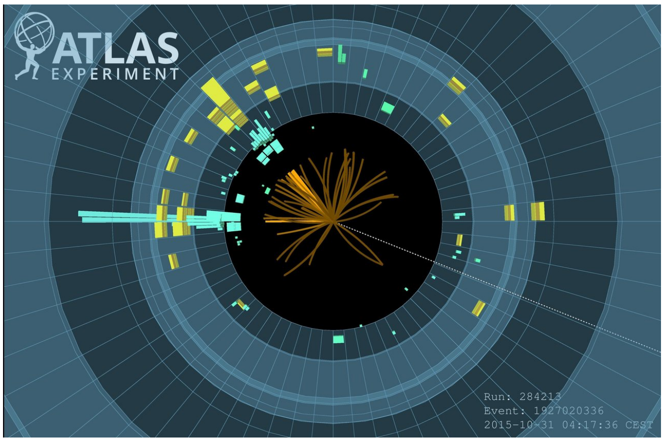
# Higgs boson observed decaying to b quarks

10 July 2018



Event display for the H?bb decay analysis with the ATLAS detector. Credit: ATLAS Collaboration/CERN

On 9 July, at the 2018 International Conference on High Energy Physics (ICHEP) in Seoul (South Korea), the ATLAS experiment reported a preliminary result establishing the observation of the Higgs boson decaying into pairs of b quarks, furthermore at a rate consistent with the Standard Model prediction.

The Brout-Englert-Higgs mechanism solves the apparent theoretical impossibility of weak vector bosons (W and Z) to have mass. The discovery of the Higgs boson in 2012 was a triumph of the Standard Model. The Higgs field can also be used in an elegant way to provide mass to charged fermions (quarks and leptons) through interactions involving Yukawa couplings with strength proportional to the particle mass. The observation of the Higgs boson decaying into pairs of ? leptons provided the first direct evidence of this type of interaction.

Six years after its discovery, the ATLAS experiment at CERN observed about 30 percent of the Higgs boson decays predicted in the Standard Model. However, the favoured decay of the Higgs boson into a pair of b quarks (H?bb), which is expected to account for almost 60 percent of all possible decays, has remained elusive up to now. Observing this decay mode and measuring its rate is a mandatory step to confirm or disconfirm the mass generation for fermions via Yukawa interactions, as predicted in the Standard Model.

At the 2018 International Conference on High Energy Physics (ICHEP) in Seoul (South Korea), the ATLAS experiment reported a preliminary result establishing the observation of the Higgs boson decaying into pairs of b quarks at a rate consistent with the Standard Model prediction. It is necessary to exclude at a level of one in 3 million the probability that the decay detection arises from a fluctuation of the background that could mimic the process. When such a probability is at the level of only one in 1000, the detection is qualified as "evidence." Evidence of the H?bb decay was first provided at the Tevatron in 2012, and a year ago by the ATLAS and CMS Collaborations, independently.

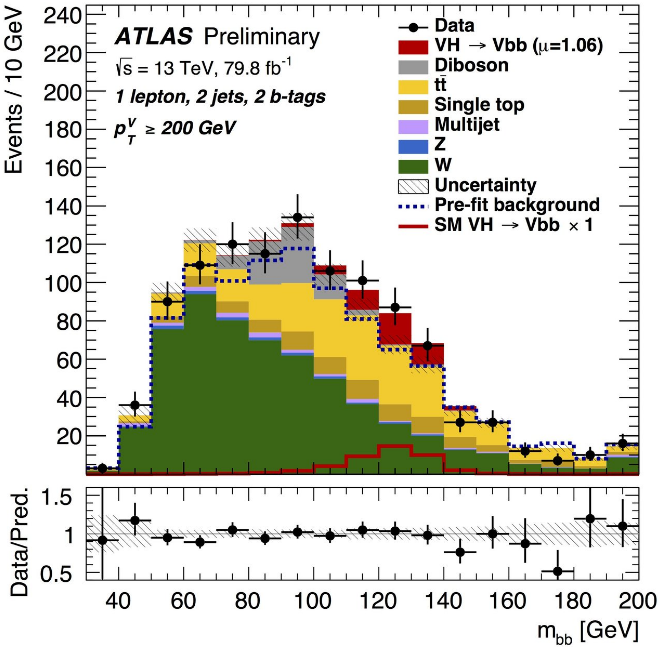


Figure 1: Distribution of mbb in the (W???)(H?bb) search

channel. The signal is shown in red, the different backgrounds in various colours. The data are shown as points with error bars. Credit: ATLAS Collaboration/CERN

**Combing through the haystack of b quarks**

Given the abundance of the H?bb decay, and how much rarer decay modes such as H??? had already been observed at the time of discovery, why did it take so long to achieve this observation?

The main reason is that the production process for the Higgs boson in proton-proton interactions leads to a single pair of particle jets originating from the fragmentation of b quarks (b-jets). These are almost impossible to distinguish from the overwhelming background of b-quark pairs produced via the strong interaction (quantum chromodynamics or QCD). To overcome this challenge, it was necessary to consider production processes that are less copious, but exhibit features not present in QCD. The most effective of these is the associated production of the Higgs boson with a vector boson, W or Z. The leptonic decays, W???, Z??? and Z??? (where ? stands for an electron or a muon) provide signatures that allow for efficient triggering and powerful QCD background reduction.

