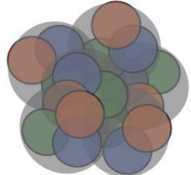


Hadron Physics / QCD Scientific Working Group

C I N P



I C P N

Canadian Institute of Nuclear Physics

Institut canadien de physique nucléaire

Svetlana Barkanova, Town Hall Meeting, June 13, 2025

CINP



ICPN

Subatomic Physics Long Range Plan | Canadian Institute of Nuclear Physics Institute Canadien de Physique Nucléaire

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Hadron Structure/QCD Working Group

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Scientific Working Groups

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- [Key Questions in Nuclear Physics](#)
- [Hadronic Physics/QCD](#)
- [Nuclear Structure](#)
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- [Education and Training](#)

Important Links

- [Subatomic Physics Long Range Plan](#)
- [NSERC News](#)
- [SAPES Chair Reports \(2010-\)](#)

Canadian theorists are major contributors to lattice calculations and to predictions based on ChPT and are closely working with experimentalists on planning the measurements and providing theory input, such as radiative corrections. Experiments designed to make detailed comparisons with QCD predictions are high-priority endeavours of research at facilities across the USA, Europe and Japan, with goals of obtaining: a tomographic view of the quarks and their motion within the nucleon; the elucidation of the role of gluons and gluon self-interactions in nucleons and nuclei; and a detailed understanding of how QCD governs the transitions of quarks and gluons into pions, protons and neutrons. Hadron spectroscopy has become even more exciting since evidence for new types of groupings in heavy-quark systems have been found: tetraquark and pentaquark, candidates in the charmonium sector, and hybrids in the light-quark sector probed in pion production.

Canadians have leadership roles in a number of experiments at offshore facilities, including detailed measurements of proton, kaon and pion structure, and investigations of the spectrum of hybrid mesons containing explicit gluonic degrees of freedom. For example, a Canadian group led experimental efforts at JLab to extract the photon-beam asymmetry for η and η' , resulting in a Ph.D. thesis and a publication [The GlueX Collaboration, S. Adhikari et al., Phys. Rev. C 100, 052201(R) (2019)]. The extracted beam asymmetry afforded comparisons to theoretical models, and indicated the dominance of natural parity exchange in the reaction mechanism. Canadians looking forward to extending the meson structure and meson spectroscopy studies at the upcoming Electron-Ion Collider.

Key Question #2: What are the phases of strongly interacting matter, and what roles do they play in the cosmos?

Nuclei make up 99.9% of the visible matter in the universe. At the highest densities, yet at still rather low temperatures, the quarks making up the nucleons of nuclear matter may form a new state of matter, which is color-superconducting. Exotic nuclear matter can also be created by colliding nuclei at relativistic energies. In this case, 'nuclear temperatures' can reach values that represent a state of matter (the quark-gluon plasma) as it existed during the first moments after the Big Bang. This is an active field of study at international facilities such as RHIC in the USA, and the LHC at CERN. There are a number of very active Canadian theorists who are making significant contributions to our understanding of the phase diagram of nuclear matter. Their work has significant bearing on the quest to characterize the properties of the quark-gluon plasma, and for our understanding of astrophysical phenomena such as neutron star structure and the evolution of the early universe. In recent years, the nuclear theory group at McGill University has developed and put forward a 3D, relativistic, viscous fluid-dynamical approach that has been successfully used to model the time-evolution of the high-energy nuclear collisions. A fundamental question in all studies of the many-body effects observed in high energy heavy ion collisions is whether the observed correlations develop dynamically or are already present in the initial states. A new approach has recently been constructed [Scott McDonald, Sangyong Jeon, Charles Gale. Nucl. Phys. A982 (2019) 239] which properly takes into account the the evolution in full 3-dimensional space. Importantly, the physics of the IP-Glasma relies on that of saturation: the scale at which the non-linearities of the gluon field manifest themselves. The exploration of the saturation regime is a central theme of the Electron-Ion Collider which will push our study of QCD to new



