Measurements of Higgs boson production cross sections in the $H \rightarrow \tau\tau$ decay channel in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

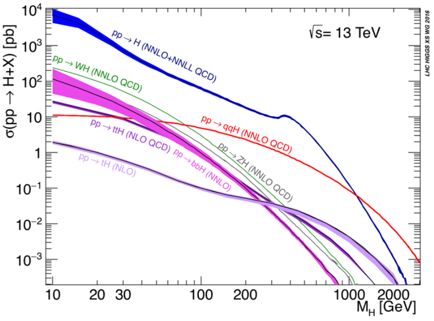
Kristina Mihule
on behalf of the ATLAS collaboration

Charles University, Prague

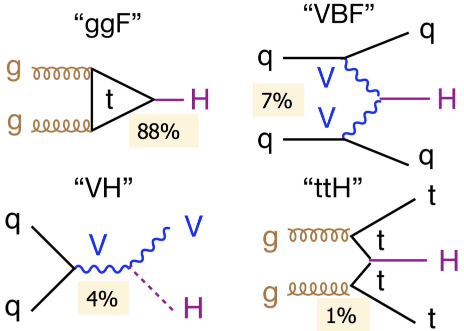
Higgs 2021, October 2021

The ATLAS H production measurement in $H \to \tau\tau$

- Aims for precise measurements of the cross section of the Higgs boson production in experimental categories following four production modes:
  - ggF: a dominant production mode
  - VBFH: a characteristic event signature, a BDT-based MVA tagger developed
  - $t\bar{t}H$ and VH where top and V decay hadronically: processes are recognized with BDTs
- Measuring Higgs boson production cross sections with the simplified template cross section (STXS) in ggH and VBF production modes: binned in $p_T(H)$, m_{jj}, and N_j

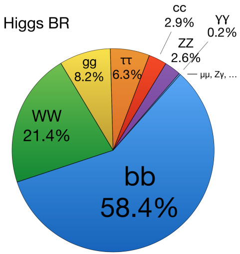


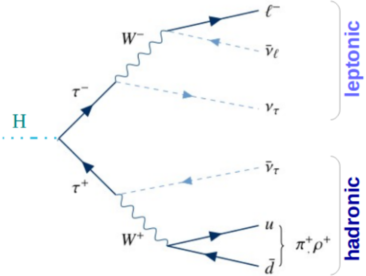
LHC Higgs WG



Higgs boson decay to a pair of τ-leptons

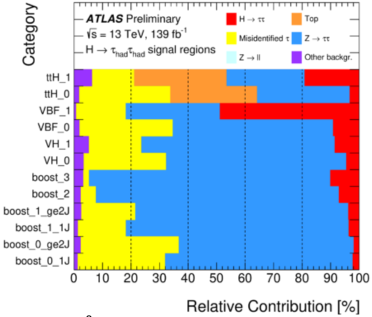
- $H \to \tau\tau$ is the second most frequent Higgs boson decay to fermions: branching ratio is 6.3%
- $H \to \tau\tau$ analysis measures production cross section and parameters of the $H\tau\tau$ coupling
- The most up-to-date measurements are based on the data collected LHC Run 2 (2015-2018) [ATLAS-CONF-2021-044].
- Various di-tau decay modes are included: $\tau_h\tau_h$, $\tau_h\tau_e$, $\tau_h\tau_\mu$, $\tau_e\tau_\mu$

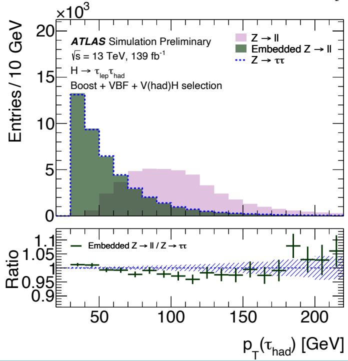




Background estimation

- The irreducible $Z\tau\tau$ background:
  - Control regions (CRs) based on object-level embedding (real Zll data: light leptons $\rightarrow$ simulated τ's) $\rightarrow$ validation of MC $Z\tau\tau$ modelling with embedded Zll, p_T distribution correction, constraining normalization
  - MC modeling in signal region (SR)
- The events where taus are faked by jets – data-driven assessment:
  - Fake factor method ($\tau_{\text{had}}\tau_{\text{had}}$, $\tau_{\text{had}}\tau_l$ where $l = e, \mu$)
  - Matrix element method ($\tau_e\tau_\mu$)
- *Top* events are MC-modeled $\rightarrow$ normalization constraining, modeling check in CRs
- Other background processes (*Zll*, di-boson, W+jets,..) – MC simulation

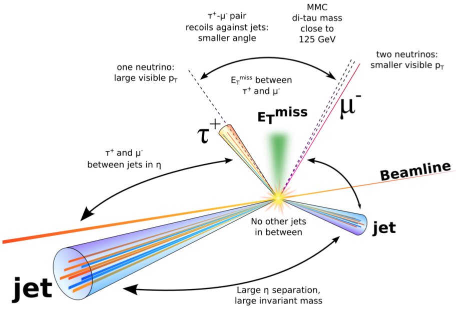




[ATLAS-CONF-2021-044]

Di-tau mass estimation: Missing Mass Calculator

- The invariant mass of the di-tau system is used by the analysis as the final discriminant variable in the determination of the signal
- Reconstruction of the Higgs boson mass (i.e. $m_{\tau\tau}$) is challenging due to the presence of non-detectable neutrinos
- The Missing Mass Calculator (MMC) [1012.4686] assumes neutrinos are the only source of missing transverse energy (MET).
- For each event, kinematically possible configurations (variations of particles four-momenta) of the visible



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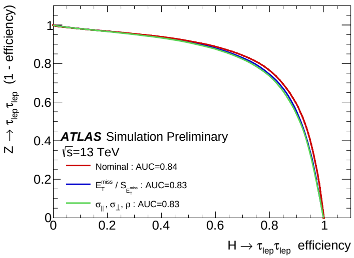
The solution with the highest probability $\mathcal{L} = -\log(\mathcal{P}_{\text{total}}) = -\log(\mathcal{P}(\Delta R_{\text{vis,miss 1,p}_{\tau\,1}}) \times \mathcal{P}(\Delta R_{\text{vis,miss 2,p}_{\tau\,2}}) \times \mathcal{P}(\not{E}_{\text{T x,y}}) \times \mathcal{P}(E_{\text{vis. }\tau\,1}) \times \mathcal{P}(E_{\text{vis. }\tau\,2})) \times \mathcal{P}(m_{\text{miss 1}}) \times \mathcal{P}(m_{\text{miss 2}})$ is set as a final estimator of m_H.

Mass estimator performance

- The MMC output depends on MET resolution → need a good MET proxy
- Various options to estimate missing transverse energy resolution were tried: via parametrization on $\sum E_T$, $\Delta\phi_{ll}$, μ and through object-based MET significance [ATLAS-CONF-2018-038]
- The number of iterations during the phase space scanning was optimized
- Reasonable separation between the signal and background is observed: 80% $Z \to \tau\tau$ rejection at 80% $gg \to H \to \tau\tau$ acceptance
- The MMC resolution is about 15-20 GeV.



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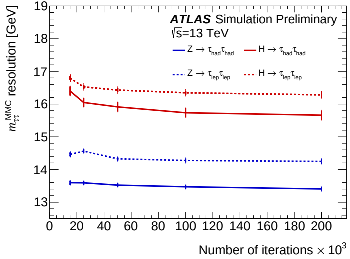

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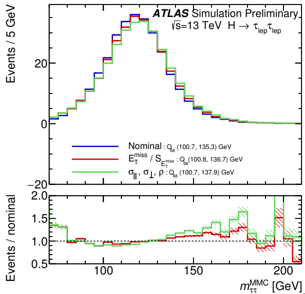

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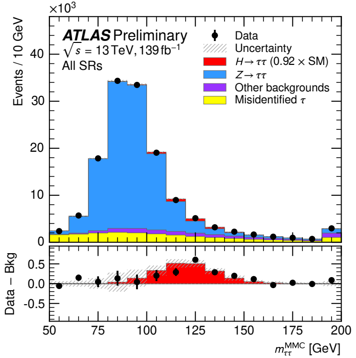
Statistical analysis. STXS results

- The reconstructed $M_{\tau\tau}$ is a discriminant in the final fit, 32 SRs, 6 top CRs, 30 $Z\tau\tau$ CRs
- Systematic uncertainties with the largest impact on $\Delta\sigma/\sigma(pp \to H \to \tau\tau)$ are signal theory (8.7%), jet & E_T^{miss} (4.5%), and MC statistical (4.0%) uncertainty
- Simultaneous fit with 9 cross-sections in kin. volumes within the STXS framework:
  - precision of 24% for VBF $pp \to H\tau\tau$ in the m_{jj} >350 GeV bin
  - precision within 40% for $gg \to H \to \tau\tau$ in the $p_T(H)$ >200 GeV range



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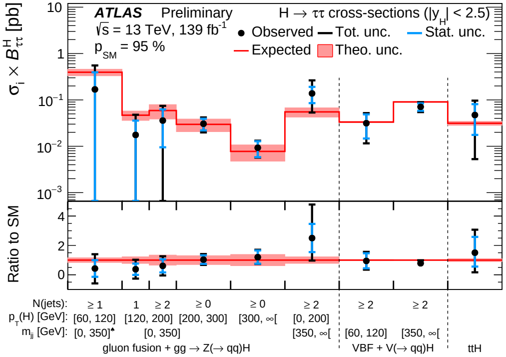

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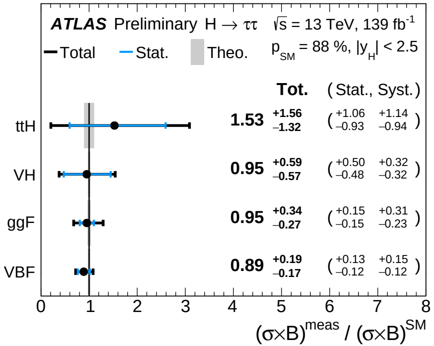
Summary on SM $pp \to H \to \tau\tau$ measurements

- The production cross-section of the $pp \to H \to \tau\tau$ process is measured to be 2.94 ± 0.21 (stat)$^{+0.37}_{-0.32}$(syst) pb
- For the first time, VBF $H \to \tau\tau$ production is observed with significance of 5.3 and strong constraints
- The observed significance for $gg \to H \to \tau\tau$ is 3.9 sigma
- All inclusive and exclusive measurements are consistent with the Standard Model prediction



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