ATLAS and CMS diphoton resonance searches at 13 TeV

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January 13th, 2016

Overview

- ATLAS
  - ✓ https://cds.cern.ch/record/2114853

Search for resonances decaying to photon pairs in 3.2 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

The ATLAS Collaboration

Abstract

This note describes a search for new resonances decaying to two photons, with invariant mass larger than 200 GeV. The search is optimized for scalars such as those expected, for example, in models with an extended Higgs sector. The dataset consists of 3.2 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV recorded with the ATLAS detector at the Large Hadron Collider. The data are consistent with the expected background in most of the mass range. The most significant deviation in the observed diphoton invariant mass spectrum is found around 750 GeV, with a global significance of about 2 standard deviations. A limit is reported on the fiducial production cross section of a narrow scalar boson times its decay branching ratio into two photons, for masses ranging from 200 GeV to 1.7 TeV.

- CMS
  - ✓ https://cds.cern.ch/record/2114808

Search for new physics in high mass diphoton events in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration

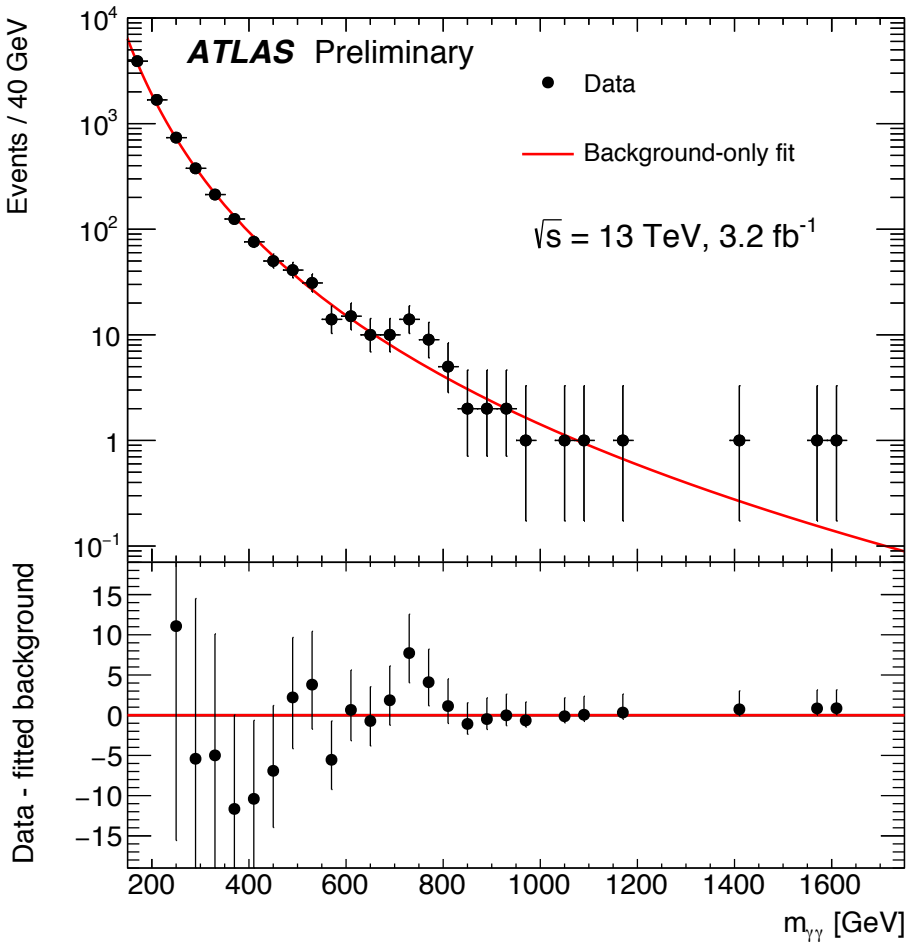
Abstract

We report on a search for new physics using high mass diphoton events. The search employs 2.6 fb^{-1} of pp collision data collected by the CMS experiment in 2015 at a center-of-mass energy of 13 TeV and it is aimed at extradimensional models leading to resonant production of two photons. Limits on the production cross section of Randall-Sundrum gravitons decaying to two photons are obtained in the range 500-4500 GeV.

