Non-resonant and resonant Di-Higgs searches at ATLAS and CMS

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On behalf of the *ATLAS* and *CMS* collaborations

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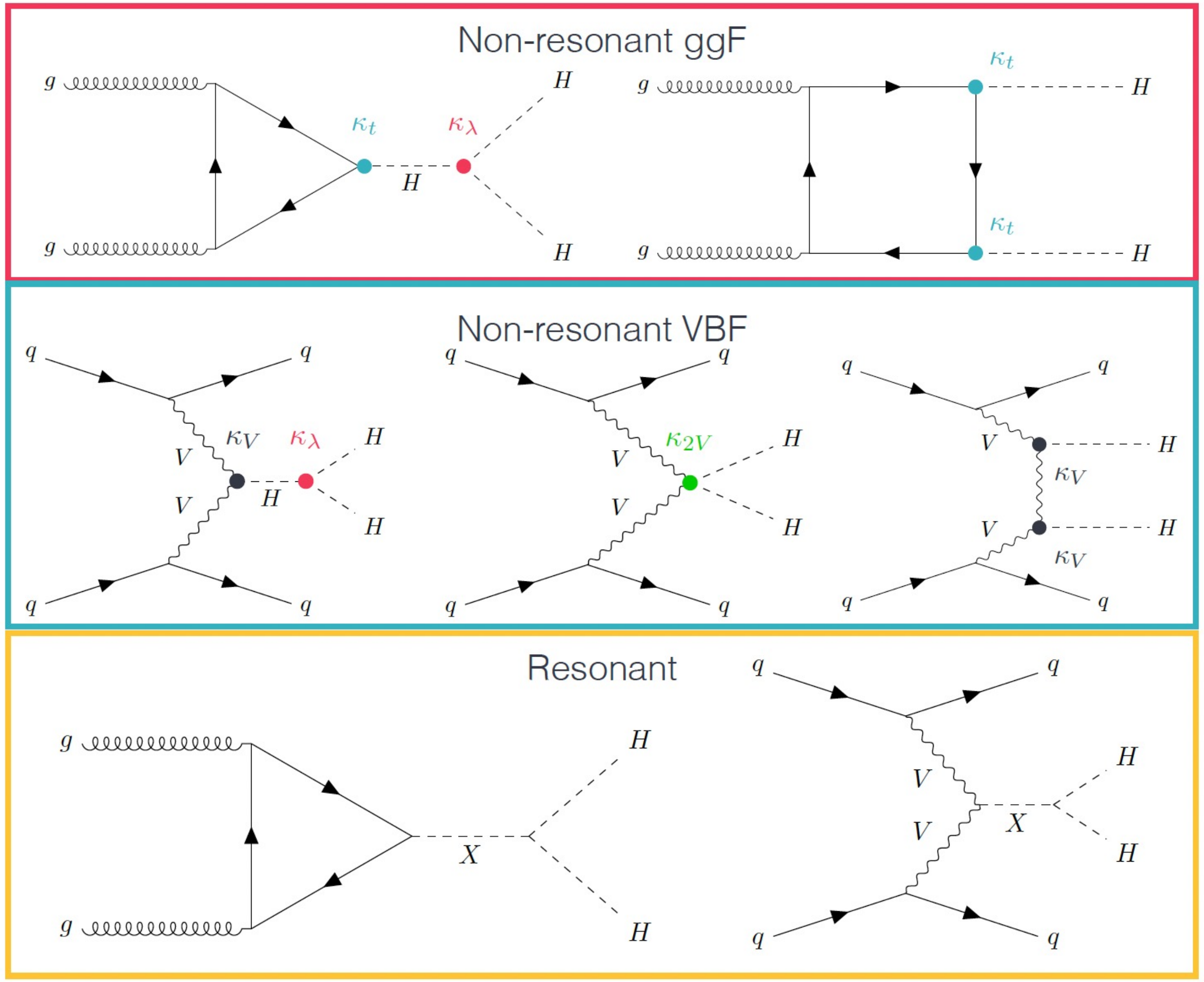
Introduction



Higgs pair production process gives access to the value of the Higgs self-coupling $\boldsymbol{\kappa_\lambda} (= \boldsymbol{\lambda_3} \,/\, \boldsymbol{\lambda_{3,SM}})$, which describes the shape of the Higgs potential:

$$V(H) = \frac{1}{2}\, m_H^2 H^2 + \lambda_3 H^3 + \frac{1}{4}\, \lambda_4 H^4 + O(H^5)$$

- Non-resonant $\boldsymbol{ggF}$ production mode:

  Destructive interference between the two diagrams

  $\rightarrow\ \sigma_{SM}^{ggF}(HH) = \mathbf{31.05\ fb} \quad @13TeV$

- Non-resonant $\boldsymbol{VBF}$ production mode:

  Unique sensitivity to $\boldsymbol{\kappa_{2V}}$, but more rare process

  $\rightarrow\ \sigma_{SM}^{VBF}(HH) = \mathbf{1.73\ fb} \quad @13TeV$

- Resonant process $\boldsymbol{X \rightarrow HH}$ is predicted by many extensions of the SM:

  electroweak singlet models, two-Higgs-doublet models, MSSM, …

HH decay modes

Larger BR from $H \rightarrow bb$ decay, required by the majority of analyses for one of the two H decays.
For the second Higgs, analyses focus on different decay modes, in particular the most used are:

- $\boldsymbol{b\bar{b}b\bar{b}}$: larger BR, but challenging backgrounds from multijet production
- $\boldsymbol{b\bar{b}WW}$: second leading BR, large $t\bar{t}$ background, searches in both semi-leptonic and di-leptonic final states
- $\boldsymbol{b\bar{b}\tau\tau}$ and $\boldsymbol{b\bar{b}ZZ}$: smaller BRs, leptons (e/μ) or hadronic-τ used for triggering depending on the final state
- $\boldsymbol{b\bar{b}\gamma\gamma}$: smallest BR but very sensitive analysis thanks to the excellent acceptance ($\gamma\gamma$ trigger) and reconstruction resolution

	bb	WW	ττ	ZZ	γγ
bb	33%				
WW	25%	4.6%			
ττ	7.4%	2.5%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
γγ	0.26%	0.10%	0.029%	0.013%	0.0005%

The most updated results in all channels will be presented, with emphasis on 2021 results, covering also the Resonant searches.

ATLAS $36\ fb^{-1}$ combined results

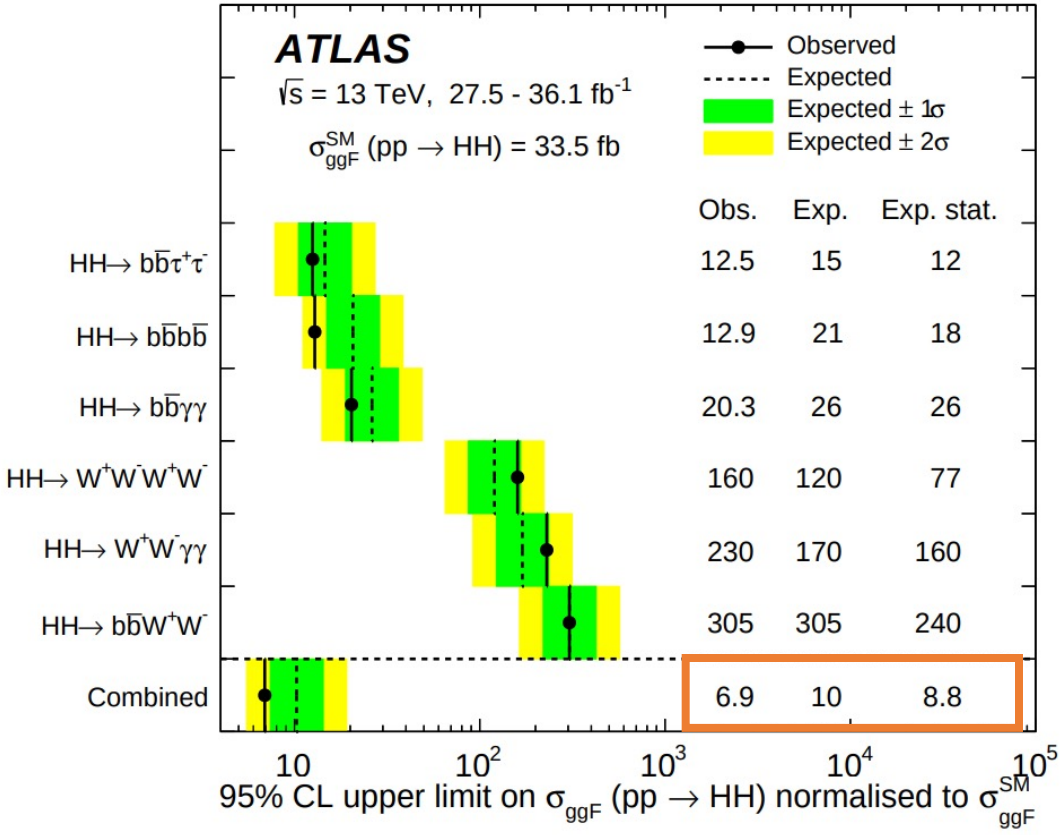
- Non-resonant Higgs pair production searched in six different decay channels:
  $b\bar{b}b\bar{b}$, $b\bar{b}\tau\tau$, $b\bar{b}\gamma\gamma$, $WWWW$, $WW\gamma\gamma$, $b\bar{b}WW$

- The 3 most sensitive channels have been combined obtaining a better limit on the HH cross section production

- New round of $b\bar{b}b\bar{b}$, $b\bar{b}\tau\tau$ and $b\bar{b}\gamma\gamma$ analyses with $139\ fb^{-1}$

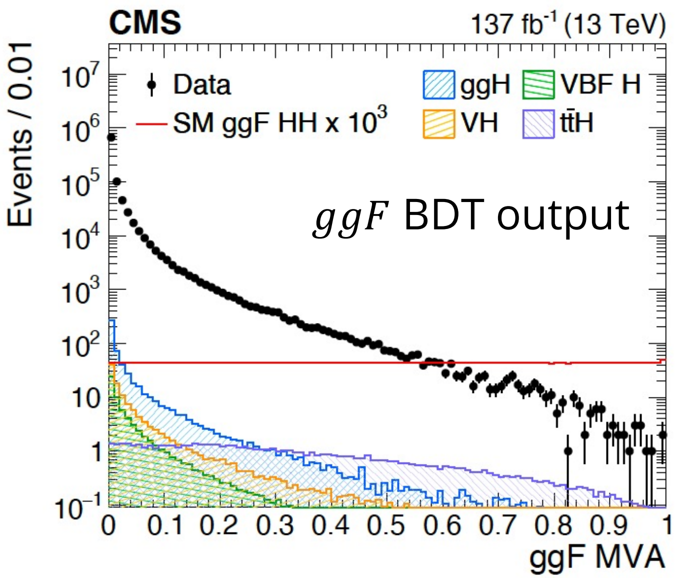
- New analyses focusing on (semi-) leptonic final states:
  $b\bar{b}WW$, $b\bar{b}\ell\ell$ and multilepton

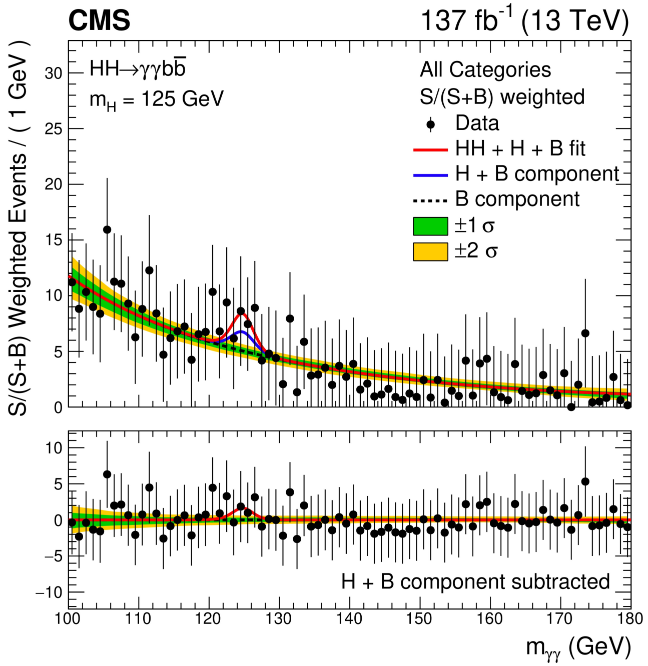
Physics Letters B 800 (2020) 135103



CMS $HH \rightarrow b\bar{b}\gamma\gamma$ $(137\ fb^{-1})$

- Two BDTs are used to discriminate ggF and $VBF\ HH$ signals from backgrounds
- Additional **Deep Neural Network (DNN)** to further improve the separation **against $t\bar{t}H$**
- 12 ggF and 2 $VBF\ HH$ optimised regions are defined from cuts on: BDT outputs and $\widetilde{M}_X = m_{b\bar{b}\gamma\gamma} - m_{b\bar{b}} - m_{\gamma\gamma} + 2m_H$
- Backgrounds estimated from 2D fit to $m_{\gamma\gamma}$ and m_{jj} side bands in all regions
- Maximum Likelihood fit to $m_{\gamma\gamma}$ and m_{jj} distributions to extract the HH signal





Observed (expected) limits at 95% CL:

- $\sigma^{HH}_{ggF+VBF} < 7.7\ (5.2) \times \sigma^{HH\ SM}_{ggF+VBF}$
- $-3.3\ (-2.5) < \kappa_\lambda < 8.5\ (8.2)$

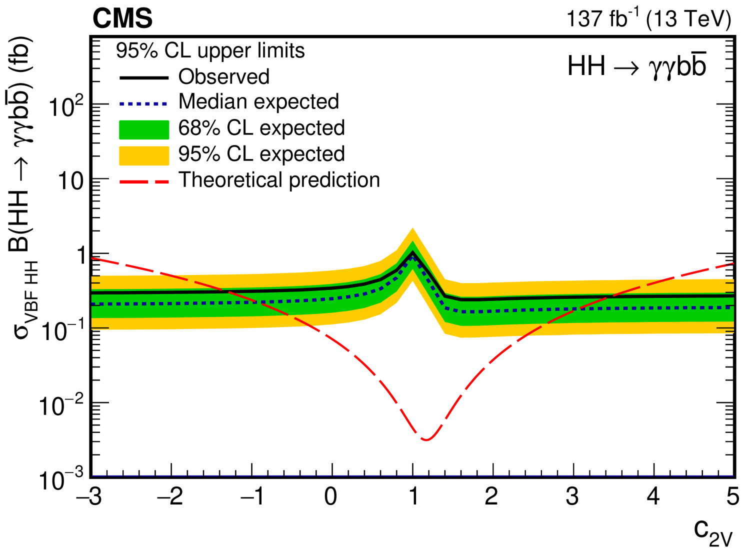
Stat. limited

Limits on σ^{HH}_{VBF} obtained fixing σ^{HH}_{ggF} to its SM value:

