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

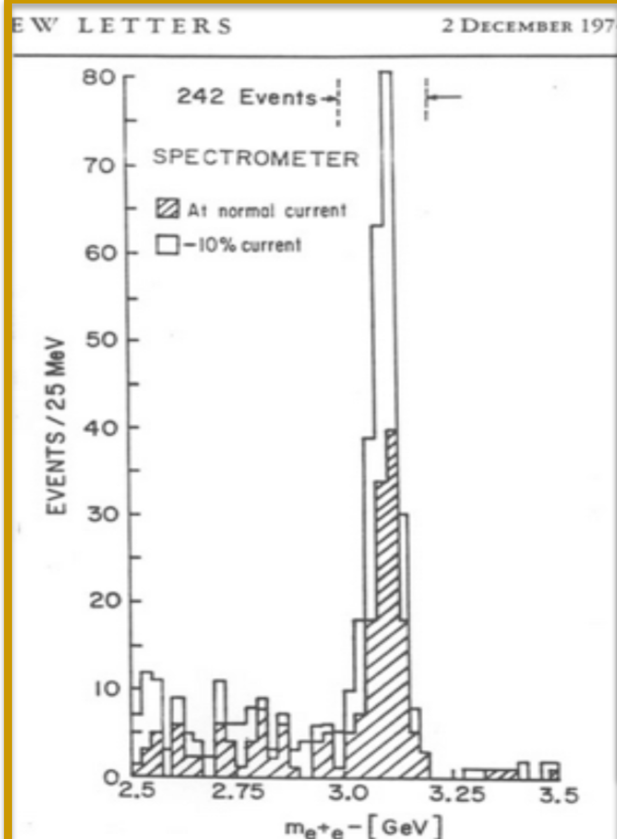
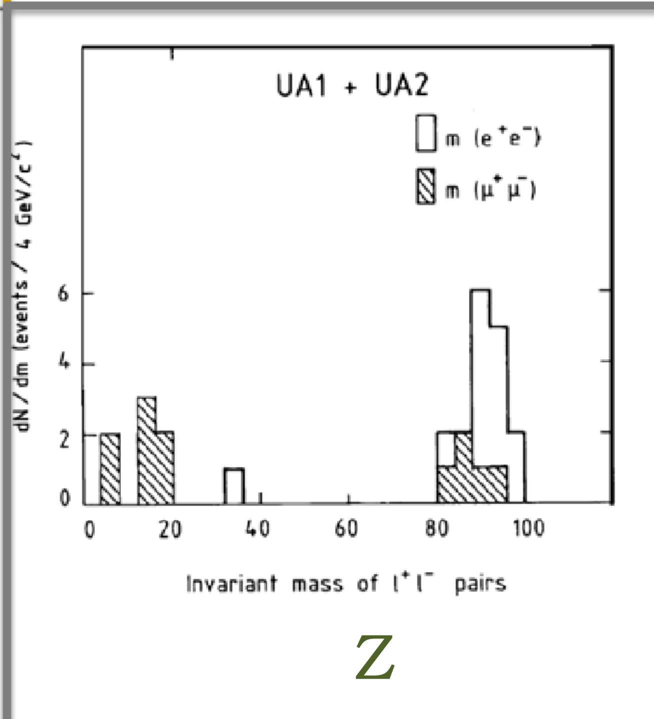
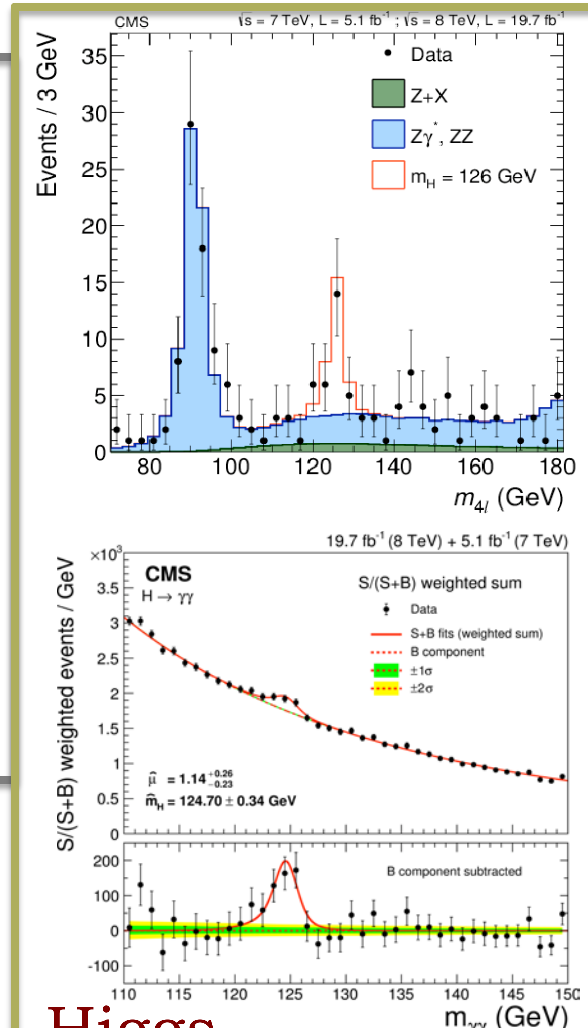


FIG. 2. Mass spectrum showing the existence of J. sults from two spectrometer settings are plotted owing that the peak is independent of spectrometer rrents. The run at reduced current was taken two nths later than the normal run.

