Design of the zero degree calorimeter for the EIC

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The Electron Ion Collider (EIC) is a future particle collider scheduled for construction in the US. By colliding electrons and protons or nuclei, the EIC will be a powerful tool to examine the structure inside of protons and nuclei. A new electron beam facility is planned to be built and will be operated together with the existing ion beams at the Brookhaven National Laboratory. The expected beam energies are 5–18 GeV for electrons and 41–275 GeV for protons, providing the highest centre-of-mass energy of 141 GeV. The EIC will cover a large kinematic region, which allows for the investigation of the parton dynamics in protons and nuclei.

In some of the key EIC physics programs,[1)] it is essential to detect hadrons or photons from collisions in the far-forward region of the ion-beam direction. A suite of detectors will be placed there, in addition to the central detector at the collision point. The Zero Degree Calorimeter (ZDC) is one of the far-forward detector systems and will detect photons and neutrons. It will be placed ∼40 m downstream of the collision point, with an aperture of ∼4.5 mrad.

The first ZDC design is considered based on the physics requirements for the ZDC. Examples of measurements that need the ZDC are as follows:[1)]

- Exclusive vector meson production in $e + A$ collisions, which is sensitive to gluon saturation,[2)]
- Spectator-neutron-tagged $e+d$ deep inelastic scattering, which is sensitive to the nuclear effect in deuterons,
- Meson structure measurements,
- Leading neutron measurements.

The required performance is as follows:

- Tagging of $O(100)$ MeV photons with >90% efficiency and an energy resolution of 20–30%,
- Detection of 20–40 GeV photons with an energy resolution of $\frac{35\%}{\sqrt{E(\mathrm{GeV})}}$ and a good position resolution of $O(1)$ mm,
- Detection of neutrons with energy up to the ion beam energy with an energy resolution of $\frac{50\%}{\sqrt{E(\mathrm{GeV})}} + 5\%$, a position resolution of $\frac{3\mathrm{mrad}}{\sqrt{E(\mathrm{GeV})}}$, and a large lateral size of 60 cm × 60 cm.

To fulfill these requirements, the ZDC is designed as a complex of detectors, namely a Crystal calorimeter and three types of sampling calorimeters: ALICE FoCal-E[3)] style Tungsten-Silicon (W/Si), Lead-Silicon (Pb/Si), and Lead-Scintillator (Pb/Sci) calorimeters.

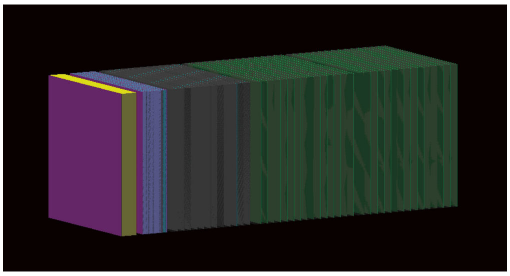

Fig. 1. ZDC design. Particles arrive from the left side of the figure. The detector consists of a 7 cm crystal layer (yellow) with a silicon pixel layer attached in front (magenta), 22 layers of tungsten/silicon planes (light purple) with an additional silicon pixel layer in front, 12 layers of lead/silicon planes (gray), and 30 layers of lead/scintillator planes (green), corresponding to a thickness of $8X_0$, $22X_0$, $2\lambda_I$, and $5\lambda_I$, respectively. The total size is 60 cm × 60 cm × 162 cm. The segmentation on each layer is as follows: 3 cm × 3 cm for the crystal, 1 cm × 1 cm for standard silicon layers, 3 mm × 3 mm for silicon pixel layers, and 10 cm × 10 cm for scintillators.

The Crystal calorimeter is intended for the energy measurement of low-energy photons. The W/Si calorimeter will measure the rest of the photon energy and the shower development of photons and neutrons. Silicon pixel layers are inserted for position measurement. Silicon layers are used in the Pb/Si calorimeter for radiation hardness and for the neutron shower measurement. The last Pb/Sci calorimeters are intended to measure the neutron energy.

The design is studied and optimized using the Geant4[4)] simulation. The simulation has a few missing pieces, *e.g.*, no readout materials included for crystals and scintillators. However, it allows the study of baseline performance of the detector complex. Figure 1 shows the optimized design. The performance is studied against single photons and single neutrons. It has an energy resolution better than the requirement and a position resolution for photons better than 2 mm.

The design will be further optimized based on its cost, radiation hardness, and the full simulation. The optimization includes the choice of materials for the crystal, such as $PbWO_4$ (this study) and LYSO.

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