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The CEPC, Structure, Potential and Controversy

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Abstract

The Collider is the most important equipment in high energy physics (HEP). After the finding of the higgs boson in Large hadron collider (LHC), Scientists in China decided to build a new collider, Circular Electron Positron Collider (CEPC). The CEPC has many advantages over the LHC, which gives the potential in HEP field. It is important to discuss the advantages of it and how it may compensate to the LHC to illustrate the benefits of it's construction.

Keywords

CEPC; LHC; high energy physics; collider.

1. INTRODUCTION

1.1. The Standard Model and Its Limitation

The universe is made of tiny particles such as molecules which are then made of smaller scale of particles named atom or ion. However they are not the basic particles either. Rutherford bombarded a metal film with a beam of alpha rays and found that a small number of alpha particles changed direction at large angles, on the basis of which he proposed a model of planetary atomic structure: there is a positively charged core, the nucleus, in the atom. Rutherford also discovered proton in nucleus. It was not until 1932 that Chadwick found the neutrons.[1] In today's theory, quarks and leptons composite the proton or neutrons together. HEP is to study those small scale of particles.

The Standard Model (SM) is the most successful theory to explain the phenomena of particles. The SM holds that the world consists of the fermions, the gauge bosons and the Higgs bosons.[1] Particles change their states of motion and interact with each other by exchanging bosons. It describes the interaction of three fundamental interactions: electromagnetic, weak, and strong interaction.

Despite its great success, the SM itself can hardly be regarded as an ultimate theory. The SM faces a number of problems. Here are some major reasons to extend the SM: [3][4]

a. What kind of form that the Higgs interaction must take? Why are the masses of particles so different in the Standard Model? And how to explain the values of mass of quarks and leptons? The Standard Model also predicts zero neutrino mass, contradicting current experimental observations.

b. The SM Particle accounts for only 5% of all matter in the universe. The SM can neither explain why the stars and nebulae are made of protons, neutrons and electrons but not their antiparticles nor explain why is there far more matter in the visible universe than antimatter?

c. The SM dosen't tell the answer whether the Higgs boson is an elementary particle, or a particle composed of more fundamental components? Why Higgs boson become the only one scalar particle in the SM.

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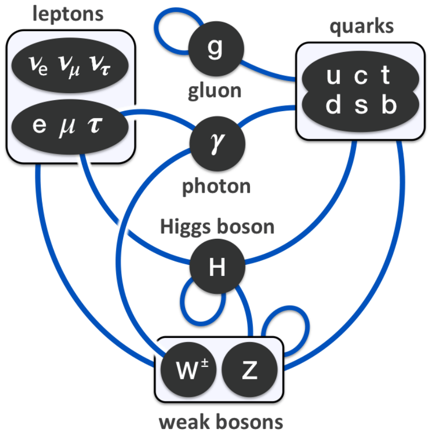

Figure 1. [2] In the today's theory, there are twelve kinds of elementary particles (fermions) and four kinds of elementary forces. Six of fermions are leptons, others are quarks. The forces operate through bosons: the gluon for strong force, the W+- and Z0 for weak force, the photon for electromagnetic force. The fermions gain mass through Yukawa coupling of bosons

d. Cosmology predicts that in the very early days of the universe, the scale of the universe underwent a very rapid, exponential increase. The Standard Model cannot explain this process.

e. How to explain the huge difference between the electroweak energy scale and the Planck energy scale of up to 17 magnitudes.

Because of these limitations, it is generally accepted that there must be more fundamental physical laws of nature beyond the Standard Model. For example, the Supersymmetry and String theory can solve some problems above.

As the source of the mass, the Higgs field is closely related to the above problems. Almost all the free parameters in SM are directly related to the Higgs field.[4] The deviation of the nature of the Higgs boson from the predictions of the SM reflects the energy scale for the existence of new physical laws.[4] The study of the Higgs could bring us to a deeper understanding of the universe.

1.2. Prospects for the Collider

In 2012, physicists discovered the Higgs Boson at CERN's LHC, completing the last piece of the puzzle of the SM. The discovery of the Higgs Boson culminated the success of the SM.

There are plans to upgrade or construct better colliders in the future.

The upgrade from LHC to HL-LHC is undergoing. In 2020, the phase-I upgrading will be done. Then, the phase-II upgrade will be on the way to implementation. The HL-LHC will substantially extend the mass reach in searches for many signatures of new physics and significantly extend the study of the properties of the Higgs boson.[5]

China also proposed an ambitious plan to build the CEPC after the finding of the Higgs bosons. In the plan, the CEPC will accumulate data of 5.6ab-1 over seven years of operation, producing one million clean Higgs instances, measuring the Higgs particle properties to 1% accuracy, and allowing the scanning of new physical principles at 10 TeV energy scales at mass-center energies of 240 GeV which is also an order of magnitude beyond the LHC. The CEPC was designed to start to construct at 2022, finish at 2030. [6] However, it didn't win the fund in China's 13th Five-Year Plan.[7] Scientists in China may look for longer time to plan for it.