J/Psi



Z

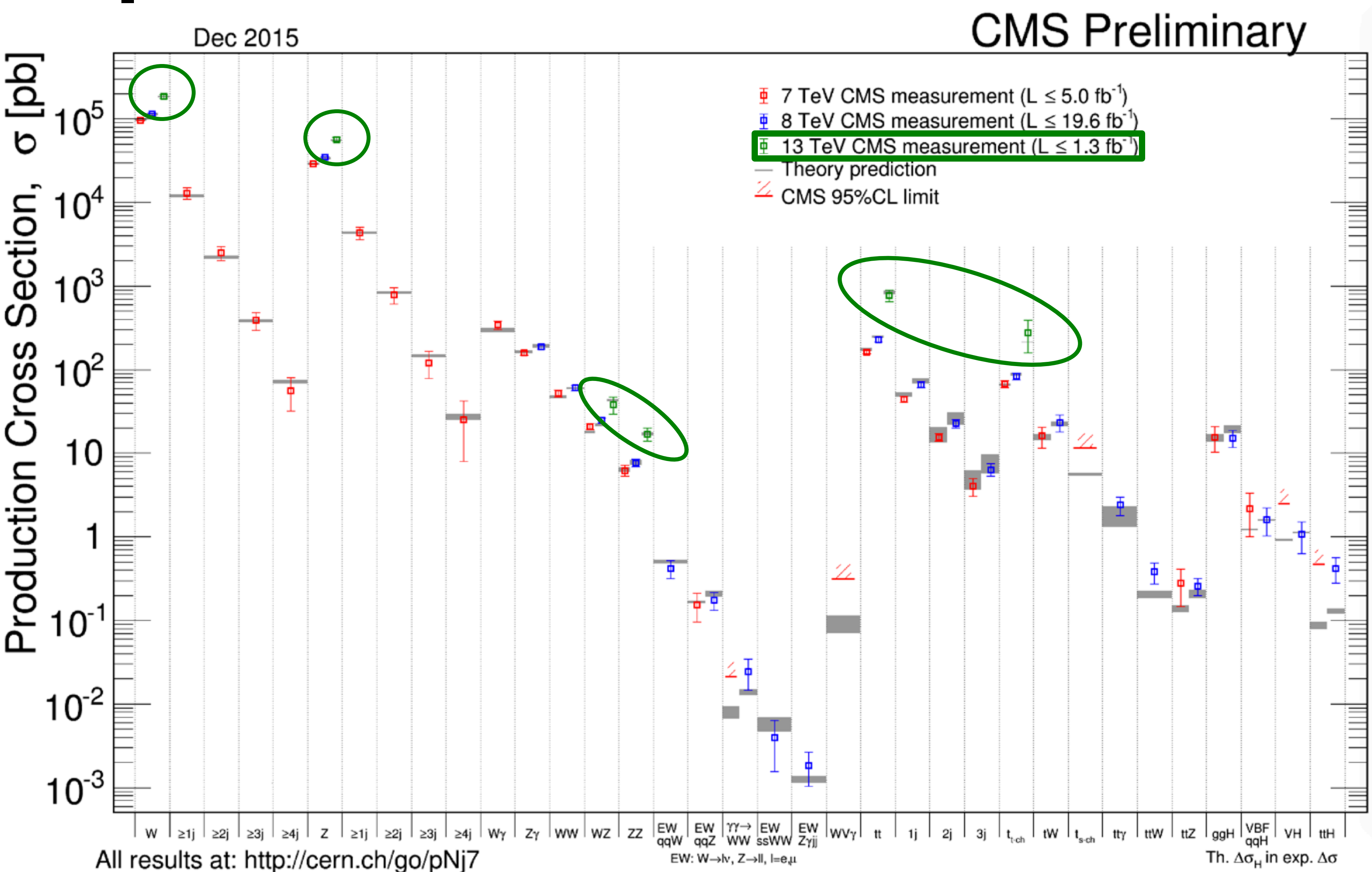


Higgs

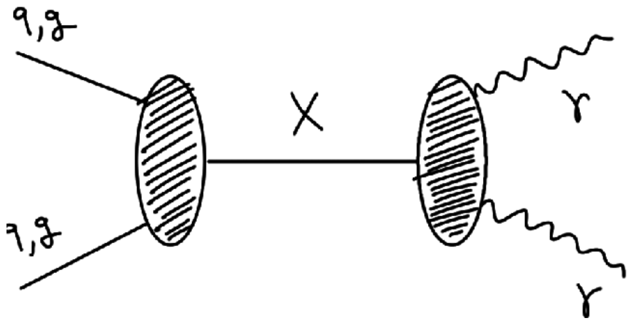
The CMS Collaboration

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

Standard Model with CMS



Diphoton bump search



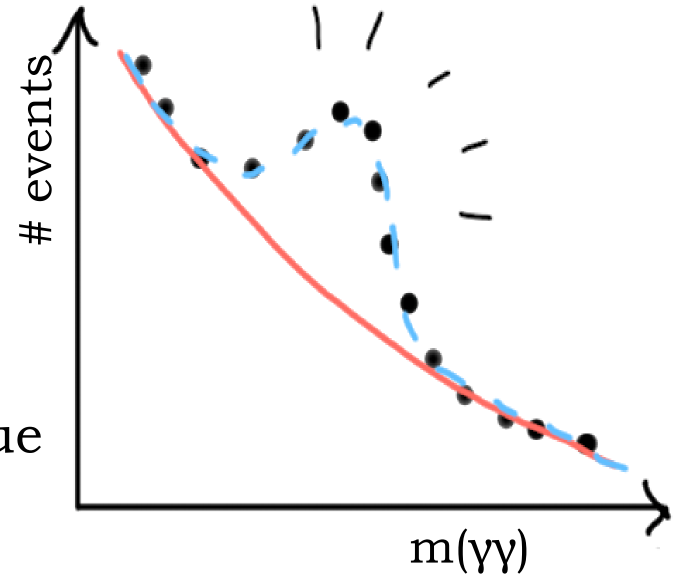
Clean final state at hadron colliders

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

2) Reconstruct the γγ invariant mass

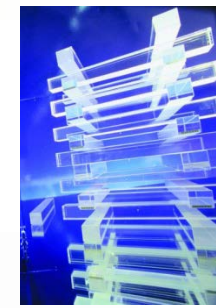
$$M = \sqrt{2E_1E_2(1-cos\theta)}$$

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



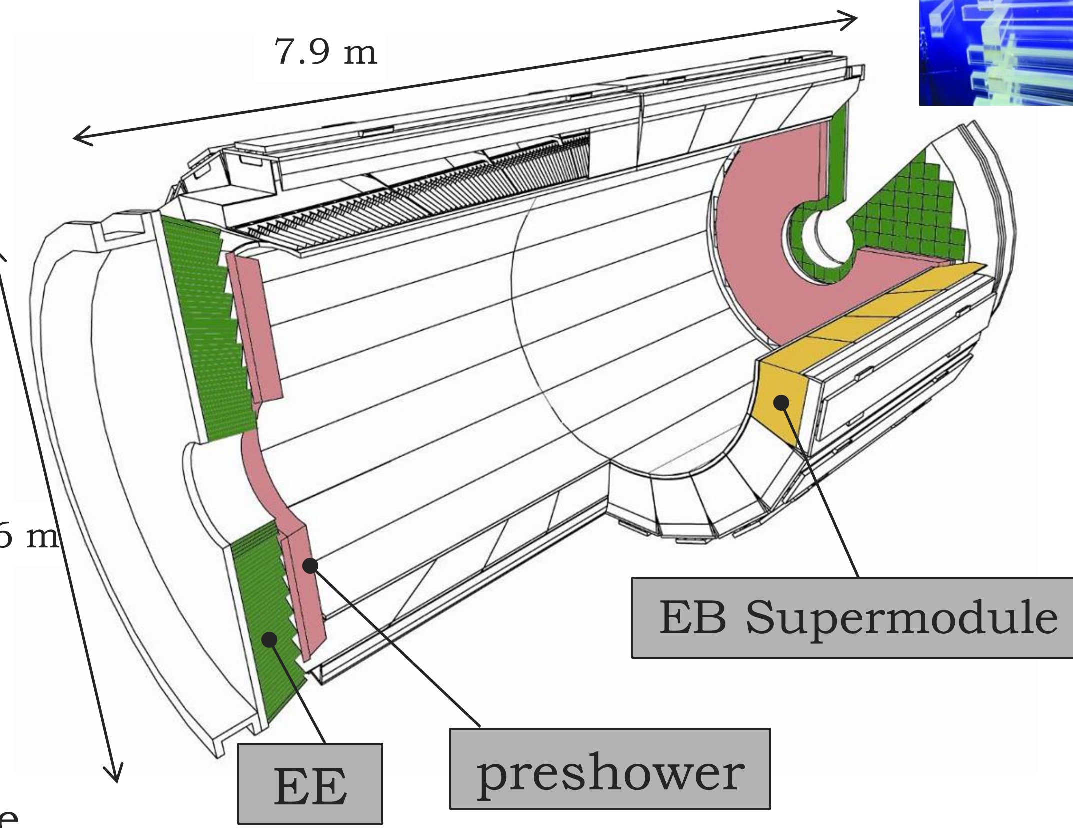
3) Signal extraction

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

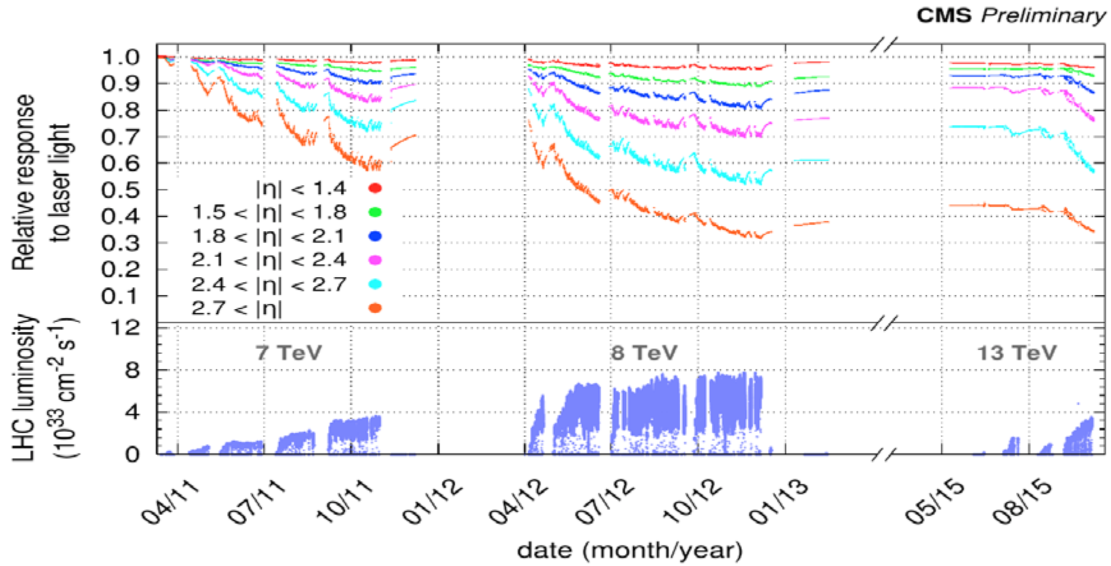


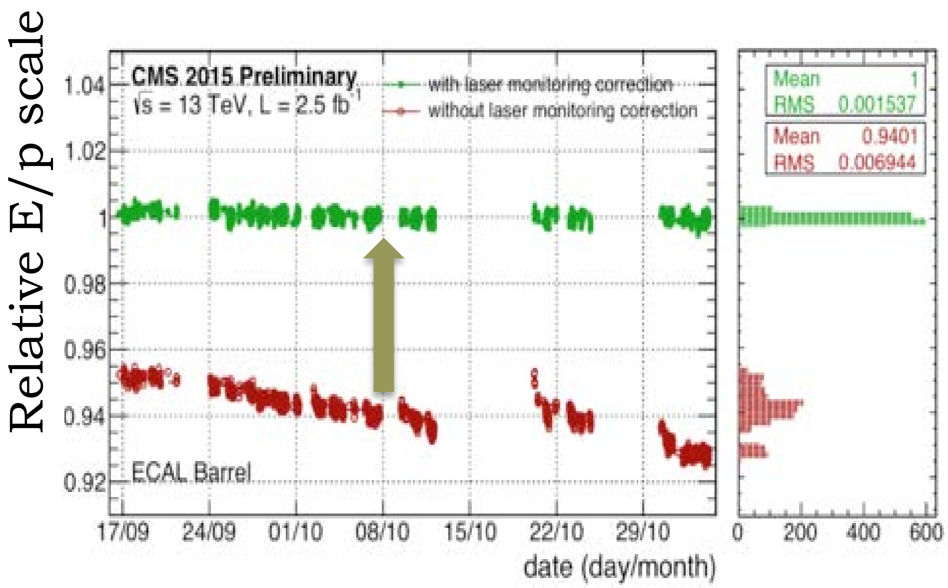
Design energy resolution:
~0.5% for $E(\gamma)>100$ GeV

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

Crystal transparency loss

Relative crystals response to laser light vs time



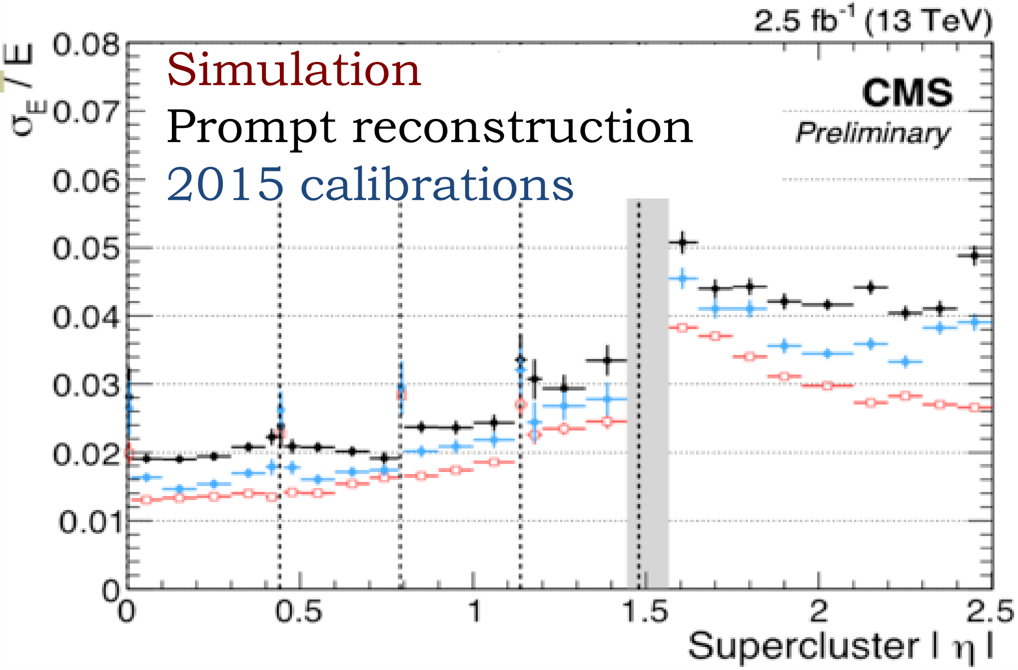


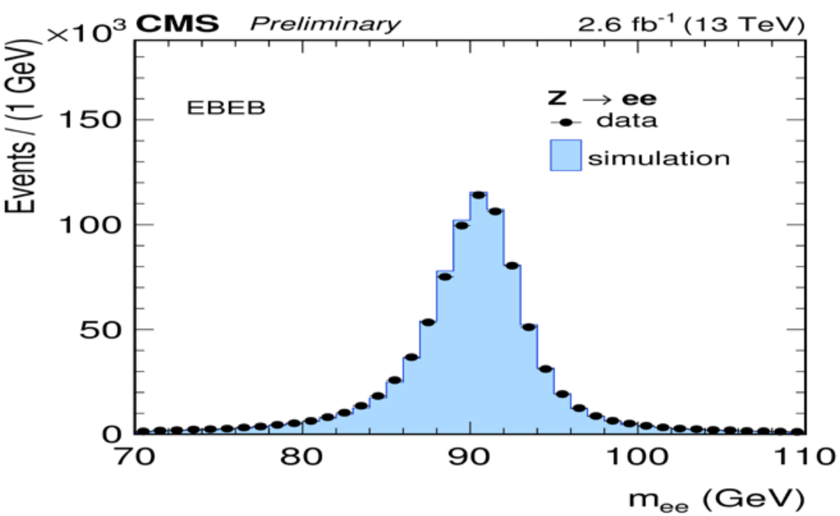
Stable energy scale achieved after laser correction ***in prompt reconstruction***

Barrel:

- ✓ average signal loss ~6%
- ✓ RMS stability ~0.15%

Energy scale and resolution





Prompt reconstruction used for the analysis.

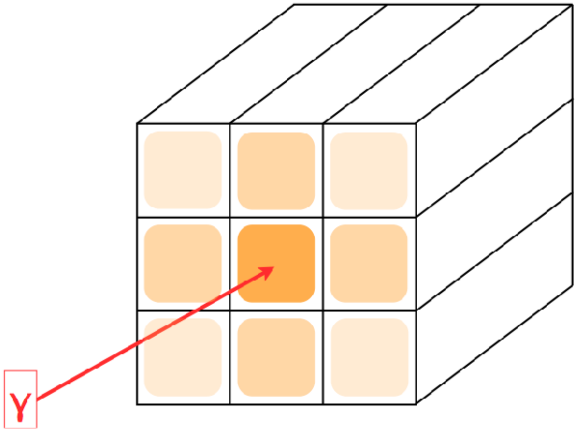
New calibration coefficients (2015 data) available.

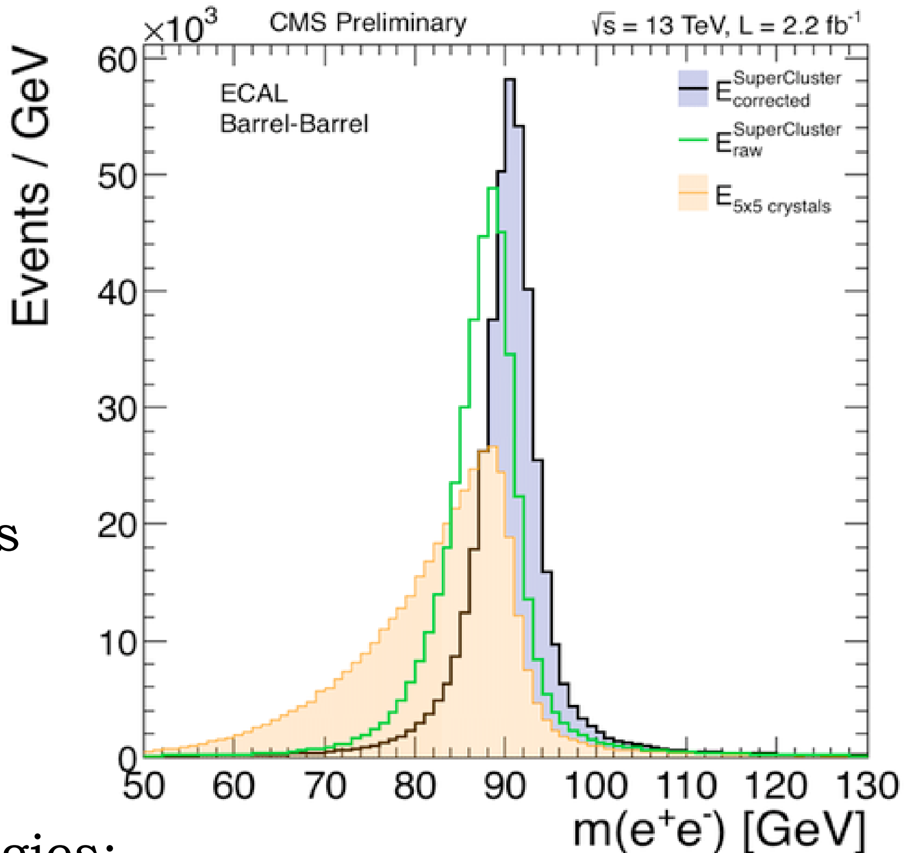
Significant improvement in energy resolution with new calibrations:

