CEPC Accelerator EDR Phase Working Plan (preliminary)

2024 – 2027

（Nov. 4, 2023 draft）

CEPC EDR general goals :

According to the general CEPC plan, CEPC Conceptual Design Report (CDR) was completed in Nov. 2018, after the completion of CEPC accelerator TDR in 2023, CEPC accelerator will enter into the Engineering Design Report (EDR) phase (2024-2027), which is also the preparation phase with the aim for CEPC PROPOSAL to be presented to and selected by Chinese government around 2025 for the construction start during the ”15th five year plan (2026-2030)” (for example, around 2027) and completion around 2035 (the end of the 16th five year plan).

CEPC Accelerator EDR Plan and Scope:

According to the general CEPC plan, CEPC Conceptual Design Report (CDR) was completed in Nov. 2018, and the CEPC accelerator Technical Design Report (TDR) will be formally released in 2023 after international review(s) (including a CEPC accelerator cost review). Thereafter, CEPC accelerator will enter into the Engineering Design Report (EDR) phase (2024-2027), which is also the preparation phase with the aim for CEPC PROPOSAL to be presented to and selected by Chinese government around 2025 for the construction start during the ”15th five year plan (2026-2030)” (for example, around 2027) and completion around 2035 (the end of the 16th five year plan). CEPC accelerator complex as the centroid of the CEPC, carries ~90% of the project cost, with regard to the country's selection decision of the 15th 5-year plan, in EDR phase, the general goals for CEPC accelerator complex are:

Breakdown of CEPC Accelerator EDR working plan and goals (2023-2025)

According to the CEPC and CEPC Accelerator EDR general goals described above, CEPC accelerator key subsystems working plans and goals, each year to do list (items) and deliverables, milestones, etc. are briefly described as follows:

(A) Based on the CEPC TDR accelerator design, demonstrate a complete and coherent feasibility EDR design, which will guarantee the construction, commissioning, operation, and upgrade possibilities .

(B) The CEPC EDR accelerator design should guarantee the physics goals with required energies (Higgs, W and Z pole, with ttbar as upgrade possibility) and corresponding required luminosities with 30MW synchrotron radiation power/beam as a baseline, and 50MW as upgrade possibility.

(C) Based on the CEPC TDR accelerator key technology R&D achievement, complete the accelerator engineering design and necessary EDR R&D to be ready for industrial fabrications.

(D) Complete a practical procurement strategy and logistics with both domestic and international suppliers.

(E) In collaboration with local government, CAS and MOST (central government), CEPC sites converge from serval candidates to a EDR construction site satisfying the required geological conditions, electric power and water resources, social and environment conditions, domestic and international transportation network conditions, international science city, and sustainable development , etc.

(F) Complete detailed construction site geological studies and corresponding site dependent civil engineering design and general utility facility design.

(G) Complete the radiation, security, environment assessment studies and necessary documents –so called CEPC PROPOSAL, around 2025 ready for the application to the central government to get the formal approval of construction in the “15th five year plan” Make detailed analysis and preparation for the human resources needed for the completion of CEPC construction.

(H) Make detailed analysis and preparation for the human resources needed for the completion of CEPC construction.

(I) In the Engineering Design Phase, create and maintain a complete database, such as cost items with information regarding technology maturity (TRL), design completeness, and cost basis, to identify and prioritize areas for R&D, prototyping and industrialization.

(J) Wort out a detailed construction time line and plan in relation with industrial fabrications, measurements, transportations, storage warehouses, installation, human resource evolution, etc.

(K) Workout details on 3% installation and 3% commissioning items of the total accelerator cost.

(L) Improve design maturity of several systems (particularly MDI and cryogenics) and develop system integration.

(M) Implement the risk-mitigation plan in the production and procurement plans to eliminate major risk during the mass production, providing multiple vendors and multiple production lines (for example, demonstrate automatic magnets production line and NEG coated vacuum chambers mass production facility).

(N) Consider re-optimizing the technical design of components and systems with large electricity consumption taking into account both capital and operational expenditure

(O) Define unambiguously what constitutes the end of the construction project.

(P) For labour-intensive, high-volume activities, in particular the components of the collider and booster, refine and review the production model to check the availability of in-house resources.

(Q) Risk assessment and risk management

(R) Based on TDR cost estimate, make an updated EDR cost estimate.

(S) Carefully consider the recommendations from CEPC accelerator TDR review and TDR cost review committees, IARC and IAC, etc.

(T) Continues efforts in green collider and sustainable development with energy saving technologies, wast heat reuse, energy recovery, and green energy utilization, etc.

(U) Establish more international collaborations, international involvement, and industrial preparations both from domestic and international companies and suppliers.

(V) Refine the CEPC management structure in relation with host lab.

(W) Refine the CEPC construction funding modes.

(X) Obtain the necessary EDR plan and scope related fundings.

(Y) Complete "CEPC Proposal" around 2025 ready for application of final selection of the 15th 5-year plan, and complete EDR around 2027 before the construction.

(Z) With aim of start the construction around 2027~2028 and complete the construction and put CEPC in to commissioning around 2035.

According to the CEPC EDR general goal and CEPC Accelerator EDR plan and scope (A to Z) described above, CEPC accelerator key subsystems working plans and goals (2024 - 2027), each year to do list (items) and deliverables, milestones, etc. are briefly described in the breakdown 35 WGs as follows:

1) CEPC Collider ring (Yiwei Wang)

2023-2025：Further tradeoff between the collider lattice, MDI, booster to get a more adequate machine design and further improve the dynamic aperture for the bare machine.

Establish the more realistic lattice with polarization systems, energy measurement systems, the complex interaction region components, realistic finite length fringe field and so on.

Face to the engineering design, trade off the accelerator physics requirements and the technology to establish parameters for future engineering.

Improve the global corrections and emittance tuning with errors.

Investigate more static errors including effect of BPM errors and multi-field errors, the long range alignment errors and the beam-based alignment for the main magnets et al.

Investigate on the dynamic error effects and possible feedback, including the injection jitter, the power source jitter, the ground motion with realistic data from the candidate sites.

Perform tracking simulations with a realistic lattice and strong-strong beam-beam interaction, to study the effects of machine errors on the beam-beam performance and the interplay with the luminosity-tuning knobs.

Establish the detailed procedures for the first turn injection, tuning, operation, different modes switching et al. Establish the tools and soft wares for tuning and operation.

2) **Booster ring (D. Wang)**

2024: RF Beam loading study for the bunch structure with half ring distribution (Higgs mode & ttbar) to confirm the beam stability and the CEPC overall timing structure.

