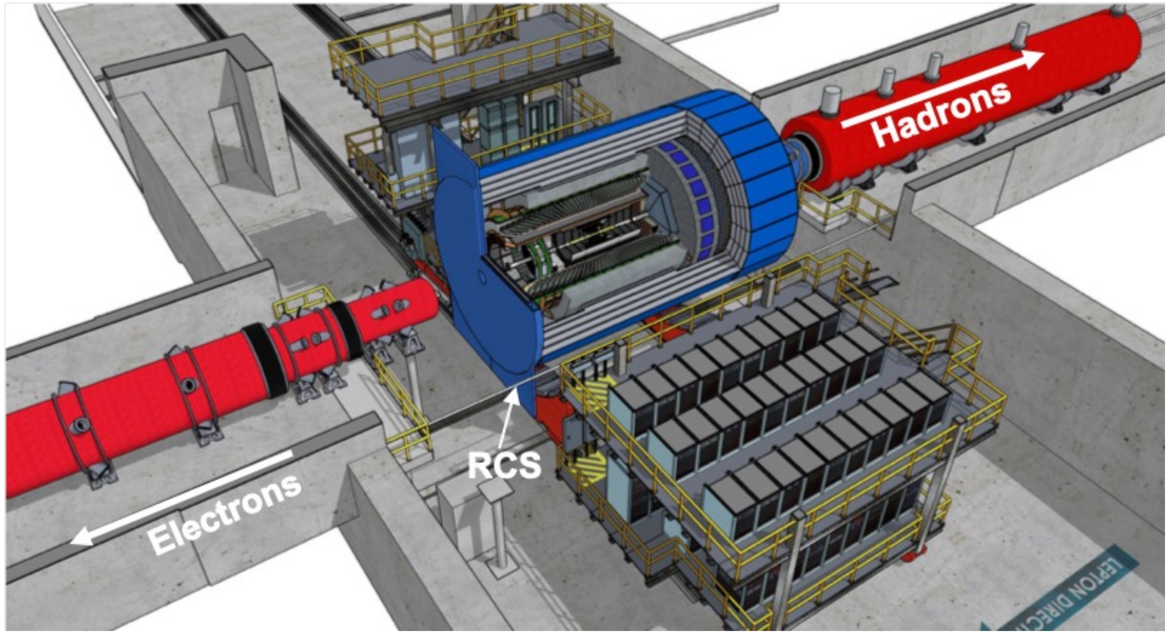
ePIC Software & Computing Report

Markus Diefenthaler (Jefferson Lab) for the ePIC Collaboration

Role of Software & Computing



"Software is the soul of the detector"
(Ian Shipsey, University of Oxford)

Great software for great science:

- **Design and Construction:** Simulations are essential for evaluating performance and determining physics reach.
- **Operation:** Autonomous experimentation and control using software/AI. Prompt processing of data.
- **Research:** Software enables discovery.

- We **work together**, on a global scale and with other fields, on great software for great science.

- We focus on **modern scientific software & computing practices** to ensure the **long-term success of the EIC scientific program** throughout all CD milestones.

ePIC Software & Computing Review (October 20–22, 2023)

[Agenda | Report]

- Convened by and reporting to the host labs: Haiyan Gao (BNL) and David Dean (Jefferson Lab).
- **EIC Computing and Software Advisory Panel (ESCAC)**: Frank Wuerthwein (chair, UCSD), Mohammad Al-Turany (GSI), David Brown (LBNL), Simone Campana (CERN), Pere Mato (CERN), Christoph Paus (MIT), Heidi Schellman (OSU).

- **Five charge questions** posed in the context of being 10 years away from data:

Charge question	**Review Outcome**:
Is there a comprehensive and cost effective long term S&C plan? **ECSAC Recommendations:** • We recommend that ECSJI verify the readiness of simulation and reconstruction for the TDR by May 2024. • We recommend that ePIC document a first computing needs assessment by the next ECSAC review, in roughly one year.	Yes.
Are there adequate plans for integrating international partners?	Yes.
Are S&C plans integrated with HEP/NP community developments? **ECSAC Recommendation:** • We recommend that the ePIC collaboration starts, by the time of next year's ECSAC review, an evolving list of software dependencies that includes: the packages, who the primary supporters are, and what the ePIC collaboration contributes to them.	Yes.
Are there sufficient S&C resources to deliver the TDR?	Yes.
Do BNL/JLab joint institute plans integrate sufficiently with experiment S&C?	Yes.

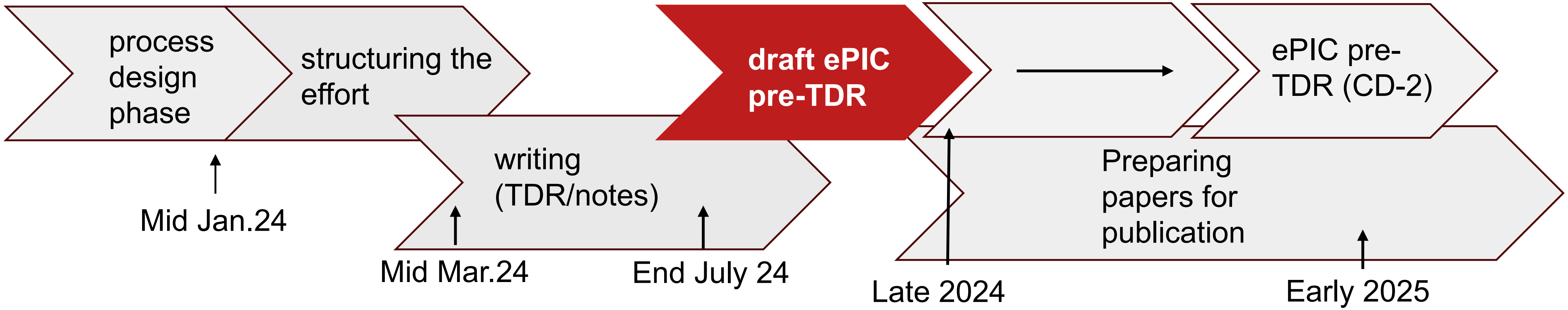
Priorities

Technical Design Report

Collaboration Engagement

Computing Model

TDR Strategy and Publications



- ePIC Software & Computing is essential to the TDR, providing **advanced software** and **simulation productions** that are the **input for detector and physics studies**:
  - ***"Software and Simulation Readiness for TDR"*** parallel session and plenary discussion at the ANL collaboration meeting, where we extensively defined the remaining development tasks, drawing on significant input from the collaboration at large.
  - Good progress since collaboration meeting, improving the accuracy of the simulations and building up the reconstruction in shared priorities with DSCs and the PWGs.

- A **publication** on the *"**ePIC Streaming Computing Model**"* is planned for CSBS, based on the existing report.

