Search for high mass resonances decaying to charged-lepton or photon pairs at CMS

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on behalf of the
CMS Collaboration

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Lake Louise Winter Institute
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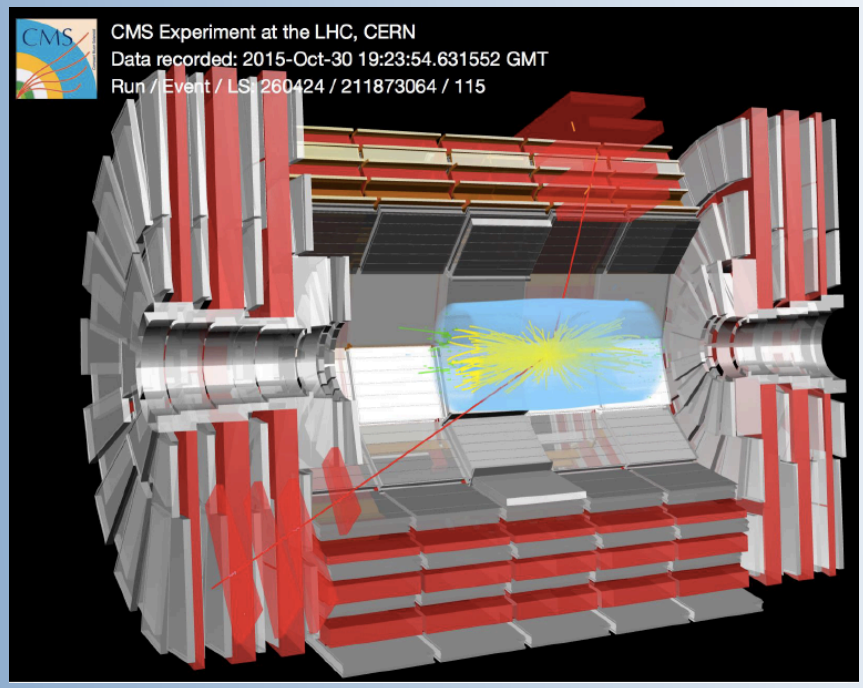
Physics Institute III A

RWTH AACHEN UNIVERSITY

Outline



$M = 2.4\,\text{TeV}$

Introduction

CMS PAS-EXO-15-005 [1]

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Motivation

- New massive neutral spin-1 particle (Z')
- Decay to charged lepton pairs ($\mu^+\mu^-$ or ee)

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Analysis key points

- 2015 data set of upto $2.8\,\mathrm{fb}^{-1}$ of proton-proton data at $\sqrt{s} = 13\,\mathrm{TeV}$
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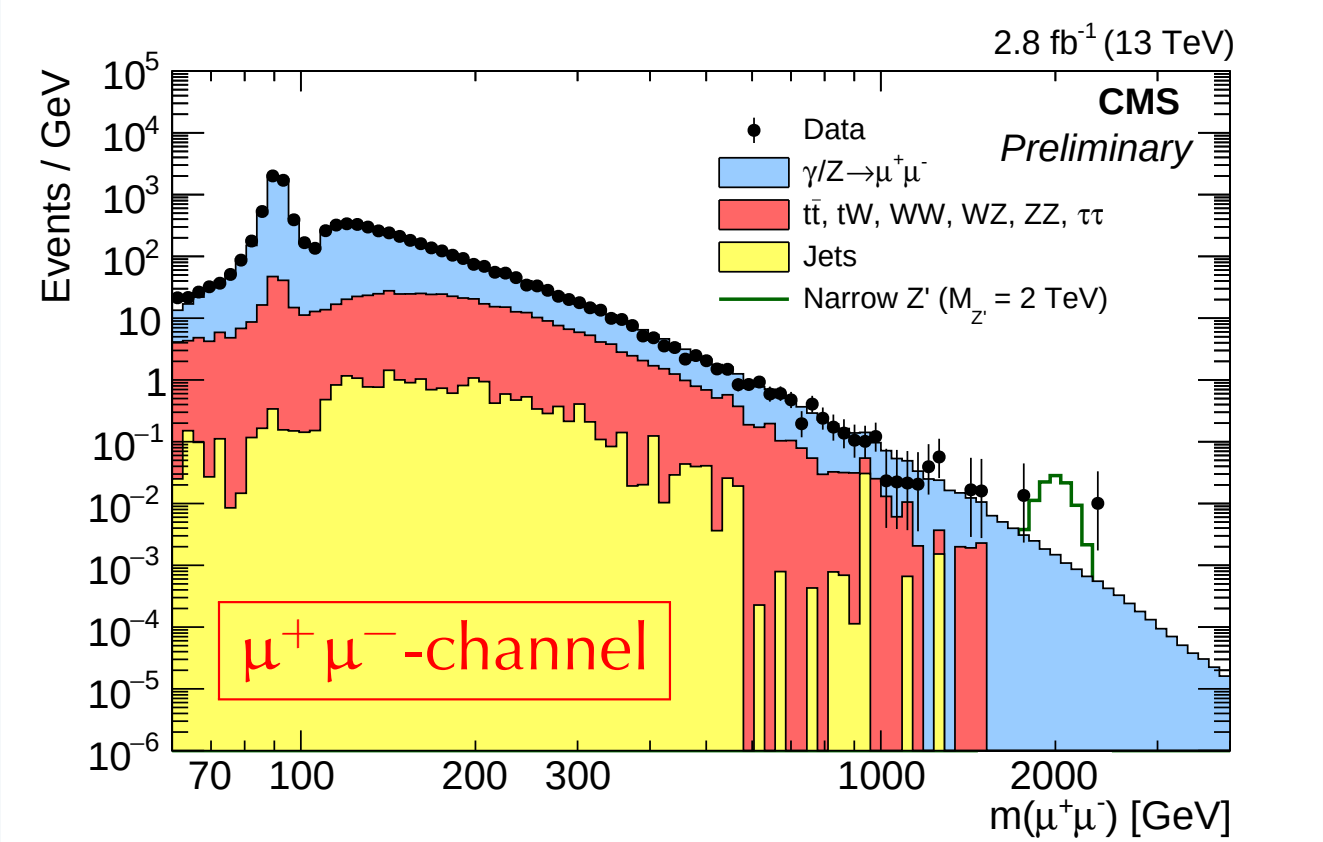
Event selection

- Trigger:
  Double electron ($E_T > 33\,\text{GeV}$) or single muon ($p_T > 50\,\text{GeV}$)
- Dedicated high E_T/p_T identification criteria for electron / muon
- Signal efficiency (relative to acceptance) at $M = 1\,\text{TeV}$: $\sim 75\%$ ($\sim 89\%$) for electrons (muons)

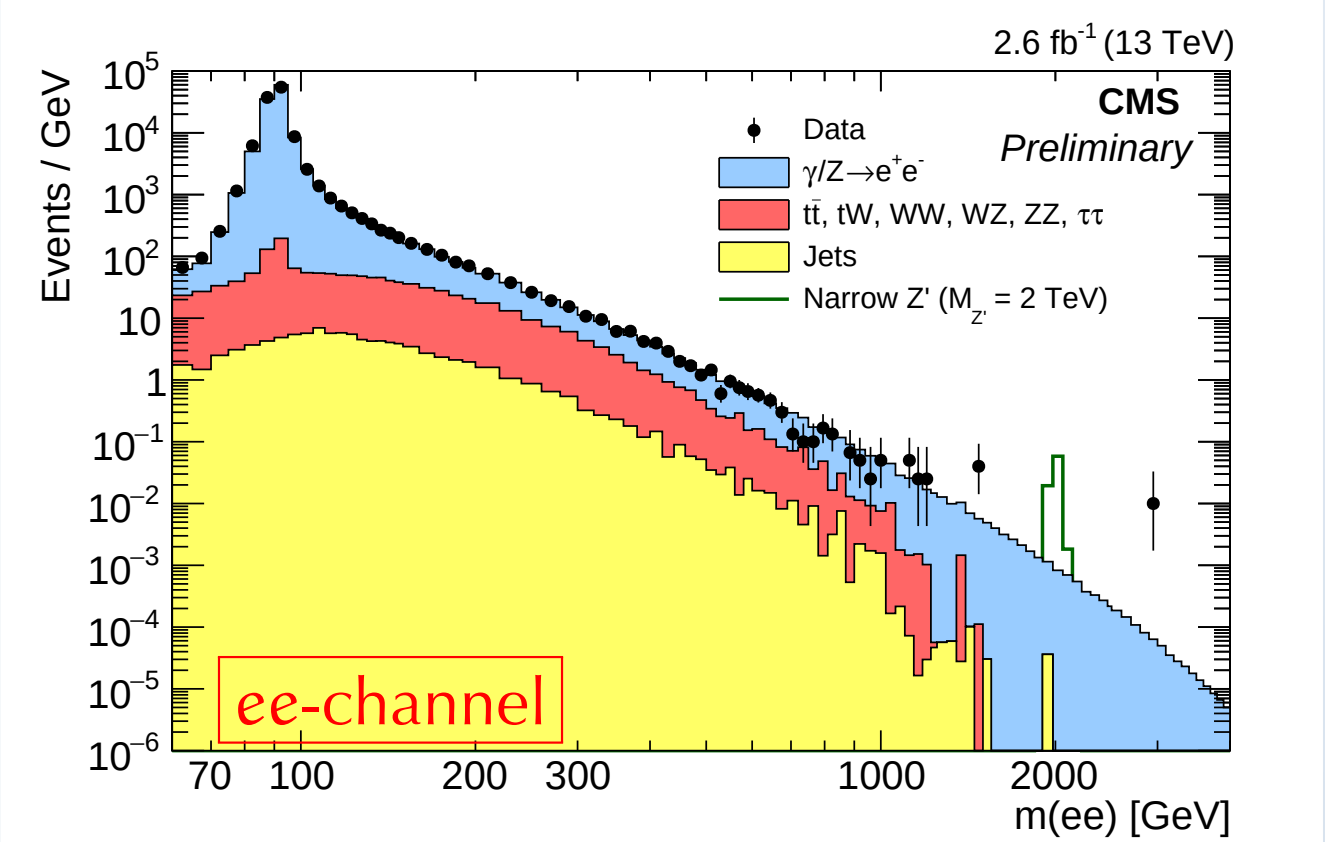
Dimuon mass spectrum



- Acceptance: $p_T > 53$ GeV and $|\eta| < 2.4$
- Dedicated high p_T identification criteria for muons
- Muons have opposite charge

- Muon backgrounds: Simulated with POWHEG and PYTHIA 8
- Misidentified muon background: Determined from data

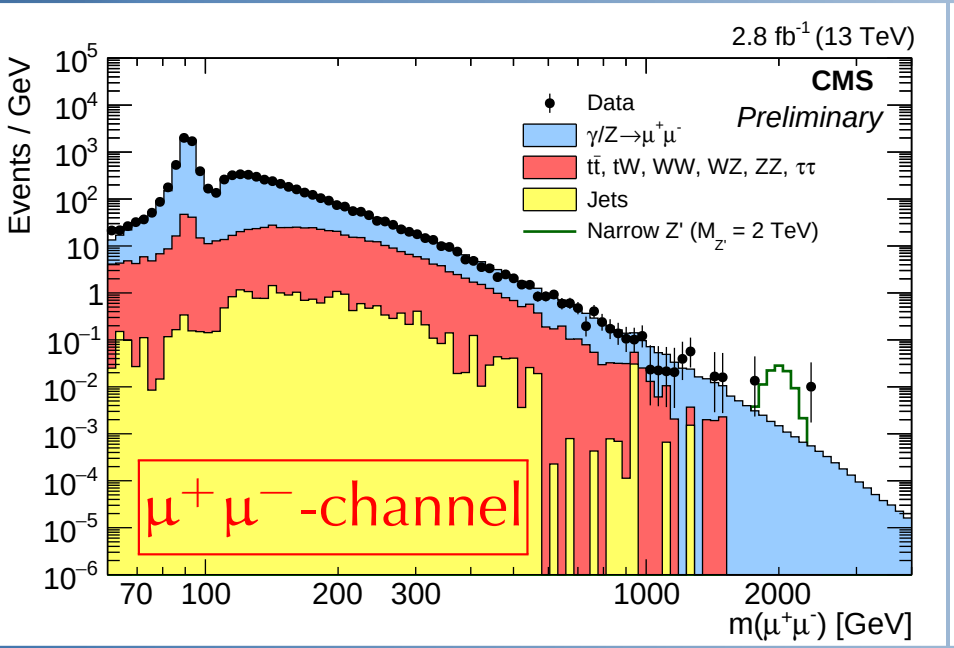
Dielectron mass spectrum

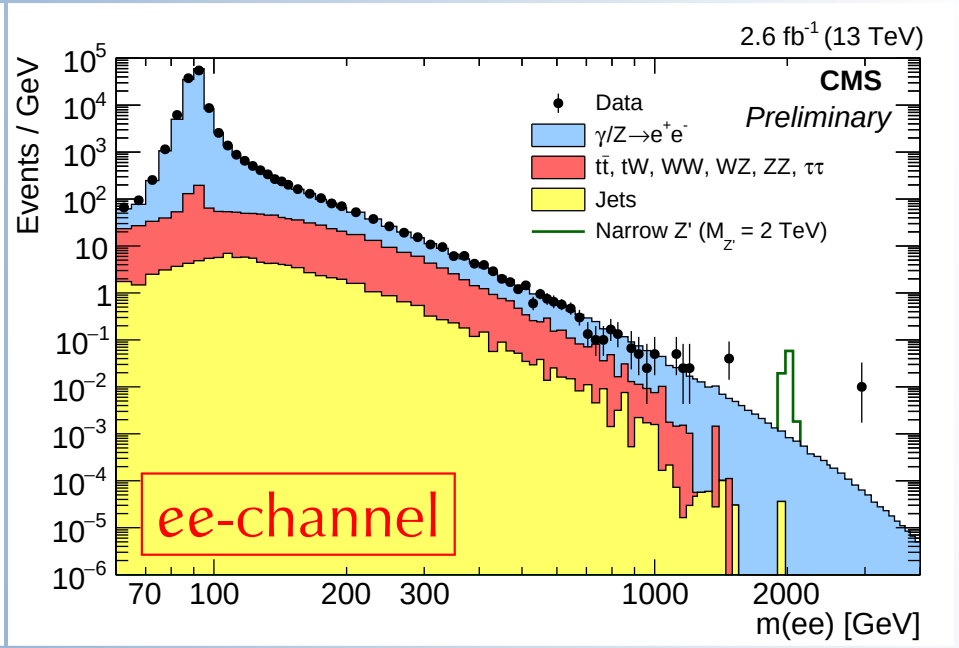


- Acceptance: $p_T > 35$ GeV and $|\eta| < 1.4$ or $1.6 < |\eta| < 2.5$
- Dedicated high E_T identification criteria for electrons

