

LHC Days in Split

29 September - 4 October 2014

Diocletian's Palace / Palazzo Milesi/

Split, Croatia

Beyond-Standard-Model Higgs searches with the ATLAS detector

Xiaohu SUN on behalf of the ATLAS Collaboration

Institute of High Energy Physics, CAS

29 Sept 2014

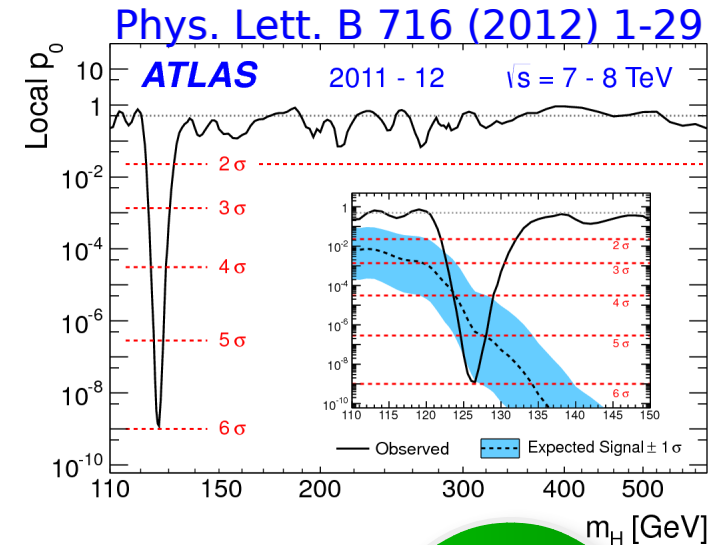


中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

After SM Higgs boson discovery



- The Higgs boson was discovered in summer 2012 and current measurements of its properties are compatible with the SM predictions
- To answer the questions not solved by the SM, one can indirectly look for new physics or can directly go beyond the SM, where additional Higgs bosons may exist:
 - dedicated BSM signal searches
 - scan for a heavier SM-like Higgs boson
 - charged Higgs searches



BSM searches: 2HDM framework

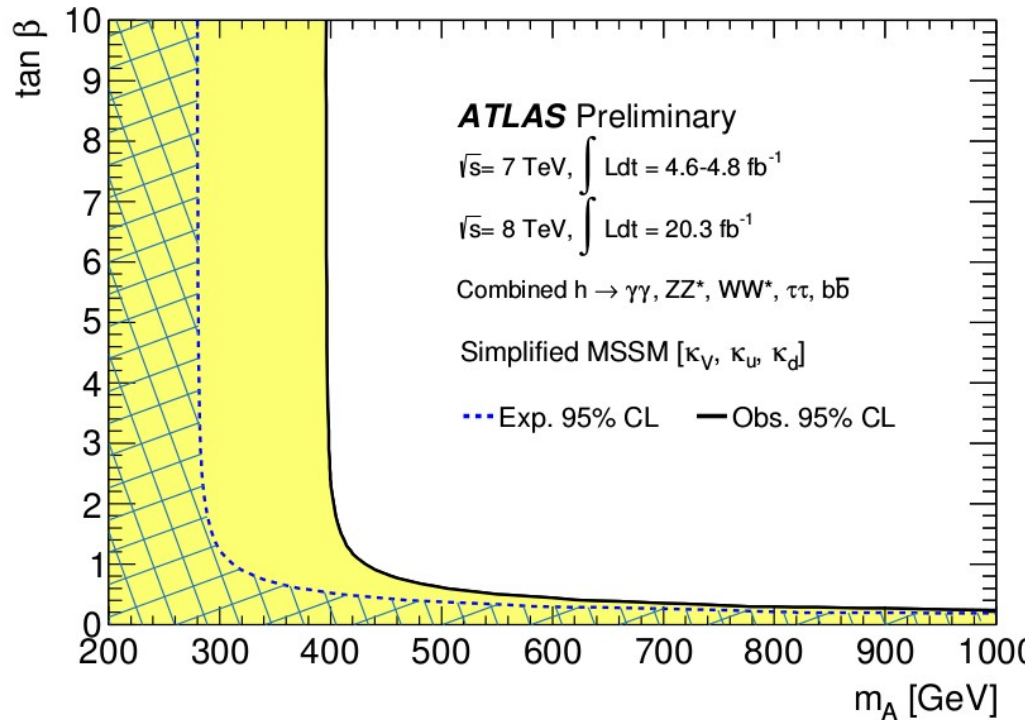


- Predicted Higgs bosons:
 - h, H : CP -even neutral
 - A : CP -odd neutral
 - H^\pm : Charged
- Parameters:
 - $m(h), m(H), m(A), m(H^\pm)$: masses
 - α : mixing angle of h and H
 - $\tan\beta$: ratio of vev's

	Type I	Type II	Type III	Type IV
ξ_h^V	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$	$\sin(\beta - \alpha)$
ξ_h^u	$\frac{\cos \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\sin \beta}$
ξ_h^d	$\frac{\cos \alpha}{\sin \beta}$	$-\frac{\sin \alpha}{\cos \beta}$	$\frac{\cos \alpha}{\sin \beta}$	$-\frac{\sin \alpha}{\cos \beta}$
ξ_h^l	$\frac{\cos \alpha}{\sin \beta}$	$-\frac{\sin \alpha}{\cos \beta}$	$-\frac{\sin \alpha}{\cos \beta}$	$\frac{\cos \alpha}{\cos \beta}$
ξ_H^V	$\cos(\beta - \alpha)$	$\cos(\beta - \alpha)$	$\cos(\beta - \alpha)$	$\cos(\beta - \alpha)$
ξ_H^u	$\frac{\sin \alpha}{\sin \beta}$	$\frac{\sin \alpha}{\sin \beta}$	$\frac{\sin \alpha}{\sin \beta}$	$\frac{\sin \alpha}{\sin \beta}$
ξ_H^d	$\frac{\sin \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\cos \beta}$	$\frac{\sin \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\cos \beta}$
ξ_H^l	$\frac{\sin \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\cos \beta}$	$\frac{\cos \alpha}{\sin \beta}$	$\frac{\sin \alpha}{\cos \beta}$
ξ_A^u	$\cot \beta$	$\cot \beta$	$\cot \beta$	$\cot \beta$
ξ_A^d	$-\cot \beta$	$\tan \beta$	$-\cot \beta$	$\tan \beta$
ξ_A^l	$-\cot \beta$	$\tan \beta$	$\tan \beta$	$-\cot \beta$

Indirect searches

- SM Higgs couplings constrain BSM
- SH Higgs invisible decays

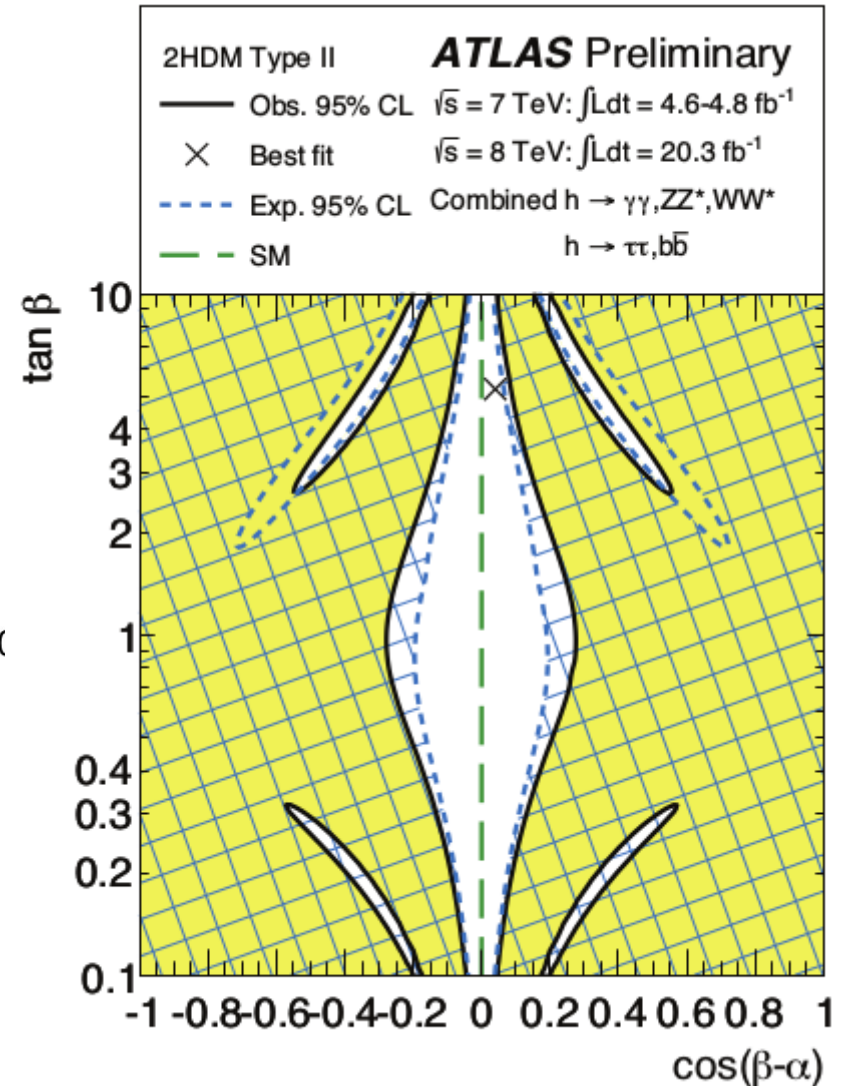


$$\kappa_V = \frac{s_d(m_A, \tan\beta) + \tan\beta s_u(m_A, \tan\beta)}{\sqrt{1 + \tan^2\beta}}$$

$$\kappa_U = s_u(m_A, \tan\beta) \frac{\sqrt{1 + \tan^2\beta}}{\tan\beta}$$

$$\kappa_D = s_d(m_A, \tan\beta) \sqrt{1 + \tan^2\beta}$$

exclusions in plane of $m(A)$ vs $\tan\beta$
in a simplified MSSM model
(no new decay mode other than SM's)



