



Search for a High-Mass Higgs Boson in Bosonic Decay Modes at ATLAS

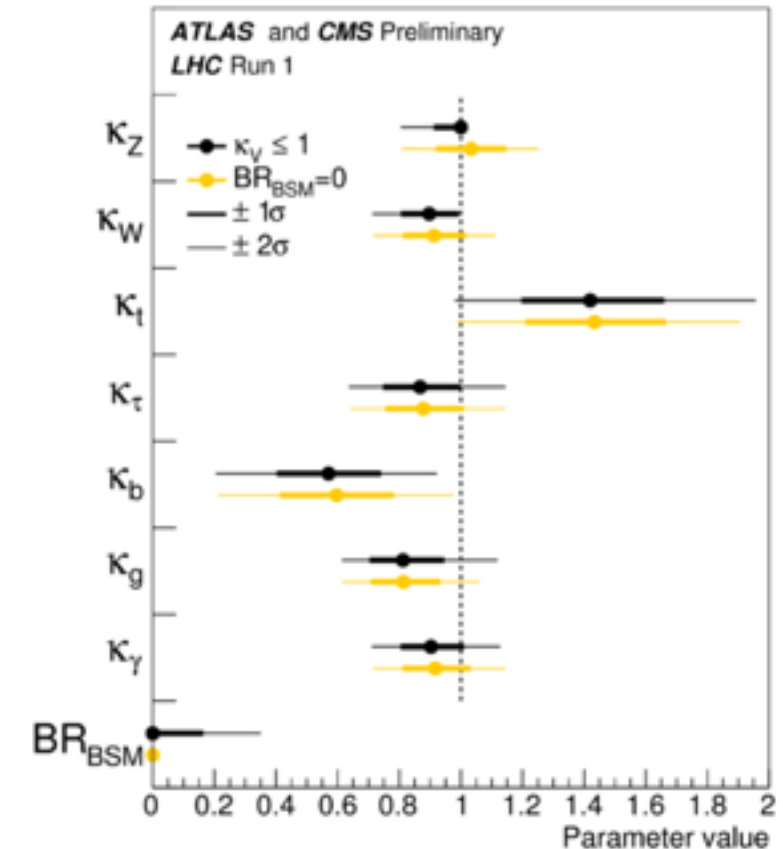
SUSY'16

Melbourne, Australia

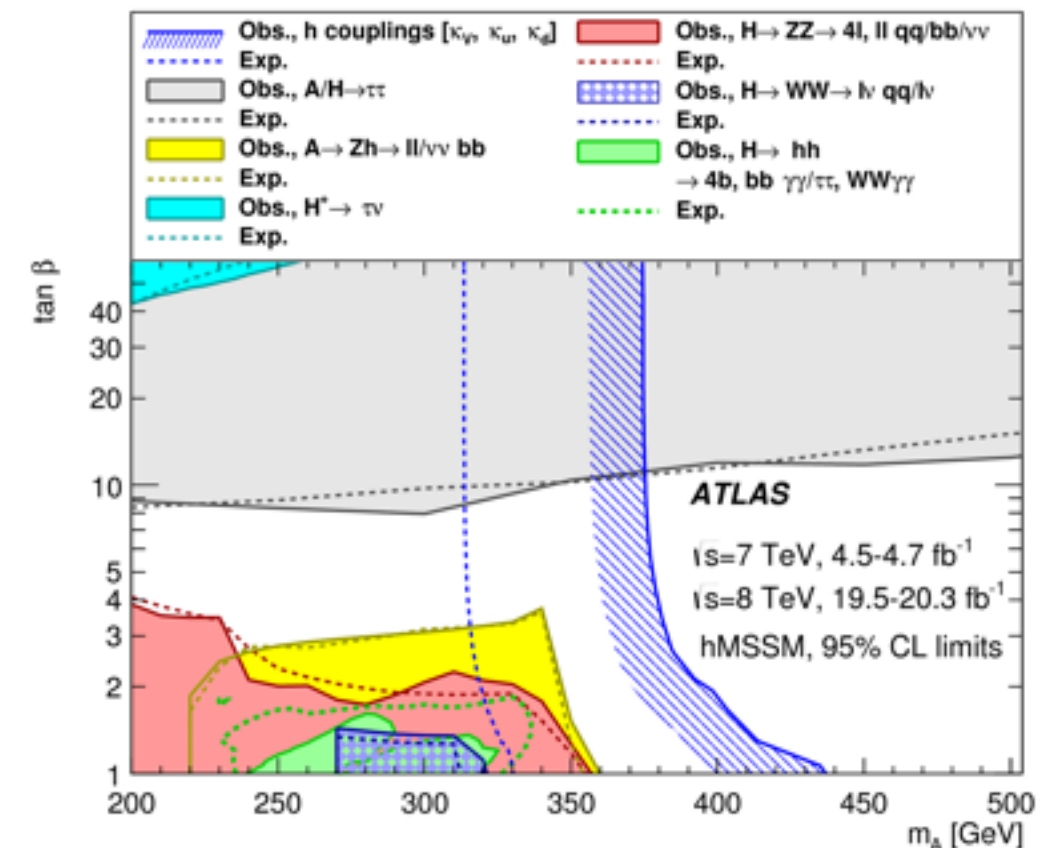
Dmitri Tsybychev on behalf of ATLAS Collaboration
Stony Brook University, USA

Introduction

- Discovery of a neutral scalar particle at LHC of mass ~ 125 GeV has provided important insight into the electroweak symmetry breaking mechanism!
- Many searches were performed in run-1, with 7 and 8 TeV centre-of-mass energy at the LHC
- Experimental results show consistency with the SM Higgs boson
- It is still possible that observed boson is one physical state of an extended scalar sector. Many BSM theories require two or more Higgs doublets
- Benchmark scenarios:
 - hMSSM
 - 2HDM, ...



Phys. Rev. D 92, 092004 (2015)



