Real-Time Workflows at FRIB Using EJFAT/E2SAR and ESnet

Aaron Chester[1], Ilya Baldin[2], Giordano Cerizza[1], Ben Crider[3], Derek Howard[4], Yatish Kumar[4], Sean Liddick[1,5], Paul Reece[1], Tom Rockwell[1], Bashir Sadeghi[1], Stacey Sheldon[4], and Jerry Vasquez[1]

[1]Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, [2]Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, [3]Department of Physics and Astronomy, Mississippi State University, Mississippi State, Mississippi 38762, [4]Energy Sciences Network, Lawrence Berkeley National Laboratory, Berkeley, California 94720, [5]Department of Chemistry, Michigan State University, East Lansing, Michigan 48824

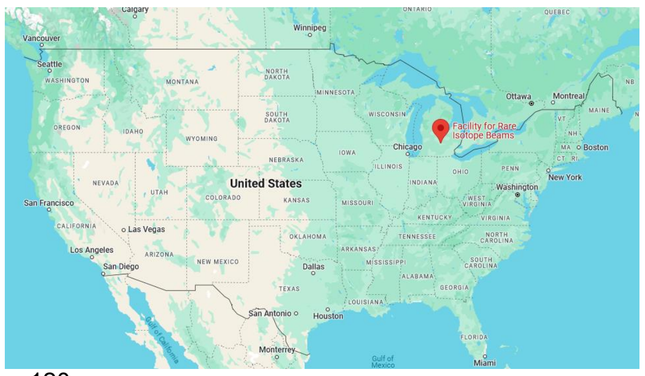
Overview of The Facility for Rare Isotope Beams (FRIB)

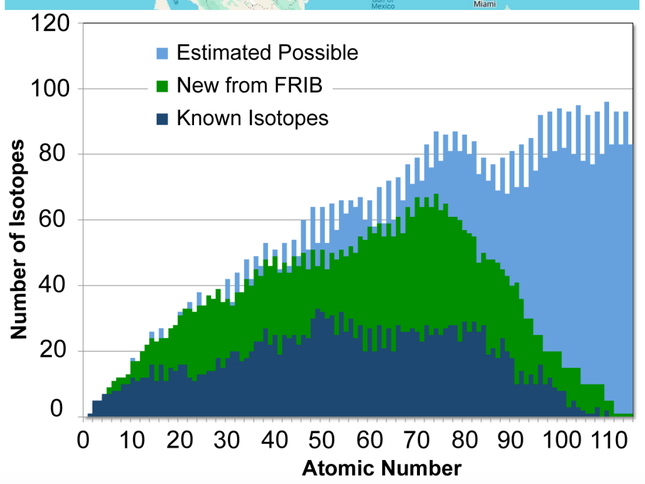
The Facility for Rare Isotope Beams (FRIB) is a scientific user facility funded by the US Department of Energy Office of Science, Michigan State University, and the State of Michigan.

The key feature of FRIB is a high-power LINAC which can operate at a maximum power of 400 kW, delivering beams from oxygen to uranium at up to 200 MeV/u to fast, stopped, and re-accelerated beam experimental areas.

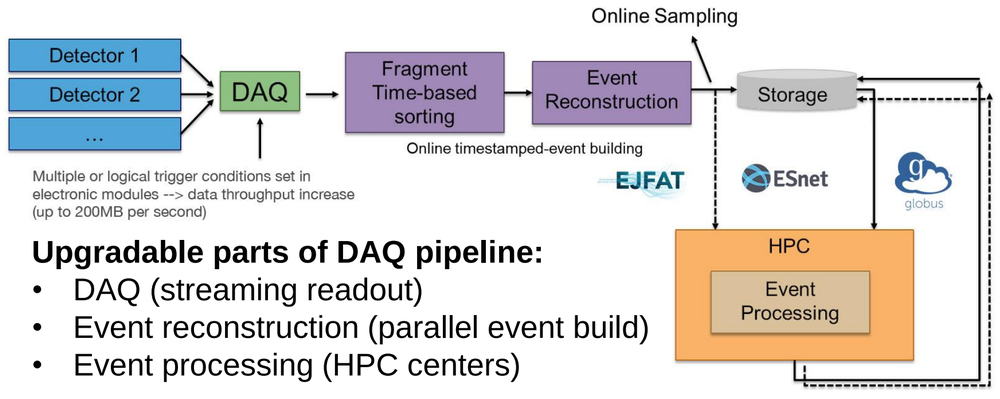
Beginning operation in May 2022, FRIB has a user organization representing ~1800 users spread across 53 countries, 125 colleges universities, and 13 national labs.

