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Detector optimization at CEPC

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The detector optimization is a critical task in the design of the CEPC detector to ensure that the physics goals of the CEPC project will be achieved. On one hand, in order to make the best use of all Higgs bosons generated at CEPC, the detector design should consider high-efficiency reconstruction and precision measurement of all the physics objects including leptons and jets, and of other key spatial and kinematic variables including the displaced vertices, charged track trajectories, missing energy and momentum of jets. . On the other hand, the cost and the operation of the detector , such as power consuming and active cooling, should also be taken into account. Starting from a baseline that follows the ILD detector design, a series of detector optimization studies have been performed. This report will summarize the progresses and results.

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1. Introduction

After the Higgs boson was discovered at the LHC [1, 2, 3]. Comparing to the data set leads to the Higgs discovery, the LHC will continue to accumulate much higher integrated luminosity in its future operation at higher center of mass energies. These data will largely enhance our understanding to the Higgs boson [4]. On the other hand, as the LHC is a hadron collider, its Higgs measurement precision is limited by various systematic uncertainties.

Compared to the LHC, an electron positron collider has very distinguish advantages in the measurements of Higgs boson properties. First, it is free of QCD backgrounds, almost every Higgs boson can be recorded and reconstructed. Secondly, the beam energy and polarization of the initial states are precisely defined. Consequently, the electron positron collider can provide absolute measurements for Higgs couplings [5, 6]. Therefore, an electron-positron Higgs factory is an essential step in understanding of the nature of Higgs boson.

The Circular Electron Positron Collider (CEPC) is a Higgs factory proposed by the Chinese high energy physics community [6]. The CEPC will operate at a center-of-mass energy of 240-250 GeV with an instantaneous luminosity of 2×10^{34} cm^{-2}s^{-1} at each interaction point. With two detectors operating over 10 years, the CEPC will accumulate 5 ab^{-1} of integrated luminosity and 10^6 Higgs boson events.

2. CEPC Detector

The CEPC conceptual detector design, as illustrated in Fig. 1, takes the ILC detector designs (e.g. ILD and SiD) [7, 8] as a reference. It fulfils the requirement of the physics program at the lepton collider with precision measurements of the Higgs boson at $\sqrt{s} \sim 240$ GeV. For the initial study, the ILD detector has been chosen as the starting point for the CEPC detector design.

In order to accommodate the CEPC collision environment, some necessary changes have been made to the Machine Detector Interface and sub-detector design. The CEPC design, for instance, has a significantly shorter focal length $L^{\star}$ of 1.5 m than that of the ILC design (3.5 m), which indicates that the final focusing magnet QD0 will be placed inside the CEPC detector. In addition, unlike the ILC detectors, the CEPC detector will operate in continuous mode, which imposes special considerations on power consumption and subsequent cooling of the sub-detectors.

Another major change in the CEPC detector is that the thickness of magnetic field return yoke for both barrel and end-cap regions is reduced since the CEPC does not require the detector to operate in Push-Pull mode as designed for the ILC.

As illustrated in Fig. 1, the CEPC detector consists of the following sub-detectors:

- A vertex detector (VTX) constructed with high spatial resolution pixel sensors. The vertex detector is placed very close to the interaction point (IP), with an inner radius of 16 mm. This vertex detector ensures excellent tagging capability of b-/c-quark jets and τ-leptons.

- A silicon tracker composed of Silicon Inner Tracker (SIT), Forward Tracking Disks (FTDs), Silicon External Tracker (SET) and End-cap Tracking Disks (ETDs). The VTX and SIT provide excellent spatial measurements near the IP, crucial for vertex reconstruction and jet flavor tagging. The SET and ETD, on the other hand, provide excellent spatial resolution

