Searches for High Mass BSM Scalars in Zγ and $\gamma\gamma$ Final States

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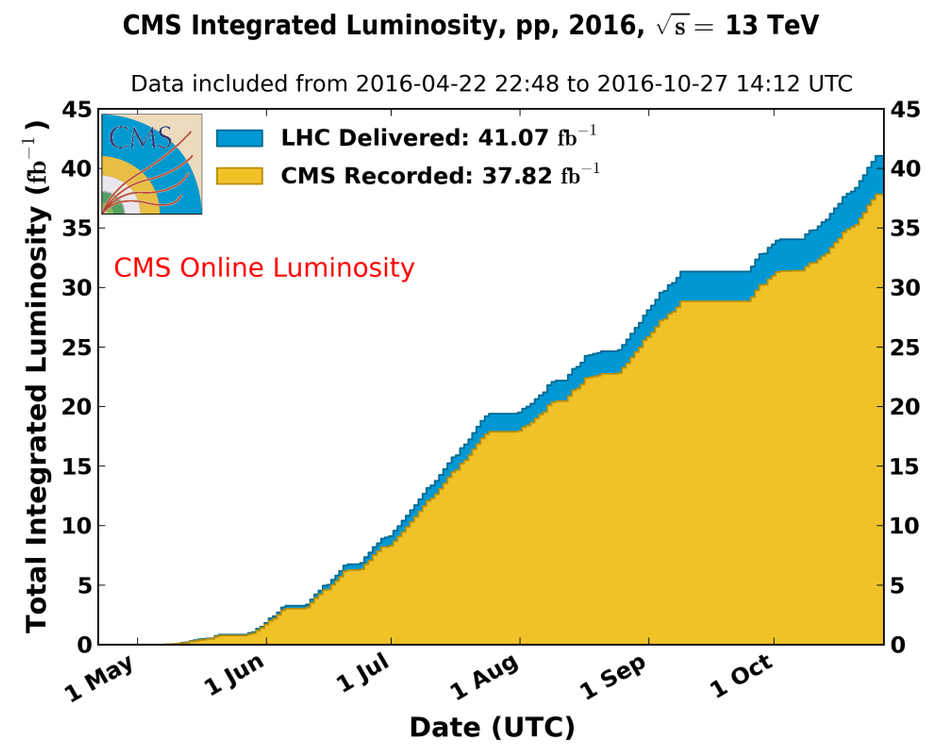
Introduction

- Many BSM theories predict additional heavy scalar bosons
  - **$Z\gamma$ / $\gamma\gamma$ decay: clear experimental signature**
- LHC 13 TeV operation give us a good chance to search them
  - **37.8 fb^{-1} recorded by the CMS detector in 2016: already exceeded total Run-I statistics**

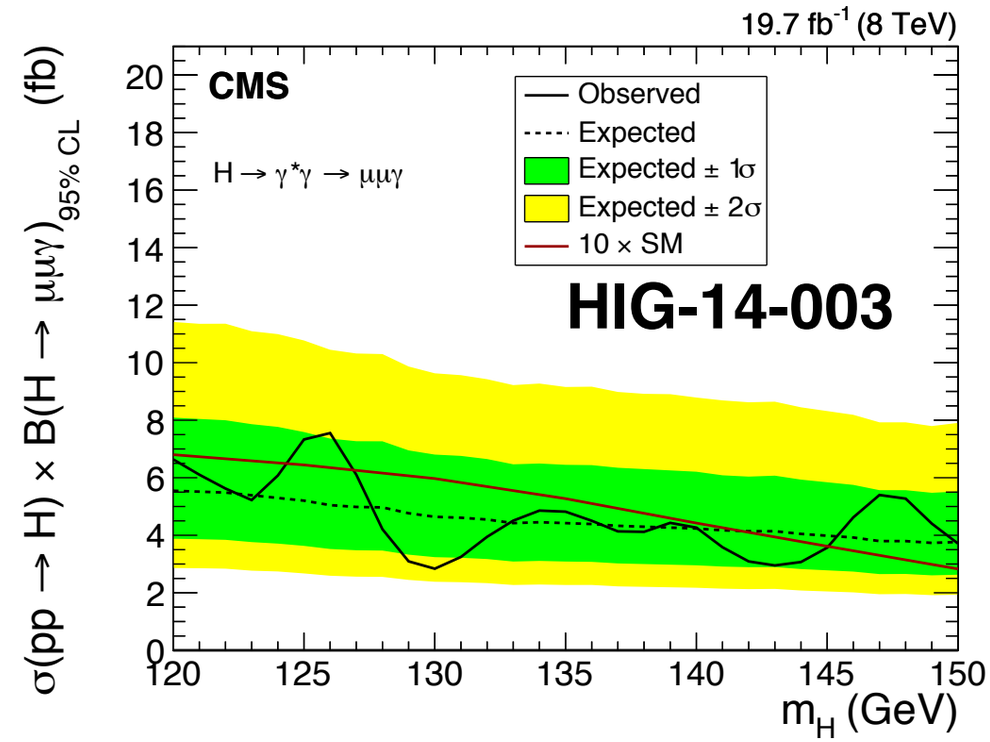


- This talk covers the latest results of the following searches
  - **$X \to Z(ll)\gamma$ (EXO-16-034), $X \to Z(qq)\gamma$ (EXO-16-035), $X \to \gamma\gamma$ (EXO-16-027, Phys. Lett. B 767 (2017) 147)**
- Analysis strategy
  - **looking for an excess over SM backgrounds in the invariant mass spectrum**
  - **fit the data with a background model and use the signal shapes for the limits**
  - **benchmark scenarios:**

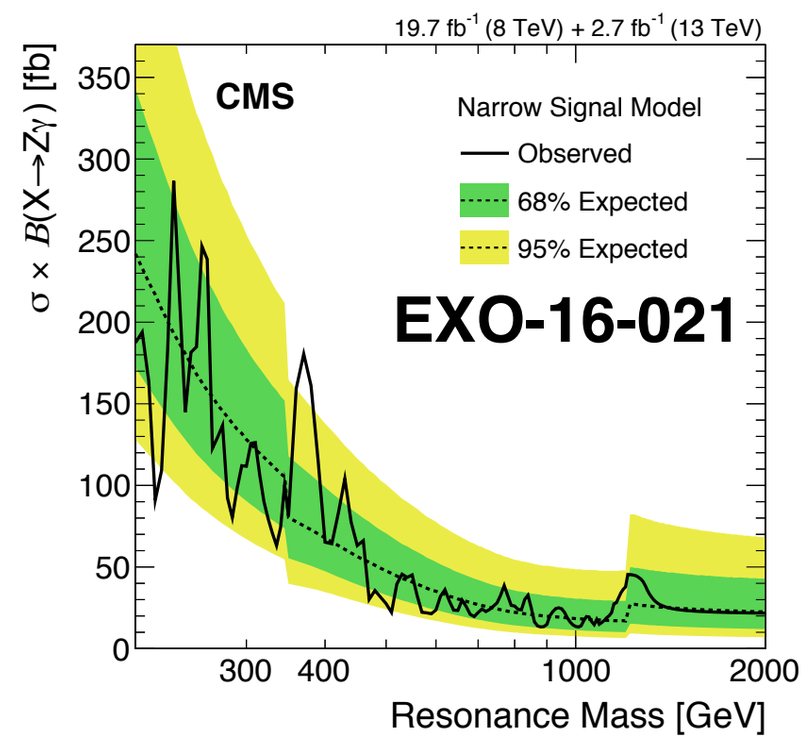
	$Z(ll)\gamma$	$Z(qq)\gamma$	$\gamma\gamma$
Spin	0	0	0, 2
Width	0.014%	0.014%, 5.6%	0.014%, 1.4%, 5.6%

