Search for new Physics in final states with leptons or photons (EXO) with the CMS detector

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March 10th, 2016

New Physics predictions

- The **Standard Model is a successful theory** full of experimental supports
- Confirmed also by the recent discovery of a **Higgs boson** with a mass of 125 GeV by ATLAS and CMS
- Some notable omissions of the SM: hierarchy problem, lack of a dark matter candidate, absence of gravity…
- Many **theories Beyond SM** developed
- **Common signature of many new Physics BSM is a new massive particle**
  - **Extra dimensions models**: solution of the hierarchy problem lowering the effective Planck scale by "diluting" gravity in additional dimensions
    - predict excitations of the gravitational field (spin-2 gravitons) separated by a characteristic mass scale
  - **GUT and Sequential Standard Model** (SSM)
    - predict new heavy gauge bosons.

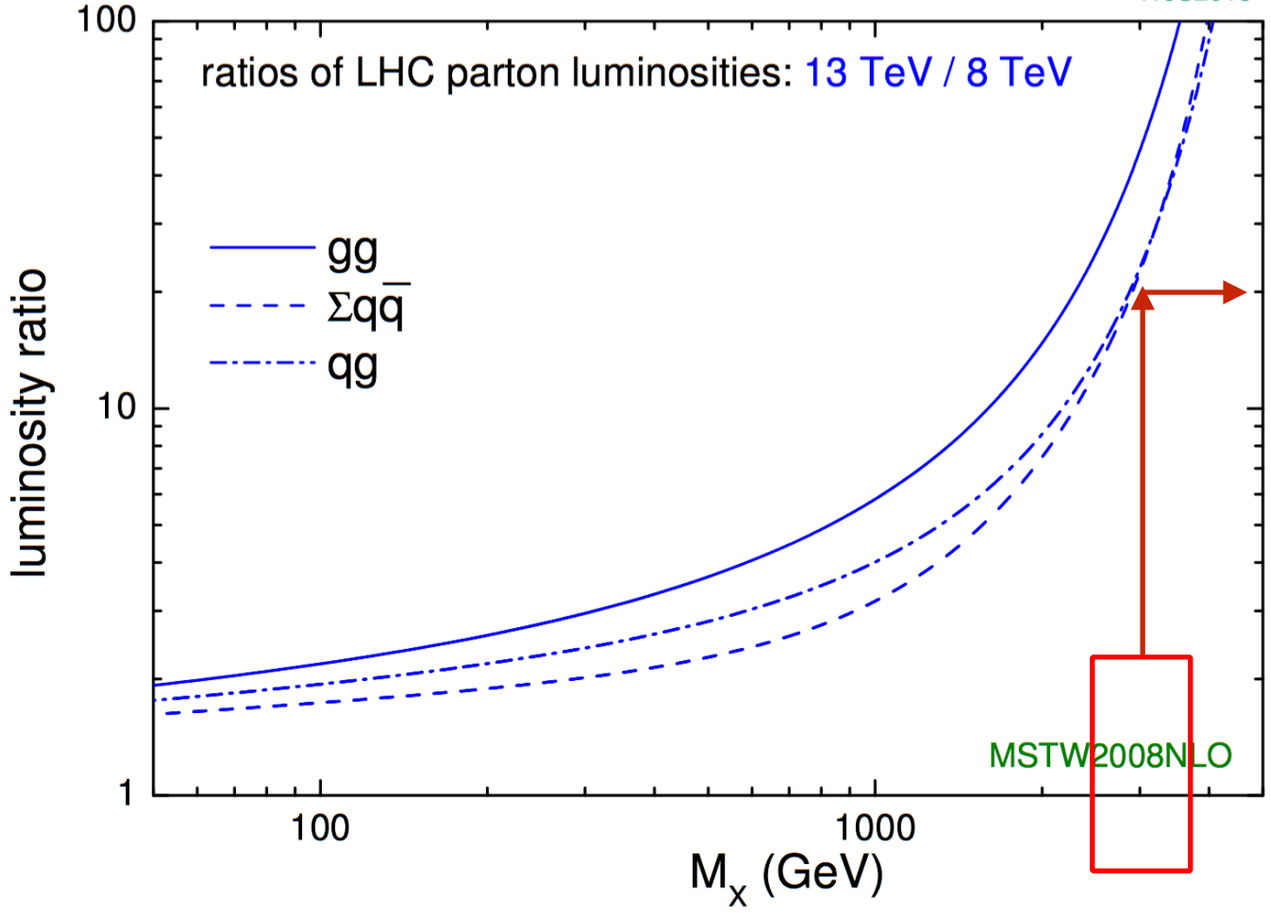
Introduction

13 TeV data:

- unique chance to test new mass ranges
- for new bosons of M=3 TeV, same sensitivity of 8 TeV Run reached with ~1fb^{-1}

http://www.hep.ph.ic.ac.uk/~wstirlin/plots/plots.html

WJS2013



OUTLINE:

1. Search for new charged gauge bosons decaying in lepton + MET
2. Search for new neutral gauge bosons decaying in a lepton pair
3. Search for extra dimensional (RS models) models in di-photon

Very clean experimental signatures!

Strategy:

- Search for a localized excess in the di-photon/ di-lepton/lepton+MET mass compatible with the production of a new resonance

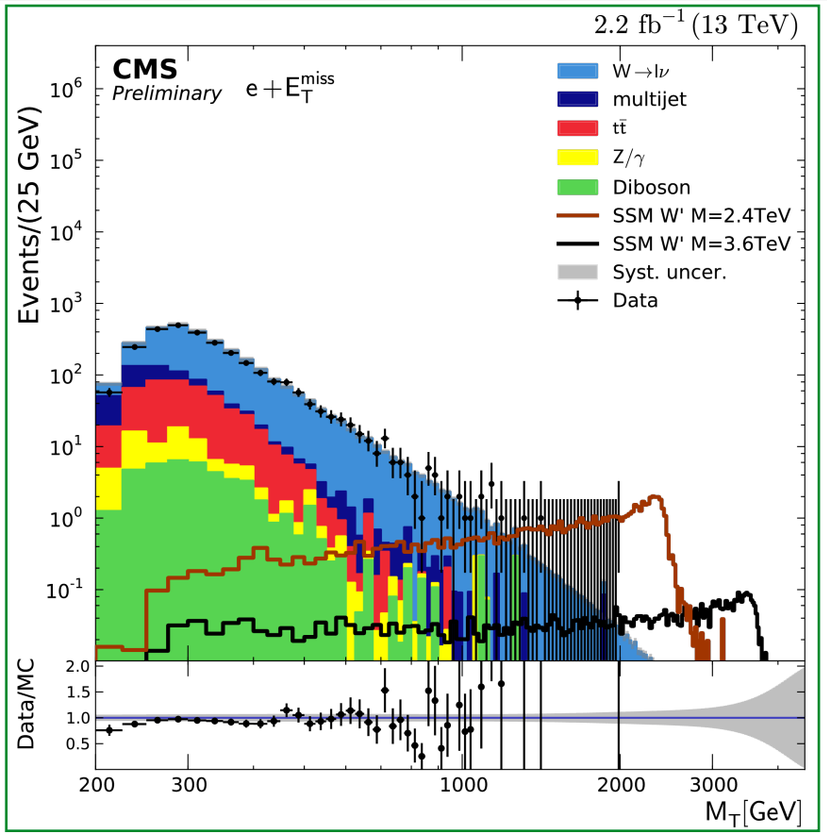
Challenges:

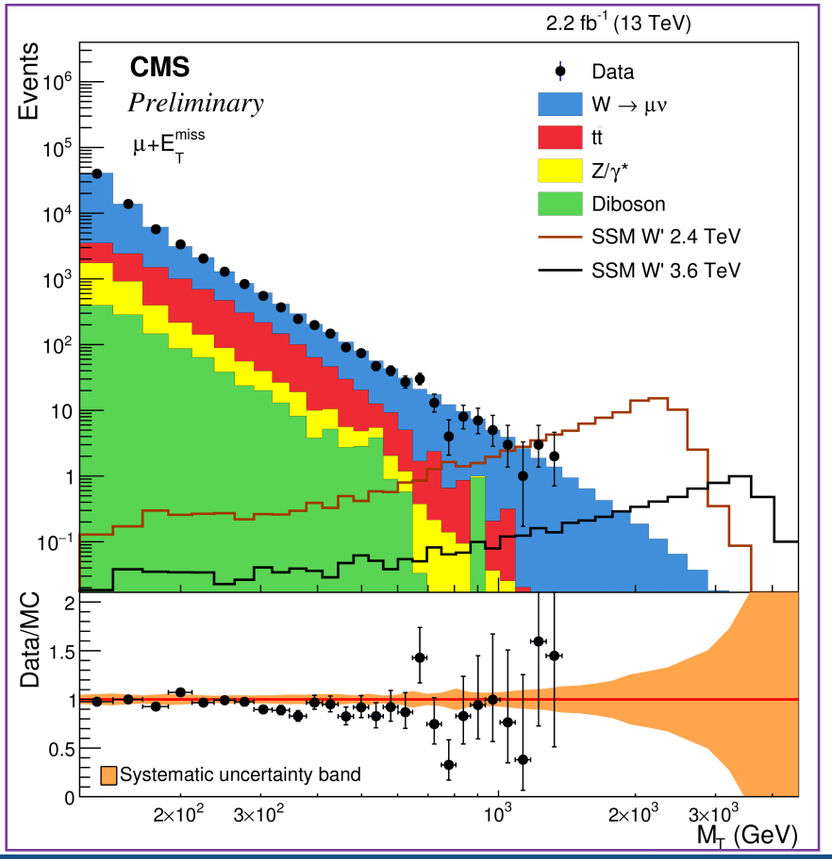
- High signal efficiency while effectively removing reducible background
- Detector response at very high energy
- Reconstruction and identification specific for high-energy objects

W′ -> e/μ +MET

13 TeV

CMS EXO-15-006





Heavy gauge boson W′ decaying into lepton+MET

Experimental signature:

- high-energy e (p_T> 130 GeV) + E_T^{miss}
- high-energy μ (p_T> 53 GeV) + E_T^{miss}

Strategy:

- lepton selection optimized for high-energy
- balanced decay for background suppression $0.4<p_T/E_T^{miss}<1.5$,
- $\Delta\Phi > 0.8\pi$ (back-to-back configuration)
- **lepton veto**: no other **electrons** (**muons**) with **pt>35 GeV** (**25 GeV**)
- W′ (3 TeV) A*ε: 75% for both channels

Background:

- main **irreducible** W→lν; **reducible** ttbar, Z/γ*, dibosons (estimated from MC)
- **multijet** background for electron channel estimated from data

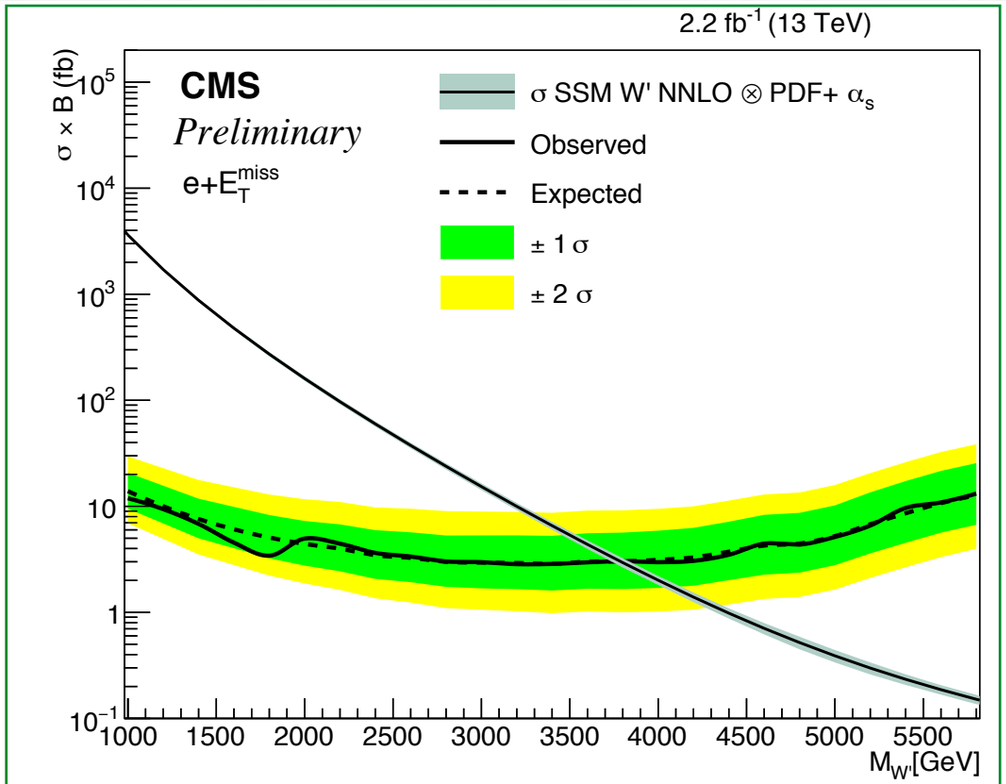
Highest mass events: at **M_T = 2 TeV** (electron channel) **1.3 TeV** (muon channel)

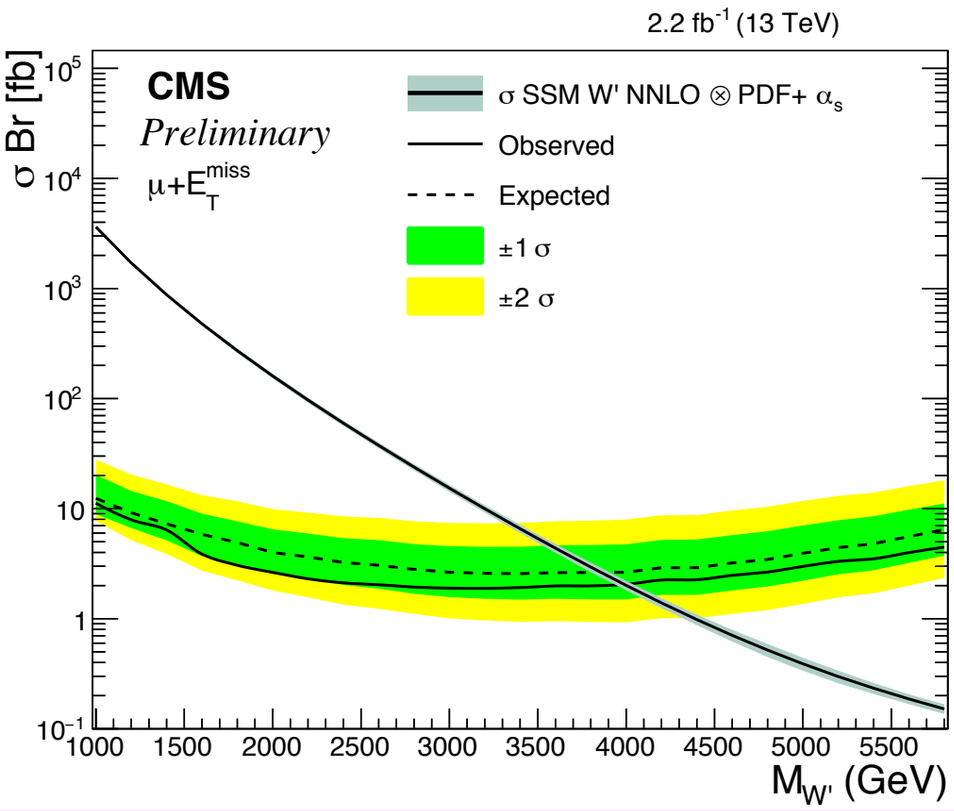
More details: talk A. Escalante

Good agreement between data and MC

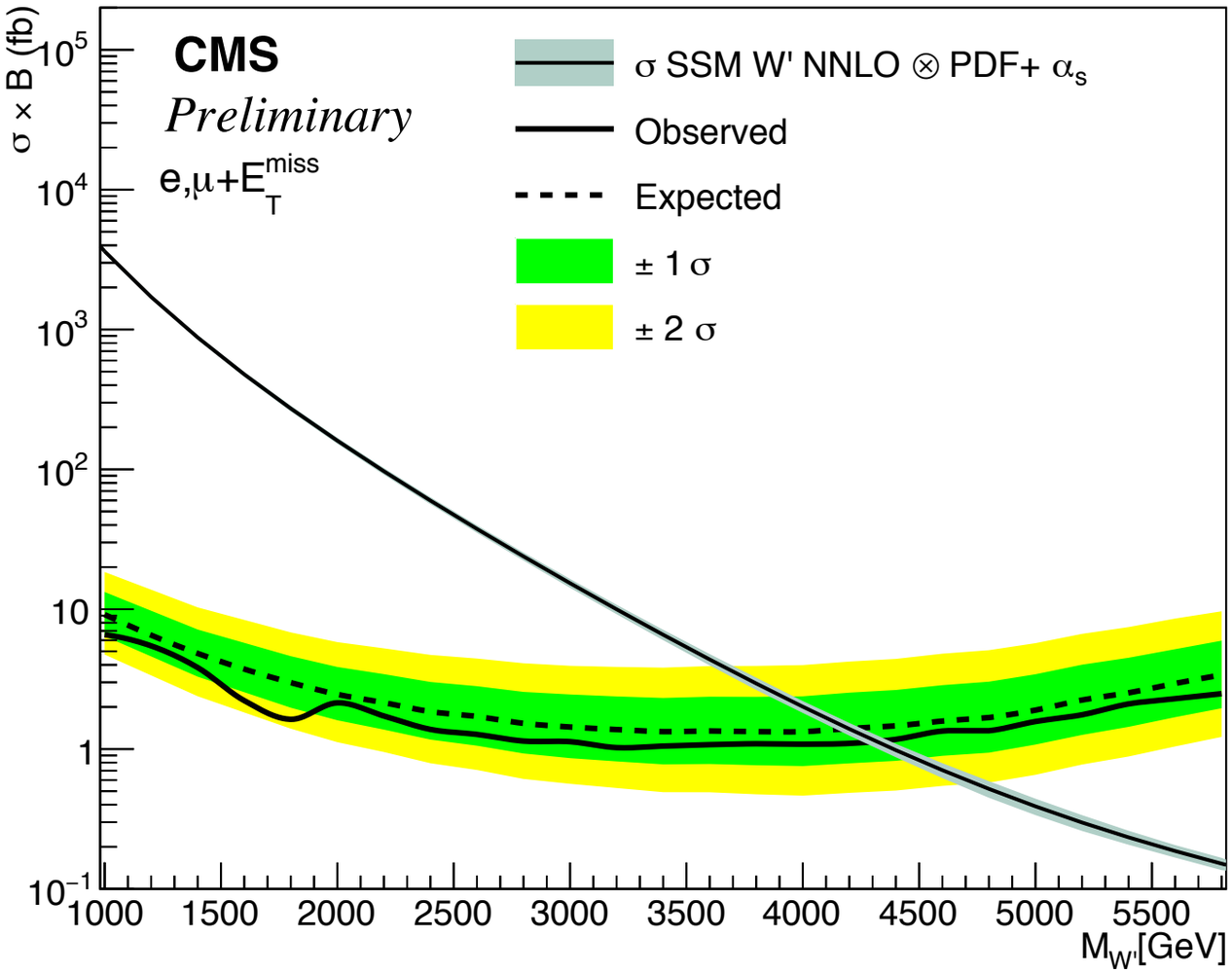
W′ -> e/μ +MET

13 TeV





CMS EXO-15-006



Limits on the production cross section*BR for M_T>1 TeV
(where Run-II data are more sensitive)

