High Mass Higgs to WW or ZZ

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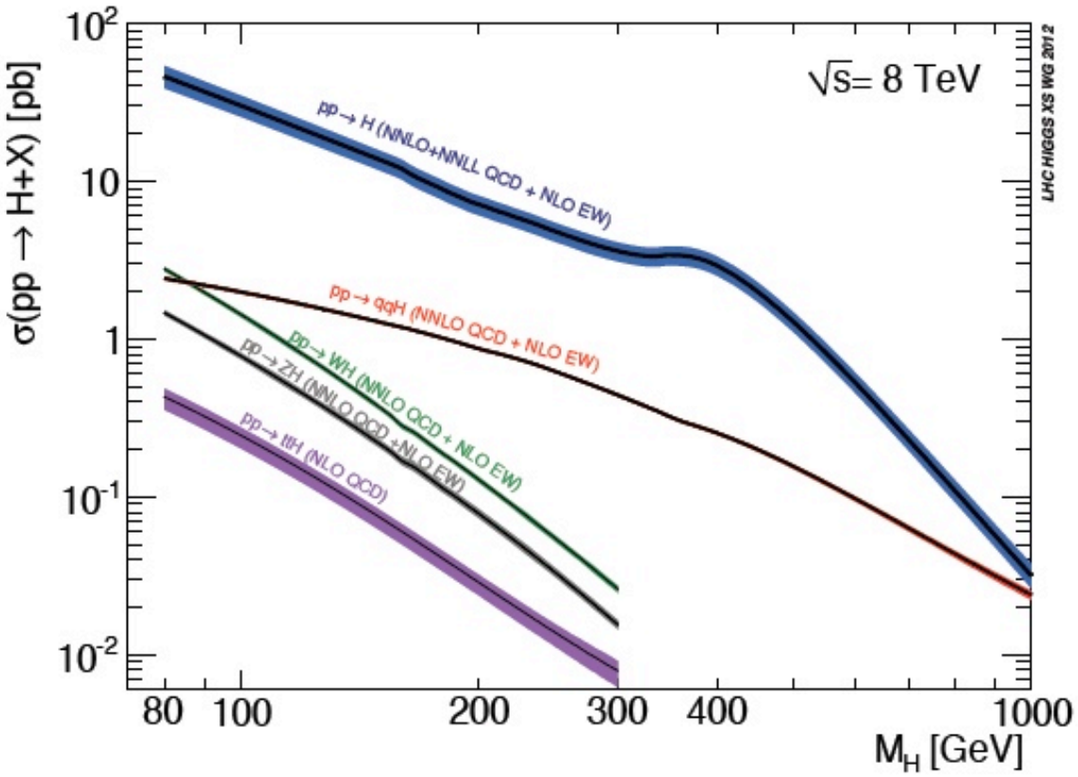
On behalf of ATLAS and CMS collaborations

Higgs Hunting 2013

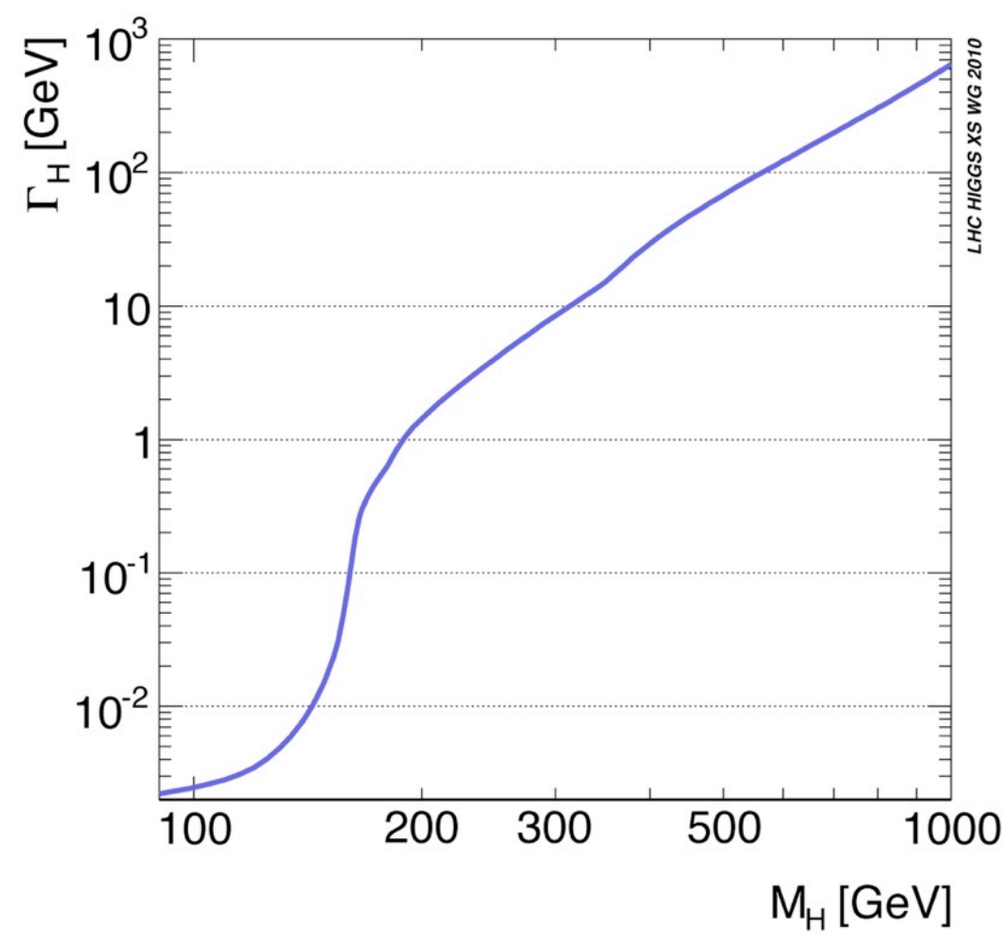
Introduction

- A light Higgs boson of mass around 126 GeV discovered in 2012
- Compulsory to complete search for SM-like heavy Higgs boson
  - Legacy results for SM Higgs exclusion up to 1TeV; to conclude the SM chapter
- BSM scenarios predict existence of additional resonance at high mass, with couplings similar to SM Higgs
  - Re-interpretation of high mass search in light of h(126) discovery
- Most recent results from ATLAS and CMS reported here
  - Up to 5 fb^{-1} @ 7 TeV and 20 fb^{-1} @ 8 TeV

Differences from low mass search



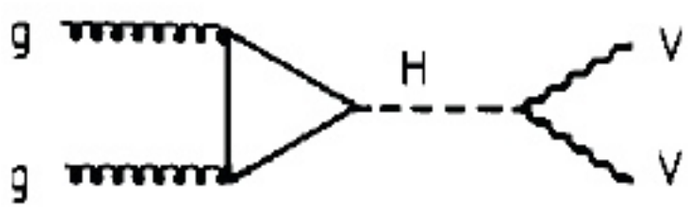
- SM Higgs predominantly decays into WW or ZZ in high mass region
  - Cross section decreases with m_H; high BR channels favored in high mass search
- VBF cross section becomes comparable with ggF



- Large SM Higgs width
  - Narrow width approximation breaks down; Higgs lineshape is corrected to match results from complex-pole scheme approach
  - Interference between signal and continuum background is large

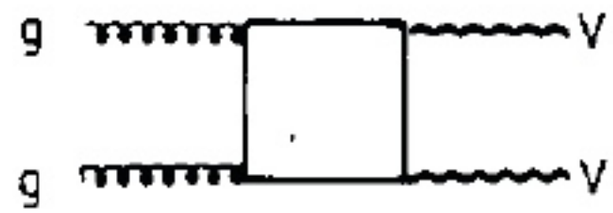
Interference

Signal

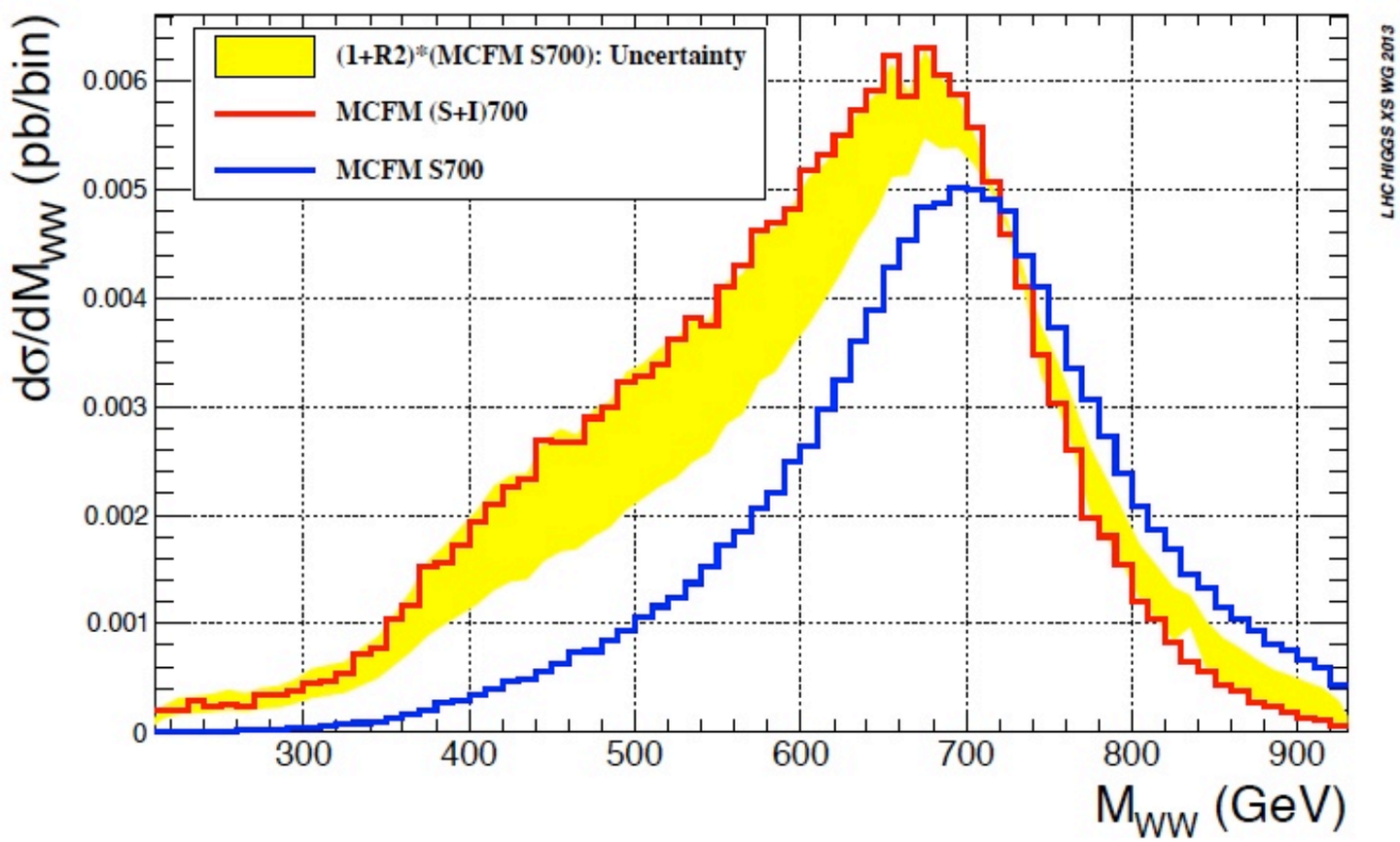


interferes with

Background



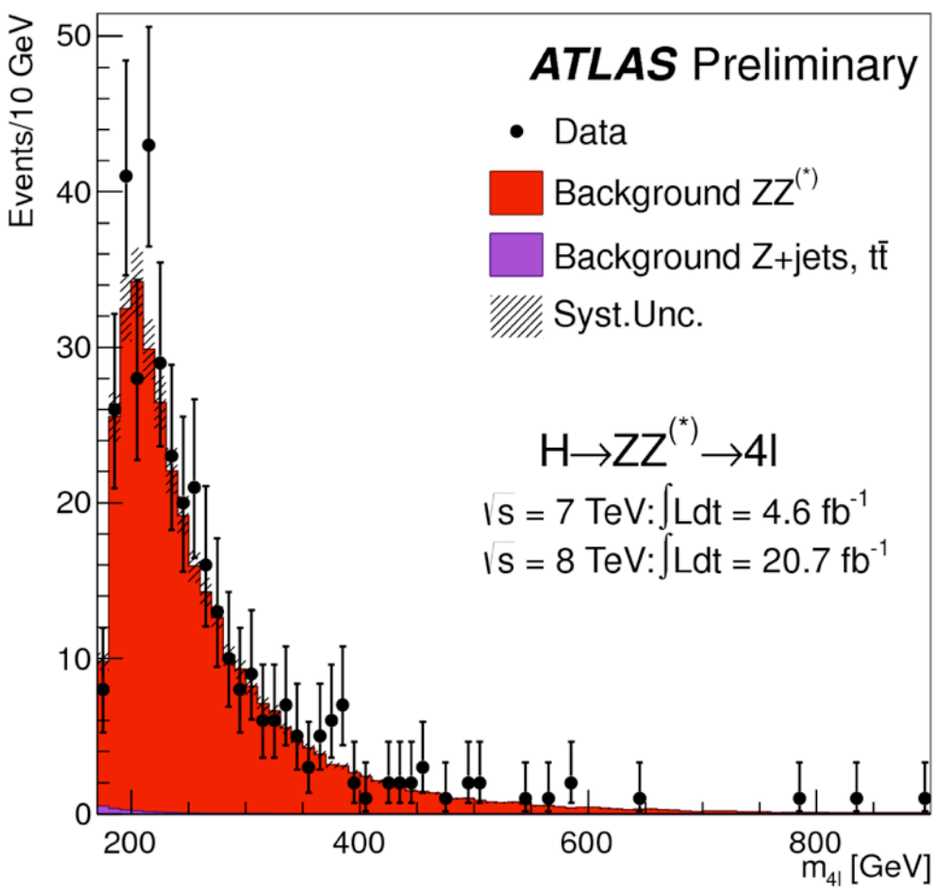
Estimated using MC which include interference (MCFM, gg2VV, aMC@NLO);
Effects to both total cross sections and distributions

