Search for New Scalar Diphoton Resonances in ATLAS

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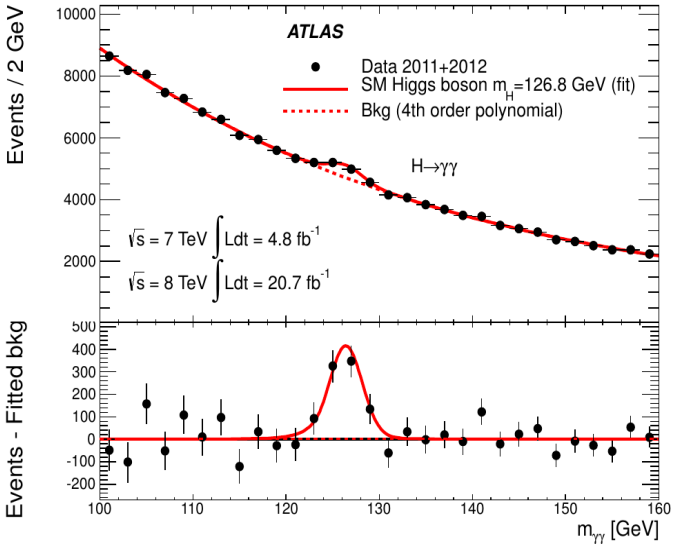
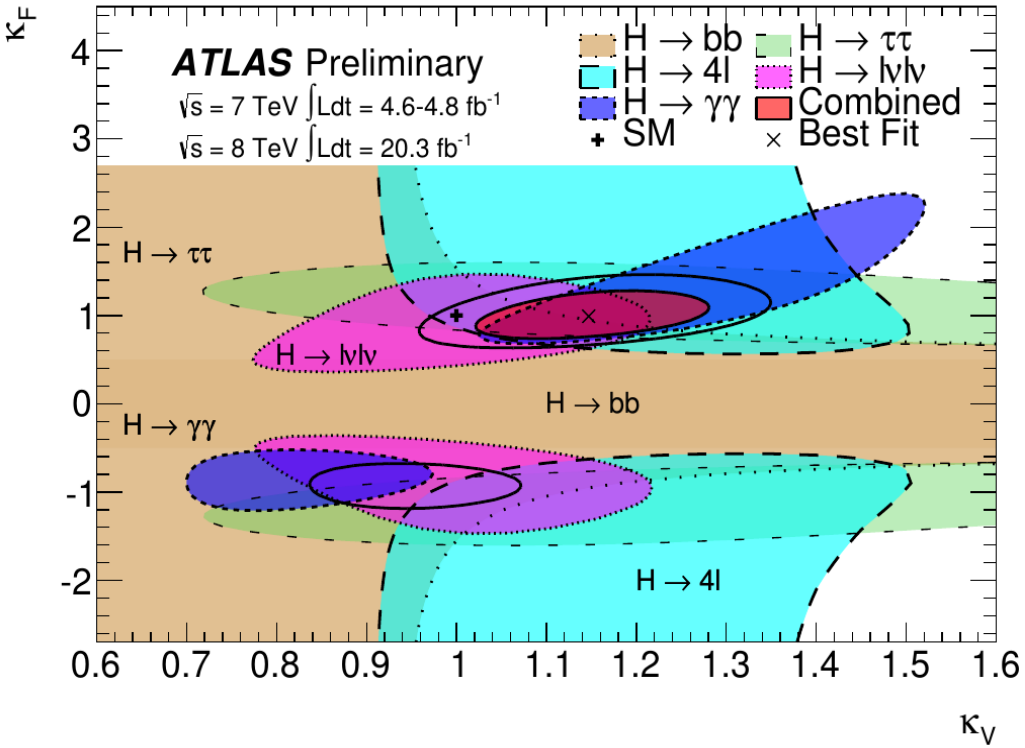
Introduction

One of the main question for ATLAS and CMS today: is **the Higgs boson "just" the SM one, or is there something else ?**

- Powerful probes through Higgs properties but so far fully compatible with SM
- **Alternative**: Search directly for BSM signals





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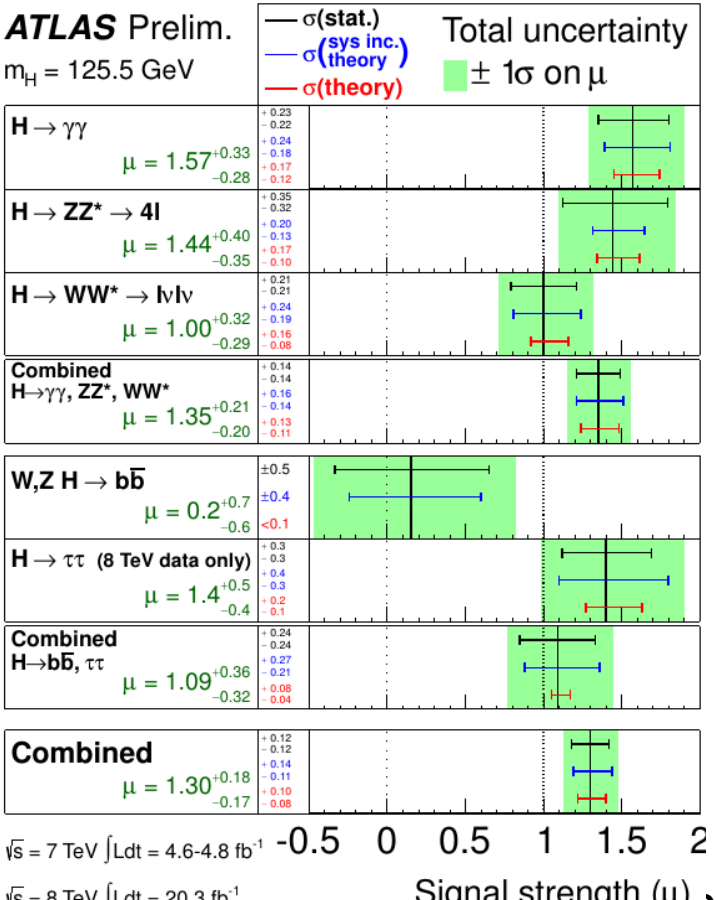

Is there something else ?

- **Exotic Searches :** Focused on "large" high-mass signals
- **Complementary** : Higgs searches extended to Higgs-like states
  - Extend search ranges
  - set limits on σxBR if no signal
- **Already done at high mass for H->WW, ZZ**
- **What about γγ ?** CMS result for the "standard" search window

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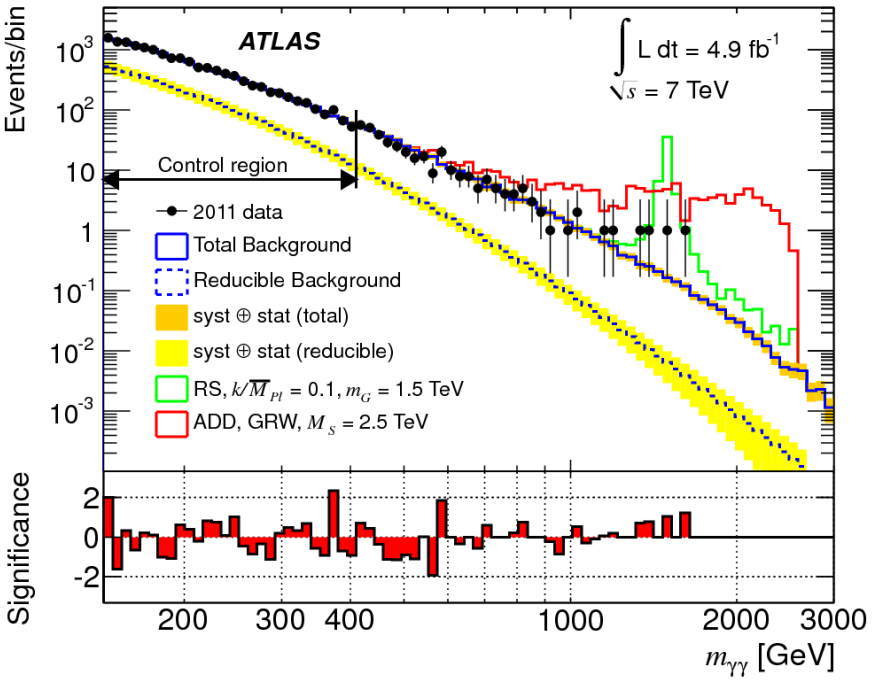

