Brookhaven National Laboratory Jefferson Lab U.S. DEPARTMENT OF ENERGY

Summary of Electronics, Readout and DAQ and Streaming Computing WG Joint Workfest

ePIC Electronics and DAQ WG Conveners

Fernando Barbosa (JLab), Jeff Landgraf (BNL)

Streaming Readout WG Conveners

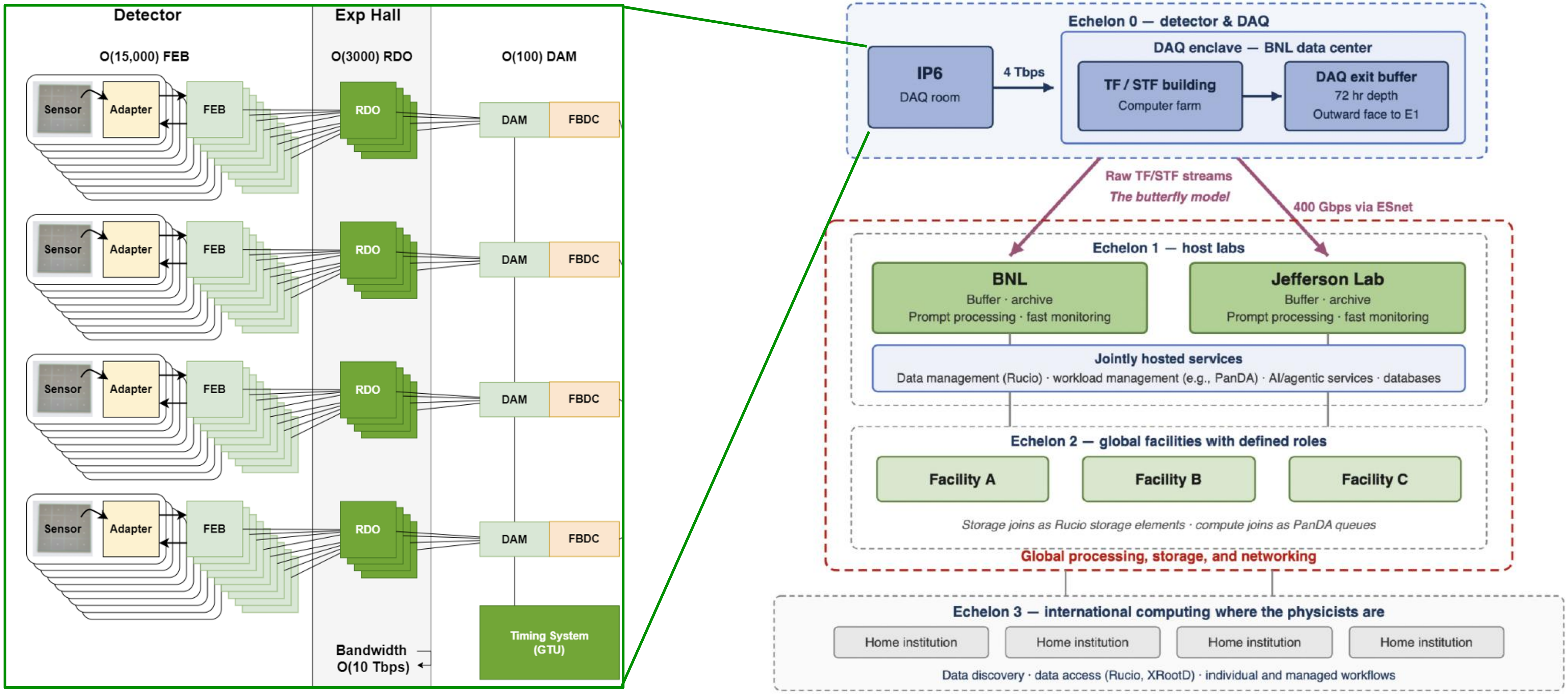
Marco Battagalieri (INFN), Taku Gunji (University of Tokyo), Jeff Landgraf (BNL)

Software / Computing Management

Markus Diefenthaler (JLAB), Torre Wenaus (BNL)

Electron-Ion Collider

Overview of readout/DAQ/SRO computing system



Challenges: Integrating $O(10\ \text{Tbps})$ streaming data flow from $O(15{,}000)$ FEBs to global Echelon facilities requires seamless alignment of hardware interfaces, timing systems (GTU), and distributed workflows (Rucio/PanDA) without hardware trigger throttling.

Workfest Outlines and Objectives

Wed 15/07

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09:00	**Introduction & Streaming DAQ: Overview, Requirements and Timeline**	*Jeff Landgraf*	*Room 225 (Humanities LT), Gilbert Scott Building*	09:00 - 09:35	
	Echelon 0 - Echelon 1 Interface, Status and Open Questions (Discussion)	*Jeff Landgraf et al.*	*Room 225 (Humanities LT), Gilbert Scott Building*	09:35 - 10:10	DAQ/Streaming
10:00	**Echelon 2 Participation Model (and Discussion)**	*Dr Markus Diefenthaler*	*Room 225 (Humanities LT), Gilbert Scott Building*	10:10 - 10:30	Streaming
	Coffee Break		*1A The Square, Gilbert Scott Building*	10:30 - 11:00	
11:00	**NP-HPDF Project**	*Dr Markus Diefenthaler et al.*	*Room 225 (Humanities LT), Gilbert Scott Building*	11:00 - 11:20	Streaming
	Streaming Readout Background Suppression	*Dmitry Romanov*	*Room 225 (Humanities LT), Gilbert Scott Building*	11:20 - 11:40	
	BNL Orchestration Testbed	*Dmitrii Kalinkin*	*Room 225 (Humanities LT), Gilbert Scott Building*	11:40 - 12:00	Streaming
12:00	**Streaming Reconstruction**	*Takuya Kumaoka*	*Room 225 (Humanities LT), Gilbert Scott Building*	12:00 - 12:20	

Thu 16/07

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09:00	**Summary of ASIC Internal Reviews**	*Fernando Barbosa et al.*	*Humanities Lecture Theatre (225), Gilbert Scott Building*	09:00 - 09:20	
	CALOROC Status	*Pedro Pablo DUMAS ZIEHLMANN*	*Humanities Lecture Theatre (225), Gilbert Scott Building*	09:20 - 09:40	Electroncs (ASIC, RDO, GTU)
	ASIC 65nm / 130nm Fabrication for CALOROC / EICROC	*Frederic Dulucq*	*Humanities Lecture Theatre (225), Gilbert Scott Building*	09:40 - 10:00	
10:00	**Generic RDO Status**	*Miklos Czeller*	*Humanities Lecture Theatre (225), Gilbert Scott Building*	10:00 - 10:20	
	dRICH RDO	*Alessandro Lonardo et al.*	*Humanities Lecture Theatre (225), Gilbert Scott Building*	10:20 - 10:40	Electroncs (ASIC, RDO, GTU)
	Coffee Break		*Humanities Lecture Theatre (225), Gilbert Scott Building*	10:40 - 11:00	
11:00	**GTU**	*William Gu*	*Humanities Lecture Theatre (225), Gilbert Scott Building*	11:00 - 11:20	
	How to best Collaborate on DAQ Hardware / Software (Discussion)	*Taku Gunji*	*Humanities Lecture Theatre (225), Gilbert Scott Building*	11:20 - 11:40	DAQ Streaming
12:00	**SRO Calibrations**	*Marco Battaglieri et al.*	*Humanities Lecture Theatre (225), Gilbert Scott Building*	11:40 - 12:40	

- **Goals of these sessions**
  - **Communication between groups with very different perspectives**
  - **Updating collaboration regarding the specific progress being made**
  - **Feedback from collaboration**

ASIC Development Status

- **ASIC Selection:**
  - 6 ASICs (CALOROC, ALCOR, EICROC, FCFD, FCFD Variant, SALSA) + 1 Discrete COTS across 26 subsystems.
- **Progress:**
  - Testing actively ongoing with various sensors (AC-LGAD, SiPM, MPGD, HRPPD).
  - CALOROC QA/QC plan established as a template.
- **Key Issues:**
  - ALCOR: Resolving BGA packaging (UBM process).
  - EICROC / CALOROC: Porting designs away from 130 nm node to 110nm or 65nm.

