Expression of Interest (EOI)
Questionnaire

Please indicate the name of the contact person for this submission:

Barbara Jacak (Lawrence Berkeley National Laboratory and University of California, Berkeley)

Institutions

Lawrence Berkeley National Laboratory and University of California, Berkeley

Introduction

This is an expression of interest in the Electron Ion Collider (EIC) from Lawrence Berkeley National Laboratory (LBNL) and the University of California, Berkeley (UC Berkeley). Our two institutions work closely together on Nuclear Physics Research.

When it comes into operation, the EIC will be the premier facility in the world for the study of QCD in hadronic systems. Our goal is to participate in the design and construction of the accelerator, the design and construction of the detectors, their commissioning and operations, and the experimental program which will follow. Our principal detector interest is in a state-of-the-art silicon tracking and vertexing system for the general-purpose EIC central detector. This is directly aligned with our physics interests in measurements with scattered electrons, jets, heavy quarks, tagged hadrons, and exclusive vector-meson production.

LBNL is a multi-purpose DOE laboratory, managed by the University of California (UC), and supported by the DOE Office of Science through its program offices (ASCR, BES, BER, HEP, NP, and FES), with substantial additional funding from EERE and other applied DOE offices, ARPE-E, and NNSA. LBNL operates five National User Facilities for the Office of Science (ALS, Molecular Foundry, NERSC, ESnet, JGI); designs and builds state-of-the-art instrumentation; and has a targeted research portfolio in discovery science.

LBNL is very familiar with large multi-laboratory projects such as the EIC detectors. Multi-lab partnership, with a project office at a lead lab, has become the norm for complex detector projects managed under DOE Order 413.3(b). Our present portfolio of scientific projects includes some for which we are the lead lab, and others for which we have responsibility for significant scope at WBS Level 2 or 3.

Project	Office	SC Labs (lead lab first)	LBNL Responsibilities	Most recent Milestone
ALS-U	BES	**LBNL**, BNL	Lead lab, most major subsystems except power supplies	CD-1/3A
GRETA	NP	**LBNL,** ANL, ORNL	Lead lab, most subsystems	CD-3
ALICE Upgrade	NP	**ORNL**, LBNL	ITS Upgrade	CD-4
LHC ATLAS	HEP	**BNL,** ANL, LBNL, SLAC	Global mechanics at level 2, strips and pixels at level 3	CD-2
LHC AUP	HEP	**FNAL**, BNL, LBNL	Nb_3Sn cable winding and quadrupole assembly at level 2	CD-2/3A
CMB-S4	HEP	**LBNL**, ANL, BNL, FNL, SLAC	Lead lab, sensors, small aperture telescopes at level 2	CD-0
DUNE	HEP	**FNAL**, BNL, LBNL, SLAC, ANL	Near detector lead lab, cryogenic ASIC	CD-1

ESnet6	ASCR	**LBNL**	Lead lab, infrastructure upgrades, procurements	CD-1/3A
NERSC-9	ASCR	**LBNL**	Lead lab, procurements, network software.	CD-3

LBNL has worked closely with BNL on nuclear and high energy physics projects for three decades. In nuclear physics, LBNL played a major role in RHIC detector construction, was the lead lab for the STAR detector, and fabricated the STAR TPC. More recently, we led the design, construction, commissioning, and operation of the Heavy Flavor Tracker (HFT) pixel detector, the world's first Monolithic Active Pixel Sensor (MAPS) based detector to be installed at a collider. LBNL has been involved in many aspects of STAR physics analysis for the heavy ion and RHIC spin programs. We manage the use of the considerable NERSC computing resources made available to ALICE and STAR, including simulations that directly support detector design and system integration. Recent scientific accomplishments include the heavy flavor analysis from the HFT which showed conclusively that heavy mesons are thermalized in the collisions, analysis of the beam energy scan data, and the original goals of the spin physics program. In high energy physics, we played a major role in the original ATLAS tracking with BNL as lead lab, and we are presently working on the ATLAS HiLumi upgrade with BNL as lead lab, and on the LHC Accelerator Upgrade project with FNAL as lead lab and BNL as a collaborator. LBNL has been a long-term proponent of the EIC with considerable roles and contributions at all its stages so far.