The FRIB scientific program covers a broad range of nuclear science, from nuclear structure, astrophysics, fundamental symmetries, and societal applications and benefits such as isotope harvesting for nuclear medicine.



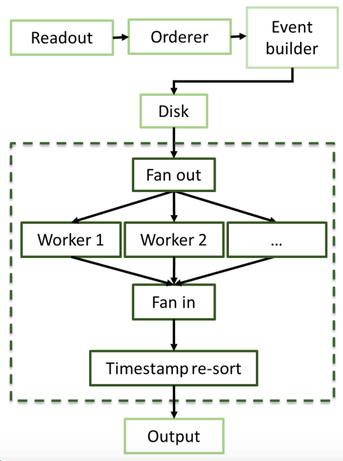


FRIB Data Acquisition Architecture



Upgradable parts of DAQ pipeline:

- DAQ (streaming readout)
- Event reconstruction (parallel event build)
- Event processing (HPC centers)



Process-level pipeline parallelism

- Separate readout and timestamp sorting

Parallel analysis framework

- Plugin library for user analysis, parallel task distribution via OpenMPI or 0MQ

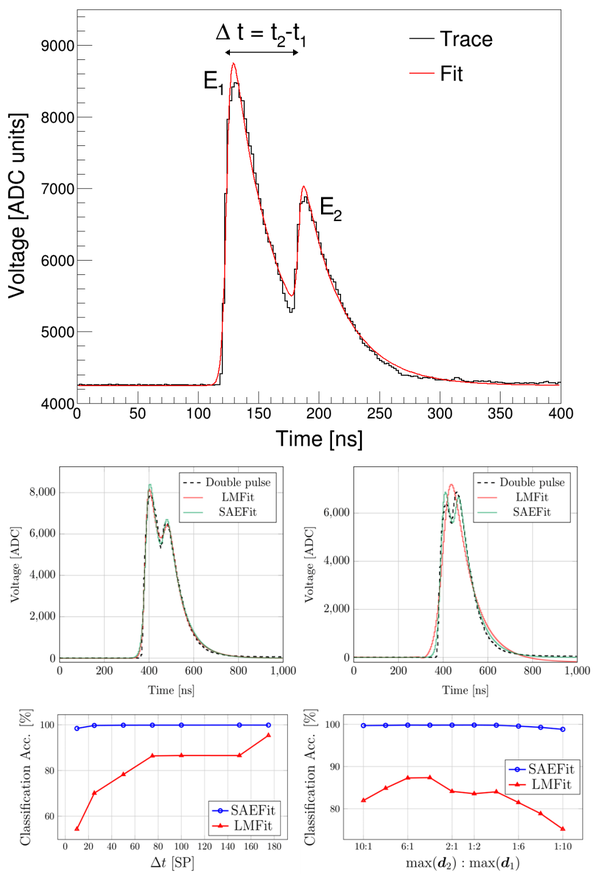
Event-editing software

- Filters (parallel software trigger), body editors (add to or modify event data)

Rate limited by DAQ hardware backplane

- 80 MB/s VME64, 109 MB/s PCIe

Connecting FRIB Science to HPC Facilities: Real-time Workflows using EJFAT/E2SAR and ESnet

