Electron-Ion Collider

Prospects for **Canadian** Involvement

Wouter Deconinck, University of Manitoba
for the EIC Canada Collaboration (eic-canada.org)

University of Manitoba

Mount Allison University

University of Regina

With material by Michael Gericke, Dave Hornidge, Garth Huber, Juliette Mammei, Zisis Papandreou. Supported in part by NSERC.

What is the EIC Canada Collaboration?

- **Coordinating the Canadian participation in the Electron Ion Collider**
- Chartered in 2020 after CD-0 decision and site selection
- Active initiatives:
  - Engagement with the 2022-2036 **Canadian Subatomic Physics Long Range Plan**
    - For previous editions and town hall sessions schedule: subatomicphysics.ca
  - Submission of Subatomic Physics **EIC Project Research Grants** (targeted for Fall 2020)
  - Interfacing with partner organizations (drumming up support):
    - National funding agencies and research facilities (NSERC, CFI, TRIUMF)
    - International partners (EIC UG, BNL, JLab, working groups and consortia)
  - Submission of **Expression of Interest** for Potential Cooperation to BNL / JLab
- Current membership:
  - PIs at U. Regina, U. Manitoba, Mt. Allison U.
  - Associate memberships targeted at e.g. theory community
- Management plan, members, leadership and further details at eic-canada.org

EIC Canada Collaboration

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 site selection of Brookhaven National Lab and the first critical decision (CD-0) establishing mission need. The project aims to complete the next two critical decisions by 2026 and to start operation 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.

Contact

For information on joining or contributing, please contact Wouter Deconinck.

1. Scientific Research in Canada

Canada: “Factor of 10” Rule

	Canada	**US**
Area	10M km^2	10M km^2
Population	38M	330M
GDP (US$ PPP)	$1.7T	$20.5T
Provinces/States	10	50
Territories	3	14
Federalism	Provinces ≈ National	States < National

Credit: Jonathan Bagger, TRIUMF

Canadian Subatomic Physics Long Range Plan

- **Timeline:** Process started June 2020. Report will cover **2022-2036**, and is planned to be updated every 5 years.
- **Scope:** nuclear and particle physics, at accelerator and underground facilities, including theory, at domestic (TRIUMF, SNOLAB) and international facilities that Canadians have substantial roles.
- The LRP process is driven by the research community, and involves widespread consultation.
  - Two national institutes, the Canadian Institute of Nuclear Physics (CINP), and the Institute of Particle Physics (IPP), are tasked to consult within their respective communities and prepare briefs for the LRPC. **The EIC falls within the purview of the CINP.**
- **Use:** The LRP guides investments by the funding agencies, particularly NSERC and CFI, but is not binding.
- **Final report due:** Sept 30, 2021

Canadian Subatomic Physics Long Range Plan

- The LRPC is to assess the feasibility, technical readiness and risks associated with particular endeavors, and make recommendations to possibly lessen negative impacts they may have, or enhance positive ones.
- **Selected LRP 2017-21 Recommendation:**
  - ***Position Canada for key leadership roles in strategic projects and initiatives by supporting activities in potential future flagship endeavours. Those projects with significant Canadian participation should continue to receive support: ATLAS at the High-Luminosity LHC, Belle II, Hyper-Kamiokande, ILD at ILC, Moller and SoLID at JLab, nEXO at SNOLAB, and UCN/nEDM at TRIUMF.***
  - **Later in document, EIC is mentioned as a possible future project: *"Internationally, there has also been much activity towards the construction of an Electron-Ion Collider (EIC) in the US in the coming decade. Canadian nuclear physicists are taking roles in the planning and prototyping for this new facility, the scientific case for which has been favourably reviewed."***

Canadian Subatomic Physics Long Range Plan

Key questions in 2017-2021 Long Range Plan:

- What is the nature of physics at the electroweak scale and beyond?
- What is the nature of neutrino masses?
- What is the nature of Dark Matter in the Universe?
- What structures underlie the forces and matter in the Universe?
- **How does the structure of nuclei emerge from nuclear forces?**
- **How does QCD determine hadrons' properties and the phases of hadronic matter?**
- How were the heavy elements formed in the Universe?

Similar structure as NAS Report on the Electron-Ion Collider.

