STUDY OF WH PRODUCTION AT LHC USING DIFFERENT EVENT GENERATORS

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In this paper, the angular features of the signal and background processes of the associated production of the Higgs boson with W-boson are presented. Signal and background processes are generated using the CompHEP, POWHEG and PYTHIA generators. Monte Carlo data are processed in ROOT software. We also compared the shape of the distributions of kinematic variables obtained from different generators and found that the shape of these distributions is similar for different generators. Significant deviation of POWHEG distributions from other generators can be explained by the fact that it uses NLO correction while other generators use LO approximation.

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1. INRTODUCTION

One of the important production mechanism for the Higgs bosons in the Standard Model is its associated production with the $W^{\pm}$ -boson, $q\bar{q} \rightarrow W^{\pm}H$, where the $W^{\pm}$ bosons decay into leptons and the Higgs boson decays into a $b\bar{b}$ pairs. This work is motivated by the fact that observing the decay of the Higgs boson into a pair of $b\bar{b}$ quarks is a very important discovery for particle physics. There are various generators for simulating processes used in high energy physics to study the properties of elementary particles and fundamental interactions. It is very useful to compare the results from different event generators, and to try to understand the differences. The choice of event generators depends on the level of agreement of the data obtained from it with the experimental data, but when presenting the results of the selected event generator, it can be criticized. This work was done by using CompHEP [1], PYTHIA [2] and POWHEG [3] Monte Carlo event generators, which are designed to calculate the total cross sections and provide kinematic distributions for processes with several particles in the final state. The Leading Order (LO) or Next-to-Leading Order (NLO) Parton Distribution Functions (PDF) can be used depending on the generators. The generated Monte Carlo events were analyzed using the ROOT program [4]. Comparison of the results obtained from different generators are presented. CompHEP starts with the Feynman rules for the Lagrangian of the gauge model and calculates the matrix element for any process defined by the user. CompHEP is able to compute basically the lowest order (LO) cross sections and distributions with several particles in the final state (up to 6-7). It can take into account, all quantum chromodynamics (QCD) and electroweak (EW) diagrams, masses of fermions and bosons and widths of unstable particles.

The PYTHIA program appeared to solve the problem related to drawing strings in proton-proton processes. We used the latest version (v8) of the PYTHIA program [5]. The working procedure with the generator was divided into several stages. The first one is the initialization phase. It defines all basic characteristics of the future generated process. The next step is the generation cycle. At this stage, the events that will be generated and analyzed later are set up. And at the last stage, after the completion of the generation process, we get the result as an event file.

The main idea in POWHEG is to generate the hardest process first. After that the event is feed to any shower generator for subsequent, softer radiation. The first POWHEG concept was the realization of Z pair production in hadronic collisions. Processes such as the gluon fusion production of Higgs boson, Drell-Yan vector boson production, and single-top production were later included. POWHEG is implemented for generic processes using the POWHEG BOX package. It allows automatically create own POWHEG implementation for a process with given NLO matrix elements. The POWHEG BOX is a general computer framework for implementing NLO calculations in programs according to the POWHEG method. It also provides a library where included processes are made available to users. It can be connected with all modern Monte Carlo shower programs.

2. SIMULATION OF SIGNAL AND BACKGROUND SAMPLES

The procedure for generating events in PYTHIA is strictly organized: switches and parameters cannot be changed during the run, therefore, it is necessary to initialize the generation completely before generating events. To get the correct results, you need to give a fairly accurate recipe for the structure of the run. The process of generating events using the PYTHIA generator consists of several stages. First, at the initialization stage, we select the process which is needed. At this stage, you can change the default value of the beam energy. After setting the number of

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events, the event generation process starts. At the beginning of the generation process information for the first event is printed to ensure that everything is working as planned. At the last stage, we receive the results of the generation as a table for the first event and as an LHE or root file that contains information about all events.

The CompHEP package is designed to calculate cross sections and generation of hard (basic) processes from matrix element (lagrangian) in the lowest order of perturbation theory. No higher order correction and hadronization are possible. CompHEP is divided into two separate parts, symbolic and numerical ones. The symbolic program is compiled and conserved in the installation area. The numerical binary is designed from several libraries and C code generated by the symbolic program. The calculation of signal and background processes in the program is carried out by determining the model of the interaction of elementary particles, which is necessary to continue work. The first thing user should do is to choose the desired model. The procedure for generating events with CompHEP was exercised as in [6].

The first step in the generation of the code for a new process in POWHEG is to create a directory under the main POWHEG BOX and to work from inside this folder. This directory is called the process folder, from where all script files have to be executed. For a complete generation process, the basic necessary steps are performed as in [7].