Scalar Resonance in VV channel

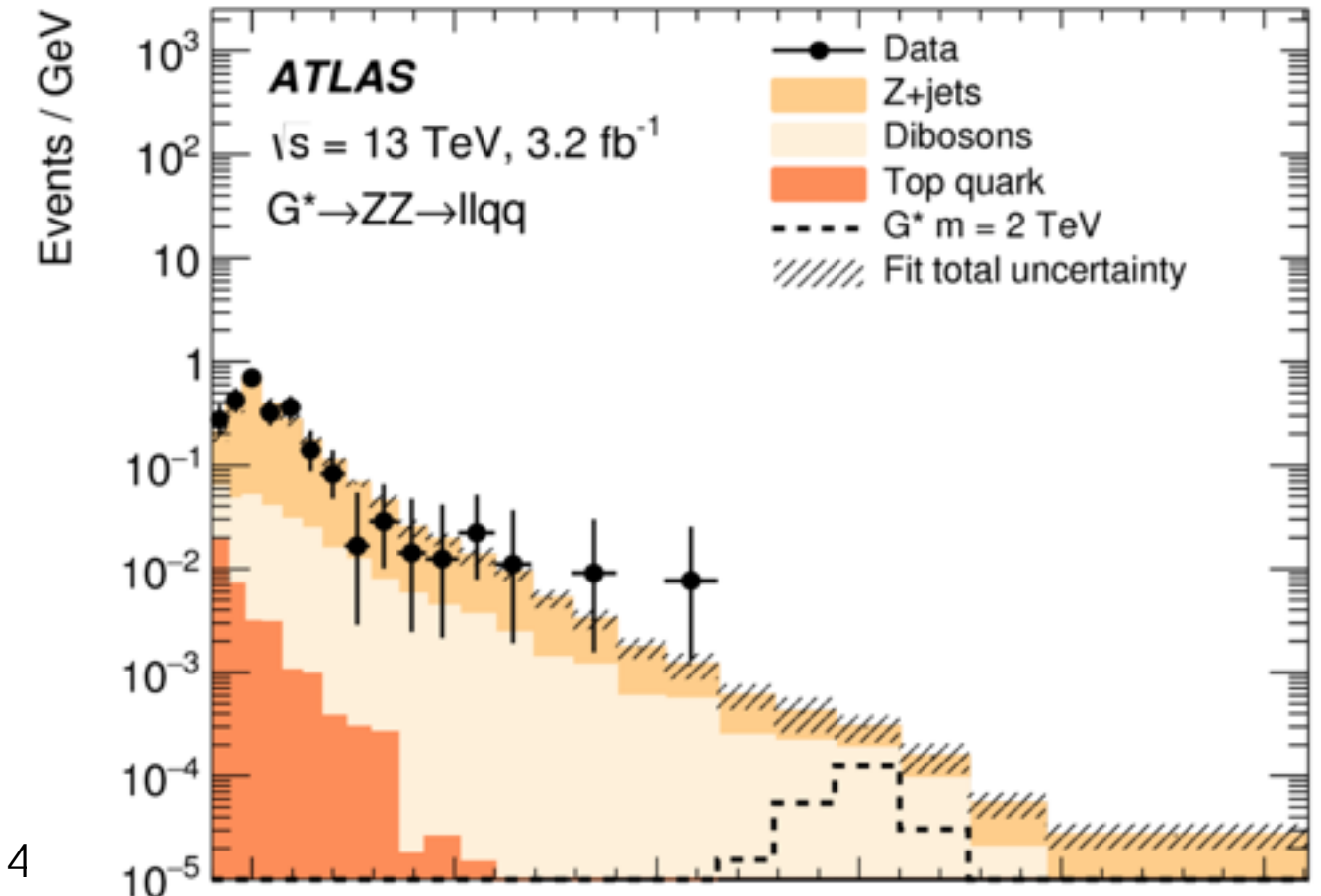
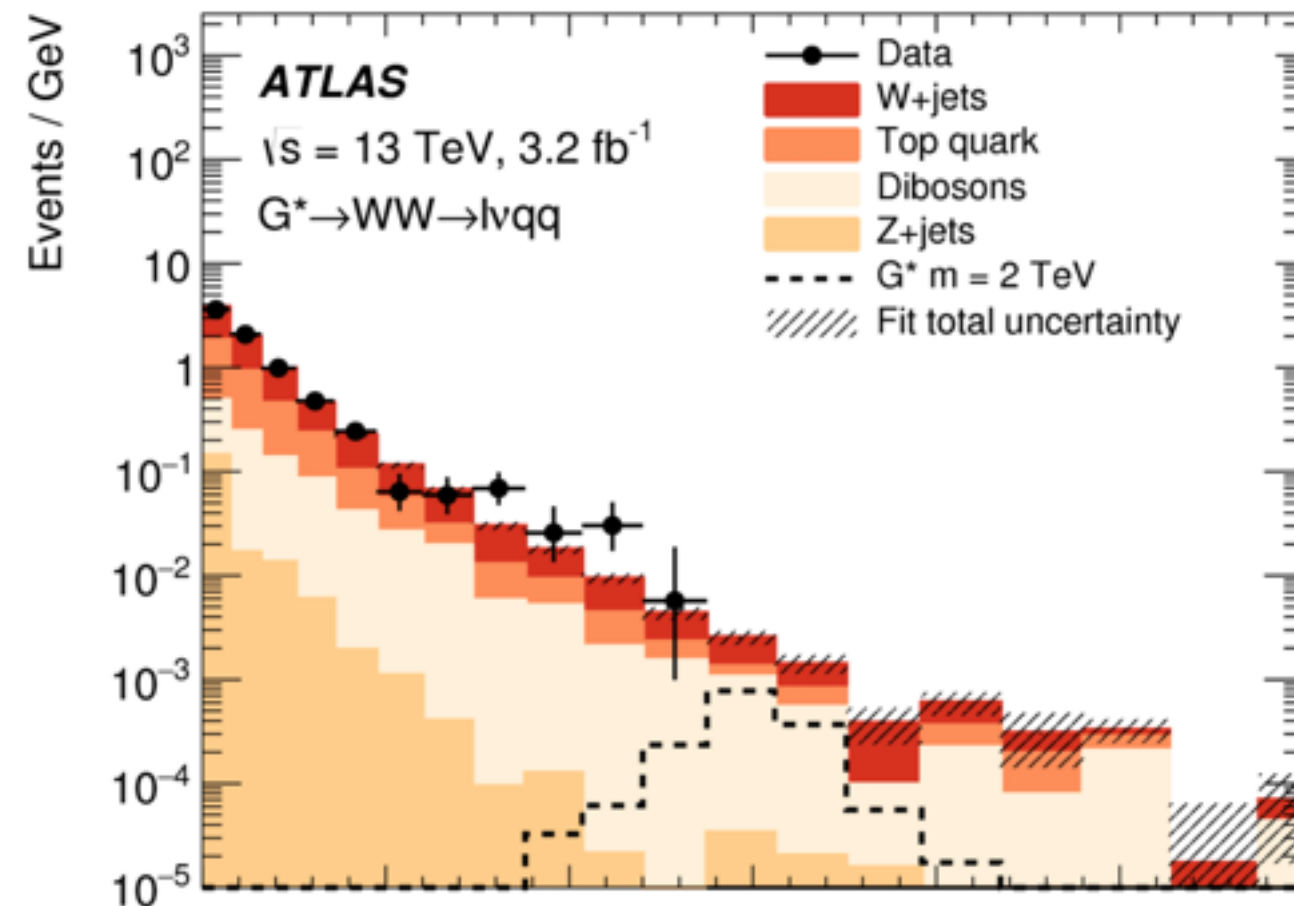
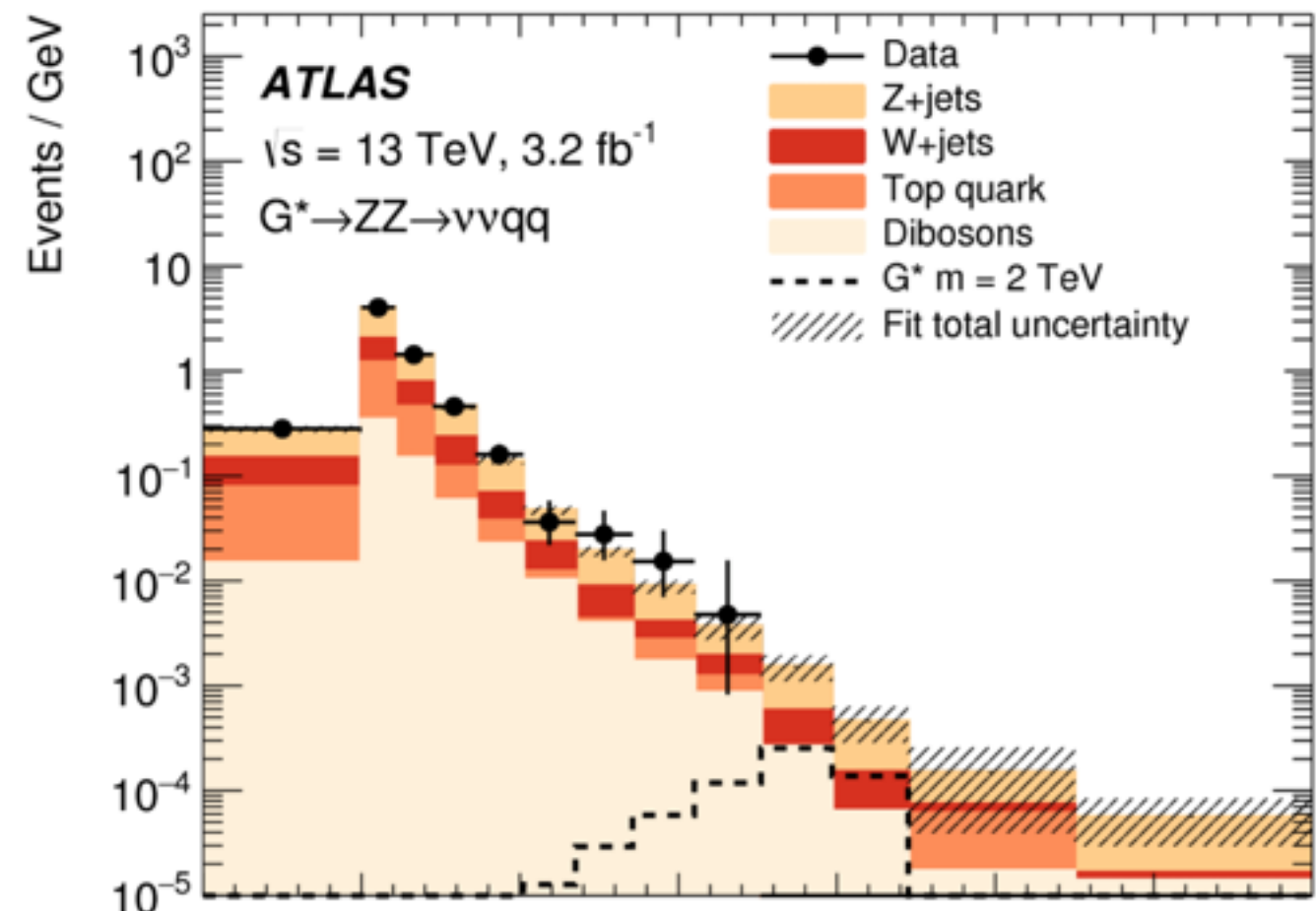
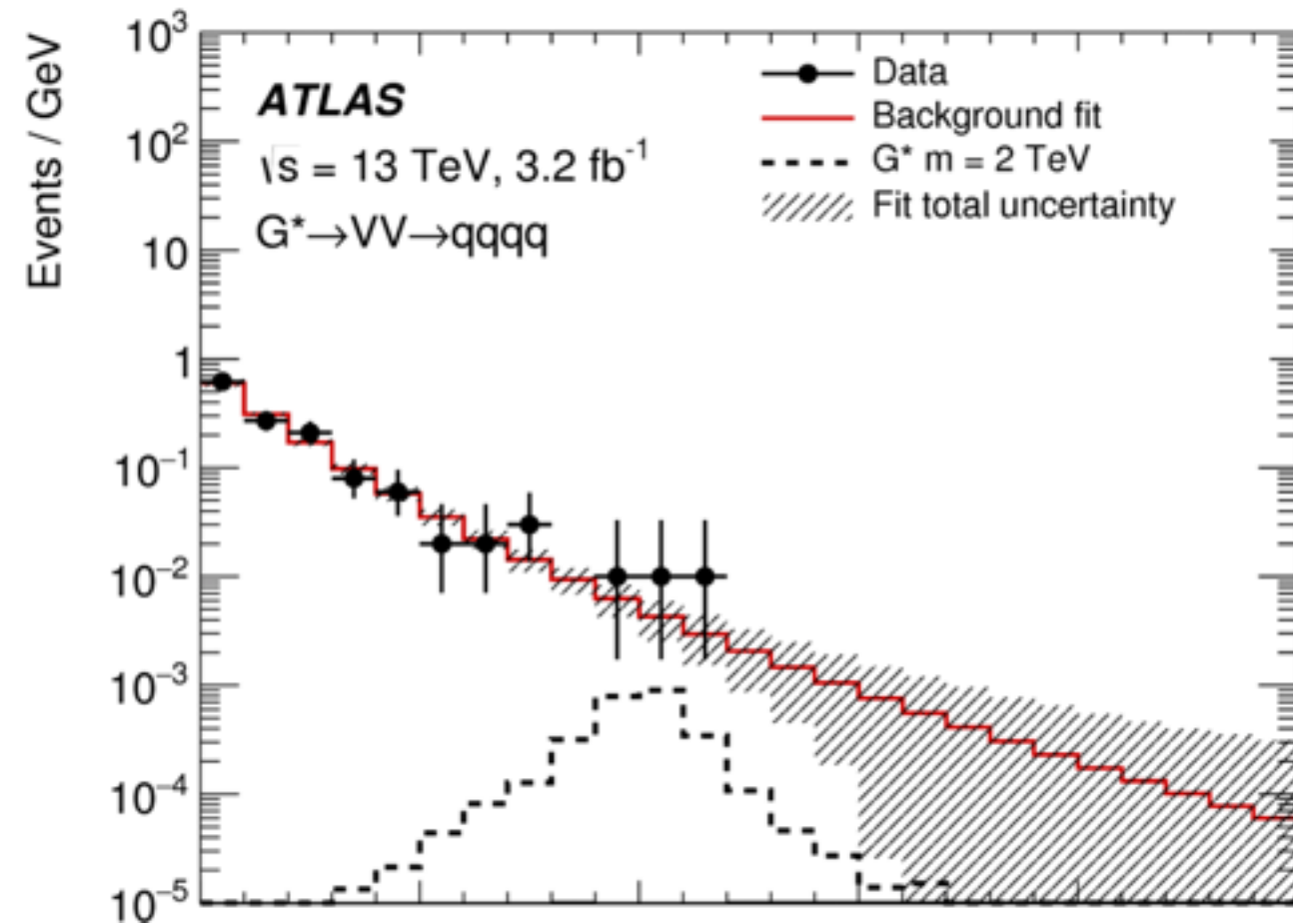
- At least one boson decays hadronically (mass consistent with W or Z)
 - V reconstructed as large R jet (J) only
- Different VV states are orthogonal
- Background estimate from control regions
 - V+jets large R jet mass sideband
 - top pairs inverted b-jet veto
 - included in final fit to further constraint

| Selection level | Channel | | | |
|------------------|--|--|---|---|
| | $qqqq$ | $\nu\nu qq$ | $\ell\nu qq$ | $\ell\ell qq$ |
| Trigger | Large-R jet, $p_T > 360$ GeV | E_T^{miss} | $E_T^{\text{miss}}(\mu\nu qq)$ or single electron ($e\nu qq$) | single electron or muon |
| Large-R jet | $\geq 2, N_{\text{trk}} < 30,$ $p_{T,J_1} > 450$ GeV, $p_{T,J_2} > 200$ GeV | $\geq 1,$ $p_{T,J} > 200$ GeV | | |
| Baseline leptons | 0 | 0 | ≥ 1 | ≥ 2 |
| Good leptons | 0 | 0 | 1 medium μ or tight [†] e | 2 e or 2 μ , loose + medium |
| Topology | $E_T^{\text{miss}} < 250$ GeV, $ y_{J_1} - y_{J_2} < 1.2,$ $\frac{p_{T,J_1} - p_{T,J_2}}{p_{T,J_1} + p_{T,J_2}} < 0.15$ | $E_T^{\text{miss}} > 250$ GeV, $p_T^{\text{miss}} > 30$ GeV, $ \Delta\phi(\mathbf{E}_T^{\text{miss}}, p_T^{\text{miss}}) < \frac{\pi}{2},$ $ \Delta\phi(\mathbf{E}_T^{\text{miss}}, j) > 0.6$ | no b -jet with $\Delta R(j, J) < 1.0,$ $E_T^{\text{miss}} > 100$ GeV, $p_{T,\ell\nu} > 200$ GeV, $p_{T,J}/m_{\ell\nu J} > 0.4,$ $p_{T,\ell\nu}/m_{\ell\nu J} > 0.4$ | $p_{T,J}/m_{\ell\ell J} > 0.4,$ $p_{T,\ell\ell}/m_{\ell\ell J} > 0.4,$ $83 < m_{ee}/\text{GeV} < 99,$ $66 < m_{\mu\mu}/\text{GeV} < 116$ |
| Discriminant | m_{JJ} | m_T | $m_{\ell\nu J}$ | $m_{\ell\ell J}$ |

[†] The electron, if over 300 GeV in p_T , need only be medium.

