# Measurements of the Higgs production cross section in the $H \to \tau\tau$ decay channel with the ATLAS experiment


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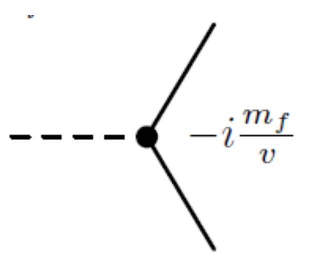
ATLAS EXPERIMENT


## 1. Introduction

- $H \to \tau\tau$ is a considerably important decay channel because it allows to directly measure Yukawa coupling
- B.R. 6.32 %
- Analysis performed with data collected by the ATLAS experiment during 2015 and 2016 for an integrated luminosity of 36.1 fb$^{-1}$ at $\sqrt{s} = 13$ TeV (improvement of Run 1 result)



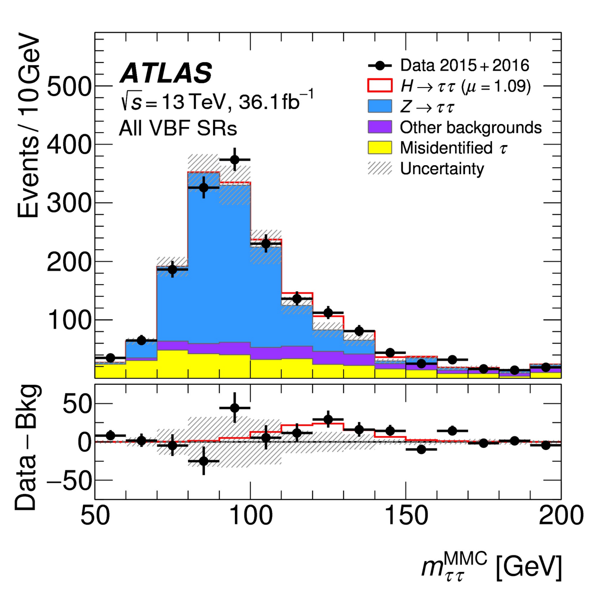

- 3 subchannels according to the $\tau$ decay
  - Lep-Lep $ee/\mu\mu/e\mu$ B.R. 12.4%
  - Lep-Had $e/\mu + \tau_{had}$ B.R. 45.6%
  - Had-Had $\tau_{had} + \tau_{had}$ B.R. 42.0%
- Complicated signature:
  → $\tau_{had}$ reconstruction and identification of hadronic taus, difficult due to significant backgrounds from QCD jets
  → $m_{mmc}$ Higgs invariant mass reconstruction done with the Missing Mass Calculator (MMC), likelihood based algorithm which takes into account missing transverse momentum due to neutrinos

## 2. Selections

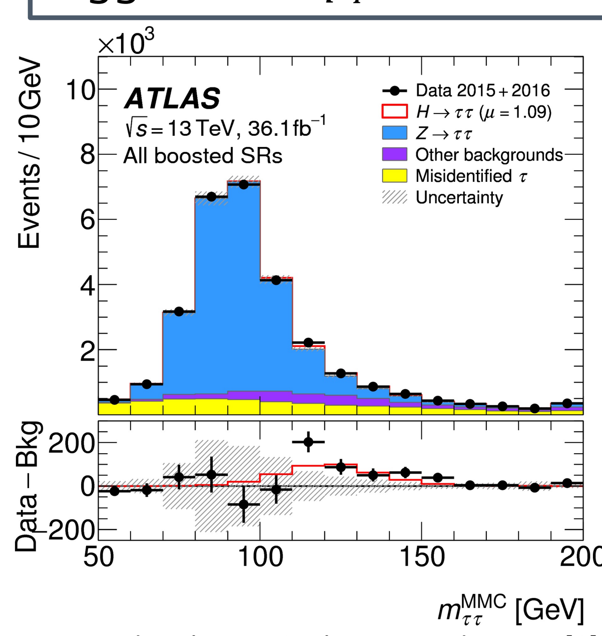
- 2 kinds of signal regions (SRs) for each decay channel exploiting different Higgs production processes (they are further divided in subregions)

VBF: targeting Vector Boson Fusion events, characterized by two high $p_T$ jets with $|\Delta\eta(j,j)| > 3$ and $m_{jj} > 400$ GeV

