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 decay channels, H →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 of background events. However, the Z boson to leptons decay channel would allow to suppress the background processes. [2, 3].

Higgs boson

The Higgs boson is the particle expected in the SM which has neither spin nor electric charge. Higgs field will provide mass to other particles depending on how much they interact: Heavier particles have larger coupling to the Higgs field.

The Higgs boson can be produced through various mechanisms such as gg fusion, vector boson fusion, $t\bar{t}$ fusion, in association with a W or Z boson (Figure 1).

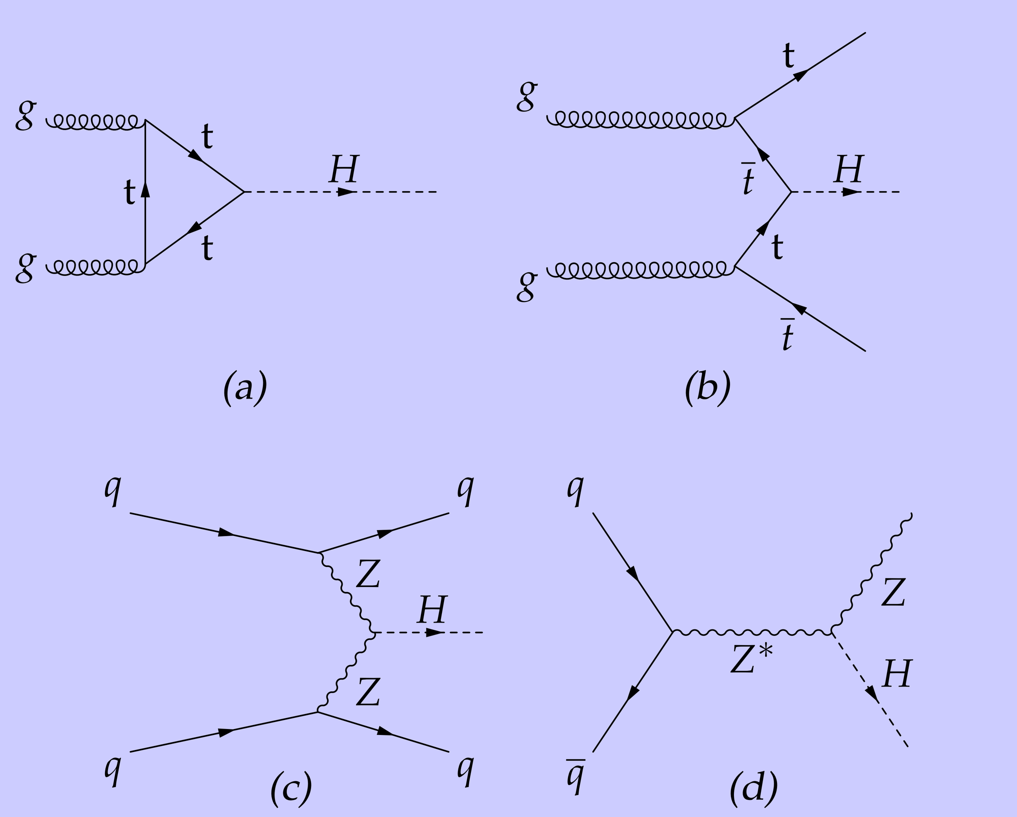


Figure 1
Different types of Higgs boson production mechanisms (a) gg fusion (b) $t\bar{t}$ fusion (c) ZZ fusion (d) ZH production

Method

We consider associated production of a Higgs boson with a vector boson, ZH, when 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 (Figure2).

