Searches for New Resonances Decaying to Di-Higgs at ATLAS

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On behalf of the ATLAS collaboration
Higgs 2020 Conference

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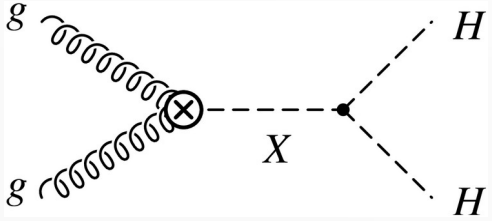
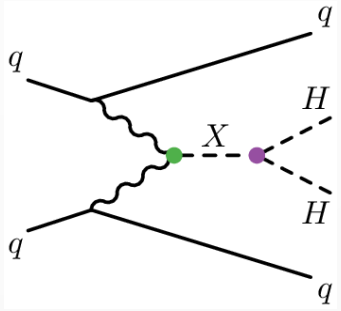
BSM Di-Higgs Production at LHC

- In the Standard Model (SM), the di-Higgs production cross section is very small.
  - ggF: 31fb, VBF: 1.7fb @ 13 TeV.
- Physics beyond the Standard Model (BSM) can enhance the production rate.
  - Modified couplings – ggF: $\kappa_\lambda \kappa_t$; VBF: $\kappa_\lambda \kappa_V \kappa_{2v}$
  - New resonance that decays to di-Higgs.
- For resonance, we are searching for:
  - Spin-0 particles: predicted by Two-Higgs-Doublet-Models (2HDM) and Electroweak Singlet (EWK-singlet) Models.
  - Spin-2 particles: predicted by Randall-Sundrum (RS) model of wraped extra dimension.

Topic of this talk





Di-Higgs Decay Channels

- Focus on resonance di-Higgs production searches:
- Publications using ATLAS 2015~2016 dataset (36.1fb^{-1}) covers:
  - bbbb, bbWW, bbττ, bbγγ
  - WWWW, WWγγ
  - Data 15~16 combination result: Phys. Lett. B 800 (2020) 135103
- New publications using ATLAS Full Run2 (2015~2018, 139fb^{-1}) dataset:
  - bbbb (VBF): JHEP 07 (2020) 108
  - bbττ (boosted topology): arXiv: 2007.14811

Higgs Decay	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.07%	
γγ	0.26%	0.10%	0.03%	0.01%	<0.001%

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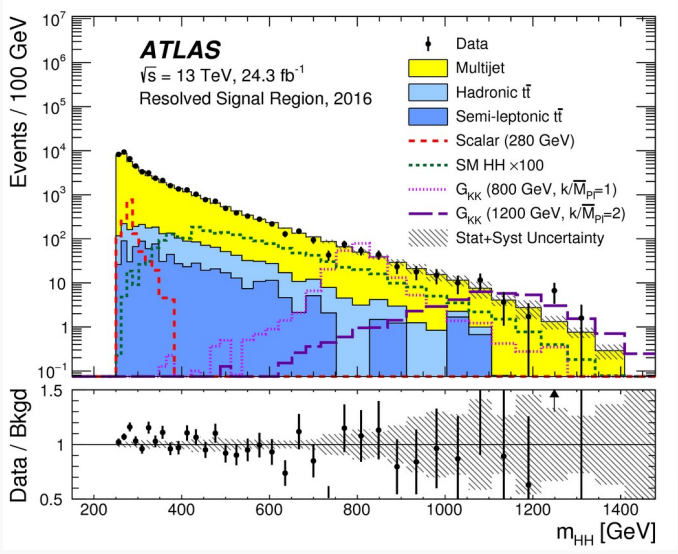
Results from 2015~2016 Dataset

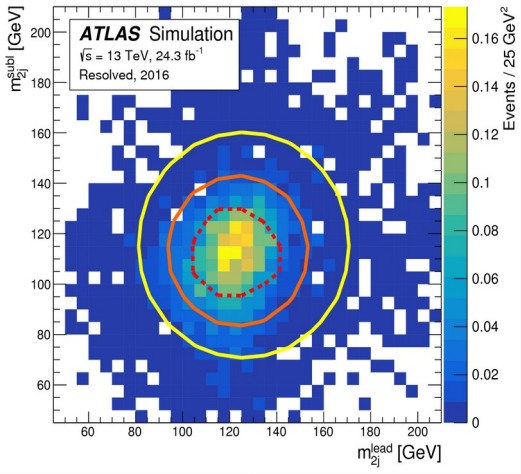
- Overview of individual channels
- Statistical combination results

HH→bbbb

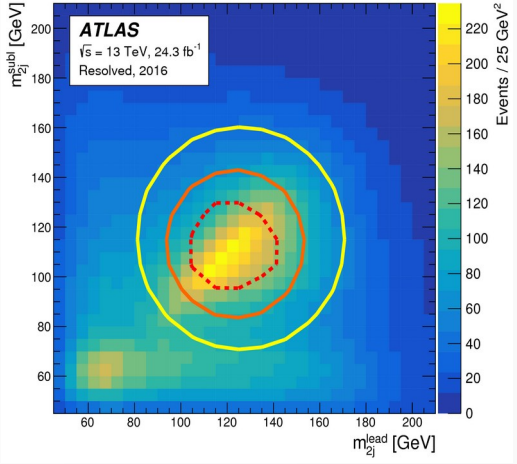
- **HH→bbbb:** high BR, low S/B
  - Resolved analysis: Four small-R jets, both b-tagged.
  - Boosted analysis: Two large-R jets, both have 1/2 associated b-tagged track jets.
- Backgrounds: multi-jet (data-driven) and top-quark pair.



