Beyond the SM Higgs Searches in the CMS Experiment

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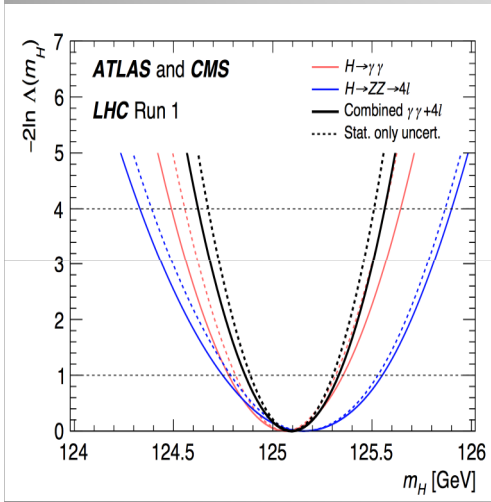
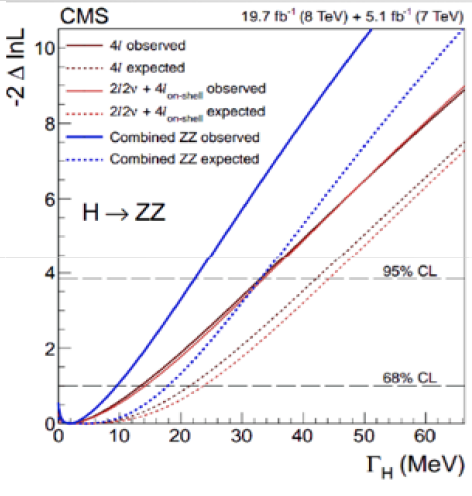
- Exotic Higgs Decays
- Search for new Higgses: high and low mass
  - 2HDM, MSSM, NMSSM…
- Charged Higgs searches
- Summary

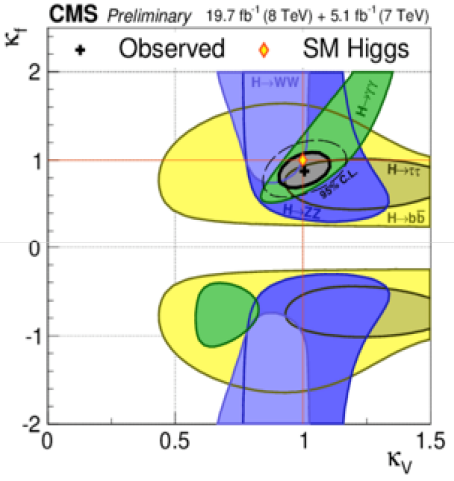
- No significant signal to report so far
- Exclusions of BSM space

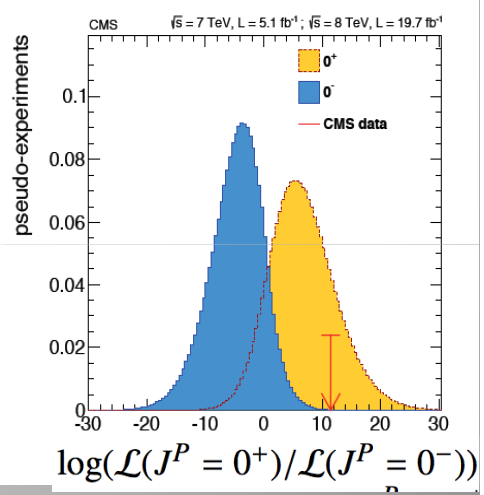
The Higgs Particle

We know already a lot on this Brand New Higgs Particle!!









Mass = CMS+ATLAS
125.09 ±0.21(stat)
±0.11(syst) GeV

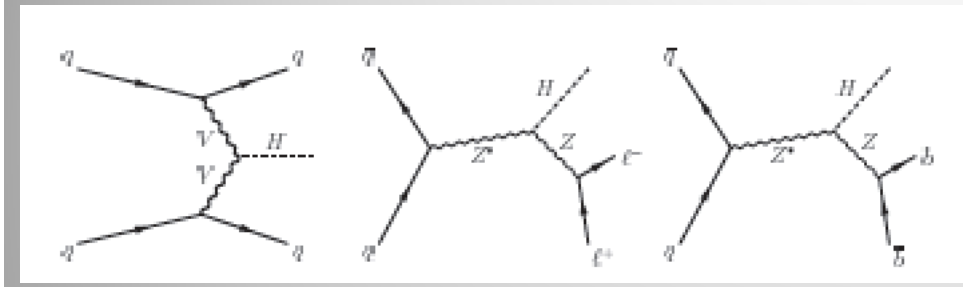
Width =
A: < 24 MeV
C: < 22 MeV
(95%CL)

Couplings are within 20% of the SM values

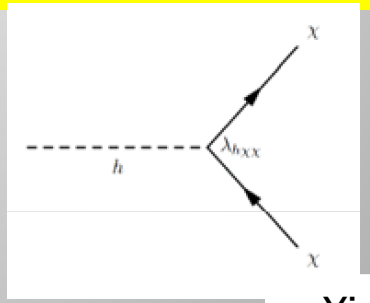
Spin =
$0^{+(+)}$ preferred over 0^{-},1,2

SM-like behaviour for most properties, but continue to look for anomalies, i.e. unexpected decay modes or couplings, multi-Higgs production, other Higgses…

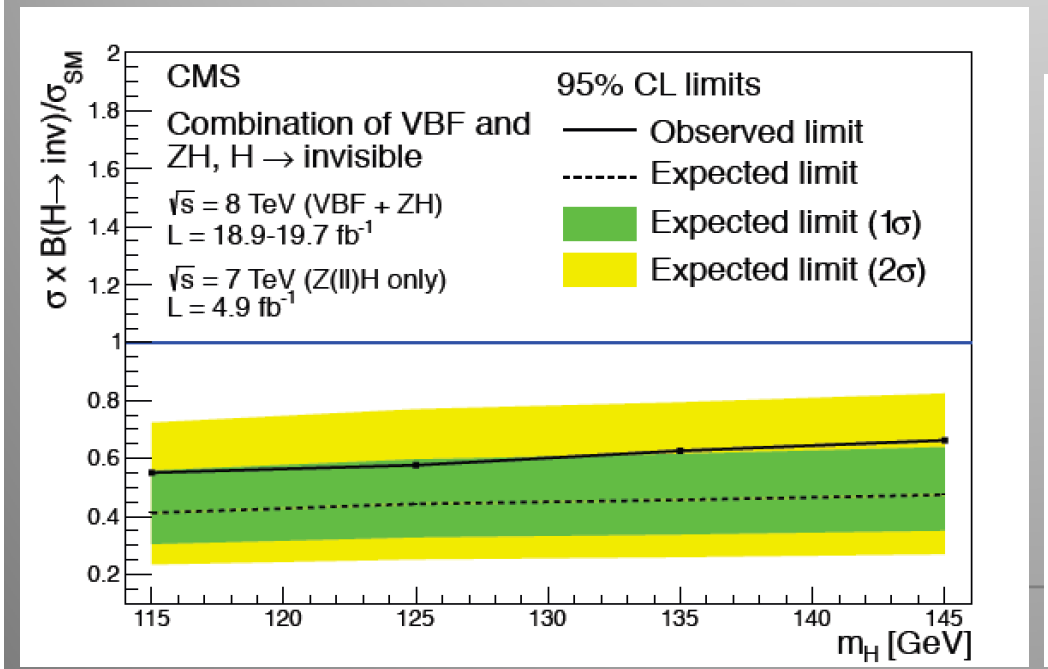
Invisible Higgs Decay Channel



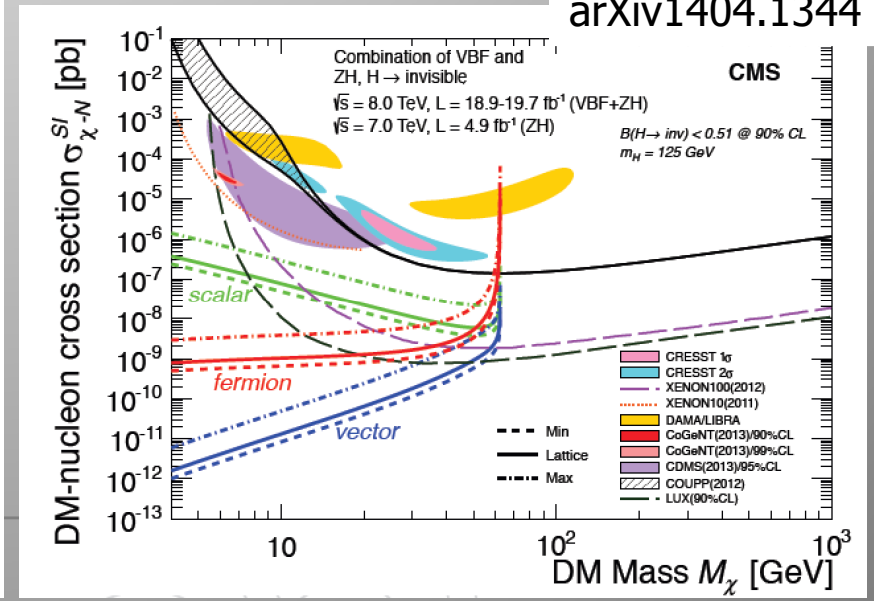
Search for invisible Higgs decays using
Z+H → 2 leptons + missing E_T
VBF H → 2 jets + missing E_T
Possible decay in Dark Matter particles
(if $M<M_H/2$): Higgs Portal Models



Combined result from the three channels
BR(H→invisible)<58%(44% exp) at 95% CL.
for a Higgs with a mass of 125 GeV



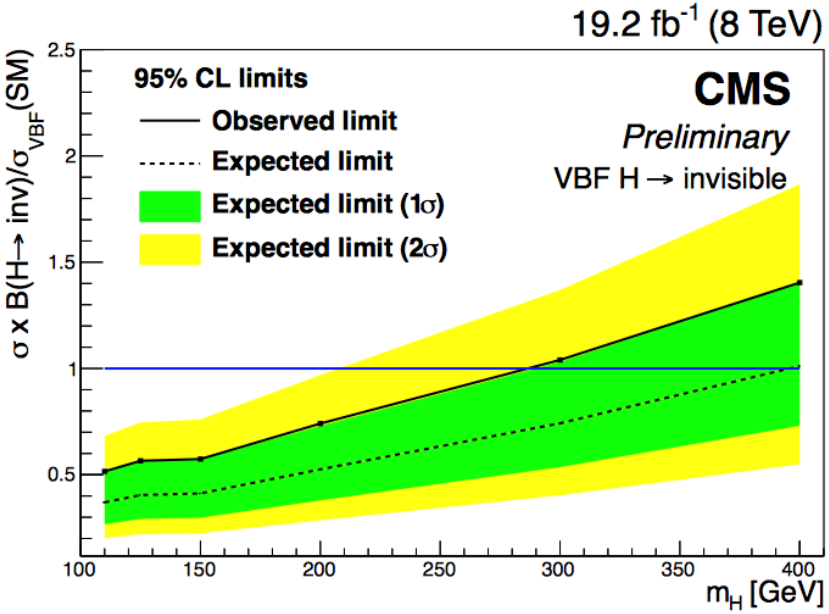
arXiv1404.1344



New: Invisible Higgs in VBF

- VBF process with $p_T > 35(30)$ GeV, $M_{jj} > 700$ GeV and $\Delta\eta_{jj} > 3.5$ parked dataset with 11 fb^{-1} in run1
- BR(H → inv) = 0.57 (0.40) observed (expected) at 95% CL. Previous CMS limit level in the VBF channels was 0.65 (0.49)
- The 95% C.L. observed (expected) limit combining all channels is 47% (35%) for a SM 125 GeV Higgs boson.

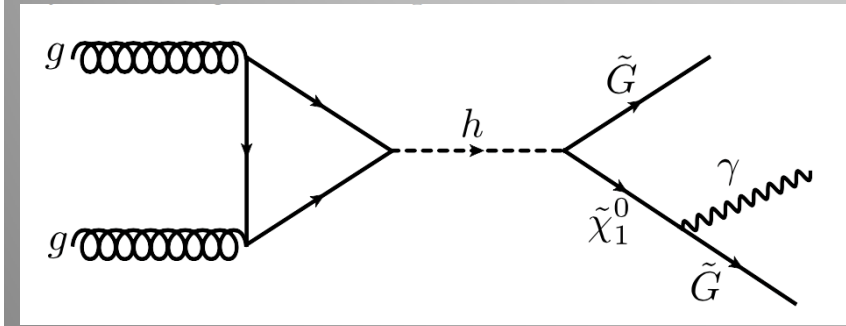
HIG-14-038

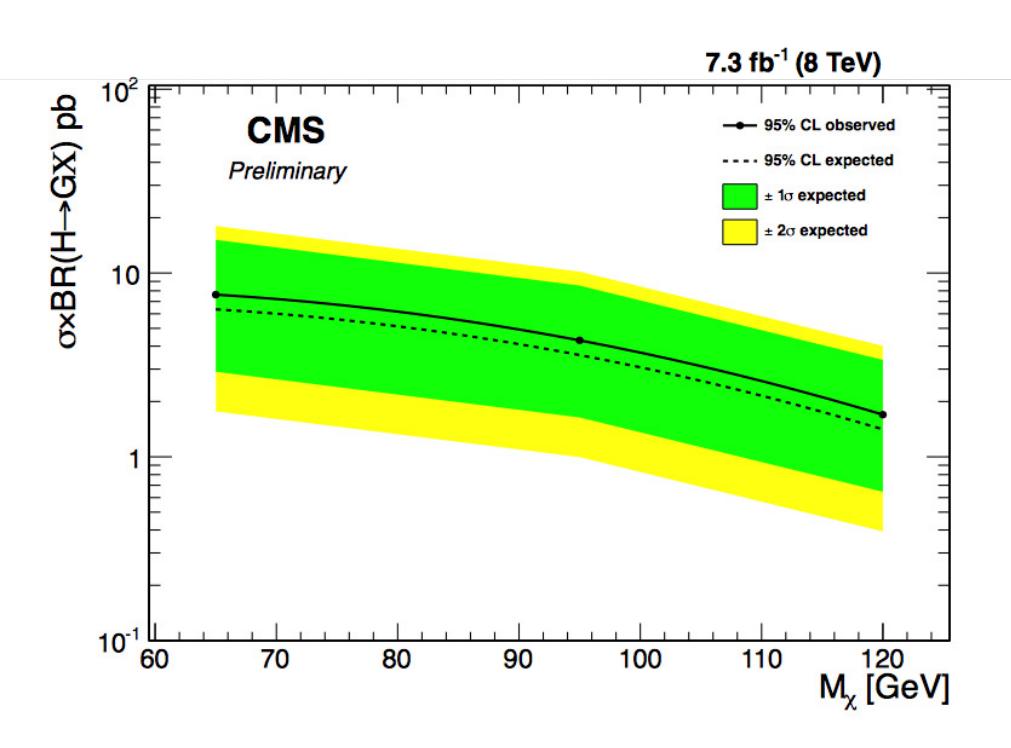


Search for Photon and Missing E_T

- Exotic Higgs decay to photon and MET (GMSB Models)
- Using the parked data set with low energy single-photon thresholds for searches based on 7.3 fb^{-1}
- Search for a photon with a transverse energy of at least 45 GeV and missing transverse energy

HIG-14-025

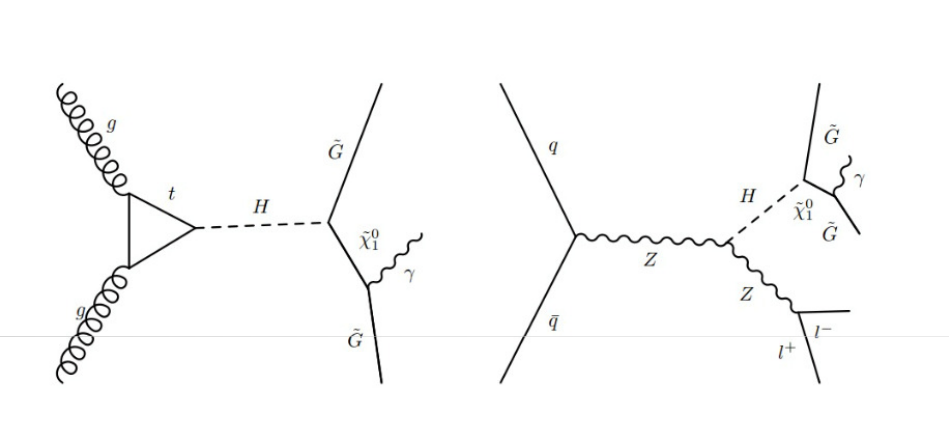




No signal: cross section x BR limits in the range 1.8-8 pb

Search for Photon and Missing E_T

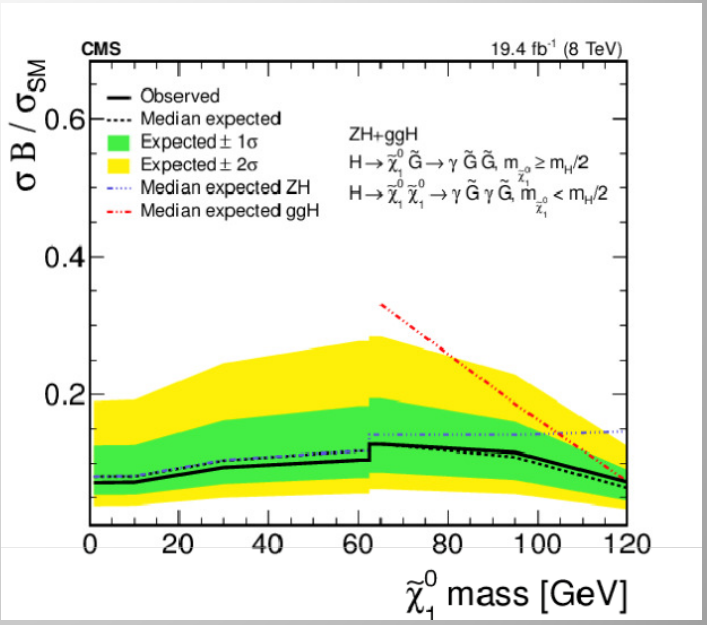
Extended for the publication with HZ channel

