



## Search for non-resonant Higgs boson pair production in the $b\bar{b}\tau^+\tau^-$ final state using Run 2 + partial Run 3 data recorded by the ATLAS detector

---

Leonardo Splendori on behalf of the ATLAS Collaboration

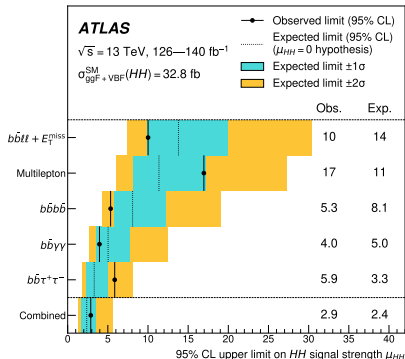
September 18th 2026, Higgs Hunting

# Introduction

The  $HH \rightarrow b\bar{b}\tau^+\tau^-$  final state provides a sweet spot between di-Higgs branching ratio and signal purity.

## Key points:

- Drives limits on HH in [latest combination](#).
- Two decay channels for  $\tau^+\tau^-$ :
  - $\tau_{\text{lep}}\tau_{\text{had}}$
  - $\tau_{\text{had}}\tau_{\text{had}}$
- Main backgrounds:
  - $t\bar{t}$
  - Z+Heavy Flavour
  - Jet  $\rightarrow$  fake- $\tau_{\text{had}}$
- Signal separated from plethora of backgrounds using MVA methods.
- Results:
  - HH signal strength.
  - Limits on  $\kappa_\lambda$  and  $\kappa_{2V}$ .



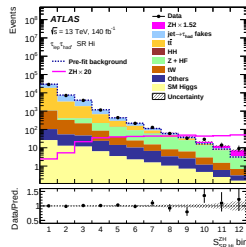
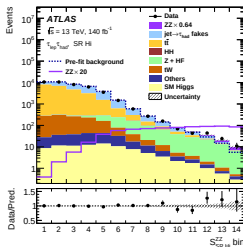
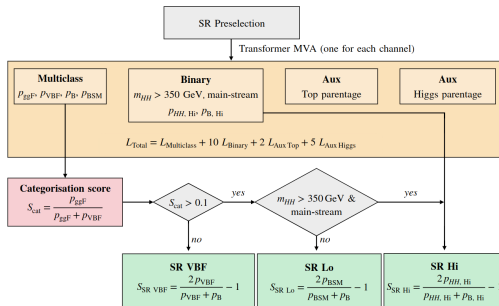
More details on the analysis shown in [Salah-Eddine's talk](#).

# MVA Strategy

Multi-task transformer-based architecture:

- Multiclass: ggF, VBF, signal/background scores, BSM signals.
- Binary: signal/background scores in high-mass region.
- Aux: auxiliary tasks used in training.
- Inspired by flavour-tagging algorithms such as [GN2](#).

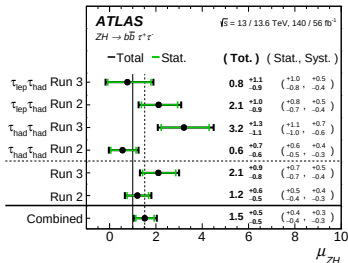
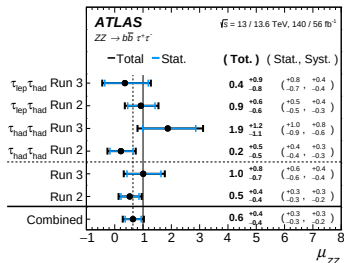
Separate models for  $\tau_{\text{lep}}\tau_{\text{had}}$  and  $\tau_{\text{had}}\tau_{\text{had}}$ . Analysis validated by considering ZZ or ZH as our signal. Model retrained with same strategy, hyperparameters and inputs.



# Results: ZZ and ZH

Measurement performed to validate the complex analysis strategy.

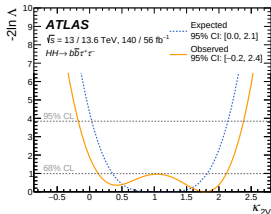
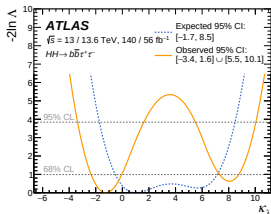
- Fitted signal strengths,  $\mu$ , for ZZ (top) and ZH (bottom) processes.
- Results from combined fits to Run 2 and Run 3 data.
- Individual signal strengths fitted per channel and/or run period.
- ZZ observed (expected) significance at  $1.8\sigma$  ( $2.7\sigma$ ).
- ZH observed (expected) significance at  $3.5\sigma$  ( $2.4\sigma$ ).
- First evidence for**  
 $ZH \rightarrow b\bar{b}\tau^+\tau^-$  process.