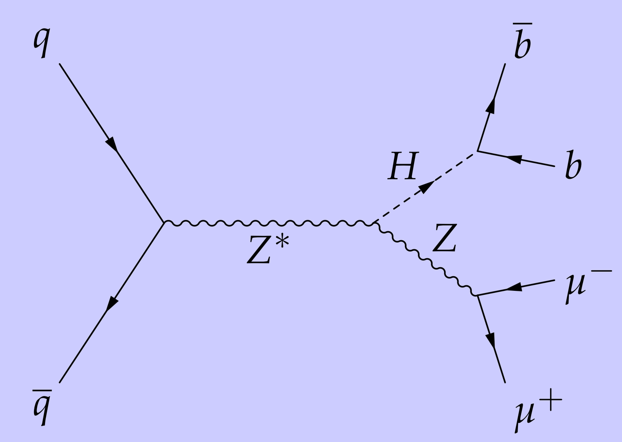


Figure 2
Feynman diagram for associated production of Higgs boson with Z boson

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. However, 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 $ZH \rightarrow \mu^+\mu^- b\bar{b}$ production. In this event, we switched off all the decay modes except $b\bar{b}$ for the Higgs boson and $\mu^+\mu^-$ 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.

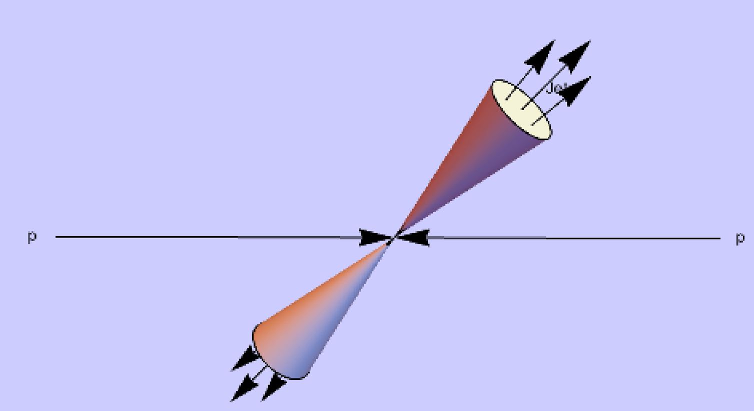


Figure 3
An example of two jet event produced in pp collisions.

Di-jet invariant mass and other parameters

The 4-vector of a jet is defined as:

$$p^J = (E^J, \mathbf{p}^J)$$

From this information, the di-jet invariant mass can be calculated as:

$$M^2 = m_1 + m_2 + 2(E_1 E_2 - \mathbf{p}_1 \cdot \mathbf{p}_2)$$

Moreover, we can calculate transverse momentum, rapidity and azimuthal angle as

$$p_T^J = \sqrt{\left(p_x^J\right)^2 + \left(p_y^J\right)^2}$$

$$\eta_T^J = \frac{1}{2} \ln \left(\frac{E^J + p_z^J}{E^J - p_z^J} \right)$$

$$\phi^J = \tan^{-1} \frac{p_y^J}{p_x^J}$$

respectively. We can also calculate distance between jets by

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

Data and analysis

In our simulation, we set pp collisions center-of-mass energy to be 8TeV 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.

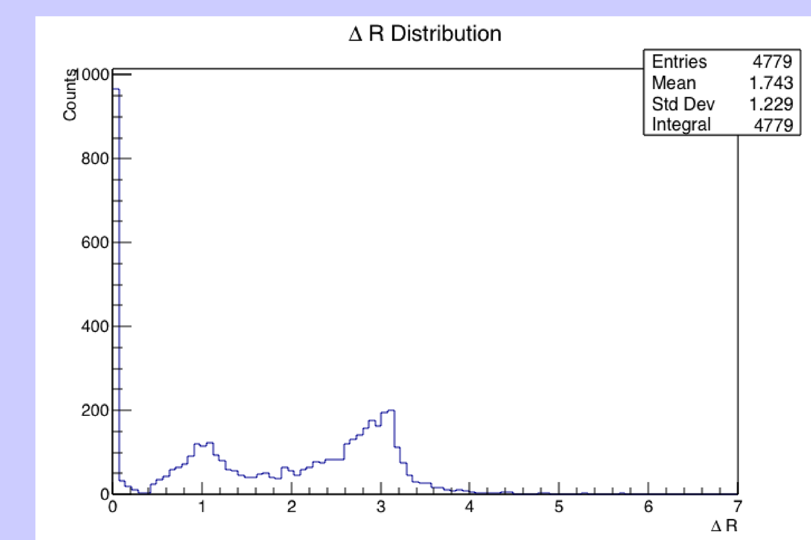
$m_H = 125$ GeV at $\sqrt{s} = 8$TeV				
Process	Cross section × BR [fb]	Acceptance [%]		
		0-lepton	1-lepton	2-lepton
$q\bar{q} \rightarrow (Z \rightarrow \ell\ell)(H \rightarrow b\bar{b})$	14.9	–	1.3 (1.1)	13.4 (10.9)
$gg \rightarrow (Z \rightarrow \ell\ell)(H \rightarrow b\bar{b})$	1.3	–	0.9 (0.7)	10.5 (8.1)
$q\bar{q} \rightarrow (W \rightarrow \ell\nu)(H \rightarrow b\bar{b})$	131.7	0.3 (0.3)	4.2 (3.7)	–
$q\bar{q} \rightarrow (Z \rightarrow \nu\nu)(H \rightarrow b\bar{b})$	44.2	4.0 (3.8)	–	–
$gg \rightarrow (Z \rightarrow \nu\nu)(H \rightarrow b\bar{b})$	3.8	5.5 (5.0)	–	–

