Optimization of a search for Higgs boson pair production in the $b\bar{b}W^{+}W^{-}$ channel using proton-proton collision data at $\sqrt{S}$ =13 TeV with the ATLAS detector

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Abstract

We present the optimization study of a search for Higgs Boson pair production in the channel in which one of them decays to $b\bar{b}$ quark jets and other decays to W boson pair with subsequent decays of the W boson pair to $l\nu qq$. We select cuts based on event kinematics and show that the number of signal over $t\bar{t}$ background can be improved. This analysis is performed using Monte Carlo samples that have the full ATLAS detector simulation.

Introduction

As far as we know, there are two kinds of particles in nature; one is matter particles known as fermions which are the building blocks of matter and other one is force-carrying particles known as bosons which intermediate interaction between fermions. There are four known fundamental forces in the universe; the strong force, the weak force, the electromagnetic force and the gravitational force. The particles and their interaction except gravity force are explained in the theory developed over the last several decades known as the Standard Model (SM) of particle physics. It is believed that the SM is not a complete theory of nature because it does not explain some of the known phenomena like matter-antimatter asymmetry, neutrino oscillations, dark matter, and dark energy etc. There are some theoretical models to address such shortcomings of the SM. Among these are Supersymmetry (SUSY), Composite Higgs etc.

The Large Hadron Collider (LHC) is the largest particle accelerator in the world, which collides protons at very high energy. Such collisions result in the production of subatomic particles, many of which have already been discovered by previous accelerators. One notable exception is the Higgs boson which have already discovered at the LHC in 2012. The collision may also result in new particles predicted by theory and that are not yet discovered. One of such possibilities is the production of Heavy Higgs bosons which may subsequently decay to two SM Higgs [1, 2]. This SM Higgs boson then decays through one of the known channels to other SM particles. When two protons collide at high energy, SM Higgs particles may be created by the coupling of gluons or by the interactions between fermions. Higgs pairs are produced via a range of partonic sub processes. The most dominant process is demonstrated as Feynman diagram in Figure1.

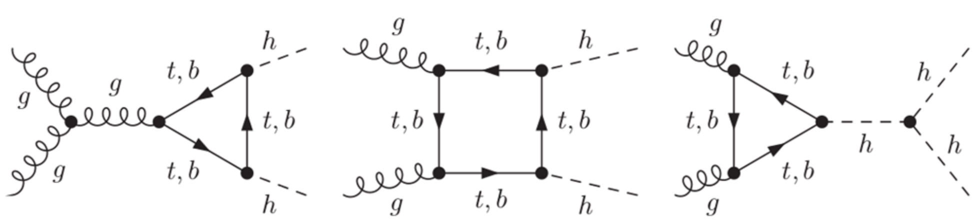


Figure1: Feynman diagram for Interaction between gluons to produce di-Higgs

We present an optimization study of a search for such di-Higgs production in the above mentioned channel. Based on the event kinematics, we apply several selection cuts in order to reduce the dominant background while keeping the signal efficiency high.

ATLAS Detector

ATLAS detector consists of several concentric cylindrical detectors around the particle collisions point [3]. It has four main major components. Inner Detector tracks the charged particles by detecting their interactions with the different systems of sensors of detectors. It is surrounded by magnetic fields parallel to beam axis which helps measure the momentum of the charged particles. The layer outside of the Inner Detectors is the Calorimeter which measures the energy of electrons, protons and hadrons. Electromagnetic calorimeter can measure the energy of electrons or protons. Hadronic calorimeter measures the energy of hadrons, particles that contains quarks such as protons and neutrons. Muon Spectrometer can detect the track of muon and its curvature using magnetic field which ultimately allow us to calculate its energy and momentum. Magnet System bends the path of charged particles that passes through the detectors which can provide information on the particles momentum.