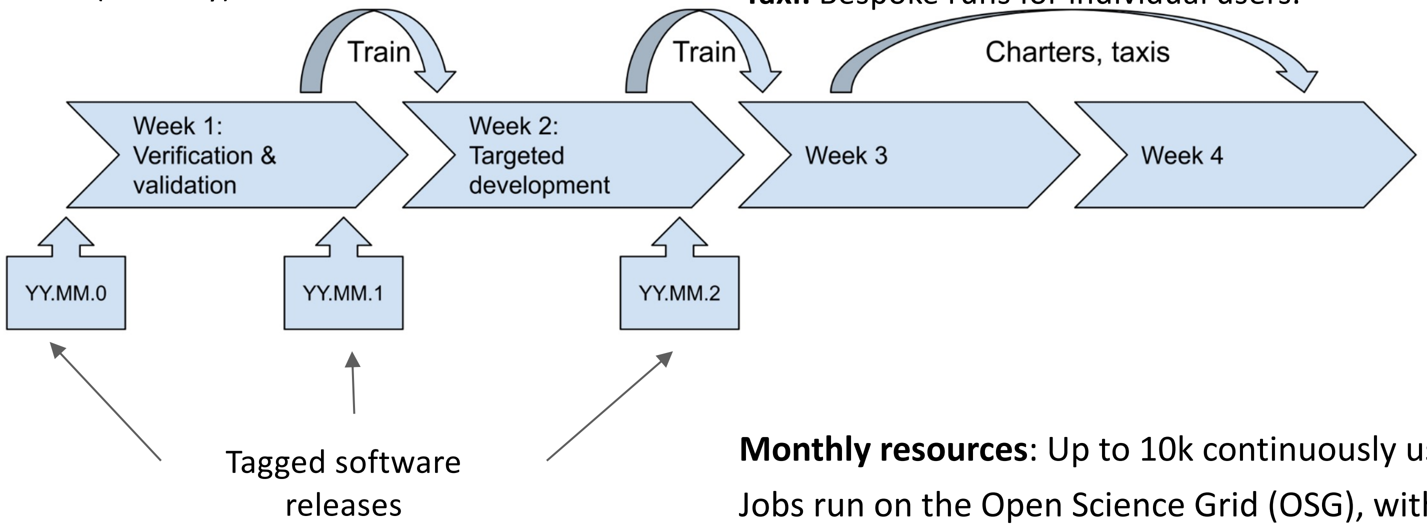
Monthly Simulation Productions

1. **Continuous deployment** of the software used for detector and physics simulations.
2. **Regular updates** of simulation productions for detector and physics studies in preparation for the TDR (and subsequent CD milestones).
3. **Timely validation and quality control** for simulation productions on datasets that require substantial time and resources. Focus on **benchmarks driven by Continuous Integration** (CI), a process that automates the testing and building of software.

Train: Major central campaign at a fixed (monthly) schedule.

Charter: Special interest runs for working groups.

Taxi: Bespoke runs for individual users.



Broad science program for the EIC: The selection of physics processes and associated Monte Carlo simulations for the TDR has been finalized with the Physics Working Groups.

Monthly resources: Up to 10k continuously used cores (about 500 core-years).

Jobs run on the Open Science Grid (OSG), with output stored on host labs.

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Onboarding

Landing Page for Onboarding New Users:

- This page includes a continuously updated and improved list of **useful links**, **software tutorials**, and **frequently asked questions**.
- Any member of the collaboration can **directly contribute by submitting change requests**.

Landing Page

Get started

ePIC Tutorials

HEP Software Training Center

FAQ

Welcome to the **ePIC Landing Page**!

Our mailing list: eic-projdet-compsw-l@lists.bnl.gov

Subscribe here: https://lists.bnl.gov/mailman/listinfo/eic-projdet-compsw-l

Community Building

Regular meetings to drive forward priority targets and provide an avenue for new collaboration members to engage.

12 pages of detailed notes that enabled software progress, pushed the review preparations, and informed our planning.

Discussed: Status and plans; software and simulations for TDR, tutorials; streaming computing; software projects with HEP.

User Learning

Software tutorial series, most recent during CERN meeting, covering four key topics:

1. **Overview of ePIC Software** (Holly Szumila-Vance, Jefferson Lab)

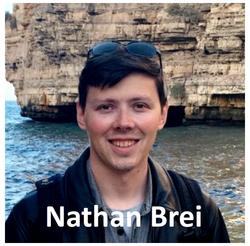
   Eic-shell Easy to get started locally… in only 1 line!

   ```
   curl -L get.epic-eic.org | bash
   ```

   Based on container images, the same images are used for simulation campaigns.

2. **Working with Simulation Output** (Stephen Kay, University of York)
3. **Simulating Detectors and Their Readout** (Simon Gardner, University of Glasgow)
4. **Reconstruction Algorithms** (Nathan Brei, Jefferson Lab)

45 participants from Africa, Asia, and Europe.



Priorities

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Computing Model

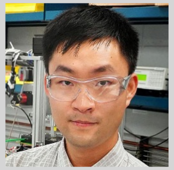
Streaming Computing Model WG

- Works in synergy with Electronics and DAQ WG.
- Defined requirements and high-level design for a **computing model** that enables **rapid data processing for physics analyses**:
  - Built on streaming readout developments at Jefferson Lab and BNL.
  - Synergies with SPADI-Alliance in Japan for streaming readout developments.
  - Streaming Readout XII or XIII workshop will be hosted in Japan.
  - Synergies with developments in real-time processing at CERN.

- Started documenting the ePIC Streaming Computing Model that can be redefined further with international partners.
  - **Successful review** by EIC Computing and Software Advisory Committee in October 2023.
  - **Review finding**: *"The ePIC collaboration is doing all the right things to make progress towards exploiting in-kind contributions to Computing & Software for ePIC."*

