Submission: Canadian Participation in the Electron-Ion Collider

Contact person: W. Deconinck, *wouter.deconinck@umanitoba.ca*

Revised: 2025-May-16

The total page limit is 4 pages of text. Groups with more than four members can increase their word limit by 10% for each additional member, up to 200% total.
The EIC Canada length limit is 4*(1+(11-4)*0.1)=6.8 pages of text.

1 Executive Summary (300-500 words)

The Electron-Ion Collider (EIC) will be a new US$2.8B particle collider facility to be built at the start of the next decade at Brookhaven National Laboratory (BNL), Long Island, New York, by the US Department of Energy (US-DOE). The EIC is the only new collider worldwide to be built in the foreseeable future and the first in this century, which naturally makes it the next subatomic physics *discovery* machine. At the EIC, polarized electrons will collide with polarized protons, light ions, and heavy nuclei at luminosities far beyond what is presently available (see Fig. 1). The facility will answer fundamental questions about the origin of mass and spin, and about gluon dynamics. During the construction phase (2027–2034), EIC Canada aims to construct (with support from CFI-IF) the end-of-sector readout electronics and the interaction region crab cavities for the proton storage ring. During the operations phase (2034-2041), EIC Canada will lead a physics program studying the origin of mass through meson form factors, the strong dynamics giving rise to exotic hadrons, and the search for new physics in the electroweak sector; all topics enabled by the high luminosity, high polarization, and excellent resolution of the EIC and ePIC detector.

2 Research Description (800-1200 words)

2.1 Research Goals and Methodology (300-500 words)

The EIC will uniquely address profound questions about nucleons and how they are assembled to form nuclei. In addition, the EIC presents significant opportunities that connect to neutrino, high-energy and particle physics, as well as astrophysics.

How does the mass of the nucleon arise? While gluons have no mass and u, d quarks are nearly massless, the total mass of a nucleon (proton or neutron) is 100 times greater than the mass of its three valence quarks. The largest contribution to the nucleon mass originates from the gluon field energy. The EIC will determine, for the first time, the relative spatial size of the distributions of valence quarks, sea quarks, and gluons, and the spatial structure of the different contributions to the energy density and pressure forces in the nucleon. Studies of π and K structure over a broad Q^2 range will probe the contributions of quark and gluon energy to the hadronic mass, and exclusive production of J/ψ and Υ will probe contributions of the trace anomaly.

How does the spin of the nucleon arise? Understanding nucleon spin in terms of quark and gluon spin and angular momentum contributions has been an essential goal since the discovery by the EMC Experiment that quark polarization contributions comprise only ∼30% of nucleon spin. The EIC will dramatically improve our understanding by studying the resolution dependence of polarized Deep Inelastic Scattering (DIS), and by measuring exclusive reactions, where precise knowledge of the spin of gluons combined with Generalized Parton Distribution (GPD) sum rules allows isolating the contribution of the orbital angular momentum of gluons.

What are the emergent properties of dense systems of gluons? The nature of gluons in matter, i.e. their arrangements or states, and the details of how they hold matter together, is not well known. Experiments at the EIC will be able to explore modifications of the quark distributions in nuclei in the limit of low Bjorken-x, x_B, where the number of gluons in the target is very large.

What is the composition of exotic hadrons? The EIC has the potential to produce hadronic resonances, which are exotic in nature, in photoproduction reactions in the heavy-quark sector. Such studies would confirm observations from previous experiments and provide complementary insight into their composition (tetraquarks, pentaquarks, molecules, etc.).

What lies beyond the Standard Model? The study of electroweak and beyond the Standard Model physics program relies on the high luminosities enabled by Canadian crab cavities. It includes the precision study of neutral current inclusive scattering to test the Standard Model to extract neutral current inference structure functions and the search for physics beyond the Standard Model in the form of charged-lepton flavor violation.

Methodology Answering the above questions relies crucially on the *1000-fold increase of collision intensity* compared to previous electron-proton collider facilities (enabled in part by the accelerator infrastructure in this project) and on the *polarization of both the electron and ion beams* which has not been realized at any previous collider. The EIC is unique in several other aspects as well:

- The *collision center-of-mass energy will be variable* by almost a factor 10, from 29 to 140 GeV. This capability is necessary to study the proton at multiple energy and distance scales and has not been available at previous colliders.

