Development of ePIC zero-degree calorimeter

Y. Goto[*1] for the EIC-Japan Group

We are participating in the ePIC experiment, which is an international collaboration at the electron-ion collider (EIC) at Brookhaven National Laboratory in the United States.[1)] The central detector of the ePIC experiment is a detector system that covers a wide angular range unique to collider experiments; however, the detectors on the colliding beam lines, called far-forward and far-backward detectors, play a major role that cannot be covered by the central detector alone.

The zero-degree calorimeter (ZDC) is a calorimeter located in the direction of the hadron beam about 35 m far-forward from the beam collision point between the hadron and electron beam lines, where only neutral particles (mainly neutrons and photons) produced in the collisions are detected. The ZDC design is currently underway with a crystal scintillator as an electromagnetic calorimeter and a hadron calorimeter with an iron + SiPM detector embedded plastic scintillator tile sandwich type. Figure 1 shows the ZDC located between the hadron and electron beam lines.

ZDC plays a major role in the study of the mass of mesons in addition to protons because the detection of neutrons and Λ particles at ZDC makes it possible to study the internal structure and origin of the mass of the mesons produced as their partners. The difference in their emergent contributions can be clarified because it is considered that protons and mesons have completely different contributions from quark and gluon energies and condensation.

In the study of the origin of mass at EIC, the quark-gluon structure of nucleons, hadrons, and nuclei is investigated not only as an one-dimensional structure with respect to the collision axis, which has been studied so far; however, it also has a three-dimensional structure extended transversely to the collision axis and including degrees of freedom such as orbital motion. This requires the detection of processes that exclusively measure all particles produced in collisions and requires coherent diffraction processes.

In EIC, ZDC has the ability to detect spectators, recognize coherent diffraction events in electron + nucleus (e + A) collisions, characterize the collider for each event using neutron multiplicity in e + A collisions, study the origin of mass, and perform many other roles. The ZDC is among the most important detectors for ensuring exclusive and coherent diffraction processes. Incoherent events can be isolated by identifying the break-up of the excited nucleus. The evaporated neutrons produced from the break-up in the diffraction process can be used in ∼90% of the cases to separate coherent processes. In addition, photons from the de-excitation of the excited nuclei can help identify incoherent processes even in the absence of evaporated neutrons.

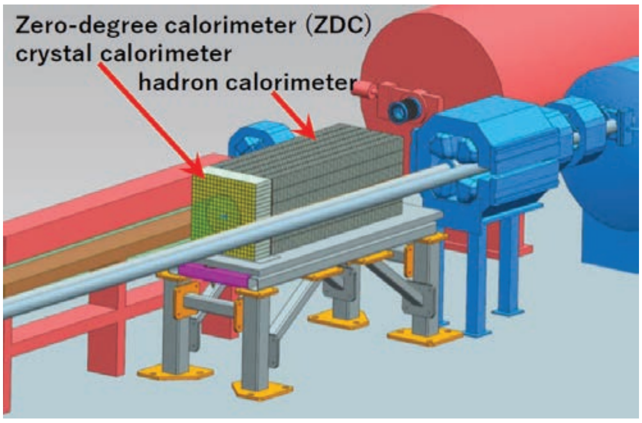

Fig. 1. ZDC located between the hadron and electron beam lines.

In the ePIC radiation doses and particle fluences, the ZDC neutron fluence is smaller than 10^{12} neutron/cm^2 for six month operation. This is not demanding; however, the degradation may occur for crystals and/or photon sensors because of radiation The dynamic range of the crystal calorimeter is a clear challenge. ∼100 MeV photons from e + A "quasi-coherent" reactions and ∼10–100 GeV photons possible from other exclusive processes (including Λ decay, *etc.*) should be covered.

The first section of the ZDC is designed with a layer of crystal calorimeter towers, each 8 radiation lengths (X_0) thick. This layer is composed of 2 × 2 cm^2 crystals arranged in a 30 × 30 grid. LYSO is selected as a crystal material for its high light yield and suitability to measure low energy photons. The first test beam experiment for the crystal calorimeter prototype was performed in February 2024 using 50–800 MeV positron test beam at the ELPH facility (now the RARiS facility) in Tohoku University in Japan for conducting gain, energy resolution, position dependence, and angular dependence, and its data analysis is underway. The prototype modules have been made by the Taiwan group.

The development of the hadron calorimeter is conducted in collaboration with the University of California, Riverside, USA, and the evaluation of a particle shower detection method using simulations is in progress. Two simulation calculations and evaluations are ongoing: Λ identification and low-energy photon identification; the angular resolution is a common thread.

Reference

1) R. Abdul Khalek, *et al.*, Nucl. Phys. A **1026**, 122447 (2022).

*1 RIKEN Nishina Center

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