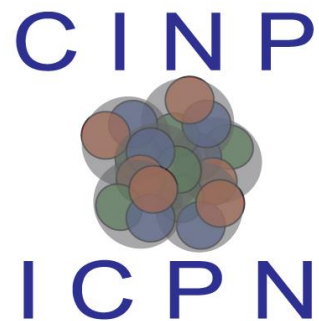
Submitted to the CINP Long-Range Plan Brief Committee Hadronic Physics/QCD Experiment, June 2025:

Experimental Probes of Hadron Structure at Jefferson Lab

G.M. Huber, Z. Papandreou, A. Teymurazyan, Department of Physics, University of Regina, Regina, SK, D. Hornidge, Department of Physics, Mount Allison University, Sackville, NB

Hadron Polarizability Experiments at Mainz and Duke, *D. Hornidge*

Canadian Participation in the Electron-Ion Collider, *W. Deconinck*



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).

PLENARY I — Working group chairs give summaries of briefs submitted to date

8:40SK/10:40ET/7:40PT Nuclear Structure — Corina Andreoiu (20+10)

9:10SK/11:10ET/8:10PT Nuclear Astrophysics — Greg Christian (20+10)

9:40SK/11:40ET/8:40PT Hadronic Physics/QCD — Svetlana Barkanova (20+10)

10:10SK/12:10ET/9:10PT Fundamental Symmetries — Jeff Martin (20+10)

10:40SK/12:40ET/9:40PT Nuclear Theory — Alex Gezerlis (20+10)

11:10SK/13:10ET/10:10PT Education, Training, EDI — Ruben Sandapen (20+10)

11:40SK/13:40ET/10:40PT Major Issues for CINP brief, to guide our discussions — Garth Huber (20+10)

PLENARY II — New projects

12:45SK/14:45ET/11:45PT Wouter Deconinck - Canadian Participation in the Electron-Ion Collider (10+2)

BREAKOUT SESSIONS

14:40SK/16:40ET/13:40PT Hadronic Physics/QCD (15)

Chair: Svetlana Barkanova Secretary: Alex Gezerlis

The Canadian Hadronic/QCD Effort

G.M. Huber, Z. Papandreou, A. Teymurazyan,

Department of Physics, University of Regina, Regina, SK

D. Hornidge, *Department of Physics, Mount Allison University, Sackville, NB*

“Can the theory of quark and gluon confinement quantitatively describe the detailed properties of hadrons?”

Perspectives on Subatomic Physics in Canada 2006–2016.

- Theory: **QCD** describes the strong force in terms of quarks and gluons.
- Nobel Prize in 2004 for **Asymptotic Freedom** in the **pQCD** regime. . .
- However, in the non-perturbative region, **QCD** is still unsolved.

