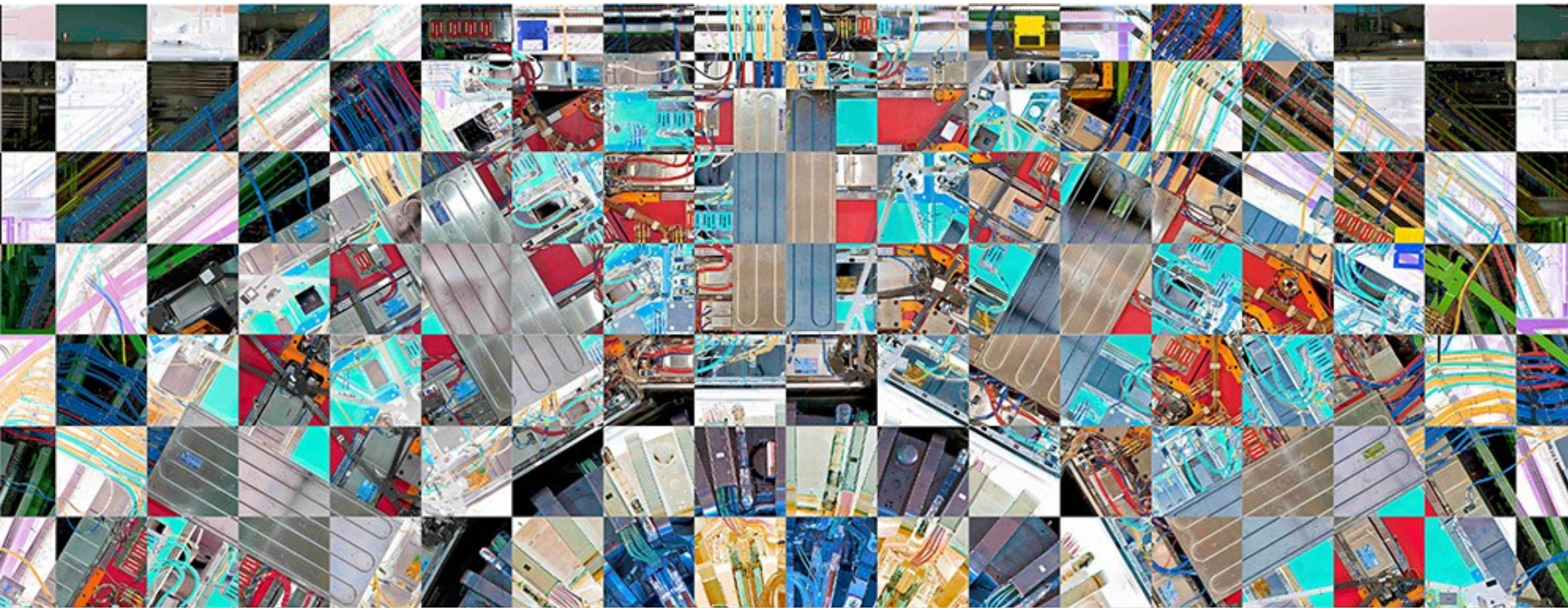
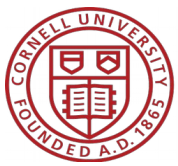


Is there a X(750) signal?

Livia Soffi
on behalf of the CMS Collaboration

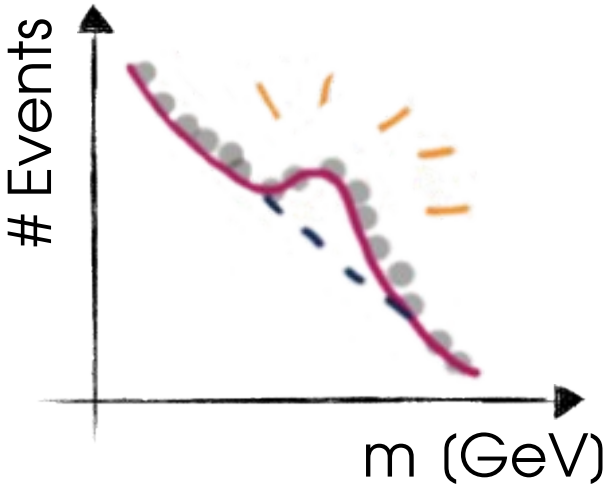


Cornell University

One question, tons of questions..

- Is there a preferred decay channel?
- Possible nature of the signal (spin nature)?
- Possible model interpretation?
- Observed compatibility in 8/13 TeV data?
- Natural width?
- Extra objects in the event?
- Possible production modes?

Is there a X(750) signal?

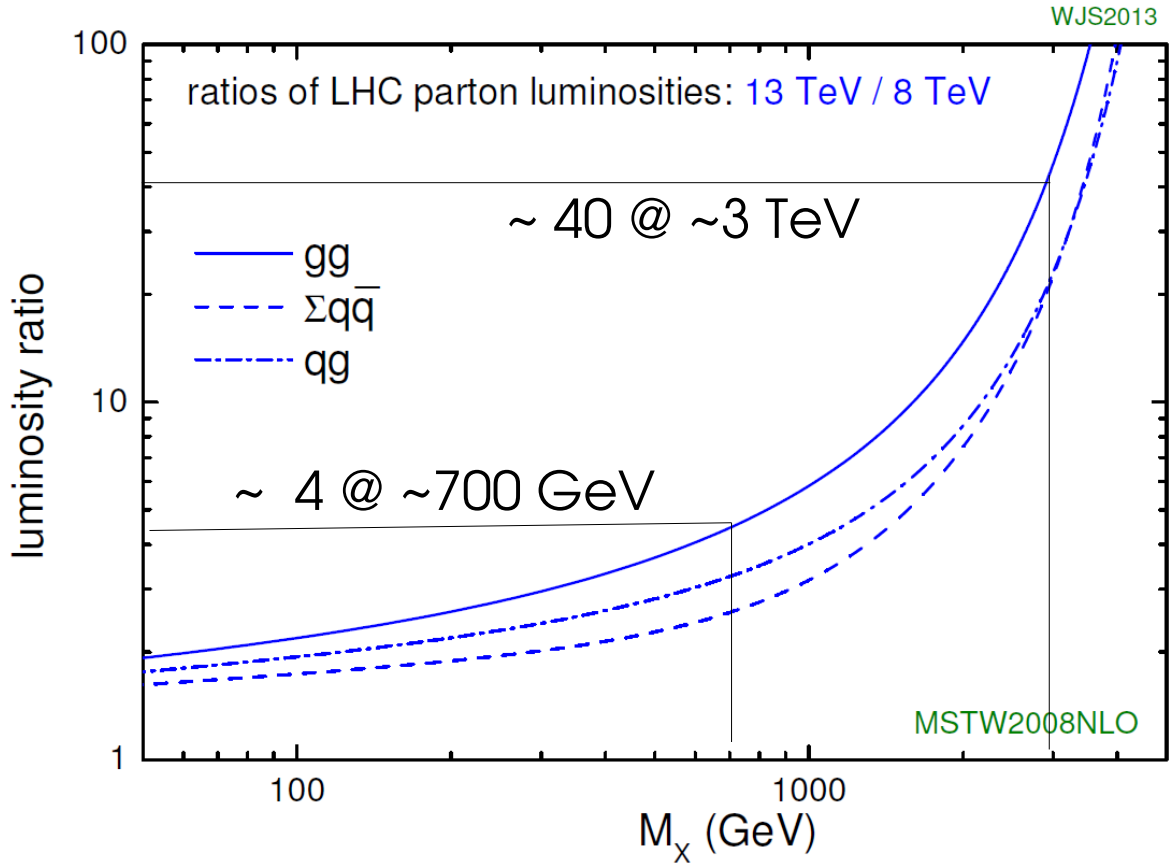


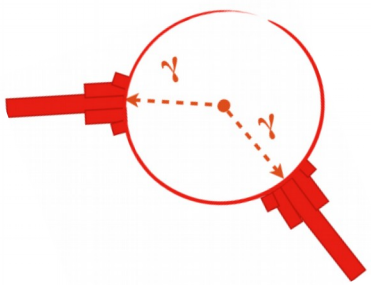
Introduction

- Bring LHC close to design parameters:

- Increase √s to 13 TeV
- 3 fb^{-1}@13 TeV → Run 1 sensitivity for M_X>≈2 TeV

- Dramatically increase discovery potential

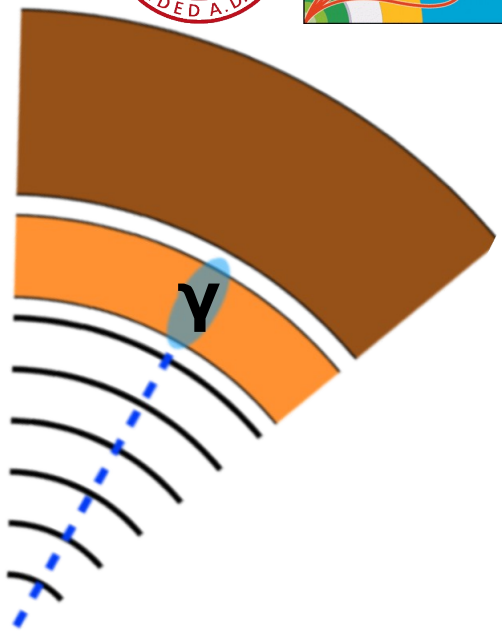


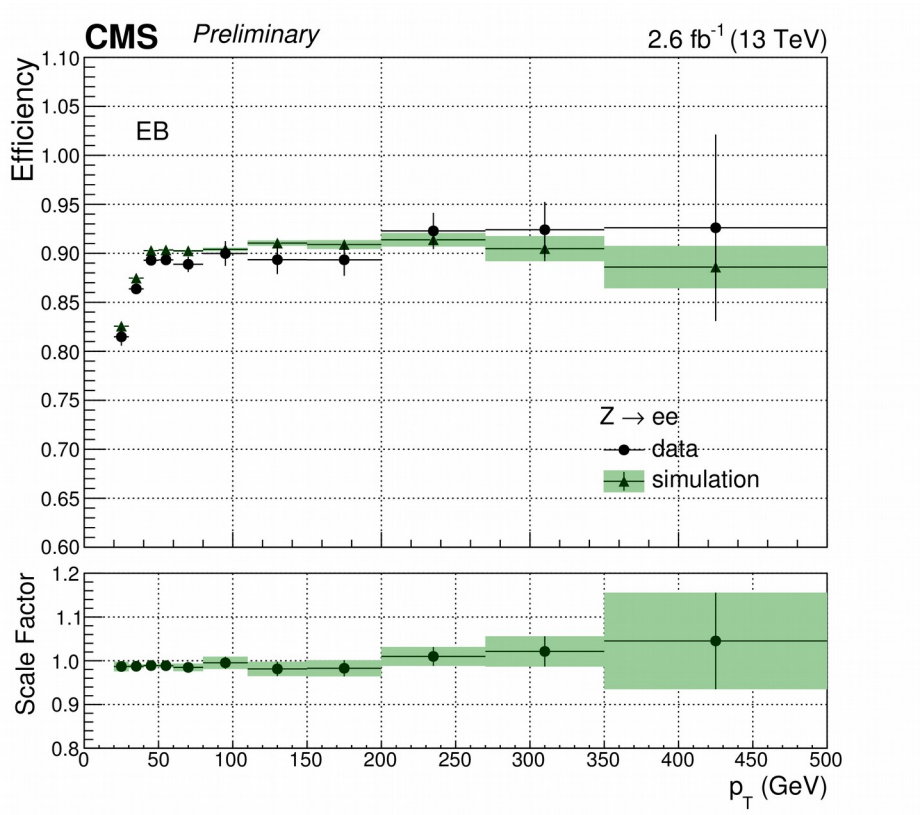


→ Although small x-sections, channels w/ photons provide very clean signature to discover new physics

Photon Reconstruction

- Reconstructed from the energy deposits in the ECAL, grouping them into superclusters.
- No associated tracks in the inner detectors
- Diphoton HLT Trigger with $E_T > 60$ GeV
- **Dedicated Photon ID for high-p_T objects**





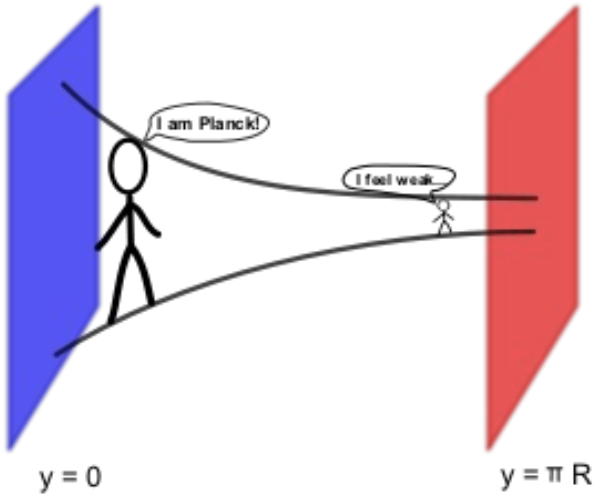
- **97% of total E contained in 5x5 matrix of crystals**
- Crystal Saturation E: → 1.7 (2.8) TeV

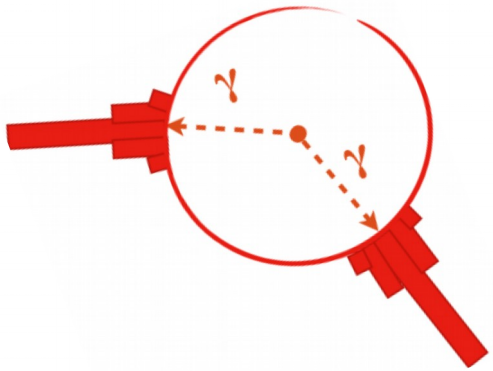
CMS-EGM-14-001

High-Mass Diphoton Search

Resonant production of high mass diphoton pairs generic prediction of several extensions of SM.

- **Spin 0** → heavy scalar in non-minimal Higgs sectors → **2HDM**
- **Spin 2** → models postulating the existence of additional space-like dimensions → **ADD** → **RS**





- **Signature of resonant production: localized excess of events in the diphoton invariant mass spectrum.**

CMS-EXO-16-018

What is new w.r.t. Dec `15?

	Mass range (GeV)	Channel-to-channel calibration constants	Dataset Used	Lumi (fb^{-1})	Spin interpretation
EXO-15-004	500-4500	Run1	3.8 T	2.7	2
EXO-16-018	**500-4500**	**Run2 -2015 data**	**3.8+0 T**	**3.3**	**0,2**

Mar`16

- Data re-reconstruction, using updated channel-to-channel calibration, completed over the winter shutdown.

