

Higgs boson production and decay rate measurements with the ATLAS experiment

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On behalf of the ATLAS Collaboration

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University of Oxford, UK



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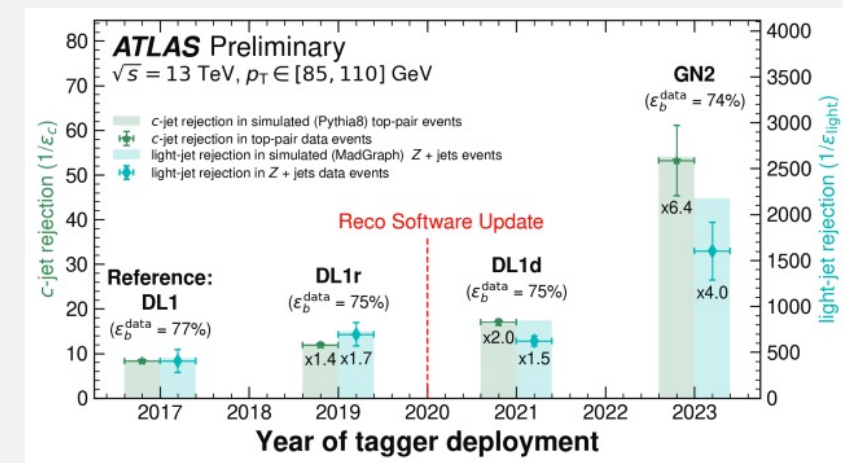
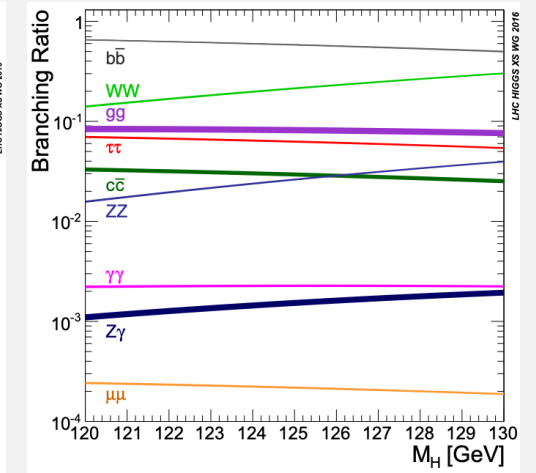
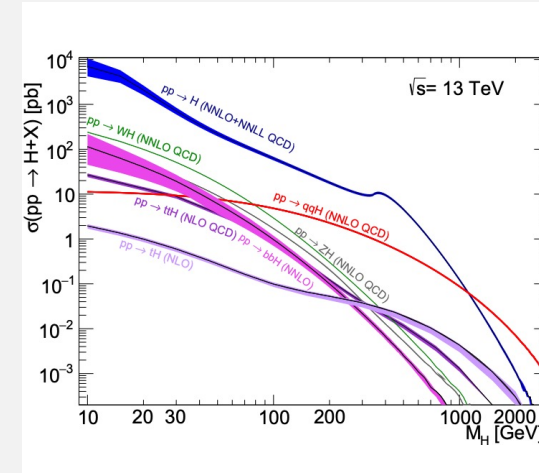


ATLAS
EXPERIMENT



● Introduction

- Since the Higgs boson discovery in 2012, increasingly precise measurements of its production and decay have provided stringent tests of the Standard Model.
- Important aspects of the Higgs sector remain to be explored:
 - **Rare production** and **decay** modes.
 - Higgs interactions in **high- p_T** regimes.
- LHC Run3 opens **new opportunities**:
 - **Growing dataset** at $\sqrt{s} = 13.6$ TeV.
 - **Detector upgrades** after Long Shutdown 2.
 - **Advanced analysis techniques**, including GNN and Transformers.

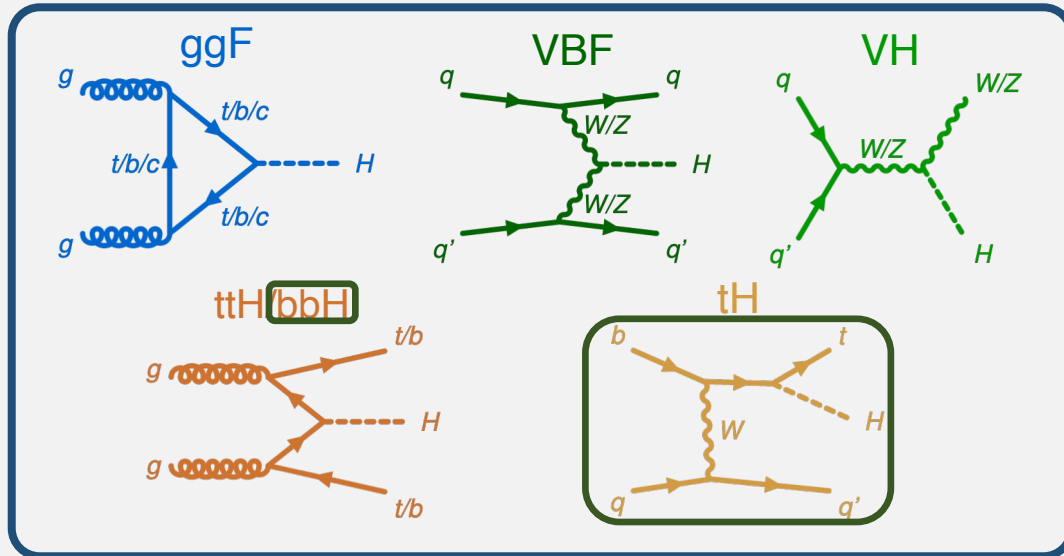


[1] Arxiv: 1610.07922

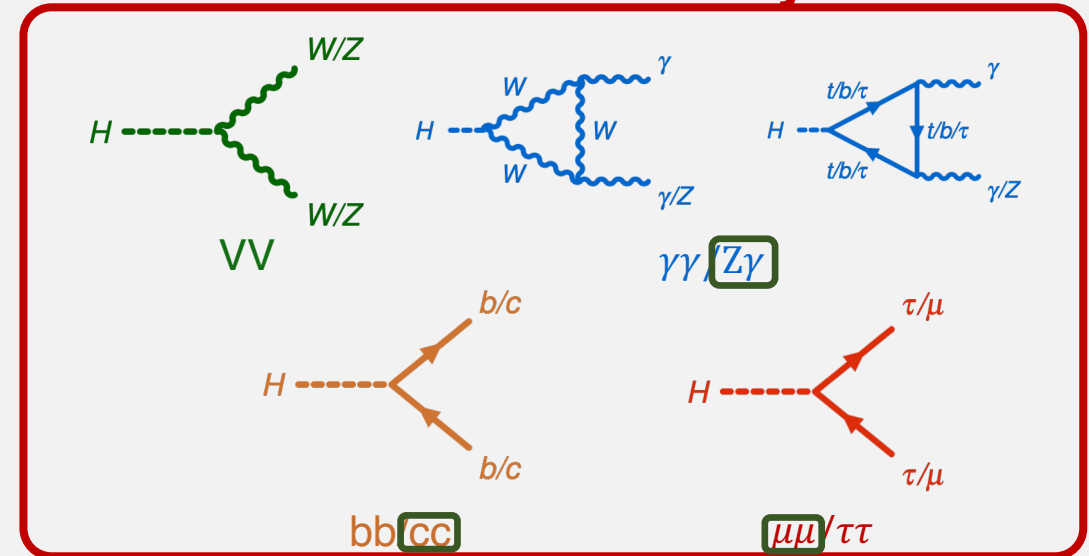
[2] ATLAS briefing

● Higgs production and decay modes

Production Modes



Decay Modes



☐ Not yet observed

Focus of this talk:

- **Precision measurements**: $H \rightarrow ZZ^* \rightarrow 4\ell$ cross sections and coupling constraints
- **Rare processes**: ttH and tH production and $H \rightarrow \gamma^*\gamma \rightarrow \ell\ell\gamma$
- **Boosted regime**: $H \rightarrow bb$ and $H \rightarrow \tau\tau$ at high p_T^H

