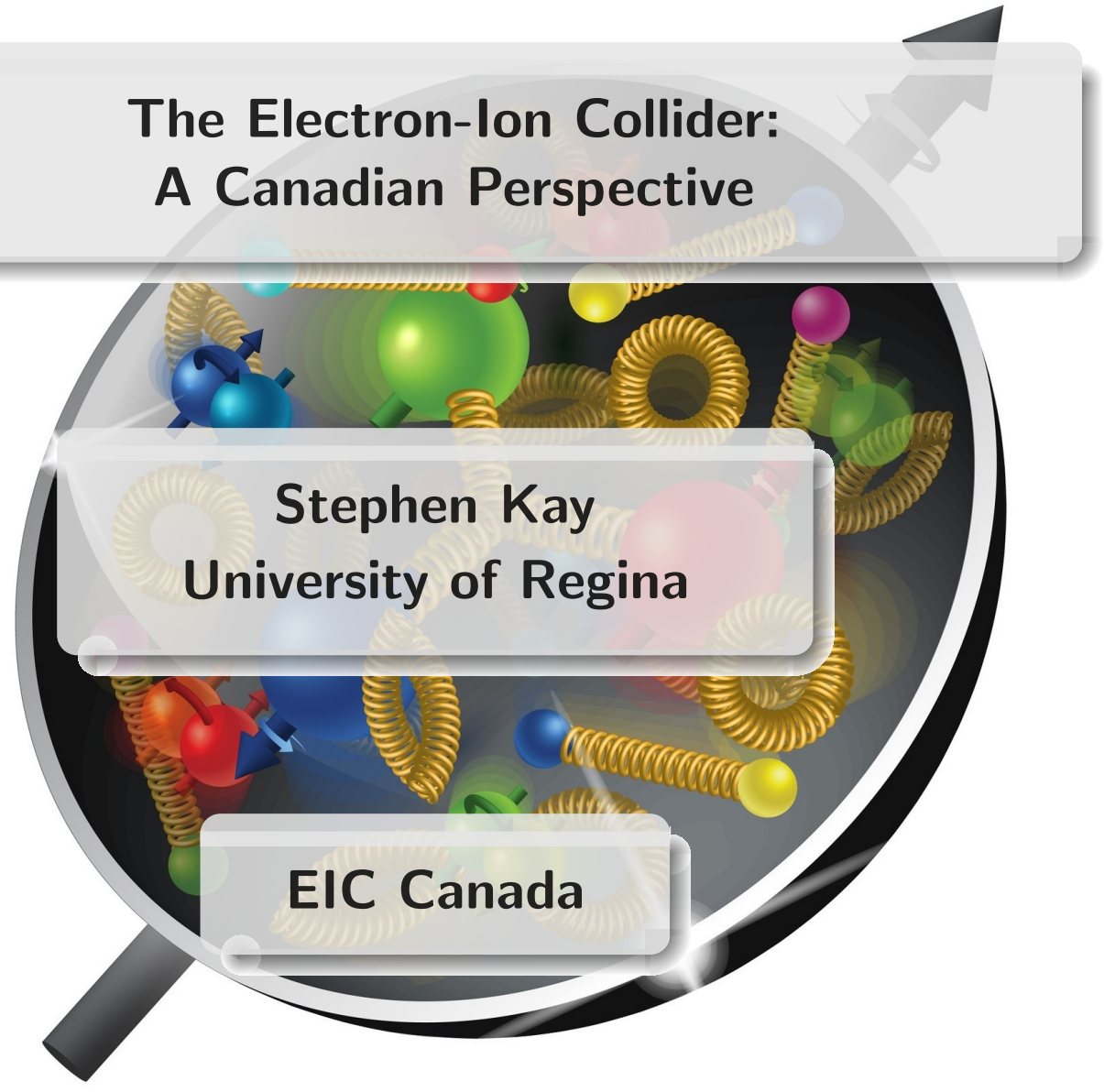
The Electron-Ion Collider: A Canadian Perspective