Boosted: targeting Gluon Fusion events, which fail the VBF selection and are characterized by a high $p_T$ Higgs boson, $p_T^H > 100$ GeV




$m_{MMC}$ distribution in the VBF region [1]

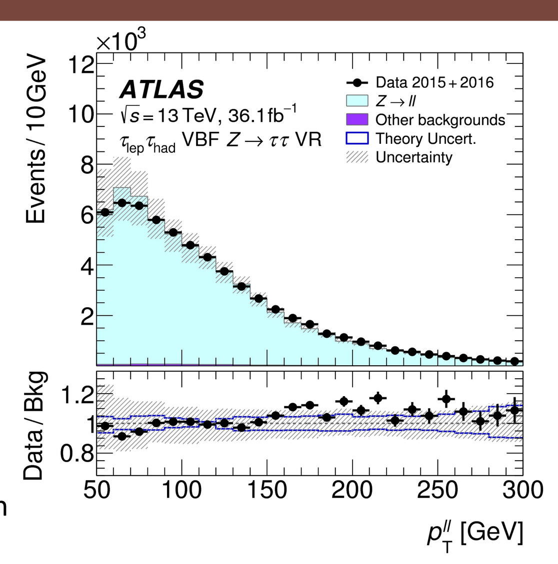



$m_{MMC}$ distribution in the Boosted region [1]

- Dedicated control regions (CRs) for constraining normalisation of simulated backgrounds: $Z \to ll$, Top
- A dedicated validation region (VR) for checking the $Z \to \tau\tau$ modelling but not used in the fit

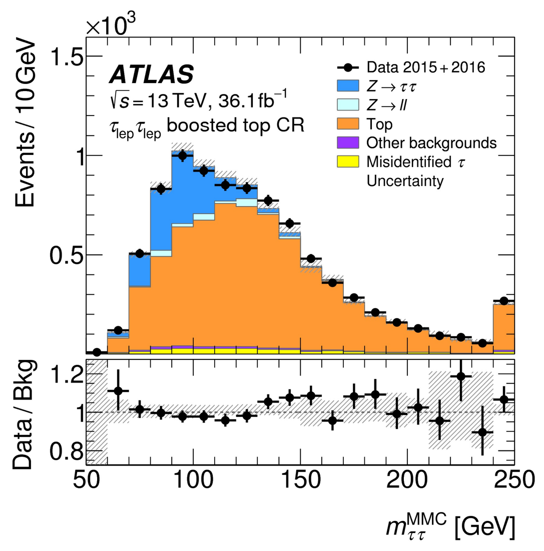
## 3. Background estimation

- $Z \to \tau\tau$ main irreducible background (50-90%), estimating using Monte Carlo samples, Sherpa NLO
  - Normalisation from fit to data, correlated across the channels but two different parameters for VBF and Boosted
  - The $Z \to \tau\tau$ VR construction is based on lep-lep SR selection using $Z \to ll$ events and it is used to verify the $Z \to \tau\tau$ modelling



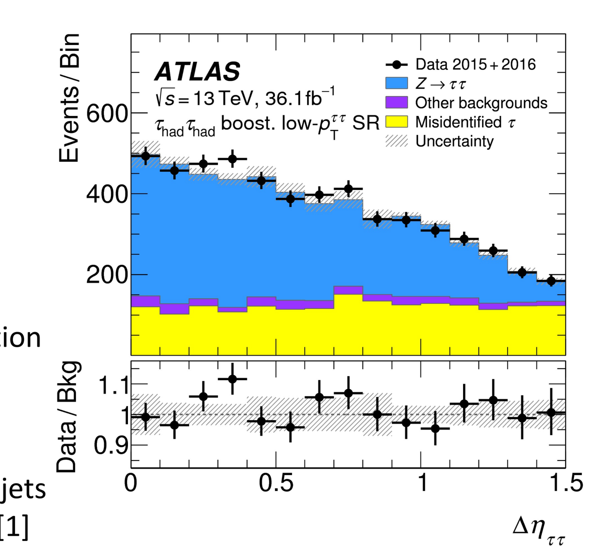

Dilepton $p_T$ distribution in the $Z \to \tau\tau$ validation region (lep-had) [1]

- Control regions for $Z \to ll$ (lep-lep) and Top (lep-lep and lep-had)
  - $Z \to ll$: $80 < m_{ll} < 100$ GeV
  - Top: requirement to have $b$-tagged jets