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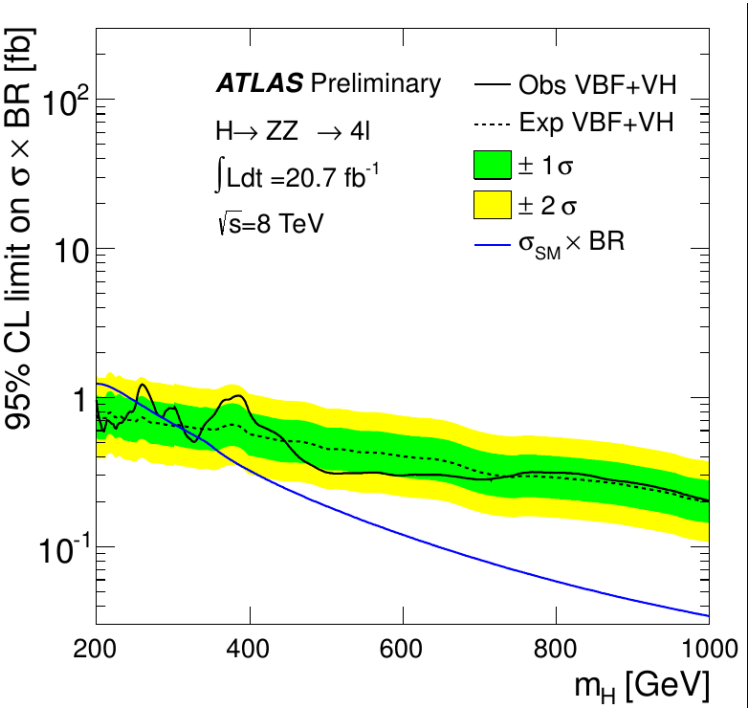
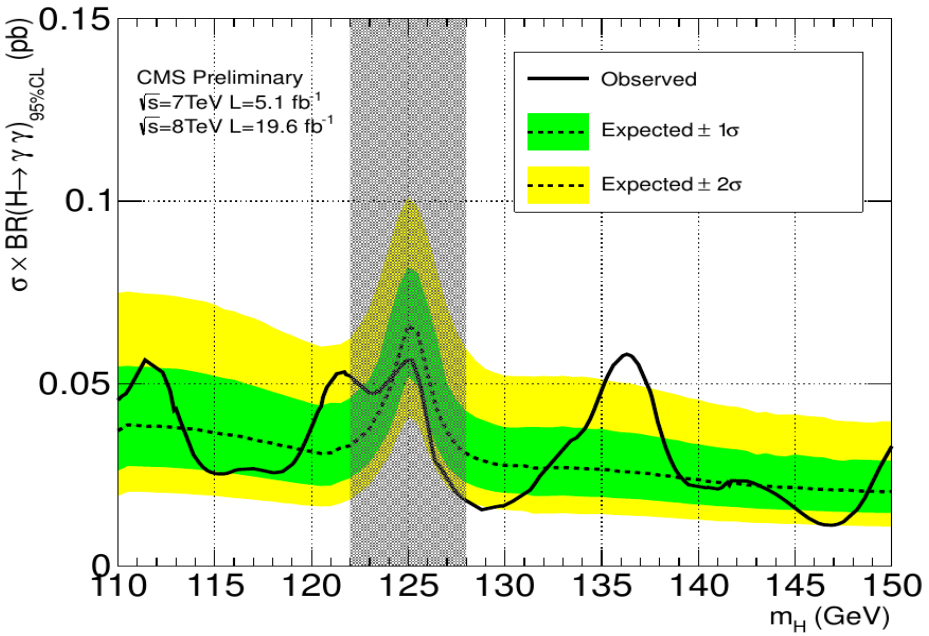




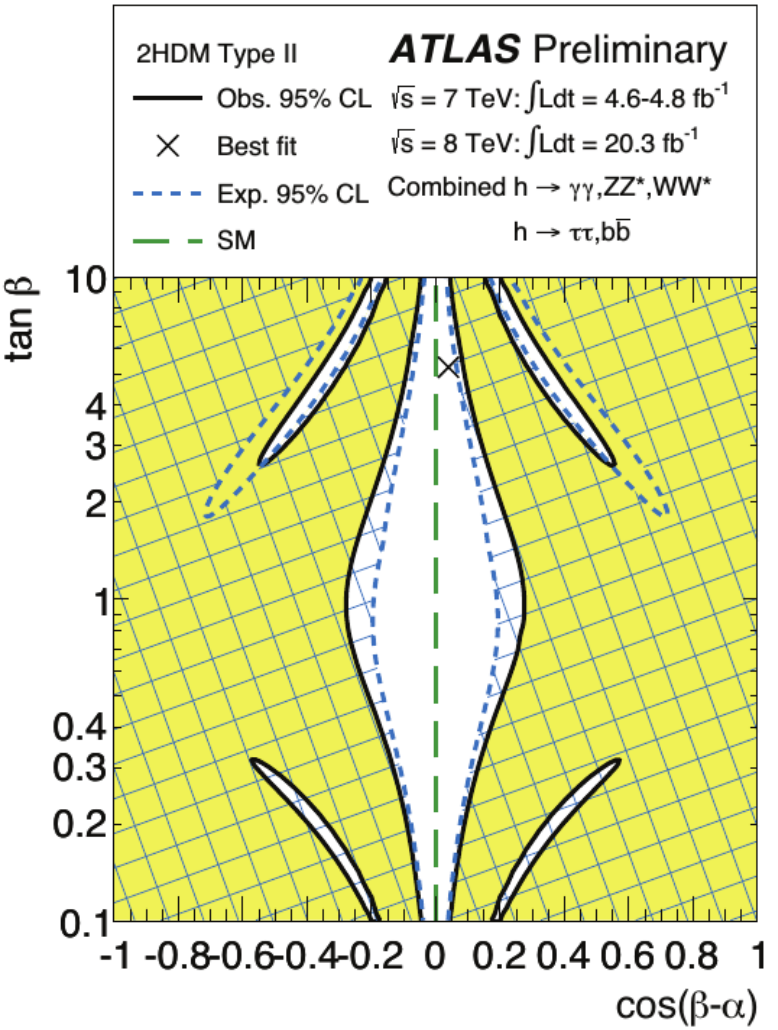
CMS-PAS-HIG-13-016

Models with Extra Higgs-like Resonances

- Typical target: **models with extended Higgs sector**
  - **2HDM**: 2 extra neutral Higgses H, A, can decay to $\gamma\gamma$ (small tan β)
  - Also possible signals in the context of **NMSSM**, **Extra Higgs singlet,...**

- **Complementary** to constraints from Higgs properties measurements

- Hard to make $\Gamma_{\gamma\gamma}$ large, so to get non-negligible BR($\gamma\gamma$), usually need small Γ
  $\Rightarrow$ **Narrow state**



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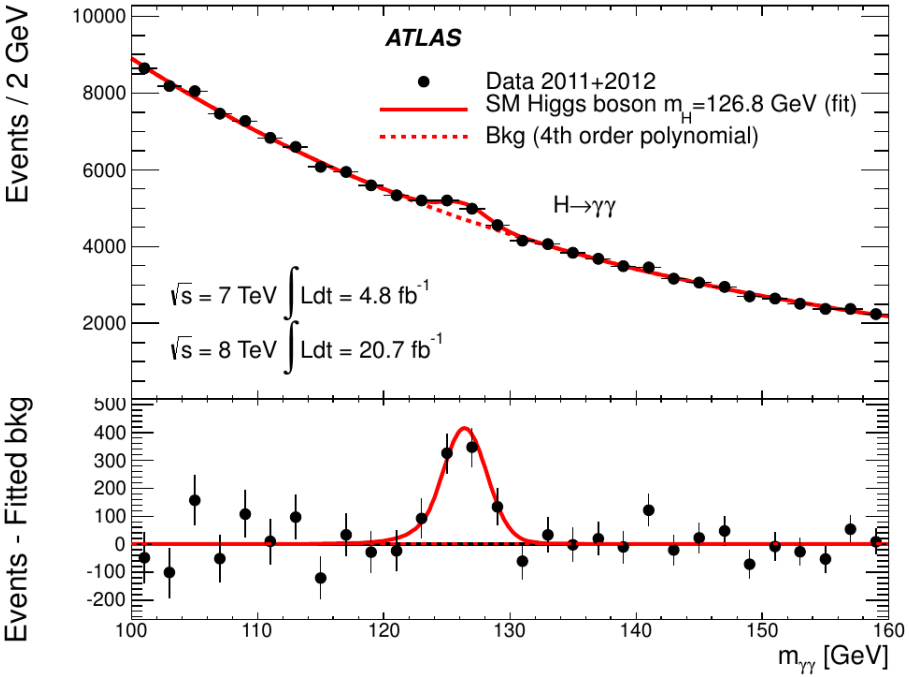
Standard H→γγ Search

- Small bump on smooth background
  - mainly γγ, γjet, jj bkgs
- **Template fit** using analytical shapes for signal and bkg
- **Selection :**
  - $E_{T1} > 40$ GeV, $E_{T2} > 30$ GeV,
  - $100 < m_{\gamma\gamma} < 160$ GeV
  - Consider $110 < m_H < 150$ GeV



- **Categories**: separate out specific regions:
  - central/non-central η, low/high p_T, conv/unconv photons
  - VBF-like, VH-like configurations

Challenges for Extended search

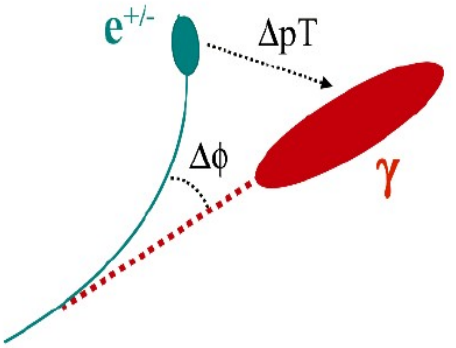
- Need to **describe the signal and background over a much wider mass range**
- Below 100 GeV, need to deal with **$Z \rightarrow ee$ background**
- **$H \rightarrow \gamma\gamma$** also treated as a background.
- **Make the result as general as possible**, so it is applicable to a wide range of models
  - Avoid most categories

Overview of the Analysis

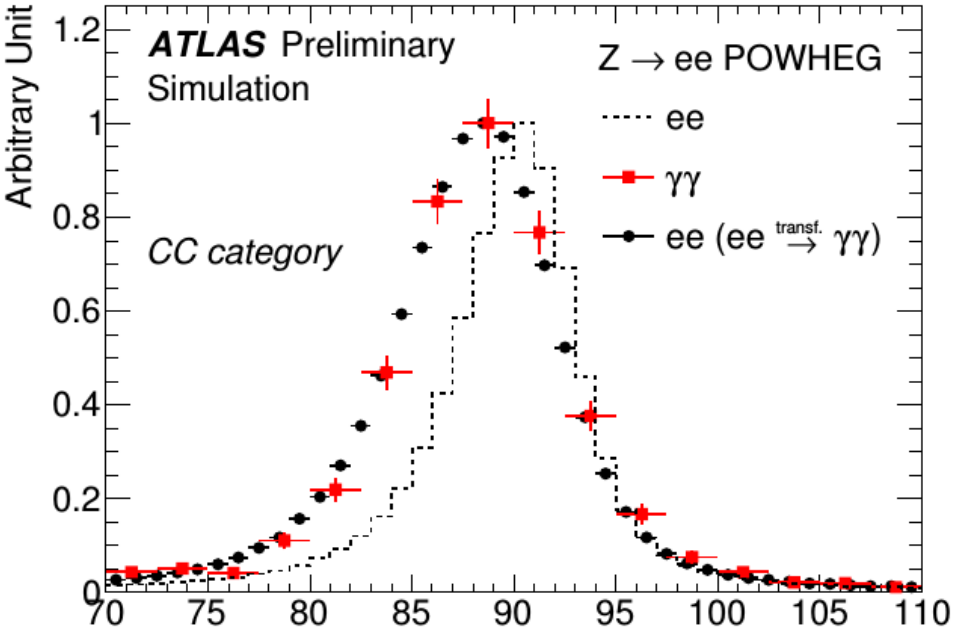
- Extend search to **$60 < m_{\gamma\gamma} < 700$ GeV**
- **Photons**: same reconstruction, identification as standard $H \rightarrow \gamma\gamma$ analysis: ~70% eff
  - Require $|\eta| < 2.37$, excluding Barrel/EC transition $1.37 < |\eta| < 1.56$.
  - photon ID using calorimeter shower shapes, + tracks for convesions
  - calorimeter-based and track-based isolation
- **Model-independence**
  - Report **fiducial cross-section**
  - remove most categories
  - **8 TeV data only**. Use full 2012 dataset (**20.3 fb^{-1}**)
- **Separate low-mass ($60 < m_{\gamma\gamma} < 120$ GeV) and high-mass ($100 < m_{\gamma\gamma} < 700$ GeV) regions**

