INDRA-ASTRA: Evaluation & Development of Algorithms & Techniques for Streaming Detector Readout

Hindu mythology

INDRA Deity of lightning, thunder, rains and river flows

INDRA-ASTRA Indra's weapon

Jefferson Lab

INDRA Facility for **I**nnovations in **N**uclear **D**ata **R**eadout and **A**nalysis

INDRA-ASTRA LDRD on streaming readout

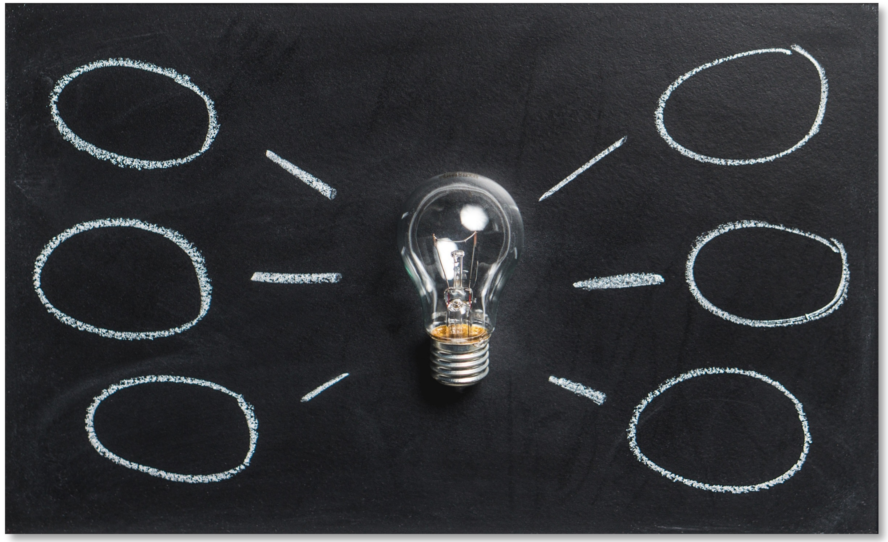
J. Bernauer (SBU), D. Blyth*(ANL), C. Cuevas*, M. Diefenthaler, A. Farhat**(ODU), W. Gu*, G. Heyes*, E. Pooser (JLAB → GTRI), B. Raydo*, Dmitry Romanov**

* Only FY19, ** Only FY20

Towards the next-generation research model in Nuclear Physics

Science & Industry remarkable advances in electronics, computing, and software over last decade

Evolve & develop **Nuclear Physics research model** based on these advances



Role of computing Data processing from DAQ to analysis largely shaped by kinds of computing that has been available
Example Trigger-based readout systems

Advances in electronics, computing, and software Unique opportunity to think about new possibilities and paradigms
Example Streaming readout systems

History Enabling the Next Generation Research Model for Nuclear Physics (Chris Cuevas, Graham Heyes, Markus Diefenthaler, Rik Yoshida)

- Why think about this?
  - Nuclear Femtography is a new science requiring an understanding of multi-dimensional correlations. The current NP research model is arguably not-adequate.
  - NP research model has not changed for over 30 years. There have been remarkable advances in computing, analytics and microelectronics capabilities. We want to see if these advances can fundamentally improve the research model.
- How to think about this.
  - Rethink the way experiment is compared to theory. Do computing advances enable a different way to do this? (Event Level Analysis, **ELA**)
  - Rethink the way experimental data is handled. Are there ways to speed up the analysis, in the context of **ELA**, of the data given modern compute and data handling capabilities. (Additive Event Model, **AEM**)
  - Rethink the way we read out the data from the Front-End and how they are assembled into events, in view of **ELA** and **AEM**. (**Streaming Readout**)
- Each item **ELA**, **AEM**, and **Streaming Readout** has its own merits and implementing them on their own has immediate advantage.
- However, most efficient **ELA** implies **AEM**, and ultimate efficiency of the Research Cycle can be achieved when **Streaming Readout** feeds **AEM → ELA**.
- ELA + AEM + Streaming Readout (**EASR?**) could be a model for accelerating discovery in NP.

