

Search for heavy resonances decaying to Higgs bosons at the ATLAS & CMS

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On behalf of the ATLAS&CMS collaboration

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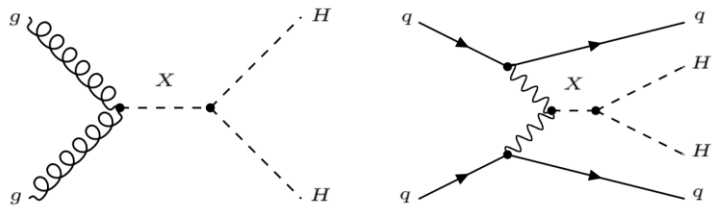


Heavy resonances decaying to Higgs

Predicted in several extensions of Standard Model (SM)

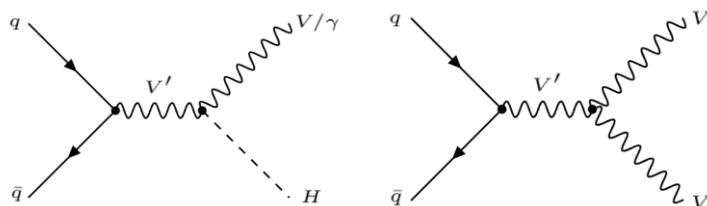
Spin-0 radion (Randall-Sundrum)

Spin-2 graviton (Randall-Sundrum)



Gluon-Gluon Fusion (ggF) Vector Boson Fusion (VBF)

Spin-1 vector (Heavy Vector Triplet)



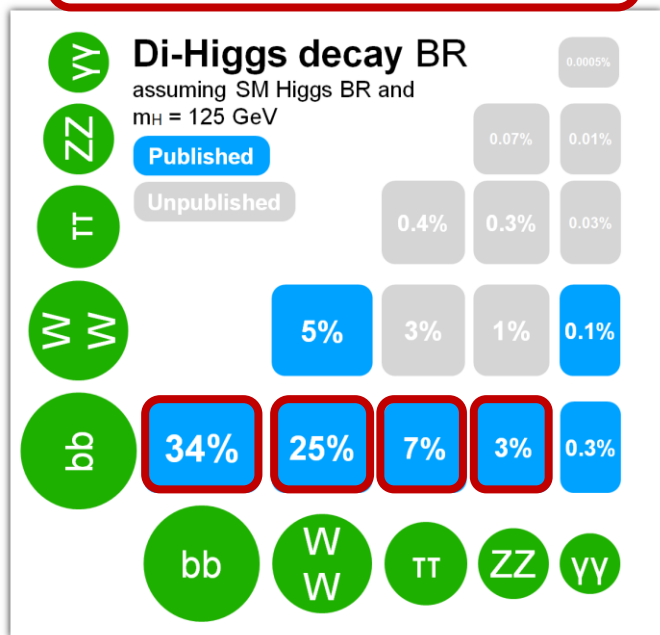
VH

VV, not covered in this talk

H/V could be resolved or boosted, depends on resonance mass.

