Search for BSM physics in di-photon final states at CMS

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On behalf of the CMS Collaboration

ICHEP 2016, Chicago Aug 5th

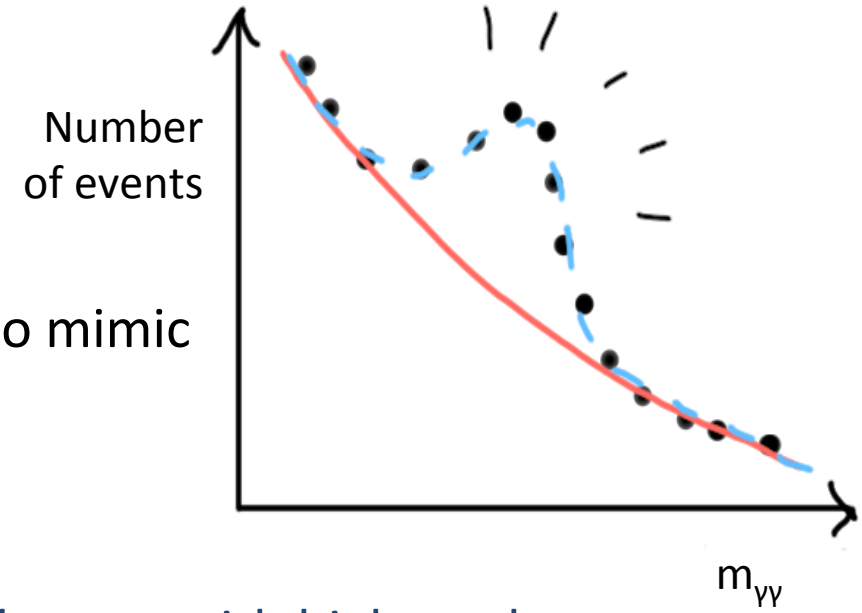
Why di-photon searches

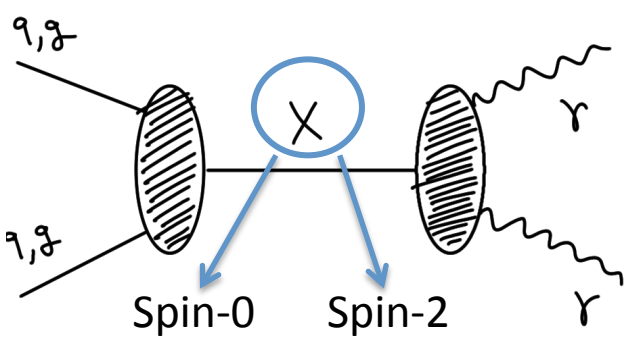
Fully reconstructed resonances: simplest way to discover new particles

Statistically significant peak over a smooth background

- experimentally robust
- small systematics
- difficult for unknown backgrounds to mimic

⇒ *simple yet striking signature!*





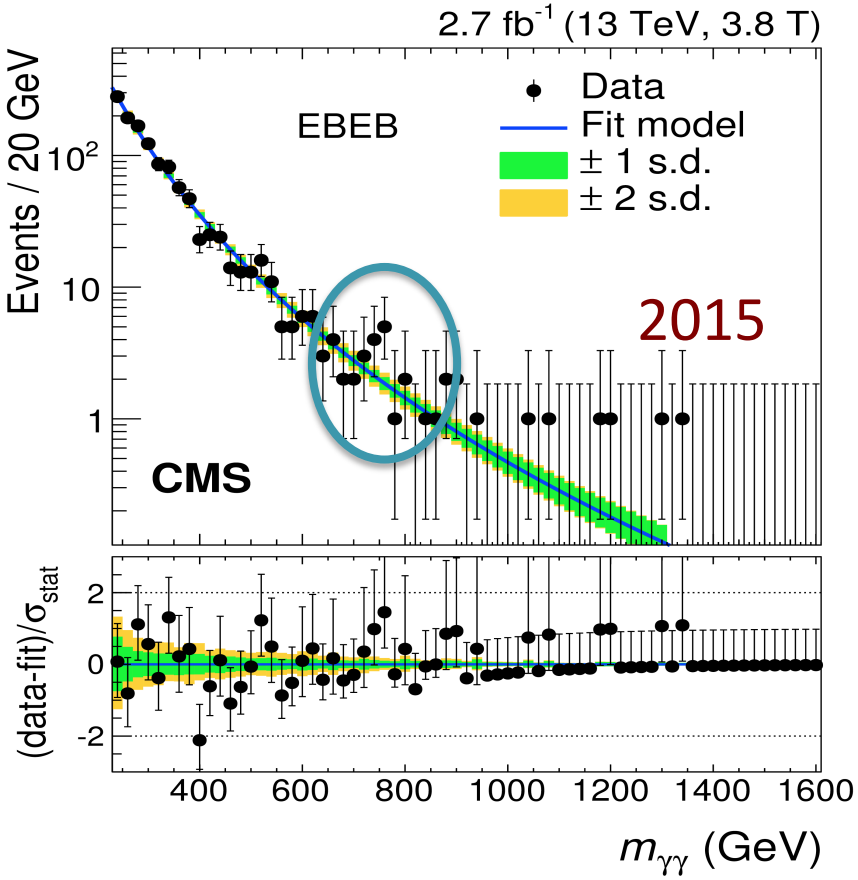
Final states with high p_T photons:

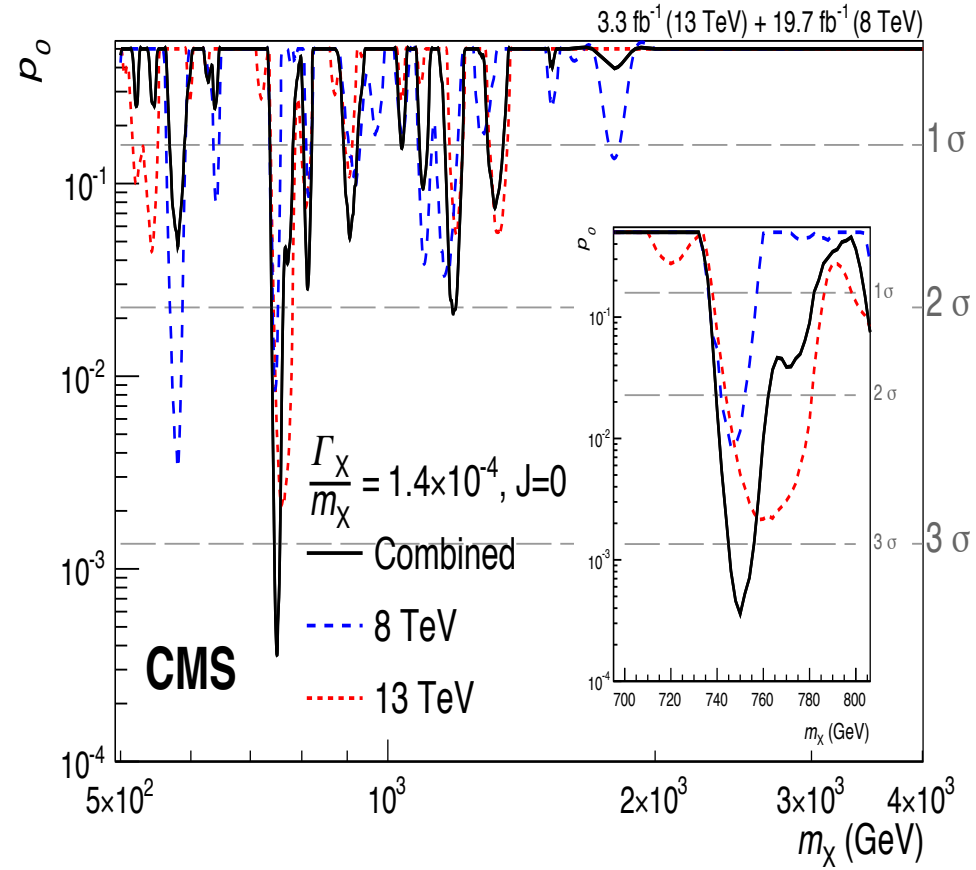
- relatively low background at hadron colliders
- good mass resolution

Many theoretical motivations

Recap of 2015 results

Phys.Rev.Let. 117(2016), no. 5, 051802





	2015	2015 + 8TeV
Mass (GeV)	760	750
Local significance	2.9σ	3.4σ
Global significance	<1σ	1.6σ

Recap of 2015 results

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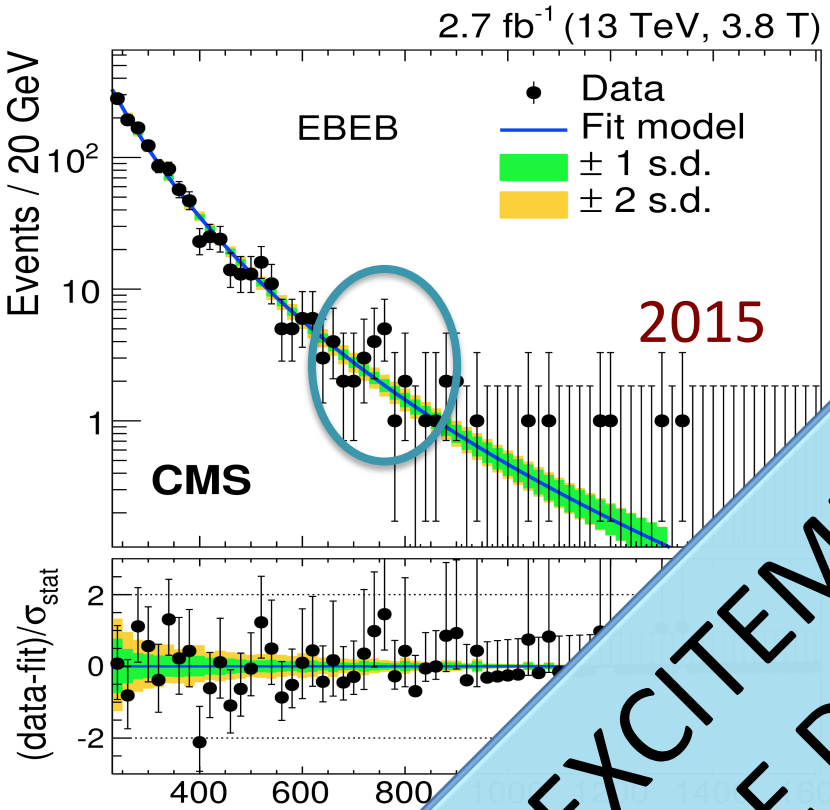

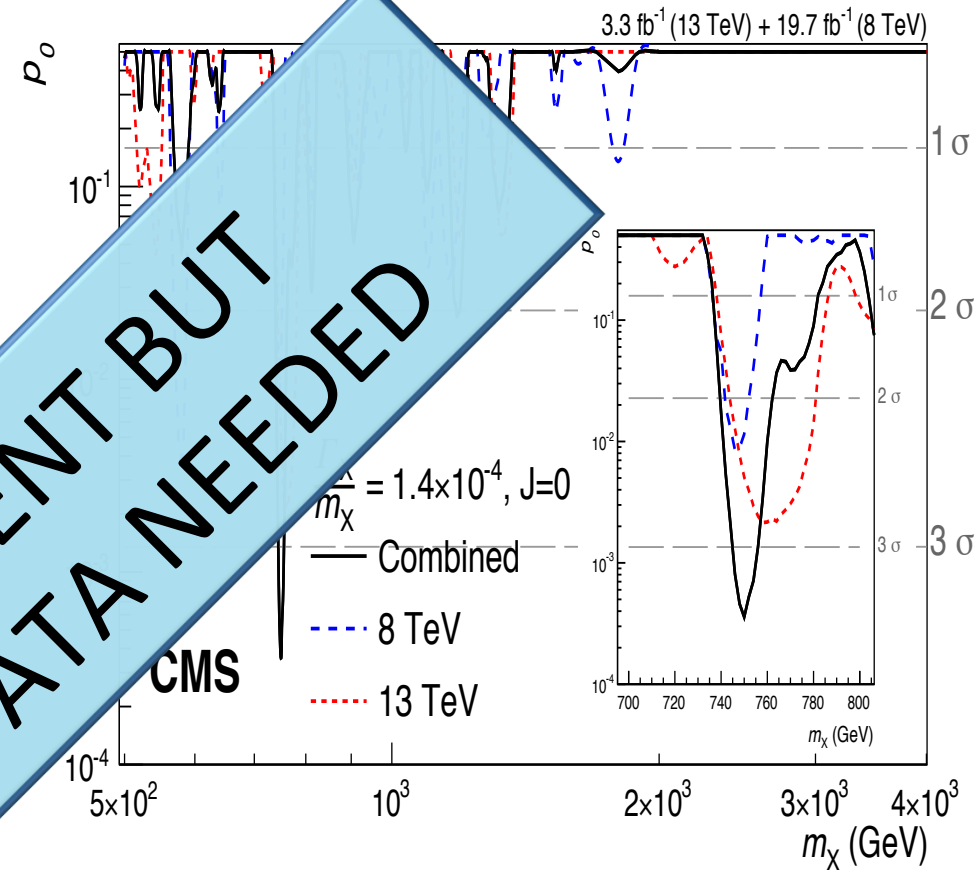

EXCITEMENT BUT MORE DATA NEEDED

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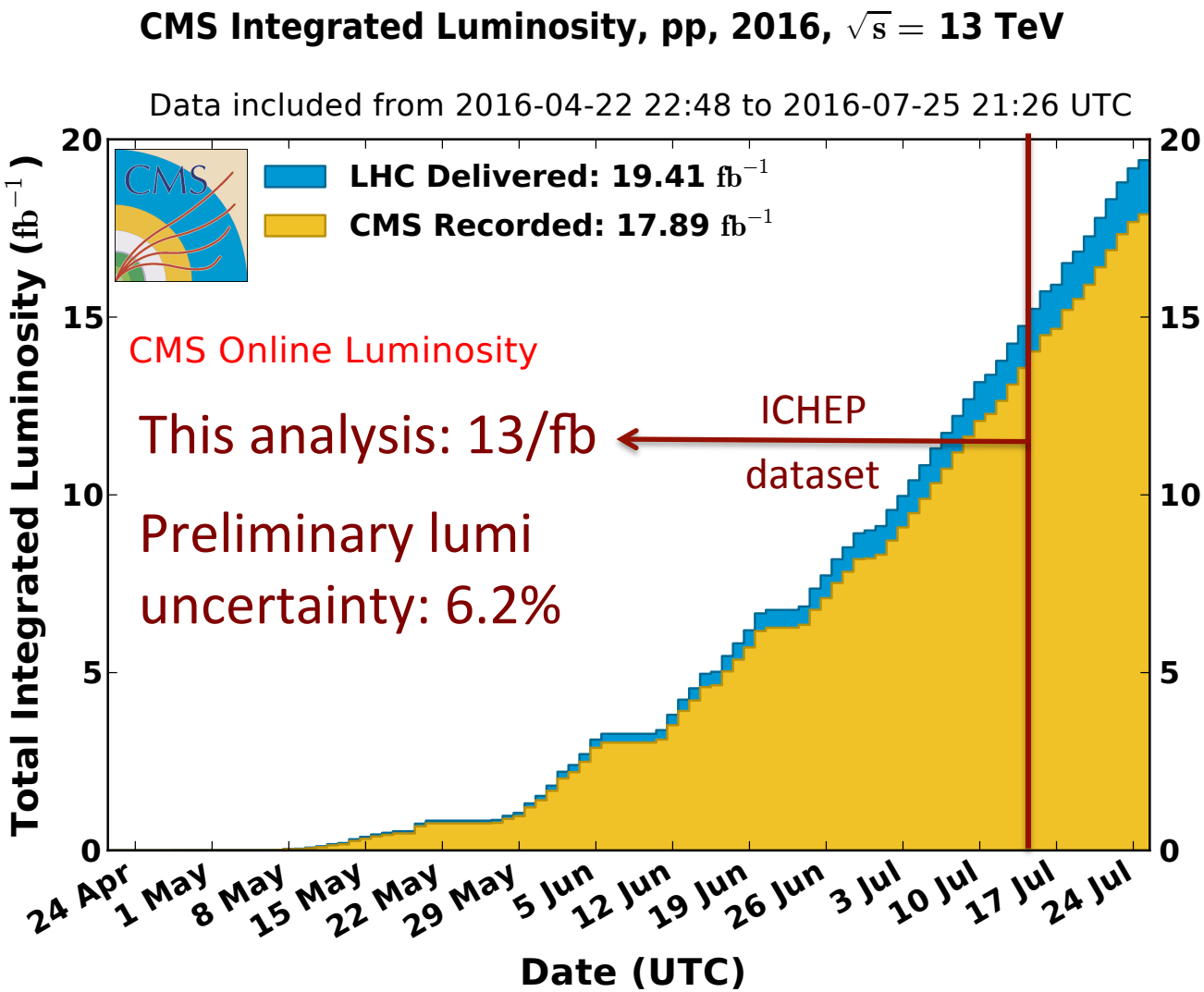
CMS 2016 dataset



Wonderful LHC performance!

Analysis in a nutshell

Search for a localized excess in the di-photon invariant mass spectrum

Events selection: 2 high p_T isolated photons

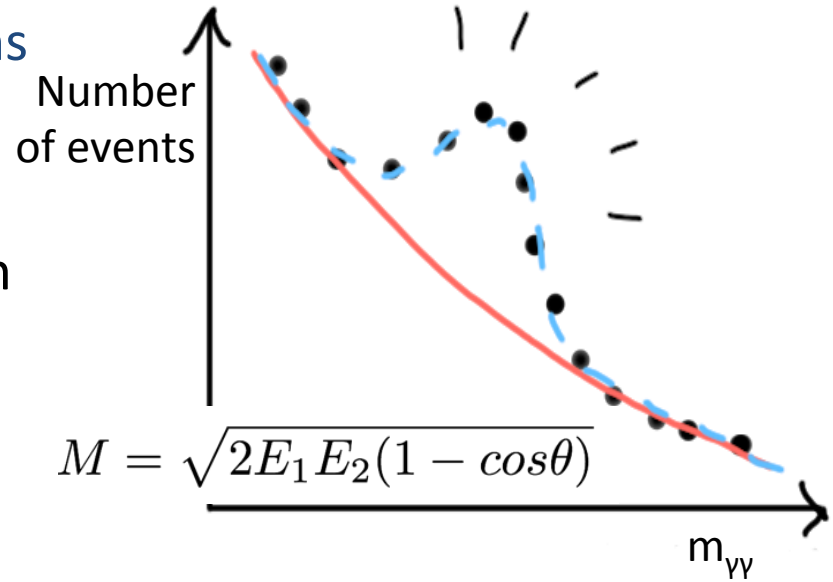
- Robust criteria

Signal modeling with data-driven inputs

- Efficiencies, energy scale and resolution
- Good detector understanding needed

Background modeling

- Parameterization from data



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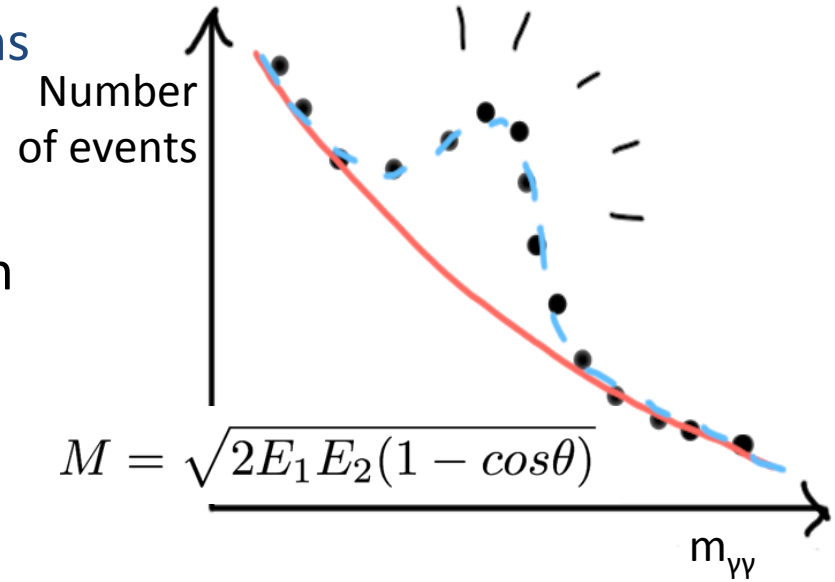


