BRIC Biomedical Research & Innovation Center

Scalable Streaming Readout For Dynamic Medical Imaging

JLab - FY25-26 - Applied Research - LDRD

9/16/2026

Cameron Clarke

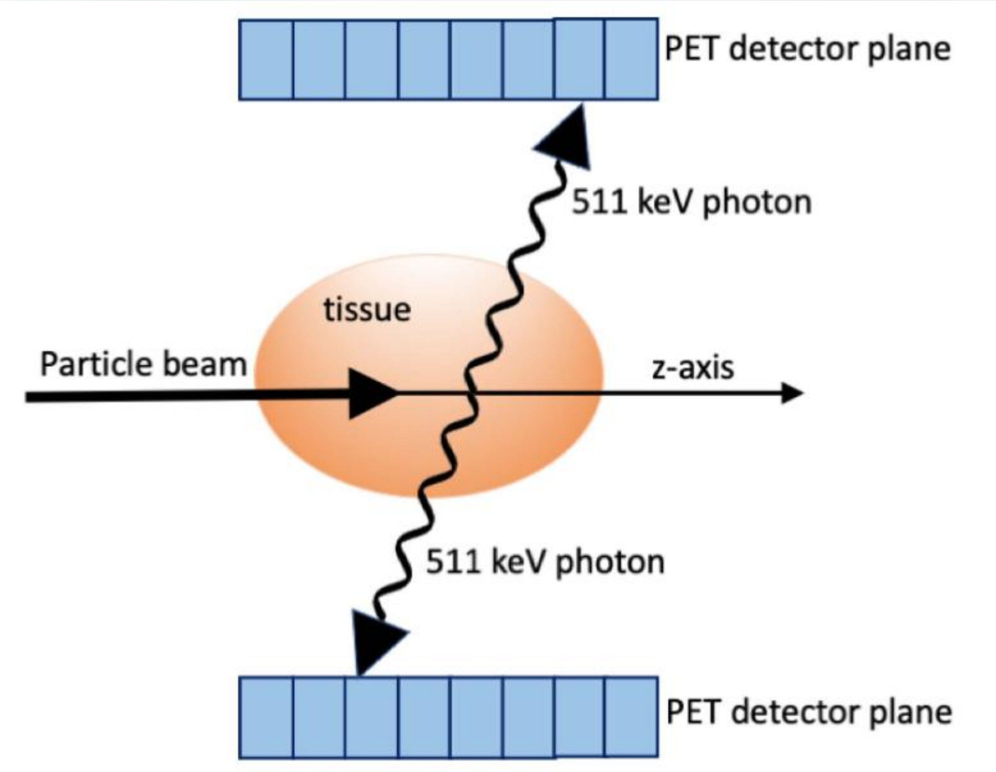
Detector Development Group

Jefferson Lab

U.S. DEPARTMENT of ENERGY

Outline

- Introduction
  - Nuclear and Accelerator context at JLab
  - The Biomedical Research and Innovation Center (BRIC)
- Streaming Readout for PET Imaging
- LDRD SRO Project – FY25+FY26
- Next Steps



PET Imaging cartoon for radiotherapy monitoring. Adapted from Kraan et al. (2024)

Kraan, Aafke Christine, and Alberto Del Guerra. "Technological developments and future perspectives in particle therapy: A topical review." IEEE Transactions on Radiation and Plasma Medical Sciences 8, no. 5 (2024): 453-481.

Introduction – Nuclear and Accelerator context at JLab

The Thomas Jefferson National Accelerator Facility

- Nuclear physics to medicine connection, spanning groups
  - Fast Electronics and DAQ group
  - Experimental Physics Software and Computing Infrastructure group
  - Detector Development group
- Streaming Readout DAQ and Analysis
  - JLab 12 GeV upgrade platform --> EIC next gen
  - New paradigm of big-data + rapidly editable DAQ
  - Flash ADCs for digitizing triggerless signals
  - VXS Trigger Processor data pipelining
  - Next-gen analysis engines (JANA2, ERSAP, etc.)
  - ES-NET accelerated load balancing (EJFAT)
- JLab Biomedical Research and Innovation Center (BRIC) formed to formally capitalize on latent capacity

Top left: A new SRF accelerator cavity assembly ready for installation
Top right: Ground level view of the experimental Hall A spectrometer
Bottom: Aerial view of CEBAF and experimental hall bunkers

Biomedical Research and Innovation Center

BRIC Recently Formed: www.jlab.org/BRIC

⇒ Formed in March, 2023

⇒ To be a central hub at JLab:

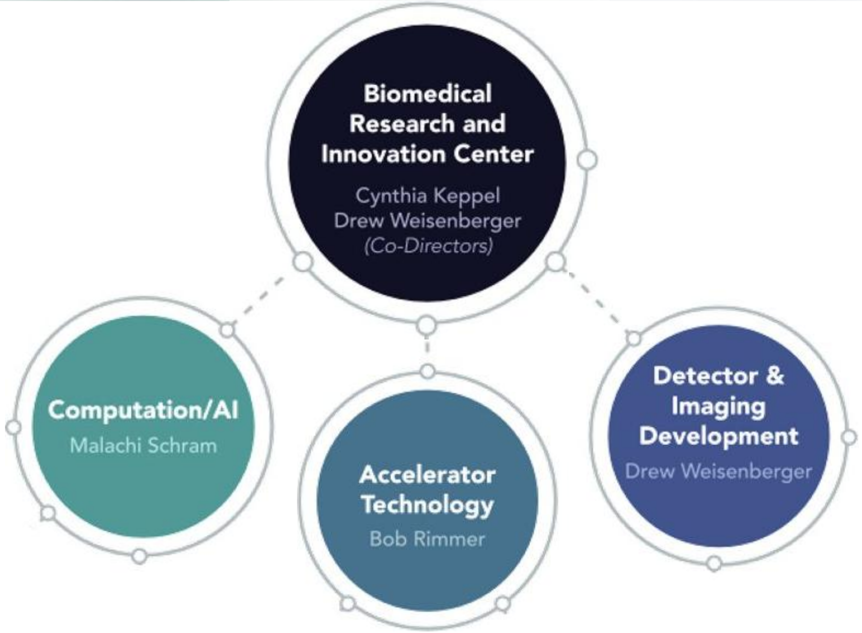
- Highlight to internal and external stakeholders
- Health, biological and medical applications
- Relevant to Jefferson Lab's expertise

⇒ To provide:

- Supportive, collaborative environment
- So biomedical efforts can thrive and expand
- Establish and maintain NIH/DOE connections

⇒ I joined in 2024 to support BRIC efforts

- Work in Radiation Detector and Imaging Group
- Previously did PCCT at Canon, Hall A PhD in 2021



BRIC Ribbon Cutting, March 24, 2023

Streaming Readout for PET Imaging

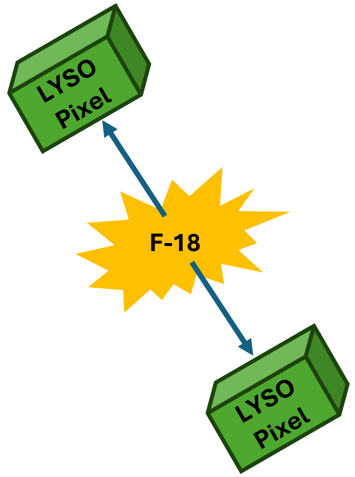
Jefferson Lab

Applying Modern Nuclear Physics DAQ to triggerless imaging

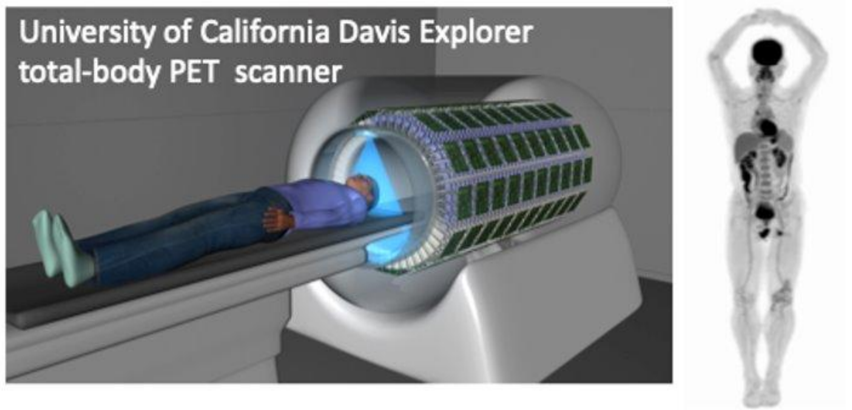
- Permits many detectors for improved sensitivity for TB-PET imaging
- Requires distributed computing and in-software coincidence logic

Traditional PET	SRO-PET
Scintillator	Scintillator
Sensor	Sensor
FE-electronics	ASICs (triggerless) = FE-electronics + DAQ with serial digital output
DAQ electronics	
Coincident electronics	Stream Aggregator + Optical Ethernet network
Computer image reconstruction	Computer (SRO-DAQ software) and Image reconstruction

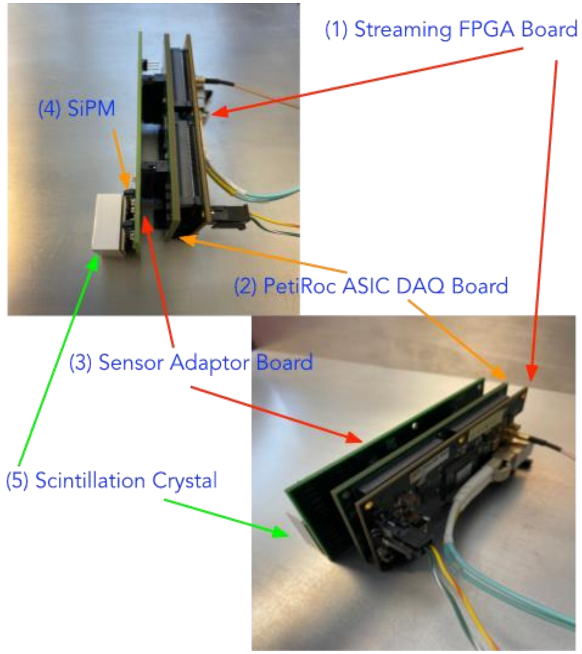
Triggered vs. Streaming Paradigm



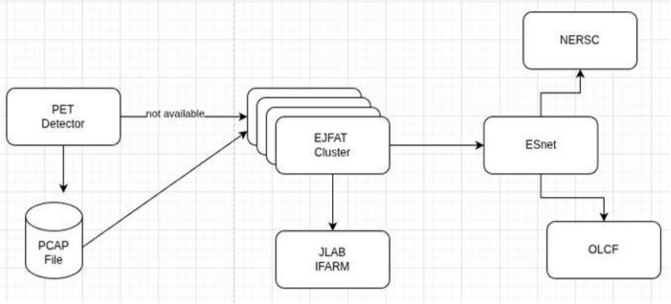
Cartoon of annihilation and 511 keV gammas to scintillators for PET imaging



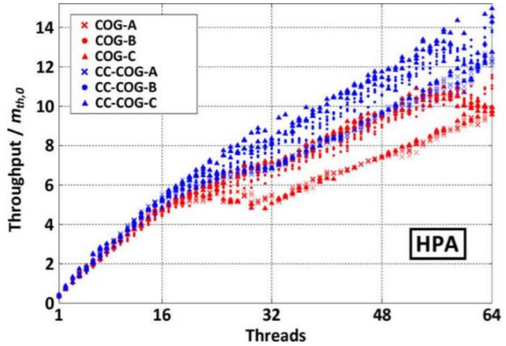
Rendering of UC Davis EXPLORER system (left) and a representative total-body PET scan (right)



Pre-LDRD Prototype System



Potential Distributed Streaming Configuration



From Goldschmidt, et al. (2013)

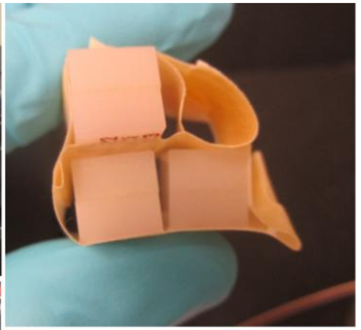
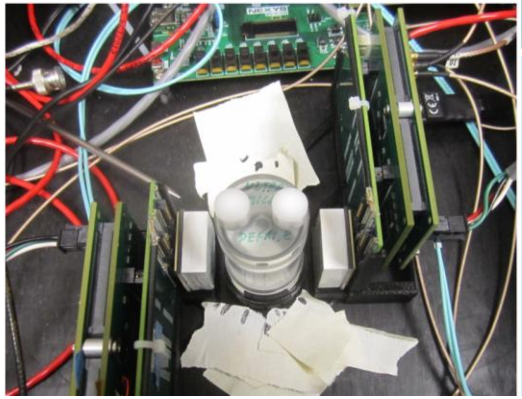
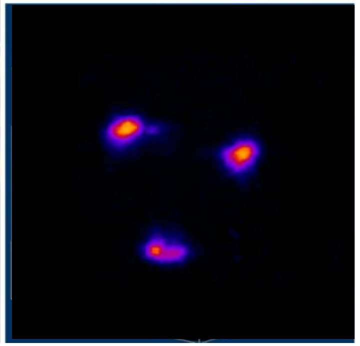
Goal:
Scalable distributed data analysis matching Philips' "EXPLORER" developments

