A Machine-Detector-Analysis Interface for the EIC

Markus Diefenthaler (Jefferson Lab)

Role of Software Working Group in Yellow Report initiative

Develop

Support

Workflow environment for EIC simulations

- **to use** (tools, documentation, support) **and**
- **to grow with user input** (direction, documentation, tools)

Involvement from EICUG

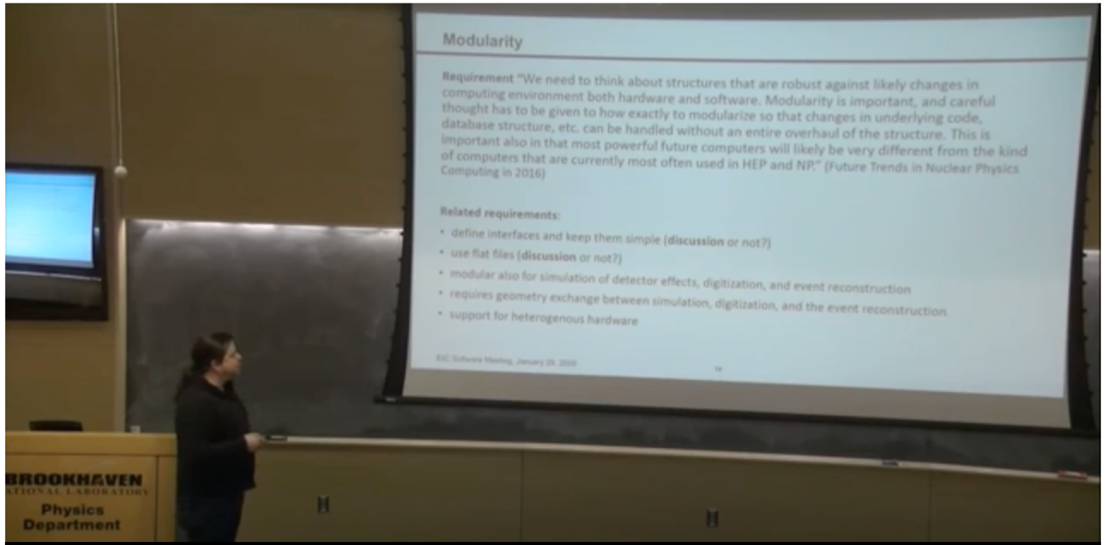
- **Coordinate simulations**
- **Analysis preservation** Make software available and integrate it.
- **Design detectors**
- **Developing reconstruction algorithms**
- **Develop physics analysis**
- **Input for next-generation software**

Discussion within Software Working Group

Greenfield event-processing software := community-wide project on event-processing software freeing us from the legacy of existing options while leveraging everyone's experience. The project will define requirements and build up the simulation toolkit / framework on these requirements. Input by the wider scientific and software & computing communities is encouraged.

01/21 Discussion of Software requirements
01/29 Discussion of Software requirements
03/10 Software & Computing Round Table

- **Topic** Frameworks for Greenfield Experiments
- Scott Snyder (BNL) **Future frameworks: ATLAS perspective**
- Christopher Jones (FNAL) **Lessons Learned from CMS Framework Development**
- Kyle Knoepfel (FNAL) **The art Framework: What It Is and Why**



