Advanced Physical Research
Vol.3, No.1, 2021, pp.14-18

STUDY OF THE STANDARD MODEL HIGGS BOSON IN THE ATLAS EXPERIMENT

F.N. Ahmadov[1,2*]

[1]Institute of Physics, ANAS, Baku, Azerbaijan
[2]Joint Institute for Nuclear Research, Dubna, Russia

Abstract. In this work, we propose to use new angular variables as a cut which can reduce background events more than signal events. These variables are cosine of angle between the directions of charge lepton in W rest frame and the direction of the W boson in the WH center-of-mass frame, and the cosine of the angle between the direction of the W boson and the initial particles (q or $\bar{q}$) in the WH center-of-mass frame. Monte Carlo events are generated with CompHEP. Significant differences were found between the distributions of the proposed angular variables for the signal and background processes. Similar results were obtained when testing these angular variables with events from PYTHIA.

Keywords: *Standard model, Higgs boson, ATLAS experiment.*

Corresponding Author: *F.N. Ahmadov, Joint Institute for Nuclear Research, 141980, Dubna, Russia, e-mail: fahmadov@jinr.ru*

Received: *30 November 2020;* ***Accepted:*** *10 December 2020;* ***Published:*** *15 April 2021.*

1. Introduction

The Higgs (H) boson until 2012 was the last fundamental unobserved particle in the Standard Model (SM). And therefore, the search for the existence of this particle was the main goal of the LHC and Tevatron accelerators. In the SM, the existence of the Higgs boson explains the origin of the mass of all particles (Higgs, 1964;Englert& Brout,1964). But before experiment observation, the mass of the Higgs boson was unknown. On July 4, 2012, the ATLAS and CMS experiments at the Large Hadron Collider announced the observation of a new particle with a mass of ~125 GeV (ATLAS Collaboration, 2012; CMS Collaboration,2012). Since the lifetime of the Higgs boson is very short, only its decay product can be observed in the detector. The Higgs boson can decay into any particle-antiparticle pair other than the top quark. The first observed decay channels of the Higgs boson are decays into a pair of photons and Z-bosons (with further decay into e^+e^- or $\mu^+\mu^-$) pairs. The Higgs boson with a mass of 125 GeV mainly decays into a pair of $b\bar{b}$ quarks (decay probability 58%) (ATLAS Collaboration, 2015). Therefore, observation and analysis of this decay channel is very important for studying the Higgs boson.

In a proton-proton collision, the Higgs boson is produced through the following channels: gluon-gluon fusion (ggH), vector boson fusion (VBF), associated production with vector bosons (WH or ZH) and with top anti-top pair ($t\bar{t}H$). The ggH process has the largest cross section, but for the Higgs boson decay to $b\bar{b}$ this process has a very large background, which comes from QCD. Therefore, this channel is not a favorable channel for the Higgs boson decays into quark anti-quark pairs. The vector boson fusion channel is good if the Higgs boson mass was 160 GeV. The associated production of

Higgs boson with vector bosons or $t\bar{t}$ pair is a promising channel for the $H \to b\bar{b}$ decay. Due to the fact that the cross section for the associated production of the Higgs boson with the W-boson is several times larger than the associated production with the $t\bar{t}$ pair, we use the WH production process for the $H \to b\bar{b}$. In contrast to the ggH in the WH production process the decay of the vector boson into leptons makes it possible to use these leptons to strongly suppress the multi-jet background from QCD.

In this work, only the leptonic (electron or muon) decay of the W boson is considered. In the experiment, due to the complexity of reconstructing and distinguishing from a quark jet, the decay of W into a tau quark was not considered. In the final state, we get 4 particles, a charged lepton (e or μ), neutrino, b and anti b quark ($WH \to lvb\bar{b}$). But with this final state many background processes arise. We have considered two of them that are difficult to suppress using standard cuts for kinematic variables. The first one is $WZ \to lvb\bar{b}$ because of the close mass of Z and H it is difficult to distinguish it from the signal. And the second one is $Wb\bar{b} \to lvb\bar{b}$, which has a very large cross section. Despite the use of the limitation on the transverse momenta and other kinematic variables of the final particles strongly suppresses the number of events in the second background process, there is still an event that is an order of magnitude larger than the signal.

2. New variables to reduce background events

The cross sections for background processes for each Higgs boson production process are at least several orders of magnitude larger than for signaling processes. The cuts used so far were not enough to separate signal events from background ones. Therefore, we are looking for new variables that will be used as a cut to separate the signal from the huge background events. We propose the following angular variables as new variables:

1. $\cos\theta_\ell$ - cosine of angle between the direction of charged lepton in the rest frame of the W-bosons and W-boson in the WH center-of-mass frame (c.m.f.);
2. $\cos\theta_W$ - cosine of angle between direction of initial particles and direction of W-boson in WH c.m.f.

These angles are shown in Figure 1.