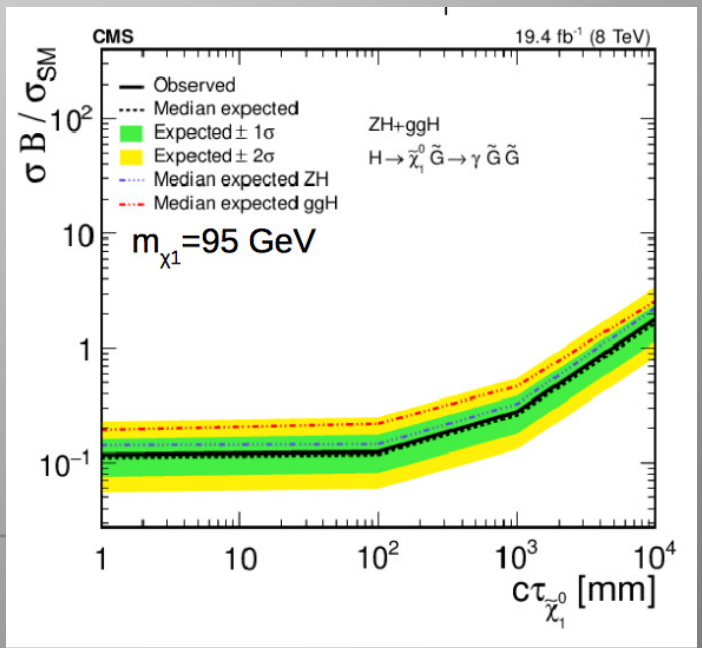


arXiv:1507.00359

- $h \to \tilde{G}+\chi_1$ ($m_h/2 < m_{\chi 1} < m_h$)
- $h \to \chi_1\chi_1$ ($m_{\chi 1} < m_h/2$) 2 photons

Limits expressed versus neutralino mass and cτ of the neutralinos

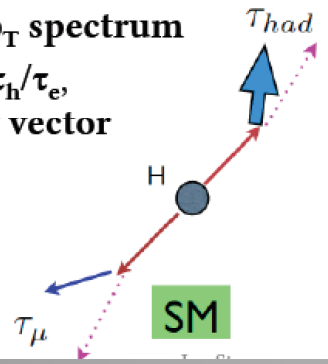


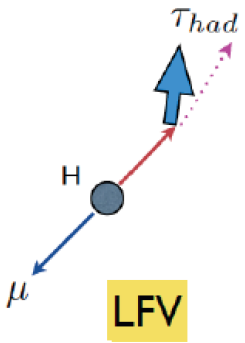


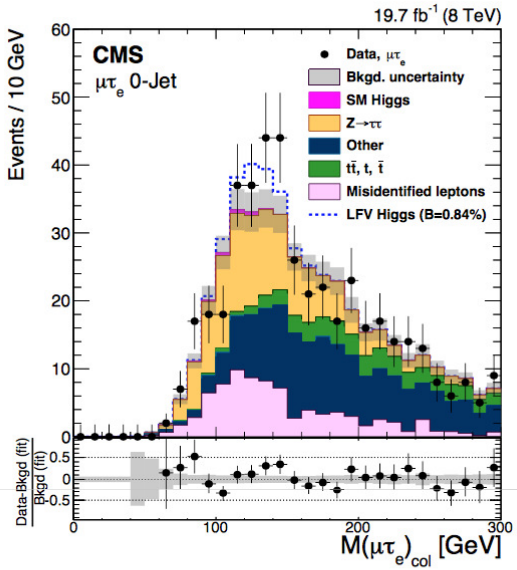
Search for LFV Decays: H →μτ

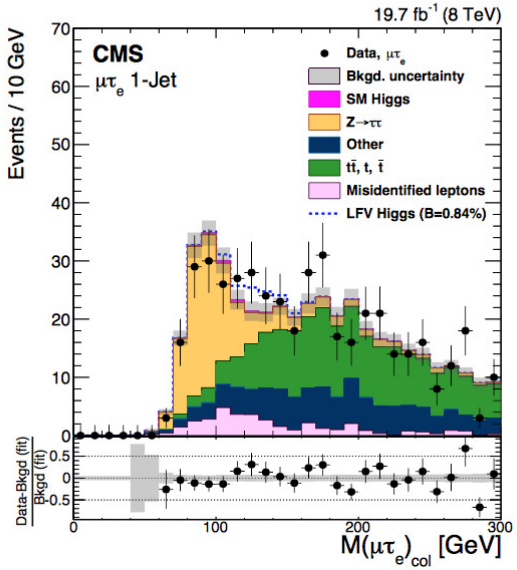
arXiv:1502.07400

- Previous best limits on B(H⟶μτ) <~ 10% from reinterpretation of LHC H⟶ττ searches and from τ⟶μγ arXiv:1209.1397
  - **Can do better with first dedicated search**
- Consider hadronic (τ_h) and electron (τ_e) tau decays
- Same basic event selection and jet categories as SM H⟶ττ analysis (0-jet, 1-jet, VBF-tag)
- Differences in kinematics
  - **Harder muon p_T spectrum**
  - **Δϕ between μ, τ_h/τ_e, missing energy vector**



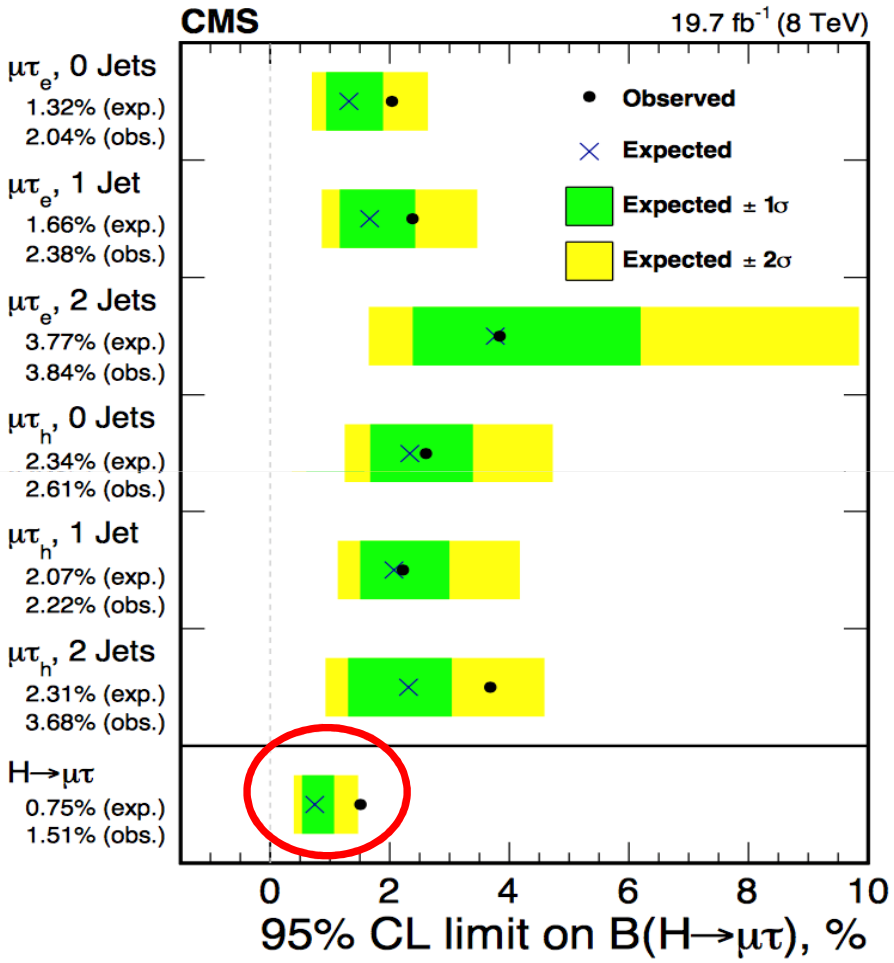






Search for LFV Decays: H →μτ

- Comparable sensitivity from all channels
- $\mathcal{B}(\mathrm{H} \to \mu\tau) < 1.51\%$ at 95%
- **Large improvement of previous limits**
- Background-only p-value of 0.010 (2.4 σ)
  - Best fit $\mathcal{B}(\mathrm{H} \to \mu\tau) = (0.84^{+0.39}_{-0.37})\%$.



Mild excess giving a 2.4σ effect… To be watched!!!
Not contradicted by ATLAS at EPS… ☺

Probing the Yukawa Couplings

- The Limit on the Branching ratio can be used to place limits on the off-diagonal yukawa couplings

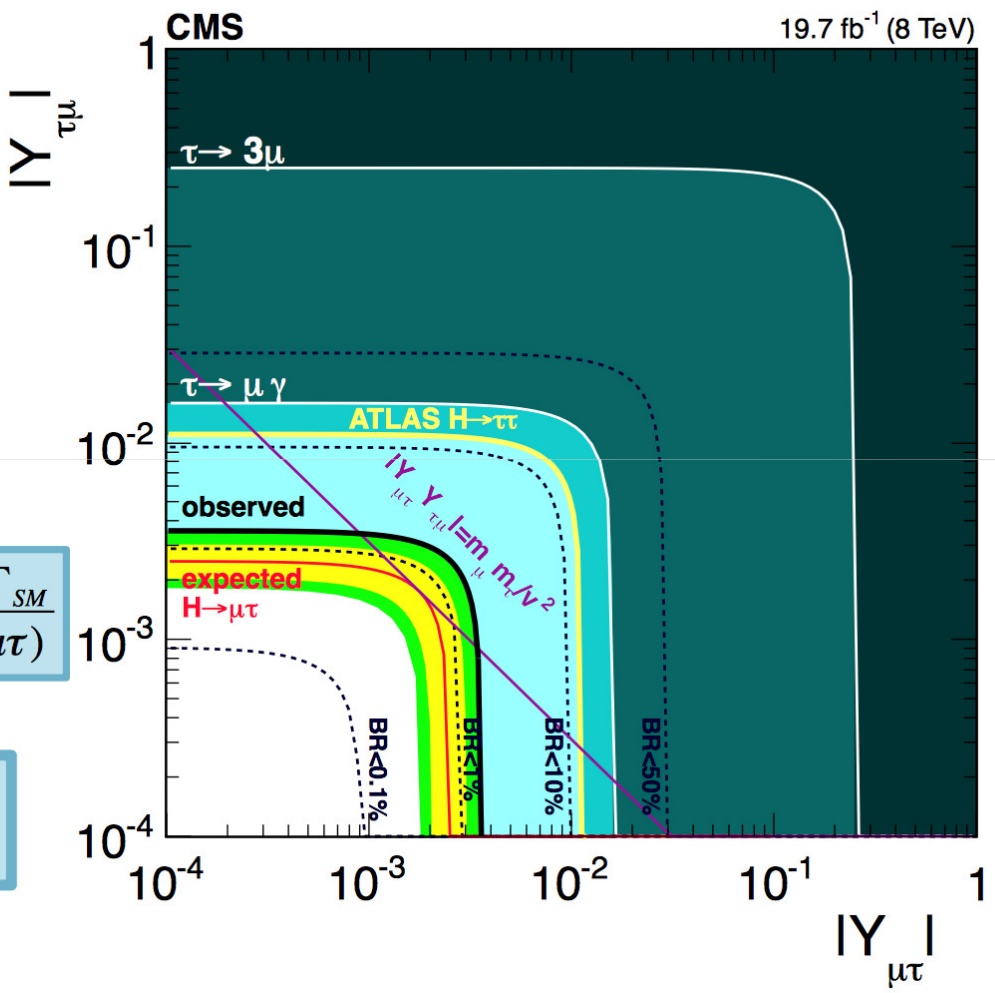
SM values

$$Y = \begin{pmatrix} \boxed{Y_{ee}} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & \boxed{Y_{\mu\mu}} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{\tau\mu} & \boxed{Y_{\tau\tau}} \end{pmatrix}$$

$$\left(|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2\right) = \frac{8\pi}{m_h} \frac{BR(h \to \mu\tau)\Gamma_{SM}}{1 - BR(h \to \mu\tau)}$$

$$\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} < 0.0036$$

(at 95% CL)