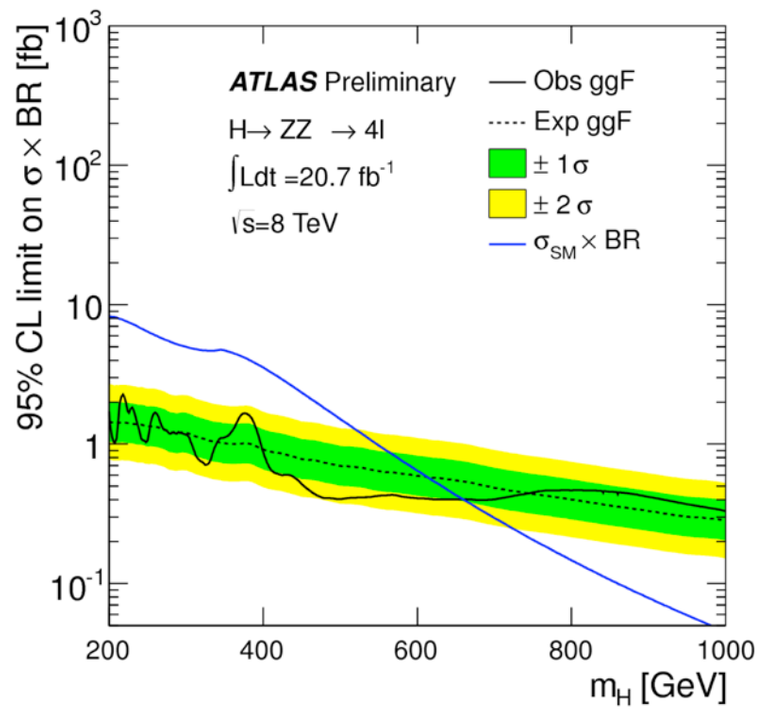


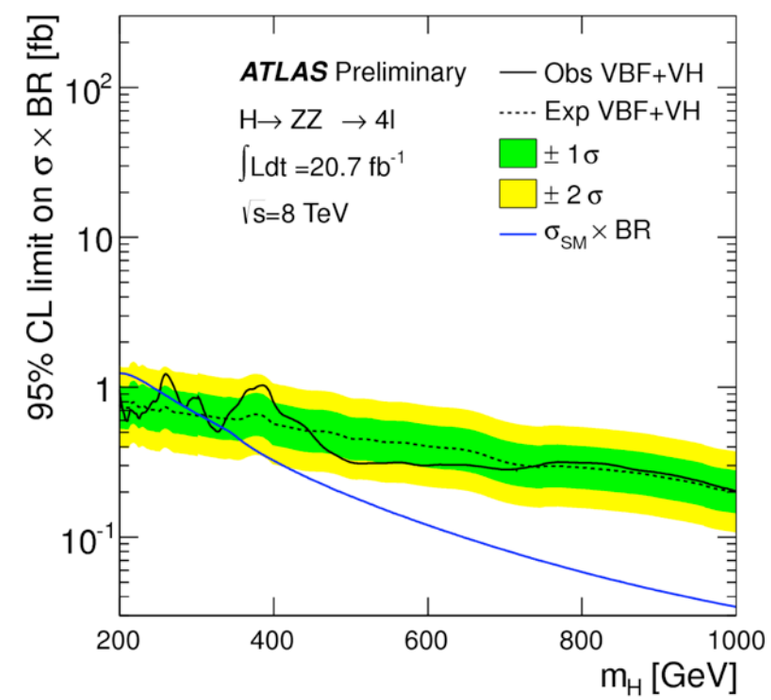
H->ZZ->2l2l'

Fully reconstructed mass with excellent resolution;
Clean signature, good sensitivity over wide mass range;
Limited by statistics at high mass

ATLAS-CONF-2013-013
4.6+20.7fb^{-1}

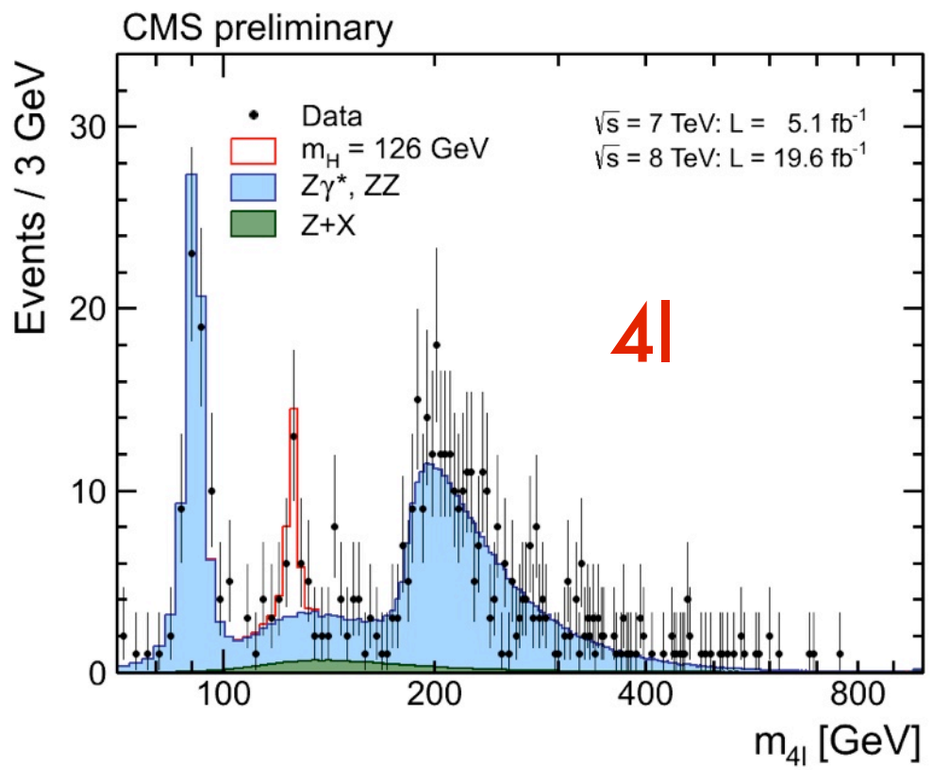


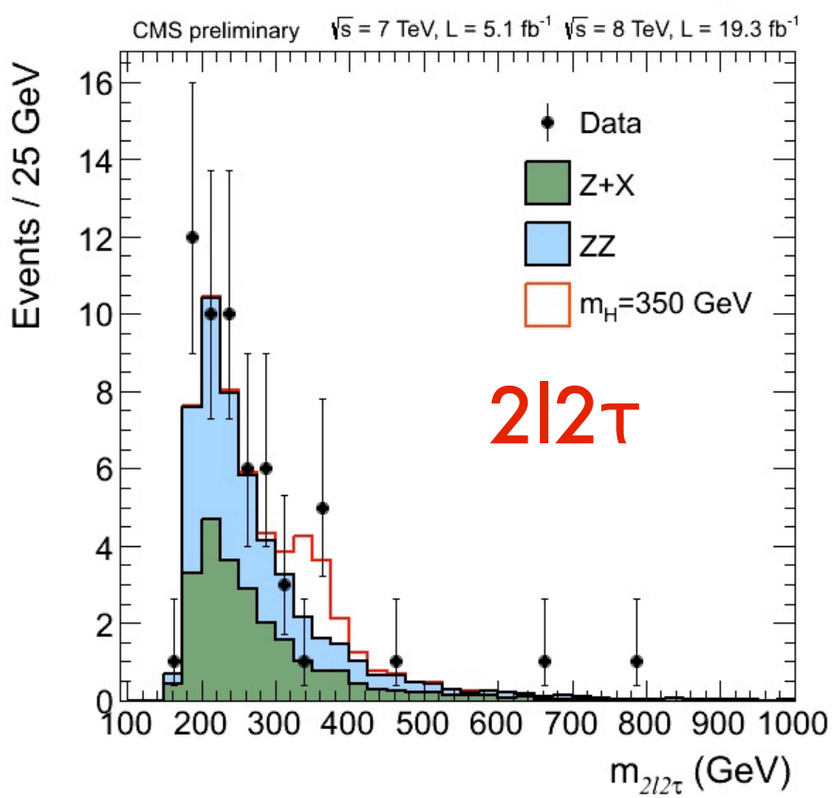




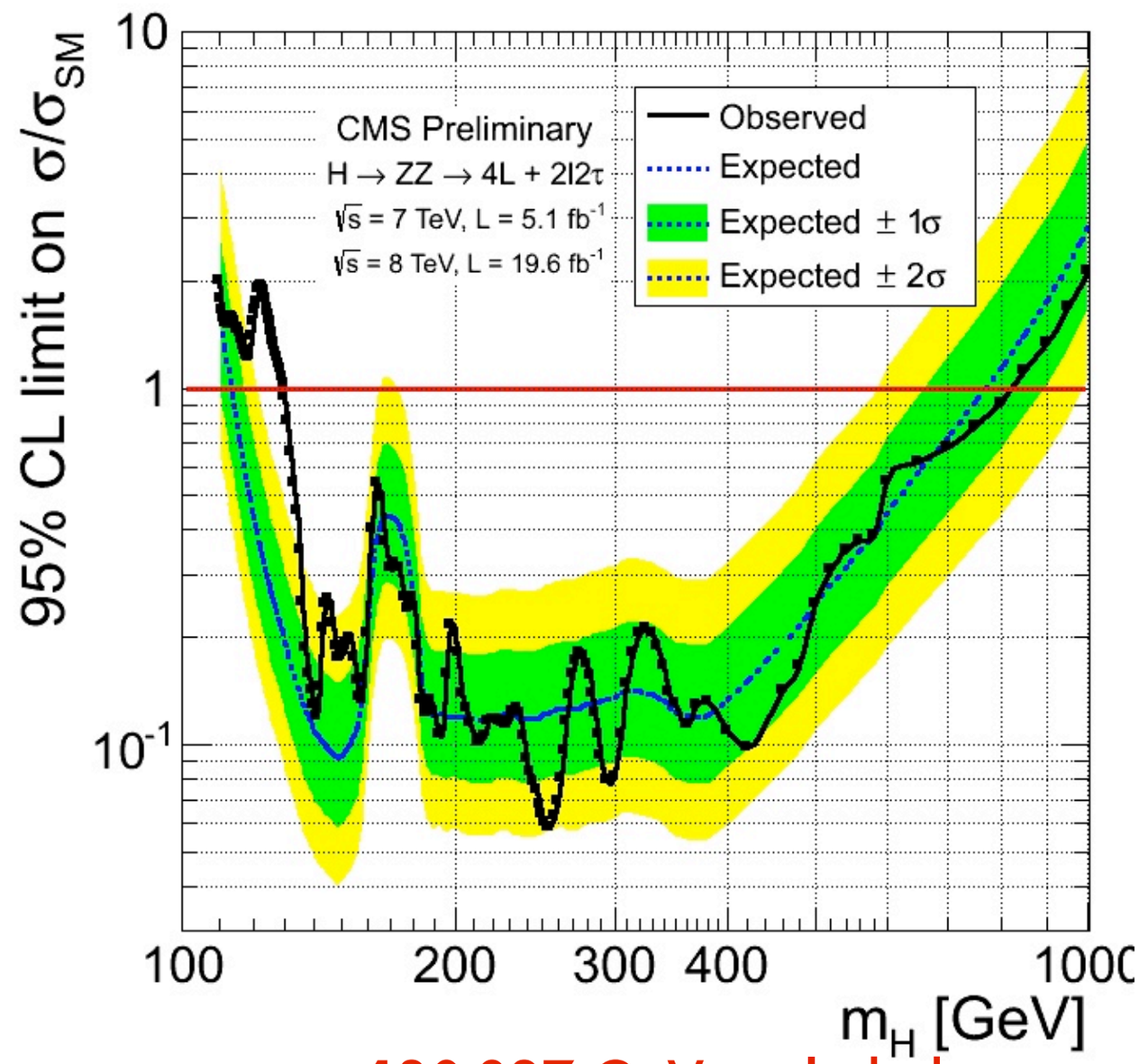
Limits on cross section times branching ratio for ggF and VBF+VH production separately

H->ZZ->2l2l′





CMS-PAS-HIG-13-002
(5.1+19.6fb⁻¹)