- Additional **0.6 fb^{-1}** dataset, recorded at **B=0T** analyzed
  - **Dedicated photon identification.**
  - **Dedicated vertex selection.**
  - **→ 10% improvement on top of the re-calibration.**

- Results interpreted in terms of **spin-0 and spin-2** resonances.
  - → J=0: assumed gluon-fusion production, J=2: RS-graviton
  - → Three widths ($\Gamma/m=1.4\times10^{-4}$, 1.4×10^{-2}, 5.6×10^{-2})

CMS-EXO-16-018

New ECAL channel-to-channel calibration

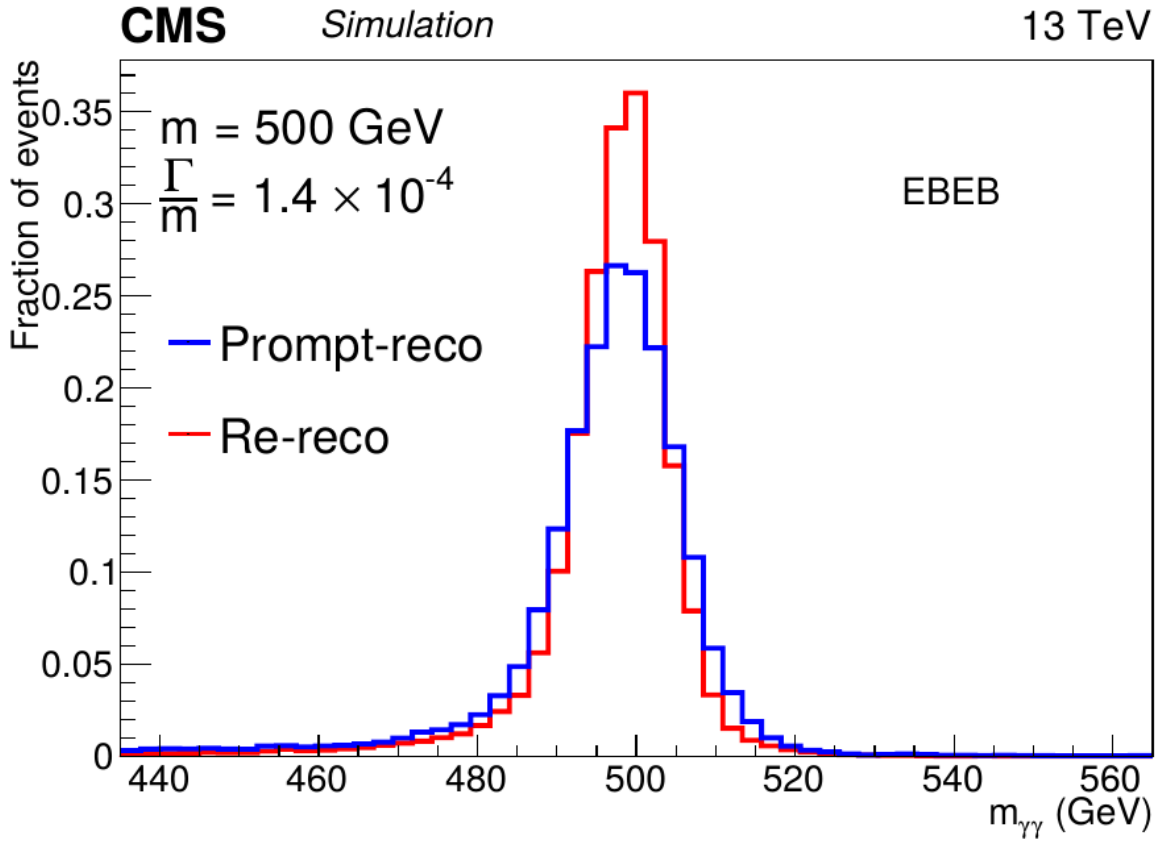
- ECAL calibration crucial for **energy resolution**

Mar`16

  - Over the winter shutdown data re-reconstructed using **new channel-to-channel calibration obtained for the 2015 dataset**.

→ **30% improvement in mass resolution above 500GeV.**

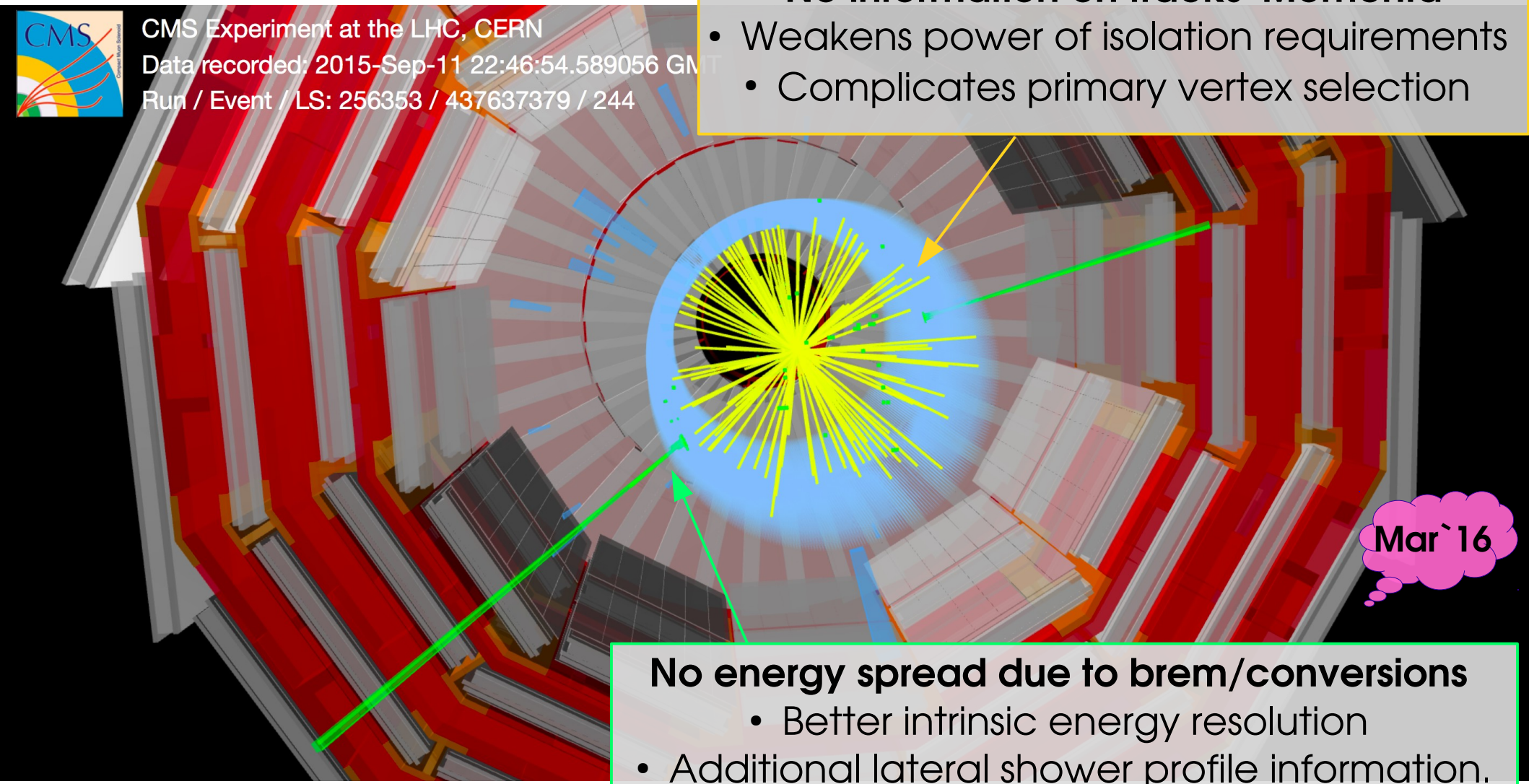
→ **~10% improvement in analysis sensitivity**



CMS-EXO-16-018

0 T data challenges

- Significant re-thinking of the analysis needed to use data without magnetic field.



No information on tracks' Momenta

- Weakens power of isolation requirements
- Complicates primary vertex selection

No energy spread due to brem/conversions

- Better intrinsic energy resolution
- Additional lateral shower profile information.

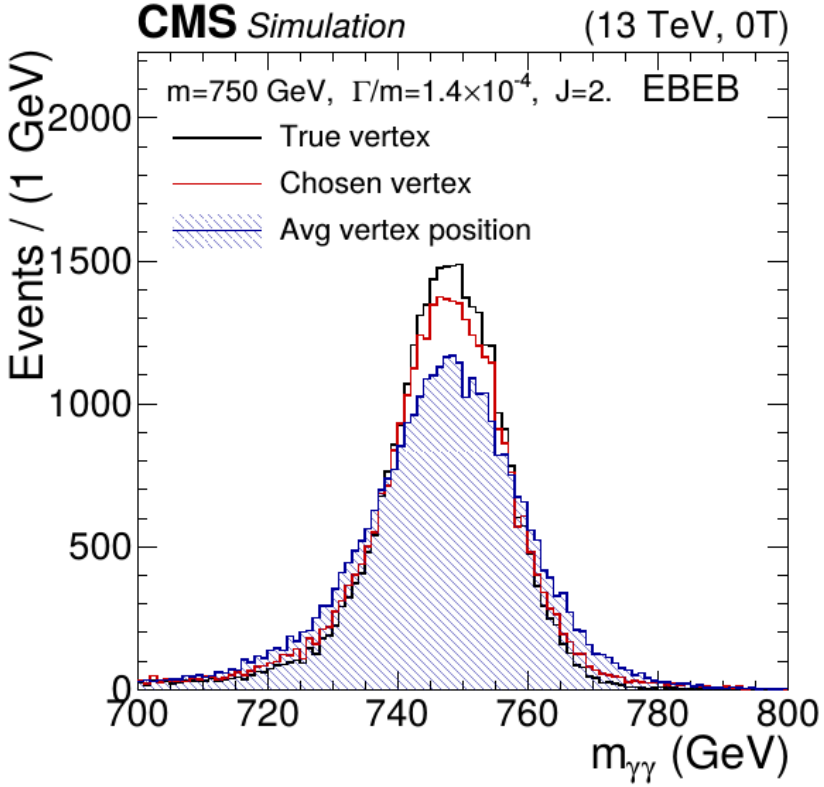
CMS-EXO-16-018

Vertex Identification

- Good mass resolution depends on choosing right vertex

  → **B=3.8T**: Multivariate **method** using recoil and tracks kinematics, trained for SM H → γγ

  → **B=0T**: Simpler algorithm based on **track-counting** Vertex with the highest track multiplicity

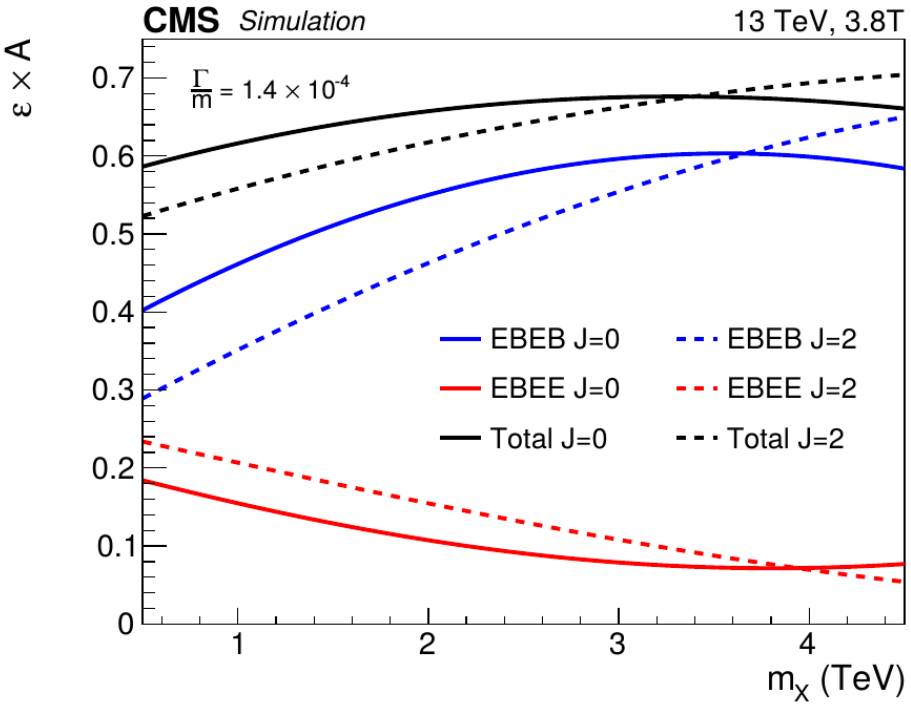


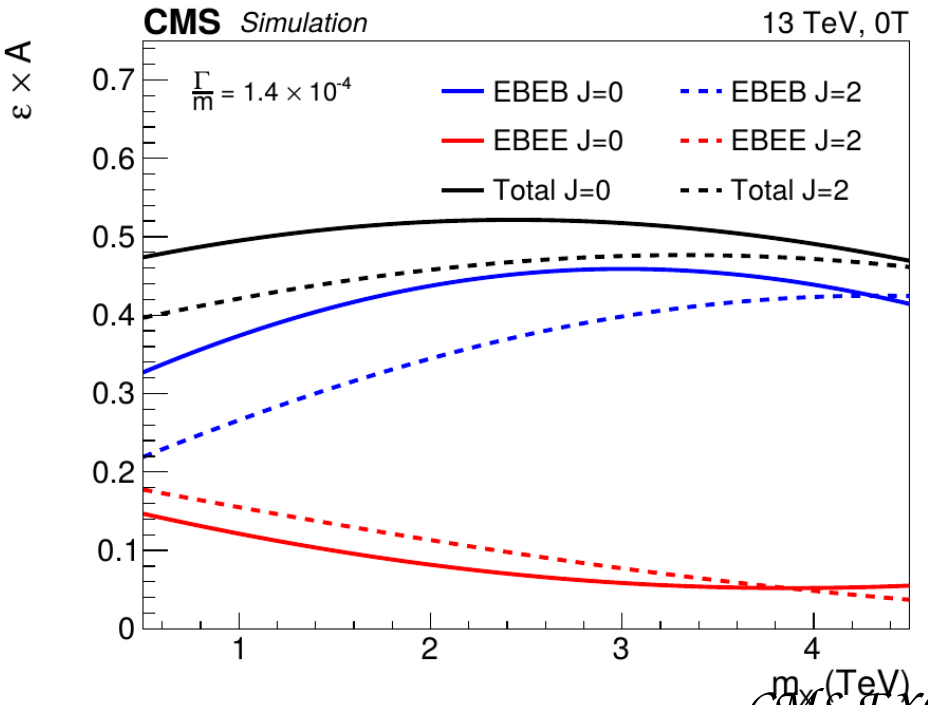
Mar`16

CMS-EXO-16-018

Analysis Overview

- Split events in categories: **(EB-EB, EB-EE) x (3.8 T, 0 T)**
- Search region: **$M_{\gamma\gamma}$ > 500 GeV**
- Select events with two photons of **p_T> 75 GeV**
- Dedicated photon ID with isolation:
  → B= 3.8 T : ε =90%
  → B= 0T : ε =80% (EB) – 70% (EE) (less efficient ele-veto)