H→ eτ and H→eμ results will be released soon

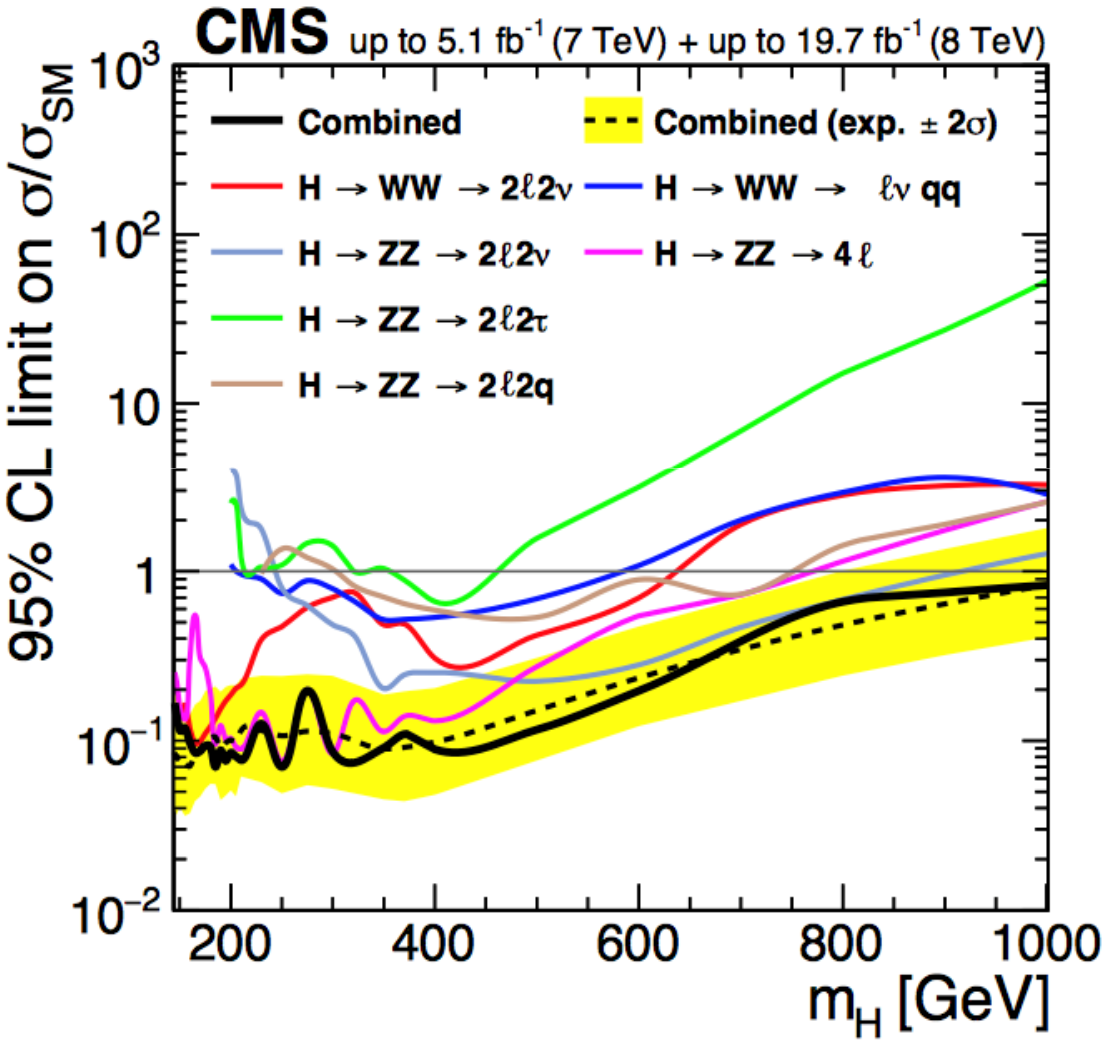
High Mass Search: Higgs → ZZ,WW

High mass Higgs searches with SM channels WW, ZZ with full 2012 statistics

Sensitivity reaches now up to ~ 1 TeV for SM cross sections

Results also interpreted in EWK singlet model

arXiv:1504.00936



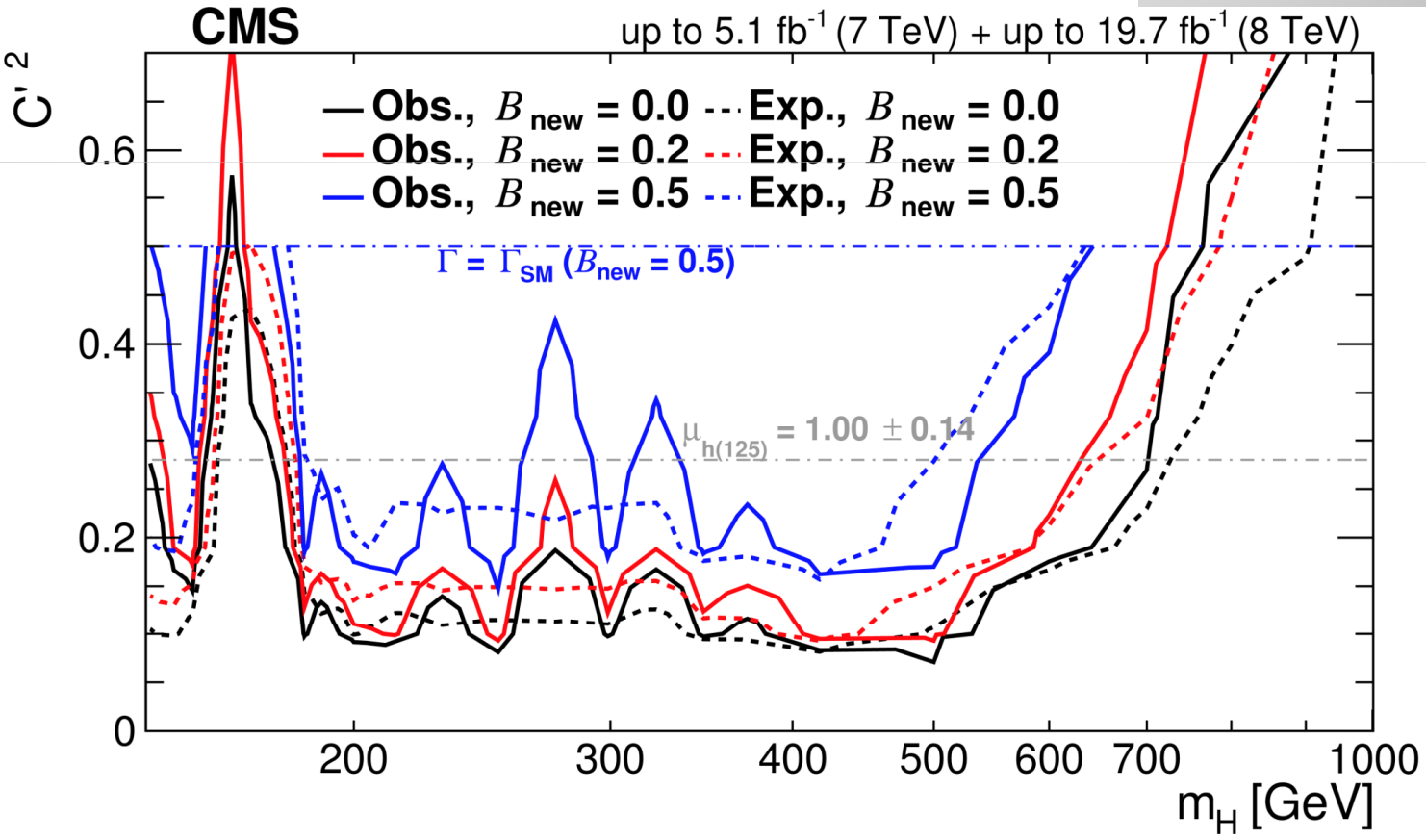
High Mass Search: Higgs → ZZ,WW

- Reinterpretation in terms of EW singlet extension of SM in terms of model parameters:
  - B_{new} : branching fraction of the EW singlet to non-SM decay mode
  - C' : the scale factors of the couplings with respect to the SM of the high-mass Higgs boson
- Only consider cases with $\Gamma_H \leq \Gamma_{SM}$

arXiv:1504.00936

unitarity condition

$$C^2 + C'^2 = 1$$

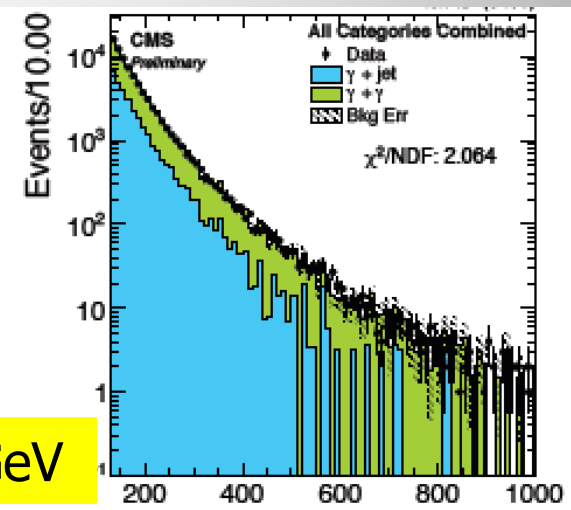


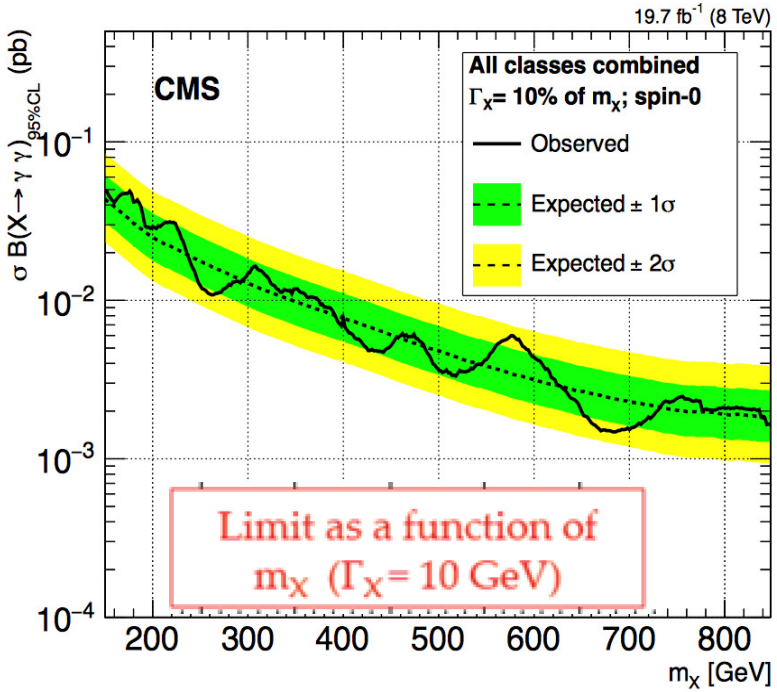
High Mass Search: Higgs → γγ

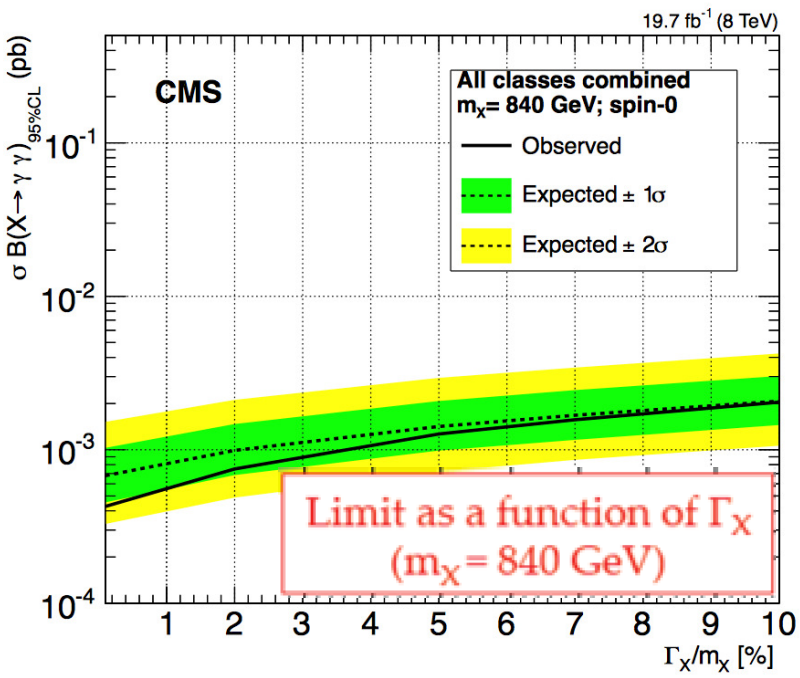
arXiv:1506.02301

- Simplified cut-based selection
- Signal model is double Crystal-Ball convoluted with Breit-Wigner
  - Such that the signal width and mean scale appropriately with m_H
- Limits on σ_{xs}•BR produced as a function of m_X and Γ_X

No excess found (for small/big width): 150-850 GeV





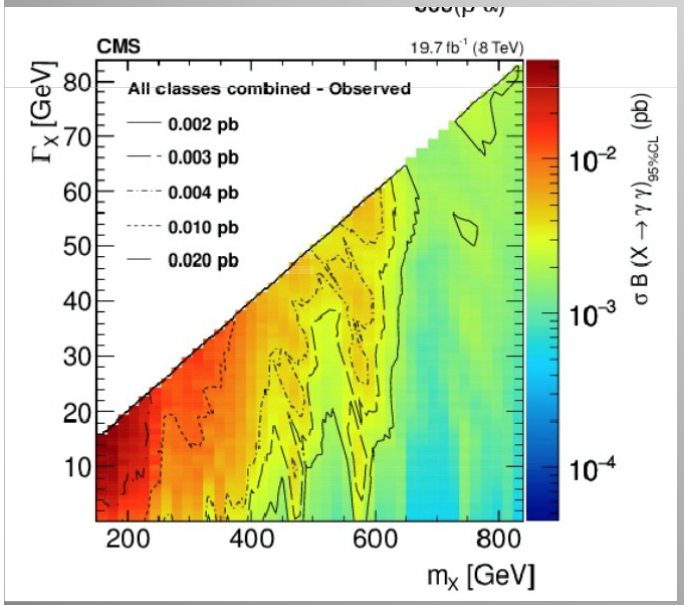


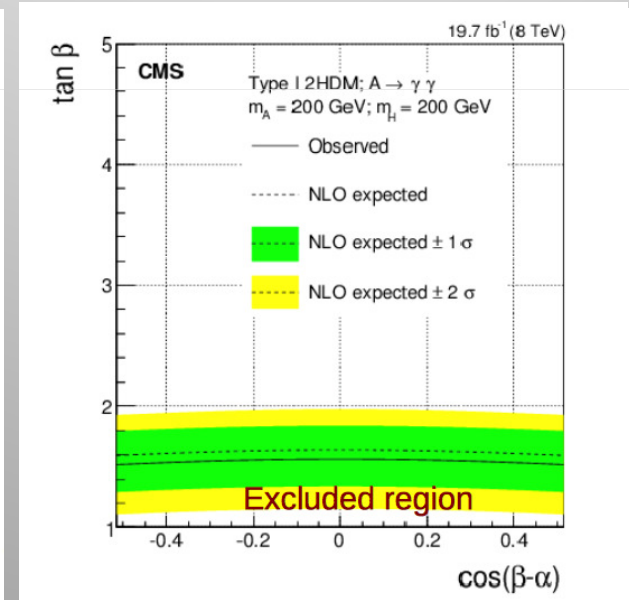
High Mass Search: Higgs → γγ

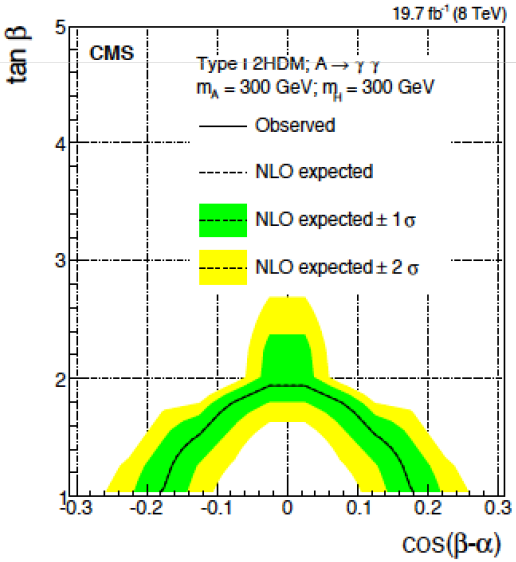
Test 2HDM models (Type-I)

H and A production and decay to two photons depend on α and β parameters

Exclusion region only for A decay to two photons



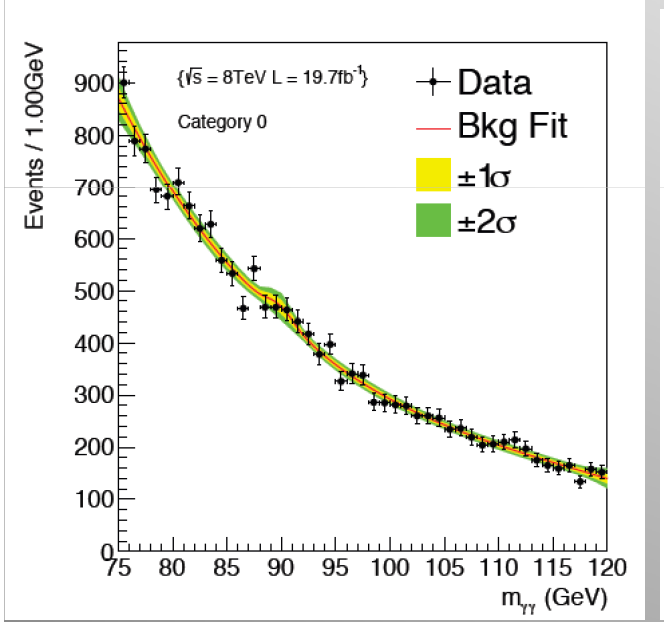


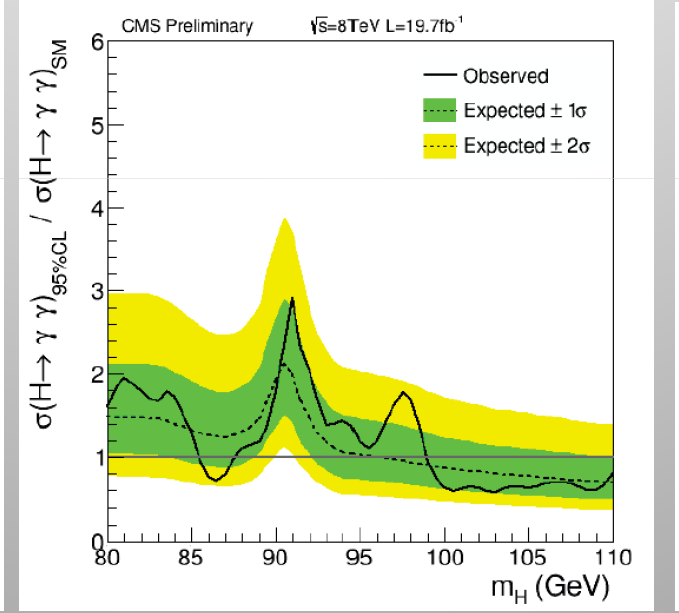


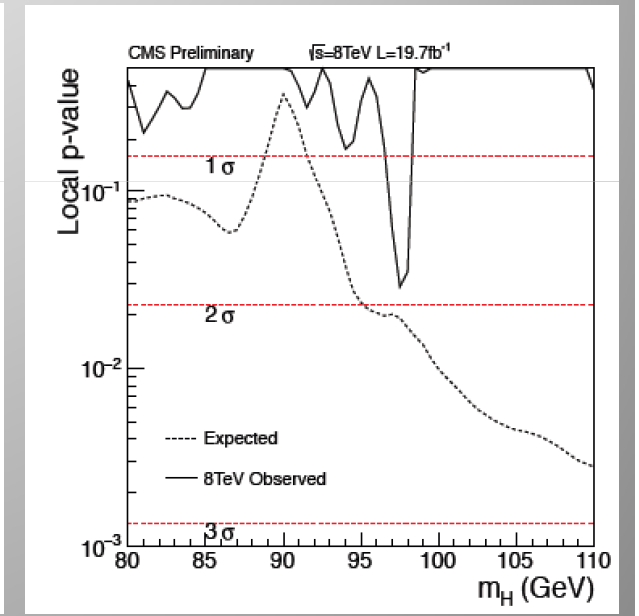
Low Mass Search: Higgs → γγ

New: Search for excess of events in range 80 < $m_{\gamma\gamma}$ < 110 GeV
The main challenge is the region around 90 GeV
- Include extra 2-sided crystal ball function for electron missID @ 90 GeV

