

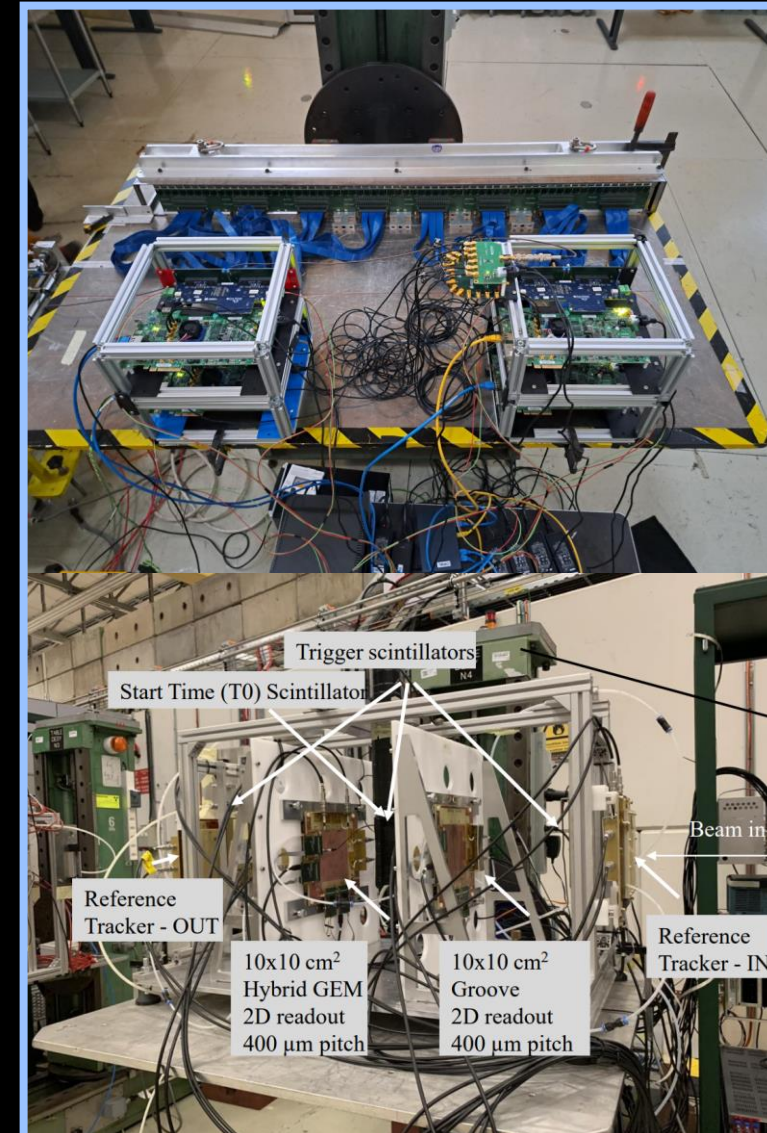
Test Beam Software Support

Derek Anderson (JLab) and others
ePIC Weekly S/C Meeting
October 29th, 2025



Intro | Test-Beam Support & Data-Taking Readiness

- **Critical period for EIC:** beginning to move into construction!
 - Several test beams (TB) already happened and many being planned
 - ☞ cf. this week's [TIC meeting](#)
 - **Left:** setups from LFHCAL (upper) & MPGD (lower) 2024 TBs at CERN PS
- **From software side:** want to support test beams as much as possible
 - And want to begin preparing for real data-taking
 - ☞ TB data allow for practicing reconstructing / analyzing real data
 - The earlier we start, the better!
- Held dedicated workfest on topic at Summer 2025 EIC UGM/ePIC CM
 - ∴ **In this talk:** will summarize workfest and provide recent updates

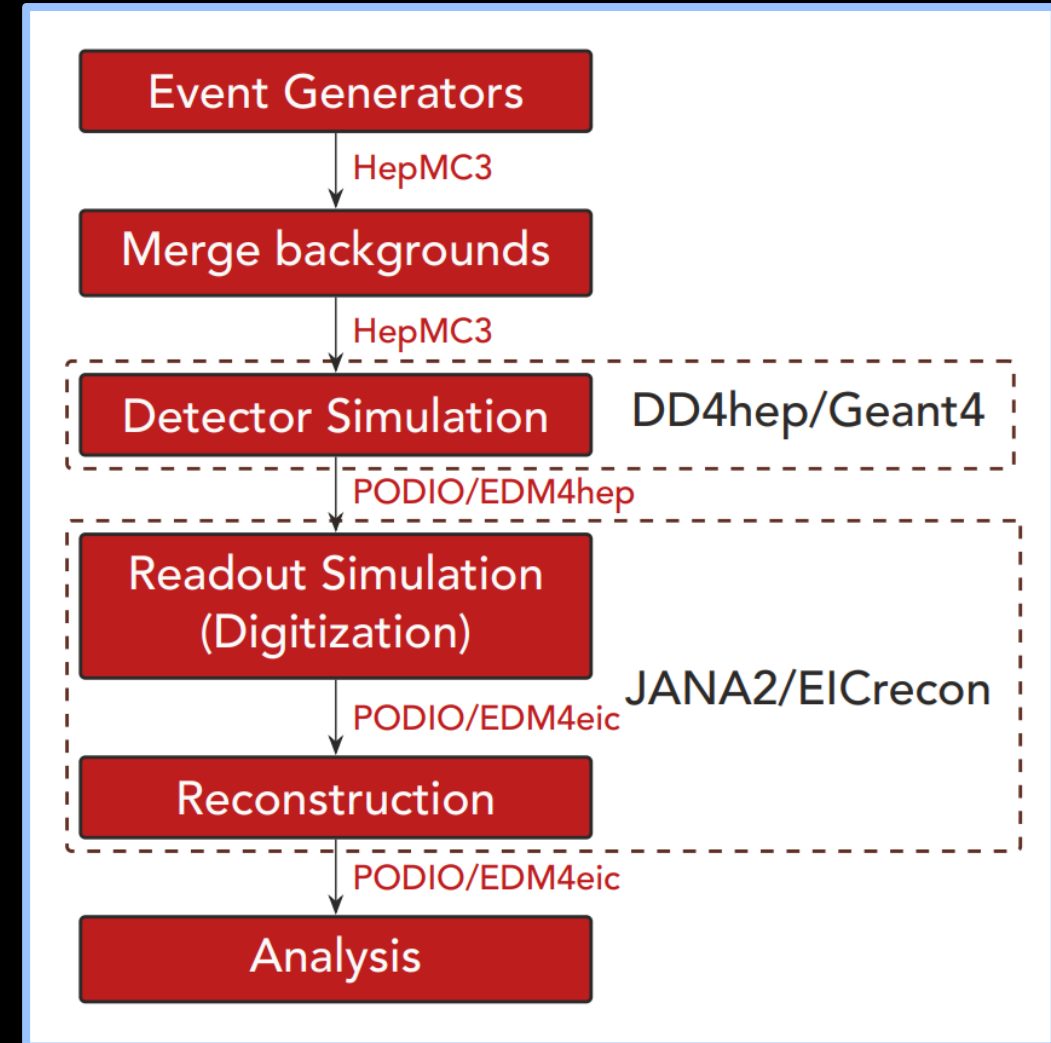


Tristan Protzman (LU), CPAD2024

Kondo Gnauvo (JLab), CPAD2024

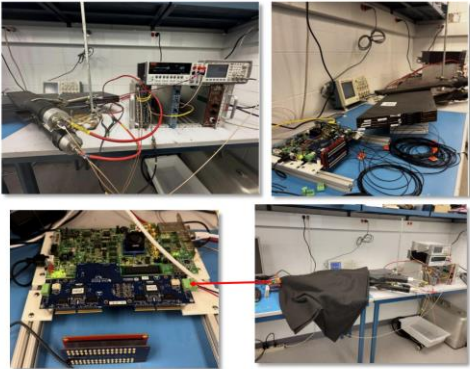
Intro | Reminder: the ePIC Software Stack

