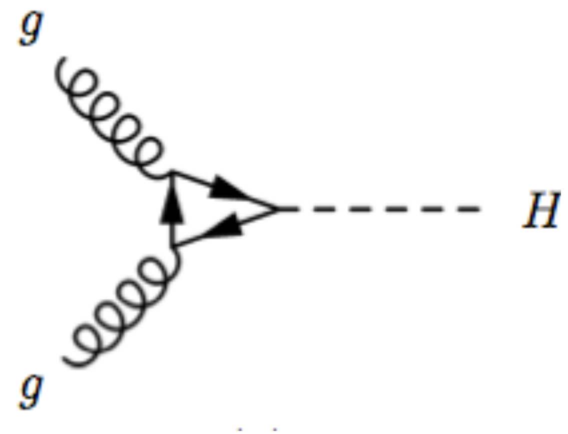
# Cross-section measurements for boosted $H \to \tau\tau$ with ATLAS experiment

ATLAS-CONF-2026-005

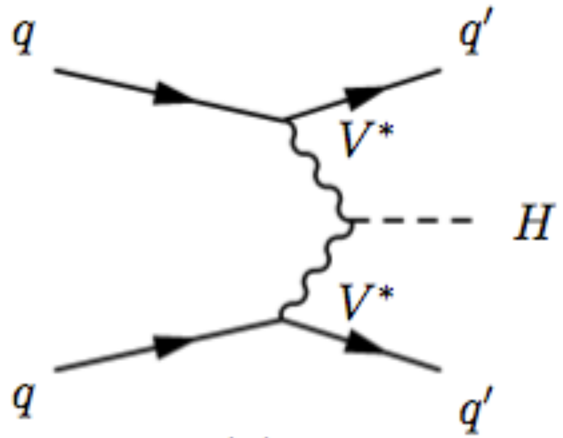
Antonio De Maria

第十二届中国物理学会高能物理分会

# Higgs boson production modes

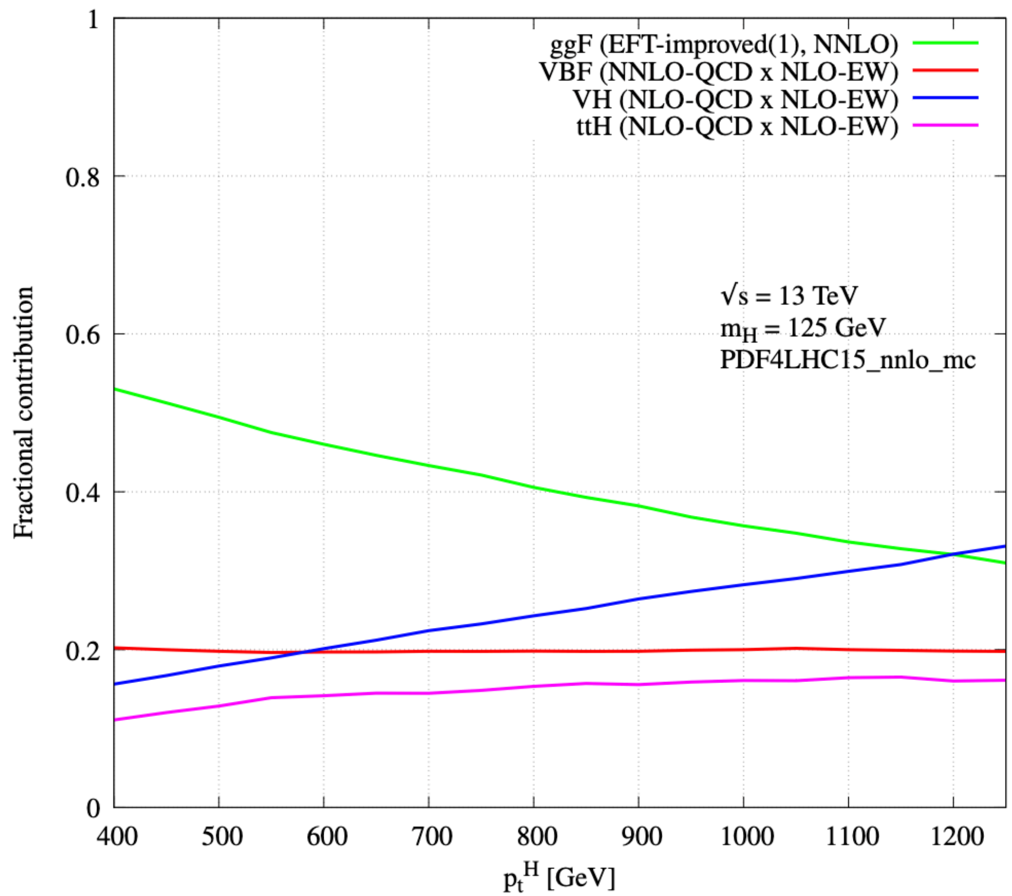


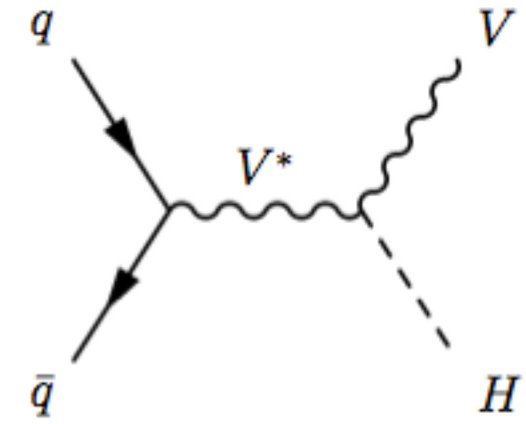

Gluon fusion (ggF)



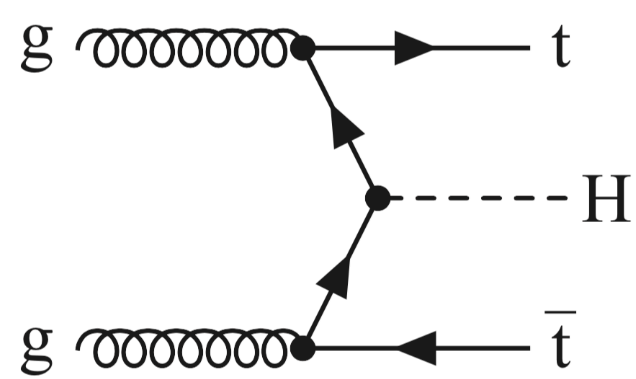

Vector boson fusion (VBF)

[arxiv-2005.07762](https://arxiv.org/abs/2005.07762)



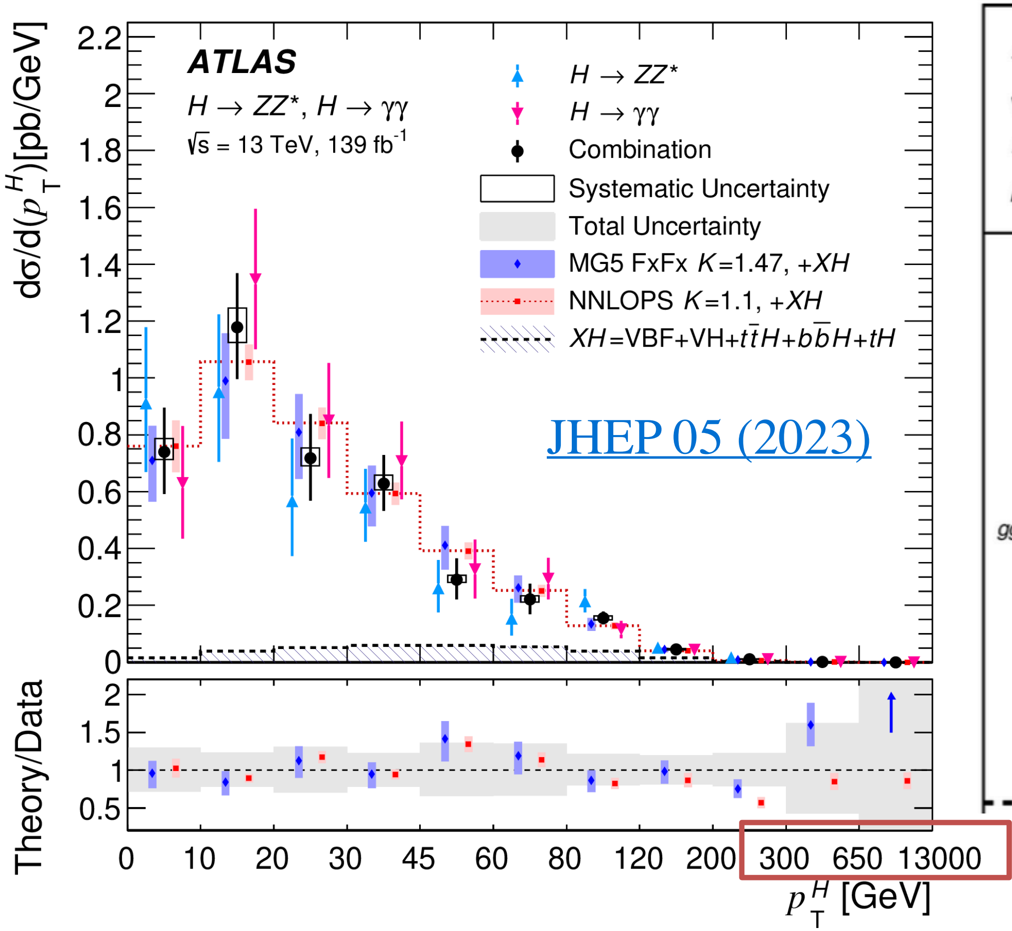




Associated production with a gauge boson (VH)