Low-Mass Search ($60 < m_{\gamma\gamma} < 120$ GeV)

- Lower photon E_T cuts to **$E_{T1,2} > 22$ GeV** (using lower trigger thresholds)
- **Use 3 conversion categories: N_{conv}=0,1,2** to mitigate DY background
- **Use Z→ee to determine DY template**
  - e→g fakes mostly with large bremsstrahlung, so add MC-based correction to describe γγ template
- **DY Normalization**: e→γ fake rates computed from data

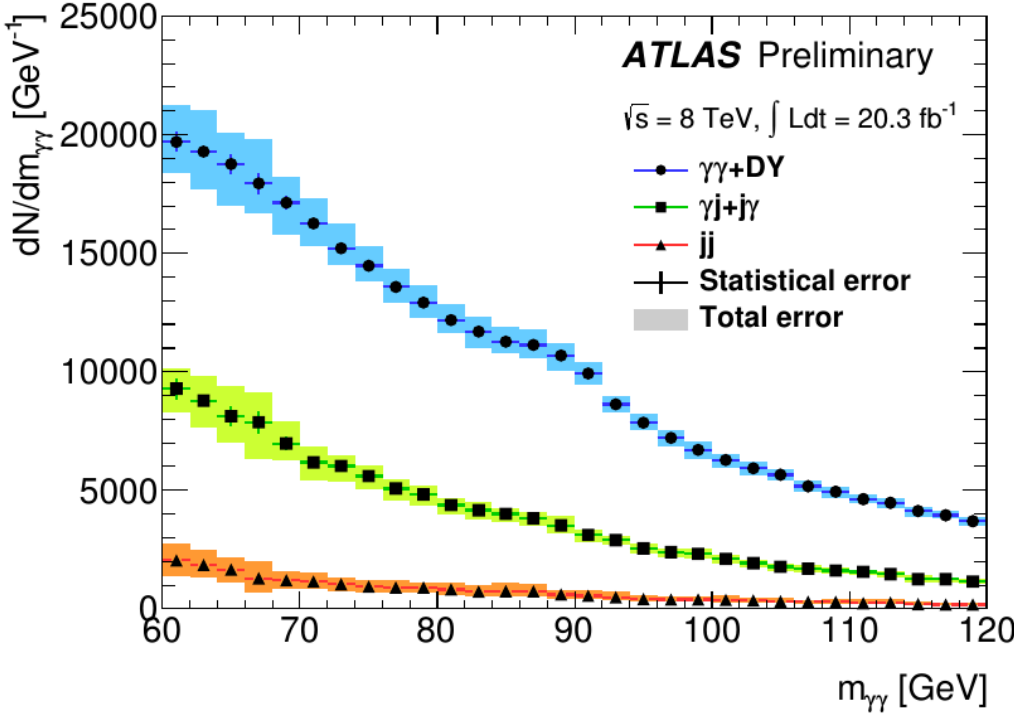


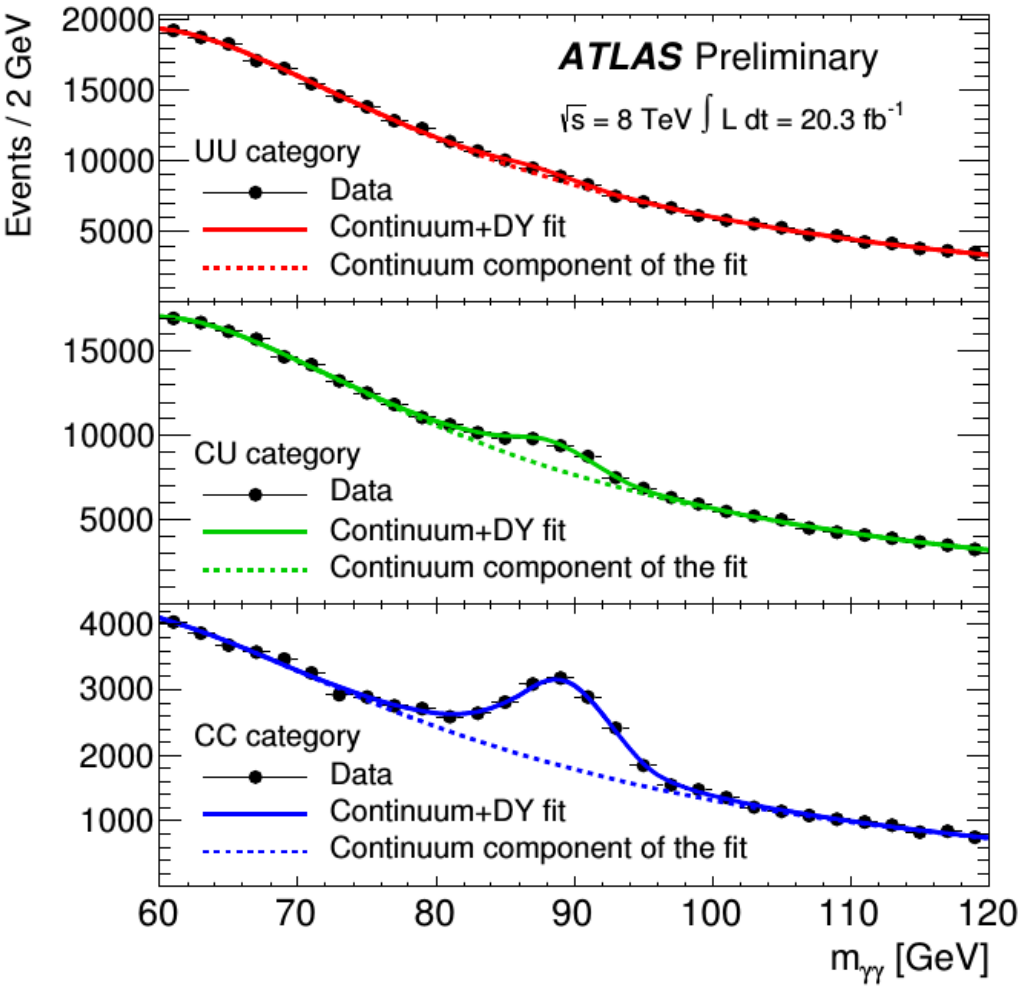
γ conversion category	UU	CU	CC
N_{data}	272184	253804	63224
N_{DY}	1080 ± 260	3400 ± 600	2700 ± 250
f_{DY}	15.0%	47.3%	37.7%
f_X	48.7%	42.5%	8.8%



Low-Mass Search

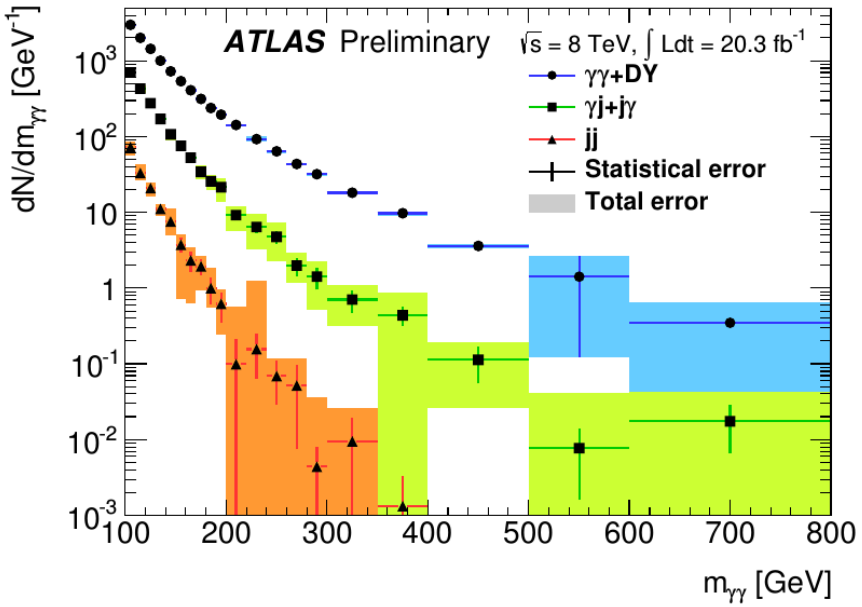
- **Continuum Background :**
  - Mainly γγ, γj, jj and non-Z DY tails.
  - Use Landau+Exponential shape, parameters and N_{cont} free in the fit
- Need sidebands on either side of signal peak: covers **$65 < m_X < 110$ GeV.**

