

Search for additional BSM Higgs bosons or BSM decays of the 125 GeV Higgs boson with the ATLAS Detector

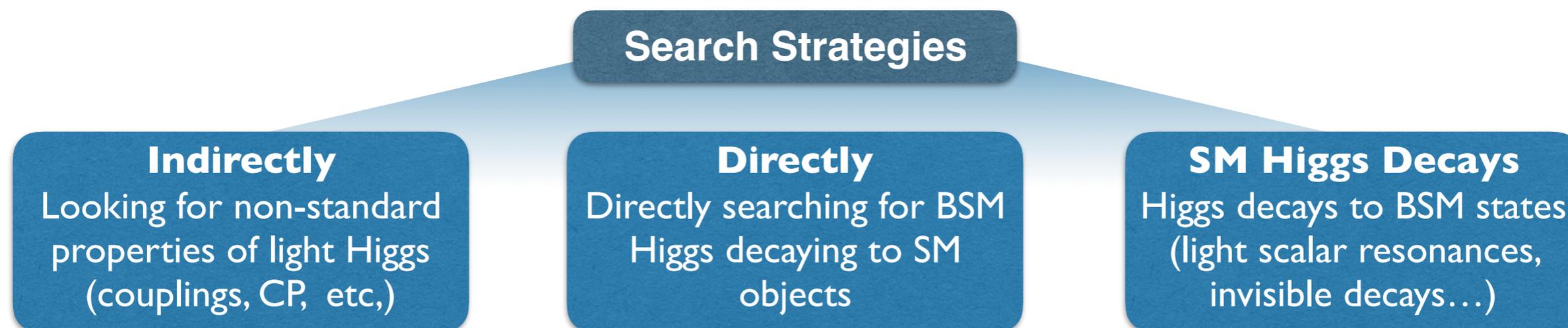
Tom Schwarz
University of Michigan



On behalf of the ATLAS Collaboration

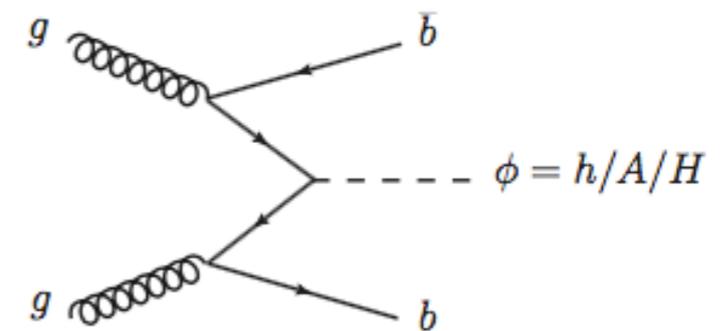
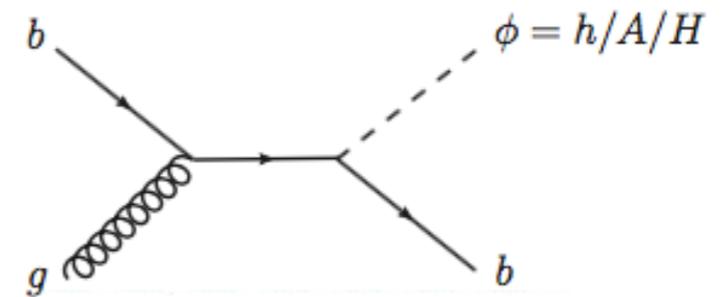
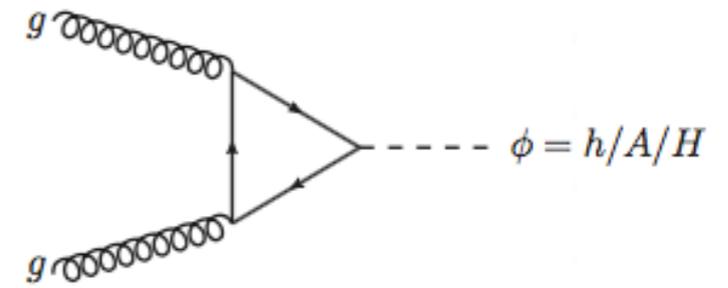
Lake Louise Winter Institute 2018
February 18-24, 2018

- ◆ Discovery of a neutral scalar particle of mass ~ 125 GeV at the LHC confirmed a predicted electroweak symmetry breaking mechanism in nature. Experimental results indicate this particle is consistent with a SM Higgs boson.
- ◆ However, this does not exclude a more complicated Higgs sector, where several new particles appear, in addition to the assumed 125 GeV SM Higgs.
 - Additional EW singlet: H
 - Two Higgs doublet models (2HDM): H, A, H^\pm
 - Two Higgs doublet + singlet models
 - Higgs triplet models (SM doublet + triplet): $H^{\pm\pm}$

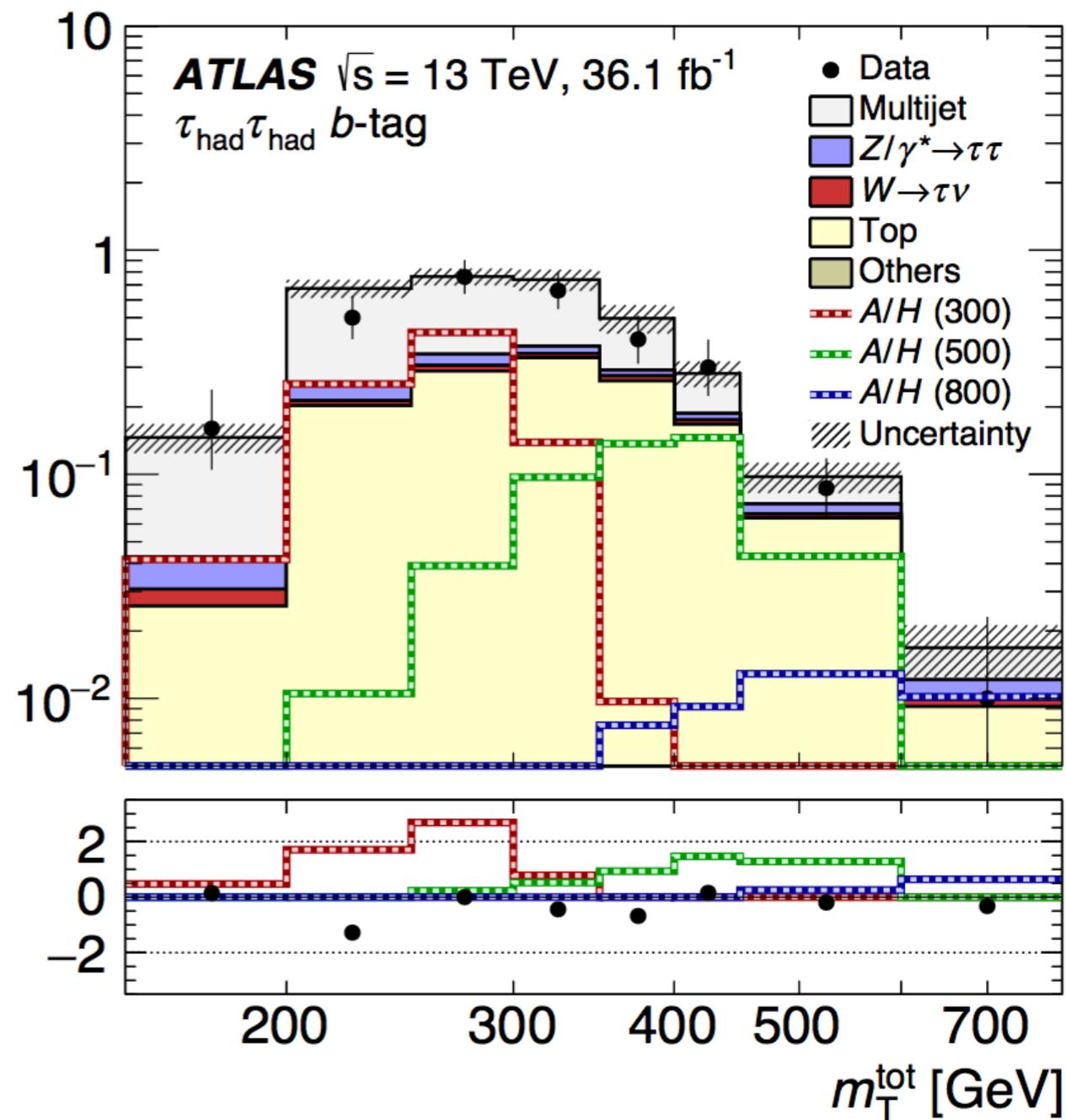
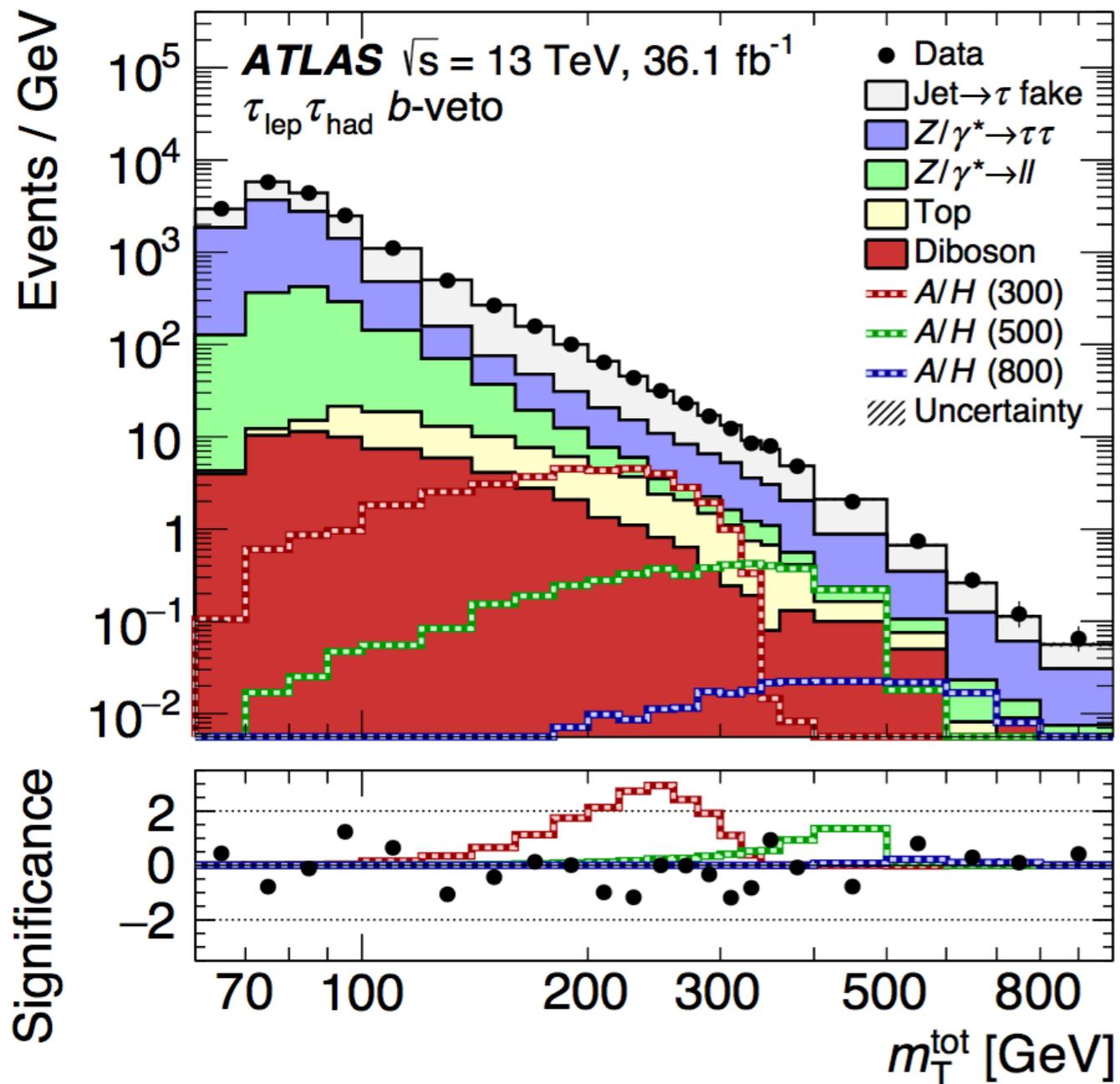


