Expression of Interest in Contributions to the Electron-Ion Collider: Forward Silicon Vertex/Tracker Developments

Los Alamos National Laboratory *

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Please indicate all institutions collectively involved in this submission of interest:

We are collaborating with several institutions and consortium below for the proposed forward silicon tracker detector. The current listed institutions/consortium are listed in Table 1:

Los Alamos National Laboratory	Brookhaven National Laboratory
Jefferson Laboratory	Argonne National Laboratory
Fermi National Accelerator Laboratory	Karlsruhe Institute of Technology
Rice University	Temple University
University of Michigan	UC Santa Cruz
University of Heidelberg	UC consortia
LGAD consortia	

Table 1: Collaboration list

Please indicate the items of interest for potential equipment cooperation:

The LANL EIC team would like to contribute to the EIC silicon vertex/tracking detector design, construction, commissioning and operation. Our primary focus is for a proposed forward silicon tracker with pseudorapidity coverage from 1 to 3.5 in the nucleon/nuclei beam going (forward) direction at IP-6 of the EIC. LANL LDRD is currently supporting this effort from FY20-FY22 with a funding of $5M. Meanwhile, we are open to collaborate on the other EIC detector sub-systems such as the central, backward silicon vertex/tracking detectors and/or a precision timing detector based on the LGAD technology.

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The LANL team has more than 20 years of experience in leading silicon detector R&D, construction and operation. We have successfully built the Forward Silicon Vertex Detector (FVTX) [1] for the PHENIX experiment at RHIC. We are leading the sPHENIX MVTX [2] construction based on the ITS-2 [3] technology. Moreover, we have world-class mechanical and electrical engineers at the lab.

In addition to experienced personnel, Los Alamos National Laboratory has significant resources to aid in these tasks:

1. Facility and resources at LANL:

   - The Los Alamos Neutron Science Center (LANSCE) houses a linear accelerator that produces an intense beam of 800 MeV protons. Radiation hardness studies of silicon sensors and associated electronics can be carried out using both the proton beam and neutrons of varying energies from the LANSCE spallation targets.
   - Several thousand square feet of modern clean room space with class 100 is available for detector and electronics handling and assembly.
   - Los Alamos houses some of the most powerful high-performance computing facilities in the US. LANL personnel can request time on the machines for Monte Carlo simulations to aid detector development.
   - LANL has two silicon R&D labs which have been used to carry out the detector R&D work for PHENIX Forward silicon VerteX detector (FVTX) and sPHENIX MAPS based vertex detector (MVTX). Ongoing silicon R&D work for the proposed EIC forward silicon tracking detector has utilized these labs, which provide the dry cabinet storage, CAEN/Keysight High/Low Voltage supplies, triggering, spatial/timing measurements and environmental chamber for low temperature measurements.

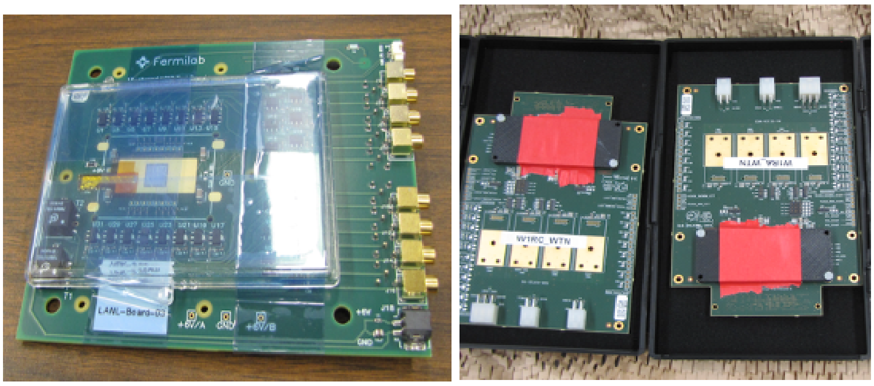

Figure 1: LGAD sensor under detector R&D at LANL is shown in the left. MALTA sensor under detector R&D at LANL is shown in the right.