Summary of Previous Analyses

- Run-I (8 TeV)
  - **started around SM Higgs mass**
  - **extended to high masses**
  - X → Z(ll)γ: HIG-14-003 (Phys. Lett. B 753 (2016) 341), HIG-14-031, HIG-16-014
  - X → Z(qq)γ: EXO-16-025
  - X → $\gamma\gamma$: HIG-14-006 (Phys. Lett. B 750 (2015) 494), HIG-14-037



- Run-II
  - **higher collision energy: 8 → 13 TeV**
  - **focus on the high mass region**
  - 2015:
    - ➡ X → Z(ll)γ: EXO-16-019, EXO-16-021 (JHEP 01 (2017) 076)
    - ➡ X → Z(qq)γ: EXO-16-020
    - ➡ X → $\gamma\gamma$: EXO-15-004, EXO-16-018 (Phys. Rev. Lett. 117, 051802 (2016))

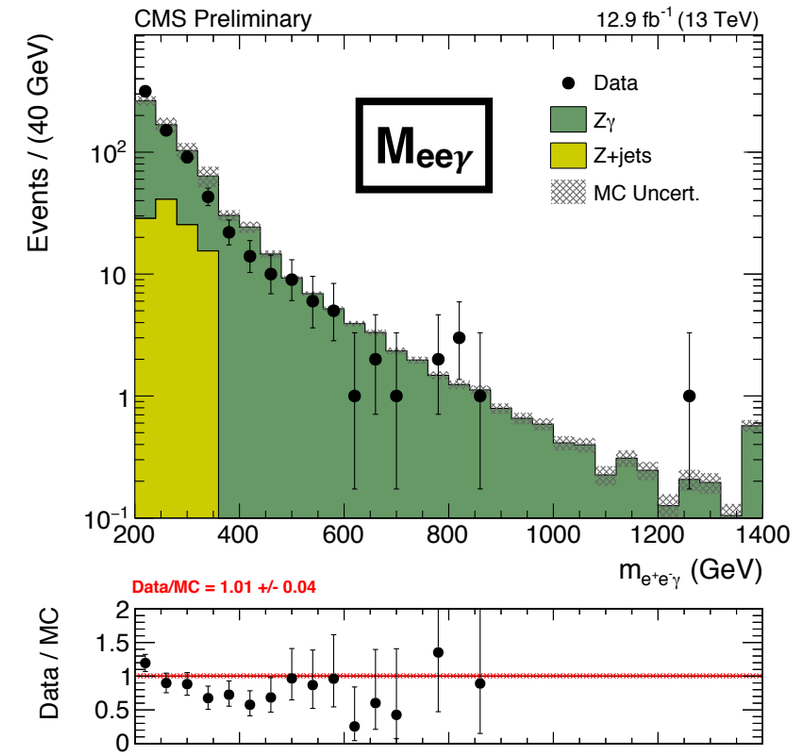


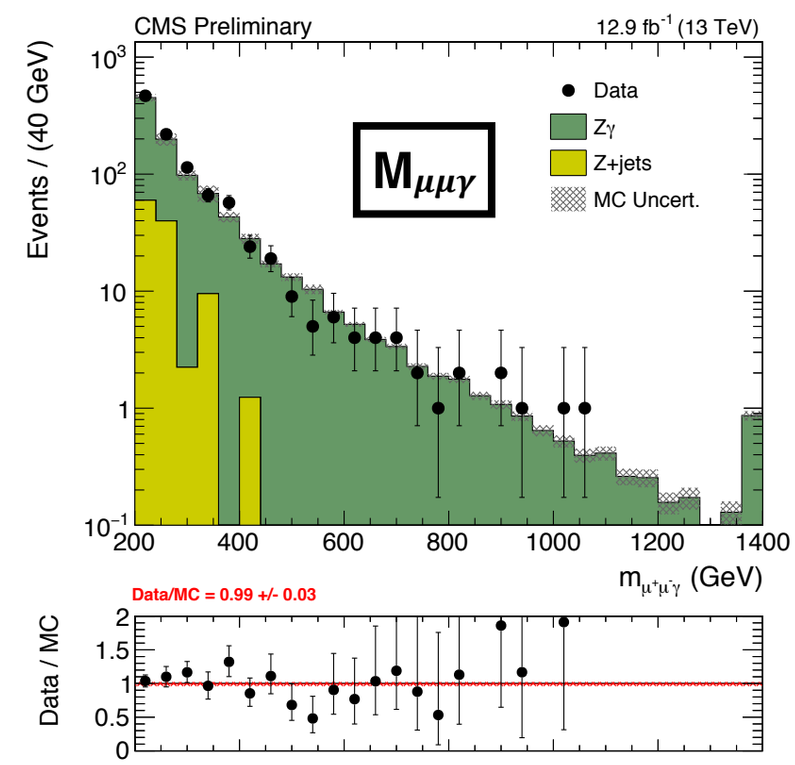
Data and Simulations

- Data
  - **collected by the CMS detector during LHC 13 TeV operation in 2016 until August (12.9 fb^{-1})**
  - **passing standard quality criteria for all components of the CMS detector**
- Background simulations:
  - **used for only background bias studies**
  - $X \to Z(ll)\gamma$: $Z(ll)\gamma$ (aMC@NLO), Z+jets (MadGraph)
  - $X \to Z(qq)\gamma$: γ+jets (aMC@NLO), QCD multijet (PYTHIA)
  - $X \to \gamma\gamma$: $\gamma\gamma$ (Sherpa), γ+jets (aMC@NLO), QCD multijet (PYTHIA)
  - Sherpa, MadGraph, aMC@NLO:
    - ➡ interfaced with PYTHIA for parton showering and hadronization
- Signal simulations
  - generated at leading order with PYTHIA

Event Selection: X → Z(ll)γ

- Triggers
  - ee channel: the combination of **double electron triggers**
  - $\mu\mu$ channel: the combination of **single muon triggers** and **double muon triggers**
- Dilepton
  - leading p_T > 25 GeV, subleading p_T > 10 GeV, $|\eta|$ < 2.4
  - **50 < M_Z < 130 GeV**
- Photon
  - p_T > 40 GeV, $|\eta|$ < 2.5
  - **ΔR > 0.4 from each identified lepton**
- Z(ll)γ
  - **photon p_T / $M_{Z\gamma}$ > 40/150**
  - $M_{Z\gamma}$ > 200 GeV





