



# Higgs: Beyond the Standard Model

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On behalf of the ATLAS Experiment



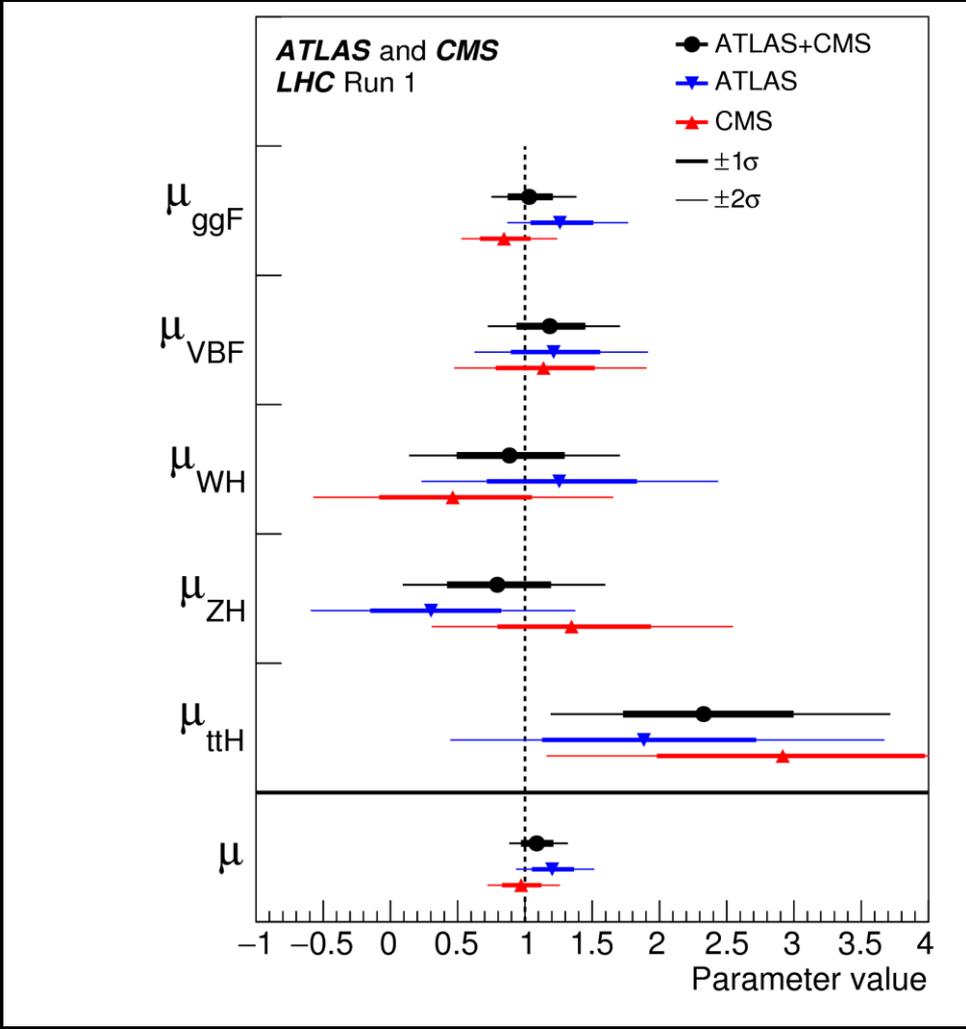
# (B)SM Higgs

H(125) Looks very SM like so far

Many measurements on-going to search for new phenomena in the Higgs sector at ATLAS

- Deviations in SM measurements
- Lepton flavor violation in decays
- Invisible decays
- Charged Higgs bosons
- Heavy scalars
- Light scalars
- Heavy resonances
- Non-resonant signatures

Too much to cover in this talk!





# Lepton Flavour Violation

LFV possible in many different models

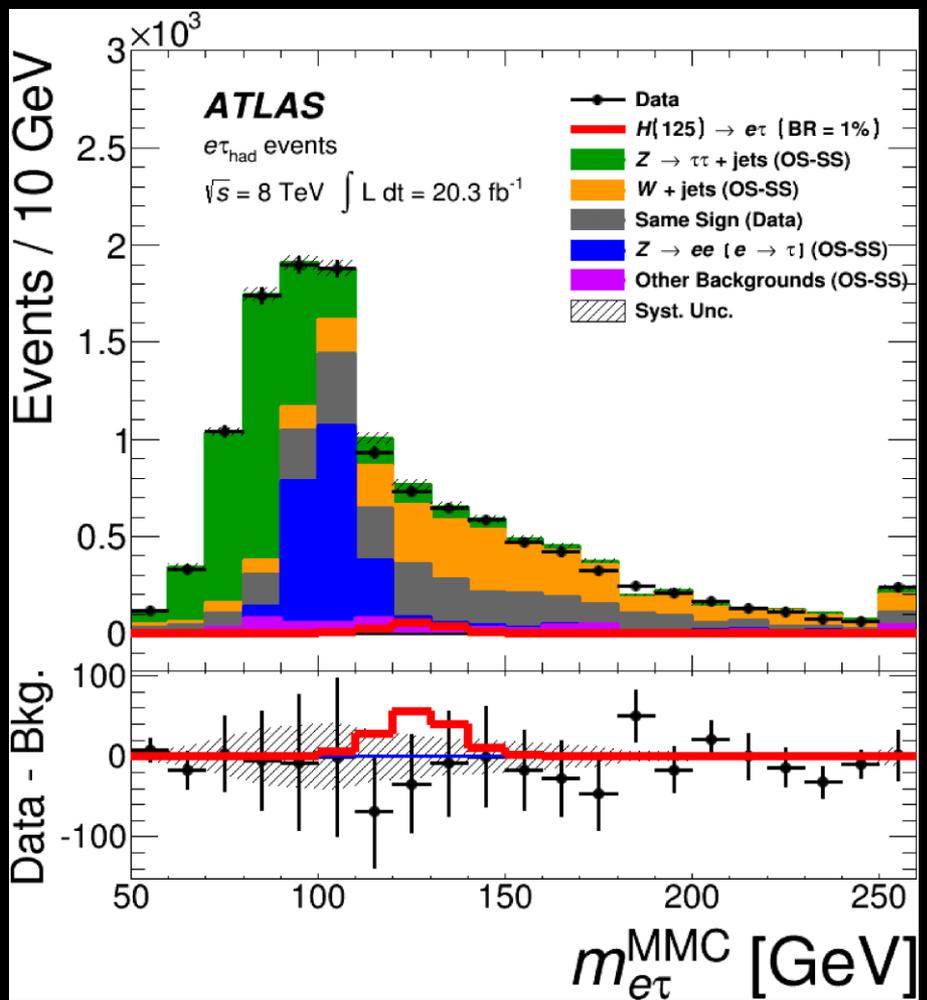
New publication of search for LFV in decays of H (and Z)

Two key (H) analyses:

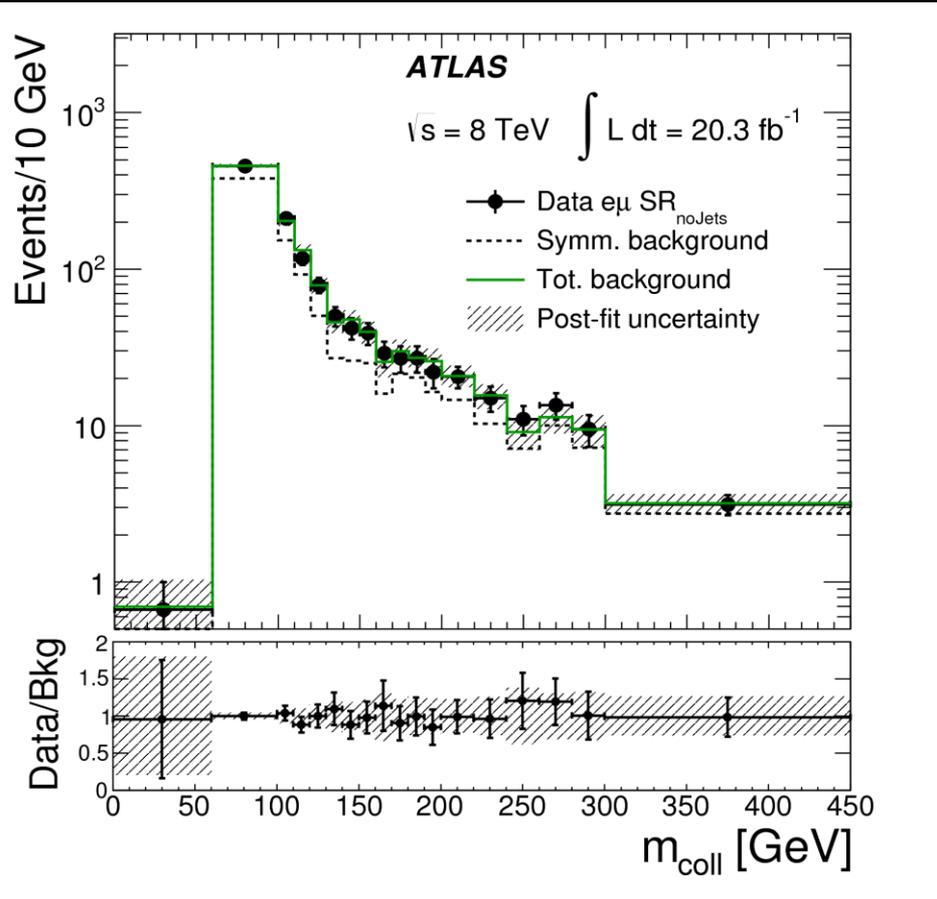
$$H \rightarrow e\tau_{had}$$

$$H \rightarrow l\tau_{lep} \quad (l = e, \mu)$$

And combination with previous  $H \rightarrow \mu\tau_{had}$



# Lepton Flavour Violation



$$H \rightarrow e\tau_{had}$$

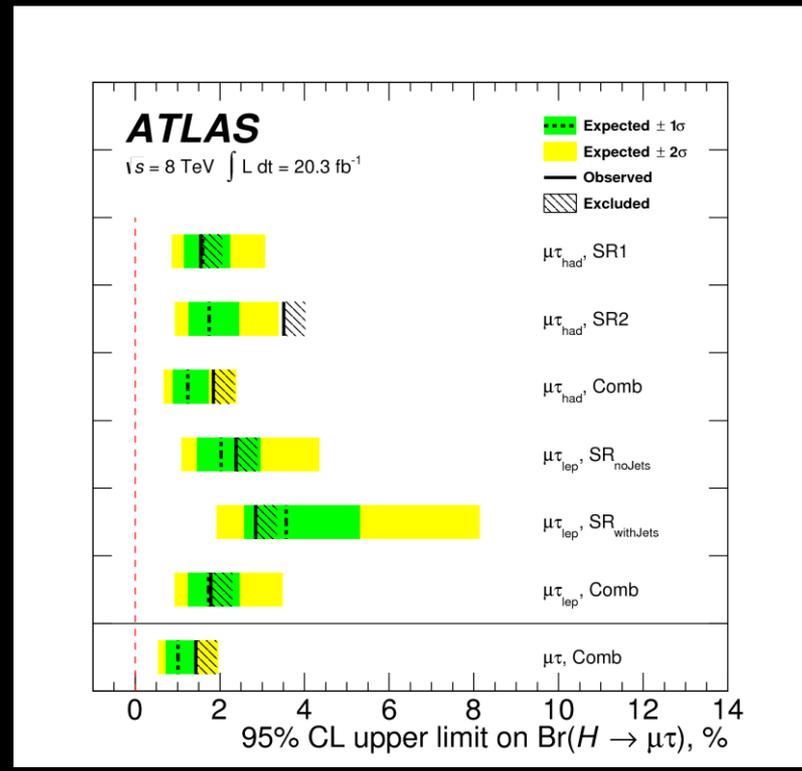
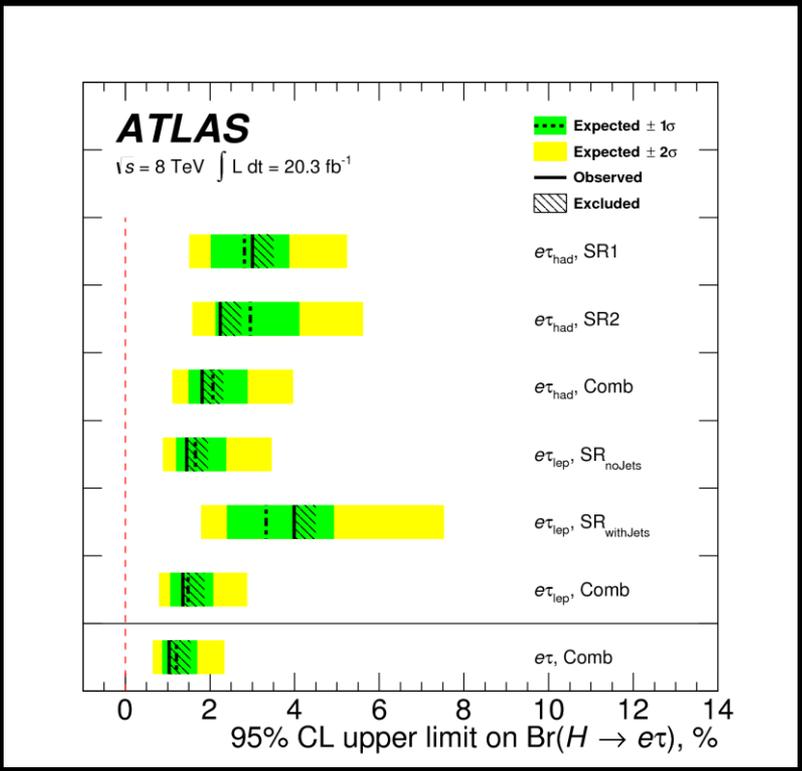
Fit for H(125) and set limits on BR(LFV) in two signal regions (W dominated and Z dominated backgrounds)

$$H \rightarrow l\tau_{lep} \quad (l = e, \mu)$$

Signature is OS  $\mu e + MET$

Exploit symmetry in backgrounds under interchange of  $\mu$  and  $e$   
 (split into categories with and w/o jet activity)

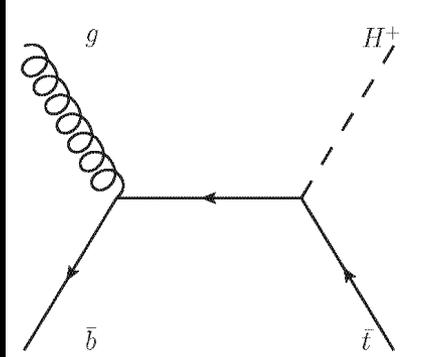
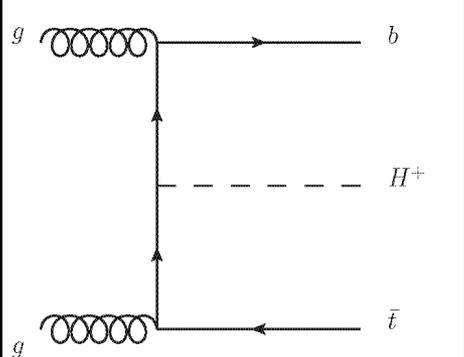
# Lepton Flavour Violation



Limits assuming  $BR(H \rightarrow \mu\tau) = 0$  or  $BR(H \rightarrow e\tau) = 0$  respectively

# Charged Higgs: $H^+ \rightarrow tb$

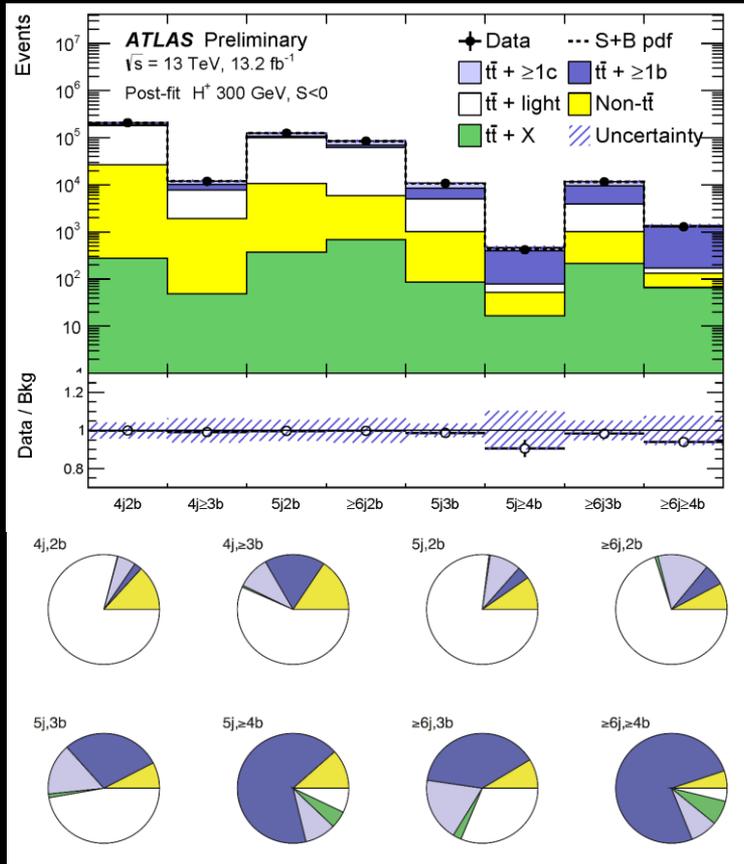
Many models predict charged Higgs boson  
Including 2HDM, triplet models etc



