Determination of the CPV Higgs mixing angle in ZZ-fusion

at 1.4 TeV CLIC

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**Answers to the referee**

Abstract, 3rd line: …, in full simulation of a detector and machine and physics related backgrounds.

**Q: What is machine if not detector?**

**Answer:** In this sentence we refer to **machine background** and physics background, where machine background originates form beam-beam interactions while physics background is a concurrent physics process to the signal. Machine background are thus Beamstrahlung photon conversions (into leptons and hadrons) overlaid over every physical event in the digitization phase of simulation.

In the spirit of your question, ‘machine’ will be the accelerator and even the whole region of a detector at very small polar angles near the beam pipe is referred to machine – detector interface (MDI) region.

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Page 2, 3rd paragraph:

**Q: The [2] refers to your analysis presented in [1], doesn't it?**

**Answer:** Reference [2] refers not only to [1] (that was preliminary result), but gives the overall status of CPV studies at future facilities, primarily e+e-.

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Page 3, Section 2:

Driven by the CLIC physics program, CLICdet [6] detector is optimized for the precision Higgs physics program with all detector subsystems placed within magnetic field of 4 T to enable Particle Flow Algorithm (PFA) [7].

**Q: Can you elaborate more? You are talking about one magnet system placed where? Also, what does that have to do with Particle Flow?**

**Answer:** Solenoid magnet with a field of 4 T is interleaved with iron yoke hosting the muon chambers. All other detector subsystems (vertex, tracking detectors and calorimeters) are placed inside the solenoid in order to enable continuous monitoring of the charged particles banded by the magnetic field. This approach is called Particle Flow. Classically, one would put only tracker in the magnetic field for momentum determination, while energy will be complementary measured with calorimeters outside of the magnetic field. Since position/energy resolution of calorimeters is much inferior to those of tracking detectors, overall performance of measurements and particle identification will be influenced by limitations of calorimetry (hadron calorimeters in particular). At the other hand, Particle Flow Algorithm (PFA) leaves to calorimeters solely only neutral hadron identification (HCAL) and photon identification (ECAL). PFA enables jet energy resolution below 5% (depending on a jet-energy) what would be impossible in classical approach.

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Page 3, Section 2:

Vertex and tracking detectors are all silicon detectors enabling charge particle reconstruction and identification. **Only photons** and neutral hadrons are left to be measured at electromagnetic and hadronic calorimeters, respectively.

**Q: How do you measure electrons then? Electrons are important for this analysis, you want to mention how are they reconstructed.**

**Answer:** In the PFA approach electrons are reconstructed in combination of information from all tracking detectors and ECAL. We’ve added this sentence to the text accordingly.

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Page 3, Section 3:

As the signal final state is $e^{-}e^{+}$+ 2jets: $e^{-}e^{+}\rightarrow He^{-}e^{+}(H\rightarrow b\overbar{b})$ we select two isolated electrons per event, where the electron is considered isolated if passed cuts on: … and two-dimensional requirement of cone energy vs. electron energy $(E\_{cone}^{2}<9 GeV∙E\_{trk}+9 GeV^{2})$, where the cone energy $(E\_{cone})$ **sums up all particle energies** in a cone size of approximately $6°$ around the isolated electron track with energy $E\_{trk}$.

**Q: Where? In EM calorimeter?**

**Answer:** For us, electron is a Particle Flow Object (PFO). It is resulting construct obtained on the basis of information from the central tracker and ECAL. Also, tracks or to be more precise four-momenta of other particles come as PFOs. Requirements above, including special isolation are imposed on PFO objects (this is done using a special processor of the reconstruction package called Isolated Lepton Finder (F. Gaede and J. Engels, *Marlin et al - A Software Framework for ILC detector R&D*, EUDET-Report 2007-11, (2007)).