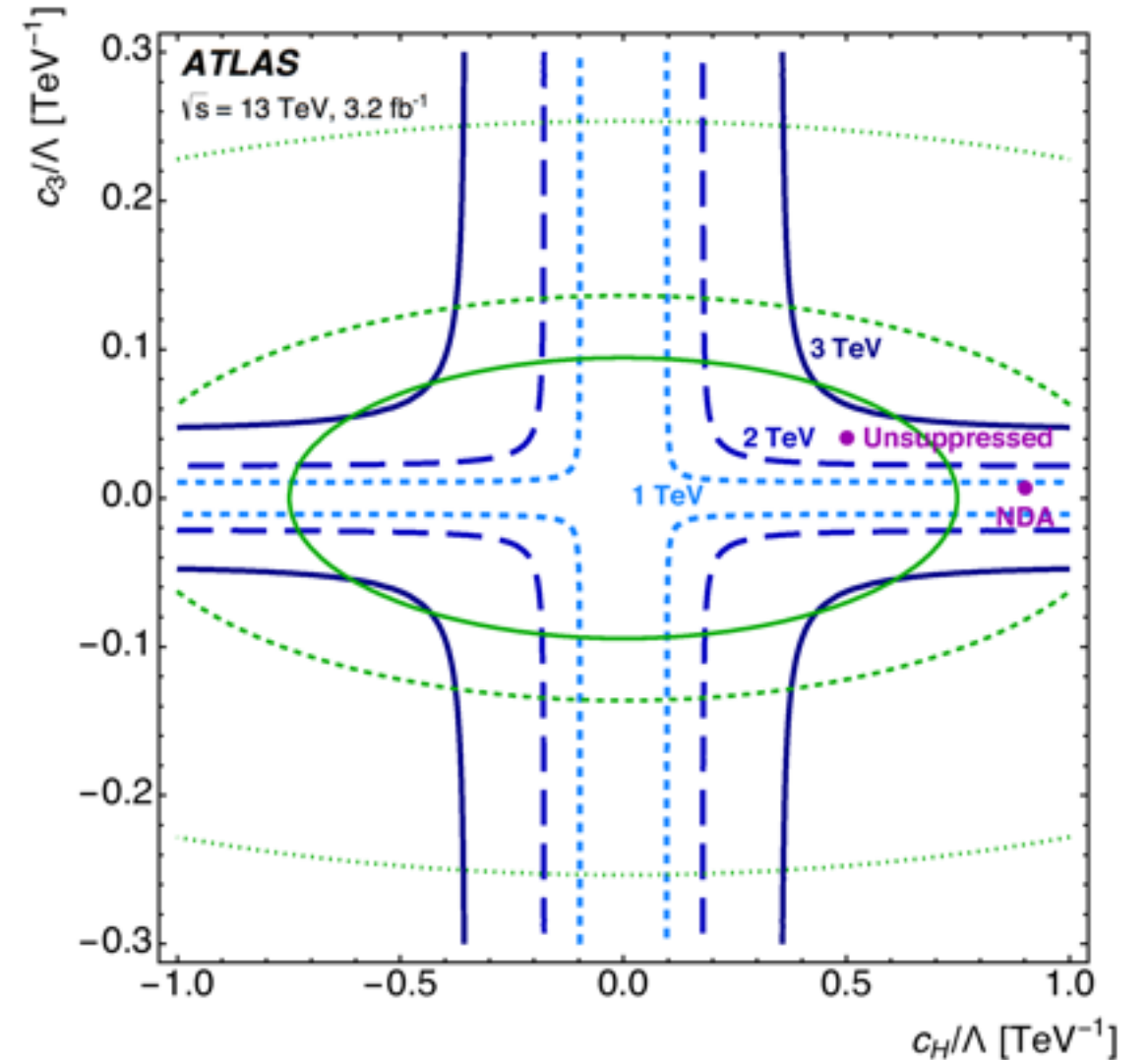
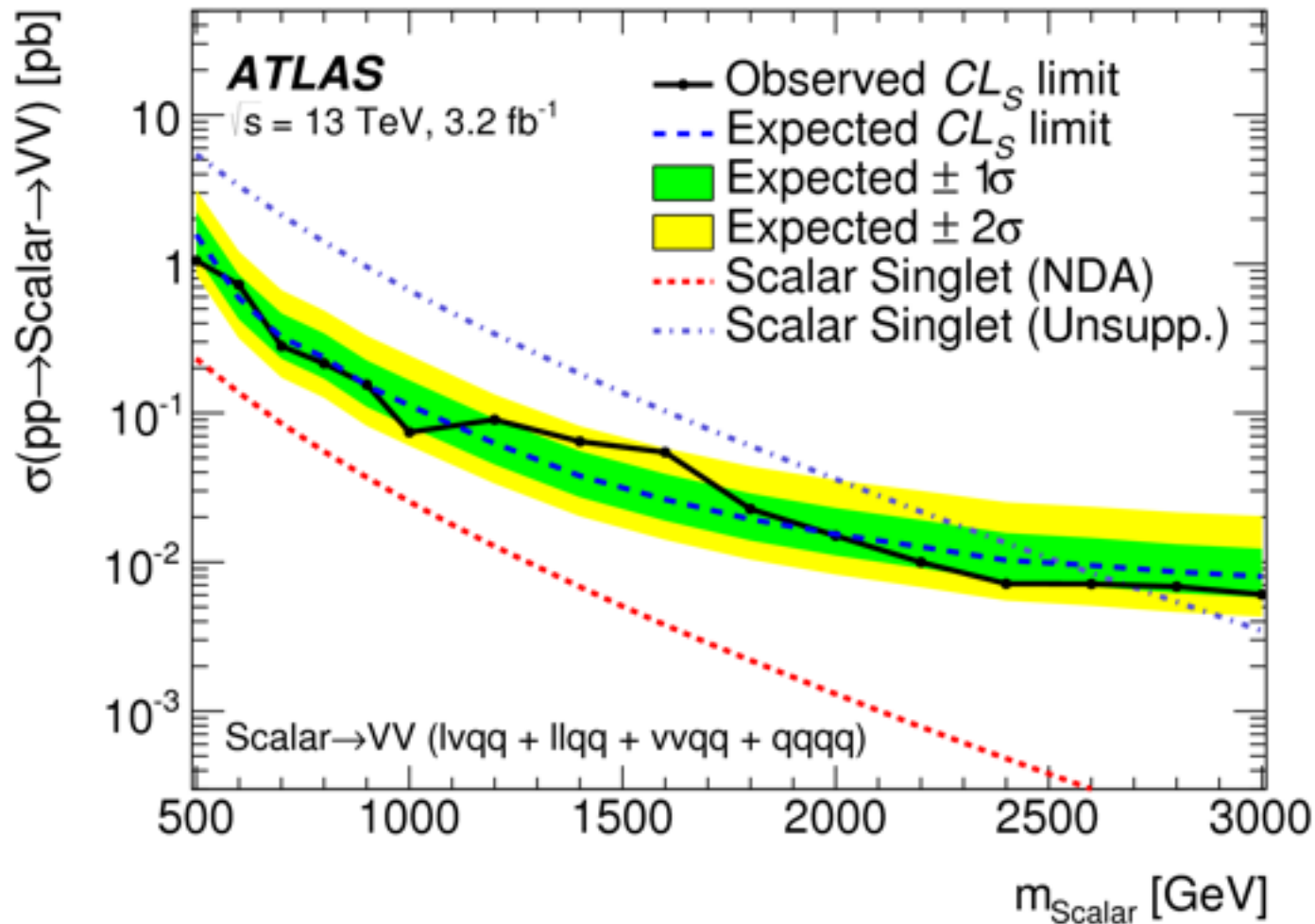
Scalar Resonance in VV channel

[arXiv:1606.04833](https://arxiv.org/abs/1606.04833)



Scalar VV Resonance Results

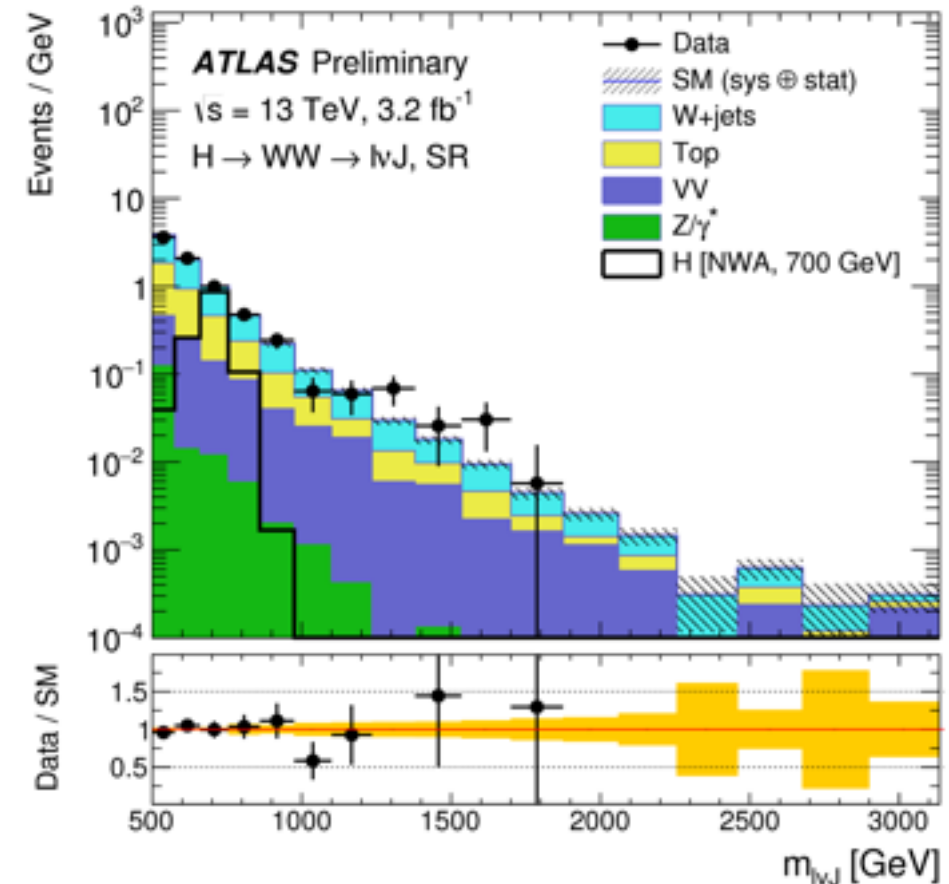
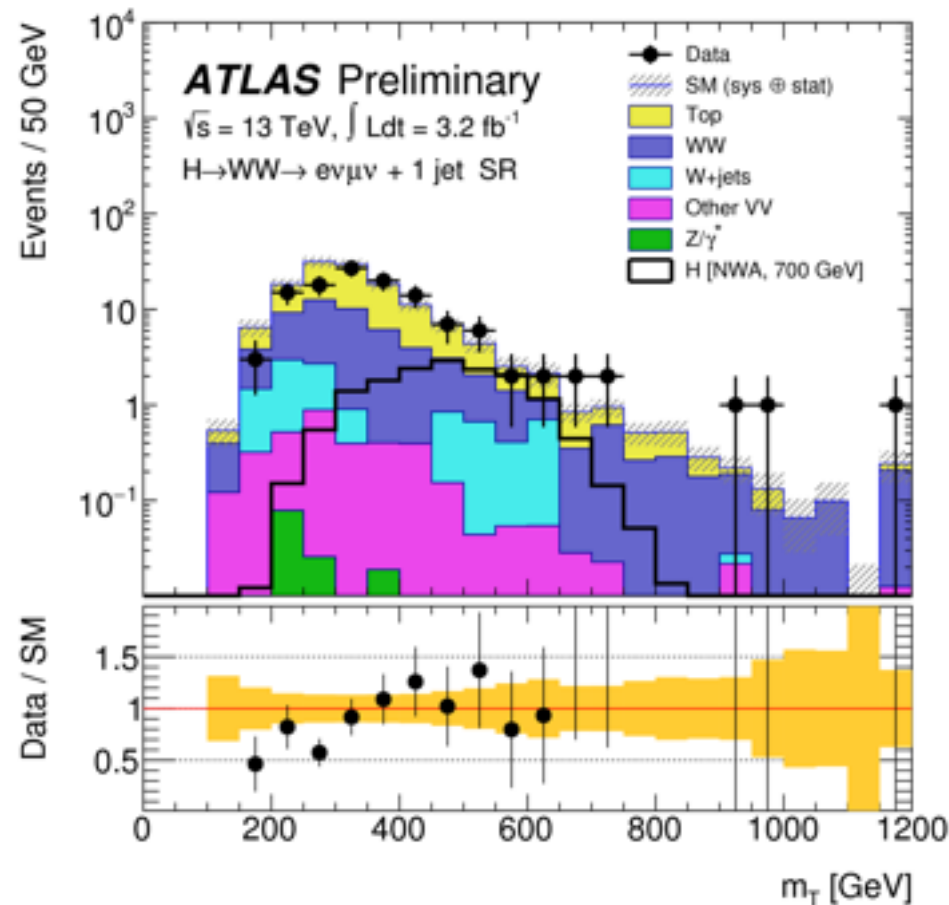
[arXiv:1606.04833](https://arxiv.org/abs/1606.04833)



- No significant excess observed in data
- Interpret results as model independent limits on σ at 95% CL for a scalar particle with narrow width
 - Compare with CP-even scalar singlet model for NDA (BR $VV > 99\%$) and Unsuppressed scenario (R. Franceschini et al, JHEP 03 (2016) 144)
 - c_3 coupling to gluons and c_H couplings to Higgs
 - $\Gamma/m < 5\%$ for points inside ellipse

