Exploring di-Higgs in Lepton-Tau Final States

Babar Ali for the ATLAS Collaboration

1 HH Production at the LHC

At the LHC, the dominant HH production mode in the Standard Model (SM) is gluon-gluon fusion (ggF) with a cross-section of 31.1 ± 24.15% fb [1]. The two ggF HH production modes, the top-quark box and the self-interaction triangle, interfere destructively. The cross-section and the shape of the m_{HH} distributions change as the strength of the self-coupling κ_λ varies.

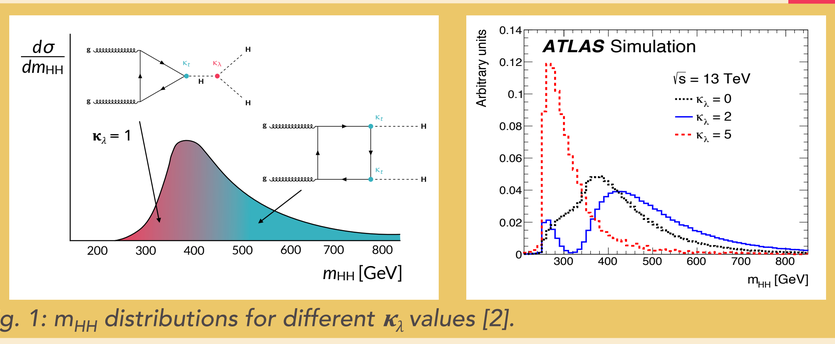
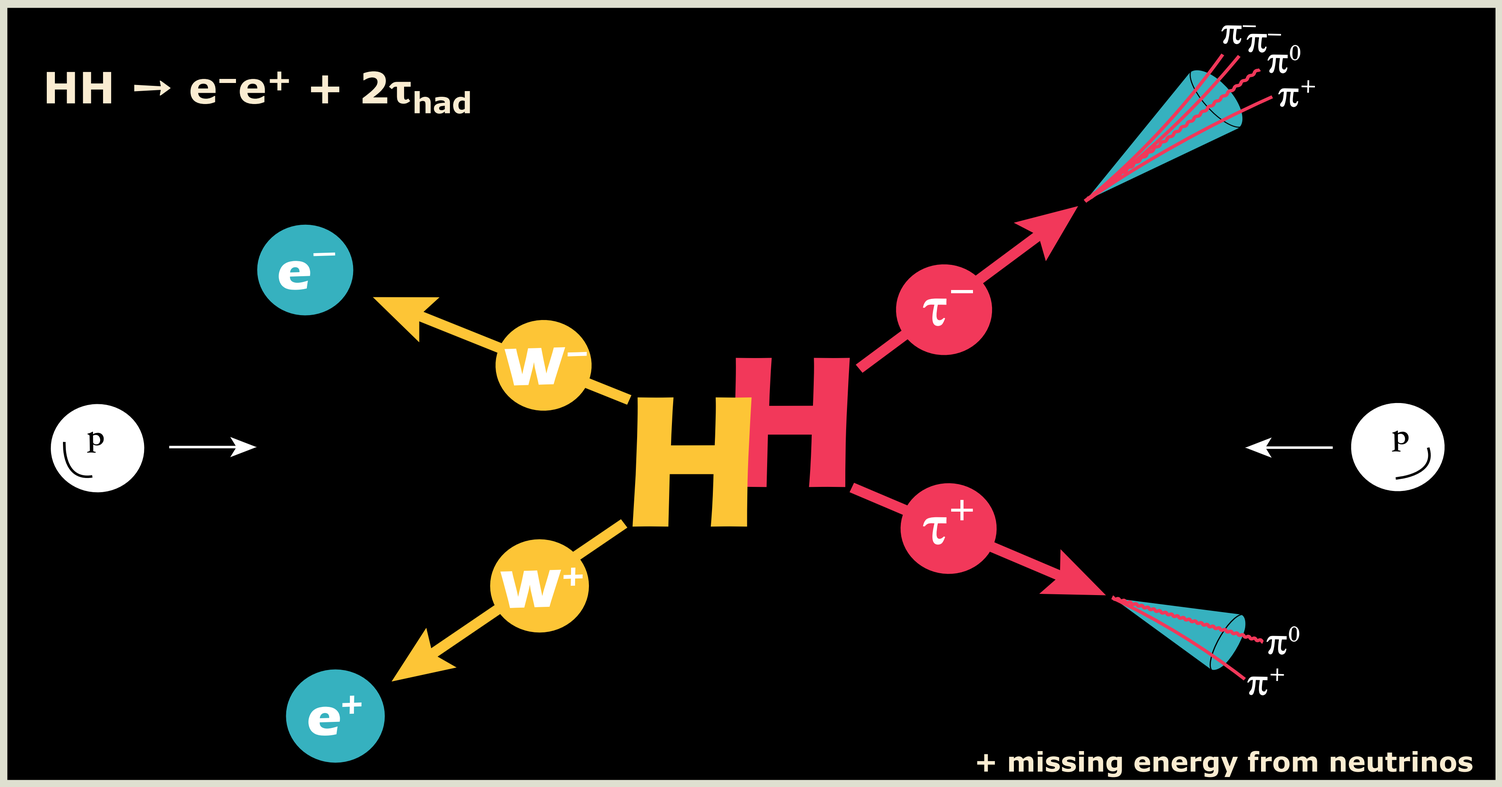


