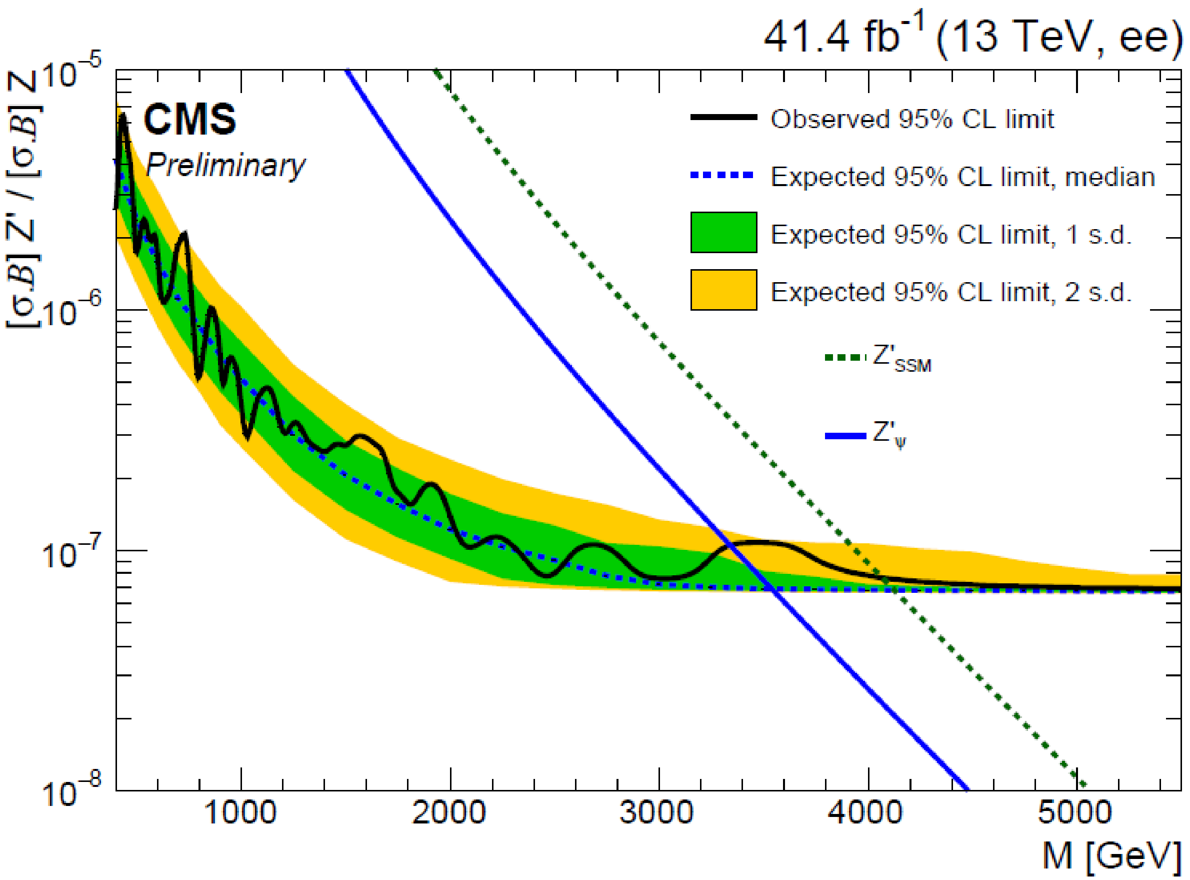
| $m_{ee}$ range [ GeV ] | Observed yield | Total background | DY | $t\bar{t}$ + other prompt bkgd | Multijet |
|---|---|---|---|---|---|
| 120 – 400 | 271776 | 280587 ± 18317 | 222377 ± 15713 | 53192 ± 3977 | 5018 ± 2509 |
| 400 – 600 | 4868 | 4850 ± 330 | 3268 ± 217 | 1455 ± 129 | 127 ± 63.5 |
| 600 – 900 | 1106 | 1058 ± 78 | 829 ± 63 | 203 ± 18 | 25 ± 12.5 |
| 900 – 1300 | 193 | 203 ± 18 | 176 ± 16 | 24 ± 3 | 3.5 ± 1.75 |
| 1300 – 1800 | 44 | 38 ± 4 | 35 ± 4 | 2.2 ± 0.6 | 0.7 ± 0.35 |
| > 1800 | 10 | 8.1 ± 1.2 | 7.8 ± 1.2 | 0.2 ± 0.0 | 0.1 ± 0.05 |