- ✓ 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

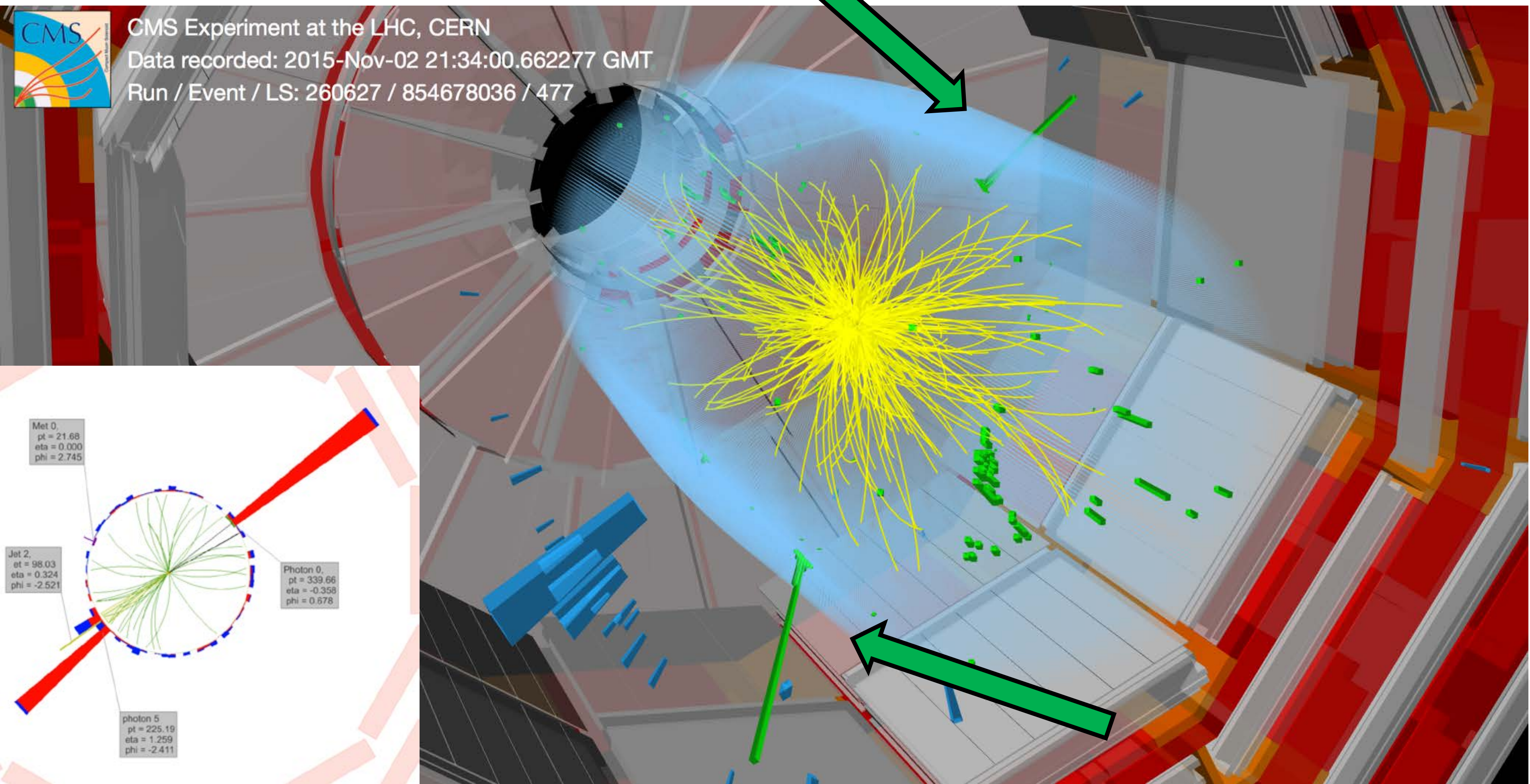
- ✓ clustering optimized to have the best energy resolution

Reconstruction and selection strategies:

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

Diphoton event display

m(γγ) = 745 GeV

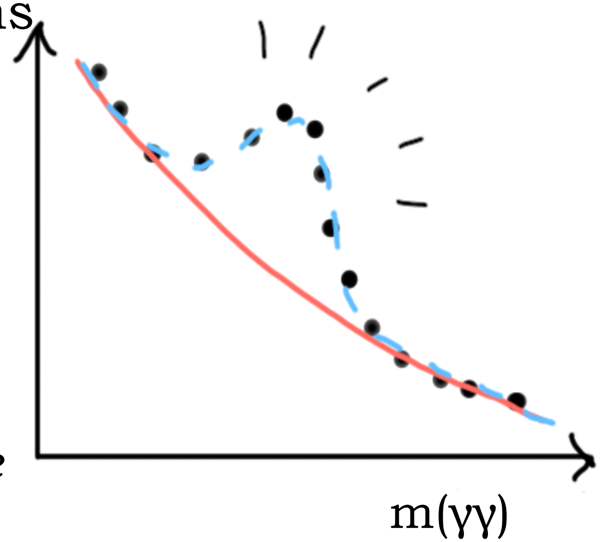


High mass diphoton searches

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 √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 √s = 8 TeV	150-850	8	19.7
CMS-PAS-EXO-12-045	Search for high-mass diphoton resonances in pp collisions at √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:

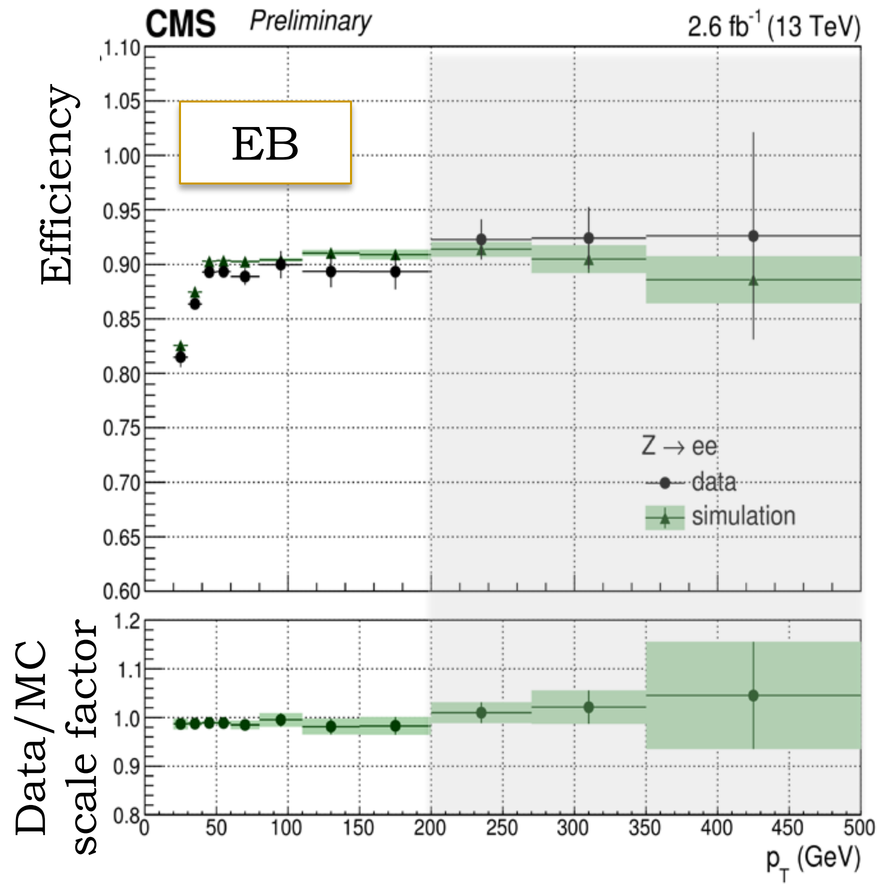
- ✓ *Analysis built on SM Higgs search experience*
  - ✓ *same methods used*
- ✓ *Only solid techniques exploited*
  - ✓ *nothing very fancy for this first round*
- ✓ *Selection developed before looking to the data:*
  - ✓ *cut based selection*
  - ✓ *fully blind analysis*

=> 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

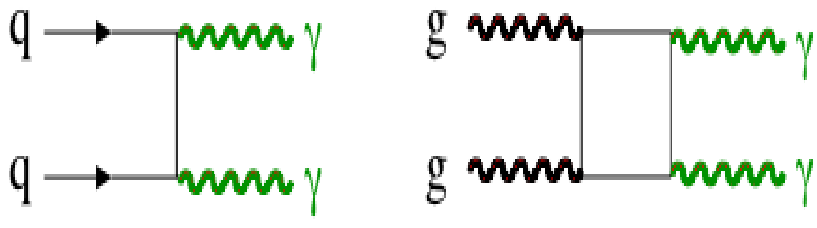
Zee and high mass DY to check scale and resolution

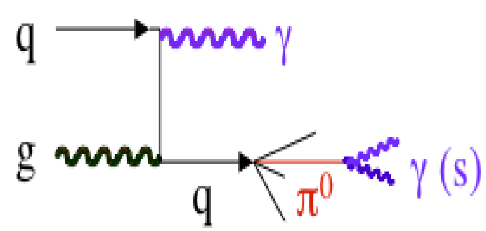
- ✓ results compatible within 0.5%

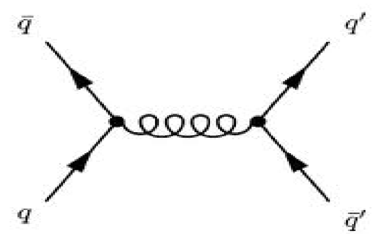
Backgrounds

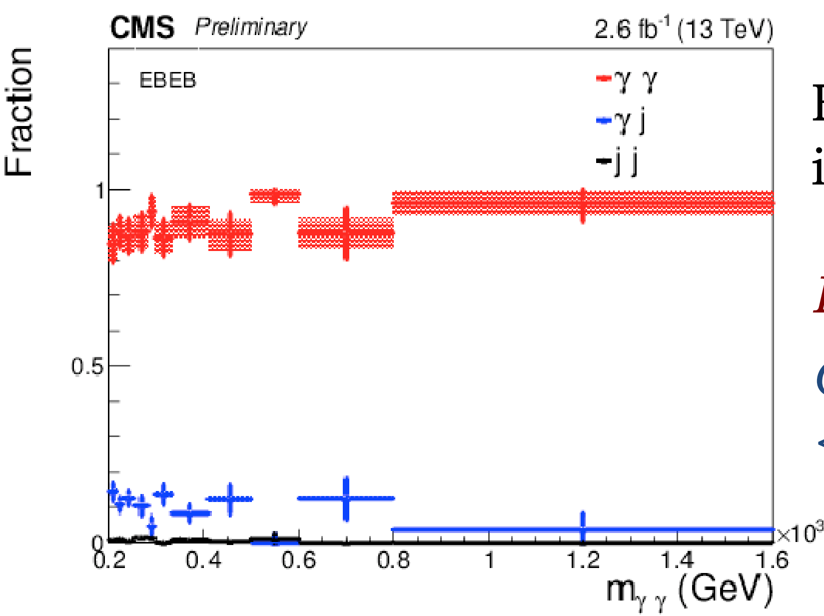
Direct γγ SM production
irreducible

Dijet and γ+jet production
reducible







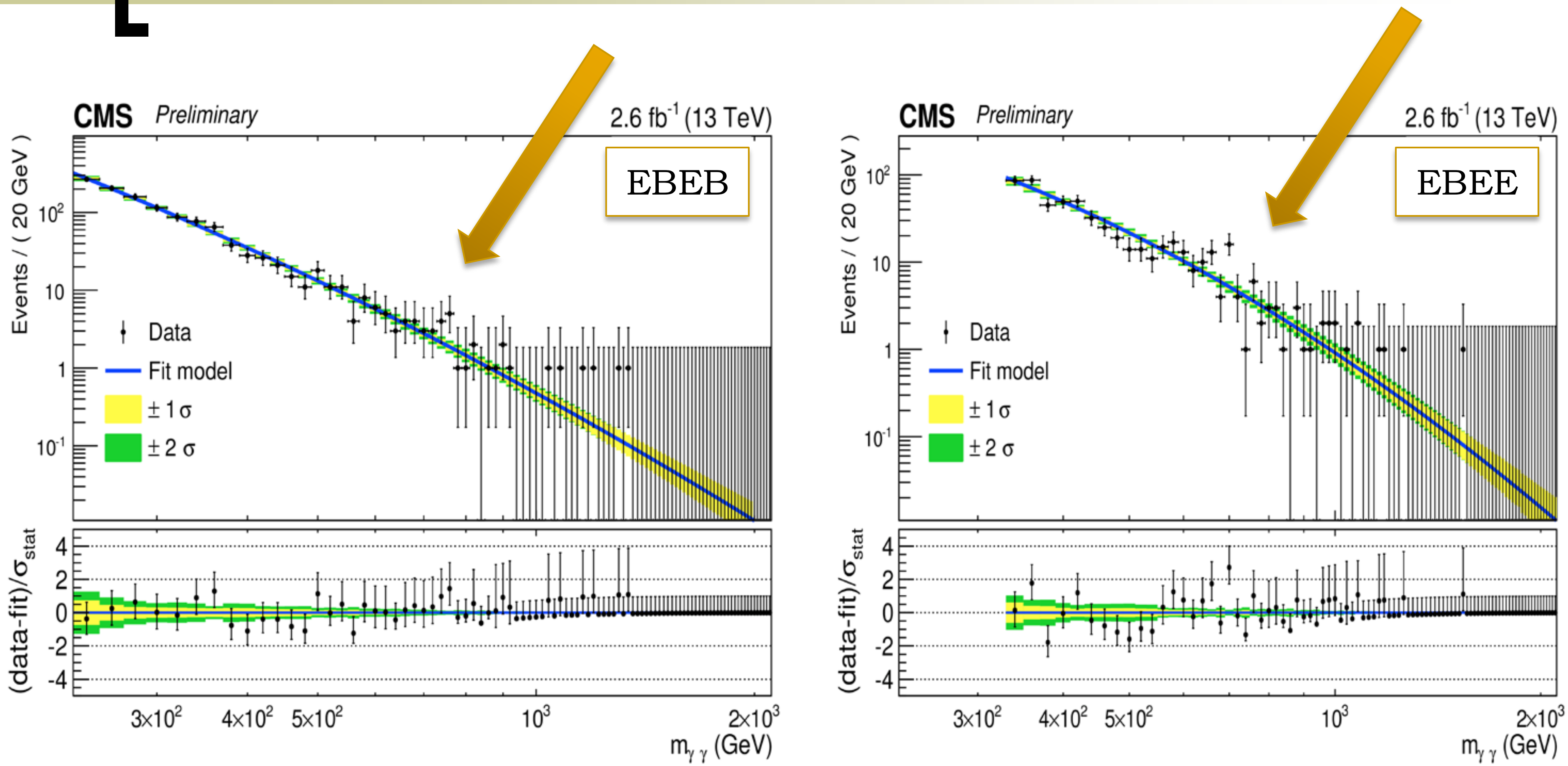


Background composition measured in data using template fits

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 → Γ_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