For  $M_{H^+} > M_{top}$  associated production with t dominates

Categories events based on jet and b-jet multiplicities define CR and SR

BDT used to discriminate in SR

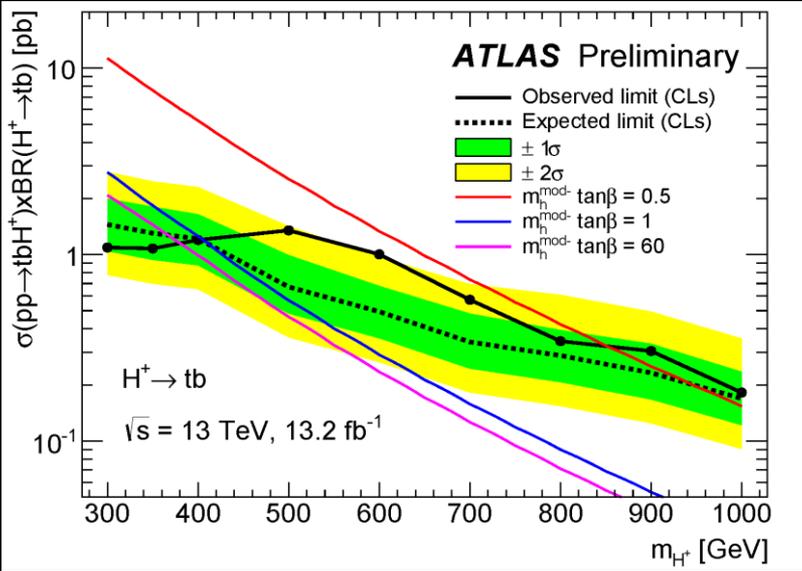
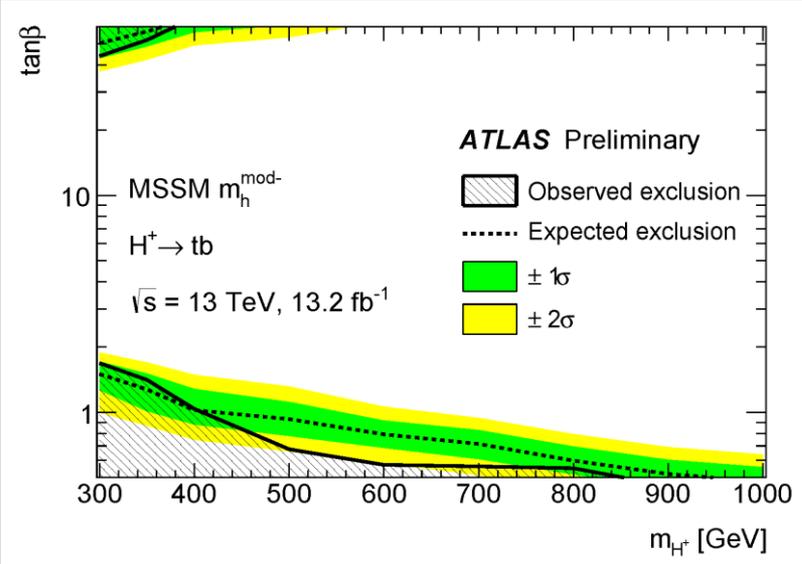




# Charged Higgs: $H^+ \rightarrow tb$

Many models predict charged Higgs boson  
Including 2HDM, triplet models etc

$t\bar{t} + \geq 1$  b-jet modelling and flavour  
tagging systematics are dominant



No significant excess observed



# Charged Higgs: $H^+ \rightarrow \tau\nu$

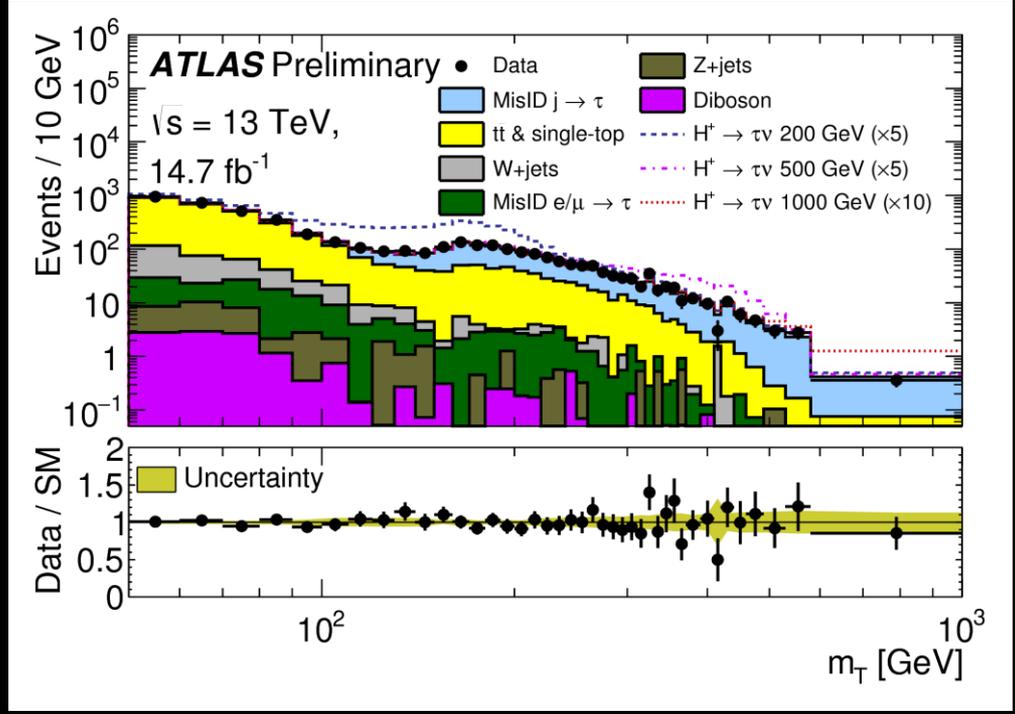
Many models predict charged Higgs boson  
Including 2HDM, triplet models etc

Search for  $H^+ t \rightarrow \tau\nu$  in hadronic  
final states:

$\tau_{had} + 3jets (>=1 \text{ b-tagged})$

Low mass region dominated by  
top backgrounds.