Canadian Research Funding Environment

- Natural Science and Engineering Research Council (NSERC)
  - ~~Similar to National Science Foundation operating grants~~ (for everyone else but not for us)
  - Subatomic Physics has dedicated CA$28.7M funding envelope (2021-2022), separate from all other sciences (~6% of total NSERC funding pool), stable arrangement since 1991.
  - Funds distributed primarily through **multi-PI projects** (65%), individual grants (17%), and major resources support (11%)
  - Primary funding source for **operational student/staff funding**
  - No large top-down programs like DOE SC
- Canadian Foundation for Innovation (CFI)
  - Similar to National Science Foundation Mid-scale RI-1, but with 1:1 matching required
    - from any partner (province, international partner)
    - in-kind or financial
  - Primary funding source for **major research infrastructure** (including research start-up)

Canadian Research Funding Environment

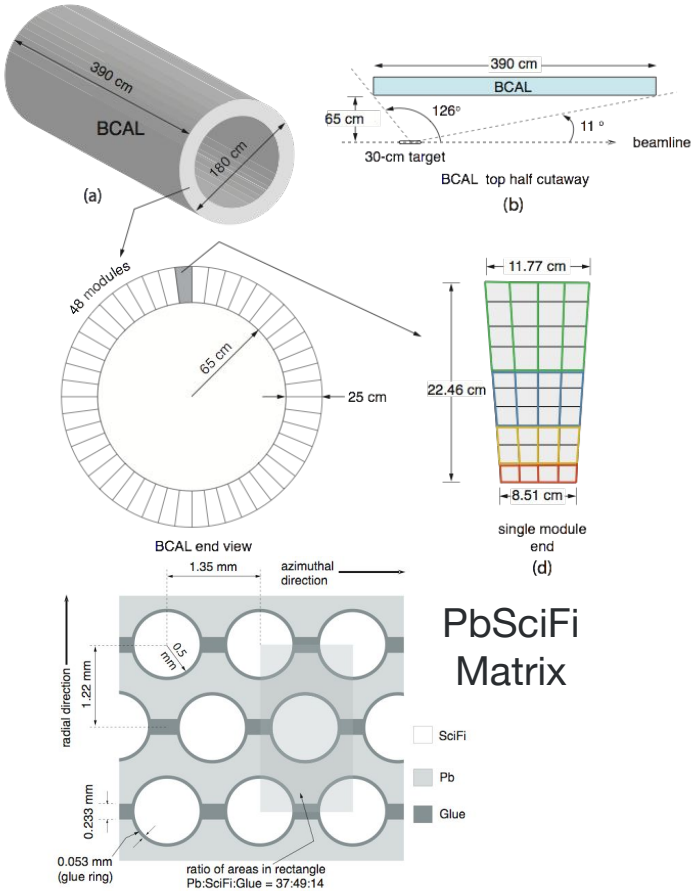
- National Research Council (NRC)
  - National science facilities
  - Primary funding source for **TRIUMF** at $250M / 5 years (with $145M from other sources)
  - TRIUMF priorities governed by 5 year plan (currently 2020-2025)
    - “Drive national and international collaboration in research, technology, innovation”
    - Based on community input (Subatomic Physics Long Range Plan)

Other useful tidbits:

- Low indirect cost rate (“overhead”), typically ~ 20%
  - Accounted through separate stream from government to universities based on total research portfolio; not accounted as part of tri-council research grants.
  - Individual negotiation possible (JLab GlueX BCAL: 10%).

2. Major Canadian Contributions to International Research Projects

The GlueX Barrel Calorimeter



Key Features

- E-M sampling calorimeter (9.5% samp. fraction)
- 750,000 double-clad scintillating fibers
- 0.5mm Pb corrugated sheets
- BCAL: 28 tonnes
- Shower reconstruction and PID

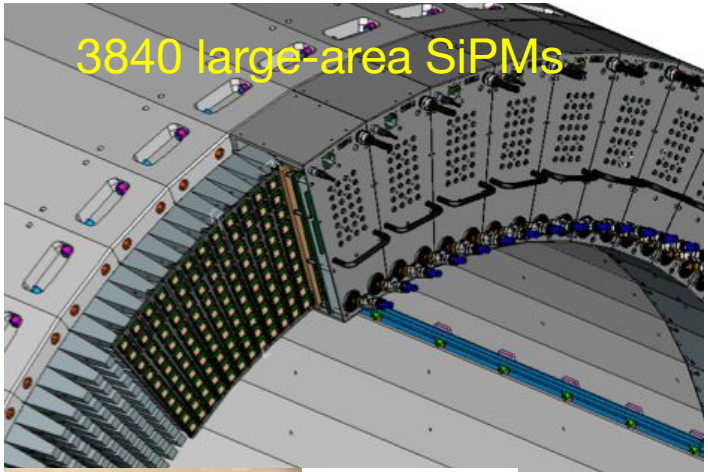
International funding:

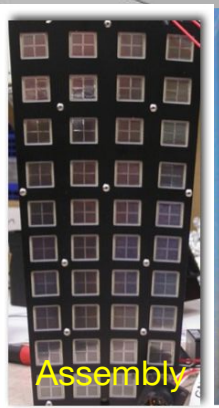
- US$10M from DOE (without electronics)
- NSERC operating funds for labour

International consortium:

- U. Regina (Canada)
- U. Tecnica Federico Santa Maria (Chile)
- U. Athens (Greece)
- Carnegie Mellon U.
- Indiana U.
- Jefferson Lab