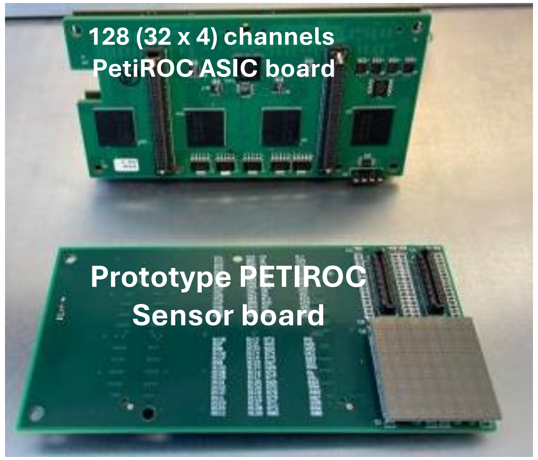
Streaming Read-Out DAQ and Analysis pre-LDRD

SRO DAQ for triggerless PET

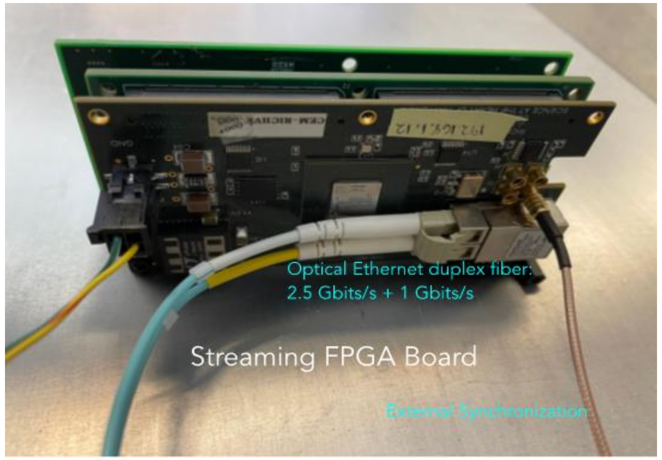
- Prototype tested at UMAB Core Imaging Facility
- Pre-LDRD prototype “works” but not “great”
- Struggles at even a low data-event rate
- Motivates: shift to FPGA digitization and timeslices

UMAB Core Imaging Facility:
Siemens Inveon PET/CT (left)
and JLab SRO PET prototype (right)

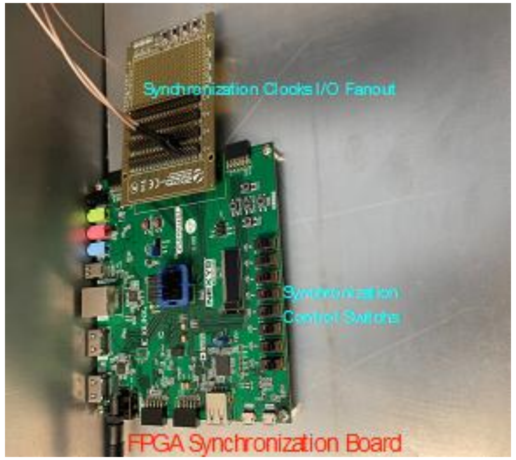







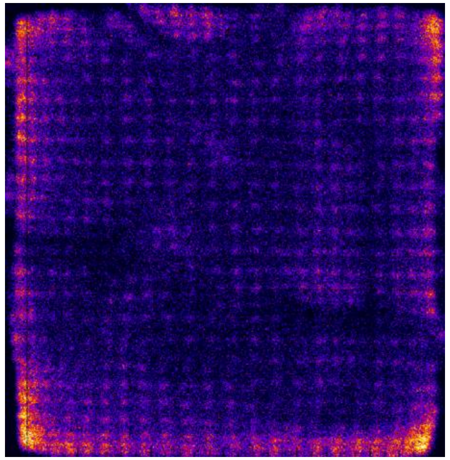
Prototype SiPM + ASIC boards



FPGA stream producing board



FPGA sync board

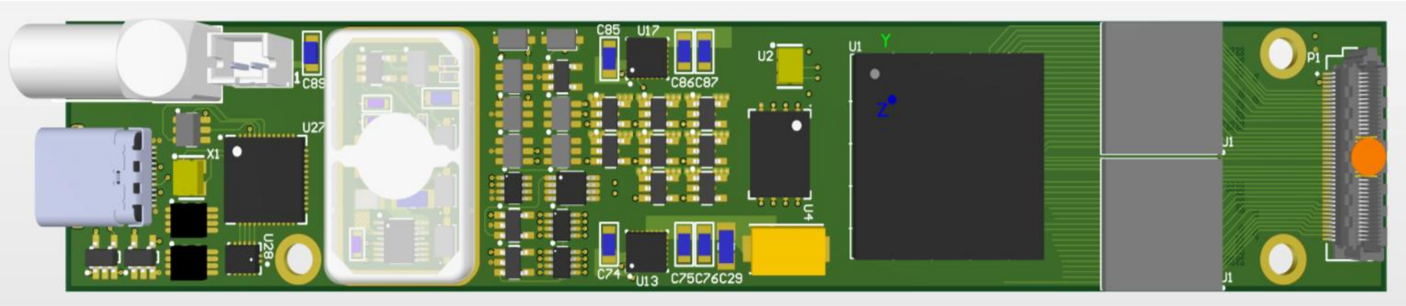


Too-fine crystals “Flood Map”