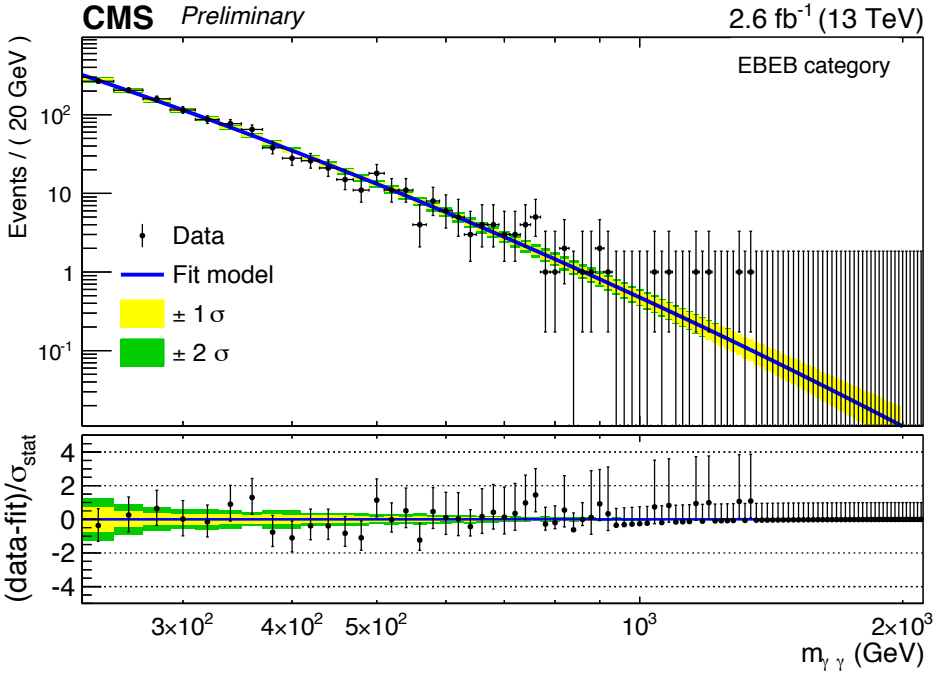
- ✓ 3.2 fb^{-1}
- ✓ Optimized for scalars
- ✓ 2.6 fb^{-1}
- ✓ Optimized for spin-2

What are we talking about?

- ATLAS



- CMS



Selections

- ATLAS
  - ✓ **Trigger**
    - $E_T^{\gamma 1} > 35$ GeV, $E_T^{\gamma 2} > 25$ GeV
    - Loose quality
    - Fully efficient for $E_t^{\gamma} > 40$ GeV
  - ✓ **Offline**
    - $|\eta| < 2.37$, 1.37-1.52 excluded
    - $E_T^{\gamma 1} > 40$ GeV, $E_T^{\gamma 2} > 30$ GeV
    - **$E_T^{\gamma 1} > 0.4\ m_{\gamma\gamma}$, $E_T^{\gamma 2} > 0.3\ m_{\gamma\gamma}$**
      - **Effectively deplete EndCaps**
    - Tight quality (cuts) + isolation
    - Select $m_{\gamma\gamma} > 150$ GeV
    - **Search $m_{\gamma\gamma} > 200$ GeV**
  - ✓ **Efficiency** (ggF Scalar)
    - $m_X \sim 200$ GeV → ~ 35%
    - $m_X > 600$ TeV → > 40 %

- CMS
  - ✓ **Trigger**
    - $E_T^{\gamma 1} > 60$ GeV, $E_T^{\gamma 2} > 60$ GeV
    - H/E < 0.15
    - Fully efficiency for $m_G > 600$ GeV
  - ✓ **Offline**
    - $|\eta| < 2.5$, 1.44-1.57 excluded
      - At least one γ with $|\eta| < 1.44$
      - No E-E combination
    - **$E_T^{\gamma 1} > 75$ GeV, $E_T^{\gamma 2} > 75$ GeV**
    - Tight quality (cuts) + H/E < 0.05 + isolation
    - Select $m_{\gamma\gamma} > 230$ GeV (320 if EC γ)
    - **Search $m_{\gamma\gamma} > 500$ GeV**
  - **Efficiency** (RS Gravitons)
    - $m_G \sim 600$ GeV → ~ 30%
    - $m_G \sim 2$ TeV → ~ 45%

Signal modeling

- ATLAS
  - ✓ **Signal properties**
    - **Higgs-like scalar**
      - **m_X = [200 GeV - 2 TeV]**
    - Different production modes
      - ggF (Powheg-box), VBF (Powheg-box+ Pythia) , VH, ttH (Pythia)
      - systematic uncertainties to avoid "model" dependence
    - **Narrow Width Approximation (NWA)**
      - Full Simulation
      - Width ~ 4 MeV for all m_X
    - **Large Width Approximation (LWA)**
      - **Width 1%-10% m_X**
      - Theoretical line shape convoluted to detector response
      - Powheg implementation of a large-width scalar resonance when assuming SM-like couplings (BW distribution with a mass-dependent width + dependence of propagator on the gg parton lumi)
  - ✓ **Implementation**
    - Double-Sided Crystal Ball parameterization
      - Simultaneous fit of parameter parameterization

- CMS
  - ✓ **Signal properties**
    - **RS Graviton**
      - **m_X = [500 GeV – 4.5 TeV]**
      - $\tilde{\kappa} = \sqrt{8\pi}\kappa / m_{Pl}$
        $0.01 < \tilde{\kappa} < 0.2$
      - Theoretical line shape convoluted to detector response

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

  - ✓ **Implementation**
    - Moment morphing

Background modeling

- ATLAS
  - ✓ Data driven γγ purity (wrt γγ, γj)
    - **~ 90%**
  - ✓ **Functional form** $x = \frac{m_{\gamma\gamma}}{\sqrt{s}}$

$$f_{(k)}(x; b, \{a_k\}) = (1 - x^{1/3})^b \, x^{\sum_{j=0}^{k} a_j (\log x)^j}$$

$$f_0(x; b, a_0) = (1 - x^{1/3})^b \, x^{a_0}$$

  - ✓ Bias evaluated on MC
    - **"Spurious signal"**
    - S+B fits to high-statistics of background MC
    - Fitted S component must be smaller then 20% of expected background uncertainty at given mass
  - ✓ **F-test on data to evaluate need for higher order in background function**

- CMS
  - ✓ Data driven γγ purity (wrt γγ, γj)
    - **~ 90%** ~ 80% (**BB**, BE)
  - ✓ **Functional form**

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

  - ✓ Bias evaluated on MC
    - Additional uncertainty assigned to background parameterization
    - **From fit MC pseudo-experiment (toys)**
    - **Assigned if median of pull distributions from toy fits toys is larger than 0.5**

Systematic uncertainties

- ATLAS

(not given by CMS)

(crucial to decode NWA ATLAS result!)