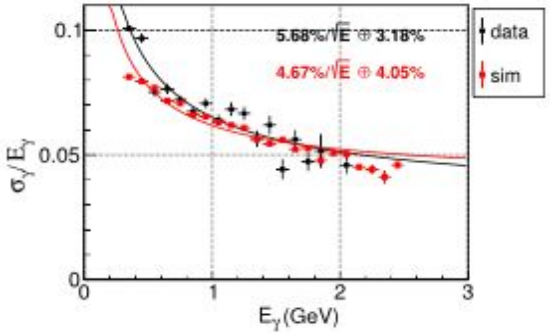
Readout and Performance

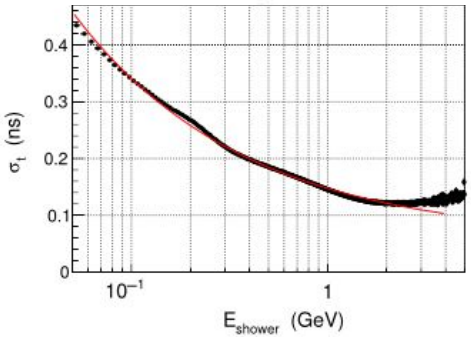




Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 896, 11 July 2018, Pages 24-42

Construction and performance of the barrel electromagnetic calorimeter for the GlueX experiment

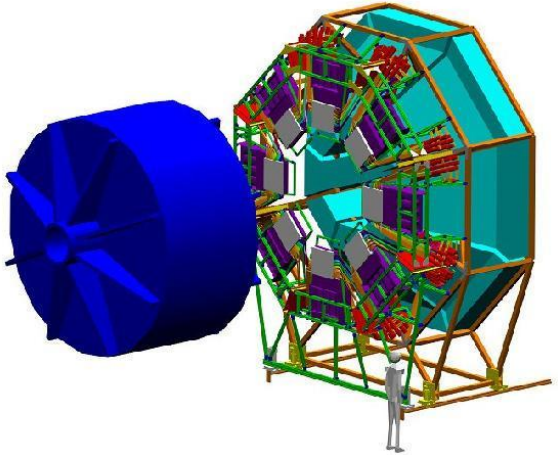


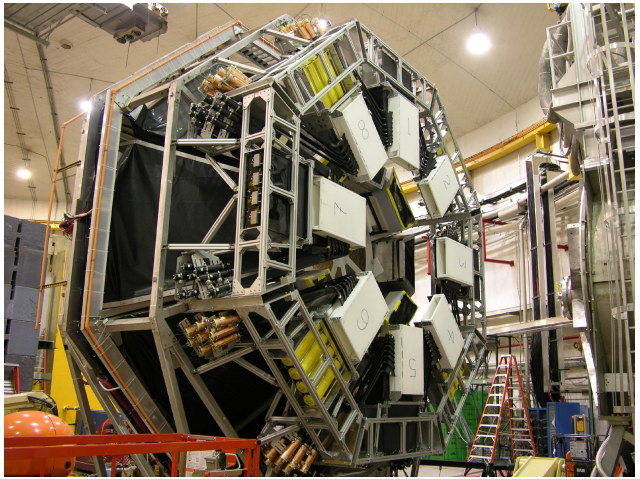


Canadian Contribution To Gzero (1995-2012)

U. Manitoba and TRIUMF Contributions:

- 300 phototube bases for the Focal-Plane Scintillation detectors
- All (72) of the Cryostat-Exit Scintillation detectors
- Half (4) of the back-angle Aerogel-Cerenkov detectors
- The "Mini-Ferris wheel" support structure for the detectors
- An automated large-volume field mapping device
- Customized "parity" Voltage-to-Frequency electronic modules
- ~$3M of Canadian funding
- Significant analysis contributions

