FY 2024 LDRD Proposal

Program: DRD

Proposal Title: Streaming Readout Real-Time Development and Testing Platform

Principal Investigator, Division: David Lawrence , CST

Co-Investigator:

Contributors: Vardan Gyurjyan, CST
Xinxin "Cissie" Mei, CST

Advisors/consultants: Marco Battaglieri, INFN
Markus Diefenthaler, ENP
Sergey Furletov, ENP
Sergey Boyarinov, ENP

Budget ($K)	Total	FY24	FY25	FY26
	$545k	$271k	$274k	N/A

Streaming Readout Real-Time Development and Testing Platform

David Lawrence

1. Proposal Abstract

We will develop a full-scale design, testing, and validation platform for Streaming Readout Data Acquisition (SRO) systems. It will be capable of connecting an experimental Hall to the JLab Computer Center, HPDF, or an offsite compute resource (e.g. NERSC). This will be in support of the JLab S&T vision as described in the TJNAF 2022 annual plan [1]. The platform will combine existing hardware and software components so that complete SRO systems can be configured and tested at scale. Complete SRO systems will include receiving data from the Front End Electronics (FEE), applying multiple levels of data filters, storage components, calibration components, and reconstruction components. The proposed platform will allow full SRO ecosystems to be developed and tested at high bandwidth using existing hardware components at JLab (networks, CPUs, GPUs, FPGAs, and storage) and existing software components (ERSAP, JANA, CLARA, PHASM, EJFAT/IRIAD, JIRIAF). Components that do not exist will have software simulators inserted to provide an *effects-based* simulation. Complete monitoring of all components in the system will be developed to identify pain points and help determine resources that will be needed to implement final system designs. This will be the first time many of these components, some of which were developed specifically for SRO, will be combined into a single SRO system. This fills a critical gap in the development and deployment of full streaming systems for future JLab experiments like SoLID [2], CLAS12 operations at high luminosity [11] ,TDIS [3], and ePIC [4] at EIC.

2. Background and Significance

A design and validation platform is needed to fully realize SRO systems for future experiments like SoLID, CLAS12, TDIS, and ePIC. SRO systems will include data reduction, consolidation, and filtering algorithms. Some will be run close to the detector and some will be run remotely using high bandwidth network connections. Some algorithms will benefit from the use of heterogeneous hardware such as GPUs and FPGAs while some may need large numbers of CPU cores spread over multiple nodes. Different experiments will draw from a common set of these software and hardware components, but the exact configuration will be unique to each experiment. The proposed work would develop a platform where these various components can be connected into a complete system for the purposes of developing, testing, and validation of designs before investing heavily in hardware or in experiment-specific software development. Figures 1 and 2 illustrate a simple configuration that could be implemented by the platform. A major part of the platform will be a monitoring system that will allow evaluation of the performance of each individual component. This will allow not only evaluation of the system as a whole, but will point experimenters to components where a different technology choice may be more appropriate for their specific experiment. It is noted that such a monitoring system would naturally be useful to fully deployed SRO systems during running experiments as well.

One of the most significant benefits of an SRO system when compared to a traditional triggered system is the ability to base decisions on which data to keep and which to discard using reconstructed values [10]. For example, charged particle tracking has historically been difficult to include in a triggered system due to the slowness of the detector (e.g. drift chambers) and the expensive computation that is needed within the short latency times required by front end electronics hardware [5]. A streaming system eliminates these issues by deferring the decision until the data is in a compute node where latency is not an issue. Reconstructed values though will require some level of calibration. Thus, calibration components and data pools will be necessary components of most SRO systems. The proposed platform will include these so that their effects can be evaluated on a fully designed system. A platform that allows a complete SRO system (including simulated components) is needed to test advanced algorithms [9] to ensure performance while in a full SRO ecosystem.

