Measurement of the $t\bar{t}H$ production in the $H \to \gamma\gamma$ decay channel and search for the dimuon decay of the Higgs boson with the ATLAS detector

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ATLAS EXPERIMENT

Introduction

- In the SM, the BHE mechanism is responsible for the masses of the Fermions via their interaction with the Higgs boson.
- This implies that the strength of the interaction characterized by the **Yukawa couplings**, is proportional to Fermion masses.
- The measurement of the $t\bar{t}H$ production and $H \to \mu\mu$ decay processes provides direct access to these interactions.
- ATLAS has released the $t\bar{t}H(H \to \gamma\gamma)$ and $H \to \mu\mu$ results, using the full Run 2 (139 fb^{-1}) dataset of pp collisions at $\sqrt{s} = 13$ TeV.

$t\bar{t}H(H \to \gamma\gamma)$ Analysis (139 fb^{-1}, ATLAS-CONF-2019-004)

- The coupling of the Higgs boson to the top quark is of particular importance as the top is the heaviest particle in the Standard Model.
- Indirect test of the top Yukawa coupling have been performed by probing gluon fusion production and diphoton decay loops.
- However, **Higgs production in association with a top quark pair** ($t\bar{t}H$) presents a direct, tree-level test of the top Yukawa coupling.
- In ATLAS, $t\bar{t}H$ production is measured by targeting various Higgs decay channels, such as $\gamma\gamma$, four-lepton, multi-lepton, and $b\bar{b}$.
- The $t\bar{t}H(H \to \gamma\gamma)$ channel is currently the most sensitive.

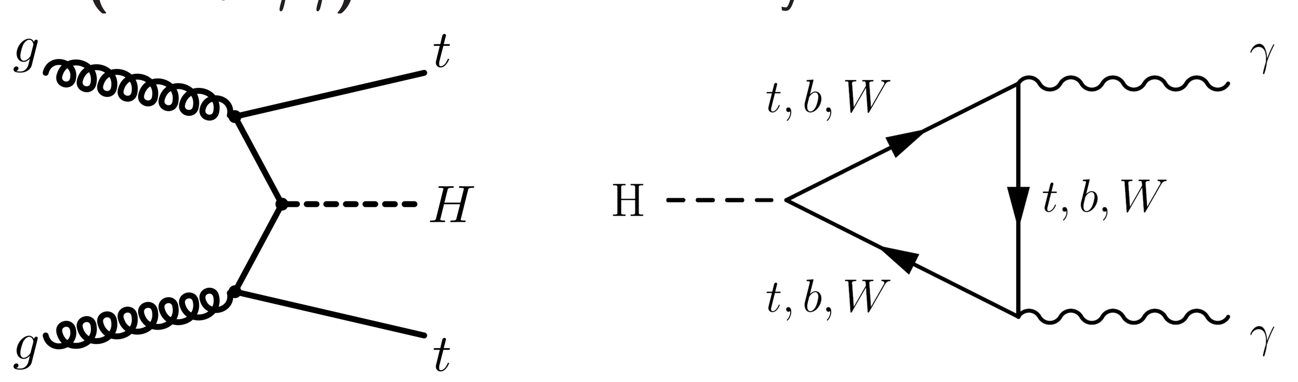

Figure 1: Representative diagrams for the $t\bar{t}H$ production and the $H \to \gamma\gamma$ decay.

- Events with two photons are selected, and split into two regions, hadronic and leptonic, depending on presence of isolated leptons in the final state.
- The main backgrounds include non-resonant background (e.g. $\gamma\gamma$, $t\bar{t}\gamma\gamma$) and resonant non-$t\bar{t}H$ Higgs background (e.g. ggF, tH).

- In each region, a boosted decision tree (BDT) is trained using the **XGBoost** package.
- Excellent separation between signal and background is achieved by focusing on kinematic variables (such as p_T and η) of the photons, jets, and leptons.

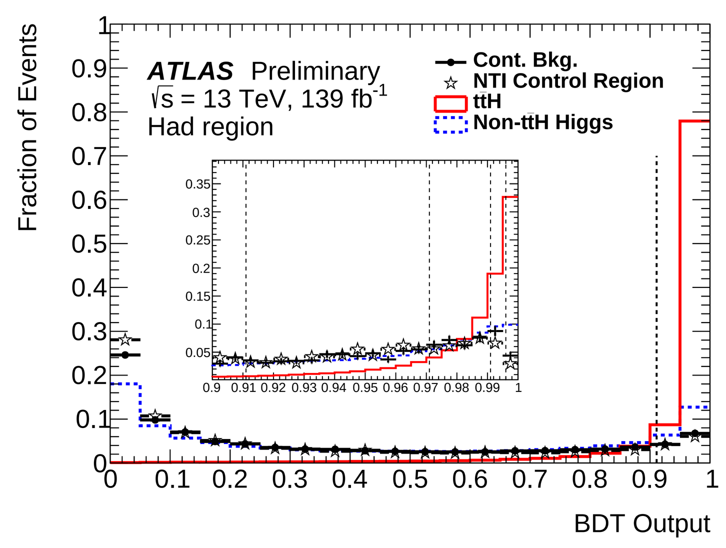

Figure 2: The BDT outputs in the hadronic region of the $t\bar{t}H(H \to \gamma\gamma)$ analysis.