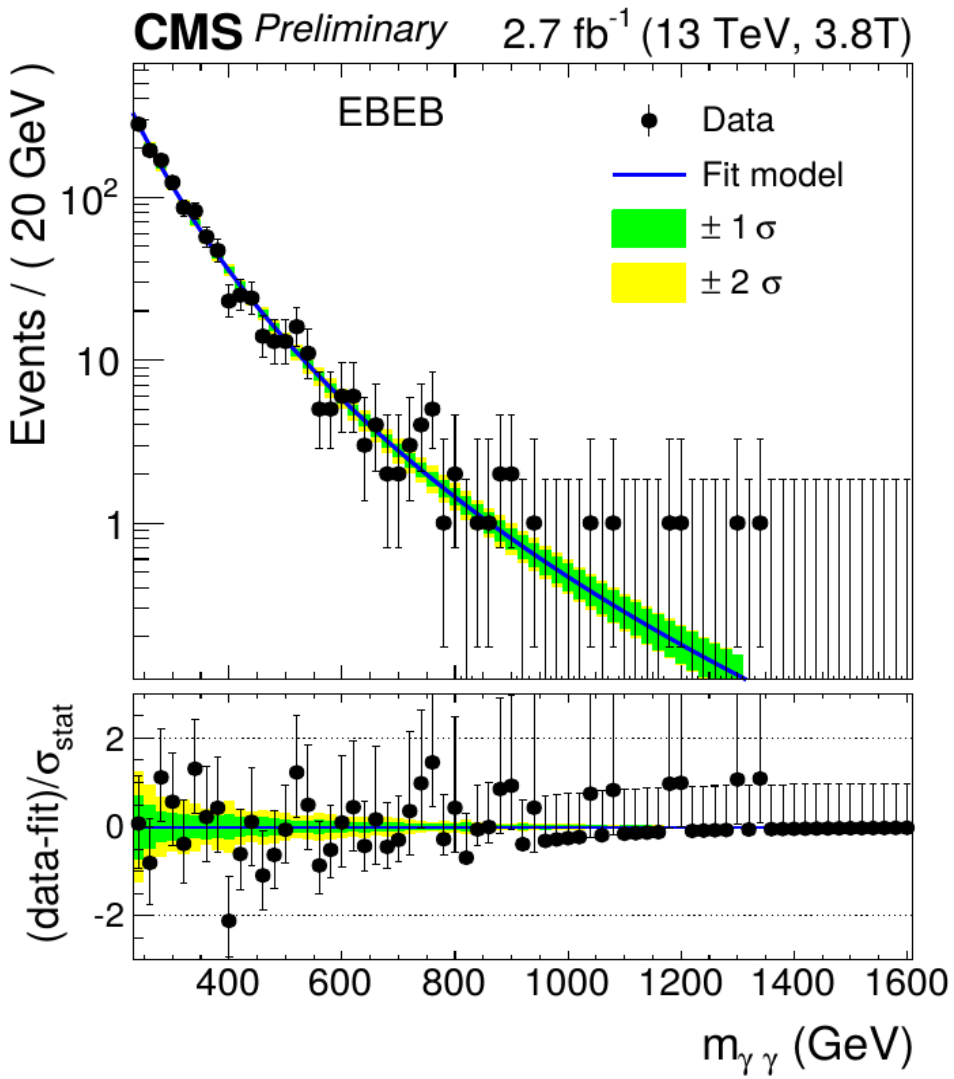


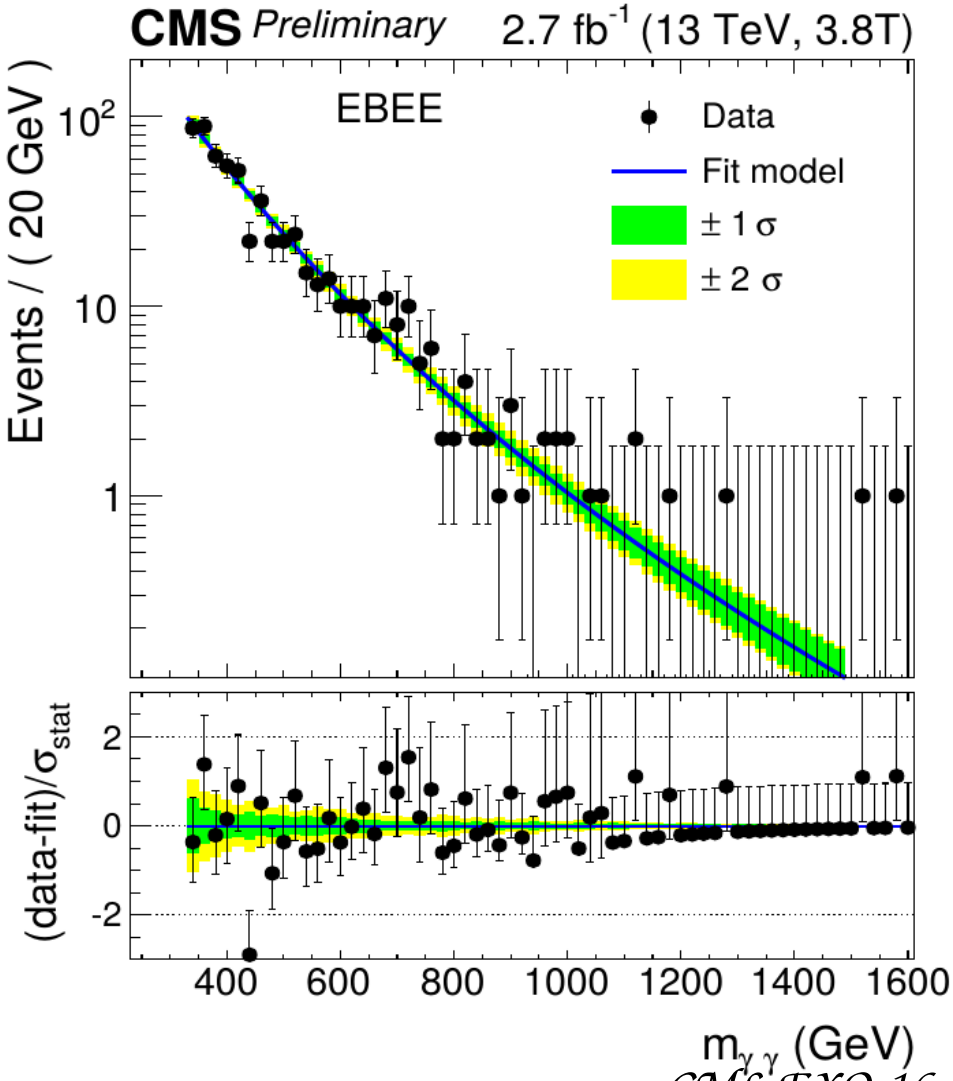
CMS-EXO-16-018

Mass Spectra @ 3.8 T

- **Fit $M_{\gamma\gamma}$ in 0.5-4.5 TeV in 4 categories: (EBEB, EBEE)x(3.8T, 0T)**

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

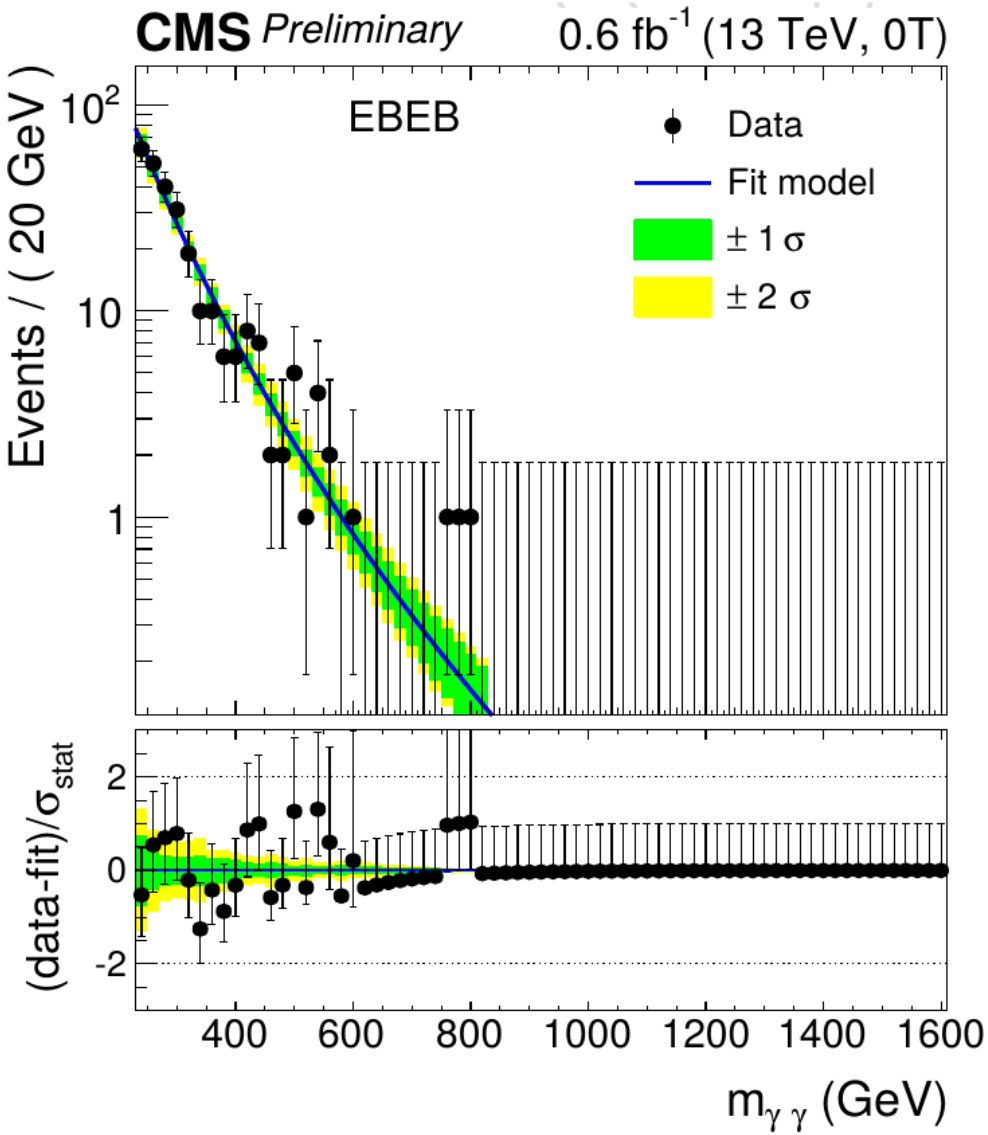


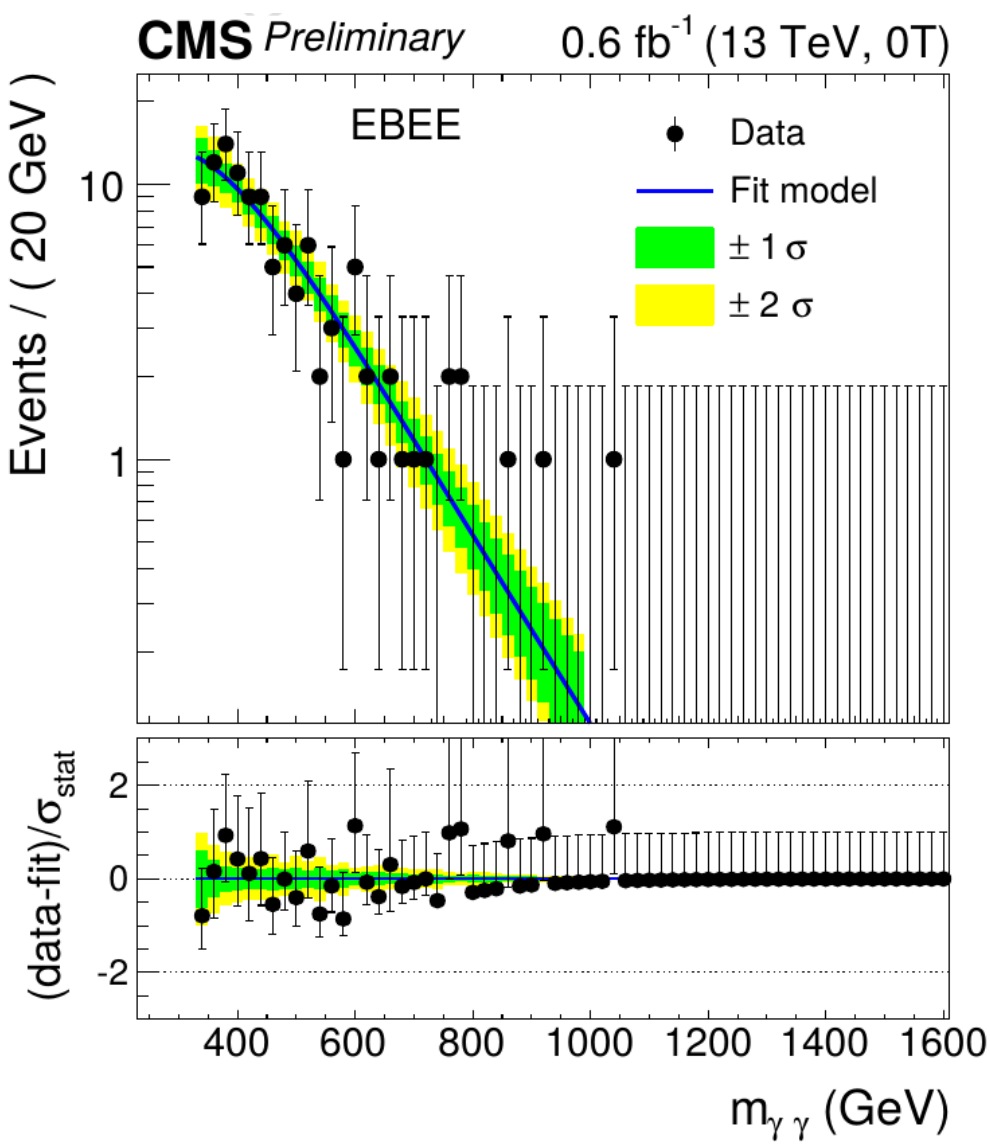


CMS-EXO-16-018

Mass Spectra @ 0 T

Mar`16





CMS-EXO-16-018

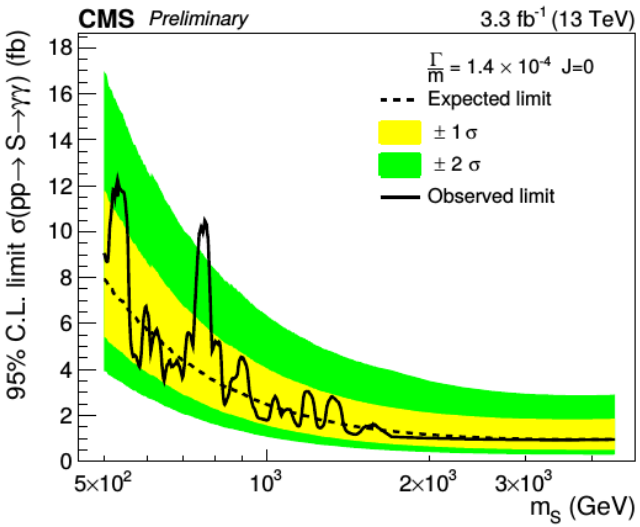
Upper Limits & P-values

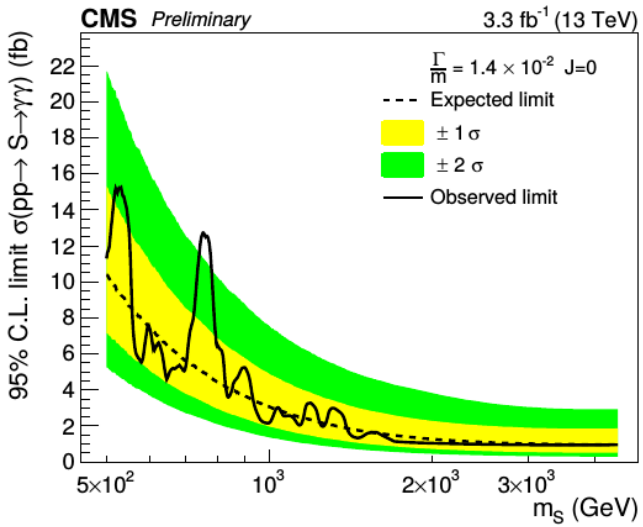
- Show results combining 3.8T and 0T datasets
- **Spin-0 / Spin-2 results interpretation, for 3 width hypotheses**

