Experimental results using the decay of the Higgs to taus and muons

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The Sixth Annual Large Hadron Collider Physics conference LHCP 2018, Bologna, 05/06/2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

ATLAS EXPERIMENT

CMS Compact Muon Solenoid

DESY.

Introduction

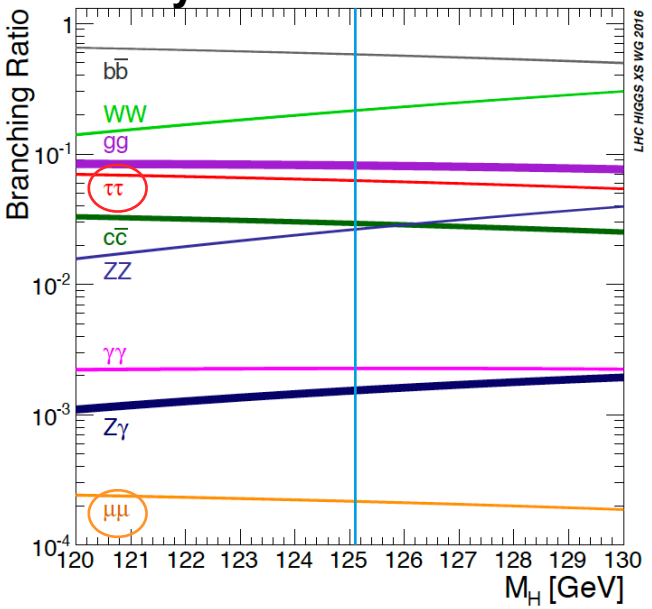
precise measurements of Higgs Yukawa couplings important test of SM

- deviation from SM would be sign for new physics

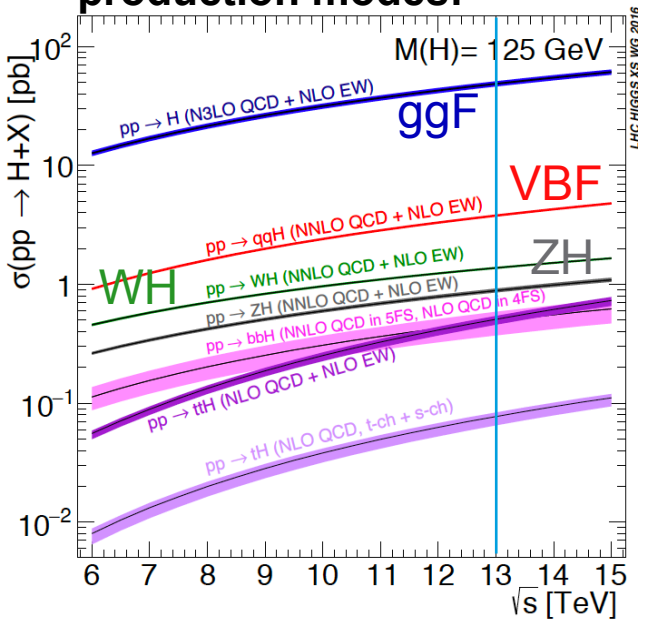
- observation of couplings to top quarks in ttH production
  (talk by Jelena Jovicevic, ATLAS & Karim El Morabit, CMS on Monday)
- evidence for couplings to bottom quarks
  (talk by Andrew Stuart Bell on Tuesday)

- status of **leptonic channels** covered in this talk:
  - **search for H → μμ**
  - **H → ττ** (ggF, VBF, WH & ZH production)

decay channels:



production modes:



Search for H → μμ

ATLAS : 36.1 fb^{-1} (2015 + 2016 data), CMS: 35.9 fb^{-1} (2016 data)

ATLAS: Phys. Rev. Lett. 119 (2017) 051802,
CMS: PAS HIG-17-019

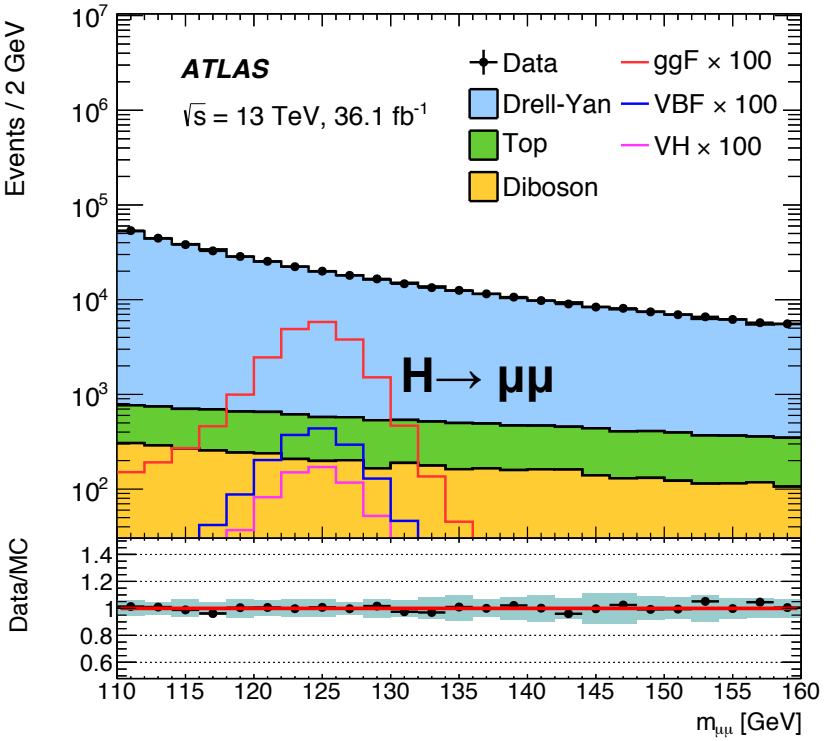
very rare process, but high di-muon mass resolution makes channel accessible

selection strategy:

- 2 oppositely charged muons
- 110 GeV < $m_{\mu\mu}$ < 150 GeV (CMS)
  110 GeV < $m_{\mu\mu}$ < 160 GeV (ATLAS)
- VBF categories: ≥ 2 jets

main backgrounds:

- Z/γ* → μμ
- (tt & di-boson production)



Search for H → μμ

Event categorization

ATLAS:

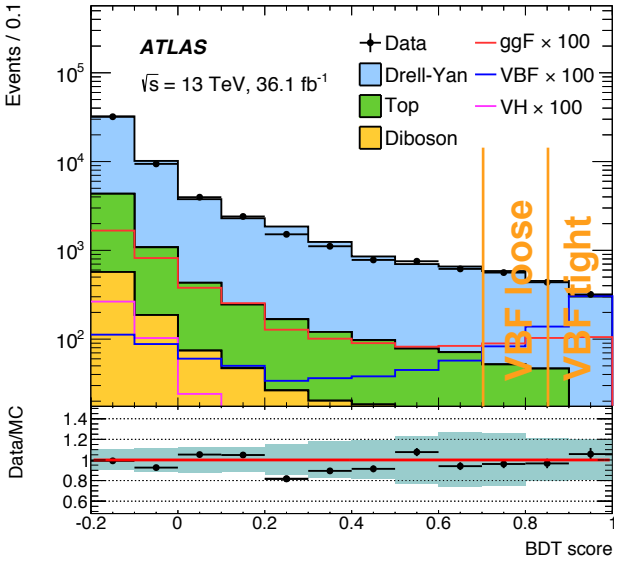
- **2 VBF categories** defined by **BDT output**
- **6 ggF categories** defined by **$p_T^{\mu\mu}$ and $|\eta^{\mu}|$**

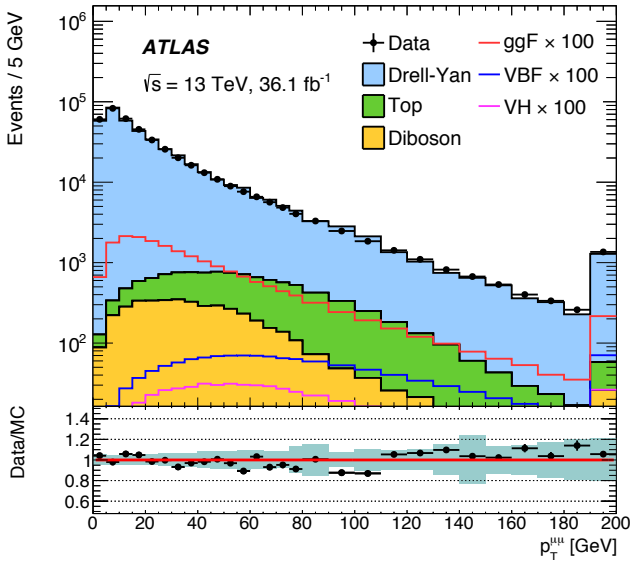
exploit harder $p_T^{\mu\mu}$ spectrum in signal & better muon p_T resolution in central detector parts

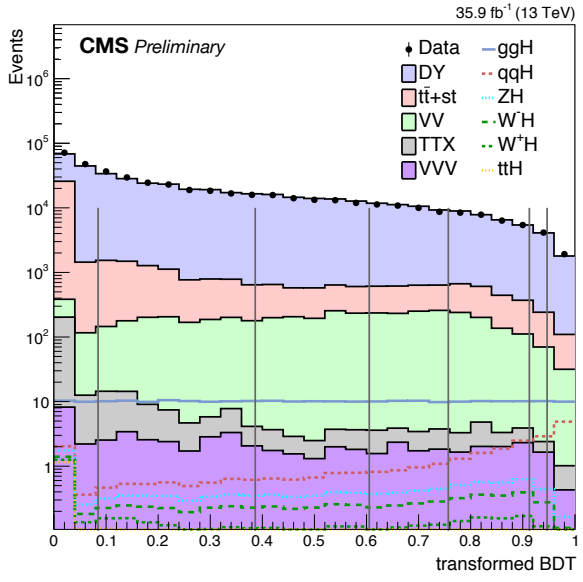
CMS:

- **15 categories** based on optimized cuts on **BDT output and $|\eta^{\mu}|$**

BDT variables: m_{jj}, $p_T^{\mu\mu}$, $\Delta\eta_{jj}$ …

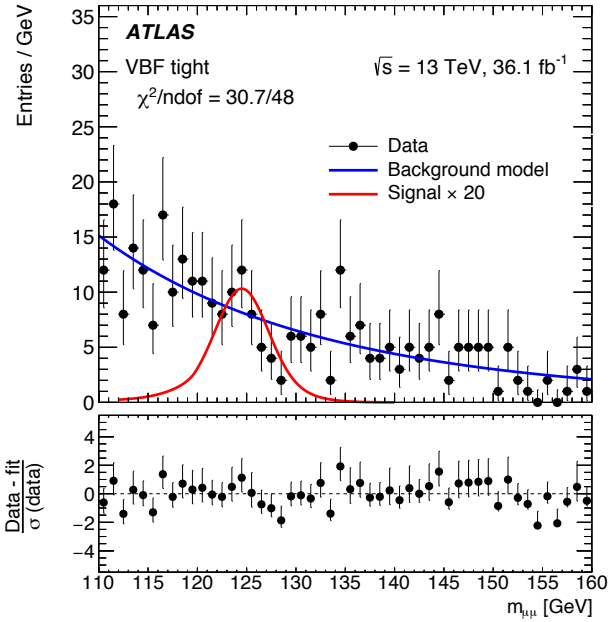


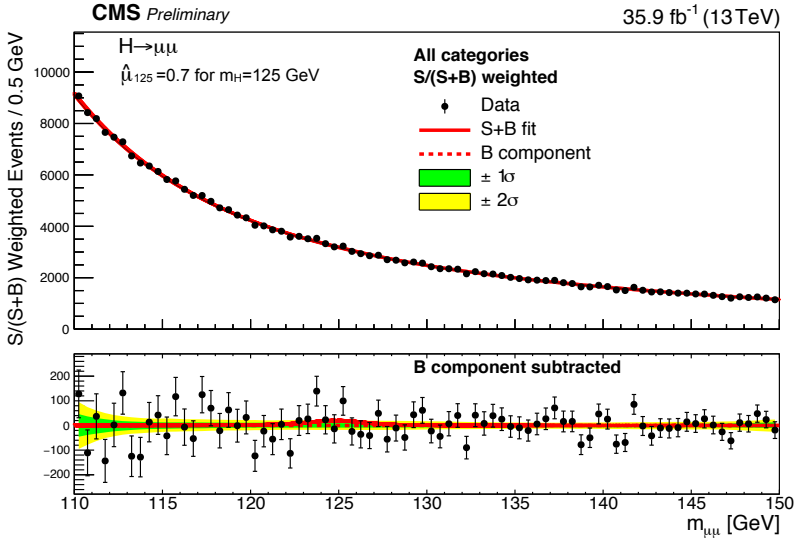




Search for H → μμ

Results & interpretation





analytic functions used to describe signal and background distributions

no significant excess observed

combined Run I + II results:	**CMS**	**ATLAS**	(at m_H = 125 GeV)
• upper limit on $(\sigma^*BR)/(\sigma^*BR)_{SM}$ of	**2.64 (1.89)**	/ **2.8 (2.9)**	obs. (exp) at 95% C.L.
• best fit signal strength **μ** of	**$0.9^{+1.0}_{-0.9}$**	/ **-0.1 ± 1.4**	

Observation of H → ττ

ATLAS-CONF-2018-12
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ATLAS EXPERIMENT

ATLAS : 36.1 fb^{-1} (2015 + 2016 data)

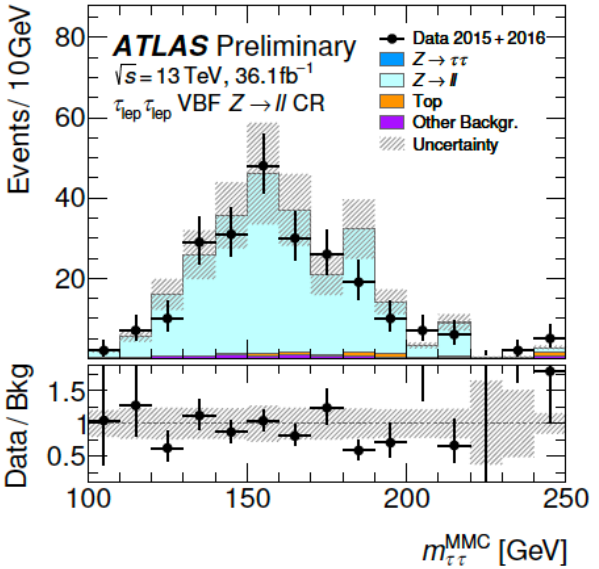
selection strategy:

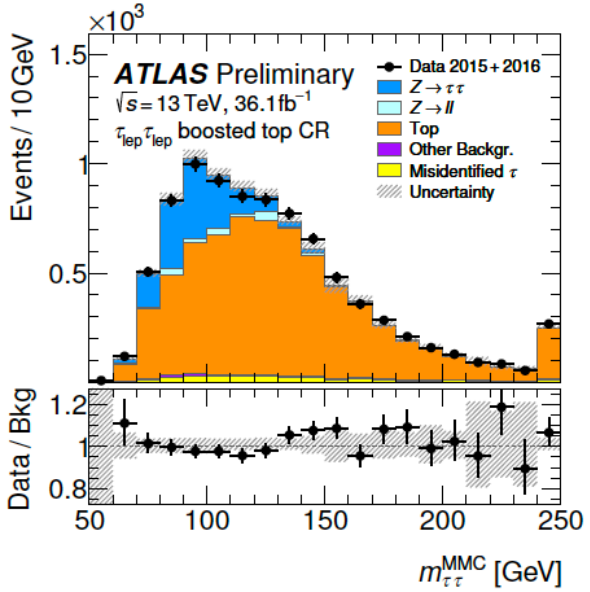
- channels: **eμ / ee / μμ / eτ$_h$ / μτ$_h$ / τ$_h$τ$_h$**
- ≥ 1 jet
- **VBF categories:**
  - second high-p$_T$ jet in opposite detector hemisphere than p$_T$-leading jet, large invariant mass of di-jet system (m$_{jj}$)
  - VBF dominated, up to 30% contribution from ggF

- **boosted categories**
  - high-p$_T$ jet recoiling against Higgs
  - ➡ large p$_T^{ττ}$
  - ggF dominated, between 10-20% from VBF & VH

Higgs candidate reconstructed from visible tau decay products and E$_T^{miss}$ using likelihood approach

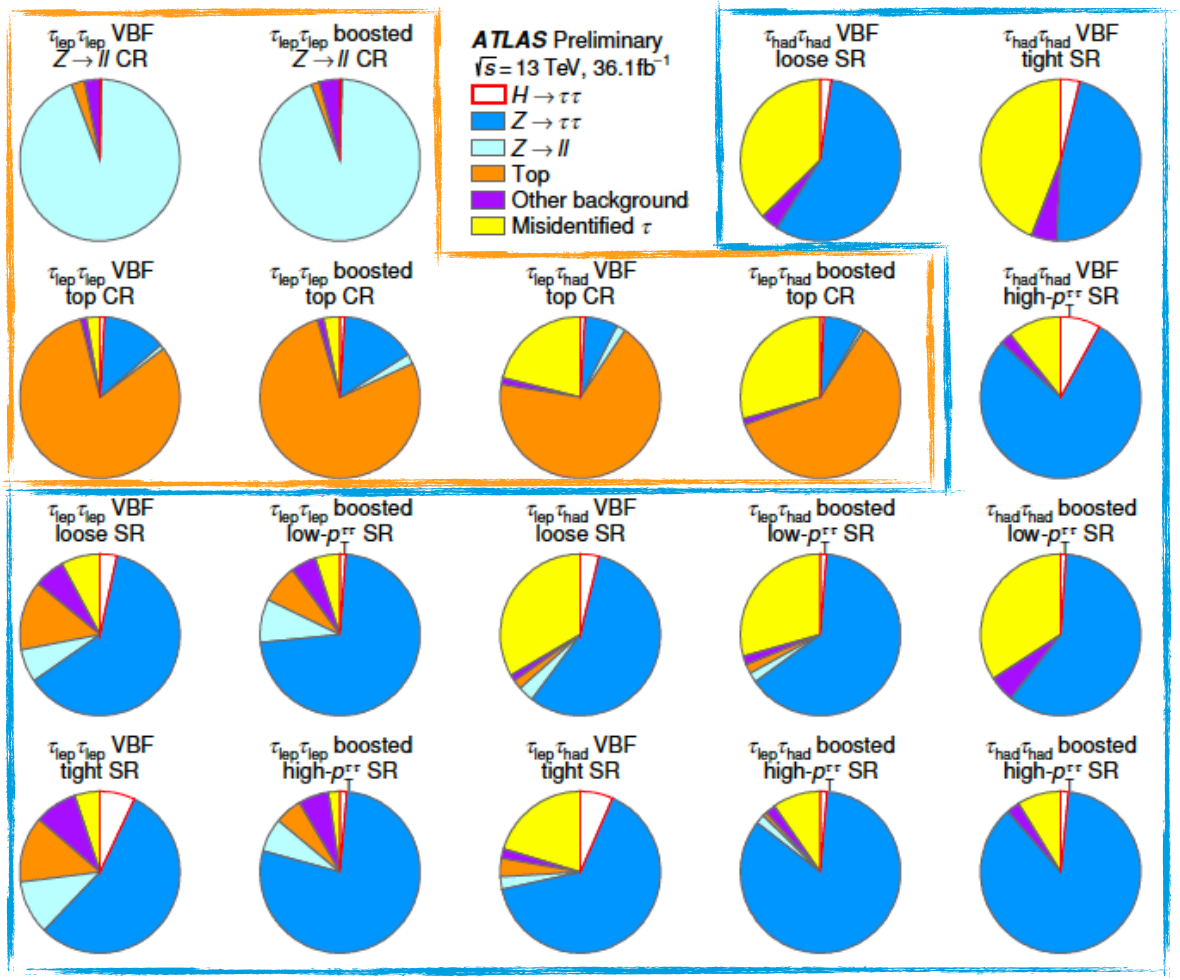
m$_{ττ}$ used for extraction of results with likelihood fit





Observation of H → ττ

Event categorization & background estimation



signal regions:
VBF and boosted categories split by $p_T^{\tau\tau}$, $\Delta R_{\tau\tau}$ & m_{jj} requirements

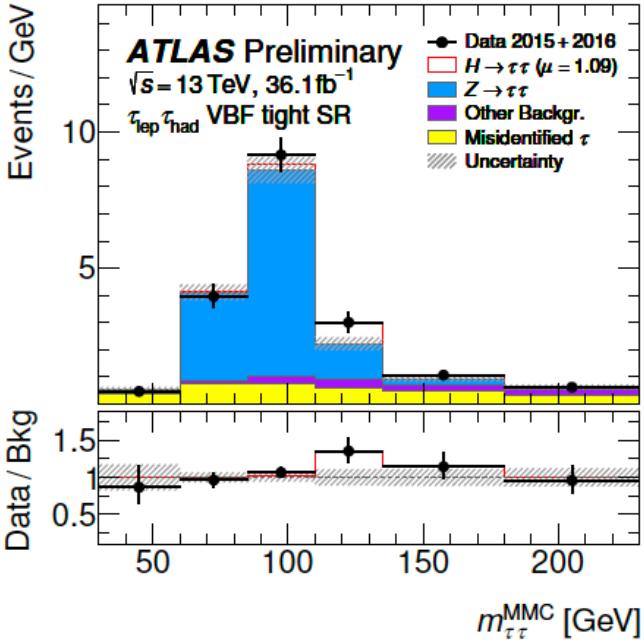
control regions: constrain normalization of Z → ll and top background processes

data driven estimation of background with jet misidentified as e, μ or τ_h

Z → ττ from simulation (Sherpa NLO), normalization constrained in SR

Observation of H → ττ

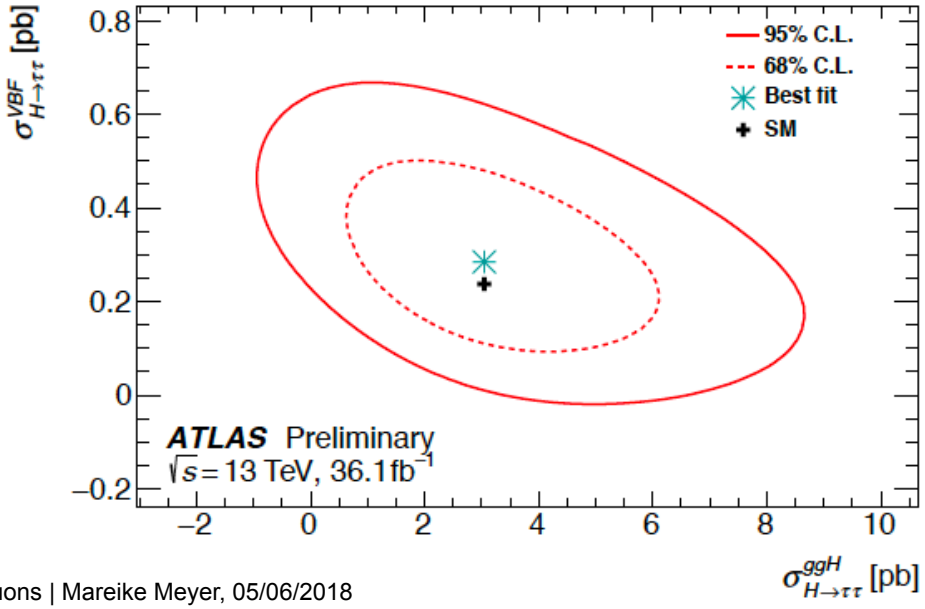
Results & interpretation



- obs. (exp.) significance of **4.4 σ** (4.1 σ) at m_H = 125 GeV
- signal strength :
  μ = 1.09 $^{+0.18}_{-0.17}$ (stat) $^{+0.27}_{-0.22}$ (syst) $^{+0.16}_{-0.11}$ (theory syst)
- $\sigma^{VBF}_{H\to\tau\tau}$ = 0.28 ± 0.09 (stat) $^{+0.11}_{-0.09}$ (syst) pb
- $\sigma^{ggF}_{H\to\tau\tau}$ = 3.0 ± 1.0 (stat) $^{+1.6}_{-1.2}$ (syst) pb
- in agreement with SM predictions

combination with Run I data:

- obs. (exp.) significance of **6.4 σ** (5.4 σ)



Observation of H → ττ

CMS: 35.9 fb^{-1} (2016 data)

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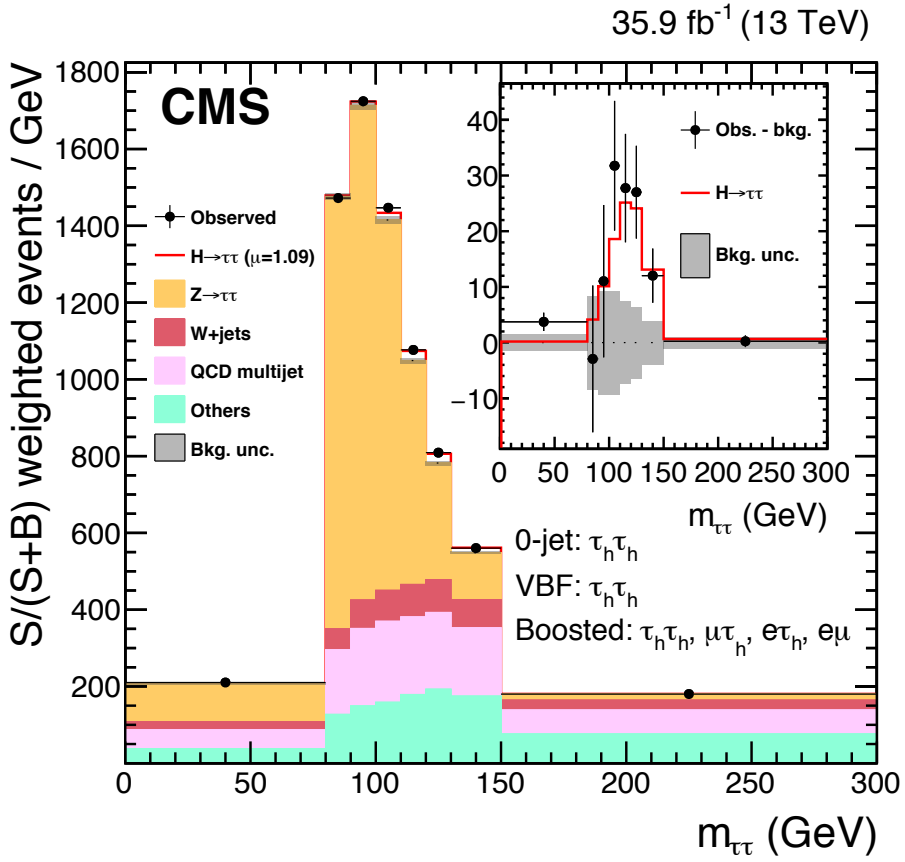

Results of combination with Run I data:

- best-fit signal strength : **μ = 0.98 ± 0.18** at m_H = 125.09 GeV
- obs. (exp.) significance of **5.9 σ** (5.9 σ)

$H \rightarrow \tau\tau$ in WH & ZH

CMS: 35.9 fb^{-1} (2016 data)

CMS PAS HIG-18-007
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search channels:

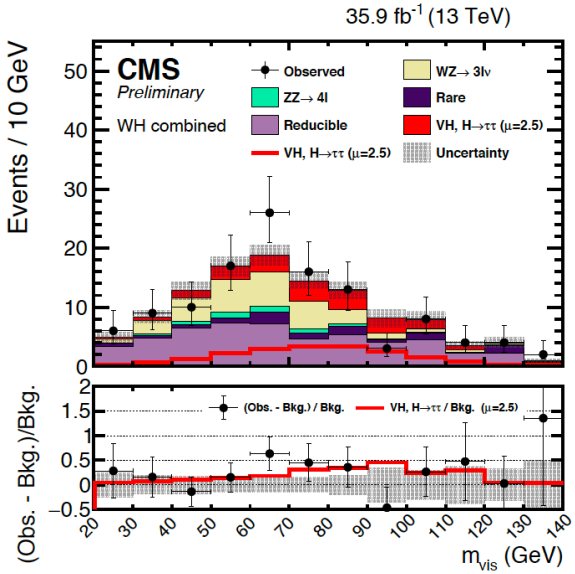
- W ($\rightarrow$ **ev / μν**) H ($\rightarrow \tau\tau \rightarrow$ **μτ_h / $\tau_h\tau_h$**)
- Z ($\rightarrow$ **ee / μμ**) H ($\rightarrow \tau\tau \rightarrow$ **eτ_h / μτ_h / eμ / $\tau_h\tau_h$**)

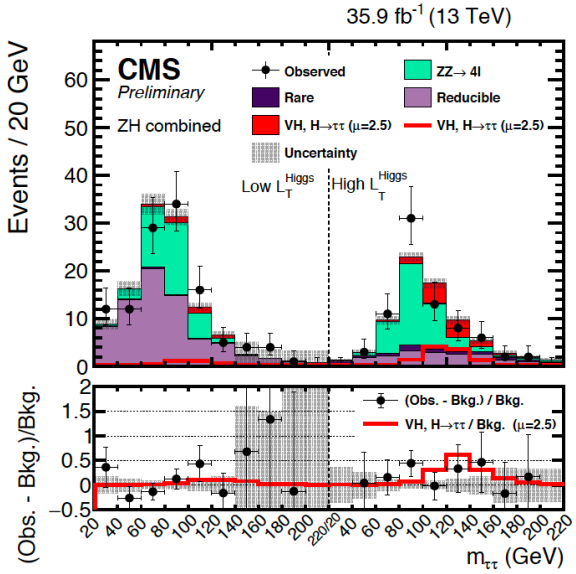
reconstruction of Higgs candidate

- m_{vis} in WH: sub-leading p_T light lepton, τ_h / $\tau_h\tau_h$
- $m_{\tau\tau}$ in ZH: leptons not assigned to Z boson candidate
- ➡ reconstructed masses used for extraction of results

background estimation:

- background with jet misidentified as e/μ/τ_h from data
- di- & tri-boson production, $t\bar{t}V$, H $\rightarrow$ VV & $t\bar{t}H$ from simulation





$H \rightarrow \tau\tau$

Combination of ggF, VBF & WH, ZH analyses

CMS PAS HIG-18-007
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WH / ZH alone:

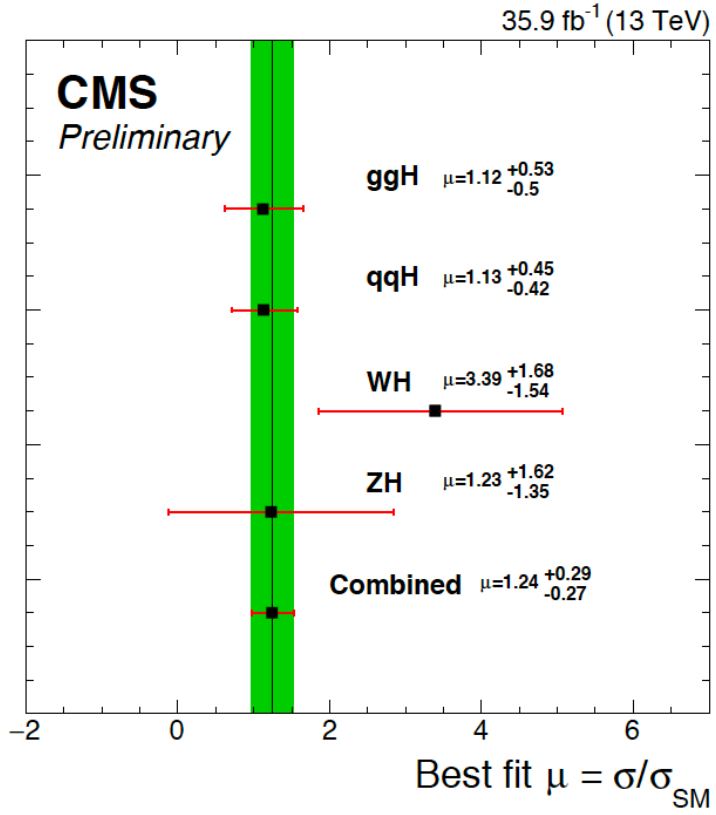
- best-fit signal strength : $\mu = 2.54^{+1.35}_{-1.26}$
- obs. (exp.) significance of **2.3 σ** (1.0 σ)

combination with ggF and VBF analysis (2016 data):

- re-weighting of p_T^H in ggF events to spectrum from NNLOPS generator, updated ggF cross section uncertainty

- best-fit signal strength : $\mu = 1.24^{+0.29}_{-0.27}$
- obs. (exp.) significance of **5.5 σ** (4.8 σ)

➡ **observation level reached with 2016 data alone**

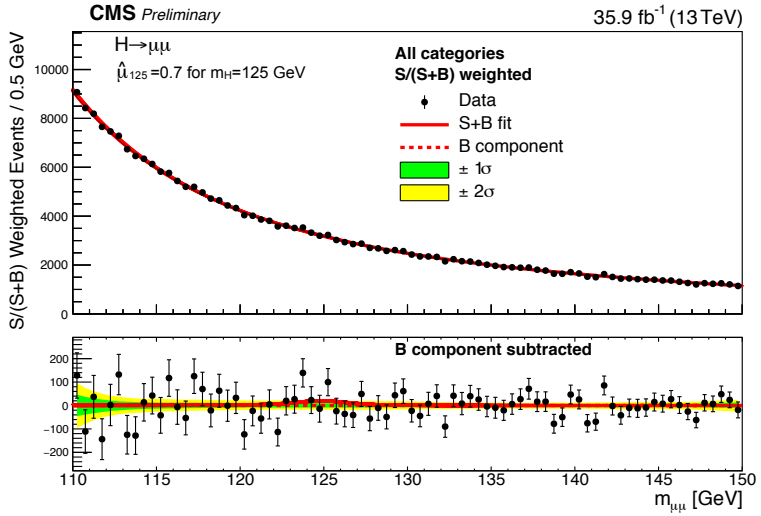


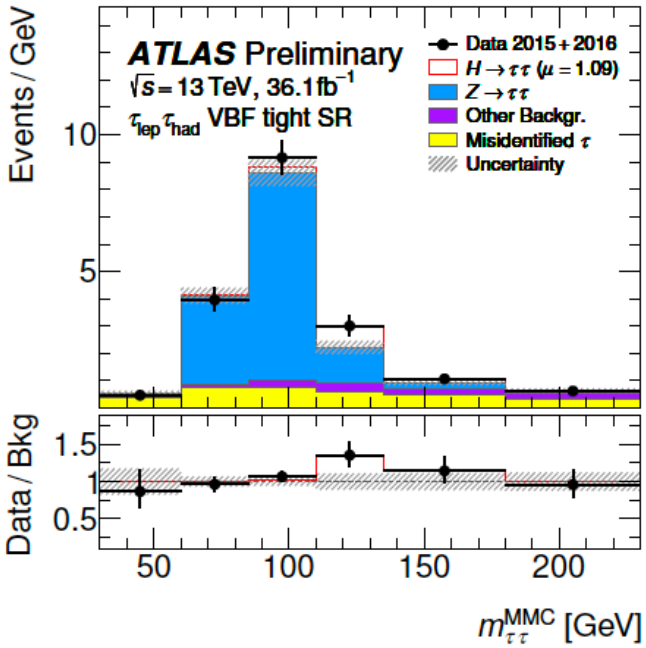
Summary

Precise measurements of Higgs Yukawa couplings are important tests of the SM.

Search for H → μμ:

- no significant excess observed
- **remarkable sensitivity achieved already in middle of Run II**





Measurement in H → ττ:

- updated H → ττ ATLAS results

➡ **observation of H → ττ confirmed by ATLAS**

- new CMS result in WH & ZH

➡ **observation level reached with Run II data alone by combining ggF, VBF and VH analyses**

Thank you for your attention!

Backup

Observation of H → ττ

CMS: 35.9 fb^{-1} (2016 data)

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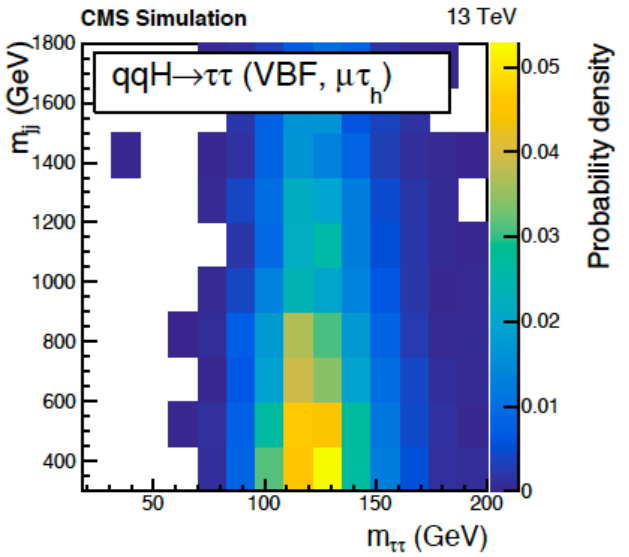
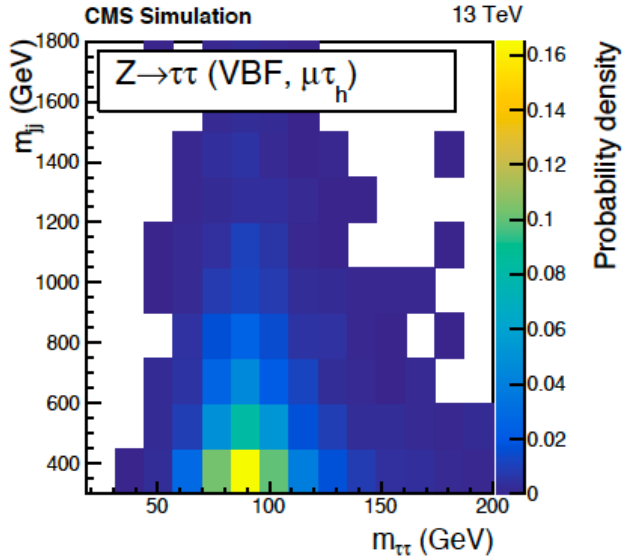
selection strategy:

- channels: **eμ / eτ$_h$ / μτ$_h$ / τ$_h$τ$_h$**
- **0-jet category** (target ggF processes):
  - large background contribution
    - ➡ constrain systematic uncertainties
- **VBF category:**
  - second high-p_T jet
  - large invariant mass of di-jet system (m_{jj})
- **boosted category :**
  - ≥ 1 jet, not in VBF
  - dominated by ggF production with high-p_T jet recoiling against Higgs
- 2D distributions used to extract results

$m_{\tau\tau}$: reconstructed from visible tau decay products and E_T^{miss}



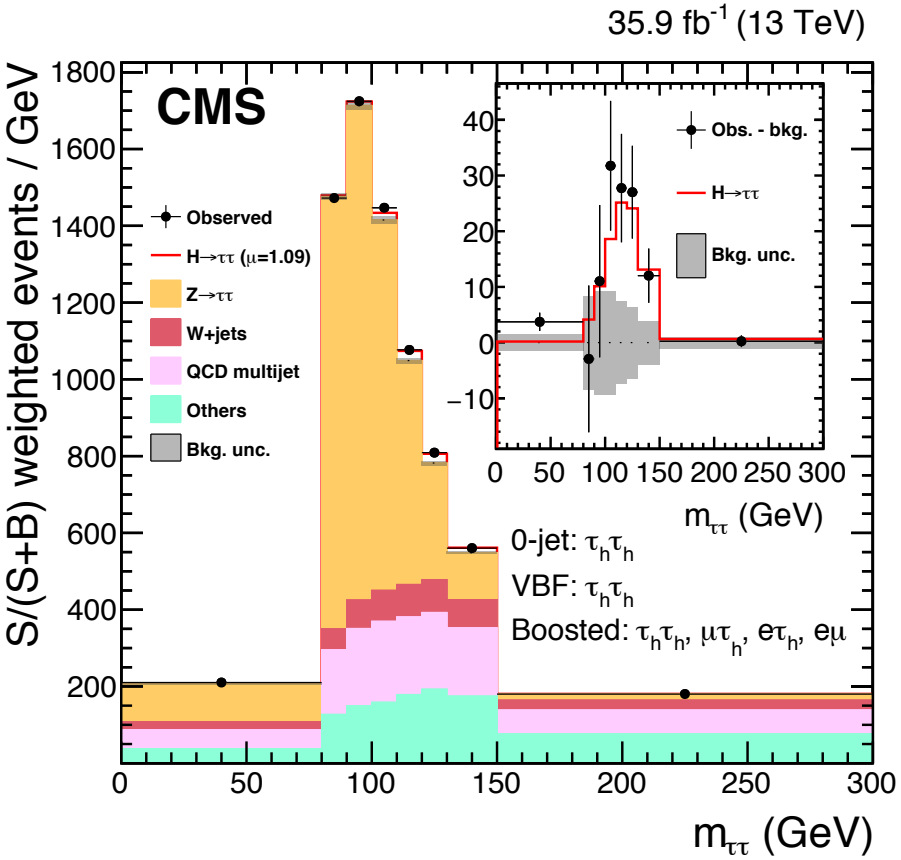


Observation of H → ττ

Background estimation & results

Z → ττ : simulation, corrections derived in Z → μμ control region

W + jets: simulation, normalization constrained in control region



QCD multijet: from data in control regions with same-sign leptons and anti-/ relaxed isolation

$t\bar{t}$: simulation, normalization constrained in control region

Results of combination with Run I data:

- best-fit signal strength : **μ = 0.98 ± 0.18** at m_H = 125.09 GeV
- obs. (exp.) significance of **5.9 σ** (5.9 σ)