- The collision of an electron (a well-understood point particle) with a proton or ion (the less-understood object under study) *differs fundamentally* from the collision of two protons or ions with each other, or of two electrons with uncontrolled creation of secondary particles, which are the only modalities available at colliders currently in operation or planned for the next decade.

- The ePIC detector (see Fig. 2) will be the first subatomic physics detector *designed in and for the era of artificial intelligence (AI)*. Design parameters were optimized with AI, and high-granularity technologies are chosen in the anticipation of data-driven AI algorithms for electron/pion identification.

The development of tomographic images of the structure of nucleons requires the separation of reactions along multiple kinematic dimensions. Instead of only the longitudinal momentum of the struck quark, or only the transverse impact parameter of the collision, or only the momentum transfer from the electron to the nucleon, a full tomography of the proton requires separating along all dimensions simultaneously.

2.2 Seven-year year outlook (200-300 words)

The EIC project is moving rapidly and steadily. Over the next seven years, the EIC community plans to achieve the next critical decisions (CD): CD-3C (third long lead procurement, mid-2026), CD-2 (performance baseline, early 2026), and CD-3 (start of construction, early 2027).

EIC Canada is concentrating its efforts on several high priority areas:

Barrel Imaging Calorimeter (BIC) The EIC physics topics lead to unique requirements for the electromagnetic calorimeter design, as nearly all channels require detection of the scattered electron for momentum or energy reconstruction and particle identification. The Barrel (electromagnetic) Imaging Calorimeter (BIC) is a hybrid imaging calorimeter (see Fig. 3) that is cost-effective in relation to its excellent performance in energy and spatial reconstruction and particle identification, and its design is driven by Argonne National Lab (ANL), U Regina, and U Manitoba. We have submitted a CFI-IF application to fund the Canadian contributions to the BIC (see Fig. 4) and expect to complete this construction by 2029.

Superconducting RF Crab Cavities The accelerator work is part of a separate submission. To summarize, TRIUMF's accelerator physicists and engineers have the expertise to support the construction of the advanced EIC accelerator complex as a Canadian in-kind contribution. The main contribution described will be the unique 394 MHz crab cavity cryomodule system for the hadron storage ring (HSR) and the electron storage ring (ESR). The submitted CFI-IF application also includes the Canadian contributions to this crab cavity cryomodcule system.

Simulations in support of the EIC physics program The Regina group is leading feasibility studies of charged pion and kaon form factor measurements at the EIC, in support of the "mass of the nucleon" scientific question. In addition to their obvious physics value, our π^+ and K^+ form factor feasibility studies are important for detector design validation, as they provide well-defined but challenging final states that test the far-forward event reconstruction, and help the Collaboration understand the far-forward detector requirements. This work will be ongoing for the next 2-4 years.

The Manitoba group is performing studies of projected electroweak (EW) and beyond the Standard Model (BSM) physics at the EIC. It relies on the high luminosities enabled by the Canadian crab cavities described above. We are developing machine learning-based event selection of exotic processes, and assess the systematic uncertainties in measurements of electroweak structure functions. Because of their topology (balanced jets, large missing p_T), Charged Lepton Flavor Violating (CLFV) events mimic neutral current DIS, charged current DIS, and photo-production backgrounds. We are therefore approaching event selection as a multi-variate event selection problem with machine learning solutions.

2.3 Long-term vision (200-300 words)

A recent EIC project schedule is shown in Fig. 5. Currently, the EIC physics program is projected to begin in FY34, and is expected to continue for $\sim$20 years.

We project that the Canadian detector construction and commissioning efforts will result in an increase to 15 HQP by 2029, and the start of physics data taking will result in an increase to 21 HQP supervised by an integrated 5.6 FTE investigators and funded researchers. The start of the first North American collider of this century will be associated with significant scientific interest. In the first years of the 2030s, significant new results will be published by the detector collaboration(s), both in the form of instrumentation performance publications and initial physics results with the ePIC detector. In the years after 2034, when the EIC will have reached full design parameters including hadron cooling and double polarization, numerous other publications will result.