- Electron backgrounds: Simulated with POWHEG and PYTHIA 8
- Misidentified electron background: Determined from data

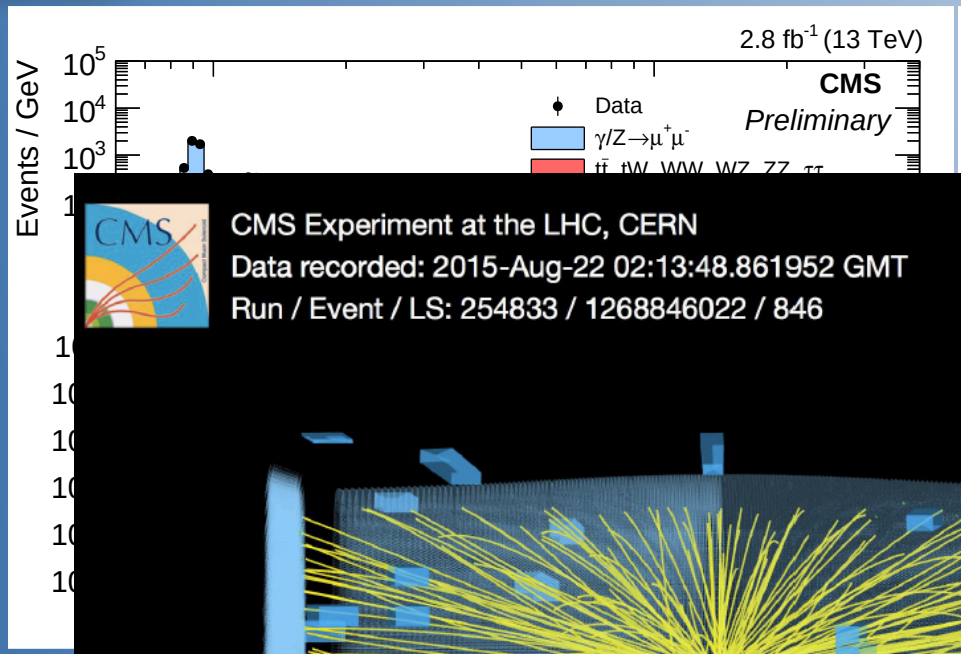
Dilepton mass spectrum

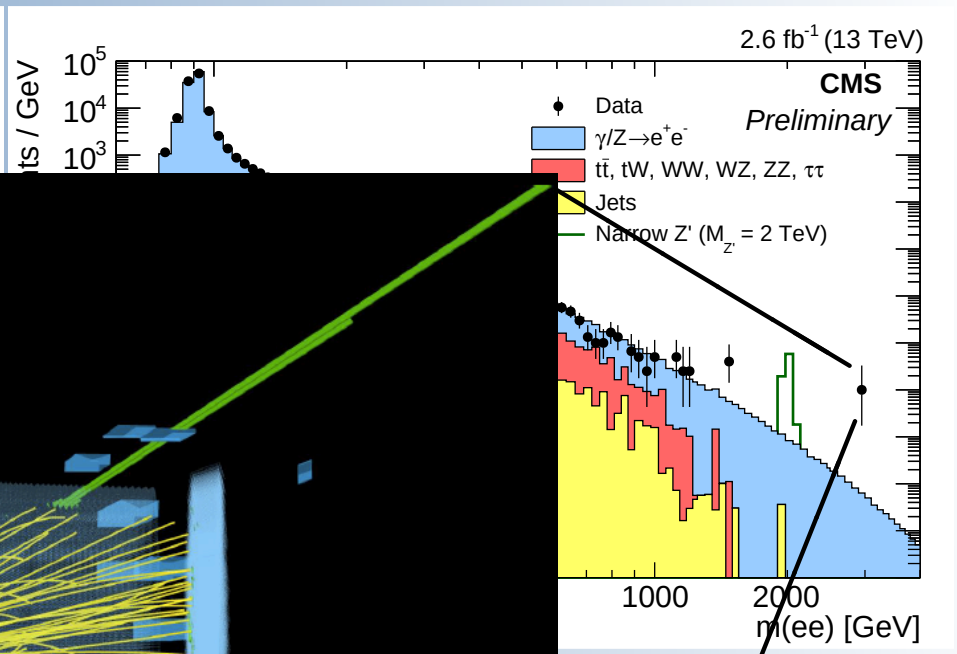




- The total background prediction is normalized to the data in the region $60 < M < 120$ GeV
- Dominant systematic uncertainties:
  - Signal efficiency modelling: 4 – 6% (electrons) and 7% (muons)
  - Parton density description of the background: from ~ 5% (at 500 GeV) to ~ 20% (at 3 TeV)

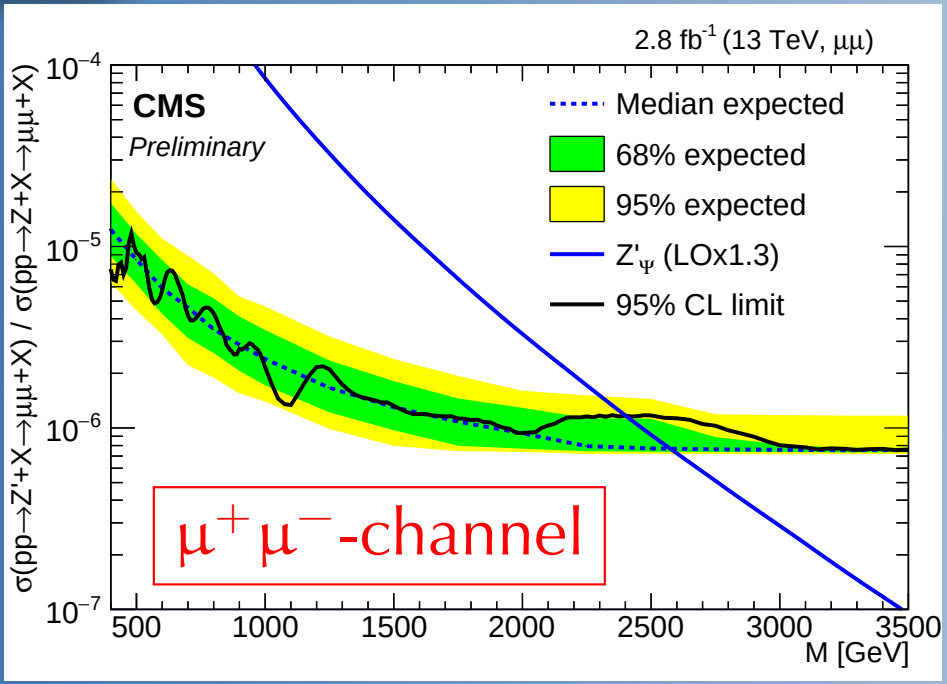
Dilepton mass spectrum





CMS DP-2015-039 [2]

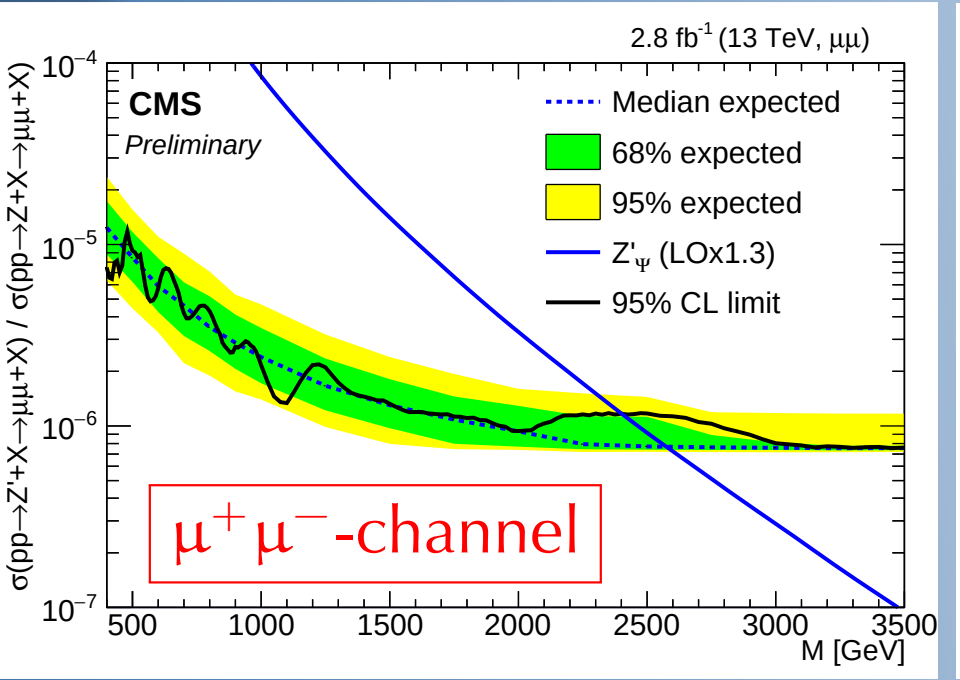
Statistical interpretation: dimuon

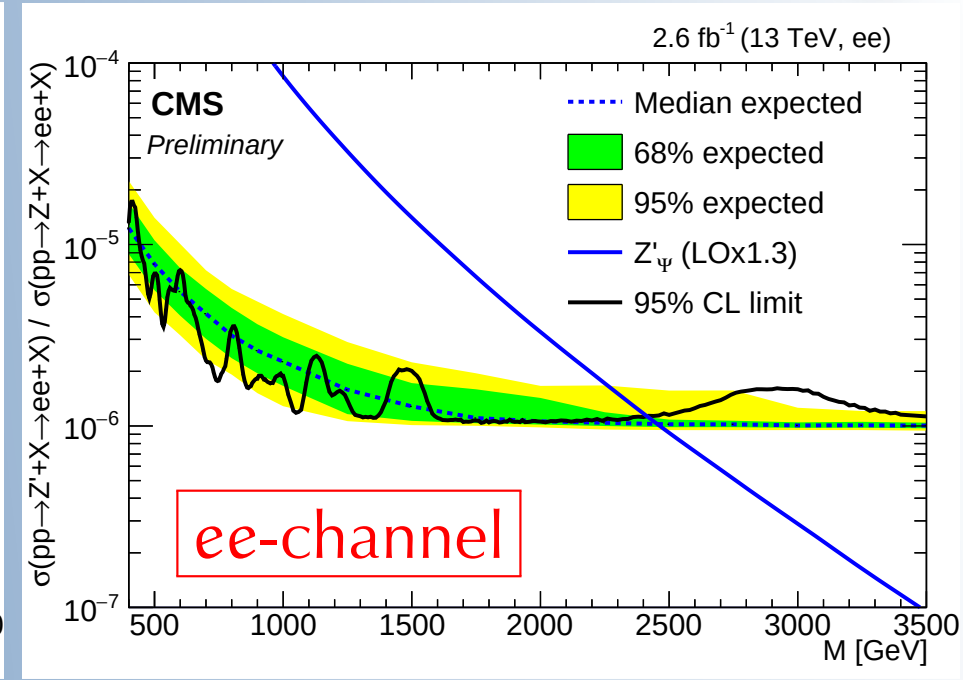


- Set limit on the ratio of the Z' cross section to the Z/γ^* cross section in the mass window $60 < M < 120$ GeV
- Bayesian unbinned likelihood
- Signal model: Breit-Wigner convoluted with Gaussian

Channel	Z'_ψ (0.6%) obs/exp (TeV)
μμ	2.40/2.55

Statistical interpretation: dielectron





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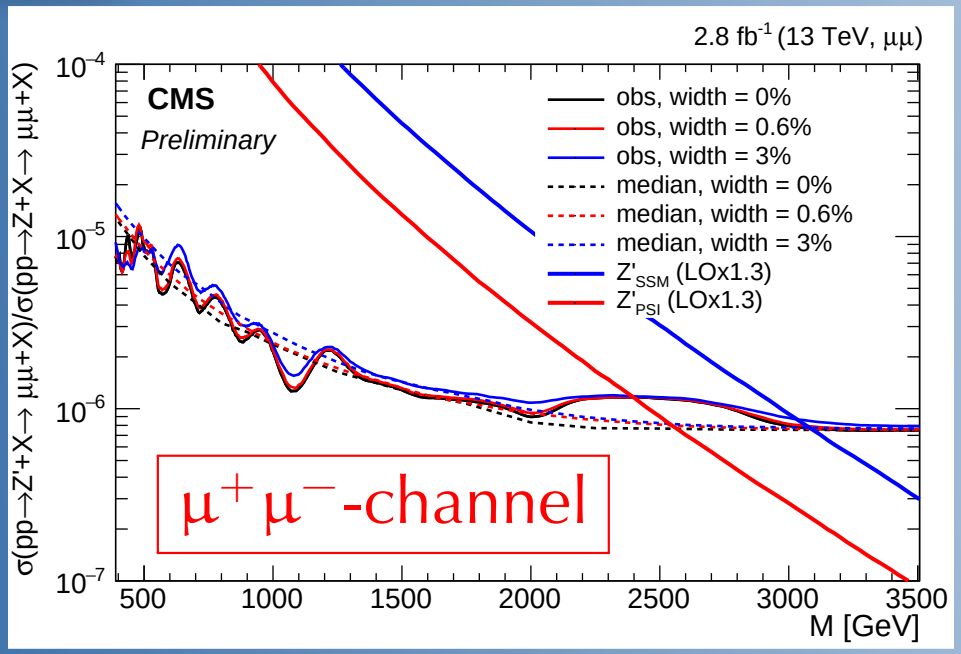
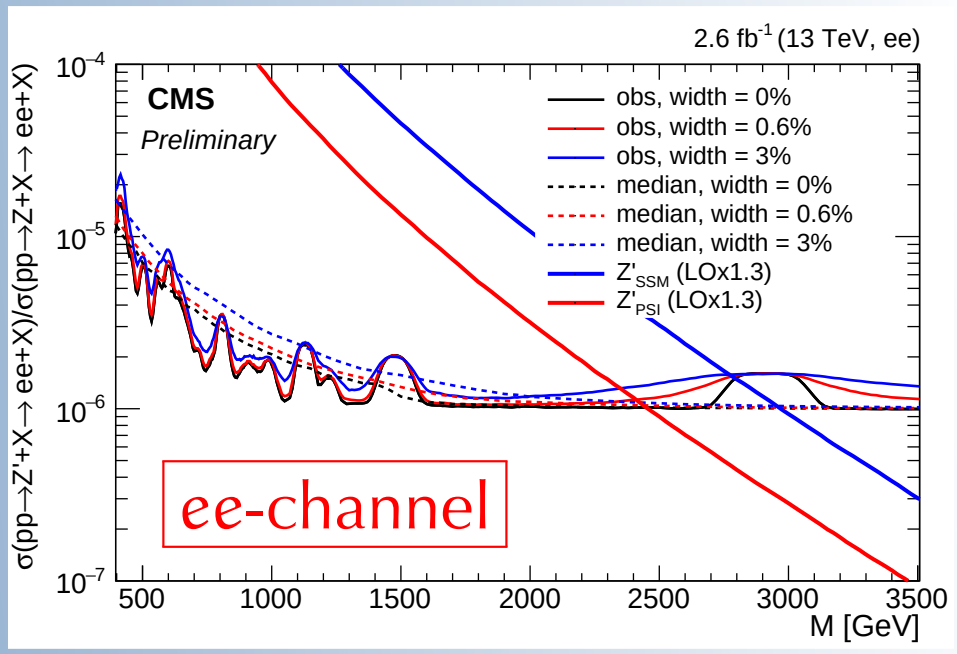
- Bayesian unbinned likelihood
- Signal model: Breit-Wigner convoluted with Gaussian

