CEPC’s Features and Expectation for the Future

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Abstract: This report will briefly introduce the CEPC and its booster and collider, which are the main components of CEPC. To get a more accurate physical model of the universe, CEPC has been enhanced in many design aspects and will outperform the original LHC in many aspects. CEPC will also help scientists discover many unanswered questions, such as dark matter, and it will focus on electroweak physics. CEPC has a strong potential in high-energy physics and the scientific community as a whole.

1. Introduction
The study of the fundamental structure of matter has led to the development of science for centuries. The Large Hadron Collider (LHC) is the main tool that people use to find those elementary particles. It is a high-energy physics device that accelerates the protons and collides them to explore new particles and new physics mechanisms. The greatest contribution of LHC is the discovery of the Higgs boson, which represents the completion of the Standard Model. But there are still many unanswered questions in the standard model. For example, what is Gravity and what is dark matter, extra. Therefore, people decided to build a new collider with higher energy and higher luminosity, which is the circular electron-positron collider (CEPC). CEPC will provide an unmatched opportunity for precision measurements and searches for physics beyond the Standard Model.

2. Overview
The circumference of the CEPC is about 50 to 100 km long, and the width of the tunnel is about 7 meters to save the land and shield the radiation. The tunnel will be buried at a depth of about 50 to 100 m below ground to avoid affecting the buildings on the ground. And the geological conditions are generally granite. The center-of-mass energies for CEPC are 240 GeV, 91 GeV, and 160 GeV, and the luminosities are $3 \times 10^{34}$, $32 \times 10^{34}$, and $10 \times 10^{34}$ cm$^{-2}$s$^{-1}$, respectively. This detector was proposed in September 2012 and if all goes well construction is expected to take place between 2030 and 2040. After it is completed, it will run for “Seven years as a Higgs factory, followed by 2 years for operation in Z mode and 1 year for operation in W mode.”(CEPC Conceptual Design Report, Volume I - Accelerator, P17) And this will lead to a lot of valuable experimental data.
Figure 1: This figure depicts a schematic of the overall layout of the future CEPC. It includes the booster, the collider ring, and the collision point (IP1 and IP2 for CEPC).

Figure 2: These graphs show the Booster vs. collider (Left) layouts and the cross-section of the tunnel (Right).

3. Booster
CEPC contains multiple systems and detectors, of which the booster is a very important part. It requires very low internal pressure, with an average pressure of less than $3 \times 10^{-8}$ Torr, to minimize beam loss and errors caused by internal gases. Also to maintain superconductivity, the booster will operate at a temperature of 2K which is a temperature colder than outer space. And this temperature requirement will be carried out through superfluid helium. Superfluid helium can easily penetrate all parts of superconducting devices, giving them better thermal stability.

Another goal is to make sure that the booster can have the same geometry shape as the collider so they can share the same tunnel. And this has high requirements on the construction accuracy of the booster, the horizontal position error of the booster needs to be controlled below $+0.17$ m. In the current design, the booster is placed on top of the collider and has the same length as the collider. There is one exception which is the IR region, the booster will pass from the outer side of the collider ring to avoid a conflict with the CEPC detectors.

There are many factors in the booster that can cause an error in the orbit. The booster is also equipped with 1054 vertical correctors and 1054 horizontal correctors to eliminate those errors. This will make the orbit more precise. After the orbit correction, the maximum orbit error is less than 1 mm. The following figure shows the differences between the orbit before the correction and after.
CEPC uses magnets to accelerate particles and while its material selection has many requirements to have sufficient performance while minimizing cost. 3 types of magnets have been used: dipoles, quadrupoles, and sextupole magnets. Most of them are dipoles. The core components of dipoles magnets will use steel-aluminum laminations and the coils will use aluminum conductors instead of regular copper to reduce the cost. And for the power supply, there is only one power source to supply all the dipole magnets, and all the dipole magnets are connected in series. There is 0.77MV power supplied for total and a 10% to 15% safety margin for both current and voltage.

4. Collider and its Limitations

After a period of acceleration in the booster and reaching a very high velocity, the particles will move to the collider ring and collide at the 2 collision points. (Showed in Figure 1, from booster ring(green) to the collider ring(purple) and collide at IP1 and IP2)

And there are a few limits and constraints for the parameter for the collider:
1. Maximum SR power for a single beam < 30 MW to control the total AC power of the project.
2. The beam-beam tune shifts < 0.11 for Higgs, 0.13 for W, and 0.096 for Z to prevent the blow-up of the beam emittance.
3. Beam lifetime is about 80 minutes and the requirement for energy acceptance is 1.35% including errors and beam-beam nonlinearities.
4. The energy spread induced by beamstrahlung has < 40% of natural energy spread for Higgs to maintain the uniformity of beam energy.
5. The HOM power per 2 cell cavity < 2 KW to fully extract its power.

(CEPC Conceptual Design Report, Volume I - Accelerator, Pg 38, Constraints for Parameter Choices, The CEPC Study Group)

Luminosity is also a very important part of the collider. The higher the luminosity of the collider is, the better performance we will get. However, there are many limitations that lead to the inability to increase the luminosity without limits, such as insufficient energy, and the interaction between the beam and the beam. The beam-beam force will excite the synchrotron radiation which is Beamstrahlung. Because the energy of the photons emitted by the beam-beam force is much higher than the magnets, so it will increase the spread and therefore cause energy loss. And also it will lengthen the bunch and may reduce the beam lifetime.
5. Searching for Dark Matter

Dark matter is one of the biggest unanswered problems in the world. The total amount of dark matter in the universe can be determined from the observations of the anisotropy of the cosmic microwave background radiation (CBR), which shows there are 26.8% of matter in the universe is dark matter, and 68.3% is dark energy that drives the accelerated expansion of the universe. Only 4.9% is the ordinary matter that we normally contact with. (Figure 6) Therefore, an important goal of CEPC is to find dark matter. Since we cannot observe dark matter directly, we expect to find dark matter indirectly through the coupling of dark matter.

A widely accepted theory suggests that dark matter is composed of weakly interacting massive particles (WIMP) with masses and interaction strengths around the electroweak scale. Because the CEPC’s strength is electroweak physics, we expect to use CEPC to find the dark matter particles that are in electroweak multiplets or mixtures of electroweak multiplets. At the same time, there are other detectors in the world trying to find dark matter, if they successfully find the dark matter, this function of CEPC will not be deprecated, we can still use CEPC to learn the characteristics and properties of dark matter.
matter more deeply.

There are mainly 2 forms that dark matter could be. The first is if the DM is a nearly pure electroweak multiplet. These particles have very small interactions with the Higgs boson and are very difficult to detect at the LHC, so we can use CEPC to study them. A second possibility is that the DM lies in a mixed electroweak multiplet with couplings to the Higgs boson, but such an event is very hard to be detected and cannot tell if that is an accident or an approximate symmetry. This is the blind spot for direct detection.

6. Conclusion
Humans never stop exploring the unknown, no matter what obstacles are in front of us, we will do everything we can to overcome. The last brick in the SM was added by the Higgs boson, but there are still more questions beyond the SM that haven't been answered yet such as the dark matter. Therefore CEPC, which has the most advanced technology of mankind, is one of the means to answer. The construction of CEPC will also drive the growth of a large number of high-tech maturity, and will constantly challenge the limits of existing industrial technology and become the source of many new technologies. Scientists have given a lot of expectations to CEPC and hope CEPC can bring us a lot of new knowledge and a new world led by those discoveries.

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