EIC Expression of Interest: EIC Streaming Readout

M.L. Purschke[1], J. Huang[1], J.C. Bernauer[2,3], A. Deshpande[2], and D.J. Abbott[4]

[1]*Brookhaven National Lab, Upton, NY*
[2]*Stony Brook University, Stony Brook, NY*
[3]*Riken BNL Research Center, Upton, NY*
[4]*Jefferson Lab, Newport News, VA*

1 Introduction

Data Acquisition systems currently under development and likely to be in use in the EIC era are making a shift away from classic triggered readout setups to a *streaming readout* (SRO) paradigm. As an example, the sPHENIX [1] DAQ system consists of legacy electronics with classic triggered readout for the calorimeters, and a new streaming readout system for the inner tracker detectors. The streaming readout components for the sPHENIX Time Projection Chamber (TPC), the Intermediate Tracker (INTT), and the inner vertex detector (MVTX) are currently in advanced stages of development.

Already now, a number of R&D efforts to read out EIC detector prototypes in laboratory setups and at test beams are using a variant of the sPHENIX data acquisition system ("RCDAQ"). RCDAQ natively supports streaming readout and is used for the majority of EIC-themed detector R&D efforts at BNL and SBU.

Concurrently at JLab there have also been R&D efforts into supporting streaming readout within the existing experiments with the expectation that future experiments in all experimental halls will run with a fully streaming DAQ system. Tests have been made in Hall B using the CLAS12 detector and using existing custom and commercial hardware, modified to support streaming readout. New custom electronics are being designed with streaming support in mind for future upgrades. The JLab DAQ system, CODA, can continue to be used to operate both the traditional triggered systems as well as future streaming ones.

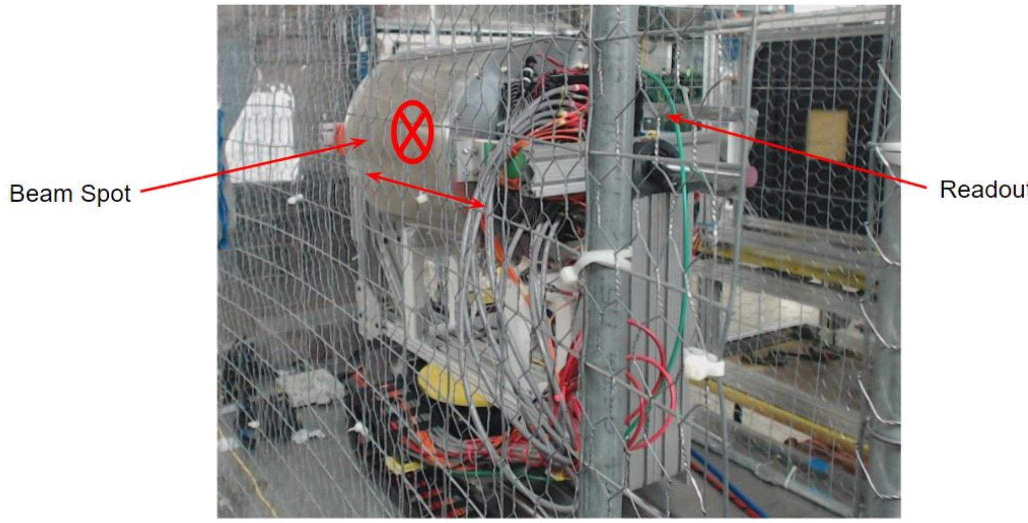
2 Examples of Streaming Readout

2.1 Streaming Readout in sPHENIX

An example of a detector in a test beam is a prototype of the sPHENIX TPC that was tested at the FermiLab Test Beam Facility (FTBF) in 2019 using a streaming readout format. The TPC prototype, shown in Fig. 1, was moved perpendicular to the beam to get particle tracks at different distances away from the pad plane, resulting in different drift lengths.

The chosen technology for this streaming readout system is a FPGA card designed for the ATLAS experiment, called "FELIX". The card is PCIe-based and has a large number (up to 48 pairs) of fiber inputs to connect to the front-end cards. The board has a powerful FPGA for data processing, zero-suppression, and data compression.