Source	Uncertainty
Background modeling °•	
Spurious signal	$2-10^{-3}$ events, mass-dependent
Background fit	≤ 50%–≤ 20% of the total signal yield uncertainty, mass- and signal-dependent
Signal modeling °•	
Photon energy resolution	$^{+[55-110]\%}_{-[20-40]\%}$, mass-dependent
Signal yield •	
Luminosity	±5%
Trigger	±0.63%
C_X *factors* •	
Photon identification	±(3–2)%, mass-dependent
Photon isolation	±(4.1–1)%, mass-dependent
Production process	±3.1%

- CMS
  - ✓ Bias term on parametric background model (no size given)
  - ✓ Luminosity : 4.6%
  - ✓ Trigger and photon ID : 10%
  - ✓ Signal PDF : 6% *(not in ATLAS, several production processes)*
  - ✓ Photon energy scale : 1% *(negligible in ATLAS)*

Statistical treatment

- ATLAS
  - ✓ Profile likelihood ratio

$$q_0(m_X, \alpha) = -2 \log \frac{L(0, m_X, \alpha, \hat{\hat{\nu}})}{L(\hat{\sigma}, m_X, \alpha, \hat{\nu})}$$

  - ✓ Look Elsewhere Effect
    - 1D → several mass hypothesis in NWA scan
    - 2D → several mass and width hypothesis

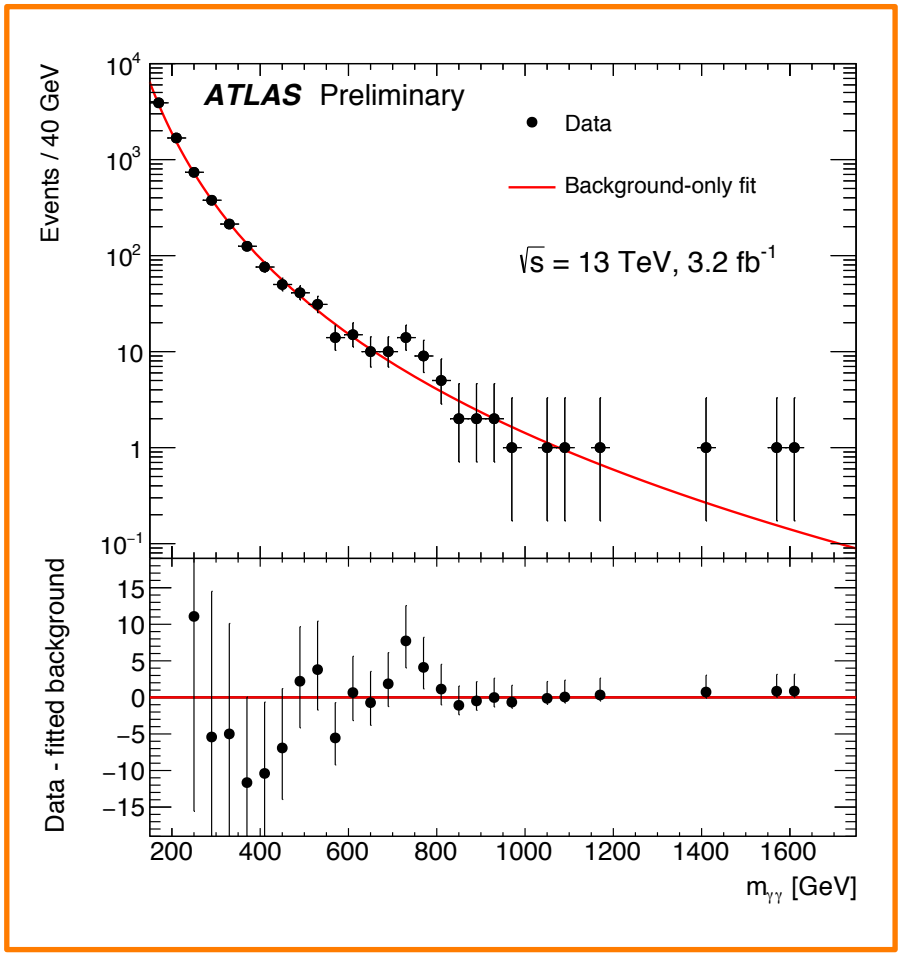
- CMS
  - ✓ Profile likelihood ratio

$$q(\mu) = -2log\frac{L(\mu \cdot S + B|\underline{\hat{\theta}}_{\mu})}{L(\hat{\mu} \cdot S + B|\underline{\hat{\theta}})}$$