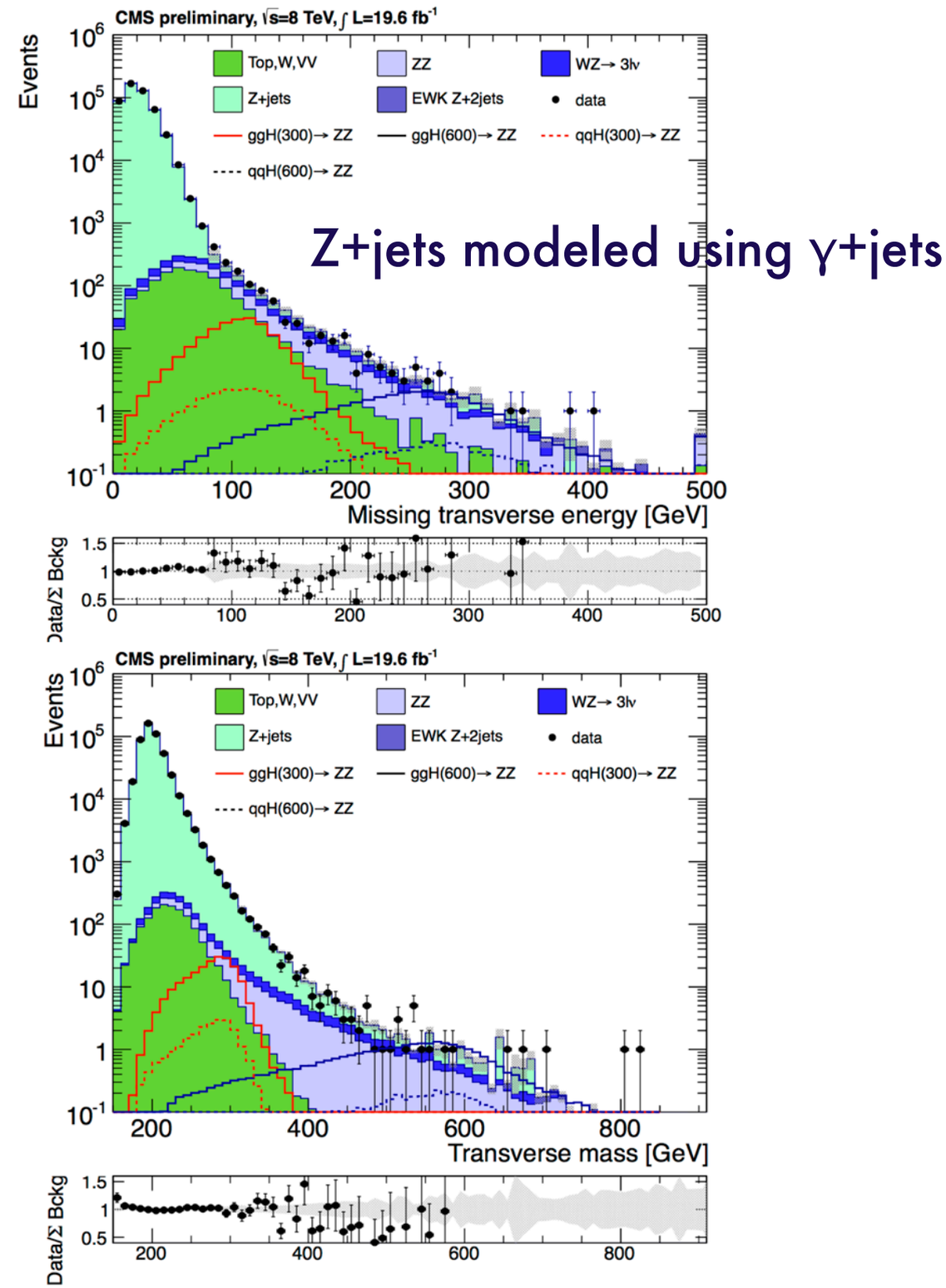


130-827 GeV excluded
(including 2l2τ)

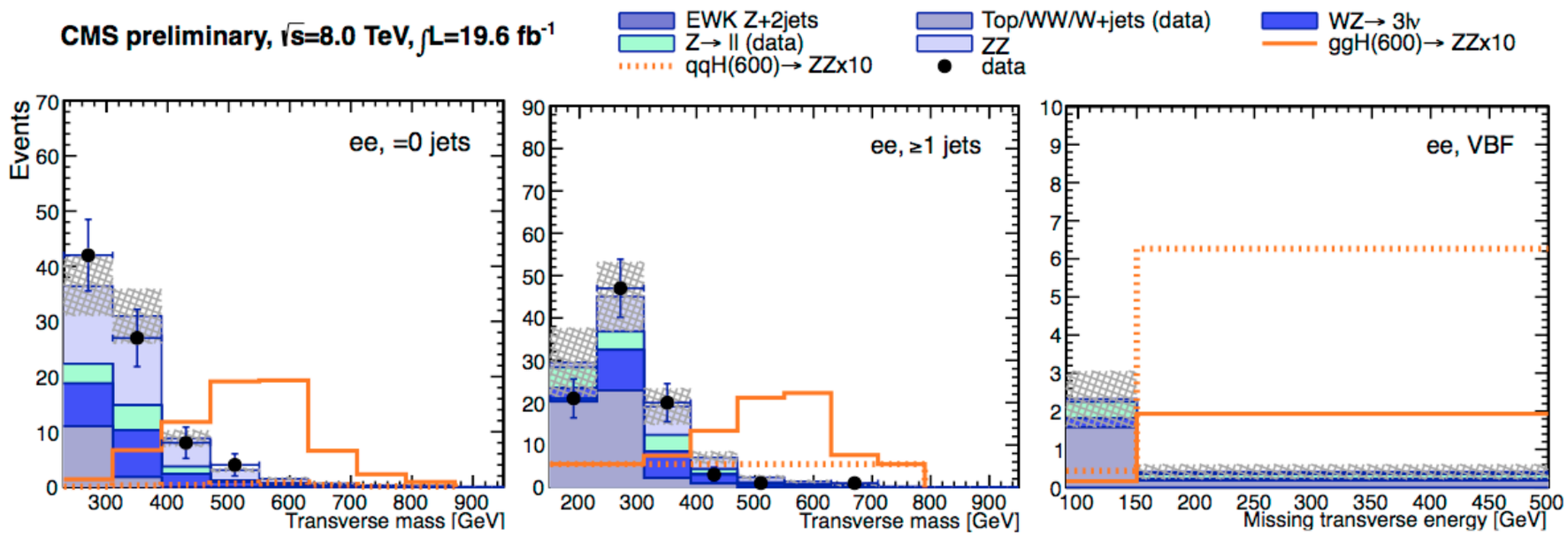
H->ZZ->2l2ν

CMS-PAS-HIG-13-014
(5.0+19.6fb^{-1})

- Competitive branching fraction
- Required a pair of isolated e or μ (p_T>20 GeV) from Z boson decay + large E_T^{miss}; no mass peak
- Challenge: Z+jets background - fake E_T^{miss} from jet mis-measurement
- Event categories: VBF, ggF(0jet, ≥1jet)
  - Optimized separately for VBF and ggF
  - m_H dependent E_T^{miss} cut in ggF category



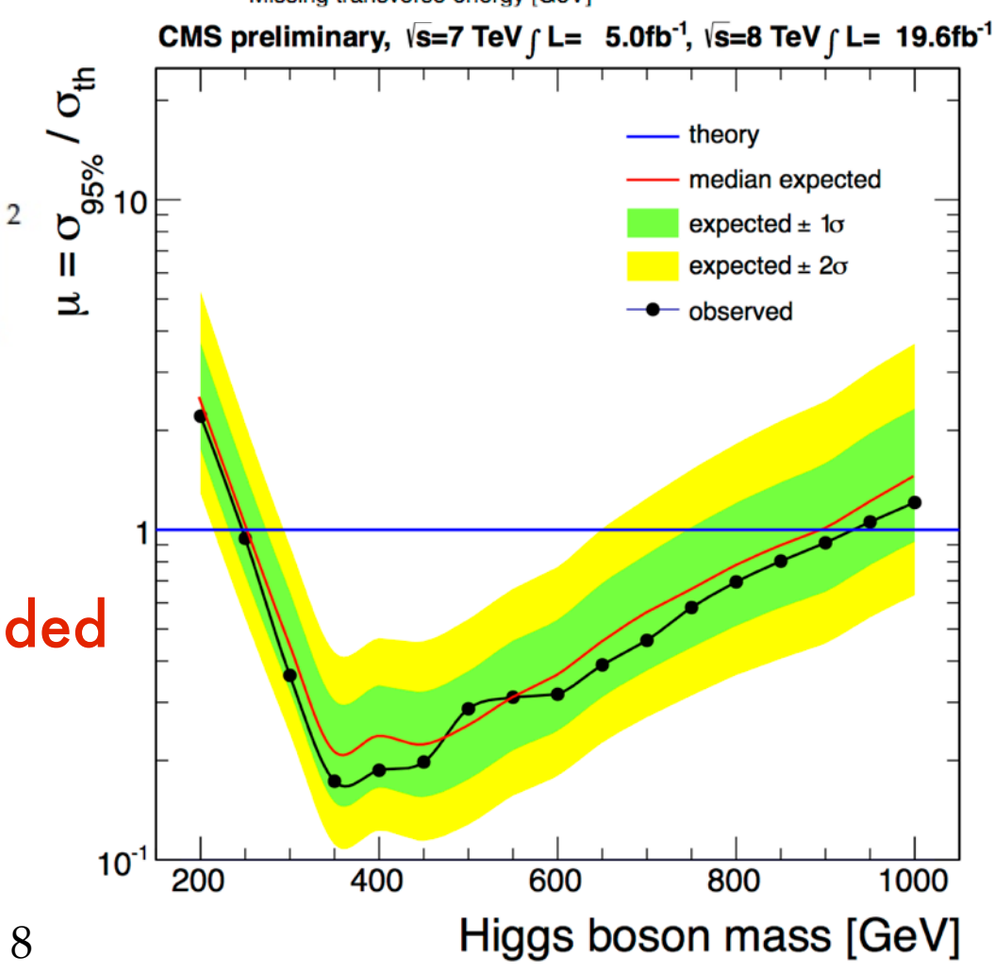
H->ZZ->2l2ν



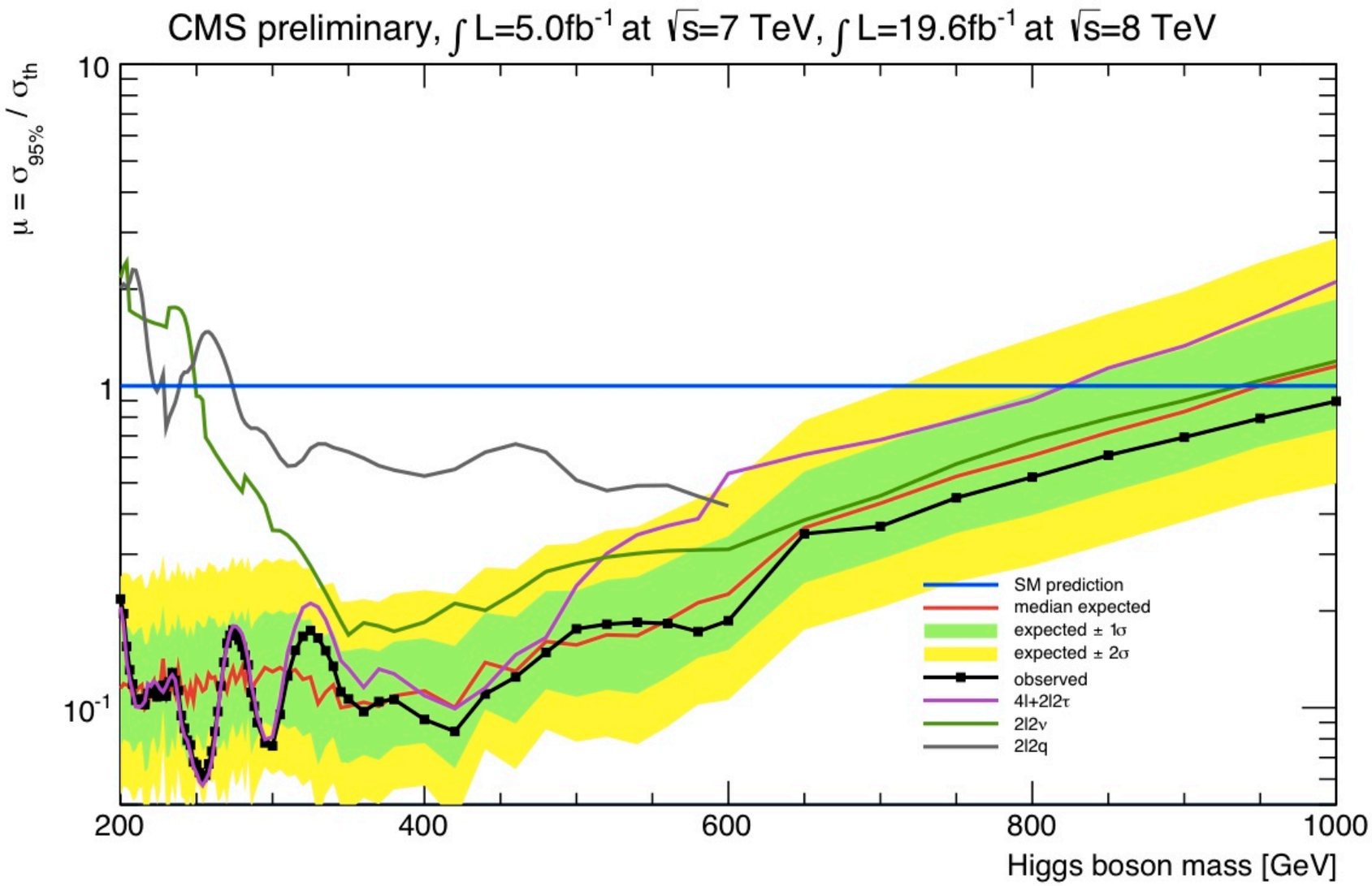
Shape based: M_T(ggF), E_T^{miss}(VBF)

$$M_T^2 = \left[\sqrt{p_T(\ell\ell)^2 + M(\ell\ell)^2} + \sqrt{E_T^{miss\,2} + M(\ell\ell)^2}\right]^2 - \left[\vec{p}_T(\ell\ell) + \vec{E}_T^{miss}\right]^2$$

248-930 GeV excluded



CMS H->ZZ combination



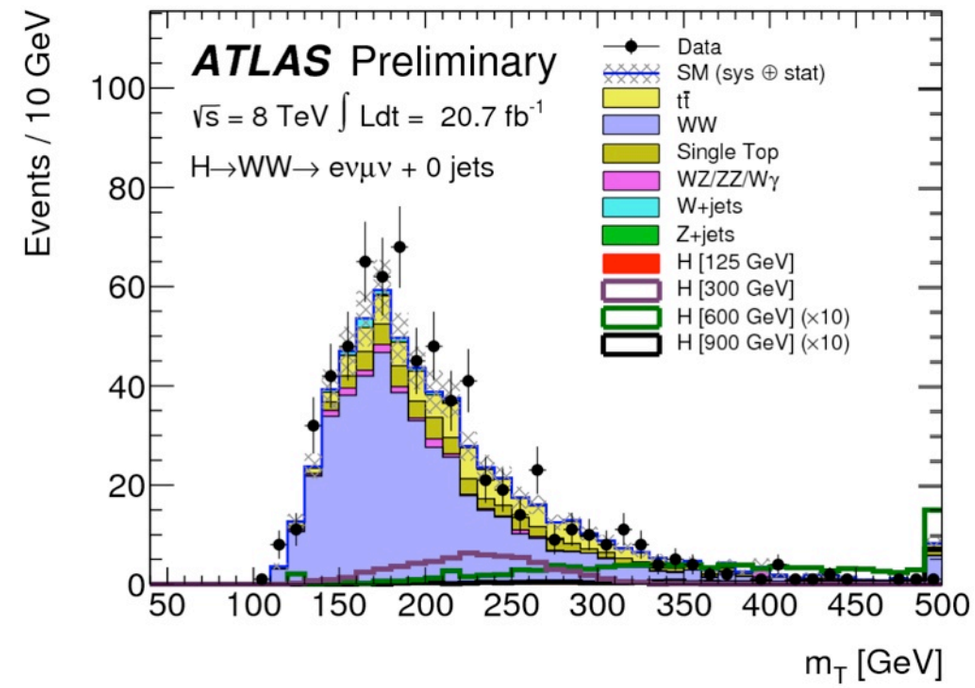
Combination of H->ZZ->2l2l'(4l+2l2τ), H->ZZ->2l2v and H->ZZ->2l2q
(Observed limits for individual channels superimposed)

