Silicon Vertex Detector for circular electron positron collider

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 identification of heavy-flavor (b- and c-) quarks and τ leptons is essential for the CEPC physics program. It requires precise determination of the track parameters of charged particles, permitting reconstruction of the displaced decay vertices of short-lived particles. This drives the need for a vertex detector with a low material budget and high spatial resolution. The vertex detector needs to have high readout speed in order to handle a high data rate in high-luminosity collision at Z pole running. The detailed requirements of the CEPC vertex detector is listed below.

Excellent Spatial Resolution $< 3\ \mu m$

Readout $<$ 500 ns readout dead time in Z pole running (25 ns bunch spacing).

Fluence $6.2\times10^{12}\ \mathrm{n_{eq}/cm^2}$ per year, for ten years running.

The total ionizing dose (TID) > 3.4 MRad per year, for ten years running.

Material budget $<$ 0.15% $\mathrm{X_0}$ per layer;

Power Consumption < 50 mW/cm^2 (constraint by material budget for cooling)

Detector occupancy <1%.

Questions

The Snowmass 2021 provides a great opportunity for international collaborations on vertex detector R&D for the future electron-positron collider. CEPC vertex detector design optimization and technology R&D is an important area to get involved in. This letter outlines several major ongoing research tasks on the CEPC vertex detector, as listed in the following:

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

Silicon Sensors Tracking solid-state sensors suitable for extremely low-material tracking devices. Typically, these would integrate both sensing and read-out units, have low power consumption, and good robustness against radiation. Examples, monolithic CMOS imaging sensors, monolithic Silicon on Insulator (SOI) sensors.

- R&Ds are needed to shrink the pixel pitch to 16 μm (binary read-out) in order to accomplish the required 3 μm single-point resolution.
- R&Ds of read-out architecture needs to be optimized to cope with high data rate from high-luminosity collisions at Z pole running, while keeping low power consumption.
- SOI sensors need a careful study on the irradiation of large scale chips and of low power designs, Although the TID tolerance of the SOI process has been improved dramatically by the introduction of Double-SOI and the optimization of transistor doping recipe.

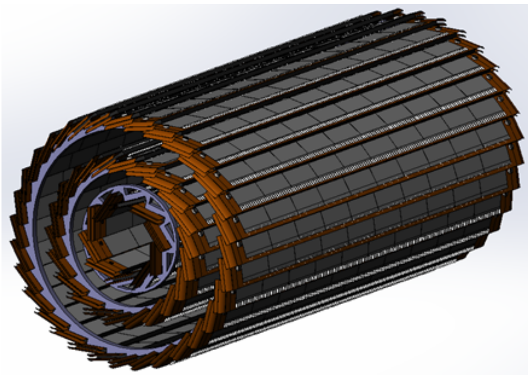
- R&Ds of a new generation of large size (20cm) monolithic sensors with stitching technology.

Low-mass solid-state tracking detectors prototype Tracking devices with multiple layers based on solid state sensors, with a low-material budget.

In CEPC baseline design, the vertex detector is conceived as a barrel structure with three concentric cylinders of double-sided layers as shown in Fig. 1. The main mechanical structure is called a ladder. Each ladder supports sensors on both sides. Ladders need to integrate mechanical support, power and signal connections, and have sufficient stiffness to avoid vibration. R&D is needed for mechanical support of the ladder, in order to fulfill stringent requirements in terms of minimum material budget and highest stiffness. Ladders are linked to the layout of the cooling system that will be adopted to remove the heat dissipated by the sensors.

Cooling systems CEPC vertex detector will be air-cooled or depend on innovative low-mass cooling systems. The cooling system is integrated in the mechanical structure. The CEPC vertex detector's cooling system must balance the conflicting demands of efficient heat dissipation with a minimal material budget. Innovative low-mass cooling systems (air cooling and active cooling with micro-channel cooling) have been considered.

Data Acquisition System Overall design of the Data Acquisition System, especially to handle high data rate at CEPC Z pole runs



(a)

Figure 1: Schematic view of CEPC vertex detector.

Contacts

The contact people from the CEPC vertex detector studies to the Snowmass 2021 study groups are as follows:

Vertex Detector Zhijun Liang, João Guimarães da Costa,Ouyang Qun

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