Searches for Higgs boson like high mass resonances in the bosonic decay channels with ATLAS and CMS

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on behalf of the ATLAS and CMS collaborations

EUROPEAN PHYSICAL SOCIETY
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EUROPEAN PHYSICAL SOCIETY
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Higgs beyond the SM

the Higgs mechanism makes the SM consistent. What if it is not only a scalar field but something more?

Electroweak Singlet

an additional Electroweak Singlet which mixes to the SM Higgs doublet: two CP-even bosons should be there - features are mainly SM-like

	h	H
cross section	$C^2 \times \sigma_{SM}$	$C'^2 \times \sigma_{SM}$
width	$C^2 \times \Gamma_{SM}$	$C'^2/(1-B_{new}) \times \Gamma_{SM}$
branching ratio	$BR_{h,SM}$	$(1-B_{new}) \times BR_{h,SM}$

C^2 and C'^2 are scaling constants wrt/ the SM quantities
from unitarity: $C^2 + C'^2 = 1$
Free parameters: B_{new}, C^2 and C'^2 m_H

2 Higgs Doublet Model

Higgs-like mechanism achieved with two doublets: 5 Higgs-like bosons are there
2 CP-even: h and H / a neutral CP-odd: A / two charged bosons: H^+ and H^-
Free parameters are:

- the masses of the bosons
- tanβ - the ratio between the vacuum expectation values of the doublets
- α - the mixing angle between the two doublets

- different types of 2HDM models are obtained with different assumptions on the symmetry of the Lagrangian

Overview of the searches

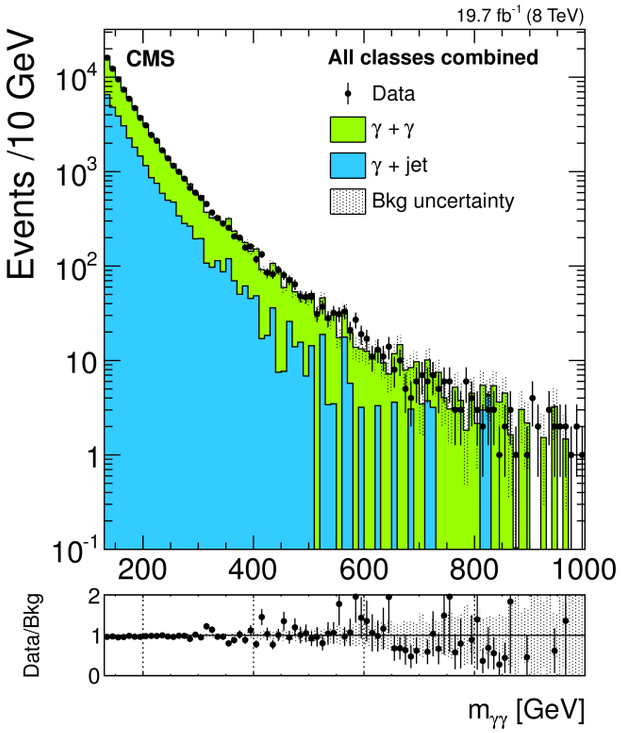
	final state	ATLAS	CMS
H→γγ	γγ	L = 20.3/fb $\sqrt{s}$ = 8TeV MI 65 < m_H < 600 GeV	L = 19.7/fb $\sqrt{s}$ = 8TeV MI, SM, spin 2, 2HDM 150 < m_H < 850 GeV
H→ZZ	4l	*brand new* L = 20.3/fb $\sqrt{s}$ = 8TeV MI, 2HDM 140 < m_H < 1000 GeV	L = 19.7/fb $\sqrt{s}$ = 8TeV L = 5.1/fb $\sqrt{s}$ = 7TeV SM, EWS 145 < m_H < 1000 GeV (also include τ for 4l)
	2l2v		
	2l2q		
	2v2q		-
H→WW	lvlv	*brand new* L = 20.3/fb $\sqrt{s}$ = 8TeV MI, SM 220 < m_H < 1000 GeV	L = 19.7/fb $\sqrt{s}$ = 8TeV L = 5.1/fb $\sqrt{s}$ = 7TeV SM, EWS 145 < m_H < 1000 GeV
	lvqq		

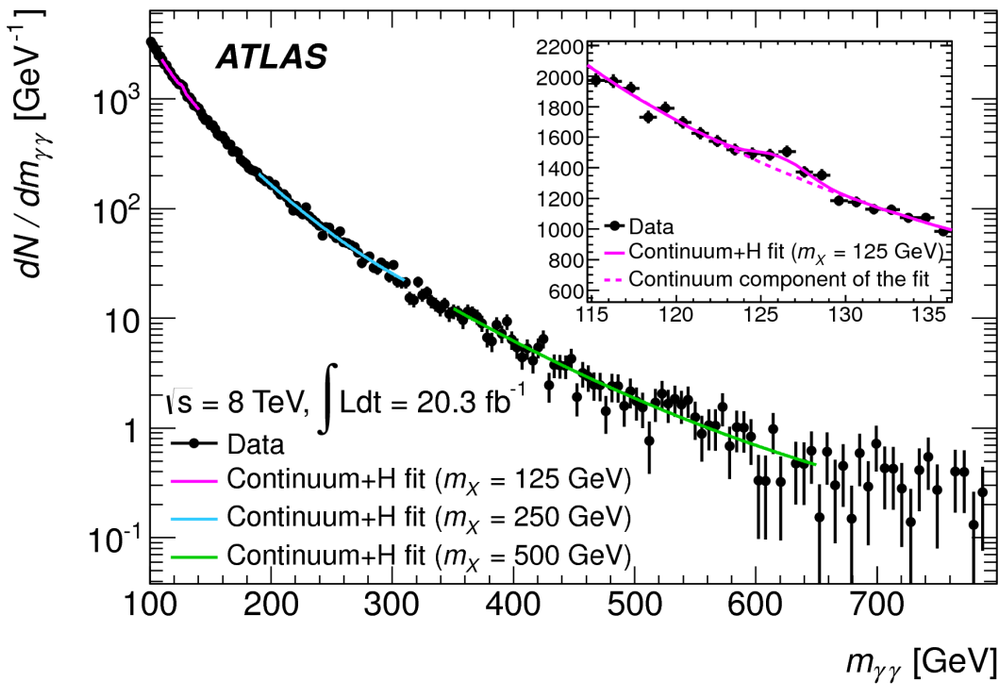
MI = Model Independent (usually narrow width), SM = SM-like, EWS = Electroweak Singlet, 2HDM

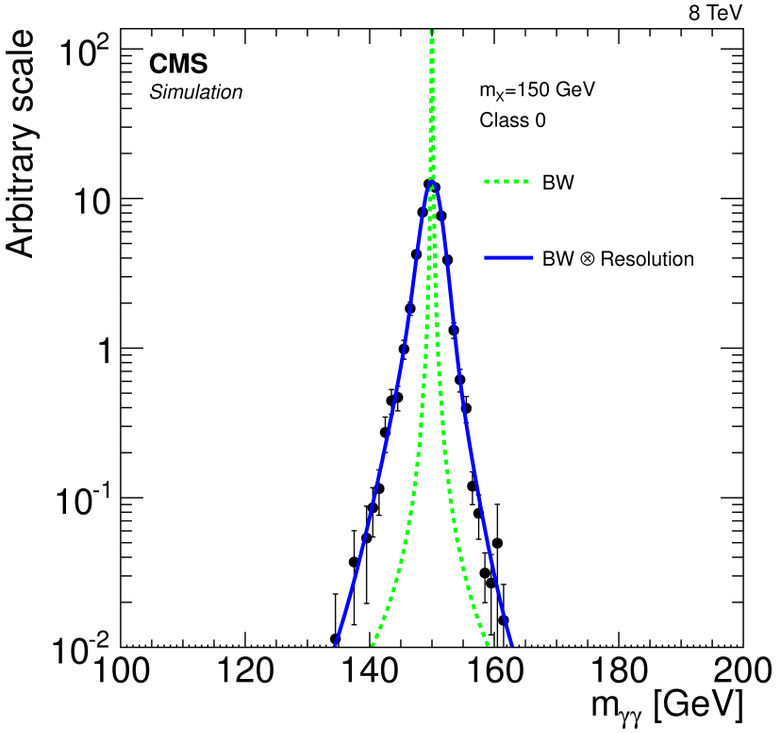
H→γγ in general

ATLAS: arXiv:1407.6583
CMS: arXiv:1506.02301

Study events with two prompt photons: look at the $m_{\gamma\gamma}$ spectrum looking for a peak on top of a smoothly falling background





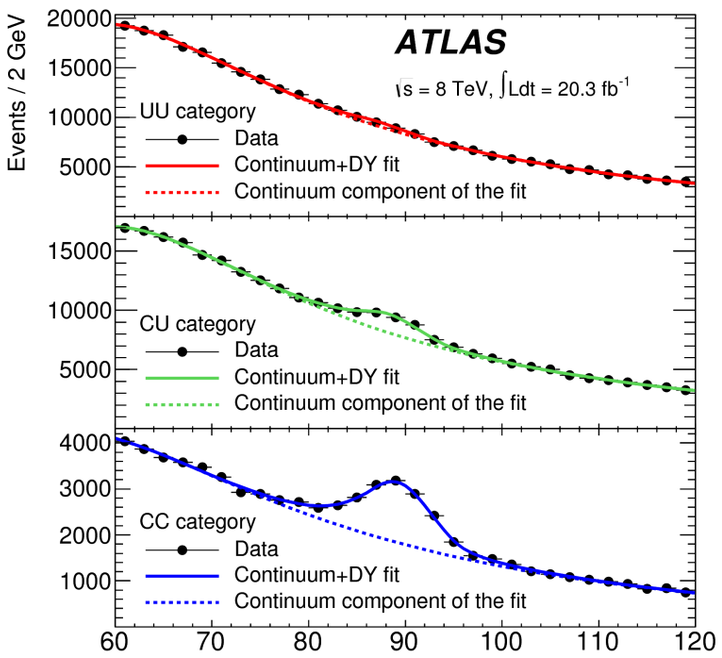


the fit is performed on the $m_{\gamma\gamma}$ distribution: to constrain the background a "wide" region of the spectrum is used whose range varies with the value of m_H being probed

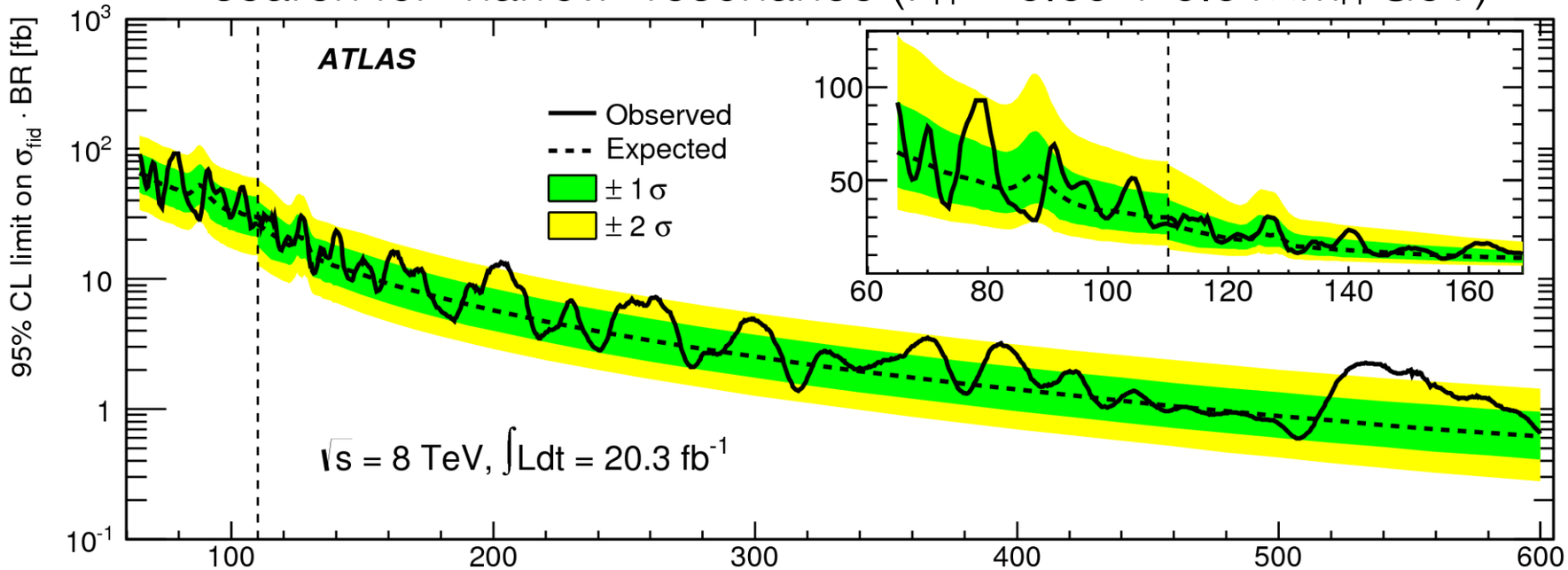
H→γγ: results

ATLAS: arXiv:1407.6583
CMS: arXiv:1506.02301

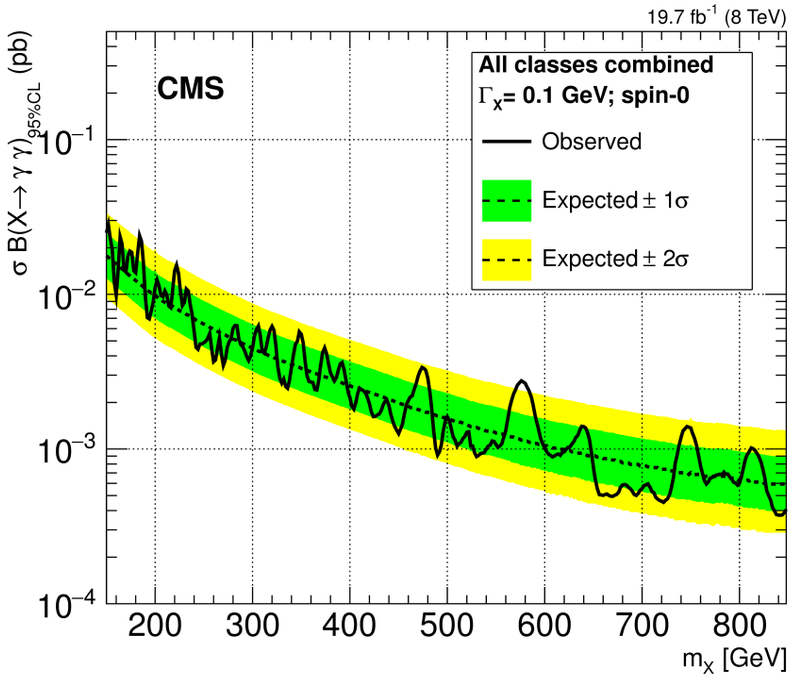
DY/Z contamination in the "low" mass region