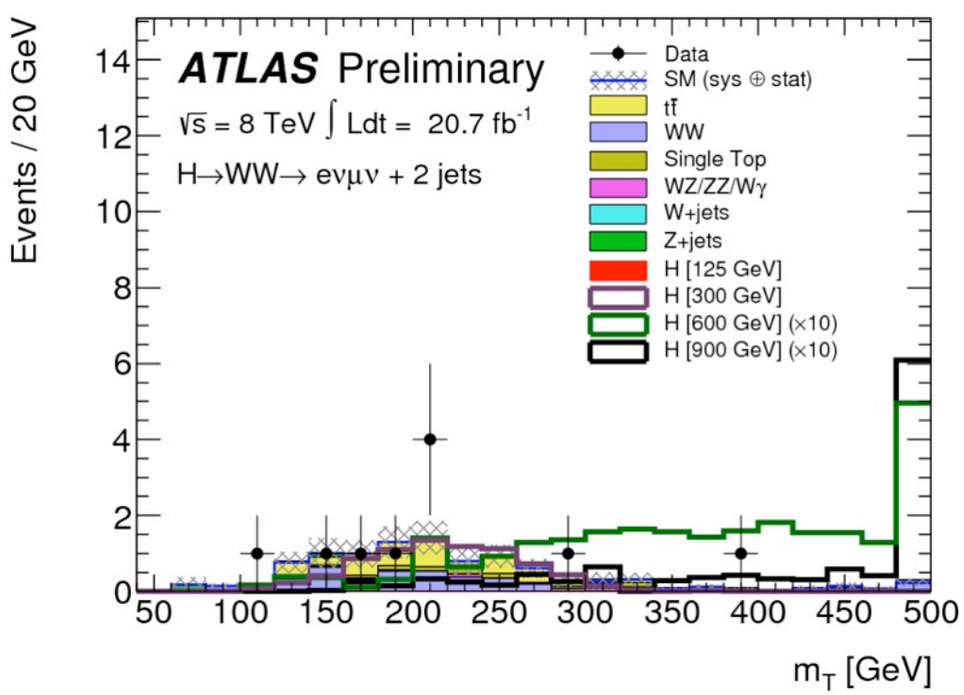
2l2l' is the most sensitive at below 500 GeV;
2l2nu dominates at above 500 GeV

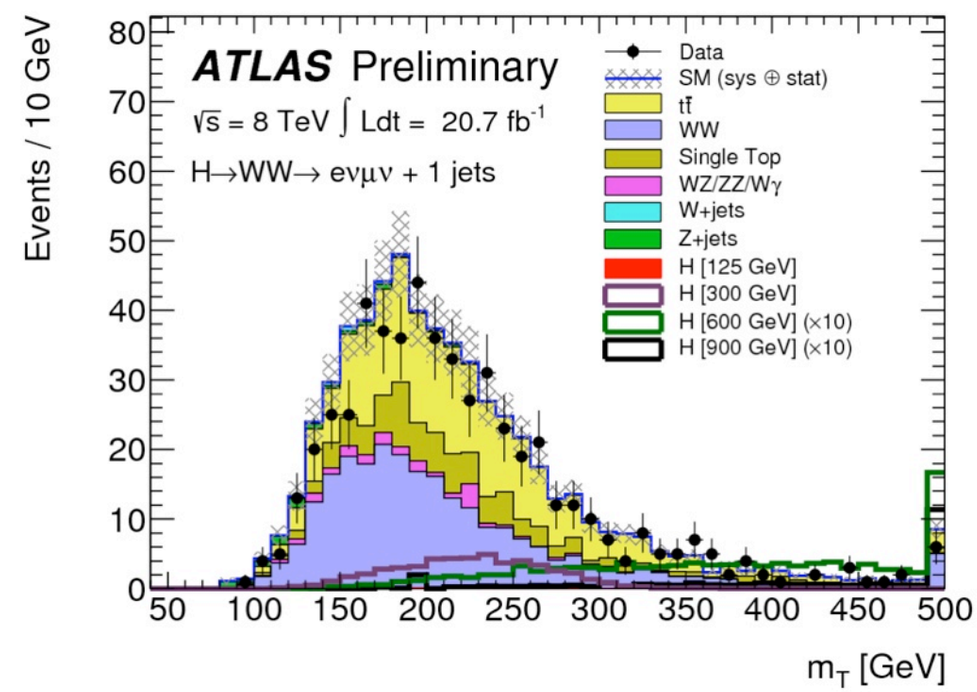
H->WW->lvl'v'

ATLAS-CONF-2013-067
(20.7fb^{-1})

- Two isolated, opposite charged leptons (p_T>40 GeV) and E_T^{miss} ; no mass peak
- Only different lepton-flavor (eνμν) used
- Event categories: 0jet, 1jet, ≥2jet(VBF)
- Top and WW backgrounds normalized to data control regions
- M_T is used as the discriminating variable





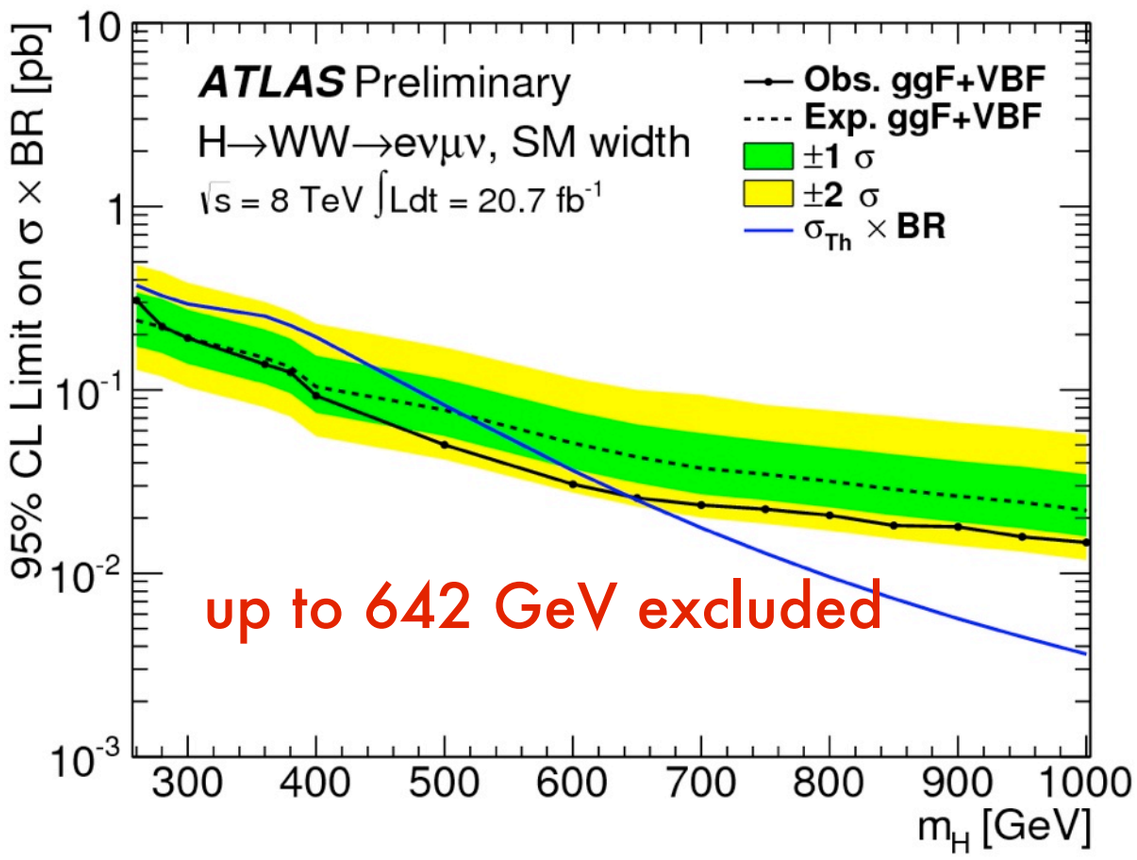


$$m_T = ((E_T^{\ell\ell} + E_T^{miss})^2 - |\mathbf{p}_T^{\ell\ell} + \mathbf{E}_T^{miss}|^2)^{1/2} \text{ with } E_T^{\ell\ell} = (|\mathbf{p}_T^{\ell\ell}|^2 + m_{\ell\ell}^2)^{1/2}$$

H->WW->lvl'v'

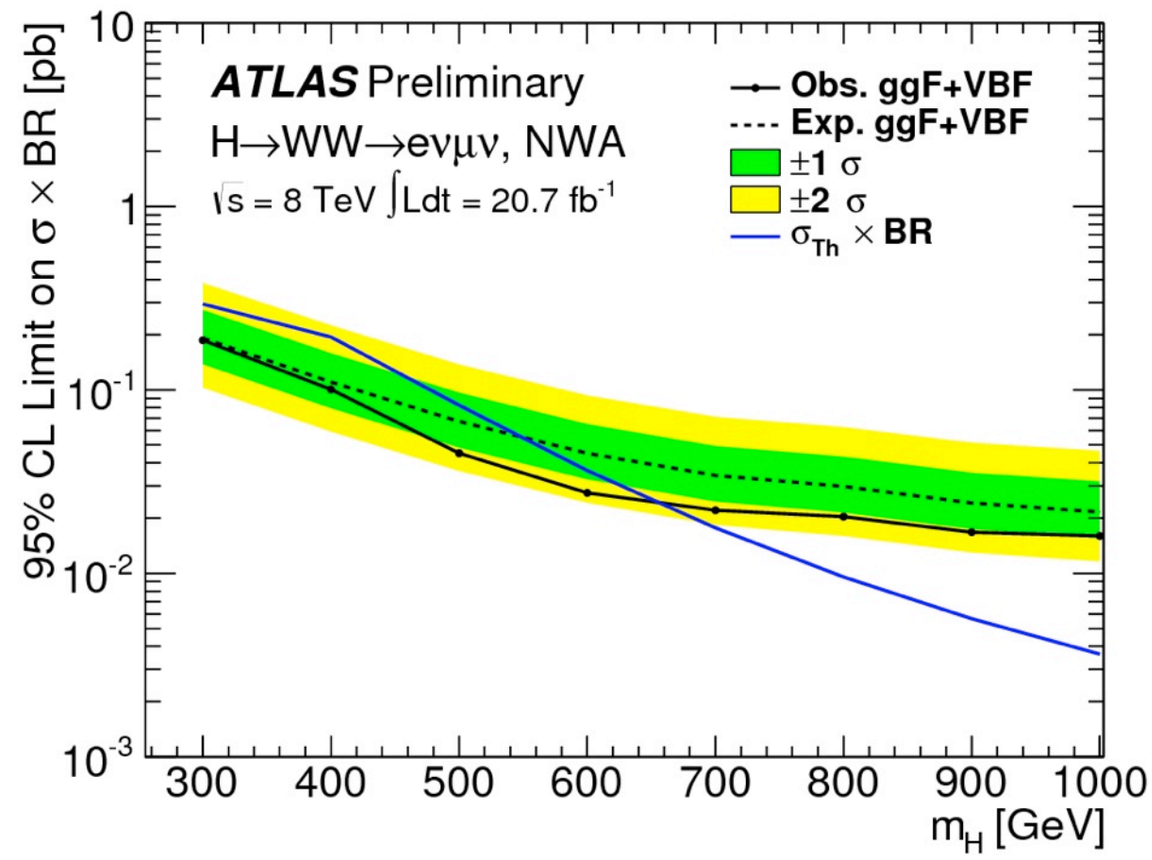
Analysis performed using two different assumptions on Higgs width:

SM Higgs width and lineshape



Fixed 1GeV wide BW lineshape

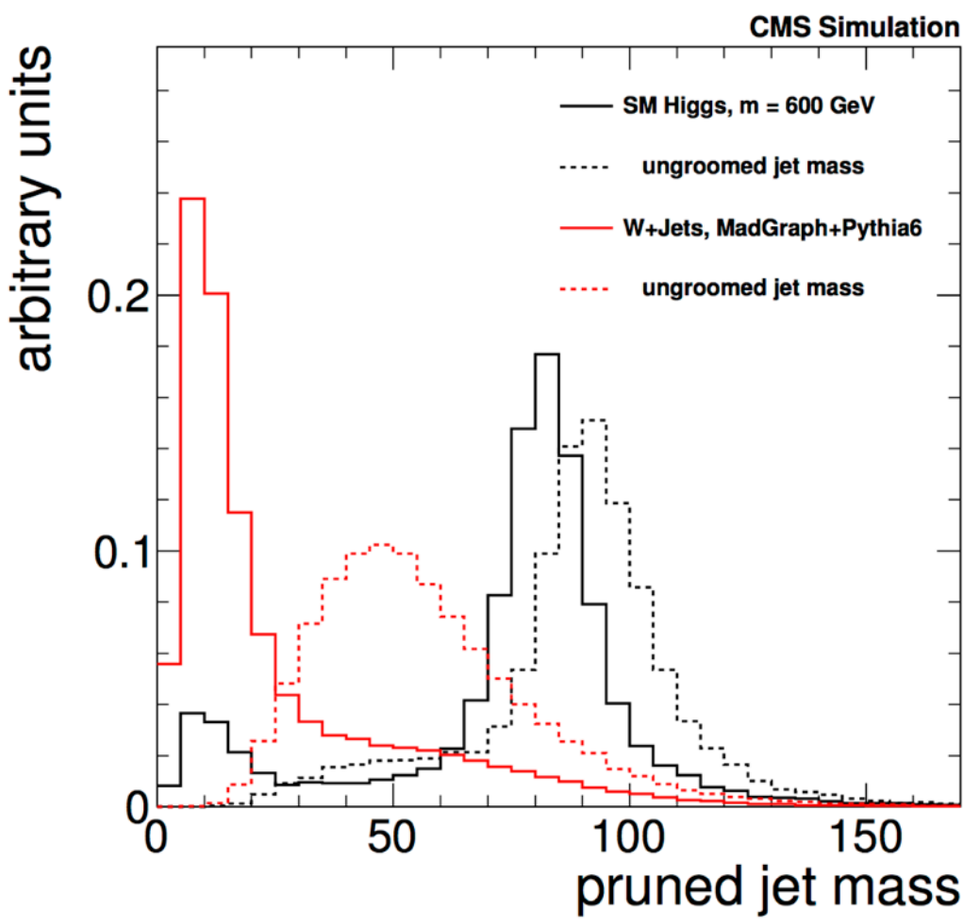
Motivated by h(126) mixing with EW singlet model