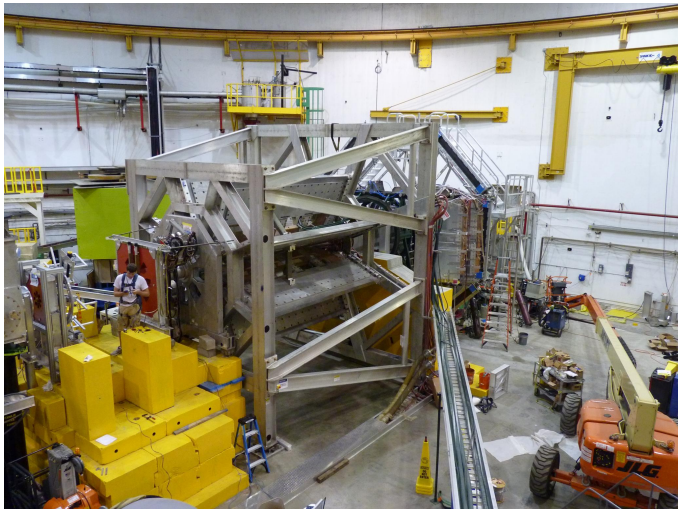


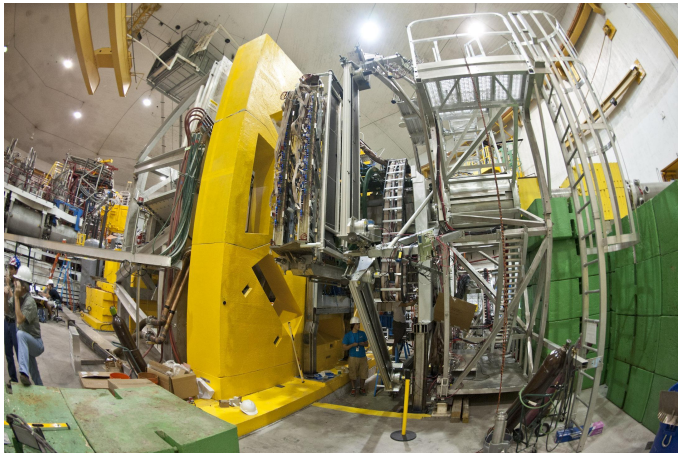


Canadian Contribution To QWeak (2004-2018)

U. Manitoba and TRIUMF Contributions:

- Design and Engineering of the large Toroidal magnet
- Design and Construction of the Magnetic Field Mapper
- Spectrometer Optics and Systematics
- Design of the main quartz Cherenkov detectors
- Main detector mounting structure
- Main detector PMT bases
- Integrating electronics (preamps + ADC boards)
- ~$3.5M of Canadian funding
- Large scale analysis contributions

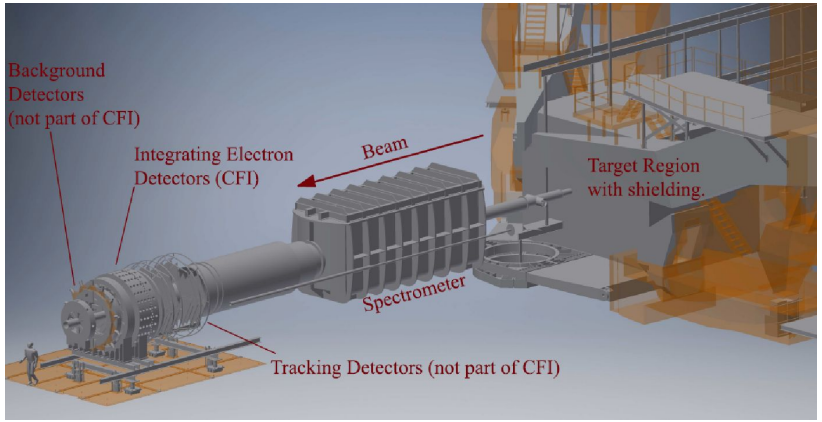


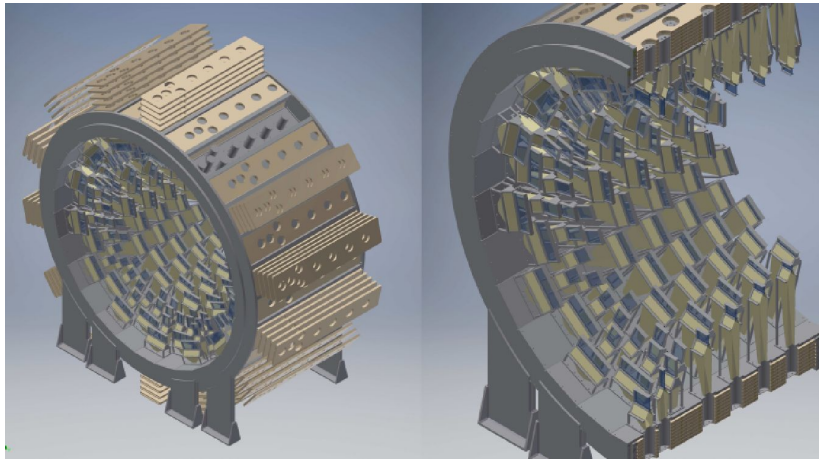


Canadian Contribution To MOLLER (2010 - present)

U. Manitoba and TRIUMF Contributions:

- Magnetic Spectrometer Design
- Design of the main quartz Cherenkov detectors
- Main detector mounting structure
- Main detector PMT bases
- Integrating electronics (preamps + ADC boards)
- Simulation and analysis software framework
- ~$1M of NSERC funding so far
- ~$6M of CFI funding pending for construction of the main detectors