At the test beam at Fermilab, we found that our event rate capability could be significantly increased by running the FELIX readout in "streaming mode". We still triggered the front-end card with signals from the FTBF beamline, however, the FELIX cards are oblivious to how the FEE actually arrived at the decision to send up the data. But by allowing the FELIX card to store the data in streaming format, one does not need to wait for all data to be fully transmitted. In streaming mode, while data from trigger n are already



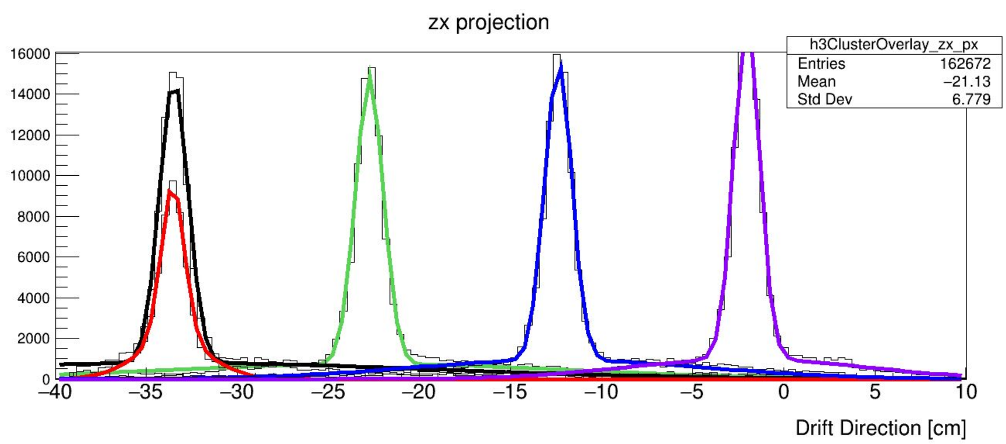


Figure 1: Left: The TPC prototype shown in the test beam which is read out with FELIX and RCDAQ-based DAQ. The red cross-hair indicates the approximate beam position. Right: The reconstructed drift distance for 4 different positions of the TPC prototype relative to the beam.

arriving, other parts can still be transmitting data from trigger $n-1$, or even $n-2$. In streaming mode, there is no need to wait for the completion of the data transmission from a given trigger, as the data parts are later re-assembled by their embedded clock information. That is what led to the increased event rate in streaming mode.

The tremendous benefits of streaming readout become obvious in the plans of the sPHENIX collaboration. The sPHENIX DAQ system needs to combine the streaming readout mode of the tracking system with the triggered readout of the calorimeters and the Minimum-Bias detector for "full" events with the data from all detectors present. These are the most important events that we*must* take. However, the tracking system still has capacity for additional tracking system-only events that can be interleaved with the full events.

This is shown in Fig. 2. The upper plot shows the data produced as a function of time by the TPC. The center plot shows the data portions acquired and stored the correspond to triggered events in the calorimeters. After that, we can "back-fill" free capacity in the tacking system with as many tracking system-only events as our storage capacity allows (lower plot).

This approach, applicable for both p+p and p+A running, significantly increases the statistics for Heavy

Figure 2: A simulation of the TPC data stream. The upper figure shows the continuously streaming data as a function of time, expressed as the beam crossing count (BCO). The dashed red lines denote accepted triggers. The lower figure shows the portion of the streaming data correlated with the accepted triggers. Each of the short blue sections in the lower figure is at least 13 μs long. The 4^{th} and 5^{th} trigger around BCO 1800 "extend" the TPC readout period, as do the triggers around BCO 2800 and 5000. The lower figure shows conceptually how we can "back-fill" free capacity by accepting additional tracking system-only events.

These accomplishments are intricately connected to the EIC, via the technical progress in large-scale SRO DAQ and computing, and via physics cases such as probing the universality of the gluon Sievers effect via the HF observables [2].

