Expression of Interest (EOI)
Questionnaire

(Use this template for your document. The document can be at most 10 pages long, in this style, font and font size, but you can have appendices and do not have to include the tables in the page count. There is no prescribed format of the document, but you are asked to address the questions below. It is understood that maybe not all questions can be answered precisely, everybody is asked to fill the questions as good as currently possible. All submitted public Questionnaires will be viewable here (https://indico.bnl.gov/event/8552/). You can also submit a separate document with certain information you would only like to be viewable by the EIC Project. DEADLINE FOR SUBMISSION: NOVEMBER 1.)

Please indicate the name of the contact person for this submission:
(we ask for one main contact person per submission. You can as needed provide further contacts, but there should be one primary contact)

Boleslaw Wyslouch

Please indicate all institutions collectively involved in this submission of interest:
(even if institutions can submit on their own, it is highly encouraged to form groups to work together within their country, their geographical region, or as a general consortium)

Laboratory for Nuclear Science, Massachusetts Institute of Technology

Please indicate the items of interest for potential equipment cooperation:
(indicate experimental equipment components, including those integrated in the interaction regions, each separately)

See the attached overview which includes EoI: ECCE, EEEmCal and Streaming Readout.

Please indicate what the level of potential contributions are for each item of interest:
(e.g. indicate if contributions are for full in-kind experimental equipment components – we have provided a rough direct cost estimate for many components in an appendix (see slide 10 & 11 at https://indico.bnl.gov/event/7449/contributions/35863/attachments/27277/41597/EIC.Comp.Det.032020.eca.pptx, if contributions are for partial in-kind experimental equipment components, if contributions are for in-kind labor contributions, etc.).

See the attached overview

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

(e.g., indicate if you include engineering and design activities or assume those to come from the EIC Project, if you assume certain material costs to be covered by the EIC Project, if you rely on existing capabilities at the labs, etc. Try to be as inclusive as you can be.).

In this EoI we focused on the gathering information about our university's participation, to gauge the interest and capabilities. The specifics of engineering and design work will depend on the specific choices, as the idea for the detector(s) develop

Please indicate the labor contribution for the EIC experimental equipment activities:
(e.g., for each cooperation and/or institution list the number of senior staff, the number of postdocs, and the number of graduate and undergraduate students that you plan to dedicate to the EIC experimental equipment activities. Similarly, please list the number of engineers, designers and technicians included in your potential cooperation).

The time commitment of members of the different LNS groups in the EIC efforts described in this EoI is anticipated to be as follows:

Group Name	Professor	Research Professor	Staff Scientist	Postdoc	Graduate Student	Undergrad. student	Engineer	Designer	Technician	Total Sum
Hadronic Physics (Hen, Milner, Williams)	0.3		1.3	1	1	1				4.6
Heavy Ion Physics (Lee, Roland, Wyslouch)	0.3		0.3		0.5	0.2				1.3
Bates R&E Center (Kelsey, Wyslouch)	0.1	0	0	0	0	0	1	1	2	4.1

NOTE: FTE in the above table represents the annual fractional full time equivalent (FTE).
NOTE: for a professor, full-time equivalent research time may be limited to 25% max, for a research professor (or a sabbatical) or a staff scientist limited to 50% max, for a postdoc maybe 100%, and for a grad. student perhaps 50% (on average). For an undergraduate student research time (on average) is limited to 20% max.

(Repeat this table for each institution, or include the information for the whole group/consortium together in one table as shown above. ***This reflects an annual average FTE estimate.*** *Please state below for how many years you estimate this average cooperation level to be valid.)*

It is anticipated that the collaborative effort of MIT to cooperate on the EIC Project related to the detector construction is to include (at an annual basis) 0.7 full-time equivalent FTEs of a professor, 1.6 FTE of a research scientist, 1.0 FTE of a postdoctoral researcher, and 1.5 FTEs of Ph.D. students. The technical collaborative effort contributed is to include up to 1 FTE of a mechanical engineer, 1 FTE of a designer, and 2.0 FTE of a technician. We anticipate the duration of this collaborative effort to cooperate on the EIC Project to start at the design phase and to be for a period of multiple years. The participation of engineers, designers and technicians will be driven by the design and construction schedule and it may vary with time.