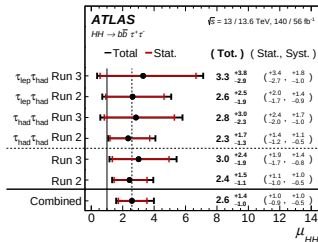
Strong validation of the analysis methodology.

# Results: HH

- Observed 95% CL upper limit:  $\mu_{HH} < 5.3$  (expected:  $\mu_{HH} < 2.4$ ).
- Higgs self-coupling:  $\kappa_\lambda \in [-3.4, 1.6] \cup [5.5, 10.1]$  at 95% CL (expected:  $\kappa_\lambda \in [-1.7, 8.5]$ ).
- Quartic Higgs-vector boson coupling:  $\kappa_{2V} \in [-0.2, 2.4]$  at 95% CL (expected:  $\kappa_{2V} \in [0.0, 2.1]$ ).

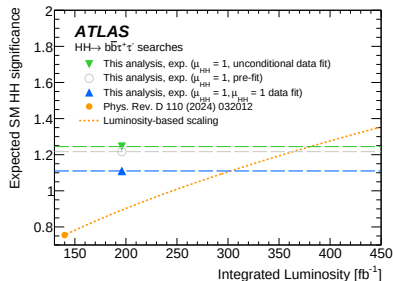
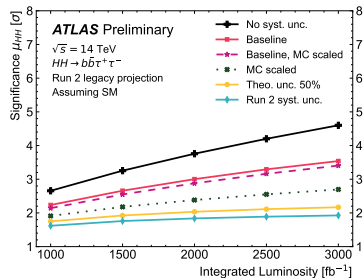


HH signal strength:  $\mu_{HH} = 2.6^{+1.4}_{-1.0}$  with 2.6 $\sigma$  significance (1.2 $\sigma$  expected), compatible with the SM prediction at 1.65 $\sigma$ .



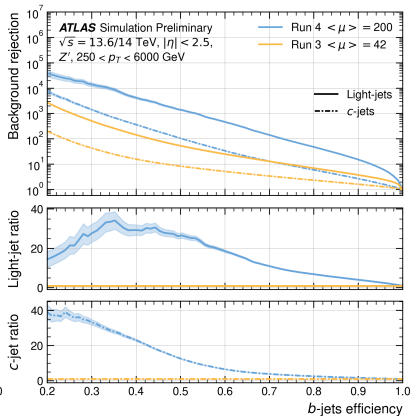
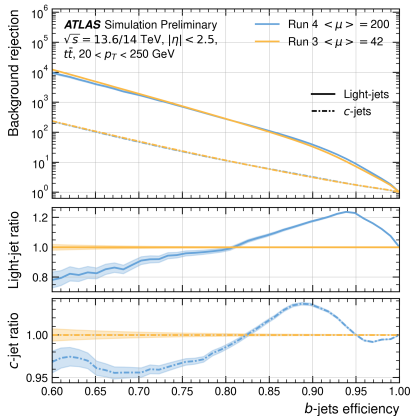
Projection of  $HH \rightarrow b\bar{b}\tau^+\tau^-$  sensitivity at HL-LHC **available**:

- Based on the full Run 2 analysis.
- Integrated luminosities of 1000, 2000, and 3000  $\text{fb}^{-1}$ .
- At 3000  $\text{fb}^{-1}$ , expected SM Higgs-pair sensitivity at  $3.5\sigma$  ( $4.6\sigma$  with stat. uncertainties only).
- Results demonstrate HL-LHC potential to probe Higgs pair production, constrain deviations from SM.
- Maintaining performance at the analysis level vital to our physics programmes.



## Example: FTAG @ HL-LHC

- GN2 algorithm retrained on Run 4 simulations.
- **ROC curve:** Characterizes performance of binary classifier by comparing signal efficiency with background rejection.
- For flavour tagging,  $b$ -jet efficiency  $\epsilon_b$  compared against rejection of  $c$ - and light-flavour jets.
- Compatible to Run 3 at low  $p_T$ , improvement up to  $\times 40\%$  at high  $p_T$ .
- Improvement attributed primarily to **ITk**, with improved tracking efficiency and impact parameter resolution.



- Search for non-resonant  $HH \rightarrow b\bar{b}\tau^+\tau^-$  production using the full Run 2 and Run 3 datasets.
- Validation measurements of  $ZH$  and  $ZZ$  are consistent with the SM predictions.

Large improvement over lumi-scaled projections based on Run 2:

- Improved b-tagging.
- Advanced transformer-based signal extraction.
- Sums up to a 40% improvement over luminosity scaling.

Studies ongoing to understand how our techniques will work at HL-LHC.

Maintaining (hopefully improving) performance of vital importance.