LBNL has the necessary project management and engineering expertise to be the lead lab for construction of the EIC general-purpose detector (TPC $300M). However, we understand that because of the strong partnership in place between BNL and JLab, lead lab responsibility for the general-purpose detector will likely be shared between them. In this case, we would propose to take responsibility for one or more level 2 subsystems within the detector sub-project, with support of the UC EIC Consortium and the EIC Silicon Consortium. Given our scientific interests, recent experience, and core competence with Silicon-based vertex detectors (STAR-HFT, ALICE-ITS, sPHENIX MVTX, ATLAS upgrade) we are very interested in taking management responsibility for a state-of-the-art silicon tracking and vertexing system for the general-purpose EIC central detector. There are exceptional opportunities to leverage the MAPS sensor developments which have been taking place at the LHC. We are working with a strong international collaboration and have initiated the EIC Silicon Consortium to make this happen for the EIC. We would emphasize that construction of a silicon tracking and vertexing system of this scale will itself be a multi-institution international activity. We have also initiated the UC EIC Consortium, and look forward to partnering with other institutions in this effort. Depending on how the second detector project evolves, LBNL would be interested to manage it, especially if it targets one of our principal physics interests.

The far-forward detector system plays a key role in several physics topics of interest to the group. The system involves multiple silicon tracking stations, and the B0 tracker development may benefit from the R&D done as part of the EIC Silicon Consortium. Current development of the EIC Zero-Degree Calorimeter (ZDC) is largely based on the ALICE FoCal. We contributed to the development of the ALICE FoCal and have expertise to take part in the silicon power and readout systems of the EIC ZDC. Because of the overlap with our physics interest and other detector R&D activities, we have joined the EIC Far-Forward Detector Consortium EoI.

Other parts of the detector where LBNL could play a significant role would be electronics (especially FPGA-based systems), magnets, slow controls, software and computing, and data acquisition. Our recent experience with developing streaming readout for the large acceptance Gamma-Ray Energy Tracking Array (GRETA) is also indicative of opportunity for EIC.

LBNL uses a matrix management model for engineering and other resources (mechanical and electrical engineers, technicians, project controls, EHS, QA/QC, etc.). This allows us to ramp up engineering staffing rapidly and allocate resources efficiently between projects. The envisioned EIC detector construction time-frame meshes well with our ongoing participation in the LHC upgrades and ALS-U which will be substantially complete by this time.

Please indicate the items of interest for potential equipment cooperation:

As noted in the introduction, our goal is to participate in the design and construction of the accelerator, in the design and construction of the detectors, their commissioning and operations, and in the experimental program which will follow. Our principal detector interest is in a state-of-the-art silicon tracking and vertexing system for the general-purpose EIC central detector. We have already made substantial progress towards this goal through relevant experience at STAR and ALICE, and EIC-specific R&D (eRD16 and eRD25).

LBNL is a founding member of the EIC Silicon Consortium. The goal of this consortium is to develop an integrated technical solution – MAPS chip, support structures, power distribution, cooling, control, and ancillary parts – capable of tracking and vertexing in the central region of a general-purpose EIC detector. The product of this effort is intended as a silicon-based tracking and vertexing solution that can be used at either or both interaction points in the EIC ring. The configuration (number of barrel layers, disks, spacing, etc.) will likely be different in the two detectors, but the need for high precision inner tracking and vertexing is almost certain to be present in both.

The members of this consortium believe that the most effective way to achieve this goal is to join the ongoing effort at CERN which is developing a new MAPS sensor based on the Tower-Jazz 65 nm process. This will be used in the upcoming ALICE ITS3 upgrade. The requirements for the ITS3 and for an EIC tracking sensor have very broad overlap and the synergies of joining an already funded effort strongly increase the probabilities of success. A more detailed description of the current path that leads to an EIC optimized sensor and associated infrastructure can be found in the eRD25 EIC generic detector R&D proposal.

Specific LBNL-based efforts to be part in the EIC Silicon Consortium are described in detail in the EIC Silicon Consortium EoI, which is submitted separately. In short, these efforts include:

- Collaborating on the silicon design with an emphasis on low-power circuitry, stitching process yields, and serial powering,
- Targeted R&D on services and supports to meet the EIC traversed material needs,
- Mechanical and electrical design for the barrels and disks, their cooling, and supports.