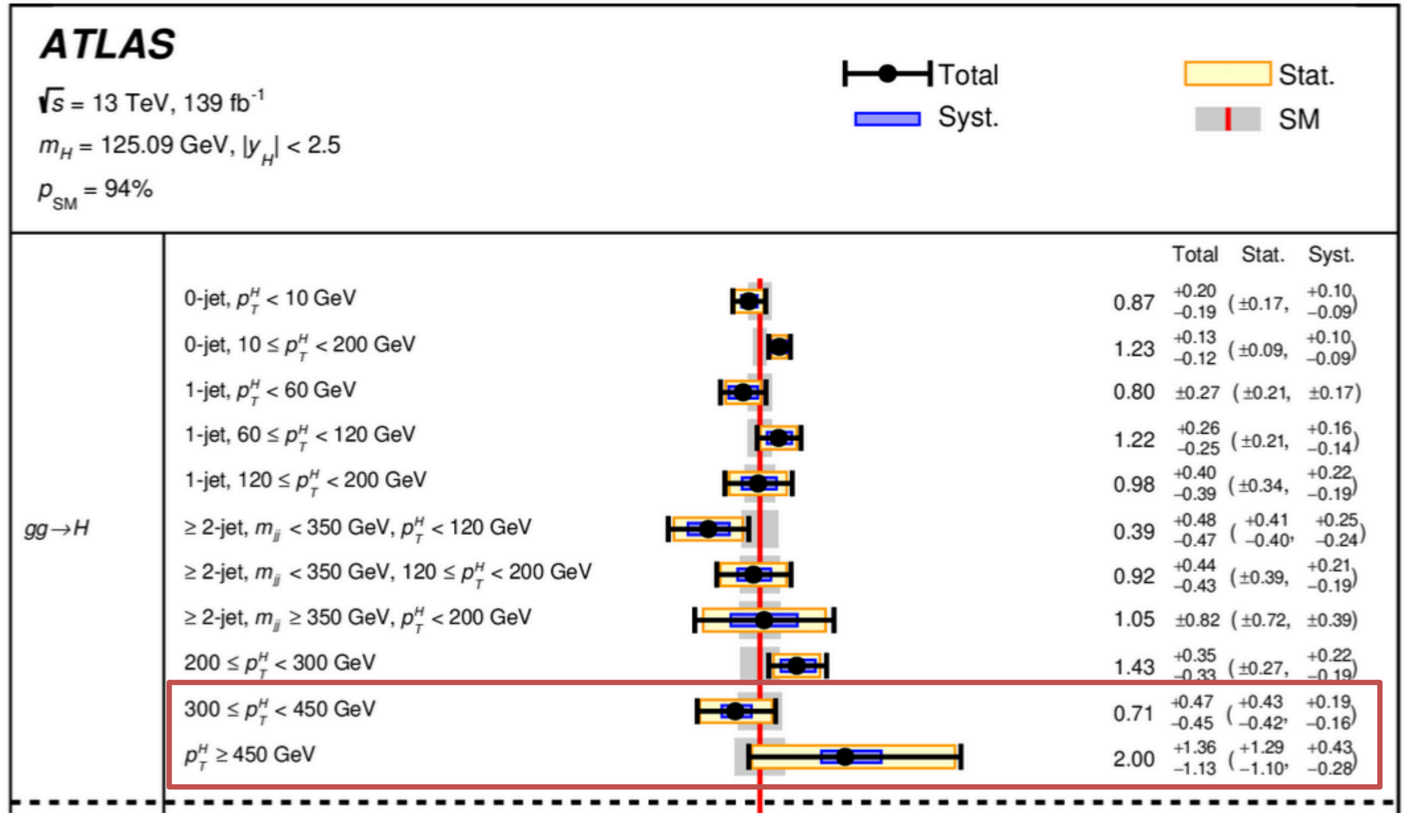



Associated production with a $t\bar{t}$ pair (ttH)

# Differential cross-section/STXS results in ATLAS




JHEP 05 (2023)

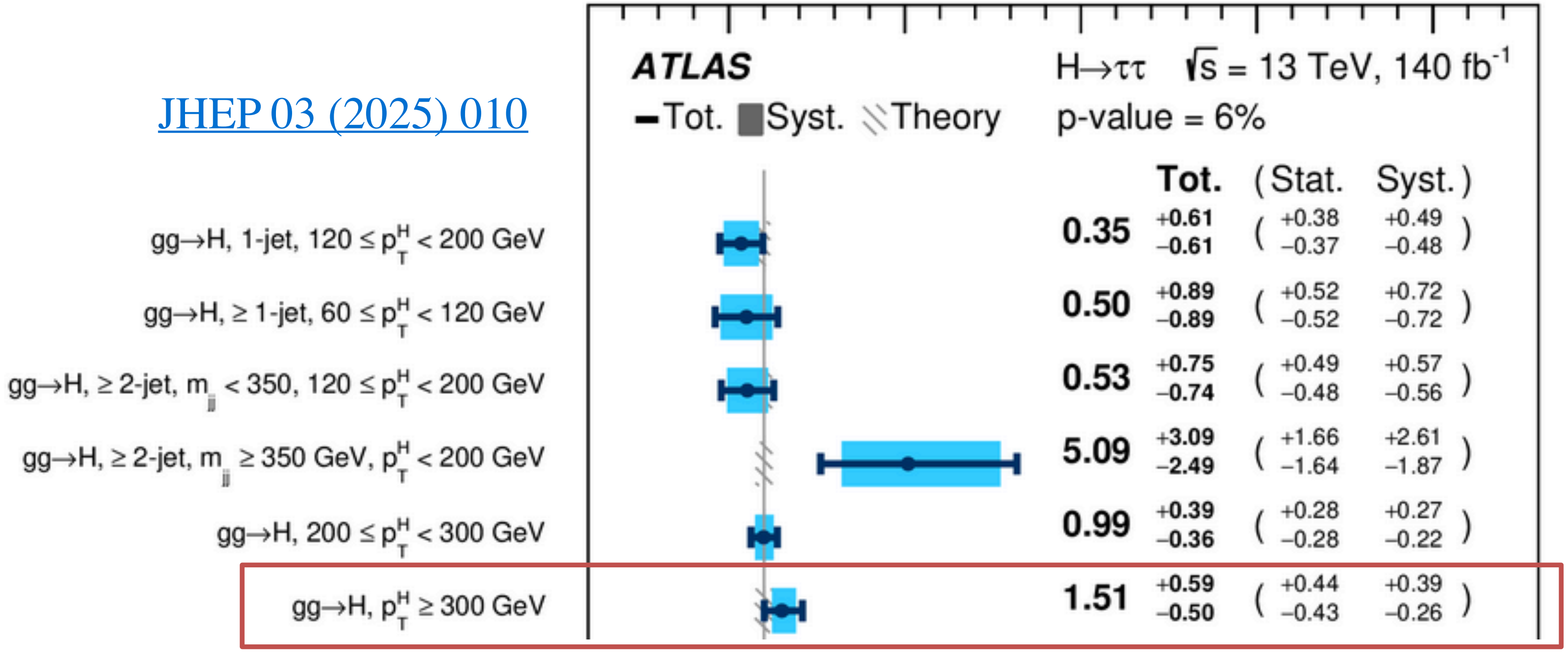



Nature 607 52 (2022)

- From differential and STXS measurements only limited coverage for high $p_T(H)$ regime, due to low cross-section (e.g. $\sigma_{p_T(H)>450\text{ GeV}} = 6 \times 10^{-4}\sigma_H$ ) and experimental challenges for reconstructing boosted events from the trigger and overlapping objects

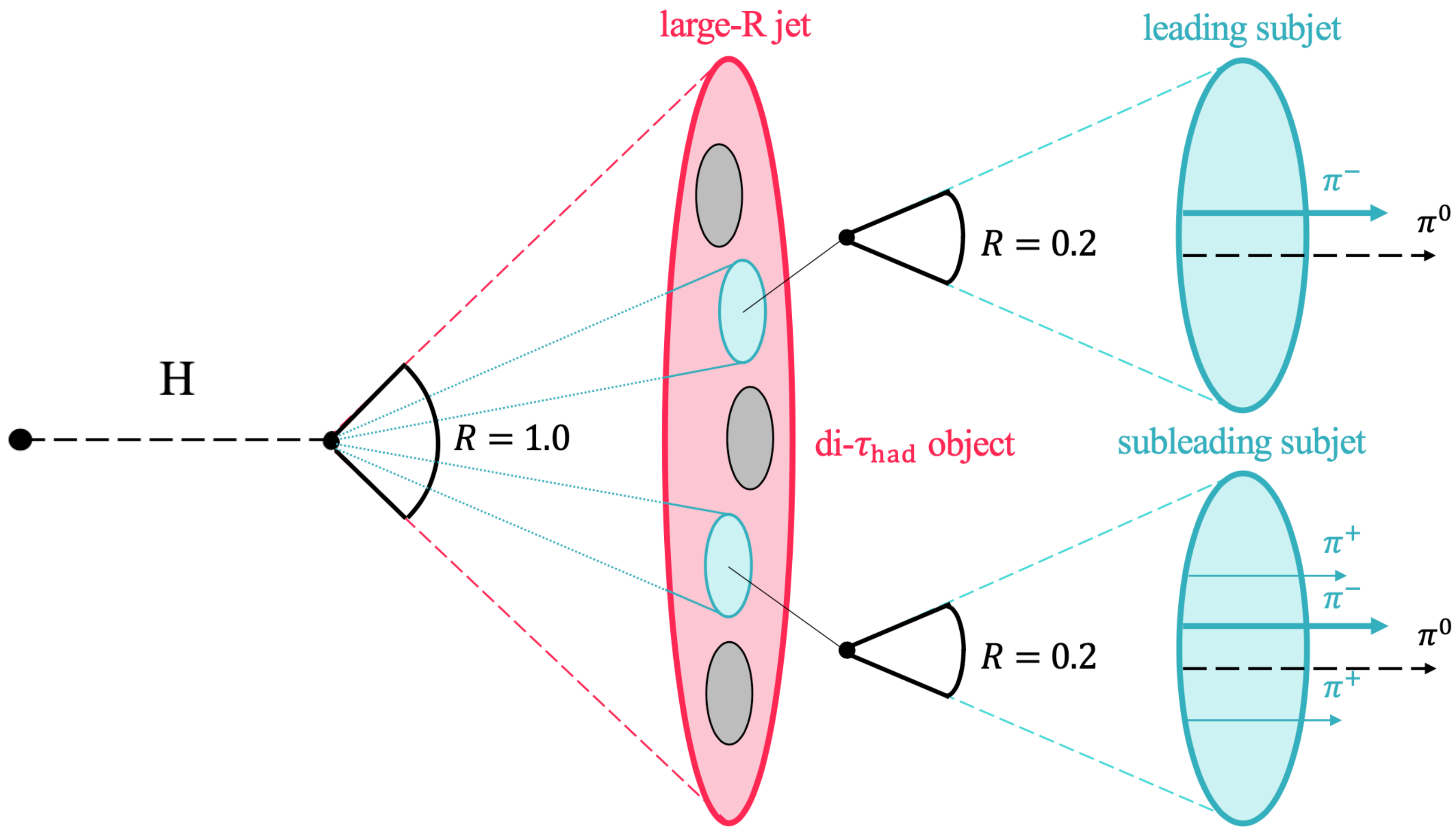
# Introduction to boosted $H \rightarrow \tau\tau$ measurement