- **Right:** an overview of the ePIC software stack
 - 1) MCEGs simulate physics channels + backgrounds
 - 2) [GEANT4](#) + [DD4hep](#) simulates detector response
 - 3) [JANA2](#) + [EICrecon](#) simulates digitization and runs reconstruction
 - 4) [PODIO](#) structures flow of data through simulation, reconstruction to analysis
 - 5) Flat output format facilitates analysis in wide range of analysis frameworks
- ☞ **Stack is flexible enough to support simulation/reconstruction of both main detector and TB setups**
 - Working in stack *now* prepares us for real data taking *later*
 - And is *very* useful for reproducibility!
 - ∴ **Now working towards supporting TBs!**

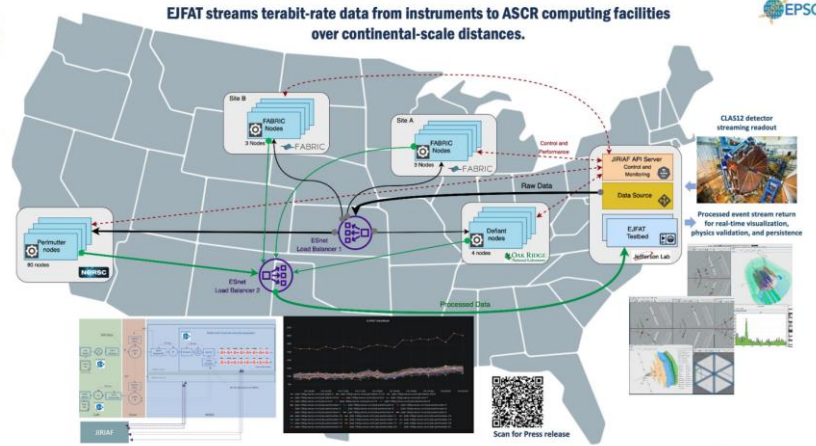


EIC UGM Workfest | Morning Talks

ROC readout in our Hcal Lab @BNL



5 BHcal tiles with the ePIC SiPMs connected to the H2GCROC3 card
Read out via the KCU105 FPGA board
Readout fully implemented in RCDAQ



Wednesday, July 16, 2025

Gyurjyan@EICUG/EPIC

Jefferson Lab
SPADI Alliance
Signal processing and data acquisition infrastructure alliance
toward the EIC/FAIR for sustainable development

Introduction | Software to Readout Interface

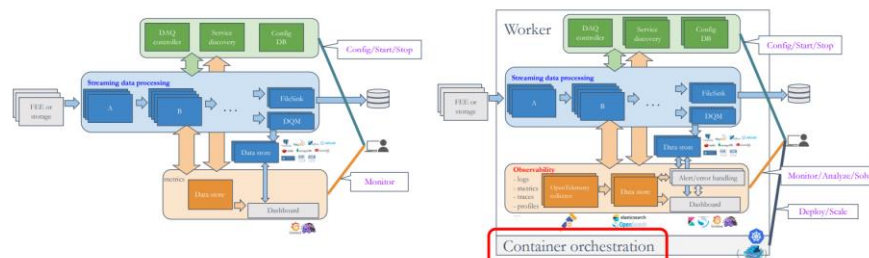


NestDAQ

Ver. 1

vs.

Ver. 2.0



Manually restart a process if it die

Key feature in Ver 2.0
→ Automatic process / workflow management

EIC User Group & ePIC Joint Collaboration Meeting - DAQ Experience 3: NestDAQ/SPADI - Jul. 15, 2025 - Nobu Kobayashi

23

- 2-part workfest at recent EIC UGM aimed at interfacing software stack to TB data

- Joint morning session w/ E&DAQ hosted talks on

- › Select DSC TB experience (BIC, LFHCal/EEEMCal)
- › Common DAQ frameworks

- 3 DAQ Frameworks discussed:

- **Martin Purschke (BNL)** discussed RCDAQ, highlighting its portability
- **Vardan Gyurjyan (JLab)** discussed CODA+ERSAP, highlighting its streaming capabilities
- **Nobuyuki Kobayashi (OU-RCNP)** discussed nestDAQ, highlighting its throughput & integration with 3rd-party software

- **Workfest goal:** prepare a demonstrator analysis chain going from data readout to final chain using our software ecosystem

- Important exercise for several reasons

- 1) We want to **support users at test beams**,
- 2) This helps us practice using our **software in real data taking**
- 3) And encourages users to start practicing with software

- The earlier we can start with these, the better!

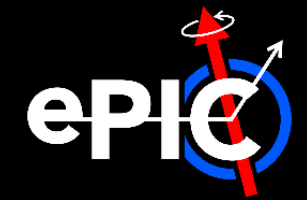
Discussion	Auditorium, Thomas Jefferson National Accelerator Facility	09:30 - 09:50
Coffee Break		
Overview of EIC Requirements and Tools	Derek Anderson	09:55 - 10:15
DAQ Experience 1: RCDAQ	Martin Purschke	10:15 - 10:45
DAQ Experience 2: CODA/ERSAP	Vardan Gyurjyan	10:45 - 11:00
DAQ Experience 3: nestDAQ/SPADI	Nobuyuki Kobayashi	11:00 - 11:15
Discussion	Auditorium, Thomas Jefferson National Accelerator Facility	11:15 - 11:30
Discussion	Auditorium, Thomas Jefferson National Accelerator Facility	11:30 - 12:00

July 16th, 2025

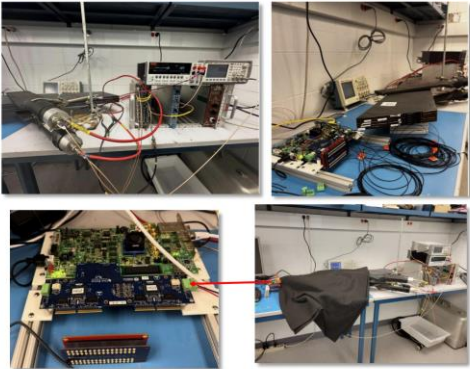
Software Interface to Readout, EIC UGM 2025

2

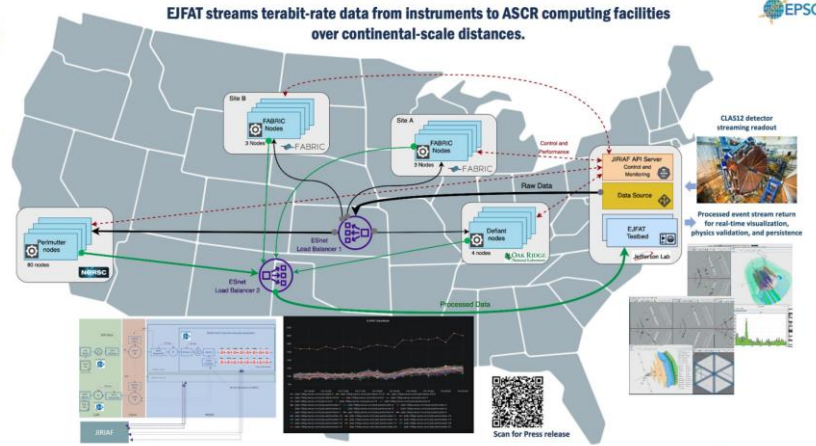
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Wednesday, July 16, 2025

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Introduction | Software to Readout Interface



NestDAQ

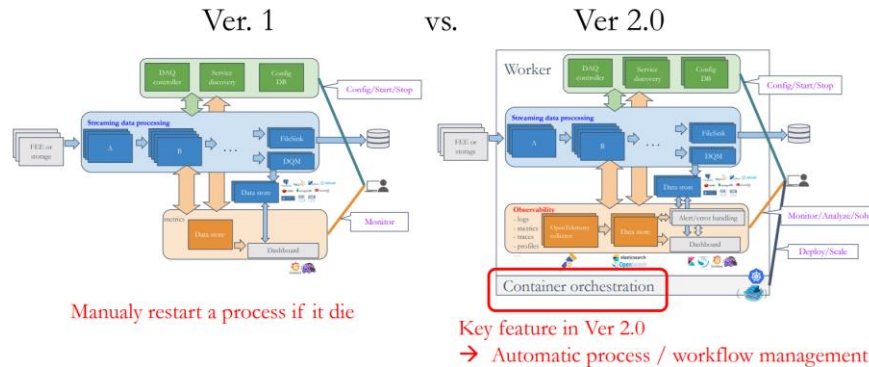
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July 16th, 2025