Event Selection: $X \to Z(qq)\gamma$

- Triggers
  - the combination of **single photon triggers** and **single jet triggers**
- Photon: $p_T > 200$ GeV, $|\eta| < 1.44$
- Wide jet: **boosted qq → reconstructed as a single jet with wide cone size**
  - **clustered with anti-kT algorithm with a cone size of $\Delta R < 0.8$**
  - $p_T > 200$ GeV, $|\eta| < 2$
  - **$\Delta R > 1.1$ from an identified photon**
  - **pruned with the Cambridge-Achen algorithm**
  - **75 GeV < M_J^{pruned} < 105 GeV**
  - **split into two subjets by reversing the final iteration in the clustering**
- Subjets: **b-tagged** / **anti-b-tagged**
- $M_{Z\gamma} > 600$ GeV

Event Selection: $X \to \gamma\gamma$

- Trigger:
  - **double photon trigger**
- Diphoton:
  - p_T > 75 GeV, $|\eta|$ < 2.5
  - **at least one photon with $|\eta|$ < 1.44**
    - ➡ Two categories: **EBEB** (both $|\eta|$ < 1.44) and **EBEE** (one $|\eta|$ < 1.44, the other $|\eta|$ > 1.44)
  - $M_{\gamma\gamma}$ > 230 GeV (EBEB) / 320 GeV (EBEE)

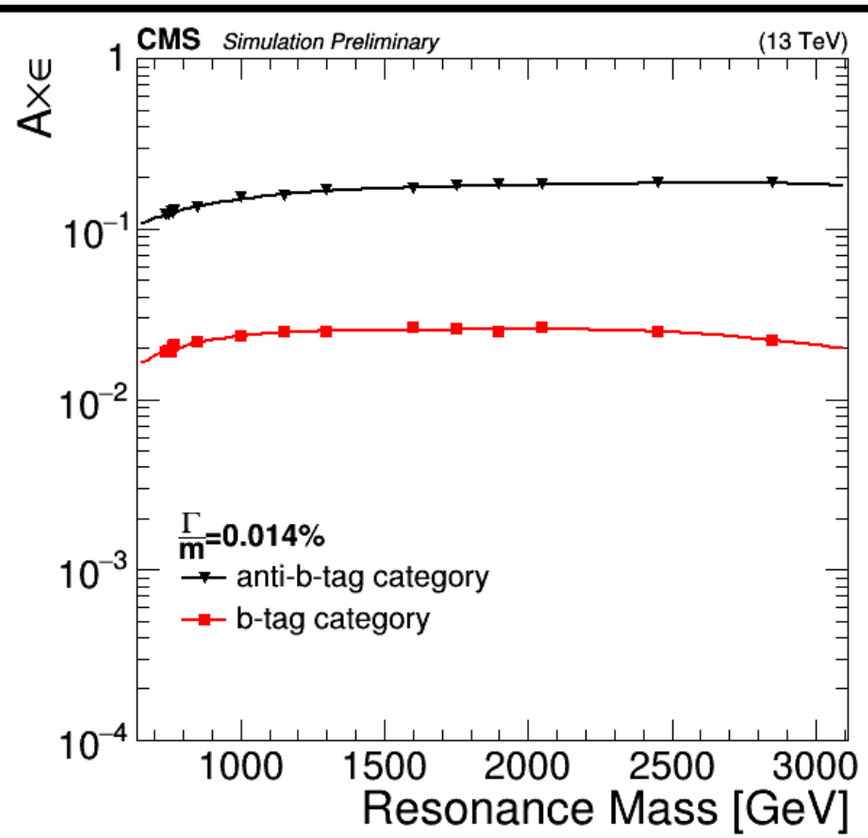
Background Modeling

- Parameterized by a smoothly falling function of invariant mass
  - **$f(M_{Z\gamma}) = M_{Z\gamma}^{a + b \log(M_{Z\gamma})}$**
- Background bias study is based on
  - Z(ll)γ, $\gamma\gamma$: simulations in the signal region
  - Z(qq)γ: data and simulations in the side band (50 GeV < M_J^{pruned} < 70 GeV)
- To estimate a bias: **test a pull between the background model and test models**
  - generate pseudo-experiments from the fit of a test model to MC
  - fit the background model to pseudo-experiments and compute pulls
  - **criterion: |median of pulls| < 0.5**
  - if not, apply **an extra uncertainty** until the median is brought back in 0.5
  - **the extra uncertainty is assigned as a systematic**

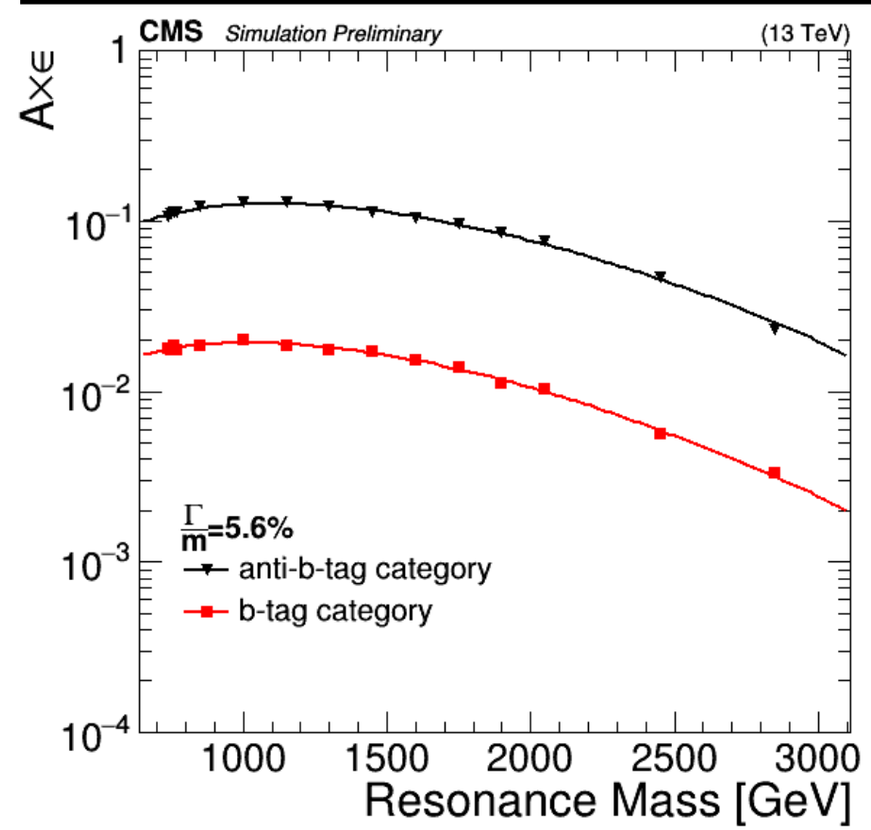
Signal Modeling

- Signal shape in the invariant mass spectrum
  - Z(ll)γ, $\gamma\gamma$: **Double-sided Crystal Ball**
  - Z(qq)γ: **Crystal Ball + Gaussian**
- Shape parameters and total selection efficiencies from simulation
  - **measured by the simulated sample at each mass point and interpolated through polynomial fits**

Selection efficiency in Z(qq)γ (0.014%)



Selection efficiency in Z(qq)γ (5.6%)

