Searches for BSM Higgs at ATLAS

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on behalf of the
ATLAS Collaboration

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ATLAS EXPERIMENT
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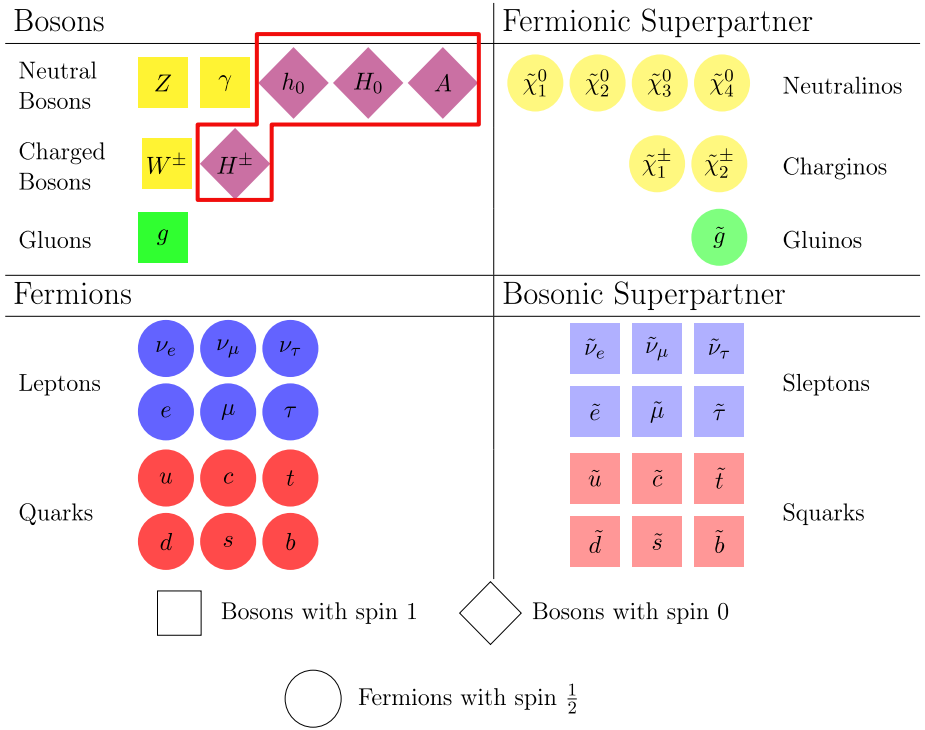
INSTITUTE OF NUCLEAR AND PARTICLE PHYSICS
ErUM-FSP T02 ATLAS

Standard Model extension

- **Simple extension to to Standard Model SM:**
  - 2 Higgs Doublet Models (2HDM)
  - Higgs triplet extensions
- Part of models like
  Minimal supersymmetric SM (MSSM)
- **Higgs content:** h^0, H^0, A, $H^{\pm}$
- Searches for BSM Higgs Bosons commonly interpreted in
  - hMSSM and m_h^{125} models
  - Parameterized at tree level by
    m_A and **$\tan(\beta) = v_u/v_d$**



PDG Phys. Rev. D 98, 030001 (2018)

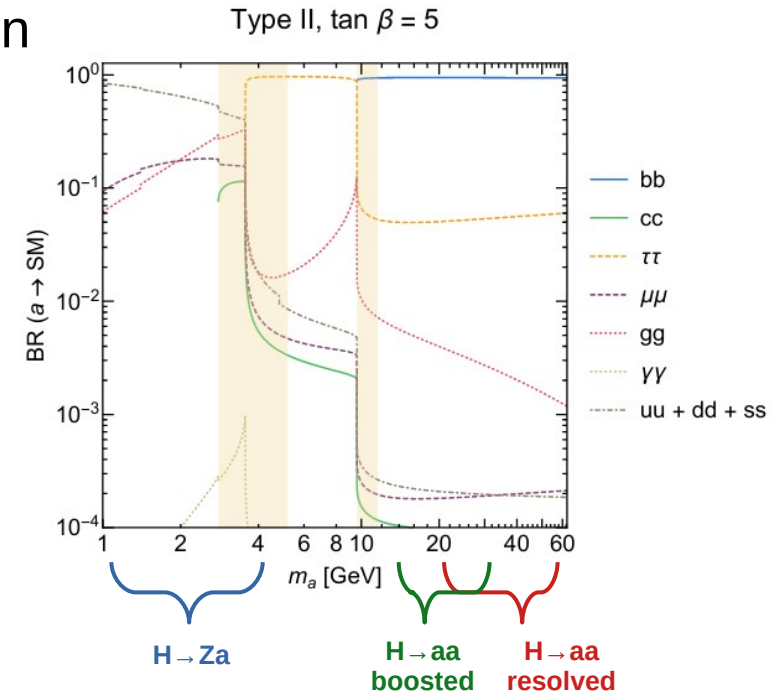
Searches for BSM Higgs at ATLAS

Search channel	L [fb^{-1}]	Comments	Reference
$H \rightarrow aa \rightarrow bb\,bb$	36	Light neutral Higgs	JHEP 10 (2018) 031 (resolved) arXiv:2005.12236 **(boosted)**
$H \rightarrow Za$	**139**	Light neutral Higgs	arXiv:2004.01678
$H^+ \rightarrow \tau^+\nu_\tau$	36	Charged Higgs	JHEP 09 (2018) 139
$H^+ \rightarrow tb$	**139**	Charged Higgs	ATLAS-CONF-2020-039
$H^+ \rightarrow ll\,l\nu$	36	Charged Higgs	Phys. Lett. B 787 (2018) 68
$H^{++} \rightarrow W^+W^+$	36	Charged Higgs	Eur. Phys. J. C (2019) 79: 58
$H^{++} \rightarrow l^+l^+$	36	Charged Higgs	Eur. Phys. J. C 78 (2018) 199
$A \rightarrow Zh$	**139**	Heavy neutral Higgs	ATLAS-CONF-2020-043
$A/H \rightarrow \tau\tau$	**139**	Heavy neutral Higgs	PRL 125 (2020) 051801
Di-Higgs searches presented in **Janas talk**			

Searches for light neutral Higgs

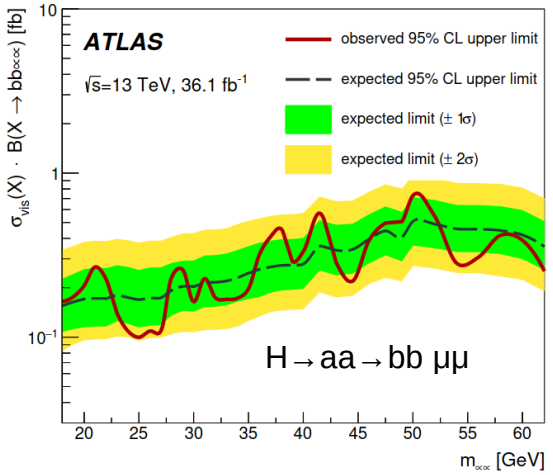
- Extended Higgs sector in NMSSM (2HDM+S) predict existence of light CP-odd neutral ***a*** Boson
- **Models with light a Boson:**
  - Mediator between DM and SM particles
  - Can explain:
    galactic center gamma ray excess,
    baryogenesis …
- **When m_a sufficiently low:**
  - $H_{125\ GeV} \rightarrow aa$
  - $H_{125\ GeV} \rightarrow Za$