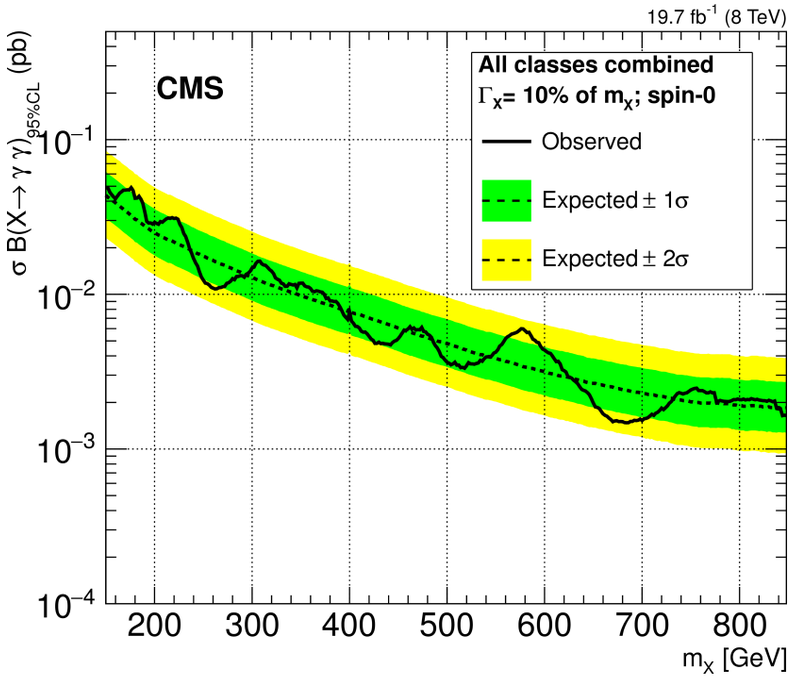
search for "narrow" resonance (Γ_H = 0.09 + 0.01×m_H GeV)



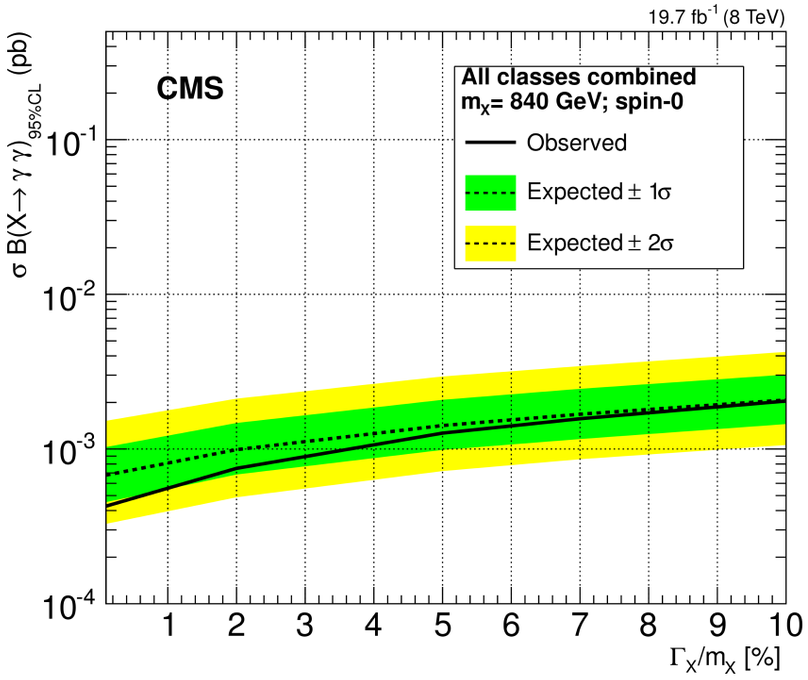
search for "narrow" resonance (Γ_H = 0.1 GeV)



search for "wide" resonance (Γ_H = 0.1×m_H)



fixed mass, scan the width



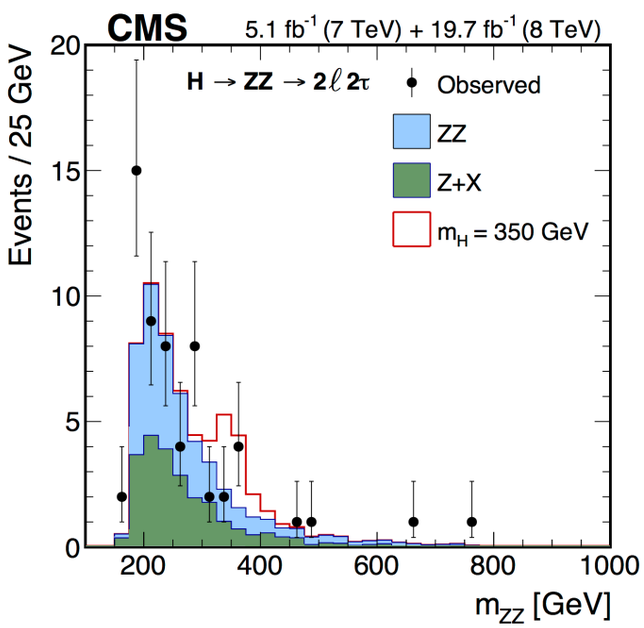
H→ZZ in general

ATLAS: arxiv:1507.05930
CMS: arXiv:1504.00936

Has higher cross section, background contamination and composition heavily varies as a function of the final state

Events are split according to the number of jets in order to optimise the selection for the different production mechanisms
VBF category is based on ≥2 jets with high m_{jj} and high $|\Delta\eta_{jj}|$

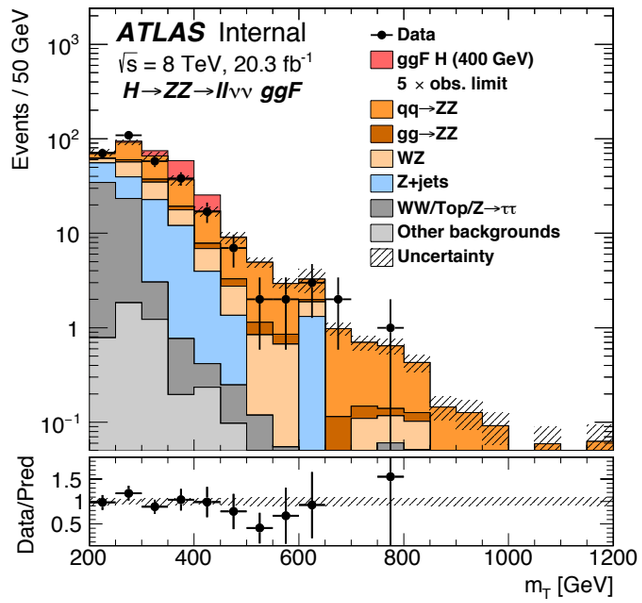
HZZ4l



final state with 4 isolated leptons
very high S/B
excellent mass resolution
m_{4l} used in the final fit
CMS also uses the 2l2τ final state

it is crucial to reject events with E_T^{miss} coming from mismeasured objects - it is done requiring high angular separation between the E_T^{miss} and the high-p_T objects, as well as energy balance

HZZ2l2ν

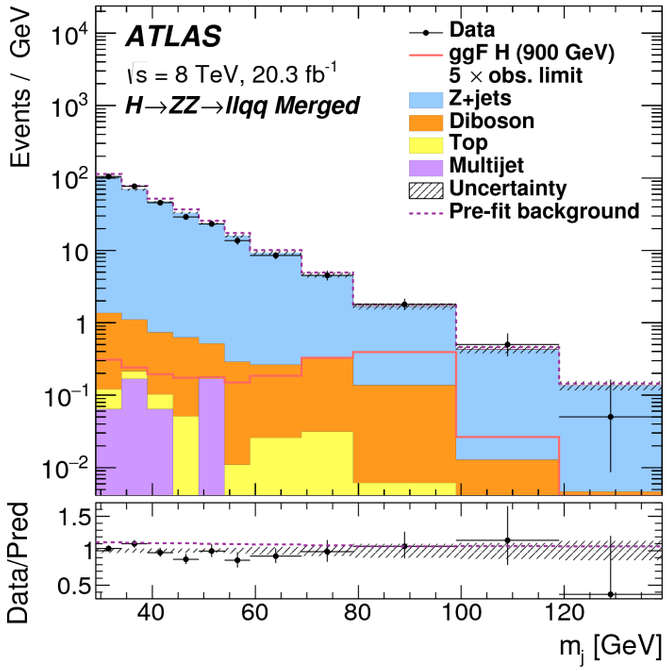


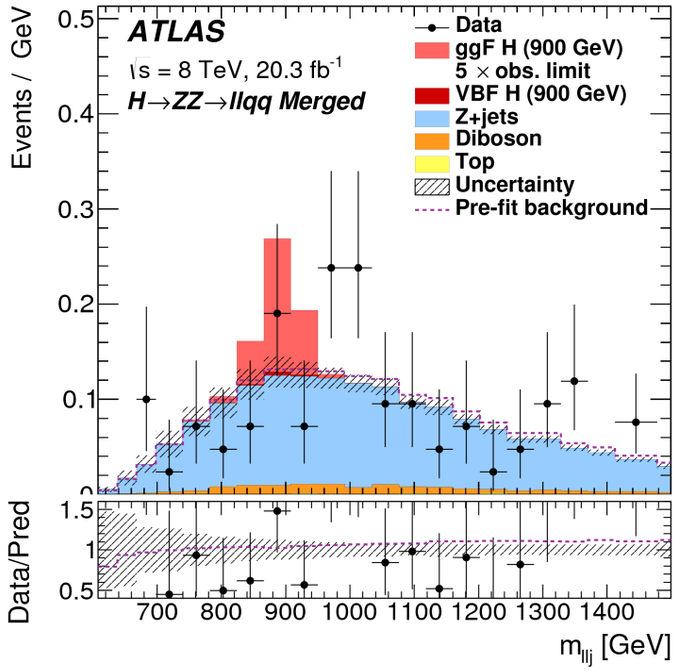
H→ZZ with jets

ATLAS: arxiv:1507.05930
CMS: arXiv:1504.00936

Final states with jets benefit from higher cross sections, but have to deal with much higher background

HZZ2l2q

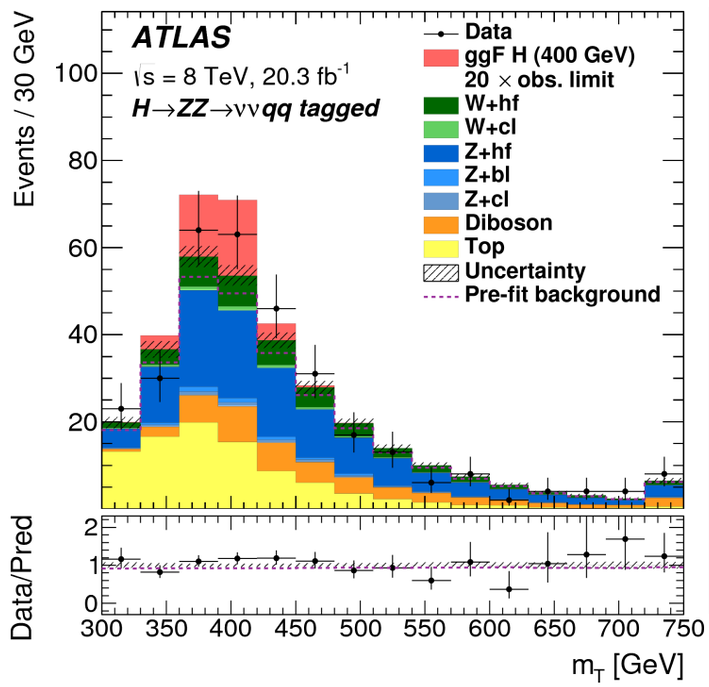




Dedicated categories for $m_H \gtrsim 600$ GeV when the two jets start to merge:
CMS uses "fat" jets and substructure variables in the merged channel
ATLAS uses the same "narrow" jets used in the resolved analysis

ATLAS only:
based on E_T^{miss} trigger
any lepton is vetoed down to 7 GeV
cuts to reject mismeasured E_T^{miss}, leptonic control regions in common with the 2l2q final state