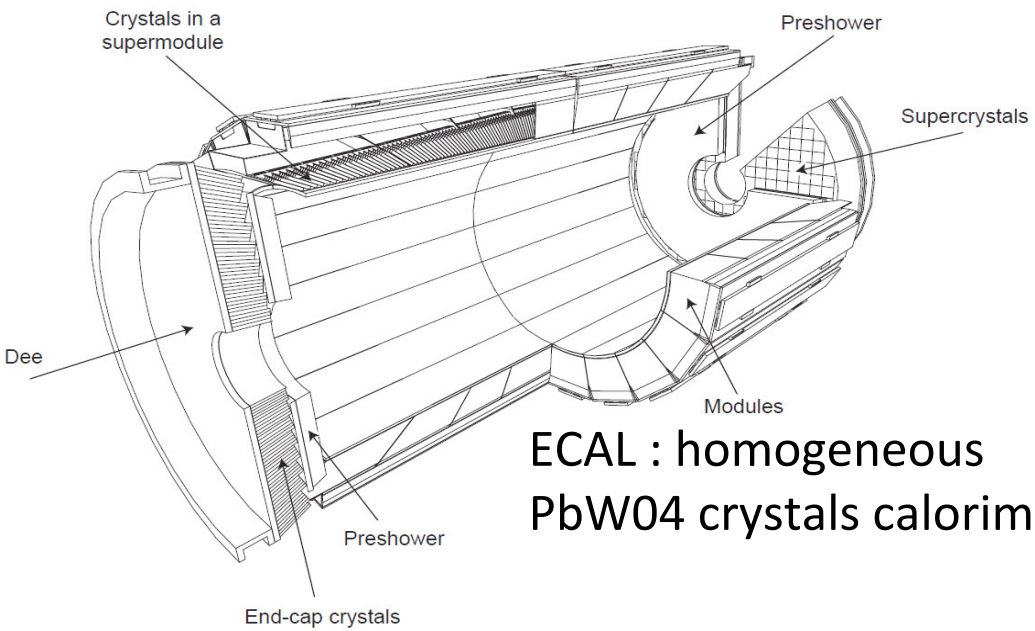
Solid techniques exploited

Potential improvements investigated while keeping the 2016 analysis blind

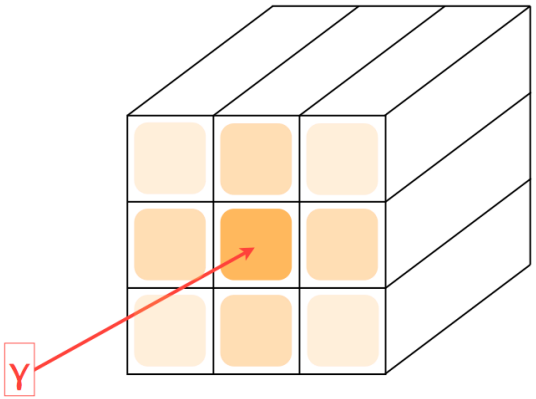
No significant gain found

- No selection change applied: basically same analysis as last year

Photons in CMS



ECAL : homogeneous PbW04 crystals calorimeter



Photons reconstructed from energy deposits in clusters of ECAL crystals

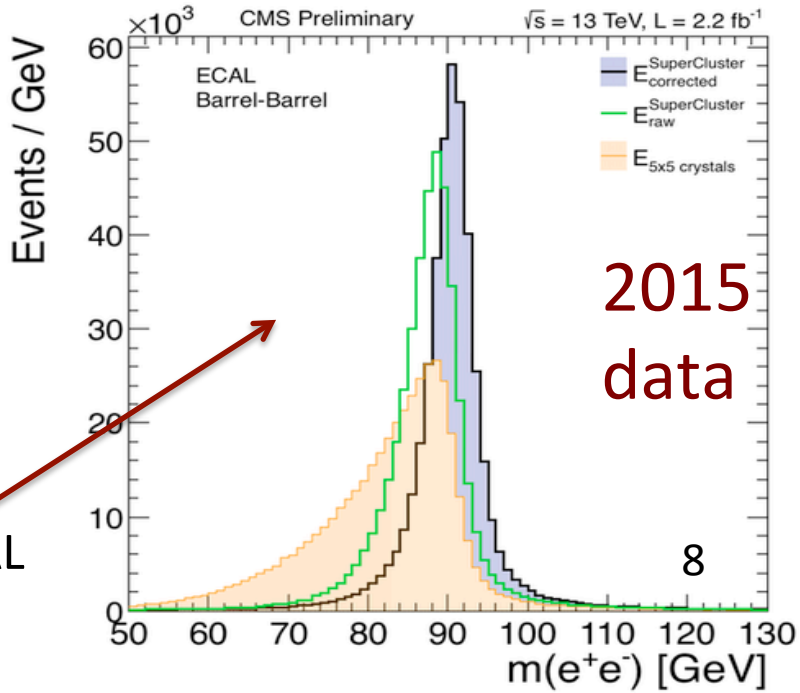
- No associated track

97% energy contained in a 5x5 matrix

Clustering optimized to collect radiated energy

- up to $2X_0$ distributed material in front of ECAL

Energy from multivariate regression



Selection criteria

High Level Trigger

2 photons, p_T>60 GeV

Offline kinematic selection

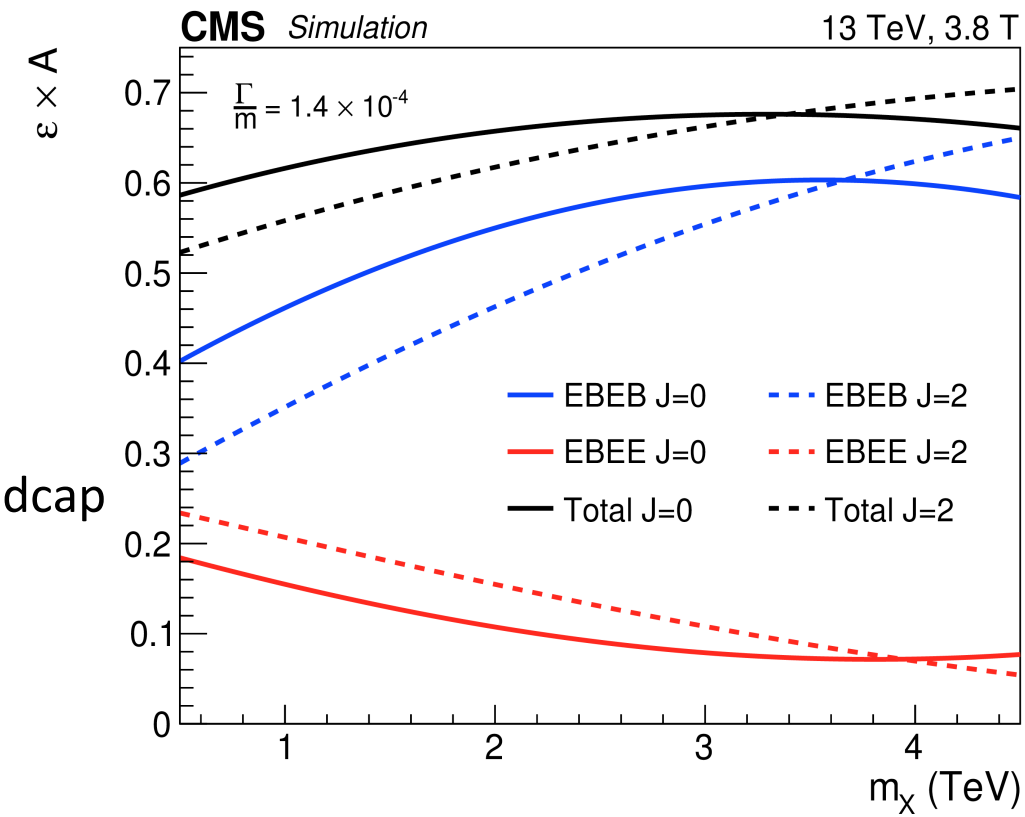
- Fixed p_T cut, p_T > 75 GeV
- ECAL fiducial region (|η|<2.5)

2 event categories

- EBEB: both γs in the barrel
- EBEE: one γ in barrel, one in endcap
- Based on S/B ratio

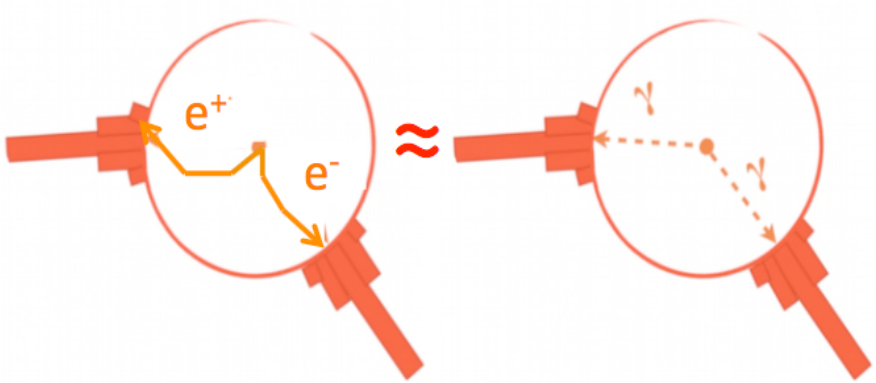
Identification requirements:

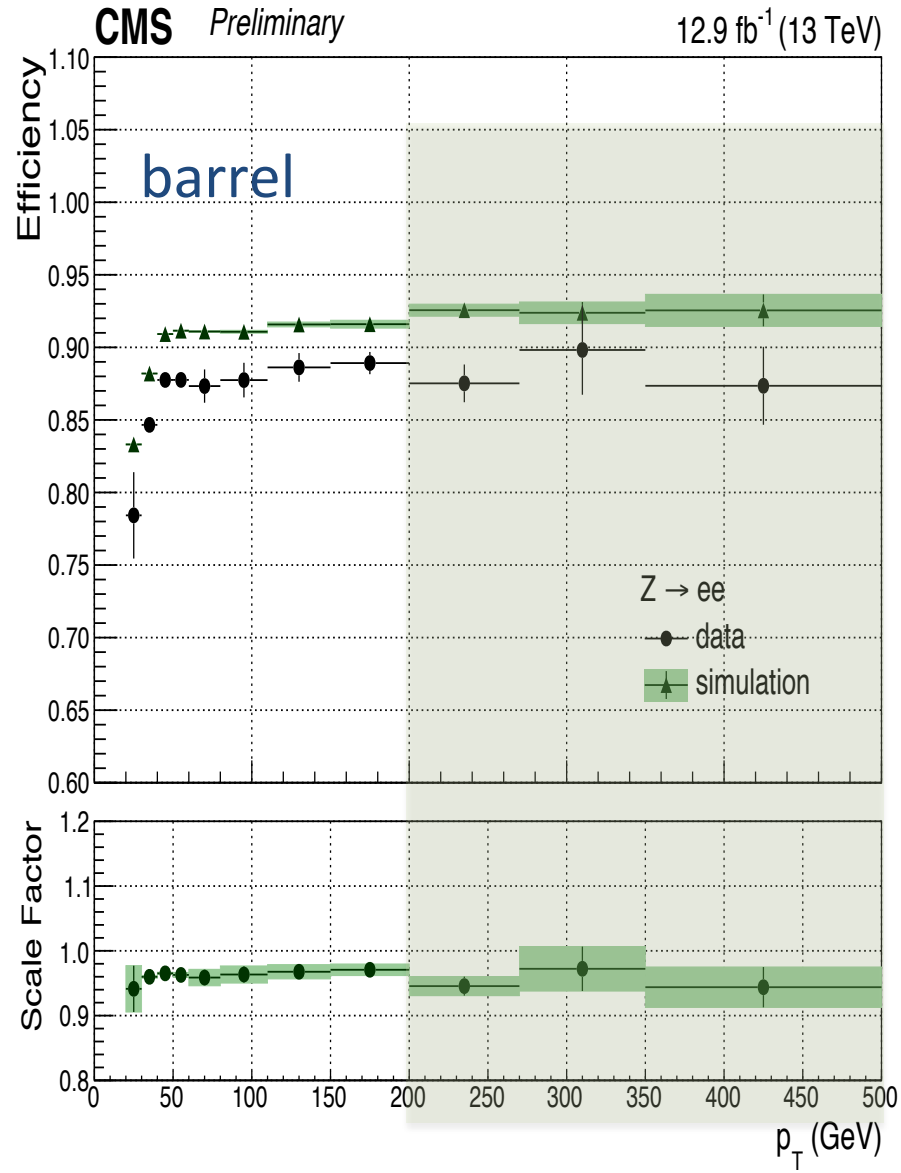
- Shower shape and isolation
- No associated track
- γγ selection efficiency:
  - ~85% in EBEB
  - ~80% in EBEE



Small differences due to different Kinematics for different spin hypothesis

Efficiency measurement





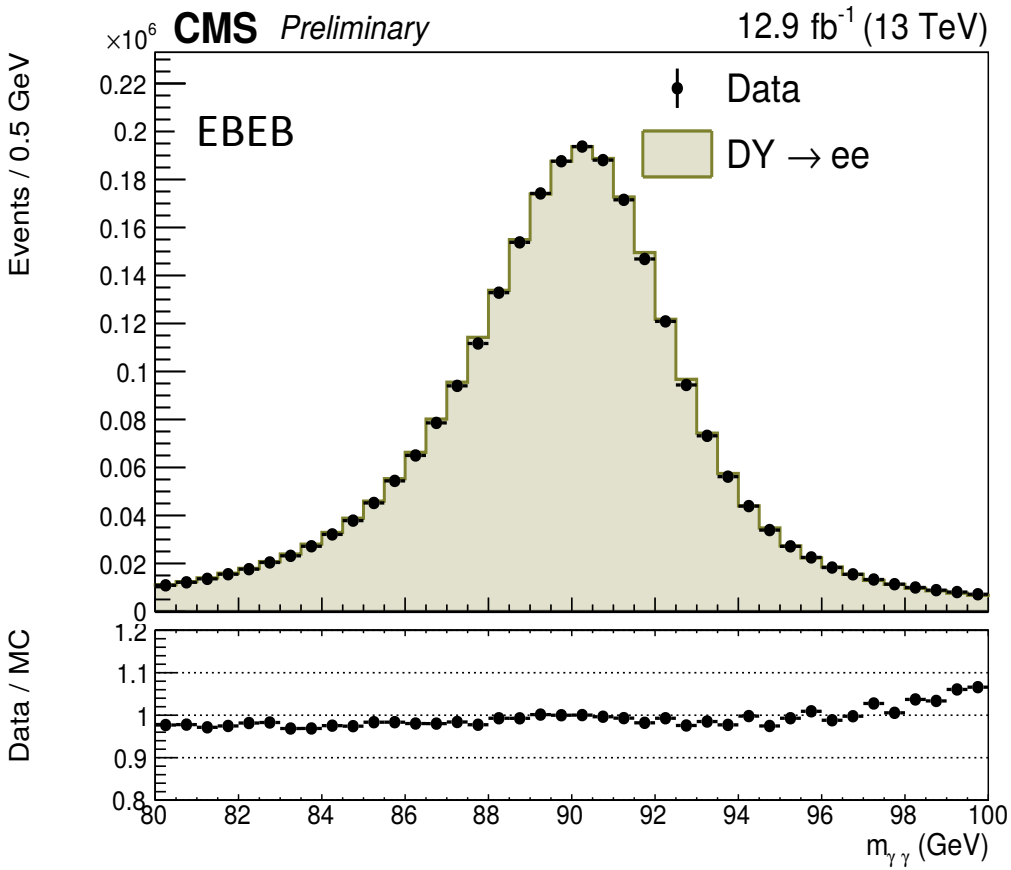
Tuned in MC and validated in data

- Z->ee events
- Z->μμγ events for electron veto requirement

Data/MC scale factors

- computed for EB and EE
- almost constant in p_T
- non compatible with 1
  - included in signal modeling

Photon energy scale and resolution



Measured with Z in data at O(0.1%) level in bins of η and cluster shape

- simultaneously adjust scale and resolution

Good agreement in term of shape and normalization after all corrections

Energy scale stability vs E_T checked with boosted Zs up to ~150GeV

- Deviations within a few permilles
- 1% uncertainty to account for extrapolation to larger momenta

Signal modeling

Statistical interpretation from simultaneous fit to $m_{\gamma\gamma}$ distribution in the two analysis categories

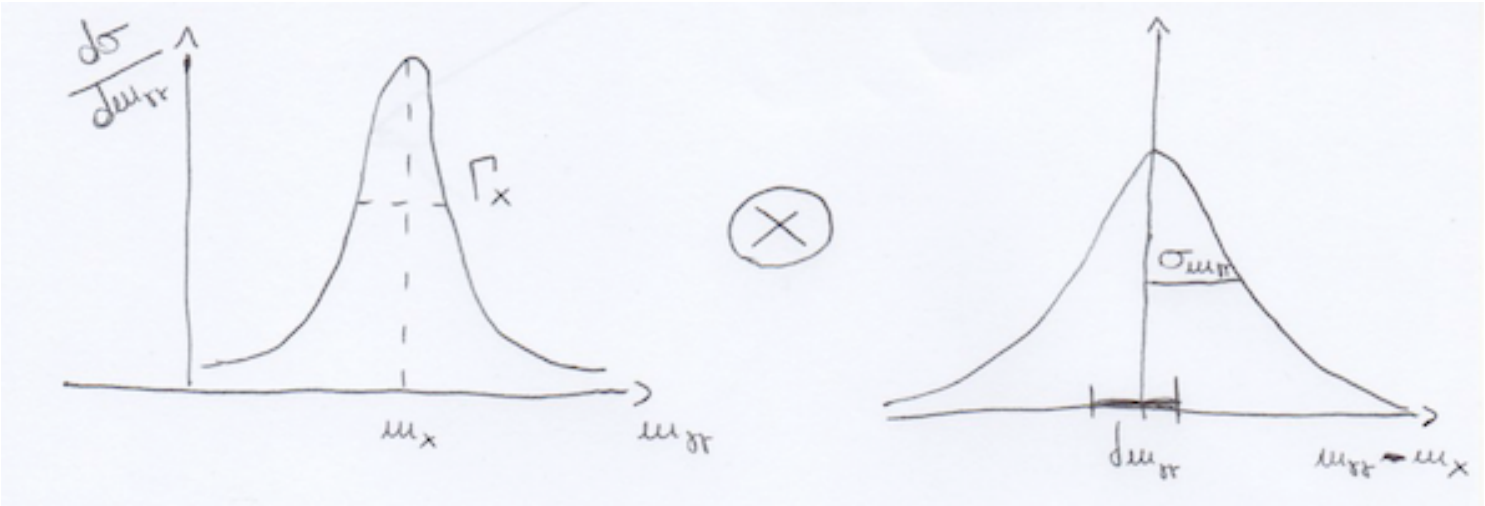
Signal shape: convolution of intrinsic line-shape and detector resolution

- σ_m/m ~1% (EBEB) , 1.5% (EBEE)
- Spin-0 and spin-2
- m_X : 0.5 - 4.5 TeV
- $\Gamma/m = 1.4\times10^{-4}$, 1.4×10^{-2}, 5.6×10^{-2} (k=0.01, 0.1, 0.2 for RS Graviton)

Detector resolution dominates

Comparable resolution and width

Resonance width dominates

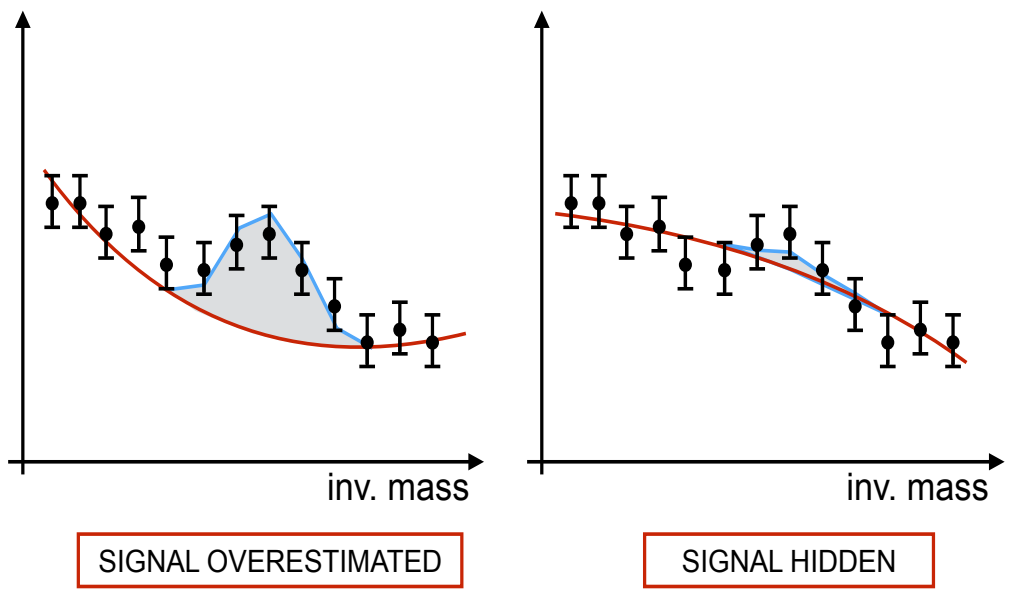


Background modeling

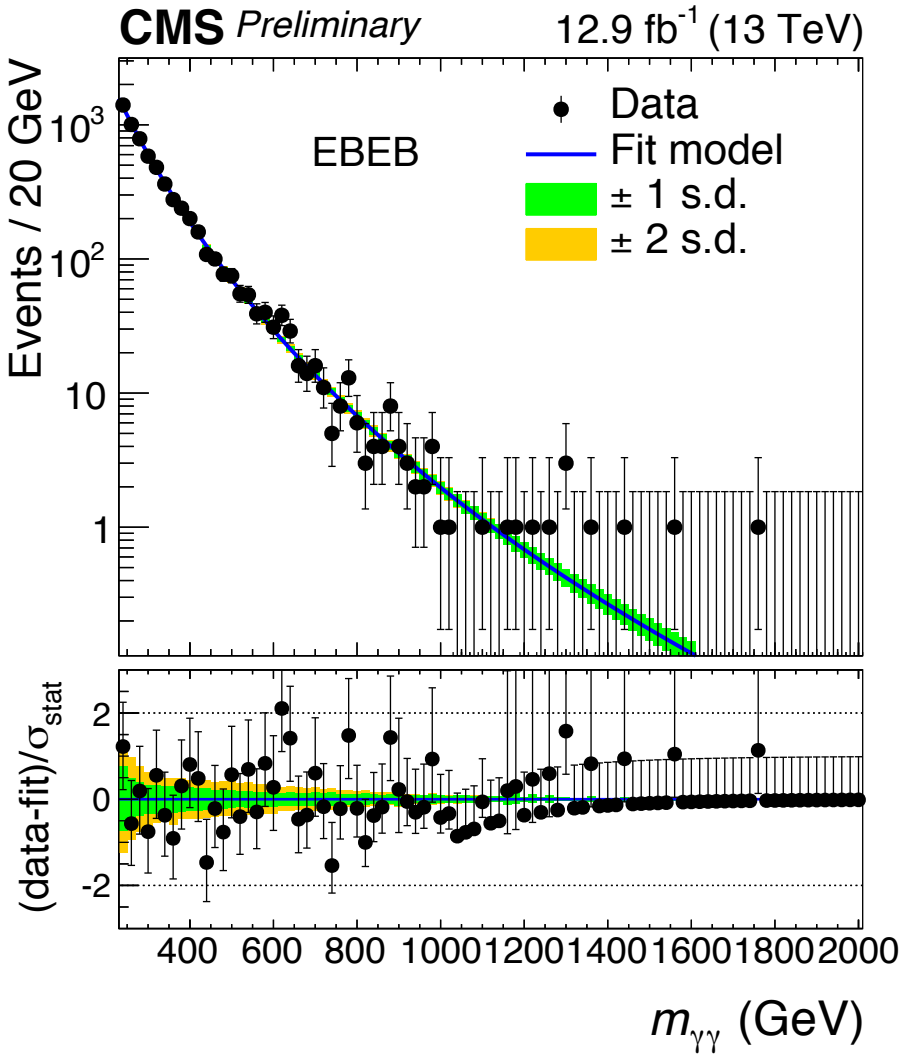
Statistical interpretation from simultaneous fit to $m_{\gamma\gamma}$ distribution in the two analysis categories

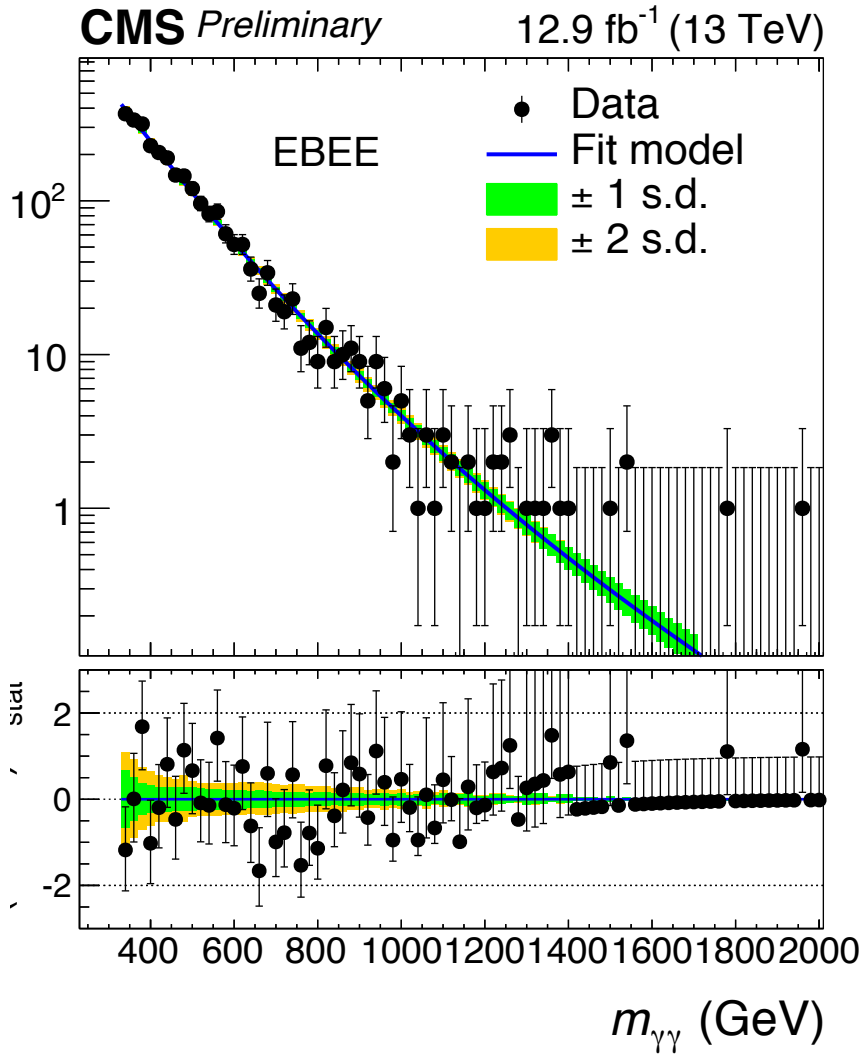
Background model

- Parametric fit to data with empirical function $f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\cdot\log(m_{\gamma\gamma})}$
- Independent shape for each category
- Model coefficients: nuisance parameters in the hypothesis test
- Possible mis-modeling studied on MC and included as a "bias term"