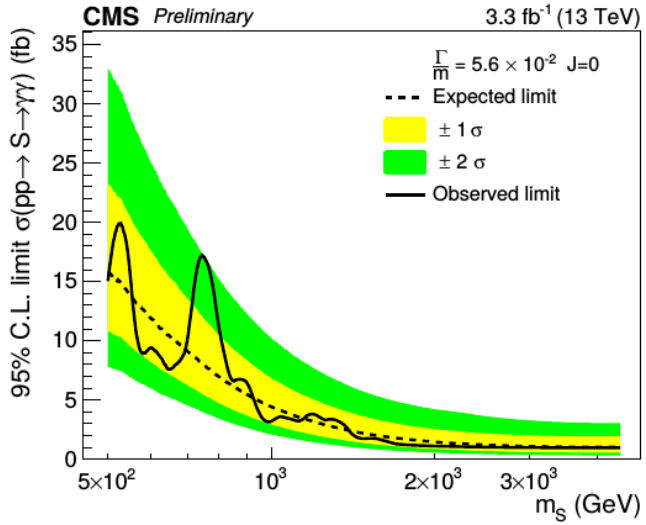
CMS-EXO-16-018

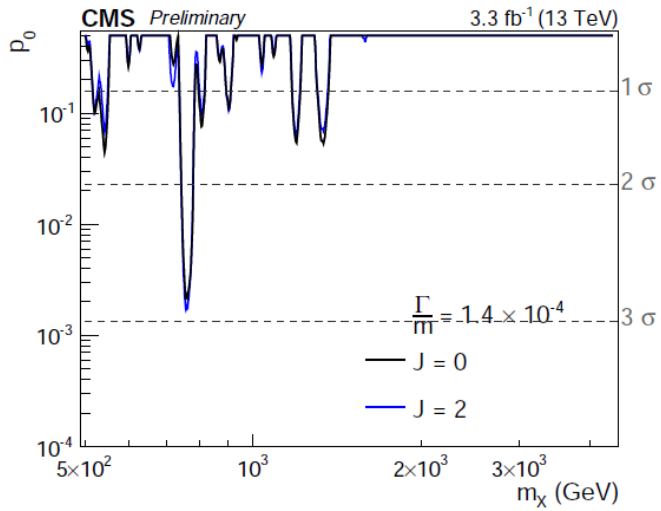
$\Gamma/m = 1.4\times10^{-4}$ $\Gamma/m = 1.4\times10^{-2}$ $\Gamma/m = 5.6\times10^{-2}$

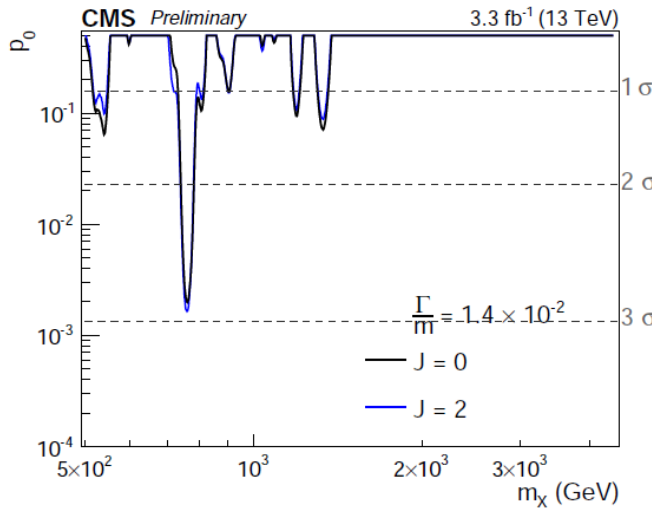
Spin 0

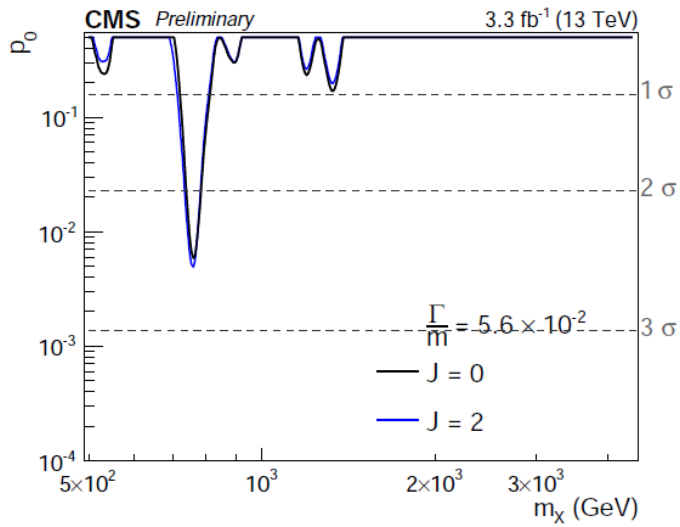






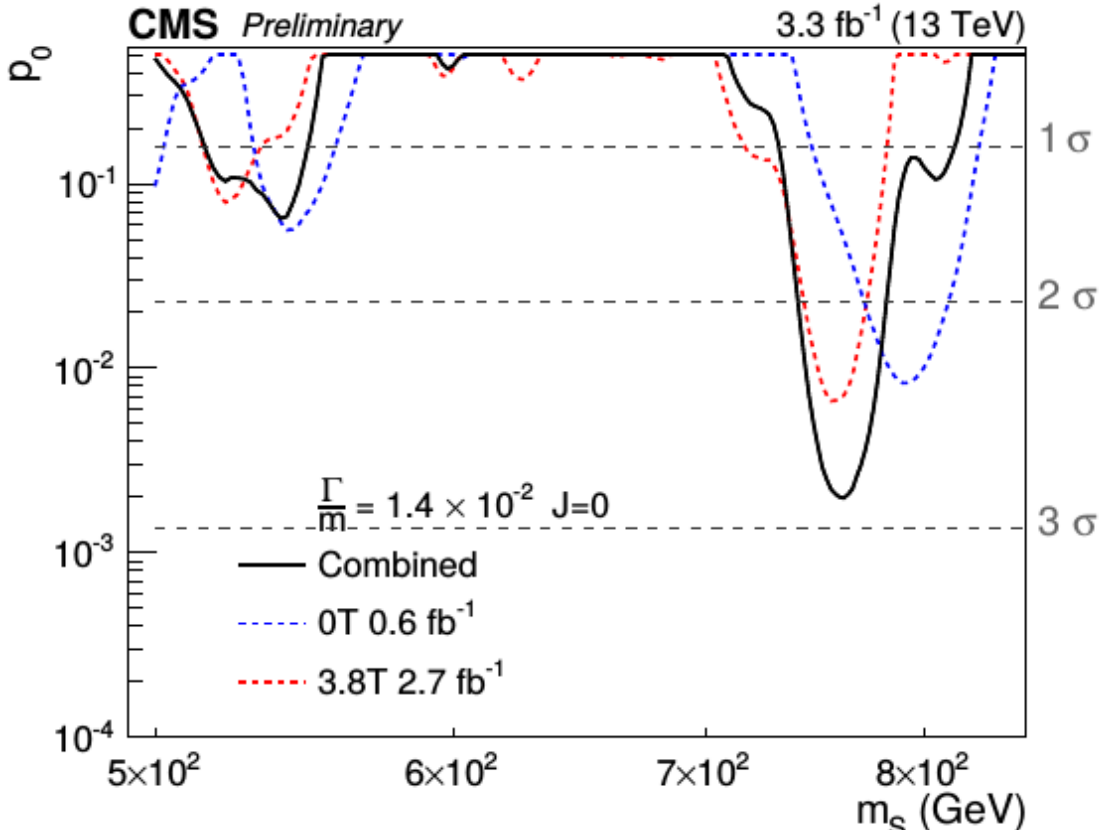






Significance of largest excess

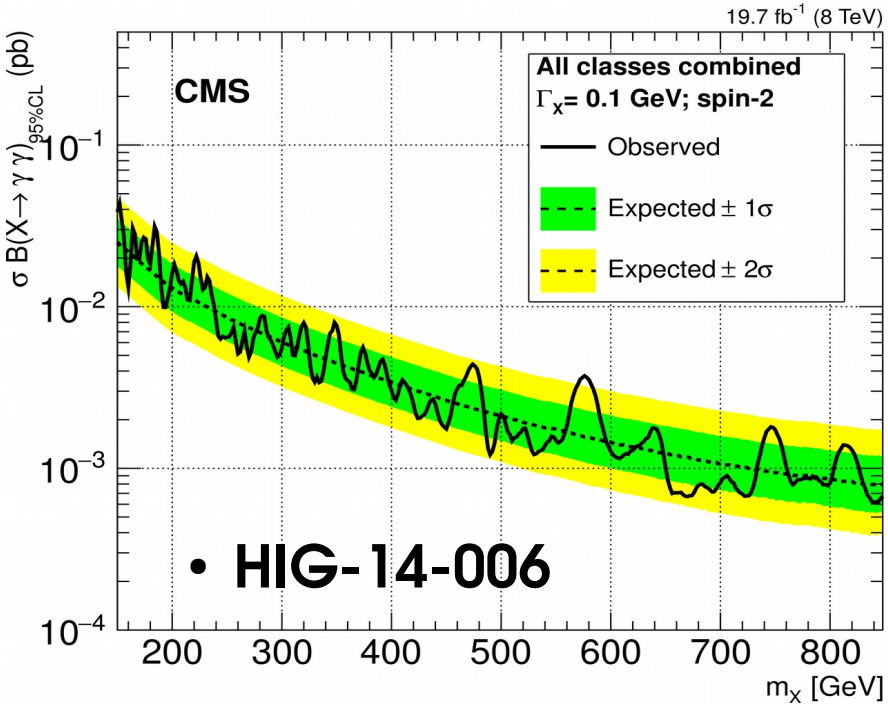
- Largest excess observed for **m_X = 760 GeV and narrow width hypotheses**
- **Local significance: 2.8-2.9σ** depending on the spin hypothesis.
  → Trial factors from sampling distribution of min(p_0), considering all the 6 signal hypotheses (spin and width).
- **"Global" significance < 1σ**
- Excess mostly driven by EBEB, 3.8T category.

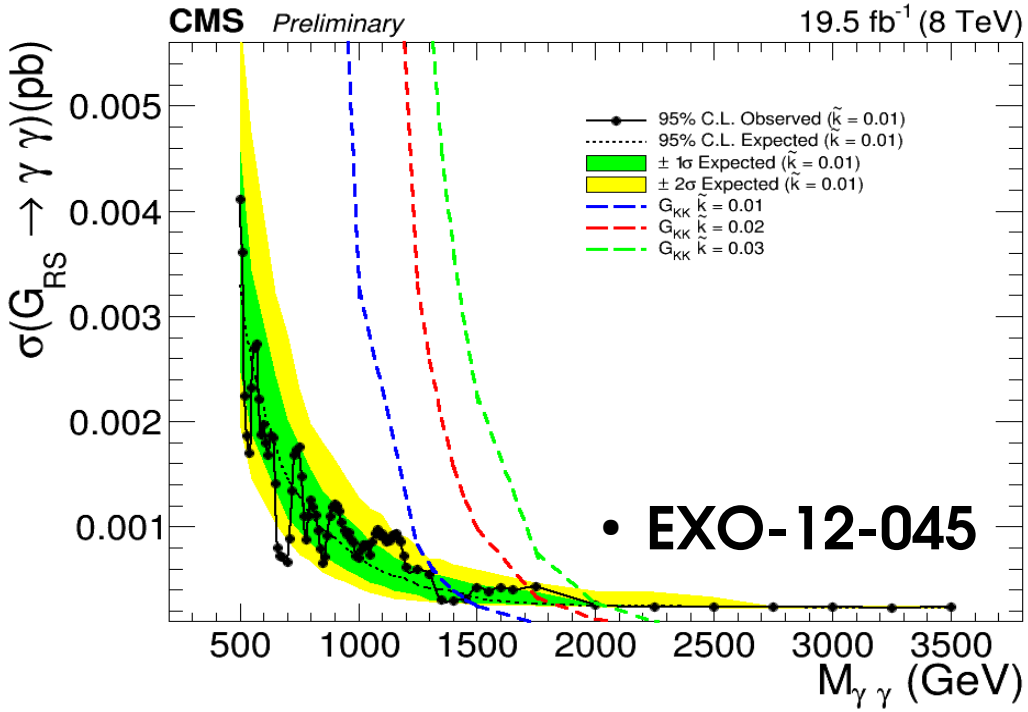


CMS-EXO-16-018

Combined Analysis of 8 and 13 TeV Data

- CMS presented two searches for diphoton resonances at 8 TeV.
  - **HIG-14-006**: (*PLB 750 (2015) 494*) search range **150-850 GeV**
  - **EXO-12-045**: search range **500-3000 GeV**



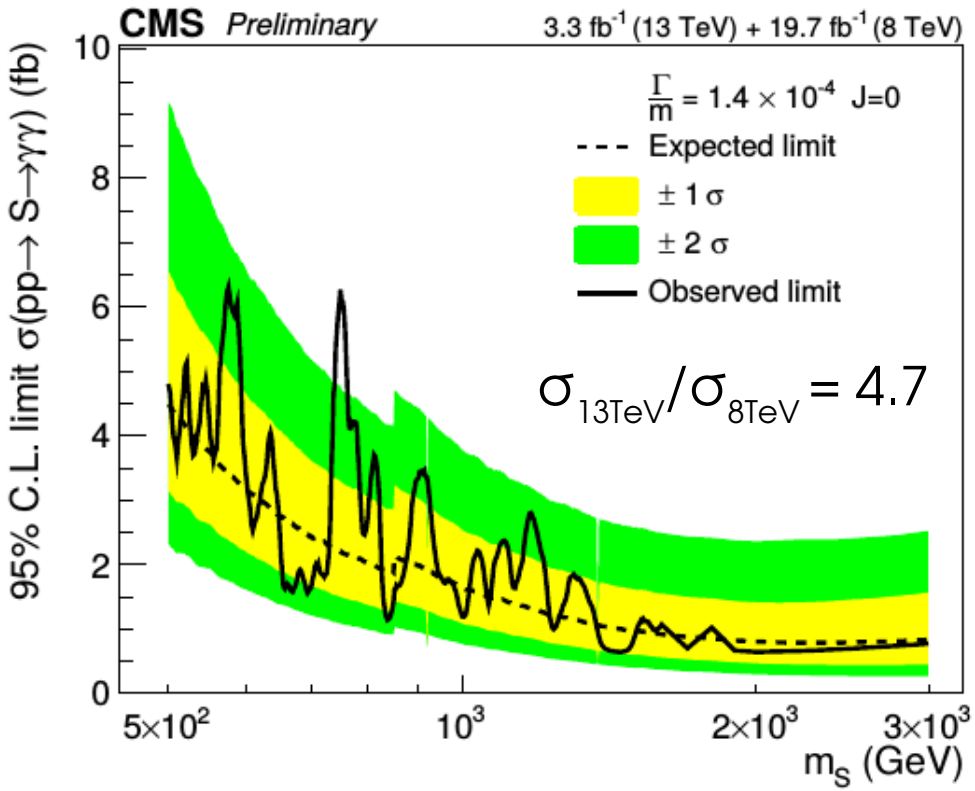


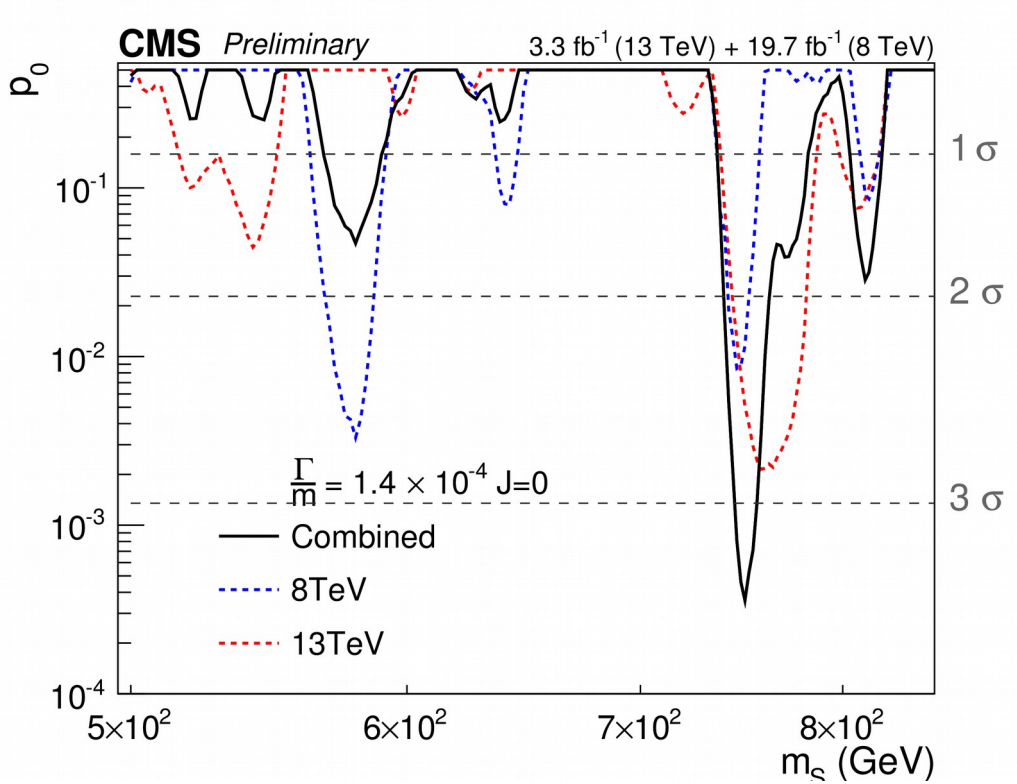
- Combination in all 6 signal hypotheses tested at 13TeV.
- **At each mass, use analysis with best expected sensitivity: HIG-14-006 in 500-850 GeV, EXO-12-045 otherwise**

CMS-EXO-16-018

Results Normalized to 13 TeX x-sec

- Compared to single analyses, sensitivity improved by 20-40%





- Largest excess observed at $\mathbf{m_X = 750\ GeV}$ and for narrow width.