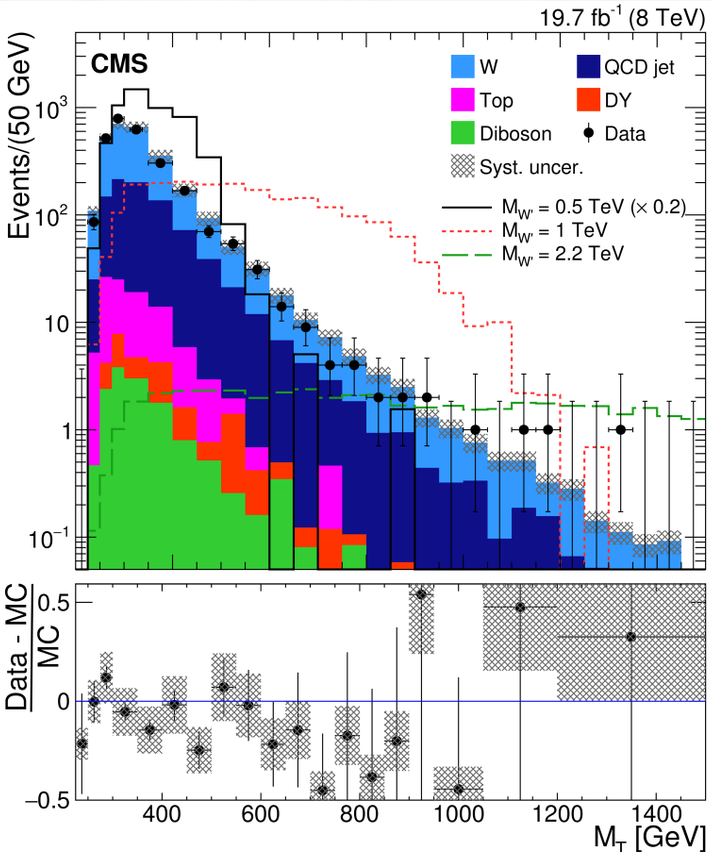
W'_{SSM} of masses less than 4.4 TeV are excluded

(tighter limits than Run1: W′ excluded with a mass less than 3.28 TeV)

W′ -> τ +MET

8 TeV

CMS EXO-12-011



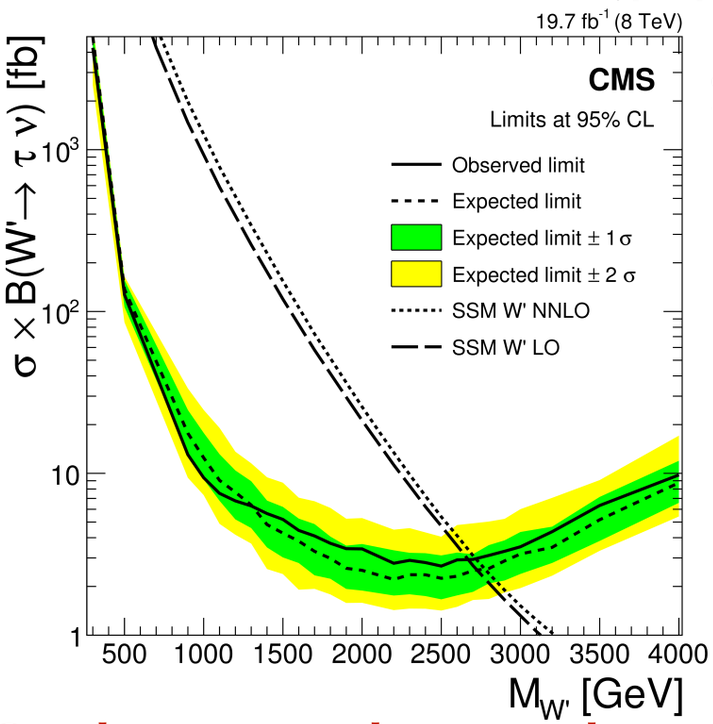
Heavy gauge boson W′ decaying into hadronic tau + MET

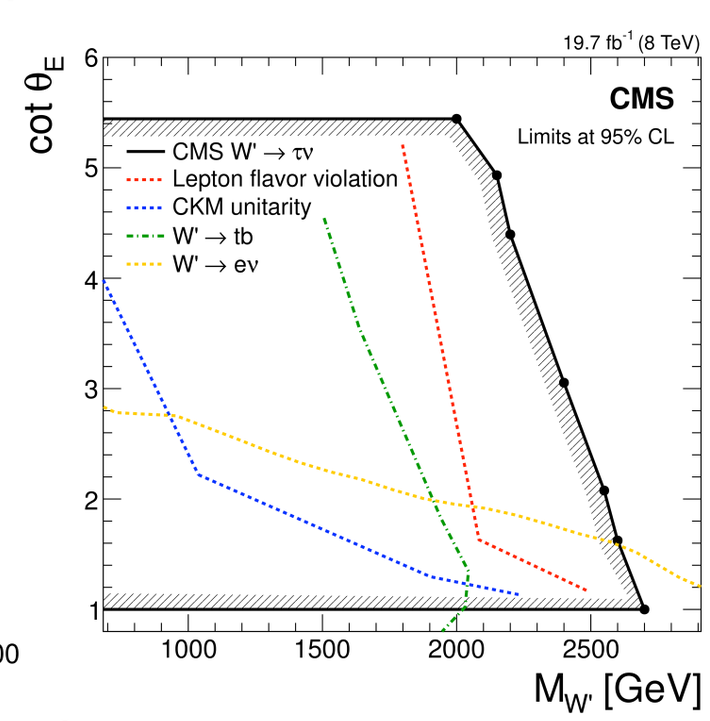
Experimental signature:

- τ_h (pT>100 GeV) + E_T^{miss} (> 140 GeV)

Strategy:

- hadronic tau reconstruction optimized for high-energy
- balanced decay for background suppression $0.7<p_T/E_T^{miss}<1.5$,
- $\Delta\Phi > 2.4$ (back-to-back configuration)
- lepton veto: no other loose-ID and isolated leptons
- W′ (3 TeV) A*ε: 42%*16%





Background:

- main **irreducible** W→ τ_h ν; **reducible** W→ e/μ+ν, t production, Z/γ*, dibosons (estimated from MC)
- **QCD jet** background estimated from data

Good agreement between data and MC

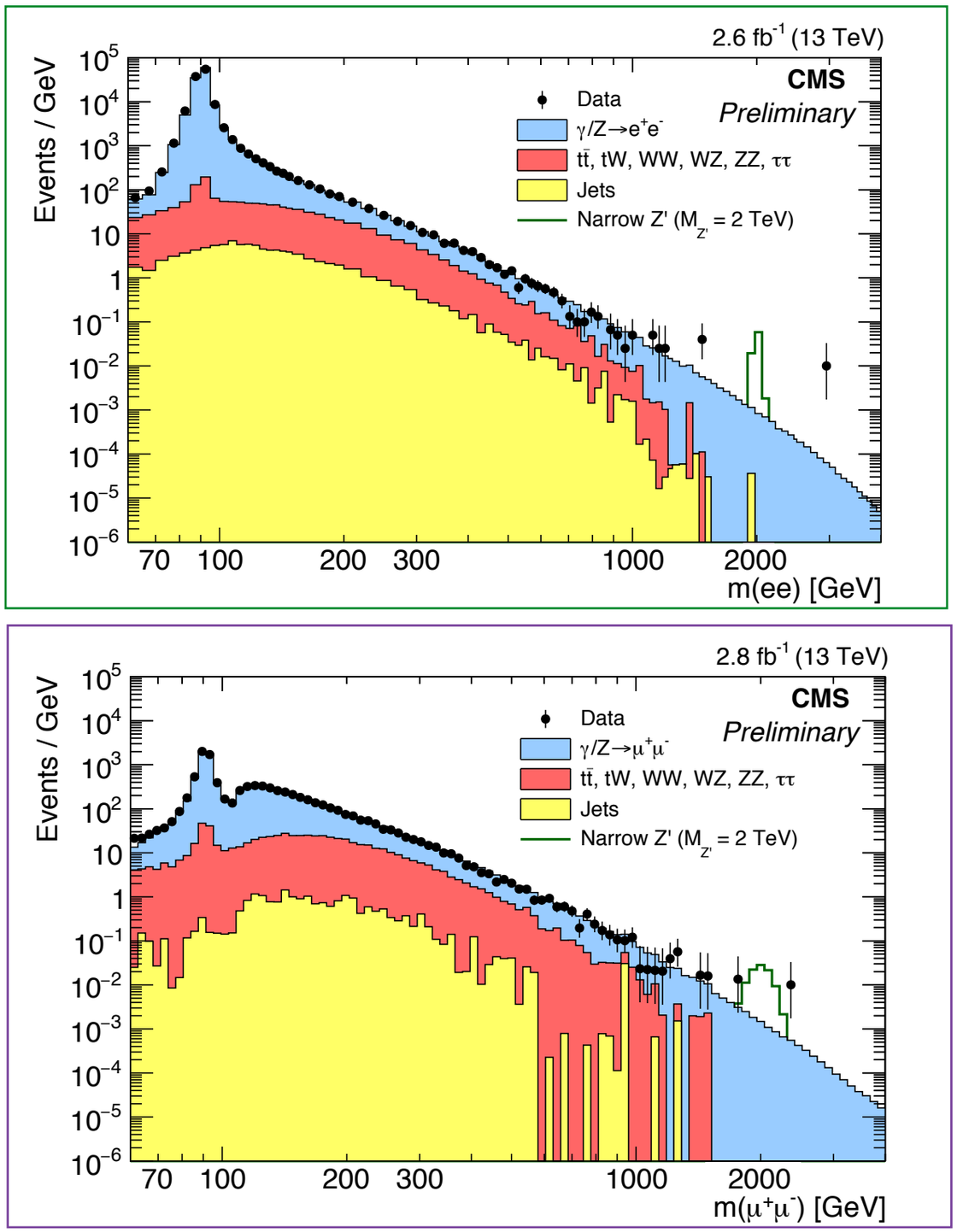
The W'_{SSM} is excluded for masses $0.3<M_{W'}<2.7$ TeV.

Limits on the W′ as a function of the coupling parameter $\cot\theta_E$ for the Non Universal Gauge Interaction Model

$Z' \rightarrow ee/\mu\mu$ (1/3)

13 TeV

CMS EXO-15-005



Good agreement between data and MC

Heavy gauge boson (Z′) decaying into a lepton pair

Experimental signature:

- high-energy electron pair (p_T>35GeV)
- high-energy muon pair (p_T> 53 GeV)

Strategy:

- specific high-energy lepton ID
- **Z′->ee**
  - **2 categories**: Barrel-Barrel (**BB**) and Barrel-Endcap (**BE**)
  - A*ε (1 TeV) = 75±8% / 70±10%
  - mass resolution (1 TeV) = 1.4% / 1.8%
- **Z′->μμ**
  - A* ε (1 TeV) = $89 \pm {}^{+11}_{-14}$%
  - mass resolution (1 TeV) = 4%

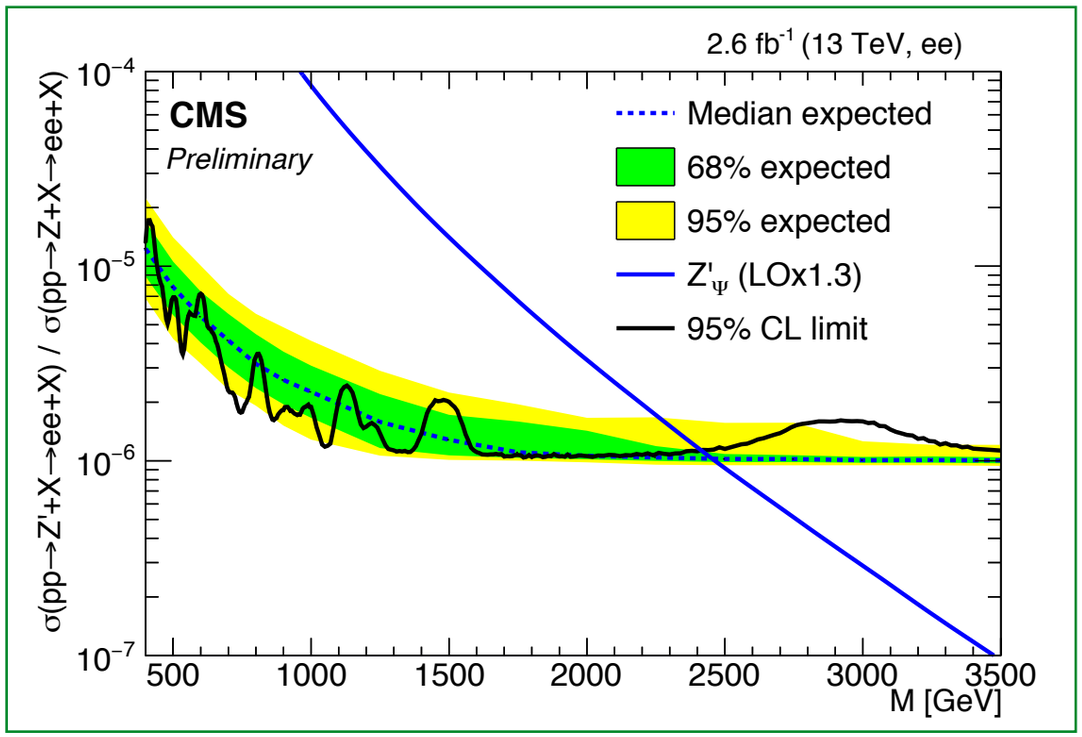
Background:

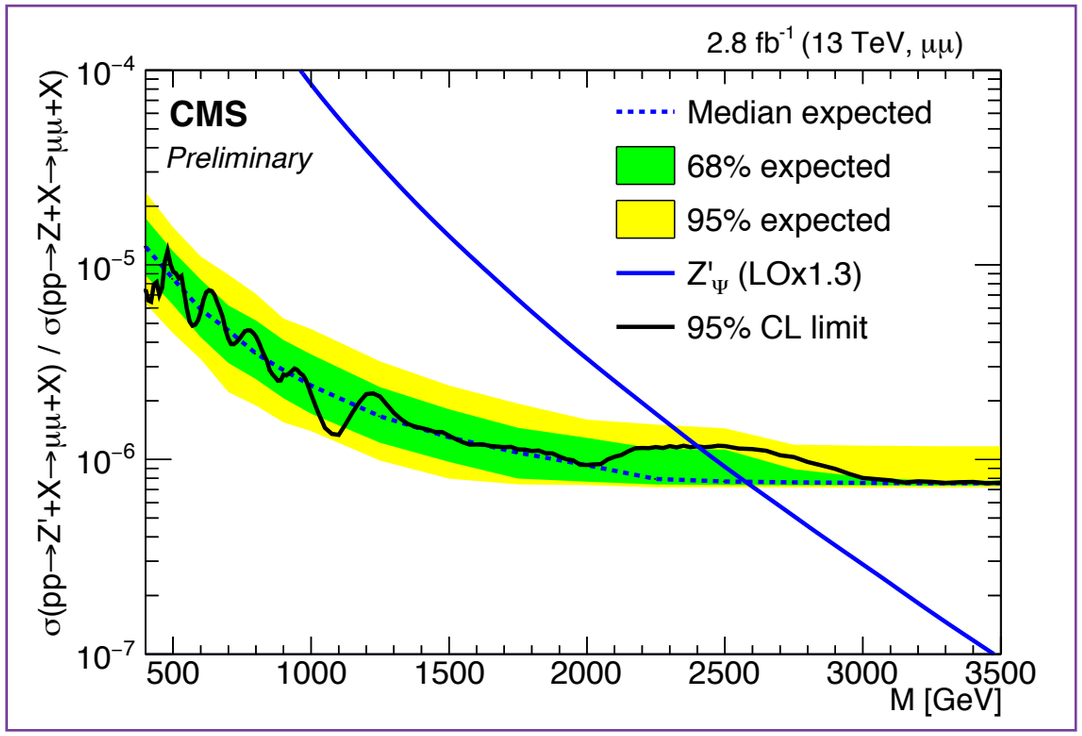
- main **irreducible** Z/γ* , **reducible** ttbar, tW, dibosons (estimated from MC)
- **multijet** background < 3% (1%) of the total background for dielectrons (dimuons) > 500 GeV(estimated from data)
- MC background normalised at the Z peak

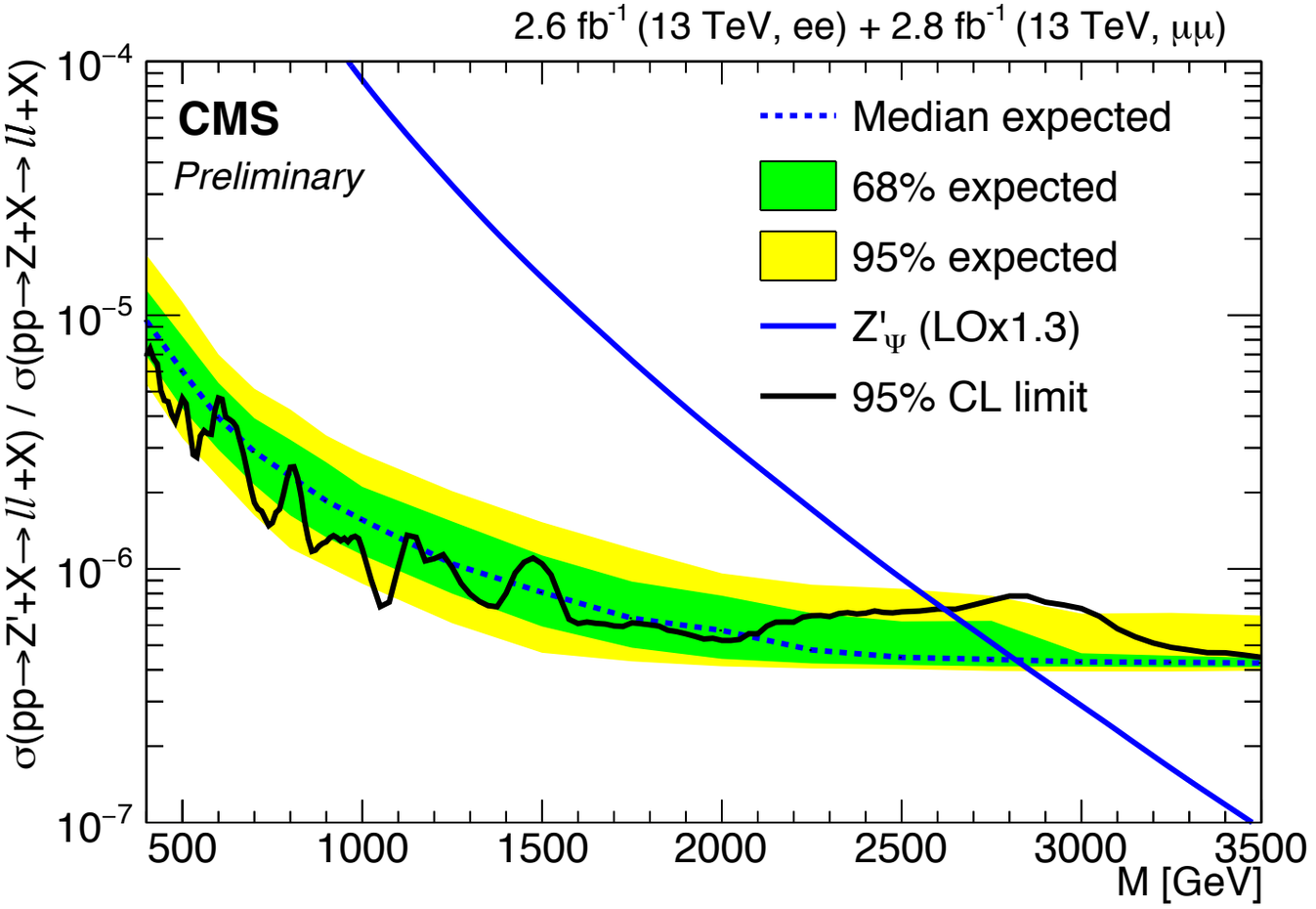
$Z' \rightarrow ee/\mu\mu$ (2/3)