Version		Status	Notes
EICROC0A	4x4	Under test	Improved testability
EICROC0B	4x4	Under test	Peak and Wilkinson ADC
EICROC1	32x32	Under test	inverter issue
EICROC1, rev	32x32	Submitted, available July 2026	revised metal layer
EICROC2	32x32	Submission Q1 2027	Design with Digital on Top, high rate, derandomizer, zero-suppress

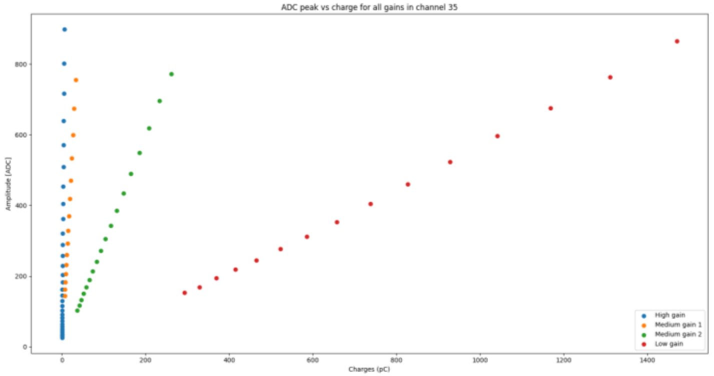
Version		Status	Notes
ALCOR-32	32 ch	Complete	System tests continue
ALCOR-64	64 ch	Under test	UBM process packaging not robust
ALCOR-64, rev MPW	64 ch	Submission Q3-Q4 2026	New MPW with alternative packaging process
ALCOR-64	64 ch	Submission Q1-Q2 2028	Production

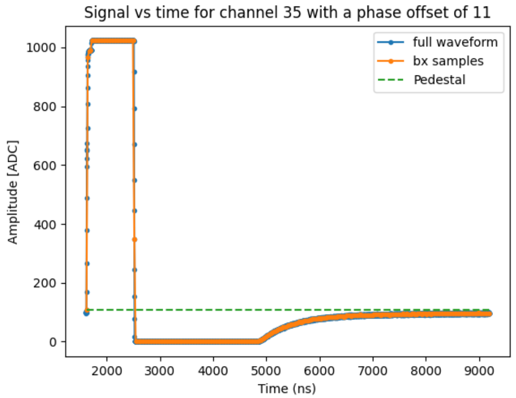
Version		Status	Notes
CALOROC1A/B	36 ch	Under test	Testing 1B first
CALOROC2	36 ch	Submission Q1 2027	Version selected for final production and availability for system detector tests. First production quantities
CALOROC3	36 ch	Q1 2028	Final production quantities

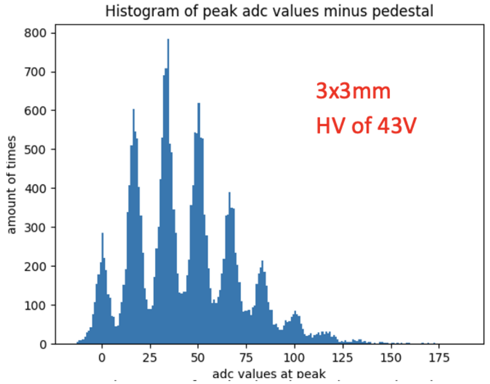
Version		Status	Notes
FCFD1.1	6 ch	Completed	Frontend only. Multiple tests with strip sensors from Hamamatsu
FCFD1.2	6 ch	Submitted April 2026	Full functionality: Discriminator, TDC, ADC, I2C, simplified readout. Tests starting in July 2026
FCFD2.0	32 ch	Submission Q2 2027	Full functionality
FCFD3.0	32 ch	Submission Q2 2028	Production

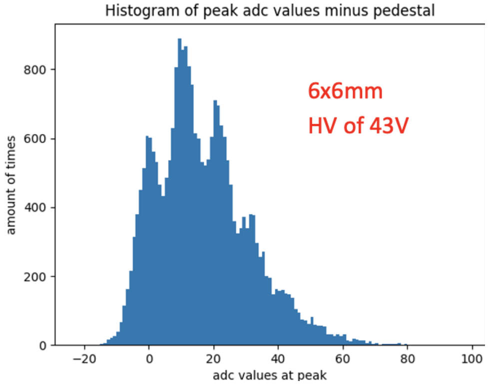
CALOROC developments

- CALOROC-1A (Low SiPM capacitance)/ 1B (wide dynamic ranges, High SiPM capacitance) available for testing.
- CALOROC-A analog measurements underway, first results similar to H2GCROC
- CALOROC-B first measurements are encouraging:
  - High Gain / Gain switching
  - Linearity
  - Charge Resolution
  - Timing
  - Time to baseline
  - Crosstalk
  - SiPM measurements
  - Single Photo-electron measurements
- Discussed some issues seen and possible solutions will be deployed in the next PCB design to suppress digitial noise coupling etc..









Discussion on 130 nm or new 65 nm/110 nm

- The fabrication issues with TSMC stopping the 130 nm production line
  - Tape out before Sept. 2026 remain possible but not possible since then.
  - Production of exiting products continues.
  - Very informative as regards steps towards changing the fabrication chain
- Discussion about moving to 65 nm regardless of the availability of 130 nm lines due to the risk of losing them in the future

TSMC130	TSMC65	UMC110	XFAB130	VIS130
5M 1T 1U RDL C4	5M 2T 1U RDL C4	5M 1T 1U no C4?		As TSMC130
Radhard 200 Mrad	Radhard 200 Mrad	Bump @ 5 Mrad	N/A	Which fab
ER : 300 k$	ER : 750 k$	ER : 300 k$?		
EIC	EIC, LHCb	EIC, LHCb, ALICE		
AGH, Lisbon,SLAC	FNAL,BNL,CERN	Torino		
Discontinued	Perennity ?	Low volume	6-9 months fab	Available when ?

Technology choice

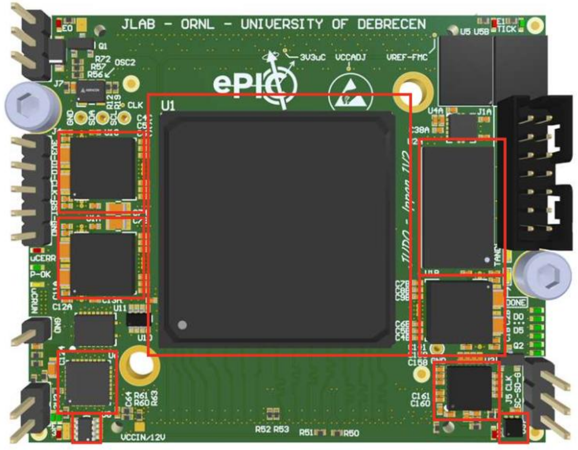
- ❑ CNRS funding vs tech. choice
  - ❑ Funding for R&D was based on 130nm prices (caloroc and eicroc)
  - ❑ EIC recognition as French priority project (IR*) may ease access to lower node (selection ~ end 2026)
- ❑ To keep synergies between ROCs, a common tech. node is preferable
  - ❑ So driven by EICROC (due to its x8 size compared to CALOROC)
- ❑ Schedule if TSMC 65 chosen:
  - ❑ More IP available (ADC, PLL, IO PADS, Bandgap etc)
  - ❑ C4 by TSMC / OSAT + through CERN (payment)
  - ❑ ~12 months delay
- ❑ Schedule if UMC 110 chosen:
  - ❑ Few IP available (ADC, PLL, IO PADS, Bandgap etc)
  - ❑ C4 outsourced + through IMEC (payment)
  - ❑ Better perennity ?
  - ❑ ~18 months delay

Generic RDO development

- The cencept: to design a FPGA module that is common, scalable, easy to maintain, and replaceable
  - The selected FPGA family is from AMD – UltraScale+ Aritx / Kintex, 16nm
  - Relatively small daughter board (DB)
  - Motherboard (MB)
    - Testing DB and replacing KCU-105

- CALOROC – calorimeter full chain test - 4:1 aggregation will be done
- Rack mounting (planned for SVT): it's in the brainstorming phase. Discussions are needed
- If you need test article and if you would like to join testing, please let us know

module size is: 60.5 x 50 mm



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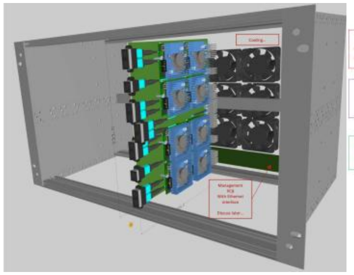
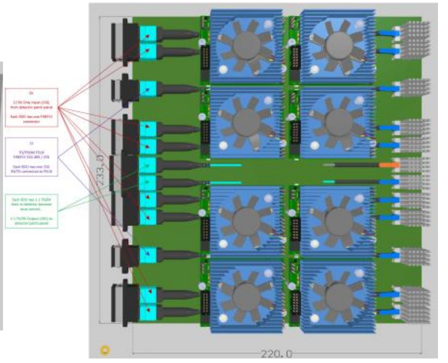
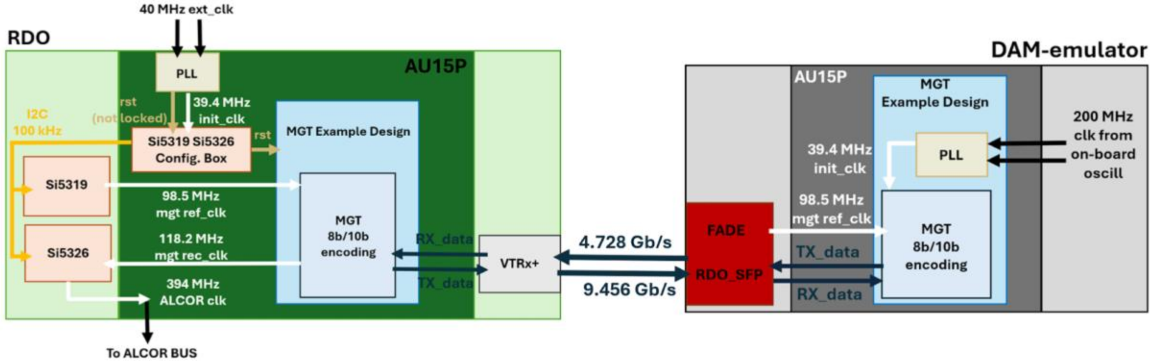


