Search for non-resonant Higgs boson pair production in the 2b+2l+E_T^{miss} final state in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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Enlightening the beauty of the Higgs

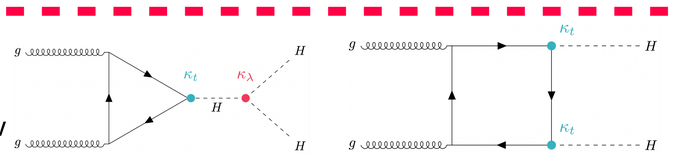
Introduction

- Everything starts form here : Discovery of **Higgs boson** on July 4, 2012
  - Major efforts are ongoing to understand its properties, including the Higgs self-coupling
  - Using **Standard Model** (**SM**) predictions as a reference for these studies and to probe possible **Beyond-the-SM** (**BSM**) scenarios.
- The Higgs pair production (**HH**) is a direct way to measure the Higgs self-coupling
  - Major **HH** production modes:

gluon-gluon Fusion (ggF)

$\sim k_\lambda$

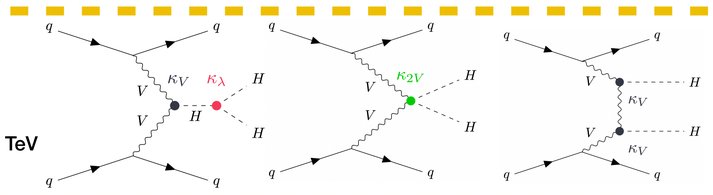
$\sigma_{ggF}(pp \to HH) = 31.05$ fb at $\sqrt{s} = 13$ TeV



Vector Boson Fusion (VBF)

$\sim k_\lambda$, k_{2V}

$\sigma_{VBF}(pp \to HH) = 1.72$ fb at $\sqrt{s} = 13$ TeV



- **SM HH** production is an extremely rare process:
  - Predicted cross-section **~1000** smaller than **single-Higgs** production: **Very challenging measurement**
  - **BSM** modifications to the self-coupling may lead to higher cross-sections at $\sqrt{s} = 13$ TeV.
  - A combination of different **HH** decay modes enhances the sensitivity to the **HH** observation.

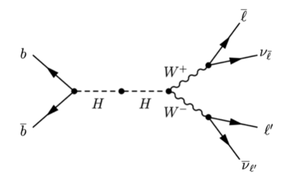
	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

$b\bar{b}ll + MET$ Analysis Overview & Strategy

- **Analysis goal** : Enhance sensitivity in measuring non-resonant **HH** production in both the **ggF** and **VBF** production modes
  - Help in the **HH** combination
- Multiple **HH** decay channels contribute to $b\bar{b}ll + MET$ final state ($l = e, \mu$) :

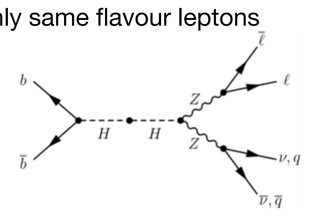
bbWW

- $BR_{HH \to bbll+MET} = 1{,}62\,\%$
- W-pair has spin correlation
- small m_{ll} and $\Delta\Phi_{ll}$



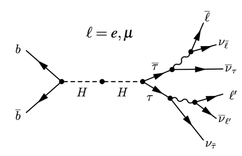
bbZZ

- $BR_{HH \to bbll+MET} = 0.095\,\%$
- m_{ll} close to Z peak or small for offshell Z
- only same flavour leptons