Status of resonant search in HH/VH

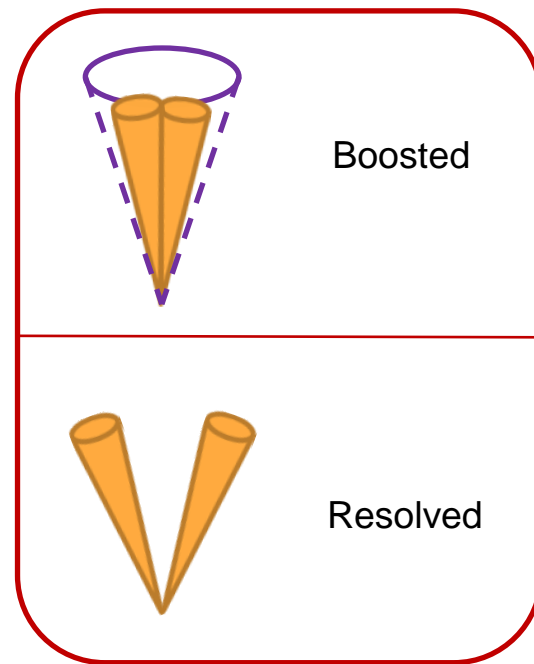
**New results since
previous LHCP**



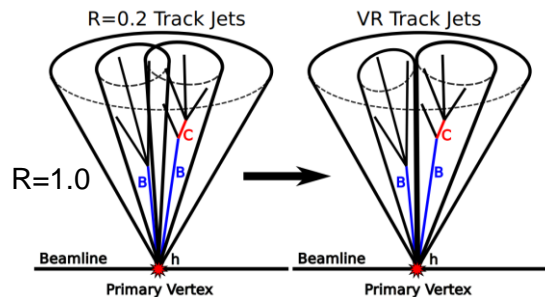
	ATLAS	CMS
$HH \rightarrow bbbb$	ggF JHEP01(2019)030 (36.1 fb ⁻¹)	ggF PLB 781 (2018) 244 (35.9 fb ⁻¹)
	VBF arXiv.2001.05178 (126 fb ⁻¹)★	
$HH \rightarrow bbWW^*$	JHEP04(2019)092 (36.1 fb ⁻¹)	JHEP 10 (2019) 125 (35.9 fb ⁻¹)★
$HH \rightarrow bbZZ^*$		CMS-PAS-HIG-18-013 (35.9 fb ⁻¹)★
$HH \rightarrow bb\tau\tau$	PRL.121.191801 (36.1 fb ⁻¹)	JHEP01(2019)05 (35.9 fb ⁻¹)
	ATLAS-CONF-2020-012 (139 fb ⁻¹)★	
$HH \rightarrow bb\gamma\gamma$	JHEP11(2018)040 (36.1 fb ⁻¹)	PLB 788 (2018) 7 (35.9 fb ⁻¹)
$VH \rightarrow qqbb$	PLB 774 (2017) 494 (36.1 fb ⁻¹)	EPJC 77, 636 (2017) (35.9 fb ⁻¹)
	CERN-EP-2020-073 ((139 fb ⁻¹))★	
$VH \rightarrow qq\tau\tau$		JHEP01(2019)051 (35.9 fb ⁻¹)
$VH \rightarrow lv/\bar{l}l/\nu\nu\ bb$	JHEP11(2018)051 (36.1 fb ⁻¹)	

General search strategy

- > Trigger:
 - 1+ lepton: single/double e/μ
 - 0 lepton: large-R or b-tagged jet
- > At least one H(bb) candidate in most cases:
 - Largest branching fraction
 - “Boosted” scenario: 1 boosted jet
 - > Higgs identification is critical
 - “Resolved” scenario: 2 resolved jet
- > Main background: multi-jets, $t\bar{t}$ bar...
 - Estimated in a control region from data or MC simulation



Highly boosted Higgs identification



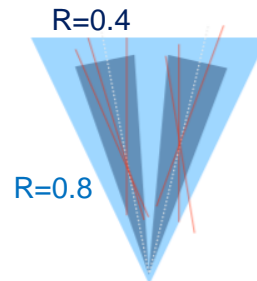
Variable-radius jet
based [bb tagger](#)

- Various of boosted Higgs taggers in ATLAS&CMS:

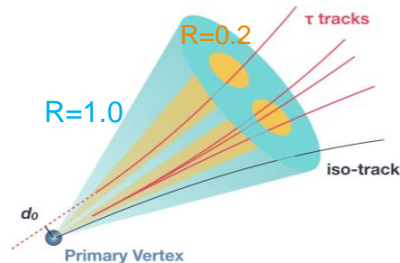
$H \rightarrow b\bar{b}$

$H \rightarrow \tau\tau$

...



Combined-Secondary-Vertex
(CSVv2) [b tagger](#)



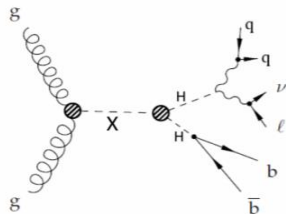
Boosted di-tau (H->di-tau)



Results in “boosted” HH scenario

$HH \rightarrow bbWW^*$ from CMS (35.9 fb⁻¹)

> Semileptonic $WW \rightarrow qql\nu$ ($l = e, \mu$)