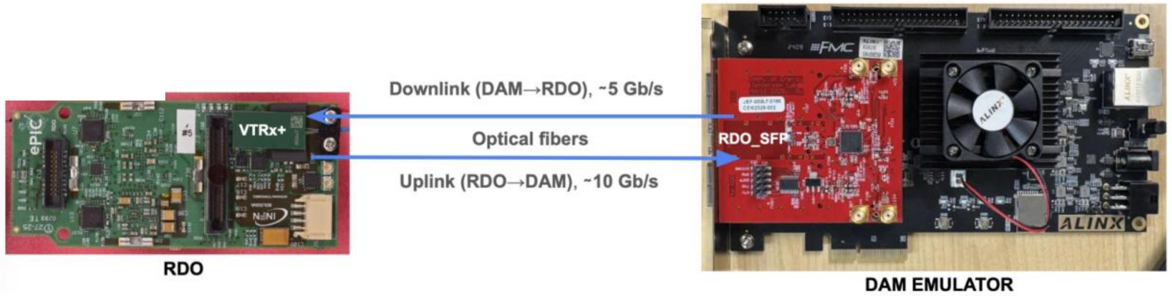


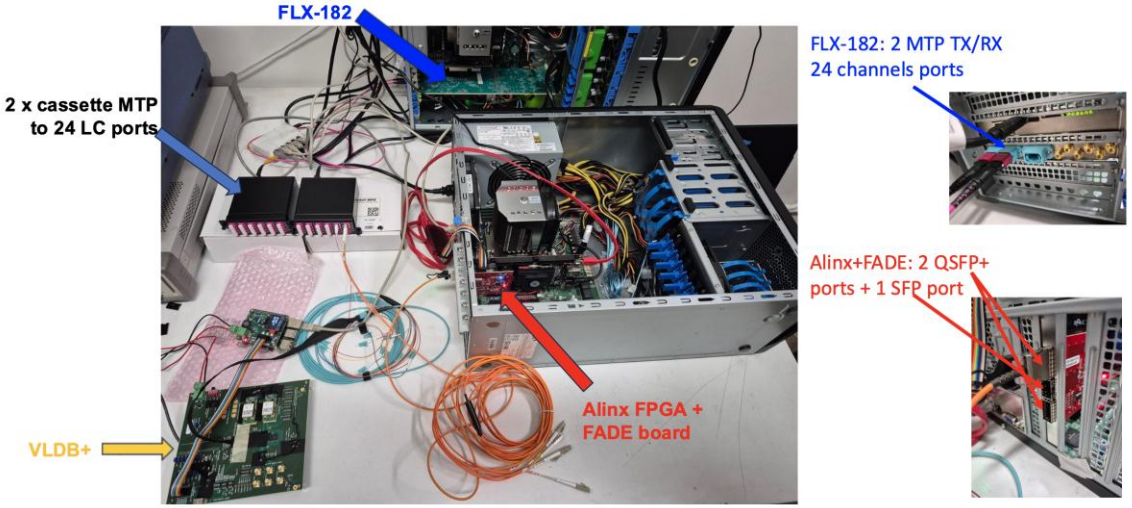
dRICH RDO development

- A lot of progress made so far using RDO and DAM emulator setup
  - Recovered clock quality and phase stability
    - This could be common in many ePIC subsystems. Centralized common FW development? (to be followed)
  - Protocol and dataformat considerations
    - centralized ePIC standards?
  - RDO-DAM (Felix 182)-GTU communication
    - ALINX+FADE as GTU emulator
  - RDO radiation tests
    - All components individually validated
    - Full RDO card exposure → (December 2026)

- By end of 2026, RDO v1.1 will be ordered.

