1 Canadian Participation in the Electron-Ion Collider

Ver 2.0: 2020-July-10

The Electron Ion Collider (EIC) is a major new collider facility scheduled to be built on Long Island, New York, by the US Department of Energy in the current decade. At the EIC, polarized electrons will collide with polarized protons, polarized light ions, and heavy nuclei at luminosities far beyond what is currently available. The facility will answer several fundamental questions central to completing an understanding of atoms and integral to the agenda of nuclear physics today.

The EIC project achieved two milestones in 2019-2020, with the first critical decision (CD-0) establishing mission need, and with the site selection of Brookhaven National Lab. The project aims to complete the next three critical decisions by the end of 2023, and to start operations by 2030. The EIC Users Group is coordinating the international efforts to instrument the two interaction regions of the collider, with Expressions of Interest invited by November 2020.

Canadian subatomic physicists have participated intensively in the planning of this new facility and have chartered a multi-institutional EIC Canada Collaboration to coordinate participation. We anticipate that the Canadian participation in the first new North American collider in this century will become similar in scope as, *e.g.*, the Canadian participation in the Belle II experiment.

2 Executive Summary

Major Scientific Goals The significance of the science to be addressed by the Electron Ion Collider, and its importance to nuclear physics in particular, and to the physical sciences in general, was highlighted in a report by the US National Academies of Sciences, Engineering, and Medicine [G.A. Baym *et al.*, Eds., Jul 2018]. The report identified three core questions:

- How does the mass of the nucleon arise?
- How does the spin of the nucleon arise?
- What are the emergent properties of dense systems of gluons?

In addition, the report highlights connections with other areas, from technology and workforce development, to high energy physics, astrophysics, condensed matter and atomic physics.

International Context As a major international facility, the world-wide Electron Ion Collider efforts are driven by an active User Group of more than 1000 subatomic physicists at more than 200 institutions in 31 countries on all 6 inhabited continents. While the national laboratories are coordinating the accelerator design, the User Group is driving the development of the collider detectors through international Physics, Detector, and Software Working Groups. To coordinate the Canadian participation, and provide a single national body to represent Canada in discussions with the User Group, we have chartered the EIC Canada Collaboration (`http://eic-canada.org`).

Methodology Expanding on programs in experimental and theoretical nuclear physics, hadronic physics, heavy ion physics, and electroweak physics, Canadian participation in the Electron Ion Collider will focus on detector design and physics program development (2022–2026), detector construction (2026–2030), and operations (2030 and beyond).

Medium-Term Plans (2022–26) Over the course of the next Long Range Plan, the Canadian Electron Ion Collider development activities will focus on simulation and computing infrastructure, polarimetry, and calorimetry.

Long-Term Plans (2027–2036) In the decade after the next Long Range Plan, the Electron Ion Collider will be commissioned and data taking will begin. The Canadian activities will transition from a focus on hardware design and construction, to installation, data taking, and initial physics analysis.

HQP and Other Impacts The Canadian theoretical and experimental subatomic physics groups significantly connected to Jefferson Lab and Brookhaven National Lab research in the US are expected to become substantially involved in this next generation effort. We anticipate that the Canadian participation in the Electron Ion Collider will grow from the current 1.3 FTEs to a steady state of 5.6 PI FTEs, 5 research associates, 10 graduate students and 8 undergraduate students by the time operations start ($\sim$2030). By the middle of the next Long Range Plan, we anticipate that as many as 10 individual PIs (not FTEs) will be involved.

3 Research Description

3.1 Facility Overview

The Electron Ion Collider (EIC) will consist of a polarized electron ring with a variable beam energy from 10 to 20 GeV, and an ion ring with a variable beam energy from 50 to 250 GeV, allowing for beams of polarized protons, deuterons and ^{3}He, as well as unpolarized nuclei up to lead and uranium. This range of energies will allow for center of mass energies $\sqrt{s}$ from 20 to 100 GeV (upgradeable to 140 GeV) with a collision luminosity $\mathcal{L}$ of 10^{33-34} cm^{-2} s^{-1} (optimal luminosity of 10^{34} cm^{-2} s^{-1} at $\sqrt{s} \approx 105$ GeV, about 1000 times larger than at HERA, the only previous electron–proton collider). Despite the high luminosity, the interaction rate and multiplicity/occupancy rate are manageable compared to the proton–proton collisions at the Large Hadron Collider (LHC). Event rates up to 10^5 Hz per unit solid angle are expected.

The EIC will be built at the Brookhaven National Laboratory in Upton, New York, where the Relativistic Heavy Ion Collider (RHIC) has collided two beams of polarized protons or of unpolarized heavy ions with each other for the past two decades in the STAR and PHENIX experiments. The EIC project will require the addition of a new rapid-cycling polarized electron synchrotron, and the upgrade of one of the existing hadron ring with electron cooling and new spin transport elements (see Figure 1).

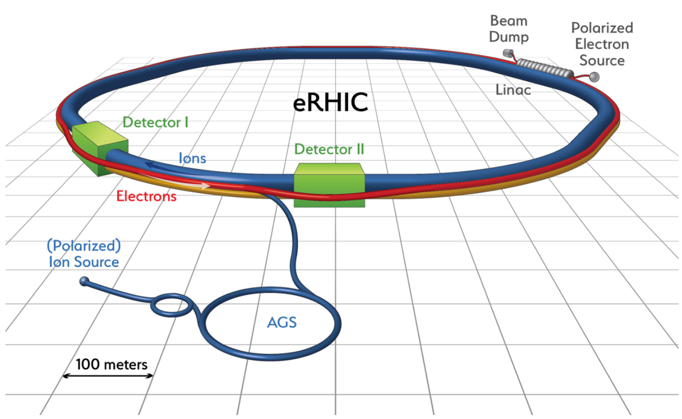

Figure 1: The Electron Ion Collider adds a polarized electron beam to the existing Relativistic Heavy Ion Collider (RHIC) accelerator complex with its two hadron rings, substantially avoiding the need for civil construction. Two interaction regions will allow for dedicated collider detectors.

