ATLAS Beyond Standard Model Higgs Results

Higgs Hunting 2017

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Introduction

- Discovery of a neutral scalar particle of mass ~ 125 GeV at the LHC confirmed the predicted electroweak symmetry breaking mechanism of the SM
- Experimental results show consistency with the SM Higgs boson
- Is there only one Higgs doublet (SM) or the Higgs sector is more complex?
- Various BSM models predict additional Higgs bosons:
  - Additional EW singlet: h, H
  - Two Higgs Doublet Model (2HDM): $h, H, A, H^{\pm}$
  - Two Higgs doublet + singlet Model
  - Higgs triplet models (SM doublet + triplet): $H^{\pm\pm}$

Strategies that use Higgs to find new physics:

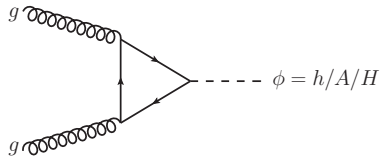
Indirectly, by looking for non-standard properties of light Higgs (couplings, CP, LFV decays...)

Directly, by explicit search for BSM Higgs decaying to SM objects

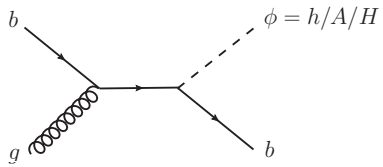
Higgs decays to BSM states (light scalar resonances, invisible decays, LLP...)

Heavy Neutral Higgs in Fermion Final States

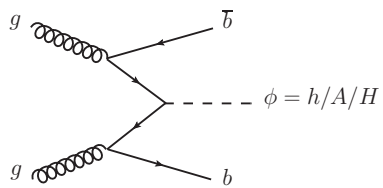
- Neutral MSSM Higgs boson at the LHC:
  - gluon-gluon fusion
  - b-associated production



- In the MSSM, the heavy Higgs boson couplings to down-type fermions (τ, b) are strongly enhanced for a large part of the parameter space for large $\tan\beta$



- $H/A \to t\bar{t}$ is kinematically accessible at low $\tan\beta$ and masses $\geq 2m_t$



Searches for heavy neutral Higgs in fermion final states in ATLAS

$A/H \to \tau\tau$	ATLAS-CONF-2017-050
$A/H \to t\bar{t}$	CERN-EP-2017-134, to be submitted to Phys. Rev. Lett.

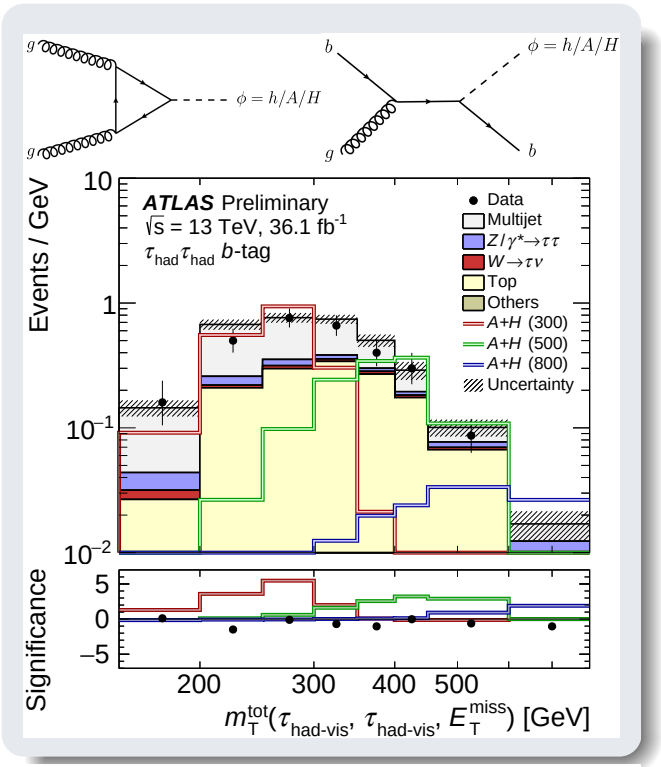
Heavy Neutral Higgs

$A/H \to \tau\tau$ in 36.1 fb^{-1} of pp collisions at 13 TeV

- Two τ decay modes considered:
  - All hadronic final state ($\tau_{\text{had}}\tau_{\text{had}}$), 0 or ≥ 1 b-jet
  - Semileptonic final state ($\tau_{\text{lep}}\tau_{\text{had}}$), 0 or ≥ 1 b-jet
- Discriminating variable:

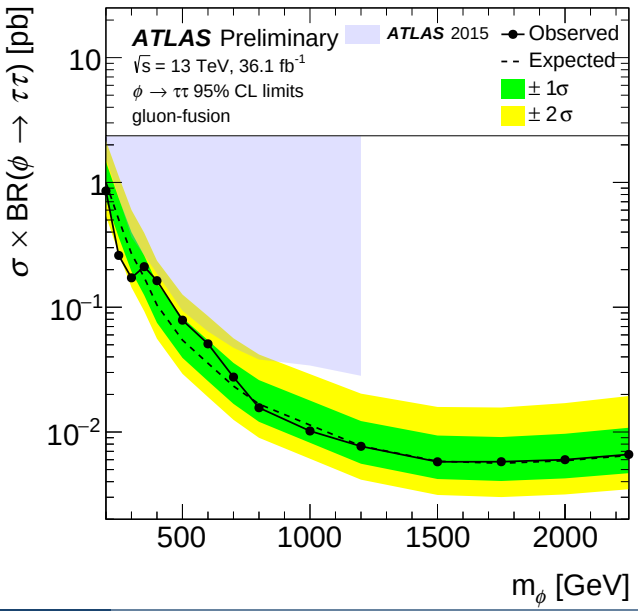
$$m_{\text{T}}^{\text{tot}} = \sqrt{(p_{\text{T}}^{\tau_1} + p_{\text{T}}^{\tau_2} + E_{\text{T}}^{\text{miss}})^2 - (\mathbf{p}_{\text{T}}^{\tau_1} + \mathbf{p}_{\text{T}}^{\tau_2} + \mathbf{E}_{\text{T}}^{\text{miss}})^2}$$

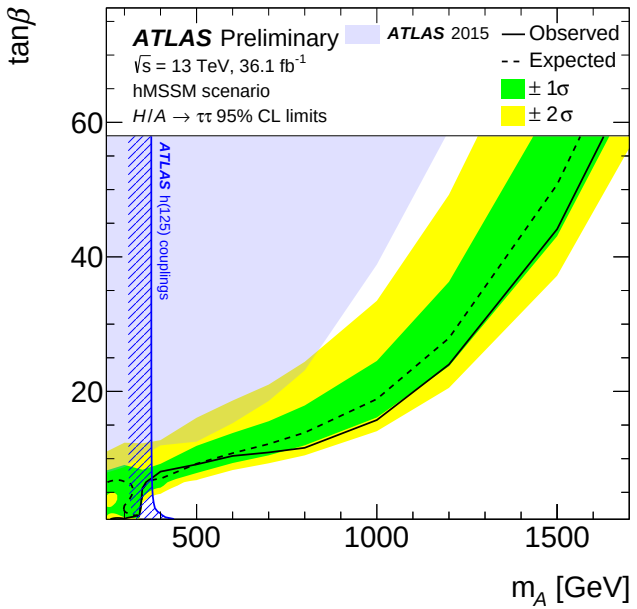
- Observed $\sigma \times BR$ limit for ggF: 0.85 pb - 5.8 fb for m_ϕ range of 200 GeV - 2.25 TeV
- Interpretation in the hMSSM: excluded $\tan\beta > 1.0$ for $m_A = 250$ GeV and $\tan\beta > 45$ for $m_A = 1.5$ TeV



Main backgrounds:

- Misidentified jet as τ

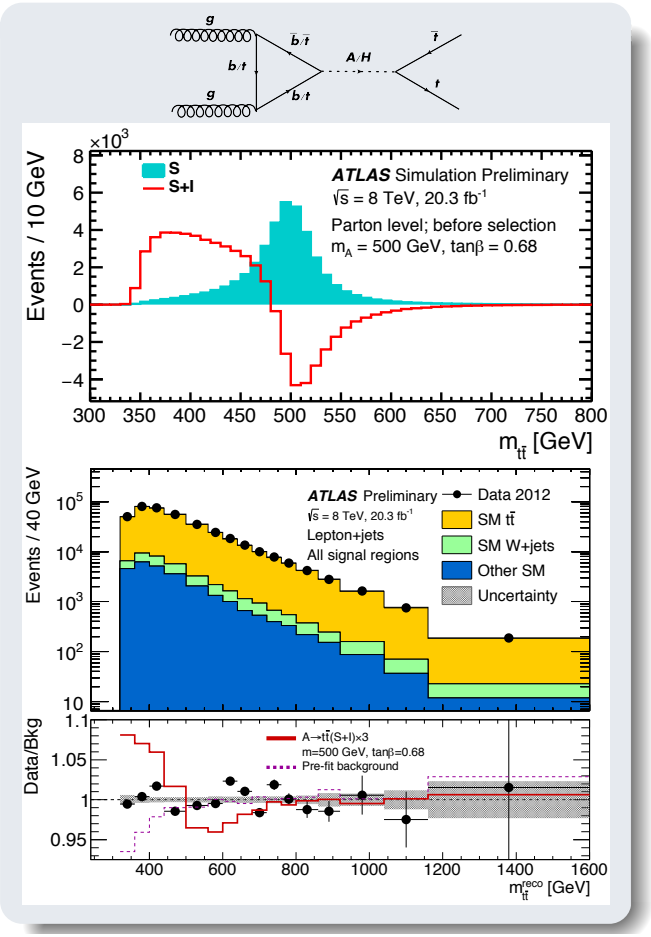


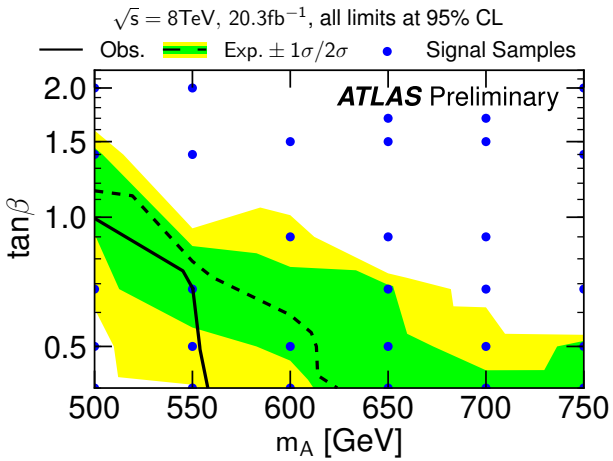


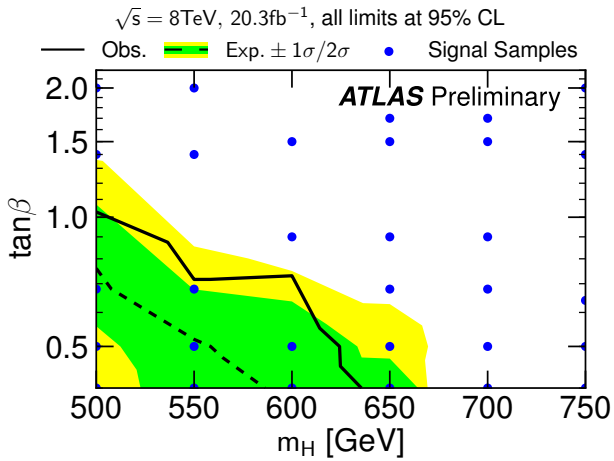
Heavy Neutral Higgs

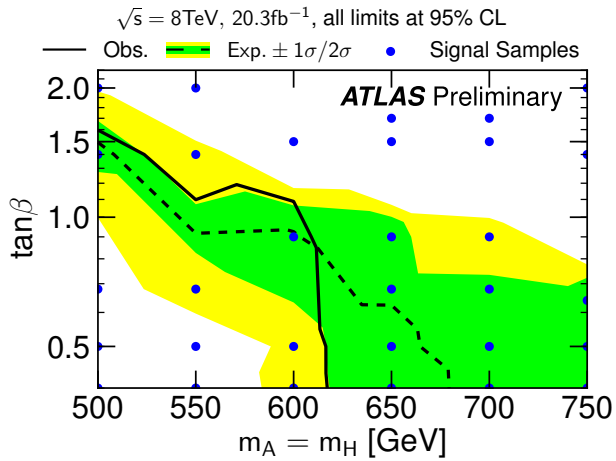
$A/H \to t\bar{t}$ in 20.3 fb^{-1} of pp collisions at 8 TeV

- Significant interference between $gg \to t\bar{t}$ production and $A/H \to t\bar{t}$
- 1 lepton (e or μ), ≥ 4 jets, $E_{\mathrm{T}}^{\mathrm{miss}}$
- Discriminating variable: $m_{t\bar{t}}^{\mathrm{reco}}$
- Resolved kinematics considered
- Limits take interference into account
- Observed limits for type-II 2HDM:
  $\tan\beta < 0.69$ for $m_A = 550$ GeV, $\tan\beta < 0.72$ for $m_H = 550$ GeV, $\tan\beta < 1.1$ for $m_{A/H} = 550$ GeV









Heavy Neutral Higgs in Boson Final States

- Several theories beyond the Standard Model, like the EWS or 2HDM models, predict the existence of high mass Higgs particles, which could decay into final states with Weak bosons

Searches for heavy neutral Higgs in boson final states in ATLAS

$H \to ZZ \to \ell\ell\ell\ell/\ell\ell\nu\nu$	ATLAS-CONF-2017-058
$H \to WW \to \ell\nu qq$	ATLAS-CONF-2017-051
$A \to Zh \to \ell\ell b\bar{b}$	ATLAS-CONF-2017-055