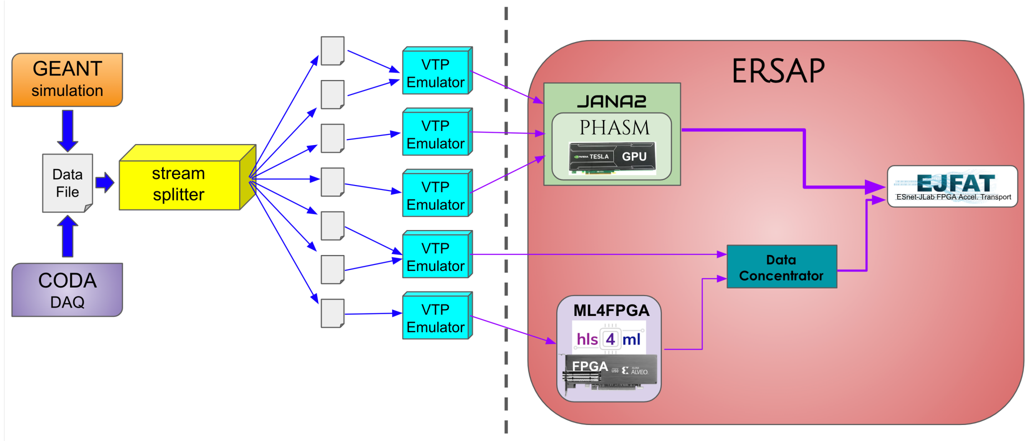


Figure 1: The figure above is an illustration of the first half of a simple configuration the platform would support. (See Figure 2 for the second half). Components on the left side of the dashed line would make up the multi-stream source that could be replaced with live data streams from a real detector. To the right of the dashed line is a multi-architectural configuration that communicates the filtered and partially processed data to a remote site via EJFAT.

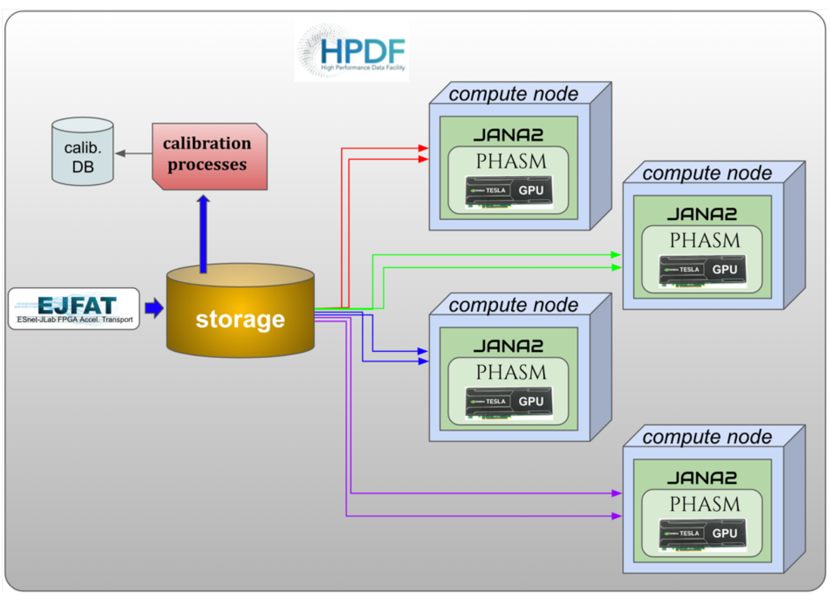


Figure 2: The figure above represents an example configuration supported by the platform for the remote site. Here, data received from EJFAT is sent to temporary storage while near-real-time calibrations are performed. Once the calibrations are ready, data is distributed to the compute resources which may also implement multiple compute architectures.

JLab is the appropriate place to develop such a platform since copious data are available from current running experiments and several software and hardware tools developed at JLab will be connected by this effort. This project is one part of a natural continuation of the Streaming Grand Challenge [7]. Work has already been done at JLab on a small scale to implement a fully working SRO system [8]. However, a much larger push is needed to move this to the scale of future JLab experiments. Moreover, considering the current physics program and the number of scheduled experiments, JLab represents the ideal test bed for the final system in real conditions. It is noted that CLAS12 already has a full set of VTP hardware and upcoming network upgrades will provide for the full infrastructure to stream data. They are also considering a GPU-based tracking system as part of a level-3 trigger design. This could be incorporated as a component of the proposed platform.