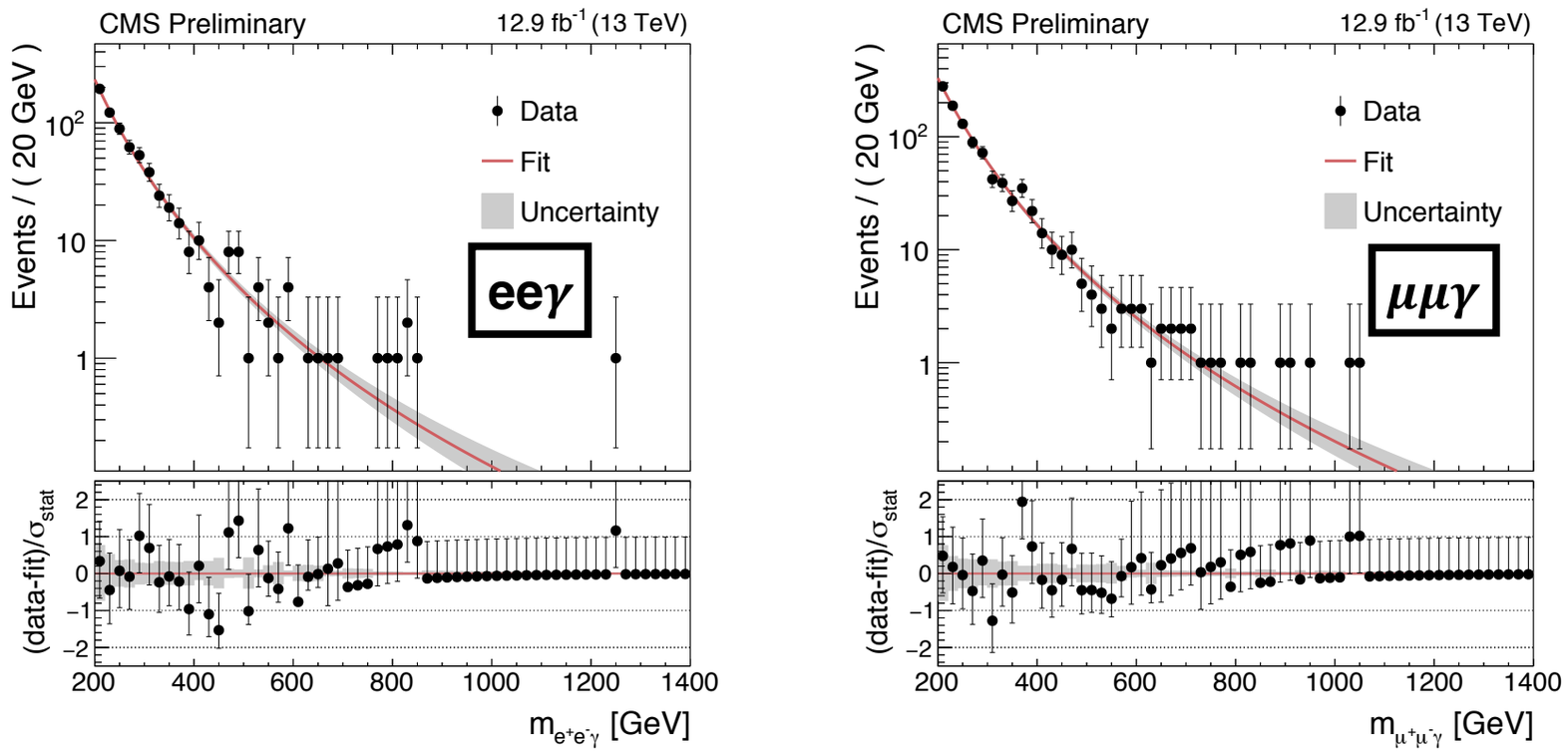


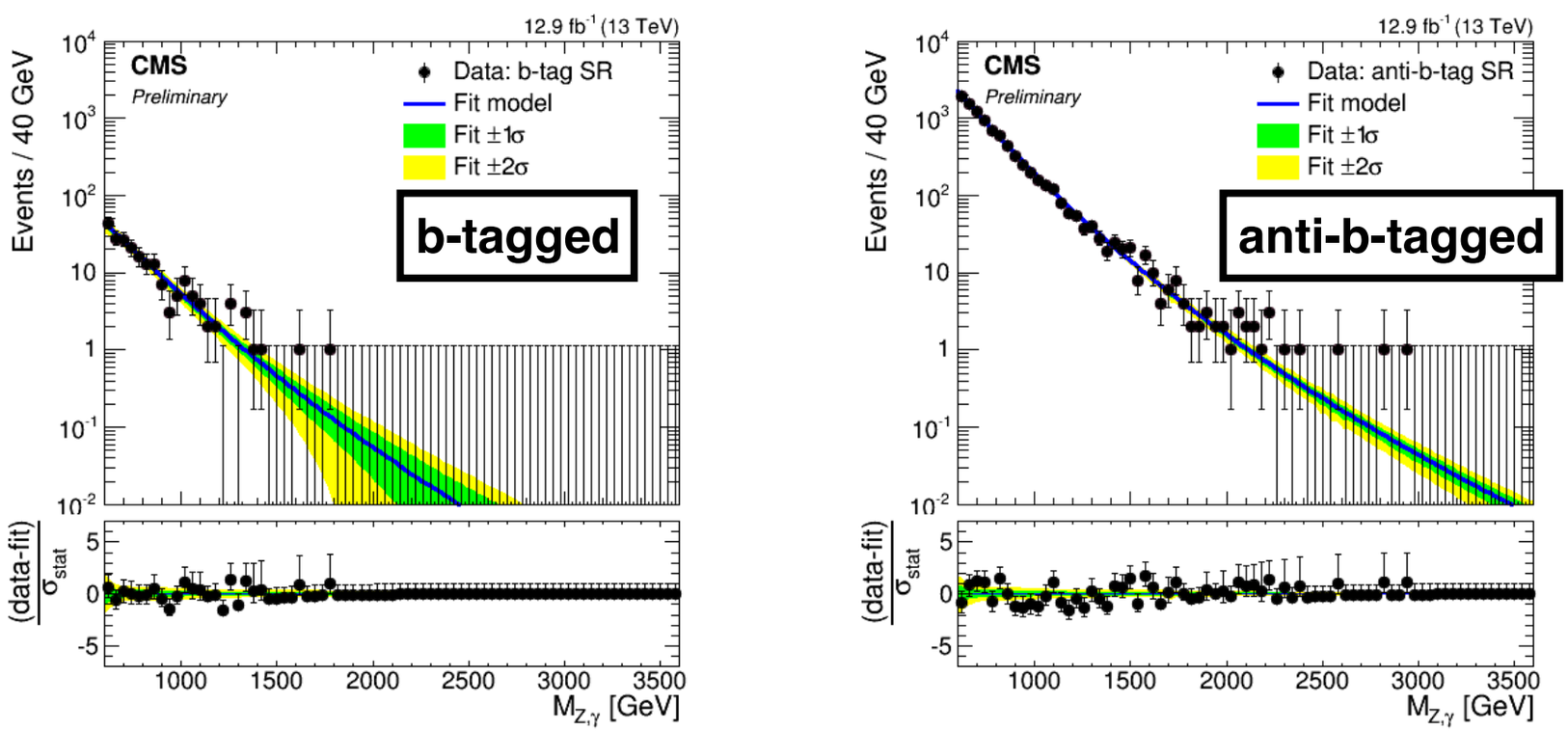
Systematics

- (O: considered, X: not)