Redundancy study for the BPM and correctors. Try to reduce the number of BPM, correctors, and also optimize the quadrupole's length according to the cost issue.

2025: Injection efficiency simulations both at injection energy and extraction energy, especially for the swap-out injection scheme, including the effect of the transverse-mode coupling instability and errors.

Dynamic simulations with complete set of errors to check the transmission efficiency.

Check the possibility of lower power consumption with faster booster ramping scheme.

2026: Booster table ramping design is proposed.

Booster machine/beam commissioning plan is proposed.

Instrumentation and beam-tuning scheme to control beam parameters in top-up injections, including to reduce effects from beam tail/halo particle loss on detector backgrounds and the final focus (FF) quadrupole quenching is devised.

3) Linac (+damping ring) (C. Meng, J.R. Zhang, D. Wang)

2024:

1） Optimization of the physics design, especially double-bunch acceleration simulation; Error study of damping ring;

2） Optimize design of C-band accelerating structure. Process the prototype. Develop C-band RF element, such as pulse compressor, load, directional coupler etc;

3） Further optimize the 5 cell cavity design;

4） Design the new S/C-band phase reference line system using laser and optical fiber to transmit 2860MHz/5712MHz phase reference signal over a long distance, providing stable kilometer level phase reference signal for the low-level RF system of linac and DR. In 2023, on the basis of the existing 500MHz phase reference signal transmission system developed on HEPS, the S band signal transmission system scheme will be redesigned, taking into account L band (1.3GHz), determining the key components to be replaced and added, and fully mastering and developing the laser optical path of photoelectric transceiver.

2025:

1） Availability analysis of the Linac; Error study and preliminary engineering design;

2） Build or find a C-band high power test bench and test the RF system, verify the accelerating gradient. The accelerating gradient aim is 50MV/m on the high-power test. According to the test result, made a new test bench of one unit. One klystron to two accelerating structures;

3） If there is funding, Process the DR normal conducting 5 cell cavity. Cold test of the DR normal conducting 5 cell cavity;

4） Develop the low noise RF front-end and frequency synthesizer for the C-band LLRF system, and build a prototype MTCA LLRF system based on domestic hardware;

5） Optimize some control circuits and chassis processes to further improve the accuracy and stability of the developed system, develop and complete the first prototype, and meet basic indicators.

2026:

1） Determine the final scheme of the Linac including damping ring;

2） Find a suitable beam test bench and conduct beam experiments for the C-band accelerator tube, aimed at 41MV/m with beam;

3） If the machining of the cavity is completed, use PAPS test bench to do the high-power test of the DR normal conducting 5 cell cavity;

4） The prototype will undergo long-term stable operation testing and further optimization and improvement on BEPCII or other test benches.

4) MDI (S. Bai)

2024: Improve the efficiency and accuracy of background simulation to narrow the difference with future experiments, including the improve the quality of the all the generation tools, the interface between different tools, and also made the new version of the beam background simulation toolkit dedicated to CEPC simulation.

2024: Processing and manufacturing of IR beam pipes, including beryllium pipe and tungsten alloy beam pipe. To make prototypes of the beryllium beam pipe, and to improve the key technology such as the manufacture of the pure beryllium pipe, the choice of the coolant, the estimation between the coolant and the pipe in radiation environments, the welding between beryllium and other materials like aluminum, the window to LumiCal, and so on.

2025: Overall integration and installation for all components in the MDI. Specific installation procedure. Cryostat including Final doublet installation alignment. Lumical and Beryllium pipe installation alignment.

5) Connection transport lines and timing (X.H. Cui)

2024: Complete optimization design on the connection transport line, give an explicit waiting time and restrictions due to the bucket selection for different Energy modes.

2025: Perform a simulation of the whole injection/extraction process including errors, have injection efficiency optimizations. State how much variation in bunch charge due to intermittent linac failure is acceptable.

2026: Review on the design strategy, and complete the EDR document.

6) **Collider magnets (M. Yang)**

2024: Complete the magnetic field measurement and performance analysis of the long prototype of the dual aperture dipole magnet, and optimize the design further. Complete the optimization design of dual aperture quadrupole magnet of full-length magnet.

2025: Complete the physical and mechanical design of the sextupole and corrector magnet. Considering construction cost, a short dual aperture dipole magnet is made of low carbon steel material to study its magnetic properties. Develop a new prototype of double aperture quadrupole magnet. Develop a sextupole magnet prototype.

2026: Complete the magnetic field measurement and analysis of dual aperture quadrupole magnet and sextupole magnet. Complete the Engineering Design Report of Collider magnet system.

Factories need for CEPC Collider magnets:
We will need 8 qualified factories to work for 5.5 years to finish the mass production of the collider magnets. At the same time, we take the magnetic field measurements with 20 sets of measurement systems in 6 years.

7) Booster magnets (W. Kang)
2024: Set up a long rotating coil field measurement system to measure harmonic errors of the magnets for the Booster.

2025: Develop a full scale dipole-sextupole combined magnet and a full scale quadrupole magnet for the Booster.

2026: Finish the test of the two full scale magnets and demonstrate the feasibility of fully verified technologies of the prototype magnets through R&D with engineering design of CEPC booster magnets towards the mass production of the booster magnets in an industrial way.

2027: Well prepared for the realization of the CEPC booster magnets with good understanding of the cost and industrial involvement; explore the feasibility of the automatic production and test lines for the future mass production of the magnets.

8) Magnet power sources (B. Chen)
2024:
According to the design requirements of accelerator physics, through communication with the magnet system, the power supply parameters are optimized to determine the type and quantity of the power supply.

According to the power supply of different power categories, based on the research and development results in TDR, we discussed the design scheme of the power supply with the manufacturer to meet the requirements of the actual construction of CEPC (e.g. safe and reliable, convenient debugging, convenient maintenance, compact structure and reasonable cost).

According to the number of power supplies, as well as the production capacity of the manufacturer, We chooses to cooperate with 2 to 3 manufacturers for the high-power power supply, 4 to 5 manufacturers for the medium-power power supply and 4 to 5 manufacturers for the low-power power supply.

The manufacturer is responsible for the electronic circuit design and mechanical structure design of the power supply to optimize the size and cost of the power supply, we are responsible for the topology design and simulation of the power supply, the hardware design and software development of the digital power supply control module to meet the performance requirements of the power supply.

In 2024, the design scheme of the power supply is determined, and the topology design and simulation of the power supply are completed. At the same time, the hardware design and software development of the digital power supply control module are started.

2025:

According to the result of topology simulation, cooperate with the manufacturer to design electronics circuit and mechanical structure. The design should consider the high availability, high reliability, electromagnetic compatibility, as well as the convenience of maintenance and replacement. At the same time, the cost of power supply is optimized and the production cycle is evaluated. Digital control board hardware development.