- **Goal:**
  Develop real-time design, testing and validation platform for streaming readout systems for future JLab experiments leveraging on the existing systems developed at JLab and developing the ones that are missing.

- **Objectives:**
  1. Develop software platform capable of configuring and launching various existing software and hardware **SRO** components as a **complete chain**.
  2. Develop **monitoring** system capable of monitoring performance of all components specifically for identifying **bandwidth** and **compute bottlenecks**.
  3. Develop proxy components that can effectively **simulate** performance of specific **hardware** or **software components** that do not currently exist.
  4. Develop **multi-stream software source** that can take existing experimental or simulated data and broadcast it into the system with time structure and stream count that mimics a running experiment.
  5. Configure a system comparable in size and bandwidth to a future JLab experiment (e.g. SoLID) which includes a **400Gbps** transfer requirement from the counting house to the Computer Center, at least one **FPGA** component and one **GPU** component for at-scale testing.
  6. Identify potential issues relevant to a future **HPDF** in receiving and processing SRO data, including from **remote**, non-JLab **experiments**.

- **How this helps position JLab for the future**:
  As new experiments commence and data volumes rapidly increase, the Nuclear Physics community is actively exploring the next generation of data processing and analysis workflows to optimize scientific output. A key focus of this discussion is achieving seamless data processing from detector readout to physics analysis and enabling the rapid turnaround of data for publications through advanced scientific computing.

  Jefferson Lab has been at the forefront of these discussions and has made substantial investments in the development of the next generation of data processing and analysis workflows. Many essential components required for seamless data processing and rapid data turnaround, such as streaming readout, heterogeneous computing, and AI/ML capabilities, are already available. Jefferson Lab has also submitted a proposal for a High-Performance Data Facility, aimed at facilitating heterogeneous computing and enabling next-generation data analysis for the wider scientific community.

  Our project aims to provide a dedicated platform for the design, testing, and validation of data processing and analysis workflows specifically tailored for streaming readout experiments. Leveraging the prior investments made by Jefferson Lab, our project will interconnect various components through the proposed platform. This initiative will greatly facilitate the design, testing, and validation of streaming readout experiments at CEBAF12, CEBAF20+, and EIC, playing a crucial role in integrating upcoming data-intensive experiments with advanced scientific computing. The primary driver behind this endeavor is ensuring the rapid turnaround of data for publications, thereby solidifying Jefferson Lab's position as the preeminent laboratory for experimental Nuclear Physics in the coming decades.

Furthermore, this project will significantly contribute to the accessibility of experimental results and foster a research model where experiment and theory work hand in hand. By establishing a rapid cycle of new experimental measurements and advances in phenomenology and fundamental theory, Jefferson Lab will emerge as a leader in the collaborative progress of experimental and theoretical Nuclear Physics. Lastly, the project aligns with Jefferson Lab's new role as a laboratory for advanced scientific computing research. The research and development conducted on streaming readout, heterogeneous computing, AI/ML, and next-generation workflows for data processing and analysis are closely interconnected with various research topics within DOE ASCR and have broader applications across other scientific disciplines. This includes those that would utilize an HPDF facility.

- **Distinction from JIRIAF project:**
  It is recognized that the JIRIAF LDRD project which is being proposed for renewal this year has aspects which may seem similar to this proposal. Especially for anyone not familiar with the subject matter. Distinctions between the two are clarified here.

  - **Identification of bottlenecks:** Current and next-generation experiments involve intricate workflows for processing and analyzing recorded data. The JIRIAF project aims to effectively manage these workflows and dynamically monitor their components to anticipate any potential bottlenecks *during production running*. The objective of the project outlined in this proposal is to develop an expert platform capable of *designing and optimizing* workflows for *future* streaming readout experiments. This platform will encompass all aspects of computing and data workflows in both current and next-generation experiments. By conducting large-scale tests, the platform will identify potential bottlenecks in the designs and optimize them for performance and cost efficiency. Moreover, the platform will provide valuable insights into the computing resources required, aiding in purchasing decisions or planning purposes.