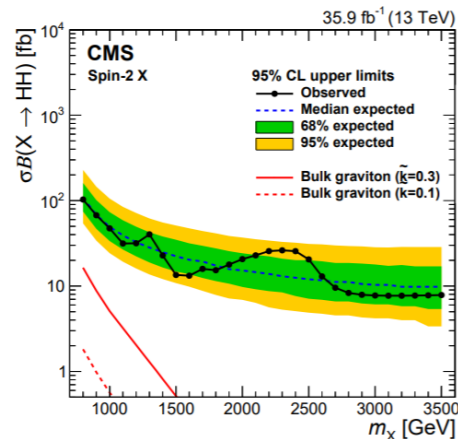
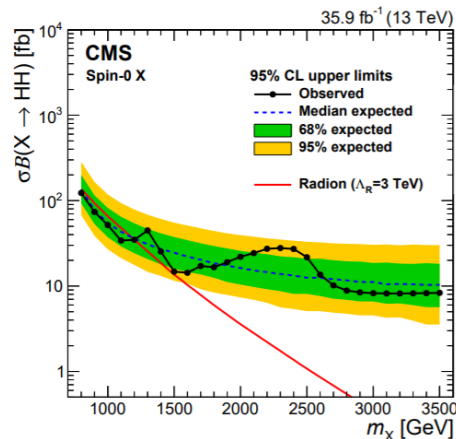
> Optimized for resonance mass > 0.8 TeV

> Boosted $H \rightarrow WW^*$

- Reconstructed by a large-radius jet ($\Delta R=0.8$) and a nearby lepton.

> Boosted $H \rightarrow bb$

- Based on large-radius jet, two b-tagged ([CSVv2](#)) subjects

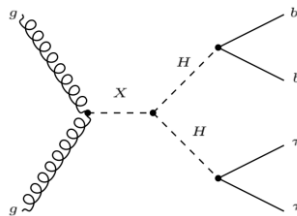


- **Best result to date for $bbWW^*$ channel**
- Spin-0:
 $\sigma_{95\%CL} \cdot B(X \rightarrow HH) : \in (123 - 8.3) \text{ fb at } (0.8 - 3.5) \text{ TeV}$
- Spin-2:
 $\sigma_{95\%CL} \cdot B(X \rightarrow HH) : \in (103 - 7.8) \text{ fb at } (0.8 - 3.5) \text{ TeV}$

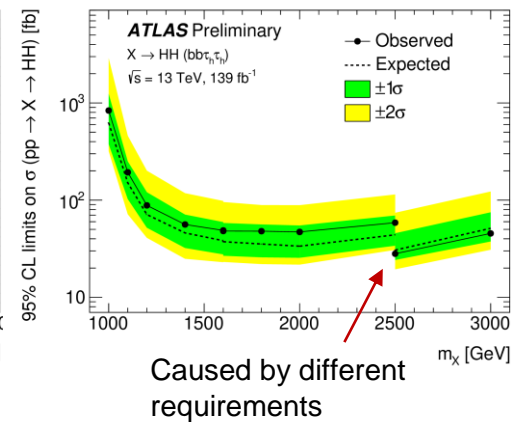
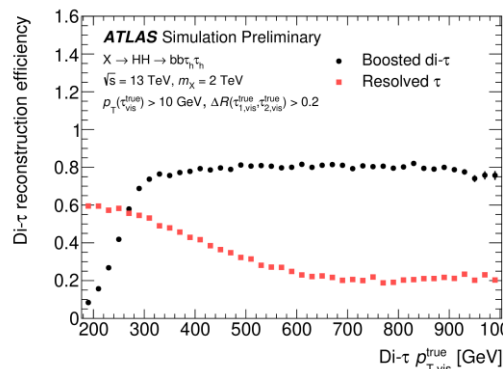
$HH \rightarrow bb\tau\tau$ from ATLAS (139 fb⁻¹)



- > First search of $X \rightarrow HH$ with full run2 data



- > Boosted $H \rightarrow bb$
 - Based on large-R jet, two b-tagged ([MV2c10](#)) variable-radius subjets
- > Boosted $H \rightarrow \text{tautau}$ (both hadronic)
 - Boosted Di- τ tagger
 - BDT with tracking, vertexing and calorimeter info.