JHEP 03 (2025) 010



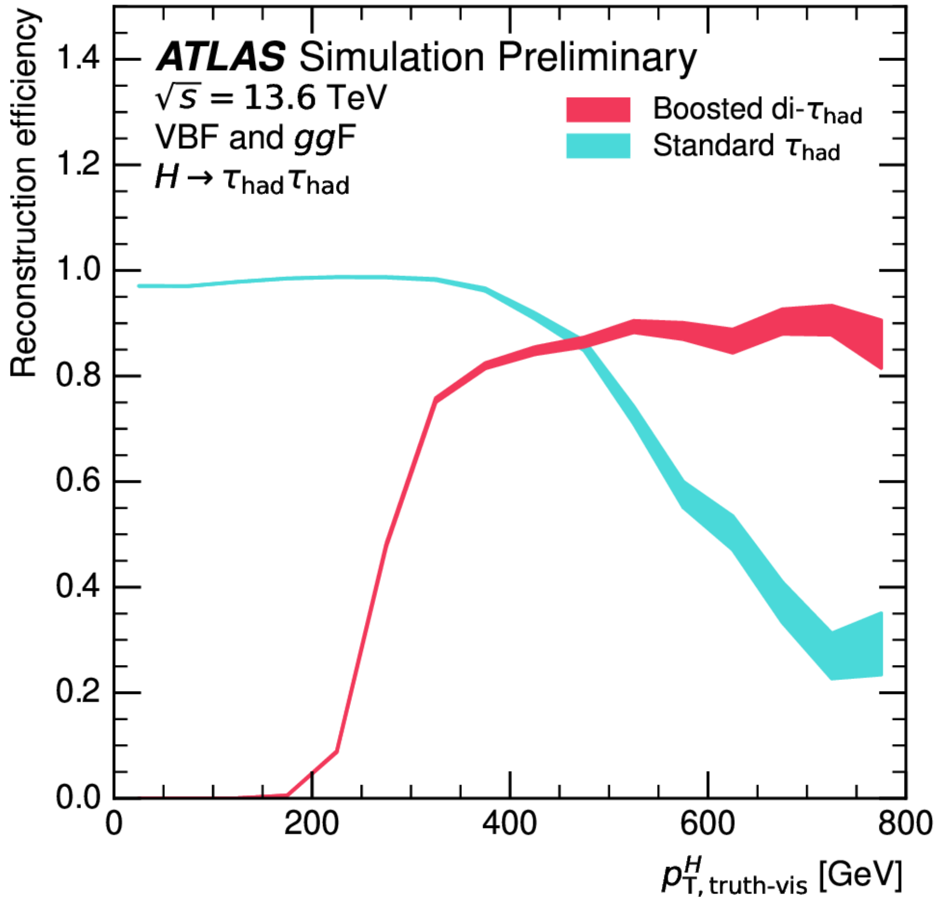

- From the latest $H \rightarrow \tau\tau$ measurements using standard $\tau$ reconstruction, only an inclusive measurement for ggF production mode with $p_T(H) > 300$ GeV is available
  - Beyond this limit, the standard $\tau$ reconstruction suffer from high inefficiency due to the tau-jets overlapping and being merged in a single large-R jet
- Use dedicated di-$\tau$ reconstruction to perform the first cross-section measurements of boosted Higgs boson in the di-$\tau$ final state in ATLAS

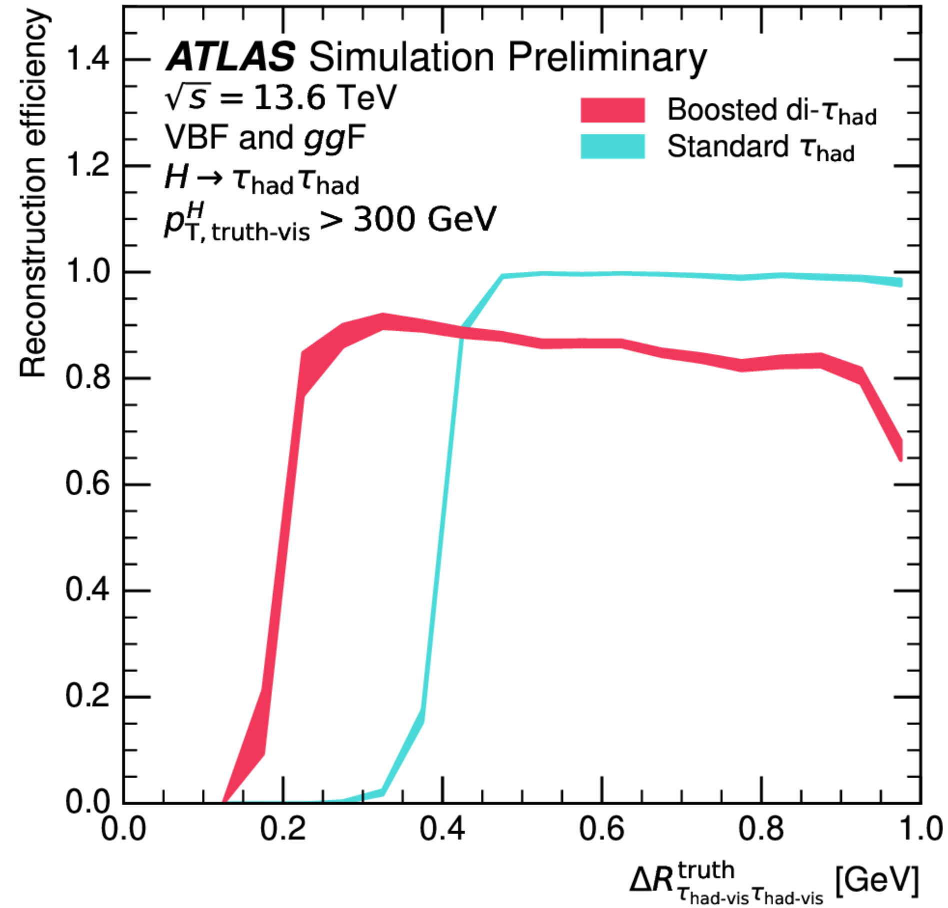
# Di-$\tau$ reconstruction summary




- Di-$\tau$ reconstruction seeded by large-R jet (R=1.0) developed in JHEP 11 (2020) 163 for $HH \rightarrow bb\tau\tau$
- Re-clustering to build small R-jets (R=0.2), called "subjets", and then associate tracks to subjets
- The two leading subjets are considered to contain the $\tau$ decay products