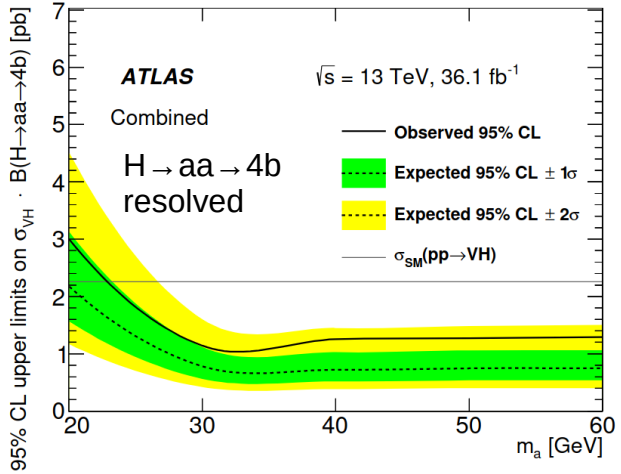
Phys. Rev. D 90, 075004 (2014)



Current light Higgs results

- Results based on 2015 and 2016 data
- **H → aa → bb μμ**
  Phys. Lett. B 790 (2019) 1
- **H → aa → bb bb (resolved)**
  JHEP 10 (2018) 031
- **H → aa → γγ jj**
  Phys. Lett. B 782 (2018) 750
- **H → aa → 4l**
  JHEP 06 (2018) 166

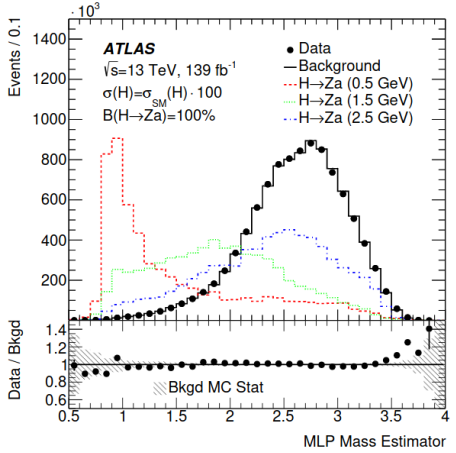


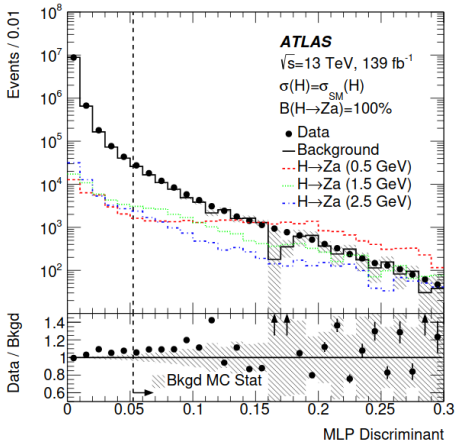


H → Z a → ll+jet

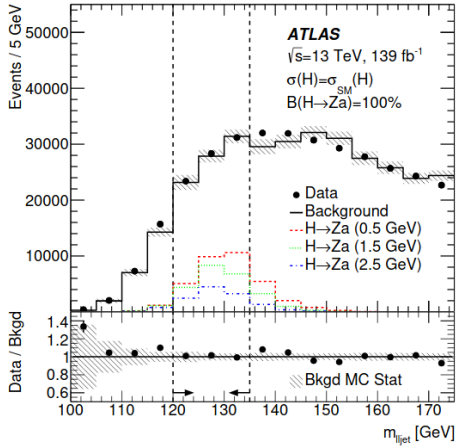
- **Searching masses from:**
  0.5 GeV ≤ m_a ≤ 4 GeV
- Events triggered by lepton triggers
- Selecting 2 lepton (Z), 1 jet (a)
- **2-staged Multi-Layer-Perceptron (MLP) based on jet tracks:**
  - 1st MLP estimates m_a
  - 2nd MLP discriminates QCD vs jets from a-decay

New! Full Run2





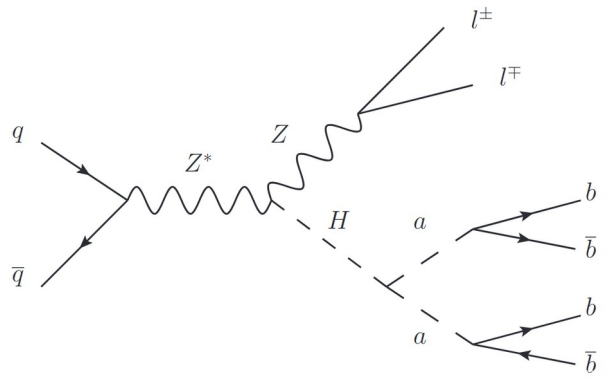
a mass [GeV]	$a \to gg$		$a \to s\bar{s}$	
	Exp	Obs	Exp	Obs
0.5	16^{+6}_{-5}	17		
0.75	19^{+7}_{-5}	20		
1.0	17^{+7}_{-5}	18		
1.5	20^{+8}_{-6}	22	19^{+7}_{-5}	20
2.0	26^{+10}_{-7}	27	23^{+9}_{-6}	24
2.5	38^{+15}_{-11}	40	32^{+12}_{-9}	33
3.0	75^{+29}_{-21}	78	65^{+25}_{-18}	68
3.5	110^{+40}_{-30}	120		
4.0	320^{+130}_{-90}	340		



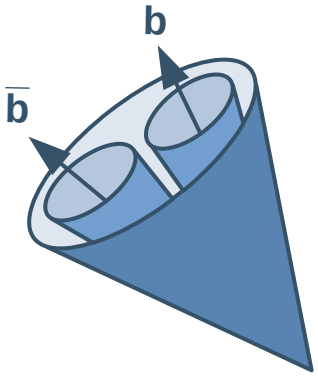
95% CL upper limit on ***σ*(pp→H)*Br*(H→Za)** in pb.
Quoted for ***Br*(a→gg)** and ***Br*(a→ss) = 100%**.

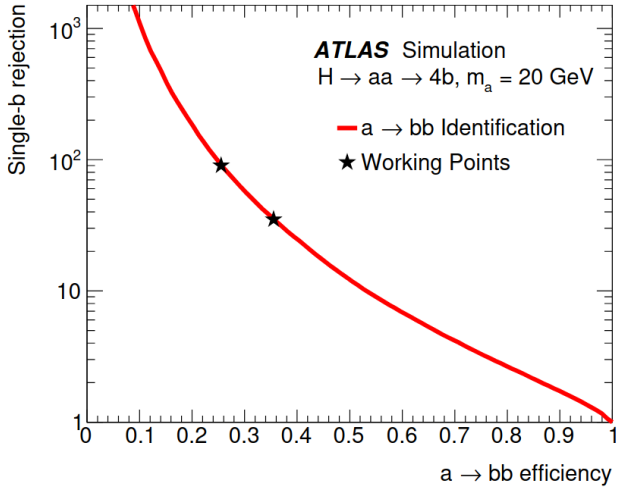
$H \rightarrow aa \rightarrow bb\,bb$

New Boosted Tagger



- **Searches for 15 GeV < m_a < 30 GeV**
  - Merging jets from $b\bar{b}$ system
  - Associated production with $Z \rightarrow ll$
- **Dedicated double b-tagger:**
  - Recluster R=0.4 jets to R=0.8 jets
  - Reconstructing track-based subjets in large radius jets
  - Dedicated identification (ID) for $b\bar{b}$ system
  - Separates $b\bar{b}$-jets from b-jets

