Search for new physics in high mass diphoton events: CMS results.

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750 GeV Forum at DESY

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Zeuthen – 3rd February 2016

Motivation

Looking for fully reconstructed resonances at higher center-of-mass energy is the golden way to new particle discoveries.

- LHC Run2: new data taken at $\sqrt{s}$= 13 TeV

Statistically significant peak over a smooth background.

- Very clear signature
- Experimentally robust
- Small systematic effects
- Model independent probe to new physics

Past discoveries

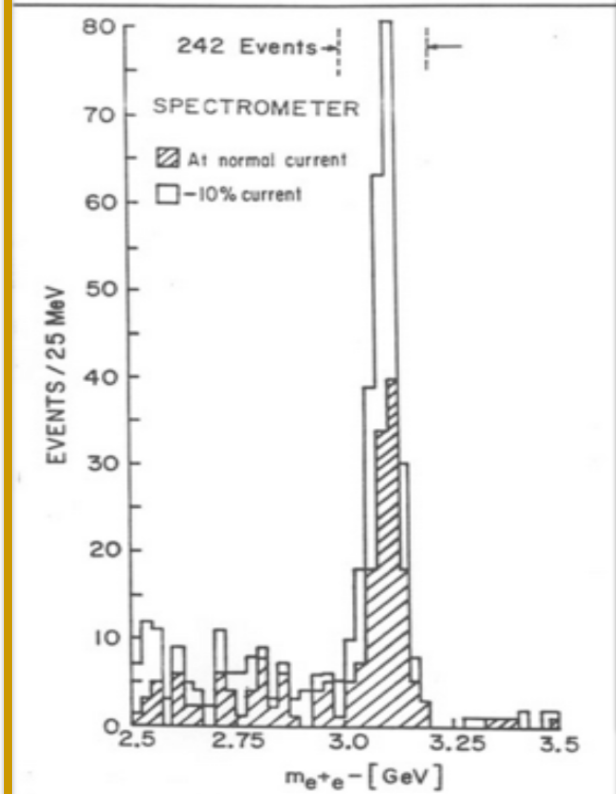
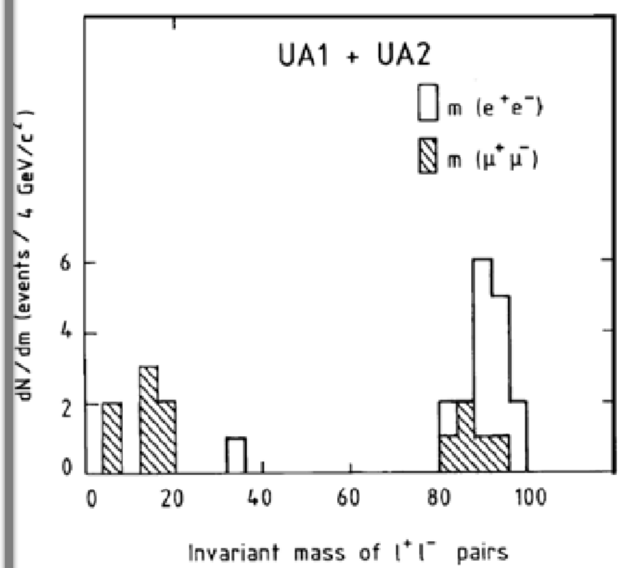
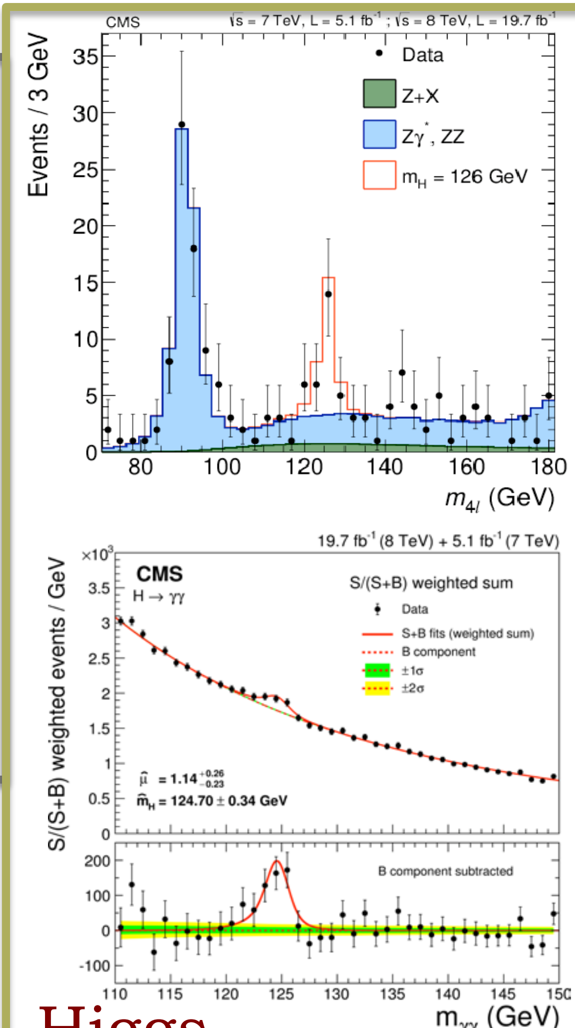


FIG. 2. Mass spectrum showing the existence of J. sults from two spectrometer settings are plotted owing that the peak is independent of spectrometer rrents. The run at reduced current was taken two nths later than the normal run.