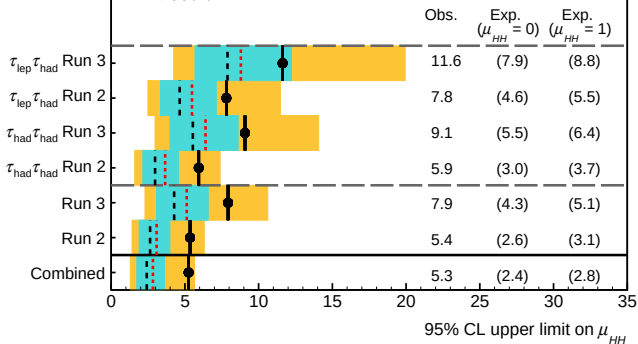
**Thank you for your attention!**

# ATLAS

$\sqrt{s} = 13 / 13.6 \text{ TeV}, 140 / 56 \text{ fb}^{-1}$

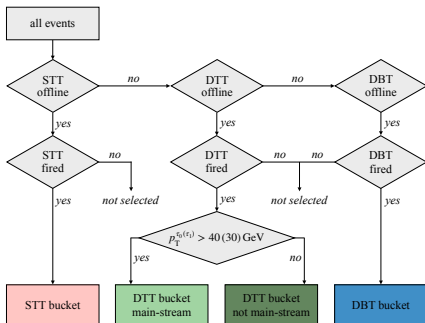
$HH \rightarrow b\bar{b}\tau^+\tau^-$

● Obs.  
 - - - Exp. ( $\mu_{HH} = 0$ )  
 . . . Exp. ( $\mu_{HH} = 1$ )  
 Exp. ( $\mu_{HH} = 0$ )  $\pm 2\sigma$   
 Exp. ( $\mu_{HH} = 0$ )  $\pm 1\sigma$



# BACKUP: Triggers

- For the  $\tau_{\text{lep}}\tau_{\text{had}}$  channel, single-lepton triggers (SLTs).
- Trigger bucketing strategy in place for the  $\tau_{\text{had}}\tau_{\text{had}}$  channel.



## STT offline selection

$p_T^{50} > 180 \text{ GeV}$   
(100 or 140 GeV in 2015 and parts of 2016)

## DTT offline selection

Nominal      Only DTT with 2L1 jets fired

$p_T^{50} > 40 \text{ GeV}$        $p_T^{50} > 40 \text{ GeV}$

$p_T^{51} > 30 \text{ GeV}$        $p_T^{51} > 30 \text{ GeV}$

$p_T^{52} > 70 \text{ GeV}$        $p_T^{52} > 50 \text{ GeV}$

$p_T^{53} > 20 \text{ GeV}$        $p_T^{53} > 50 \text{ GeV}$

$\Delta R_{\tau\tau} < 2.5$  (from 2017)

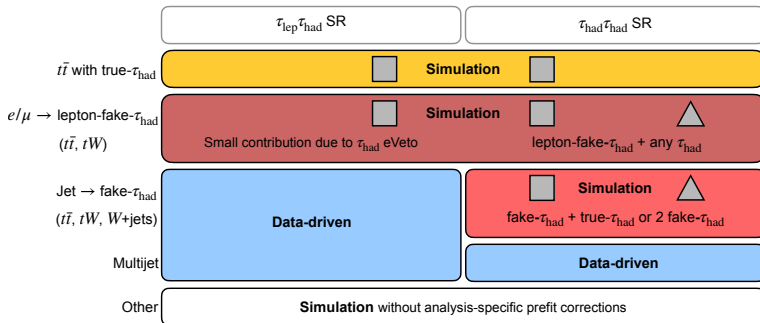
(2023 :  $p_T^{50} > 35 \text{ GeV}$ ,  $p_T^{51} > 25 \text{ GeV}$ )

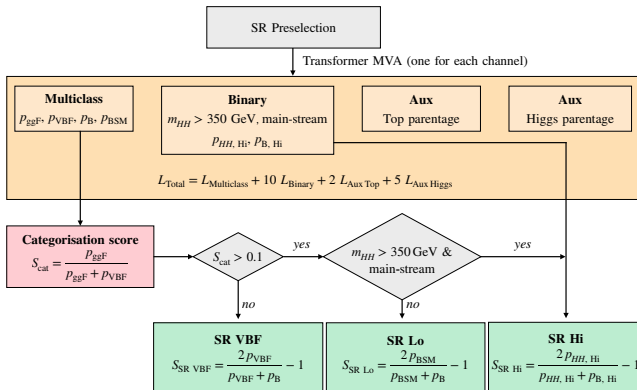
## DBT offline selection

Ordered  $\{p_T^{50}, p_T^{51}, p_T^{52}, p_T^{53}, \dots, p_T^{5n}\} > \{85, 60, 50, 25\} \text{ GeV}$

# BACKUP: Backgrounds

-   $t\bar{t}$  reweighing (derived in the  $t\bar{t} - e\mu$  CR)  
 Scale factors per jet  $\rightarrow$  fake- $\tau_{\text{had}}$  (derived in the  $\tau_{\text{lep}}\tau_{\text{had}} - t\bar{t}$  CR)





# BACKUP: Categorized log likelihood

