Development of zero-degree calorimeter for EIC

Y. Goto,[*1] T. Chujo,[*2] Y. Itow,[*3] J. H. Lee,[*4] H. Menjo,[*5] Y. Miyachi,[*6] I. Nakagawa,[*1] K. Nakano,[*1,*7] T. Sako,[*1,*8] R. Seidl,[*1] T. -A. Shibata,[*1,*7,*9] K. Tanida,[*1,*10] and Y. Yamazaki[*11]

We propose the development of zero-degree apparatus in the Electron-Ion Collider (EIC) experiment. Zero-degree detectors play critical roles in a number of important physics topics at EIC.[1)] We will study the requirements and technologies of zero-degree detectors and mainly develop a position-sensitive zero-degree calorimeter (ZDC).

In electron + nucleus collisions, exclusive vector meson production in a diffractive process is one of the key measurements at EIC. For the coherent process in which the nucleus remains intact, the cross section dependent on the momentum transfer (t) can be translated to the transverse spatial distribution of gluons in the nucleus and is thus considered to be directly sensitive to the gluon saturation. This requires accurate determination of the coherence of the reaction, which must be determined by identifying the breakup of the excited nucleus. Evaporated neutrons from the breakup in the diffraction process can be used to separate the coherence with the highest probability ($\sim$90%). In addition, photons from the de-excitation of the exited nucleus signal incoherence in the absence of evaporated neutrons. This leads to a requirement to measure neutrons and photons precisely at near zero degree to complete the coverage of coherence tagging in a wide t range.

Collision geometry is an important measure in electron + nucleus collisions for an event-by-event characterization. It has been proposed that collision geometries can be tagged through forward neutron multiplicities emitted at near zero degree.[2)] Constraining collision geometry quantities such as the "traveling length" of the struck parton in the nucleus, which is correlated with the impact parameter of the collision, is very meaningful in studies of nuclear medium effects. With the determination of collision geometry in these measurements, higher-precision constraints can be achieved to enhance our understanding of the nuclear structure.

In electron + deuteron and helium-3 collisions at EIC, physics programs require the tagging of forward neutrons as spectators to identify the target nucleon. It constrains kinematics for studies of the short-range correlation (SRC). The SRC is a nucleon-nucleon interaction at a very short distance. It shows how nucleons form a nucleus, and has a deep connection to how the quark-gluon structure of a nucleon in a nucleus is modified, which is a phenomenon known as the EMC effect.[3)] Experiments have shown it is universal that $\sim$20% of nucleons are in SRC pairs. These SRC pairs have high momentum and are spatially very close to each other. Almost all of these SRC pairs are found to be similar to a quasi-deuteron at its high-momentum tail. In addition to the SRC study in electron + nucleus collisions, we will be able to understand the deuteron as a baseline of the SRC pair in electron + deuteron collisions at zero degree.

In electron + proton collisions, the leading proton and neutron productions in DIS were measured, and their production mechanisms were studied at HERA by comparison with the fragmentation process and one-pion exchange (OPE) process. The results support that the OPE process dominates the production, but there are still tension in detailed understanding of the mechanism and comparison between ZEUS[4)] and H1[5)] data. In addition to the production cross section measurement, the spin asymmetry measurement of the leading baryons in polarized electron + proton collisions will give us useful additional information for the study of the production mechanism. The data will also be used to understand the energy flow and development of the event generator, and applied for understanding the air shower evolution of high-energy cosmic rays and the neutrino interaction.

We will conduct the following studies in the future; 1) a photon detector study at a low energy <300 MeV, 2) a prototype study of ZDC with position sensitivity, and 3) a radiation hardness study of scintillators. We would like to maximize the physics capability by studying detector design, development, and simulation.

*1 RIKEN Nishina Center
*2 Tomonaga Center for the History of the Universe, University of Tsukuba
*3 Institute for Space-Earth Environmental Research, Nagoya University
*4 Physics Department, Brookhaven National Laboratory
*5 Graduate school of Science, Nagoya University
*6 Department of Physics, Yamagata University
*7 Department of Physics, Tokyo Institute of Technology
*8 Institute for Cosmic Ray Research, University of Tokyo
*9 College of Science and Technology, Nihon University
*10 Advanced Science Research Center, Japan Atomic Energy Agency
*11 Graduate School of Science, Kobe University

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