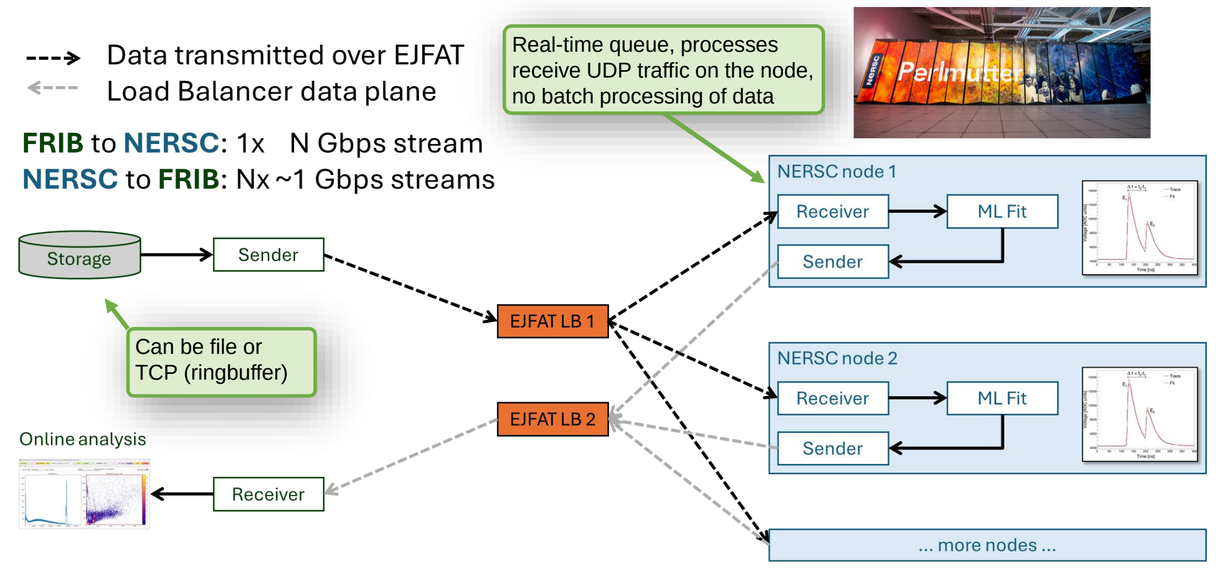


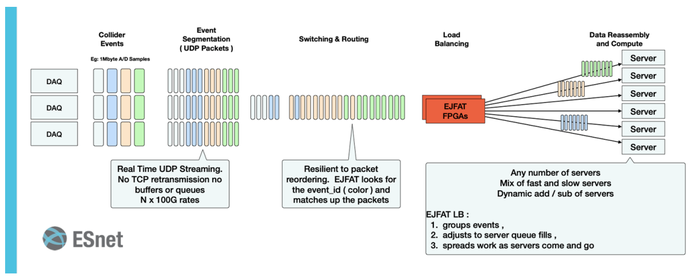
[Top left] A radioactive ion beam is implanted into a $CeBr_3$ scintillator detector. Isomeric states populated following the β decay of the implanted ion result in a characteristic double-pulse signal which is fit with a model response function to extract the isomer lifetime[1,2]. The model response function must:

- Classify events containing one or two pulses
- Accurately and precisely estimate model parameters

[Middle left] Comparison of an iterative, nonlinear least squares method using the Gnu Scientific Library's Levenburg-Marquardt solver (LMFit), and a machine-learning inference method using a Siamese autoencoder neural network architecture (SAEFit)[3].

[Bottom left] The SAEFit approach offers improved classification, parameter estimation and is less computationally intensive than LMFit[3].