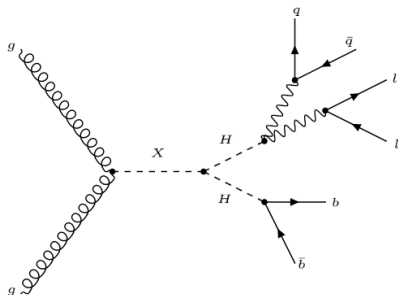
- Boosted di-tau tagger is developed and performed well
- Spin-0 :
 $\sigma_{95\%CL} \cdot B(X \rightarrow HH) \in (88 - 46) \text{ fb at } m(X) \in (1.2 - 3) \text{ TeV}$



Results in “resolved” HH scenario

$HH \rightarrow bbZZ^*$ from CMS (35.9 fb⁻¹)

> First search with $ZZ \rightarrow jjll (l = e, \mu)$



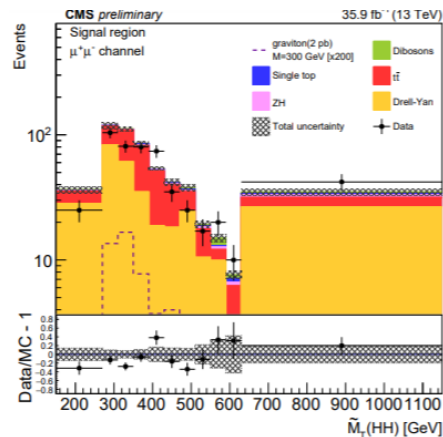
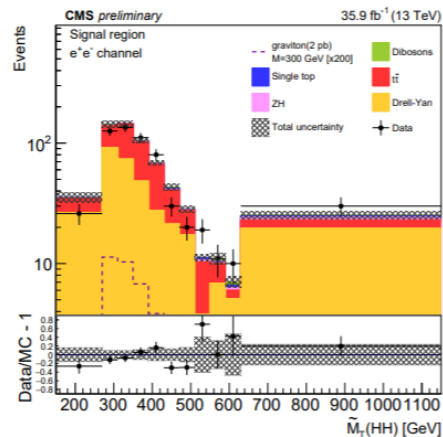
> Four resolved jets

- At least one b-tagged ([Combined MVA](#)) jet

> Two leptons

- opposite sign of charge

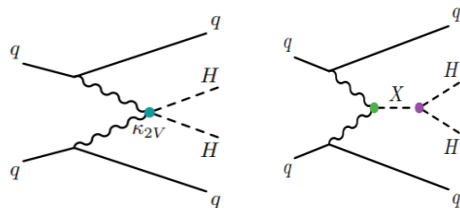
> Combine with [bbl \$\nu\nu\$](#)



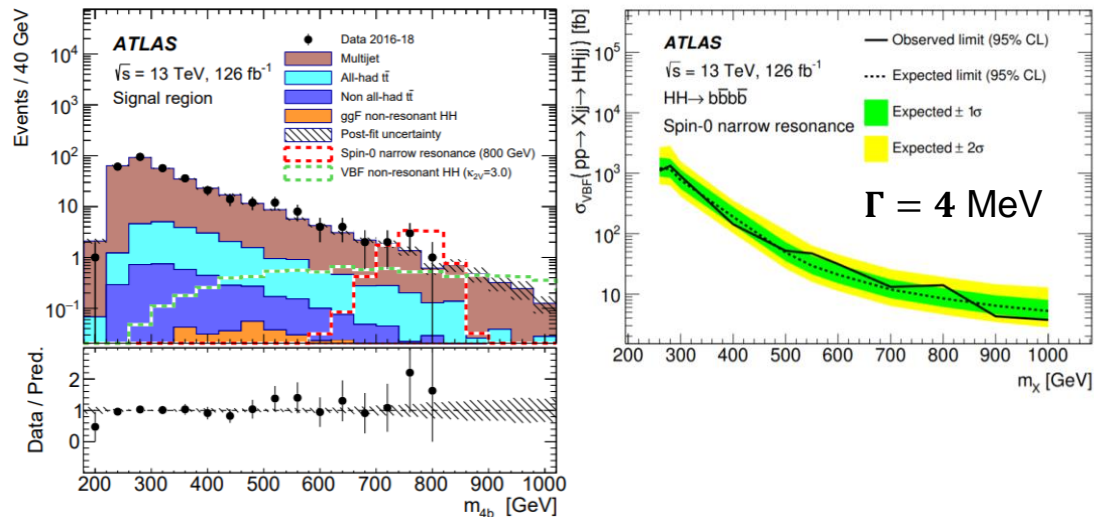
- Spin-0:
 $\sigma_{95\%CL} \cdot B(X \rightarrow HH) \in (164 - 3.95) \text{ pb}$ at $m(X) \in (0.26 - 1) \text{ TeV}$
- Spin-2:
 $\sigma_{95\%CL} \cdot B(X \rightarrow HH) \in (117 - 3.82) \text{ pb}$ at $m(X) \in (0.26 - 1) \text{ TeV}$
- From $bbWW^*$, $\sigma_{95\%CL} \cdot B(X \rightarrow HH) \sim 100 \text{ fb}$ at 0.8 TeV