2. Silicon detector R&D and characterization for two options for the proposed Forward Silicon Tracker (FST):

- **LGAD**: Low-Gain Avalanche Detector [4, 5, 6, 7] which can provide time resolutions on the order of a few picoseconds, which can be suitable for 4D space-time tracking and particle identification using time of flight. The AC-LGAD [8] which is under R&D provides improved spatial and timing resolutions. The plan is to carry out occupancy studies in simulation, optimization of the LGAD sensor design [9], exploring LGAD mechanical systems and ASIC design. For the relevant R&D, We are collaborating with UCSC who leads the LGAD design and associated developments, ANL who has major contributions to the EIC TOPSITE conceptual detector design and developments, Rice Univ. who is a main member of CMS endcap timing layer based on the LGAD for HL-LHC, FNAL who designs the readout electronis for the LGAD.
- **HV-MAPS (e.g. MALTA)** : asynchronous readout CMOS monolithic pixel developed for the ATLAS detector [10, 11, 12]. This technology can provide high position resolution and <10 ns time resolution, which allows hit information to be resolved inside the period of a beam crossing. Faster temporal resolution has been achieved for the MALTA sensor and high radiation tolerance ($> 10^{15}$ n_{eq}/cm^2) has been demonstrated at a shaping time at 25 ns [13]. We are considering the other HV-MAPS technologies such as the ATLASPIX3 [14] or Mupix [15] sensors. Their performances are documented in the corresponding references. For the HV-MAPS associated R&D, we are collaborating with colleagues from KIT, Univ. of Heidelberg, FNAL and the other institutions.

Please see Table 2 for the summarized performance of the LGAD and the MALTA technologies. Ongoing R&D for different silicon sensor technologies will improve achieve better timing and finer spatial resolution and get low material budgets. Through the R&D studies, we will determine a detector design that uses these technologies can meet the EIC radiation tolerance requirements.

Parameter	LGAD or AC-LGAD	MALTA
Technique	Low Gain Avalanche Diode	180 nm Tower Jazz HV-MAPS
Pixel size	current 1.3mm $\times$ 1.3mm towards 100 μm $\times$ 100 μm, $\sim$ 10 μm spatial resolution is achieved with the new design.	36.4 μm $\times$ 36.4 μm, $\sim$ 7 μm spatial resolution.
Integration time	300-500 ps	< 5 ns
Thickness per layer	$< 1\% X_0$	$< 0.5\% X_0$
Power consumption	under R&D	80 mW/cm^2
Noise level	under R&D	10^{-5} with low threshold
Radiation tolerance	$\sim 1.5 \times 10^{15}$ n_{eq}/cm^2	$> 10^{15}$ n_{eq}/cm^2

Table 2: Comparison of the LGAD and MALTA sensor performance

3. FST detector design and tracking performance:

   A hybrid design for the proposed FST based on the ITS-3 type and MALTA technologies has been implemented in the Fun4All framework with the integration of RICH and GEM detectors, as shown on the left and right of Figure 2), respectively. Detector material budgets (Figure 3) and tracking performance have been evaluated with the integrated detector systems, in which the first three planes of FST use the ITS-3 type technology and the rest utilizes the MALTA technology. The momentum resolution and the resolution of the distance of the closest approach (DCA) in the transverse direction are expressed as $\Delta p/p = Ap \oplus B$ and $DCA_{2D}(p_T) = A/p_T \oplus B$, respectively. A and B in the equations are the fitting parameters which are listed in Table 3 and 4.