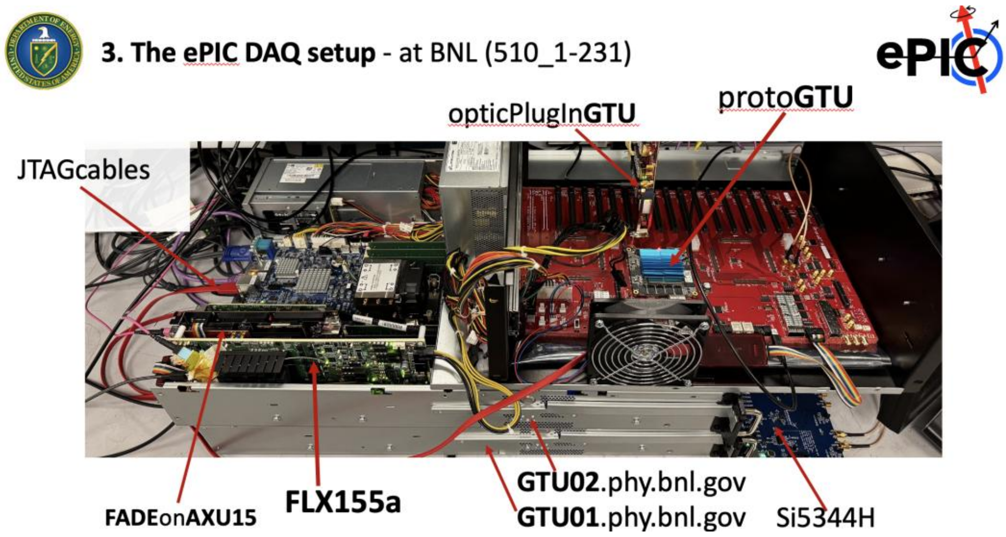


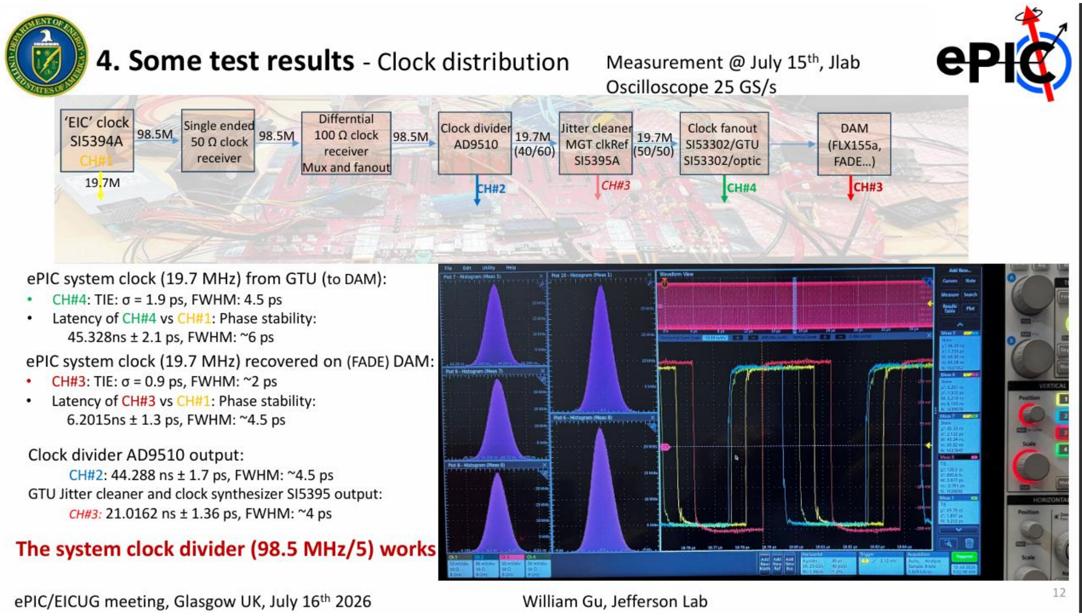




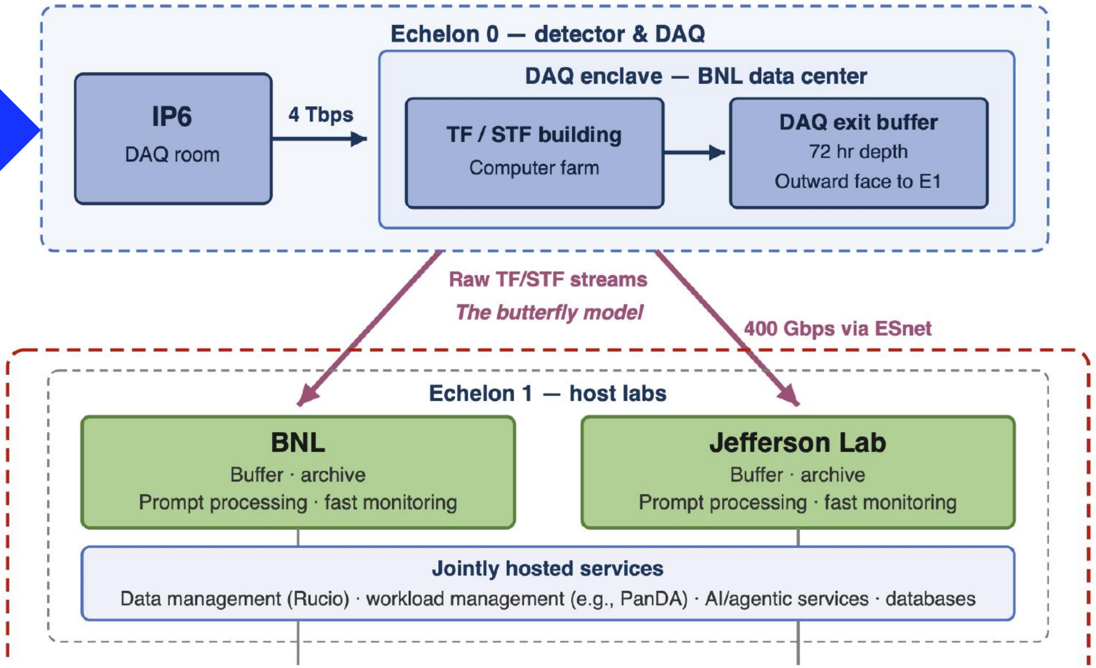
GTU development

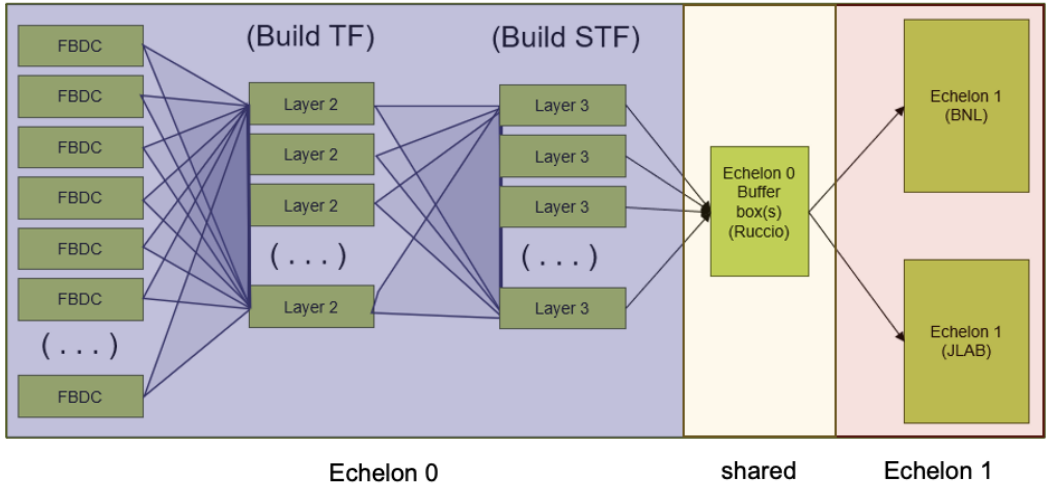
- **System & Testbed Status**
  - GTU design based on custom DAM/ProtoGTU FPGA boards.
  - **BNL and JLab testbed established**
- **Verified Performance**
  - **Ultra-Low Clock Jitter**
    - Clock recovery and distribution measured at **< 2 ps RMS jitter**,
  - **Downlink Control & Triggering**
    - Stable broadcast of timing frames, triggers, and slow-control packets achieved.
- **Next Steps**
  - implement the GTU downlink receiving firmware in DAM
  - DAQ software development, subsystem run-control test
  - connect with real RDO (with or without LpGBT chip);
  - make a clock phase monitoring board.





E0 DAQ middleware development





Streaming DAQ Middleware

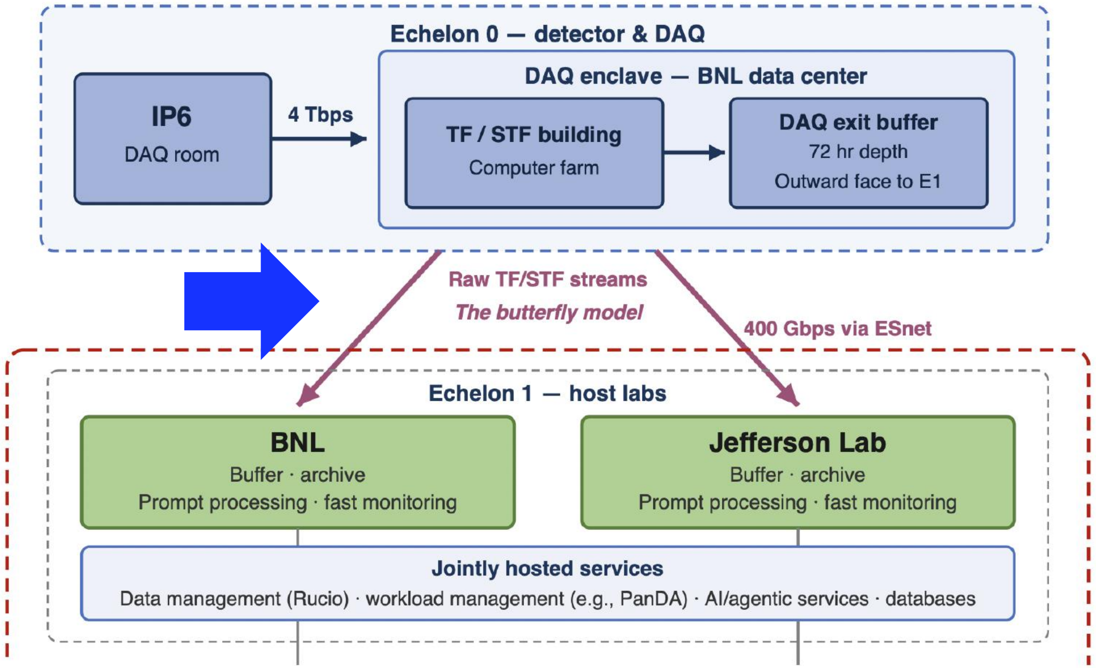
- Read out detector data and build detector payloads (e.g. GTU, FELIX)
- Construct TimeFrames (0.6msec) based on heartbeat triggers
- Aggregate detector TimeFrames into Super TimeFrames (STFs, 0.6sec)
- Buffer STFs/TFs at Echelon-0 (Sink)
- Interface to Run-Control, etc

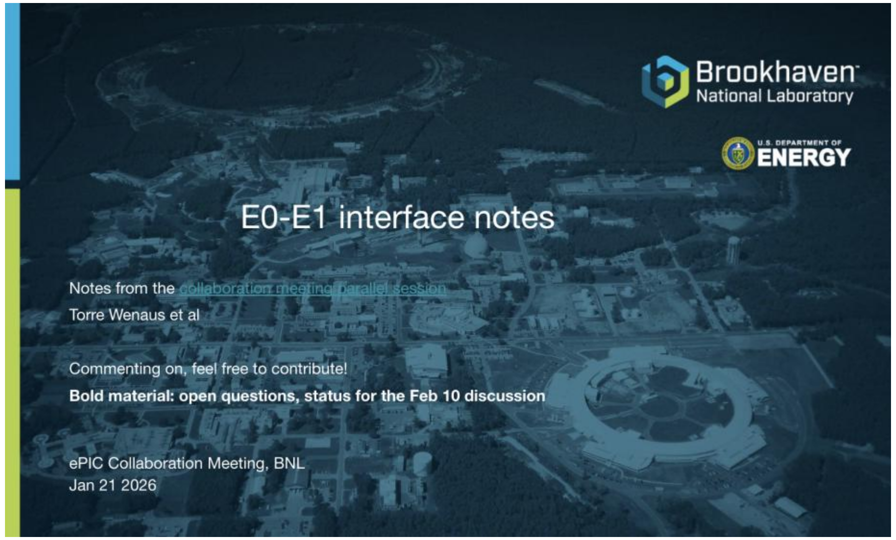
Ongoing developments

- RCDAQ (sPHENIX)
- NestDAQ (SPADI-Alliance, Japan)
- CODA/JANA2 /ERSAP (JLab)

We've set up meetings (at first with conveners) to try to detail what the collaboration will look like

