Fast simulation of the CEPC conceptual detector with Delphes and its validation *

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Abstract: In this paper, the DELPHES is used to simulate the detector on the Circular Electron-Positron Collider (CEPC). The geometry and performance of the CEPC detector are presented. The fast simulation in the DELPHES framework is validated with a few benchmark processes, including $\mu\mu H$ and H to inclusive decay, $q\bar{q}H$ and H to invisible, and $\nu\bar{n}u$ and H decaying via double W bosons. The comparisons between DELPHES and the full simulation, which is based on Geant4 & Marlin, shows that the Dephes can simulate CEPC detector well.

Key words: CEPC, DELPHES , Fast simulation

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1 Introduction

CEPC[1, 2] is a next generation electron-positron collider proposed by Chinese scientists. The machine is expected to collide electron and positron beams at the center-of-mass energy of 240- 250 GeV to maximize the Higgs production cross section through the $e^+e \rightarrow ZH$ process, with an instantaneous luminosity of 2×10^{34} cm$^{-2}s^{-1}$. CEPC is designed to deliver a total of 5 ab^{-1} integrated luminosity to two detectors in 10 years, over 10^6 Higgs events will be produced during this period. The large statistics with clean backgrounds will enable CEPC to perform Higgs precision measurements, Standard Model (SM) tests, and searches for potential new physical phenomenons. In order to investigate sensitivity to new physics, theorists would get involved and various new models would be tested. To save computing time and to simplify the procedure of full detector simulation and reconstruction, a dedicated fast simulation tool is highly demanded.

Delphes [3] is a fast simulation framework developed in 2009, and the latest prime version was released in 2013, which is designed for phenomenological studies on the simulation of various detector designs. The Delphes framework simulates the response of a detector composed of an inner tracker, electromagnetic and hadron calorimeters, and a muon system. All are organized concentrically with a cylindrical symmetry around the beam axis. The energy and momentum are smeared according to the resolutions of detector. Eventually, all kinds of particles are reconstructed with algorithm based on PFA[4] philosophy, then clustering into jets with FastJet [16] .

This paper is organized as following. In Sect. **2**, the CEPC detector concept are introduced briefly. Then in Sect. **3**, the MC generation, full simulation of detector, and framework reconstruction are summarized. In Sect. **4**, some benchmark processes are chosen to the validate the simulation of the Delphes on CEPC by comparing the fast and full simulaitons, including $e^+e^- \rightarrow \mu^+\mu^- H$ and Higgs $\rightarrow$inclusive, $e^+e^- \rightarrow q\bar{q}H$ with Higgs decaying into invisible, $e^+e^- \rightarrow \nu\bar{\nu}H$ with Higgs coupling to W boson pair, and $e^+e^{-}\!\rightarrow ZH \rightarrow 2(q\bar{q})$. In the end the conclusion remarks are presented.

2 CEPC detector conceptual design

The CEPC detector concept design[1] takes the ILC detector, ILD[5, 6], as a reference and adopts the philosophy of PFA, which benefits from a high granularity calorimetric system.

The CEPC detector consists of three main sub-detectors and a superconducting solenoid of 3.5 T. The three sub-detectors are, from inner to outer, a hybrid tracking system composed of several silicon based devices and a Time Projection Chamber (TPC), a high granularity calorimetry system, and a Muon detector.

The hybrid tracking system has five parts. A vertex detector (VTX), constructed with high spatial pixel sensor, is placed very close to the interaction point (IP) and the inner radius is only 16 mm. The VTX provides very precision measurements of the IP position of tracks and events, which is used for the $b-/c-$jet flavor tagging and τ-tagging. A Silicon Inner Tracker (SIT) is just outside and cooperating with the VTX for vertex reconstruction and flavor tagging. A set of Forward Tracking Disks (FTDs) are placed in the forward region to increase the geometric acceptance of tracking system with coverage up to $|\cos\theta| = 0.99$. A Silicon External Tracker (SET) and End-cap Tracking Disks (ETD) are taken as the outermost layer of whole tracker system, which provide precision position measurements of tracks entering the calorimetric system. The TPC, with a 2.35m half-length and 1.8m outer radius, provides about 200 hits per track and 100μm resolution in $r\phi$ plane, which allow for excellent pattern recognition, track reconstruction efficiency, and potential dE/dx-based particle identification.

A calorimetric system consisting of Electromagnetic Calorimeter (ECAL) and Hadron Calorimeter (HCAL) with very fine granularity is placed inside the solenoid. The system plays an essential role in the Particle-Flow Algorithm (PFA), providing excellent separation of showers from different particles and jet energy resolution of 3-4%.

A superconducting solenoid of 3.5 T is surrounding the calorimetry system. The return yoke is placed outside the solenoid. The CEPC muon system acts as the muon identifier, the solenoid flux return yoke and the support structure for the whole spectrometer. High muon detection efficiency, low hadron mis-identification rate, modest position resolution and large coverage are the main concerns of the design.

3 Monte Carlo generation, detector simulation and reconstruction

For CEPC detector design and optimization, a whole set of ZH signal processes and Standard Model (SM) backgrounds have been prepared[7] with generic Monte-Carlo generator Whizard 1.95 [8]. To simulate the detector response, a full simulation package, Mokka [9], based on Geant4 [10] and a fast simulation framework with Delphes [3] are used. The Particle Flow Algorithm (PFA) philosophy is utilized in the reconstruction of both the full and fast simulation.

After full simulation, hits in different sub-detector are digitized properly and reconstructed with reconstruction software framework Marlin [11]. A dedicated PFA, Arbor[12], is adopted for particle reconstruction, and the alternative PFA, Pandora [13], is taken as reference. Jets are reconstructed with LCFIPlus package[14], where a e^+e^- k_t algorithm [15], often referred to also as Durham algorithm, is used for jet-clustering.

