**EIC-Japan Expression of Interest**

**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)*

**Yuji Goto, RIKEN,** **goto@bnl.gov**

**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)*

The EIC is a great research opportunity for Japan, and we are working to form a Japanese group.

We are forming a high-energy accelerator-based experimental group in the field of both nuclear and particle physics, which holds regular study meetings and workshops.

In Japan, the Science Council of Japan (SCJ) developed a master plan for large-scale research programs in academia (Master Plan 2020) in 2019-2020. The EIC was recognized as an important international collaborative research project as a long-term research plan by the Future Planning Committee of the Committee on Nuclear Physics, and was proposed to the Master Plan.

As a result, the EIC was selected as an academic major research project, although it was not selected as a priority project in the Master Plan 2020, yet.

The EIC-Japan group would like to design and construct forward detectors of the EIC detector, especially calorimeters, to lead the study of forward and the very forward physics. The forward detectors are one of the most important detectors for precisely reconstructing certain types of events of the deep inelastic scattering (DIS) process, which is the basis of all research at EIC. By measuring the forward and the most forward jets, hadrons, photons, and electrons and studying their correlations, we can precisely determine the spin and internal orbital motion of partons in the nucleon, which is still poorly understood. In particular the contribution of gluons, sea quarks and orbital angular momentum to the proton spin is still a mystery. Additionally, our understanding of the most forward events will greatly enhance the development of the QCD-based event generators. This will also greatly contribute to eliminating uncertainties in other high-energy particle experiments and cosmic ray observations.

Subsequently, in addition to the proposals in the master plan, we have expanded our activities as a Japanese group to include a group interested in building a silicon detector. The team is open for new collaborators. The following collaborators are particularly welcome: expertise in silicon sensors in general, readout electronics, signal transmission, mechanical/electrical engineering, slow control systems, etc., Eastern Asian institutes taking geographical advantage.

In this submission of the EOI from the EIC-Japan group, following institutions are involved.

* Yamagata Univ.
* RIKEN
* Kobe Univ.
* Shinshu Univ.
* Univ. of Tsukuba
* Tsukuba Univ. of Technology
* Japan Atomic Energy Agency, JAEA
* Nihon Univ.
* High Energy Accelerator Research Organization, KEK
* Tokyo Metropolitan College of Industrial Technology

We are collaborating with high-energy groups (mainly working at LHC-ATLAS; Kyushu Univ., KEK), cosmic-ray groups (mainly working at LHCf & RHICf; ICRR Univ. of Tokyo, Nagoya Univ.). They cannot participate in this EOI, but we will keep the close collaborations.

We are also collaborating with the EIC-Korea groups (Korea Univ., Sejong Univ., Pusan Univ.). They will submit their own EOI.

**Please indicate the items of interest for potential equipment cooperation:**

*(indicate experimental equipment components, including those integrated in the interaction regions, each separately)*

1. Forward hadron calorimeter

We have participated in the development of the hadron calorimeter in collaboration with the UCLA/STAR/eRD1 group. The one that has been developed as the STAR FCS is a 38-layer Fe/Sci sandwich calorimeter, collecting light with WLS and read out by SiPM. Since the energy resolution of this detector is 70%/√E (GeV)) + constant/noise term, the one for EIC requires higher energy resolution. We would like to expand our collaboration to develop a dual readout calorimeter.

In electron-proton collisions, performance of the forward hadron calorimeter is a key item in the cross-section measurements in the high Bjorken x region, where a struck quark goes forward. The position and energy measurements of hadrons take a crucial role especially in the charged current process e q → ν q’, where the struck electron escapes from the detector as a neutrino. In this case the DIS kinematic variables have to be reconstructed from the angular and energy distribution of the hadronic final state. Also in neutral current events at high x as well as low y the hadronic method of reconstructing the DIS kinematics significantly improves the resolution.

Neutral current electron-proton scatterings are sensitive to the total number of quarks and anti-quarks in the proton and charged current scatterings have sensitivity to isospin structure of nucleons. Precise measurements of them in the high-x region are expected to improve the understanding of the traditional proton PDFs used in LHC physics, leading to improved precision of the LHC measurements.

In polarized and unpolarized measurements the region covered by the hadronic reconstruction method is important to understand the scale evolution of transverse momentum dependent distributions functions in the high-x region from low to high scales. This is important in terms of the nucleon structure to understand the QCD dynamics well, but also connects directly to the understanding of differential Higgs and other heavy boson measurements at the LHC. The charged current events provide a natural parton flavor separation via the weak interaction that is crucial to various nucleon spin structure measurements and complements semi-inclusive DIS contributions to it. Furthermore, jets have been identified as an important tool in the study of the nucleon structure. Apart from the crucial neutral component in jets, a forward hadronic calorimeter may also help improve the resolution of charged hadrons’ energies.