  - **Platform simulation components vs. JIRIAF physical component agent**: The simulation components that will be developed under the current proposal would be configurable to either *exercise*, or effectively *simulate* the component. For example, floating point operations would actually be executed by the simulation component. By contrast, the JIRIAF project will create an *agent* for each component. The agent itself will not use any significant resources, but instead will continuously gather metadata information from a real component that is part of the JIRIAF workflow. Thus, JIRIAF will *monitor* a production workflow in a digital-twin like way while this proposal will implement a platform that actually *stresses the hardware* in a way akin to a data challenge.

3. Research Plan

- **Approach:**

Objective 1: **Process Launcher:** The software that will be used to configure and launch each component does not itself need to be highly performant. The highly performant and specialized codes will already be encapsulated in the components themselves that that will have been developed outside of this project (sans objectives 3 and 4 below). The most appropriate language for this will be something like python3 or possibly julia. The configurations themselves should be expressible in a static file format to allow other tools for editing and visualization of the configurations to be developed in the future. A configuration format such as YAML would be a good choice as it is widely supported across numerous programming languages. For inter-process communication that will need to support both local and wide area networks, ZeroMQ or a similarly common, open source product will be used.

Objective 2: **Monitoring System:** The monitoring system will be developed using an appropriate set of existing free or open source tools such as Prometheus, and Grafana. Both Prometheus and Grafana are already in use in other places at JLab which will allow leveraging local expertise, installations, and network configurations. Additional visualization tools will need to be developed as part of this project. These will be web-based were appropriate, though some specialized tools may also be needed. Advanced monitoring for continuous data validation will also be needed. Use of the AI/ML based Hydra [6] monitoring system would be appropriate for this purpose.

Objective 3: **Proxy Components:** The proxy components that will allow effects-based simulations will be developed using a performant language such as C++. These components will need to read in and write out data streams to mimic the operation of the real component that does not currently exist. For example, a proxy component that is used to represent a reconstruction algorithm that is expected to read data from a single stream, perform X Mflops/kB, and write roughly 1/2 of the data to the output. The proxy would need to understand the header information of the incoming stream enough to modify it for the output, but would not need to understand the payload. It would also need to exercise enough dummy operations on the CPU cores to mimic the X Mflops/kB it was configured for.

Objective 4: **Multi-stream Event Source:** The multi-stream event source will need to be written in a highly performant language such as C++ or possibly Java. Data will be read from a file that is either in an experimental raw data format such as EVIO or simulated event data format such as ROOT. For data that is not already in a format that includes DAQ system indexing (e.g. simulated data) it will need to apply an inverse translation table to convert from detector component indexing. The DAQ indexing is needed to identify the crate/slot/channel element the data would have originated from so it can be sent over the appropriate output stream so as to mimic live data. This component will require multiple processes spread over multiple compute nodes in close coordination in order to achieve the high bandwidths needed.

Objective 5: **High Bandwidth Test:** Configuring a full scale system that includes both real and proxy components and testing it at high bandwidth is necessary to demonstrate the platform's core functionality. Current expectations are to have a 400Gbps link available between the Hall A,B,C counting house and the Computer Center in CEBAF Center sometime in FY2024. The high speed testing will be coordinated to occur when the beam is down so that the full bandwidth will be available for the testing periods. The SoLID experiment serves as an example of the type of high bandwidth experiments being anticipated to run at JLab in the future. It will then serve as a useful guide for the testing configuration, even if the configuration is not an exact match for SoLID. There are currently eight U280 FPGA cards in the Computer Center purchased for use with the EJFAT project which would be available to use for these tests. Similarly, the Scientific Computing farm will have a few dozen GPUs (mostly Tesla T4's) available that could also be utilized for these tests. Utilizing real hardware components will be an important part of the platform and so will need to be included for the full scale configuration testing. We will utilize existing components developed outside of this project to exercise the heterogeneous components. For example, PHASM, CLAS12 tracking, and the EIC R&D project: ML4FPGA [12].