VBF $HH \rightarrow bbbb$ from ATLAS (126 fb⁻¹)

- > First search of VBF HH
- > Uniquely sensitive to κ_{2V} compared with ggF



- > 4 resolved b-tagged jets
 - Multi-variable ([MV2c10](#)) algorithm
 - 70% tagging efficiency
- > Two VBF jets



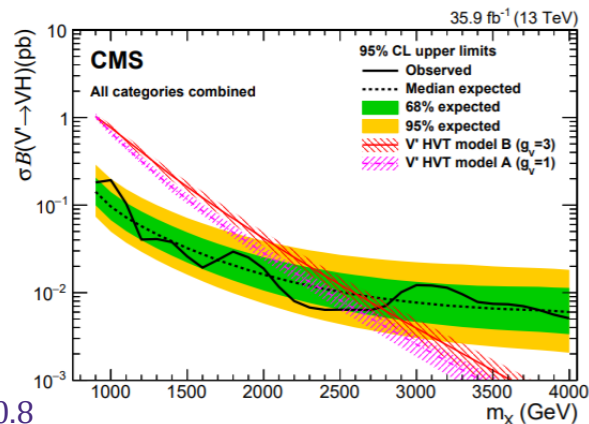
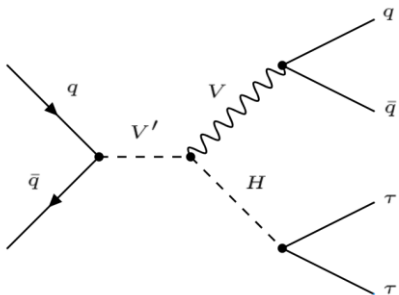
- Spin-0:
 $\sigma_{95\%CL} \cdot B(X \rightarrow HH) \in (\sim 1000 - \sim 4) \text{ fb at } m(X) \in (0.26 - 1) \text{ TeV}$
- Non-resonant $\sigma_{95\%CL}(VBF HH) : 1450 \text{ fb}$
- Exclusion: $\kappa_{2V} < -0.56$ and $\kappa_{2V} > 2.89$



Results in “boosted” VH scenario

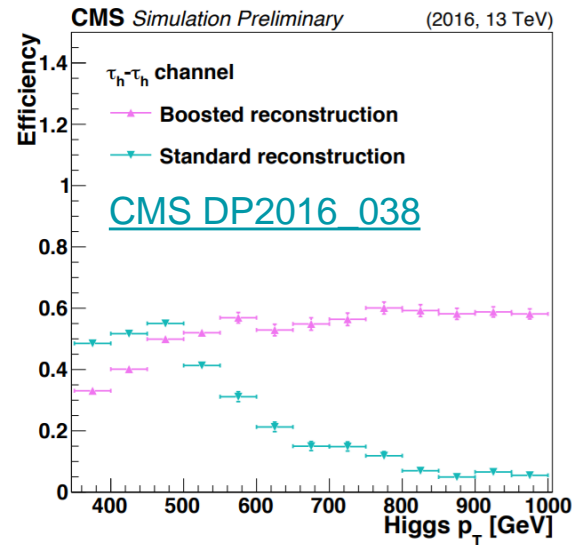
Search for V' with VH from CMS (35.9 fb⁻¹)

