Report of the Review of the Circular Electron Positron Collider Conceptual Design Report

This report was prepared by the international review committee:

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The report is based on v2.0 of the Conceptual Design Report and presentations by and discussions with the CEPC team during the three-day review from 13-15 September in Beijing, People’s Republic of China.

Introduction

The field of elementary particle physics, or high energy physics, deals with the smallest constituents of the Universe and explores the laws of nature at the shortest distances. For all of the last century and in particular in the last five decades, the field experienced an uninterrupted success of theoretical advancements and experimental discoveries. This epoch culminated with the discovery of the Higgs boson at the CERN Large Hadron Collider (LHC) in 2012. The “Standard Model” of elementary particle physics now offers, for the first time in the history of science, a self-consistent description of the fundamental constituents of matter at the smallest scale and their interactions. This description complies with the laws of quantum mechanics and special relativity, and can in principle be extrapolated down to distances at small as the Planck scale, where one expects quantum gravitational effects to play a role. However, this description is not complete and cannot account for several astrophysical and cosmological observations, starting from the imbalance between matter and antimatter and the abundance of dark matter observed in galaxies. In addition, the Higgs boson itself brings in more fundamental theoretical questions associated to the size of quantum corrections (i.e. including, but not limited to, the naturalness of the Higgs mass). From this point of view, the Standard Model appears only as an approximate, incomplete description that needs to be incorporated into a new, more fundamental theory at higher energies. The Higgs boson is in a pivotal position potentially connecting high energy physics, cosmology, astro-particle physics, and lepton-quark flavor physics.

The experimental program in high energy physics worldwide is extremely dynamic and vibrant. While neutrino experiments, B factories, and dark matter searches are all in the pipeline, the LHC with its luminosity upgrade will lead the way for the next two decades exploring the energy frontier. However, the LHC will not reach the desirable precision in Higgs measurements to probe beyond a new physics scale of 1 TeV. A “Higgs factory” is clearly called for. Historically, any new particle discovery, from the strange quark and on, had always led to a particle “factory”, an experimental facility where the properties of the new particle were studied in detail, pinpointing its role in the overall theoretical scheme. The Higgs boson should be no exception. Among the Higgs factory proposals, the International Linear Collider (ILC) has been under consideration for decades and is more mature in design. The international high energy physics community is enthusiastically waiting for a decision by the Japanese government for its construction in Japan. At CERN, a more ambitious proposal, the Compact Linear Collider (CLIC), may take us to a higher energy regime.

More recently, the proposals of circular colliders, the “Future Circular Collider” (FCC) at CERN and the “Circular Electron-Positron Collider” (CEPC) in China have drawn significant attention in the international community. The CEPC is an ambitious large scientific project proposed by the Chinese high energy physicists. Its main goal is to study Higgs physics to explore the nature of electroweak symmetry breaking and to reveal the dynamics of the electroweak phase transition, which took place about a nanosecond after the Big Bang and led to the Universe as we know it today. CEPC also plans to examine the W and Z electroweak bosons to an unprecedented precision, offering an intimate knowledge of two key elements of the Standard Model. The CEPC has a great potential to uncover new physics at the next energy scale.

Executive summary

The review committee congratulates the CEPC study team with the successful completion of the conceptual design report (CDR). The document provides a complete, and very readable, description of the project. The scientific goals presented in the report are well motivated and aligned with the priorities of the international high-energy physics community. The report also presents a conceptual design for the CEPC experiments, with plausible solutions to address the main challenges. We believe that the studies reported in the CDR fully achieved the goals appropriate at this stage of the project, and we strongly encourage the CEPC team to proceed with the preparation of the technical design report.