Heavy Neutral Higgs in Fermion Final States

- ◆ In the MSSM (type II 2HDM), the heavy Higgs boson couplings to down-type fermions (τ , b) are strongly enhanced for a large part of the parameters space for large $\tan \beta$
- ◆ Recent result at ATLAS searches for $A/H \rightarrow \tau\tau$ in 36.1 fb^{-1} of pp collisions at 13 TeV - **JHEP 01 (2018) 055**.
- ◆ Two τ decay modes considered:
 - All hadronic final state ($\tau_{\text{had}} \tau_{\text{had}}$) with 0 or ≥ 1 b-jet
 - Semi-leptonic final state ($\tau_{\text{lep}} \tau_{\text{had}}$) with 0 or ≥ 1 b-jet
- ◆ Primary background for both channels are jets misidentified as a τ . Data driven techniques are used to estimate and model these backgrounds.
- ◆ However, top quark and $Z \rightarrow \tau\tau$ events are significant backgrounds in the $\tau_{\text{lep}} \tau_{\text{had}}$ channel for events with and without a b-jet, respectively.
- ◆ Discriminating variable is the total transverse mass of the system

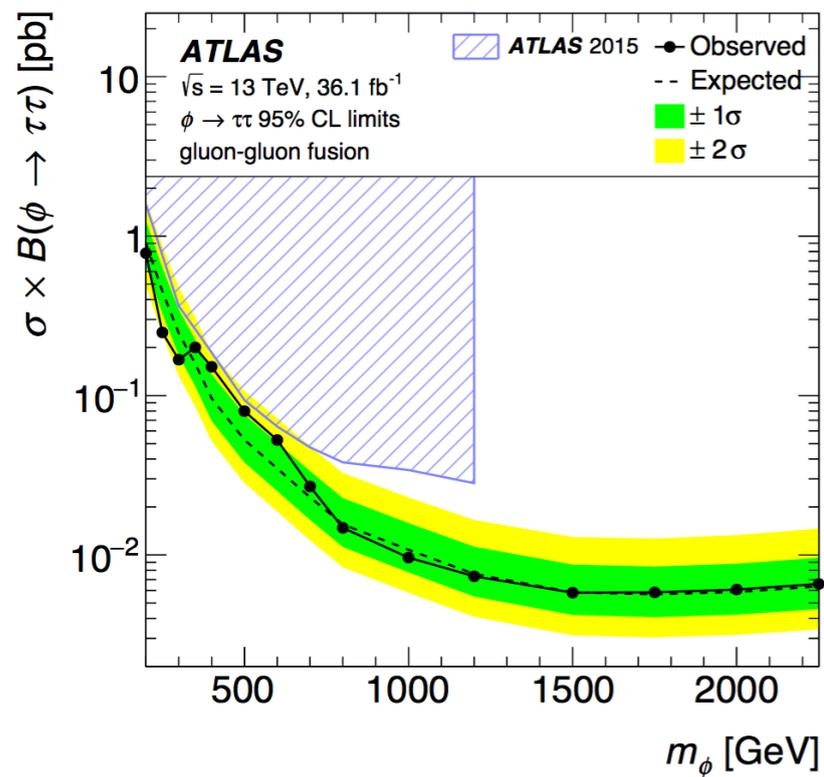


A/H $\rightarrow \tau\tau$ in 36.1 fb⁻¹

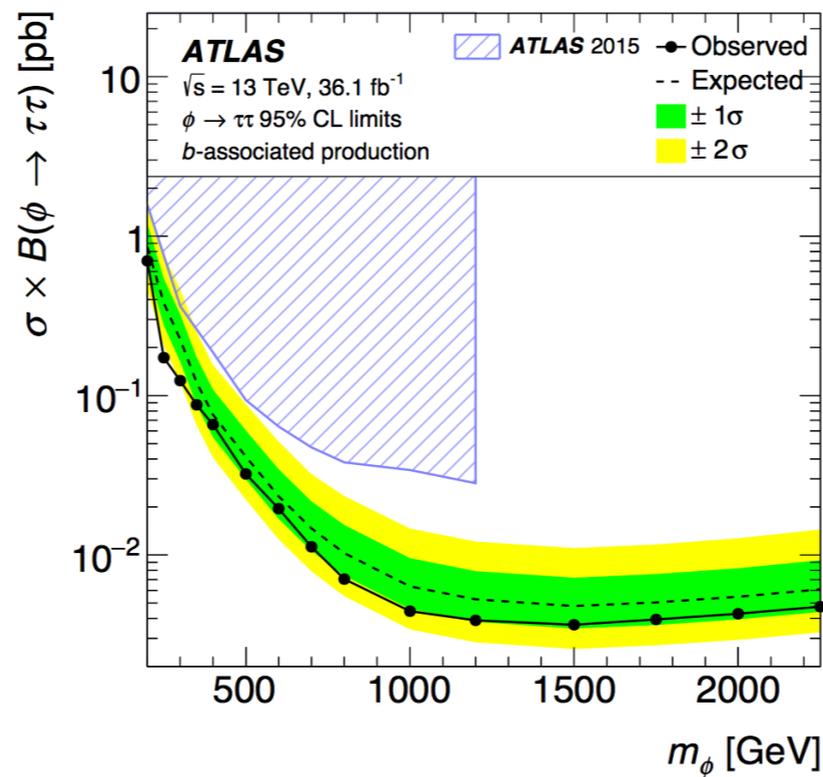


A/H \rightarrow $\tau\tau$ in 36.1 fb⁻¹

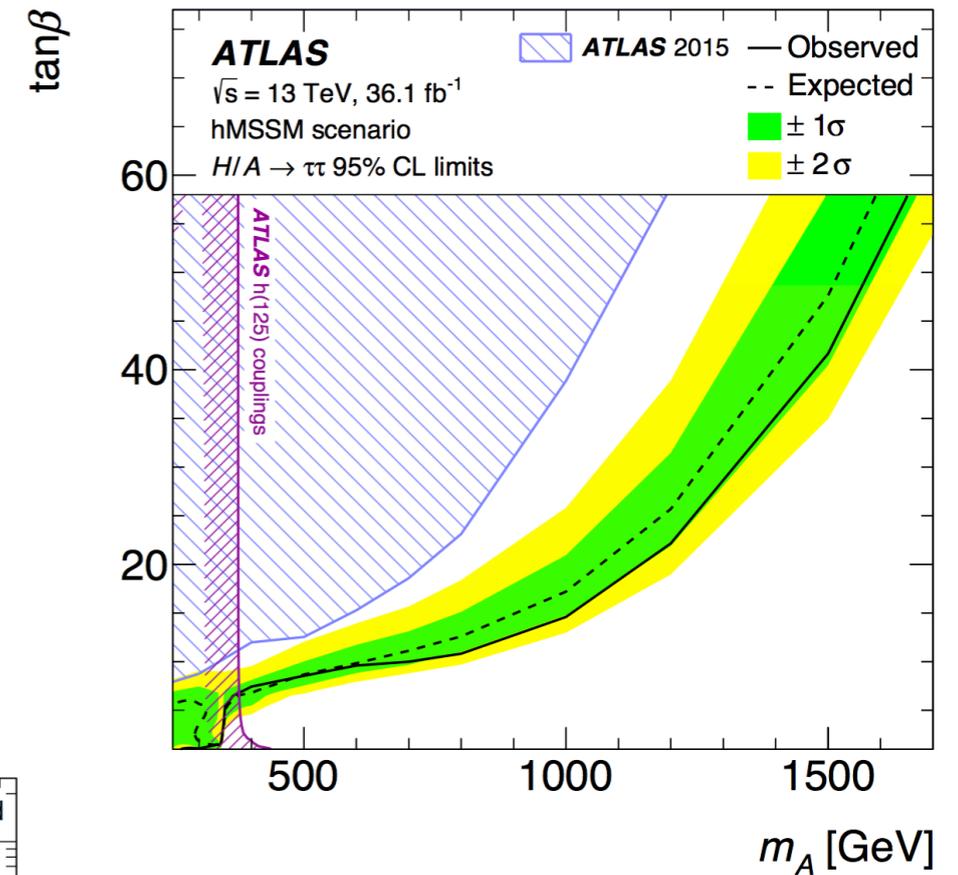
- Observed $\sigma \times \text{BR}$ limit for ggF: 0.78 pb - 5.8 fb for m_ϕ range of 200 GeV to 2.25 TeV
- Observed $\sigma \times \text{BR}$ limit for b-associated production: 0.70 pb - 3.7 fb for m_ϕ range of 200 GeV to 2.25 TeV
- Interpretation in the hMSSM: excluded $\tan \beta > 1.0$ for $m_A = 250$ GeV and $\tan \beta > 42$ for $m_A = 1.5$ TeV



(a) $\phi \rightarrow \tau\tau$ (gluon–gluon fusion production)



(b) $\phi \rightarrow \tau\tau$ (*b*-associated production)



Heavy Neutral Higgs in Boson Final States

◆ Several theories beyond the Standard Model, such as 2HDM models, predict the existence of high mass Higgs particles which can decay into final states with Weak bosons.