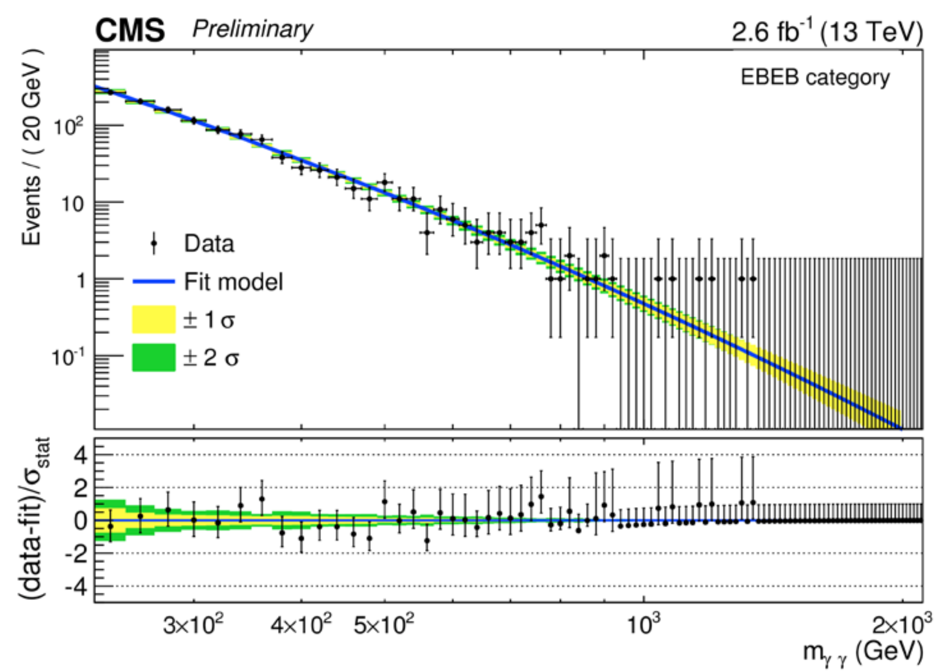
Background modelling

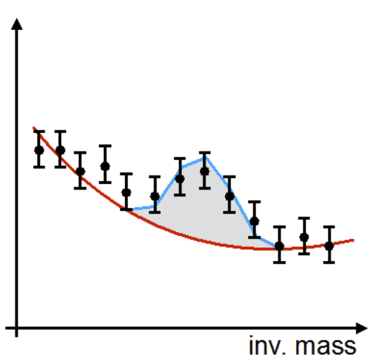
Background $m_{\gamma\gamma}$ shape:

- ✓ 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

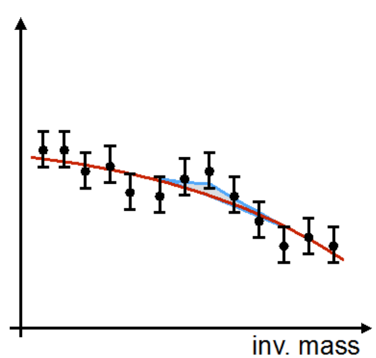
Background fit accuracy determined using MC

- ✓ possible mis-modelling: <1/2 of background statistical uncertainty
- ✓ extra uncertainty: signal-like component added to the model



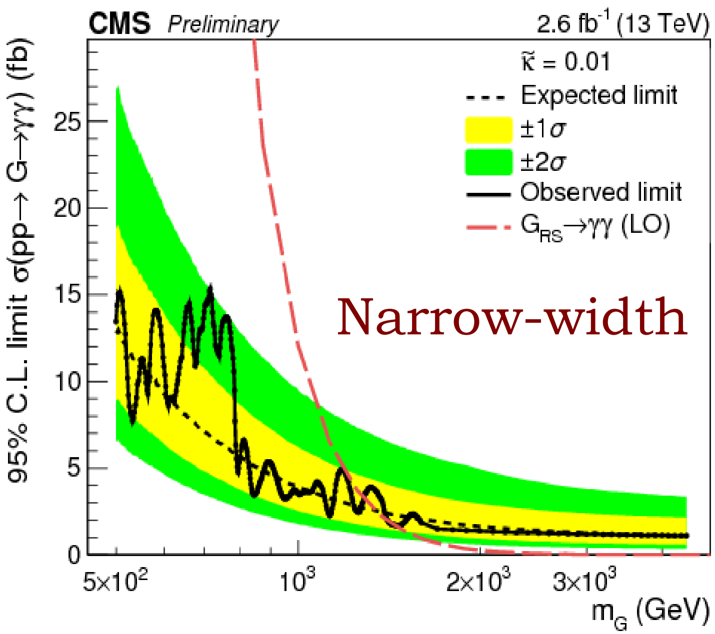


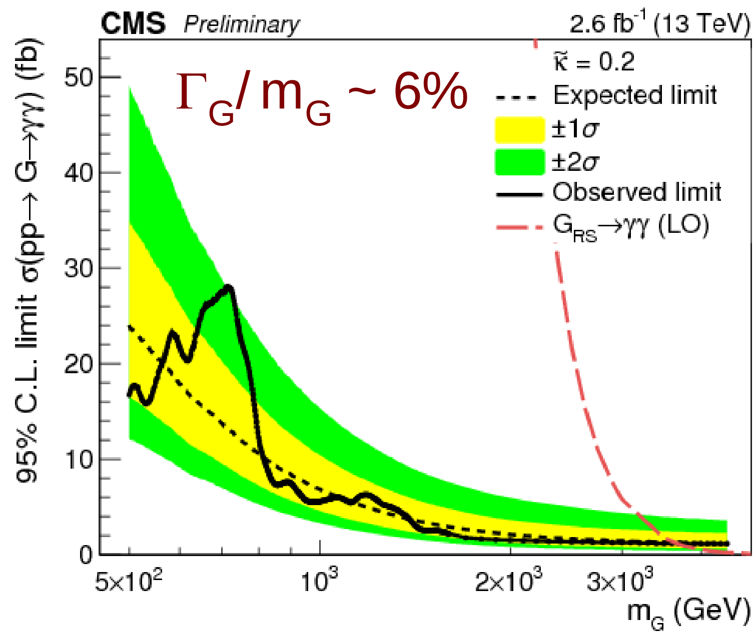
SIGNAL OVERESTIMATED



SIGNAL HIDDEN

Interpretation: exclusion limits

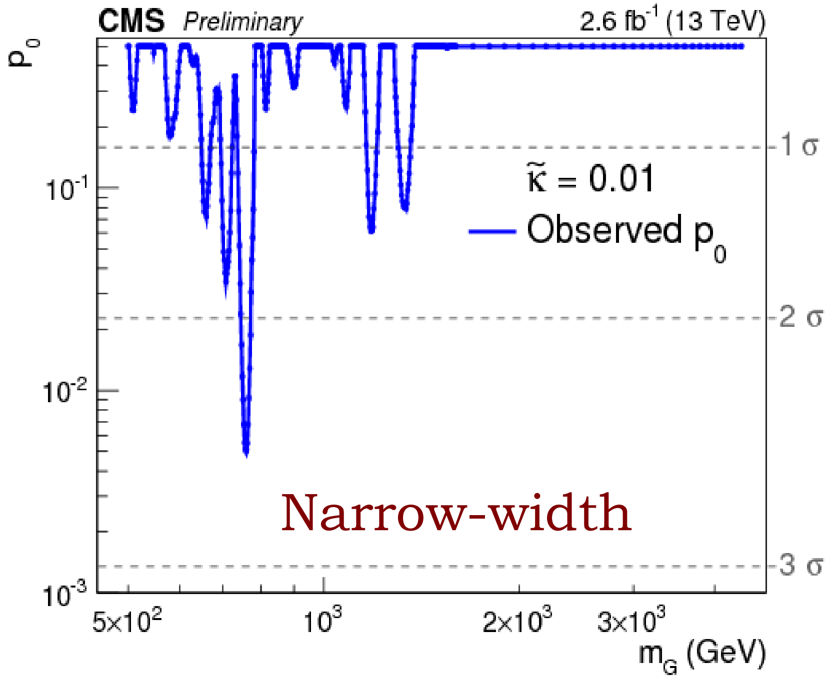


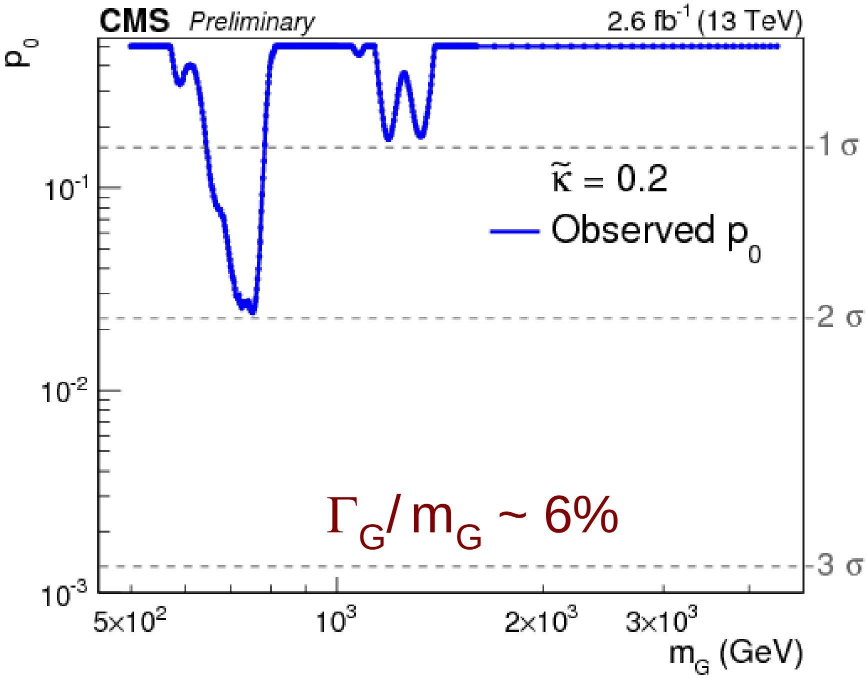


Expected and observed limits on Graviton cross section x diphoton BR (ATL-PHYS-PUB-2011-11 / CMS NOTE-2011/005):