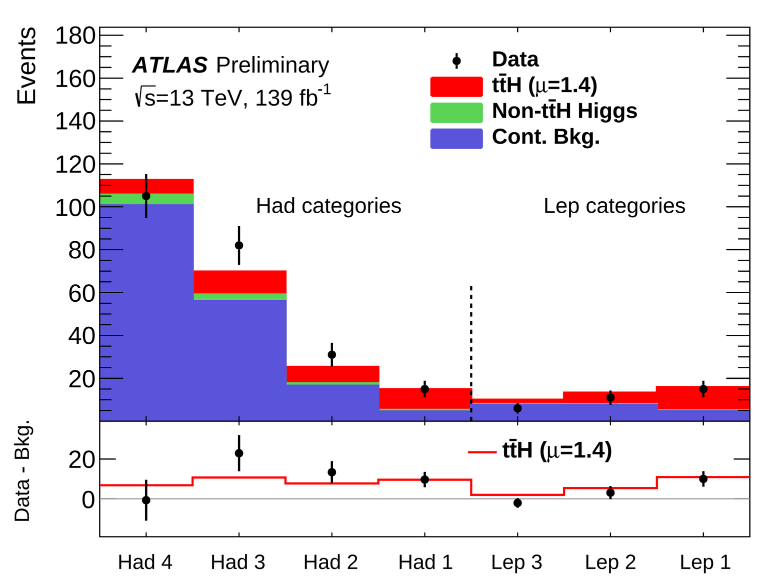

Figure 3: The observed data, expected background, and expected $t\bar{t}H$ signal in the $t\bar{t}H(H \to \gamma\gamma)$ analysis categories.

- **Four hadronic categories** and **three leptonic categories** are defined based on the BDT discriminant.
- The $t\bar{t}H$ signal yield is obtained from a simultaneous fit to the diphoton mass $m_{\gamma\gamma}$ spectrum across all categories.

- The observed (expected) significance is $\mathbf{4.9\sigma}$ $(\mathbf{4.2\sigma})$: the $t\bar{t}H$ production is observed in the diphoton decay channel.
- The $t\bar{t}H$ production cross section times the $H \to \gamma\gamma$ decay branching ratio is measured to be $\mathbf{1.59^{+0.43}_{-0.39}}$ fb, consistent with the SM prediction of $\mathbf{1.15^{+0.09}_{-0.12}}$ fb.

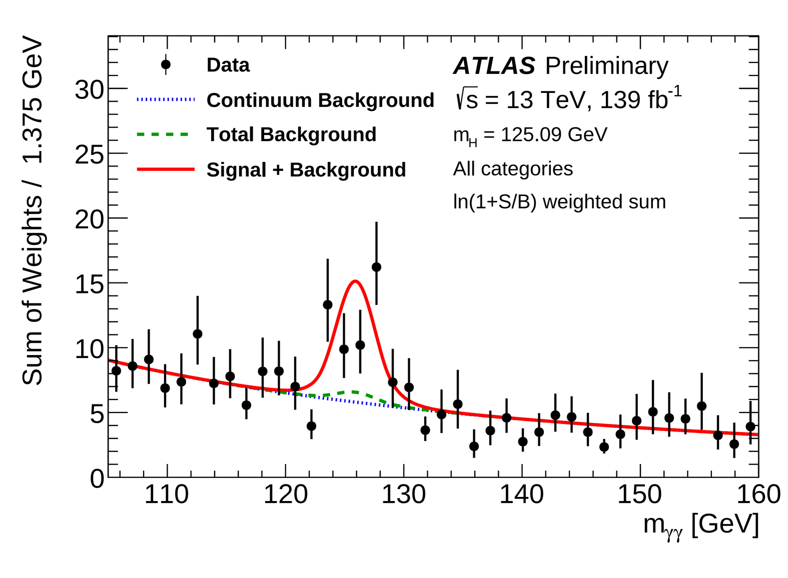

Figure 4: The diphoton mass spectrum of the selected events in all 7 categories of the $t\bar{t}H(H \to \gamma\gamma)$ analysis, weighted by ln(1+S/B) of each category.