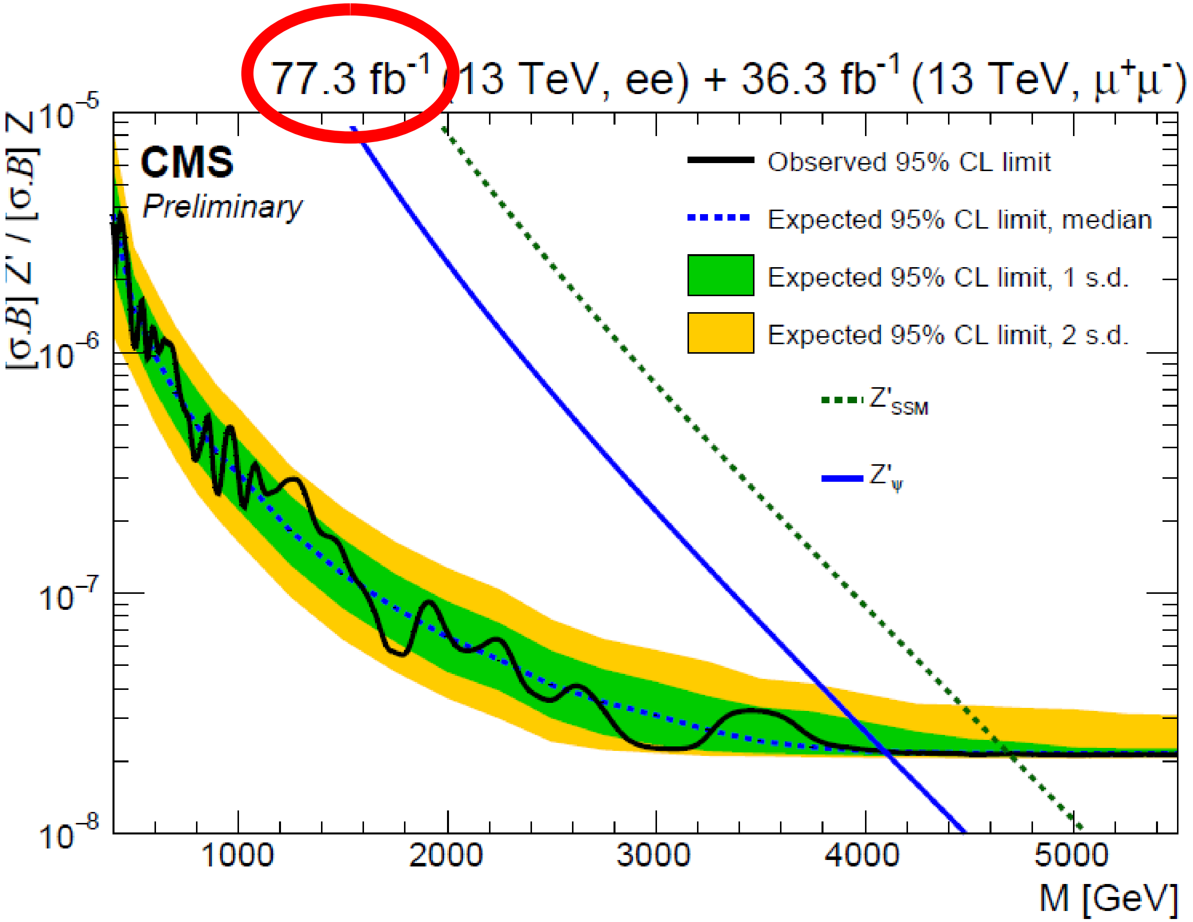


# Limits

EXO-18-006




- The limits are expressed as function of $R_\sigma$, which is the ratio of the cross section for di-lepton production via a Z' boson to the measured cross section for di-lepton production via the Z boson.

$$R_\sigma = \frac{\sigma(\mathrm{pp} \to \mathrm{Z}' + X \to \ell\ell + X)}{\sigma(\mathrm{pp} \to \mathrm{Z} + X \to \ell\ell + X)}.$$

# Summary

- A search for high mass resonances decaying to the di-electron final state has been performed using the proton-proton collision dataset at a center-of-mass energy of 13 TeV collected by CMS in 2017, and corresponding to an integrated luminosity of 41.4 $fb^{-1}$.