H → WW

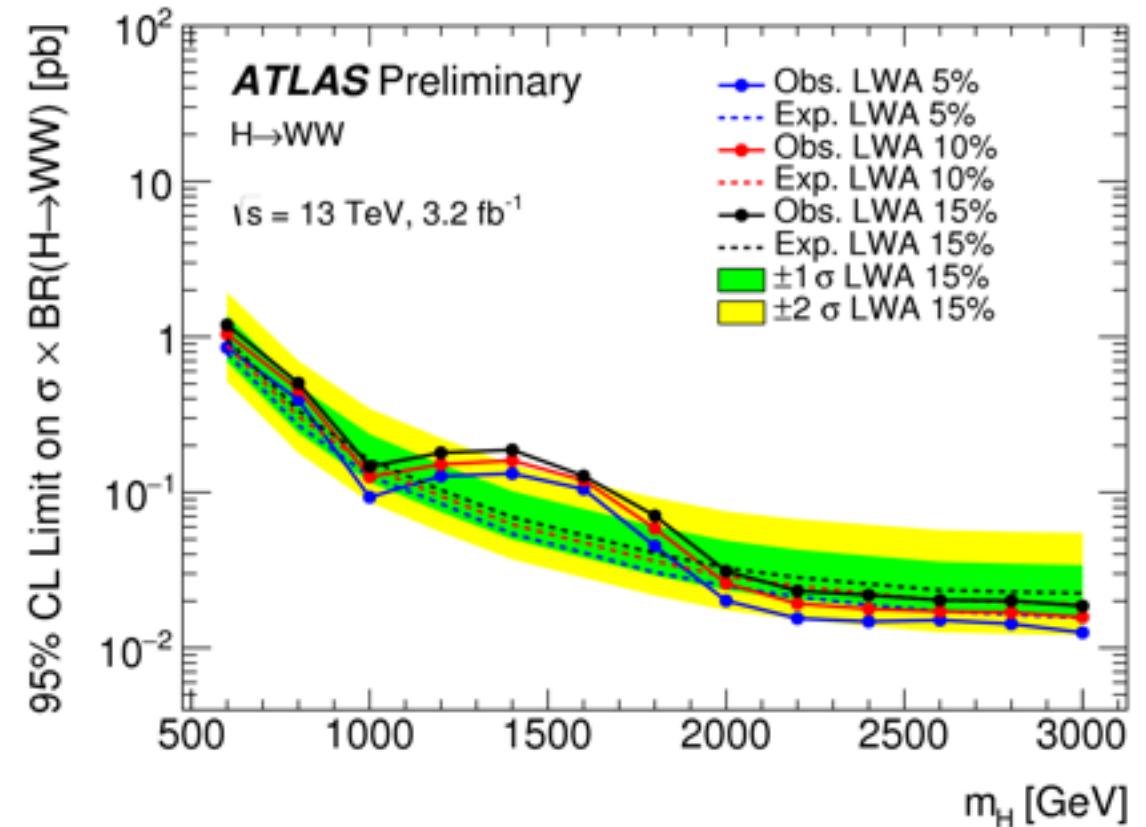
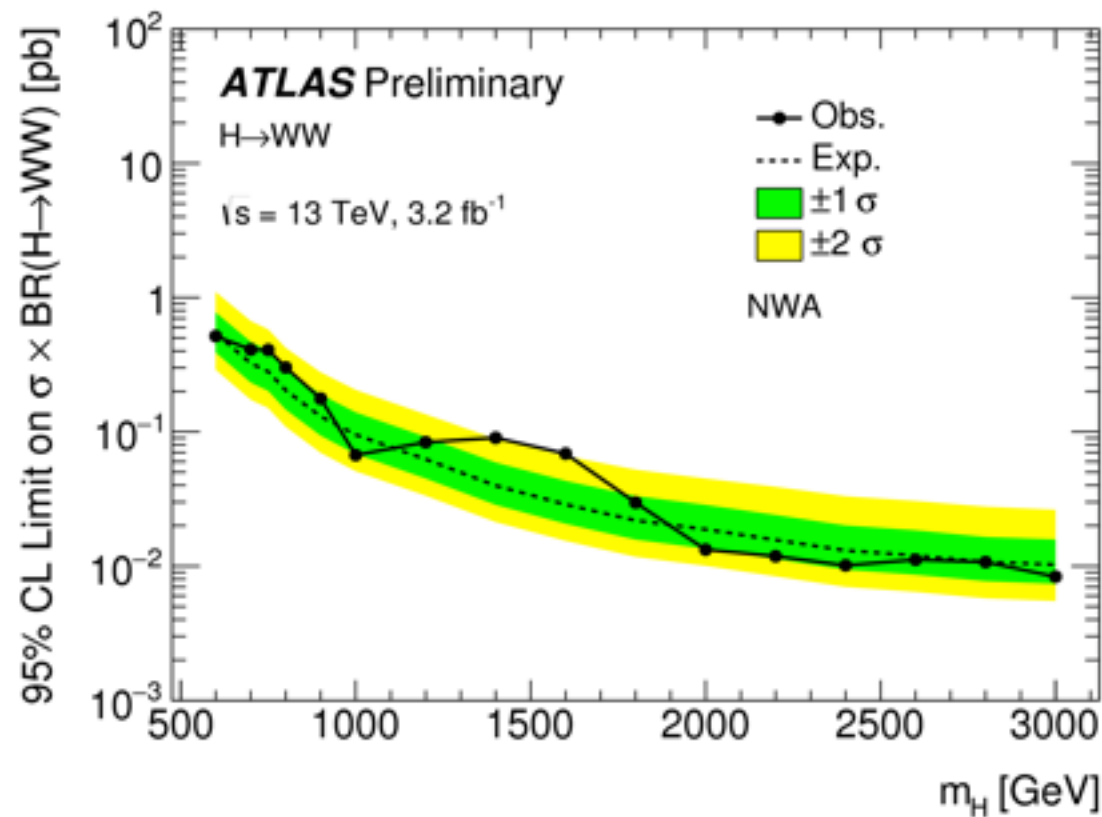
ATLAS-CONF-2016-021



- SR split by Njet (0, 1, ≥2) due to different background composition
- Dominant backgrounds
 - ttbar and W+jets
 - Estimated in control regions
- Discriminant transverse mass of $l\nu' + \text{MET}$
- Signals in mass range 0.5 TeV – 3 TeV
 - Narrow width to up to 15%
- Dominant backgrounds
 - ttbar and W+jets
 - Normalized using CRs in simultaneous fit
- Discriminant $m_{l\nu J}$
 - hadronically decaying W reconstructed as large R jet
 - neutrino z-momentum reconstructed from W mass constrain

$H \rightarrow WW$

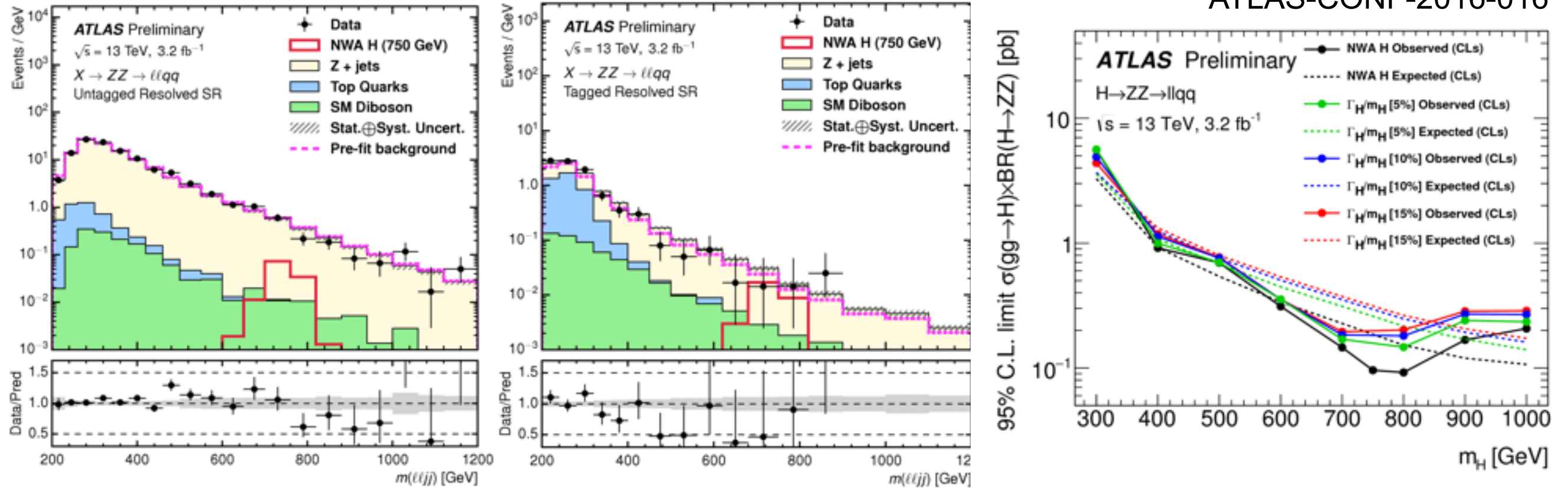
ATLAS-CONF-2016-021



- No excesses observed, set limits on $\sigma \times \text{BR}$
- ggF and VBF contributions combined in NWA limit
- Better sensitivity in $l\nu qq$ channel, especially at higher masses
- Improved sensitivity over Run I (JHEP01(2016)032)

$H \rightarrow ZZ \rightarrow \ell\ell qq$

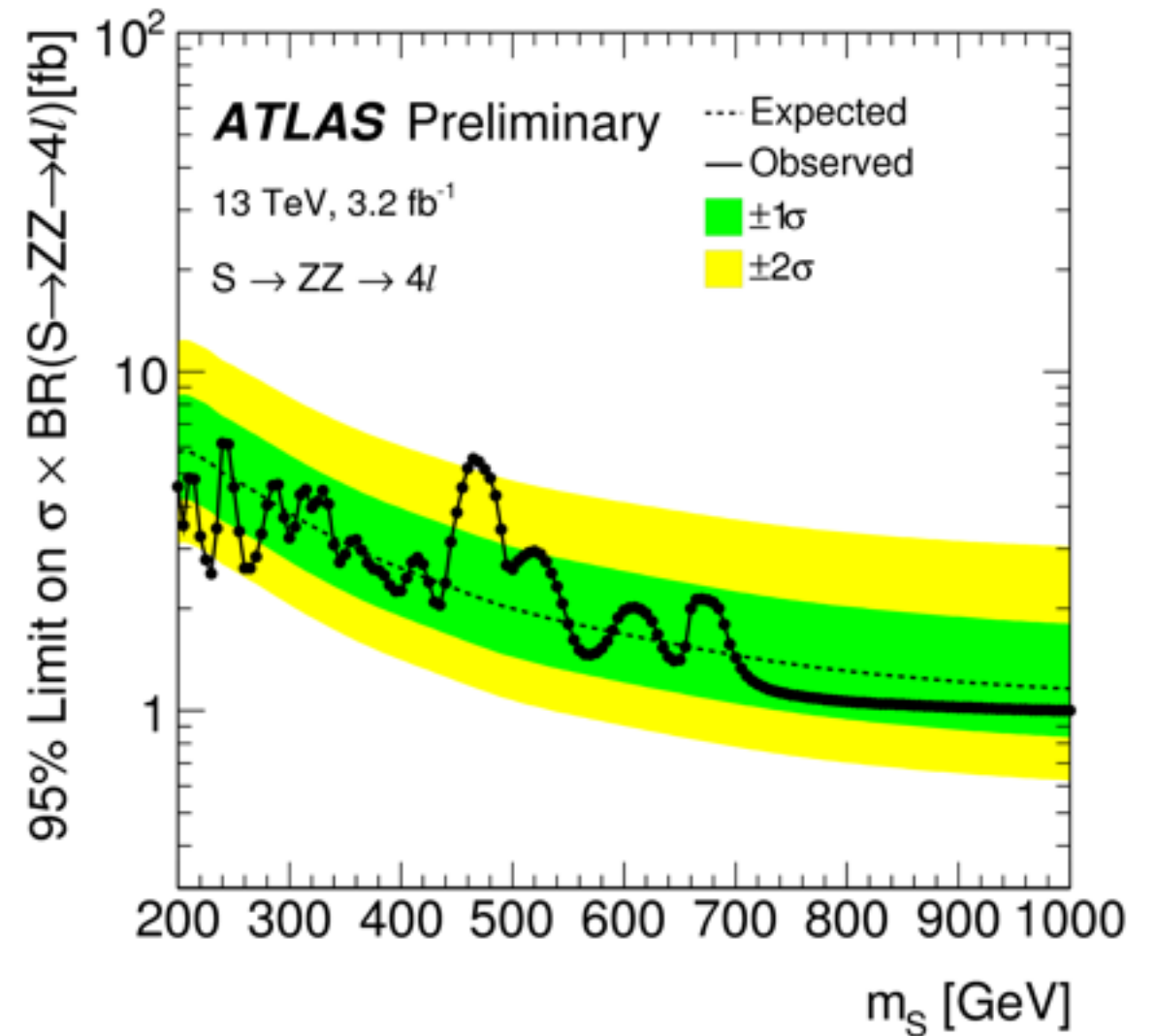
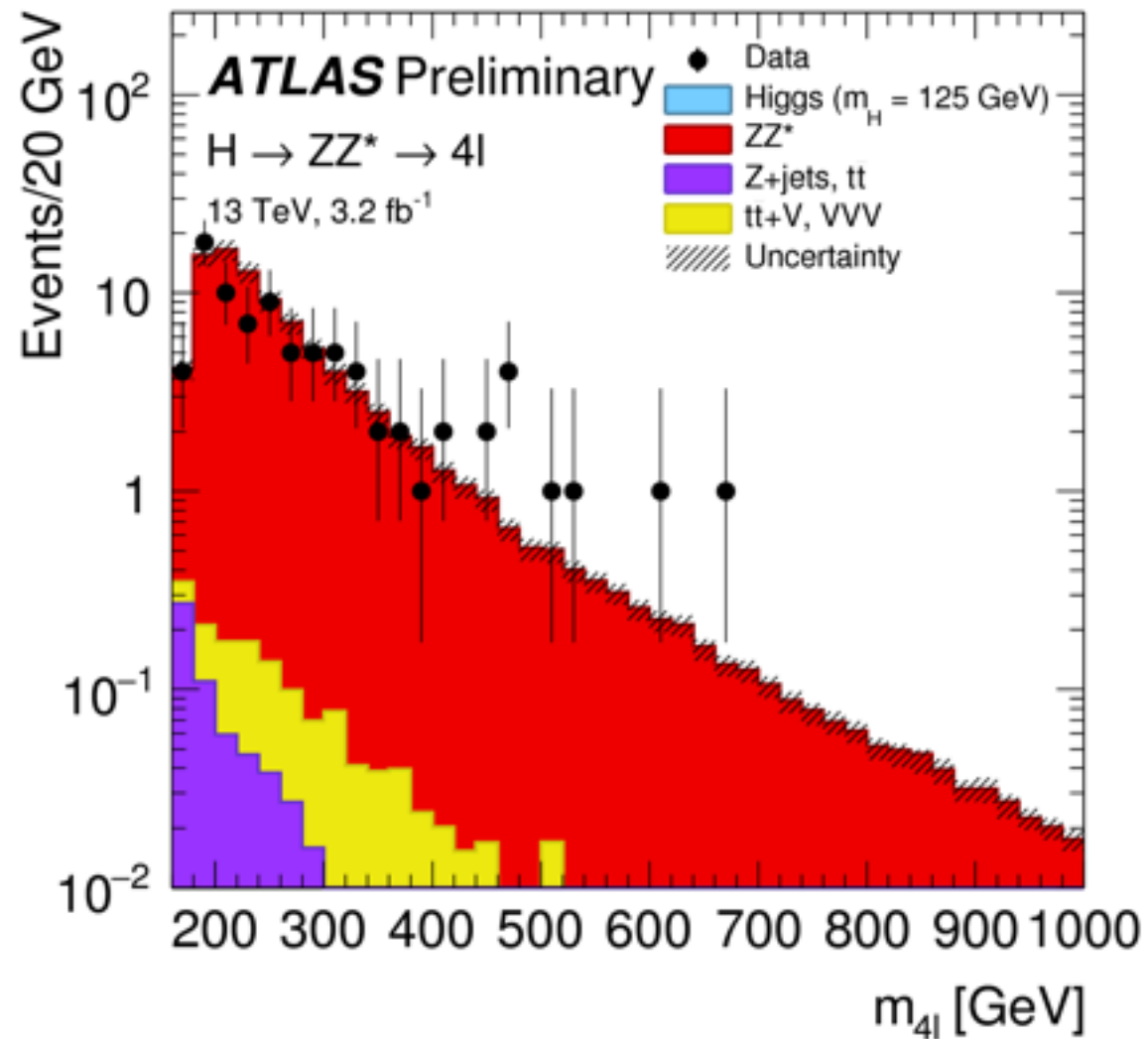
ATLAS-CONF-2016-016



