Search for non-resonant HH in 2b+2l+MET final states

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Theoretical Motivation

- Higgs potential after symmetry breaking

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

In the SM, $\quad \lambda_3 = \lambda_4 = \lambda^{SM} = \dfrac{m_H^2}{2v^2}$

- Our direct knowledge of the Higgs boson potential shape is very limited

- Other shapes could have caused the same physics, well motivated by cosmological arguments and beyond-SM (BSM) physics.

- Deviation of the coupling strength from SM (measured by the coupling modifier $\kappa_\lambda = \lambda_3 / \lambda_{SM}$) may point to new physics

- Ref: DOI:10.1038/s42254-021-00341-2
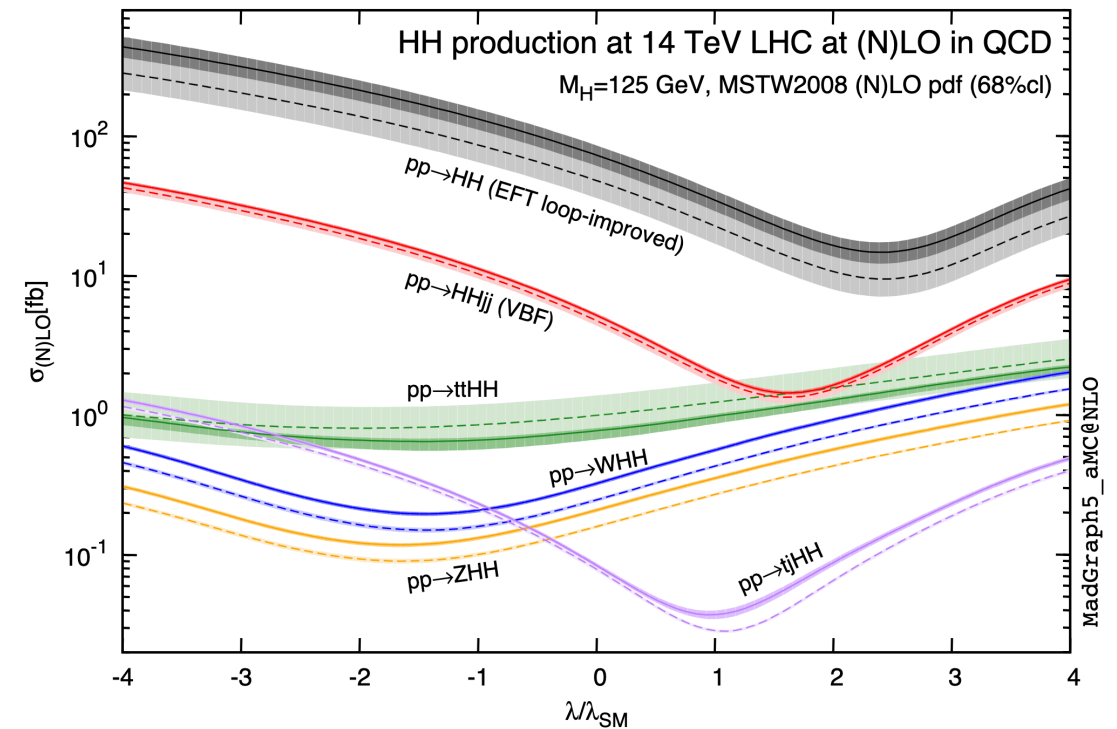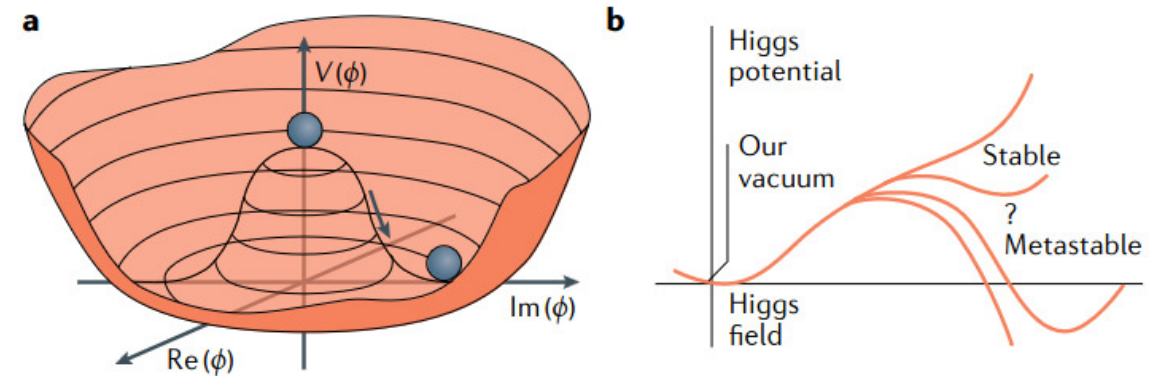
- Ref: DOI:10.1016/j.physletb.2014.03.026