Di-Higgs Signal



Multi-jet background



- Signal Region: selected by 2D Higgs mass window.
- Resonance search range: 260~1400 GeV (resolved), 800~3000 GeV (boosted)[*].
- **Dominates the sensitivity at high mass region.**

[*] Statistical combination is performed in the overlapping range.

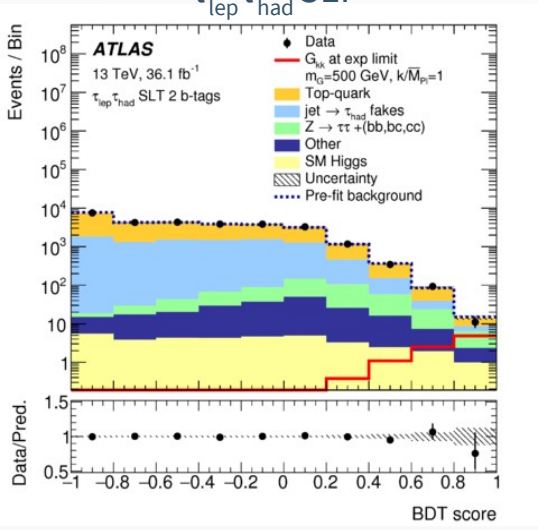
JHEP 01 (2019) 030

HH→bbττ

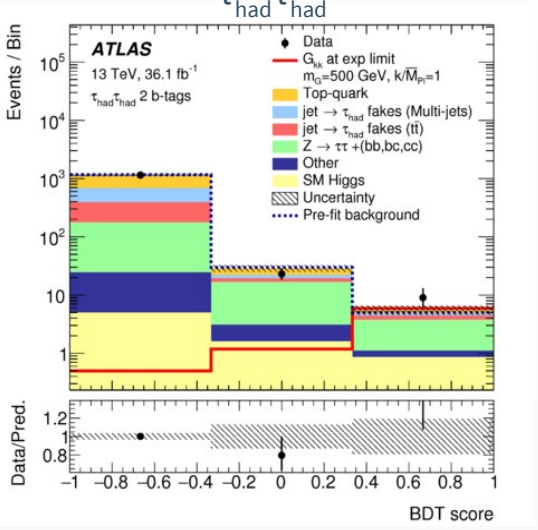
- **HH→bbττ:** medium BR, medium S/B
- 2 b-tagged jets and 2 τ-lepton.
  - $\tau_{had}\tau_{had}$: 2 hadronic decay τ.
  - $\tau_{lep}\tau_{had}$: 1 leptonic + 1 hadronic decay τ.

Event Categories		
$\tau_{lep}\tau_{had}$		$\tau_{had}\tau_{had}$
Single-lepton trigger (SLT)	Lepton + τ_{had} trigger (LTT)	Single-τ_{had} trigger or Di-τ_{had} trigger

$\tau_{lep}\tau_{had}$ SLT



$\tau_{had}\tau_{had}$



Discriminate variable: Output of Boosted Decision Tree (BDT)

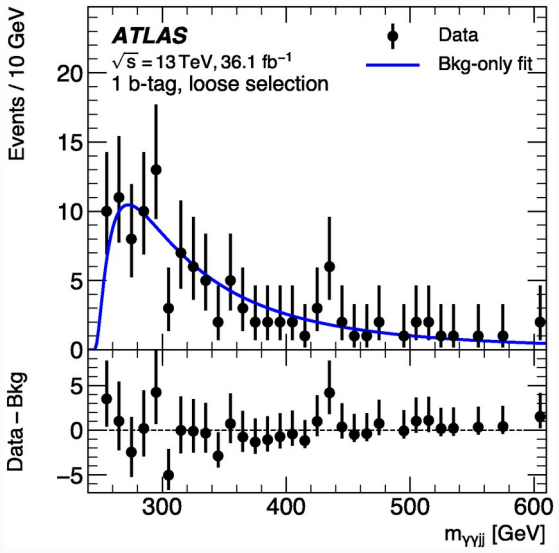
- Multi-variable analysis strategy.
- Backgrounds: top-quark pair, jet→τ_{had} fake (data-driven) and Z→ττ+heavy flavour jets.
- Resonance search range: 260~1000 GeV.
- **Best sensitivity in the medium mass ragion.**

Phys. Rev. Lett. 121 (2018) 191801

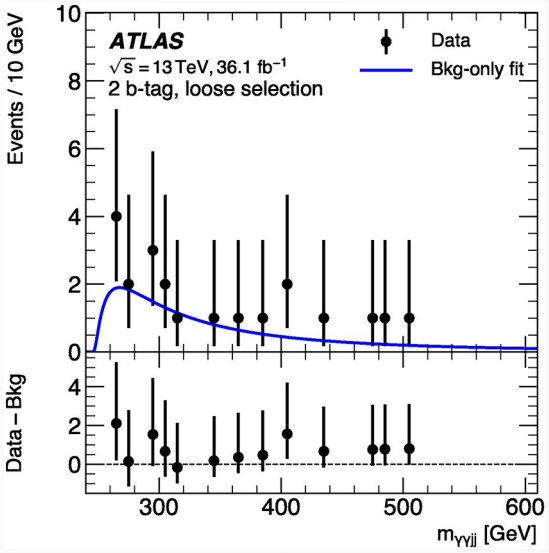
HH→bbγγ

- **HH→bbγγ:** low BR, high S/B
- 2 jets and 2 high-p_T photons.
  - Require 2 b-tagged jets or 1 b-tagged jets + another jet chosen by a BDT.
- Categorisation based on number of b-tagged jets and kinematics of jets.
  - "Tight" for M > 500 GeV.
  - "Loose" for M < 500 GeV.
- Backgrounds: γγ+jets, single Higgs