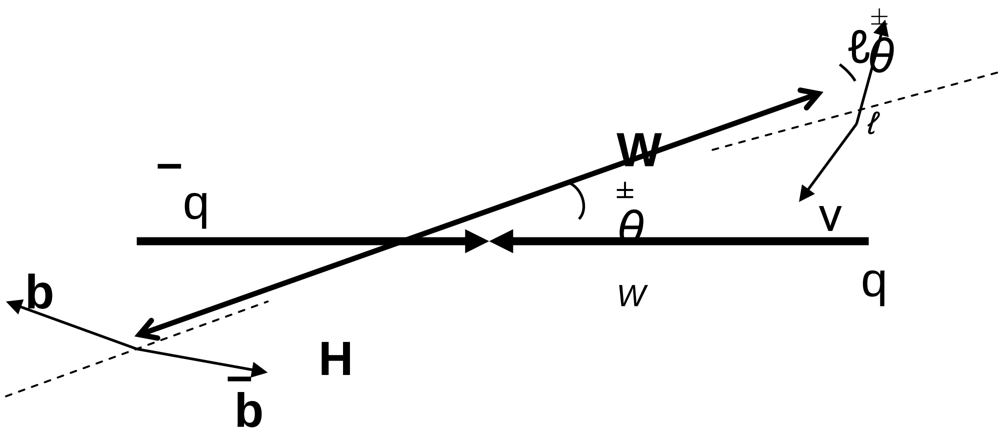


Fig. 1. Scheme of associative production of WH in the $q\bar{q}$ c.m.f

The differential cross section for WZ production can be given in terms of spin density matrix elements (SDM) (L3 Collaboration, 2003; OPAL Collaboration, 2004).Angular distribution for lepton in the rest frame of the W boson in terms of the diagonal elements of the SDM is given as follows:

$$\frac{1}{\sigma}\frac{d\sigma}{dcos\theta_l} = \rho_{--}\frac{3}{8}(1+cos\theta_l^*)^2 + \rho_{++}\frac{3}{8}(1-cos\theta_l^*)^2 + \rho_{00}\frac{3}{4}sin^2\theta_l^*$$

And for the Z-boson, this angular distribution can be written as follows:

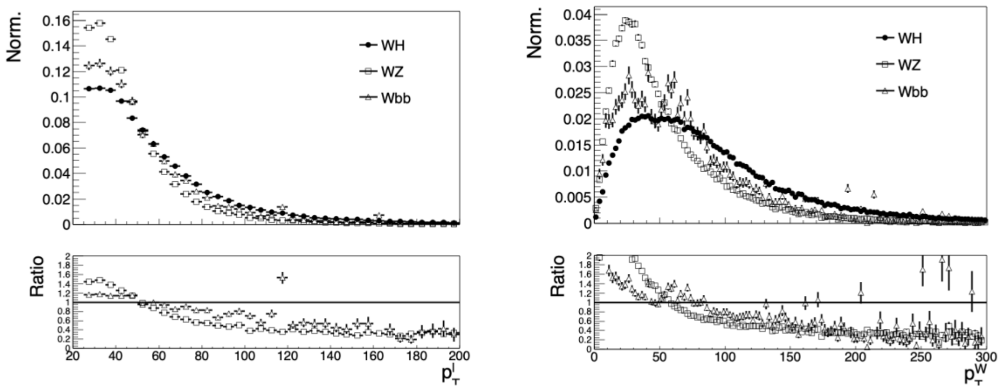
$$\frac{1}{\sigma}\frac{d\sigma}{dcos\,\theta_l} = \rho_{--}\frac{3}{8}(1+cos\theta_l^{*2} + 2\cdot A\cdot cos\theta_l^*) + \rho_{++}\frac{3}{8}(1+cos\theta_l^{*2} - 2\cdot A\cdot cos\theta_l^*) + \rho_{00}\frac{3}{4}sin^2\theta_l^*\ .$$

As we know, the Higgs boson is a scalar particle, and the spin of the Z-boson is equal to one. Therefore, the angular distribution of the lepton (from W decay) will differ for the WH and WZ processes.

3. Angular distribution for signal and background

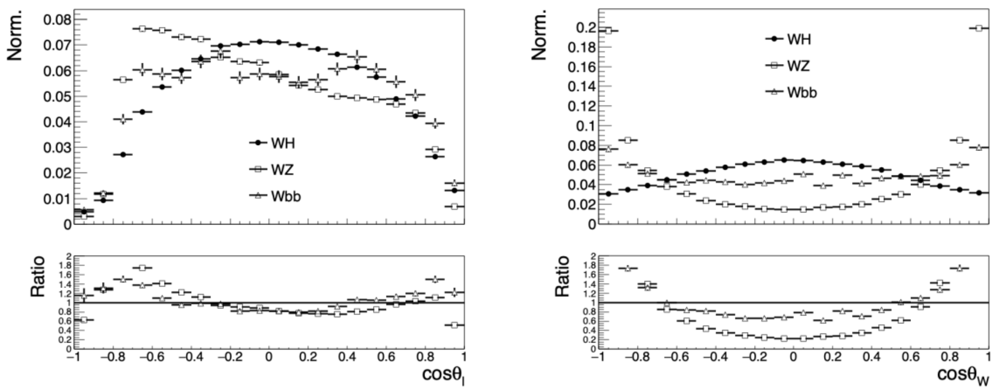
We used CompHEP program to generate the MC events for signal and background processes. To obtain the distribution of new variables, the generated event files were processed using the ROOT programs. When we generate signal and background events, information about the four-momentum of all particles is saved in the output file. Using this information, we can calculate the mentioned new angular variables.