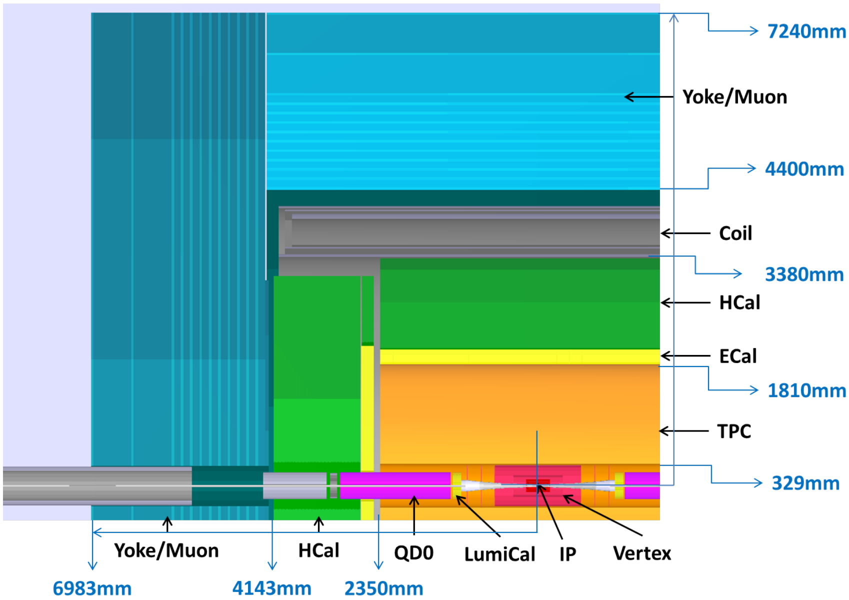

Figure 1: Overview of the CEPC detector.

with the maximal possible track arm length, therefore improving the track momentum resolution of charged particles. The FTD significantly increases the geometric acceptance of the tracking system with coverage of $|\cos\theta| < 0.99$.

- A Time Projection Chamber with a half-length of 2.35 m and an outer radius of 1.8 m. The TPC provides a large number of spatial points ($\sim$200 hits per track) and spatial resolution in $r\phi$ plane better than 100 μm. It has excellent pattern recognition and track reconstruction efficiency (better than 97% for tracks with $p_{\mathrm{T}} > 1$ GeV).

- A calorimetry system consisting of Electromagnetic Calorimeter (ECAL) and Hadron Calorimeter (HCAL) with very fine granularity. The system plays an essential role in the Particle-Flow Algorithm (PFA) [9, 10, 11, 12]), allowing excellent separation of showers from different particles, and provides jet energy resolution of 3 – 4%.

- A superconducting solenoid of 3.5 T, surrounding the calorimetry system. The return yoke is placed outside the solenoid.

- A muon detector with tracking layers installed in the return yoke.

The CEPC detector design is mainly driven by several selected benchmark physics processes as shown in Table 1. Precise measurements of the Higgs mass and cross section through the $Z \to \ell^+\ell^-$ recoil method requires high track momentum resolution provided by the tracking system. This also makes the measurement of the rare decay process of $H \to \mu^+\mu^-$ accessible. Measurements of $H \to b\bar{b}$, $c\bar{c}$, gg branching ratios imply excellent flavour-tagging capability for the vertex detector. In addition, many interesting physics processes appear in multi-jet final states, requiring jet energy resolution of 3 – 4%. This can be achieved with the combination of the high granularity calorimetry system and the PFA algorithm.

Table 1: Required performance of the CEPC sub-detectors for critical benchmark Higgs processes.

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_{\mathrm{T}}) \sim 2\times10^{-5}$
$H \to \mu^+\mu^-$	$\mathrm{Br}(H \to \mu^+\mu^-)$		$\oplus 1\times10^{-3}/(p_{\mathrm{T}}\sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{Br}(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p\sin^{3/2}\theta)\ \mu\mathrm{m}$
$H \to q\bar{q},\ VV$	$\mathrm{Br}(H \to q\bar{q},\ VV)$	ECAL, HCAL	$\sigma_E^{\mathrm{jet}}/E \sim 3-4\%$
$H \to \gamma\gamma$	$\mathrm{Br}(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

3. Detector optimization

From the detector point of view, the precisions of the mass and cross section of Higgs are mainly determined by the precision of tracking system, which strongly depends on tracker radius. The tracking system of CEPC conceptual detector consist of a silicon system and a main tracker of TPC. Larger TPC radius gives better momenta resolution at a higher detector construction cost.