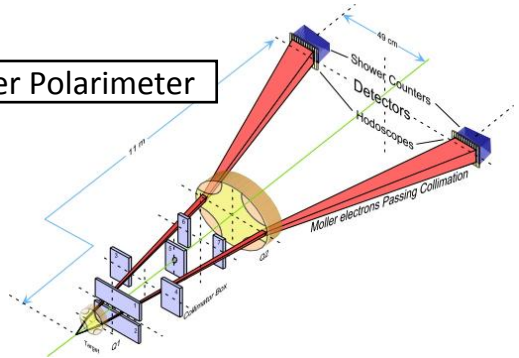
Precision Polarimetry at JLAB Hall A

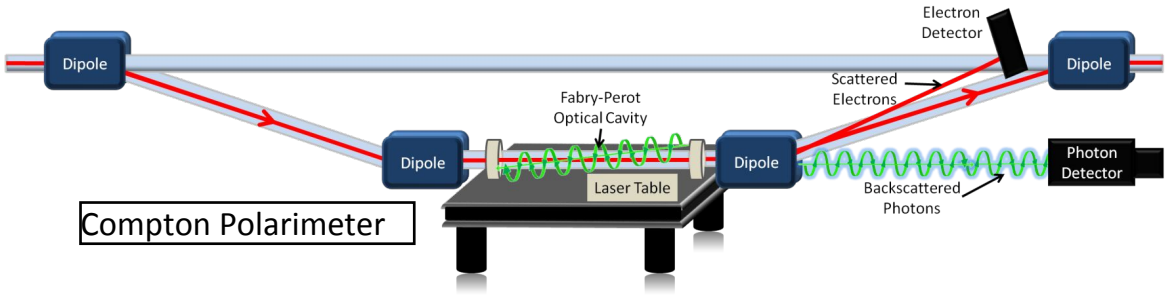
Precision PVES experiments require measurement of the beam polarization to sub - $\frac{dP}{P} = 1\%$

- Møller polarimeter to measure absolute beam polarization to <1% at low beam currents
- Known analyzing power provided by polarized iron foil in high magnetic field

- Use Compton polarimeter to provide continuous, non-destructive measurement of beam polarization
- Known analyzing power provided by circularly-polarized laser beam

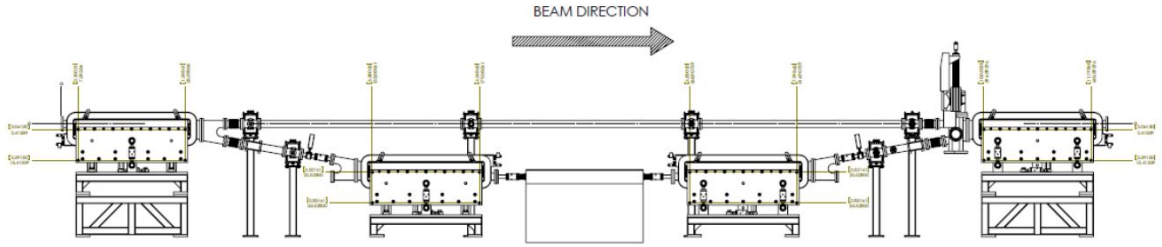
Møller Polarimeter



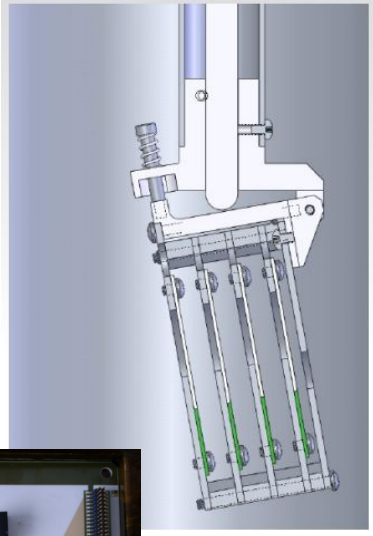


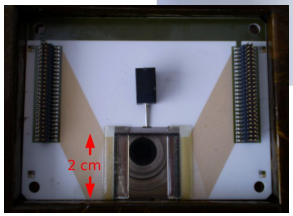
Compton Polarimeter

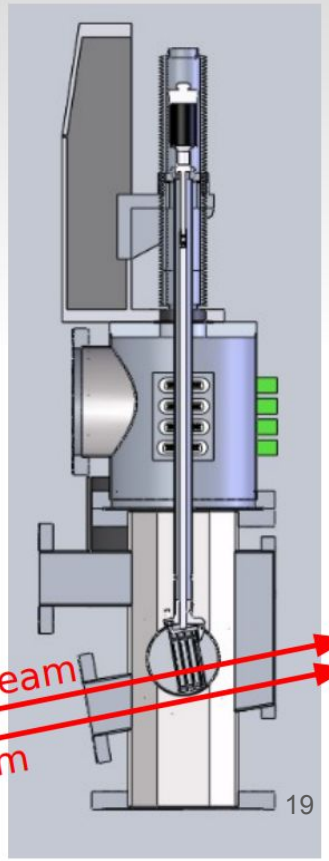
Precision Polarimetry at JLAB Hall C



- Rad-hard **CVD diamond tracker** (4 layers)
- Development U. Winnipeg, U. Manitoba, pre-amp electronics by TRIUMF
- NSERC, TRIUMF