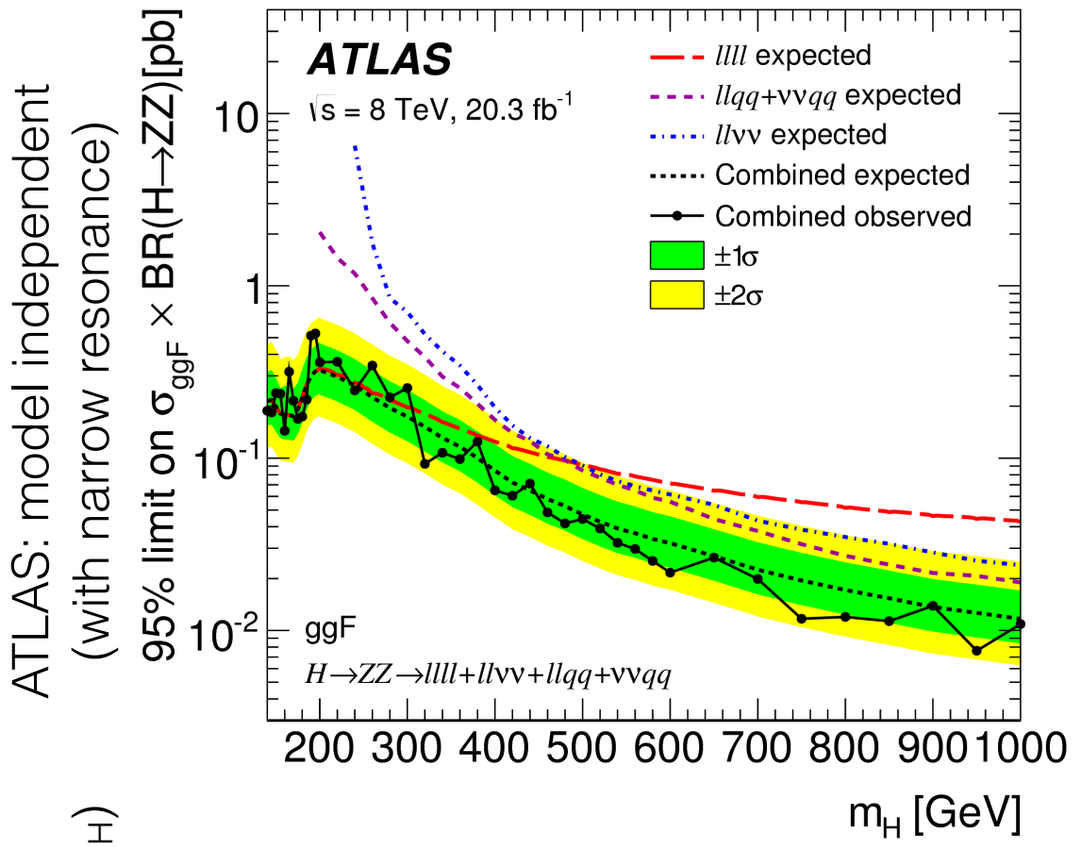
HZZ2νq

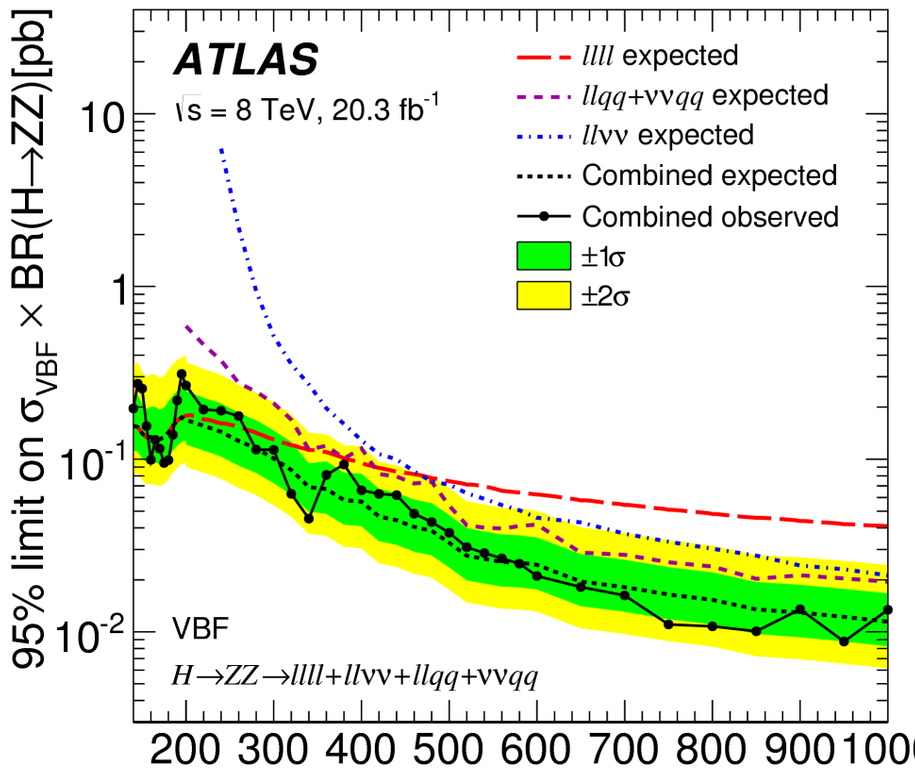


H→ZZ: results

ATLAS: arxiv:1507.05930
CMS: arXiv:1504.00936

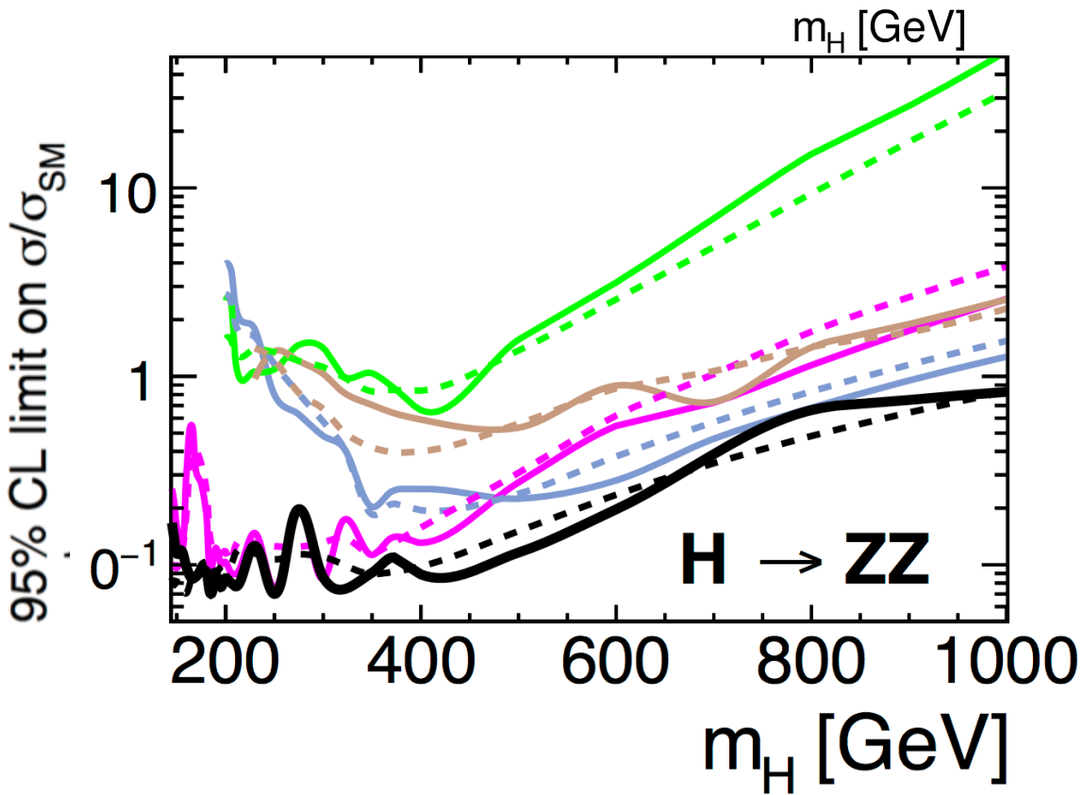
ATLAS: model independent
(with narrow resonance)





These results aren't really comparable because of the extremely different width assumed for the signal

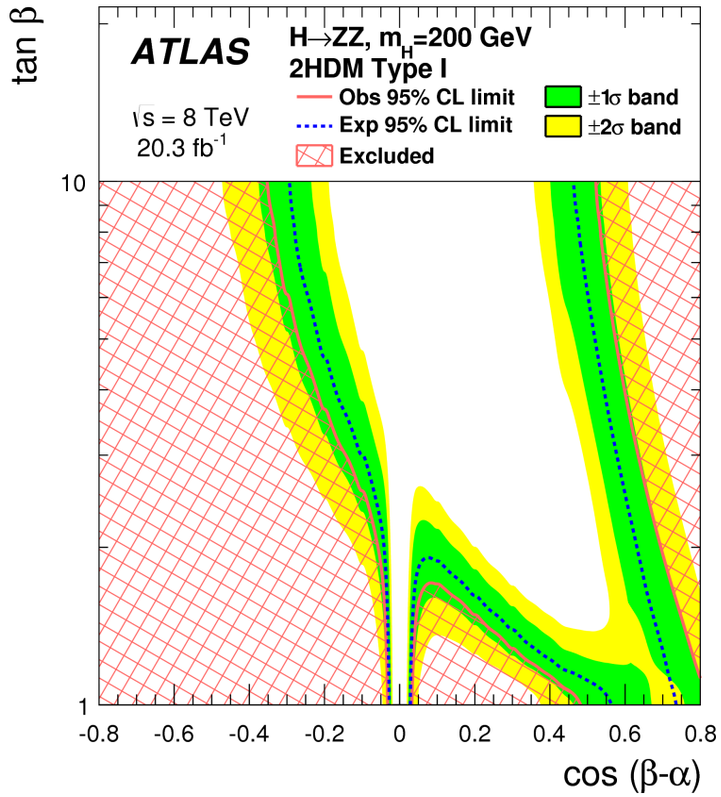
CMS: SM-like
(i.e. width increases with m_H)