Analysis Overview – arXiv:2310.11286v1

Main production mode is gluon fusion (ggF):

- Strongly suppressed by the interference effect $\sigma_{ggF}(pp \rightarrow HH) = 31.05 \, fb$ at $\sqrt{S} = 13$ TeV

- Sensitive to trilinear self-coupling κ_λ

- Previous paper optimized only for bbWW channel (Phys. Lett. B 801 (2020) 135145)

- This version optimized three channels ($bbWW, bb\tau\tau$, and $bbZZ$)
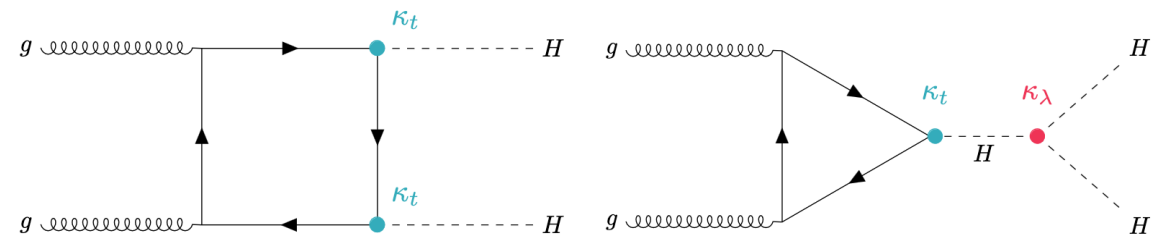
Next leading production mode is Vector Boson Fusion (VBF):

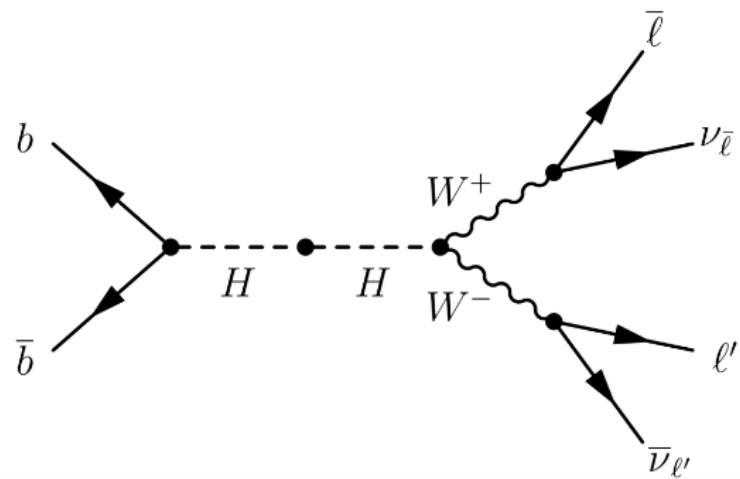- $\sigma_{VBF}(pp \rightarrow HH) = 1.726 \, fb$ at $\sqrt{S} = 13$ TeV

- Sensitive to κ_λ and to κ_{2V}

- First-time implementation in this analysis
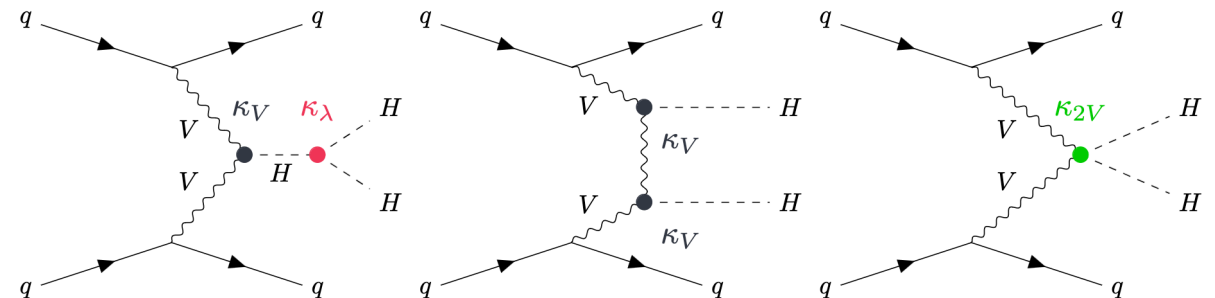
Decay Channels
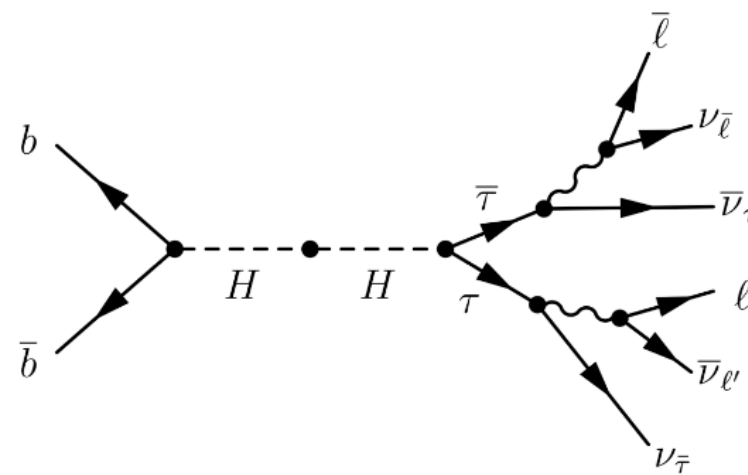
multiple HH decay channels contribute to bbll + MET final state (l = e, μ)