The high luminosity means that the electron beam must be injected from the polarized source with its final polarization of 85% and in flexible spin patterns, building on the operational experience of the Jefferson Lab program. The RHIC facility has operated successfully with polarized proton beams of 80%, and has demonstrated a polarized ^{3}He source at 85%.

Two interaction regions will each allow for a collider detector. Due to the asymmetric nature of the collision (in contrast to, *e.g.* Belle II or the LHC), the detectors are highly asymmetric as well (see Figure 2–4).

Three classes of events are of interest and determine the detector requirements.

- *Inclusive measurements* ($ep/eA \to e'X$), in which either the scattered electron or the full

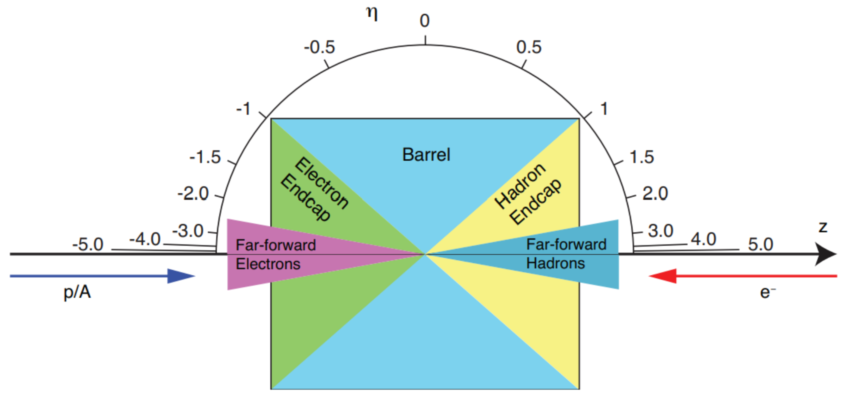

Figure 2: The Electron Ion Collider interaction regions define the collider detector layout, with the combination of barrel detectors at small pseudo-rapidity η, forward electron and hadron endcap detectors, and far-forward electron and hadron plugs. The neutron/photon zero-degree calorimeter far downstream at right is not shown.

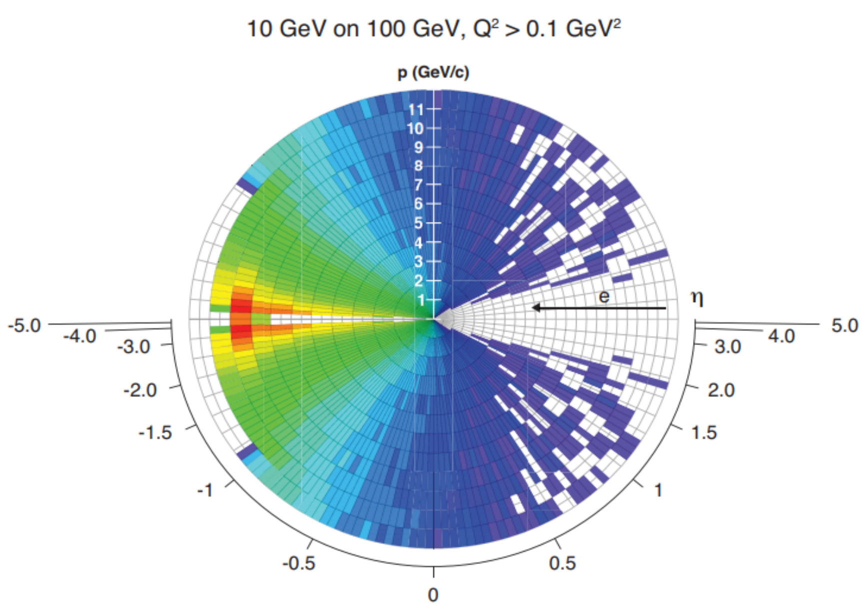

Figure 3: This expected scattered electron distribution in momentum p and pseudo-rapidity η for a representative electron–proton beam energy combination at the Electron Ion Collider demonstrates the importance of electron identification in the barrel and forward electron regions.

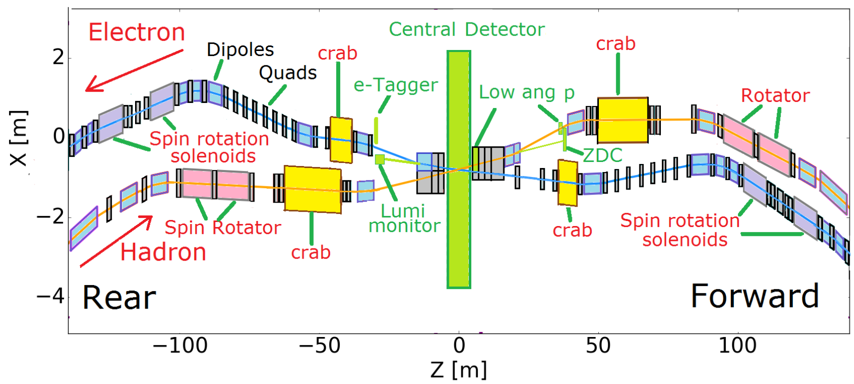

Figure 4: At the Electron Ion Collider interaction regions, the electron and hadron beams intersect with a 25 mrad crossing angle. The 9 m of space free of accelerator elements allows for detection of transverse momentum p_T down to 200 MeV.

scattered hadronic debris is detected with high precision, require good electron identification and excellent electron energy/momentum and angular resolution.