- Merged and resolved reconstruction of the $Z \rightarrow qq$ decays
 - Resolved analysis further split in two b-tagged jet and untagged jet categories
 - Dominant backgrounds Z+jets and $t\bar{t}$ estimated from CR regions
- Discriminant is the invariant mass $m_{\ell\ell jj} / m_{\ell\ell jj}$
- The three signal regions and four CRs are fit simultaneously
 - Constrain the normalization of the Z+jets and Top backgrounds
- Data consistent with SM predictions

$$H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$$

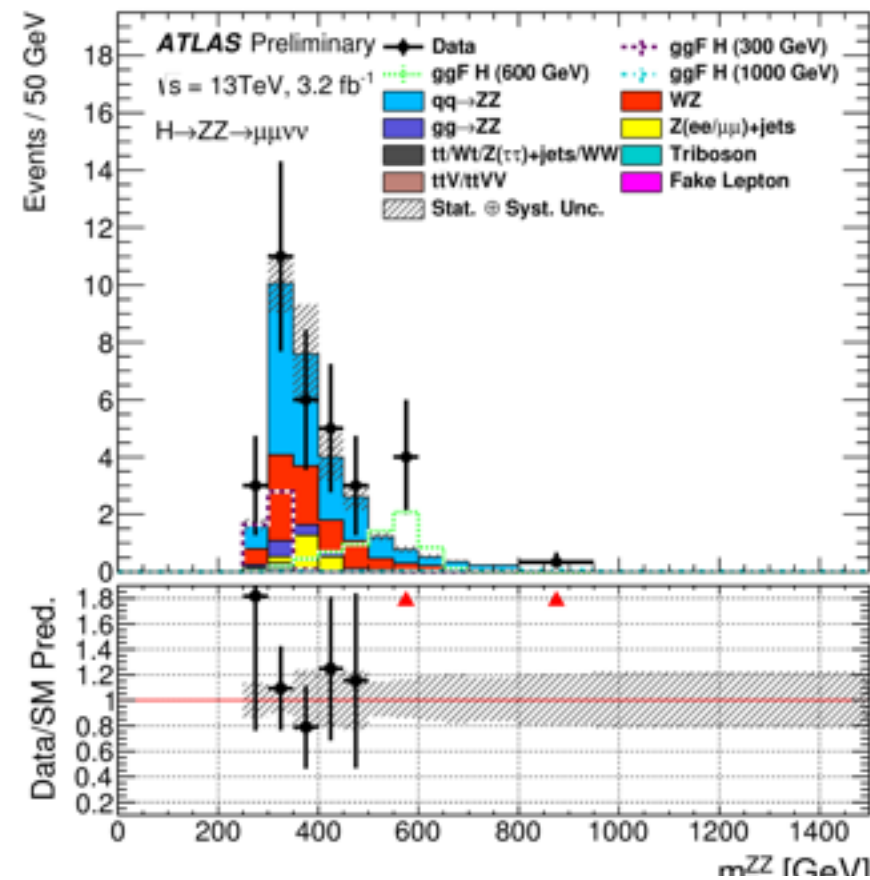
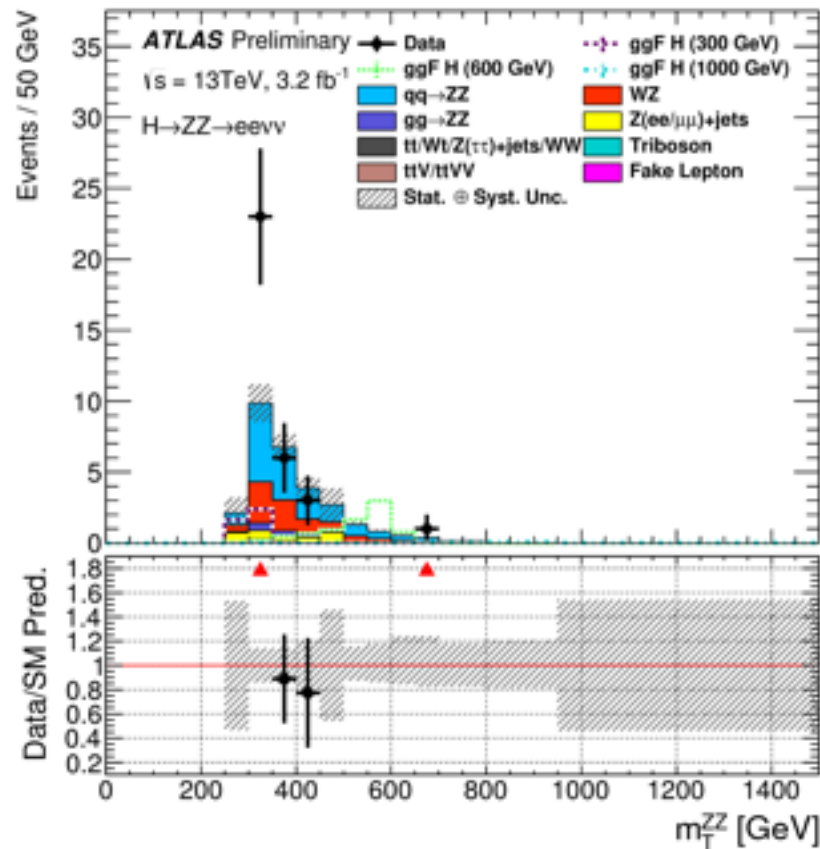
ATLAS-CONF-2015-059



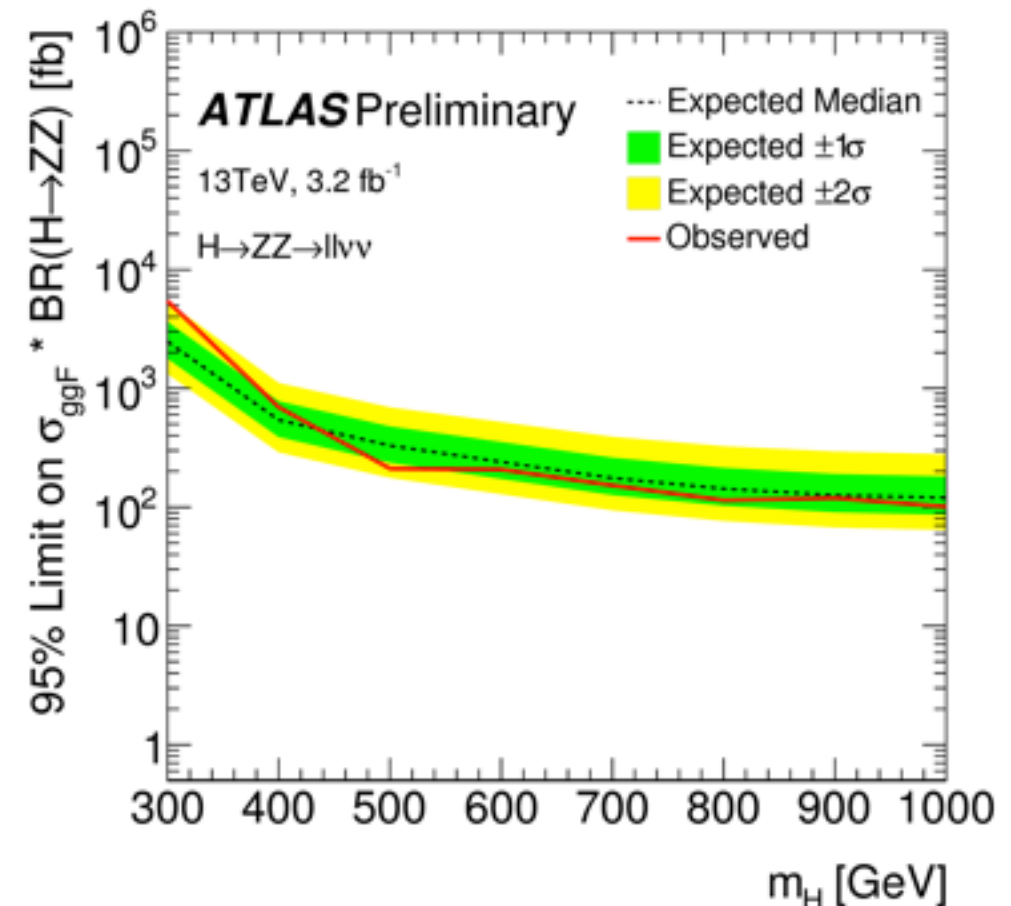
- $4\mu, 4e, 2e2\mu$ final state
 - low backgrounds
- di-lepton invariant mass close to m_Z
 - two Z-candidates
 - Discriminant m_{4l} used in the likelihood fit

$$H \rightarrow ZZ \rightarrow ll\nu\nu$$

ATLAS-CONF-2016-012

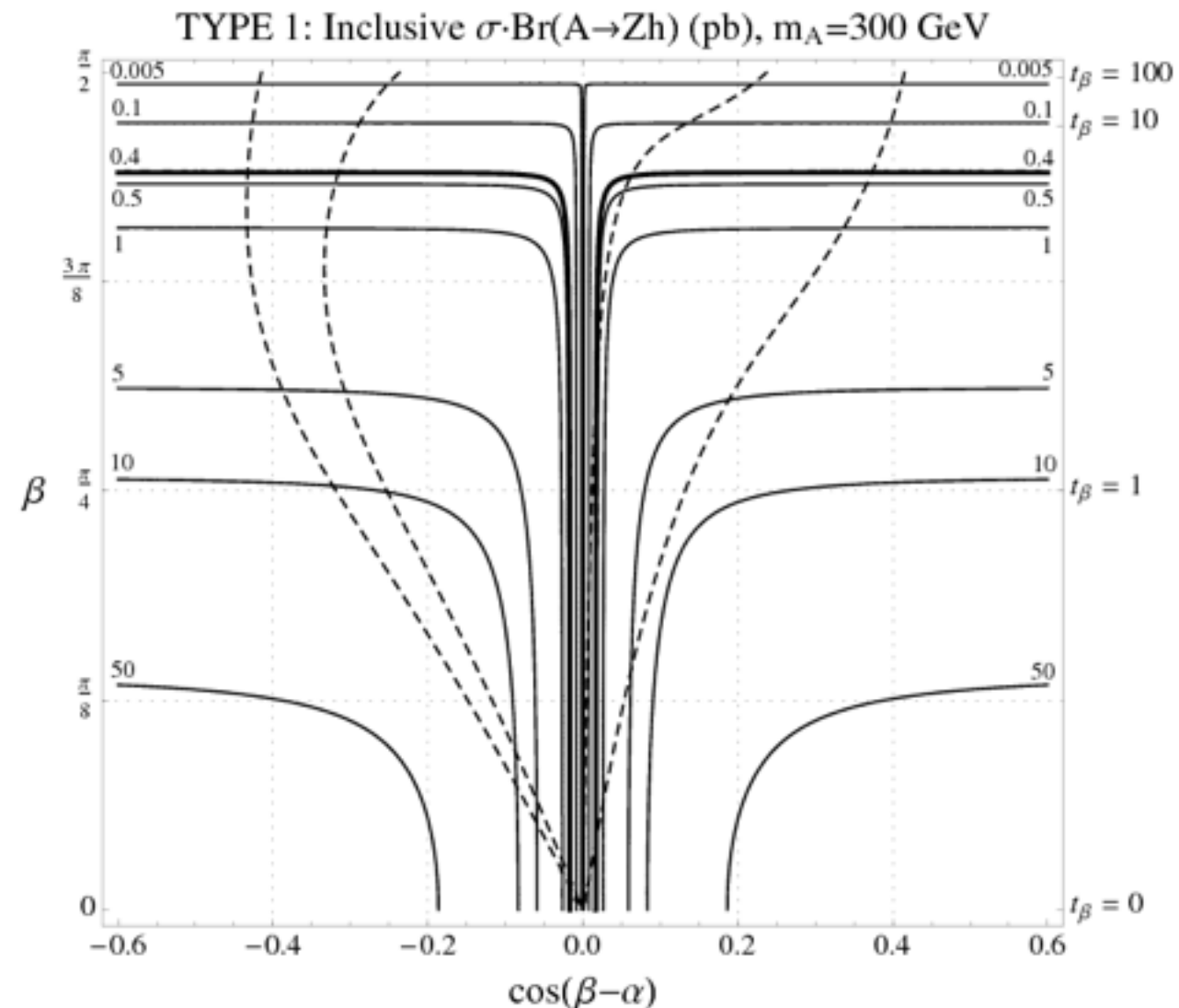


- high- p_T leptons, large MET
- larger branching ratio than $l+l-l'+l'-$
- less backgrounds than with $Z \rightarrow qq$
- Important backgrounds: ZZ, WZ, Z+jets
 - 3-lepton CR for WZ normalization
- $e\mu$ CR for inclusive estimate of WW, tt,Wt,and $Z \rightarrow \tau\tau$ processes
- discriminating variable: m_T^{ZZ}