Software Interface to Readout, EIC UGM 2025

2



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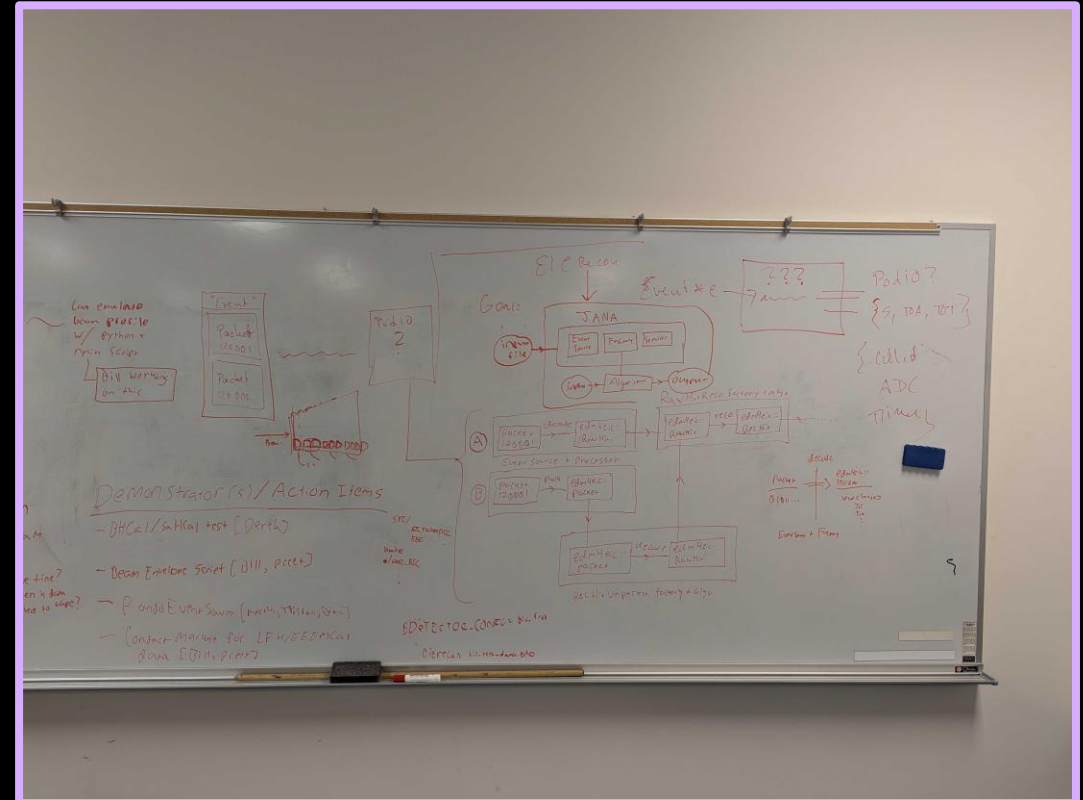
- 2-part workfest at recent EIC UGM aimed at interfacing software stack to TB data

– [Join morning session w/ E&DAQ](#) hosted talks on

- › Select DSC TB experience (BIC, LFHCal/EEEMCal)
- › Common DAQ frameworks

- Updates on all 3 today!

- RCDAQ: later this talk
- CODA+ERSAP: later this talk
- NestDAQ: following talk by Nobuo & Taku



- 6/22

EIC UGM Workfest | Hackathon Action Items

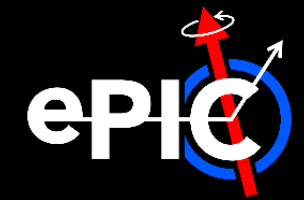
- **Right:** action items from workfest
 - Fall into a few categories
 - a) Data availability
 - b) Simulation
 - c) Infrastructure
 - d) Demonstrators for working with raw data
- **Note:** 2024 BIC TB good candidate for CODA example JEventSource/Processor
 - Also can build on work of 2023 streaming tests with ERSAP + JANA2
 - Will discuss more in Grand Challenge Dispatch section

Action items

- ✓ [Bill] Get LFHCAL/EEEMCal TB data in XrootD/Rucio [Bill]
- ✓ [Derek] Create channel to share TB code
- ✓ [Bill, Preet] Complete beam-envelope script for npsim
- 🖥️ Create example JEventSource/Processors for raw data
 - (Step 1) [Martin, Tristan] Create test code with random hits
 - (Step 2) [Martin, Tristan] Then expand code to process RCDAQ data
 - (Follow-up) [TBD] Exercise should be repeated for CODA and NestDAQ data
- 🖥️ [Derek] Finish standalone BHCAL (saHCAL) custom plugin demonstrator
- ✓ [Derek] Finish implementing HGCROC type