- ✓ 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

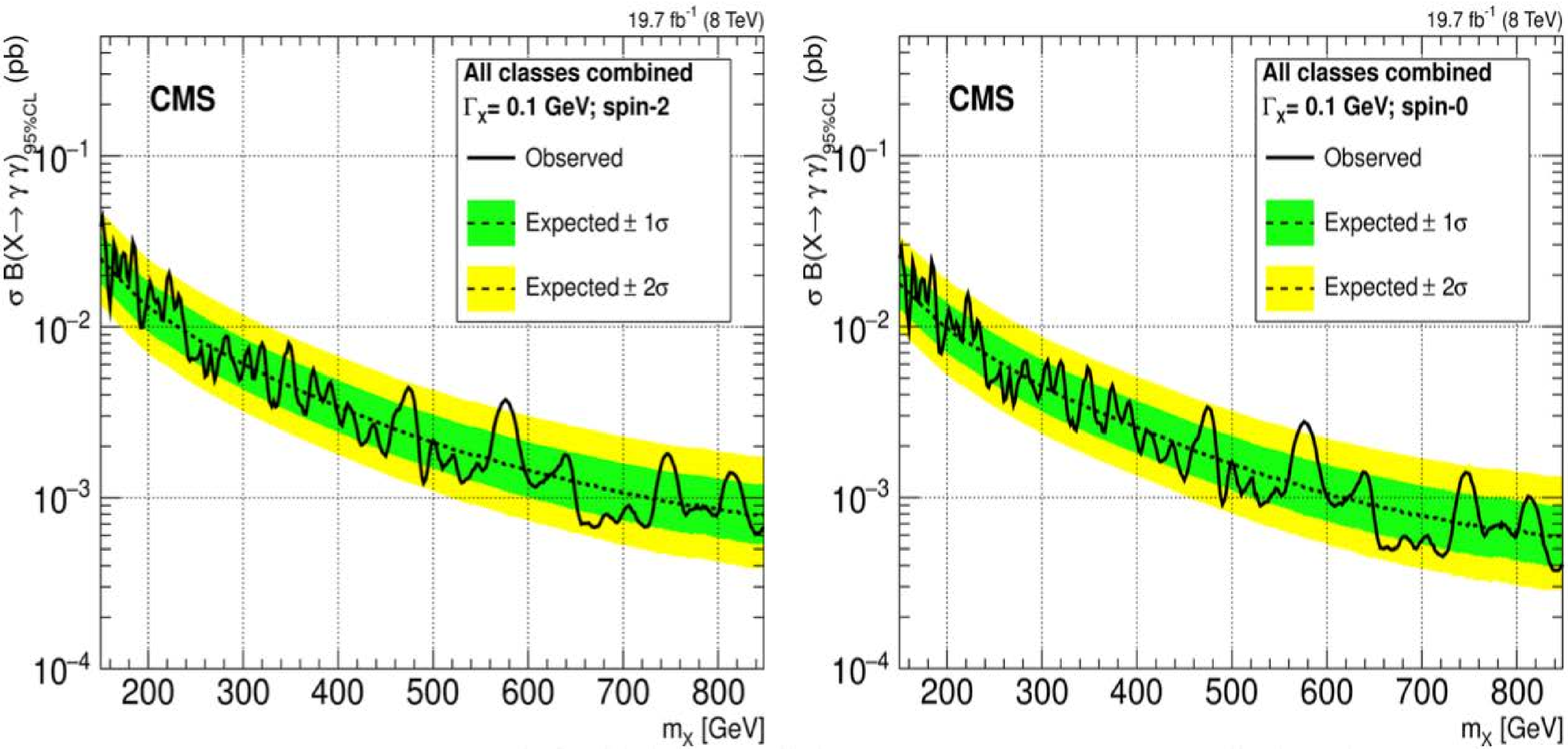




- ✓ **Largest excess for m_G=760 GeV in the narrow width hypothesis**
- ✓ Local significance 2.6 σ
  - ✓ significance reduced to 1.2 σ when accounting for Look Elsewhere Effect in m_G (E. Gross and O. Vitells, arXiv:1005.1891v3)
  - ✓ LEE in k further decreases significance

Spin hypothesis

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

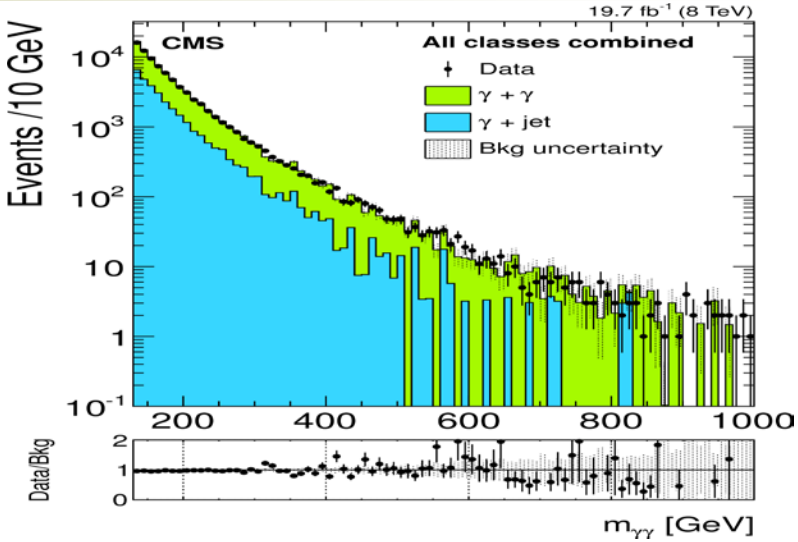


8 TeV analysis: limit shape is quite similar

Comparison to 8 TeV search

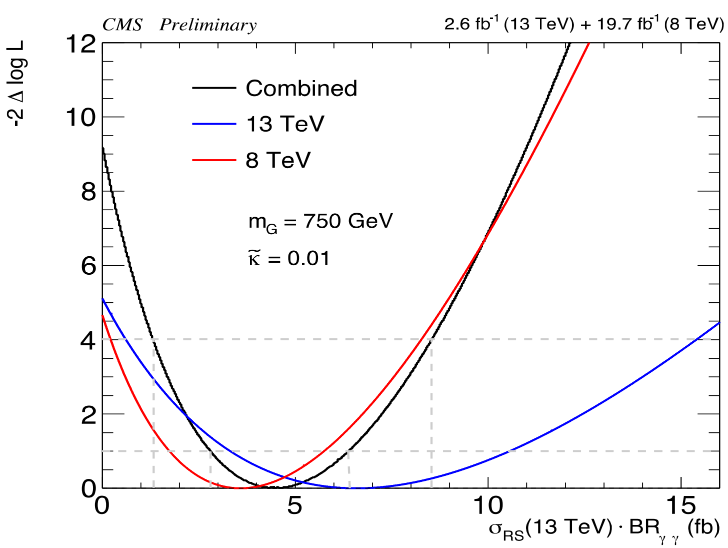
Combination with 8 TeV results in narrow width hypothesis

- ✓ 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

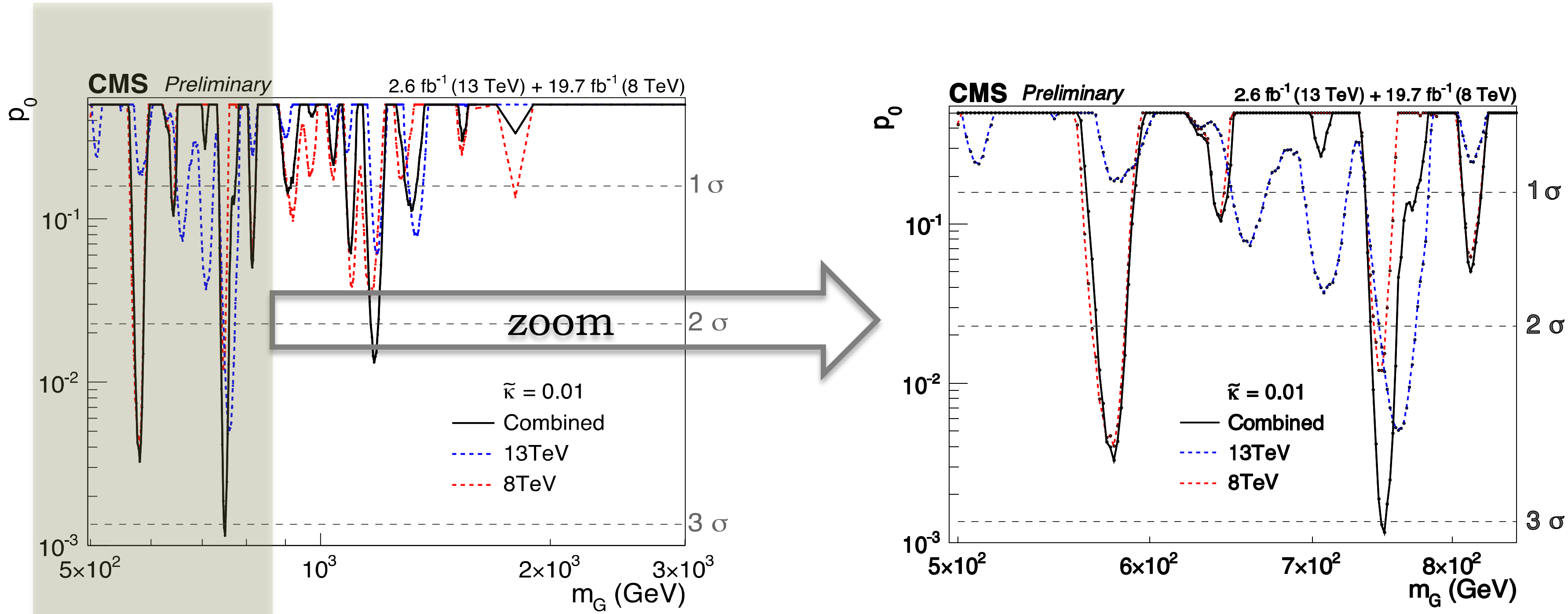


- ***Compatible equivalent cross-sections within uncertainties***
- ***13 TeV result not in contradiction with 8 TeV***

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

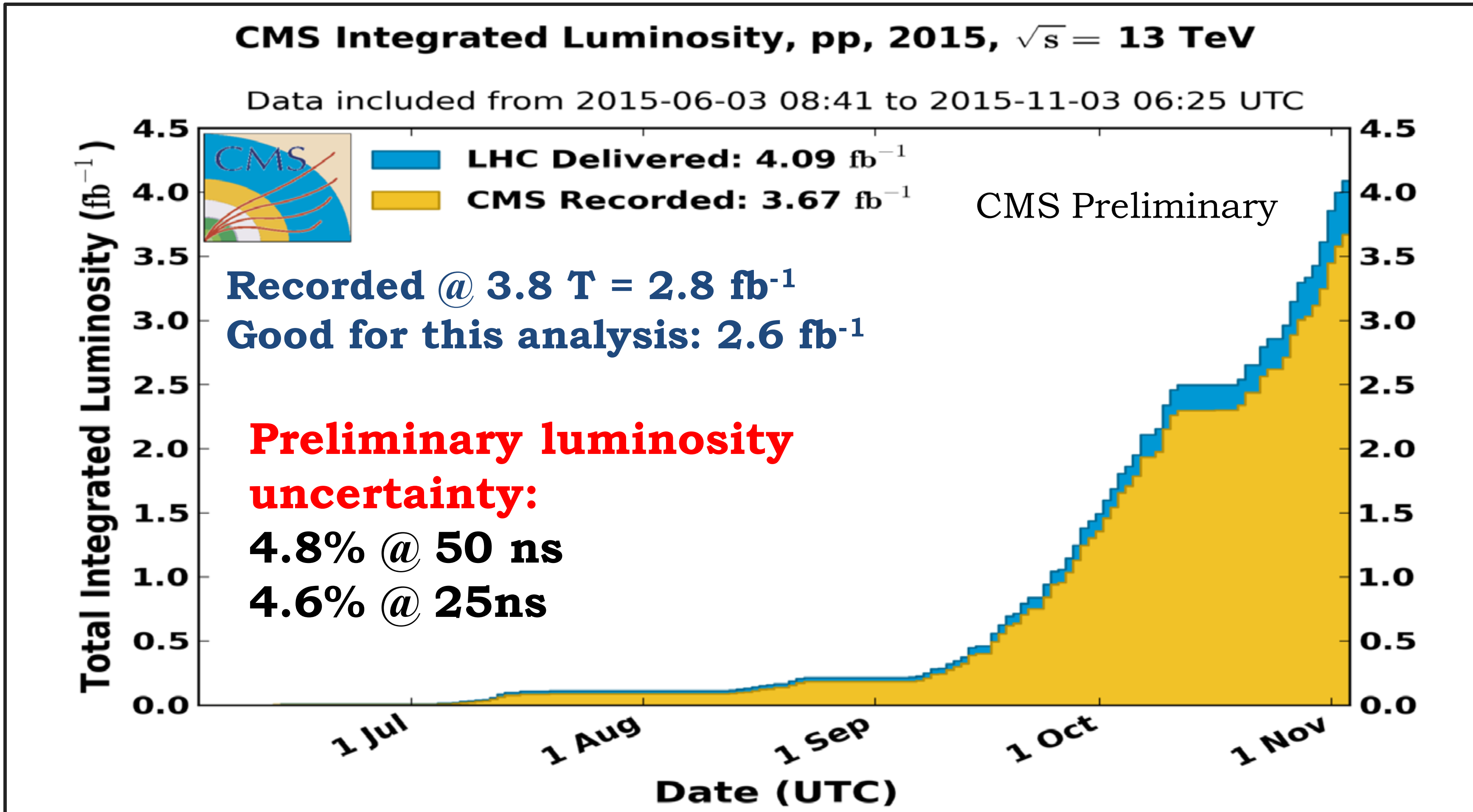
- Observed diphoton mass spectrum **in agreement with Standard Model expectations**
- Strongest constraint on production cross-section set
- Simple and robust analysis strategy

- **Modest excess for mass ~760 GeV**
  - local significance of 2.6 σ assuming narrow width signal
  - global significance of <1.2 σ
  - 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 ?