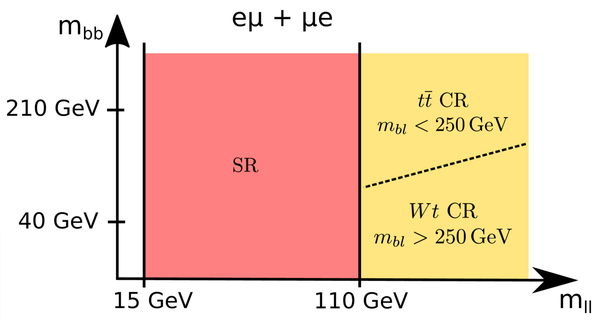
bbττ

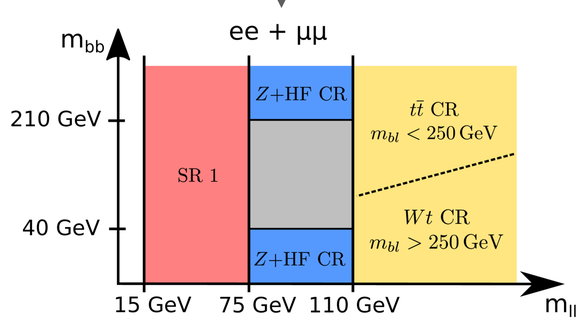
- $BR_{HH \to bbll+MET} = 0.91\,\%$
- light leptons are collinear to τ-lepton (m_{ll}^{coll})



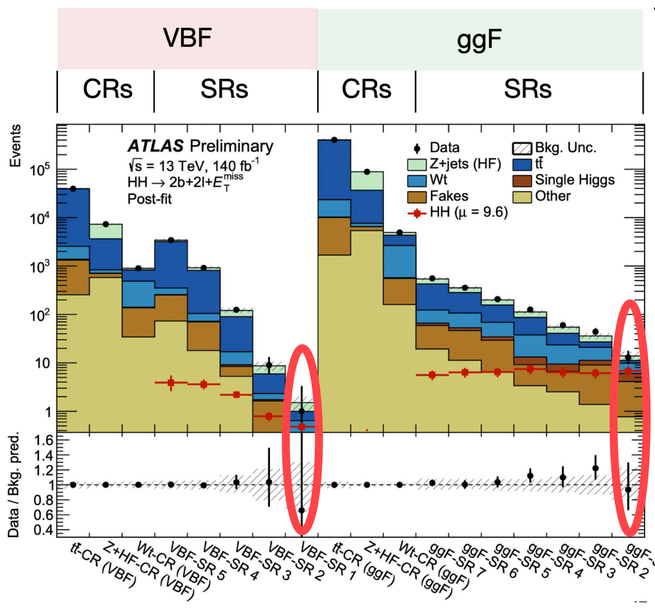
Event Selections

- Exactly two light opposite charge leptons passing single- and di-lepton trigger selections.
- Exactly two b-jets passing the **DL1r 77%** efficiency working point.
- Single and control regions categorized based on lepton-flavour, lepton-pair and b-jet pair masses.





- Fit **MC** to **data** in both signal and control regions.
- Extracted signal strength and set upper limits on **HH** production cross-section ($\sigma_{pp \to HH}$)).
- Used separate normalization factors for VBF-like and ggF-like event categories + Ensured consistent region definitions.
- Pre-fit event yields adjusted for correlated systematics.
- **A downward fluctuation of the data in the last bin of DNN/BDT distributions is observed.**



VBF Category

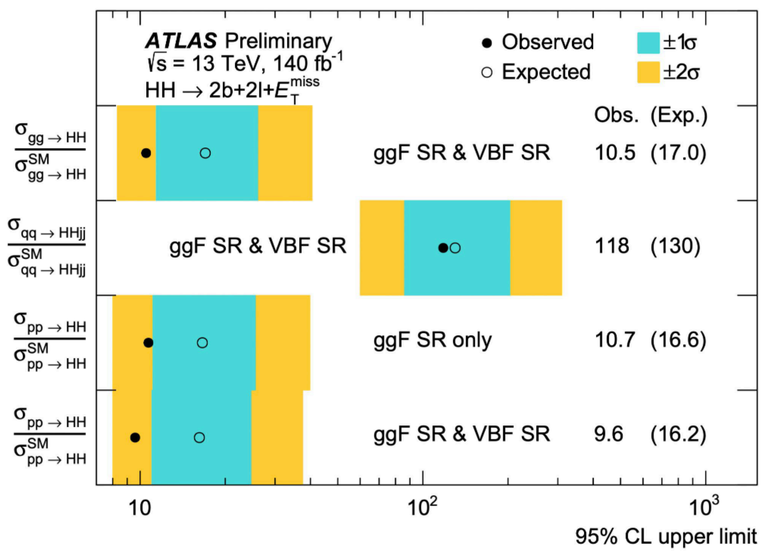
- **B**oosted **D**ecision **T**ree (**BDT**) : VBF **HH** signal vs. backgrounds (including ggF **HH** events) => maximum background events O(10^3)