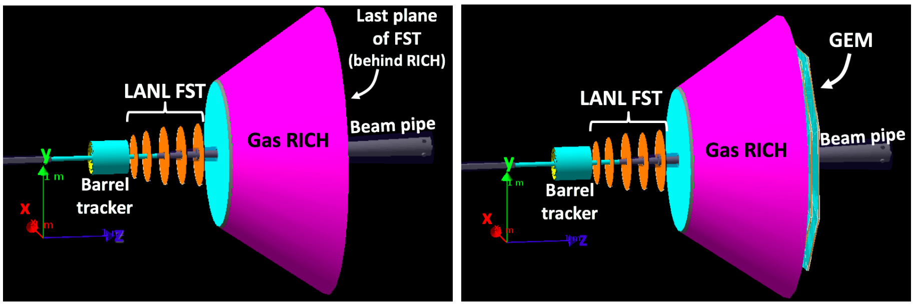

Figure 2: Left: proposed six-plane Forward Silicon Tracker (FST) shown in orange has been implemented within the Fun4All framework in integration with the EIC beam pipe, the barrel silicon vertex detector and the forward Gas RICH detector. The last plane of the FST at the far-z location is covered by the Gas RICH in this figure. Right: similar detector system setup, but the most forward plane of 6-disk FST design is replaced by a three-plane GEM tracker.

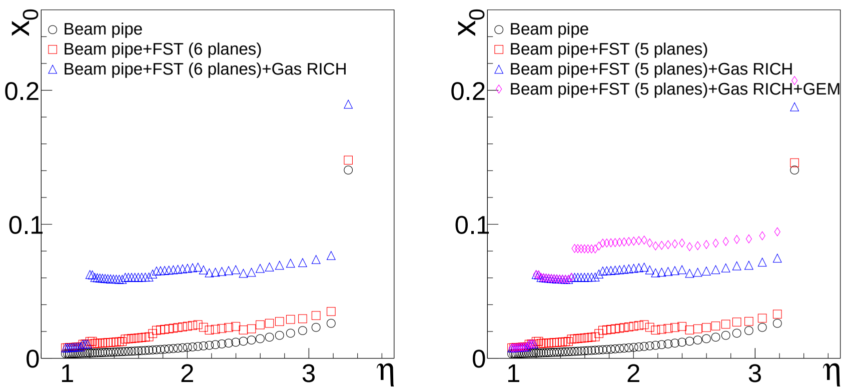

Figure 3: Material budgets as a function of pseudorapidity of different detector system setups correspond to Figure 2.

4. Silicon detector readout demonstration and integration.
   LANL has a long history of developing readout systems for various detectors for high energy nuclear and particle experiments, including the FVTX

Table 3: Fitting parameters of the momentum resolution of different detector system setups.

η	B field	FST (6 planes) + RICH		FST (5 planes) + RICH + GEM	
		A (%/GeV)	B (%)	A (%/GeV)	B (%)
0.0–0.5	BeAST	0.310	0.457	0.309	0.475
	Babar	0.605	0.892	0.608	0.915
0.5–1.0	BeAST	0.259	0.494	0.263	0.494
	Babar	0.513	1.035	0.513	1.010
1.0–1.5	BeAST	0.040	0.551	0.032	0.597
	Babar	0.077	1.120	0.070	1.088
1.5–2.0	BeAST	0.018	0.448	0.013	0.445
	Babar	0.039	0.882	0.026	0.876
2.0–2.5	BeAST	0.035	0.682	0.028	0.704
	Babar	0.070	1.374	0.051	1.402
2.5–3.0	BeAST	0.062	1.306	0.062	1.336
	Babar	0.127	2.607	0.123	2.629
3.0–3.5	BeAST	0.095	2.069	0.095	2.278
	Babar	0.189	4.305	0.189	4.868

Table 4: Fitting parameters of DCA_{2D} resolution of different detector system setups.

