SEARCH FOR HIGH-MASS RESONANCES IN THE DILEPTON FINAL STATE IN P-P COLLISIONS WITH THE CMS DETECTOR

XXXII Workshop - Young Scientist Forum
La Thuile (AO) ITALY, February 25th - March 03rd

Filippo Errico

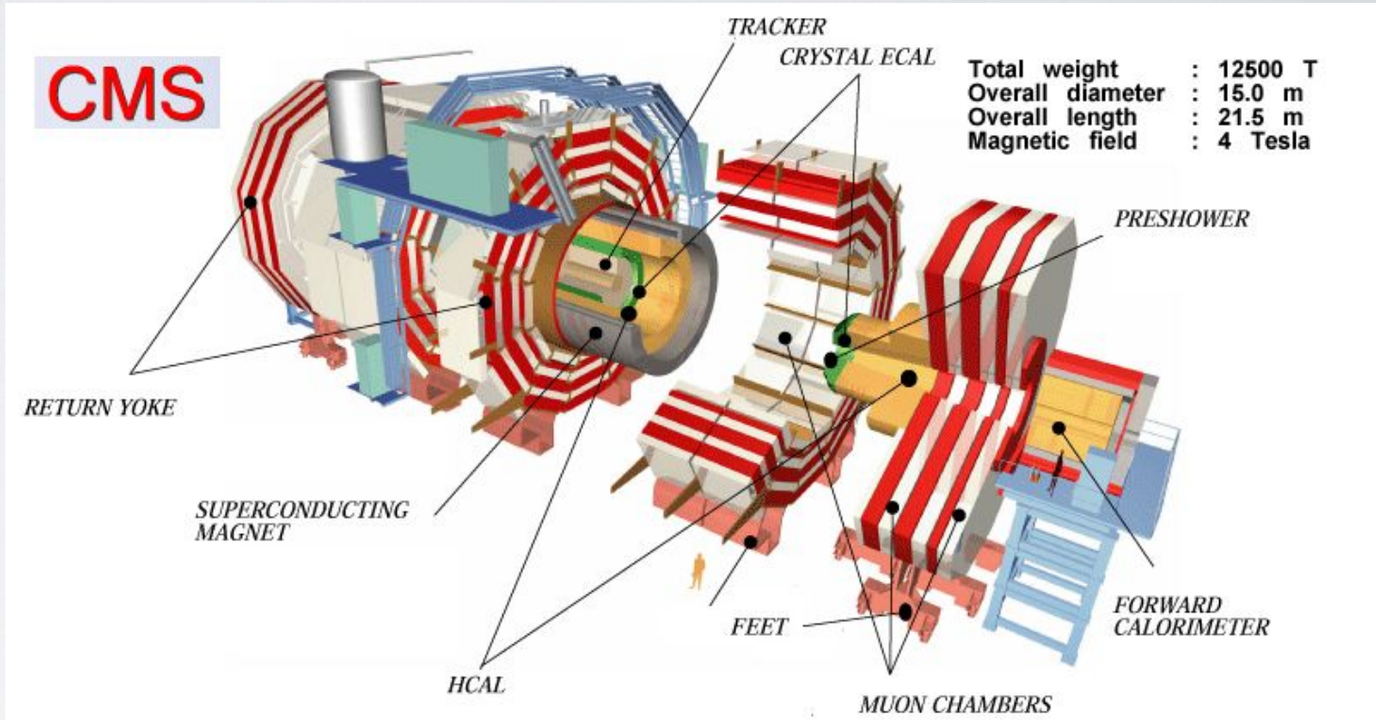
University and INFN Bari

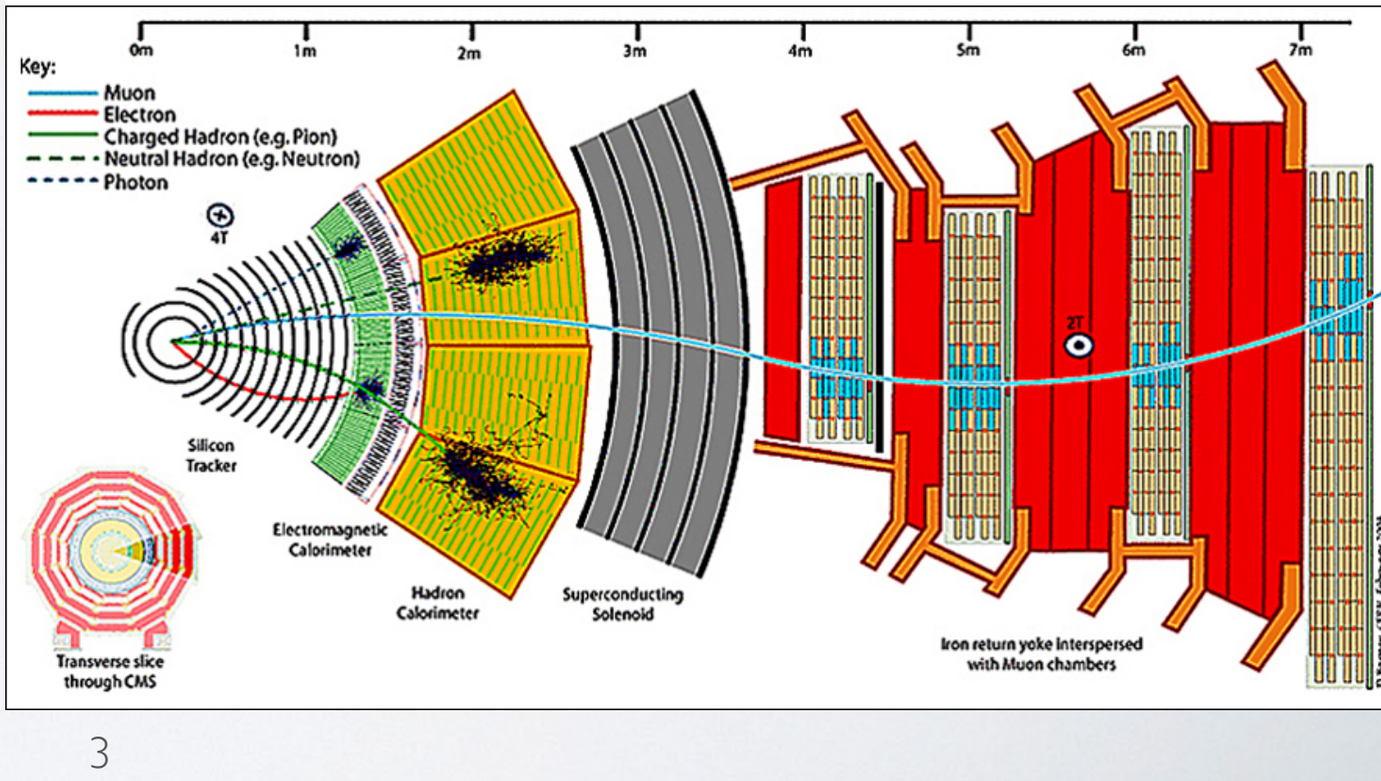
on behalf of the CMS Collaboration

HERE WE ARE…

- Standard Model (SM) provides a successful description of particle physics.
- Still open issues are present: lack of a dark matter candidate, absence of gravity,.
- Many models developed to extend Standard Model
- New neutral massive resonance is a common signature:
  - ❖ GUT (Z'_{ψ}) and Sequential Standard Model (Z'_{SSM}) [spin - **1**]
  - ❖ Extra dimensions model (Kaluza-Klein graviton G_{KK}) [spin - **2**]