2016 mass spectra





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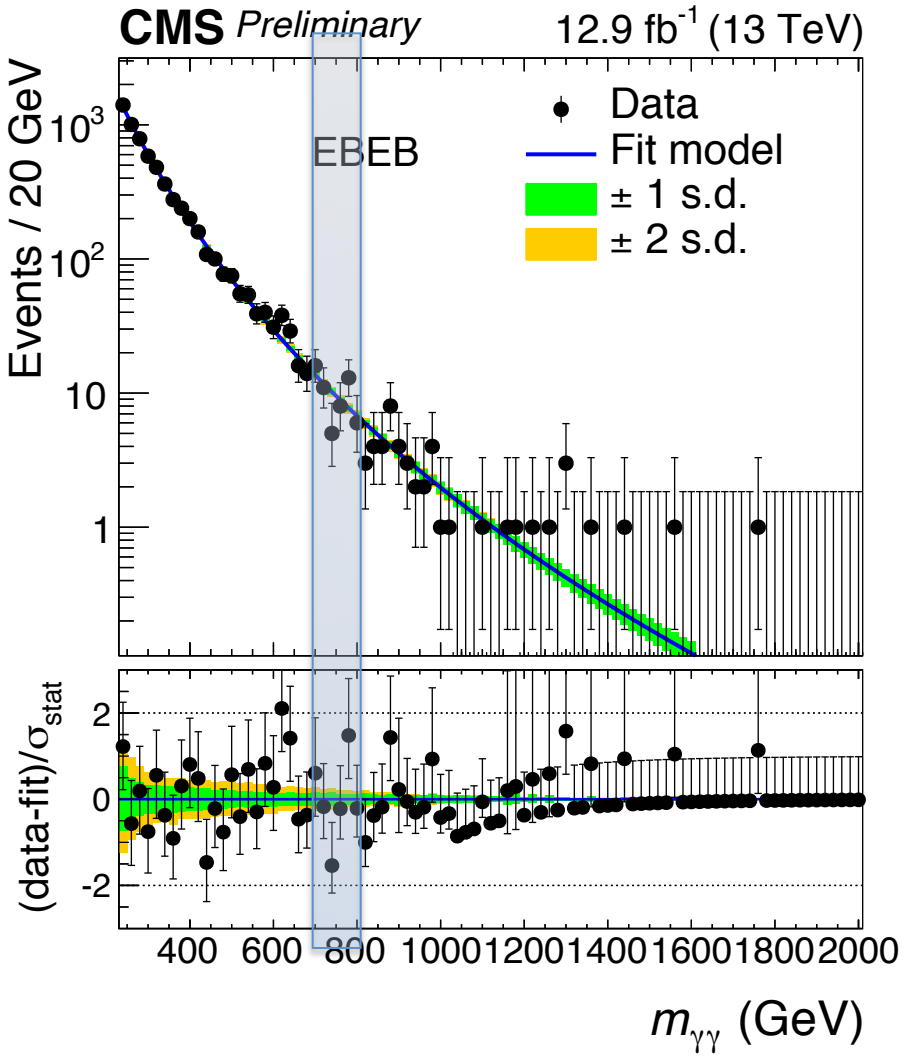
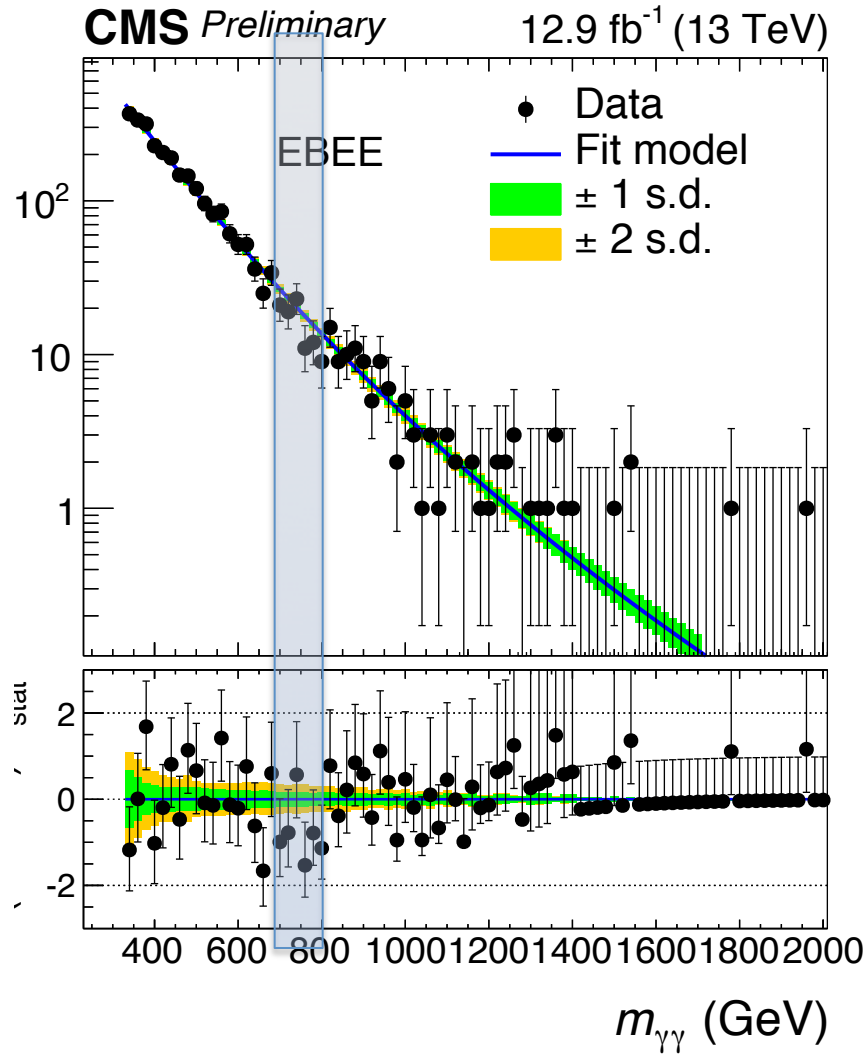
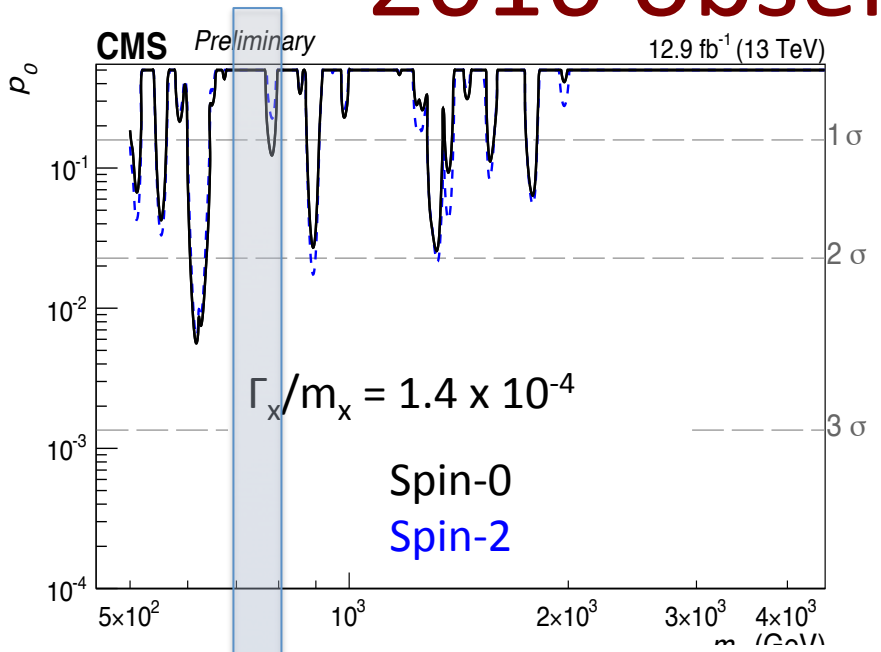
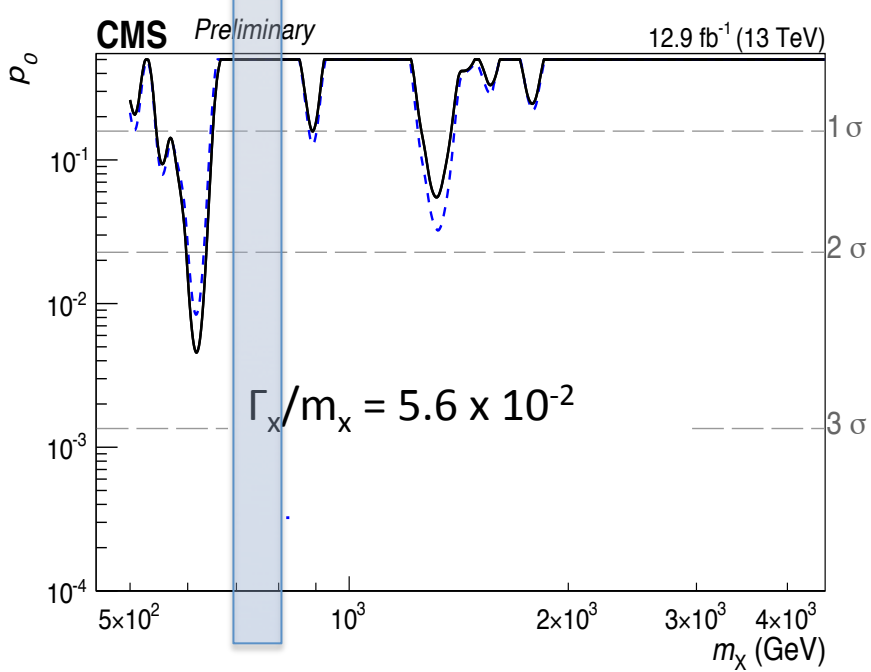




Data consistent with Standard Model expectations

2016 observed p-value



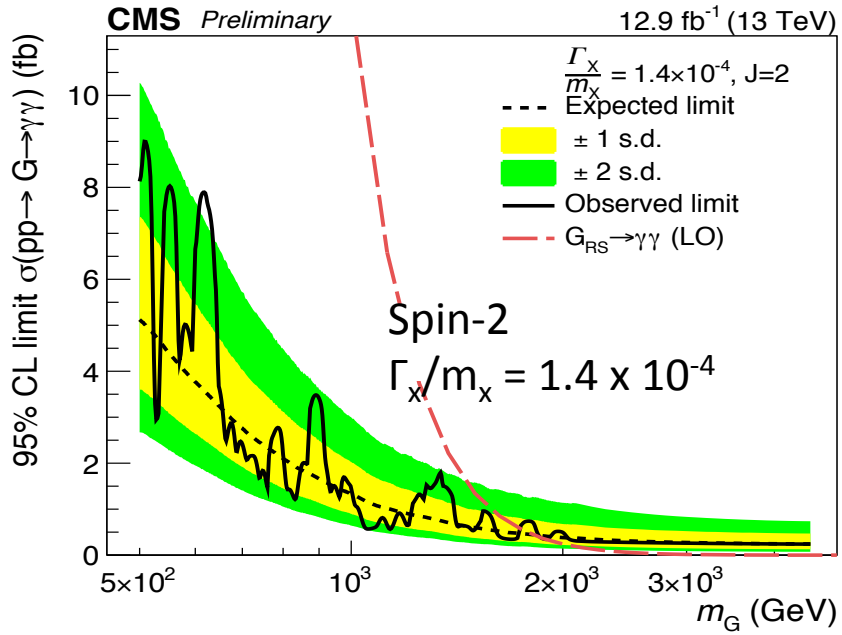


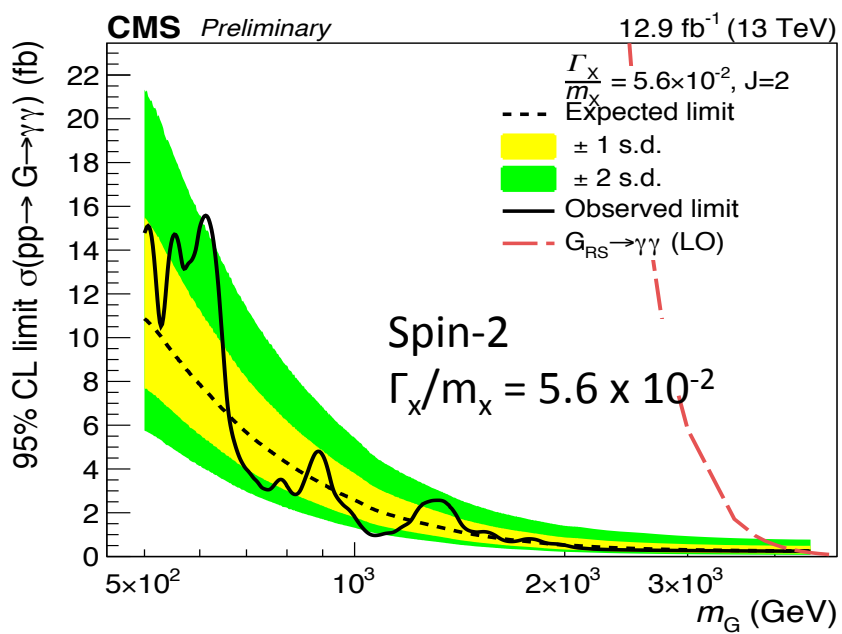
No significant excess in proximity of 750 GeV

Largest excess now observed for m_X~620GeV
Local significance (narrow width): ~2.4-2.7σ

Showing only plots for selected width and spin hypothesis.
All other plots available in backup

2016 exclusion limits





Coupling	Exclusion
0.01	$m_G < 1.75$ TeV
0.1	$m_G < 3.75$ TeV
0.2	$m_G < 4.35$ TeV

Exclusion limits for RS Graviton (LO cross-sections)

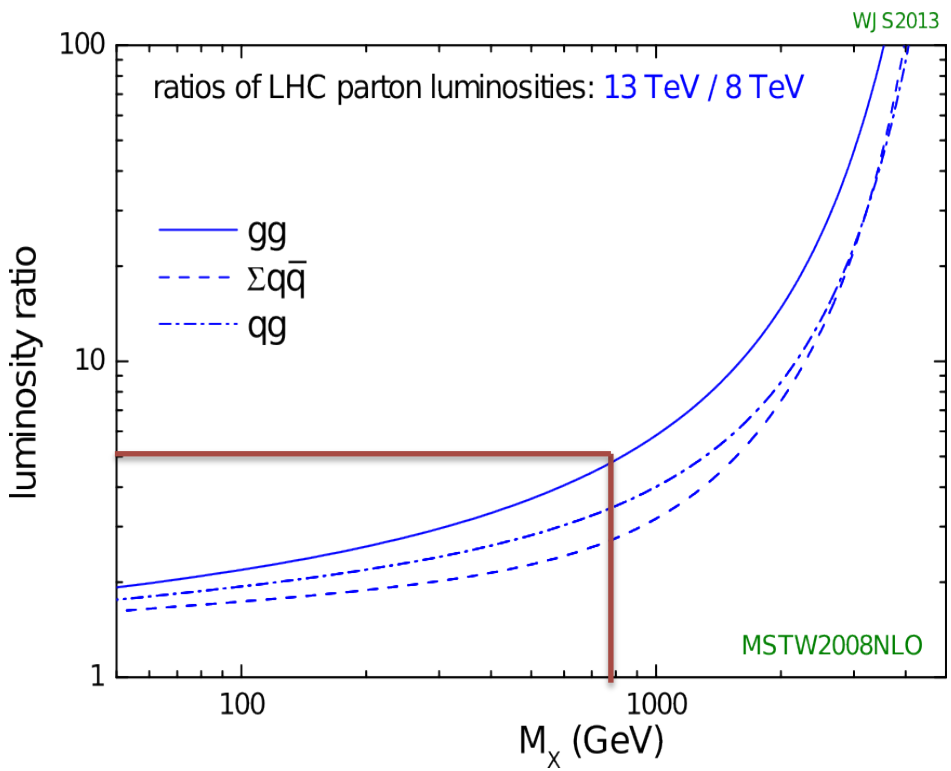
- in agreement with expectations

8TeV + 13TeV

Combination of results from

- 19.7/fb at √s = 8TeV
- 3.3/fb at √s = 13TeV (2015)
- 12.9/fb at √s = 13TeV (2016)

CMS publications	√s [TeV]
CMS-PAS-EX0-16-027 (new)	8 / 13
PRL 117, 051802 (2016)	8 / 13
PLB750 (2015) 494–519	8

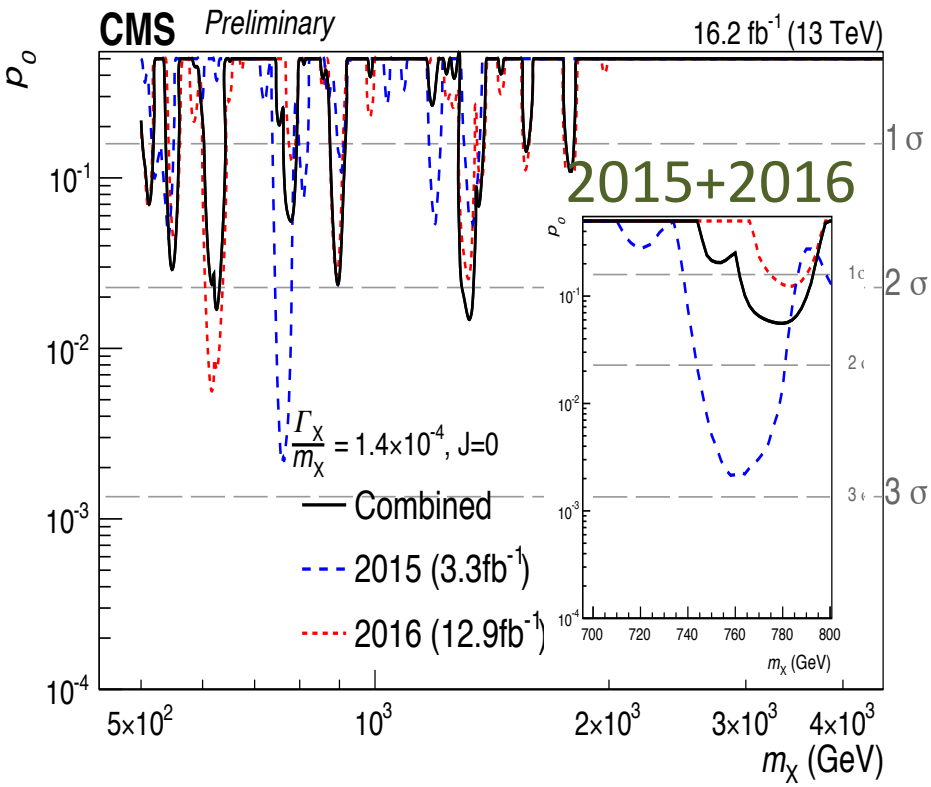


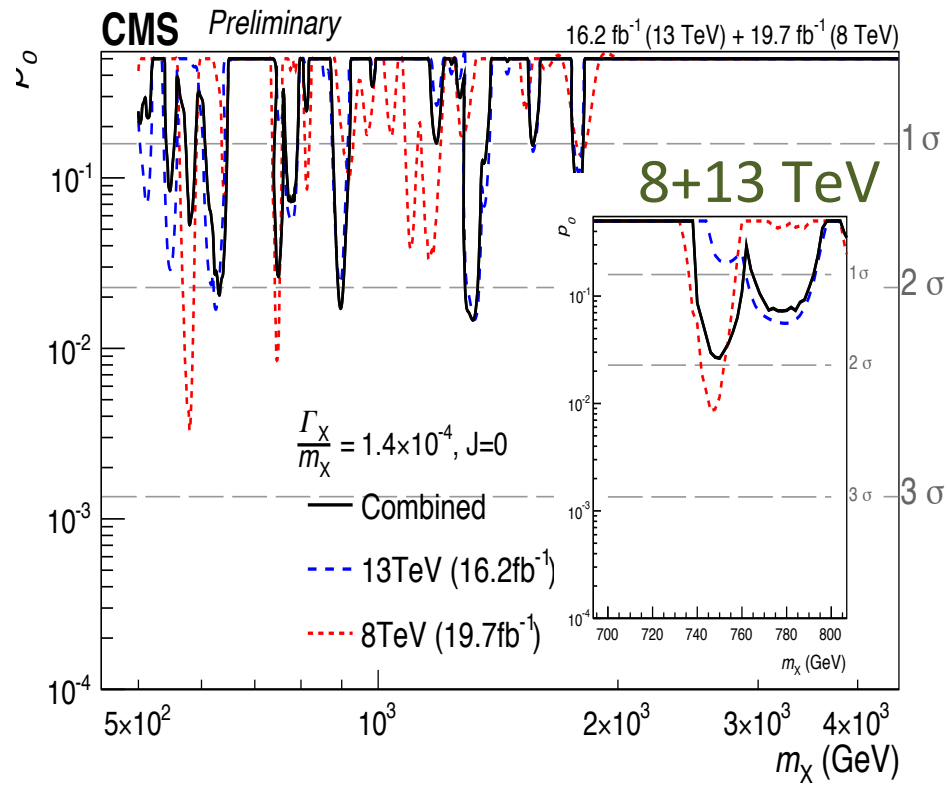
@750GeV:

σ(13TeV)/σ(8TeV) = 4.5 spin-0

= 4.2 spin-2

Run1+Run2 significance





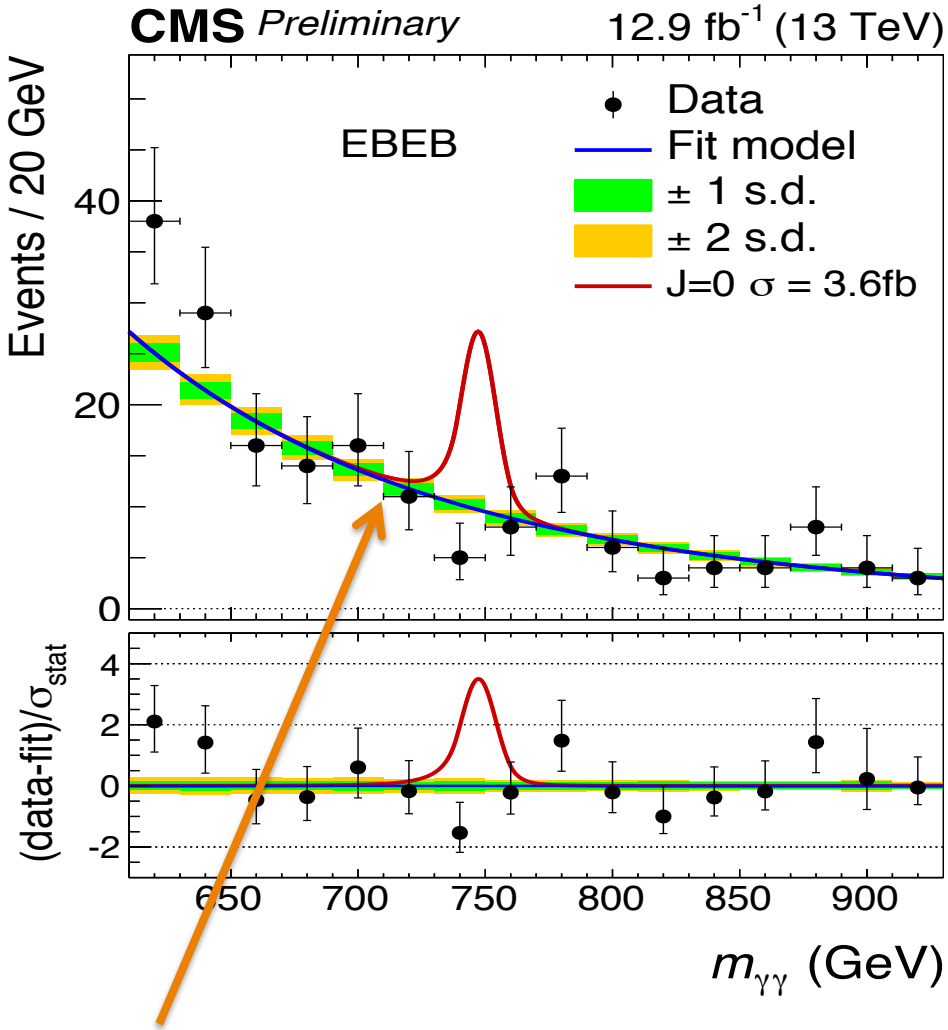
Spin-0, $\Gamma_x/m_x = 1.4 \times 10^{-4}$ hypothesis

Local excesses around 750GeV:

2015 only: 2.9σ ⟶ 2015+2016: <1σ

8TeV+2015: 3.4σ ⟶ 8TeV+2015+2016: <2σ

Compatibility among results



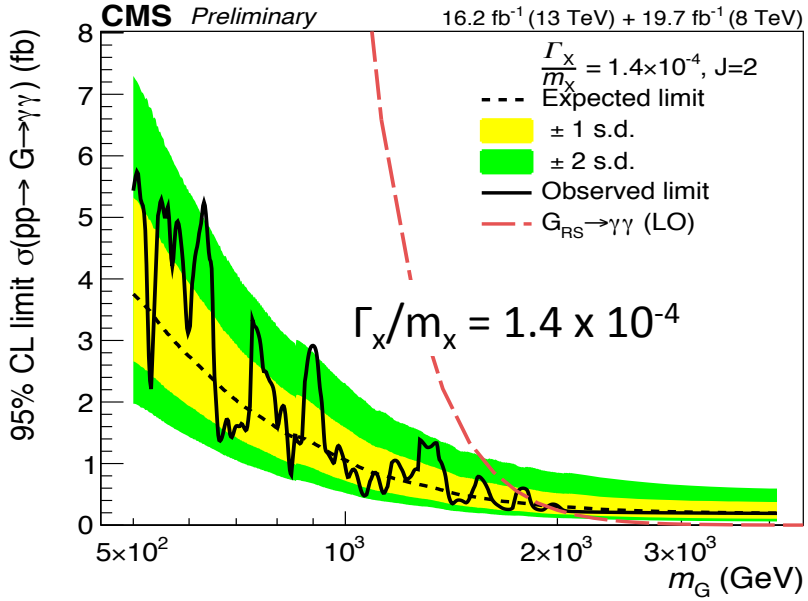
A signal with cross-section as the largest excess in 2015+8TeV would look like this

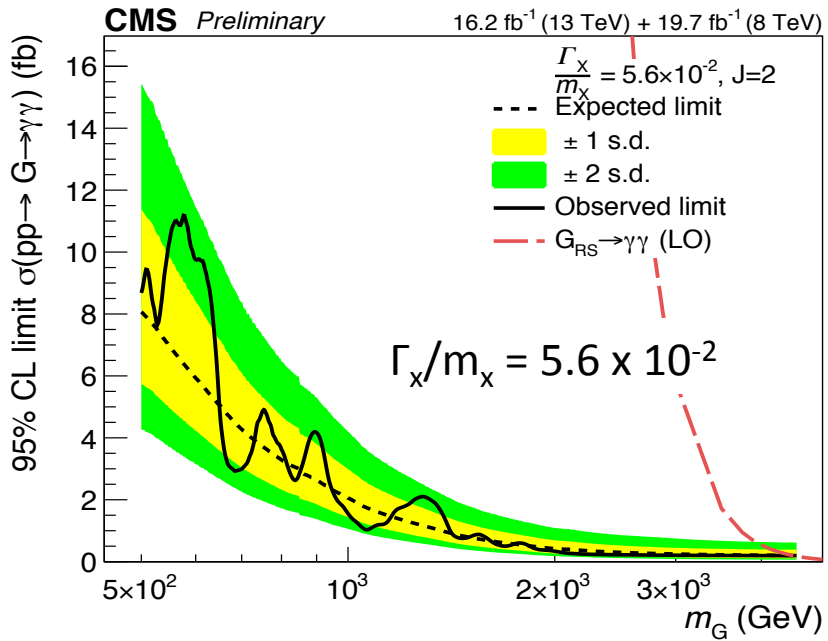
Compatibility of data at m_X=750GeV tested with a likelihood ratio test.