- $\sigma^{HH}_{VBF} < 225\ (208) \times \sigma^{HH\ SM}_{VBF}$
- $-1.3\ (-0.9) < \kappa_{2V} < 3.5\ (3.1)$

2D scans to the κ_t vs κ_λ and κ_{2V} vs κ_λ planes

$t\bar{t}H$ category added to improve the sensitivity to κ_t



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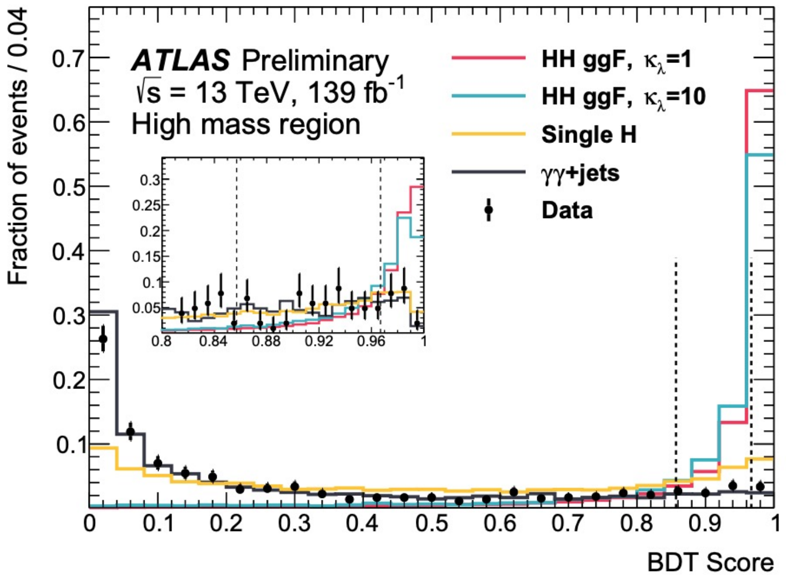
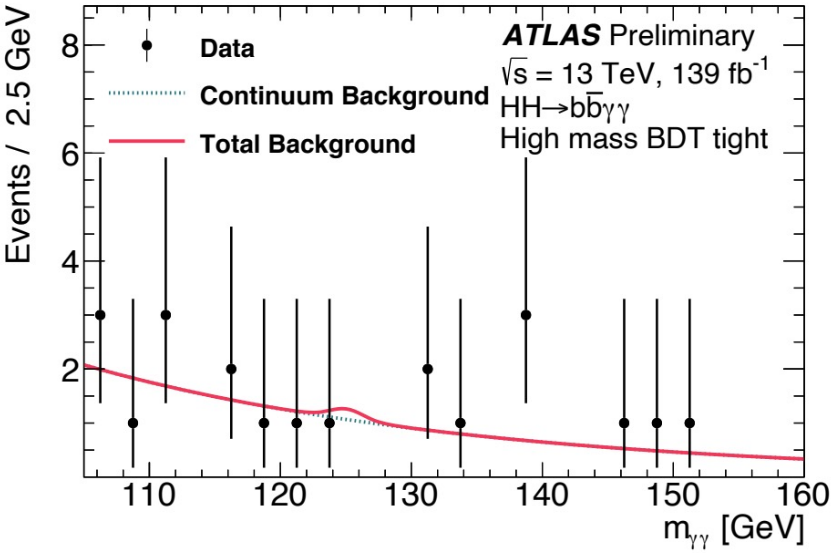
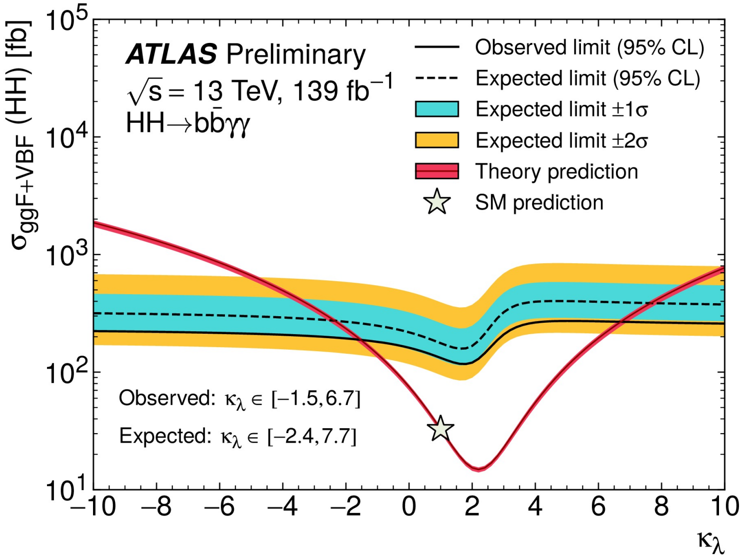
ATLAS $HH \to b\bar{b}\gamma\gamma$ $(139\ fb^{-1})$

- Cuts are on $m^*_{bb\gamma\gamma} = m_{bb\gamma\gamma} - m_{bb} - m_{\gamma\gamma} + 250\ GeV$ (high/low mass) and BDT scores (loose/tight), resulting in 4 categories
- BDT trained for each mass region vs $\gamma\gamma$, $t\bar{t}H$, ggH, and ZH backgrounds
- The analysis is optimised for $ggF\ HH$. However, $VBF\ HH$ events are also considered as signal
- Backgrounds estimated from fit to $m_{\gamma\gamma}$ side bands
- Fit to $m_{\gamma\gamma}$ in $105 < m_{\gamma\gamma} < 160\ GeV$ range in all the regions to extract HH signal







Observed (expected) limits at 95% CL:

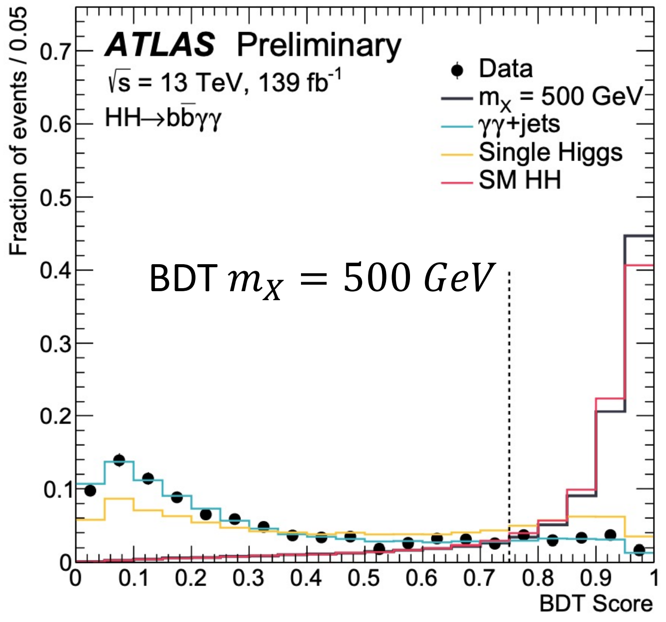
- $\sigma^{HH}_{ggF+VBF} < 4.1\ (5.5) \times \sigma^{HH\ SM}_{ggF+VBF}$
- $-1.5\ (-2.4) < \kappa_\lambda < 6.7\ (7.7)$

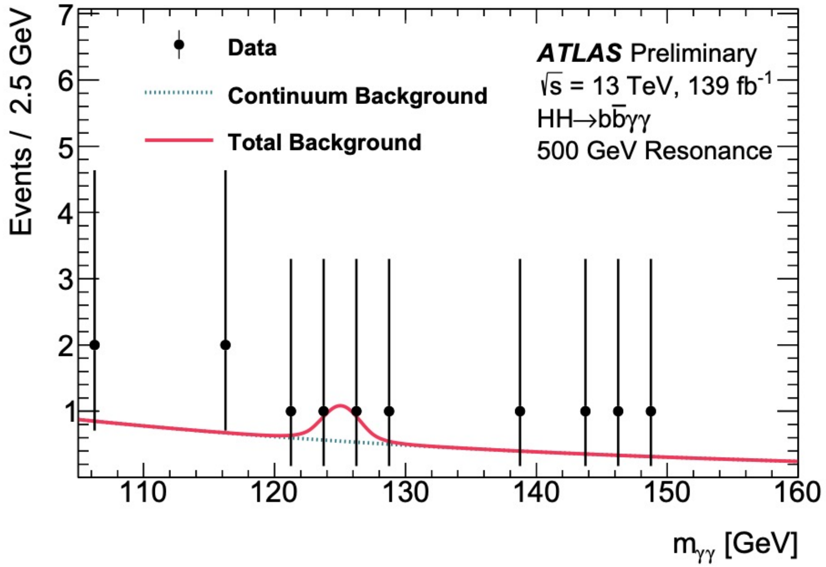
Statistically limited results

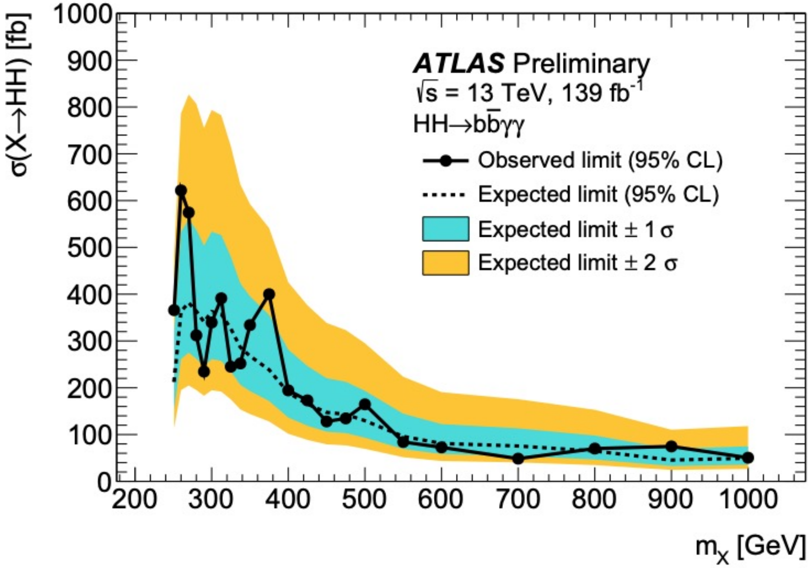
ATLAS-CONF-2021-016

ATLAS $X \to HH \to b\bar{b}\gamma\gamma$ (139 fb^{-1})

- Resonant analysis targeting $X \to HH \to b\bar{b}\gamma\gamma$ with masses m_X from 251 to 1000 GeV
- A single BDT is trained for all resonance masses with a two steps architecture:
  - First BDT to discriminate signal against $\gamma\gamma$ and $t\bar{t}\gamma\gamma$ backgrounds
  - Second BDT to discriminate signal against single Higgs background
  - Combined output used to define analysis regions, with mass-dependent cuts applied to define SRs for the different tested mass points
- Background estimate and fit procedure as in non-resonant analysis, with the SM HH expected signal counted together with the other backgrounds







ATLAS-CONF-2021-016

CMS $HH \rightarrow b\bar{b}b\bar{b}$ $(138\ fb^{-1})$

Resolved (ggF and VBF) and boosted (only VBF) analyses

Resolved (CMS-PAS-HIG-20-005):

- ggF and $VBF\ HH$ events are classified trough a BDT
- $\chi = \sqrt{(m_{H_1} - 125GeV)^2 + (m_{H_2} - 120GeV)^2}$ distance used to build SRs and CRs

Boosted (CMS-PAS-B2G-21-001):

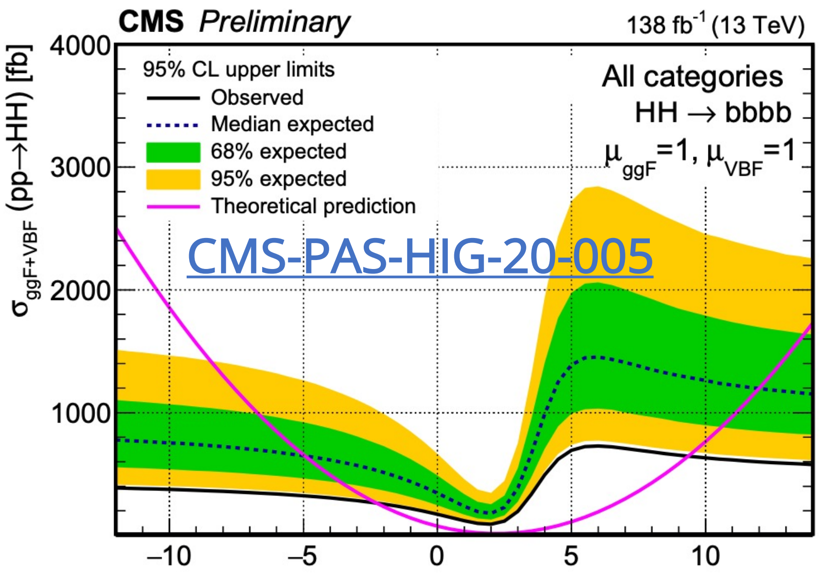
- ParticleNet multiclass classifier to discriminate between large-radius jets from $H \rightarrow b\bar{b}$ decays and those from QCD multijet processes
- 3 regions defined based on the MVA output: High, Medium and Low purity