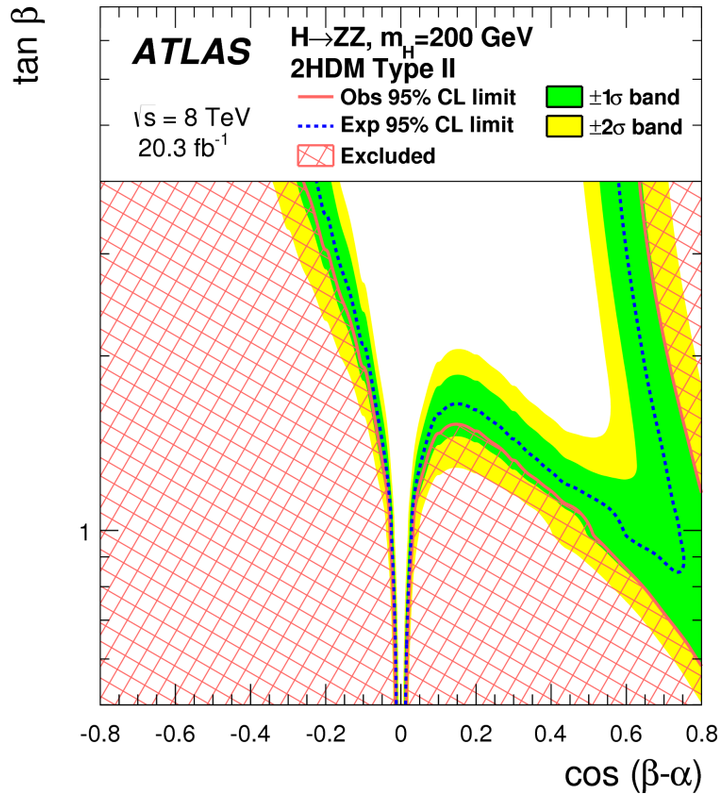


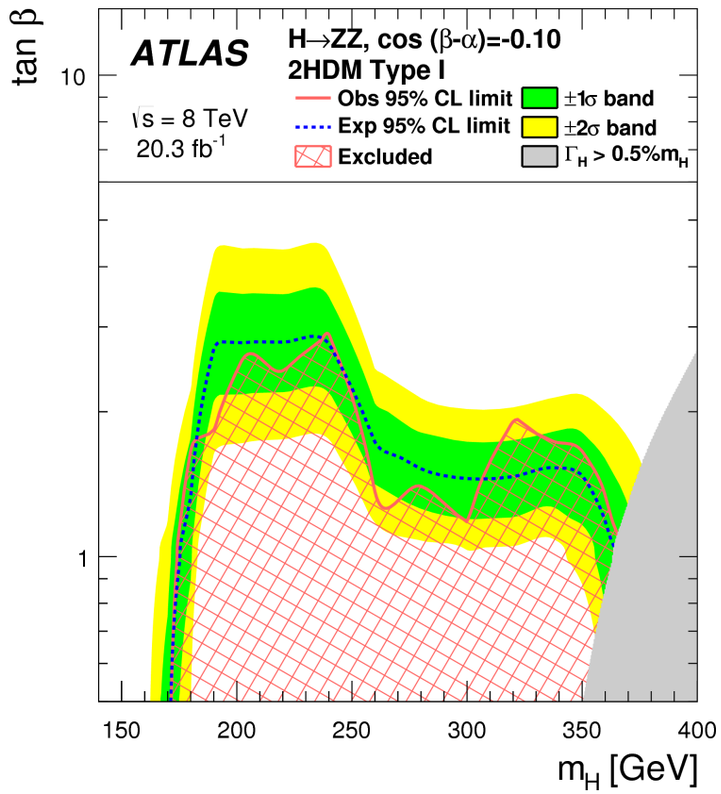
H→ZZ 2HDM

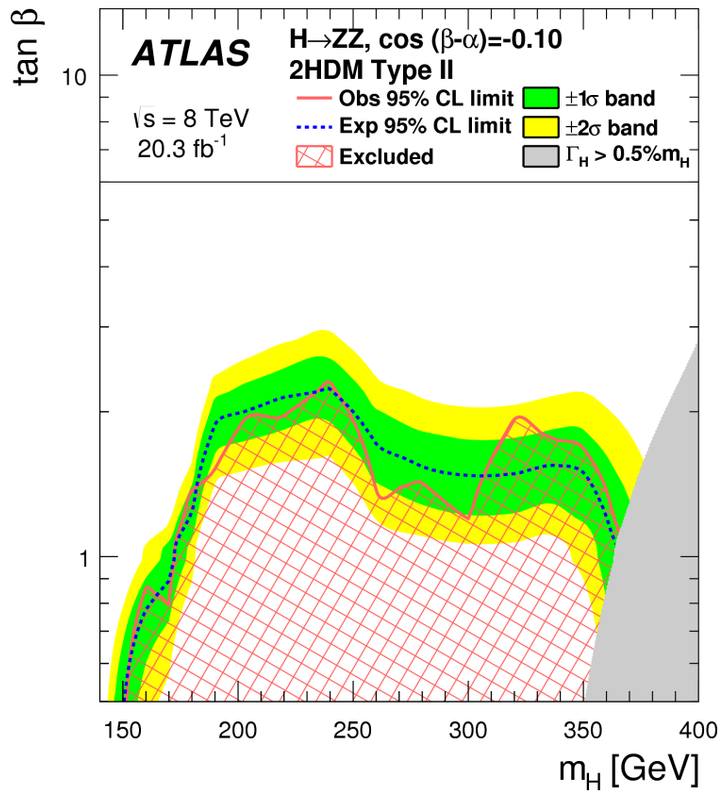
ATLAS: arxiv:1507.05930

Limits for “low” values of tanβ, run 2 will tell us more about the 2HDM models









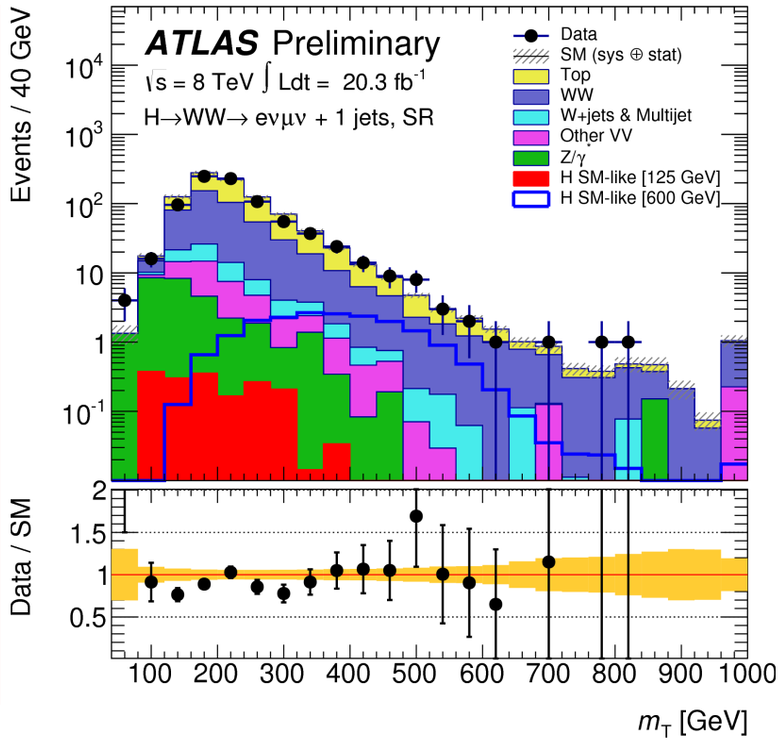
H→WW in general

ATLAS: HIGG-2013-19
CMS: arXiv:1504.00936

Has the highest cross section / background contamination and composition heavily varies as a function of the final state

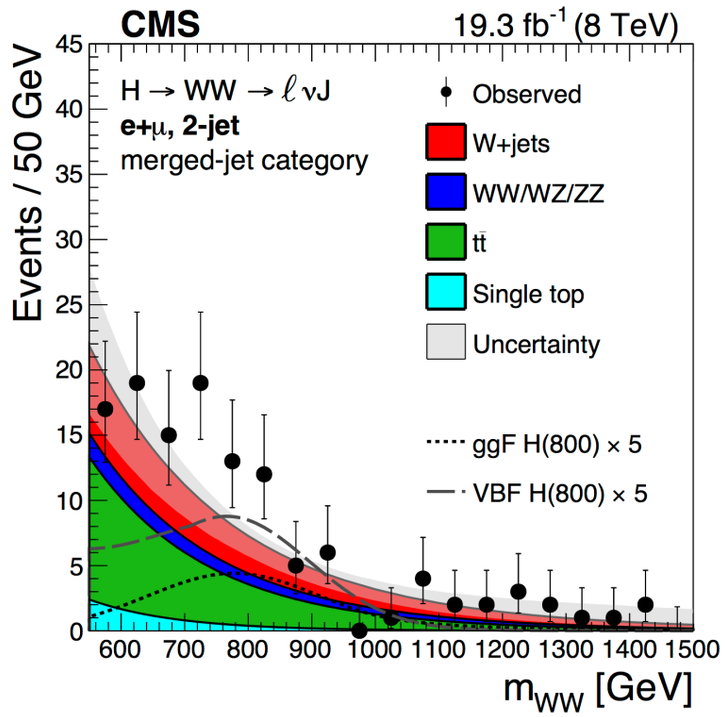
Events are split according to the number of jets in order to optimise the selection for the different background compositions
VBF category is based on ≥2 jets with high m_{jj} and high $|\Delta\eta_{jj}|$

HWW/lvlv



2 high-p_T leptons and large E_T^{miss}
b-jet veto to reduce the top contamination
transverse mass used as final discriminant

merged channel (based on fat jets) used for high m_H
both ATLAS and CMS "reconstruct" the neutrino p_z using a W constraint

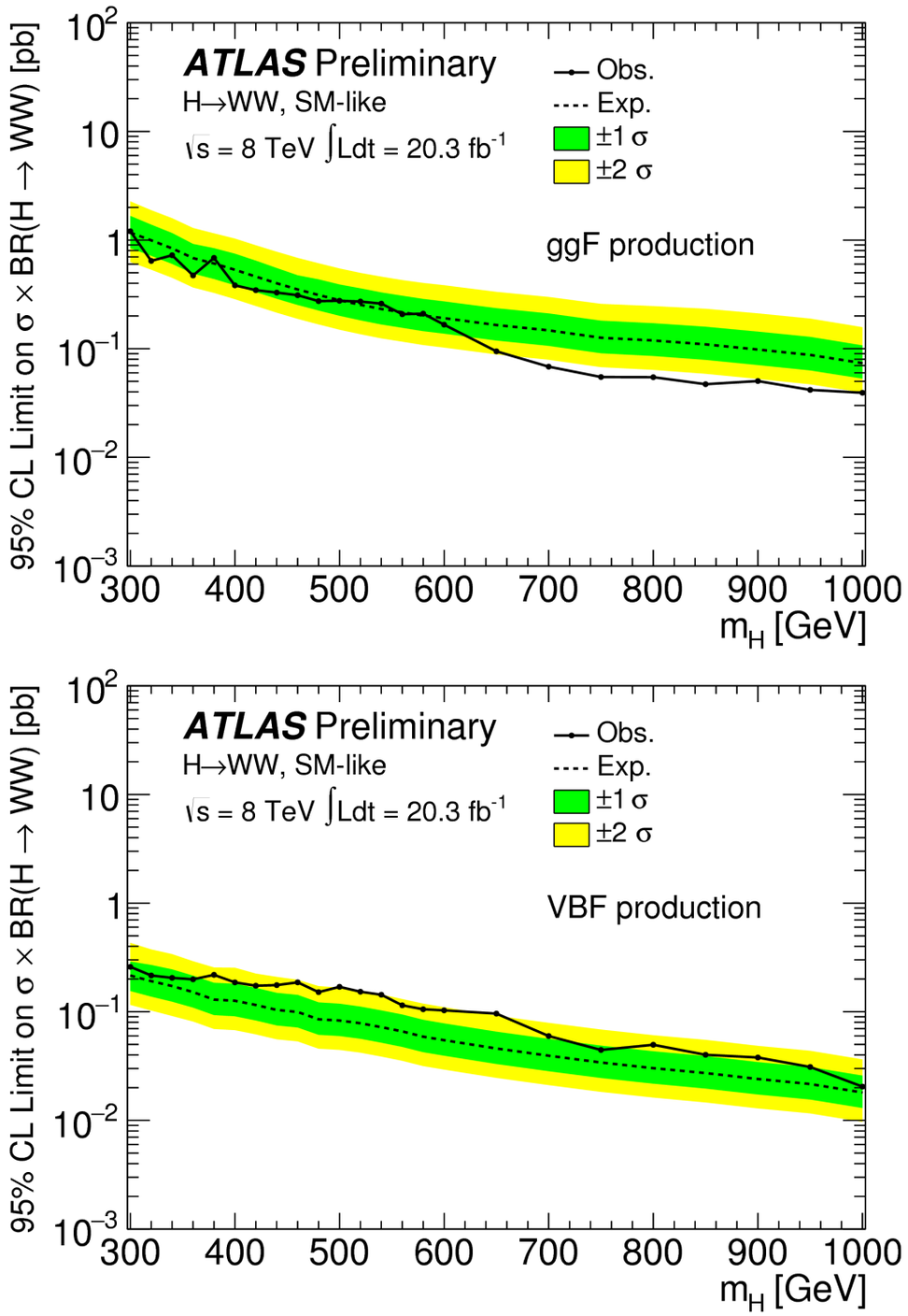


HWW/lvqq

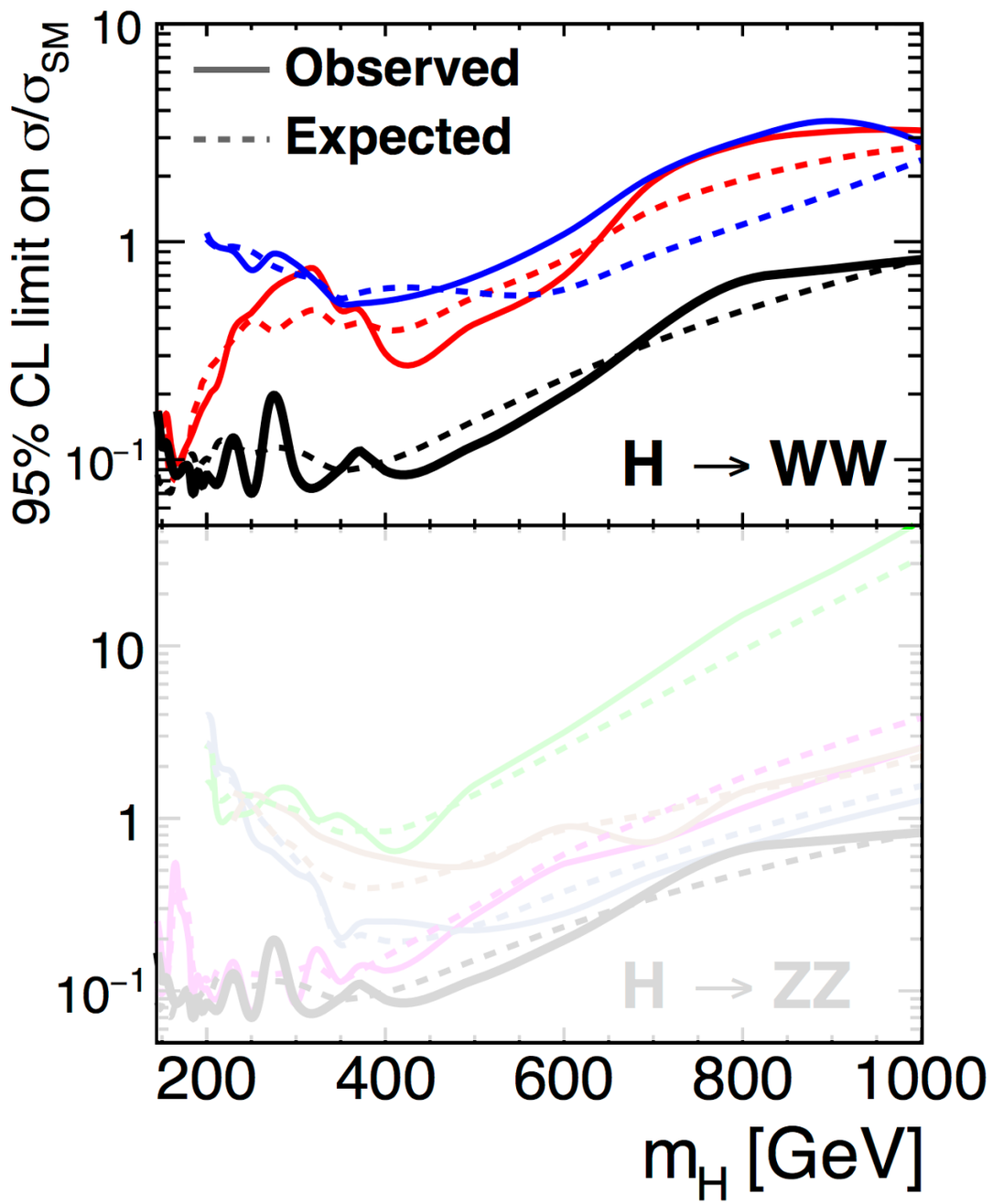
H→WW results (SM-like)