Objective 6: **Insights for HPDF:** The platform will be a tool for developing, testing, and validating SRO systems that utilize remote compute facilities. Here, "remote" can mean the Computer Center relative to the Counting House. Similarly, the HPDF is expected to serve as a remote compute facility for experiments outside of JLab. The proposed platform tool will provide valuable insights into how to best use the HPDF to support experiments. The approach to obtaining this objective will be to partner with a remote facility such as BNL or NERSC to perform some limited testing once the project matures. Exercising a high bandwidth application where the data originates at JLab and is sent to a remote compute facility will give valuable insight on how the HPDF might handle data streaming in from a remote site. A reach goal will be "bouncing" the data stream(s) we send to a remote site back to the HPDF as an additional testing phase.

- **Milestones:**

Y1Q1
- **M01**: Create prototype ERSAP configurations for INDRA and CLAS12 test systems
- **M02**: Identify or capture SRO formatted data from CLAS12 and INDRA test systems with data tag/filtering capability (output data ready for further offline processing)
- **M03**: Evaluate existing solutions for configuring and launching remote distributed processes
- **M04**: Establish code repository(s), project site, and method of documentation

Y1Q2
- **M05**: Create stream splitter program for EVIO or HIPO data formatted files
- **M06**: Create stream splitter program for simulated data in PODIO for ePIC
- **M07**: Create VTP emulator using files produced by stream splitter
- **M08**: Create controller program to synchronize multiple VTP emulators

Y1Q3
- **M09**: Determine appropriate schema for all aspects of monitoring system.
- **M10**: Establish databases for monitoring system using existing JLab servers.
- **M11**: Integrate Hydra as monitoring component.

Y1Q4

- **M12**: Integrate off-line data analysis framework into platform for CLAS12 data
- **M13**: Integrate off-line data analysis framework into platform for ePIC or GlueX simulated data
- **M14**: Integrate example JANA2 analysis into platform

Y2Q1

- **M15**: Create configurable CPU proxy component
- **M16**: Create configurable GPU proxy component (hardware and software)
- **M17**: Create configurable FPGA proxy component (hardware and software)
- **M18**: Create functioning hardware GPU component (e.g. CLAS12 L3)
- **M19**: Create functioning hardware FPGA component (e.g ML4FPGA)

Y2Q2

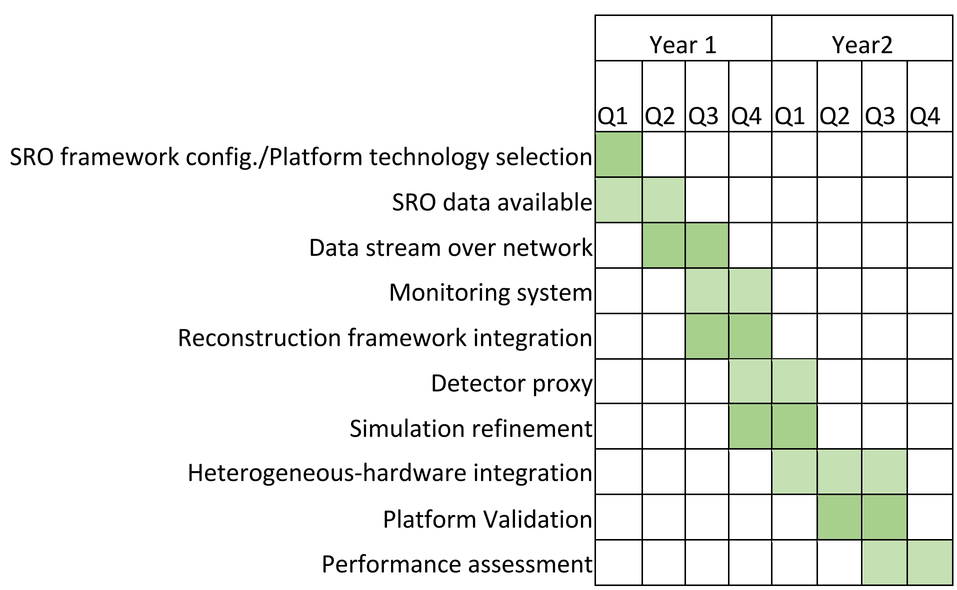
- **M20**: Impose artificial time structure on stream sources to mimic beam-like conditions
- **M21**: Configure simulation of full SRO system using existing JLab hardware resources