J/Psi



Z

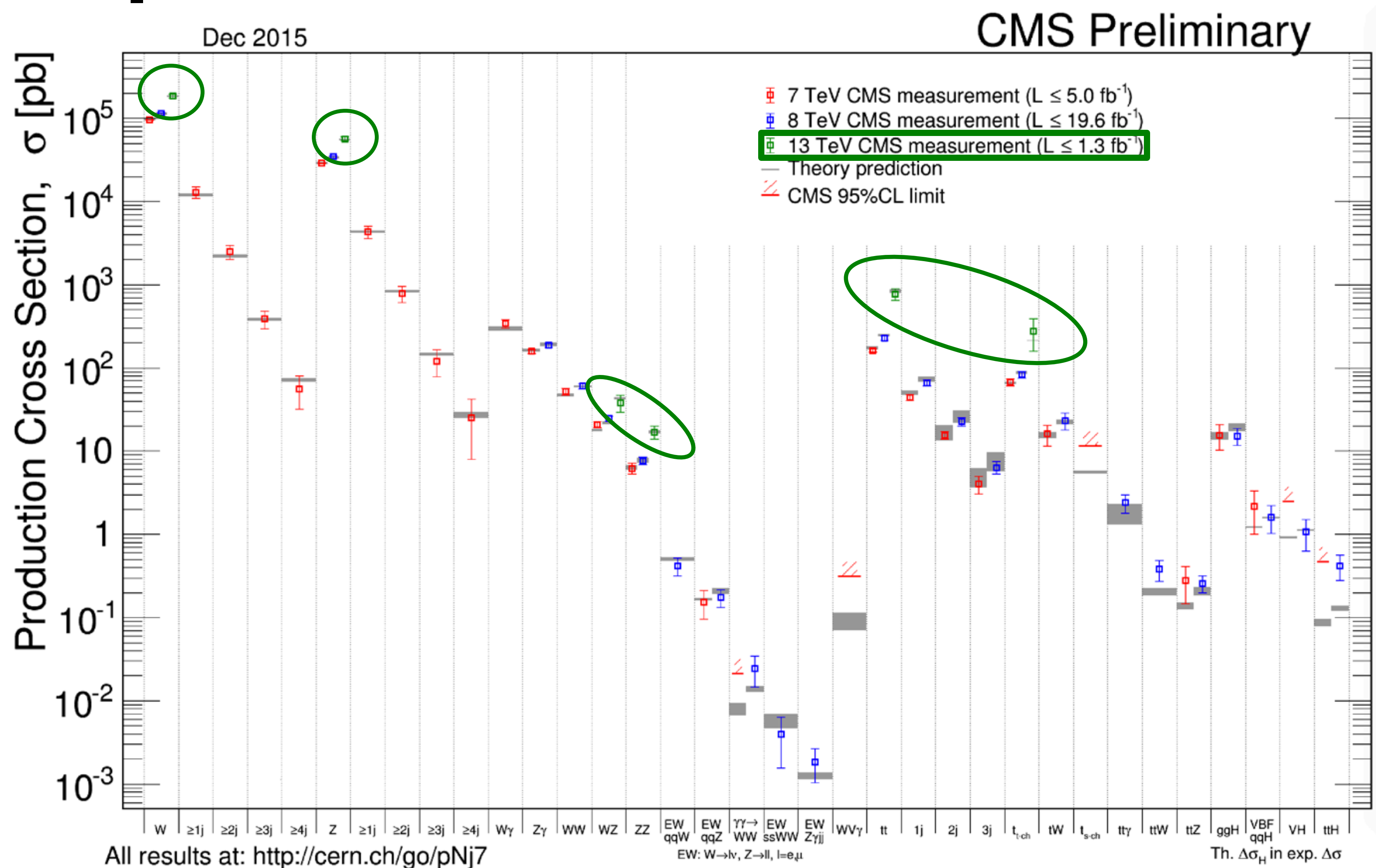


Higgs

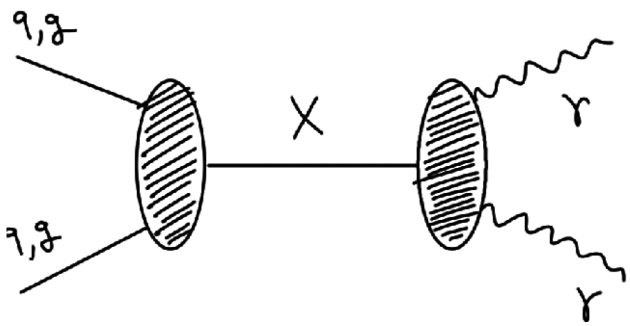
The CMS Collaboration

1700 physicists, 700 students, 950 engineers/technicians, 180 institutions from 43 countries

Standard Model with CMS



Diphoton bump search



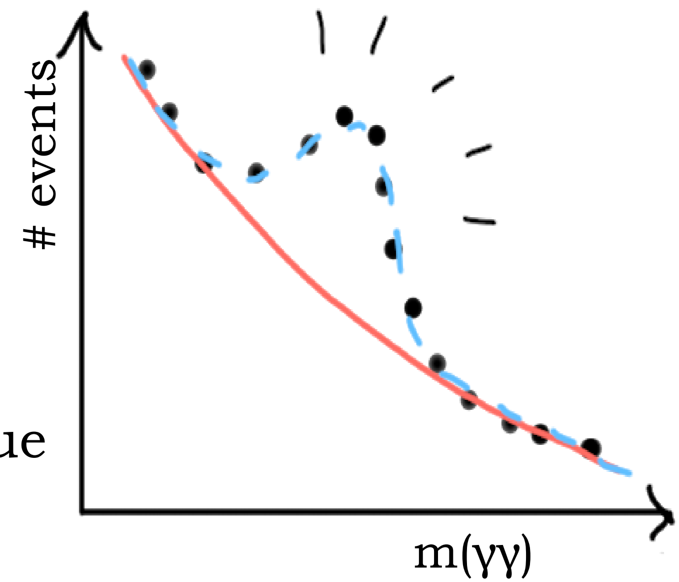
Clean final state at hadron colliders

1) Define the event selection: 2 isolated photons
   - ✓ must be loose and model-independent

2) Reconstruct the γγ invariant mass

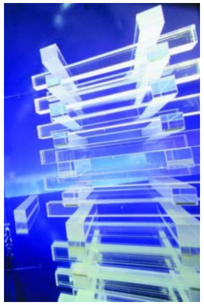
$$M = \sqrt{2E_1 E_2 (1 - cos\theta)}$$

   - ✓ photon reconstruction
   - ✓ energy resolution and scale
   - ✓ dedicated vertex identification technique



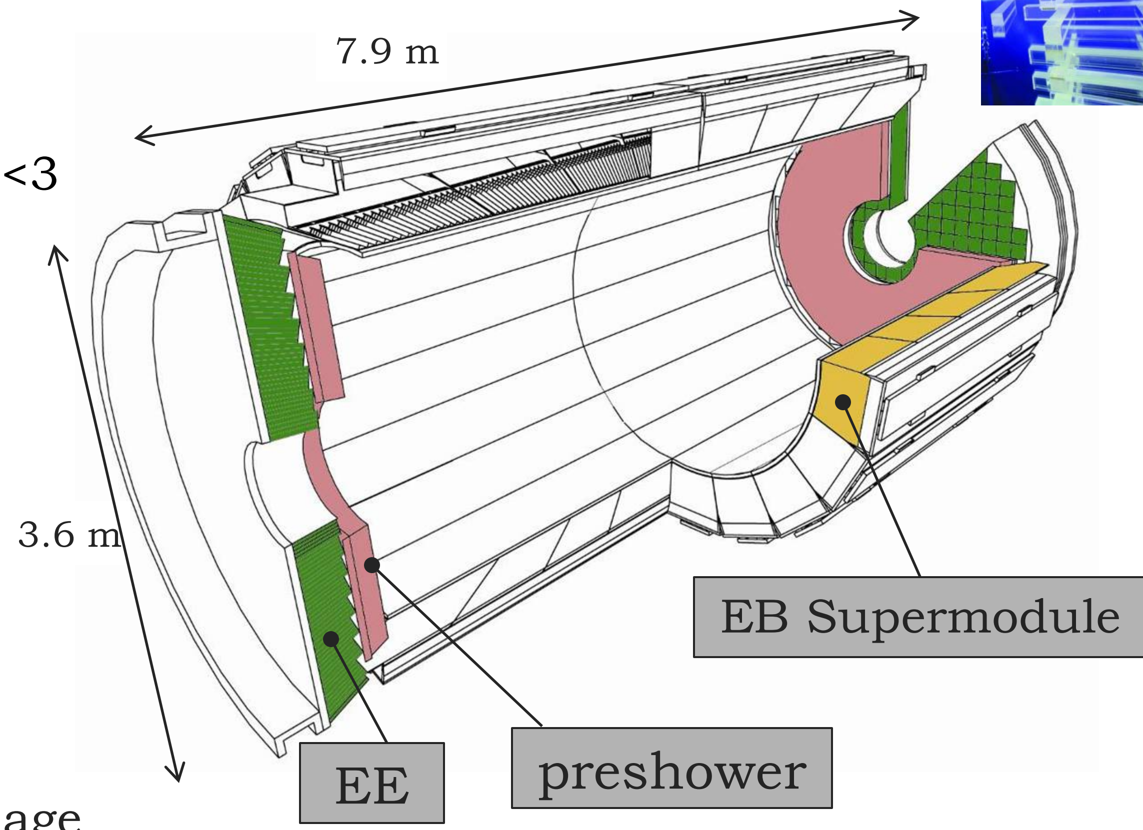
3) Signal extraction

CMS Electromagnetic Calorimeter



Lead Tungstate ($PbWO_4$) homogeneous crystal calorimeter

- 75848 $PbWO_4$ crystals
- Barrel (EB): $|\eta|<1.48$
- Endcaps (EE): $1.48<|\eta|<3$
- APD/VPT photodetectors