The detector model implemented in the DELPHES is same as the one in full simulation but with some necessary simplifications. For the charged tracks simulated with DELPHES, there is a common strategy to smear their momentum. The angular resolution is assumed to be perfect, so that the smearing only applied to the transversal momentum. In practice, the resolution of their momentum is described as a Gaussian, which is parameterized function of p_t and η. The values for the simulation is $\sigma = \sqrt{0.001^2 + (10^{-5}p_t)^2}$ as required in CEPC pre-CDR. Then the charged tracks are reconstructed according to the user-defined probability, which are listed in Tab. 1.

Table 1. Efficiencies for charged tracks(%)

	$P_t \leq 0.1$	$P_t > 0.1$
$\eta \leq 3.0$	0	100
$\eta > 3.0$	0	0

For neutral objects which mainly rely on the calorimetric system, some points should be emphasized: 1. The fake rate for electrons, muons and photons is not implemented in the current version of DELPHES ; 2. The photon conversions into electron-positron pairs are ignored neither. Both the true photons and electrons reaching calorimeter without a reconstructed track are considered as photon in DELPHES .

The overall reconstruction of particles implemented in DELPHES is mainly based on a perfect PFA . For the charged tracks, the reconstruction involves both the tracker system and the calorimetric system. Since the resolution of tracking system is better than this of calorimeter in the CEPC energy region, it can be convenient to use the tracking information within the tracker acceptance for estimating the charged particles momenta. The efficiencies could be parameterized as a function of the energy and pseudo-rapidity. For a preliminary study, the present parameters are listed in Tab. 2, which are consistent those of full simulation and reconstruction.

Table 2. Effciencies for identification of γ, $e^{\pm}$, $\mu^{\pm}$

	Energy≤ 2.0	Energy> 2.0
$\lvert\eta\rvert \leq 1.5$	0	0.99
$1.5 < \lvert\eta\rvert \leq 3.0$	0	0.99
$\lvert\eta\rvert > 3.0$	0	0

In order to get same performance of jet-clustering, e^+e^- k_t algorithm is also used for the results of fast simulation. The exclusive mode of fast jet is used and all input particles are forced into fixed number of jets without any y_{ij} or P_t cuts, which can be applied at analysis stage.

4 Validation with full simulation

The simulation and reconstruction in DELPHES has to be validated by comparing the resolution of output objects to those of full simulation, as well as the efficiencies. Three benchmark processes are selected for the validation, which cover all the main physics objects of CEPC experiments, such as tracks, photons, and (multi-)jets final sates.

For this purpose, all the relevant distributions should be compared to check the shapes, the resolutions, and efficiencies. In these plots, the outputs from DELPHES approximately agree with the full simulation cases, some points should be mentioned:

4.1 $e^+e^- \to \mu^+\mu^- h$

For $\mu^+\mu^- h$ channel and $q\bar{q}h$ channel, the di-muons and di-jets come from Z boson decay, and Higgs is tagged from the recoiling side, so the invariant mass of those systems represent Z meanwhile the recoiling mass is Higgs. But in $nnh \to WW^*$, the Z boson decays invisibly into neutrinos, all the visible information comes from WW^* and eventually from Higgs, so in Fig. 6 and Fig. 5 the invariant mass represent Higgs and recoiling side is Z.

