Search for new heavy resonances decaying in di-lepton or di-photon pairs at CMS

Giuseppe Fasanella

Overview

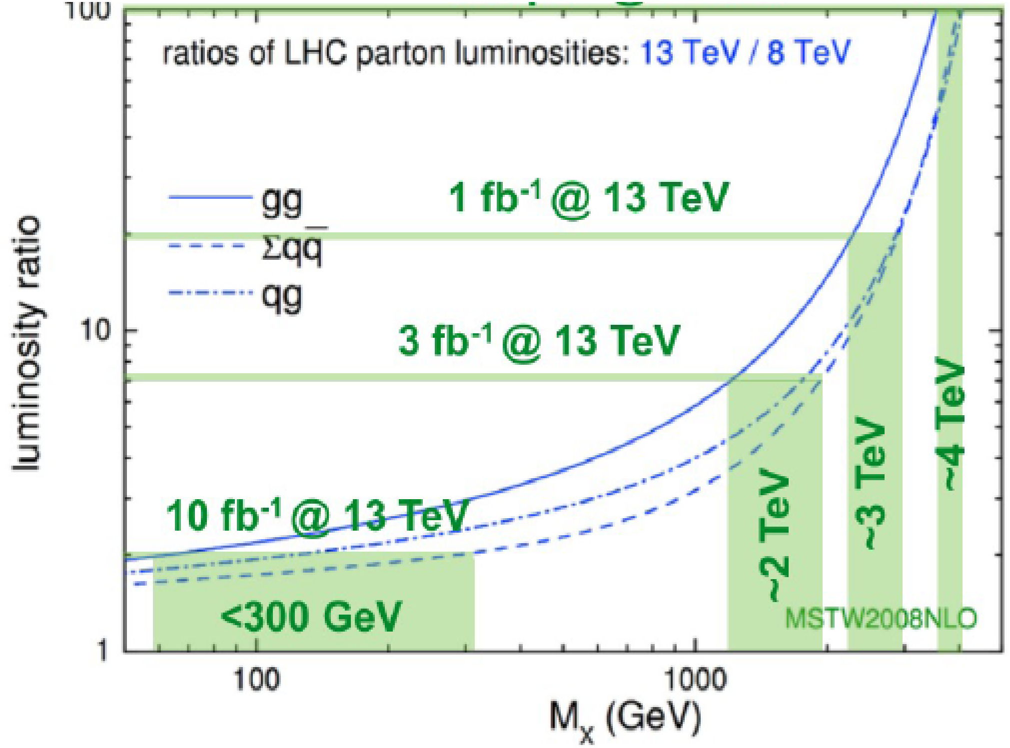
- **Introduction and motivation**
- **Di-electron channel** (most updated public results)
- **Di-photon channel** (most updated public results)
- **Conclusions**

Analyzed datasets:

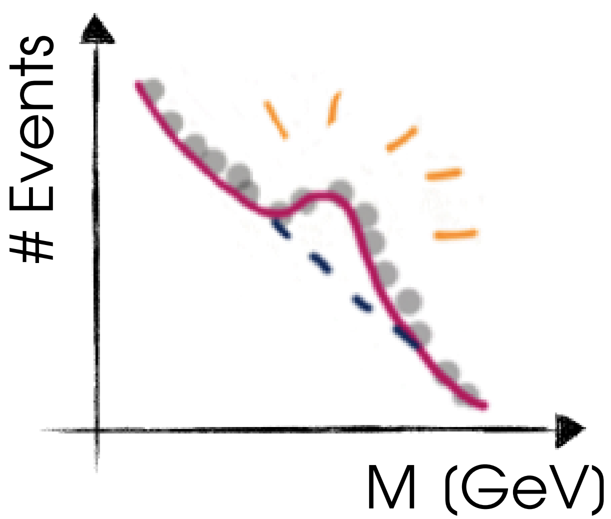
- **L=2.7 fb^{-1}** collected with **B=3.8 T**
- **L=0.6 fb^{-1}** collected with **B=0T** (diphoton channel only: first time in CMS)

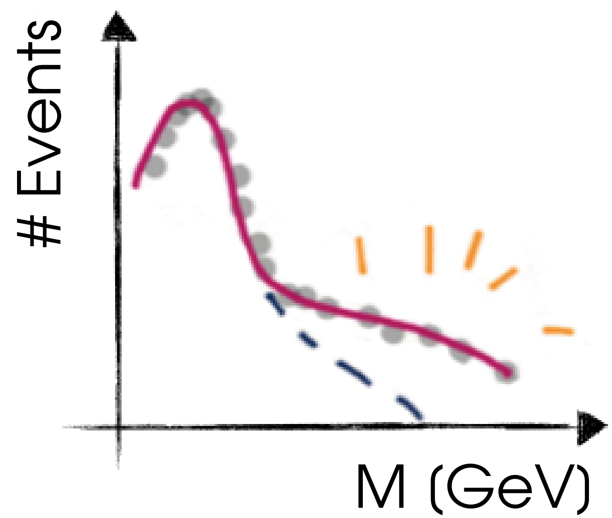
Introduction

- RUN2 brings LHC close to design:
  - Increase $\sqrt{s}$ to 13 TeV
  - exploit the parton luminosity ratio
- Dramatically increase discovery potential



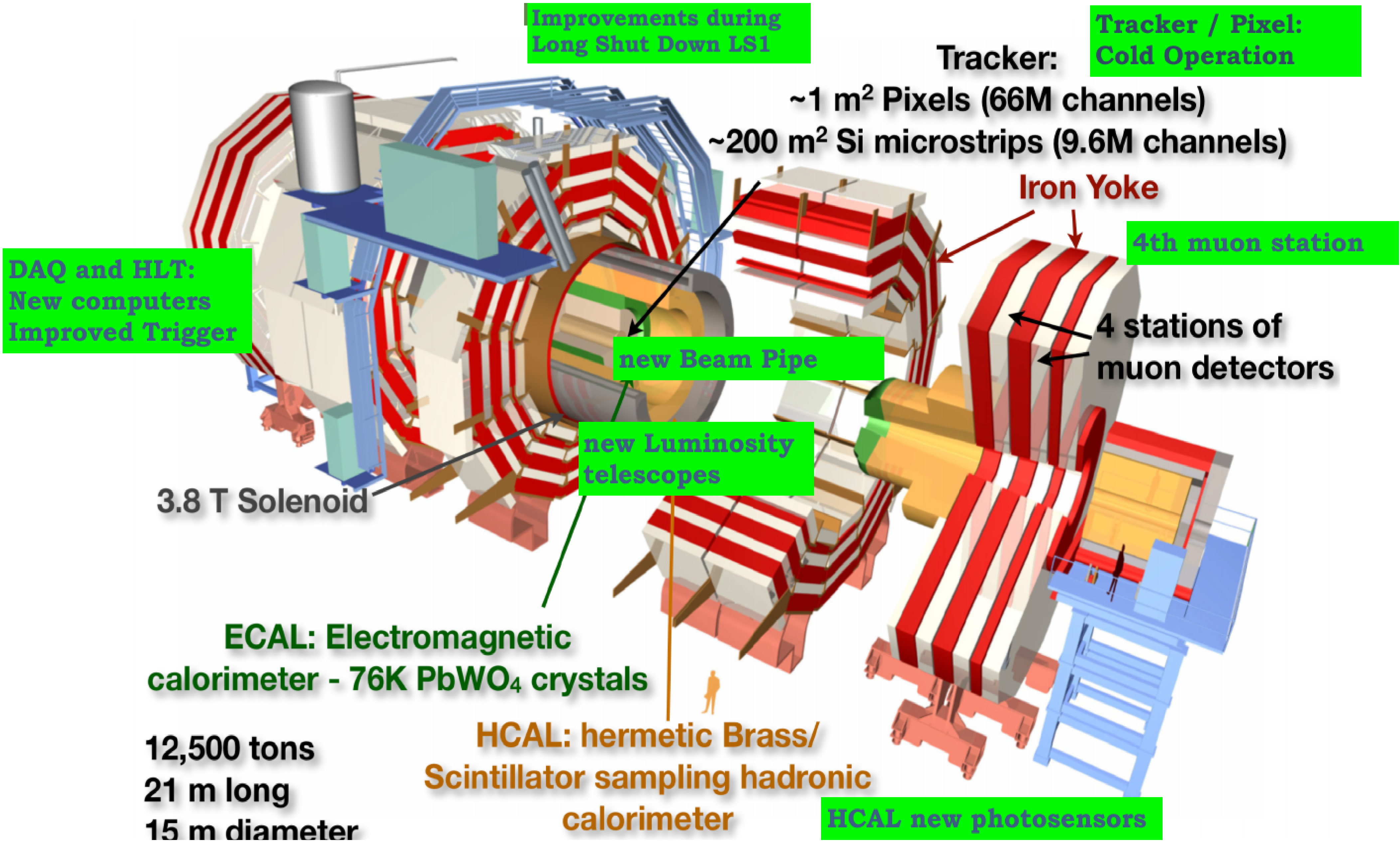
- **Two main experimental strategies:**
- Bumps over a continuous background
- Excesses in some kinematic distributions





→ Although small x-sections, channels w/ leptons and photons provide the cleanest signature to discover new physics

CMS detector for Run2



Di-electron channel

Event Selection

- High energy electron pairs (**HEEP**) selection is used
- Cut-based selection designed to be highly efficient at high E_T
- Events categories: **Barrel-Barrel (BB)** or **Barrel-Endcap (BE)**
- The highest mass pair M_{ee} is selected

Variable	Barrel	Endcap
E_T	> 35 GeV	> 35 GeV
range	$\|\eta_{sc}\| < 1.4442$	$1.566 < \|\eta_{sc}\| < 2.5$
isEcalDriven	=1	=1
$\|\Delta\eta_{in}^{seed}\|$	< 0.004	< 0.006
$\|\Delta\phi_{in}\|$	< 0.06	< 0.06
H/E	<1/E + 0.05	< 5/E + 0.05
$\sigma_{i\ i}$	n/a	<0.03
E^{2x5}/E^{5x5}	>0.94 OR E^{1x5}/E^{5x5} > 0.83	n/a
EM + Had Depth 1 Isolation	<2+0.03*Et +0.28*rho	<2.5 +0.28*rho for Et<50 else
		<2.5+0.03*(Et-50) +0.28*rho
Track Isol: Trk Pt	<5	<5
Inner Layer Lost Hits	<=1	<=1
$\|dxy\|$	<0.02	<0.05

Mass resolution & ID efficiency

- Mass resolution: data/MC discrepancy at the Z peak + MC contribution at higher mass

↓

  - **EB-EB**: Mass resolution ~ **1.3 % for M_{ee} > 2 TeV**
  - **EB-EE**: Mass resolution ~ **1.8 % for M_{ee} > 2 TeV**

- ID efficiency: Scale factors for data and MC are studied using **tag and probe method** using DY events

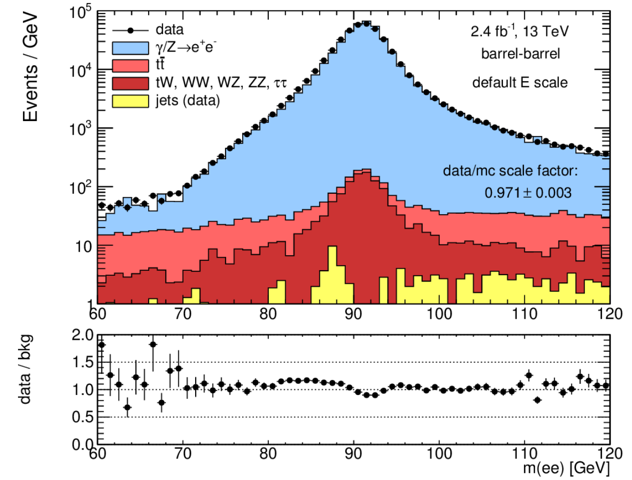
↓

close to 1 and flat vs E_T

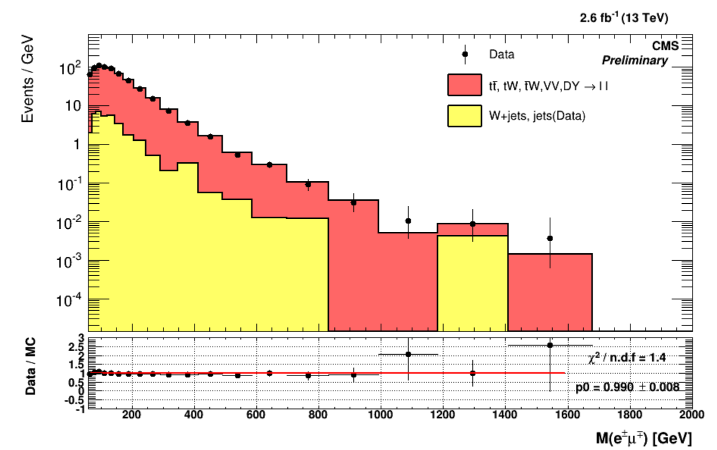
Z' to di-electron: backgrounds

Three main types of SM backgrounds (BG) in the di-electron channel

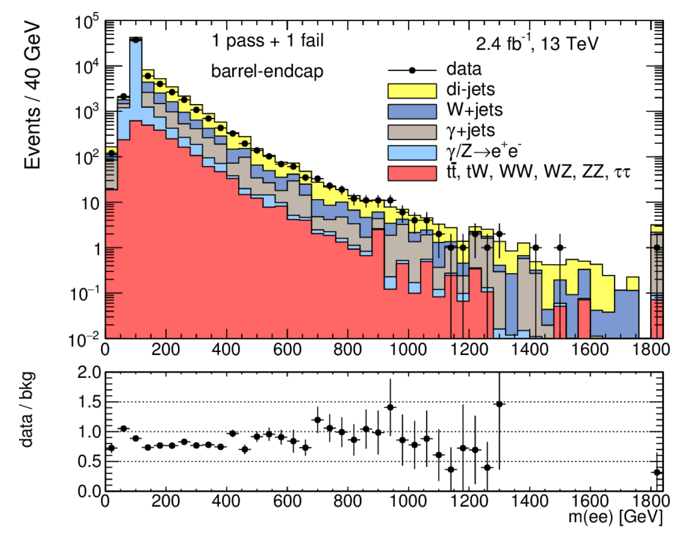
- The most significant one is the irreducible **SM Drell-Yan** (DY) process
  - Backgrounds predicted using Powheg-pythia8