YouTube channel of the EIC User Group

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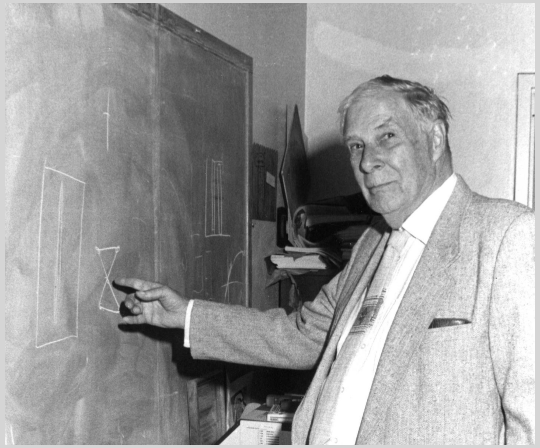
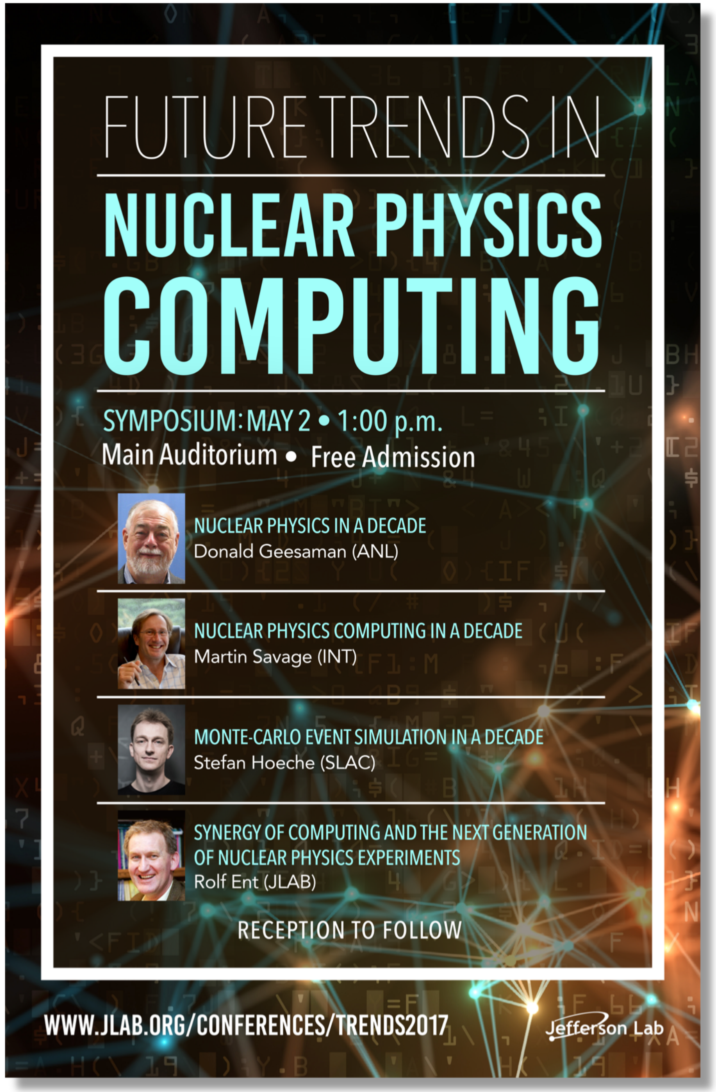
The role of Software & Computing



Richard Hamming (1962) *"The purpose of computing is* ***insight****, not numbers."*

Martin Savage (INT, 2017) *"The next decade will be looked back upon as a* ***truly astonishing period in Nuclear Physics*** *and in our understanding of fundamental aspects of nature. This will be* ***made possible by advances in scientific computing*** *and in how the Nuclear Physics community organizes and collaborates, and how DOE and NSF supports this, to take full advantage of these advances."*

Data & Analysis



- All scientists of all levels, worldwide, should be enabled to actively participate in the Nuclear Physics data analysis.
- To achieve this goal, we must develop analysis toolkits using modern and advanced technologies while hiding that complexity:
  - resolving this tension means putting a priority on the user experience and functionality (user-centered design).
- We must emphasize **data** as much as **analysis**:
  - experimental data must be open access, readily accessible and in a self-describing formats
  - data must be trackable and linked to publications

Donald Geesaman (ANL, former NSAC Chair) "*It will be **joint progress of theory and experiment** that moves us forward, not in one side alone*"

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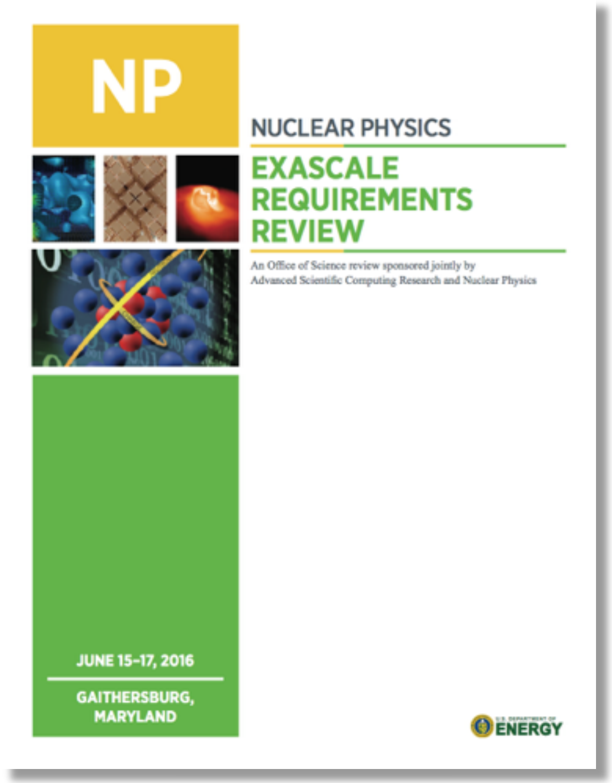
Implications of Exascale Computing

As presented to the NAS in 2018

Past efforts in lattice QCD in collaboration with industry have driven development of new computing paradigms that benefit large scale computation. These capabilities underpin many important scientific challenges, e.g. studying climate and heat transport over the Earth.