Data used in this talk:

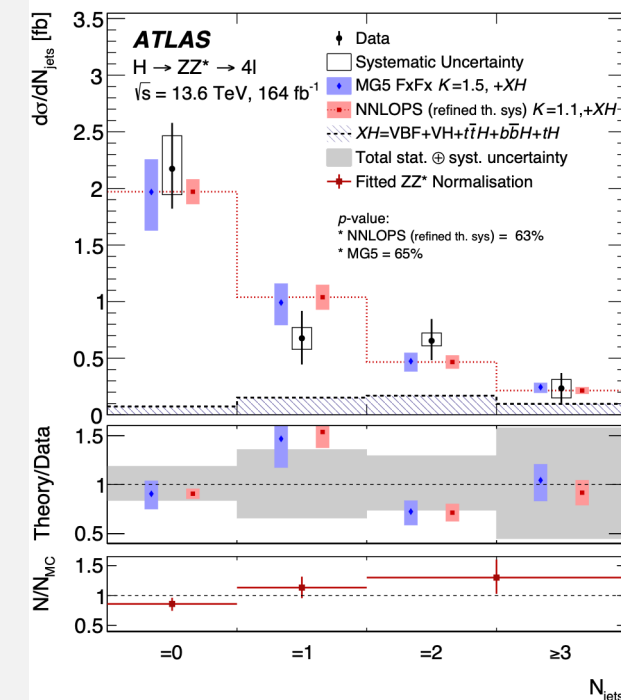
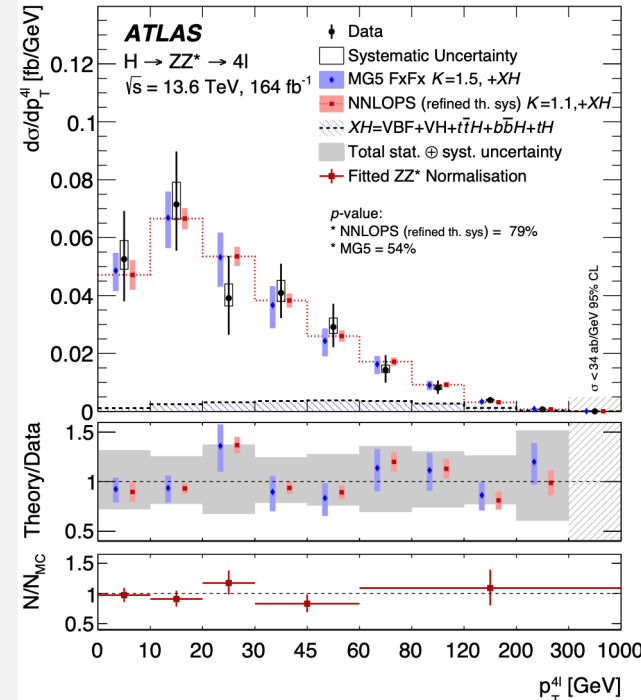
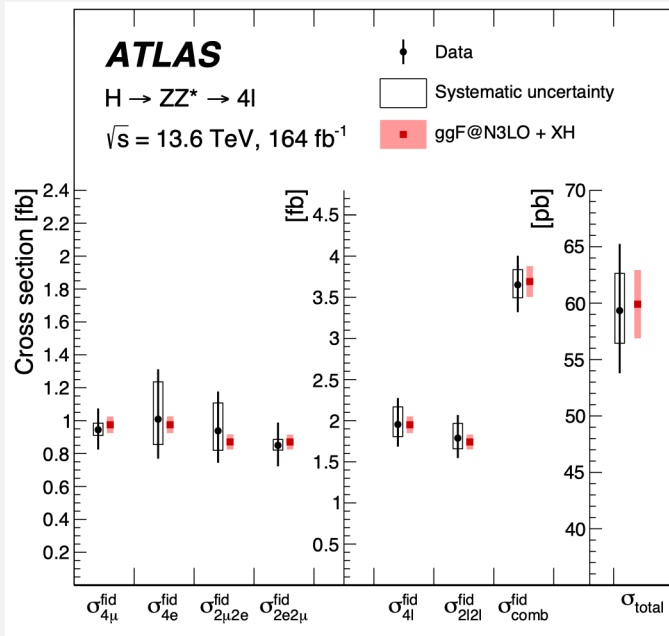
Full Run 2 (140fb^{-1} at $\sqrt{s}=13\text{ TeV}$) and **partial Run 3** (up to 164fb^{-1} at $\sqrt{s}=13.6\text{ TeV}$)

• $H \rightarrow ZZ^* \rightarrow 4\ell$: inclusive and differential cross-sections

- Fiducial and differential cross sections are extracted from binned likelihood fits to the reconstructed $m_{4\ell}$ spectrum and unfolded to particle level.
- Current partial Run 3 precision is comparable to that obtained with the full Run 2 dataset.

$$\sigma_{\text{fid}} = 3.65 \pm 0.30 \text{ (stat.) } {}^{+0.18}_{-0.16} \text{ (sys.) fb} = 3.65 {}^{+0.35}_{-0.33} \text{ fb}$$

Consistent with the SM
($\sigma_{\text{fid}}^{\text{SM}} = 3.68 \pm 0.17 \text{ fb}$)



• $H \rightarrow ZZ^* \rightarrow 4\ell$: production mode cross-sections

JHEP 08 (2026)052

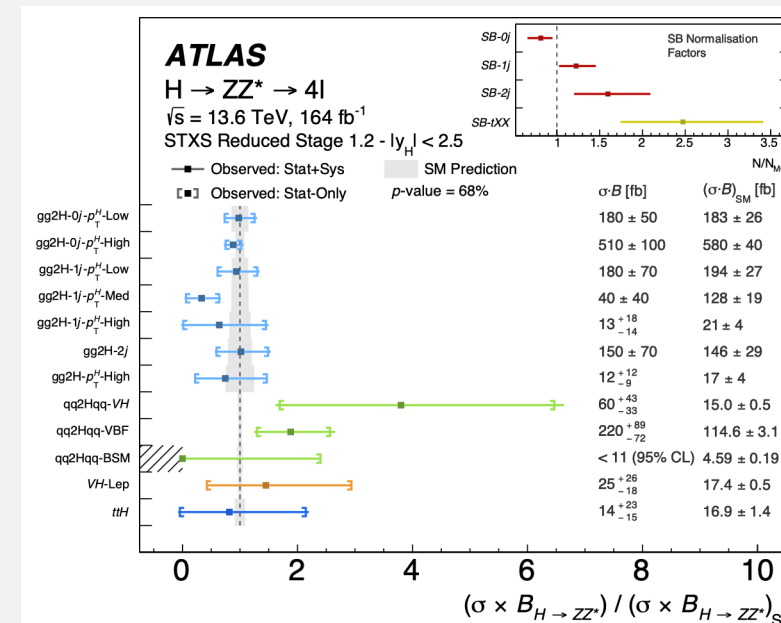
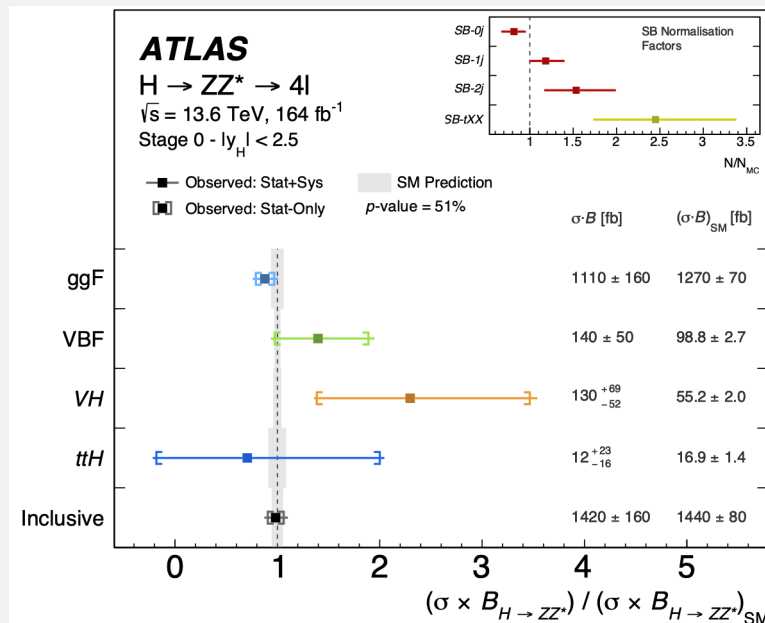