A series of simulation studies [13] shows the precisions of the mass and cross section of Higgs can be parameterized as the function of the TPC radius, which is shown in the left panel of Fig 3. The precision of Higgs decaying into two photons highly depends the resolution of electromagnetic calorimeter (Ecal), the right panel of Fig 3 shows the dependence.

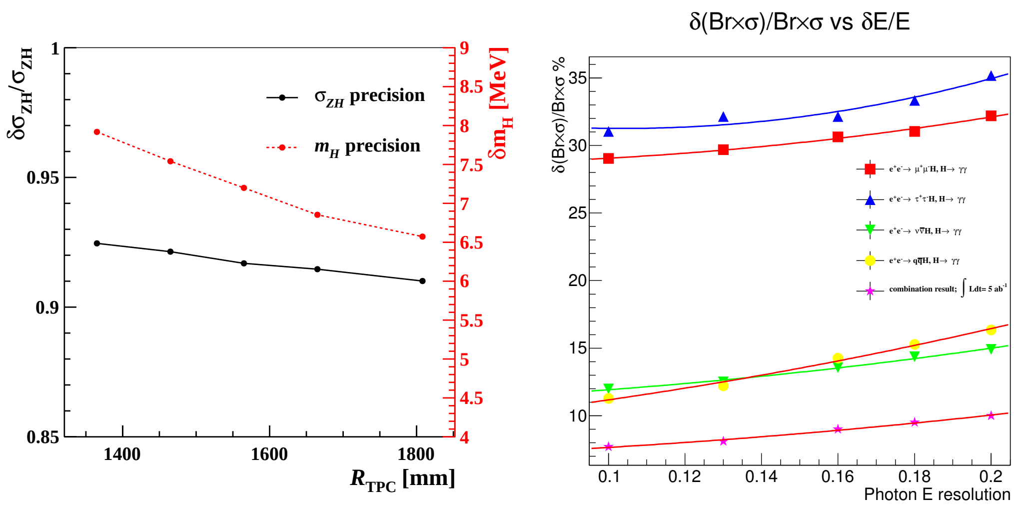

Figure 2: Dependences of the bench mark physics measurements on detector parameters. Left, the dependence of the precisions of ZH cross section and Higgs mass on the TPC radius; Right, the precision of branching fraction $H \to \gamma\gamma$ versus the resolution of electromagnetic calorimeter

The CEPC conceptual detector takes the ILD as a reference. The ILD is designed to work up to 1 TeV but the CEPC is dedicated to Higgs physics at $\sqrt{(s)} = 240$ GeV. Careful studies show that cost of CEPC can be significantly reduced by enlarging the cell size of calorimeter and radius of CEPC , as well as the Yoke. In this case the detector still meets the requirement of physics goal and is active cooling free.

4. A conceptual design of an alternative detector

At CEPC, the design of a pure silicon detector is initialized. The full simulation and reconstruction software are under tuning. In the design, 6 layers silicon strips are used instead of TPC as the main tracker, which is expected to provide very precise position measurements of charged tracks and to work at high event rate environment, like Z pole. Based on the first results, it obtains similar performance compared with the TPC- based one.

5. Summary and prospectives

A TPC-based detector is being optimized to maximize the physics exponentials of 5 ab^{-1} integrated luminosity data. A series of optimization on the TPC and on the calorimeter are performed. A pure silicon design of detector is proposed and the reconstruction software is under development.

In near future, the R&D of CEPC detector will focus on the detector design and optimization of a TPC-based and a pure silicon detector with full simulation. We will devote ourselves to develop simulation and reconstruction tools and finalize the detector optimization. The Machine-Detector Interface (MDI) will be studied in great details to make experiment realistic, including the synchrotron radiation and beam backgrounds [3], as well as the precision luminosity monitor and beam energy calibration. All these efforts will be included in The Conceptual Design Report of CEPC — The Detector Volume.

Recently, the CEPC project received the funding support from the Ministry of Science and Technology of China (MOST). This is the first time that Chinese government supports the R&D of CEPC.

Acknowledgement We would like to express our gratitude to the BESIII collaboration which provides the computing resources and to the people who set up the distributed computing. Without them, the detector design and optimization can not be performed smoothly and effectively. The CEPC detector group is a very active and open- minded team. Those who are interested in physics, detector, software and computing techniques are more than welcome to join us.

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