Expression of Interest (EOI) Questionnaire

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

- Prof. Dr. Mariusz Przybycień
  AGH University of Science and Technology
  Faculty of Physics and Applied Computer Science

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

- AGH University of Science and Technology (AGH UST), Al. Mickiewicza 30, 30-059 Kraków, Poland.
- Brookhaven National Laboratory (BNL), Upton, NY 11973, USA.
- Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences (IFJ PAN), Ul. Radzikowskiego 152, 31-342 Kraków, Poland.
- Temple University (TU), 1925 N. 12th Street, Philadelphia, PA 19122, USA.

Please indicate the items of interest for potential equipment cooperation:

Precise luminosity measurement at the EIC, with $\delta L/L < 1\%$, and of 10^{-4} for relative bunch-to-bunch measurements, is both crucial to achieve its main physics goals and very challenging – for $e+p$, ≈ 10 hard bremsstrahlung photons are expected every 10 ns; for e+Au, more than hundred of such photons, at the nominal luminosity.

Rear electron detectors will also suffer from event pileup ($e+p$: ≈ 3 bremsstrahlung electrons every 10 ns, assuming its acceptance range $0.65 < E'/E < 0.85$. For the e+A collisions the event pileup will scale approximately with Z^2/A).

We propose to deal with the above problems by installing several dedicated sub-detectors in the lepton hemishpere. The detectors are briefly described below, and their locations are schematically shown in Fig. 1.

Lepton hemisphere instrumentation:

- Bremsstrahlung Calorimeters (PHOT)
  Two movable calorimeters will measure unconverted bremsstrahlung photons. A high-resolution photon calorimeter will be used to perform regular, very precise, reference bremsstrahlung measurements in special conditions with low event pileup. On the other hand, a radiation hard, highly segmented and very fast photon calorimeter will be used to precisely measure "photon energy flow" even at highest event pileup. In addition, to monitor synchrotron radiation background, two segmented, fast X-ray detectors are foreseen, to be developed in collaboration with accelerator instrumentation groups.

- Converted Photons' Detectors (SPEC)
  A spectrometer system will measure bremsstrahlung using the photon conversions in the beam-pipe exit window. Both the original photon energy and its emission angle will be precisely reconstructed.

- Rear Electron Detectors (Taggers)
  These detectors will allow for the precise reconstruction of the momenta of electrons scattered in very rear direction and will include highly segmented calorimeters as well a very fast and robust hodoscope. In addition, to properly correlate rear electrons with events registered by central detectors, segmented detectors will be installed, to provide a picosecond resolution ToF information, separately for each electron registered in Taggers.