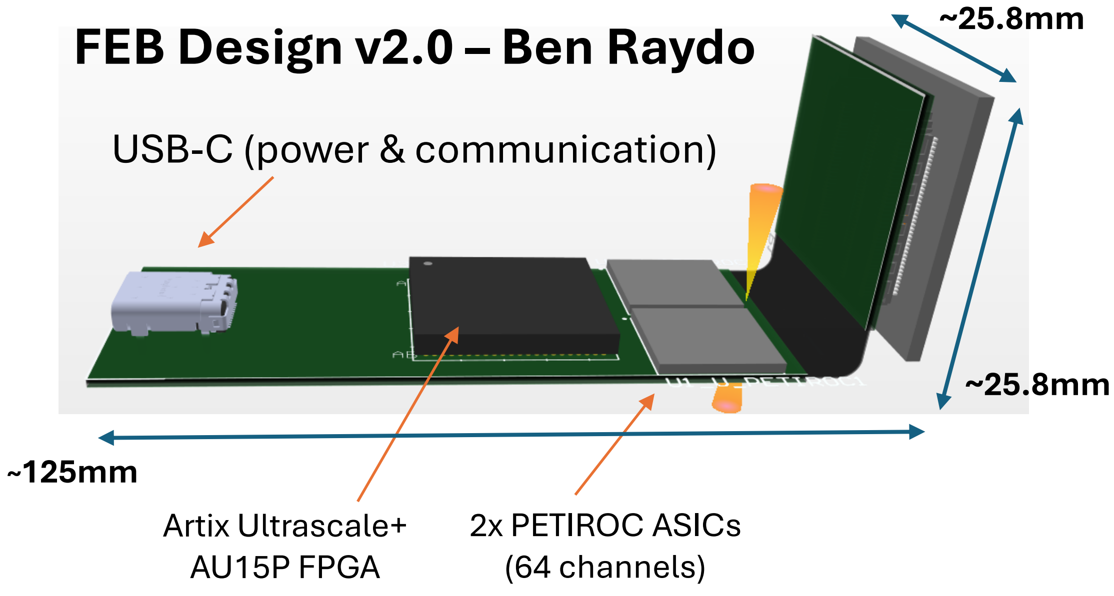
LDRD SRO Project – FY25+FY26

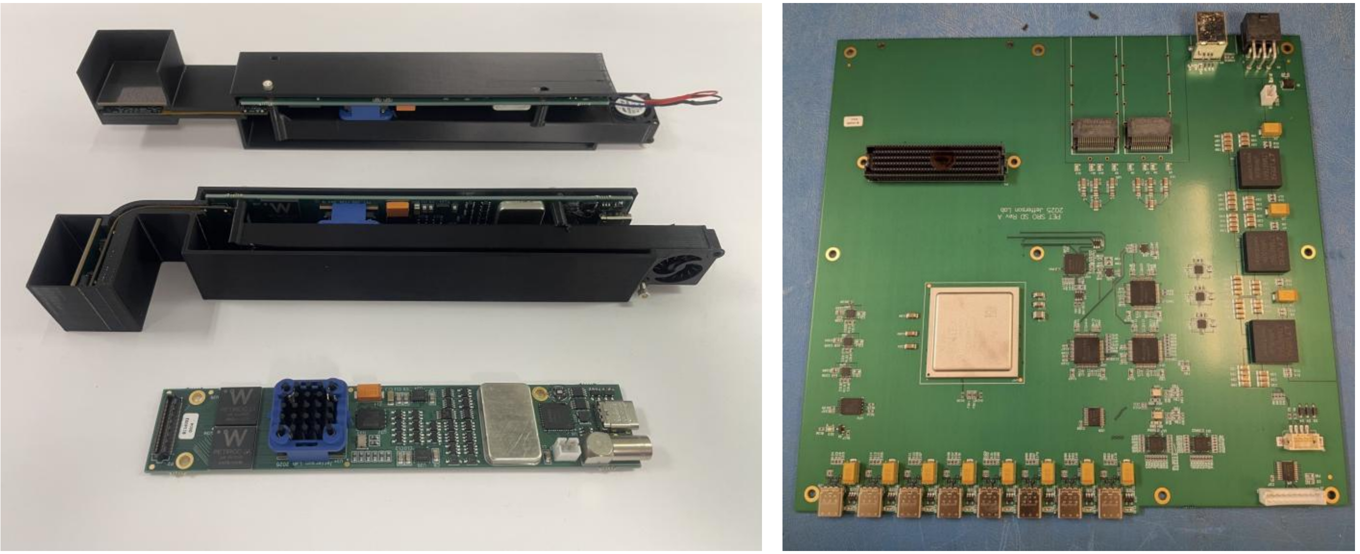
SRO DAQ for PET/triggerless

- Designed a new modular front-end board (FEB) with all active components on-PCB
- New signal/sync distribution board (SD) with chainable distributed global clock
- FEBs and SD produce local power distribution and 10 Gbps data streams



Front-end Board CAD: SiPM connector (far right), ASICs (right), FPGA (right middle), and power (left), and USB-C ethernet (far left)





New modular FEBs (left), signal and sync distribution board (right)