- Exclusive event categories target ggF, VBF, VH, and $t\bar{t}H$ production modes.
- Set Transformer classifiers improve production-mode separation in selected categories.
- Cross-sections are measured at Stage 0^[1] and in reduced Stage 1.2 regions defined by jet activity and Higgs boson kinematics.

$$\sigma_{|y_H| < 2.5} \times \mathcal{B}(H \rightarrow ZZ^*) = 1.42 \pm 0.16 \text{ pb}$$

Consistent with the SM:

- Stage 0: $p_{SM} = 51\%$
- Reduced Stage 1.2: $p_{SM} = 68\%$



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[1] In the Stage-0 fit, $b\bar{b}H$ is included in ggF, while $t\bar{t}H$ is included in $t\bar{t}H$, with their relative contributions fixed to the SM predictions.

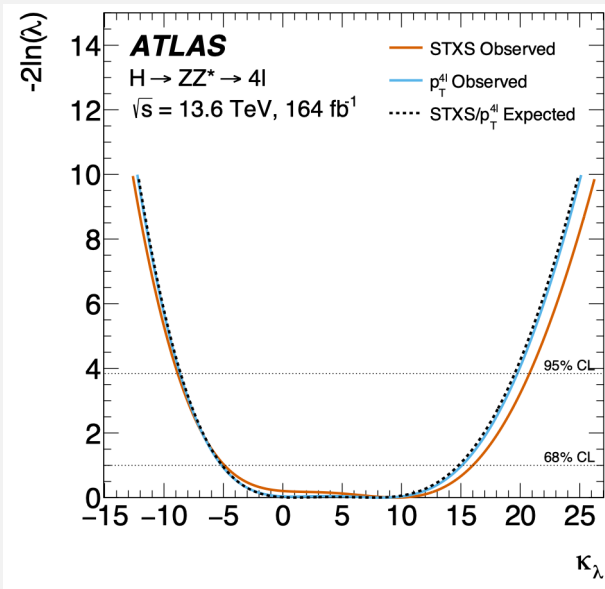
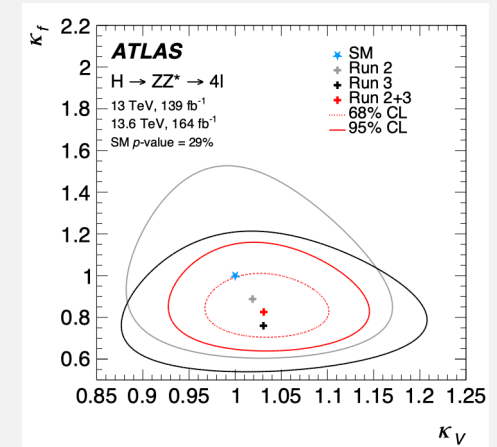
● $H \rightarrow ZZ^* \rightarrow 4\ell$: constraints on Higgs couplings

- The Run 2 and Run 3 production-mode measurements are combined to constrain the universal coupling modifiers κ_f and κ_V .

$$p_{SM} = 29\%$$

→ 40% tighter constraint on κ_V relative to Run 2

→ 25% tighter constraint on κ_f relative to Run 2



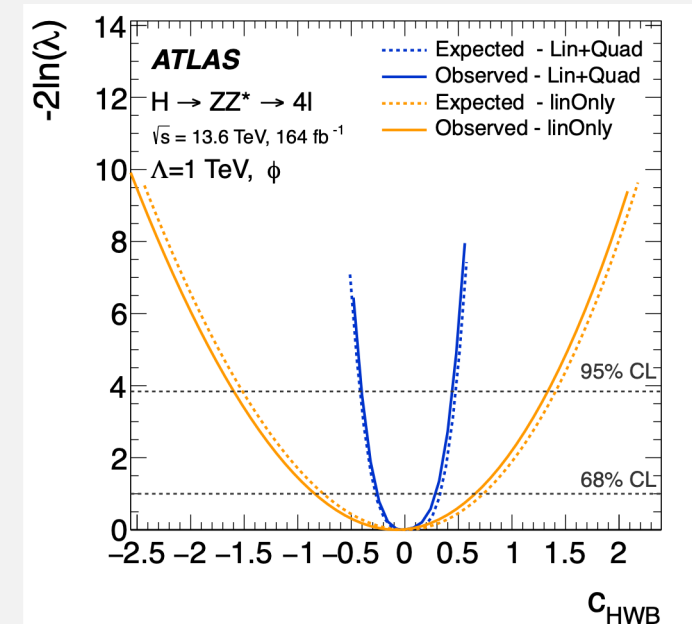
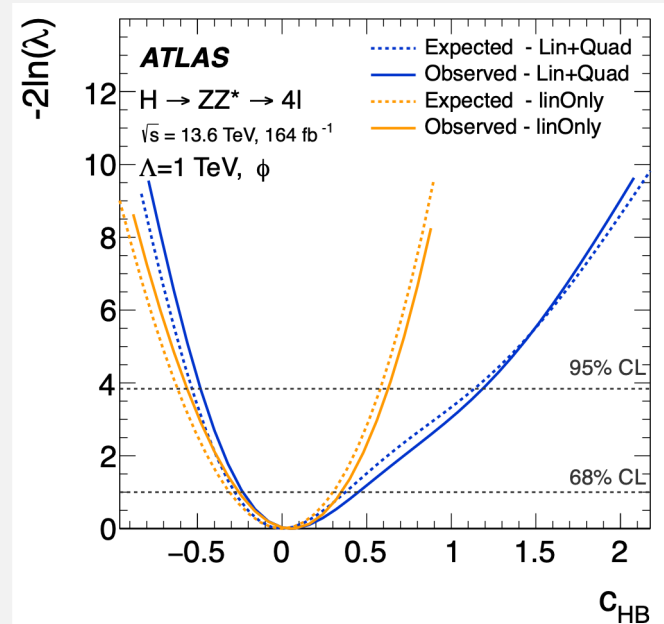
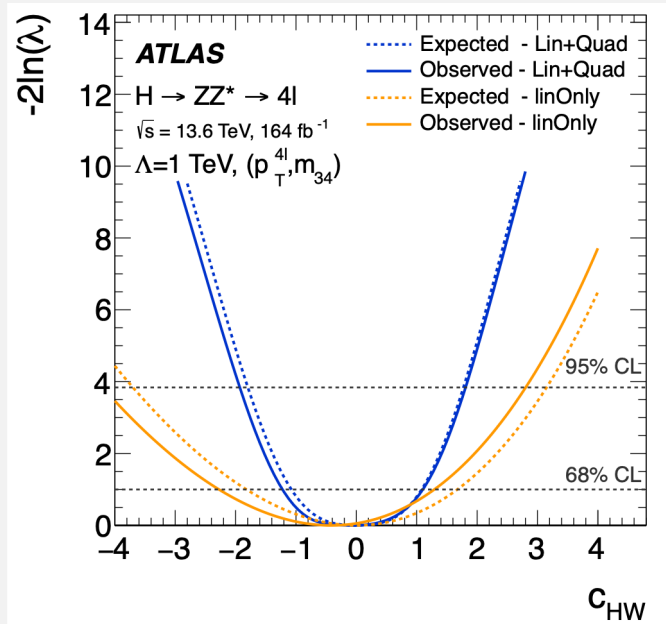
- The $p_T^{4\ell}$ and STXS measurements constrain κ_λ through loop-level effects in single-Higgs production and decay using only the **partial Run 3 data**.