- *Semi-inclusive measurements*, in which the scattered electron is detected in coincidence with at least one hadron, require hadron identification ($\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$) over a wide kinematic range, and good vertex resolution for charm and bottom separation.

- *Exclusive measurements*, in which all scattered particles are detected, require high rapidity coverage, including a zero degree calorimeter for neutrons/photons.

Based on these requirements, detectors will be developed by several international consortia. The first phase of this process is currently underway through a Yellow Report process, and Expressions of Interest (EoIs) by countries or geographical regions interested in potential EIC equipment cooperation are due by November 2020. We anticipate that an EoI from the EIC Canada Collaboration will be among them.

3.2 Physics Program

The EIC will uniquely address three profound questions about nucleons (neutrons and protons) and how they are assembled to form the nuclei of atoms. In addition, the EIC presents significant opportunities that connect to neutrino, high energy, particle physics and astrophysics.

How does the mass of the nucleon arise? The problem is that while gluons have no mass, and u, d quarks are nearly massless, the nucleons that contain them are heavy; the total mass of a nucleon is some 100 times greater than the mass of the valence quarks it contains (see Figure 6). The largest contribution to the mass of the proton originates from the gluon field energy. In this sense, the source of visible mass in the universe is not the Higgs field, but the gluon field. By selecting the energy and resolution of the virtual photon, an EIC can address different regions of Bjorken x going from the regime of moderate x dominated by valence quarks to the small x regime controlled by sea quarks and gluons. These types of experiments have been carried out

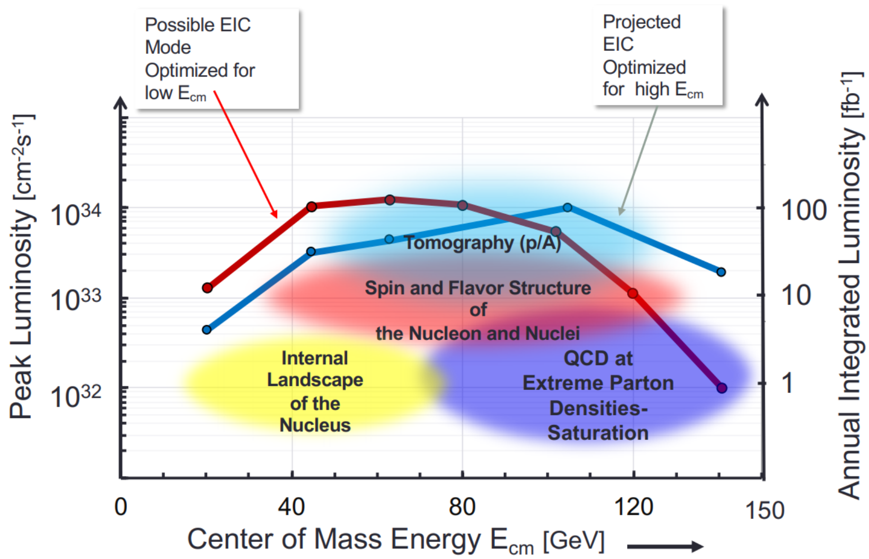

Figure 5: The opportunity to use a variety of electron-ion center of mass energies enables rich physics potential at the EIC, from studying the internal structure of the nucleons and nuclei, to the tomographic visualization of the correlated three-dimensional structure of the nucleon at the femtoscale. The ongoing Yellow Report process will provide input to the detailed accelerator design to identify at which center of mass energy the luminosity should be optimized.

before, but the EIC will add several new dimensions by studying the distribution of partons in the plane transverse to the motion of the nucleon, and by determining their transverse motion. These measurements will provide tomographic images of nucleons and nuclei, to determine: the relative spatial size of the valence quark, sea quark, and gluon distributions; the spatial structure of the different contributions to the energy density and pressure forces in the nucleon; and the spatial distribution of gluons in a large nucleus.

How does the spin of the nucleon arise? How the angular momentum, both intrinsic as well as orbital, of the internal quarks and gluons gives rise to the known nucleon spin is not understood. The quark polarization contribution to the nucleon spin is only about 30 percent. The remainder of the spin must reside in orbital angular momenta of quarks and gluons or gluon polarization. Polarized proton–proton collisions at the Relativistic Heavy Ion Collider (RHIC) have provided the first evidence for a nonvanishing gluon spin polarization in the proton. A central goal of the EIC program is to provide a determination of the gluon spin contribution and its orbital angular momentum. These measurements would be based on the resolution dependence of polarized Deep Inelastic Scattering (DIS). This dependence arises from quark and gluon partons radiating additional partons. When a polarized gluon radiates a quark-antiquark pair, the spin orientation of the gluon is transferred to the quark and the antiquark. This effect can be measured using polarized electron scattering with a polarized proton beam. The orbital angular momentum of gluons can be probed via the exclusive measurements described. Precise knowledge of the spin of gluons combined with sum rules of the generalized parton distributions (GPDs) determined in these measurements offer the possibility of isolating the contribution to the nucleon spin of the orbital