The EIC will be the facility in the era of high precision QCD and the first Nuclear Physics facility in the **era of Exascale Computing**. This will affect the interplay of experiment, simulations, and theory profoundly and result in a new computing paradigm that can be applied to other fields of science and industry.



Petascale-capable systems at the beamline

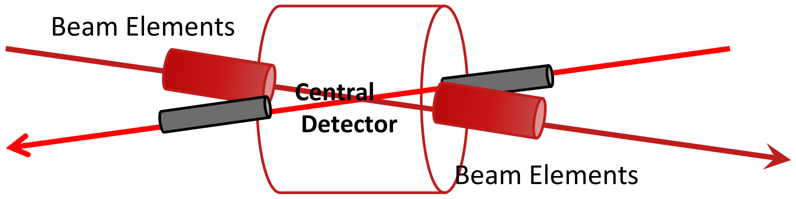
- **unprecedented compute-detector integration**, extending work at LHCb
- requires fundamentally new and different algorithms
- computing model with AI at the DAQ and analysis level and a compute-detector integration to deliver **analysis-ready data from the DAQ system**:
  - responsive calibrations in (near) real time
  - real-time event reconstruction and filtering
  - physics analysis in (near) real time

A similar approach would allow **accelerator operations** to use real-time simulations and AI over operational parameters to tune the machine for performance **Now LAB 20-2261 FOA**

Machine-Detector Interface

Integrated interaction region and detector design to optimize physics reach

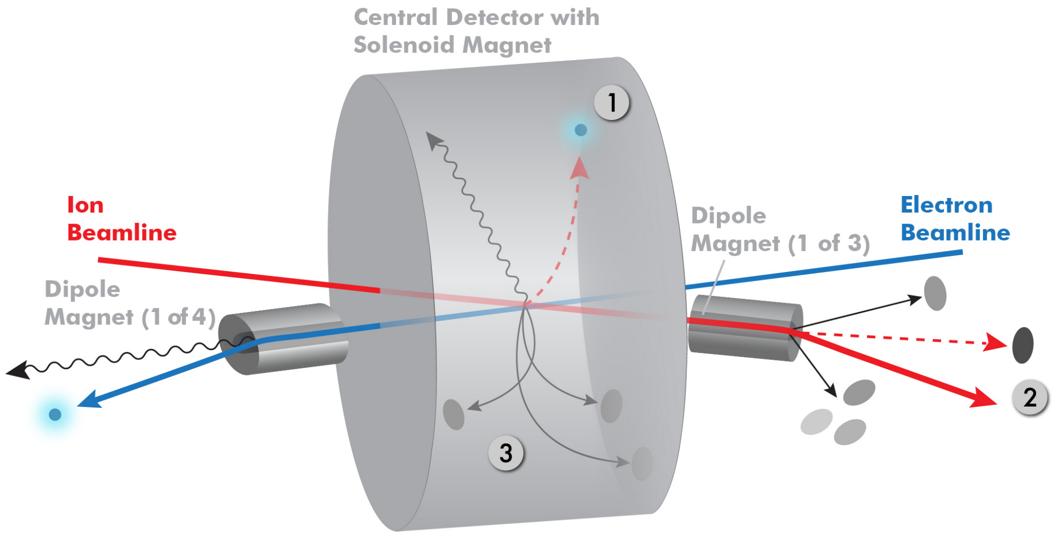
The aim is to get **~100% acceptance** for all final state particles, and measure them with good resolution.



