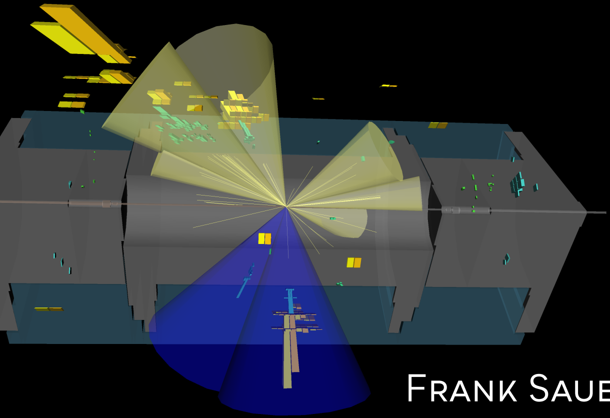
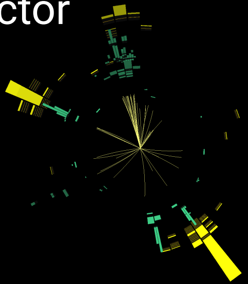
Measurements of Higgs boson production in decays to two τ leptons with the ATLAS detector





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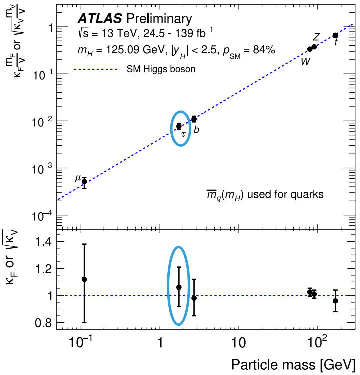
Event: 901388344
2016-05-20 17:40:04 CEST

FRANK SAUERBURGER
on behalf of the ATLAS Collaboration
October 21, 2021

ATLAS EXPERIMENT

Motivation

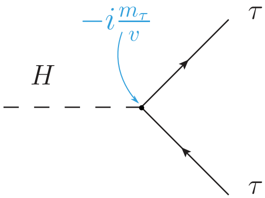


[ATLAS-CONF-2020-027]

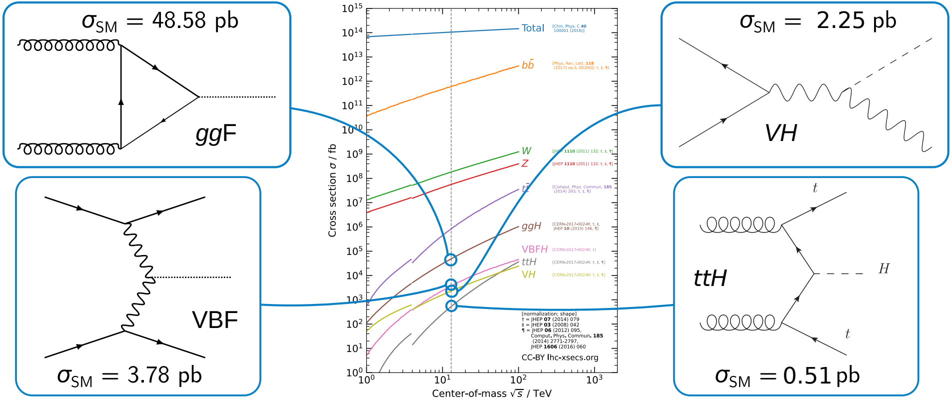
Spontaneous symmetry breaking and Yukawa interaction

$$\mathscr{L} \subset -\frac{\sqrt{2}m_\tau}{v}\left[(\bar{\nu}_\tau\,\bar{\tau})_L \phi\,\tau_R + \bar{\tau}_R \phi\,(\nu_\tau\,\tau)_L\right]$$

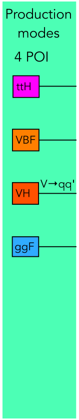
$$\rightarrow \mathscr{L} \subset -m_\tau\bar{\tau}\tau - \frac{m_\tau}{v}\bar{\tau}\tau h$$



Production modes

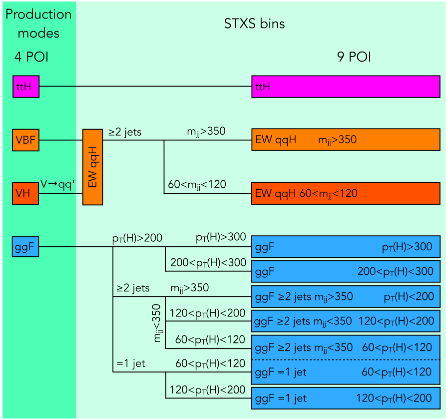


Analysis targets four H production modes



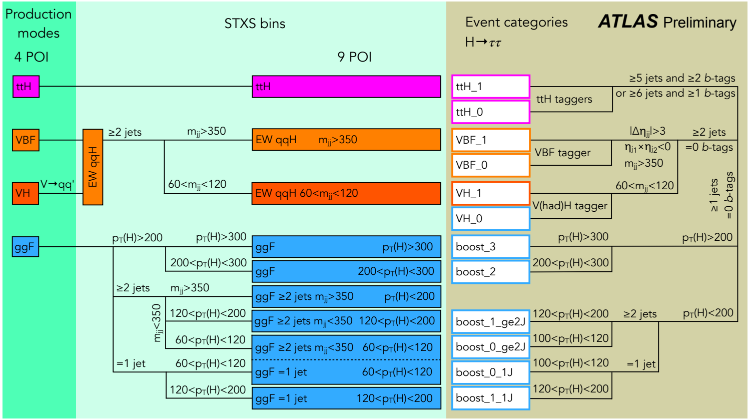
[ATLAS-CONF-2021-044]

Analysis categories



[ATLAS-CONF-2021-044]

Analysis categories

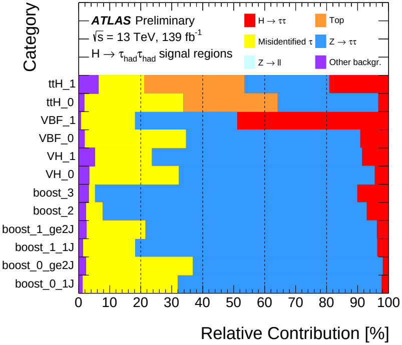


[ATLAS-CONF-2021-044]

Background composition

Dominant backgrounds

- $Z \to \tau\tau$
  - Monte Carlo simulation
  - 70% overall, up to 90% in boosted
  - Normalization from dedicated, embedded Control Regions
- Misidentified τ
  - Data-driven estimation
- Top
  - Monte Carlo simulation
  - Dedicated Control Regions

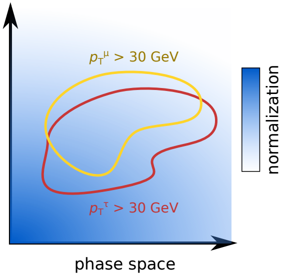


Signal region composition with $100\,\text{GeV} < m_{\tau\tau}^{\text{MMC}} < 150\,\text{GeV}$

Simplified embedding procedure

Motivation

Phase space mismatch between SR ($Z \to \tau\tau$) and CR ($Z \to \ell\ell$)



$\to$ How to define matching CR?

Procedure

In control region

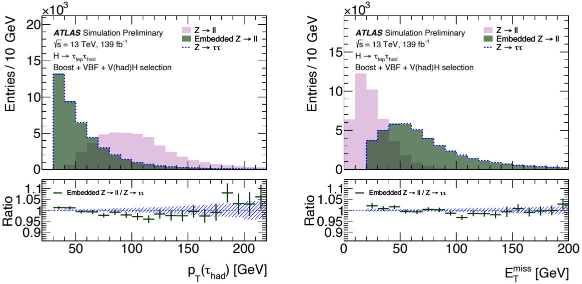
1. Select $Z \to \ell\ell$ events
2. Unfold ℓ reconstruction, identification and isolation effects
3. Scale p_ℓ by parametrized τ decay effects
4. Reweight to account for efficiencies

Simplified embedding procedure

Validation

Compare embedded $Z \to \ell\ell$ (MC)

to $Z \to \tau\tau$ (MC)



Good closure

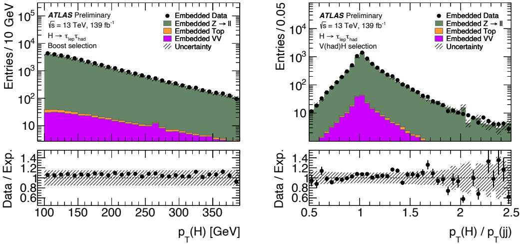
Procedure

In control region

1. Select $Z \to \ell\ell$ events
2. Unfold ℓ reconstruction, identification and isolation effects
3. Scale p_ℓ by parametrized τ decay effects
4. Reweight to account for efficiencies

Simplified embedding procedure

- Kinematic distribution in embedded $\tau_{\text{lep}}\tau_{\text{had}}$ selection
- Event selection in CR with embedded quantities
- $Z \to \ell\ell$ events assigned to exactly one channel
- Data-MC comparison in CR to normalize $Z \to \tau\tau$ (MC) SR
- Reduced extrapolation uncertainties



Introduction
Background modelling
Machine learning
Results

Data-driven estimation of misidentified τ

$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ and $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$

- Jets misidentified as τ_{had}
- Background estimated with **fake factor** method

$$N_{\text{fake}}^{\text{SR}} = (N_{\text{Data}}^{\text{anti-}\tau} - N_{\text{MC, no jet}}^{\text{anti-}\tau}) \times \mathscr{F}$$

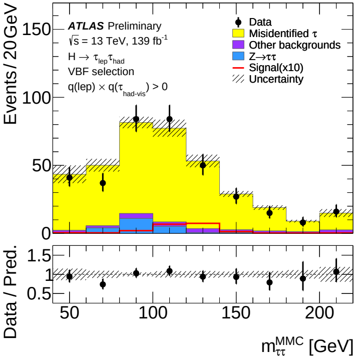
$\tau_e\tau_\mu$

- Misidentified leptons
- Data-driven **matrix method**

$$(N_{\text{tight/loose}}) = \left[\text{eff. matrix}\right](N_{\text{real/fake}})$$

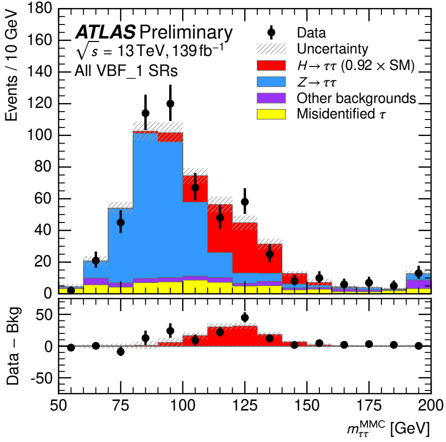
For all channels

Assign uncertainties $O(5-30\%)$



Missing mass calculator

- At least two neutrinos in the final state
- Individual contributions to $E_{\mathrm{T}}^{\mathrm{miss}}$ not measured
- Perform likelihood scan using angles between measured particles and $E_{\mathrm{T}}^{\mathrm{miss}}$
- Find most probable Higgs boson mass m_{MMC}
- Most important discriminant

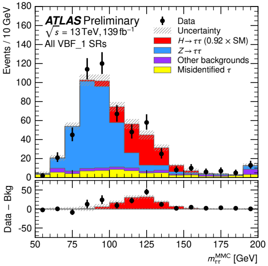


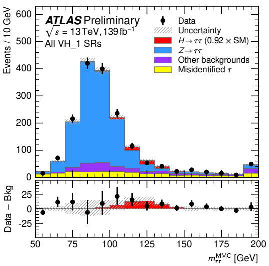
VBF tagger

- Targeting VBF topology (two forward jets)
- Rejecting: ggF and $Z \to \tau\tau$
- Trained on jet kinematics

VH tagger

- Reject non-VH production modes
- Trained on jet and Higgs kinematics



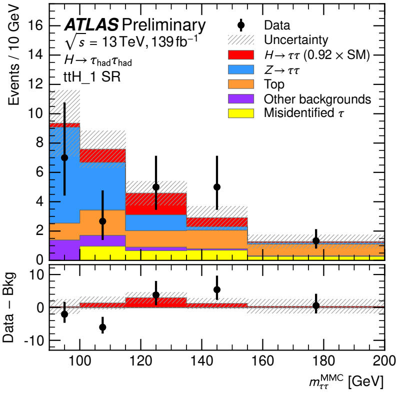


Targeted signal frac.: 94% in VBF_1 66% in VH_1

Machine learning

BDTs for ttH

- Employ two BDTs
- Reject tt and $Z \to \tau\tau$ background
- Trained on jet, τ, H and $E_{\mathrm{T}}^{\mathrm{miss}}$ properties
- Define ttH_1 with rectangular cuts
- ttH signal fraction in ttH_1: 92%

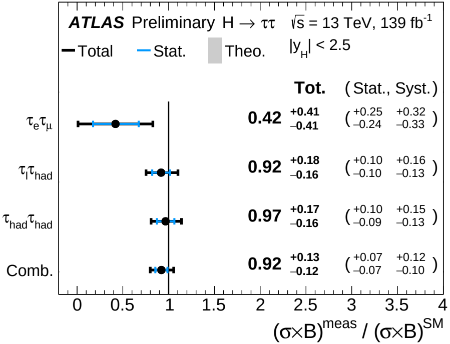


Measured cross sections

Measurements for different PoIs

1. Total cross section
2. Cross section per production mode
3. 9 bins of STXS stage 1.2

Results are in agreement with the SM



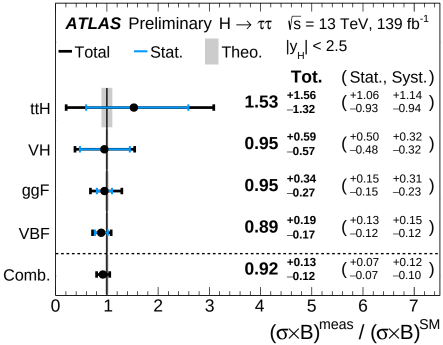
Total Cross section

$$(\sigma \times \mathrm{BR})^{\mathrm{obs}} = 2.90 \pm 0.21\,(\mathrm{stat})\,^{+0.37}_{-0.32}\,(\mathrm{syst})\,\mathrm{pb}$$

Measurements for different PoIs

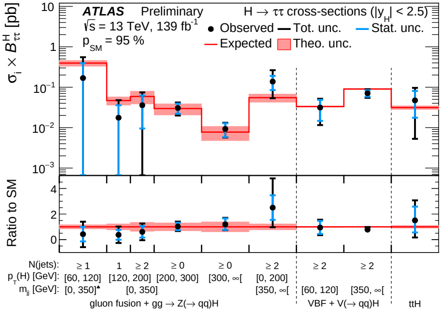
1. Total cross section
2. Cross section per production mode
3. 9 bins of STXS stage 1.2

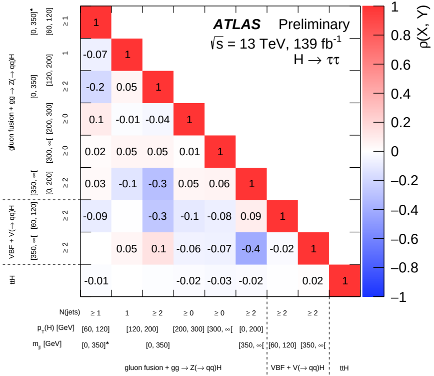
Results are in agreement with the SM



- Strong constraints on VBF cross-section
- Observation of VBF process at 5.3σ

Measurement in 9 bins of STXS stage 1.2





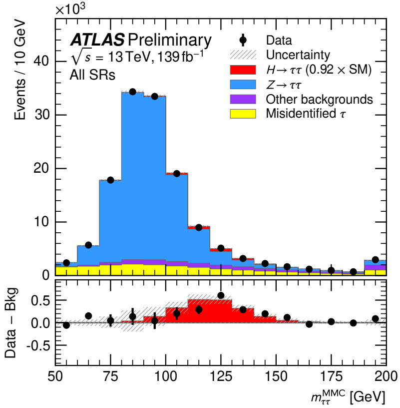
Conclusion

- Total measured $H \to \tau\tau$ cross section

$$2.90 \pm 0.21\,(\text{stat})\,{}^{+0.37}_{-0.32}\,(\text{syst})\,\text{pb}$$

- Inclusion of four production modes
- Observation of VBF $H \to \tau\tau$ at 5.3 σ
- Improved precision[†] from 27% to 14%
- STXS measurements in 9 bins
- Results in agreement with SM

→ More precise measurements in future with refined analysis techniques and Run 3 dataset

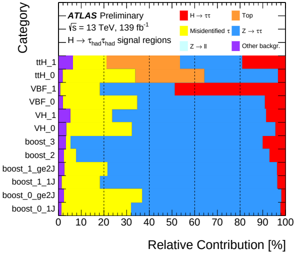


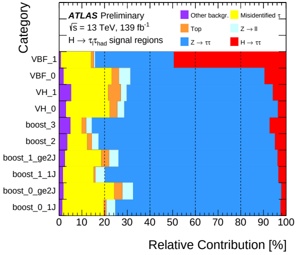
† wrt. Phys. Rev. D **99**,072001 (2019)

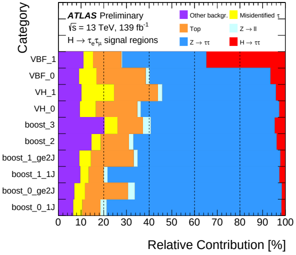
Backup

Signal region composition

Signal region composition with $100\,\text{GeV} < m_{\tau\tau}^{\text{MMC}} < 150\,\text{GeV}$

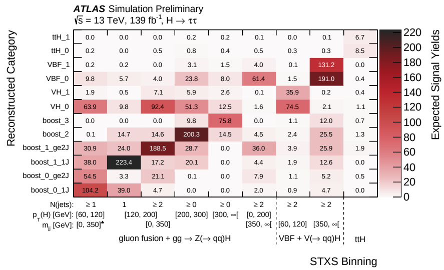




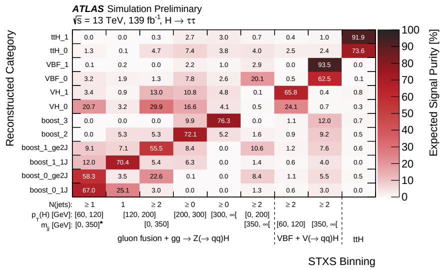


Expected signal

Expected signal yield

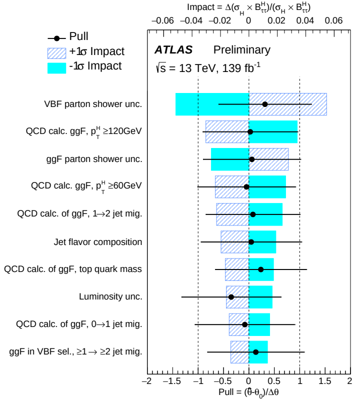


Expected signal purity



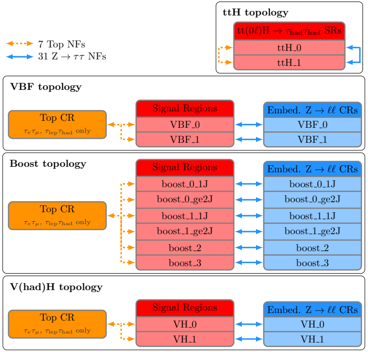
Systematic uncertainties

- Largest systematic uncertainties from signal theory uncertainties (8.1%)
- Largest experiemntal uncertainty (4.2%)

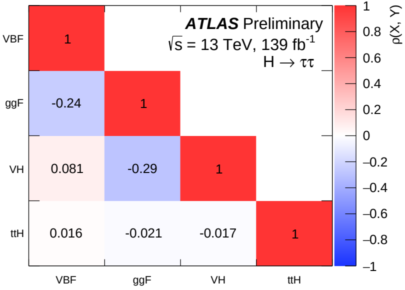


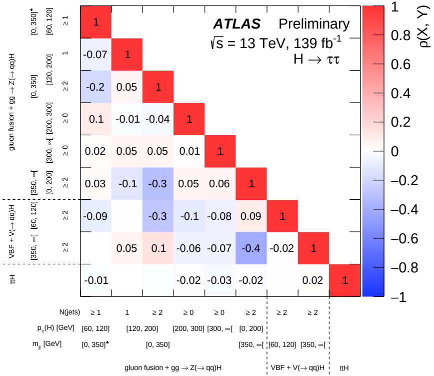
Fit structure

- Normalization of Top background from Top control regions
- Normalization of $Z \to \tau\tau$ from kinematically embedded $Z \to \ell\ell$

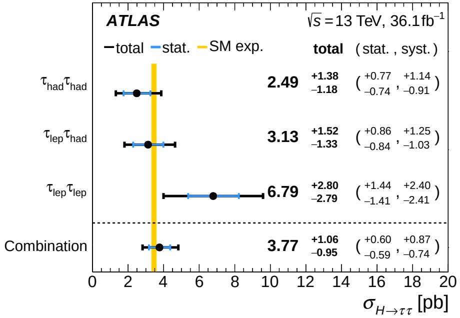


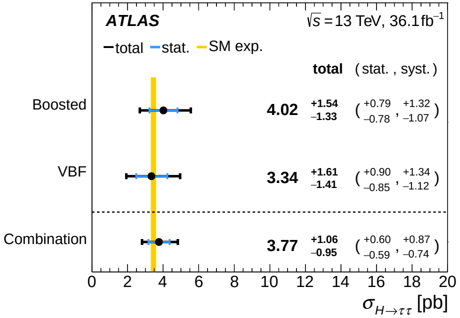
Signal correlation





Partial Run 2 dataset





[Phys. Rev. D **99**,072001 (2019)]