  → **Local significance: 3.4σ**

  → Taking into account mass range 500-3500 GeV and all signal hypotheses, **"global" significance** becomes **1.6σ**

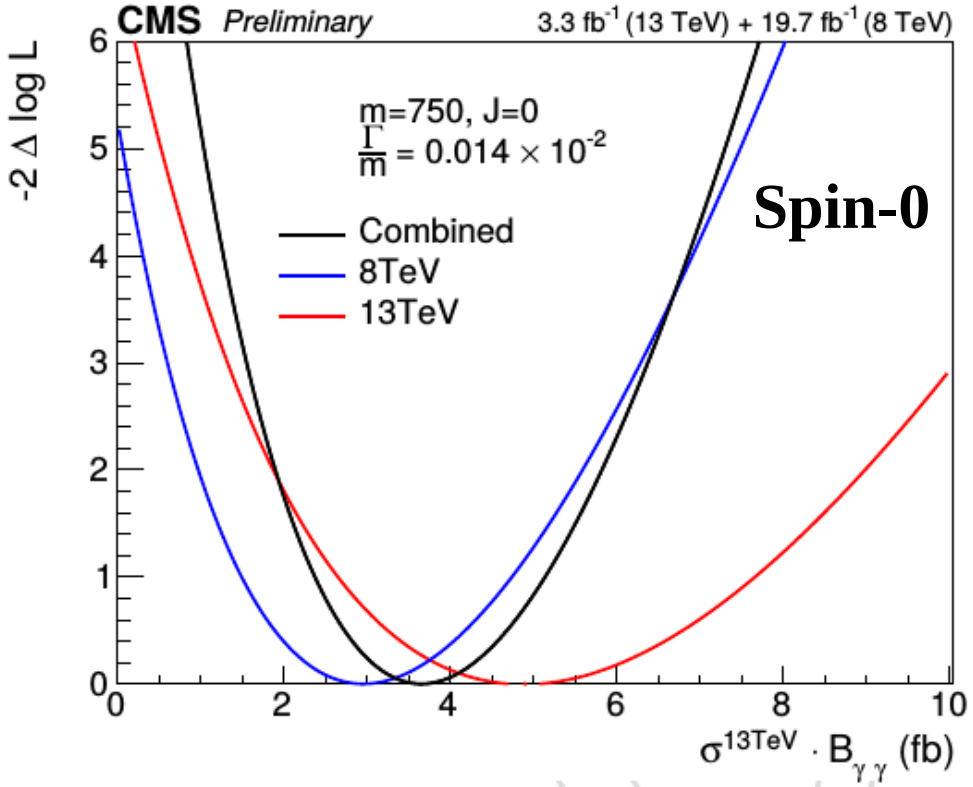
CMS-EXO-16-018

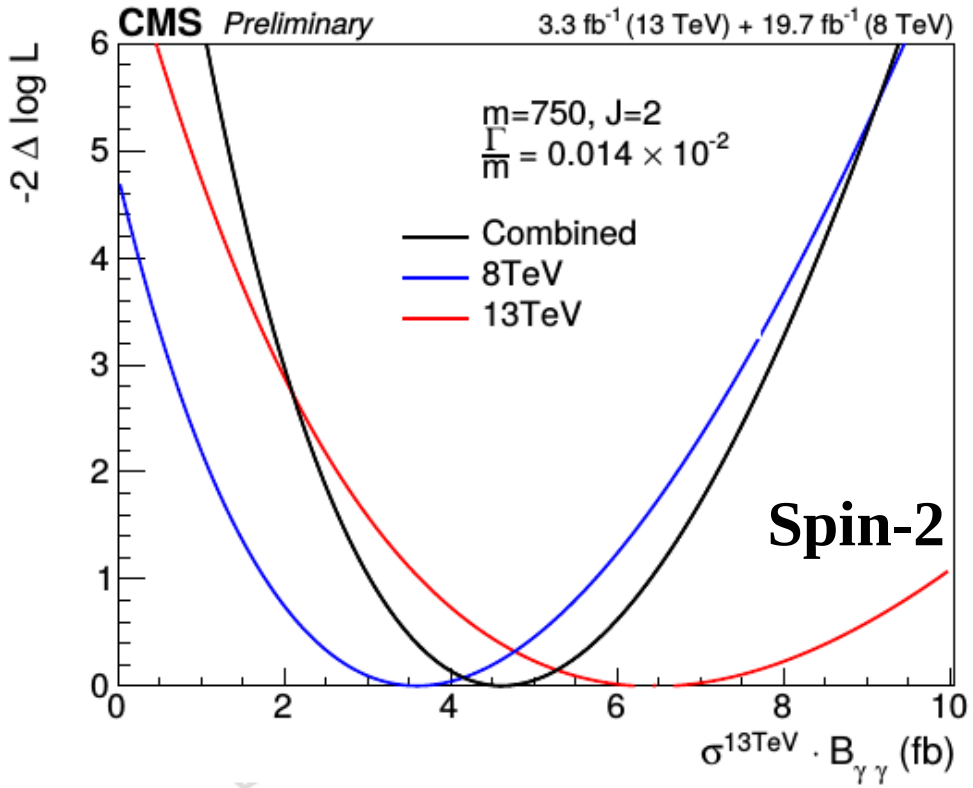
Consistency between 8 and 13 TeV

- Evaluated through **likelihood scan vs equivalent σ_{13TeV} at m_X = 750 GeV** under both spin (narrow-width) hypotheses.

- Cross section ratios at 750GeV:
  → For spin 0 ($gg \rightarrow S$): $\sigma_{13TeV}/\sigma_{8TeV} = 4.7$
  → For spin 2 (RS): $\sigma_{13TeV}/\sigma_{8TeV} = 4.2$

→ Compatible results observed in both datasets.





CMS-EXO-16-018

Z+γ Resonances

- Search for new resonances decaying to Z+γ could shed more light on the 750 GeV excess

- Look for **A→ Z+γ**, with either Z→ ee or Z→μμ

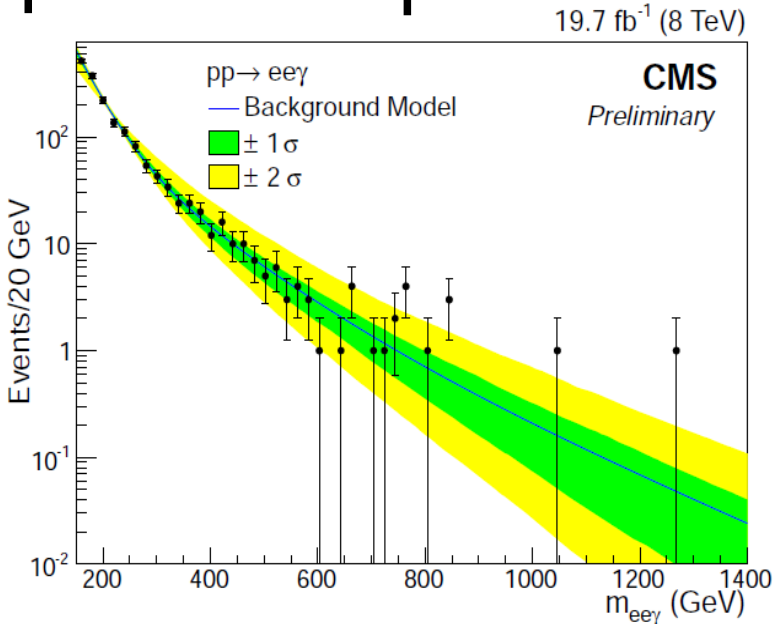
Signature: clean final-state topology giving rise to a clear peak in the invariant mass distribution

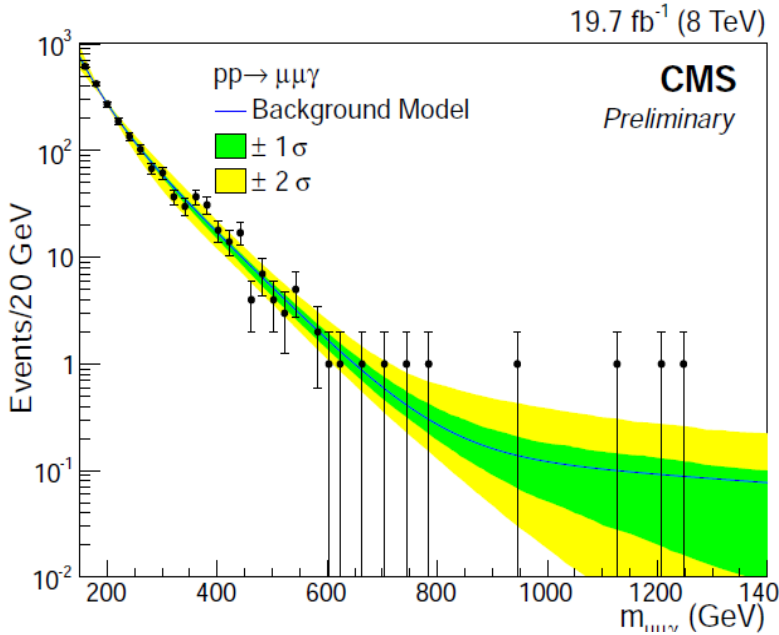
- Similar signature as in diphoton analysis → Search strategy measures the non-resonant background directly on data, and looks for localized excesses

- Dedicated event selection:
  - M_Z in 50-130 GeV
  - $P_{T1,2}$ > 25,20 GeV
  - $P_{T\gamma}$ > 4/15 $M_{Z\gamma}$
  - $M_{Z\gamma}$ > 200 GeV