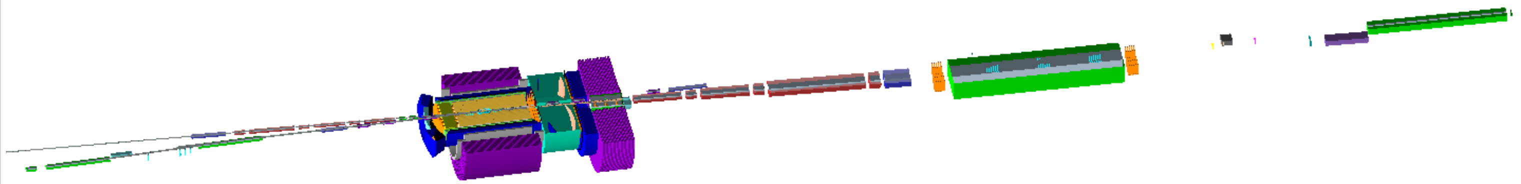
Experimental challenges:

- beam elements limit forward acceptance
- central Solenoid not effective for forward

Possible to get ~100% acceptance for the whole event.



Extended IR and Detector Region with far-forward detection



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Beyond Machine-Detector Interface

Integration of DAQ, analysis and theory to optimize physics reach

Integration of DAQ, analysis and theory

- research model with seamless data processing from DAQ to data analysis:
  - not about building the best detector
  - but the best detector that fully supports Streaming Readout and fast alignment calibration, and reconstruction algorithms for (near) real-time analysis

The role of Streaming Readout at the EIC

Think out of the box

- The way analysis is done has been largely shaped by kinds of computing that has been available, e.g., **trigger systems**.
- This is an unique opportunity for Nuclear Physics to think about new possibilities and paradigms that can and should arise, e.g., **Streaming Readout**.

Challenges in data acquisition

- precision of the science depends on statistics which leads to:
  - development of detectors that can handle high rates
  - improvements in trigger electronics - faster so can trigger at high rates.
- beam time is expensive so data mining or taking generic datasets shared between experiments is becoming popular:
  - loosen triggers to store as much as possible
  - think about sharing datasets from the start
  - science is global – so distribute and share data handling
- some experiments are limited by event-pileup, overlapping signals from different events, hard to untangle in firmware.
  - Leads to different readout schemes, often trigger-less

Benefits of Streaming Readout

Move complexity from hardware to software

- enhances flexibility
- reduces complexity
- relaxes hard time constraints
- allows more scientists to contribute (merge of DAQ, online and maybe also offline groups)
- allows cost-effective use of resources
- easier integration of detectors with large data rate (e.g., EIC Vertex detector with 240 GB/s)

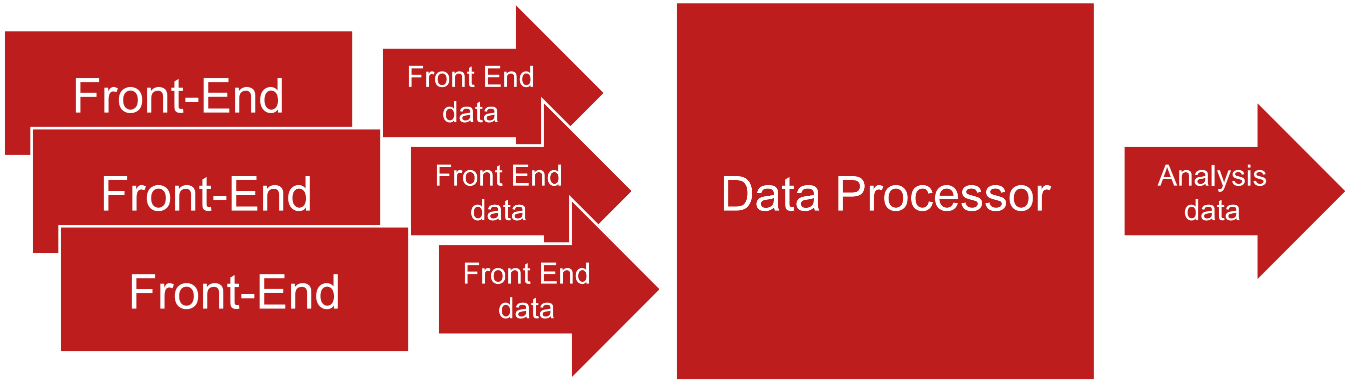
Possible challenges

- real-time integration with accelerator
- how to commission / understand accelerator, detector, and analysis software at the same time

Blurring of Online and Offline

- Traditional model of online vs offline environments very distinct
- With calibration and Level-3 (L3) triggering somewhere in-between.
- Driven by a combination of the physics being studied and detector technologies the offline-online distinction is being blurred, and in some cases removed:
  - Detectors such as TPCs that are difficult to integrate into the traditional online data flow - defer integration processing until later:
    - **sPHENIX implementation** TPC is Streaming Readout but in the current design only snippets which are associated with triggers are saved, thus following the standard triggered scheme (where the raw data associated with a trigger).
  - Level 3 triggers requiring partial or complete reconstruction to deduce the rate to mass storage.
  - Reconstruction and data compression to reduce rates to tape (LHCb).
  - Trigger rates and detector topologies that are hard/expensive to deal with in electronics, defer to software (SoLID, GRETA).