◆ $H \rightarrow ZZ \rightarrow \ell\ell\ell\ell / \ell\ell\nu\nu$ in 36.1 fb⁻¹ of pp collisions at 13 TeV -

arXiv:1712.06386v1

◆ Searching for High Mass Higgs in $H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$

- Two pairs of isolated leptons with same-flavor and opposite sign
- Discriminating variable $m_{4\ell}$

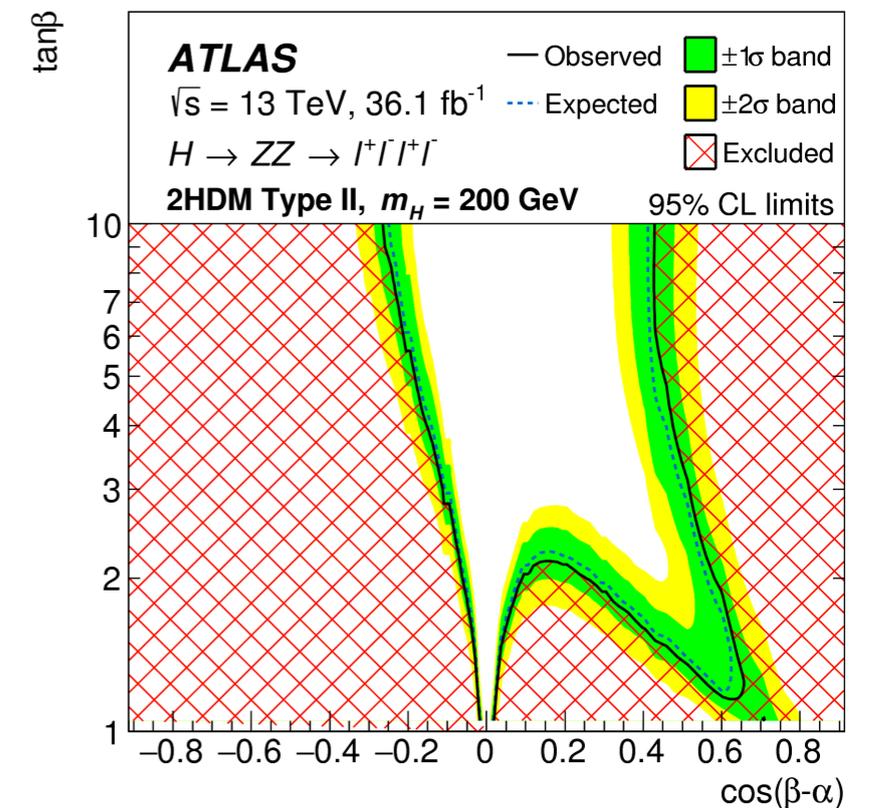
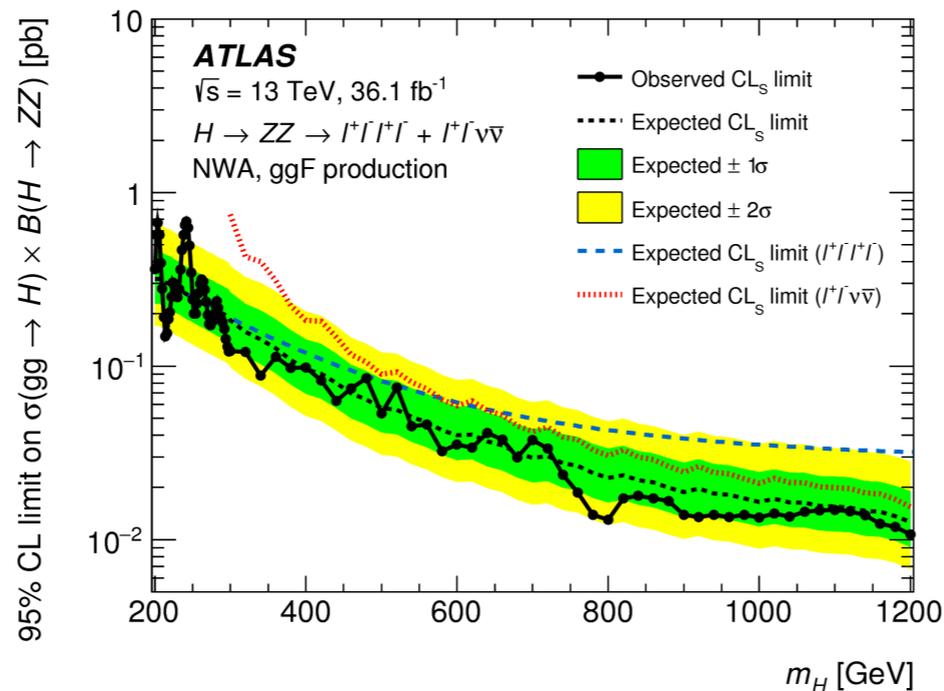
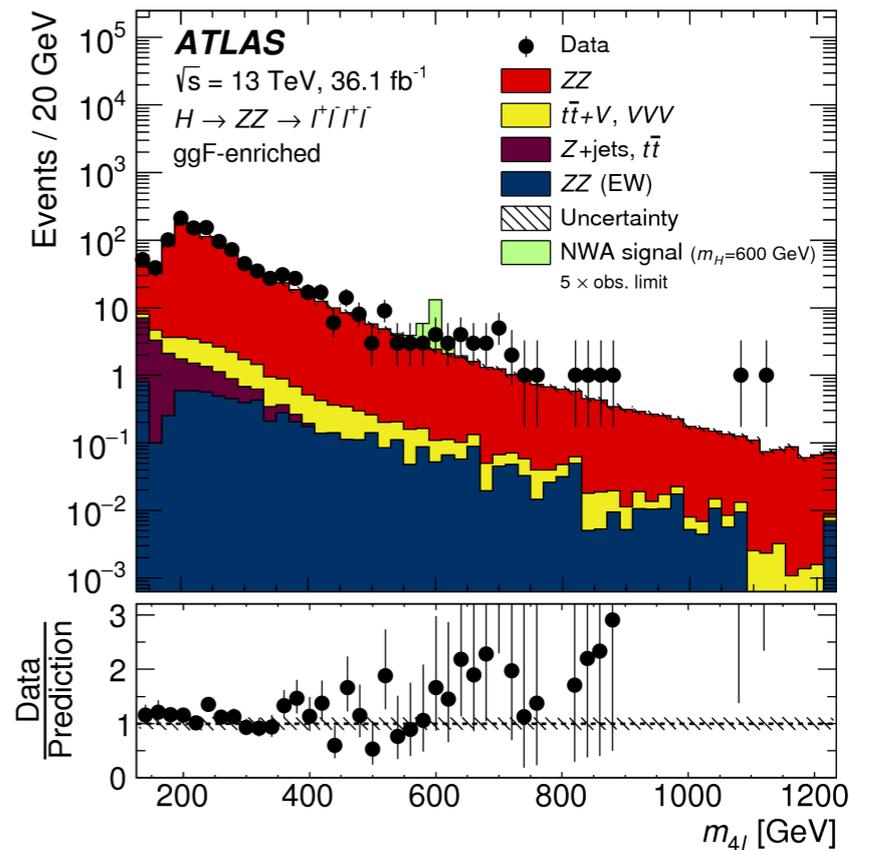
◆ Searching for High Mass Higgs in $H \rightarrow ZZ \rightarrow \ell\ell\nu\nu$

- Two leptons consistent with originating from a Z boson

• Discriminating variable:
$$m_T = \sqrt{\left[\sqrt{m_Z^2 + (p_T^{\ell\ell})^2} + \sqrt{m_Z^2 + (E_T^{\text{miss}})^2}\right]^2 - \left[p_T^{\ell\ell} + E_T^{\text{miss}}\right]^2}$$

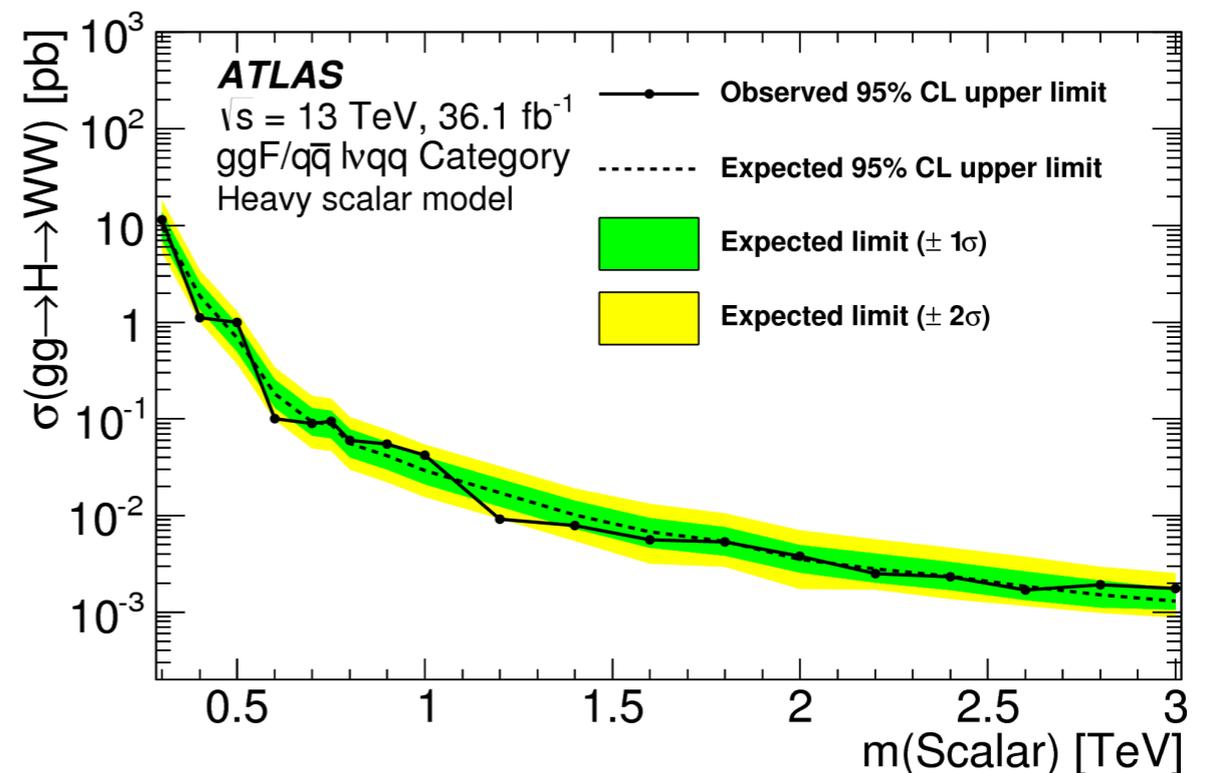
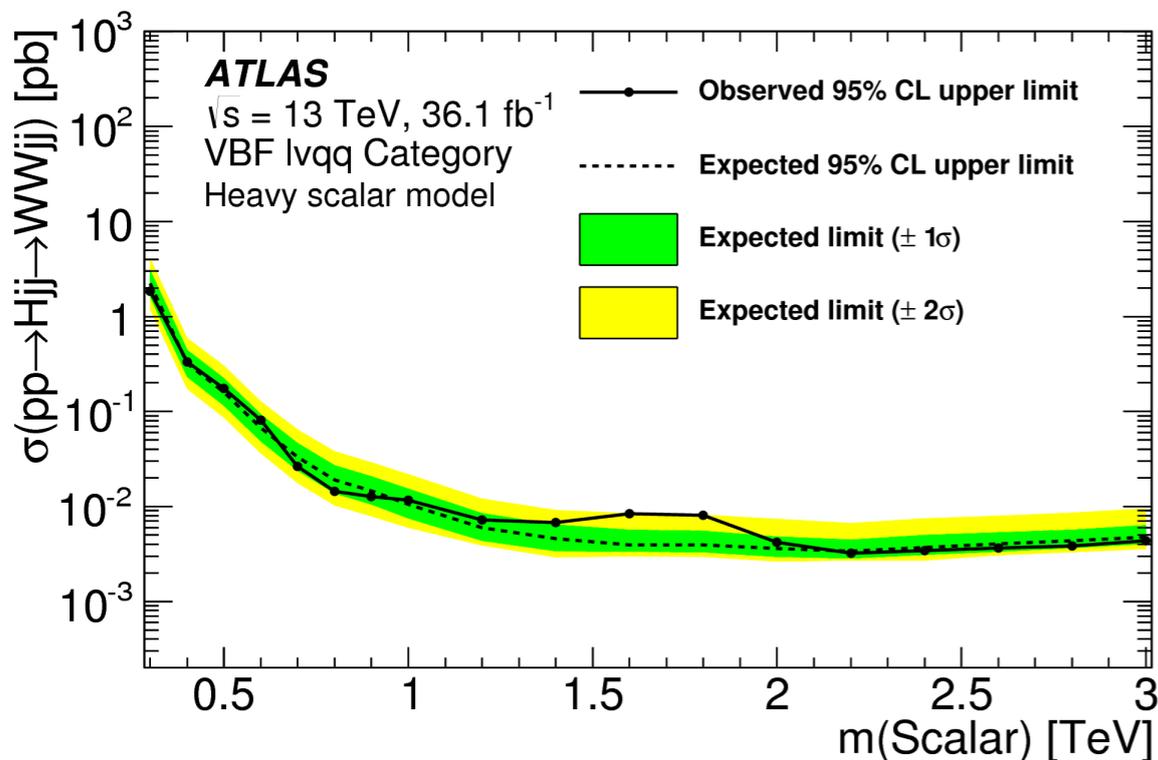
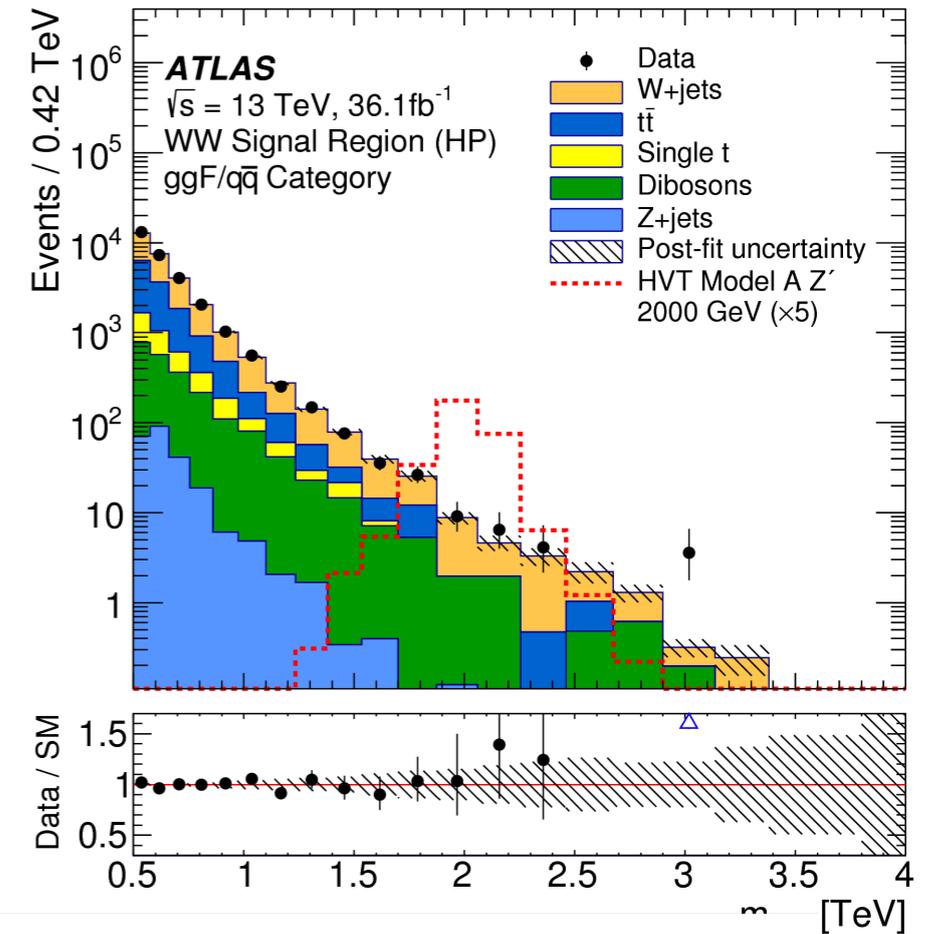
◆ Narrow for ggF and VBF and large width (1-10% of m_h) for ggF signal hypothesis tested.