However, the Higgs boson signal remains orders of magnitude smaller than the remaining backgrounds arising from top quark or vector boson production, which lead to similar signatures. For instance, a top quark pair can decay as tt?[(W???)b][(W?qq)b] with a final state containing an electron or a muon and two b quarks, exactly as the (W???)(H?bb) signal.

The main handle to discriminate the signal from such backgrounds is the invariant mass, $m_{bb}$, of pairs of b-jets identified by sophisticated "b-tagging" algorithms. An example of such a mass distribution is shown in Figure 1, where the sum of the signal and background components is confronted to the data.

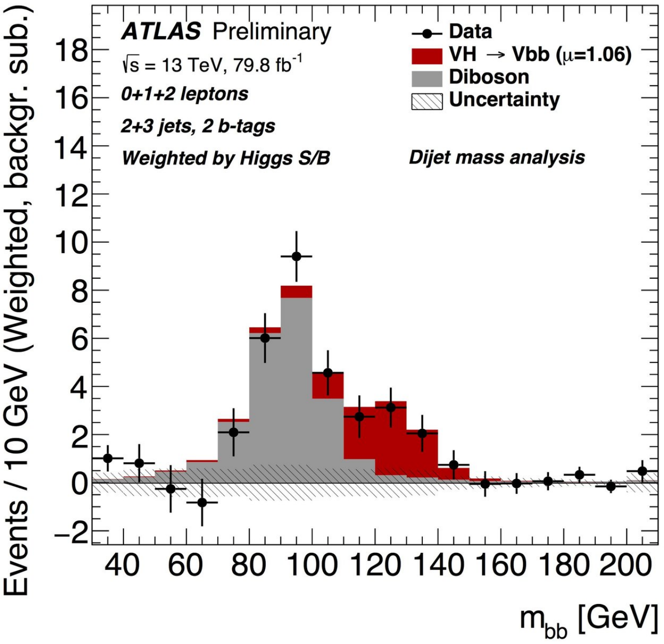


Figure 2: Distribution of mbb from all search channels combined after subtraction of all backgrounds except for WZ and ZZ production. The data (points with error bars) are compared to the expectations from the production of WZ and ZZ (in grey) and of WH and ZH (in red). Credit: ATLAS Collaboration/CERN

When all WH and ZH channels are combined and the backgrounds (apart from WZ and ZZ production) subtracted from the data, the distribution shown in Figure 2 exhibits a clear peak arising from Z boson decays to b-quark pairs, which validates the analysis procedure. The shoulder on the upper side is consistent in shape and rate with the expectation from Higgs boson production.

This is, however, not sufficient to reach the level of detection that can be qualified as observation. To this end, the mass of the b-jet pair is combined with other kinematic variables that show distinct differences between the signal and the various backgrounds, for instance the angular separation between the two b-jets, or the transverse momentum of the associated vector boson. This combination of multiple variables is performed using the technique of boosted decision trees (BDTs). A combination of the BDT outputs from all channels, reordered in terms of signal-to-background ratio, is shown in here. It can be seen that the signal closely follows the distribution expected from the Standard Model. The BDT outputs are subjected to a sophisticated statistical analysis to extract the "significance" of the signal. This is another way to measure the probability of a fake observation in terms of standard deviations, ?, of a Gaussian distribution. The magic number corresponding to the observation of a signal is 5?.

The analysis of 13 TeV data collected by ATLAS during Run 2 of the LHC in 2015, 2016 and 2017 leads to a significance of 4.9? – almost sufficient to claim observation. This result was combined with those from a similar analysis of Run 1 data and from other searches by ATLAS for the H?bb decay mode, namely where the Higgs boson is produced in association with a top quark pair or via a process known as vector boson fusion (VBF). The significance achieved by this combination is 5.4?.

Furthermore, combining the present analysis with others that target Higgs boson decays to pairs of photons and Z bosons measured at 13 TeV provides the observation at 5.3? of associated VH (V = Z or W) production, in agreement with the Standard Model prediction. All four primary Higgs boson production modes at hadron colliders have now been observed, of which two only this year. In order of discovery: (1) fusion of gluons to a Higgs boson, (2) fusion of weak bosons to a Higgs boson, (3) associated production of a Higgs boson with two top quarks, and (4) associated production of a Higgs boson with a weak boson.

With these observations, a new era of detailed measurements in the Higgs sector opens up, through which the Standard Model will be further challenged.

**More information:** Observation of H ? bb decays and VH production with the ATLAS detector: atlas.web.cern.ch/Atlas/GROUPS … ATLAS-CONF-2018-036/

Provided by ATLAS Experiment
APA citation: Higgs boson observed decaying to b quarks (2018, July 10) retrieved 20 June 2019 from https://phys.org/news/2018-07-higgs-boson-quarks.html