Backup

CMS operation @ 13TeV



- ✓ 2015 operations strongly affected by a contamination of the magnet cold box
- ✓ Thanks to the effort of many, *~¾ of delivered luminosity collected with full B field*

CMS Operation in 2015

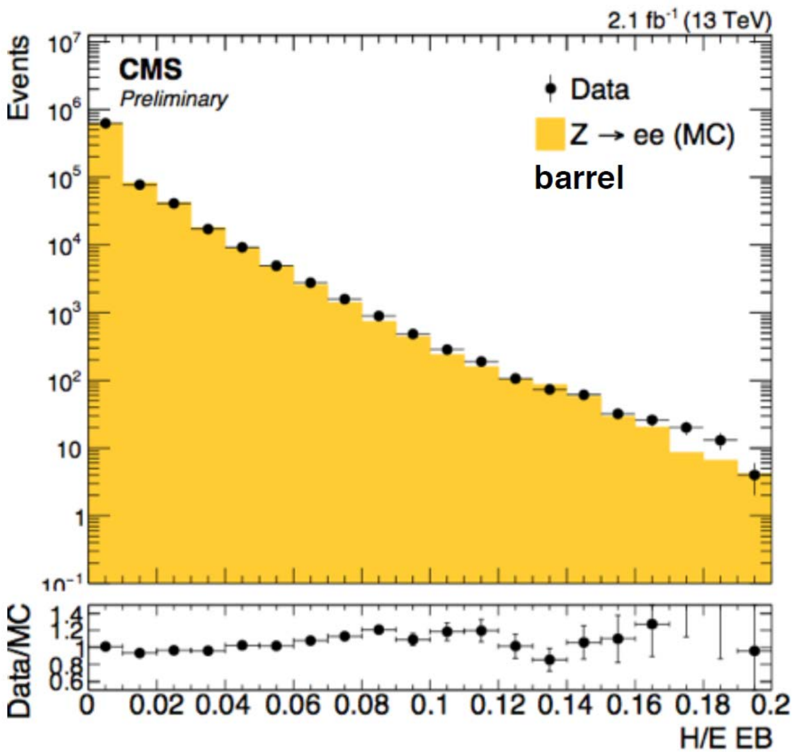
- At the end of the Long Shutdown 1 we realized that the **performance of the cryogenic system feeding Liquid He to our Magnet was severely impaired by a contamination of the Cold box**
- This has affected our operation in 2015: a large effort from the **CERN cryogenic and technical departments associated to our Technical Coordination have limited the impact, allowing to collect ~¾ of the delivered luminosity with full magnetic field.**
- The detector and new acquisition system was ready from the start of LHC running at 13 TeV: **we have logged data with efficiency well above 90% with trigger thresholds similar or lower than the ones at Run I**
- **A detailed plan of repair and cleaning of the cryo system, to be executed during the Year End Technical Stop, is ready** and foresees the system to be ready for Physics production by the first week of April, i.e. well ahead of the start of physics production of LHC in 2016

Physics objects @ 13 TeV

Excellent comprehension of electrons, photons, muons, jets, MET

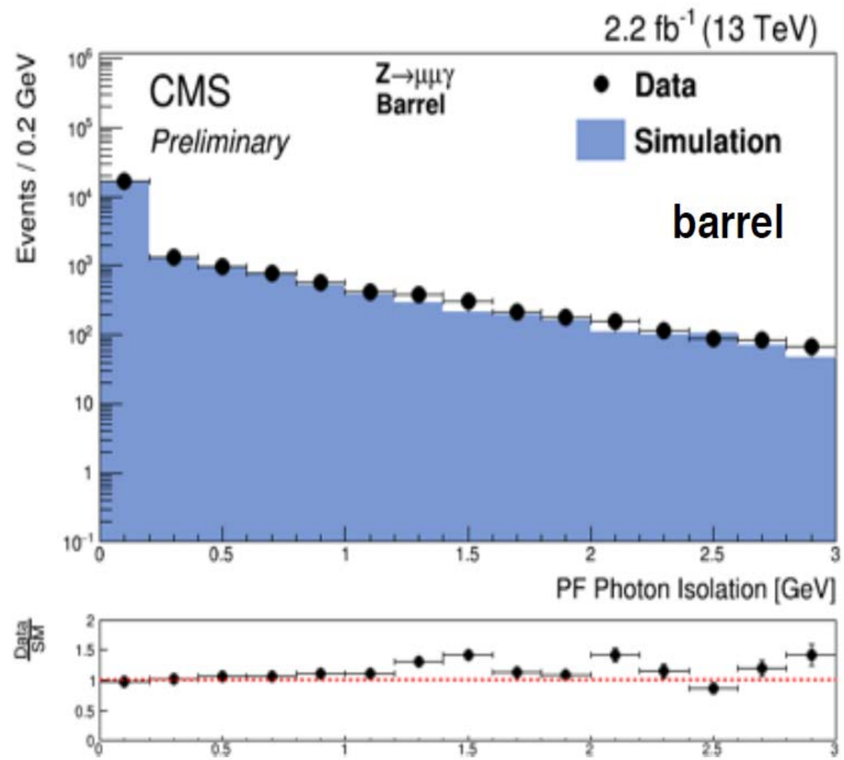
Electrons from Z decays

- HCAL / ECAL energy

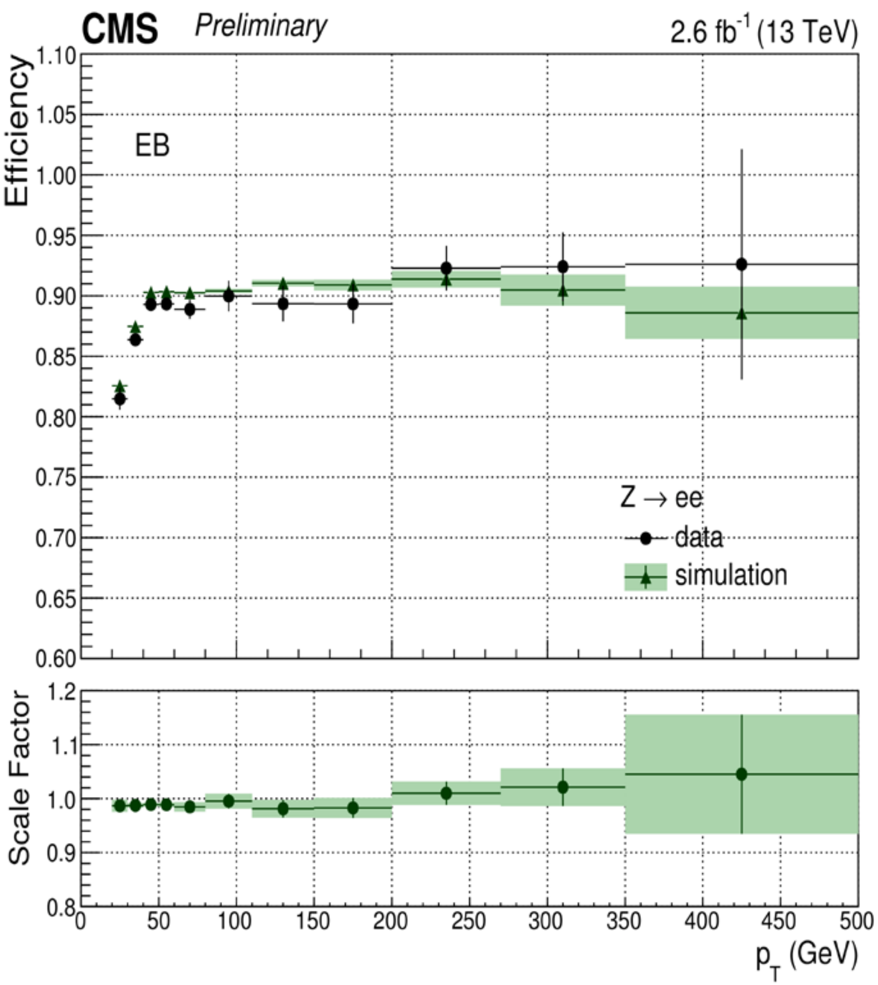


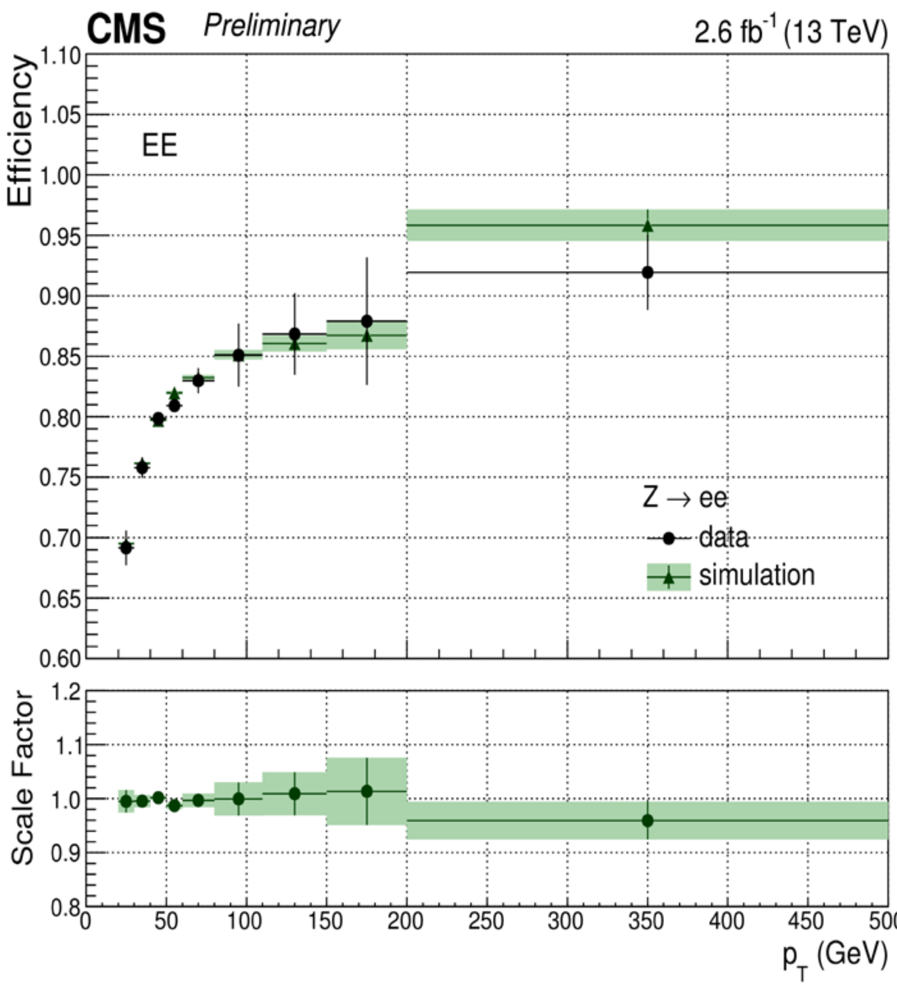
Photons from radiative Z decays

- Relative e.m. isolation



Photon selection efficiencies





Photon energy scale and resolution

Energy scale and resolution corrections estimated using 13TeV Z->ee events

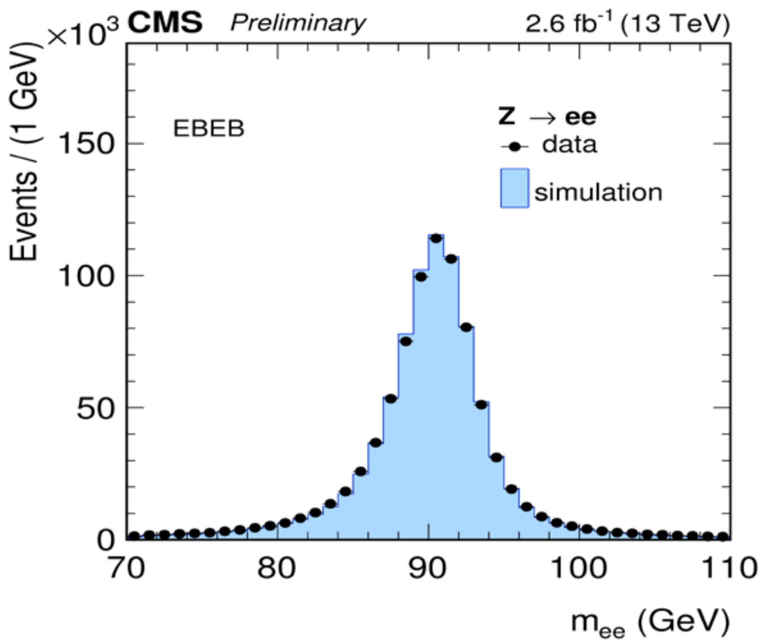
- ✓ in different photon categories
- ✓ maximum likelihood analysis performed while modifying energy

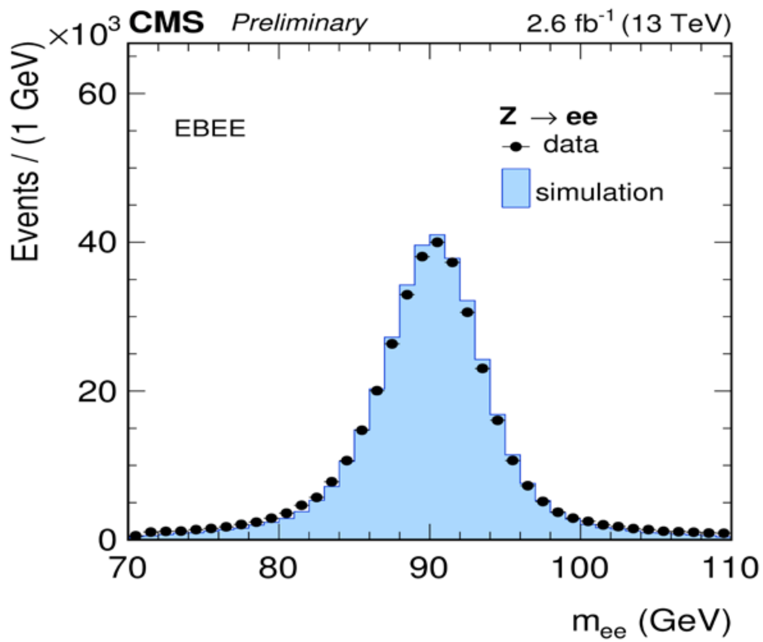
Extrapolation to high mass checked with high mass DY events