ATLAS: HIGG-2013-19
CMS: arXiv:1504.00936

ATLAS - 8 TeV data



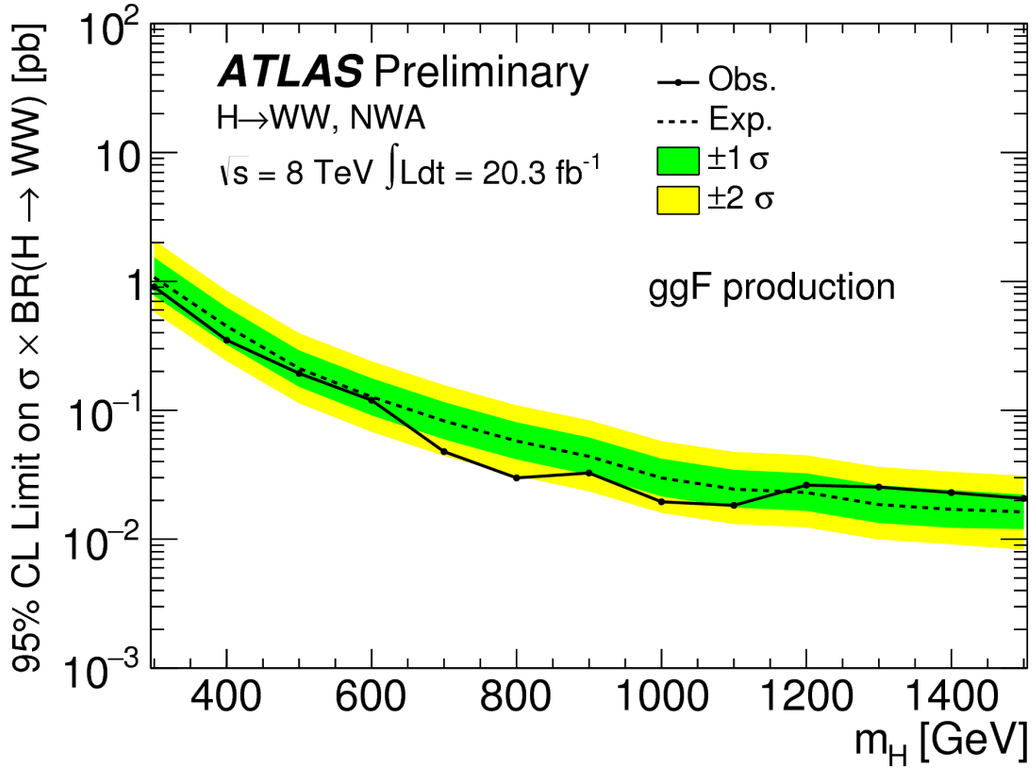
CMS - 7 TeV + 8 TeV data

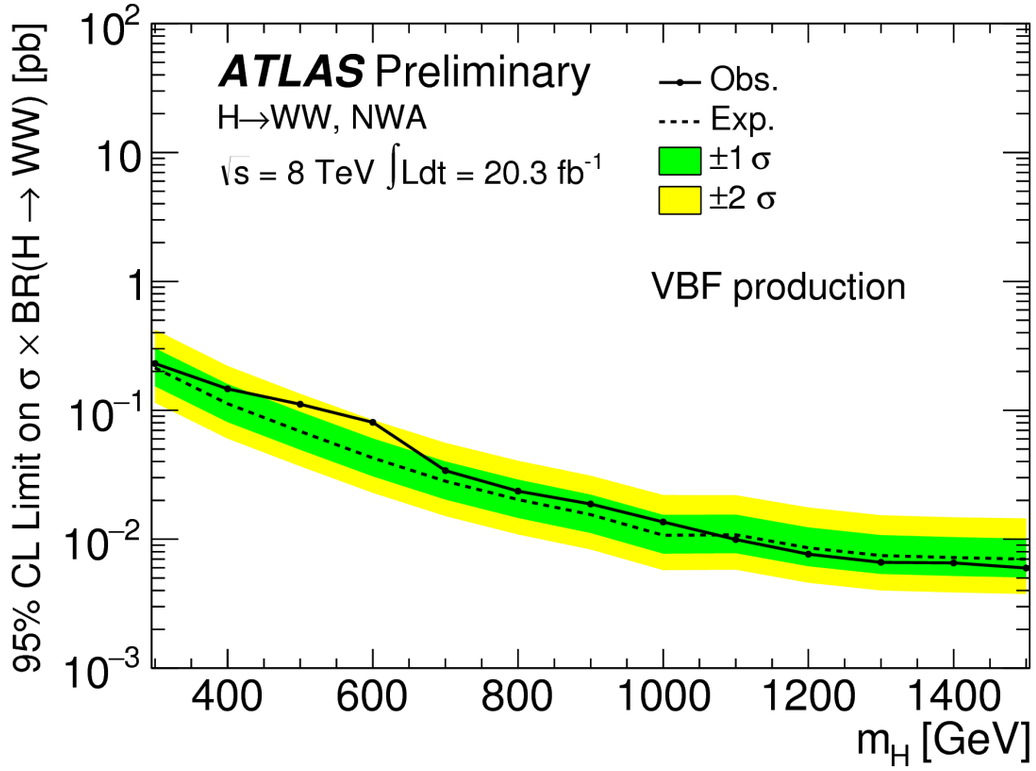


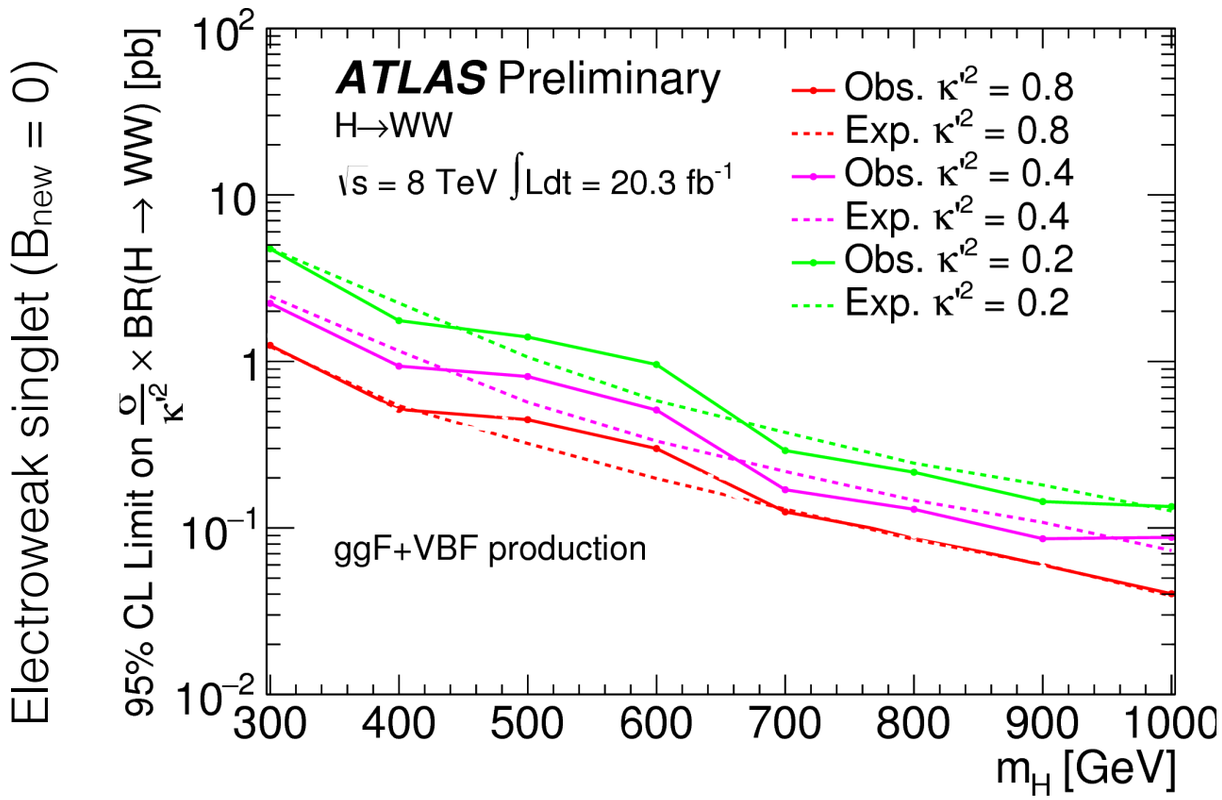
H→WW results

ATLAS: HIGG-2013-19

ATLAS only: narrow width signal



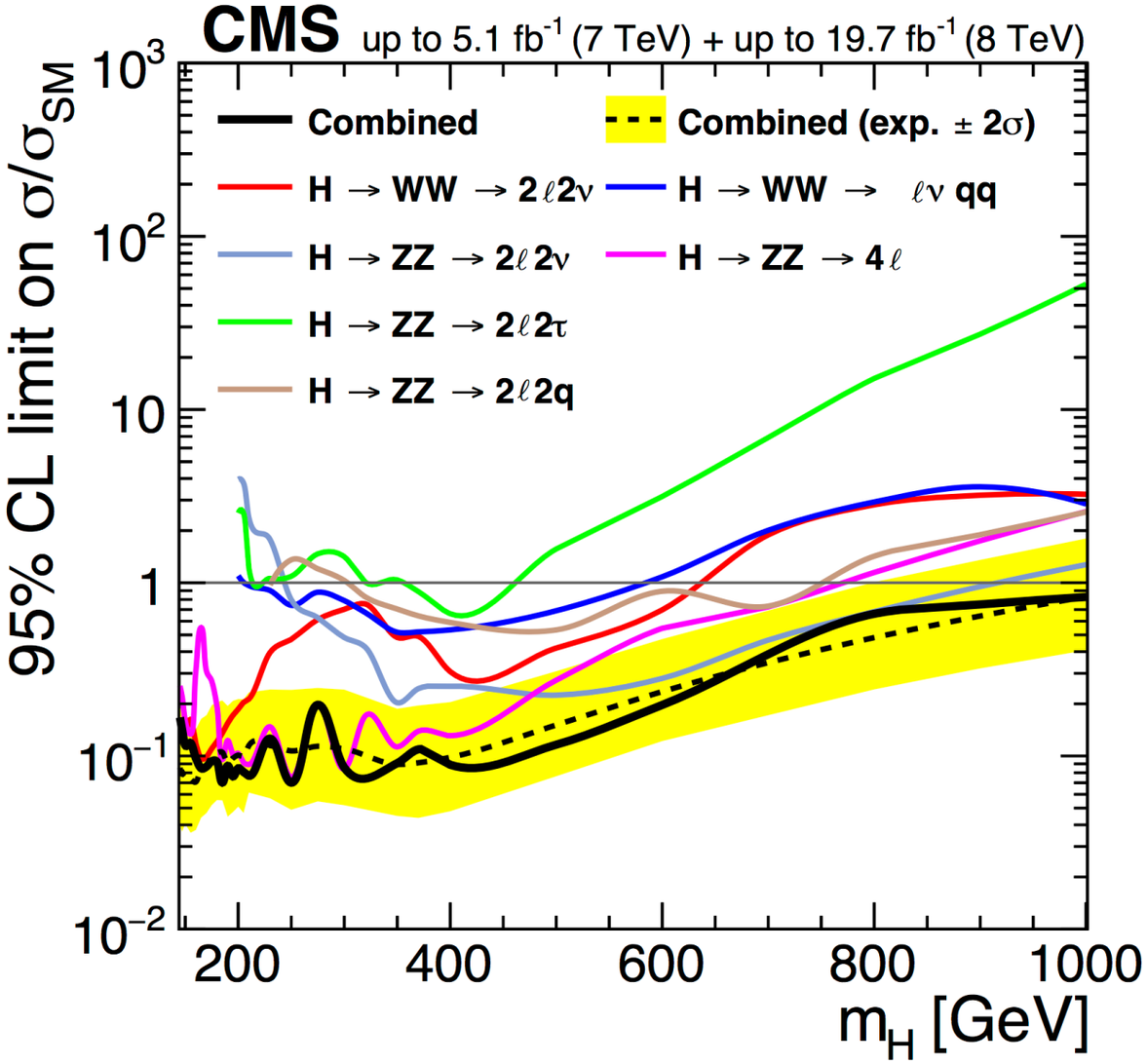


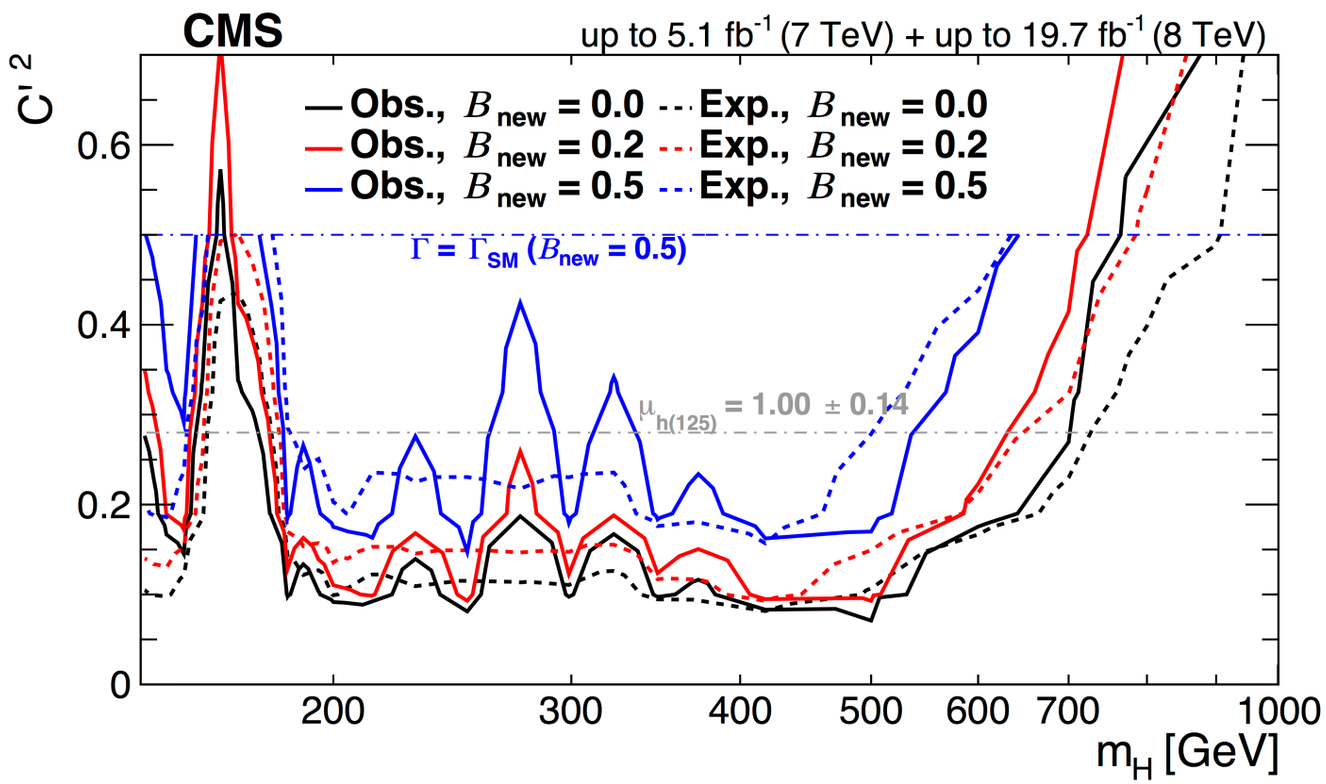


H→ZZ/WW: results

CMS: arXiv:1504.00936

CMS only: SM-like + EWS





Summary

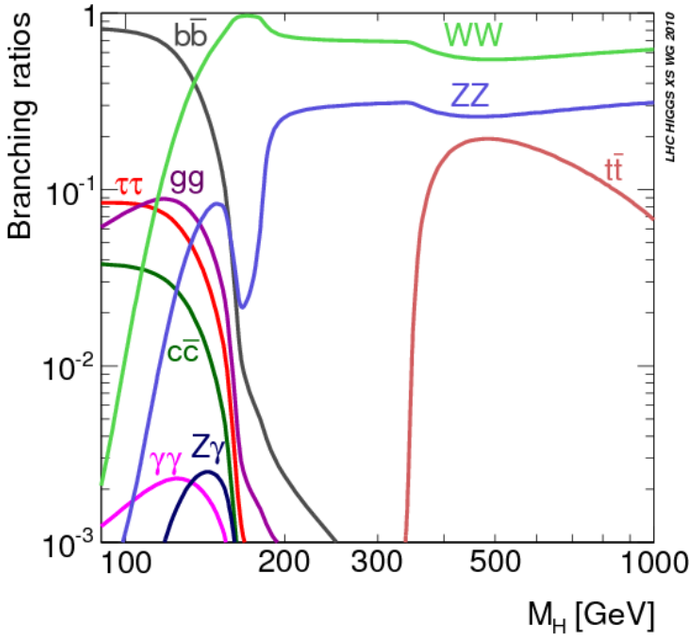
- A wide mass range is probed in the γγ, WW and ZZ decay modes looking for new resonances
  - each different final states is characterised by its own peculiarities: different background composition and expectation, experimental challenges
- This is done probing several models: SM-like, narrow resonance, EWS, 2HDM