✓ = Done

🖥️ = In progress/To-do

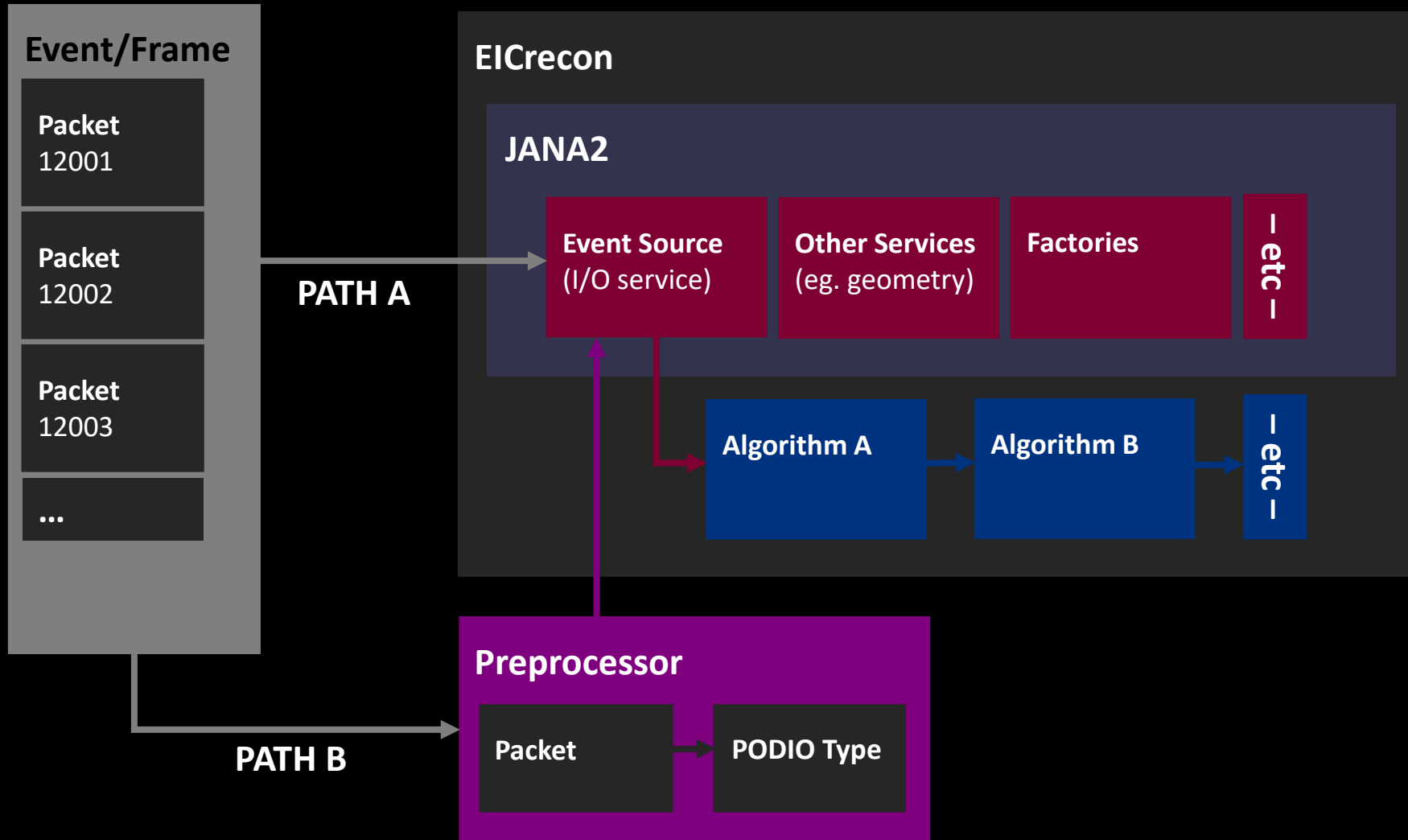


EIC UGM Workfest | Envelope Script and TB Snippets

- Bill Lee (MSU) and Preet Mann (SBU) have since completed their beam envelope script
 - Simulates beams received during tests via npsim
 - 👉 **Overview and tutorial later this meeting!**
- **To share TB-related code:** we now have a dedicated [Test Beam Snippets](#) repo!
 - Like snippets, no guarantee of code maintenance
 - But provides channel to stage and share code aimed at test beams, stands, benches, etc.

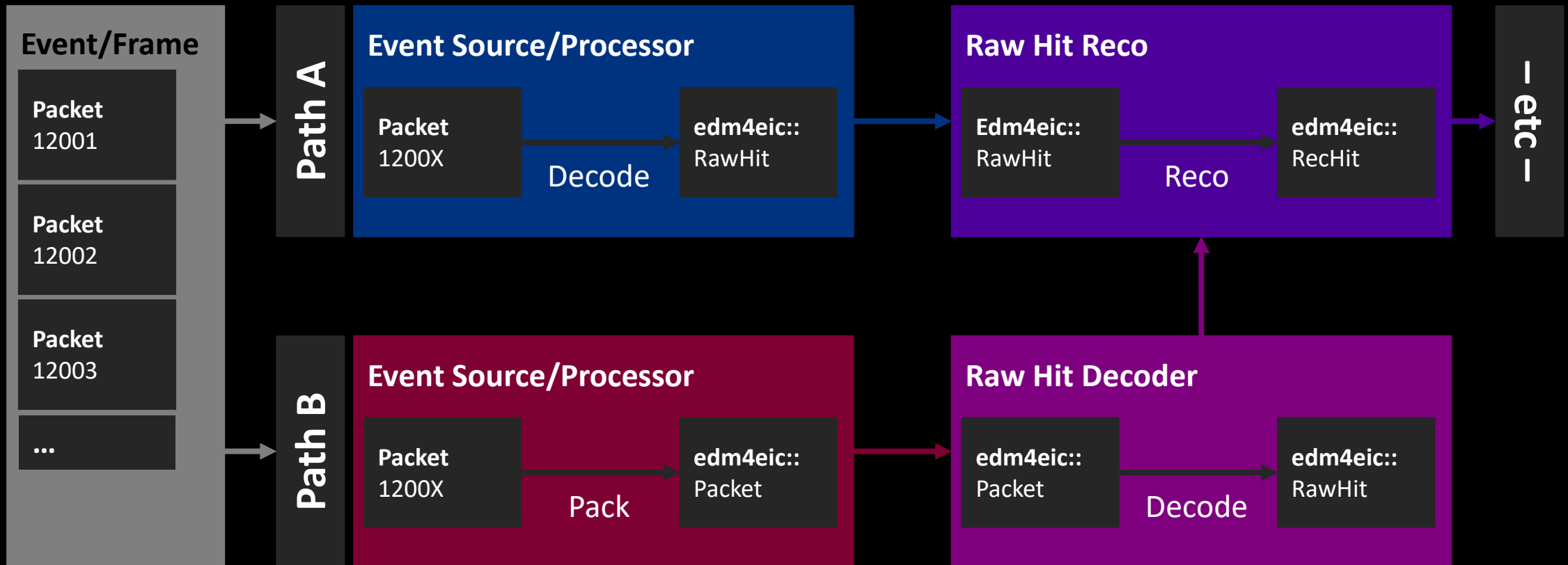
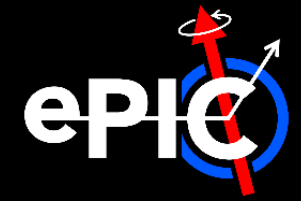
The screenshot shows the GitHub interface for the repository 'test-beam-snippets'. The repository is public and has 1 branch and 0 tags. It was created by user 'billlee77' and has 10 commits. The repository description is 'A repository to share code for EIC test beams'. The repository contains several files and directories: 'Beam/beam_envelope', 'Bench', 'Common', 'Setup', and 'README.md'. The 'README' file is selected and shows the title 'Test Beam Snippets' and a description: 'A repository to share code for Electron-Ion Collider (EIC) test beam, bench, setup, etc. analysis and operations. Note that this repository is intended solely to share useful code snippets, and any code committed here has no guarantee of maintenance.' The repository also has a 'commit activity' section showing 0 commits in the last month, and a 'code size' section showing 13.7 KiB. The repository is part of the 'EIC Github Organization' and has 2 forks and 0 stars.

Interfacing | EICrecon Input



- **Central question at hackathon:** how do we process real data with EICrecon? I.e.
 - a) How does data *arrive* at EICrecon (raw packets, PODIO types, etc.)?
 - b) And if it arrives raw, how do we unpack it?
- **Left:** 2 approaches to answer question (a)
 - Consensus in room was **Path B** is fine for TBs
 - But **Path A** necessary for actual data taking

Interfacing | Potential Algorithm Flows



Interfacing | TB Example: LFHCAL

- **Thought Experiment:** what would it take to process the 2024 LFHCAL TB data in EICrecon?
 - 1) Implement geometry in DD4hep**
 - In progress at [epic#881](#)
 - Crucial for simulations and **consistent geometry description**
 - 2) Prepare data for EICrecon processing either**
 - a) By creating a preprocessor (saHCal demonstrator), or
 - b) Implementing a custom JEventSource
 - 3) Create an EICrecon plugin to run desired algorithms**
 - Illustrated in saHCal demonstrator