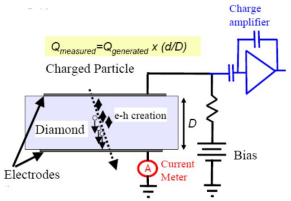






PHYSICAL REVIEW X **6,** 011013 (2016)

Precision Electron-Beam Polarimetry at 1 GeV Using Diamond Microstrip Detectors



Credit: Jeff Martin, U. Winnipeg

Canadian Participation in ATLAS

ATLAS Canada collaboration: 40 faculty, 10 institutions, 4 provinces, 150 people

Combination of funding sources:

- NSERC: Base operational and research support
- CFI: Phase 2 HL-LHC upgrades
  - Liquid Argon Calorimeter
  - ITk Silicon Tracker
- CERN: CFI matching requirements using international contributions to ATLAS
- NRC: Tier-1 Centre operations, through TRIUMF
  - Tier-2 Centres at Simon Fraser U., U. Victoria, U. Waterloo (ComputeCanada-managed)

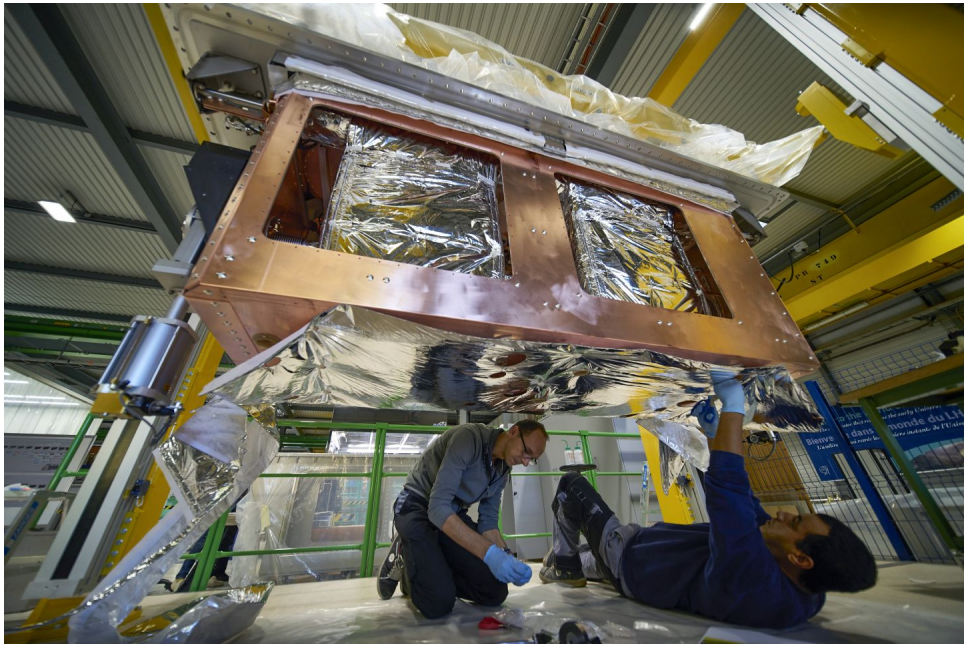
Credit: Jonathan Bagger, TRIUMF

Canadian Participation in LHC-HL Upgrade

LHC-HL crab cavity ‘coldboxes’

- Particle accelerator development effort led by TRIUMF
- Funded by $10M direct ministerial decision, outside any of the usual funding agencies

Example of a Canadian contribution to accelerator infrastructure, which is not traditionally included in subatomic physics.