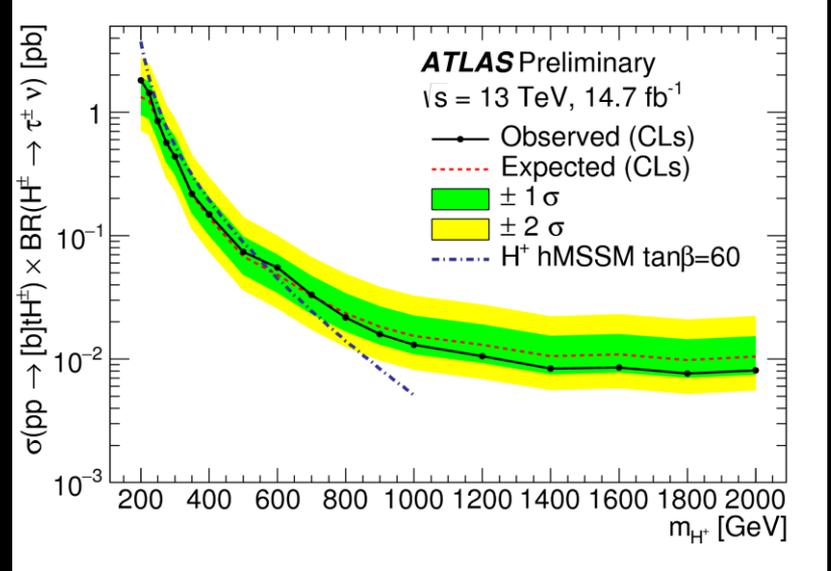
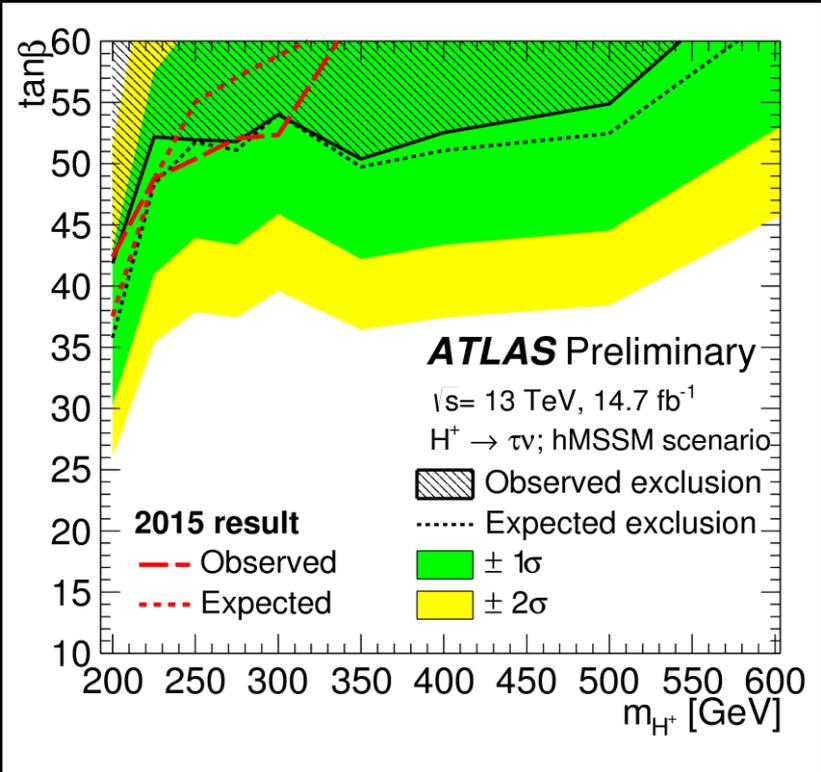
High mass region dominated by  
multi-jet backgrounds with fake-  
taus





# Charged Higgs: $H^+ \rightarrow \tau\nu$

Many models predict charged Higgs boson  
Including 2HDM, triplet models etc

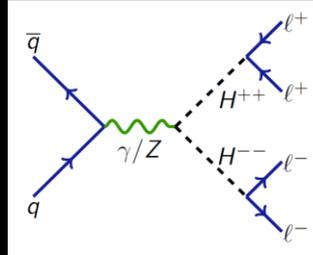


Uncertainties on fake-rates and top backgrounds dominate systematics

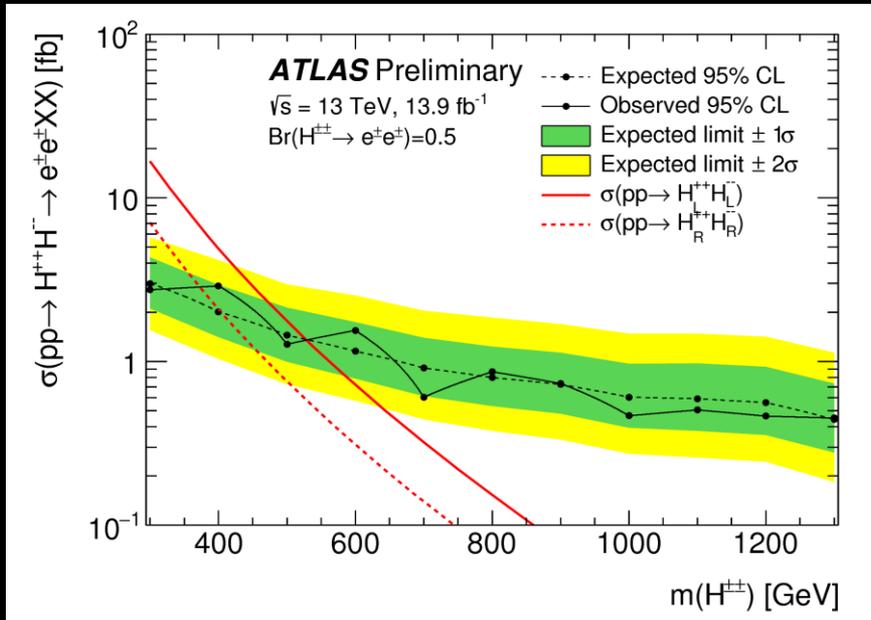
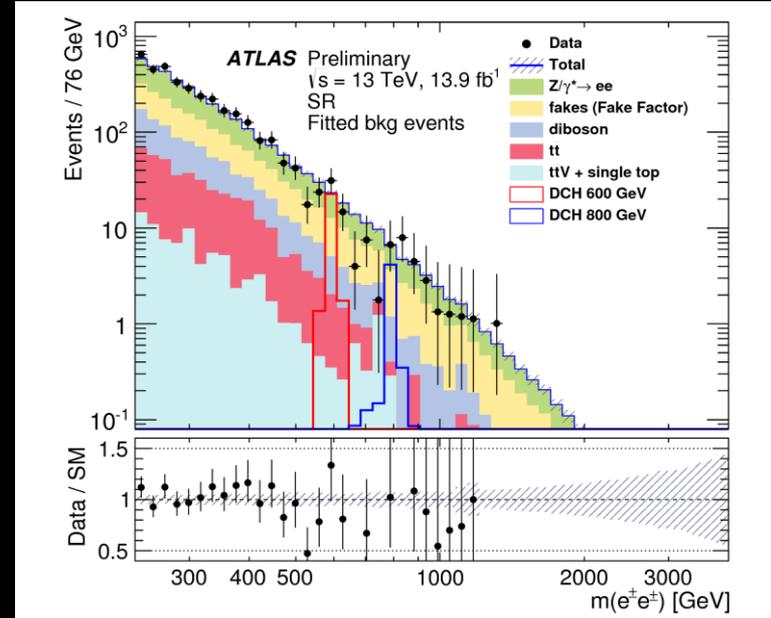
Limits set using  $M_T$  as discr. Variable interpreted in various scenarios (hMSSM shown)

# Doubly charged Higgs

Run 2 search for  $H^{++} \rightarrow e^{\pm}e^{\pm}$   
 Run1 : JHEP 03 (2015) 041



Main background from charge-misid  $Z \rightarrow ee$   
 Next biggest from “fake” and non-prompt electron backgrounds



