Letter of intent for the HORIZON-INFRA-2025 call

ALLEN4EIC:

A Heterogeneous, Open-Access Framework for Real-Time High-Throughput Data Processing

Project leaders:

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Abstract

This project proposes to adapt the Allen real-time processing framework, developed at LHCb, for use at the ePIC experiment at the Electron-Ion Collider (EIC). By leveraging GPU-based and heterogeneous computing architectures, the project will enable scalable, low-latency event reconstruction and calibration tailored to ePIC's streaming readout. A core outcome is a modular, open-source software infrastructure offering Virtual Access to real-time data processing pipelines and validation tools. This service will empower researchers to test and deploy high-throughput workflows remotely, supporting FAIR data practices and advancing collaborative, reproducible research in hadron physics.

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1 Research Objectives

This project will adapt the **Allen real-time processing framework**, developed by LHCb at CERN, for use at the **ePIC experiment** at the future Electron-Ion Collider (EIC). The goal is to build a modular, open-access software infrastructure for high-throughput, real-time event processing, enabling scalable workflows that will be shared with the broader research community through a **Virtual Access** model.

The ePIC detector, the flagship experiment at the Electron-Ion Collider (EIC), is being developed with a fully streaming data acquisition system, one of the first in nuclear and particle physics. This architecture enables continuous readout of the entire detector, with rapid processing supported by artificial intelligence to facilitate autonomous calibration, detector alignment, and validation of reconstructed physics events [1]. To meet the performance demands of such workflows, the collaboration is exploring the use of heterogeneous computing resources, particularly GPUs.

Allen is a proven, open-source framework that currently powers LHCb's first-level trigger, processing 30 million bunch crossings per second using GPU-based resources [2]. Its architecture supports cross-platform portability (x86, CUDA, and soon ARM), integrates Python configuration with high-performance C++/CUDA code, and includes built-in tools for performance monitoring. Unlike FPGA-based solutions, Allen achieves microsecond-scale processing using commodity hardware, making it ideal for the heterogeneous compute environments used at ePIC. Its energy efficiency and scalability have been studied in detail as part of LHCb's real-time computing evolution [3].

At ePIC, Allen's role would shift from its use at LHCb as a trigger-level filter to a downstream data processing tool, with a focus on autonomous calibration of detector systems. A first application will target the ePIC **backward electromagnetic calorimeter**, a detector currently under design and construction at IJCLab.

As part of the ODISSEE (HORIZON-INFRA-2024-TECH-01) project, the IN2P3 Allen team has received funding to modularize the generally usable components of Allen, particularly those related to code portability, high-throughput execution, and monitoring, separating them from the algorithms specific to the LHCb use case. A first version of the *AllenCore* framework is scheduled for release in Q1 of 2026. This is therefore the right time to begin planning for non-LHCb applications that can be built on top of the framework. Our project will thus extend Allen to a new experimental domain, supporting ePIC's specific data structures, geometry, and real-time requirements. A demonstrator pipeline will be deployed on a French computing cluster configured to emulate a **future EIC Echelon-2** computing site.

To implement this, we request support for one postdoctoral researcher (36 months) to:

- Integrate ePIC geometry and simulated data formats into AllenCore;
- Design a performant low-level data model informed by LHCb experience;
- Develop a real-time processing pipeline for ePIC's streaming architecture;
- Implement calibration and reconstruction algorithms;
- Extend validation and benchmarking tools to assess computational and physics performance.

The resulting infrastructure will be containerized, openly licensed, and supported by documentation and training materials to ensure wide reusability across the hadron physics community.

Scientific and Infrastructure Impact

This project will demonstrate the broader applicability of Allen as a sustainable, high-performance framework for real-time data processing in hadron physics. It will establish an open-access, containerized software suite, including real-time pipelines, validation tools, and documentation, integrated with the European Open Science Cloud (EOSC) ecosystem. Training workshops, both in-person and online, will equip researchers with skills in real-time computing, FAIR data stewardship, and EOSC-compatible workflows. In doing so, the project directly supports the Horizon call's goals of improving access to advanced research infrastructure services and preparing the next generation of researchers to exploit them effectively.