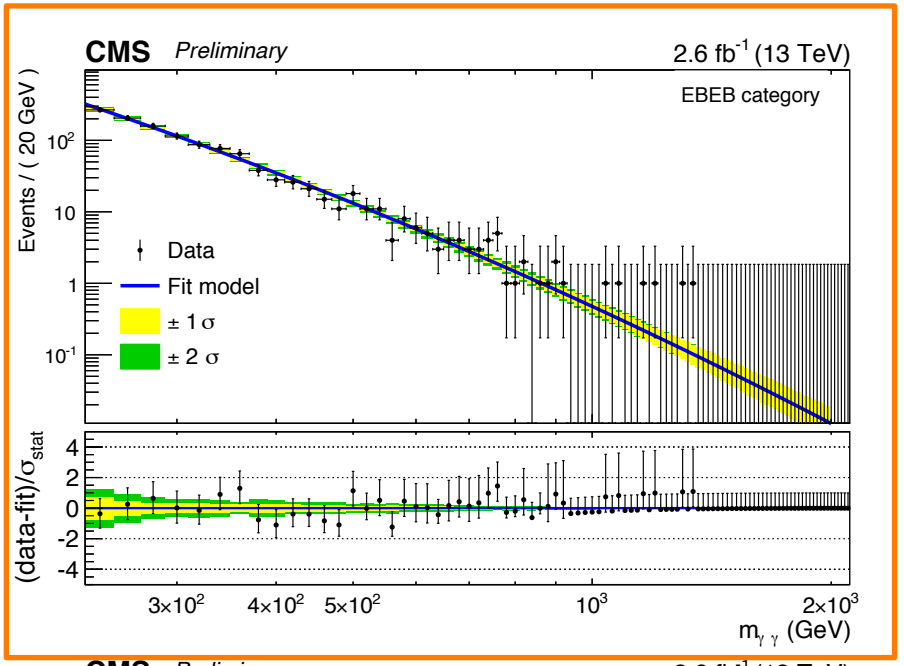
  - ✓ Look Elsewhere Effecct
    - 2D → several mass and $\tilde{\kappa}$