1-btag Loose



2-btag Loose

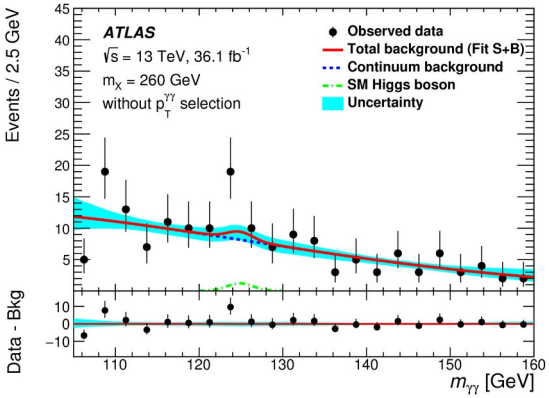


- Signal region is selected by requirements on di-photon and di-jet invariant mass.
- Resonance search range: 260~1000GeV.
- **Dominate the sensitivity in low mass region.**

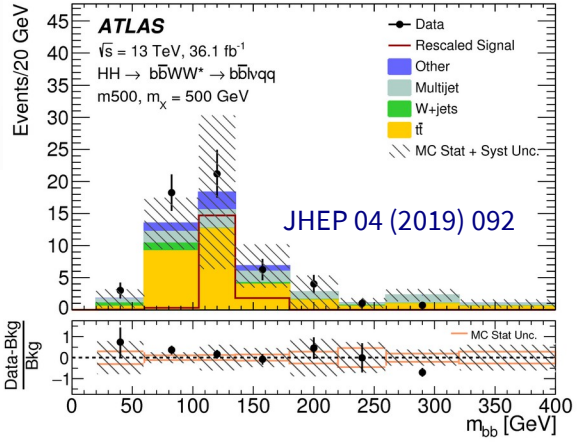
JHEP 11 (2018) 040

Additional Channels

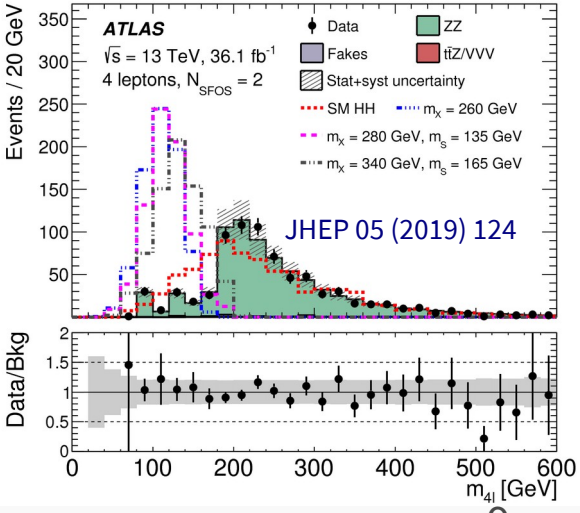
- Leptonic final states → Low background.
- Less sensitive due to neutrino in H→WW.
- **HH→bbWW**
  - WW → lvqq, resolved + boosted analysis
  - Resonance search range: 500~3000 GeV
- **HH→WWγγ**
  - WW → lvqq. Final Discriminant: mγγ
  - Resonance search range: mass < 500 GeV.
- **HH→WWWW**
  - Including 2/3/4-lepton channels, categorised by lepton flavours.
  - Resonance search range: mass < 500 GeV. Also search for X→SS (heavy scalar S)