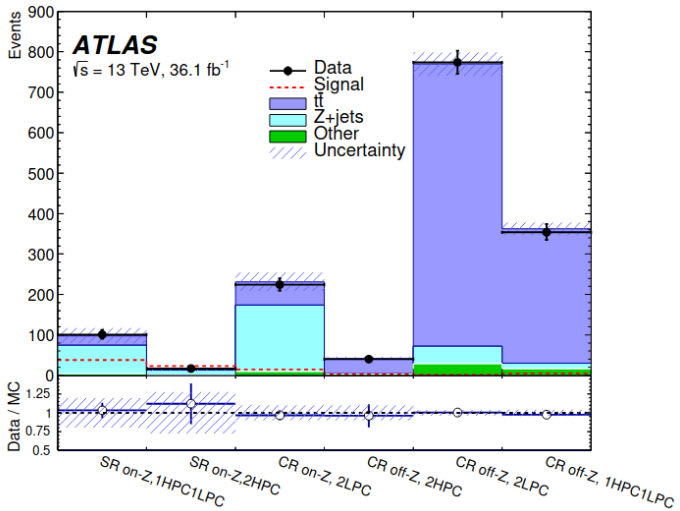


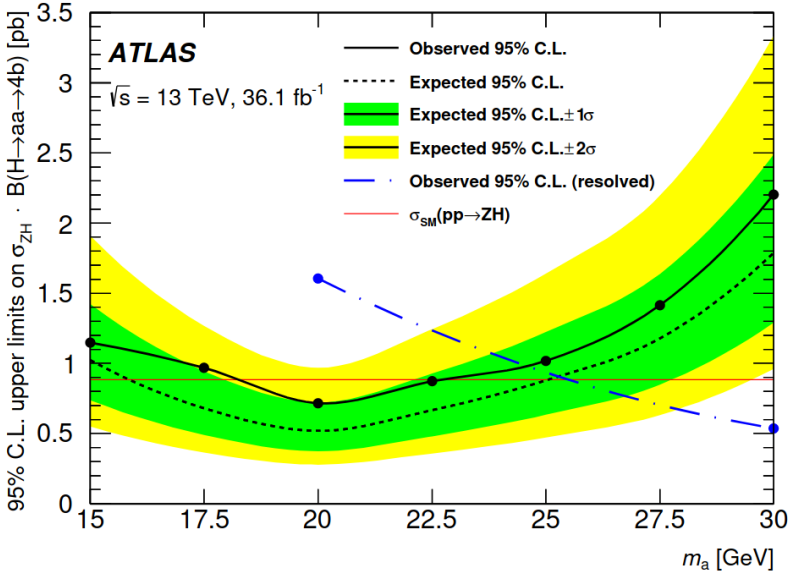


$H \rightarrow aa \rightarrow bb\,bb$

New Boosted Tagger

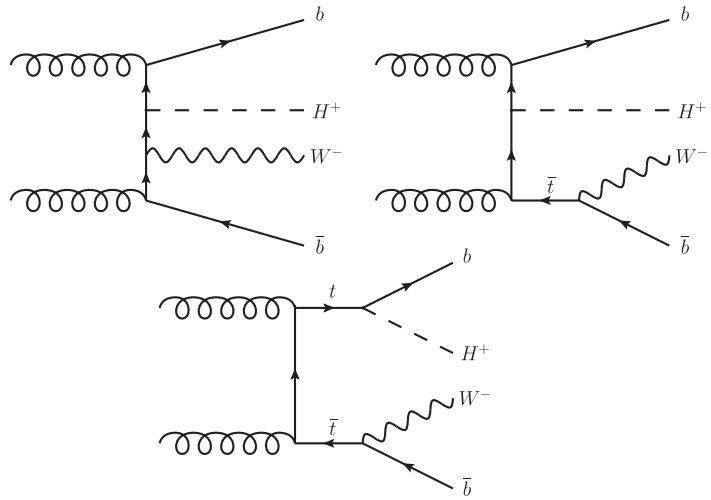
- Two leptons with $m_{ll} \sim m_Z$
- Two bb-taged reclustered jets
- **Regions defined by:**
  - Loose or Tight ID $b\bar{b}$-jets
  - pass/fail Z selection cuts
- One bin analysis of all regions
- Improves results from resolved analysis



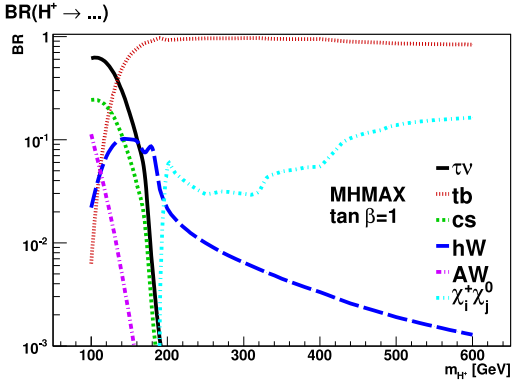


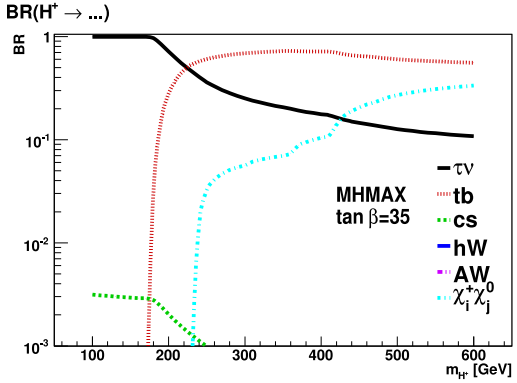
Searches for charged Higgs

- **Singly charged Higgs Bosons:**
  H^+ resonance part of Higgs sector in 2HDM scenarios:
  - hMSSM
  - m_h^{mod+}, m_h^{mod-}, m_h^{max}



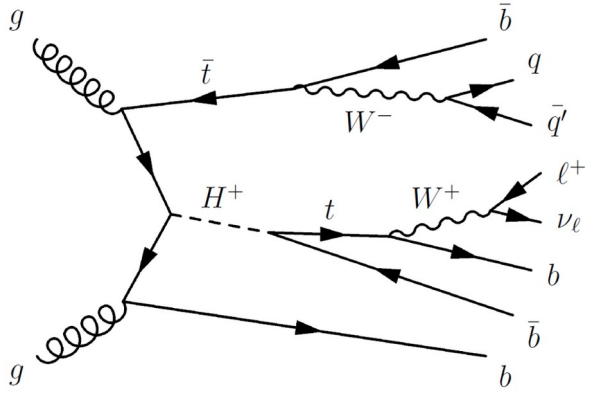
- **High mass – low tan(β)**
  strong coupling to tb
- **Low mass – high tan(β)**
  strong coupling to $\tau\nu_\tau$