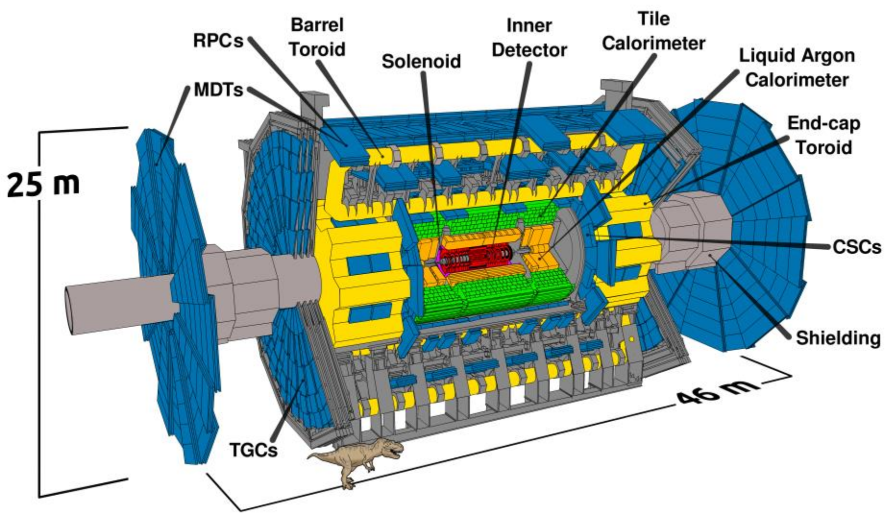


Figure2: ATLAS detector and its components [4].

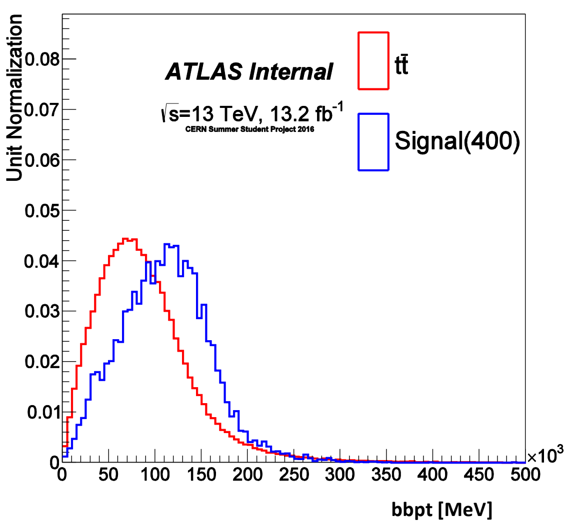
Pre-selection and analysis method

There are many different processes that can end up with similar final state particles. So it is useful to know background processes which can produce same final state as the signal. We suppose Heavy Higgs with mass 400 GeV decay to two SM Higgs boson, $H \rightarrow hh$. Pair produced Higgs bosons can decay in many particles like $h \rightarrow b\bar{b}$ or h$\rightarrow W^{+}W^{-}$. We choose the channel in which one of the Higgs bosons decays hadronically to two b quarks and other decays to pair of W bosons. One of the W pair decays to leptons and other decays to quarks.

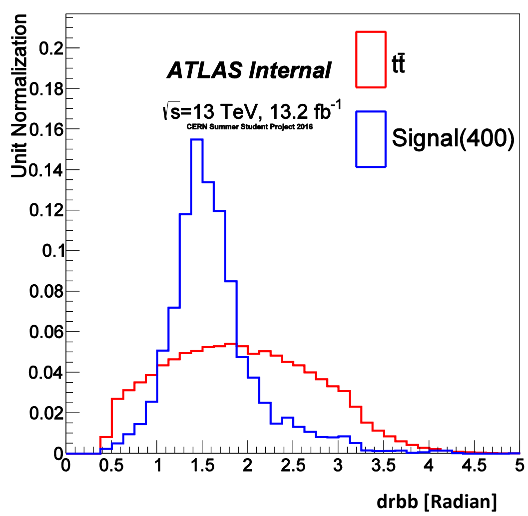
Hence our final state consists of two b-quarks, two light quarks, a charged leptons and a neutrino. This signature appears as two b-jets, two light jets, a charged lepton and missing transverse energy in the detector respectively. The dominant background comes from pair produced top quarks; $pp \rightarrow t\bar{t}$. These top quarks can further decay to similar final product as di-Higgs. By analyzing various kinematics of final state particles like pt (transverse momentum), dr (angular separation), ht (scalar sum of transverse momenta of lepton, neutrino, hadronic W and b jets), we can choose the appropriate selection cuts. We can apply cut and improve signal sensitivity, the ratio of number of signal over number of background (S/B).