- The observations are consistent with the expectations of the standard model.

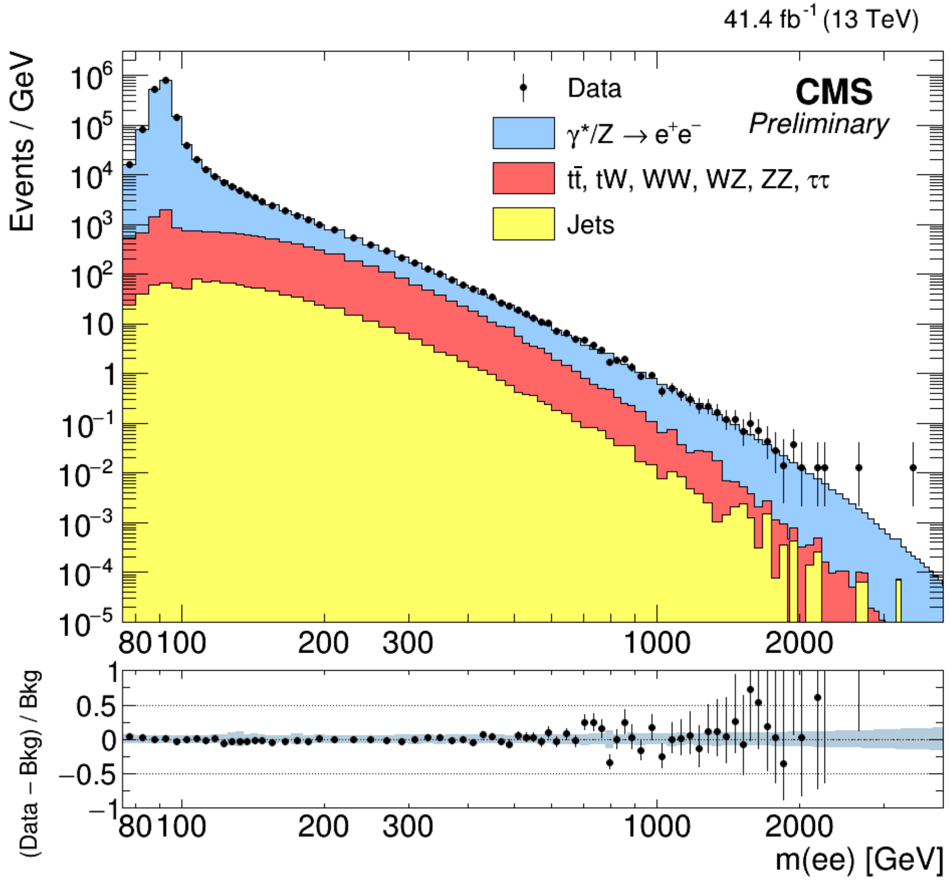
- Upper limits on the cross section times branching ratio of new resonances are calculated for different models and lower mass limits are set for various $Z'$ resonances.

| Channel | Model | Obs. limit [TeV] | Exp. limit [TeV] |
|---|---|---|---|
| ee (2017) | $Z'_{SSM}$ | 4.10 | 4.15 |
| | $Z'_{\psi}$ | 3.35 | 3.55 |
| ee (2016 and 2017) + $\mu\mu$ (2016) | $Z'_{SSM}$ | 4.7 | 4.7 |
| | $Z'_{\psi}$ | 4.1 | 4.1 |

Thanks!