- The second most important BG comes from **real electrons** in processes with W and Z bosons involved
  - **WW**
  - **tt** (but self-vetoing due to the top boost at high energy)
  - tW, WZ, ZZ, $Z/\gamma^* \rightarrow \tau\tau$
  - These processes are **flavor-symmetric:**
  - Confirm the MC is well modeled by looking at the e-mu spectrum



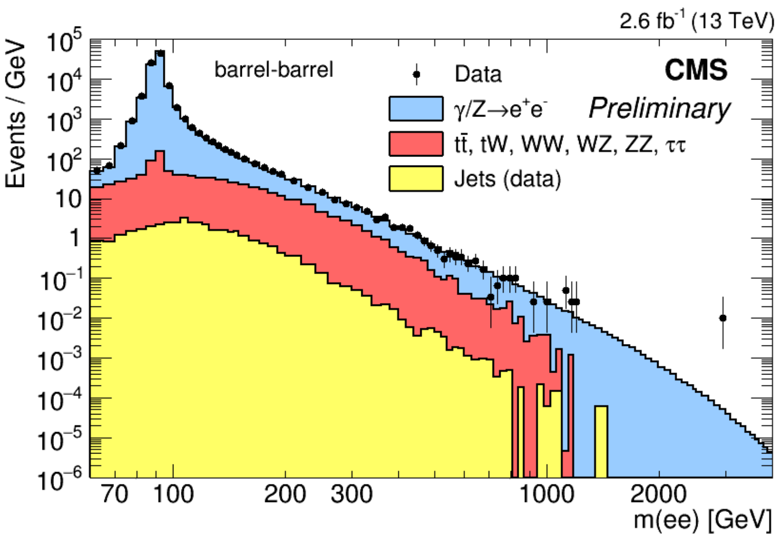
- The third type of background is the **jet background**, where one or more jet is misidentified as an electron (di-jets events, W + jets ...)
  - Estimated directly with data (**Fake Rate method**)

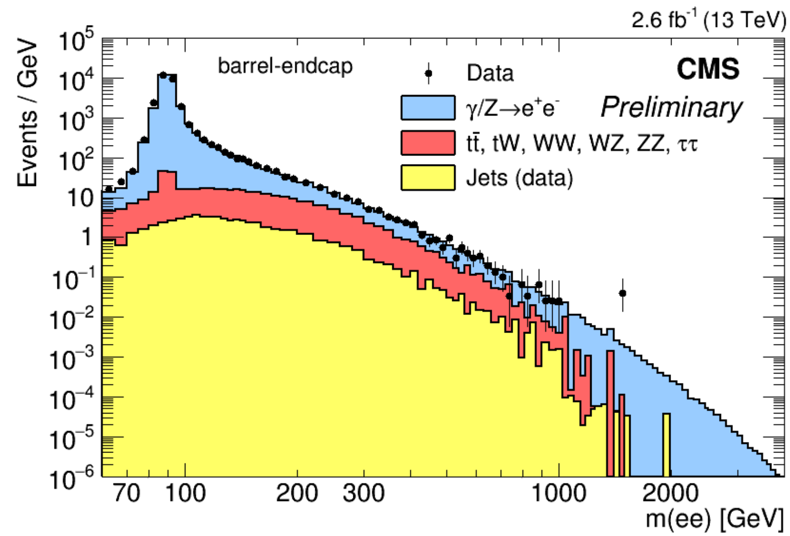


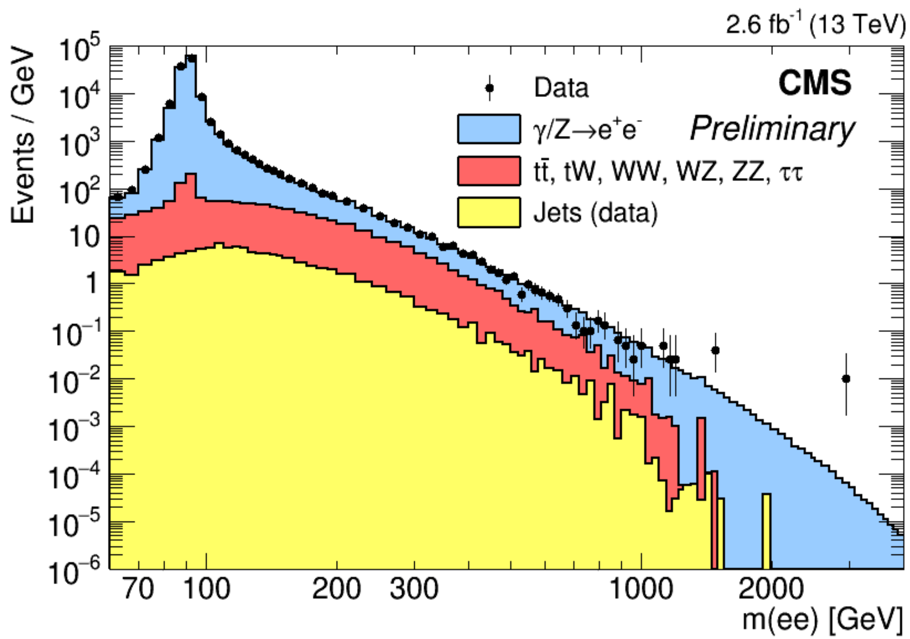
*Plots from **CMS-EX0-15-005**

Mass spectra

- (Data -background)/background is consistent with 0



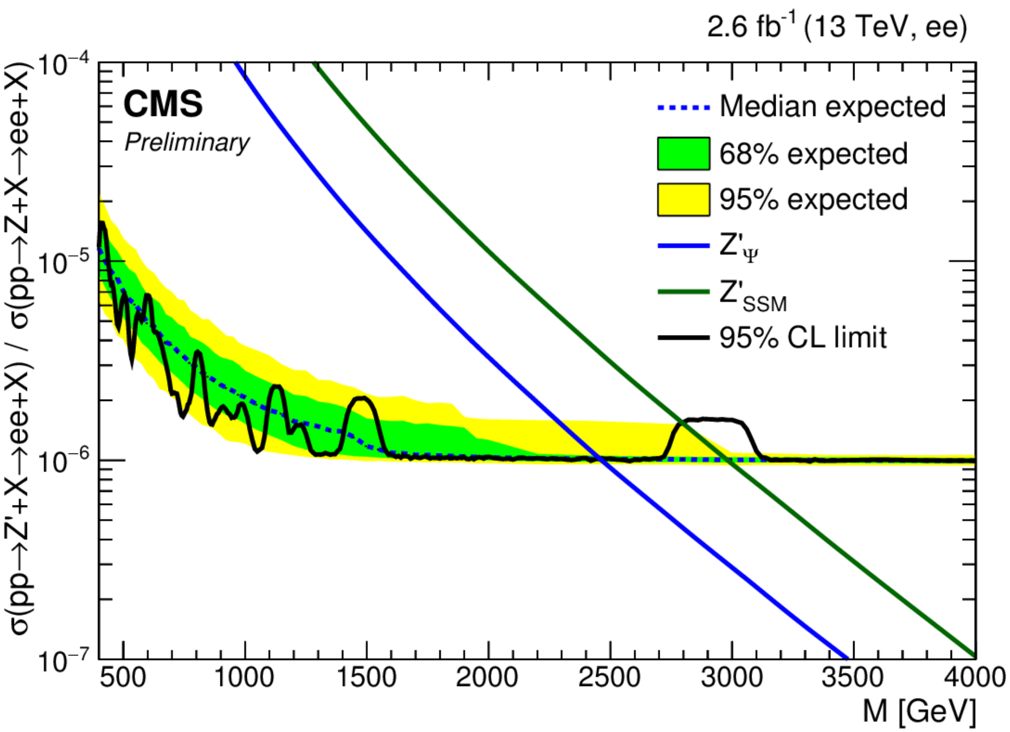


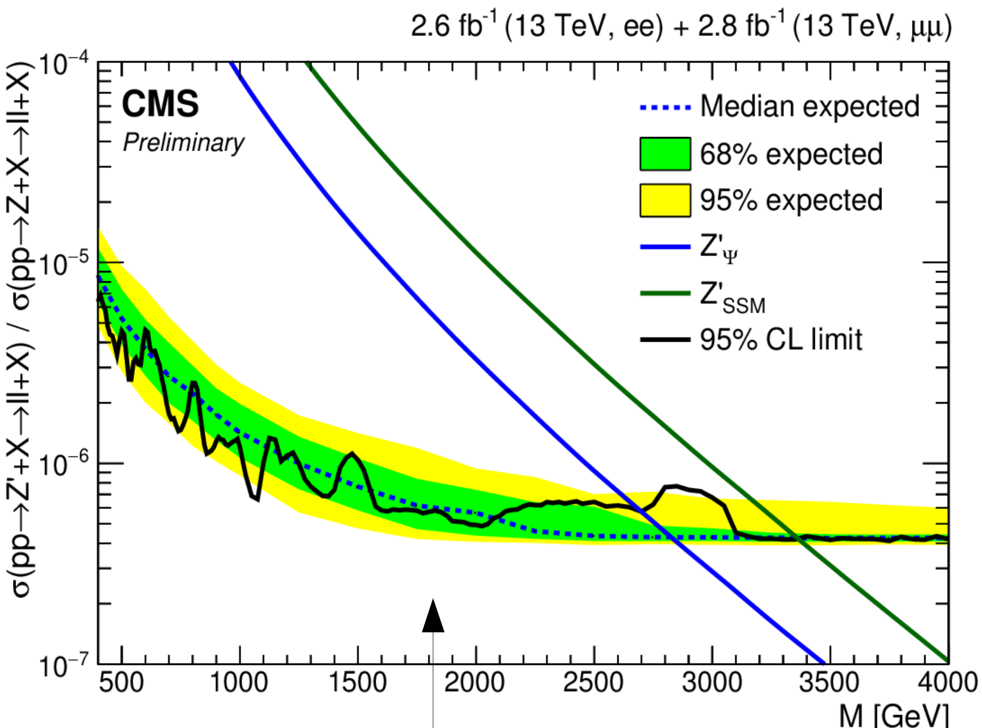


*Plots from **CMS-EX0-15-005**

Limits

- **Bayesian** unbinned likelihood with a flat prior for the signal cross-section and log-normal priors for signal and bkg uncertainties
- The integration is doing via the Metropolise-Hasting algorithm





Combined with di-muon channel

*Plots from **CMS-EX0-15-005**

Di-photon channel

Analysis strategy

- Select events with two photons of **p_T> 75 GeV**
- Photons are required to pass a dedicated photon ID with isolation:
- B= 3.8 T **L=2.7 fb^{-1}**: 90% efficiency
- B= 0T **L=0.6 fb^{-1}** : 80% (EB) – 70% (EE) efficiency (less efficient electron-veto)

- Split events in categories: **(EB-EB, EB-EE) x (3.8 T, 0 T)**
- Search region: $M\gamma\gamma$ > 500 GeV (background fits start below)

- Results interpreted for 3 widths and 2 resonance spin hypothesis scenarios

Data-driven methods:
- Efficiency scale factors from $Z \rightarrow ee$ with TP technique
- Energy scale and resolution corrections

Vertex selection

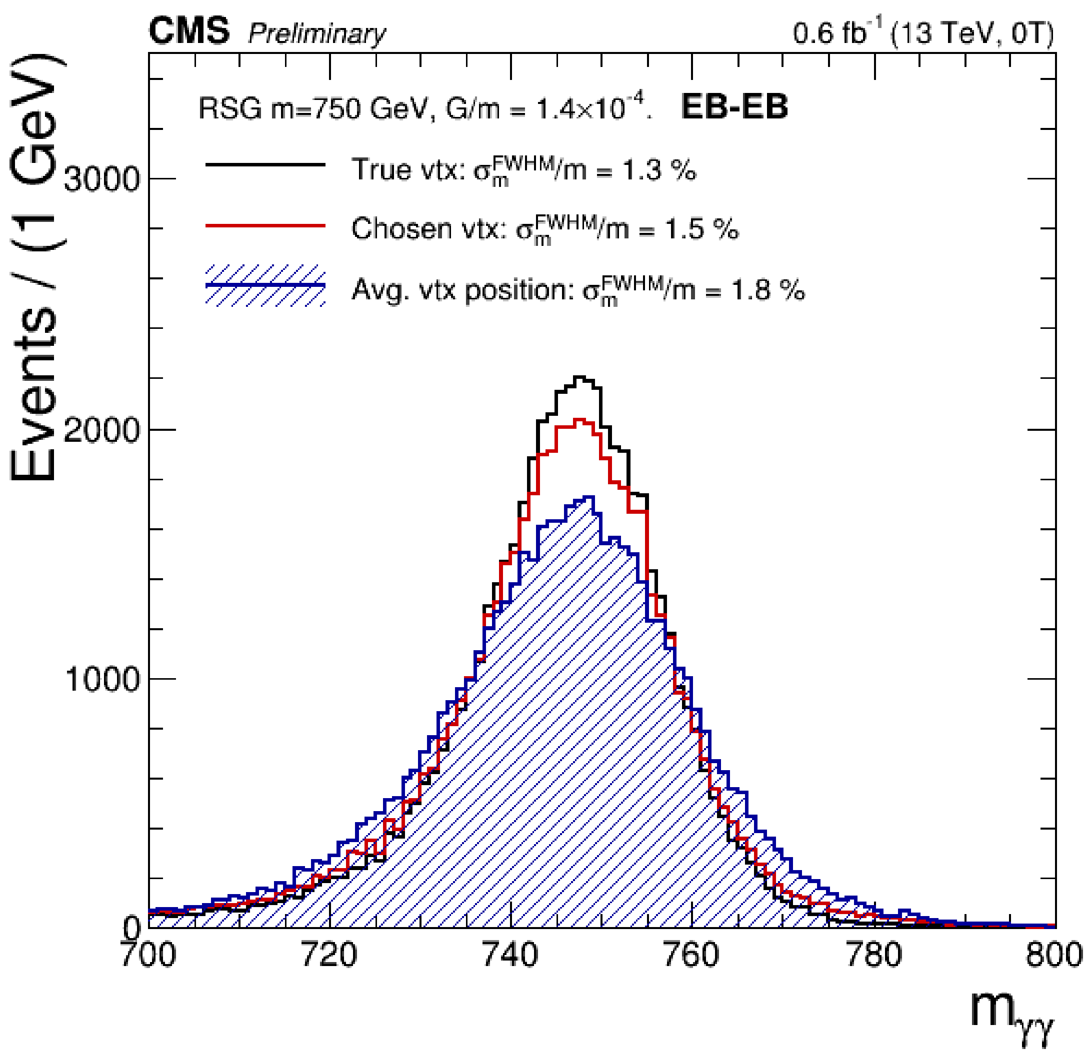
@ 3.8 T:

- $H \rightarrow \gamma\gamma$ BDT vertex is used

@ 0 T:

New algorithm needed

- Vertex selected with the highest track multiplicity (robust approach)
- Alternative methods tested

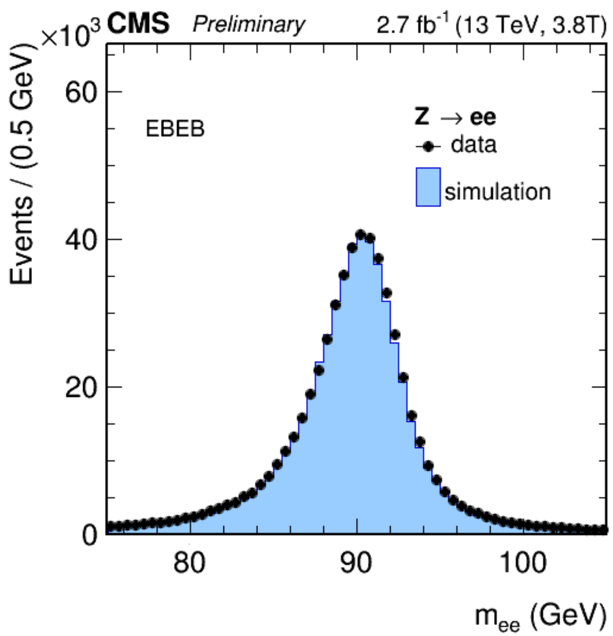


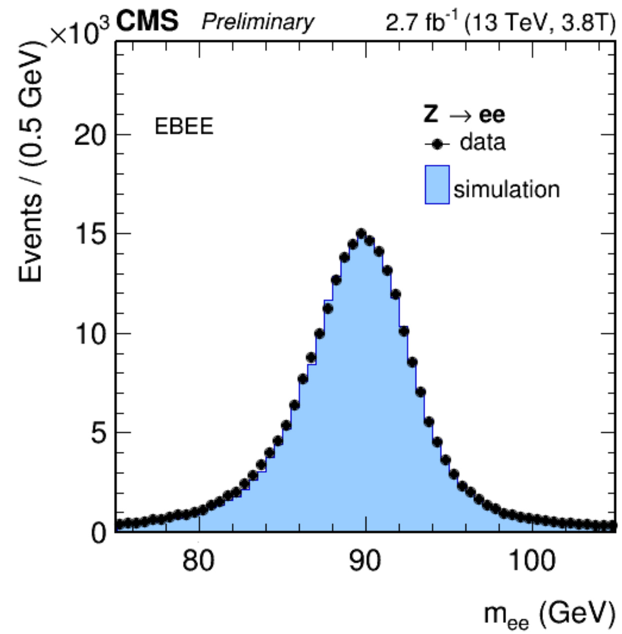
*Plot from **CMS-EX0-16-018**

Energy corrections

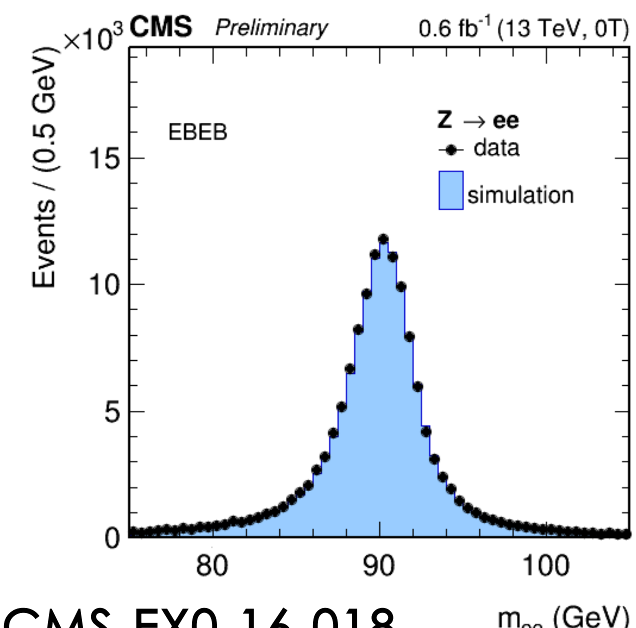
MC used as a **template** to fit the data

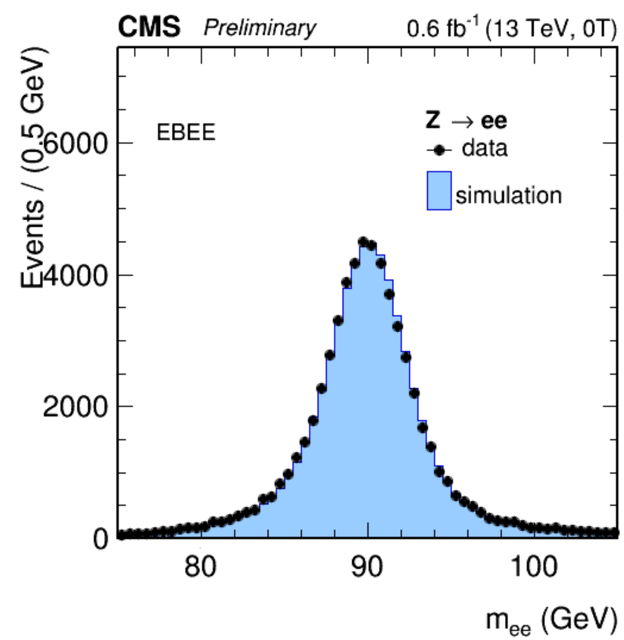
3.8 T





0 T

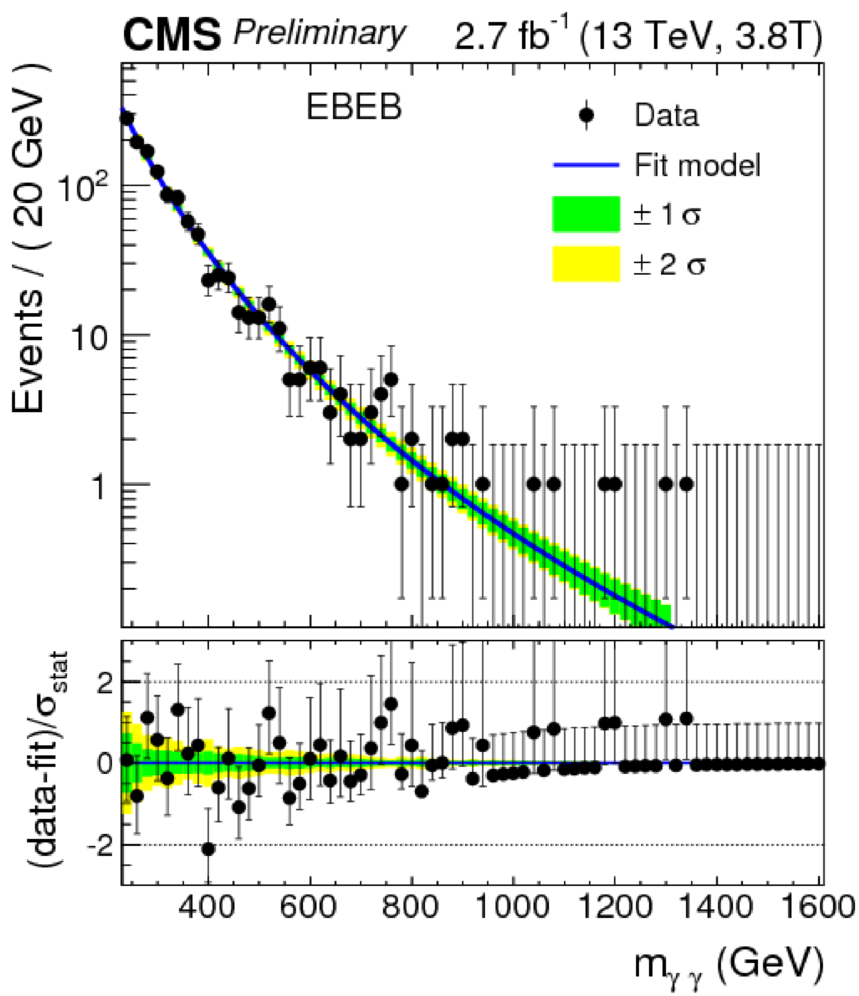


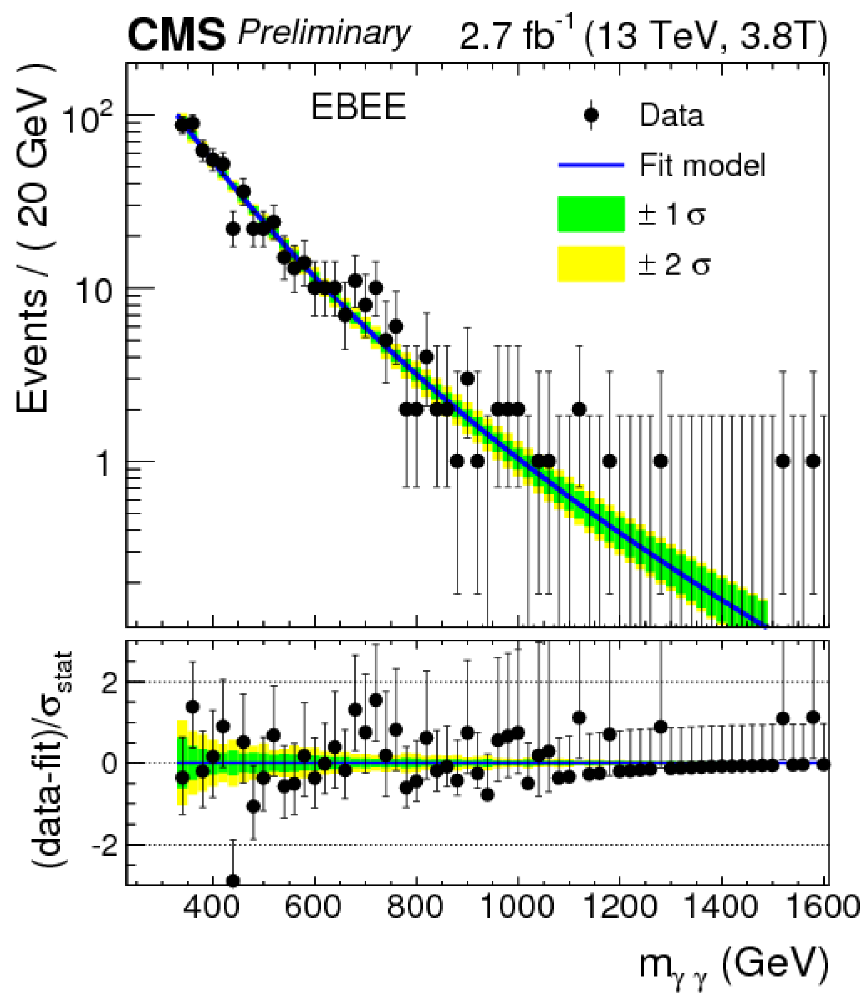


*Plots from **CMS-EX0-16-018**

Mass spectra @ B=3.8 T

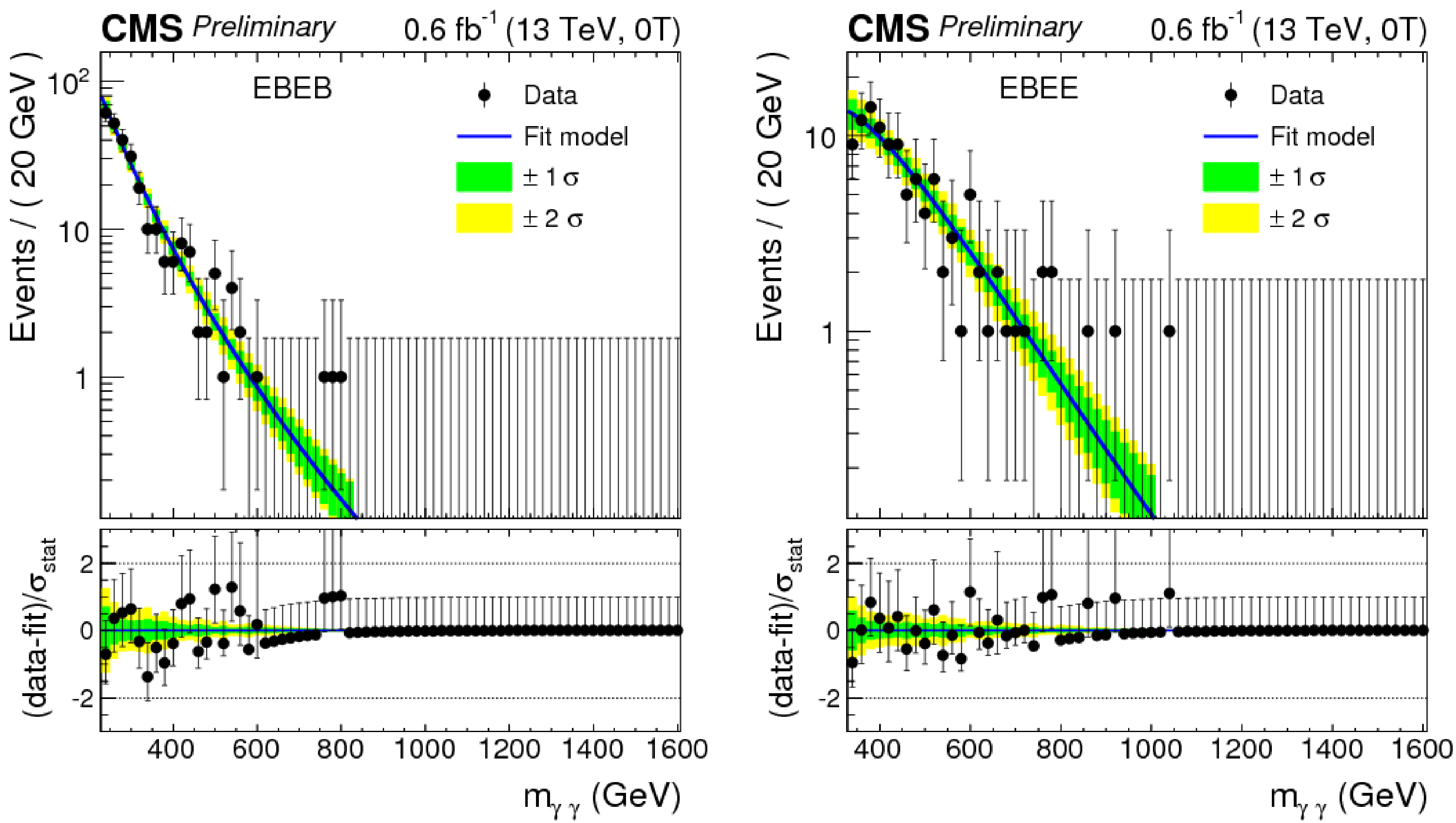
$$f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\cdot\log(m_{\gamma\gamma})}$$