Compatibility at the level of

- 13TeV data only: 2.7σ
- 8TeV+13TeV data: 2.4σ

Run1+Run2 limits





Sensitivity driven by 2016 dataset

13TeV

Coupling	Exclusion
0.01	$m_G < 1.95$TeV except for [1.75, 1.85]
0.1	$m_G < 3.85$ TeV
0.2	$m_G < 4.45$ TeV

<u>8TeV contribution:</u>

~10% at low mass, negligible at high mass

Conclusions

Search for new resonances decaying to di-photon pairs presented, based on 12.9/fb of 13TeV CMS 2016 data

- Mass region between 0.5 and 4.5 TeV
- Tested hypothesis: spin-0 and spin-2 resonances with different widths

Data consistent with Standard Model expectations

Modest excess presented based on 2015 (+ 8TeV) data in the region around 750 GeV not confirmed by the new data

- Results at 750GeV compatible at level of 2.4σ

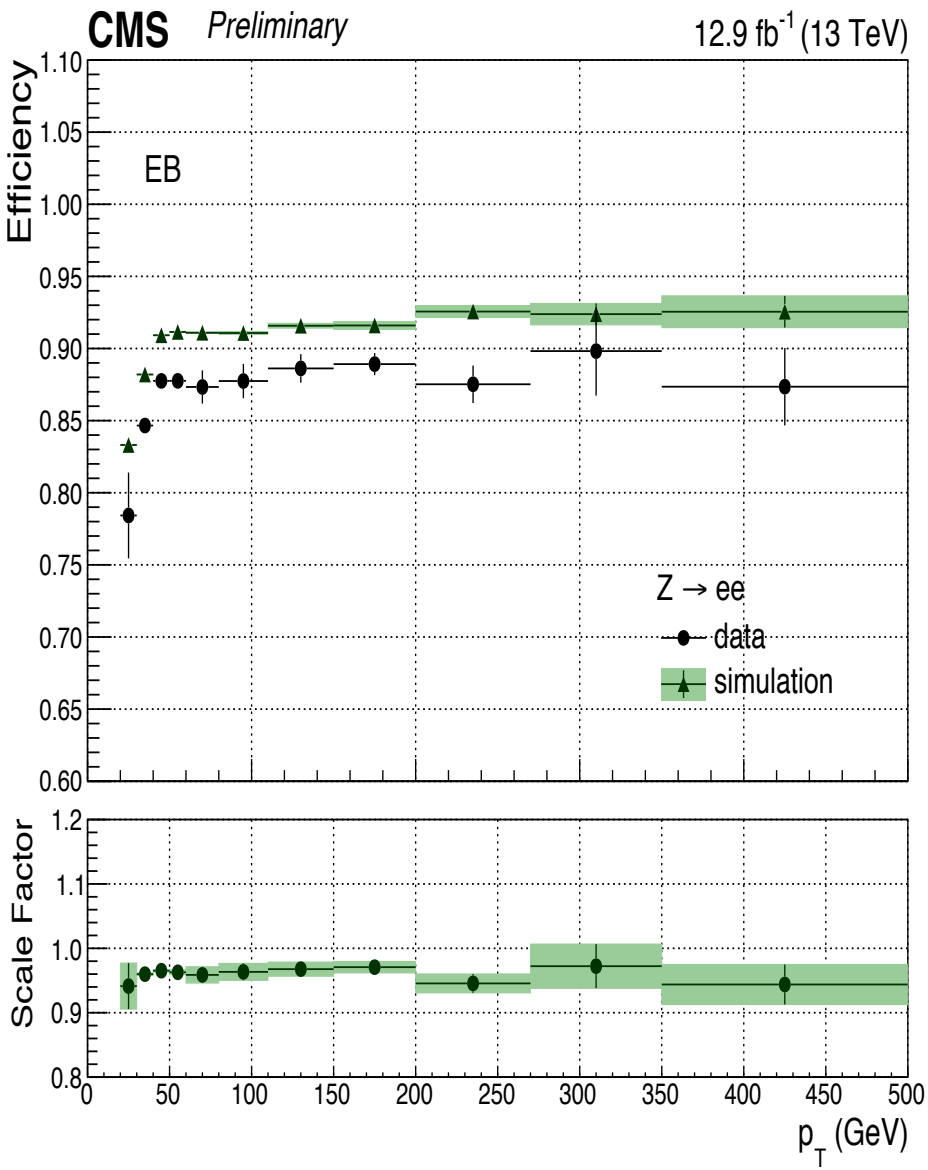
2016 data combined with 2015 and 8TeV data

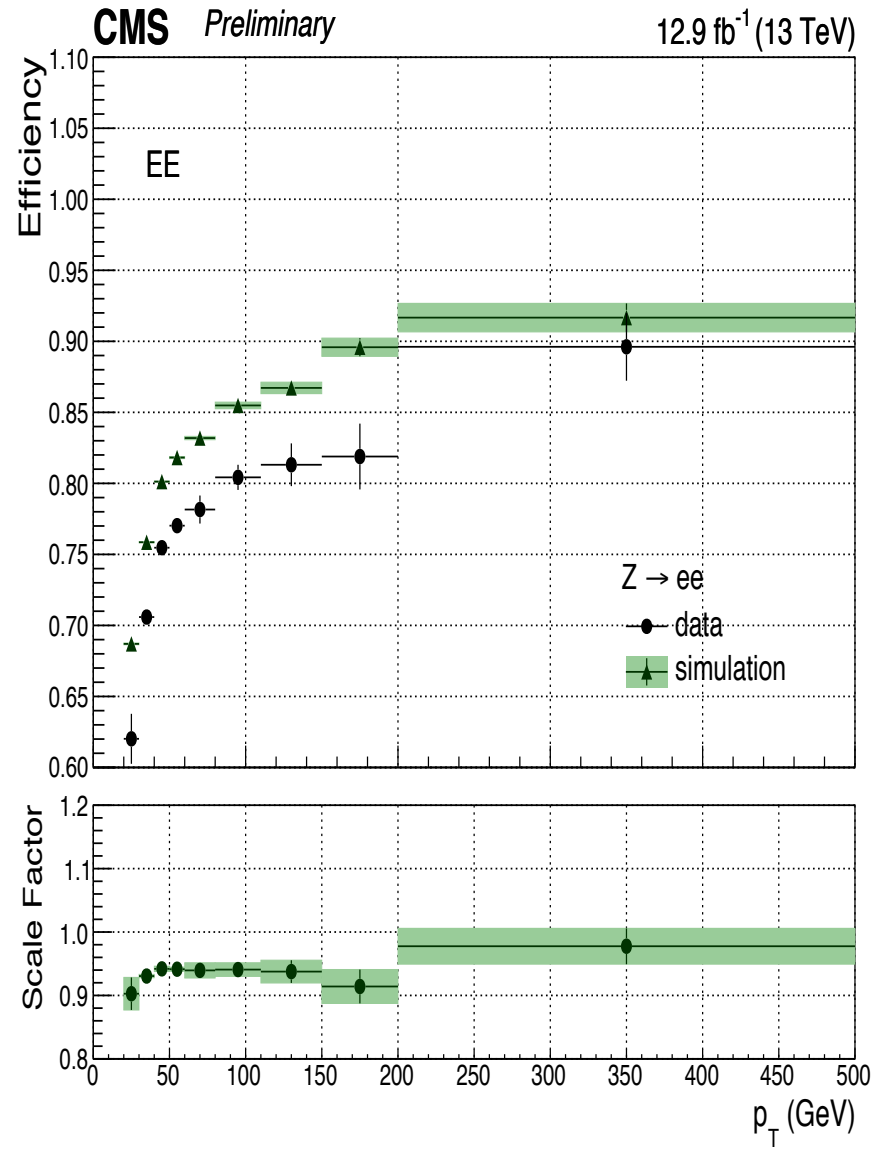
Limits set on the production cross section times di-photon branching ratio

- Negligible contribution of the 8TeV dataset
- 2016 data dominating limits and significances

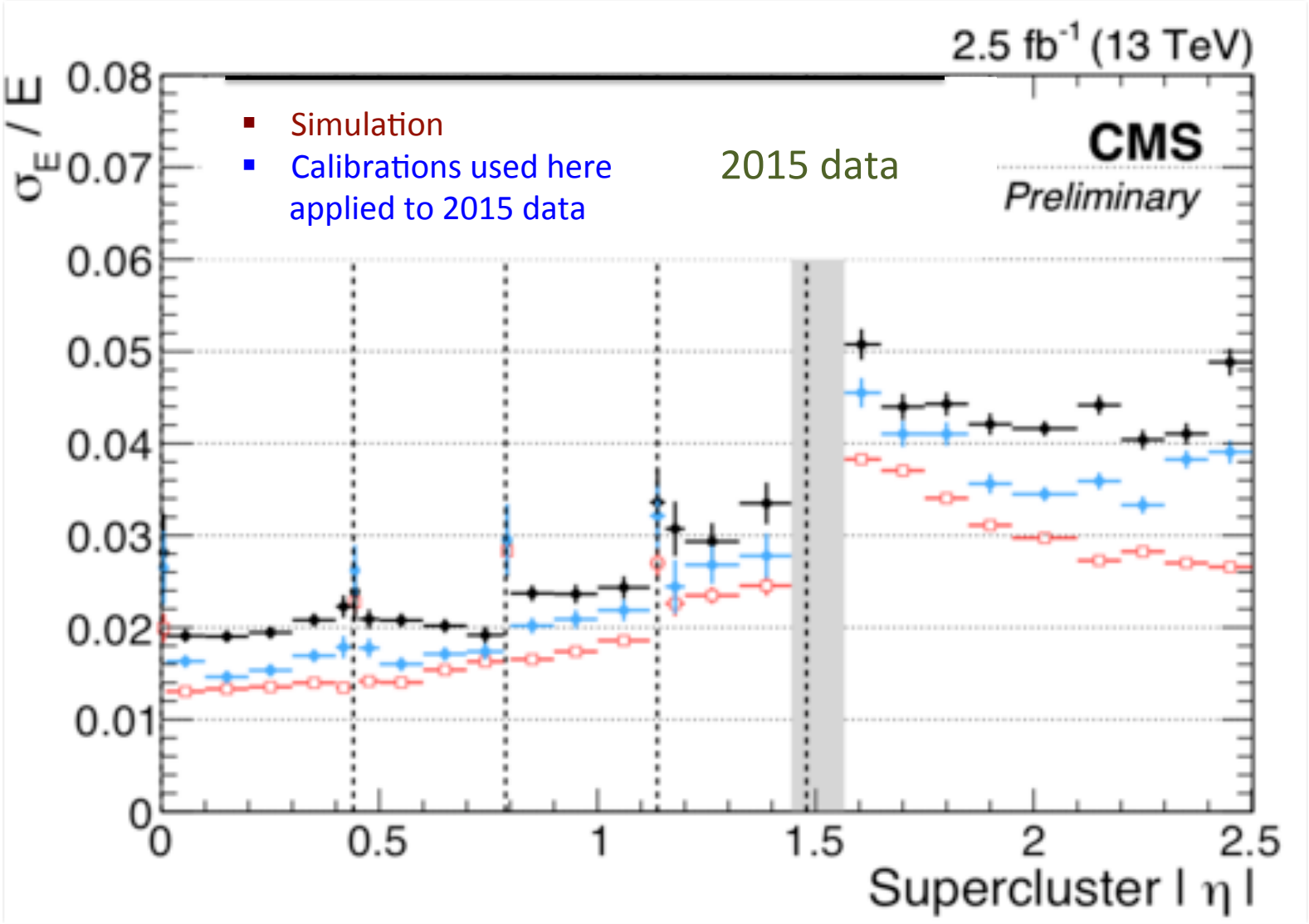
Backup

Photon selection efficiencies



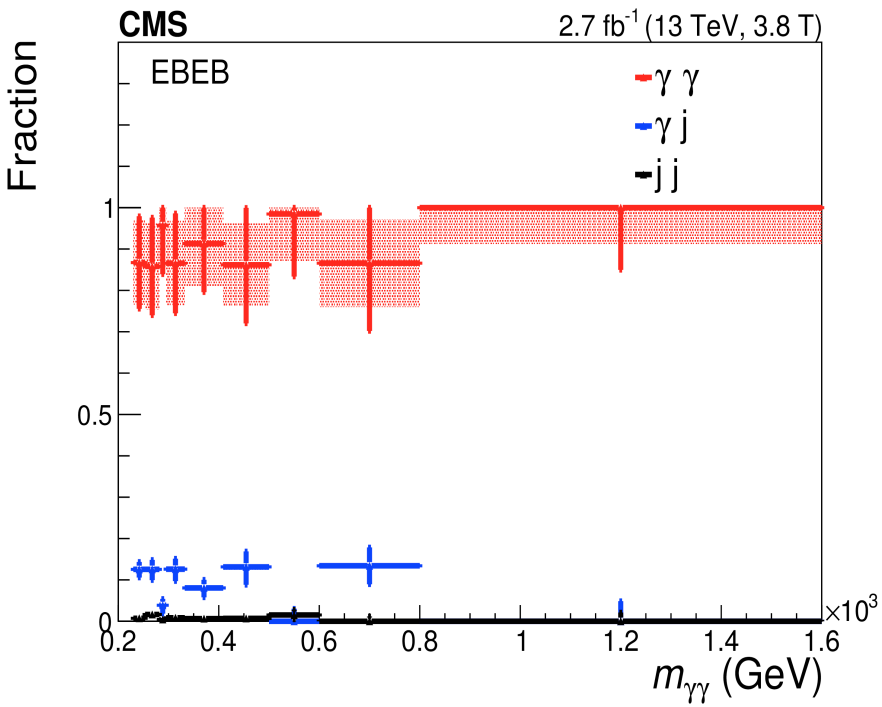


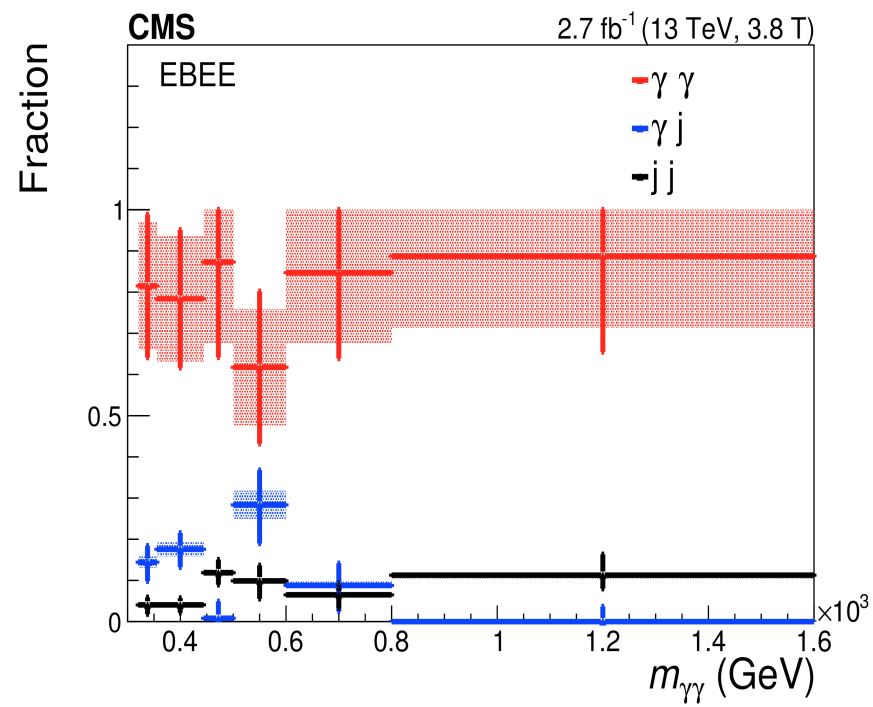
Energy calibration



Background purities

2015 plots. Consistent purities measured this year





Dominant contribution: 2 prompt photons

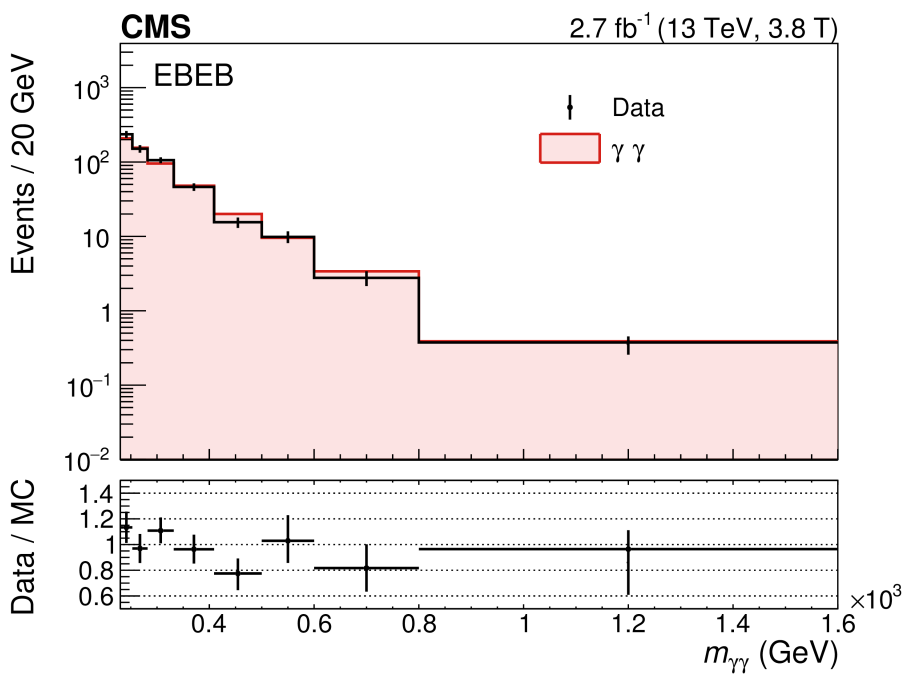
QCD and photon+jets: <10% (20%) in EBEB (EBEE)

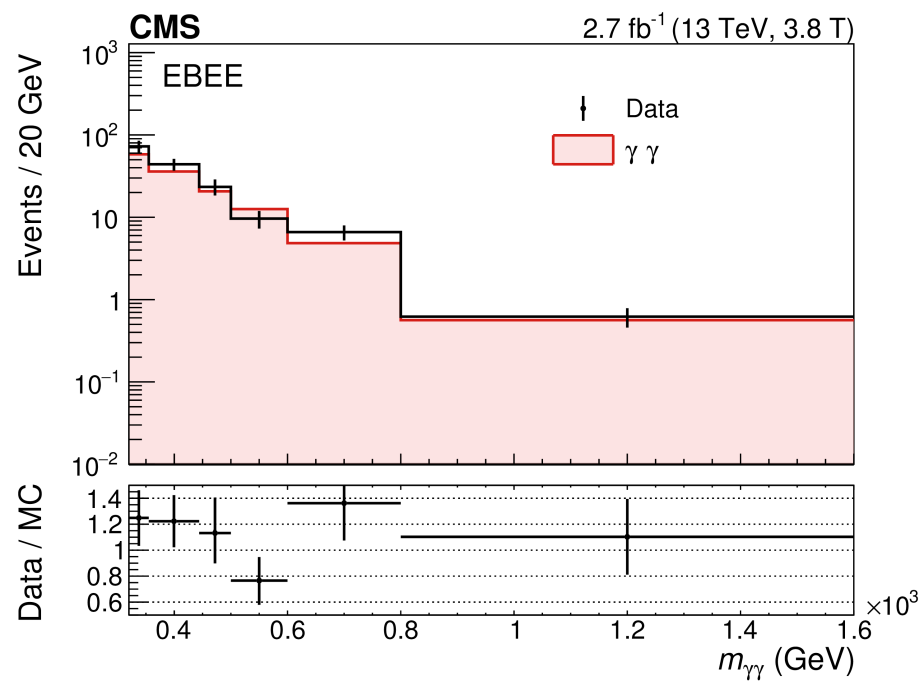
Background composition, closure test

Data driven prediction for the prompt-prompt component compared with theory

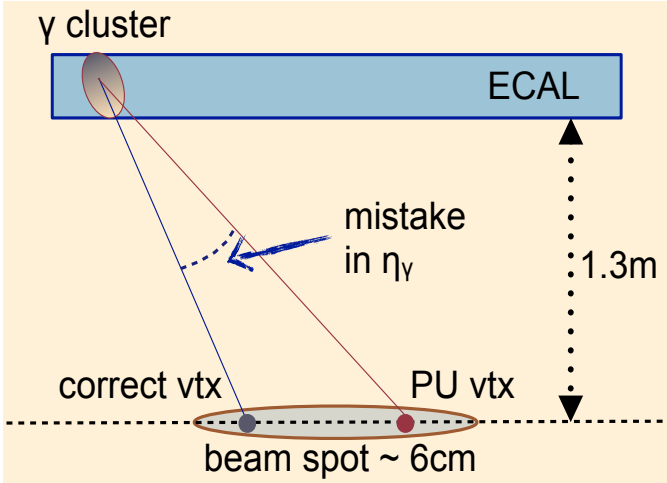
✓ Sherpa generator rescaled to 2γNNLO

<u>2015 plots</u>. Consistent purities measured this year





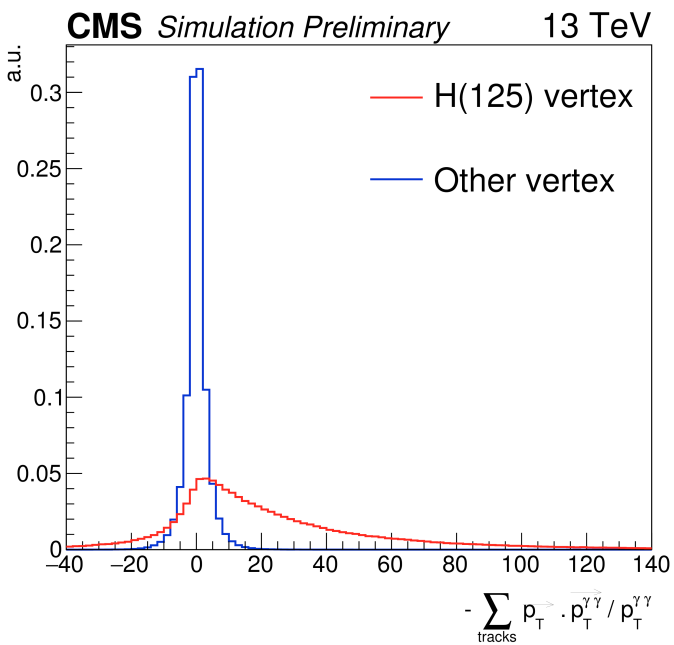
Vertex determination

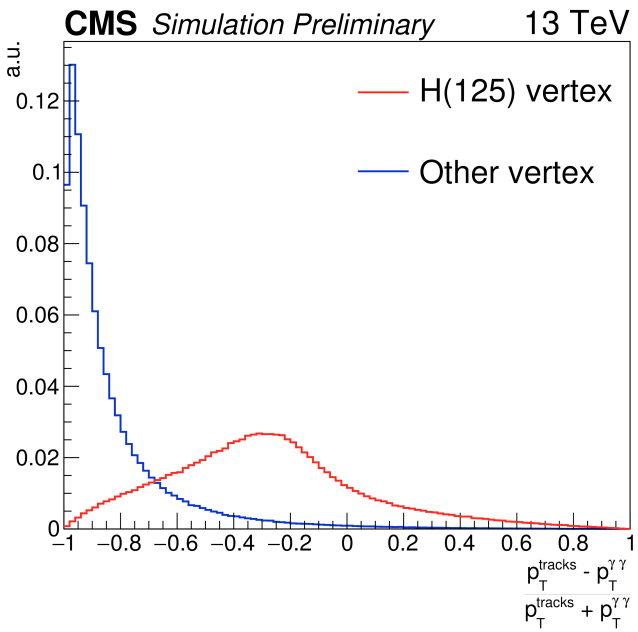


Interaction vertex identified using recoiling tracks and conversions when present: Sum(p_T^2), $p_T(\gamma\gamma)$ vs p_T(tracks), Z(conv)