Action items

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✓ = Done

🖥️ = In progress/To-do

HGCROC Data Model | Data Model and Changes

- **Critical for TB analyzers:**
can the data model accommodate your data?
 - Eg. most calos will readout w/ variant of CMS HGCROC, **the CALOROC**
 - Test HGCROCs already used in 2024 LHFAL/EEEMCal TBs
- But existent RawCalorimeterHit doesn't fully capture HGCROC output...
 - ∴ **Prepared 2 proposals for HGCROC implementation (right)**

```

268 +
269 + edm4eic::RawCALOROCHit:
270 +   Description: "Raw hit from a CALOROC/HGCROC chip"
271 +   Author: "D. Anderson, S. Joosten, N. Novitzky"
272 +   Members:
273 +     - uint32_t type           // Chip type, 0 - type 1A (readout in on
274 +     - uint64_t cellID        // Detector specific (geometrical) cell
275 +     - int32_t samplePhase    // Phase of samples in [# samples], for
276 +     - int32_t timeStamp      // [TDC counts]
277 +   VectorMembers:
278 +     - uint32_t amplitude     // If type == 0 - waveform amplitudes st
279 +     - int32_t timeOfArrival   // Calculated times of arrival, i.e. time
280 +     - int32_t timeOverThreshold // Calculated times over threshold, i.e.
281 +   ExtraCode:
282 +     declaration: "
283 +       bool isType1A() const {return getType() == 0;}\n
284 +       bool isType1B() const {return getType() == 1;}\n
285 +       /// If type == 1, retrieve the low gain readout (lower 16 bits) at a
286 +       uint16_t getLowGainAmplitude(const size_t sample) const {\n
287 +         assert(sample < getAmplitude().size());\n
288 +         return getAmplitude(sample) & 0xFFF;\n
289 +       }\n
290 +       /// If type == 1, retrieve the high gain readout (upper 16 bits) at a
291 +       uint16_t getHighGainAmplitude(const size_t sample) const {\n
292 +         assert(sample < getAmplitude().size());\n
293 +         return getAmplitude(sample) >> 16;\n
294 +       }\n
295 +     "
296 +
194 + ## An individual sample output by an HGCROC chip
195 + edm4eic::HGCROCSample:
196 +   Members:
197 +     - uint16_t ADC           // [ADC Counts], amplitude of signal duri
198 +     - uint16_t timeOfArrival // Time of arrival (TOA) [TDC counts], no
199 +     - uint16_t timeOverThreshold // Time over threshold (TOT) [TDC counts]
200 +     - bool TOTInProgress    // Flag which indicates if a TOT fired in
201 +     - bool TOTComplete      // Flag which indicates if a TOT calculat
202 +
203 +   datatypes:
204 +
205 +   edm4eic::Tensor:
206 +
207 +   @@ -265,6 +274,17 @@ datatypes:
274 +   ## =====
275 +   ## Calorimetry
276 +   ## =====
277 +
278 + edm4eic::RawHGCROCHit:
279 +   Description: "Raw hit from an HGCROC chip"
280 +   Author: "D. Anderson, S. Joosten, T. Protzman, N. Novitzky, D. Kalinkin"
281 +   Members:
282 +     - uint64_t cellID        // Detector specific (geometrical) cell
283 +     - int32_t samplePhase    // Phase of samples in [# samples], for
284 +     - int32_t timeStamp      // [TDC counts]
285 +   VectorMembers:
286 +     - edm4eic::HGCROCSample sample // ADC, Time of Arrival (TOA), and Time
287 +

```

HGCROC Data Model | Implementation and Digitization

- **EDM4eic#116 merged ahead of 2025.10.0 campaign**
 - edm4eic::RawHGCROCHit now available for use!
- This type valuable not only for TB analysis
 - ☞ **But also critical for development of more realistic digitization models**
- **Minho Kim (ANL)** now working on algorithm utilizing HGCROC type for digitization in the BIC
 - Algorithm will be penultimate stage in BIC digitization chain
 - ☞ **And will be applicable to all other calos using HGCROCs!**

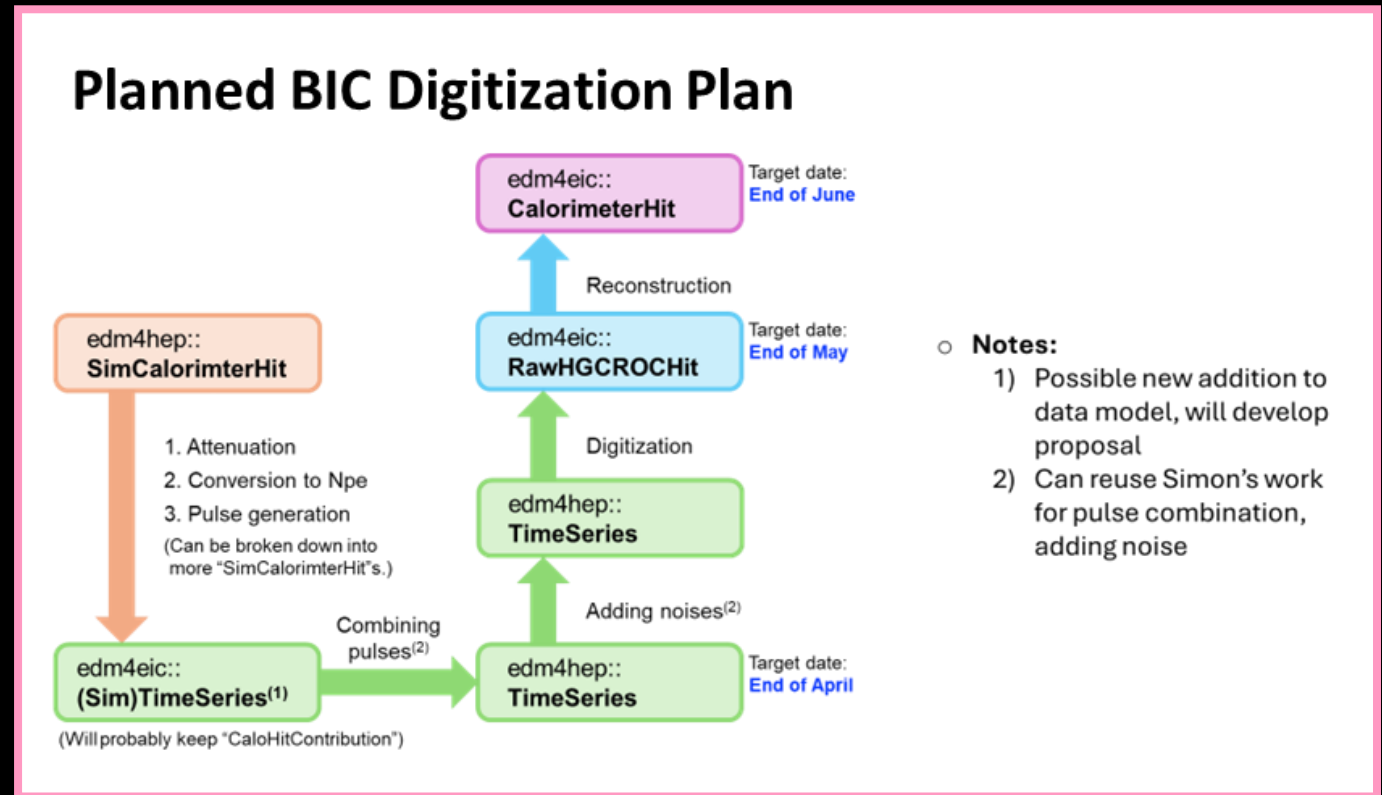
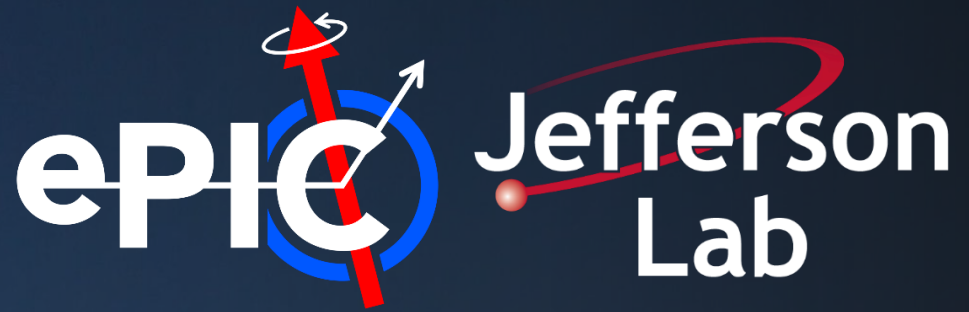


Figure: planned algorithm chain for simulation of BIC digitization. Work being driven by Minho Kim (ANL) and Simon Gardner (Glas)



JLab Streaming Grand Challenge Dispatch

Hanjie Liu (JLab), Raiqa Rasool (JLab)
David Lawrence (JLab), Dmitry Romanov (JLab)



Grand Challenge | Dispatch (1/3)

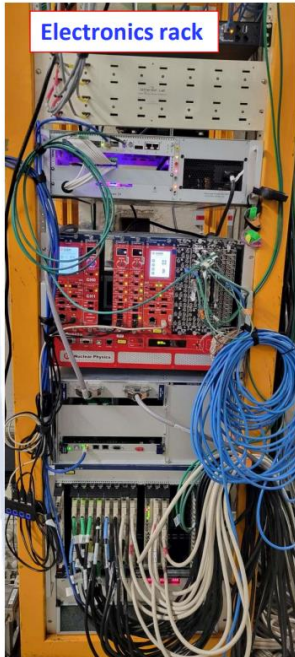


- **SRO Grand Challenge:** JLab initiative started in 2018 to develop a whole-detector approach to SRO pipeline
- Dmitry Romanov (JLab) prepared test using CODA+JANA2
 - For 2023 ML-FPGA TB at FNAL using uRWell TB stack
- ☞ **Should explore extending work to EICrecon!**

