Development of concepts of streaming DAQ and computing for ePIC

T. Gunji[*1,*2,*3] for the EIC-Japan Group

The Electron-Ion Collier (EIC) will be built at Brookhaven National Laboratory to explore the fundamentals of quark chromodynamics to high precision, with particular focus on unraveling the quark-gluon substructure of the nucleon and of nucleus and dynamics in the nucleon and nucleus.[1)] The ePIC collaboration was formed in 2023 to achieve the experiment at the EIC and currently consists of almost 850 members from 185 institutions. The ePIC detector covers a broad pseudorapidity range, $-4 \leq \eta \leq 4$, consisting of central barrel detectors positioned within a large acceptance solenoid of 1.7 T, and far-forward and backward detectors spanning an approximate length of 90 m. The design of the interaction region and ePIC detectors have been optimized to achieve close to 100% acceptance for all final state particles and ensure their high precision measurements. The ePIC data acquisition will be implemented as a flexible, scalable, and efficient streaming system, where the streaming readout means the continuous collection of data from the detectors without any selection by a hardware trigger. It follows developments in several nuclear and high-energy experiments such as ALICE,[2)] LHCb,[3)] and the experiments at JLab.[4)] The advantages of streaming data acquisition (DAQ) include the replacement of custom L1 trigger electronics with commercial computing, and enabling us to study the complicated event selection, which cannot be triggered by hardware. In 2024, the concept of streaming DAQ and computing was developed, as briefly summarized in this article.

The ePIC detector consists of 24 detectors using different readout technologies. Each digitized signal is streamed from the detectors with a time-stamp that uniquely identifies its position on the time domain. This time-stamp is used to aggregate the information from all detectors and to build a "time-frame," which corresponds to the picture of the entire detector taken at a certain time. Each frame is then streamed to an online computing farm where CPUs and hardware accelerators such as GPUs and FPGAs perform prompt reconstruction, apply a selection algorithm, and create a software "trigger" to decides if an objective "event" is present in the time-frame and deserves to be further reconstructed. Subsequently, these time-frame data is further streamed into dedicated computing facilities to allow the full reconstruction. In addition to these real time processing, if technically feasible, ePIC is planning to record time-frame data before applying the software trigger, which will enable the unbiased raw data to re-processed with improved event selection. The full reconstruction of an event requires the application of the detector's calibration and alignment into the reconstruction pipeline. The first set is obtained by processing a short amount of data taken during the commissioning. More precise evaluation of calibration will be performed using production runs, and dedicated workflows will be implemented in the prompt reconstruction. The global timing distribution system will be crucial for the streaming readout to ensure that the data from different detectors can be synchronously aggregated. This will be provided based on a copy of the accelerator bunch crossing clock (running at 98.5 MHz). A subset of these systems will require a jitter on the order of 5 ps to achieve required timing resolutions for the fast timing and time-of-flight detectors (20–30 ps).

The maximum interaction rate at the EIC is expected to be 500 kHz. The expected data rate off the detector is O (10–100 Tb/s), and digitized data off the detectors will be aggregated in the PCIe-based data aggregation boards (DAM) and filtered using an FPGA on the DAM will be sent to the online farm (Echelon1) in host labs (BNL and JLab) at the rate at O (100 Gb/s). Each online farm node represents a multi-core server with minimally support 32–64 cores and will support PCIe-based GPUs and/or FPGAs. Further filtered or prompt-reconstructed data will be sent to the distributed computing facilities in various countries (Echelon2) for the full reconstruction. The high performance network between Echelon1 and Echelon2 is expected to support a 100/400 Gbps bandwidth connections based on the ESnet network funded by DOE-SC.[5)] In next a few years, we will begin the development of streaming framework, online processing workflows, and their orchestration, including workload management. We will build a small-scale testbench and full chain tests of streaming from Echelon0 to Echelon2.

References
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*1 RIKEN Nishina Center
*2 Quark-Nuclear Science Institute, University of Tokyo
*3 Center for Nuclear Study, University of Tokyo

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