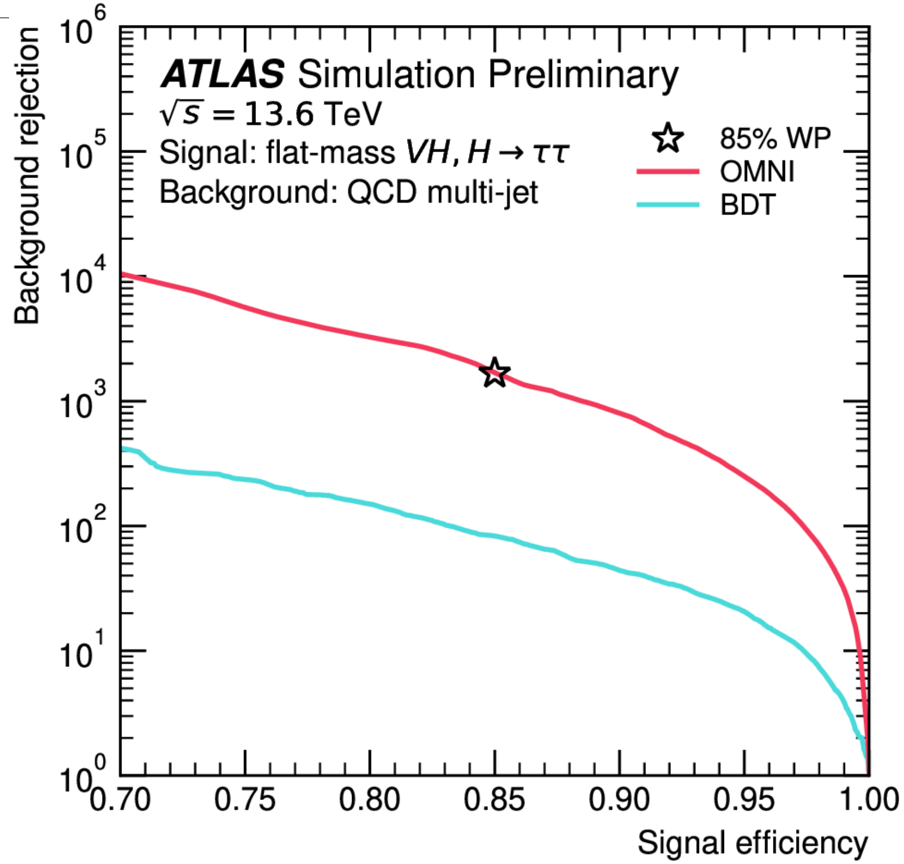
# Di-$\tau$ reconstruction performance

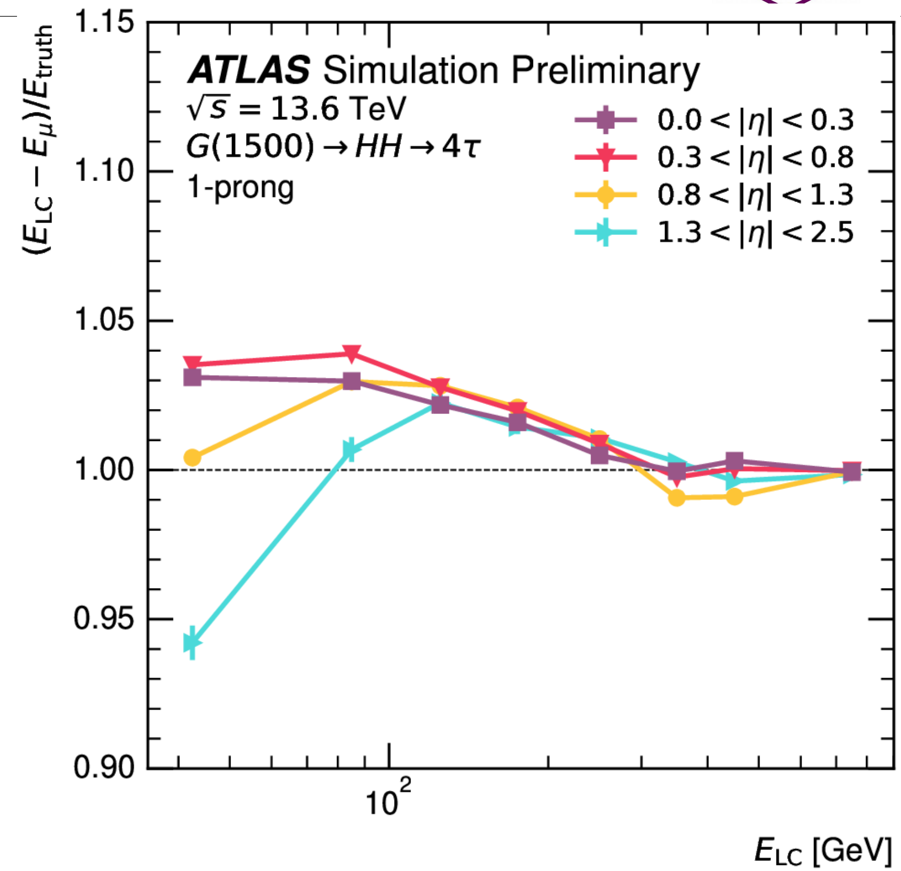



- Standard $\tau$ reconstruction optimised for isolated $\tau$ with low jet activity outside of $\Delta R < 0.2$
- Di-$\tau$ reconstruction outperforms the standard $\tau$ reconstruction (ATL-PHYS-PUB-2022-044) in the high $p_T(H)$ regime, corresponding to a separation between the two $\tau$ of $\Delta R(\tau, \tau) < 0.4$

# Di-$\tau$ identification and energy calibration




- New transformed based di-$\tau$ identification algorithm (OMNI tagger) supersede BDT based identification; ~10 times better background rejection at the same signal efficiency
  - Misidentified background becomes 3% of the total background after applying OMNI selection
- Energy scale for the subjets measured in multiple steps: 1) MC-MC calibration (Eur. Phys. J. C 75 (2015) 303), 2) $\chi^2$ fit on the visible di-$\tau$ mass and 3) final value determined in situ in the final fit

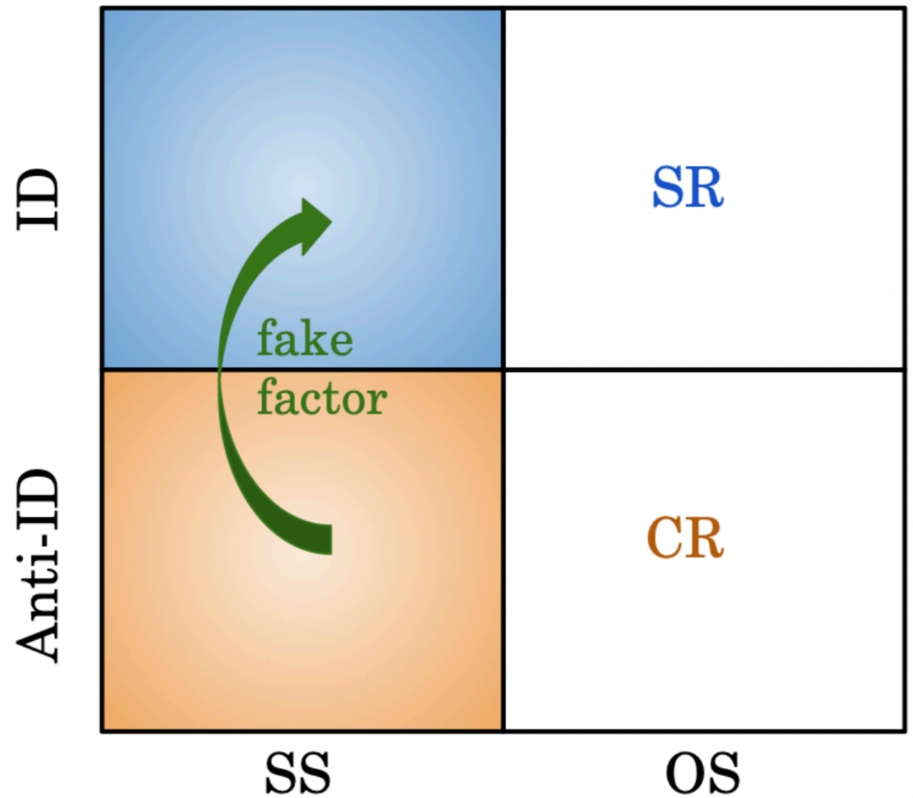
# Event selection and categorisation

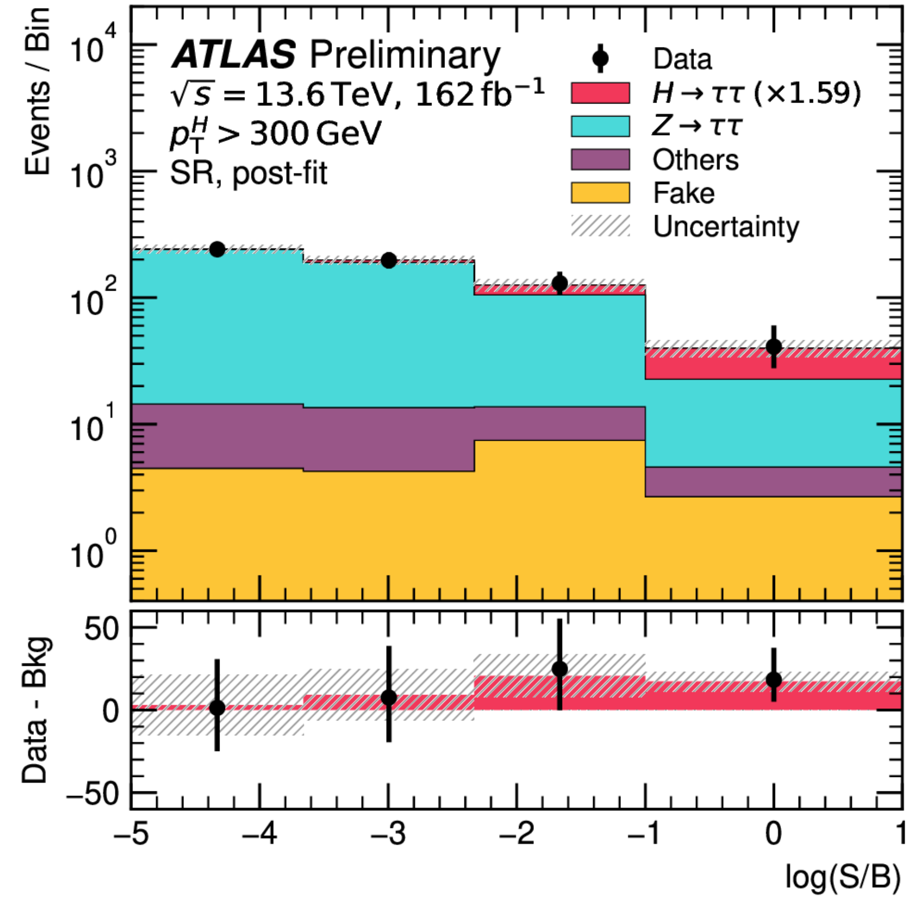
- Selection based on an OR of small/large R jet, $E_T^{miss}$ and $\tau$ triggers
  - optimised $p_T$ threshold for each selection based on the available triggers for each year
  - reach a signal selection efficiency of 98%

- Events classified using the OMNI tagger in signal region (SR) and a control region (CR) for the background estimation

| Object | Signal region | Control region |
|---|---|---|
| | Pass 85% OMNI WP | Fail 85% OMNI WP |
| Di-$\tau_{\text{had}}$ | $N_{\text{subjets}} \geq 2$<br>$\Delta R(\text{di-}\tau_{\text{had}}, \text{lead jet}) > 0.4$<br>$N_{b\text{-jets}} = 0$ | |
| Subjets | $N_{\text{tracks}}^{\text{sj}_1,\text{sj}_2} \in \{1,3\}$<br>$p_{\text{T}}^{\text{sj}_1} > 50$ GeV<br>$p_{\text{T}}^{\text{sj}_2} > 15$ GeV<br>$q_{\text{sj}_1} * q_{\text{sj}_2} = -1$ | |
| $E_{\text{T}}^{\text{miss}}$ | $E_{\text{T}}^{\text{miss}} > 60$ GeV | |
| Combined | $E_{\text{vis},i}/E_{\tau,i} > 0$<br>$N_{\text{tracks}}^{\text{di-}\tau_{\text{had}}} - N_{\text{tracks}}^{\text{sj}_1} - N_{\text{tracks}}^{\text{sj}_2} = 0$<br>$\lvert\Delta\phi(E_{\text{T}}^{\text{miss}}, \text{sj}_1 + \text{sj}_2)\rvert < 1.3$ | |

# Background estimation



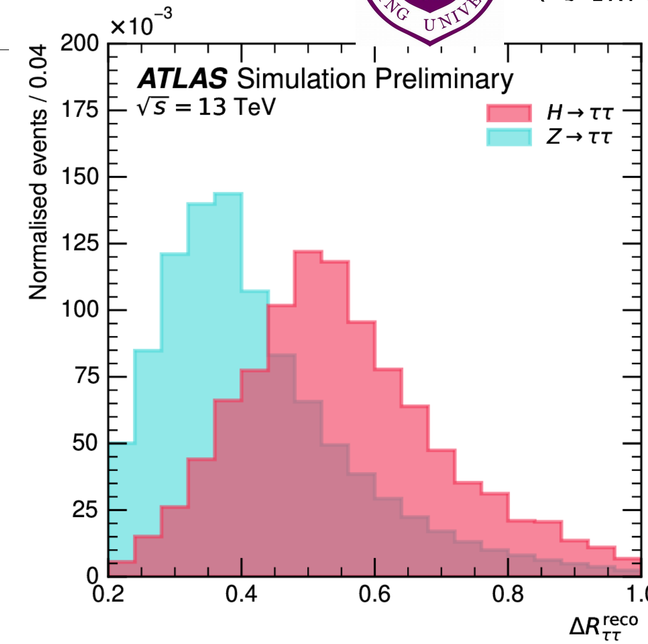



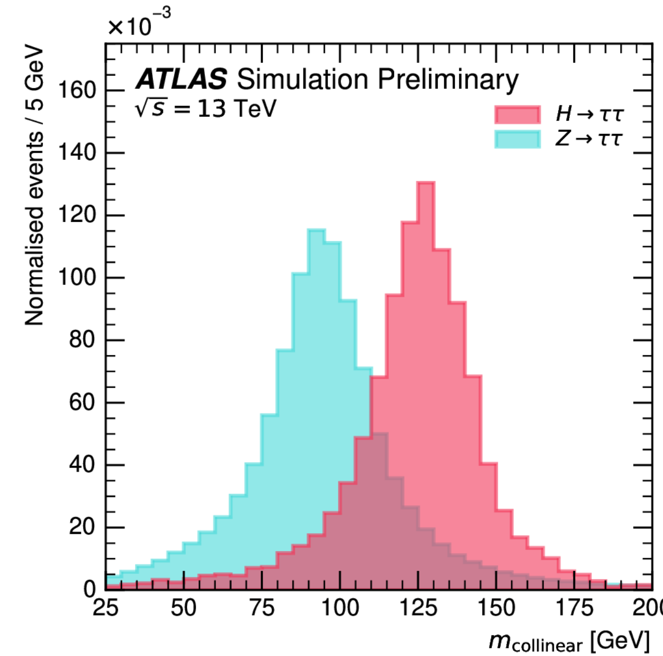

- Background in the SR mostly from $Z \to \tau\tau$
- Fake background mostly due QCD multijet, estimated using the fake-factor method
  - Use di-$\tau$ identification and the di-$\tau$ charge to build the CRs for the fake-factor calculation ([Eur .Phys. J. C85 (2025) 1441](#))