Channel	Z'_ψ (0.6%) obs/exp (TeV)
μμ	2.40/2.55
ee	2.40/2.45

Statistical interpretation: width effect

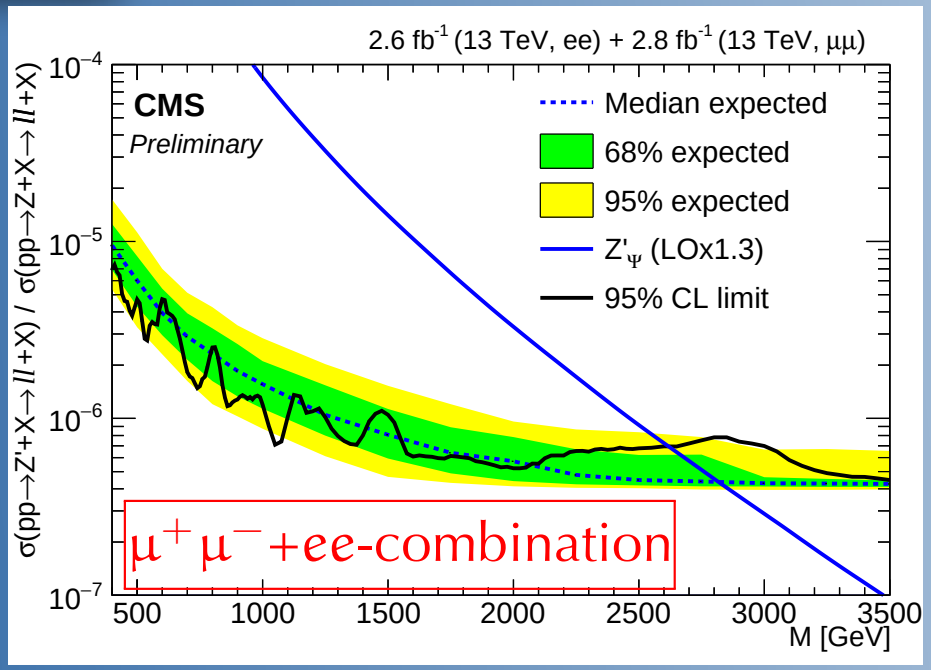


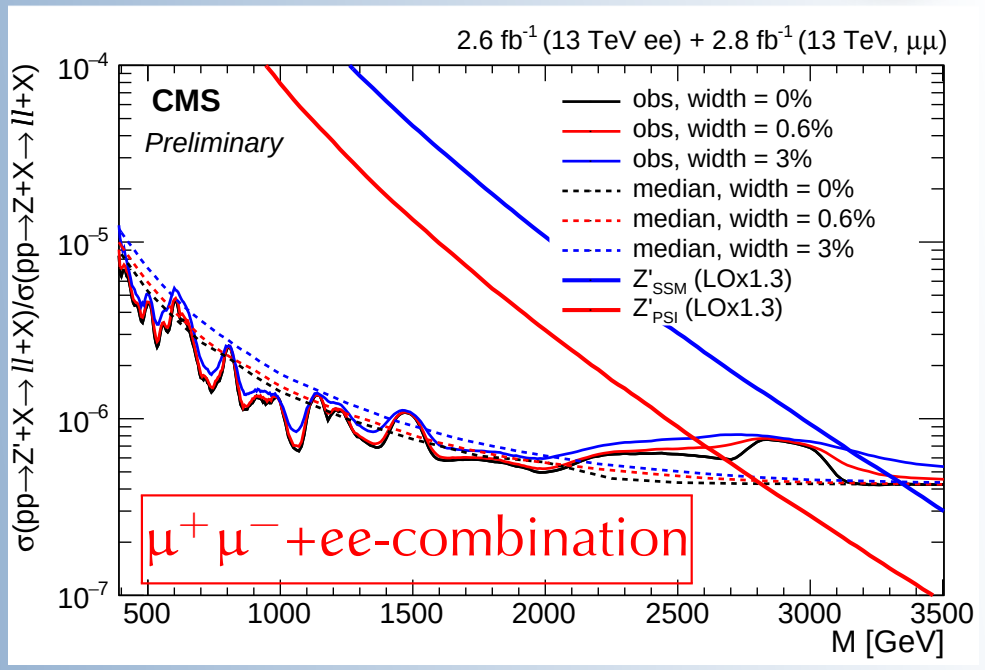


- Set limit on the ratio of the Z′ cross section to the Z/γ* cross section in the mass window $60 < M < 120$ GeV
- Bayesian unbinned likelihood
- Signal model: Breit-Wigner convoluted with Gaussian

Channel	Z'_{ψ} (0.6%) obs/exp (TeV)	Z'_{SSM} (3%) obs/exp (TeV)
μμ	2.40/2.55	3.00/3.05
ee	2.40/2.45	2.75/2.95

Statistical interpretation: combination





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- Bayesian unbinned likelihood
- Signal model: Breit-Wigner convoluted with Gaussian

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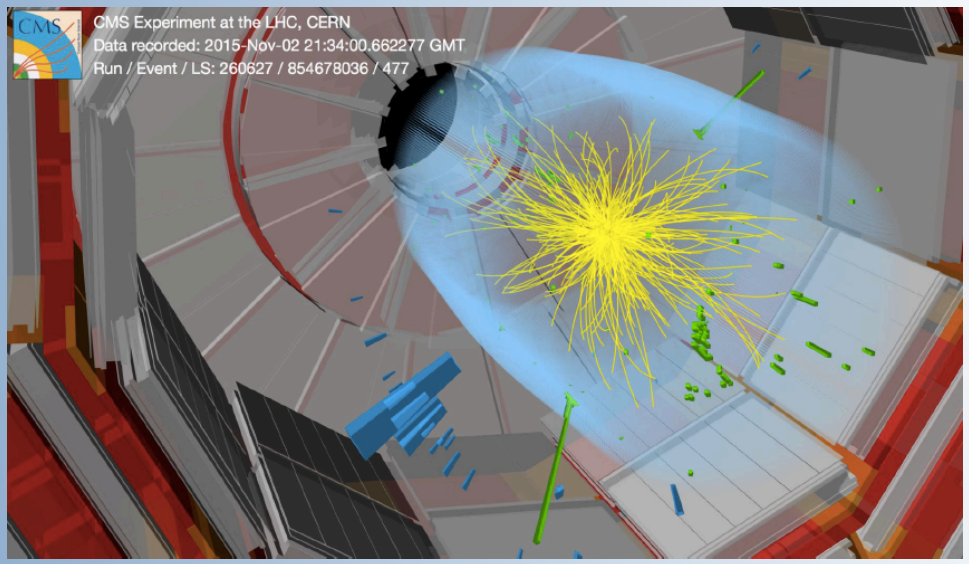
μμ	2.40/2.55	3.00/3.05
ee	2.40/2.45	2.75/2.95
μμ + ee	2.60/2.80	3.15/3.35

Outline

$M = 745\,\text{GeV}$



Introduction

CMS PAS-EXO-15-004 [3]

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CMS PAS-EXO-15-004 [3]

Motivation

- New massive neutral spin-2 particles (graviton G)
- Decay to photon pairs ($\gamma\gamma$)
- Model parameters: effective coupling ($\tilde{\kappa}$), resonance mass (m_G)

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- Model parameters: effective coupling ($\tilde{\kappa}$), resonance mass (m_G)

Analysis key points

- 2015 data set of up to $2.6\,\text{fb}^{-1}$ of proton-proton data at $\sqrt{s} = 13\,\text{TeV}$
- Search for high mass resonances
- Perform a blinded analysis in the signal region $m_{\gamma\gamma} > 500\,\text{GeV}$

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CMS PAS-EXO-15-004 [3]

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- Decay to photon pairs ($\gamma\gamma$)
- Model parameters: effective coupling ($\tilde{\kappa}$), resonance mass (m_G)

Analysis key points

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- Search for high mass resonances
- Perform a blinded analysis in the signal region $m_{\gamma\gamma} > 500\,\text{GeV}$

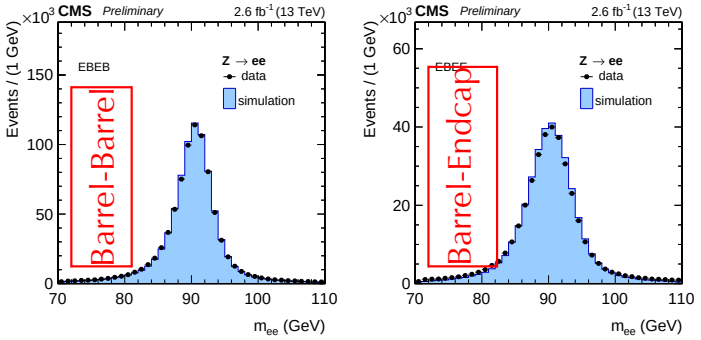
Event selection

- Dedicated high E_T identification criteria for photons
- Final selection efficiency at $m_G = 1\,\text{TeV}$: $\sim 36\%$ ($\sim 20\%$) in the barrel (endcaps)

Reconstruction/selection

Photon reconstruction

- Reconstruct the shower shape in the ECAL
- Use multivariate regression techniques to correct for:
  - Pileup
  - Conversion
- Cross check with $Z \rightarrow e^+e^-$ events



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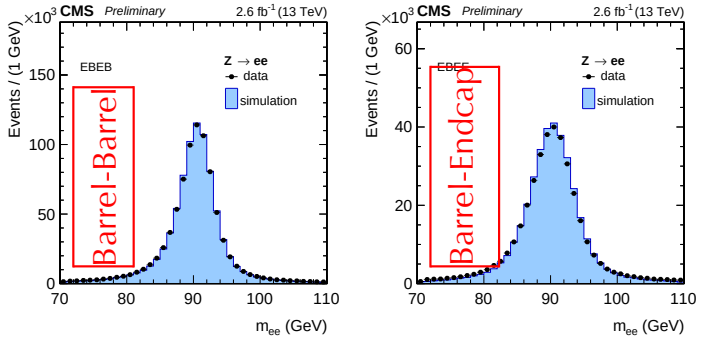
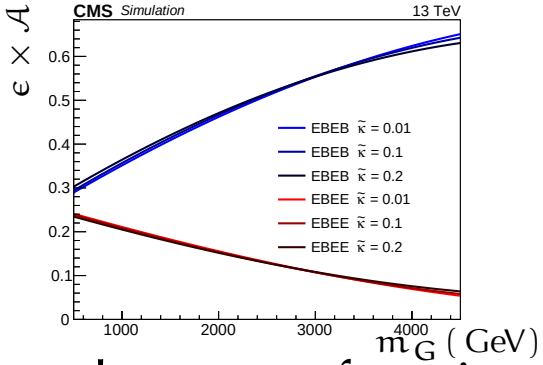


Event selection

- Trigger: Double photon ($p_T > 60$ GeV)
- $p_T^\gamma > 75$ GeV and $m_{\gamma\gamma} > 230$ GeV (> 320 GeV)
- Split events into:
  - Both photons in barrel (EBEB, $|\eta| < 1.44$)
  - One photon in endcap (EBEE, $1.44 < |\eta| < 2.5$)

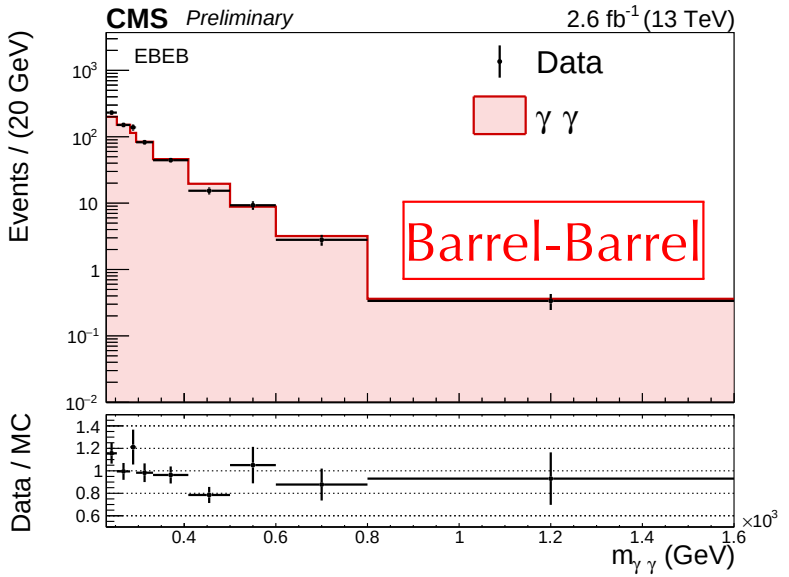


- If more than one diphoton pair, highest scalar sum of p_T is used

Background composition

Data/Monte Carlo comparison

- Simulated prompt diphoton events from SHERPA 2.1
- Compared to observed data corrected for fake photons