The CEPC is an ambitious project that can bring China to the first ranks of global particle physics. The central piece of the programme sees the CEPC operated as a Higgs boson factory at a centre-of-mass energy of 240 GeV, where the CEPC experiments will measure the Higgs boson couplings. The CEPC program offers a more precise and more model-independent characterization of the Higgs boson than can be performed at the LHC, and allows to measure several couplings that are not accessible at the LHC at all. The conceptual design report also provides a convincing case for electroweak precision measurements made possible by high-luminosity runs at the Z-pole and the W-pair production threshold. These landmark precision measurements in the Higgs and electroweak sectors, with exquisite indirect sensitivity to physics beyond the Standard Model, yield a compelling physics case. The scientific potential of the CEPC project is supported by solid studies and is widely recognized by the international particle physics community. Complementary to the precision program, the large samples of Higgs and Z-bosons yield an unrivalled direct discovery potential for searches for rare decays. Finally, the conceptual design report demonstrates the breadth of the programme, with an exploration of the potential of the project for QCD, flavour and neutrino physics.

The review committee encourages the CEPC study group to extend the studies presented in the conceptual design report in several directions, keeping a close eye on new developments. A deeper understanding is needed of the synergy with the LHC and possible new hadron collider facilities, as well as the inter-relations between precision measurements in e^+e^- collisions at different center-of-mass energies. We encourage the CEPC study group to investigate the potential of the CEPC project for QCD, flavour and neutrino physics in greater depth.

The conceptual design of the CEPC experiments presents several solutions for the main detector subsystems. Chinese institutes are actively involved in developing the relevant detector technology, often in the framework of international detector R&D collaborations. Several groups from outside China have joined the CEPC project, bringing with them valuable expertise. It is plausible that the presented suite of subdetectors technologies satisfy the stringent requirements of the CEPC precision physics programme.

The international experimental collaborations that are to design and build two competitive experiments for the CEPC must down-select the available sub-detector designs and integrate them into an integrated and coherent design that is optimized for overall performance. At this stage, the current, conceptual designs must be taken to the level of an engineered, technical design and the viability of key technologies must be demonstrated in large-scale prototypes. We recommend that the benchmark studies for the detector performance be intensified, such that decisions are informed by a thorough understanding of the impact of the design on the scientific return of the project. A comparison on an equal footing should be possible of all sub-detector options, using a detailed Monte Carlo simulation including the relevant background processes.

Several challenges are identified, where more work is needed towards a technical design report. The design of the forward region is highly conditioned by the presence of the focussing magnets and their compensating coils, while the requirements on mechanical alignment and stability are an order of magnitude more stringent than in previous experiments. The Z-pole run, with a lower magnetic field and high event rate, represents a challenge for the tracker design and requires a detailed strategy for the data acquisition and processing capacity of the experiment. With the 100% duty cycle of the machine the power management of the subdetectors becomes a priority.

Detailed findings and recommendations

These recommendations should be understood as suggestions to guide and prioritize the work towards a complete technical design report for the CEPC experiments.

Physics case

Findings: the committee unanimously congratulates the CEPC team for the exposition of the physics case in the CDR. The document is clear, pleasant to read both by experts and by people not acquainted with collider physics. The CDR forms a comprehensive document that (1) demonstrates a wide range of studies that are well documented and presented in detail, giving strong confidence in the results presented, (2) provides interesting examples of sensitivities worked out in detail, and (3) establishes the impressive reach for new physics searches in the context of scenarios addressing several of the SM shortcomings to answer fundamental questions.

Higgs physics.

Findings: At a center-of-mass energy of 240 GeV the CEPC operates as a Higgs boson factory. In seven years the facility is expected to produce approximately 1 million $e^+e^- \to ZH$ events that allow a direct and model-independent scrutiny of its properties and its interactions with nearly all other elementary particles. The capabilities of CEPC as a Higgs factory are carefully evaluated and convincingly presented. The potential for precise Higgs coupling measurements significantly exceeds the precision that can be achieved at the Large Hadron Collider and is very competitive compared to other proposals for electron-positron colliders. The main modes, $\tau\tau/b\bar{b}/c\bar{c}/gg$, are well covered. In the WW/ZZ channels, it would be helpful to report separately all the leptonic and hadronic channels.