Stephen Kay
University of Regina

EIC Canada

Outline

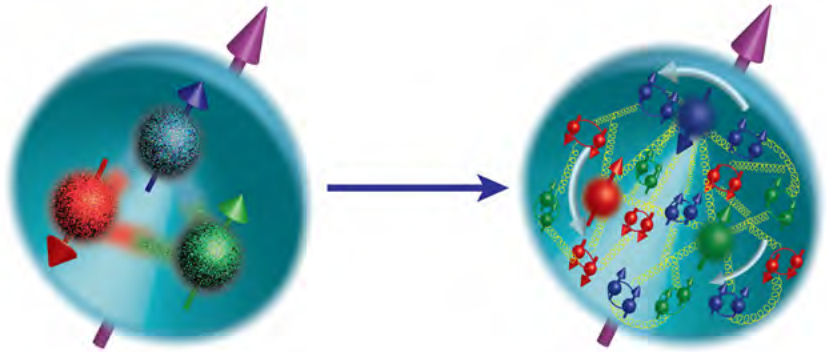
- Why an EIC?
- The EIC - A unique facility
- EIC Users Group
- EIC Canada activities

Cover Image - Brookhaven National Lab, https://www.flickr.com/photos/brookhavenlab/

Emergent Dynamics in QCD

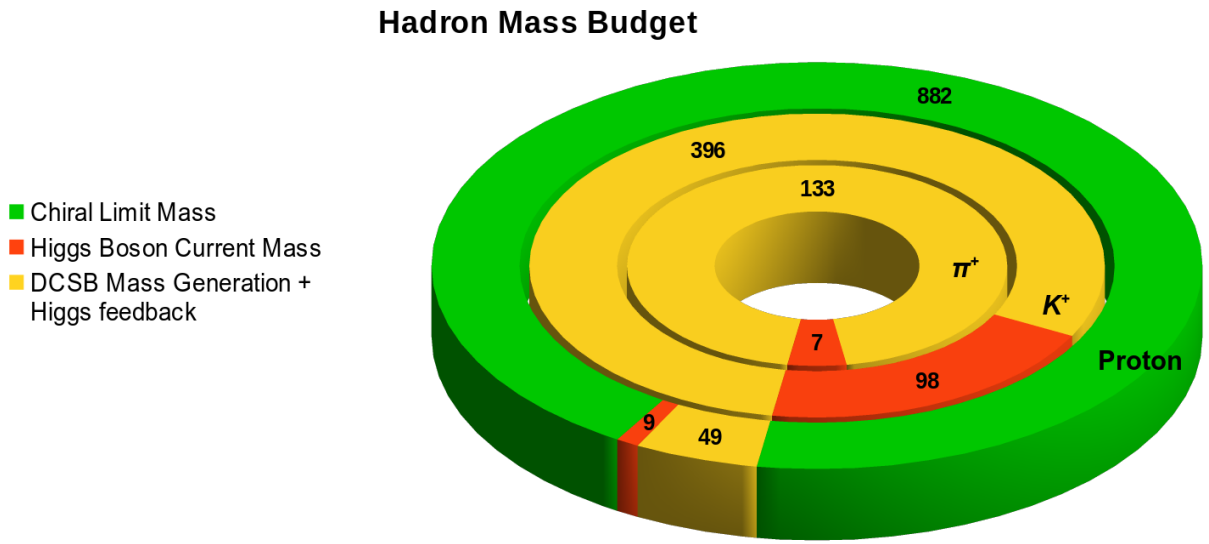
- Consider the proton, a baryon with *uud* valence quarks

$$m_p \approx 938\ MeV/c^2,$$
$$m_u \approx 3\ MeV/c^2, m_d \approx 6\ MeV/c^2,$$
$$(2 \times 3) + 6 = 938?$$



- Where does the mass come from?
- Massless gluons and nearly massless quarks, through their interactions, generate most of the mass
- $\sim 99\%$ of the mass of hadrons $\rightarrow$ most of the visible mass in the universe!