# Signal vs background separation through BDT

- BDT trained to discriminate signal over background using event/di-$\tau$ variables.
- Discrimination between signal and $Z \to \tau\tau$ mostly through the di-$\tau$ mass built under the collinear approximation hypothesis (invisible part of the $\tau$ decay from the neutrinos collinear to the visible decay products)
- BDT discriminant used as fit variable to extract the results

| Variable | Definition |
|---|---|
| $p_{\mathrm{T}}^{\mathrm{sj}_1}$ | $p_{\mathrm{T}}$ of the leading subjet |
| $p_{\mathrm{T}}^{\mathrm{sj}_2}$ | $p_{\mathrm{T}}$ of the subleading subjet |
| $m_{\mathrm{vis}}$ | visible mass, defined as the mass of the vectorial sum of the leading and subleading subjets |
| $m_{\mathrm{collinear}}$ | invariant mass estimated under the collinear approximation hypothesis |
| $\Delta R(\mathrm{sj}_1, \mathrm{sj}_2)$ | angular separation between the leading and subleading subjets |
| $p_{\mathrm{T,\,reco}}^{H}$ | magnitude of the vectorial sum of two leading di-$\tau_{\mathrm{had}}$ subjets and $E_{\mathrm{T}}^{\mathrm{miss}}$ |
| $E_{\mathrm{T}}^{\mathrm{miss}}$ | missing transverse energy |
| $E_{\mathrm{T}}^{\mathrm{miss}}$ centrality | quantification of where the $E_{\mathrm{T}}^{\mathrm{miss}}$ lies between the two subjets of the di-$\tau_{\mathrm{had}}$ system in the azimuthal plane |
| $E_{\mathrm{vis}}^{\mathrm{sj}_1}/E_{\tau_{\mathrm{had}}}^{\mathrm{sj}_1}$ | the ratio of visible energy to the total energy of the leading subjet |
| $E_{\mathrm{vis}}^{\mathrm{sj}_2}/E_{\tau_{\mathrm{had}}}^{\mathrm{sj}_2}$ | the ratio of visible energy to the total energy of the subleading subjet |

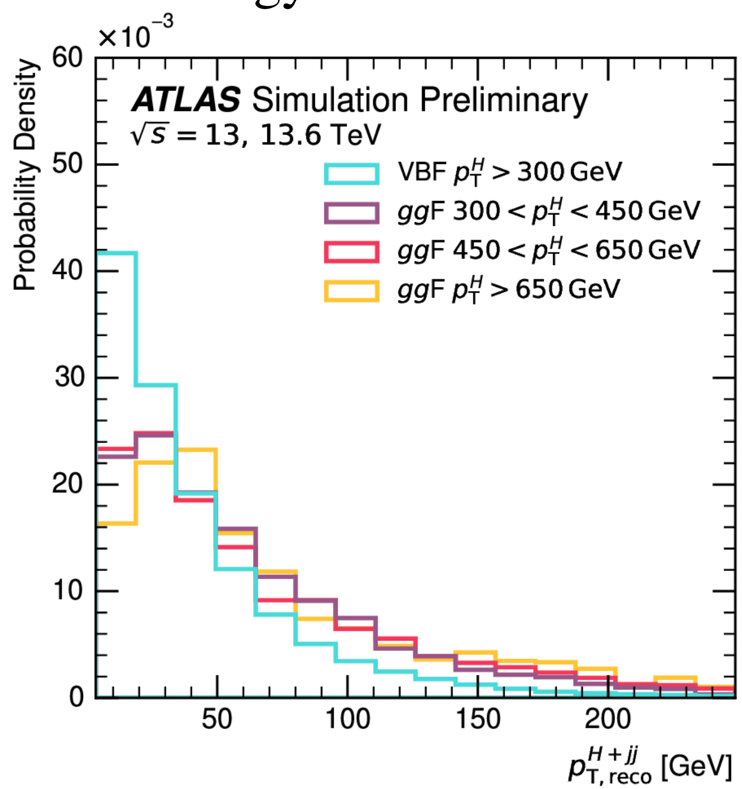


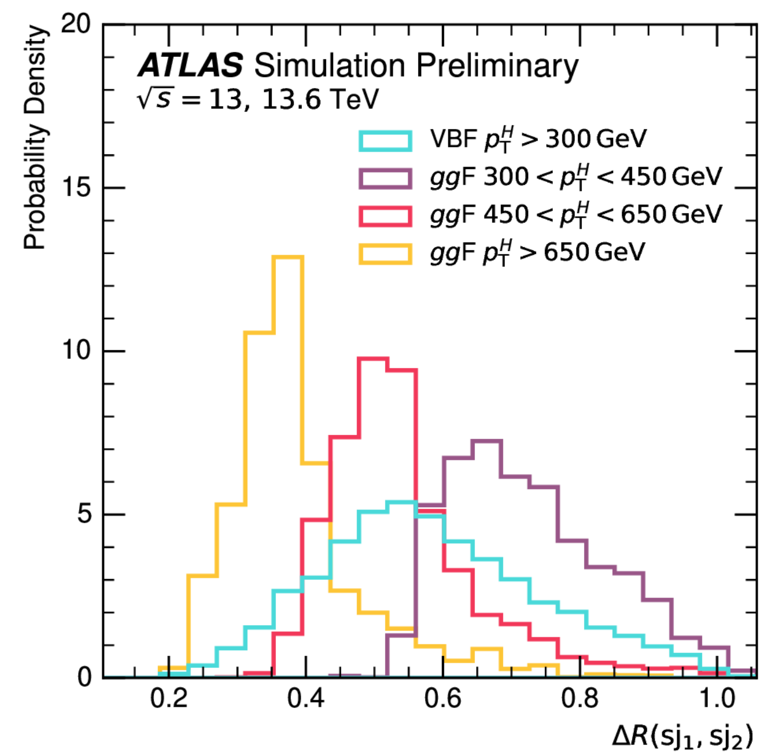



# Signal region categorisation through BDT

- An additional BDT is trained to discriminate VBF and ggF in different $p_T(H)$ intervals ([300,450] GeV, [450,650] GeV and $>$ 650 GeV) aligned with STXS bin definition
- Use this categorisation BDT to build analysis SR; within each region, select events with low signal vs background BDT score to build the $Z \to \tau\tau$ CRs
  - Two $Z \to \tau\tau$ CRs (one for VBF-like and one for ggF-like events), used to constrain the Z normalisation and measure di-$\tau$ energy scale

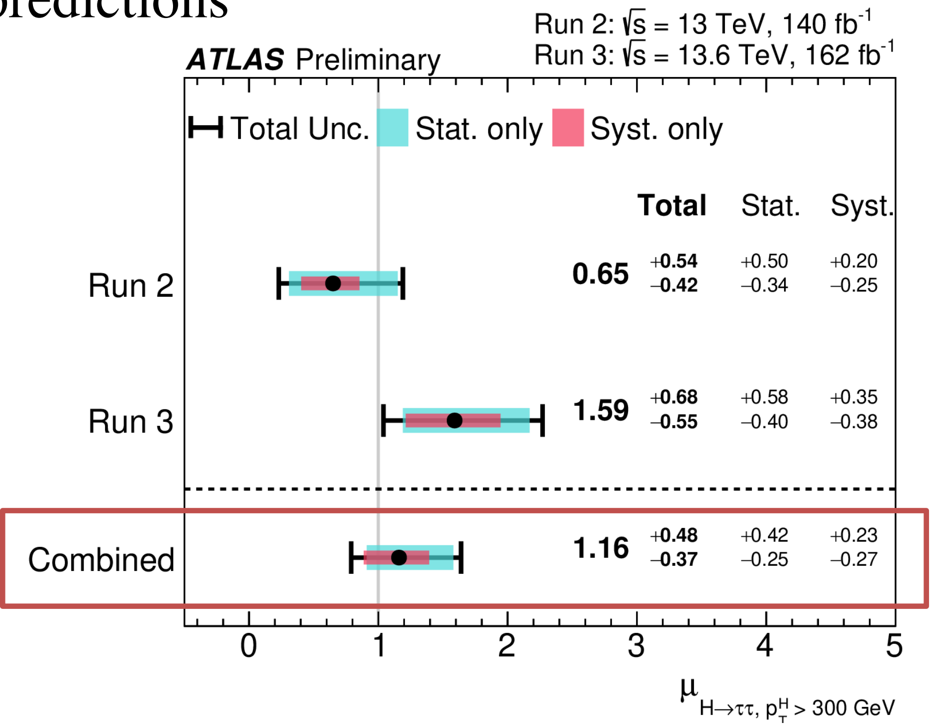
Achieved ~75% (40-60%) purity for VBF (ggF selection from high to low $p_T(H)$)