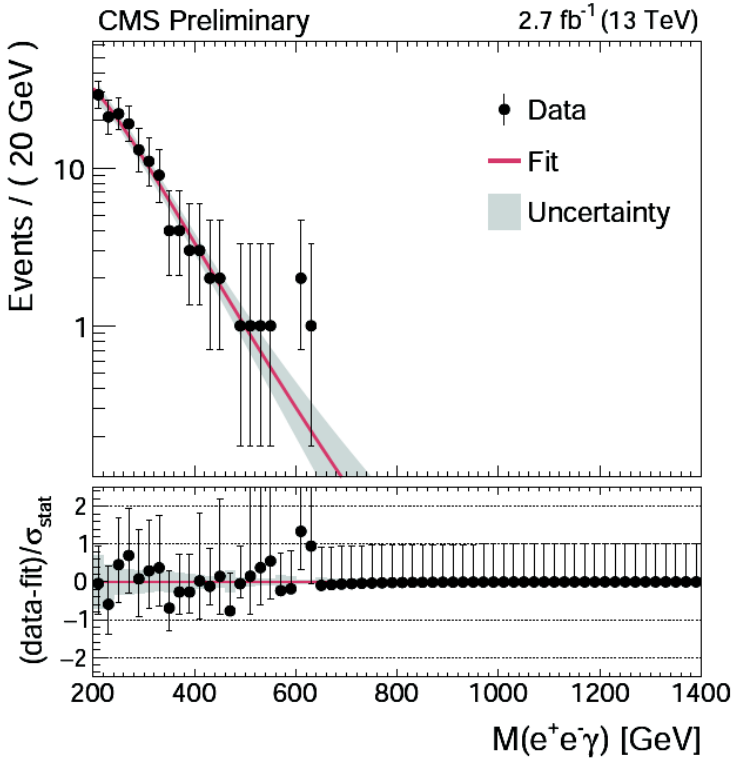
CMS-EXO-16-019

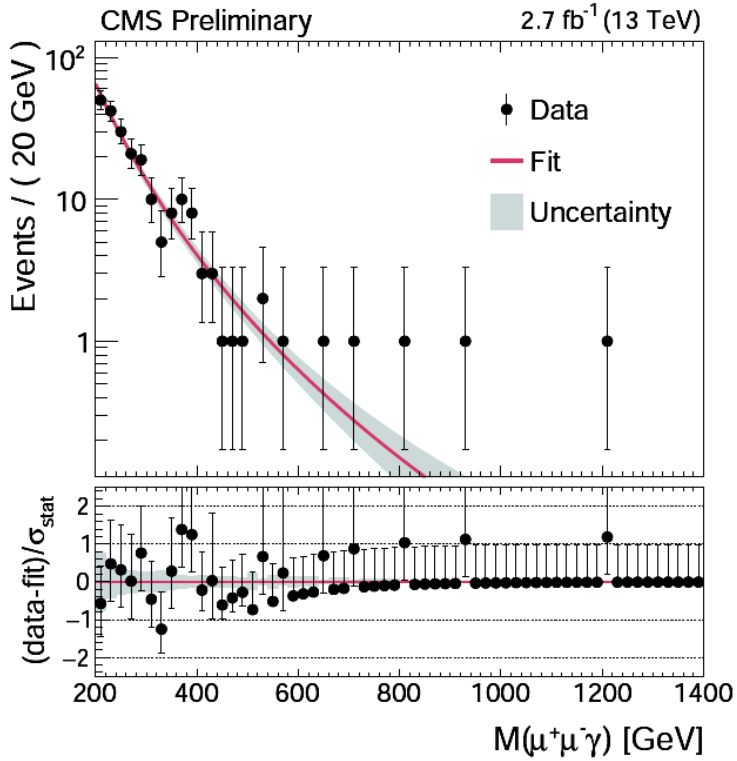
Z+γ Mass Spectra





- 8 TeV

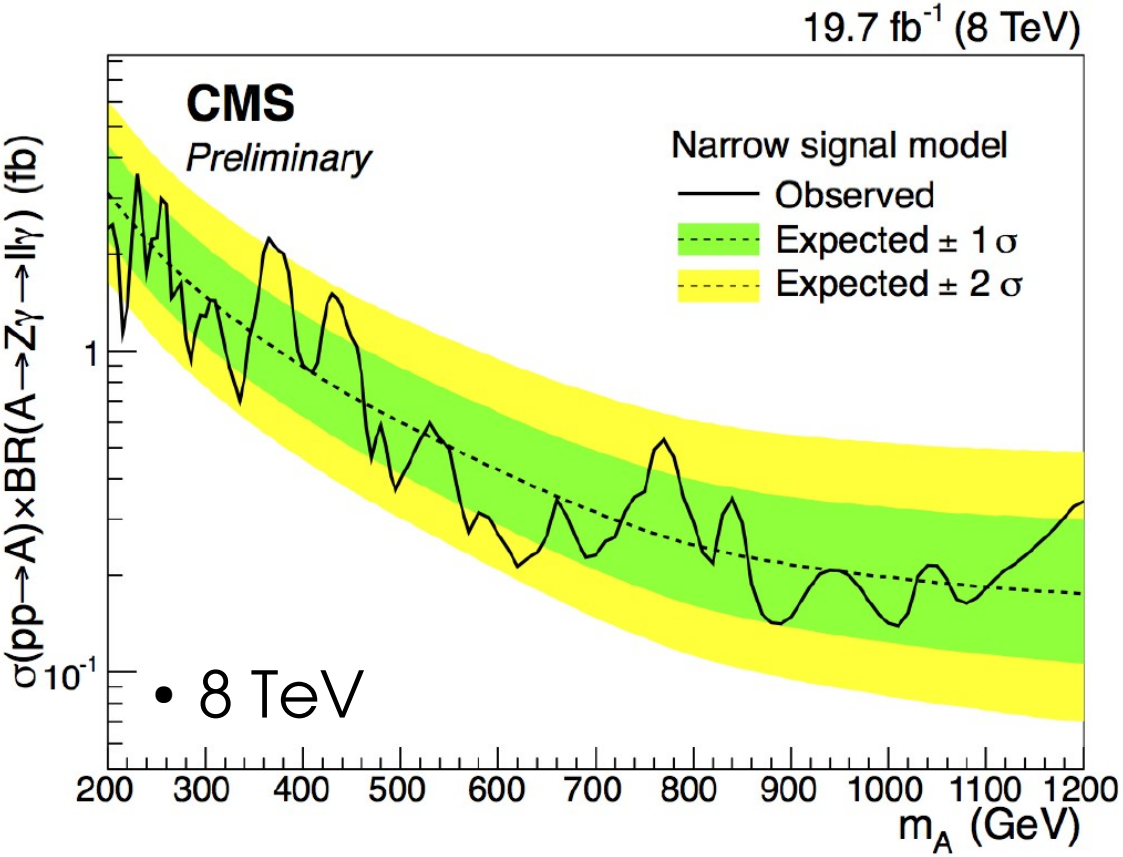


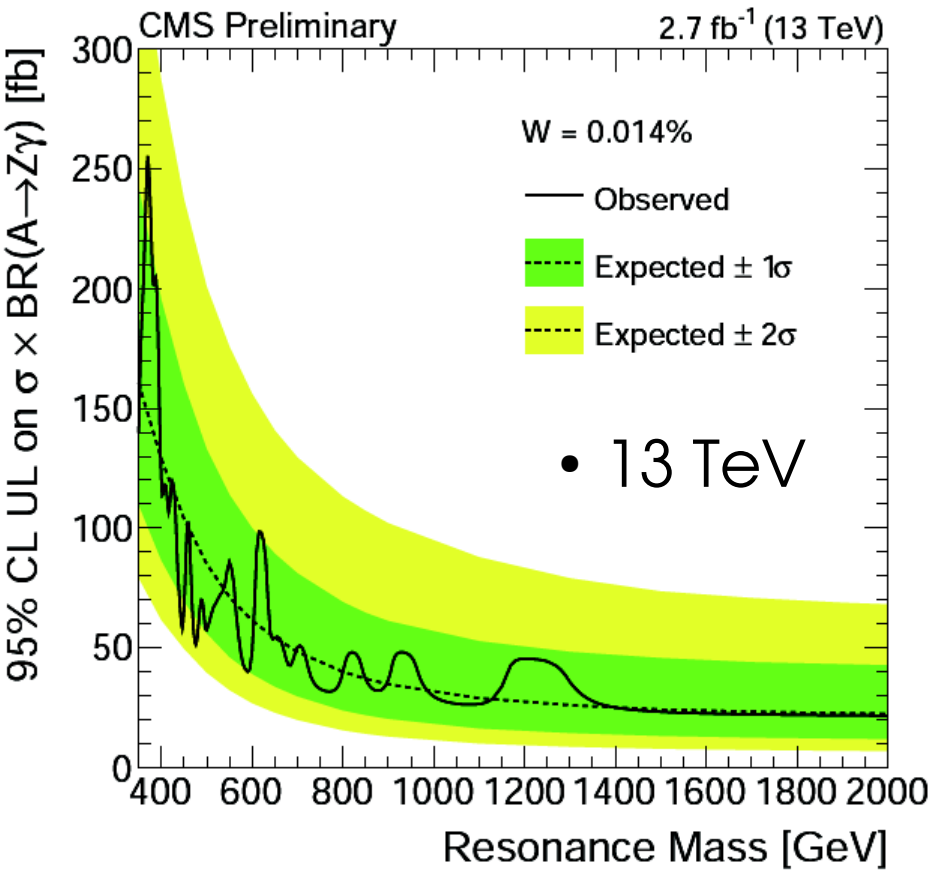


- 13 TeV

CMS-EXO-16-014
CMS-EXO-16-019

Z+γ Analyses Results





- 13 TeV results do not include $Z \to l^+l^-$ BR

CMS-EXO-16-014

CMS-EXO-16-019

Outlook and Prospects

- Huge increase of LHC energy opens **new territory to explore in the hunt for new physics**

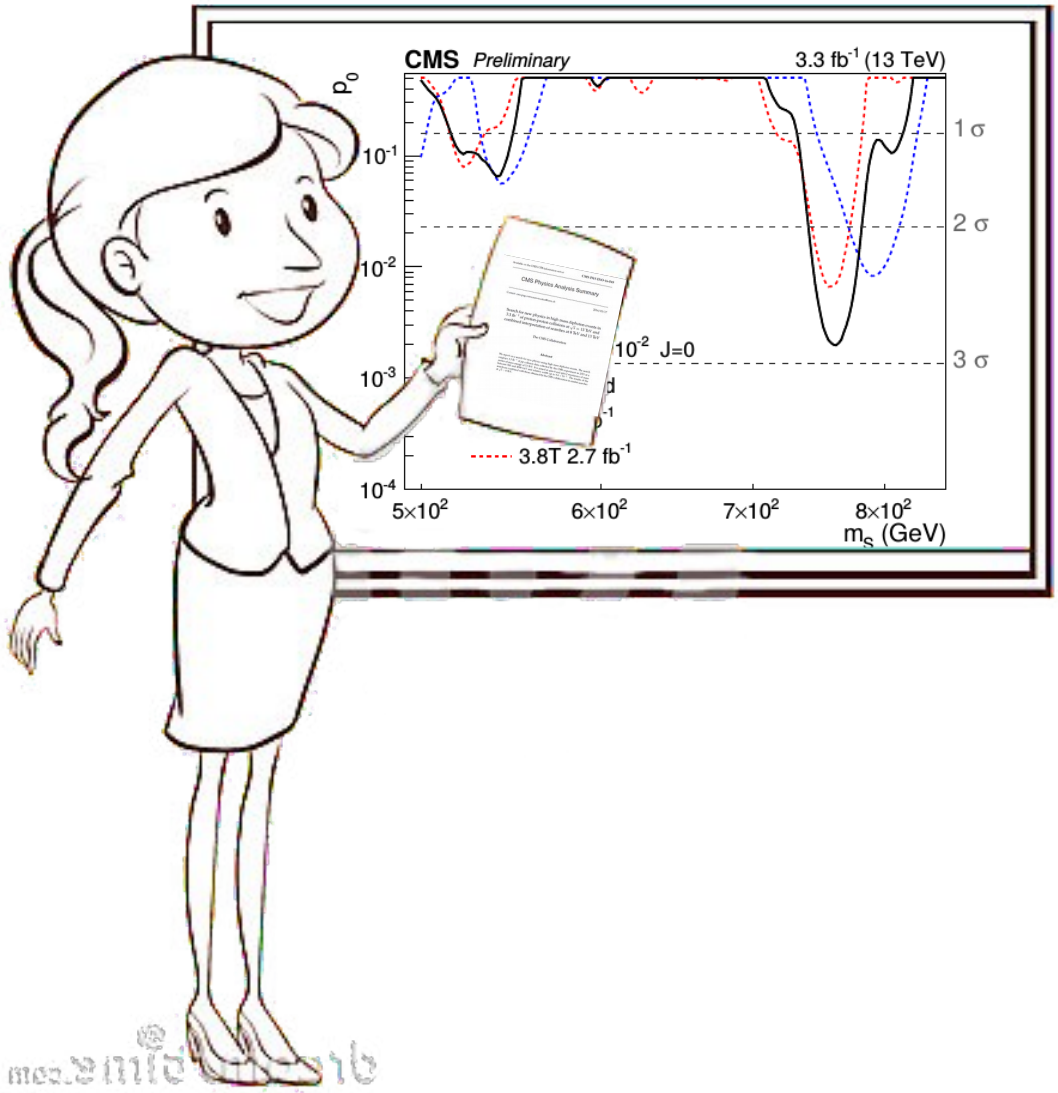
- **Diphoton resonances search offer a powerful** way to probe BSM physics

- **Low-significance excesses** seen in diphoton channel around a mass of 750 GeV and narrow natural width
  → Local (global) significance of the excess (8+13 TeV):
  3.4 (1.6) σ

- **Getting ready for more data** and investigate new aspects of the resonance:
  → width and spin measurements
  → associated production: γγ+X
  → correlated final states (WW, tt, VV, Zγ, YY->γγγγ)

Back to a couple of months ago...

LHC Seminar 03/29/16:
https://indico.cern.ch/event/473192/



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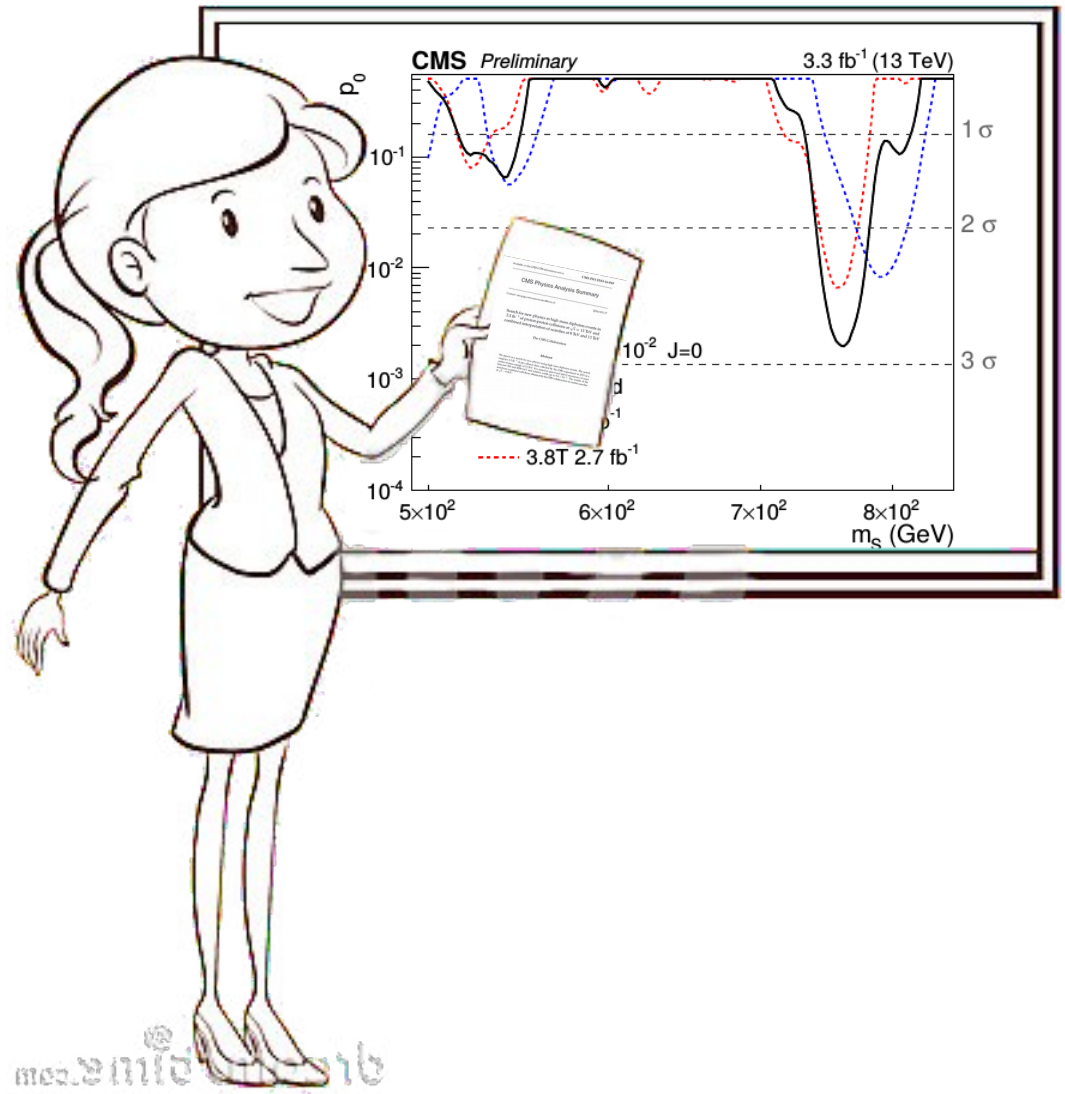
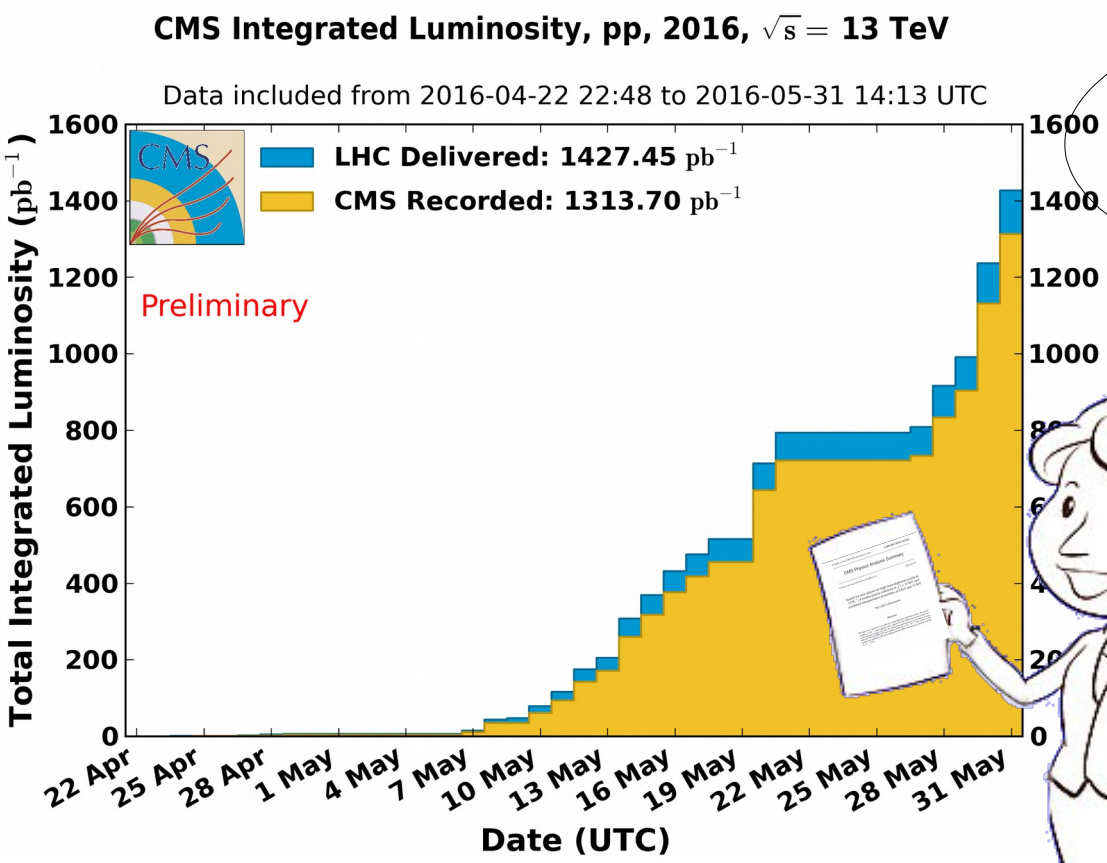
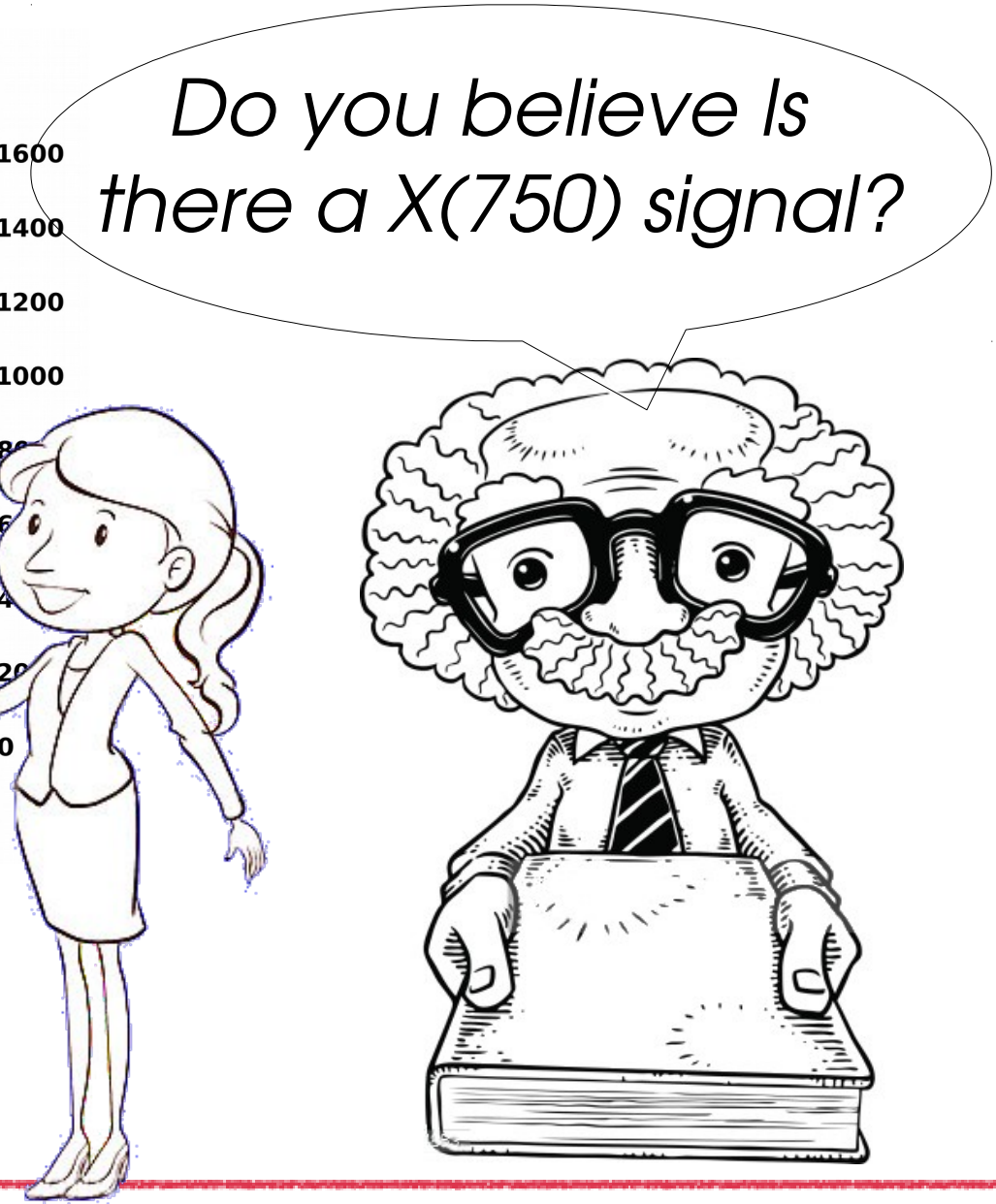