$m_{MMC}$ distribution in the Top CR (lep-lep) [1]

- Jets misidentified as $\tau$ or $e/\mu$ (QCD, W/Z + jets): data-driven techniques
  - Template built in a dedicated CR and normalisation retrieved from CR extrapolation (lep-lep)
  - Fake factors derived in a dedicated CR and applied to SR events, normalisation from CR extrapolation (lep-had)
  - Template built in a dedicated CR and normalisation retrieved from fit to data (had-had)




$\Delta\eta_{\tau\tau}$ distribution in a Boosted signal region (had-had), misidentified jets are in yellow [1]

## 4. Statistical analysis

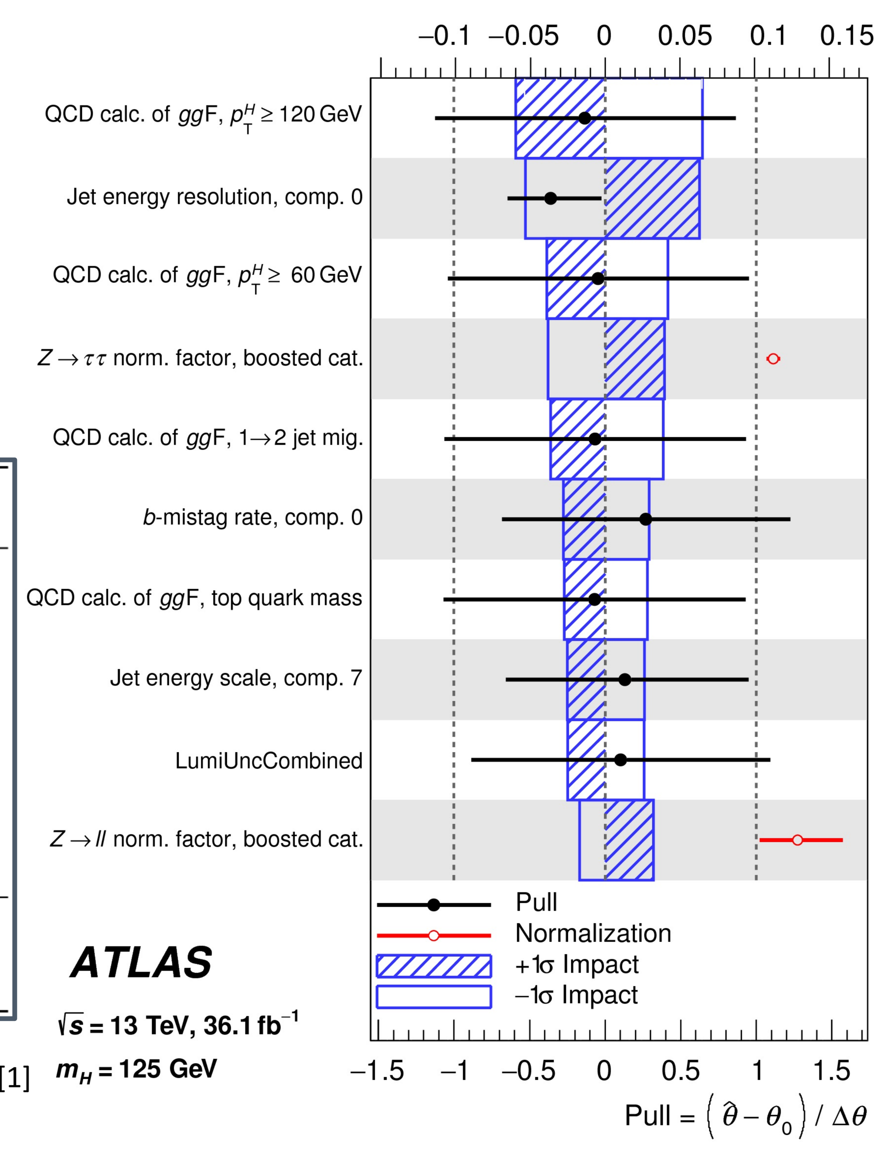
- Maximum likelihood fit to extract the parameter of interest $\sigma_{H\to\tau\tau} \equiv \sigma_H x\, \mathcal{B}(H \to \tau\tau)$ where $\sigma_H$ is the total cross section for all Higgs production processes (their relative contribution is assumed to be equal to the Standard Model prediction)
- Higgs invariant mass distribution $m_{mmc}$ used in the signal regions as the fitting variable
- Control regions used to constrain the normalisation of backgrounds
- Systematic uncertainties taken into account in the fit model as nuisance parameters