Slide by Sergey Furletov (JLab) and Dmitry Romanov (JLab)


Beam test at FermiLab

Jefferson Lab
Thomas Jefferson National Accelerator Facility



Electronics rack

- ❑ JANA2 has been tested to receive data from the DAQ and save it as evio and/or root files.
 - JANA2 also used for offline conversion and processing data.
- ❑ DAQ rates during spill :
 - Raw data rate: ~100 MB/s; Trigger: 1.5 kHz
 - Pulse mode data rate (SRS raw) : ~45 MB/s ; Trigger: 2.5 kHz
 - Data collected: 1.1 TB



Counting room working place: DAQ successfully worked in 2 modes : CODA and cDAQ

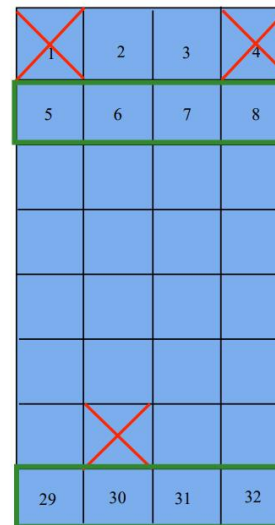
12/02/23 Sergey Furletov Workshop on Streaming readout XI 13

Grand Challenge | Dispatch (2/3)

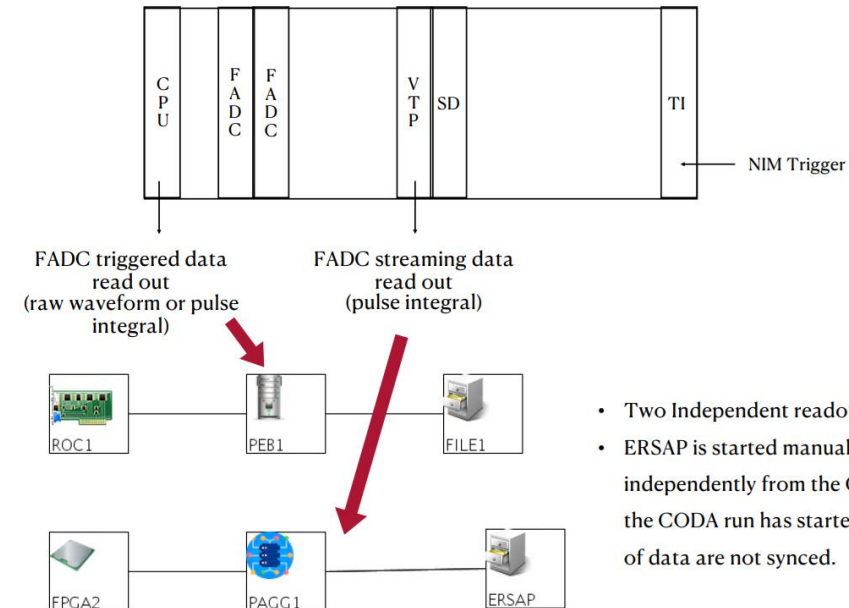
- Hanjie Liu (JLab) has set up and is analyzing a SRO test stand at JLab
 - 4x8 PMTs (3 bad)
 - Data read out by CODA, streaming w/ ERSAP
- **Data read out along 2 paths simultaneously**
 - a) 1 triggered,
 - b) 1 streamed w/ online software filter

Slide from
Hanjie Liu (JLab)

Work summary – Oct 13 2025



NIM trigger: (5 OR 6 OR 7 OR 8) AND (29 OR 30 OR 31 OR 32)



- Two Independent readout path per run
- ERSAP is started manually and independently from the CODA (after the CODA run has started) → two sets of data are not synced.

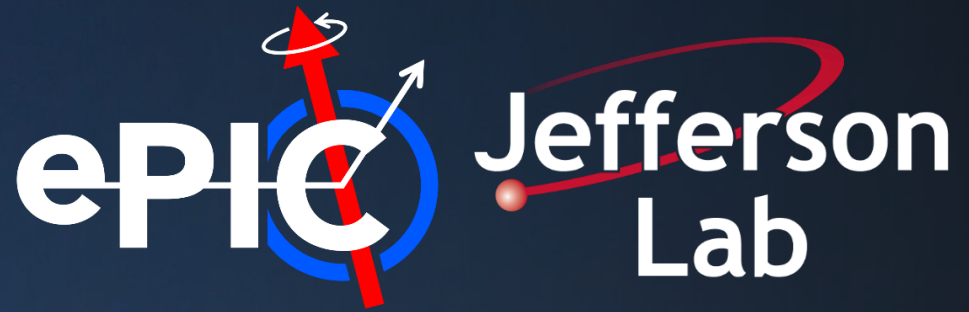
- Raiqa Rasool (JLab) profiling use of TTrees vs. RNTuples in JAPAN-MOLLER software
 - 👉 **RNTuples show improved CPU utilization, processing speeds**
- While not *directly* relevant to TBs, **this work is critical for future data-taking**

**Slide from
Raiqa Rasool (JLab)**

TTree vs RNTuple

Metric name	TTree	RNTuple
Total time	85 sec	30 sec
Time/event	4.25 ms	1.5 ms
Rate	235 Hz	667 Hz
CPU Utilization	90.9%	99.2 %
Total samples	85k	30K

Note: Data collected using 'perf record -F 999', i.e., 999 samples/second



Update on RCDAQ Integrations

Weibin Zhang (UCR), Xilin Liang (UCR),
Martin Purschke (BNL), Norbert Novitzky (ORNL),
Eric Mannel (BNL)



ePIC ZDC test beam at the BNL NSRL

Weibin Zhang, Xilin Liang, Martin, Norbert, Eric

The ePIC ZDC is a close sibling to the forward HCal insert (similar hardware)

23 Layers of absorber with 5x5 scintillator/SiPM readout

The NSRL is a paid-for by NASA with $\leq 2.5\text{GeV}$ p beams, and ions

Whenever there is beam, we can "play auxiliary beam dump" – completely opportunistic (and free). We actually received a warm welcome there!

We use the current H2GROC3, the ZCU105, and RCDAQ to read out as many channels as we can (5 layers = 125 of 144 max)

We have the setup in place but not seen actual beam yet – the target area is open this week for us to install

We can show you some cosmics...



Beam Dump



1

Slides from
Martin (BNL)