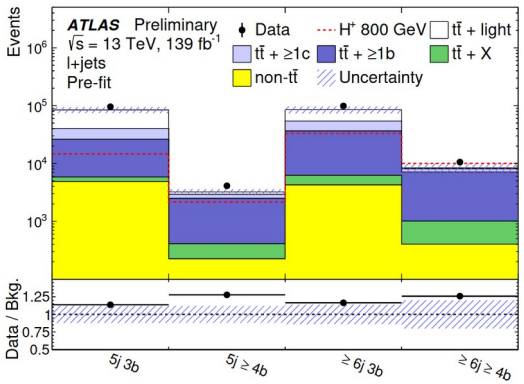


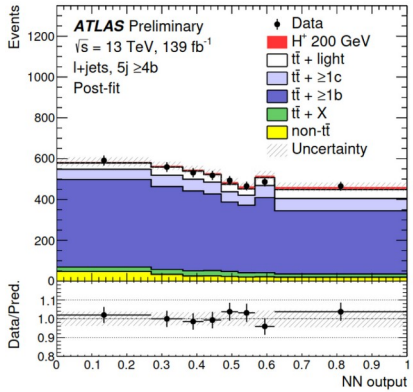
$H^+ \rightarrow tb$

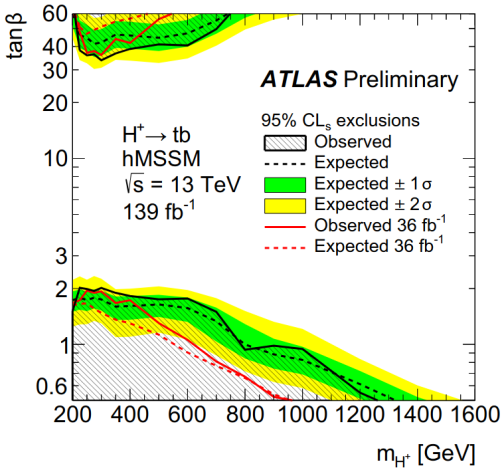
New! Full Run2

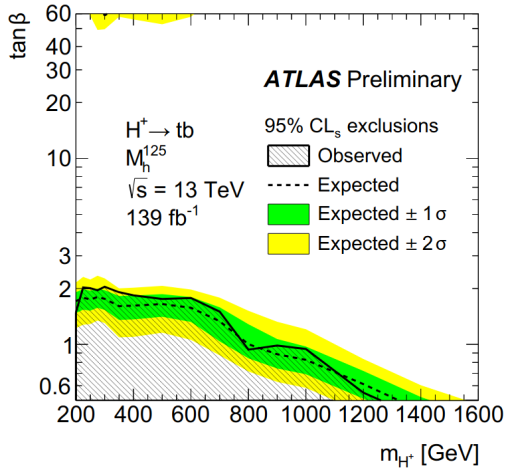


- Events triggered by single lepton trigger
- 1 light lepton, ≥ 5 jets (≥2 b-jets)
- Categories based on number of jets and b-jets in final state
- **Parameterized Neural Network as final discriminant**





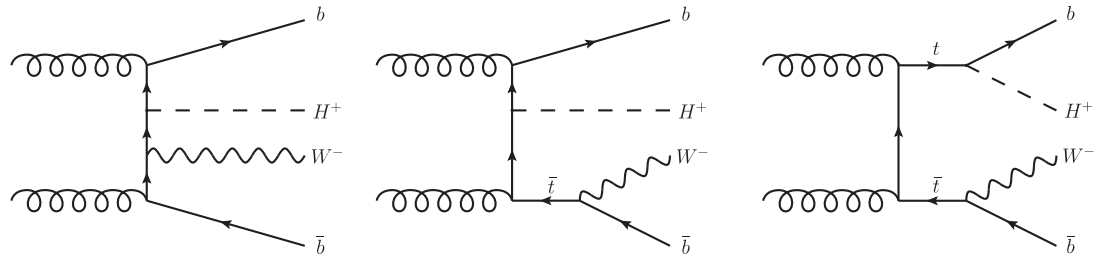


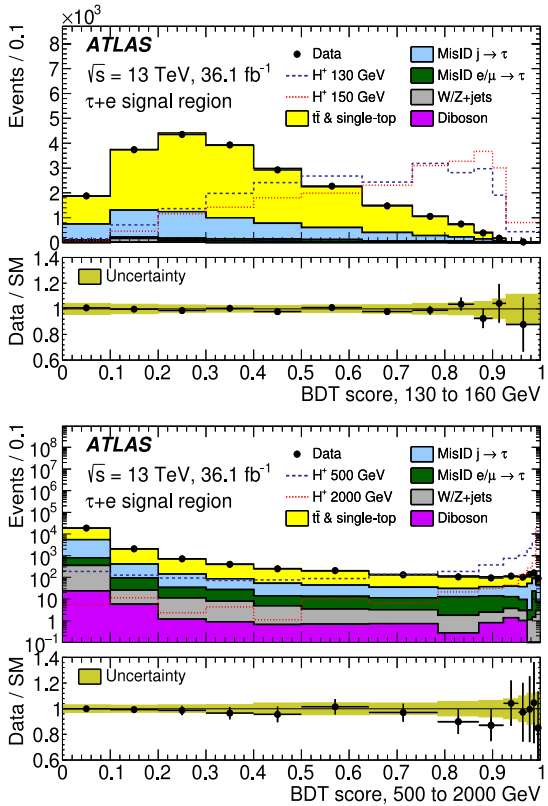


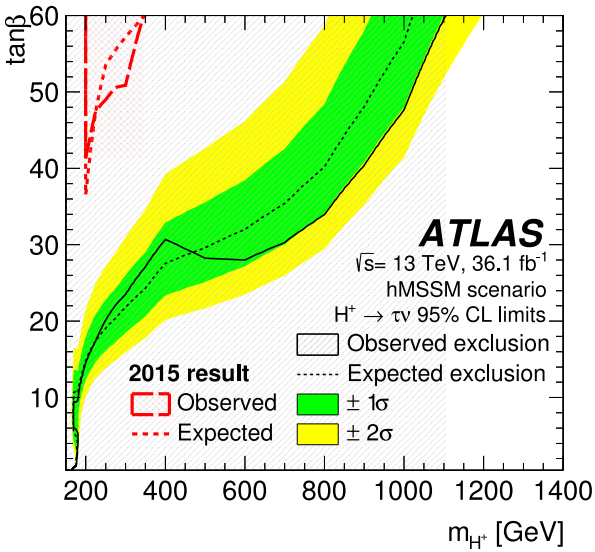
$H^+ \rightarrow \tau^+\upsilon$

- Selecting 1 $\tau_{had\text{-}vis}$
- At least one b-jet
- Additional jet (**τ+jet**) or one additional lepton (**τe**, **τμ**)
- Triggered by E_T^{miss} (τ+jets) and single lepton triggers (τl)

- **Boosted Decision Tree score as final discriminant**
- Optimized for different H^+ mass intervals