# Back up

# 2017 dataset results for $Z' \rightarrow ee$

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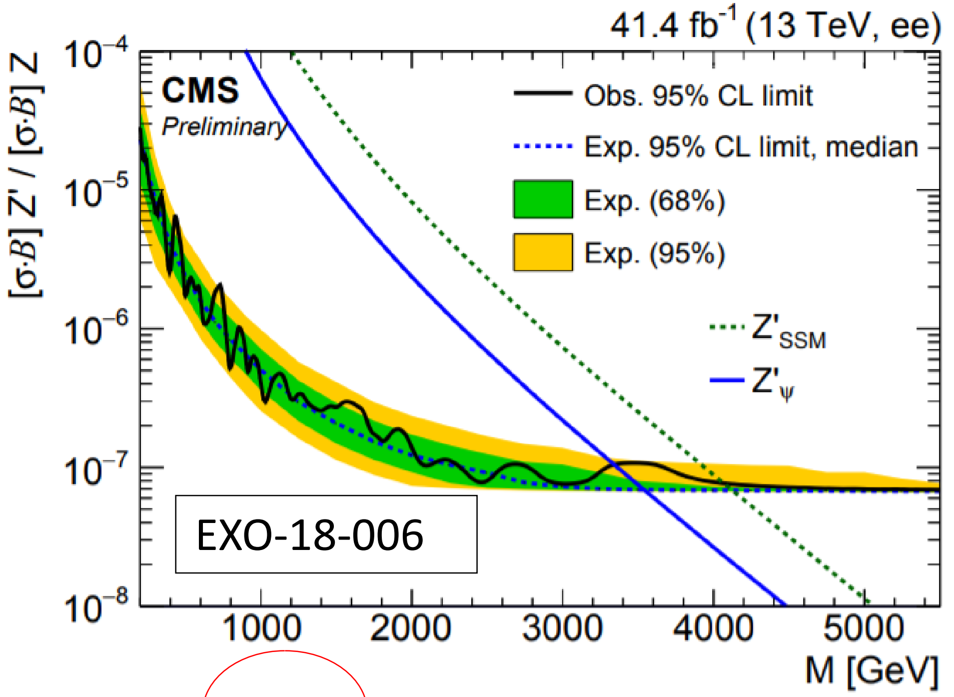