ISSN: 2472-3703
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Figure 2. [6] a possible time plan for CEPC

This paper will discuss the structure of the CEPC, the physical potential of it, how it make complementary to HL-HLC and the controversy on whether construct it or not.

2. THE CEPC

2.1. Accelerator

In the planing, the CEPC will be built in a 100km long circumference tunnel about 100m underground, start from 2022, finish at 2030. This tunnel also accounts the place for future SPPC in establishment.[8] Figure3 shows the cross section of the tunnel. The two inner ones are the booster and collider which belong to the CEPC. There set a distance of 2.4m to avoid magnetic interference with each other. The outside one is the planned SPPC.[6]

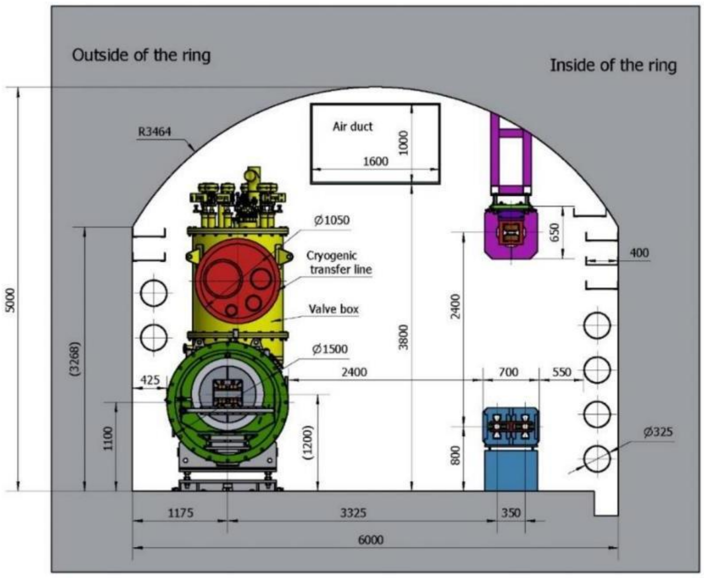

Figure 3. [6] Cross section of the tunnel

Figure 4 displays the layout. The CEPC uses the Linac to accelerate the electrons and positrons to a certain velocity. Then by two transfer lines, electrons and positrons travel respectively to booster in opposite directions. Through off-axis injection, electrons and positrons then transfer into blue line and red line respectively. At the two interaction point , where the blue line meets the red line, collides happen.

There are three modes in the CEPC: the Higgs, W and Z modes. These three modes are going to run for seven, two and one years separately. Two off-axis injection regions are used for running in the all three modes, while on-axis injection regions are only use for Higgs mode. The special on-axis injection scheme can be used for keeping a sufficient margin in dynamic aperture at the extraction energy in Higgs mode.[6]

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RF stations are set for re-acceleration of electrons and positrons after their energy loss by radiation. During the Higgs mode, the electron beam and the positron beam only fills half of the ring so that the e+ and e- bunches take turns to pass the RF cavities. During the W and Z modes, all bunches fill all around the electron and positron rings.[6]

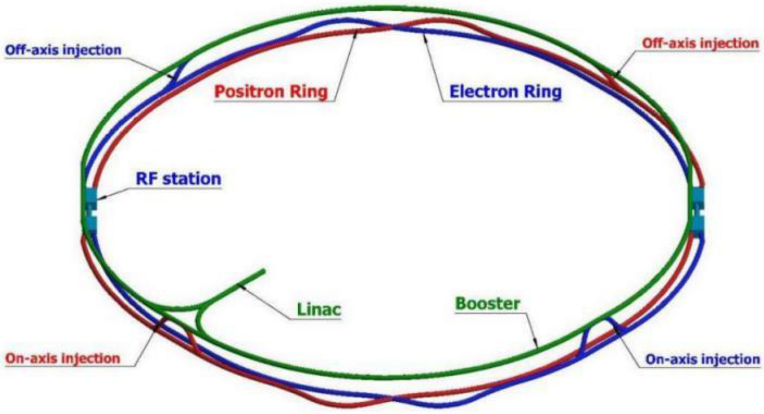

Figure 4. [6]: Layout of the CEPC

The detector is made of a drifting cylindrical chamber which is then surrounded by an electromagnetic calorimeter. While The electromagnetic calorimeter is located inside of the superconducting solenoid.[9]