Eur. Phys. J. C 78 (2018) 1007



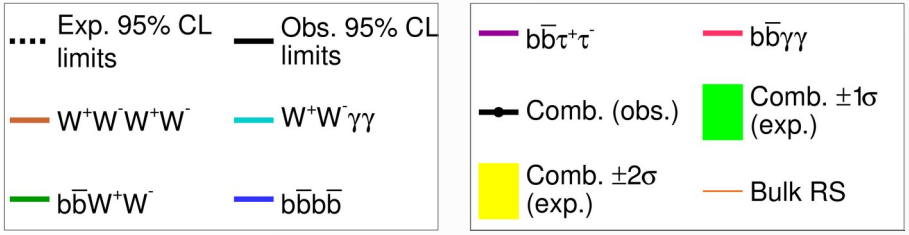
JHEP 04 (2019) 092

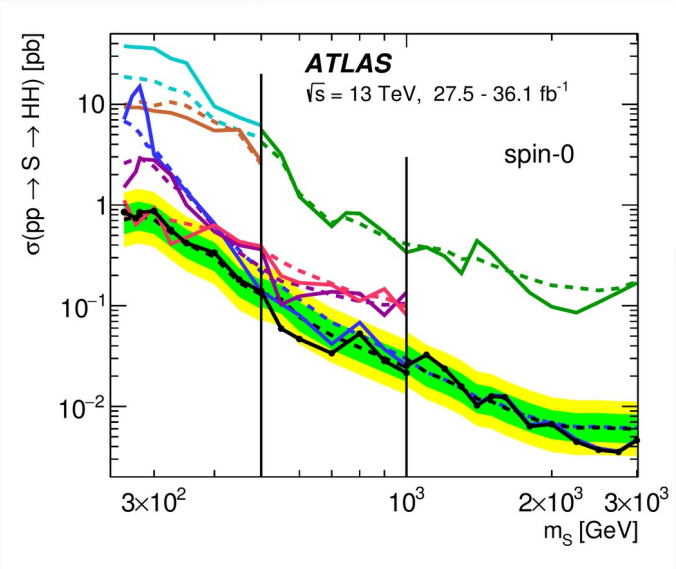


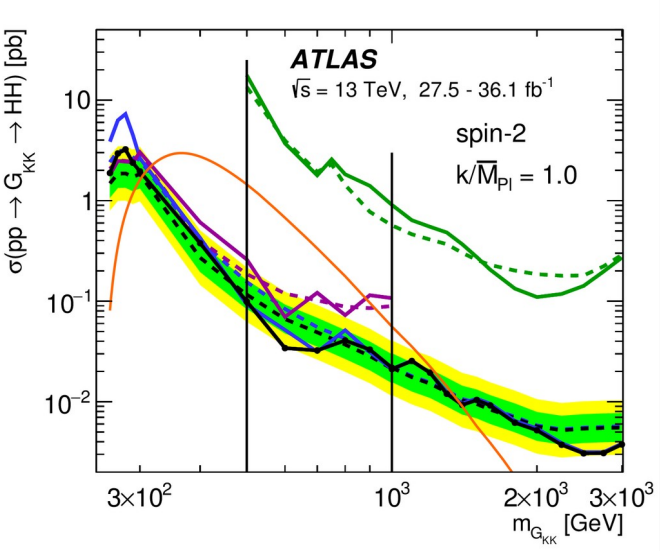
JHEP 05 (2019) 124

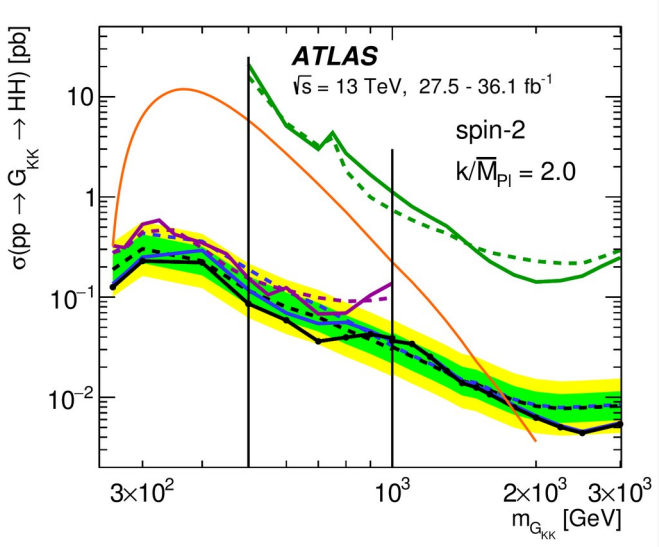
HH combination

- Limits on the production of:
  - narrow width scalar particle in 2HDM model.
  - spin-2 Kaluza-Klein (KK) gravitons in RS model.









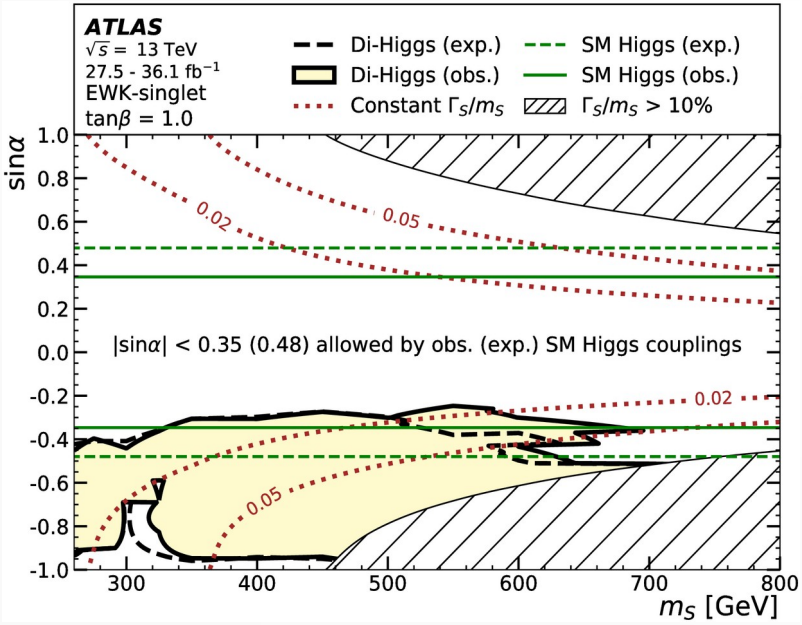
Observed upper limits on cross section:
0.8 pb @ 260 GeV ~ 0.005 pb @ 3TeV

In the case $k/\overline{M}_{pl}$=1.0 (2.0), the RS model is excluded at 95% CL in the graviton mass from 310 (260) GeV to 1380 (1760) GeV.