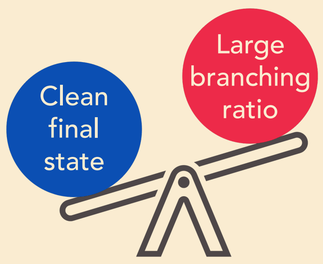
Fig. 1: m_{HH} distributions for different κ_λ values [2].



2 How does ATLAS search for HH?

- No single 'golden channel' with the clearest and cleanest signature exists. HH decay modes require a trade-off between higher branching ratios and cleaner final states.
- Main channels are HH → 4b (high background), HH → bb$\tau\tau$ (moderate), and HH → bb$\gamma\gamma$ (tiny but identifiable) [3].
- Di-Higgs soup: ~6.5% of HH events decay into final states where HH system is not fully reconstructible, combined in the multilepton channel.

	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%



3 HH → Multilepton: Analysis Overview

- Targeted final states include multiple light leptons, hadronic taus (τ_{had}), and diphoton final states with additional leptons or taus.
- Analysis covers HH decays into 4V, 4τ, VV$\tau\tau$, bbZZ, $\gamma\gamma$VV, and $\gamma\gamma\tau\tau$ [1].

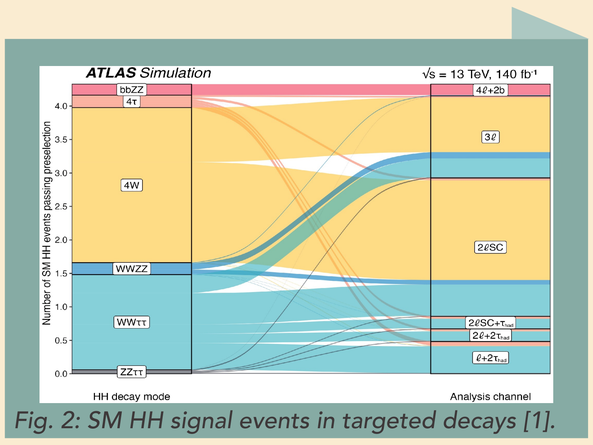


Fig. 2: SM HH signal events in targeted decays [1].

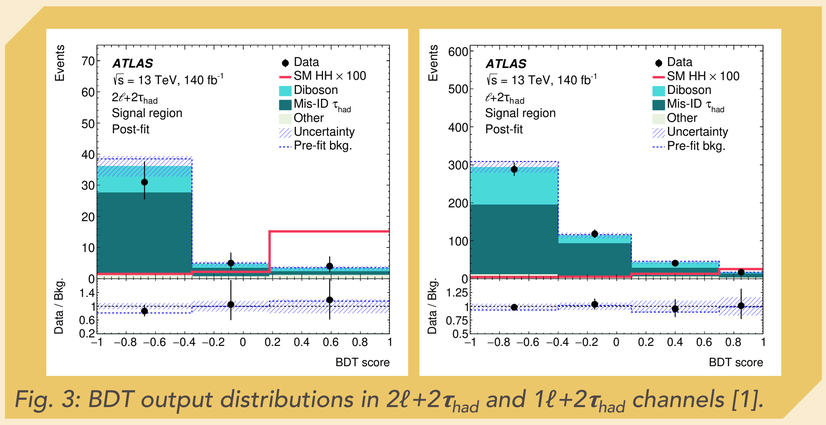


Fig. 3: BDT output distributions in 2ℓ+2τ_{had} and 1ℓ+2τ_{had} channels [1].

- Boosted decision trees (BDTs) employed to separate signal from backgrounds.
- Backgrounds with prompt leptons are estimated using Monte Carlo simulation, with dominant backgrounds normalized to data in control regions.
- Processes with misidentified τ_{had} are estimated using data-driven fake-factor method.

4 HH → Multilepton: Key Findings

- ATLAS performed its first search for HH production in the multilepton final state, comprising 9 sub-channels, limited by statistical precision on available data.
- Observed (expected) upper limits on the HH signal strength at 95% CL under the background-only hypothesis are set at **17 (11)** times the SM prediction [1].
- Observed (expected) constraints on the Higgs self-coupling modifier κ_λ at 95% CL are **$-6.2 < \kappa_\lambda < 11.6$ ($-4.5 < \kappa_\lambda < 9.6$)** [1].
- These results were combined with other HH channels, setting an observed (expected) upper limit of **2.9 (2.4)** times the SM prediction on HH production at 95% CL [3].