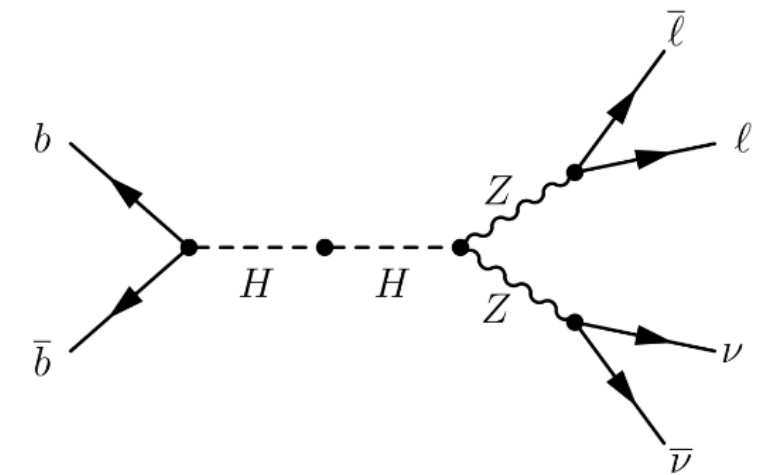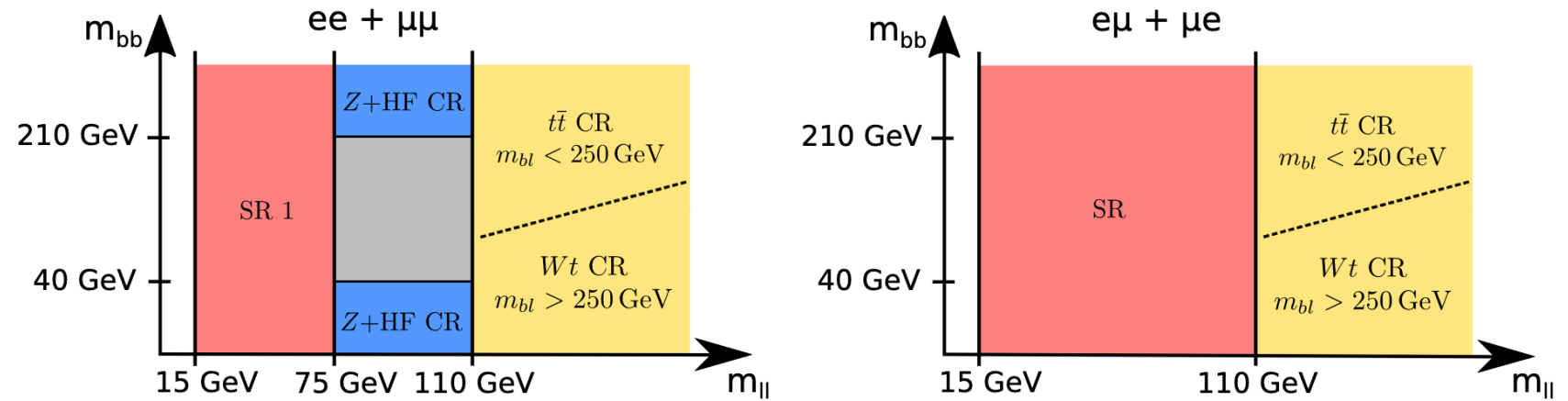**bbWW**   **bbττ**   **bbZZ**

- Combined analysis is necessary: Due to the large overlap between the tree final states: $bbWW$, $bb\tau\tau$, and $bbZZ$.