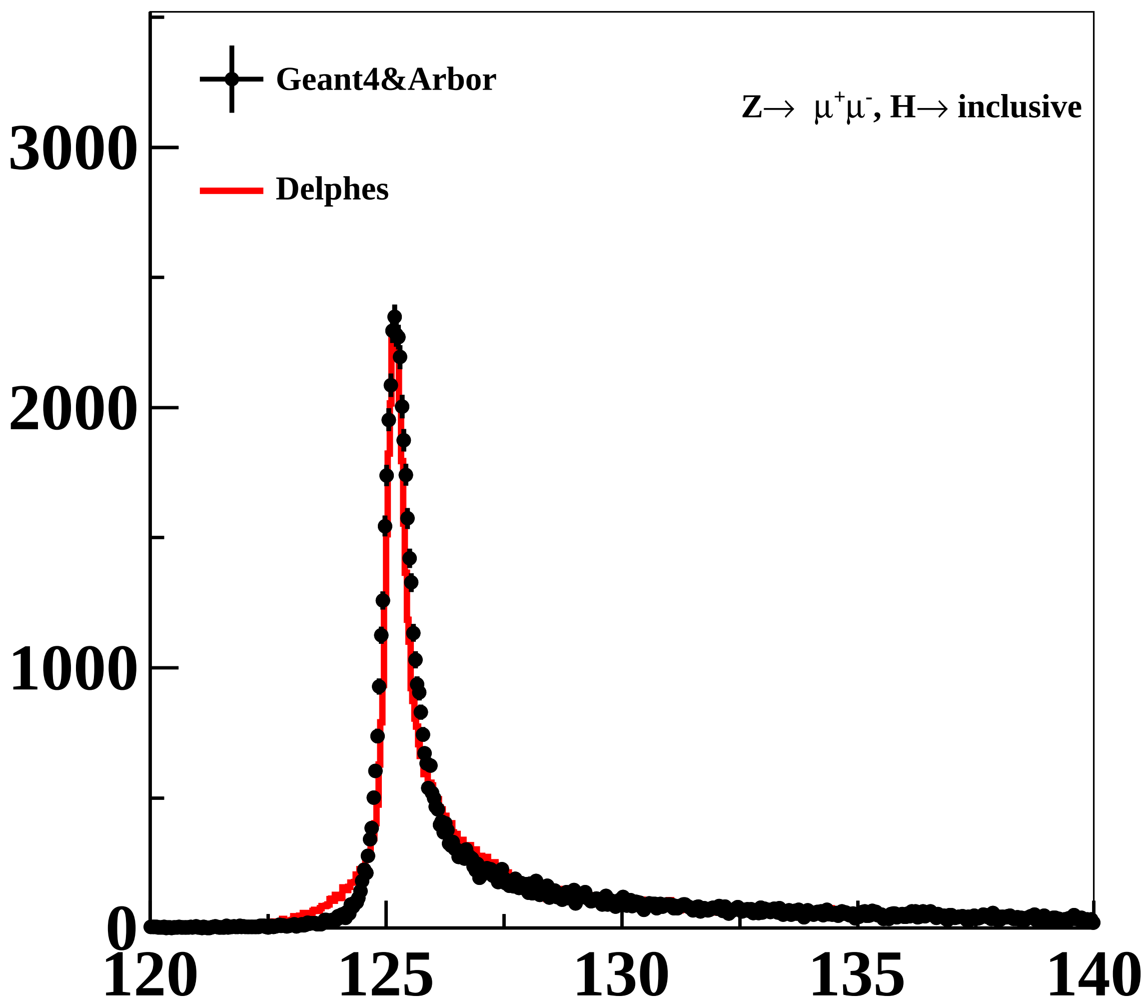

Fig. 1. Recoiling mass against $\mu^+\mu^-$.

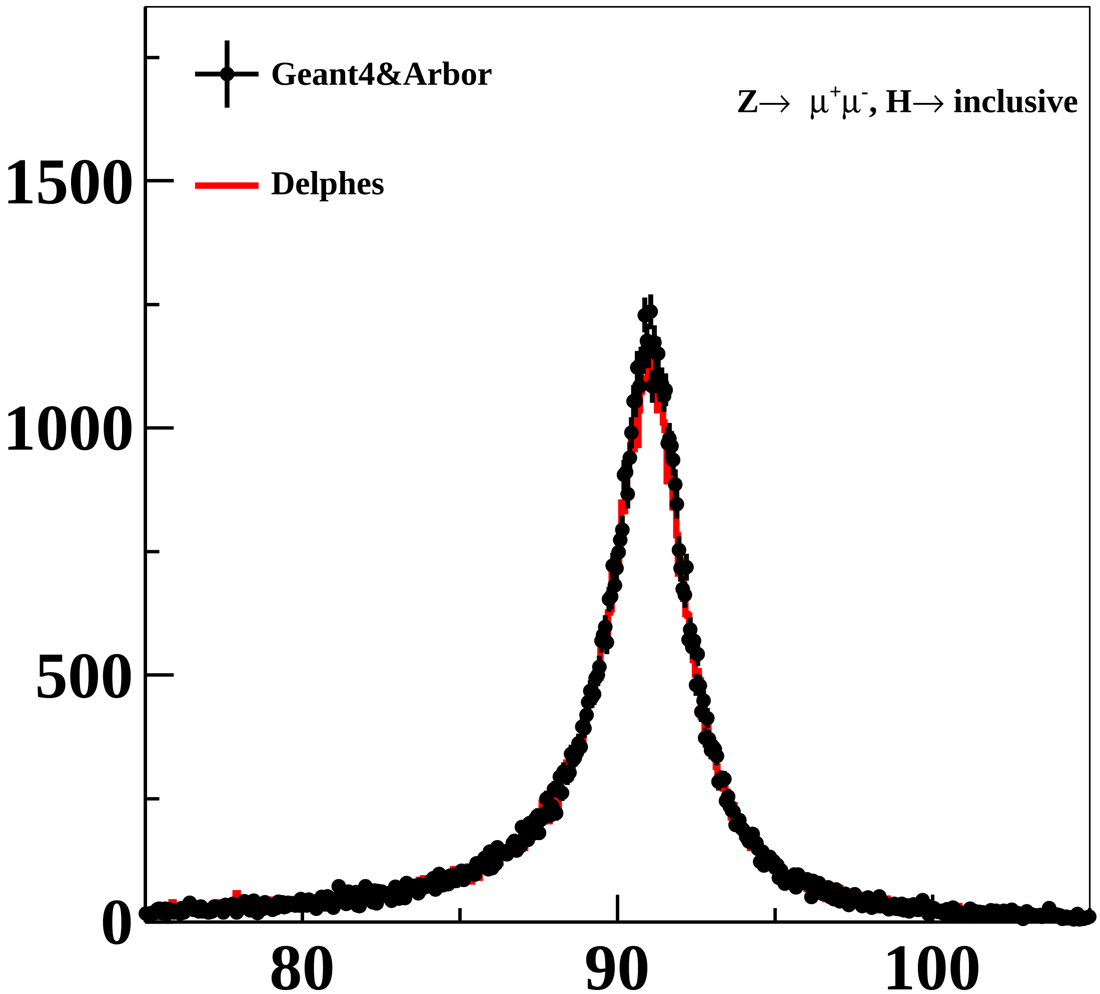

Fig. 2. Invariant mass of $\mu^+\mu^-$.

4.2 $e^+e^- \to q\bar{q}h, h \to$ invisible and $e^+e^- \to \nu\bar{\nu}H, H \to q\bar{q}$

The Z mass in $q\bar{q}h$ channel is rescaled after Arbor's output, the final effect of the rescaling is a translation from right to left in X axis. This operation could be considered as an calibration for the reconstruction scheme.