Figure5 shows the central part of an interaction point of the CEPC. The length of Beampipe is 14cm and inner diameter is 28 mm. The distance of the final focused magnet from the collision point L= 2.2 m. Horizontal collision crossing angle is 33mrad which allows enough room for a superconducting quadrupole 2-in-1 vacuum chamber at room temperature. The LumiCal is situated from 0.95m to 1.11m away from the IP. The inner radius of LumiCal is 28.5mm and outer radius is 100mm. In the arc region are the Twin-aperture dipoles and quadrupoles. Here sets a distance of 35cm between the two beams. For guaranteeing the flexibility in the optics, the magnets in the other regions as well as the sextupoles are powered independently with each other.[6]

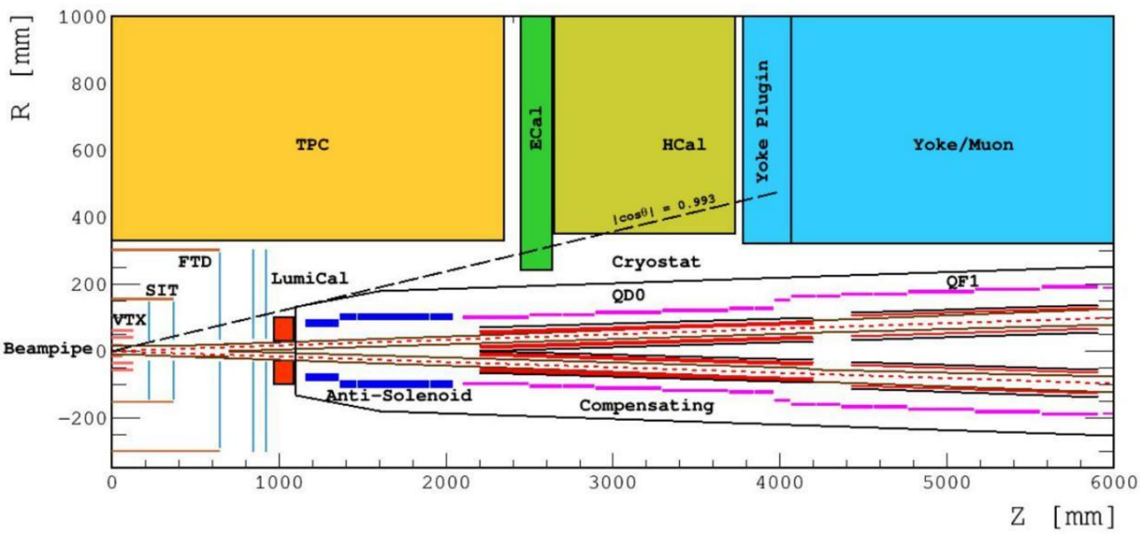

Figure 5. [6]: Interaction point

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2.2. Physical Potential

The CEPC could answer some crucial questions within its accuracy range: If the Higgs is a composite particle composed of new particles with an energy scale below 10 TeV, then the CEPC can confirm that; If the branching ratio of Higgs particles decaying to dark matter particles is greater than 0.1%, then the CEPC will be able to prove that the Higgs field contributes to the mass of dark matter particles; The CEPC can measure the phase transition properties of the Higgs field to determine whether the Higgs field has a first-order phase transition in the early universe, and thus whether the Higgs field can support the universe to produce enough matter.[8]

Some other potentials includes: [9]

Dark matter(DM): The CEPC has the potential in measuring DM properties or even find the DM for the first time. The CEPC's strength is electroweak physics. So if DM resides in an electroweak multiplet, there will be chances of measuring DM. There also exists some possibilities of the CEPC to find the DM first when DM is a nearly pure electroweak multiplet or DM lies in a mixed electroweak multiplet with couplings to the Higgs boson, but the coupling of the lightest mass eigenstate has a small coupling to the Higgs boson. If DM dosen't reside in an electroweak multiplet, it may still interact with the SM particles through gauge-invariant "portal"operators. In that case, it would play an crucial role in detecting and testing these SM portals to dark matter. For dark matter masses smaller than mH/2, the decay channel H→SS/χχ is open, which produces the signal of Higgs boson invisible decays. The CEPC could reach a sensitivity of 0.31% (95% CL) on the branching ratio of Higgs boson invisible decays. When dark matter mass below mH/2, the CEPC provides considerable sensitivity to Higgs portal models. Moreover, the CEPC could search for flavor-violating decays to detect if the portals are with additional SM-sector physics. A portal-agnostic method could be used by simply searching for a generic signal like a single photon plus missing energy in some certain situations like when completely new charged particles, independent of DM, exist and couple to DM.

Higgs and SUSY: Even though the LHC have already excluded a large regions of the natural supersymmetric parameter space, there still remains the blind spots that could be covered by precision Higgs coupling measurements, which still gives chances to prove SUSY. The indirect test to the MSSM Higgs sector to the TeV scale seems possible with the Percent-level CEPC sensitivity to corrections of the Higgs coupling to the bottom quark. The CEPC also has the potential to detect a set of loop-level modifications to Higgs and electroweak observables in the SUSY models.