3 Applications and Noteworthy Impacts (200-300 words)

The development of state-of-the-art accelerator and detector technologies and computational methodologies for analyzing complex datasets will drive technological innovation.

Advanced Computing The EIC is the first collider to be designed, built, and operated in the era of AI. Detector layouts were informed by AI studies at U. Regina, and event reconstruction algorithms using AI on simulated data productions are being developed at U. Manitoba.

Photodetectors for Medical Imaging The large-scale application of silicon photomultipliers (SiPMs) and associated electronics in the ePIC detector may spawn innovations in medical imaging technologies, as demonstrated by the previous collaboration between the U. Regina group and SensL (now part of the onsemi group) on the GlueX calorimeter readout which led to the development of large-area SiPMs now used in commercial and medical applications.

Enhanced Particle Beam Technologies enabled by Superconducting Cavities As demonstrated by the JLab accelerator group with whom we collaborate on the EIC crab cavity design, Nb_3Sn superconducting radiofrequency cavities have the potential to revolutionize the way accelerating cavities are used for both medical isotope production and beam therapy. Higher beam currents in smaller form factors can make these technologies portable for use in remote communities.

4 Recommendations (200-300 words)

1. The research direction "From quarks and gluons to nuclei" should include Canadian participation in the construction and exploitation of the Electron-Ion Collider and its primary ePIC detector, as a flagship project.
2. The broad physics outcomes of the Electron-Ion Collider present opportunities for engagement from many fields in subatomic physics research.
3. In large international collaborations, the Canadian subatomic physics community has a unique responsibility to ensure that the values of equity, diversity, and inclusion are promoted, in particular where other collaborators are unable to do so.
4. Highly qualified personnel supported by project funding continue to be compensated at insufficient levels. An increase in the subatomic physics envelope associated with a concerted effort at increasing student stipends would ensure that we can compensate students at the levels they deserve.
5. Predictable CFI Innovation Fund timelines are essential to allow planning for submissions in the context of large international collaborations.

4.1 Impact and Scope

X	i	Essential	These are experiments with very broad physics impact addressing multiple core physics questions, in which the Canadian investigators have core responsibilities.
	ii	Impactful	These are experiments with strategic physics impact, addressing a single core physics question, with a large Canadian contribution.
	iii	Potential	These are experiments with smaller physics program leading to highly impactful results in a specific area.
	iv	Winding down	These are experiments that are expecting to reach the end of their lifespan within the timespan of the long range plan.

4.2 Duration

The expected horizon of funding and physics delivery of this experiment from 2025 onwards and towards completion of the physics objectives of the project.

If your project involves sub-projects with different time frames, please make a version of this table for each one.

X	α	more than 15 years
	β	10-15 years
	γ	5-10 years
	δ	5 years
	ϵ	Just starting

4.3 Investigator Commitment

Collaboration size alone is not a critical criterion. However, since SAPES has increasingly emphasized project investigator (PI) commitment in their funding decisions, we are asking for a full time FTE sum as an element of the classification of projects. Please use the research hours/month currently reported by the PIs, as well as the time commitment projection used in your medium-term research outlook.

Now	7yr Outlook		
		I	> 2000 hr/mo
		II	$1500 - 2000$ hr/mo
		III	$1000 - 1500$ hr/mo
	X	IV	$500 - 1000$ hr/mo
X		V	$150 - 500$ hr/mo
		VI	< 150 hr/mo

4.4 Lifecycle Status

X	+	at the beginning of the life cycle of the experiment, growing
	o	in steady state, delivering
	-	at the end of the life cycle of the experiment, winding down or looking to wind down

Appendices (not included in the page limit)