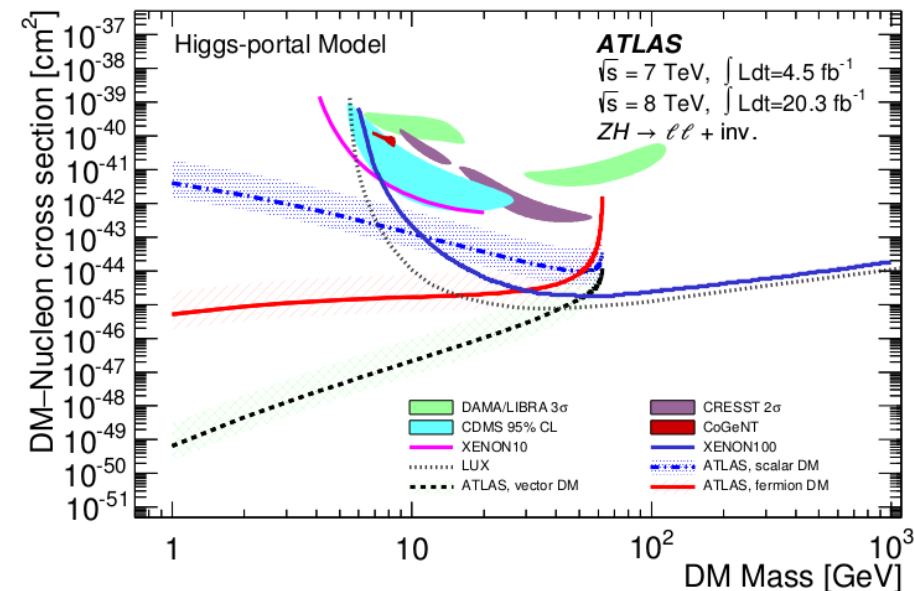
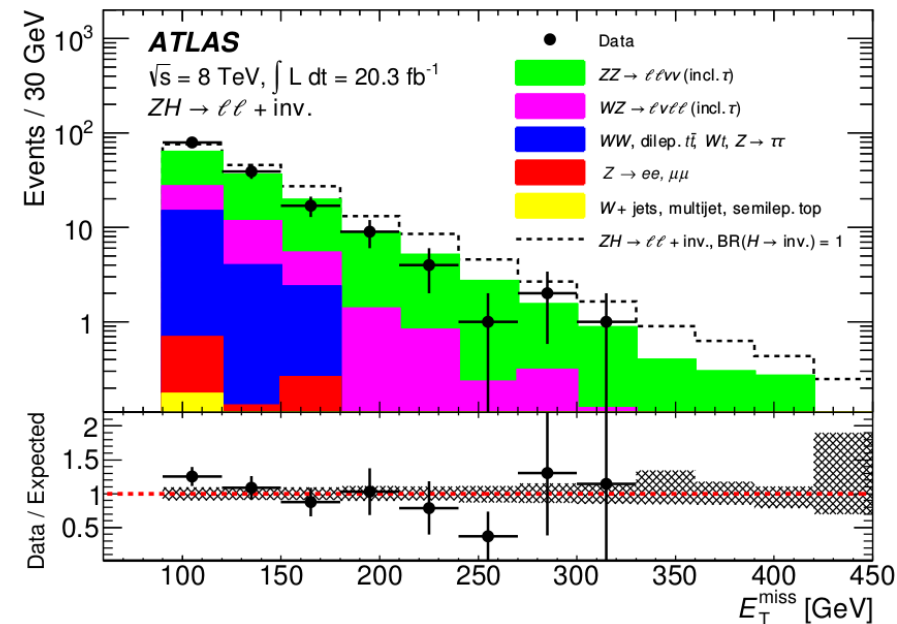
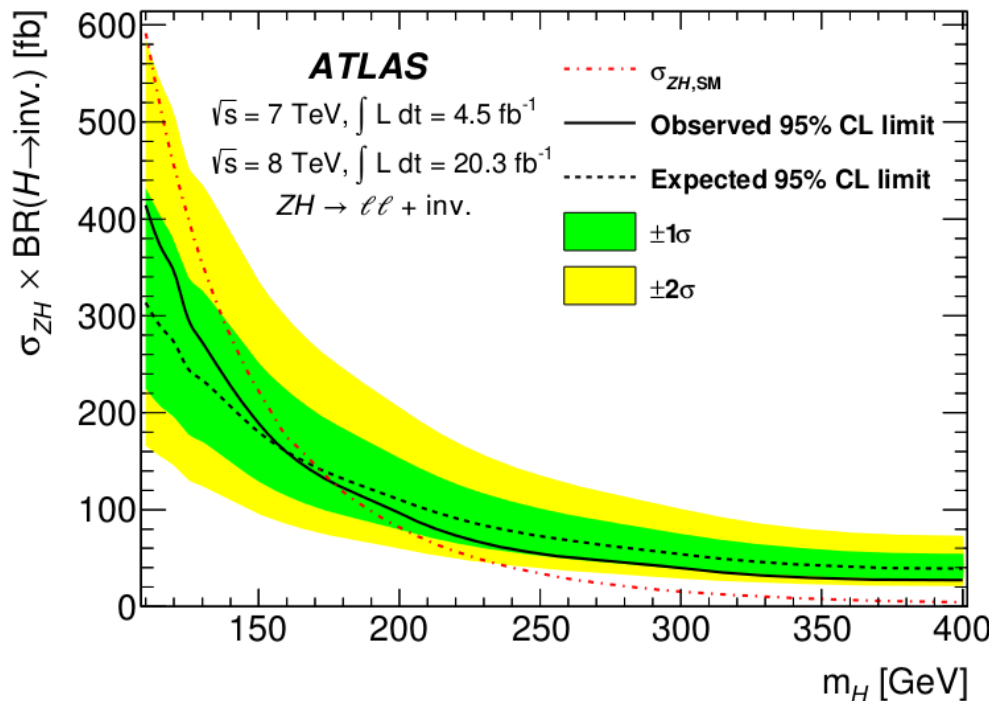
exclusions in plane
of type II 2HDMs

SM Higgs invisible decays

Phys. Rev. Lett.
112, 201802 (2014)



- Look for: invisible decays of a SM Higgs produced in association of a Z boson
- Signature: $m(\ell\ell)$ close to Z boson, no jets, $\ell\ell$ -system balances *missing* E_T
- Strategy: fit on *missing* E_T template



set limits on inv. decay BR and on Higgs portal to **Dark Matter**

BSM signal searches

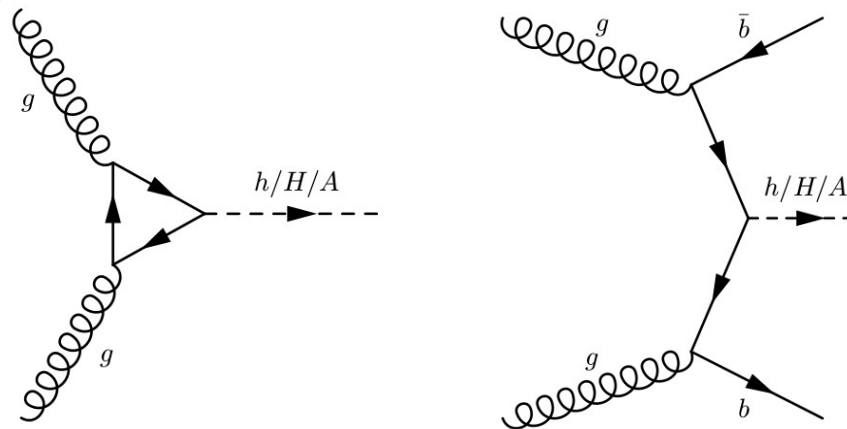
- MSSM $h/H/A \rightarrow \tau\tau$: **90 - 1000** GeV
- 2HDM $H \rightarrow WW \rightarrow \mu\nu e\nu$: **135 - 300** GeV
- Resonance $X \rightarrow hh \rightarrow b\bar{b}\gamma\gamma$: **220 - 500** GeV
- Resonance $X \rightarrow hh \rightarrow b\bar{b}b\bar{b}$: **500 - 1500** GeV

MSSM $h/H/A \rightarrow \tau\tau$

arXiv:1409.6064 [hep-ex]

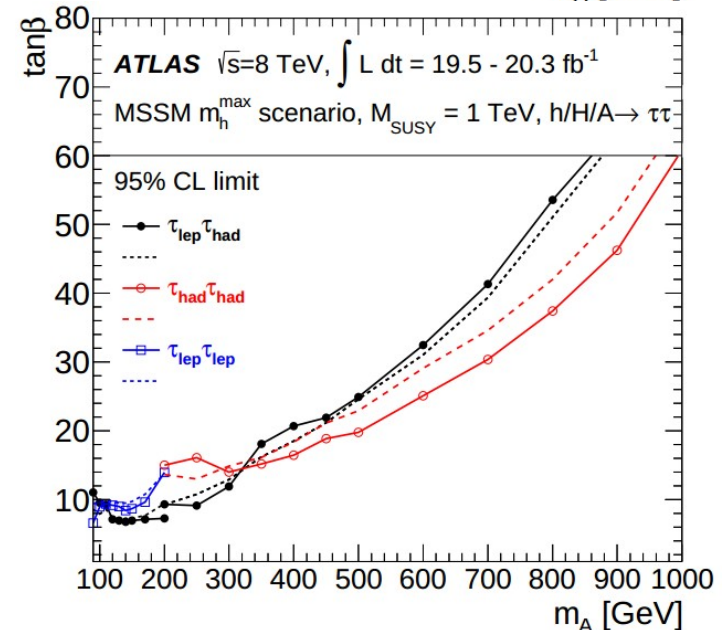
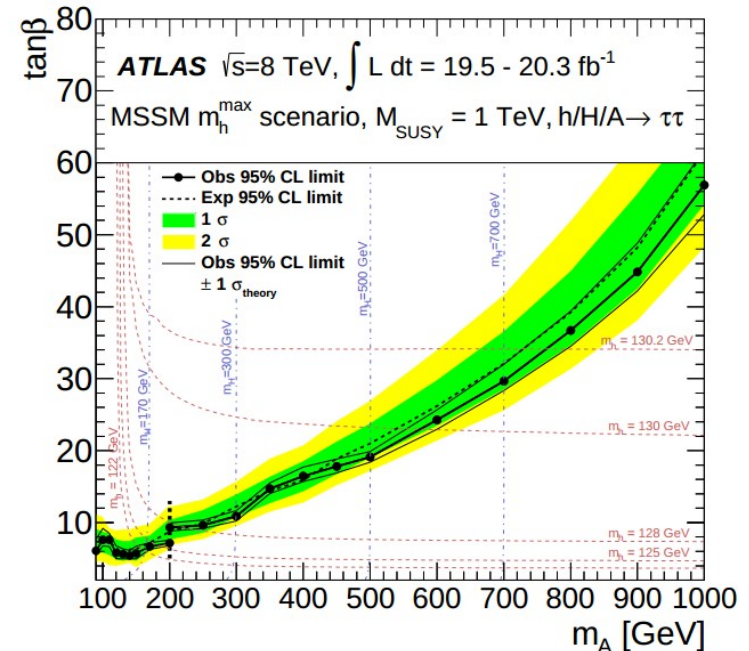