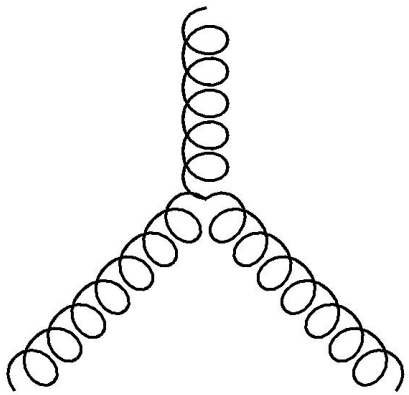
Emergent Dynamics in QCD



- Only the portion in red is from the Higgs current!
- Need to account for more than just protons!
- Properties of hadrons are emergent phenomena
- Experimental insight crucial to complete understanding of how hadrons and nuclei emerge from quarks and gluons

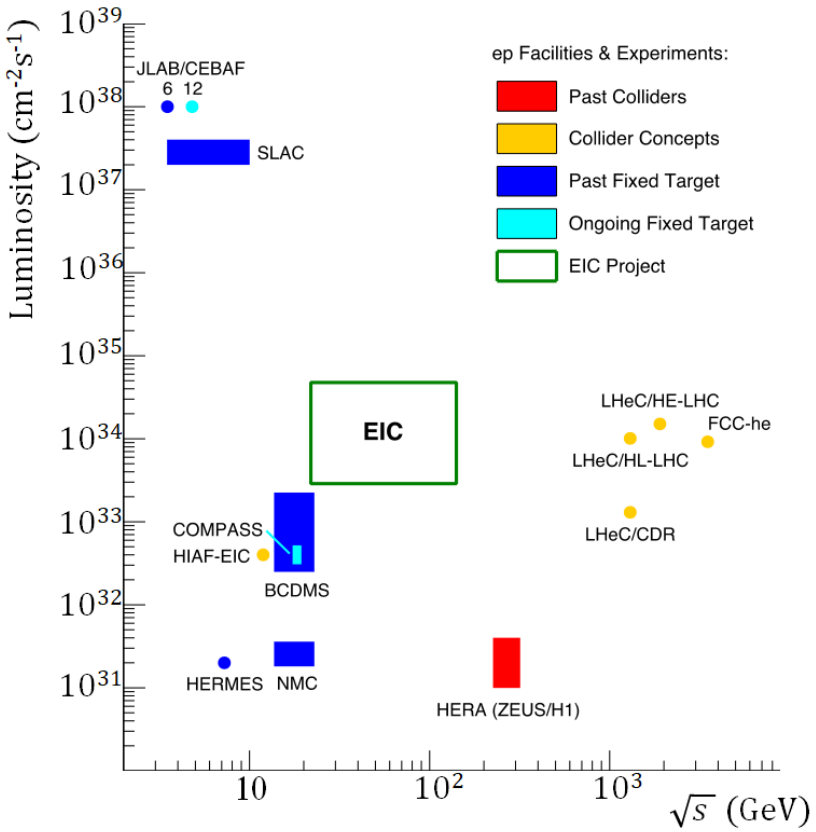
Why an Electron-Ion Collider?

- Interactions and structure are not isolated ideas in nuclear matter
  - Quarks bound by gluons, gluons self interact
  - Observed properties of nucleons and nuclei (mass, spin) emerge from this complex interplay



- Advancing our understanding of this dynamic matter could be transformational
- The Electron-Ion Collider (EIC) is the right tool
  - Answering the open questions requires a versatile machine
  - High Luminosity ($10^{33} - 10^{34}\ cm^{-2}s^{-1}$)
  - Both beams polarised
  - Different species (d, Pb, ^{3}He, Au...)
  - Variable beam energies (e^- $5 - 18\ GeV$, Ion $41 - 275\ GeV$)
  - Need to precisely image quarks, gluons and their interactions

The EIC - A Unique Facility



- A lot of Deep Inelastic Scattering (DIS) facilities in the world
- However, if we need:

Image - A. Desphpande, modified,
`https://sites.nationalacademies.org/cs/groups/bpasite/documents/webpage/bpa_178993.pdf`

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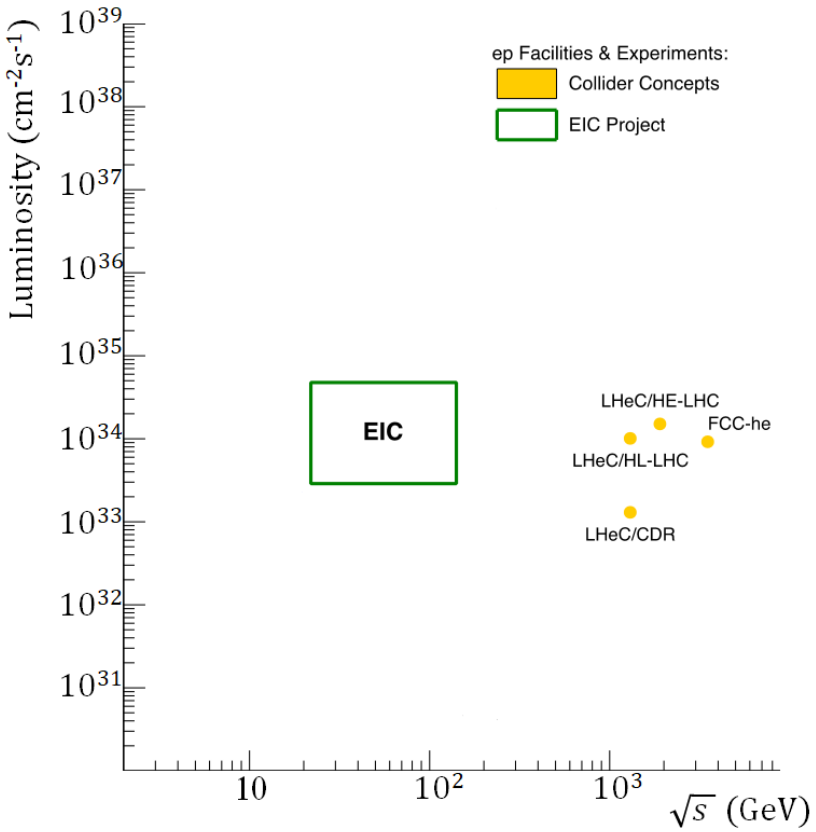

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  - High luminosity
  - Wide range in $\sqrt{s}$

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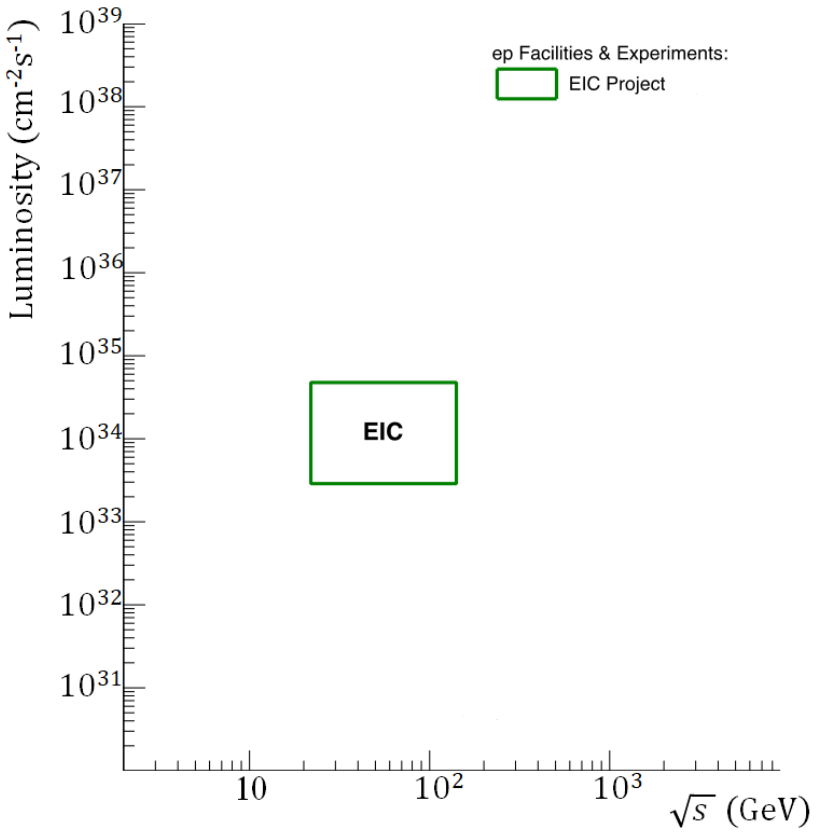