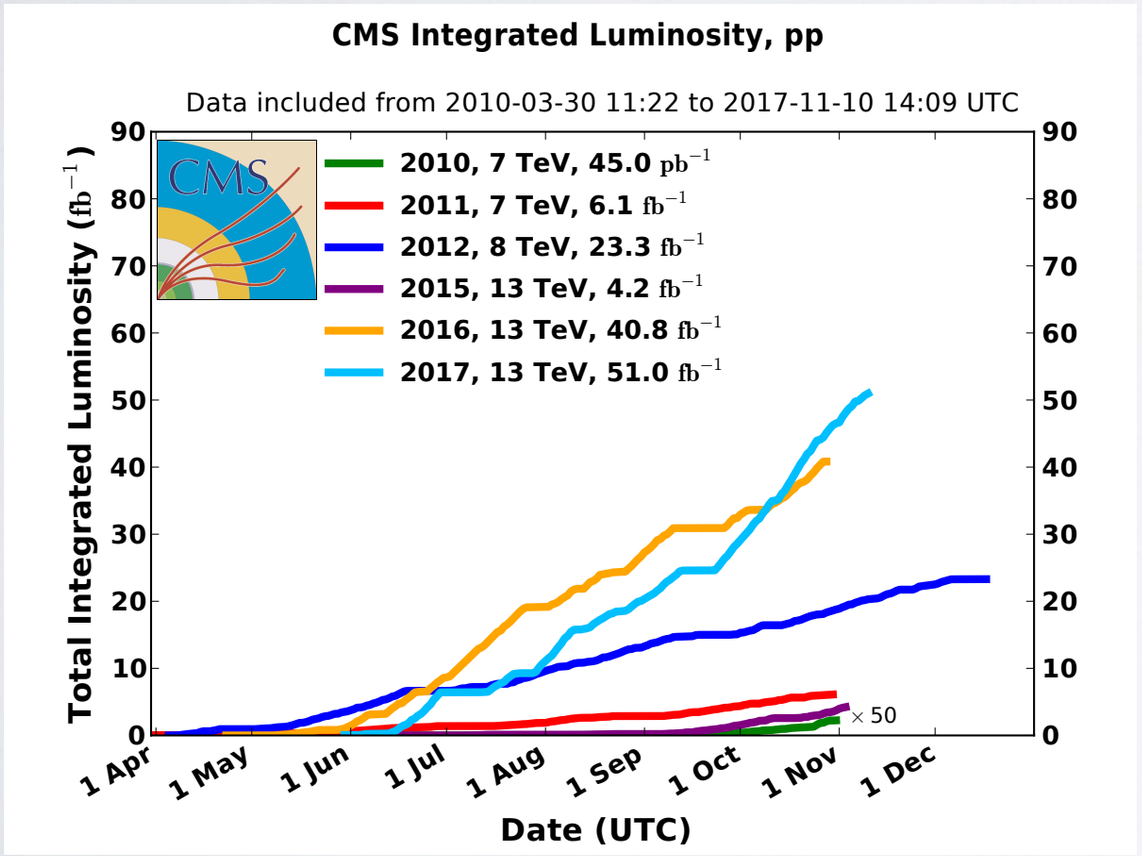
THE CMS DETECTOR





OVERVIEW

- Search for high mass resonances performed in the **dilepton** channel (electrons and muons).



Results using data collected during:

- Run I (20 fb^{-1}) combined with 2015 (2.9 fb^{-1}) [Phys. Lett. B 768 (2017) 57]
- 2016 (13 fb^{-1}) [CMS PAS EXO-16-03]
- 2017 (42 fb^{-1}): performance plots

EVENT SELECTION

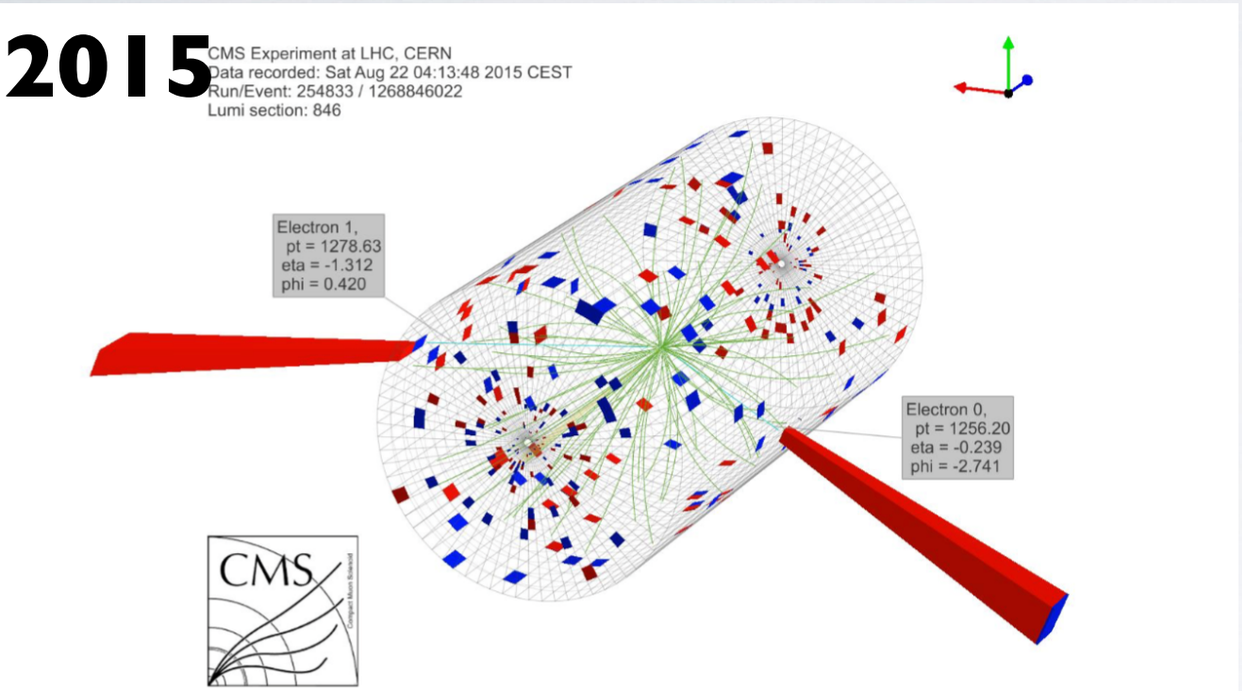
- Search for resonance decaying to lepton pairs (**ee** or **μμ**)

- **Electron channel:**
  - At trigger level, traverse energy (E_T) > 33 GeV
  - In the offline reconstruction: E_T > 35 GeV and $|\eta_C|$ < 1.4442 or 1.566 < $|\eta_C|$ < 2.5
  - Candidates are required to pass a dedicated high energy electron selection criteria (HEEP)
  - Isolation requirement
  - At least one electron in the barrel region

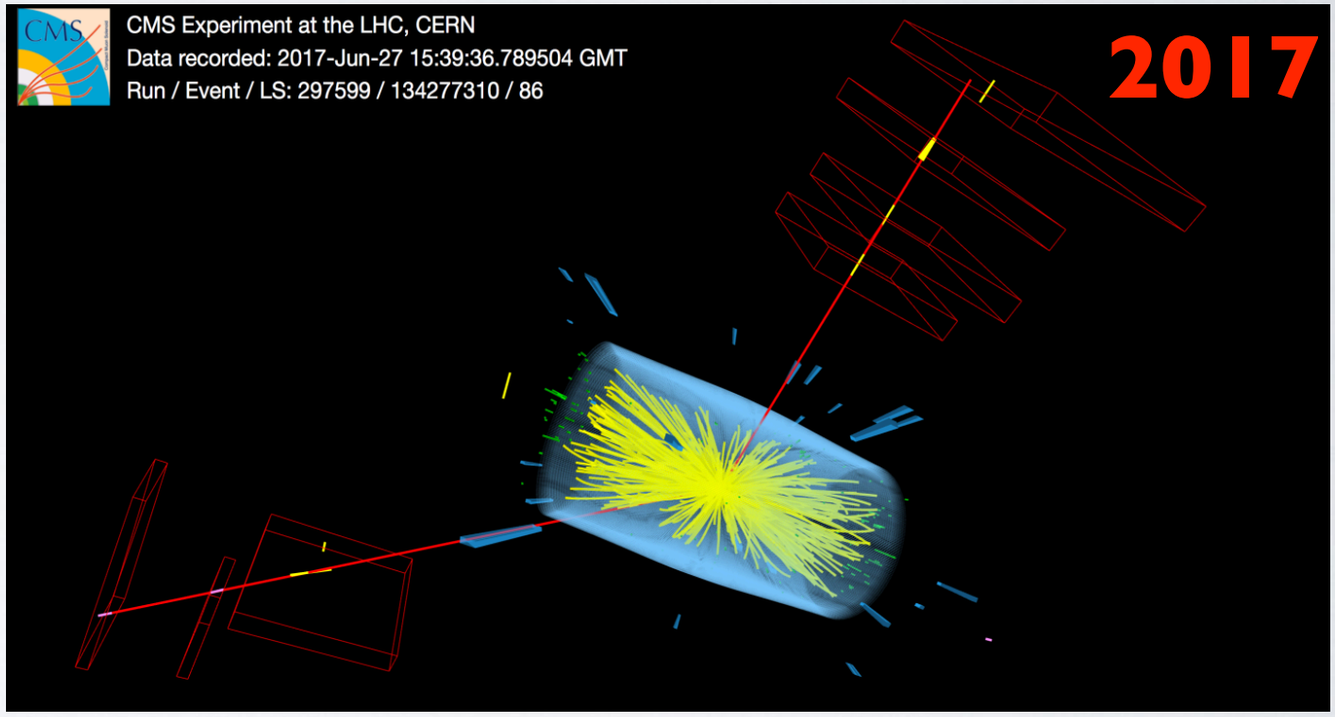
- **Muon channel:**
  - At trigger level, transverse momentum (p_T) > 50 GeV/c
  - In the offline reconstruction: p_T > 53 GeV/c and $|\eta|$ < 2.4
  - High-p_T muon ID
  - Isolation requirement
  - Opposite charge
  - Constraint on the dimuon vertex χ^2 and on 3D angle