❖ Large multijet background estimated from data

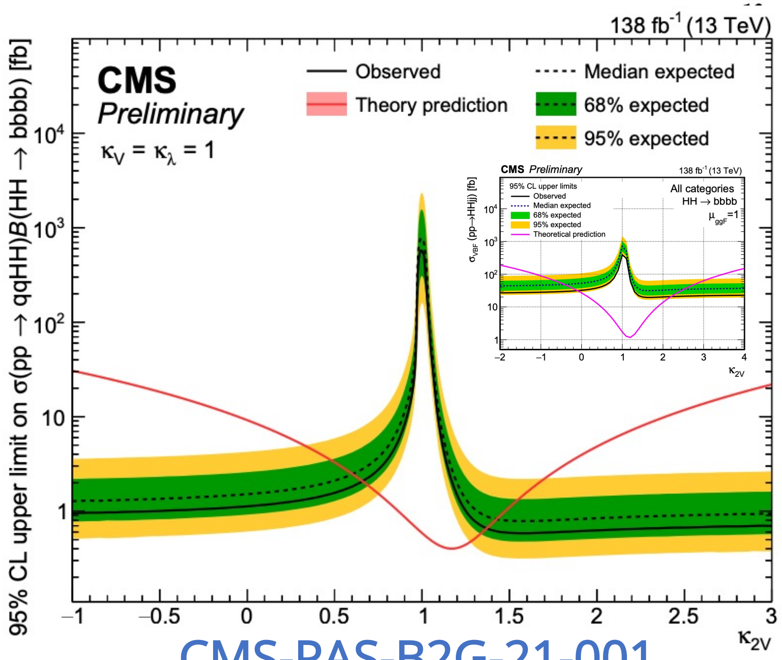
❖ Binned maximum likelihood fits done on all SRs and CRs to extract limits

Observed (expected) limits at 95% CL:

- $\sigma^{HH}_{ggF+VBF} < 3.6\ (7.3) \times \sigma^{HH\ SM}_{ggF+VBF}$
- $-2.3\ (-5.0) < \kappa_\lambda < 9.4\ (12.0)$
- $-0.1\ (-0.4) < \kappa_{2V} < 2.2\ (2.5)$
- $\mathbf{0.6\ (0.6) < \kappa_{2V} < 1.4\ (1.4)}$ **Boosted**



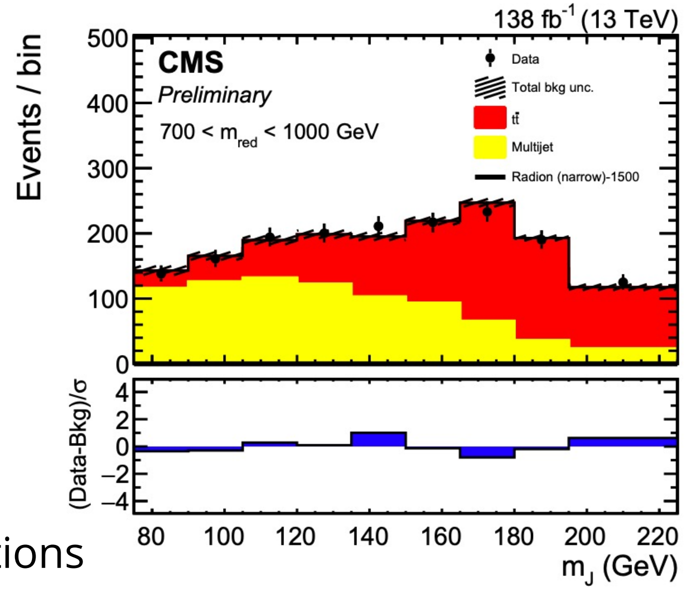
CMS-PAS-HIG-20-005

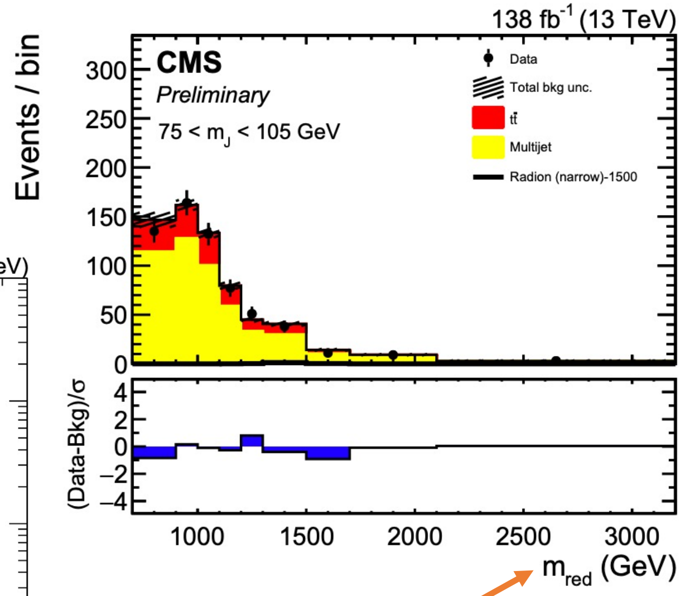


CMS-PAS-B2G-21-001

CMS $X \to HH \to b\bar{b}b\bar{b}$ (138 fb^{-1})

- Resonant analysis targeting massive BSM resonance X with a mass m_X of $1 - 3\ TeV$
- Fully boosted or semi-resolved topologies studied: 1 or 2 large-R jets in the event
- Merged $H \to b\bar{b}$ jets are identified with a DNN tagger, used also to categorize events
- Reduced mass variable m_{red} used to mitigate jet energy and mass resolution fluctuations
  Fully boosted analysis: $m_{red} = m_{JJ} - (m_J - m_H) - (m_{J2} - m_H) > 750\ GeV$
  Semi-resolved analysis: $m_{red} = m_{Jjj} - (m_J - m_H) - (m_{jj} - m_H) > 750\ GeV$
- Background: dominant QCD from data, $t\bar{t} + jets$ templates from MC fit to data in each bin of 2D (m_J, m_{red}) space.

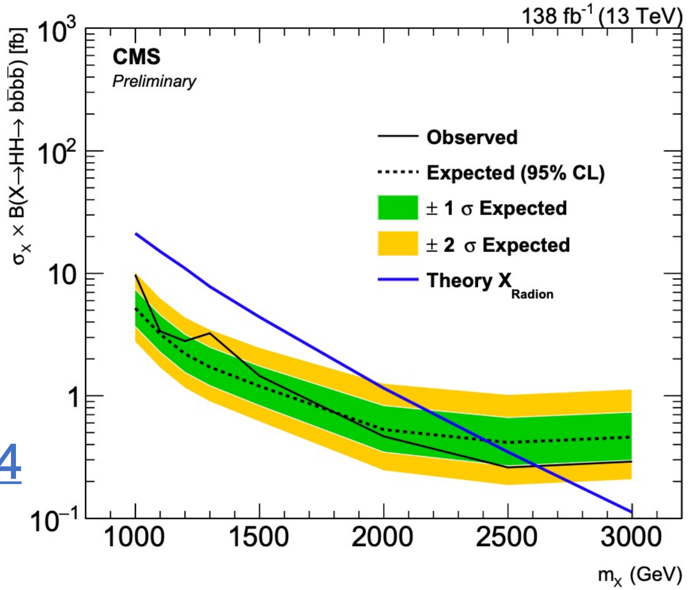


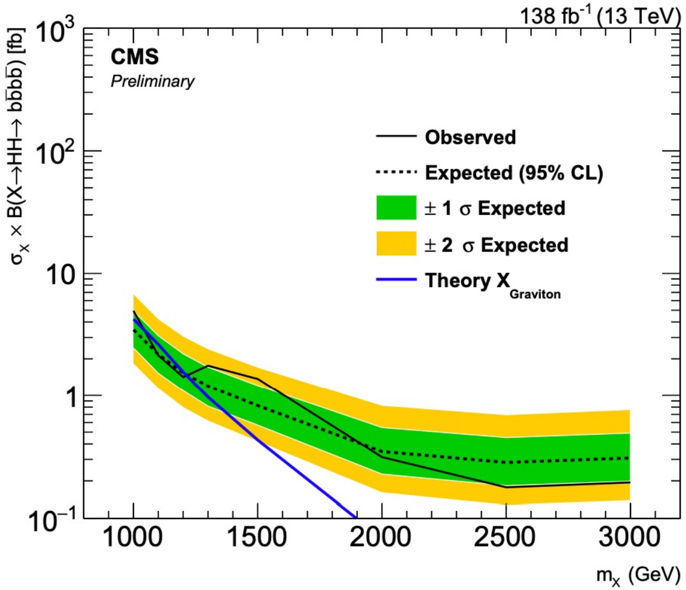


8 – 10% improvement in mass resolution

A likelihood fit to data, combining the different categories, is used to test the signal hypothesis

[CMS-PAS-B2G-20-004]





ATLAS $X \rightarrow HH \rightarrow b\bar{b}b\bar{b}$ $(126 - 139\ fb^{-1})$

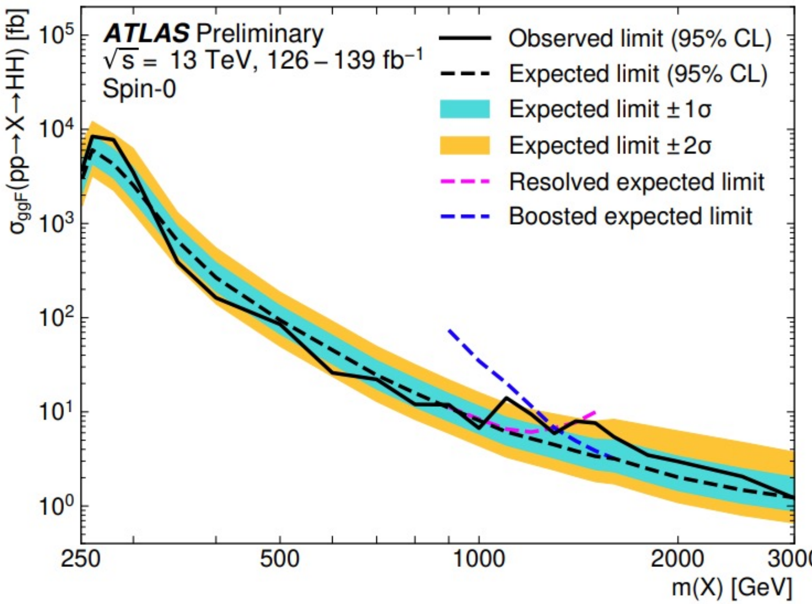
Resolved topology analysis:

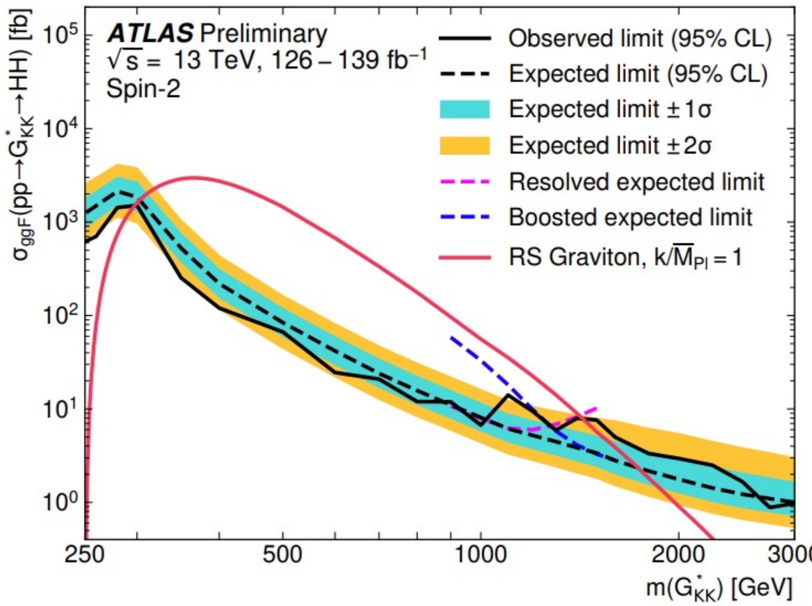
- Resonances ranging $m_X \in [251{,}1500]\ GeV$
- BDTs are used to pair b-jets
- Data-driven background (~95% multijet, rest $t\bar{t}$): NN reweighting correction applied

Boosted topology analysis:

- Resonances ranging $m_X \in [900{,}3000]\ GeV$
- At least two large-radius jet requirement
- B-tagging done with track-jets: 1 or 2 b-tags
- Three categories: 2b, 3b and 4b
- Multijet background is data-driven, tt from MC

❖ Signal regions are defined in m_{H_1}, m_{H_2} plane
❖ Fit done on m_{HH} distribution
❖ Limits set at 95% CL on spin-0 and spin-2 narrow resonance signal hypotheses





Most significant excess at $1100\ GeV$ with local (global) significance of:
$2.6\ \sigma\ (1.0\ \sigma)$ for spin-0
$2.7\ \sigma\ (1.2\ \sigma)$ for spin-2
signal models

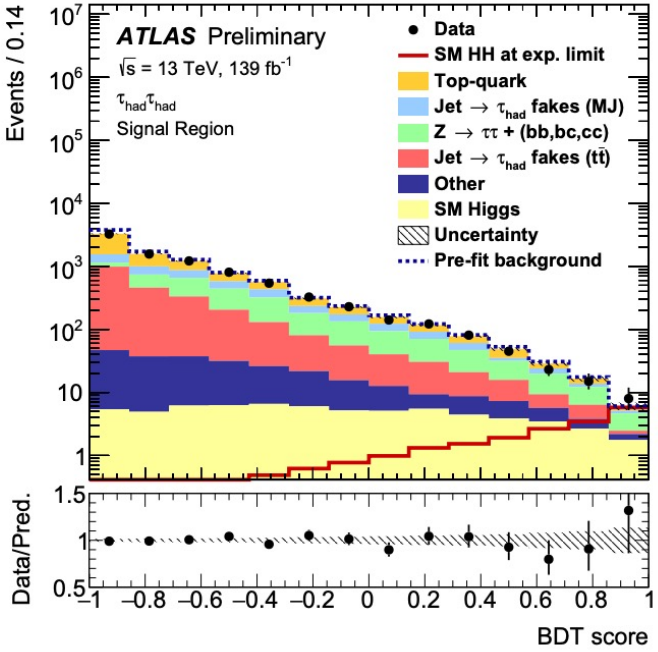
ATLAS-CONF-2021-030

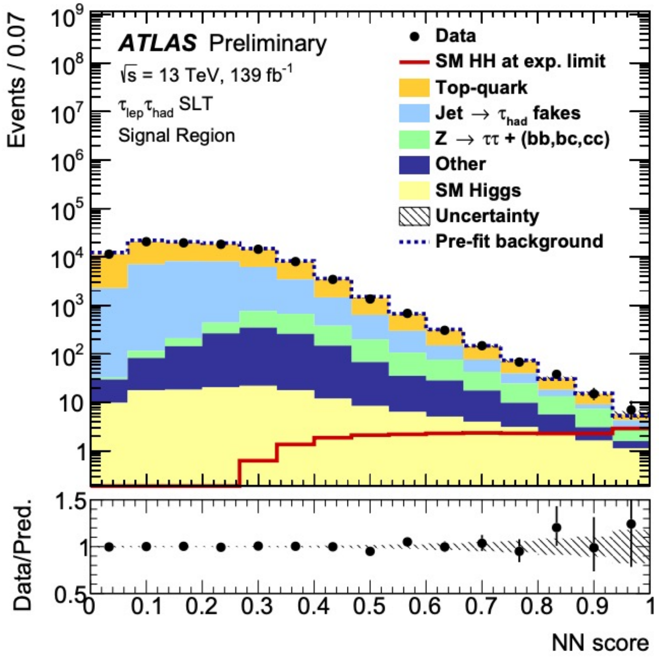
ATLAS $HH \rightarrow b\bar{b}\tau\tau$ (139 fb^{-1})

