Particle Flow Calorimeters for the Circular Electron Positron Collider

The discovery of the Higgs boson at the Large Hadron Collider marks the completion of the Standard Model (SM), it also opens a window for probing new physics beyond the SM. The Circular Electron Positron Collider (CEPC) [1] has been proposed as a Higgs factory to study the Higgs boson with an unprecedented precision. It also serves as Z-factory when operating at the Z pole. Since it was proposed, the CEPC design studies have progressed through a couple of stages, culminating in the publication of the Conceptual Design Report (CDR) [2,3].

To fully exploit the potential of the CEPC for the Higgs and electroweak physics, all possible final states from decays of the intermediated vector bosons (W,Z) and Higgs boson need to be identified and reconstructed with high sensitivity. In particular, to clearly distinguish between hadronic final states of $H \to WW$ and $H \to ZZ$, a 3-4% di-jet invariant mass resolution is required. Such a requirement needs a jet energy resolution (JER) of about 30%/$\sqrt{E}$ (GeV) This would be about a factor of two better than that provided by the LEP detectors and the currently operating detectors at the LHC.

A promising approach capable to achieve a jet energy resolution of 3-4% is Particle Flow Algorithm (PFA) [4,5]. The basic idea of the PFA is to make full use of the inner tracker, electromagnetic and hadronic calorimeters to determine the energy/momentum of each particle in a jet. A finely segmented and compact calorimetry system with high granularity in three dimensions is crucial to the reconstruction and identification of every single particle shower in a jet, and hence to realize the PFA. The CEPC baseline detector concept includes a PFA calorimetry system consisting of an electro-magnetic calorimeter and a hadronic one both with extremely high granularity. Worldwide studies have been carried out within the CALICE collaboration [6] to develop compact PFA calorimeters. Several prototypes with high granularity using different technologies have been developed, and exposed to particle beams to gain in-depth understanding of the PFA calorimetry performance [4,5]. There are still various detector technology options that need to be further explored to address challenges from stringent performance requirements for the CEPC detector design.

Questions

The Snowmass 2021 provides a great opportunity for the US particle physics community to get involved in the CEPC physics and detector studies particularly towards its technical design. CEPC PFA calorimeters design optimization and technology R&D is an important area to get involved. This letter outlines several major ongoing research tasks on the CEPC PFA calorimeters, as listed in the following:

PFA Scintillator-Tungsten ECAL (Sci-W ECAL) technological prototype. A highly granular calorimeter with a scintillator-tungsten sandwich structure is one option for the PFA ECAL in the CEPC baseline detector conceptual design. The design of the CEPC Sci-W ECAL largely follows that of the ILD Sci-W ECAL, which realizes a very high effective granularity with less channels by using scintillator strips arranged in a way that strips in adjacent layers are orthogonal to each other. To fully validate the Sci-W ECAL detector concept and demonstrate its actual performance, a full-size Sci-W ECAL prototype with readout electronics embedded in the detector is under construction as a joint effort of the CEPC calorimeter group and some ILC-ILD detector R&D groups from Japan. The key parameters for this technological Sci-W ECAL prototype are 22 cm $\times$ 22 cm for transverse area, $24X_0$ for thickness, and 5 mm $\times$ 5 mm for effective cell size. The scintillator strips are read out using SiPMs with a small pixel size of 10 or 15 μm to provide a large dynamic range for measurement of high energy EM showers. The prototype has been fully assembled and integrated with readout electronics and DAQ. A LED-based SiPM monitoring and calibration system has also been developed and integrated into the readout electronics. The prototype is now being commissioned with cosmic rays and is anticipated to be ready for test beam in later 2020.

PFA Scintillator-Steel HCAL (Sci-Fe HCAL) technological prototype. There are significant similarities between the Sci-Fe HCAL and Sci-W ECAL detector options in that both of them use the technology of scintillator directly coupled to SiPM. A major difference is the different scintillator cell size and geometry. While the Sci-W ECAL uses small scintillator strip, the Sci-Fe HCAL uses large scintillator tiles. The Sci-Fe HCAL concept is adopted as one PFA HCAL option for the CEPC PFA calorimetry system. To validate the Sci-Fe HCAL technology option for its application to the CEPC experiment, a large scale Sci-Fe HCAL technological prototype which could contain hadronic showers with energy up to 100 GeV is being developed by the CEPC calorimeter group. The current effort is focused on optimizing the design of the CEPC Sci-Fe HCAL including cell size, number of sampling layers, total thickness of absorber, thickness of scintillator tile etc., and developing techniques and devices for production of key components for the prototype e on a large scale. A fully integrated readout electronics together with a SiPM monitoring and calibration circuit will be developed. The construction of the Sci-Fe HCAL technological prototype is expected to be completed in 2022. The prototype will then be tested with high energy hadron beams at CERN in late 2022 or early 2023. The data from the test would be also valuable to studies of hadronic showering physics as well as to demonstration of the performance of the Sci-Fe HCAL.

Active cooling system for PFA calorimetry Due to the high granularity design of PFA calorimeters, the number of readout channels of calorimetry system is extremely large. Because the CEPC operates at continuous mode, the power dissipation produced by the embedded readout system could reach about 100kW. It is therefore crucial to design an active cooling system to bring the heat out of the CEPC PFA calorimeters. Feasibility and design studies of active cooling based on water or gas will be carried out.

Contacts

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