- $p_T^{4\ell}$: $-8.8 < \kappa_\lambda < 19.9$ (95% CL)
- **STXS**: $-9.0 < \kappa_\lambda < 20.9$ (95% CL)

*In each interpretation, only the displayed κ parameters are floated; all other coupling modifiers are fixed to their SM values.

• $H \rightarrow ZZ^* \rightarrow 4\ell$: SMEFT interpretations

- Six SMEFT coefficients affecting Higgs couplings to electroweak bosons are probed: **3 CP-even** (c_{HW}, c_{HB}, c_{HWB}) and **3 CP-odd** ($c_{H\widetilde{W}}, c_{H\widetilde{B}}, c_{H\widetilde{WB}}$).
- The double-differential ($p_T^{4\ell}, m_{34}$) measurement provides the best expected sensitivity to c_{HW} , while the decay angle ϕ constrains the other coefficients.
- Linear-only and linear-plus-quadratic SMEFT predictions are compared.



No significant deviation from the SM is observed

$P_T^{4\ell}$: four-lepton transverse momentum.

m_{34} : inv. mass of the sub-leading lepton pair.

ϕ : angle between the two Z decay planes.



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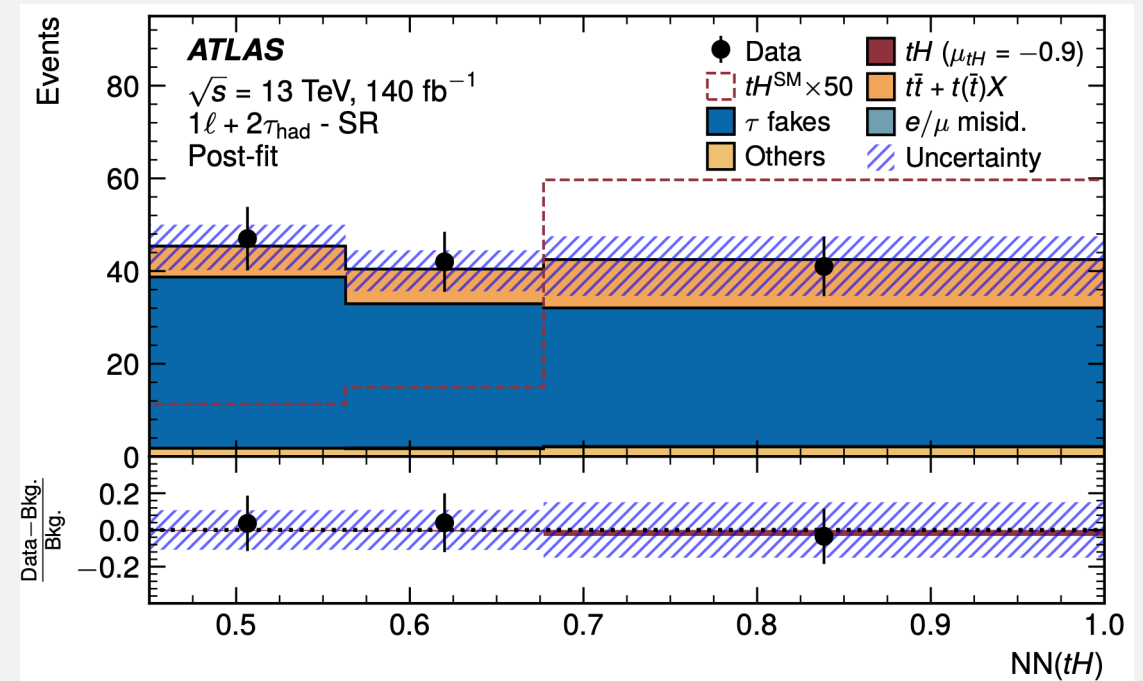
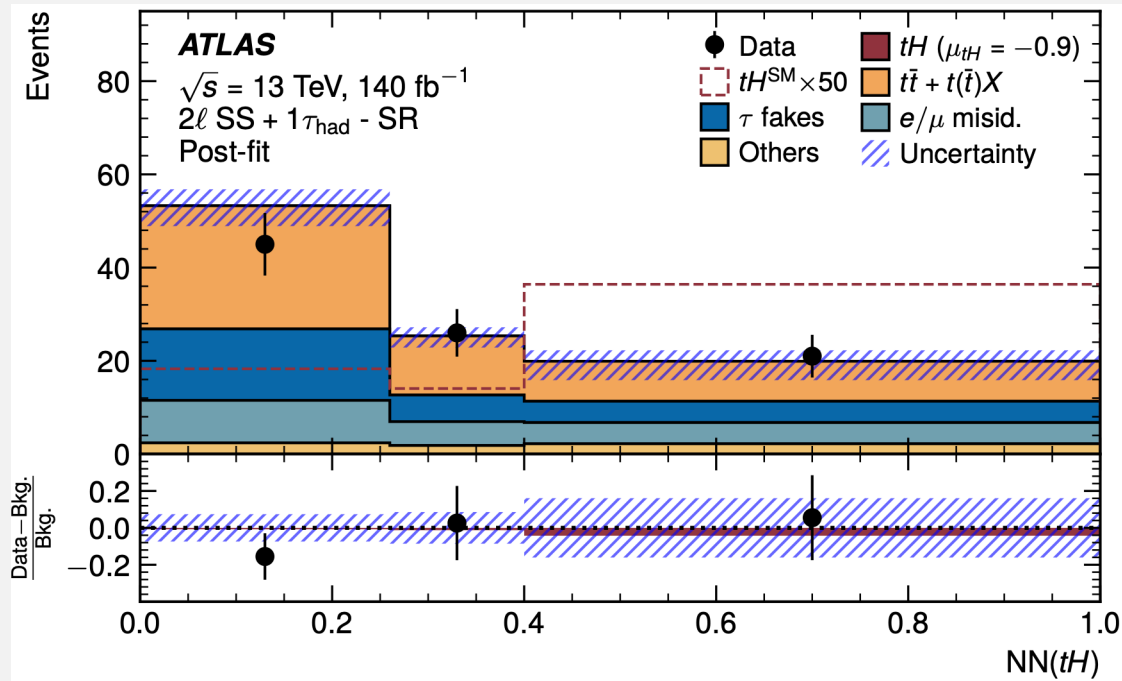
* One Wilson coefficient is varied at a time, with all others fixed to 0.

Search for tH production

Arxiv: 2607.27708



- tH production rate is probed through $H \rightarrow \tau\tau$ with two new final states with Run 2 data only: $2\ell + 1\tau_{\text{had}}$ and $1\ell + 2\tau_{\text{had}}$.
- Channel-specific NNs are used to separate signal from background.