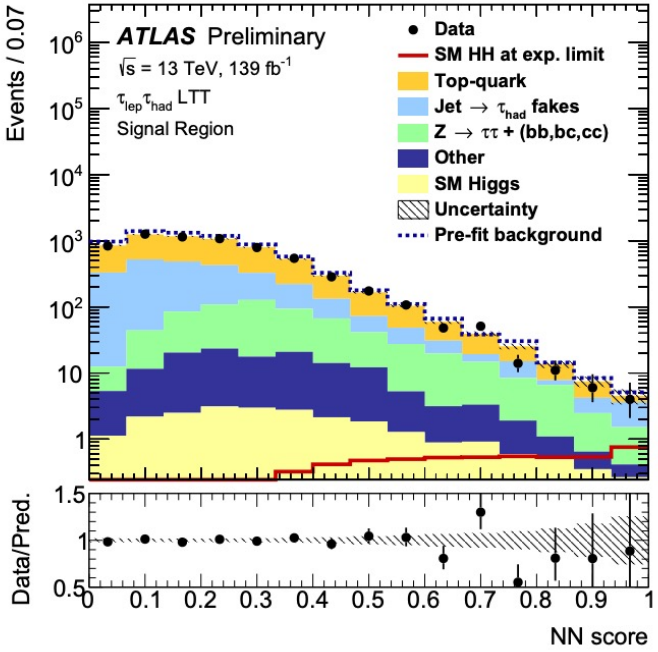
- Semi-leptonic and full hadronic τ decays are considered: $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$
- Triggers: single-tau or di-tau for $\tau_{had}\tau_{had}$, single-lepton (SLT) or lepton+tau (LTT) triggers for $\tau_{lep}\tau_{had}$
- MVA analysis strategy: BDT in $\tau_{had}\tau_{had}$ category, NN in $\tau_{lep}\tau_{had}$ categories (split per trigger type)
- Fake-tau background estimated from data
- Maximum Likelihood fit on MVA output distributions in the three event categories, and to the m_{ll} distribution in the $Z + HF$ CR

Observed (expected) limits at 95% CL:

➢ $\sigma^{HH}_{ggF+VBF} < 4.7\ (3.9) \times \sigma^{HH\ SM}_{ggF+VBF}$ combining all the categories

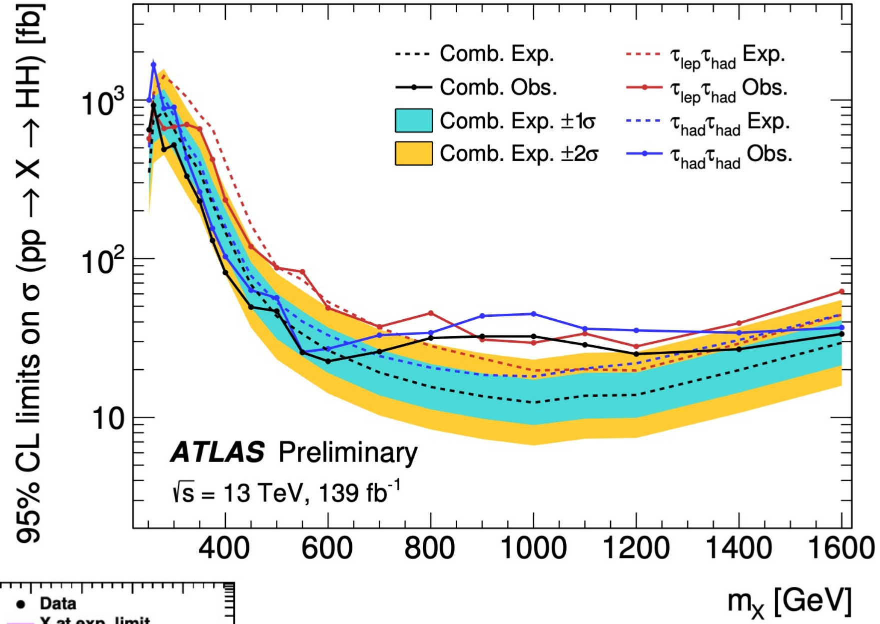


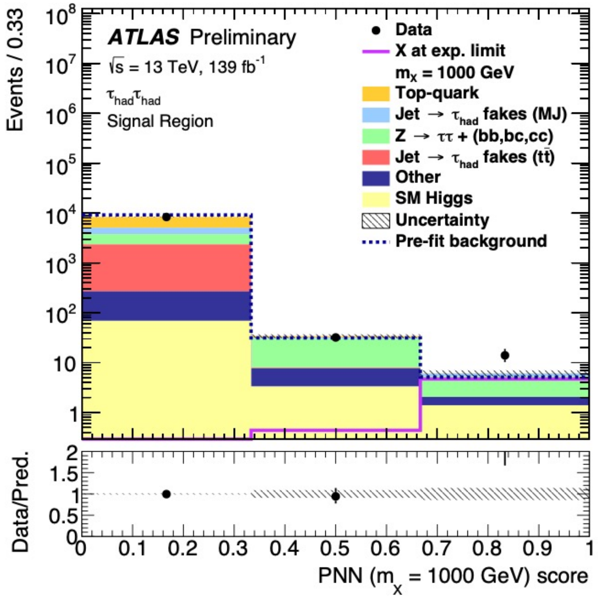


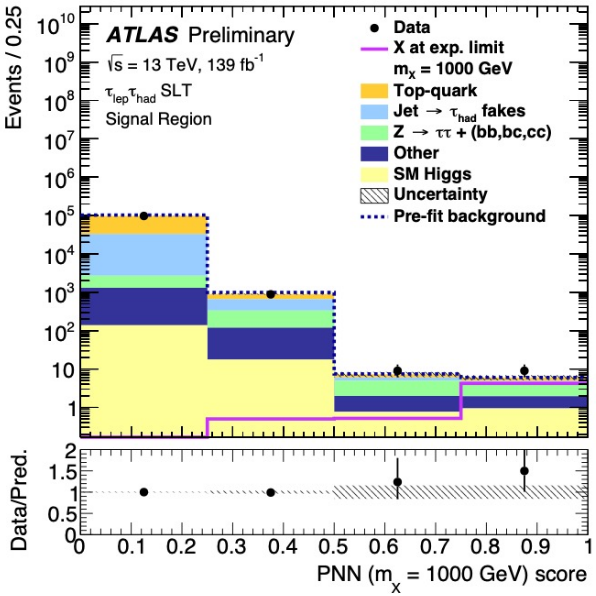


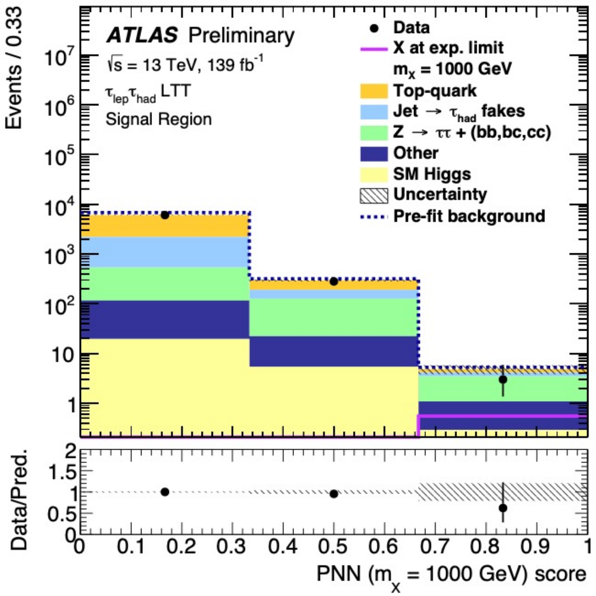
ATLAS $X \to HH \to b\bar{b}\tau\tau$ (139 fb^{-1})

- Resonant HH production search targeting resonance masses m_X between 260 and 1600 GeV
- Same event selection and categorization of the non-resonant analysis
- Parametrised Neural Network (PNN) in the mass of the heavy resonance
- Same background modelling and fakes estimation of non-resonant analysis
- Maximum Likelihood fit on PNN output distributions in the three event categories, and to the m_{ll} distribution in the $Z + HF$ CR







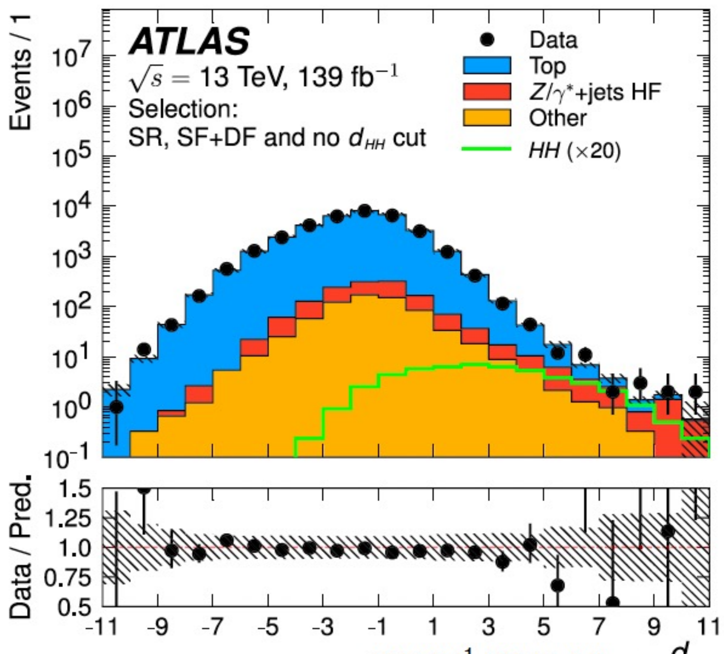


At $m_X = 1\ TeV$ found the largest excess with a local (global) significance of $3.0\ \sigma\ (2.0^{+0.4}_{-0.2}\ \sigma)$

$HH \rightarrow b\bar{b}WW/ZZ$ searches

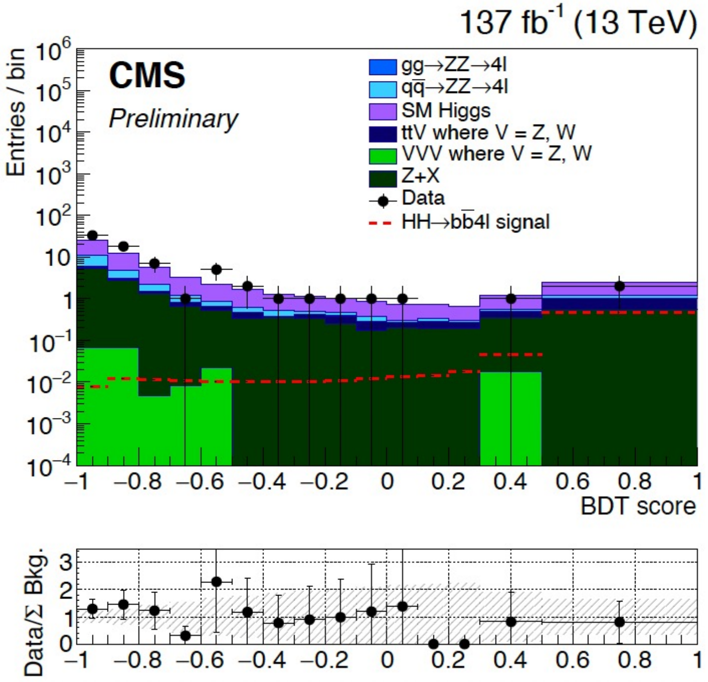
ATLAS $HH \rightarrow b\bar{b}\ell\ell$ analysis ($139\ fb^{-1}$ Phys.Lett. B 801(2020)135145):

- 90% of total signal yield in SR from $b\bar{b}WW$, 9% $b\bar{b}\tau\tau$ and 1% $b\bar{b}ZZ$
- Multi-class NN trained on ggF signal vs Top, $Z/\gamma^* \rightarrow \ell\ell$ and $Z/\gamma^* \rightarrow \tau\tau$
- Fit on combined NN output d_{HH}: $\sigma_{ggF}^{HH} < 40\ (29) \times \sigma_{ggF}^{HH\ SM}$ at 95% CL



CMS $HH \rightarrow b\bar{b}ZZ \rightarrow b\bar{b}4\ell$ analysis ($137\ fb^{-1}$ [CMS PAS HIG-20-004](CMS PAS HIG-20-004)):

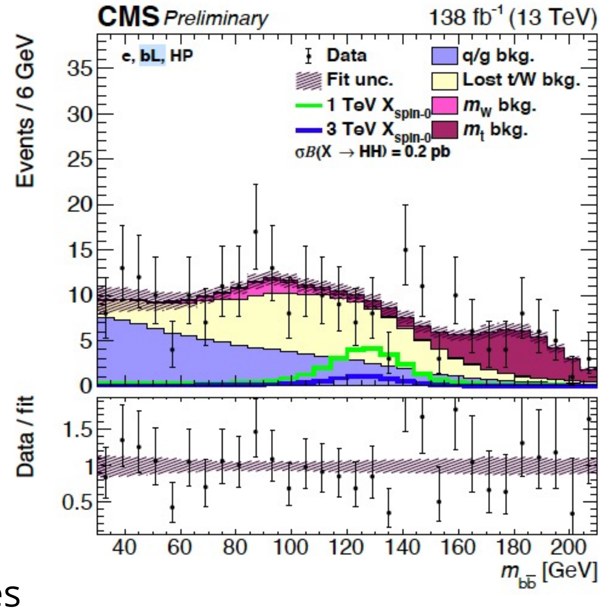
- 9 BDTs trained (for each data taking year and lepton flavour $4e/4\mu/2e2\mu$)
- Fit on BDT outputs: $\sigma_{ggF}^{HH} < 30\ (37) \times \sigma_{ggF}^{HH\ SM}$ at 95% CL