Complete the hardware development of digital control board.

According to the topological simulation results, cooperate with the manufacturer to design the electronic circuit and mechanical structure. Design should consider high availability, high reliability, electromagnetic compatibility, and ease of later maintenance and replacement. At the same time, the cost of power supply is optimized and the production cycle is evaluated.

Complete the development of digital control board hardware. At the same time, hardware description program design and soft core design are carried out, and function test is carried out on the hardware.

2026:

Develop the prototype of the power supply embed the digital control board in cooperation with the manufacturer. Test the power supply performance, and optimize the digital control program according to the test results. Complete the development of the prototype, make it finally reach the target, and meet the conditions of industrial production.

9) Electrostatic-magnet separator (B. Chen)

2024:

According to the design requirements of accelerator physics, the physical design of the electrostatic-electromagnetic separator is optimized to improve the field uniformity and reduce the beam impedance.

In CEPC collision ring, 32 sets of electrostatic-electromagnetic separators need to be installed in the RF region. According to the production capacity of the manufacturer, we need choose to cooperate with 2 to 3 manufacturers. Based on the research and development results of the prototype in TDR, the design scheme of the separator will be discussed with the manufacturer to meet the requirements of the actual construction of CEPC. In order to optimize the production process and reduce production costs.

The overall physical design of the electrostatic magnetic separator will be completed in 2023.

2025:

According to the physical design of the separator, cooperate with the manufacturer to complete the mechanical structure design of the separator and the design of key components (including Electrode, Vacuum chamber, HV metal-ceramic support, HV feedthrough, magnet coil and overall support, etc.). Design should consider high availability, high reliability, ease of processing, easy installation, and ease of maintenance and replacement later. At the same time, the cost of the separator was optimized and the production cycle was evaluated.

2026:

Cooperate with the manufacturer to develop and test the separator prototype to check the feasibility of the technology. Through the prototype development, the manufacturers master the key technology and process flow, so that it has the conditions to achieve industrial production

10) SC quadrupoles (Y.S. Zhu)

SC quadrupoles (Y.S. Zhu)

In EDR phase, the general goals for superconducting magnets in CEPC Interaction Region are:

(A) Complete the Engineering Design Report for superconducting magnets in CEPC Interaction Region, including double aperture quadrupole magnets Q1a, Q1b, Q2 and anti-solenoid.

(B) Perform pre-research on superconducting quadrupole coil using high-temperature superconductor (HTS Bi-2212 or YBCO).

To guarantee CEPC be completed in 2035, two superconductor factories and two superconducting magnets factories are needed to finish the production of superconducting magnets in CEPC Interaction Region.

For superconducting magnets in CEPC Interaction Region in EDR phase, each year to do list (items) and deliverables, milestones are briefly described as follows:

2024:

1 Finish the Optimization design of superconducting magnets in CEPC Interaction Region, including double aperture quadrupole magnets Q1a, Q1b, Q2 and anti-solenoid.

3 Perform the conceptual design of quadrupole magnet using high temperature superconductor.

2025:

1 Finish full 3D magnetic field analysis with all magnetic components together, and evaluate magnetic performance of each superconducting magnet.

2 Perform the experimental research and test on high temperature superconductor for superconducting quadrupole (HTS Bi-2212 or YBCO).

2026:

1 Finish the winding, fabrication and cryogenic test of a short superconducting quadrupole coil using high temperature superconductor.

2 Finalize the engineering design report for superconducting magnets in CEPC Interaction Region.

11) SRF system for collider ring (J. Y. Zhai, P. Sha)

2024:

- Engineering design of the full-scale Higgs 6x2-cell 650 MHz cryomodule.
- Beam operation of the 2x2-cell 650 MHz test cryomodule.
- Continue to study beam-cavity interaction and LLRF control.

2025-2026:

- 650 MHz components design and performance improvement R&D.
- Fabrication of the 650 MHz prototype 6x2-cell cryomodule (cavities and other components).
- Operation of the 2x2-cell 650 MHz test cryomodule replaced with high Q cavities, variable high power input couplers and high power HOM couplers.
- High gradient high Q and new material 650 MHz cavity R&D for ttbar.

2027:

- Assembly and testing of the Higgs 650 MHz prototype 6x2-cell cryomodule.
- Prepare for mass production of the Higgs 650 MHz cavities and cryomodule.
- Engineering design of the 650 MHz cryomodule for the high luminosity Z mode.
- Engineering design of the 4x5-cell 650 MHz cryomodule for the ttbar mode.

12) SRF system for booster ring

2024:

- Assembly and testing of the high Q 1.3 GHz cryomodule.
- Engineering design (modification) of the Higgs 1.3 GHz cryomodule.
- Continue to study beam-cavity interaction and LLRF control.

2025-2026:

- High gradient high Q and new material 1.3 GHz cavity R&D for ttbar.
- Fabrication of the Higgs 1.3 GHz prototype cryomodule (cavities and other components).
- Engineering design and key components R&D of the high current 1.3 GHz cryomodule for Z mode.

2027:

- Assembly and testing of the Higgs 1.3 GHz prototype cryomodule.
- Prepare for mass production of the Higgs 1.3 GHz cavities and cryomodule.
- Fabrication of the high current 1.3 GHz cryomodule (cavities and other components) for Z mode.

13) Cryogenic system (R. Ge and Mei Li)

2024:

Continue to deeply optimize the cooling scheme design of the CEPC superconducting cavity and superconducting magnet side (particularly the detector magnet), combining the 3D mechanical layout and more detailed process calculations to optimize a cryogenic cooling scheme that can meet the actual functional requirements while also facilitating later maintenance and requiring less construction investment.

2025:

Discuss the technical parameters and development progress of key equipment with domestic manufacturers, such as a large helium refrigerator, a 2K JT heat exchanger, and multiple cryogenic transfer lines, etc.

Large helium refrigerator: jointly with FULLCRYO Corporation, the development of 15kW@4.5K helium refrigerator will be carried out, and the development task will be completed in 2025.

Joule Thomson (JT) Heat exchanger R&D: jointly with Suzhou Sanchuan Heat Exchanger Co., Ltd, company to conduct the heat exchanger research and design works, and conduct the experimental test.

2026:

Complete EDR documentation and optimize the power consumption and construction cost tables of the cryogenic system.

Valve boxes and cryomodules design: Discuss the technical parameters with factories (Hefei Juneng Electro Physics High-tech Development Co., Ltd, Wuxi Innovation Technology Co., Ltd, Vacree Technologies Co., Ltd, etc.) to conduct the valve boxes and cryomodules design works, , in order to promote the continued development of the CEPC industrial alliance.