Combination of the two new final states:

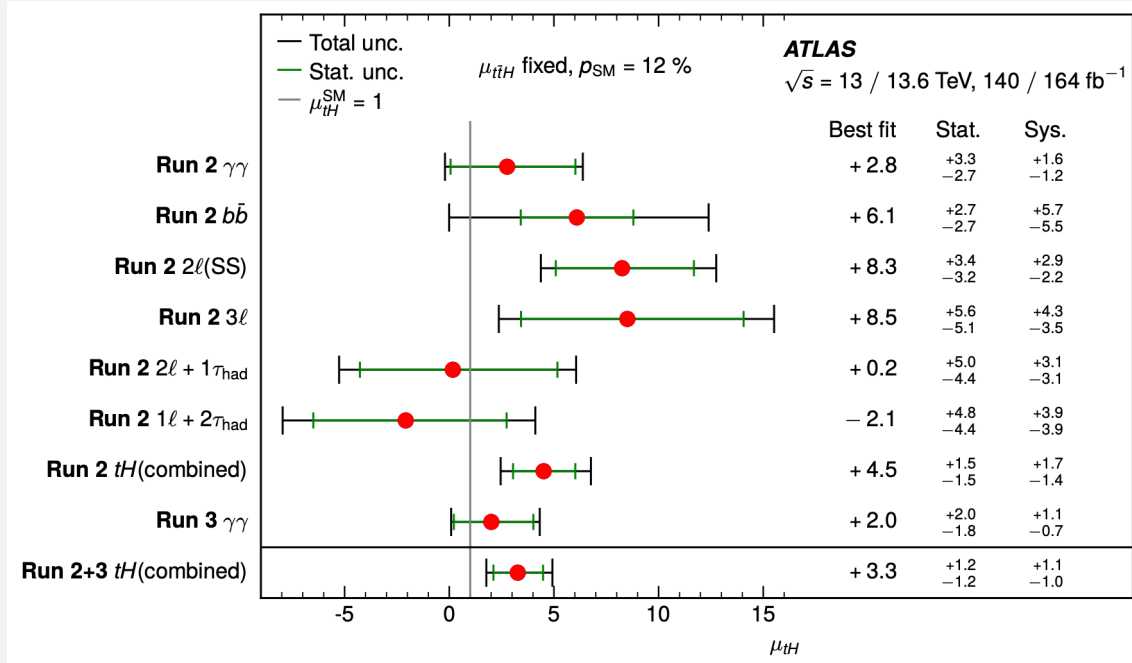
$$\mu_{tH} = -0.9^{+4.4}_{-4.2}, \quad 95\% \text{ CL obs. (exp.) upper limit: } 8.6(9.3) \times \text{SM}$$

Search for tH production

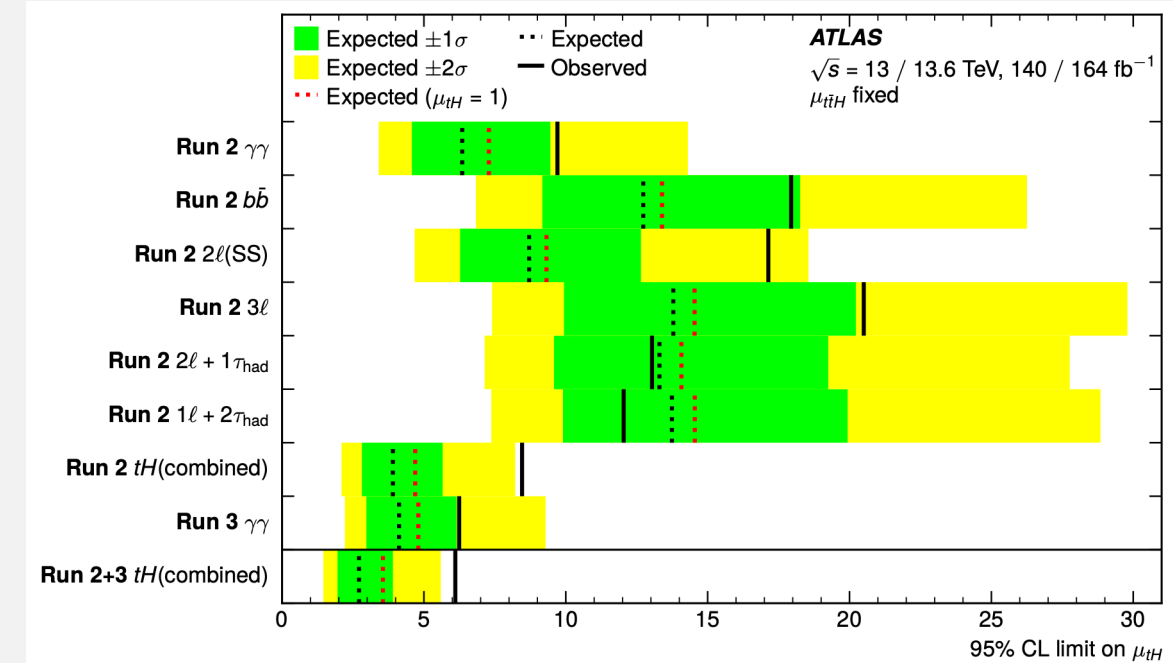
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- The new $H \rightarrow \tau\tau$ channels are combined with other Run 2 tH searches and partial Run 3 $H \rightarrow \gamma\gamma$ result. (μ_{tH} is fixed to 1 during combination)



$\mu_{tH} = 3.3^{+1.7}_{-1.5} = 3.3 \pm 1.2(\text{stat.})^{+1.1}_{-1.0}(\text{sys.})$
2.3 σ observed (0.8 σ expected)



95% CL obs.(exp.) upper limit: 6.1(2.7) $\times$ SM

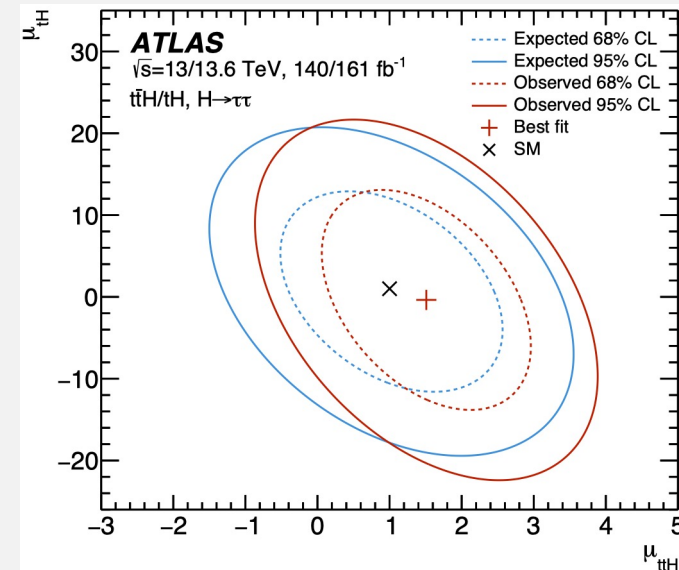
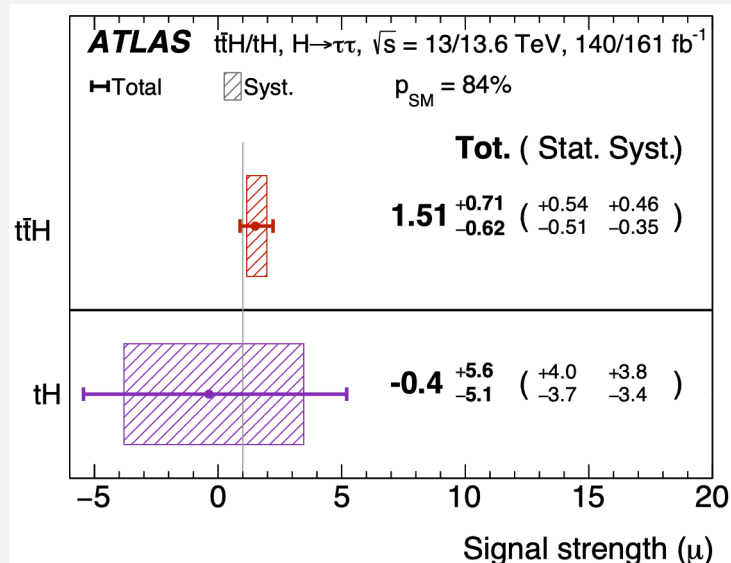
Most precise tH measurement to date

• Simultaneous ttH and tH measurement in $H \rightarrow \tau\tau$ [Arxiv: 2607.27276](https://arxiv.org/abs/2607.27276)

- The analysis targets hadronic top-quark decay and $H \rightarrow \tau_{\text{had}}\tau_{\text{had}}$.
- **GNTau**, a transformer/GNN based τ identifier, is used for the first time in ATLAS.
- A **four-class BDT** categorizes events as ttH , tH , $Z \rightarrow \tau\tau$ or $t\bar{t}$.
- Both μ_{ttH} and μ_{tH} are floated in a simultaneous profile-likelihood fit.