*Plots from **CMS-EX0-16-018**

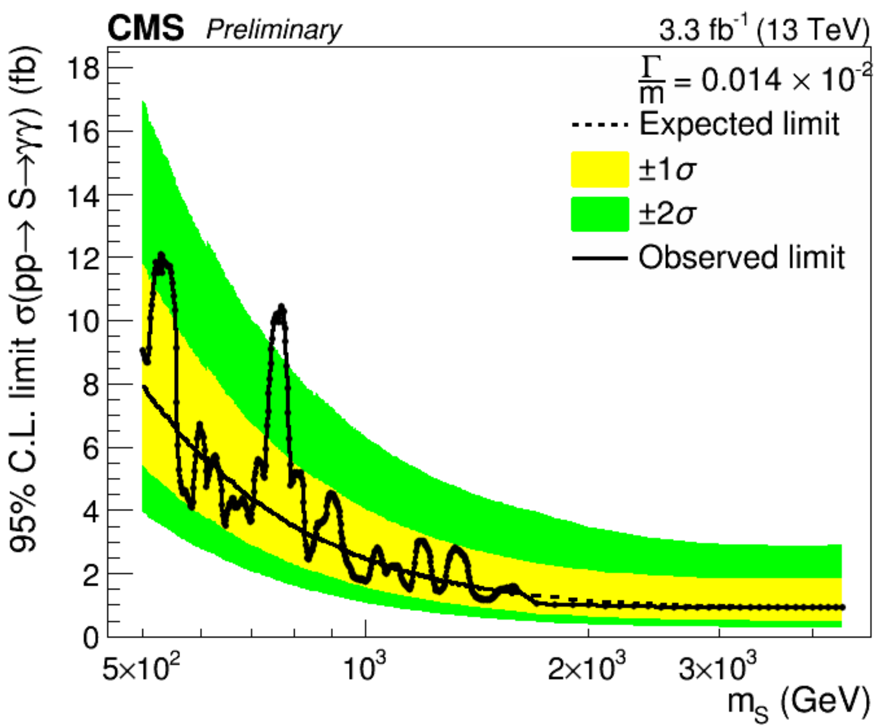
Mass spectra @ B=0 T



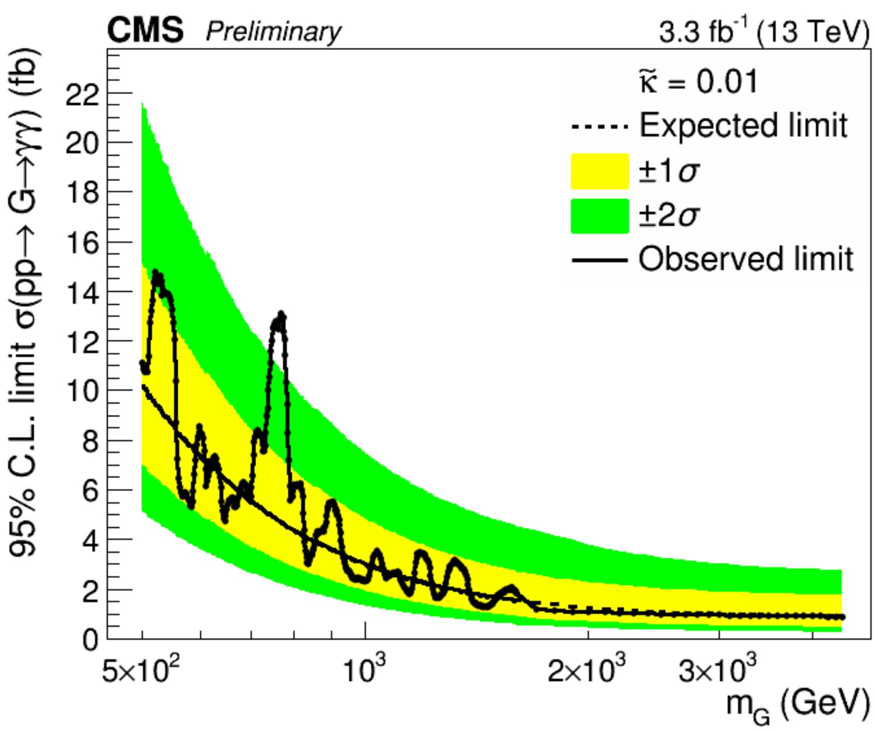
*Plots from **CMS-EX0-16-018**

Exclusion Limits: (3.8 T + 0 T)

- 10% improvement in sensitivity adding 0T



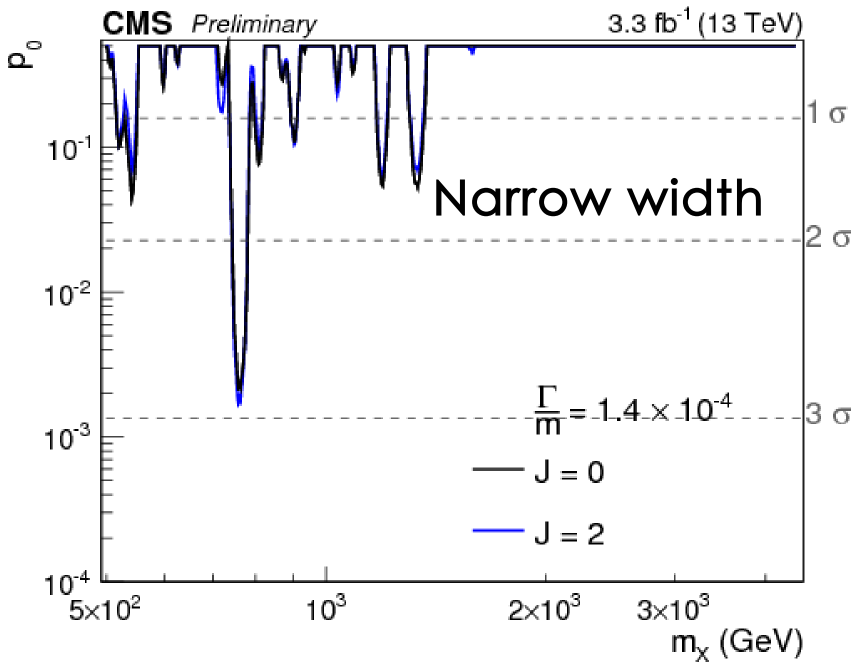
Spin 0; Narrow width

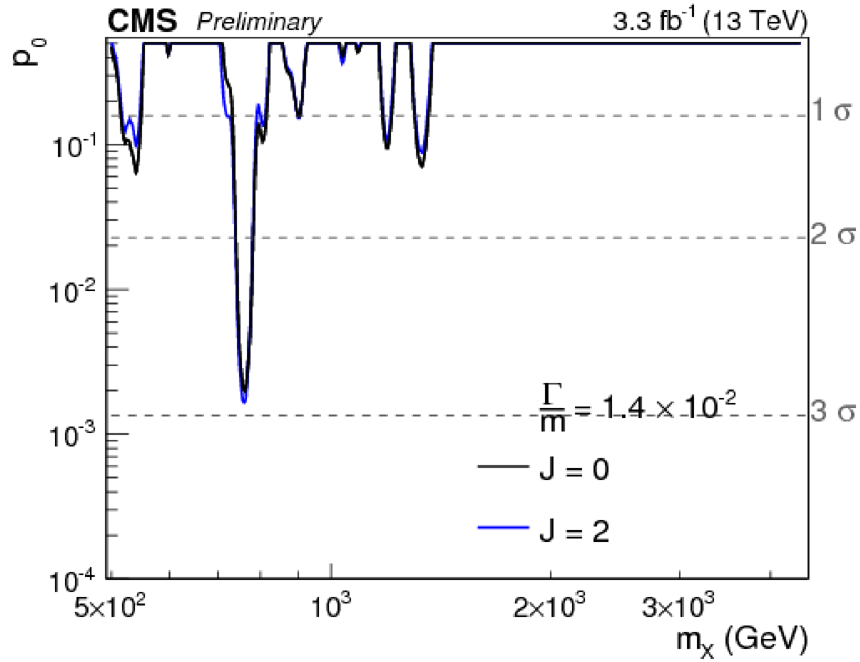


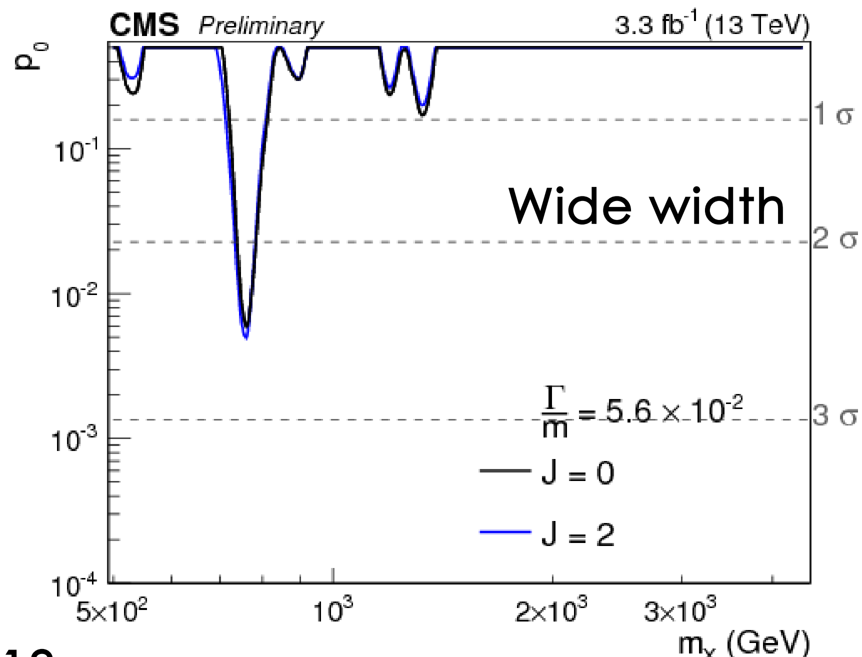
Spin 2; Narrow width

*Plots from **CMS-EX0-16-018**

p values @ (3.8 T + 0 T)







→ Global significance < 1 σ

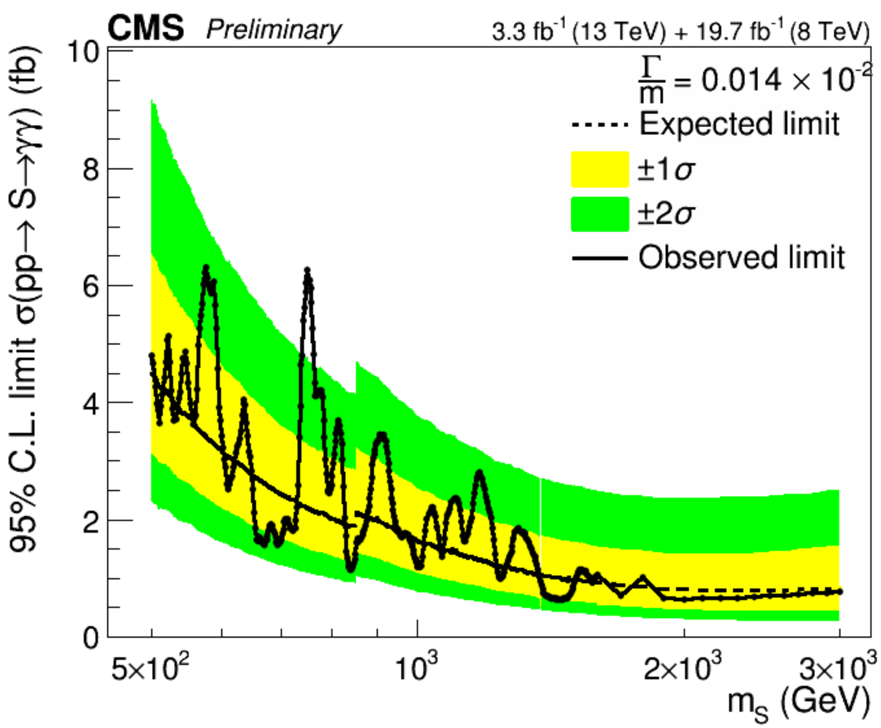
*Plots from **CMS-EX0-16-018**

Combination with 8 TeV results*

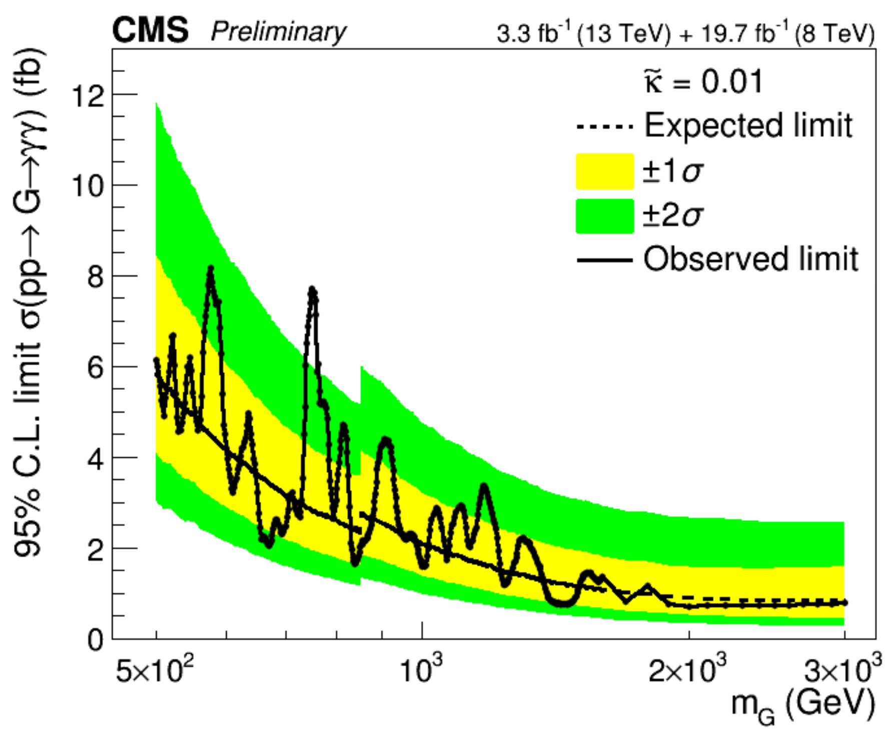
* Taking the **most sensitive result from 2 different analyses**:
HIG 14-006, Phys Lett B 750 (2015) 494-519 (for M<850 GeV)
EXO 12-045 for M> 850 GeV