- No significant excess is found over the SM predictions and exclusion limits on the tested hypotheses are set
  - the SM-like Higgs over the whole mass range (145-1000 GeV) combining WW and ZZ final states is excluded
  - a large part of the C'^2 vs m_H space is excluded for various B_{new}
- Results from ATLAS and CMS are hard to compare because of the different hypotheses tested
- Looking forward for results using run 2 data to shed more light on what is out there!

Backup

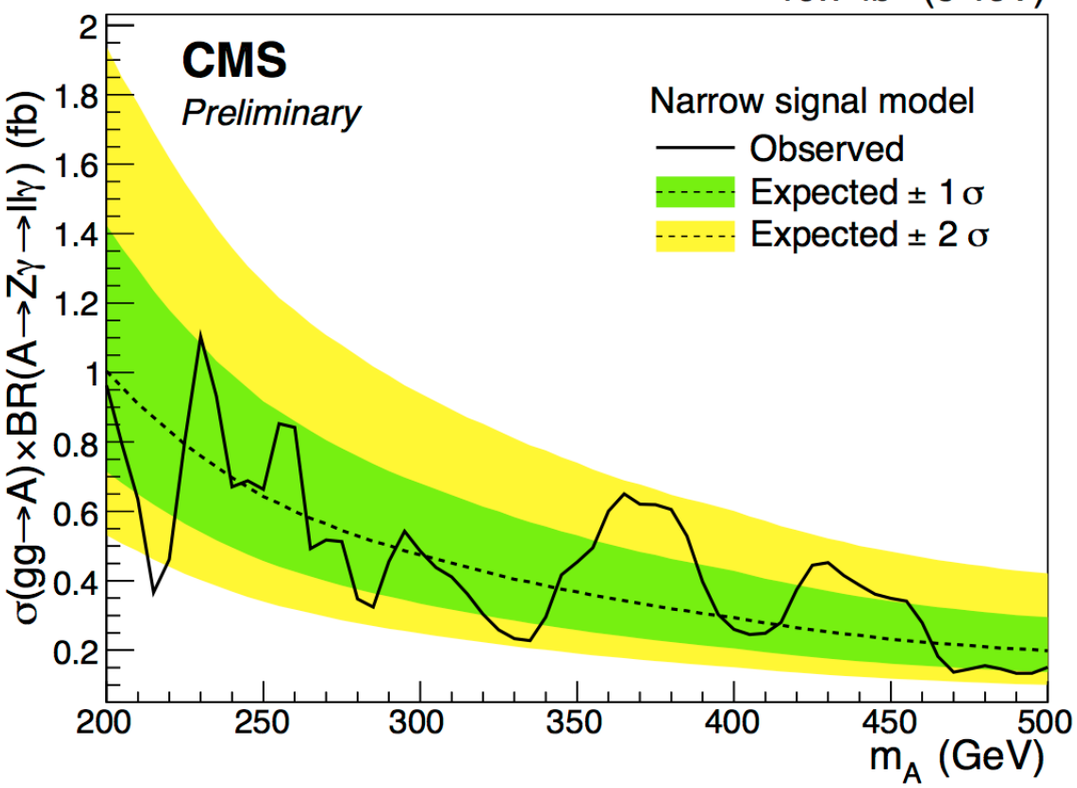
Bonus: H→Zγ

ATLAS: arxiv:1407.8150
CMS: CMS-PAS-HIG-14-031

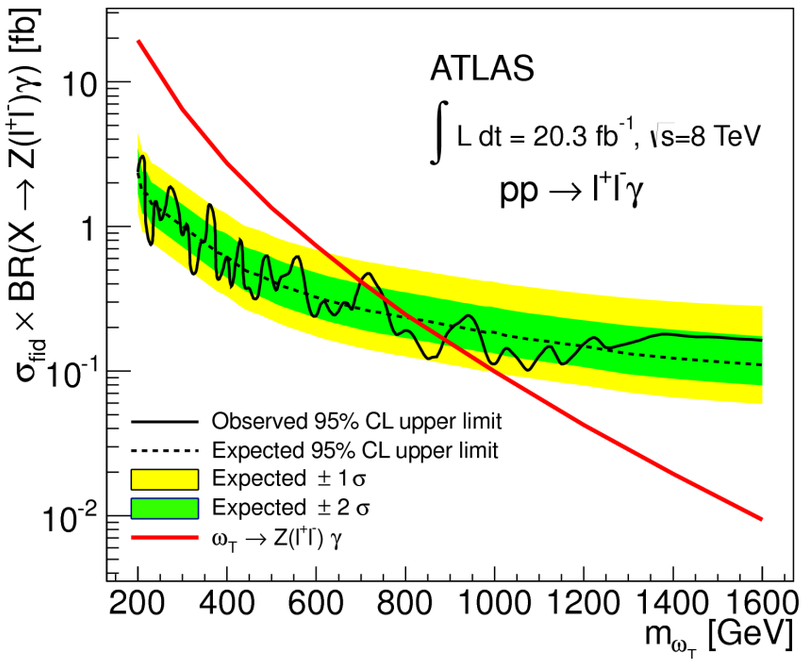
ATLAS and CMS had no sensitivity to the SM hypothesis in run 1, but other models (Technicolor) foresee additional heavy bosons with enhanced Zγ branching ratio