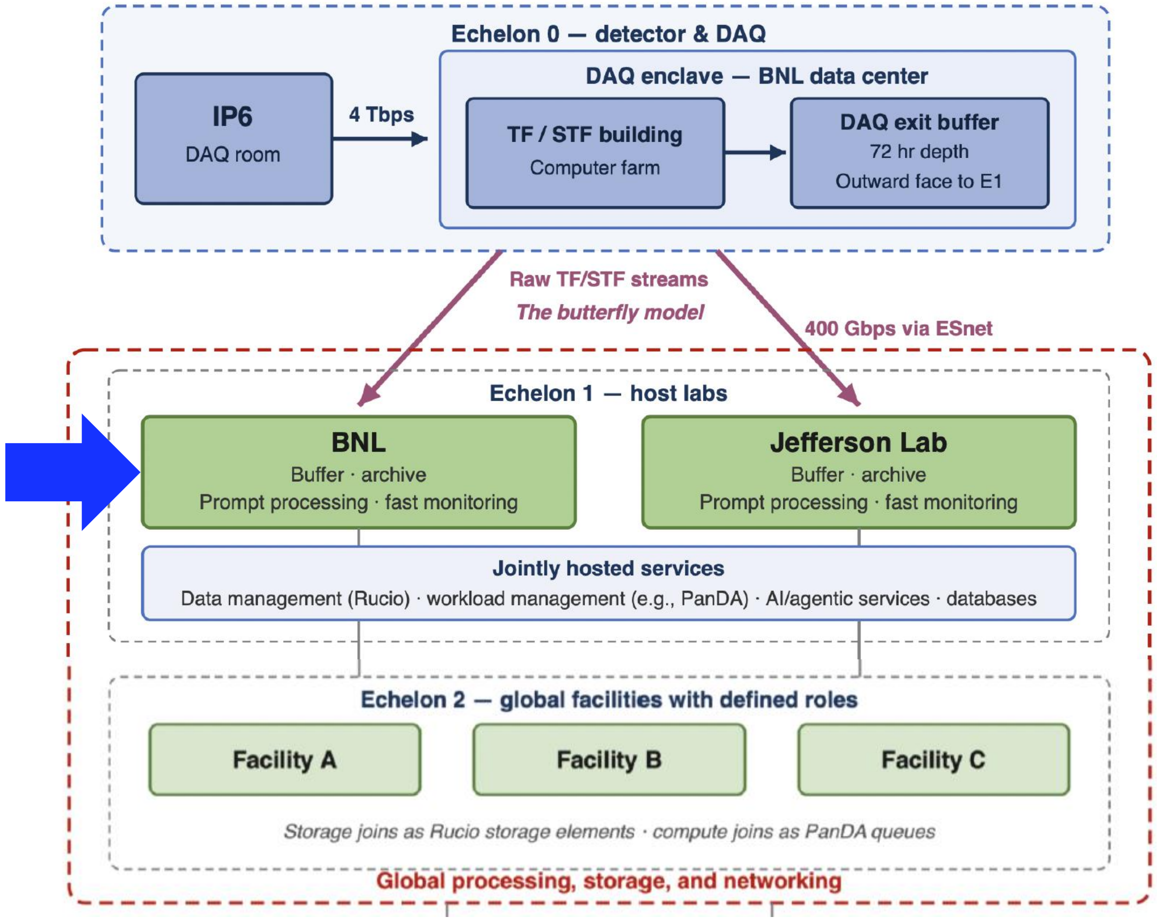
E0-E1 interface discussion





- **E0-E1 interface notes under evolving for the next SC review (Oct. 2026)**
  - Interface requirs a robust design encompassing:
    - raw data/sub-time-frame structures
    - message-based control flows
    - conditions database synchronization for online/offline calibration
    - state machine definitions
    - scalable AI (MCP) integration for operational monitoring and feedback.
- **Main open questions**
  - Raw-data and STF definitions
  - Evolution of the state model and transition rules
  - Latency requirements
  - Calibration and conditions databases
  - Information and control interfaces between E0 and E1
  - AI readiness and AI-enabled control

E1: Streaming Orchestration testbed



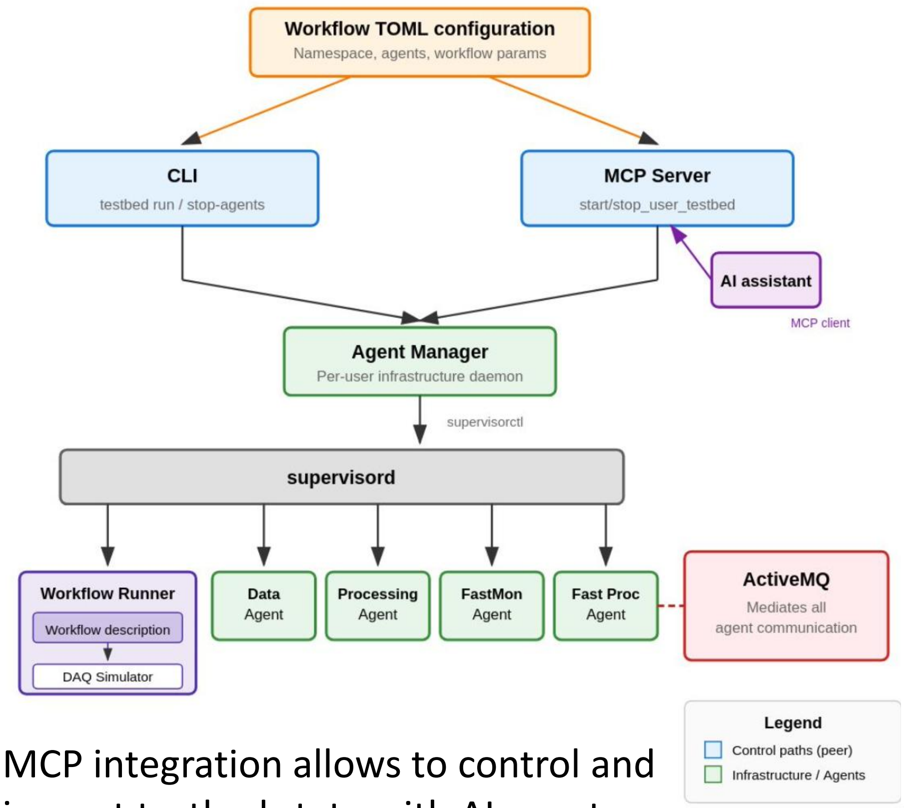
- **Handles data / process execution after data is written to buffer-boxes**
- **Combines:**
  - Panda for initiating jobs
  - Rucio for data management
  - Communication with Echelon2
  - Snakemake for evaluating tasks & dependencies
  - ActiveMQ agents to with interface via command lines or MCP control
  - DAQ emulator with simplified state-model
  - “Prompt” tasks are on full reconstruction tasks
  - “Fast” tasks are on partial STF for rapid turn-around (monitoring) purposes

- **Integrate these components on a common infrastructure with the testbed**

-

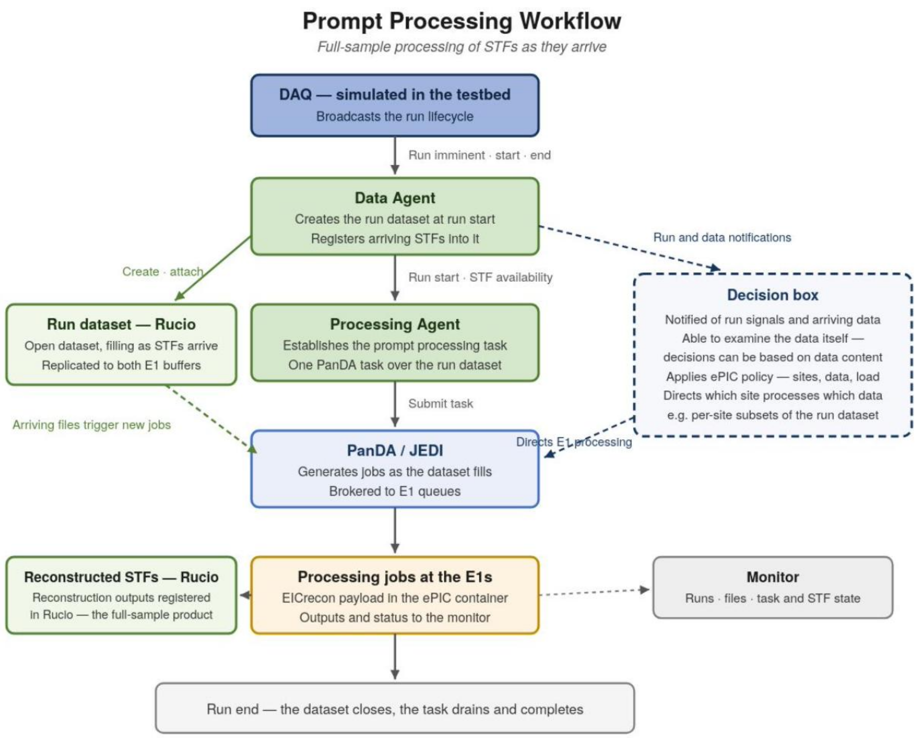
E1: Streaming Orchestration testbed

Agent Orchestration and communication



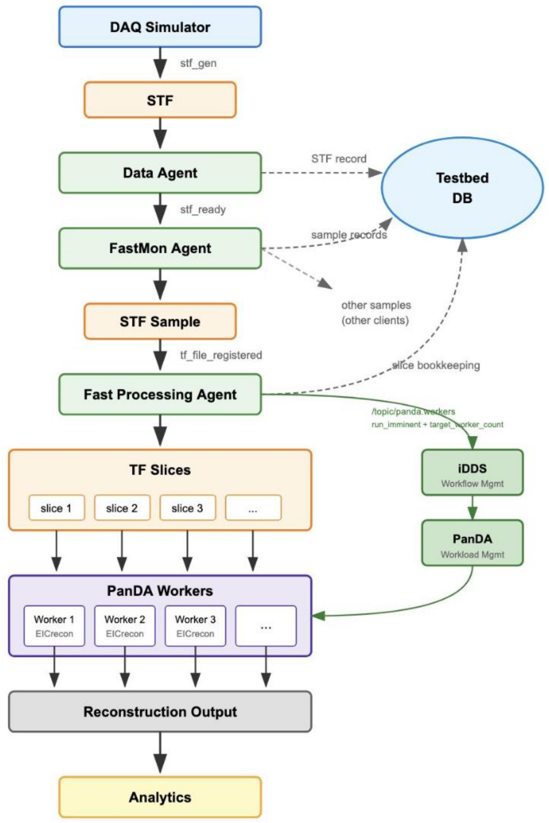
MCP integration allows to control and inspect testbed state with AI agents
Agents are connected to ActiveMQ messaging bus
Agent-to-agent communication in a Echeloned environment (BNL ↔ Osaka)