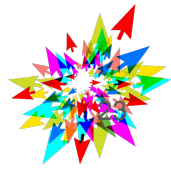
Credit: TRIUMF

3. Anticipated EIC Involvement

Canadian Involvement in EIC Software WG

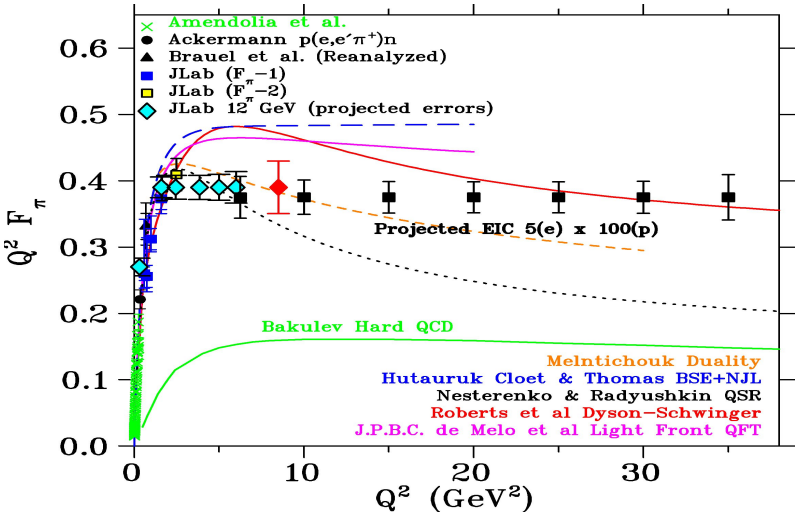
- Core involvement in EIC UG SWG
- **Containerization** of standard EIC software:
  - Development and deployment of docker and singularity containers for ESCalate
    - Docker hub: electronioncollider/escalate
  - Coordination of EIC Open Science Grid spaces on CernVM-FS
    - /cvmfs/eic.opensciencegrid.org/singularity
    - /cvmfs/singularity.opensciencegrid.org/electronioncollider/
- **Packages** of versioned EIC software (with spack):
  - Development and support of packages for most EIC software
  - Coordination of EIC software package tree for HPC sites
    - /cvmfs/eic.opensciencegrid.org/packages
- **User-centered design**: understand how users want to use the software
  - User-support tutorials on singularity, jupyter, spack at EIC SWG and other meetings
- Interface to ComputeCanada resources (270k cores, incl. ATLAS Tier-2)

```
$ spack install mpileaks
$ spack install mpileaks@3.3
$ spack install mpileaks@3.3 %gcc@4.7.3
$ spack install mpileaks@3.3 %gcc@4.7.3 +threads
$ spack install mpileaks@3.3 cppflags="-O3 -g3"
$ spack install mpileaks@3.3 target=skylake
$ spack install mpileaks@3.3 ^mpich@3.2 %gcc@4.9.3
```



Pion form factor as probe of emergent mass generation in hadrons

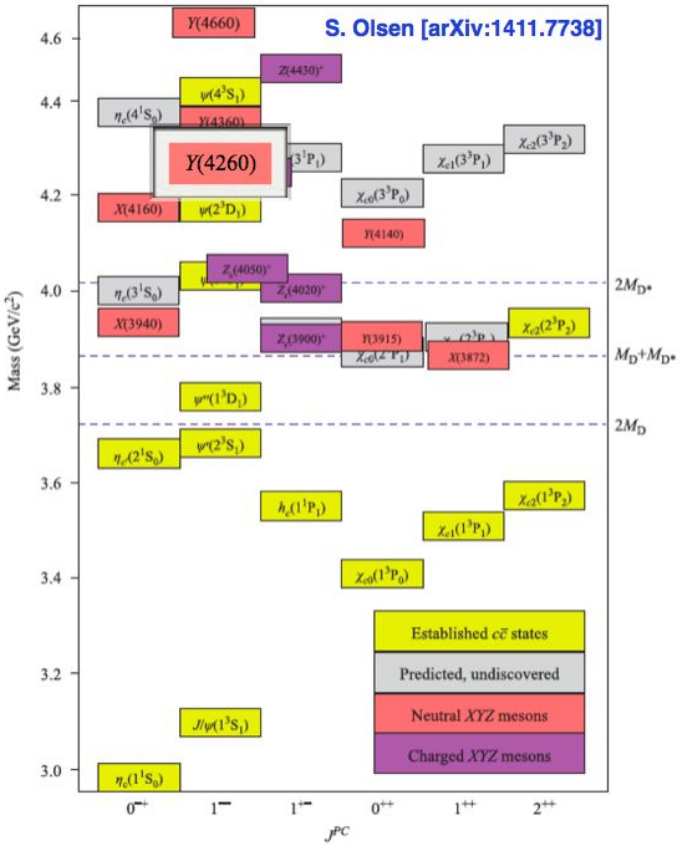
- Electromagnetic form factors of charged pion (F_π) and kaon (F_K) are rich source of insights into the roles played by confinement and Dynamical Chiral Symmetry Breaking in fixing the hadron's size, mass, defining the transition from strong- to perturbative-QCD domains.
- Regina group is responsible for simulations evaluating the feasibility of pion form factor measurements at EIC. Contributing to exclusive and diffractive WG efforts for Yellow Report.
- Plan to extend to feasibility studies of kaon form factor in future.



Projections published in Eur.Phys.J. A **55** (2019) 190.

EIC Spectroscopy

XYZ States



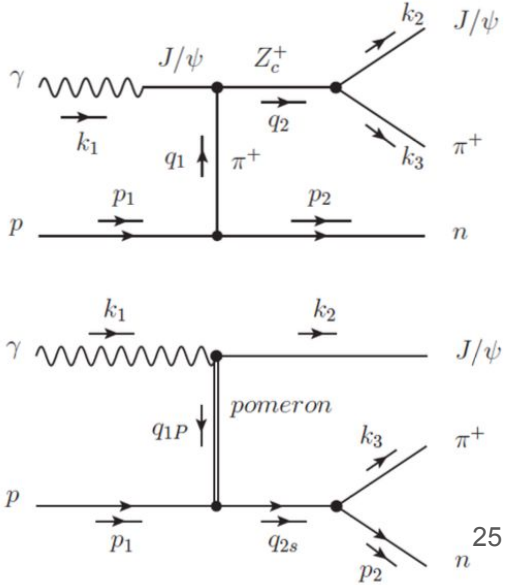
- Many new states observed in the last decade
- Not predicted by standard charmonium models
- Interpretation: resonant states, meson molecules, re-scattering effects, etc.
- Bottomonium exotic sector studies needed
- Electro-/photo-production allows access to different kinematics which can help confirm their resonant nature