HIG-14-037





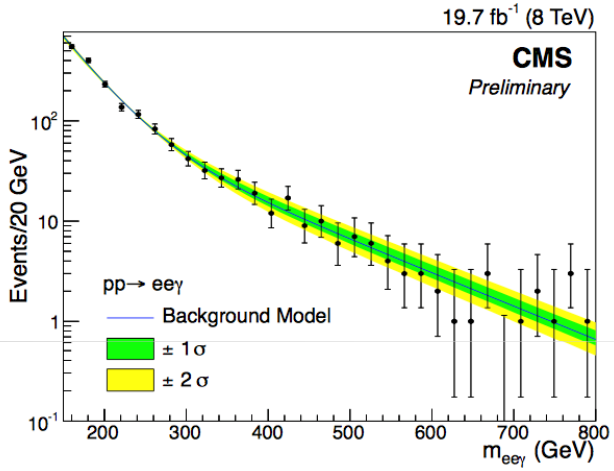


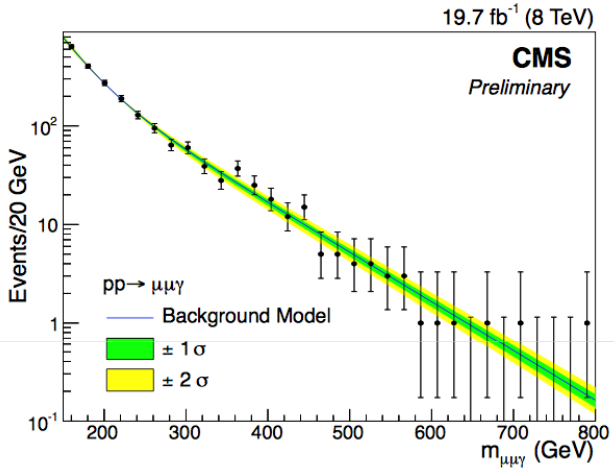
Max deviation around 97.5 GeV (1.9σ w/o LEE)

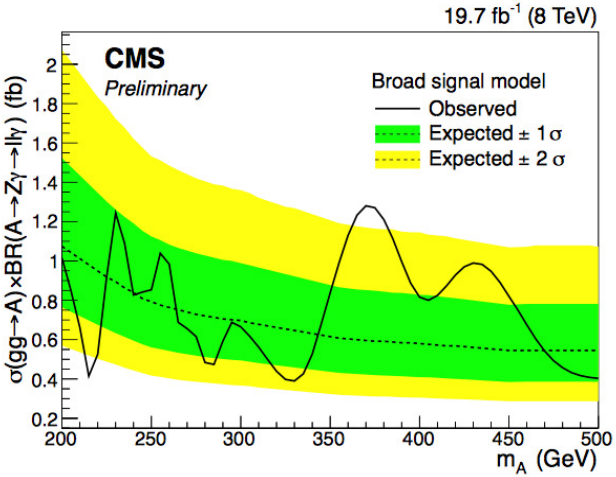
No significant excess found

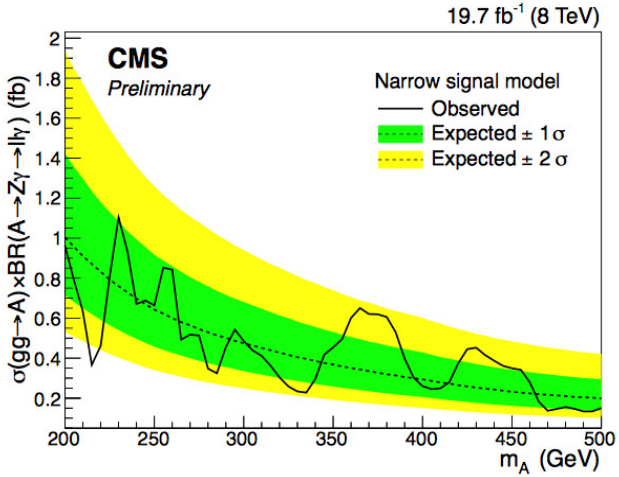
High Mass Search: Higgs → Zγ

- No excess SM predictions in the 200--500 GeV mass range. Observed limits are between 0.2 and 1.4 fb.







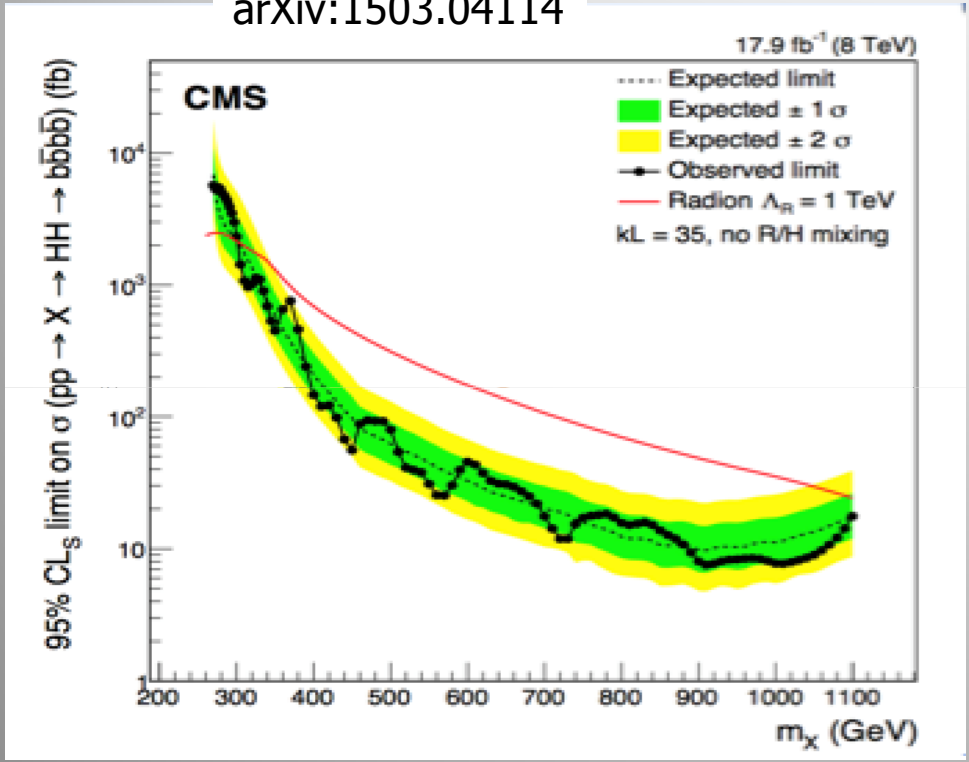


HIG-14-031

Search for X→HH→bbbb and γγbb

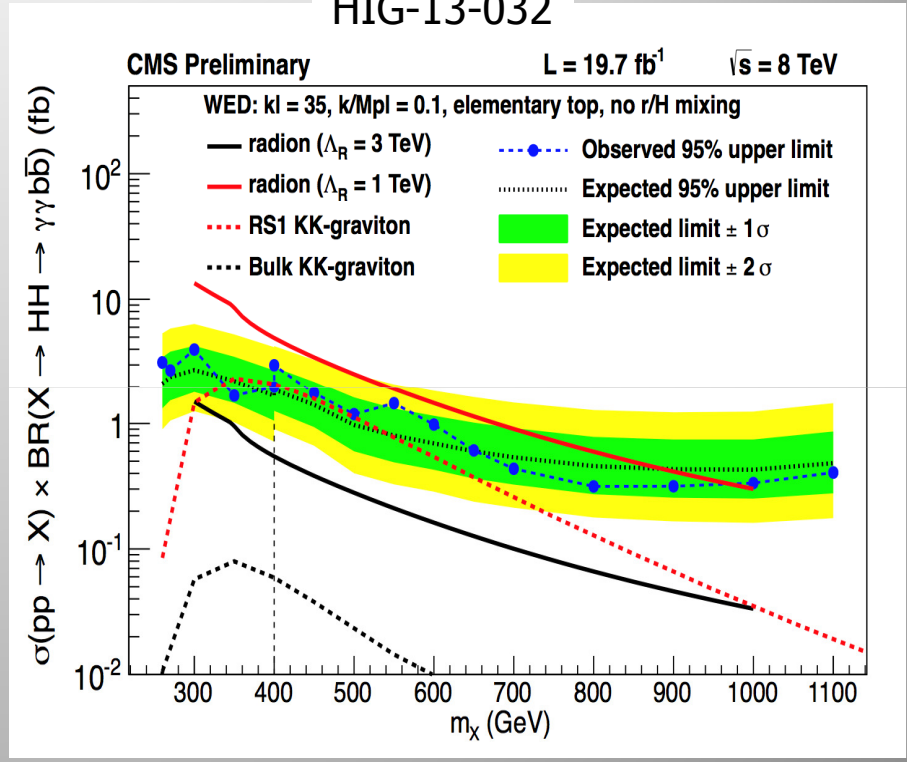
$$pp \rightarrow X \rightarrow H(b\bar{b})H(b\bar{b})$$

arXiv:1503.04114



$$X \rightarrow HH \rightarrow \gamma\gamma b\bar{b}$$

HIG-13-032



Search for Resonant production

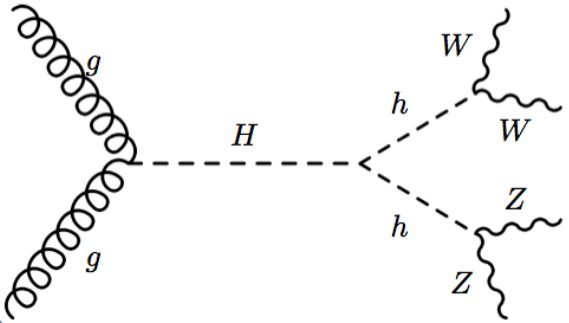
Studies for spin-0 or spin-2 Resonances

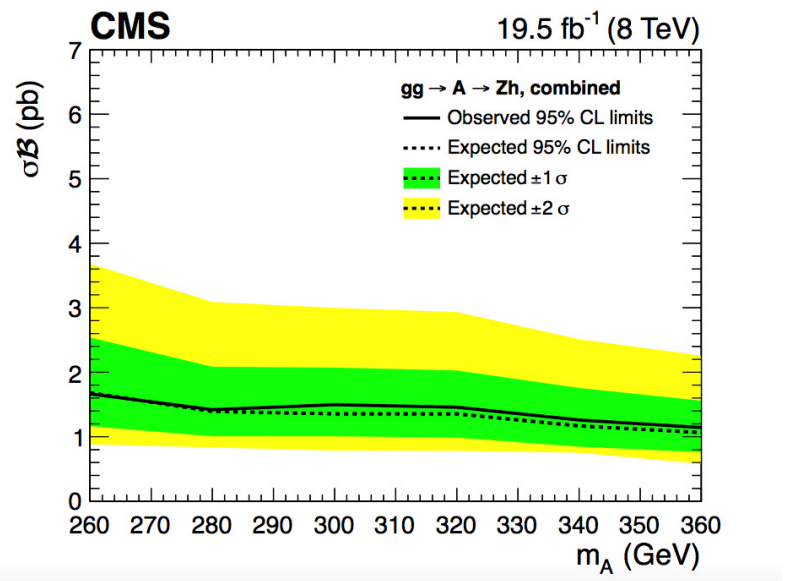
No signal found in the range of 270-1100 GeV!

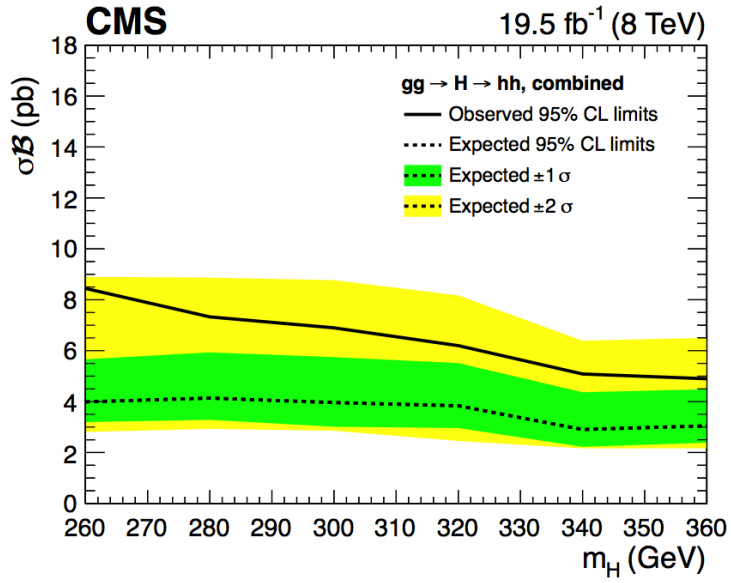
Search for H→hh and A→Zh

arXiv:1410.2751

- Search for decays of heavy scalar H→hh and pseudo-scalar Higgs boson A→Zh
  - h is a SM-like Higgs boson
  - h is assumed to have SM branching fractions
- Use multileptons and γγ+leptons channels