$$\mu_{ttH} = 1.51^{+0.71}_{-0.62}, \quad \mu_{tH} = -0.4^{+5.6}_{-5.1}$$

- Correlation between μ_{ttH} and μ_{tH} : -34%.
- $ttH(H \rightarrow \tau\tau)$ observed(expected) significance: **2.6 σ** (1.8 σ)

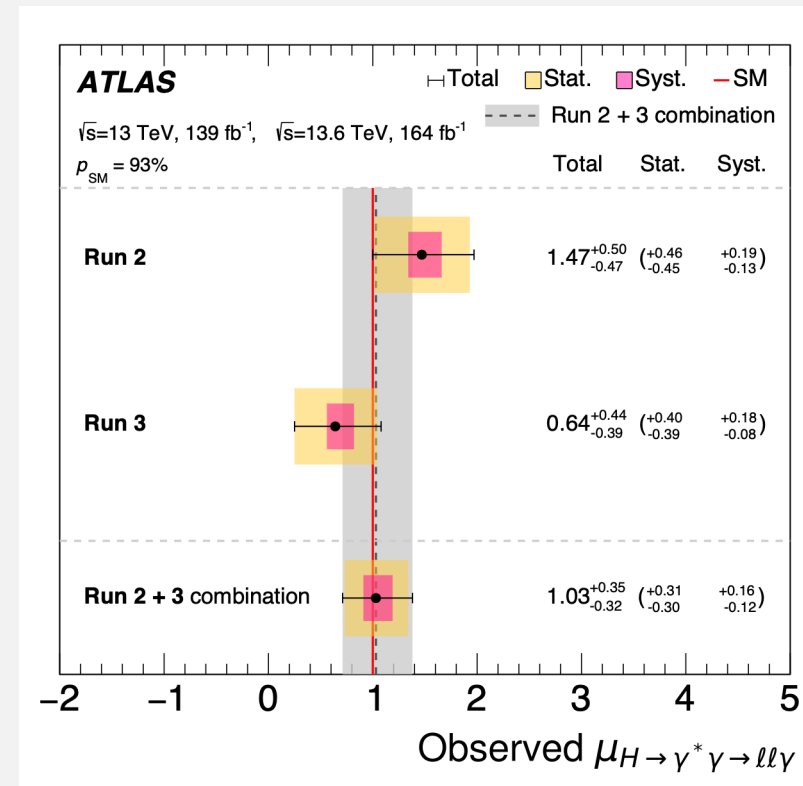
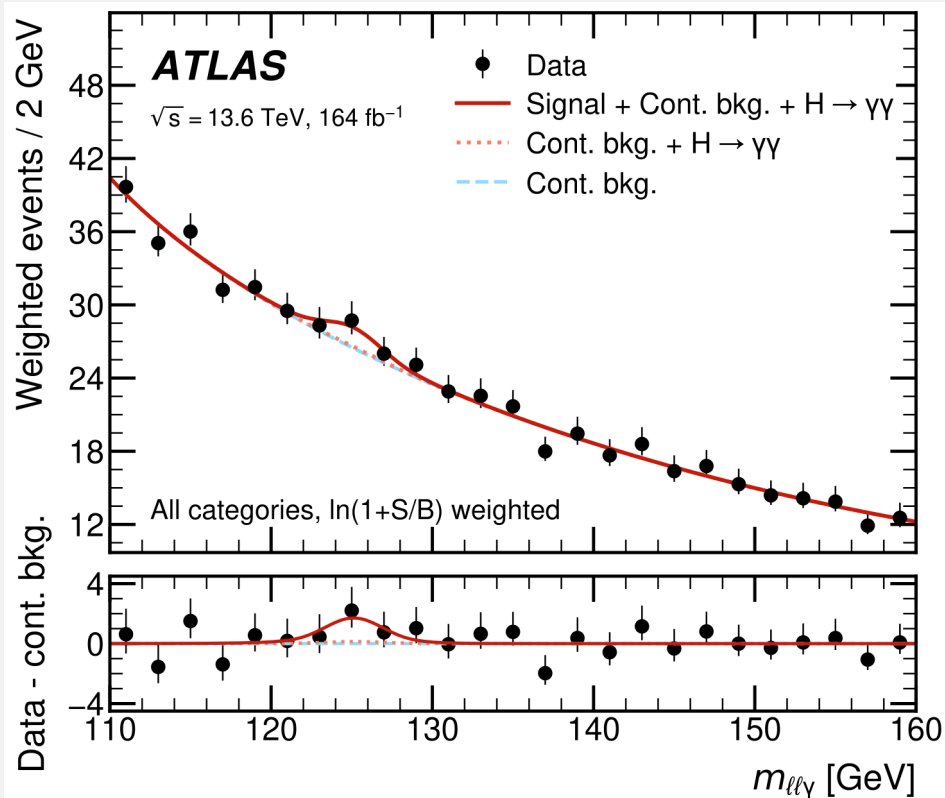
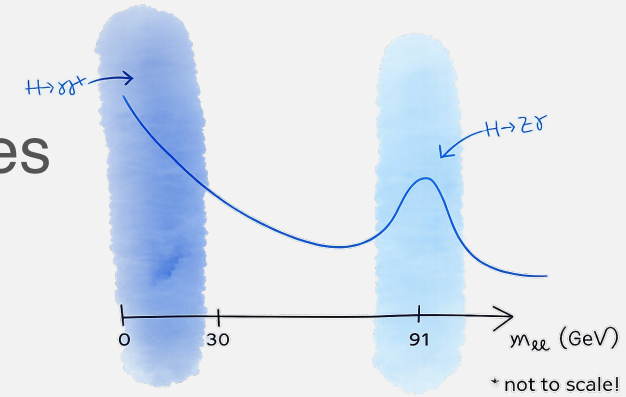


