

## Higgs(general) at ATLAS

WEI-MING YAO<sup>1,2</sup>

ON BEHALF OF THE ATLAS COLLABORATION

*Physics Division**Lawrence Berkeley National Lab., Berkeley, CA 94720, USA*

The ATLAS Higgs results are reviewed using Run-2 data taken at a center-of-mass energy of 13 TeV with up to an integrated luminosity of  $80 \text{ fb}^{-1}$ . So far, the data are consistent with the standard model expectations. ATLAS now has observed the Higgs Yukawa coupling to the third generation fermions with  $H \rightarrow \tau\tau$ ,  $t\bar{t}H$ , and  $H \rightarrow b\bar{b}$  in the VH process. The Higgs boson will continue to provide an important probe for new physics and beyond.

PRESENTED AT

11<sup>th</sup> International Workshop on Top Quark Physics  
Bad Neuenahr, Germany, September 16–21, 2018

---

<sup>1</sup>Work supported by the Office of Science, Office of High Energy Physics, of the U.S. Department of Energy under contract DE-AC02-05CH11231.

<sup>2</sup>Copyright [2019] CERN for the benefit of the ATLAS Collaboration. CC-BY-4.0 license.

# 1 Introduction

The observation of Higgs boson (H) by ATLAS and CMS in July 2012 [1, 2] marked the completion of the standard model (SM) and opened the way to explore the Higgs sector that is responsible for electroweak symmetry breaking (EWSB). In this contribution, I will review some recent ATLAS Higgs results using Run-2 data at a center-of-mass energy of 13 TeV with up to an integrated luminosity of 80 fb<sup>-1</sup>.

## 2 Higgs production and property measurements

The Higgs boson at the LHC is predominantly produced via the ggF, VBF, VH, and ttH processes. There are five H decay channels playing an important role at the LHC, which are  $H \rightarrow b\bar{b}$ ,  $WW^*$ ,  $\tau\tau$ ,  $ZZ^*$ , and  $\gamma\gamma$ .

### 2.1 Higgs bosonic decays

The Higgs production is studied in the  $H \rightarrow \gamma\gamma$  and  $H \rightarrow ZZ^* \rightarrow 4l$  decay channels using Run-2 data [3, 4]. Figure 1 shows the invariant masses of di-photon and the four-leptons. The signal strength is defined as the ratio of the observed yield to its SM prediction. It is measured to be  $\mu_{H \rightarrow \gamma\gamma} = 1.06 \pm 0.08^{+0.11}_{-0.09}$  and  $\mu_{H \rightarrow 4l} = 1.19 \pm 0.12^{+0.10}_{-0.09}$ , respectively. Many fiducial and differential cross sections are also measured, which are in excellent agreement with the Monte Carlo predictions.

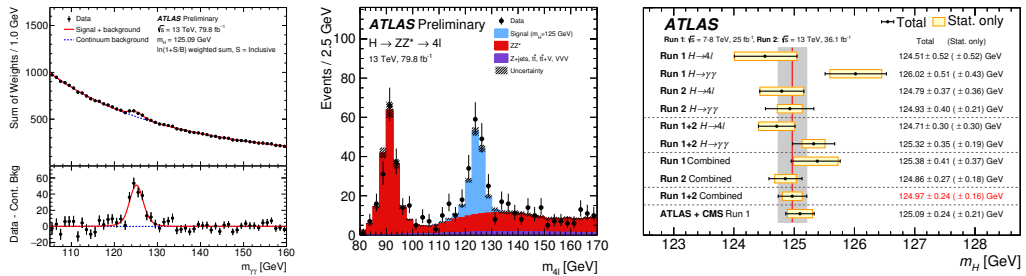


Figure 1: The weighted diphoton invariant mass spectrum in all the analysis categories(left) and the inclusive four-lepton invariant mass(middle) are observed in 79.8 fb<sup>-1</sup> of 13 TeV data. The summary of  $m_H$  measurements from the individual and combined analyses (right) use 36 fb<sup>-1</sup> of Run-2 data [3, 4, 6].

The  $H \rightarrow \gamma\gamma$  and  $H \rightarrow 4l$  events are also used to measure  $m_H$  in Run-2 data [5]. The results from each of the individual channels and their combination with Run-1 are shown in Figure 1. The ATLAS combined Higgs mass is  $m_H = 124.97 \pm 0.24$  GeV, which is compatible with the LHC Run1 measurement of  $125.09 \pm 0.24$  GeV [6].

The Higgs boson width ( $\Gamma_H$ ) is expected to be too small to be measured directly at the LHC, but it can be constrained indirectly through the off-shell  $H \rightarrow ZZ$  production and background interference effects [7]. Studies based on the channels  $H \rightarrow ZZ^* \rightarrow 4l$  and  $H \rightarrow ZZ \rightarrow 2l2\nu$  using Run2 data [8] allowed to set an upper limit, at 95% confidence level, of 14.4 MeV (15.2 MeV expected) on  $\Gamma_H$ .