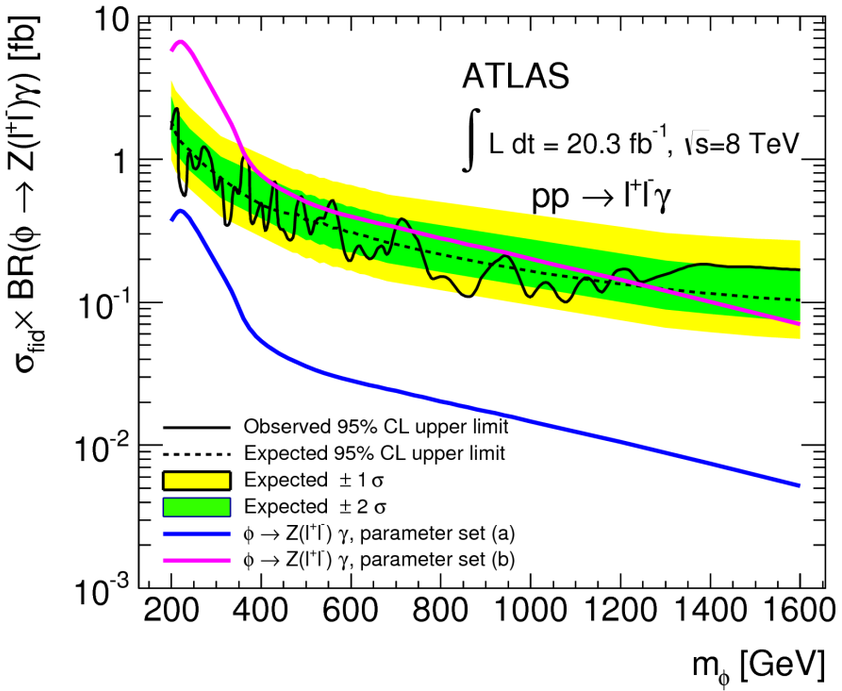
CMS - Minimal Conformal Technicolor



ATLAS



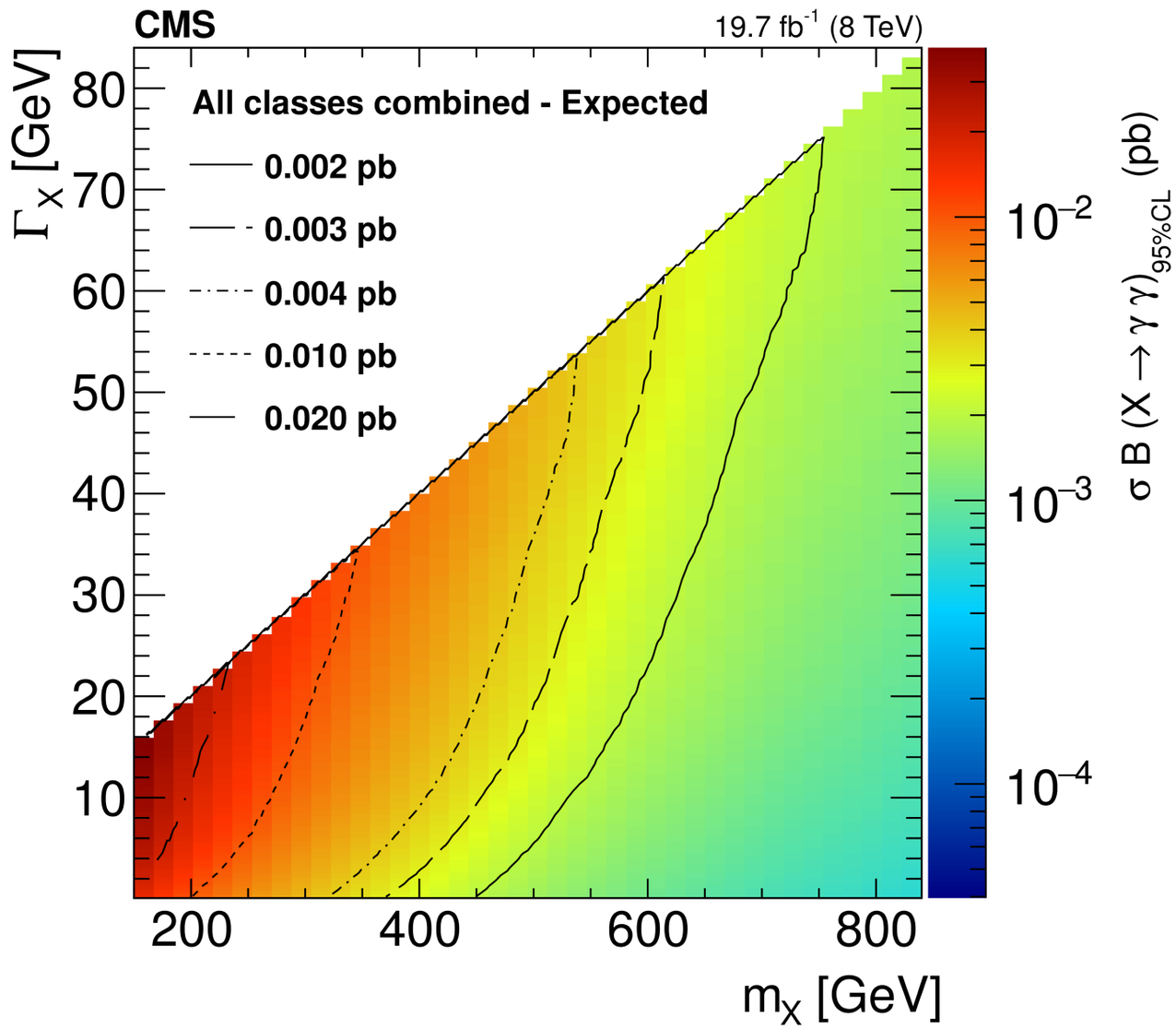
Low Scale Technicolor

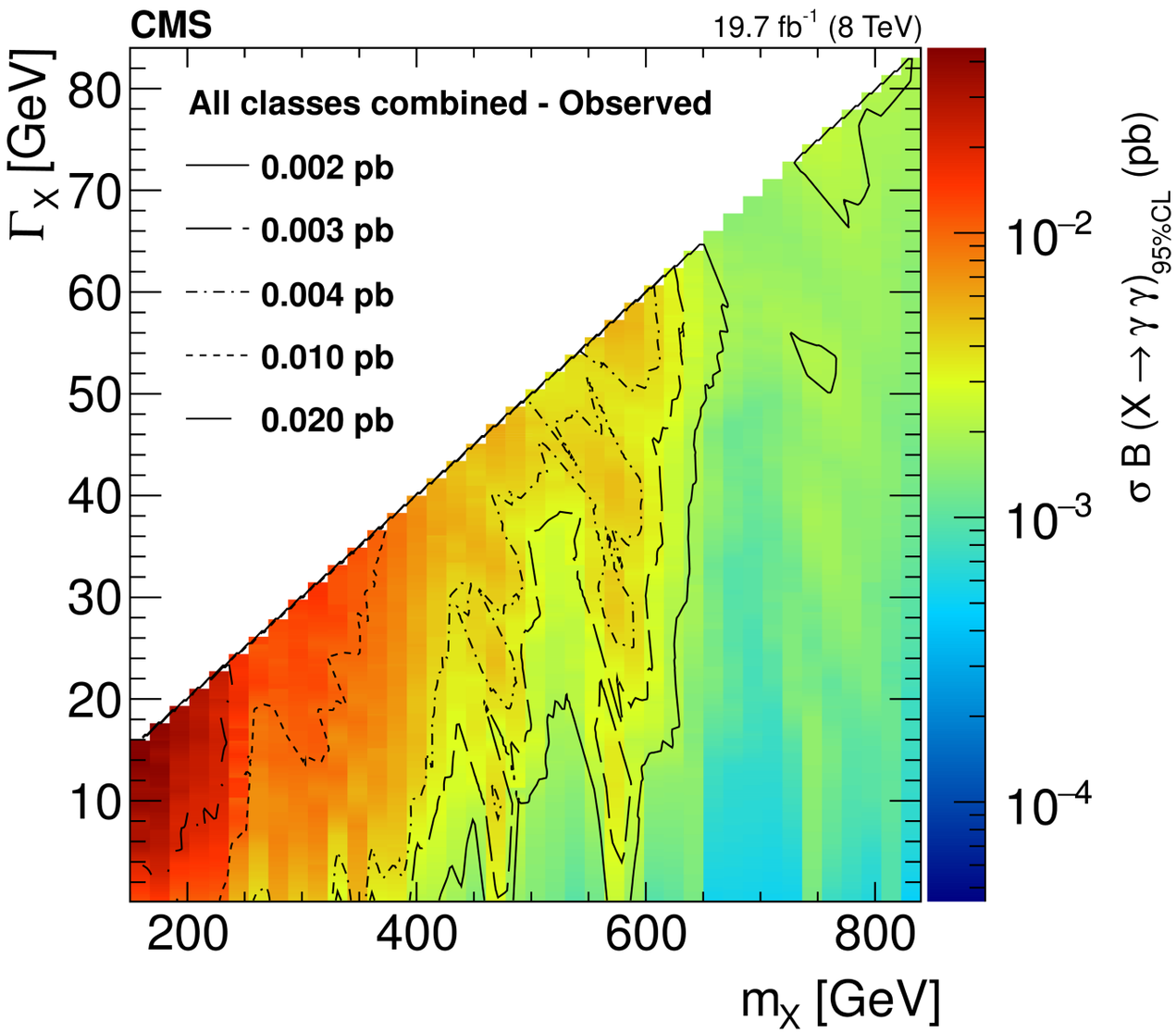


Phenomenological model for a new composite scalar

CMS full H→γγ result

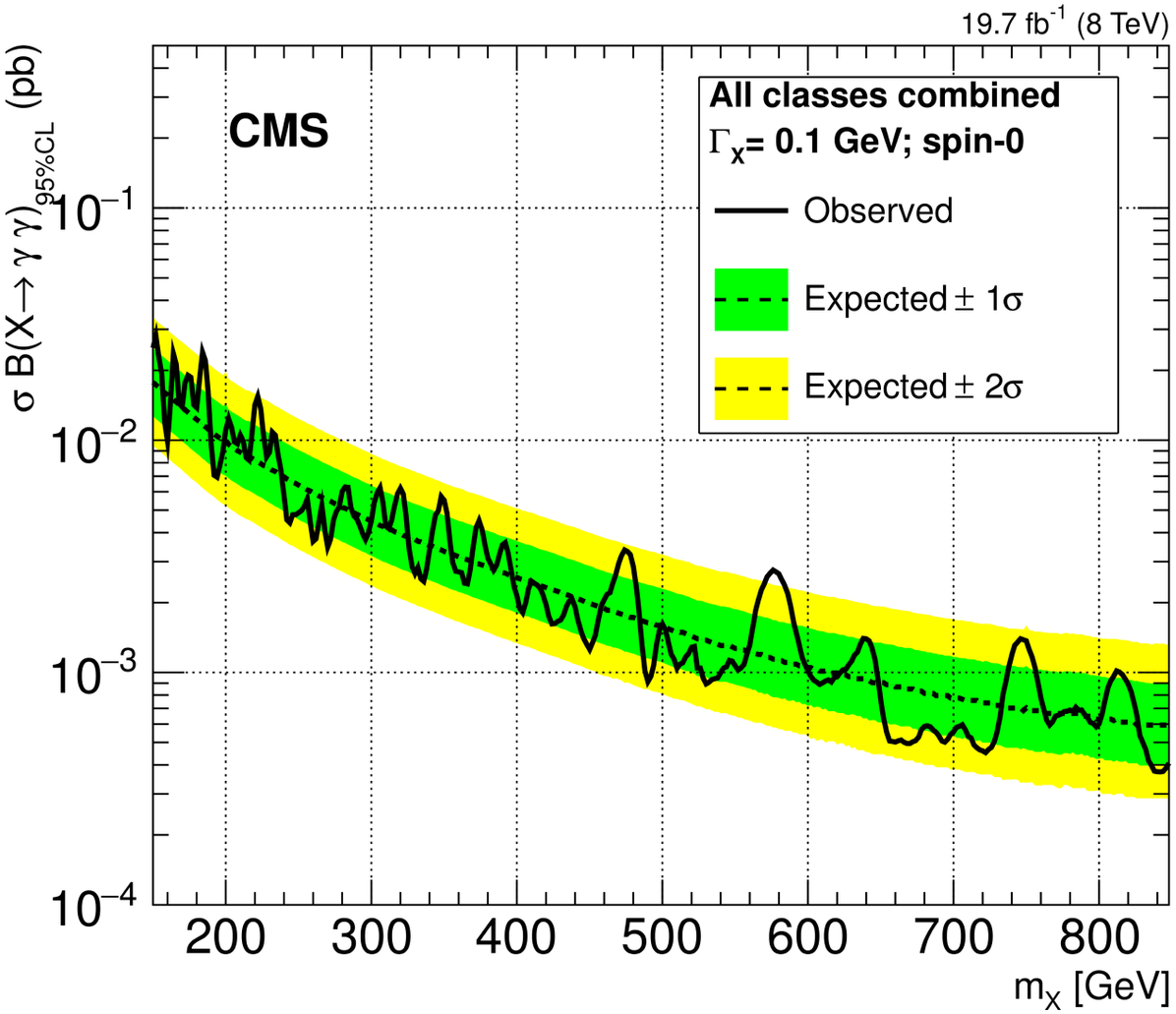
CMS: arXiv:1506.02301

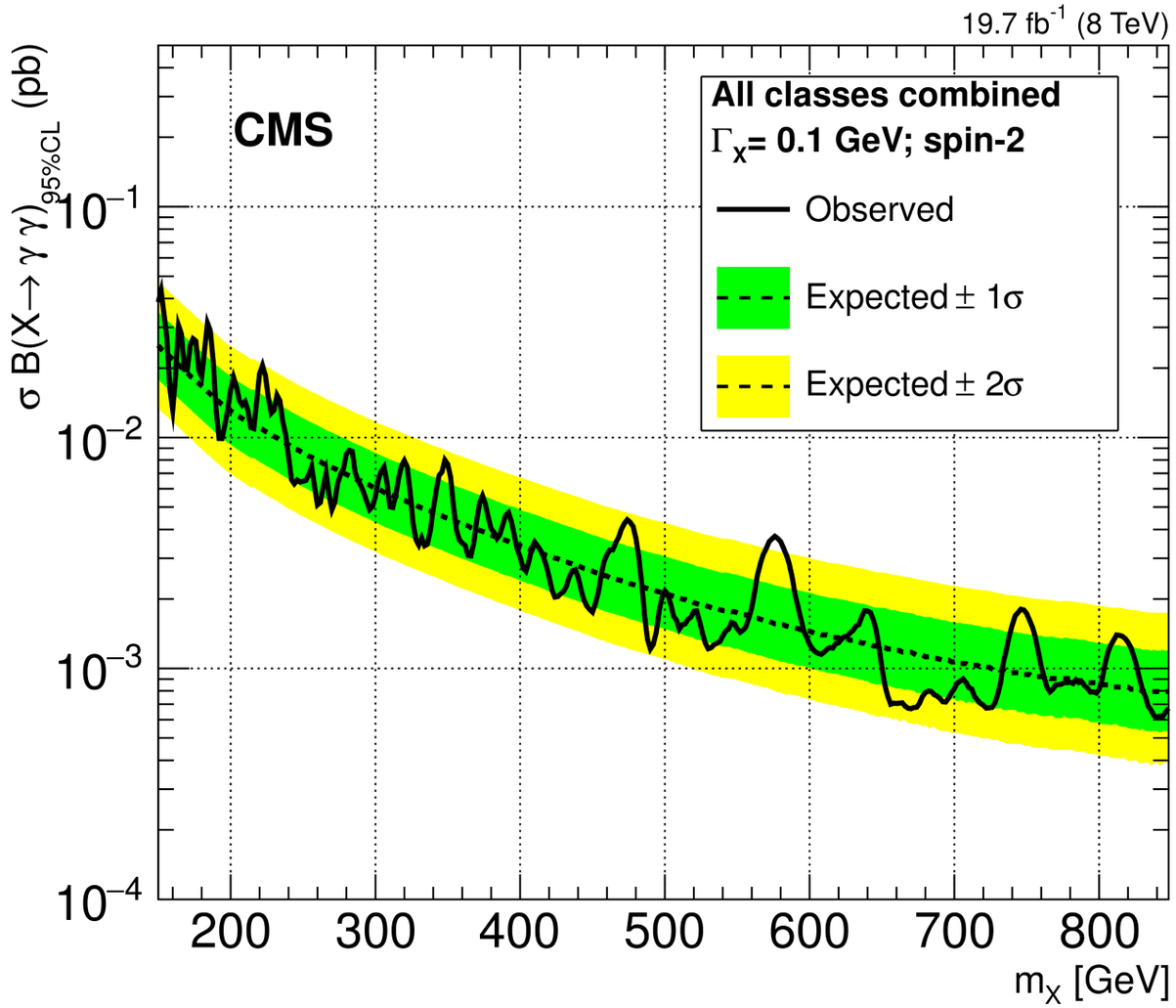




CMS H→γγ: spin-0 vs spin-2

CMS: arXiv:1506.02301

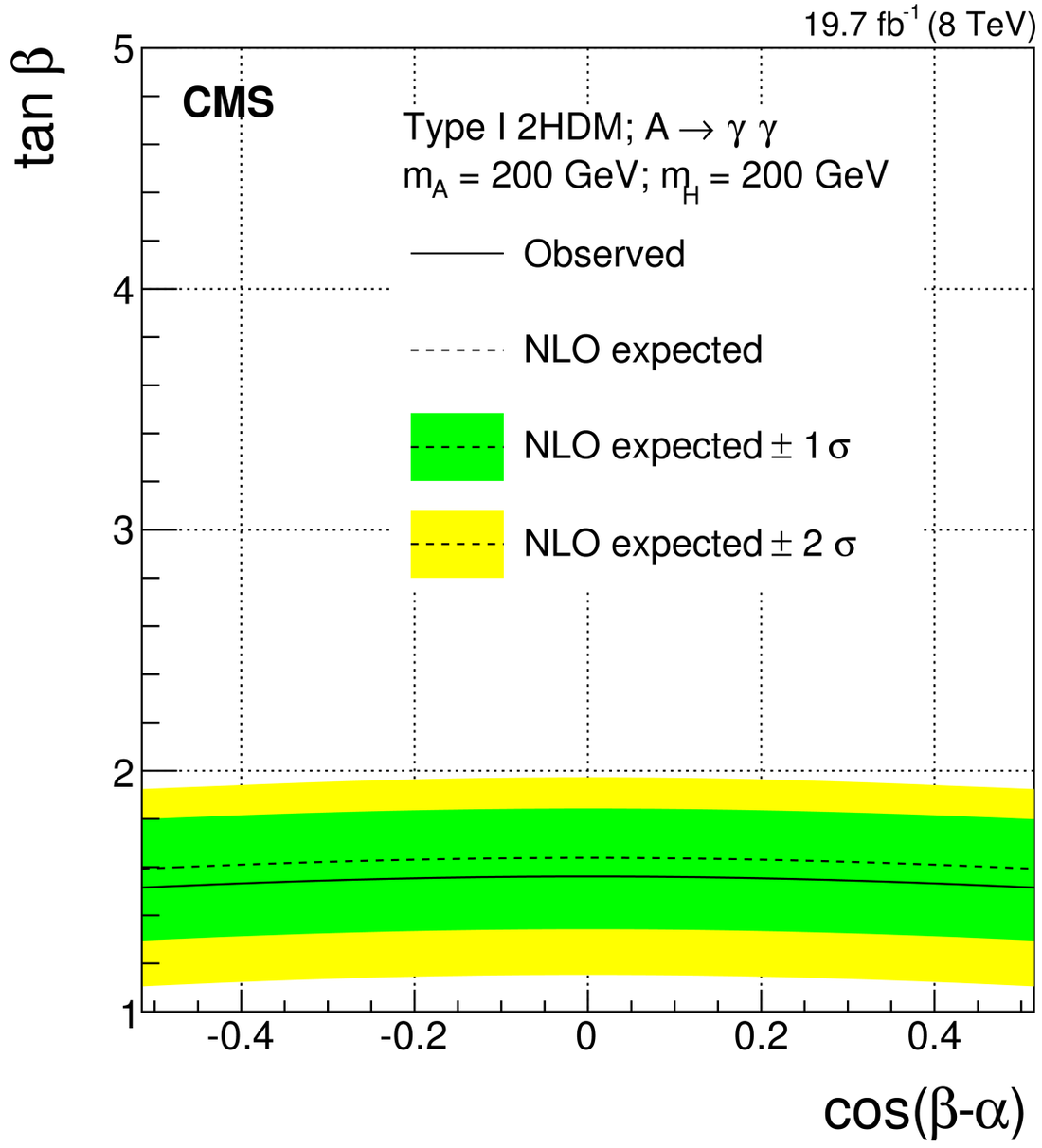


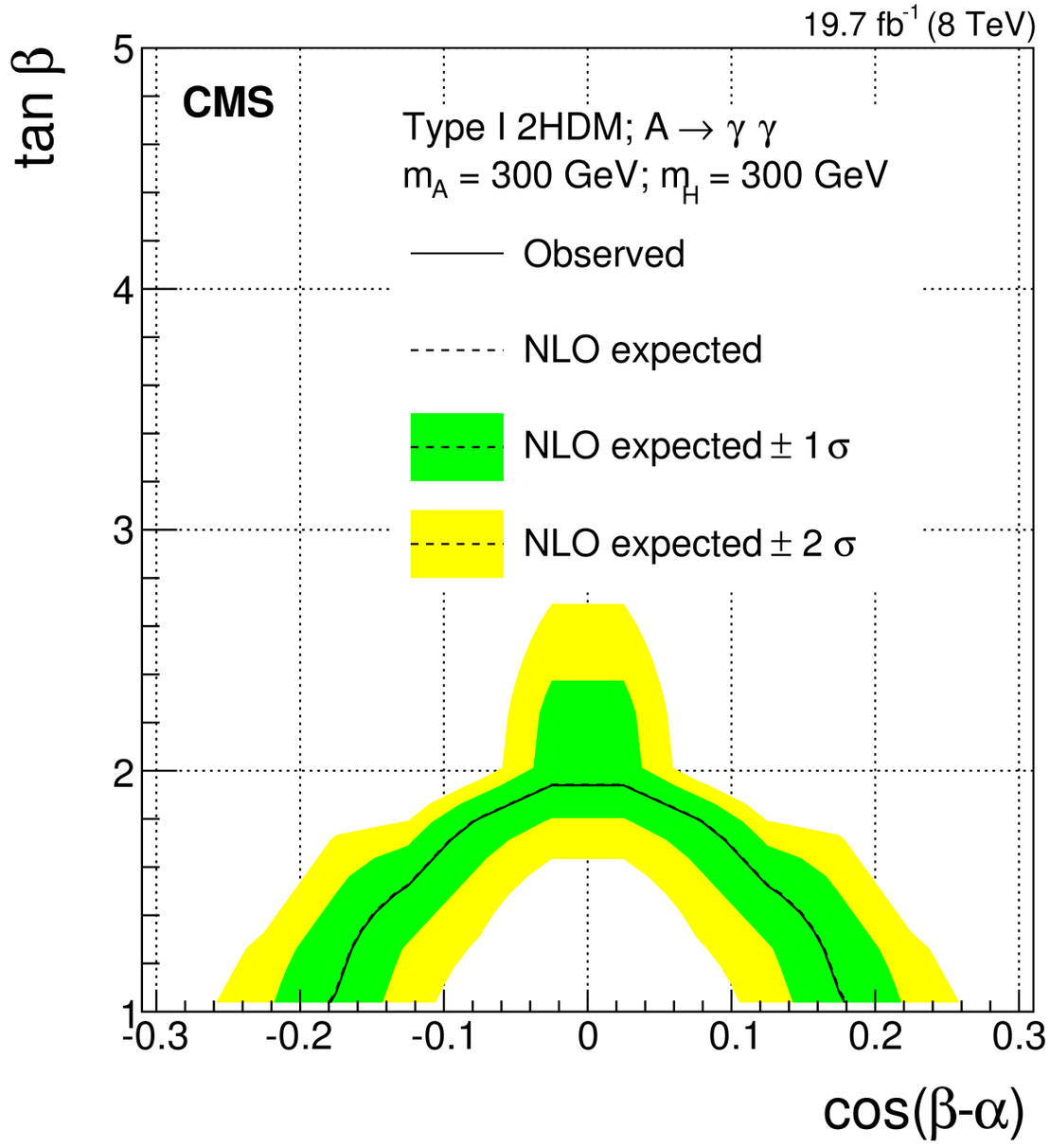


H→γγ: 2HDM results

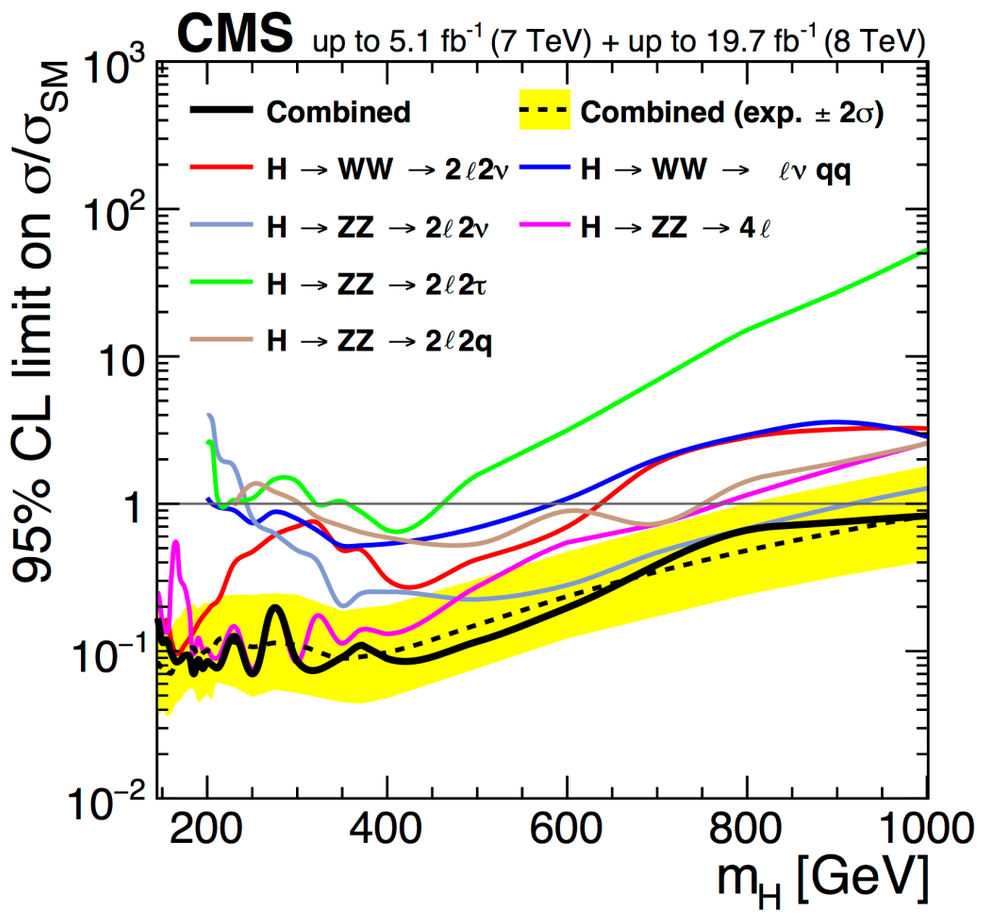
CMS only:
arXiv:1506.02301

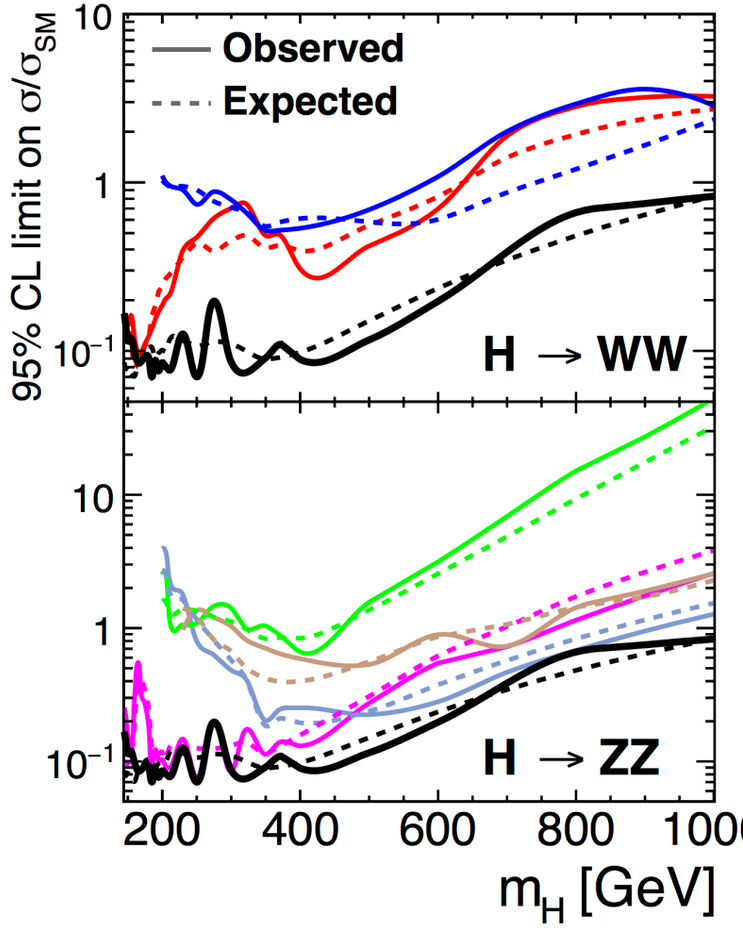
Concerning the 2HDM models CMS sets limits on A→γγ
("no region of the phase space can be excluded for the decay of the heavy H scalar")

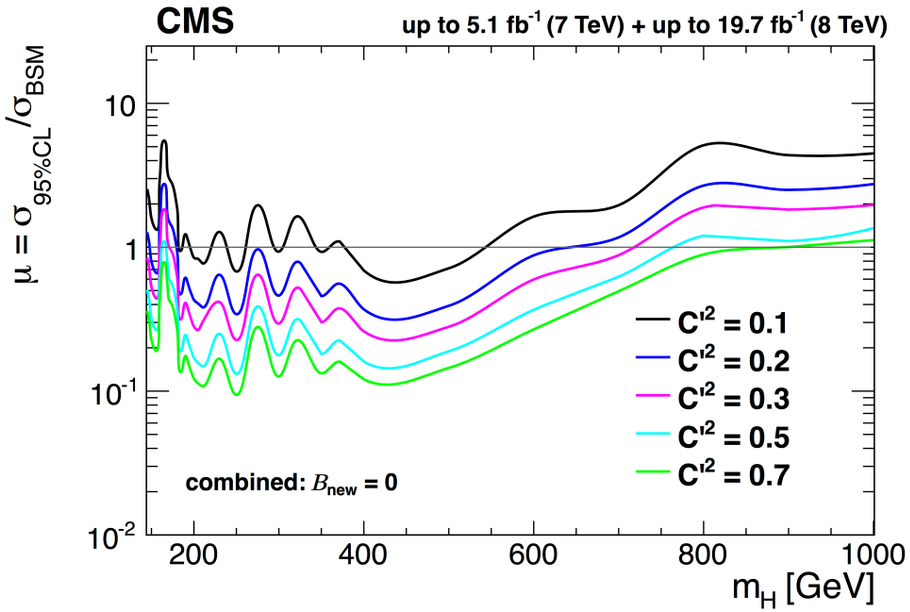




CMS: H→ZZ/WW


CMS up to 5.1 fb-1 (7 TeV) + up to 19.7 fb-1 (8 TeV)