14) RF power sources and power distribution (collider, booster and linac) (Z.S. Zhou)

2024:

1) Accomplishment of high-power test for P band high efficiency klystron, starting of high-power test for MBK.

2) Development of C band 80MW klystron for CEPC linac.

2025:

1) Accomplishment of high-power test for MBK.

2) Development of high efficiency klystron with higher voltage and multi-stage collector.

3) Accomplishment of high-power test for C band 80MW klystron.

2026:

High power test of high efficiency klystron with more than 80% efficiency.

15) Instrumentation and feedbacks (Y.F. Sui and Y.H. Yue)

2024: Continued certificating beam measurement technologies at BEPCII and HEPS, such as beam position monitor electronics, beam loss detector and synchrotron radiation-basedmeasurement. Carry out the experiment of beam feedback system at BEPCII and HEPS.

2025: Carry out research on the industrialization of BPM electronics and beam loss monitor systems with CIPC member or other potential partners. Find out the final solution of BI device batch manufacturing. This way we can determine the number of manufacturers.

2026: Training people in HEPS and BEPCII for the completion of CEPC construction. Complete detail the beam instrumentation engineering design report for every sub-systems. Prepare the EDR of beam instrumentation system. Based on the current estimation, at least 3 manufacturers are required to produce BPM detectors and 2 manufacturers are needed for BPM electronics to quarantee cepc beam instrumentation be completed in 2035. After the batch trial production and completion of the engineering design report, more accurate estimates of manpower can be provided.

16) Mechanical system (H.J. Wang and Minxian Li)

2024:

The expectant progresses are:

(a) The final magnet support scheme (such as individual girder or common girder), the structure design of some typical magnet supports. The deformation and vibration (modal) simulation and optimization of typical supports.

(b) The structure design of the collimator for background, and the rough scheme of the collimator for machine protection.

(c) Further assessment and mechanical design of the remote vacuum connector at MDI.

(d) A basically determined design of the support for cryostats at MDI. The deformation and vibration (modal) simulation and optimization of the whole cryostat-support assembly, including the rough assessment of Lorenz force, quench cases and temperature change.

(e) Make a definite interface with detector mechanics, and refine the mechanics layout of all the accelerator components on base of TDR design.

2025:

The expectant progresses are:

(a) The structure design of more magnet supports.

(b) The structure design of the collimator for machine protection, *and begin the necessary technique study if possible.*

(c) The development and test of the remote vacuum connector if possible (this part is relatively independent and important for the integral scheme of MDI, which we think a prototype is necessary).

(d) The structure design of the support for cryostat at MDI, including the detailed FEA, *and begin the necessary* *technique study if possible (eg. Vibration and alignment related techniques).*

2026:

The expectant progresses are:

(a) The structure design of all kinds of supports which needs to be finished at EDR stage.

(b) Finish all the development and technique studies if there has any.

(c) Optimize all the designs.

(d) Finish the EDR report.

(e) Make a scheme for the machine of all components.

The rough factory requirement from 2026 to 2035.

The production of all components is supposed from Jan. 2026 to Jan. 2031. We investigate some factories like Hefei Keye and Beifangcheliang. The IHEP colleague and factory requirements are as follows.

** Here we just make a rough estimation, and take the 50% capacity of Beifangcheliang as the reference for 1 factory. If the item doesn't need one fulltime IHEP colleague or 1 factory, it is written as 1.*

1) Dipole supports in Collider: 1 IHEP colleague, 2 factories, 2026.1-2031.1.
2) Quadrupole supports in Collider: 1 IHEP colleague, 1 factory, 2026.1-2031.1.
3) Sextupole supports in Collider: 1 IHEP colleague, 1 factory, 2026.1-2031.1.
4) Corrector supports in Collider: 1 IHEP colleague, 1 factory, 2026.1-2031.1.
5) Vacuum device supports in Collider: 1 IHEP colleague, 1 factory, 2027.1-2031.1.
6) Instrumentation supports in Collider: 1 IHEP colleague, 1 factory, 2027.1-2031.1.
7) Collimators: 1 IHEP colleague, 1 factory, 2026.7-2031.1.
8) MDI mechanics: 1 IHEP colleague, 1 factory, 2027.1-2031.1
9) RF module supports in Collider: 1 IHEP colleague, 1 factory, 2029.1-2030.10.
10) Dipole supports in Booster: 1 IHEP colleague, 2 factories, 2026.1-2031.1.
11) Quadrupole supports in Booster: 1 IHEP colleague, 1 factory, 2026.1-2031.1.
12) Sextupole supports in Booster: 1 IHEP colleague, 1 factory, 2029.1-2031.1.
13) Corrector supports in Booster: 1 IHEP colleague, 1 factory, 2028.1-2031.1.
14) Vacuum device supports in Booster: 1 IHEP colleague, 1 factory, 2027.1-2031.1.
15) Instrumentation supports in Booster: 1 IHEP colleague, 1 factory, 2027.1-2031.1.
16) RF module supports in Booster: 1 IHEP colleague, 1 factory, 2029.1-2030.10.
17) Bunching system support, EBTL supports and magnet supports in Linac and Damping ring: 1 IHEP colleague, 1 factory, 2028.7-2031.1.
18) (Positron) Accelerating structure support: 1 IHEP colleague, 1 factory, 2027.7-2031.1.
19) Vacuum device supports in Linac and Damping ring: 1 IHEP colleague, 1 factory, 2028.7-2031.1.
20) Instrumentation supports in Linac and Damping ring: 1 IHEP colleague, 1 factory, 2028.7-2031.1.

17) Vacuum system (Y.S. Ma)

1. Optimization of NEG coating:

NEG coating is used to sustain the vacuum of beam pipe and supress the e-cloude of positron ring. Because the resistance of NEG coating increases with the hickness increases, but the life of the NEG coating decreases significantly when the thickness is less than 200nm, it is necessary to optimize the thickness and impedence of NEG coating.

2024: Optimization the thickness of NEG coating distribution along the vacuum chamber.

2025~2026: Optimization the resistance of NEG coating.

2. Optimization the layout of vacuum system.

2024~2026: The vacuum layout is strongly dependent on physics, magnets, mechanical, etc. It is necessary to optimize the detail structures and dimensions of vacuum chambers, RF shielding bellows, and the distribution of ion pumps with the other system changes. The baking method and materials used for the vacuumc chambers of collider should be carefully selected and study due to the limited space between magnets and very high energy of synchrotron radiation.