Streaming readout and its opportunities

Definition of streaming readout

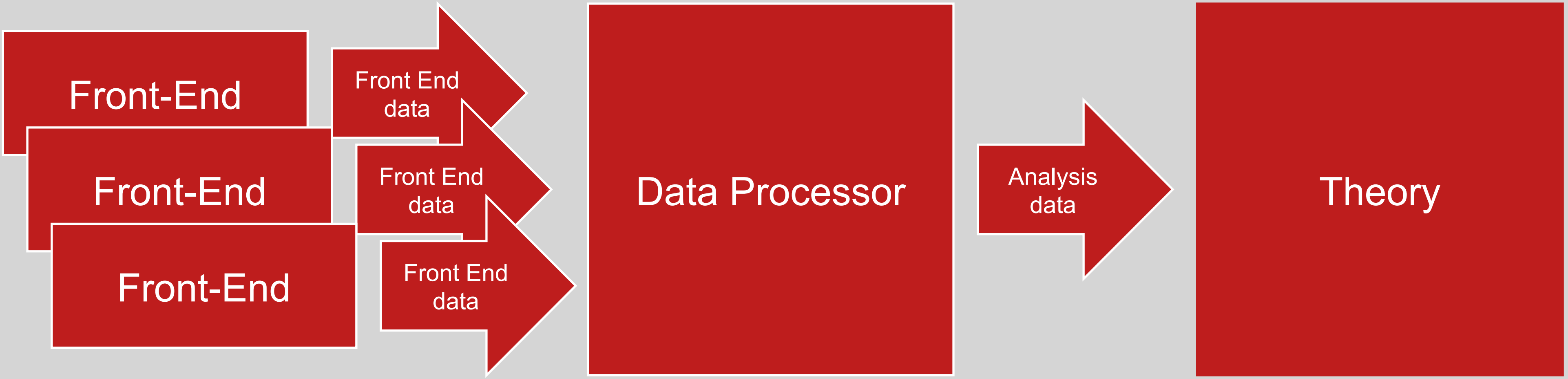
- data is read out in continuous parallel streams that are encoded with information about when and where the data was taken.

Advantages of streaming readout

- opportunity to streamline workflows
- take advantage of other emerging technologies, e.g. AI / ML

Integration of DAQ, analysis and theory to optimize physics reach

- seamless data processing from DAQ to analysis using streaming readout



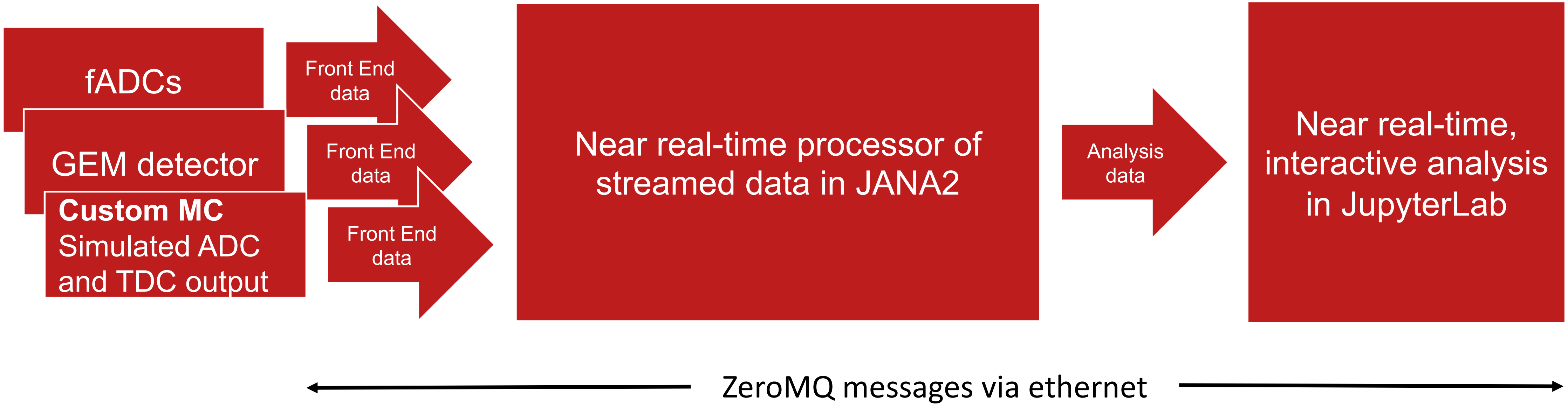
- opportunity for near real-time analysis using AI / ML (alignment, **calibration**, reconstruction)
- opportunity to accelerate science (significantly faster access to physics results)