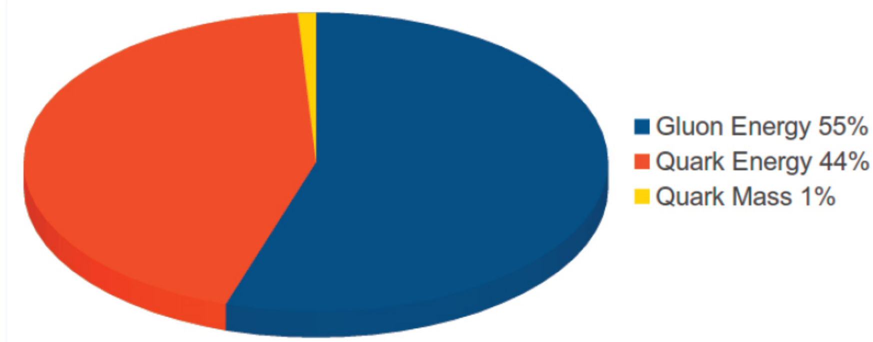

Figure 6: The mass of the nucleon originates not only in the mass of its constituent quarks, but overwhelmingly from the energy in its quark and gluon fields.

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. Gluons in matter are somewhat like dark matter in the universe, unseen but playing a crucial role. The EIC would be able to study the gluons that bind quarks and antiquarks into nucleons and nuclei with unprecedented precision. A central goal of such studies is to explore the limit of low Bjorken x, where the number of gluons in the target is very large. Here, the description of the nucleus in terms of colored degrees of freedom is expected to simplify dramatically, and discovery of a new type of state composed of dense gluon matter is also expected. The EIC would also be able to explore modifications of the quark distributions in nuclei. These issues are fundamental to an understanding of the matter in the universe.

Connections with other fields Nuclear physics also includes high-priority programs in neutrino physics and fundamental symmetries. Neutrinos are messengers from hot and dense environments like the solar interior, type II supernova explosions, and cooling neutron stars. Neutrinos also provide an important window into fundamental symmetries and possible extensions of the Standard Model of particle physics. One central question is whether the neutrino is its own antiparticle, which would imply that neutrinos would violate lepton number conservation. Evidence for lepton number violation is being sought in neutrinoless double beta decay experiments, and nuclear physicists are actively working toward a ton-scale detector of such processes. Electron accelerators have also made important contributions to the study of fundamental symmetries. JLab studies parity-violating electron scattering, and a series of past and planned experiments, QWeak, Measurement Of Lepton Lepton Elastic Reactions (MOLLER), and Solenoidal Large Intensity Device (SoLID), study the evolution of the fundamental electroweak coupling, and search for physics beyond the Standard Model. An EIC would naturally extend this program, studying fundamental symmetries at higher energies.

3.3 Current Canadian effort

Multiple groups are already active in the EIC program. Below we describe the current and projected Canadian subatomic physics efforts at U. Manitoba, U. Regina, and Mount Allison U.

Pion form factors as probe of emergent mass generation in hadrons The elastic electromagnetic form factors of the charged pion and kaon, $F_\pi(Q^2)$ and $F_K(Q^2)$, are a rich source of insights into basic features of hadron structure, such as the roles played by confinement and Dynamical Chiral Symmetry Breaking (DCSB) in fixing the hadron's size, determining its mass, and defining the transition from the strong- to perturbative-QCD domains. Studies during the last decade, based on JLab 6-GeV measurements, have generated confidence in the reliability of pion electroproduction as a tool for pion form factor extractions. Forthcoming measurements at the 12-GeV JLab will deliver pion form factor data that are anticipated to bridge the region where QCD transitions from the strong (color confinement, long-distance) to perturbative (asymptotic freedom, short-distance) domains.

At EIC, pion form factor measurements can be extended to still larger Q^2, by measuring ratios of positively- and negatively-charged pions in quasi-elastic electron-pion (off-shell) scattering via the $p(e, e'\pi^+)n$ and $n(e, e'\pi^-)p$ reactions, accessed with proton and deuterium beams. Huber's group at U. Regina has written an event generator and have performed simulations demonstrating the feasibility of these measurements. The measurements would be over a range of small $-t = -(p_p - p_n)^2$, and gauged with theoretical and phenomenological expectations, to again verify the reliability of the pion form factor extraction.

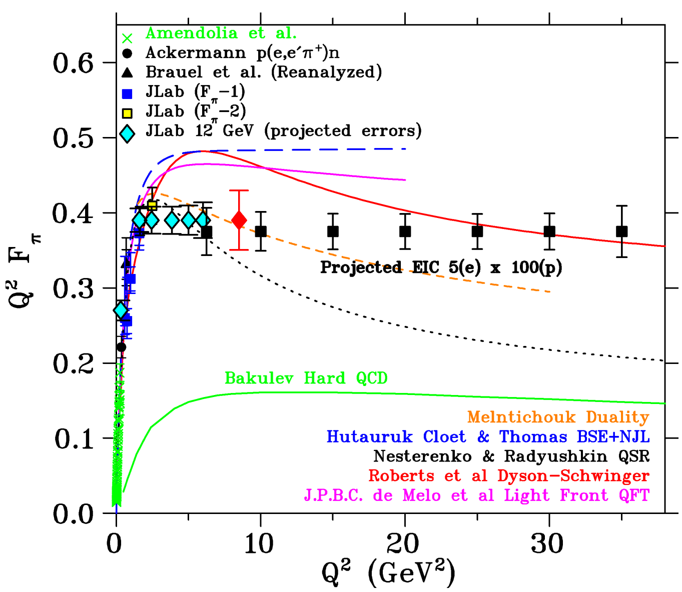

Figure 7: Existing data (blue, black, yellow, green) and projected uncertainties for future data on the pion form factor from JLab (cyan, red) and EIC (black), in comparison to a variety of hadronic structure models. The EIC projections clearly cover a much larger Q^2 range than the JLab measurements, providing access to the mass These results have been published in Eur.Phys.J.A **55** (2019) 190.