R1: The Higgs analyses and the sensitivities in the measurement of the Higgs couplings are well documented and studied in the context of various prominent models of new physics. It would be helpful to establish what is the CEPC power in discriminating among these different models through a global fit.

R2: Highlight the capability of CEPC to establish the Higgs couplings to the second generation of quarks (and leptons).

R3: Understand the indirect sensitivity to the top quark Yukawa coupling and Higgs self coupling in a global analysis at next-to-leading order accuracy of low-energy Higgs data

R4: In the $H \to$ invisible channel, it would be helpful to report the relative importance of the leptonic and hadronic Z decay channels as the latter one fixes the goal of the jet energy resolution.

R5: In the $ZH \to ZZ\gamma$ channel, we recommend to consider the decay of one Z into charged leptons in addition to the neutrino channel.

EW precision measurements

Findings: The CEPC can collect over 10^{11} events by running at the Z-pole for 1-2 years. This is a unique opportunity offered only by large circular e^+e^- colliders and distinguishes the CEPC program from that of linear colliders such as the International Linear Collider or the Compact Linear Collider.

R6: The unique opportunities to perform landmark precision electroweak measurements should be presented more prominently as one of the guaranteed deliverables of the project.

R7: A broken-down presentation of the theoretical, parametric and experimental uncertainties will provide a better understanding of the limiting systematic uncertainties. The main challenge should be clearly identified for each of the EW precision measurements.

Top physics

Findings: The CEPC run plan does not envisage operation at or above the top-quark pair-production threshold (~350 GeV). The measurements of the top mass and top electroweak couplings are important, both for their own sake, and because of their impact on the electroweak fit and Higgs coupling measurements. It is currently unclear if and when top quark pair production at an e^+e^- collider will be possible.

R8: Make sure the accelerator design remains compatible with operation at energies above the $t\bar{t}$ production threshold.

New Physics searches

Findings: unknown particles may be within kinematic reach of the CEPC and yet avoid detection at the LHC due to their weak couplings or final states with large QCD backgrounds. In such cases, CEPC can significantly improve on the HL-LHC discovery reach. The CEPC will have unparalleled sensitivity to rare flavor-violating Z decays. The CDR documents an impressive capability to search for new physics in rare decays of Higgs and Z bosons; search for dark photons via the radiative return process; and search for dark matter (WIMP) pair-production in the photon+missing energy channel.

R9: Establish the CEPC sensitivity to flavour-violating couplings of the Higgs boson.

R10: Explore the CEPC sensitivity to probe hidden sector DM production mechanisms such as freeze-in or axion mis-alignment.

R11: There is currently a large interest in models with long-lived particles. It would be useful to study what are the prospects at CEPC to probe these scenarios. Is the very clean detection environment offered by CEPC an advantage over hadron machines?

Flavour physics

Findings: The Z-pole run of the CEPC will produce a sample of 10^{11} b-quark events, comparable to Belle II. Unlike Belle II, large samples of B_s mesons and b baryons will be produced, and the large boost of the produced b hadrons may provide an advantage in constraining decays with missing energy. It is very encouraging to see a first exploration of this physics and we encourage the CEPC study group to continue and extend its effort in this area.

R12: Work out quantitative prospects for a few well-motivated “golden” benchmark channels, where the CEPC program is especially powerful, to demonstrate that CEPC can provide competitive flavour physics results even after the completion of the LHCb and Belle II programs.

R13: It is important to assess whether the flavour physics program can be executed with the current detector design. In particular, full simulation studies should elucidate the requirements imposed by these processes on the detector performance, and make sure that the detector design takes this into account.

Quantum Chromo Dynamics

Findings: The CEPC will provide a laboratory for studying QCD in a clean environment with a well-understood, color-singlet initial state. This may allow for an improved measurement of the strong coupling constant and shed some light on difficult theoretical issues in jet physics such as non-global logarithms.