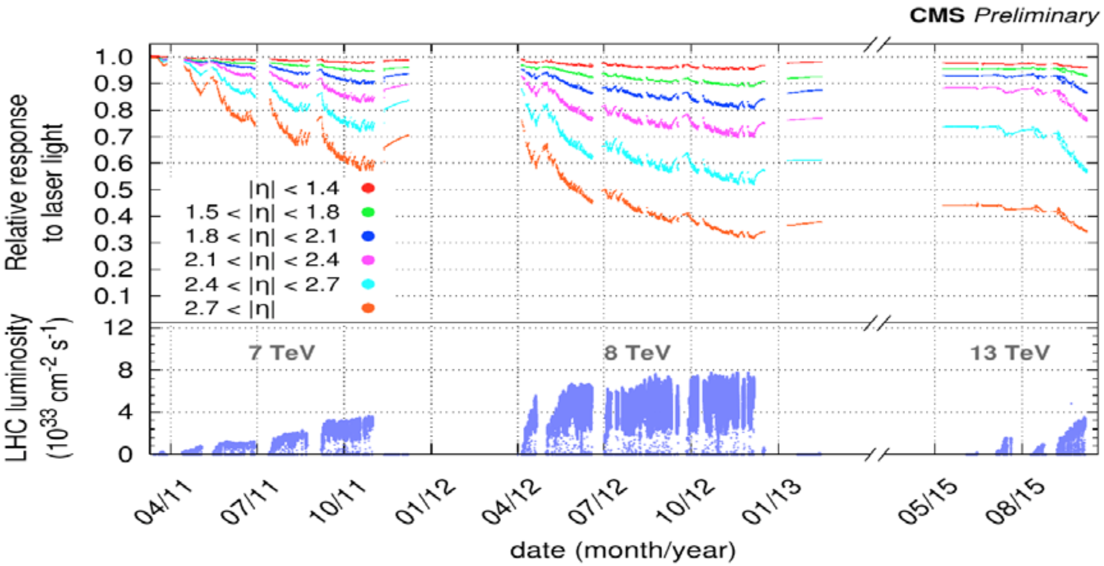


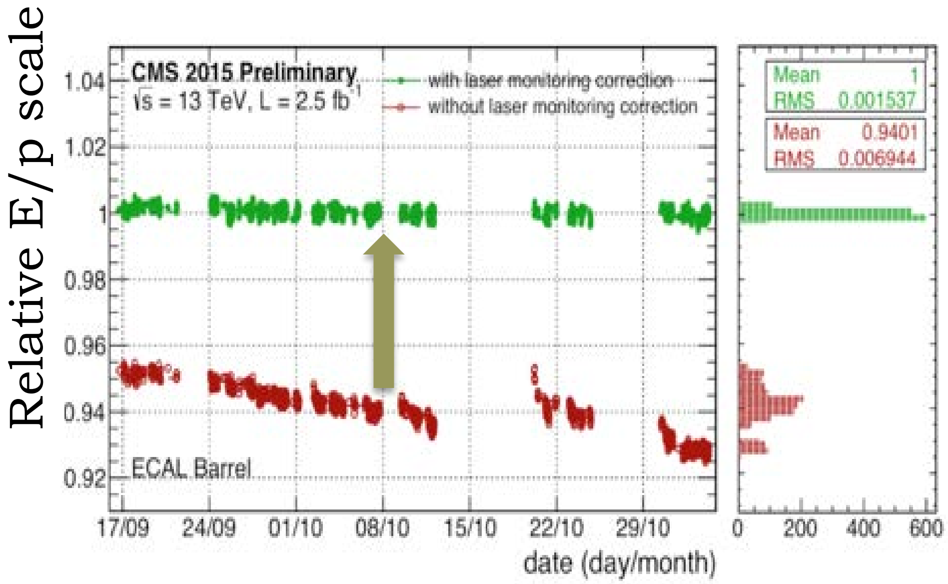
Design energy resolution:
~0.5% for $E(\gamma)>100$ GeV

- Critical issues:
  - Transparency loss due to radiation damage
  - Precision of in-situ calibration

Crystal transparency loss

Relative crystals response to laser light vs time





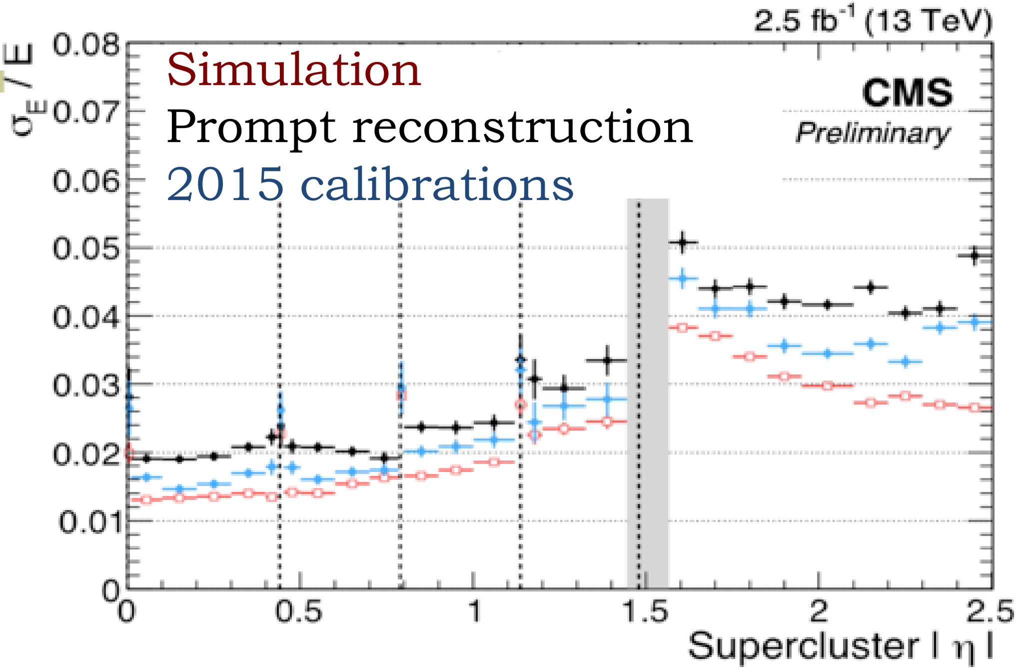
Stable energy scale achieved after laser correction ***in prompt reconstruction***

Barrel:

✓ average signal loss ~6%

✓ RMS stability ~0.15%

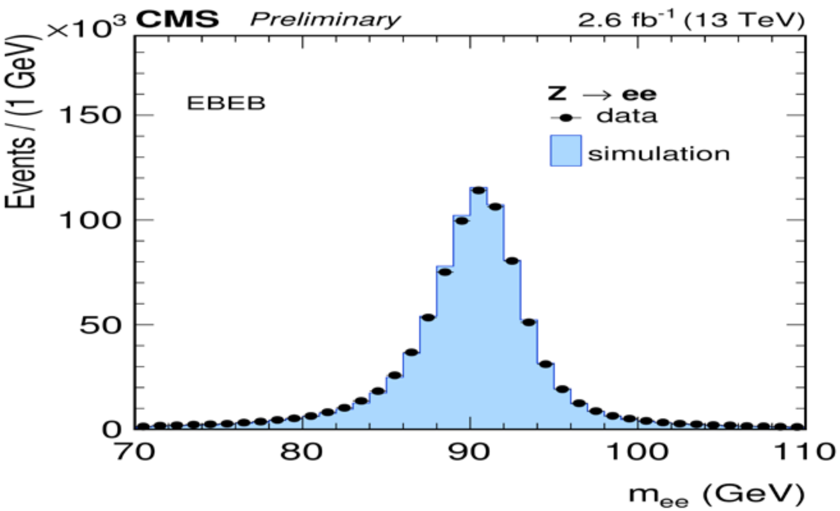
Energy scale and resolution



Prompt reconstruction used for the analysis.
New calibration coefficients (2015 data) available.

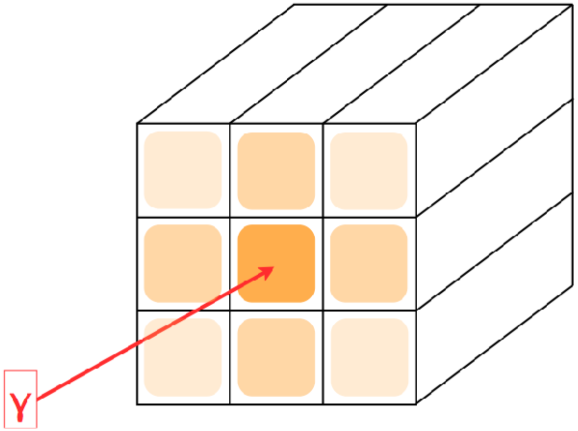
Significant improvement in energy resolution with new calibrations:

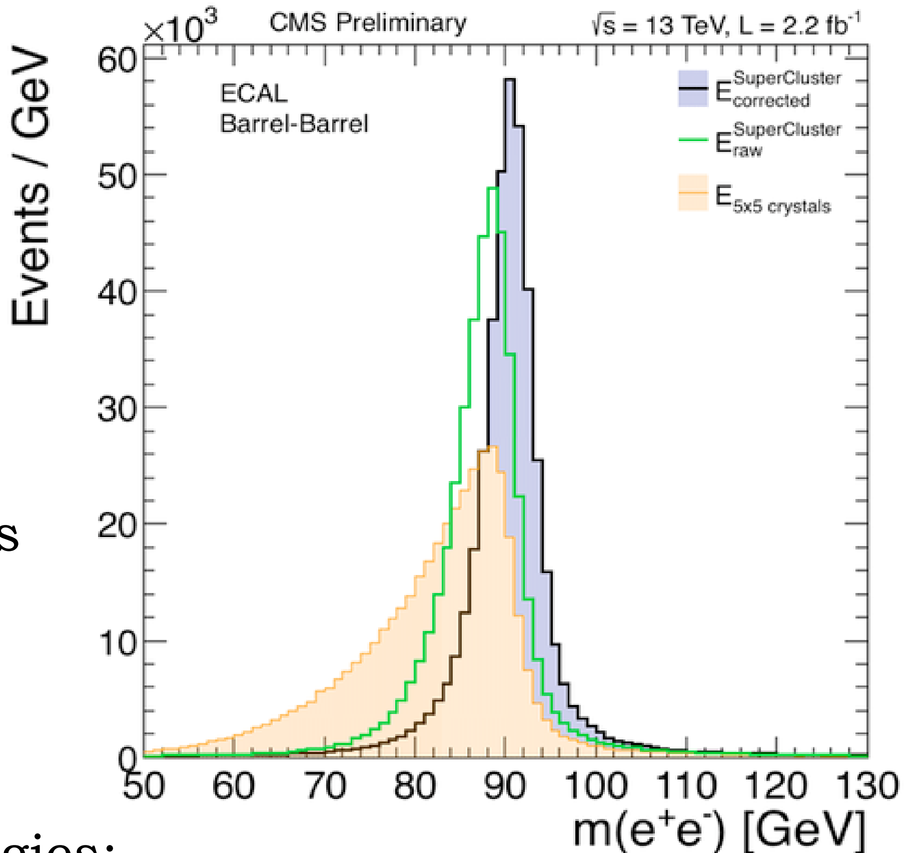
- ✓ barrel: resolution ~Run1
- ✓ endcaps: still worse (statistical precision)



Energy scale and resolution checked in data => analysis-level corrections applied

Photon clustering





Photon = energy deposits in clusters of ECAL crystals

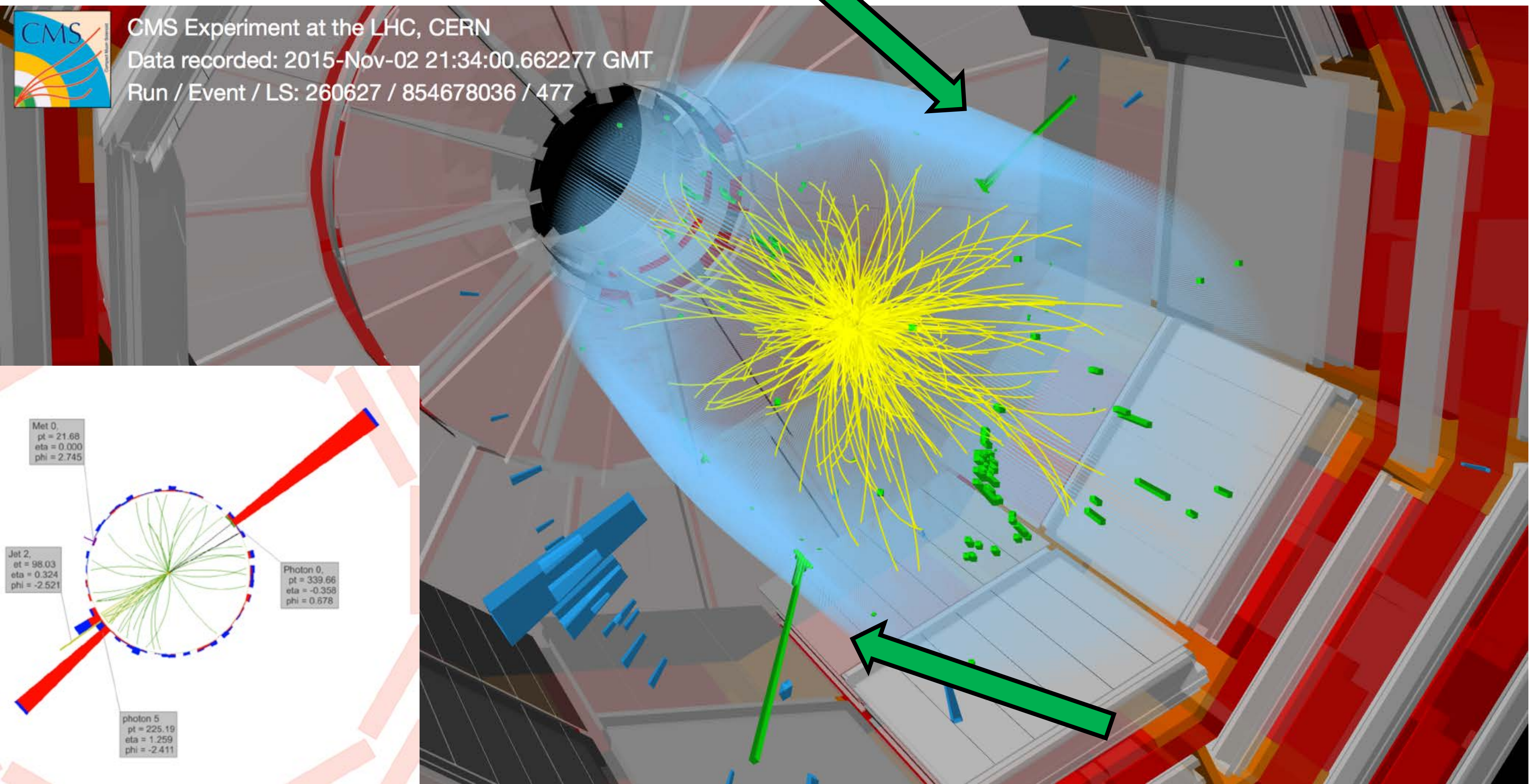
- ✓ clustering optimized to have the best energy resolution

Reconstruction and selection strategies:

- ✓ tuned on simulation and validated in data
- ✓ main control samples: Z->ee and Z->μμγ

Diphoton event display

$m(\gamma\gamma)$ = 745 GeV



High mass diphoton searches

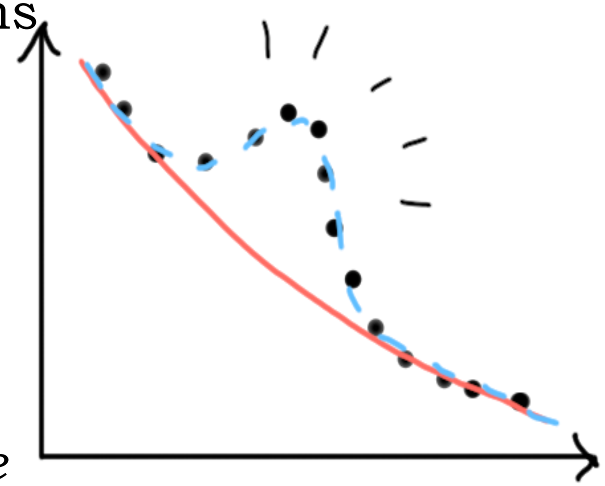
Ref	Title	M_X[GeV]	$\sqrt{s}$ [TeV]	$\mathcal{L}$ [fb^{-1}]
CMS-PAS-EXO-15-004	**Search for new physics in high mass diphoton events in proton-proton collisions at $\sqrt{s}$ = 13 TeV**	**500-4500**	**13**	**2.6**
PLB 750 (2015) 494–519	Search for diphoton resonances in the mass range from 150 to 850 GeV in pp collisions at $\sqrt{s}$ = 8 TeV	150-850	8	19.7
CMS-PAS-EXO-12-045	Search for high-mass diphoton resonances in pp collisions at $\sqrt{s}$ = 8 TeV with the CMS Detector	500-3000	8	19.7

Analysis in a nutshell

1) Define the event selection: 2 isolated photons

2) Reconstruct the γγ invariant mass:

3) Signal extraction



Some considerations:

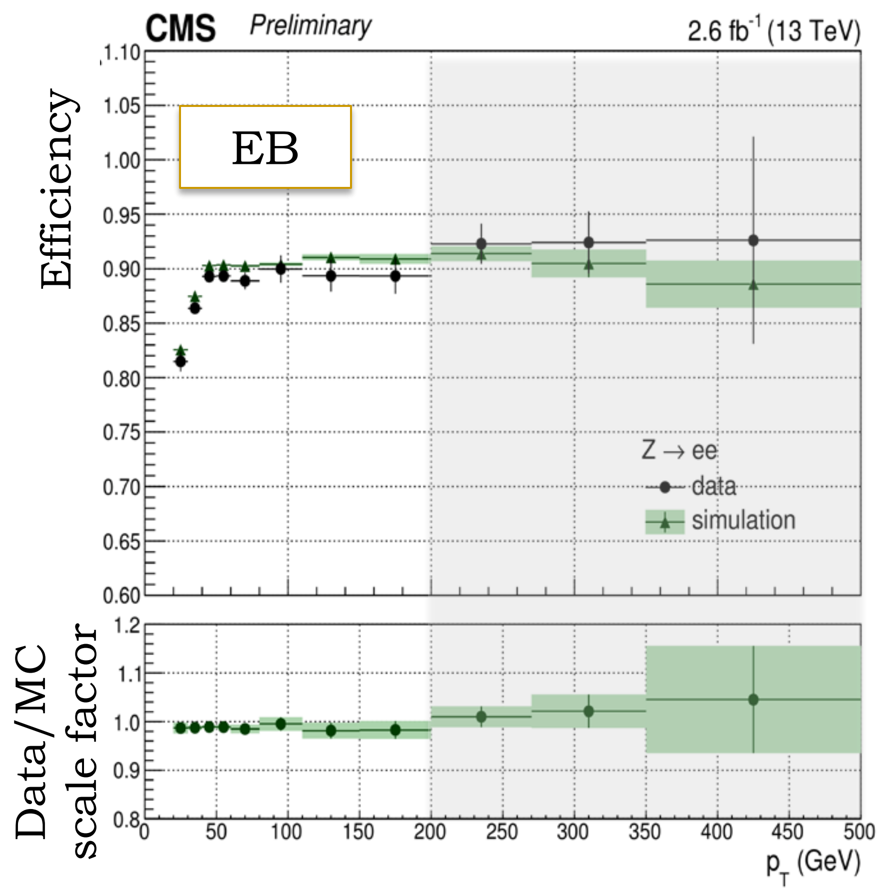
- ✓ *Analysis built on SM Higgs search experience*
  - ✓ *same methods used*
- ✓ *Only solid techniques exploited*
  - ✓ *nothing very fancy for this first round*
- ✓ *Selection developed before looking to the data:*
  - ✓ *cut based selection*
  - ✓ *fully blind analysis*

=> Goal: have a robust analysis up to high p_T

Event selection

Simple event selection

- ✓ HLT: 2 photons, p_T>60 GeV
- ✓ Offline selection:
  - ✓ p_T > 75 GeV
  - ✓ ECAL fiducial region
  - ✓ dedicated photon selection (isolation, H/E, shower shape)
- ✓ 2 event categories:
  - ✓ EBEB: both γ in the barrel
  - ✓ EBEE: one γ in EB, one in EE
  - ✓ events with 2γ in EE discarded



Zee to check efficiencies

- ✓ data/MC scale factors compatible with 1, constant at high p_T

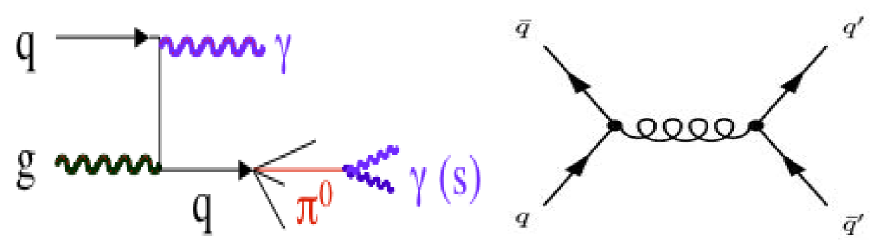
Zee and high mass DY to check scale and resolution

