Expression of Interest (EOI): Fast timing silicon detectors for EIC detectors

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2 Participating Institutes

- Argonne National Lab (ANL)
- Brookhaven National Lab (BNL)
- Organisation de Micro-Électronique Générale Avancée (OMEGA), Ecole Polytechnique
- Fermi National Lab (FNAL)
- Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN)
- Laboratoire de Physique des 2 Infinis Irène Joliot Curie (IJCLAB)
- Los Alamos National Lab (LANL)
- Massachusetts Institute of Technology (MIT)
- Oak Ridge National Lab (ORNL)
- Rice University (Rice)
- Stonybrook University (Stonybrook)
- University of California, Santa Cruz (UCSC)
- University of Illinois, Chicago (UIC)
- University of Kansas (KU)

[1] primary contract

3 Potential Equipment Cooperation

The Consortium, consisting of more than a dozen institutions, is interested in collaborating with the project on the development of a fast-timing silicon detector technology based on Low Gain Avalanche Diode (LGAD) designs that suits the specific requirements of various sub-detector systems to accomplish the physics goals of the Electron-Ion Collider (EIC).

The list of the sub-detector systems that the Consortium expresses interest for includes (but is not limited to) **time-of-flight (TOF), generic 4D tracker, TOPSiDE, 4π hybrid LGAD/SOI tracker, preshower, and Roman Pots**.

The main goals of the Consortium are the following:

- Determine the needs of high precision timing measurements as well as spatial granularity of the above-mentioned sub-detector concepts for a variety of physics benchmarks at the EIC, guided by the Yellow Report study.
- Develop LGAD-based sensors and readout electronics that are capable of fulfilling the corresponding requirements.
- Leverage the established expertise on LGAD-based timing systems and facilities available in the Consortium, and especially those developed for the High-Luminosity LHC (HL-LHC) upgrade of the ATLAS and CMS experiments, in order to design and build in the most cost effective way EIC sub-detectors that meet the corresponding performance requirements.

The Consortium experience and expertise span a broad spectrum of activities including LGAD sensor R&D for the HL-LHC, EIC (i.e. TOPSiDE as well as eRD24, eRD29 projects) and other future collider experiments; LGAD production QA/QC, readout electronics (e.g. front-end, back-end and off-detector), power supply systems, mechanical support and infrastructure, detector commissioning and operation for the LHC experiments (i.e. CMS, ATLAS).

Details on specific aspects of fast-timing silicon detectors the Consortium would like to contribute to are briefly summarized below:

- **LGADs sensor R&D:** To meet the PID requirement with TOF for EIC physics, a time resolution of at least 20 ps per layer is needed over the low to intermediate momentum range. The Consortium will be working on achieving this goal, specifically by thinning the LGADs sensor active volume thickness and optimising other parameters, e.g. the intrinsic gain. Extensive R&D in this direction is already ongoing in several institutes in the Consortium. To apply the LGAD technology to a tracking detector, intra-pad gaps in standard LGADs have to be minimized. New concepts, such as AC-coupled LGADs (AC-LGADs) and Trench-Isolated LGADs (TI-LGADs), are promising candidates to realize this goal. The Consortium aims at developing these technologies further and reach a level of maturity to make them reliable for use in EIC detectors. Several activities on AC-LGADs are already ongoing at BNL and UCSC.

- **ASIC R&D:** The needs for better timing performance and finer granularity also pose significant challenges to the readout electronics and specifically to the ASIC readout chips. Present ASIC chips designed for CMS and ATLAS timing detectors have a jitter on the order of 20–30 ps, and a pixel granularity of 1.3×1.3 mm^2. Reduced granularity will make it more difficult to fit all the circuit components within the available space, and is also likely to lead to significantly increased power consumption due to increased total number of channels. The Consortium will collaborate on addressing these challenges. The eRD24 team led by BNL has started the R&D together with colleagues from IJCLAB to develop an ASIC chip with a size of 0.5×0.5 mm^2 that meets the requirements set by the Roman Pot detector, by optimizing the current ATLAS chip (ALTIROC) design. A finer granularity may be needed for the tracker application, which would require new architectural designs and more advanced fabrication processes. Institutes members of the Consortium have experience on the development of readout electronics and plan to contribute to the development of the most appropriate readout system for a fast-time tracking system. The Consortium will work on understanding the requirement, developing the chips and addressing related problematics, e.g. clock jitter and distribution, based on their established expertise.