Evidence for $H \rightarrow \gamma^* \gamma \rightarrow \ell \ell \gamma$

Arxiv: 2608.03369



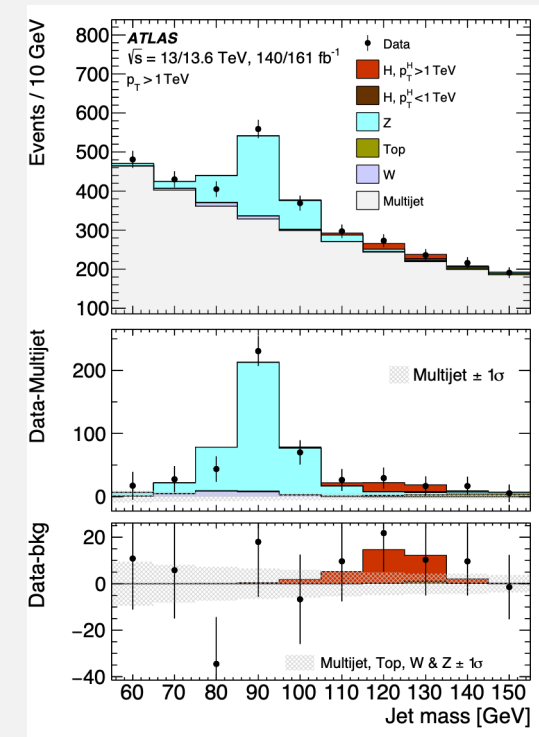
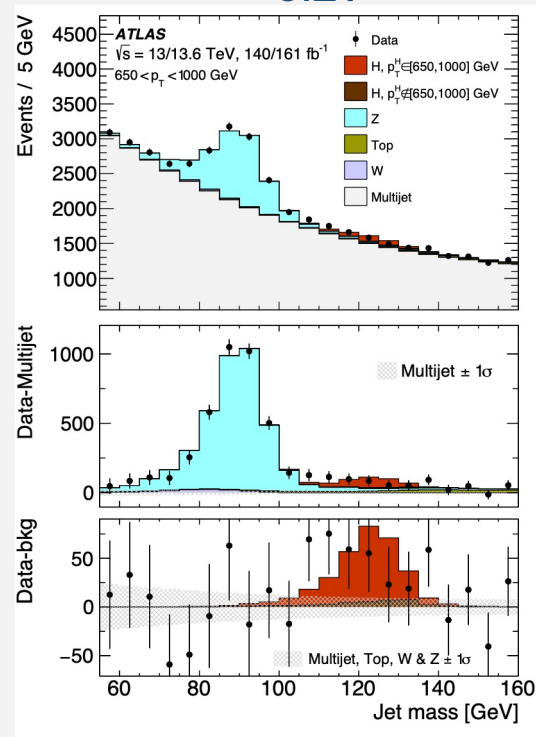
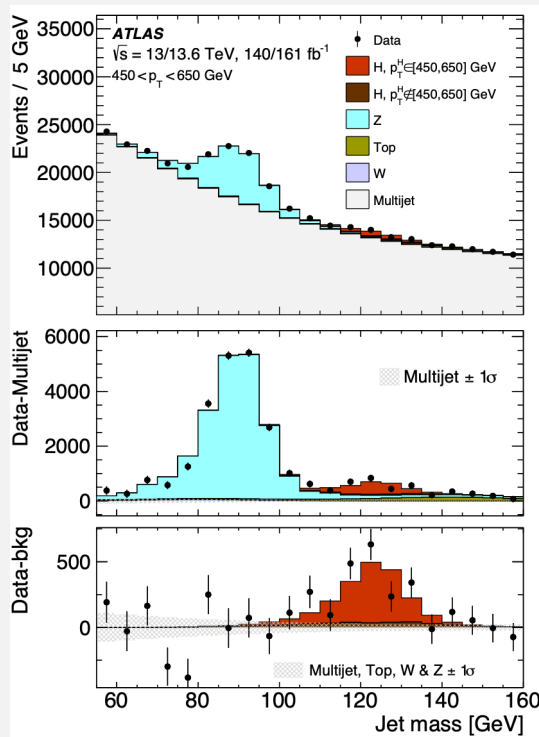
- Targets $H \rightarrow \gamma^* \gamma \rightarrow \ell \ell \gamma$ in the low $m_{\ell \ell}$ region ($m_{\ell \ell} < 30$ GeV).
- A dedicated **BDT-based** merged-electron identification improves the expected significance by 5% relative to the Run 2 strategy.
- The combined Run 2+3 result is consistent with the SM:
Observed (expected) significance: **3.4σ** (3.3σ)



Evidence for boosted inclusive $H \rightarrow bb$ production [PRL 137, 071801 \(2026\)](#)

- Higgs candidates are reconstructed as single large- R jets with $p_T > 450$ GeV.
- Two **transformer-based** tools improve the analysis: **GN2X**^[1] suppresses multijet background, while **BJR**^[2] improves the jet-mass resolution by about 30%.
- Combined Run 2+3 result: **3.8σ** observed (2.5σ expected).

$$\mu = 1.53 \pm 0.27(\text{stat.}) \pm 0.33(\text{exp.}) \pm 0.17(\text{theory}).$$

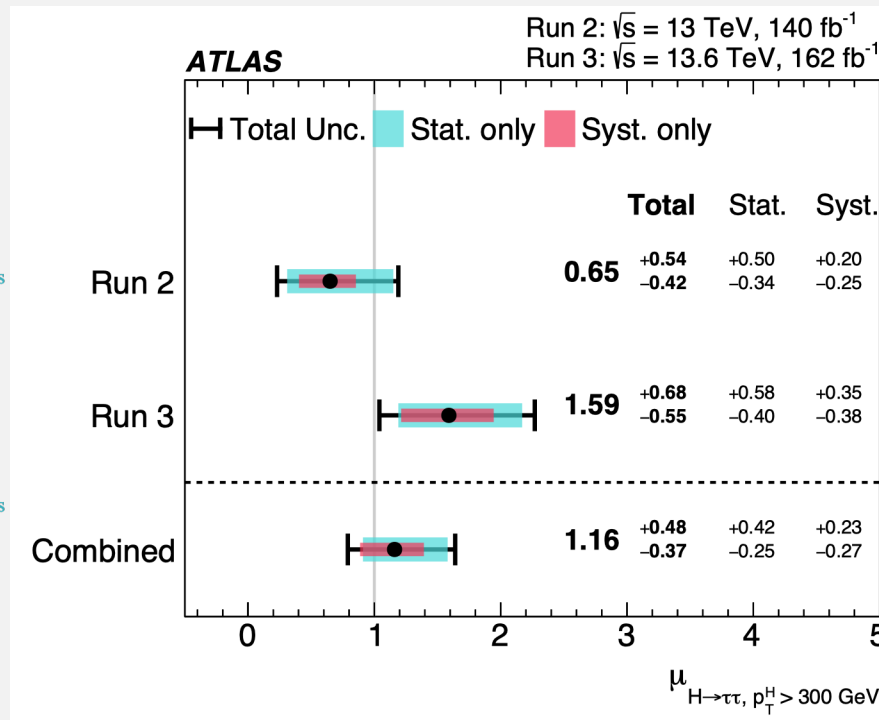
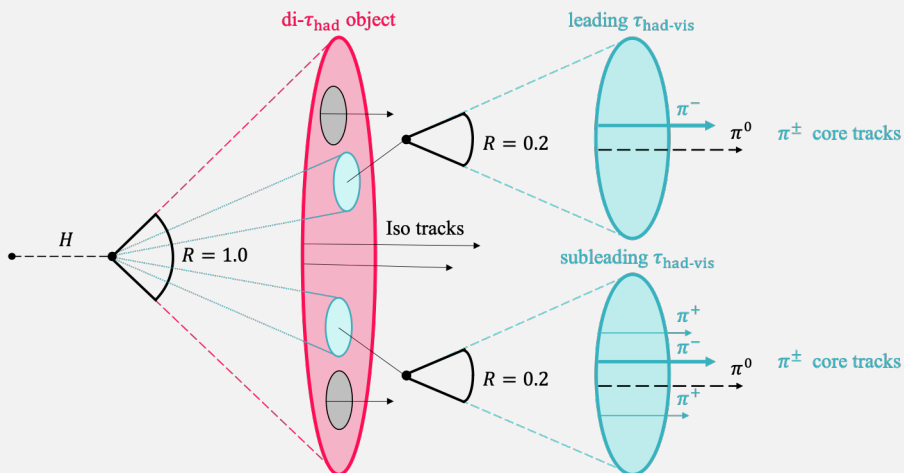


• Evidence for boosted $H \rightarrow \tau\tau$ production

Arxiv: 2607.22193



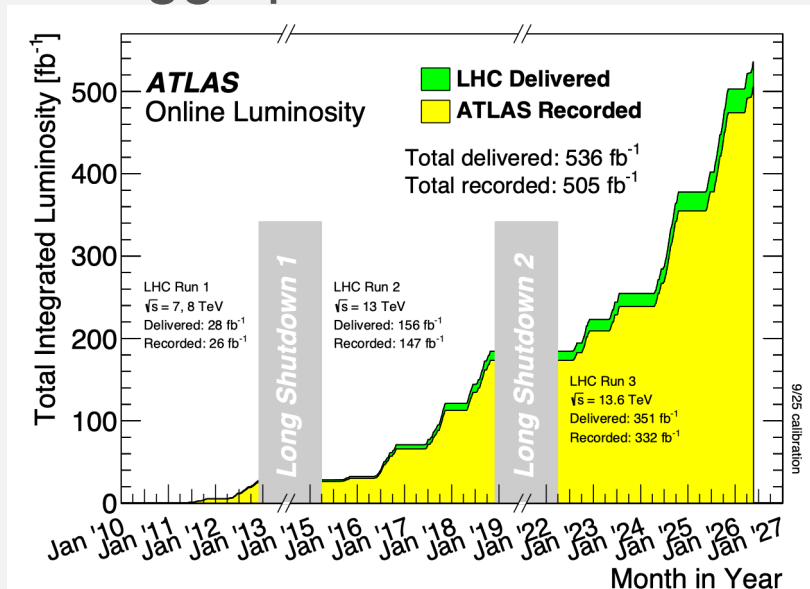
- Dedicated di- τ_{had} reconstruction resolves two nearby hadronic τ decays within a large- R jet.
- The transformer-based **OMNI tagger** achieves more than an order-of-magnitude improvement in background rejection relative to the BDT reference.
- The boosted ggF and EW qqH STXS measurements are **compatible** with the SM.
($p_{SM}=52\%$ for Run 2 and $p_{SM}=70\%$ for Run 3)



Combined Run 2+3 for inclusive $p_T^H > 300$ GeV:
3.8 σ obs. (3.3 σ exp.)
 $\mu = 1.16^{+0.48}_{-0.37}$

● Conclusion

- ATLAS is extending Higgs-boson rate measurements to rarer processes and higher transverse momenta, while improving precision in established channels.
- The results presented are **compatible with the Standard Model**, with substantial room for improvement in rare and boosted processes.
- **Larger datasets** will improve statistical precision, particularly for rare and boosted Higgs processes.