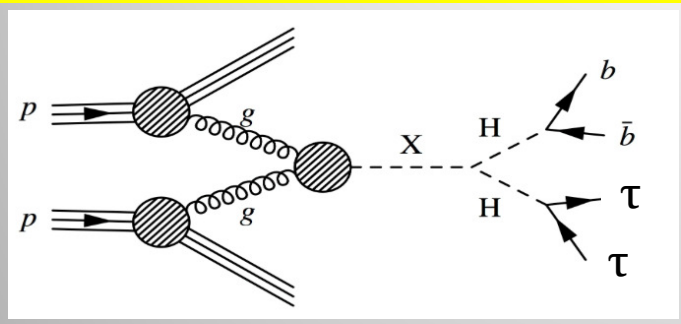


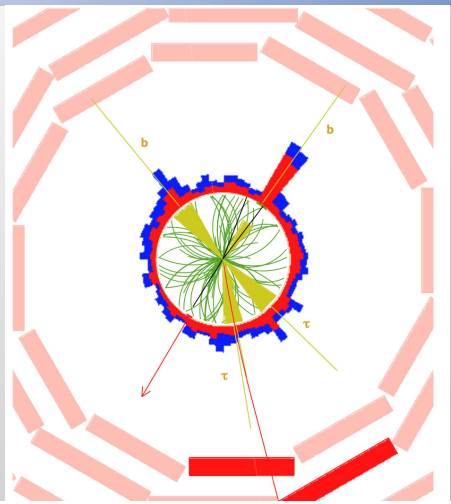


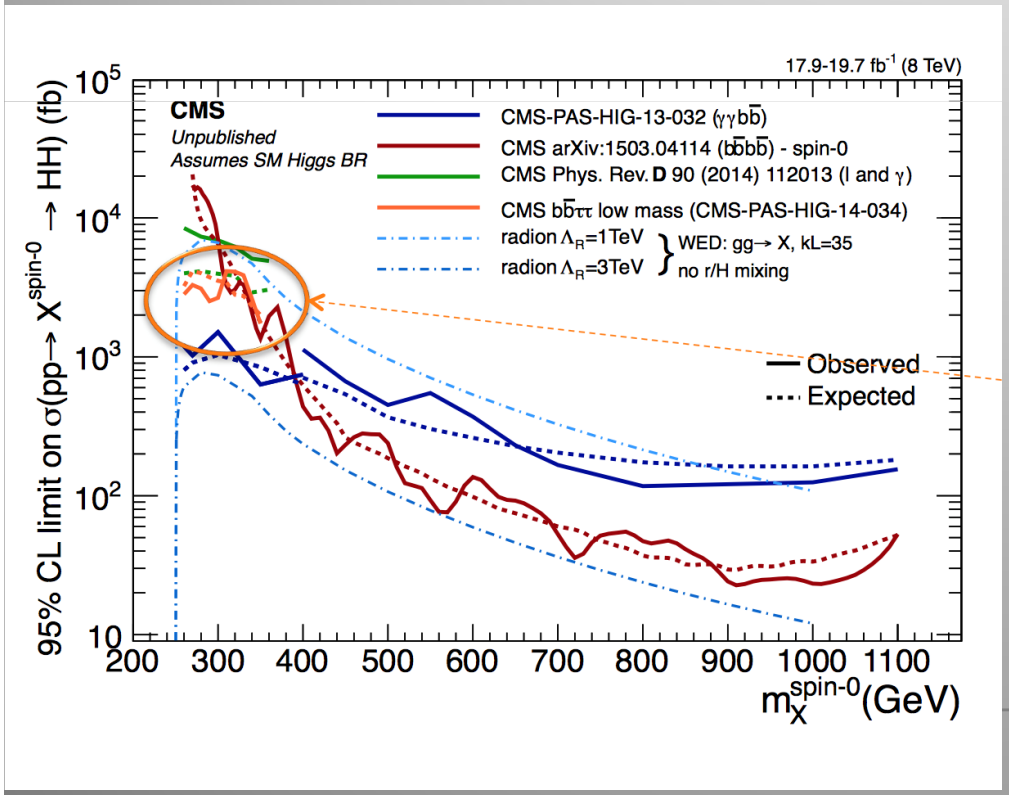


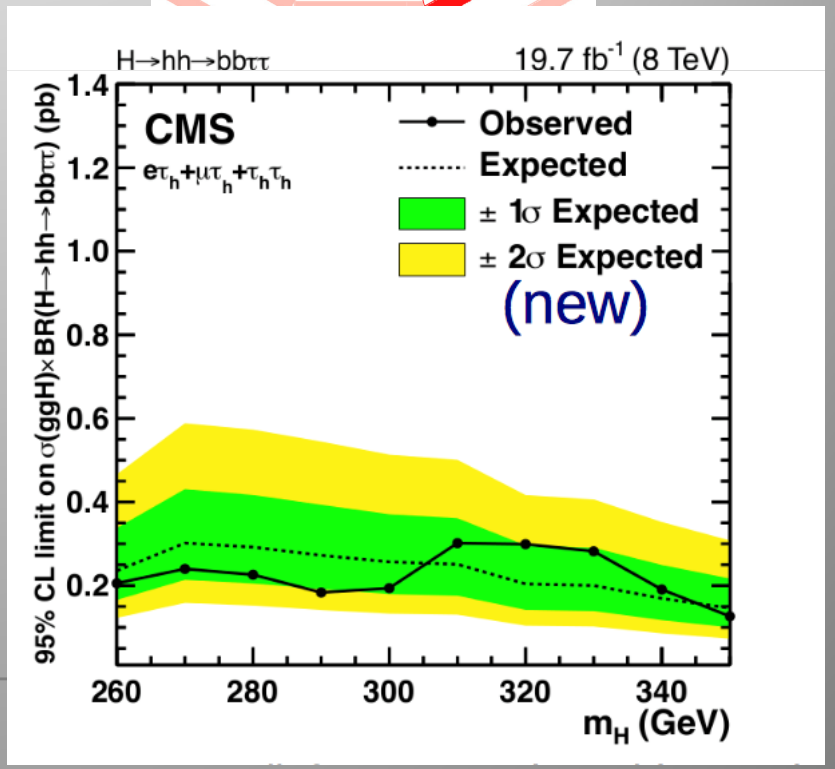
Search for X→HH→bb tautau

New channel studied! No excess observed









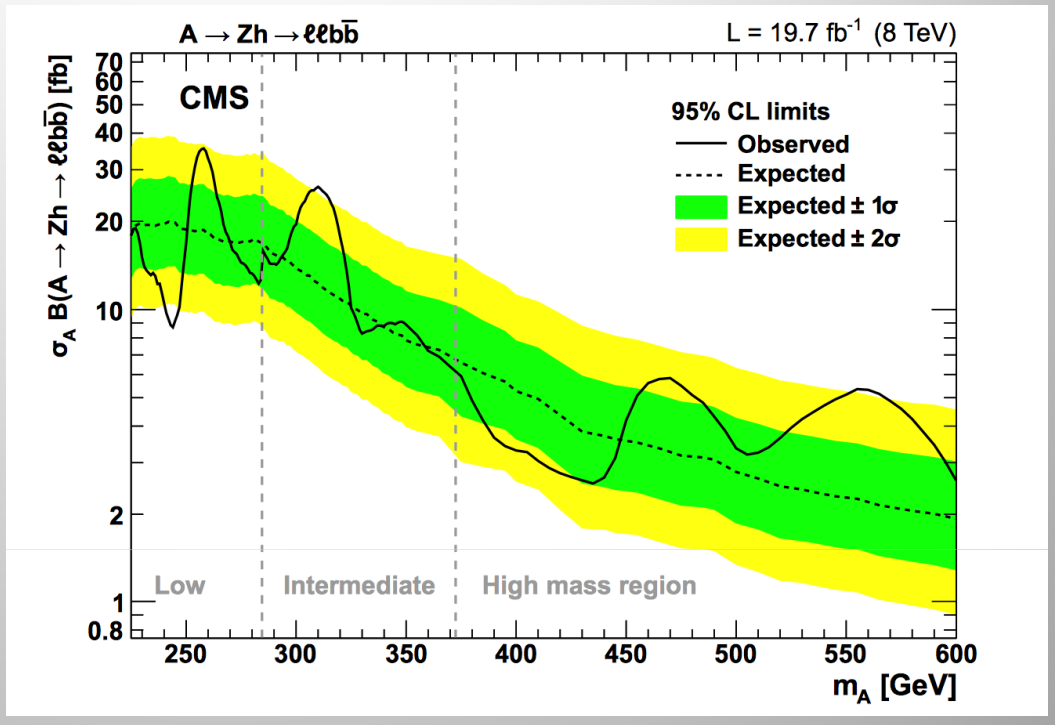
Search for A→Zh with h→bb

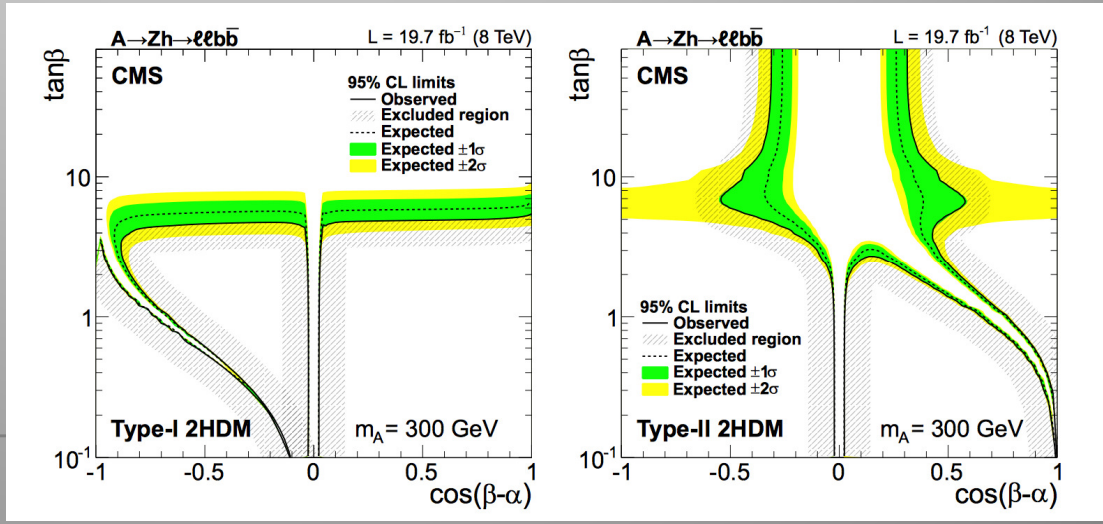
arXiv:1504.04710

Interpretation in 2HDM models of type-I and type-II

Max deviation around 560 GeV (2.5σ w/o LLE)

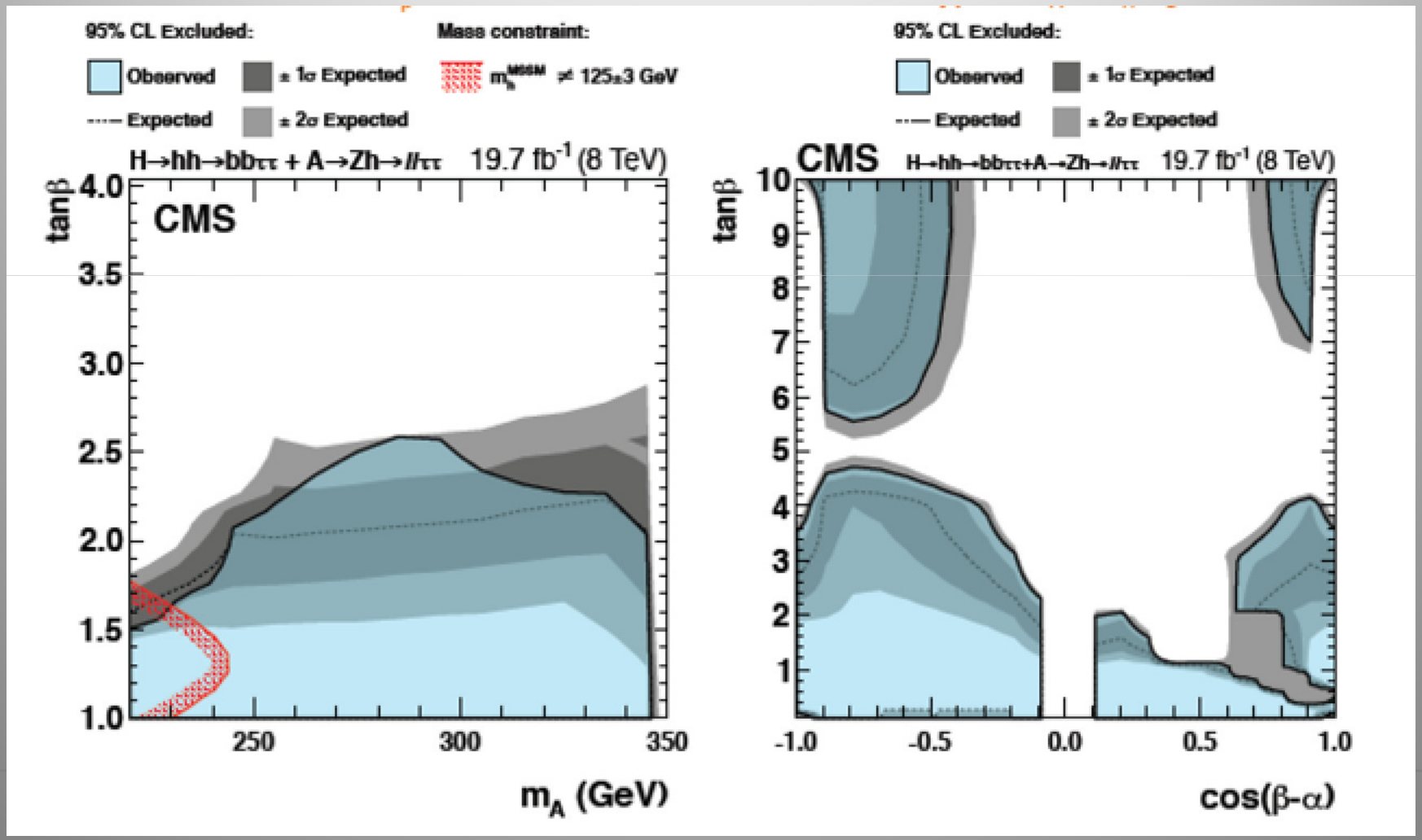
No significant excess observed





Combination of A→Zh and H→hh

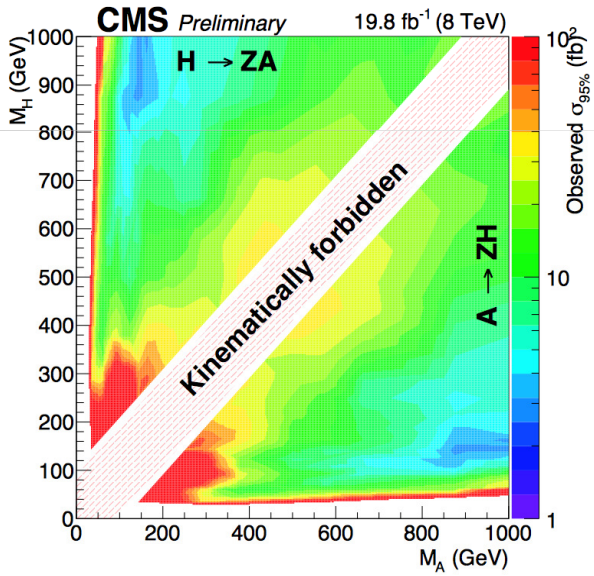
Several channels can be combined for defined BSM models
Eg H→hh + A→ZH ⟨ Exclusion limits

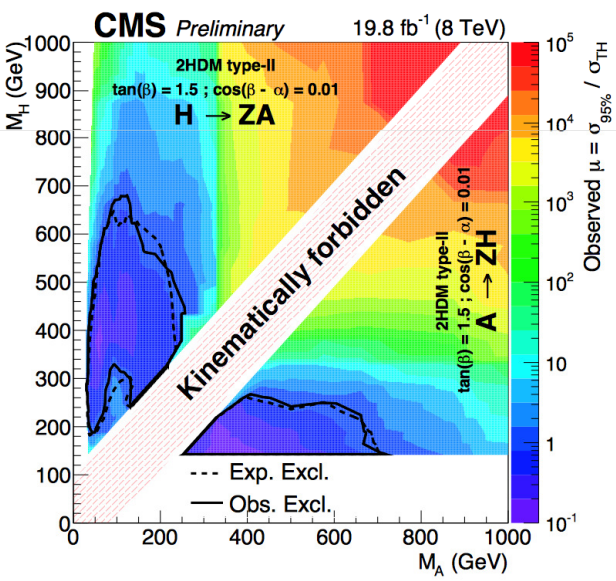


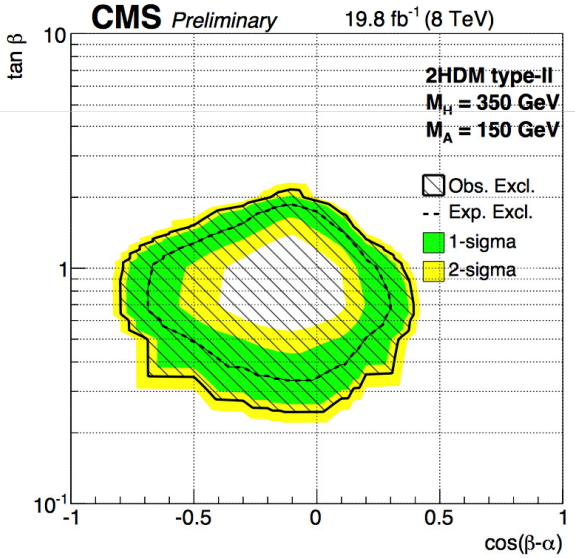
Search for H→ZA and A→ZH

With A/H decaying into bb or ττ: No excess observed

2HDM interpretation with non-degenerate H and A and m_h= 125 GeV
Eg for explaining the matter-antimatter asymmetry
Choose specific model to present results (parameters values)



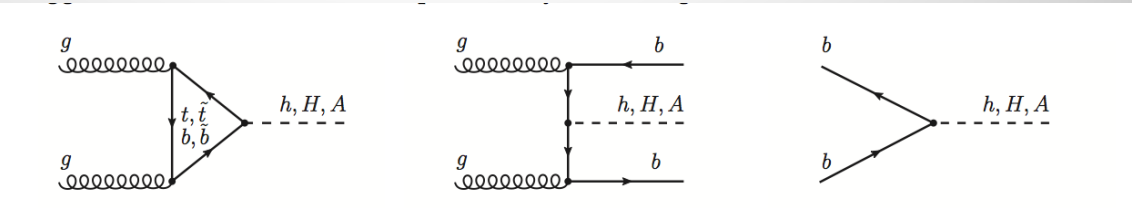




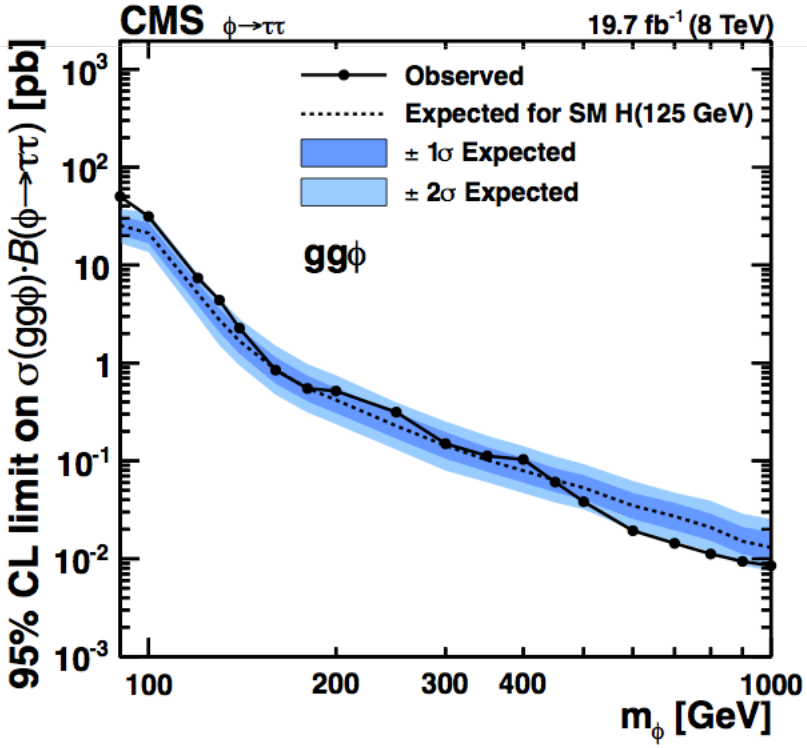
- Limit as function of m_H and m_A for cos(β − α)=0.01, tanβ=1.5
- Limit as function of tanβ and cos(β − α) for m_H = 350 GeV, m_A = 150 GeV

