**Study of the Higgs Boson in ZH associated production**

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### Introduction

A new particle has been discovered at Large hadron Collider (LHC) in 2012 with the properties compatible with those predicted by the Standard Model (SM). It was discovered in bosonic decay channels, $H \rightarrow WW$, $ZZ$ or $\gamma\gamma$ and the measured mass is $m_H = 125$ GeV. Nevertheless, if this new particle was the Higgs boson predicted by the SM, there should be decay channels with fermion pairs. The goal then would be to observe $H$ decays in a fermion pair. Branching fraction of Higgs to $b\bar{b}$ is theorized to be 0.577 which indicates this process dominates among all other decay channels.

There are various difficulties related to the $H \rightarrow b\bar{b}$ decay channel. Since the final state of this decay is a pair of $b$ quarks, which in turn fragment into jets, it will come with overwhelming background of multijet production with huge production cross section. The cross section for associated $ZH$ production is small compared to those predicted by the Standard Model (SM). It was discovered in bosonic decay channels, $H \rightarrow WW$, $ZZ$ or $\gamma\gamma$ and the measured mass is $m_H = 125$ GeV. Nevertheless, if this new particle was the Higgs boson predicted by the SM, there should be decay channels with fermion pairs. The goal then would be to observe $H$ decays in a fermion pair. Branching fraction of Higgs to $b\bar{b}$ is theorized to be 0.577 which indicates this process dominates among all other decay channels.

### Method

We consider associated production of a Higgs boson with a vector boson, $ZH$, in which $H$ decays to $b\bar{b}$ and $Z$ decays to muons. The leptonic decay of the $Z$ allows to suppress the background events. The Feynman diagram for this process is shown below (Figure 2).

![Feynman diagram for associated production of Higgs boson with Z boson](image)

In order to observe Higgs boson in this process we need to find $b\bar{b}$ pair produced as a result of its decay. However, these quarks cannot be observed in the detector directly since their short lifetime, and they fragment into a stream of particles that we call a “jet”. Therefore we first need to identify the jet originated from $b$ (or $\bar{b}$), the $b$-jet. A $b$-tagging algorithm is employed to identify these $b$-jets.

When two high energy protons collide, various particles will come out from the interaction point that can create a number of jets not coming from the Higgs boson. The invariant mass of two $b$-jets that are the decay products of the Higgs boson would give a resonance peak near the $m_H = 125$ GeV.

### Monte Carlo and jet finding algorithm

Monte Carlo method is used to simulate events happening in pp collisions at LHC. We used Pythia 8 event generator to simulate $ZH \rightarrow y^+y^- b\bar{b}$ production. In this event, we switched off all the decay modes except $b\bar{b}$ for the Higgs boson and $y^+ y^-$ for $Z$. To identify the jets we used anti-$k_t$ jet clustering algorithm to capture stable particles. Anti-$k_t$ algorithm is a sequential recombination jet algorithm which aggregates first closest constituents.

![Different types of Higgs boson production mechanisms](image)

![An example of two jet event produced in pp collisions](image)

### Data and analysis

In our simulation, we set pp collisions center-of-mass energy to be 8 TeV and rest mass of $Z$ and $H$ to be 91.19 GeV and 125 GeV, respectively. Cross section of our process given by Pythia is $\sigma = 4.811 \pm 0.617$ fb.

We generated 1000 events of $ZH \rightarrow y^+y^- b\bar{b}$ with phase space $p_T$ minimum set at 150 GeV. The main goal of this simulation was to see when, at what values of the transverse momenta $p_T$ the two $b$-jets start merging into a single jet. We would then treat un-merged and merged jets separately, e.g. calculate distance between jets by $\Delta R = \sqrt{\Delta \phi^2 + \Delta \eta^2}$

![Di-jet invariant mass and other parameters](image)

### Conclusion

In this analysis, we searched the method to identify b-jet by excluding muon jet from our jet lists. Theoretically, if one particle had huge momentum, its decay products will tend to come close to each other as $p_T$ increases due to relativistic boost effect. In the future, we will study in details the separation of two b-jets as a function of the Higgs boson $p_T$ and devise methods to calculate the di-jet invariant mass for merged b-jets so that they yield the Higgs boson mass of 125 GeV (Figure 4).

![Comparison of the Higgs mass from ATLAS group](image)

### References


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