Lineshape	Production mode	$\sigma \cdot \mathcal{B}$ (fb)		
		m_H = 300 GeV	m_H = 600 GeV	m_H = 1 TeV
SM-like	ggF	250	34	19
	VBF	40	16	10
NWA	ggF	230	32	29
	VBF	39	12	10

H->WW->lνqq'

- Analysis performed for mass range [600-1000] GeV; large branching ratio due to hadronic decay of W
- Single isolated μ(e) with p_T>30(35) GeV, large E_T^{miss}
- A jet containing the entire hadronic decay of W
  - W bosons are highly boosted (required p_T>200 GeV)
  - Jet substructure techniques are used in identifying the hadronic W

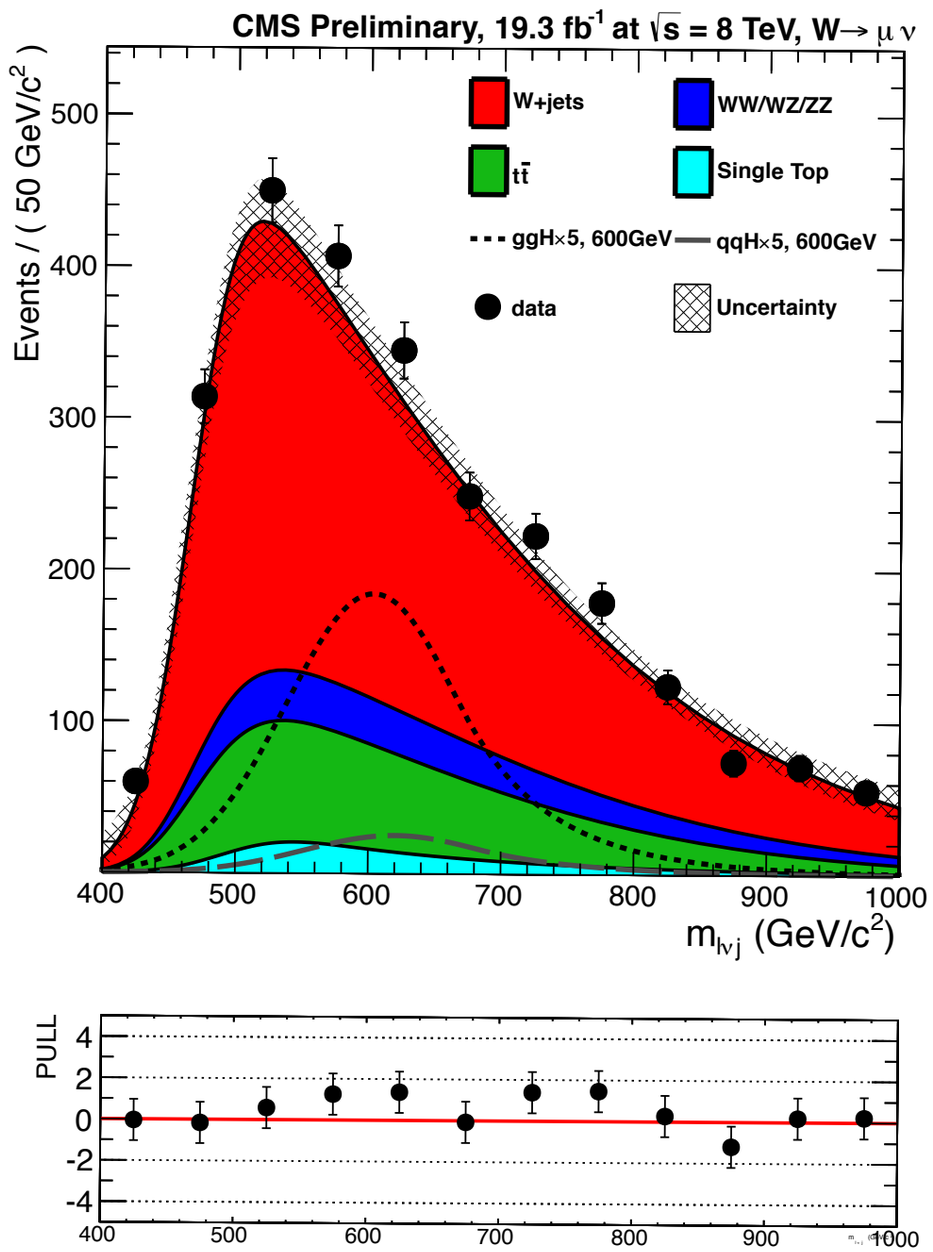


CMS-PAS-HIG-13-008
(19.3fb^{-1})

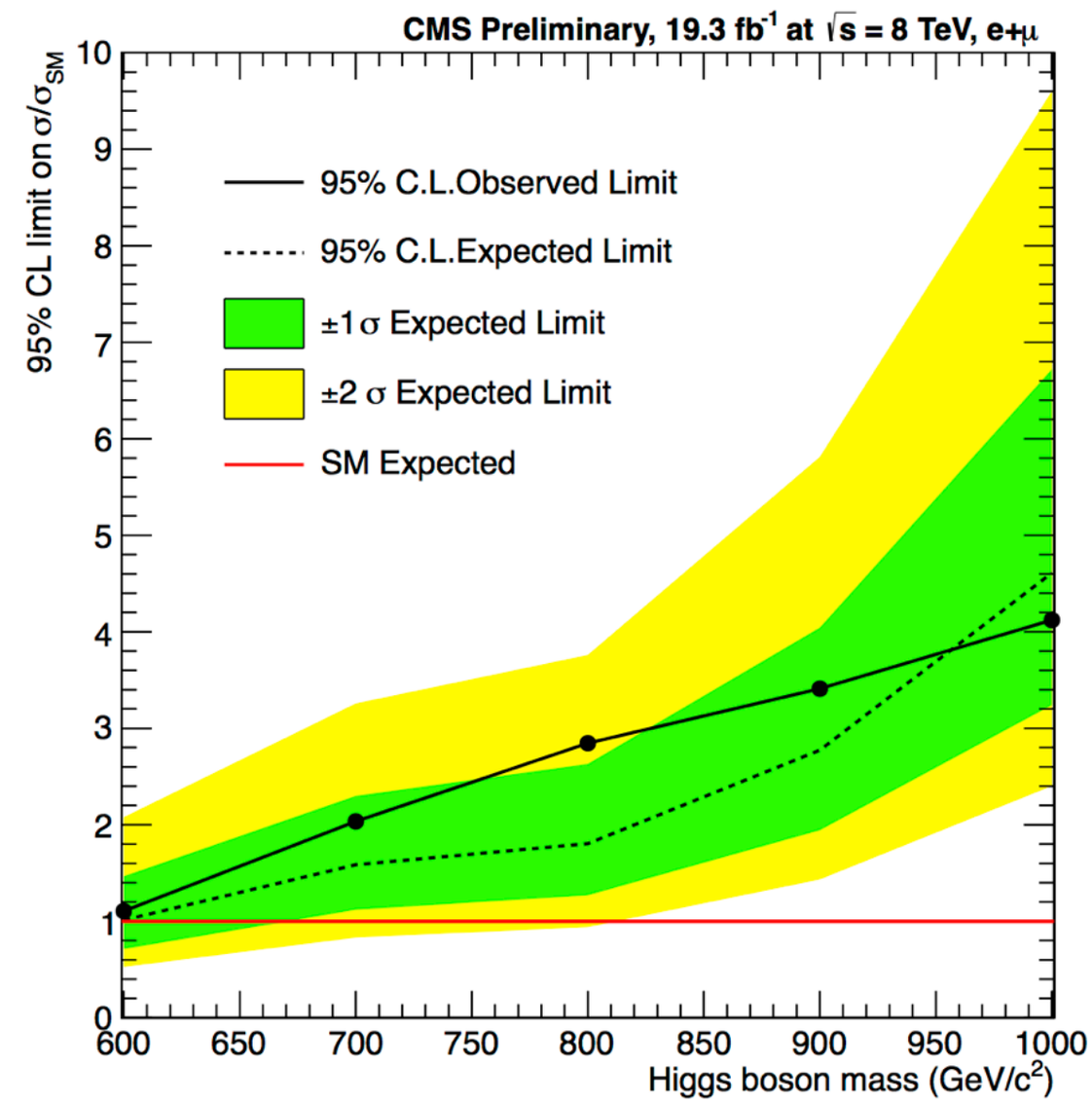
The highest p_T jet by Cambridge-Aachen clustering algorithm (R=0.8) selected as hadronic W.

Jet pruning algorithm improves separation between signal and background.

H->WW->lνqq′



M(lνJ) reconstructable



1.1(4.2) times SM for 600(1000)GeV

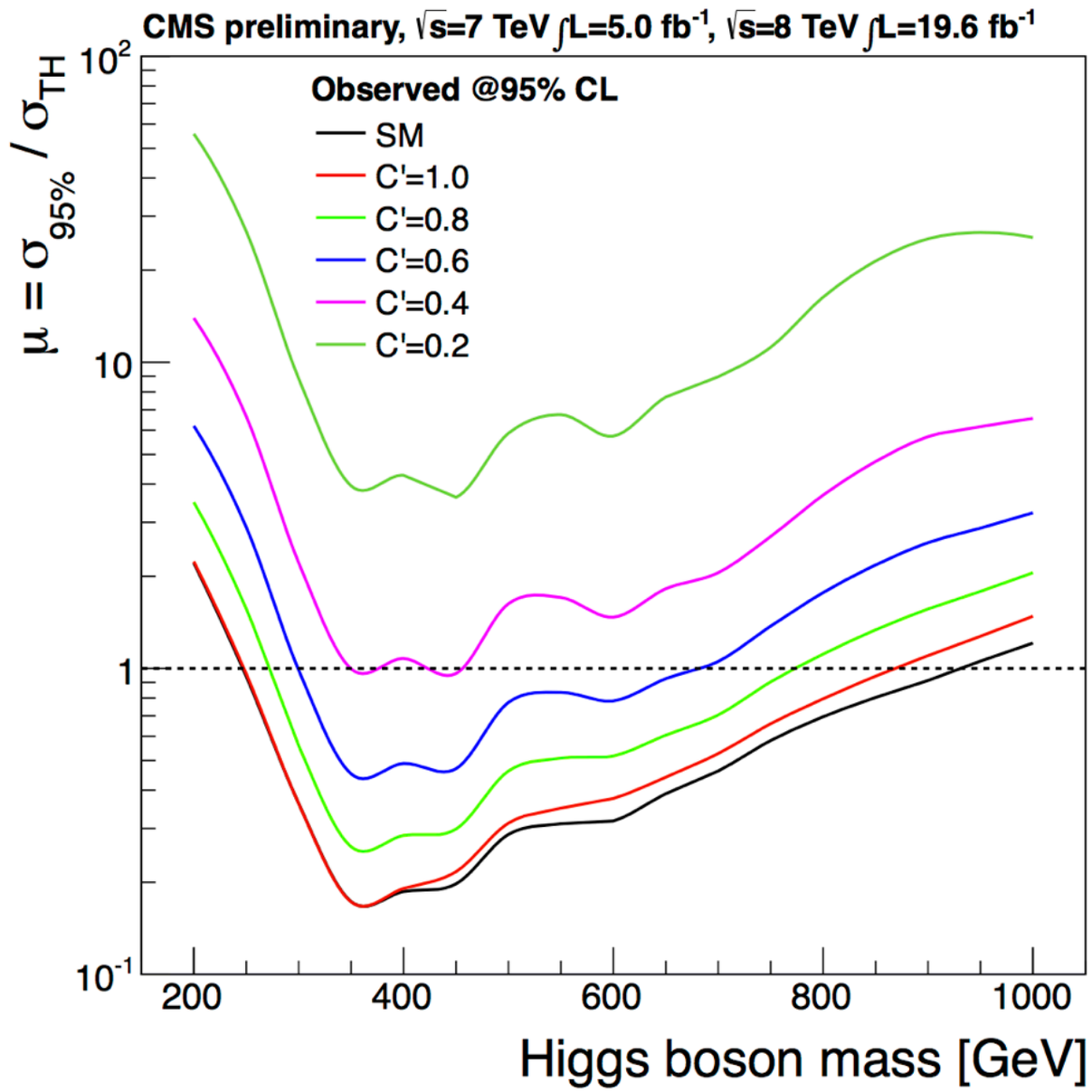
h(126) mixing with EW singlet

- Generic BSM benchmark to start with: minimal extension of SM
- A new, heavy Higgs boson mixes with h(126)
  - Reduction of the h(126) couplings wrt SM by C
  - Heavy Higgs couplings wrt SM: C'
  - Unitarity implies: $C^2+C'^2=1$
- The heavy Higgs may decay to new states: BR_{new} (e.g. H->hh)
- Signal strength and width of the heavy Higgs
  - $\mu'=C'^2(1-BR_{new})$; $\Gamma'=C'^2\Gamma_{SM}/(1-BR_{new})$
  - Current studies focus on the case $\Gamma'\leq\Gamma_{SM}$