Seamless integration of DAQ and analysis using AI/ML

LDRD goal

prototype components of streaming readout at NP experiments
→ integrated start to end system from detector read out through analysis
→ comprehensive view: no problems pushed into the interfaces

prototype near real-time analysis of NP data
→ inform design of new NP experiments



Streaming readout tests

fADCs

GEM detector

Custom MC
Simulated ADC and TDC output

Front End data

Front End data

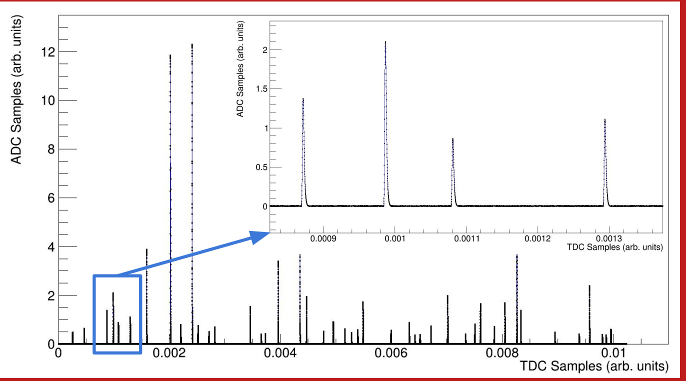
Front End data

Near real-time processor of streamed data in JANA2

Analysis data

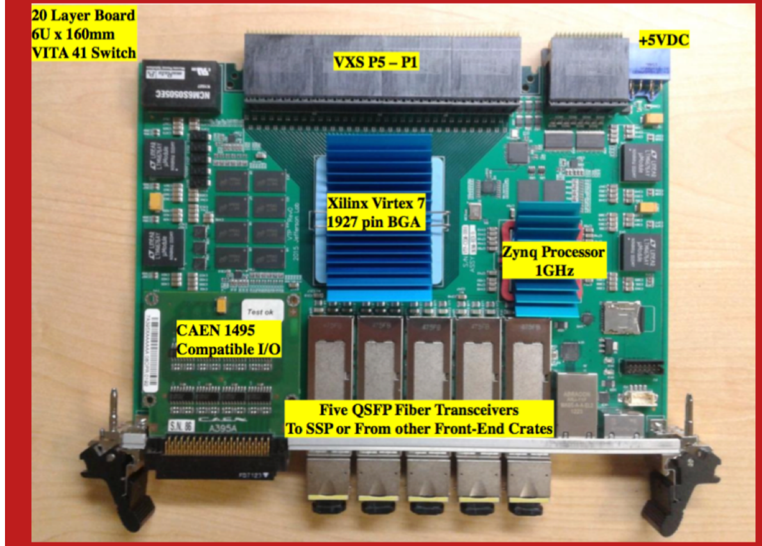
Near real-time, interactive analysis in JupyterLab