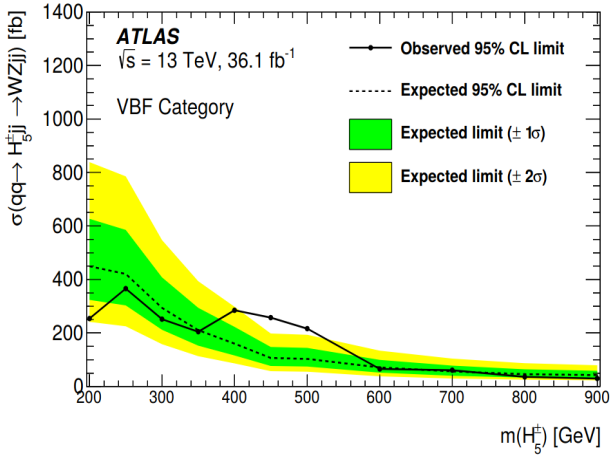


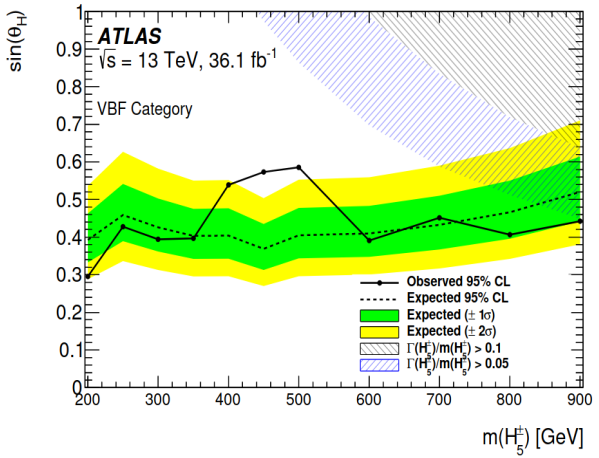




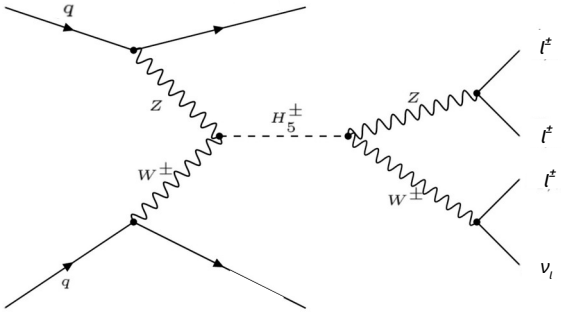
Further charged Higgs searches

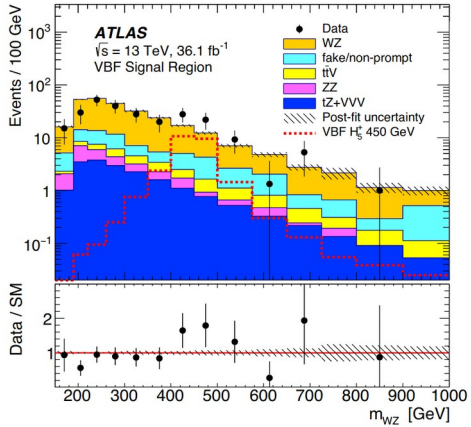
- **H^+ in triplet extensions**
  - Georgi–Machacek model: 1 real and complex triplet
  - Produced via vector-boson fusion (VBF)





- Searched for in WZ → ll lν analysis
  Phys. Lett. B 787 (2018) 68
- Selecting 3 leptons assigned to vector-boson

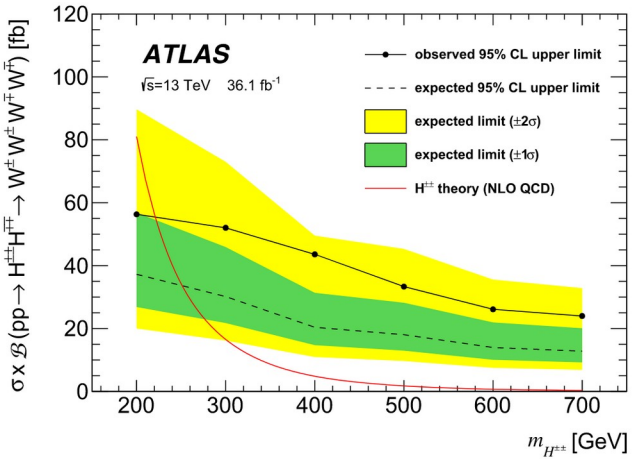




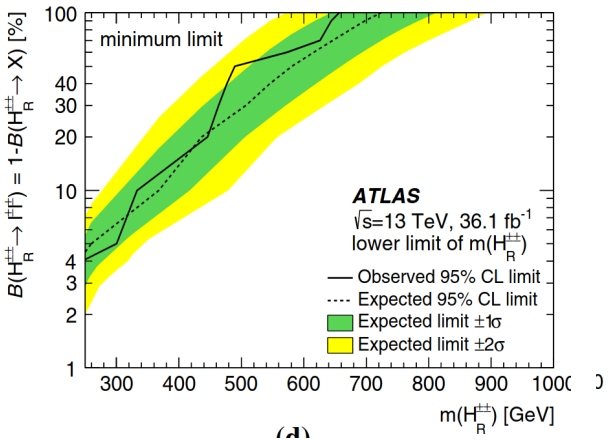
- **For VBF:** 2 jets opposite in η

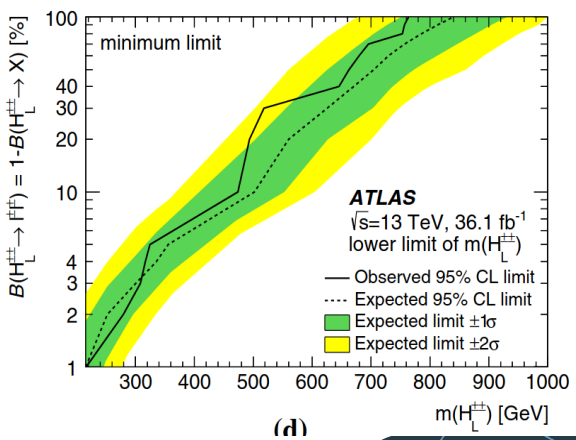
Doubly-charged Higgs searches

- **Doubly Charged Higgs searches:**
  - Models with hypercharge Y=2 triplet
  - After EWSB: $H^{\pm\pm}$ $H^{\pm}$ A^0 H^0 h



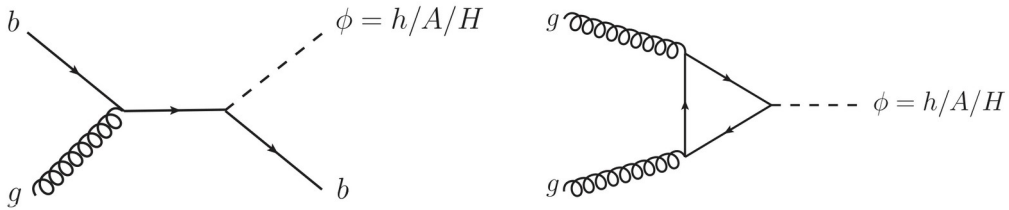
- Searched for in final states:
  - $H^{++} \rightarrow W^+ W^+$
    Eur. Phys. J. C (2019) 79:58
  - $H^{++} \rightarrow l^+l^+$
    Eur. Phys. J. C 78 (2018) 199