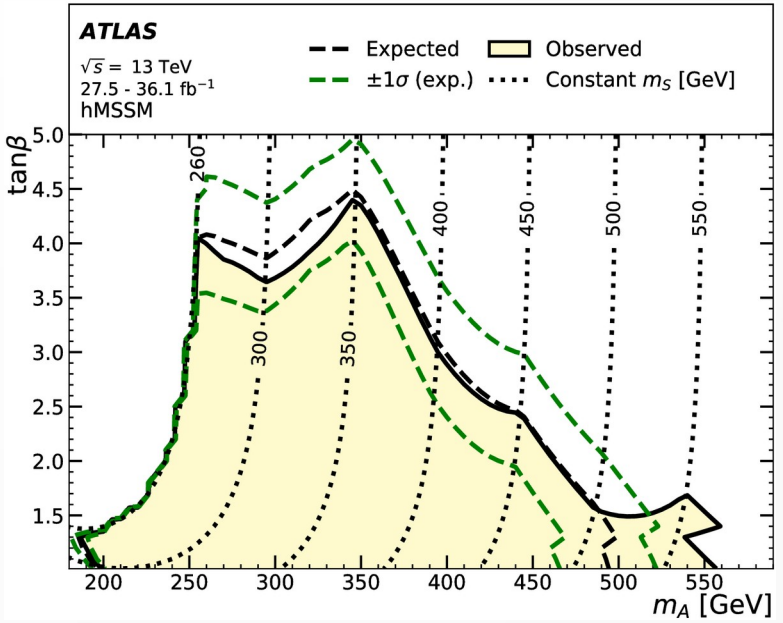
Phys. Lett. B 800 (2020) 135103

HH combination

- Interpreted into Minimal Supersymmetric Standard Model (hMSSM scenario) and EW-singlet model. Several parameter spaces are excluded.



For EWK-singlet model at tanβ = 1.0, exclude the heavy scalar paricle mass from 260 GeV to 700 GeV, depending on sinα



For hMSSM, exclude the heavy pseudoscalar particle mass from 190 GeV to 560 GeV, depending on tanβ

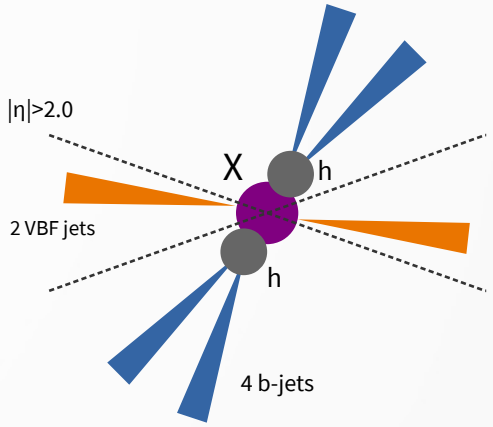
Phys. Lett. B 800 (2020) 135103

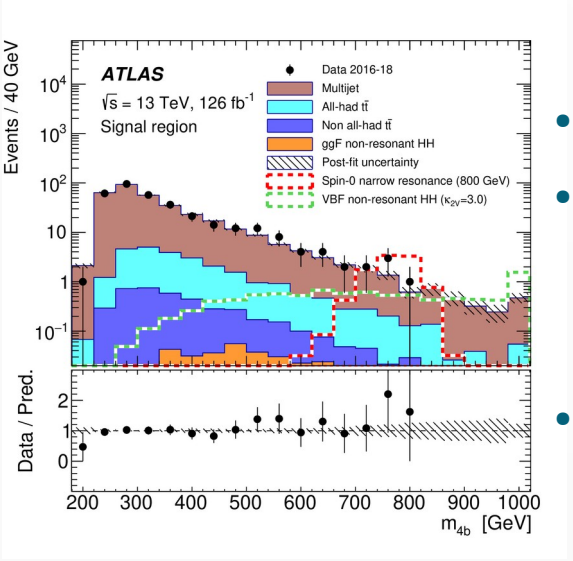
Results from Full Run2 Dataset

- VBF HH→bbbb
- HH→bbττ Boosted Analysis

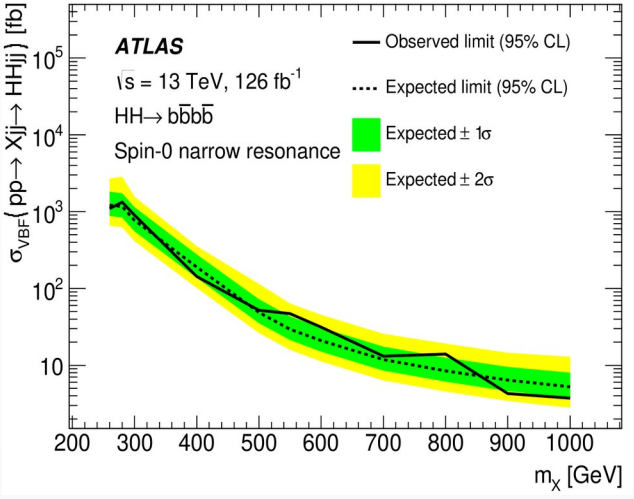
VBF HH→bbbb

- First **VBF** HH production result at ATLAS
- Most sensitive to κ_{2v} in non-resonant production, also has access to resonant production.
- VBF selection: two high p_T jets that have large rapidity gap and large invariant mass.
- General strategy is similar as ggF analysis.





- Search range: 260 ~ 1000 GeV
- Limits are set on the resonant production cross section via VBF
  - 1pb @ 260 GeV, 4fb @ 1TeV
- Both narrow and broad width hypotheses are considered for the resonance.



