CEPC Detectors Letter of Intent

The Circular Electron Positron Collider (CEPC) is a large international scientific facility proposed [1,2] to probe the Standard Model (SM) and potentially uncover new physics beyond the SM (BSM). The CEPC program spans a wide range of center-of-mass energies and beam luminosities to achieve the highest yields of Higgs, W, and Z bosons produced in the exceptionally clean environment of an e^+e^- collider. The vast amount of bottom quarks, charm quarks and τ-leptons produced in the decays of the Z bosons also makes the CEPC an effective B-factory and τ-charm factory. Hence, the CEPC offers an unmatched opportunity for precision measurements and searches for BSM physics. The CEPC physics program, accelerator and detectors are presented in the CEPC Conceptual Design Report (CDR) [3, 4].

The current CEPC design accommodates two Interaction Points (IPs), each housing one large international detector. To deliver the physics program outlined above, the CEPC detector concepts must meet the stringent performance requirements. The detector designs are guided by the principles of large and precisely defined solid angle coverage, good particle identification, precise particle energy/momentum measurement, efficient vertex reconstruction, and excellent jet reconstruction: identification of individual jets, precise determination of the jet 4-momentum, jet flavor, and jet charge. Two primary detector concepts have been introduced in the CDR [4]. One detector concept, used as the basis for the physics performance studies, incorporates the particle flow principle with a precision vertex detector, a Time Projection Chamber (TPC) and a silicon tracker, a high granularity calorimetry system, a three Tesla superconducting solenoid followed by a muon detector embedded in a flux return yoke. A variant of this detector incorporates a full silicon tracker without the TPC. A second concept, called IDEA detector, is based on a precision vertex detector, a large drift chamber tracker with a silicon wrapper, a dual readout calorimeter, a two Tesla solenoid, and a muon detector based on μ-RWELL technology. Both options are considered to be valid solutions for the CEPC detectors, but the final two CEPC detectors are still to be defined. It is likely the ultimate CEPC detectors will be composed of the detector technologies included in these concepts, but other technologies are also being investigated. Recently, a compact detector concept based on a high-granularity crystal calorimeter is being explored and other ideas are encouraged.

Specific Letters of Intent for CEPC Detector R&D have been submitted. Most of them cover research that also applies to other circular or linear electron colliders. These include letters on the IDEA concept [5], machine-detector interface [6], vertex detector [7], time projection chamber [8], cluster counting drift chamber [9], time of flight detector [10], particle flow calorimeter [11], high-granularity crystal calorimeter [12], dual readout calorimeter [13], superconducting detector solenoid [14], muon scintillator detector [15] and chambers based on the μ-RWELL technology [16]. In addition, one LoI on software was submitted to the Computational Frontier with the Key4HEP group [17], and 17 LoIs on CEPC Physics were submitted to the Energy Frontier.

Questions

To maximize the CEPC physics output, global optimizations of the detector design and operation scenarios are indispensable. In addition, to develop the detector concepts into full-scale technical designs for the planned two detectors, a set of critical R&D tasks has been identified. Prototypes of key detector components will be built and tested. Mechanical integration, thermal control and data acquisition schemes must be developed. Industrialization of the detector component fabrication will be pursued. International collaborations will need to be formed before the detector designs can be finalized and the technical design reports can be developed. Some of the key challenges to be addressed in the near future, and for which we would welcome collaboration, are:

Physics Requirements Quantify the detector performance requirement towards the inclusive CEPC physics program (Higgs, EW, Flavor, QCD, and BSM researches) via benchmark physics measurements and analyses.

Software, reconstruction and computing Fast and efficient simulation tools, common software frameworks and computing systems providing efficient analysis and resources sharing that will allow a worldwide community to participate. Development of reliable digitization to validate sub-detectors. Advanced reconstruction algorithms optimized for different detectors, including taking advantage of Machine Learning techniques. [17]

Fast Integrated Sensors Tracking solid state sensors suitable for extremely low-material tracking devices. Typically, these would integrate both sensing and readout units, have low power consumption, and good robustness against radiation. Examples are monolithic CMOS and Silicon on Insulator (SOI) sensors. [7]

Low-mass solid state tracking detectors Tracking devices based on solid state sensors, with low-material budget. Typically such detectors will be air cooled or depend on innovative low-mass cooling systems, and explore innovative low-mass materials. [7]

Gas Detectors Large volume gas detectors that can sustain large particle rates. New readout schemes, novel materials and techniques that can ease industrialization and lower cost. Examples are drift chambers, TPC and micro pattern gas detectors, such as μ-RWELL. [8, 9, 16]