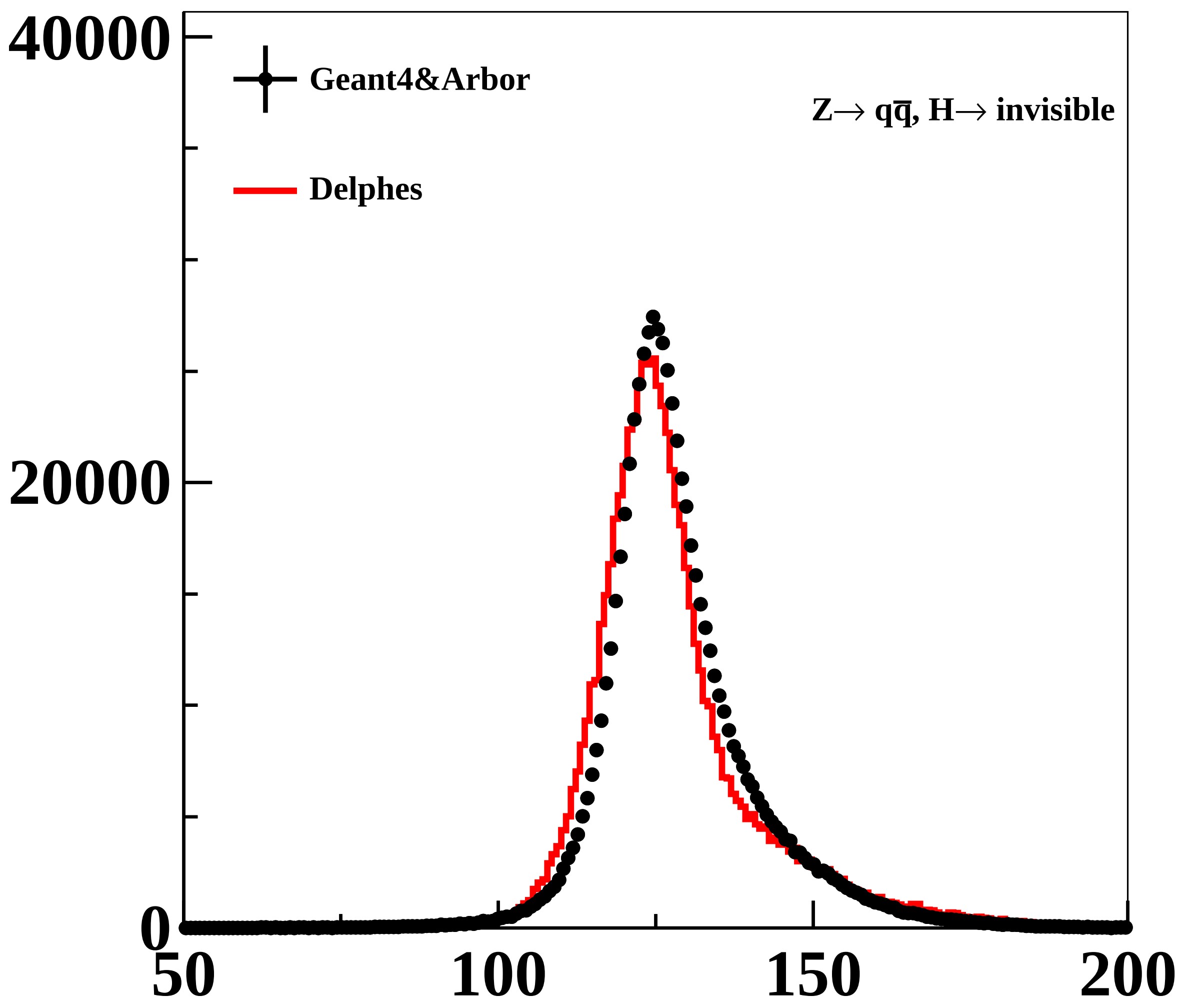

Fig. 3. Recoiling mass against $q\bar{q}$.