3. The number of manufacturers that can participate in a production process may depend on the bidding methods outlined in the bidding document or the purchasing management regulations. For example, for a standard vacuum device, one supplier may be sufficient. However, for a more complex device like the vacuum chamber, it may be necessary to engage multiple suppliers to complete the production process. For instance, in the case of the copper vacuum chamber of collider, one large manufacturer could complete the entire production, but to ensure the project's time limit or to be more competitive in cost and quality, it may be possible to find three or more manufacturers to complete the production. So the number of suppliers for different vacuum devices may vary.

Ultimately, the number of suppliers will depend on the specific requirements of the project and the available resources. Under those considerations, the number of suppliers of different vacuum devices can be shown as follows:

Devices	Number of manufactures	Qualifacition
Copper vacuum chambers	3~4	Having a professional background in vacuum processing. Or their production have been used in accelerator
Al vacuum chambers	2~3	
S.S vacuum chambers	2~3	
Manifold for SIP, Gauge & RGA	2~3	
RF shielded bellows	2~3	
NEG coating	2~3	
Ion pump	1~2	
Molecular pump	1~2	
Gate valve	1~2	
Roughing valve	1~2	
Vacuum gauge	1~2	
Residual gas analyzer	1~2	
Helium leak detector	1~2	
Vacuum heating	1~2	

18) Control system (G. Li)

2024: Further discuss with the device group and confirm accelerator control requirements and specifications. If possible, several prototypes built to research and solve key technologies such as timing system，MPS，Network and database，etc. Meanwhile, actively establish and deepen cooperative relations with other accelerator complex (such as KEKB) and the international EPICS community (if possible, invite foreign control expert to work at CEPC for a period time). Also pay attention to the application of new technologies in accelerator control systems such as artificial intelligence, Internet of Things, edge computing and machine learning。

2025: On the basis of the prototypes, test parameters and performance specifications of above systems, such as the delay of timing signals in long-distance transmission, jitter, etc., the response time of the machine protection system, the latency of the network system, massive database storage technology and so on. Propose suggestions for improvement and optimize the design scheme. Recruit and train a team for CEPC control system.

2026: Discuss the control requirements again with the equipment groups，who sign a technical contact list with.

Continue prototype research on key technologies. Evaluate budgets and CPM plans。Specify various types of control rules and specifications, manage and constrain control system development including third-party partner companies. Be ready for the design and construction of CEPC control system. Due to the fact that both of controllers and computer servers are COTS, procurement only needs to be made six months or a year in advance.

19) Conventional facilities

2024: （1）The investigation of alternative sites will continue, including detailed analysis of the natural environment, hydrogeology, water source and electricity conditions, etc. （2）Identify the needs of the accelerator for conventional facilities, and there will be no major changes later.

2024: In-depth engineering design for key candidate sites, including civil engineering, power distribution system, ventilation and air conditioning system, cooling water system, compressed air system, etc. (1) The overall civil construction plan has been gradually improved; (2) Basically complete the design of the power distribution scheme of the project and the process design of other systems.

2025: Investigate cooperative manufacturers (about 400) and find out the production capacity and production cycle of equipment; Statistics general facilities main equipment materials. Prepare the budget, complete the system scheme design, prepare and complete the conventional facilities engineering design report.

(Prerequisite: The design Institute fully cooperate and support, invest enough resources to ensure that the content of the EDR report in the Conventional facilities section meets the requirements of the project proposal. In order to meet the requirements of 2026, the design institute needs to complete the preliminary design and construction drawing design within 2025, which will cost a lot of manpower and funds.)

20) Environment, health and safety issues (Guang Yi Tang and Zhongjian Ma)

In terms of environmental impact assessment, significant progress has been made in evaluating prompt radiation, including random beam losses in straight and arc sections, as well as point losses in the beam dump, along with their corresponding dose distributions. The next phase involves determining the beam losses in all other regions of the accelerator beamline, including the damping ring, transport lines from the straight section to the booster, transport lines between the booster and collider, injection and extraction points, interaction regions, and RF regions. A Monte Carlo model will be established to assess the prompt dose distribution. From the perspective of induced radioactivity, the production rates of radioactive nuclides in cooling water, exhaust gas, underground water have been calculated assuming uniform beam losses. The next step is to determine the overall production rates of radioactive nuclides in cooling water, exhaust gas, underground water and soil, considering all beam loss scenarios. Additionally, the production rates of radioactive nuclides in equipment such as magnets and beam pipes will be calculated. This will enable us to determine the distribution of induced radioactivity dose within the tunnel. Furthermore, the engineering design and evaluation of radiation dose monitoring systems and personal safety interlock systems will be undertaken. These works will be finished in 2024.

From 2025 onwards, the preparation of the environmental impact assessment document will commence. In addition to the aforementioned evaluations of prompt radiation and induced radioactivity dose distribution, as well as the assessment of radioactive nuclides in cooling water, exhaust gas, and solid waste, detailed engineering information will be required. This encompasses comprehensive structural diagrams of both above-ground and underground buildings, including the precise locations of ventilation shafts, transportation tunnel layouts, and the arrangement of ground buildings. Effective coordination and collaboration with auxiliary facilities designers and civil engineering designers will be essential. Before the end of this year, a competent company will be entrusted to compile the environmental impact assessment document.

In terms of equipment safety, efforts will be focused on optimizing the shielding design around components such as beam pipe flanges, bellows, and vacuum pumps to minimize their impact on magnet coils. Furthermore, attention will be given to the shielding design for electronic devices within the tunnel. By improving the equipment layout and implementing local shielding, simulations will be conducted to evaluate the radiation exposure to electronic devices across various systems, leading to the development of the final design solution. These will be finished in 2026. The public engagement and background surveys for the environmental impact assessment stage will be conducted in this year, and the environmental impact assessment approval will be obtained prior to the project commencement.

21) Machine protection beam dump (Zhongjian Ma, X.H.Cui, and Yuting Wang)

- **2024**: Complet the design and simulation work of the beam dump beamline, as well as the collimator simulation and preliminary design parameters under beam loss conditions.
  - 1. Design the beamline system based on specific requirements, including the design of injection and extraction modes. Design and optimize the parameters of the dilution kicker magnet to achieve accurate beam dumping.
  - 2. Conduct simulation work: Use relevant physics simulation software to simulate the beamline and beam behavior, validating the design and optimization parameters. Perform thermal analysis, evaluating the thermal effects and temperature distribution of graphite and iron materials in the beam dump.
  - 3. Assess radiation levels: Estimate and analyze the radiation levels of electronic devices in the tunnel. Based on the estimation results, implement necessary radiation protection measures to ensure the safe operation of the devices.
  - 4. Perform collimator simulation and preliminary design: Use beam simulation software such as SAD to simulate the collimators under beam loss conditions. Based on the simulation results, determine the preliminary design parameters for the collimator, including dimensions, materials, and positioning.