- **System design, engineering and construction:** Constructing a full-scale detector requires significant work on the system-level design, prototyping and engineering. Members of the group have been involved in the construction of many large-scale experiments at HERA, RHIC, SLAC, Jefferson Lab and the (HL-)LHC. In particular, the Consortium plans to apply its members' experience with LGADs-based timing detectors developed for CMS and ATLAS experiments to the construction of high performance, cost-effective EIC detectors. For example, CMS heavy ion physics groups are key participants of the CMS Endcap Timing Layer (ETL) project, being responsible for LGADs sensor QA/QC (KU), ASIC prototyping tests and and production QA/QC (UIC), readout electronics and power supply systems (Rice), as well as mechanical support, cooling system and infrastructure (MIT and IFJ PAN).

4 Potential contributions are for each item of interest

Extensive R&D in the generic area of LGAD sensor and associated readout electronics is already ongoing, and the necessary equipment and instrumentation for the R&D phase are already available, as funded by internal funding sources by several institutes (ANL, LANL, UCSC, BNL), NASA (KU), KA25, LDRDs and eRD29 (Rice, KU, ORNL). Test labs for LGADs are available at many institutes to provide measurements of timing and space resolution, charge collection efficiencies, with probe stations, radioactive sources and lasers, in warm and cold conditions, data analysis, readout boards. The BNL's Instrumentation Division has the capability to design and fabricate LGADs sensors, provide wire and bump bonding of test assemblies, test stations electrical equipment for testing. FNAL can provide beam test facilities, which have already been used for various LGAD-related R&D. Colleagues from IJCLAB offer expertise and equipment for ASIC design, while IFJ PAN offer labor, expertise and infrastructure concerning the test data analysis, software development, mechanical design and construction for the Roman Pot system, including integration with the EIC, as well as the irradiation tests using on-site proton cyclotrons with energy range of 5-230 MeV. ORNL mainly focuses on the overall integration of the system including all mechanical support structures, cooling and power, as well as the development of an integrated continuous readout system featuring on-the-fly data processing with a full systems engineering approach and professional project management. ANL can leverage its Argonne Micro Assembly Facility (AMAF) towards module assembly and loading. ANL also has a permanent pixel telescope at the Fermilab test facility, and experience with integration with data-acquisition systems. Furthermore, the ANL group can offer labor and expertise from ATLAS (CERN) towards the design and construction of necessary carbon fiber structures (local and global mechanics) as well as the cooling system. Finally ANL has on-site facilities to test radiation-hardness, and capabilities towards CMOS development and the development of on-detector services.

5 Assumptions about items from EIC Project

While design capabilities (TCAD license and expertise), equipment, test lab, clean rooms and related expertise are available at most institutes and national labs, it is assumed that the members of the consortium will be able to secure funds from national or international funding agencies (e.g. IN2P3/CNRS, Polish Ministry of Science and Higher Education), as well as from the project to provide necessary funds for M&S and labor in the R&D phase (for example for fabrication and testing of detector prototypes such as sensors, ASICs etc.) and in the production phase.

6 Labor Contributions

The time commitment of members of the LGAD Consortium for the EIC efforts described in this EoI is summarised below and broken down in the following table.

While at this point in time the information on committed labor is not available for all institutes, based on the information currently available it is anticipated that the collaborative effort of the

INSTITUTION	Professor	Research Professor	Staff Scientist	Postdoc	Graduate Student	Undergraduate Student	Engineer	Designer	Technician	Total Sum
ANL	0	0	0.55	1.00	0	0	0.30	0.50	0	2.35
BNL	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
FNAL	0	0	0.04	0.04	0	0	0.05	0	0	0.13
LANL	0	0	0.50	0.50	0	0	0.10	0	0	1.10
MIT	0.20	0	0.10	0.50	0.50	0	0.50	0.50	0.50	2.80
ORNL	0	0	1.00	0	0	0	0.80	0	0.60	2.40
Rice	0.20	0	0	1.00	1.00	0	1.00	0	0	3.20
Stony Brook	0.01	0	0	0.20	0	0	0	0	0	0.21
UCSC	0.80	0	0.20	0.20	0.20	3.00	0.10	0	0	4.50
UIC	0.20	0	0	0.50	0.50	0	0	0	0	1.20
KU	0.20	0	0	2.00	1.00	0	0	0	0	3.20
IJCLAB	0	0	0.40	0	0.30	0	0	0	0	0.70
IFJ PAN	0.20	0	0.40	0	1.00	1.00	2.00	1.00	5.00	10.60