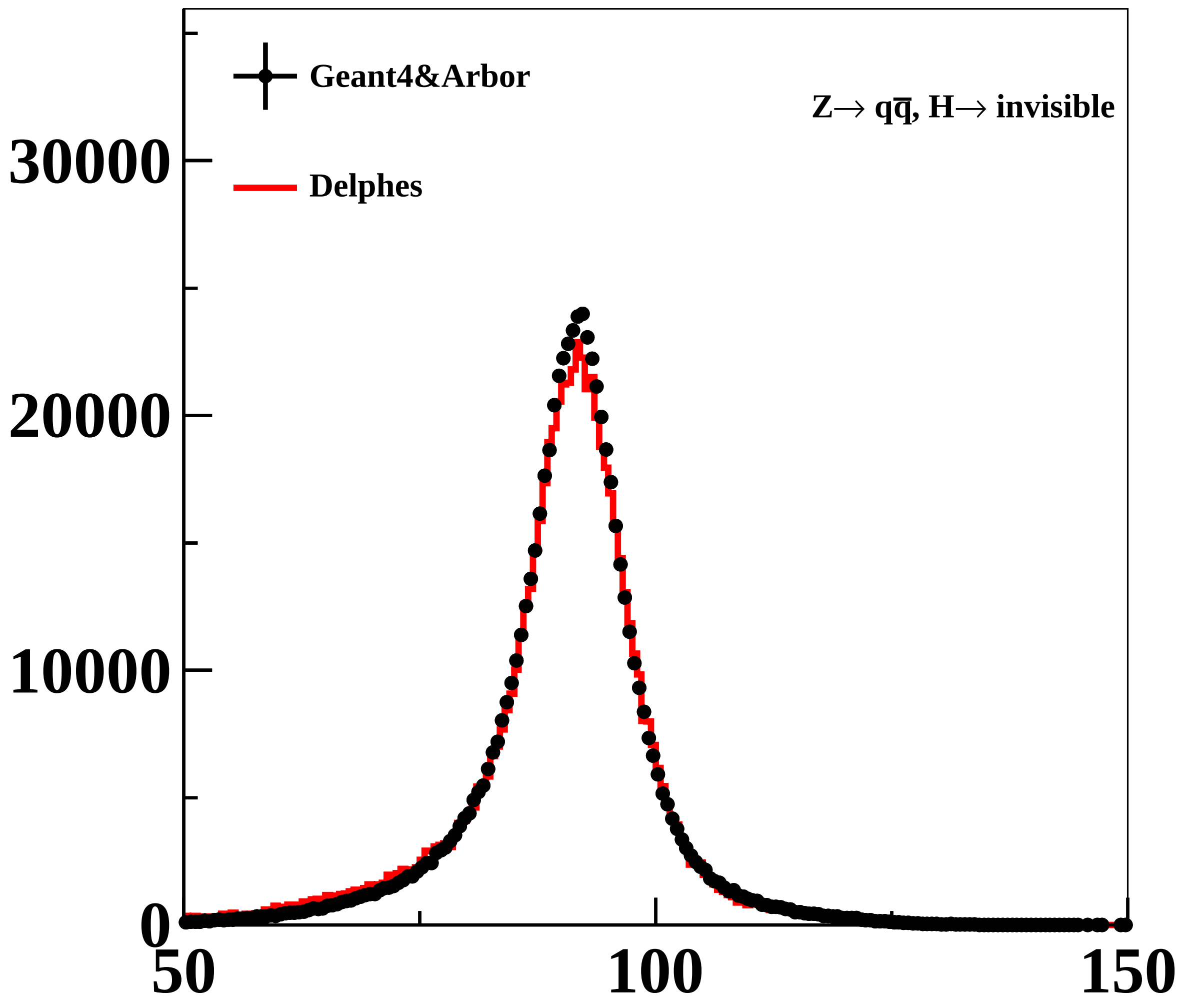

Fig. 4. Invariant mass of $q\bar{q}$.

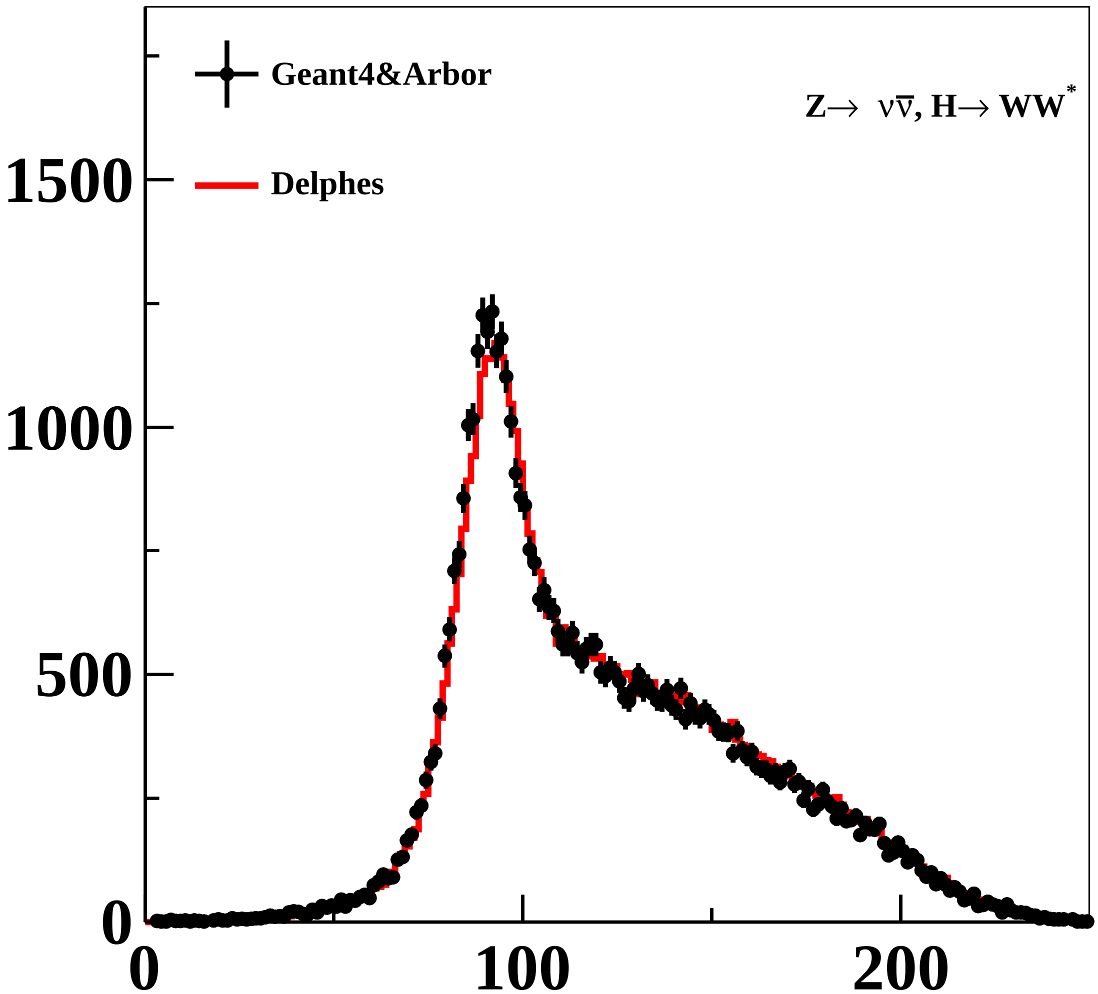

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Fig. 5. Recoiling mass against WW^* in $n\bar{n}h \rightarrow WW^*$.