First of all, we need to check widely used variables such as the transverse momentum of the intermediate and final states particles. Figure 2 shows the transverse momentum of a charged lepton and a W-boson, for WH signals (full circle), WZ (open square) and $Wb\bar{b}$ (open triangle up) backgrounds. From the distribution for signal and background events, it can be seen that, in the low transverse momentum region, background events have advantages, and in the higher transverse momentum region, vice versa, as expected. Figure 3 shows the new angular variables defined above. The types of histograms for signal and background are the same as in Figure 2. In Figure 3a shows the distributions of the cosine of the charged lepton decay angle in the W rest frame relative to the W direction at $q\bar{q}$ c.m.f. and Figure 3b shows the cosine of the W-boson polar angle from the collision axis at $q\bar{q}$ c.m.f.



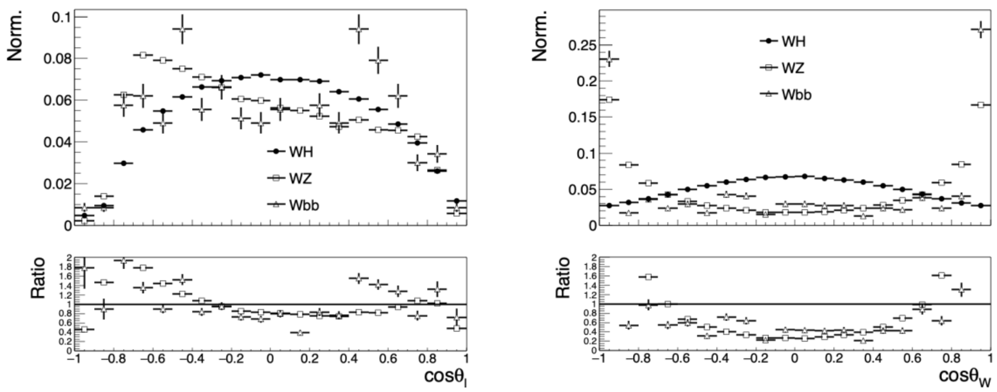
a *b*

Fig. 2. Distributions of the transverse momentum of the charged lepton (*a*) and W-boson (*b*)



a *b*

Fig. 3. Distributions of (*a*) the cosine of the charged lepton decay angle in the *W* rest frame relative to the *W* direction in the $q\bar{q}$ c.m.f. and (*b*) the cosine of the *W*-boson polar angle from the collision axis in the $q\bar{q}$ c.m.f. for *WH* signal, *WZ* and $Wb\bar{b}$ background events. Data received from CompHEP



a *b*

Fig. 4. Distributions of (*a*) the cosine of the charged lepton decay angle in the *W* rest frame relative to the *W* direction in the $q\bar{q}$ c.m.f. and (*b*) the cosine of the *W*-boson polar angle from the collision axis in the $q\bar{q}$ c.m.f. for *WH* signal, *WZ* and $Wb\bar{b}$ background events. Data received from PYTHIA

4. Conclusion

It can be seen from the distribution of the angular variable that most of the signal events are located in the central region, while background events are mainly located at the edges. This difference allows these angular variables to be used as cuts. The same variables are also checked with the data obtained using PYTHIA. As it can be seen in Figure 4, the angular distributions obtained from the PYTHIA data are similar to those obtained from the CompHEP data. This similarity confirms that the spin information is taken into account by both generators and that these angular variables are calculated correctly.

References

Higgs, P.W. (1964). Broken symmetries, massless particles and gauge fields. *Physics Letters*, 12, 132-133.

Englert, F., & Brout, R. (1964). Broken Symmetry and the Mass of Gauge Vector Mesons, *Physical Review Letters*, 13, 321-323.

ATLAS Collaboration. (2012). Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, *Physics Letters B*, 716, 1-29.

ATLAS Collaboration. (2015). Search for the bb decay of the Standard Model Higgs boson in associated (W/Z)H production with the ATLAS detector, *Journal of High Energy Physics*, 1501, 069 (1-87).

CMS Collaboration. (2012). Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, *Physics Letters B*, 716, 30-61.

L3 Collaboration. (2003). Measurement of W polarization at LEP, *Physics Letters B*, 557, 147-156.

OPAL Collaboration. (2004). W boson polarization at LEP2, *Physics Letters B*, 585, 223-236.