## 2.2 Higgs fermionic decays

The Higgs Yukawa coupling can be probed either indirectly at the loop level or directly at the tree-level. Any deviation from SM could be a sign of new physics. The discussion of the ATLAS observation of ttH can be found elsewhere [9].

ATLAS has recently observed  $VH$  production ( $V = W$  or  $Z$ ) with  $H \rightarrow b\bar{b}$  [10]. The  $VH$  process is most sensitive to  $H \rightarrow b\bar{b}$ . In order to separate signal from background, the analysis is divided into several channels based on the number of charged leptons from the  $V$  decay and a trained BDT. Figure 2 shows a cumulative  $\log(S/B)$  from all channels. The fitted signal strength is  $\mu_{VH \rightarrow b\bar{b}} = 1.16 \pm 0.16 \pm 0.20$ , which gives an observed significance of  $4.9 \sigma$  with an expected of  $4.3 \sigma$ . The combination with Run-1 data gives  $\mu_{VH \rightarrow b\bar{b}} = 0.98 \pm 0.14 \pm 0.16$  and an observed significance of  $4.9 \sigma$  (expected  $5.1 \sigma$ ). We have also repeated the search by fitting the  $b\bar{b}$  invariant mass only as shown in Figure 2, giving a consistent result. ATLAS further combines the  $H \rightarrow b\bar{b}$  results in  $VH$  with other processes of VBF and ttH, resulting in observed significance of  $5.4 \sigma$  (expected  $5.5 \sigma$ ). The  $VH$  production is also combined using three H decay channels  $b\bar{b}$ ,  $\gamma\gamma$ , and  $4l$ , which gives an observed significance of  $5.3 \sigma$  (expected  $4.8 \sigma$ ).

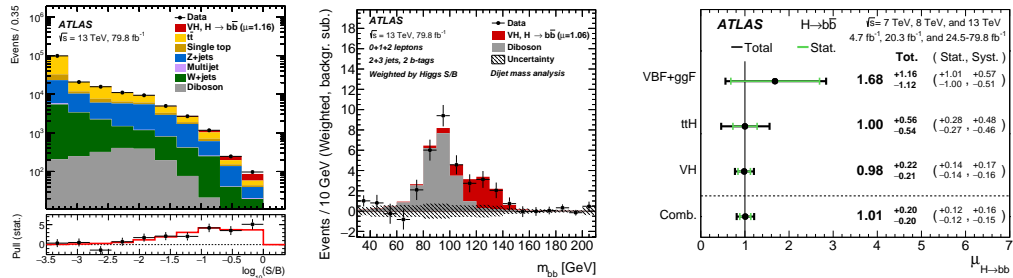


Figure 2: In the search for  $VH(b\bar{b})$ , event yield as a function of  $\log(S/B)$  (left) and the  $m_{b\bar{b}}$  in data after subtraction of all background with the dijet-mass analysis (middle) are shown in  $79.8 \text{ fb}^{-1}$  of Run2 data. Fitted  $\mu_{H \rightarrow b\bar{b}}$  from  $VH$ ,  $ttH$ , and  $VBF+ggF$  along with their combinations using all the data (right) [10].

The  $H \rightarrow \tau\tau$  channel has results from Run-2 with  $36.1 \text{ fb}^{-1}$  [11]. The di- $\tau$  events are selected in three final states of  $\tau_{lep}\tau_{lep}$ ,  $\tau_{lep}\tau_{had}$ , and  $\tau_{had}\tau_{had}$  that are further divided into 13 categories targeting VBF production and ggF in the boosted

region. The signal strength is measured to be  $\mu_{H \rightarrow \tau\tau} = 1.09^{+0.18+0.31}_{-0.17-0.25}$ , which gives an observed significance of  $4.4 \sigma$  (expected  $4.1 \sigma$ ). After combining with Run-1 results, an observed significance of  $6.4 \sigma$  (expected  $5.4 \sigma$ ) is obtained. The 2-D fitted ggH and VBF cross sections are in good agreement with the SM predictions.

The search for the  $H \rightarrow \mu\mu$  decay is also updated using  $80 \text{ fb}^{-1}$  of Run-2 data [12]. No excess of events over the known backgrounds is observed and a 95% CL upper limit on the signal strength of 2.1 (expected 2.0) is set.