13 TeV

CMS EXO-15-005







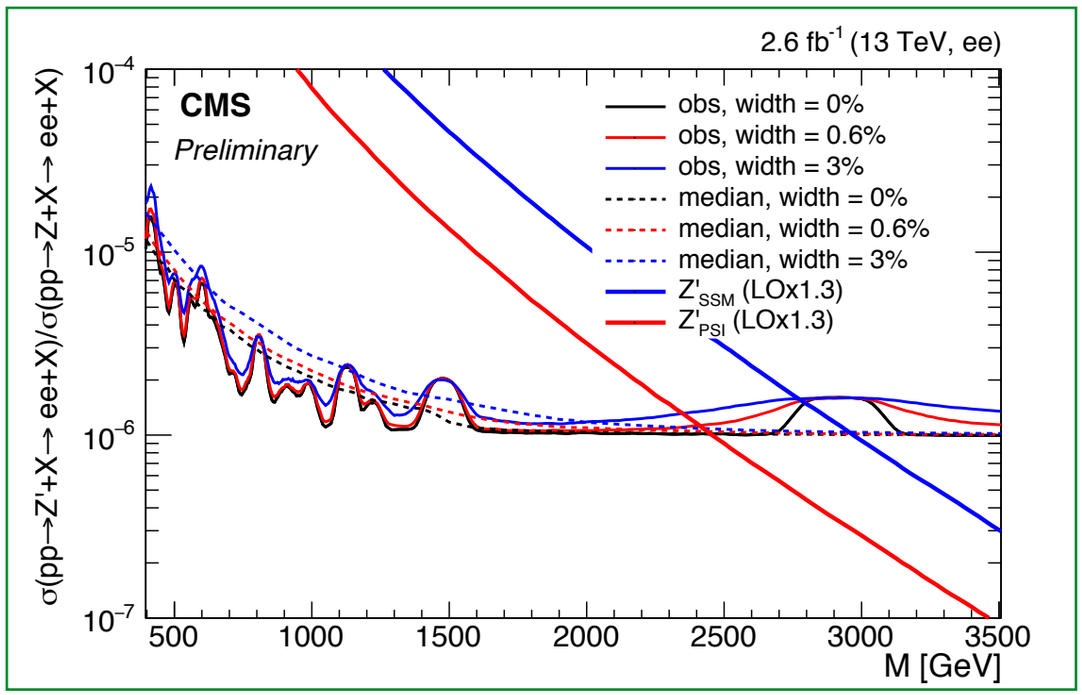
Limits at 95% C.L. on the ratio of Z′ cross section to Z/γ* cross section assuming a narrow resonance

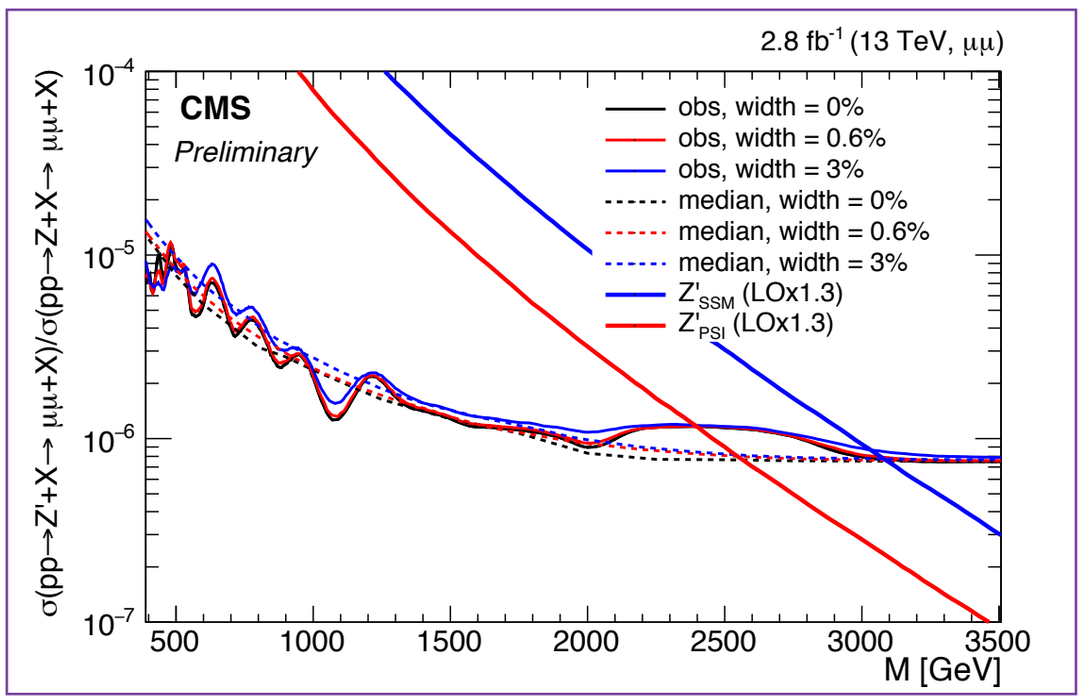
- background model from simulation
- signal pdf: convolution of BW (input of 0%, 0.6% (Z'_{ψ}) or 3% (Z'_{SSM})) with a Gaussian

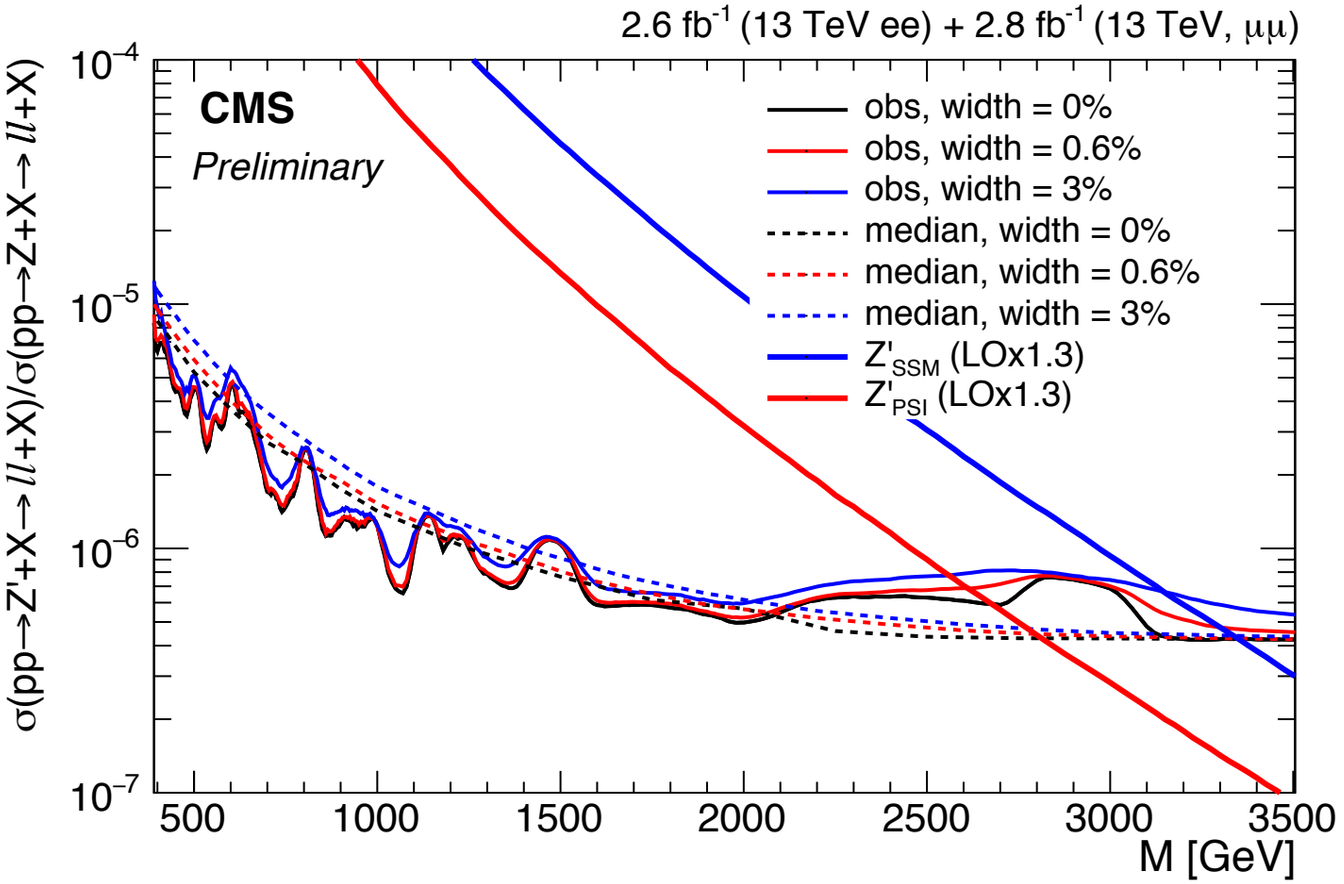
$Z' \rightarrow$ ee/ μμ (3/3)

13 TeV

CMS EXO-15-005

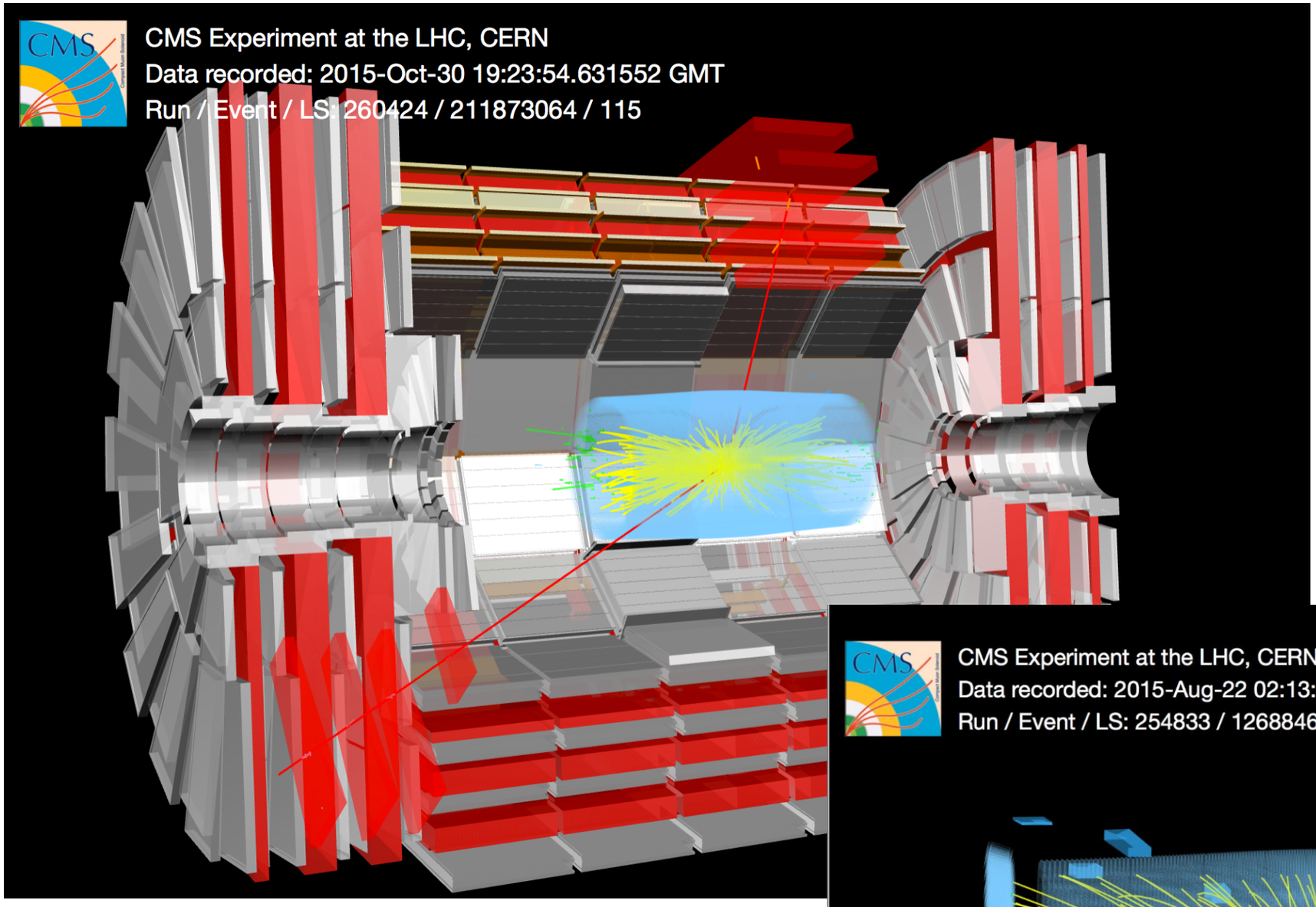






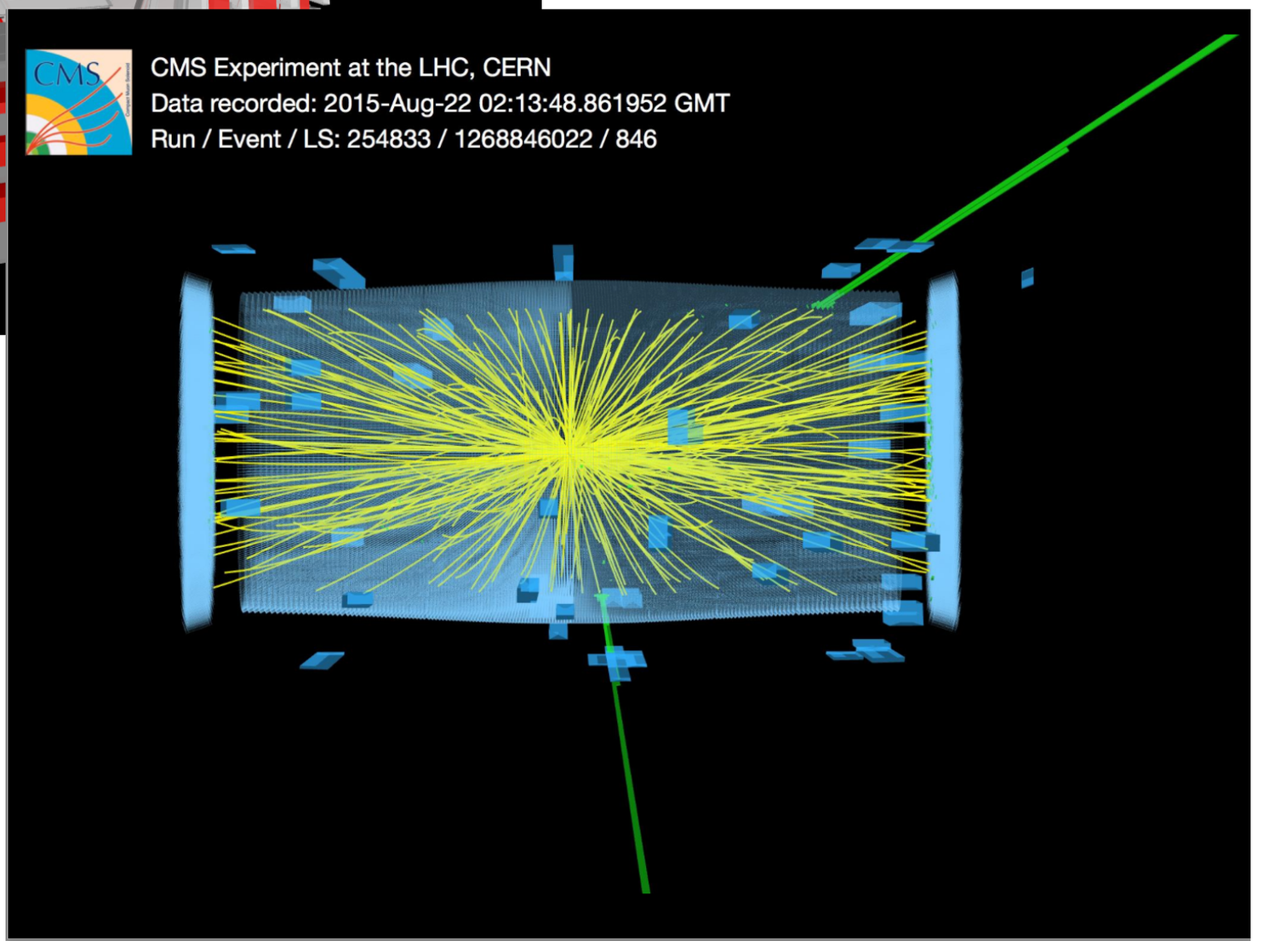
The limit exclude a Z'_{SSM} with a mass less than 3.15 TeV and Z'_{ψ} with a mass less than 2.6 TeV.