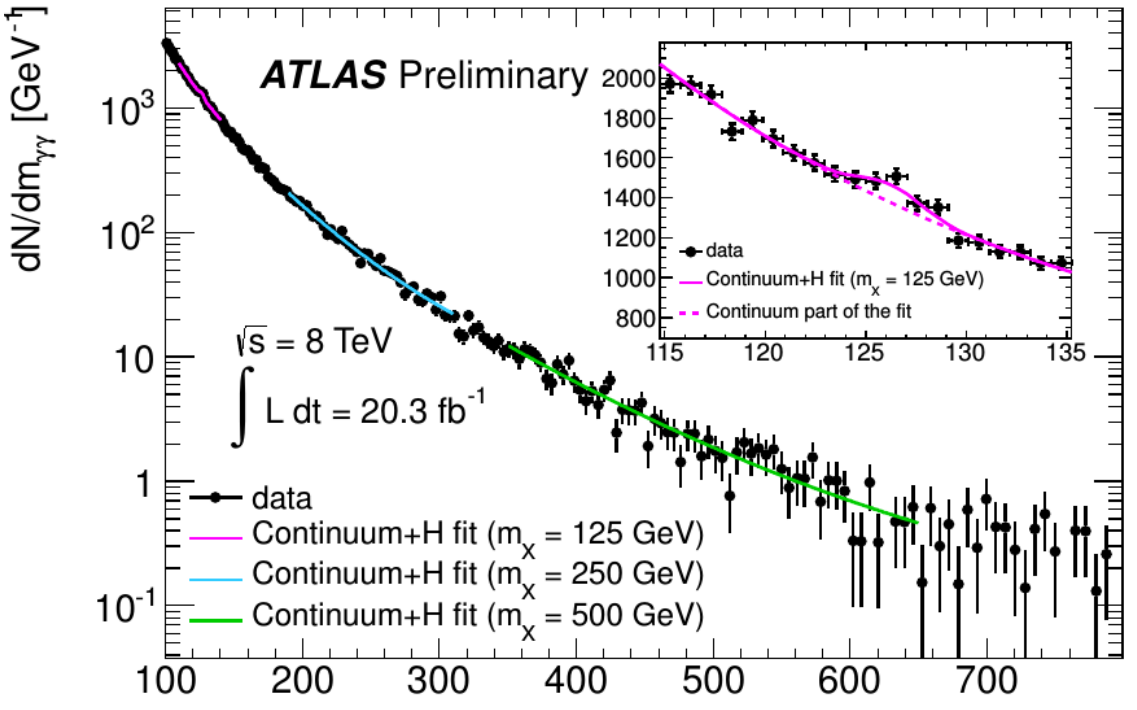




High-Mass Search ($100 < m_{\gamma\gamma} < 700$ GeV)

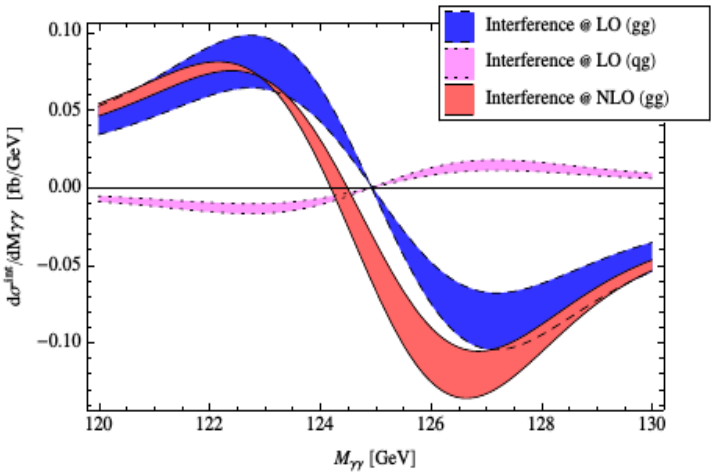
- Relative cuts $E_{T1}/m_{\gamma\gamma} > 0.4$, $E_{T2}/m_{\gamma\gamma} > 0.3$ to improve sensitivity at high mass
- Use **sliding window** $m_X - w < m_{\gamma\gamma} < m_X + w$, $w = 40 \cdot (m_X - 110)/100 + 10$ GeV
  - **exp(am+bm²)** shape in each interval, parameters and N_{cont} free in the fit
- **No categories**
- **Higgs**: use PDG mass $m_H = 125.9$ GeV, $\mu = 1$ (SM yield).
- Extend analysis up to $m_{\gamma\gamma}$=700 GeV, when statistics run out
- Covers $110 < m_X < 600$ GeV.





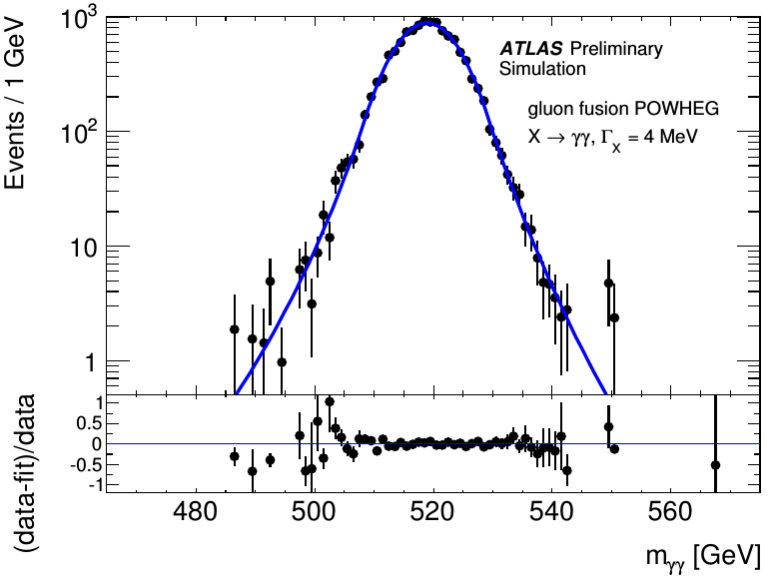
Signal Description

- Assume **narrow width** for all masses.
  - Valid for Γ **<~ 1 GeV + 0.01·m_X**
- **Neglect interference with continuum**
  - Interference is model-dependent
  - Significant distortion of signal peak for Γ~GeV

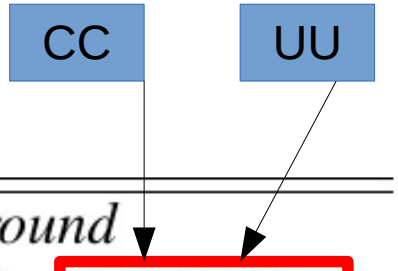


Lance J. Dixon and Ye Li ,
Phys. Rev. Lett. 111, 111802 (2013)

- Describe signal shape using "**Double-sided Crystal Ball**" shape
  - Parameters determined as functions of m_X for $65 < m_X < 600$ GeV
  - Allow peak position and width to float in the fit, constrained by Energy-scale and resolution measurements.



Systematics



Signal yield		*Drell-Yan background*	
Luminosity	2.8 %	Normalization[2]	9 – 25 %
Trigger	0.5 %	Peak position[2]	1.5 – 3.5 %
γ identification[12]	1.6 – 2.7 %	Template shape[2]	1.5 – 3 %
γ isolation[1]	1 – 6 %	*Higgs background*	
Energy resolution[12]	10 – 40 %	Cross-section[3]	9.6 %
Signal peak position		Branching ratio	4.8 %
Energy scale	0.6 %	C_X *factor*	
Continuum $\gamma\gamma, \gamma j, jj$ *background*		Topology[1]	3 – 15 %
Signal bias[1]	1 – 67 events	Pile-up[1]	1 – 3 %

Leading systematic: **resolution uncertainty**

10% at low mass, up to 40% at ~600 GeV

Looking for Peaks

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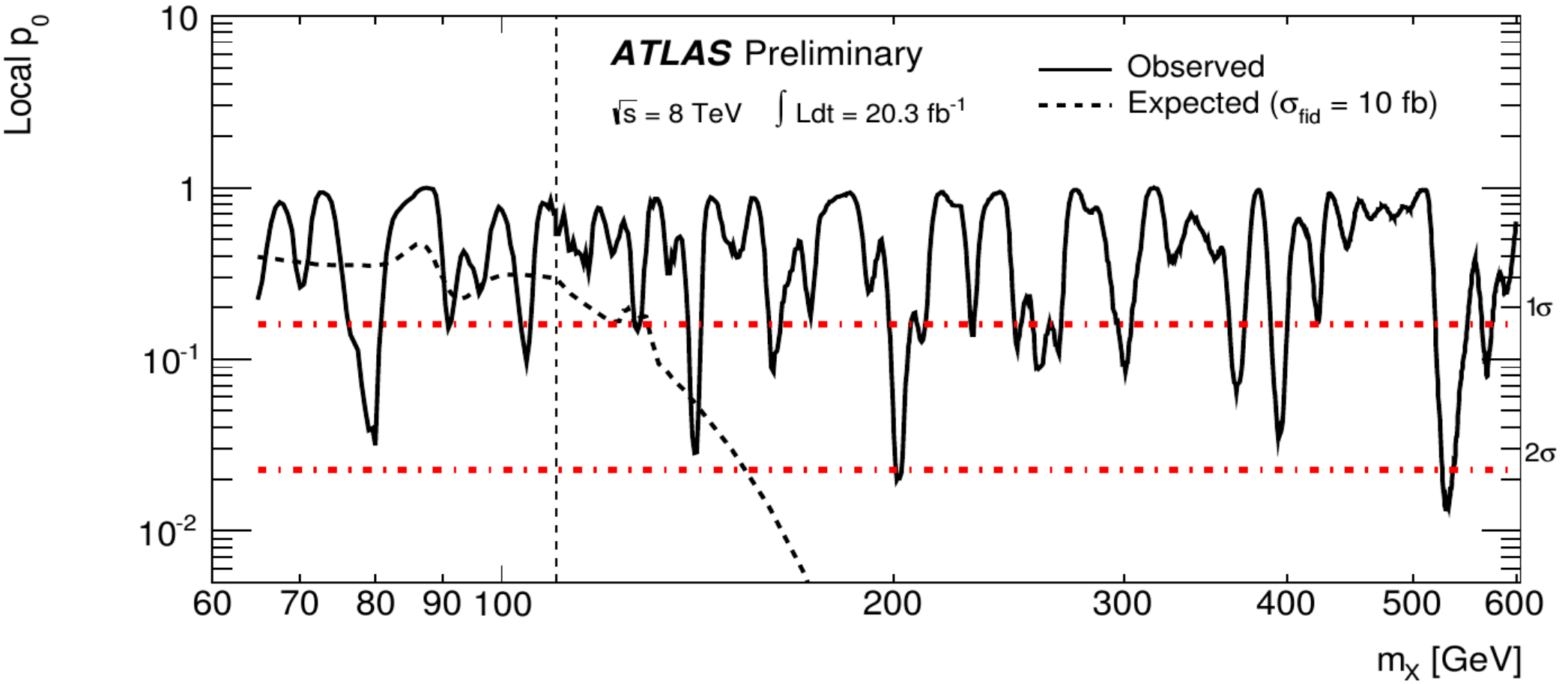