Latest



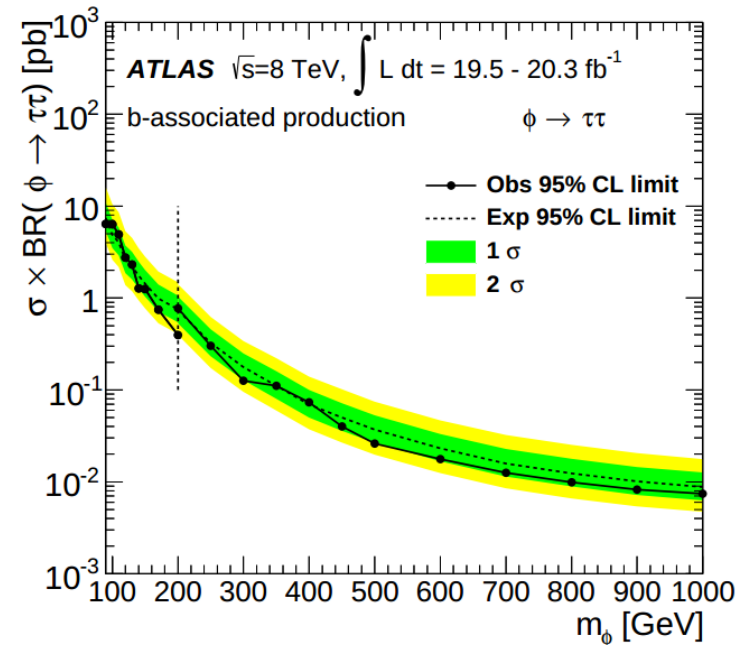
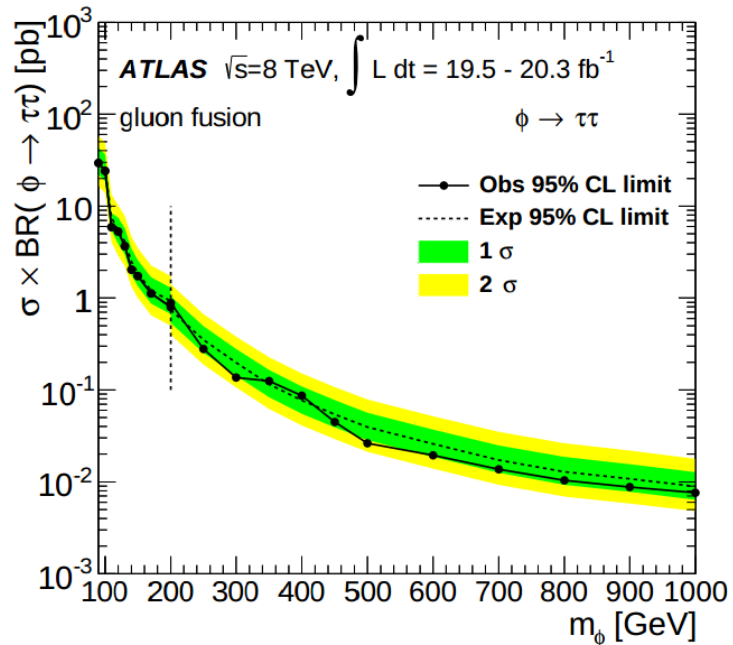
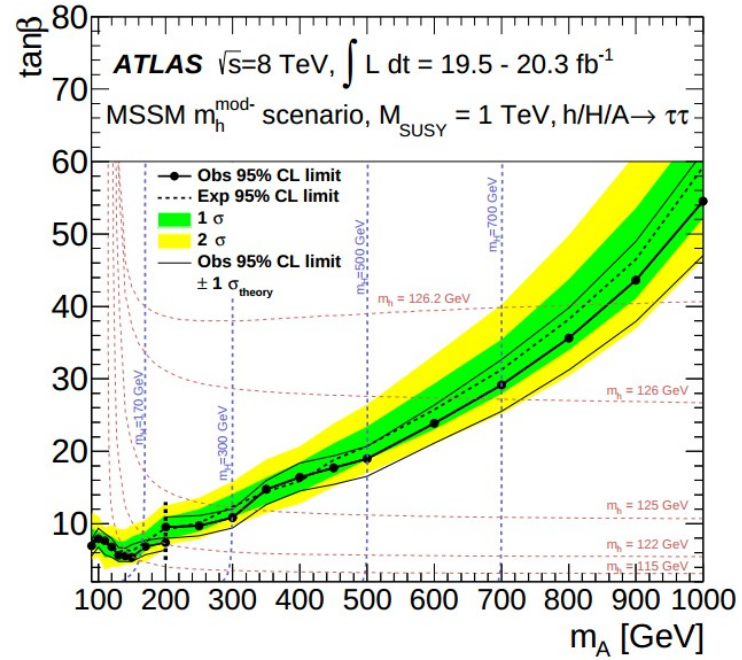
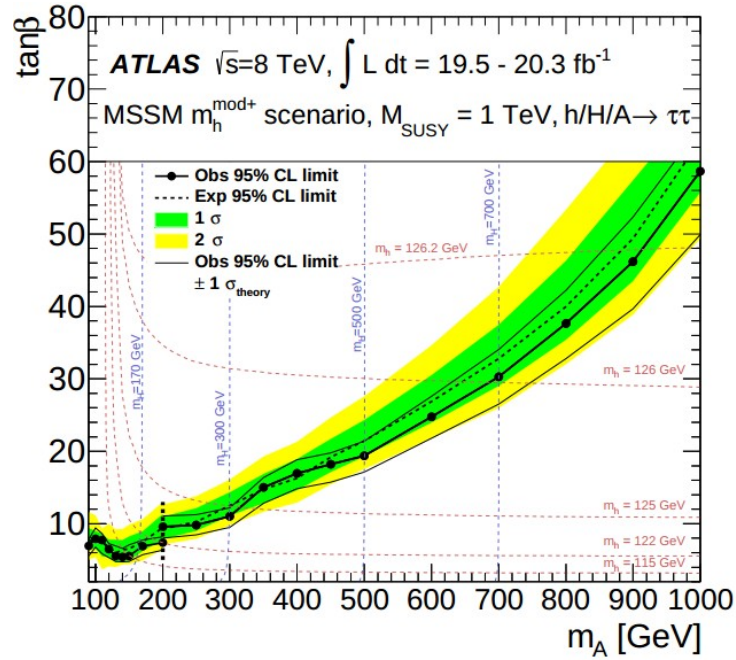
- Look for: a neutral Higgs with narrow width
- Signature: two τ in three final states, lephad, hadhad, lelep
- Strategy: **90 - 200 GeV**, lelep (fit on MMC), lephad (fit on MMC), **200 - 1000 GeV**, lephad (fit on MMC), hadhad (fit on M_T)