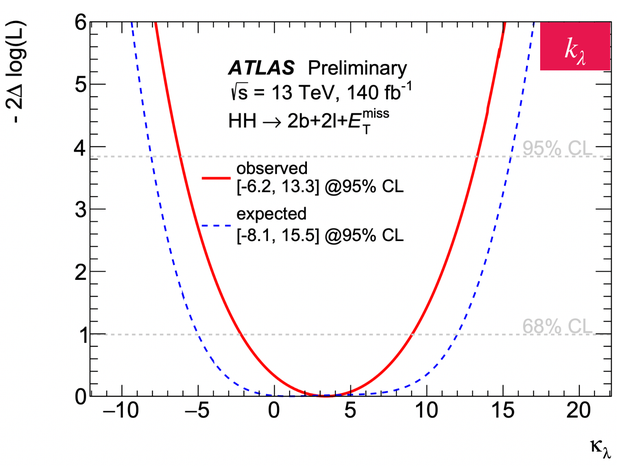
ggF Category

- **D**eep **N**eural **N**etwork (**DNN**) with multi-output architecture : ggF **HH** signal vs. background processes => maximum background events O(10^2)

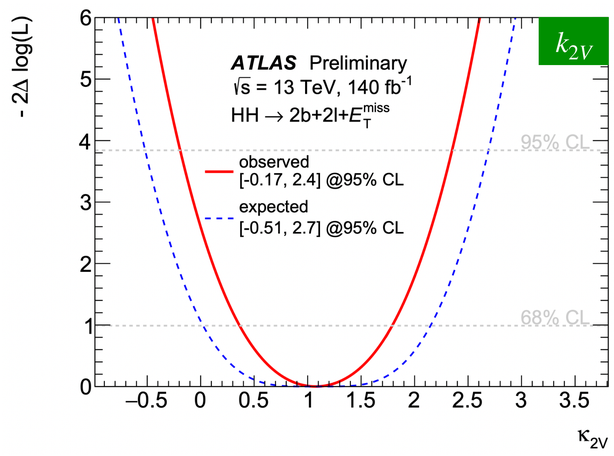
Results and Discussion

- Observed and expected upper limits on the ratios of the **HH** production cross section to the corresponding **SM** prediction $\sigma_{HH}/\sigma_{HH}^{SM}$ at 95% confidence level.
- Tighter observed limits compared to expected due to the under-fluctuation of data.
- **Significant improvement (9.6 (16.2) times the SM prediction)** compared to the **previous analysis (40 (29) times SM)** in both **observed** and **expected limits** of approximately **76% (44%)** due to re-optimized **DNN**.





- Likelihood scans have been performed on k_λ and k_{2V} parameters.
- Observed results are slightly better constrained due to **downward data fluctuation**
  - -6.2 < k_λ < 13.3 (exp: -8.1 < k_λ < 15.5)
  - -0.17 < k_{2V} < 2.4 (exp: -0.51 < k_{2V} < 2.7)



Summary

- Full Run 2 **HH** to $2b + 2l + E_T^{miss}$ analysis performed, including VBF **HH** production for the first time.
  - Significant improvement in limits on ggF and VBF **HH** production.
  - Significant improvement in limits on k_λ and k_{2V} .
- Employ the analysis in combination with other channels (QR code [1]).
- Anticipate new exciting results using the Run 3 dataset.
- Significant improvements from the HL-LHC era may lead to the observation of **HH** production at high confidence levels.

[1]

Reference

- Full analysis details: Scan the QR code [2].

[2]

FSAC

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