LGAD Consortium to cooperate on the EIC Project is to include (at an annual basis) 1.81 full-time equivalent FTEs of professors, 3.19 FTEs of staff scientists, 5.94 FTEs of postdoctoral researchers and 4.50 FTEs of Ph.D. and 4.00 FTEs of undegraduate students. The technical collaborative effort contributed is to include up to 4.85 FTEs of (mechanical or electronics) engineers, 2.00 FTEs of designers, and 6.10 FTEs of technicians.

While we expect the duration of this collaborative effort to include the detector R&D and design phase and to extend to the pre-production and production phases, for a period of approximately 10 years, i.e. until the completion of the EIC detectors, the indicated commitments cover an initial period up to about 2025, and are subject to securing appropriate funds from national and international agencies as well as from the project. For instance, IFJ PAN will apply for funding to Polish Government; the fulfilment of the obligations concerning present EoI depends on the allocation of funds by the Ministry of Science and Higher Education, and a decision is expected by mid-2022.

7 Timing Constraints

Member institutes of this Consortium are currently participating in experiments at RHIC (STAR, sPHENIX) and the LHC (CMS, ATLAS), and EIC detector R&D projects (eRD24, eRD29) operated by the BNL.

The eRD24 and eRD29 activities are fully aligned with the objectives of this EoI and the level of these activities is expected to be maintained in the future EIC detector program.

Commitments to RHIC experiments by a number of institutes (LANL, ORNL, Rice, UIC and BNL) mainly involve the continuous operation of the STAR detector, as well as commissioning and operation of the new sPHENIX detector until 2025. After 2025, while maintaining some level of RHIC physics analyses, STAR and sPHENIX member institutes are expected to become fully engaged in realizing the EIC detector.

Several member institutes of the CMS collaboration (MIT, Rice, UIC, KU) are involved in constructing the CMS endcap timing layer based on the LGADs for HL-LHC upgrades, and some institutes are member of the ATLAS Collaboration with commitments in the upgrade of the pixel or strip silicon tracker, ITk (ANL, BNL, UCSC), or the High Granularity Timing Detector, HGTD (IJCLAB). These activities (including detector assembly and commissioning) are expected to last until the end of construction and start of the HL-LHC in 2028. A significant fraction of the member groups will proceed with the EIC detector development in parallel, by carrying along their experience gained at the LHC and leveraging personnel expertise (e.g. engineers).

ANL FTEs are for FY2021and FY2022, where the majority of the funding comes from Argonne LDRD, Program Development Funds and programmatic funding. As the ANL commitment in other projects winds down, more staff and postdoc FTEs will become available towards the EIC.

Part of the colleagues from IFJ PAN is presently involved in the ATLAS Roman Pot system (data analysis, technical issues such as software, alignment, experimental infrastructure, TDAQ). The involvement of the IFJ PAN technical staff in EIC activities is planed for 2023-2030.

8 Other Information

No other information is provided.

9 Cross-reference to other EOI's with involvement of team members

- "Expression of Interest (EOI) for the EIC Collider Detector ("ECCE") Consortium" (Or Hen, Tanja Horn, John Lajoie)
- "Expression of Interest in Contributions to the Electron-Ion Collider: Forward Silicon Vertex/Tracker Developments" (Xuan Li)
- Expression of Interest in "Precise central silicon tracking and calorimetry with integrated parallel and continuous readout for an EIC detector" (ORNL, Vanderbuilt U., Wayne State U.)
- General Software Expression of Interest
- EoI for the EIC Project "Forward Instrumentation in the Electron Hemisphere" (IFJ PAN participation)
- EoI by Argonne National Laboratory, contact Zein-Eddine Meziani (ANL)