◆ Impact of the interference h-H background has been studied.



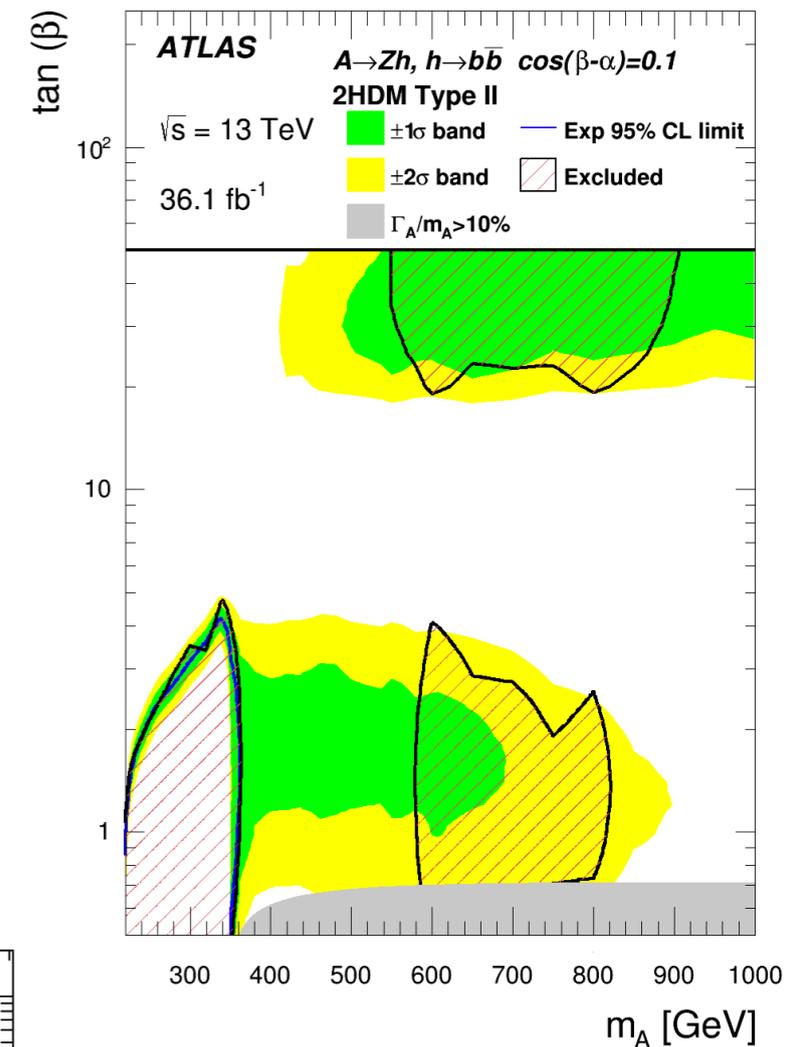
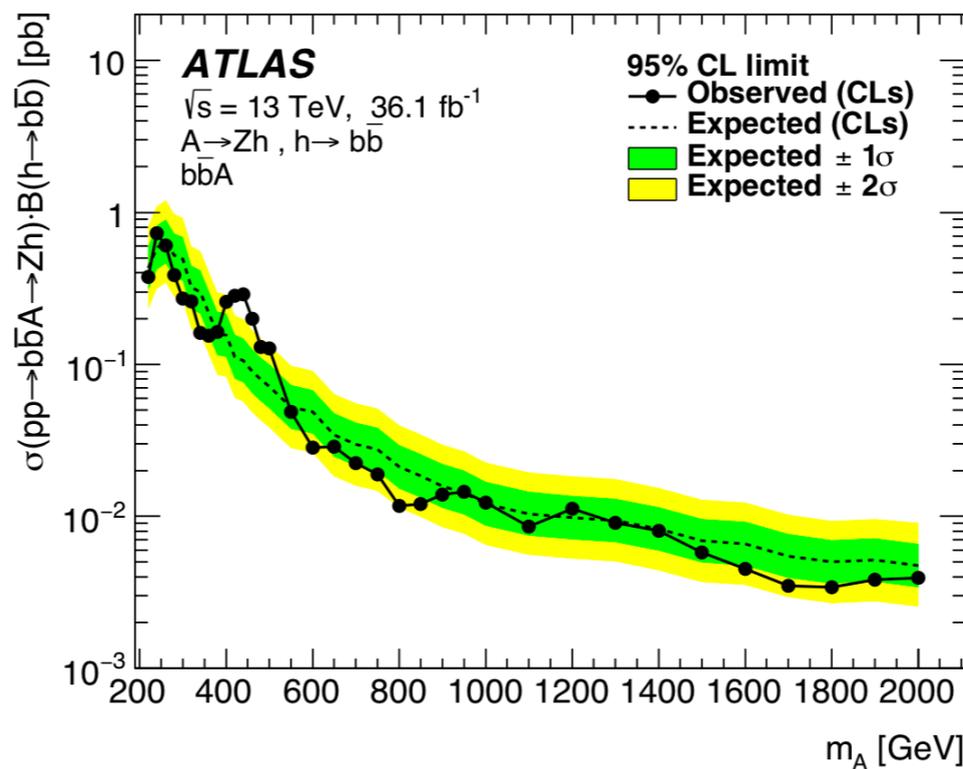
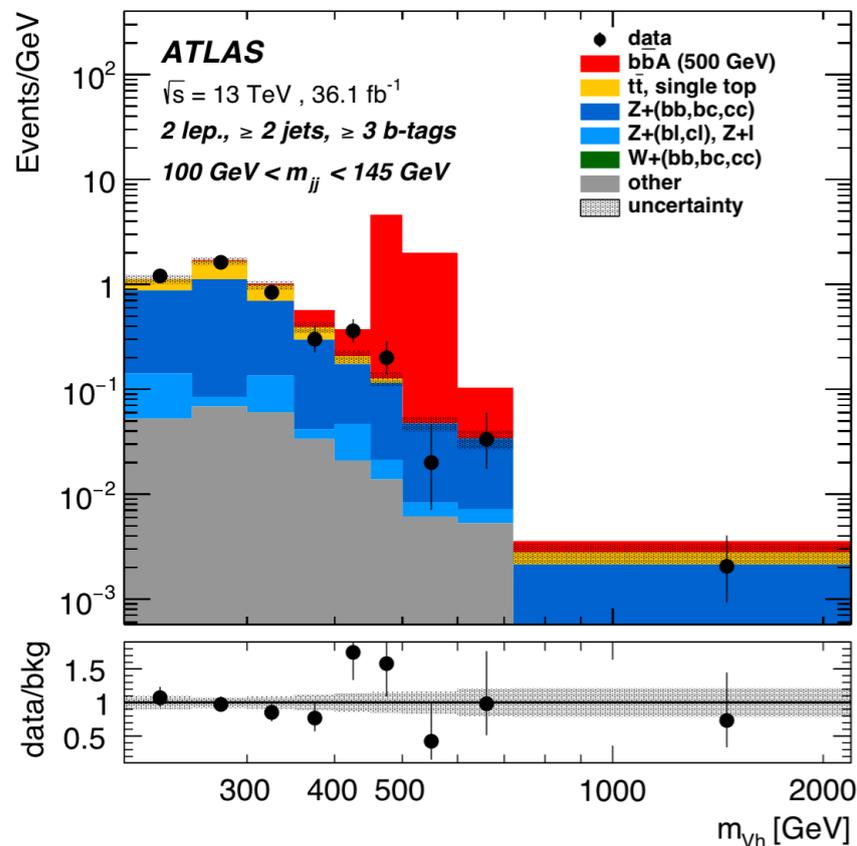
Heavy Neutral Higgs in Boson Final States