> Search for W' and Z' in HVT



> Boosted $V \rightarrow qq$

- Based on large- R jet with a $R = 0.8$
- Tagged by [pileup per particle identification](#)
- Boosted $H \rightarrow \tau\tau$ ($\tau_{had}\tau_{had}, \tau_{had}\tau_{lep}$):
 - Large- R ($R = 0.8$) jet based on [Cambridge–Aachen algorithm](#)

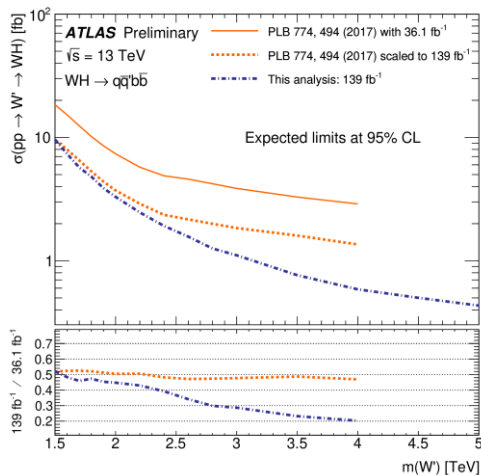
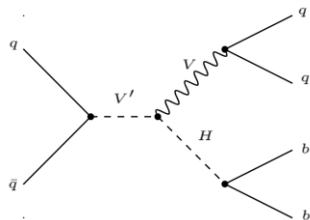


- V' :
 $\sigma_{95\%CL} \cdot B(V' \rightarrow VH) : \in (180 - 5) \text{ fb at } (0.9 - 4) \text{ TeV}$
- Exclusion: $W'(Z')$: 2.6 (1.8) TeV for Model B

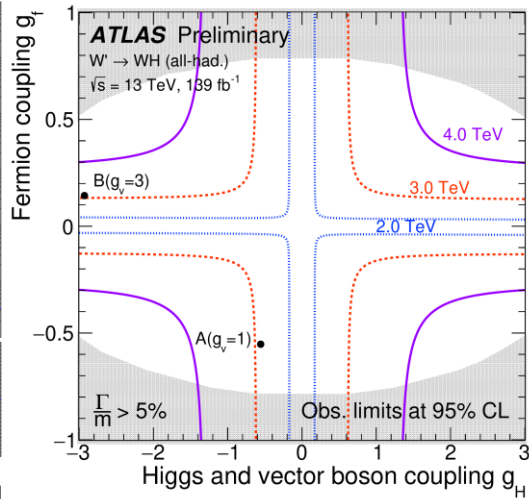
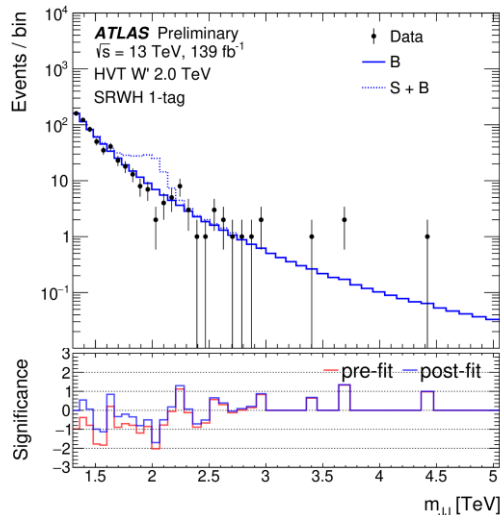
Search for V' with VH from ATLAS (139 fb⁻¹)