Fractional impact of systematic uncertainties on $\sigma_{H\to\tau\tau}$:

- Signal theory uncertainties: QCD scale for ggF
- Jet energy resolution
- Background statistics

| Source of uncertainty | Impact $\Delta\sigma/\sigma_{H\to\tau\tau}$ [%] Observed | Expected |
|---|---|---|
| Theoretical uncert. in signal | +13.4 / −8.7 | +12.0 / −7.8 |
| Background statistics | +10.8 / −9.9 | +10.1 / −9.7 |
| Jets and $E_T^{miss}$ | +11.2 / −9.1 | +10.4 / −8.4 |
| Background normalization | +6.3 / −4.4 | +6.3 / −4.4 |
| Misidentified $\tau$ | +4.5 / −4.2 | +3.4 / −3.2 |
| Theoretical uncert. in background | +4.6 / −3.6 | +5.0 / −4.0 |
| Hadronic $\tau$ decays | +4.4 / −2.9 | +5.5 / −4.0 |
| Flavor tagging | +3.4 / −3.4 | +3.0 / −2.3 |
| Luminosity | +3.3 / −2.4 | +3.1 / −2.2 |
| Electrons and muons | +1.2 / −0.9 | +1.1 / −0.8 |
| Total systematic uncert. | +23 / −20 | +22 / −19 |
| Data statistics | ±16 | ±15 |
| Total | +28 / −25 | +27 / −24 |

Systematic uncertainties impact on $\sigma_{H\to\tau\tau}$, grouped in categories [1]



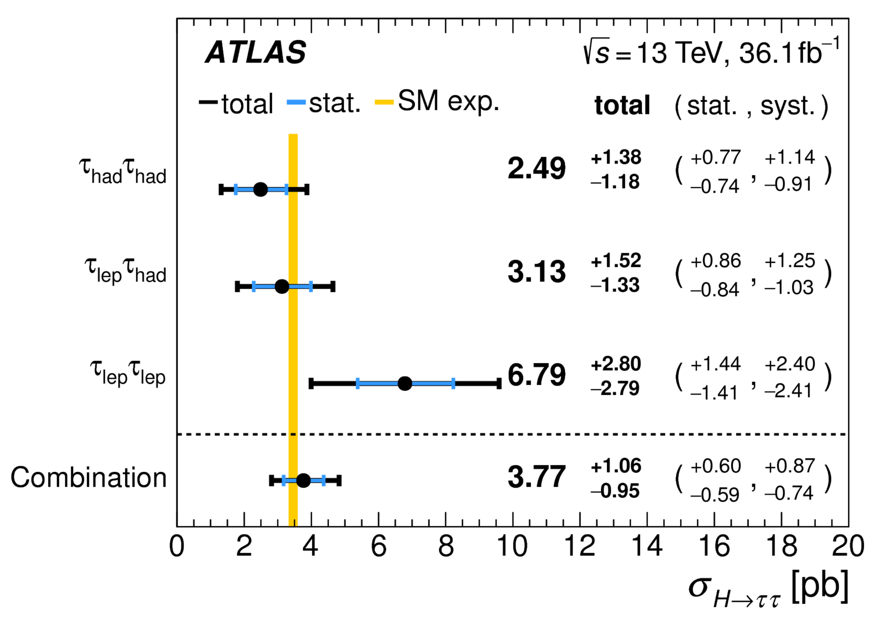

Systematic uncertainties impact on $\sigma_{H\to\tau\tau}$ [1]