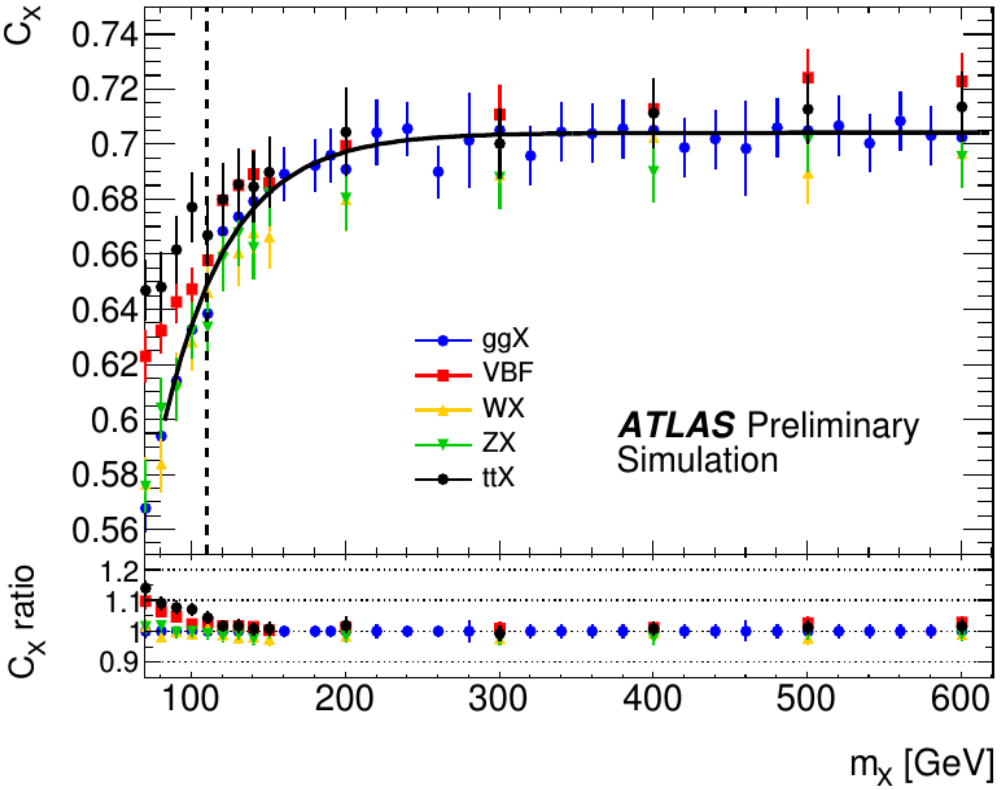
- Only 2 points with local significance ~2σ, at m_X~200 GeV and ~530 GeV
- **Global significance < 0.1σ – No signal!**

Fiducial Cross-Section Definition

- Report **Fiducial cross-section** inside truth acceptance
  - **$E_{T\gamma 1}$, $E_{T\gamma 2}$ > 22 GeV (m_X < 110 GeV)**
    $E_{T\gamma 1}/m_{\gamma\gamma}$ > 0.4, $E_{T\gamma 2}/m_{\gamma\gamma}$ > 0.3 (m_X > 110 GeV)
  - **$|\eta_\gamma|$ < 2.37**
  - **Truth-level isolation < 12 GeV within ΔR=0.4**
- Compute cross-section as

$$\sigma_{\text{fid}} \cdot BR(H \to \gamma\gamma) = \frac{N_{\text{data}}}{C_X \cdot \mathcal{L}} \text{ with } C_X = \frac{N_{\text{MC}}^{\text{reco}}}{N_{\text{MC}}^{\text{fid}}}$$

- Truth closely follows reco selection
  ⇒ Reduces model-dependence
  - Checked on the 5 usual Higgs production modes
  - Residual ttH/ggF difference used as systematic
- **Should apply fiducial cuts at generator level when testing models**



Limit

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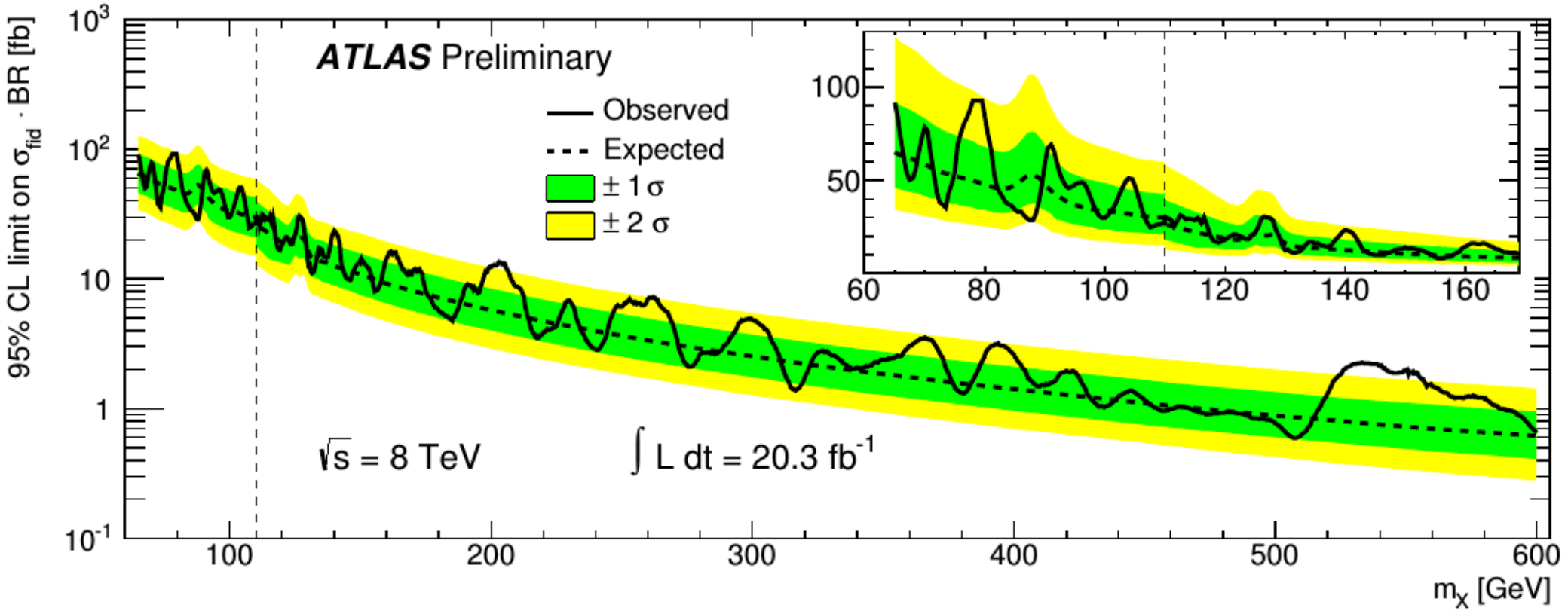


Covers almost an order of magnitude in mass

Ranges from **~100 fb** at 65 GeV to **~1 fb** at 600 GeV.

Outlook

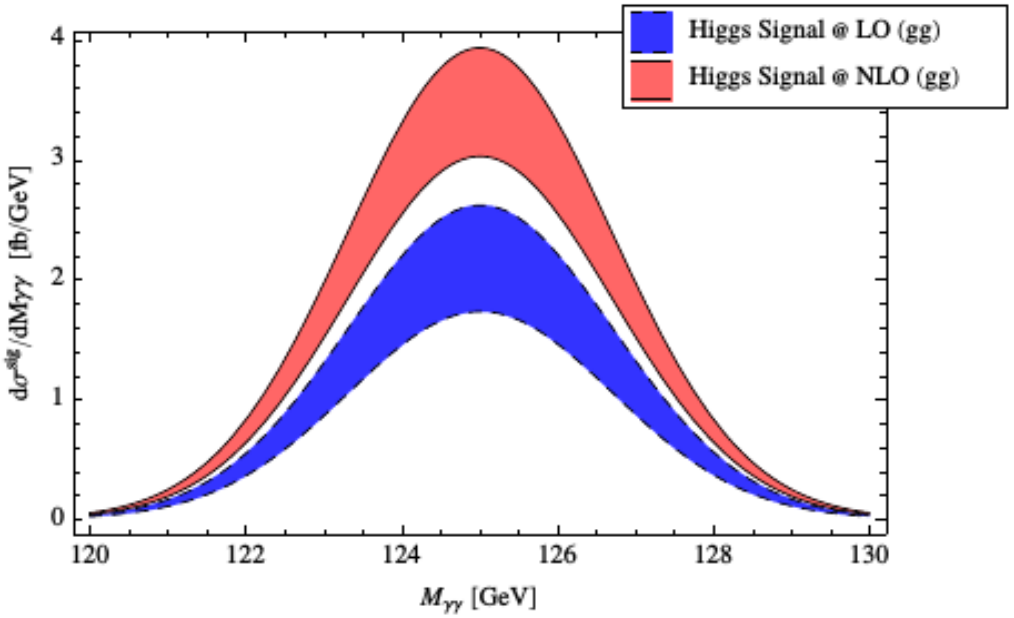
- Search for $\gamma\gamma$ resonances over a much wider range than previous studies