- ◆ $H \rightarrow WW \rightarrow \ell\nu qq$ in 36.1 fb^{-1} of pp collisions at 13 TeV
- [arXiv:1710.07235](https://arxiv.org/abs/1710.07235)
- ◆ 1 lepton (e or μ), E_{T}^{miss}
 - ≥ 1 large-R jet (boosted analysis)
 - ≥ 2 small-R jets (resolved analysis)
- ◆ Discriminating variable: $m(\ell\nu)$ or $m(\ell\nu jj)$ where the $p_{\nu z}$ obtained from a W mass constraint
- ◆ Narrow width ggF and VBF signal hypothesis

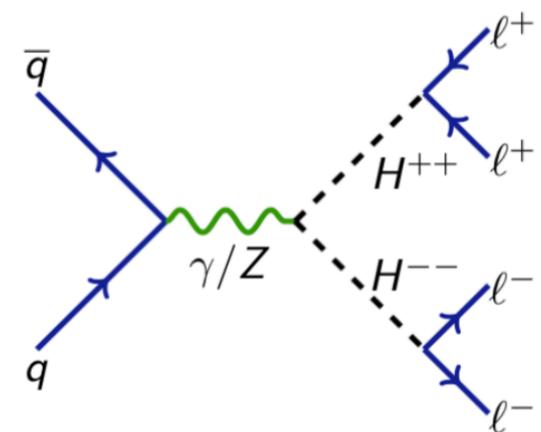
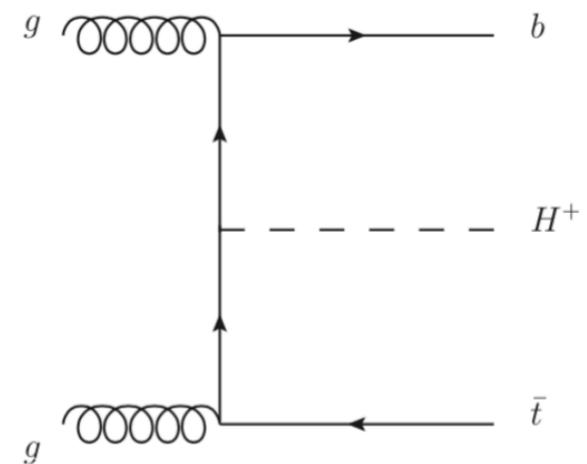
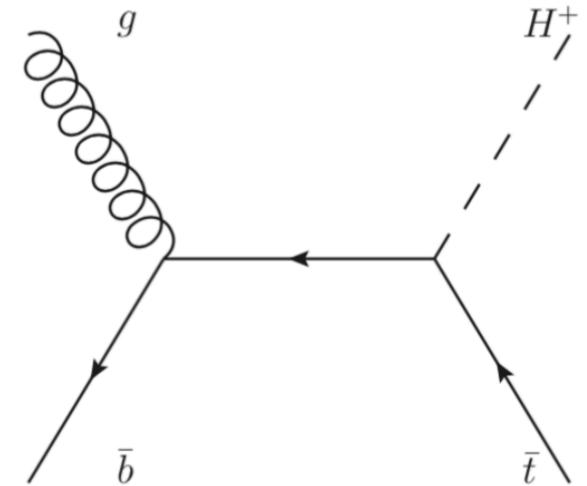


Heavy Neutral Higgs in Boson Final States

- ◆ $A \rightarrow Zh \rightarrow \ell\ell bb$ in 36.1 fb^{-1} of pp collisions at 13 TeV - [arXiv:1712.06518](https://arxiv.org/abs/1712.06518)
- ◆ Two channels based on Z decays
- ◆ 0-/2-lepton combined limited presented separated for ggF and bbA
- ◆ Mild excess at $m_A = 440 \text{ GeV}$
 - Arises mostly from 3+ b-tag region in the 2-lepton channel
 - Local (global) significance: 3.6 (2.4) standard deviation



- ◆ Any extension to the Higgs sector, beyond adding a single scalar, implies the existence of charged scalars (2HDM, NMSSM, Triplet...)
- ◆ Dominant production is in association with top quarks in most benchmark models
- ◆ At high mass $H^\pm \rightarrow t\bar{b}$ is the dominant decay mode in type-II 2HDM
- ◆ $H^\pm \rightarrow \tau\nu$ 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 $H^{\pm\pm}$

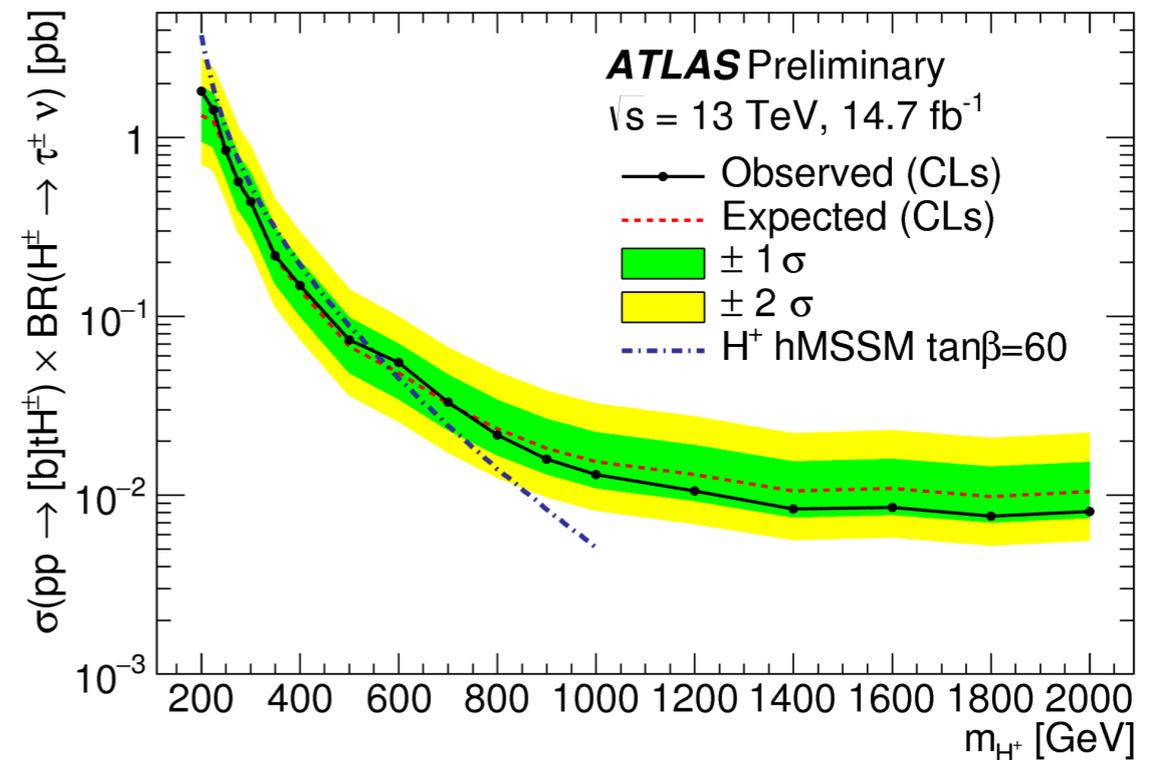
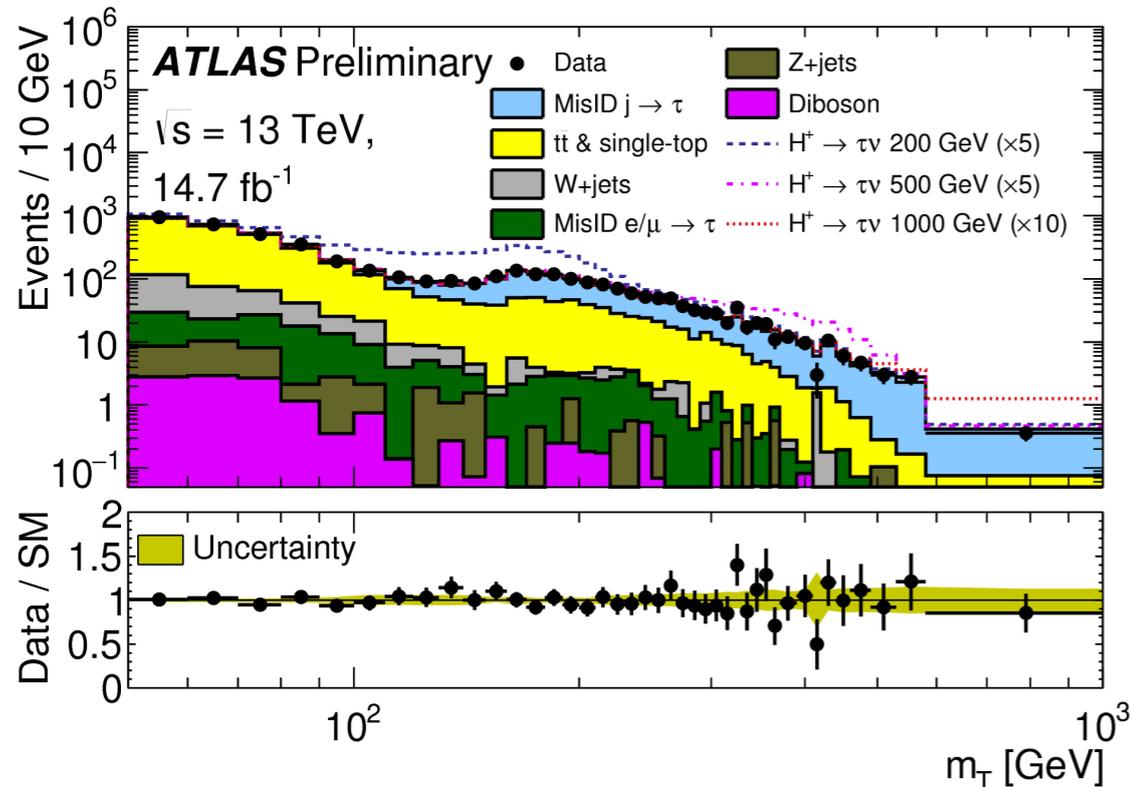
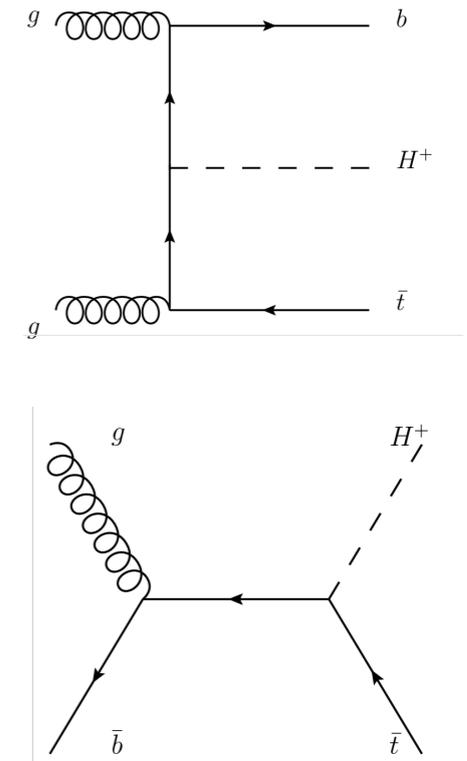


Search for Charged Higgs in $\tau + \text{jets}$ in 14.7 fb^{-1}

- ◆ The search targets the $\tau + \text{jets}$ channel in top-quark-associated H^\pm production with a hadronically decaying W boson and τ lepton in the final state.