- A lot of Deep Inelastic Scattering (DIS) facilities in the world
- However, if we need:
  - High luminosity
  - Wide range in $\sqrt{s}$
  - Polarised lepton **and** ion beams (p, d, ^{3}He)
  - Nuclear beams
- Only the EIC ticks all of the boxes
- EIC is unique

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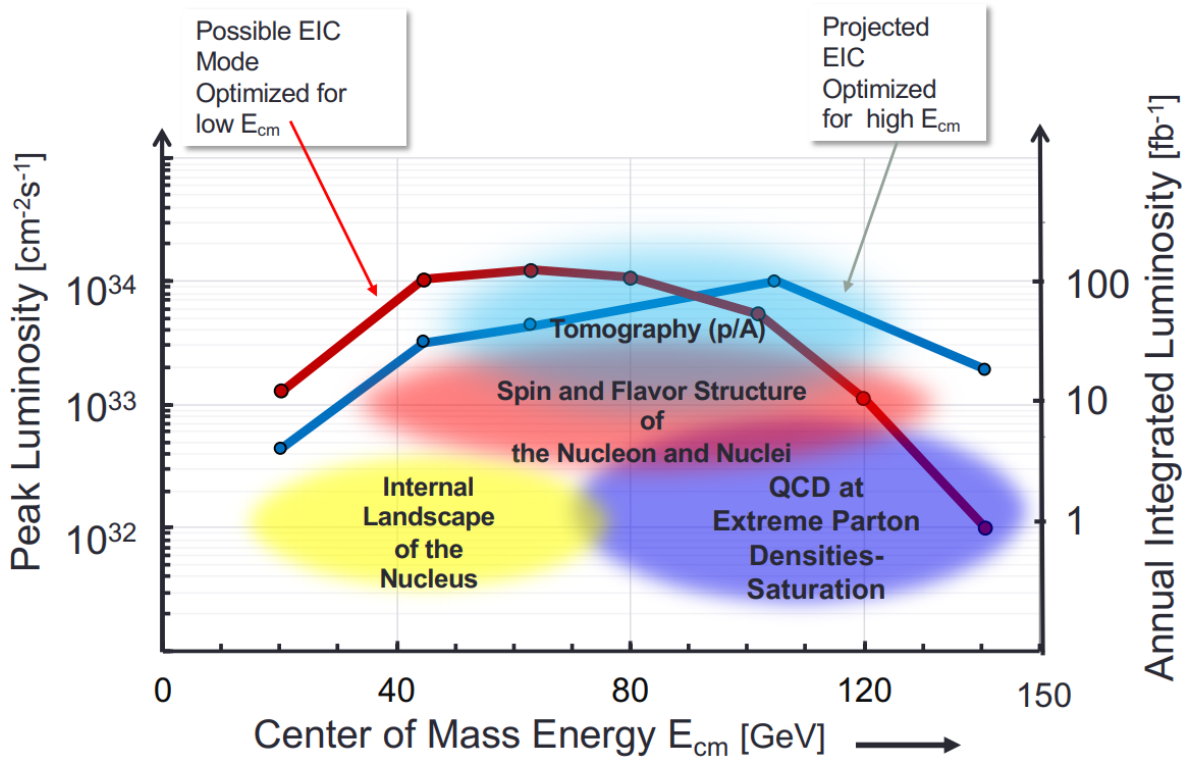
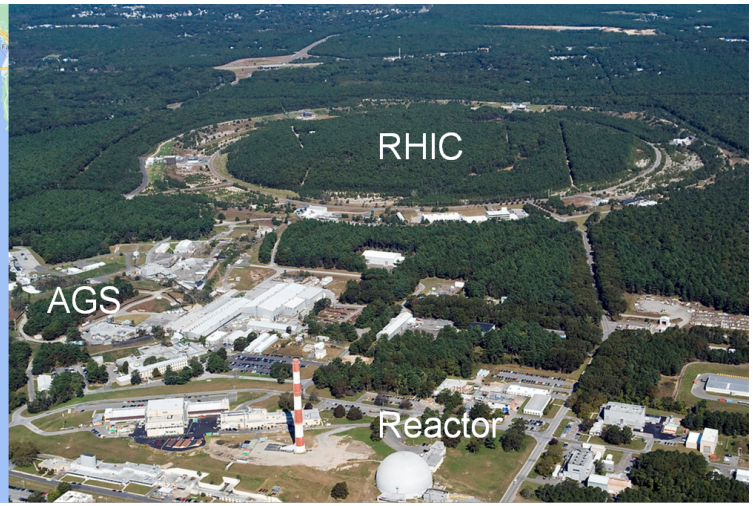
The Benefits of Being Unique