η	B field	FST (6 planes) + RICH		FST (5 planes) + RICH + GEM	
		A (μm·GeV)	B (μm)	A (μm·GeV)	B (μm)
0.0–0.5	BeAST	30.17	16.86	30.84	16.78
	Babar	30.56	16.75	32.55	16.97
0.5–1.0	BeAST	32.14	17.37	32.83	17.28
	Babar	32.99	17.21	34.76	17.46
1.0–1.5	BeAST	39.47	14.39	40.73	14.06
	Babar	40.92	13.93	42.62	14.15
1.5–2.0	BeAST	48.49	8.43	51.56	7.36
	Babar	49.30	8.21	53.72	7.32
2.0–2.5	BeAST	54.79	14.16	59.58	11.48
	Babar	57.00	13.97	61.83	11.54
2.5–3.0	BeAST	81.63	21.13	83.90	20.35
	Babar	84.77	21.15	86.97	20.45
3.0–3.5	BeAST	95.90	30.01	104.95	31.55
	Babar	96.37	30.68	105.17	32.77

and MVTX silicon trackers. Recently, LANL has successfully developed a hybrid design to readout ALICE ITS-2 ALPIDE sensors into sPHENIX DAQ system through FELIX back-end board developed for ATLAS experiment, capable of full streaming readout.

The LANL group is interested in developing an integrated readout system for EIC silicon trackers, capable of data processing (such as zero-suppression and clustering) in the front-end electronics next to the detector. The number of fiber channels for data streaming from the IR to the back-end electronics would be reduced by orders of magnitude if we can stream cluster and track information instead of ADC counts as done in conventional experiments. An approach such as this would also allow the possibility of Real-Time Analysis (RTA), which transfers physics information to data storage through online processing and analysis at the detector level. LANL is gaining experience in the RTA developed by the LHCb experiment [16, 17] for the upcoming Run III LHC run. Our experience in LHCb can be valuable in developing a similar system for the EIC detector.

5. Silicon detector mechanical structure design.

   LANL has a long history of contribution to mechanical design in different kinds oh high energy experiments. Recent contributions include the mechanical structure design for the sPHENIX MVTX detector as shown in Figure 4. We are aware of the challenges and uniqueness of the design of the EIC mechanical structure, given the compactness of the detector, the asymmetry of the collision species and the beam crossing angle. There currently are R&D efforts underway to look at new vertex detector ideas and materials that may be used in the next generation vertex detector, specifically the effort currently underway at CERN's ALICE detector group looking forward to the Run 4 time frame at the LHC, along with ATLAS and CMS. Studies are underway using carbon foam materials as well as flexible silicon detectors that may be capable of wrapping around a beam-pipe.

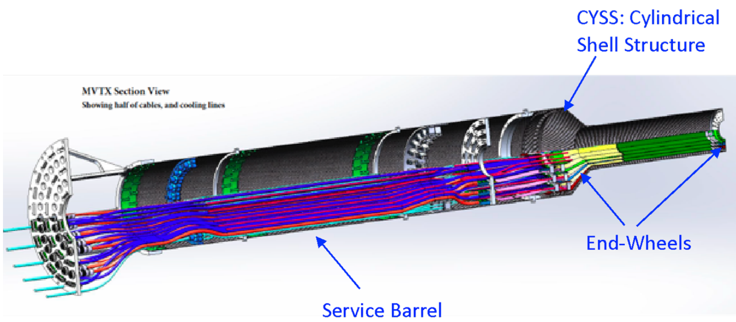

Figure 4: sPHENIX MVTX detector with the service barrel designed led by the LANL team.

6. Silicon detector integration with the other EIC detector subsystems.

   The recent LANL FST design has been integrated with the EIC beam pipe, the barrel silicon tracker and the forward GAS RICH in the Fun4All framework as shown in Figure 2. Ongoing work includes integration with the other forward EIC detector sub-systems such as a forward Time of

Flight (ToF) detector based on the LGAD technology. Detector integration of the LANL FST and the other EIC detector subsystem (e.g. GEM/MPGD tracker) have shown better tracking performance compared to a standalone detector.

7. Computing.

   detector and physics simulation studies for the proposed Forward Silicon Tracker (FST) detector has been summarized in [18]. We have developed the full analysis framework for the proposed FST geometry implementation, tracking performance evaluation and associated heavy flavor hadron/jet studies in fast and full simulation. We are interested in developing the streaming readout and real time analysis in collaboration with the other institutions.