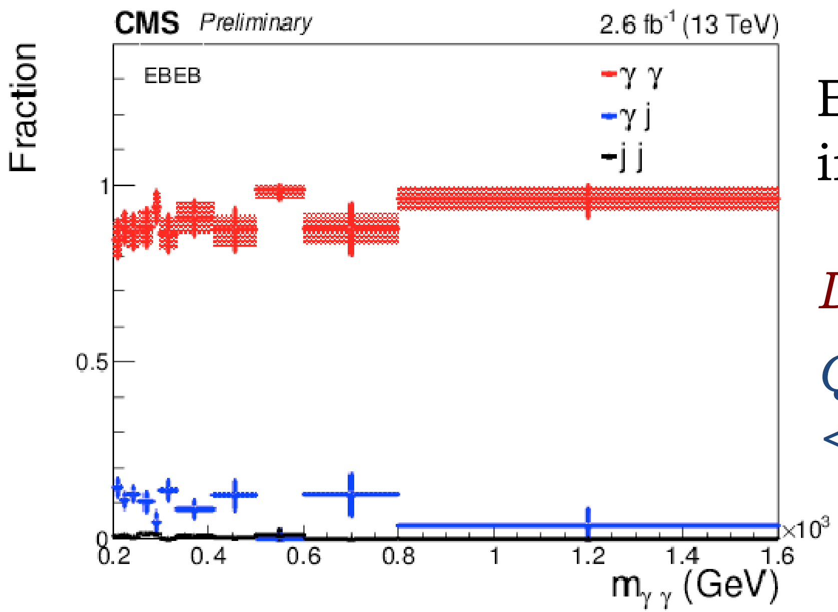
- ✓ results compatible within 0.5%

Backgrounds

Direct γγ SM production
irreducible

Dijet and γ+jet production
reducible



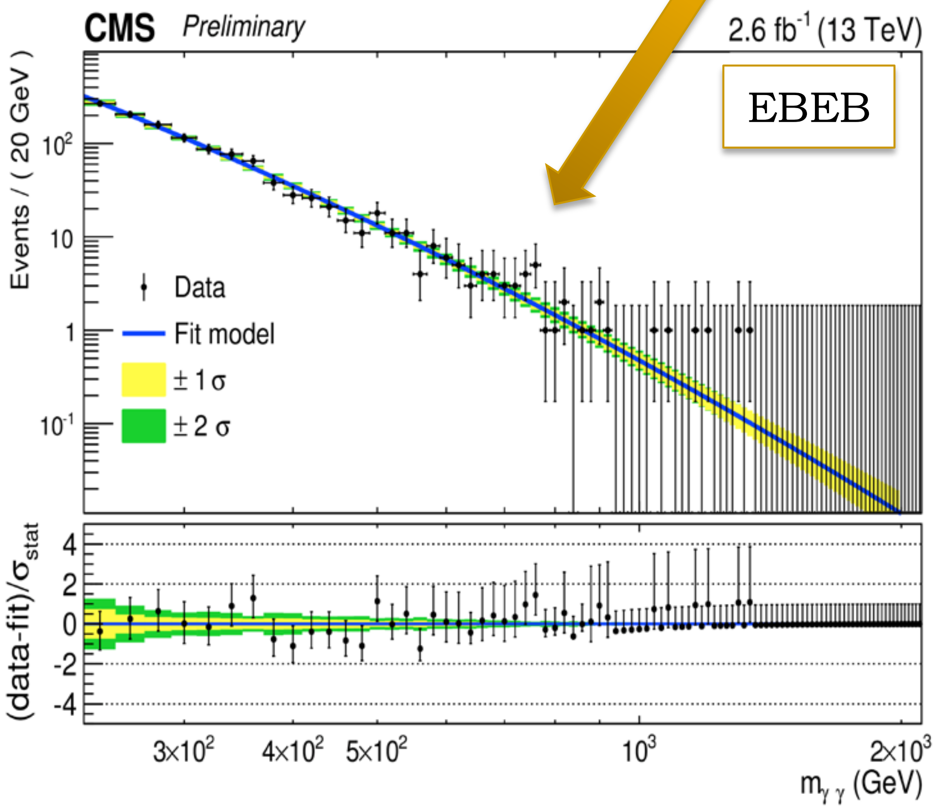


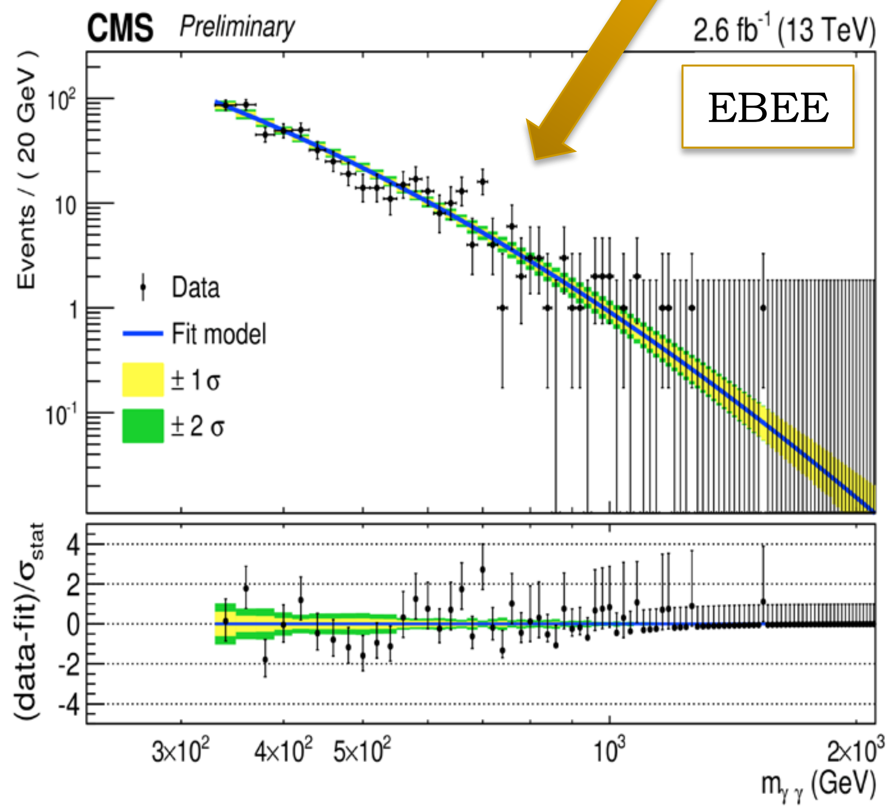
Background composition measured in data using template fits

Dominant contribution: 2 prompt photons

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

Mass spectra





Selected event $m_{\gamma\gamma}$ spectra in the two categories

Signal modelling

- Shape of the signal: combination of the intrinsic width of the resonance and the ECAL detector response.
- Benchmark model: spin2 RS Graviton
  - scan of two parameters (mass and effective coupling) chosen a priori
  - mass range: 500-4500 GeV
  - scan of the coupling: 0.01-0.2 $\rightarrow \Gamma_G/m_G$ = 0%-6%
- Detector response modeled on fully simulated signal sample with negligible intrinsic width

m_G (GeV)	category	$\tilde{\kappa}$	FWHM (GeV)	$\tilde{\kappa}$	FWHM (GeV)
500	EBEB	0.01	14	0.2	36
500	EBEE	0.01	22	0.2	42
1000	EBEB	0.01	27	0.2	74
1000	EBEE	0.01	43	0.2	85

Background modelling

Background $m_{\gamma\gamma}$ shape:

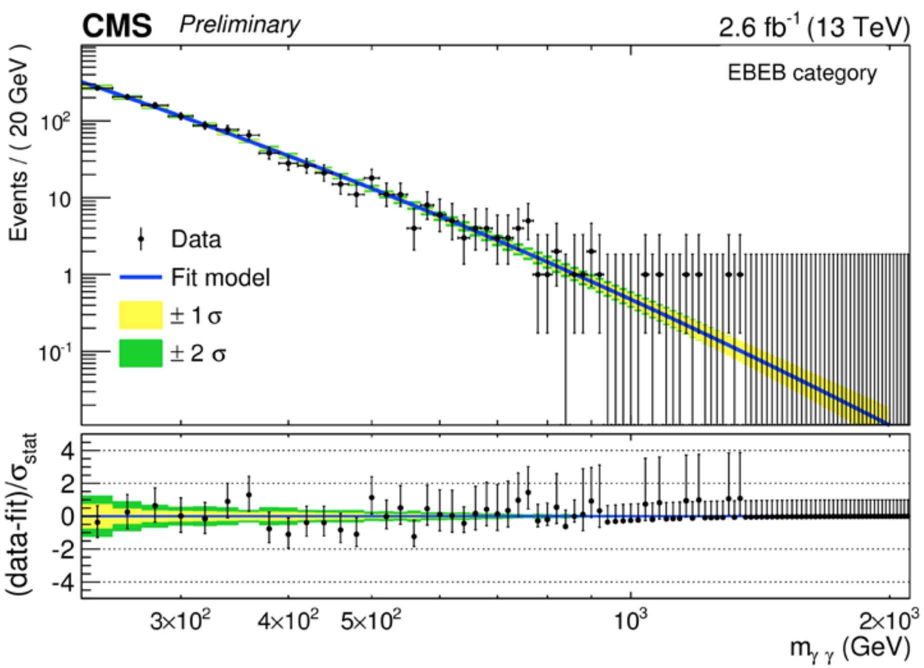
✓ parametric fit to data $f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\cdot\log(m_{\gamma\gamma})}$ (several function tested)

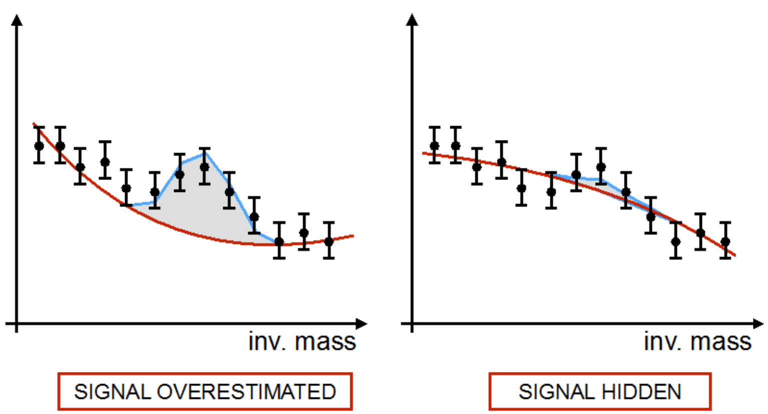
✓ model coefficients: nuisance parameters in the hypothesis test

Background fit accuracy determined using MC

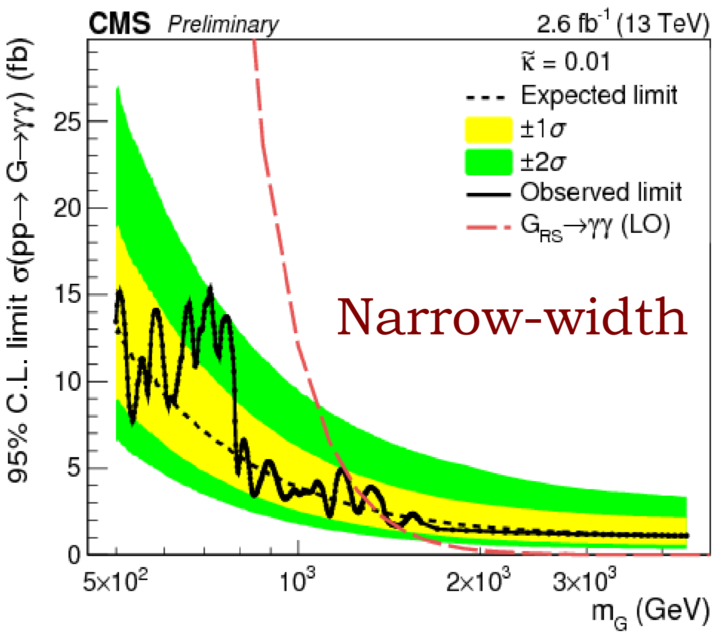
✓ possible mis-modelling: <1/2 of background statistical uncertainty