Developed streaming readout simulations

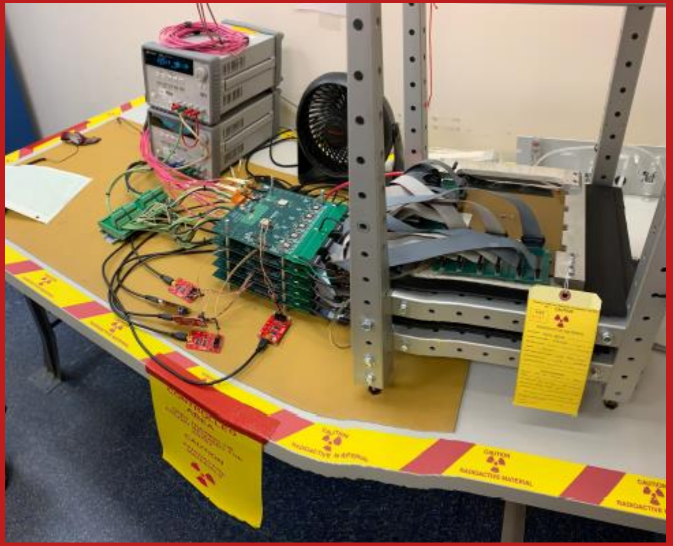


Demonstrated how to integrate any MCEG into streaming readout

Streaming readout of fADC250



TDIS Streaming Readout Prototype



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Streaming readout software

fADCs

GEM detector

Custom MC
Simulated ADC and TDC output

Front End data

Front End data

Front End data

Near real-time processor of streamed data in JANA2

Analysis data

Near real-time, interactive analysis in JupyterLab

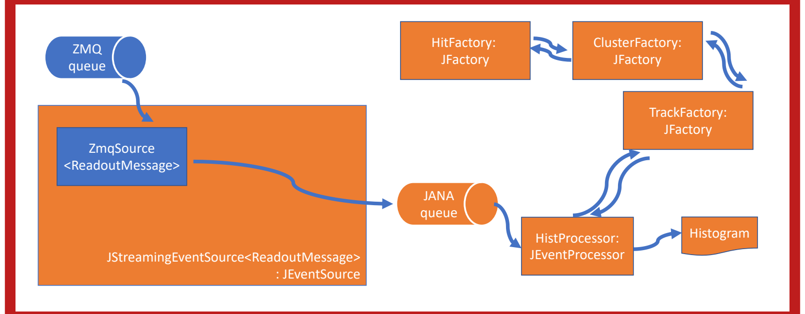
ZeroMQ messages via ethernet

Developed messaging library

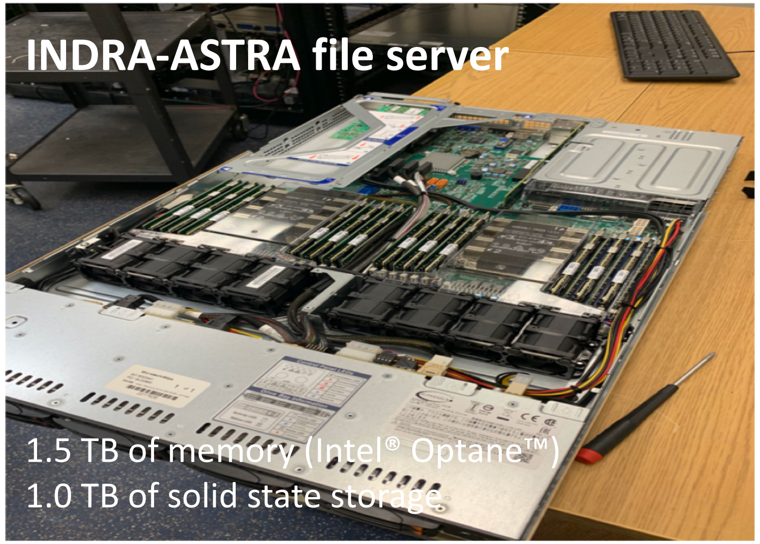
- receiving data from streaming data source
- sending it efficiently over the network (TCP)
- re-broadcasting the data using the ZeroMQ messaging protocol
- subscribing to a stream of data

tested at rates up to ~50 Gbit/s

JANA2 for parallel processing of streamed data (with LD2014)