(8 TeV limits of 2.90 TeV (Z'_{SSM}) and 2.57 TeV (Z'_{ψ}) surpassed)



13 TeV

CMS DP -2015/039



Highest mass events:

2.4 TeV for the muon channel

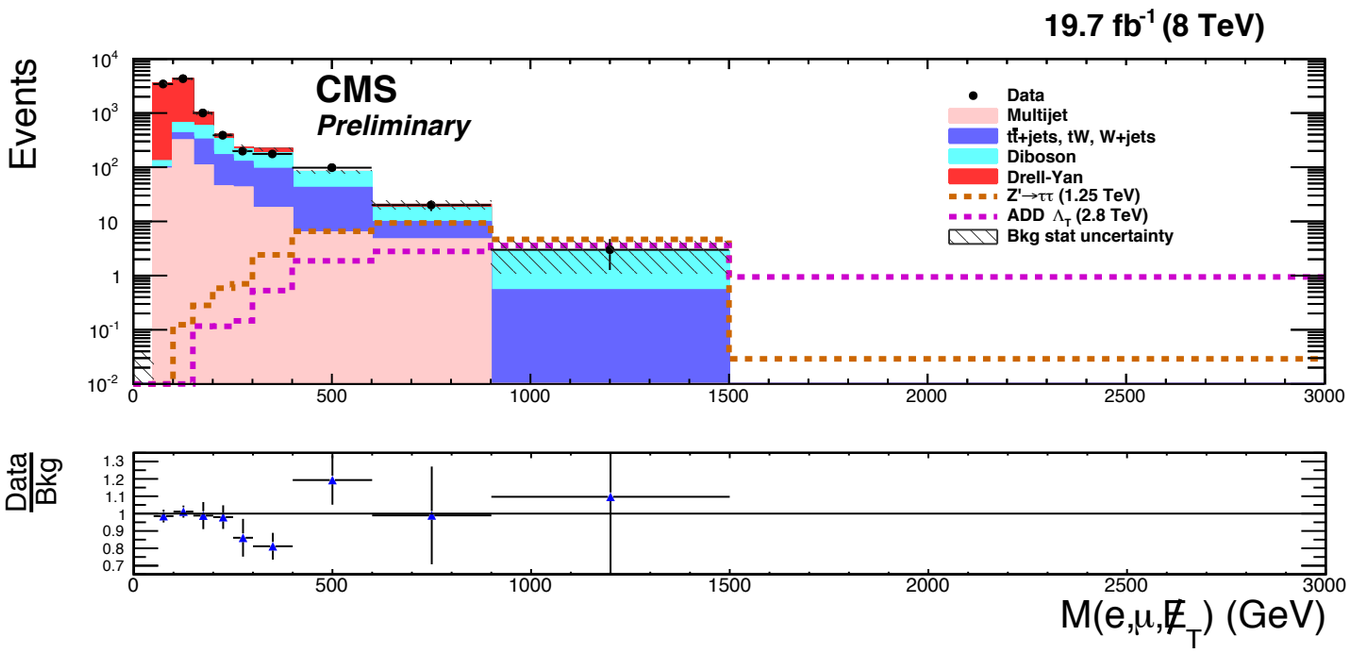
2.9 TeV in the electron channel (local **p-value** to observe at least one event in the range m(ee) > 2.8 TeV is **3.6%**)

$Z' \rightarrow \tau\tau$

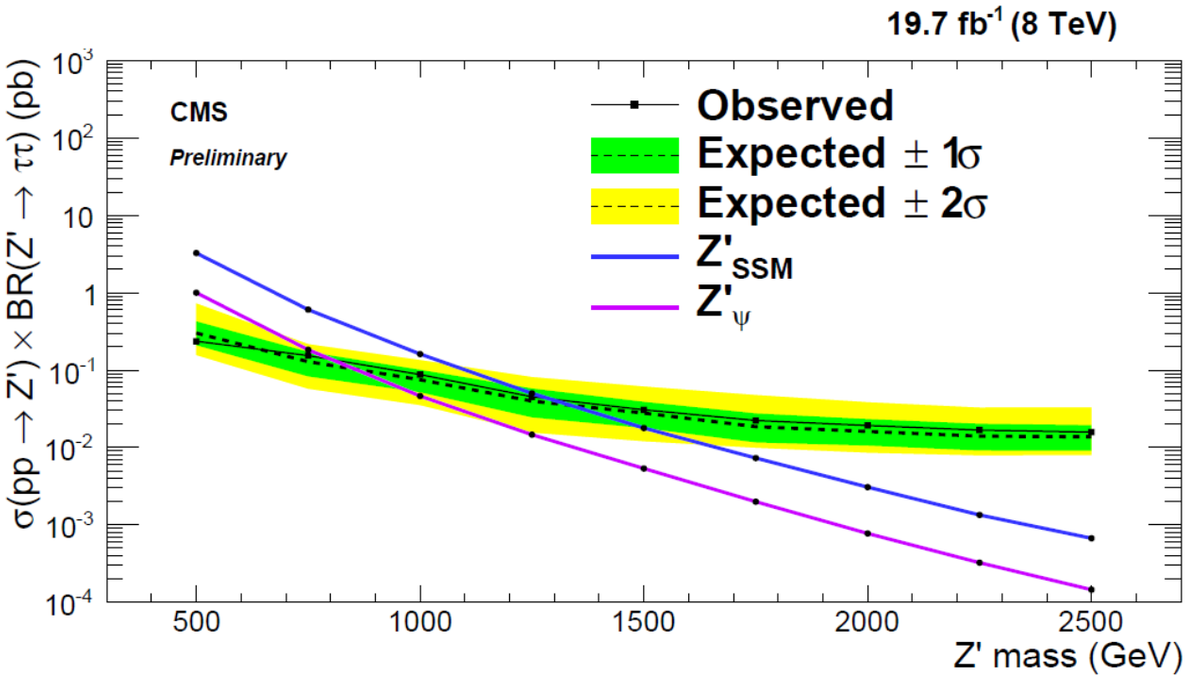
8 TeV

CMS EXO-12-046

Heavy gauge boson (Z′) decaying into a tau pair (eμ final state)



Good agreement between data and MC



Experimental signature:

- electron (Et > 20 GeV |eta|<2.5) + muon (pt>20 GeV |eta|< 2.1)

Strategy:

- back-to-back (e, μ) (cosΔΦ(e,μ)<-0.95)
- missing transverse momentum direction originating from tau decays
- no b-tagged jets
- A* ε (1.25 TeV) = 41±1%

Background:

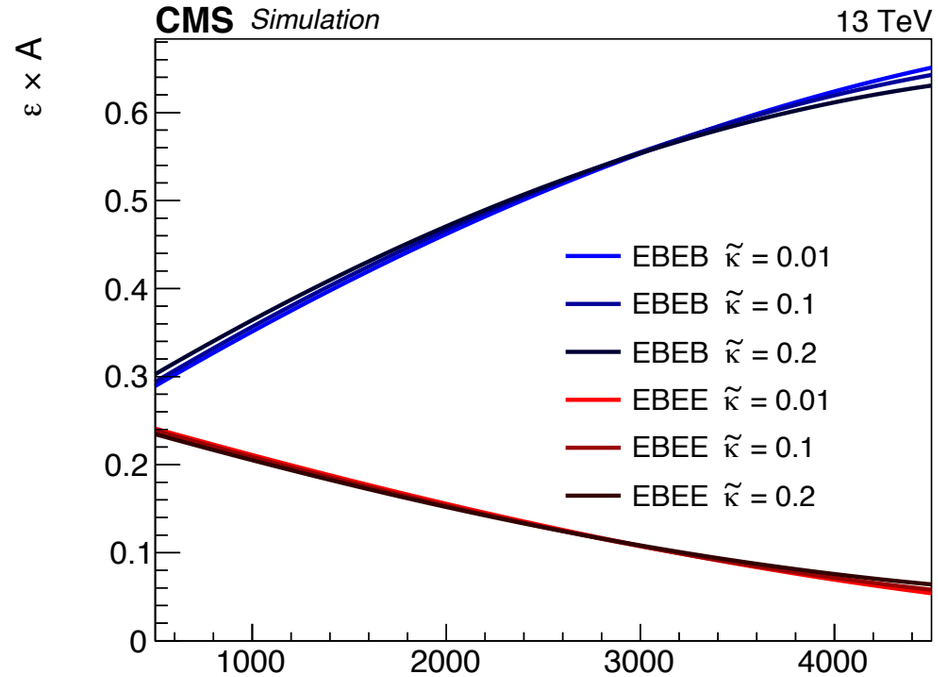
- main Z/γ* at low mass, WW at high mass, **reducible**, tW, dibosons (estimated from MC)
- ttbar and **multijet** background(estimated from data)

The limit exclude a Z'_{SSM} with a mass less than 1.3 TeV and Z'_{ψ} with a mass less than 810 GeV.

Di-photon (1/3)

13 TeV

CMS EXO-15-004

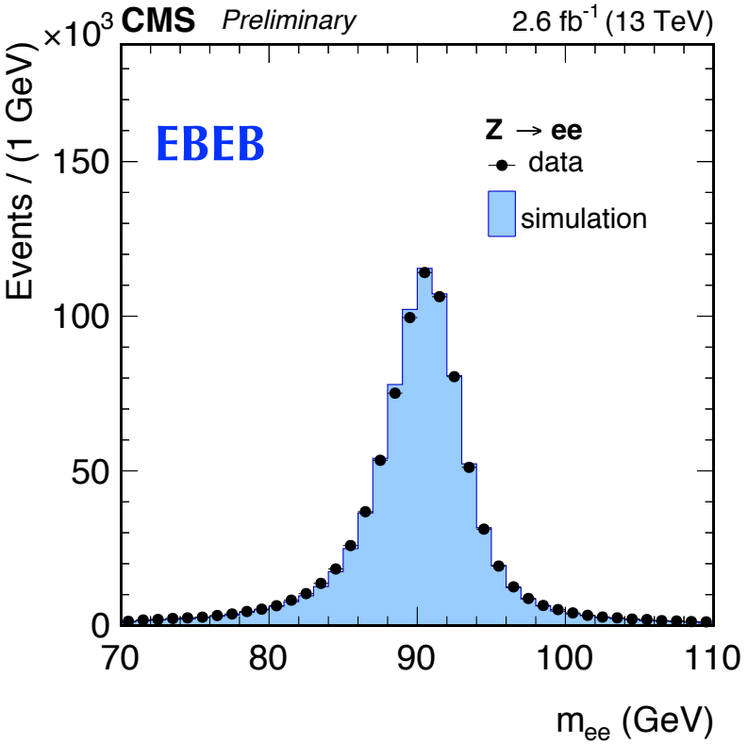


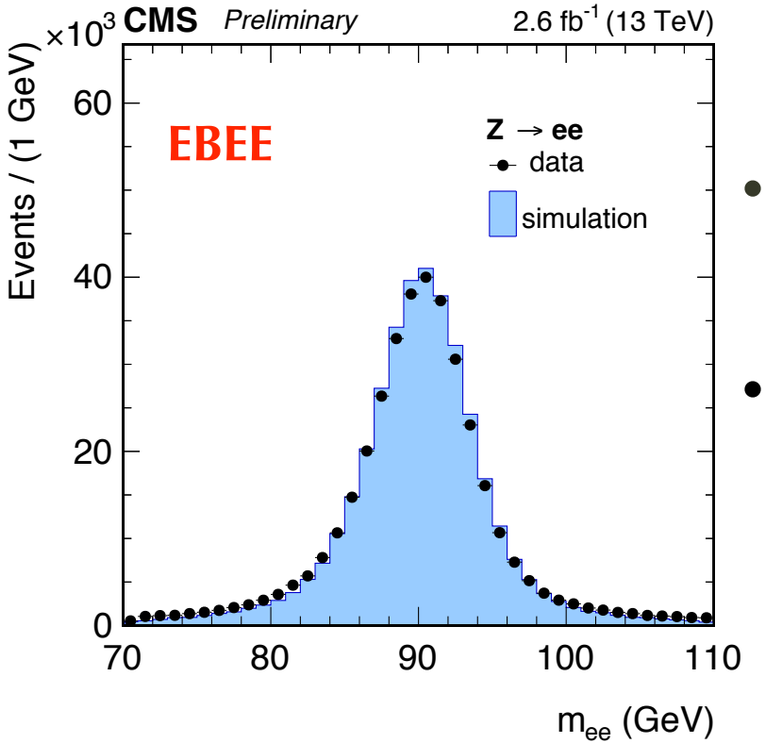
Search for RS graviton with 3 assumptions on coupling constant $\tilde{\kappa}=\kappa/m_{Pl}$: $\tilde{\kappa}$ = 0.01 (narrow), 0.1, 0.2 (wide)

Experimental signature: pair of photons (p_T> 75 GeV; I_{ch} < 5 GeV (in 0.3 cone around the photon direction))

Strategy:

- **2 categories**: (Barrel-Barrel) **EBEB** and (Barrel-Endcap) **EBEE**
- control region $m_{\gamma\gamma}$> **230** (**320**) GeV
- signal region $m_{\gamma\gamma}$> 500 GeV

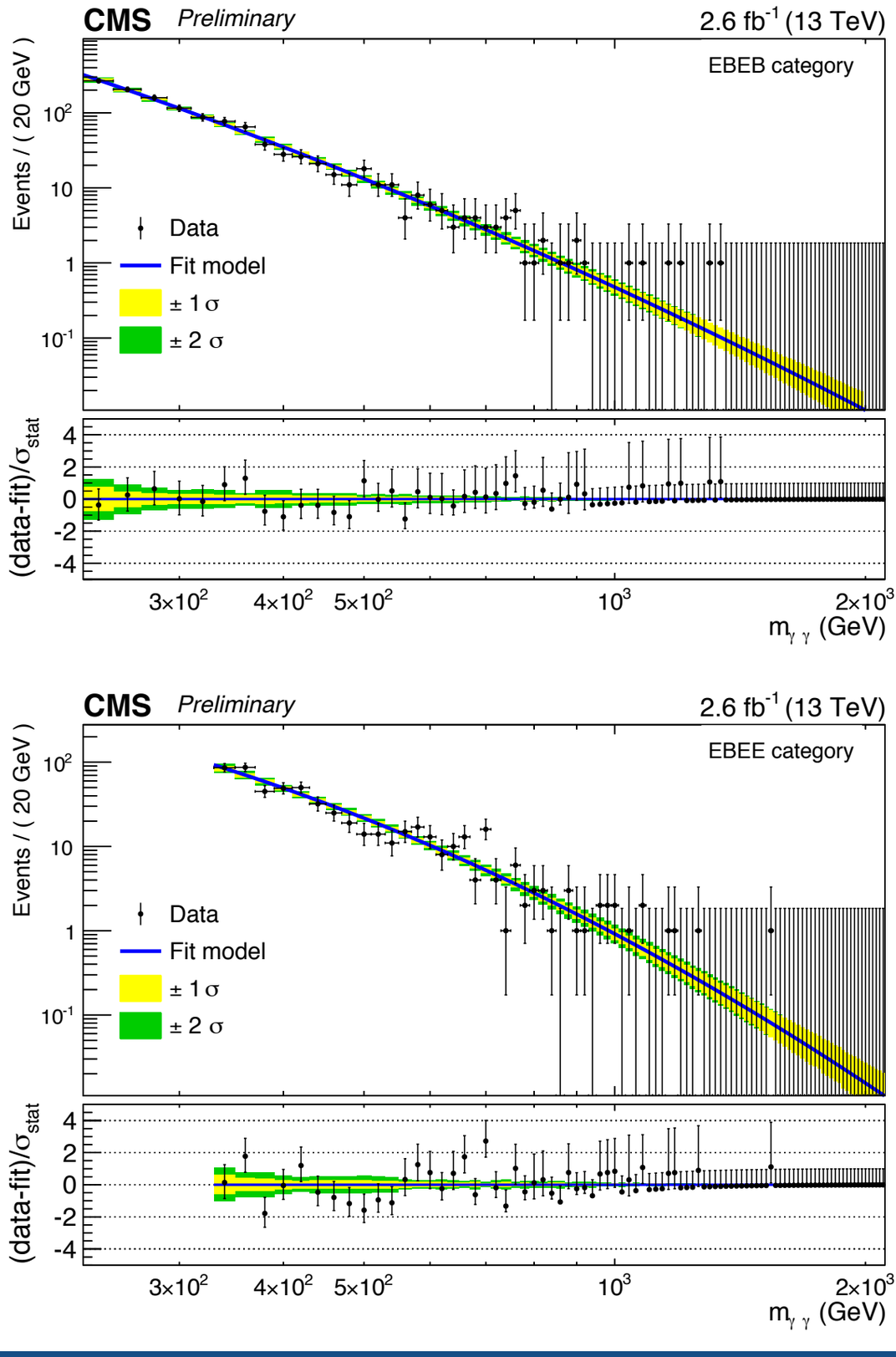




- dedicated **photon ID** (ε=~90% per photon; ~10(20)% of reducible background in the signal region)
- energy scale and resolution calibration using data-driven inputs (Z→ee events)

Di-photon (2/3)

13 TeV

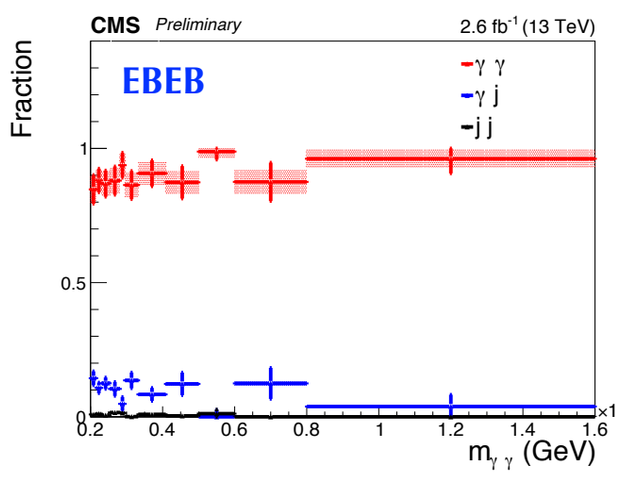


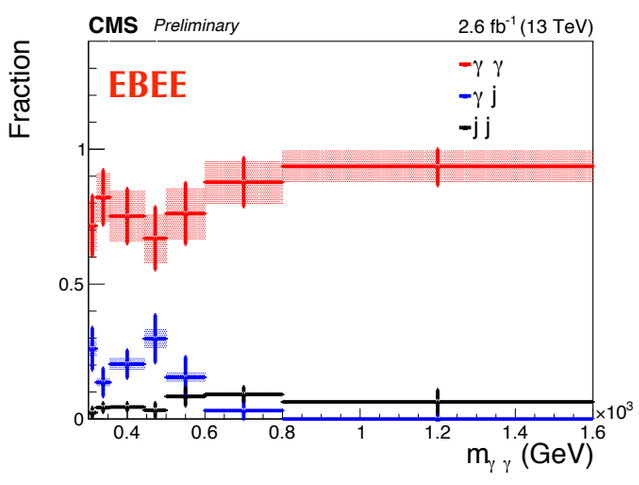
CMS EXO-15-004

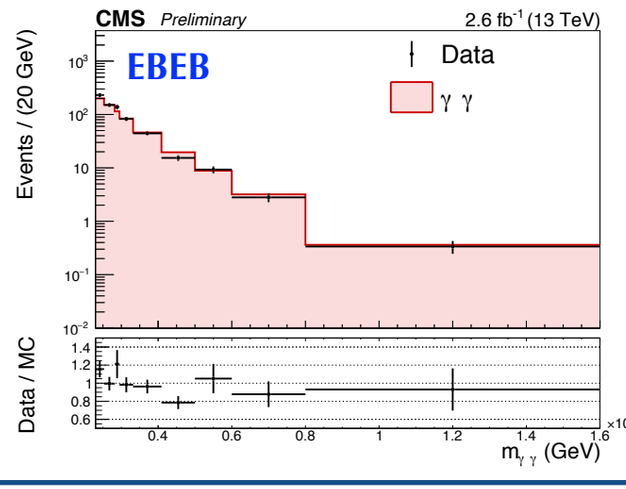
Background:

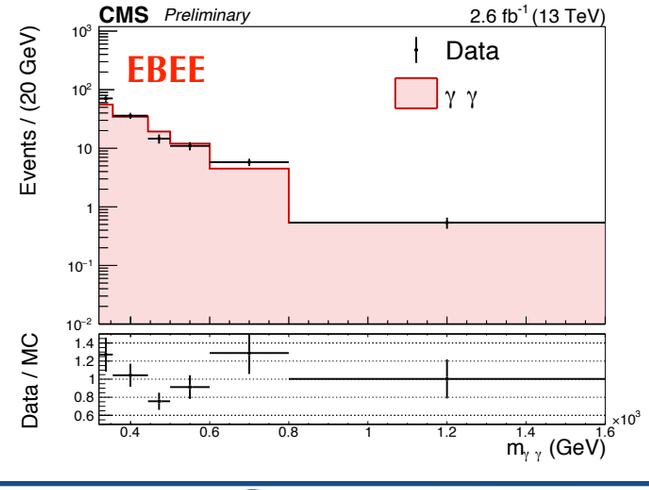
- main **irreducible γγ** direct production, **reducible γ-j** and **j-j**)
- good agreement between data-driven estimation and estimations from MC
- **background model from parametric fit in data**

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



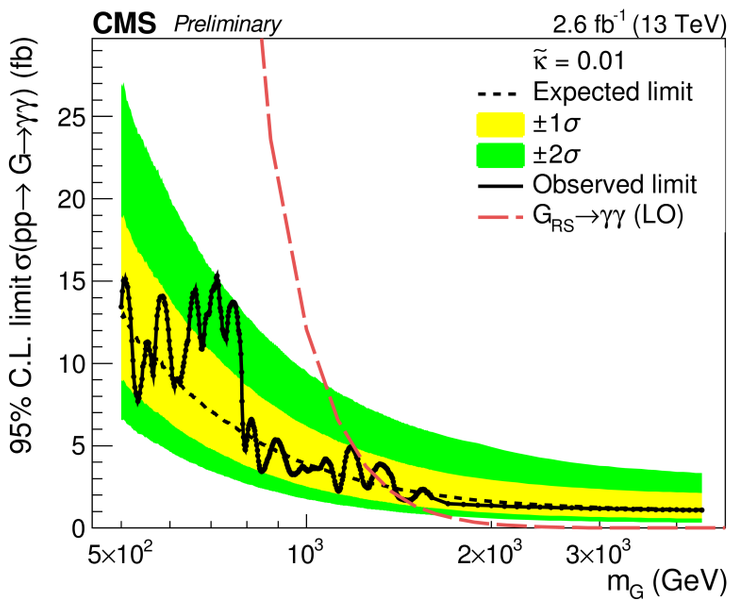




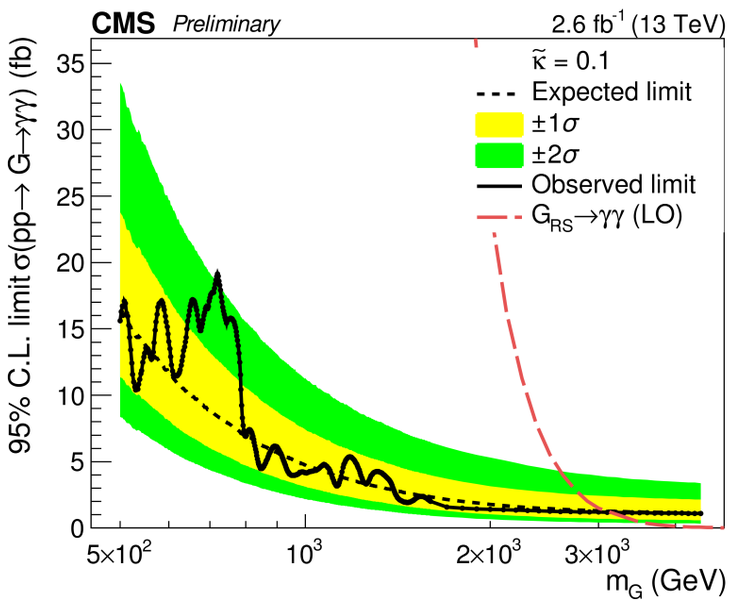


Di-photon (3/3)

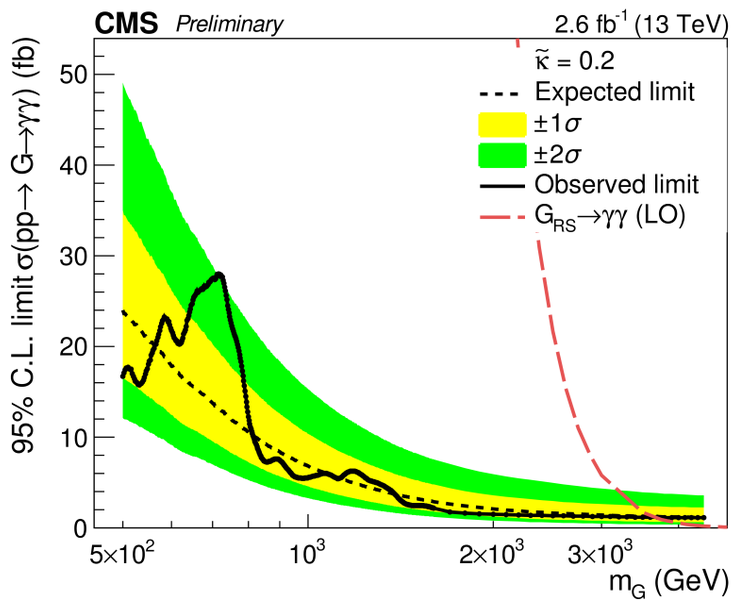
13 TeV



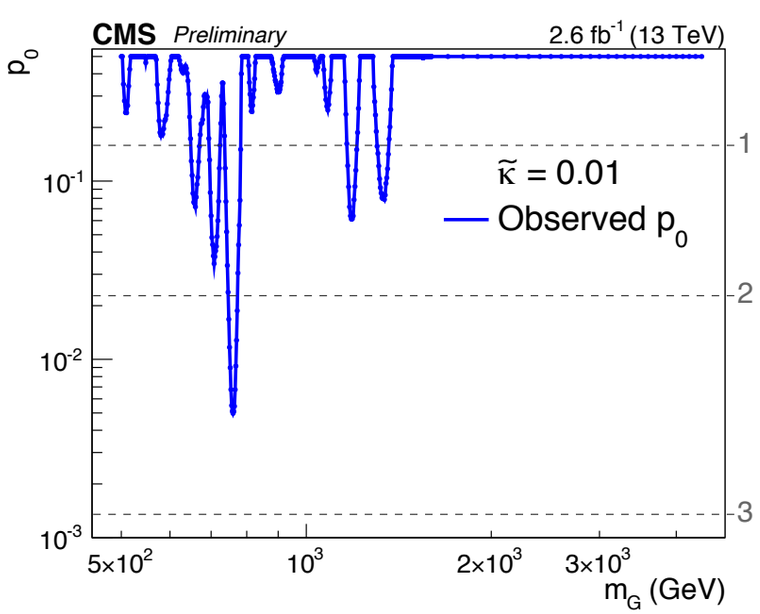
$\tilde{\kappa} = 0.01$ (**Narrow width**)

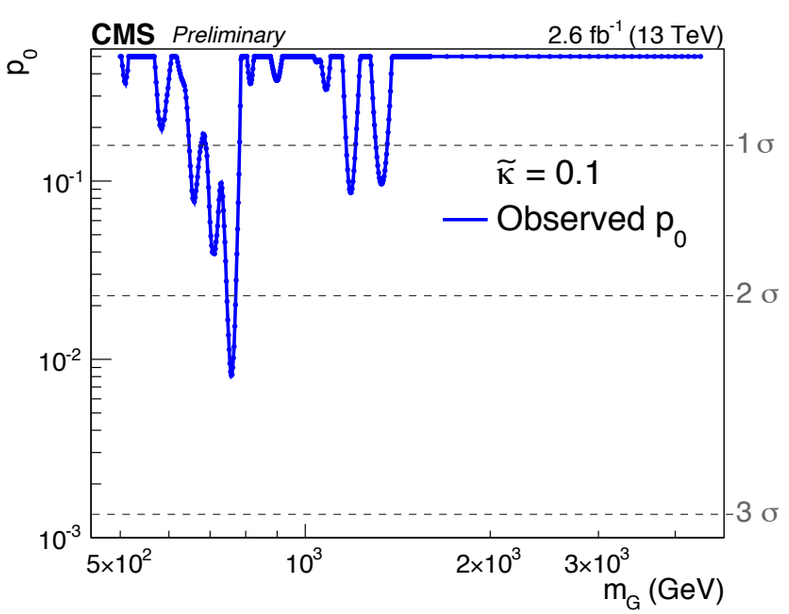


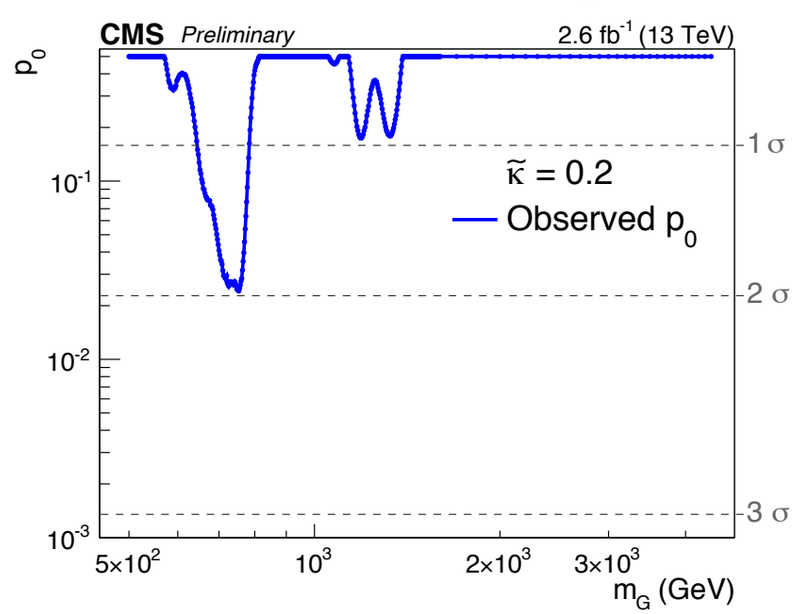
$\tilde{\kappa} = 0.1$



$\tilde{\kappa} = 0.2$ (**Wide width**)

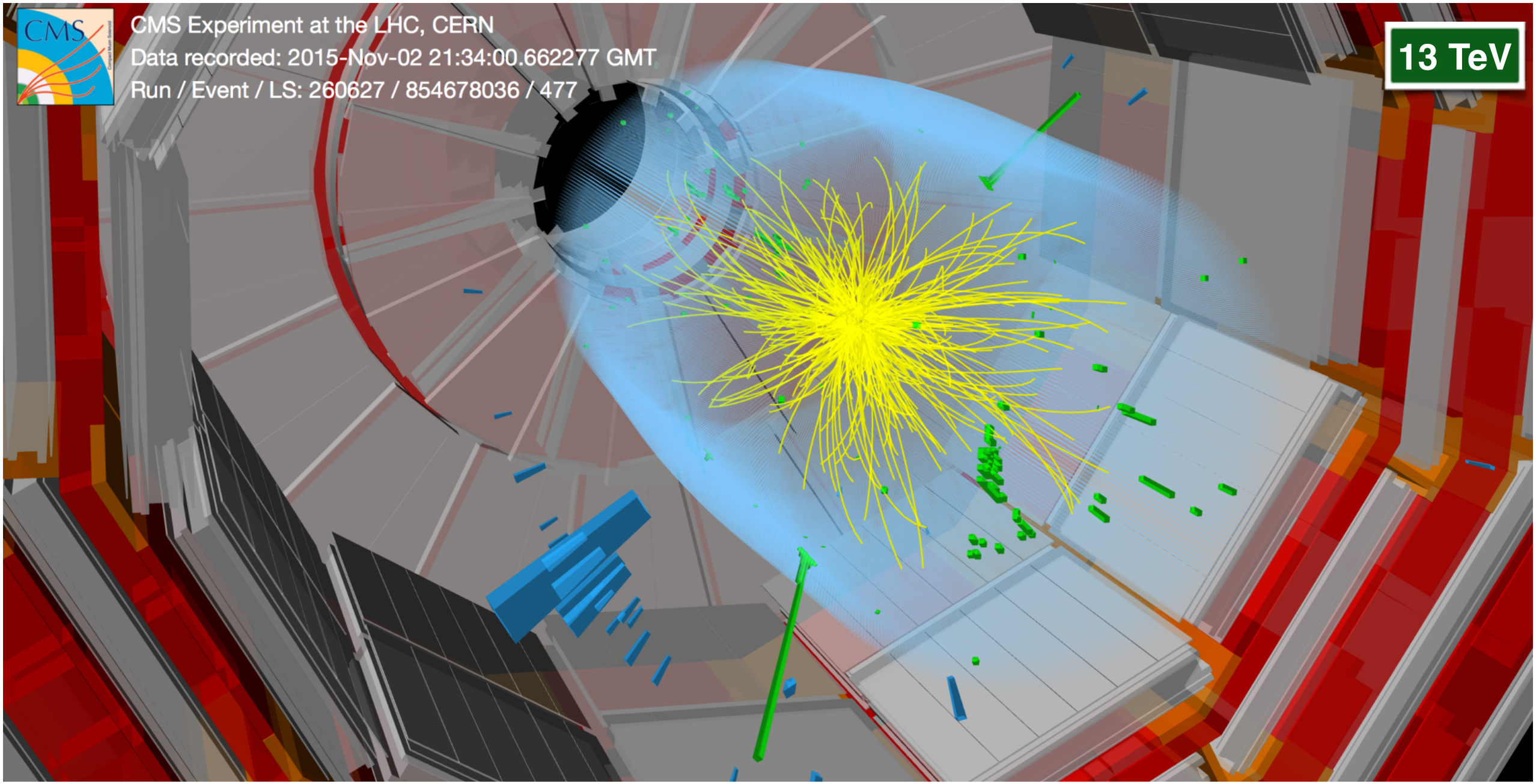






- **RS graviton of mass below 1.3 TeV, 3.1, 3.8 TeV excluded for $\tilde{\kappa}$ = 0.01, 0.1, and 0.2**
- **Local p-value (760 GeV) ~ 2.6σ** (narrow width, excess of events in the BB)
- **Global p-value ~ 1.2σ**

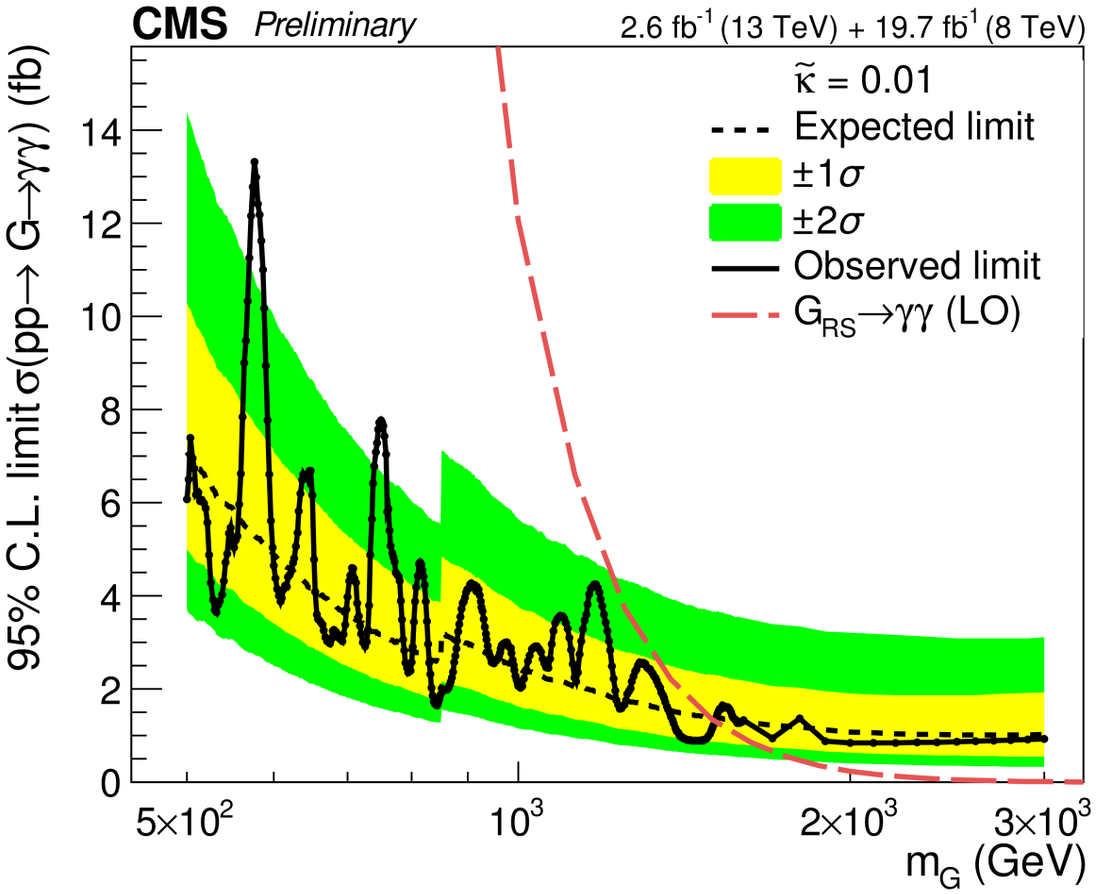
CMS EXO-15-004

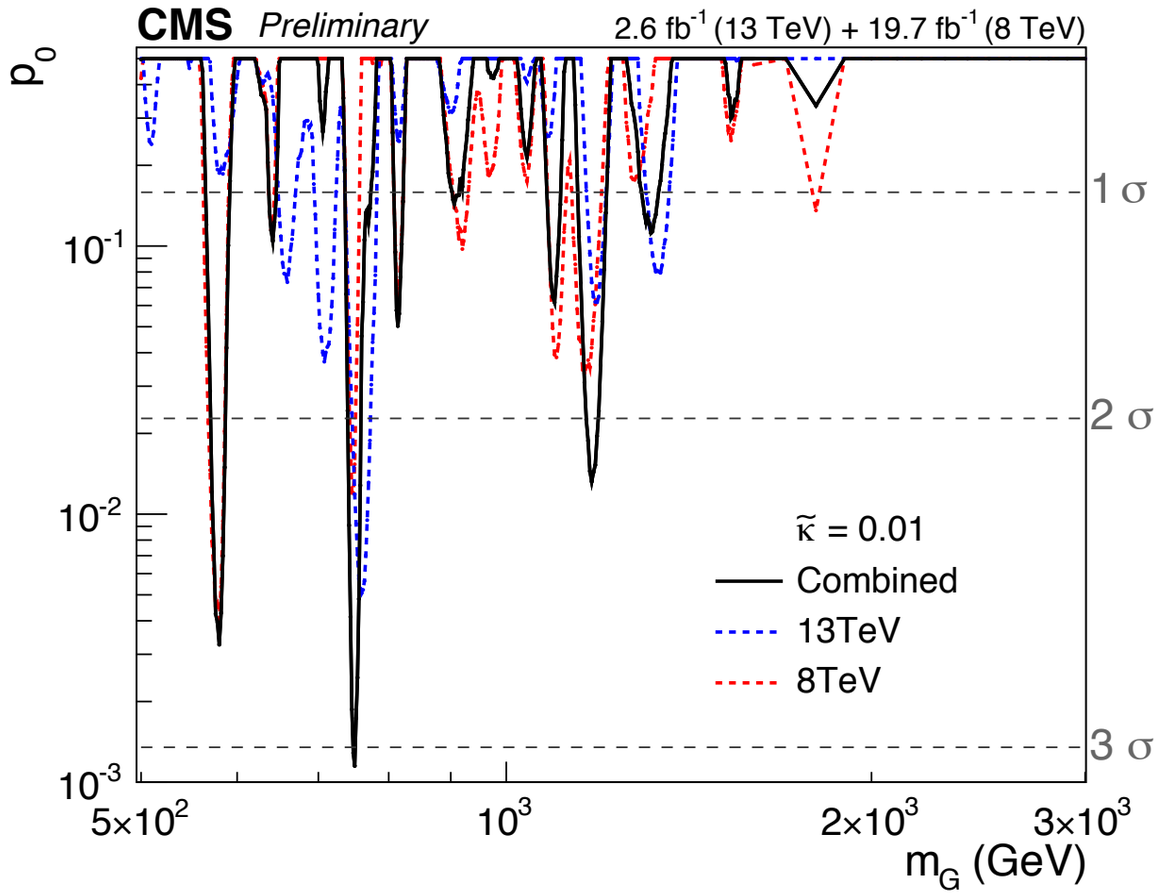


Di-photon event with m(γγ) = 745 GeV

Di-photon 13 TeV + 8 TeV

CMS EXO-15-004





8 TeV + 13 TeV combination for narrow width model:

- ratio of the signal production cross section 8 TeV/13 TeV= 0.24 at 750 GeV
- exclusion limits obtained with the combined analysis improved by 20-30 % for $m_{\gamma\gamma} < 1.5$ TeV
- **Local p-value (750 GeV) ~3σ**
- **Global p-value ~ 1.7σ**