A consistent and robust EIC pion form factor data set will probe deep into the region where $F_\pi(Q^2)$ exhibits strong sensitivity to both emergent mass generation via DCSB and the evolution of this effect with distance scale. Figure 7 shows the EIC projections for possible pion form factor measurements. The pion form factor projections assume an integrated luminosity of 20 fb^{-1} with a 5 GeV electron beam colliding with a 100 GeV proton beam. Simulation work to refine the eRHIC detector requirements is ongoing, as part of EIC Yellow Report efforts.

Due to its strange quark content, roughly 1/3 of the K^+ mass is due to the Higgs mechanism, while the π^+ mass is barely influenced by the Higgs and is almost entirely generated by DCSB. Thus, the comparison of the charged pion and charged kaon form factors over a wide Q^2 range would provide unique information relevant to understanding the generation of hadronic mass. Planned simulation work for 2021-23 include extensions to the case of the charged kaon, assuming that measurements by Huber's group at the 12-GeV JLab on exclusive kaon electroproduction beyond the resonance region at $-t \leq 0.9$ GeV^2 and Q^2 up to ~ 5 GeV^2 confirm the feasibility of this technique.

Electroweak mixing angle measurements and tests of the Standard Model Precision measurements of fundamental observables in the electroweak sector of the Standard Model have allowed us to impose strict limits on the existence of potential new physics beyond the Standard Model. Canadian subatomic physicists were instrumental in such experiments at Jefferson Lab in the PV-DIS experiment (Nature, 506, 67–70, 2014) and QWeak experiment (Nature, 557, 207–211, 2018).

The EIC presents opportunities for isoscalar hadrons, *i.e.* electron–deuteron collisions, which have never been available. Measurements of interference structure functions $F_1^{\gamma Z}$ and $F_3^{\gamma Z}$ in polarized electron–unpolarized deuteron scattering will allow for clean separation of the weak vector and weak axial-vector quark couplings, and determination of the electroweak mixing angle $\sin^2\theta_W$ in the poorly explored region between 10 and 70 GeV (see Figure 8). Additionally, the measurements of $F_3^{\gamma Z}$ will improve our knowledge of the V_{ud} term in the u-quark unitarity relation for the CKM matrix, another avenue for Standard Model tests.

New channels for Standard Model tests of lepton flavor violation present themselves through $e^- \to \tau^-$ decays. At the anticipated integrated luminosities of 100 fb^{-1}, this channel holds discovery potential for leptoquarks, R-parity violating supersymmetry, leptophobic Z' bosons, and other charged lepton flavor violation theories.

In Spring 2020, the U. Manitoba members of the EIC Canada Collaboration organized a (virtual) workshop on Electroweak and Beyond the Standard Model physics at the EIC that attracted over 80 theoretical and experimental subatomic physicists. The outcomes of this workshop are directly impacting the Yellow Report process.

Accurate knowledge of the electron beam polarization is important for the electroweak mixing angle program. The U. Manitoba group plans to apply its expertise in Compton polarimetry at HERA, Jefferson Lab, and the EIC. The development of Compton polarimetry for the EIC has significant synergies with the upgrade of the Belle II facility to use polarized electrons in their high energy ring.

Light and heavy quark spectroscopy Interactions and structures are convolved with each other in nuclear matter. The observed properties of nucleons and nuclei emerge out of this complex system. Achieving an understanding of this dynamical system promises to be transformational.

Strong QCD dynamics results in many-body correlations between quarks and gluons and, as

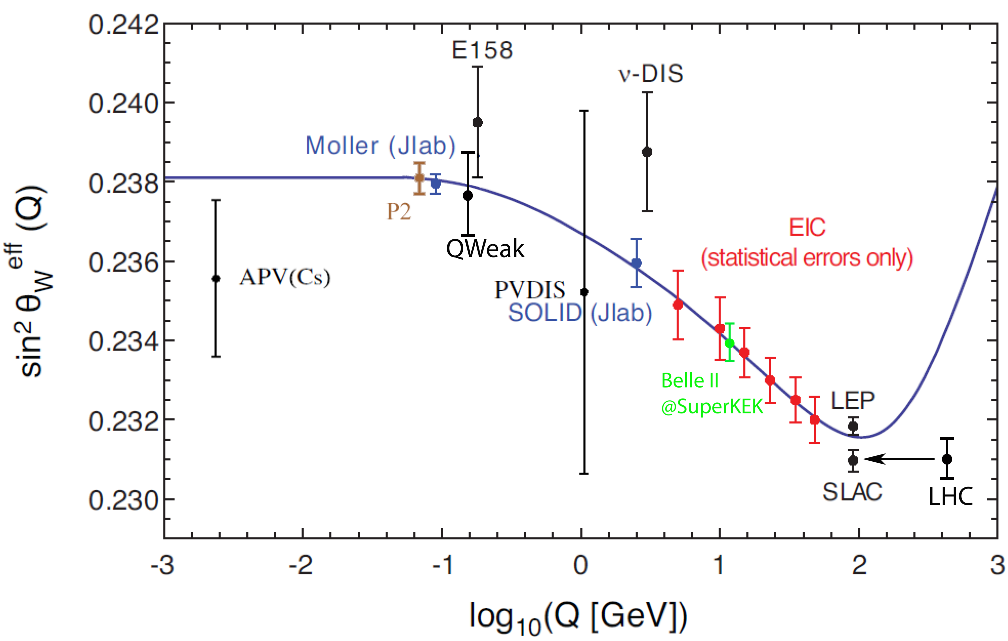

Figure 8: Available and anticipated (Moller, SOLID, Belle II) measurements of the electroweak mixing angle at facilities worldwide are compared with projected measurements and their uncertainties at the EIC for a variety of kinematic conditions. The EIC projections cover an energy scale μ between the low-energy regime and the Z-pole where little data is currently available. These projections have been published in Eur.Phys.J.A (2017) 53:55.