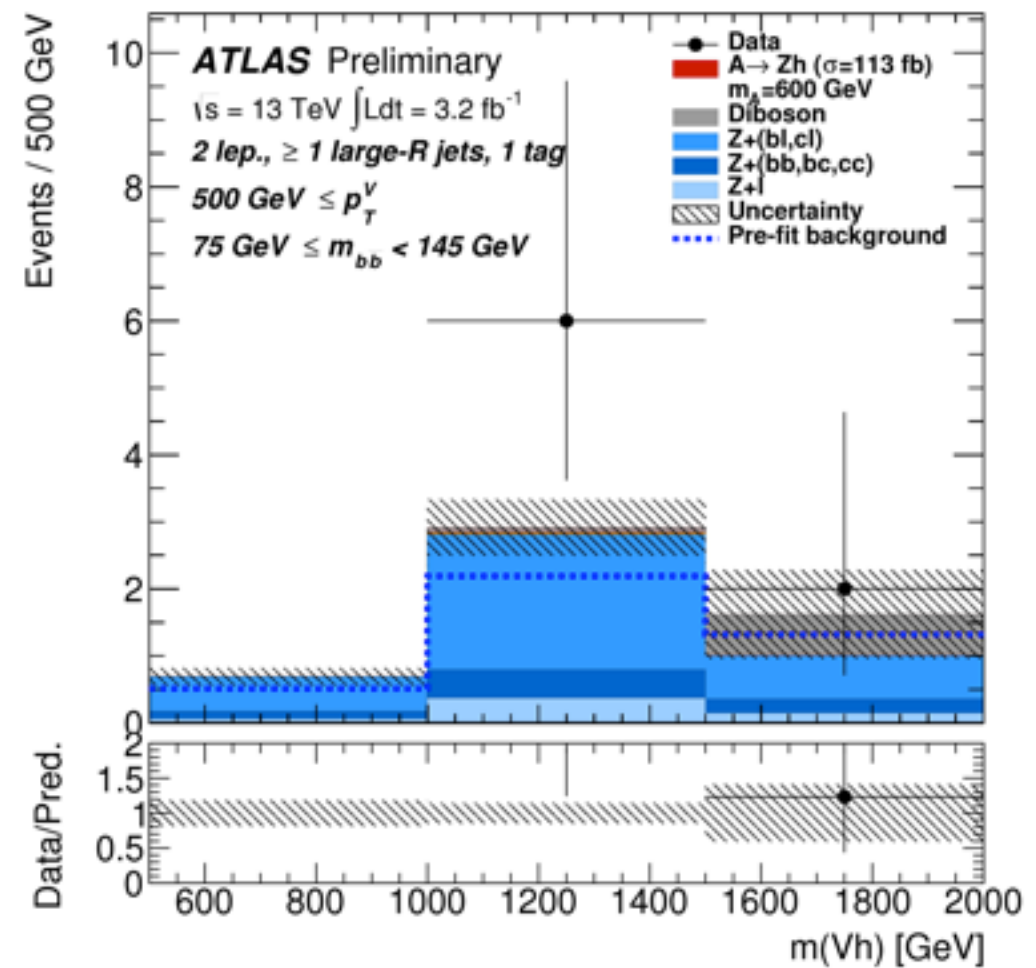
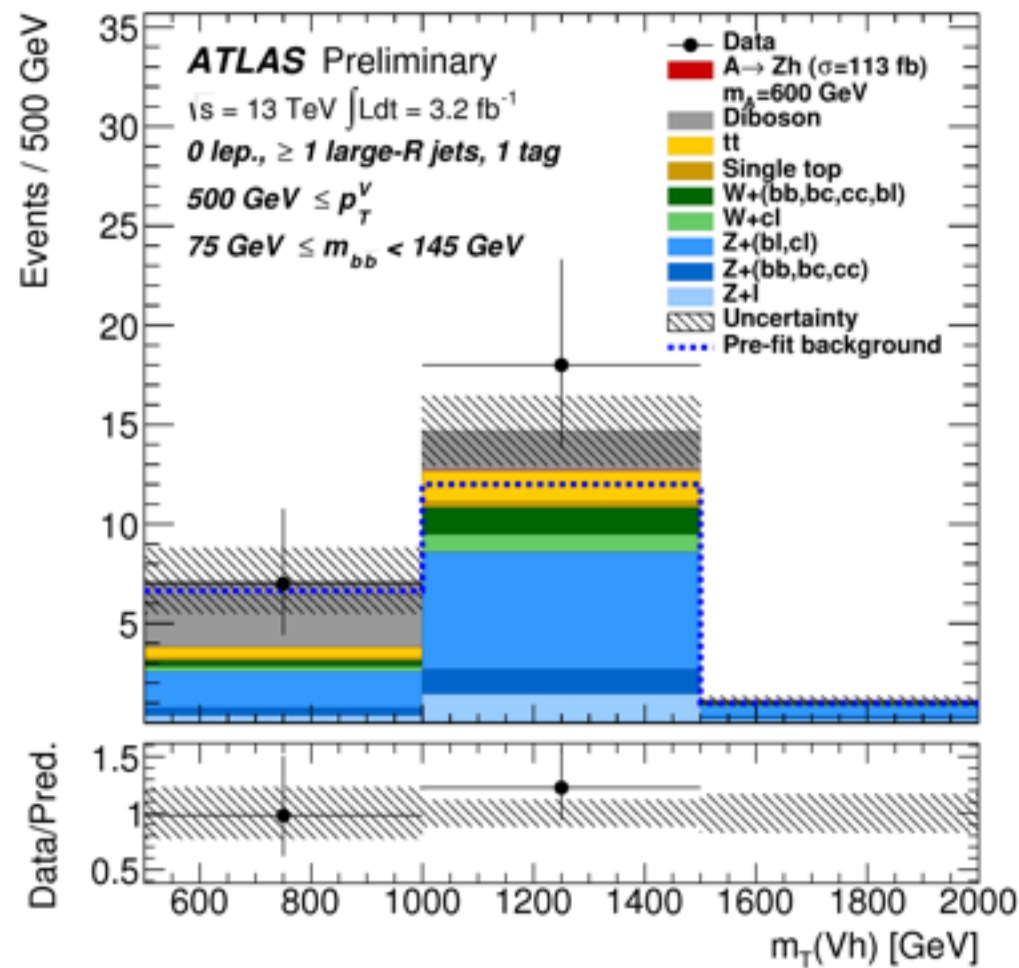
CP-odd $A \rightarrow Zh$

- The $A \rightarrow Zh$ decay rate can be dominant for part of the 2HDM parameter space, especially for m_A below the $t\bar{t}$ threshold and low $\tan\beta$
- complimentary to $A \rightarrow \tau\tau$ searches
- $\tan\beta$ - ratio of vev of two Higgs doublets
- α - defines mixing angle in CP even sector
- Search for the resonant production of a pseudoscalar CP-odd Higgs boson A , decaying into $Z(\rightarrow ll, \nu\nu) h(\rightarrow b\bar{b})$, $l=e,\mu$
- Reconstruct Z boson or large MET



CP-odd $A \rightarrow Zh$

ATLAS-CONF-2016-015

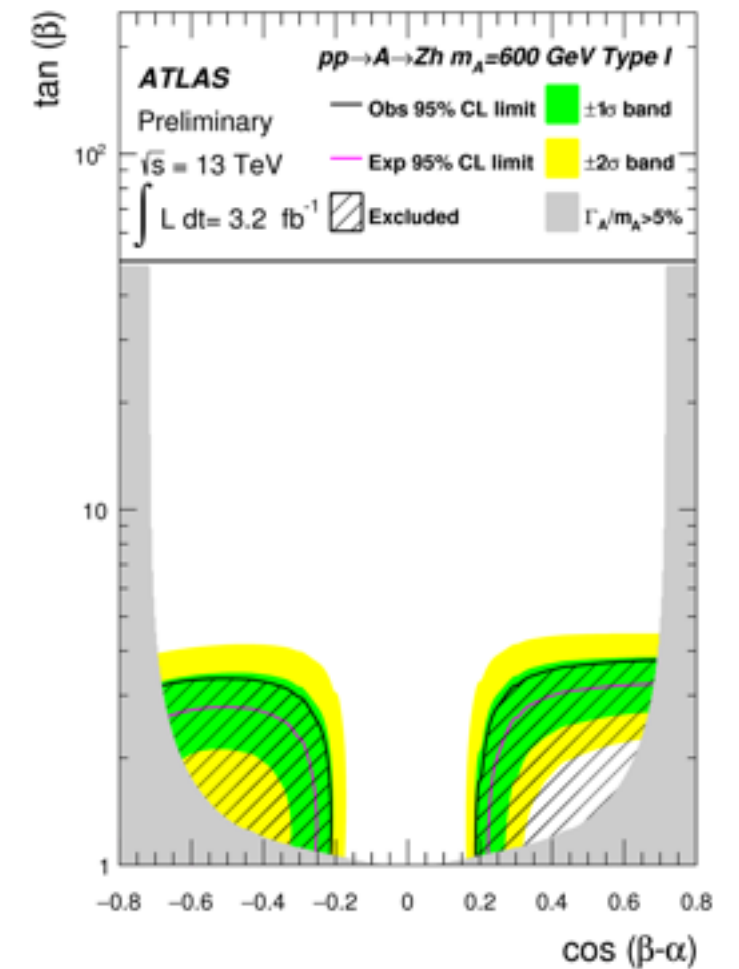
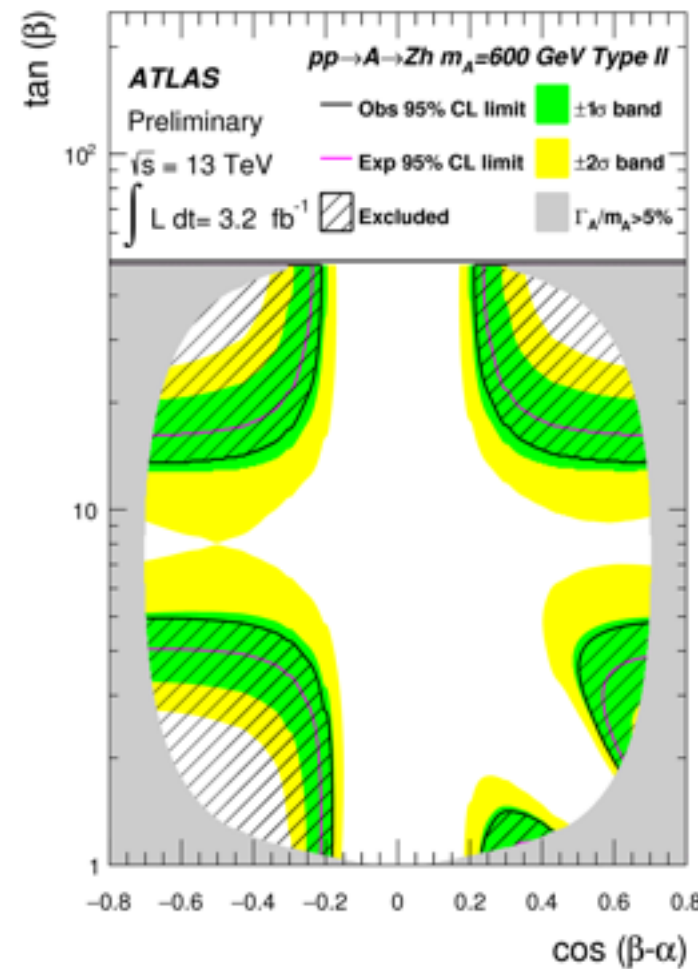
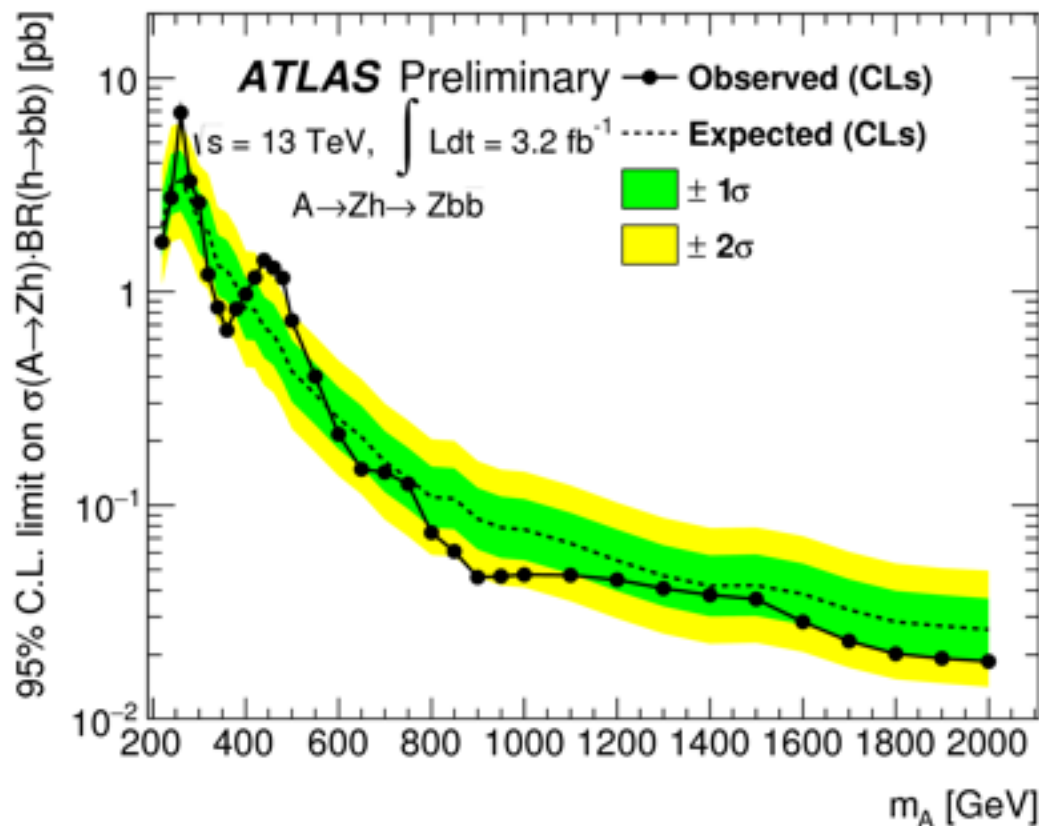
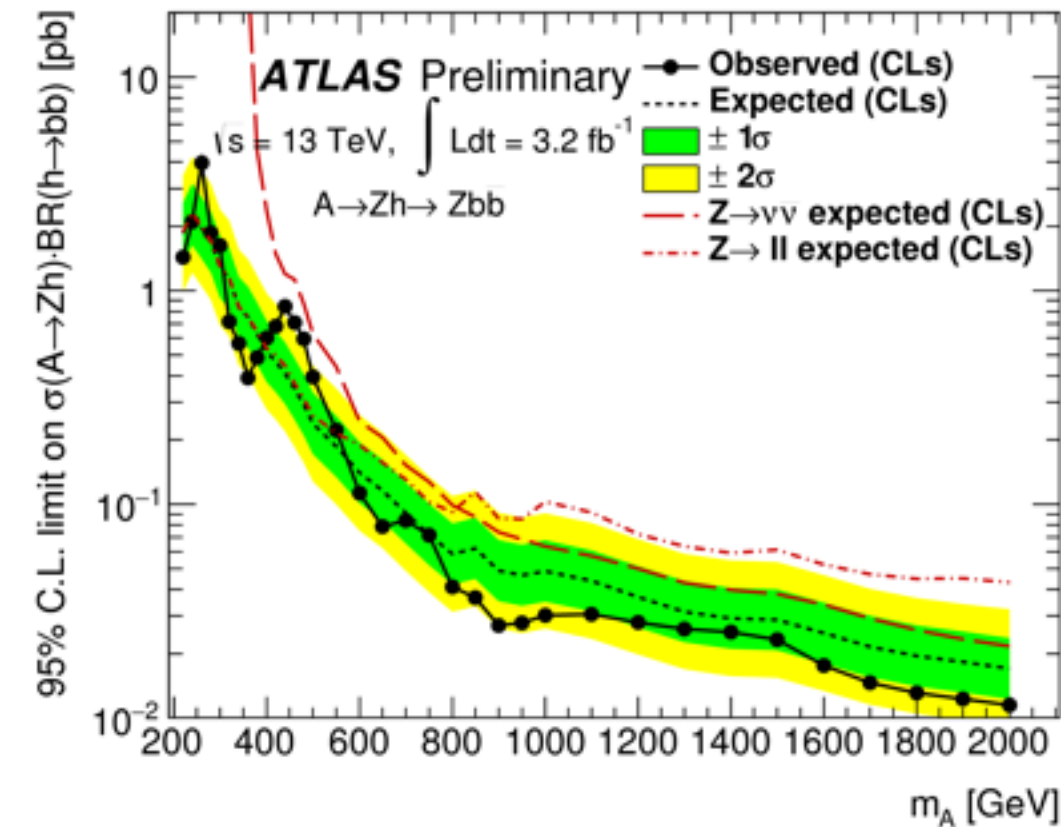