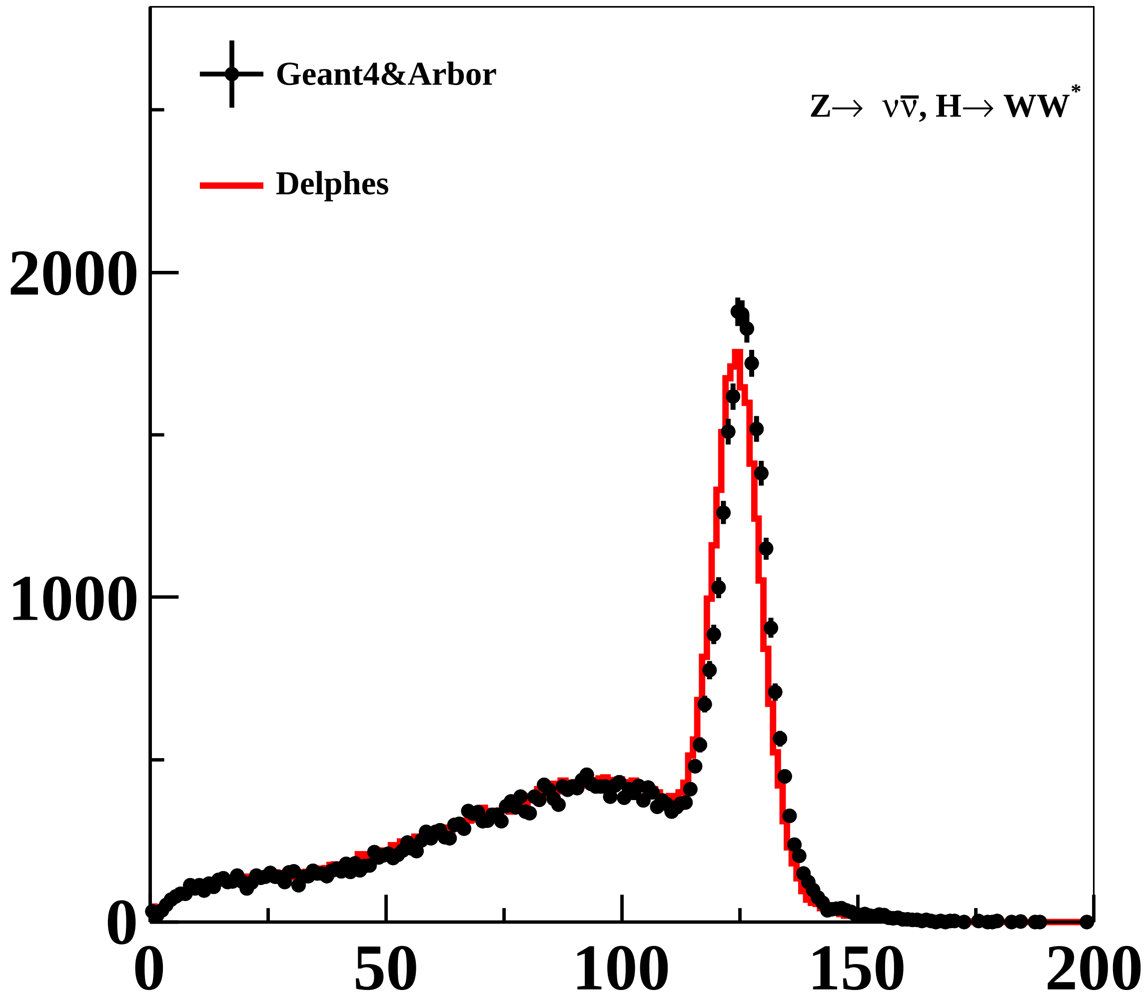

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Fig. 6. Visible mass in $n\bar{n}h \rightarrow WW^{*}$.