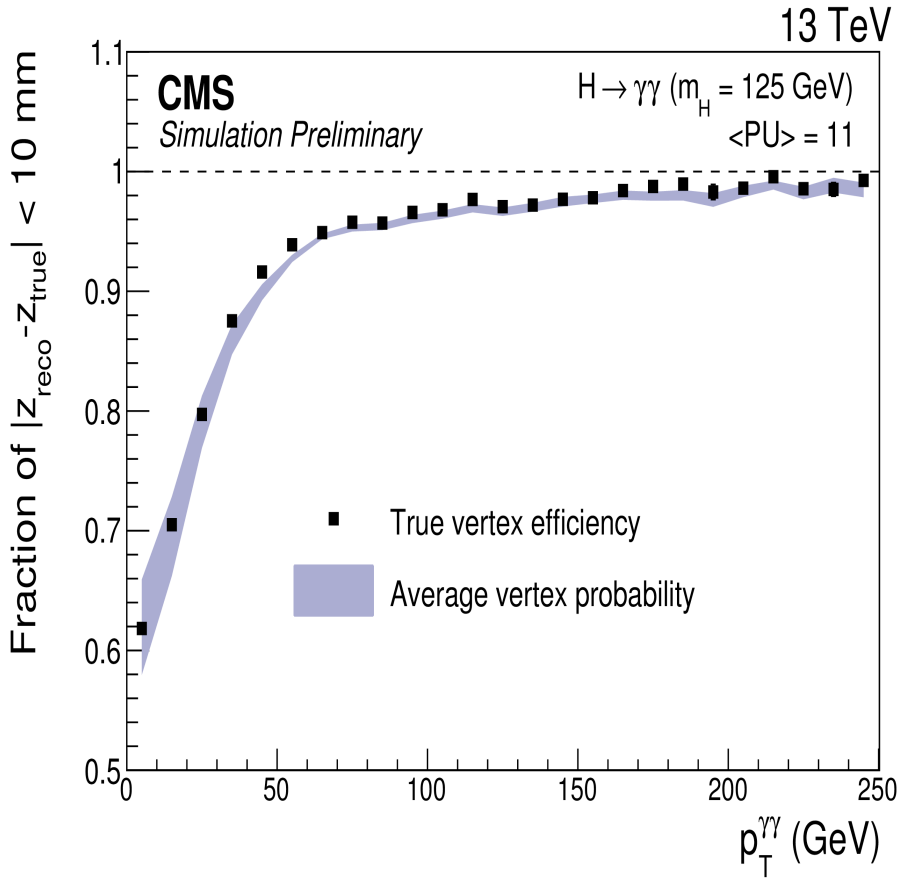
Combined in a BDT

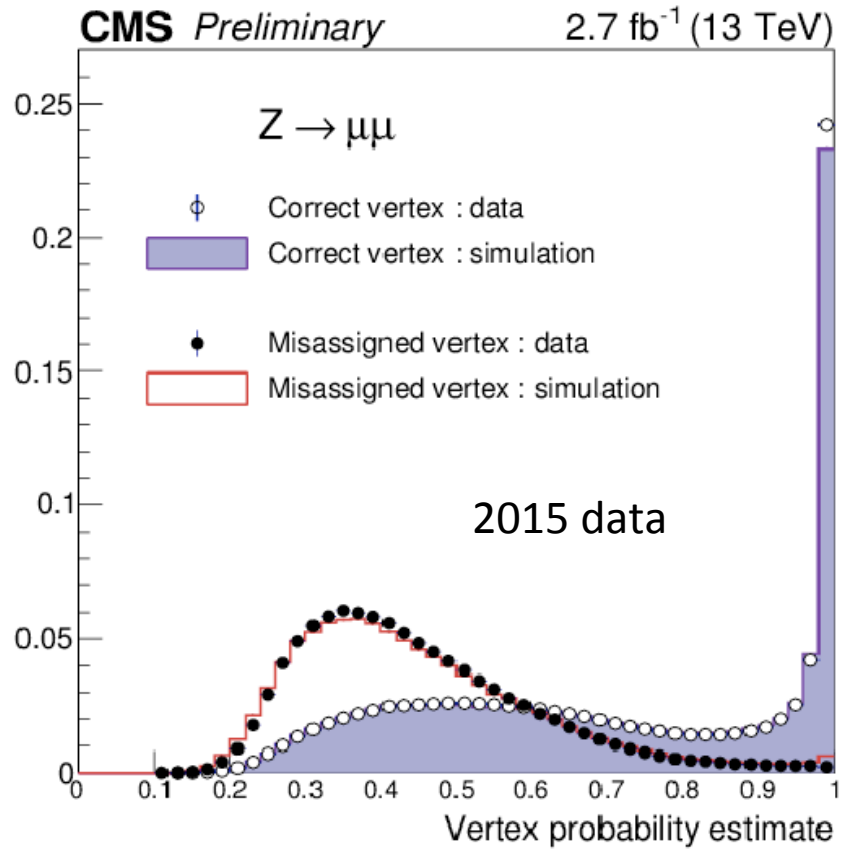
Same as in H->γγ analysis





Vertex ID performance





Probability to assign the correct vertex in H->γγ analysis

Background model

Parametric 1dim fit to data in the 2 categories, $f(m) = m^{a+b\log(m)}$

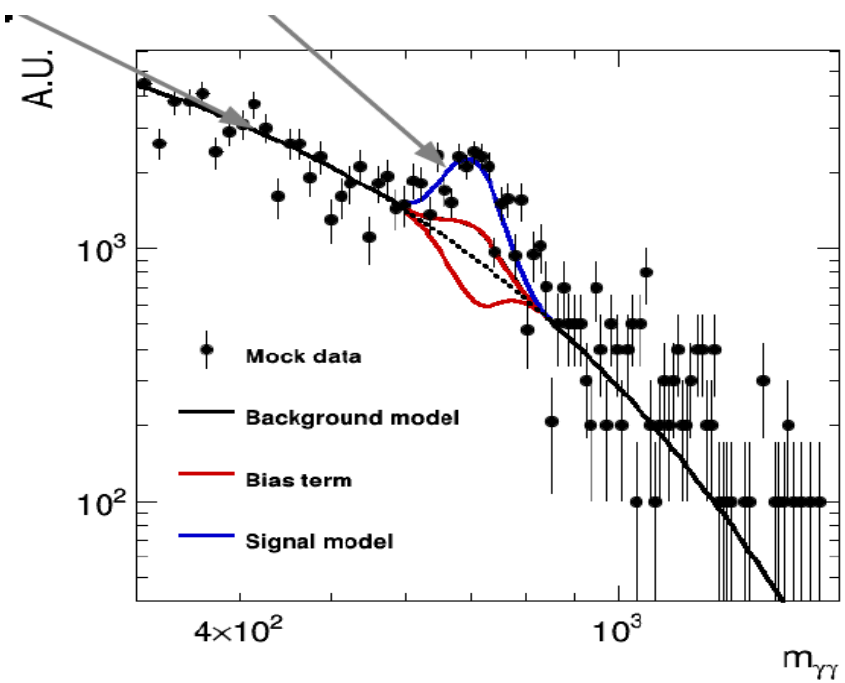
- Model coefficients treated as unconstrained nuisance parameters in the hypothesis test

Goodness of background fit assessed locally in $m_{\gamma\gamma}$ using MC

- Study pull of mean number of background events
- Model ok if $b = |\text{median}(p)| < 0.5$ for all windows
  - Uncertainty on mean number of B events underestimated by < 10%
- If not => error increased with a bias term

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

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



Bias term = signal like component added to the model

- negligible impact on sensitivity

Systematics

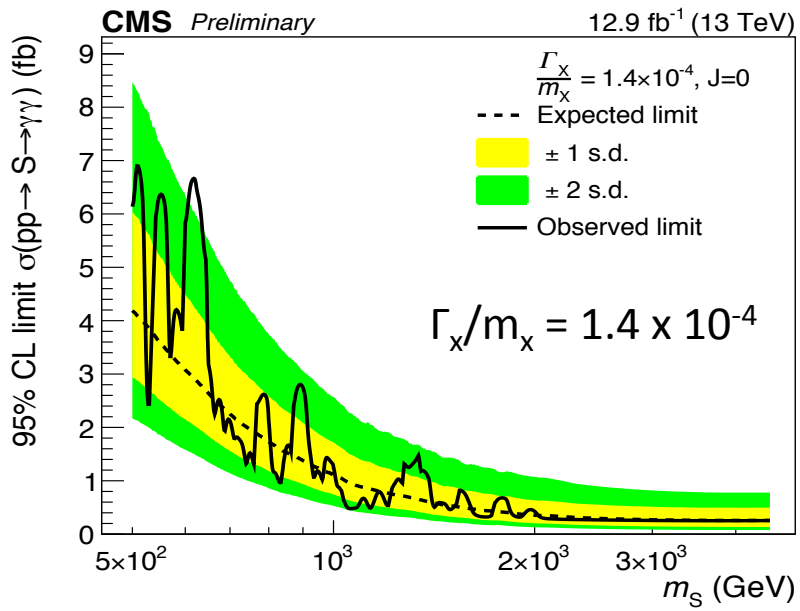
Signal model:

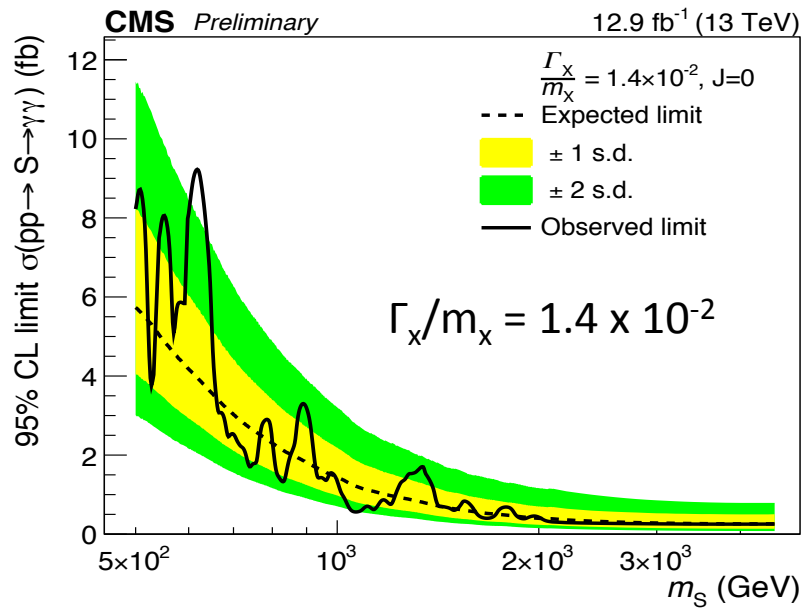
- Luminosity: 6.2%
- Trigger and photon selection: 6%
- Photon energy scale: 1%
- Photon energy resolution: 0.5%
- PDF: 6%

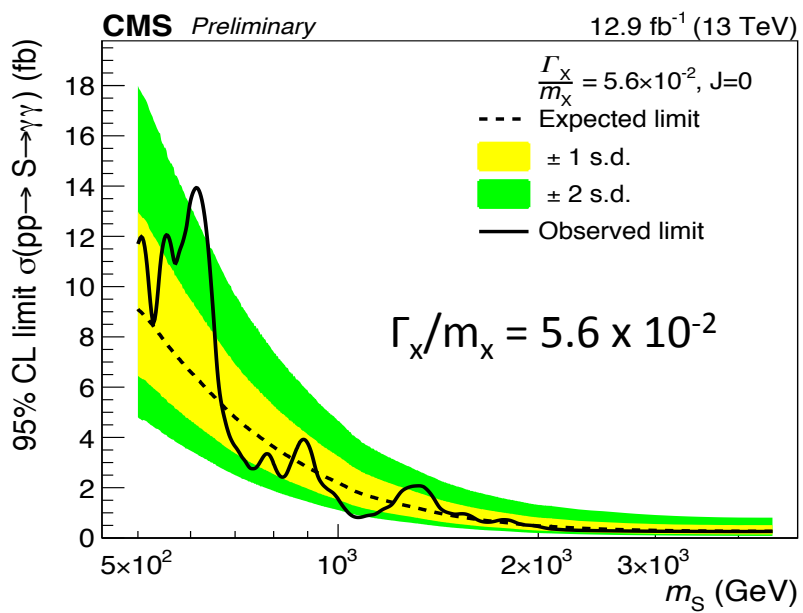
Background model:

- Bias term only
- [Parameter coefficients: unconstrained nuisance parameters
  - contribute to statistical error]

