ATLAS Measurements of $H \to \tau\tau$

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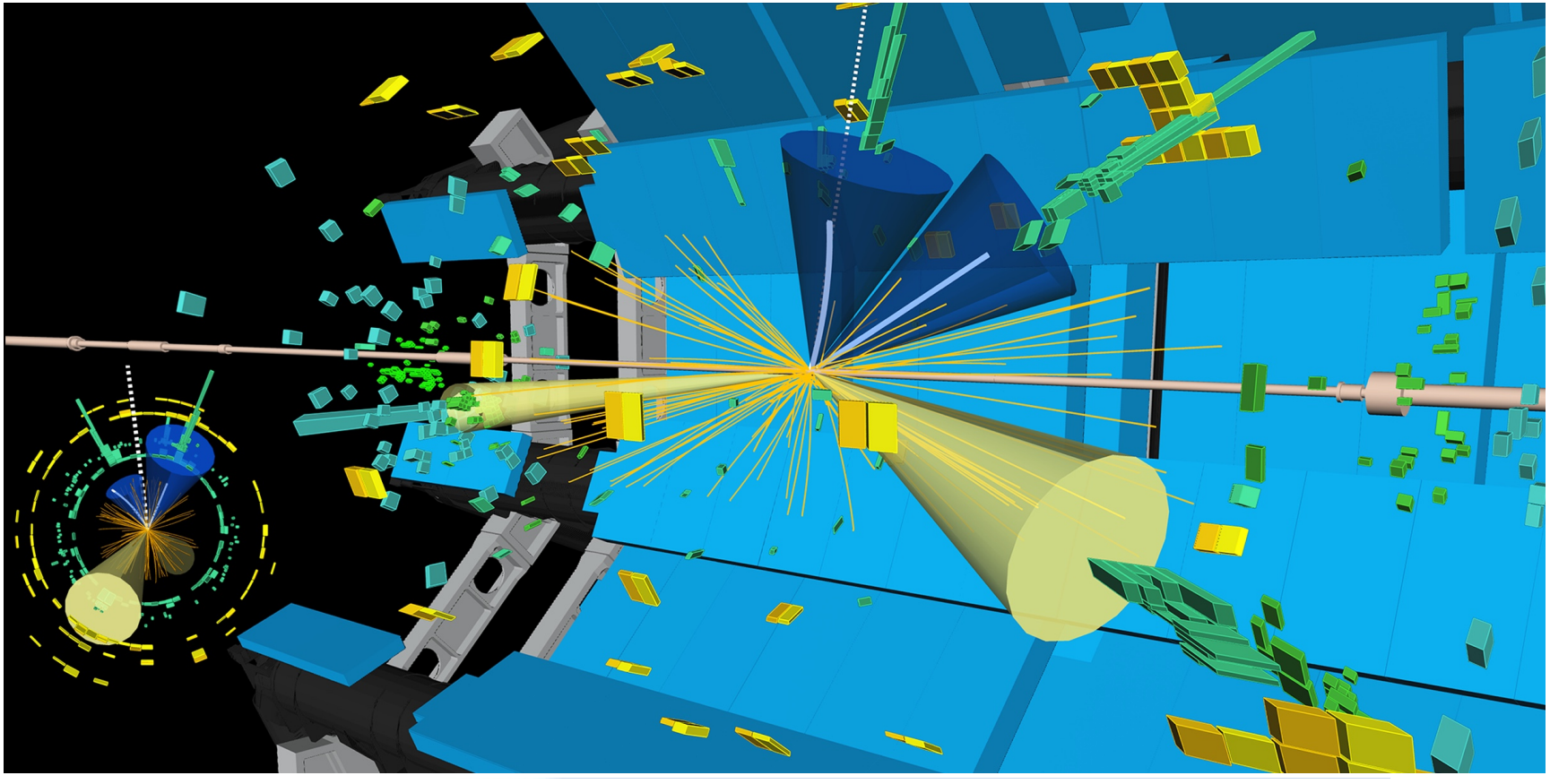
19th July 2024