In this paper, we considered $pp \to WH \to l\nu b\bar{b}$, as a signal process, $pp \to WZ \to l\nu b\bar{b}$ and $pp \to Wb\bar{b} \to l\nu b\bar{b}$ as background processes, where $l = e^{\pm}$ or $\mu^{\pm}$. The energies of the first and second beams (protons) were set to 6500 GeV, i.e. a total energy was 13 TeV. In all generators, 125 GeV was taken as the mass of the Higgs boson. Table 1 illustrates some features of the generators used in this work.

Table 1. Main features of the generators for signal process

	CompHEP	PYTHIA8	POWHEG
# event	320000	320000	310000
Type of calculation	LO	LO	NLO
Parton-distribution function (PDF)	CTEQ6l1	CTEQ6l1	CTEQ6M

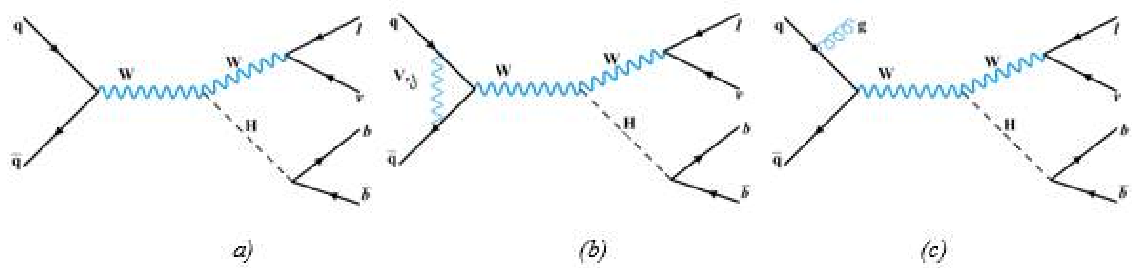


Fig. 1. Feynman diagrams for WH process at LO (a) and at NLO (b,c) as EW and QCD corrections to the LO respectively.

The LO and some NLO Feynman diagrams for the $pp \to WH \to l\nu b\bar{b}$ process are shown in Figure 1. The difference in transverse momentum distributions between the LO and NLO event generators can be seen in Figure 2. It should be noted that the differences between LO and NLO generators are not limited to the difference in the PDFs they use.

Another difference between them is that at the hard scattering level the formers use tree level matrix elements while the latter use one loop matrix elements. In the case of generating events with NLO matrix elements you improve the precision by lowering the dependencies of the renormalisation and factorization scales. The cross-section in the next to leading order approximation can be different from the cross-sections in the leading order by up to 30%. There are number of background processes that have large cross sections. In this work, we propose and use some variables ($cos\theta_l$, $cos\theta_W$) that will help to solve the background dominance problem.

3. EVENT SELECTION AND DATA ANALYSIS

Due to the big amount of background events, the search for signal events is complicated. Therefore, the choice of kinematic variables is important for the signal event selection. Some of the variables are determined using an approach that was used in the analysis at LEP [8] and in the ATLAS experiment [9]. One of these variables is transverse momentum of the charged lepton from the W decay (Figure 2). Another variable we use is the angle of the charged lepton in W rest frame relative to the W direction in WH or WZ/ $Wb\bar{b}$ center of mass system for the signal and background processes respectively. To determine this angle, we have to transform all momenta from laboratory system to the WH center-of-mass frame (c.m.f.). Then we rotate the direction of the W-boson so that it coincides with the z-direction. Finally, we transform momentum of W boson along the z- axis to rest frame of W-boson. Since the same variable for other particles of final state (neutrino, b and anti b-quarks) depends on each other and does not provide additional information, we define this variable only for the charged lepton. Figure 3*a* presents the comparison of the distributions of 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 figure 3b - the cosine of the W-boson polar angle with respect to the collision axis in the $q\bar{q}$ c.m.f. for events that are received from POWHEG, PYTHIA8 and CompHEP generators. Before creating these plots, we select events by applying a cut to some kinematic variables. These variables and applied cuts are as follows:

- The transverse momentum of a charged lepton, b- and anti b-quarks are required to be greater than 25 GeV, and for neutrinos - greater than 20 GeV.
- The pseudorapidity of the charged lepton, b- and anti-b-quarks should be within [-2.5, +2.5].
- The transverse momentum of the W boson must be greater than 150 GeV.

These cuts were selected according to those used in the analysis of experimental data [10]. They are related to the possibilities of reconstruction and calibration of the jets and leptons and suppression of the detector effects.

