

Simulation study of Dual-Readout Calorimeter for a forward calorimeter at the Electron-Ion Collider

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Abstract. The Electron-Ion Collider (EIC) is a future particle accelerator to be built at the Brookhaven National Laboratory, and the primary purpose of experiments at the EIC is to resolve the question of partonic structure of nucleons and nuclei. To achieve the physics goals of the EIC, a hadron calorimeter of high energy resolution is required at forward rapidity. A Dual-readout Calorimeter (DRC) which has been developed for future collider experiments is considered as an upgrade option of the forward hadron calorimeter for the ECCE experiment at the EIC. The DRC consisting of two types of optical fiber, Cherenkov and Scintillation fibers, can achieve high energy resolution by measuring a fraction of electromagnetic shower in a hadronic shower. A performance study of DRC for the EIC such as geometry, material, and energy resolution is ongoing based on the existing simulation framework for high energy experiments, and the DRC simulation details will be transported to the EIC simulation framework. In this presentation, we will introduce the simulation study of the DRC for the EIC.

1 Introduction

The primary purpose of the Electron-Ion Collider (EIC) is to study the partonic structure of protons and nuclei more accurately [1]. It is required to be equipped high-quality detectors to achieve precise measurements. At forward rapidity where hadrons are going, electromagnetic (EM) and hadronic calorimeters will be located to measure hadrons and jets, and the required hadronic energy resolution is $50\% / \sqrt{E} \pm 10\%$.

Dual-Readout Calorimeter (DRC), proposed as the main calorimeter in the IDEA detector at the Future Circular Collider [2], can also be utilized for experiments at the EIC. The DRC is a sampling calorimeter consisting of absorber material and two types of optical fiber; Cherenkov and Scintillation fibers. The left panel of Fig. 1 shows a cross-sectional view of the DRC tower, and fibers of yellow and blue color are two different types of fibers. The different responses of EM particles and hadrons in two fiber types can provide information to determine the EM fraction of each hadron shower. The right panel of Fig. 1 shows a correlation of calibrated energy in Cherenkov and Scintillation fibers, data points from hadrons are located around the straight line. The corrected energy is calculated by applying a rotation matrix with the angle θ , and a better energy resolution can be achieved. See the recent review for more details on the DRC [3].

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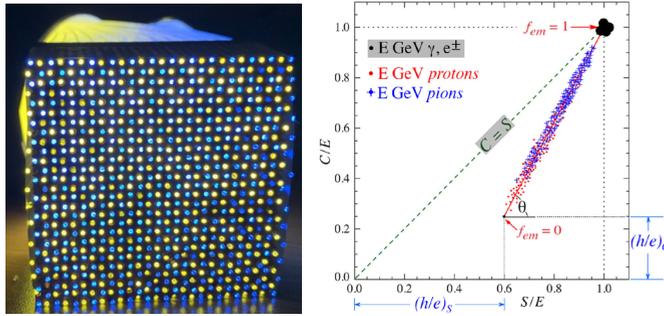


Figure 1. Left: Cross-sectional view of the DRC tower, Right: Correlation of energy in two channels for photons, electrons, and hadrons.

2 Performance study with GEANT4 simulation

A simulation framework for the DRC with GEANT4 has been developed for experiments with future e^+e^- colliders. We utilize the framework and use towers located at the endcap region for the simulation study. We change the tower length from 2.5 m to 1.25 m for the EIC design. Copper is used as an absorber material for the reference design, and performance with other materials like iron and tungsten is also studied. Electrons, charged pions, and jets with various energies are used to evaluate the detector performance.

2.1 Single EM particle

Energy calibration is performed separately for Cherenkov and Scintillation fibers using simulations with 20 GeV electrons. The results of the calibration are shown on the left panel of Fig. 2. The middle panel of Fig. 2 shows the energy resolution for electrons as a function of energy, and the resolution of the two channels is similar. We use a linear combination of two channels for the final energy measurement, and the energy resolution is $11\%/\sqrt{E} + 0.6\%$. In terms of energy linearity shown on the right panel of Fig. 2, the ratio between measured energy and beam energy is within 1% in a wide range of beam energy.

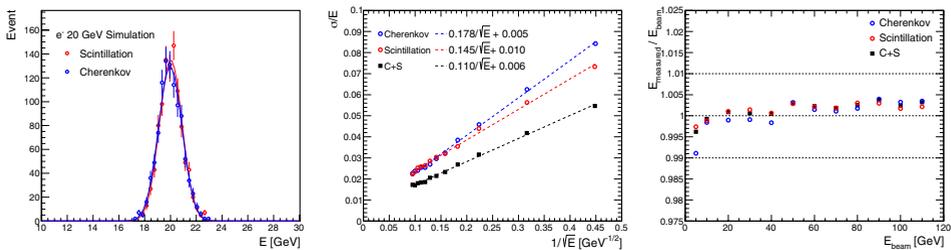


Figure 2. Left: Energy distribution of two channels for 20 GeV electrons. Center: Energy resolution for electrons with each channel and combined channels. Right: Energy linearity (ratio of measured energy to beam energy) for electrons.