Last, several diffractive measurements require either the positive identification of the forward going proton, or, as in the case of collisions with nuclei, that a large rapidity gap between central particles and the beam remnant exists. In such a case the forward hadronic calorimeter can provide the hermeticity to identify such a case of events.

1. Zero-degree calorimeter (EM & hadron)

We have proposed EIC detector R&D in collaboration with Kansas Univ. and other collaborators, which has been approved as eRD27 this year. In this program, we will conduct;

1. a photon detector study at a low energy < 300 MeV, cooperating with eRD1 for crystal and glass scintillators,
2. a prototype study of ZDC with position sensitivity, with the ALICE-FoCal technology and the LHC-ZDC technology with a fused silica, and
3. a radiation hardness study of scintillators.

We have developed a potential zero-degree apparatus for the Electron-Ion Collider (EIC) experiment. Zero degree detectors serve critical roles for a number of important physics topics at EIC. We will study requirements and technologies of zero-degree detectors, and mainly develop a position-sensitive zero-degree calorimeter (ZDC).

In electron + nucleus collisions, exclusive vector meson production in diffractive process is one of the key measurements at the EIC. For the coherent process where the nucleus remains intact, the momentum-transfer (t) dependent cross section can be translated to the transverse spatial distribution of gluons in the nucleus, thus considered to be directly sensitive to the gluon saturation. This requires accurate determination of the coherence of the reaction, which must be determined by identifying the breakup of the excited nucleus. Evaporated neutrons from the breakup in the diffraction process can be used to separate the coherence most probably (∼90%). In addition, photons from de-excitation of the exited nucleus signals incoherence in absence of evaporated neutrons. This leads to a requirement to measure neutrons and photons at near zero degree precisely to complete the coverage of coherence tagging in a wide t range.

Collision geometry is an important measure in electron + nucleus collisions for an event-by-event characterization. It has been proposed that collision geometries can be tagged through forward neutron multiplicities emitted at near zero degree. Constraining collision geometry quantities like “traveling length” of struck parton in nucleus, which is correlated with the impact parameter of the collision, is very meaningful in the studies of nuclear medium effects. With the determination of collision geometry in these measurements, our understanding of nuclear structure can be constrained with higher precision.

In electron + deuteron and helium-3 collisions at EIC, various physics programs require the tagging of forward neutrons as spectators to identify the target nucleon. It constrains kinematics for studies of the Short-Range Correlations (SRC). The SRC is a nucleon-nucleon interaction at very short distance which shows high momentum nucleon in the nucleus rest frame. It shows how nucleons form a nucleus, and has a deep connection to how the quark-gluon structure of a nucleon in a nucleus is modified, known as the EMC effect. Experiments have shown it is universal that ∼20% of nucleons are in SRC pairs. These SRC pairs have high momentum and spatially very close each other. Almost all of these SRC pairs are found to be similar to a quasi-deuteron at its high momentum tail. In addition to the SRC study in electron + nucleus collisions, we will be able to understand the deuteron as a baseline of SRC pair in electron + deuteron collisions at zero degree.

In electron + proton collisions, leading proton and neutron production in DIS were measured and their production mechanisms were studied at HERA by comparing with fragmentation process and one pion exchange (OPE) process. The results support that the OPE process dominates the production. In addition to the production cross section measurement, the spin asymmetry measurement of the leading baryons in polarized electron + proton collisions will give us useful additional information for the study of the production mechanism. The data also will be used to understand the forward energy flow and the development of dedicated event generators which can then be applied to improve the understanding of air shower evolution of high-energy cosmic rays and neutrino interactions.

1. Silicon detector

Heavy flavor quarks are highlighted in EIC as the ideal probe to study open questions in QCD, such as mass/flavor dependence of the energy loss, fragmentation and hadronization modification in the nuclear medium, nPDFs, gluon Sivers effect and so on. The silicon sensor detectors are the key technology commonly employed for the heavy flavor detection by observing their decay vertex precisely. The performance of the silicon sensors thus plays a crucial role to pursue the research in the heavy flavor physics in satisfactory level.

We propose to apply Silicon sensor based on silicon-on-insulator monolithic pixel (SOIPIX) detector technology which has been developed by KEK group. The SOIPIX has demonstrated world’s best tracking resolution of 0.68 ±0.006 μm in a silicon detector using 120 GeV FNAL’s test beam. The SOIPIX is employed as the inner vertex detector of 4π silicon hybrid detector (4PISHDEIC) proposed by ANL an BNL Collaborators. We are developing collaboration with 4PISHDEIC group.