95% CL limit on σ/σSM
Combined
Combined (exp. ± 2σ)
H → WW → 2ℓ2ν
H → WW → ℓν qq
H → ZZ → 2ℓ2ν
H → ZZ → 4ℓ
H → ZZ → 2ℓ2τ
H → ZZ → 2ℓ2q
mH [GeV]


95% CL limit on σ/σSM
Observed
Expected
H → WW
H → ZZ
mH [GeV]


CMS
up to 5.1 fb-1 (7 TeV) + up to 19.7 fb-1 (8 TeV)
μ = σ95%CL/σBSM
C'2 = 0.1
C'2 = 0.2
C'2 = 0.3
C'2 = 0.5
C'2 = 0.7
combined: Bnew = 0
mH [GeV]

Interference

There are several sources of interference in these analyses:

- h(125) + SM continuum
  - fixed in the SM, varies in other models (e.g. 2HDM) depending on the free parameters (tanβ)
  - ATLAS restricts the 2HDM interpretation where the effect is negligible
- h(125) + H
  - varies with the width assumed for H
  - both ATLAS and CMS neglect it (it's covered by conservative systematics)
- H + SM continuum
  - varies with the width assumed for H
  - ATLAS restricts to values of Γ_H in which H is still "narrow"
  - CMS takes it into account