	Z(ll)γ	Z(qq)γ	$\gamma\gamma$
Luminosity	✓	✓	✓
PDF	✓	✓	✓
Pileup		✓	
Trigger	✓	✓	
Efficiency	✓	✓	✓
e/γ energy scale and resolution	✓	✓	✓
μ momentum scale and resolution	✓		
Jet energy & mass scale and resolution		✓	

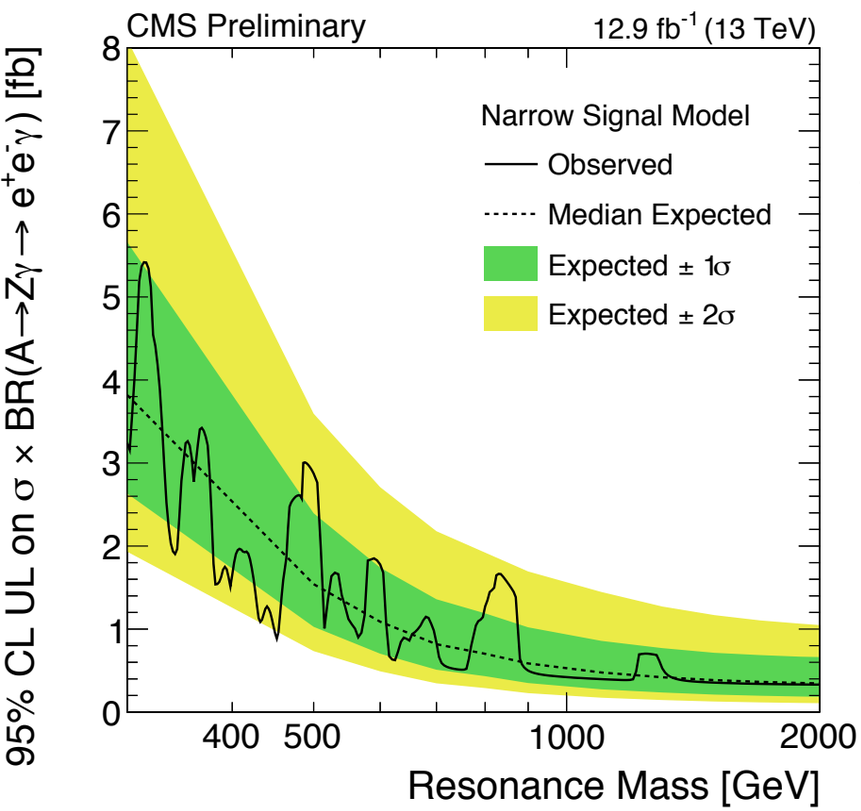
Invariant Mass Spectra: X → Zγ



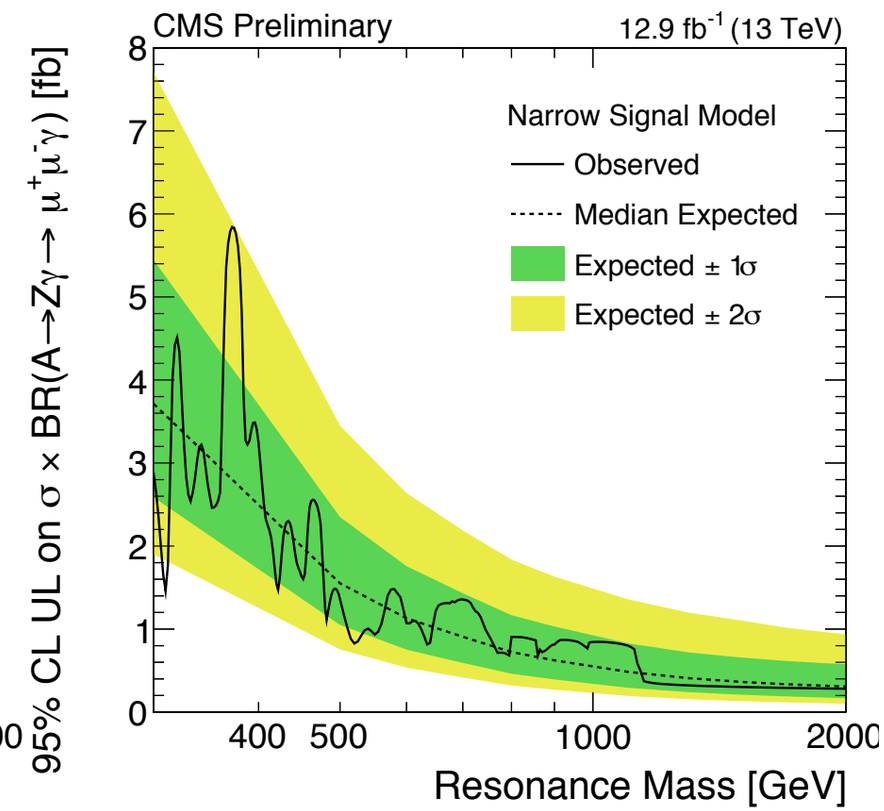


Limits: X → Z(ll)γ