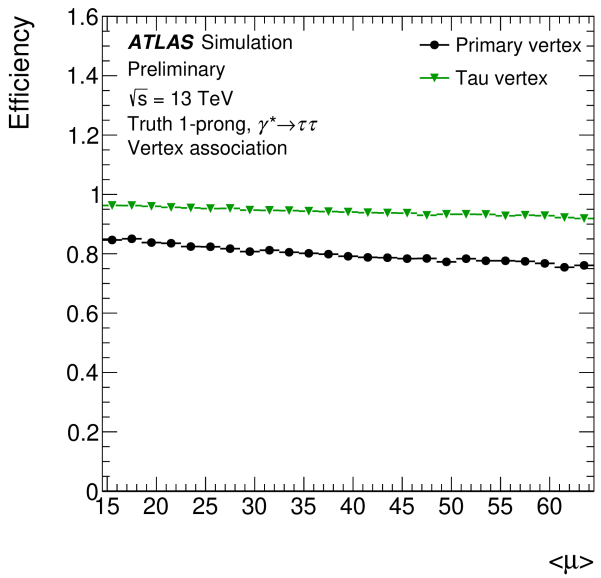


Introduction

- The τ-lepton is the heaviest lepton and therefore has the largest coupling to the Higgs boson.
- This motivates studying the process $H \to \tau\tau$ to probe the couplings to leptons.
- The branching ratio of $H \to \tau\tau$ is 6% which results in it being in a unique position of **having sufficient statistics** and **low enough backgrounds** for precise measurements of Higgs production.
- Today I will go through 2 measurements that take advantage of this:
  - $VH(\to \tau\tau)$ Analysis – released December 2023
  - Updated STXS results – **First seen at LHCP last month**
- **These represent some of the legacy Run 2 ATLAS results in this channel!**
- Looking to Run 3, where over 100 fb^{-1} have already been recorded, we can expect in the future further precise measurements in this channel, but as analyses are complicated the focus has been on exploiting the Run 2 data with the best possible precision.

Reconstructing hadronic τ-leptons [link]

- τ-leptons decay either into a lepton and 2 ν, τ_{lep}, or hadronically with 1 ν, τ_{had}.
- Both leptonic and hadronic decays are used in these analysis with the lepton reconstruction following the usual ATLAS electron and muon reconstruction.
- The majority of hadronic τ-lepton decays consist of 1 or 3 charged particles.
- Additionally, calorimeter information as well as track displacement and secondary vertex information are also key for their reconstruciton.
- For Run 3 new algorithms have been developed to:
  - correctly identify the τ production vertex



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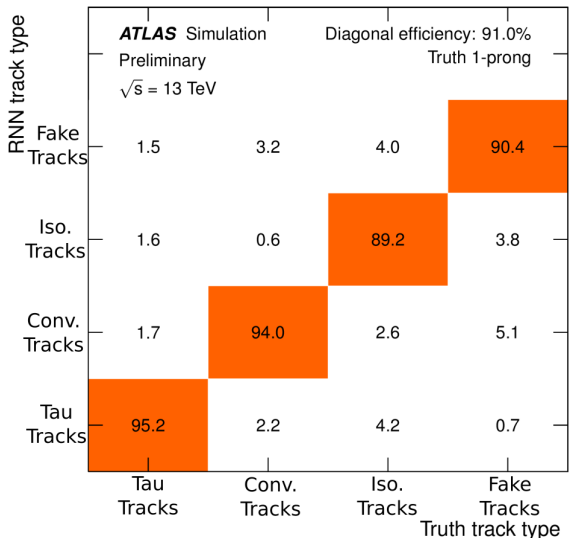

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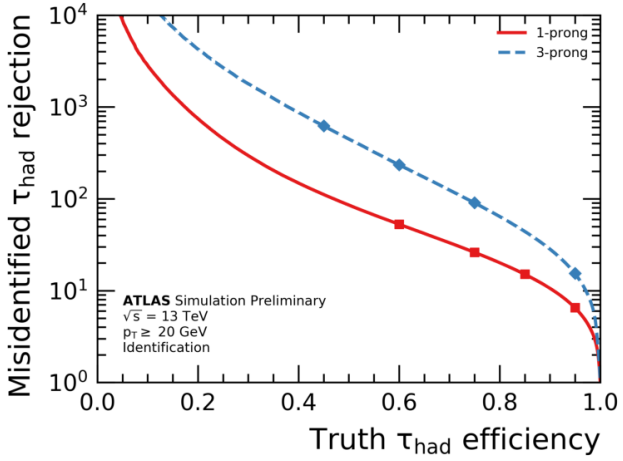

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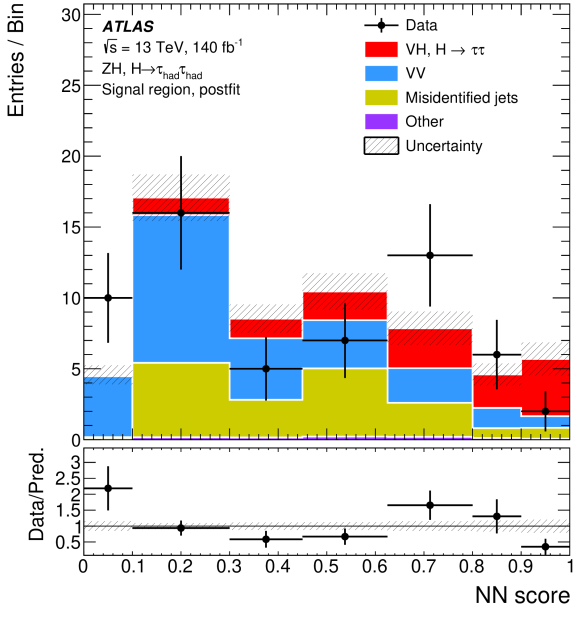
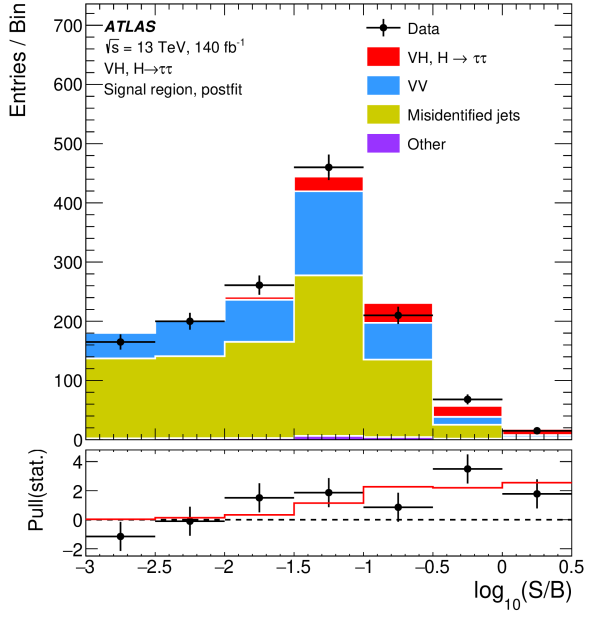
- For Run 3 new algorithms have been developed to:
  - correctly identify the τ production vertex
  - a *recurrent neural network* to classify tracks
  - a RNN to identify τ-leptons against jets and a separate one to veto electrons
- These show promising improvements which will increase the sensitivity of future $H \to \tau\tau$ results and such performance improvements underpin many ATLAS analyses.

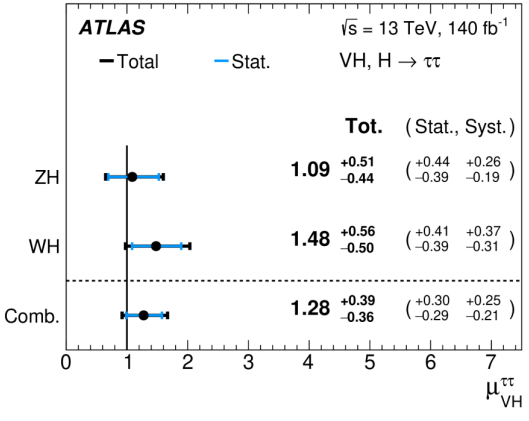
$VH(\to \tau\tau)$ Analysis [link]

$VH(\to \tau\tau)$ Analysis

- For this analysis only leptonic decays of W, Z are considered with the hadronic ones covered by the next analysis I'll show.
- Neural Networks using the 4-vectors and derived quantities (eg. ΔR) is used to separate signal and background.
- 4 separate NNs are used for each of W, Z and $\tau_{lep}\tau_{had}, \tau_{had}\tau_{had}$.
- Overall 4.2σ is seen over the case of no VH production and a signal strength of $\mu = 1.28 \pm 0.3(\text{stat}) \pm 0.2(\text{sys})$ is achieved.



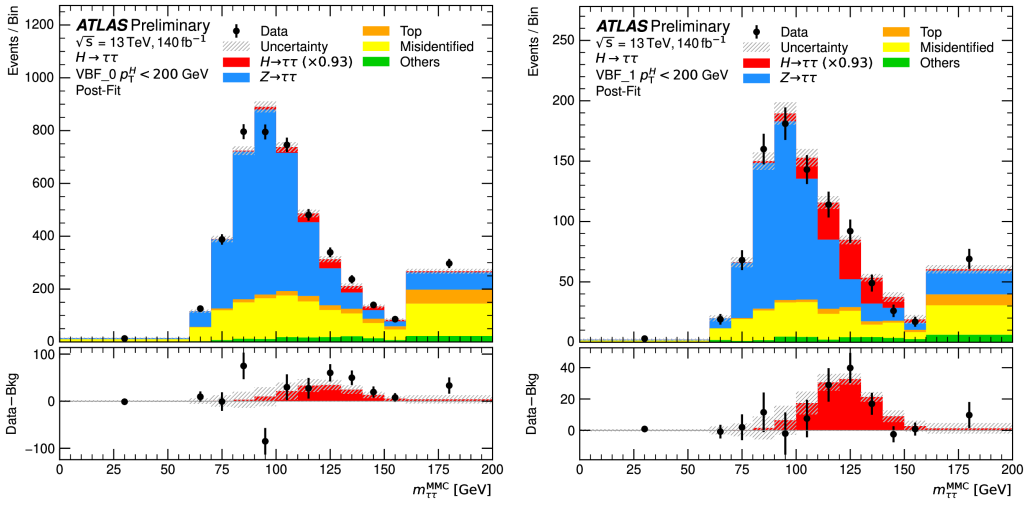




$H \to \tau\tau$ STXS Analysis [link]

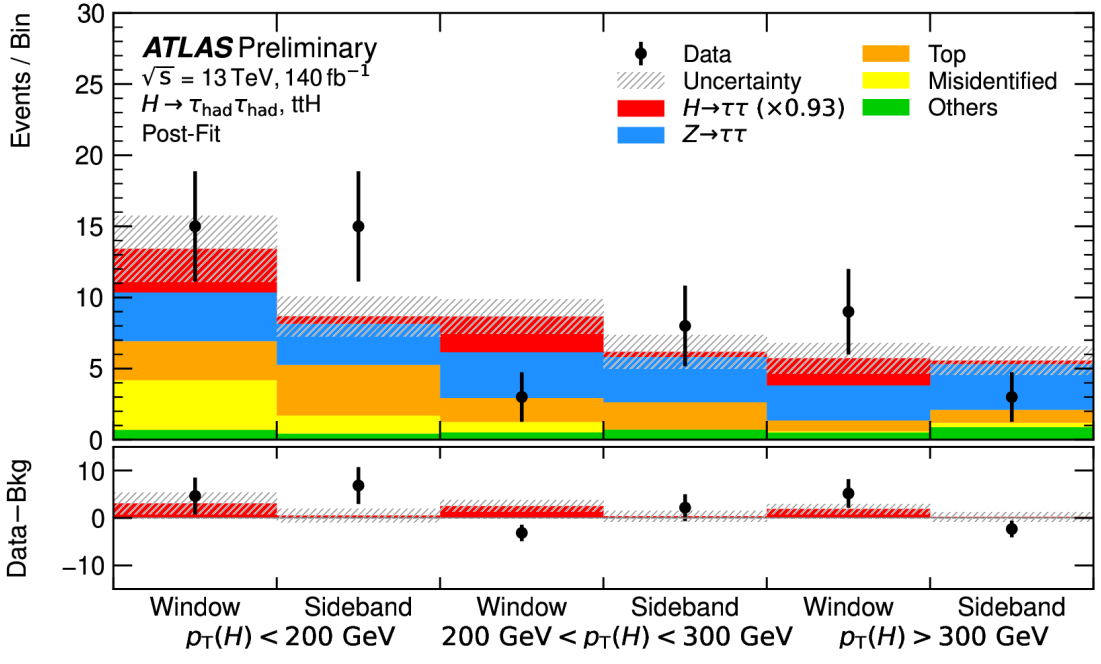
$H \to \tau\tau$ STXS Analysis: Selection & Strategy

- Previously the full Run 2 dataset was used to measure various bins in the STXS framework [link]
- This previous analysis of the Run 2 data gave the highest precision measurement of the VBF process, but only measured the inclusive cross-section, and also presented the first $t\bar{t}H$ measurement in this channel.
- This **new** measurement improves signficantly on the previous one splitting VBF into 8 kinematic regions and enhancing the $t\bar{t}H$ measurement using ML techniques.
- The strategy followed a similar path constructing *control regions* for the major backgrounds normalization (including using kinematic embedding for $Z \to \tau\tau$), and then fitting the mass distribution to separate the primary background (Z) from signal.
- A BDT was used as a final step to separate a high purity, low stats region from a low purity, high stats region.



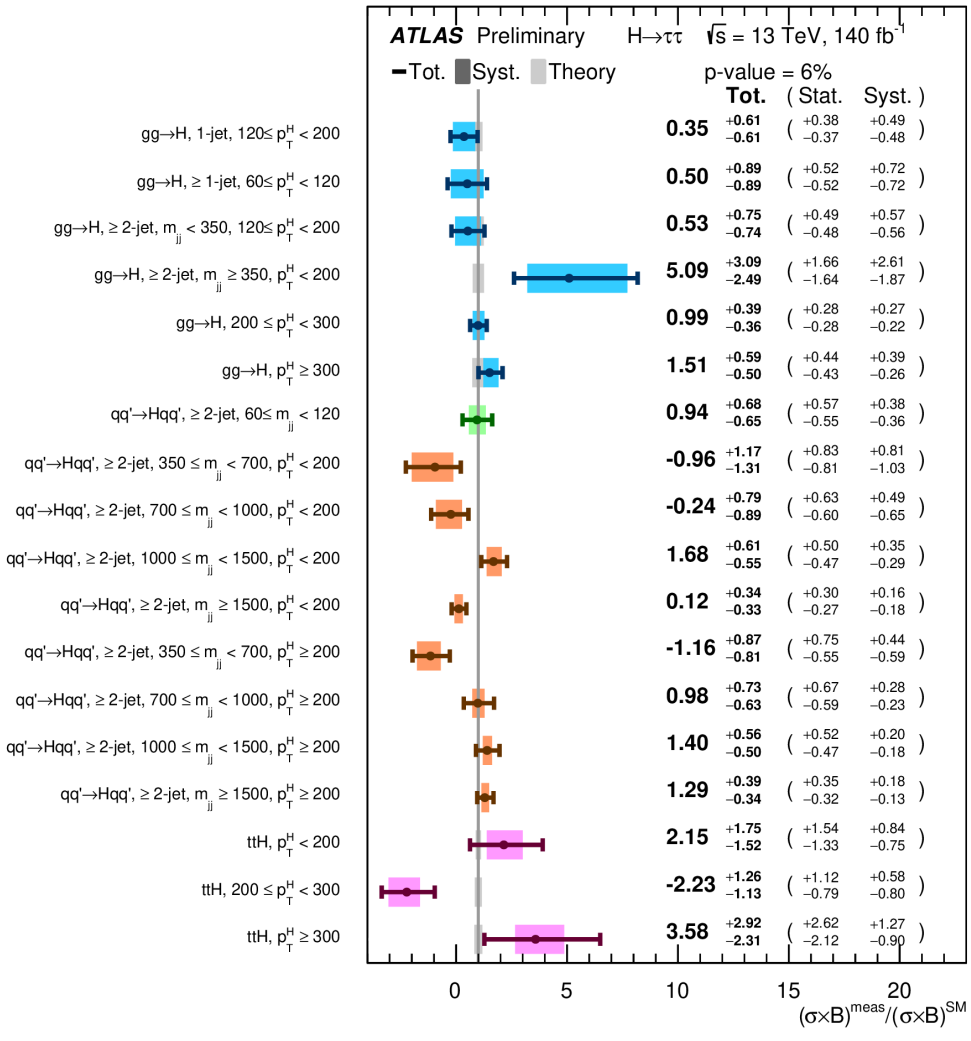
$H \to \tau\tau$ STXS Analysis: p_{T}^{H} Reconstruction & ttH BDT

- Many aspects were optimized to produce this result, but some notable new developments include;
  - Using a neural network to reconstruct the Higgs p_T which results in a dramatic, 50%, improvement in the resolution
  - Optimizing the separation between the low and high stats regions
  - Using a multi-class boosted decision tree (BDT) to categorize the $t\bar{t}H$ events from Z and Top backgrounds with inverted cuts used to form control regions.



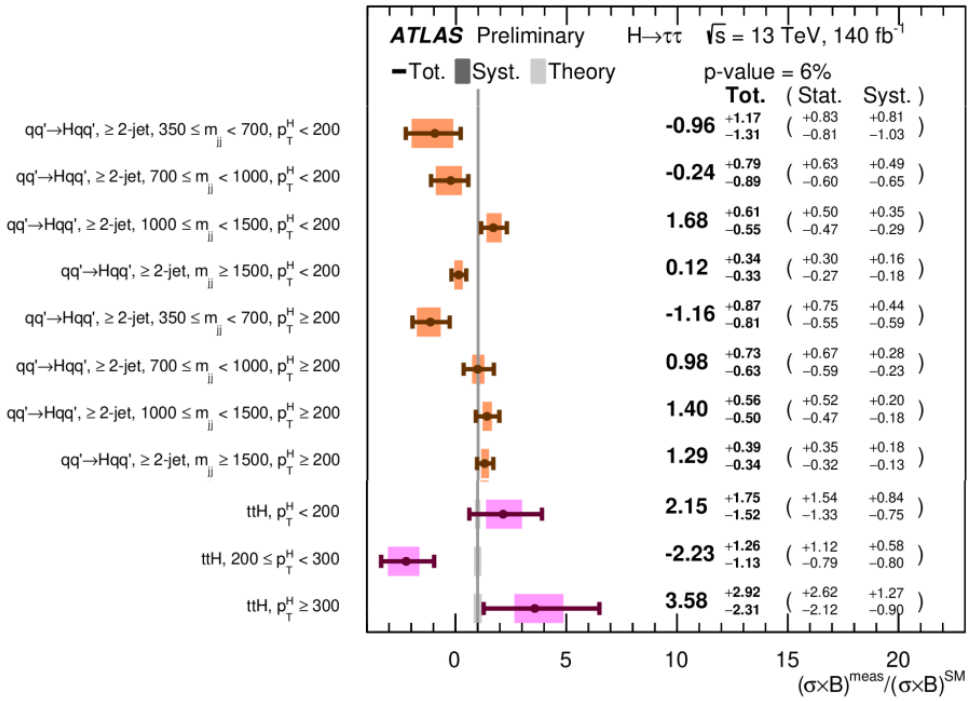
$H \to \tau\tau$ STXS Analysis: Results

- Reasonable agreement with SM with a p-value of 6%.



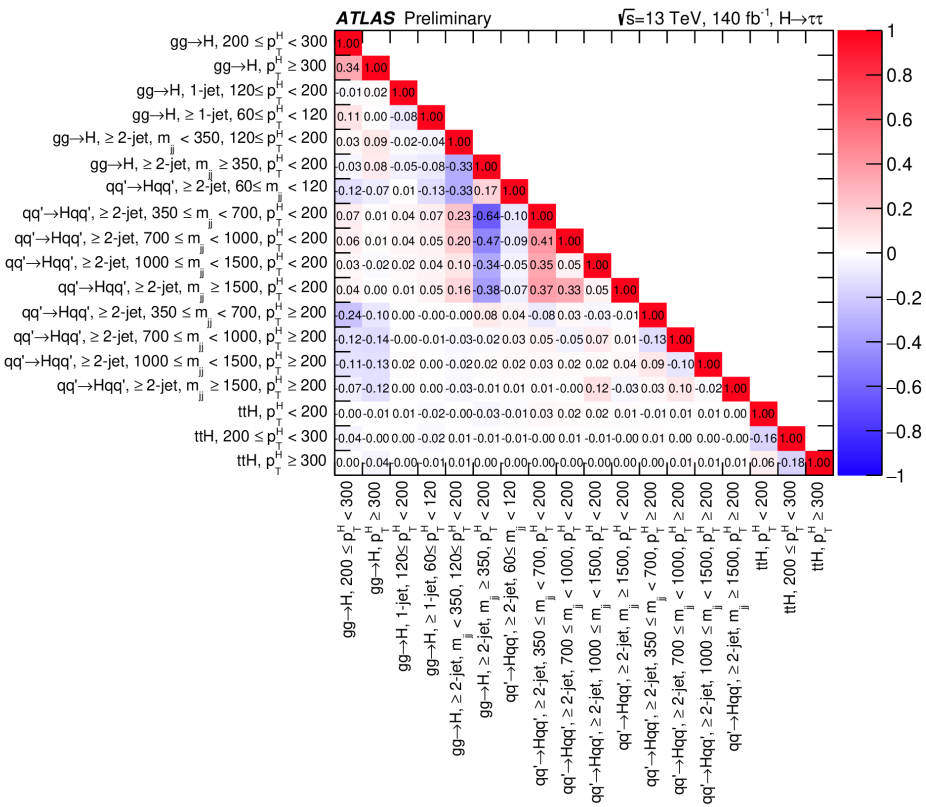
$H \to \tau\tau$ STXS Analysis: Results

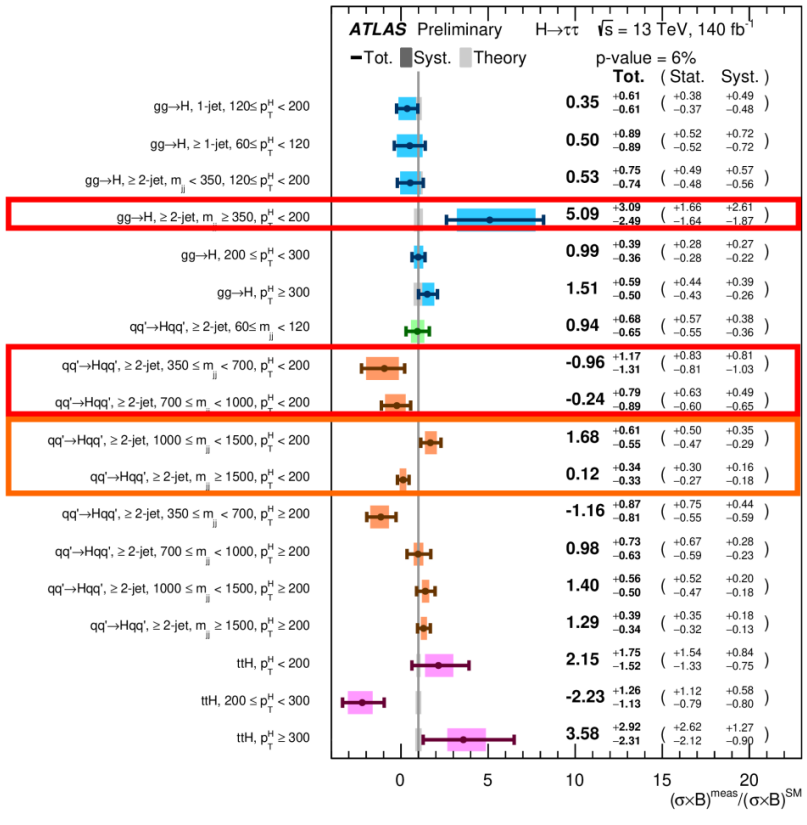
- Focusing on the new kinematic regions we have 8 VBF and 3 $t\bar{t}H$ regions.
- For VBF, this is the first measurement in multiple m_{jj} bins for the higher p_{T}^{H} selection and the most precise for the lower p_{T}^{H} selection, demonstating the power of this channel at probing VBF production.
- The $t\bar{t}H$ results remain statistically limited and additionally upper limits on the cross-section in each bin are derived for these regions.



$H \to \tau\tau$ STXS Analysis: Results – correlations

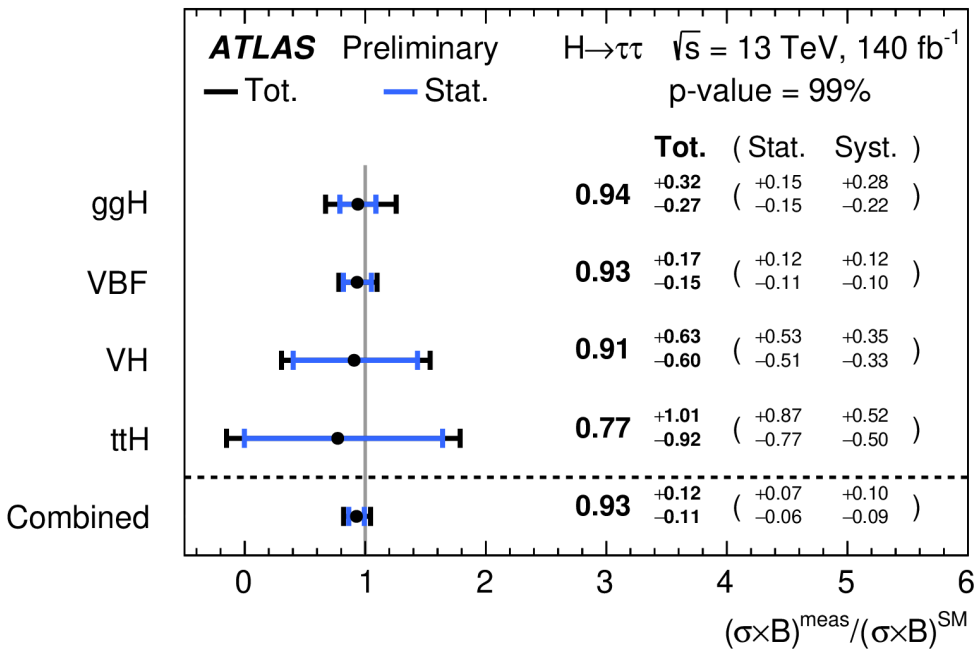
- It should also be noted that while there is some power from the analysis to separate ggF events which have high m_{jj} and VBF events there are still large anti-correlations between the ggF region and some of the VBF regions.
- This is reflected in the uncertainties on the measurements in these regions and also explains the reasonable overall p-value obtained.





$H \to \tau\tau$ STXS Analysis: Results

- The fit is also performed for the four production modes, and for the case of a global modification of the signal strength which tests the Higgs coupling to τ-leptons (assuming no other new physics).
- These also show good agreement with the SM predictions.
- They also show improvements over the previous analysis due to the finer binning and analysis improvements with an 8% improvement in the global signal strength and a $\sim 25\%$ improvement in the $t\bar{t}H$ signal strength.



Conclusions

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- I have shown the latest Run 2 legacy $H \to \tau\tau$ results from ATLAS.
- So far the data are in good agreement with the SM predictions but our understanding of the Higgs sector is rapidly improving.
- Additionally to measuring the coupling of the Higgs boson to τ-leptons the $H \to \tau\tau$ channel is seen to be a powerful way of exploring Higgs boson production.
- The Run 2 data is still a rich source for learning more about the Higgs boson as the legacy results are released.
- With our increasingly precise and powerful experimental tools/analysis techniques and increasing dataset we can look forward to probing the Higgs sector further in the coming years with Run 3 data.