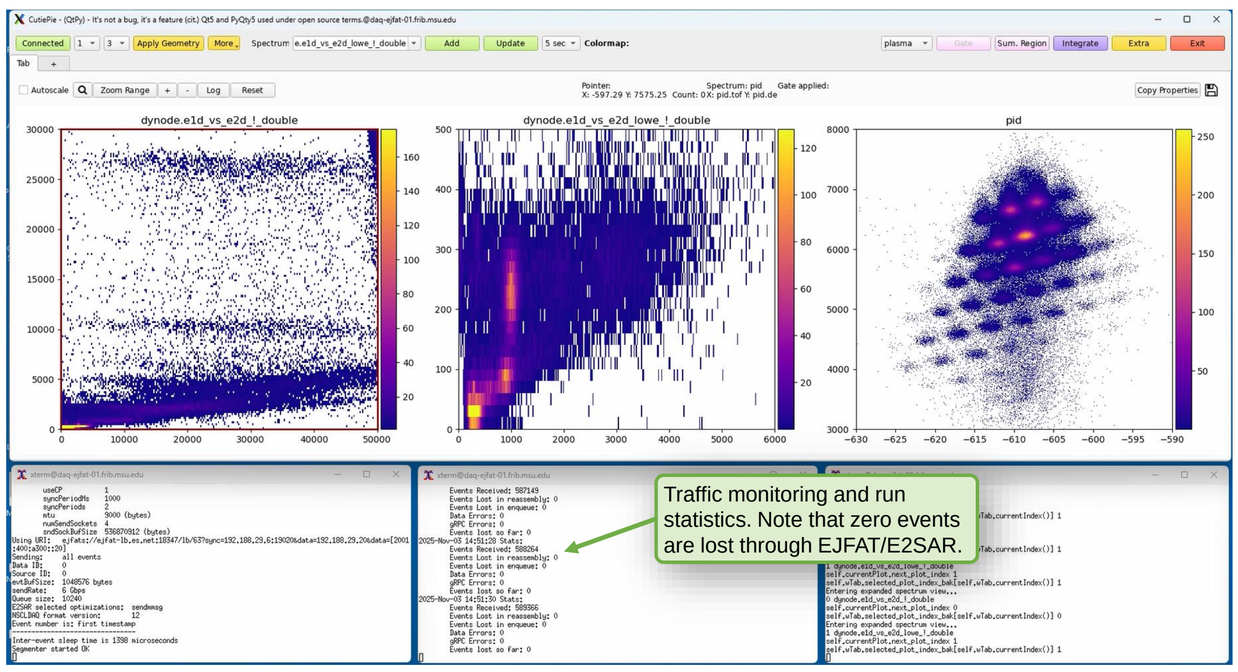


Streaming workflow using E2SAR event segmentation and reassembly and EJFAT load-balancing FPGAs. E2SAR is integrated into the sender and receiver applications.

No intermediate files are written, operate exclusively on UDP and TCP streams.

[1]A. Chester et al., Phys. Rev. C **104** (2021) 054314; [2]A. Chester et al., Phys. Rev. C **105** (2022) 024319; [3]B. Sadeghi et al., Nucl. Inst. Meth. A **1082** (2026) 170971

Online Analysis of Data Processed at Perlmutter



Online analysis and monitoring of the data-processing workflow incorporating the machine-learning inference fitting. [Left] The horizontal bands are characteristic of β-delayed isomeric states depopulating via a low-energy γ ray or electron. [Middle] Circular dots are characteristic of isomer-to-isomer transitions. [Right] Particle identification plot. Each spot represents a different radioactive isotope in the beam.

Summary and Conclusions

- Developed a real-time workflow for distributed analysis of production FRIB experiment data offsite at NERSC.
- Use of real-time queue: latency-free analysis without batch processing.
- Integrated EJFAT/E2SAR data transfers and ML-inference fitting into standard FRIBDAQ online analysis tools to support real-time data processing.
- Processed 615 GB of data (15 hours of run time) in 20 minutes using 8 Perlmutter nodes at an average rate of 525 MB/s (hardware limited).
- Extensible framework for handling additional use cases for data streaming to HPC or between FRIB and other laboratories.
- Excellent support from EJFAT team, positive user experience.

Acknowledgements

Giordano Cerizza, Sean Liddick, Rebeka Lubna, Paul Reece, Tom Rockwell, Bashir Sadeghi, Jerry Vasquez

Ilya Baldin

Eli Dart, Yatish Kumar, Jason Zurawski

Debbie Bard, Nicholas Tyler

Rafael Ferreira da Silva, Brian Etz, Ross Miller

Ben Crider

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB) Operations, which is a DOE Office of Science User Facility under Award Number DE-SC0023633.