4.3 $e^+e^- \to ZH \to 2(q\bar{q})$

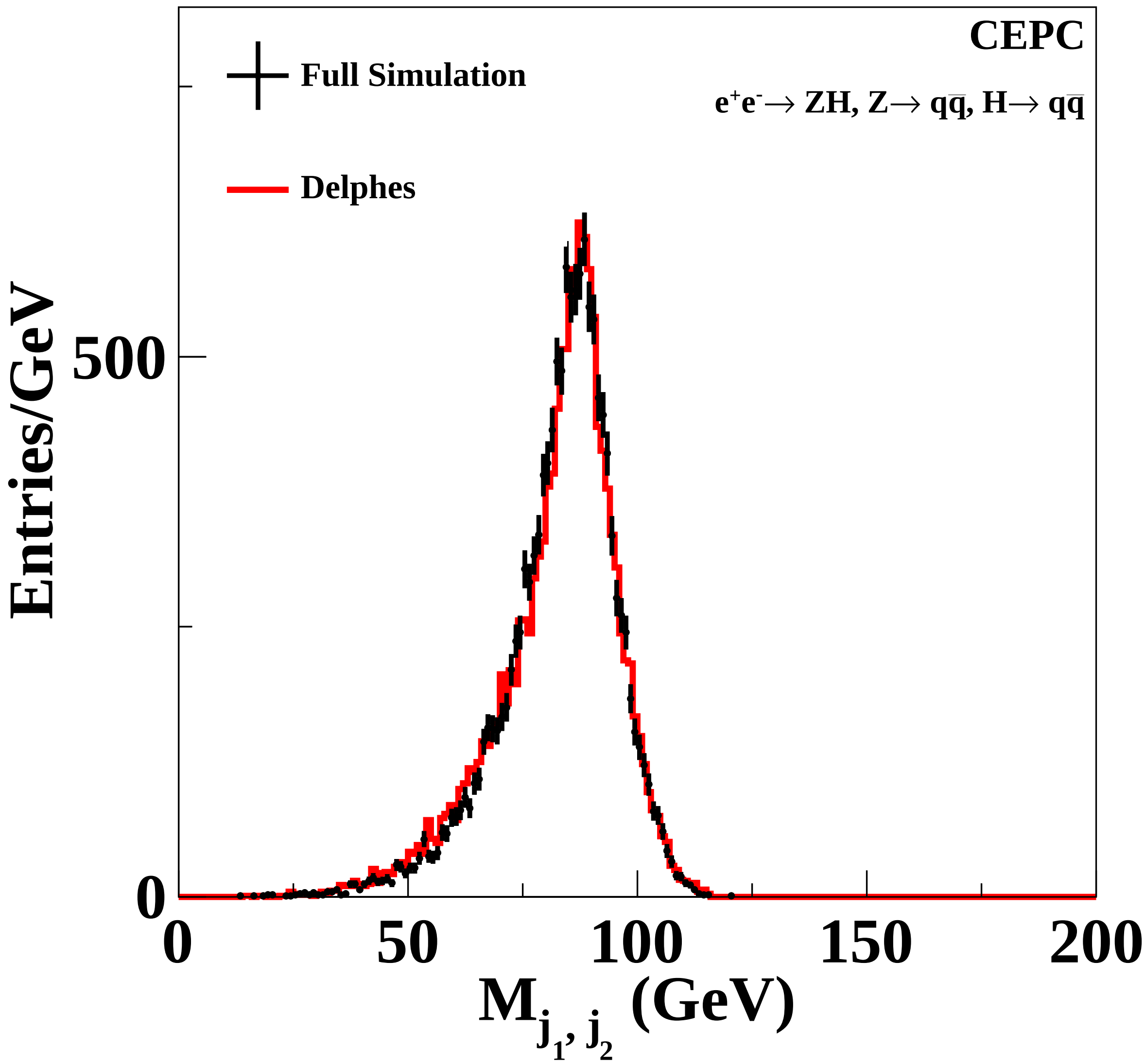

Fig. 7. Invariant mas of jet pair, peaking at Z mass.