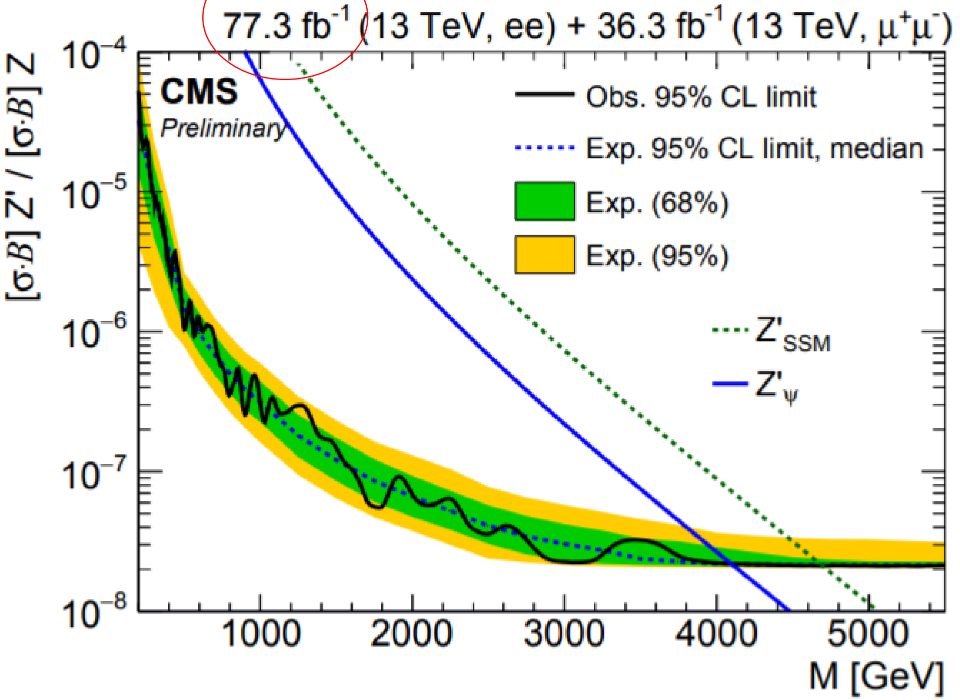
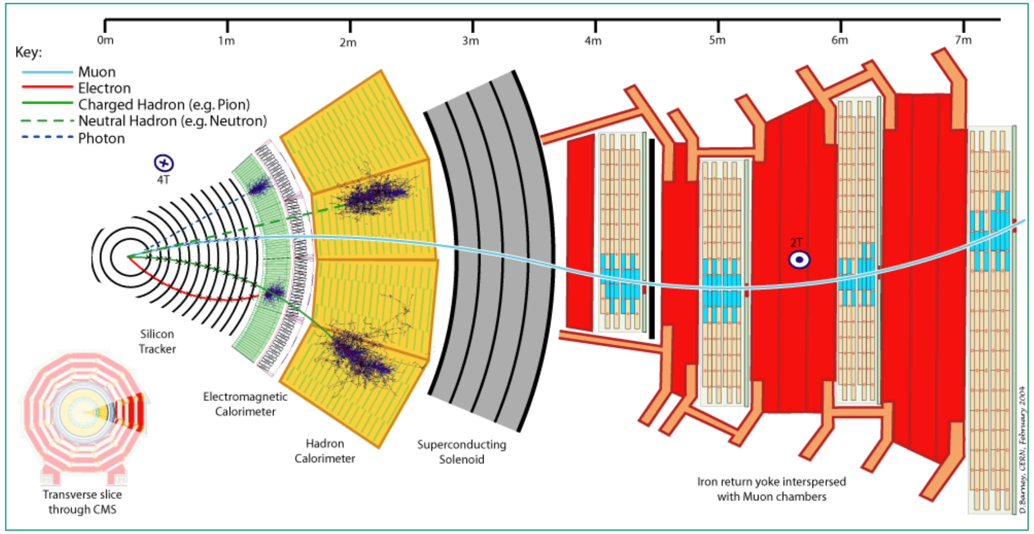
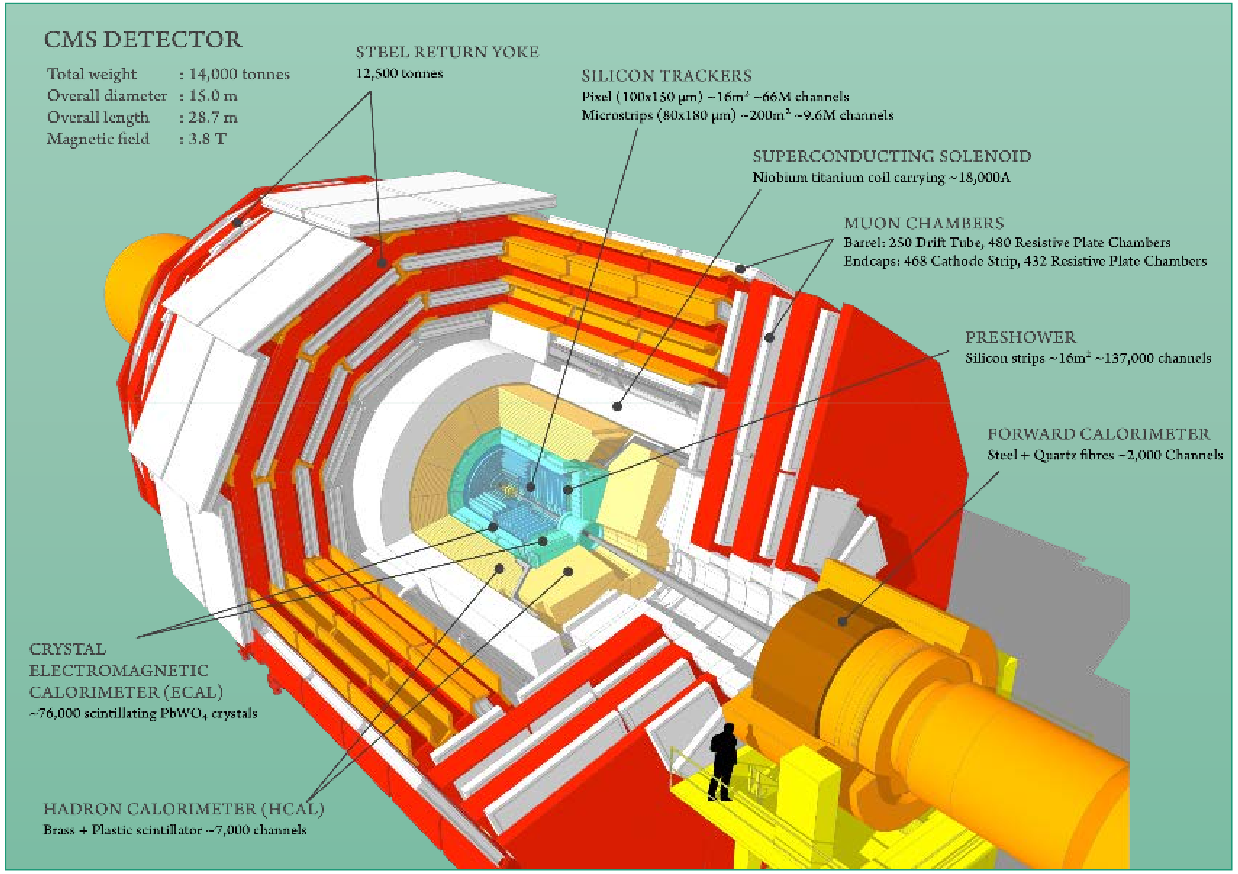