- Categorize events based on:
 - number of charged leptons
 - number of b-tagged jets
 - resolved vs merged jets
 - transverse momentum of the Z, low ($<500 \text{ GeV}$) and high

- Final discriminant:
 - 0-lep transverse mass of bb + MET
 - 2-lep invariant mass $m(Zh)$

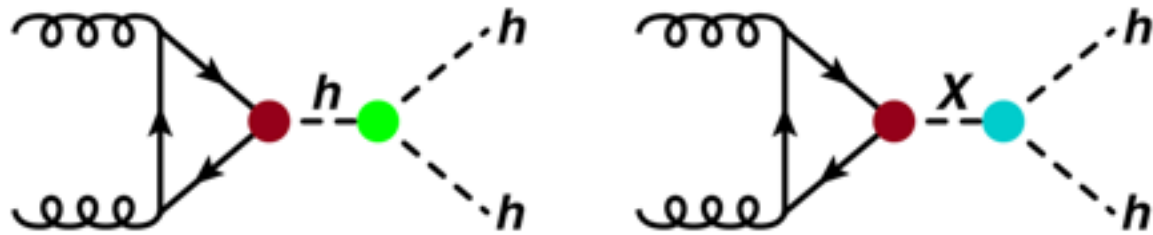
CP-odd $A \rightarrow Zh$

ATLAS-CONF-2016-015



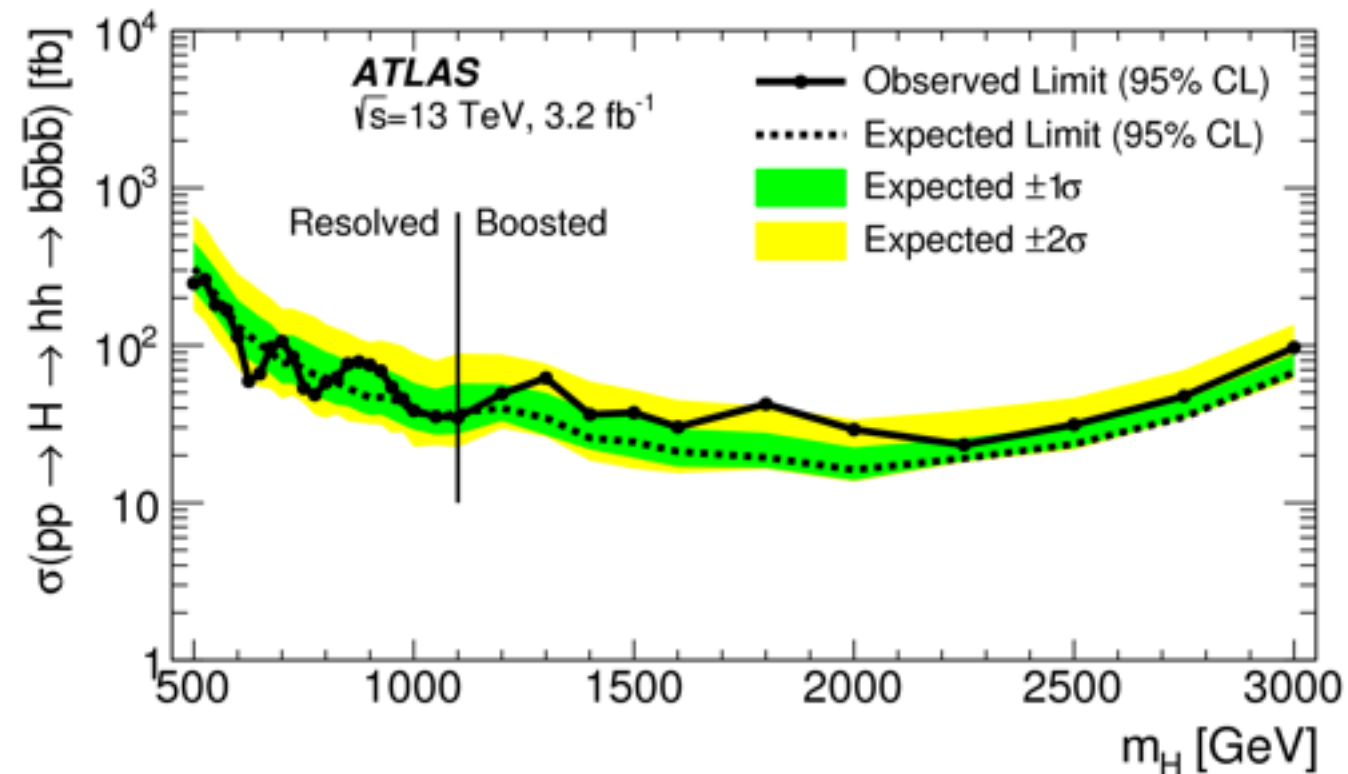
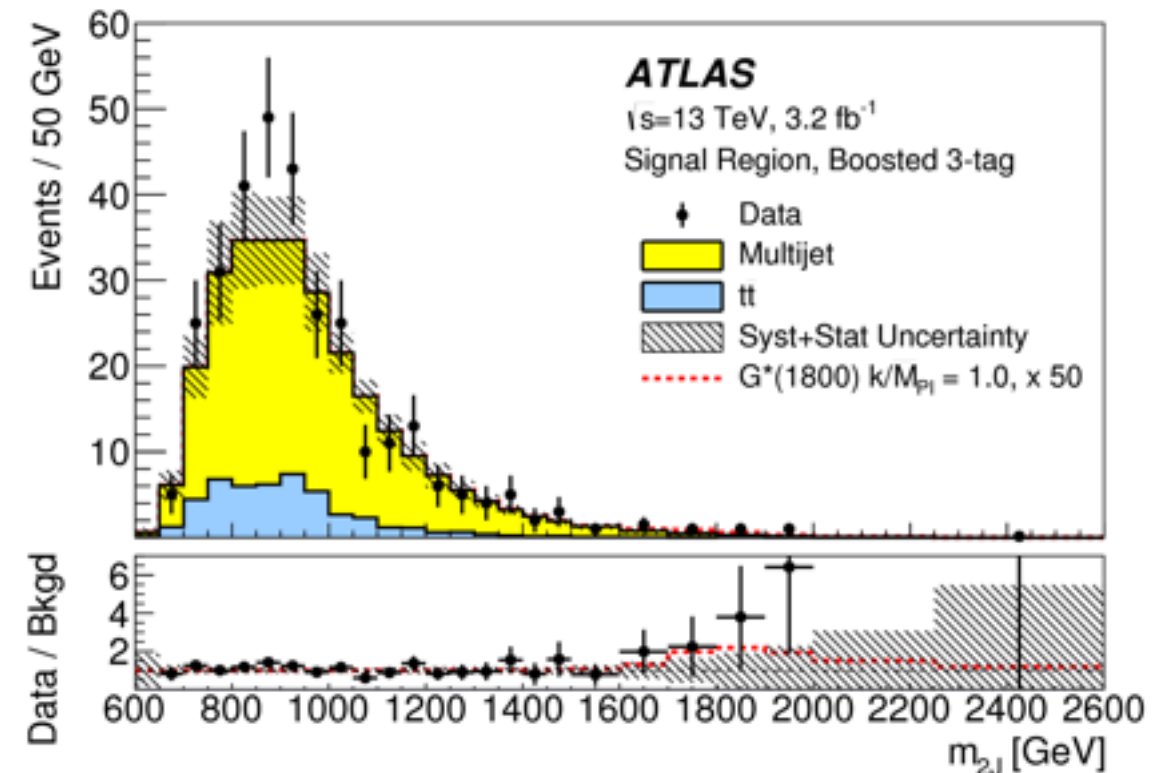
- Interpretation of the σ limits in the context of Type-I and Type-II 2HDMs as a function of the parameters $\tan\beta$ & $\cos(\beta - \alpha)$ for $m_A = 600 \text{ GeV}$
- Considering only points in parameter space where $\Gamma_A/m_A < 5\%$ (narrow-width A boson)