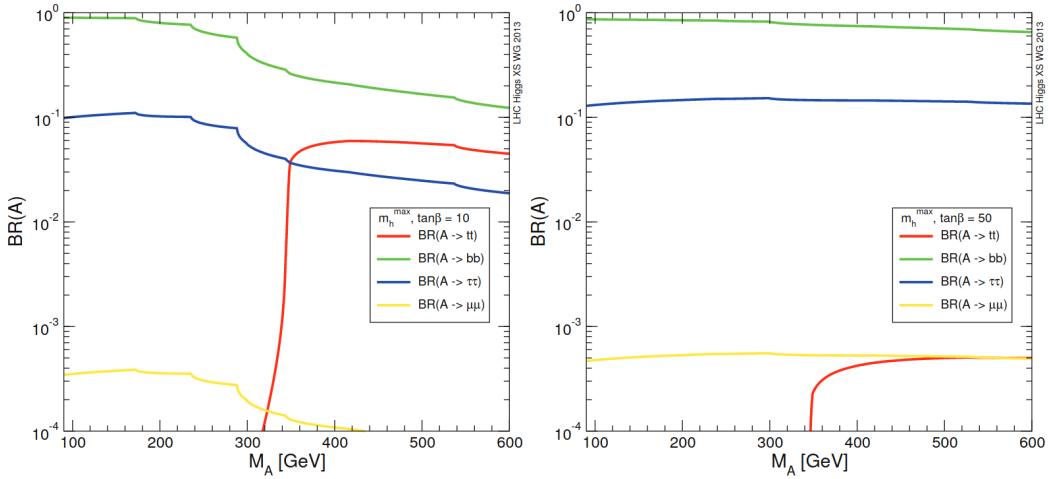




Searches for heavy neutral Higgs

- Heavy neutral Higgs Bosons part of Higgs sector in MSSM
- **Production Modes:**
  - Gluon-gluon fusion
  - b-associated production
- **MSSM Models predict:**
  - Increased coupling to heavy SM particles
  - Large tan(β) → increased coupling to 3rd generation down-type fermions



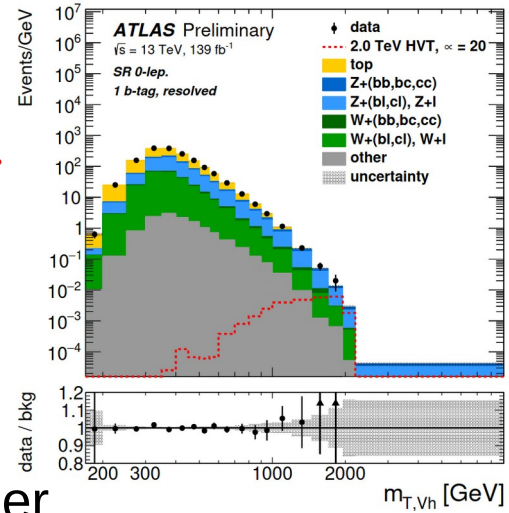


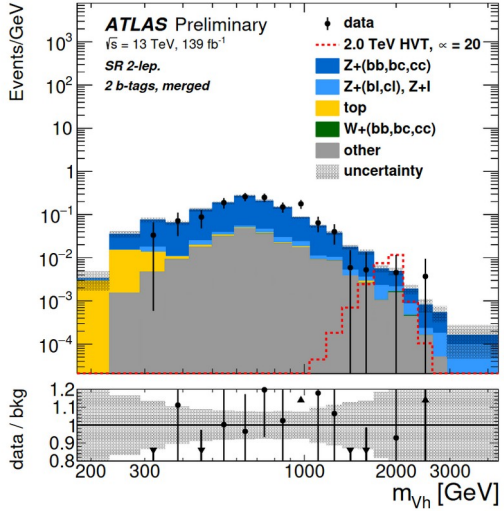
Handbook of LHC Higgs Cross Sections: 3. Higgs Properties

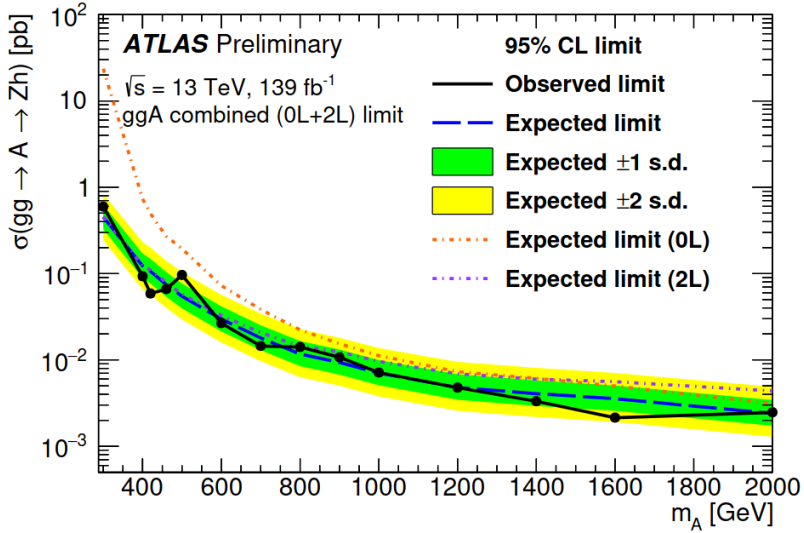
A → Zh

New! Full Run2

- **Two channels:**
  - **Zh →** $\nu\bar{\nu}$ **b**$\bar{\text{b}}$ (0l)
  - **Zh →** l^+l^- **b**$\bar{\text{b}}$ (2l)
- E_T^{miss} (0l) and single lepton (2l) trigger used
- E_T^{miss} > 150 GeV (0l) or 2 identified leptons (2l)
- **Categorization:**
  - Resolved, Merged b$\bar{\text{b}}$ system
  - 1 or 2 b-tags
- $m_{T,Vh}$ (0l) and m_{Vh} (2l) as final discriminant