	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%

Event Selections

Preselection

- single and dilepton triggers

- exactly two light leptons of opposite charge

- exactly two b-tagged jets

Further selections for VBF category

- at least 2 extra non-b-tagged jets with $p_T > 30$ GeV

- $\Delta\eta_{jj} > 4$ for the couple of non-b-tagged jets with the highest $\Delta\eta_{jj}$

- $M_{jj} > 600$ GeV for the couple of non-b-tagged jets with the highest reconstructed mass

- SR1: target bbWW, $bb\tau\tau$ and bbZZ

- Major background from Top, Z+jets, CRs defined to constrain these backgrounds:

  - Top CR split into TTbarCR and WtCR

  - Zll CR: also used in $bb\tau\tau$ analysis

ML techniques

Multi-class neural network trained with Keras+Tensorflow used for ggF category :

- Output nodes for ggF signal, top-quark processes and others backgrounds

- Bayesian hyperparameter optimisation with Optuna

- Used 20 top out of 43 initial input features

- As final discriminant, signal score is used

- Final Signal Regions: bins with maximum background events (102) → 7 bins used
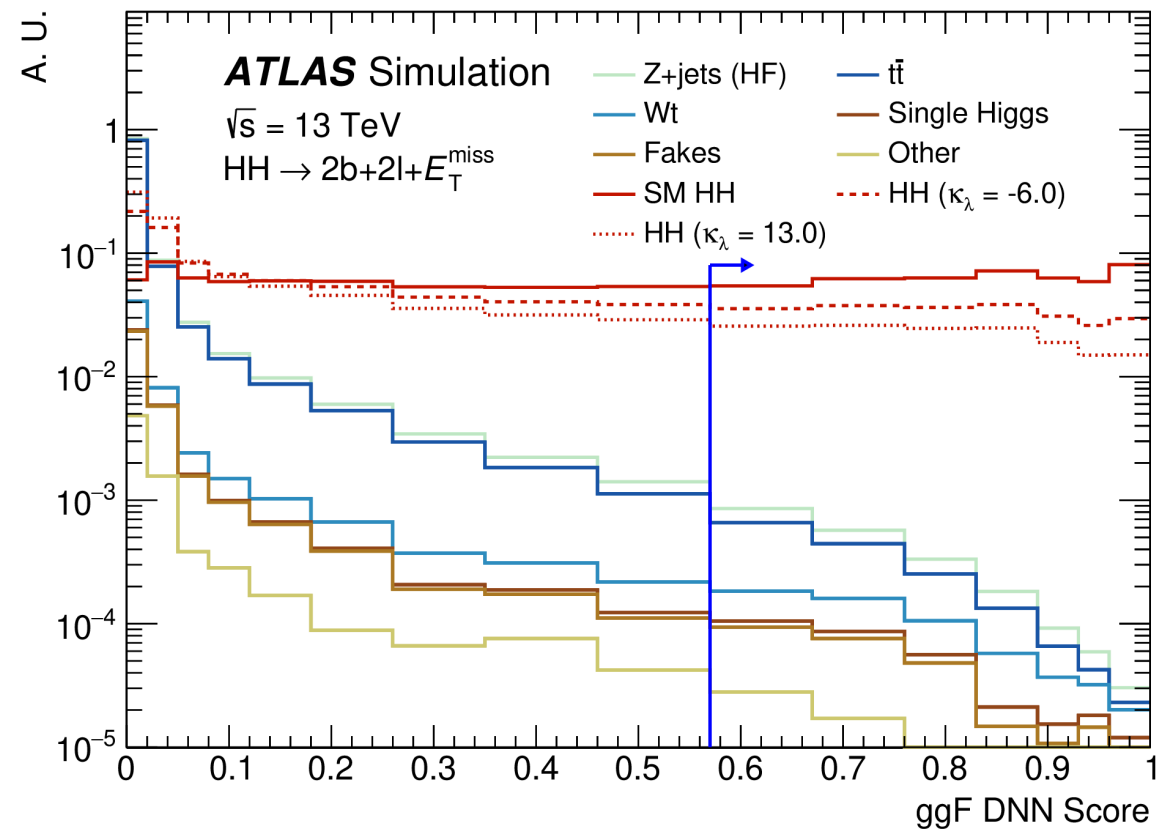
ML techniques

TMVA Boosted Decision Tree used for VBF category :

- Used κ_λ = 0 signal in training, for all signal points → showed overall best performance