Prompt STF file processing workflow



Testing with mock STF data files, but operation with real EICrecon payload was demonstrated

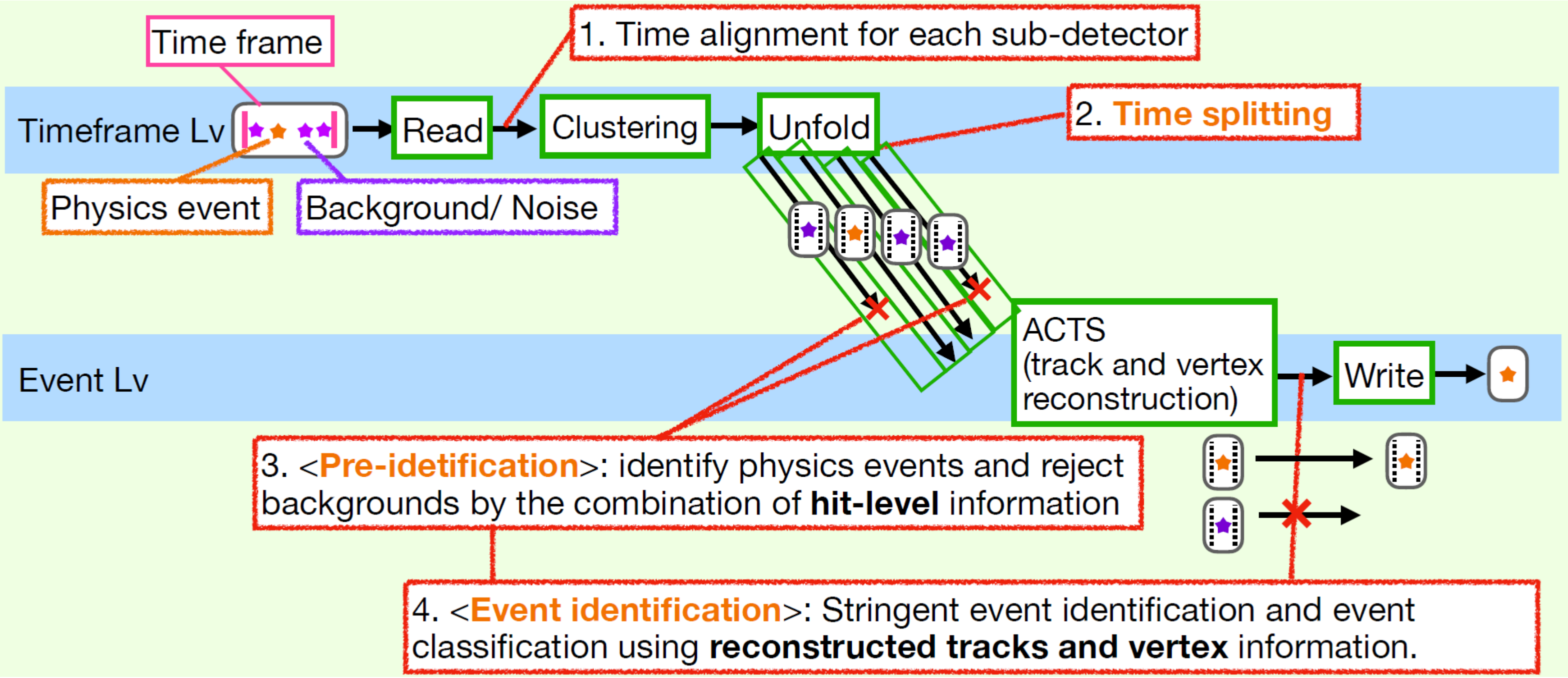
Fast processing workflow

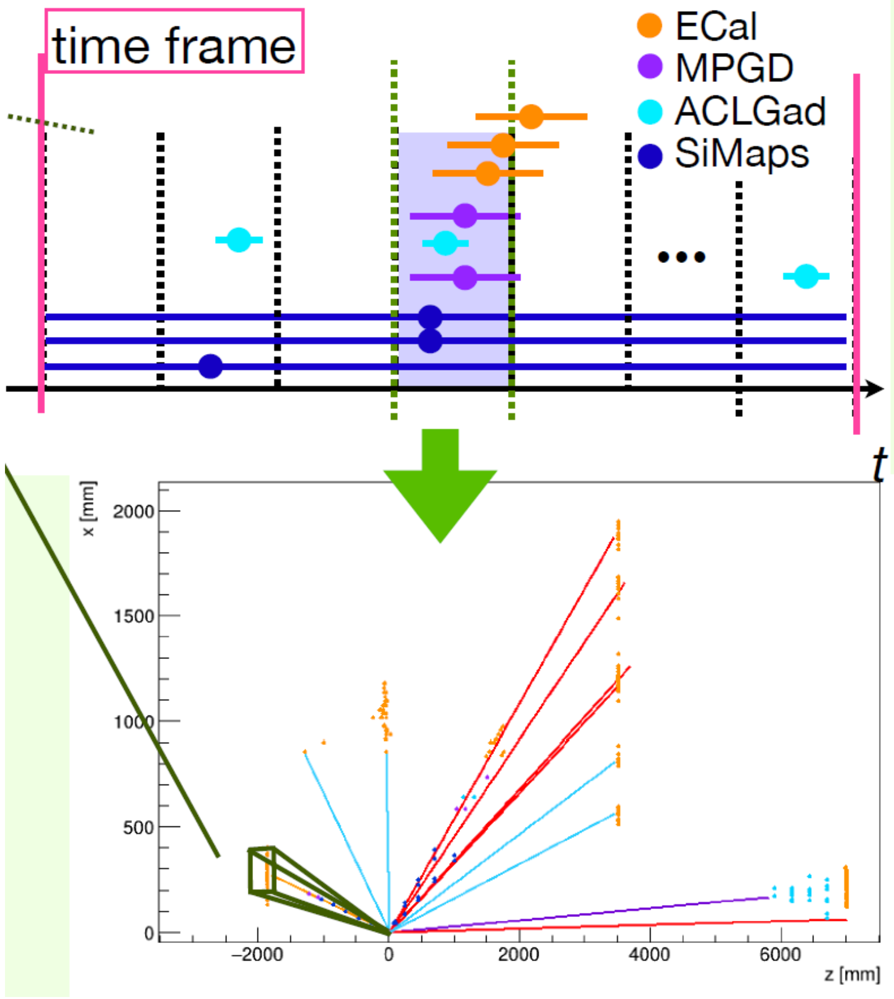


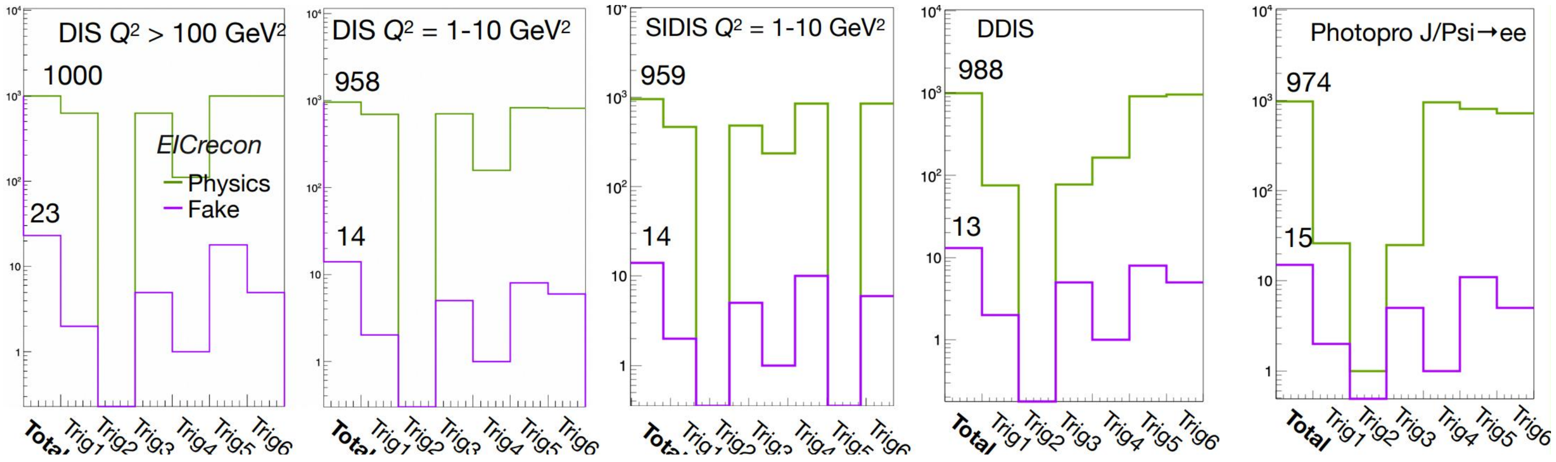
Full chain from STF to PanDA workers is now working with a real EICrecon payload in ZMQ server mode

E1: Streaming Reconstruction

- Example of STF processing. Current focus is for identifying events from BG.