**HOT
OF THE
PRESS!**

> Search for W' and Z' in HVT with full run2 data

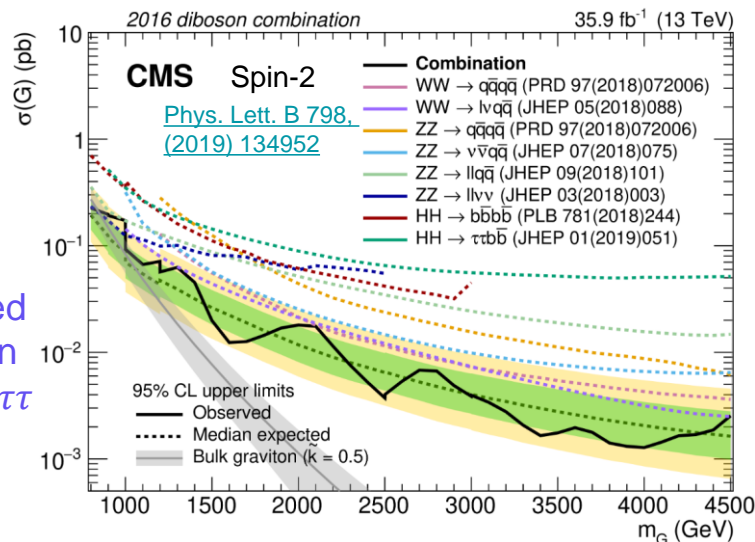
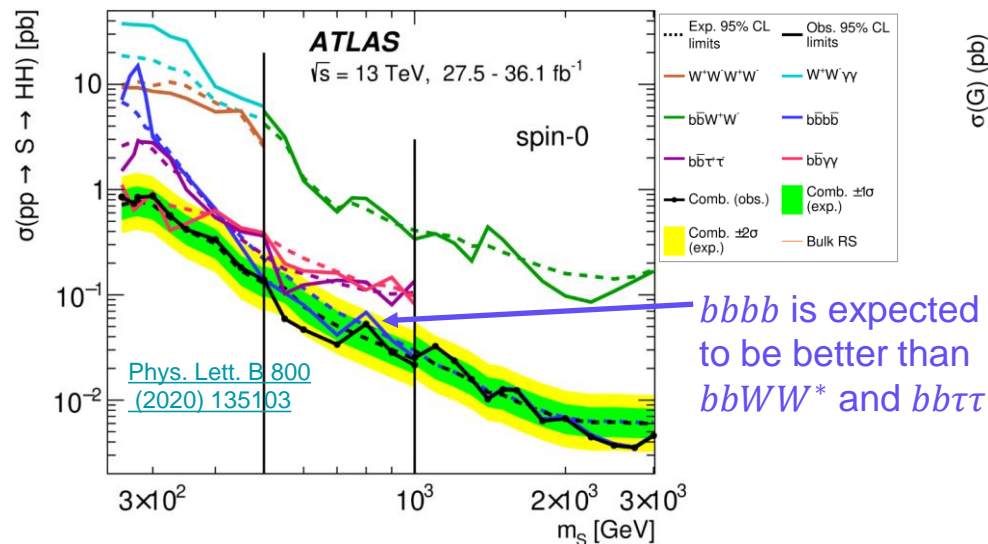


Improvement in
sensitivity come
from boosted
H/V taggers



- W' :
 $\sigma_{95\%CL} \cdot B(W' \rightarrow WH)$: 6.8 fb at 1.5 TeV, 0.53 fb at 5.0 TeV
 $m_{lower}(W')$: 2.9 TeV (model A) and 3.2 TeV (model B)
- Z' :
 $\sigma_{95\%CL} \cdot B(Z' \rightarrow ZH)$: 8.7 fb at 1.5 TeV, 0.53 fb at 1.5 TeV
 $m_{lower}(Z')$: 2.2 (model A) and 2.65 (model B) TeV

Current HH combination ($\sim 36 \text{ fb}^{-1}$)



The new combination is waiting for full run2 results.