Please indicate if there are timing constraints to your submission:
(e.g., indicate any known or anticipated timing profile assumed in your EOI. This can include anticipated time frames folding in constraints due to ongoing commitments, due to ongoing R&D and its anticipated completion date, etc.)

Please indicate any other information you feel will be helpful:
(e.g., this could be things like assembly and storage space at your institute, clean rooms and class, special skills or machine shops, or perhaps some pointers to past accomplishments – you can expand on those in an appendix. If you could make existing engineering, design or technician labor available to the EIC experimental equipment but would rely on funds coming from the EIC Project you can also list those here).

See the attached materials

EIC Expression of Interest

O. Hen, J. Kelsey, Y.-J. Lee, R. Milner, G. Roland, M. Williams, B. Wyslouch

Laboratory for Nuclear Science,
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October 30, 2020

1 Overview

The study of QCD is a major activity at MIT with about 20% of the Physics Department faculty leading experimental and theoretical research in the Laboratory for Nuclear Science (LNS) funded by the U.S. Department of Energy Office of Nuclear Physics (ONP). Major current interests include the study of the QCD phase diagram at the LHC and RHIC, the study of hadron structure using electron scattering at Jefferson Lab and DESY, lattice QCD simulations and effective field theory. The Bates Research & Engineering Center, operated by LNS, provides essential technical support for both the experimental and high performance computing aspects of the MIT research. For two decades, MIT-LNS has played a leadership role in making the scientific and technical case for the EIC and in this document expresses the MIT institutional interest in contributing to the realization of the EIC project.

2 RHIC IP8 and ECCE

MIT physicists and engineers play a leading role in the sPHENIX experiment curently under construction in the IP8 interaction region at RHIC. Prof. Roland is co-spokesperson of sPHENIX (since 2015) and research scientists Camelia Mironov and Christof Roland have served in various leadership roles in construction of the MVTX micro-vertex detector and the sPHENIX computing effort. DOE has recently made major investments in RHIC IP8 infrastructure, including the 1.4T superconducting solenoid magnet, cryogenic support, and structural components, including the magnet flux return, electronics racks with power, cooling and safety systems. Previous studies have demonstrated that these IP8 infrastructure components, as well as several other sPHENIX subsystems, can be suitable elements of a fully capable EIC detector. Reuse of this equipment affords significant, cost, risk and schedule benefits. More details can be found in the related ECCE EOI, in which MIT-LNS plays a leading role.

3 Forward Detection

Forward detectors at the EIC will allow for measurements of quasi-elastic and 'tagged' inelastic reactions. The detection of forward nucleons and fragments will allow to correlate the nuclear states associated with the measured partonic dynamics, providing novel insight into the interplay between nuclear and parton dynamics in nuclei.

Prof. Hen is a co-convener of the EIC users group yellow-report working group on 'Diffraction and forward tagging'. This group is leading the simulation study of novel reactions that relay on forward tagging capabilities, and quantifies the detector characteristics that are needed to realize them. We are interested in following up on this effort by helping to realize the forward detector package. Specifically, we are interested in building forward neutron calorimeters and time-of-flight systems.

This interest builds on our most recent experience building the CLAS12 backward-angle neutron detector [1] and associated laser calibration system [2].

4 Electron Endcap Electromagnetic Calorimeter

The EIC is a unique collider with diverse physics topics that impose unique requirements on the detector design. Nearly all physics processes require the detection of the scattered electron in the electron endcap (forward rapidities). The requirement of high-precision detection is driven mainly by inclusive DIS where the scattered electron is critical for all processes to determine the event kinematics. Excellent electromagnetic calorimeter resolution of better than $2\%/\sqrt{E}$ is required at small scattering angles, while very good resolution is acceptable at larger angles. The highest resolution in electromagnetic calorimeters can be provided by homogeneous materials, e.g. PWO crystals and glass. We would like to collaborate with the project to help realize scattered electron detection in the electron-going direction covering pseudorapidity -3.5 to -1 with an electromagnetic calorimeter. The team has a long-standing track record with the construction of homogeneous EM calorimeters based on high-resolution crystals and glass.