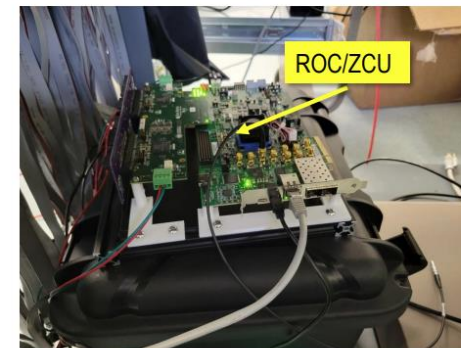
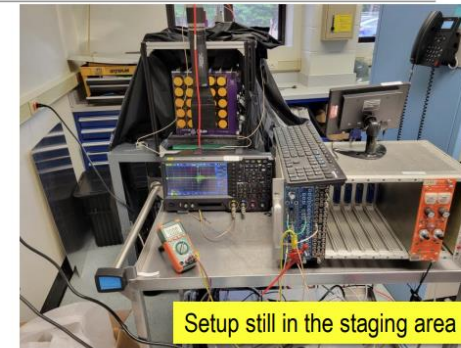
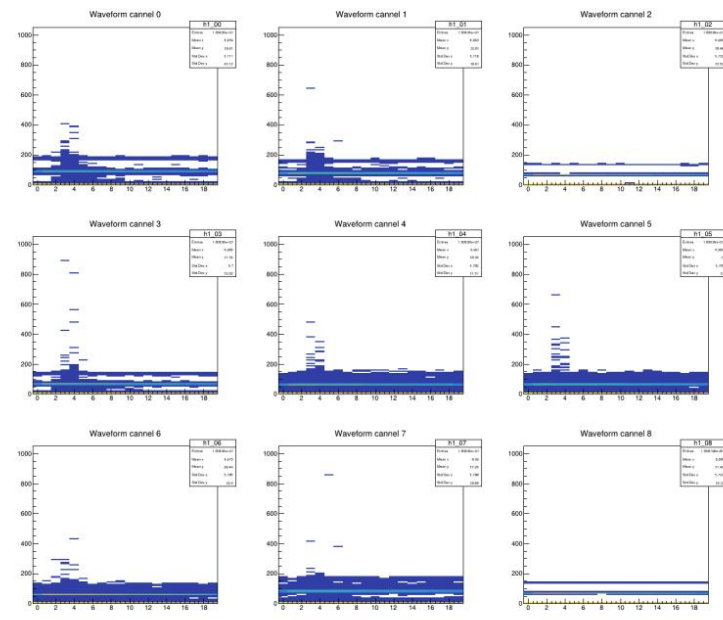
The setup

Pretty standard: 2 scintillator paddles to make a trigger, detector behind it

Same DAQ setup, online monitoring etc etc as from the BHCaI

As promised, some cosmes (more once we see beam)

Slides from
Martin (BNL)



Related work, and other test setups

1) Software integration

- Dmitry and Martin are working on the full test beam data
-> EICrecon integration, interrupted by actual tests...

2) We have 2 additional active test [not necessarily beam] setups that we support:

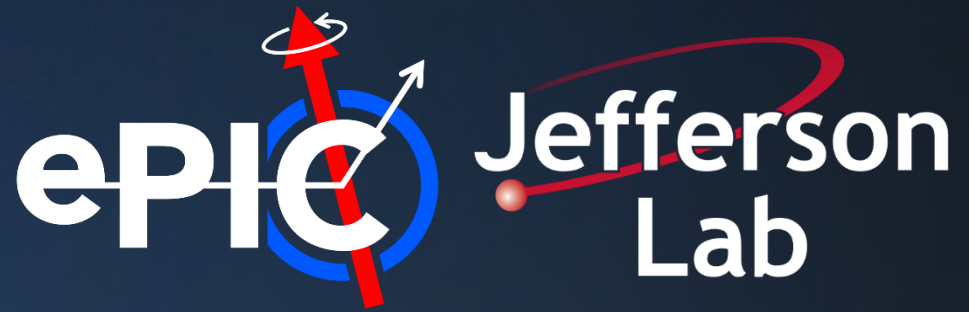
- pfRICH (Alexander's) HRPPD magnetic field test (not a test *beam* per se, but close in spirit)
- and the continuing tests we do with the BHCAL prototype.

More about the EICrecon status next time.



3

Slides from
Martin (BNL)



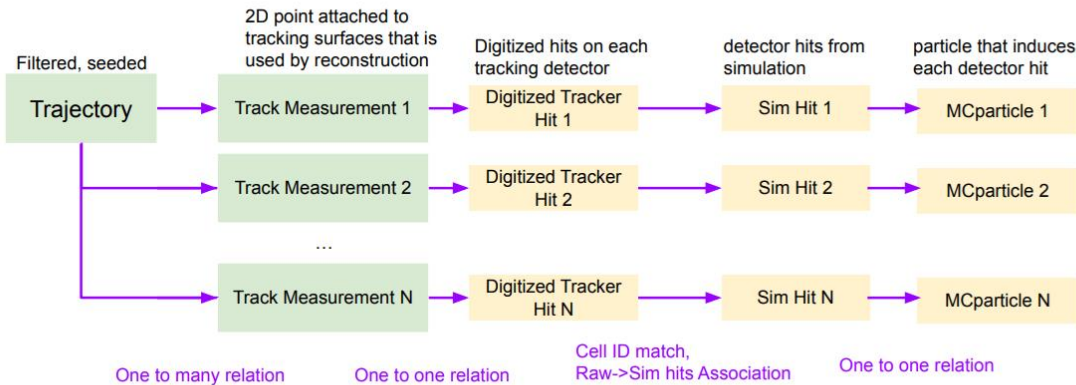
Thanks!



Backup | Studying Background Impact

Beam Background Impact at Track Level

- Match trajectory to simulated particles



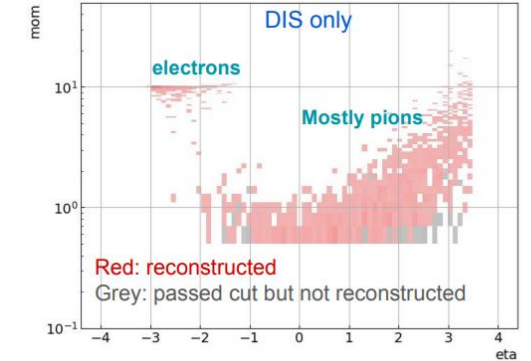
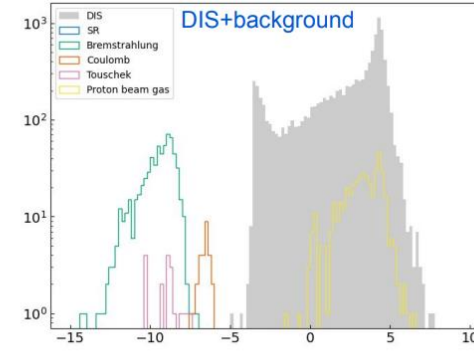
Efficiency: fraction of primary particles that are associated with tracks.
Purity: for a given track, fraction of hits from one particle.

20

Event sample inspection

- Basic particle selection:

- Primary (un)decayed particle:
 - generatorStatus==xxx1 or xxx2
 - Charged
 - Momentum > 0.5 GeV
 - 4 < eta < 4
 - Vertex.r < 1mm, abs(Vertex.z) < 100mm
 - Particle endpoint **outside** of a barrel with
 - 850 < z < 1000mm (4th endcap disk)
 - r < 270mm (L3 barrel)
- So that it has high chance to go through 4 layers



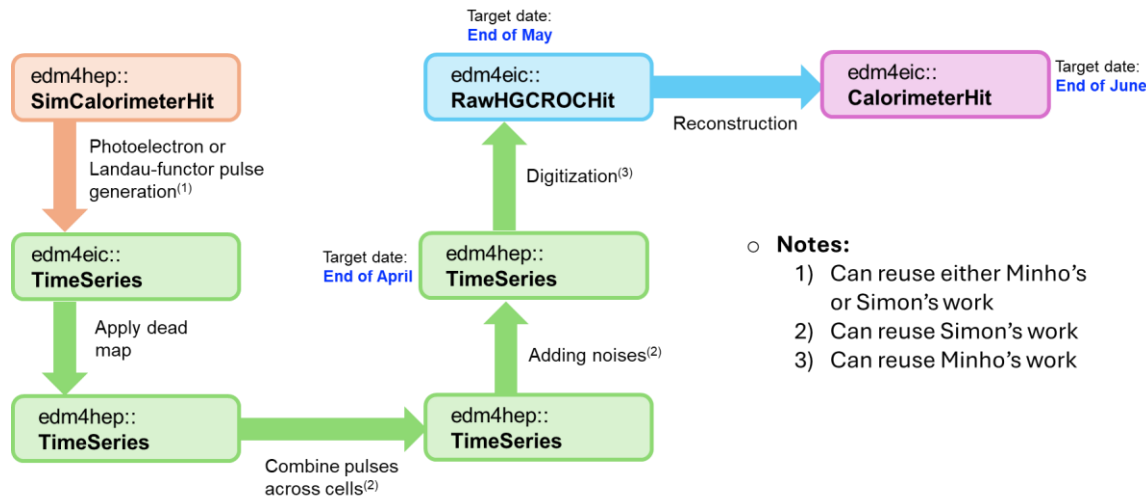
21

- Recent push: moving towards reconstruction + analysis in more realistic environments, incl. backgrounds
 - Studies of impact on tracking being led by Shujie Li (LBNL), Mito Funatsu (UCB), and more