a result, hadron structure emerges. Traditionally, the manifestation of hadrons in nature has their spectrum dominated by colorless "quark model" states — such as quark-antiquark pairs (mesons) and quark triplets (baryons) — while gluonic degrees of freedom are difficult to observe or suppressed. A question arises: how do the quark and gluonic degrees of freedom that are present in the fundamental QCD Lagrangian manifest themselves in the spectrum of hadrons?

In hadron spectroscopy there are standard quarkonium states but also a host of unexpected resonances have appeared that are not well reconciled with the usual charmonium interpretation. Specifically, one of the challenges in the charmonium sector at the moment is that if all the bumps that are seen are true resonances, it's not clear what the underlying degrees of freedom are (multiquark states, molecules, etc.). One great advantage of electro-/photo-production is that most of these states have been seen in e^+e^- annihilation or decays, and electro-/photo-production allows access to different kinematics which can help confirm their resonant nature and exclude them being kinematical effects; this is particular important for Z-states. In addition, not only are these states created in larger numbers than e^+e^- annihilation experiments, but one has a well-controlled initial state (e-p) which makes determining the J^{PC} of these states a lot easier than, say, at the LHC. In addition, the bottomonium exotic sector needs to be explored with sufficient detail, in order to achieve a comprehensive and consistent understanding of both sectors.

New states need to be confirmed such as $\tilde{X}(3872) \to J/\psi\pi\pi$, the observed charged charmonium structure observed by BESIII and Belle (Figure 9), and CLEO [PLB 727 (2013) 366] in decay of Y(4260) to $Z_c^+(3900) \to J/\psi\pi$ needs to be studied, as do pentaquarks [H. Blin, A. Piloni et al. (JPAC), PRD94, 034002] whose confirmation in photo- and electro-production will be the first step towards elucidating their nature. These studies are statistically limited at the B-factories and difficult/impossible at LHCb. Experimentally, the EIC will offer centre of mass variability with minimal loss of luminosity, which is a critical feature in the study of the onset of interesting QCD phenomena. EIC is the perfect lab to carry out thorough studies of hadron spectroscopy and to address the remaining open questions in that field.

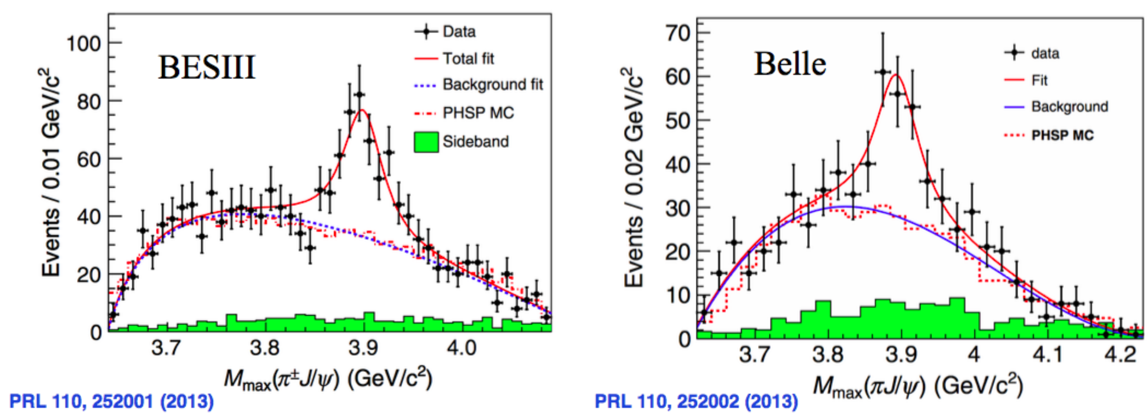

Figure 9: Charged charmonium structure observed by BESIII (left) [PRL 110, 252001 (2013)], and Belle (right) [PRL 110, 252002 (2013)] in the decay of $\Upsilon(4260)$.

An EIC Physics Working Group has been formed focusing on light and heavy spectroscopy at EIC. This group plans to demonstrate a strong physics case for a hadron spectroscopy program at EIC, which will be included in the next EIC Physics Book. Studies have commenced using event generators and simulating the kinematics (Figure 10 left two panels) and signal-to-noise

(Figure 10 right two panels), which will help define the detector design. The Regina-GlueX group that has joined the EIC Spectroscopy effort, which has a strong contingent of GlueX collaborators from the USA. Likewise, the group has joined the EIC Calorimetry group (with BNL and JLab participants) where the group's experience in building the 30 ton sampling fraction, electromagnetic barrel calorimeter (BCAL) for GlueX will be leveraged, as will the expertise in testing and deploying silicon photomultipliers.