Moving beyond the sensor R&D and initial design effort within the EIC Silicon Consortium, LBNL proposes to perform the following additional construction effort towards a state-of-the-art tracking and vertexing subsystem:

- Management and technical oversight of silicon detector design and construction,
- Design and fabrication of carbon composite support and services structures,
- Electronic design of powering and readout,
- Global system level design of associated services,
- Radiation effects testing at the Berkeley Accelerator Space Effects (BASE) facility,
- Optimization and commissioning of detector components.

In addition, we will determine what role the MAPS sensor development as part of the EIC Silicon Consortium can play in the far-forward B0 tracking system and propose to participate in the design and construction of the ZDC, as described in the EIC Far-Forward Detector Consortium EoI.

Please indicate what, if any, assumptions you made as coming from the EIC Project or the labs for your items of interest:

LBNL is an Office of Science Laboratory. Augmentation of construction costs from other DOE sources is not possible. However, in the past, the Office of Nuclear Physics has allowed scientific effort to be redirected to a broad range of tasks that can be undertaken by physicists. Technical resources including, engineers, project controls, QA, system engineering, EHS professionals, and technicians will be supported by the project. All of these skills are available at LBNL.

Presently, the groups at LBNL and UC Berkeley have support from DOE nuclear physics to take part in ongoing experiments at the LHC, RHIC, and JLab. Support targeted for EIC activities has come from Generic Detector R&D Program awards (eRD16 and eRD25), Professor Barbara Jacak's Distinguished Scientist Fellow Award, a UC *Multicampus Research Programs and Initiatives* pilot award, and LBNL Laboratory Directed Research and Development funds. Pertinent to this EoI, these funds have enabled the conceptual development of hybrid and all-silicon tracking and vertexing solutions for the general-purpose EIC central detector.

Please indicate the labor contribution for the EIC experimental equipment activities:

The time commitment of members of the LBNL and UC Berkeley group in the EIC efforts described in this EoI is anticipated to increase over time. We summarize here the current status as well as future plans. The table shows planned commitments in three phases: initial R&D phase (Phase 1), final design phase immediately following CD-2 (Phase 2), and final construction and commissioning phase (Phase 3).

We note that LBNL is part of the EIC Silicon Consortium and has joined the ALICE ITS3 project with the goal of developing a third generation MAPS sensor variant which is optimized for the EIC. We estimate the LBNL silicon sensor development level of effort at 1.5 FTE Staff

(3 individuals), 1 FTE Postdoc (2 individuals), and 0.9 FTE Student (3 individuals) for a total of 3.4 FTE for approximately the next two years.

Silicon tracking and vertexing system design involves a significant amount of simulation effort, followed by collaboration with Engineering Division staff to translate the conceptual design into a real design. Simulation and design efforts are underway, and will continue for 1–2 years at a comparable level of staffing. We are also examining a number of physics channels, performing detailed simulations to specify performance of EIC detector subsystems including, but not limited to, the silicon tracking and vertexing subsystem.

In the Table, the annual overall FTE numbers are given. We show the annual sum over the activities, as well as the anticipated ramp-up of personnel contributing to the EIC detector project, divided into the three phases noted above.

	Professor	Research Professor	Staff Scientist	Postdoc	Graduate Student	Undergrad. student	Engineer	Designer	Technician	Total Sum
LBNL										
Phase 1			3.3	1.7	0.5	0.4				5.8
Phase 2			5.0	1.3	0.5	0.4				7.2
Phase 3			5.3	1.5	0.5	0.4				7.7
UC Berkeley										
Phase 1	0.15			0.0	0.8	0.2				1.15
Phase 2	0.15			0.5	0.8	0.4				1.85
Phase 3	0.25			0.5	1.5	0.4				2.65

NOTE: The values in the above table represent the annual fractional full time equivalent (FTE).

Please indicate if there are timing constraints to your submission:

As noted in the introduction, the various projects underway at LBNL and UC Berkeley mesh rather well with the ramp-up of scientific effort toward developing EIC detectors. This conclusion entails assumptions on currently anticipated timelines, which may of course change as the EIC Project overall timelines develop. However, we anticipate that LBNL effort and funding will follow a commensurate schedule, as both are funded primarily by the DOE.