2016 exclusion limits

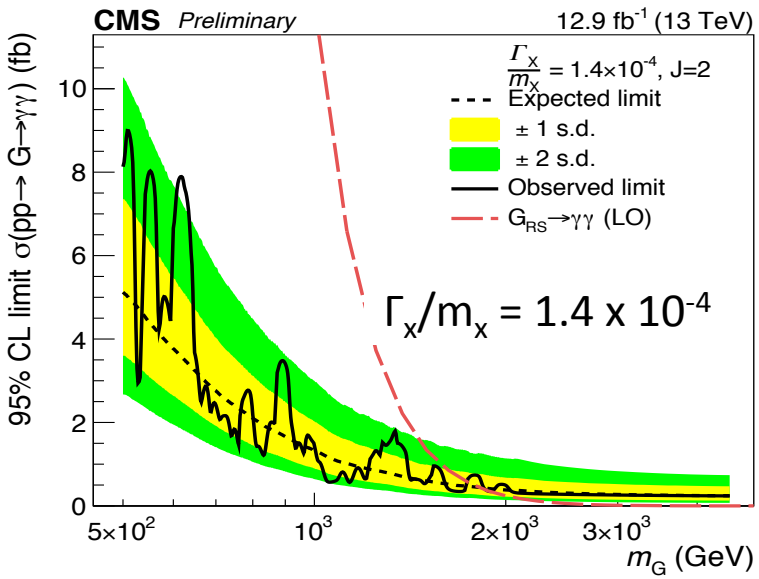


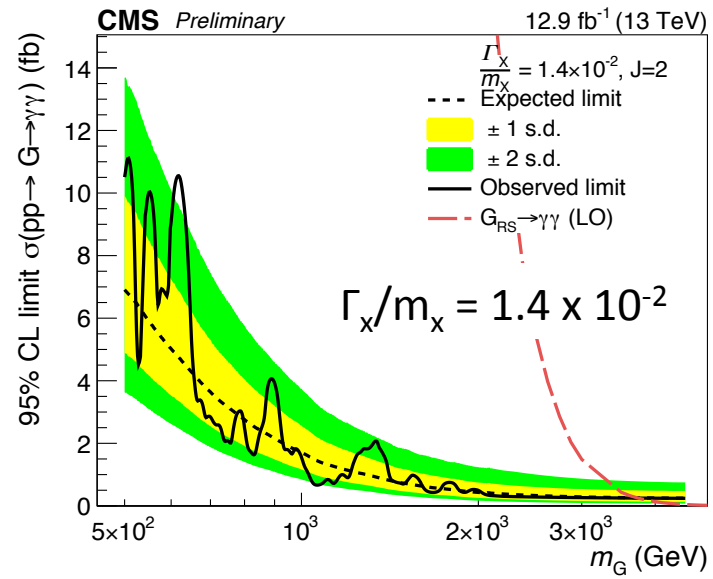


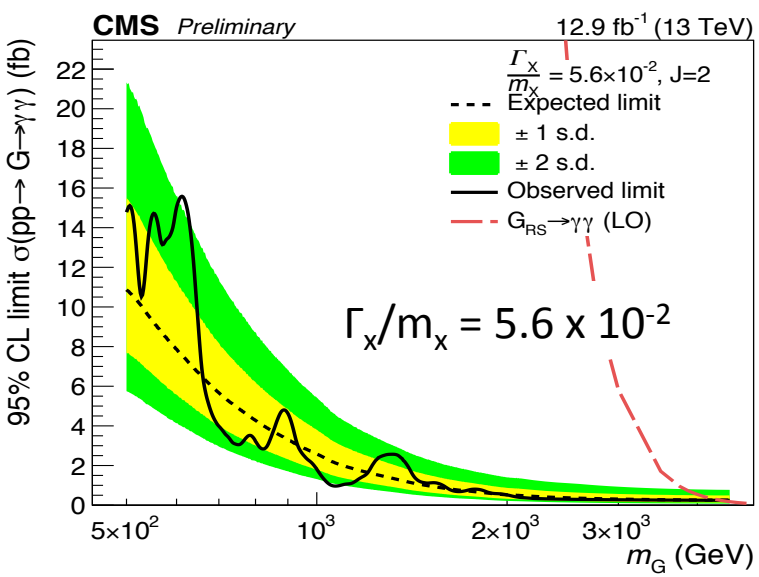


Spin-0

2016 exclusion limits

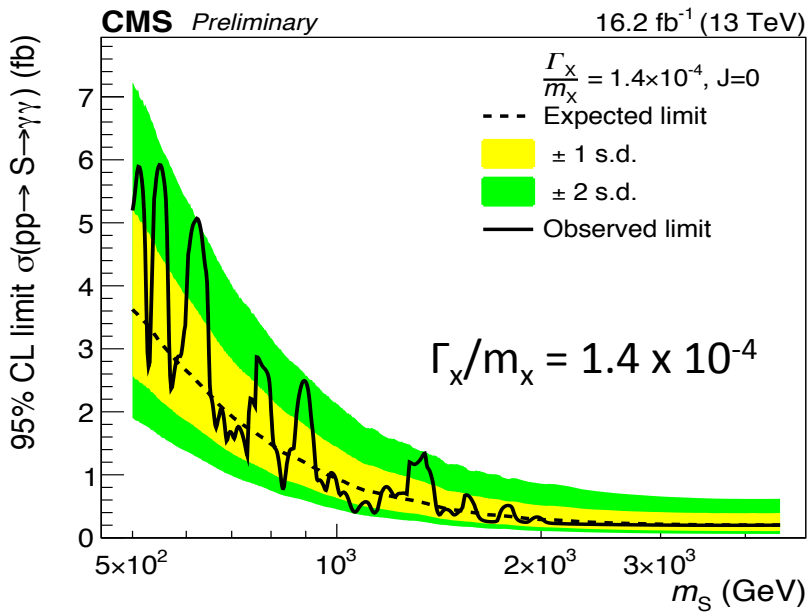


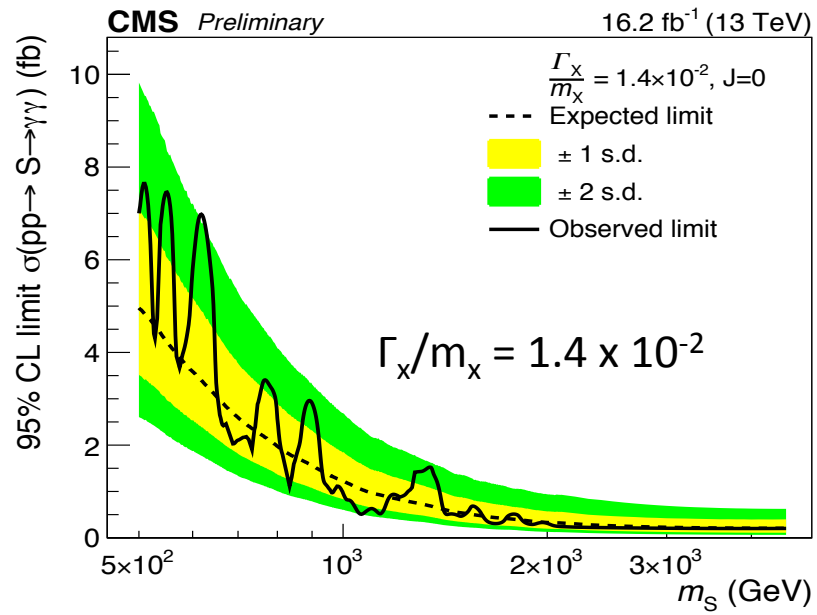


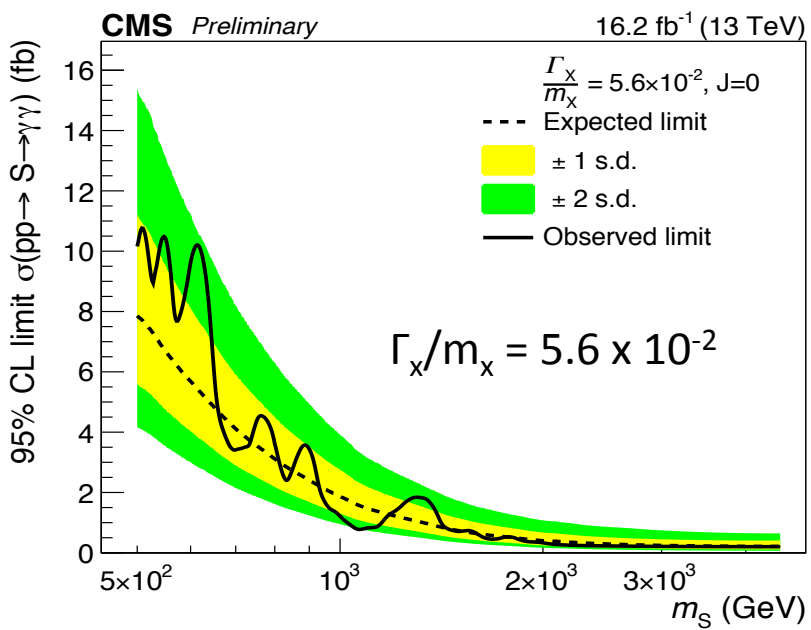


Spin-2

2015 + 2016 exclusion limits

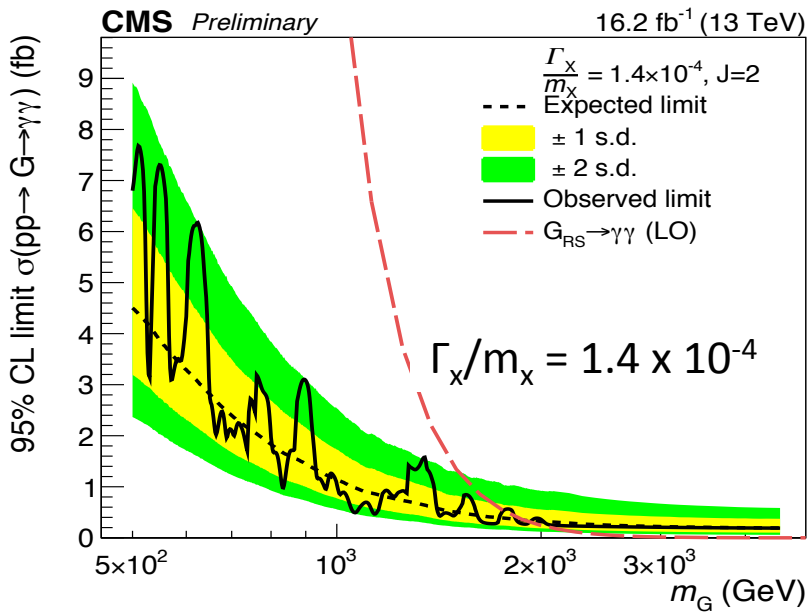


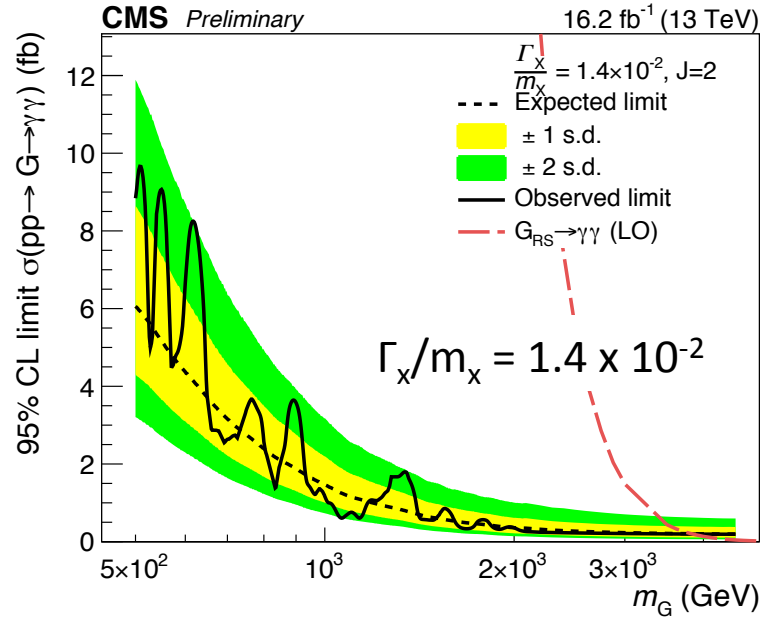


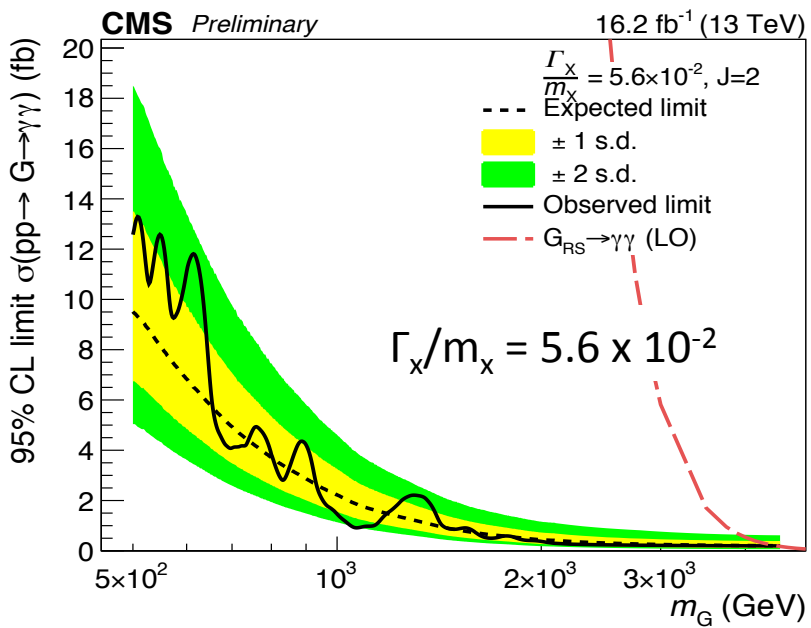


Spin-0

2015 + 2016 exclusion limits

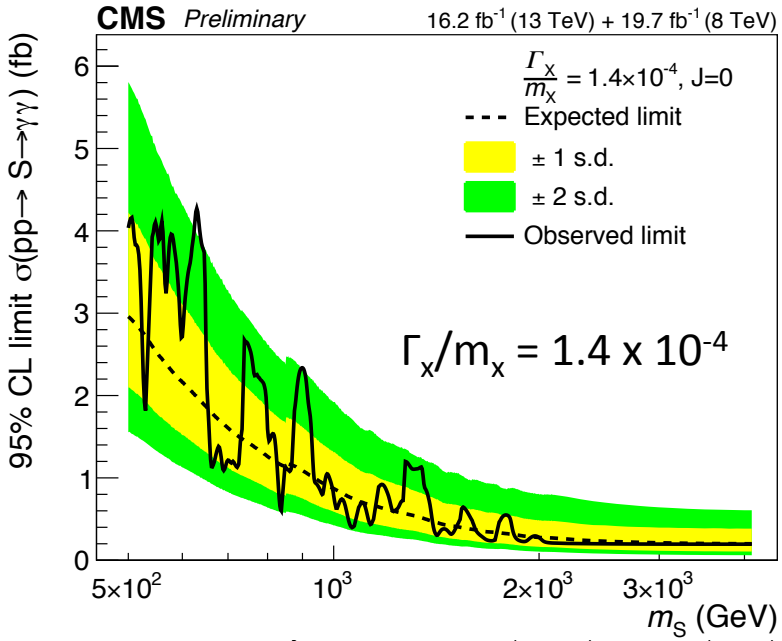


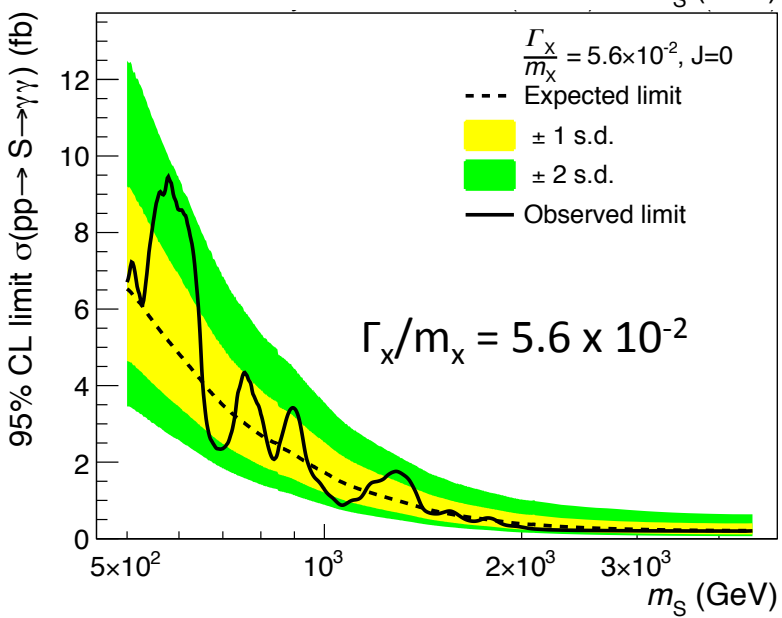


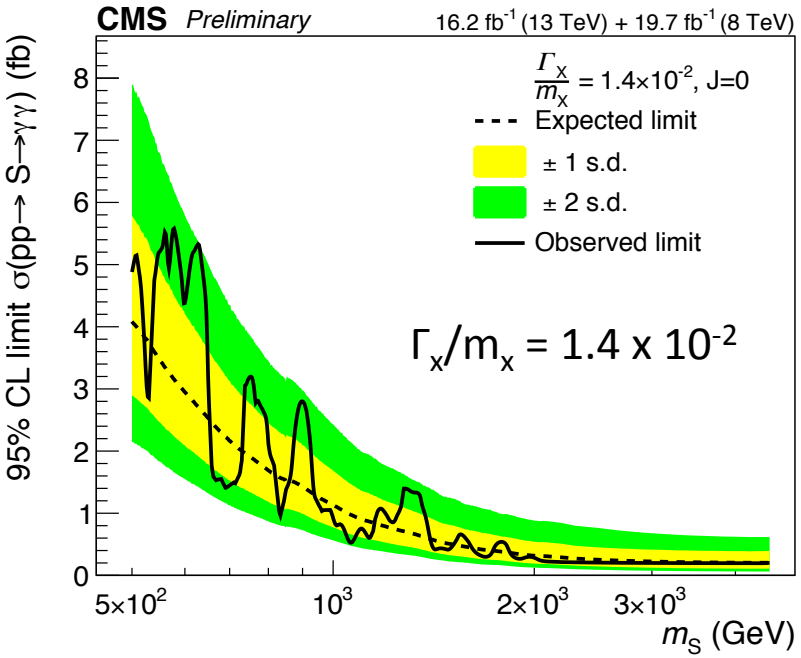


Spin-2

8TeV + 13TeV exclusion limits

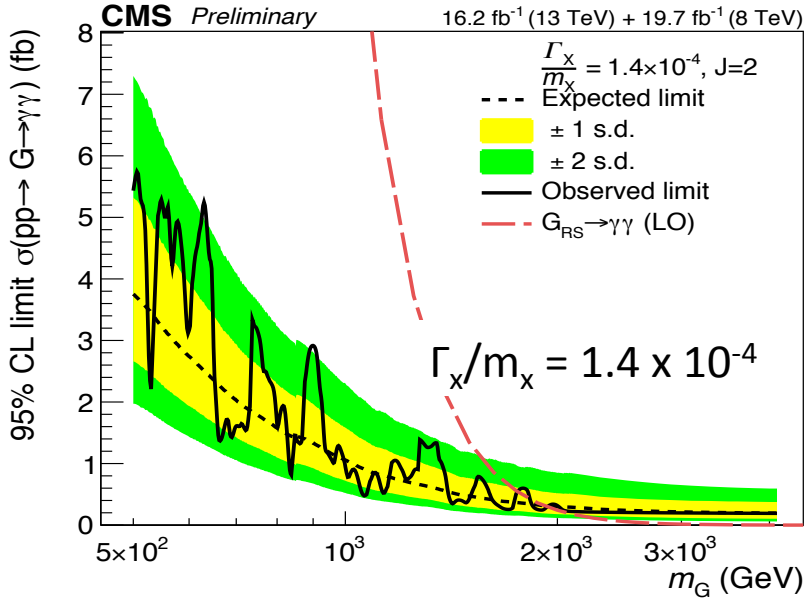


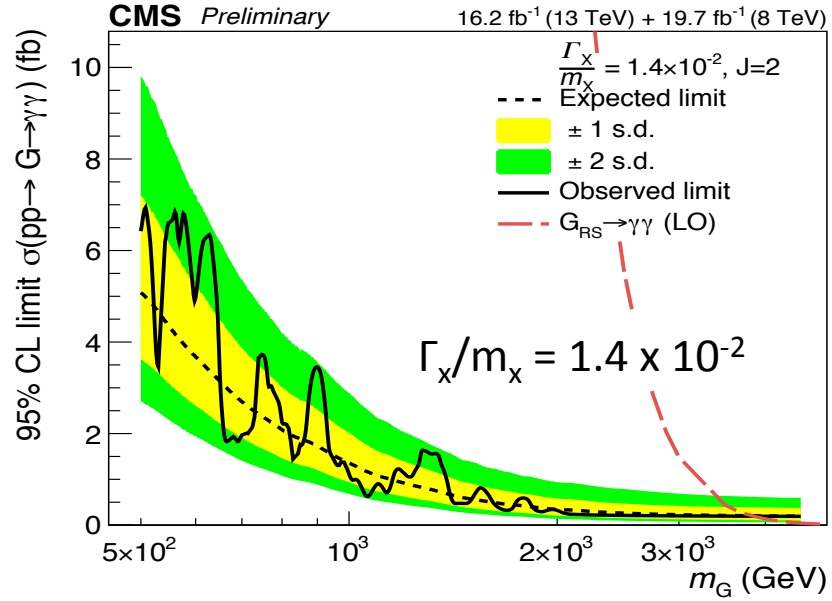


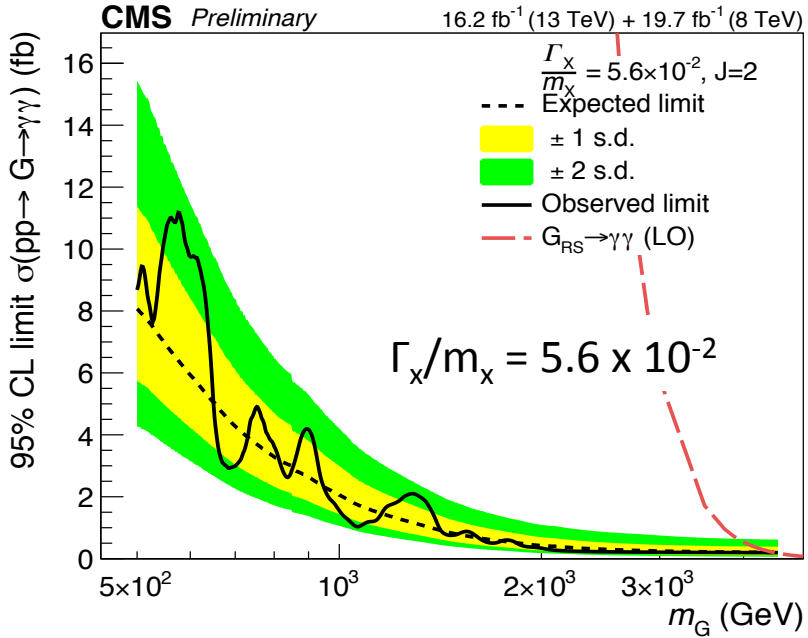


Spin-0

8TeV + 13TeV exclusion limits

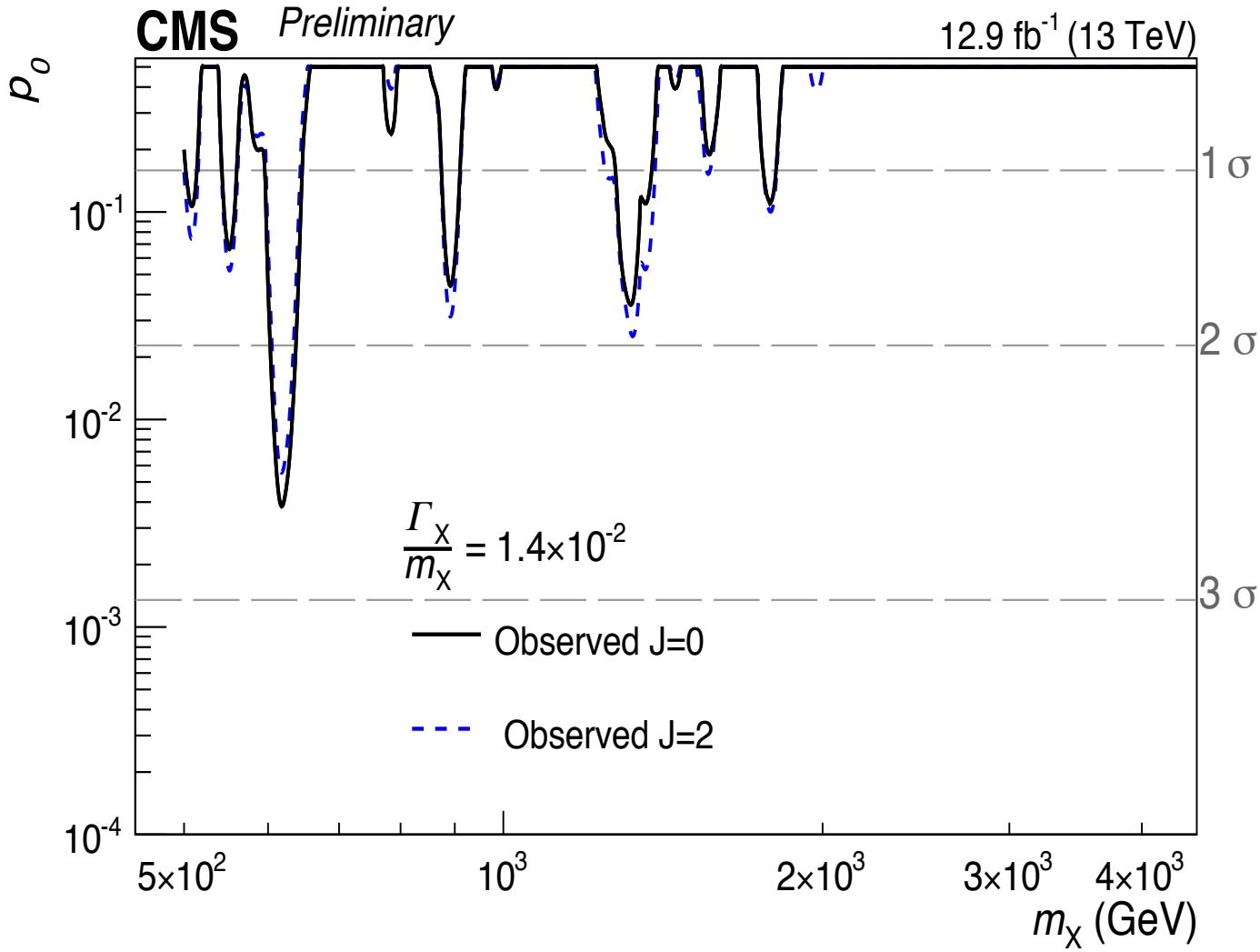




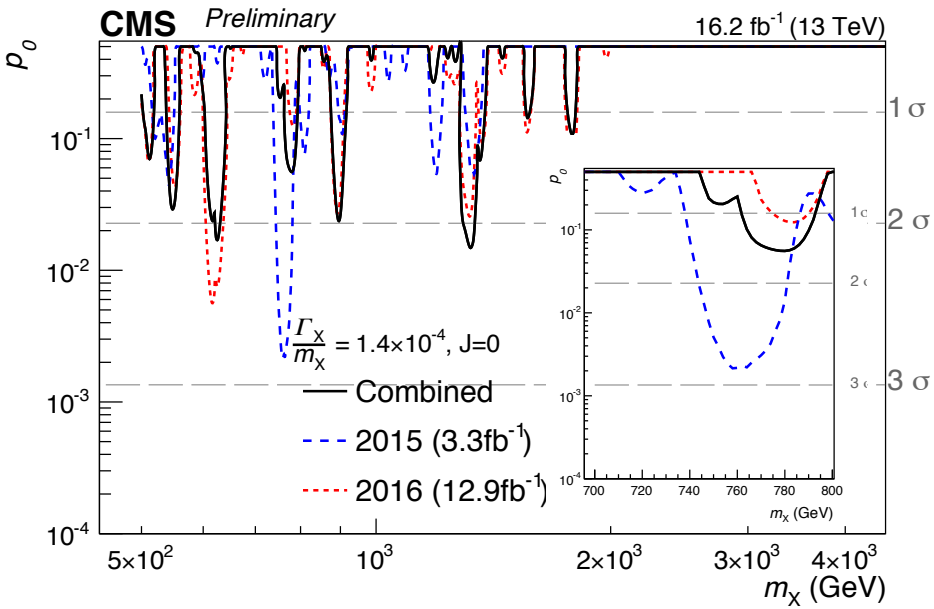


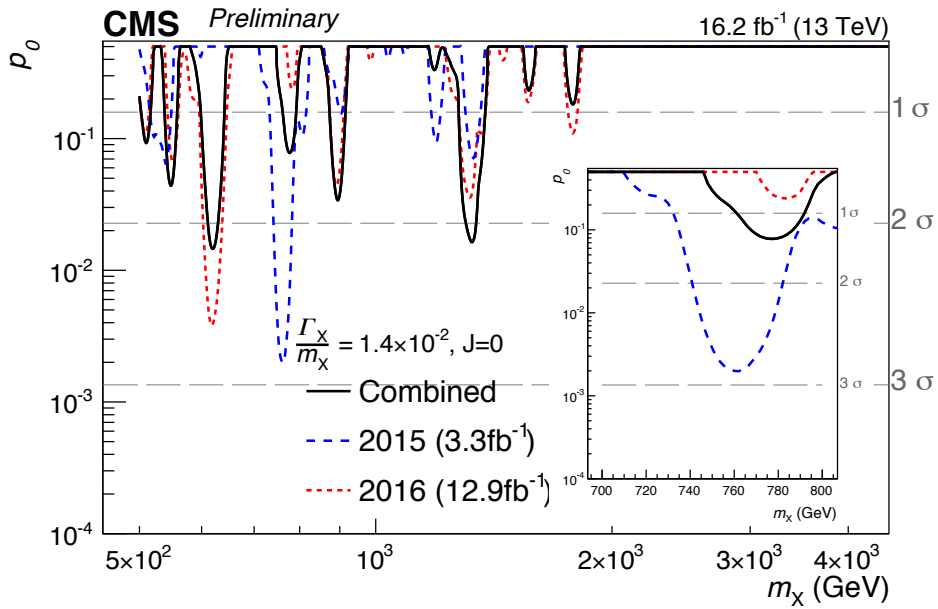
Spin-2

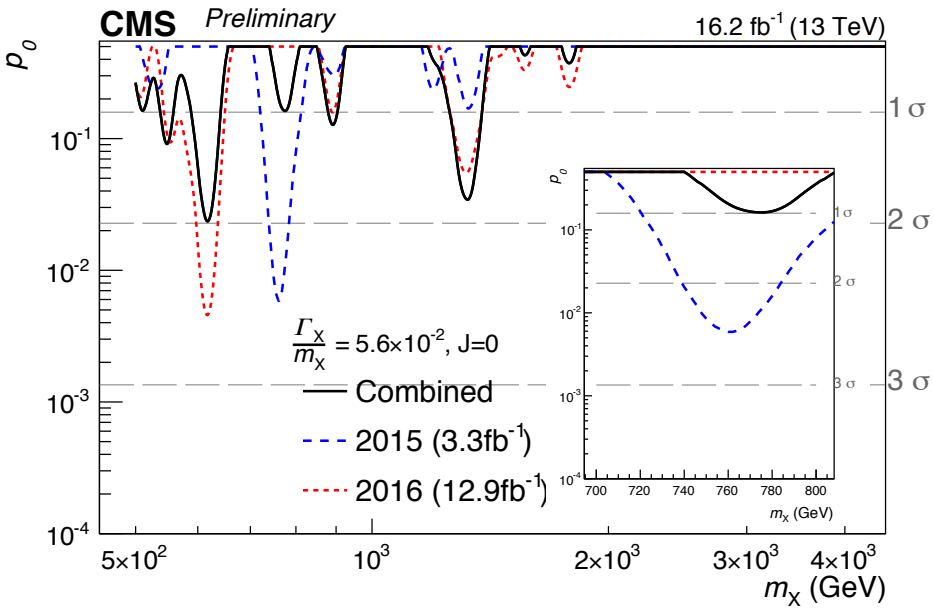
2016 p-value (intermediate width)