ATLAS-CONF-2016-088

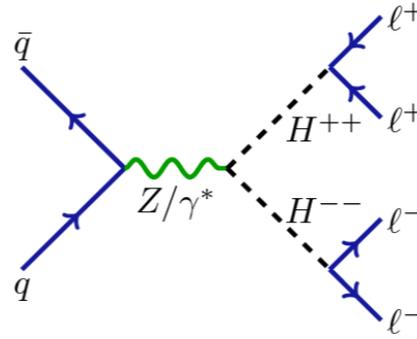
- ◆ Data is selected to require three high momentum jets ($p_T > 25 \text{ GeV}$) with at least one jet 'b-tagged'. A single high momentum τ lepton candidate ($p_T > 40 \text{ GeV}$) is required. The event must have transverse missing energy larger than 150 GeV .
- ◆ The discriminating variable for this analysis is the total transverse momentum in the event.
- ◆ No evidence of a charged Higgs boson is found. For the mass range of $m_{H^\pm} = 200 - 2000 \text{ GeV}$, upper limits are set on the production cross section of the charged Higgs boson with the subsequent decay $H^\pm \rightarrow \tau \nu$ in a range of $2.0 - 0.008 \text{ pb}$.



Doubly Charged Higgs

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

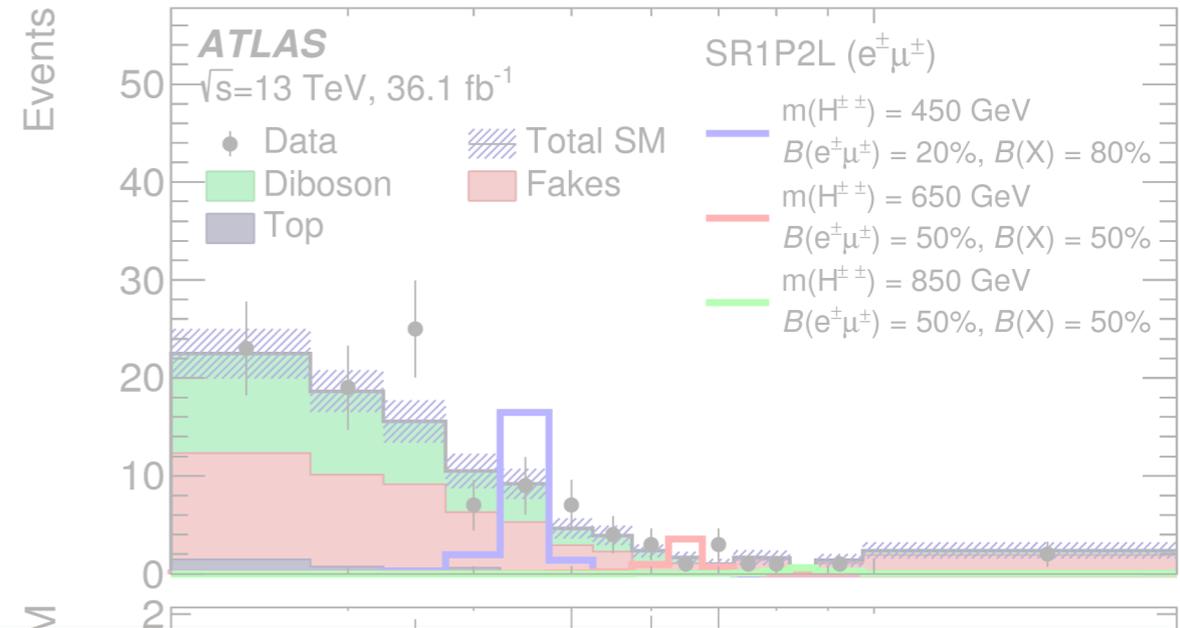
◆ Drell-Yan production of a pair decaying into two pairs of same-sign leptons



◆ 2, 3 or 4 leptons (e or μ), veto events with b-jets

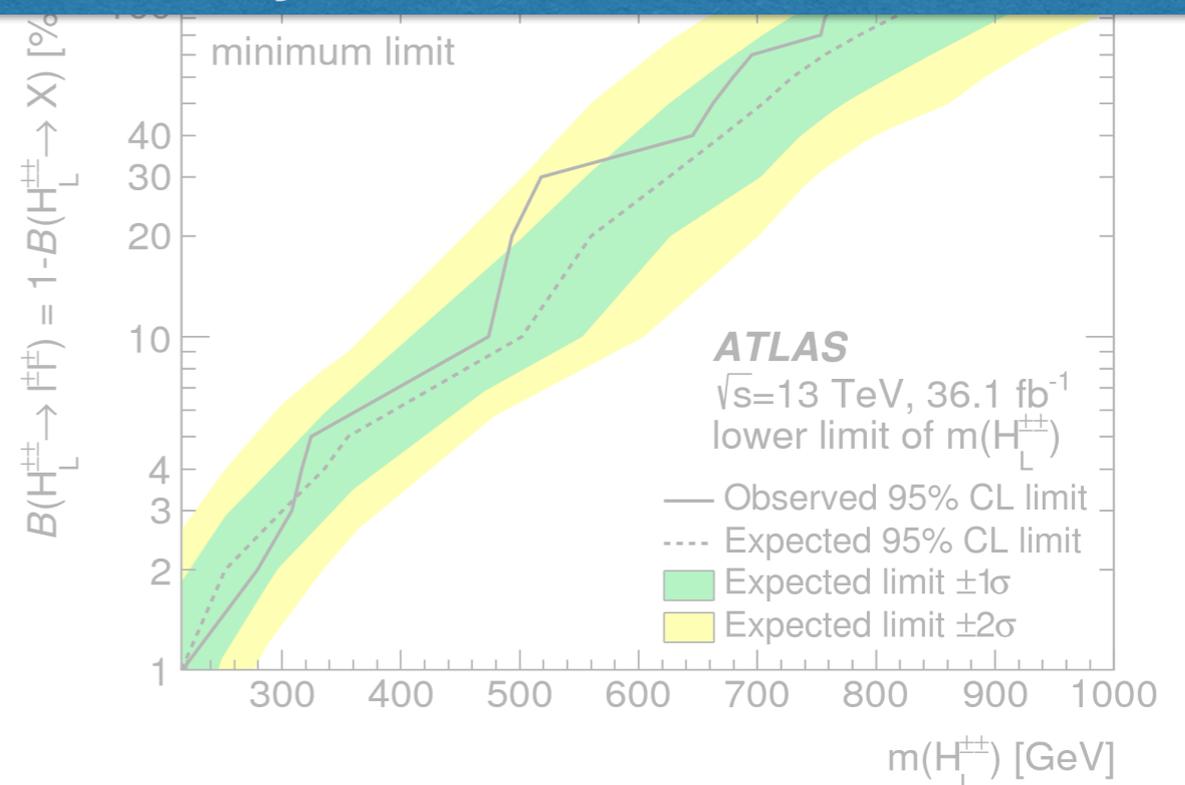
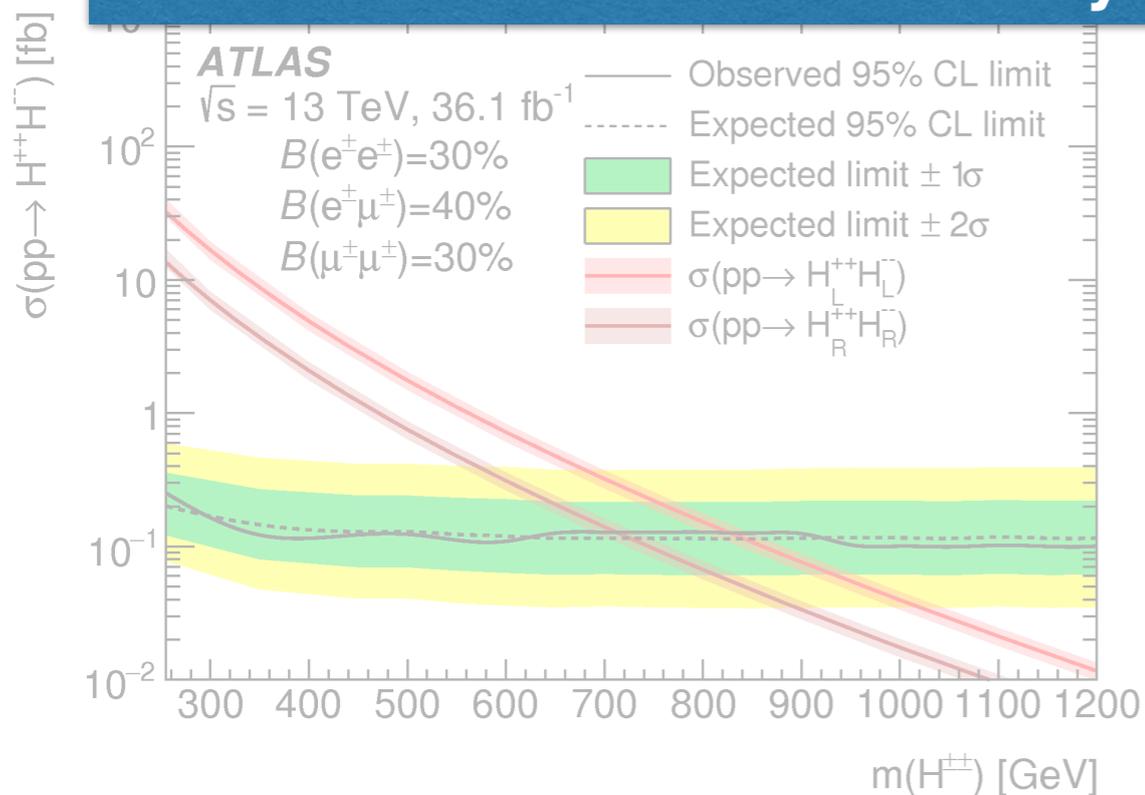
◆ Discriminating variable: $m_{\ell^\pm\ell^\pm}$ or $\bar{M} = \frac{m^{++} + m^{--}}{2}$