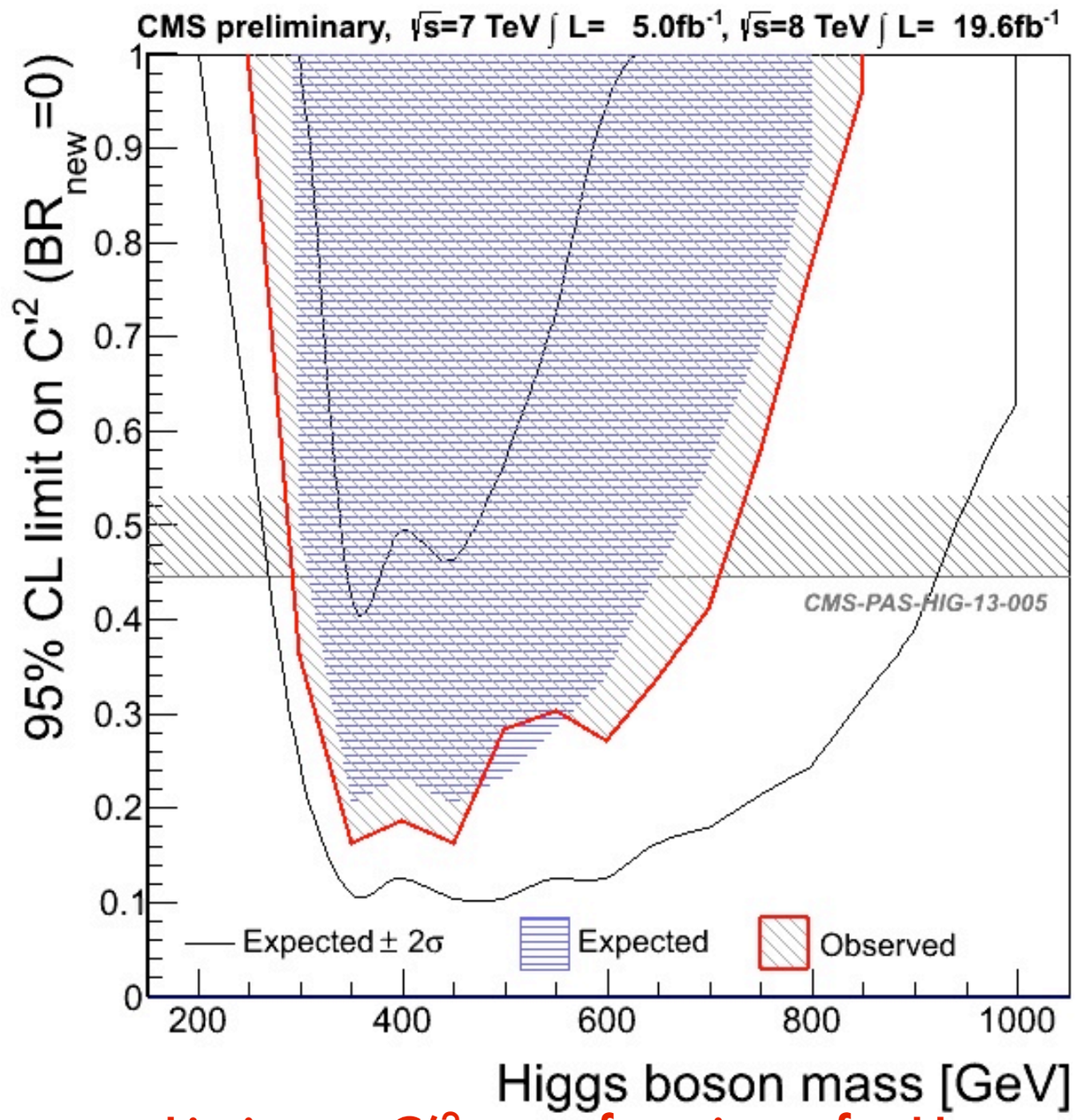
H->ZZ->2l2ν

Assumed $BR_{new}=0$

CMS-PAS-HIG-13-014
(5.0+19.6fb^{-1})



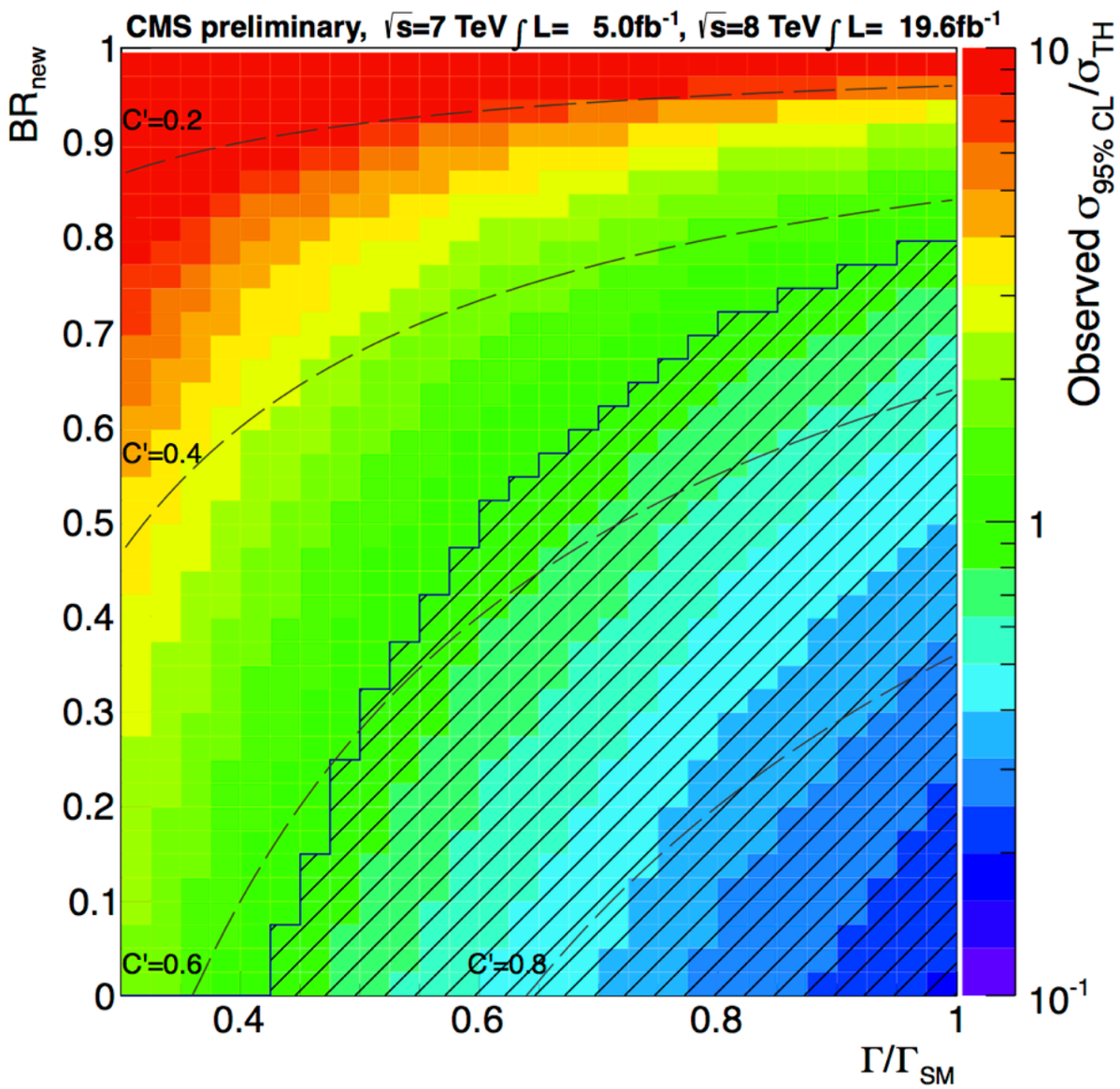
Limits on signal strength for various values of C′ as a function of mH