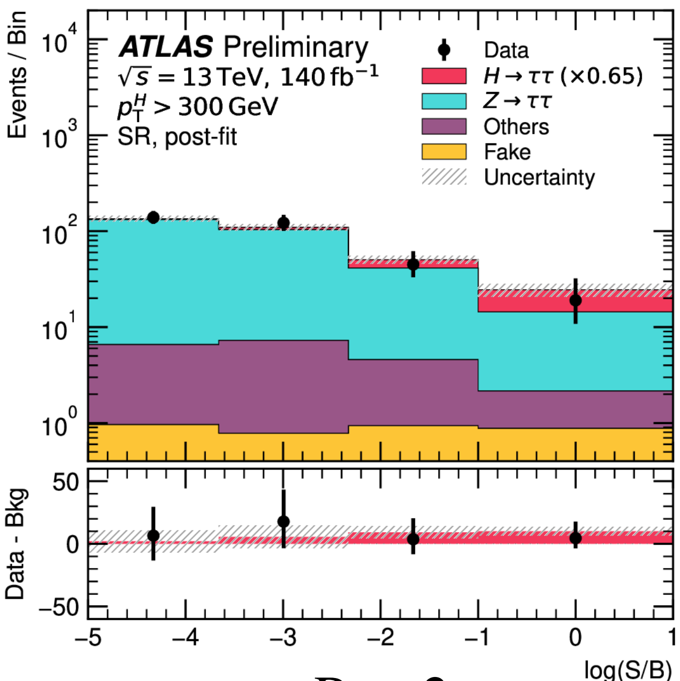


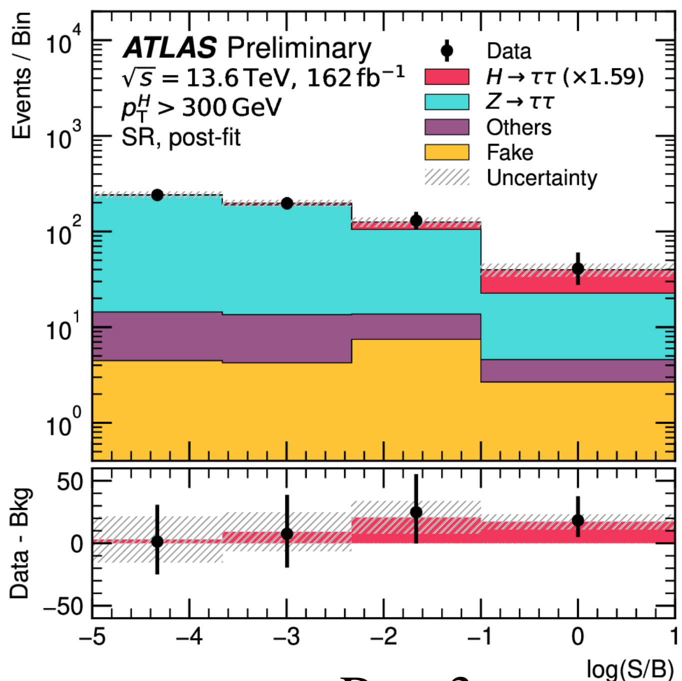
# $H \to \tau\tau$ inclusive measurement results

- Perform a fit to measure the total signal strength considering all Higgs boson production modes
- Evidence of Higgs boson production for $p_T(H) > 300$ GeV with obs. (exp.) significance of 3.8 (3.3) $\sigma$
- Combined signal strength compatible at 69% with the SM predictions
- Results dominated by statistical uncertainty




Run 2




Run 3

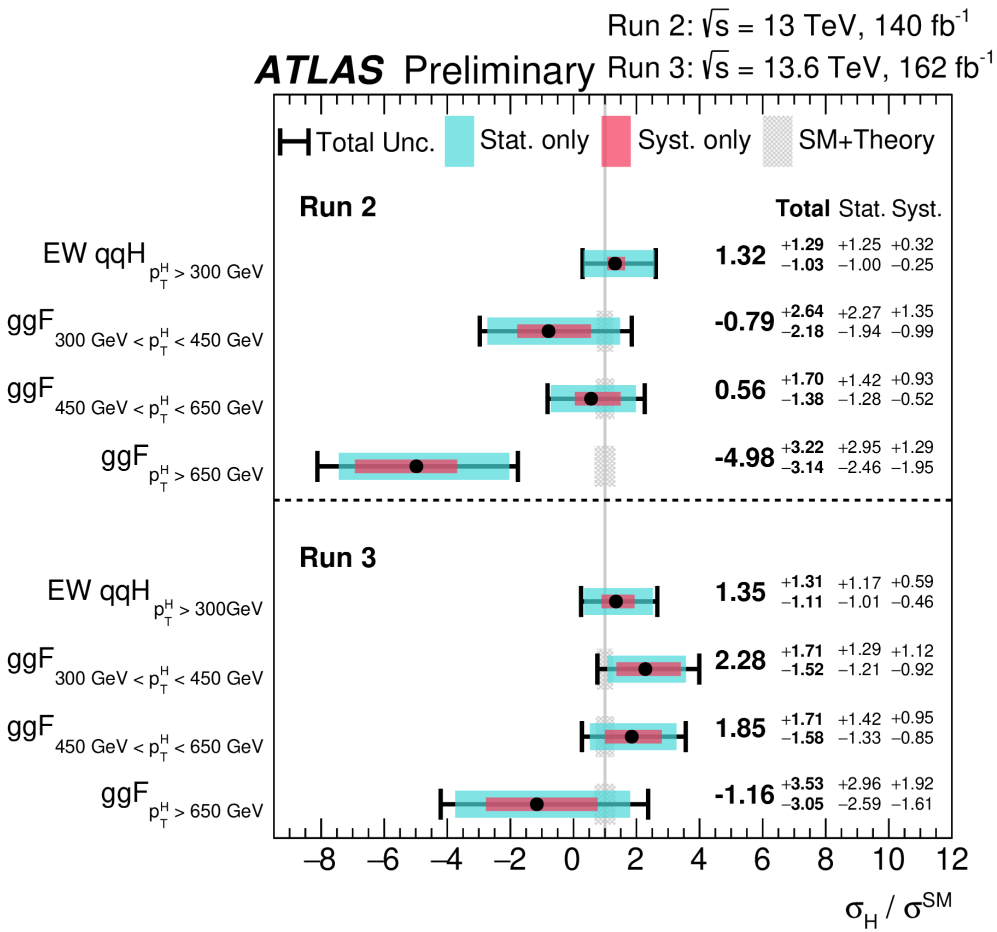
| | Signal significance $p_T^H > 300$ GeV [$\sigma$] | |
|---|---|---|
| | Observed | Expected |
| Run 2 | 1.7 | 2.1 |
| Run 3 | 3.6 | 2.6 |
| Combined | 3.8 | 3.3 |

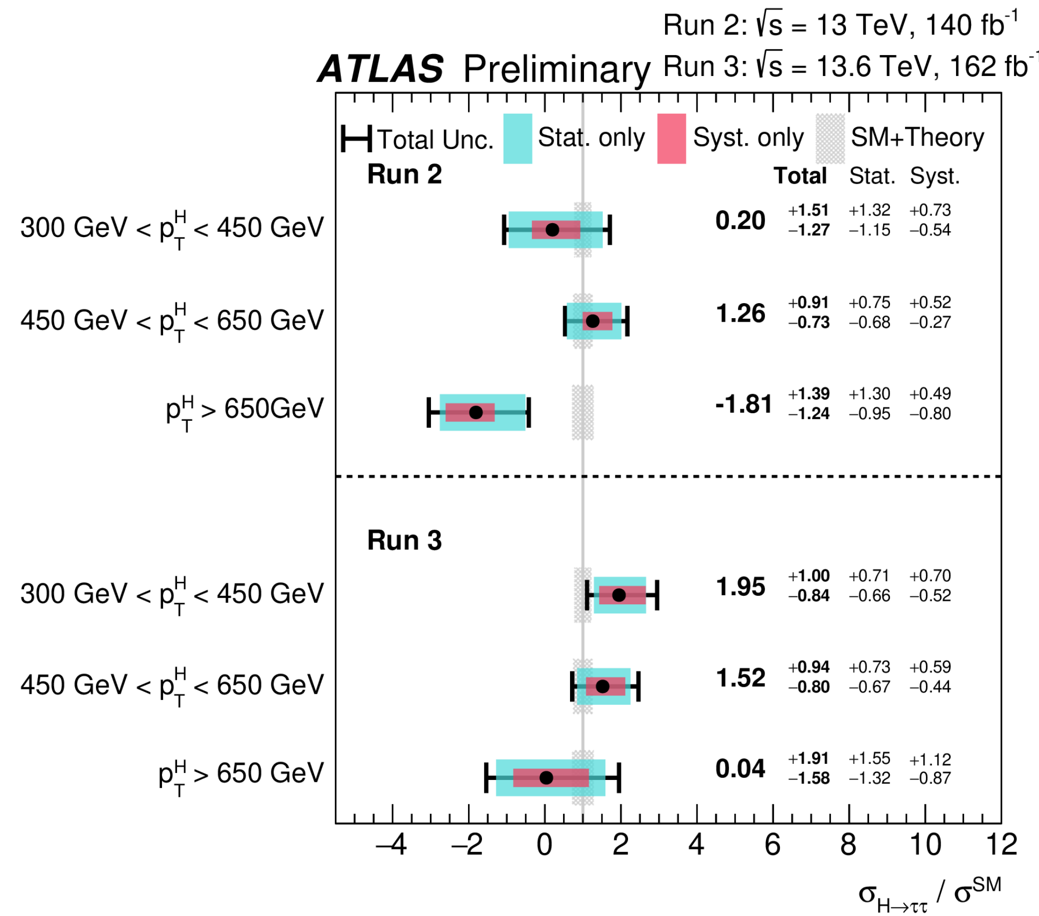
# Uncertainty breakdown

| Source of uncertainty | Impact on the signal strength Observed | Impact on the signal strength Expected |
|---|---|---|
| Theoretical scale/phase space uncertainty on signal | 0.15 | 0.13 |
| Di-$\tau_{\text{had}}$ energy scale acceptance, Run 2 | 0.12 | 0.08 |
| Misidentified $\tau_{\text{had}}$, Run 3 | 0.10 | 0.08 |
| Background sample size | 0.07 | 0.06 |
| Jet and $E_{\text{T}}^{\text{miss}}$ | 0.07 | 0.06 |
| Di-$\tau_{\text{had}}$ identification | 0.04 | 0.03 |
| Parton shower and PDF uncertainty on signal, Run 2 | 0.04 | 0.03 |
| Parton shower and PDF uncertainty on signal, Run 3 | 0.02 | 0.02 |
| Di-$\tau_{\text{had}}$ energy scale acceptance, Run 3 | 0.02 | 0.03 |
| Theoretical uncertainty in $Z$ + jets processes | 0.01 | 0.02 |
| Misidentified $\tau_{\text{had}}$, Run 2 | 0.01 | 0.04 |
| Di-$\tau_{\text{had}}$ energy scale MC-MC calibration | 0.01 | 0.01 |
| Luminosity Run2 | 0.01 | 0.01 |
| Luminosity Run3 | 0.01 | 0.01 |
| Total systematic uncertainty | 0.25 | 0.21 |