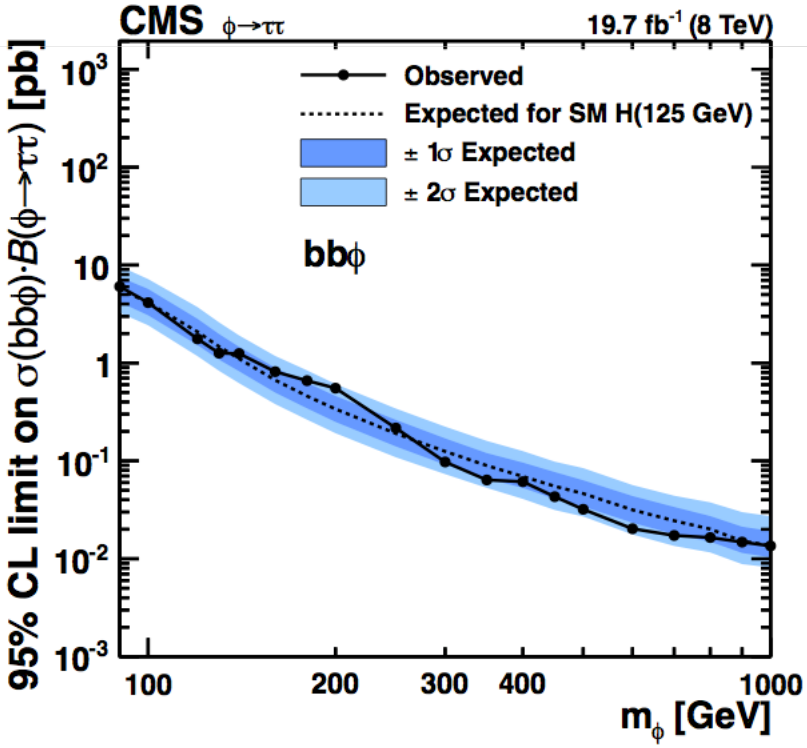
MSSM Neutral Higgs → Tau Tau

arXiv:1408.3316



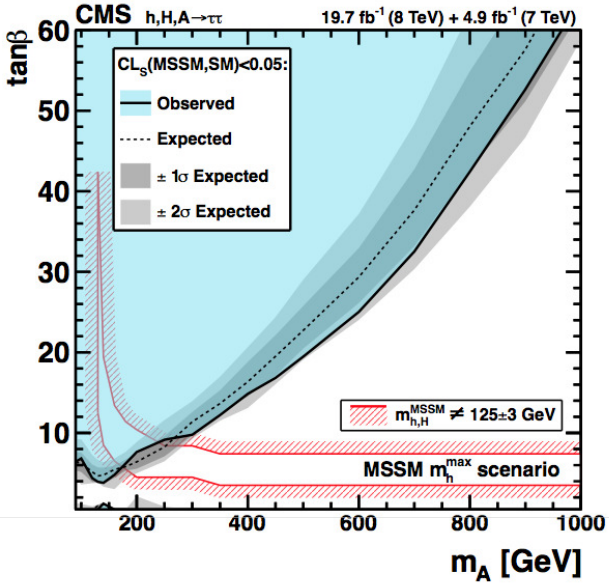
- Study of the Neutral Higgs h/H/A to tau tau
- Include channels with associated b-quark production
- Upper limits on σ.BR (95% CL)





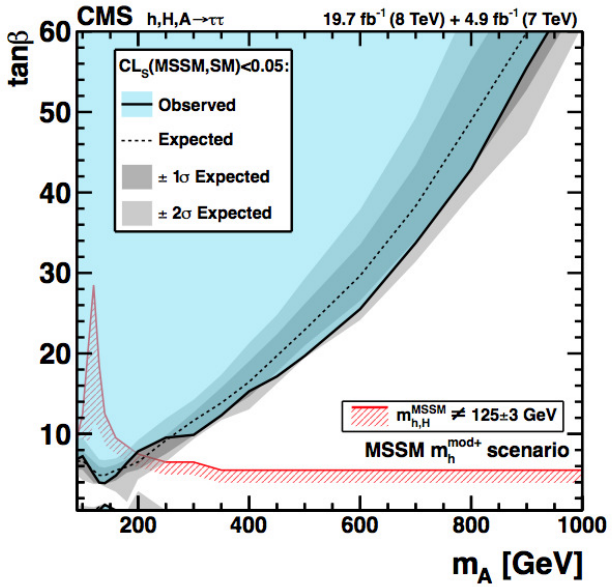
MSSM Neutral Higgs → Tau Tau

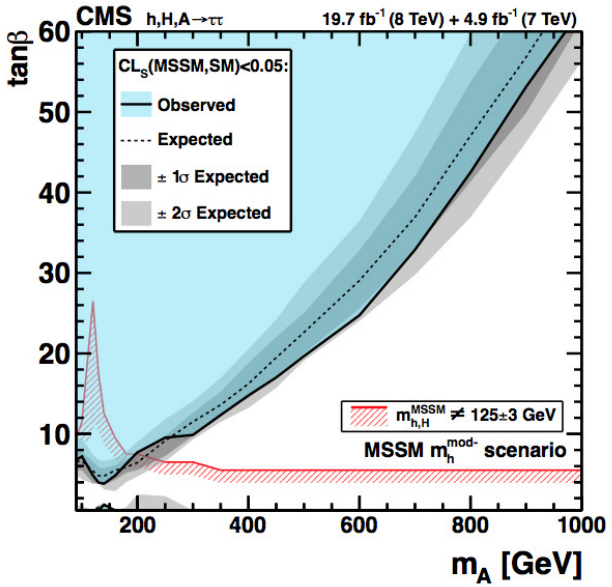
- Study of the Neutral Higgs h/H/A to tau tau
- Include channels with associated b-quark production
- No excess found so far –> exclusions (95% CL)



arXiv:1408.3316

m_h^{max} scenario; m_h^{mod+} and m_h^{mod+} scenarios with modified stop mixing



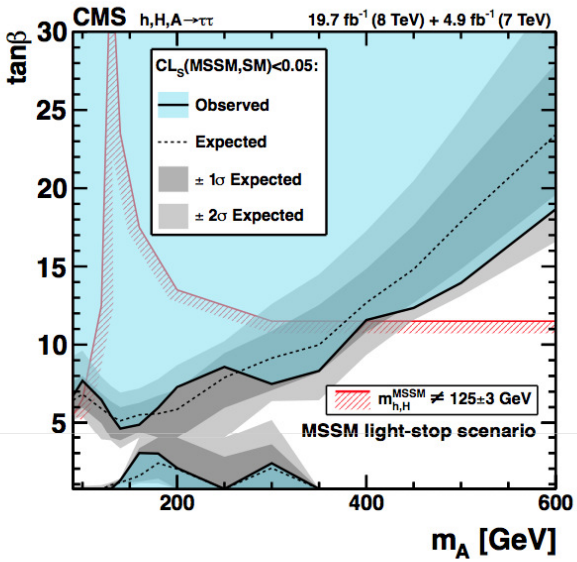


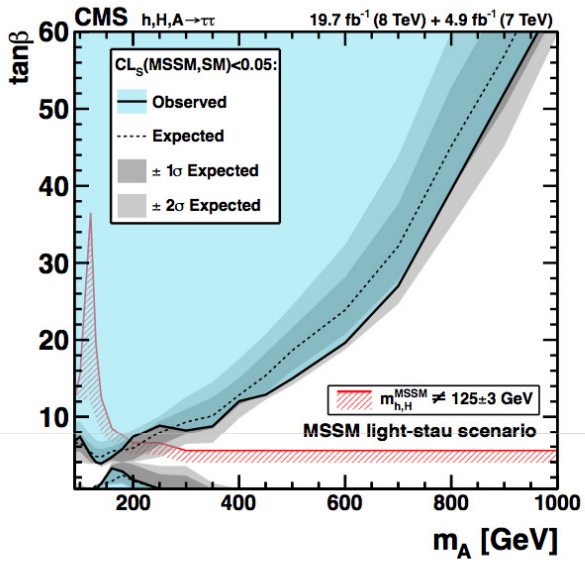
MSSM Neutral Higgs → Tau Tau

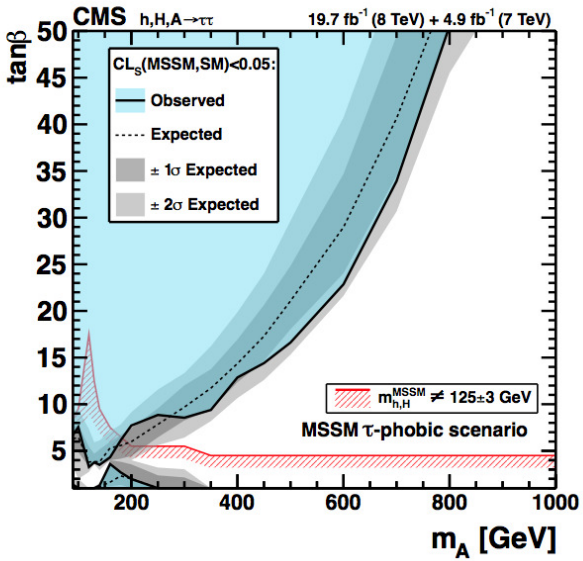
arXiv:1408.3316

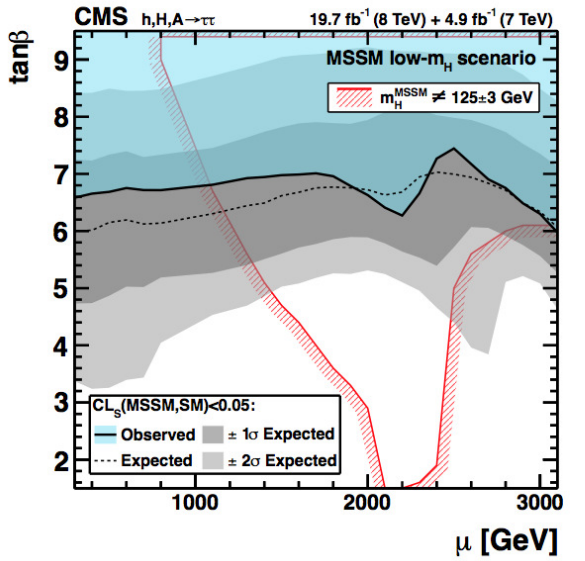
- Study of the Neutral Higgs h/H/A to tau tau
- Include channels with associated b-quarks
- No excess found so far –> exclusions (95% CL)

Light stop, light stau, Tau-phobic and low M_H scenarios







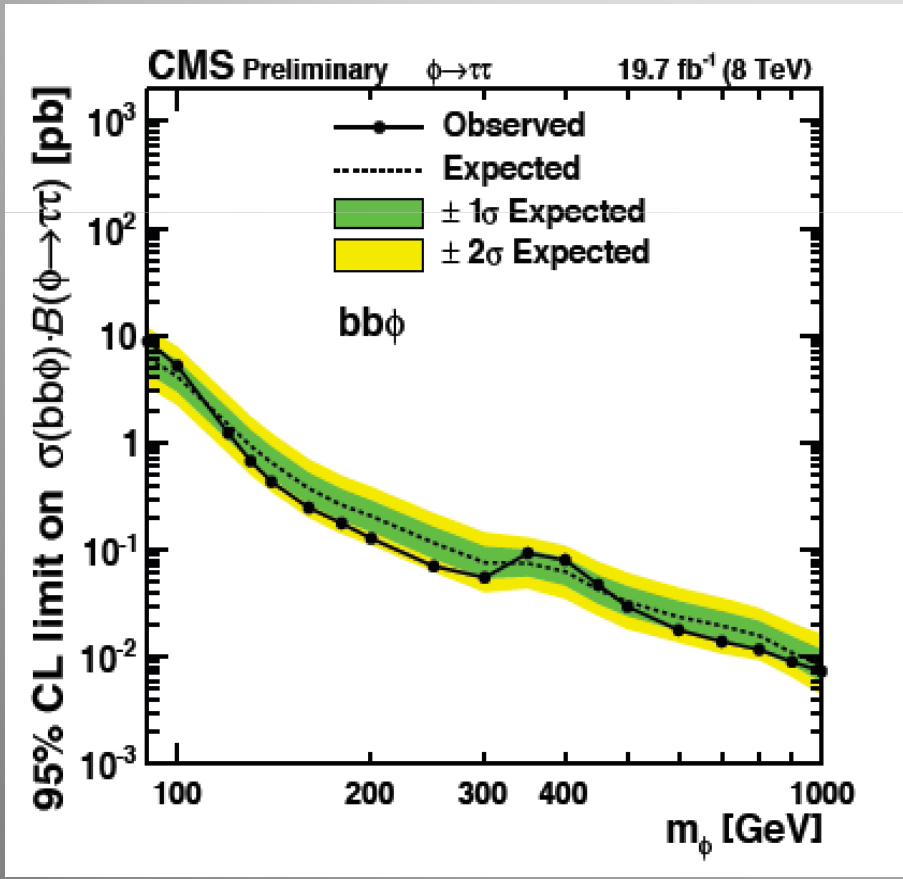


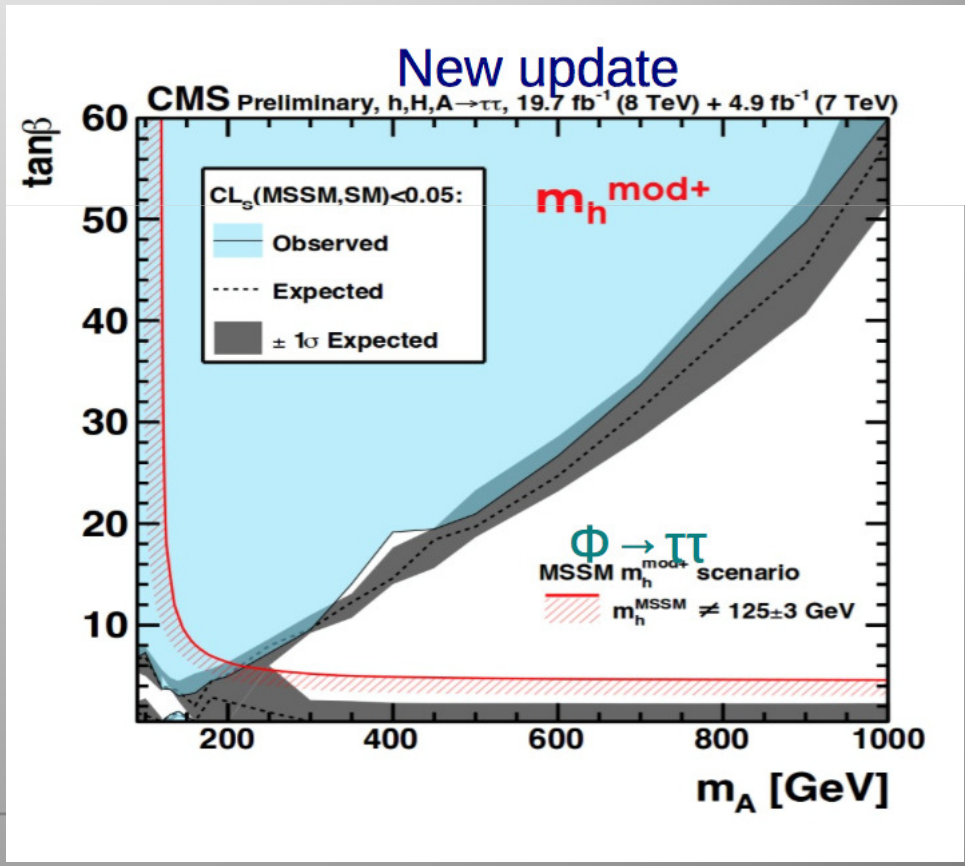
MSSM Neutral Higgs → Tau Tau

NEW: Update of the MSSM results with new tau finder
Reanalysis of the 2011/12 data.
MVA hadronic tau analysis, b-quark categories and hadronic tau p_T categories…