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Page 4, 1st paragraph:

**Q: So preselection is 2 isolated electrons and two jets? What are the pT cuts on jets? Any b-tagging?**

**Answer:** Yes, in the preselection we looked for exactly 2 isolated electrons and 2 jets. This condition was not enough to suppress background, so we further apply multivariate analysis. In multivariate analysis based on Boosted Decision Tree (BDT) method several sensitive observables are used to train the software. Here we list them: invariant mass of di-jet system (sitting on the Higgs mass), energy of final state e+ and e-, missing momentum per event, polar angle of the reconstructed Higgs, number of PFO objects per event, transverse momentum of final state electron and positron system and jet transition variables. Considered background doesn’t have electron spectators in the final state, so the best separation variable is transverse momentum of final state electron and positron system. Second ranked are jet transition variables ($logy\_{23}, logy\_{12}$). No pT cut on jets is applied, except in the kT jet reconstruction algorithm where pT is used to define effective distance between particles.

b-tagging is not applied because we do not use jets (only) as event identifiers but rather electron spectators. b-tagging will be important if we would like to eliminate concurrent e+e- -> e+e-H (H-> qq, q≠b) processes, what we do not do here. Even more, these processes are planned to be added to the signal in the later stage of the study, as they contain the very same HZZ vertex of interest for CPV.

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Page 4: **BDT efficiency** is found to be 94%, where a signal efficiency is 81% and the overall background rejection rate is 99.9%. Stackplot of the Higgs boson invariant mass after the MVA is illustrated in Figure 3 (right).

**Q: How do you define efficiency here? Also, you must introduce some cut here? This whole sentence should be rephrased.**

**Answer:** MVA (and here BDT) assumes the method output variable BDT cut-off value of 0.16, meaning that every event with the associated BDT output less than 0.16 is rejected as a background. The sentence clarifying this is added in the caption of Figure 3: ‘Stackplot of the Higgs boson invariant mass after the MVA is illustrated in Figure 3 (right). It is obtained by restricting the BDT output variable to be larger than 0.16 on event-by-event basis. ’

Efficiency is naturally the ratio of number of events after and before the MVA application.

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Page 4, Figure 3 (left)

**Q: Usually for these plots signal on top of background is shown, not vice versa.**

**Answer:** Figure 3 (left, right) is done in a required way of plotting signal and background within the CLICdp Collaboration (so called CLICdp Style, shared in a macro to provide uniform graphical presentation of CLICdp results). It can be found throughout CLICdp papers, and we list two just for illustration: H. Abramowicz et al. (CLICdp Collaboration), Higgs physics at the CLIC electron-positron linear collider, [Eur. Phys. J. C 77, 475 (2017)](https://epjc.epj.org/articles/epjc/abs/2017/07/10052_2017_Article_4968/10052_2017_Article_4968.html), Physics and Detectors at CLIC: CLIC Conceptual Design Report, edited by L. Linssen, A. Miyamoto, M. Stanitzki, and H. Weerts, Technical Report No. ANL-HEP-TR-12-01, [CERN-2012-003](https://cds.cern.ch/record/1425915?ln=en), DESY 12-008, KEK Report 2011-7, (2012).

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Page 5, Figure 5:

**Q: Did you say that scalar is psi=0 and pseudoscalar is psi=pi/2?**

**Answer:** Yes.

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Page 5, Figure 6 caption: $ΔΦ$ for **signal** after full simulation, reconstruction and selection, corrected for acceptance and detector reconstruction effects (red). Generated distribution (black).

**Q: Which signal?**

**Answer:** Throughout the text, the signal is: $e^{-}e^{+}\rightarrow He^{-}e^{+}(H\rightarrow b\overbar{b})$, where Higgs boson is produced in ZZ-fusion, thus CPV study is addressing the HZZ vertex. It is interesting to note that CPV in vector boson fusion is not analyzed yet at future Higgs factories and that there are no results above 1 TeV at e+e- machines for any Higgs production channel [2]. So, although our estimates are very preliminary, they are interesting being the first of this kind.

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Page 6, … There is ongoing optimization of the fit to extract $Ψ\_{CP}$ from the $ΔΦ$ distribution. Preliminary fit of $ΔΦ$ distribution from Figure 6 indicates $ΔΨ\_{CP}$ **absolute statistical precision** of < 10 mrad.

**Q: How do you get this precision?**

**Answer:** To extract the CPV mixing angle ΨCP from the $ΔΦ$ distribution given in Figure 6 (red line), a preliminary fit is performed. The fit needs additional tuning and discussion within the collaboration, so the result on $Ψ\_{CP}$ precision can be taken only as an indicator of the order of magnitude. We modify the text accordingly: ‘Preliminary fit of $ΔΦ$ distribution from Figure 6 indicates the order of magnitude of $Ψ\_{CP}$ absolute statistical precision to be ~10 1 mrad.’

**General remark by the authors: All typos are corrected.**