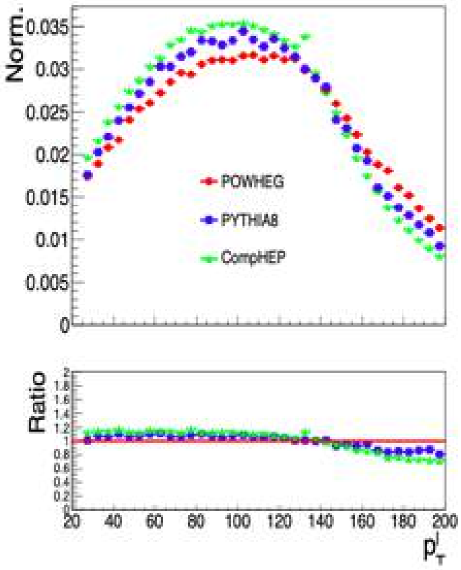
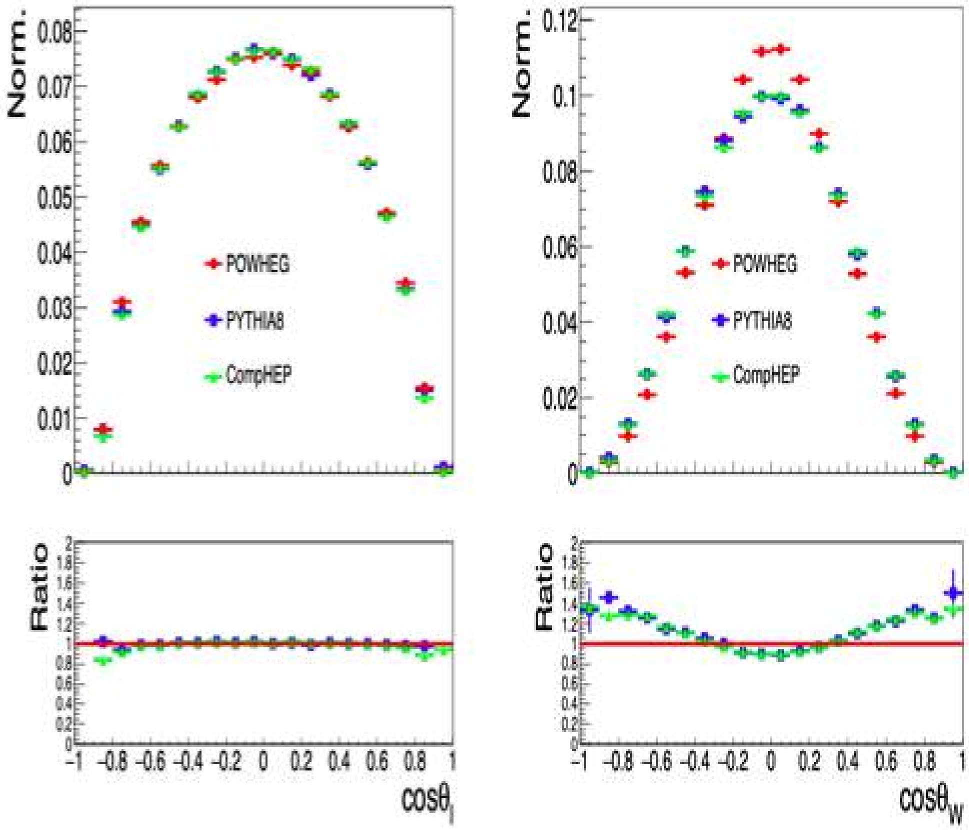


Fig. 2. Distributions of the transverse momentum of the charged lepton.



(*a*) (*b*)

Fig. 3. Distributions of the cosine of the charged lepton (a) 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 different generators.