- **2025**: A detailed analysis of the collimator is required to investigate injection failures, asynchronous beam-dump-kicker firing, or sudden beam-loss phenomena. Further studies should be conducted to understand the collimation necessary for controlling beam-induced backgrounds near the detectors and protecting critical accelerator components. These studies should include evaluating beam-loss tolerances, analyzing collimator survival/damage under realistic conditions, and assessing the impact of chosen collimation apertures on beam lifetimes and the impedance budget.

  2026: Review the design scheme and complet the EDR design report.

22) CEPC high energy gamma ray beamlines (Y.W. Wang and Y.S. Huang)

2024: Further optimization of the lattice with wigglers to get a local higher quality beam for the synchrotron radiation. Complete the static and dynamic error correction or mitigations for the beam and SR lines. Complete the optimization design and prototype testing the gamma camera.

2025: Complete the engineering design of the magnets, vacuum system and mechanics system for synchrotron radiation station. Complete the optimization design of the gamma-ray focusing system.

2026: Complete the engineering design of the tunnel and experimental hall, vertical shafts for synchrotron radiation station. Complete the engineering designs of the gamma camera and the gamma-ray focusing system. Complete the Validation tests of gamma cameras and gamma focusing lenses on inverse Compton gamma light sources. Summarize the engineering designs for the CEPC high energy gamma ray station and applications.

23) Alignment and installation

2024: Carry out error accumulation control research. Compared with existing accelerator complexes, CEPC has a much larger scale. Error accumulation will become a serious problem. To realize error accumulation control, it needs to research datum establish methods, new measurement methods and new data processing methods. The goal is to establish an error accumulation control scheme which can be applied for CEPC alignment.

2025: Verify CEPC alignment design. Rely on BEPCII, CSNS, HEPS, CEPC prototype component and CEPC simulation tunnel to verify the alignment scheme. The goal is to demonstrate the complete and coherent feasibility of CEPC alignment design.

2026: Detail the installation scheme. With the further research of CEPC, the type and number of components and the engineering progress arrangement will become more detail, the installation scheme need to be adjusted accordingly. The goal is to give a detailed installation plan, including the installation work content, work schedule, human resources and component installation scheme.

In order to achieve the required alignment accuracy of CEPC component and ensure the normal operation of the beam, it is necessary to procure and process certain instruments and equipment to support the alignment installation work. When procuring and processing these instruments and equipment, the following aspects need to be considered:

1. Precision: The precision of instruments and equipment is a crucial factor in ensuring the accuracy of alignment installation. It is essential to select instruments and equipment with high precision to ensure accurately positioning and measurement during the alignment process.

2. Stability: The stability of instruments and equipment is crucial for long-term operation and maintaining the accuracy of alignment installation. It is important to choose instruments and equipment with good stability to ensure smooth alignment throughout the project duration.

3. Reliability: The reliability of instruments and equipment is a key factor in ensuring the smooth progress of alignment installation work. It is important to choose instruments and equipment that have been validated and proven to be reliable to minimize failures and repair time, and ensure the continuity of work.

Additionally, it is necessary to ensure that the procurement and processing of equipment meet the requirements of the engineering construction. Close collaboration with suppliers and professional organizations is crucial to develop a reasonable timeline and to monitor the manufacturing and delivery progress of the equipment. This is essential to ensure that the CEPC construction is completed according to the predetermined schedule. Timely communication and resolution of potential issues and delays are important to ensure the smooth progress of the project. The instruments to be procured, the number of instruments, the number of manufacturers, and their planned delivery times are listed in Table 1-1:

Table 1-1 The instruments number, manufacturer number and planned delivery time of Survey and alignment.

instrument	number	manufacturer number	delivery time/month
Double star static GPS	16	1	3
Optical level	32	1	6
Digital level	8	1	5
Laser tracker	69	1	18
Reflector	424	1	18
Total station	16	1	5
FARO arm	8	1	6
Transit square	32	1	5
Electronic gradienter	32	1	3
Zenith plummet	8	1	5

Visual instrument	19	1	18
Hydrostatic level	200	1	10
Indoor GPS	2	1	5
Alignment telescope	2	1	3
Tool microscope	4	1	5
CMM	4	1	6
Laser interferometer	8	1	5
absolute multiline	4	1	12
Baseline guide	4	1	12
All-around target	1700	2	17
UPS power	69	1	3
Instrument trolley	40	1	6
Notebook computer	36	1	3
Desktop computer	20	1	3
Work station	12	1	3
gyro-theodolite	4	1	6
Relative gravimeter	2	1	6

The equipment to be fabricated, the number of equipment, the number of manufacturers, and their planned delivery times are listed in Table 1-2:

Table 1-2 The equipment number, manufacturer number and planned delivery time of Survey and alignment.

equipment	number	manufacturer number	delivery time/month
Instrument stand	80	2	9
Instrument lifting stand	32	1	6
Laser alignment system	2	1	12
Reference parts	52	2	6
Measuring equipment	60	3	6
Alignment tools	32	2	6
Setting out tool	16	1	3
Tunnel network floor control point	36518	10	18
Tunnel network wall control point	36518	4	18

24) Beam driven plasma injector for CEPC (D.Z. Li)

2024:

- Detailed error tolerance analysis for new baseline (10→30 GeV).
- Further optimization of the Linac for plasma injector.
- Plasma dechirper and e- acceleration experiments at SXFEL

2025:

- Start-to-end simulation
- Two-beam PWFA experiment @ SXFEL
- Prototype of meter-scale plasma channel based on laser ionized underdense gas
- Construction of PWFA Lab at IHEP based on BEPC-II linac

2026:

- PWFA experiment (external injection, etc.) at IHEP PWFA lab.
- Simulation studies on staging and full energy plasma injector.
- kHz cm-scale plasma source prototype

25) CEPC polarization design (Z. Duan)

2024-2025: Identify the boundary conditions that spin rotators and polarimeters be implemented into a future version of the collider ring lattice, help the lattice designers devise a lattice version with the possibility to insert spin rotators at a later stage. Carry out preliminary experiments of resonant depolarization technique at BEPCII. Extend the study of beam polarization operation to higher beam energies, like the Higgs energies.

2026: Clarify the hardware specifications of polarized electron sources, asymmetric wigglers, solenoid spin rotators. Discuss with related hardware systems to establish a long-term plan for hardware design and R&D for key items. Continue the resonant depolarization experiments in HEPS booster, as a test of concepts for CEPC.