2.2 Streaming Readout at Jefferson Lab

Turning to JLab developments, recent tests in experimental Hall B used the CLAS12 Forward Tagger detector (FT calorimeter + hodoscope) as a streaming source (see Fig. 3). The signals were digitized by JLab VXS-based flash ADCs and streaming via a VXS crate backplane to an FPGA based crate processor (JLab VTP). For each crate these data were aggregated into two 10Gb ethernet links per crate and then to a special CODA streaming readout component (CODA SRO) effectively replacing CODA based event builders typically used in the triggered mode. This component aggregated and reformatted the six input streams and then passed the data onto "back-end" online processing software.

Nominally the performance for this system generated between 4-5Gb of data per link off the crates. The CODA SRO aggregation and processing was able to keep up with the highest data rates. Only after the back-end processing was implemented was the system not able to maintain the highest rates.

3 Our Interest

The general interest here is really two-fold. Existing experimental programs at both laboratories (BNL and JLAB) are operationally evolving toward streaming data acquisition models independent of the EIC project. The degree to which we can collaborate and share common standards both in hardware designs as well as in firmware and software development for the respective programs, the better we can establish a clear and tested path forward for the EIC streaming DAQ model. We in turn can also facilitate better support for much of the testing that will be done as part of the EIC detector and front-end electronics development that will be going by various collaborations (who are involved at both labs) many years in advance of EIC construction.

[1] https://indico.bnl.gov/event/7881/

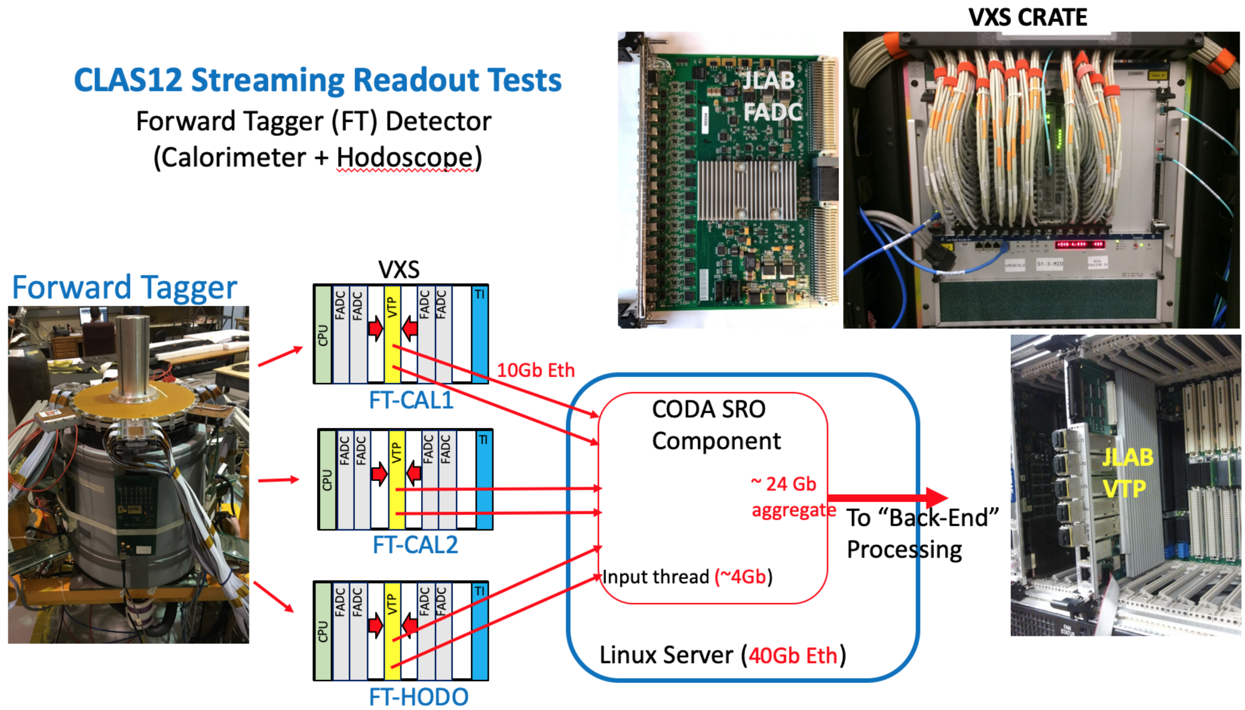


Figure 3: Schematic and general performance for the JLab CLAS12 Forward Tagger streaming readout test setup.