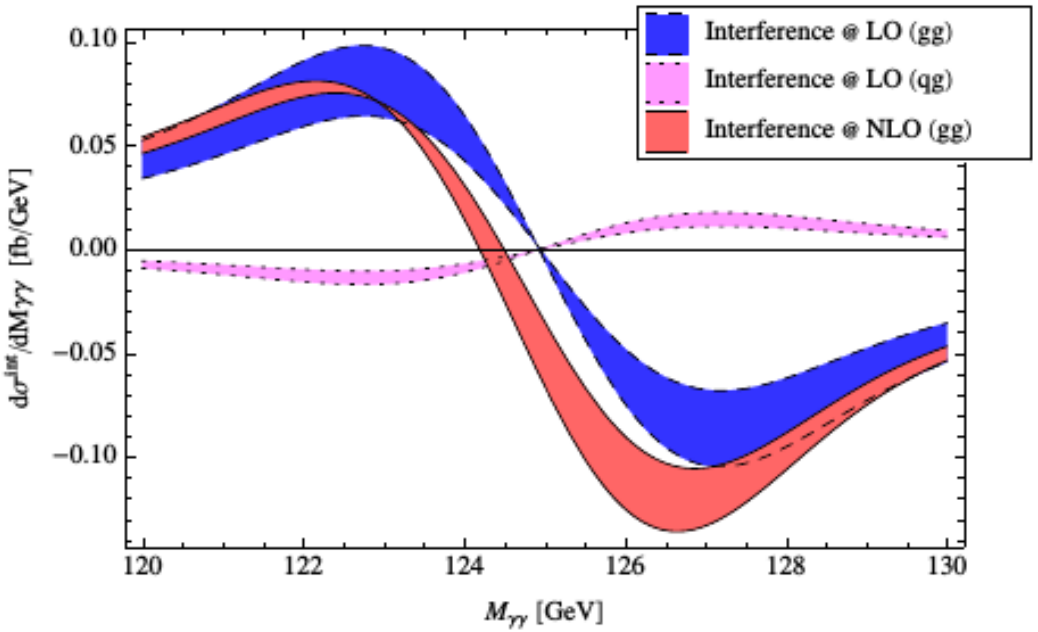
- **No signal observed...**

- **Fiducial Cross-section** limit applicable to a wide range of models
  - will be released in HepData format, together with a RIVET routine, to make comparisons with theory easier

Backup

Interference



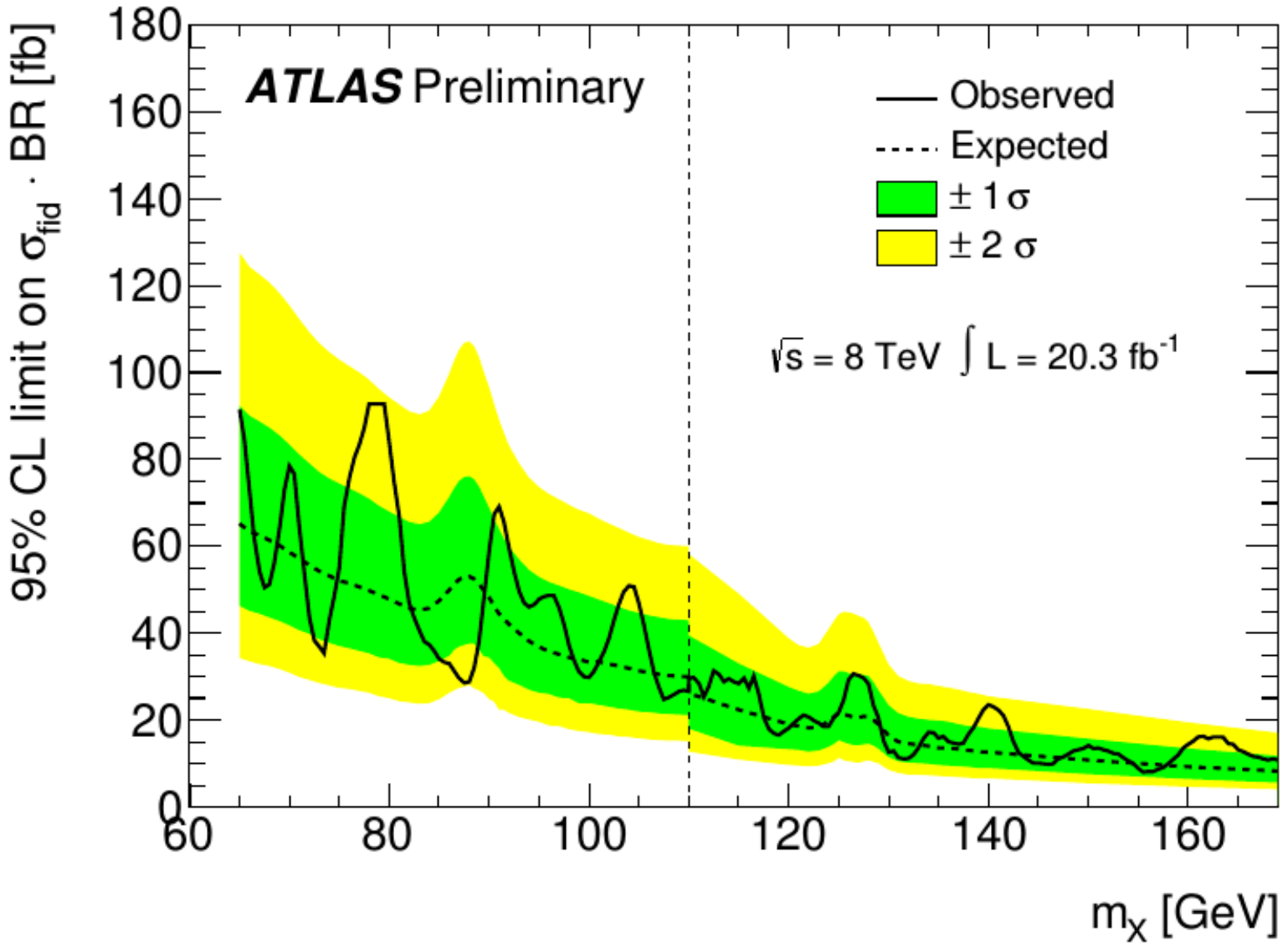


$$\frac{d\sigma^{\rm sig}}{dM_{\gamma\gamma}} = \frac{S}{(M_{\gamma\gamma}^2 - m_H^2)^2 + m_H^2\Gamma_H^2},$$

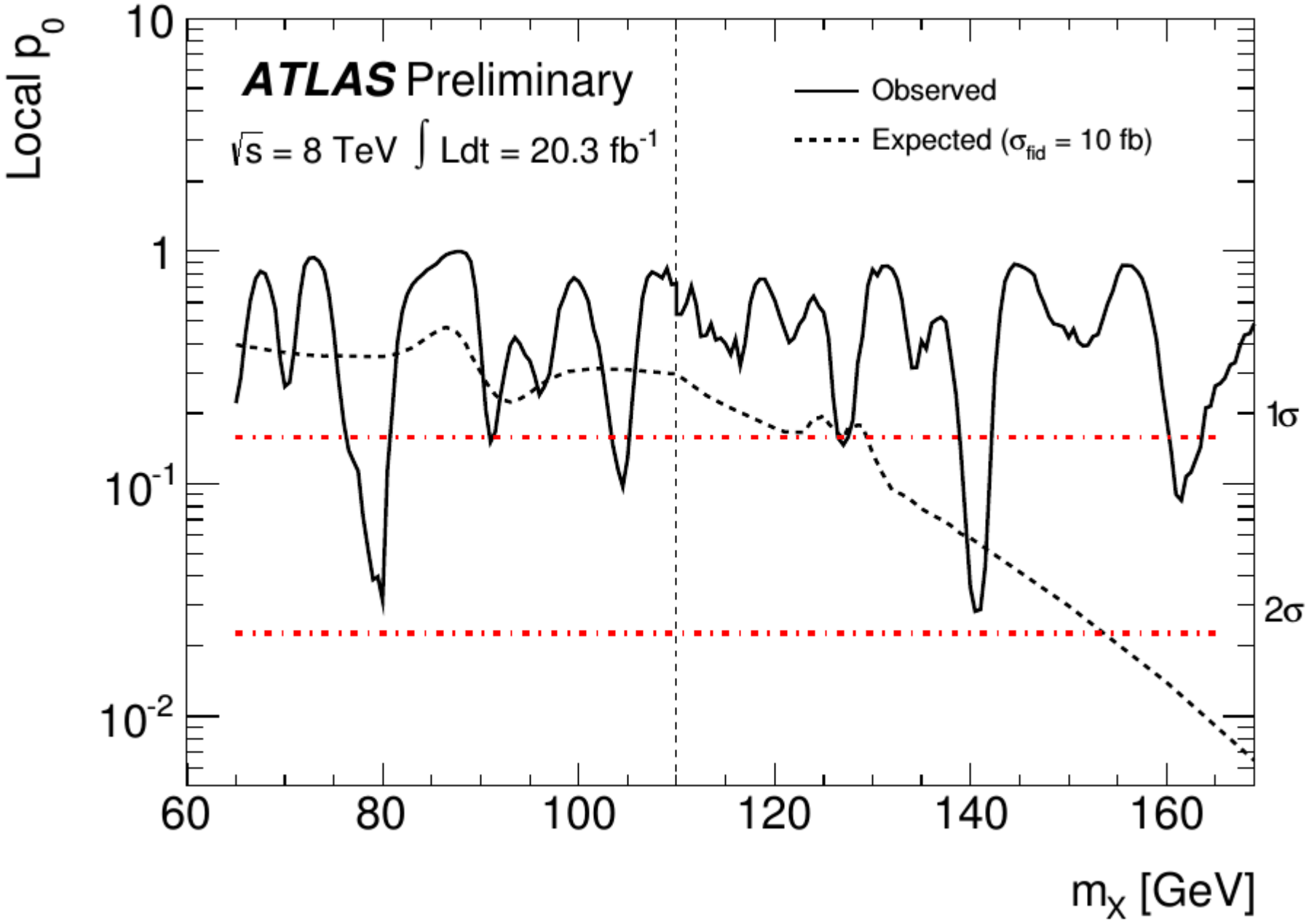
$$\frac{d\sigma^{\rm int}}{dM_{\gamma\gamma}} = \frac{(M_{\gamma\gamma}^2 - m_H^2)R + m_H\Gamma_H I}{(M_{\gamma\gamma}^2 - m_H^2)^2 + m_H^2\Gamma_H^2}.$$