Streaming Computing Model WG Conveners

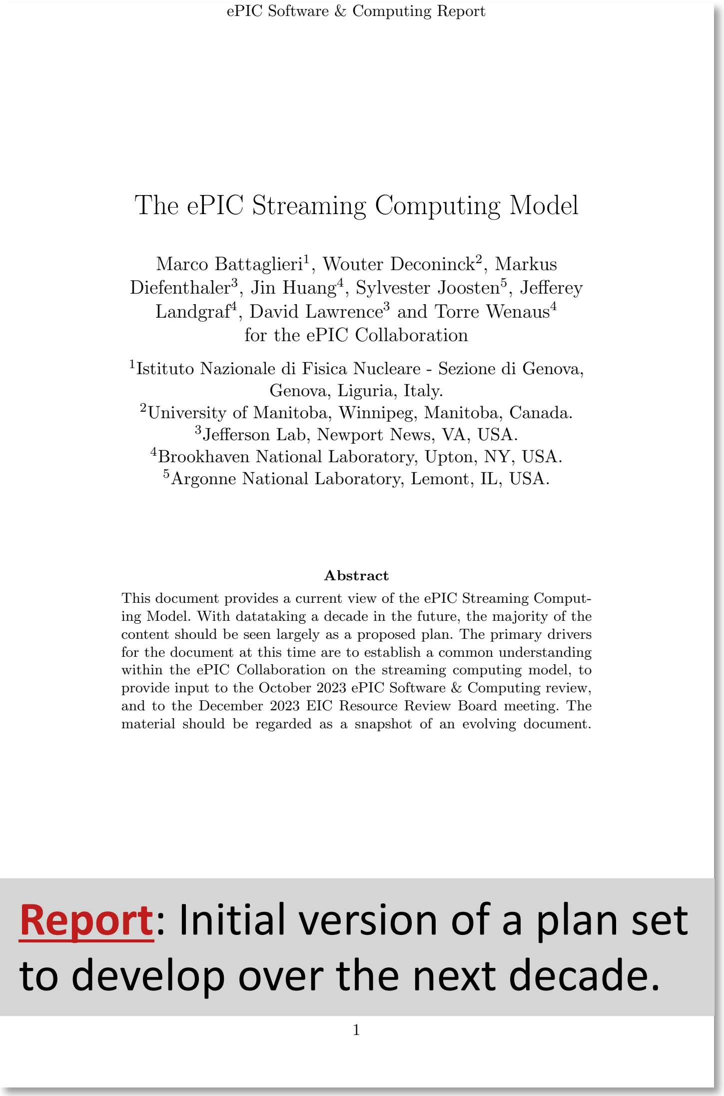
Marco Battaglieri (INFN Genova)



Jin Huang (BNL)

Jeff Landgraf (BNL)

ePIC Streaming Computing Model



ePIC Software & Computing Report

The ePIC Streaming Computing Model

Marco Battaglieri[1], Wouter Deconinck[2], Markus Diefenthaler[3], Jin Huang[4], Sylvester Joosten[5], Jeferey Landgraf[4], David Lawrence[3] and Torre Wenaus[4] for the ePIC Collaboration

[1]Istituto Nazionale di Fisica Nucleare - Sezione di Genova, Genova, Liguria, Italy.
[2]University of Manitoba, Winnipeg, Manitoba, Canada.
[3]Jefferson Lab, Newport News, VA, USA.
[4]Brookhaven National Laboratory, Upton, NY, USA.
[5]Argonne National Laboratory, Lemont, IL, USA.

Abstract

This document provides a current view of the ePIC Streaming Computing Model. With datataking a decade in the future, the majority of the content should be seen largely as a proposed plan. The primary drivers for the document at this time are to establish a common understanding within the ePIC Collaboration on the streaming computing model, to provide input to the October 2023 ePIC Software & Computing review, and to the December 2023 EIC Resource Review Board meeting. The material should be regarded as a snapshot of an evolving document.

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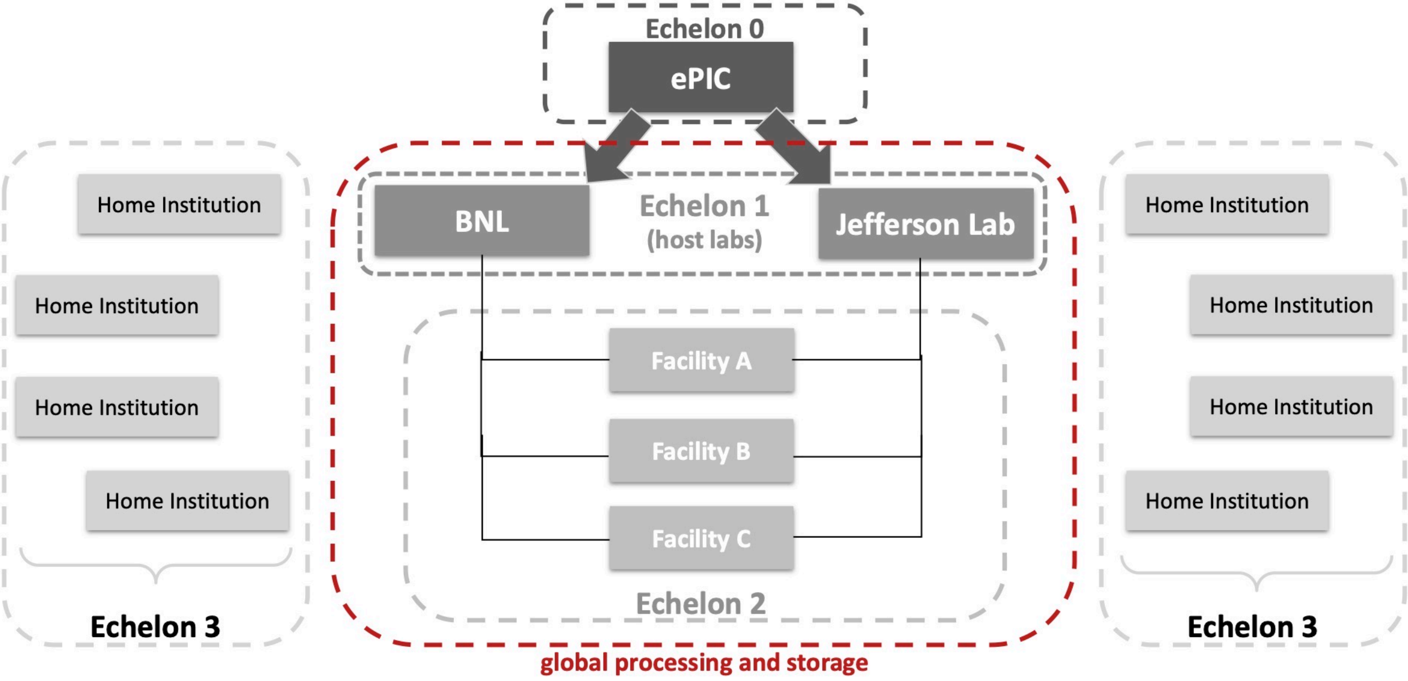
Report: Initial version of a plan set to develop over the next decade.



Echelon 0: ePIC experiment.

Echelon 1: Crucial and innovative partnership between host labs.

Echelon 2: Essential global contributions.

Echelon 3: Full support of the analysis community.

Compute-Detector Integration to Accelerate Science

- **Problem** Data for physics analyses and the resulting publications available after O(1year) due to:
  - Complexity of NP experiments and their organization.
  - Time-consuming detector alignment and calibration as well as reconstruction and data validation.
- **Goal** **Rapid turnaround of 2-3 weeks for data for physics analyses**.