R14: A quantitative study of prospects for QCD precision measurements is needed, such as the potential to improve the measurement of the strong coupling constant α_s.

Neutrino physics

If the mechanism responsible for neutrino masses operates at the weak scale, CEPC may be able to test it by searching for lepton-number and lepton-flavor violating processes. The CDR provides examples in which such searches will reach deep into the parameter space allowed by existing constraints.

Balance of the programme

Findings: The conceptual design report demonstrates the breadth of the physics program with a discussion of the potential of the CEPC in several areas. Solid studies are available for the main selling points of the project, Higgs and electroweak precision measurements and direct searches for signatures of new physics. The report also explores the potential of CEPC in several other areas, such as QCD, flavour physics and neutrino physics.

R15: We encourage the CEPC study group to continue and extend the effort to explore the potential of CEPC beyond the established Higgs/electroweak programme.

Synergy and flexibility

Findings: The overall competitiveness of the CEPC program and the optimization of the plan for operation of the collider depend on external developments. The approval of large collider facilities in other parts of the world can alter the balance considerably. Signs of physics beyond the Standard Model, be it in searches at the LHC, in departures from SM predictions in flavour physics or low energy experiments, the appearance of a signal in direct or indirect dark matter detection experiments, or elsewhere, may also shed a different light on the physics case presented in the CDR.

R16: We recommend that the prospect studies for CEPC, and in particular for BSM searches, continue to evolve in response to new developments and opportunities in the theoretical and experimental landscape. A physics working group should periodically review new developments and initiate CEPC physics studies in response, when appropriate.

R17: Document the opportunities of synergy between CEPC and (HL-)LHC on Higgs physics as well as on diboson studies. In particular, in the $h \rightarrow \mu\mu$ and $h \rightarrow \gamma\gamma$ results, it would be interesting to report what is the added value of CEPC in the combination with LHC measurement.

R18: Even if no runs above 240 GeV are foreseen at the CEPC, it would be interesting to quantify the impact on the Higgs coupling analysis of e^+e^- collisions above the $t\bar{t}$, ZHH and $t\bar{t}h$ thresholds.

Interplay of precision measurements

Findings: The conceptual design report presents the potential of a large number of precision measurements. A global analysis (i.e. in the electroweak fit or global effective-field-theory interpretation of the measurements) should be performed that links these different measurements and runs at different center-of-mass energies. The overall optimization of the run plan should be better justified.

R19: The interplay of the runs at lower energies with the extraction of the Higgs couplings should be understood and quantified.

Machine detector interface

Findings: the delicate interplay between the accelerator design (presented in IHEP-CEPC-DR-2018-01, arXiv:1809.00285) and the design of the experiments is presented in the conceptual design report and the review process. The machine-detector-interface issues pose severe challenges on the overall design of CEPC. In particular, the beam-induced backgrounds are notoriously difficult to predict and could impose limits on the luminosity and detector performance. The vertex detector design is particularly sensitive to hits from machine backgrounds. In the progression towards a technical design report the conceptual descriptions in the CDR needs to be worked out in detail.

R20: It is crucial that the MDI group ensures an efficient communication between the machine and detector design groups. A common protocol to keep track of design changes in each system should be developed.

R21: The synchrotron radiation as well as stray particles should be evaluated with off-design beam orbits of up to several mm.

R22: The effect of injection should be evaluated, as it could increase particles in the tail regions of the beam and affect backgrounds.

R23: The assembly procedure of the MDI region should be defined, including a strategy to attach heavy metal masks for synchrotron photons.

R24: A more detailed study of HOM heating seems to be desirable, including possible resonances. The possibility of active Be pipe cooling, not foreseen in the conceptual design, should be considered until conclusive evidence is found that no cooling is needed.

R25: The beam halo masks placed around the ring often produce more background by increasing stray particles. Realistic and detailed GEANT study of masks would be useful.