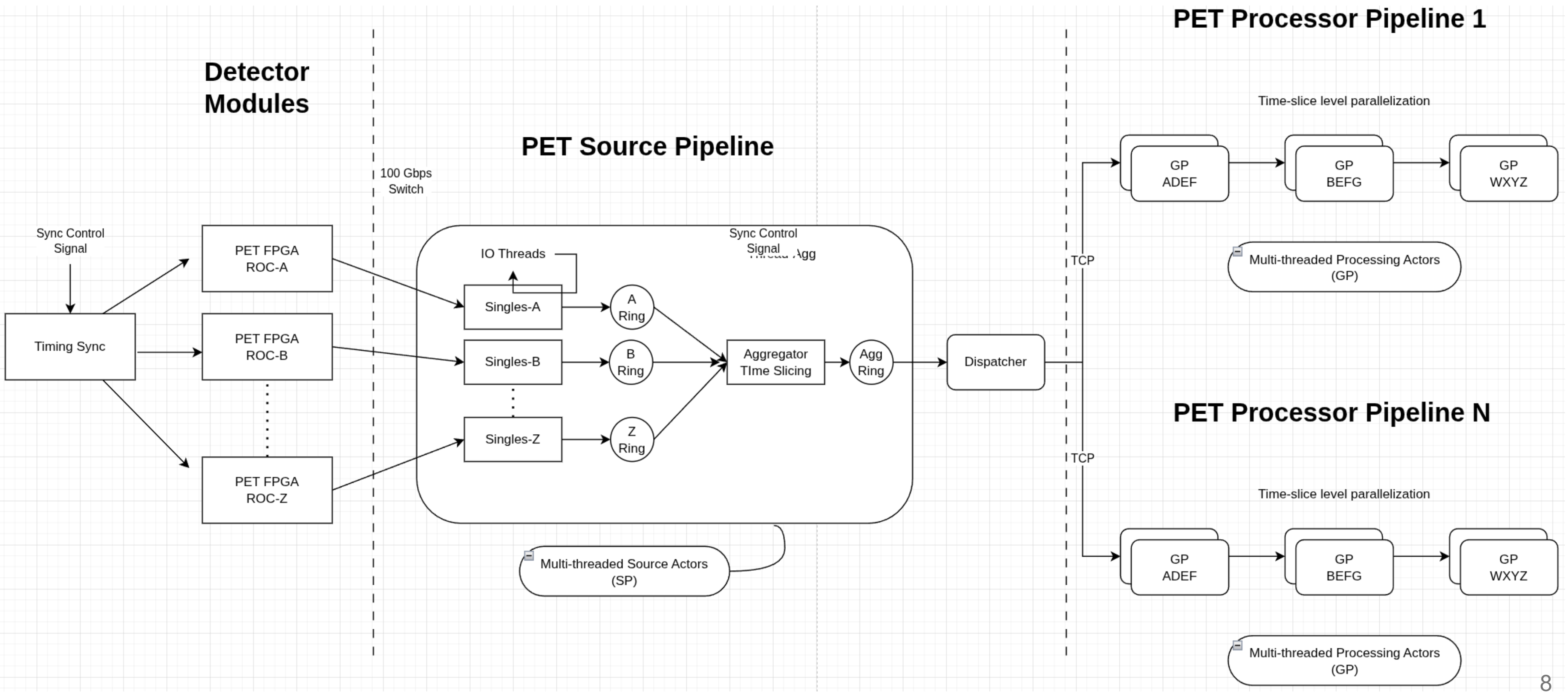
LDRD SRO Project – FY25+FY26

SRO DAQ for PET/triggerless

- JLab's Kafka-esque platform: *Environment for Real-time Streaming, Acquisition, and Processing (ERSAP)*
- Design well-buffered (internal), vertical (multi-threading) and horizontal (multi-node) architectures
- Implement ES-NET JLab Accelerated Transport (EJFAT) load balancer FPGA system for scaling

Updated ERSAP-powered streaming architecture:

- **Factorized**: micro-services actors
- **Buffer scaling**: inputs + outputs wait for idle CPU
- **Vertical scaling**: multi-threading actors
- **Horizontal scaling**: multi-node
- **Recombination**: (not shown) enables horizontal parallelization everywhere
- **Outputs**:
  - Prometheus.io metrics
  - Grafana monitoring
  - Kmax GUI monitoring
  - Calibration actors
  - Near-real-time "coincidence" line-pairs for PET reconstructions



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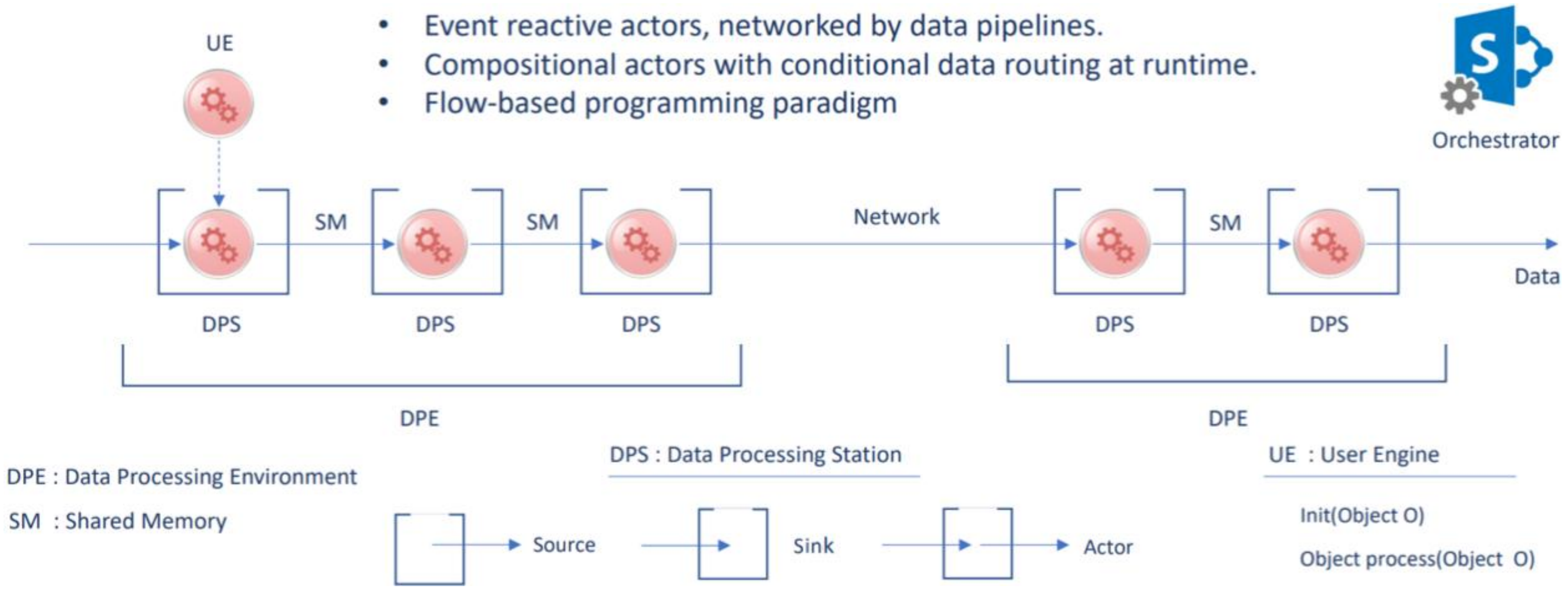

Schematic diagram of the ERSAP microservices architecture.