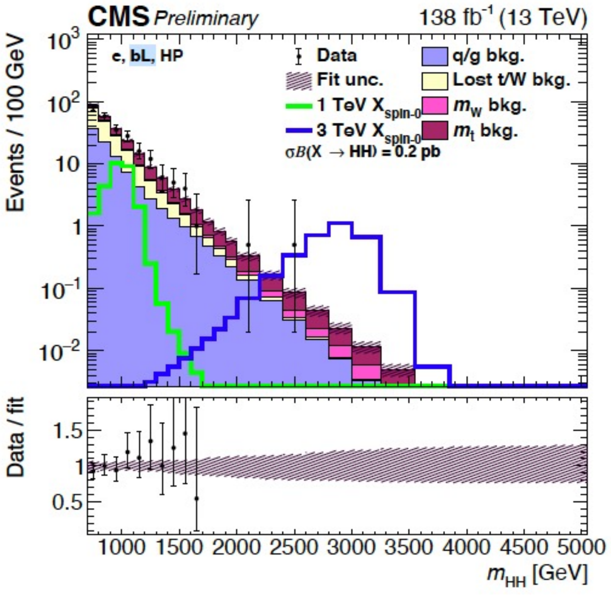


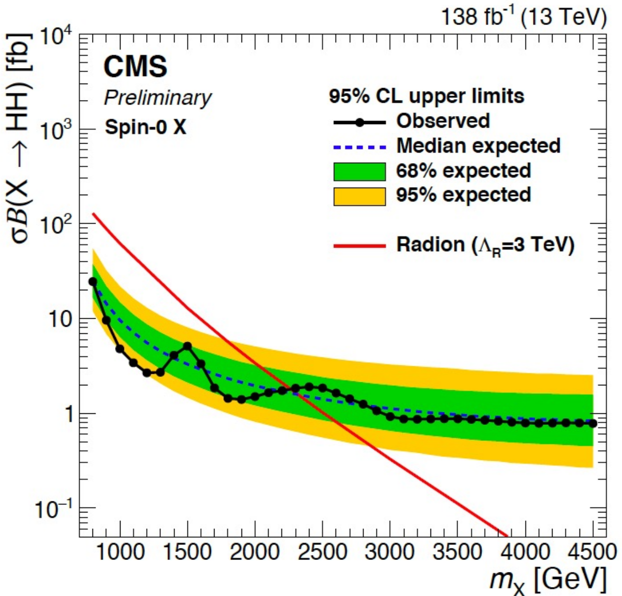
ATLAS $b\bar{b}WW$ 1-lepton analysis (published in JHEP 04 (2019) 092 with $36\ fb^{-1}$) is under re-optimisation with full Run2 dataset using MVA approach to deeply improve the previous limit of $305 \times \sigma_{ggF}^{HH\ SM}$ at 95% CL

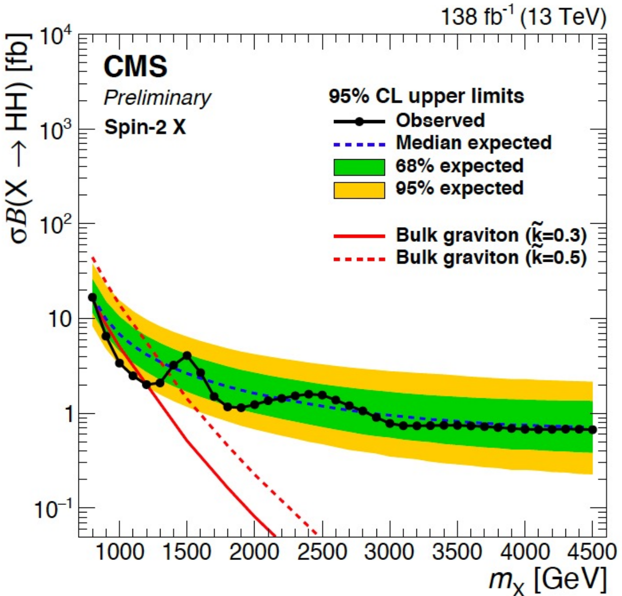
CMS $X \to HH \to b\bar{b}qql\nu$ or 2ℓ ($138\ fb^{-1}$)

- Single lepton and dilepton final states: $HH \to b\bar{b}WW^* \to b\bar{b}qql\nu$ or $b\bar{b}l\nu l\nu$, $HH \to b\bar{b}\tau\tau \to b\bar{b}l\nu\nu l\nu\nu$
- m_X between 800 GeV and 4.5 TeV: $H \to bb$ boosted → AKT8 jet
- 1-lepton channel:
  - Boosted $W \to qq$ decay reconstructed with 1 large-radius jet
  - Likelihood-based reconstruction of $H \to WW^*$ 4-momentum
  - Events divided in e/μ categories
- 2-lepton channel:
  - Events split in same-flavour (SF) and opposite-flavour (OF) categories





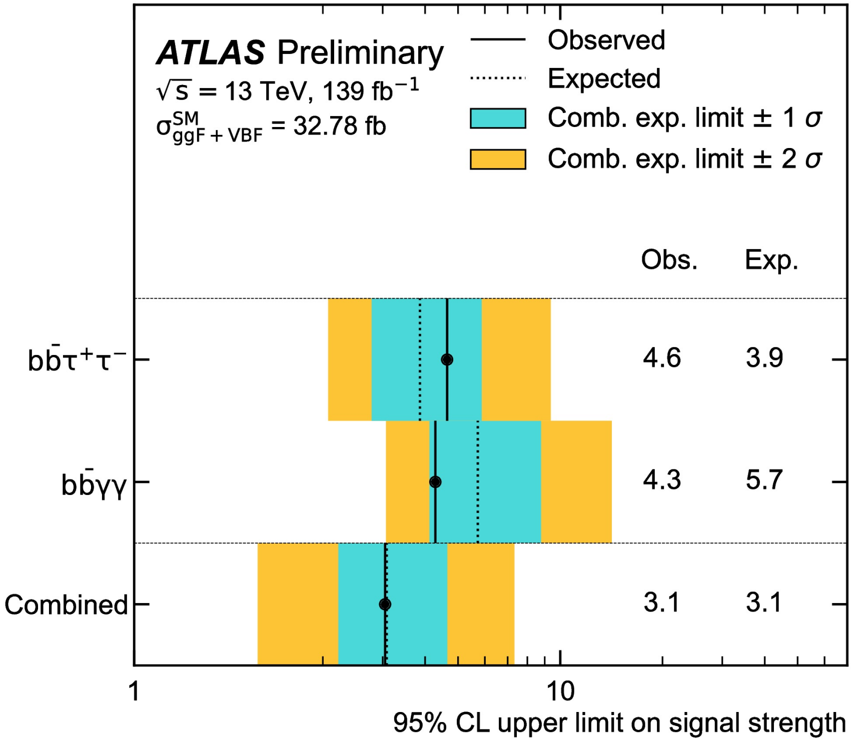


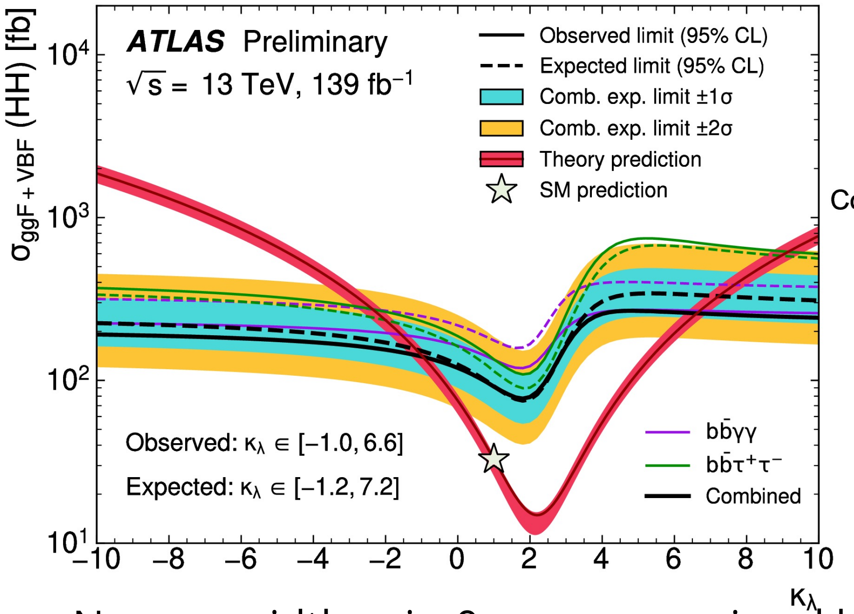


- Additional categorization for loose/tight (bL/bH) bb-tagging and low/high-purity (LP/HT) of the $W \to qq$ jet substructure → 12 regions in total
- $t\bar{t}$, $W + jets$ and multijet backgrounds from MC templates
- Simultaneous 2D fit on m_{bb} and m_X distributions in all the regions
- 95% CL limits set for spin-0 and spin-2 resonance masses

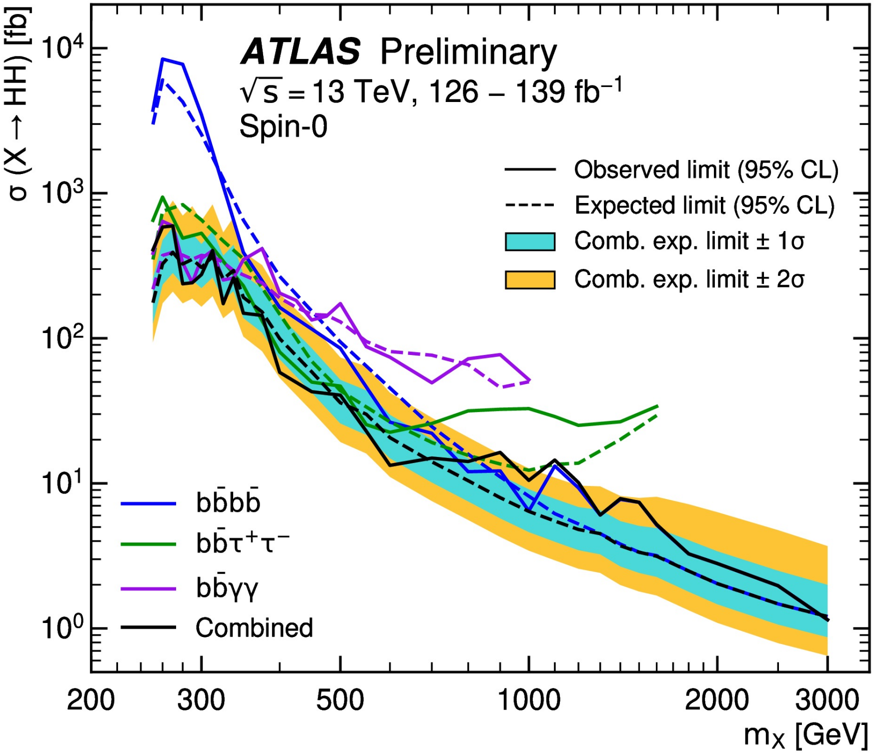
ATLAS combination

- Preliminary combination of the non-resonant and resonant HH searches
- The combination of $\boldsymbol{b\bar{b}\tau\tau}$ and $\boldsymbol{b\bar{b}\gamma\gamma}$ full Run2 non-resonant analyses leads to improved observed (expected) limits at 95% CL:
  - $\boldsymbol{\sigma^{HH}_{ggF+VBF} < 3.1\ (3.1) \times \sigma^{HH\,SM}_{ggF+VBF}}$
  - $\boldsymbol{-1.0\ (-1.2) < \kappa_\lambda < 6.6\ (7.2)}$





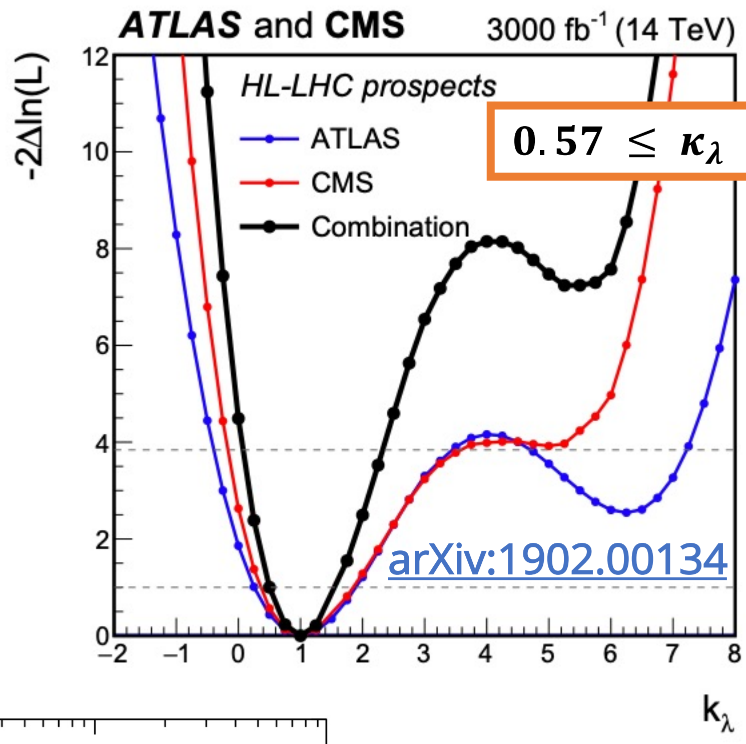
ATLAS-CONF-2021-052



- Narrow-width spin-0 resonance signal hypothesis tested in $\boldsymbol{b\bar{b}b\bar{b}}$, $\boldsymbol{b\bar{b}\tau\tau}$ and $\boldsymbol{b\bar{b}\gamma\gamma}$ ATLAS analyses
- Each analysis lead the combined sensitivity in different m_X regions between 251 GeV and 3 TeV
- Largest excess at 1.1 TeV with local (global) significance of 3.2 σ(2.1 σ)