- Considering VBF HH signal, ggF HH treated as background

- Final SRs: bins with maximum O(103) background events → 5 bins used
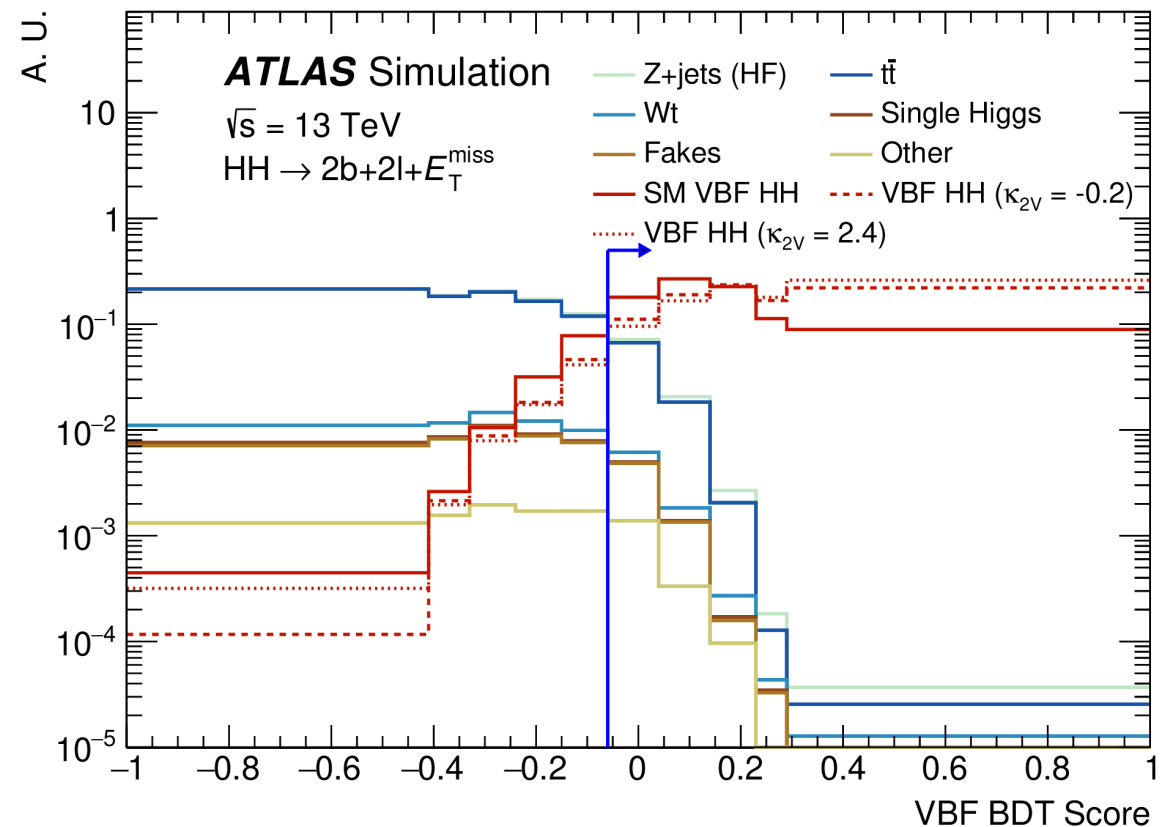
Fit Strategy

- Simultaneous maximum-likelihood fit using all regions

- Separate normalization factors for VBF-like and non-VBF-like regions

- All regions used for μ *SIG*, upper limit on $\sigma(pp \to hh)$, κ_λ-scan and κ_{2V}-scan