Forward region:

Findings: The design of the forward region is strongly affected by the position of the focusing magnets and the compensating coils, that enter far into the detector. The performance of the luminosity detector is essential for the CEPC physics program. The challenges include tight geometrical constraints, significant material budget in front of the calorimeter, high radiation rates, and non-uniform magnetic field with substantial radial component. Additional difficulties arise from non-zero beam crossing angle, leading to the boost of Bhabha events in the horizontal plane. The design proposed in the CDR consists of a 400kg silicon-tungsten calorimeter, for identification of Bhabha events, accompanied by a laser monitoring system and an optional silicon/diamond tracking detector, to aid the geometrical acceptance determination. The overall reconstruction of Bhabha events follows the method developed by the OPAL collaboration at LEP. Uncertainties in the relative position of the luminosity calorimeter with respect to the beam and uncertainties in the track trajectories from non-uniformity of the magnetic field may lead to degradation of the luminosity measurement. The required 0.1% for the 240 GeV run is more than sufficient to reach an 0.5% precision on the ZH cross section measurement. This seems within reach, as a similar precision was proven at LEP. The specification of 0.01%.for the Z-pole data taking is significantly more challenging and a detailed study is required to mitigate the risk that the luminosity uncertainty may limit the potential of the Z-pole run.

R26: A detailed assessment of the mounting stability of the luminosity calorimeter with realistic support structures is required for the technical design report.

R27: A strategy should be worked out to determine the relative alignment of the silicon/diamond tracker with respect to the main tracking detector.

R28: An estimate should be made of the uncertainties in measurements of the complex magnetic field generated by the compensating solenoids and quadrupoles and their effect on the luminosity measurement.

R29: Consider alternative methods for the luminosity measurement in the Z-pole run, based on larger angle Bhabha scattering measured in the calorimeter and gamma-gamma production. Further R&D and beam tests with a full prototype of the detector, to demonstrate feasibility of the measurement, are encouraged.

Detector requirements

Findings: The next step of converging on real detectors for the TDR phase will involve difficult choices between the available technologies. To guide those, it is important that the performance requirements are clear and well understood. In the conceptual design report detector requirements are often stated in a confusing multitude of forms, and sometimes not fully consistent. It is understood that these requirements are only guidelines, not rules.

R30: Sharpen the formulation of the detector requirements where possible and keep track of the impact of the design on important benchmark analyses.

Jet energy resolution requirement: The requirement to distinguish hadronic decays of W and Z-bosons is one of the key drivers of the detector design. The CEPC study team has performed a number of very interesting studies that clarify the impact of jet flavour on the performance. Still, the justification of the 4% resolution is based on smearing analyses and should be firmed up.

R31: Perform a comparative benchmark analysis for the $H \rightarrow$ invisible branching ratio measurement in the different detector concepts.

Tracking requirements: The requirement on the momentum resolution is very important for the physics goals, but it remains a little opaque where the precise requirements come from. The efficiency requirements are somewhat loosely defined. This is very relevant when not all the proposed tracking solutions meet the stated requirements.

R32: Consider the leptonic recoil mass analysis for the momentum requirement. The $H \rightarrow \mu\mu$ branching ratio measurement is likely driven by the LHC.

R33: Define a uniform and fully specified tracking efficiency metric and requirement, spelling out the denominator, and limiting the allowed fake rate.

R34: The tracking efficiency in relatively dense environments (jets, τ-decays) should be benchmarked to compare the pattern recognition capabilities of the different detector options.

R35: The efficiency for tracks with a displaced vertex merits further study. A study of K^0 efficiency versus radius would be useful in itself and instructive for long-lived particles.

Particle identification requirement: The particle ID requirement is a crucial concern. It is unlikely to be met by all detector designs. A tight requirement on particle ID conditions the detector design and may require a dedicated R&D and design effort on, for instance, detector technologies with timing capabilities in the 10-100 ps range. The added value of particle ID in the physics program is currently not understood at a quantitative level.