Set limits on $\tan\beta$ as a function of $m(A)$



MSSM $h/H/A \rightarrow \tau\tau$

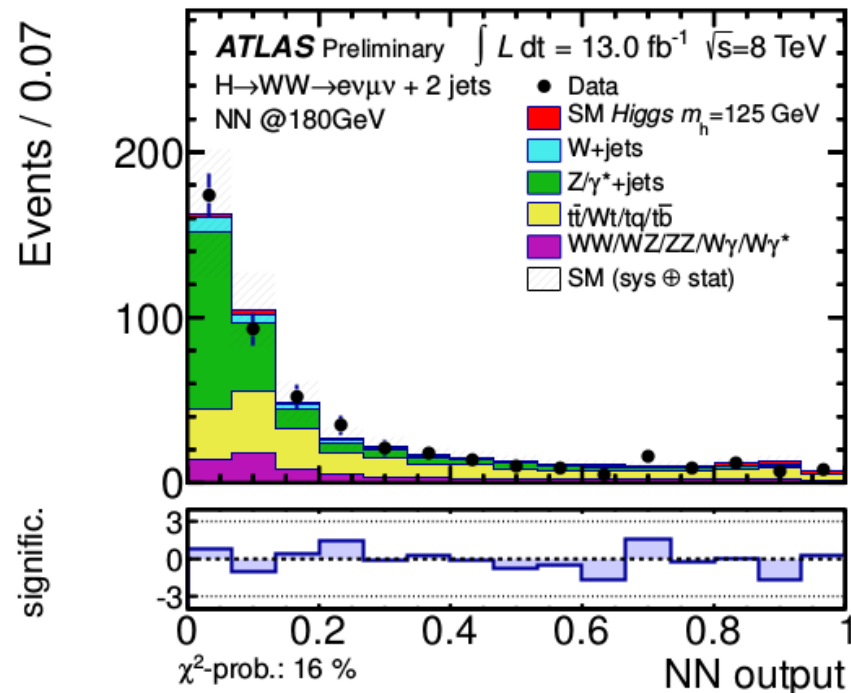
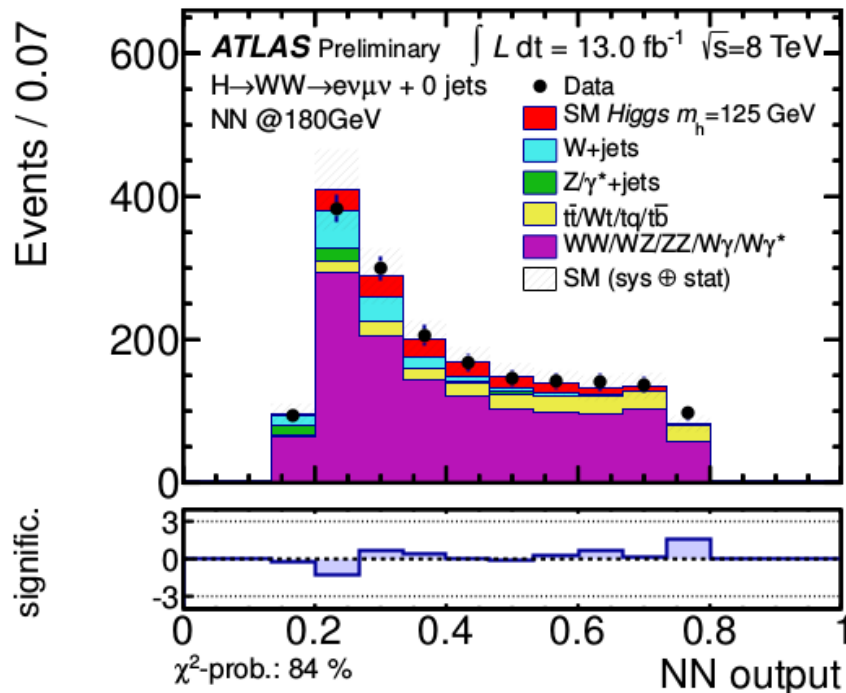
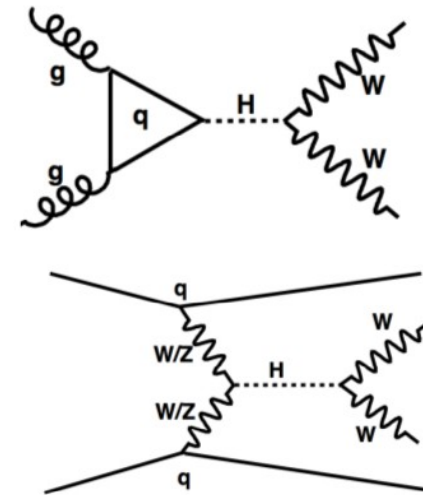
arXiv:1409.6064 [hep-ex]



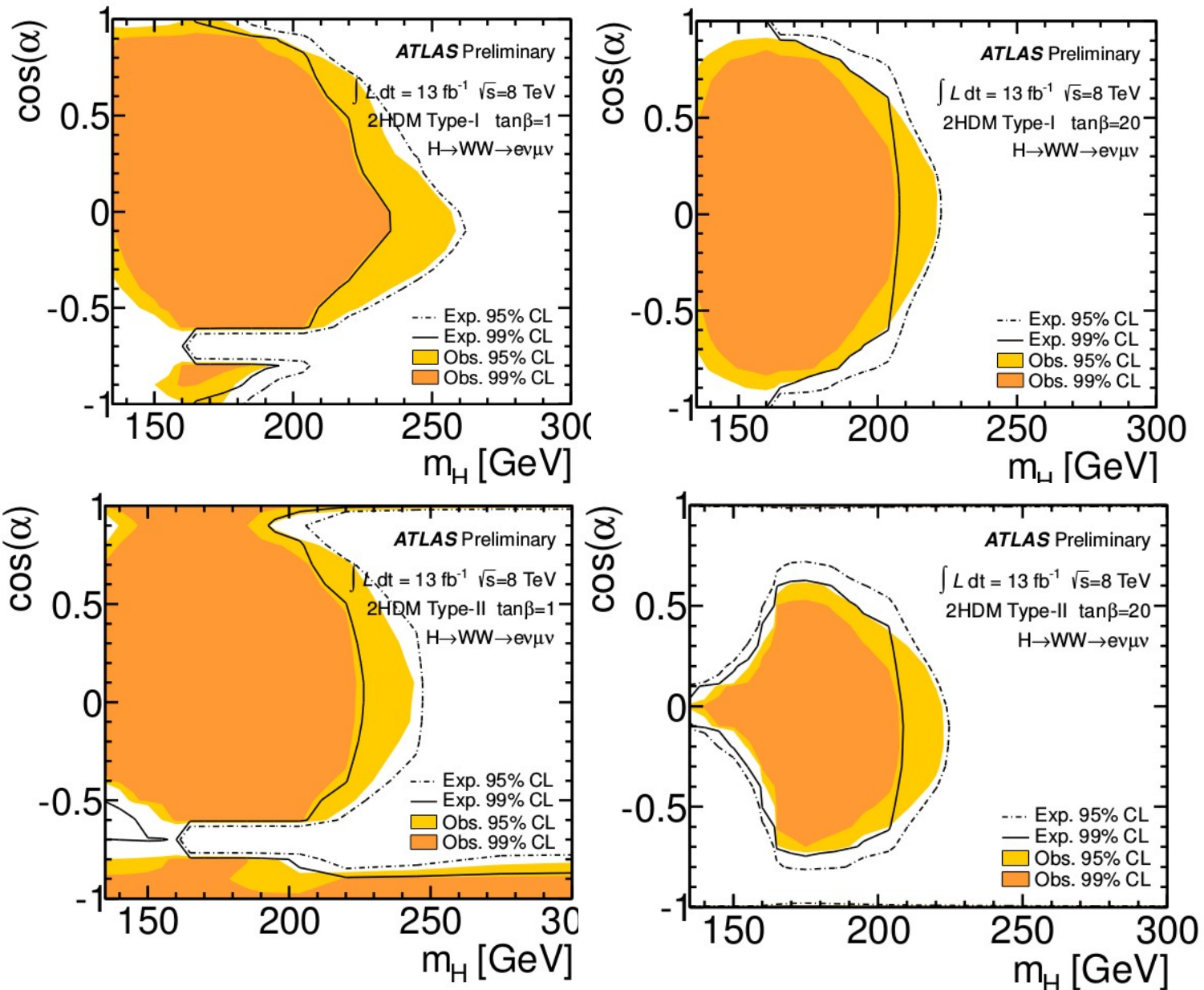
$H \rightarrow WW \rightarrow \mu\nu e\nu$



- Look for: a neutral heavy Higgs with narrow width
- Signature: two high p_T leptons with different flavors, large *missing* E_T , two channels (0 jet for *ggF*, 2 jets for *VBF*)
- Strategy: fit on ANN *NeuroBayes*®



Signal hypothesis includes both h and H
 leading to a simultaneous fit of the light and heavy Higgs



Make exclusions in $\cos\alpha$ vs $m(H)$ for different $\tan\beta$

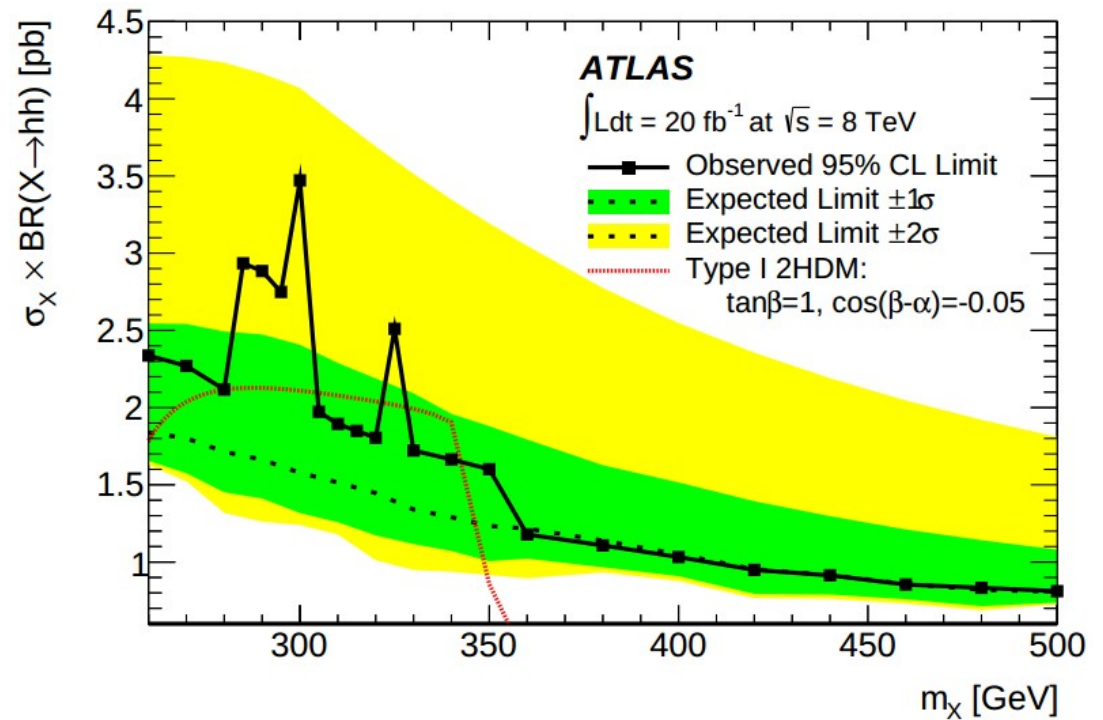
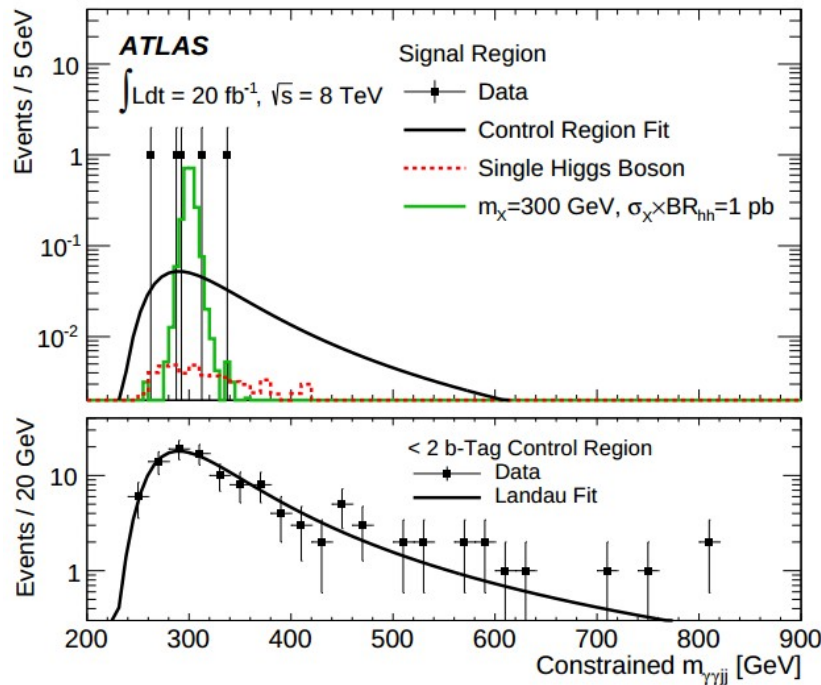
$X \rightarrow hh \rightarrow b\bar{b}\gamma\gamma$