Calorimetry Calorimeters capable of delivering excellent jet and electromagnetic energy resolution, of the order of about $30\%/\sqrt{E}$ and $10\%/\sqrt{E}$, respectively. High-granularity calorimetery based on novel techniques such as Silicon-based calorimetry, scintillators+SiPM-based detectors, or crystals. Dual Readout calorimetry based on fibers or crystals. [11–13]

Particle Identification Some particle identification (PID) capability is available in some of the detector solutions, for instance in the TPC and Drift Chamber. Study the requirements for PID, and alternative solutions, including high-precision timing detectors capable of delivering single-track resolution better than 30 ps (e.g. based on LGAD sensors or crystals). [8–10]

Muon detector Large area muon detector based on long strip scintillator + wavelength shifting fibre + SiPM with high μ-ID performance. Time resolution better than 1 ns will be helpful for PFA and long-lived particle searches. Investigation of low-cost large area micro pattern gas detectors that can provide independent tracking. [15, 16]

Detector Magnet Low-mass and high-field magnet design. Reinforced superconductors and high-temperature superconductors cables. Design of an ultra-light cryostat system. [14]

Machine Detector Interface The MDI represents one of the most challenging tasks for the CEPC project. Topics to study include the interaction region layout and integration, the final focusing magnets, the beam pipe, the detector radiation backgrounds and the luminosity instrumentation. [6]

Detector integration Overall design of the Data Acquisition System, high-performance cooling and detector mechanics, including low-mass mechanical structures. [6, 7]

Contacts

The contacts for general questions on the CEPC Detector and Physics studies to the Snowmass 2021 study groups are: João Guimarães da Costa (IHEP, CAS), Jianchun Wang (IHEP, CAS), Jin Shan (Nanjing University), Manqi Ruan (IHEP, CAS).

References

[1] The CEPC-SPPC Study Group, *CEPC-SPPC Preliminary Conceptual Design Report, Volume I - Physics and Detector*, . http://cepc.ihep.ac.cn/preCDR/volume.html. IHEP-CEPC-DR-2015-01, IHEP-TH-2015-01, IHEP-EP-2015-01. 1

[2] The CEPC-SPPC Study Group, *CEPC-SPPC Preliminary Conceptual Design Report, Volume II - Accelerator*, 2015. http://cepc.ihep.ac.cn/preCDR/volume.html. IHEP-CEPC-DR-2015-01, IHEP-AC-2015-01. 1

[3] The CEPC Study Group, *CEPC Conceptual Design Report, Volume I - Accelerator*, arXiv:1809.00285 [physics.acc-ph]. 1

[4] The CEPC Study Group, *CEPC Conceptual Design Report, Volume II - Physics and Detector*, arXiv:1811.10545 [physics.hep-ex]. 1

[5] *IDEA Detector*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/EF/SNOWMASS21-EF1_EF4-IF3_IF6-096.pdf. 1

[6] *Machine Detector Interface at the Circular Electron Positron Collider*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/AF/SNOWMASS21-AF3_AF7-IF9_IF6_Hongbo_Zhu-245.pdf. 1, 2

[7] *Silicon Vertex Detector for Circular Electron Positron Collider*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF0_Zhijun_Liang-169.pdf. 1, 2

[8] *Time Projection Chamber R&D*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF5-EF1_EF4-183.pdf. 1, 2

[9] *The IDEA Drift Chamber for a Lepton Collider*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/EF/SNOWMASS21-EF3_EF4-IF3_IF5-031.pdf. 1, 2

[10] *Time of Flight Detector for Circular Electron Positron Collider*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF7_CEPC-190.pdf. 1, 2

[11] *Particle Flow Calorimeters for the Circular Electron Positron Collider*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF6_IF0-176.pdf. 1, 2

[12] *High-Granularity Crystal Calorimetry*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF6_IF0_Yong_Liu-064.pdf. 1, 2

[13] *Dual-Readout Calorimetry*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF6-008.pdf. 1, 2

[14] *Solenoid Magnet R&D*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/AF/SNOWMASS21-AF3_AF7-IF9_IF0-247.pdf. 1, 2

[15] *Muon Scintillator R&D*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF4-189.pdf. 1, 2

[16] *μ-RWELL detector*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF5-EF4-007.pdf. 1, 2

[17] *Key4hep*, Snowmass LoI. https://www.snowmass21.org/docs/files/summaries/CompF/SNOWMASS21-CompF2_CompF5-034.pdf. 1, 2