HIG-14-029

Huge gain ~70%!
i.e. like 3x the lumi

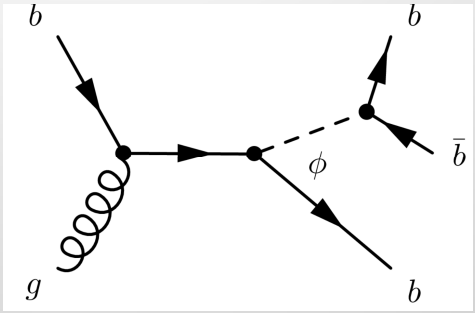


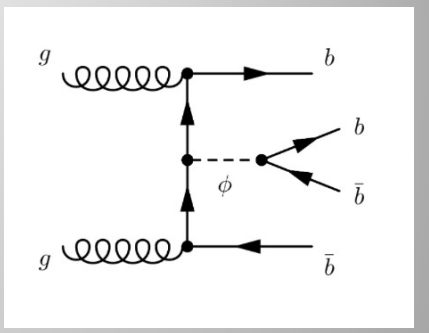


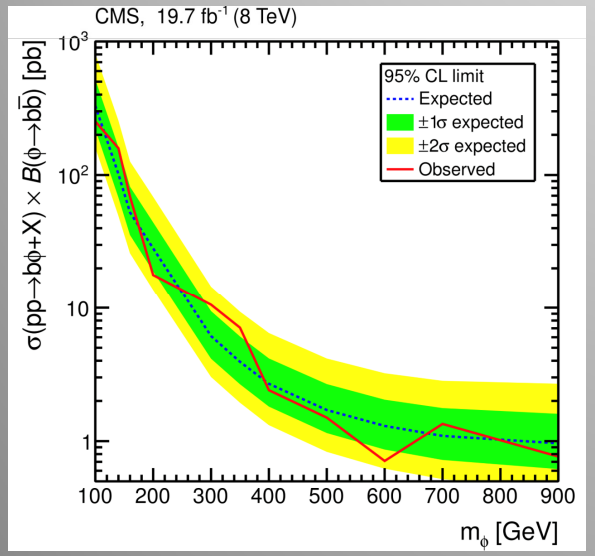
MSSM Neutral Higgs → bb

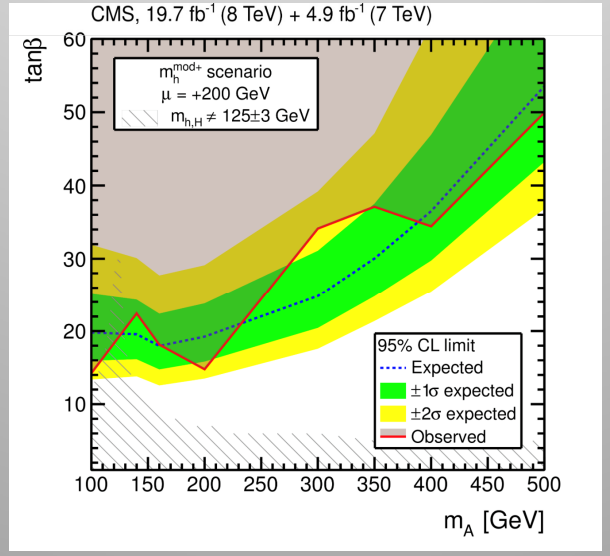
arXiv:1506.08329

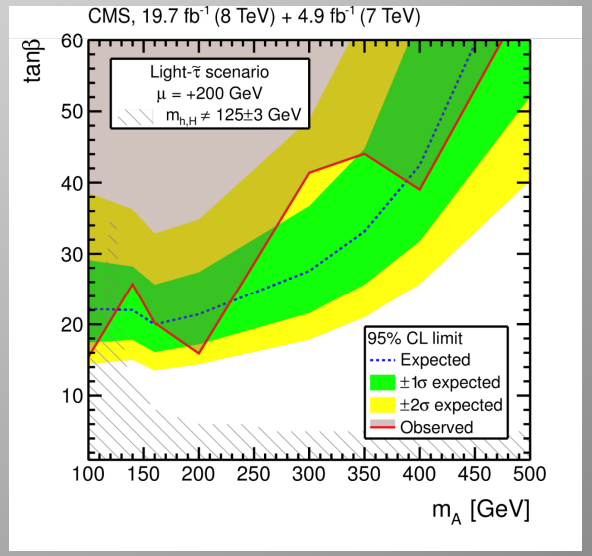
Search for H->bb with one or two b-quarks associated







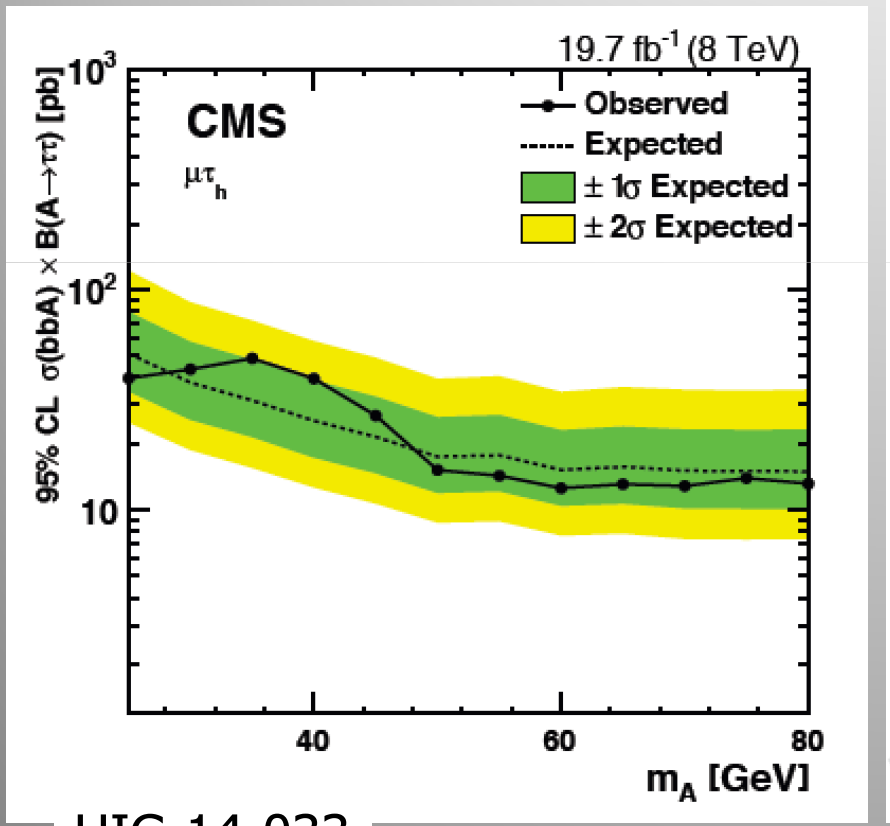




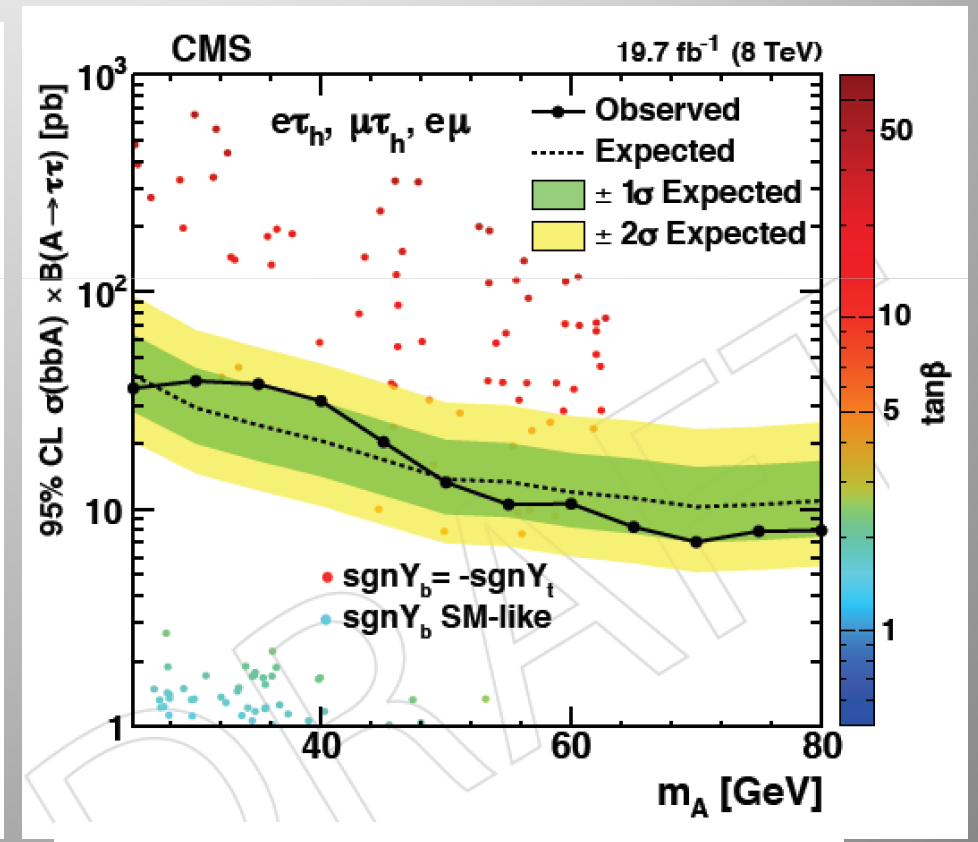
Exclusion limits for different MSSM scenarios

Search for Low Mass Pseudoscalar

Search for production in association with a pair of b-quarks
- Decay of the A boson into a pair of tau-leptons
- Coverage from 25 < M_A < 80 GeV. No excess observed



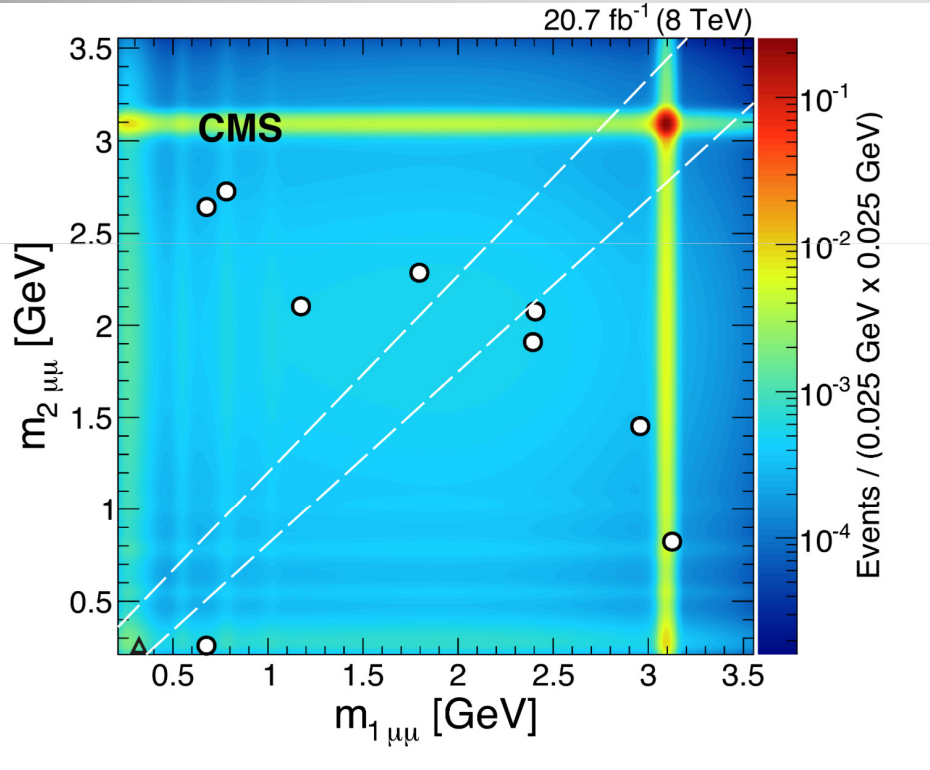
HIG-14-033

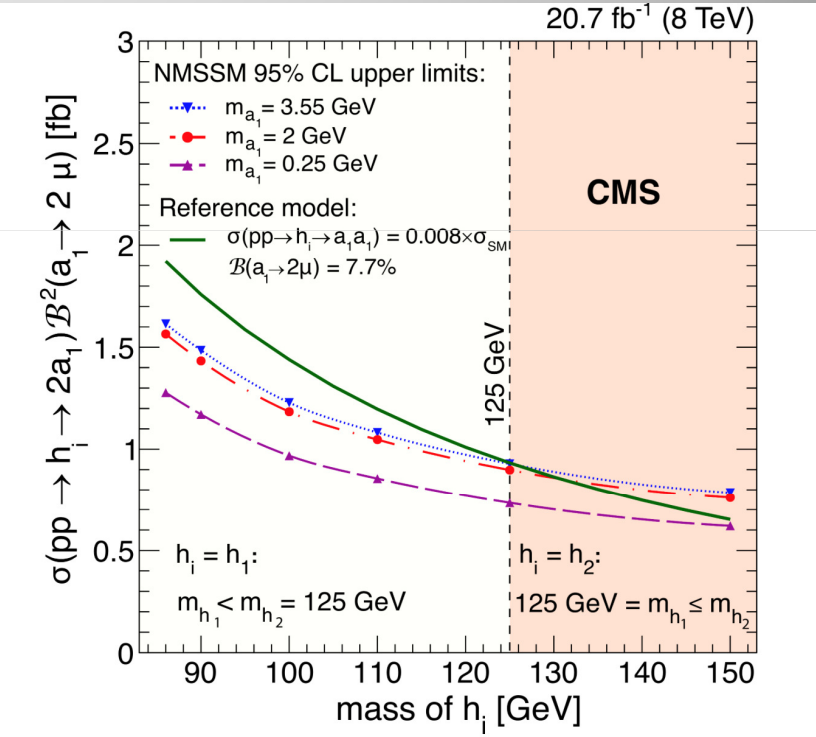


Points are typical production cross sections for bbA in 2HDM models 9

Search for a Light NMSSM Higgs

- Search for pair production of new light bosons a1 decaying each to muons
- Explore low mass range of dimuons (< 3.5 GeV)
- One event in the $m_{1\mu\mu} \cong m_{2\mu\mu}$ region, compatible with background



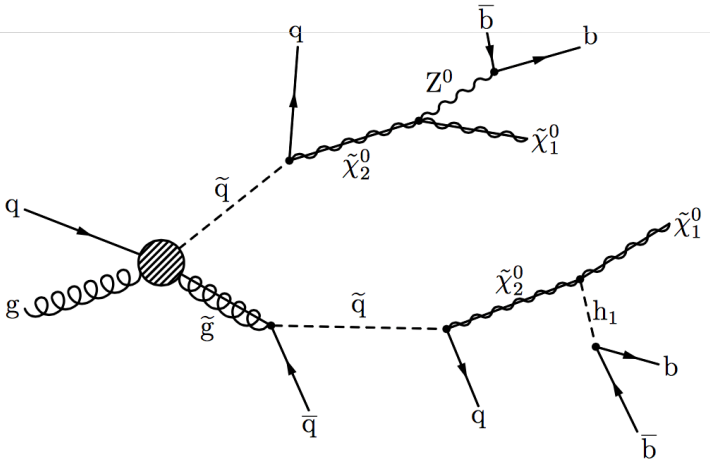


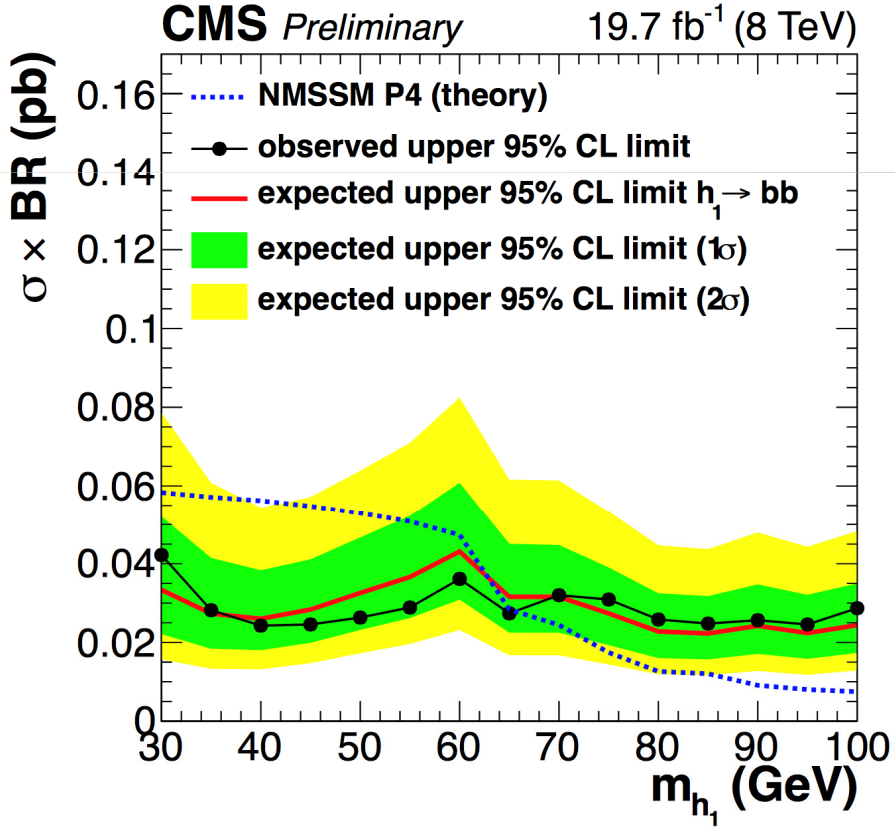
arXiv:1506.00424

Search for a Light NMSSM Higgs

Search for light Higgs boson produced in a cascade of supersymmetric particles, and decaying into b-quarks.
NMSSM in order to avoid H/Charged higgs degeneracy
→Search for event with high HT/MET and 2 light quark jets and at least 2 b-jets. No excess observed.