R36: Decide if particle ID is a requirement and what performance is needed. Investigate the value of pion/kaon separation in bottom and charm analyses, and in flavour physics.

Photon energy resolution requirement: the requirement is currently not well justified. The committee feels good photon resolution is important, but insufficient information to quantify it is available.

R37: Quantify the value of the photon energy resolution in bremsstrahlung recovery in $Z \rightarrow ee$, pion reconstruction in τ decays ($H \rightarrow \gamma\gamma$ is likely dominated by the LHC).

Overal detector design and performance:

Findings: Detailed designs are presented for the main sub-systems of the CEPC experiment. It is plausible that the vertex detector, tracker, calorimeter, magnet system, forward detectors and muon system can meet most, if not all, of the challenging requirements of the CEPC project. The evolution towards an optimal and integrated design for the two CEPC experiments requires a large number of important decisions to be made on the time scale of the technical design report in 2022. To make informed decisions the detector design must be guided by solid estimates of the performance. The CEPC study group builds on the Monte Carlo simulation infrastructure developed for the linear collider projects. Detailed performance estimates are actively being pursued. Currently, not all sub-detector solutions are supported and a comparison of all solutions on an equal footing is often impossible.

R38: Extend the MC simulation framework, so that sub-detector options can be compared on an equal footing.

R39: For the tracking systems, performance studies of dense events and overlaid background need to performed as soon as possible for all options.

Beside the forward region, already discussed in the MDI section of this report, the committee identifies two challenging areas, where detailed studies are required:

- Rate at the Z-pole. The luminosity at the Z-pole may well be at the edge of what the TPC, and perhaps other technologies, can handle. It also represents an important challenge for the trigger, data acquisition, and data processing strategy. LEP and LHC, for example, each exceed their design luminosity by a factor 2 (before HL-LHC).

R40: Consider what the most optimistic scenario for luminosity is and whether the solutions presented in the conceptual design report are adequate.

- Power management. Many of the detector designs presented in the conceptual design report were developed for linear collider experiments, where pulsed powering of the detector reduces the average power consumption of the detector by a large factor. In the CEPC environment the power management presents a much more severe challenge.

R41: Provide solid power consumption estimates of all detector systems and develop a viable cooling strategy for all detector options.

Vertex Detector

Findings: there is active R&D and groups are making good progress, building on large effort by the international community. Compared to other efforts toward precise and transparent vertex detectors, CEPC (with its 100% duty cycle) should place stronger emphasis on power management. Advanced processes like 65 nm CMOS or 3D-integrated devices should be pursued actively and can have a big impact on the vertex detector performance.

R42: CEPC should develop an installation scheme for all detectors, where the Vertex Detector can be installed last and access to replace the vertex detector is possible.

R43: CEPC should keep a close eye on the power consumption an active cooling system impact of the cooling on the material budget needs to be understood, especially if air cooling is insufficient.

R44: Collaboration between the Vertex and MDI group is good, and should be further strengthened.

Tracker design

Findings: The tracker design must satisfy the challenging requirement of a momentum resolution that exceeds that of existing detectors considerably, while adhering to a strict material budget. Three options are defined based on micro-patterned silicon detectors, a Time Project Chamber (TPC) and a drift chamber. For the purposes of impact parameter and momentum measurement the multiple scattering term dominates for low-momentum tracks.

R45: All tracker options should be demonstrated in full simulation including relevant beam backgrounds.

R46: A detailed understanding of the dependence of the tracking and vertexing performance on the material budget is needed.

TPC

The TPC offers good pattern recognition and particle identification with a modest material budget in the central detector. On the other hand, it is vulnerable to backgrounds and ions in the TPC volume may distort the position measurement significantly. The rate capability may not be adequate for the Z-pole run.

R47: Study the rate capability and robustness in a dense environment in detailed Monte Carlo simulations of the response to (multiple) Z-pole events and the relevant machine-induced backgrounds.

