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

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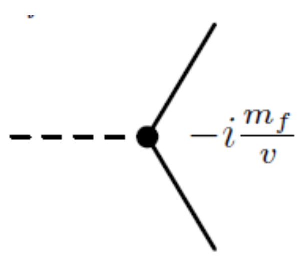
INFN

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} and $\sqrt{s} = 13$ TeV

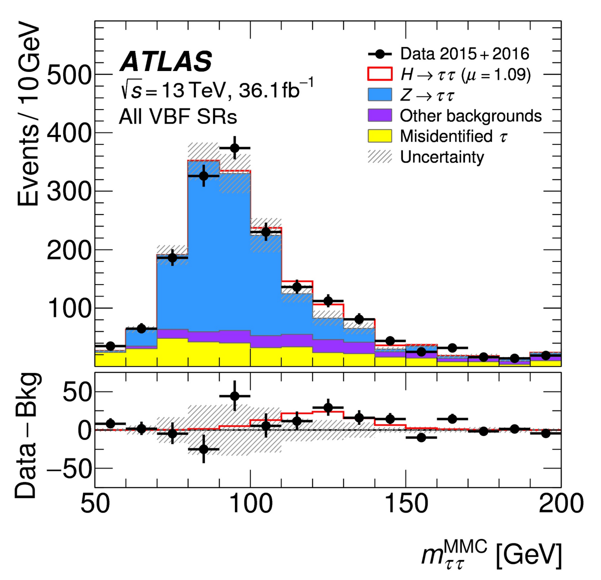


- 3 subchannels according to the τ decay
  - Lep-Lep $ee/\mu\mu/e\mu$ 12.4%
  - Lep-Had $e/\mu + \tau_{had}$ 45.6%
  - Had-Had $\tau_{had} + \tau_{had}$ 42.0%
- Complicated signature:
  → τ_{had} reconstruction and identification of hadronic taus
  → m_{mmc} Higgs invariant mass reconstruction done with the Missing Mass Calculator (MMC) algorithm which takes into account the missing transverse momentum due to neutrinos

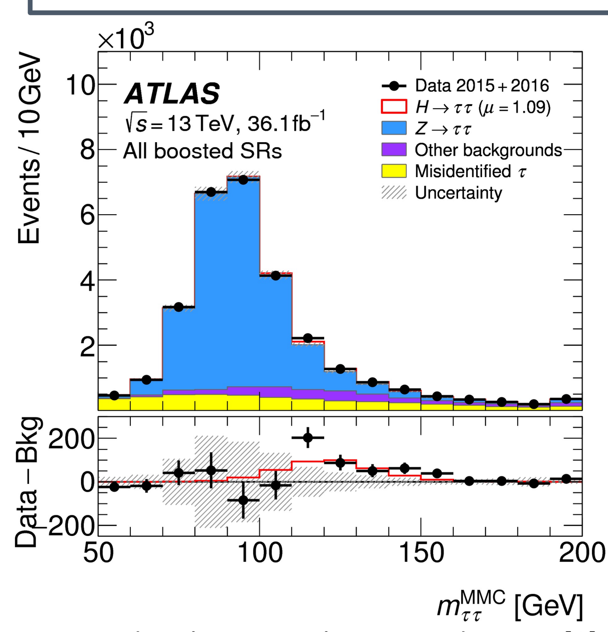
2. Selections

- 2 kinds of signal regions 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 $\lvert\Delta\eta(j,j)\rvert > 3$ 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



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

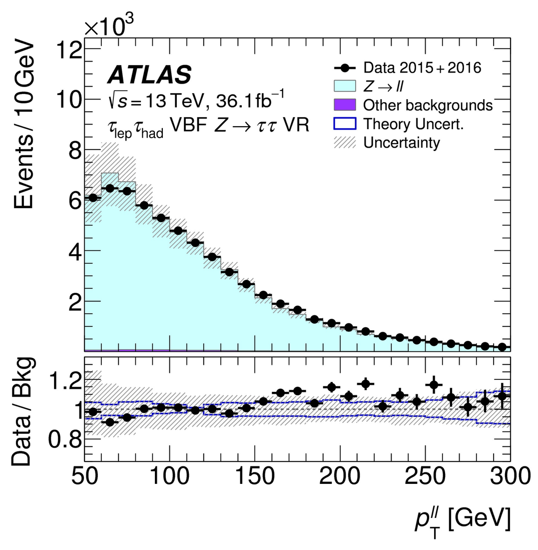


m_{MMC} distribution in the Boosted region [1]