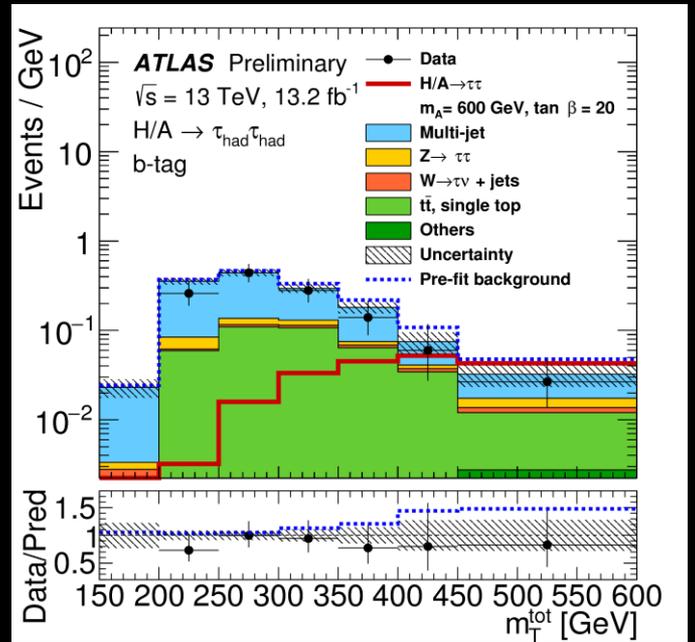
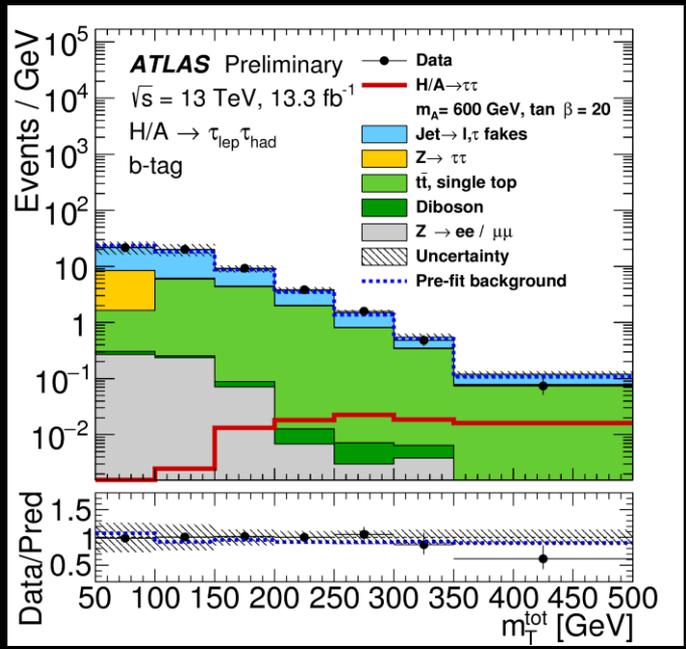
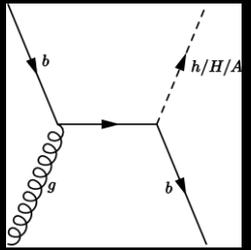
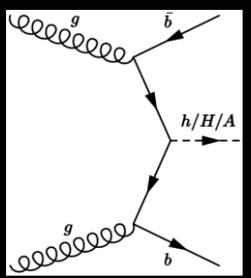
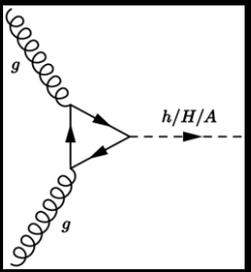
Discriminant variable  $M_{ee}$

Limits set assuming  $BR(ee)=50\%$   
 (shown) and  $BR(ee)=100\%$

# Heavy Scalars: $H \rightarrow \tau\tau$

Search for final states with two taus with one or both decaying hadronically

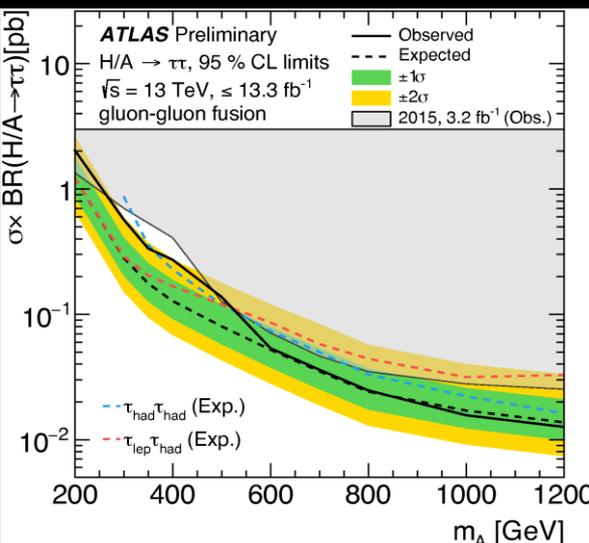
Events categorized according to b-tag multiplicity and the presence of high missing transverse energy



Total di-tau transverse mass used as discriminant variable

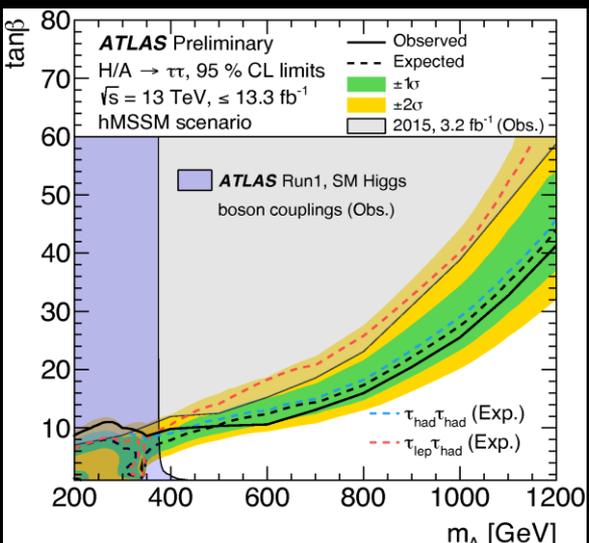


# Heavy Scalars: $H \rightarrow \tau\tau$

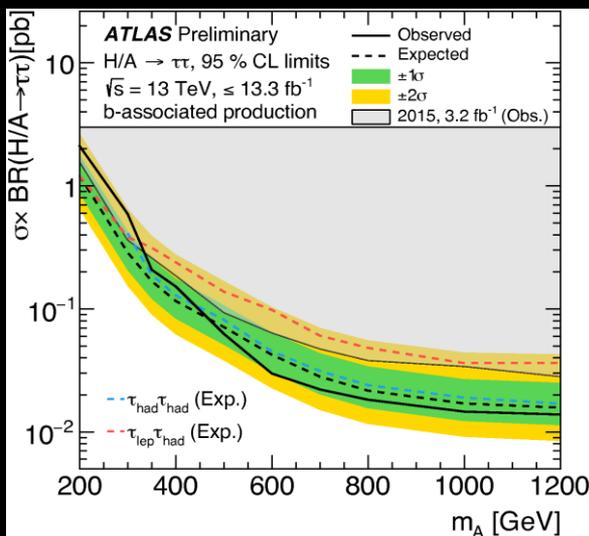


Cross section  $\times$  BR limits for gluon-gluon and b-associated production

And interpretation in  $m_h^{mod}$  and hMSSM (shown) benchmark scenarios



Important sources of uncertainties include: MET trigger modelling, fake tau modelling and fragmentation modelling in top-pair production



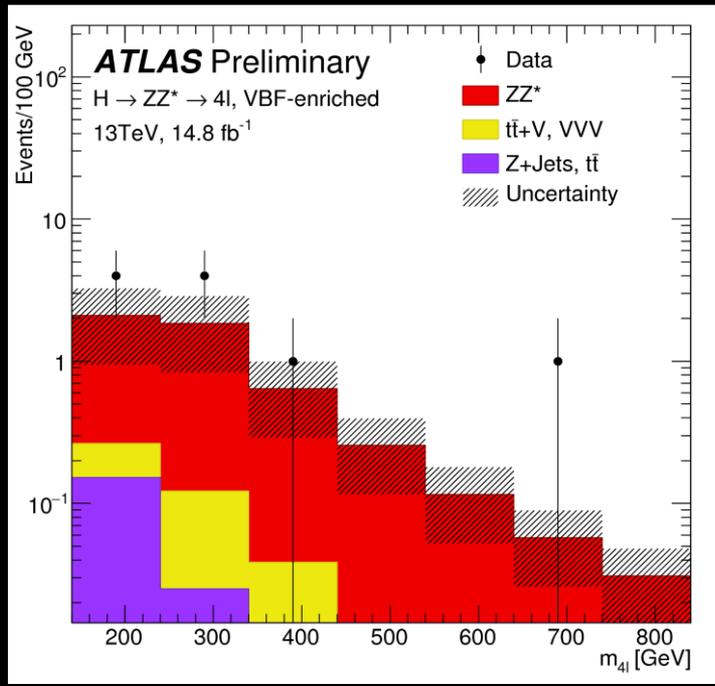
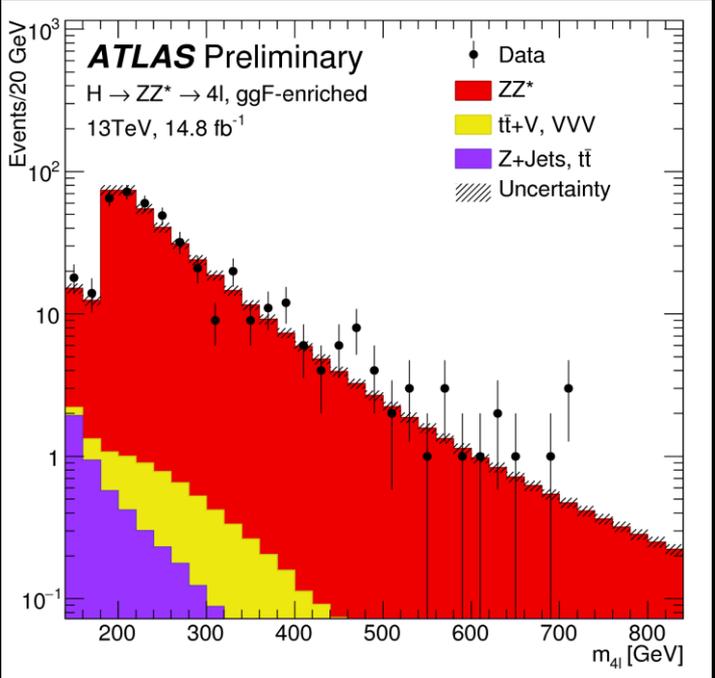
No significant excesses seen across the mass range searched