- **Solution** Compute-detector integration using:

Streaming readout for continuous data flow of the full detector information.	**AI** for autonomous alignment and calibration as well as reconstruction and validation for rapid processing.	**Heterogeneous computing** for acceleration.

Alignment and Calibration of the ePIC Detector

- **Timeline for a rapid turnaround of data** for physics analyses, **driven by detector alignment and calibrations:**

			Steady State calibrations: aim to produce final reconstruction-ready calibration within few days of physics data taking in a continous process																
Subsystem	Region	Pre-physics-operation calibrations (Cosmic, no-beam calibration, commissioning)	Task	Human intervent ion?	Data Needed	Dependecy	T0 + 12	T0 + 24	T0 + 36	T0 + 48	T0 + 60	T0 + 72	T0 + 84	T0 + 96	Monitori ng	Computi ng resourc e	Post-reconstruction calibrations (applied at analysis stages)	Comment	Subsystem
MAPS	Barrel+Disk	Threshold Scan Fake rate scan/noisy pixel masking	(See Alignment)															SRO meeting: https://indico.bnl.gov/ever Threshold Scan require substaintial DAC	MAPS
MPGD	Barrel+Disk	?	?															TIC meeting: https://indico.bnl.gov/event	MPGD
bTOF, eTOF (ac-	Barrel/Forw	Bias voltage determination ASIC baseline, noise, threshold Clock sync Time walk calibration	Gain calibration TDC bin width determination Clock offset calibration Hit position dependency (intrinsic and c-by-c)	QA	High p tracks ~1hr of production data?	Tracking, pfRICH	Data Ac Depend	Depend	Process	Processing								SRO meeting https://indico.bnl.gov/even	bTOF, eTOF (ac-lgad)
Central Detector Tracker Ali		Initial alignment	Alignment Check/Update (if needed)	QA	Prodcution data		Processing											SRO meeting https://indico.bnl.gov/even	Central Detector Tracker
pfRICH	Backward	Thresholds (noise dependent), dynamic range adjustments, timing offsets, synchronization Initial alignment	Alignment Check/Update (if needed) Time dependencies (Aerogel transparency, mirror reflectivity, Gas pressure)	?	Prodcution data		Data Ac	Processing										TIC meeting: https://indico.bnl.gov/event	pfRICH
DIRC	Barrel	Laser data?	?	?														TIC meeting: https://indico.bnl.gov/event	DIRC
dRICH	Forward	Bunch timing offset scan Threshold scan Noise masking	Track based alignment	?	High p tracks ~1hr of of production data?	Tracking	Data Ac Depend	Process	Processing									SRO meeting: https://indico.bnl.gov/ever	dRICH
bEMC	Backward	Cosmic and LED for the initial gain balancing	DIS Electron Pi0->gg events energy scale	QA	DIS electron Pi0 di-photon resonance ~1 day of production data	Tracking	Data Ac Depend	Data Ac	Process	Processing					LED			SRO meeting: https://indico.bnl.gov/ever Carlos: aiming 1% precision Planning for LED flash during productior	bEMC
AstroPix	Barrel																	TIC meeting: https://indico.bnl.gov/event	AstroPix
ScifiPb	Barrel		SiPM gain		?													TIC meeting: https://indico.bnl.gov/event	ScifiPb
fEMC	Forward	IV Scan	Pi0, eta->gg events energy scale	QA	Pi0 di-photon resonance ~1 day of production data		Data Ac	Data Ac	Process	Processing					LED		High energy cluster non-linearity	SRO meeting: https://indico.bnl.gov/ever Need pi0 filtered data for automated cali AI driven calibration?	fEMC
			Second iteration pi0 (if needed)								Processing								
bHCAL	Backward	LED	?															TIC meeting: https://indico.bnl.gov/event	bHCAL
cHCAL	Barrel	MIP calibration Gain calibration	(See hadronic e-scale calib)															SRO meeting: https://indico.bnl.gov/ever	cHCAL
fHCAL	Forward																		fHCAL
fHCAL insert	Forward																		fHCAL insert
Hadronic energy scale calib		?	Set full calo stack energy scale for hadroinc shower and jets	?	High energy hadronic showers and jets	Tracking h-PID	Data Ac Depend	Data Ac Depend	Data Ac Depend	?	?	?	?	?			Final energy scale calibration (if needed)	Comments from Oleg during SRO meeti	Hadronic energy scale ca
low Q2 Tagger	Far Backwa	Alignment?																TIC meeting: https://indico.bnl.gov/event	low Q2 Tagger
low Q2 Tagger ((	Far Backwa																	TIC meeting: https://indico.bnl.gov/event	low Q2 Tagger (CAL)
Pair Spec Tracke	Far Backwa																	TIC meeting: https://indico.bnl.gov/event	Pair Spec Tracker
Par Spec Cal	Far Backwa																	TIC meeting: https://indico.bnl.gov/event	Par Spec Cal
Direct Photon C	Far Backwa																	TIC meeting: https://indico.bnl.gov/event	Direct Photon Cal
B0 Tracking	Far Forwar	Survey alignment/Cosmic	Alignment check		MIP		Processing											SRO/FF meeting https://indico.bnl.gov/e	B0 Tracking
B0 PbWO4	Far Forwar	Survey alignment/Cosmic	SiPM gain		MIP/Gamma/Electrons		Processing								LED			SRO/FF meeting https://indico.bnl.gov/e	B0 PbWO4
Roman (Pots)	Far Forwar	laser/survey alignment Low lumi running	beam position monitors/fill by fill correction		MIP rate distribution in RP	Acc. BPM Potential use of vertex of central detector	Data Ac Depend	Processing										SRO/FF meeting https://indico.bnl.gov/e	Roman (Pots)
Off Momentum	Far Forwar						Data Ac Depend	Processing										SRO/FF meeting https://indico.bnl.gov/e	Off Momentum
ZDC PbWO4	Far Forwar	Survey alignment, timing delay	SiPM/APD gain, timing	QA	Photon		Processing								LED			SRO/FF meeting https://indico.bnl.gov/e	ZDC PbWO4
ZDC Sampling	Far Forwar	Survey alignment, timing delay	SiPM gain	QA	Single neutron		Processing								LED			SRO/FF meeting https://indico.bnl.gov/e	ZDC Sampling

Spreadsheet

Detailed discussion of alignment and calibration workflows at ePIC indicates that a **2-3 week timeline is feasible**; critical for further development of computing model.