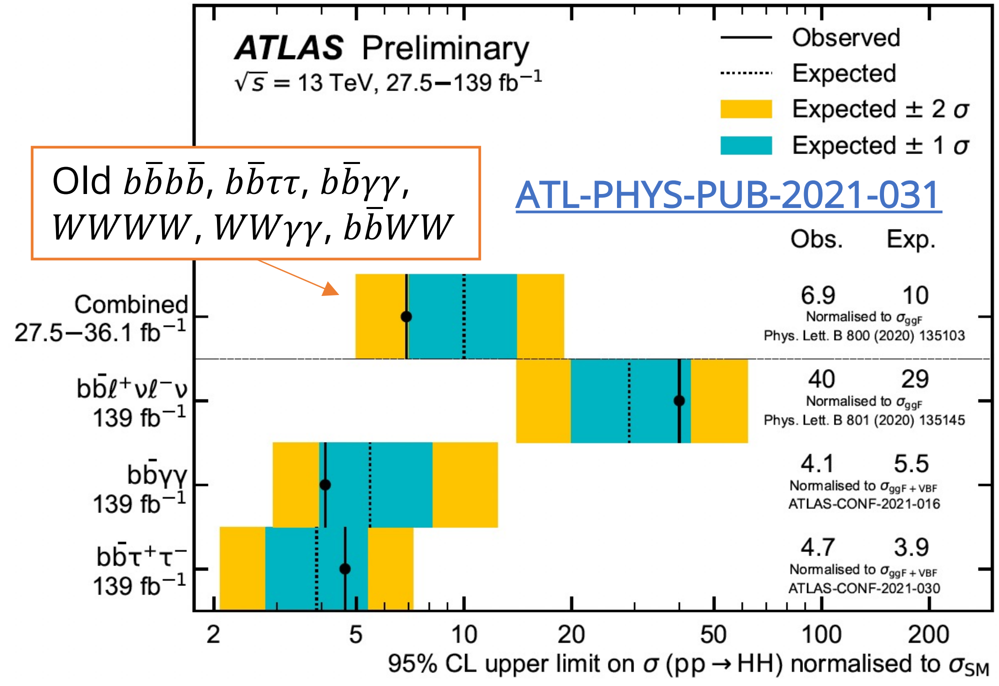
Summary

- Many new results in different HH decay channels released this year! And more channels coming soon!!!
- Improved limits with larger statistics and new MVA analysis techniques
- VBF production mode now accessible and results on κ_{2V} released
- Resonant HH limits improved with MVA boosted topology reconstruction
- Prospects done scaling partial-Run2 results to High-Lumi statistics



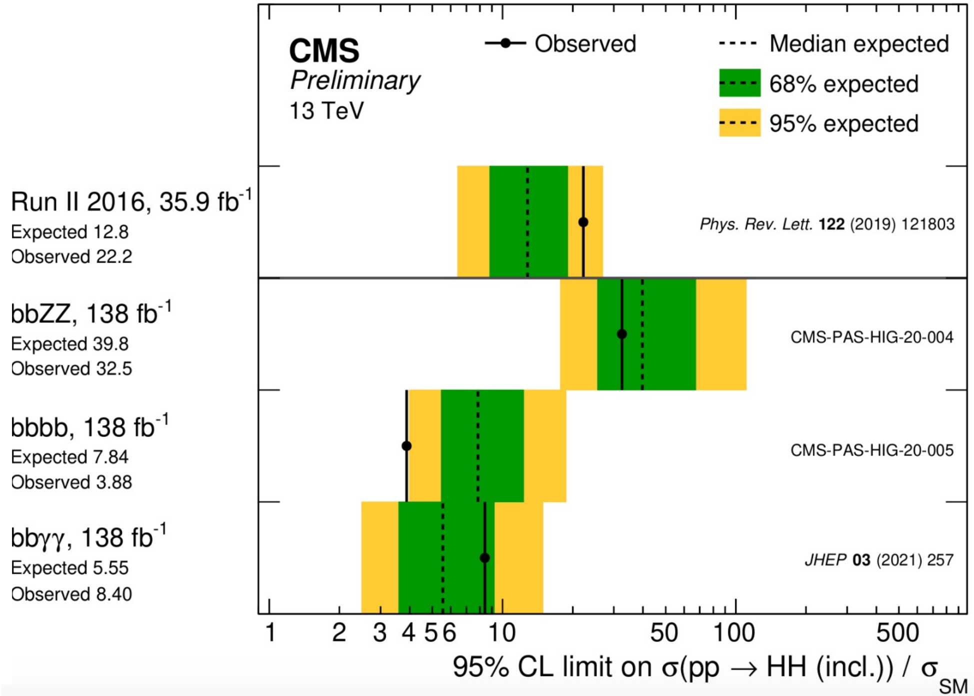
$0.57 \leq \kappa_\lambda \leq 1.5$

arXiv:1902.00134



Old $b\bar{b}b\bar{b}$, $b\bar{b}\tau\tau$, $b\bar{b}\gamma\gamma$, $WWWW$, $WW\gamma\gamma$, $b\bar{b}WW$

ATL-PHYS-PUB-2021-031



Now finishing the last analyses and combinations

Then looking forward to Run3 and High-Lumi!!

Backup

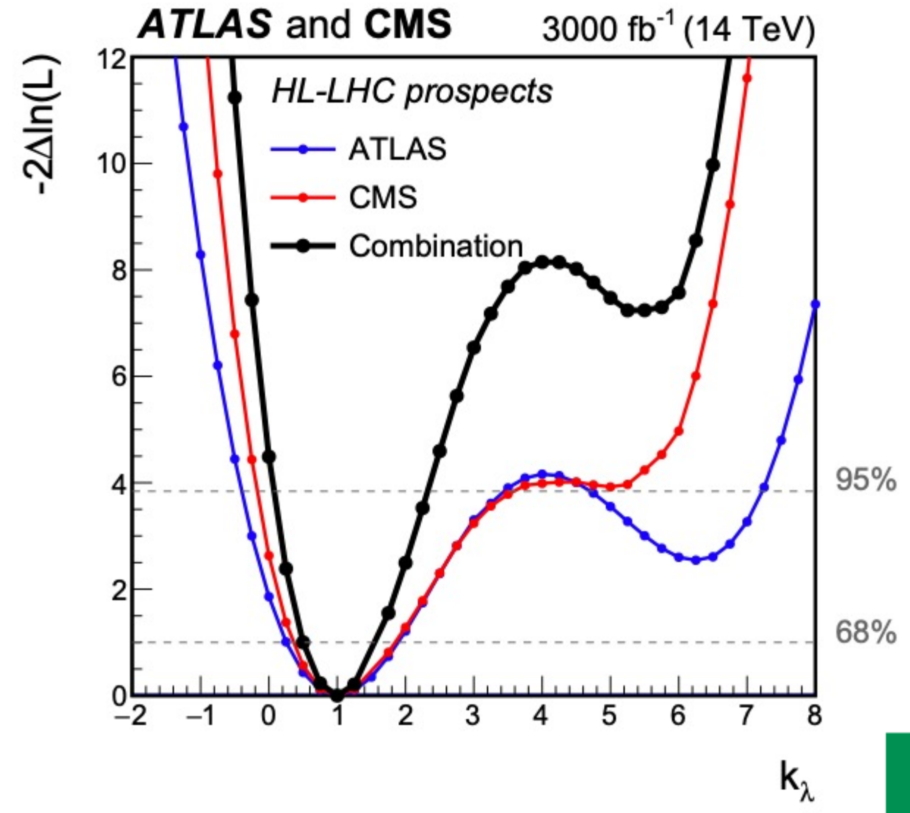
ATLAS+CMS prospects for HL-LHC

arXiv:1902.00134

- Scaling sensitivity of partial Run2 analyses (2015-2016) to $L = 3000 fb^{-1}$ and $\sqrt{s} = 14\, TeV$
- Combination done using most sensitive ATLAS and CMS analyses

$0.57 \le \kappa_\lambda \le 1.5$ with syst. unc.
Second minimum excluded at 99.4% CL

	Statistical-only		Statistical + Systematic	
	ATLAS	CMS	ATLAS	CMS
$HH \to b\bar{b}b\bar{b}$	1.4	1.2	0.61	0.95
$HH \to b\bar{b}\tau\tau$	2.5	1.6	2.1	1.4
$HH \to b\bar{b}\gamma\gamma$	2.1	1.8	2.0	1.8
$HH \to b\bar{b}VV(ll\nu\nu)$	-	0.59	-	0.56
$HH \to b\bar{b}ZZ(4l)$	-	0.37	-	0.37
combined	3.5	2.8	3.0	2.6
Significance in standard deviations	Combined 4.5		Combined 4.0	

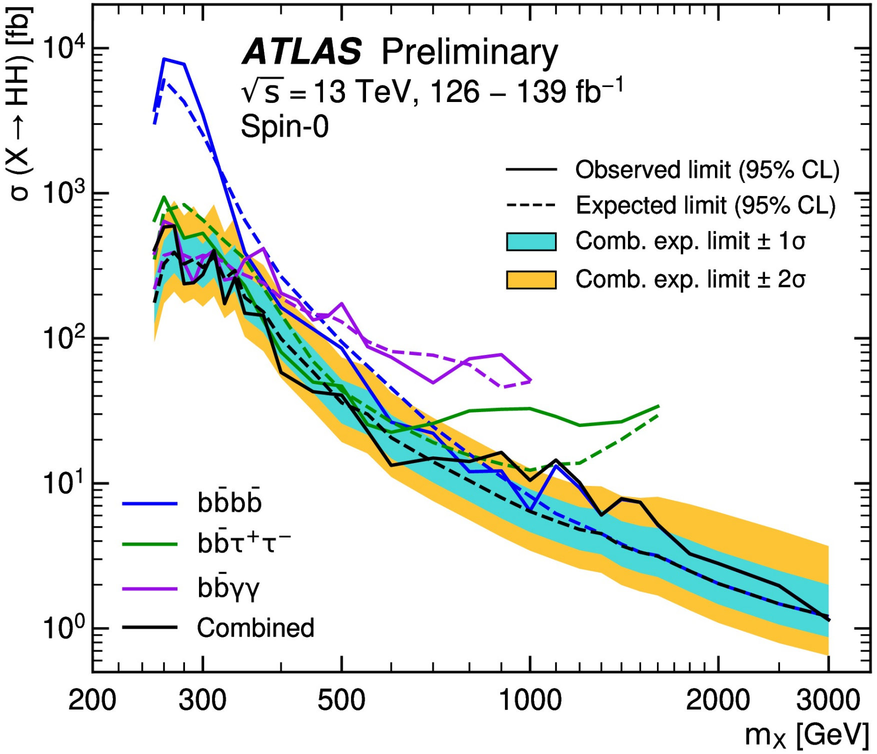


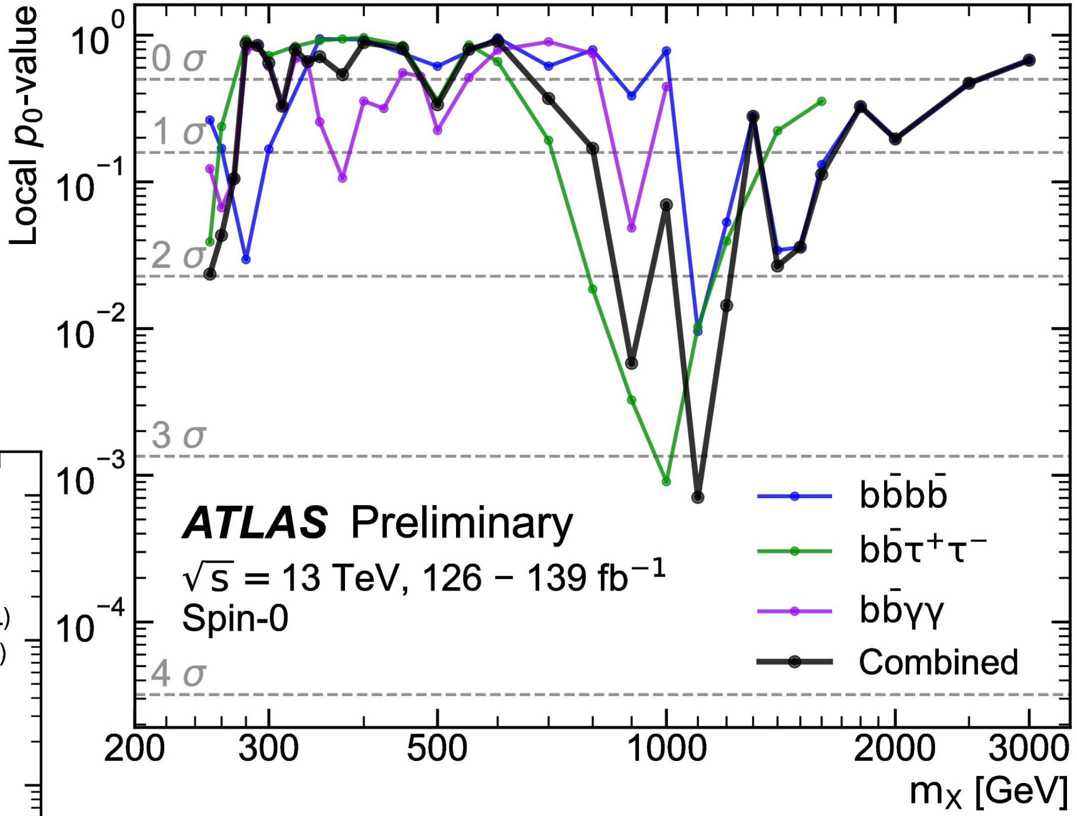
Improvements are going beyond the increase of luminosity:

- Improving performance
- Reducing systematic uncertainties (experimental and theoretical)
- Improving analysis techniques

ATLAS Run2 Resonant searches combination

- Local p0-value as a function of the heavy resonance mass m_X for the spin-0 resonance model
- Each curve represents the p_0-value corresponding to the single $\boldsymbol{b\bar{b}b\bar{b}}$, $\boldsymbol{b\bar{b}\tau\tau}$, $\boldsymbol{b\bar{b}\gamma\gamma}$ analyses, as well as the p_0-value resulting from statistical combination of the different analyses
- The largest excess in the combined limit is found at $m_X = 1.1\ TeV$ and it corresponds to a local (global) significance of $3.2\ \sigma\ (2.1\ \sigma)$