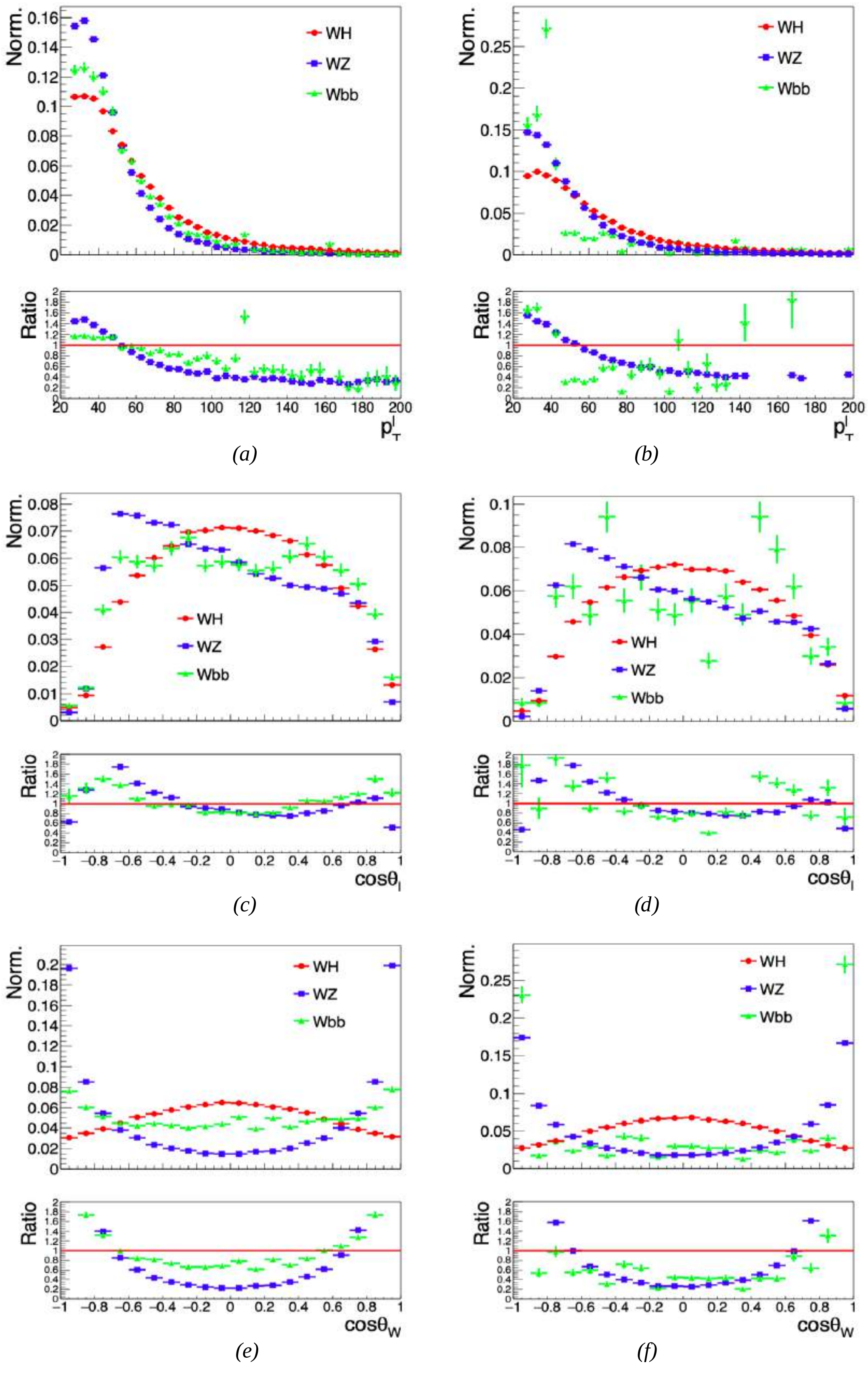


Fig. 4. Distributions of the transverse momentum of the charged lepton, the cosine of the charged lepton angle in the W rest frame relative to the W direction in the $q\bar{q}$ c.m.f. and the cosine of the W-boson polar angle from the collision axis in the $q\bar{q}$ c.m.f. for *WH*, *ZH* and $Wb\bar{b}$ events obtained (*a*, *c*, *e*) from CompHEP and (*b*, *d*, *f*) from PYTHIA8.

The distributions of some kinematic variables for the signal and background processes were compared. This procedure was repeated for events, simulated by various generators, in this case the PYTHIA8 and CompHEP generators. The distributions of three variables for signal and background samples are presented by Figures 4 (a-f). These variables are the transverse momentum of the charged lepton (a, b), 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. (c, d) and the cosine of the W-boson polar angle from the collision axis in the $q\bar{q}$ c.m.f. (e, f). The left plots (a, c, e) in Figure 4 were obtained using CompHEP generator, and the right plots (b, d, f) were obtained using PYTHIA8. In the plots, the signal is shown by a histogram with a red full circle, and WZ and $Wb\bar{b}$ are shown by a blue full square and a green full triangle, respectively. The difference in the shape of the distribution of the $Wb\bar{b}$ process between PYTHIA8 and CompHEP is due to the fact that in PYTHIA8 we cannot generate the $Wb\bar{b}$ directly, but only by generating the W+gluon and W+gamma processes, where the gluon and gamma decay into $b\bar{b}$.

4. CONCLUSION

From Figures 2 and 3, it can be seen that the shape of the distributions of variables for different generators are similar and the small difference between POWHEG and two other generators can be explained by the difference in the level of corrections (NLO and LO) that are taken into account during the event generation. It is obvious from Figures 4 that the shape of the distributions of variables for signal and background processes is very different. And these differences can be used in future analyses to suppress a large background contribution. The similarity of these distributions for the CompHEP and PYTHIA8 generators validates these variables and allows them to be used in the event selection process.

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