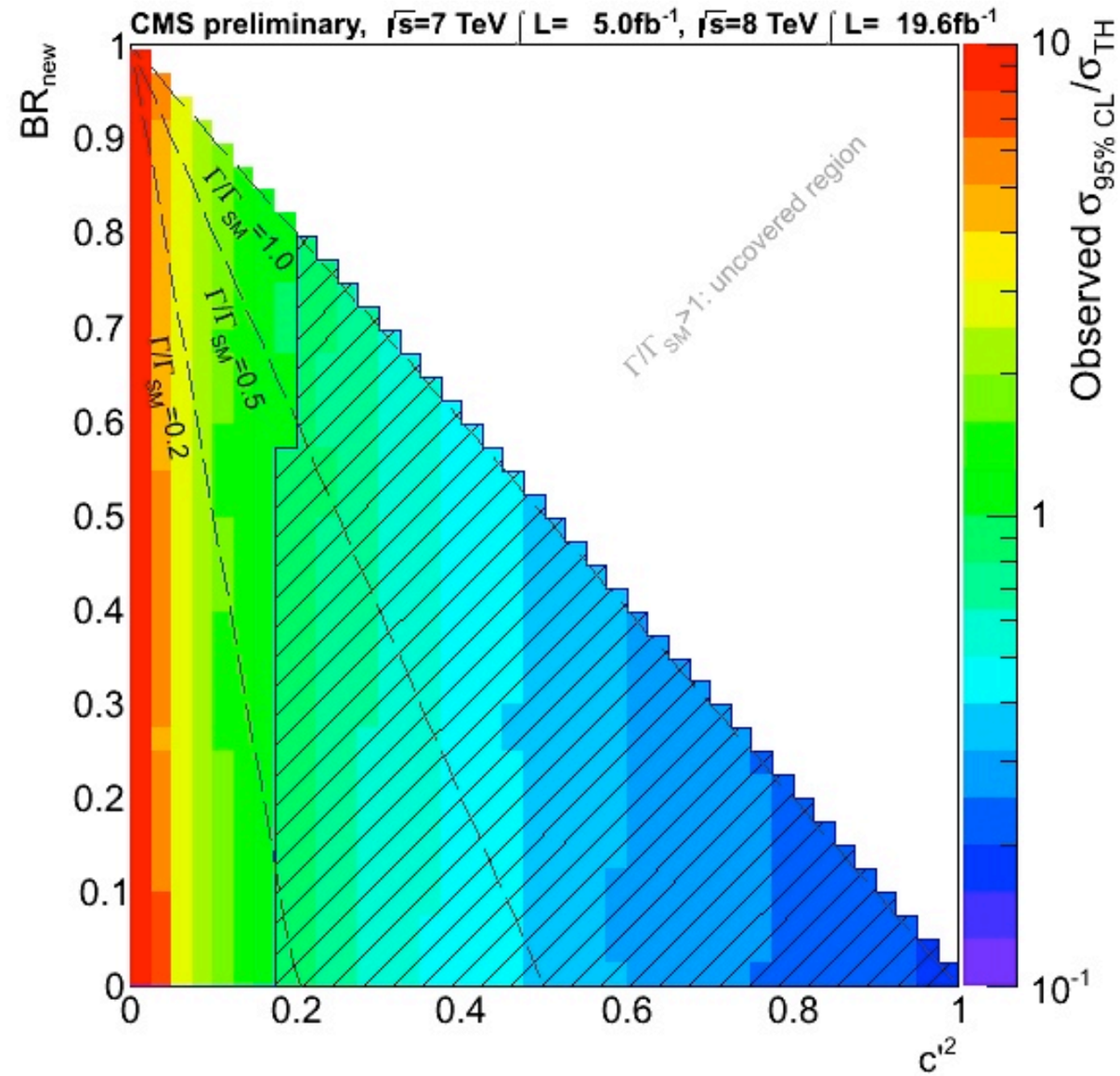


Limits on C'^2 as a function of mH

H->ZZ->2l2ν

mH=400GeV

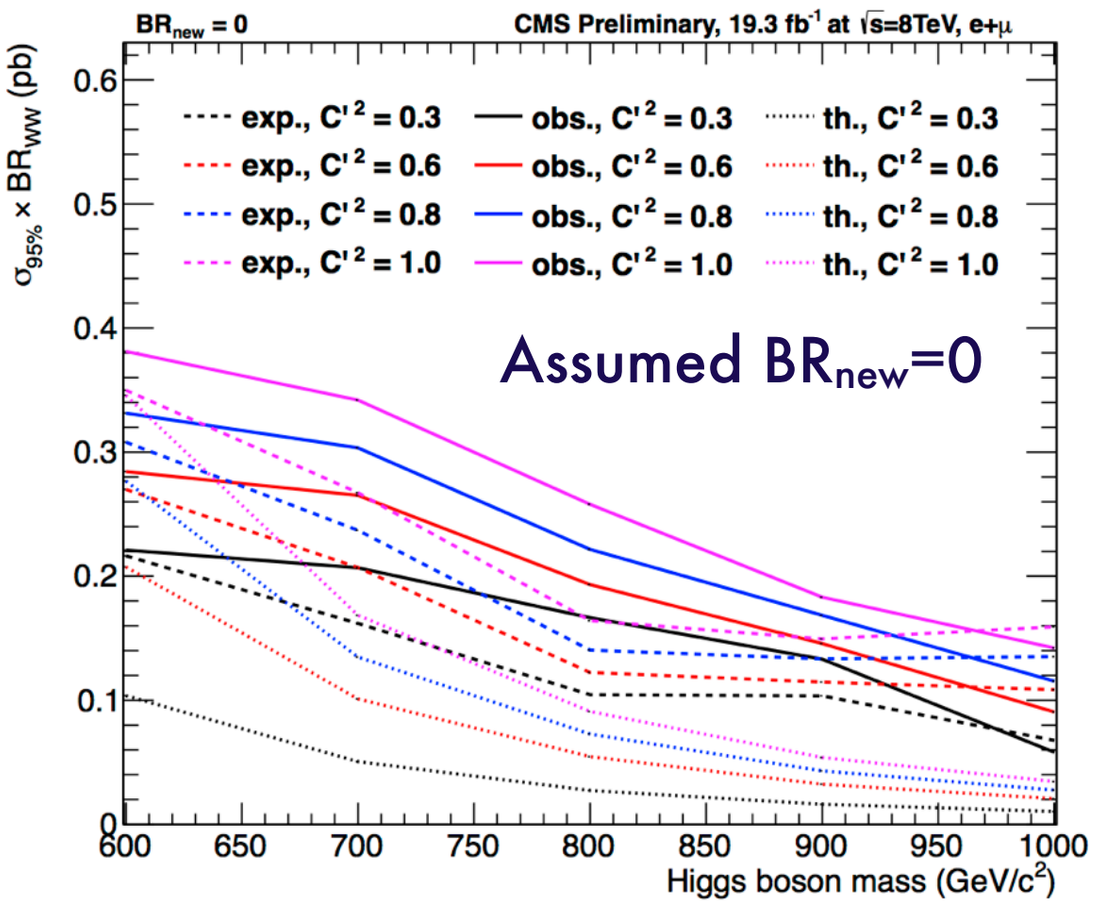


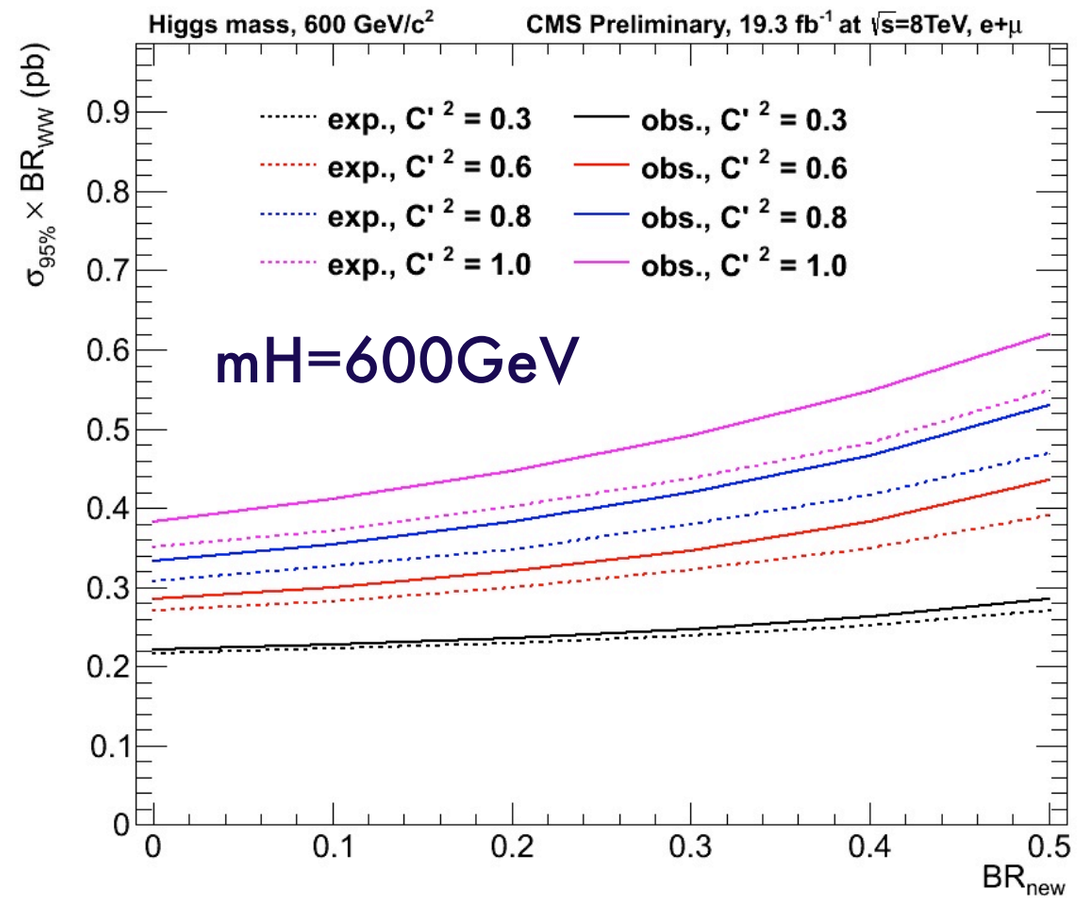


Limits on signal strength as a function of width vs BR_{new} (left) or C'^2 vs BR_{new} (right)

H->WW->lvqq'

CMS-PAS-HIG-13-008
(19.3fb^{-1})





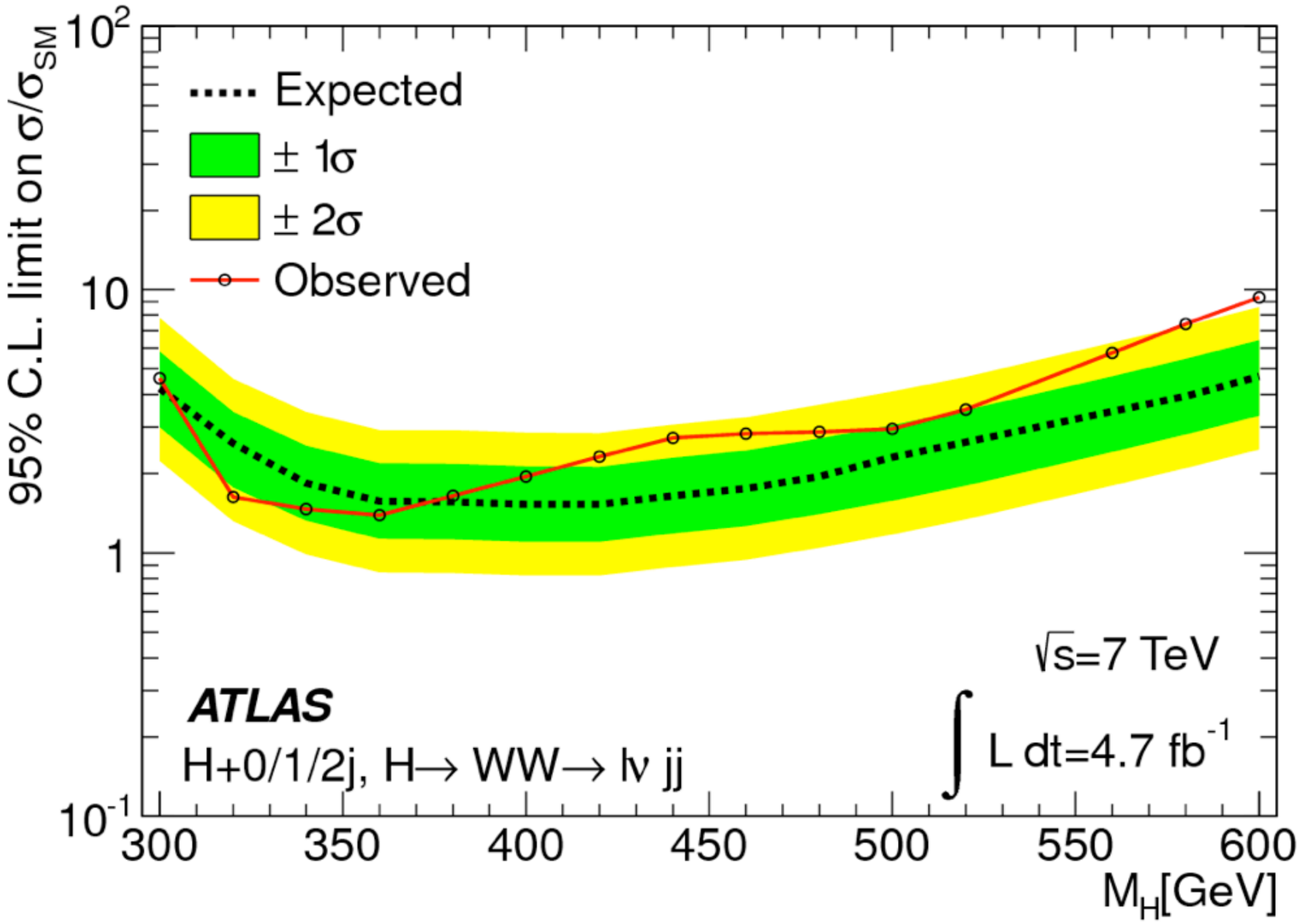
Limits on cross sections for various values of C'^{2} as a function of mH (left) or BR$_{new}$ (right)

Summary

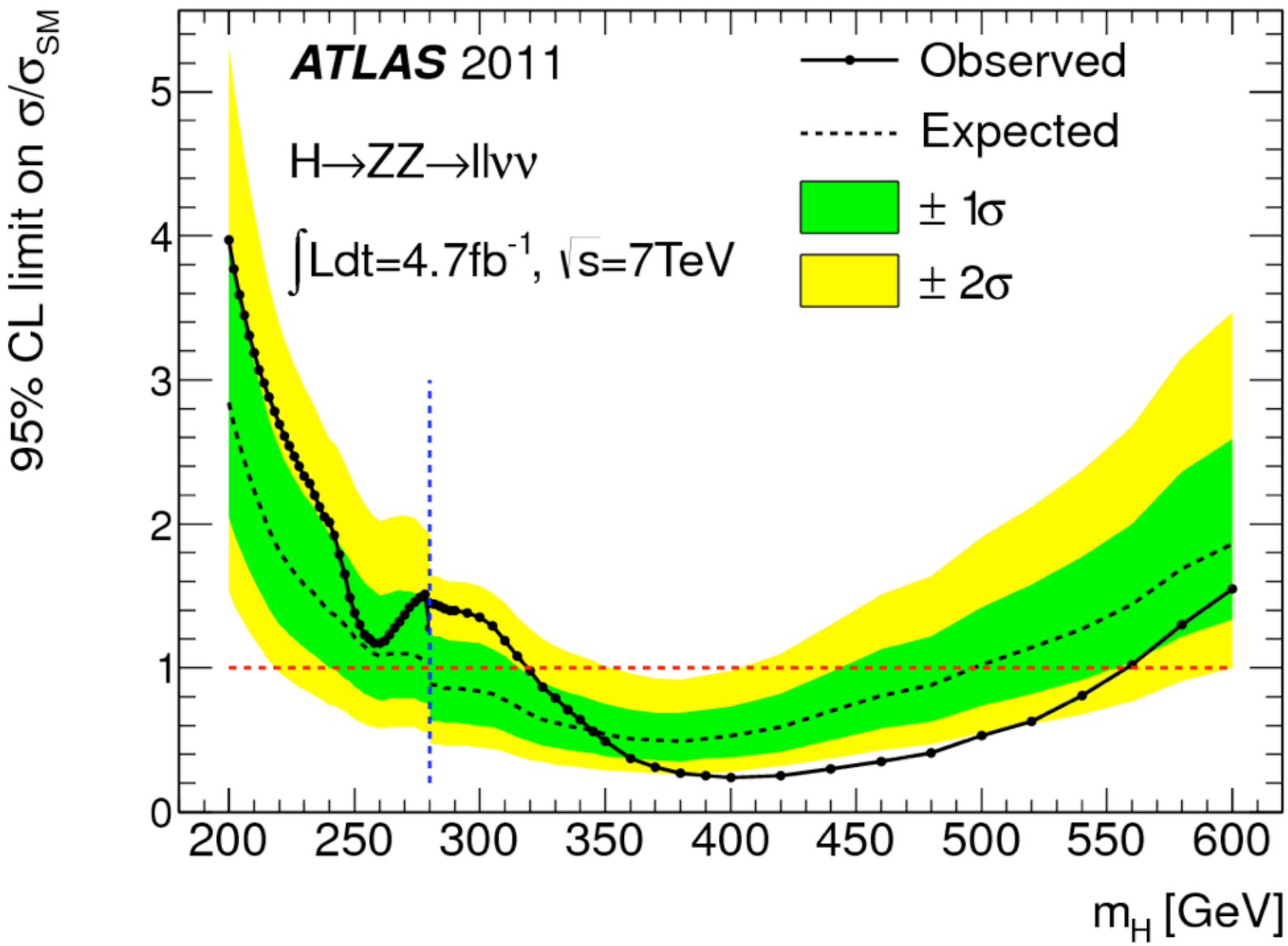
- Searches for heavy SM-like Higgs boson in H->ZZ and H->WW decay channels have been presented
- The analyses use up to 25 fb^{-1} *pp* collision data recorded by ATLAS and CMS at LHC in 2011 and 2012
- No excess above SM background expectations is observed
- Presence of a SM Higgs boson is excluded up to $O(1)$ TeV
- Results are also re-interpreted as a search for a heavy narrow EW singlet; a sizable region of parameter space has been excluded