Exclusion Limits @ (13 TeV + 8 TeV)

- Largest excess @ ~750 GeV



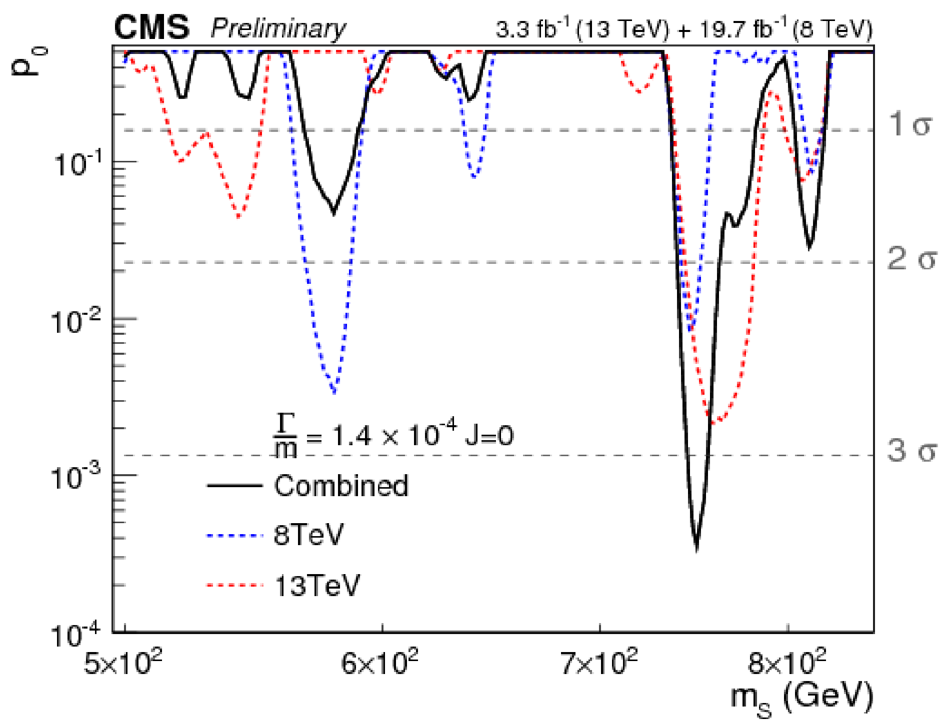
Spin 0; Narrow width

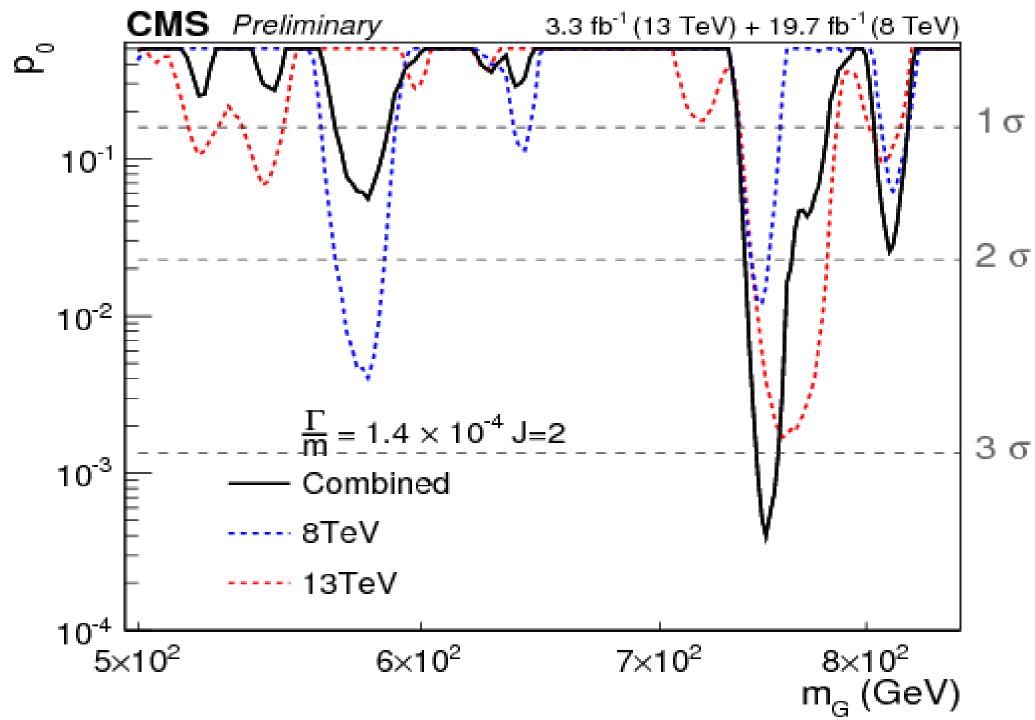


Spin 2; Narrow width

*Plots from **CMS-EX0-16-018**

p value comparison (13 TeV, 8 TeV)





→ global significance ~ 1.6 σ

*Plots from **CMS-EX0-16-018**

Summary

Di-lepton channel @ 13 TeV:
No relevant excess observed over the SM-only hypothesis. Exclusion limits set up-to ~ 3.5 TeV

Di-photon channel @ 13 TeV:
The largest excess observed @ 760 GeV for narrow width hypothesis: local p-value is ~2.8-2.9 σ (global p-value < 1 σ)

Di-photon channel @ 13 TeV + 8 TeV:
The largest excess observed @ ~750 GeV for $\Gamma/m = 1.4 \times 10^{-2}$ hypothesis: local p-value ~3.4 σ (global p-value ~ 1.6 σ)

back-up

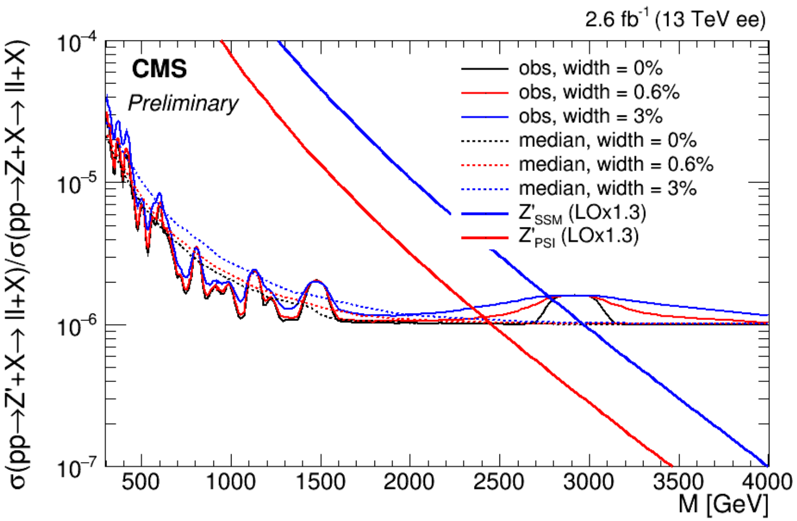
Systematic uncertainties (Z' → ee)

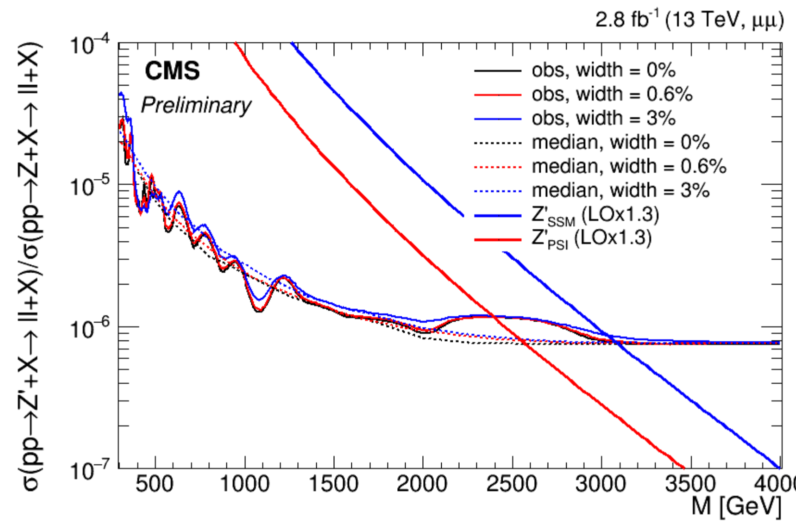
- Results are presented as a ratio of cross sections at high mass to those at the Z

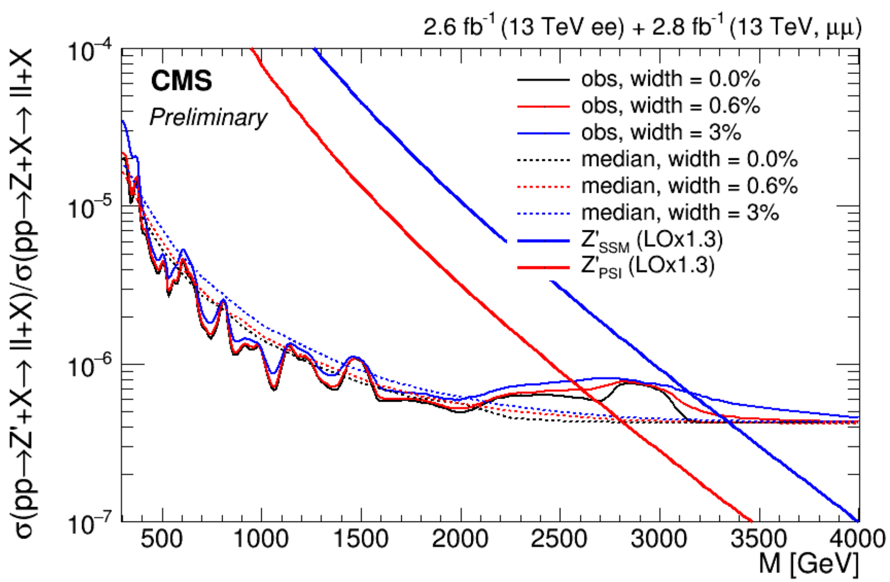
The **main sources** of systematic uncertainty are:

- **Electron ID** at high energy (assign 4%(Barrel) -6%(Endcap) per lepton)
- **PDF uncertainties** (mass dependent) from 6% to 20% up to 3 TeV
- **Energy scale uncertainties**: 2%
- The jet background uncertainty is 50% and the non DY BG is 7%
- Normalization at the Z peak ~ 2%

Limits
(different widths considered)







*Plots from **CMS-EX0-15-005**

photon ID

3.8 T

photon category	Iso_{Ch} cut (GeV)	Iso_γ cut (GeV)	H/E cut	$\sigma_{i\eta i\eta}$ cut
$\eta_{SC} < 1.4442$ non-sat.	5	2.75	5×10^{-2}	0.0105
$\eta_{SC} < 1.4442$ sat.	5	2.75	5×10^{-2}	0.0112
$\eta_{SC} > 1.566$ non-sat.	5	2.0	5×10^{-2}	0.028
$\eta_{SC} > 1.566$ sat.	5	2.0	5×10^{-2}	0.030
conversion-safe electron veto applied for all categories				

0 T

	EB	EE
Iso_γ (GeV)	< 3.6	< 3
N_{Trk}	< 4	< 4
$\sigma_{i\eta i\eta}$	< 0.0106	< 0.028
$\sigma_{i\phi i\phi}$	< 0.0106	< 0.028
$N_{missing\ hits}$	> 1	> 1

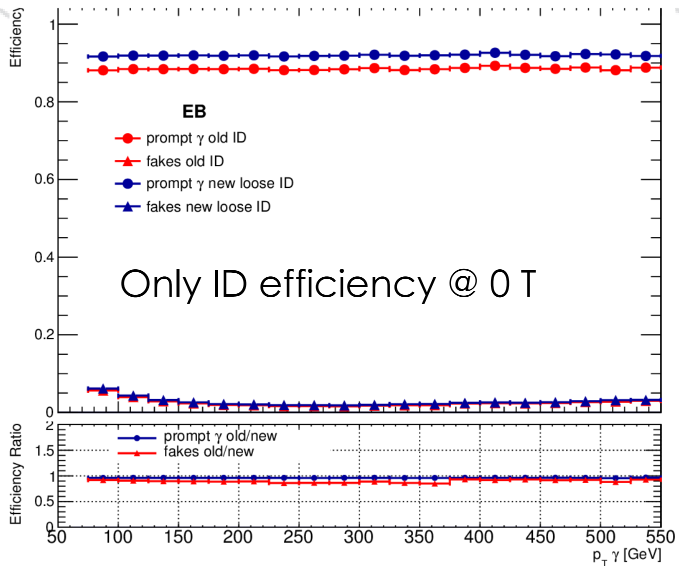
$ISO\gamma = \Sigma E_T$ of photons inside a cone ($\Delta R < 0.3$)