2015 + 2016 p-value

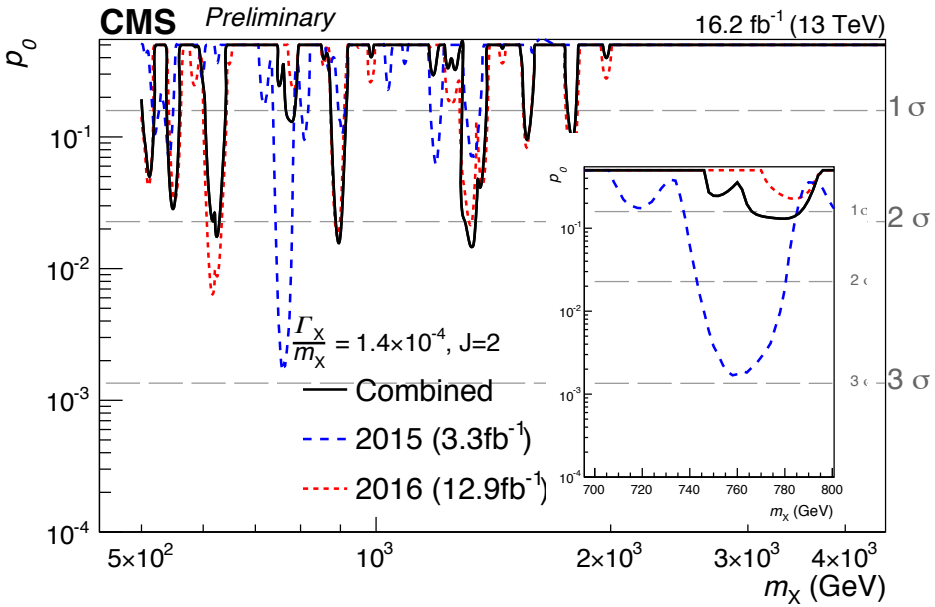


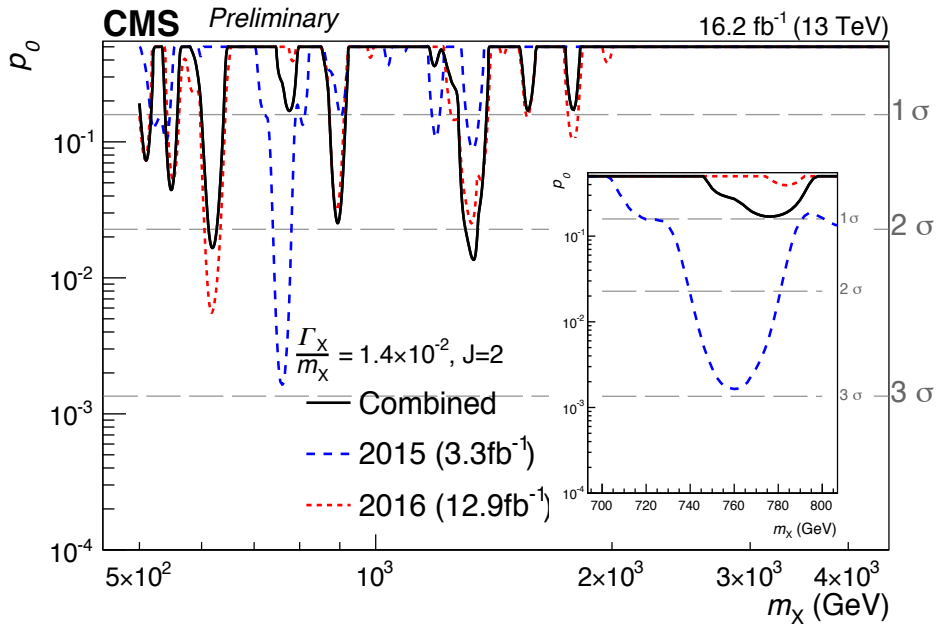


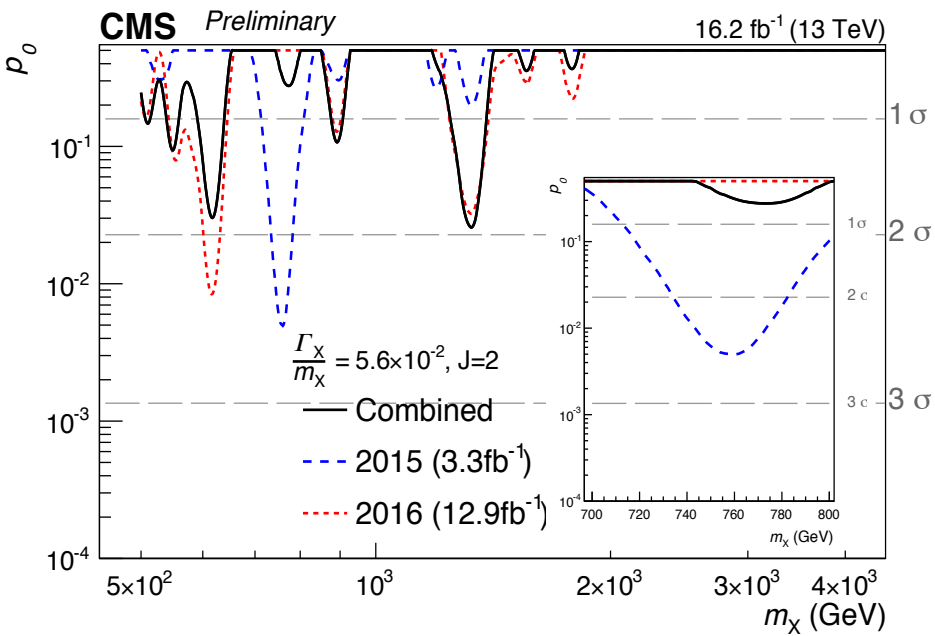


Spin-0

2015 + 2016 p-value

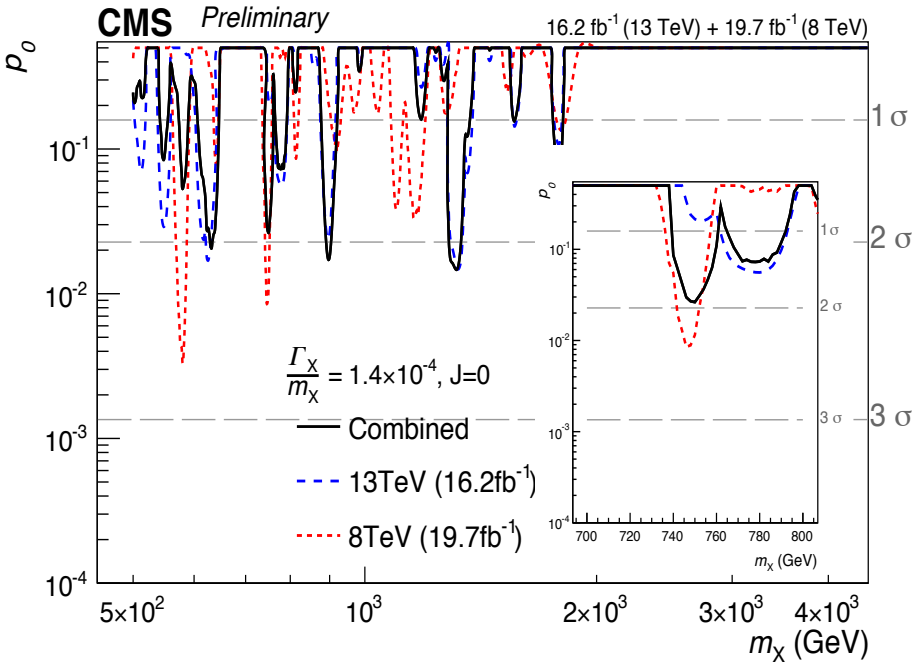


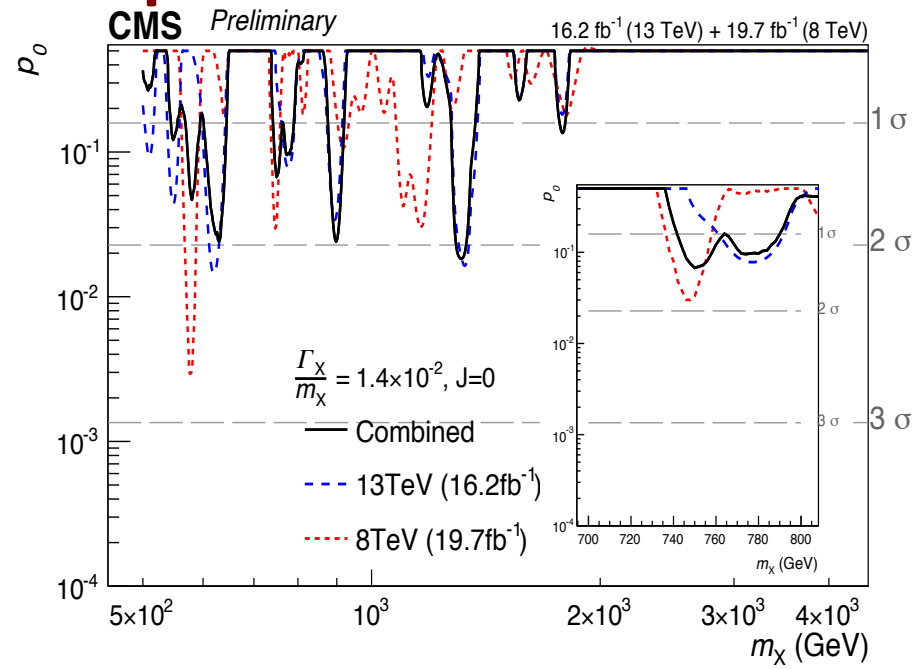


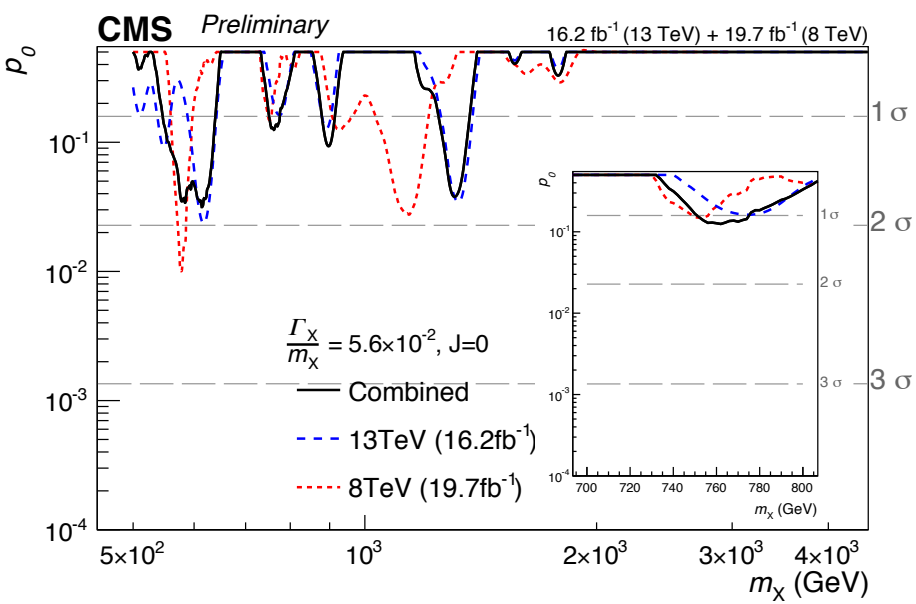


Spin-2

8TeV + 13TeV p-value

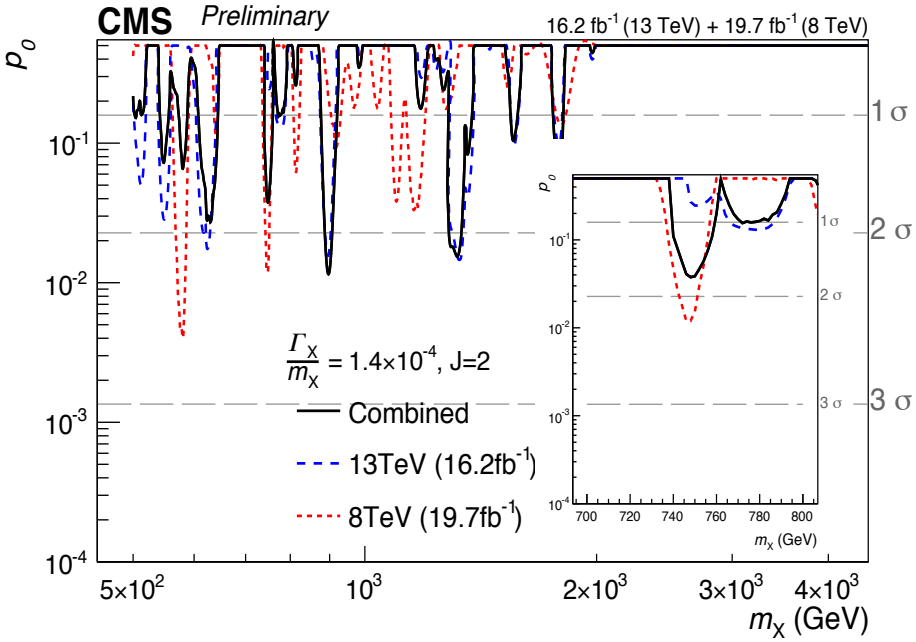


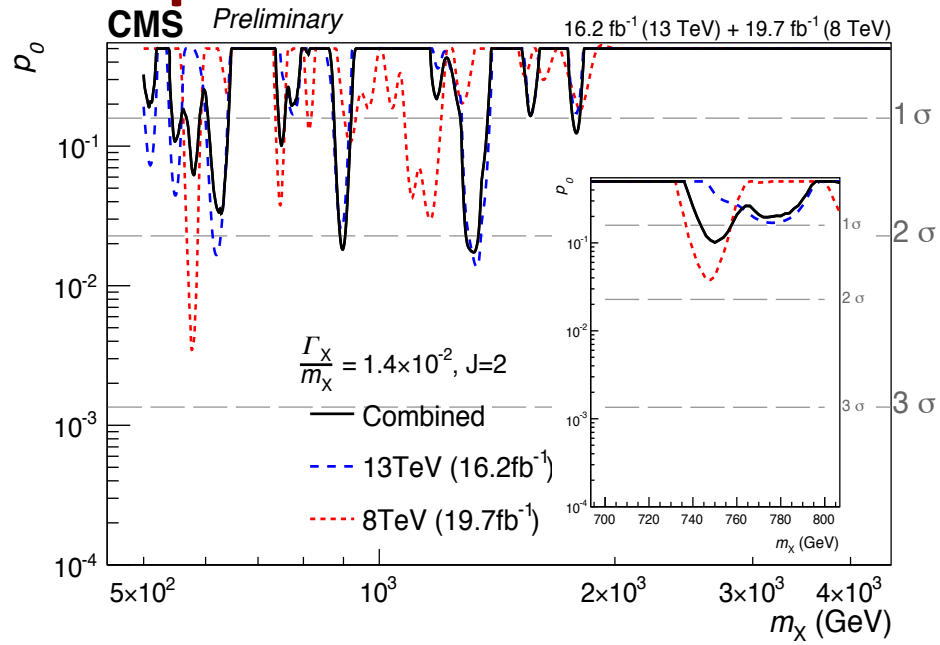


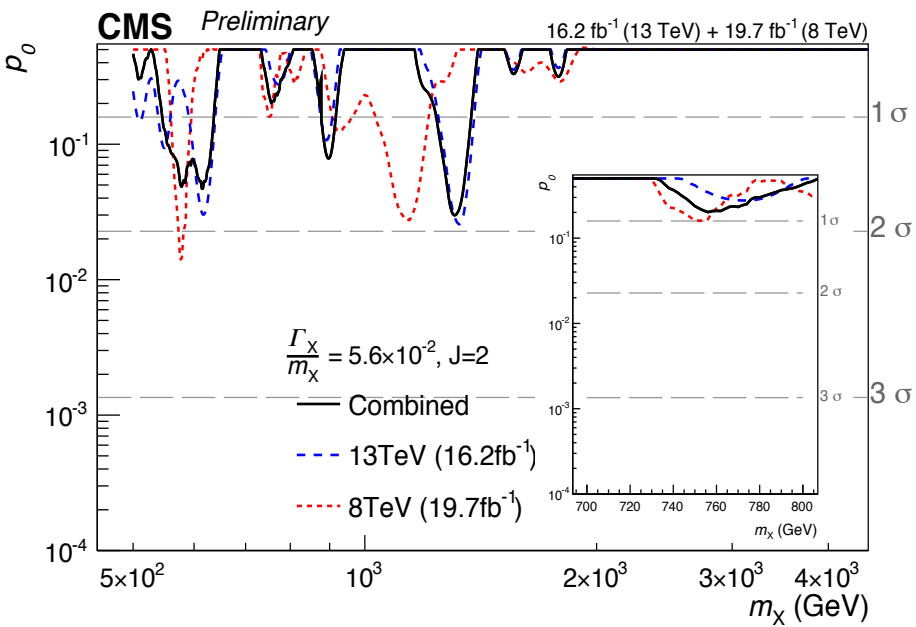


Spin-0

8TeV + 13TeV p-value

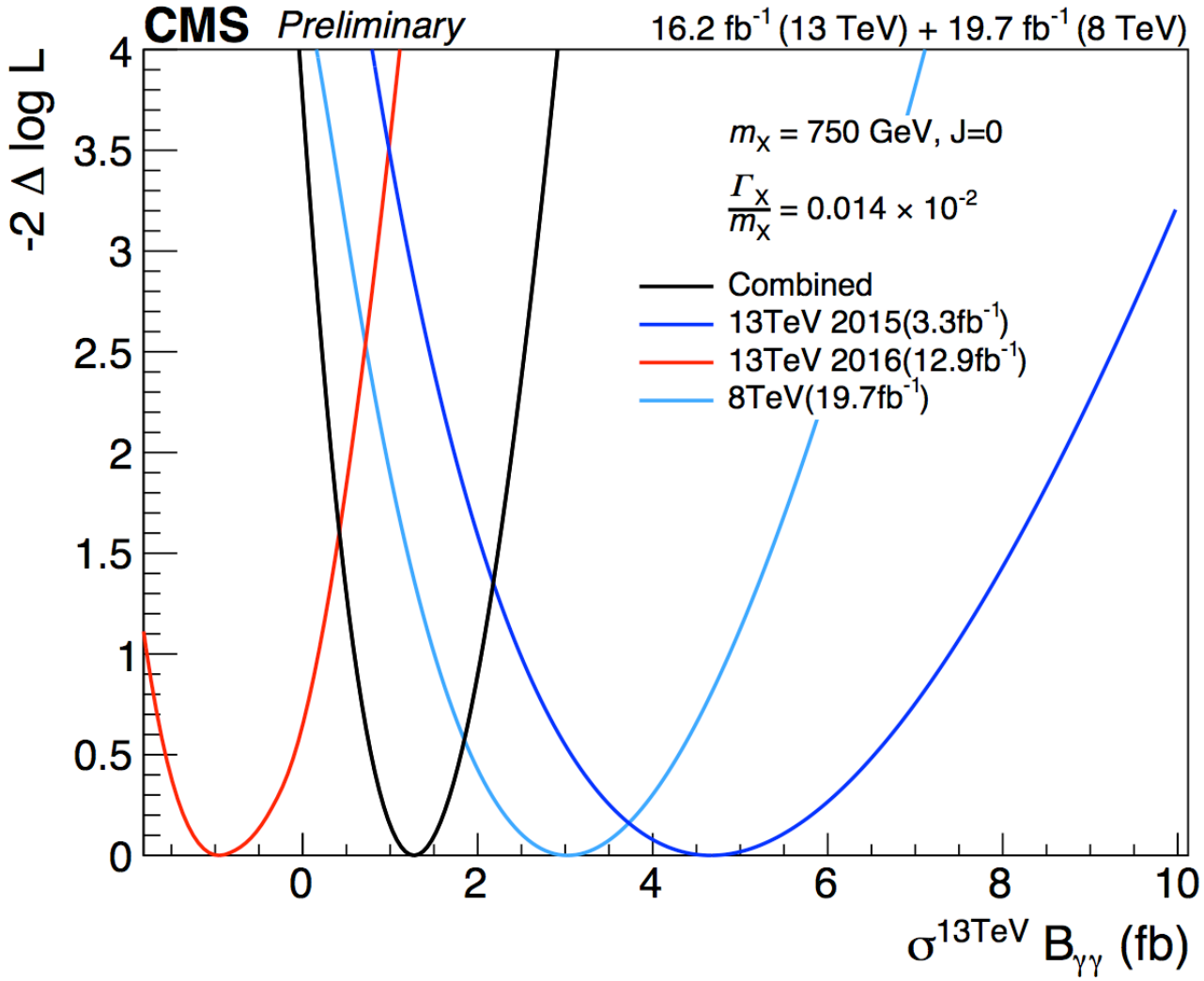






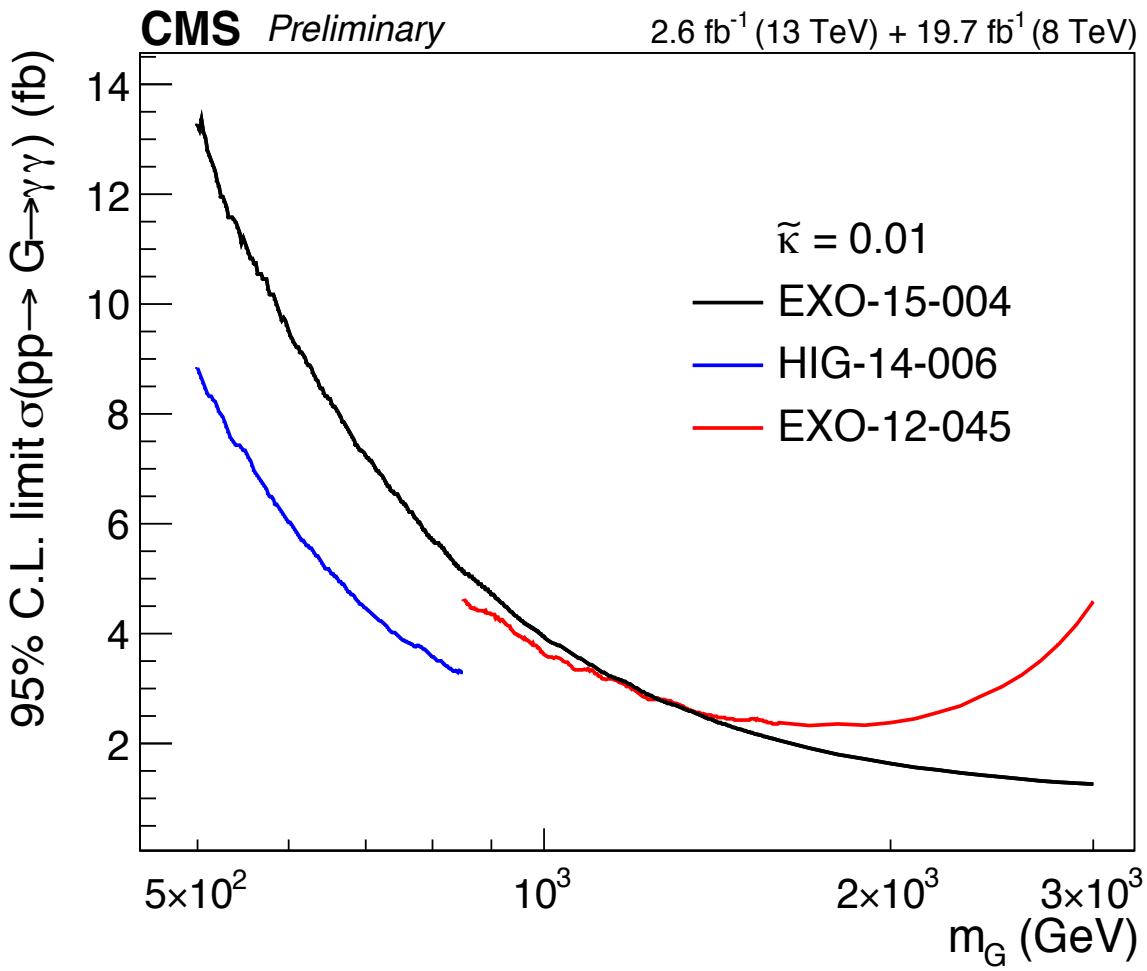
Spin-2

2016+2015+8TeV: σ likelihood scan