Do you believe Is there a X(750) signal?

Back to a couple of months ago...

LHC Seminar 03/29/16:
https://indico.cern.ch/event/473192/

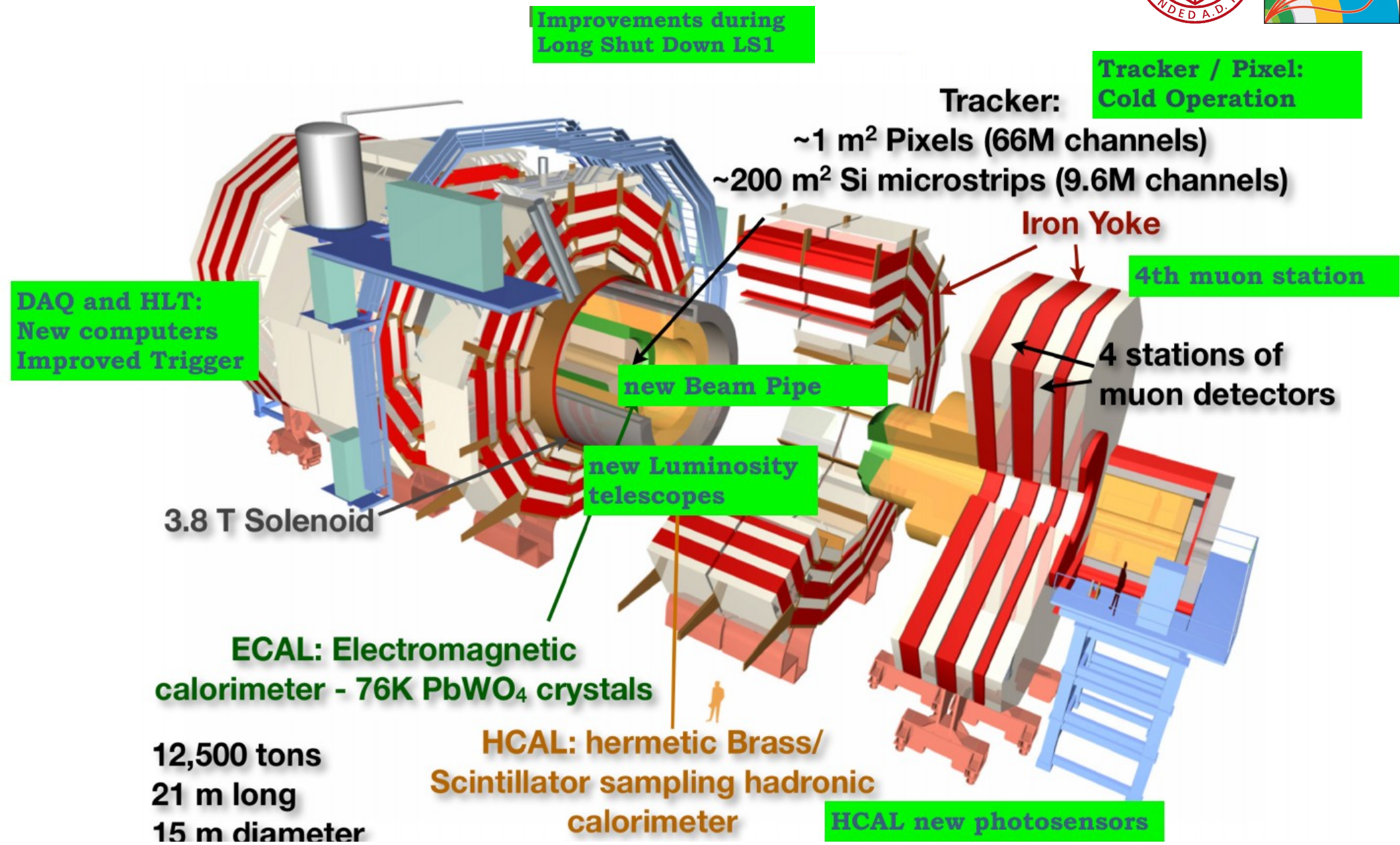




Data are the only source which speaks the truth!! :)

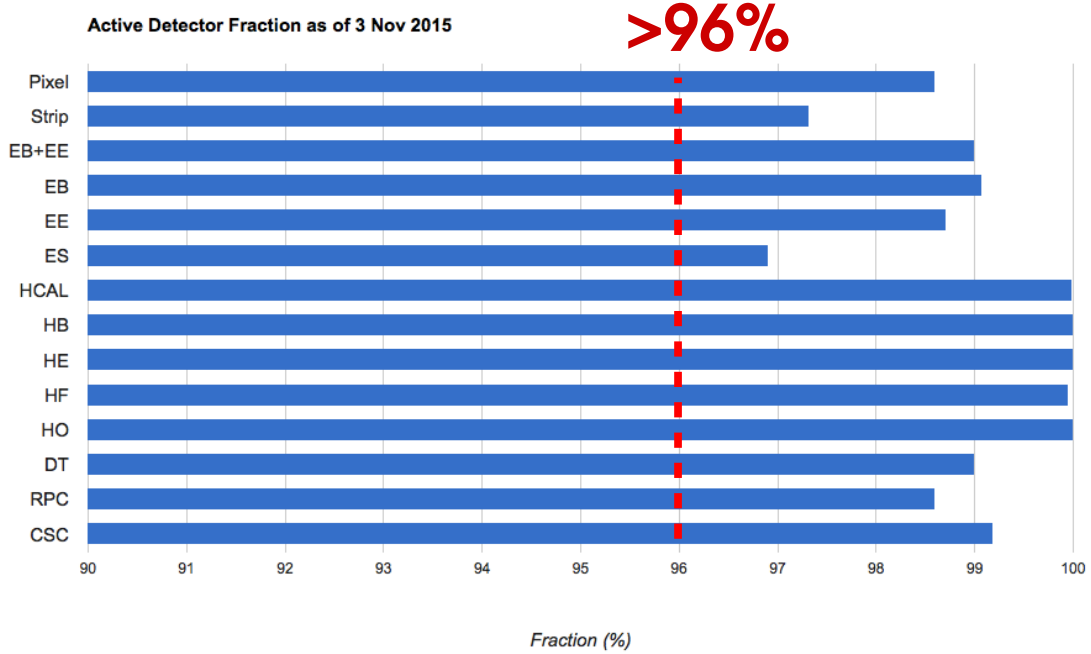
BACKUP

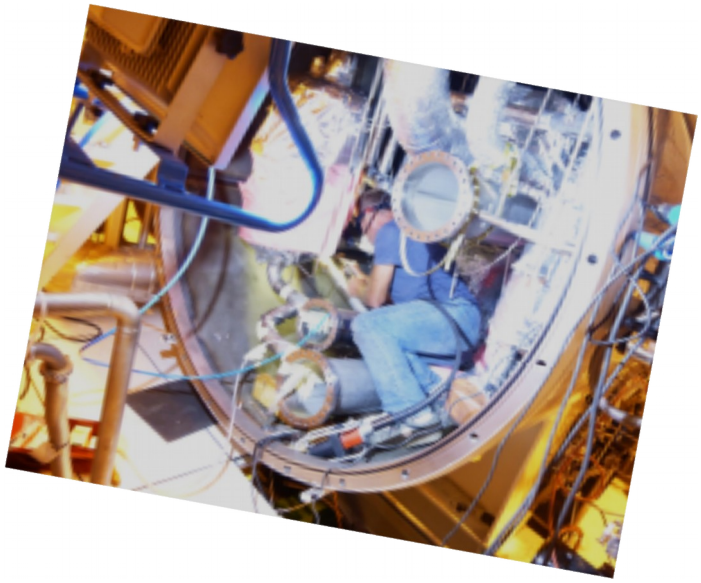
CMS detector for Run2



CMS Performance in RUN 2

Active Detector Fraction in 2015





- CMS magnet operated intermittently during 2015 due to persistent problems in the cryogenic system
- **Data collected w/o magnetic field are available to be used in physics analyses**

Available datasets

	Magnet Field	Integrated Lumi
#1	3.8 T	Up to 2.8 fb^{-1}
#2	**0 T**	**0.6 fb^{-1}**

ECAL Energy Resolution

$$\frac{\sigma_E}{E} = \frac{2.8\%}{\sqrt{E(\mathrm{GeV})}} \oplus \frac{12\%}{E(\mathrm{GeV})} \oplus 0.3\%$$

The **stochastic** term includes contributions from the **shower containment**, the number of photoelectrons and the fluctuations in the gain process.

The **noise** term of 12% at 1 GeV corresponds to a **single- channel noise of about 40 MeV, giving 120 MeV** in a matrix of 3×3 crystals.

The **constant** te
the energy resolu
electron and pho
depends on **non-**
longitudinal lig
leakage from the
orimeter, single-c
uniformity and st

The beam test setup was without magnetic field, no inert mater

High-p_T Photons IDs

- Set of identification criteria **unchanged** wrt EXO-15-004
  - Per-diphoton efficiency of 80-90%

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				

Photon identification criteria used in the analysis.