26) SppC design and compatibility with CEPC (Jingyu Tang and Y.W. Wang)

2024-2026:

1）Optimization of the SPPC lattice to follow the layout evolution of the CEPC lattice design;

2) Study of nonlinear beam dynamics with more-or-less realistic error models;

3) Study of the synchrotron radiation effects and beam screen design;

4) Further studies on the beam-beam effects and longitudinal dynamics;

5) Update design of the beam collimation system;

6) Conceptual design of the injector accelerators;

7) Study of possible bypass schemes for hosting entire CEPC and SPPC colliders including detectors in the same tunnel.

27) SppC high field magnet (Q.J. Xu)

SppC high field magnet Goal of the EDR phase: increase the field strength of the model dipole magnet to 16 Tesla with combined Nb3Sn and HTS coils; complete the engineering design of the 20-T dipole magnet with accelerator-level field quality; complete the engineering design of the cryostat for the 20-T accelerator magnets （in cooperation with the cryogenics group）.

2024: Fabrication and test of the 16-T model dipole magnet: complete the fabrication of the outer Nb3Sn coils and inner HTS coils, assembling of the magnet and the preliminary performance test.

2025: Test and training of the 16-T model dipole magnet, study of its quench and dynamic characteristics; improvement of components or structure if necessary. Magnetic and mechanical design of the 20-T model dipole magnet based on the performance of 16-T model dipole magnet. Conceptual design of the cryostat for the 20-T accelerator magnets （in cooperation with the cryogenics group）.

2026: Summary report of the 16-T model dipole magnet R&D. Engineering design of the 20-T model dipole magnet. Engineering design of the cryostat for the 20-T accelerator magnets （in cooperation with the cryogenics group）.

28) CEPC electronic documentation system (K. Huang and S. Jin)

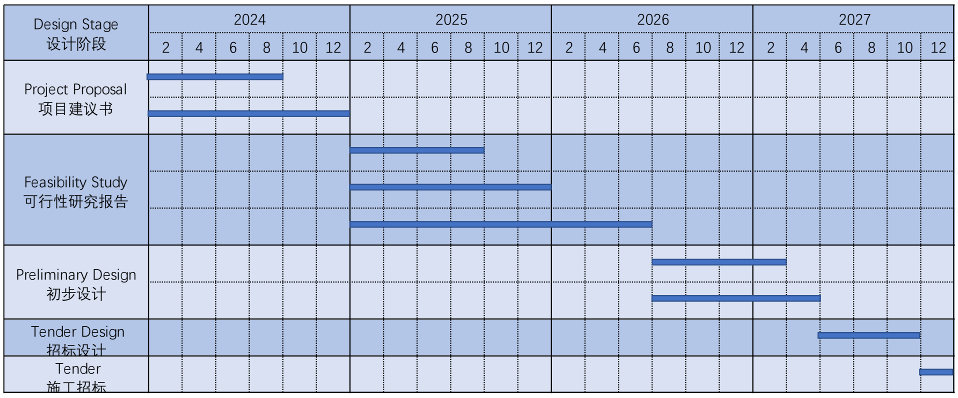
2024: Based on the achievements of 2022, the upgrade of DeepC collaborative research, development and construction management system for massive scientific facilities will be completed. The DeepC system will be initially applied in the CEPC project, and the data standard framework of CEPC project will be refined.

2025: The DeepC system will undergo a progressive upgrade, incorporating feedback from its application in the CEPC project. The multi-source data management capabilities will be further enhanced, and an intelligent search engine based on the CEPC knowledge graph will be implemented.

2026: The DeepC system will be capable of providing comprehensive project management and knowledge management services for the CEPC project, covering the digital management requirements of the CEPC project. It will enhance the efficiency of CEPC project management, and provide continuous support for the entire lifecycle of digital management throughout the construction and operation of CEPC project.

29) CEPC site preparation and civil engineering design in Qinhuangdao and Chuangchun (Y. Xiao)

Implementation Planning before Construction



30) CEPC site preparation and civil engineering design in Changsha (Yangjiang Pan and Zhiji Li)

With the goal of completing the technical design report in 2024, The preliminary planning of monographic research and the completion time nodes are as following:

1) In February 2024, Monographic study on the general structures arrangement (equivalent to the topic of selecting the general layout of the hydropower complex, the electromechanical specialty collects and regulates out the requirements for the layout of professional equipment in IHEP, and completes the layout design of supporting equipment. The civil engineering discipline carries out the building layout design according to the equipment layout results, the architectural discipline completes the overall plane layout planning and coordinates with the urban planning.

2) In February 2024, The special report on the general layout planning of construction (Determining the scope of land use)

3) In March 2024, The planning report of land acquisition and resettlement (Determining the land acquisition and resettlement investment)

4) In May 2024, Environmental impact assessment report (Determining the environmental protection investment)

5) In June 2024, Water and soil conservation scheme report (Determining the Water and soil Conservation Investment)

6) In June 2024, The special topic of labor safety (including anti-terrorism topics, industrial disease topics, and safety pre-assessment of project, to determine the labor safety investment)

7) In August 2024, The special topic of safety monitoring (Determining the monitoring investment)

8) In May 2024, The special topic on alignment and surveying control network design (Determining the measuring investment)

9) In June 2024, The special topic of access system and power supply for construction (Determining the power supply investment)

10) In June 2024, Supplementing the geological Exploration and prospecting work, ascertaining to the relation of underground construction to regional road、railways、pipeline.

11) In August 2024, Monographic Study on the earthquake-preparedness and anti-seismic (study on the effect of earthquake, and the impact of Surface road、Railways、High-speed Rail on the vibration of underground chamber, and determining the seismic fortification measures and buried depths of openings)