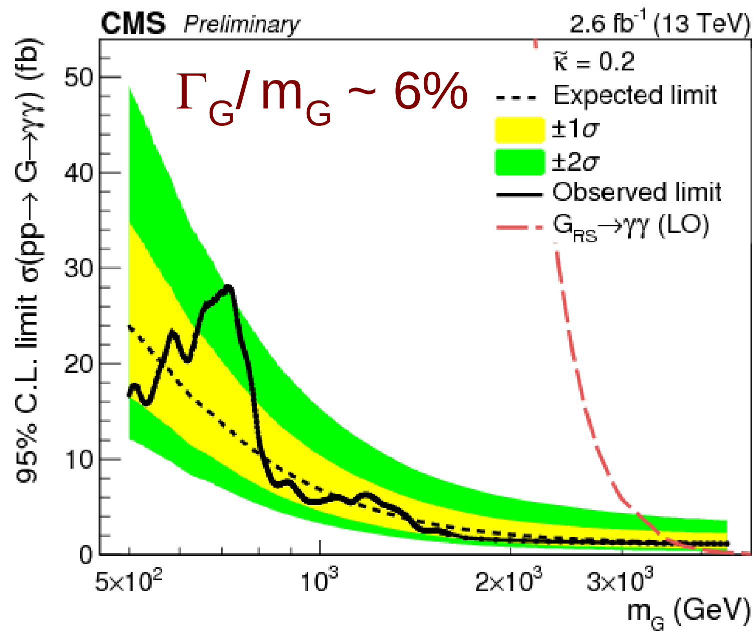
✓ extra uncertainty: signal-like component added to the model





Interpretation: exclusion limits

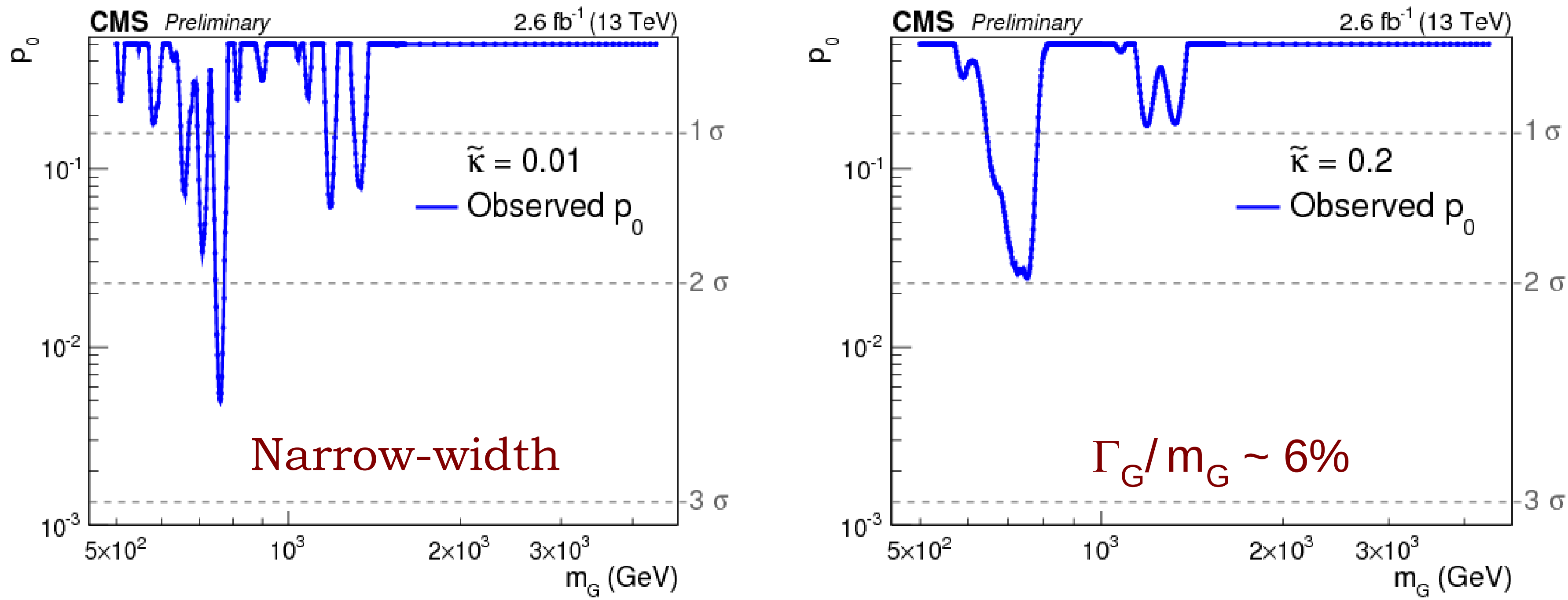




Expected and observed limits on Graviton cross section x diphoton BR (ATL-PHYS-PUB-2011-11 / CMS NOTE-2011/005):

- ✓ $m_G < 1.3/3.8$ TeV excluded ($k = 0.01/0.2$)
- ✓ Excluded range in agreement with expectations
- ✓ Observed limit deviation from expected due to excess in data

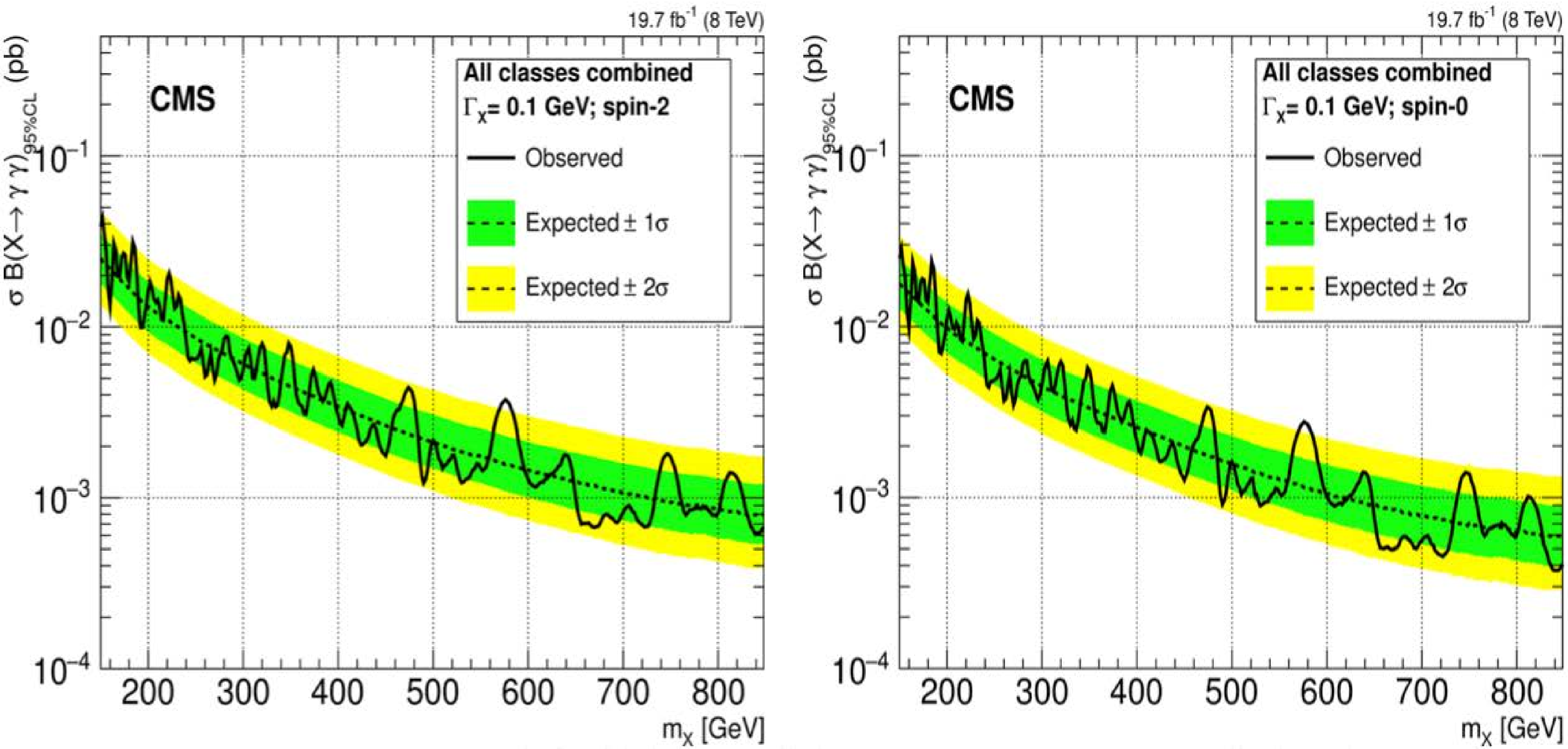
Interpretation: p value



- ✓ **Largest excess for m_G=760 GeV in the narrow width hypothesis**
- ✓ Local significance 2.6 σ
  - ✓ significance reduced to 1.2 σ when accounting for Look Elsewhere Effect in m_G (E. Gross and O. Vitells, arXiv:1005.1891v3)
  - ✓ LEE in k further decreases significance