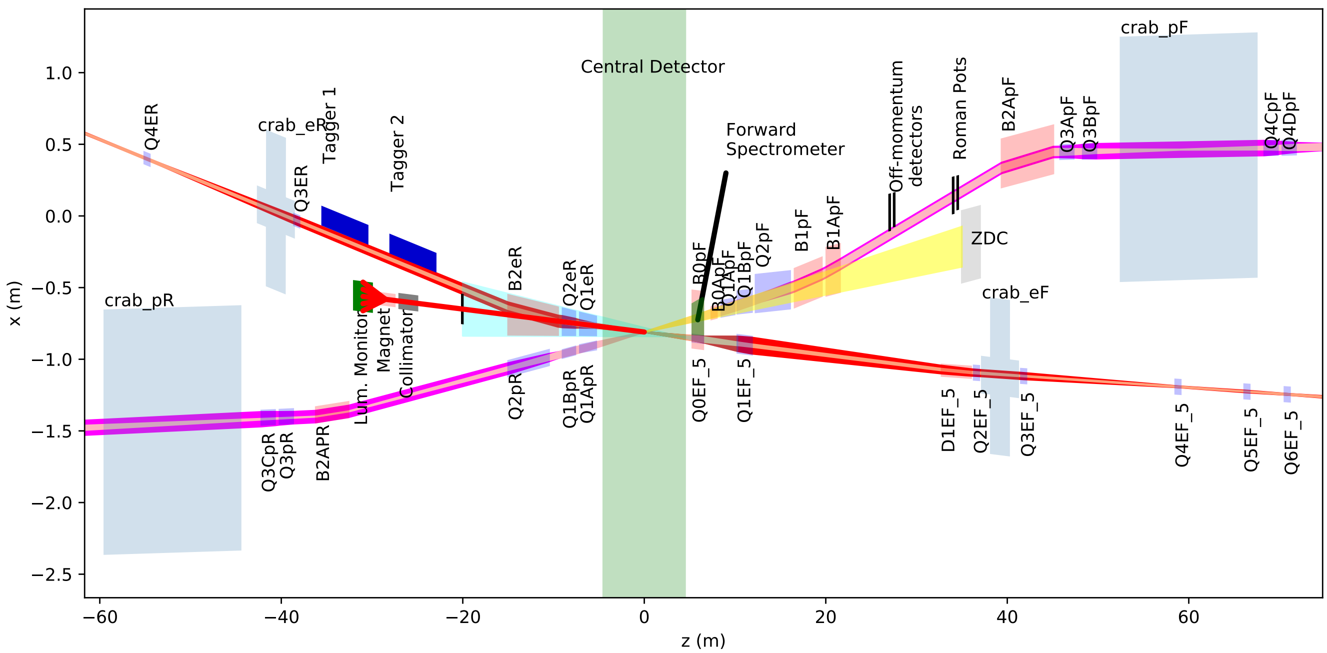

Figure 1: Layout of the EIC Interaction Region, with indicated detectors proposed in the EoI. Figure adapted from *EIC CDR*, BNL, 2020.

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

- AGH UST: We plan to design ASICs and readout electronics (with exception of the picosecond-timing detectors), as well as perform assembly of the readout boards, and integrate them with the detectors. The ASIC chips will be manufactured by industry. We plan to contribute to the development and design of the detectors.

- IFJ PAN offers personpower, expertise and infrastructure for mechanical design and construction of the detectors.

- BNL offers to use its expertise in the EIC interaction region design and long collaboration with the accelerator and specifically the EIC vacuum group to coordinate the integration of the detectors in the IR. The BNL COLD QCD group has experts on staff who have hands on experience on the ZEUS Luminosity monitor at HERA, therefore we will also be interested in the technology choices and design of the detectors.
- TU offers personpower, expertise and infrastructure for mechanical design, construction, and testing of detector components. TU has sufficient space for cosmic-ray muon and source testing if applicable. The close proximity of TU to BNL allows easy access to BNL and actively participate with graduate students in the installation and commissioning of detector components.

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

- AGH UST: We assume that the detectors will be installed in the tunnel by the BNL personnel and on the Lab's cost. We also assume that the X-ray detectors will be developed in collaboration with the EIC groups.
- TU assumes the same level of current DOE base funding, i.e. on average one postdoc and two graduate students. Additional support for one postdoc (50%) and two graduate students (50%) is provided by TU.

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

The time commitment of members of each group in the EIC efforts described in this EoI is anticipated to be as follows:

Institution name	Professor	Professor Research	Scientist Staff	Postdoc	Student graduate	Student undergraduate	Engineer	Designer	Technician	Total sum
AGH UST	0.2 0.2 0.2		0.5 0.5 0.5 0.5	1.0 0.75 0.75	0.5 0.5 0.5	0.2 0.2	0.5			7.5
BNL*										
IFJ PAN	0.2		0.2		0.3		1.0	0.5	1.0 1.0	4.2
TU	0.1	0.25		0.5	0.5	0.5	0.25		0.25	2.35

AGH UST: on average per year for 8 years, starting from 2022, in total ~ 60 FTE
BNL: on average BNL can provide 4 FTEs / year of experienced expert personpower, this includes scientific staff, postdocs, mechanical and electronic engineers and mechanical and electrical technicians, it is stressed that this personpower needs to be paid out of project funds, should these funds not be available this personpower cannot be provided.
IFJ PAN: on average per year for 8 years, starting from 2022, in total ~ 33.6 FTE
TU: Assumptions are based on the current level of support provided by the TU DOE base grant.