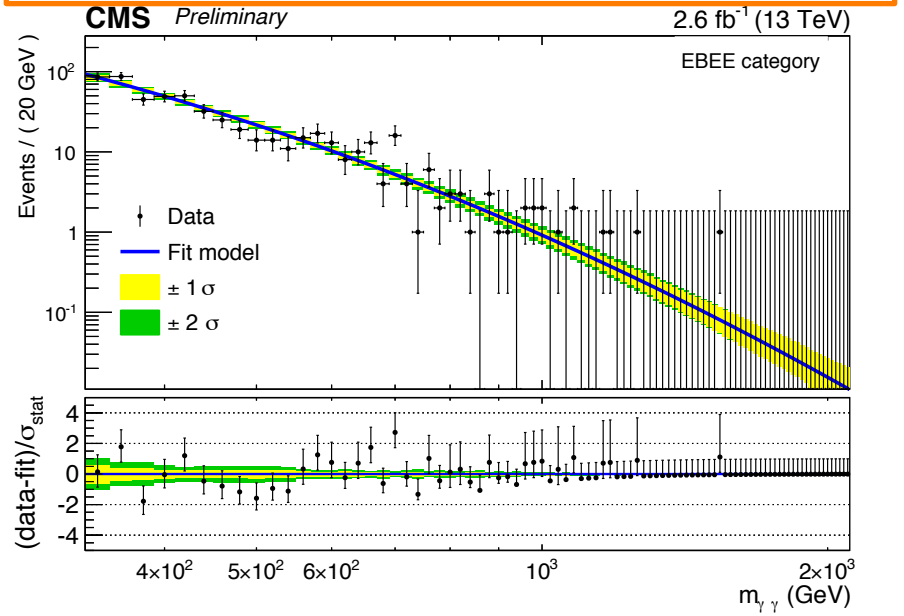
Spectrum

- ATLAS



- CMS

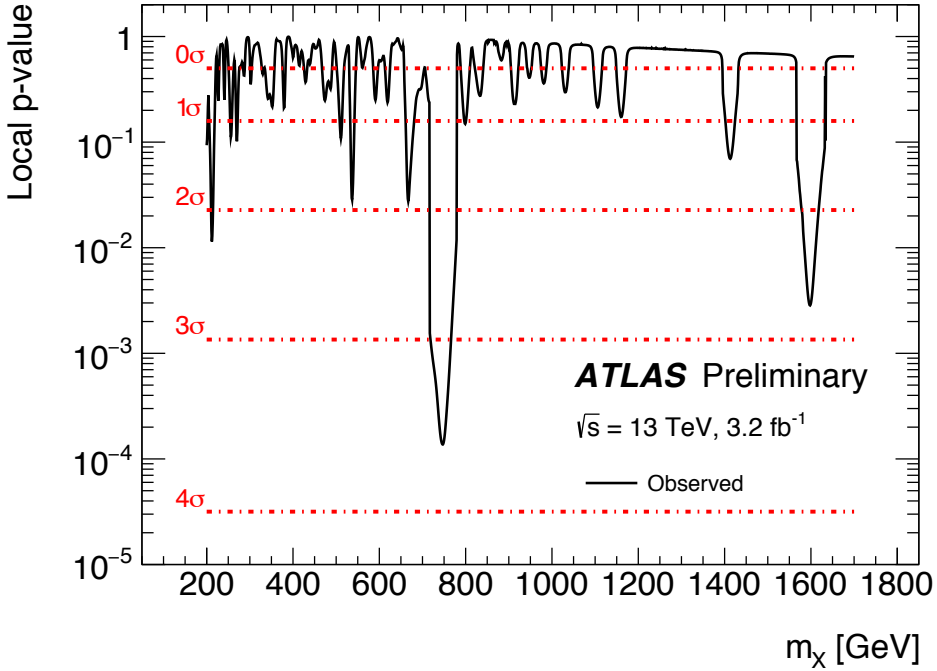




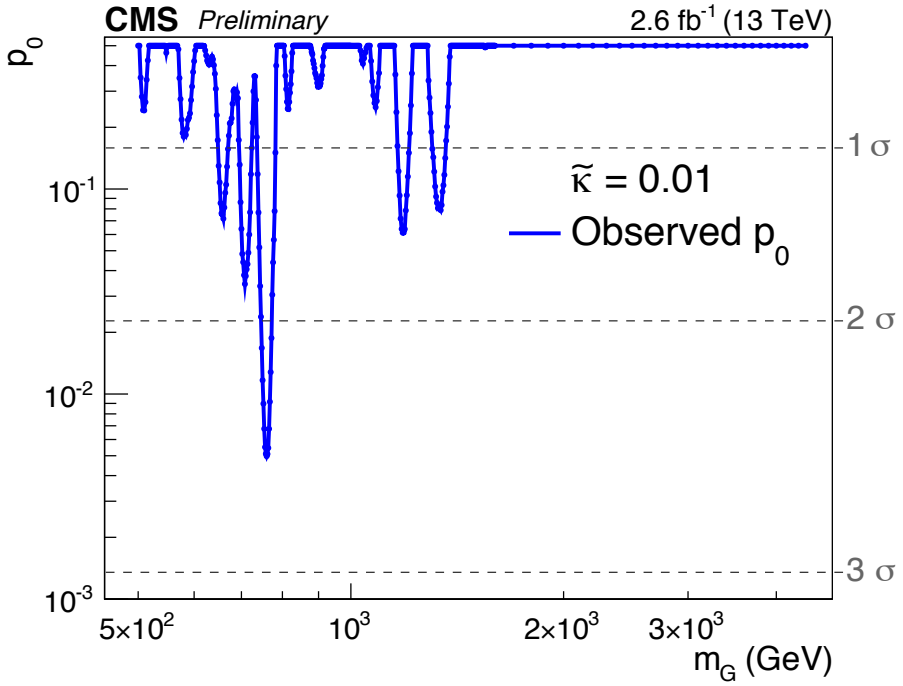
(CMS plots have different m scale!)

Significance

- ATLAS
  - ✓ NWA
    - Pull on resolution NP



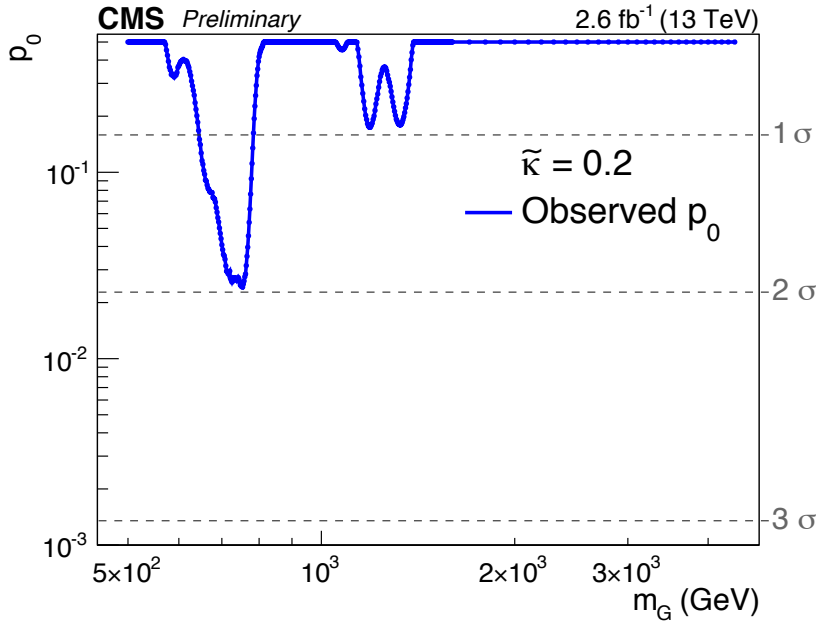
- CMS
  - ✓ $\tilde{\kappa}$ = 0.01
    - FWHM(500 GeV) BB = 14 GeV



- ✓ Local p_0 ~ 3.6 σ at ~750 GeV
- ✓ Global p_0 ~ 2.0 σ
- ✓ Local p_0 ~ 2.6 σ at ~760 GeV
- ✓ Global p_0 ~ 1.2 σ