Spin hypothesis

Spin 2 vs Spin 0: different acceptance and categories weight but **analysis not much sensitive to these differences**

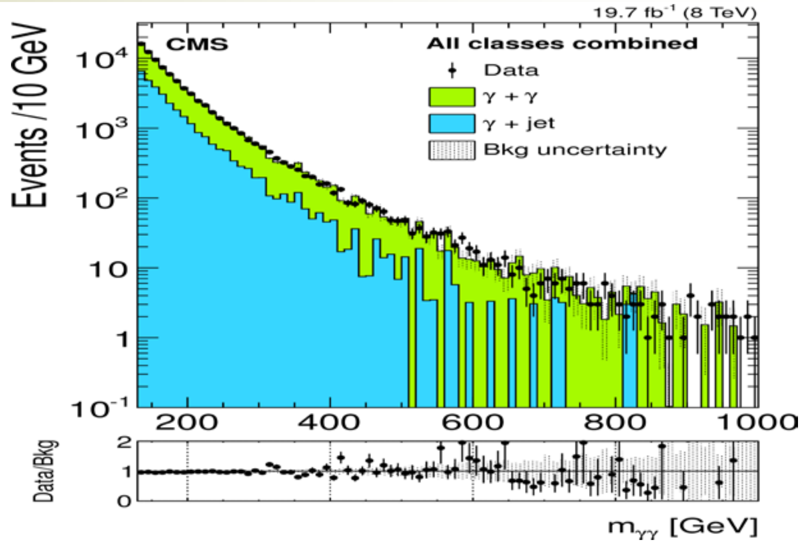


8 TeV analysis: limit shape is quite similar

Comparison to 8 TeV search

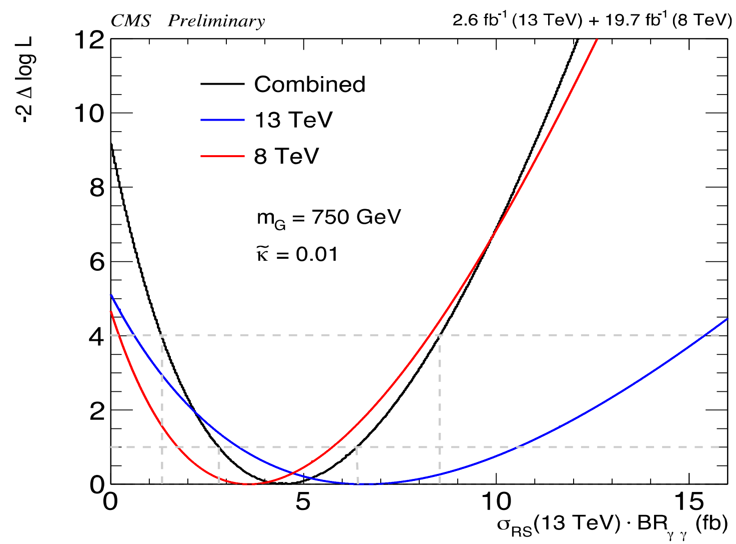
Combination with 8 TeV results in narrow width hypothesis

- ✓ different acceptance and categorizations
- ✓ most sensitive 8 TeV analysis in each mass range considered



Likelihood of fits to S+B hypothesis vs 13 TeV equivalent cross-section:

- ✓ 8 TeV limits scaled by xsec ratio
- ✓ S=RS Graviton, m_G=750 GeV, k=0.01
  - ✓ production: 90% gg, 10% qqbar
  - ✓ xsec(8TeV)/xsec(13TeV)=1/4.2=0.24

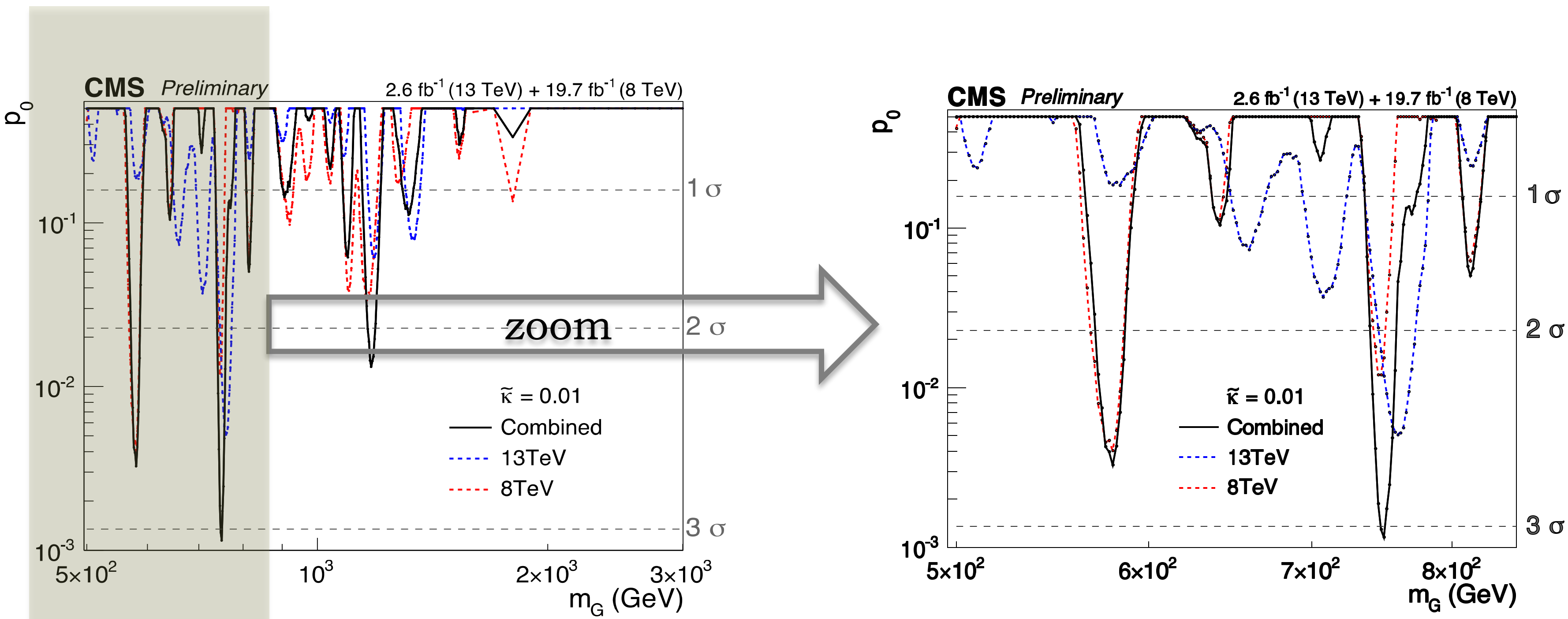


- ***Compatible equivalent cross-sections within uncertainties***
- ***13 TeV result not in contradiction with 8 TeV***

8-13 TeV combination

m_G<~1.5 TeV: combined limits 20-30% better than single inputs

Largest excess for m_G = 750 GeV
- ✓ local significance ~3σ
- ✓ reduced to <1.7σ accounting for LEE



Outlook

- Observed diphoton mass spectrum **in agreement with Standard Model expectations**
- Strongest constraint on production cross-section set
- Simple and robust analysis strategy

- **Modest excess for mass ~760 GeV**
  - local significance of 2.6 σ assuming narrow width signal
  - global significance of $<1.2\ \sigma$
  - still consistent with 8 TeV search

Few more months (~10 fb^{-1} @ 13 TeV) to determine the origin of this excess: statistical fluctuation or manifestation of new physics ?