Streaming Readout and Real-Time Processing



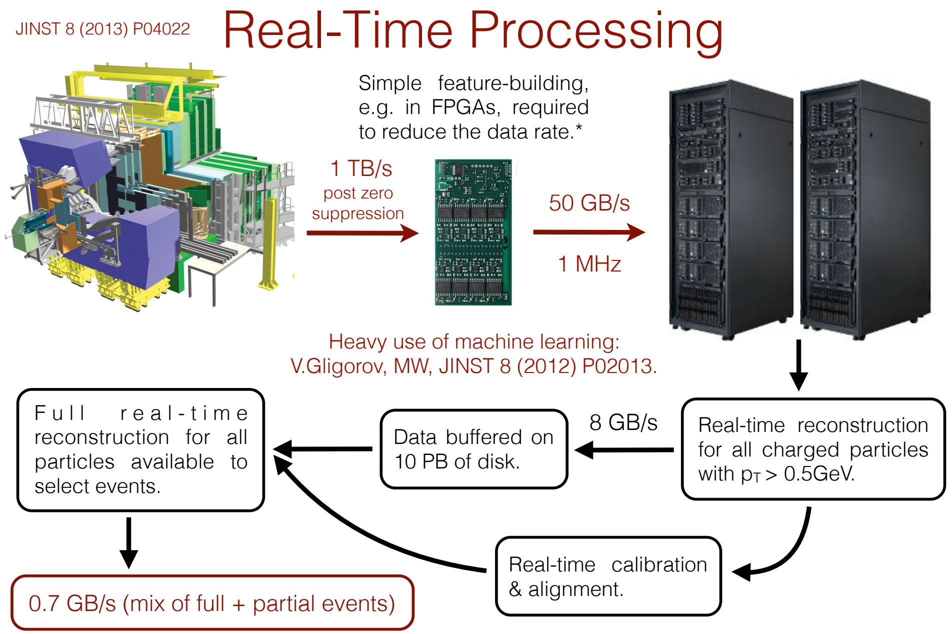
Data Processor

- assembles the data into events
- Software & Computing
- outputs data suitable for final analysis (**Analysis data**)

Features (among others)

- ideal for AI
- automated calibration and alignment
- real-time reconstruction of events
- event selection and/or labeling into analysis streams
- automated anomaly detection
- responsive detectors (conscious experiment)

LHCb Example



*LHCb will move to a triggerless-readout system for LHC Run 3 (2021-2023), and process 5 TB/s in real time on the CPU farm.