Use Cases

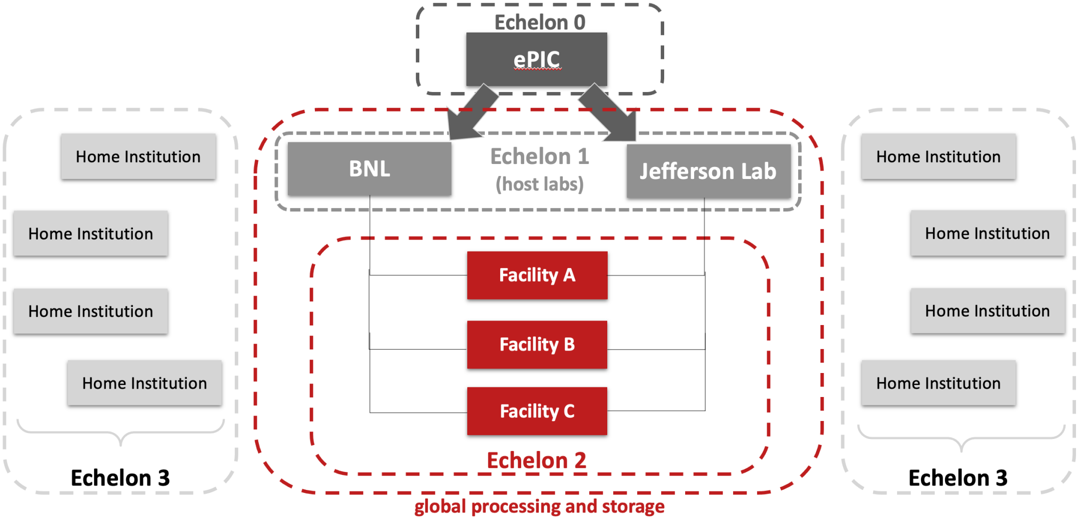
Echelon 0: ePIC Experiment
Echelon 1: Host Labs
Echelon 2: Global Processing and Data Facilities
Echelon 3: Home Institute Computing

Use Case	Echelon 0	Echelon 1	Echelon 2	Echelon 3
Streaming Data Storage and Monitoring	✓	✓		
Alignment and Calibration		✓	✓	
Prompt Reconstruction		✓		
First Full Reconstruction		✓	✓	
Reprocessing		✓	✓	
Simulation		✓	✓	
Physics Analysis		✓	✓	✓
AI Modeling and Digital Twin		✓	✓	

Echelon 2: Global ePIC Computing

ePIC is an international collaboration and so is its computing:

- **Echelon 2** includes **global resources contributed by collaborating institutions**.
- Achieving scientific goals relies on effectively using Echelon 2 resources.
- Design of computing model aims for **effective integration and management**.
- EIC RRB will oversee the compute resources for the EIC.
- Representatives from ePIC and international partners will manage the **EIC International Computing Organization** (EICO) under the leadership of the EIC Computing and Software Joint Institute (ECSJI).



In-kind computing infrastructure contributions:

- **From the review**: *"There are clearly very significant opportunities in in-kind computing infrastructure contributions."*
- Canada, Italy, and United Kingdom engaged as a proof of concept in this context:
  - Integration of resources from international partners into simulation campaigns.

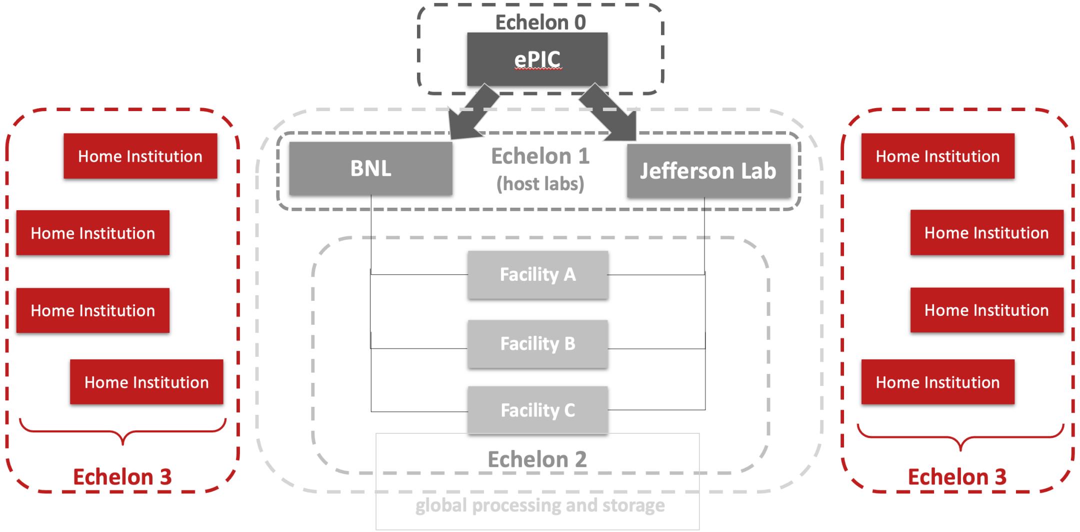
Digital Research Alliance of Canada | Alliance de recherche numérique du Canada

INFN

UKRI Science and Technology Facilities Council

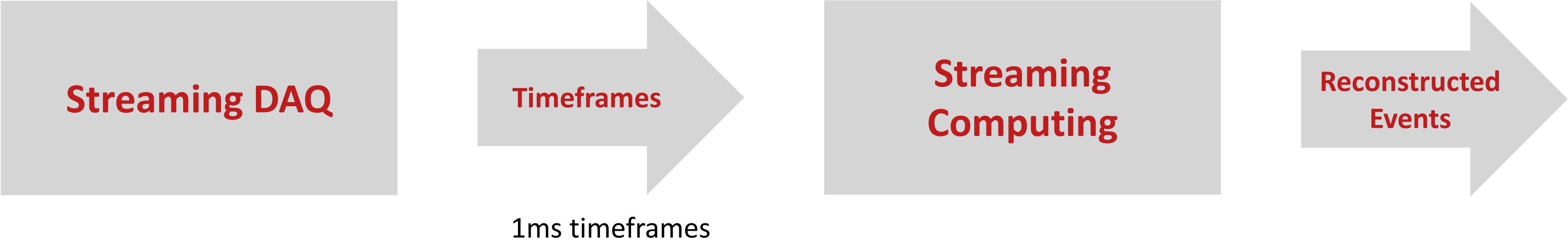
Echelon 3: Home Institute Computing

- **Echelon 3**: Component in the computing model where collaborators directly interact with the computing system:
  - Users can access ePIC Computing through various platforms like institutional clusters, work desktops, and personal laptops.
  - The role of Echelon 3 is to serve these diverse use cases.
- **Echelon 3 Resources**:
  - Both global and local to the user, similar to Echelon 2.
  - Numerous, diverse, volatile, and often have restrictions on their use.
  - Not intended to be managed as collaboration resources.
- The collaboration will provide tools, interfaces, connection points, data access mechanisms, and support to make Echelon 3 resources effective for ePIC analysis.