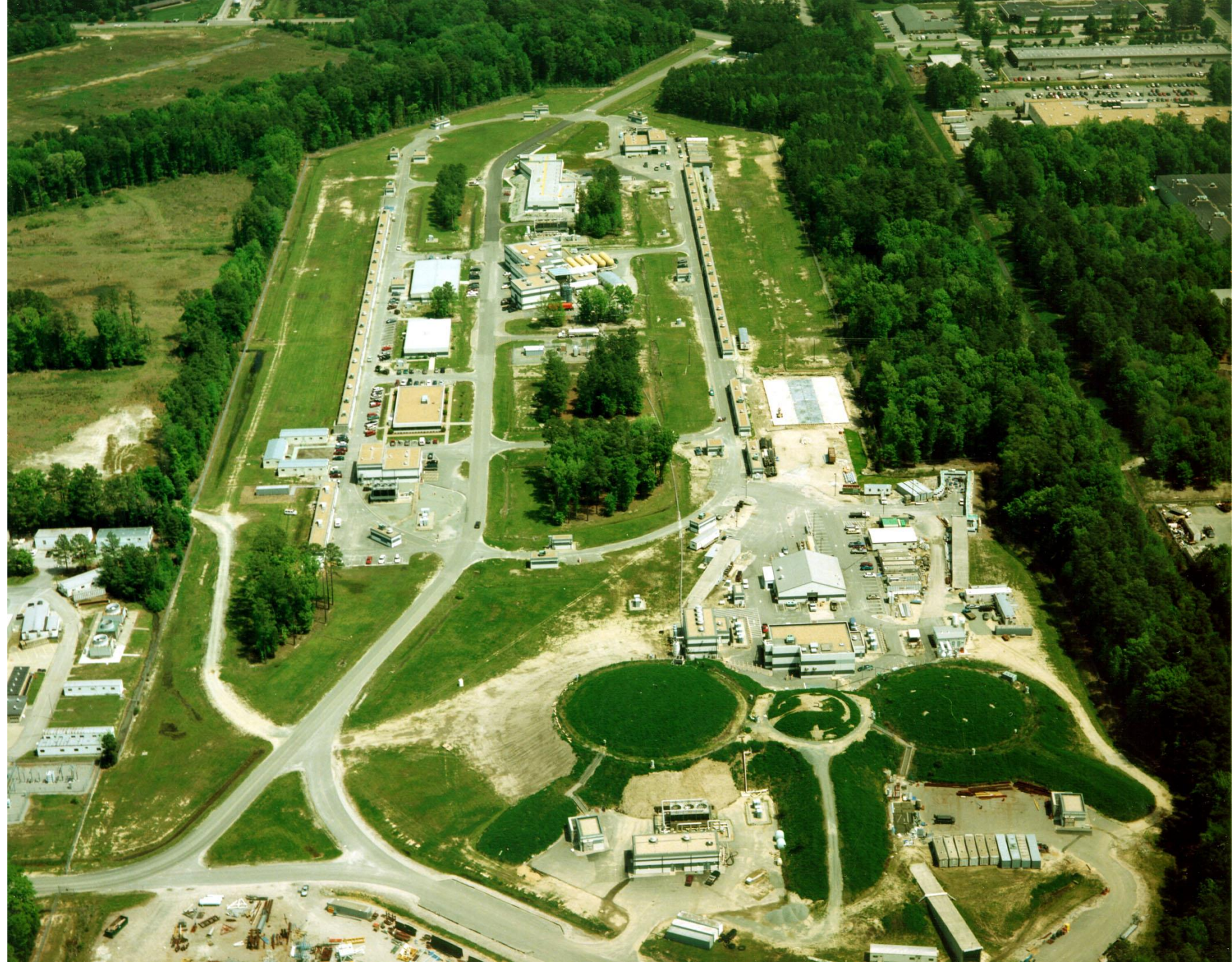
One of the top ten challenges for all of physics!

The Thomas Jefferson
National Accelerator
Facility also known as
Jefferson Lab or **JLab**

Newport News, Virginia

The Continuous Electron
Beam Accelerator
Facility (CEBAF)

Hall D – built for the
12 GeV upgrade; hosts
the GlueX experiment,
aiming to map exotic
and hybrid meson states



Canadian Program at the Jefferson Lab

Medium Term:

- Experiments in both Hall C and Hall D.
- $\pi - K$ form factor experiments in Hall C.
- GlueX-II Partial Wave Analyses and rare- η meson decays in Hall D (JEF Program).