arXiv:1406.5053 [hep-ex]



- Look for: a heavy neutral resonance with narrow width
- Signature: two isolated high p_T photons, two b -jets
- Strategy: cut based, event count

Set upper limits on $gg \rightarrow X \rightarrow hh$ production

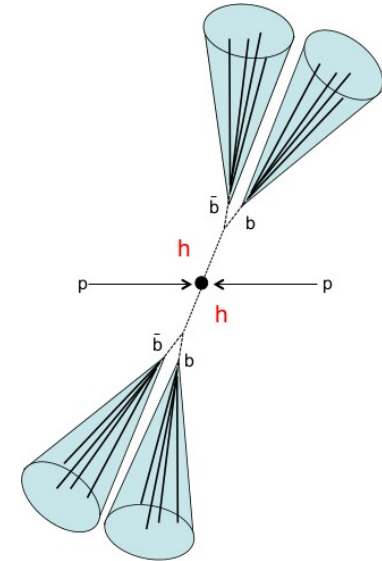


A 95% C.L. upper limit on the x-section of **non-resonant** Higgs pair production is set at 2.2 pb

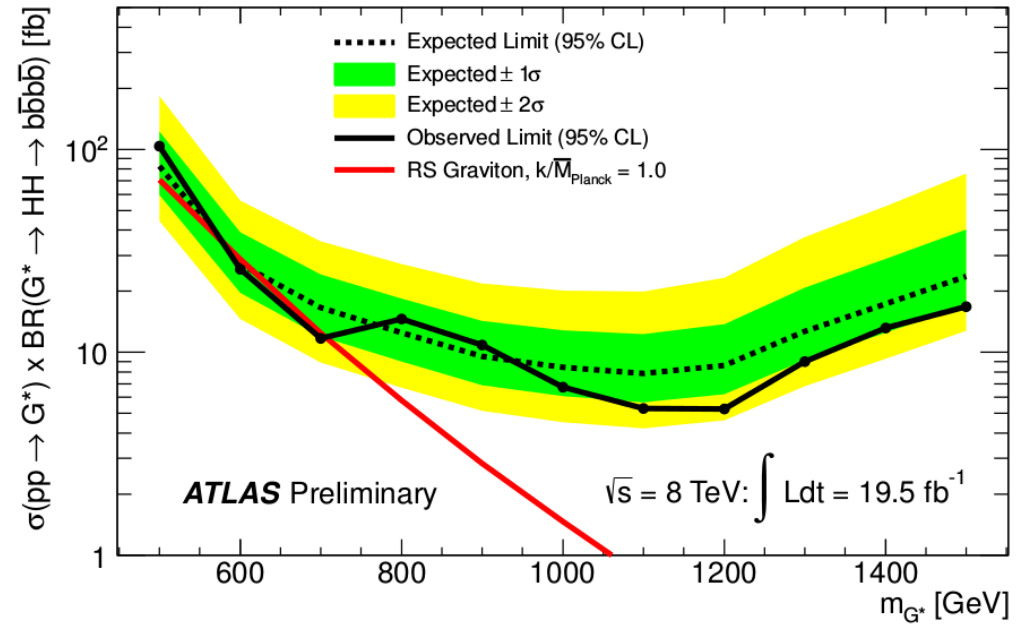
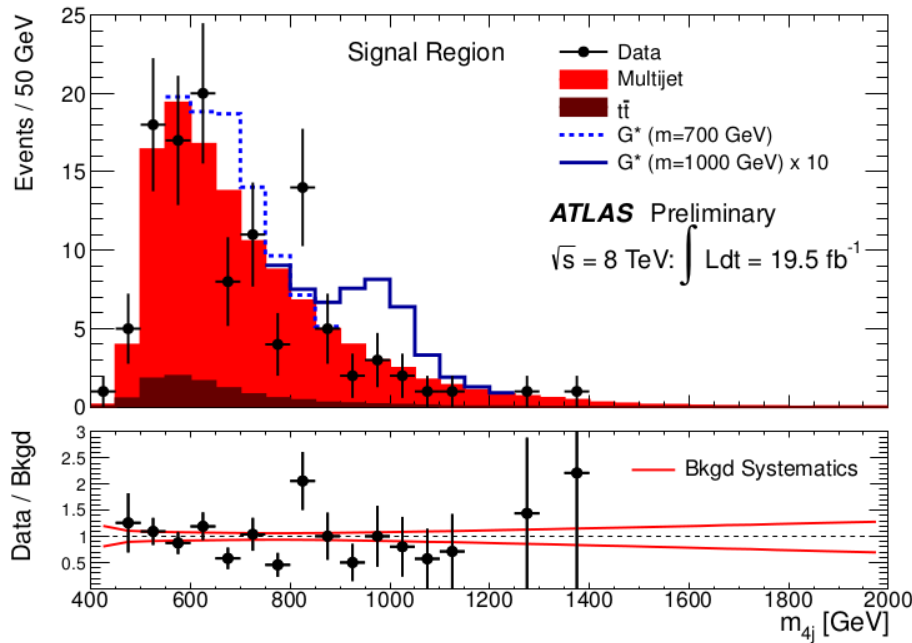
$X \rightarrow hh \rightarrow b\bar{b}b\bar{b}$



- Look for: a heavy neutral resonance
- Signature: four b -jets from two boosted dijets
- Strategy: cut based, fit on $m(b\bar{b}b\bar{b})$



Set limit on $gg \rightarrow X \rightarrow hh \rightarrow b\bar{b}b\bar{b}$



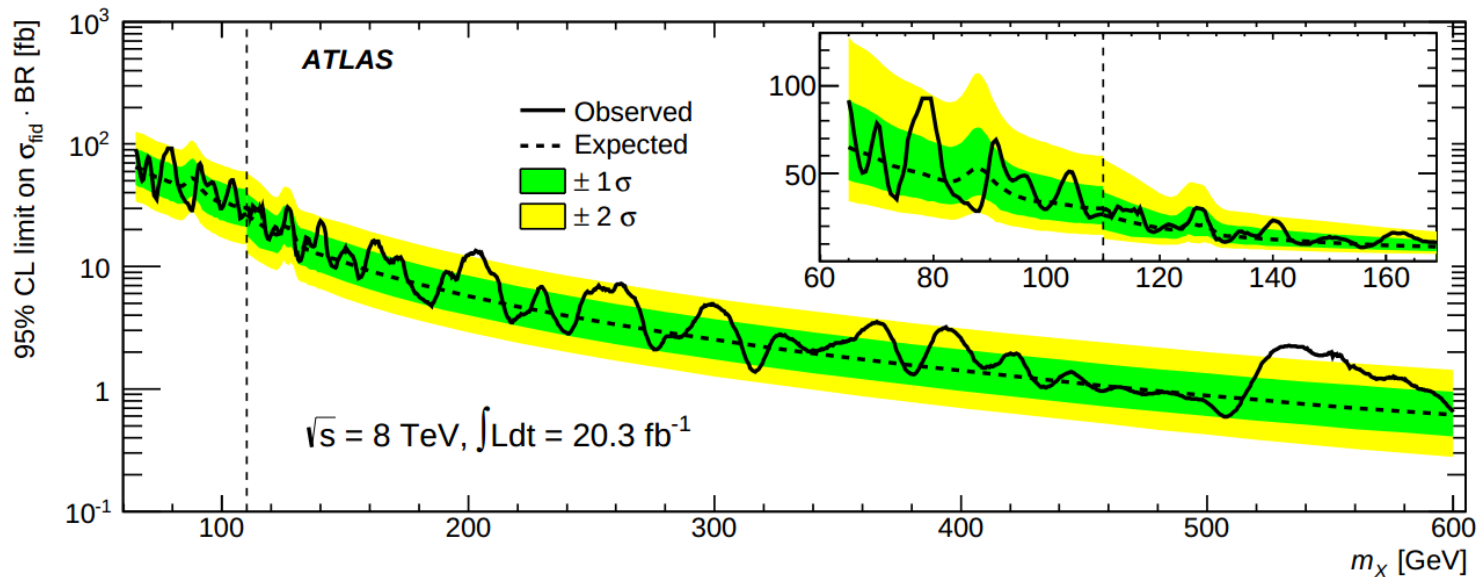
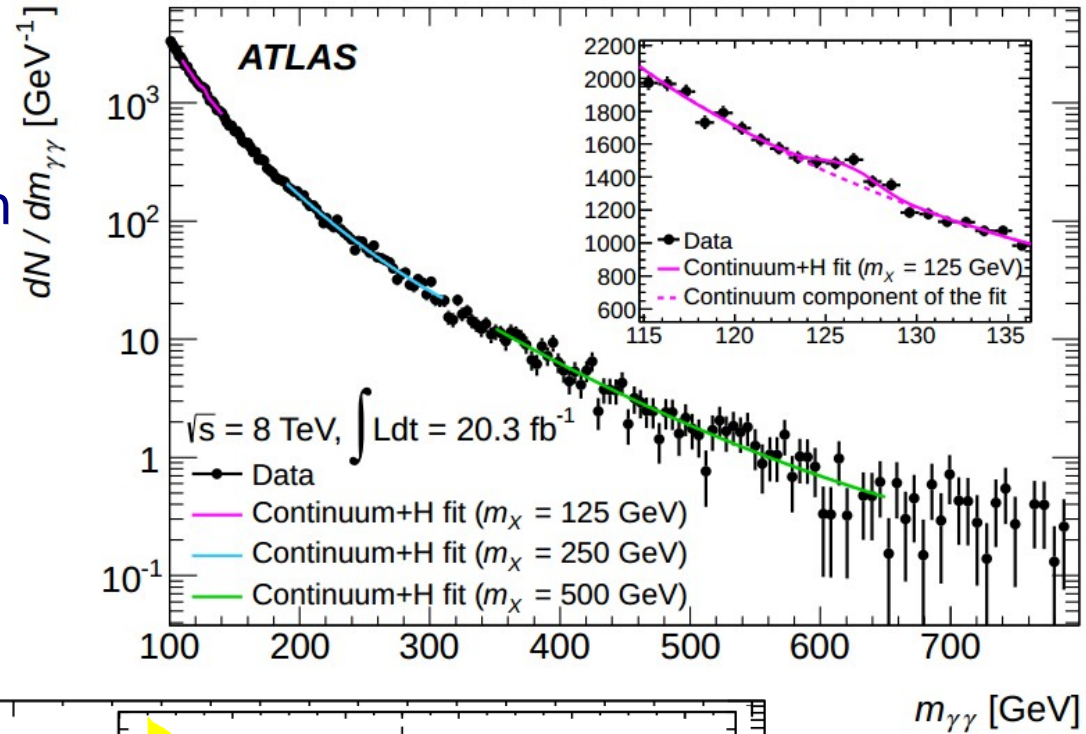
SM-like signal searches