LDRD SRO Project – FY25+FY26

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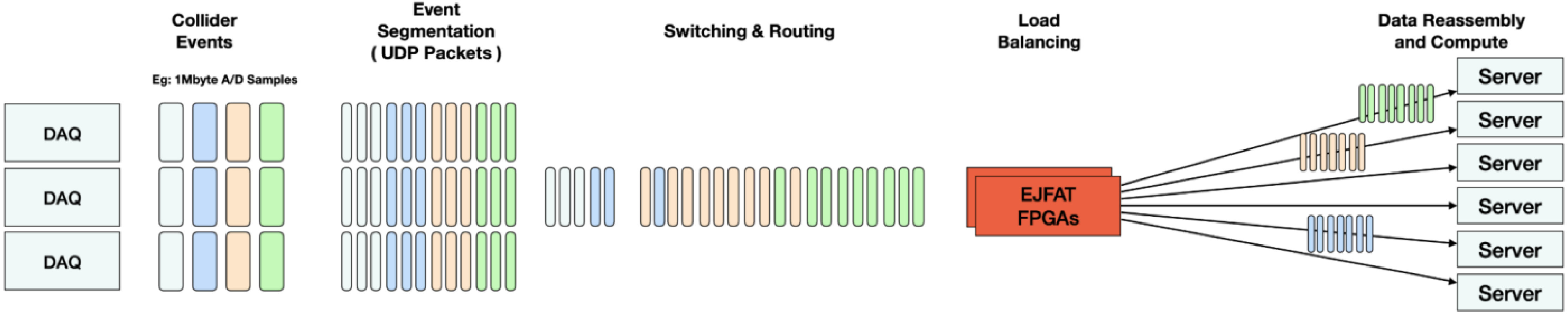


EJFAT implementation:

- Typical use case example schematic for ESnet-JLab FPGA Accelerated Transport (EJFAT).
- Deployed from JLab's EJFAT FPGA Cluster to Berkeley Lab's NERSC Perlmutter Cluster.
- Utilizes ES-NET Level-3 VPN for up-to 400 Gbps maximum bandwidth.

LDRD SRO Project – FY25+FY26

Jefferson Lab

Deployment at U Maryland School of Medicine – FDG tests with PET/CT reference Sept. 3rd-11th 2026

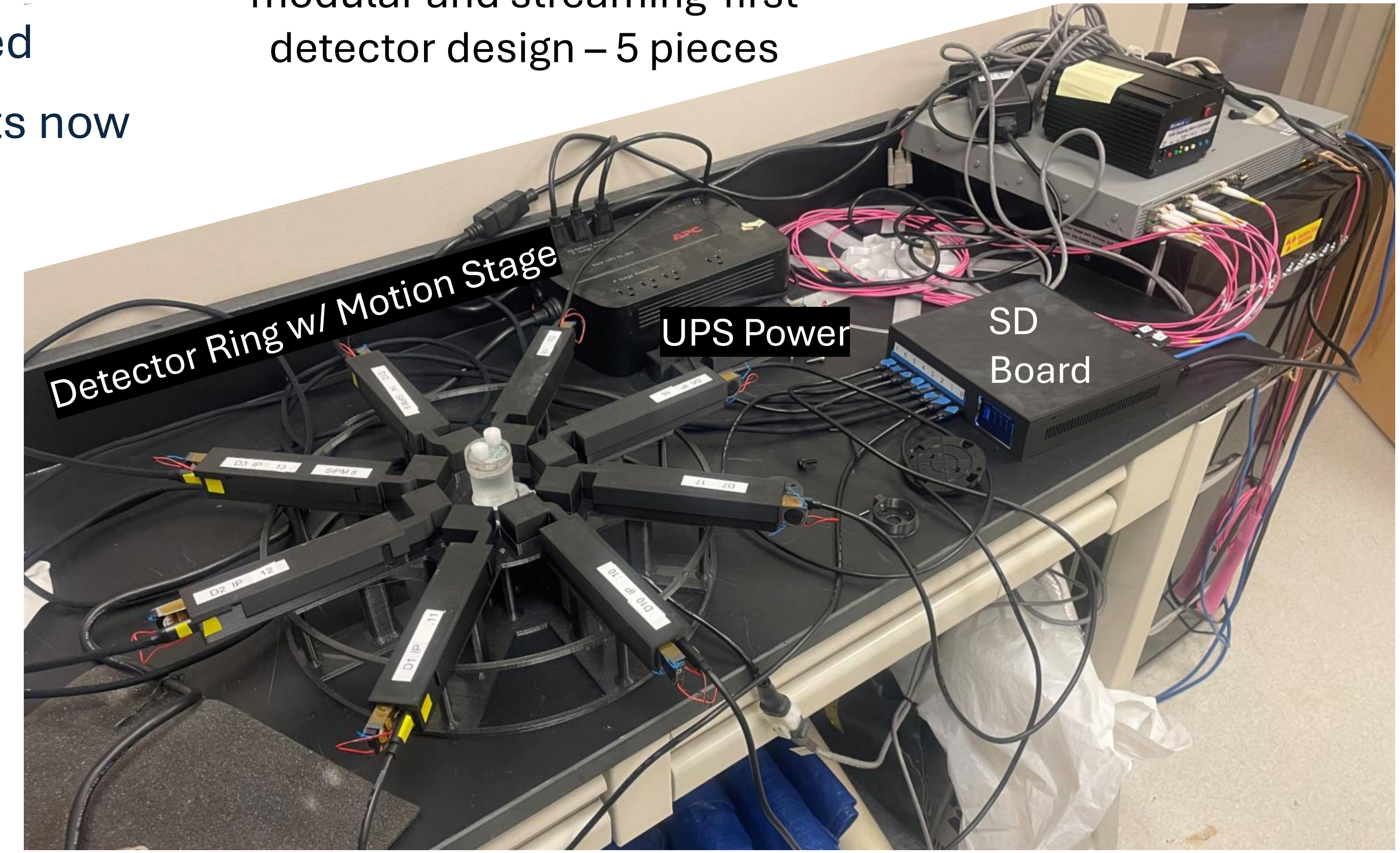
- New Streaming Front-End Boards stressed
- Single-node data ingest and processing works
- High-rate data throughput demonstrated
- Replaying raw data for HPC scaling tests now

New tests at U Maryland:
Simplified installation due to modular and streaming-first detector design – 5 pieces

- Remote Controlled Motion Controller (on top of)
- 100 Gbps Network Switch

Transports on one (1) cart (!)