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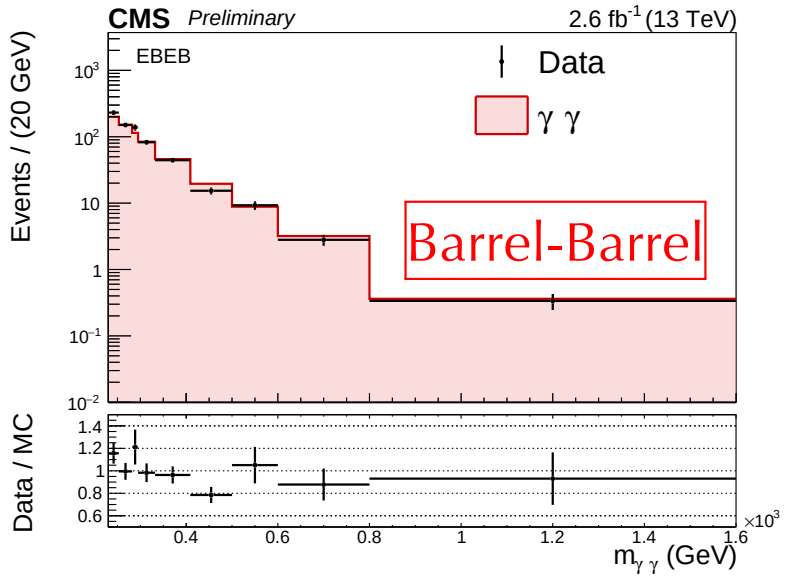
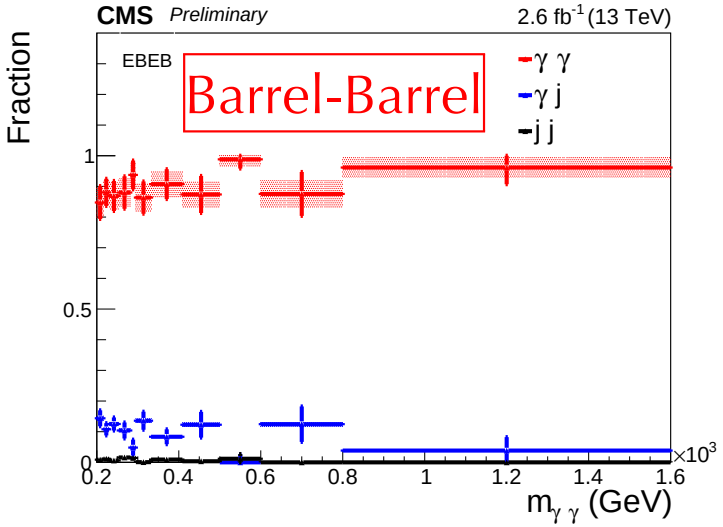


Background contribution

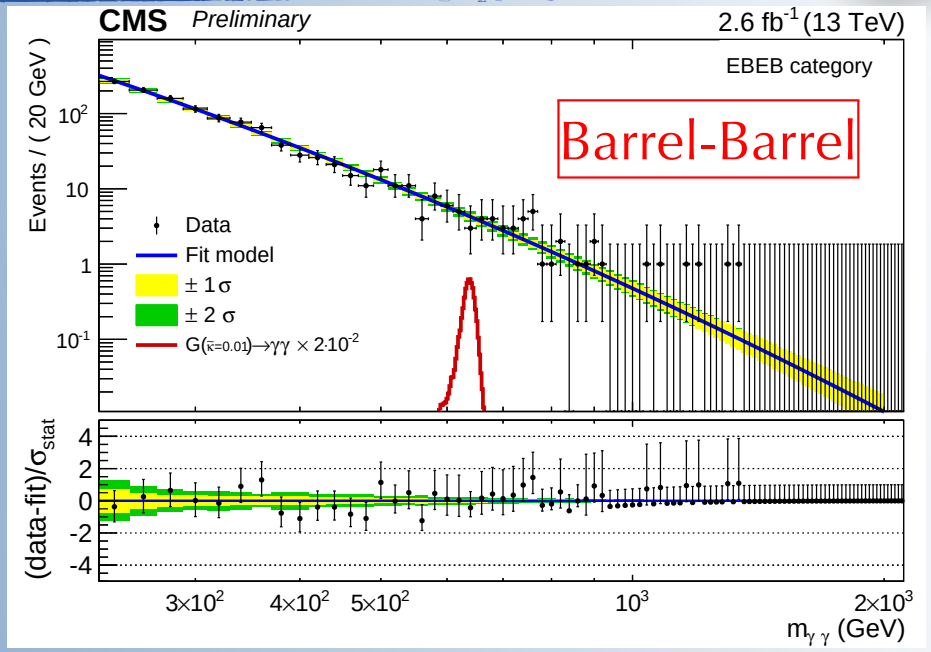
- Vary the photon isolation against charged hadrons, to derive:
  - The irreducible two prompt photon ($\gamma\gamma$)
  - The one fake, one prompt photon (γj)
  - Two fake photons (jj)

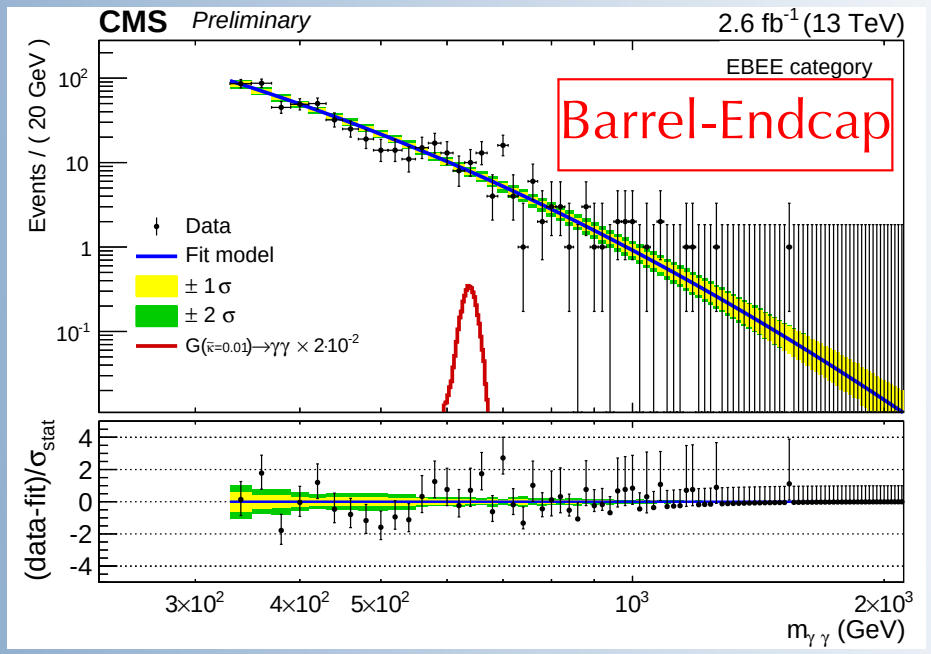
background contributions.



Mass spectrum

- Diphoton mass spectrum for the barrel-barrel and barrel-endcap categories





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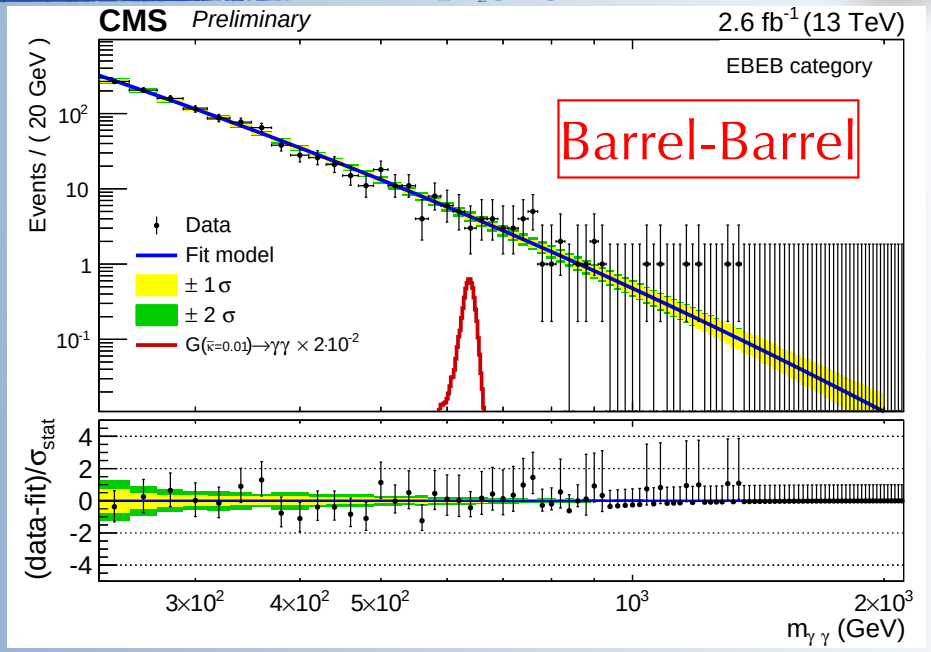
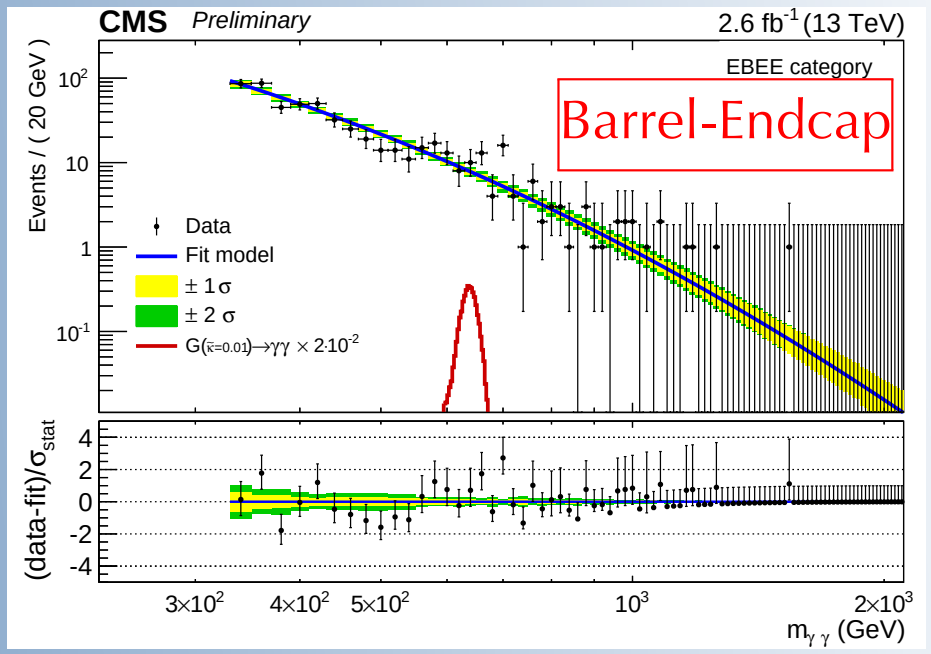
- Diphoton mass spectrum for the barrel-barrel and barrel-endcap categories
- Parametrization for statistical interpretation with