A Images, Figures and Captions

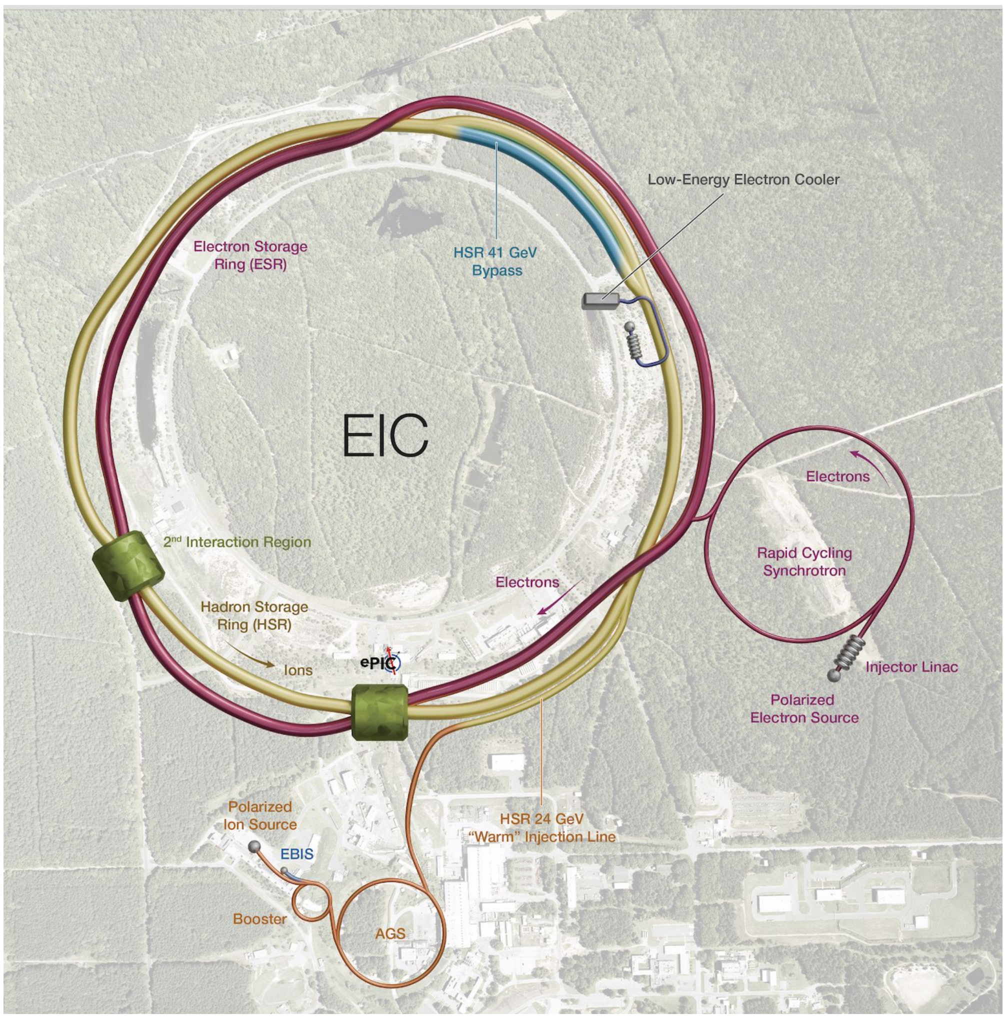

Figure 1: Layout of the EIC, with the ePIC detector and crab cavities in the 6 o'clock position.