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

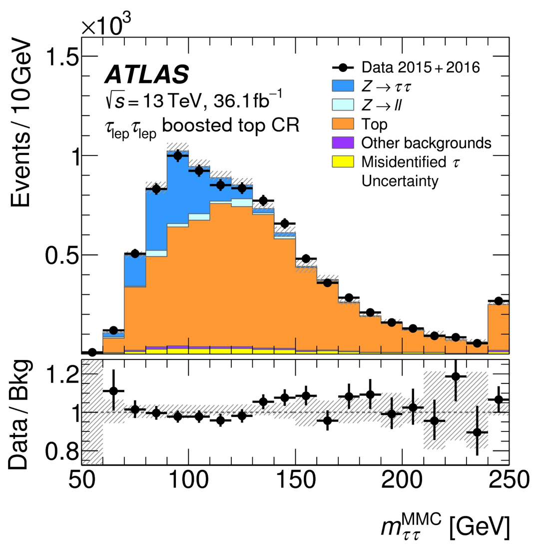
3. Backgrounds estimation

- $Z \to \tau\tau$ main irreducible background (50-90%), estimating using Monte Carlo samples, Sherpa NLO
  - Normalisation from fit to data
  - The $Z \to \tau\tau$ validation region is used to verify the correct modelling using $Z \to ll$ events



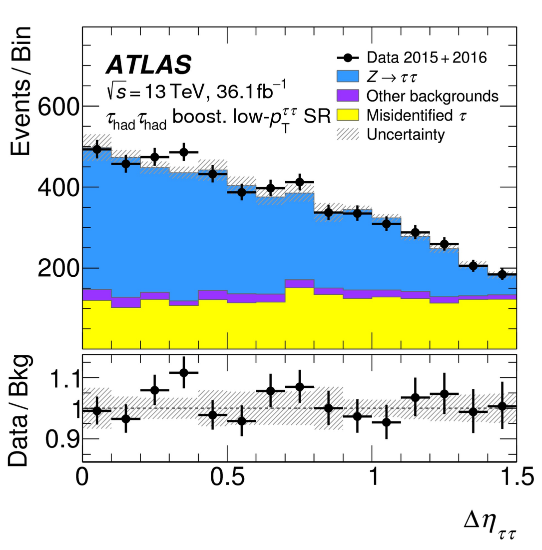
Dilepton p_T distribution in the $Z \to \tau\tau$ validation region (lep-had) [1]

- 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 τ or e/μ (QCD, W/Z + jets): data-driven techniques
  - Template built in a dedicated control region and normalisation retrieved from fit to data (had-had)



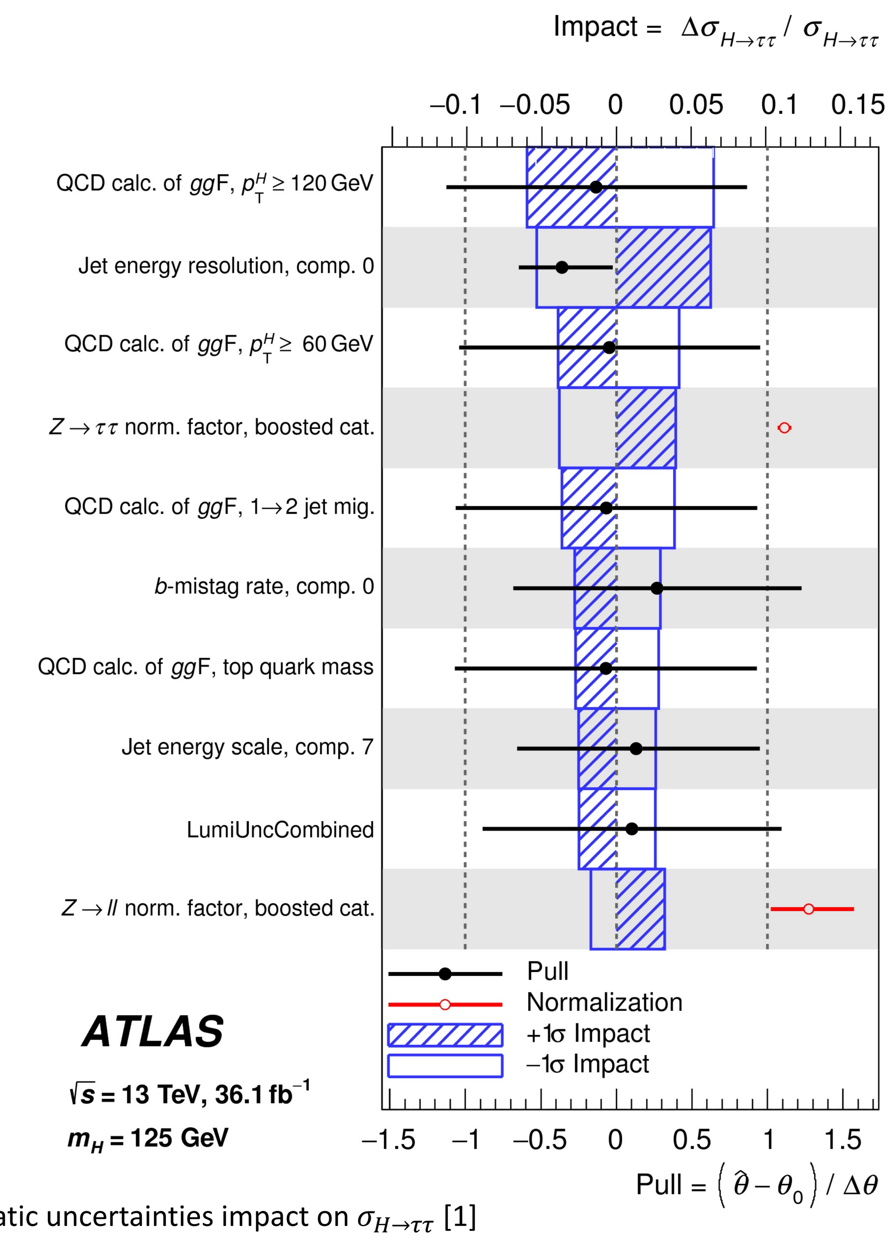
$\Delta\eta_{\tau\tau}$ distribution in a Boosted signal region (had-had), misidentified jets are in yellow [1]

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 σ_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
- 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, they are listed in decreasing order of impact on $\sigma_{H\to\tau\tau}$:

- Signal theory uncertainties (ggF): QCD scale
- Jet energy resolution
- $Z \to \tau\tau$ normalisation



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

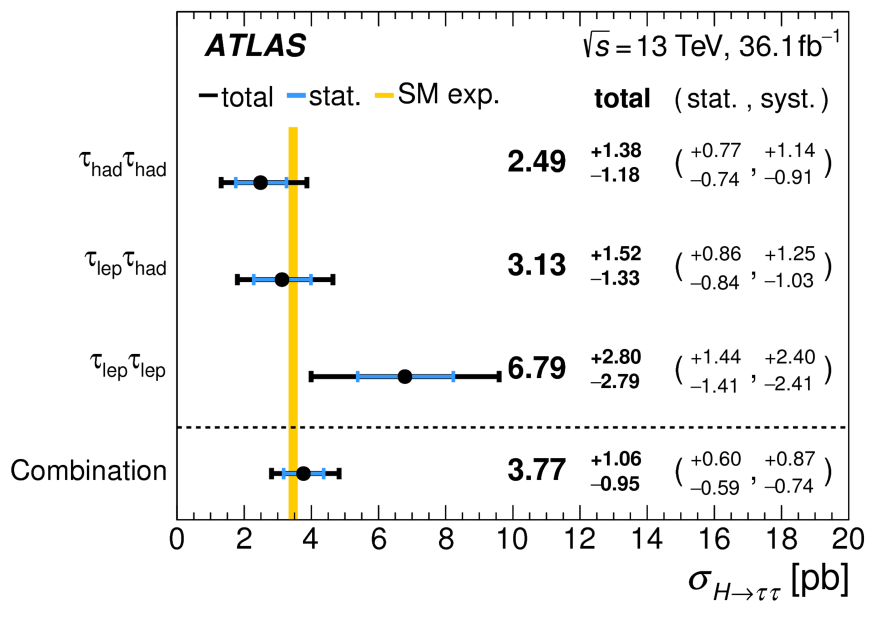
5. Results

- Observed (expected) significance of signal excess with respect to the background-only hypothesis of 4.4 (4.1) σ
- Fit with two parameters of interest, $\sigma_{H\to\tau\tau}^{VBF}$ and $\sigma_{H\to\tau\tau}^{ggF}$, in order to separate VBF and ggF production, all the other production processes are assumed to be as in the Standard Model

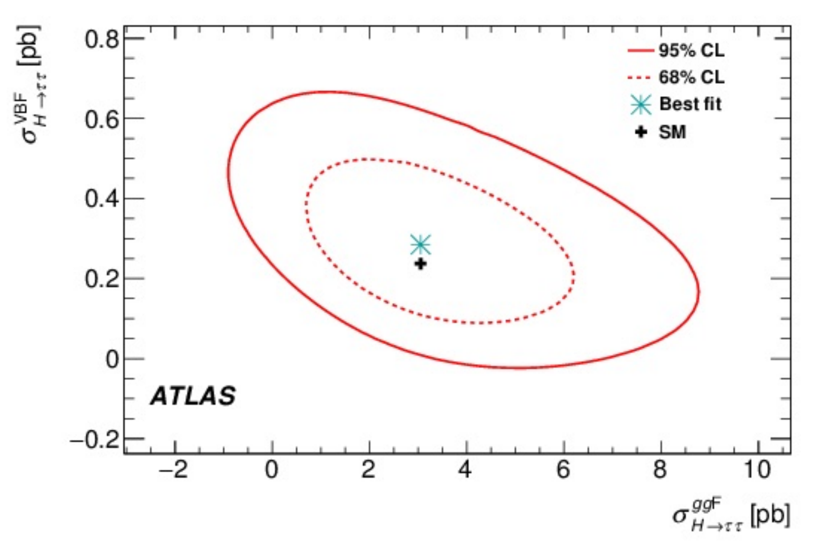
$$\sigma_{H\to\tau\tau} = 3.77^{+0.60}_{-0.59}\,(\text{stat})^{+0.87}_{-0.74}\,(\text{syst})\ \text{pb}$$

$$\sigma_{H\to\tau\tau}^{VBF} = 0.28 \pm 0.09\,(\text{stat})^{+0.11}_{-0.09}\,(\text{syst})\ \text{pb}$$

$$\sigma_{H\to\tau\tau}^{ggF} = 3.1 \pm 1.0\,(\text{stat})^{+1.6}_{-1.3}\,(\text{syst})\ \text{pb}$$



$\sigma_{H\to\tau\tau}$ 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]



2D contour plot with the 95% and 68% C.L. contours in the plane $\sigma_{H\to\tau\tau}^{VBF}$, $\sigma_{H\to\tau\tau}^{ggF}$. 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	σ [pb]	σ^{SM} [pb]
ggF	$N_{jets} \geq 1$, $60 < p_T^H < 120$ GeV, $\lvert y_H\rvert < 2.5$	1.79 ± 0.53 (stat.) ± 0.74 (syst.)	0.40 ± 0.05
ggF	$N_{jets} \geq 1$, $p_T^H > 120$ GeV, $\lvert y_H\rvert < 2.5$	0.12 ± 0.05 (stat.) ± 0.05 (syst.)	0.14 ± 0.03
VBF	$\lvert y_H\rvert < 2.5$	0.25 ± 0.08 (stat.) ± 0.08 (syst.)	0.22 ± 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 prediction

[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