Y2Q3

- **M22**: Establish working test of system that transfers >=100Gbps from CH to compute center
- **M23**: Establish working test of system that includes GPU component for portion of stream
- **M24**: Establish working test of system that includes FPGA component for portion of stream
- **M25**: Test system with remote compute facility (e.g. BNL or NERSC) at limits of available resources

Y2Q4

- **M26**: Configure system that results in stream(s) being received by JLab from external source
- **M27**: Collaborate with HPDF group to evaluate processing SRO data at JLab for external experiments
- **M28**: Complete documentation for platform to be used by non-experts



4. Summary

This project will result in a dedicated software platform for the design, testing, and validation of streaming data processing and analysis workflows. This will facilitate the design of streaming experiments where data are calibrated and reconstructed in (near) real-time for the next generation of physics experiments at JLab and EIC. It will also provide a tool that can give valuable insight into the operation of an HPDF facility that serves external experiments that stream data to the HPDF for real-time processing.

Measure of Success:

1. CLAS12 sub-detectors data will be streamed from counting house to Computer Center through a fast network link
2. GPUs and FPGAs will both be demonstrated to process stream data in conjunction with algorithms run on the CPU
3. Example calibrations, based on real data will be performed in (near) real-time;
4. Bottlenecks or limitations for processing SRO data with rates similar to those expected in operations at high luminosity (CLAS-12 HI-LUMI, SoLID, ...) will be identified.
5. Functioning monitoring user interface
6. Results shared with HPDF project team

Future Funding:
The project is not anticipated to require an additional funding stream. The resulting product will be absorbed into the collection of SRO tools currently maintained at JLab as part of the experimental program that include CODA, ERSAP, CLARA, JANA, etc.

Glossary of Acronyms

AI/ML Artificial Intelligence/Machine Learning

BNL Brookhaven National Lab

DAQ Data AQuisition

CEBAF12 The JLab 12GeV science program based on the CEBAF accelerator

CEBAF20+ A proposed JLab 20GeV (or higher) science program

CLARA CLAS12 event Reconstruction and Analyses software framework. Java-based for the CLAS12 detector

CLAS12 CEBAF Large Acceptance Spectrometer. The large detector located in Hall-B.

CODA CEBAF Online Data Acquisition system

CPU Central Processing Unit

EIC Electron Ion Collider

ePIC The first detector for the EIC. Currently under development and expected to take data in early 2030's

EJFAT ESnet/JLab FPGA Accelerated Transport. An network traffic shaping system that uses FPGAs. Designed through a ESnet and JLab collaboration.

ERSAP Environment for Real-time Streaming, Acquisition and Processing. Backend software framework for streaming data acquisition systems

EVIO EVent I/O. Data format used for transport and storage of experimental raw data at JLab. Part of CODA.

FPGA Field Programmable Gate Array. In this context, it is off-the-shelf electronics with a large FPGA chip that custom programs can be written to.

GlueX Gluonic Excitations eXperiment. The large detector located in Hall-D

GPU Graphics Processing Unit. In this context, used for large, parallel, computation (not for graphics).

HIPO I/O library and file format used by CLAS12. Similar to EVIO.

HPDF High Performance Data Facility. A proposed large compute facility to be hosted at JLab.

INDRA Data Acquisition R&D lab located in CEBAF Center at JLab.

JANA/JANA2 JLab ANAlysis framework. A C++-based package used for GlueX and ePIC

JIRIAF JLAB Integrated Research Infrastructure Across Facilities. A JLab LDRD project for automated workflow management, including job migration across facilities.