3.8 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

0 T

ISOγ = ΣE_T of photons inside a cone ($\Delta R < 0.3$)

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

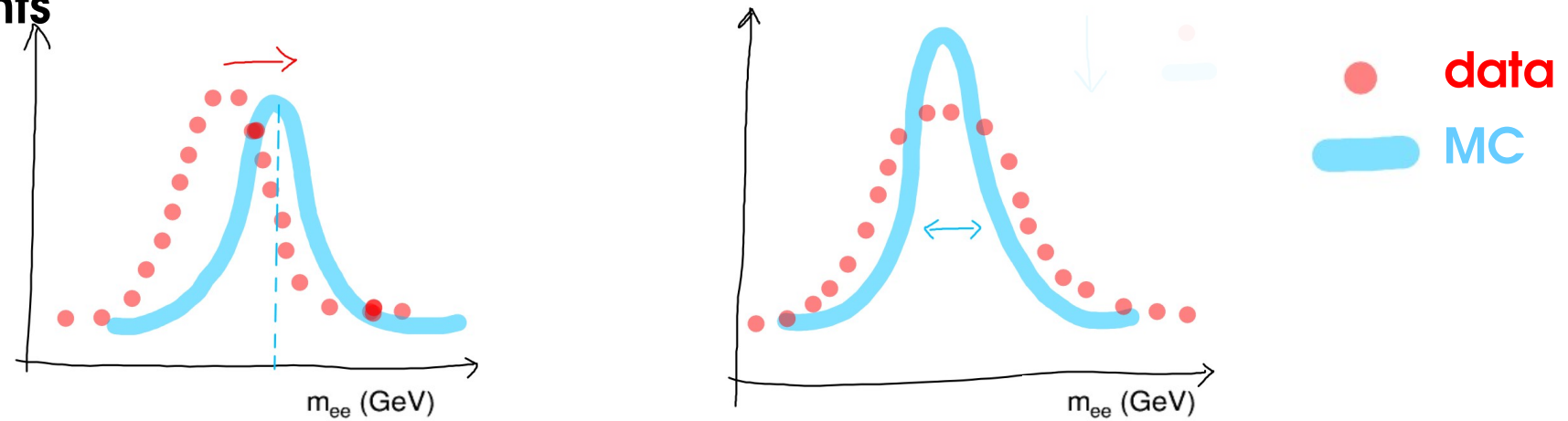
$\sigma_{i\eta i\eta}$ = shower transverse width along η σ

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

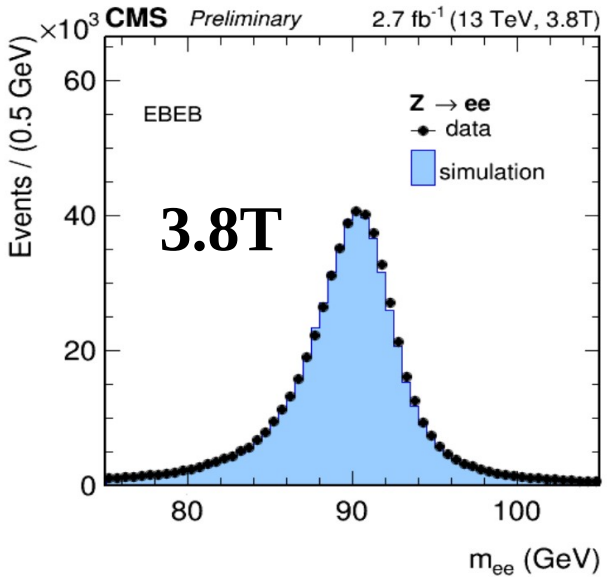
$N_{missing\ hits}$ (electron veto): photon candidate selected either if no gsfTrack associated ($N_{missing\ hits} = -1$) or if the associated gsfTrack has $N_{missing\ hits} > 1$

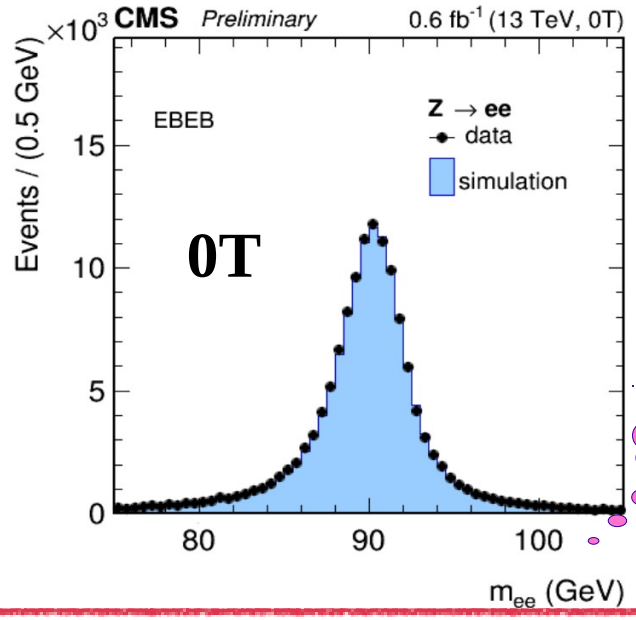
Energy Scale Corrections

- Simultaneously **adjust energy scale (data) and resolution (MC) using Z peak events**



- **Stability vs E_T** checked with boosted events up to ~150GeV.
- Deviations within **0.5(0.7)%** in barrel (endcaps).





- Dedicated energy scale calibration with 0T Z → ee events

Mar`16

High-Mass Diphoton Searches in CMS

Ref	Title	M_X range [GeV]	interpreted as			
			spin-0	spin-2	Narrow width	Large width
PLB 750 (2015) 494	Search for diphoton resonances in the mass range from 150 to 850 GeV in pp collisions at **√s = 8 TeV**	150-850	✔	✔	✔	✔
EXO-12-045	Search for High-Mass Diphoton Resonances in pp Collisions at **√s = 8 TeV** with the CMS Detector	500-3000	✘	✔	✔	✔
EXO-15-004 Dec`15	Search for new physics in high mass diphoton events in proton-proton collisions at **√s = 13 TeV**	500-4500	✘	✔	✔	✔
EXO-16-018 Mar`16	**Search for new physics in high mass diphoton events in 3.3 fb^{-1} of proton-proton collisions at √s=13 TeV and combined interpretation of searches at √s=8 TeV and 13 TeV.**	**500-4500**	✔	✔	✔	✔

DiPhoton Search Additional Infos

- 3.8 T: Background composition extracted from a template fit
  → Purity for γγ events: 80-90 % (EBEB) and 70-80 % (EBEE) (~ unchanged wrt EXO-14-004)

- 0 T: Template approach cannot be used (relies on charged isolation)
  → Lower predicted purity for B=0T: 70-80 % (EBEB) 50-60% (EBEE)

- Event migration studied for events with M > 500 GeV
  For EBEB: ~10% events go out, ~10% go in
  For EBEE: ~10% events go out, ~20% go in

Background shape mismodeling

- Goodness of fit of background model assessed locally (as a function of mγγ) using MC
  - Study pull of predicted number of background events in several mass windows

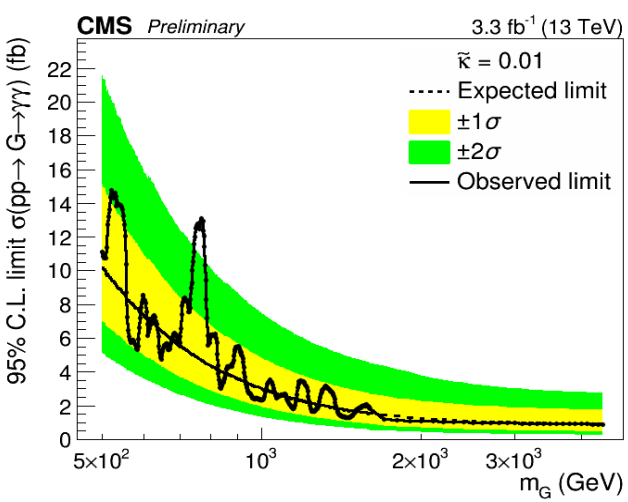
$$p_i^j = \frac{N_{\hat{g}_i}^{w_j} - N_h^{w_j}}{\sigma(N_{\hat{g}_i}^{w_j})} \quad \Rightarrow \quad \tilde{p}_j^i = \frac{N_{\hat{g}_i}^{w_j} - N_h^{w_j}}{\sqrt{\sigma^2(N_{\hat{g}_i}^{w_j}) + \beta_I^2(w_j)}}$$

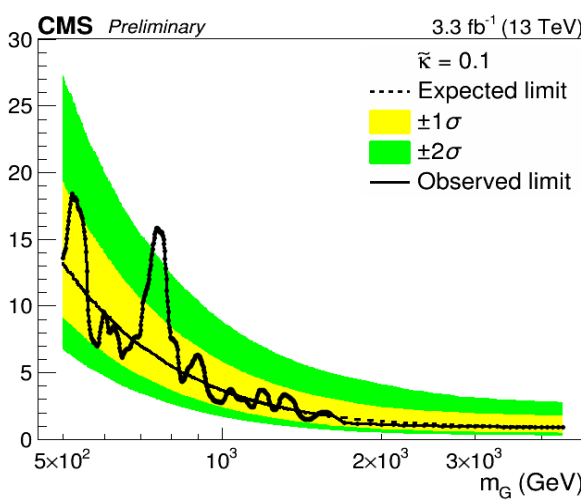
  - Model acceptable if b = | median(p) | <0.5 for all windows
  - If not, increase error by "bias term"

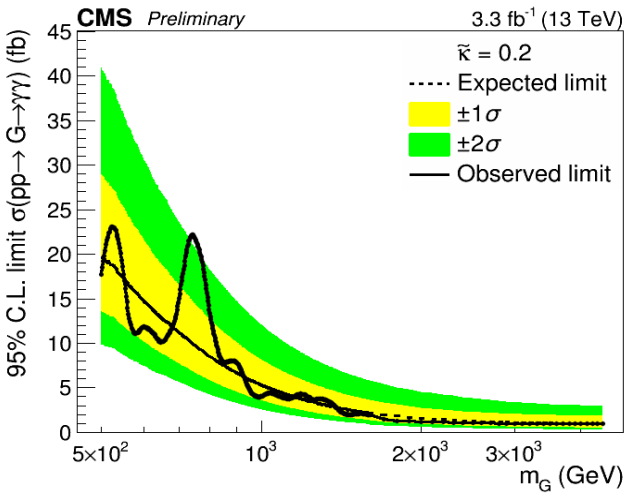
- Bias term included in hypothesis test adding a signal-like component to the background model

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

Exclusion Limits: (3.8 T + 0 T+ 8 TeV)



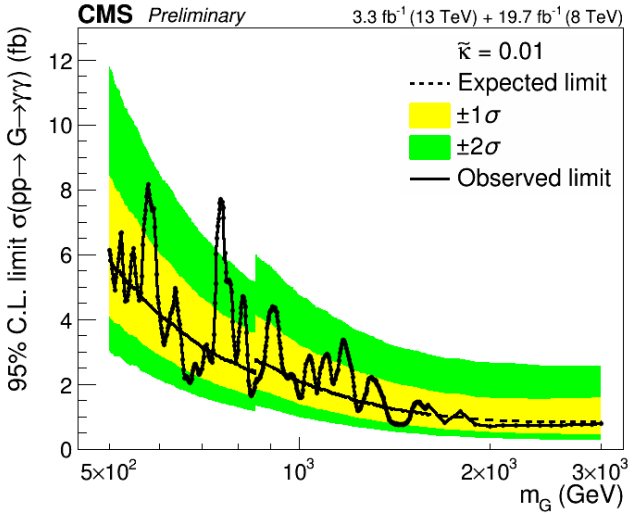


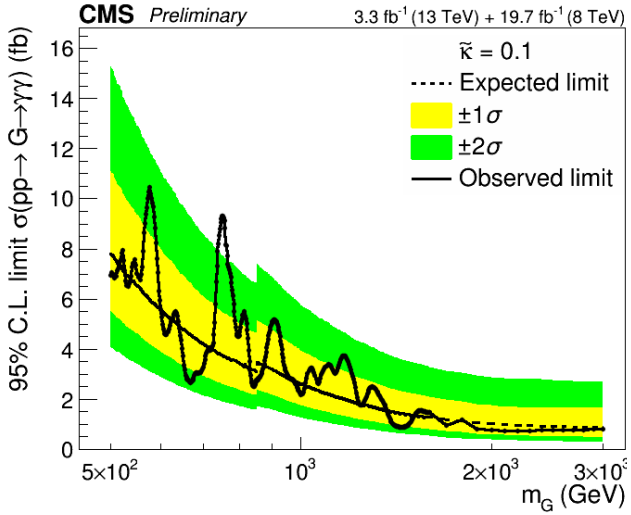


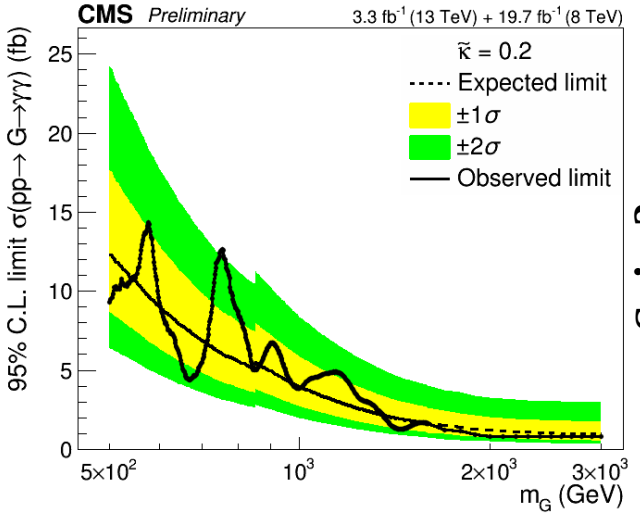
Spin 2

Narrow width

Wide width





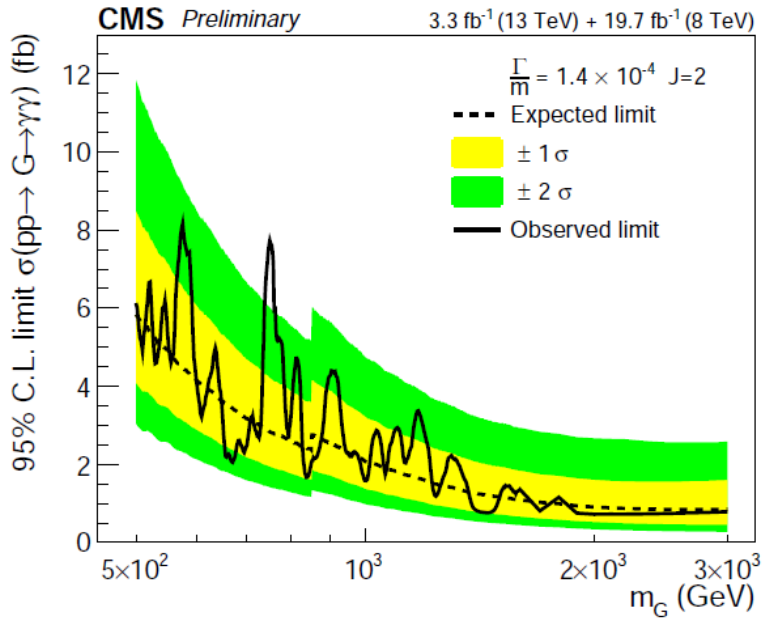


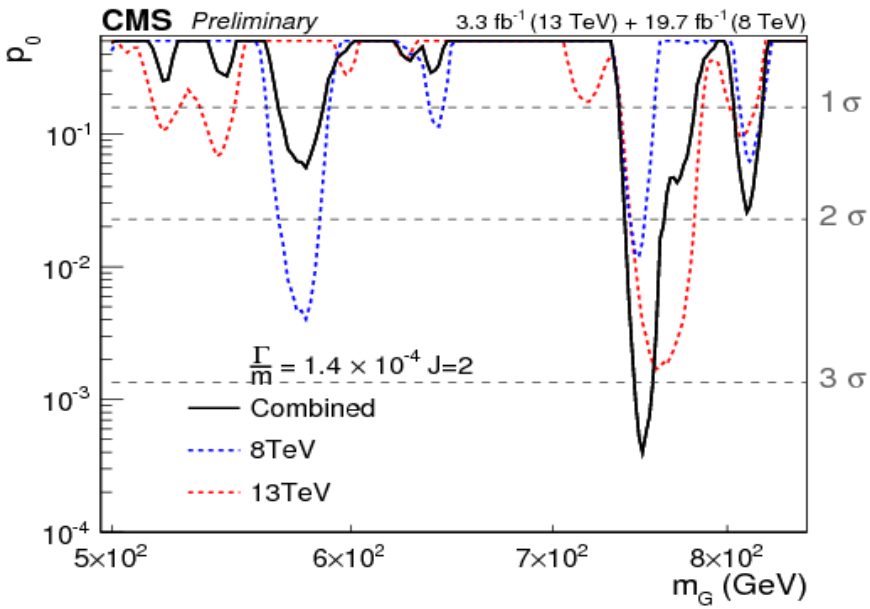
Spin 2

Spin 2 combination and LEE

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(p0) 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 for 13 TeV analysis and 1.6 for 8+13 TeV combined analysis





Z+γ Resonances

- Search for new resonances decaying to Z+γ needed to disentangle new physics in the high-mass range
- Look for **A→ Z+γ**, with either Z→ ee or Z→μμ

Signature: clean final-state topology giving rise to a clear peak in the invariant mass distribution

	√s (TeV)	Lumi (fb^{-1})	Background model	Mass Search Range (GeV)	Natural width	Signal model	UL 95% (fb)
HIG-16-0014	8	19.7	Fit $m_{ll\gamma}$ data w/ three exponential functions	200-1600	1%	From simulation	0.15-3.8
EXO-16-019	13	2.7	Fit $m_{ll\gamma}$ data w/ $f=m^{a+b \log m}$	350-2000	1.4×10^{-4} %, 5.6 %	Parametrized Model from simulation	50-300