Selection and Result

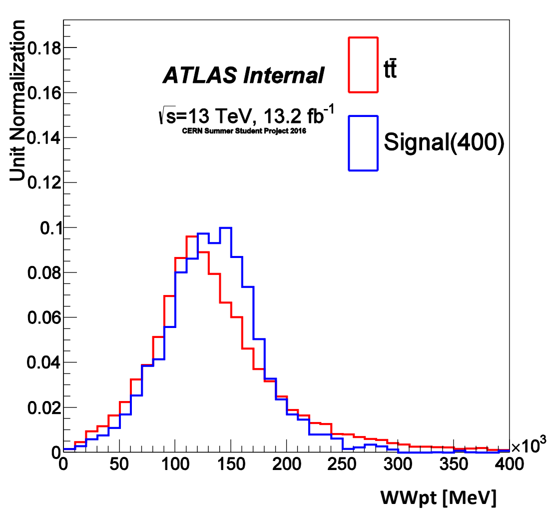
Figure 3 shows the distribution of relevant kinematic variables for both signal and $t\bar{t}$ background. Figure 3 (a) shows the distribution of transverse momenta of the bb system forming a Higgs candidate. It can be seen that the signal and background have different peaks at different values.



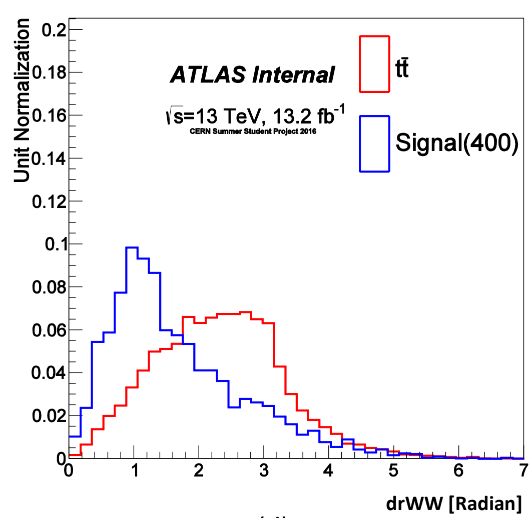
3 (a)



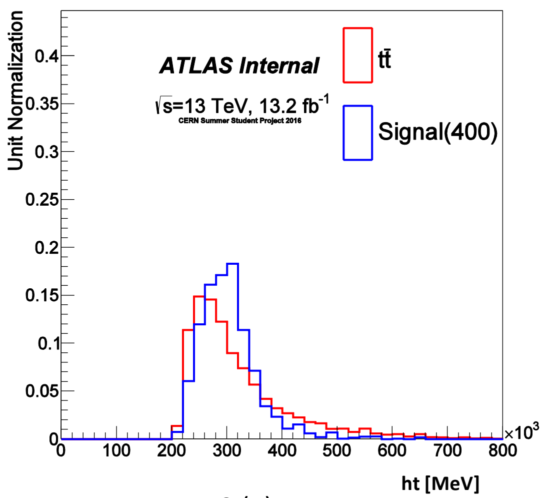
3 (b)



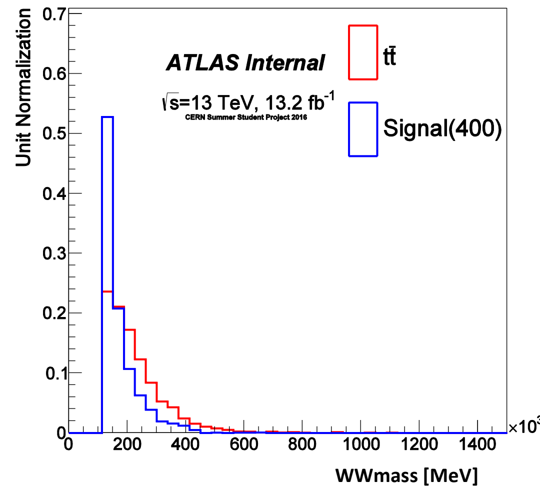
3 (c)



3 (d)



3 (e)