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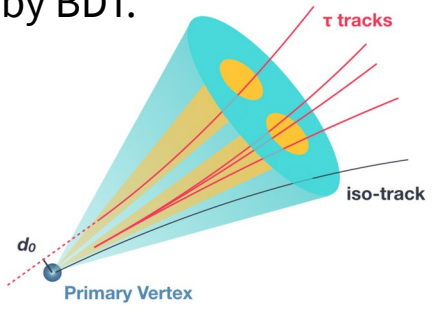
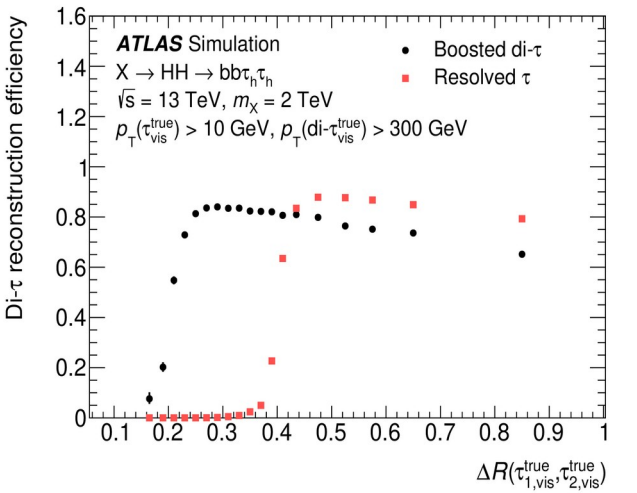
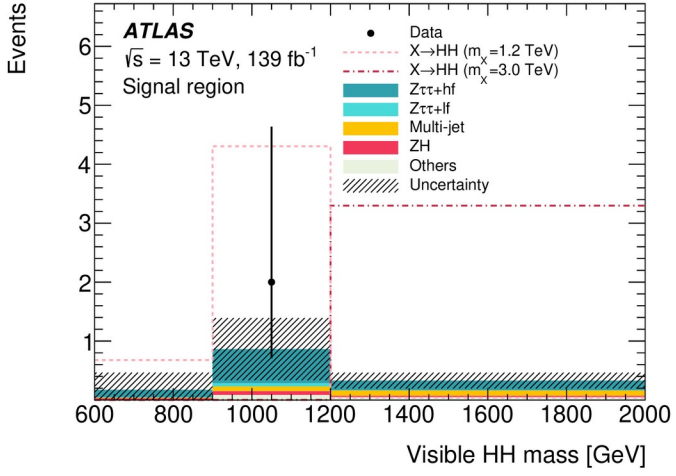
HH→bbττ Boosted Analysis

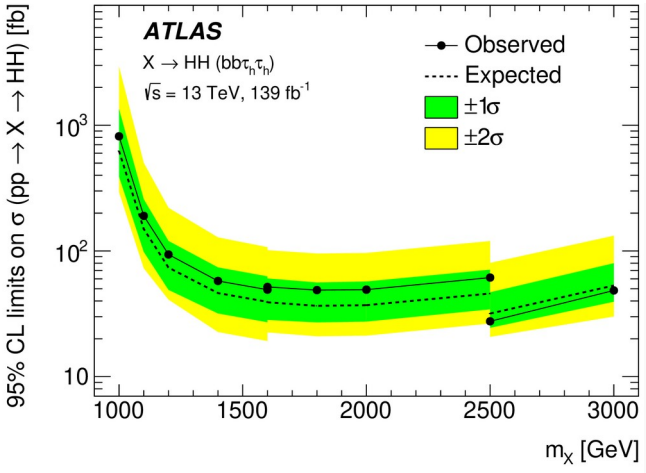
- Novel technique first time used in ATLAS to recontructed **boosted τ-pairs**
- Decay of τ-pair (fully hadronic):
  - Reconstructed as a large-R jet with R=0.2 sub-jets.
  - Identified against quark/gluon initiated jets by BDT.
- H→bb decay: large-R jet, require 2 b-tagged.
- Main backgrounds
  - Zττ + heavy flavour jets, multi-jet.







- Search range: 1000 ~ 3000 GeV. Extend the sensitive region of bbττ channel.
- Limits are set on Di-Higgs production cross section via narrow width scalar resonance particle.
- 90~30fb @ 1.2~3.0TeV



arXiv: 2007.14811

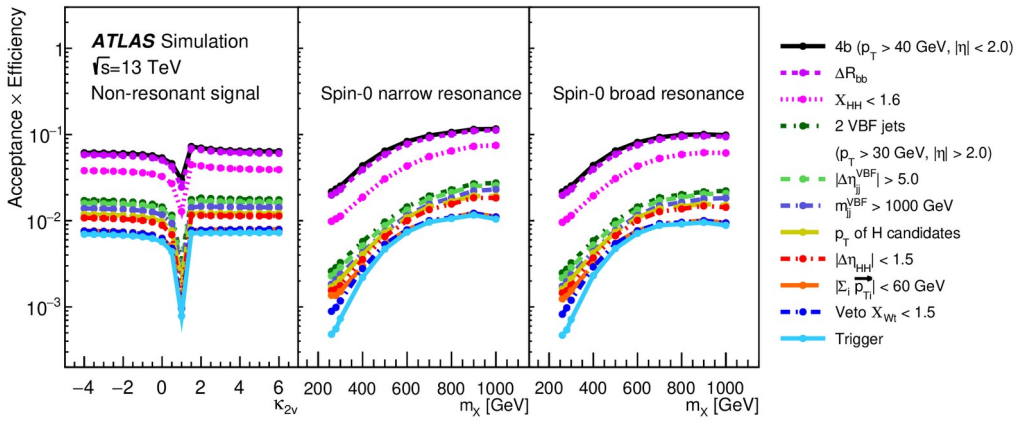
Summary

- Searches for new resonance decaying to di-Higgs have been performed in various final states.
  - Several BSM models: 2HDM, EW-singlet, RS model.
  - Search range: 260 to 3000 GeV.
- No sign of excess from Standard Model is observed so far. Upper limits on the cross section and exclusions on parameter space are reported.
- Results from new production modes and final states are presented.
- More results from full Run2 datasets will come soon!