- Comparable impact between theoretical and experimental uncertainties
- From the theoretical uncertainties, largest impact from ggF at high $p_T(H)$ (ATL-PHYS-PUB-2023-031)
- Among the experimental uncertainties, the large impact from the di-$\tau$ energy scale/identification

# $H \to \tau\tau$ STXS and differential cross-section results



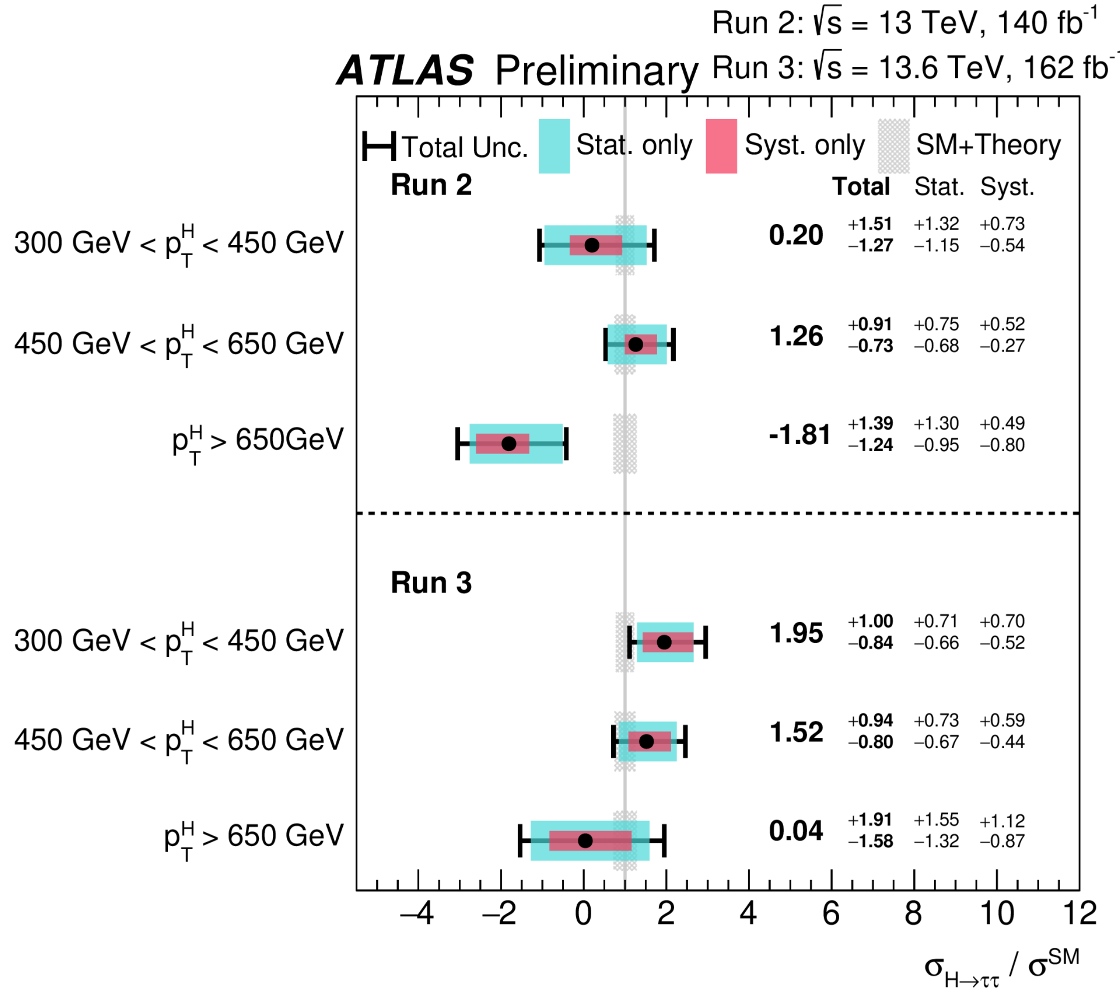




- Measure the cross-section in three ggF and one VBF bin according to the STXS scheme
- SM compatibility: 52% (70%) for Run2 (Run3)

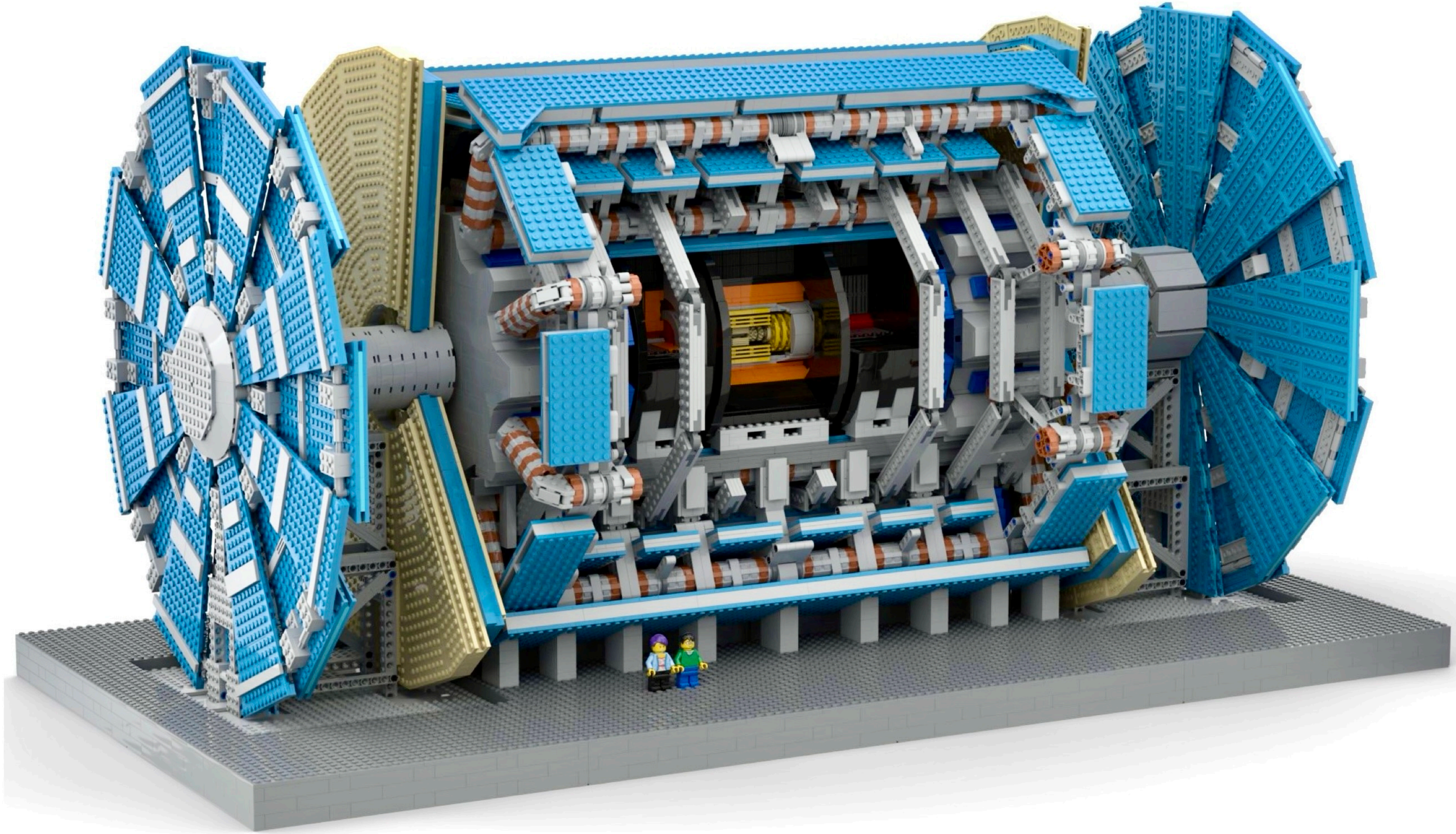
- Measure the cross-section differentially in three Higgs boson $p_T$ bins mixing all prod. Modes
- SM compatibility: 33% (56%) for Run2 (Run3)

# Summary

- New ATLAS results for $H \rightarrow \tau\tau$ channels targeting the boosted regime and using full Run 2 + partial Run 3 (2022-2024) datasets presented in this talk
- Profiting from new/updated techniques for reconstructing and identifying the Higgs boson decay products within a large radius jet
- Evidence of the Higgs boson signal for $p_T(H)$>300 GeV regime
- Differential and STXS cross section measurement results also carried out and results in agreement with SM prediction