◆ Set limits on σ assuming various BR into $e^\pm e^\pm$, $e^\pm \mu^\pm$, or



See Friday Talk: *“Searches for new phenomena in leptonic final states using the ATLAS detector”*

by Miha Muskinja



Run 2 BSM Higgs exclusion in the hMSSM

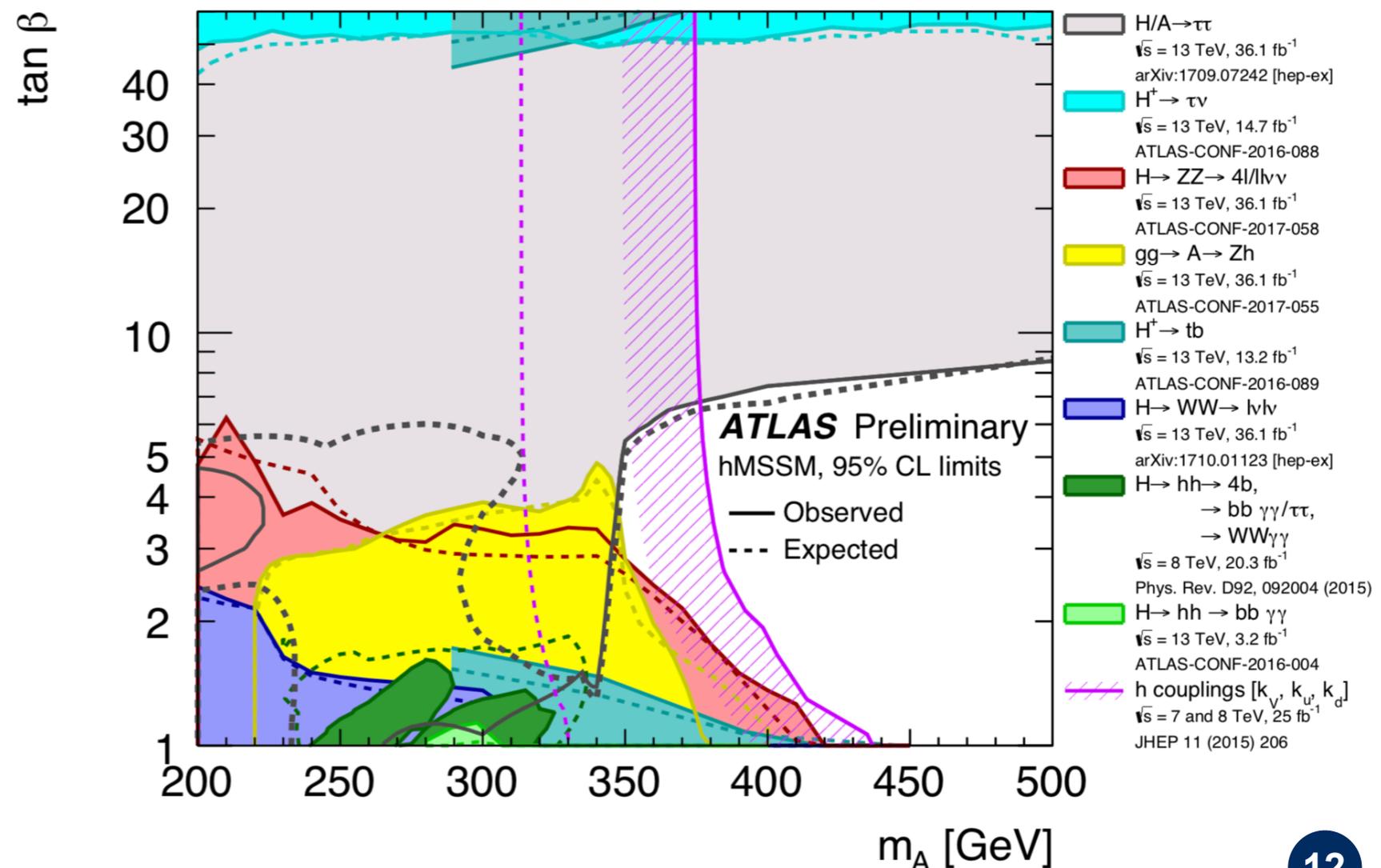
- ◆ Regions of the $[m_A, \tan \beta]$ plane excluded in the hMSSM model vis direct searches for heavy Higgs bosons and fits to the measured rates of observed Higgs boson production and decays.

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/HIGGS/>

- ◆ Limits are quoted at 95% CL and are indicated for the data (solid lines) and the expectation for the SM Higgs sector (dashed lines).

- ◆ Light shaded or hashed regions indicated the observed exclusions.

- ◆ Cross sections for Higgs production in the hMSSM are calculated up to NNLO QCD corrections for ggF and b-associated production.



Run 2 BSM Higgs exclusion in the hMSSM

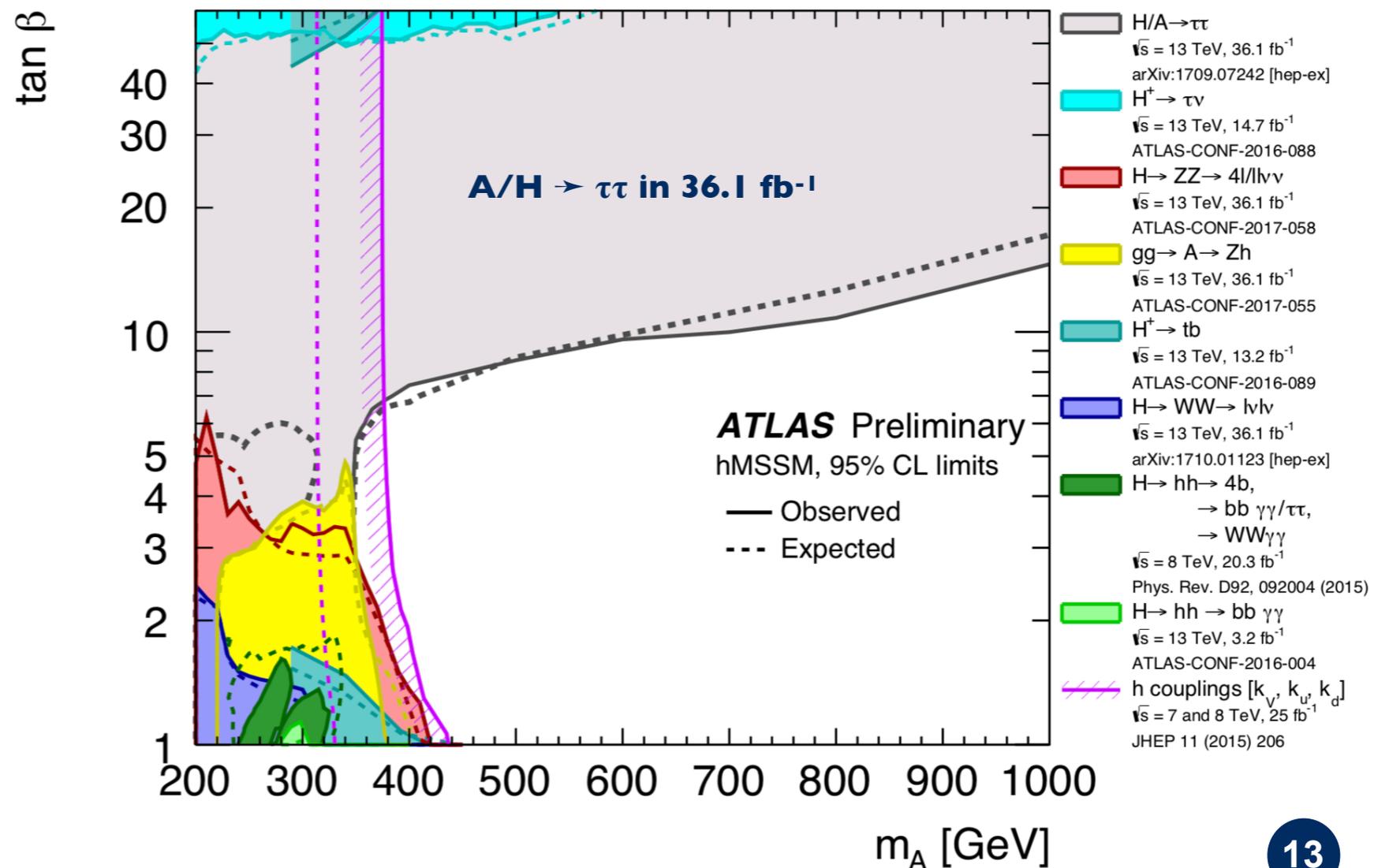
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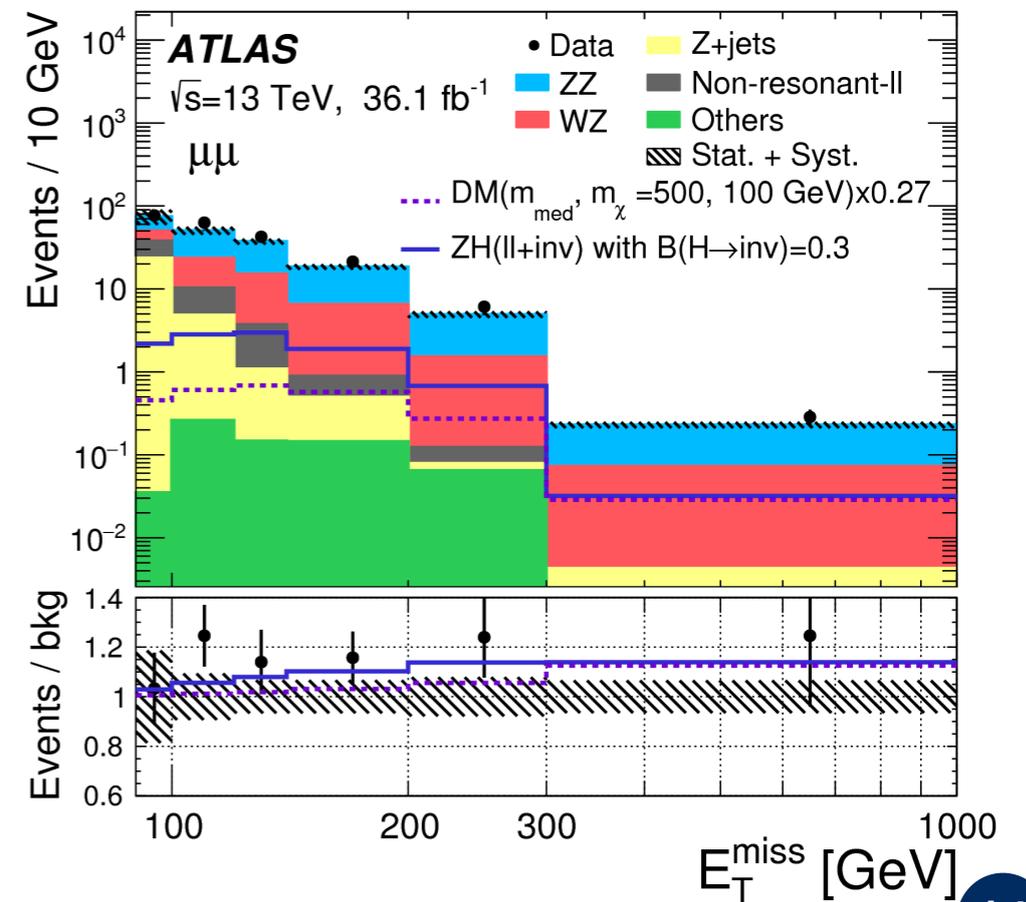
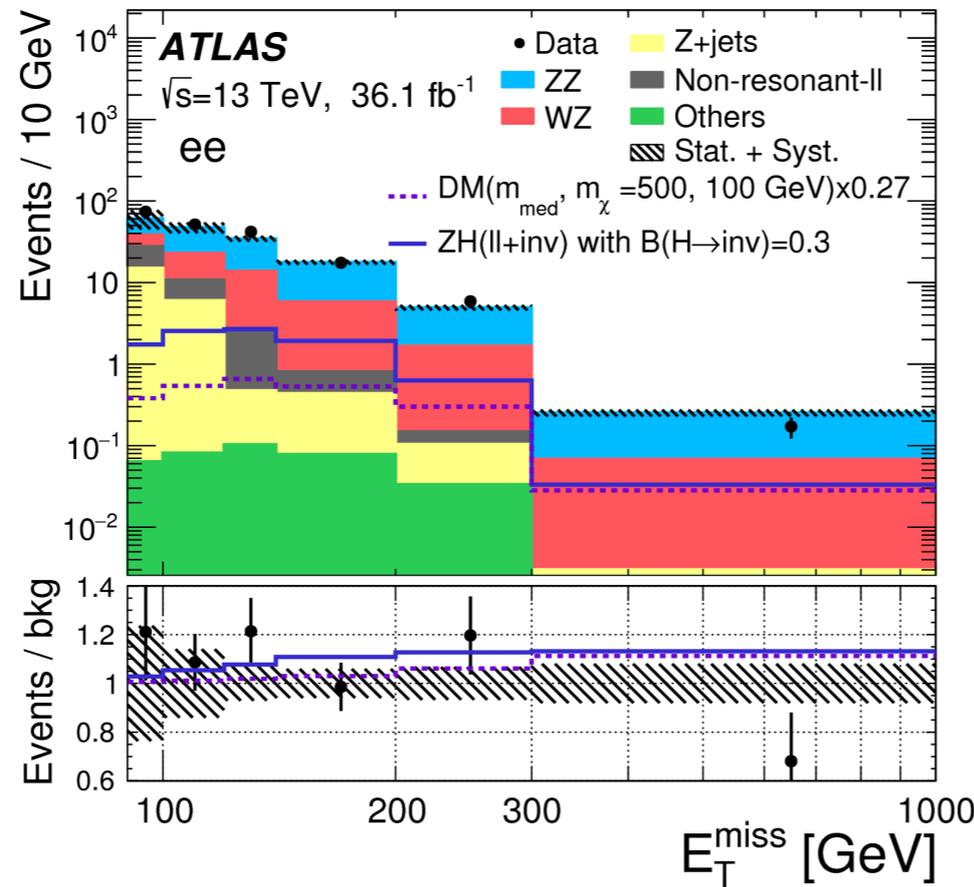
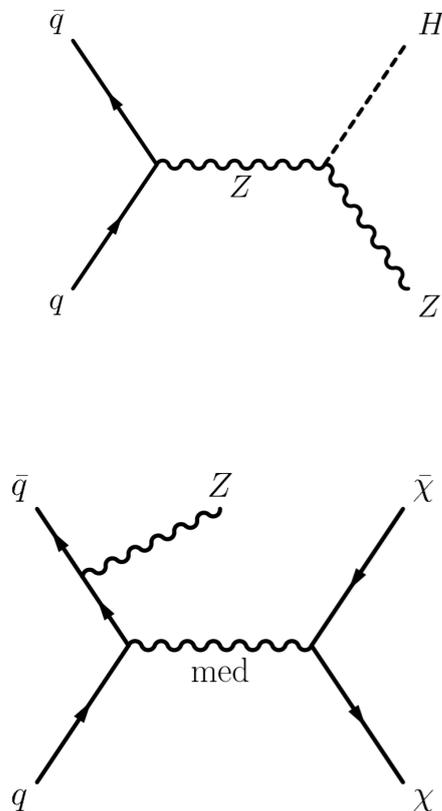
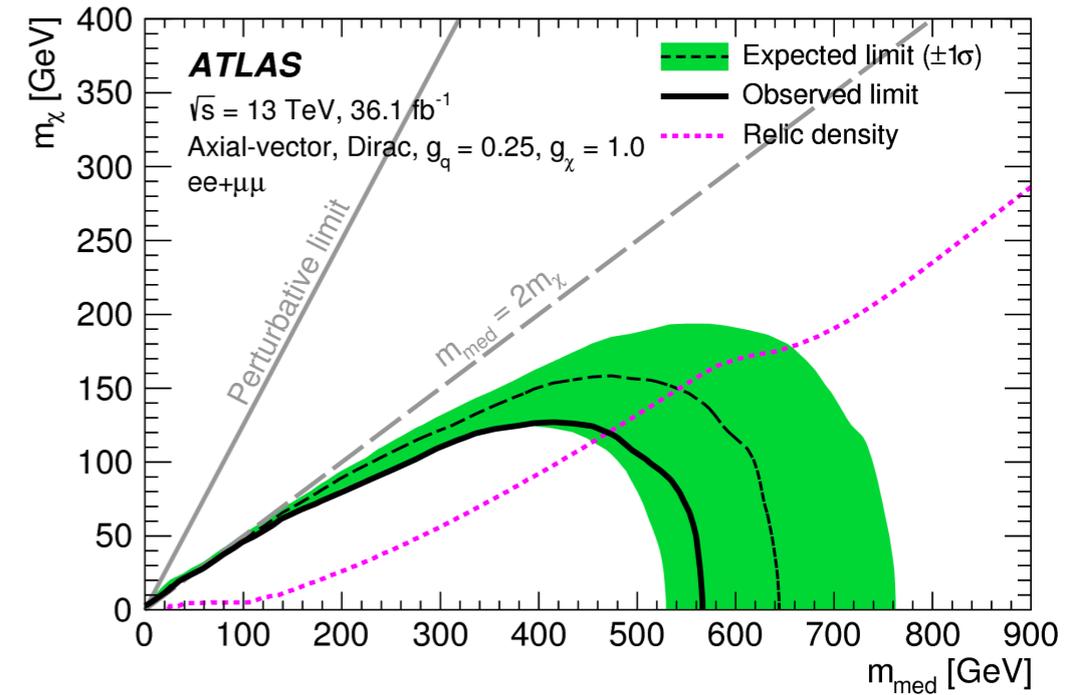
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Searching for Invisibly Decaying Higgs or Dark Matter