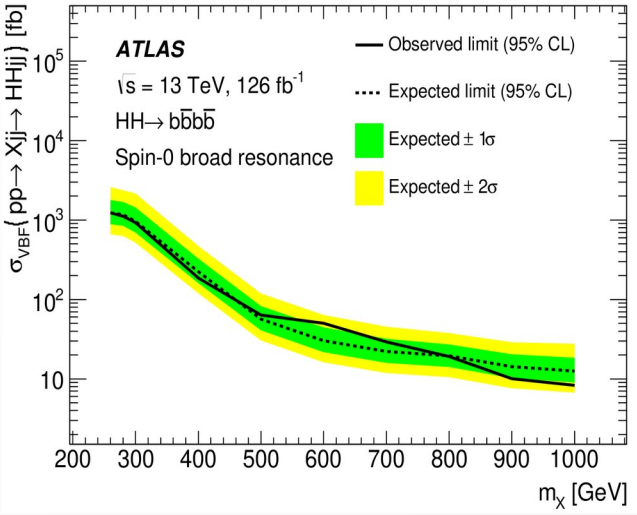
Thanks for listening!

Extra Materials

VBF HH→bbbb



Signal acceptance x selection efficiency



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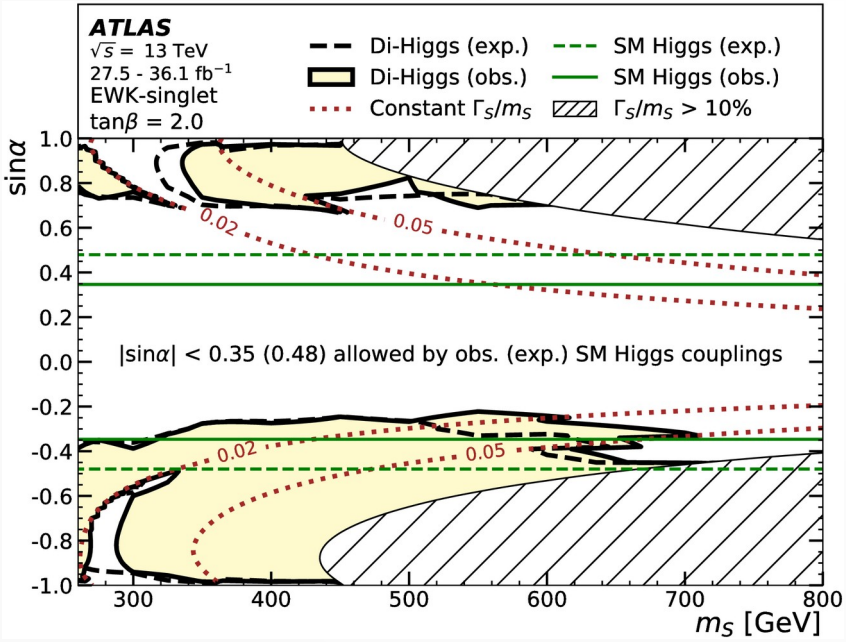
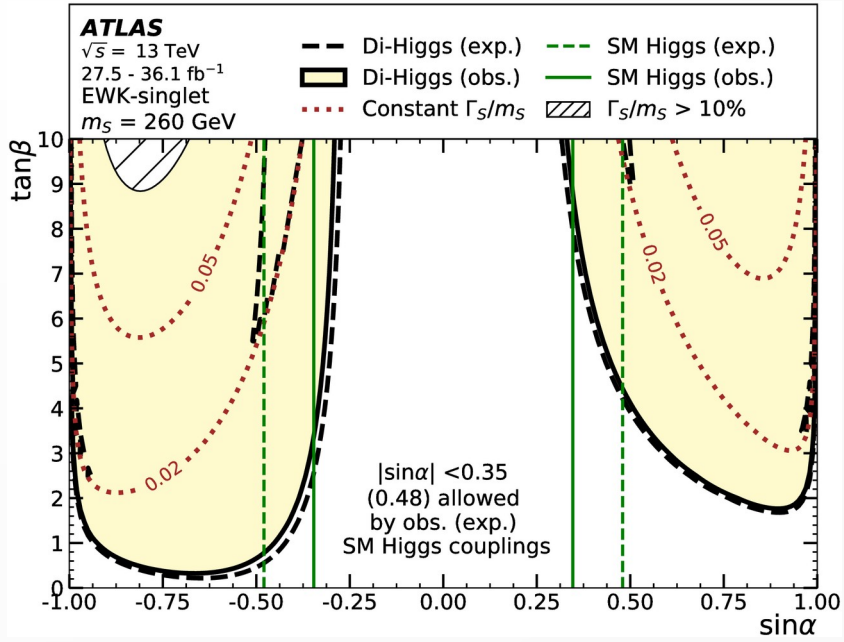
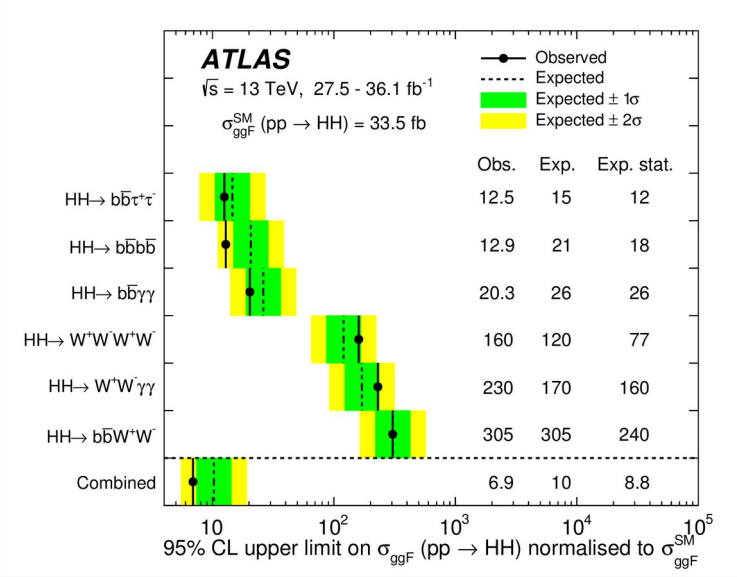
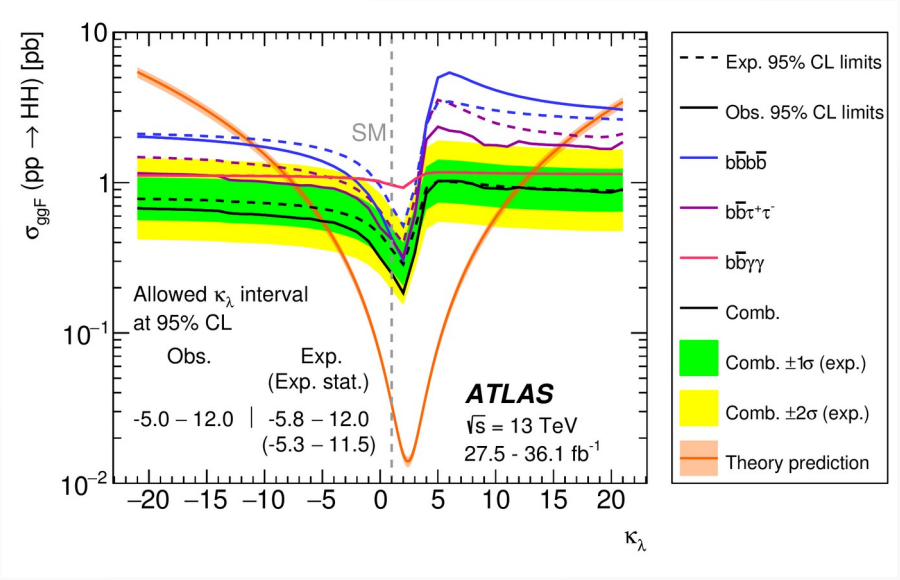
HH Combination Results