Example: $Z_c^+(3900)$

International consortium:

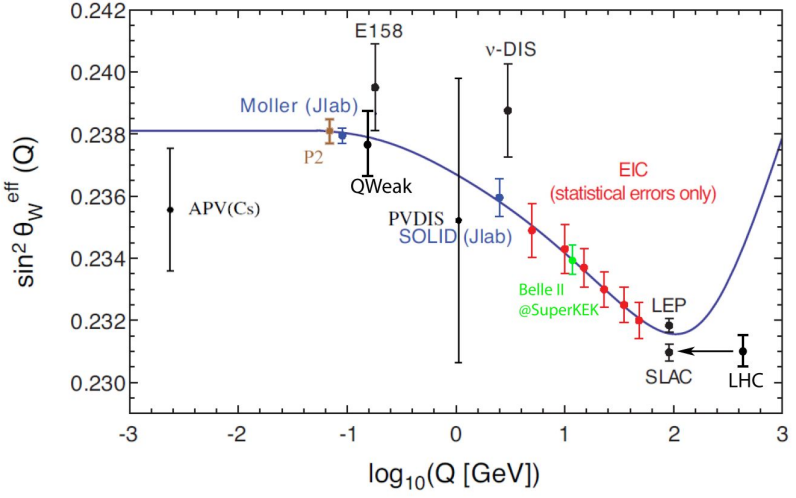
- U. Regina (Canada)
- U. Glasgow (UK)
- INFN (Italy)
- Florida State U.
- Indiana U.
- William & Mary
- Jefferson Lab
- JPAC

Active theoretical model development



Electroweak & Beyond the Standard Model Physics

- Longstanding Canadian involvement in electroweak program
  - Parity-violation: Happex, G0, Qweak, MOLLER
  - Electroweak: Belle II
  - BTSM: ATLAS at LHC and LHC-HL
- CC and NC program of precision $\sin^2\theta_W$ measurements at the EIC span unexplored region between low energy and Z-pole (LHC)
- Co-organizers of 2020 EIC EW/BSM workshop at CFNS (Deconinck, Gericke)



Ref: YX Zhao, Eur.Phys.J.A (2017) 53:55

Scale of Involvement by Canadian PIs

- EIC logically follows extensive physics programs at Jefferson Lab, Brookhaven National Lab, and connects to other existing Canadian programs
- Anticipate major detector construction effort by EIC Canada Collaboration, building on existing areas of expertise (calorimetry, polarimetry)
- EIC Expression of Interest to be submitted in Fall 2020
- NSERC SAP project funding to be submitted in Fall 2020
- Growth phase of the EIC Canada Collaboration:
  - PI FTEs: growth to ~4-5 FTEs by start of operations in 2029
  - HQP (grad students): growth to ~15-20 HQP by start of operations 2029
- Funding resources:
  - CFI: at least CA$1.5M (up to CA$6M) infrastructure on 2025-2028 timescale
  - NSERC: Growth from CA$100k/yr in 2022 to CA$550k/yr by start of operations 2029

Scope of Involvement by Canadian PIs

- **Calorimetry** and other photon sensitive detectors, incl. electronics
  - Expertise at U. Regina (GlueX BCAL), U. Manitoba (Qweak, MOLLER), TRIUMF (electronics)
  - Heavy, bulky, opportunity for land-transport of completed system
  - Component testing possible at lower labour cost in Canada
- **Polarimetry** (electron beam)
  - Expertise at U. Manitoba (JLab Compton)
  - Photon detection channel: synergy with calorimetry
  - Electron detection channel: small, rad-hard strip tracking detectors
- **Software** development

Summary

- Canada has a strong history of involvement in major international endeavors.
- In light of the **SAP Long Range Planning** process, this is an opportune time for the EIC to engage with Canadian agencies at the highest levels.
- Interactions between BNL/JLab and TRIUMF leadership may impact the priorities in the next TRIUMF 5-year plan (2025-2030).
- EIC Canada Collaboration groups have strong involvement in physics programs leading up to the EIC and in the EIC program itself.
- EIC Canada Collaboration believes it realistic that we will reach involvement of **10 faculty members by 2029**, with 20 highly qualified personnel.
- EIC Canada Collaboration projects operational funding of $550k / year by 2029, and contributions to **detector construction at the $1.5M to $6M scale**.