Conclusion

- CMS analyzed 13 TeV data searching for evidence of:
  - Heavy gauge bosons (W′) in a muon/electron + MET
  - Heavy gauge bosons (Z′) in a muon/electron pair
  - RS Graviton in a photon pair
    - 13TeV + 8 TeV results: largest excess has a local significance of ~3σ (narrow resonance at m_G = 750GeV) and a global significance of 1.7σ
- No sign of new physics beyond the SM have been found (yet)
- Run-II analyses allowed to establish NEW tighter limits on BSM processes

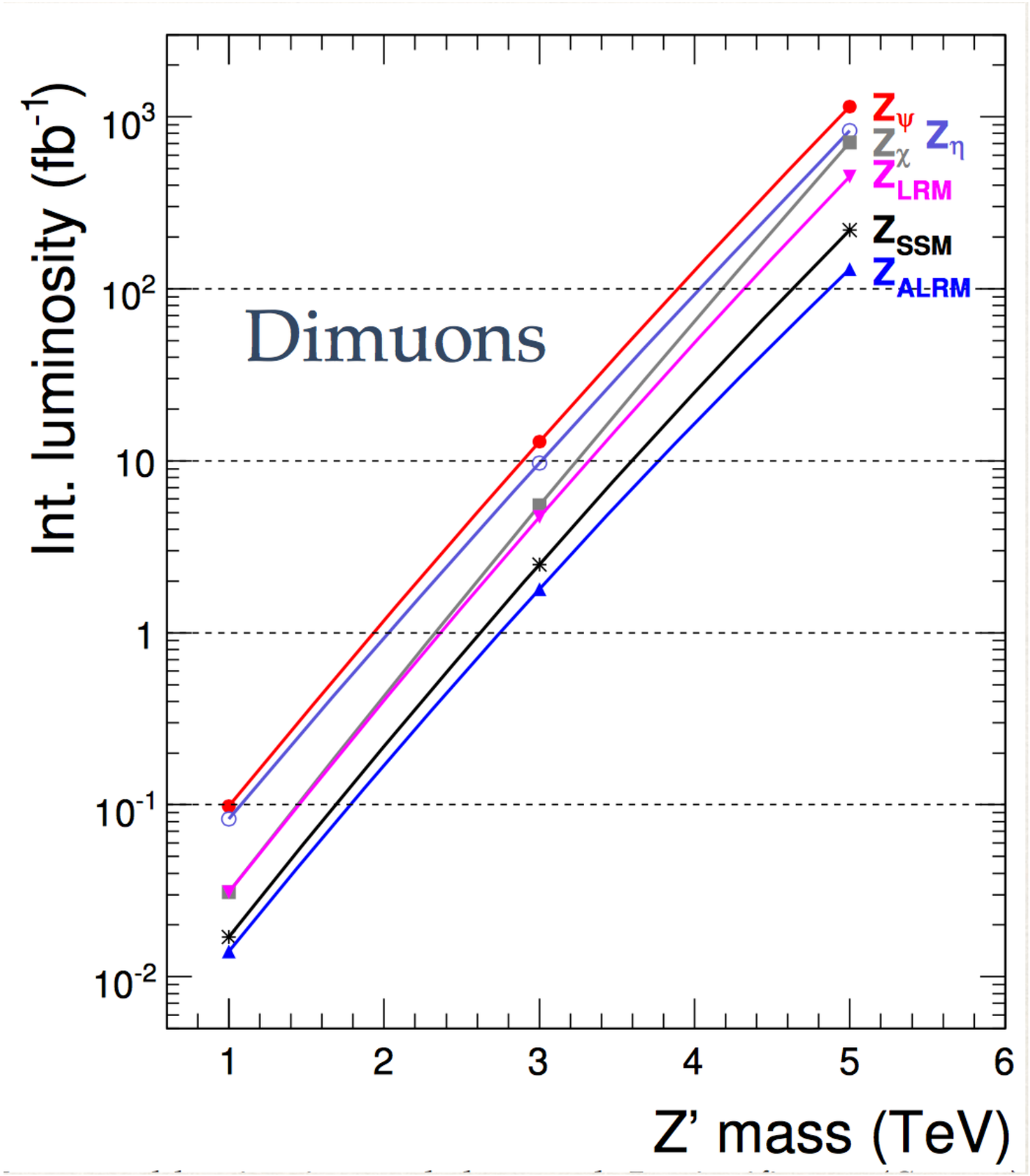
Bibliography

- **CMS-PAS-EXO-15-005**: "Search for a narrow resonance produced in 13 TeV pp collisions decaying to electron pair or muon pair final states"
- **CMS-DP-2015/039**: "Event display of a candidate electron-positron pair with an invariant mass of 2.9 TeV"
- **CMS-PAS-EXO-12-046**: "Search for high-mass resonances and large extra dimensions with tau-lepton pairs decaying into final states with an electron and a muon at $\sqrt{s}$ = 8 TeV"
- **CMS-PAS-EXO-15-006**: "Search for SSM W' production, in the lepton+MET final state at a center-of-mass energy of 13 TeV"
- **CMS-PAS-EXO-12-011:** "Search for W' decaying to tau lepton and neutrino in proton-proton collisions at $\sqrt{s}$ = 8 TeV" (arXiv:1508.04308)
- **CMS-PAS-EXO-15-004**: "Search for new physics in high mass diphoton events in proton-proton collisions at $\sqrt{s}$ = 13 TeV"

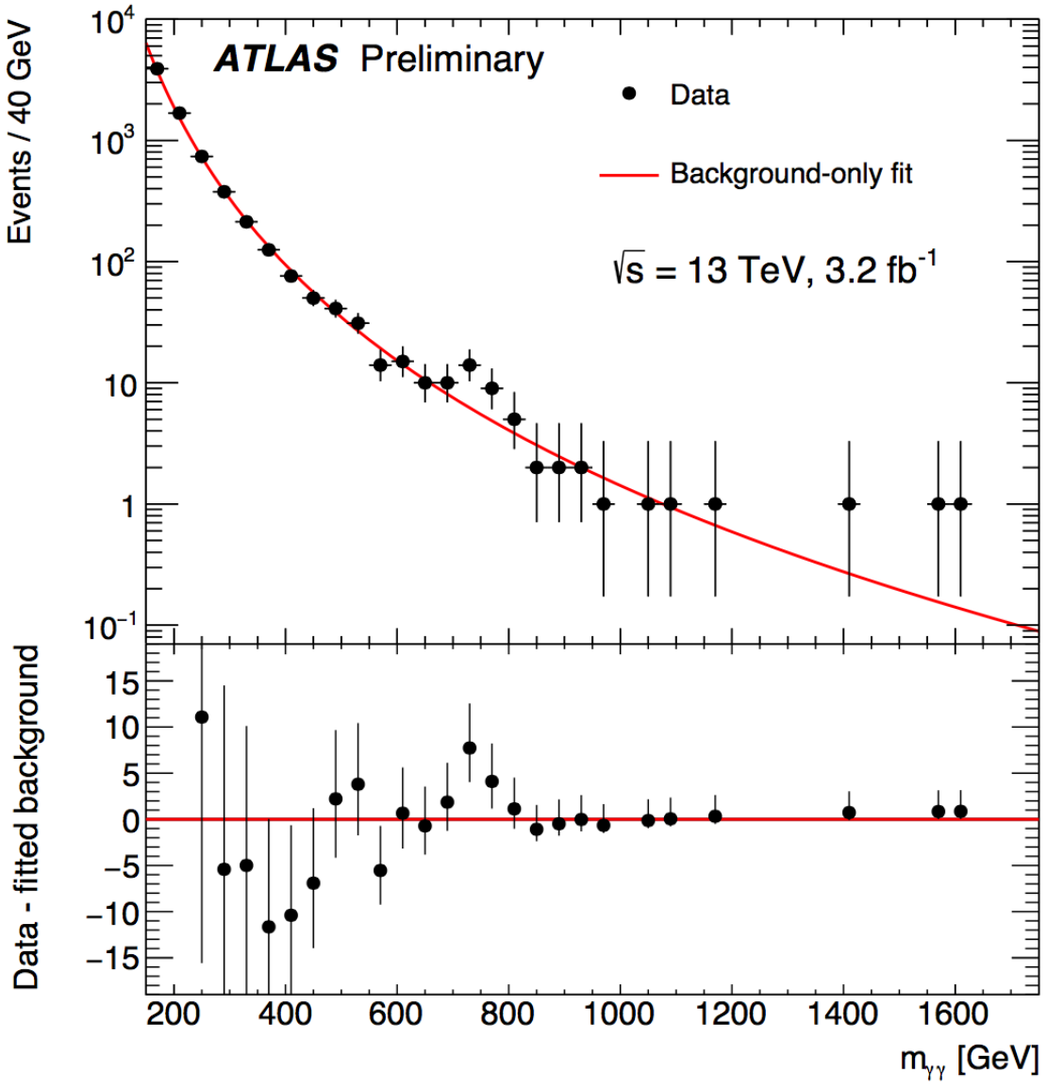
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

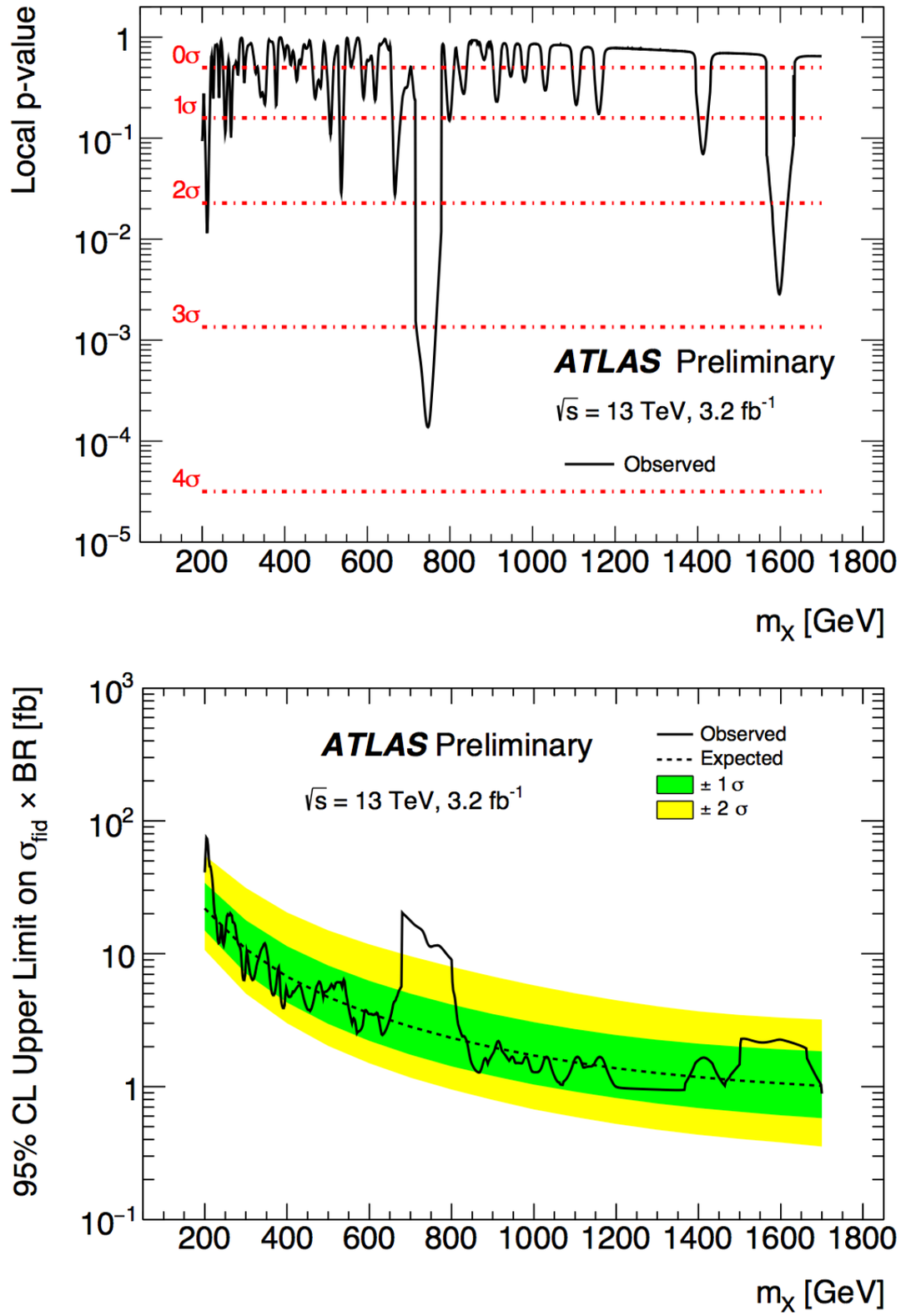
Additional slides

Z′ discovery potential



Di-photon: ATLAS





Di-photon

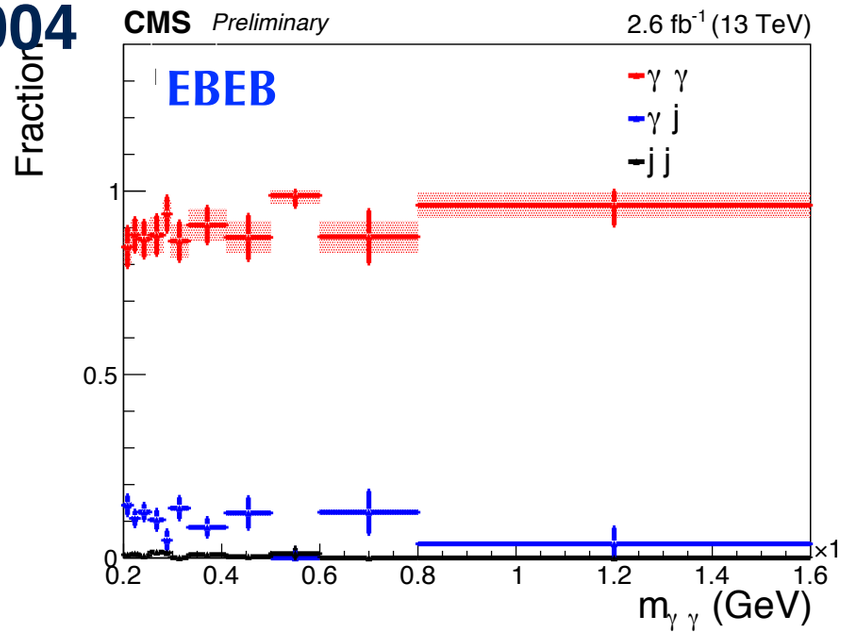
CMS EXO-15-004

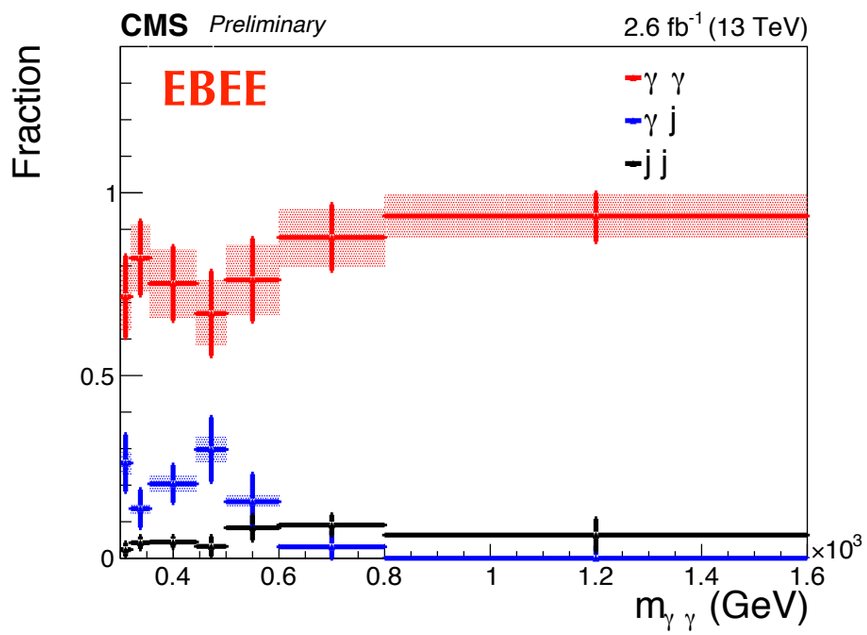
m_G (GeV)	category	$\tilde{\kappa}$	FWHM (GeV)	$\tilde{\kappa}$	FWHM (GeV)
500	EBEB	0.01	14	0.2	36
500	EBEE	0.01	22	0.2	42
1000	EBEB	0.01	27	0.2	74
1000	EBEE	0.01	43	0.2	85
2000	EBEB	0.01	54	0.2	147
2000	EBEE	0.01	76	0.2	163
3000	EBEB	0.01	96	0.2	225
3000	EBEE	0.01	110	0.2	254
4000	EBEB	0.01	121	0.2	320
4000	EBEE	0.01	150	0.2	326