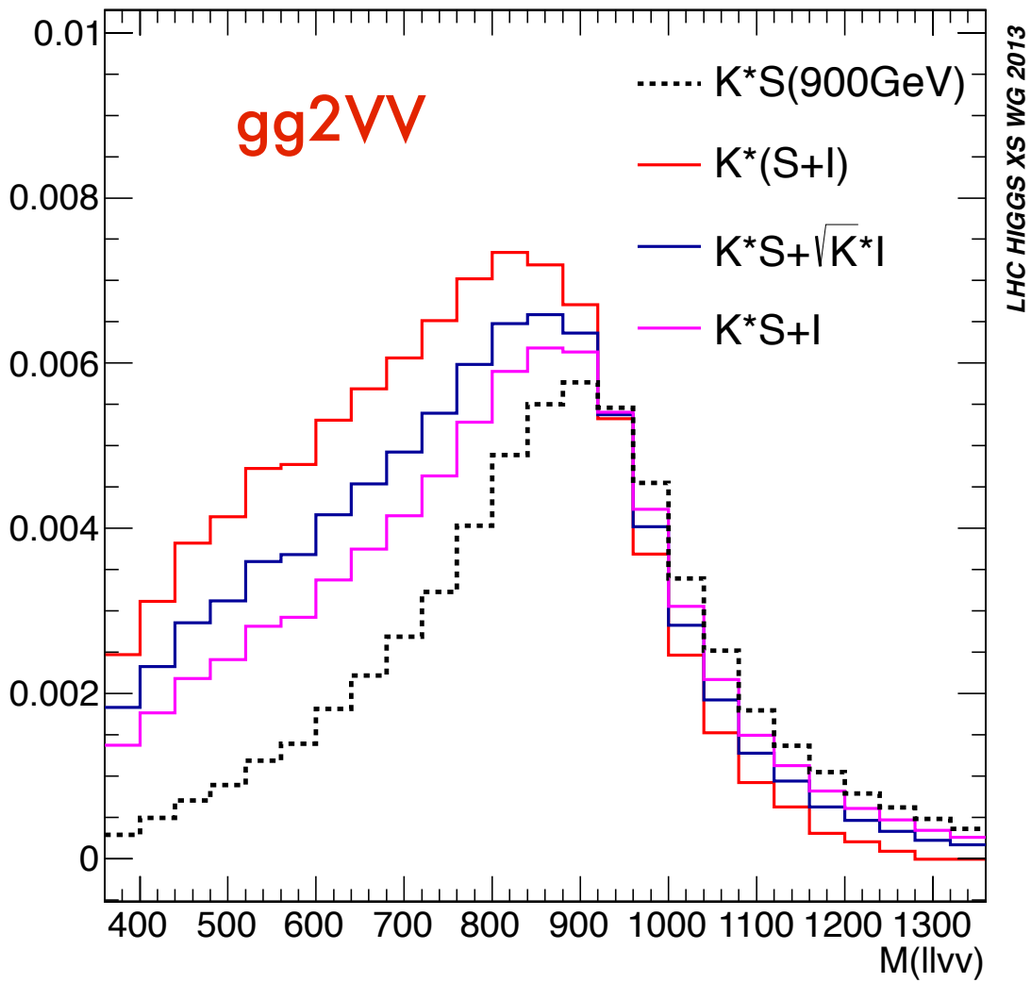
Backup

Phys. Lett. B 718 (2012) 391-410



Phys. Lett. B 717 (2012) 29-48

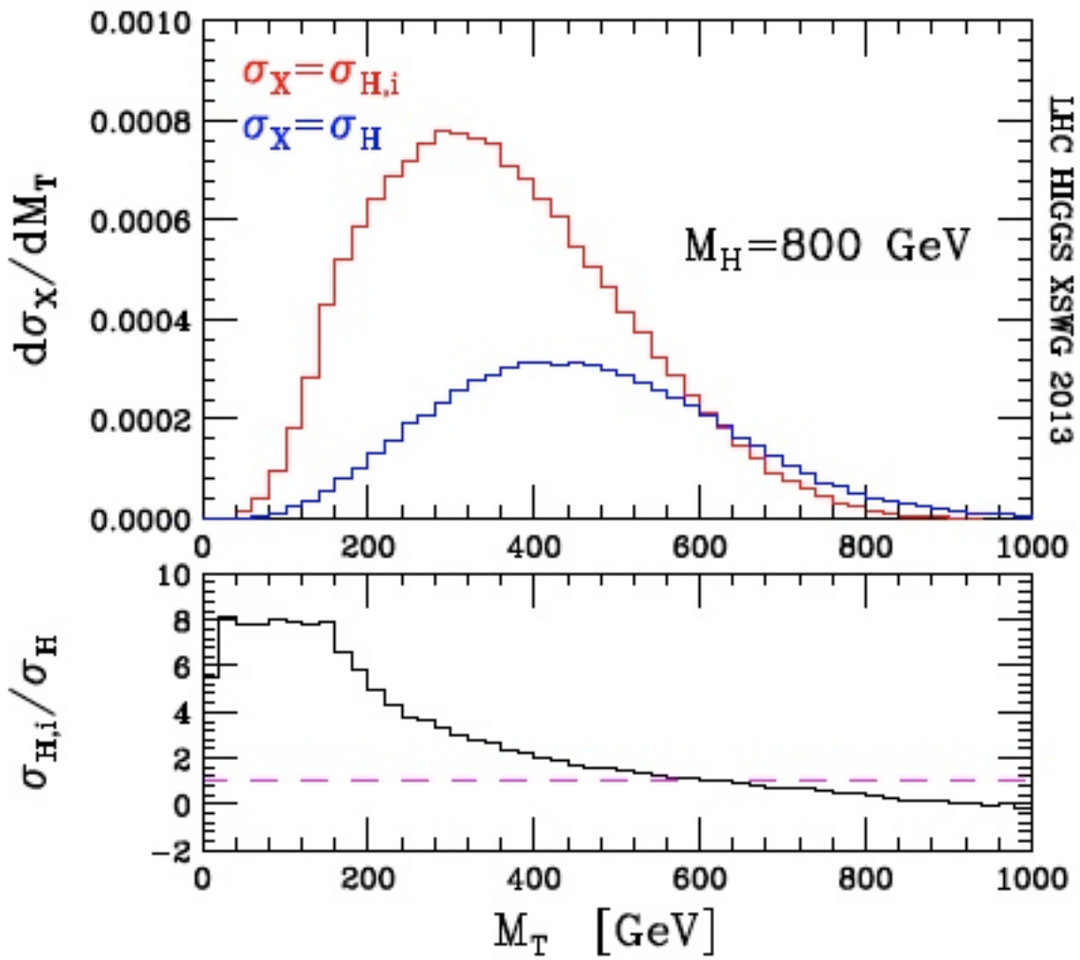


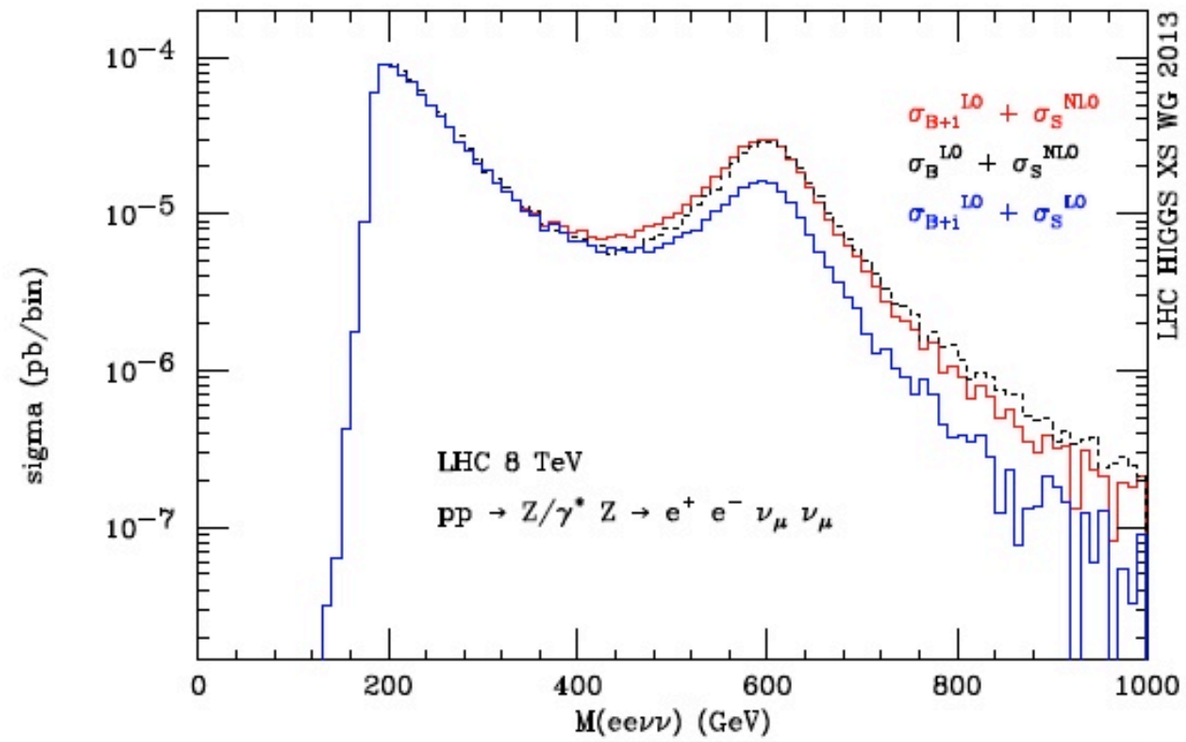


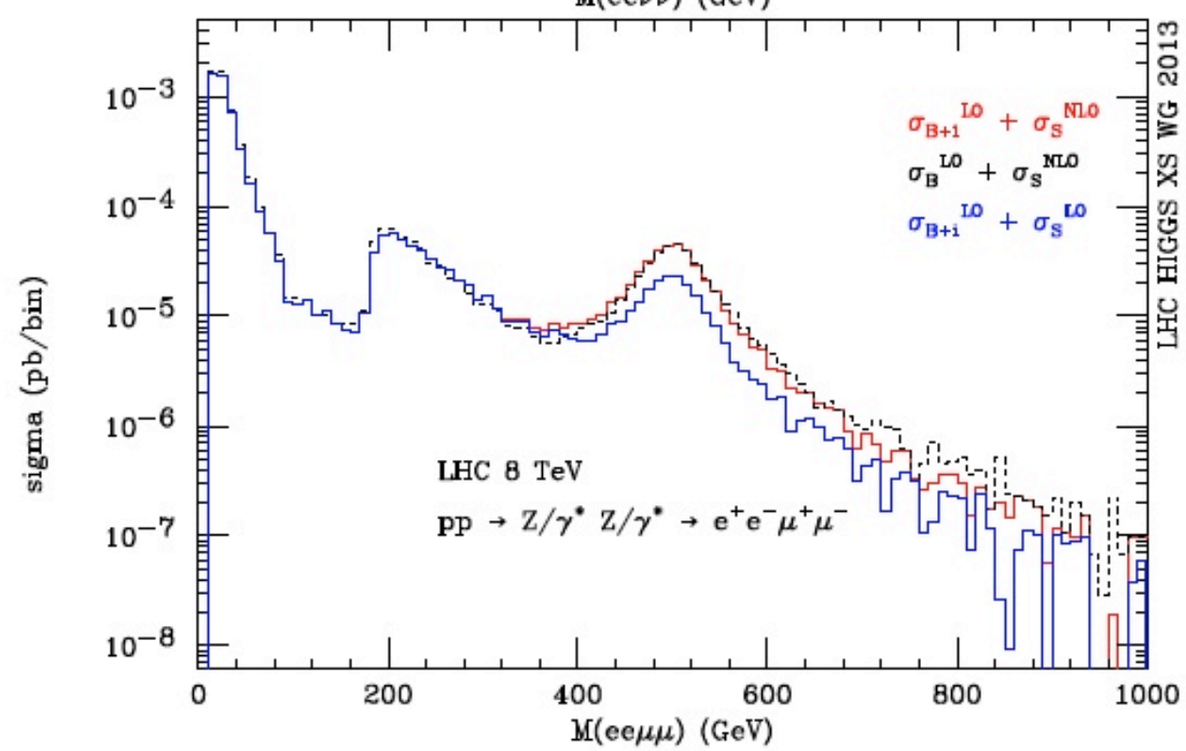
$$dS_{\mathrm{NNLO}} = K(m)\, dS$$

$$dS_{\mathrm{corr}} = dS_{\mathrm{NNLO}} + (K(m))^n\, dI, n = 0, 0.5, 1$$

NNLO K factors from G. Passarino


$\sigma_X=\sigma_{H,i}$
$\sigma_X=\sigma_H$
M_H=800 GeV
LHC HIGGS XSWG 2013
$d\sigma_X/dM_T$
$\sigma_{H,i}/\sigma_H$
M_T [GeV]


$\sigma_{B+i}^{LO} + \sigma_S^{NLO}$
$\sigma_B^{LO} + \sigma_S^{NLO}$
$\sigma_{B+i}^{LO} + \sigma_S^{LO}$
LHC 8 TeV
$pp \to Z/\gamma^* Z \to e^+ e^- \nu_\mu \nu_\mu$
sigma (pb/bin)
$M(ee\nu\nu)$ (GeV)
LHC HIGGS XS WG 2013


$\sigma_{B+i}^{LO} + \sigma_S^{NLO}$
$\sigma_B^{LO} + \sigma_S^{NLO}$
$\sigma_{B+i}^{LO} + \sigma_S^{LO}$
LHC 8 TeV
$pp \to Z/\gamma^* Z/\gamma^* \to e^+e^-\mu^+\mu^-$
sigma (pb/bin)
$M(ee\mu\mu)$ (GeV)
LHC HIGGS XS WG 2013

ATLAS H->WW->lvl'v'

Table 2: Event selection used in the analysis. The preselection applies to all final states. In the $N_{\text{jet}} \geq 2$ final state, the rapidity gap is the y range spanned by the two leading jets.

Category	0-jet	1-jet	>=2-jet
Preselection	An isolated electron and an isolated muon, with opposite charge, each with $p_{\text{T}} > 40$ GeV, $m_{\ell\ell} > 10$ GeV		
Missing transverse momentum	$E_{\text{T,rel}}^{\text{miss}} > 25$ GeV	$E_{\text{T,rel}}^{\text{miss}} > 25$ GeV	$E_{\text{T}}^{\text{miss}} > 20$ GeV
General selection	- $\Delta\phi_{\ell\ell,E_{\text{T}}^{\text{miss}}} > \pi/2$ $p_{\text{T}}^{\ell\ell} > 30$ GeV	$N_{b\text{-jet}} = 0$ - $Z/\gamma^* \to \tau\tau$ veto	$N_{b\text{-jet}} = 0$ $p_{\text{T}}^{\text{tot}} < 45$ GeV $Z/\gamma^* \to \tau\tau$ veto
VBF topology	- - - -	- - - -	$m_{jj} > 500$ GeV $\lvert\Delta y_{jj}\rvert > 2.8$ No jets ($p_{\text{T}} > 20$ GeV) in the rapidity gap; require both ℓ in the rapidity gap
$H \to WW \to \ell\nu\ell\nu$ topology	$m_{\ell\ell} > 50$ GeV $\Delta\eta_{\ell\ell} < 1.0$	$m_{\ell\ell} > 50$ GeV $\Delta\eta_{\ell\ell} < 1.0$	$m_{\ell\ell} > 50$ GeV $\Delta\eta_{\ell\ell} < 1.0$

Higgs experimental mass resolution

Channel H →	mH resolution
ZZ→4l	1-2%
ZZ→2l2ν	~10%
ZZ→2l2q	3%
WW→lνlν	~20%
WW→lνqq	~15%