Ultra-Micro Hotspot Resolution Phantom



"Pre-clinical" PET Ring - Power - Sync - Motion Controller - 100 Gbps Switch

LDRD SRO Project – FY25+FY26

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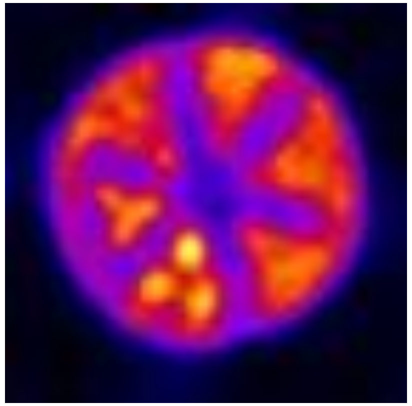
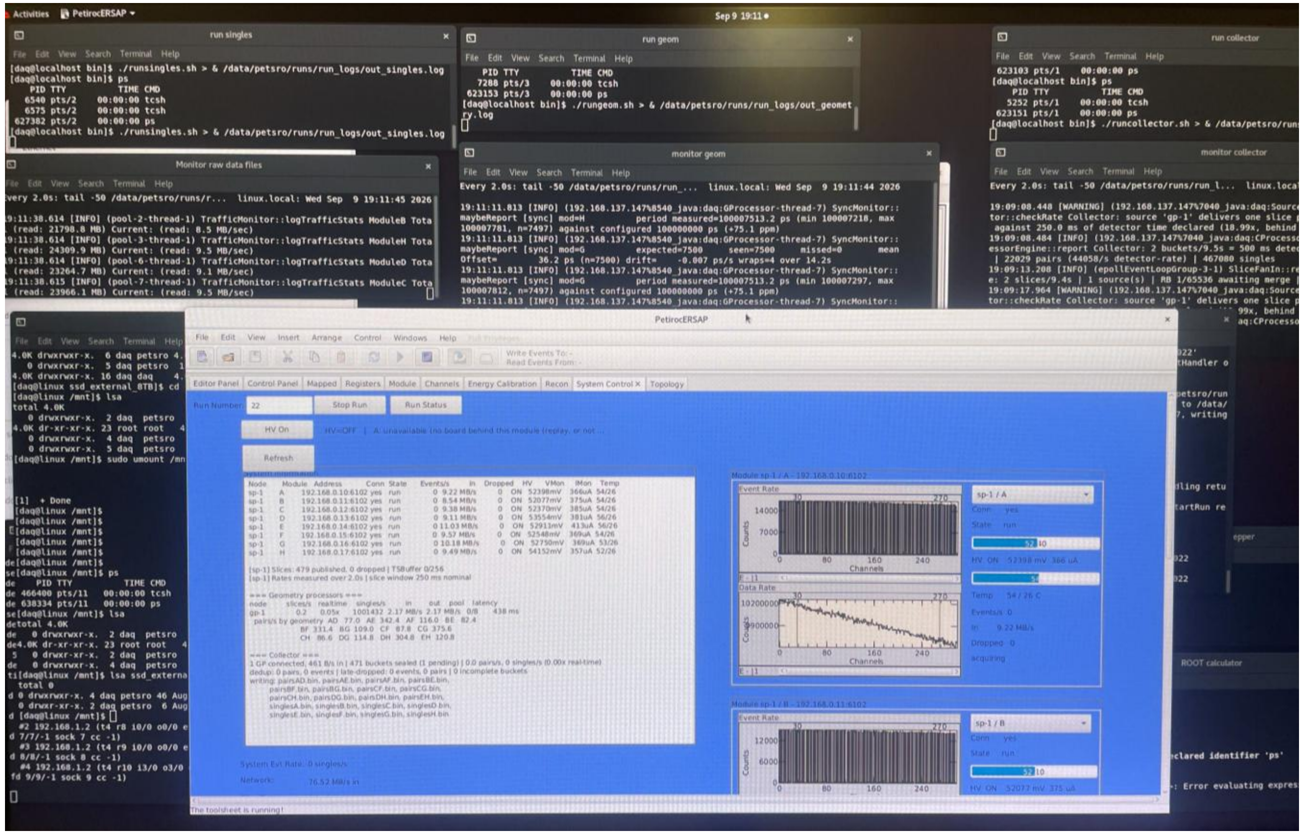
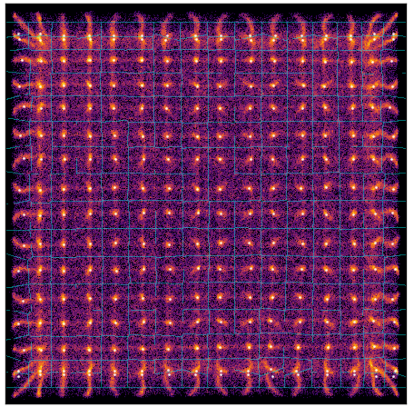
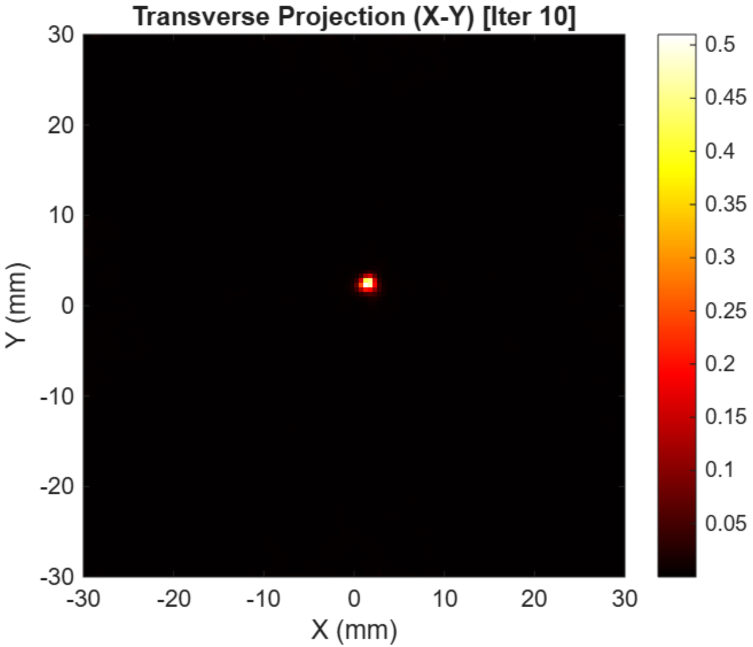
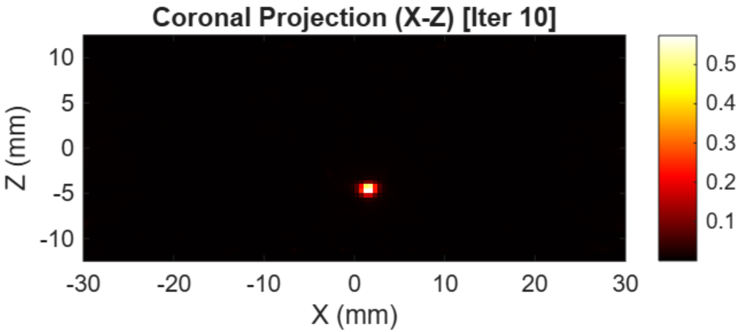