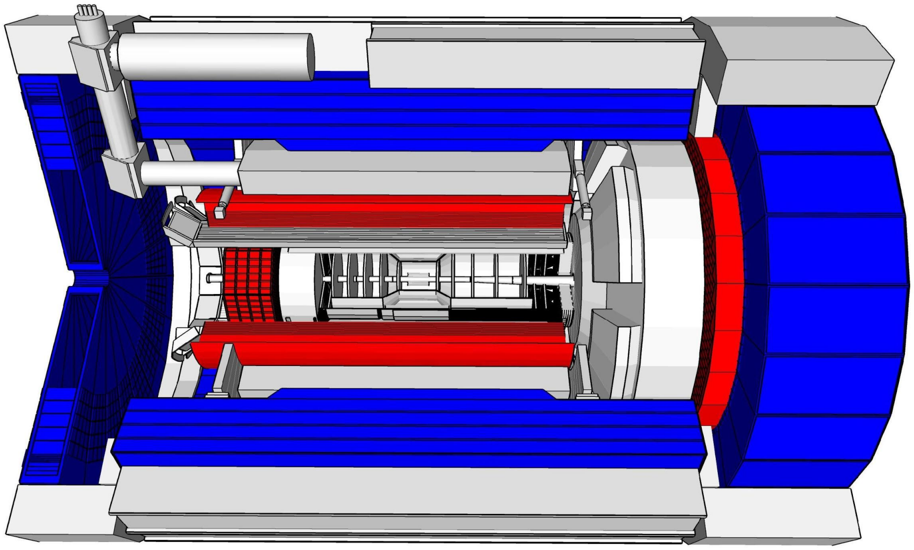

Figure 2: Schematic drawing of the 9 m-long ePIC detector. The central red calorimeter detector is the Barrel Imaging Calorimeter (BIC).

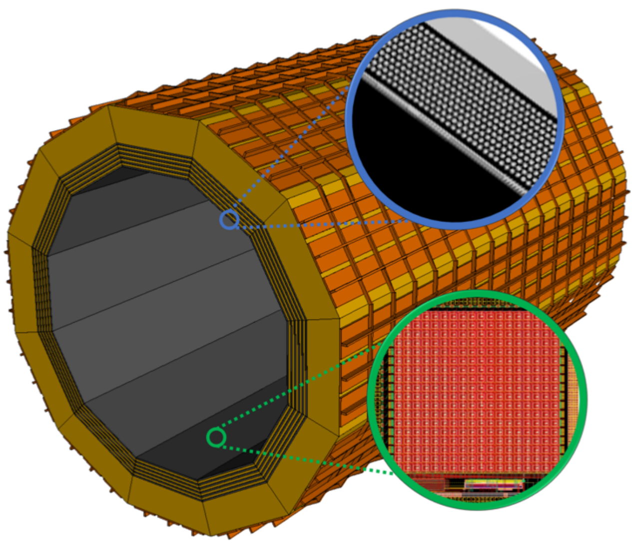

Figure 3: A sketch of the Barrel Imaging Calorimeter geometry. It is comprised of an outer "bulk" PbSciFi section, with five 2-cm-thick "imaging layers" of PbSciFi interleaved with six AstroPix tracking layers, shown in the zoomed circles, respectively. The BIC will be 435 cm long, with inner and outer radii of 82 cm and 122 cm, respectively, and will weigh ∼40 metric tons. The bulk PbSciFi section is modelled after the GlueX BCAL, built by U. Regina. Two-sided silicon photomultiplier readout will be implemented for spatial resolution along the z-coordinate (or pseudorapidity η).

