Physics Highlights at CEPC

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Abstract

The Circular Electron Positron Collider (CEPC) is a facility with a wide range of physical scope. It can serve as the Higgs, W, and Z bosons factories, allowing the study of Higgs, electroweak (EW), QCD, flavor physics as well as Beyond Stand Model (BSM) physics. Numerous studies for Higgs measurement were revised and documented after the completion of the conceptual design report (CDR) [1] and the Higgs white paper [2]. For the new nominal operation scenario [3], CEPC can deliver a few factors enhanced events yields of Higgs, W and Z bosons, it can also provide a run at a 360 GeV center-of-mass energy, enabling top coupling measurement and good improvements in Higgs precision measurement. With upgradeable running plans, physics potential is studied at CEPC on a variety of topics, such as benchmark processes of Stand Model particles and BSM searches. These highlights from recent updates will be discussed.

Keywords: CEPC, Higgs, BSM.

1. Introduction

The Higgs boson discovered by the ATLAS and the CMS Collaborations [4] [5] at Large Hadron Collider (LHC) completes the last piece of Standard Model (SM). Properties of the Higgs boson are expected to probe the underlying questions of the SM and new physics. Different from pp collider, an e^+e^- machine can provide even better accuracy for Higgs and beyond. The Circular Electron Positron Collider (CEPC) which proposed by the Chinese particle physics community in September 2012, is the first e^+e^- collider to have a such draft running as Higgs factory. The 100 km circumference tunnel can be reused to accommodate both CEPC and Super proton-proton Collider (SppC), and opens the possibilities of e-p and e-ion physics in the future. The baseline design allows for operation at 240 GeV, generating millions of Higgs bosons with 5.6 ab^{-1} data. The CEPC will also serve as a Z factory at 91 GeV and a W factory at 160 GeV, producing one trillion Z and 20 million W^+W^- pairs, respectively.

Following the release of the CEPC the CDR, the CEPC study group maintained their research. New technologies on the development of accelerator, detector and software reinforces the physics studies at CEPC. Key technologies are prospered and verified at the core accelerator sub-systems. These developments result in an update to the CEPC's nominal run plan. For instance, according to the CEPC TDR design [6], the circulating CEPC beams radiate 30 MW synchrotron radiation (SR) power per beam. The beam

SR power is upgraded to 50 MW, leading to an increase in luminosity. The luminosity of Higgs run can be upgradable from 5.6 ab^{-1} to 20 ab^{-1}. In addition to W/Z run improvement, CEPC is also upgradable to have a top run with 1 ab^{-1}. The data-taking scenario is summarized in Tab. 1.

	Operation mode	Z factory	WW	Higgs factory	$t\bar{t}$
	$\sqrt{s}$ (GeV)	91.2	160	240	360
	Run time (year)	2	1	10	5
The CDR	Instantaneous luminosity (10^{34} cm^{-2} s^{-1}, per IP)	32	10	3	-
	Integrated luminosity (ab^{-1}, 2 IPs)	16	2.6	5.6	-
	Event yields	7×10^{11}	2×10^{7}	1×10^{6}	-
New nominal	Instantaneous luminosity (10^{34} cm^{-2} s^{-1}, per IP)	191.7	26.6	8.3	0.83
	Integrated luminosity (ab^{-1}, 2 IPs)	100	6	20	1
	Event yields	3×10^{12}	1×10^{8}	4×10^{6}	5×10^{5}

Table 1: Nominal CEPC operation scheme, and the physics yield, of four different modes comparing to the CDR.

2. Physics Progress after the CDR release

After the CDR and the Higgs white paper were finished, numerous studies were updated and reported. The development on some selected toptics will be described in the following chapters.