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





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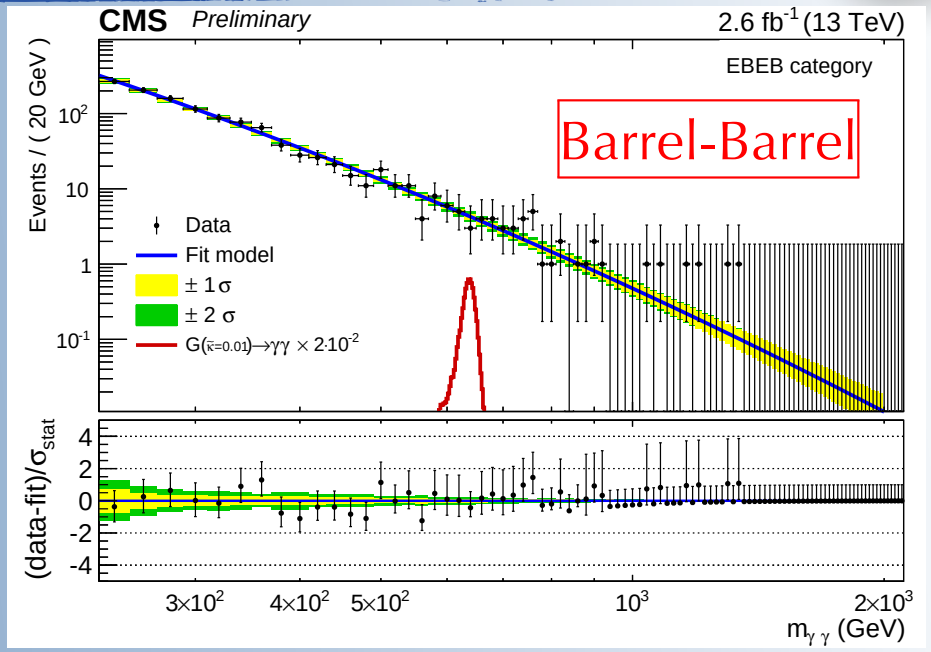
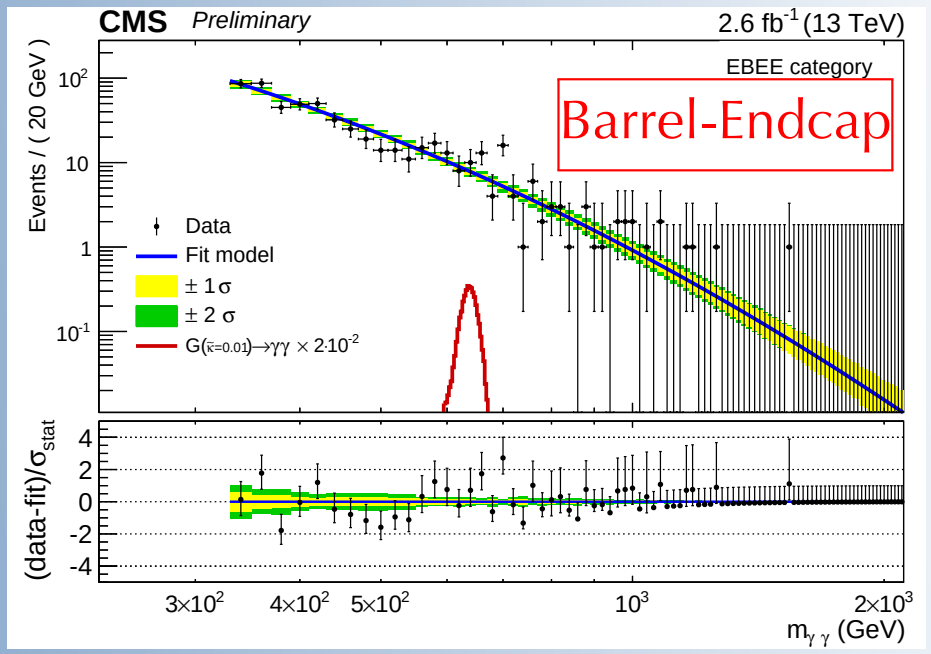
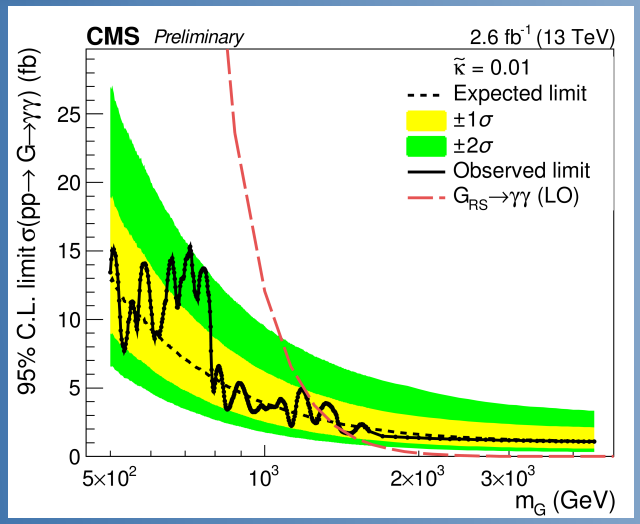
- Background systematic uncertainties:
  - Parametrization (bias term)
- Signal systematic uncertainties:
  - Luminosity (4.6%)
  - Signal efficiency (10%)
  - PDFs (6%)
  - Photon energy scale (1%)





Statistical interpretation



width = 0.1‰

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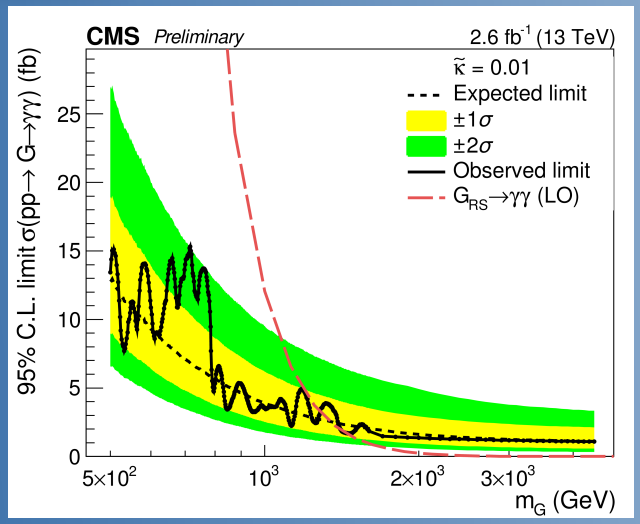

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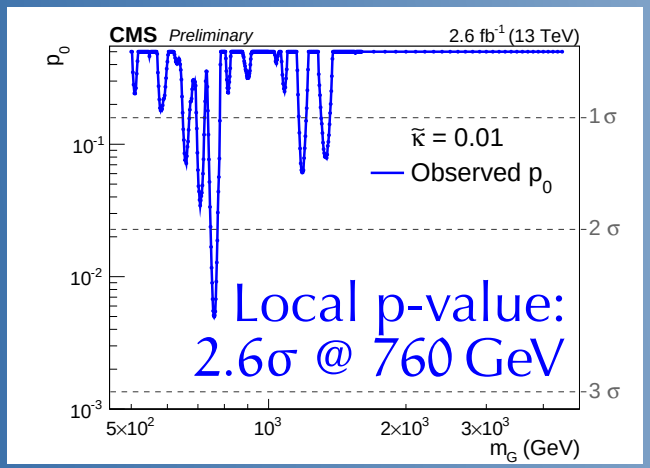
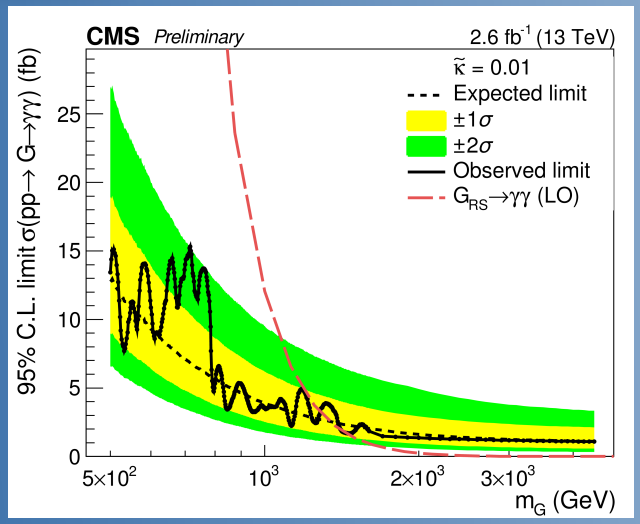
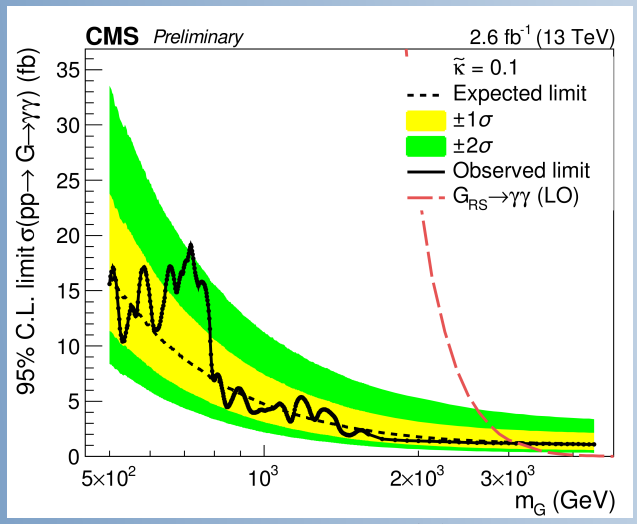


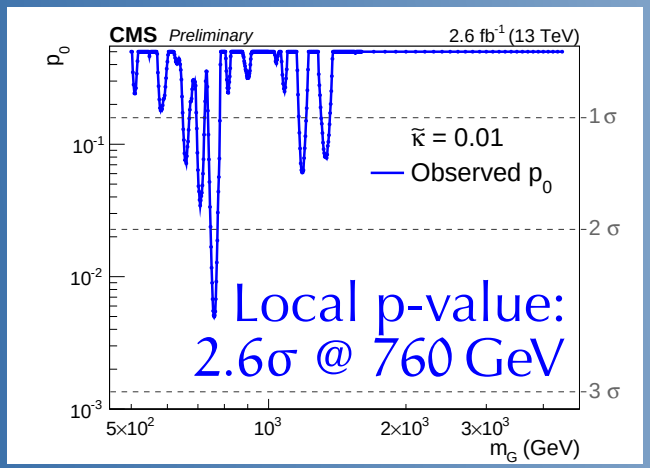
Global significance: $< 1.2\sigma$ (due to look-elsewhere-effect)

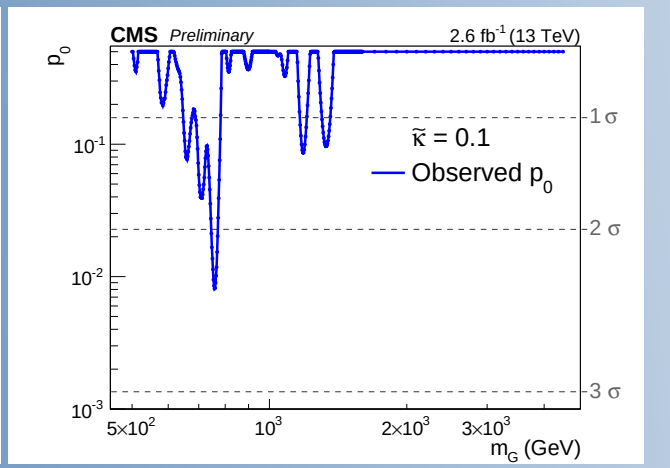
Statistical interpretation





width = 0.1‰ → width = 1%





Global significance: < 1.2σ (due to look-elsewhere-effect)

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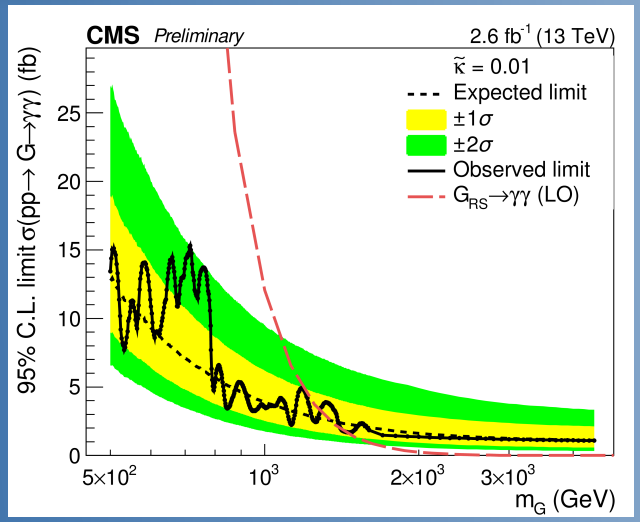
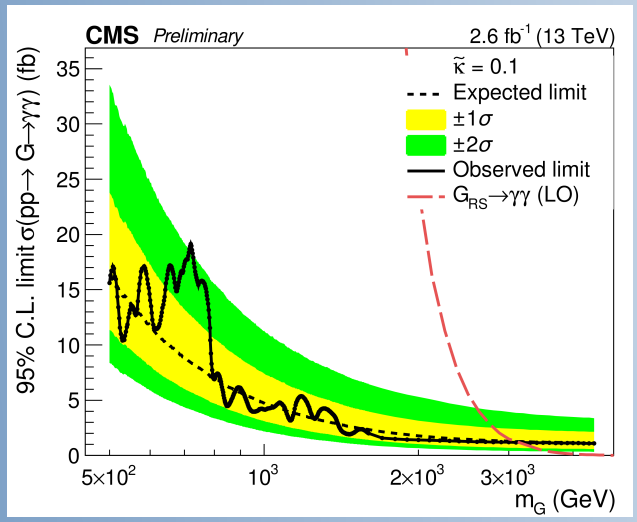
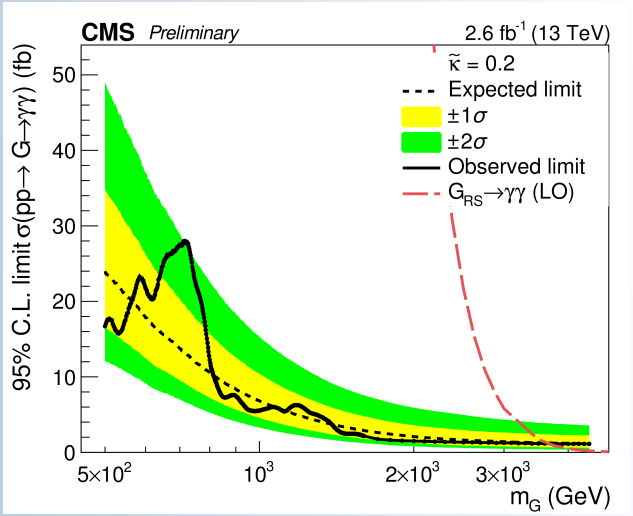
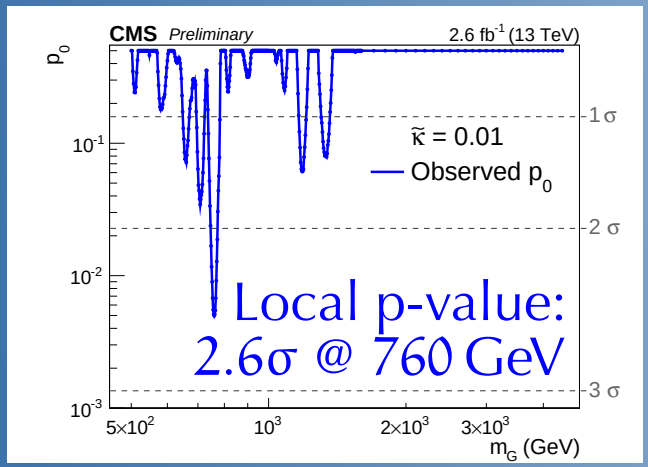
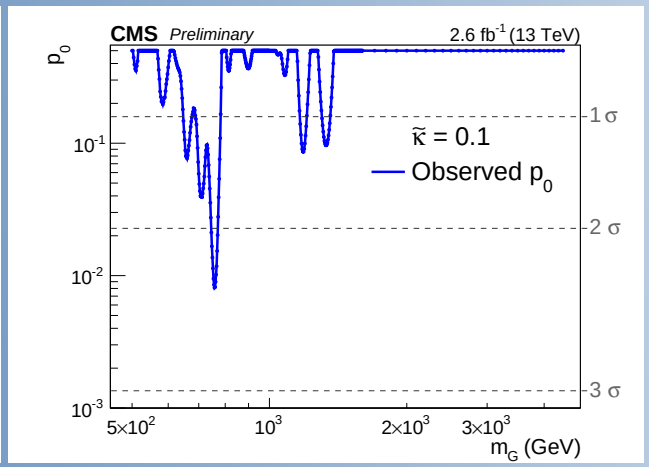