EVENT SELECTION

- Search for resonance decaying to lepton pairs (**ee** or **μμ**)



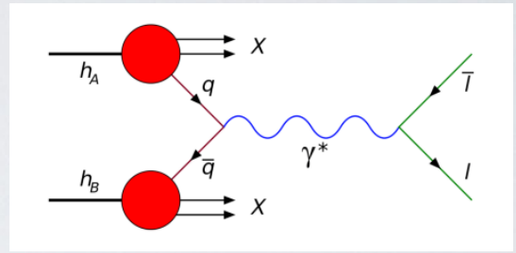
A large dielectron mass event
The invariant mass is 2.9 TeV.



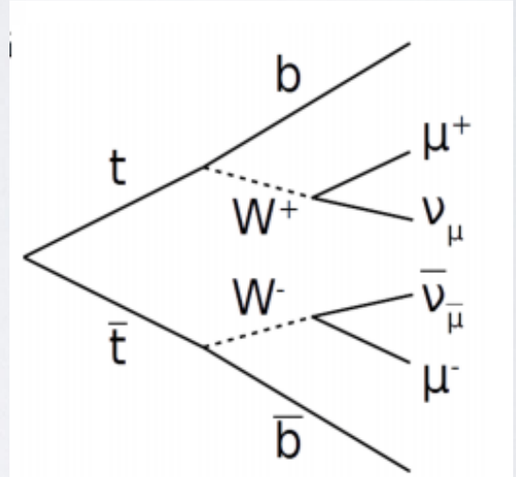
A large dimuon mass event
The invariant mass is 2.4 TeV.

BACKGROUND ESTIMATION

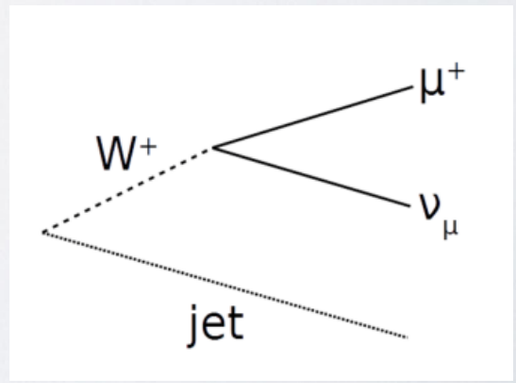
- Drell-Yan (DY) process ($Z/\gamma^* \longrightarrow e^+e^-/\mu^+\mu^-$) is the dominant (~85%) and irreducible SM background.



- Real prompt leptons from (~15%):
  - ❖ top quark - antiquark
  - ❖ single top quark
  - ❖ diboson
  - ❖ Drell-Yan in $\tau^+\tau^-$ channel



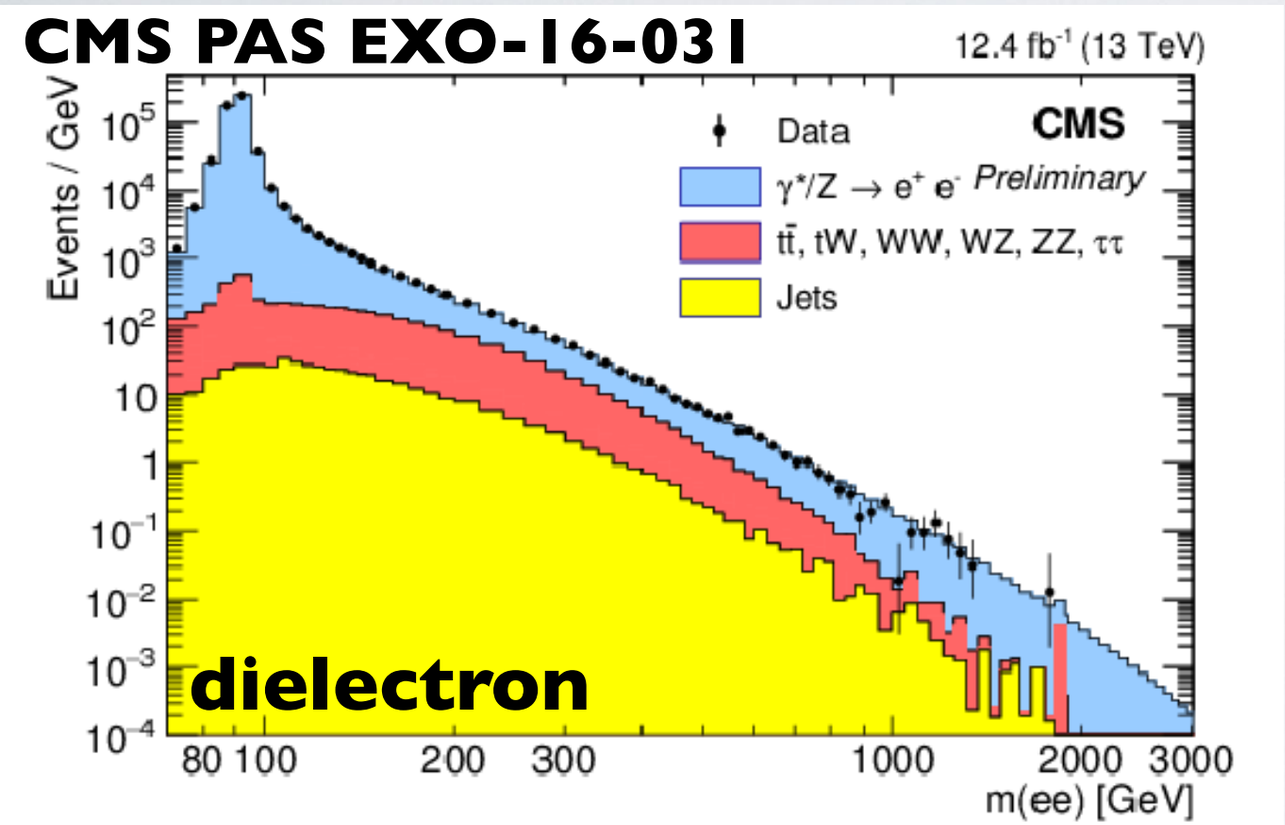
- Jets misidentification (data driven estimation) (in dielectron channel is less then 3%)