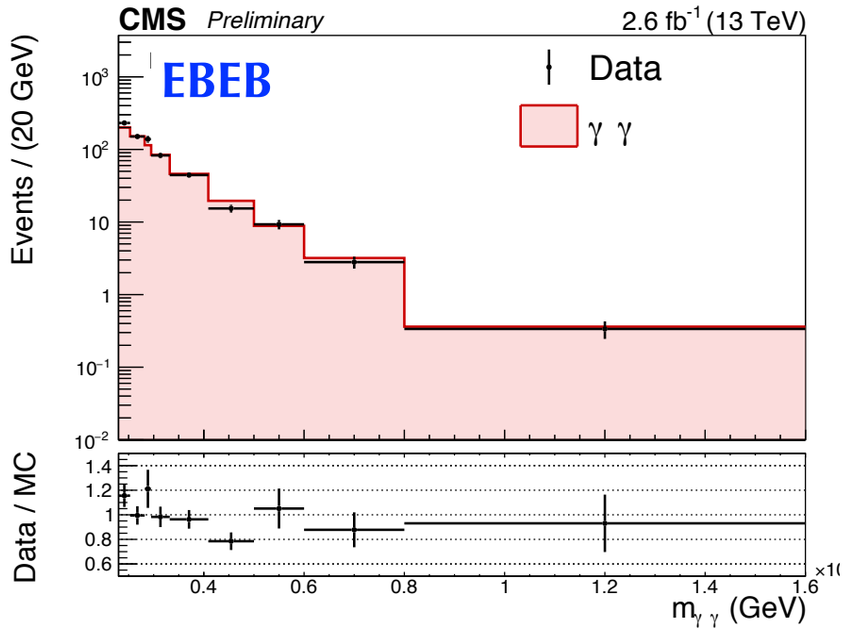
Width of the reco mass distribution for different signal hypotheses

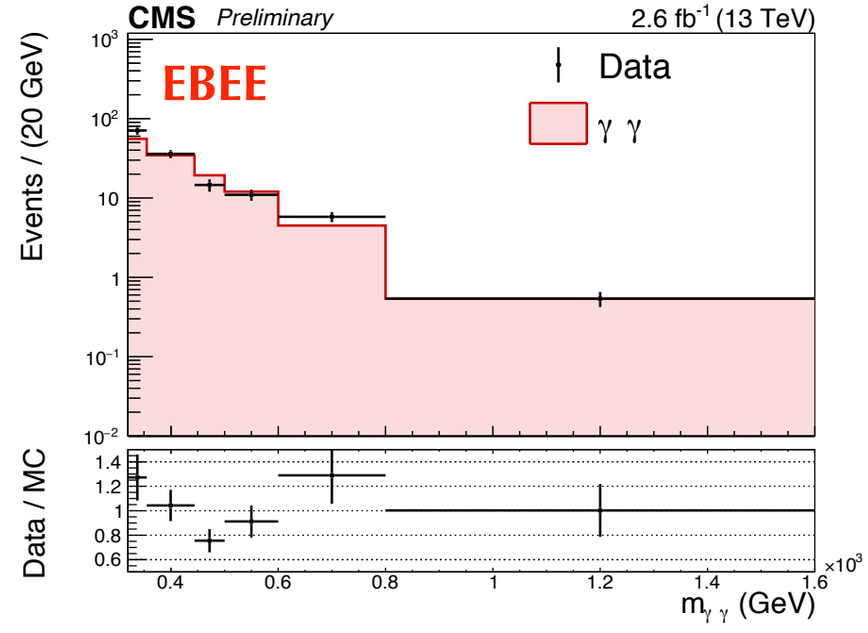
Di-photon: Background

CMS EXO-15-004







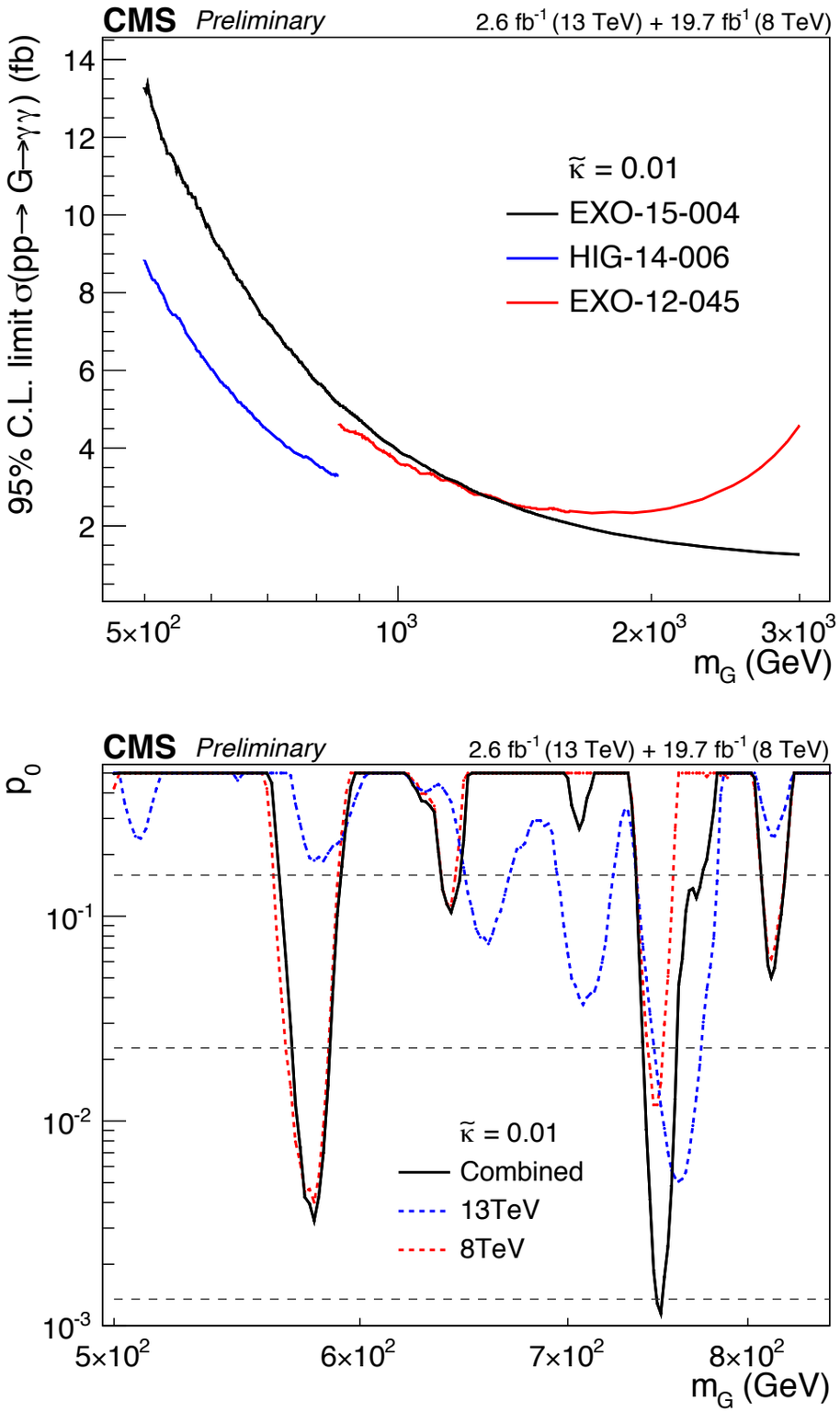


Background: main **irreducible γγ** direct production, **reducible γ-jet** and **jet-jet**)

- composition of the bkg determined through a 2D template ($I_{ch}(\gamma_1)$, I_{ch} (γ_2))
- good agreement between data-driven estimation and estimations from MC