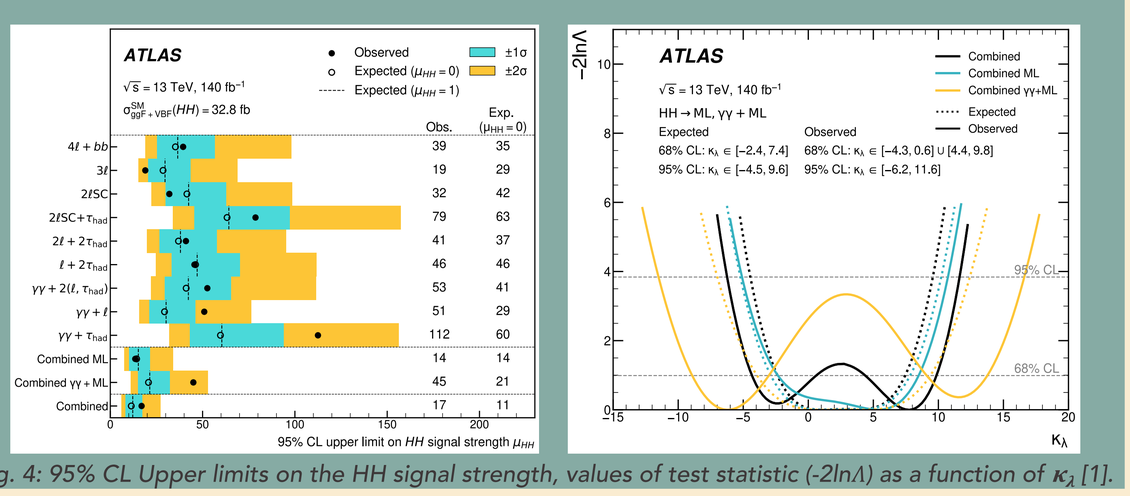


Fig. 4: 95% CL Upper limits on the HH signal strength, values of test statistic (-2lnΛ) as a function of κ_λ [1].

5 Search for X → SH in VVττ Final State

- Many beyond-the-SM theories predict a heavy scalar boson X in the X → SH process, where S is a scalar singlet (see figure 5).
- Explored the most sensitive parameter space: X mass 500–1500 GeV, S mass 200–500 GeV (18 mass points).

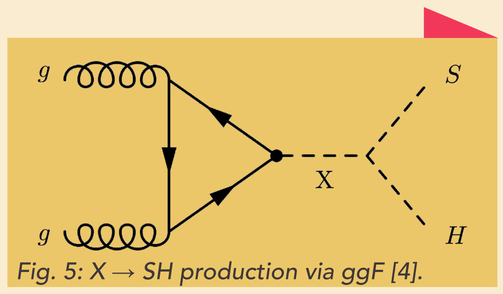


Fig. 5: X → SH production via ggF [4].

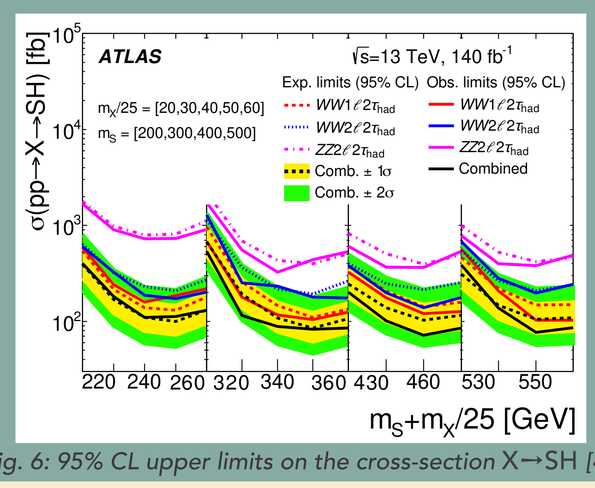


Fig. 6: 95% CL upper limits on the cross-section X→SH [4].

- Final states include one or two light leptons from S → WW, ZZ decays, and two τ_{had} candidates from H → $\tau\tau$ decays.
- The results are obtained from a binned likelihood fit to 12 parametrized BDTs.

No excess of events is observed,
95% CL upper limits on the production cross-section X → SH range from 72 fb to 542 fb (assuming SM-Higgs like branching ratio for S) are derived [4].

References

[1] arXiv:2405.20040 [hep-ex] (2024)
[2] arXiv:1906.02025 [hep-ex] (2020)
[3] arXiv:2406.09971 [hep-ex] (2024)
[4] arXiv:2307.11120 [hep-ex] (2023)

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