2.1. Higgs precision measurement

Higgs properties can be measured with a high precision in a lepton collider thanks to clean background, large statistics and well-modeled decay process. The tagging of $e^+e^- \to ZH$ events using the recoil mass method is a model independent analysis, without touching the Higgs boson itself in an event, which provides a powerful measurement of ZH cross section [7]. The Higgs boson width Γ_H can be calculated by combining the measurements of the Higgs boson production cross section and decay branching ratio, reaching a precision of 2.8%. Analysis of the individual decay modes of the $H \to b\bar{b}/c\bar{c}/gg$ [8] [9], $H \to ZZ^*$ [7], $H \to \gamma\gamma$ [10], $H \to \tau^+\tau^-$ [11], $H \to \mu^+\mu^-$ [12] and $H \to$ inv [13] were carried out by identifying the Higgs boson through their unique signatures. Besides, a global analysis based on Machine Learning is performed for the Higgs measurement, the research reaches a factor of 2 gain with respect to the results in the CDR [14].

With 20 ab^{-1} luminosity for the updated running scenarios, the inclusive Higgs cross section measurement has been improved from 0.5% to 0.26%, and the precision of the Higgs width determination is enhanced from 2.8% to 1.65% [3] for the Higgs operation mode. With the additional 1 ab^{-1} of the top run at 360 GeV in combination, CEPC enables the Higgs boson total width precision at the level of 1.1%.

2.2. Top quark, W and Z boson mass measurements

The $t\bar{t}$ run at 360 GeV opens a door to measure top properties in high precision that hadron colliders cannot reach. Currently, studies of the top mass and width measurements and top quark coupling measurements are under development. A $t\bar{t}$ run study using $t\bar{t}$ threshold method is preformed to probe the top mass and width as well as α_s [15]. One order of magnitude better precision than the hadron collider is expected. A single run at the energy where the $t\bar{t}$ cross section varies most largely in a given top mass range is found to provide the best performance. The statistical uncertainty of the top quark mass is expected to be 9 MeV assuming a limited total luminosity of 100 fb^{-1}.

With large integrated luminosity in Tab 1, the CEPC will achieve a new level of accuracy with regard to measurements of the W and Z bosons' properties. The mass of the Z boson (m_Z) is being studied at Z threshold scans runs. With a preliminay data-taking scheme, the analysis is dominated by systematic uncertainty from beam energy measurements, the statistical uncertainty can reach to about 7 keV [16]. The W boson mass (m_W) can be measured for WW threshold runs, 1.0 MeV and 3.4 MeV can be reached for the mass and width of the W boson by testing with 1-3 energy points scheme for 3.2 ab^{-1} [17].

2.3. Beyond Standard Model Physics

In addition to act as a Higgs factory, CEPC offers enormous promise for the hunt for new physics states that are produced directly with clean background. Additionally, CEPC can be sensitive to various new physics models, such as Supersymmetry, Long-Lived Particles. CEPC has good discovery potential for new physics at many scenarios which are challenging for LHC, many of the BSM prospects at CEPC are already public.

A first step in Higgs exotic decays investigation at future lepton colliders was conducted in Ref. [18]. These exotic decay considerations are driven by a broad class of BSM physics, including singlet extensions, two Higgs-doublet models (2HDM), SUSY models, Higgs portals, and gauge extensions of the SM. A most recent study, the exotic Higgs decay mode of $h \to 4\tau$ [19] shows consistent sensitivities with projection data.

An exceptional chance to explore long-lived particles that couple to Z bosons can be provided by Z-pole run with high-luminosity at CEPC. In a study of long-lived lightest neutralinos pair from Z-decays, the sensitivity estimated from several future lepton collider exceeds the projected sensitivity of the ATLAS experiment at the HL-LHC and the proposed LHC experiments [20]. For ZH production mode, an ongoing work searching new long-lived particles decaying to jets, applies AI image recognition techniques to the latest CEPC geometry setup, the exclusion limit comes to 10^{-7} with expected 4×10^6 Higgs [21].

3. Conclusion

This paper covers the progress on Higgs precision physics, Top quark, W, Z mass measurements and BSM physics. Analyses from various Higgs decay channels have been documented after the Higgs white paper complement and the CDR, several publications of them are available. With the upgradable running plans, results of SM particle measurements and BSM physics have been updated. The increased luminosity at CEPC will allow to measure the SM process with extreme precision and offer a great advantage for new physics searches.

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