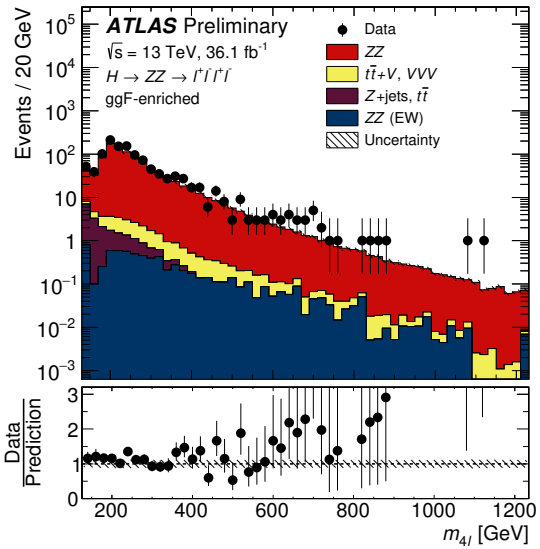
Heavy Neutral Higgs

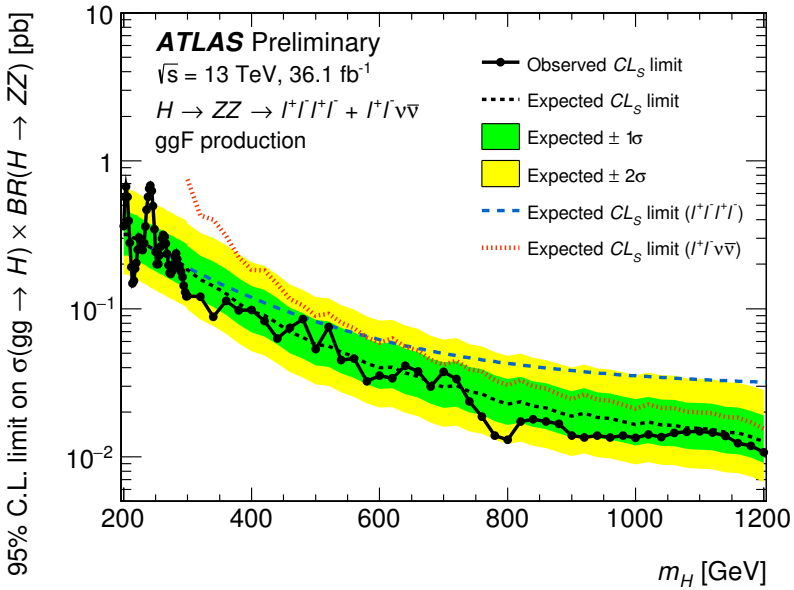
$H \to ZZ \to \ell\ell\ell\ell/\ell\ell\nu\nu$ in 36.1 fb^{-1} of pp collisions at 13 TeV

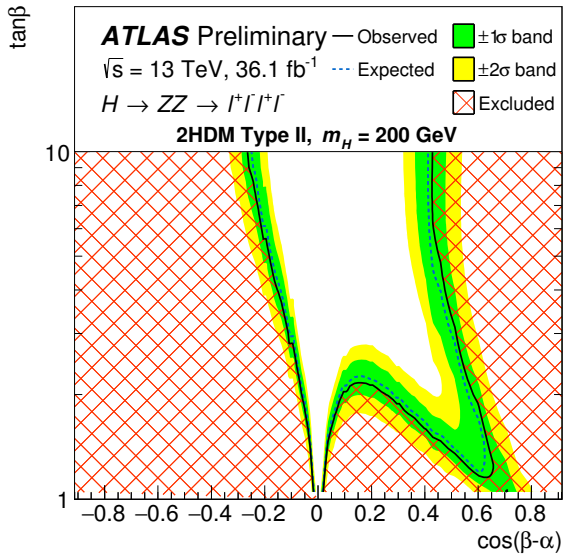
- High mass Higgs in $H \to ZZ \to \ell\ell\ell\ell$:
  - 2 same-flavour OS isolated lepton pairs
  - Discriminating variable: $m_{4\ell}$
- High mass Higgs in $H \to ZZ \to \ell\ell\nu\nu$:
  - 2 leptons consistent with originating from a Z
  - Discriminating variable:

$$m_{\mathrm{T}} = \sqrt{\left[\sqrt{m_Z^2 + \left(p_{\mathrm{T}}^{\ell\ell}\right)^2} + \sqrt{m_Z^2 + \left(E_{\mathrm{T}}^{\mathrm{miss}}\right)^2}\right]^2 - \left[\mathbf{p}_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}}\right]^2}$$

- Narrow for ggF and VBF and large width (1-10% of m_H) for ggF signal hypotheses tested