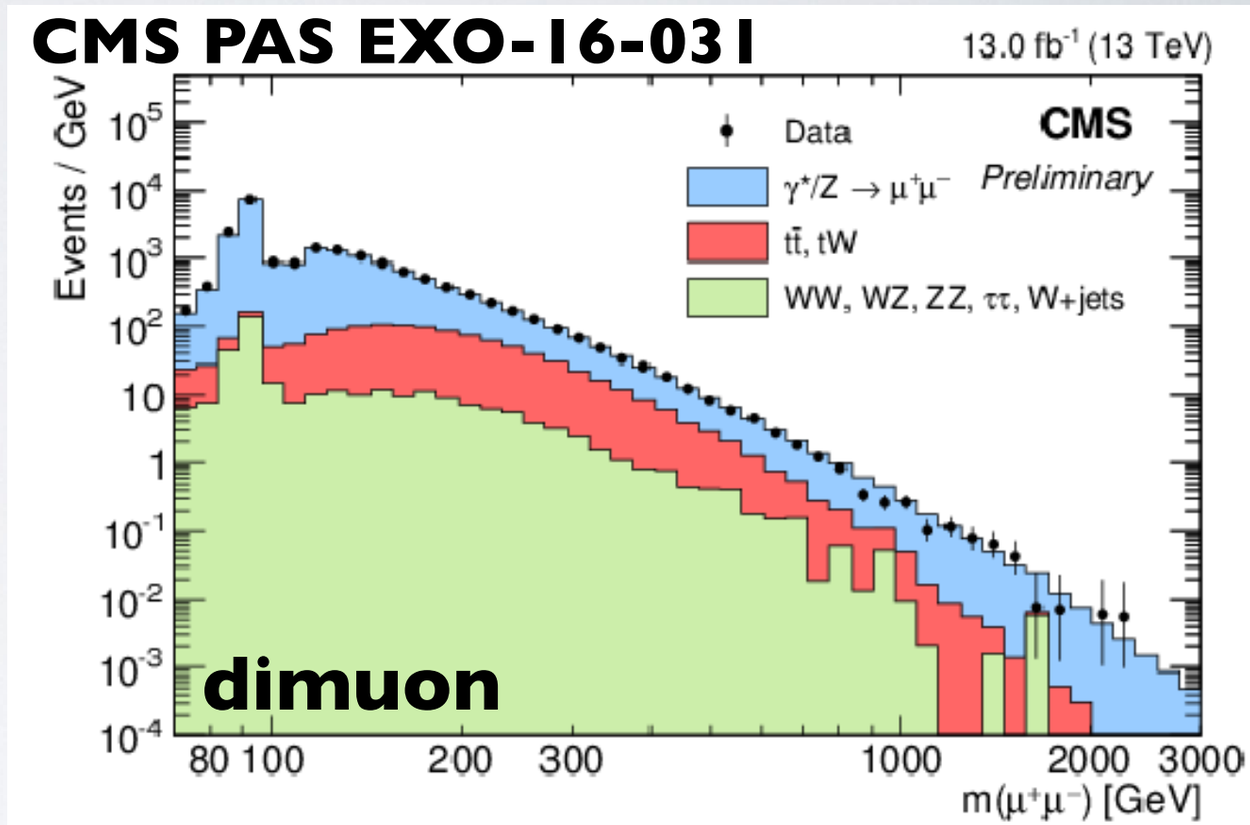


EFFICIENCY AND RESOLUTION

- Total efficiency to trigger, reconstruct and select a mass of 1 TeV:
  - ❖ dielectron pair = (75 ± 8)% for both electrons in the barrel region (BB) and (70 ± 10)% elsewhere (BE)
  - ❖ dimuon pair = (91 ± 5)% independently of **η**
- Mass resolution for a mass of 2 TeV:
  - ❖ dielectron = 1% (BB) and 1.5% (BE)
  - ❖ dimuon channel = 5.5% (BB) and 8.5% (BE)

INVARIANT MASS DISTRIBUTION - 2016 DATA

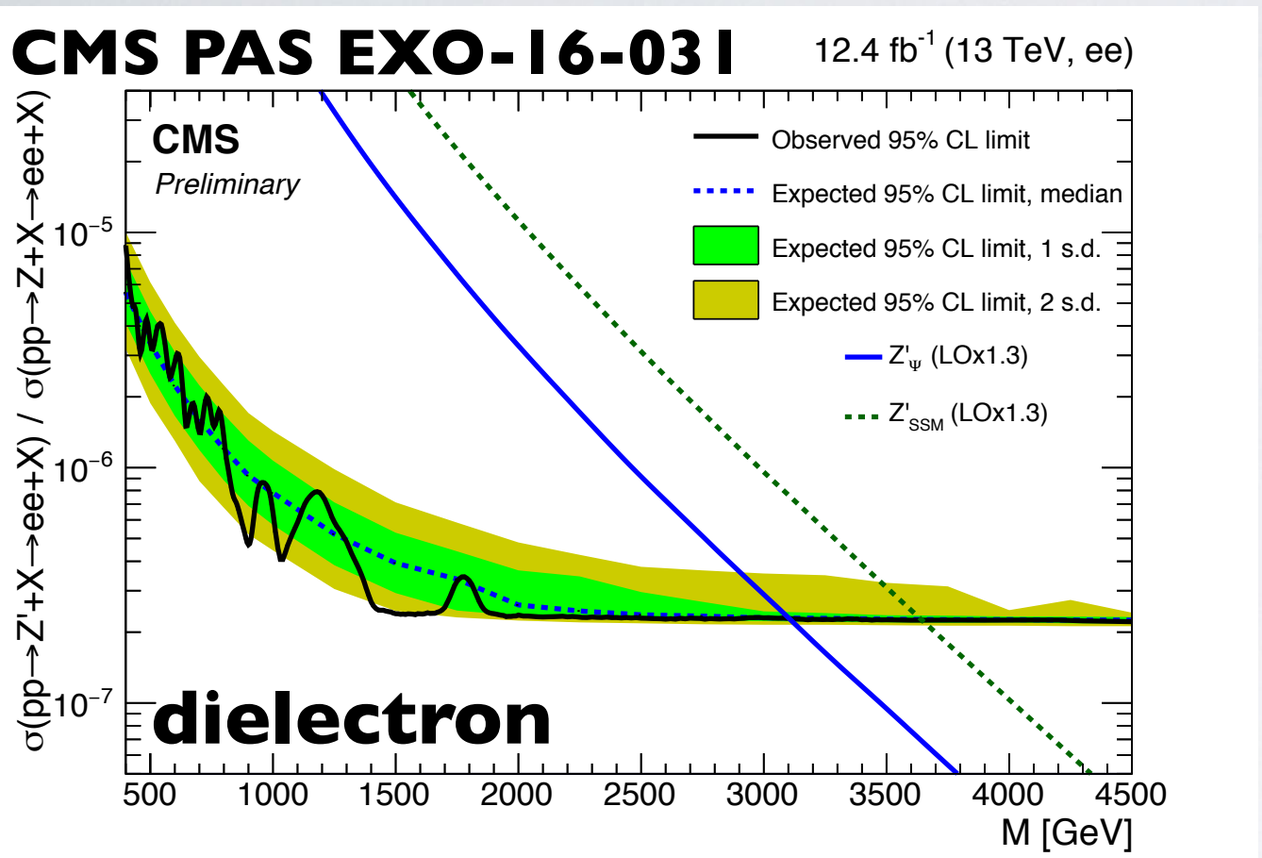


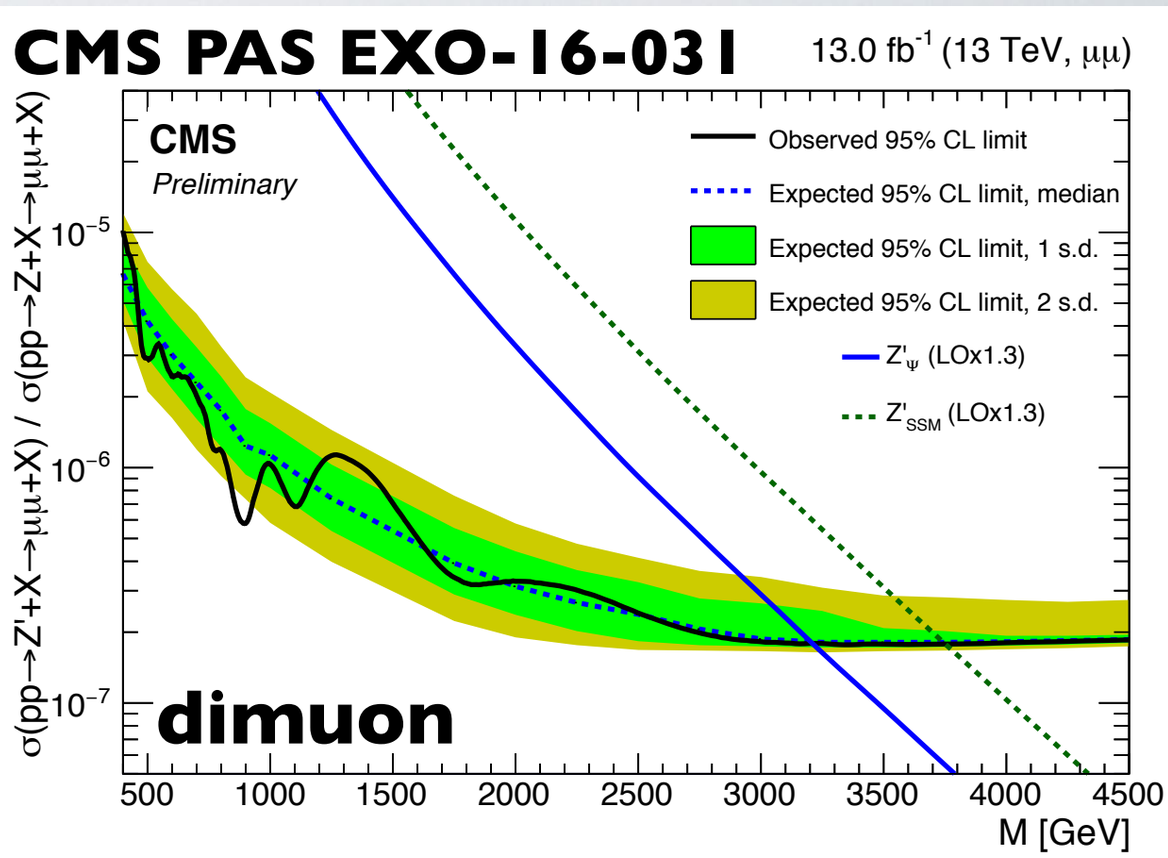


Invariant mass spectra, together with the predicted SM background.