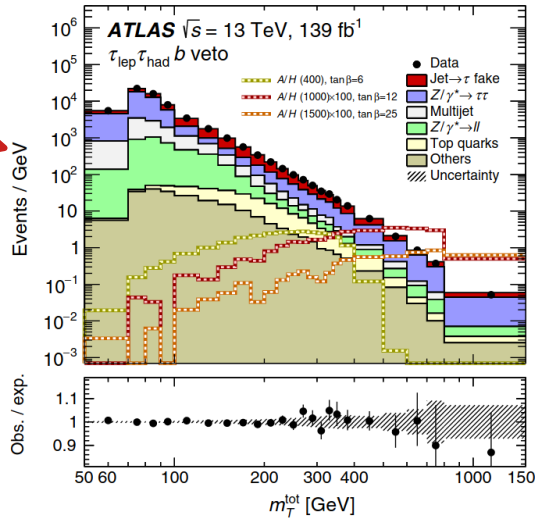


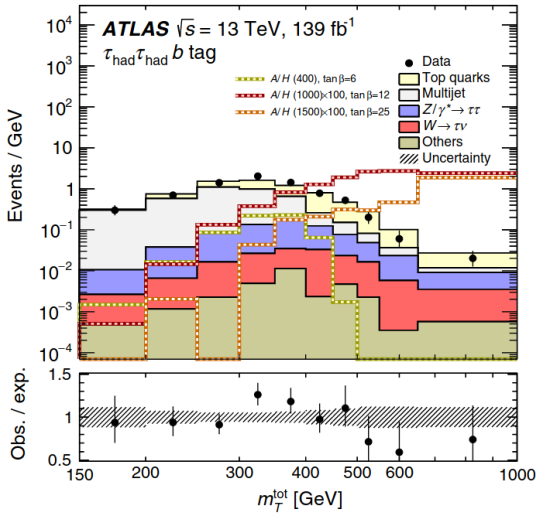


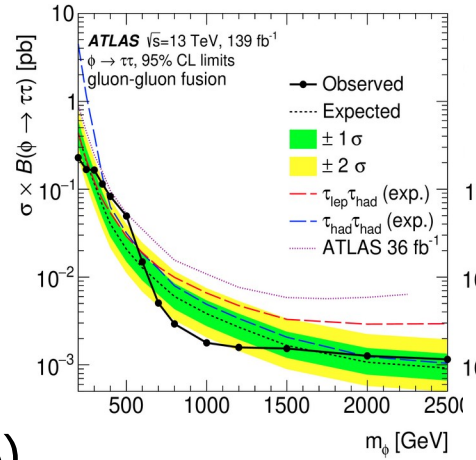
A/H → ττ

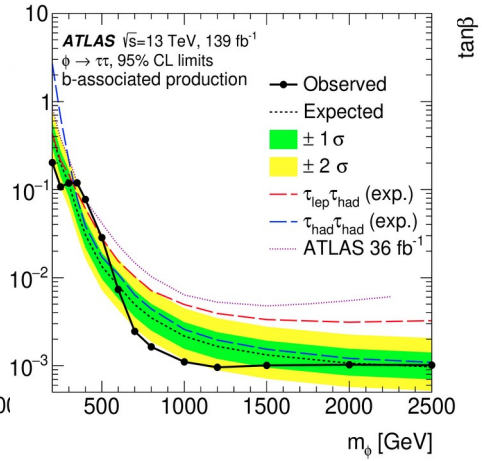
New! Full Run2

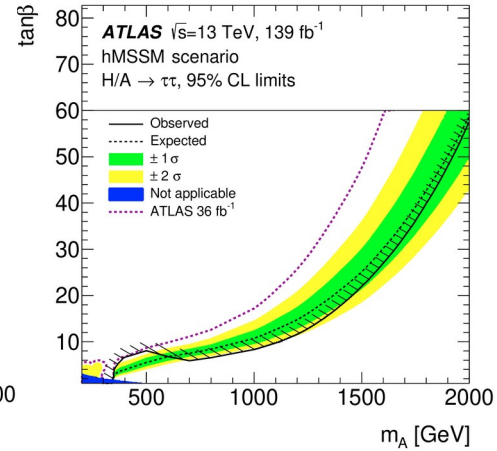
- Sensitive to H and A production
- **Two final states:** $\tau_{lep}\tau_{had}$, $\tau_{had}\tau_{had}$
- Single lepton or tau trigger
- Selecting lepton and $\tau_{had,vis}$ opposite-sign, back to back
- **Two categories: b-Tag and b-Veto**
- Especially sensitive to high mass – high tan(β)











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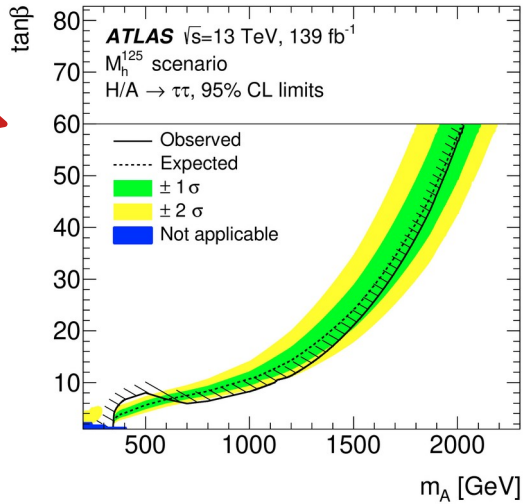
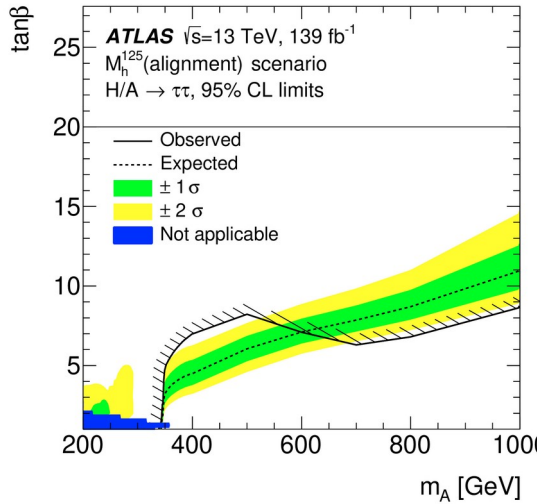
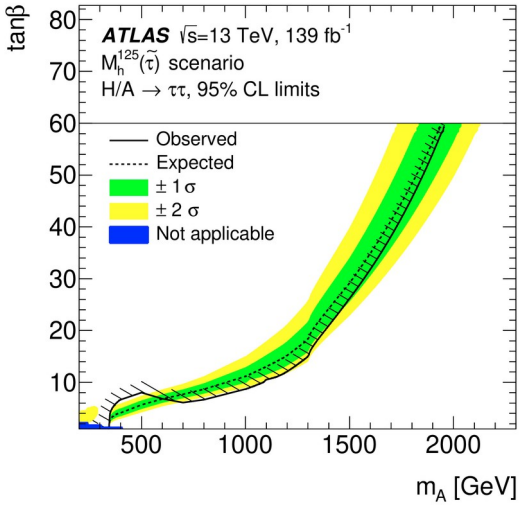
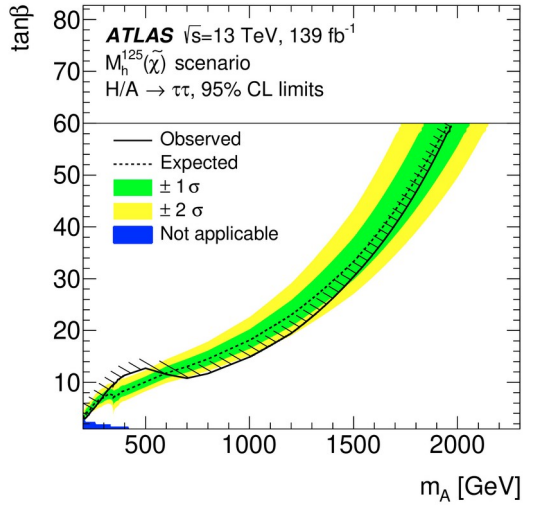