- ✓ compatible with a precision of 0.5% for m_{ee}>200 GeV

Photon energy smeared on MC to match data

- ✓ additional smearings *still room for improvement*

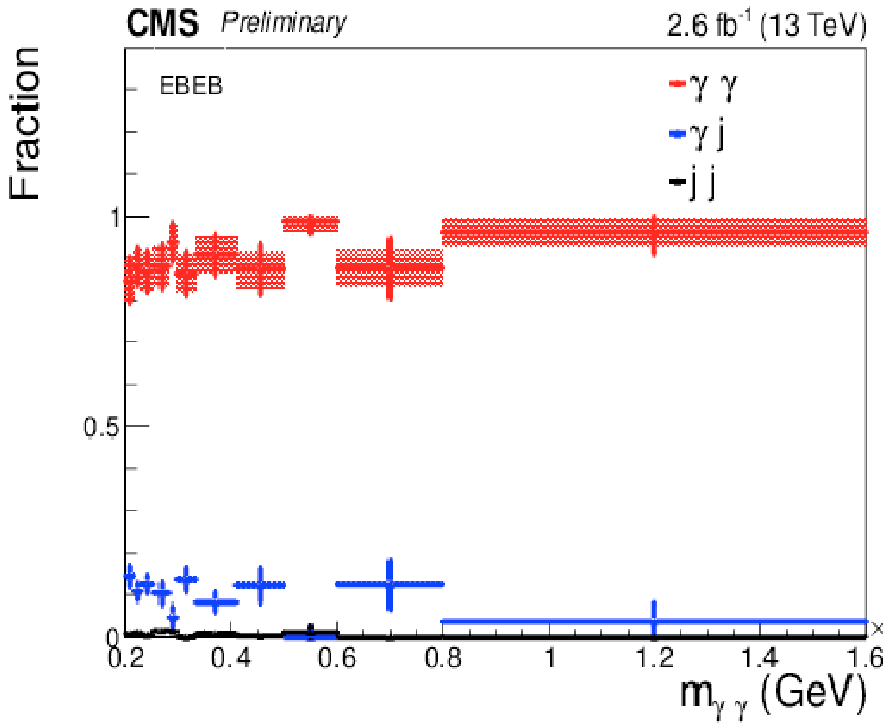


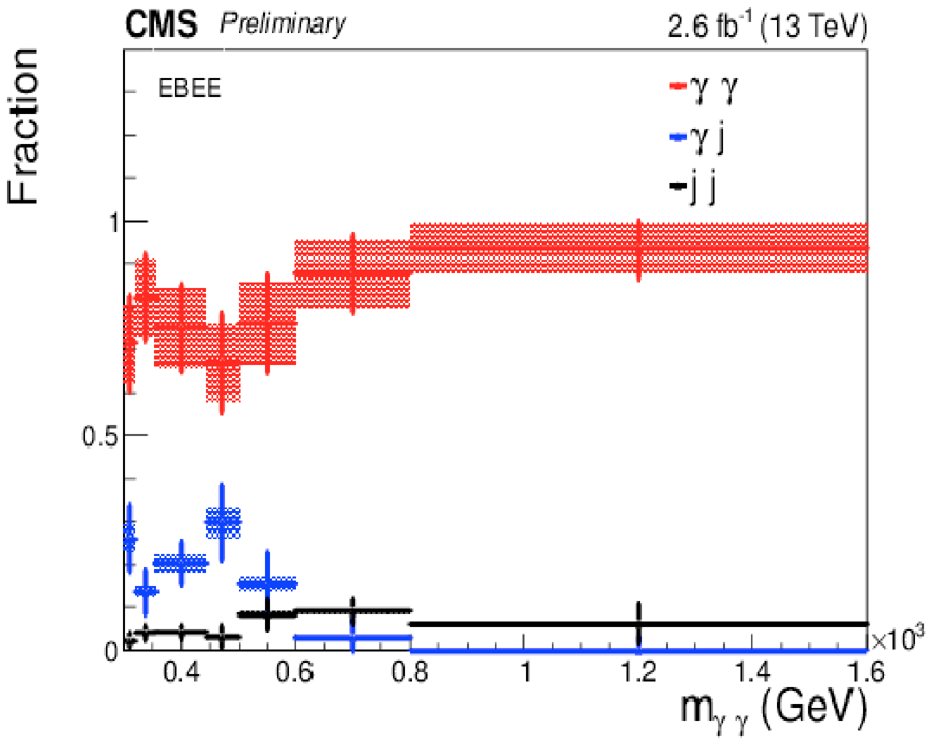


Background composition

Background estimate fully data driven => no simulation used
BUT good control of background gives confidence in the analysis

Background composition measured in data using template fits





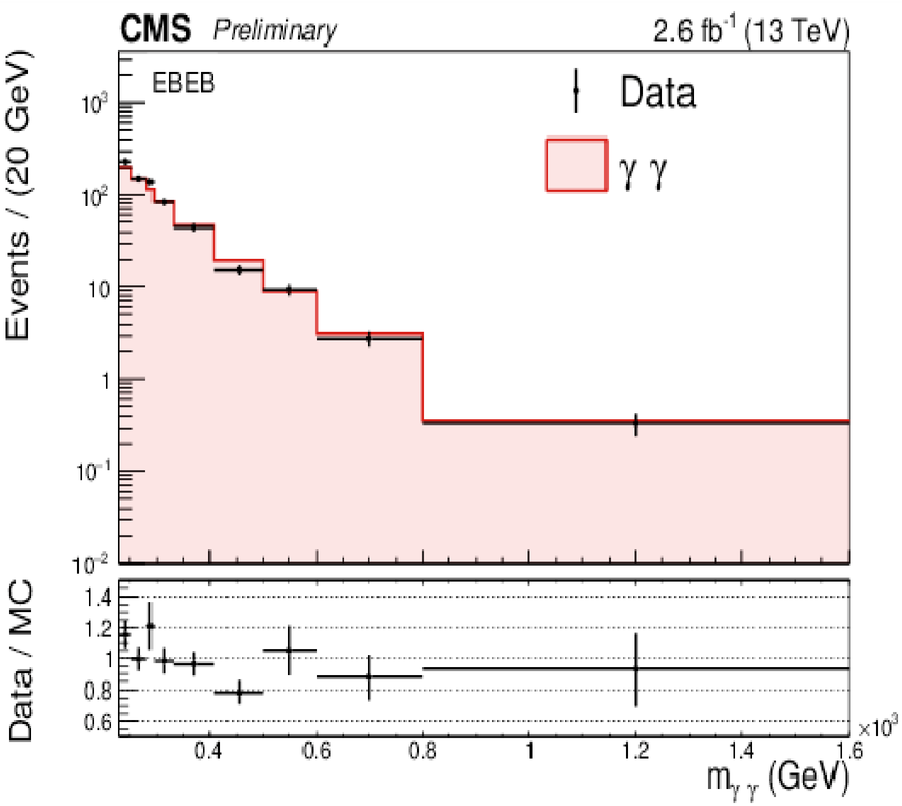
Dominant contribution: events with 2 prompt photons
Events where 1 or 2 candidates from jet fragmentation <10% (20%) in EBEB (EBEE)

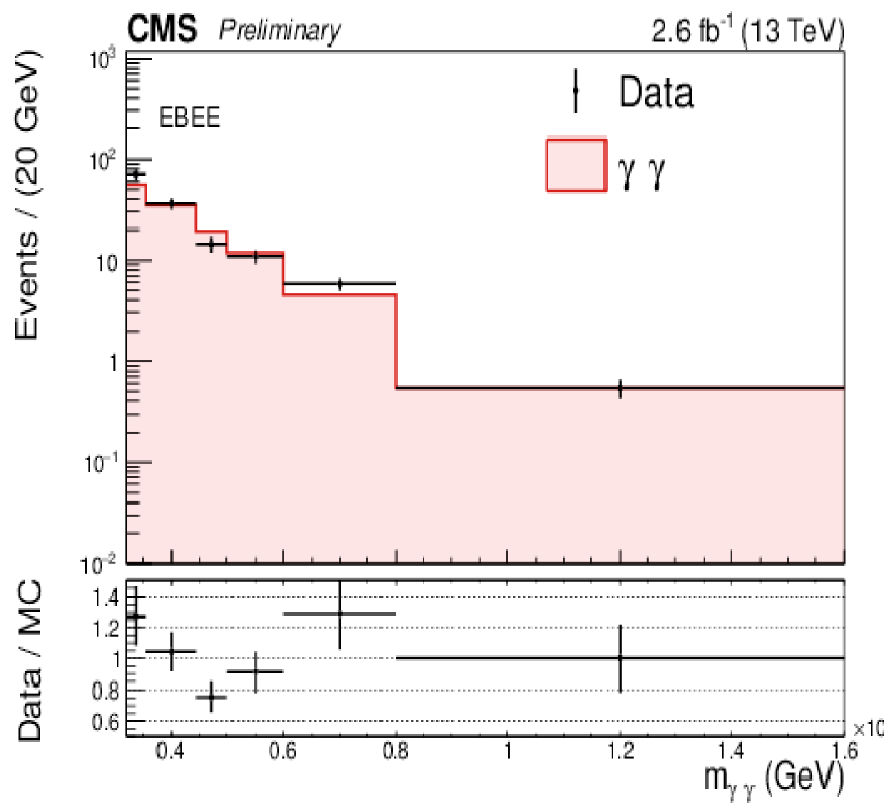
Background composition: closure test

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

✓ Sherpa generator rescaled to 2γNNLO

Good agreement observed





Systematic errors

Signal model:

- ✓ Luminosity: 4.6% on signal normalization
- ✓ Trigger and photon selection: 10% on signal normalization
- ✓ Photon energy scale: 1%
- ✓ PDF: 6% on signal normalization

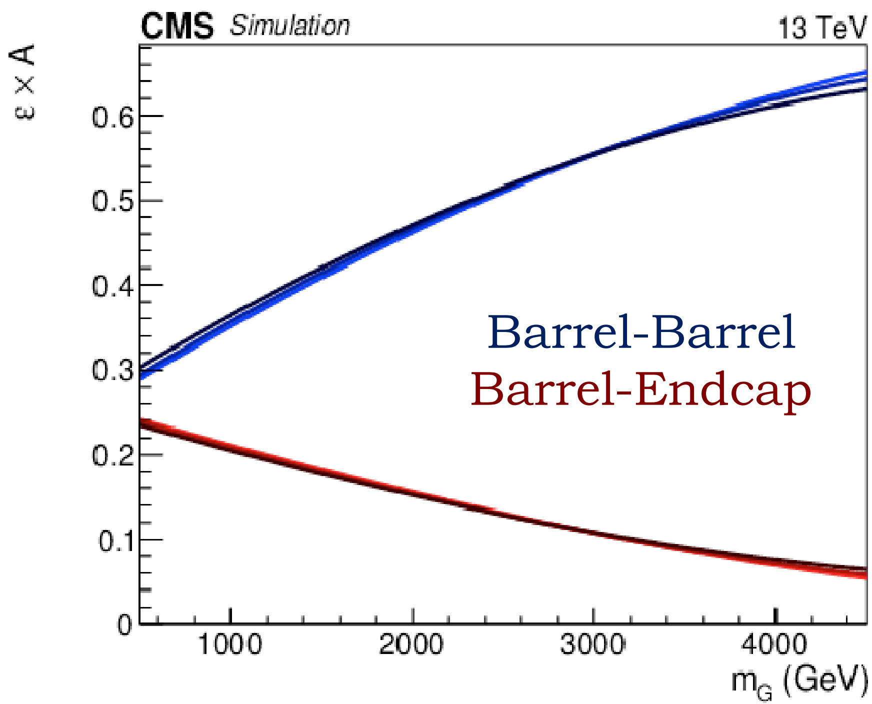
Background model:

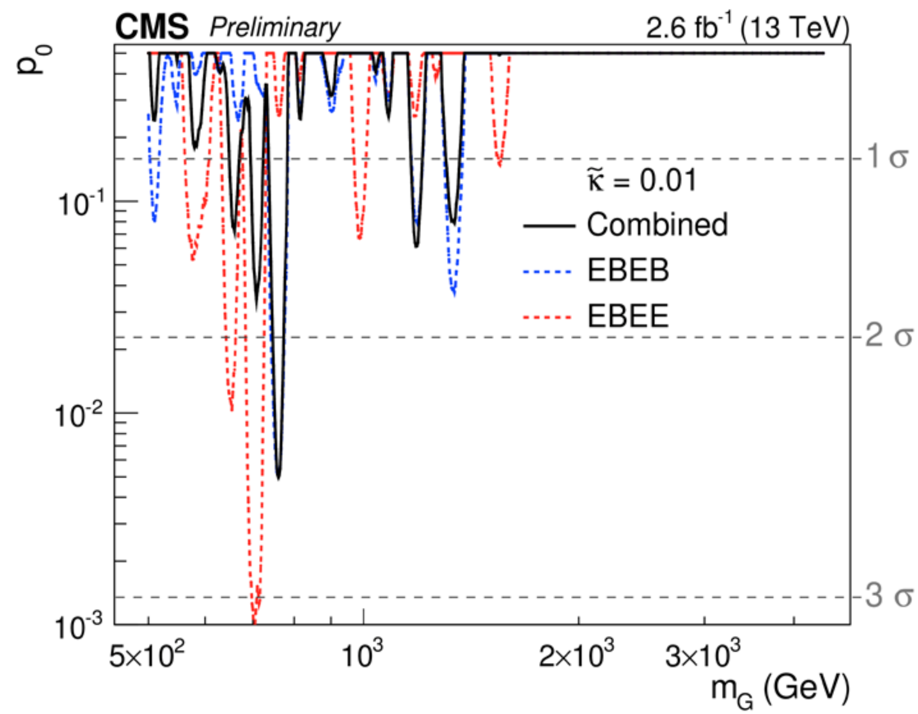
- ✓ Bias term only
- ✓ Parameter coefficients: unconstrained nuisance parameters contribute to statistical error