- Data is consistent with backgrounds and no evidence for a significant deviation is observed.
- Combining 2017 data with 2016 dataset can extend the $Z'_{SSM}$ mass limit to 4.7 TeV and $Z'_{\Psi}$ to 4.1 TeV.

# The Compact Muon Solenoid (CMS)



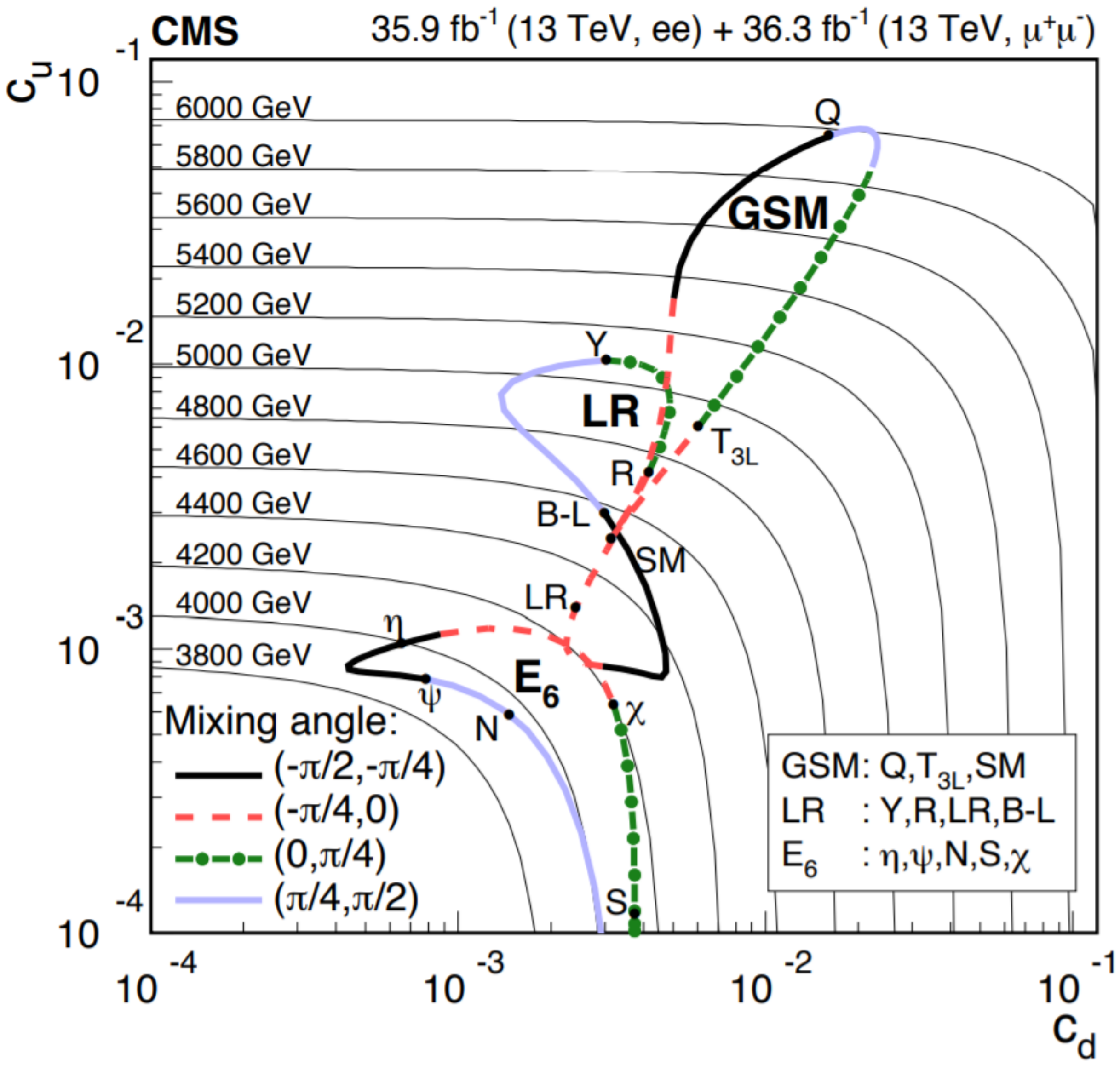

- Tracker
- Electromagnetic calorimeter (ECAL) : Barrel (central) and Endcap (forward) regions
- Hadronic calorimeter (HCAL)
- Muon detectors

| LHC year | 2015 | 2016 | 2017 |
|---|---|---|---|
| Colliding Energy | 13 TeV | 13 TeV | 13 TeV |
| LHC delivered Luminosity | 4.22 $fb^{-1}$ | 40.82 $fb^{-1}$ | 50.96 $fb^{-1}$ |
| CMS recorded Luminosity | 3.81 $fb^{-1}$ | 37.76 $fb^{-1}$ | 46.02 $fb^{-1}$ |
| <Pile-up> | 14 | 27 | 33 |