# Heavy Scalars: ZZ (a selection)

Searches for “SM-like” 4-lepton as well as diboson-resonance  $llqq$  and  $\nu\nu qq$  with Heavy Higgs interpretation (amongst others)

4-lepton final state:  $4\mu, 4e, 2e2\mu$   
Fully reconstruct Z's – on shell



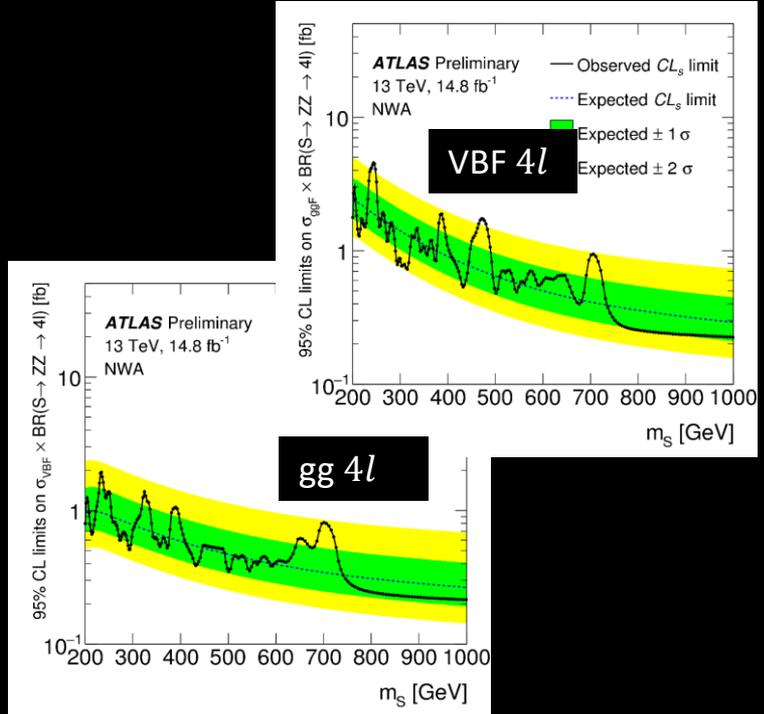
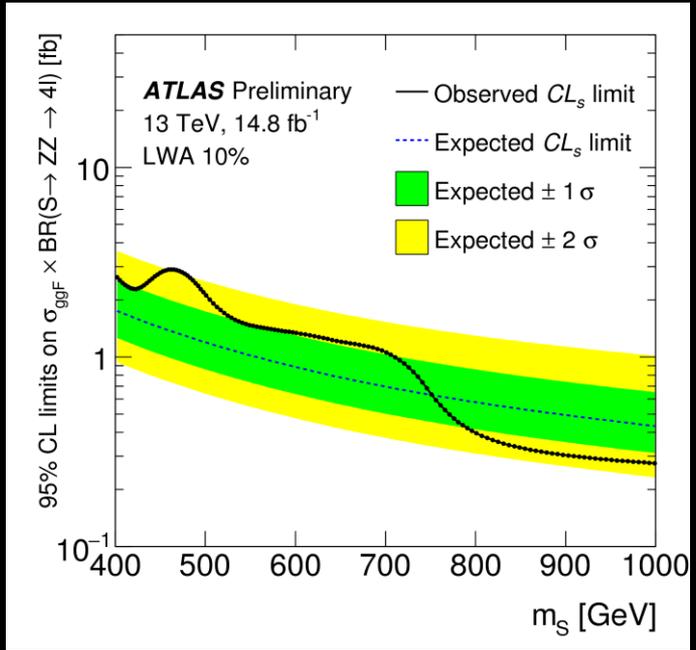
Events with two well-separated jets with high di-jet mass VBF category – otherwise gg category



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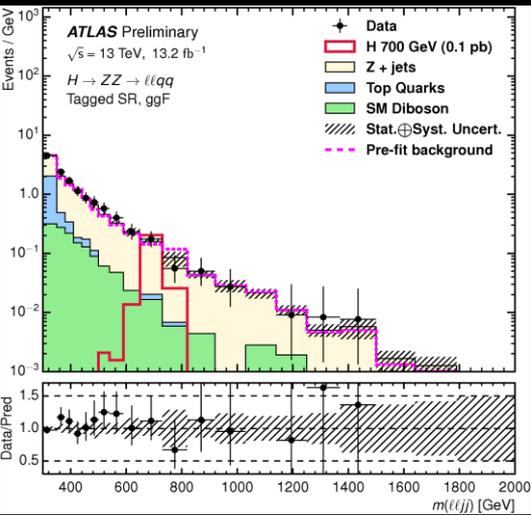
Set limits for both narrow width approx. and various large widths (10% shown)

No significant excess observed



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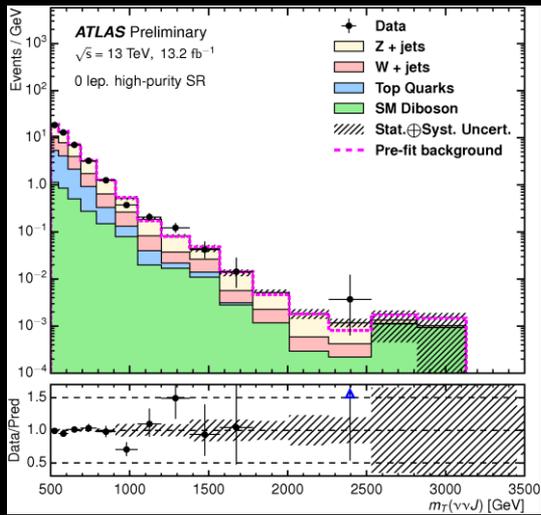
Searches for “SM-like” 4-lepton as well as diboson-resonance  $llqq$  and  $\nu\nu qq$  with Heavy Higgs interpretation (amongst others)



Additional purity from b-jet tags

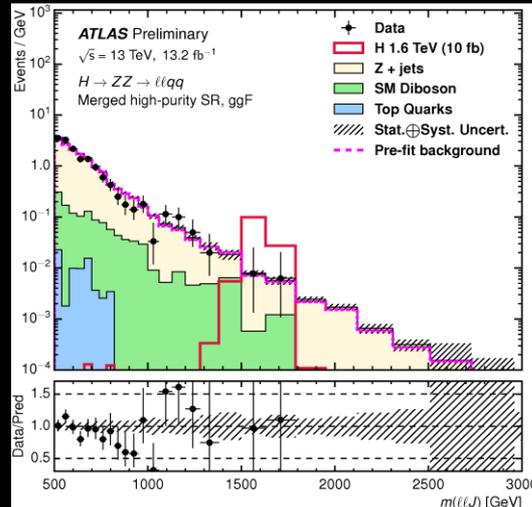
Dominant background Z+jet  
lower b-jet content

VBF channel also used)



$llqq$  or  $llj$  where  $l = e, \mu$

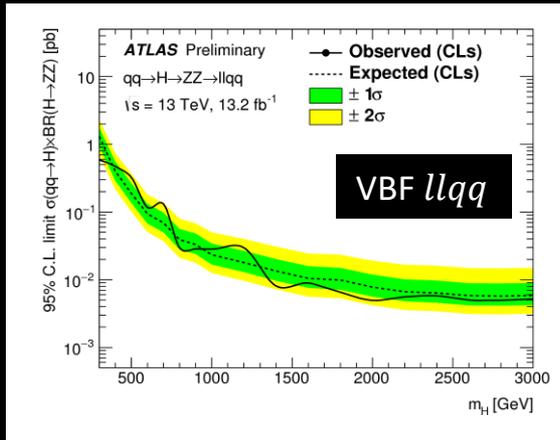
Merged and resolved jets  
– either single large-R jet  
or two distinct jets