D. Hasell and R. Milner are collaborators on the Electron Endcap Electromagnetic Calorimeter (EEEmCal) EoI led by Tanja Horn. They have interest in the mechanical design, prototyping, assembly and simulations. The MIT-Bates R&E Center staff and facilities would be utilized. The MIT-LNS contribution for the first five years is estimated at 2.5 FTEs annually, including faculty - 0.1; scientist 0.3; post-doc 0.5; grad stud. 0.5; ug. stud. 0.5; engineer - 0.2; designer - 0.2; technician - 0.2.

5 Readout and Reconstruction

MIT-LNS physicists proposed a streaming readout approach for the EIC in July, 2014. The rationale was to avoid the bias inherent in triggered readout systems and to take advantage of the advances in electronics and computing. Since then streaming readout has steadily gained support, a streaming readout consortium eRD23 has formed, and funding has been made available to organize workshops to refine streaming readout ideas and to interact with the various detector working groups.

MIT-LNS physicists have developed and implemented track reconstruction algorithms for multiple generations of collider exeriments from RHIC to the CERN-LHC, which will be further developed for future EIC applications. The goal is to devise strategies that allow reconstruction of very large data sets at a minimal CPU budget, while also keeping the manpower required for code maintenance at a minimum. The emphasis is to use detector specific code where needed, e.g., cellular automata for fast track seeding and Machine Learning supported cluster finding for high detector-occupancy reconstruction with the highest possible efficiency. On the other hand, for global track reconstruction and track parameter estimation the use of experiment-independent open source software packages is investigated to limit the manpower investment and maximize synergies across experiments. The use of GPU-supported code for tracking and event classification applications is also studied.

6 AI

The NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI), one of the inaugural NSF AI research institutes, is anchored at MIT in the LNS. The IAIFI will advance physics knowledge—from the smallest building blocks of nature to the largest structures in the Universe—and galvanize AI research innovation. The IAIFI is comprised of both physics and AI researchers at MIT, Harvard, Northeastern, and Tufts. MIT-LNS members Jesse Thaler and Mike Williams are co-leading this effort. More information can be found at iaifi.org.

MIT-LNS Research Scientist Cristiano Fanelli has already been involved in several EIC-focused AI projects, including the following: AI-optimized detector design for the EIC, using the dual-radiator RICH case as an exemplar, published in JINST [3]; DeepRICH, a deep-learning approach to reconstruction for Cherenkov imaging detectors, published in the journal *Machine Learning: Science and Technology* [4], a new journal of the Institute of Physics dedicated to high quality research in ML with a focus on multidisciplinary and technological advances in the field; and AI support for streaming readout, with preliminary results presented in Ref. [5], and a publication expected soon. Fanelli plans to join the IAIFI as an affiliate member, and to liaise with the IAIFI on topics related to AI applications for the EIC. He will devote 30% of his time to these efforts.

7 Spin Technology

MIT-LNS has expertise spanning three decades in development and realization of polarized sources, beams, targets and polarimeters. Highlights include: development of electron polarization in HERA [6]; 250 mA stored, polarized electron beam [7] in the South Hall Ring at Bates [8], first spin reversal of polarized electron beam in a storage ring [9]; polarized ^{3}He gas targets used at Bates [10], IUCF [11], HERA [12] and AmPs [13]; Compton backscattering electron beam polarimeters for BLAST [14] and Jefferson Lab [15], polarized hydrogen/deuterium target embedded in high magnetic field for BLAST [16], atomic beam source of polarized ^{3}He for nEDM [17]; and development of polarized ^{3}He ion source for RHIC [18]. We are interested in utilization of this expertise in the EIC project.

7.1 Polarized Sources

At present, the development of a polarized ^{3}He ion source for RHIC by a joint BNL-MIT collaboration is funded since 2012 by the DOE ONP R&D program for Next Generation Nuclear Physics Facilities. The MIT-LNS group led the development of high field optical pumping which takes place in the 5 Tesla field of the existing EBIS at BNL. The goal is to extract polarized, fully stripped ^{3}He ions by 2022 and subsequently inject them into RHIC.