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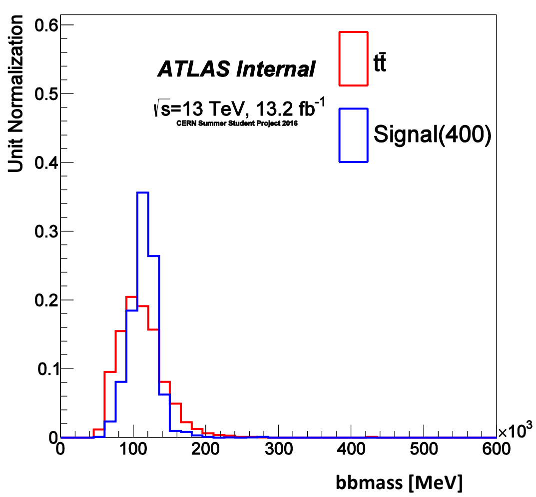
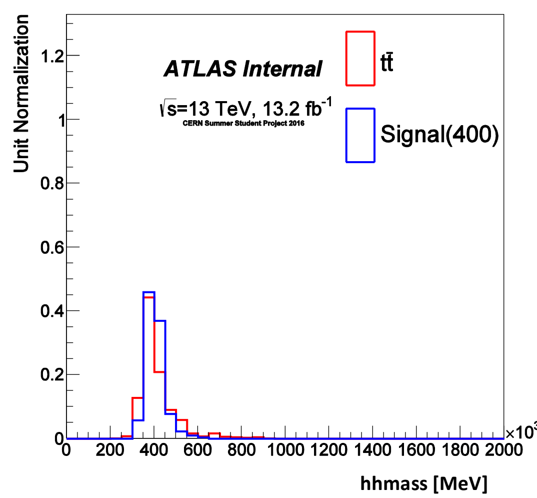


3 (g)



3 (h)

Figure3: Signal and Background distribution before and after imposing different kinematical cuts. For comparison, we plot the signal distribution for $M_H = 400\ GeV$ in blue color and ttbar background in the red color.

Therefore, we apply a cut (Cut 1) at transverse momentum of bb system greater than 100 GeV. This increases the S/B value. Figure 3 (b) shows the $drbb$, angular separation between two b-jets, distribution after applying Cut 1. Now, to improve S/B further, we again apply Cut 2 on angular separation ($drbb$) between the two b-jets between 1 rad and 1.9 rad. Then we inspect the transverse momentum of W hadron pair as shown in 3 (c) and apply Cut 3 to transverse momentum of W pair greater than 110 GeV. We apply Cut 4 to the angular separation between W hadrons within 1.6 rad for which distribution can be seen in Figure 3 (d). Then we ask for ht

in Cut 5 to be greater than 240 GeV. We further impose Cut 6 on the mass of pair of W boson to be less than 150 GeV. As in Figure 3 (g), we keep combined mass of b-jets that is produced by the decay of Higgs boson, between 90 GeV and 140 GeV (Cut7).

Table1

	Cut 0	Cut 1 bbpt >100GeV	Cut 2 1< drbb <1.9	Cut 3 WWpt >110GeV	Cut 4 drww < 1.6	Cut 5 ht >240GeV	Cut 6 WWmass < 150GeV	Cut 7 90 GeV < bbmass < 140 GeV
Signal (number of events)	17480	10230	7629	5434	3103	2892	1526	1283
Background (number of events)	407937	140878	50801	33414	8356	7294	1723	989
Ratio (Signal/Background)	0.043	0.073	0.150	0.163	0.371	0.396	0.885	1.297

We summarize our result in Table 1. Here we present the ratio of number of signal event (S) and number of background event (B) after applying various cuts. We can see that the ratio S/B is gradually increased from 0.043 before any cut to the 1.29 after applying Cut 7. These are Monte Carlo events and need to be properly treated to data luminosity. But given the distribution we believe these cuts will benefit any Higgs pair search in this final state.

Conclusion

We show that we can improve our S/B considerably by applying the given cuts on different kinematical variables in the search for the $H \to hh \to bbWW \to bbl\nu qq$ channel. We found that each of the considered cut increases S/B. It also implies that we can reconstruct the mass of Heavy Higgs with the invariant mass of its decay product. We conclude that reconstruction of the mass of Heavy Higgs is possible in this channel but the counting experiment that only counts the number of signal and background events may be more feasible. Further improvements can be made by optimizing a statistical figure of merit such as Poisson significance and normalizing the Monte Carlo events to proper data luminosity.

Reference

[1] Marsh Alison, Optimization of selection and data-driven background estimation for the boosted di-Higgs to 3b final state search

[2] Lan-Chun Lu , Chun Du, Yaquan Fang, Hong-Jian He, Huijun Zhang, Searching Heavier Higgs Boson via Di-Higgs Production at LHC Run-2

[3] https://home.cern/about/experiments/atlas

[4] http://www.jetgoodson.net/content/images/thesis/theAtlasDetector.png