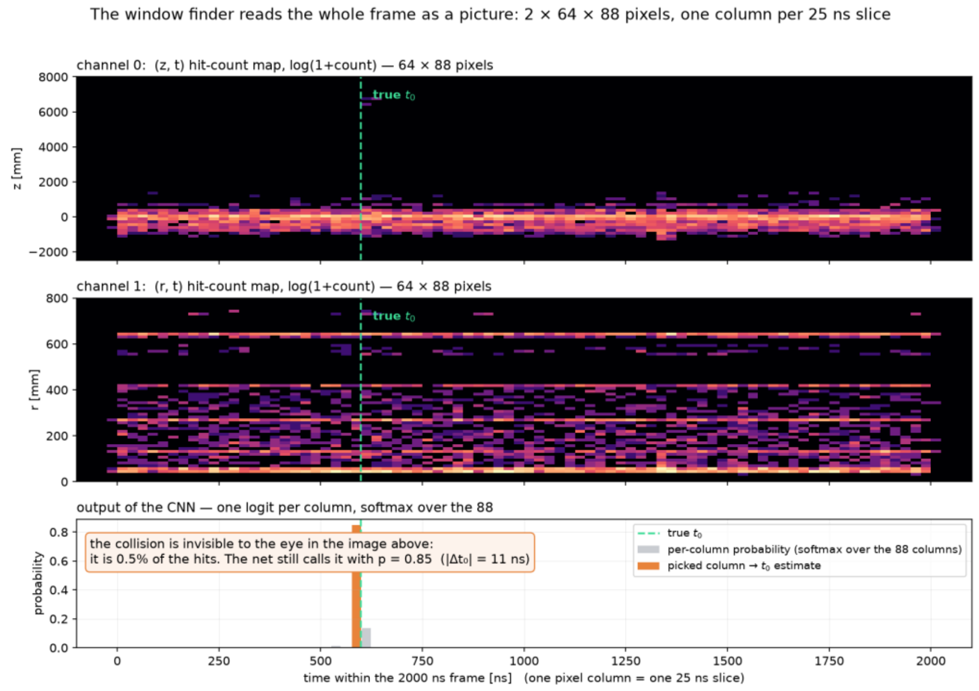




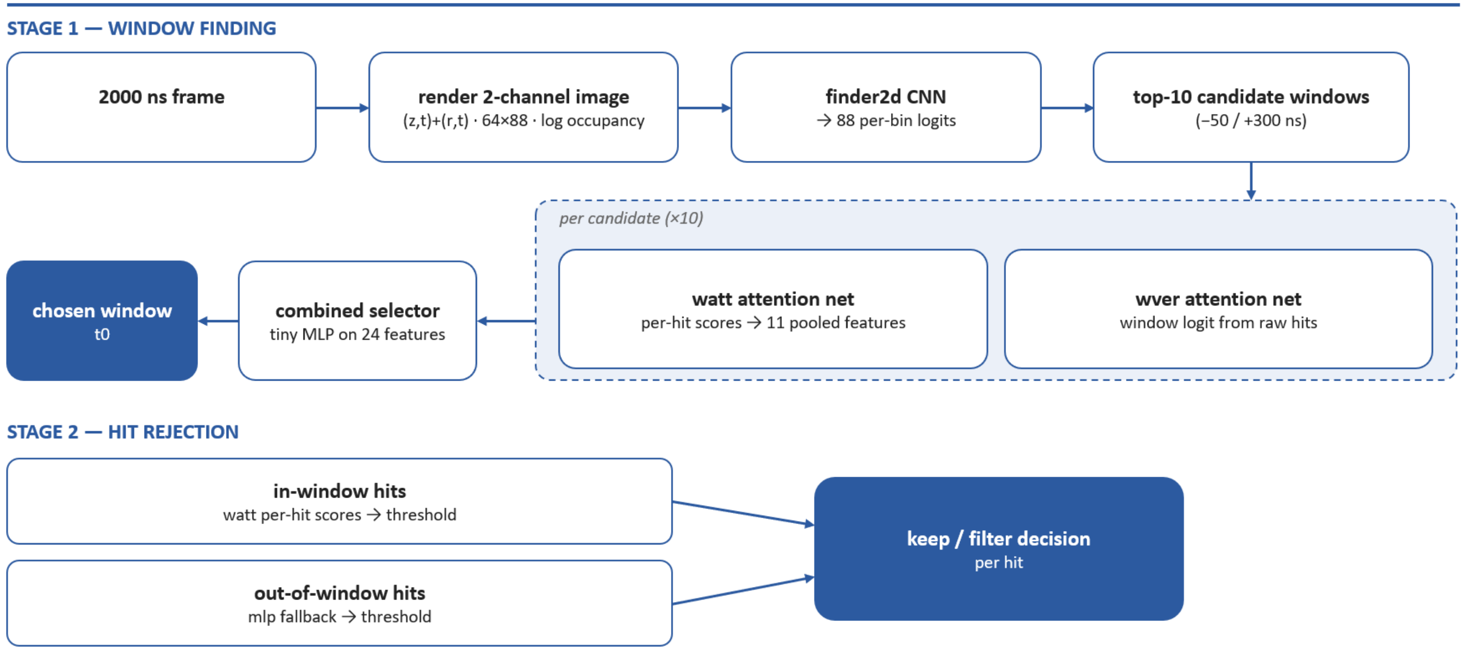


E1: Background rejection using AI

- Development of an AI-driven analysis of streaming-like frame-based data
- Integrate models within JANA2.



The framework at a glance



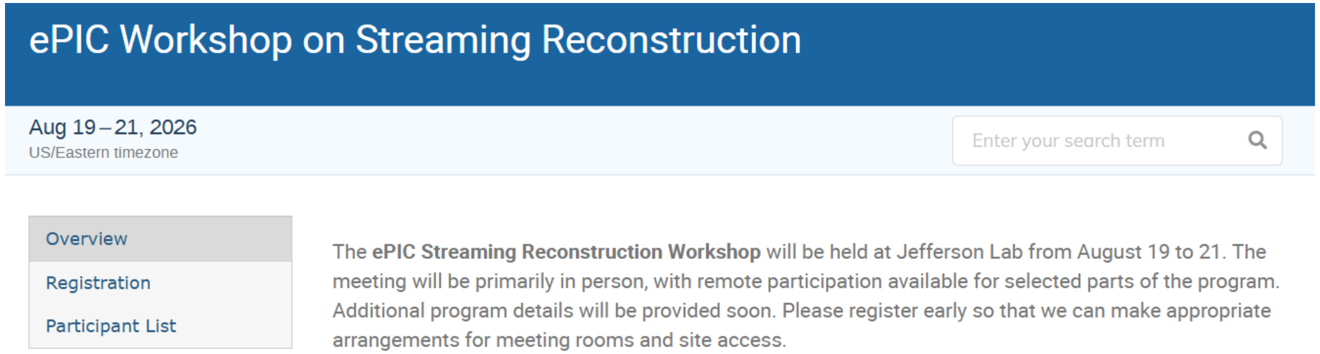
Every box is a separate ONNX model · thresholds calibrated jointly on validation for ≥ 99% total signal efficiency

An AI background filter for streaming tracker data — built, validated, and running inside EICrecon

– keeps 99% of signal hits while rejecting background at the hit level; all models ONNX on CPU: ~1 MB of weights, +34 MB RAM, ~12 ms per frame

Streaming reconstruction workshop

- https://indico.bnl.gov/event/33464/
- August 19th – August 21st at JLab

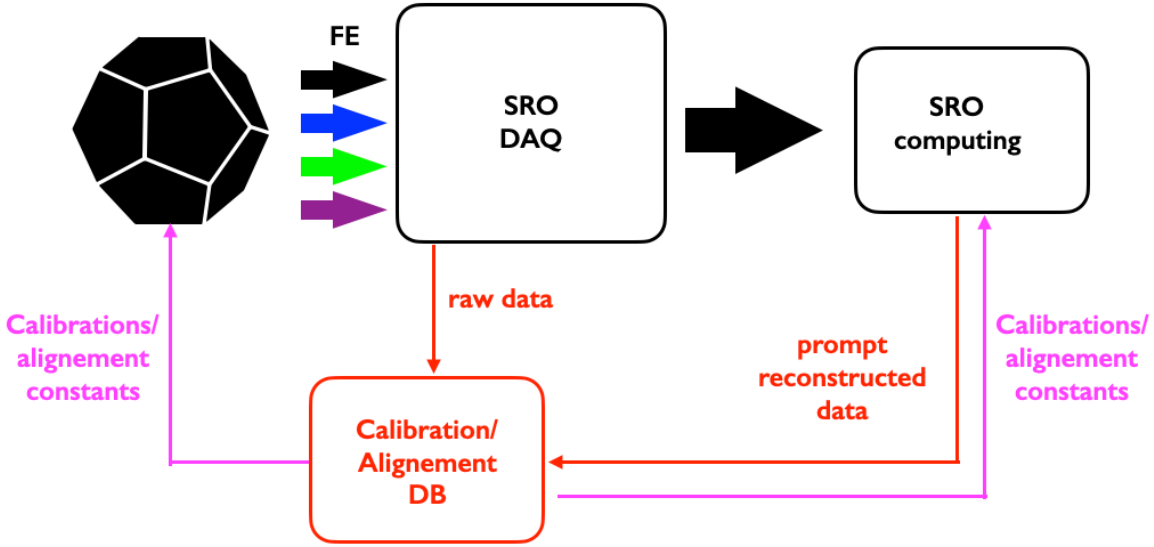


- The main objective is to align project contributors from SRO WG and Reco WG, evaluate current technical capabilities, and establish a clear roadmap for future development.
- Key goals across the 3-day workshop include:
  - **Defining Scope & Requirements:** Identifying the unique needs of streaming reconstruction, required downstream processes, and necessary computing infrastructure.
  - **Reviewing Technical Progress:** Evaluating the latest updates on reconstruction status, timeframe simulations, datasets, and performance benchmarks.
  - **Planning Next Steps:** Formulating a concrete task list, setting project timelines, assigning team responsibilities, and outlining the next steps for publication.
- **Your participation is more than welcome (and important)!**