$H \to \mu\mu$ Analysis (139 fb^{-1}, ATLAS-CONF-2019-028)

- The couplings between the Higgs boson and the third-generation fermions have already been observed.
- For the Higgs couplings with fermions of the other generations, only upper limits exist.
- The **Higgs decay to two muons** offers the best opportunity to observe the Higgs couplings with the second-generation fermions at the LHC.
- The search for the $H \to \mu\mu$ decay currently focuses on two major Higgs production modes: gluon fusion (ggF) and vector-boson fusion (VBF).

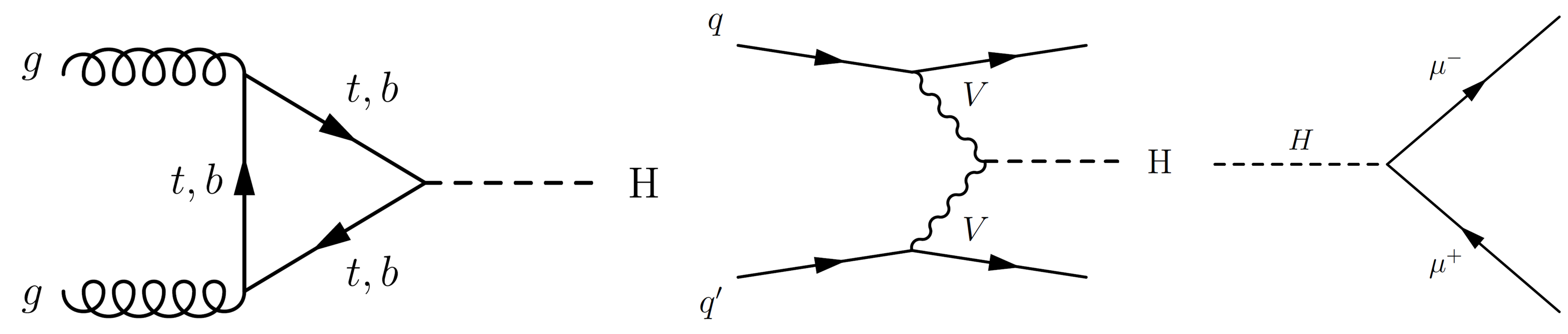

Figure 5: Representative diagrams for the ggF production, the VBF production and the $H \to \mu\mu$ decay.

- Events with two opposite-charge muons are selected, and split into 0-jet, 1-jet and $\geq$2-jet channels.
- The majority of the background is the Drell-Yan process ($Z/\gamma^* \to \mu\mu$).

- To disentangle the Higgs signal from backgrounds, the **XGBoost** package is used to train a BDT classifier in each jet channel.
- An additional BDT in the $\geq$2-jet channel is trained to explicitly target the VBF production.
- BDT inputs: kinematic variables of the dimuon system and leading jets.

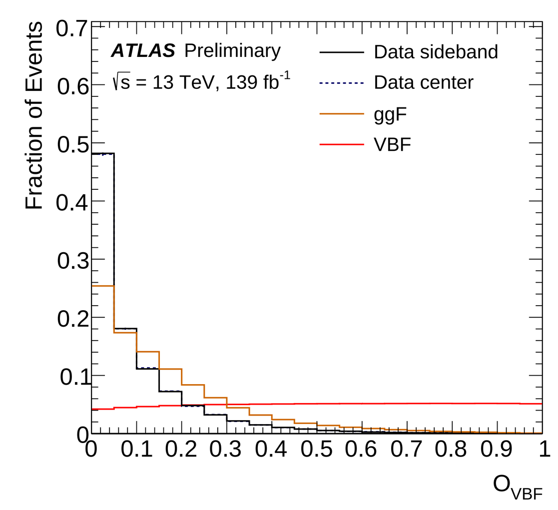

Figure 6: The VBF BDT outputs in the $\geq$2-jet channel of the $H \to \mu\mu$ analysis.