$\nu\nu jj$  analysis signature: large missing  $E_T$  and merged  $jj$  in 1 large R-jet

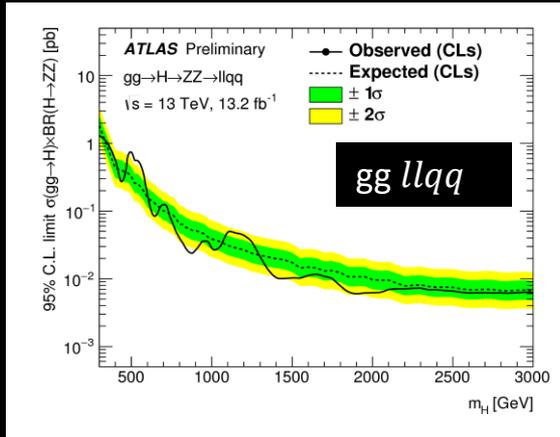
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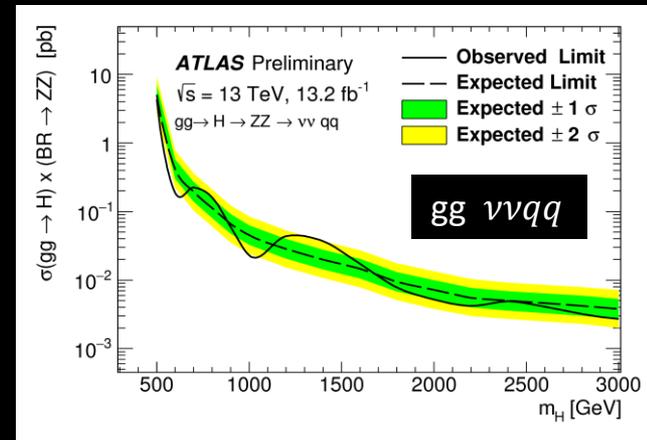


Final discriminants  $m_{llqq}, m_{llJ}$  and  $m_T(\nu\nu J)$

Interpretation possible with multiple different signal models. Heavy Scalar shown here.



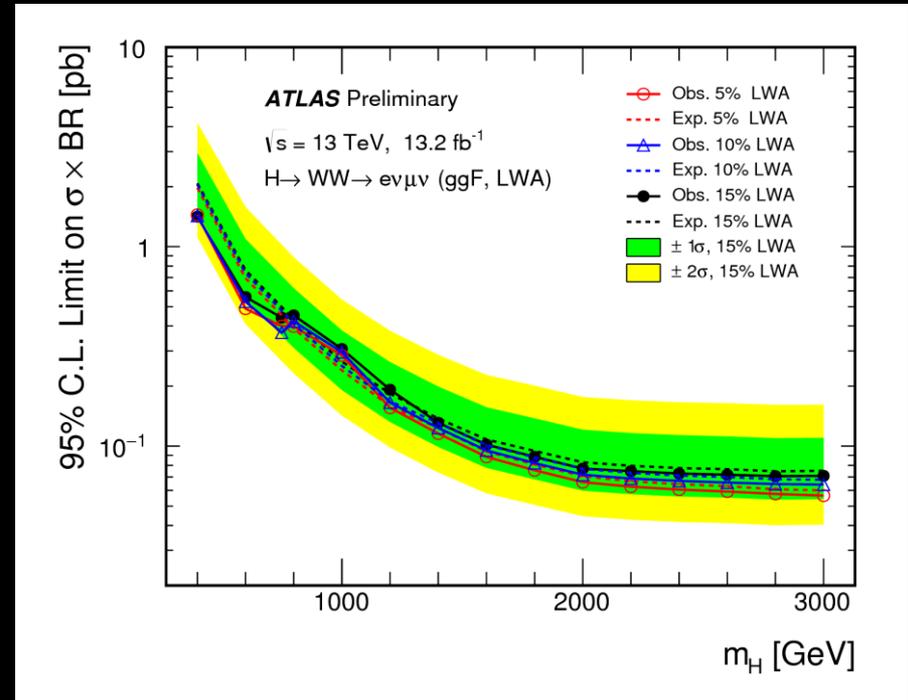
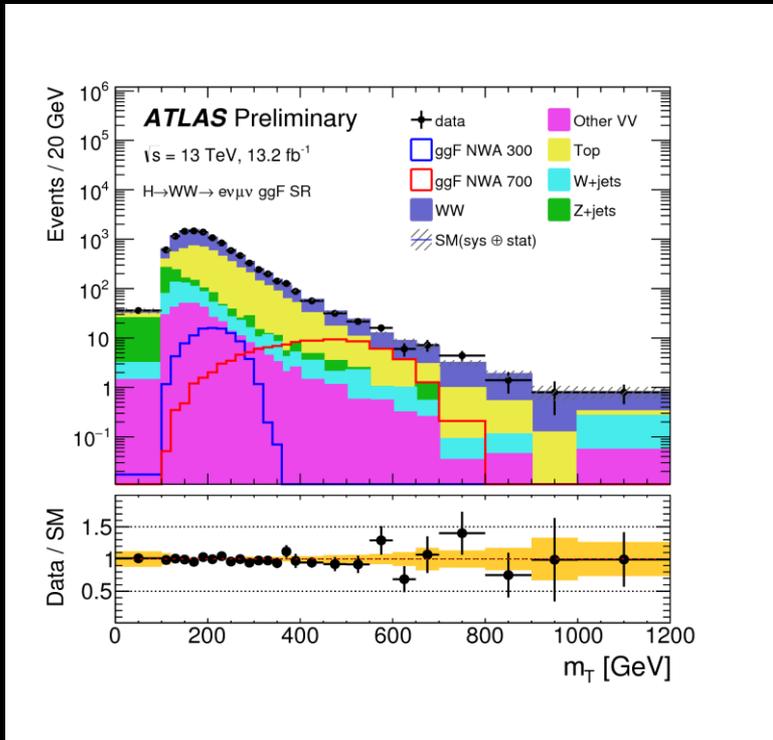
Some wiggles but no significant excess is observed



# Heavy Scalars: WW

Search for heavy scalar  $H \rightarrow WW \rightarrow e\nu\mu\nu$

Limits set using  $M_T$  as discriminant variable in NWA and various LWA scenarios



Dominant backgrounds from WW and top  
 Three categories defined: gg, VBF1 (mix VBG and gg)  
 VBF2 (high mass jet pair – dominated by VBF)

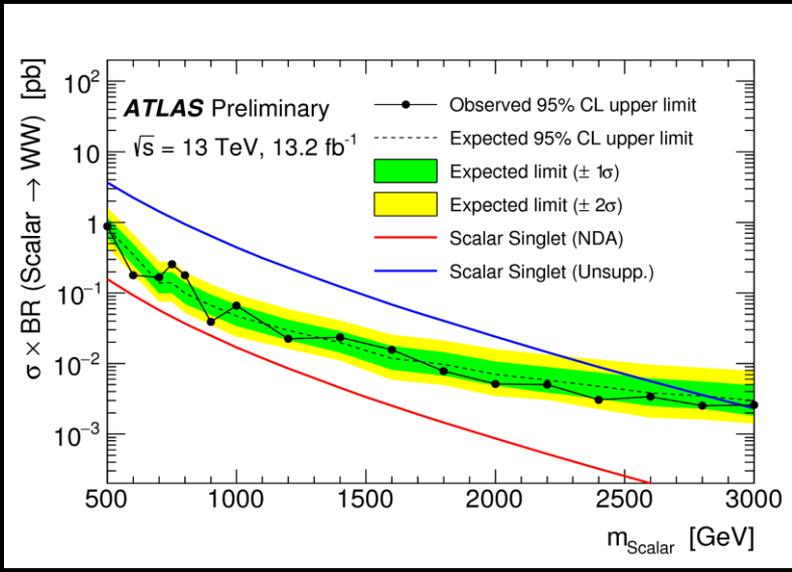
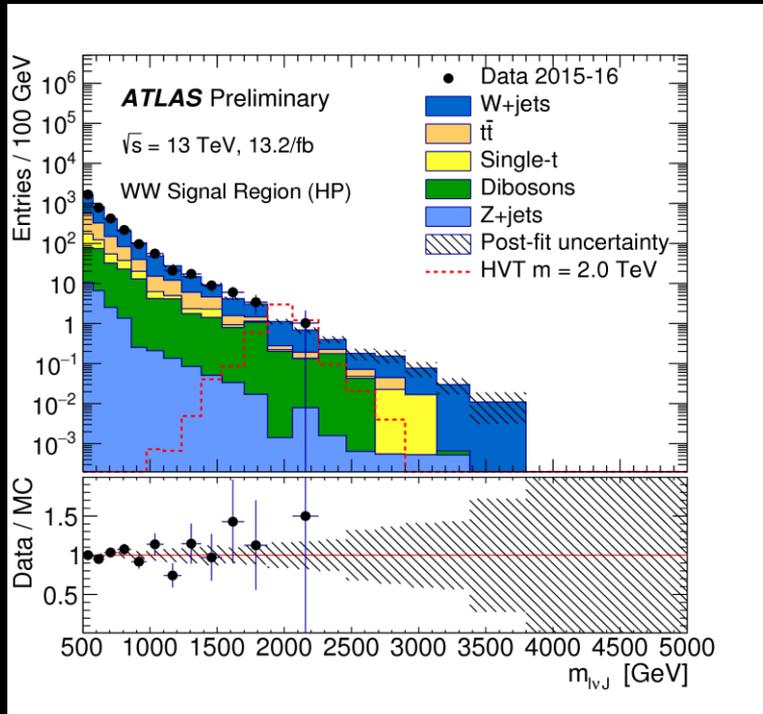
No significant excesses are observed