No evidence for a signal deviation from the SM expectations is observed.

LIMIT FOR SPIN-1 RESONANCE

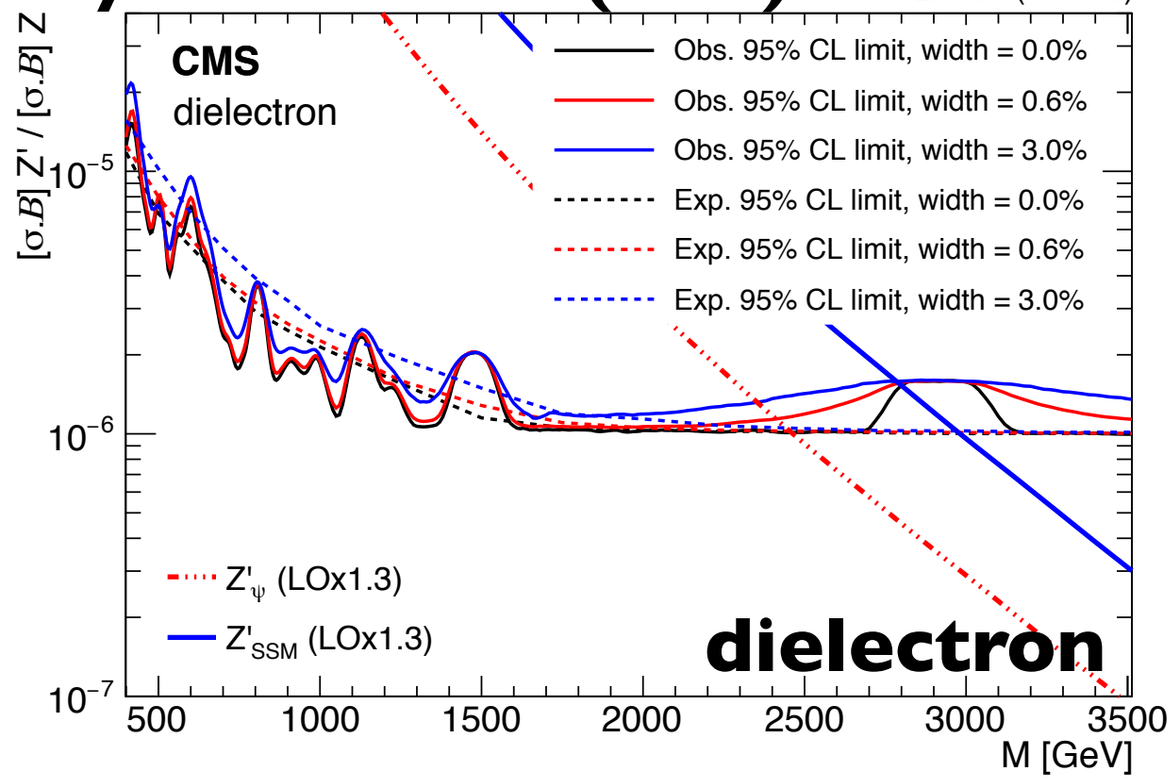




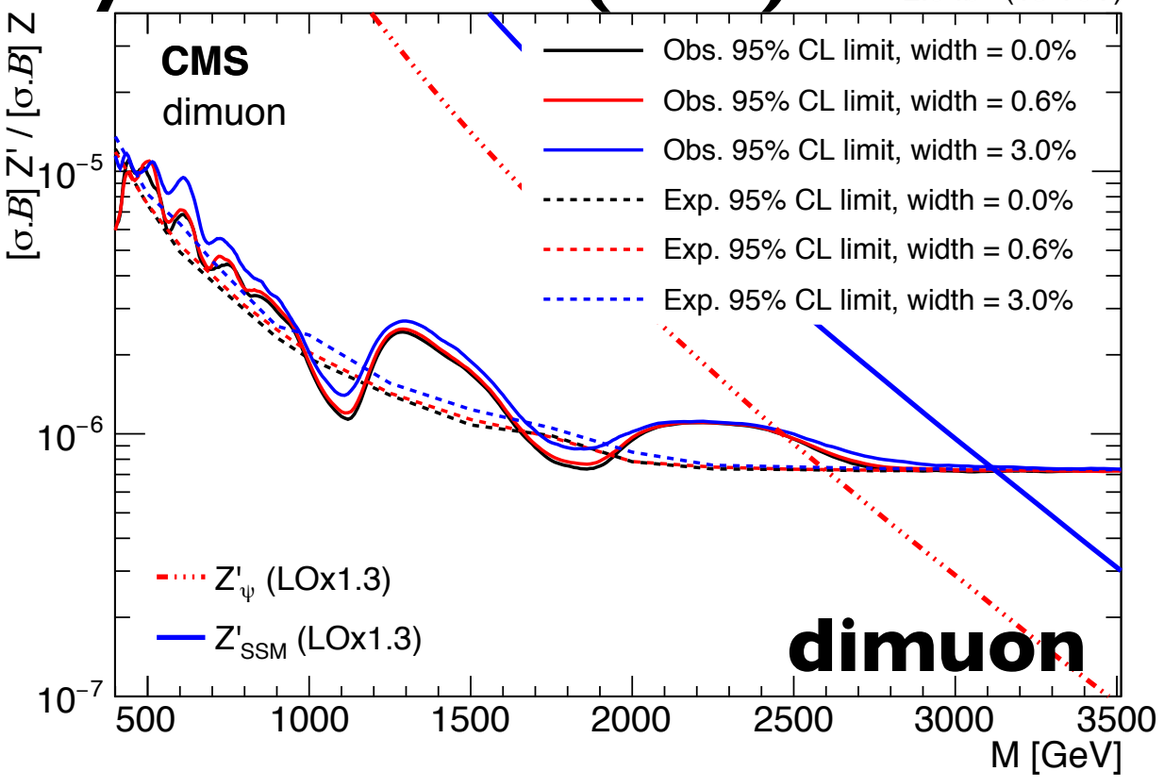
- Limit using **2016 dataset** corresponding to 13 fb^{-1}
- Width of 0.6% of the resonance mass
- 2016 limit more stringent then Run 1 + 2015 for dielectron (dimuon) channel:
  - 3.65 TeV (3.75 TeV) for Z'_{SSM}
  - 3.10 TeV (3.20 TeV) for Z'_{ψ}

TEST WITH DIFFERENT WIDTHS

Phys. Lett. B 768 (2017) 57 2.7 fb^{-1} (13 TeV)