In summary, the project will deliver a sustainable, open-access processing service that integrates into the European research infrastructure landscape, enabling wide adoption of cutting-edge real-time analysis tools in hadron physics.

2 Connection to Transnational Access infrastructures (TAs) and / or Virtual Access projects (VAs)

This project directly supports and enhances the computing infrastructure of the EIC at Brookhaven National Laboratory (BNL), where the ePIC detector is a central experimental effort. By integrating the Allen framework into ePIC's data processing pipeline, we aim to strengthen BNL's capacity to manage the EIC's demanding data rates through advanced, heterogeneous computing techniques. The development of a real-time processing solution tailored for ePIC complements the existing EIC infrastructure goals by improving computational efficiency, reducing data storage demands, and enabling rapid physics analysis. Furthermore, this collaboration aligns with BNL's commitment to fostering open, scalable, and sustainable computing environments that empower the broader nuclear and particle physics communities engaged with the EIC.

A key objective of this project is the establishment of a Virtual Access facility offering open, reusable software services tailored for real-time processing in streaming experiments. All tools and documentation will be publicly released through community repositories, enabling researchers across Europe and beyond to adapt these workflows to their own needs. This supports the Horizon call's emphasis on integrated, user-ready access to high-level research infrastructure services.

3 Estimated Budget

The project requests funding to support the following key components:

- **Personnel:** One full-time postdoctoral researcher for 36 months, based at IJCLab within the EIC group, to lead the development and integration of the AllenCore-based real-time processing pipeline for ePIC.
- **Travel and Collaboration:** A total of €60,000 over three years to support travel and collaboration among the different institutions. These funds will cover project-related meetings, workshops, and collaborative development sessions. A significant portion of this travel is expected to be to CERN, enabling direct engagement with Allen core developers and ensuring close coordination with the LHCb development team. The request also includes provisions for organizing training sessions and technical workshops.

4 Participating and partner institutions

- CNRS/IN2P3: CPPM (lead: D. vom Bruch), IJCLab (lead: C. Muñoz), LPNHE (lead: V. Gligorov)
- INFN: Genova (lead: M. Battaglieri)
- CERN (lead: S. Mariani)
- Jefferson Lab (lead: M. Diefenthaler)

The project brings together a tightly integrated team with complementary expertise. LPNHE and CPPM contribute core knowledge as developers of the Allen framework at LHCb, while IJCLab leads its adaptation to ePIC, focusing on calibration of the backward electromagnetic calorimeter. INFN-Genova, experts in streaming readout (SRO), bridge the data acquisition chain up to storage, ensuring compatibility with real-time processing. Jefferson Lab, leading ePIC computing and SRO, will provide integration support and enable testing in experimental environments. CERN and the LHCb team will assist in adapting AllenCore to new use cases. This collaboration ensures a coherent development pipeline from detector to analysis, fully aligned with the goals of open, high-performance data services.

References

[1] M. Battaglieri, W. Deconinck, M. Diefenthaler, J. Huang, S. Joosten, D. Kalinkin, J. Landgraf, D. Lawrence, and T. Wenaus, "The ePIC Streaming Computing Model," 2024. [Online]. Available: https://doi.org/10.5281/zenodo.14675920

[2] R. Aaij *et al.*, "Allen: A high level trigger on GPUs for LHCb," *Comput. Softw. Big Sci.*, vol. 4, no. 1, p. 7, 2020.

[3] R. Aaij, D. H. Cámpora Pérez, T. Colombo, C. Fitzpatrick, V. V. Gligorov, A. Hennequin, N. Neufeld, N. Nolte, R. Schwemmer, and D. Vom Bruch, "Evolution of the energy efficiency of LHCb's real-time processing," *EPJ Web Conf.*, vol. 251, p. 04009, 2021.