Expression of Interest (EOI)
Questionnaire

Please indicate the name of the contact person for this submission:
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Please indicate all institutions collectively involved in this submission of interest:
Brookhaven National Laboratory (BNL)

Please indicate the items of interest for potential equipment cooperation:

The following details some examples of laboratory expertise and interests. BNL serves as the host institution for RHIC, in which large international collaborations have installed and operated multiple detector systems, with the support of BNL expertise. BNL also has extensive experience designing and constructing major components of the ATLAS detector at LHC and in the management of the contributions of many contributing institutions. Some examples of Laboratory expertise and interests:

- Highly segmented calorimetry, with multi-function capabilities for particle identification such as high resolution timing using silicon sensors for potential applications to forward calorimetry at an EIC detector.
- Silicon technologies for low-mass trackers and high-resolution timing. One recent example is the development of LGAD devices.
- BNL expertise also extends to the areas of gaseous detectors (both for classic planar drift chambers as well as planar TPCs), Roman pots, Zero Degree Calorimeters, polarimetry and DAQ.
- Innovative solutions for trigger, data acquisition systems, tracking pattern recognition, etc., based on artificial intelligence (AI) and machine learning (ML) algorithms.
- Engineering support for integration of subsystems. It is envisioned that BNL will play a major role in integration and commissioning of the EIC detector(s).

Specific examples of detector systems installed at RHIC with BNL support include:

- Tracking
    - Large Time Projection Chambers for STAR (with Multi-Wire Proportional Chamber readout) and sPHENIX (with Gas Electron Multiplier readout)
    - Silicon strip detectors both in barrel and endcap configurations (STAR, PHENIX), most recently for the STAR forward upgrade and sPHENIX INTT
    - Monolithic Active Pixel Silicon detectors for high precision at low mass (STAR HFT, sPHENIX mVTX)
    - small-strip Thin Gap Chamber detectors (STAR forward upgrade)
- Electromagnetic Calorimetry
    - Barrel and Endcap large-area Pb-Scintillator (STAR, PHENIX) with phototube readout
    - Crystal calorimetry ($PbWO^2$, PHENIX MPD)

    - Tungsten-Fiber barrel with SiPM readout (sPHENIX)
    - Pb-Scintillator forward wall with SiPM readout (STAR forward upgrade)
    - Pb-Glass in both barrel and endcap configuration (PHENIX, STAR FMS)
- Hadronic Calorimetry
    - Large-area Fe-Scintillator with SiPM readout in the barrel configuration (sPHENIX), serving also as magnet flux return
    - High precision Fe-Scintillator forward wall with SiPM readout (STAR forward upgrade)
- Particle Identification
    - RICH, TRD, ToF of multiple technologies (PHENIX)
    - Multi-Gap Resistive Plate Chamber time of flight walls in barrel and endcap configuration, and behind magnet steel as muon tagger (STAR)
    - Extensive use of specific ionization of the TPC (STAR)
- Very forward detection
    - Roman pots to detect scattered proton (STAR)
    - Zero degree calorimeters (ZDC) for forward neutrons (all)
- Proton polarimetry
    - Carbon target CNI polarimetry for fast, relative polarimetry
    - Gas-jet polarimetry for absolute polarimetry
    - Local polarimeters (ZDC, beam-beam counters) to measure local spin rotation at the IR
- Electronics, Trigger, and Data Acquisition
    - Pipelined systems using various Application Specific Integrated Circuits (when necessary) for high throughput readout, including in full streaming mode
    - Triggering systems with bunch-by-bunch ADC, TDC information for deadtime-free decisions at low latency
    - Real-time full-detector track reconstruction in a High Level Trigger for event tagging and rapid feedback to the accelerator (STAR)
- Infrastructure and Installation
    - Extensive experience in continual upgrades to the RHIC experiments, including at largest scale the reuse and repurposing of PHENIX for the ongoing sPHENIX construction and installation

In addition, BNL has extensive involvement in High Energy Physics experiments such as ATLAS, with specific expertise in calorimetry, data acquisition and electronics, and silicon, including Low Gain Avalanche Detectors (LGAD):

- Readout ASICs, Electronics, Trigger/DAQ and system integration for high luminosity, high density collider experiments
- Development of novel silicon devices for fast timing and tracking, including tests and calibration of silicon sensors (LGAD, AC-LGAD, MAPS, HV-MAPS…)
- Tests and integration of silicon strip detectors for High-Luminosity LHC
- AI/ML algorithms for trigger and tracking reconstruction for High Luminosity LHC
- Liquid Argon calorimetry for LHC

Please indicate what the level of potential contributions are for each item of interest:

See the Other Information section for specific information on equipment components and facilities available to the project.