Exotics Higgs and Z Decays: Running at 240 GeV, the crucial Higgs boson production mechanism is Z-Higgs associated production e+e-, Z* and ZH. By using the "recoil mass" technique to tag the Higgs, it achieve high signal efficiency.

Neutrino Connection: The CEPC is also an excellent tool to study the physics of neutrino. For example, it can study neutrino mass generation as a portal to unknown new physics during both the 240 GeV and the Z-pole runs. And in some theories, such as B & L symmetry, additional "neutrinophilic" Higgs doublets, and flavor symmetries, generally predicts the existence of new particles, which could be discovered and studied at CEPC in principle.

Extended Higgs Sector: the CEPC holds the ability to inspect for new physics in terms of the Higgs sector and has a huge advancement on existing and projected limits from the LHC.

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3. THE COMPLEMENTARY OF CEPC TO HL-HLC

3.1. The Shortages of HL-HLC

Despite the accuracy of the HL-HLC measurements of the Higgs boson properties could be improved exponentially from this basis through brightness upgrades,[10] it dose have some disadvantages:

First, there is a huge background needed, where on average it takes every 10 billion proton collisions to produce a Higgs boson.[10] Second, protons are not elementary particles, and we cannot accurately determine the initial state information for each physical instance.[4]

3.2. The Advantages of the CEPC

The CEPC uses a circular electron–positron collider to produce the higgs boson, provides a clean environment and precision measurements. Compare to Protons, the electrons and positrons are the elementary particles in the SM, thus initial state information in the CEPC collider is precisely known and adjustable.[9] The CEPC can proceed Model-independent precision measurements: The majority of the higgs boson on the CEPC will be produced by the ZH process. By accurately measuring the four-momentum information on the final state Z particle, together with the known initial state information, we can calculate the four-momentum of the Higgs boson and find the Higgs boson signal through its invariant mass.[9] This method, so-called recoil mass method, does not require a direct measurement of the decay end-state of the Higgs boson. At a mass-center energy of 240 GeV, a higgs boson is produced in about every few hundred positive-electron collisions which is far frequent than that in the HLC which only generates one Higgs boson in every ten billions of proton-proton collisions.[4]

3.3. The Controversy Over the CEPC

Despite the future potential of CEPC, there is still controversy about whether to build it or not.

Some Physcist, including Chen-Ning Yang, the winner of 1957's Nobel Prize in Physics, hold the strong negative view towards construction of the CEPC at those points: The failure of SSC(Super Su-perconductive Collider) indicates that the cost of the CEPC may far exceed budget, even arriving at 20 billion dollars resulting in insufficient funding for other researches and burden to finance issue; Supersymmetry may still not be verified at the CEPC the same as other experiments before. For now, it is just a conjecture that the supersymmetric particles exist but without experimental basis. Meanwhile, the LHC has already excluded large regions of the natural supersymmetric parameter space supersymmetric partner particles; These studies cost much but cannot benefit human life in the near future; The Chinese scientists majoring in high energy are not as many as the Western world. Foreign scientists make most use of it but not Chinese ourselves.[7]

On the contrary, Yifang Wang, director of the Institute of High Energy Physics Chinese Academy of Science, argued that “Mr. Yang has opposed China's construction of high-energy accelerators since the 1970s. ” he said “Fortunately, Comrade Xiaoping followed the advice of other scientists to create today's Institute of High Energy Physics ”[11]

In the vote on whether to build the CEPC, it did not successfully apply for the funding from the 13th Five-Year Development and Reform Commission.[7] But it didn't denial of the possibility of construction in the future.

4. CONCLUSION

The SM can explain many phenomena in experiments. But it's believed not to be the final answer. After the finding of the Higgs boson, Chinese scientists proposed a plan for the CEPC which has the potential of measuring or even first find DM, detecting exotic Higgs & Z decays,

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verifying SUSY, studying neutrino physics and finding new physics. It could have great chances to answer whether the Higgs is an elementary particle, whether the Higgs contributes to the mass of the DM, whether the Higgs field can support the universe to produce enough matter within its accuracy range.

The CEPC would be the longest collider if construct. It would run in three different modes in turn: H mode for 7 years, W mode for 2 years, Z mode for 1 year. After that, the SPPC is to construct beside the CEPC.

The CEPC provides a clean environment and precision measurements, generate more Higgs bosons than HLC and have some other advantages. The potential gives instruction on future experiment. Despite the controversy, the CEPC itself dose hold a great potential in high energy field. Starting is hard but could shine a light on the future of physics.

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