Priority Target for the TDR

Prototype of event reconstruction from realistic frames:



Purpose: Demonstrate that we can reconstruct events from Streaming DAQ.

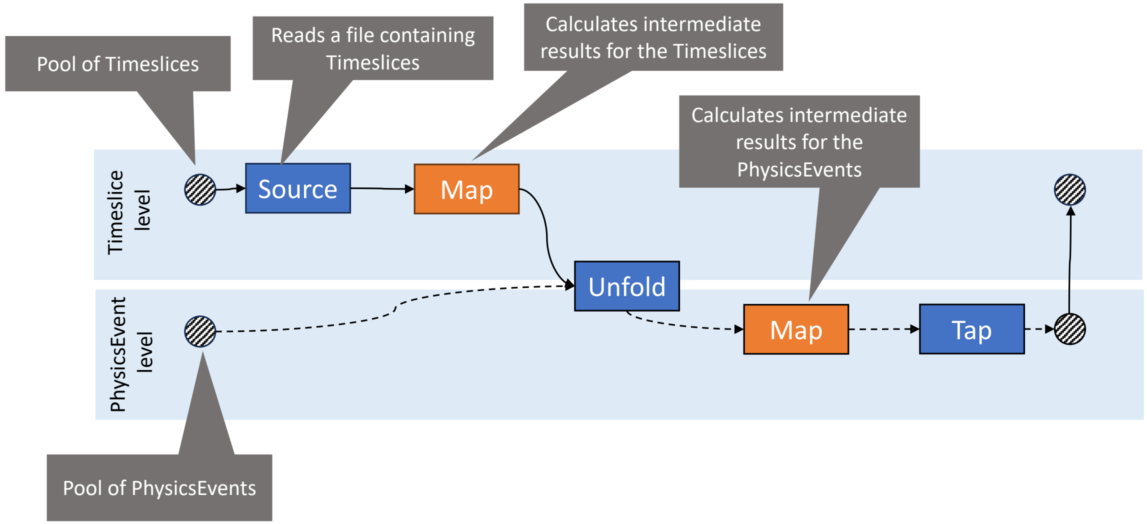
Purpose: Estimation of streaming reconstruction time for compute resource planning.

- **Follows up on ECSAC recommendation**: *"We recommend that ePIC document a first computing needs assessment by the next ECSAC review, in roughly one year."*
- We understand the event rates and data sizes but **require** a **reliable estimate for streaming data processing, a unique aspect of the ePIC experiment**.

Prototype of Event Reconstruction from Realistic Frames

Key Tasks: We limit the scope of the first prototype to the track reconstruction only. The key is to demonstrate we can correlate hits in a realistic time frame of 1ms to the various events in the time window of the MAPS of 2μs.

- Reached consensus on composition of *realistic* time frames in terms of signal and background.
- Implemented and utilized the infrastructure for building timeframes instead of events in detector simulations.
- Major update to JANA2 framework for processing of timeframes, events, and subevents:



- **Work in Progress**:
  - Adapt the track process to work with timeframes, i.e., implement Unfold algorithm.
  - Demonstrate tracking from realistic frames.

Streaming Computing Model Milestones

Milestones for TDR:

- Prototype of event reconstruction from realistic frames (due May).
- Quantitative computing model (due October).
- Work with international partners to integrate computing resources.

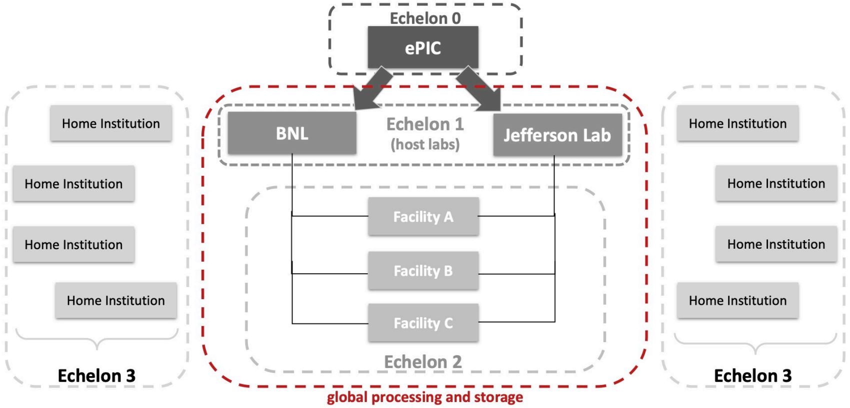
Milestones During Detector Construction Phase:

- **Ongoing planning with Electronics and DAQ WG to align on shared priorities**:
  - Provisioning DAQ and software sufficient for test beams, which can serve as small scale real-world testbeds for the developing DAQ and software. Ongoing planning with Electronics and DAQ WG to align on shared priorities.
  - Streaming challenges exercising the streaming workflows from DAQ through offline reconstruction, and the Echelon 0 and Echelon 1 computing and connectivity.
- Data challenges exercising scaling and capability tests as distributed ePIC computing resources at substantial scale reach the floor, including exercising the functional roles of Echelon 1 and 2, particularly Echelon 2, the globally distributed resources essential to meeting ePIC's computing requirements.
- Analysis challenges exercising autonomous alignment and calibrations.
- Analysis challenges exercising end-to-end workflows from (simulated) raw data to exercising the analysis model.

Summary

- The ePIC software stack is a **modern** and **modular toolkit** built from NP/HEP community tools and components from HPC and Data Science; ePIC is an **active** member of the **NP/HEP software & computing community**.

- **Streaming Readout of the ePIC Detector to maximize and accelerate science:**
  - ePIC aims for **rapid turnaround of 2-3 weeks for data for physics analyses**.
  - Timeline driven by alignment and calibrations.
- **Four tiers of the ePIC Streaming Computing Model computing fabric:**
  - **Echelon 0**: ePIC experiment and its streaming readout.
  - **Echelon 1**: Crucial and innovative partnership between host labs.
  - **Echelon 2**: Essential global contributions.
  - **Echelon 3**: Full support of the analysis community.



- **High level milestones** ensures that the agile development process is continuously confronted with real world exercising of the software and the developing realization of the computing model:
  - Priority always given to meeting near-term needs. ePIC leverages monthly production campaigns, CI-driven benchmarks, and timeline-based prioritization to **ensure timely completion of the simulation studies for the Technical Design Report**.
  - Longer range timeline progressively exercising the streaming computing model to deliver for the needs of the CD process, for specific applications, e.g. test beams, for scaling and capability challenges, and ultimately for the phases of datataking.

Backup

ePIC AI Strategy

AI is key part of all Software & Computing WGs in ePIC:

Focus on AI Development as Part of Simulation Campaigns:

- Software and computing plan and integration with NP/HEP community developments successfully reviewed by ESCAC.
- Integration of AI methods in monthly simulation campaigns as measure of AI progress.
- Ongoing work on centralization of training, management of model parameters, and workflow integration.
- **Strategic Development**: Emphasis on algorithms for fast calibrations for streaming computing workflows and PID.