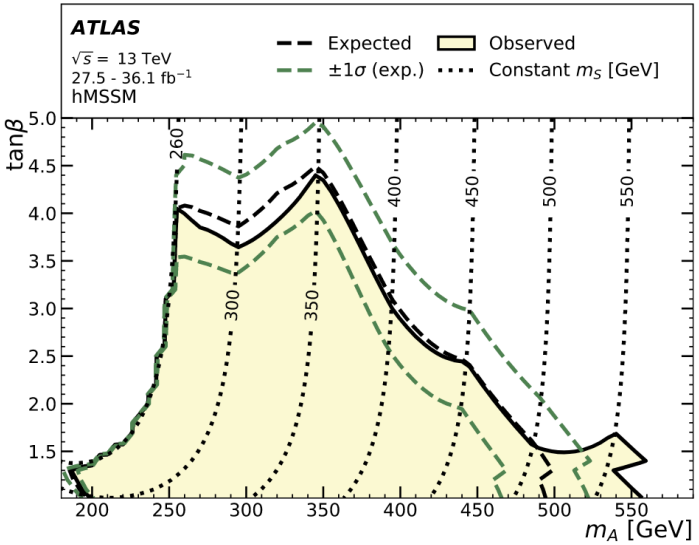


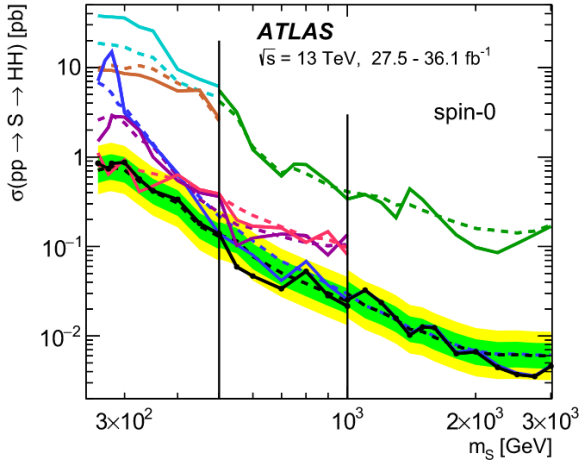


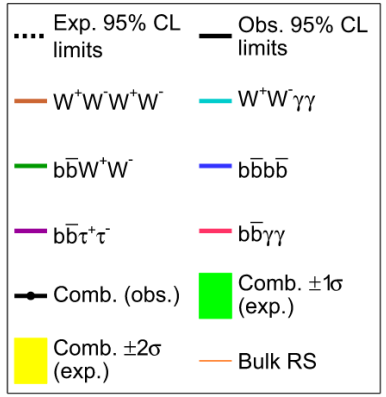
Di-Higgs combination

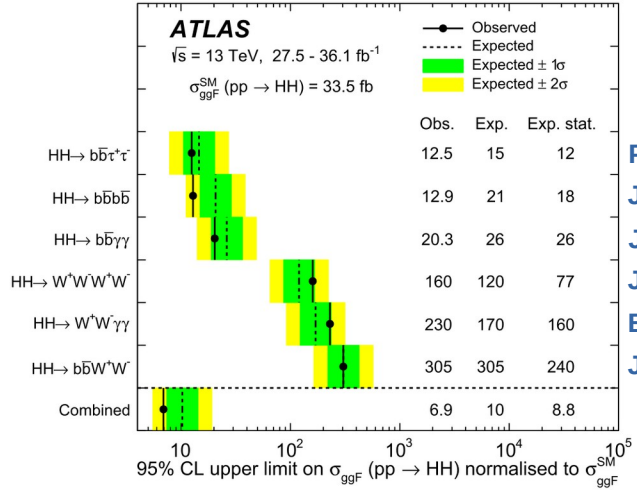
Phys. Lett. B 800 (2020) 135103

- **Many scalar to di-Higgs covered in this talk**
- Combination of searches for limits for hMSSM





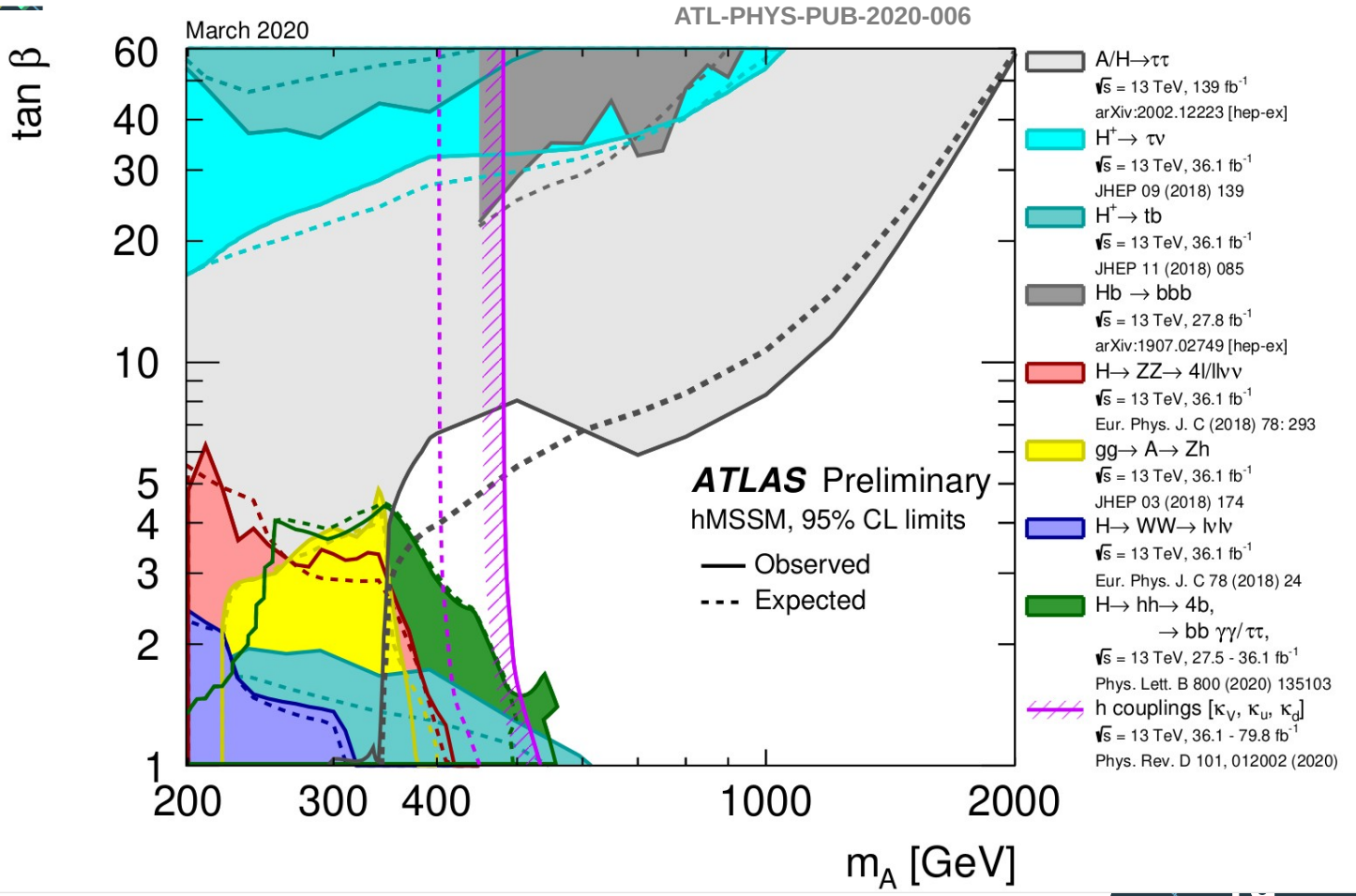




Phys. Rev. Lett. 121, 191801
JHEP 01 (2019) 030
JHEP 11 (2018) 040
JHEP 05 (2019) 124
Eur. Phys. J. C (2018) 78:1007
JHEP 04 (2019) 092

Heavy higgs results summary

- **Overlay of Run 2 results**
- **New results, since overlay:**
  - $H^+ \rightarrow tb$
  - $A \rightarrow Zh$



Summary

- Overview of different BSM Higgs searches in ATLAS
- **Full Run 2 results:**
  - $H \rightarrow Za$
  - $H^{+} \rightarrow tb$
  - $A \rightarrow Zh$
  - $A/H \rightarrow \tau\tau$
- Improvements with new double b-tagging algorithm and use of neural networks
- **Many searches covering large range of masses and decay modes**

  → tighten constraints on parameter spaces

Thanks