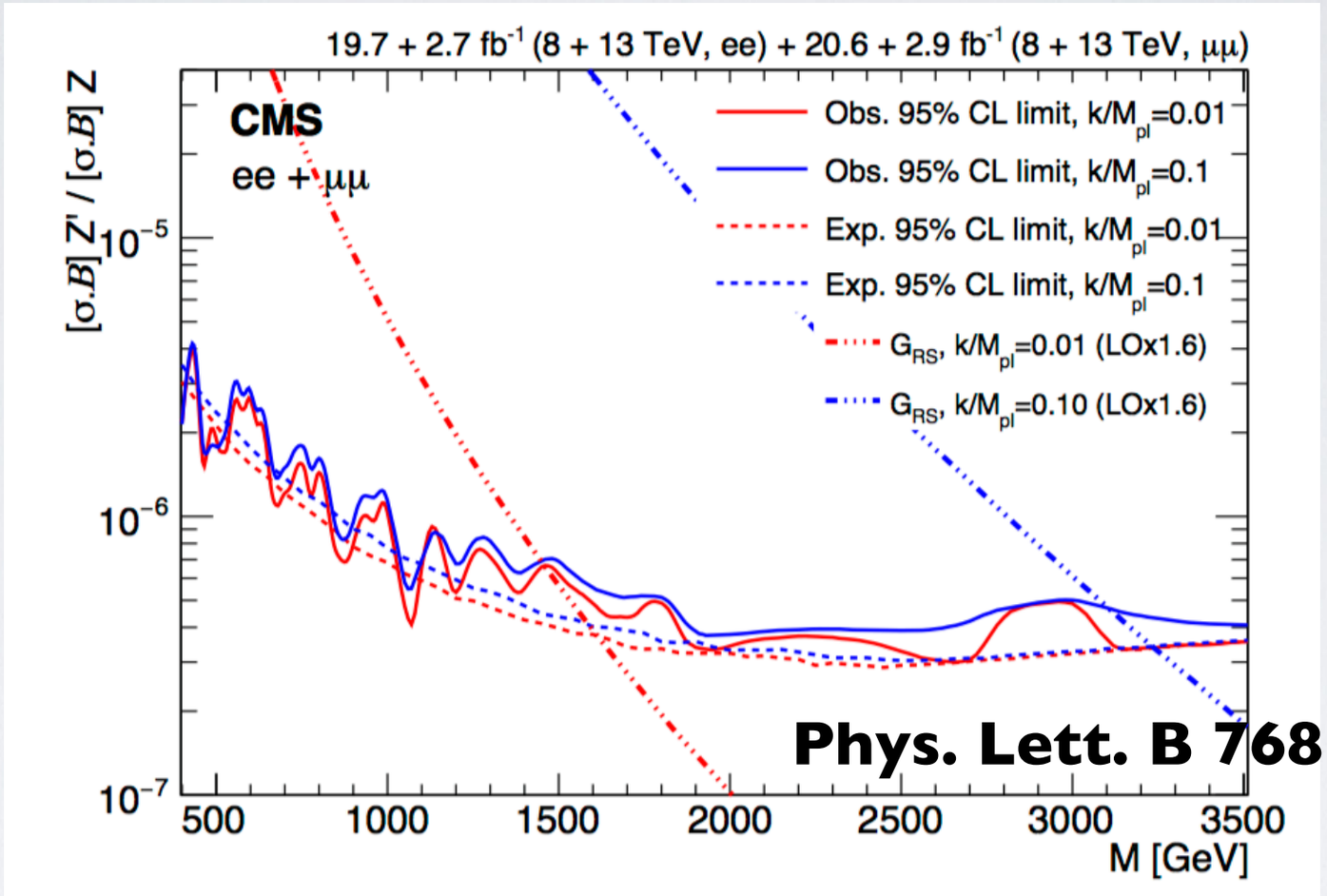


Phys. Lett. B 768 (2017) 57 2.9 fb^{-1} (13 TeV)



- Limits for 0.0, 0.6 and 3% of the **spin-1** resonance mass using **2015 only dataset**
- For mass below 1 TeV, expected limits become less stringent as the resonance mass increases
- At high masses, the limits do not exhibit any dependence on the assumed resonance width.

LIMIT FOR SPIN-2 RESONANCE



Phys. Lett. B 768 (2017) 57

- Limit using **Run 1 + 2015 dataset**
- Using two different constant coupling:
  - ✦ for 0.01 limit sets at 1.46 TeV
  - ✦ for 0.10 limit sets at 3.11 TeV

SUMMARY

Observed and expected limits for the mass of spin-**1** bosons with 2016 dataset:

Channel	Z'_{SSM}		Z'_{ψ}	
	Obs. (TeV)	Exp. (TeV)	Obs. (TeV)	Exp. (TeV)
ee	3.65	3.65	3.10	3.10
$\mu^+\mu^-$	3.75	3.75	3.20	3.20
ee + $\mu^+\mu^-$	4.0	4.0	3.50	3.50

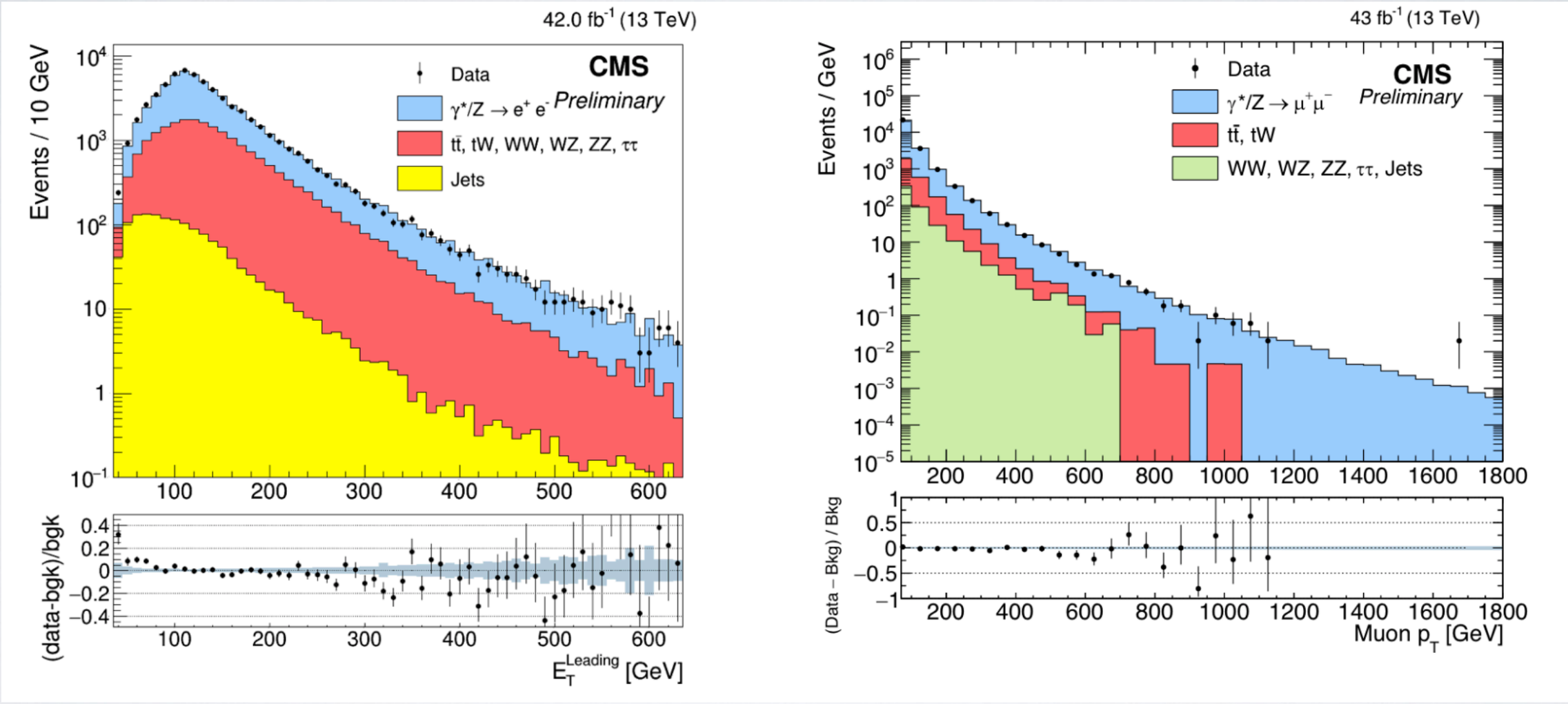
Observed and expected limits for the mass of spin-**2** bosons combining Run I and 2015 dataset:

Channel	G_{KK} ($k/\overline{M}_{Pl} = 0.01$)		G_{KK} ($k/\overline{M}_{Pl} = 0.10$)	
	Obs. (TeV)	Exp. (TeV)	Obs. (TeV)	Exp. (TeV)
ee	1.46	1.48	2.78	2.93
$\mu^+\mu^-$	1.26	1.41	3.03	3.03
ee + $\mu^+\mu^-$	1.46	1.61	3.11	3.23
ee + $\mu^+\mu^-$ 13 TeV only	1.38	1.45	2.98	3.15

2017 ANALYSIS

PERFORMANCE PLOTS

2017 PRELIMINARY RESULTS



- Electron E_T (left) and muon pT (right) distribution using 2017 data.
- Good agreement in both channels.

CONCLUSION

- Search for new high mass resonances in dilepton channel using the CMS detector has been presented.
- New limits have been set:
  - ❖ for spin-1 particle:
    - ✤ Z'_{SSM} = 4.0 TeV (previous 3.37 TeV)
    - ✤ Z'_{ψ} = 3.5 TeV (2.82 TeV)
  - ❖ for spin-2 particle G_{KK} = 1.46 TeV and 3.11 TeV with constant coupling 0.01 and 0.1.
- Analysis with full 2016 data (36.3 fb^{-1}) is forthcoming
- Preliminary 2017 results shown good agreement in dielectron and dimuon channels.

THANKS

FOR YOUR

ATTENTION

BACKUP SLIDES

THEORETICAL MODEL

- Z'_{ψ} e Z'_{χ} associated with U(**1**) group obtained with E_6 symmetry breaking within Grand unified Theory.