Significance

- ATLAS
  - ✓ LWA
    - **Minimum p_0 for width ~ 6%**
- CMS
  - ✓ $\tilde{\kappa}$ = 0.2
    - FWHM(500 GeV) BB = 36 GeV (~7%)
    - **760 GeV ~6% (EOYE seminar)**

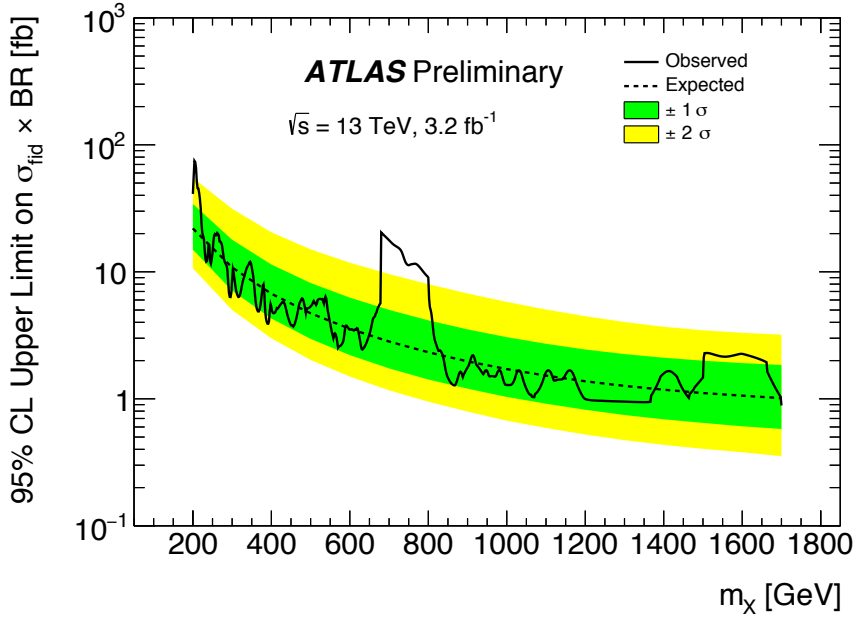


- ✓ Local p_0 ~ 3.9 σ
- ✓ Global p_0 ~ 2.3 σ

- ✓ Local p_0 ~ 2.0 σ
- ✓ No global provided

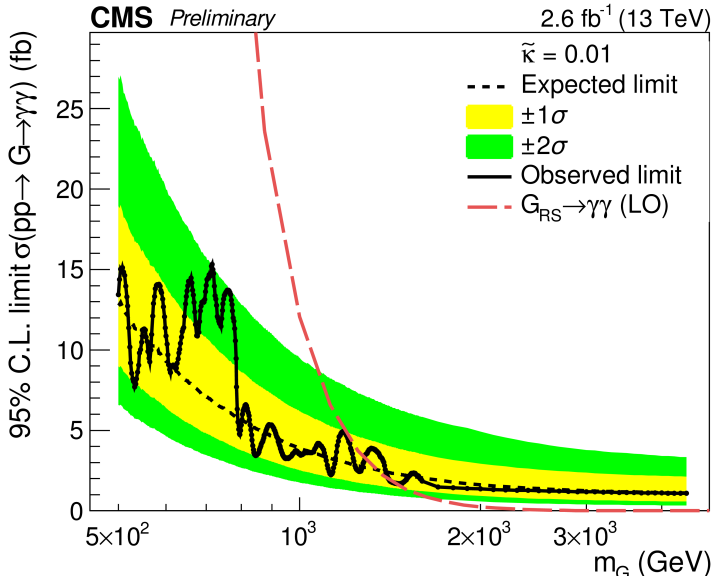
Limits

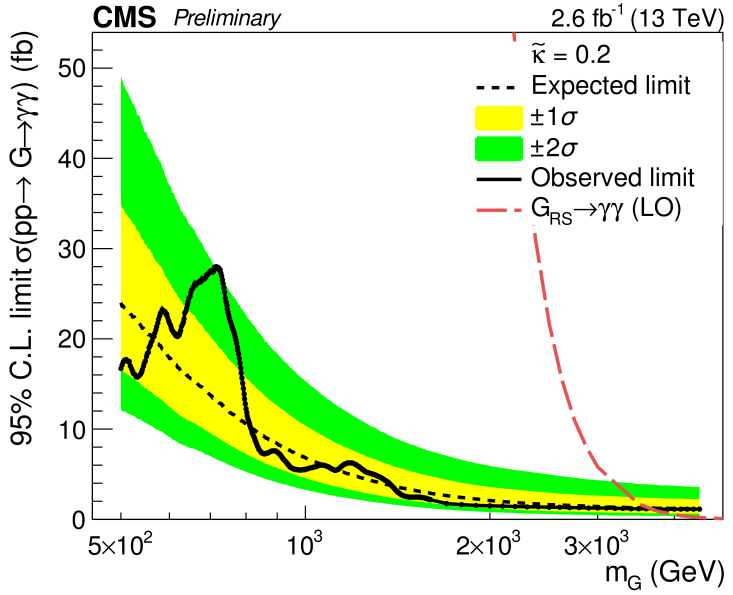
- ATLAS
  - ✓ Fiducial limit!
    - Isolation in fiducial volume definition
  - ✓ NWA