Please indicate if there are timing constraints to your submission:

- AGH UST: Because of the current commitments of the group, the actual work on the electronics for the detectors can start in the end of 2022.
- IFJ PAN: involvement of the technical staff is planed for 2023-2030.
- TU is committed to start with serious detector design work in 2022 in close collaboration with other participating institutions.

Please indicate any other information you feel will be helpful:

- AGH UST and IFJ PAN will apply for funding to the Polish Ministry of Science and Higher Education (MNiSW). The fulfillment of all our obligations depends on the allocation of appropriate funds by the Ministry. This should be known not earlier than mid-2022.
- AGH UST: We have fully equipped electronics lab (including Clean Room) and all necessary software tools (Cadence, Mentor Graphics, Synopsis, as well as Xilinx for FPGA programming) for development and testing of detectors and microelectronic devices. Members of the group have vast experience in development of electronics for high energy physics detectors (recent projects in LHCb, ATLAS, PANDA).
  Members of the group also participated in the detectors development for the luminosity measurement in the ZEUS experiment at HERA.
- IFJ PAN: Members of the group also participated in the designing, construction and running of the luminosity detectors for the ZEUS detector at HERA. They performed also a study of a precise luminosity measurement for the LHC and have an experience of working with the experimental apparatus installed in the immediate vicinity of the beams. Division of Scientific Equipment and Infrastructure Construction of IFJ PAN has a modern mechanical workshop for the design and construction of the experimental apparatus. Employees of this Division have a very broad experience gained at various high energy and nuclear physics projects as the LHC, ATLAS, XFEL, ESS and other.
- TU has a permanent clean room facility of 1800sq.ft. and a detector lab including a clean detector assembly lab of 800sq.ft. with a well equipped lab infrastructure. In addition, TU has a at least one

additional lab of 1000sq.ft. for detector assembly and testing. The TU group has access to a modern mechanical workshop for design and fabrication of detector components.

Appendix

- Luminosity requirements are very challenging to fulfill at the EIC, as experience from HERA shows [1–4]. The event pileup will be large at the EIC, especially for the case of electron-heavy ion collisions. The beam-size effect will be significant at the EIC [1], hence it needs to be properly studied to well control systematic uncertainties of the bremsstrahlung cross-section. Since the bremsstrahlung cross-section is not sensitive to the beam polarizations therefore the luminosity measurement will be independent from beam polarimetry. Precise measurements of very rear electrons are relevant not only for the photoproduction tagging but also for measurements of electrons scattered in the bremsstrahlung process. This will allow for important cross checks of photon energy scale and its detection efficiencies, including in particular photon conversions in the exit window (see below).

- To avoid significant corrections for to the geometrical acceptance, the electron beam divergence at the IP should not be too large, so all photons emitted at the angles smaller than 1 mrad should reach the luminosity detectors. All possible effort should be made to minimize the synchrotron radiation around the rear zero-angle.

- General concept of the proposed luminosity system is shown in Fig. 2. Bremsstrahlung photons are incident on photon exit window. Electron-positron pairs from photon conversion are deflected by the SPEC dipole magnet and detected in UP and DOWN detectors, positioned at a given distance from the magnet and displaced vertically (in y). Non-converted photons are detected in a photon calorimeter PHOT.