## 5. Results

- Observed (expected) significance of signal excess with respect to the background-only hypothesis of 4.4 (4.1) $\sigma$

$$\sigma_{H\to\tau\tau} = 3.77^{+0.60}_{-0.59}\ (\text{stat})^{+0.87}_{-0.74}\ (\text{syst})\ \text{pb}$$

$$\sigma^{SM}_{H\to\tau\tau} = 3.46 \pm 0.13\ \text{pb}$$

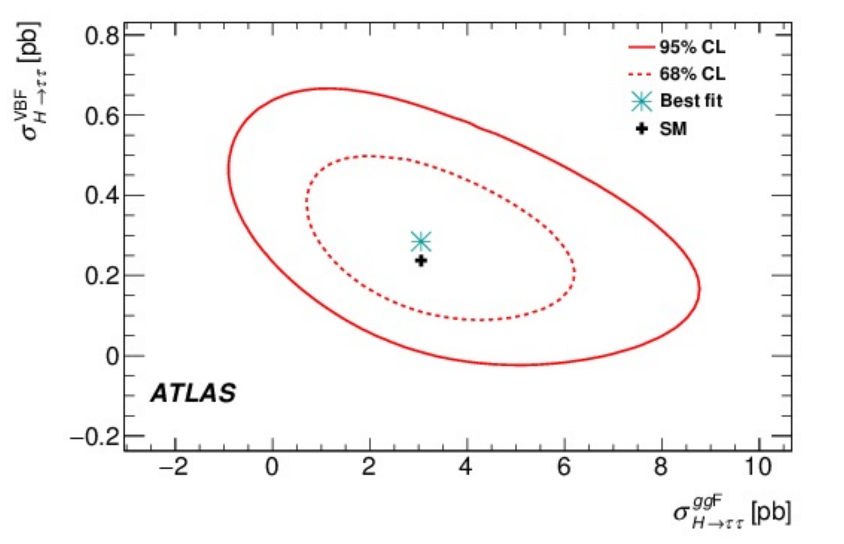



$\sigma_{H\to\tau\tau}$ measurement in the various subchannels and for the combined result. The predicted value from the standard model with its uncertainty is shown in yellow [1]

- Fit to $\sigma^{VBF}_{H\to\tau\tau}$ and $\sigma^{ggF}_{H\to\tau\tau}$, in order to separate VBF and ggF production, all the other production processes assumed to be as in the Standard Model

$$\sigma^{VBF}_{H\to\tau\tau} = 0.28 \pm 0.09\ (\text{stat})^{+0.11}_{-0.09}\ (\text{syst})\ \text{pb}$$
$$\sigma^{ggF}_{H\to\tau\tau} = 3.1 \pm 1.0\ (\text{stat})^{+1.6}_{-1.3}\ (\text{syst})\ \text{pb}$$

$$\sigma^{SM,VBF}_{H\to\tau\tau} = 0.237 \pm 0.006\ \text{pb}$$
$$\sigma^{SM,ggF}_{H\to\tau\tau} = 3.05 \pm 0.13\ \text{pb}$$




2D contour plot with the 95% and 68% C.L. contours in the plane $\sigma^{VBF}_{H\to\tau\tau}, \sigma^{ggF}_{H\to\tau\tau}$. The value predicted by the standard model is indicated by the black point while the best-fit value is shown as a star [1]

- Fit with three parameters of interest performing cross section measurements in three mutually exclusive phase space regions, the selections are based on the simplified template cross sections framework

| Process | Particle-level selection | $\sigma$ [pb] | $\sigma^{SM}$ [pb] |
|---|---|---|---|
| ggF | $N_{jets} \geq 1$, $60 < p_T^H < 120$ GeV, $\|y_H\| < 2.5$ | $1.79 \pm 0.53$ (stat.)$\pm 0.74$ (syst.) | $0.40 \pm 0.05$ |
| ggF | $N_{jets} \geq 1$, $p_T^H > 120$ GeV, $\|y_H\| < 2.5$ | $0.12 \pm 0.05$ (stat.)$\pm 0.05$ (syst.) | $0.14 \pm 0.03$ |
| VBF | $\|y_H\| < 2.5$ | $0.25 \pm 0.08$ (stat.)$\pm 0.08$ (syst.) | $0.22 \pm 0.01$ |

- Combined fit with Run 1 data collected at $\sqrt{s}$ =7 and $\sqrt{s} = 8$ TeV leads to an observed (expected) significance of 6.4 (5.4) σ
  → first $H \to \tau\tau$ observation in ATLAS
- All the measurements are in agreement with the Standard Model predictions


[1] "Cross-section measurements of the Higgs boson decaying to a pair of tau leptons in proton–proton collisions at √ s = 13 TeV with the ATLAS detector", ATLAS Collaboration, Phys. Rev. D **99**, 072001