One example is to provide the EIC community with a readily available, standard data acquisition system. We will set out with support for the FELIX card, and will add support for future electronics as prototypes become available. This will provide the community with a reference platform for both triggered and streaming readout setups that is easy to set up and use. We will use the experience gained with this platform to formulate a framework with standard features and APIs that future electronics developments should support so they can be seamlessly be integrated into the readout and analysis framework.

The current implementation based on the FELIX card allows us to deliver a usable system in a timeline fashion. At the same time, the system is flexible and not locked to the FELIX card. It can be easily adapted to other existing, or future readout solutions. The early availability of a usable system for test beams and detector development will guide the design of future iterations of the hardware and software.

4 Links to other EoIs

Direct personal links are as follows: The interest of the Physics Department at Stony Brook University in Streaming Readout is expressed in the EoI of that group, with Drs. Bernauer and Desphande as the responsible contacts. Drs. Bernauer, Deshpande, Huang, and Purschke listed here are also part of the ECCE EoI, which contains streaming readout as well. There is also overlap with the Software Working Group EoI, especially the data model section.

5 Answers to Questionaire

Please indicate the name of the contact person for this submission:
Primary Contact: Martin Purschke <purschke@bnl.gov>

Secondary Contacts: Jan C. Bernauer <jan.bernauer@stonybrook.edu>, Jin Huang <jhuang@bnl.gov>, David Abbott <abbottd@jlab.org>

Please indicate all institutions collectively involved in this submission of interest:
Brookhaven National Laboratory, Stony Brook University, Thomas Jefferson National Accelerator Facility

Please indicate the items of interest for potential equipment cooperation: Cooperation on any streaming readout hardware, including front-ends, development of compatible interface and processing cards. Integration of existing/future front-end ASICs into readout.

Please indicate what the level of potential contributions are for each item of interest: We expect in-kind labor contributions, chiefly from streaming readout-related R&D that is done at the three institutions already for other experiments. Minimal sharing of experimental equipment (electronics) for development or testing is possible.

Please indicate what, if any, assumptions you made as coming from the EIC Project or the labs for your items of interest: We assume that BNL/JLab allows Drs. Abbot, Purschke, and Huang to work on this project for a fraction of their time. We further assume that existing electronics lab facilities at BNL/JLab can be used for development purposes.

If money could be found by the EIC project or 3rd parties to support the purchase of a larger set of electronics, we could use this to support test beam times.

Please indicate the labor contribution for the EIC experimental equipment activities:

The time commitment in the EIC efforts described in this EoI is anticipated to be as follows:

Institution Name	Professor	Research Professor	Staff Scientist	Postdoc	Graduate student	Undergrad. student	Engineer	Designer	Technician	Total Sum
SBU	0.2	0	0	1.4	1.6	0.8	0	0	0	4.0

The SBU numbers reflect the efforts listed in SBU's EoI for streaming readout and assume that future funding is secured.

We anticipate this collaborative effort to start at the design phase and end with commissioning of the DAQ system with first beam.

Please indicate if there are timing constraints to your submission:

We believe that the most value can be extracted from this project if it can start early, so that the DAQ system is available for test beams etc.

Please indicate any other information you feel will be helpful:

Stony Brook University provides Dr. Bernauer's group with ample lab space (∼850 sqft). Further, the department owns a clean room and further lab space suitable for the construction of larger assemblies, which can be used by the group if required.

At BNL, we will opportunistically make use of existing lab space and equipment that is available.

References

[1] A. Adare et al. An Upgrade Proposal from the PHENIX Collaboration. 2014.

[2] PHENIX Collaboration. sPH-TRG-2020-001 sPHENIX Beam Use Proposal, 2020.