The SOIPIX group already has collaboration with IPHC (France) group where PXL detector of the STAR experiment is developed.

**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.).*

1. Forward hadron calorimeter

Although the proposal in the Master Plan is not a direct request to the Japanese Government, the construction cost of the forward hadron calorimeter is described as $8.3M, based on the STAR FCS or Fe+Sci calorimeters mentioned above, for the construction of all the detectors in the forward hadron calorimeter.

1. Zero-degree calorimeter (EM & hadron)

The ZDC is also described as a construction expense in the master plan, but at this scale, the goal is to construct the facility with a view to paying for it with large scientific research funds (e.g. JSPS Kakenhi) in the future.

EM calorimeter: $2.5M from ALICE-FoCal-E: W+Si

Hadron calorimeter: $690K from ALICE-FoCal-H: Pb+Sci

Full absorption photon detector (or just preshower detector)

1. Silicon detector

We are developing a plan for budget request and thus making a coarse estimate of the material cost of inner silicon detector of 4PISHDEIC. The SOI detector technology is to be developed mainly conducted by the dedicated silicon detector laboratory and experts in KEK. The development is to be supported by multiple domestic institutes which reside with silicon technologies in general and experiences.

**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.).*

There is no such assumption.

**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).*

At the moment Japan is not yet at a stage where an organizational commitment can be discussed as there is no budget source for EIC in Japan. Currently the EIC Japan Group is made up of those organizations that have shown interest and cooperation on an individual level and are willing to accept it. It is also at this level that the activities of the EIC Japan Group are expanded. Here we will only summarize the individual level contributions of such organizations at present. In the future, as budgetary resources become available, a wider and larger participation will be possible.

* Yamagata Univ.: 3 staff scientists (0.1 FTE × 3)

Other activities: COMPASS, SpinQuest

In long term, 2-3 undergraduate students and 1-2 graduate students will be added.

* RIKEN: 4 staff scientists (0.1 FTE × 4), 3 postdocs (1.5 FTE)

Other activities: sPHENIX, RHICf

* Univ. of Tsukuba & Tsukuba Univ. of Technology: 2 staff scientists (0.1 FTE × 2)

Other activities: ALICE

* JAEA: 1 staff scientist (0.1 FTE)

Other activities: J-PARC

* Nihon Univ.: 1 staff scientist (0.1 FTE)

Other activities: SpinQuest

* KEK: 3 staff scientists (0.1FTE × 3)

**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.)*

Budgetary progress in Japan (if it happens) may allow participation of some groups and people.

We’re working to get more groups to join the EIC-Japan group.

**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).*

1. SOI integrates both silicon sensor and readout electronics in the same wafer which is considered as the next generation silicon sensor technology. It has potential advantages compared to MAPS technology employed for the ALICE Inner Tracker System in terms of in the timing and position resolution, radiation hardness, etc. In addition, circuit density can be much high compared with standard CMOS process of same kind of node since there is no well separation in the SOI technology. The team is open to collaborate with other collaborators who are interested in developing silicon sensor detector using SOI technology other than 4PISHDEIC.
2. A framework of Detector Development Platform in KEK has been launched since 2019. This framework is open to a broad area of communities, in order to promote technology/knowledge exchanges and new collaborations and to support their detector developments using facilities in KEK. A platform for silicon detectors, led by KEK and Kyushu University researchers, has been utilized by a group of University of Tsukuba towards the development of ALICE FoCal . University of Tsukuba and RIKEN are considering using this framework for the development of the EIC equipment described in this EOI.
3. There are Silicon Sensor Industries in Japan: Hamamatsu Photonics co., Lapis Semiconductor Co. Ltd , Tohoku MicroTec Co. Ltd., A-R-Tec Co. We have a long history and experience of working together with them.
4. We are getting small-size budget for the EIC R&D in Japan. 2020.7: U.S.-Japan science and technology cooperation program in high-energy physics (special category), 2020.8: U.S.-Japan hadron physics exchange program for studies of hadron structure and QCD (2020.9-2023.9), 2021: one postdoc has been offered a position at JSPS with EIC as a research project.

**Cross-reference to other EOIs with involvement of collaborators**

* Argonne National Laboratory EOI (contact person: Zein-Eddine Meziani)
* EOI for high resolution Zero Degree Calorimeters (contact person: Michael Murray)