At present a post-doc and Bates research scientist are working full-time on the polarized ^{3}He ion source development at BNL. We envisage this level of effort continuing for the next five years. Further, we expect that an MIT graduate student will join the effort in the next two years.

R&D into high intensity polarized electron sources has been pursued at Bates in recent years and there is significant expertise to contribute to the development of a polarized electron source for EIC.

7.2 Polarimetry

A polarized ^{3}He beam in RHIC will demand a polarimeter in RHIC and the BNL-MIT collaboration is working on this.

8 The Bates Research & Engineering Center

The Bates Research and Engineering Center is a DOE supported Center of Excellence staffed by scientists, engineers, technicians, and support staff located in Middleton, MA and operated by MIT-LNS. The Bates Laboratory was established in the late 1960's and was a National User Facility for Nuclear Physics until 2005. At that time, the accelerator ceased operation and the experienced personnel were retained by the creation of a research and engineering center supporting DOE sponsored Nuclear Physics projects. Bates scientific and engineering staff bring years of experience and expertise in essential areas to scientific collaborations in nuclear physics and related areas of research. Bates is particularly adept at providing a systems (big picture) approach. Engineering expertise includes:

- CAD, structural, thermal, and fluid flow analysis and ANSYS Maxwell magnet analysis.
- Design of structures, ultra-high vacuum systems, precision motion systems, and cryogenic systems.
- Power supply design, slow controls (EPICS), high voltage systems, printed circuit board layout.
- Design and fabrication of GEM, silicon based, wire chambers, time of flight, detectors.
- Design and fabrication of gas handling and advanced cooling systems for equipment and detectors.
- Design and fabrication of polarized electron sources, polarized and un-polarized internal targets, and atomic beam sources.
- Design and fabrication of electro and permanent magnet systems.

While the Bates Center is focused on supporting design and fabrication of particle beam experimental equipment, as well as helping to train the next generation of students and post docs, it will continue to support a broad spectrum of research activities for Nuclear Physics. The small but dynamic group of highly skilled personnel routinely collaborates effectively on a substantial variety of different research projects. Examples of past and current projects include:

- (Bates) BLAST – Design and fabrication of BLAST detector including toroidal magnets, supports (with precision motion system), atomic beam source [16], vacuum system, and various detectors [19]. Redesign and installation as OLYMPUS experiment at DESY [25, 26].
- (JLab) QWeak - Design and fabrication of power supply, supports and toroidal magnet [20].
- JLab Compton Polarimeter – Design and fabrication of magnets, support system, and vacuum system [15].
- (KIT) Katrin – Design and fabrication of a scintillator, lead and copper Veto system.
- (BNL) STAR – Design and fabrication of an Intermediate Silicon Tracker and high stability cooling system [21].
- (Bates) Polarized Electron Source – Design and fabrication of a high intensity polarized electron source [7].
- (JLab) DarkLight - Design and construction of a windowless hydrogen gas target for operation with a Megawatt electron beam [22].
- JLab MOLLER – Initial design of hybrid magnet system in a vacuum chamber approach [23].
- (ORNL) nEDM – Optimization of the Atomic Beam Source (He3) for the nEDM experiment [24].
- (JLab) GlueX – Design and fabrication of DIRC detectors for forward particle identification [27].
- (BNL) sPHENIX – Design and fabrication of a silicon based inner tracker. Part of sPhenix detector upgrade [28].

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8.1 Career Research Scientist Appointments

The development of the EIC research equipment at MIT-LNS will be a substantial effort involving about 10 Physics Department faculty and their research groups over about a decade. Further, the subsequent data taking and scientific analysis will likely extend into the middle of the century. The cohort of MIT graduate students and postdocs working on EIC when it is operational will likely amount to about 40 young physicists. Career research scientist appointments in LNS will be essential to maintaining an effective and optimized MIT-LNS participation in EIC. This is very much in line with past practice where such appointments were essential to MIT contributions to CEBAF/Hall A, BLAST and PHOBOS projects in nuclear physics.

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