Signal model

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
2000	EBEB	0.01	54	0.2	147
2000	EBEE	0.01	76	0.2	163
3000	EBEB	0.01	96	0.2	225
3000	EBEE	0.01	110	0.2	254
4000	EBEB	0.01	121	0.2	320
4000	EBEE	0.01	150	0.2	326

Analysis categories

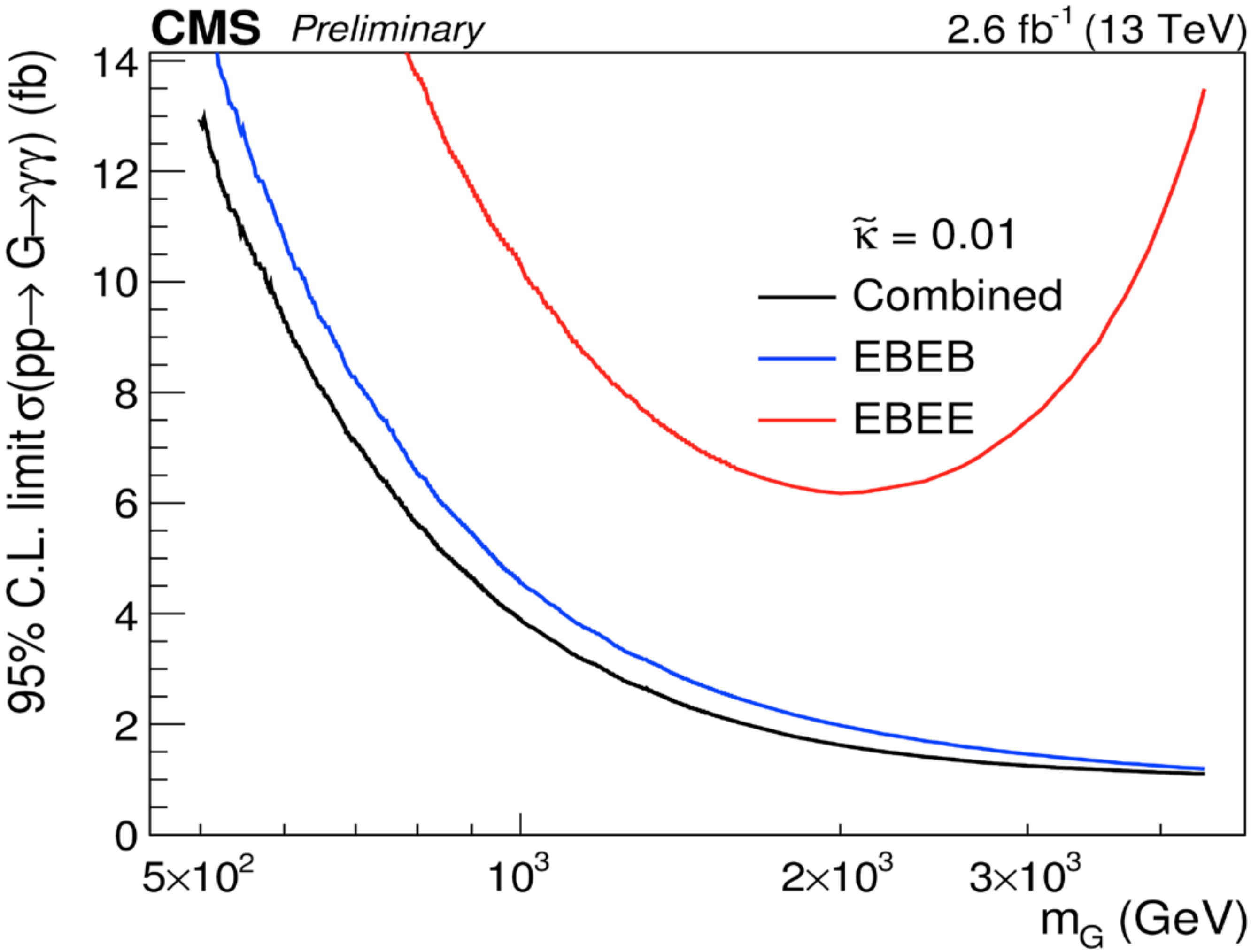




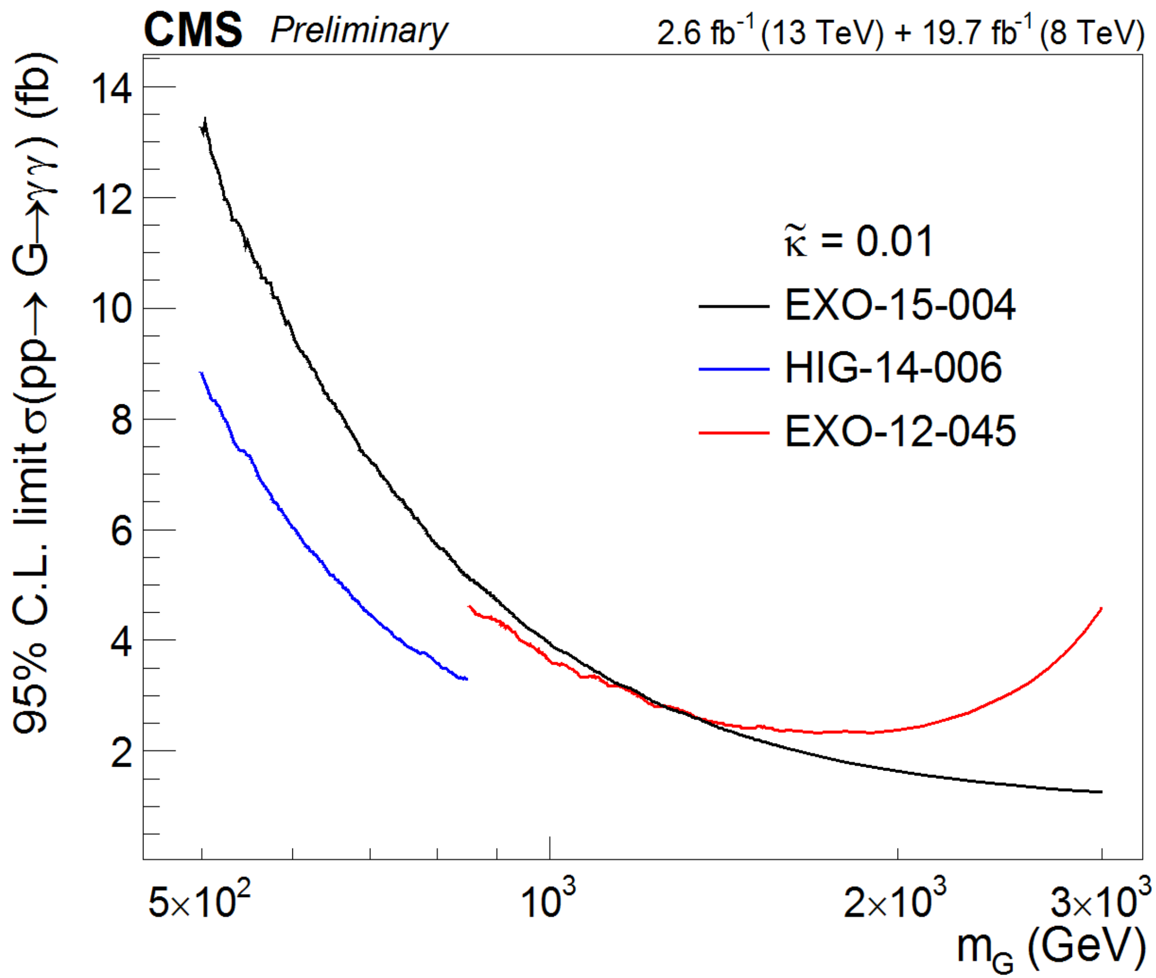
Overall efficiency x acceptance ~55% for RSG at 600GeV
Fraction of EBEE events: 10 to 45%

- **10-15% improvement from adding the barrel-endcap category**
- **Excess at 760GeV mostly in barrel**

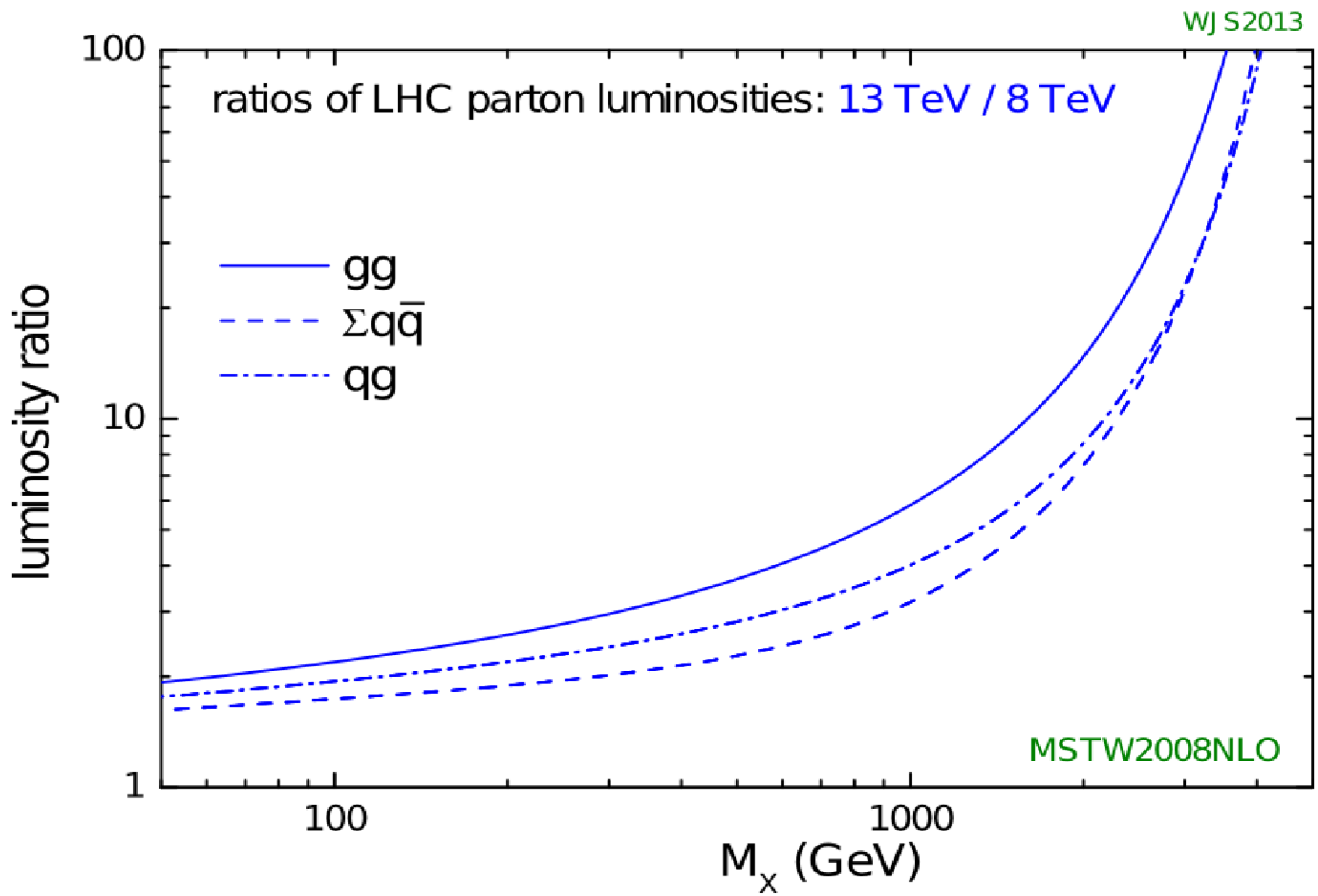
Analysis categories @ 13 TeV



Combination with 8 TeV



8 TeV vs 13 TeV



CMS vs ATLAS

	CMS	Atlas
luminosity	2.6 fb^{-1}	3.2 fb^{-1}
benchmark	Spin 2	Spin 0
selection	fixed pT cut	scaling pT cut
eff x acc @ 600GeV	~0.55	~0.40
background model	m^(a + b*log(m))	(1-x^1/3)^b x^a
fit bias	< ½ stat.uncertainty	< 1/5 stat.uncertainty
Preferred width	narrow	~6%