N_{trk} = number of tracks inside a cone ($\Delta R < 0.3$)

$\sigma_{i\eta i\eta}$ = shower transverse width along η

$\sigma_{i\Phi i\Phi}$ = shower transverse width along Φ

$N_{missing\ hits}$ (electron veto)

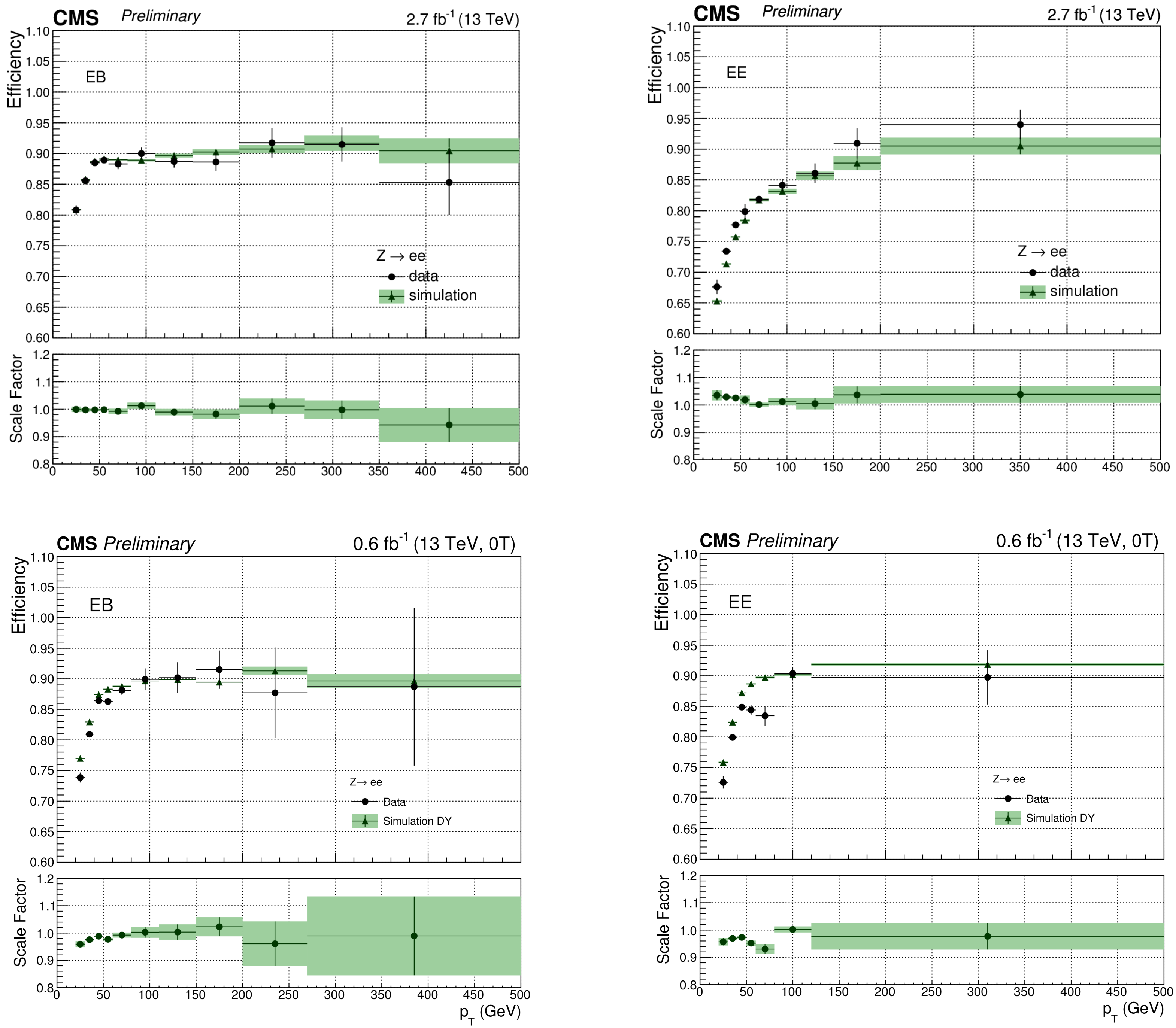


*Plots from CMS-EX0-16-018

ID efficiency

3.8 T

0 T



Interpretation

- Statistical interpration from simultaneous fit to Mγγ distribution in the 4 analysis categories: (EBEB, EBEE)x(3.8T, 0T)
- Background model: **parametric fit to data** → Possible mismodelling assessed with MC and accounted as "bias term"
- Signal model: interpolation of MC prediction (+ energy corrections and scale factors)
- **Spin-0** / **Spin-2** results interpretation, for 3 width hypotheses

Uncertainties related to possible background shape mismodeling

- Goodness of fit of background model assessed locally (as a function of $m_{\gamma\gamma}$) using MC
  - Study pull of predicted number of background events in several mass windows

$$p_i^j = \frac{N_{\hat{g}_i}^{w_j} - N_h^{w_j}}{\sigma(N_{\hat{g}_i}^{w_j})}$$

  - Model acceptable if
    b = |median(p)|<0.5 for all windows
  - If not, increase error by "bias term"

$$\tilde{p}_j^i = \frac{N_{\hat{g}_i}^{w_j} - N_h^{w_j}}{\sqrt{\sigma^2(N_{\hat{g}_i}^{w_j}) + \beta_I^2(w_j)}}$$

Stat. Uncertainty on the fit

Extra uncertainty ("bias term")

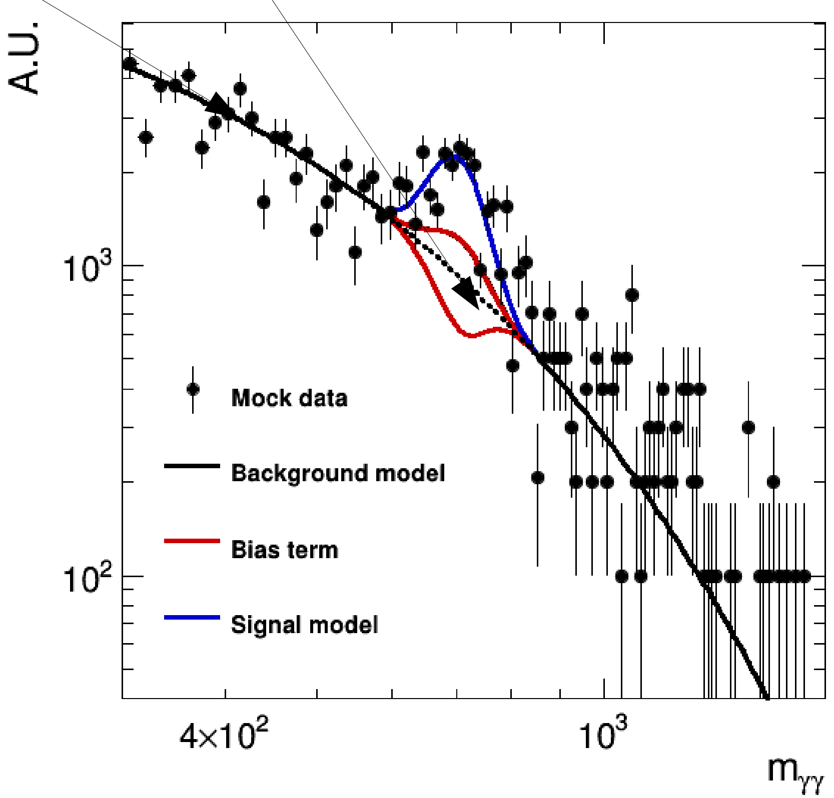
Modeling of the bias term

- Bias term included in hypothesis test adding a signal-like component to the background model

$$bkg(m_{\gamma\gamma}|\theta_{bias}) = N_{bkg}\cdot\left(\frac{N_{bkg}-\theta_{bias}}{N_{bkg}}bkg(m_{\gamma\gamma})+\frac{\theta_{bias}}{N_{bkg}}sig(m_{\gamma\gamma})\right)\cdot Gaus(\theta_{bias}|0,N_{bias})$$

  - Normalization of signal-like component constrained from result of bias study

$$N_{bias} = \int sig(m_{\gamma\gamma})\beta(m_{\gamma\gamma}) \sim FWMH(sig)\cdot\beta(m_G)$$



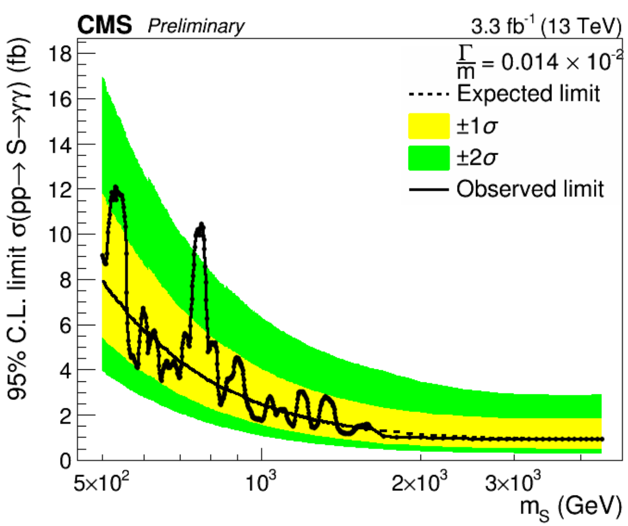
Systematic uncertainties

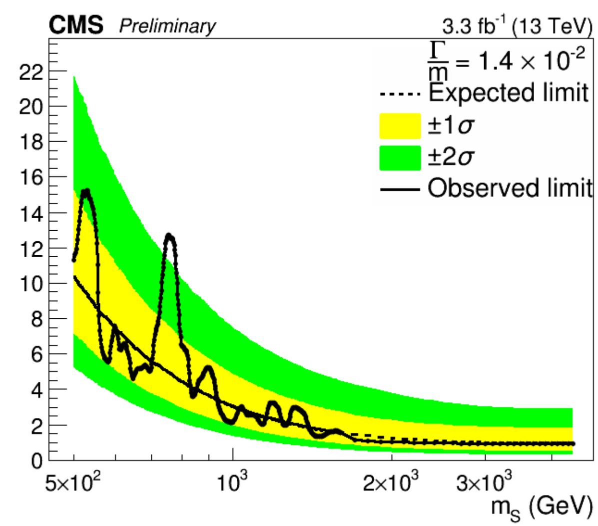
	Source	3.8T	0T	Correlation
Norm	PDFs	6%	6%	1
	Efficiency	8%	16%	0
	Luminosity	2.6%	12%	0
Shape	Energy scale EBEB	1%	1%	1
	Energy scale EBEE	1%	1%	1
	Energy scale difference	0%	1%	0
	Energy resolution EBEB	0.5%	0.5%	0
	Energy resolution EBEE	0.5%	0.5%	0

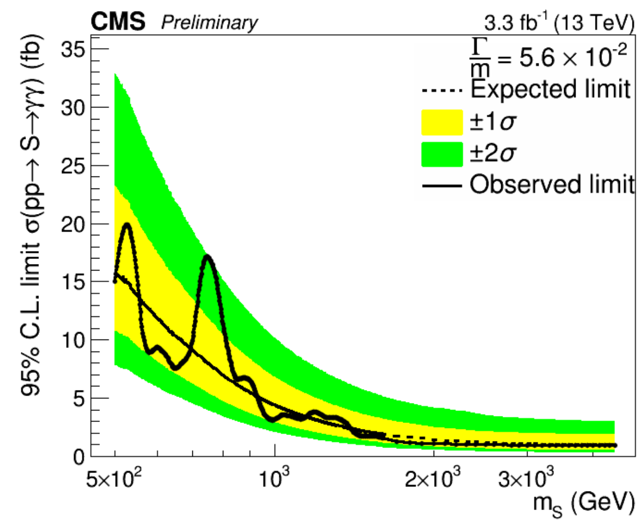
- The total uncertainty is dominated by the statistical one

Exclusion Limits: (3.8 T + 0 T)

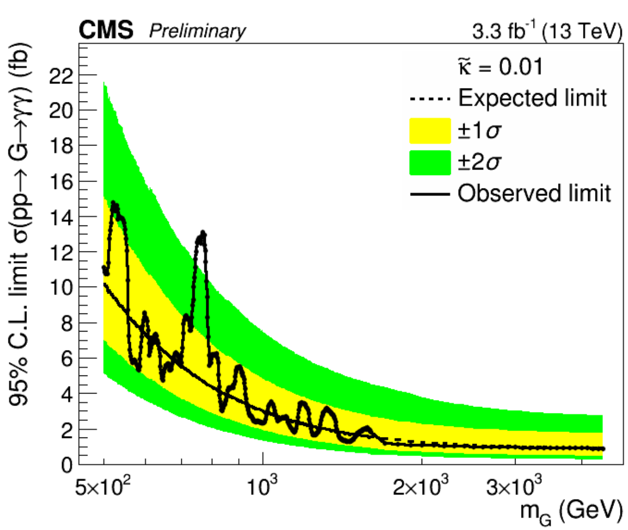
- 10% improvement in sensitivity adding 0T