  - ✓ Validity for LWA
    - Bias smaller than 10% (20%) for width 0.4% (1.4%) m_X

- CMS
  - ✓ RS Graviton

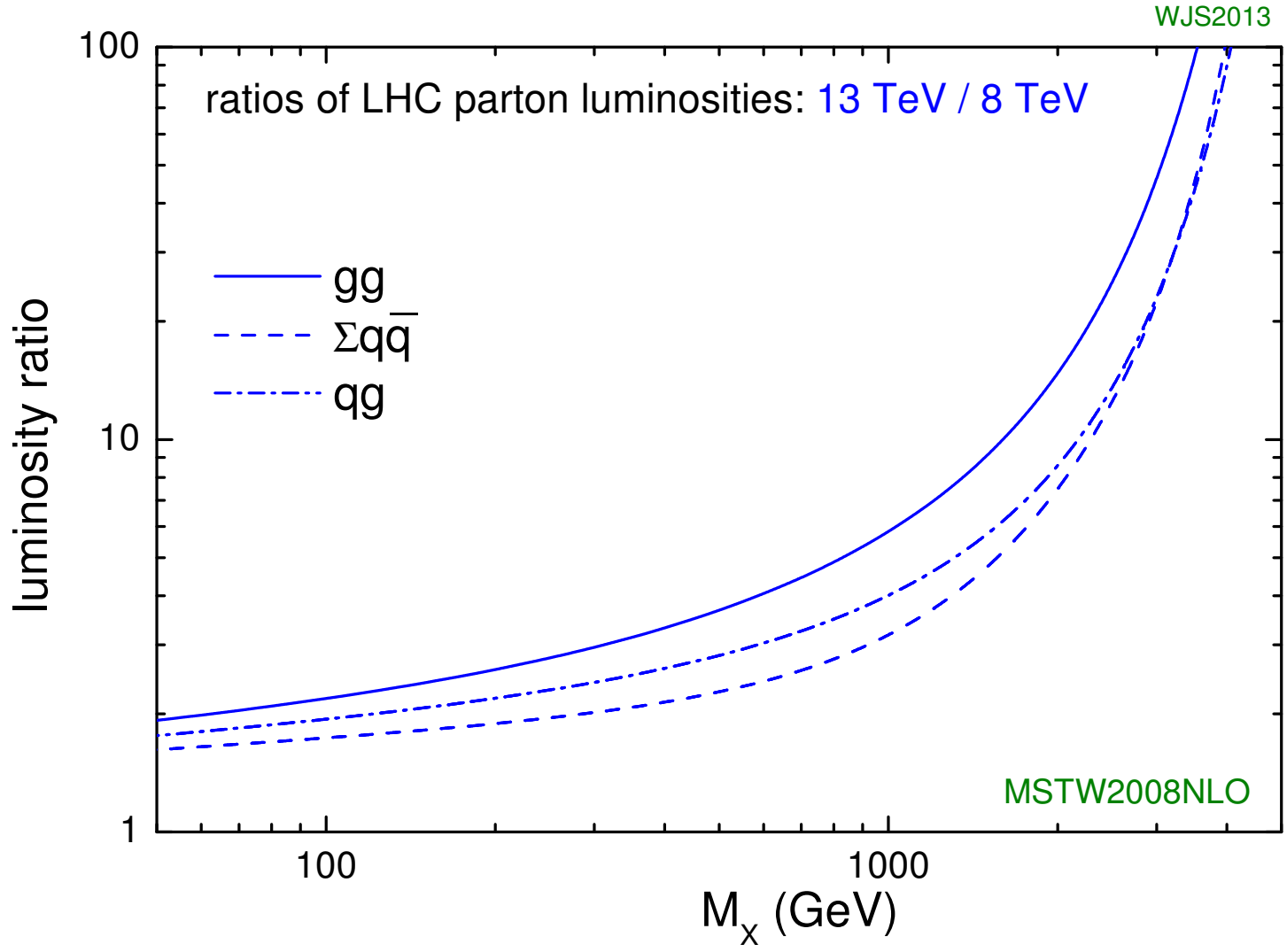




Conclusions (and perspectives?)

- **ATLAS and CMS reported mild excess in 13 TeV diphoton spectrum**
  - ✓ Around 750 (760) GeV
  - ✓ Largest local significance ~ 3.9 σ ATLAS for width ~6%
  - ✓ **Global significance is really small! No reason to get (too) excited!**
    - ATLAS: 2.3 σ , CMS: 1.2 σ
    - CMS significance largest for smaller width
- **Analyses targeting different signal**
  - ✓ ATLAS → scalar ; CMS → graviton
  - ✓ Both analyses have (sub-optimal) sensitivity to other signal
- **What can we expect before 2016 data taking?**
  - ✓ ATLAS has graviton-like analysis still to be made public…
  - ✓ Scalar analysis from CMS?
  - ✓ Better calibration in both experiments
    - energy scale (mass and significance), resolution (significance)
  - ✓ Extended compatibly/combination with 8 TeV results?
- **Otherwise, more data needed to establish excess origin**