Experimental equipment and infrastructure in the RHIC experimental halls are available for reuse to the EIC project, to the level consistent with DOE, NSF, and international procedures on dispensation of property. Potential examples include:

- Detector components of sPHENIX include:
    - 1.5T superconducting magnet and the magnet flux return steel.
    - The magnet flux return steel instrumented with Scintillating tiles and SiPM to serve as a Hadronic Calorimeter in the central region
    - An inner Hadronic Calorimeter
    - A projective Tungsten Powder - Scintillating Fiber Electromagnetic Calorimeter
    - A Time Projection Chamber with continuous readout via GEM's
    - A MAPS-based vertex tracker
- Support systems including gas systems, high voltage, and low voltage supplies
- Components of decommissioned detectors

Here we list the Expressions of Interest in which we have partnered:

- ECCE – the IP8 strategic reuse consortium
- Expression of Interest for EIC Streaming Readout
- Expression of Interest for hpDIRC
- Expression of Interest for Lepton Polarimetry
- Expression of Interest for MPGD based trackers and GEM-TRD for EIC.
- Expression of Interest for Software
- Expression of Interest from ANL on Ultrafast silicon sensors, hybrid SOI/LGAD tracker for the central region, pixelized MCP-PMTs and a gas RICH for the forward region, superconducting nanowire particle detectors, and computing for the EIC experiments
- Expression of Interest from LANL on Forward Silicon Vertex/Tracker Developments
- Expression of Interest of Silicon consortium
- Expression of Interest on Fast timing silicon detectors for EIC detectors
- Expression of Interest on the instrumentation in the lepton hemisphere

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

We assume that the project will provide support for engineering and professional staff to work on EIC design and funds for construction of sub-detectors.

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

BNL has a broad pool of skilled professionals that can contribute to the design, construction and integration activities. These will become available once sPHENIX construction and installation is complete by the end of 2022.

Please indicate if there are timing constraints to your submission:

Constraints arise from the timing of the ongoing detector upgrades (STAR complete in 2021 and sPHENIX complete in 2022) and RHIC operations ending in late spring of 2025.

Please indicate any other information you feel will be helpful:

BNL has extensive infrastructure for the construction and testing of collider detectors and their components. These facilities include:

- A large (2000 sq ft) high bay with a 15-ton crane in Building 510, currently used for the assembly of the sectors of the sPHENIX Electromagnetic Calorimeter.
- Extensive space in Building 912, currently used for assembly of the large sPHENIX Outer Hadron Calorimeter sectors
- The RHIC experimental halls 1006 and 1008, which have cranes, machining tools, clean rooms and tents, gas mixing rooms to support detector installation. 1008 is currently undergoing a major infrastructure and facilities upgrade, detailed below.
- Two clean rooms in Building 510, each of 800 sq ft.
- A wing of recently renovated laboratories in Building 510 with approximately 11,000 sq ft of laboratory space (https://www.bnl.gov/about/sustainability/LEED/RSL-II.php).

The 1008 infrastructure and facility upgrade provides modern support and services for large scientific instruments in the experimental hall. It includes the upgrade of Building 1008, support services including cryogenic supply, power supply, quench detector and control system for a 1.5T superconducting magnet, the magnet flux return steel, connection to the RHIC cryogenics facility, and all infrastructure needed to support the detector operation (cooling and ventilation, electrical transformers and power supplies, water, gas systems including gas pad and mixing house, smoke detection, fire protection, safety systems, racks, cable trays, network connection to computing center, rack room and counting house and office complex).

The RHIC experimental halls contain substantial infrastructure and equipment designed and optimized for use at a collider. Space is potentially available in these halls for the installation of prototype detectors for exposure during RHIC runs to conditions similar to that at the EIC.