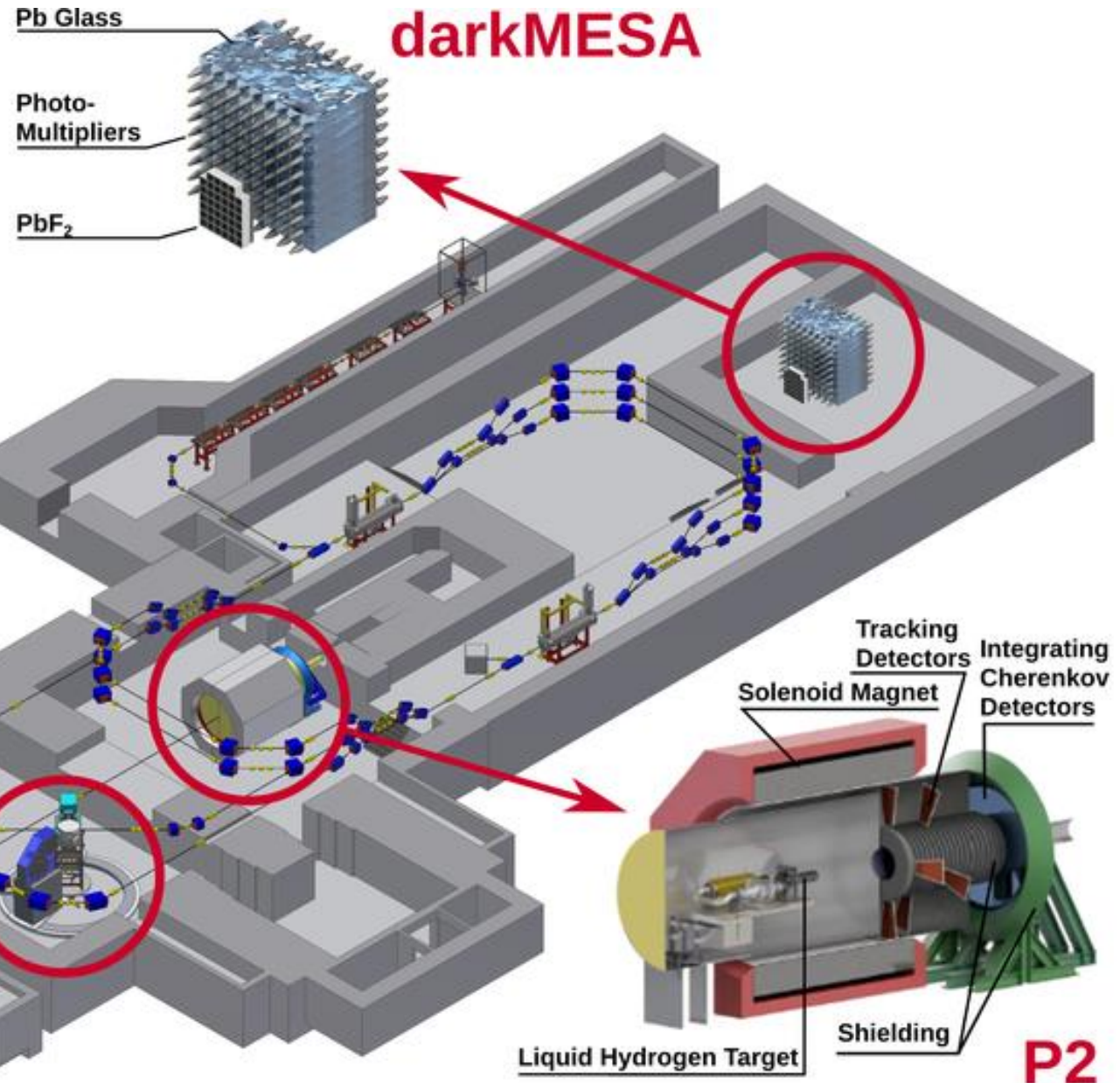
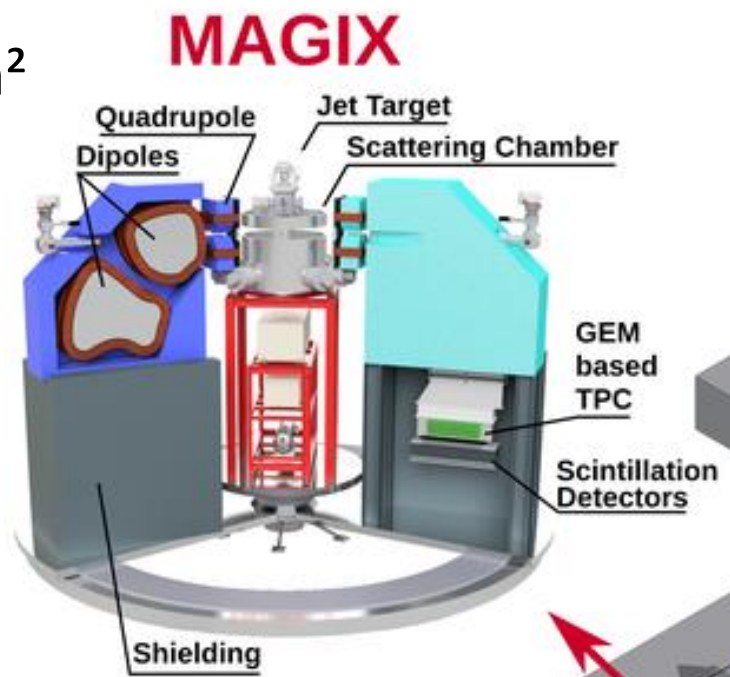
Long Term:

- GlueX-III high-luminosity-frontier running with emphasis on near-threshold charmonium production.
- SoLID experiment to come online with an increase in luminosity of 10x over existing detectors.

MESA (Mainz Energy-Recovering Superconducting Accelerator)

10^{22} e/sec/cm²

155 MeV



Canadian Contributions at the Mainz Microtron

Medium Term:

- Continue work with the A2 Collaboration.
- Extracting the Compton form factor from ^{12}C and heavier nuclei using a large-volume NaI.
- Compton scattering on nuclear targets to improve the precision of the neutron EM polarizabilities.

Long Term:

- Experiments with the MAGIX detector at the new MESA accelerator.
- Hadron Physics.
- Nuclear Astrophysics.
- Dark Matter searches.

Dave Hornidge

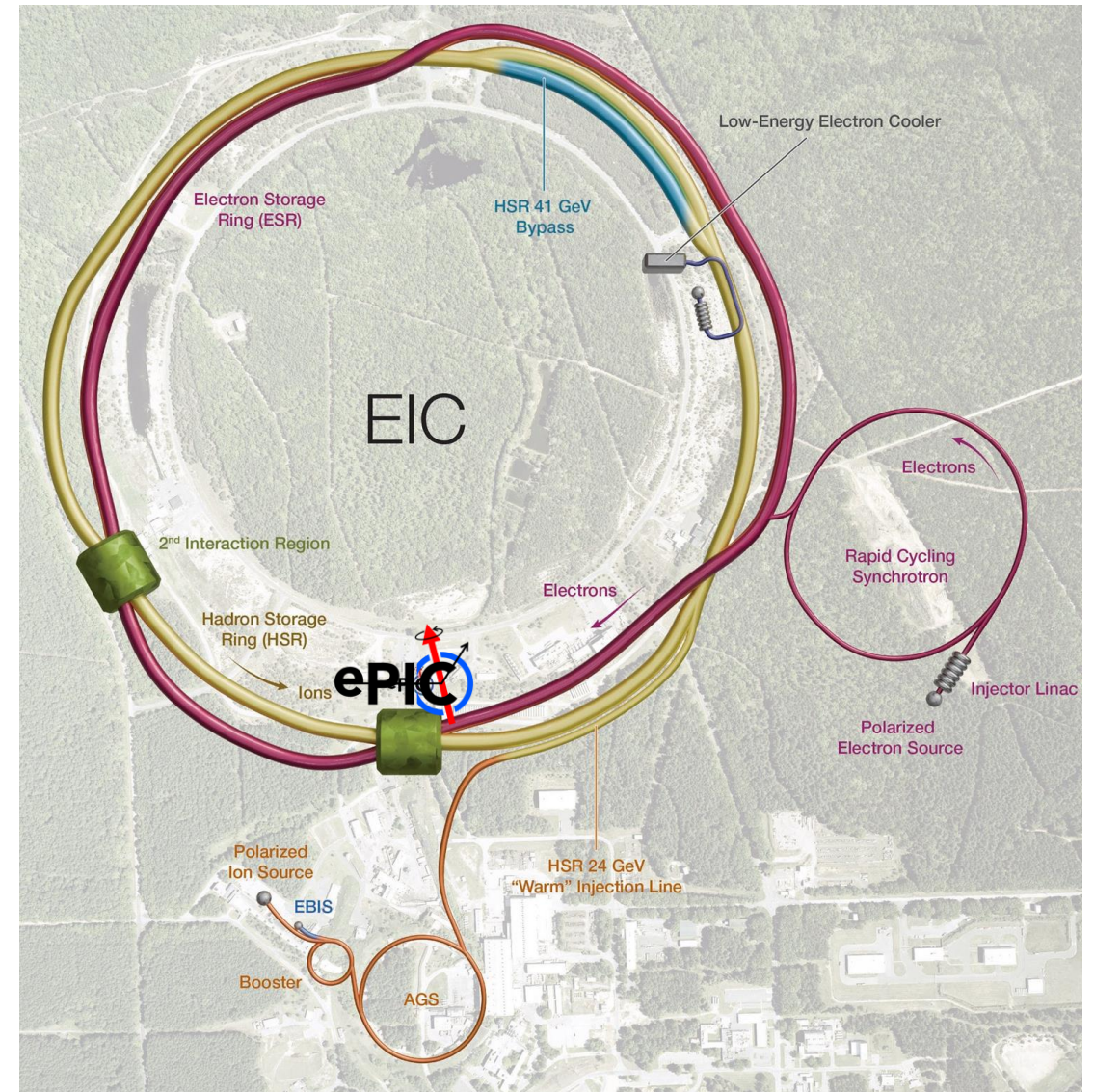
Canadian Participation in the Electron-Ion Collider