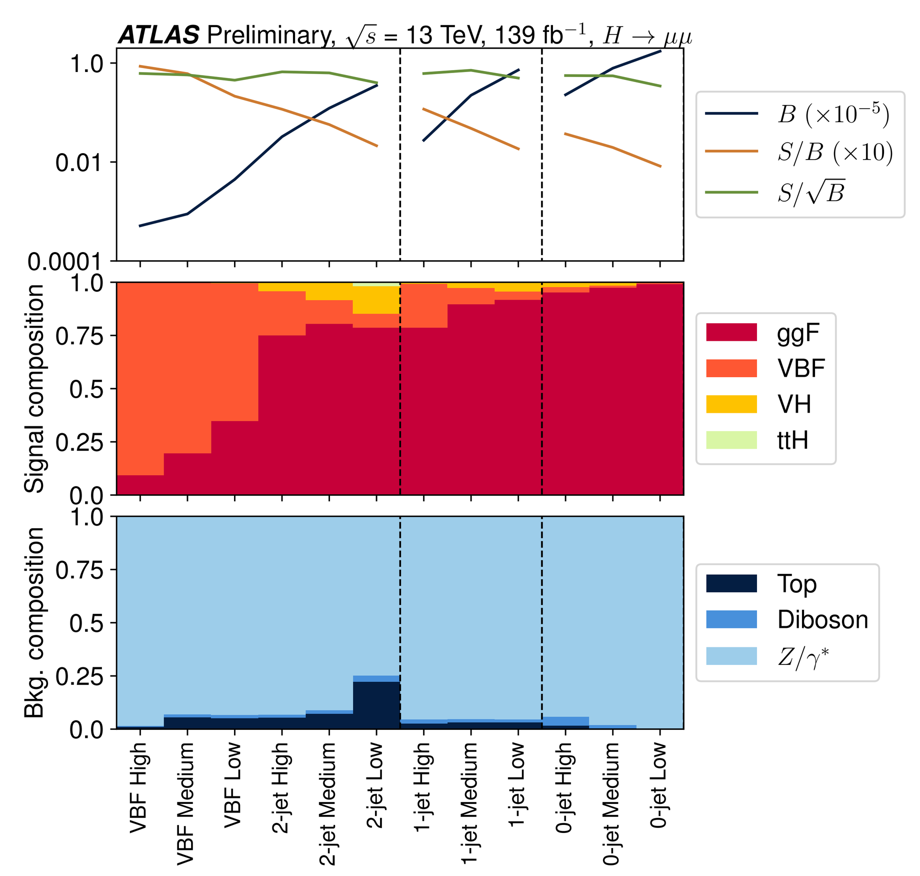

Figure 7: Summary of signal and background events in the $H \to \mu\mu$ analysis categories.

- Categorize events based on BDT scores in each channel, yielding **12 categories** in total.
- The $H \to \mu\mu$ signal yield is then extracted by a simultaneous fit to the dimuon mass $m_{\mu\mu}$ distributions of the 12 categories

- The observed (expected) significance is $\mathbf{0.8\sigma}$ $(\mathbf{1.5\sigma})$.
- The best fit value of the signal strength (μ, defined as the ratio of the observed signal yield to the one expected by the Standard Model) is $\mathbf{0.5 \pm 0.7}$, consistent with both the $\mu = 1$ and $\mu = 0$ scenarios.

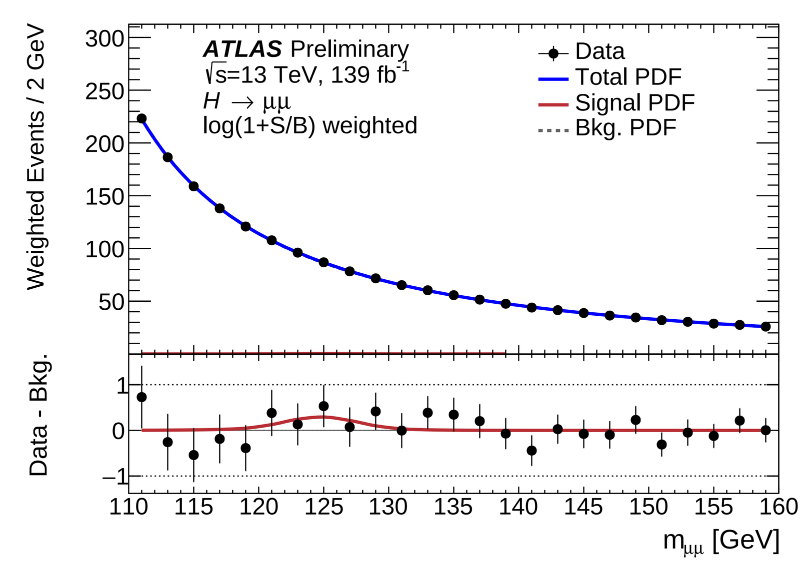

Figure 8: The dimuon mass spectrum of the selected events in all 12 categories of the $H \to \mu\mu$ analysis, weighted by ln(1+S/B) of each category.

Summary

- Based on the ATLAS full Run 2 dataset and using machine learning techniques,
  - The observed (expected) significance of the $t\bar{t}H(H \to \gamma\gamma)$ analysis is $\mathbf{4.9\sigma(4.2\sigma)}$.
  - The observed (expected) significance of the $H \to \mu\mu$ analysis is $\mathbf{0.8\sigma(1.5\sigma)}$.
- ATLAS has established the Higgs-Top Yukawa coupling, and is probing the Yukawa coupling between the Higgs boson and muon.