- For κ_{2V}-scan: ggF di-Higgs production considered as background

- Theory systematic uncertainties per process correlated across regions

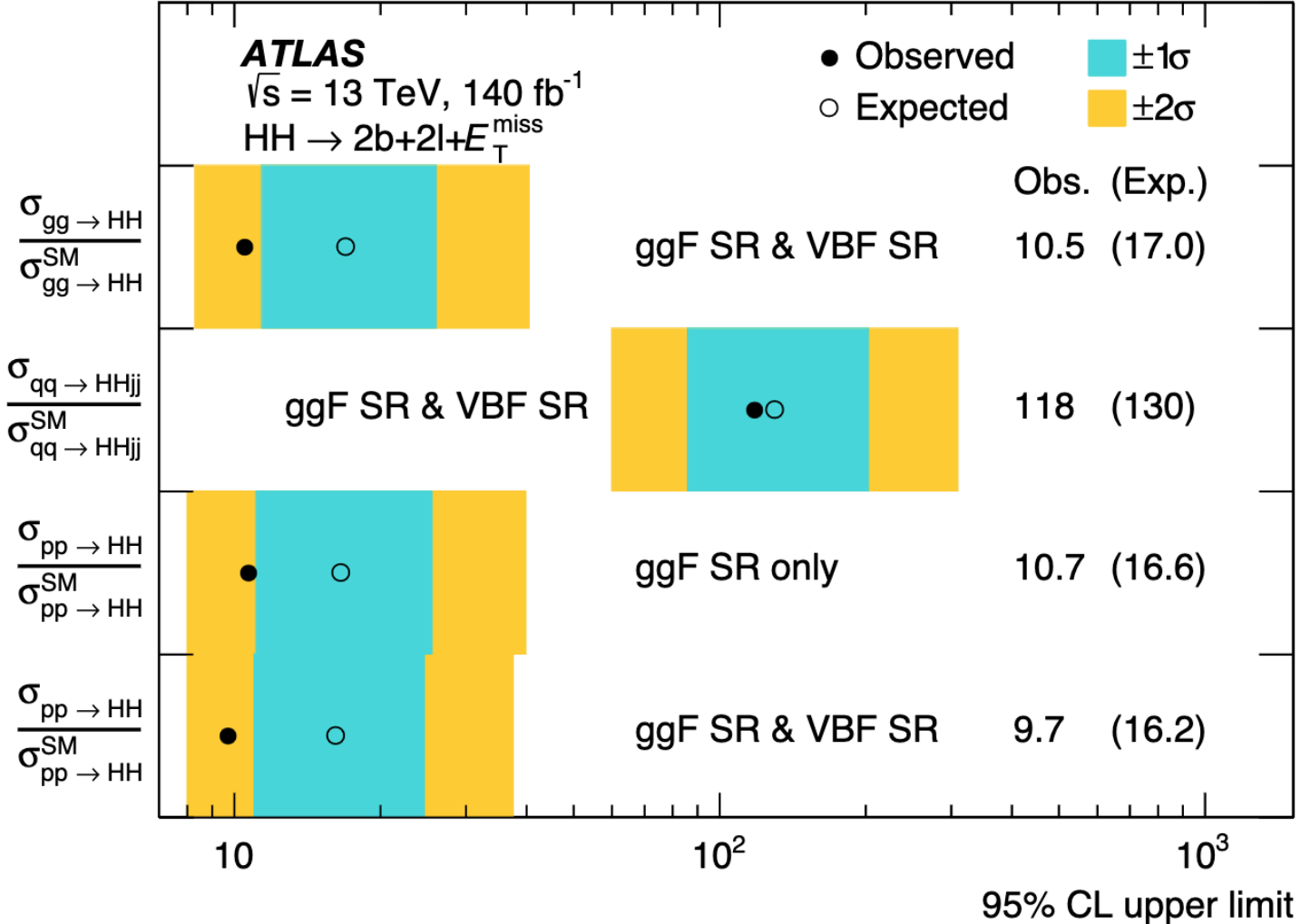- Experimental systematic uncertainties correlated for all regions