# Heavy Scalars: WW (WZ)

Search for NP in final states with  $lvjj$  in boosted topologies where two jets are reconstructed as single large-R jet.

Sensitive to multiple NP signals – RS graviton, HVT, heavy scalar (WW)



No significant excesses are observed

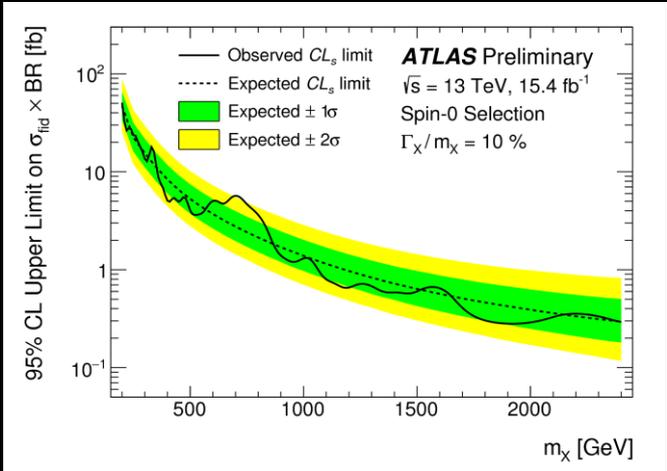
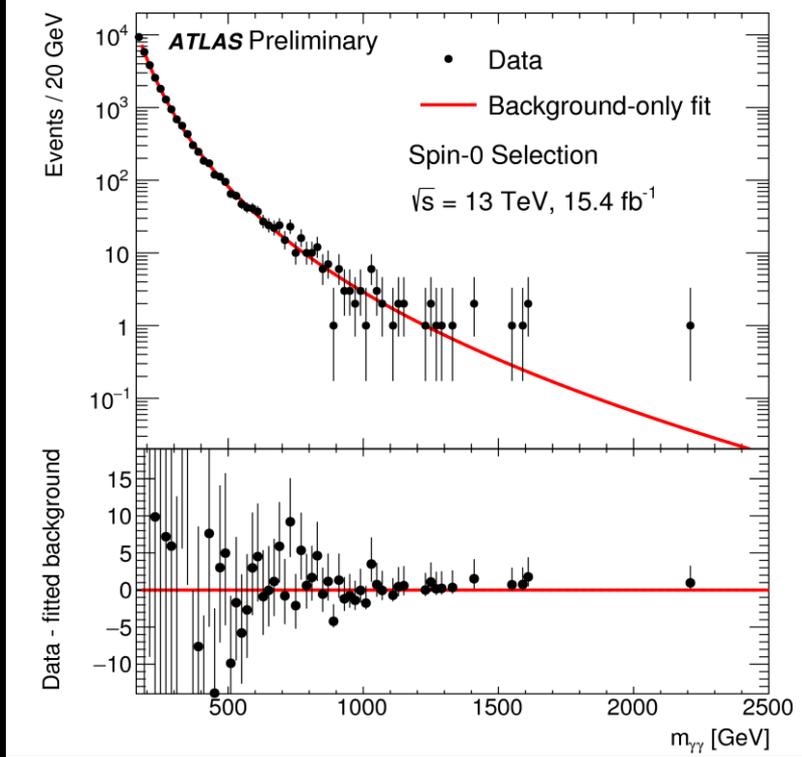


# Heavy Scalars: $\gamma\gamma$

Diphoton resonance search

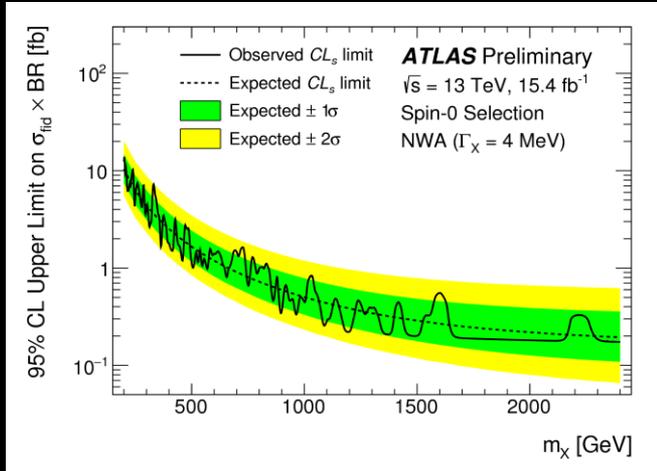
Created some excitement in 2015

Updated analysis see reduction in significance of previous excess



As with other diboson analyses – NWA and LWA interpretations

No significant excess observed



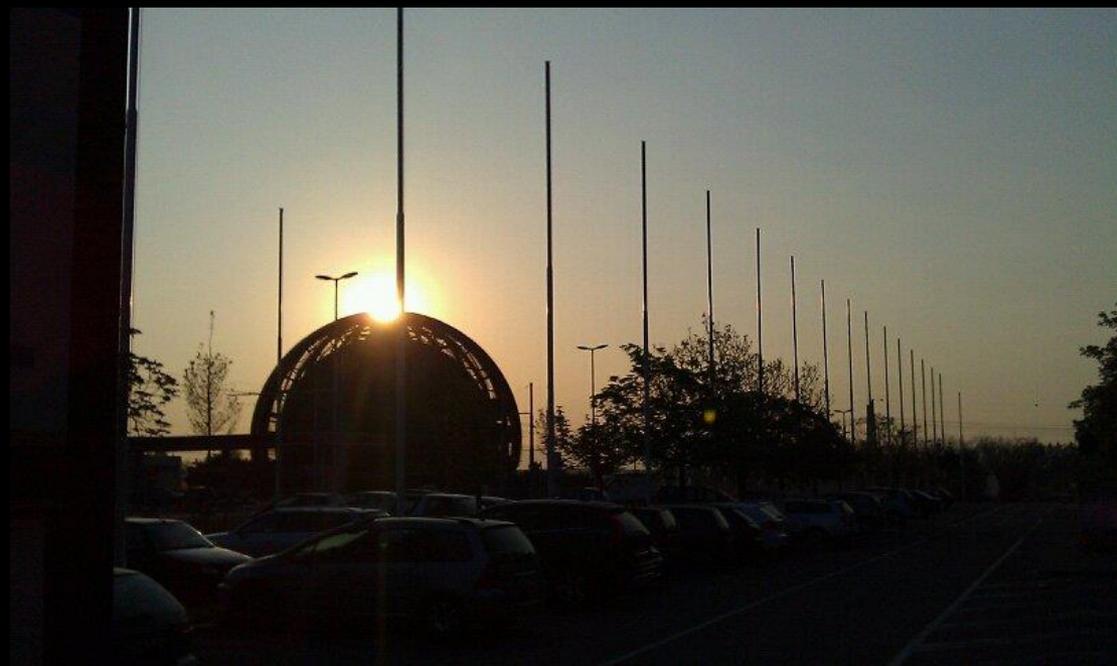


# Conclusions

ATLAS is highly active in searching for BSM phenomena in the Higgs sector

Only a small fraction of results shown here – checkout ATLAS public results for more:

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



Nothing significant has yet been observed

Lots more data to come!