Wouter Deconinck, University of Manitoba

EIC, the **first major collider** to be built in North America in the 21st century

- Reusing infrastructure of RHIC at BNL
- **Polarized electrons**, 10-20 GeV
- **Polarized light ions** (p, d, ^3He) and unpolarized nuclei \rightarrow U, 50-250 GeV
- **Center-of-mass energy** of 28-140 GeV
- **High luminosity \mathcal{L}** of 10^{33} – 10^{34} $\text{cm}^{-2} \text{s}^{-1}$
- **ePIC detector**; potential for second detector

Wouter Deconinck



Canadian Participation in the Electron-Ion Collider

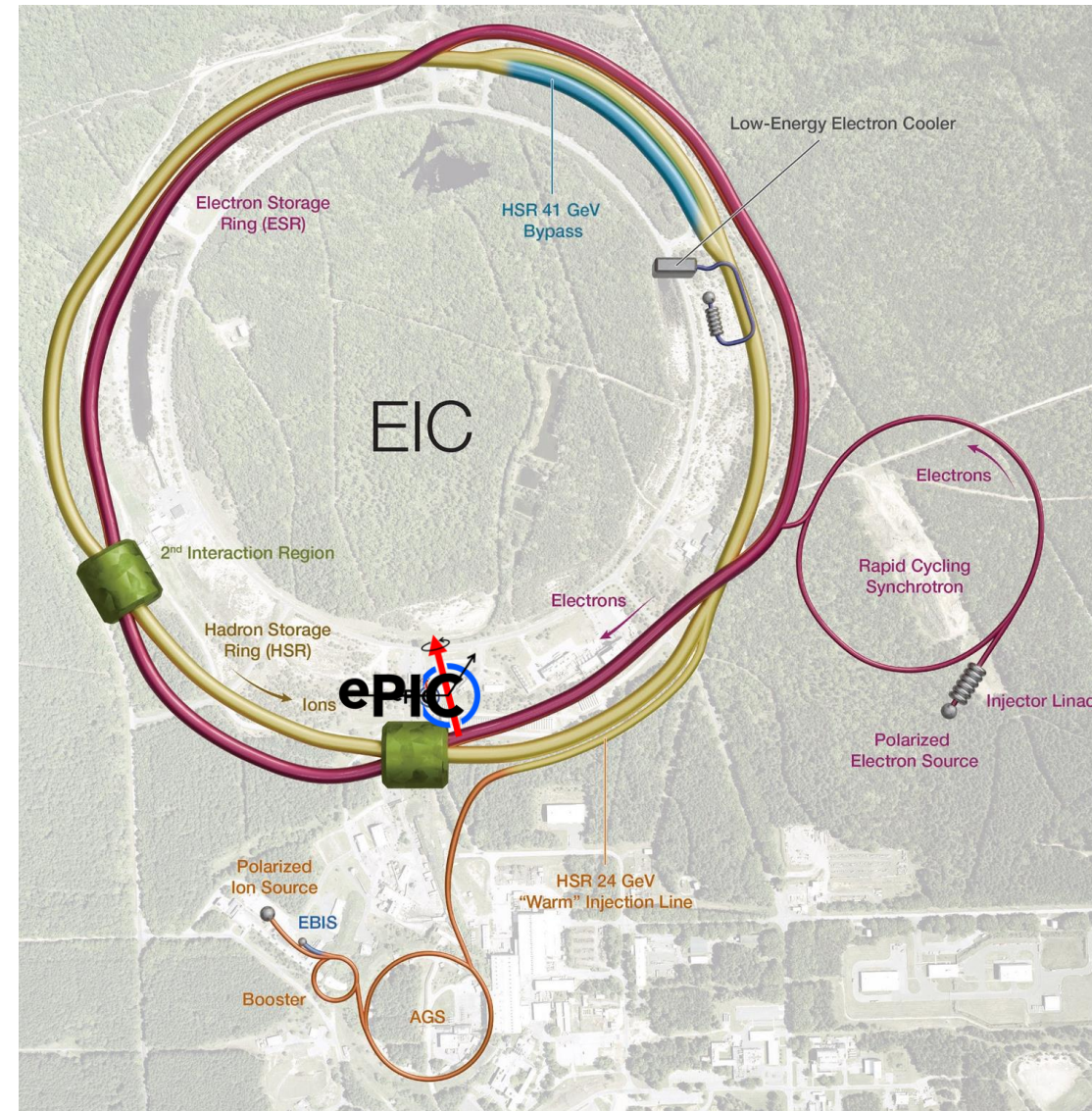
International facility with estimated cost of about US\$2.8B (US\$300M detector)

- 1500+ EIC users at ~300 institutions in ~40 countries; ~900 ePIC collaborators at 175+ institutions in 25 countries

EIC Canada at eic-canada.org



Wouter Deconinck



Canadian Participation in the Electron-Ion Collider

Canadian Infrastructure Leadership

- Superconducting RF Crab Cavities
 - Cancel beam crossing angle to enable precision physics at peak luminosity
 - Led by UVic, TRIUMF; based on expertise with Hi-Lumi LHC project
- Barrel Imaging Calorimeter (BIC)
 - High-granularity hybrid silicon + Pb/ScFi barrel calorimeter, made for the AI era
 - Excellent e/π separation, energy resolution, cluster shape information
 - Led by URegina, UManitoba, MtA; based on expertise with GlueX BCAL

Wouter Deconinck



Canadian Participation in the Electron-Ion Collider

Canadian Physics Leadership

How does the nucleon **mass** arise?

- Meson (π^\pm , K^\pm) form factors as probe for emergent mass generation
- Heavy and light quark spectroscopy: understanding exotic hadrons

How does the nucleon **spin** arise?

- First measurements of interference structure functions $F^{\gamma,\gamma^*Z,Z}_{1,2,3}$ and $g^{\gamma,\gamma^*Z,Z}_{1,4,5}$

Wouter Deconinck