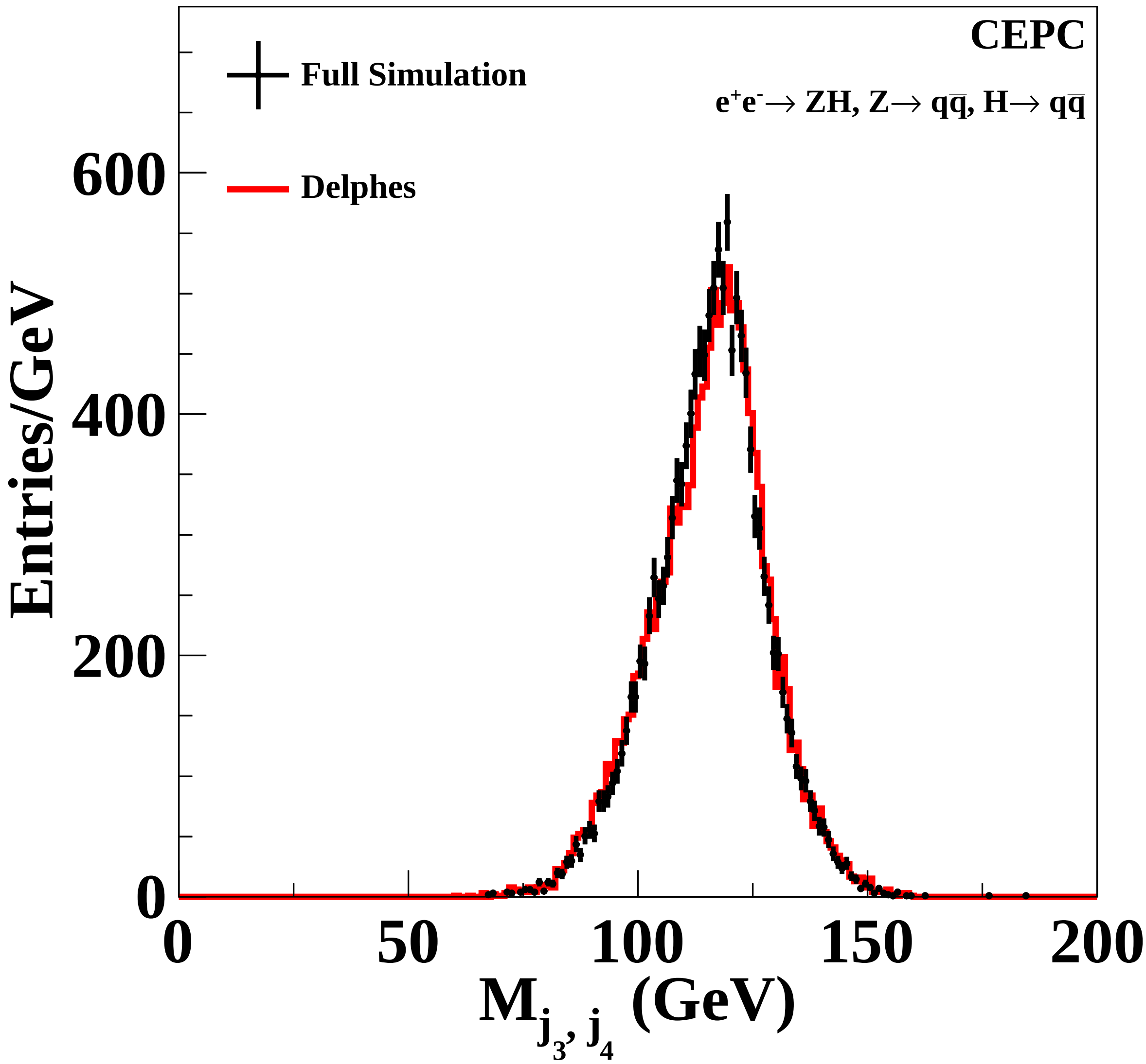

Fig. 8. Invariant mas of jet pair, peaking at Higgs mass

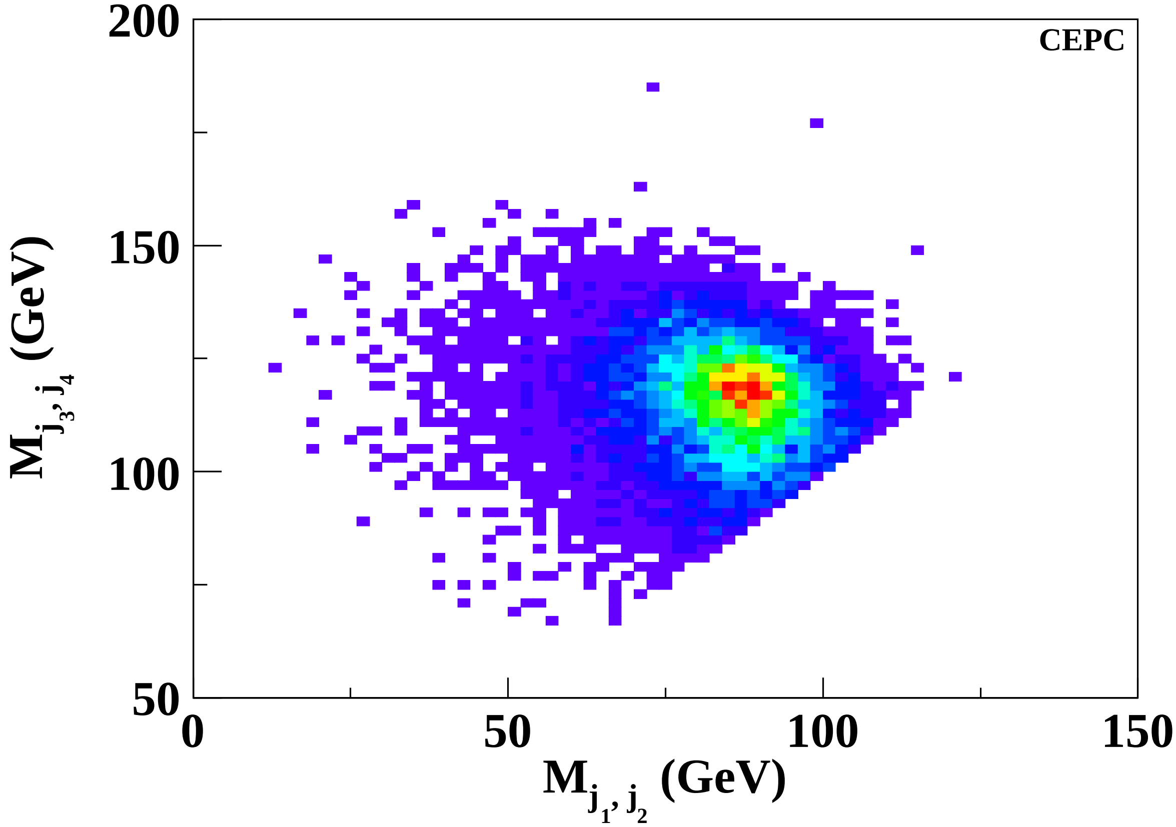

Fig. 9. Scattering plot of M_{j_1,j_2} vs. M_{j_3,j_4} for full simulation

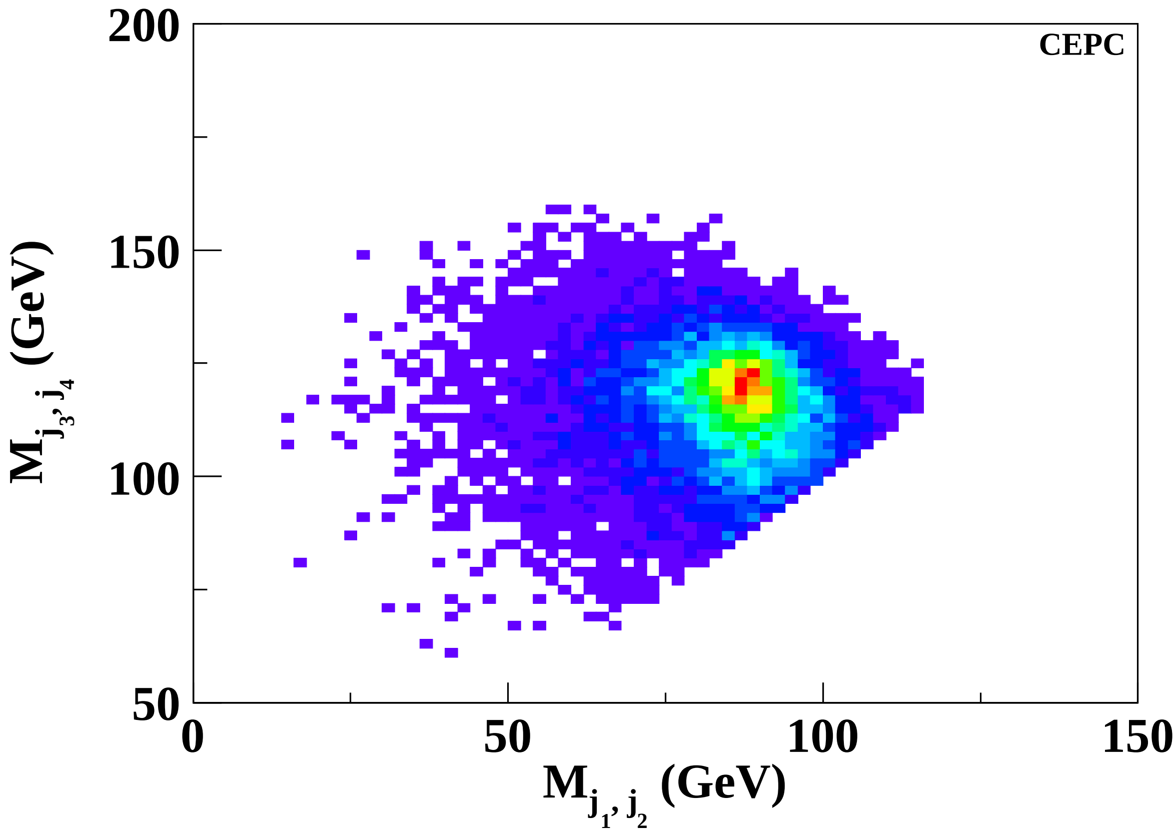

Fig. 10. Scattering plot of M_{j_1,j_2} vs. M_{j_3,j_4} for fast simulation

5 Conclusion

To validate the flexibility of DELPHES on CEPC, a comparison between DELPHES simulation and Geant4 & Arbor has been studied in this paper. In the current study, the results agree very well with our previous understanding for full simulation of CEPC. It should be noted that the DELPHES parametrization has not been all covered in this study, such as those related to flavor tagging. Meanwhile, most of the parameters have to be determined with the feedback from the full simulation.

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