- $H \rightarrow \gamma\gamma$: **65 - 600** GeV
- $H \rightarrow WW \rightarrow \mu\nu e\nu$: **260 - 1000** GeV
- $H \rightarrow ZZ \rightarrow 4l$: **200 - 900** GeV

$H \rightarrow \gamma\gamma$



- Look for: a resonance with narrow width
- Signature: two isolated photon with high p_T , three categories in low mass (65 - 110 GeV), $E_T(\gamma)/m(\gamma\gamma)$ cut in high mass (110 - 600 GeV)
- Strategy: cut based, fit on $m(\gamma\gamma)$



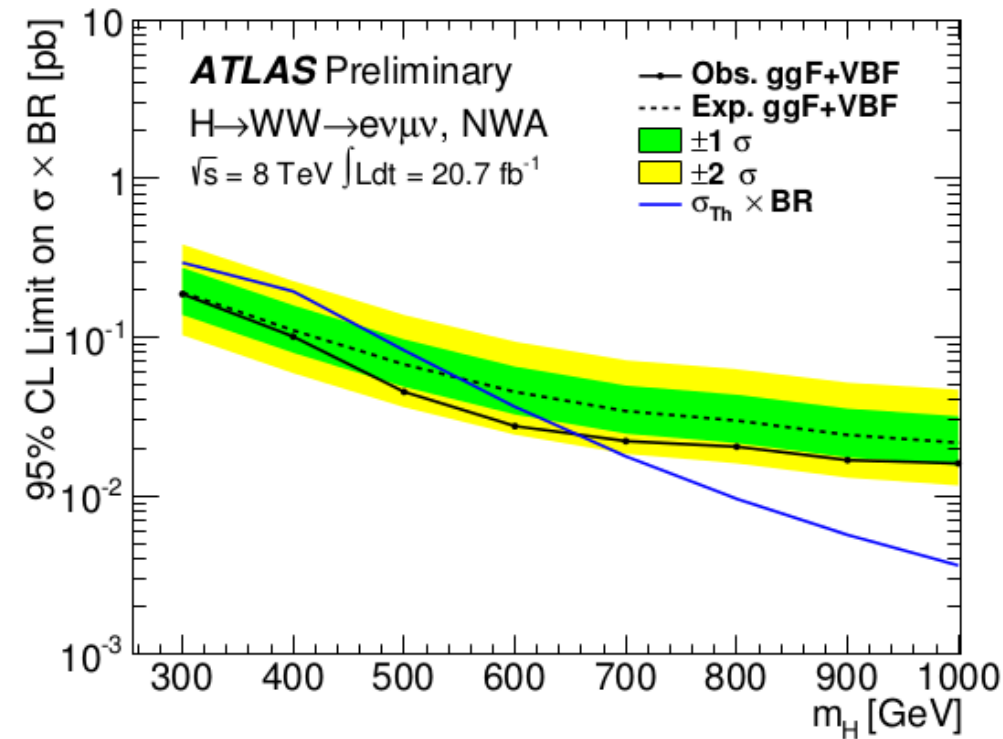
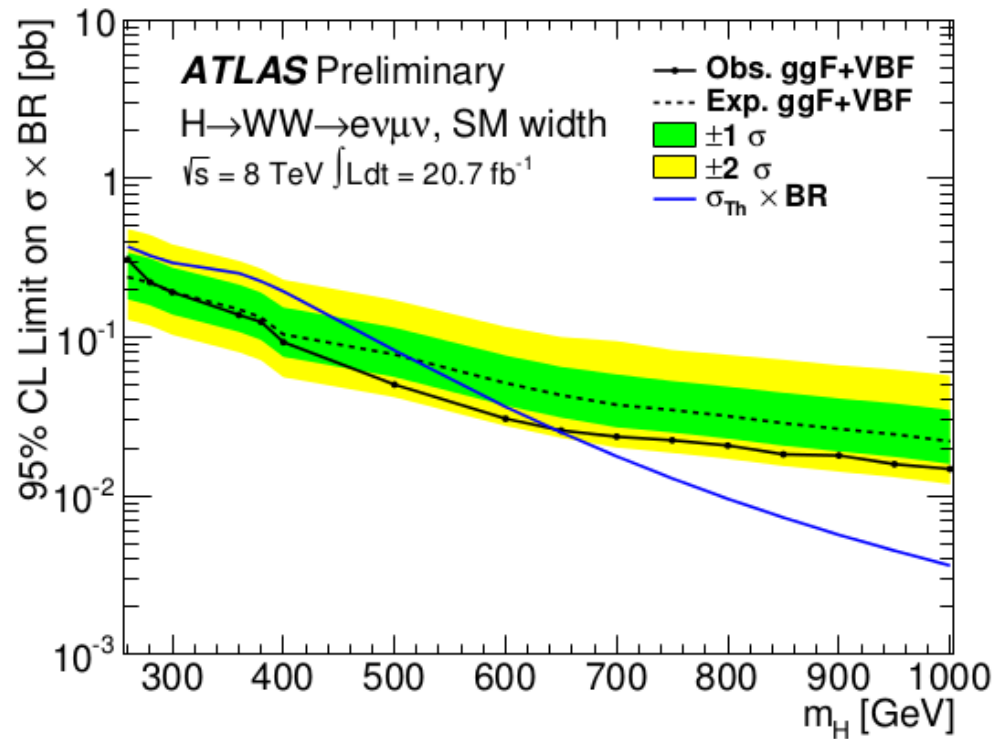
No significant evidence observed for an additional signal

$H \rightarrow WW \rightarrow \mu\nu e\nu$

ATLAS-CONF-2013-067



- Look for: a heavy Higgs boson with SM width or narrow width
- Signature: two opposite-sign high- p_T leptons with different flavors, large $missing E_T$, high $m(l\bar{l})$, b -jet veto
- Strategy: cut based, fit on $M_T(W)$