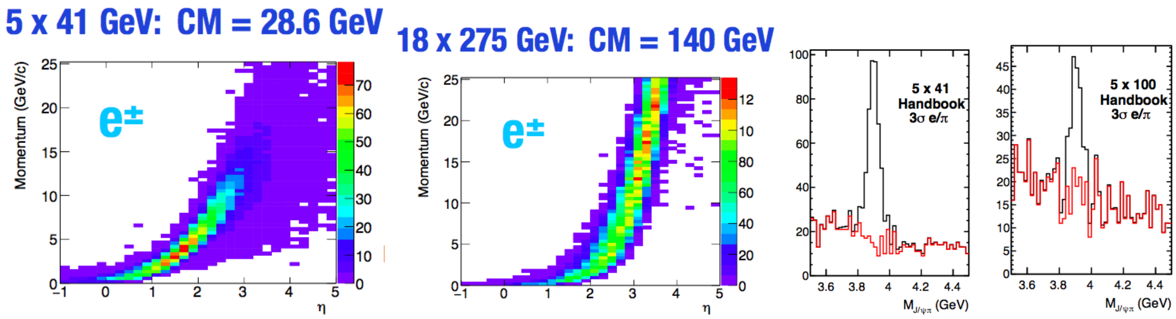

Figure 10: Simulations using the Pythia event generator for the electron momentum versus the pseudo rapidity for two different center-of-mass energies (left two plots) showing that detector requirements depend strongly on the center-of-mass energy. Also shown are the expected signal-to-noise performance on the $J/\psi\pi$ invariant mass (right two plots). The 5×41 plot has better acceptance but requires very good e/π separation.

In the 2021-2026 period, the group will be active in using/developing event generators and simulating and smearing generated events in the EIC detector framework, to study kinematical regions and see how observables depend on acceptance, achievable resolutions, etc., towards achieving the spectroscopy physics goals and in ensuring that the developed detector(s) can meet those goals. In parallel, the effort of the Calorimetry Working group is focused on collecting information about different calorimetry technologies and simulations studies, as well as examine physics-driven requirements to ECAL and HCAL calorimetry.

During the 2026-2031 period, final design, construction and commissioning of the EIC detector(s) is planned. The group will be active in calorimetry R&D and testing, together with American colleagues from JLab and BNL. The group's FTE and HQPs will increase during this period, as the GlueX and JEF projects in Hall D wind down.

3.4 Long Range Planning Visions

5 year outlook (2022–26) Over the next 5 years, the EIC community plans to achieve the next three critical decisions, CD-1 (alternative selection and cost range, by March 2021), CD-2 (final design, by September 2022), and CD-3 (start construction, by the 4th quarter of 2023). This aggressive schedule is only possible because of the strong international user community of over 1000 subatomic physicists working in concert with the joint accelerator design teams at Brookhaven National Laboratory and Jefferson Lab.

The EIC Canada Collaboration anticipates that the next 5 years will be a period of growth. Opportunities exist for subatomic physics groups with detector technology expertise to join the EIC

Canada Collaboration. The current members are in leadership positions in the detector development and physics working groups, as well as the software working groups.

By 2026, we anticipate to have grown our number of PIs to 2.5 FTE and our number of HQP to 9, following the acceptance of our Expression of Interest in international detector development efforts (to be submitted in late 2020). At that point, we will be at the start of the construction phase of a major Canadian detector component (funded through a substantial CFI investment of at least $1.5M).

Long-term vision (2027–36) In the longer term, 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 5.6 FTE. 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 two detector collider collaborations.

In order to grow the Canadian Electron Ion Collider community to this level, we will actively reach out to new PIs using the associate member positions in the EIC Canada Collaboration. We welcome new PIs to our periodic collaboration video calls. We anticipate that more extensive annual (in-person or virtual) collaboration meetings will provide another opportunity for new members to become introduced to the project.

Interface with the Jefferson Lab program There is significant synergy in the physics programs of the Electron Ion Collider and the Jefferson Lab 12 GeV facility. As the Electron Ion Collider program is ramping up, the Jefferson Lab 12 GeV program continues to take advantage of the energy upgrade completed in 2017. As of summer 2020, there are another 11 years of physics experiments approved for running at Jefferson Lab, with additional experiment proposals evaluated annually. The Jefferson Lab leadership is currently engaging in a 1-year idea gathering effort to define how their mission will be reshaped or expanded in the 2030s. However, this is unlikely to include a hardware project of similar scope as the Jefferson Lab 12 GeV upgrade or the Electron Ion Collider construction. With the completion of the upgraded detector construction and commissioning (including the new Hall D GlueX experiment that is in its third year of data taking), this bandwidth has become available to Electron Ion Collider detector design and construction efforts. While we anticipate an increasing focus on the Electron Ion Collider program, this will not come at a cost to the Jefferson Lab 12 GeV program. In particular, we want to stress that we remain committed to the success of the Jefferson Lab parity program, a unique program world-wide.

4 Recommendations

1. The EIC will uniquely address three profound questions about nucleons (neutrons and protons) and how they are assembled to form the nuclei of atoms: How does the mass of the nucleon arise? How does the spin of the nucleon arise? What are the emergent properties of dense systems of gluons?

2. Substantial involvement in the large international EIC project will confirm Canada's leadership role in scientific research and development.

3. Canadian participation in the EIC will become similar in scope as, *e.g.*, the Canadian participation in the Belle II experiment.

Appendices

A Picture Permissions

Permission is granted to the CINP, IPP, and the Long Range Planning committee to use any of the plots of data, calculations, and photographs included in this brief.

B Training of Highly Qualified Personnel (HQP)

As indicated in the attached spreadsheet, we anticipate a steady growth in the number of HQP in the EIC project. Due to the absence of data for physics analysis results to include in Ph.D. dissertation work, we anticipate that at first the HQP will skew towards research associates, M.Sc. students and undergraduate students, with Ph.D. students only included if a combination with ongoing data-producing efforts can be found. Already, current NSERC funding for EIC efforts includes one M.Sc. student. Once detector commissioning and physics data taking starts, the number of graduate students will increase significantly.