## 2.3 Higgs boson couplings

Since the main Higgs production modes have been observed by ATLAS, the combined results are used to check the consistency of the couplings with the SM and to probe BSM coupling as kappa modifiers [13]. The combined signal strengths for ggF, VBF, VH, and ttH+tH are shown in Figure 3. Two tests are performed and shown. One test assumes no physics beyond the Standard Model; in this case kappa modifiers [13] of the couplings are left floating in the fit to data simultaneously. The result is consistent with the SM with a CL of 87%. In a second test, the parameter  $B_{BSM}$  is added to the kappa-modifiers to describe explicit contributions to the Higgs width from new physics. The result,  $B_{BSM} < 0.26$  (expected 0.37) at 95% CL, is consistent with direct searches based on Run-1 data [15]. Figure 3 also shows the Higgs coupling to fermions and bosons as a function of their masses, which are in good agreement with the SM expectation.

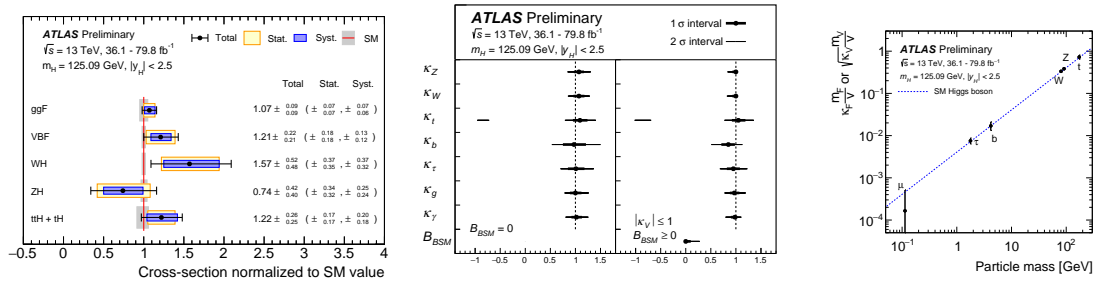


Figure 3: The measured Higgs signal strength for ggF, VBF, VH, and ttH+tH (left), the best-fit of H coupling modifiers per particle type by either  $B_{BSM} = 0$  or  $B_{BSM}$  included as a free parameters (middle), and the Higgs coupling for fermions and bosons as a function of their masses (right) are shown [13].

## 3 Search for di-Higgs production

Probing Higgs self-coupling at LHC is extremely challenging. ATLAS has searched SM di-Higgs production using  $36 \text{ fb}^{-1}$  of Run-2 data with three major di-Higgs decay

modes:  $HH \rightarrow 4b$ ,  $HH \rightarrow bb\tau\tau$ ,  $HH \rightarrow bb\gamma\gamma$ , and their combination [14]. No excess of events is observed and the combined limit on the signal strength is set less than 6.7 (10.4 expected) at 95% CL. The corresponding observed limit at 95% CL on Higgs self-coupling is between -5.0 and 12.1 (expected limit is between -5.8 and 12.0).

## 4 Conclusion

In conclusion, the ATLAS Higgs results are reviewed using Run-2 data taken at a center-of-mass energy of 13 TeV with up to an integrated luminosity of  $80 \text{ fb}^{-1}$ . So far, the data are consistent with the standard model expectations. ATLAS now has observed  $H \rightarrow \tau\tau$ ,  $ttH$ , and  $VH \rightarrow bb$ . The Higgs boson will continue to provide an important probe for new physics and beyond.

## References

- [1] ATLAS Collaboration, Phys. Lett. B **716** (2012) 1.
- [2] CMS Collaboration, Phys. Lett. B **716** (2012) 30.
- [3] ATLAS Collaboration, ATLAS-CONF-2018-028, <http://cdsweb.cern.ch/record/2628771>.
- [4] ATLAS Collaboration, ATLAS-CONF-2018-018, <http://cdsweb.cern.ch/record/2621479>.
- [5] ATLAS Collaboration, Phys. Lett. B **784** (2018) 345.
- [6] ATLAS and CMS Collaborations, Phys. Rev. Lett. **114** (2015) 191803.
- [7] N. Kauer, G. Passarino, JHEP **08** (2012) 116.
- [8] ATLAS Collaboration, Phys. Lett. B **786** (2018) 223.
- [9] See F. Hubaut's presentation in this proceeding or Phys. Lett. B **784** (2018) 173.
- [10] ATLAS Collaboration, Phys. Lett. B **786** (2018) 59.
- [11] ATLAS Collaboration, ATLAS-CONF-2018-021, <http://cdsweb.cern.ch/record/2621794>
- [12] ATLAS Collaboration, ATLAS-CONF-2018-026, <http://cdsweb.cern.ch/record/2628763>.
- [13] ATLAS Collaboration, ATLAS-CONF-2018-031, <http://cdsweb.cern.ch/record/2629412>.
- [14] ATLAS Collaboration, ATLAS-CONF-2018-043, <http://cdsweb.cern.ch/record/2638212>.
- [15] ATLAS Collaboration, JHEP **01** (2016) 172.