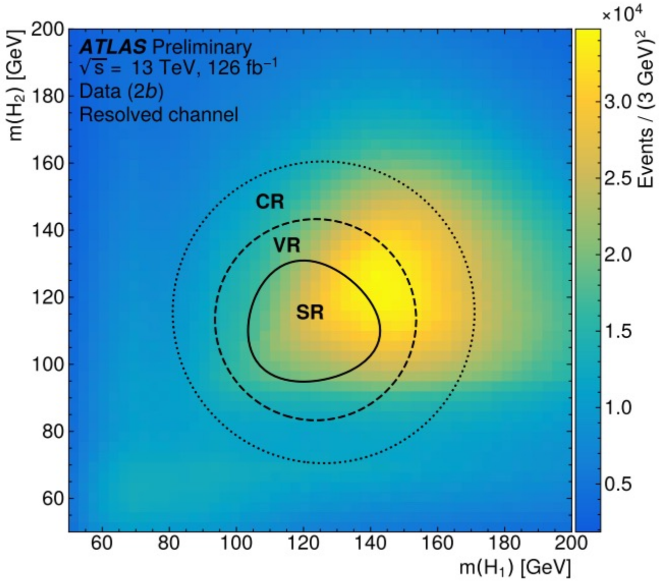


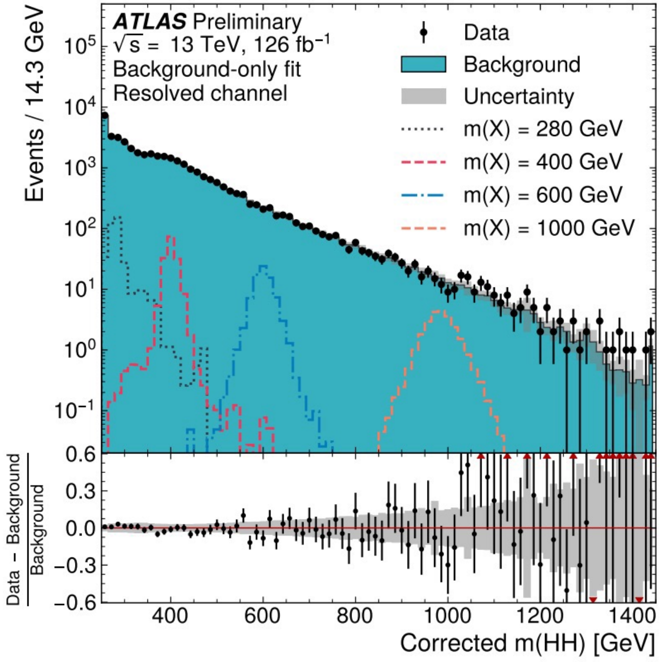
ATLAS-CONF-2021-052

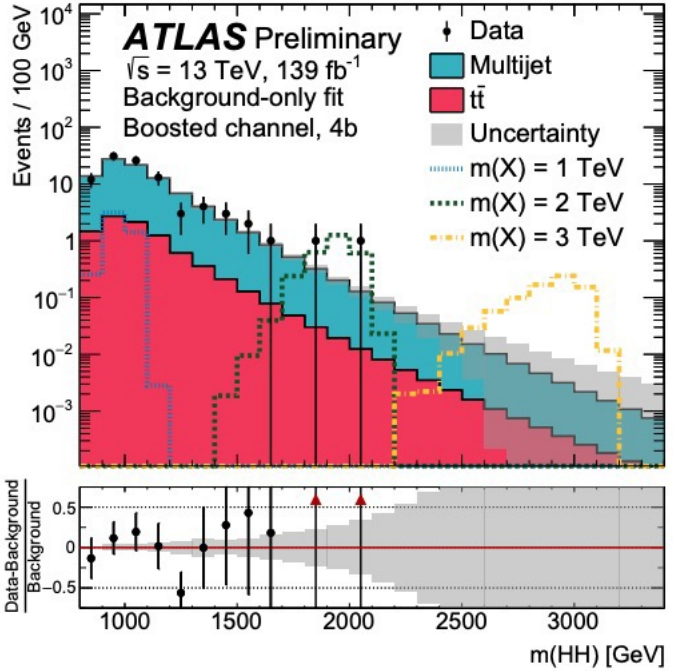
ATLAS $X \to HH \to b\bar{b}b\bar{b}$ $(126-139\ fb^{-1})$

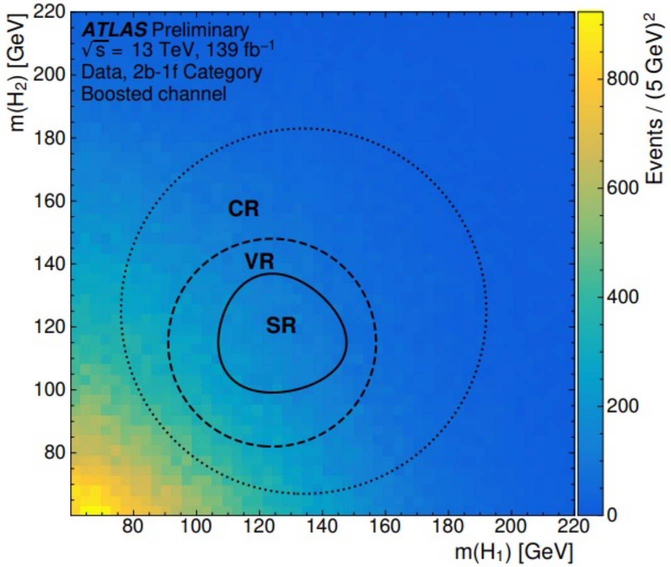
ATL-CONF-2021-035

- Signal regions are defined in m_{H_1}, m_{H_2} plane
- Fit done on m_{HH} distribution
- Limits set at 95% CL on spin-0 and spin-2 narrow resonance signal hypotheses
- Most significant excess at $1100\ GeV$ with local (global) significance of $2.6\ \sigma\ (1.0\ \sigma)$ for spin-0 and $2.7\ \sigma\ (1.2\ \sigma)$ for spin-2 signal model

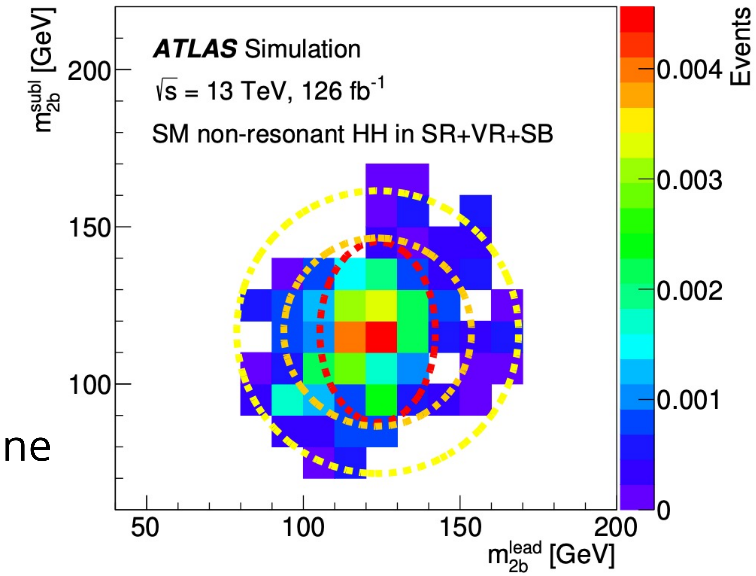








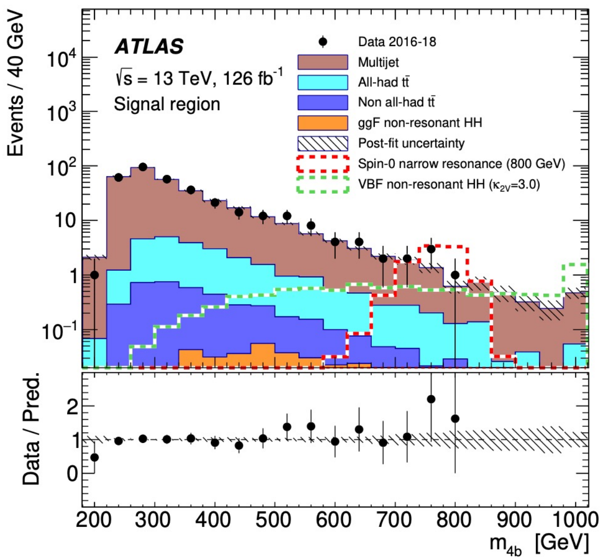
ATLAS $VBF\ HH \rightarrow b\bar{b}b\bar{b}$ $(126\ fb^{-1})$

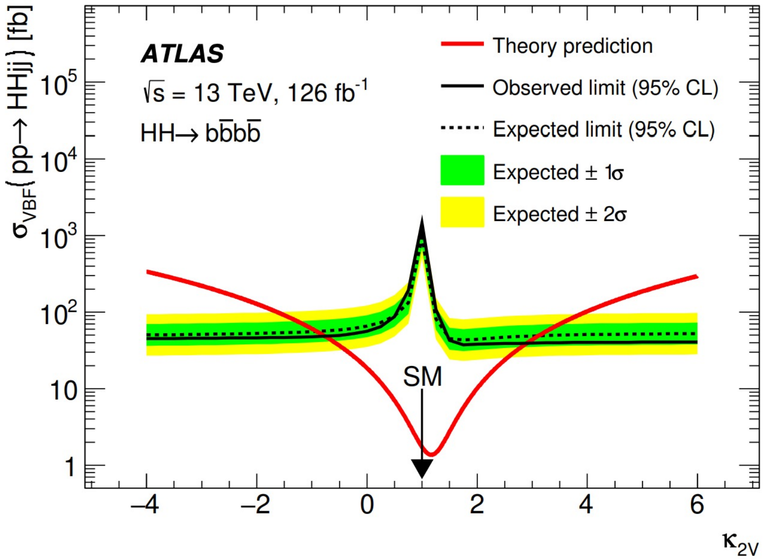


- $VBF\ HH$ candidates selected requiring 4 central b-tagged jets and ≥ 2 forward jets
- Pairing of b-jets done minimizing a distance D_{HH}:

$$D_{HH} = \sqrt{\left(m_{2b}^{lead}\right)^2 + \left(m_{2b}^{sublead}\right)^2}\ \left|\sin\left(\tan^{-1}\left(\frac{m_{2b}^{sublead}}{m_{2b}^{lead}}\right) - \tan^{-1}\left(\frac{116.5\ GeV}{123.7\ GeV}\right)\right)\right|$$

- Concentric SR, VR and side-band regions are defined in $m_{2b}^{lead}\ vs\ m_{2b}^{sublead}$ 2D mass plane
- SR is defined by $X_{HH} = \sqrt{\left(\frac{m_{2b}^{lead} - 123.7\ GeV}{11.6\ GeV}\right)^2 + \left(\frac{m_{2b}^{sublead} - 116.5\ GeV}{18.1\ GeV}\right)^2} < 1.6$
- Fit to m_{4b} distribution with $ggF\ HH$ events considered as background





Observed (expected) limits at 95% CL:

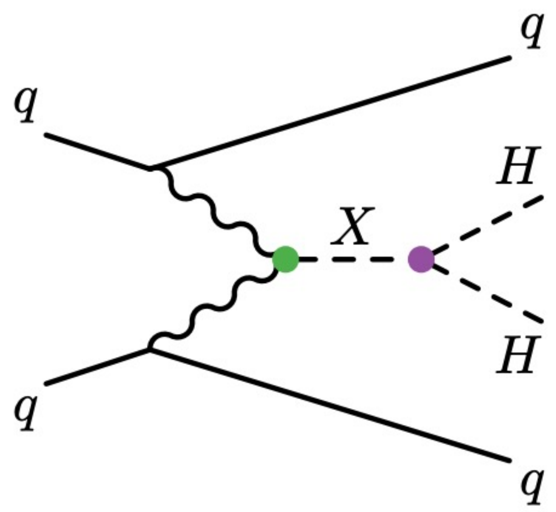
- $\sigma_{VBF}^{HH} < 1000\ (540) \times \sigma_{VBF}^{HH\ SM}$
- $-0.43\ (-0.55) < \kappa_{2V} < 2.56\ (2.72)$

Results limited by statistical precision, followed by multijet background systematics

JHEP 07 (2020) 108

ATLAS $\boldsymbol{VBF\ X \rightarrow HH \rightarrow b\bar{b}b\bar{b}}$ $(126\ fb^{-1})$

- Same event selection of the non-resonant analysis
- Two classes of signals are tested with m_X in the range $260 - 1000\ GeV$:
  - Spin-0 narrow resonance, width $4\ MeV$
  - Spin-0 broad resonance, width $10 - 20\%$ of m_X
- Fit on m_{4b} distribution for the different signal hypotheses
- Upper limits set for each mass point for the two signal classes