Table 1
The cross section times branching fractions for different decay channel [1].

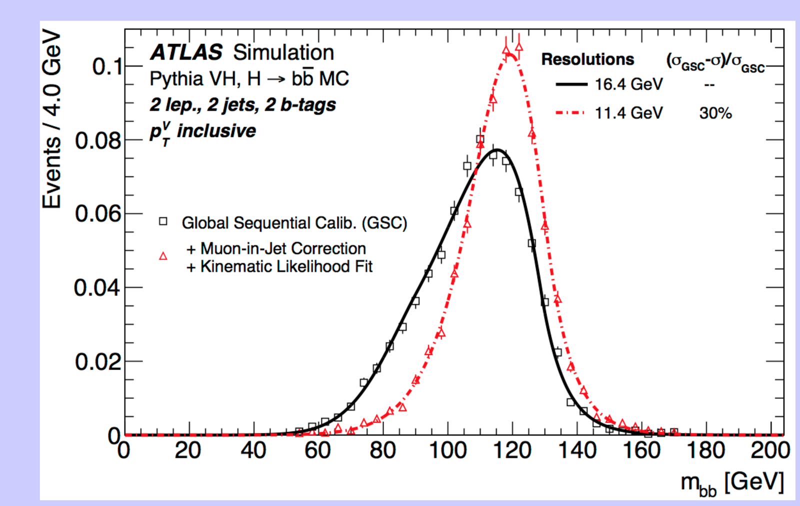
We generated 1000 events of $ZH \rightarrow \mu^+\mu^- b\bar{b}$ with phase space p_T minimum set at 150 GeV. The main goal of this simulation was to see when, at what values of the transverse momenta p_T the two b-jets start merging into a single jet. We would then treat un-merged and merged jets separately, e.g. calibrate them separately, determine the di-jet invariant mass and compare with the Higgs boson mass which should be around 125 GeV.

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 calibrate the di-jet invariant mass for merged b-jets so that they yield the Higgs boson mass of 125 GeV (Figure 4).



(a)



(b)

Figure 4
(a) ΔR distribution between any reconstructed jets.
(b) Di-jet invariant mass distribution for Higgs decay products before and after calibrations. Jet correction and kinematic fit for Higgs mass from ATLAS group [1].

If we can verify this and compare with the upcoming experimental results, we can confirm the $H \rightarrow b\bar{b}$ decay channel exists. Or exclude its existence, which would be an important test of the SM.

References

[1] Georges Aad et al. Search for the $b\bar{b}$ decay of the Standard Model Higgs boson in associated $(W/Z)H$ production with the ATLAS detector. *JHEP*, 01:069, 2015.

[2] Vardan Khachatryan et al. Search for the standard model Higgs boson produced through vector boson fusion and decaying to $b\bar{b}$. *Phys. Rev.*, D92(3):032008, 2015.

[3] Vardan Khachatryan et al. Search for a charged Higgs boson in pp collisions at $\sqrt{s} = 8$ TeV. *JHEP*, 11:018, 2015.