R48: Develop a realistic estimate of the effect of ions flowing in the TPC volume on the position measurements.

Silicon Tracking

Silicon detectors are extensively used in all modern particle physics experiments. There is no doubt that a full-silicon tracker or the supporting systems in the other tracker concepts can be built close to the specifications, but the material budget is very challenging (especially if a cooling system is required). The choice of micro-strips as the baseline should be revised and the community should pursue an active RD programme for tracking pixels.

R49: Revise the material budget and tracking performance including the material involved in cooling the detector.

Drift chamber

This is a very advanced option. It provides a decent tracking resolution and robust particle identification with a very competitive material budget. The main risk for this solution lies in the large occupancy in dense jet environments and in the presence of backgrounds.

R50: Performance estimates for pattern recognition should be made using detailed Monte Carlo simulations.

Calorimeter

Findings: The calorimetry system is devoted to a measurement of electrons, photons, τ-leptons and hadronic jets. Two approaches are presented; the first a highly granular calorimeter geared towards the use of the Particle Flow Algorithm (PFA) and requiring the reconstruction of the individual particles in the jet; the second towards of a homogeneous calorimeter with simultaneous read-out of Cherenkov and scintillating light to disentangle the electromagnetic and hadronic fractions of the shower (the dual readout concept). Chinese and Italian groups involved in CEPC have joined the CALICE and RD52 collaborations that develop these options. Most calorimeter options rely heavily on the use of silicon photo-multipliers (SiPM). It is very good to see active R&D in collaboration with Chinese industry to develop novel SiPMs.

Ultra-granular calorimeter:
The baseline approach has been carried out inside the CALICE collaboration where various prototypes, using different technologies, have been developed to demonstrate the viability of this technique. Several options are presented for the calorimetry sub-systems (i.e. the electromagnetic and hadronic sub-system of the granular calorimeter solution). On the timescale of the technical design report a clear comparison must be made of the jet reconstruction performance and other aspects, such as pion reconstruction in τ decays.

R51: Develop a cooling strategy and evaluate the impact on the performance.

R52: Perform a detailed assessment of the performance of the SiW and scintillator options for the electromagnetic calorimeter.

R53: Perform a detailed assessment of the performance of the RPC (semi-digital) and scintillator (analog) options for the hadronic calorimeter.

R54: Study the recovery time for the THGEM to ensure high rate capability is required.

Dual read-out calorimeter: The alternative solution of a dual-read-out calorimeter aims at reaching a very good hadronic resolution while maintaining excellent electromagnetic response. This solution can be compatible with the PFA approach if the fibers are readout with Silicon Photomultipliers (SiPM) and if there is a possibility of a good longitudinal segmentation.

R55: For the dual read-out or DREAM calorimeter concept full-simulation studies are required to optimize the design (longitudinal segmentation, lateral granularity).

R54: For the dual read-out or DREAM calorimeter concept a large-scale “demonstrator” prototype should be pursued on the shortest possible time scale.

Magnet system:
The CEPC experiments are to be equipped with a large solenoid that provides a 2-3 T magnetic field in the tracker volume. For the Z-pole run the magnetic field is reduced to 2 T to preserve the luminosity. Two main options are considered: a large solenoid that holds the tracker and calorimeter, or a thin solenoid between the tracker and the calorimeter. The development of coils based on high-temperature superconductor in China is very relevant especially for the latter option. A dual solenoid system is under consideration to reduce the stray field without a massive yoke.

R57: The development of novel solutions for the magnet is encouraged.

R58: The impact on the global performance of the experiment of the solenoid placement is to be understood at a quantitative level.

Muon system:

Two candidate technologies are presented for the: RPC and μRWELL. Both are mature and proven solutions that can deliver the required performance. The spatial resolution of the μRWELL detectors is considerably better than that of the RPCs. The role of the muon system in the overall muon reconstruction and identification performance is not entirely clear at this point.

R59: Study the added value and requirements of the muon system in Monte Carlo simulations.