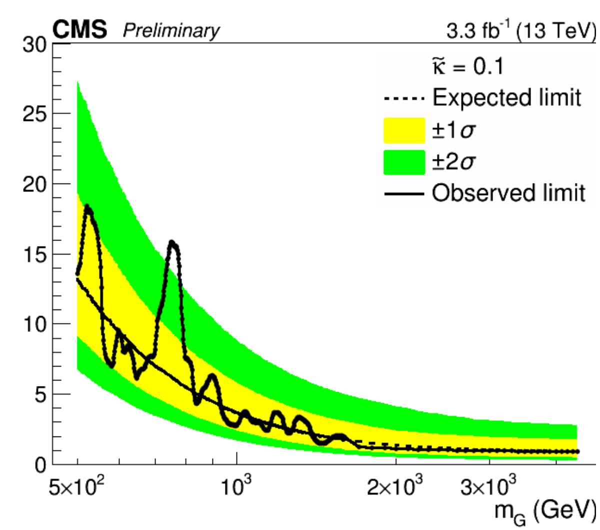


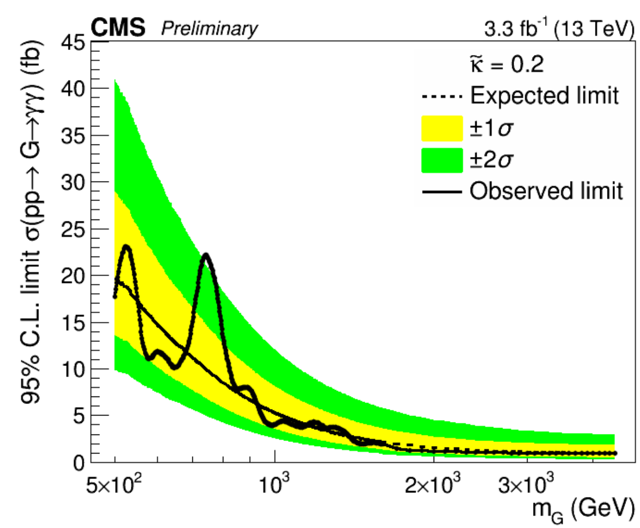




Spin 0







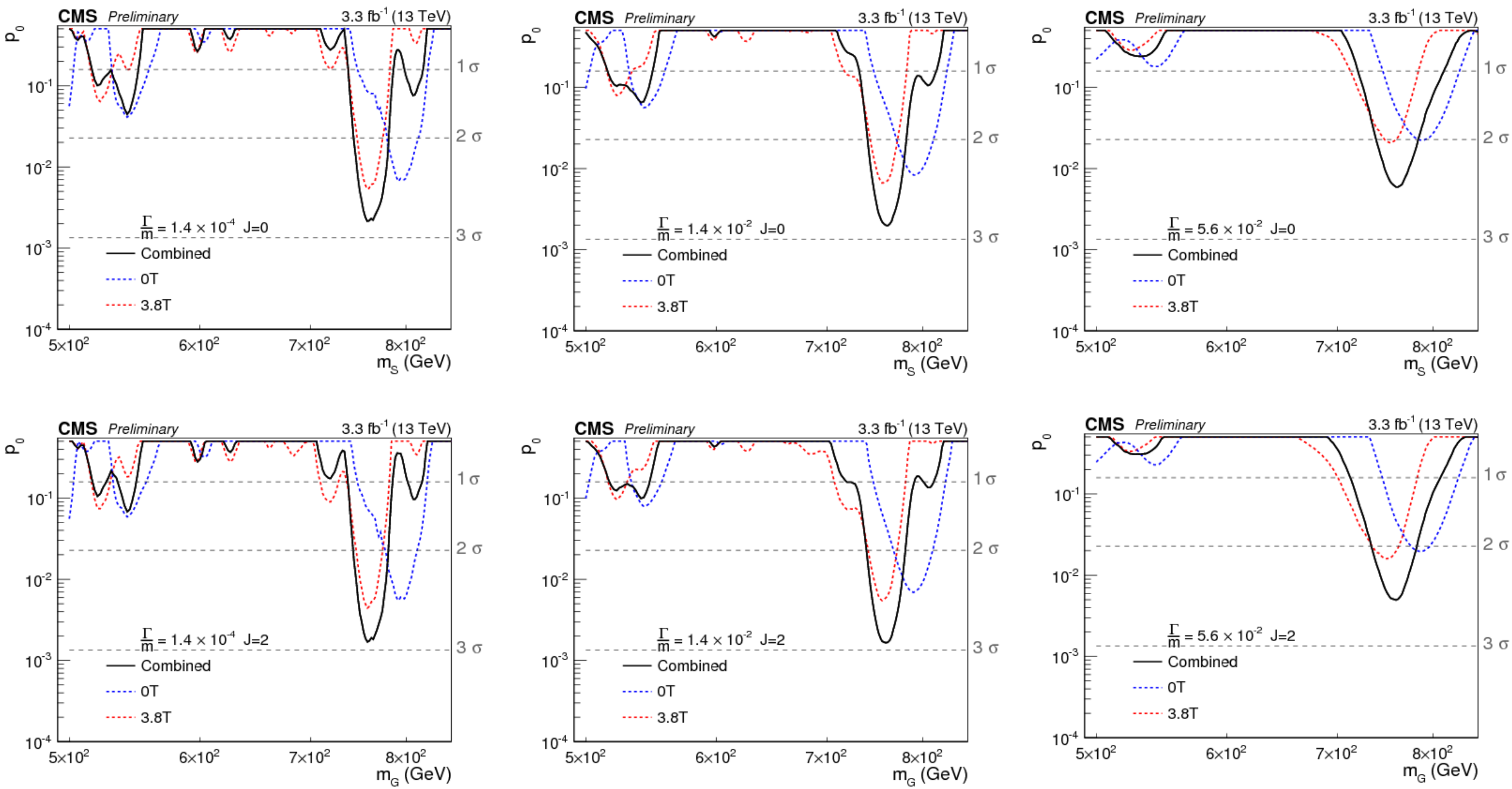
Spin 2

Narrow width

Wide width

*Plots from **CMS-EX0-16-018**

p values 3.8 T & 0 T superimposed



Spin 0

Spin 2

Narrow width

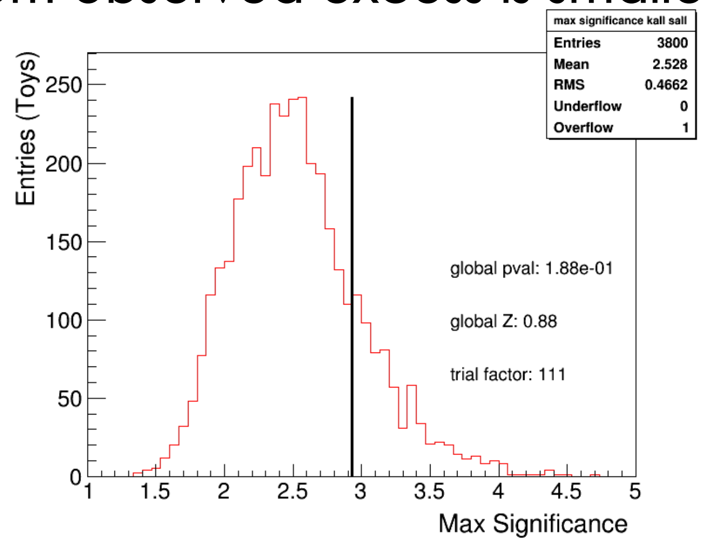
Wide width

p-values: summary

Dataset	Mass	Local p-value
3.8 T	~ 760 GeV	2.6 σ
0 T	~ 800 GeV	2.5 σ
3.8 T + 0T	~ 760 GeV	2.8-2.9 σ

Including "look elsewhere effect" for all spin & widths hyphotheses:

- Pseudo-experiments to compute bkg-only p-values for full search region for each alternative hypothesis
- min(p_0) for each pseudo-experiment considering all hypothesis (Γ, J, Mass)
- Compare global significance distribution with observed value
- **Global significance from observed excess is smaller than 1 σ**



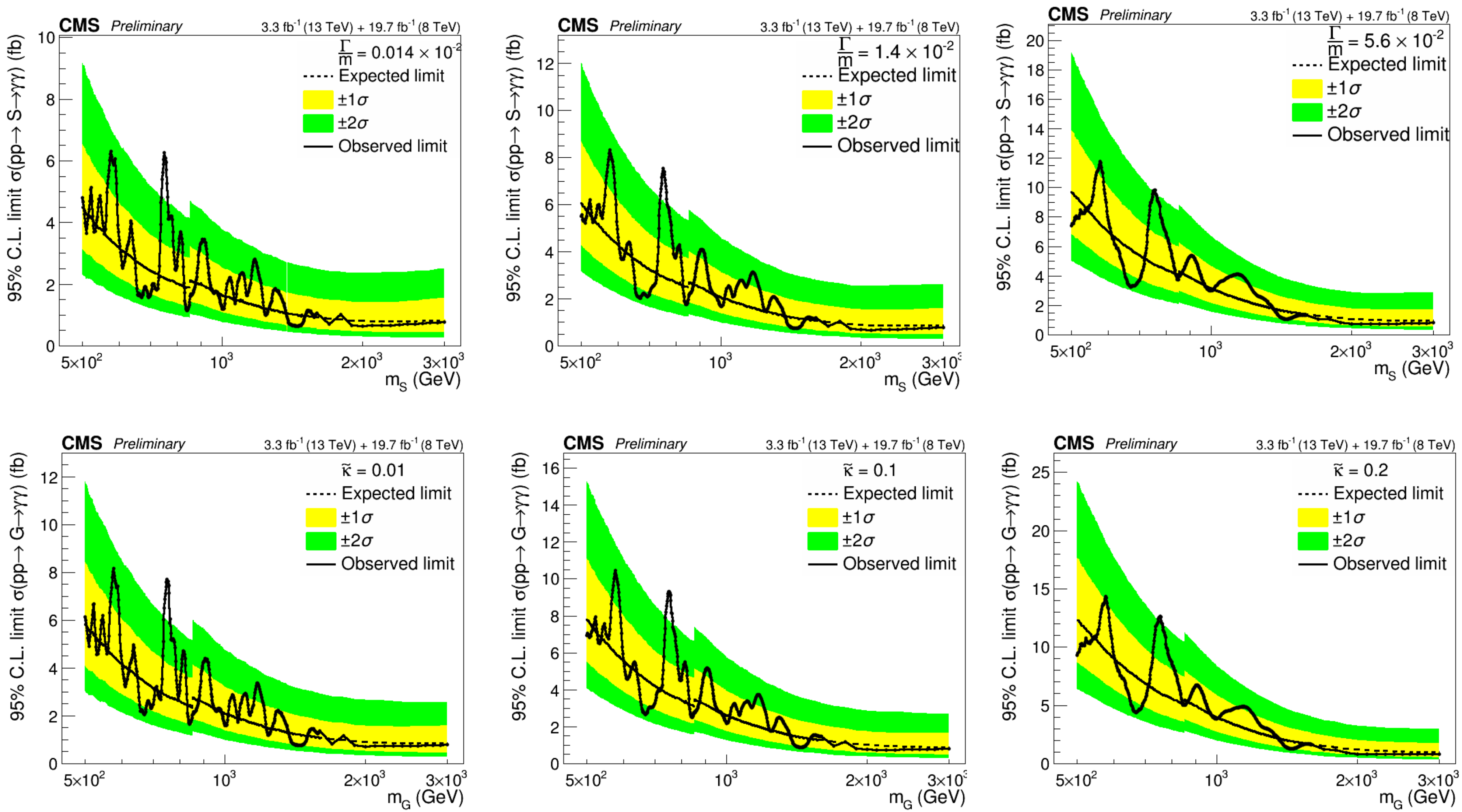
Systematic Uncertainties: correlation

- All normalization systematics assumed uncorrelated between 8 and 13TeV dataset
- Correlation model for energy scale and resolution detailed in the table below:

Source	13TeV	8T	Correlation
Energy scale EBEB	1%	0.5%	0.5
Energy scale EBEE	1%	2%	0.5
Energy resolution EBEB	0.5%	0.5%	0
Energy resolution EBEE	0.5%	0.5%	0

Exclusion Limits @ (13 TeV + 8 TeV)

- Largest excess @ ~750 GeV



Spin 0

Spin 2

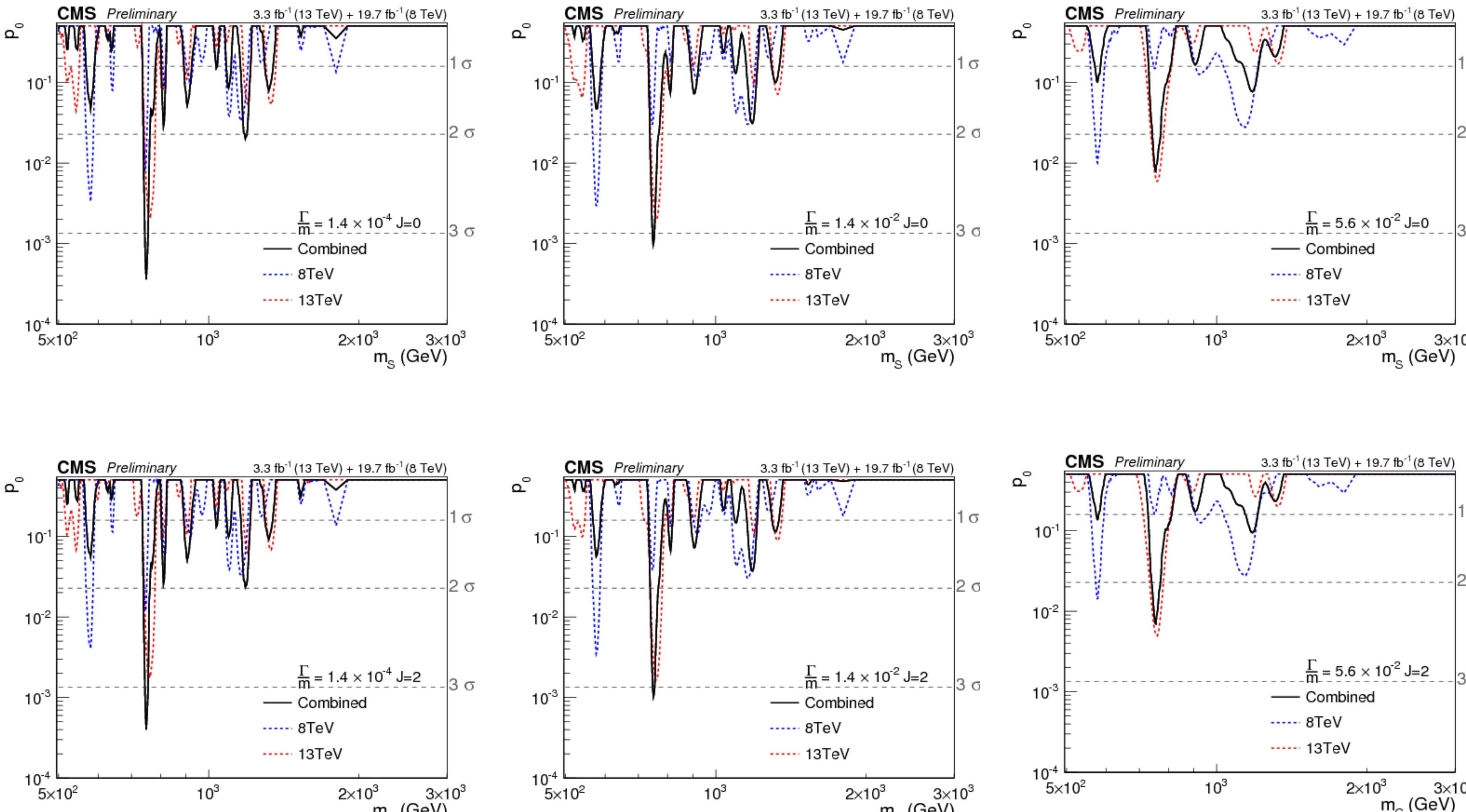
Narrow width

Wide width

*Plots from **CMS-EX0-16-018**

p value @ (13 TeV + 8 TeV)