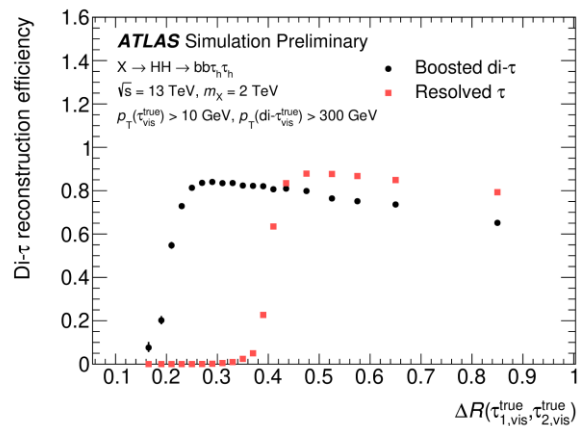
Summary



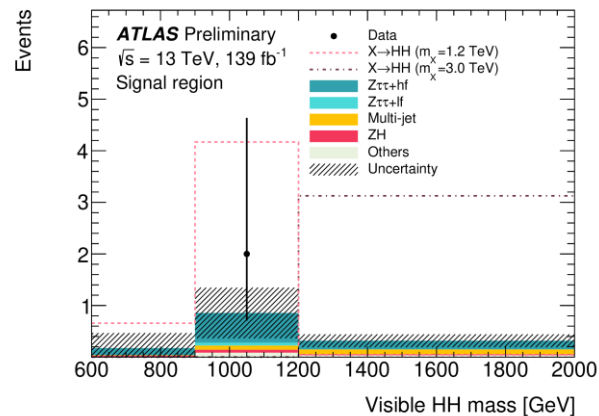
- > Several boosted Higgs tagger are developed with improved performance, enable us to search in the higher mass region
- > New results for search of heavy resonance decaying to HH/VH
 - No sign of new heavy resonance so far
 - > The most sensitive HH channel in high mass region, bbbb, are eagerly awaited.
 - More results with full run2 data from ATLAS&CMS will come, stay tune

back-up

$HH \rightarrow bb\tau\tau$ from ATLAS (139 fb⁻¹)

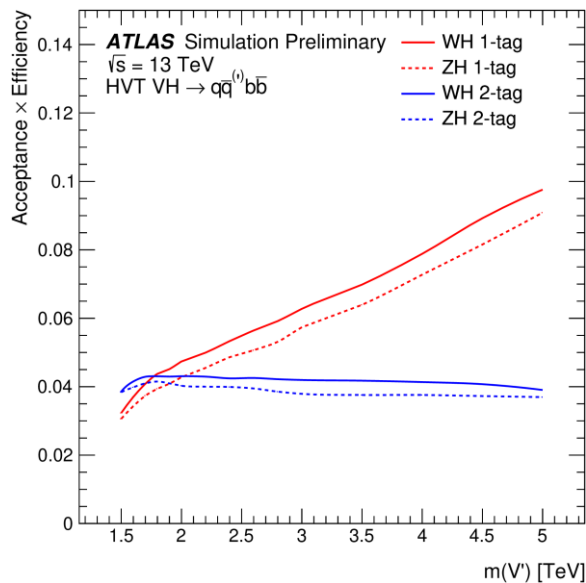


Reconstruction efficiency

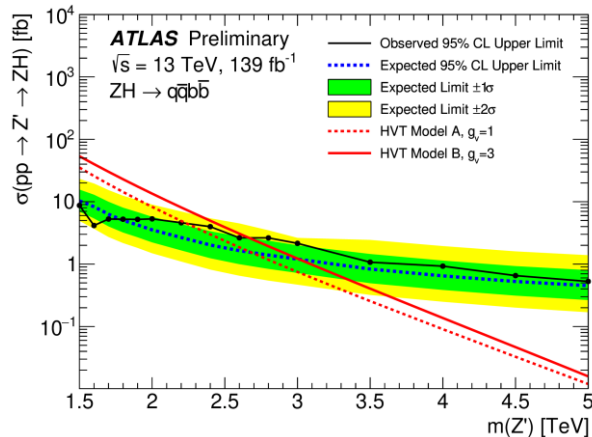
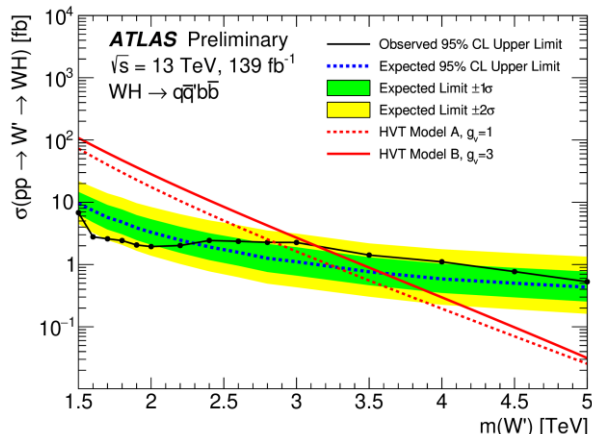


Visible mass for HH

Search for V' with VH from ATLAS (139 fb⁻¹)



Signal acceptance \times efficiency



Upperlimit on cross section for $pp \rightarrow V' \rightarrow VH$