- Z'_{SSM} associated with U(**1**): it has a Z boson SM like coupling.

- Kaluza-Klein graviton predicted within Randall-Sundrum model of extra dimensions.

EXCLUSION LIMIT

- Limits are set using a Bayesin method with an unbinned extended likelihood function.
- The signal probability density function (PDF) used is a convolution of Breit-Wigner function and a Gaussian with exponential tails (Crujiff).
- The background PDF for both channels obtained fitting mass distribution.
- Limits extract on the product of production cross section and branching fraction for Z' relative to the product of production cross section and branching fraction of a Z boson.

$$R_\sigma = \frac{\sigma(\mathrm{pp} \to \mathrm{Z}' + \mathrm{X} \to \mu^+\mu^- + \mathrm{X})}{\sigma(\mathrm{pp} \to \mathrm{Z} + \mathrm{X} \to \mu^+\mu^- + \mathrm{X})} \longrightarrow R_\sigma = \frac{N(\mathrm{Z}' \to \mu^+\mu^-)}{N(\mathrm{Z} \to \mu^+\mu^-)} \times \frac{A(\mathrm{Z} \to \mu^+\mu^-)}{A(\mathrm{Z}' \to \mu^+\mu^-)} \times \frac{\varepsilon(\mathrm{Z} \to \mu^+\mu^-)}{\varepsilon(\mathrm{Z}' \to \mu^+\mu^-)}$$

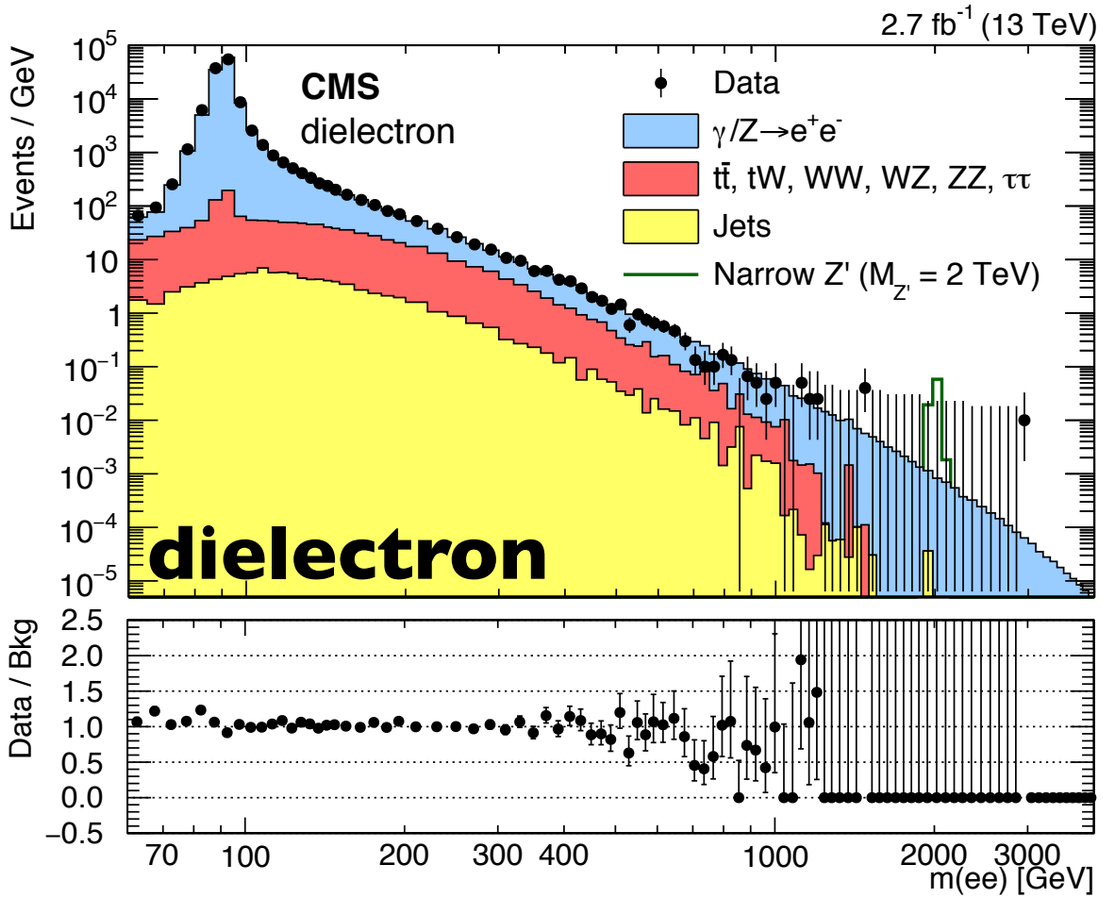
EXCLUSION LIMIT

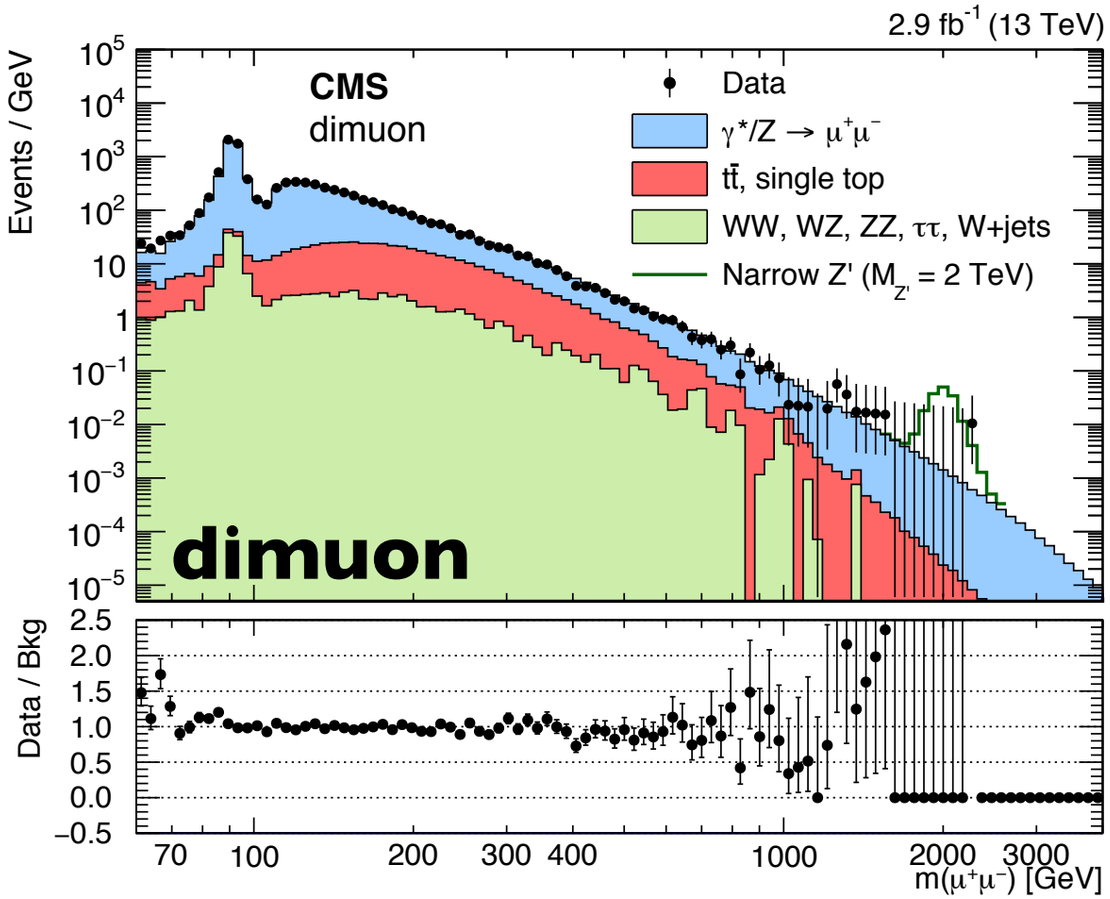
$$\mathcal{L}(\mathbf{m}|\boldsymbol{\theta},\boldsymbol{\nu}) = \frac{\mu^N e^{-\mu}}{N!} \cdot \prod_{i=1}^{N} \left(\frac{\mu_{sig}(\boldsymbol{\theta},\boldsymbol{\nu})}{\mu} f_{sig}(m_i|\boldsymbol{\theta},\boldsymbol{\nu}) + \frac{\mu_{bkg}(\boldsymbol{\theta},\boldsymbol{\nu})}{\mu} f_{bkg}(m_i|\boldsymbol{\theta},\boldsymbol{\nu}) \right)$$