- ➢ Hot Rod phantom reconstruction
- ➢ 16x16 crystal raw hit data flood map
- ➢ Point source reconstruction views



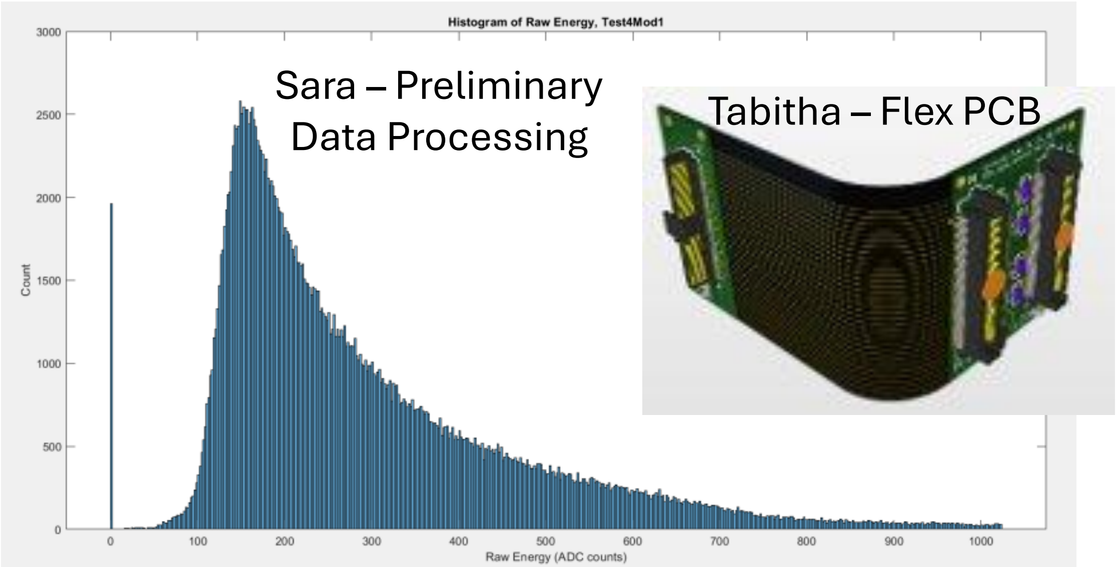


- ➢ Manually controlled DAQ interface (Kmax GUI)
- ➢ Real-time data stream processing (~10 terminals)
- ➢ Offline PET image reconstruction

LDRD SRO Project – FY25+FY26

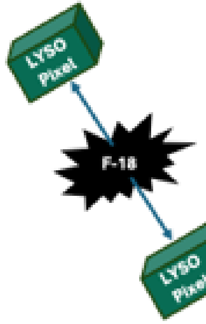
Students

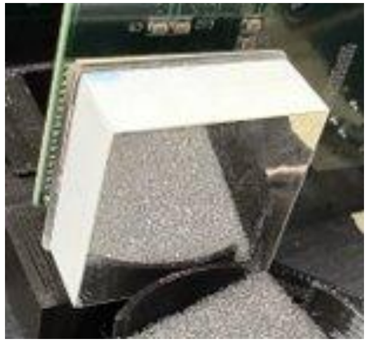
- Intern: Sara Emigholz – Verifying PET Data Processing – 2024 Summer
- High School: Malini Dharni – Motion Platform development – 2024-2025 School Year
- SULI: Jaideep Saran – Simulating PET Detectors and Rings – 2025 Summer
- SULI: Tabitha Gwaltney – Designing PCB for PET detectors – 2025 Summer
- High School: Breanna DeFonzo – Optical scintillation modeling – 2025-2026 School Year
- SULI: Bennett Lamb – Designing Streaming-Enabled Experiments – 2026 Fall (current)



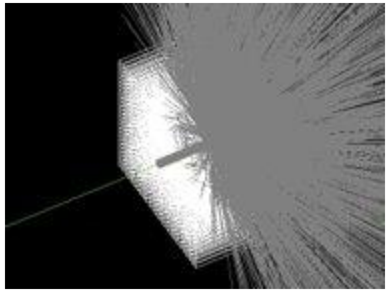
Sara – Preliminary Data Processing

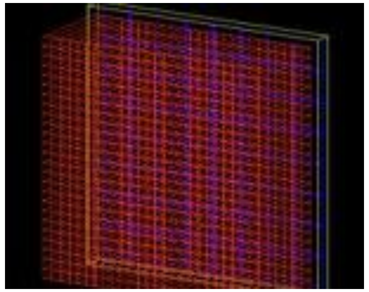
Tabitha – Flex PCB





Jaideep – Simulations for realistic “fake” stress-testing data





Next Steps

- Potential Collaborations in the works
  - University of Maryland Baltimore School of Medicine – Next-gen PET Imaging Symposium (Sept. 18th)
  - Jagiellonian University – International total-body PET collaboration explorations underway
  - Virginia Commonwealth University – invitation to utilize PET hot lab for future dynamic imaging tests
  - Einstein Hospital + Thomas Jefferson U + MikroDose LLC + U of Sevilla – Streaming Microdosimeters
- Proposed work
  - JLab LDRD FY27 proposal – Streaming FEB detectors and analysis architecture for accelerator steering
- Funded work
  - JLab LDRD FY26 in-progress – Modifying streaming FEB detectors to read out GEM tracking detectors
- Patents
  - Patent pending – Scalable ERSAP-based streaming architecture for PET imaging concept and embodiment
  - Provisional submitted – Distributed synchronization system concept and embodiment
- Papers and conferences
  - Distributed computing performance, optimizations, and suitability for Total Body PET scale at O(~10,000) detectors
  - Image quality metrics from streaming PET pre-clinical scanner with Siemens Inveon PET/CT benchmark
  - Integrated FEB + Sync Distribution + Networking instrumentation report
- Industry Tech Transfer
  - Using results to seek contacts from leading university PET groups and their Industry partners – will consider Energy I-CORP