C Equity, Diversity and Inclusion (EDI) Efforts

Our collaboration acknowledges that Black, Indigenous, and People of Color (BIPOC), white women, and other visible and invisible minorities are under-represented in the field of physics. We will come up with clear strategies to encourage participation by these groups and in addition to investing considerable time and effort in ensuring that our HQP succeed. Our plan will encompass everything from outreach to recruitment, hiring, our training environment, and finally mentorship.

One of the first steps we will undertake is to develop a *Code of Conduct* with explicit language making clear that our collaboration is welcoming to people of all races, genders, and sexual orientations, and that we are supportive of parental leave, alternative work schedules, accommodations for families, mental health issues, and disabilities. This code will require that one person in our collaboration serve as ombudsperson, and they will deal with complaints or issues in a confidential and impartial manner, especially those involving a power imbalance. We will also form a small committee made up of a subset of summer/graduate students and a postdoc, to give the junior researchers a better way to voice their opinions on issues or problems they feel strongly about. Our code will also encourage members to attend workshops on racism, sexual and gender diversity, and implicit bias. All of our universities offer such training, and anyone serving in any sort of supervisory role or on a hiring committee will be *required* to attend these workshops.

One excellent example that the Manitoba group is already involved in that combines outreach and recruiting of underrepresented groups together is the *Dr. Verna J. Kirkness Science and Engineering Education Program.* This program brings Indigenous high-school students into the research lab during the summer months and gives them a taste of how actual science is done. It is an excellent experience for both the high-school students and the scientists, who in this case are both younger students and senior researchers. It has a positive impact in both outreach by fostering ties between the university and community, and has the potential to encourage Indigenous high-school students to attend university and study science, and possibly even physics.

Another example is the LGBTQ+ advocacy of Deconinck, also in the Manitoba group. Since 2009, Deconinck has been an effective ally for LGBTQ+ physicists. As a long-time organizing member of the LGTB+Physicists organization, Deconinck regularly leads round-tables and mentoring events for gender and sexual minorities at the annual meetings of the APS and at other conferences. He co-authored the 2012 "LGBT+ Best Practices Guide for Physics and Astronomy Departments" and the 2016 APS report "LGBT Climate in Physics: Building an Inclusive Community," the first comprehensive study of the climate faced by LGBTQ+ physicists at various stages in their career. At the University of Manitoba, Deconinck is the chair of the Departmental Equity, Diversity and Inclusion committee.

Hornidge at Mount Allison has long been successful in attracting female students to his research group, and is in the process of trying to bring the Kirkness program to Atlantic Canada.

Papandreou at the University of Regina is chair of the Departmental Outreach and Recruitment Committee, where he often visits high-school classes to promote physics and he regularly meets with counsellors and helps with career fairs. On his own, he has recruited female high-school students to work in his detector lab in the summer months, which then led to a more formal project with another faculty member where they launched an undergraduate "Build Club" in 2017 with the aim of constructing devices employing microprocessors and various hardware components, including detectors. This has blossomed into a group of ten, including faculty, students, and a postdoc, where in addition to technical skills, the students gain experience in grant and report writing.

In summary, the collaboration already has valuable experience in EDI, but we are aware there is a long way to go and we are taking concrete steps to improve to get there.

D Collaboration List

As with any large new initiative we anticipate that this effort will grow beyond the current membership of the EIC Canada Collaboration. We anticipate that up to 3.5 new FTE will be joining this effort between now and the start of operations.

Co-signatories of the EIC Canada Collaboration:

- W. Deconinck (University of Manitoba)
- M. Gericke (University of Manitoba)
- D. Hornidge (Mount Allison University)
- G. Huber (University of Regina)
- J. Mammei (University of Manitoba)
- Z. Papandreou (University of Regina)

International Collaborators:

- Brookhaven National Laboratory (BNL)
- Jefferson Lab (JLab)
- EIC User Group (EIC-UG). As of July 2020, EIC-UG membership stands at 1085 members from 228 institutes in 31 countries. Membership is broadly diversified, with 42% of the

institutions from North America, 32% from Europe, 22% from Asia, with the remainder from South America, Africa, and Oceania. Experimentalists are 60% of total membership, Theorists are 25%, Accelerator experts are 14%, and Experimental support staff are 1%.

E List of Acronyms

BNL (Brookhaven National Laboratory): A DOE national laboratory in Upton, New York, which is home to a number of facilities including RHIC and the future EIC.
CFI (Canada Foundation for Innovation): Created by the Government of Canada in 1997, CFI makes investments in state-of-the-art research facilities and equipment in a wide variety of scientific disciplines.
CINP (Canadian Institute of Nuclear Physics): The organization that gathered input from the Canadian nuclear physics research community in order to put together this document.
DCSB (Dynamical Chiral Symmetry Breaking: The mechanism by which quark-gluon interactions are expected to dynamically generate most nucleon mass, ultimately accounting for $> 98\%$ of the mass of the visible universe.
EIC (Electron-Ion Collider): A new DOE nuclear physics user facility under development at Brookhaven National Laboratory.
HPC (High-Performance Computing): Leveraging large scale computing facilities or networks towards problems on scales that are prohibitive on individual systems.
HQP (Highly Qualified Personnel): Personnel obtaining advanced skills as a result of NSERC-funded research, including students, postdocs and technicians.
JLab (Jefferson Lab): The Thomas Jefferson National Accelerator Facility, located in Newport News, Virginia.
QCD Quantum Chromodynamics, the quantum field theory of the strong interaction between quarks and gluons.
US-DOE (United States Department of Energy): The federal agency responsible for most of the USA national laboratories.