E1: Streaming Calibration

- **We aim for a rapid turnaround from data to full calibrated/reconstructed data**

[Link to google spreadsheet]



Subsystem	Region	contact	Contact person	up to date? (March 2026)	Pre-physics-operation calibrations (Cosmic, no-beam calibration, commissioning)	Task	Human intervention ?	Data Needed	Dependency	T0 + 12hr	T0 + 24hr	T0 + 36hr	T0 + 48hr	T0 + 60hr
MAPS	Barrel+Disk	Taku	"Schambach, Jo" <schambachjj@ornl.gov>,	Yes	Full Threshold Scan Fake hit rate scan/noisy pixel masking Digital/Analog scan (problem pixels) Pulse Shape Scan Timing Offset Scans Other DAC scans (tbd)	(See Alignment)								
MPGD	Barrel+Disk	updated	Kondo Gnanvo <kagnanvo@jlab.org>, BOSSU Francesco <francesco.bossu@cea.fr>, Annalisa D'Angelo <annalisa.dangelo@roma2.infn.it>	Yes	nosiy and dead strips masking, pedestal and timing offset adjustment	(See Alignment)								
bTOF, eTOF (ac-lgad)	Barrel/Forward	Taku	tonko.ljubicic@gmail.com	Yes	Bias voltage determination ASIC baseline, noise, threshold Clock sync Time walk calibration	Gain calibration Eta calibration (charge sharing) 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 Acc. Dependen	Dependen	Processin	Processing	
Central Detector Tracker Alignment		Taku	Ernst Sichtermann <epsichtermann@lbl.gov>		Initial alignment	Alignment Check/Update (if needed)	QA	Prodcution data		Processing				
pfRICH	Backward	Marco	ayk@bnl.gov		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 Acc.	Processing			
DIRC	Barrel	Marco	ayk@bnl.gov		Laser data?	?	?							
dRICH	Forward	updated	francesco.noferini@bo.infn.it, roberto.preghenella@bo.infn.it	Yes	DCR vs Threshold/Vbias(det params optimization): no beam ALCOR tests pulse run (TDC calibrations: 8 params per channel): no beam Pulse laser runs (channel time offset and time walk calibrations): no beam Global time offset with respect to bunch crossing (collisions) Noise masking (no beam)	Track based alignment Time alignment	?	High p tracks ~1hr of of production data?	Tracking/Vertexing	Data Acc. Dependen	Processin	Processing		
bEMC	Backward	Marco	munoz@jlab.org, hornt@cua.edu	Yes	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 Acc. Dependen	Data Acc.	Processin	Processing	
AstroPix	Barrel	Taku	sjoosten@anl.gov											
ScifiPb	Barrel	Taku				SiPM gain		?						
fEMC	Forward	Marco	tsai@physics.ucla.edu	Yes		Pi0 events energy scale		Pi0 di-photon resonance 2-3 day of production data. Minbias. 4b evt	None	Data Acc.	Data Acc.	Processin	Processing	
			akio@bnl.gov	Yes	LED, IV Scan		QA							Processing

Updates from SVT, MPGD, TOF, dRICH, bEMC, fEMC

Implement and benchmark the framework using detector use cases

DSCs
- Algorithms
- Inputs, frequency, data type
- interdependencies
- Calibration scripts

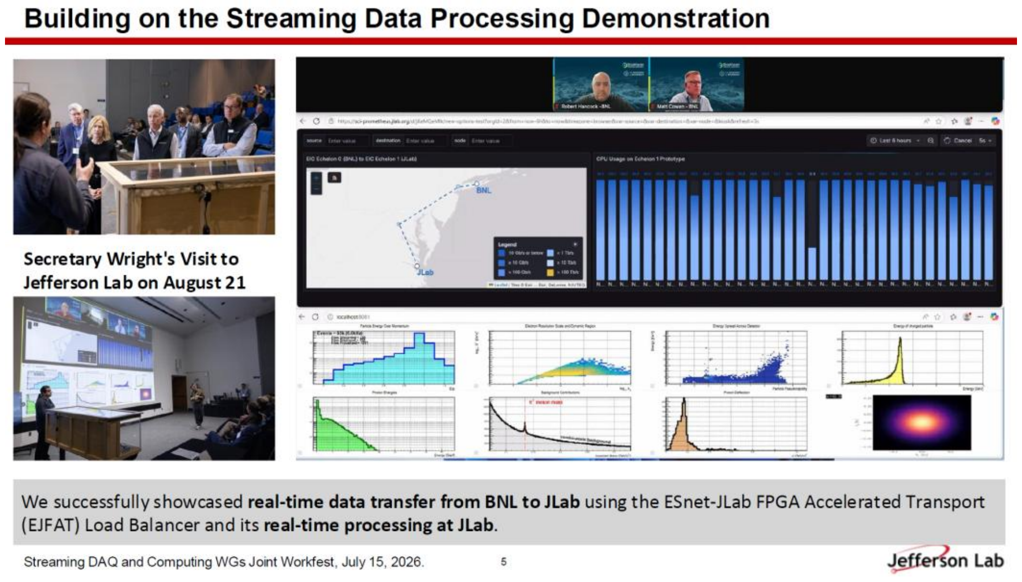
SRO-WG
- Calibration workflow in ePIC REC (JANA2)
- DB
- Framework ready for autonomous calibrations

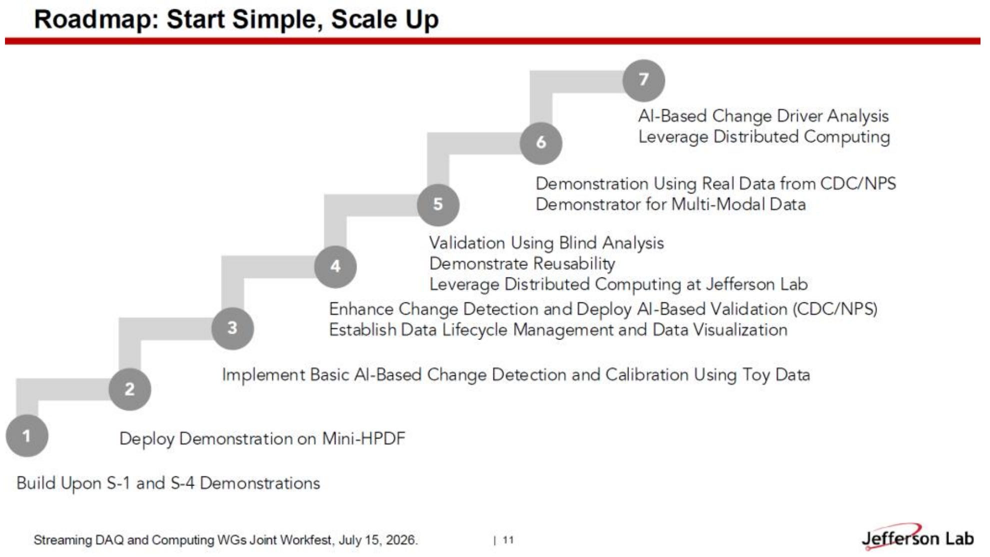
DSCs/SRO-WG
- stand alone tests
- demonstrators

USE CASES
- EECal
- SVT

SPINDLE project in JLab

- Streaming Physics INtelligence and Data Lifecycle Engine
- **Vision & Demonstration:** The SPINDLE project highlights the integration of Jefferson Lab's High Performance Data Facility (HPDF) with Nuclear Physics (NP) experiments, building on successful demonstrations of real-time streaming data transfer and processing between BNL and JLab
- **Core Technological Focus:** It addresses key technology gaps like streaming orchestration and workflow management, utilizing AI-driven closed-loop systems, FAIR data principles, and automated online calibration pipelines.
- **Implementation Strategy:** Using a 7-step scaling roadmap starting with a Mini-HPDF testbed, the team aims to enhance NP data pipelines while using nuclear physics requirements to guide the future evolution of HPDF.





Summary and Contacts

- We are seeing active progress across all layers—from custom ASIC development and front-end electronics, all the way to Echelon 0, 1, and 2, including large-scale workflow orchestration and streaming reconstruction.
- Looking ahead, as we move into the next phase of integrated detector tests, close collaboration will be absolutely vital. We must work hand-in-hand with the individual detector groups and the Reconstruction Working Group to ensure seamless end-to-end integration.

- Please join our regular meeting
  - **SRO Readout and Computing: Tuesday 9 am**
  - **Electronics and DAQ: Thursday 9 am.**
- Please subscribe (we usually use two mailing lists):
  - eic-projdet-compsw-l@lists.bnl.gov
  - eic-projdet-daq-l@lists.bnl.gov