HIG-14-030



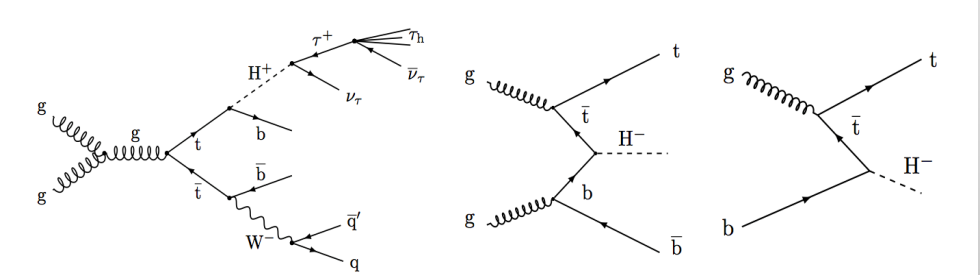


Charged Higgs Search

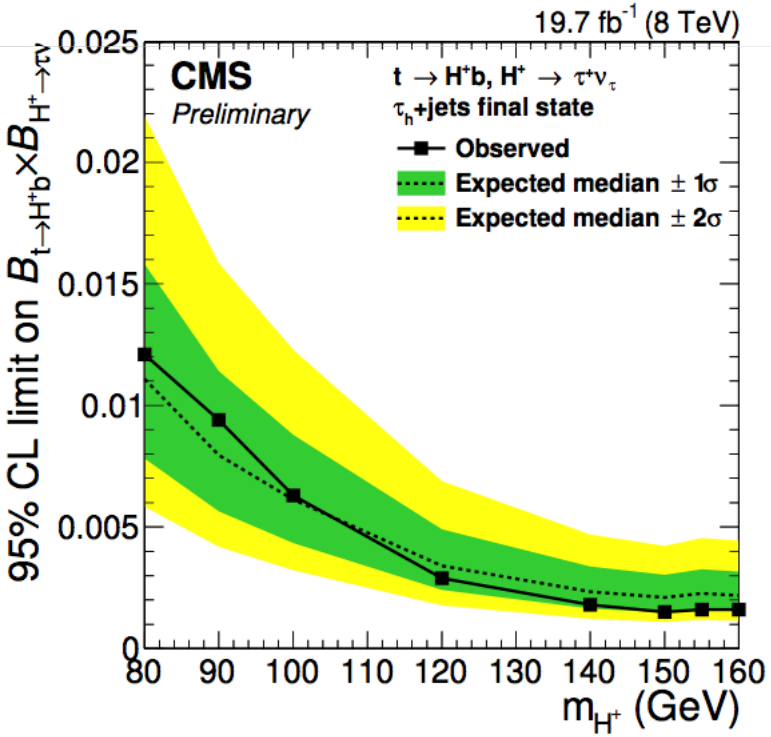
Both low and high mass, using full hadronic final states

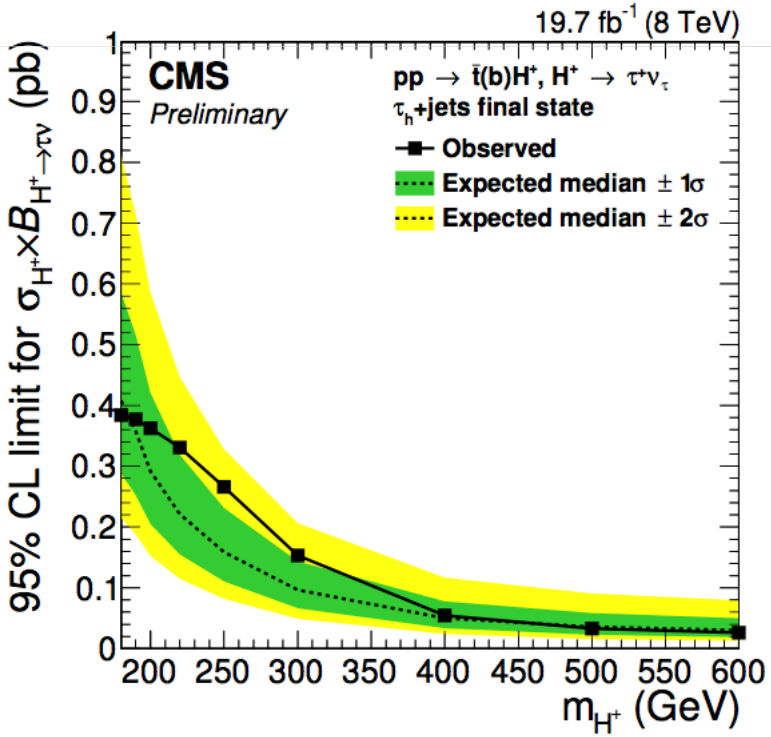
$$H^+ \to \tau^+ \nu_\tau$$

CMS-PAS-HIG-14-020



- Limits now down to 1.2%-0.16% for low mass (95%CL)
- Cross section limits 0.38-0.026 pb at high mass





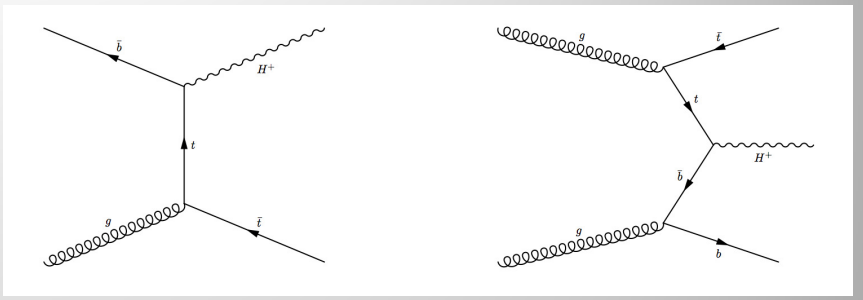
Heavy Charged Higgs Search

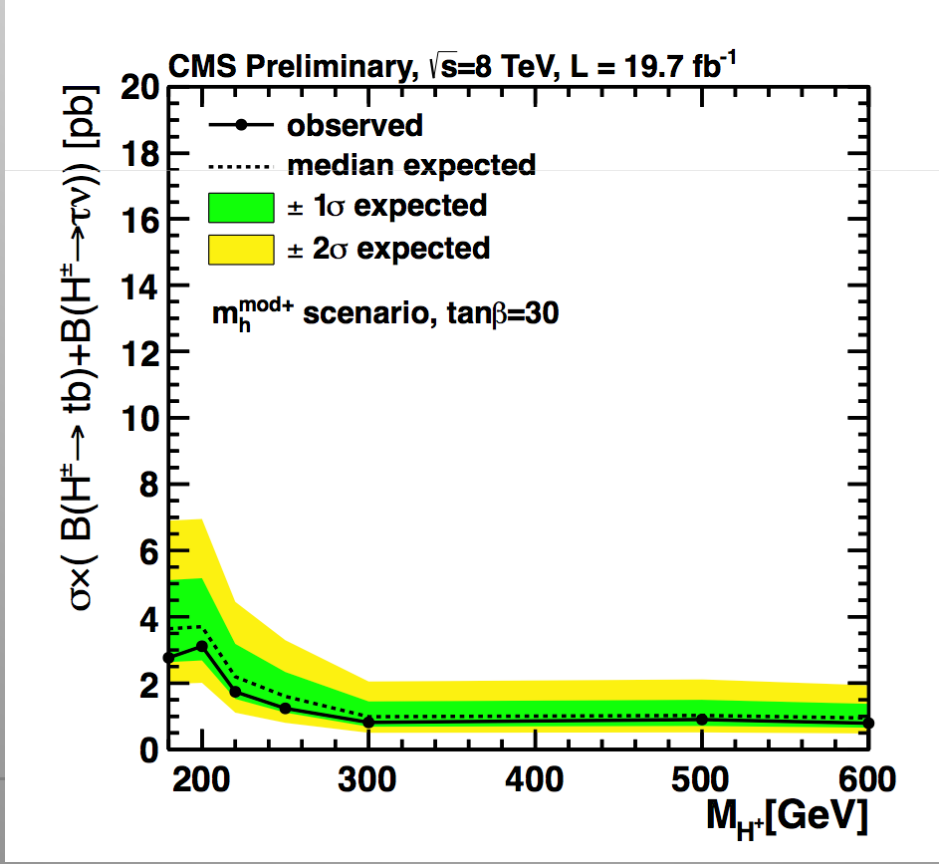
$gg \rightarrow H^+tb$

$H^+ \rightarrow tb$

$H^+ \rightarrow \tau^+\nu$

Final states with two leptons or
one lepton plus hadronic decaying tau

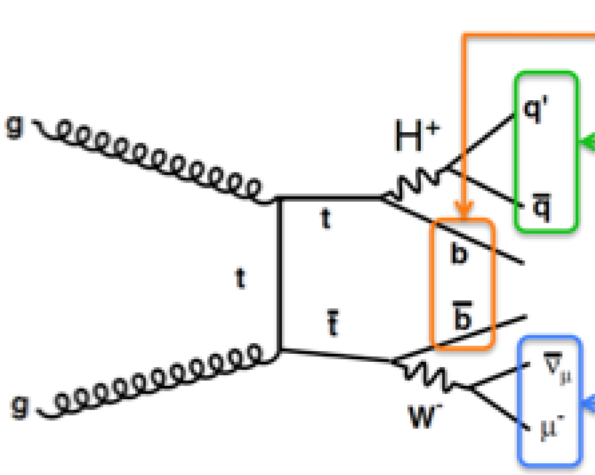




CMS-PAS-HIG-13-026

No excess observed

Search for $H^+ \rightarrow cs$



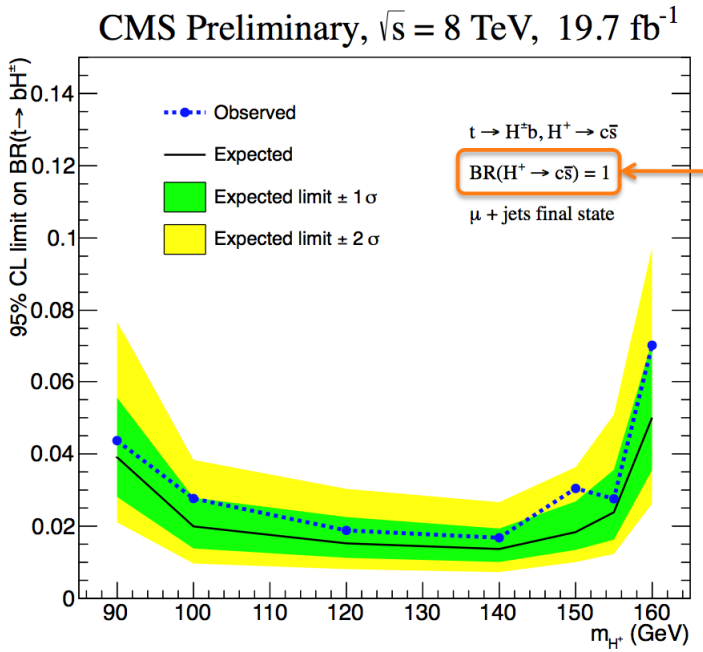
≥ 2 b-tagged jets of $P_T > 30$ GeV & $|\eta| < 2.4$

≥ 2 further jets of $P_T > 30$ GeV & $|\eta| < 2.4$

$E_T^{miss} > 20$ GeV

1 isolated muon of $P_T > 25$ GeV & $|\eta| < 2.1$

Use kinematic fits…



Limit on t → H^+b computed assuming all charged Higgs bosons to decay into dijets

HIG-13-035

Limits on the branching fraction ($t \rightarrow H^+b$) in the range of 2-7% for a mass between 90 and 160 GeV, assuming that $H^+ \rightarrow cs = 100\%$.

Summary

- The new Higgs boson is used as a tool for searches for beyond the Standard Model
- Searches for exotic decays and for Higgs partners, both at high and low masses wrt to m_h = 125 GeV, for charged and neutral partners. No new decays or particles found so far leading to exclusions of parameter space of models: MSSM, NMSSM, 2HDM, singlet models
- Most intriguing excess so far is the LFV decay of $H \rightarrow \mu\tau$. But the excess is not significant yet.
- There are many more channels that can be searched for and some result are stil to be released. This program will be strongly continued with the Run-II data
- New ideas for interesting decays or new models to explore are welcome

LFV ATLAS <-> CMS

$h \to \tau^{\pm}\mu^{\mp}$

at LHC8, 4×10^5 h s

CMS 1502.07400 : $BR(h \to \tau^{\pm}_{had,e}\mu^{\mp}) < 1.51\%$

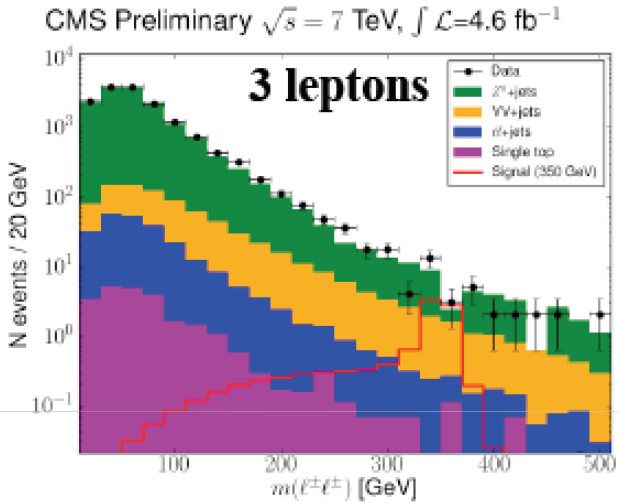
$\simeq 0.84\%$ (2.4σ)

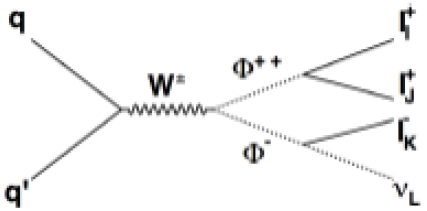
ATLAS @ EPS : $BR(h \to \tau^{\pm}_{had}\mu^{\mp}) < 1.85\%$

$\simeq 0.77\%$ (1.3σ)

Double Charged Higgs

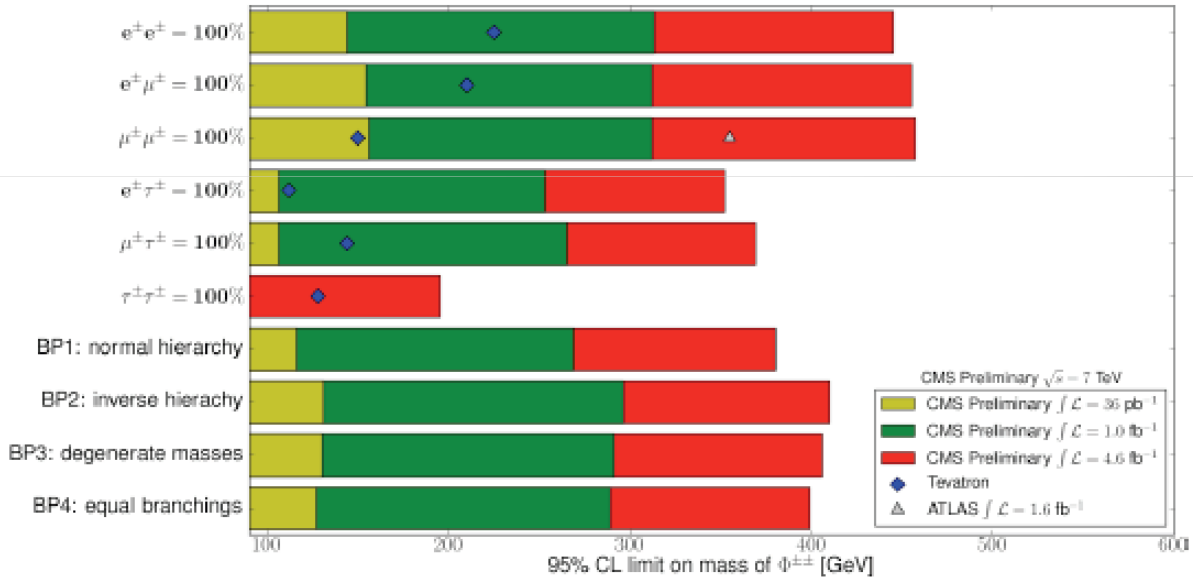
Model designed to explain neutrino masses through a scalar triplet (Φ^{++}, Φ^{+}, Φ^{o})
– Search for double and single charged Higgs

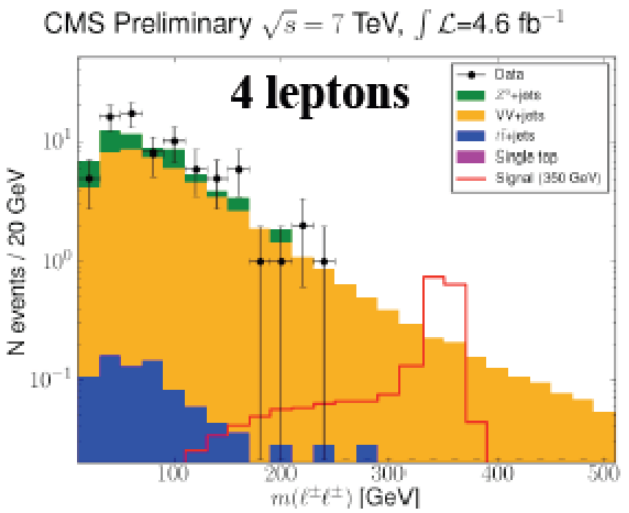


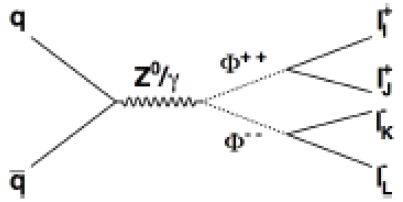


arXiv:1207.2666

Exclusion up to ~ 450 GeV







Note yet redone for 8 TeV Data