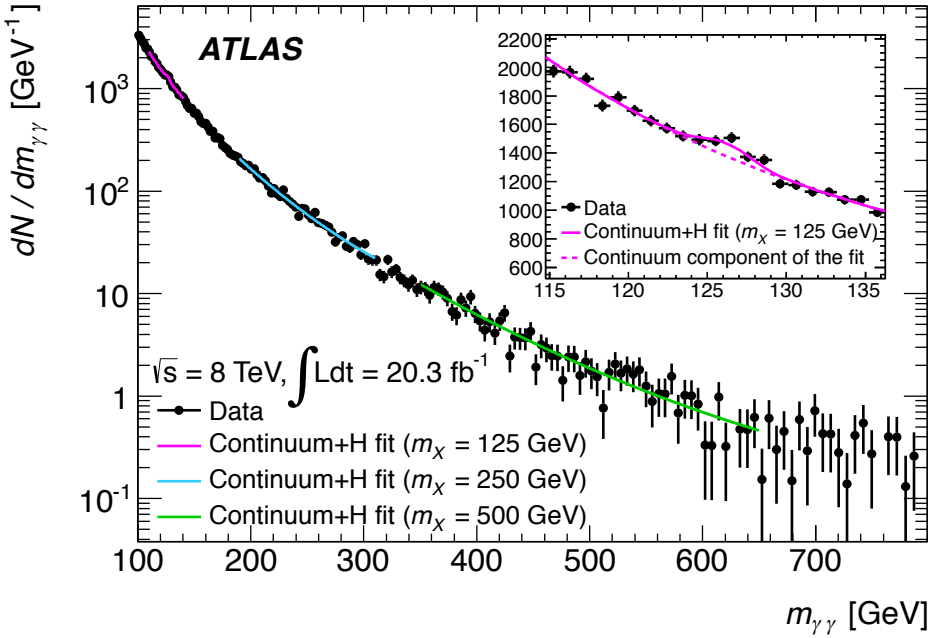
Compatibility/combination with 8 TeV results

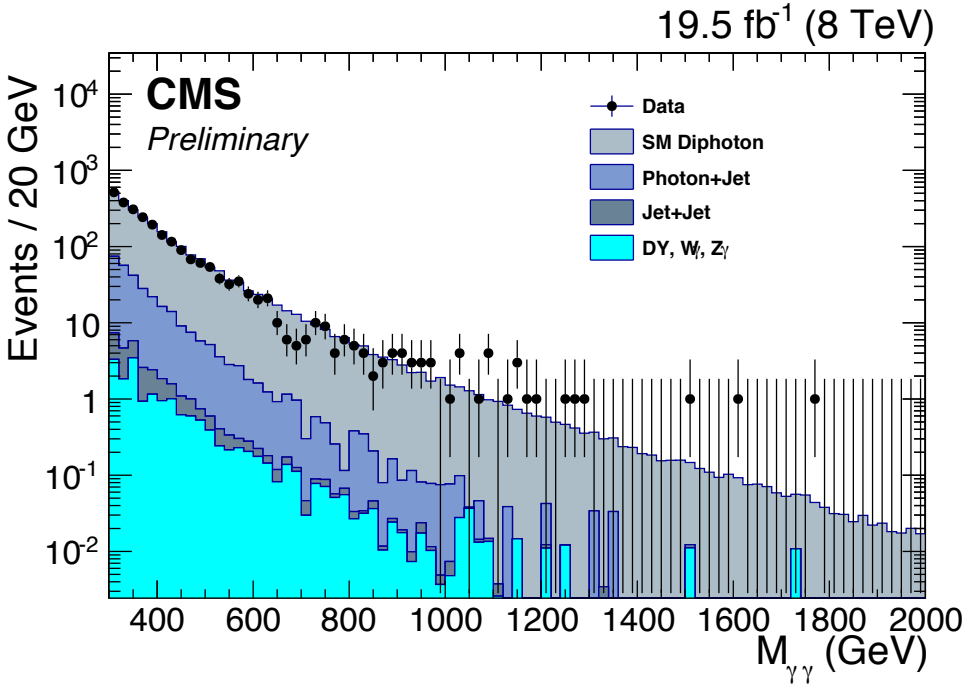


- *e.g. s*-channel gluon-initiated process → parton-luminosity ratio = 4.7

8 TeV results for compatibility/combination

- ATLAS
  - ✓ arXiv:1407.6583
  - ✓ Scalar NWA
  - ✓ m_X = [65-600] GeV
  - ✓ Preliminary extension of analysis to estimate compatibility…
- CMS
  - ✓ CMS-PAS-EXO-12-045
  - ✓ Graviton
  - ✓ m_G = 300 GeV, 2.5 TeV
  - ✓ Change in statistical treatment to enable combination





Compatibility/combination with 8 TeV results

- ATLAS
  - ✓ 8 TeV analysis → scalar
  - ✓ Compatibility
    - NWA → 2.2
    - **LWA (6%) → 1.4 σ**
- CMS
  - ✓ 8 TeV analysis → graviton
  - ✓ Combination 8 TeV + 13 TeV
    - **Local p_0 ~ 3 σ**
    - **Global p_0 < 1.7 σ**