$$X \rightarrow hh \rightarrow bbbb$$



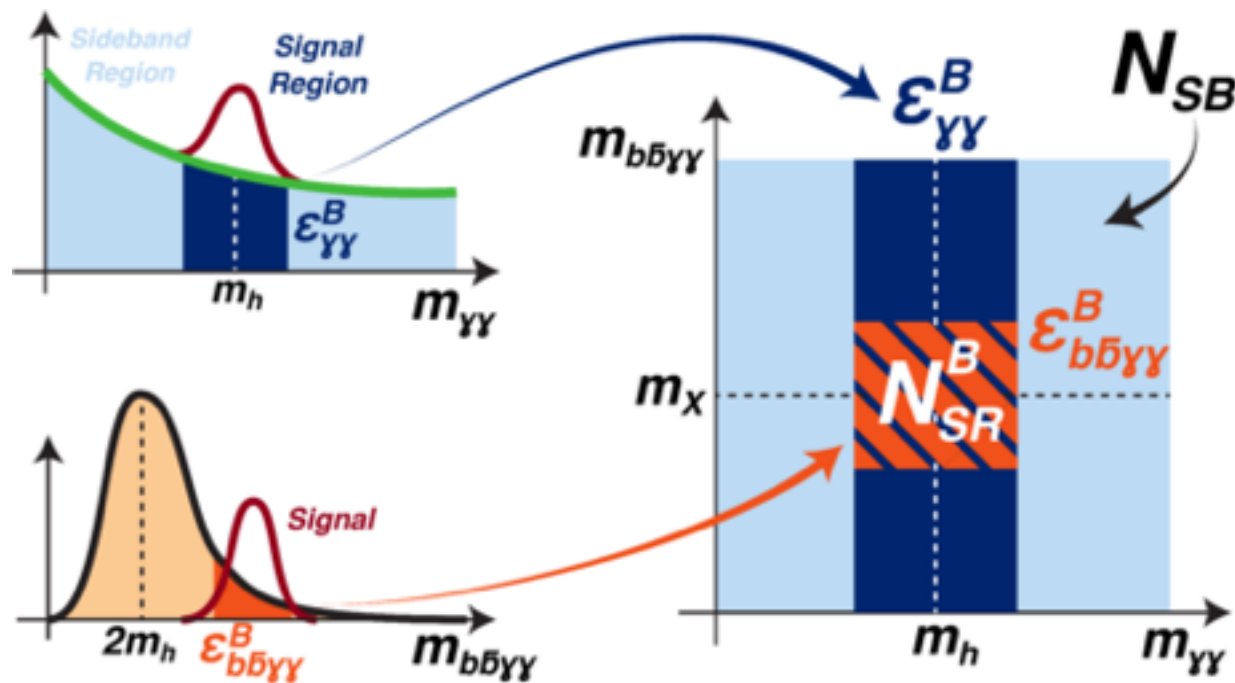
[arXiv:1606.04782](https://arxiv.org/abs/1606.04782)

- Search for resonant and non resonant di-Higgs production
 - Look for $\gamma\gamma bb$ or $bbbb$ final state
- Backgrounds
 - Multi-jet events estimated in sidebands with 2 or 4 tagged jets
 - Hadronic $t\bar{t}$ decays, in control region with inverted $t\bar{t}$ -veto
- Search categories:
 - Resolved: 4 b-jets $\Delta R=0.4$
 - Boosted: 2 large-R jets $\Delta R=1$ (boosted) with 3 or 4 b-tagged track jets
- No deviation from SM observed in signal regions
- Results interpreted for narrow width Higgs

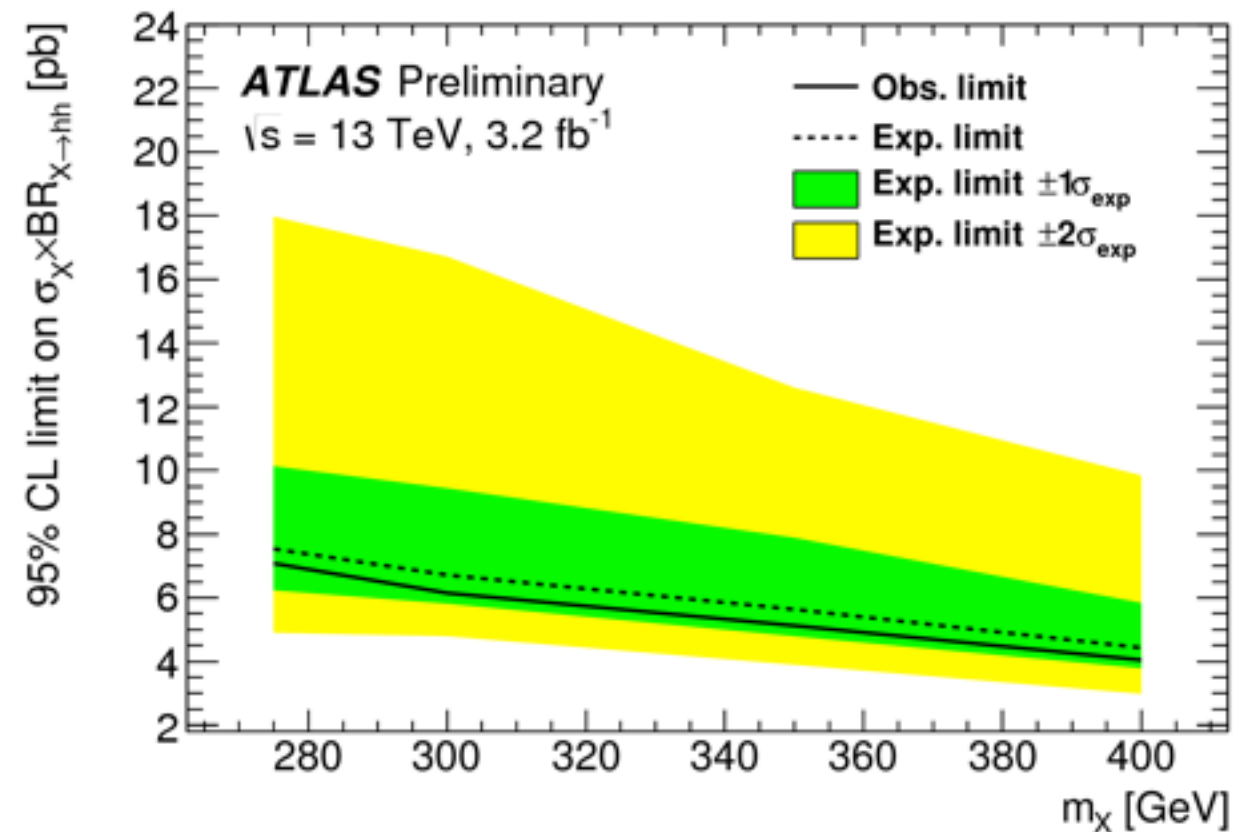
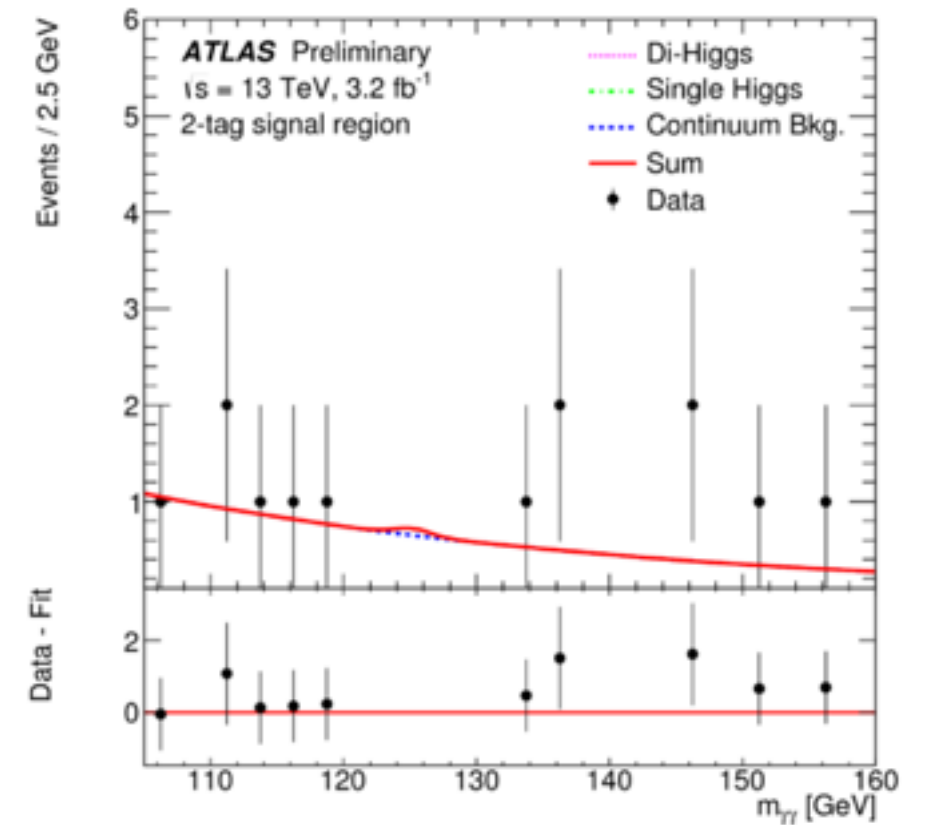


$H \rightarrow hh \rightarrow \gamma\gamma bb$

ATLAS-CONF-2016-004



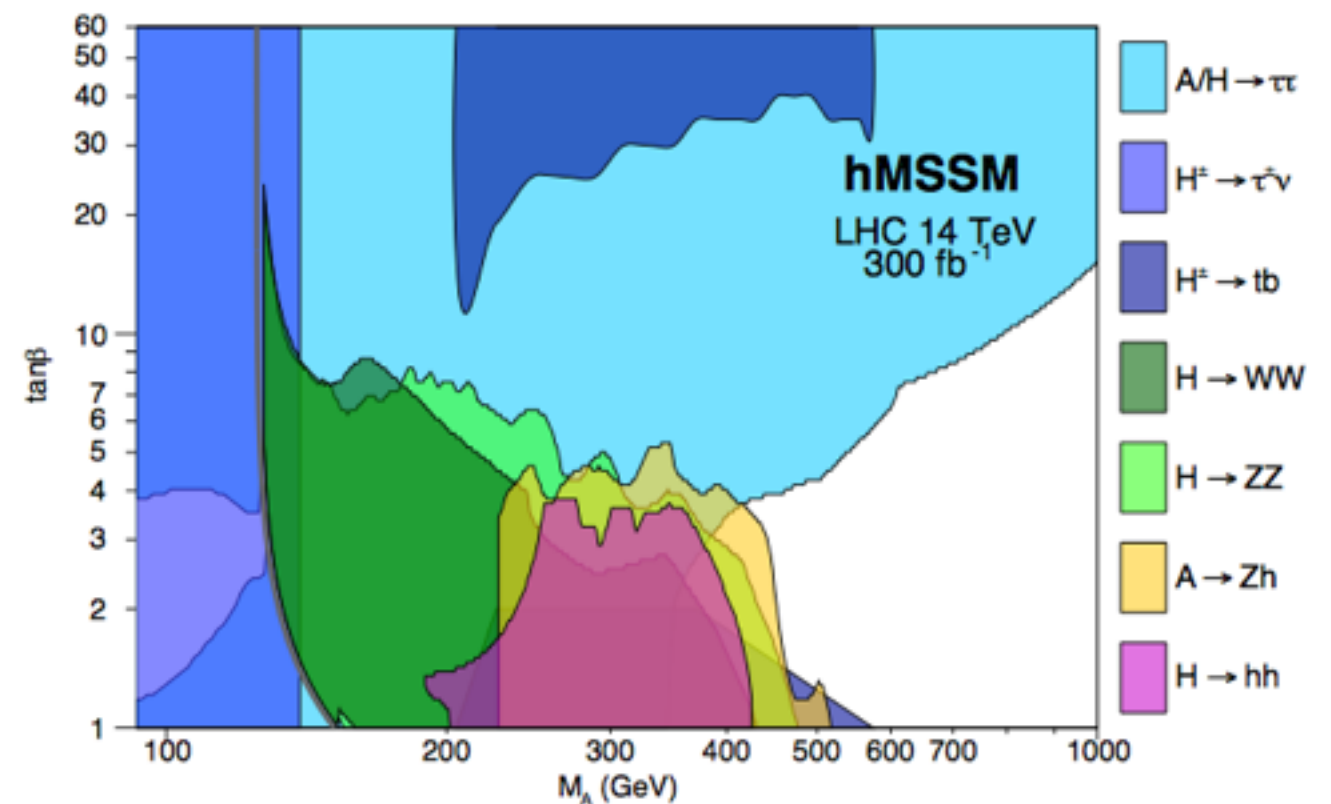
- Signal region (SR) with 2 photons and 2 b-tagged jets
- Control region (CR) with 2 photons and 0 b-tagged jets $105 \text{ GeV} < m_{\gamma\gamma} < 160 \text{ GeV}$
- $|m_{\gamma\gamma} - m_H| < 2 \cdot \sigma_{m_{\gamma\gamma}} = 3.1 \text{ GeV}$ (res. only)
- $95 \text{ GeV} < m_{bb} < 135 \text{ GeV}$
- m_X dependent cut on $m_{bb\gamma\gamma}$ (res. only), based on 95% eff. for sim. samples
- Cut and count in signal region
- 0 events observed in data
- Upper limits set vs. m_X on $\sigma_X \times \text{BR}(X \rightarrow hh)$



Summary

- Many searches for additional Higgs bosons were performed by ATLAS using the 3.2 fb of data at 13 TeV
 - In many cases results supersede Run I results
 - Boosted boson reconstruction becomes an important experimental tool
- ATLAS actively collecting data in Run II
- New results expected by the time for ICHEF
- Stay tuned and as always latest results are available at <https://twiki.cern.ch/twiki/bin/view/AtlasPublic>

Djouadi et al: hMSSM (arXiv:1502.05653)



BACKUP