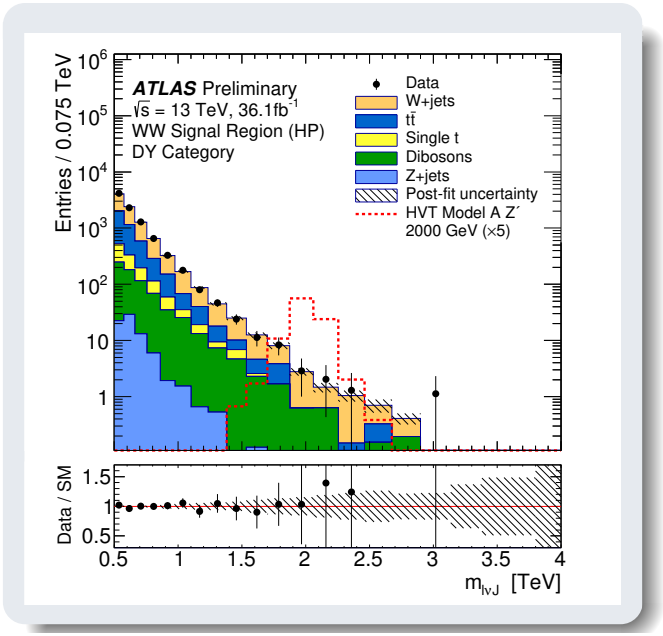


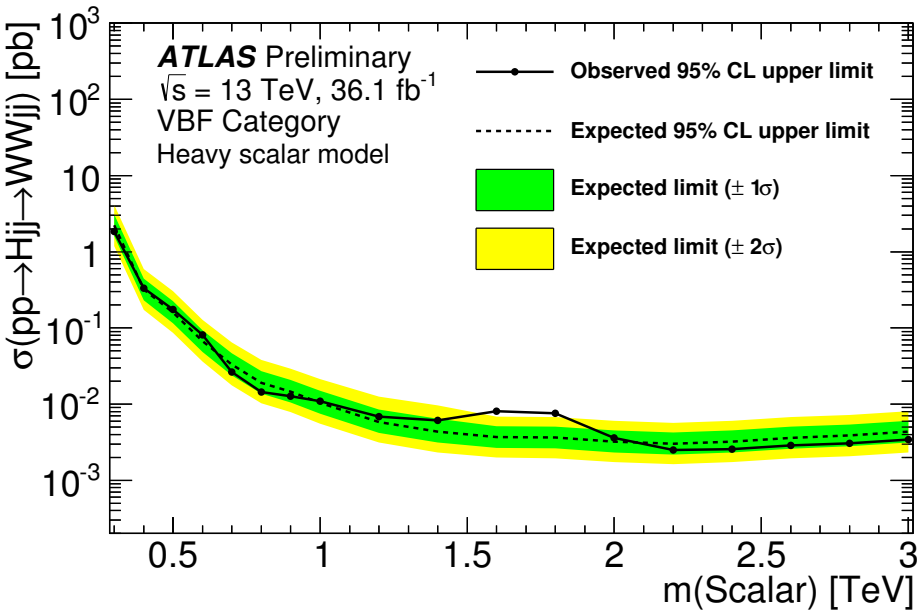


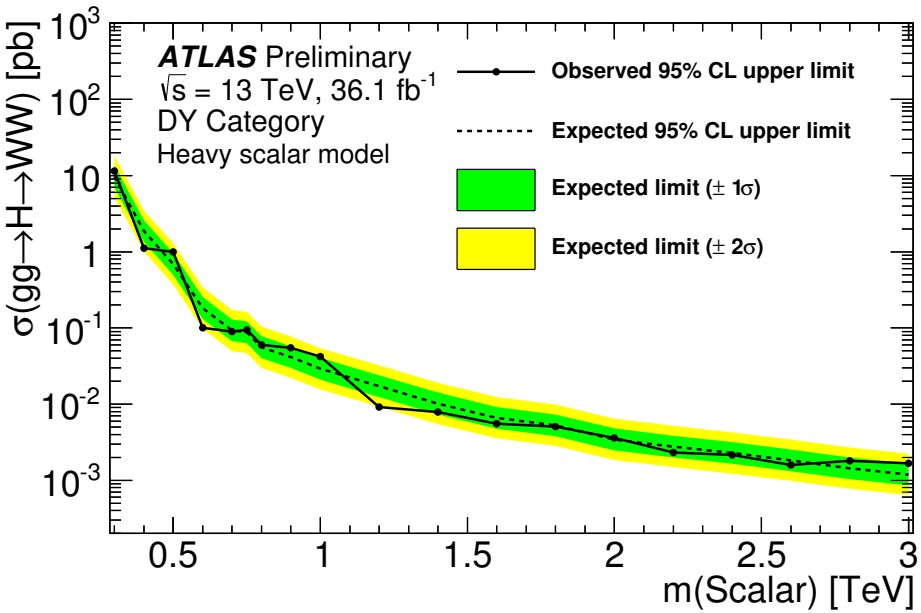
Heavy Neutral Higgs

$H \to WW \to \ell\nu qq$ in 36.1 fb^{-1} of pp collisions at 13 TeV

- 1 lepton (e or μ), $E_{\mathrm{T}}^{\mathrm{miss}}$
  - ≥ 1 large-R jet (boosted analysis)
  - ≥ 2 small-R jets (resolved analysis)
- Discriminating variable: $m_{\ell\nu J}$ or $m_{\ell\nu jj}$ where the p_Z^ν obtained from a W mass constraint
- Narrow width (ggF and VBF) signal hypotheses

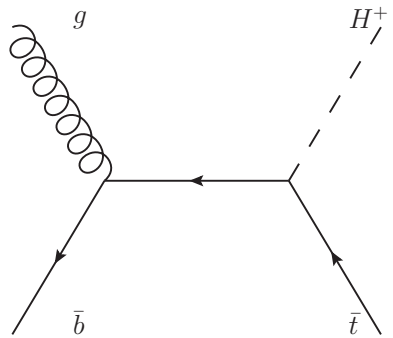


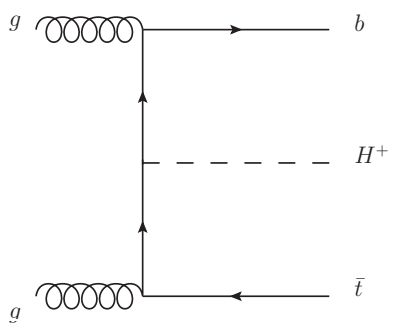


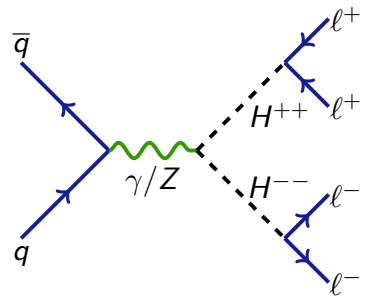


Charged Higgs

- Any extension to the Higgs sector, beyond adding a singlet scalar, implies existence of charged scalars (2HDM, NMSSM, Triplet...)
- Dominant production in association with top quarks in benchmark models
- At high mass $H^{\pm} \to tb$ is the dominant decay mode in type-II 2HDM
- $H^{\pm} \to \tau\nu$ remains significant for a large range of masses for high $\tan\beta$ in type-II 2HDM
- Addition of a Higgs triplet to SM gives doubly charged Higgs bosons $H^{\pm\pm}$