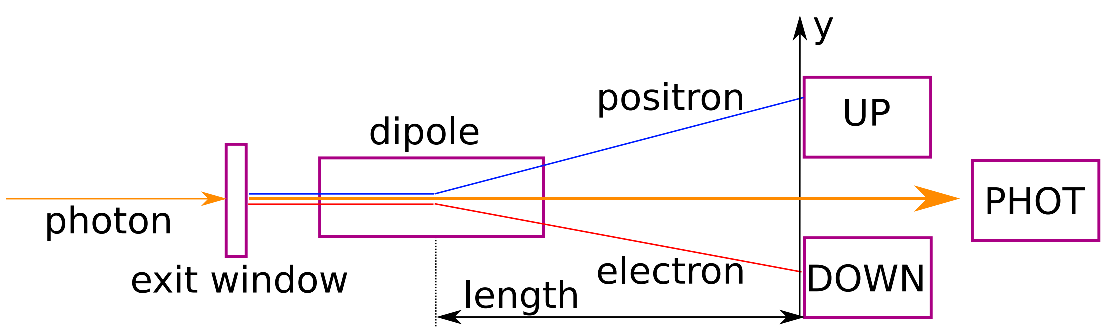

Figure 2: Proposed luminosity system.

- To control properly the e-gas backgrounds as well as the energy scales, a couple of non-colliding ("pilot") electron bunches should be kept at the EIC. In addition, regular but short calibration runs should be made with low intensity electron bunches, hence low event pileup.

- To cope with the enormous event rate (for the heavy ion case it is > 10 GHz!) the front-end electronics has to be highly specialized. Dedicated ASICs will be produced with at least 100 MHz signal sampling rate, and possibly in two versions - a high resolution version for detectors with relatively small number of channels and a low resolution one for detectors with large number of channels. Due to huge data flow a near-detector signal pre-processing will be necessary, mostly to perform zero-suppression algorithms. It will be done using dedicated FPGAs.

- Electron detectors are indicated in Fig. 1, and in Fig. 3 a possible configuration of two electron "photoproduction tagging stations" is shown. The first beam dipole magnet after the interaction point IP acts as a spectrometer magnet for electrons scattered at very small (rear) angles. Installation of two tagging stations, Tagger 1 and 2 for electrons within different momentum ranges are considered in the space between the dipole magnet and the following beam quadrupole magnet.

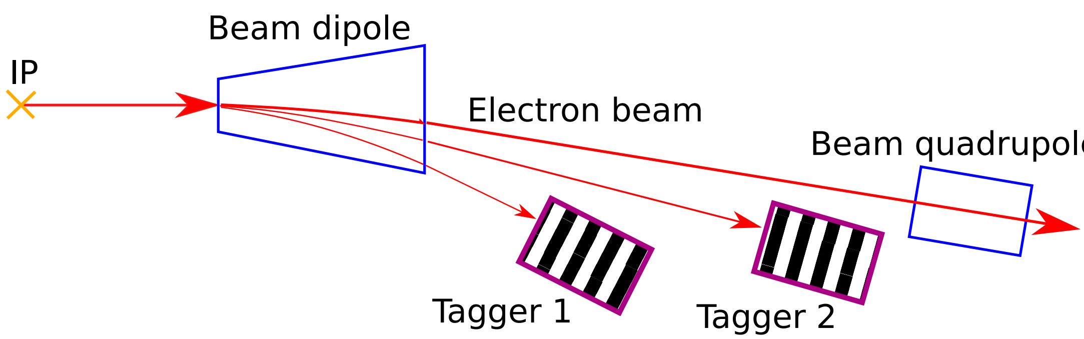

Figure 3: Electron tagging stations.

- Electron detectors will be using the same front-end ASCIs as the photon ones, with one exception. To distinguish photoproduction electrons from those due to bremsstrahlung the picosecond resolution timing detectors are needed. There, other specialized ASICs, as the CERN HPTDC for example, will be used.

References

[1] K. Piotrzkowski, talk at the Cockcroft Workshop, 2020.

[2] K. Piotrzkowski, *Experimental aspects of the luminosity measurement in the ZEUS Experiment*, PhD thesis (1993).

[3] J. Andruszków et al., *Luminosity measurement in the ZEUS experiment*, Acta Phys. Pol. B (2001) 2025.

[4] L. Adamczyk et al., *Measurement of the Luminosity in the ZEUS Experiment at HERA II*, Nucl. Instrum. Meth. A 744 (2014) 80.