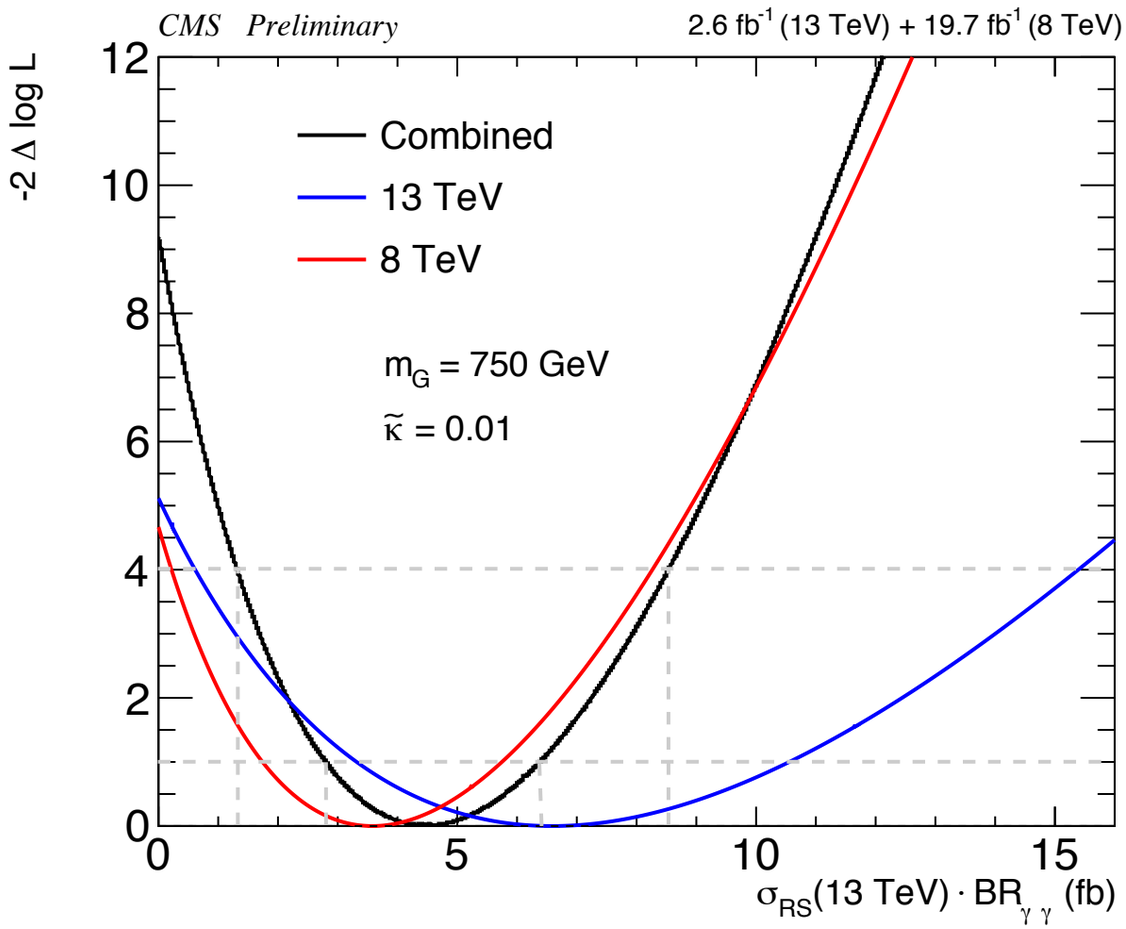
Di-photon

CMS EXO-15-004



Di-photon

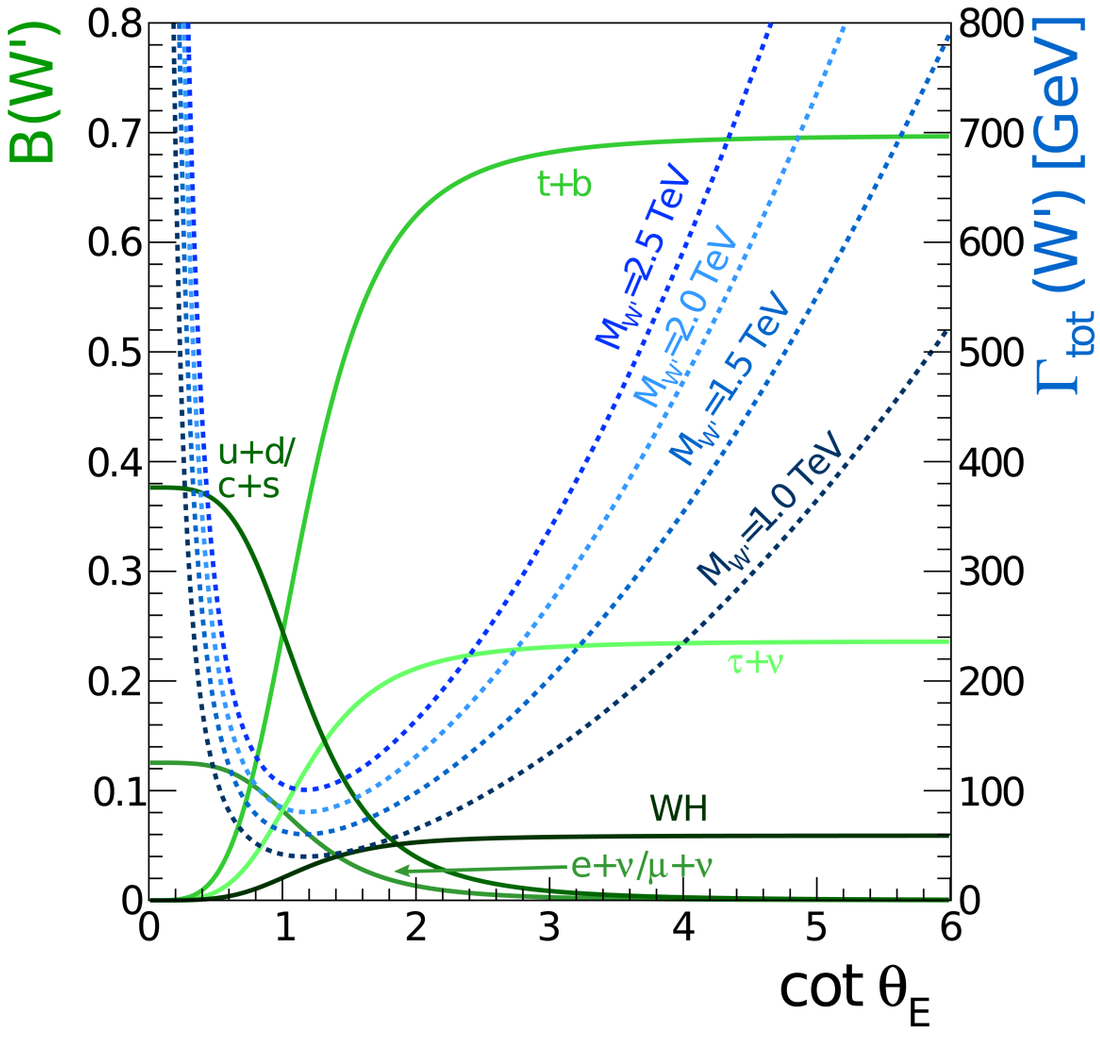
CMS EXO-15-004

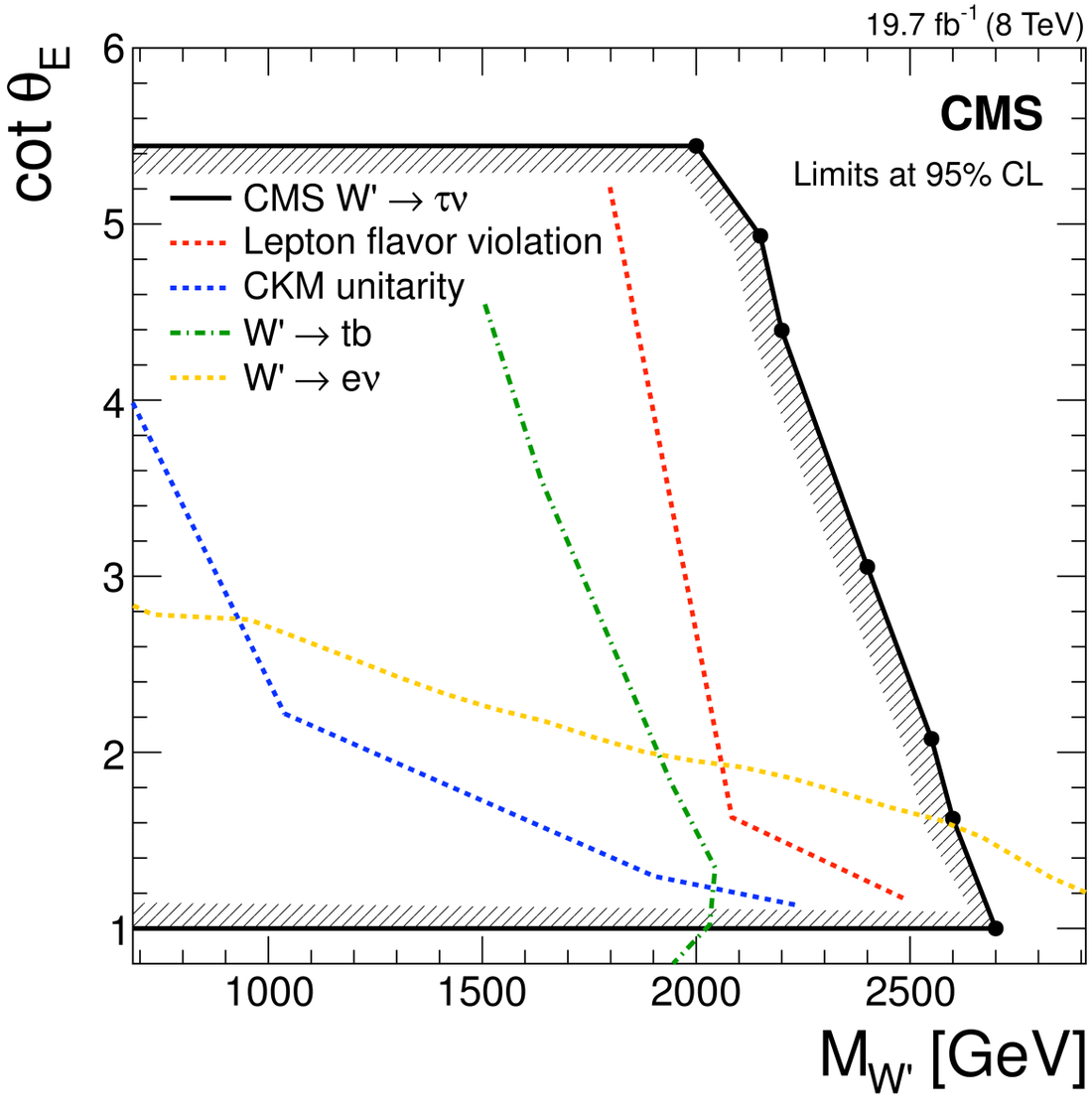


W′ -> τ +MET

8 TeV

CMS EXO-12-011

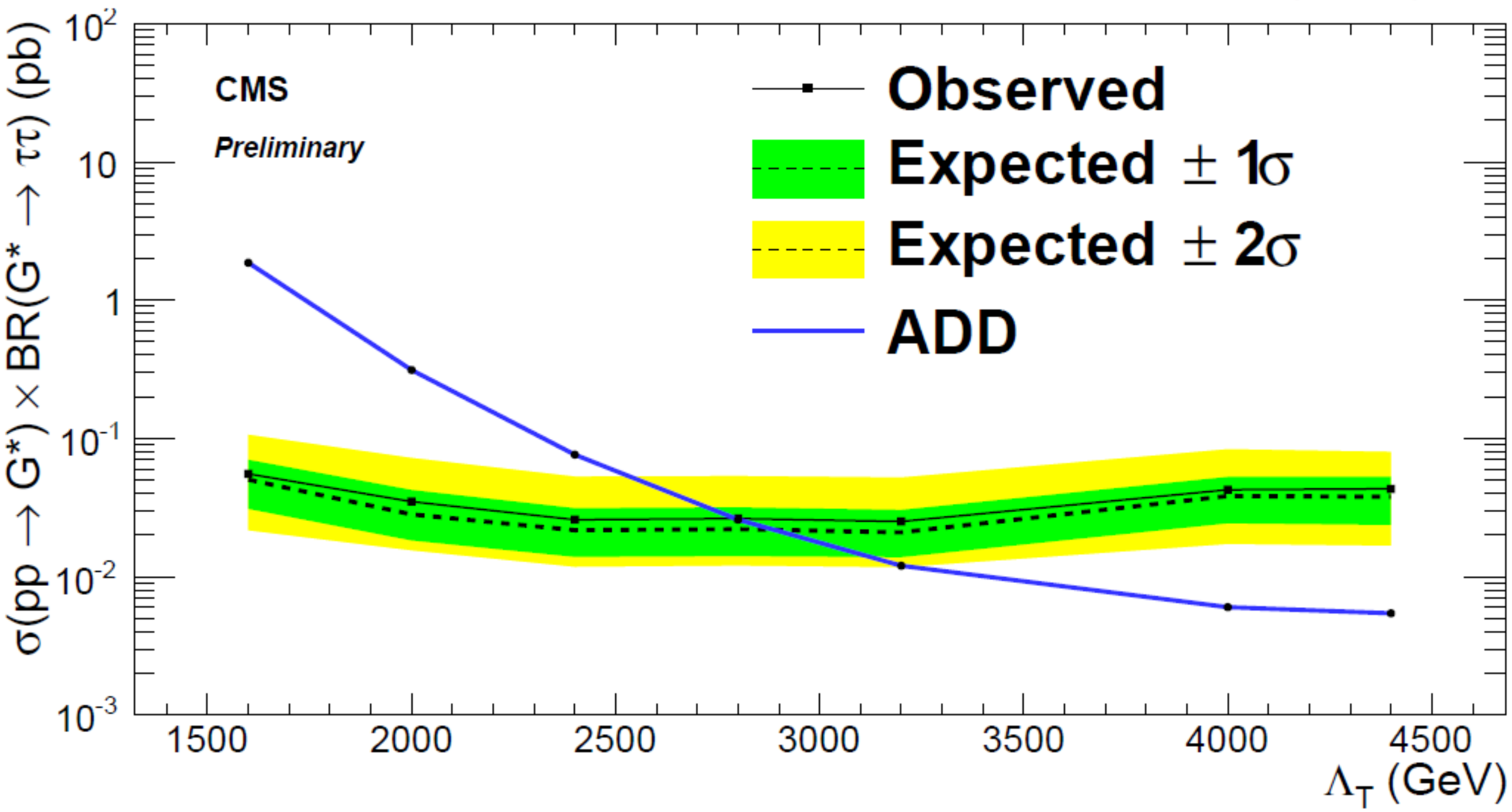




Z′ -> τ τ

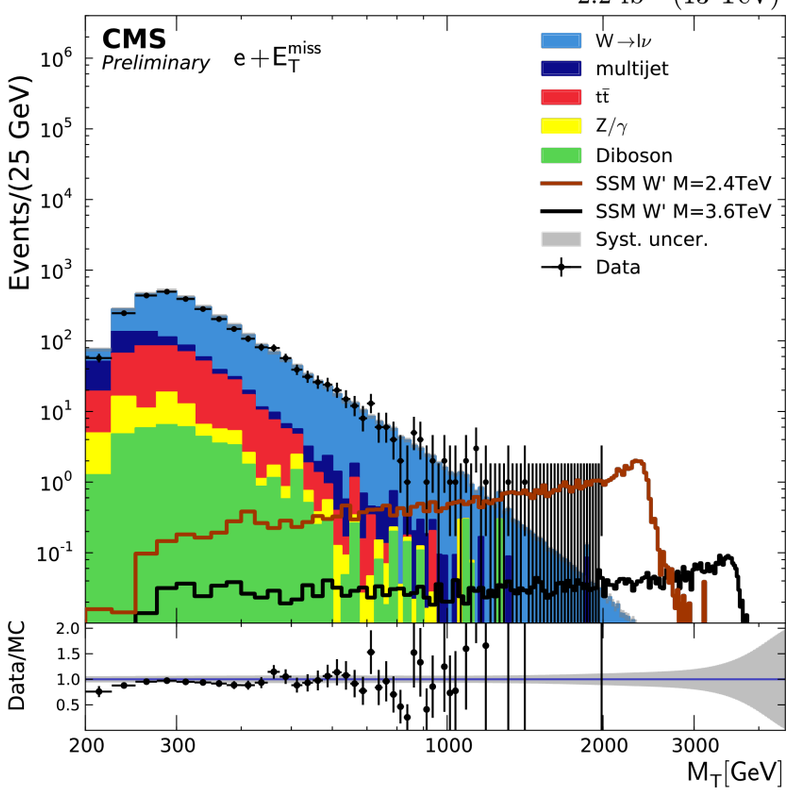
8 TeV

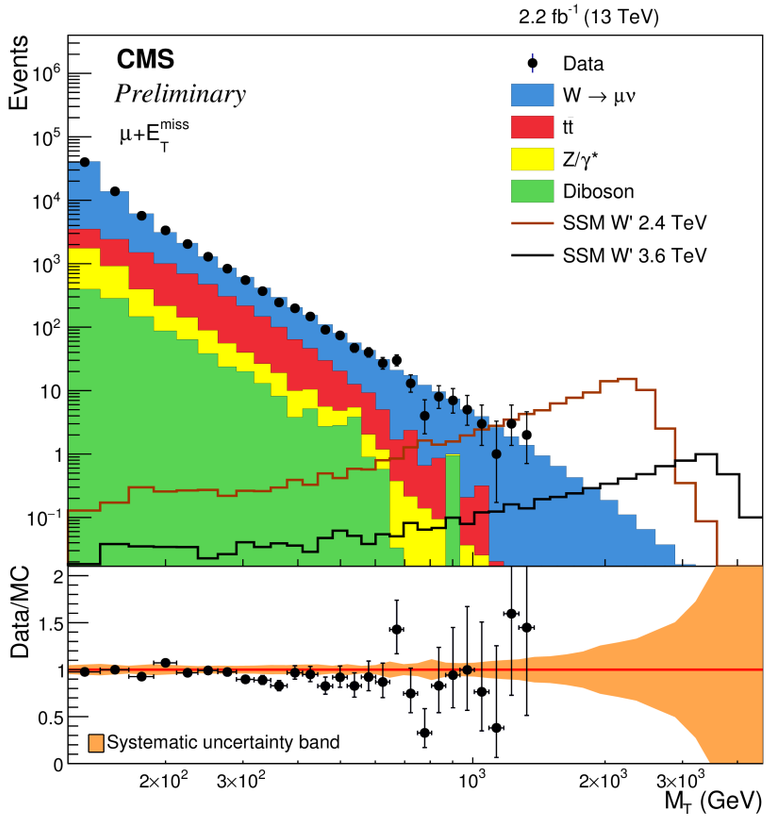
CMS EXO-12-011

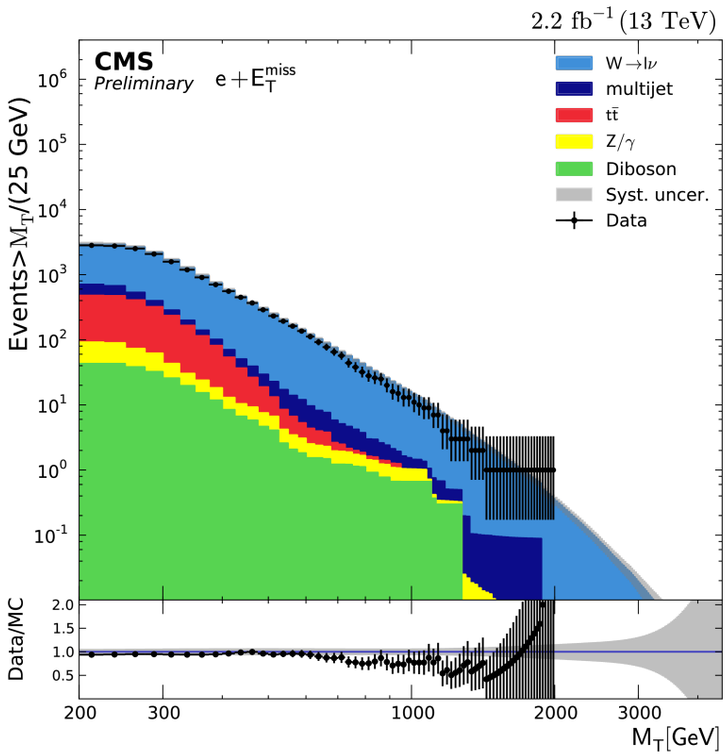


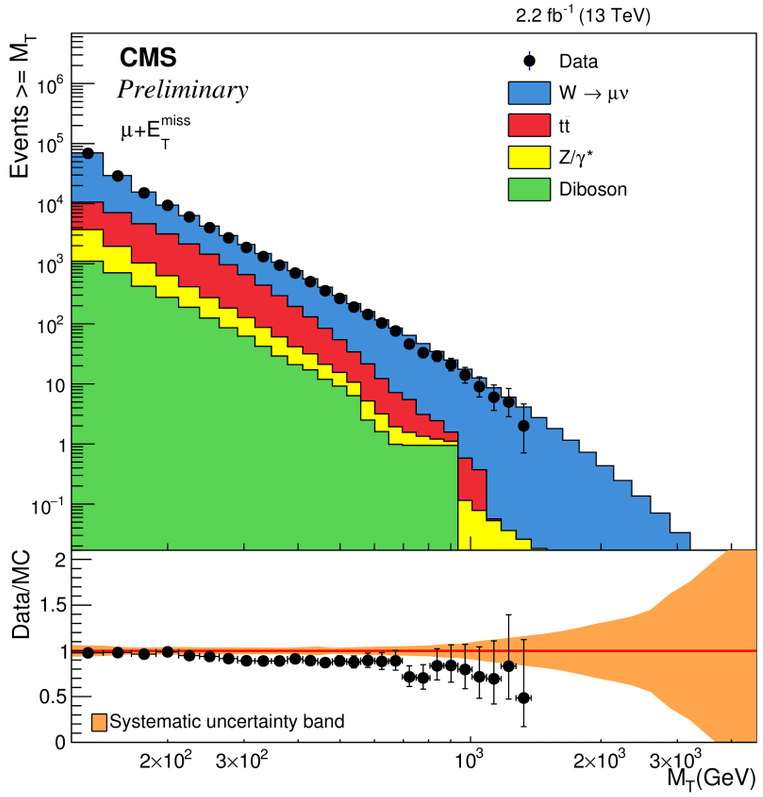
W′ -> e/μ +MET

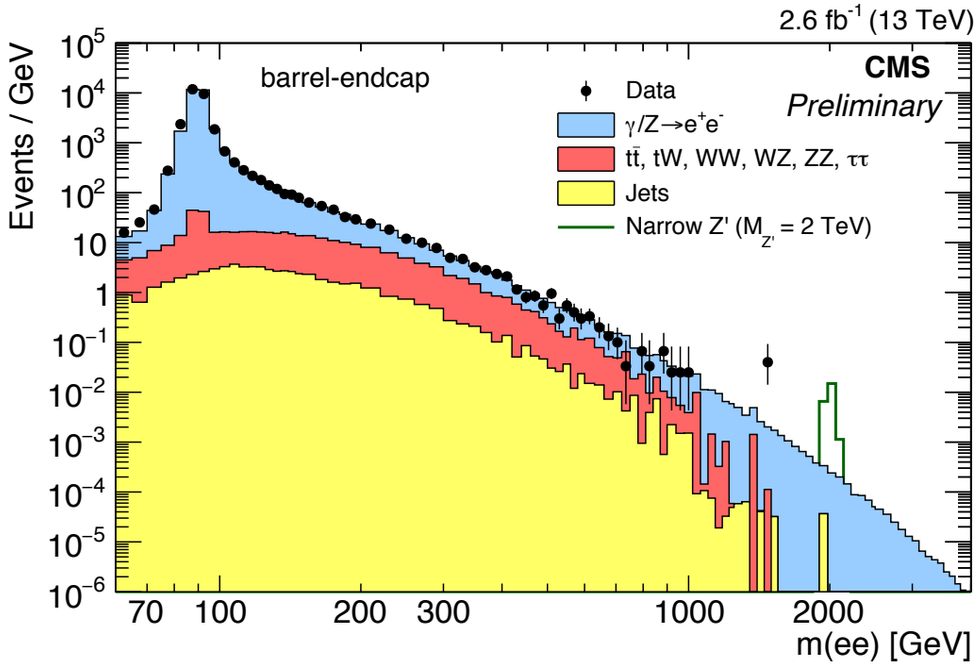
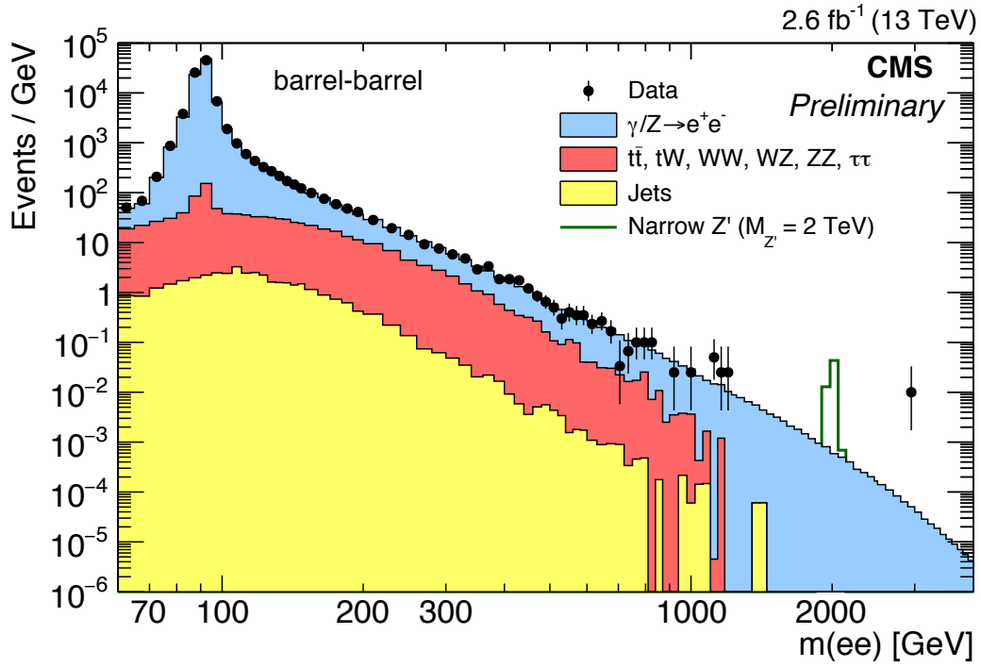
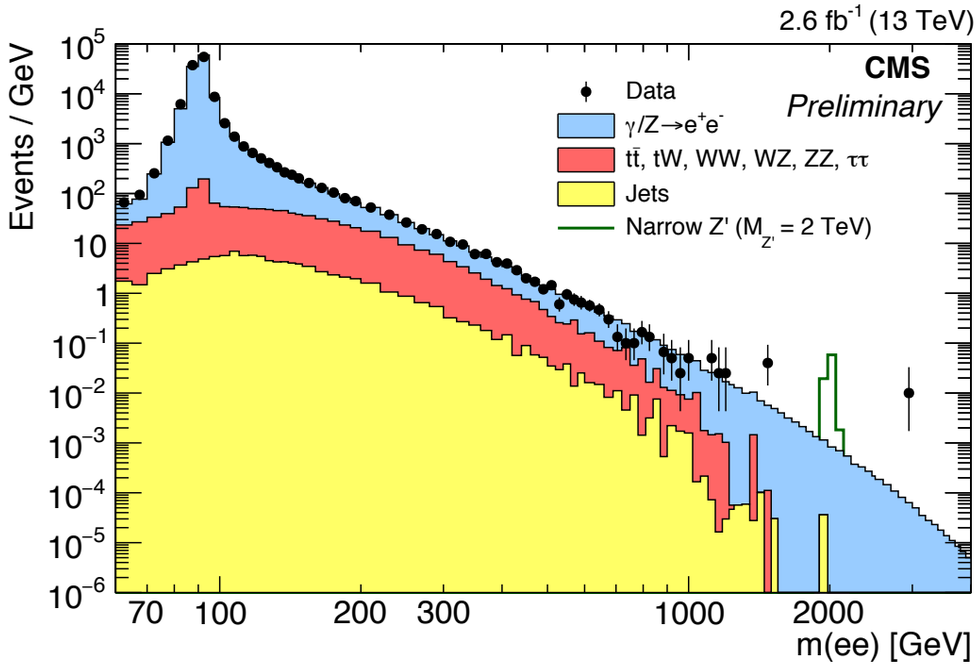
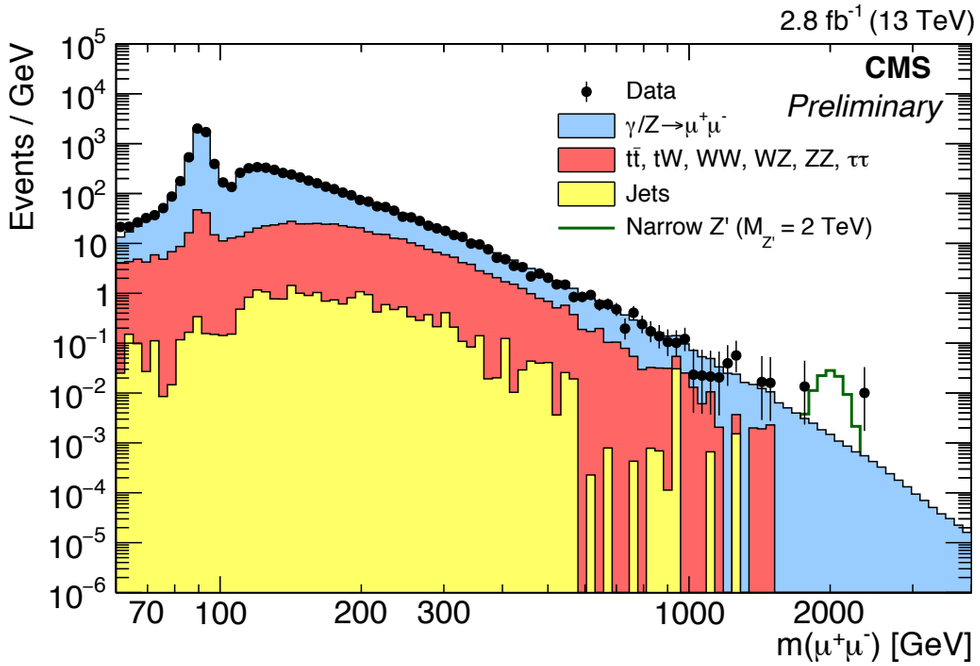
CMS EXO-15-006









Z'-> ee/ μμ

CMS EXO-15-005