Results - Post-fit plot

- All regions are included in the fit

- 7 bins are used for the ggF SR while 5 bins are used for VBF SR
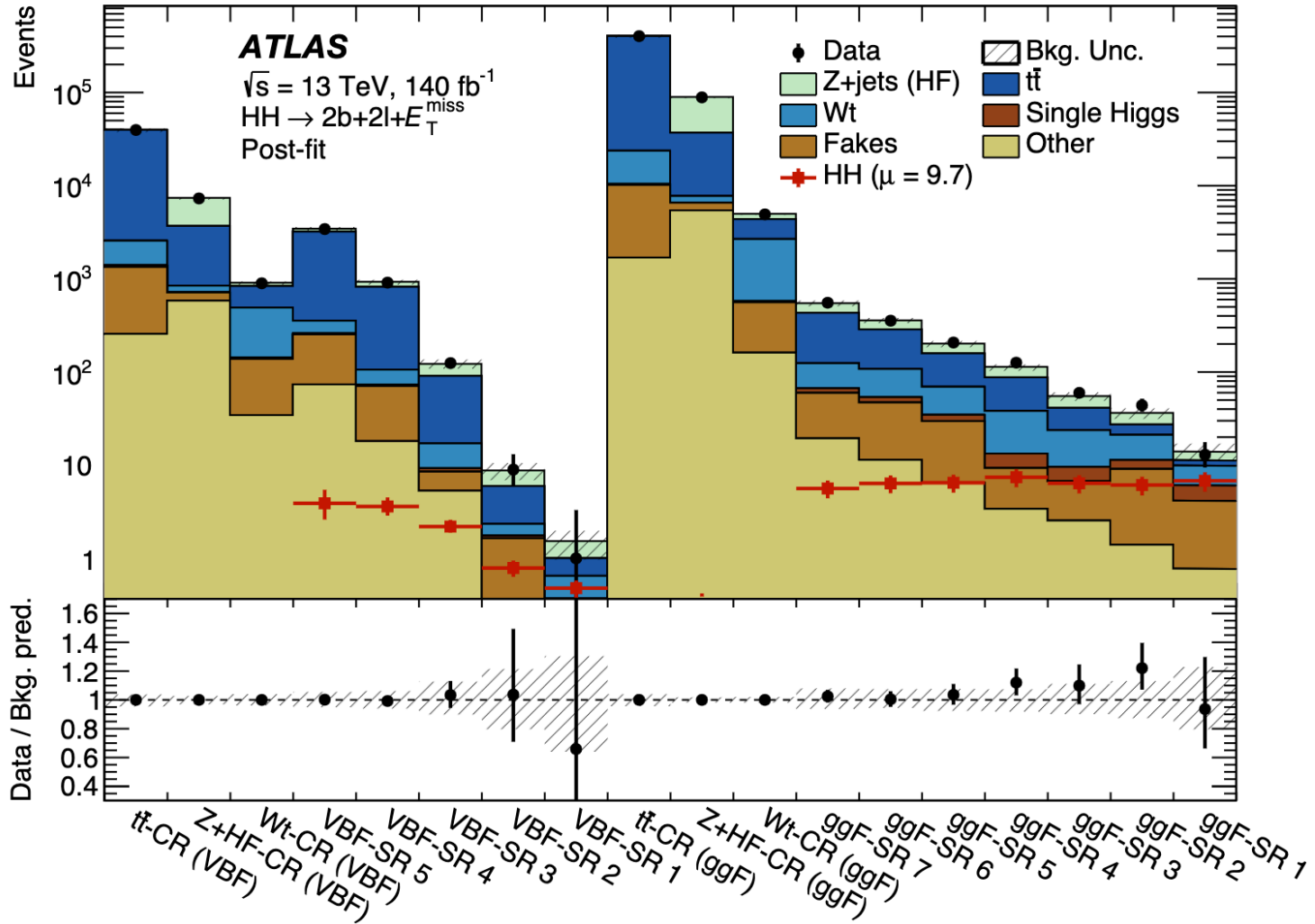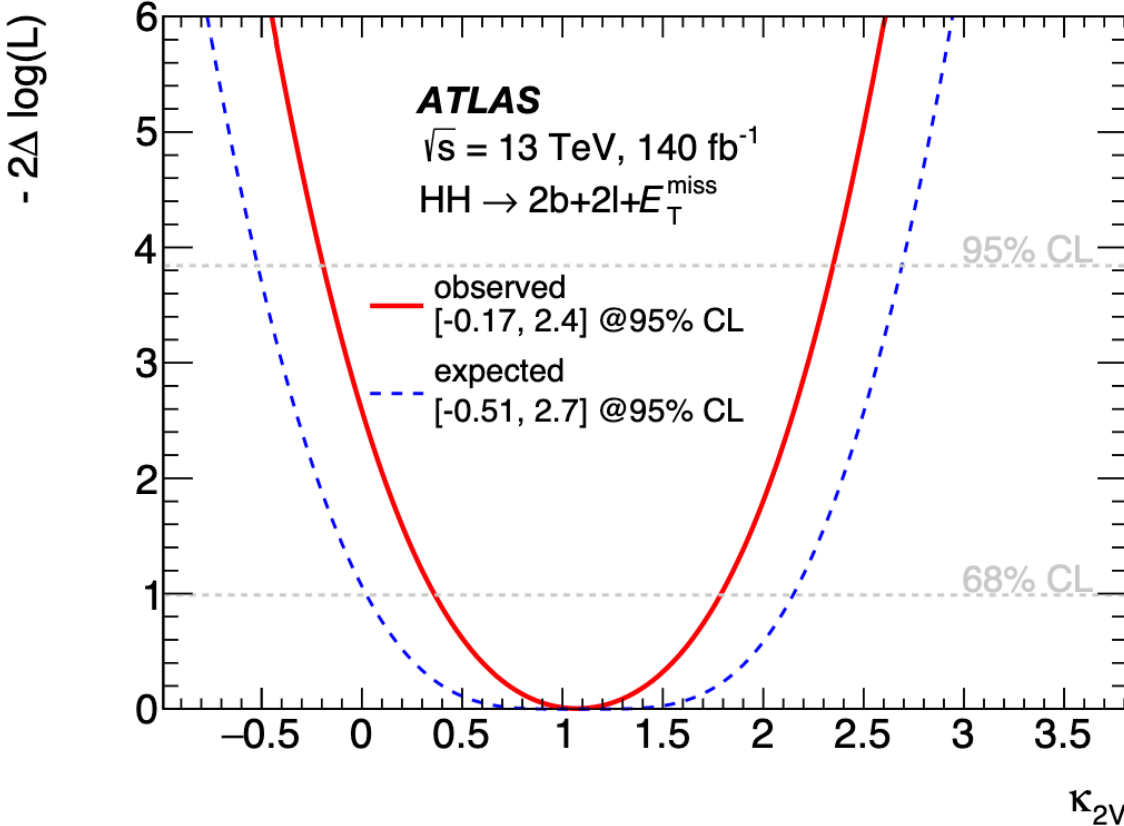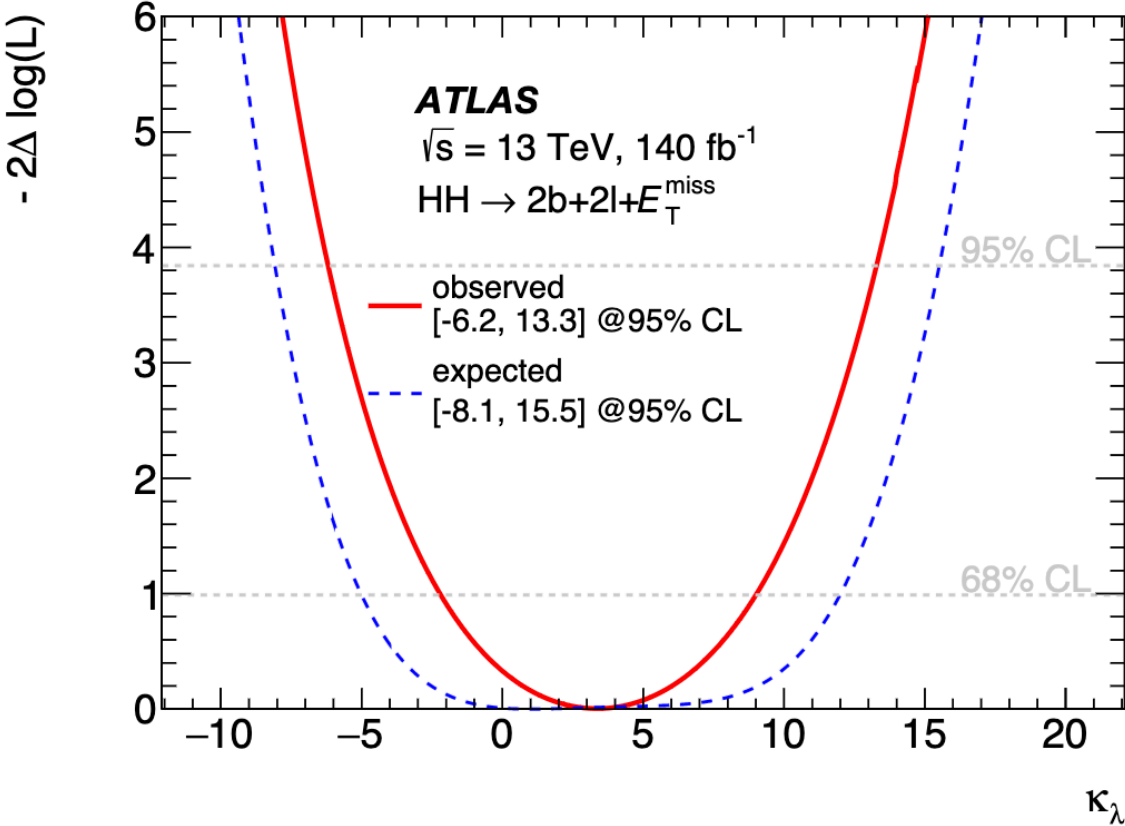
Results - limits

- Observed and expected upper limits on the Higgs boson pair production cross-section

- Significant improvement compared to the previous ATLAS search in this channel.

Kappa's scan

- Likelihood profiles of the κ_λ and κ_{2V} parameters.

Conclusion

- Search HH events in 2b+2l+MET final states has been performed

- Significant improvement achieved with respect to the previously published results

- An observed (expected) 95% CL upper limit on the cross-section for the production of Higgs boson pairs is set at 9.6 (16.2) times the SM prediction

- Stay tuned new results is coming from RUN3!