INDRA-ASTRA file server



Streaming readout analysis

fADCs

GEM detector

Custom MC
Simulated ADC and TDC output

Front End data

Front End data

Front End data

Near real-time processor of streamed data in JANA2

Analysis data

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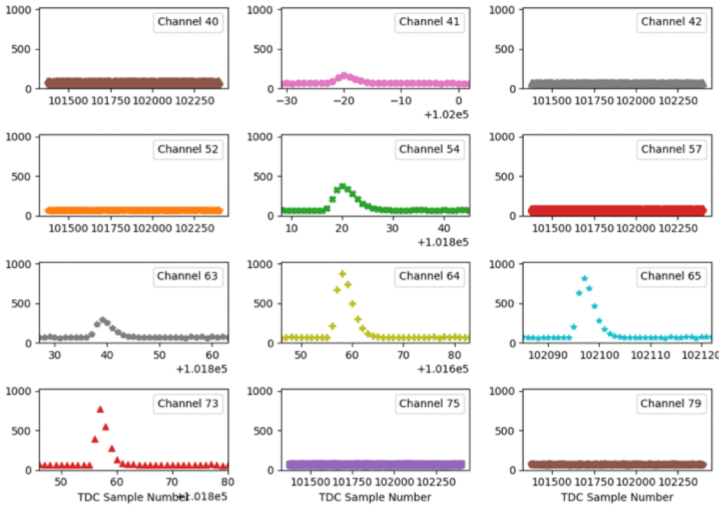
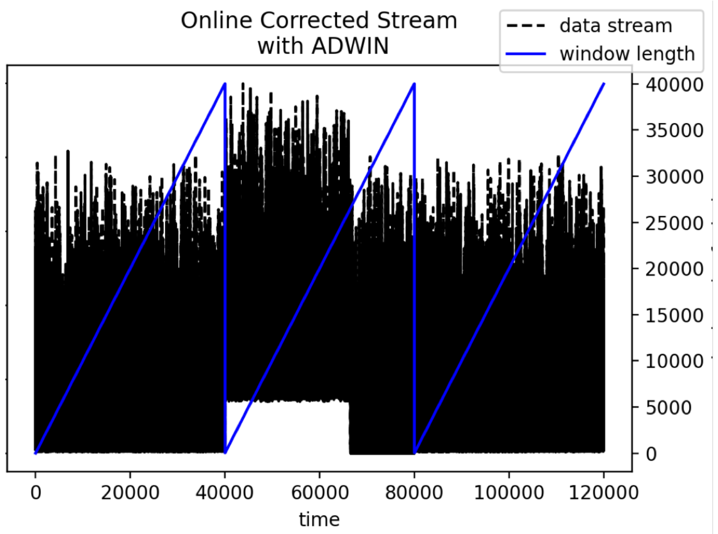
ZeroMQ messages via ethernet

Streaming plugins (data, MC)

- decoding of streamed data
- visualization of streamed data
- automated data-quality monitoring
- online calibrations
- fully extensible in JupyterLab





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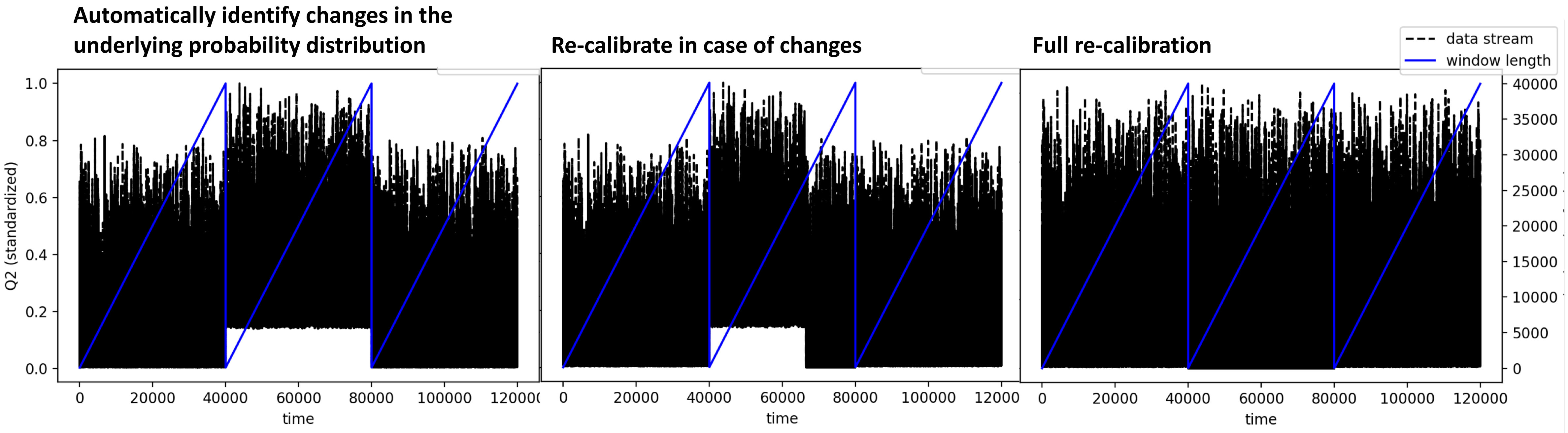
Automated data-quality monitoring and calibrations