Lance J. Dixon and Ye Li , Phys. Rev. Lett. 111, 111802 (2013)

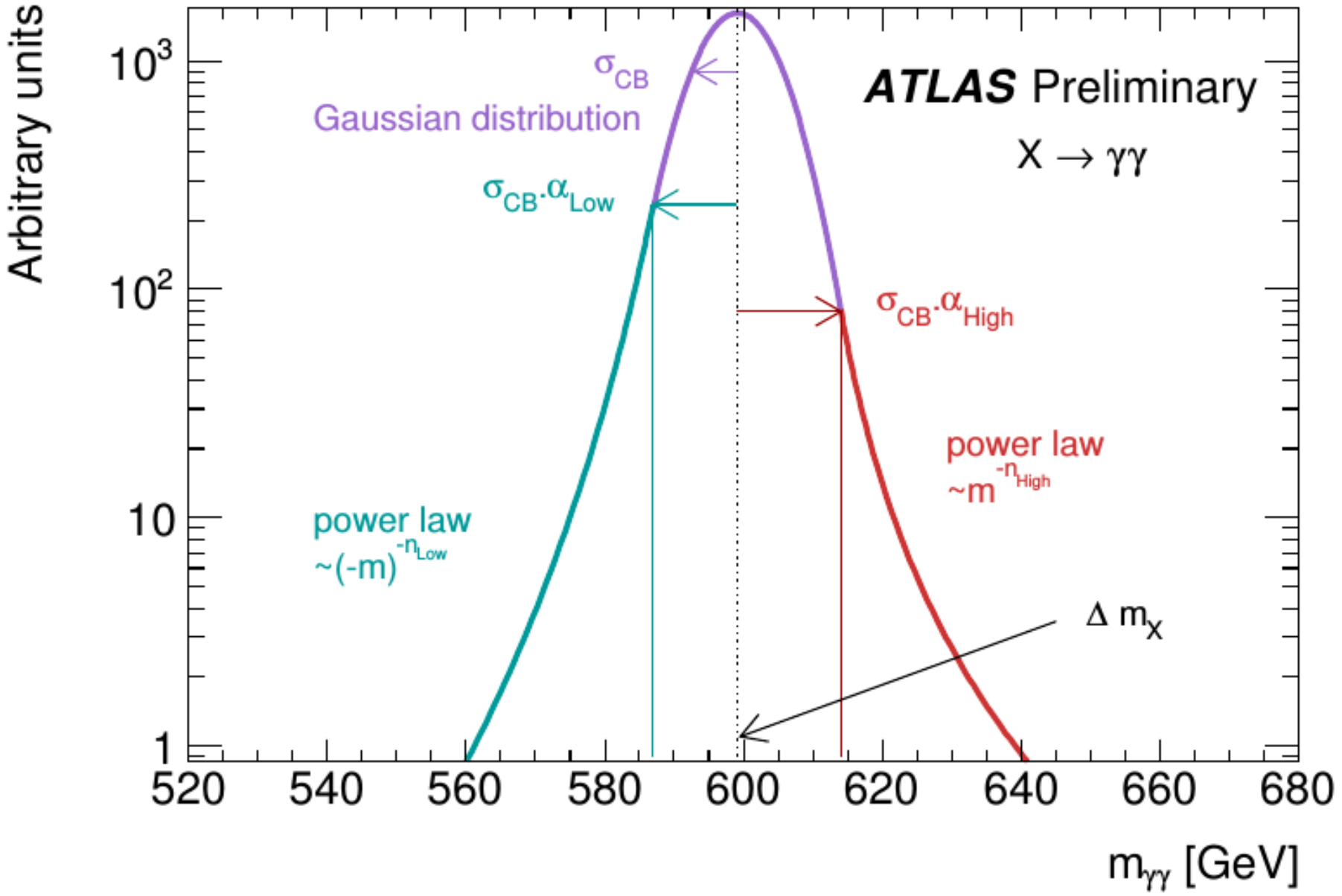
Limit: Zoom on Low Mass Region



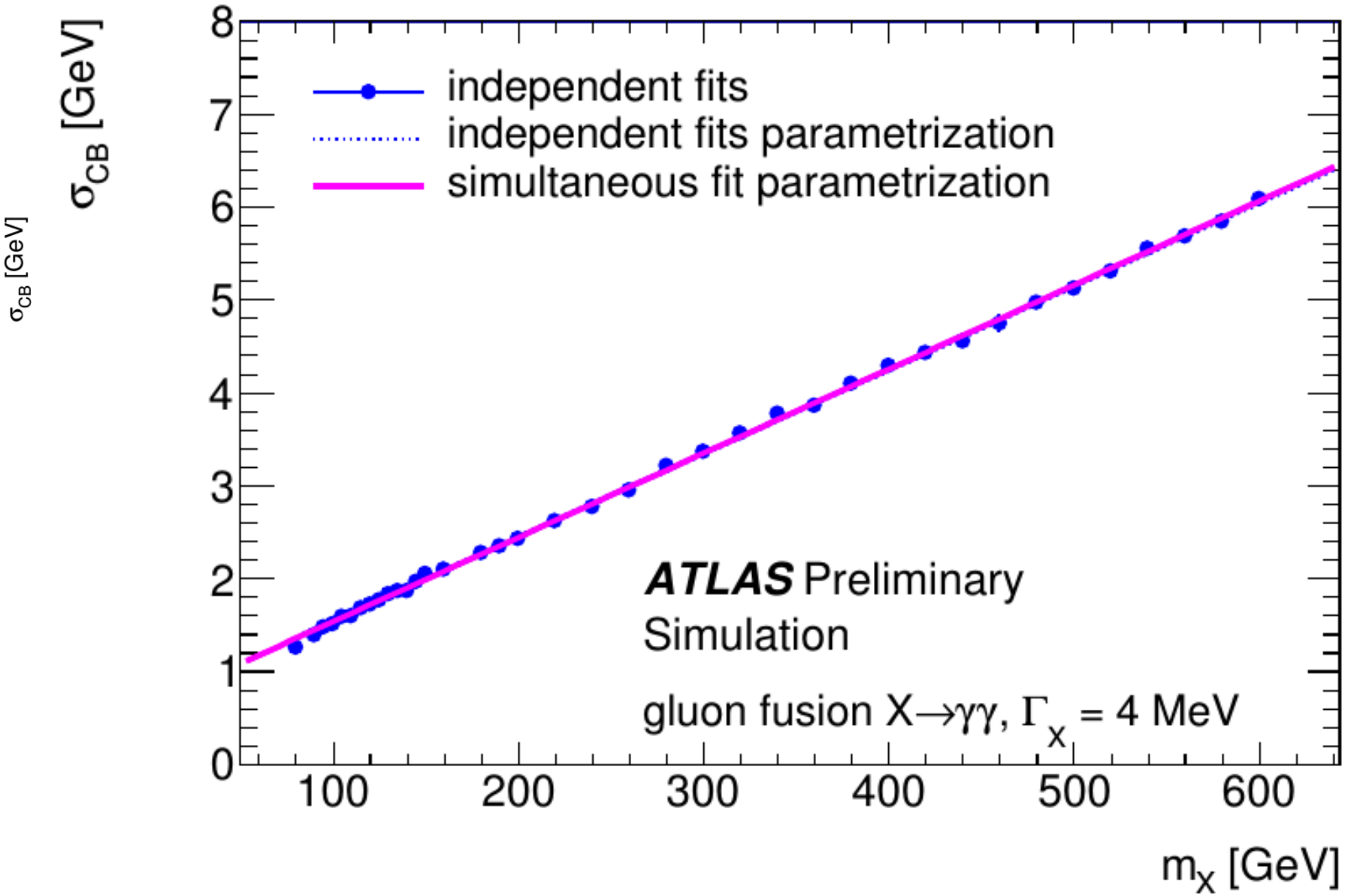
p0 : Zoom in Low-Mass Region



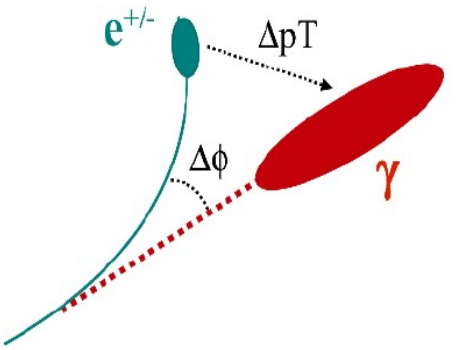
Double-Sided CB Shape



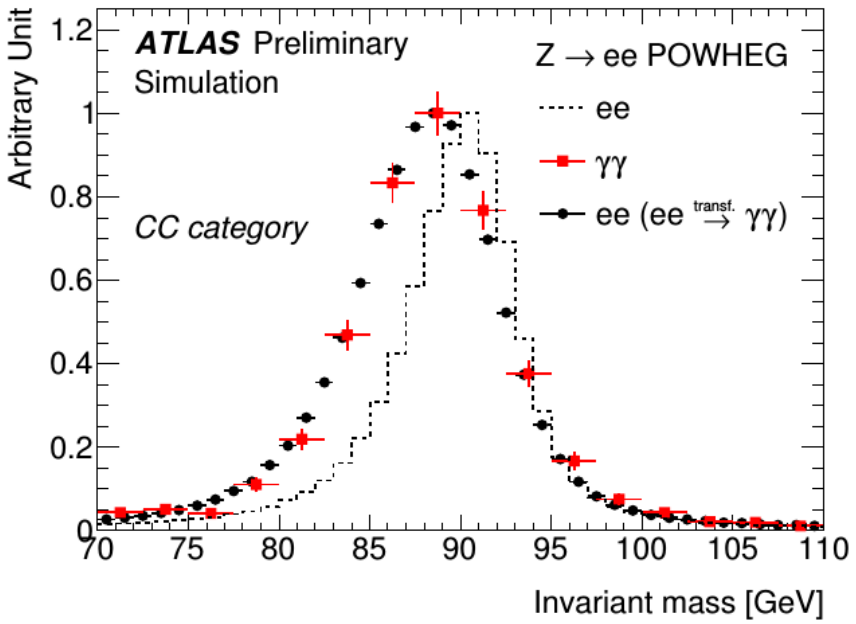
Signal Parametrization

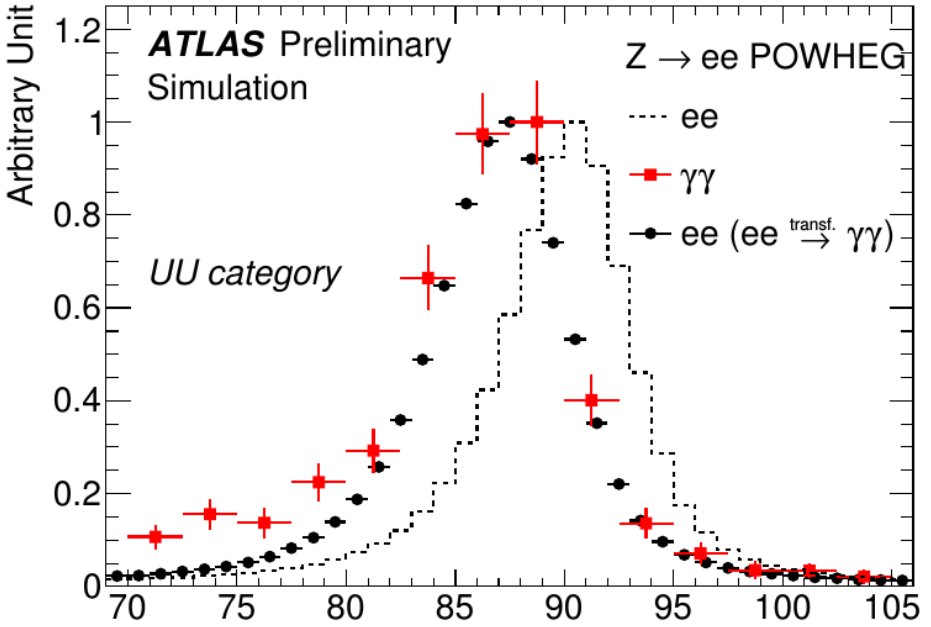


Drell-Yan Background