Collaborative Efforts:

- Knowledge transfer with NHEP experiments on AI integration in production workflows.
- Introduction of an AI challenge at the forthcoming collaboration meeting
  - Results will be showcased at CERN meeting in April 2024.

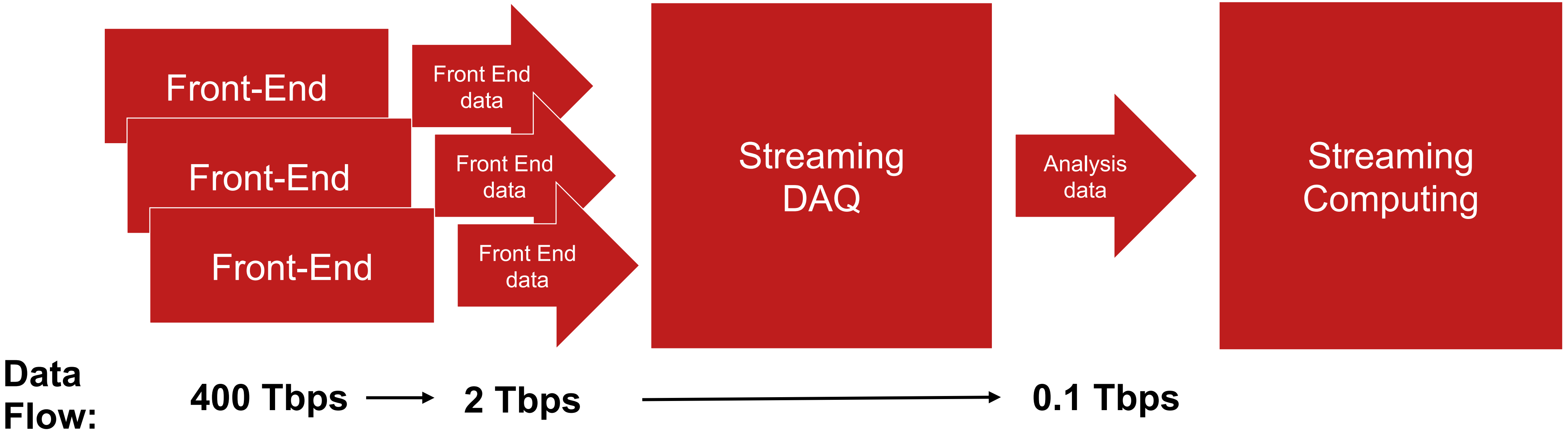
Future Directions:

- Data and analysis preservation for AI approaches.
- Distributed learning for the distributed streaming computing model of ePIC.
- Work with the theory community in NHEP on ways to advance data analysis and interpretation using AI.

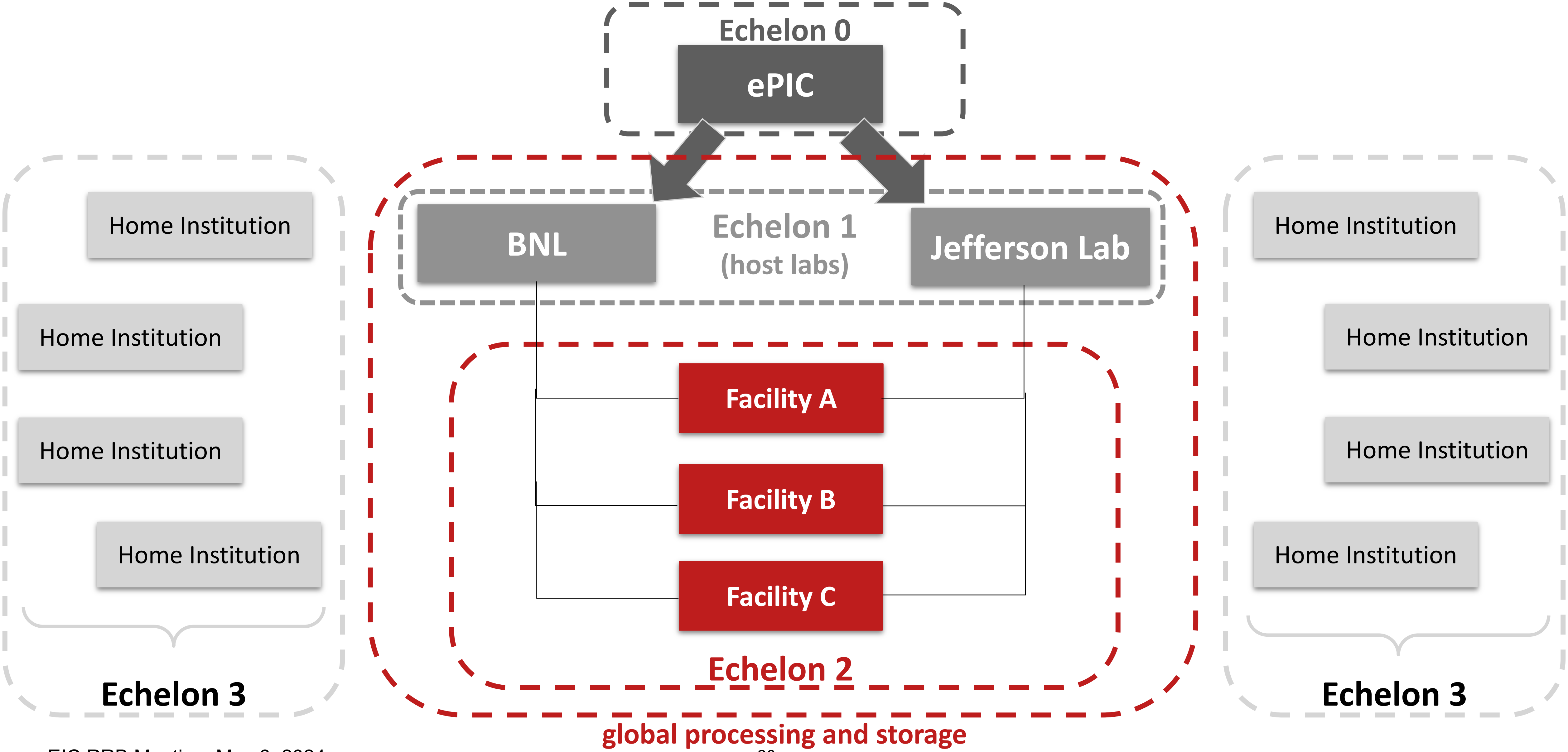
Compute-Detector Integration to Maximize Science

Broad ePIC Science Program:
- Plethora of observables, with less distinct topologies where every event is significant.
- High-precision measurements: Reducing systematic uncertainties of paramount importance.