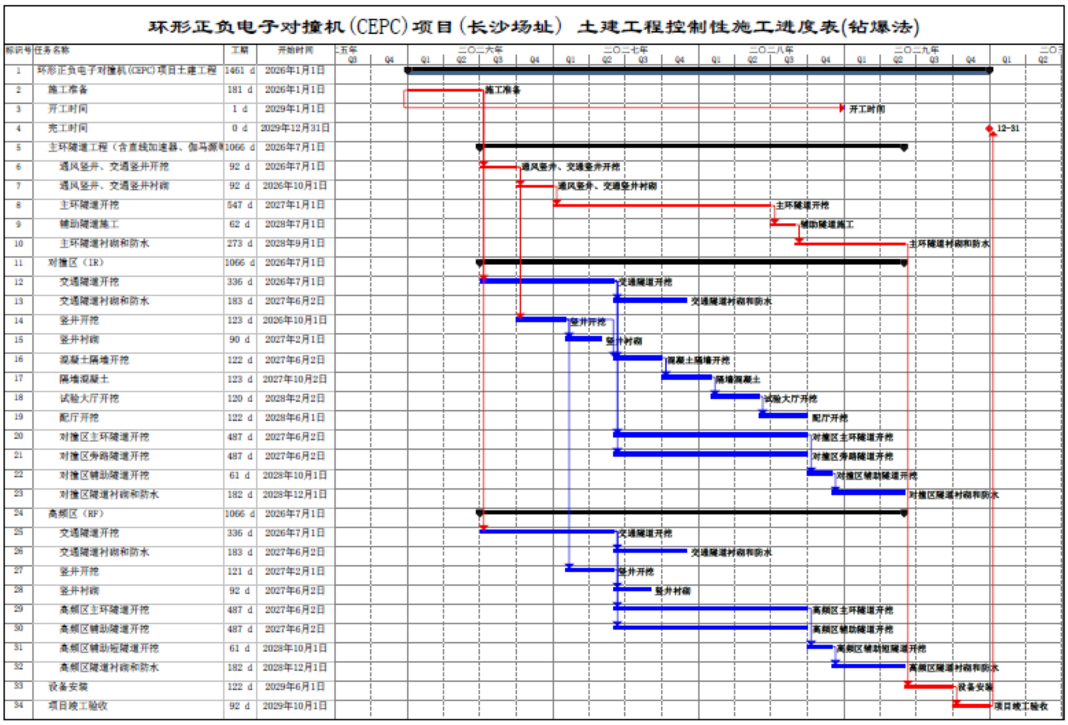
12) In September 2024, the technical design report， determine the budgetary estimate.

The preliminary planning of monographic research and the completion time nodes in the Engineering Design Review stage from 2023 to 2025 are as following:

1) In December 2024， Completing the civil engineering design of the underground part, including layout design of underground opening、excavation and support design、structural design.

2) In June 2025, Completing the electromechanical devices design of the underground part.

3) In September 2025, Completing the buildings and electromechanical equipment design of the ground part.



31) CEPC site preparation and civil engineering design in Huzhou (K. Huang)

2024: Based on the latest information, the structural design of underground and surface buildings will be further compared and optimized. The comparative analysis of the civil construction methods will also be conducted.

2025: Incorporating the latest project information, the design of auxiliary facilities for civil construction, including power supply systems, control and communication systems, firefighting systems, HVAC systems, will be further improved. The construction organization design and project schedule for the CEPC project will also be refined.

2026: The civil engineering design for the current phase of the CEPC project will be completed, and the overall investment will be determined.

32) CEPC domestic and international industry preparations (S. Jin)

2024: Preparations for industrialization and industrial development include the following key tasks:

1) Invite relevant members of CEPC and CIPC to jointly draft evaluation criteria for the industrialization and mass production of CEPC;

2) Conduct small-scale trials of the DeepC system, inviting CEPC members to complete the initial version of the DeepC architectural standards in areas such as document management, data management, and site customization.

2025: Assessing the industrialization and industrial capabilities of CEPC enterprise and promoting the application of DeepC in the industry, including:

1) Promote DeepC to the CIPC members based on both of needs of CEPC industrialization and its application in hydropower station projects;

2) Engage in in-depth discussions with related enterprises to assess the industrialization and industrial capacity of CEPC;

3) Establish external DeepC sites to attract more enterprises.

2026: Addressing the identified issues and drive problem resolution, including:

1) Evaluate the results and establish an industrialization model for CEPC, providing recommendations for mass production and logistics;

2) Promote the development of cultivation plans for components with low industrial maturity;

3) Further advance DeepC iteration and establish a more mature industrial management system.

33) Injector linac and damping ring R&D (J.R. Zhang) (combined in 3)

34) CEPC Injection/extraction system (Jinhui Chen)

The hardware of CEPC injection and extraction system mainly includes septa magnets, kickers and pulsers. It is necessary to complete the design iteration of all kinds of component through the EDR phase, verify the feasibility of the scheme, train the engineering team, and cultivate manufacturers. To ensure the CEPC being completed in 2035, it need around 25 FTEs and 4 factories.

2024：To complete the engineering design of all components, including 4 kinds of kicker system, 3 kinds of Lambertson magnets. To research manufacturers and complete procurement of components.

2025：To start the prototype R&D of trapezoidal-wave kicker system and Lambertson magnet.

2026：Complete R&D on prototype of the trapezoidal-wave kicker system and Lambertson magnet.

35) Collective effects and impedance (Yudong Liu, Na wang)

1. Develop the impedance model with more realistic hardware designs; Obtain a convinced impedance model in both longitudinal and transverse planes; Provide impedance requirements for the hardware designs along with the impedance optimization or iteration with hardware development.
2. Instability evaluations for different operation scenarios based on the impedance evaluations; Prove the effectiveness of the strategies for the instability mitigations, such as feedback, chromaticity, lattice optimizations, etc.
3. Develop investigating tools for the self-consistent simulations with both beam-beam and impedance; initial modeling of feedback system in the beam dynamics analysis.
4. More detailed simulation studies on electron cloud effects, including primary electron generation from synchrotron radiations.
5. Perform impedance measurements on the key vacuum components and test possible impedance mitigations; Conduct possible beam-based measurement on BEPCII as a support for the CEPC collective instability studies.

Appendixes

The TDR cost of CEPC project: 36.8 B RMB

The CEPC accelerator TDR cost: 18.98 B RMB.

Accelerator Total cost (Unit:100M RMB)	**189.8**	**100%**
Accelerator physics	0.8	0.42%
Collider	99.99	52.70%
Booster	41.13	21.68%
Linac and sources	18.3	9.64%
Damping ring	0.59	0.31%
Transport lines	1.57	0.83%
Common systems (cryogenic+protection+alignment)	16.63	8.76%
Installation (3%)	5.37	2.83%

Commissioning (3%)	5.37	2.83%

CEPC TDR Total Cost (Unit: 100M RMB)

CEPC Total Cost	**368**	**100 %**
Project management (1%)	3	0.82 %
Accelerator	**190**	51.63 %
Conventional facilities (Civil + General Utility)	103	27.99 %
Gamma-ray beam lines	3	0.82 %
Experiments	40	10.87 %
Contingency (8%)	29	7.88 %

CEPC Hunam Resource Evolution

Year	**Accelerator human resource**	**Accumulated spending Billion RMB**
2015	50	-
2018	100	-
2023	200	0.2
2025	300	0.3
2027	500	0.4
2031	2800	9
2035	2500	20