8. Background evaluation.

   LANL is already studying the background level related to heavy flavor and jet measurements. These studies include a detailed evaluation of the QCD backgrounds, limited vertex and momentum resolutions, ghost/fake tracks, etc. Beam related background will also be part of this study, especially the large synchrotron radiation expected from the electron beam which will increase detector occupancy.

9. Open interests.

   We are open to collaboration with the other EIC detector sub-systems that have silicon technology overlaps with the LANL's proposed forward silicon tracker such as the B0 tracker (with pseudorapidity at 4.2 to 4.5), precision timing detector based on the LGAD technology and the silicon vertex/tracking detector within the central and backward region.

Please indicate what the level of potential contributions are for each item of interest:
Currently do not have in-kind contributions.

Please indicate what, if any, assumptions you made as coming from the EIC Project or the labs for your items of interest:
Through the ongoing LANL EIC LDRD project [19] (FY20-22), we could support around 0.15 FTE mechanical engineer and 0.15 FTE electrical engineer to work on the detector R&D and detector design for the proposed EIC FST. Like most laboratories, engineering support comes primarily from project funding. LANL may be able to provide support on the longer term depending on the needs and the funding availability.

Please indicate the labor contribution for the EIC experimental equipment activities:
The time commitment of members of the Los Alamos National Laboratory group in the EIC efforts described in this EoI is anticipated to be as follows:

Annual average T&E table from now on until 2025 for the proposed forward silicon tracker developments. We listed the dedicated T&E from various institutions, and you could see the relevant T&E from unlisted institutions in either their institutional or consortium or collaboration EoI. The engineer support from LANL is based on the past experience and may vary from 2023 to 2025. The engineer contributions at LANL are based on the current LDRD support, the engineer's fraction could be increased depending on the needs and the DOE support.

Institution Name	Scientist/ Professor	Engineer	Technician	Postdoc	Student	Sum
LANL	2	0.25 (*)	0	2	1	5.25
ANL	0.4	0.3	0	1	0	1.7
Rice Univ.	0.1	0	0	0.5	0.5	1.1

Table 5: Annual average T&E table from now on until 2025. The item highlight with * is based on the current contribution and may need further adjustments.

Please indicate if there are timing constraints to your submission:
We have dedicated detector R&D for both the LGAD and HV-MAPS technologies, conceptual design of a proposed forward silicon tracker, relevant engineer contributions with the support from the LANL LDRD project from FY20 to FY22. We expect to continue our contributions with moderate changes from FY23 to FY25.

Please indicate any other information you feel will be helpful:
We are open to collaboration and look forward to collaboration work on the silicon vertex/tracking detector design, selected silicon sensor and readout R&D, sub-detector integration and computing developments.

We have carried out a series of detector/physics simulation studies which are associated with the proposed forward silicon tracker as documented in arXiv: 2009.02888. The silicon detector R&D work is ongoing with the support of a LANL LDRD project ($5M funding). LANL and the listed collaborators have in depth knowledge of the silicon detector design and construction. Good records of successful silicon detector assembly and operations are maintained for the past 20 years. We also have close collaboration with theorists at LANL and several other institutions to work on several EIC physics topics such as hadronization process in nuclear medium.

Cross-reference to the other EoI with involvements of collaborators

- "Expression of Interest (EOI) Questionnaire: Fast Time silicon sensors for EIC detectors", contact person: Wei Li, Alessandro Tricoli.
- Argonne National Laboratory's EIC EoI, contact person: Zein-Eddine Meziani.
- EIC UC consortium's EoI, contact person: Barbara Jacak.
- "Expression of Interest (EOI) for the EIC Collider Detector ("ECCE") Consortium", contact person: Or Hen, Tanja Horn, John Lajoie.
- General Software Expression of Interest, contact person: Andrea Bressan, Markus Diefenthaler, Torre Wenaus.

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