- Lowest p-value for narrow width ~ 3.4 σ



Spin 0

Spin 2

Narrow width

Wide width

*Plots from **CMS-EX0-16-018**

Global significance for (13 TeV + 8 TeV) combination

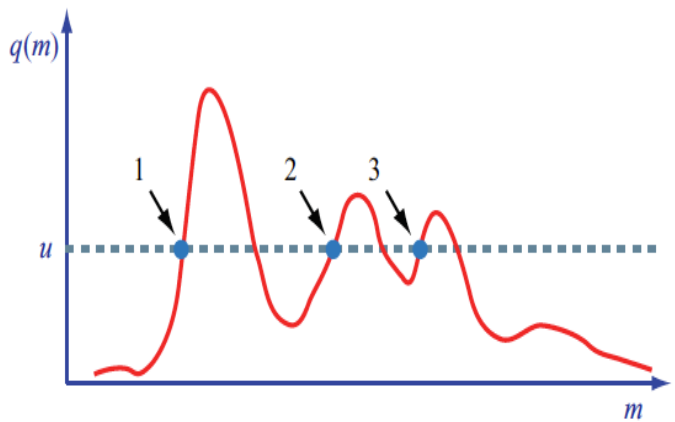
@ 8 TeV: use sliding window for mass fit (cannot throw correlated toy experiments)

Approximation:

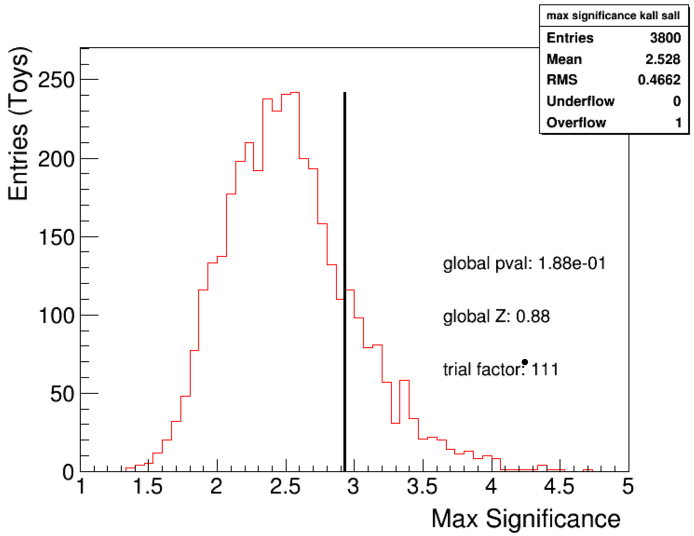
Trails factor = Trails factor(mass) x Trails factor(Γ, J | Mass)

Asymptotic formulas (crossings) (~100)

From toys @ 13 TeV ~1.3

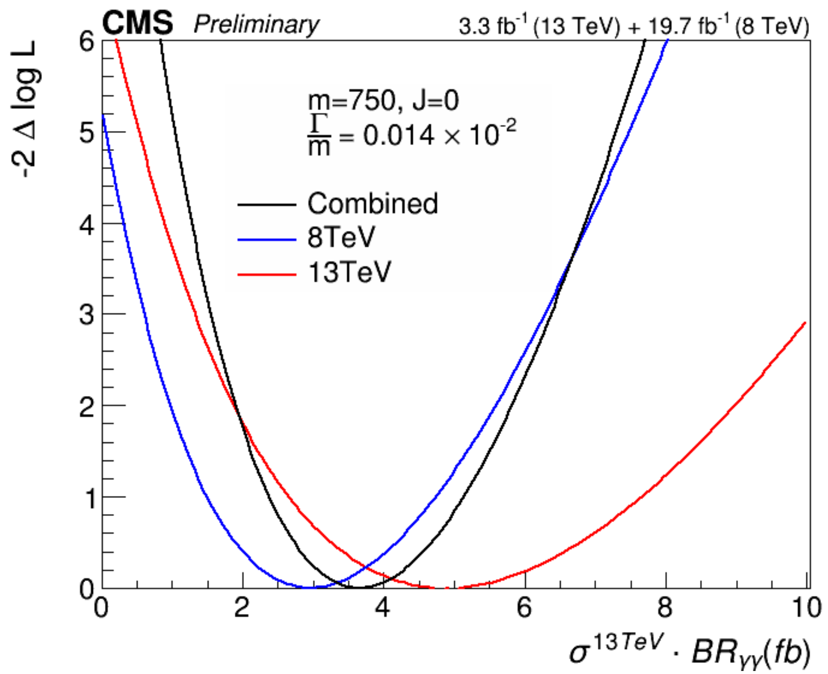


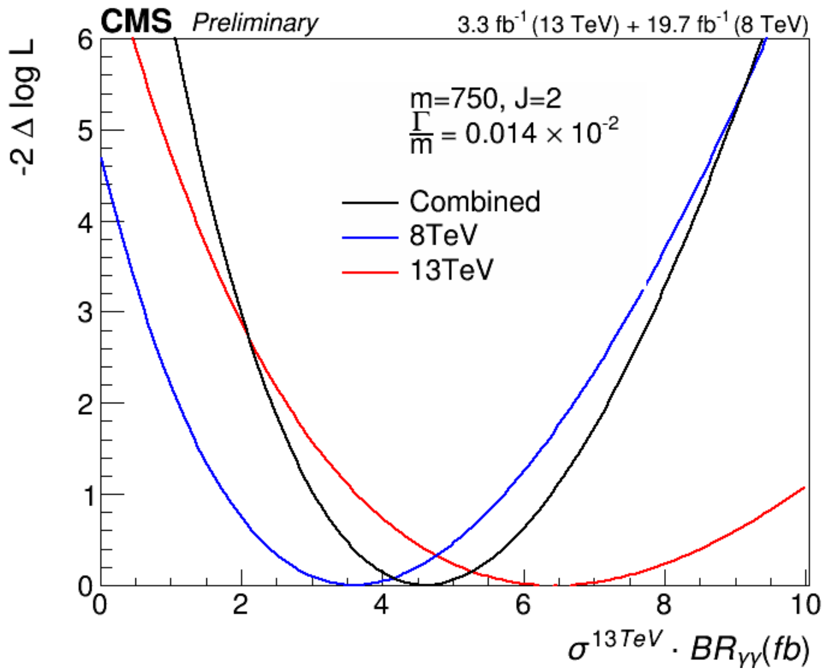
+



→ global p-value ~ 1.6 σ

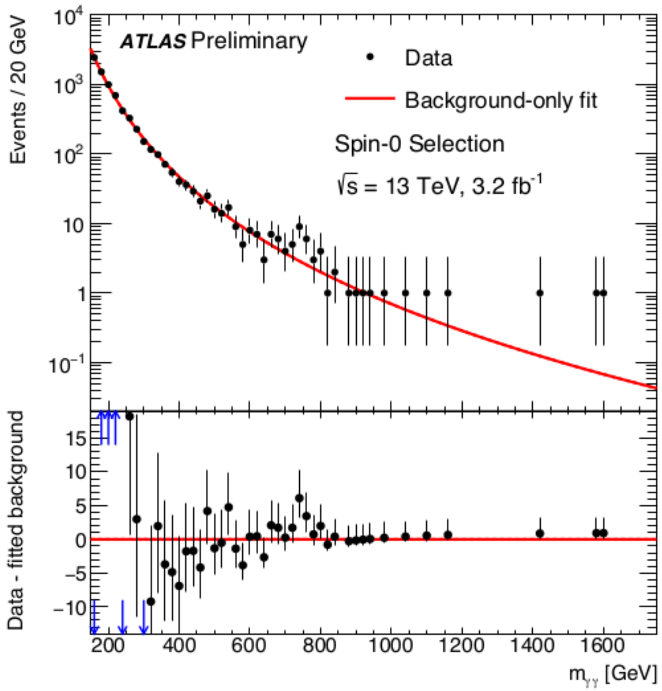
Compatibility 8 TeV & 13 TeV

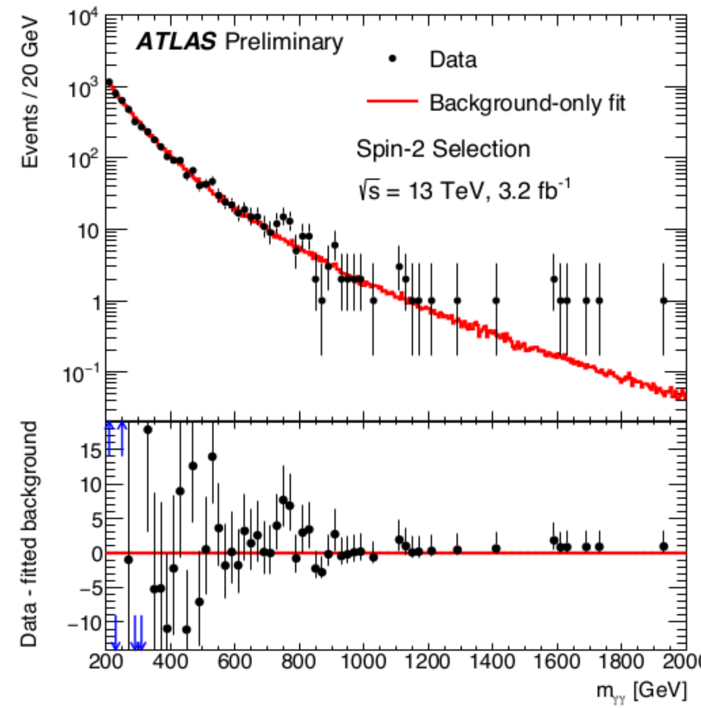


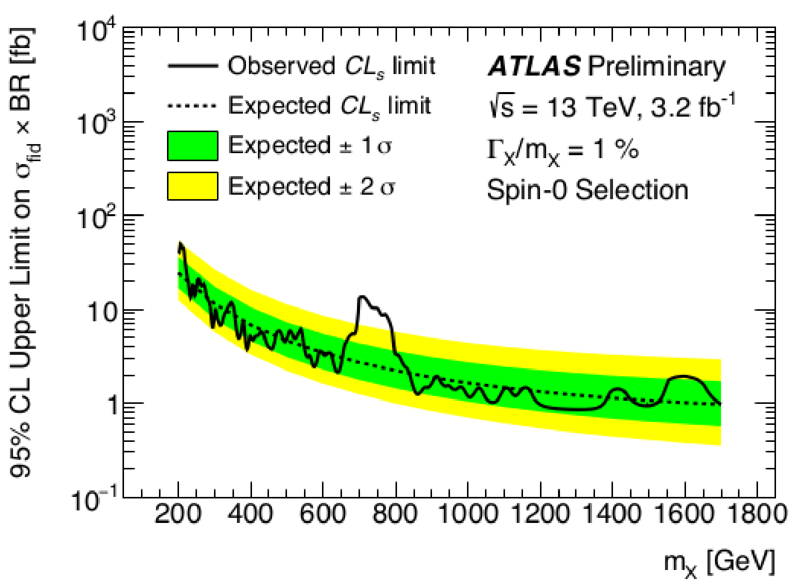


- Likelihoods of the fits to a S+B hypothesis vs equivalent x-sec
- Narrow scalar and RS graviton hypothesis @ 750 GeV chosen
- The equivalent x-sections from the 2 datasets compatible with each other (for both J=0 and J=2)

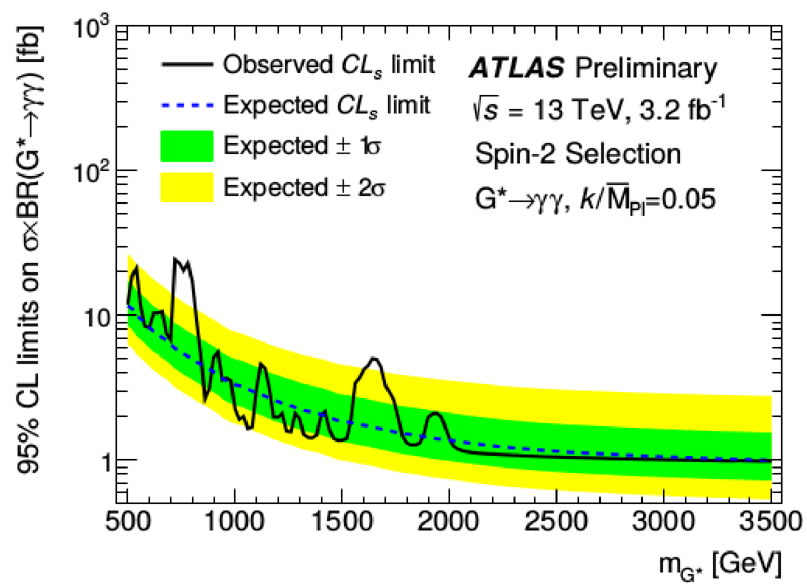
ATLAS diphoton







Spin 0



Spin 2