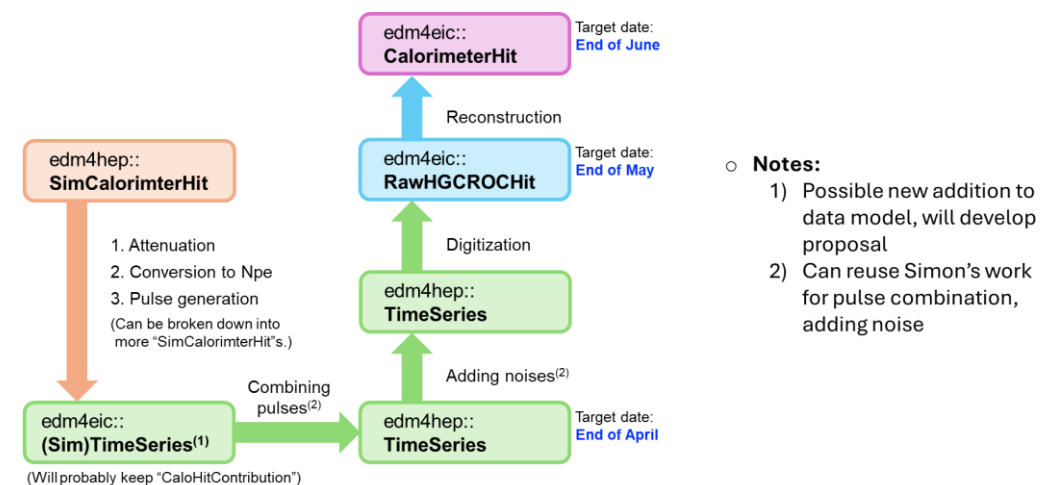
- Above: slides from Shujie's [EIC UGM talk](#) on tracking with backgrounds
 - Left: a slide illustrating relation of types in track reconstruction
 - Right: eta, momentum distributions of signal and background particles

Backup | Towards Realistic Digitization

Planned LFHCAL Digitization Model



Planned BIC Digitization Plan



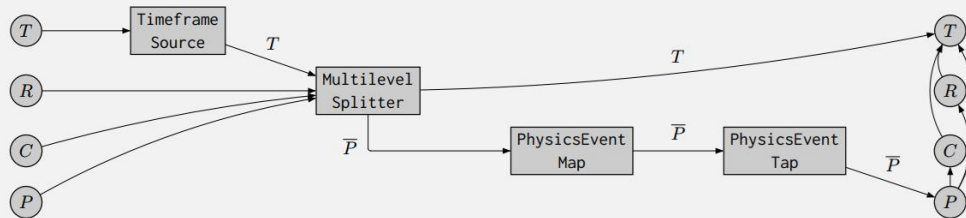
- Ongoing work to increase realism in simulation of digitization
 - **Above:** planned sequence of types/algorithms for digitization simulation in LFHCAL (left) and BIC (right)
 - LFHCAL sequence also applies to most other calos using HGCROCs
- Development being driven by **Minho Kim (ANL)** and **Simon Gardner (Glas)**

Backup | Towards SRO

Jefferson Lab

JANA2 Updates for Streaming Computing
Good news! We've already built a lot of this!

Timeframe sources with multilevel splitting



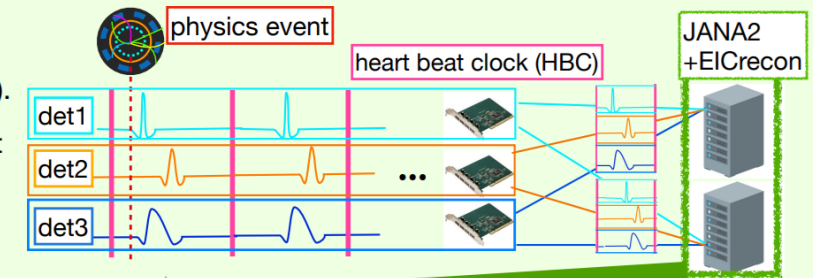
- Scenario: Begin-of-run and control events are bundled inside of timeframes
- Requires a multilevel unfold analogous to the multilevel source
- Splitter produces either $\bar{P} := P(T, R, C)$ or $\bar{P} := P(T, R(T), C(T))$ as needed

Nathan Brei (nbrei@jlab.org)

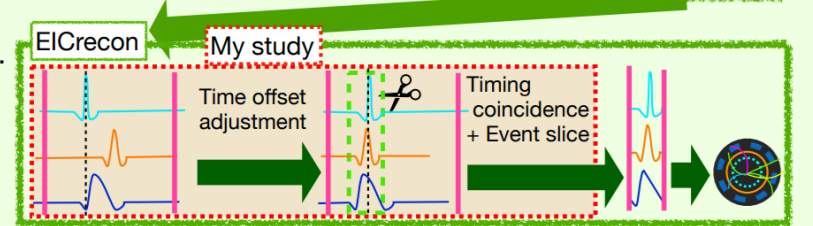
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Readout Data Flow

- The continuous signal is segmented by the Heart Beat Clock (common clock).
- The digital signals are sent to servers.
- Integrate all detector data.



- There are extraneous data.
- By building events, the data can be compact.



My study

Event extraction from streamed data and reconstruction into event data.

T.Kumaoka

2025/07/15 EICUG & ePIC Joint Meeting @ JLab

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- Significant development on EICrecon + JANA2 needed to process real & simulated streaming data
 - Nathan Brei (JLab) [talked at EIC UGM](#) about recent updates to JANA2 addressing use-cases encountered in SRO & data-taking
 - **Left:** schematic of EICrecon processing input timeframe stream with both begin-of-run and "control" events bundled in frames
- Critical algorithm for processing streamed data: the event builder
 - Takuya Kumaoka (UT-QNSI) gave [update at EIC UGM](#) on his work towards implementing an event builder
 - **Right:** illustration of the event builder

Backup | Data Model Notes

- **The Event Data Model (EDM):** how we represent our data (broadly speaking) in software
 - This [Wikipedia article](#) provides a nice summary
- **In ePIC software:** defined and managed by the [PODIO \(Plain-Old-Data I/O\) toolkit](#)
 - A single YAML file defines flat(ish) data types – eg. tracks, clusters, particles, etc. – and how they relate to each other
 - **Right:** the [edm4eic::track](#) as an example
 - PODIO auto-generates necessary c++ code to implement types
- **Critical piece of our software stack!**
 - Defines both the types themselves and the *flow* of data
 - Ie. what is the sequence of algorithms we run during reconstruction

```

453 edm4eic::Track:
454   Description: "Track information at the vertex"
455   Author: "S. Joosten, J. Osborn"
456   Members:
457     - int32_t          type                // Flag that defines the type of track
458     - edm4hep::Vector3f position          // Track 3-position at the vertex
459     - edm4hep::Vector3f momentum          // Track 3-momentum at the vertex [GeV]
460     - edm4eic::Cov6f   positionMomentumCovariance // Covariance matrix in basis [x,y,z,px,py,pz]
461     - float            time                // Track time at the vertex [ns]
462     - float            timeError           // Error on the track vertex time
463     - float            charge              // Particle charge
464     - float            chi2                // Total chi2
465     - uint32_t          ndf                 // Number of degrees of freedom
466     - int32_t           pdg                 // PDG particle ID hypothesis
467   OneToOneRelations:
468     - edm4eic::Trajectory trajectory       // Trajectory of this track
469   OneToManyRelations:
470     - edm4eic::Measurement2D measurements // Measurements that were used for this track
471     - edm4eic::Track      tracks           // Tracks (segments) that have been combined to create this track
472

```