$f_{sig}(m|\boldsymbol{\theta},\boldsymbol{\nu}) = BW(m|\boldsymbol{\Gamma}) \otimes Gauss(m|\boldsymbol{\sigma})$ $f_{bkg}(m|\boldsymbol{\theta},\boldsymbol{\nu}) = e^{g(m)}\, m^k$

- $\boldsymbol{\mu} = \boldsymbol{\mu}_{sig} + \boldsymbol{\mu}_{bkg}$ = observed events
- N = observed events above 200 GeV
- $\boldsymbol{\theta}$ = nuisance parametres:
  - ✦ signal:
    - ★ M, $\boldsymbol{\Gamma}$ = mass and width of BW
    - ★ w = gaussian width
  - ✦ background:
    - ★ parameters used to modelling the fit

INVARIANT MASS DISTRIBUTION - 2015 DATA

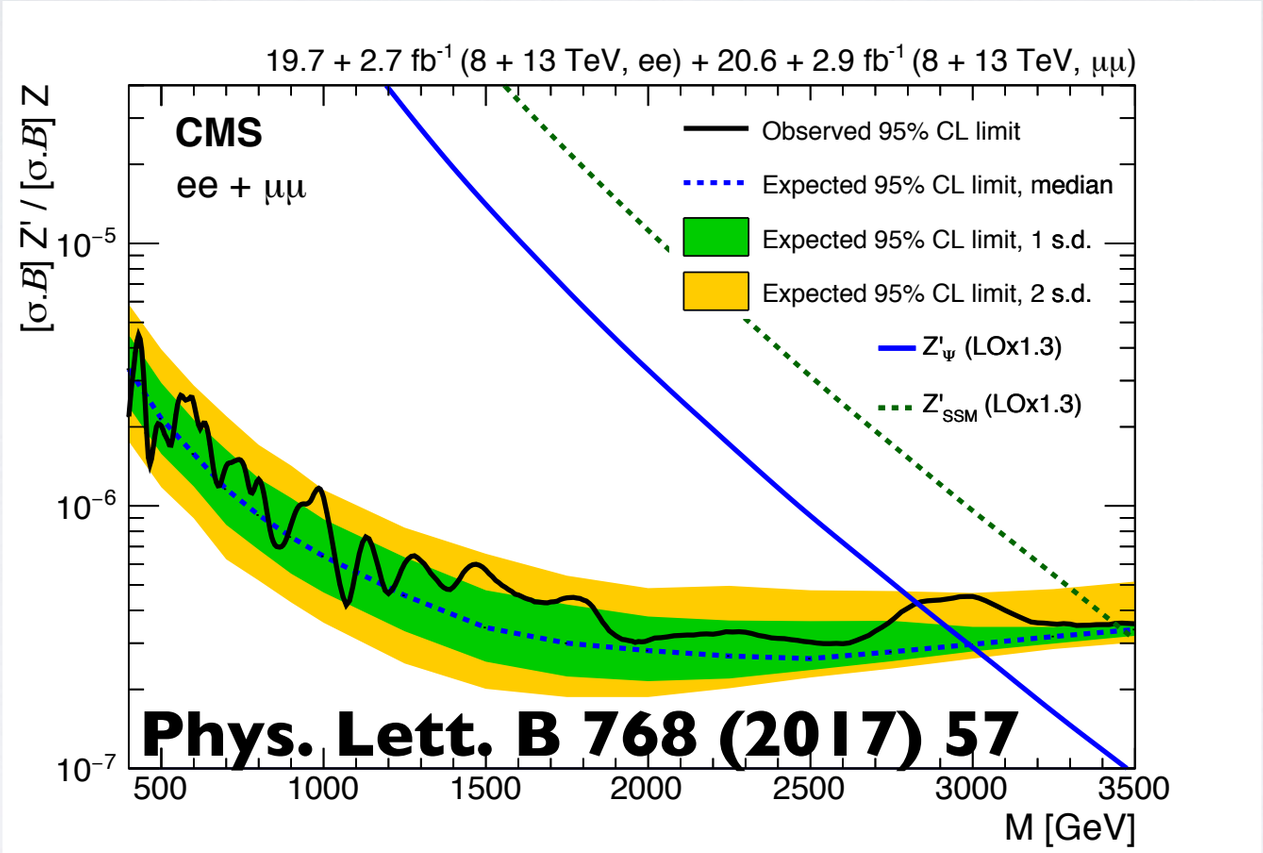




Invariant mass spectra, together with the predicted SM background.

No evidence for a signal deviation from the SM expectations is observed.

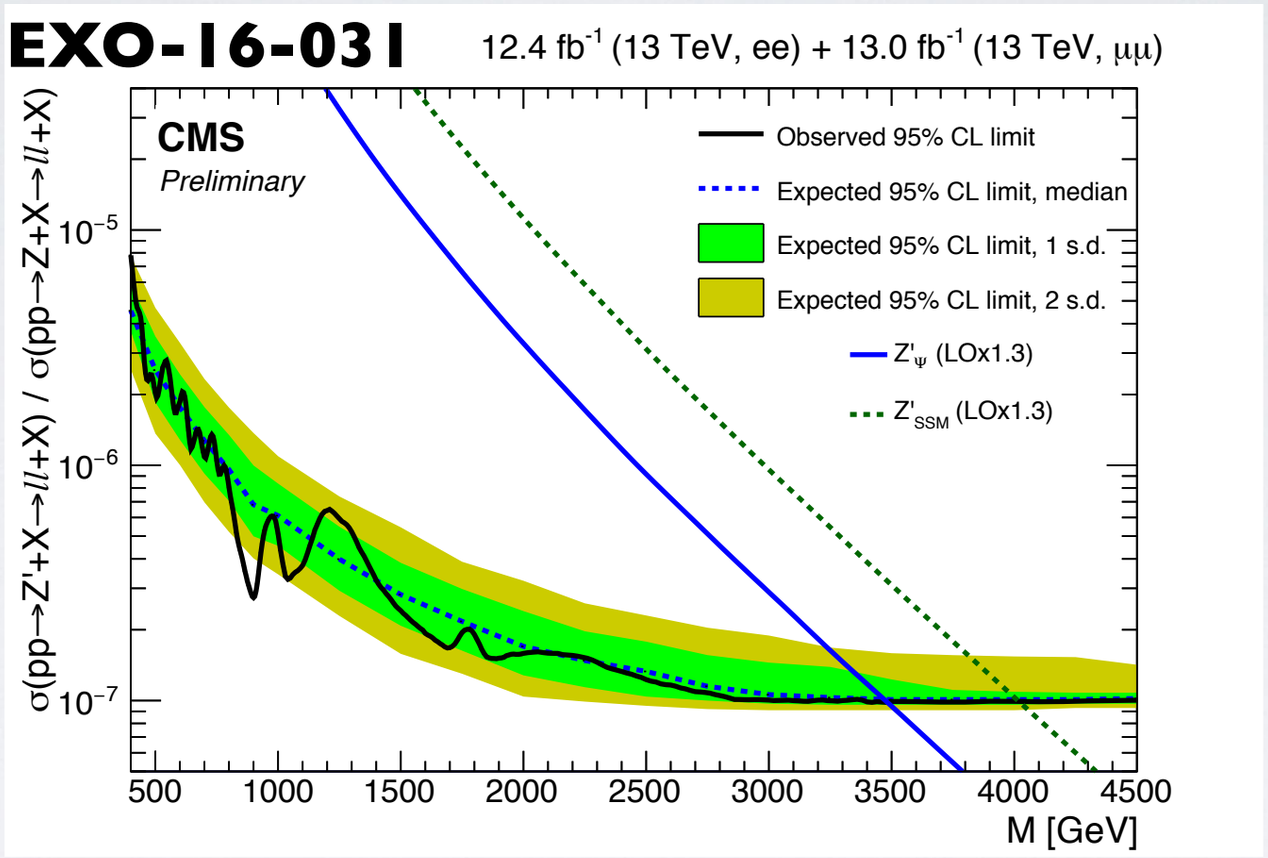
LIMIT FOR A SPIN 1 RESONANCE: 8 TEV + 13 TEV



Limit for a **spin-1** resonance with a width of 0.6% of the resonance mass combining electron and muon channel using 20 fb^{-1} (8 TeV) and 2.9 fb^{-1} (13 TeV, 2015)

LIMIT FOR A SPIN 1 RESONANCE: 2016

CMS PAS EXO-16-031



Limit for a **spin-1** resonance with a width of 0.6% of the resonance mass combining electron and muon channel using 13 fb^{-1} collected during 2016, at 13 TeV