[1]



[2]

● Conclusion

- Beyond increased luminosity, advanced machine-learning techniques can further improve sensitivity by extracting more signal information from the same data.

Machine learning is extending the reach of Higgs measurements:

Object identification

Merged- ee BDT

$H \rightarrow \gamma^* \gamma$
+5% exp. significance vs.
cut-based ID

GNTau

$t\bar{t}H/tH, H \rightarrow \tau\tau$
1.3-2.5 $\times$ higher jet
rejection than RNN

OMNI Tagger

Boosted $H \rightarrow \tau\tau$
> 10 $\times$ bkg. rejection
than BDT

GN2X

Boosted $H \rightarrow b\bar{b}$
 $\sim 500\times$ multijet rejection
with $\sim 40\%$ ϵ_{sig}

Event classification

Set Transformer

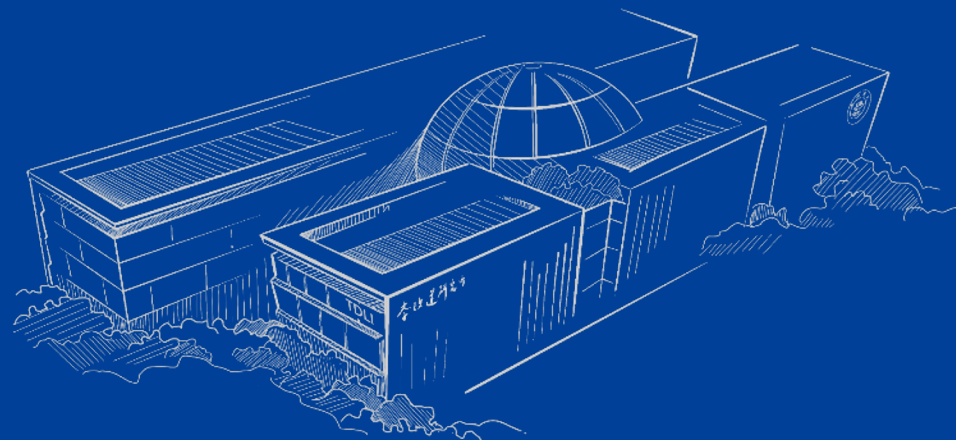
$H \rightarrow ZZ^* \rightarrow 4\ell$
Separate ggF, VBF, VH,
 $t\bar{t}H$ and bkg.

Object recon.

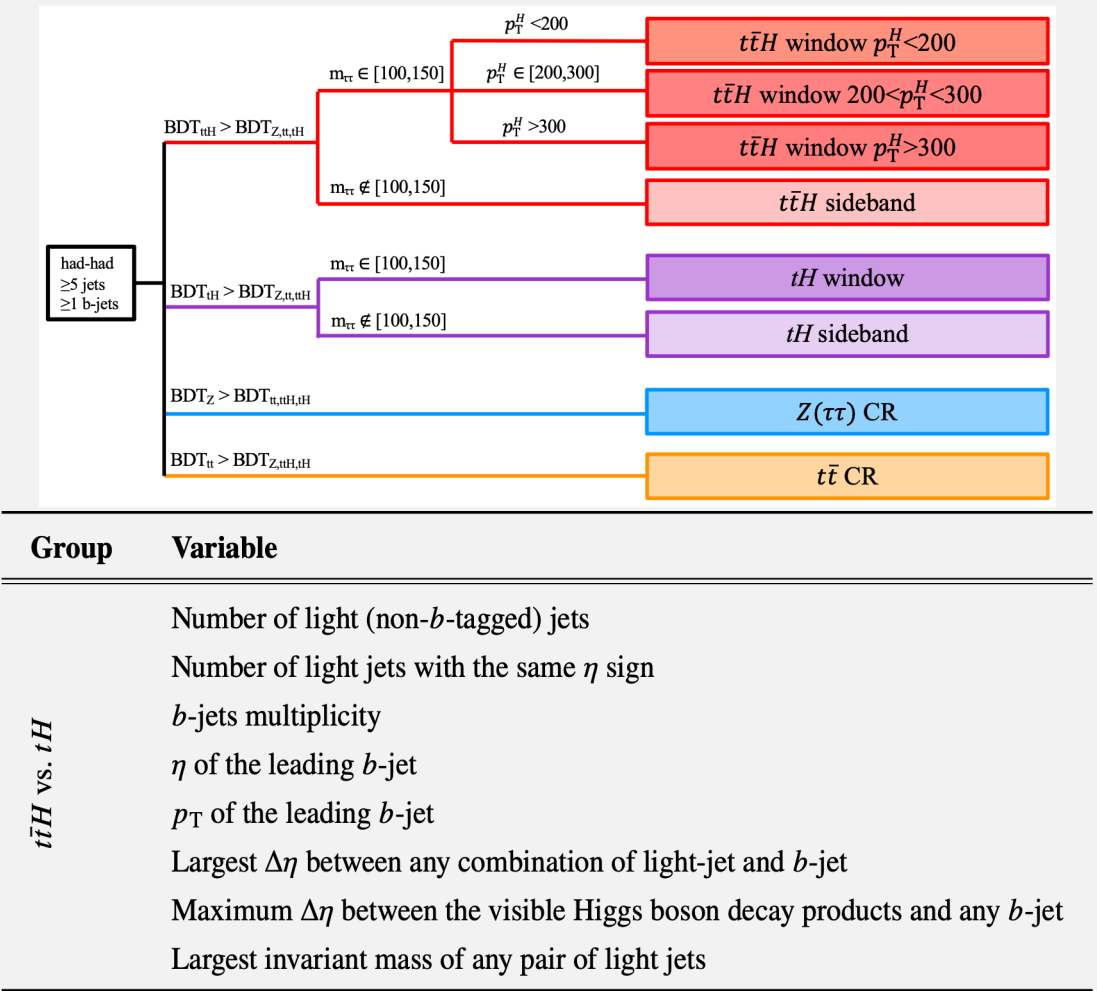
bJR

Boosted $H \rightarrow b\bar{b}$
 $\sim 30\%$ improvement in
jet-mass resolution

Thanks!



- A four-class BDT assigns events to ttH , tH , $Z \rightarrow \tau\tau$ or $t\bar{t}$ by their highest output score.
- Jet multiplicities and light-jet/ b -jet topology add discrimination between tH and ttH .
- The $100 < m_{\tau\tau}^{MMC} < 150$ GeV window defines the signal regions; sidebands and background-enriched categories constrain $Z \rightarrow \tau\tau$ and $t\bar{t}$.
- The ttH signal region is further split into three p_T^H bins; the tH signal region remains inclusive.



Backup - Boosted $H \rightarrow \tau\tau$: STXS cross-sections

Arxiv: 2607.22193



- The STXS fit separates EW qqH at $p_T^H > 300$ GeV from ggF in three p_T^H bins: 300-450, 450-650 and > 650 GeV.
- In the highest- p_T^H ggF bin, the combined 95% CL upper limit is 4.5 times the SM prediction (6.5 expected).