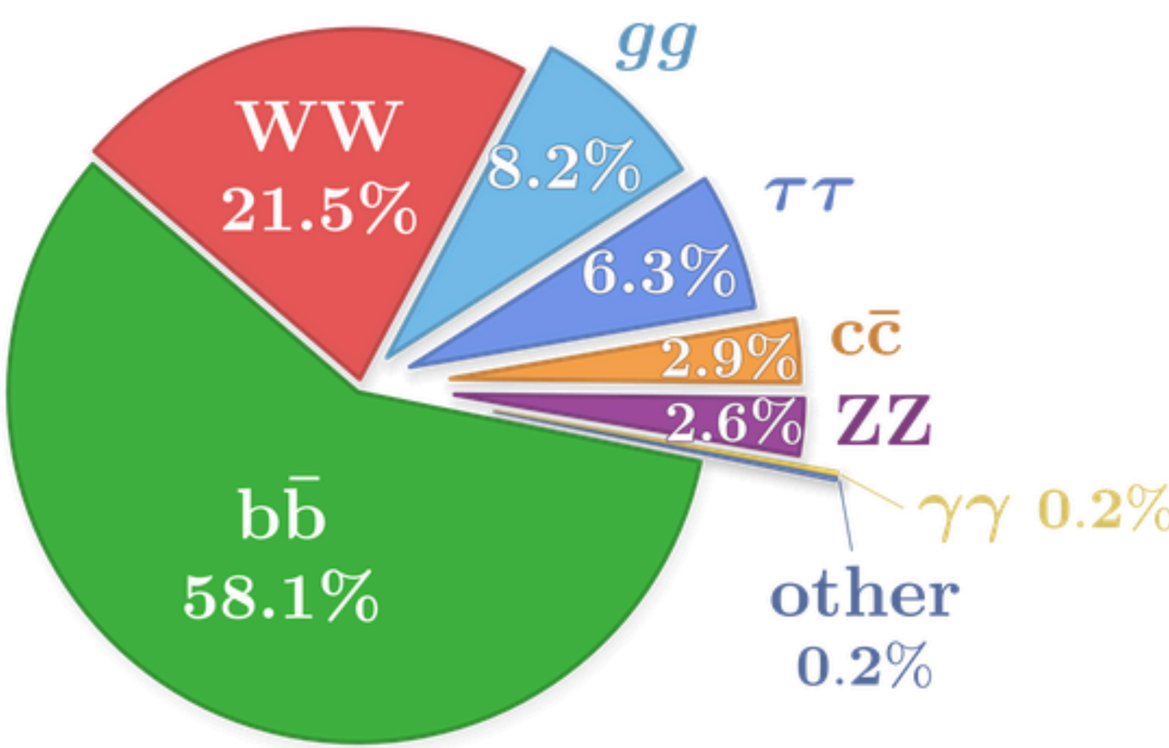



ATLAS-CONF-2026-005



*Thanks a lot for your attention*

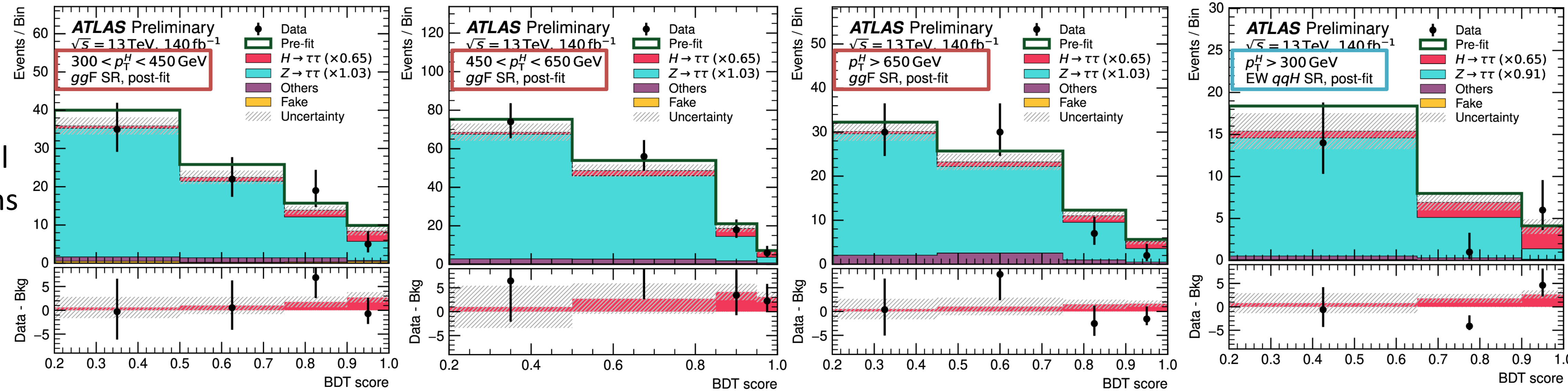
# Higgs boson decays



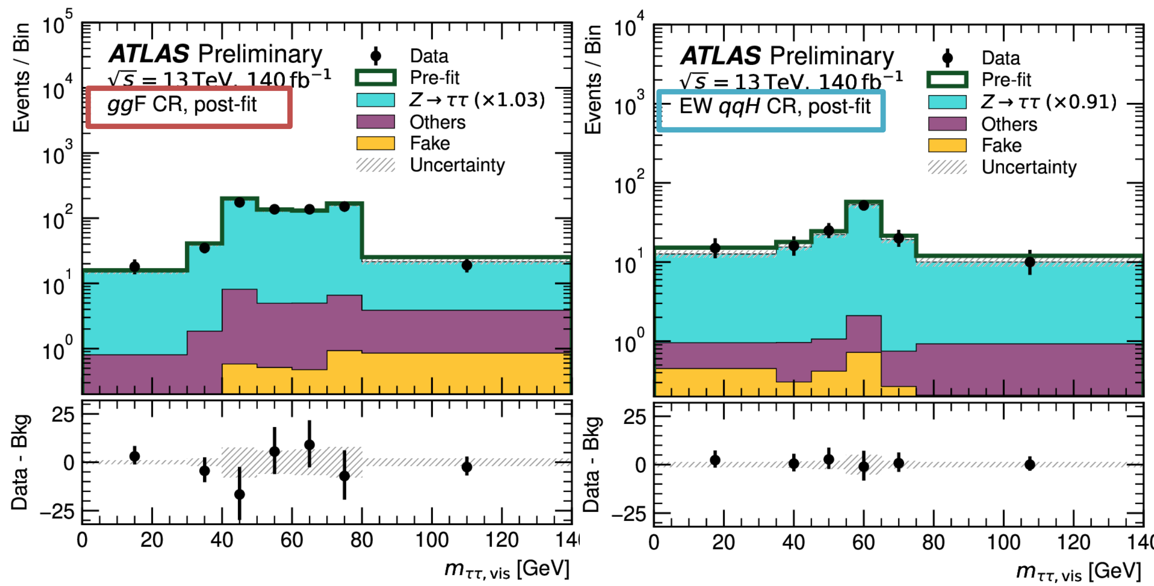

- Larger branching ratio for $H \to b\bar{b}$, $H \to WW^*$ and $H \to \tau\tau$ (~6%), however poor mass resolution and larger background contamination
- $H \to \gamma\gamma$ and $H \to ZZ^*(\to 4l)$ have lower BR but high mass resolution; therefore they can be used for precision measurements
- $H \to Z\gamma$ and $H \to \mu\mu$ now becoming accessible thanks to the large dataset and the good detector performance

# $H \rightarrow \tau\tau$ post-fit distributions - Run 2

Signal regions




Control regions

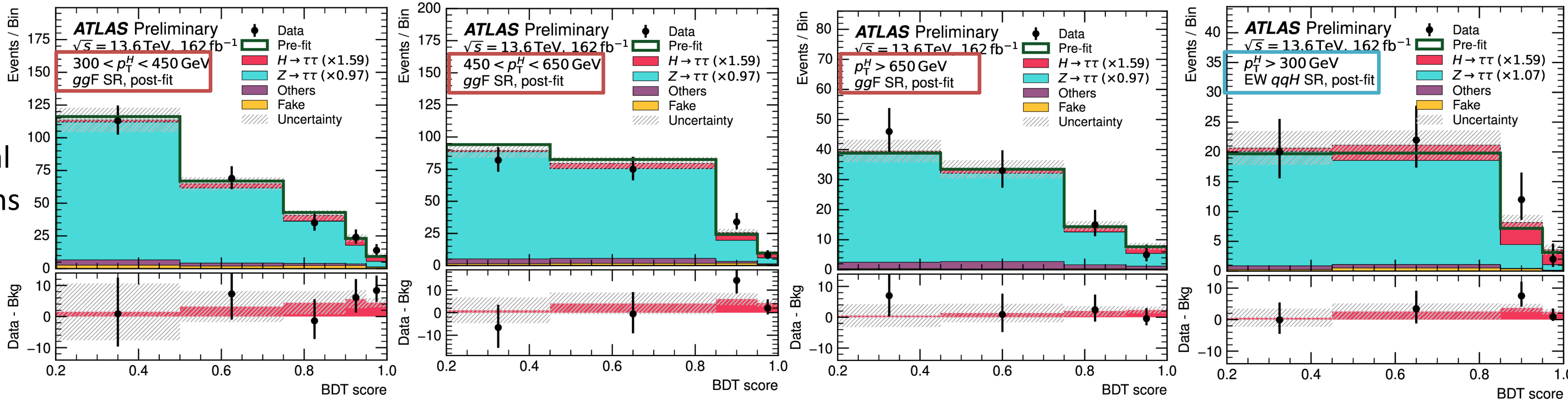



ggF enriched

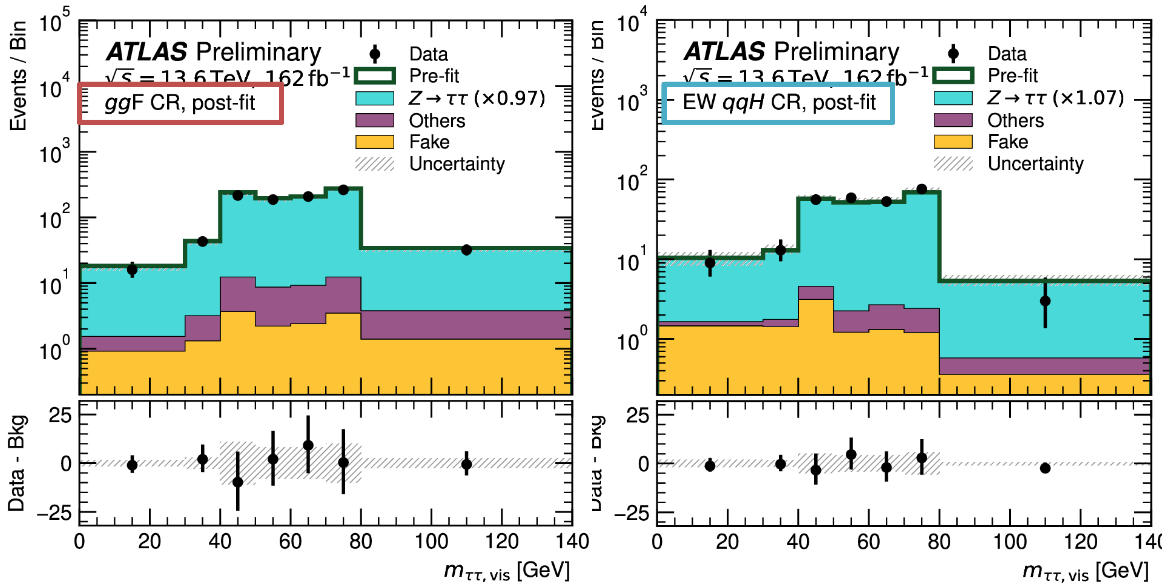
VBF enriched

# $H \to \tau\tau$ post-fit distributions - Run 3

Signal regions




Control regions




ggF enriched

VBF enriched