Markus Diefenthaler

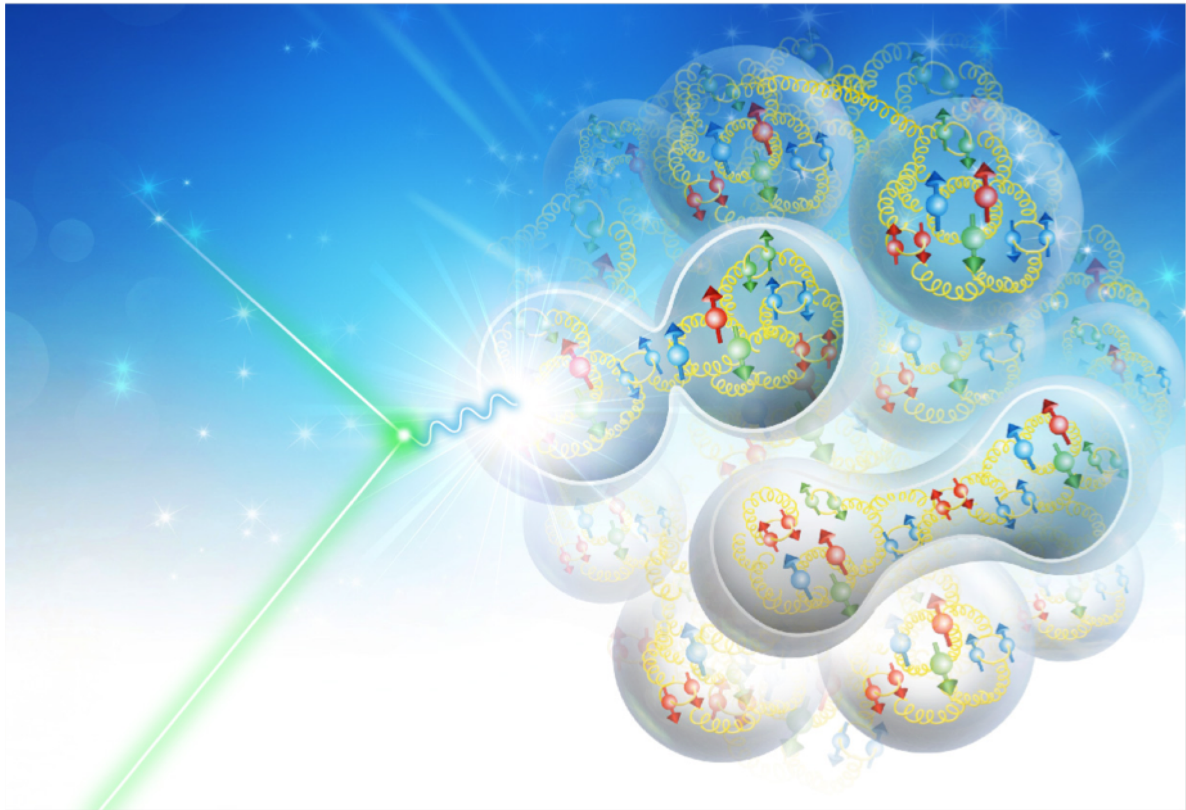
mdiefent@jlab.org

Outlook

- **Vision** Develop Machine-Detector Interfaces into a **Machine-Detector-Analysis Interface** with analysis-ready data from the DAQ system

- **Understand** requirements for DAQ / Electronics and Software & Computing, also in light of a **Machine-Detector-Analysis Interface**

- **Yellow Report Initiative** Ongoing discussion between Readout and DAQ and Software Working Groups



Discussion: Is software event triggering and building necessary?

Comments from ongoing discussion with Sergey Furletov (JLAB), David Lawrence (JLAB), Chris Pinkenburg (BNL), Maurizio Ungaro (JLAB), and Torre Wenaus (BNL):

Is software event triggering and building necessary

- We need to address noise. E-p and likely e-A is all about noise with their low multiplicity the event itself may not contribute too much to the actual event size. In Streaming Readout triggering will only reduce the amount of data which gets archived. Unlike for a lvl1 trigger where you trade one event for another you will not increase the number of interesting events.
- If we agree on analysis-ready data from the DAQ system being a goal, then we need to build events in (near) real time and also filter them according to physics interests.

Discussion: Drop raw data and keep only the reconstructed part?

Comments from ongoing discussion with Sergey Furletov (JLAB), David Lawrence (JLAB), Chris Pinkenburg (BNL), Maurizio Ungaro (JLAB), and Torre Wenaus (BNL):

At which point can we reconstruct data online, and drop the raw data to keep only the reconstructed part?

- Why would we do that? We can store the raw data for the EIC.
- Does this make sense? Often raw data is more compact then the resulting reconstructed output. Take ALICE approach to buffer data for a long time in the O2 farm for calibration and reconstruction and then only write reconstructed data to tape? Probably not allowed by DOE regulations which I think demand saving the data permanently as soon as possible.
- DUNE does this: Their event size is O(8GB) and they reduce it to O(80MB).
- The second part of the question is when we can reconstruct online. I think we can do this (near) real time if we can do calibrations online.

Discussion: Same question concerning the event selection?

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Same question concerning the event selection?

- I would give the same answer as above. If we can reconstruct in near real time, then we can also build events and select on them.

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Discussion: What sort of calibrations would be necessary?

Comments from ongoing discussion with Sergey Furletov (JLAB), David Lawrence (JLAB), Chris Pinkenburg (BNL), Maurizio Ungaro (JLAB), and Torre Wenaus (BNL):

What sort of calibrations would be necessary?

- I would calibrate the EIC in dedicated calibration runs and then update the calibrations online to account for time-dependent effects. This is an ideal case of AI. Prototypes are being developed, e.g., INDRA-ASTRA.