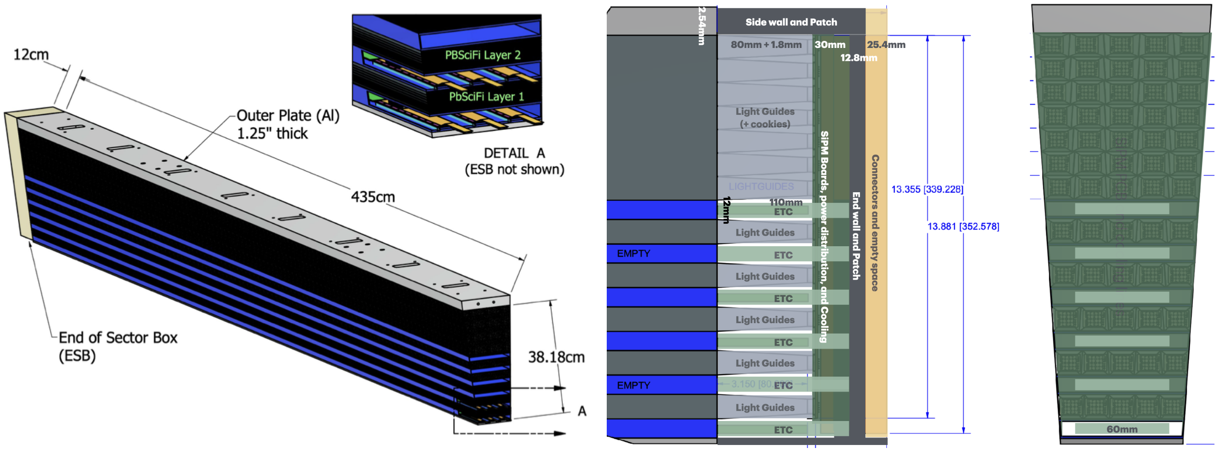

Figure 4: The left panel shows a 3D drawing of a single BIC trapezoidal sector. The central panel sketches the side view of a single sector, featuring interleaved Pb/ScFi layers and slots for trays holding AstroPix chips, followed by the Pb/ScFi bulk section. The right panel displays an end view of the PCB electronics board, which is enclosed in the ESB.

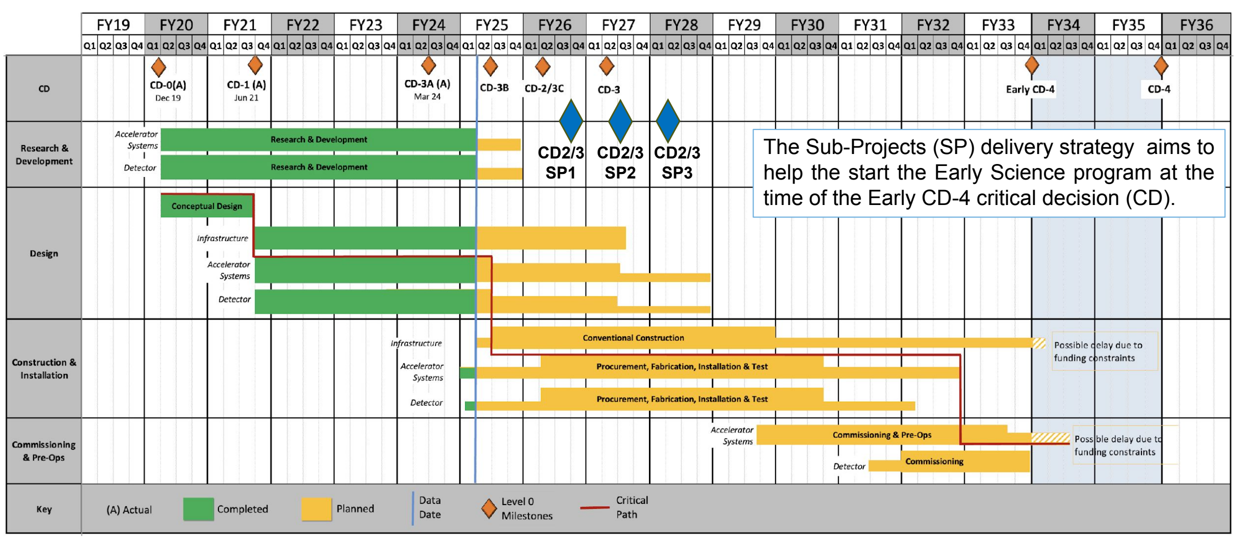

Figure 5: Top-level project schedule of the EIC with indication of Critical Decisions (CD) and Sub-Projects (SP), as of the January 2025 CD-3B review. Early physics studies will be possible during the commissioning and pre-operations phases, with increasing luminosity as time goes on.

B References

Please list references to most impactful work by your group.

Z. Ahmed, R.S. Evans, I. Goel, G.M. Huber, S.J.D. Kay, W.B. Li, L. Preet, A. Usman, "DEMP-gen: Physics event generator for Deep Exclusive Meson Production at Jefferson Lab and the EIC", Computer Physics Communications **308** (2025) 109444 1-22, arXiv: 2403.06000 [hep-ph].

A.C. Aguilar, et al., "Pion and kaon structure at the Electron-Ion Collider", European Physical Journal A **55** (2019) 190 1-15. arXiv: 1907.08218 [nucl-ex].
194 citations

J. Arrington, et al., "Revealing the structure of light pseudoscalar mesons at the Electron-Ion Collider", Journal of Physics G **48** (2021) 075106 1-47, arXiv: 2102.11788 [nucl-ex].
107 citations

A. Bylinkin, et al., "Detector Requirements and Simulation Results for the EIC Exclusive, Diffractive and Tagging Physics Program using the ECCE Detector Concept", Nuclear Instruments and Methods **A 1052** (2023) 168238 1-40 , arXiv: 2208.14575.