- ◆ Search for an invisibly decaying Higgs boson or dark matter candidates produced in association with a Z boson in pp collisions with 36.1 fb⁻¹ - **PLB 776 (2017) 318**
- ◆ Selecting events with two OS high energy leptons in a Zmass window, and a large amount of missing transverse energy (>90 GeV).
- ◆ Assuming standard model ZH production cross-section, an observed (expected) upper limit of 67% (39%) at the 95% CL is set on the BR of invisible decays of the Higgs boson with m_H = 125 GeV.
- ◆ Also extract exclusion limits on dark matter candidate and mediator masses in the framework of simplified dark matter models.

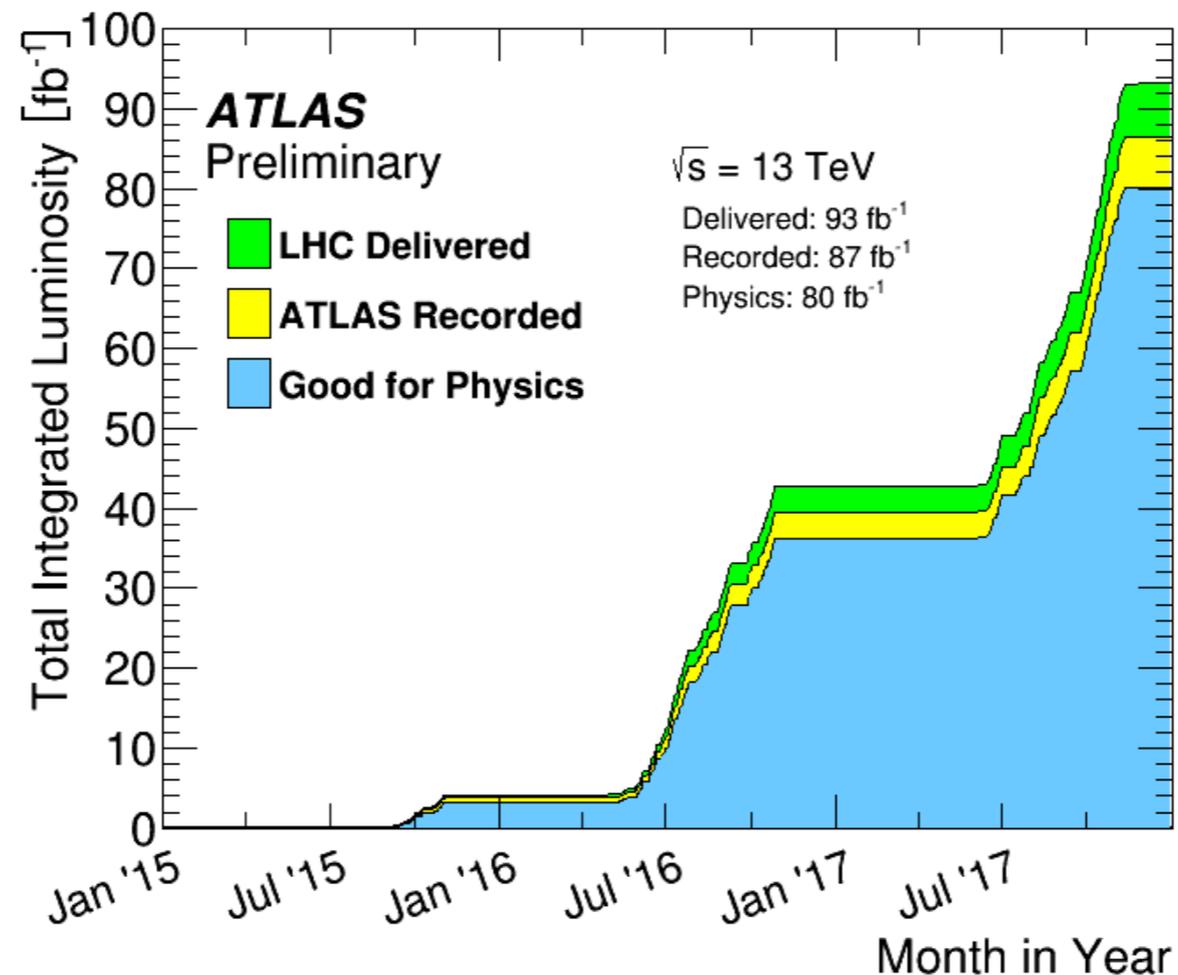


Conclusion

- ◆ Several new physics discoveries were presented, dramatically changing the way we view nature.
- ◆ ATLAS is very active in searching for BSM phenomena in the Higgs sector.
- ◆ Some recent results were presented for BSM searches, though there are many more that deserve to be covered. Please see the ATLAS public results page:

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic>

- ◆ No sign of additional Higgs boson seen in the LHC data. Exclusion limits continue to improve and limit model phase space.
- ◆ Analyses using a fraction of the data we expect to collect for Run II (Total integrated luminosity for Run II $\sim 150 \text{ fb}^{-1}$), and searches will continue beyond at the HL-LHC (3000 fb^{-1}).



Backup

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[arXiv:1610.07922 \(hep-ph\).](#)