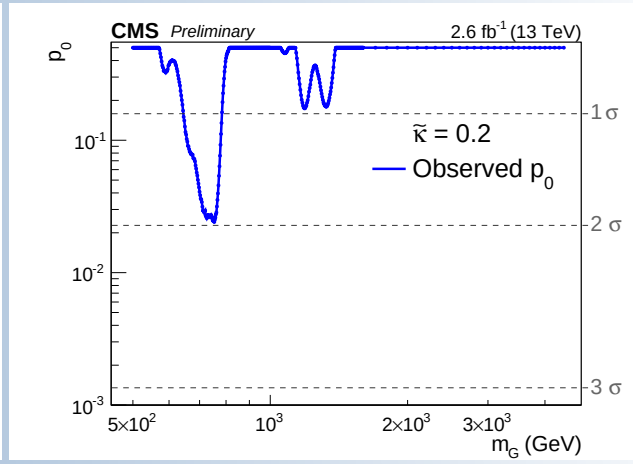




width = 0.1‰ → width = 1% → width = 6%







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Combination of 8 TeV and 13 TeV

- Perform a combination with two analyses at $\sqrt{s} = 8\,\text{TeV}$ of the diphoton final state
  - For $150 < m_{\gamma\gamma} < 850\,\text{GeV}$: Phys. Lett., B750:494-519 [4]
  - For $m_{\gamma\gamma} > 850\,\text{GeV}$: CMS PAS-EXO-12-045 [5]
- A simultaneous fit of the $m_{\gamma\gamma}$ spectra in all event categories is performed
- Systematic uncertainties are assumed to be uncorrelated

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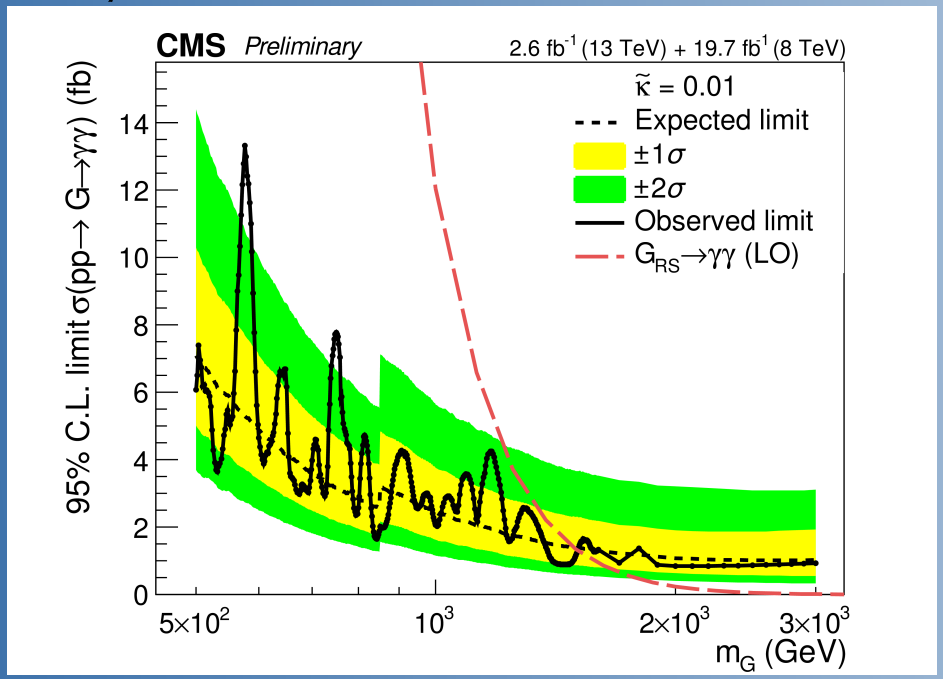
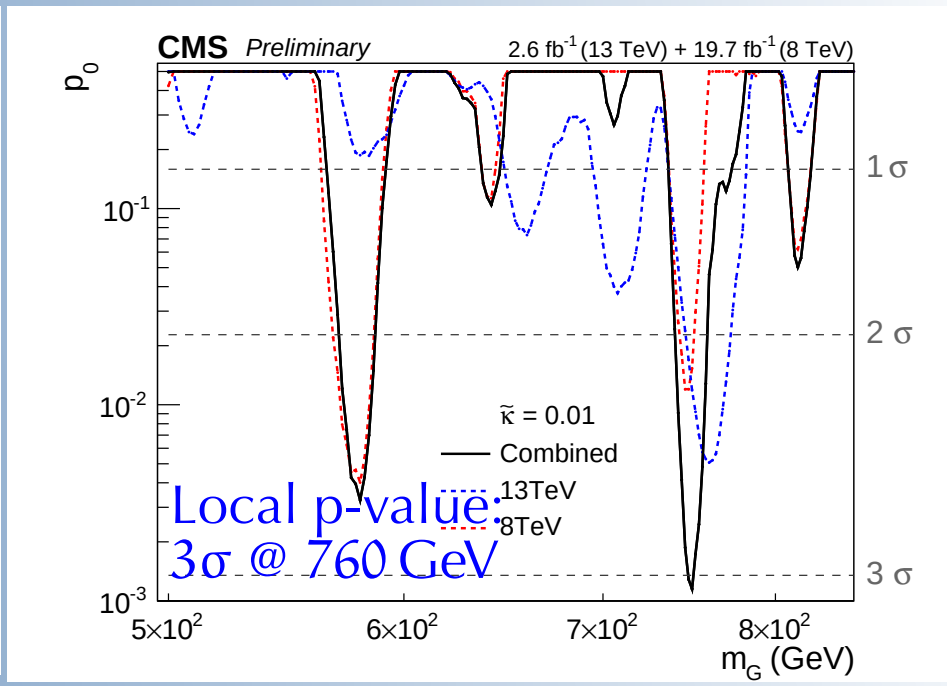
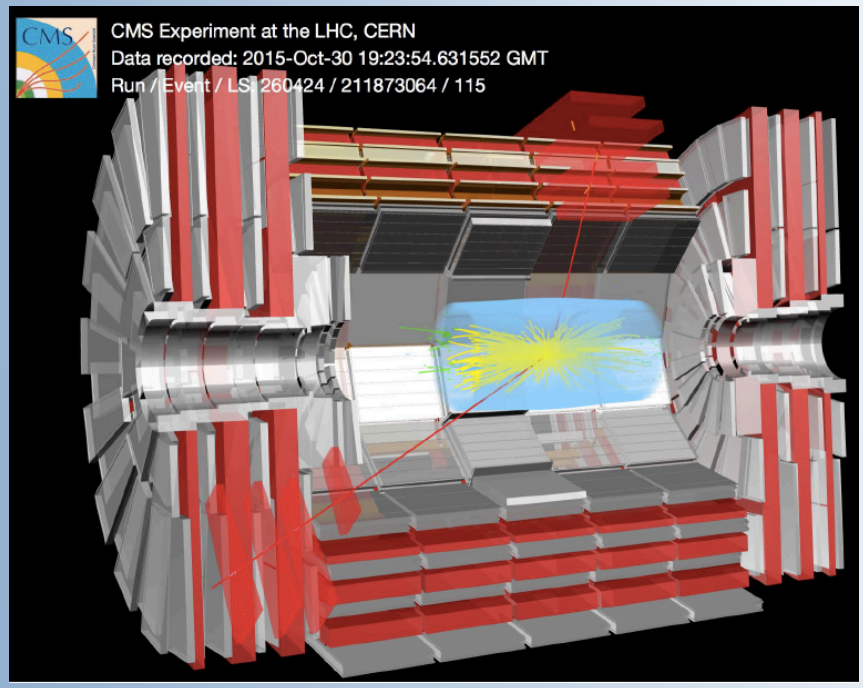
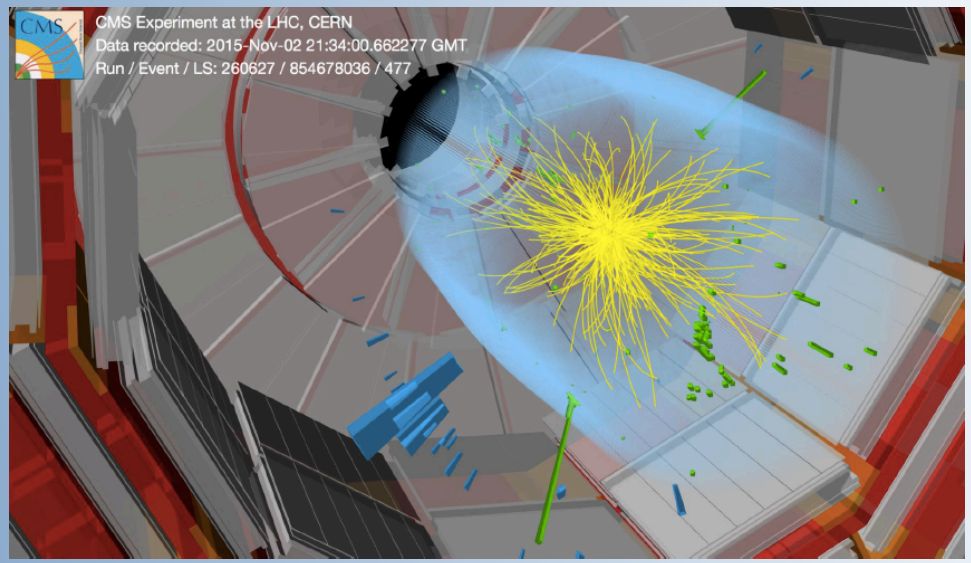




Global significance: $< 1.7\sigma$ (due to look-elsewhere-effect)

Outline





Summary and outlook

Dilepton (CMS PAS-EXO-15-005)

- Masses of $< 3.15\,\text{TeV}$ ($< 2.60\,\text{TeV}$) were excluded for the Z'_{SSM} (Z'_{ψ})
- Improvement of the 8 TeV results (2.9 TeV (2.57 TeV) for Z'_{SSM} (Z'_{ψ}))

Diphoton (CMS PAS-EXO-15-004)

- Gravitons below a mass of 1.3 TeV (3.1 TeV, 3.8 TeV) are excluded for $\tilde{\kappa} = 0.01$ ($\tilde{\kappa} = 0.1$, $\tilde{\kappa} = 0.2$)
- Largest excess in 13 TeV data was observed for $M_G = 760\,\text{GeV}$ and $\tilde{\kappa} = 0.01$:
  - Local significance: 2.6 standard deviations
  - Global significance: 1.2 standard deviations

All CMS physics results can be found at ▸ link

Outlook

- Improved and new results are expect for Moriond 2015
- New data will arrive soon ($\sim 20\,\text{fb}^{-1}$ this year)

Backup

References

Search for a Narrow Resonance Produced in 13 TeV pp Collisions Decaying to Electron Pair or Muon Pair Final States.

Technical Report CMS-PAS-EXO-15-005, CERN, Geneva, 2015.

Event Display of a Candidate Electron-Positron Pair with an Invariant Mass of 2.9 TeV.

Aug 2015.

Search for new physics in high mass diphoton events in proton-proton collisions at $\sqrt{s} = 13$ TeV.

Technical Report CMS-PAS-EXO-15-004, CERN, Geneva, 2015.

Vardan Khachatryan et al.

Search for diphoton resonances in the mass range from 150 to 850 GeV in pp collisions at $\sqrt{s} = 8$ TeV.

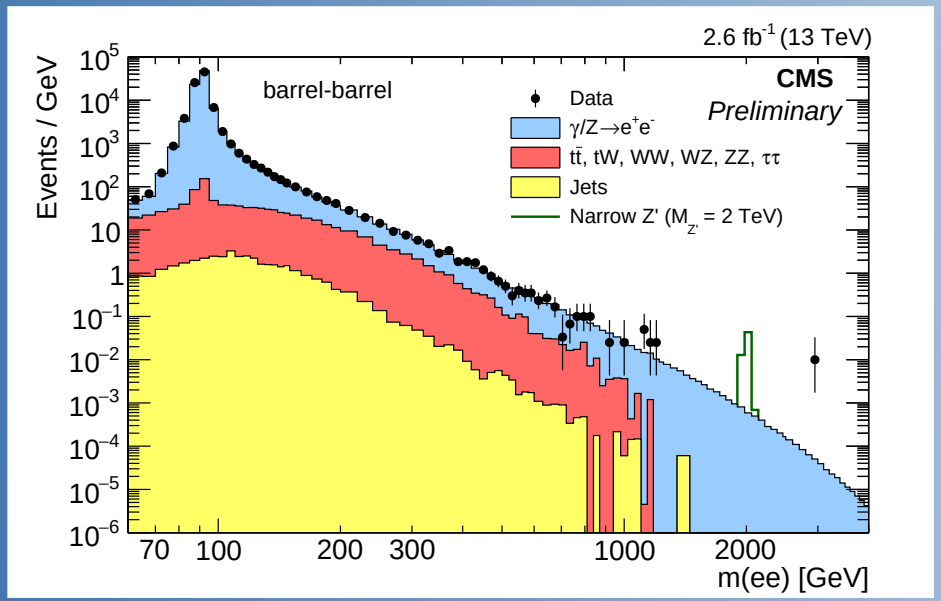
Phys. Lett., B750:494–519, 2015.