Streaming Readout Capability:
- Event selection using all available detector data for **holistic reconstruction**:
  - **Eliminate trigger bias** and provide accurate estimation of uncertainties during event selection.
- **Capture every collision signal**, including background:
  - Ideal for broad ePIC Science Program and multi-purpose detector.
  - Ideal to **reduce background** and related systematic uncertainties in measurement.



Echelon 2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ePIC
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(host labs)
Jefferson Lab
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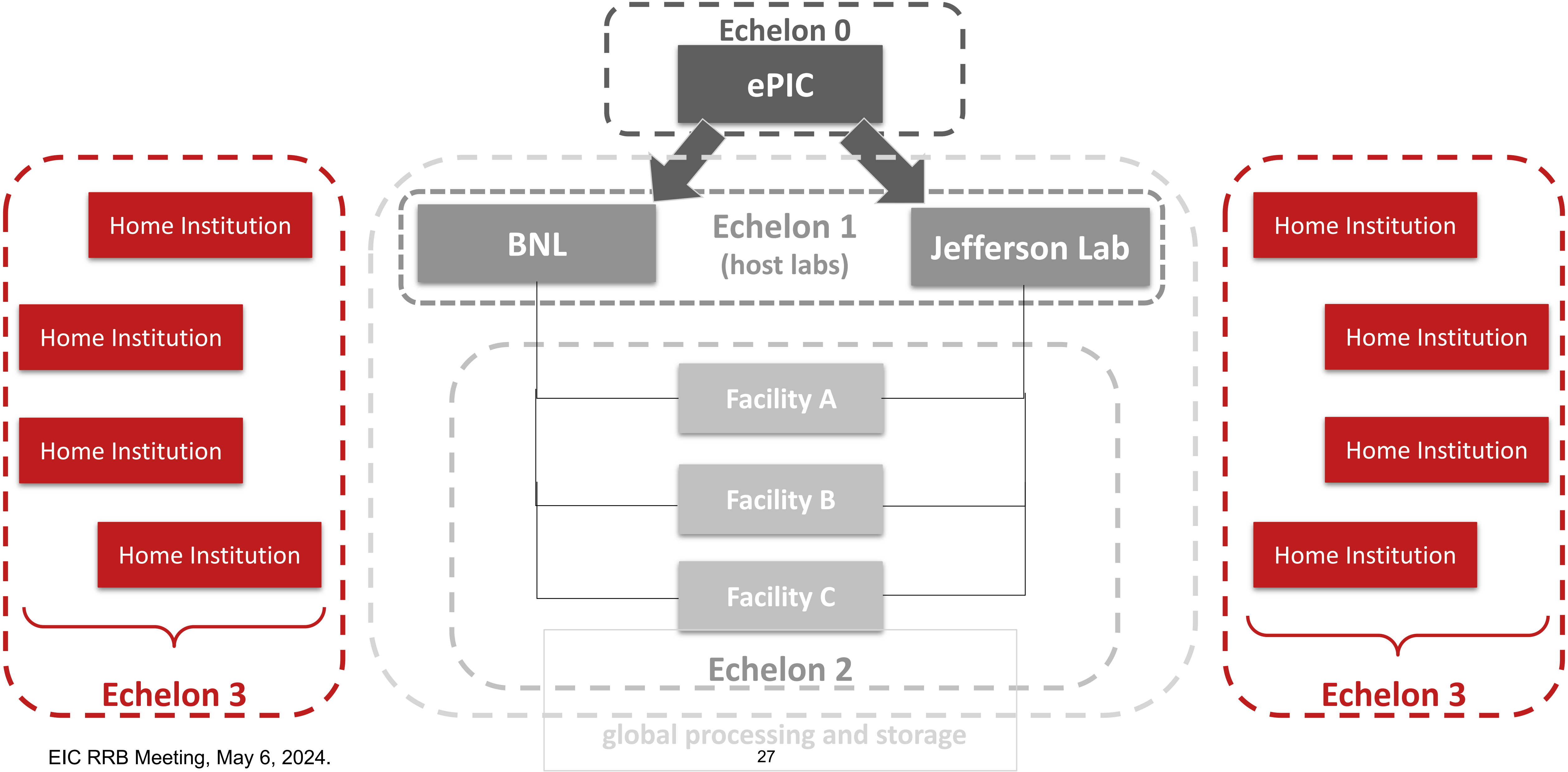
Echelon 3
global processing and storage

Echelon 3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Home Institution
Echelon 3

Computing Scale

Based on the number of electronic channels in the detector, and the occupancy you expect, what is the expected frame size?

- Streaming data is transferred in frames, collecting all data of 1ms.
- Corresponding frame size is 10MB when running at peak luminosity.

How many events do we expect to record and simulate per year, respectively?

- Assuming a 50% up-time for ½ year, we will record 15.5 billion frames in a year.
- The event rate at peak luminosity is 500kHz, which gives roughly 4 x 10^{12} events (60% background, 40% bunch crossing related):
    - Will be much lower at start of operations, where luminosity will be lower (but relatively speaking the background rate is expected to be higher).
    - A small fraction of total bunch crossings are actual physics events key to EIC observables
        - ~ 10^{10} DIS events/physics events of interest expected annually at peak luminosity.
    - Simulation targets are about 10 times the events of interest, totaling O(10^{11}) simulated events.
        - While considerable (~ 60k core years on today's hardware), this should be a realistic target in a decade.

How many core-seconds on a typical modern machine does our reconstruction and simulation take today, respectively?

- Our current simulations of background embedded events take ~17s for simulation and ~ 2-3s for reconstruction, per event.
- **Unknown**: How much this will change once changing to streaming data processing?
- **Priority target for TDR**: Prototype of event reconstruction from realistic frames.

Key Task: Realistic Time Frames

- **Electronics and DAQ WG**
  - Define the *realistic* time frames. We need a consensus on the meaning of *realistic*. **Meeting on March 21.**

- Timing distributions in simulations realistic. Very long tails due to slow neutrons.
- **Time frames definition**:
  - DIS, Proton Beam Gas, Electron Beam Gas (eventual Synchrotron radiation) should be randomly distributed according to desired beam energies and intensities.
  - Hits from simulated physics collisions events should be distributed in time according to:
    - T_{hit} = nominal event T_0 + $_{Thit\_sim}$
  - The hits for the MAPS detectors need two special characteristics:
    - The time should be set to the beginning of the 2us period it occurs within.
    - The hit should be replicated in either the prior or following 2us period depending on whether it is closer to the end of the hit period or closer to the beginning.
  - Add noise only to the MAPS and dRICH. Assume that reconstruction, e.g., cluster finding, in other detectors will suppress nearly all of the noise.