2.2 Single hadron

For the performance of hadrons, we simulate positively charged pion (π^+) with various energies. Figure 3 shows the distribution of measured energy in Cherenkov and Scintillation channel and dual-readout corrected energy, and the left (right) panel shows the simulation results using 1.25 m (2.5 m) DRC towers of copper absorber. There are tails on the left-hand side in distributions with shorter towers, which indicates a longitudinal shower leakage when using 1.25 m towers for the EIC design. Note that a small fraction of events passing through the entire detector without initiating a hadron shower is removed. To account for the non-Gaussian shape due to shower leakage, we use a standard deviation of the histogram for the energy resolution instead of the Gaussian width obtained from fit to the distribution.

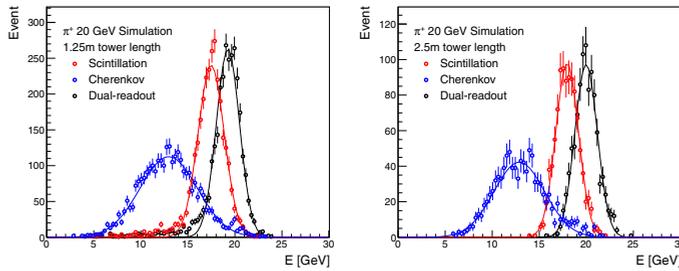


Figure 3. Left: Energy distribution of 20 GeV π^+ in 1.25 m DRC towers. Right: Energy distribution of 20 GeV π^+ in 2.5 m DRC towers.

Figure 4 shows the energy resolution and linearity obtained from π^+ simulations with the EIC design. In the left plot, the energy resolution is compared with the default length results. The energy resolution with 1.25 m towers worsens as the beam energy increases because of shower leakage. The magenta line represents the requirement of the EIC detector, and the energy resolution with 1.25 m towers still satisfies the requirement below 70 GeV. Note that a single hadron of 70 GeV is expected to be rarely produced at the EIC. Regarding the energy linearity shown on the right side, we can obtain more accurate hadron energy with the dual-readout correction method than with two single channel.

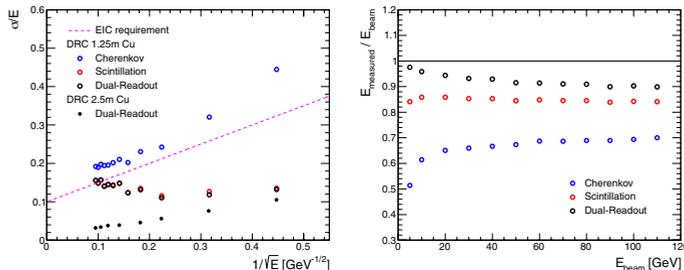


Figure 4. Left: Energy resolution for π^+ with different lengths of towers compared with the EIC requirement. Right: Energy linearity for π^+ with 1.25 m DRC towers.

2.3 Jet

We also study the performance of jet energy measurement with the EIC design of the DRC. The PYTHIA8 is utilized to generate hadrons from a single quark fragmentation, and the anti- k_T algorithm with a resolution parameter $R = 0.8$ is used to reconstruct jets. Not to use jets fragmented out of the endcap region, we select jets at least 80% of the initial quark energy is within the $R = 0.8$ range. Jets with Cherenkov and Scintillation channels are reconstructed separately, and a dual-readout correction is applied later. Figure 5 shows simulation results of jets with the DRC. The energy resolution with the EIC design is worse than the default design due to hadron shower leakage. The resolution becomes smaller as the jet energy increases, unlike in the single hadron case. This is because the energy of hadrons from jet fragmentation is not large enough to suffer from the shower leakage significantly. The magenta line represents the requirement of the EIC detector, and the energy resolution with 1.25 m towers satisfies the requirement. Regarding the energy linearity shown in the right plot, more accurate jet energy can be obtained with the dual-readout correction method.

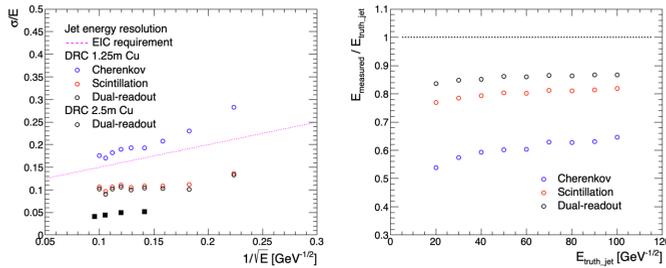


Figure 5. Left: Energy resolution for jets with different lengths of towers compared with the EIC requirement. Right: Energy linearity for jets with 1.25 m DRC towers.

3 Summary and Outlook

We have performed a simulation study of the Dual-Readout Calorimeter for experiments at the EIC. Based on the simulation framework developed for future collider experiments, a modified design with a shorter length (1.25 m) is used for the simulation of single electrons, hadrons, and jets. Although there is a longitudinal leakage of hadron showers with the EIC design, the obtained energy resolution of hadrons and jets satisfies the EIC requirement. For the plan, we will implement detailed features of the DRC simulation to the EIC simulation framework, such as optical photon propagation, light attenuation, and readout electronics.

References

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