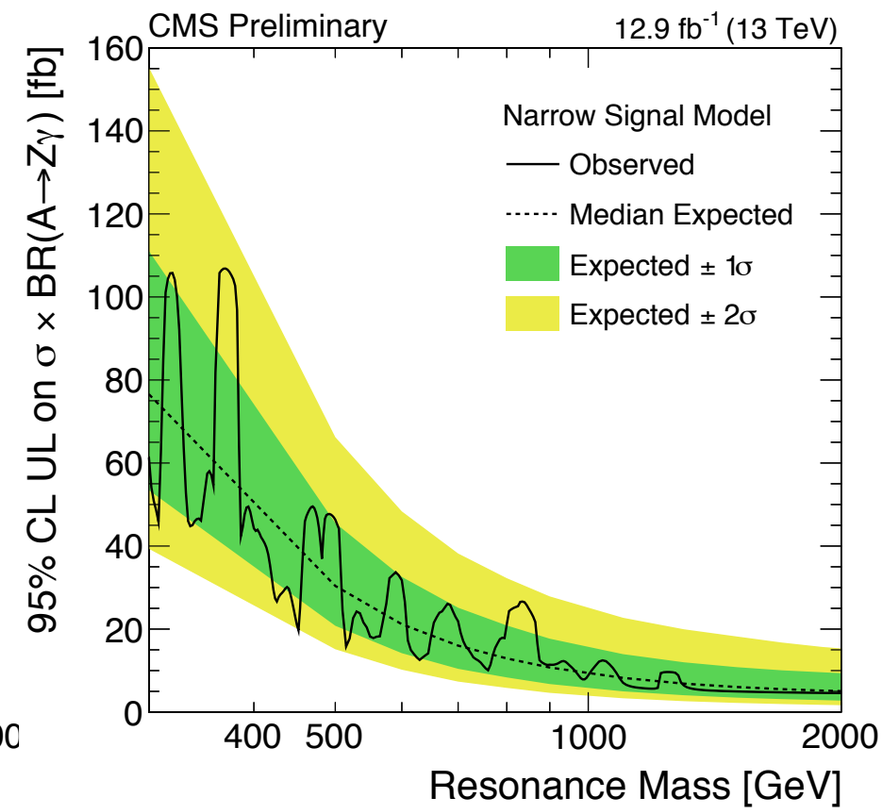
eeγ



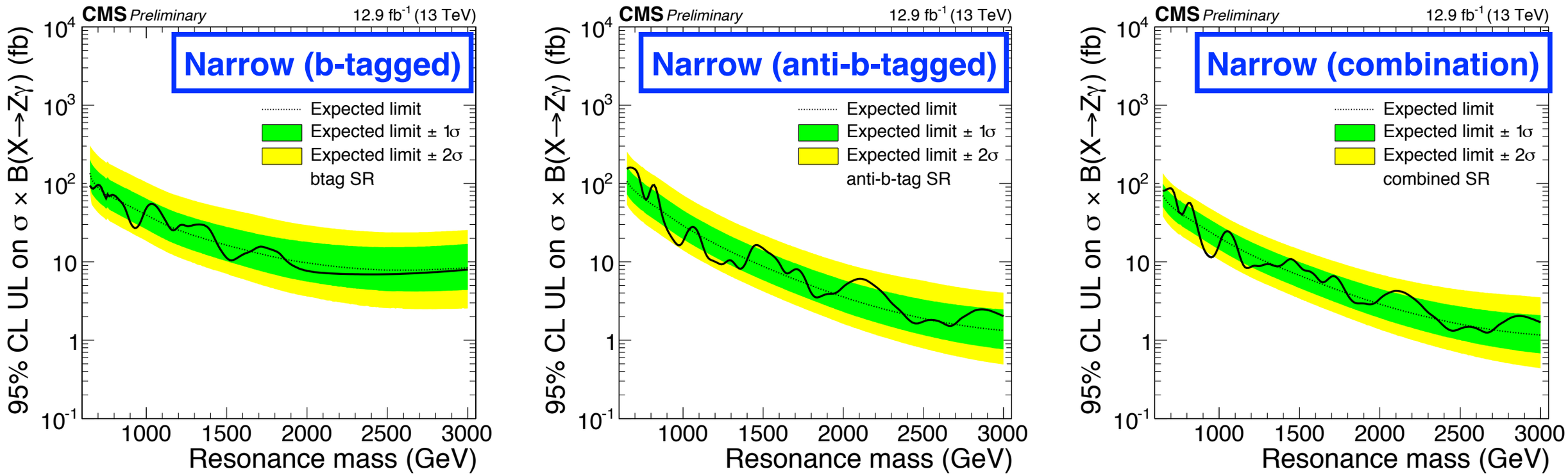
$\mu\mu\gamma$

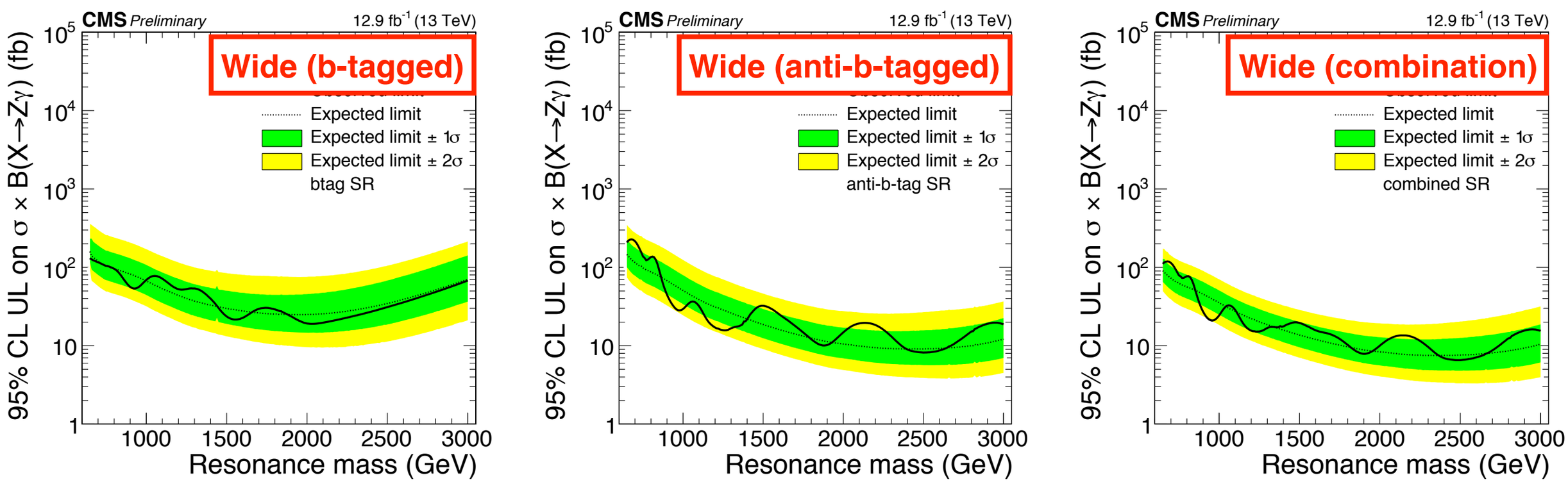


Combination

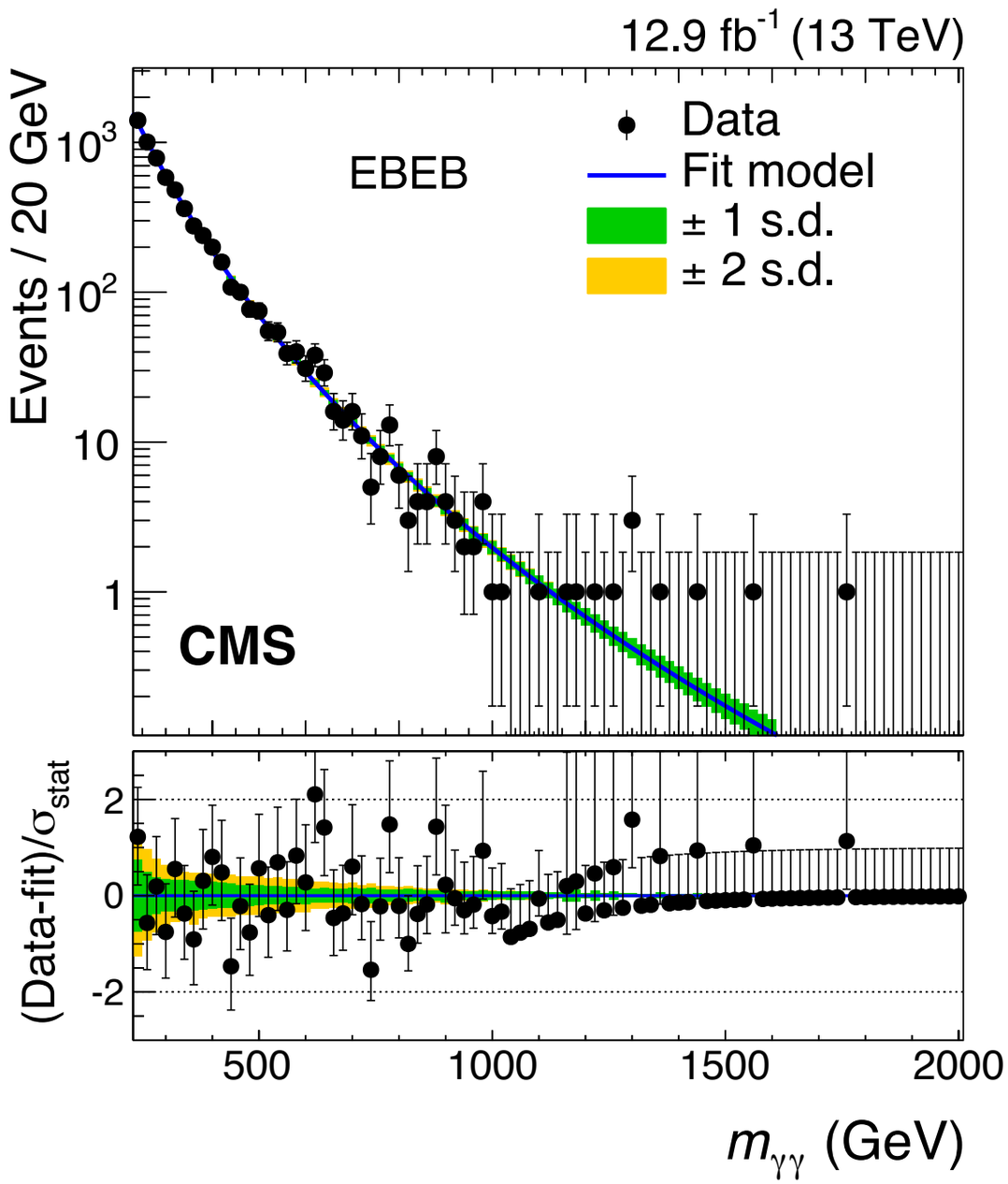


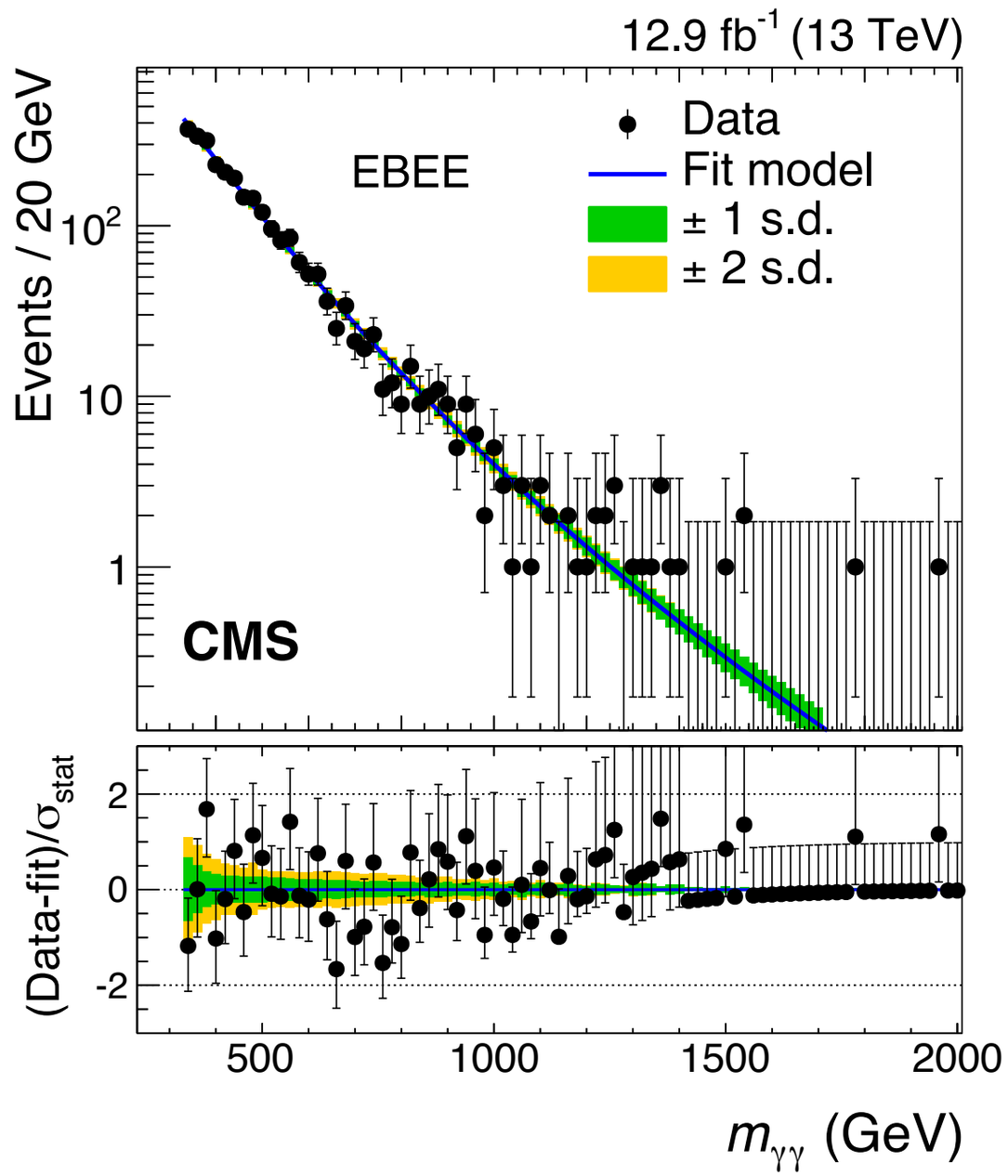
Limits: X → Z(qq)γ





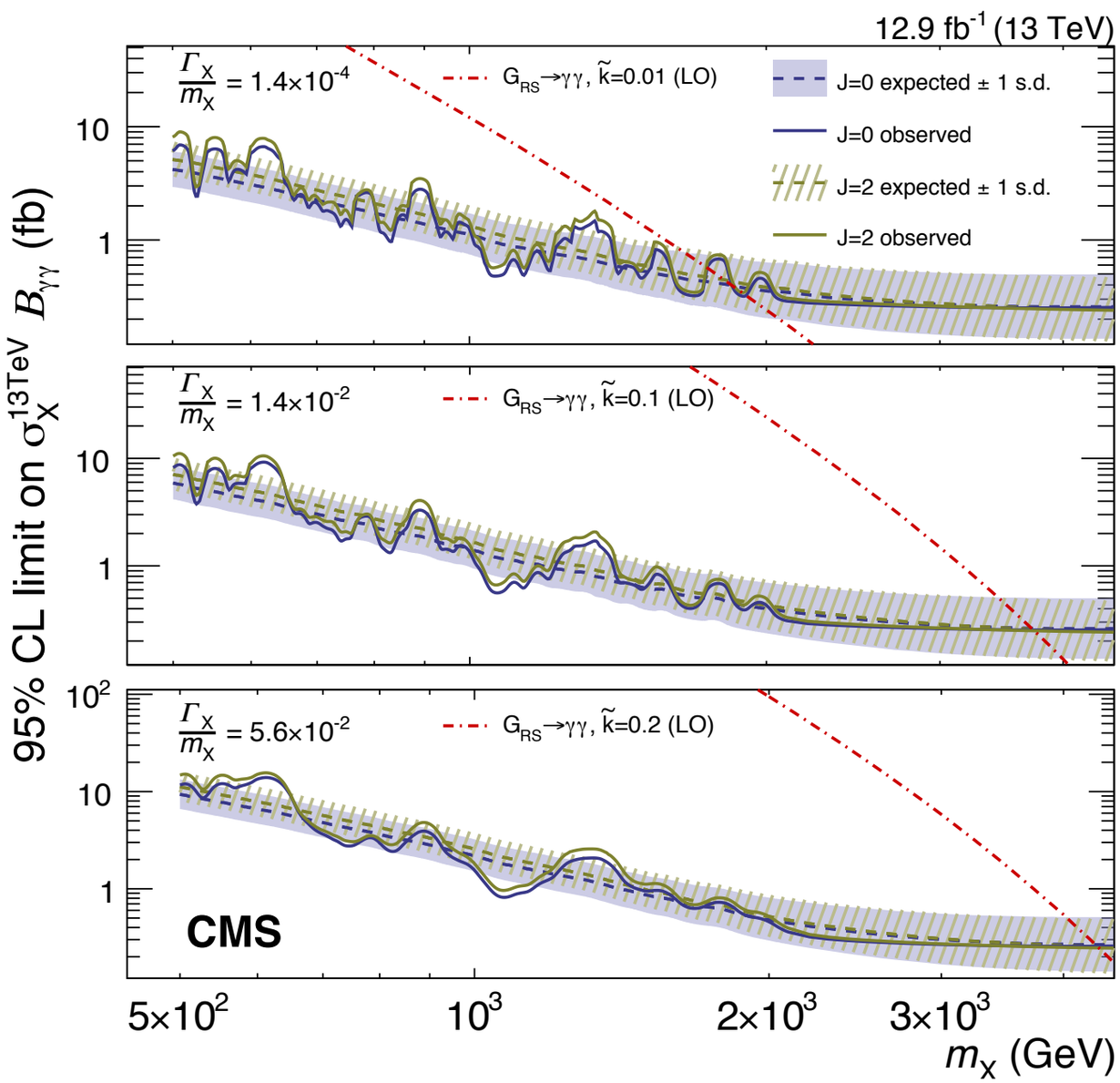
Invariant Mass Spectra: $X \to \gamma\gamma$



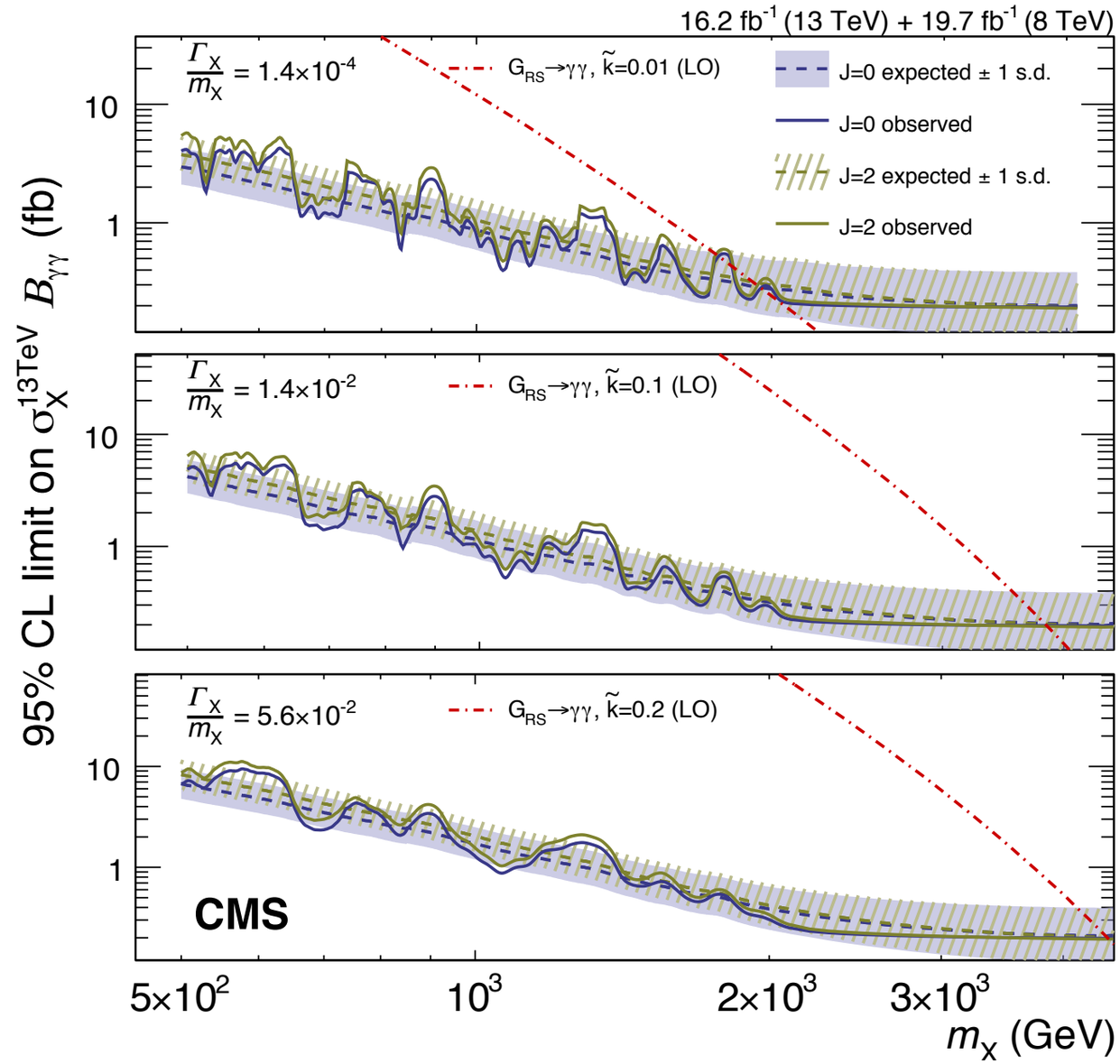


Limits: $X \to \gamma\gamma$

13 TeV (2016)



8 TeV + 13 TeV (2015 and 2016)



Conclusion

- Searches for new heavy scalars decaying to $Z\gamma$ / $\gamma\gamma$ have been performed at CMS
  - based on part of 2016 data (12.9 fb^{-1})
- No significant excess has been observed above the background only hypothesis so far
- All searches are working with full 2016 dataset and the updated results will be presented in near future. Stay tuned!

Backup

Systematics

- (O: considered, X: not)

	Z(ll)γ	Z(qq)γ	$\gamma\gamma$
Luminosity	6.2%	6.2%	6.2%
PDF	1%	2%	6%
Pileup		1%	
Trigger	4%	2%	
Efficiency	5%	32%	6%
e/γ energy scale and resolution	1%	1%	1%
μ momentum scale and resolution	5%		
Jet energy & mass scale and resolution		4%	