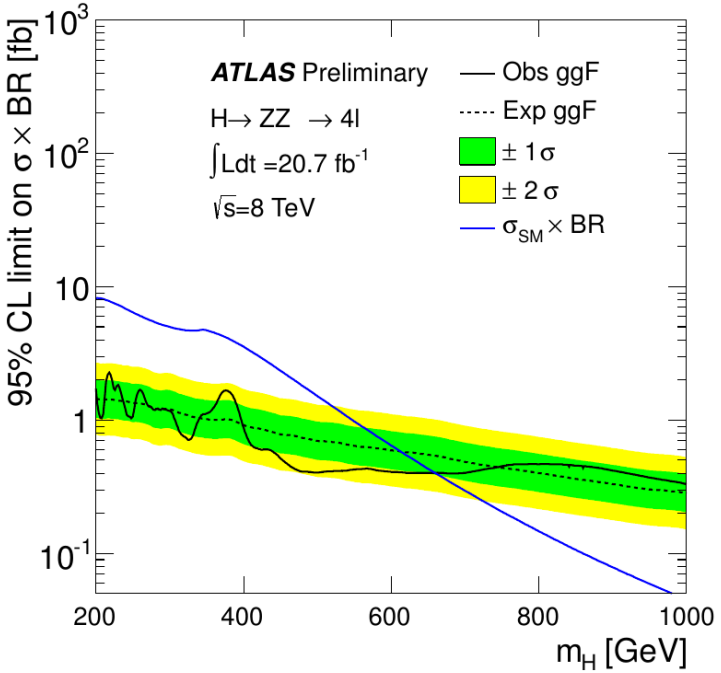


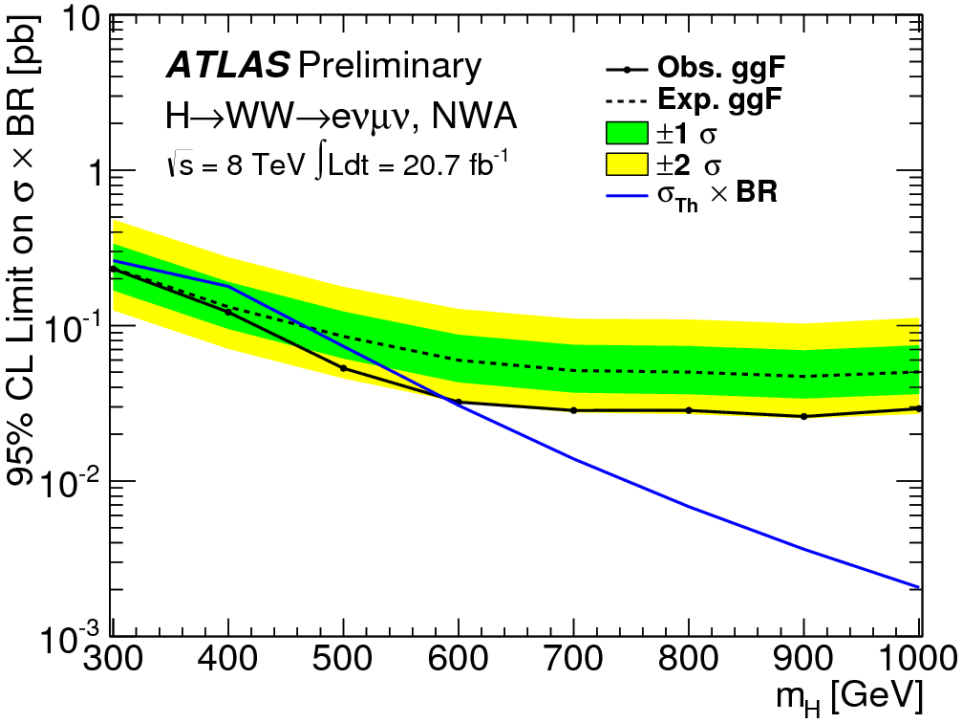
- Obtain γγ template from Z->ee by applying MC-driven transformation:
  - Shift and smear electron ET
  - Shift and smear electron Df(track, cluster)
- ~2 GeV shift in peak position, broader shape

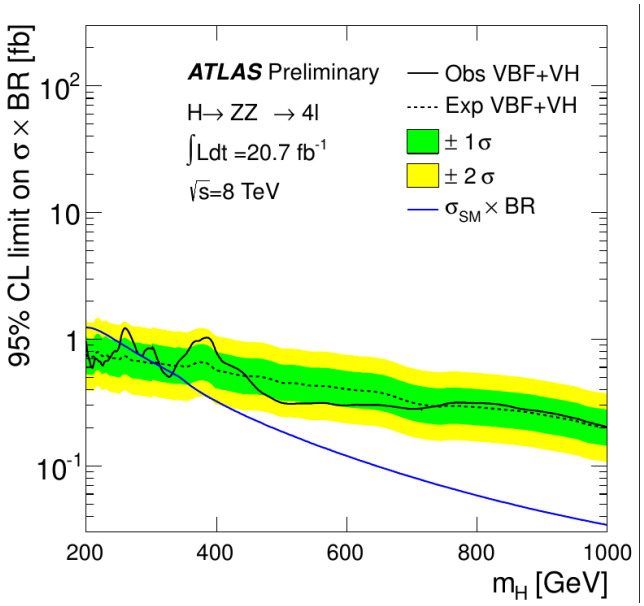


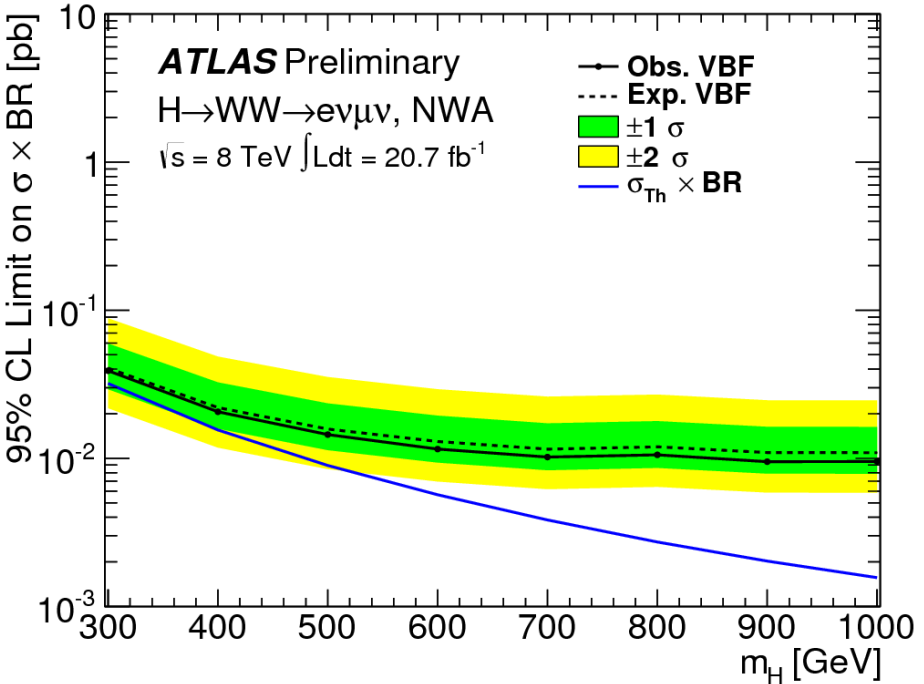


High-Mass Searches: WW, ZZ









CMS Extra γγ Resonance Search