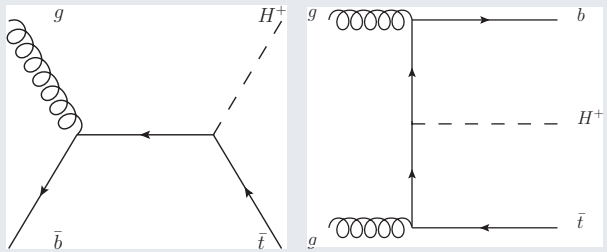
Charged Higgs searches in ATLAS

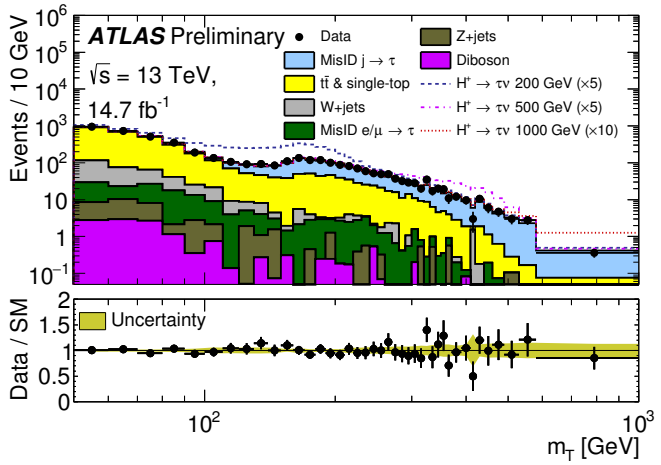
$H^{\pm} \to \tau\nu$	ATLAS-CONF-2016-088
$H^{\pm} \to tb$	ATLAS-CONF-2016-089
$H^{++}H^{--} \to \ell^+\ell^+\ell^-\ell^-$	ATLAS-CONF-2017-053

Charged Higgs

$H^{\pm} \to \tau\nu$ in 14.7 fb^{-1} of pp collisions at 13 TeV

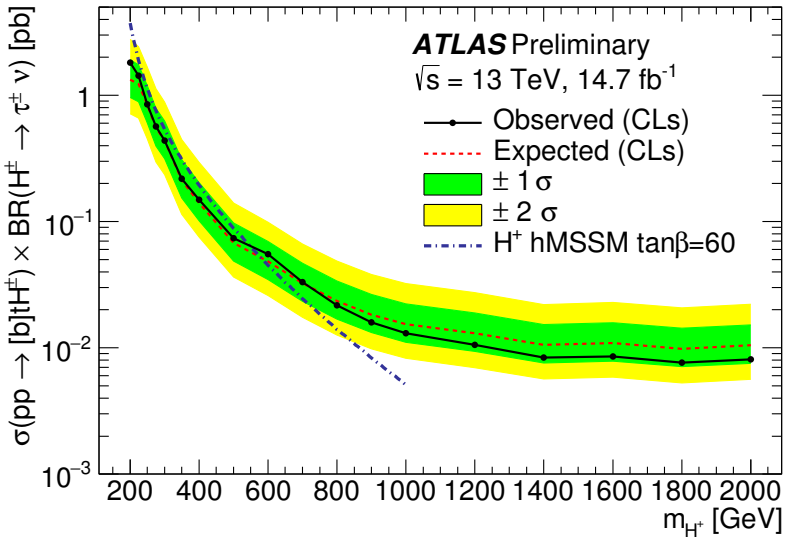
- 1 hadronic τ, veto events with e or μ, ≥ 3 jets (≥ 1 b-jet), $E_{\mathrm{T}}^{\mathrm{miss}}$
- Discriminating variable: $m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\tau}E_{\mathrm{T}}^{\mathrm{miss}}(1-\cos\Delta\phi_{\tau,E_{\mathrm{T}}^{\mathrm{miss}}})}$
- Observed $\sigma \times BR$ limit: 2 pb - 8 fb for $m_{H^{\pm}}$ range of 200 GeV - 2 TeV
- Interpretation in the hMSSM: $\tan\beta$ in the range 42 - 60 excluded for $m_{H^{\pm}} = 200$ GeV
- At $\tan\beta = 60$, $m_{H^{\pm}}$ from 200 to 540 GeV excluded

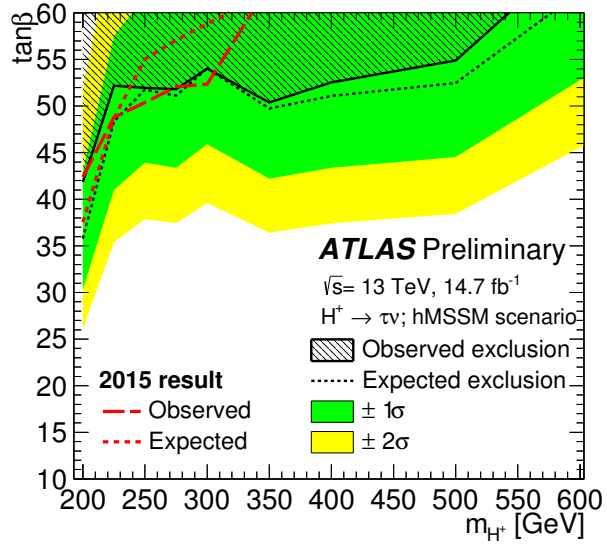




Main backgrounds:

- Misidentified jet as τ
- $t\bar{t}$ and single top

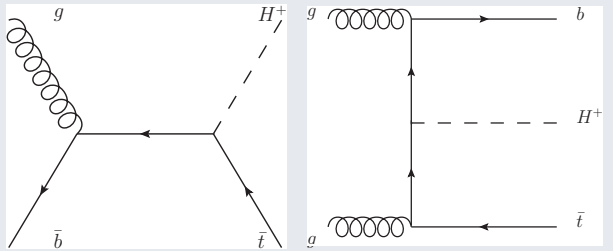


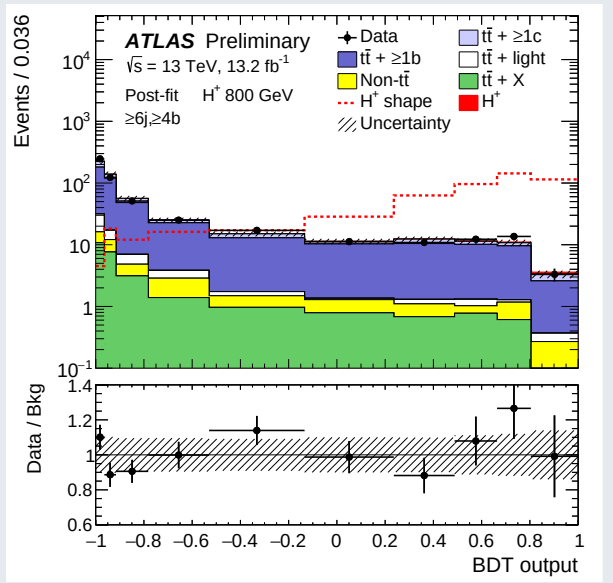


Charged Higgs

$H^{\pm} \to tb$ in 13.2 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV

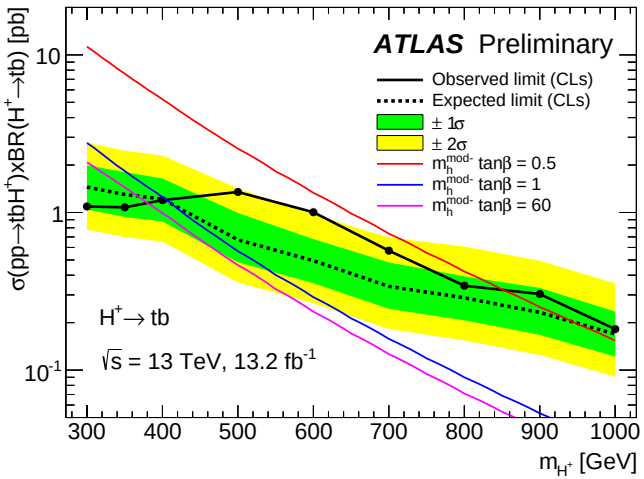
- 1 lepton (e or μ), ≥ 4 jets (≥ 2 b-jets)
- Multiple regions based on N(jets) and N(b-jets) to constrain the $t\bar{t}+\geq 1b$ and $t\bar{t}+\geq 1c$ backgrounds
- Discriminating variable: BDT score
- Observed $\sigma \times BR$ limit: 1.1 - 0.18 pb for $m_{H^{\pm}}$ range of 300 GeV - 1 TeV
- Interpretation in MSSM, e.g. $m_h^{\mathrm{mod}-}$: $\tan\beta$ in range 0.5 - 1.7 for $m_{H^{\pm}}$ range of 300 - 855 GeV
- $\tan\beta$ in the range 44 - 60 for $m_{H^{\pm}}$ range of 300 - 366 GeV

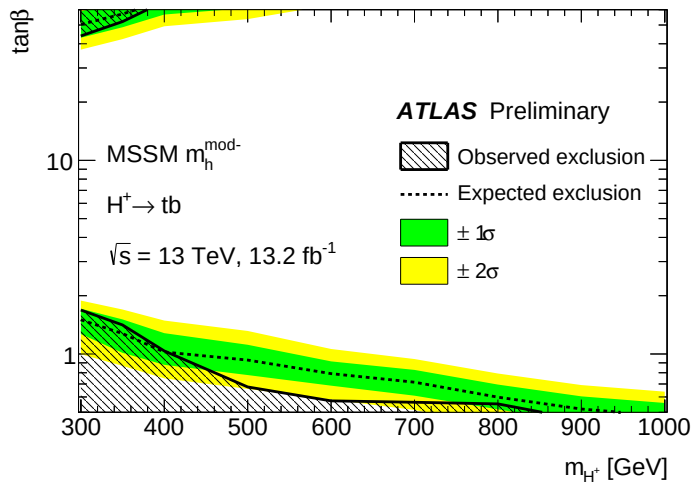




Main backgrounds:

- $t\bar{t}+$jets dominated by $t\bar{t}+\geq 1b$

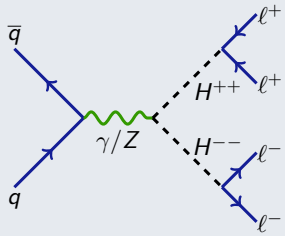


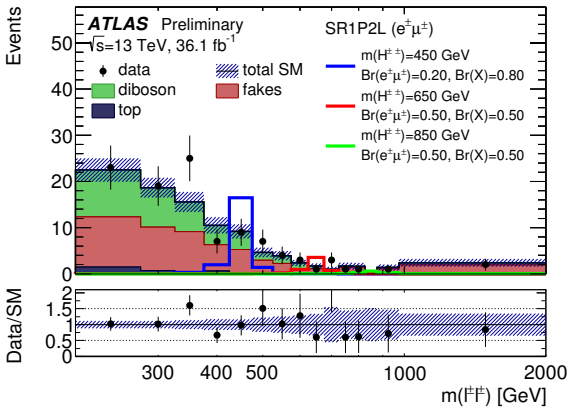


Charged Higgs

$H^{++}H^{--} \to \ell^+\ell^+\ell^-\ell^-$ in 36.1 fb^{-1} of pp collisions at 13 TeV

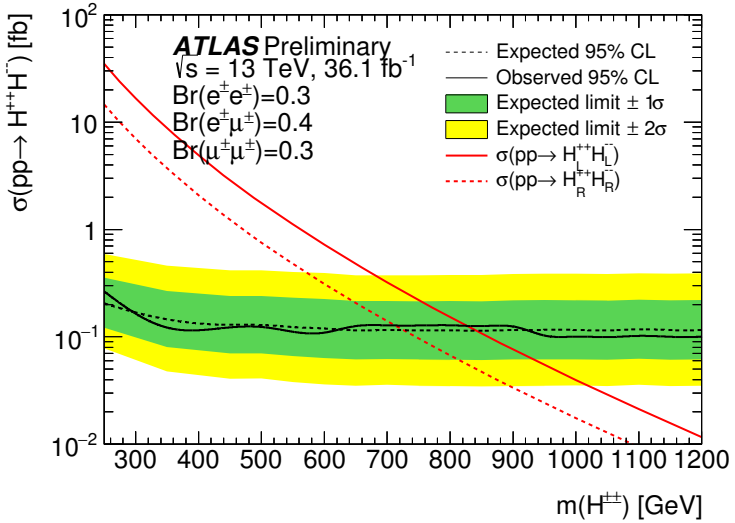
- Drell-Yan production of a $H^{++}H^{--}$ pair decaying into two pairs of same-sign leptons
- 2, 3 or 4 leptons (e or μ), veto events with b-jets
- Discriminating variable: $m_{\ell^\pm\ell^\pm}$ or $\bar{M} = \frac{m^{++}+m^{--}}{2}$
- Set limits on σ assuming various BR into $e^\pm e^\pm$, $e^\pm\mu^\pm$ or $\mu^\pm\mu^\pm$ and for $H_L^{\pm\pm}$ or $H_R^{\pm\pm}$
- For $BR(e^\pm e^\pm) + BR(e^\pm\mu^\pm) + BR(\mu^\pm\mu^\pm) = 100\%$: $m(H_L^{\pm\pm}) > 770$ - 870 GeV, $m(H_R^{\pm\pm}) > 660$ - 760 GeV excluded depending on BR composition

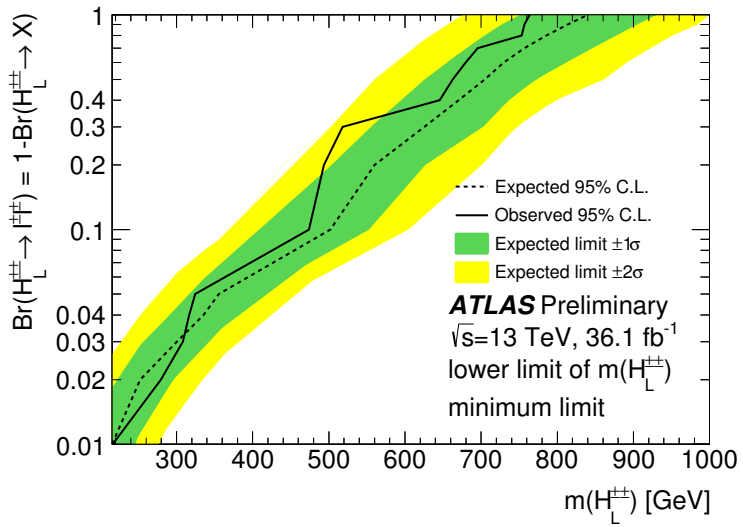




Main backgrounds:

- Diboson
- Misidentified leptons
- Leptons with misidentified charge





Conclusions & Summary

- ATLAS is highly active in searching for BSM phenomena in the Higgs sector. Effort to cover maximum topologies.
- The Run 2 data collected in 2015 and 2016 are being analyzed. A lot of new results released this Summer.
- Shown selection of recent beyond Standard Model Higgs results
- No sign of additional Higgs boson seen in the LHC data yet. Therefore, exclusion limits are set.
- Looking forward to analyze data being collected this year

Back-up

Heavy Neutral Higgs

$A \to Zh \to \ell\ell b\bar{b}$ in 36.1 fb^{-1} of pp collisions at 13 TeV

- Two channels based on Z decays
- 0-/2-lepton combined limits presented separately for ggF and bbA production
- Mild excess at $m_A = 440$ GeV
  - Arises mostly from 3+ btag region in 2-lepton channel
  - Local (global) significance: 3.6 (2.4) standard deviation