# $Z' \to \ell\ell$ limits

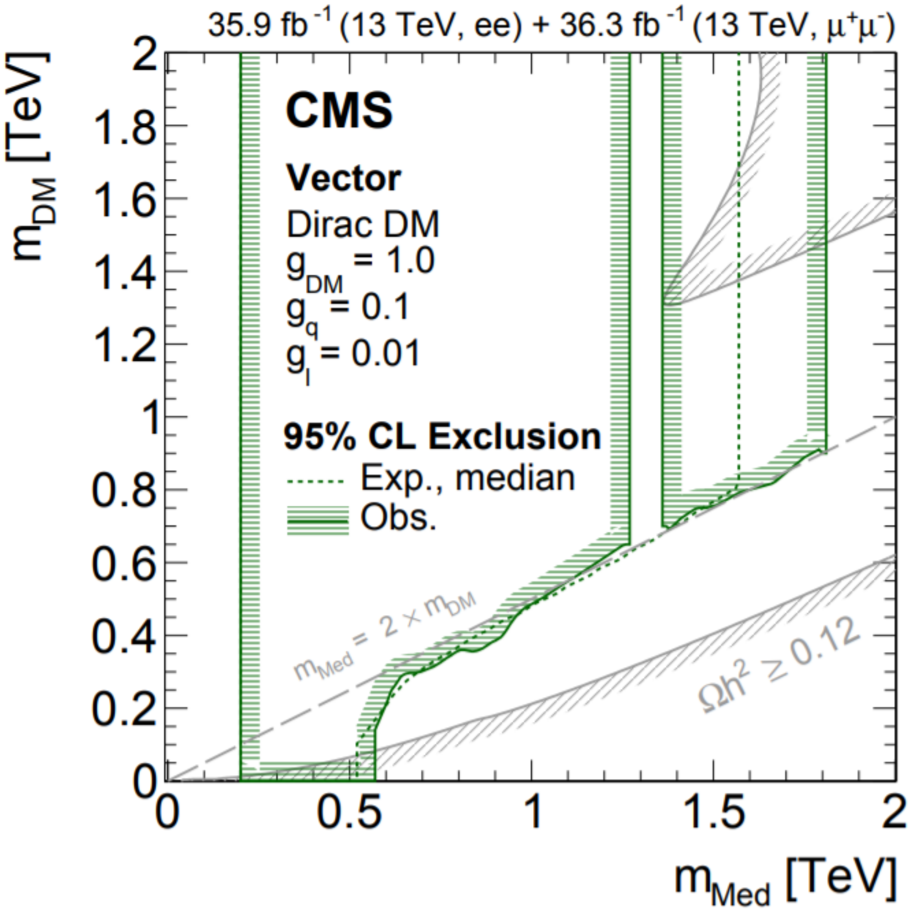
arXiv:1803.06292

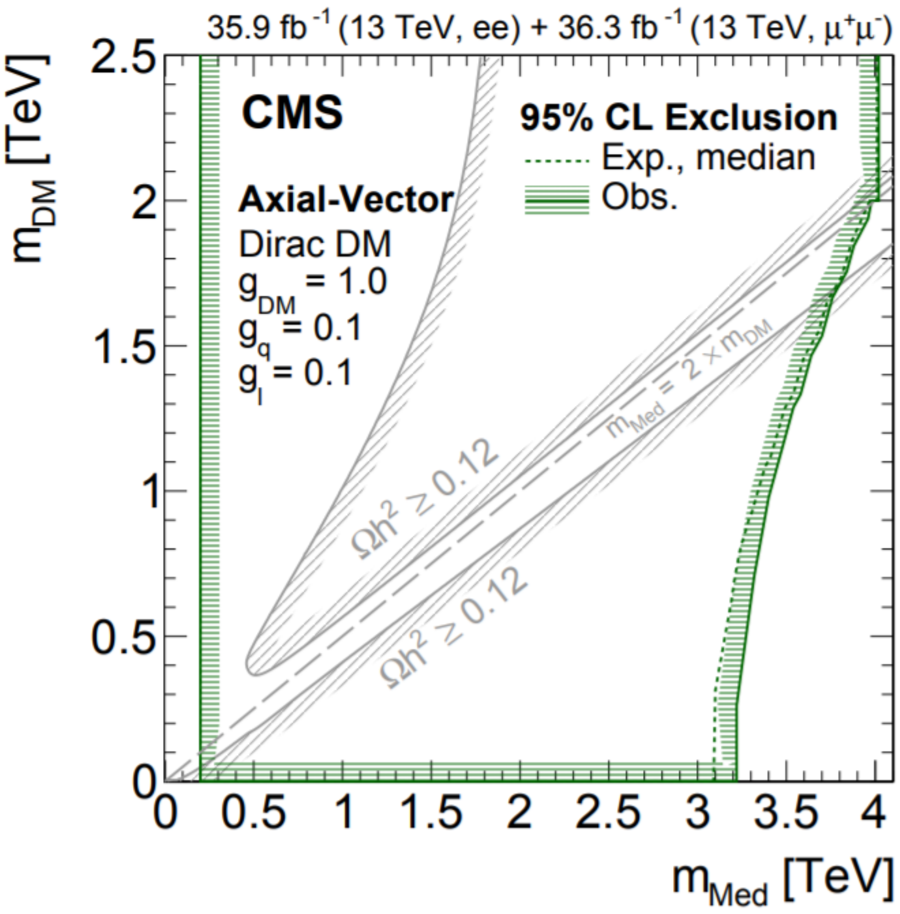
- Limits in the (cd,cu) plane obtained by recasting the combined limit at 95% CL on the $Z'$ boson cross section from di-electron and di-muon channels.
- For a given $Z'$ boson mass, the cross section limit results in a solid thin black line. These lines are labelled with the relevant $Z'$ boson masses.
- The closed contours representing the GSM, LR and E6 model classes are composed of thick segments.
- Each point on a segment corresponds to a particular model and the laction of the point gives the mass limit on the relevant $Z'$ boson.



# $Z \to \ell\ell$: Dark Matter limits

arXiv:1803.06292




- Simplified vector mediator is excluded from 0.6 to 1.8 TeV depending on $\mathrm{m_{DM}}$.
- Simplified axial-vector mediator is excluded between 3.0 to 4.0 TeV.

# 2017 results for $Z' \to ee$

EXO-18-006