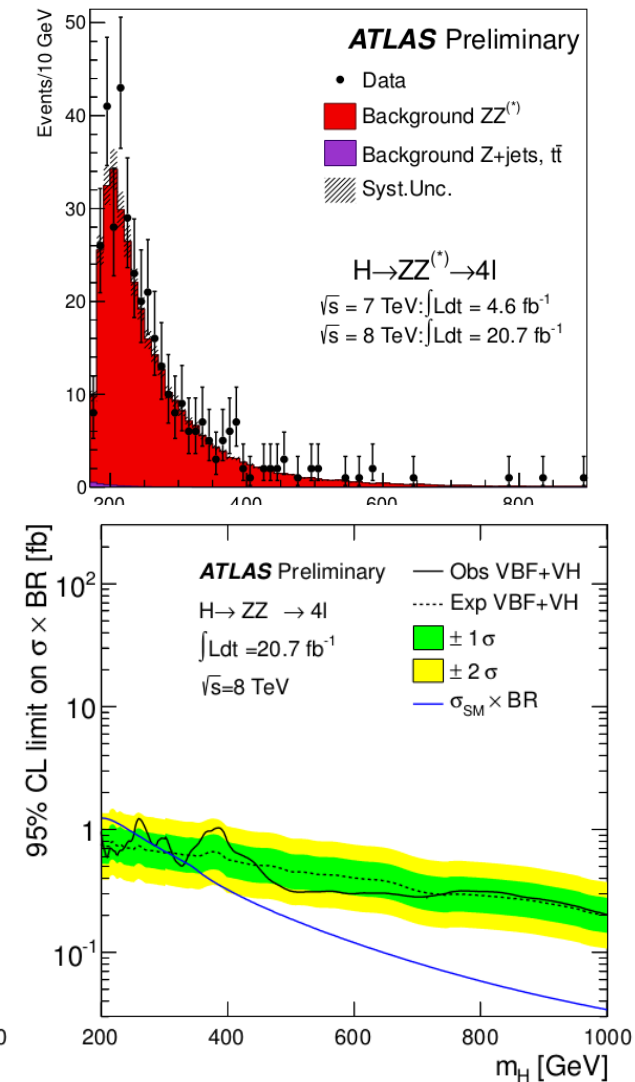
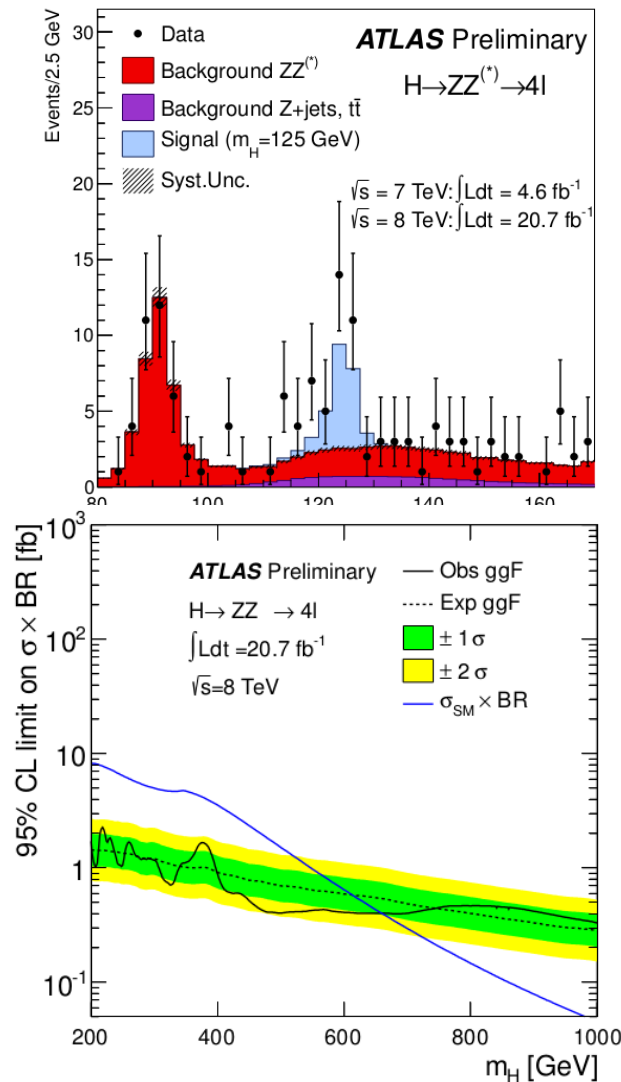


A heavy Higgs with SM width is excluded from 260 to 642 GeV

$H \rightarrow ZZ \rightarrow 4l$



- Look for: a heavy Higgs boson with SM width
- Signature: two opposite-sign same-flavor lepton pairs with high p_T lepton, three categories (VBF/VH/ggF-like)
- Strategy: cut based, fit on $m(l_1l_1)$
- A heavy Higgs with SM width is excluded up to 650 GeV



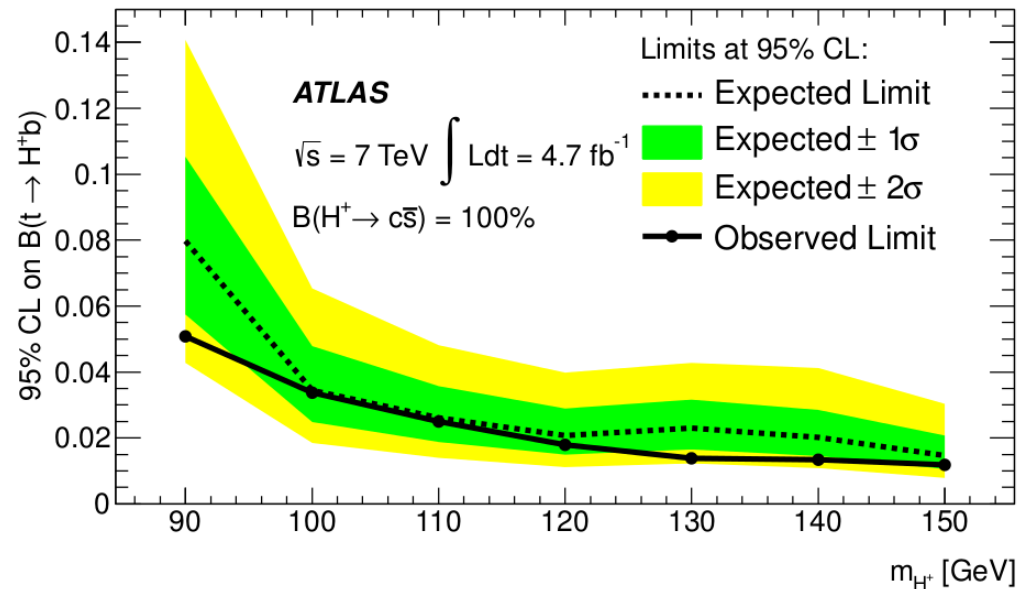
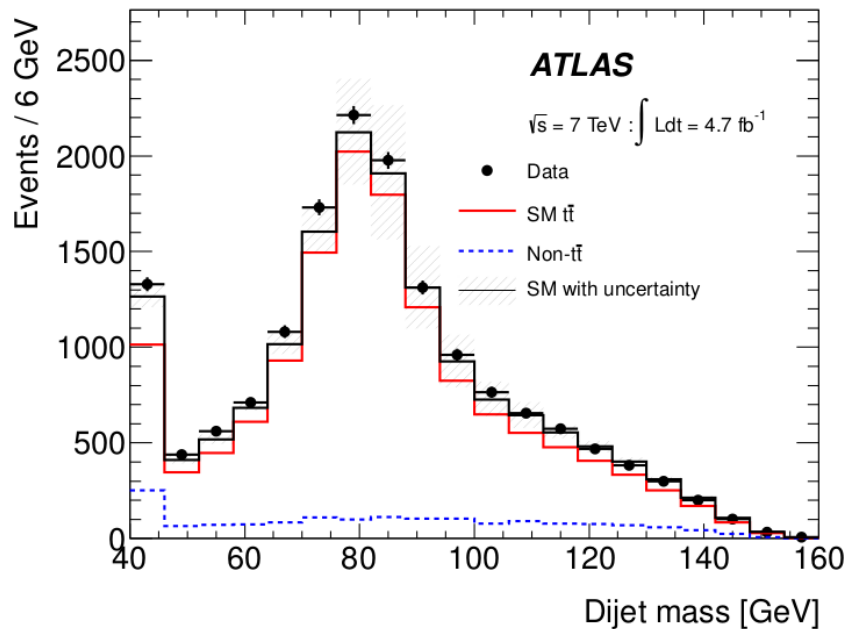
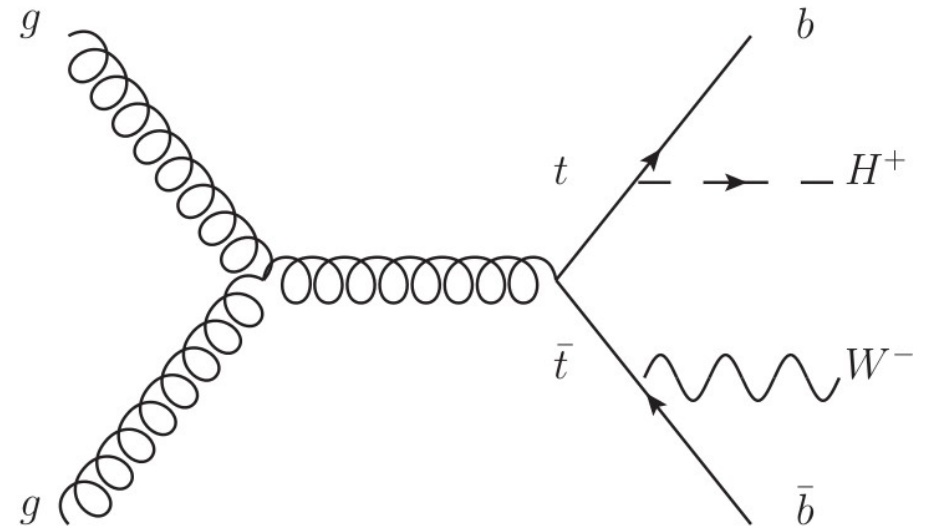
Charged Higgs searches

- $H^\pm \rightarrow c\bar{s}$ in $t\bar{t}$ production : **90 - 150** GeV
- $H^\pm \rightarrow \tau\nu$ in $t\bar{t}$ or t -associated production: **80 - 1000** GeV
- 2HDM cascade : **225 - 925** GeV