C. Fanelli, et al., "AI-assisted Optimization of the ECCE Tracking system at the Electron Ion Collider", Nuclear Instruments and Methods **A 1047** (2023) 167748 1-14, arXiv: 2205.09185 [phyics.ins-det].

V.D. Burkert, et al., "Precision Studies of QCD in the Low Energy Domain of the EIC", Progress in Particle and Nuclear Physics **131** (2023) 104032 1-74, arXiv: 2211.15746 [nucl-ex], https://doi.org/10.1016/j.ppnp.2023.104032.

C Picture Permissions

Permission is granted for re-use of all included figures.

D HQP Profiles and Testimonials

Please include here any supplementary information on training that is awkward to include in the spreadsheet.

A former M.Sc. student is now applying his expertise in EIC simulations towards the design of Small Modular nuclear Reactors (SMRs).

E Collaboration List

Tooba Ali* (University of Manitoba), Tegan Beattie (University of Regina), Sanaa Cheikh* (Mount Allison University), Wouter Deconinck (University of Manitoba), Halen Davies* (University of Regina), Michael Gericke (University of Manitoba), Dave Hornidge (Mount Allison University), Garth Huber (University of Regina), Tobias Junginger (University of Victoria), Maggie Kerr* (Mount Allison University), Oliver Kester (TRIUMF), Robert Laxdal (TRIUMF), Savino Longo (University of Manitoba), Juliette Mammei (University of Manitoba), Zisis Papandreou (University of Regina), Love Preet* (University of Regina), Bardh Quni* (University of Manitoba), Shefali* (University of Manitoba), Tomas Sosa Giraldo* (University of Manitoba), Aram Teymurazyan (University of Regina), Akshaya Vijay* (University of Manitoba), Awais Bin Zahid* (University of Regina).

Co-signatories on the NSERC grant supporting EIC Canada are underlined. HQP are indicated with an asterisk.

The ePIC Collaboration itself is a collection of hundreds of scientists and engineers representing 173 institutions from 25 countries.

F Resources

Please fill out the attached spreadsheet, with the following information:

1. Resources needed from NSERC, CFI and other Canadian agencies: dollars, faculty FTEs (explicitly list names), equipment, facilities (especially new facilities), etc.

2. Additional resources from international sources.

Please include here any supplemental information that doesn't easily fit in the spreadsheet, such as:

1. Indicate in broad terms how the dollar numbers were arrived at.

2. Please explain anything unusual, and explain the reasons for any major changes to resource requirements compared with those existing at the present time.

G List of Acronyms

ANL (Argonne National Laboratory): A DOE national laboratory in Lemont, Illinois, which is home to the Advanced Photon Source (APS).
BNL (Brookhaven National Laboratory): A DOE national laboratory in Upton, New York, which is home to a number of facilities including RHIC.
CLFV (Charged Lepton Flavor Violation): The violation of the lepton flavor symmetry in charged current weak interactions, which would indicate the presence of physics beyond the Standard Model.
DIS (Deep Inelastic Scattering): DIS is a process used in particle physics to probe the internal structure of protons and neutrons, using high-energy probes (e.g. electrons) at a target nucleon and analyzing how the electron scatters off the nucleon.
DOE (Department of Energy): The United States Department of Energy, which operates a number of national laboratories across the USA.
EIC (Electron-Ion Collider): A new DOE nuclear physics user facility proposed to be housed at Brookhaven National Laboratory.
EPIC (Electron-Proton/Ion Collider) Detector: The main EIC detector currently planned for IP6 at the EIC. https://www.epic-eic.org/
HQP (Highly Qualified Personnel): Personnel obtaining advanced skills as a result of NSERC-funded research, including students, postdocs and technicians.
ISAC (Isotope Separator and ACcelerator): A rare isotope accelerator facility, based at TRIUMF. There are two experimental halls, ISAC-I and ISAC-II.
JLab (Jefferson Lab): The Thomas Jefferson National Accelerator Facility, located in Newport News, Virginia.