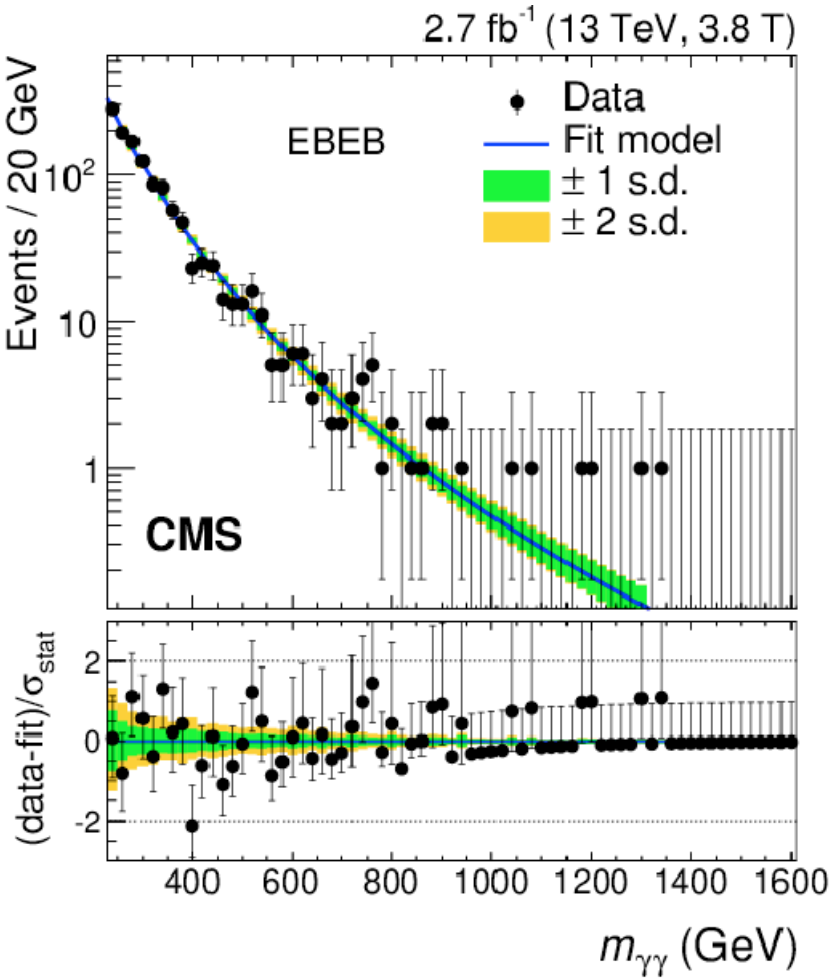


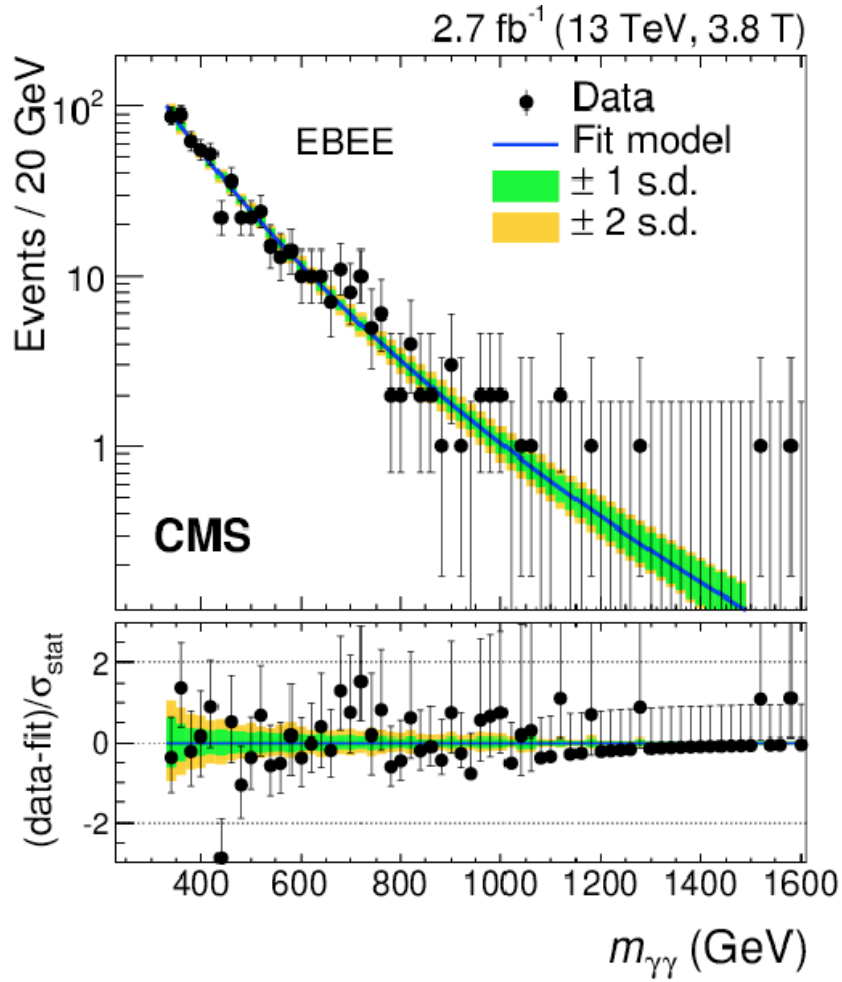
$\Gamma_x/m_x = 1.4 \times 10^{-4}$, spin-0, m_X=750GeV

8TeV analysis

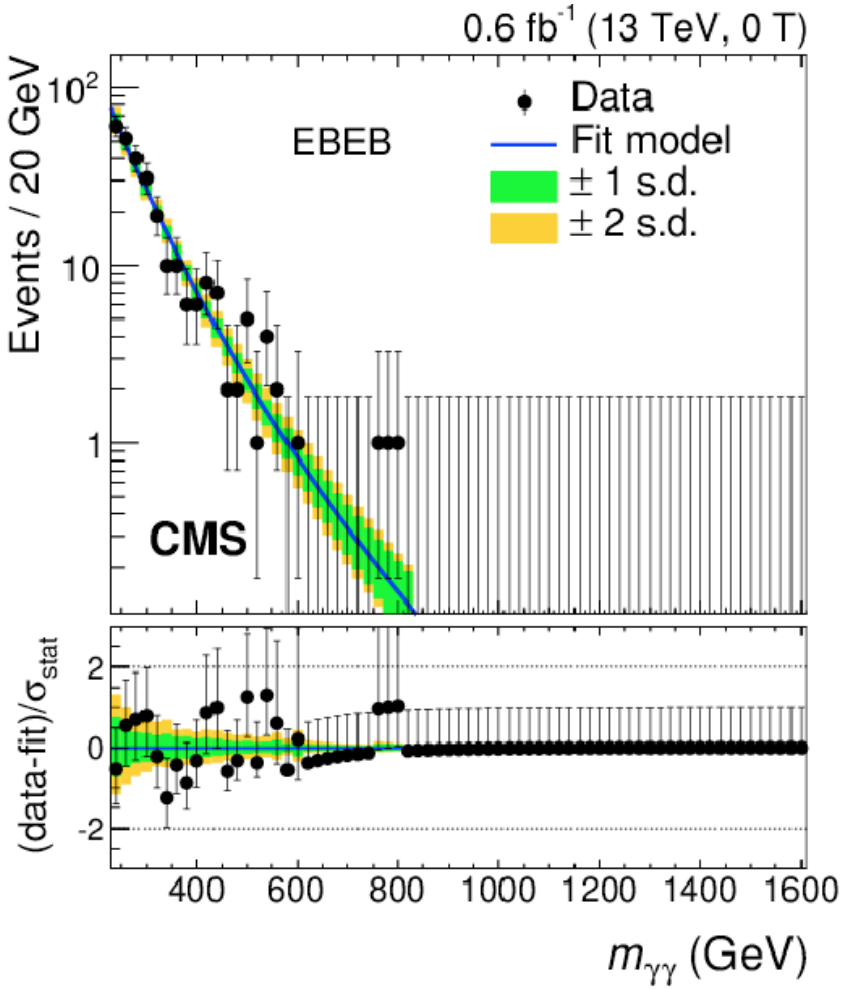


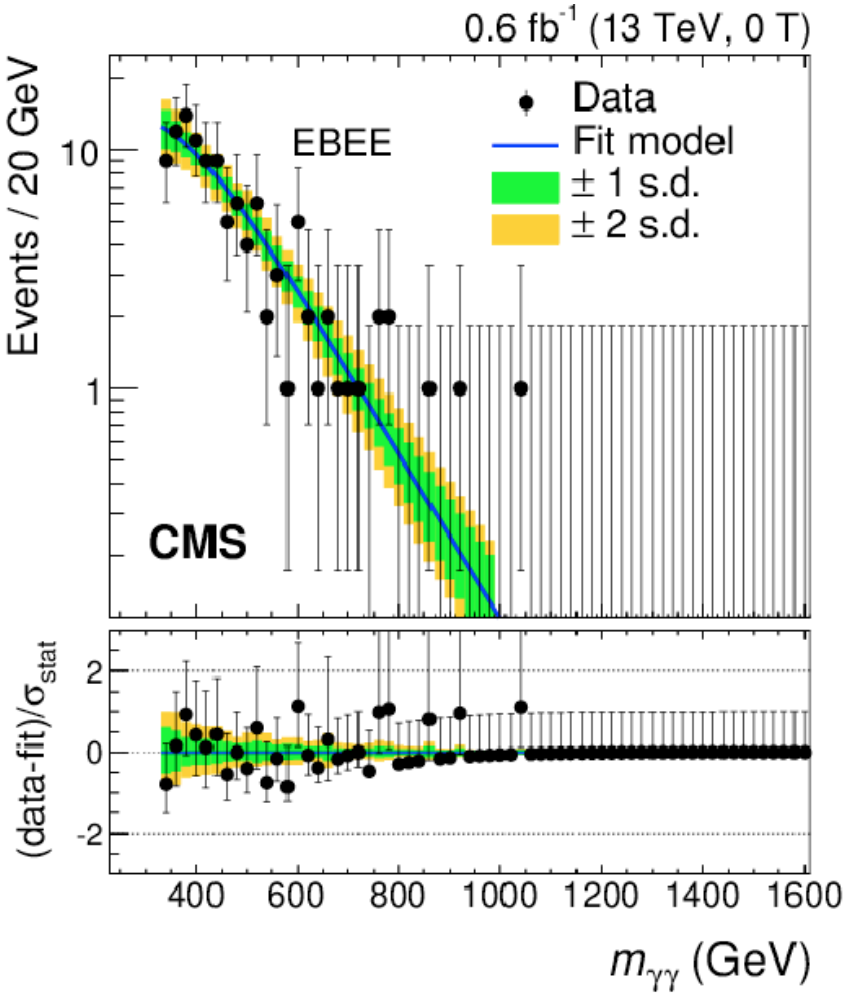
2015 data spectra, 3.8T



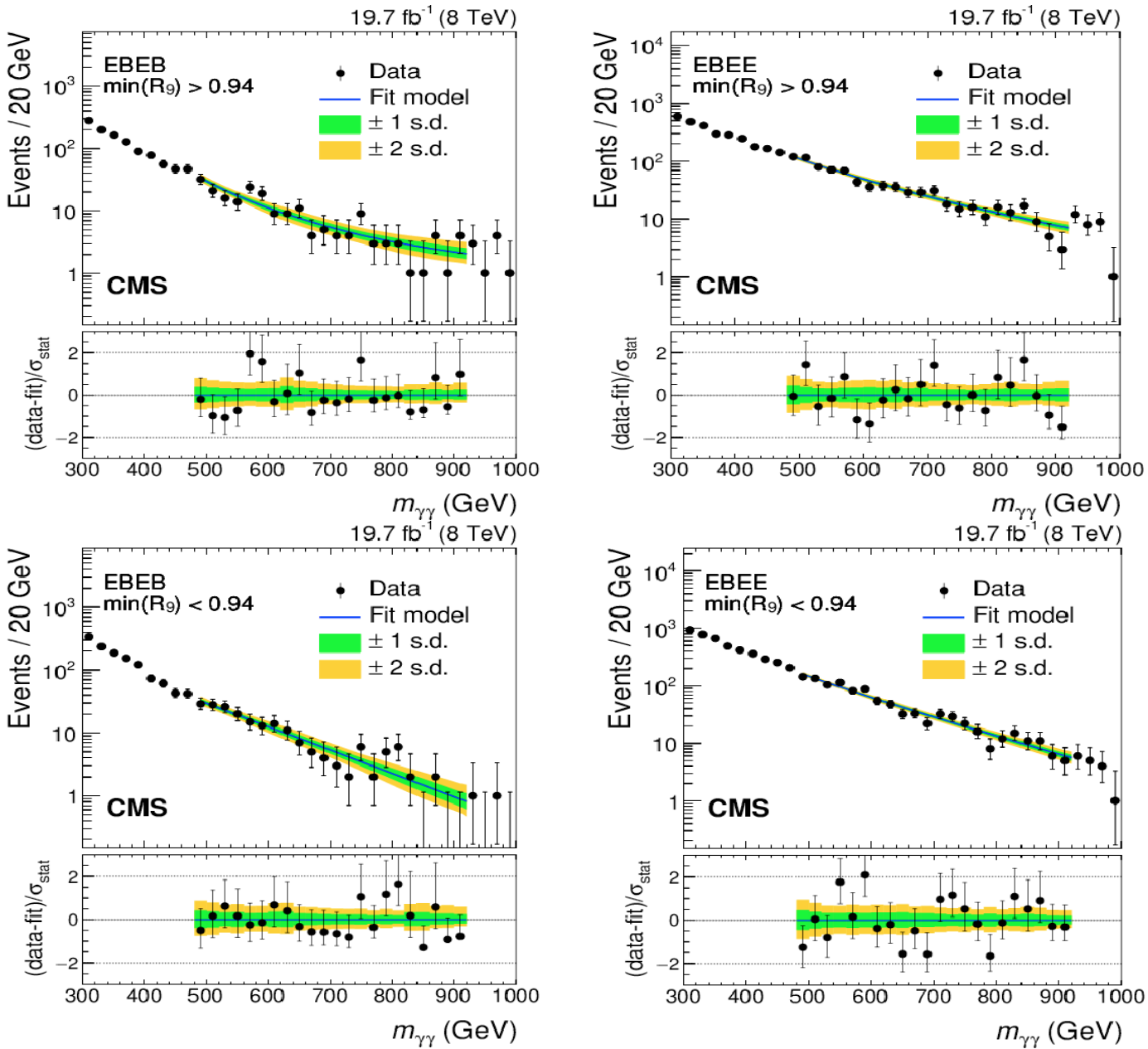


2015 data spectra, 0T

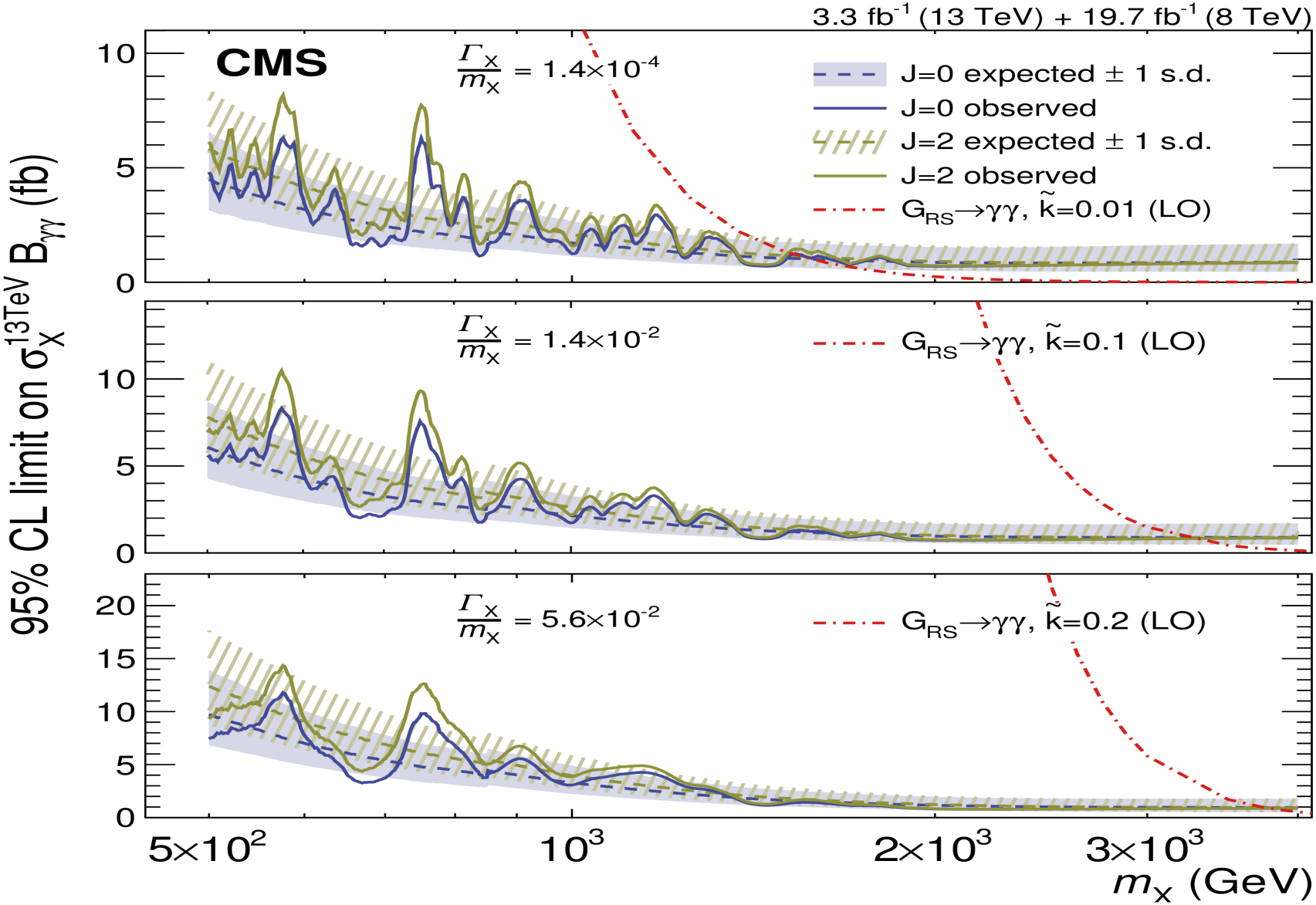




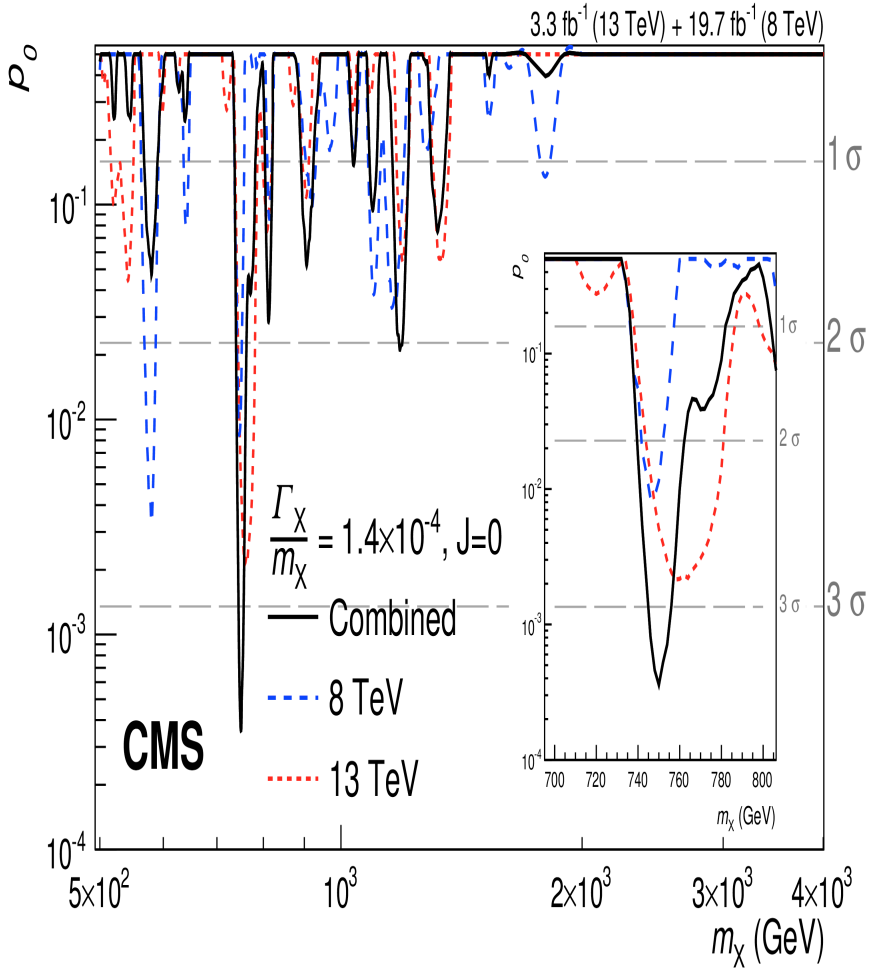
8TeV data spectra



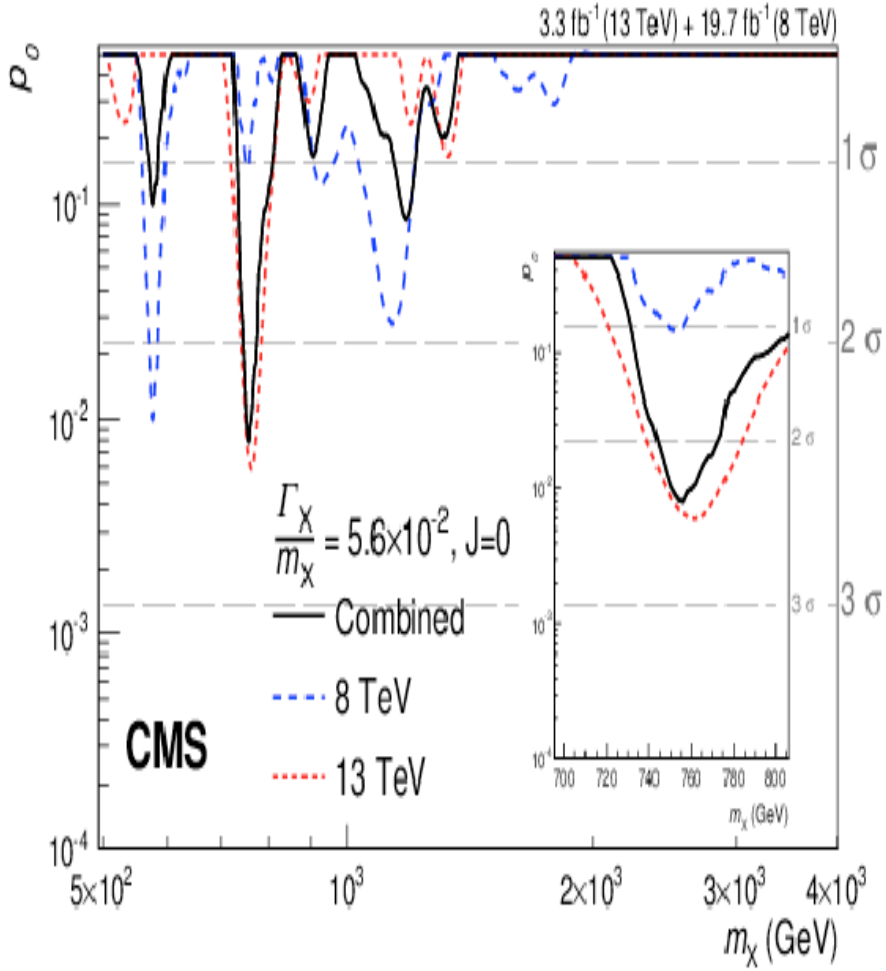
8TeV + 2015 limits



8TeV + 2015 pvalue



$\Gamma_x/m_x = 1.4 \times 10^{-4}$, J=0



$\Gamma_x/m_x = 5.6 \times 10^{-2}$, J=0

Crystals transparency