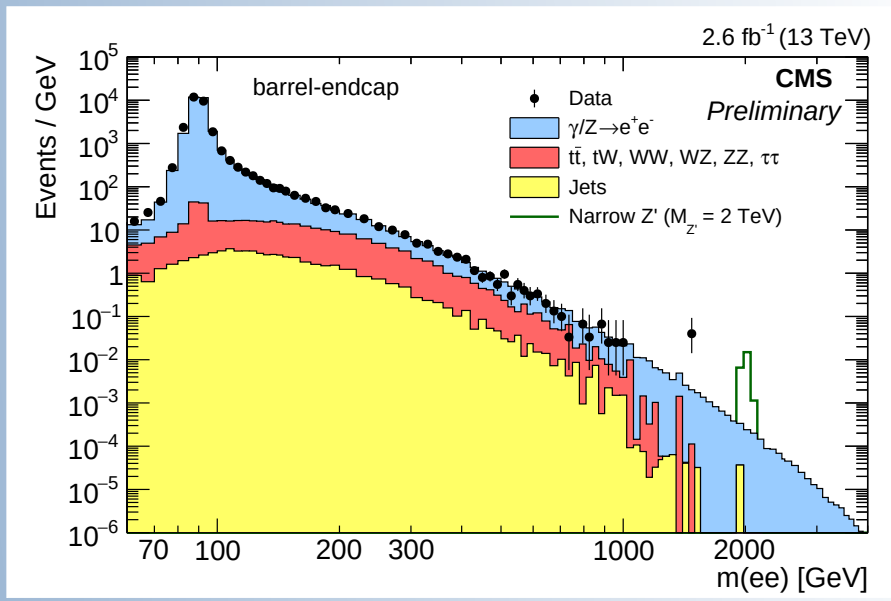
Search for High-Mass Diphoton Resonances in pp Collisions at sqrt(s)=8 TeV with the CMS Detector.

Technical Report CMS-PAS-EXO-12-045, CERN, Geneva, 2015.

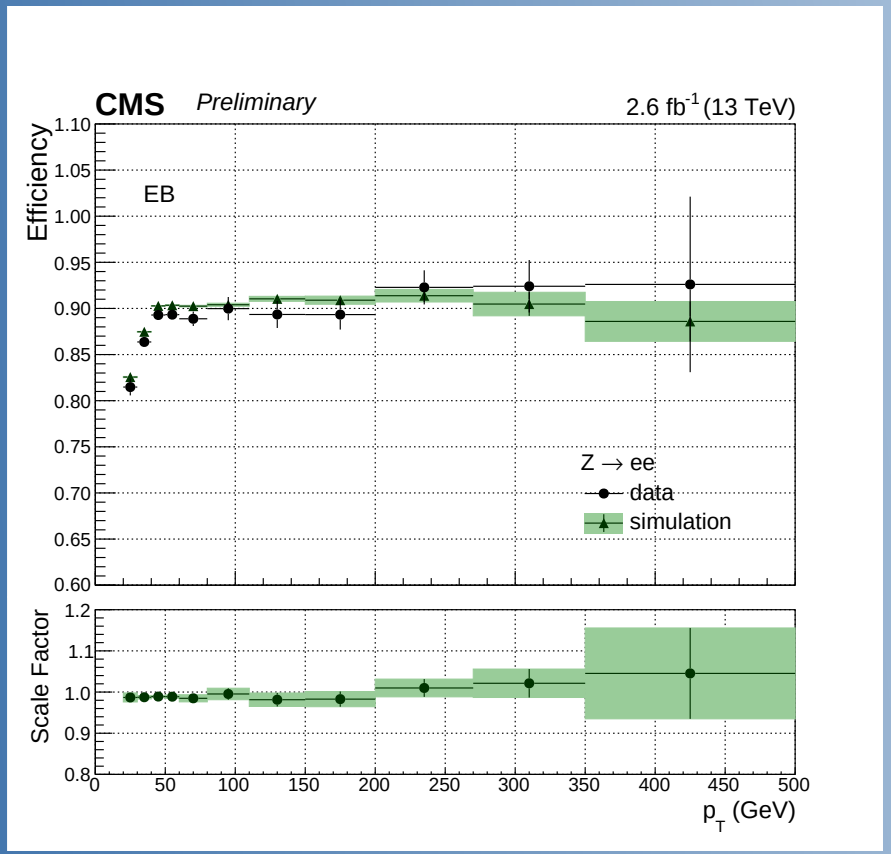
Dielectron additional plots

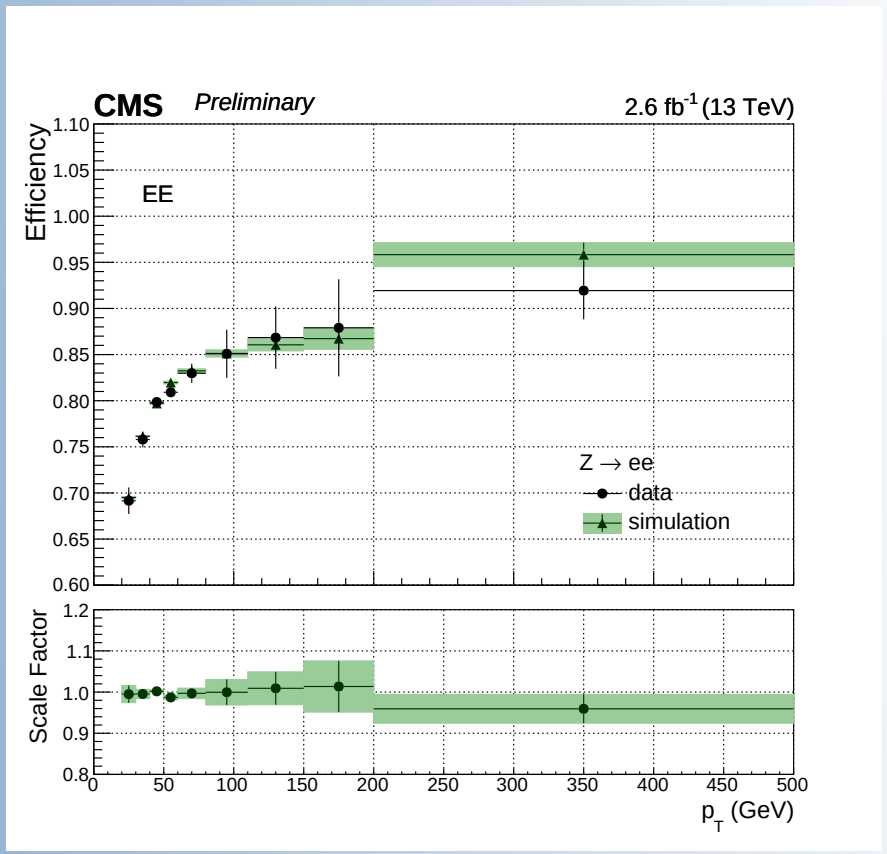
Dielectron mass spectra, split into barrel-barrel and barrel-endcap categories:



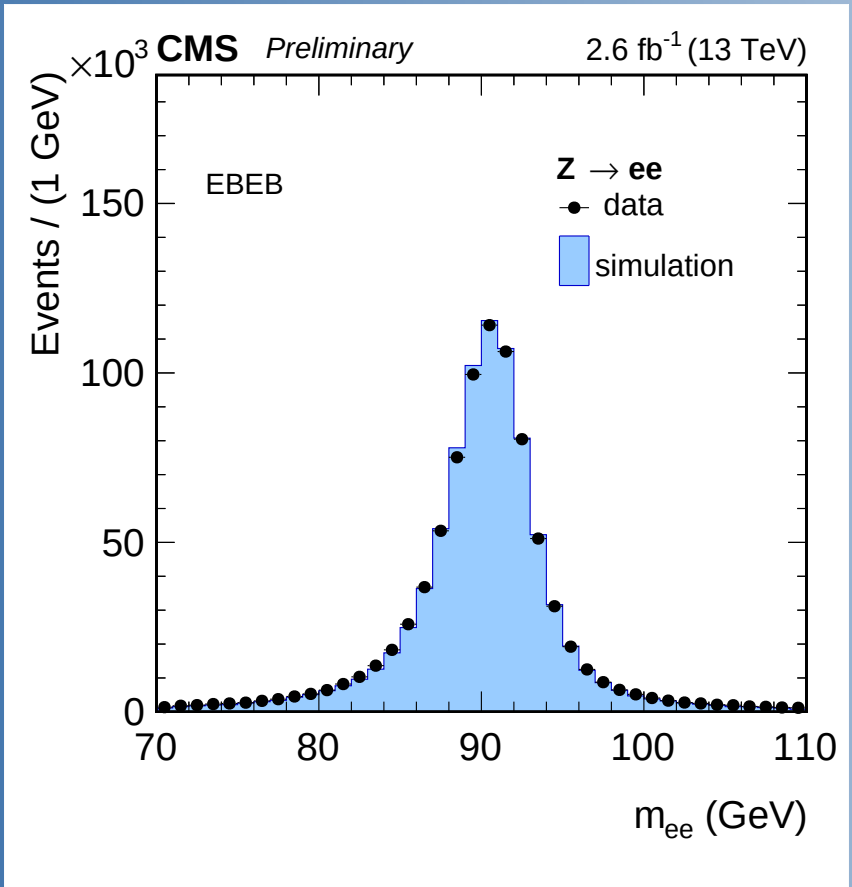


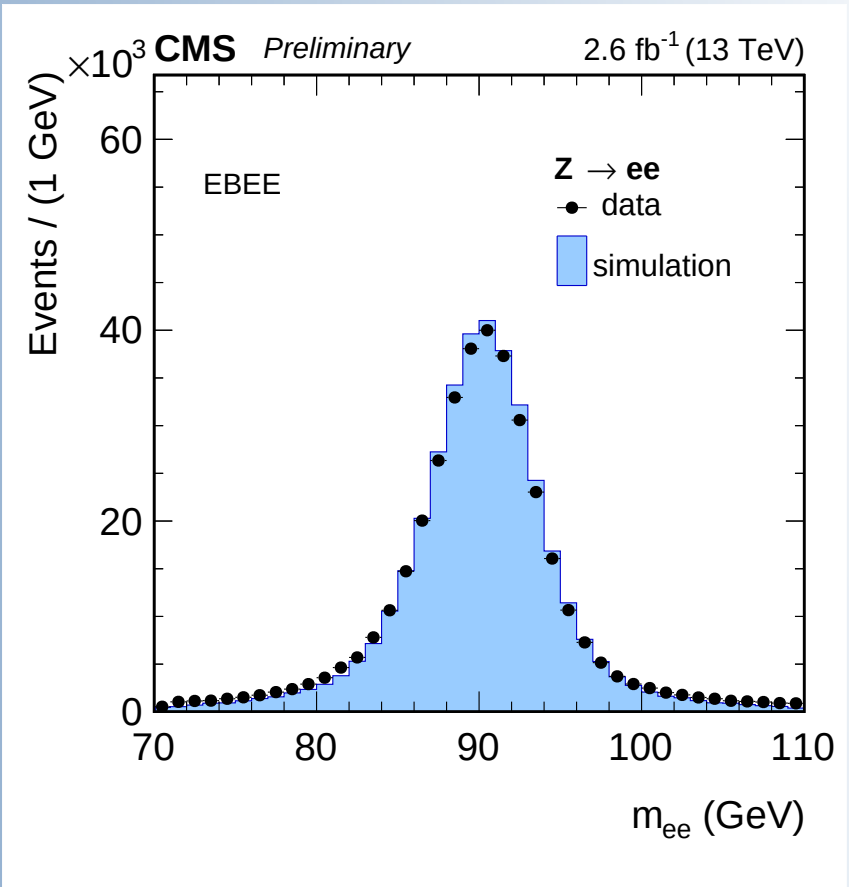
Diphoton signal efficiency





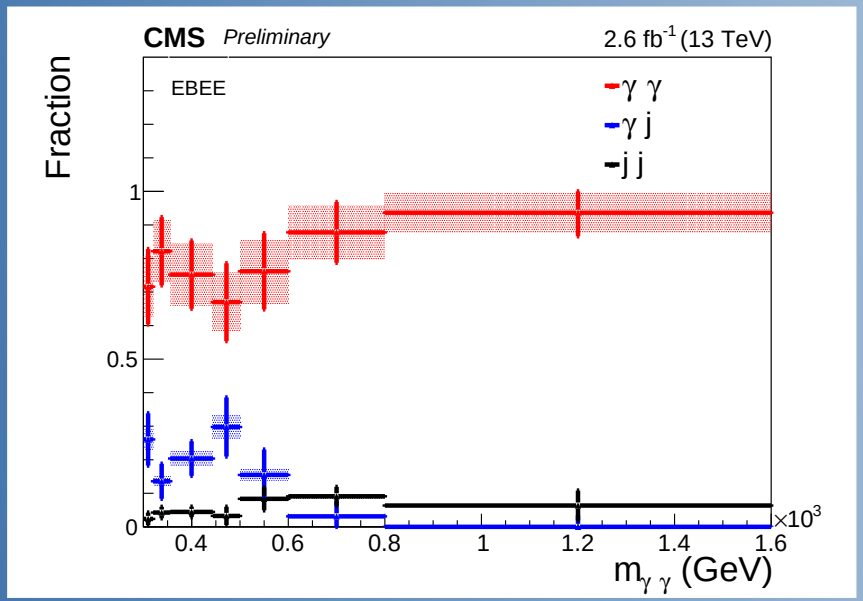
Diphoton additional plots

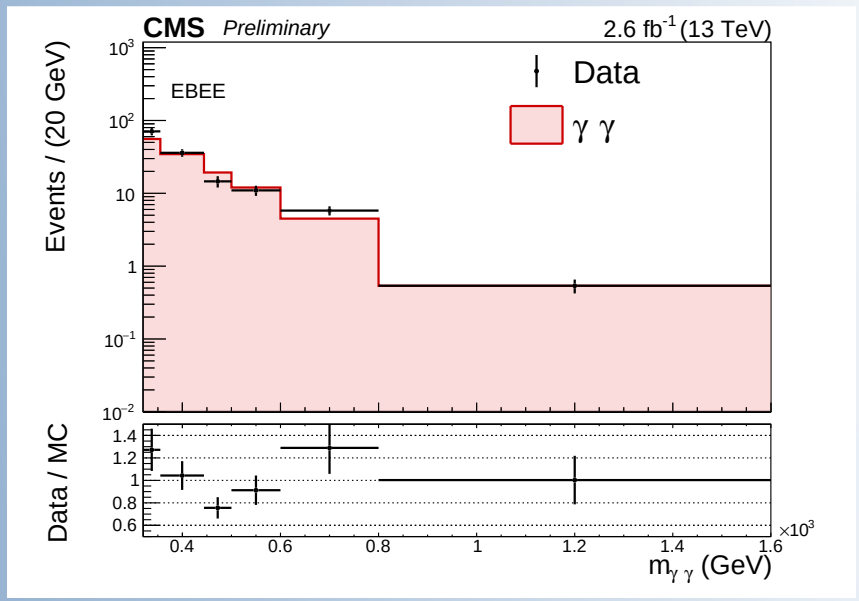




Diphoton additional plots

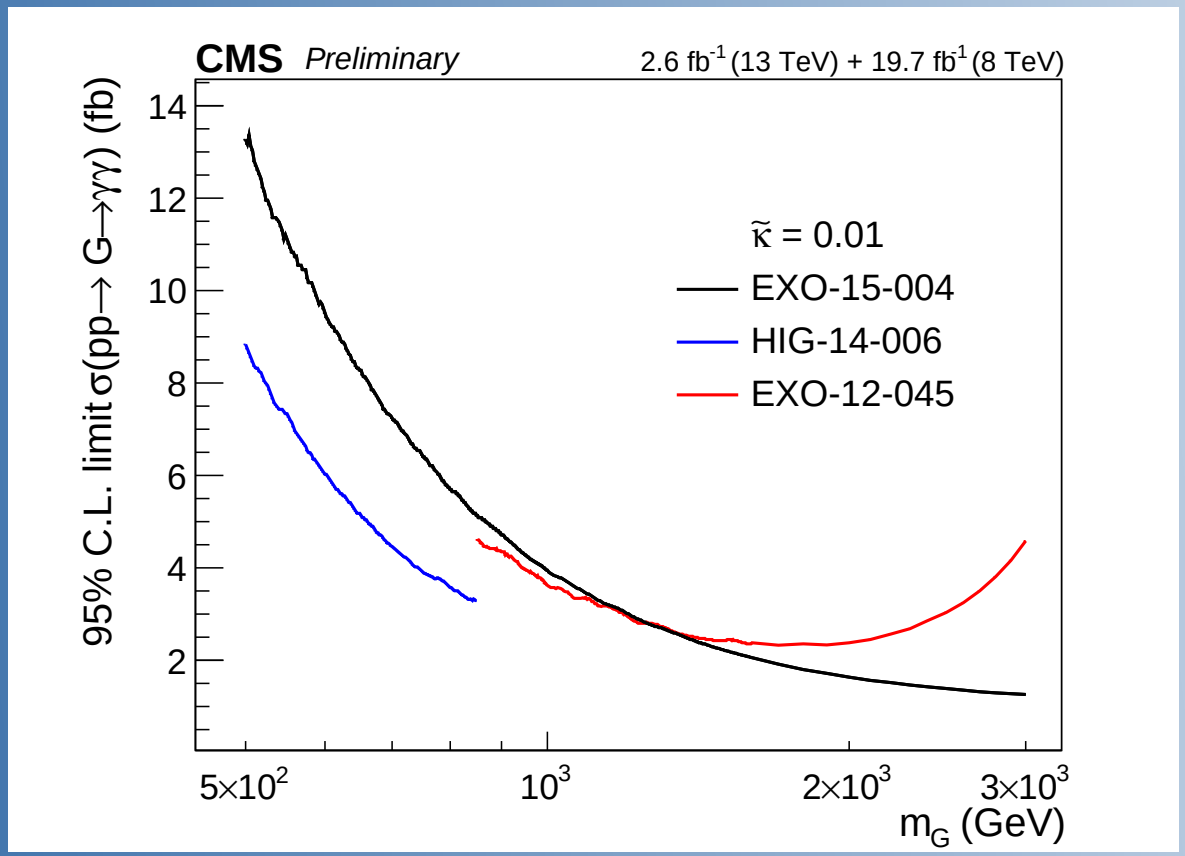
Missing plots for the barrel-endcap category of the background composition and data/MC comparison:





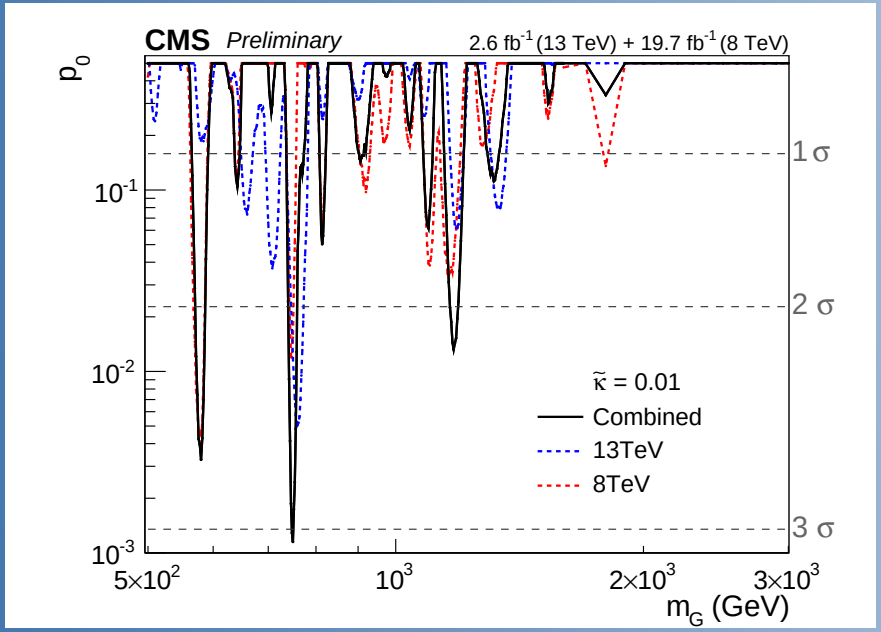
Diphoton combination plots

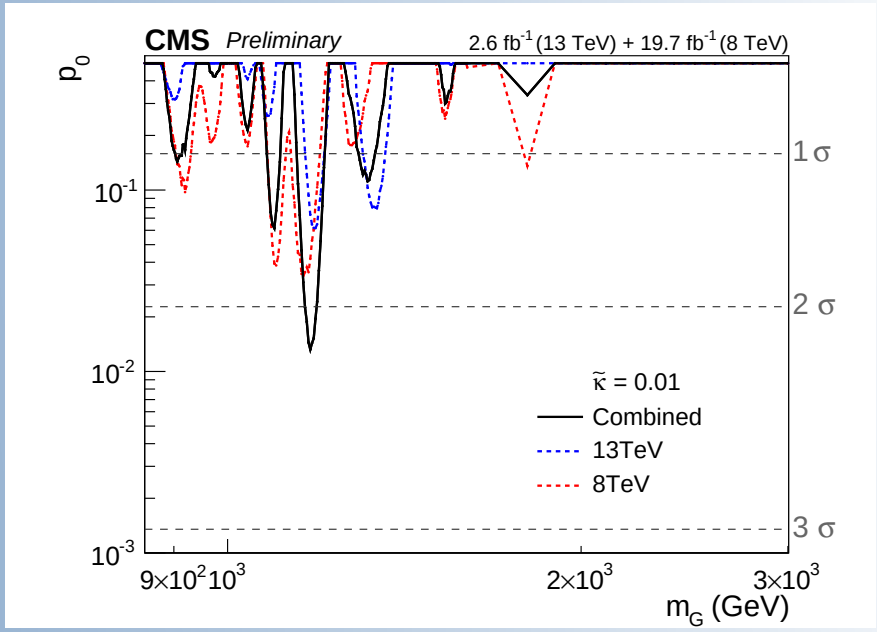
Median expected upper limit of the different analysis:



Diphoton combination plots

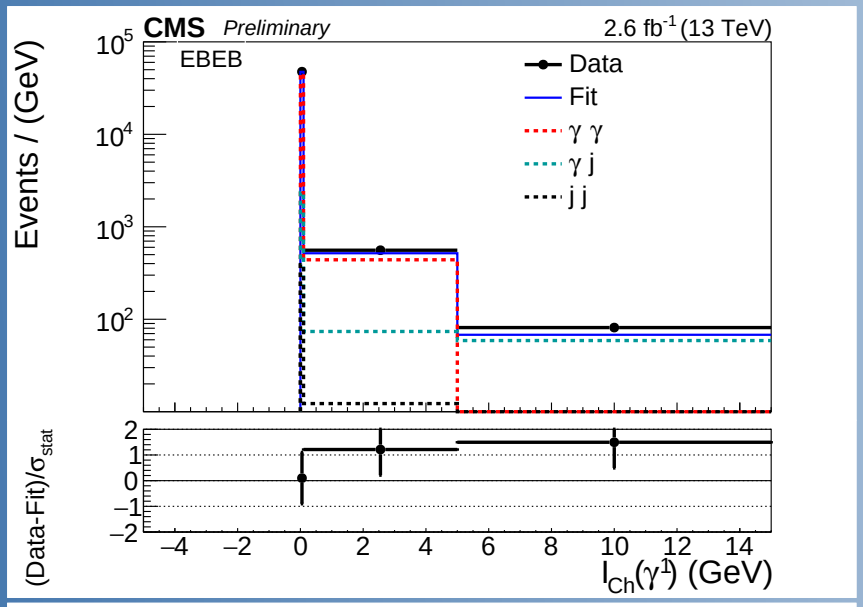
Different plotting ranges of the local p-values for the combined analysis:

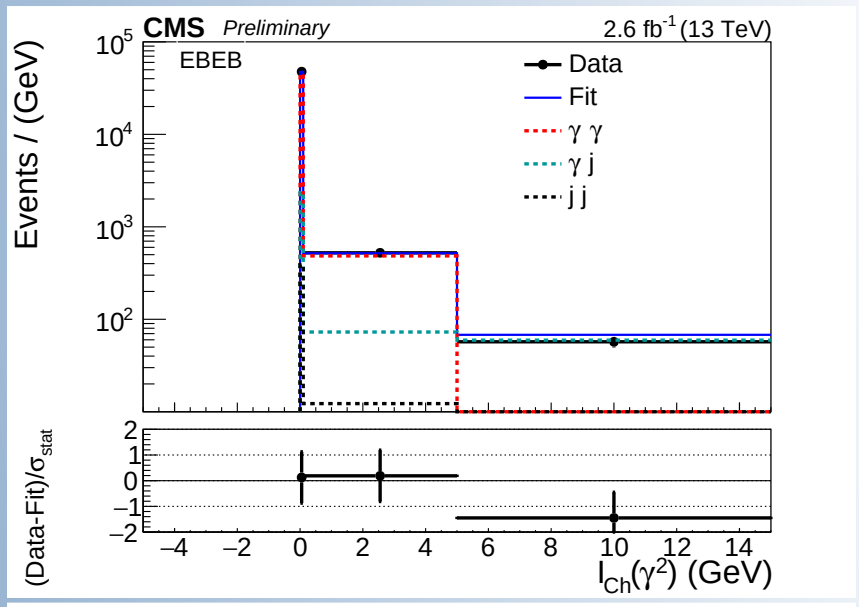


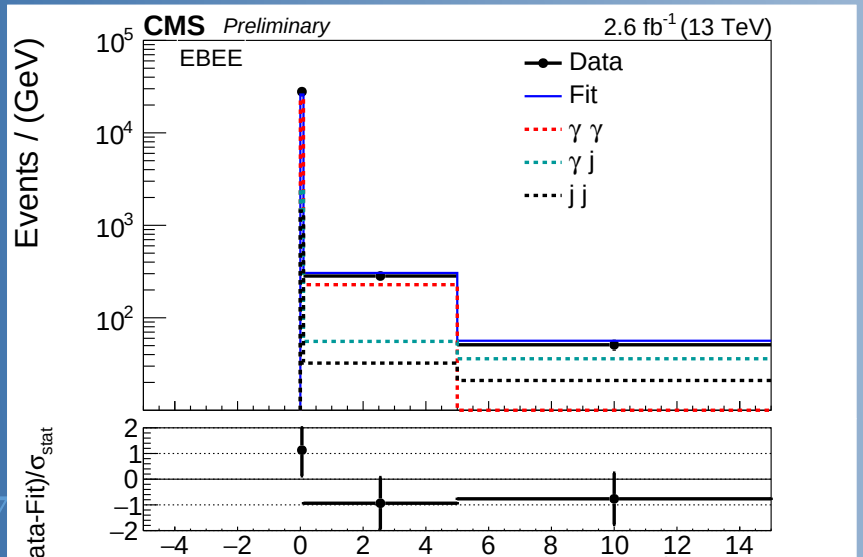


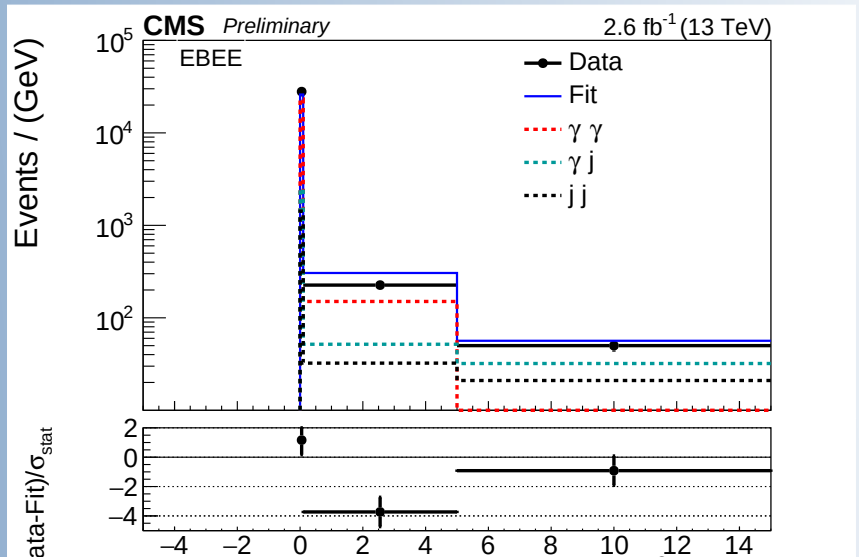
Diphoton Isolation

$$I_{Ch} = \sum_{\Delta R<0.3} p_T \text{ (pf charged hadron candidates)}$$









Diphoton combination plots

Different contributions of the barrel-barrel and barrel-endcap categories in the combined analysis: