Higgs decays to 3rd generation fermions

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On behalf of ATLAS & CMS collaboration
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Introduction

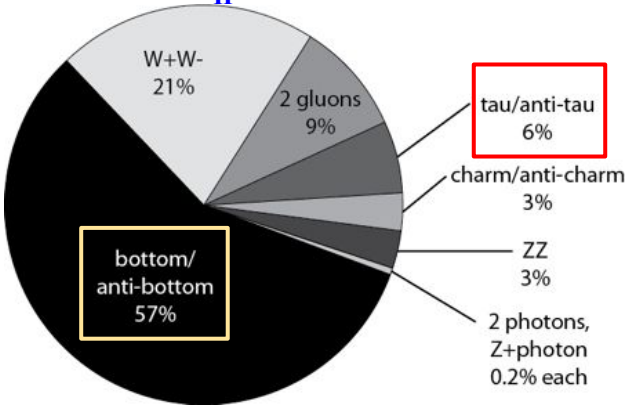
- Higgs boson properties (**mass, production rates, spins**)
  → predominantly constrained from the **bosonic couplings**
- H couplings with fermions: Hff ~ **Yukawa couplings in Standard model (SM):** $y_f \propto m_f$
  - H → **3rd generation fermions (τ or b-quarks)** offer a unique opportunity to probe y_f , due to **large branching fractions**.

- **Main experimental challenges**
  i) Degradation of the mass resolution due to neutrinos in leptonic τ decays and B Hadron decays
  ii) Quark or gluon jets are the sources of τ_h mis-identification.
  iii) Significant **QCD multijet backgrounds** for H→ bb/ $\tau_h\tau_h$

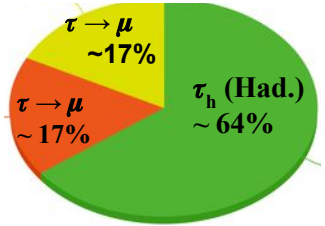
- Ample use of **machine-learning(ML)** based algorithms make these decay modes feasible by both **ATLAS** & **CMS** experiments.

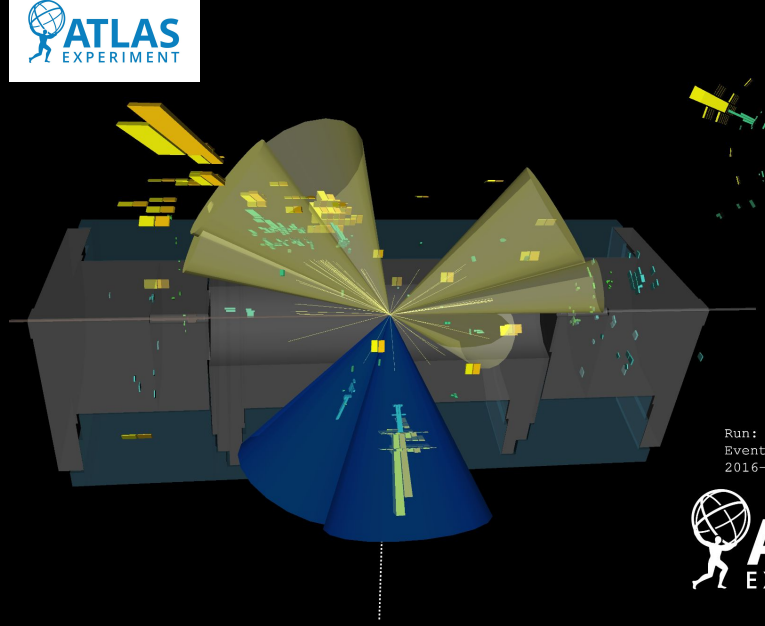
Talk by Matthew

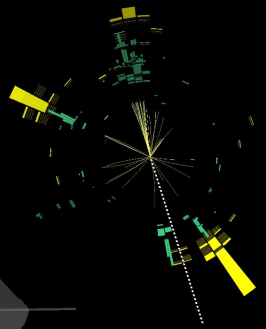
BR m_H ~ 125 GeV



τ lepton decay modes

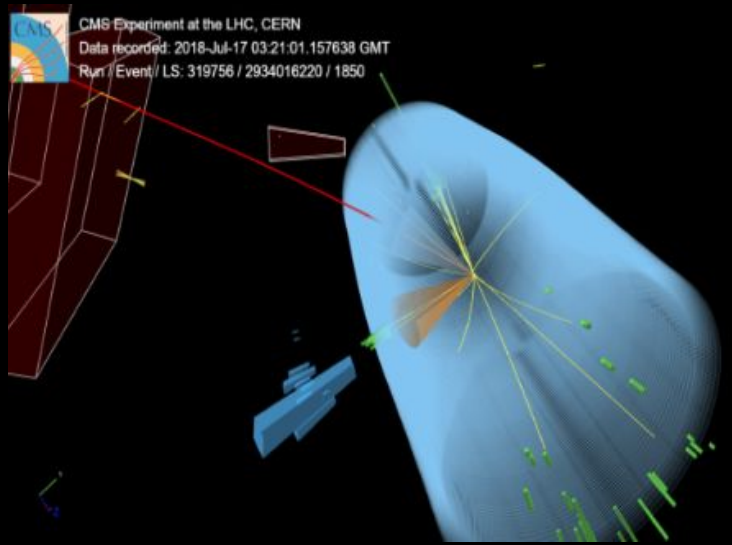






$H \rightarrow \tau\tau$

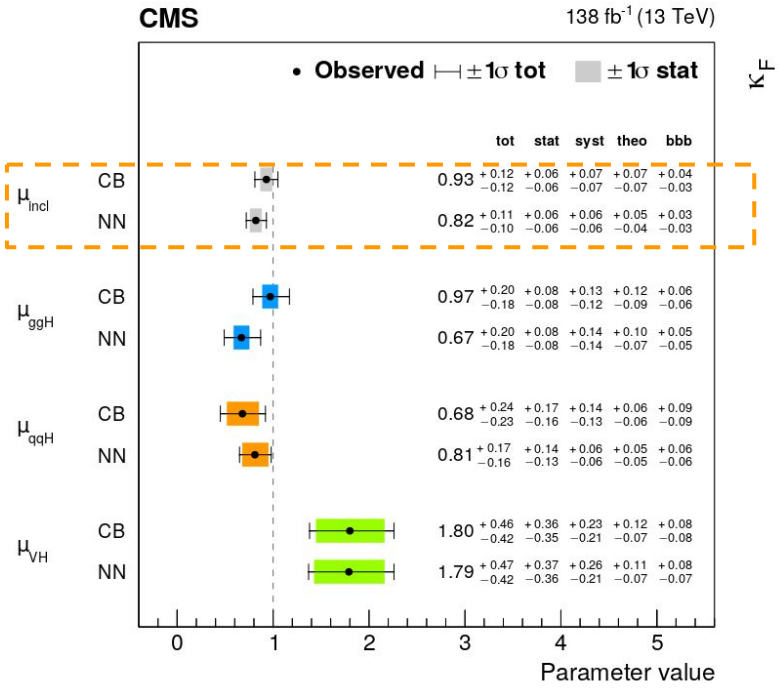
Run: 299584
Event: 901388344
2016-05-20 17:40:04 CEST

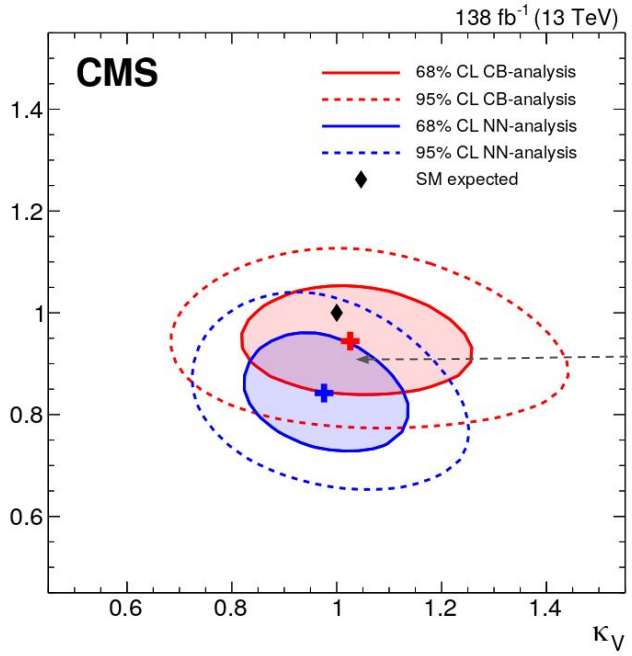


Measurements of Higgs boson decays to τ-lepton final states from CMS

→ H → $\tau\tau$ deacy allows direct coupling of Higgs to fundamental fermions
→ **Neural network based DEEPTAU** algorithm used to identify τ_h
→ All 4 dominant production modes included **ggF, VBF, VH & ttH**
→ Results interpreted in the common **Simplified Template Cross Section (STXS) version 1.2**

arXiv: 2204.12957
Submitted to EPJC



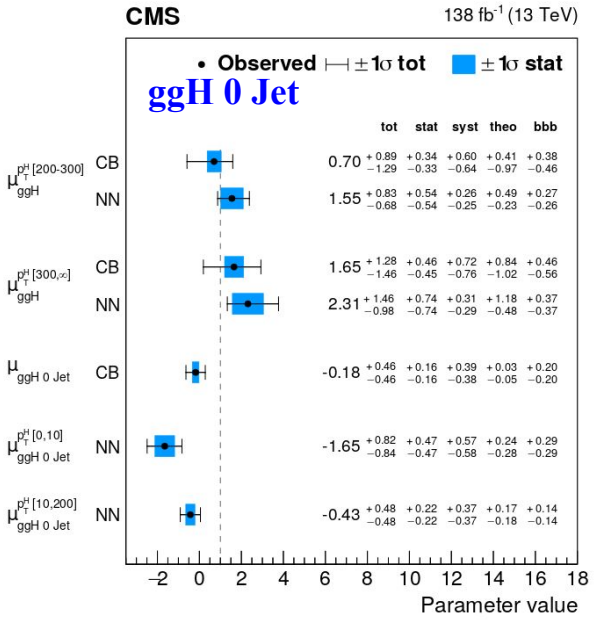


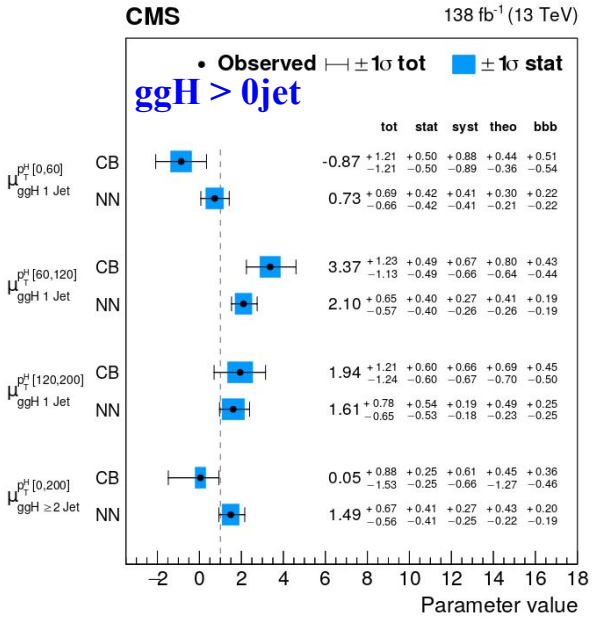
→ H→ WW decay modes also used as signal, increased sensitivity in eμ final state.
⟹ **CB analysis** is less precise but close to the SM value

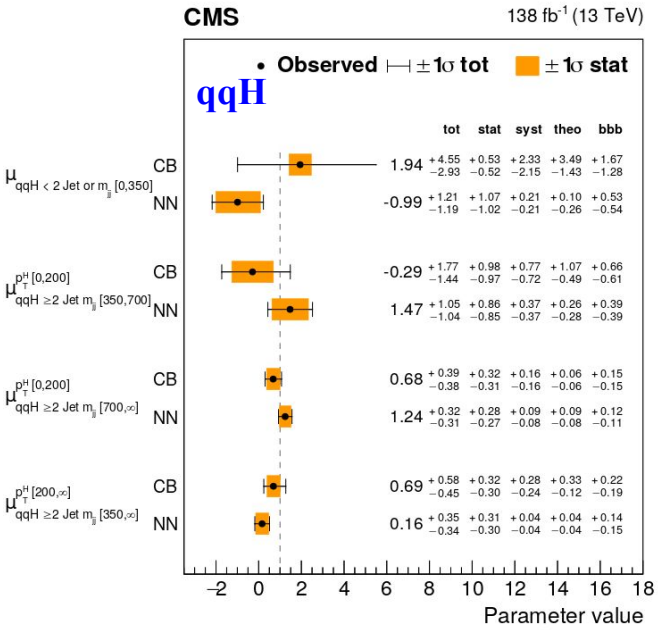
Measurements of Higgs boson decays to τ-lepton final states from CMS

Interpretation of results in STXS - framework

arXiv: 2204.12957
Submitted to EPJC







→ **Neural network (NN)** based analysis is more sensitive than the **cut based (CB)** one

→ NN targets → **best possible separation of individual STXS** bins and **backgrounds** at a same time

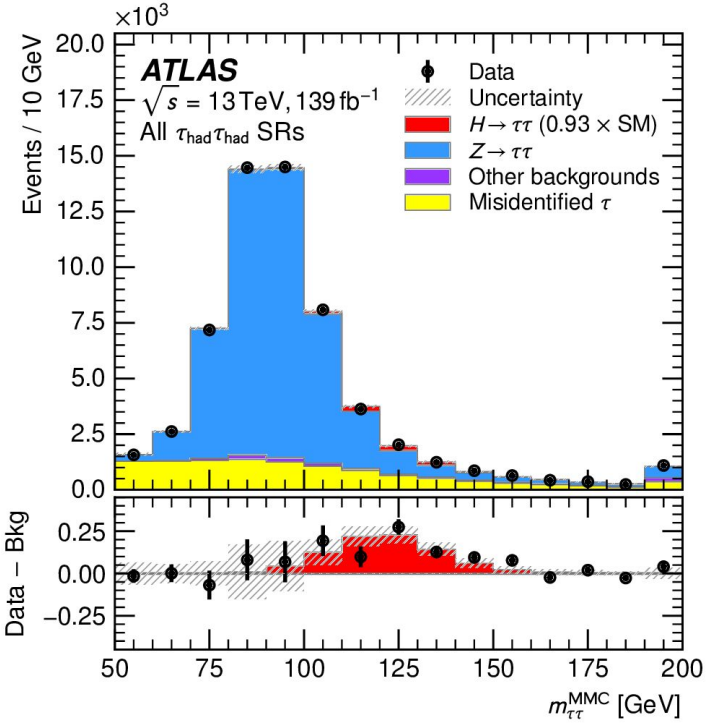
→ Constraining power depends on the individual separations among the categories

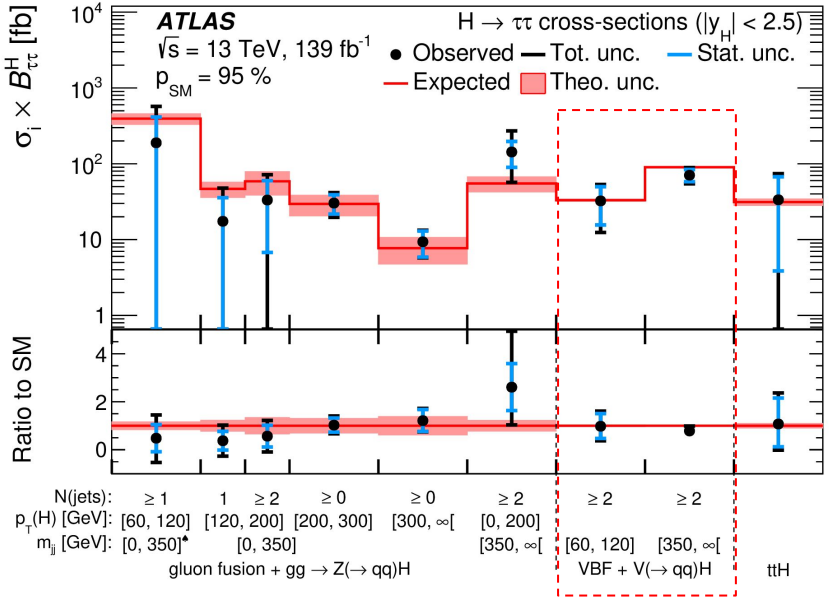
Measurements of Higgs boson decays to τ-lepton final states from ATLAS

→ All major production modes included : ggF, VBF, VH and ttH
→ Hadronic tau decay (τ_h) identified by a **Recurrent Neural Network (RNN)** based algorithm

arXiv:2201.08269
Submitted to JHEP

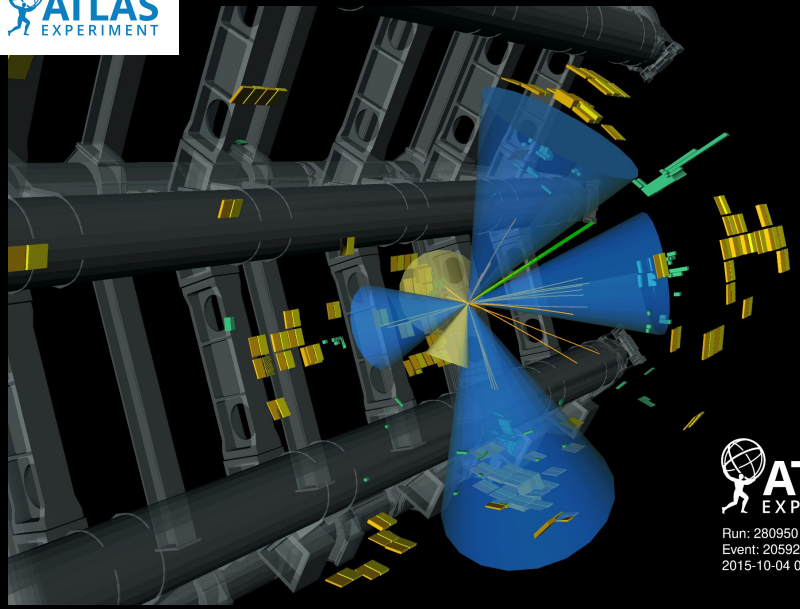
$p\,p \rightarrow H \rightarrow \tau\tau$ cross-section is measured to be $2.94 \pm 0.21(\text{stat})^{+0.37}_{-0.32}(\text{syst})$ pb

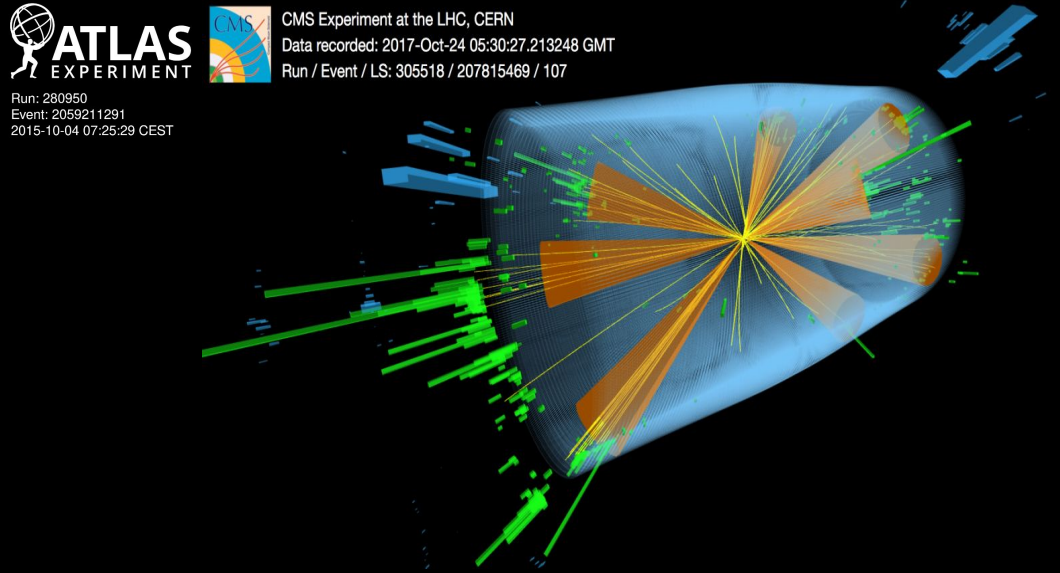




→Differential cross section, measured in **a reduced set of bins in STXS** stage-1.2 framework
→ Corresponding uncertainty **is about 20%** for the most precise bin

$H \rightarrow bb$



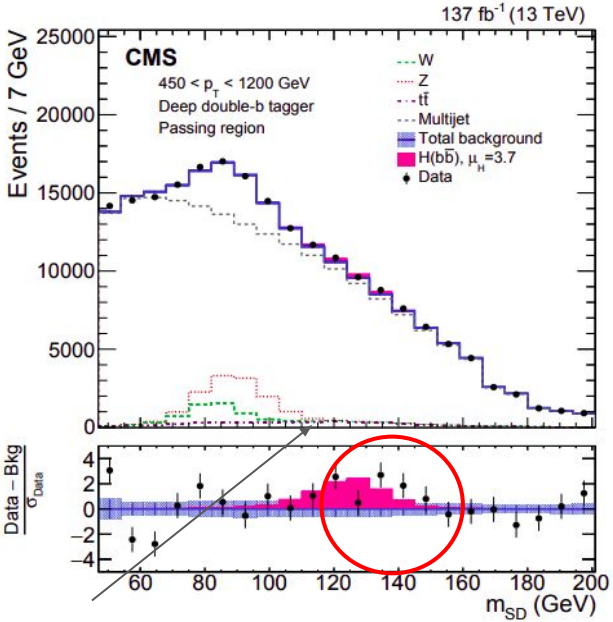


Inclusive boosted Higgs production and decay to bb from CMS

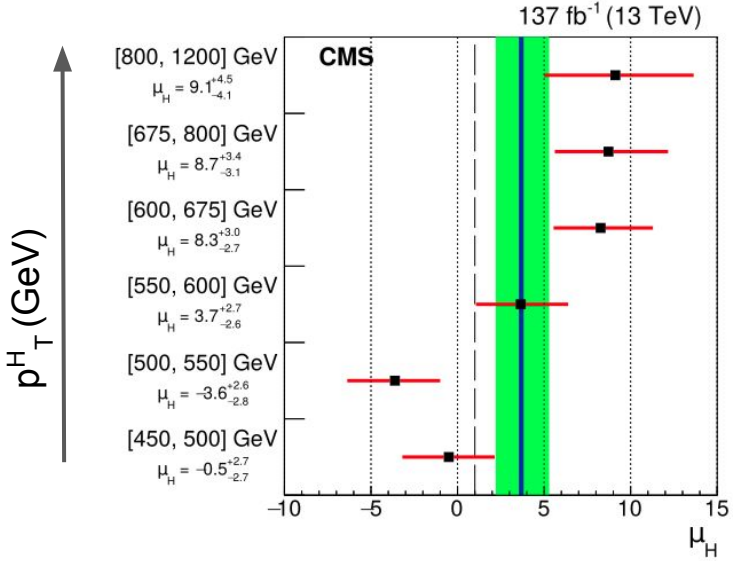
JHEP 12 (2020) 085

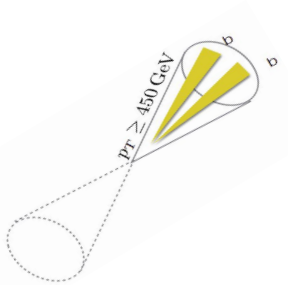
- Suitable to measure Hbb Yukawa coupling (y_b)
- High end p^H_T can resolve loop-induced contributions to the ggH process from new particles on.
- H is reconstructed using a **large radius AK8 (jet radius 0.8) jets.**

Jet soft drop mass (m_{SD}) used to extract signal



Significant reduction of tt background





Obs. (exp.) signal significance: **2.5 (0.7) σ**

Observed Signal strength:

$\mu = 3.7^{+1.2}_{-1.2}\,(\text{stat})\,^{+0.6}_{-0.7}\,(\text{syst})^{+0.8}_{-0.5}(\text{theo})$

Inclusive boosted Higgs production and decay to bb from ATLAS

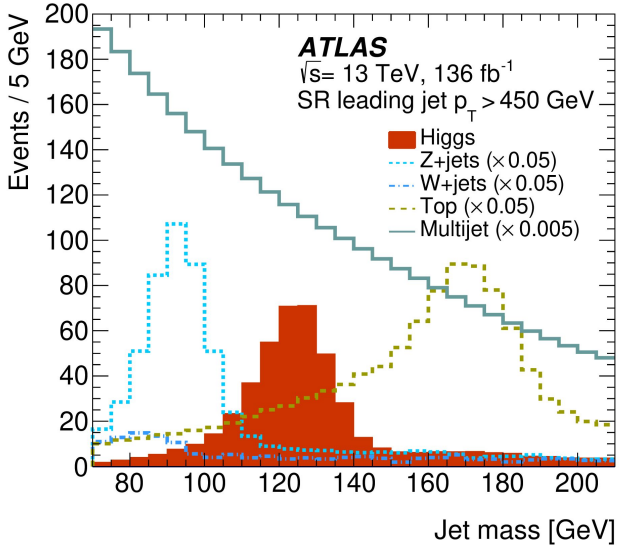
- H is reconstructed by a large radius jets.
- Events contained two fat jets
- At least one should have the two B- hadron decays, used for Higgs candidate reconstruction

Phys. Rev. D **105**, 092003

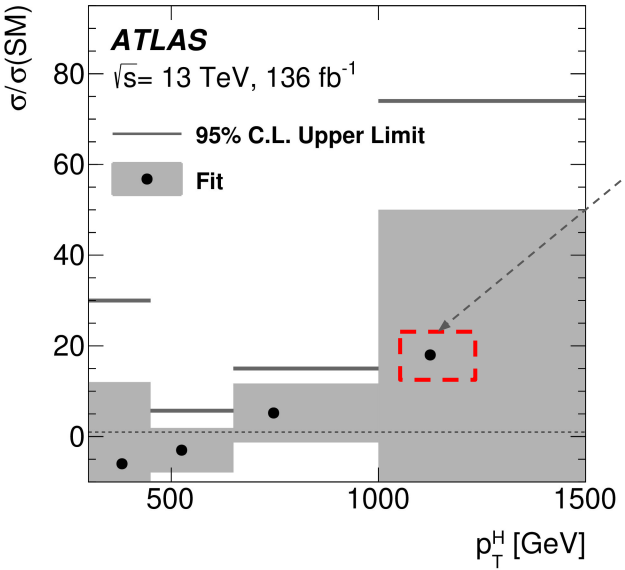
Signal strengths in the inclusive region. Rates for QCD, Z+Jets, tt processes float freely

Result	μ_H	μ_Z	$\mu_{t\bar{t}}$
Expected	1.0 ± 3.2	1.00 ± 0.17	1.00 ± 0.07
Observed	0.8 ± 3.2	1.29 ± 0.22	0.80 ± 0.06

Jet mass used to extract signal



STXS Signal strengths in differential signal region



First cross section measurement of $p_T^H >$ 1000 GeV from ATLAS

$\sigma(p_T^H > 1\ \text{TeV}) =$
$= 2.3 \pm 3.9\ (\text{stat.}) \pm 1.3\ (\text{syst.}) \pm 0.5\ (\text{theo})$ fb

Higgs boson decay into *b*-quarks in VH production (VH → bb) from ATLAS (Resolved analysis)

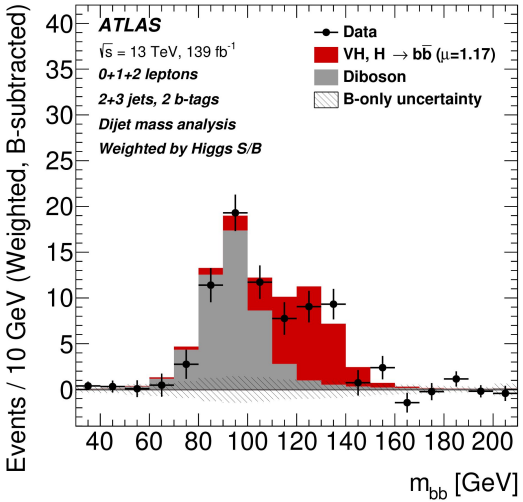
Eur. Phys. J. C 81 (2021) 178

Analysis Overview

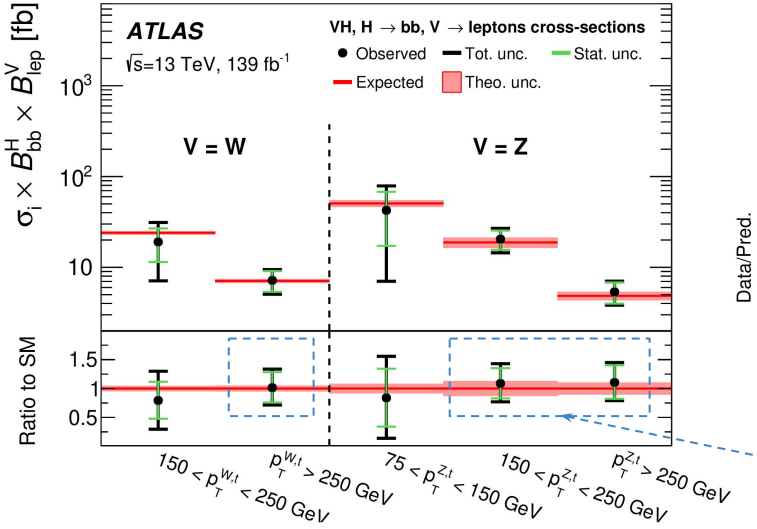
→ Tagged by leptonic decay of vector boson (W or Z)

→ Energy/momentum correction applied on the b-jet to improve mbb resolution

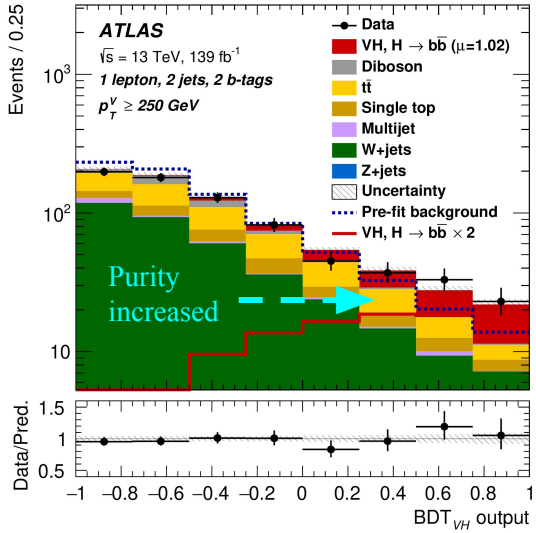
Corrections applied on b-jet scale & resolution, and m_{bb} spectrum



Cross section measured w.rt p_T^V



MVA Output scores used to extract signal



→ Measured **cross-section consistent with the Standard Model** expectations

→ Relative uncertainty is **~30% in high p^V_T bins**

→ Observed (expected) signal significance WH : **4.0 (4.1) std. dev.**

→ Observed (expected) signal significance ZH : **5.3 (5.1) std. dev.**

Observed signal strength *μ* : $1.02^{+0.18}_{-0.17}$

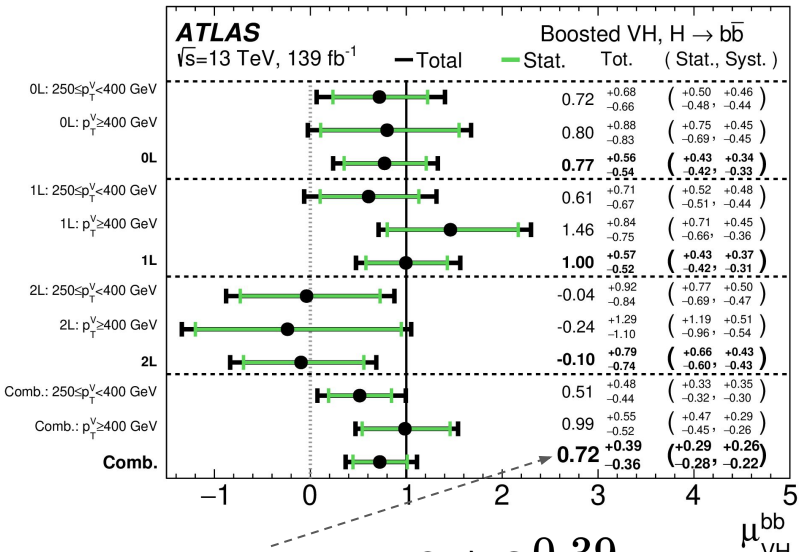
Higgs boson decay into *b*-quarks in VH production (VH → bb) from ATLAS (Boosted analysis)

Phys. Lett. B 816 (2021) 136204

Analysis Overview
→ Tagged by leptonic decay of vector boson (W or Z)
→ Targets the high p_T Higgs regime (> 250 GeV)

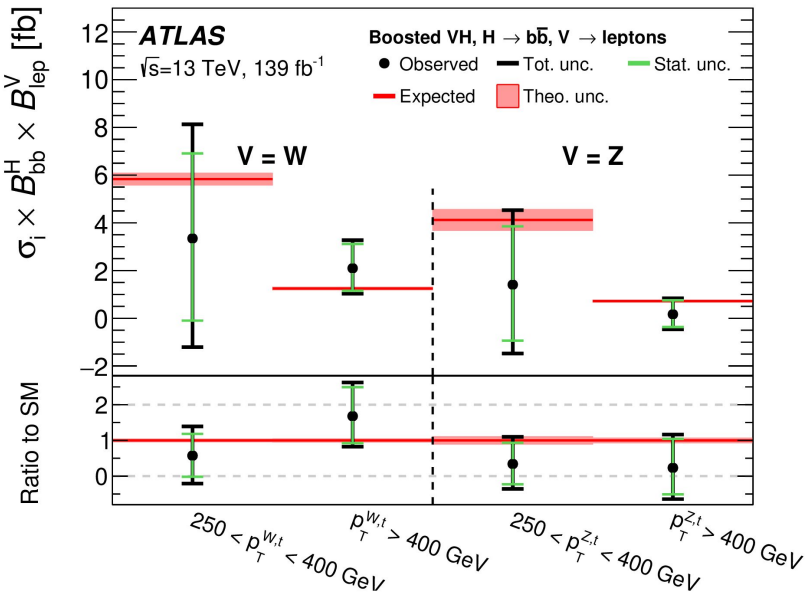
→ Observed (expected) signal significance : **2.1 (2.7) std. Dev.**

In Different analysis categories



Observed signal strength μ : $0.72^{0.39}_{-0.36}$

Cross section measured w.rt p_T^V



VH→ bb results from CMS using 2016+2017 data PRL. 121, 121801

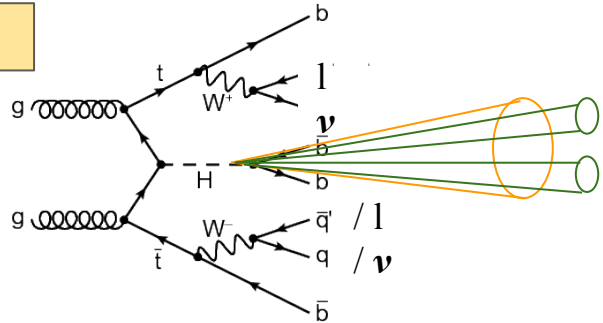
Higgs boson decay into *b*-quarks in associated production with a top-quark pair ($t\bar{t}H \rightarrow b\bar{b}$) from ATLAS

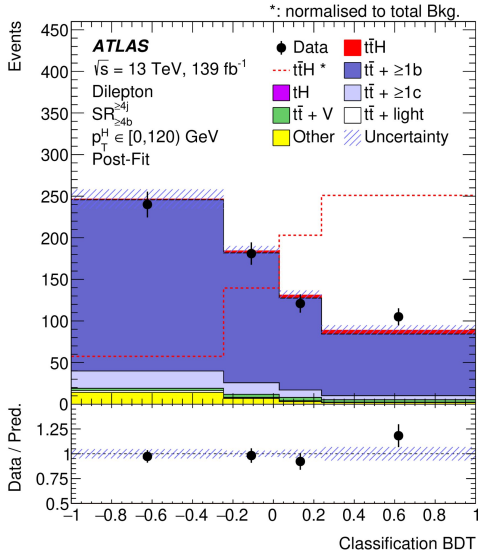
arXiv:2111.06712
Submitted to JHEP

Analysis Overview

→ Targets **semileptonic** and **di-leptonic** decay of **tt pair**

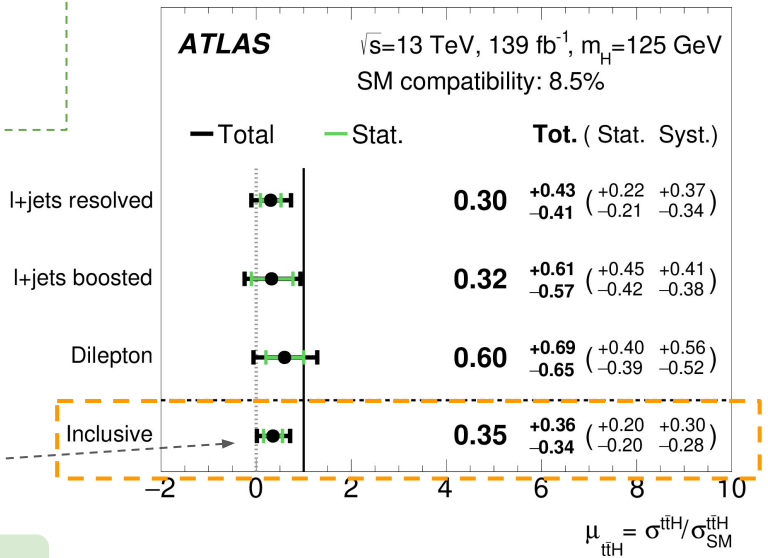
→ Results extracted for both **boosted** & **non-boosted** of Higgs p_T





Analysis is dominated by systematics, Major source : **modelling of tt + ≥ 1b bkgs**

In Different analysis categories



Observed μ lower than SM predicted value

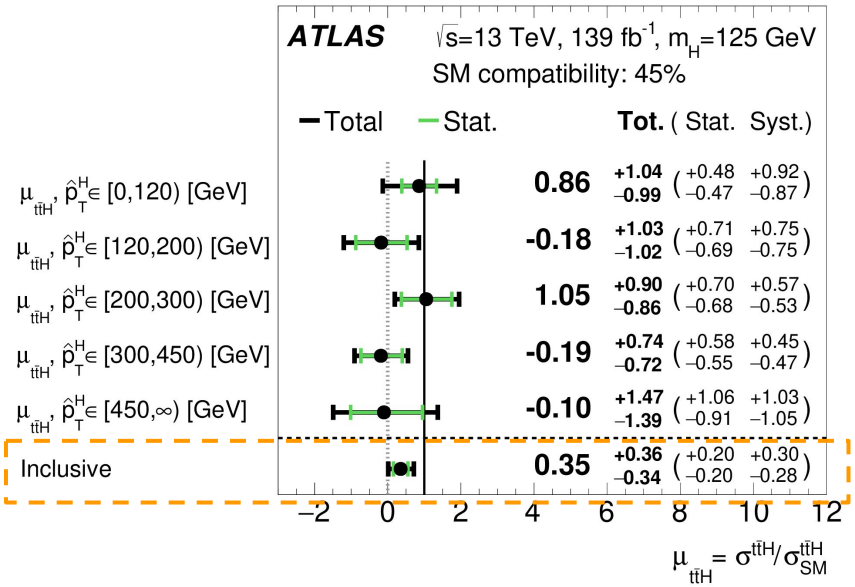
Observed (expected) signal significance : **1.0 (2.7) std. dev.**

ttH→ bb results from CMS using 2016+2017 data CMS-PAS-HIG-18-030

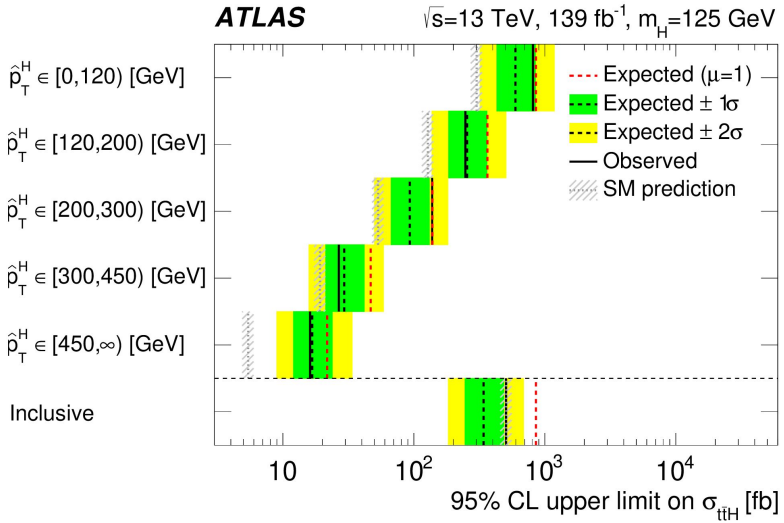
Higgs boson decay into *b*-quarks in associated production with a top-quark pair ($t\bar{t}H \rightarrow b\bar{b}$) from ATLAS

arXiv:2111.06712
Submitted to JHEP

In STXS p^H_T categories



Upper limit on cross section @95% CL In the STXS p^H_T categories



ttH→ bb results from CMS using 2016+2017 data CMS-PAS-HIG-18-030

Summary

→ From **Run-I** to **Run-II** we benefited in terms of **CoM energy** and **total data volume** and moved from **evidence to precision measurements in the Higgs sector**.

→ Higgs decays to **3rd generation fermions** have been studied by **ATLAS & CMS** collaborations.

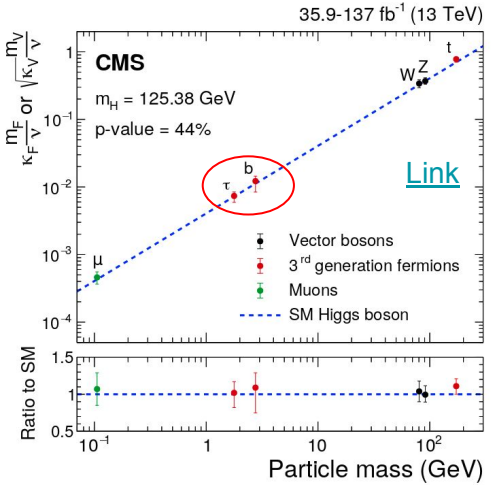
→ These are important inputs to the **global measurements of Higgs properties**.

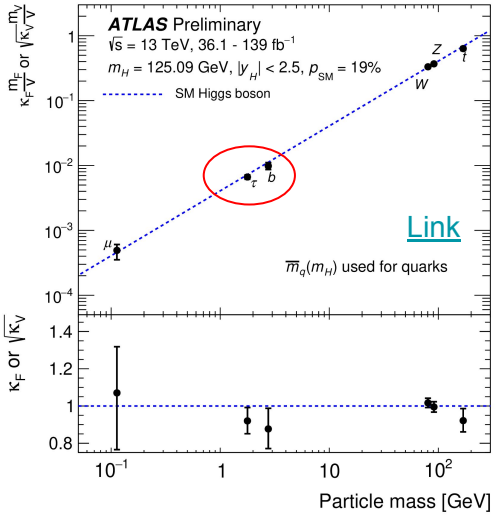
→ **Differential measurements** provide more sensitivities towards individual production modes.
All the analyses target STXS (v-1.2) common framework.

→ Till now, **good agreement of measurements with SM predictions**.

→ Run-II data analysis is not yet over, more results to come soon.

→ More precise physics interpretation will come in the upcoming Run-3 → Stay tuned!





Backup

Higgs boson decay into *b*-quarks in associated production with a top-quark pair (ttH → bb) using 2016 + 2017 Data from CMS

CMS-PAS-HIG-18-030

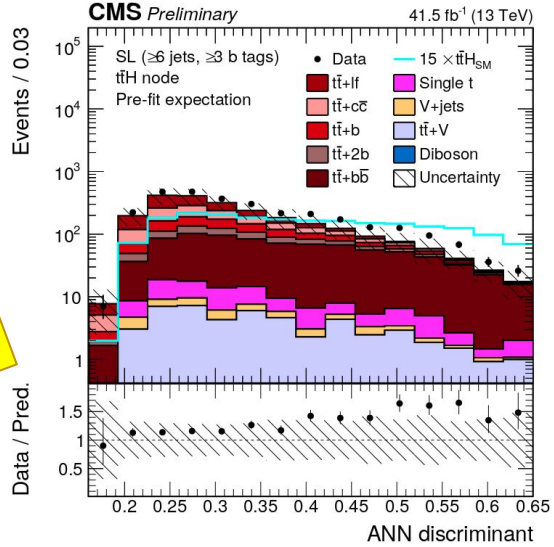
Analysis Overview

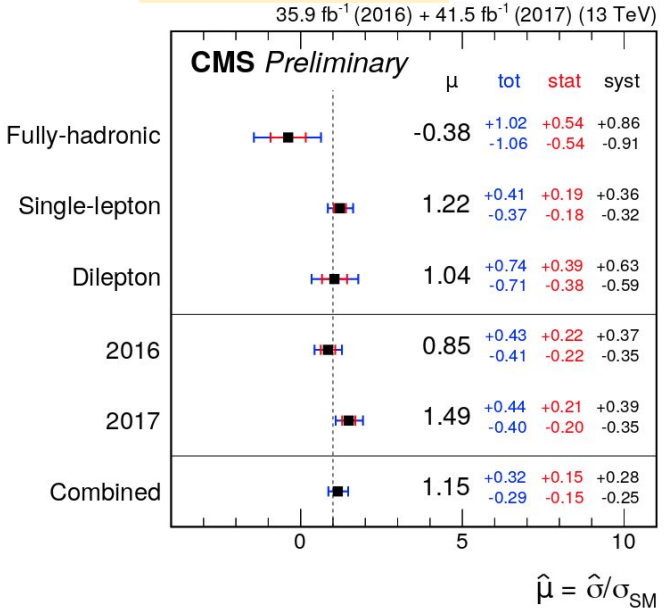
→ Targets all possible decay modes of top pairs: **hadronic, semileptonic and leptonic**

→ In the leptonic channel, the **invariant mass** of the two leptons outside of **76 < m_{ll} < 106 GeV** → suppress the **Z+jets background**

→ Events are first categorized by the number of leptons in each event → further subdivided based on jet multiplicity and flavour tagging

Multivariate analysis techniques used to gain sensitivity in individual analysis categories





Full Run-2 results coming soon

Obs. (exp.) signal significance: **3.9 (3.5) *σ***

Signal strength:

$\mu = 1.15^{+0.15}_{-0.15}\,(\text{stat})\,^{+0.28}_{-0.25}\,(\text{syst})$