$H^\pm \rightarrow c\bar{s}$



- Look for: a charged Higgs that decays 100% into $c\bar{s}$
- Signature: one high p_T lepton, large *missing* E_T , at least four jets at least two b -jets, two light jets with $m(jj)$ close to $m(H^\pm)$, kinematic fitter for $t\bar{t}$ system
- Strategy: cut based, fit on $m(jj)$



set limits on $BR(t \rightarrow bH^\pm)$

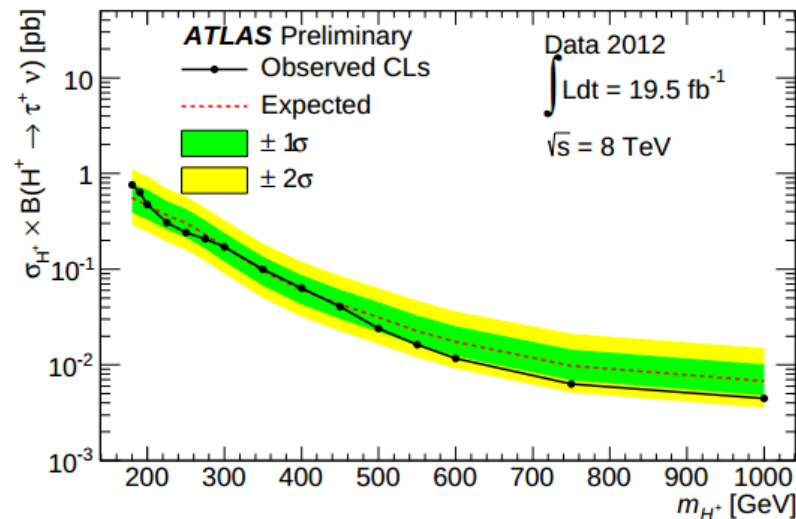
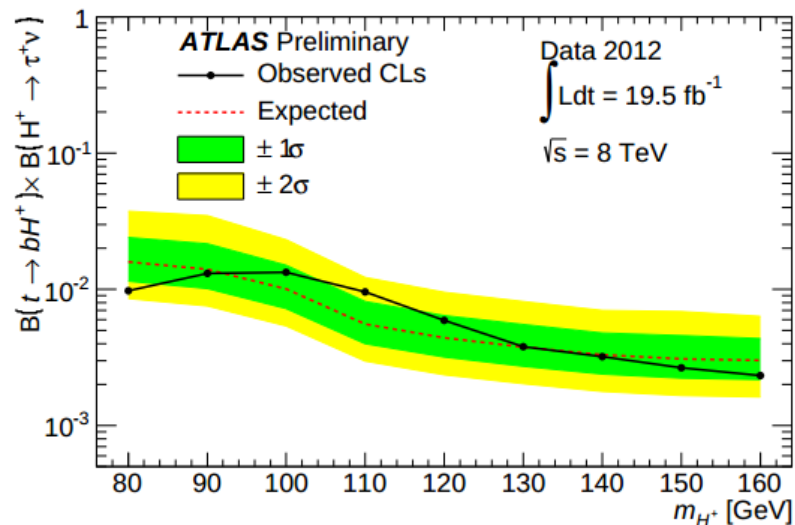
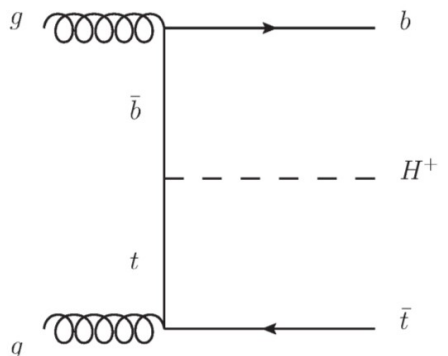
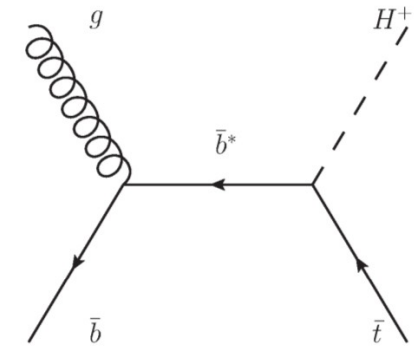
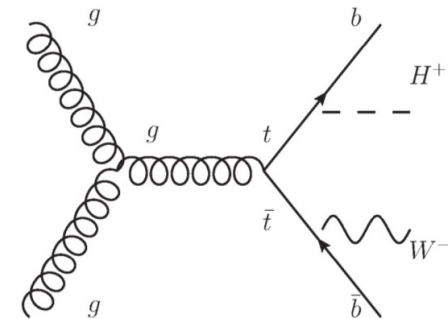
$H^\pm \rightarrow \tau\nu$



Latest

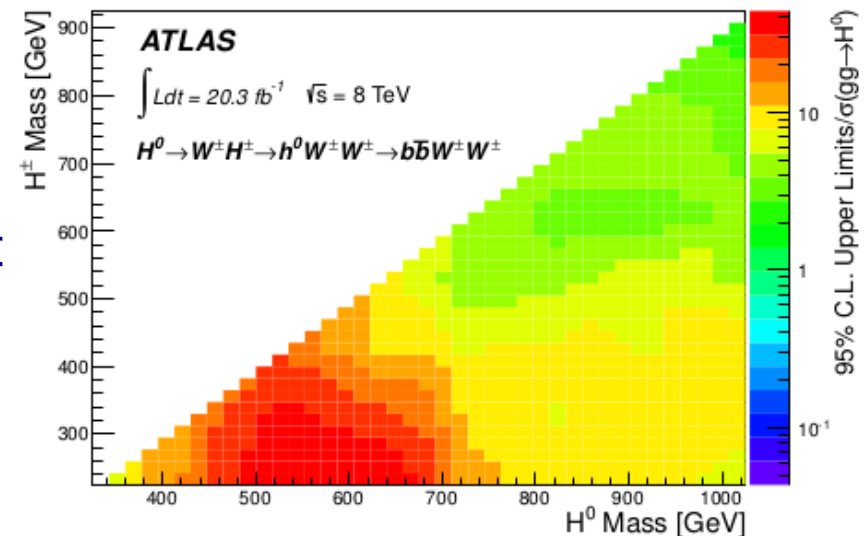
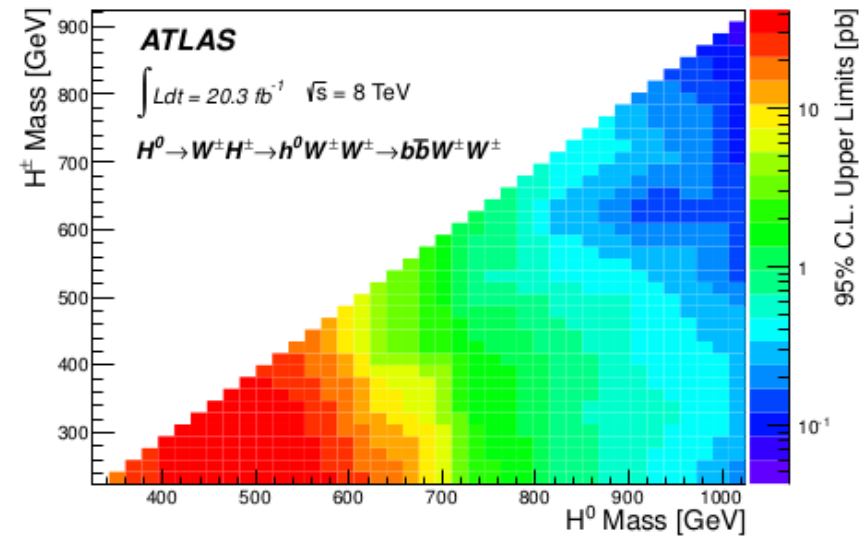
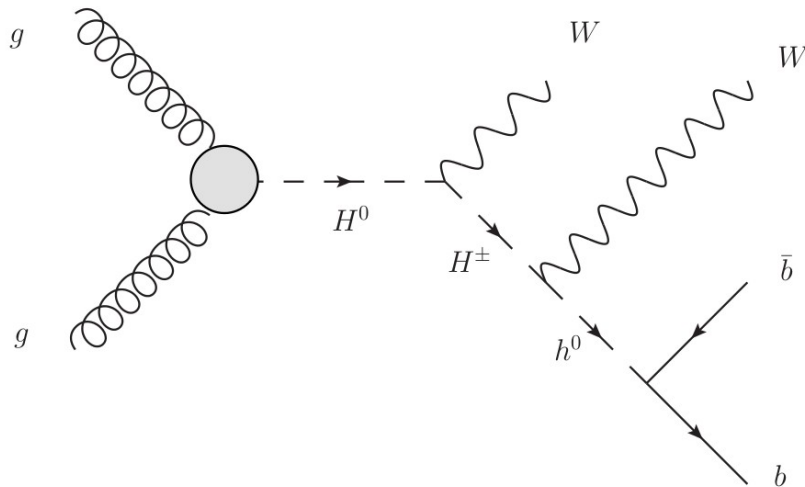
- Look for: a charged Higgs that decays 100% into $\tau\nu$
- Signature: a hadronically decayed τ , no electron, no muon, large *missing* E_T , at least four (three) jets for mass 80-160 GeV (180-1000 GeV), at least one *b*-jet
- Strategy: cut based, fit on m_T

set limits on $BR(t \rightarrow bH^\pm)$ for low mass and on $\sigma \times BR(H^\pm \rightarrow \tau\nu)$ for high mass



H^\pm cascade

Phys. Rev. D 89, 032002 (2014)



- Look for: a charged Higgs involved in a cascade of a W -boson pair and a $b\bar{b}$ -pair
- Signature: one high p_T lepton, large *missing* E_T , at least four jets, at least two b -jets
- Strategy: fit on the boosted-decision-tree distribution

set limits on x-section as a function of both charged H^\pm and neutral heavy H masses

Summary



- A large variety of searches on BSM Higgs bosons (or heavy resonances) were performed with the ATLAS detector
 - Indirect searching using SM Higgs couplings
 - SM Higgs invisible decays
 - MSSM $h/H/A \rightarrow \tau\tau$: **90 - 1000** GeV
 - 2HDM $H \rightarrow WW \rightarrow \mu\nu e\nu$: **135 - 300** GeV
 - Resonance $X \rightarrow hh \rightarrow b\bar{b}\gamma\gamma$: **220 - 500** GeV
 - Resonance $X \rightarrow hh \rightarrow b\bar{b}b\bar{b}$: **500 - 1500** GeV
 - Heavy $H \rightarrow \gamma\gamma$: **65 - 600** GeV
 - Heavy $H \rightarrow WW \rightarrow \mu\nu e\nu$: **260 - 1000** GeV
 - Heavy $H \rightarrow ZZ \rightarrow 4l$: **200 - 900** GeV
 - Charged $H^\pm \rightarrow c\bar{s}$ in $t\bar{t}$ production : **90 - 150** GeV
 - Charged $H^\pm \rightarrow \tau\nu$ in $t\bar{t}$ or t -associated production: **80 - 1000** GeV
 - 2HDM H^\pm cascade : **225 - 925** GeV
 - More are coming VERY SOON!

Hvala!

$H^\pm \rightarrow \tau\nu$ (previously)



- Searched with 7TeV data