Adapted and extended ADaptive WINdowing technique (ADWIN)

- detecting distribution changes, concept drift, or anomalies in data streams
- detection with established guarantees on the rates of false positives and false negatives
- keeps a sliding window W with the most recently read data
- whenever two sufficiently large sub-windows of W have sufficiently different means, then it is likely the corresponding expected values are different, and the older portion of the window is dropped
- prediction intervals without any prior assumption on the underlying distribution of data samples

Address Challenges of Autonomous Control and Experimentation

Follow-up Project

Develop a prototype for a fully automated, responsive detector system as a first step towards a fully automated, self-conscious experiment

R&D fully integrated with:

- streaming readout efforts at Jefferson Lab
- AI/ML initiatives at Jefferson Lab and affiliated universities

Team

Jefferson Lab

- **ENP** M. Diefenthaler, E. Jastrzembski, H. Szumila-Vance, and CLAS12 involvement
- **CST** D. Lawrence, V. Gyurjyan, and we for sure will work with N. Brei

Catholic University of America

- **Physics** T. Horn (interested)

Old Dominion University

- **Applied Numerical Mathematics** R. Fang, A. Farhat, Y. Xu

Work plan

Detector Readout	ML	Integration
Setup ERSAP prototype	Compare ADWIN2 and MULTISCALE algorithms in their capability • for identifying gradual and sudden changes in streaming data and • for distinguishing these changes from noise • for online capability	Develop a service in ERSAP to report changes and noise levels to the streaming readout system
GEM detector Monitor pedestals in real time		**GEM detector** Automatically correct for pedestals in real time
GEM detector Study cosmics and establish baseline efficiency and tracking using current, non-ML approaches	**GEM detector** • identify cosmic over background • learn what is a good efficiency for detector plane	**GEM detector** Monitor efficiency in real time (e.g., some region not seeing hits) and automatically report on changes
Calorimeter pending on CLAS12	**Calorimeter** pending on CLAS12	**Calorimeter** pending on CLAS12
		Identify limitations of automated system, e.g. by rapid changes of threshold or additional noise sources
Prepare tests in Halls A/C and B		Test integrated system in parasitic beam test

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New possibilities and paradigms for JLab 12 GeV and EIC

- seamless data processing from DAQ to analysis using streaming readout
- opportunity for near real-time analysis (auto-alignment, auto-calibration, near real-time reconstruction)
- opportunity to accelerate science

LDRD project: INDRA-ASTRA

- prototyped components of streaming readout
- prototyped near real-time analysis
- **Collaboration with Experimental Physics Software and Computing Infrastructure (EPSCI)**
  - INDRA-ASTRA fulfills need for rapid prototyping tools for DAQ and detector R&D for Nuclear Physics and beyond
  - develop INDRA-ASTRA into plugin for near real-time monitoring and auto calibrations at JLab 12 GeV and EIC