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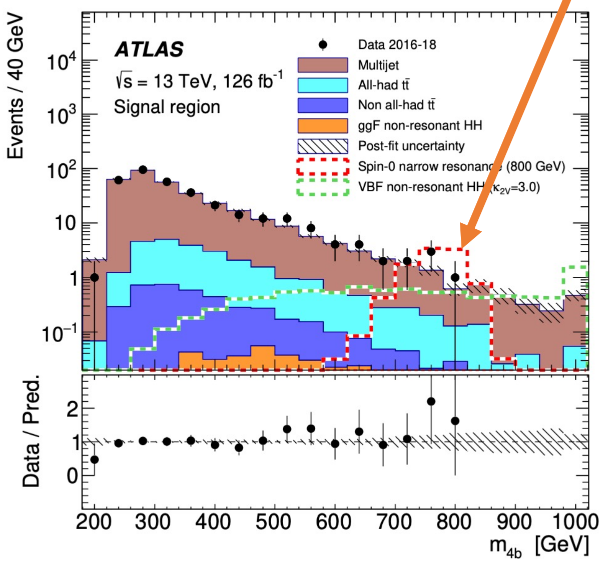
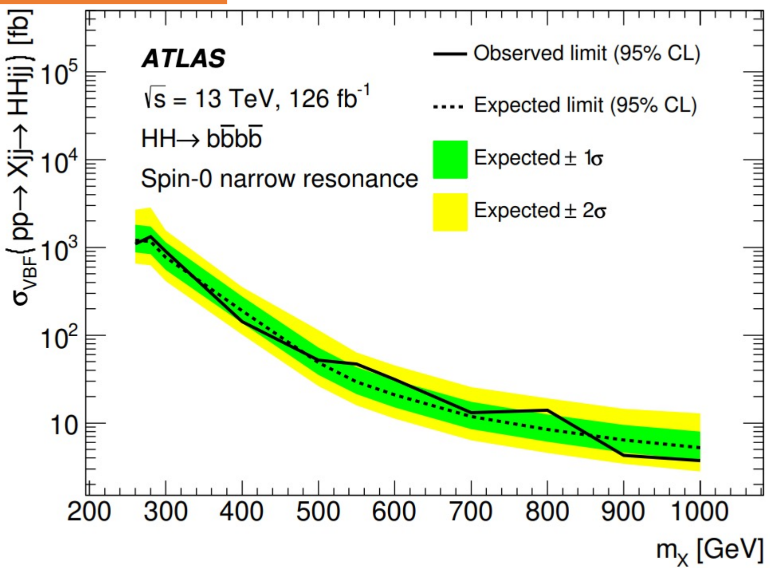
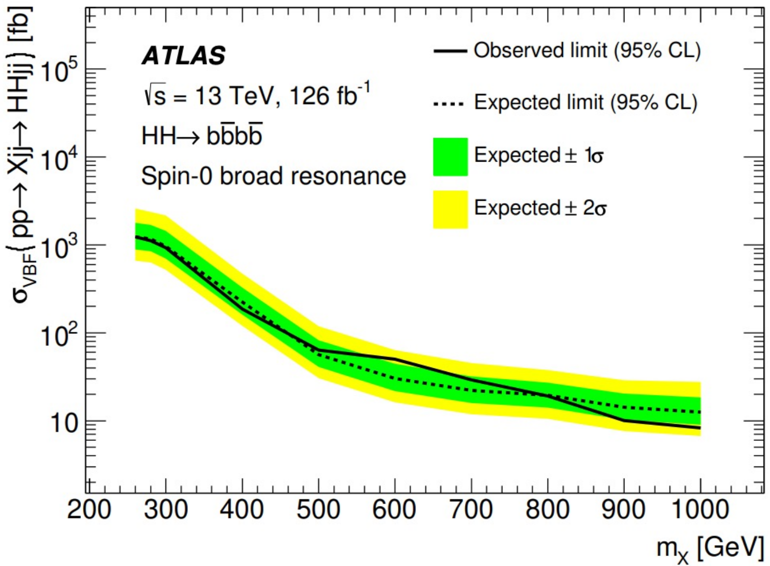
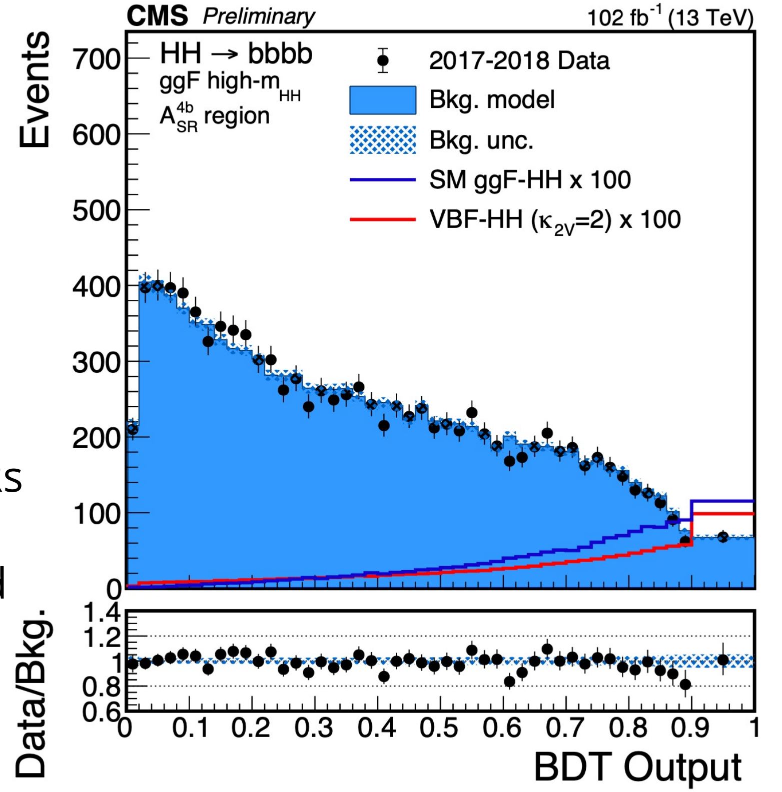
Spin-0 narrow resonance with $m_X = 800\ GeV$





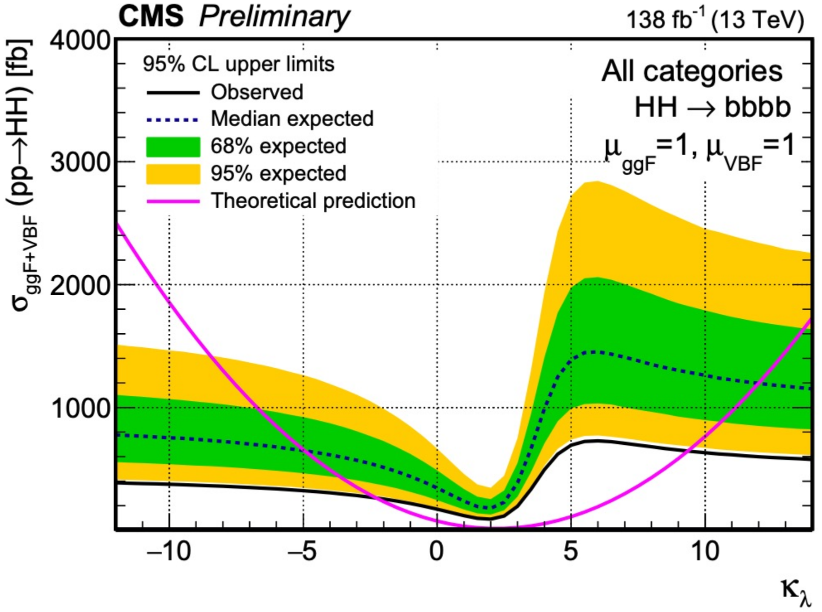


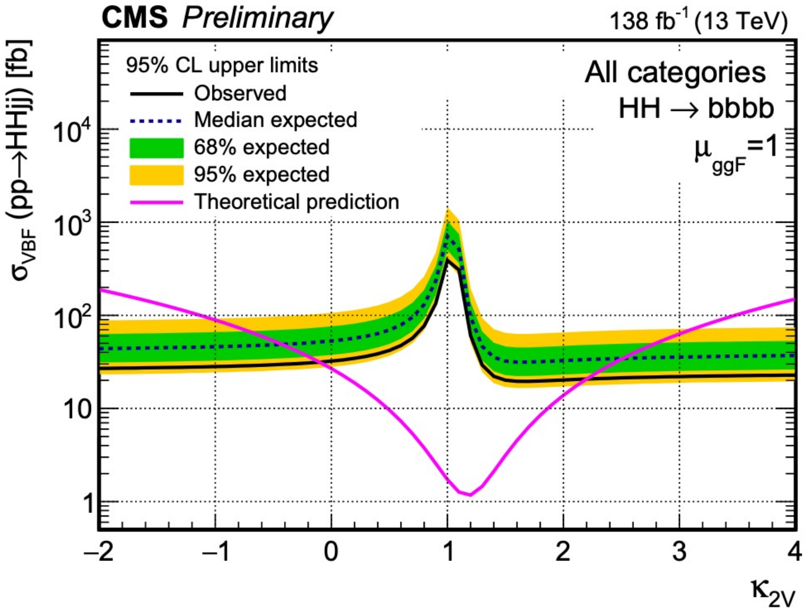
CMS $HH \rightarrow b\bar{b}b\bar{b}$ ($138\ fb^{-1}$)



Resolved (ggF and VBF) and boosted (only VBF) analyses

- ggF and $VBF\ HH$ events are classified trough a BDT
- A distance $\chi = \sqrt{(m_{H_1} - 125GeV)^2 + (m_{H_2} - 120GeV)^2}$ is used to build SRs and CRs
- The large multijet background is estimated from data and a maximum likelihood binned fit is simultaneously performed in all SRs





Observed (expected) limits at 95% CL:

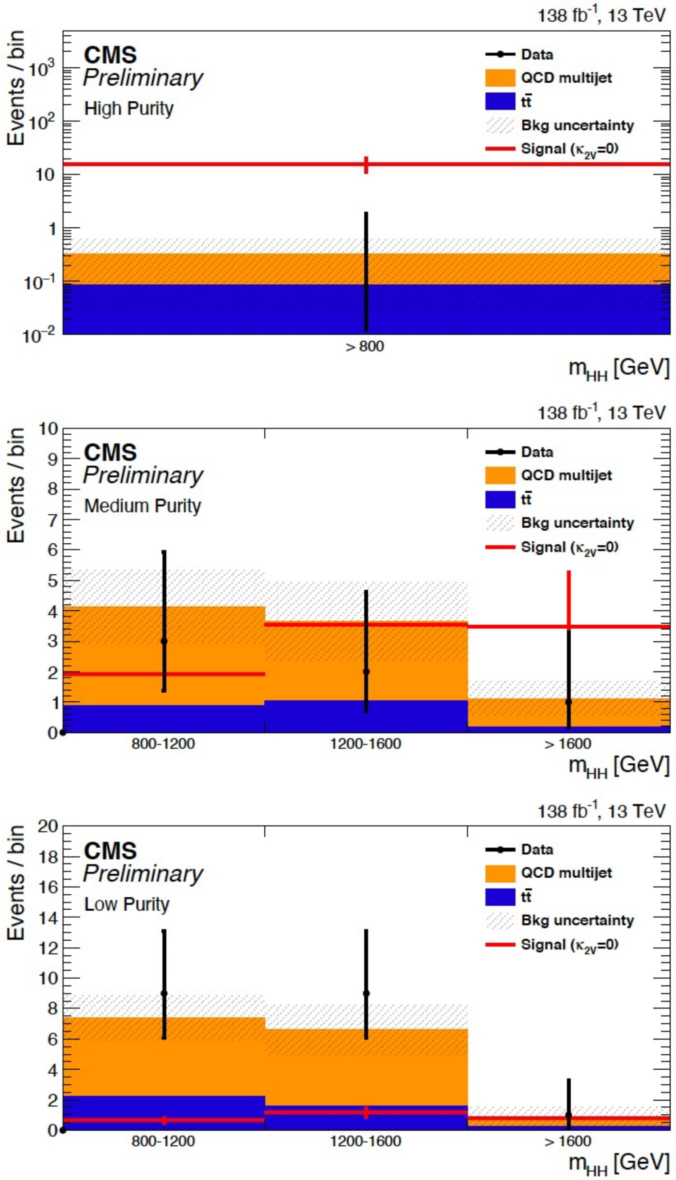
- $\sigma^{HH}_{ggF+VBF} < 3.6\ (7.3) \times \sigma^{HH\ SM}_{ggF+VBF}$
- $-2.3\ (-5.0) < \kappa_\lambda < 9.4\ (12.0)$
- $-0.1\ (-0.4) < \kappa_{2V} < 2.2\ (2.5)$

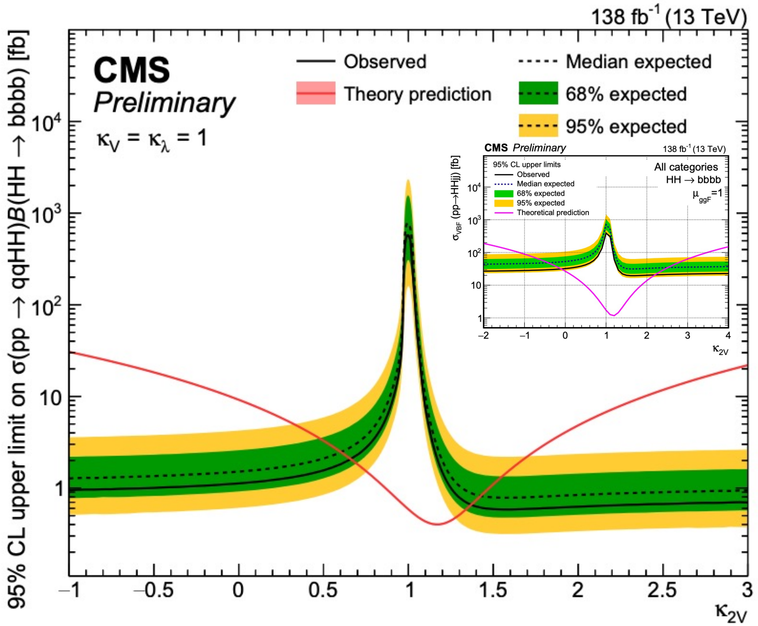
Results dominated by background modelling uncertainties

CMS-PAS-HIG-20-005

CMS $HH \to b\bar{b}b\bar{b}$ boosted $(138\ fb^{-1})$

- $\boldsymbol{VBF}$ **specific** category focused on highly boosted Higgs bosons in the $4b$ final state
- The main challenge is the efficient reconstruction of $H \to b\bar{b}$
- → ParticleNet multiclass classifier to discriminate between large-radius jets from $H \to b\bar{b}$ decays and those from QCD multijet processes
- Three regions defined based on the MVA output: High, Medium and Low purity
- Main background sources from $t\bar{t}$ and QCD multijet production, this last estimated from data in QCD-enriched CRs
- A binned maximum-likelihood fit using the m_{HH} templates is performed simultaneously with all SRs and CRs event categories





Observed (expected) limits at 95% CL:

➢ $0.6\ (0.6) < \kappa_{2V} < 1.4\ (1.4)$

CMS-PAS-B2G-21-001

CMS $X \to Hh_S \to b\bar{b}\tau\tau$ $(137\ fb^{-1})$

Not a proper "di-Higgs" production

$240\ GeV \leq m_X \leq 3\ TeV$

$60\ GeV \leq m_{h_S} \leq 2.8\ TeV$

- Search targeting a resonance X decaying in a SM Higgs and another scalar h_S:
- $H \to \tau\tau$ reconstructed in categories: $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$
- Multiclass NNs categorize events building 1 SR and 4 CRs for each final state and data taking period (45 categories)
  This classification is done for each point of the phase space with a different NN.
- An extended binned maximum likelihood fit is performed in all the categories simultaneously on the NN output distribution $\max(y_i)$ with $i = 1,..,5$
- 95% CL limits are set on $\sigma \times \mathfrak{B}$ for each mass point pair (m_H, m_{h_S})