Our effort table is laid out in terms of three phases of contributions to the EIC Project goals. The first phase consists of R&D work to specify, simulate, and design the silicon pixel vertex and tracking detector system. Phase 1 is anticipated to last for approximately two years. It is followed by Phase 2 in which design is finalized, after EIC Project CD-2. This phase is anticipated to last 2-4 years, depending on the funding profile for detectors. In Phase 3, construction is in full swing, followed by initial commissioning of the EIC detectors.

The work described in this EoI will be done in collaboration with other institutions within and outside of the U.S. This EoI shows the sum of all anticipated work at LBNL and UC Berkeley. For a specific breakdown of contributions to the EIC Silicon Consortium, please see that EoI and note that the timelines for silicon sensor development are driven by the ALICE-ITS3 schedule.

Please indicate any other information you feel will be helpful:

LBNL and UC Berkeley have local access to extensive facilities and capabilities to take on the work in this EoI. These include:

- Staff experienced in the design and fabrication of large area silicon detectors – as one can tell from the number and scope of the successful projects, the staff available at LBNL are well suited to this type of project. This covers not only the engineering aspects but the technical management, project controls, and oversight of large projects of the scale and larger than what is anticipated for the EIC silicon tracking.
- Mechanical and Electrical Engineering – The mechanical and electrical engineering departments at LBNL are highly experienced and capable. All modern electronics and readout designs including FPGA, ASIC, DSP and full custom design are well covered and the list of successful projects is extensive. Similarly, the mechanical engineering capabilities are first rate and have produced many world-leading successful projects.
- Silicon Design – LBNL has an experienced silicon design group that has experience designing all types of silicon sensors including MAPS, hybrid, strip, pad, CCD as well as readout and specialized front end ASICs.
- Carbon Fiber Composite Shops – The facilities at LBNL include both the shop itself with a full set of apparatus for fabricating large and complex structures that are tailored to the detector needs and the engineering and technician capability and experience to do the designs and fabricate and test the structures as a turn-key solution. The support structures for the ATLAS inner detector, STAR HFT, ALICE main ITS supports and many other structures were designed and fabricated at LBNL.
- Machine shops – the machine shops at LBNL have wide ranging capabilities. We have precision shops with NC machines capable of fabricating parts with down to 0.1 um precision. We have the capability to machine very large structures. We have waterjet, wire EDM and sheet metal shops that have experience with the types of structures that will be needed for the EIC detector parts. We have a complete precision measurements shop with multiple CMMs.
- Clean Rooms – LBNL has many clean room facilities including large area class 100 clean rooms where detectors for ATLAS, DESY, HFT, and many other experiments were assembled and tested.
- Radiation effects testing – LBNL has the BASE facility and staff at its 88-inch cyclotron. The capabilities are utilized by users from science and industry throughout the world.
- Computing capabilities – LBNL has played a strong role in STAR computing and is the lead lab for the ALICE-USA computing project, harnessing resources from NERSC and other facilities at LBNL as well as ORNL for ALICE.
- Network Engineering – As host of ESnet, the LBNL Scientific Networking Division has expertise in high-speed standards-based networking which can be applied to streaming readout, data distribution, and data management.

Furthermore, we would like to note:

- Nuclear Theory – LBNL has a strong nuclear theory program with long-standing interests and contributions to the development of EIC science and key observables,
- Accelerator Physics – LBNL has a strong accelerator division focused on particle accelerator design and construction, interests in the EIC magnets, RF and beam-beam modeling.
- ECR Ion Sources – LBNL has premier capabilities in ion sources; R&D on third generation ECR ion source technology is underway to enable injection of higher intensity and charge state heavy ions. In-house ion source fabrication capabilities have supported multiple accelerators.

Cross-references to other Expressions of Interest:

As described in this submission, LBNL and UC Berkeley are taking part as founding members in the UC EIC Consortium and the EIC Silicon Consortium EoIs, submitted separately. We have joined the EIC Far-Forward Detector Consortium EoI and the EoI for Software.

We have also been in contact with colleagues at ORNL and see complementarity in our approaches/EoIs that can be expected to be brought to fruition in the formation of detector collaborations. This holds also for colleagues involved in the streaming readout EoI and the EIC-Indian Consortium EoI.