The BNL Scientific Data and Computing Center (https://www.bnl.gov/compsci/SDCC/) is a multi-purpose and multidisciplinary center for high performance and high throughput computing connecting more than 2,500 researchers around the world. SDCC serves as a data center for major DOE programs such as the RHIC experiments at BNL, the ATLAS experiment at the Large Hadron Collider (LHC) at CERN in Europe and Belle II in Japan. The center currently provides over 200 PBytes of tape storage, 90 PBytes of central disk storage of diverse technologies and over 500k CPU cores. With the advent of sPHENIX data taking and the High Luminosity LHC (HL-LHC) it will grow in capacity by approximately an order of magnitude over this coming decade. The sPHENIX experiment will be moving toward a data streaming mode of operation, in which data center resources will be used for tasks that were traditionally handled by online computing. Experiments at the EIC are expected to adopt and expand on this mode of operation.

A new state of the art data center is under construction, funded by the DOE Office of Science Science Laboratories Infrastructure (SLI) program. This new data center, to be completed in 2022 with initially 4 MW power capacity, will have ample spare space for future upgrades and requirements. It will also open opportunities to develop new proficiencies in the area of high-performance data processing and analysis. In coordination with BNL's Computational Science Initiative (CSI), capabilities are being developed in the area of Artificial Intelligence (AI), data analytics, edge computing and Heterogeneous Computing, establishing SDCC as a global leader in tackling challenges of Big Data.

BNL's Advanced Technology Research Office (ATRO, https://www.bnl.gov/advtech/) consolidates core staff, research programs, and infrastructure in accelerator, detector, and related technologies to partner with academia and industry to serve as an incubator for cross-cutting initiatives to advance U.S. Department of Energy mission priorities including the EIC.

The BNL Instrumentation Division (https://www.bnl.gov/instrumentation/) has a number of facilities, including

- The Silicon Detector Laboratory is part of a series of laboratories and cleanrooms dedicated to the development of semiconductor detectors (Semiconductor Detector Laboratory). The focus of this facility is the development and production of silicon detectors
    - Cleanrooms and lab space dedicated to different parts of sensor processing, including post-processing, testing, calibration, metrology, and integration
    - Software, design, and verification tools for semiconductor detectors
- The Gaseous Detector Laboratory for development of gaseous detector systems
    - The laboratory includes a cleanroom and a suite of tools in support of different technologies developed for gas detectors
- The High Density Interconnect and Electronics Assembly Laboratory
    - A large cleanroom space with a multitude of tools for designing and fabricating interconnections – including computer-aided design software and high-tech interconnect equipment – for large international experiments.
- The Integrated Electronics Laboratory with focus on the development of Application Specific Integrated Circuits (ASICs), signal processing and electronics, DAQ and controls, Printed Circuits Boards (PCBs).
    - State-of-the-art software, design and verification tools
    - Assembly and testing infrastructure
- The Solid State Irradiation Facility (SSIF), with an 1150 Ci ^{60}Co source that can provide 1.17 and 1.33 MeV photons from 3 Gy/hr to 800 Gy/hr

The Magnet Division (https://www.bnl.gov/magnets/) has world-leading expertise in the physics and engineering of magnets. With more than 58,000 square feet of technical development space, and facilities to wind, heat treat, vacuum impregnate, construct, and test conventional and superconducting electromagnets and cables. Facilities include the following:

- Multiple cranes (up to 25 tons) throughout the facility for use in construction and testing of hardware
- Multi-axis winding machines that can wind coils up to 10 m in length
- Novel direct wind magnet technology that allows the construction of high precision multipole IR and specialty magnets up to 2.5m in length that has been used to develop IR magnets for accelerators around the globe
- A world class vertical magnet test facility that allows magnets up to 6.1m long, 71cm diameter to be tested at temperatures as low as 1.9K with currents as high as 25kA. Dipole test fields of up to 10T can be applied on cables and test coils with currents up to 10kA.
- A Nb_3Sn reaction oven with a length of 4.2m
- High precision magnetic measurement capabilities

The BNL Center for Functional Nanomaterials (https://www.bnl.gov/cfn/) is a user-oriented research center whose mission is to be an open facility for the nanoscience research community. It has extensive facilities for material fabrication and characterization that are well suited for the development, production, and testing of advanced sensor materials.