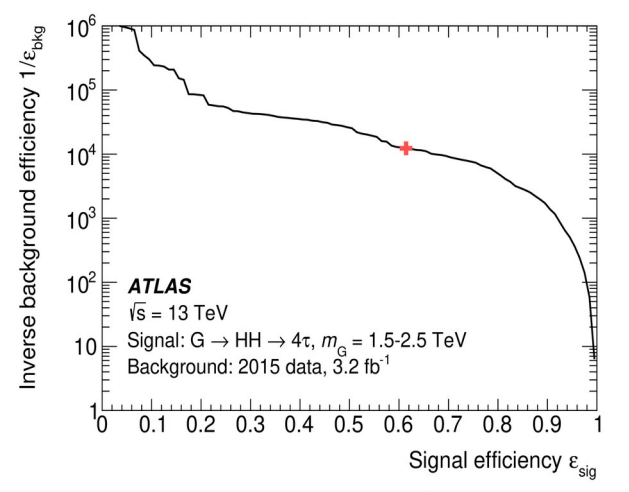
Non-resonant production combination results

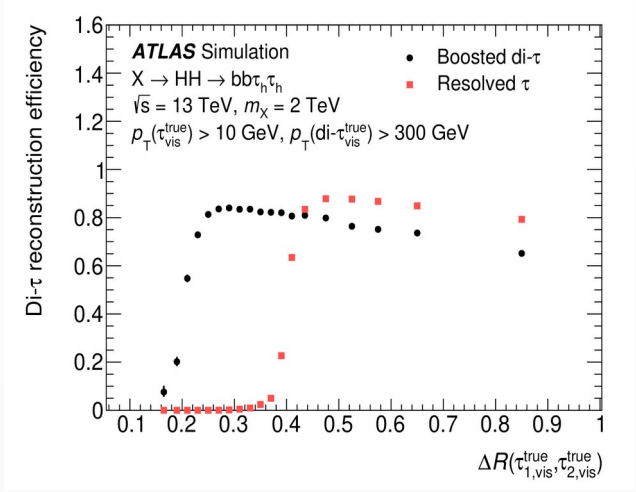


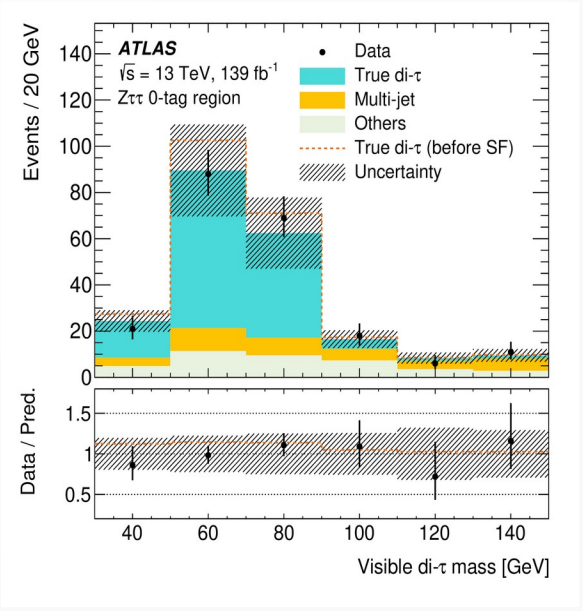


Di-τ tagging

- Decay of τ-pair (fully hadronic):
  - Reconstructed as an anti-kt R=1.0 jet with R=0.2 sub-jets.
  - Identified against quark/gluon initiated jets by BDT.
  - Tagging efficiency has been calibrated in dedicated analysis region.







bbττ Boosted Analysis