L3 Level-3 Trigger

NERSC National Energy Research Scientific Computing. A large, DOE run High Performance Computing facility located at Lawrence Berkeley National Laboratory.

ML4FPGA An EIC R&D project aimed at high speed data processing by an AI/ML model on FPGA hardware that is inlined as part of a SRO system.

PHASM Parallel Hardware viA Surrogate Models. A JLab LDRD project for automatically creating surrogate AI/ML models for offloading parts of programs to heterogeneous hardware (e.g. GPUs)

PODIO Plain Old Data I/O library. A library for implementing data models (externally written and maintained).

SoLID Solenoidal Large Intensity Device. A proposed future detector to be located in Hall-A.

SRO Streaming ReadOut. A shorthand for stream readout data acquisition systems.

VTP VXS Trigger Processing unit. A custom hardware board designed at JLab for high speed readout of front-end digitization electronics.

5. Budget

Requested Budget for Effort by Investigator									
Name of Investigator	**Role**	**FY24 Budget ($K)**	**FY24 Effort (% FTE)**	**FY25 Budget ($K)**	**FY25 Effort (% FTE)**	**FY26 Budget ($K)**	**FY26 Effort (% FTE)**	**Total Budget ($K)**	**Total Effort (%FTE)**
David Lawrence	PI	$30	10%	$31	10%				
Vardan Gyurjyan		$64	25%	$65	25%				
Cissie Mei		$45	25%	$45	25%				
Postdoc (TBD)		$124	100%	$126	100%				
	Subtotal for effort	$263	1.6	$267	1.6				
Equipment	Non-capital	4.5							
	Capital								
Subcontracts	Person/ organization								
Materials/ Supplies									
Travel		**3.5**		**6.5**					

6. Budget Justification

Personnel:

Team Member	Role	Project Contribution	Specific Aims
David Lawrence	PI	Senior project manager	1-6
Vardan Gyurjian	Contributor	SRO DAQ expert. ERSAP,CLARA,JIRIAF	1,4,5
Cissie Mei	Contributor	Benchmarking GPU,FPGA,JANA,PHASM	2,3
Postdoc (New Hire)	Contributor	Software developer	1,2,3,5,6

Requested New Hires:

Name of Hire	Type of hire (strategic, staff, PD)	Position Description/Justification	Projected Cost ($K/FY)	Expected timeline

TBD	PD	Work with senior researchers on programming, execution, and analysis tasks. (All aspects of project).	125	Full time for full 2 years of project

Equipment:

Equipment	Justification	Projected Cost ($K in FY24)
Laptop, dock, monitor, keyboard, mouse	Computer for postdoc	4.5

Materials:

Name of Material	Description	Cost per FY	Total Cost

Sub-Contracts:

Subcontract	Institution	Description/Justification	Duration	Cost/FY	Total Cost

Travel:

Activity	Destination	Name of travelers	Estimated Cost
CHEP2025	Krakow, Poland	TBD	$6500
Domestic Conference	TBD	TBD	$3500

Current and Pending FY 2024 and FY 2025 Funding:

Team Member	Project Number, Sponsor	FY 2024 %FTE Anticipated	FY 2025 %FTE Anticipated
David Lawrence	**This DRD project**	**10%**	**10%**
	SCIOPS/SCI, DOE NP (JLab OPS)	89%	89%
	AIEC (LAB20-2261 grant)	1%	0%
Vardan Gyurjyan	**This DRD project**	**25%**	**25%**
	IRIAD, DOE ASCR	6.5%	0%
	JIRIAF, DOE NP (JLab LDRD)	15%	0%
	SCIOPS/SCI, DOE NP (JLab OPS)	53.5%	75%
Cissie Mei	**This DRD project**	**25%**	**25%**
	HPDF	25%	25%
	SCIOPS/SCI, DOE NP (JLab OPS)	50%	50%
Postdoc (TBD)	**This DRD project**	**100%**	**100%**

** Identify the name of the "Other" funding source here*

7. References

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