- Broad and unique capabilities, wide range of topics examinable
- Orders of magnitude higher luminosity than previous machines
- This is unexplored terrain
- Capabilities demand frontier ideas and technologies

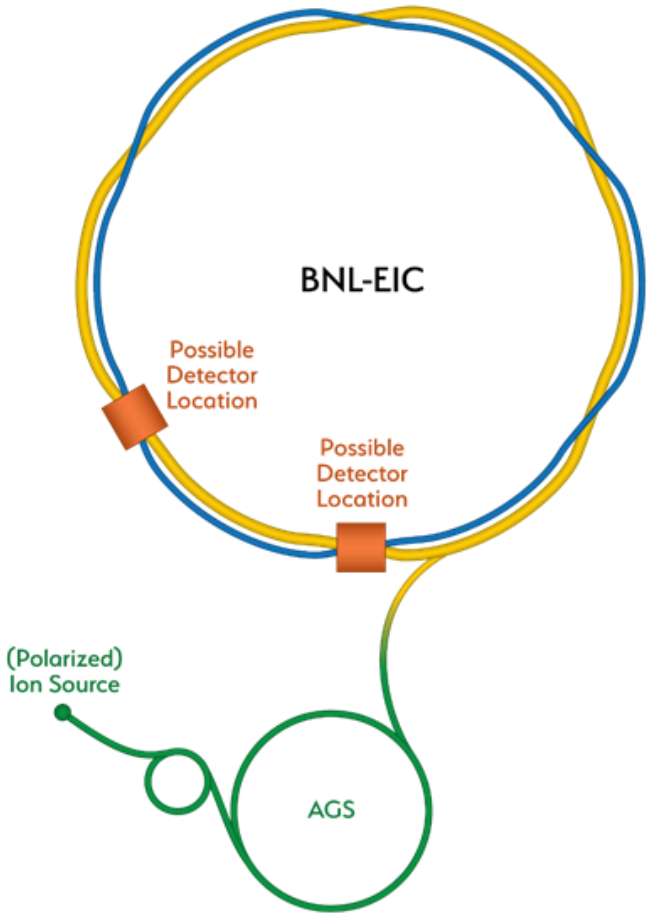


EIC Site Selection

- Major announcement in January 2020
  - Brookhaven National Lab (BNL) was chosen as the site of the future EIC
  - BNL is situated on Long Island, New York
  - Existing site of the Relativistic Heavy Ion Collider (RHIC) and the Alternating Gradient Synchrotron (AGS)

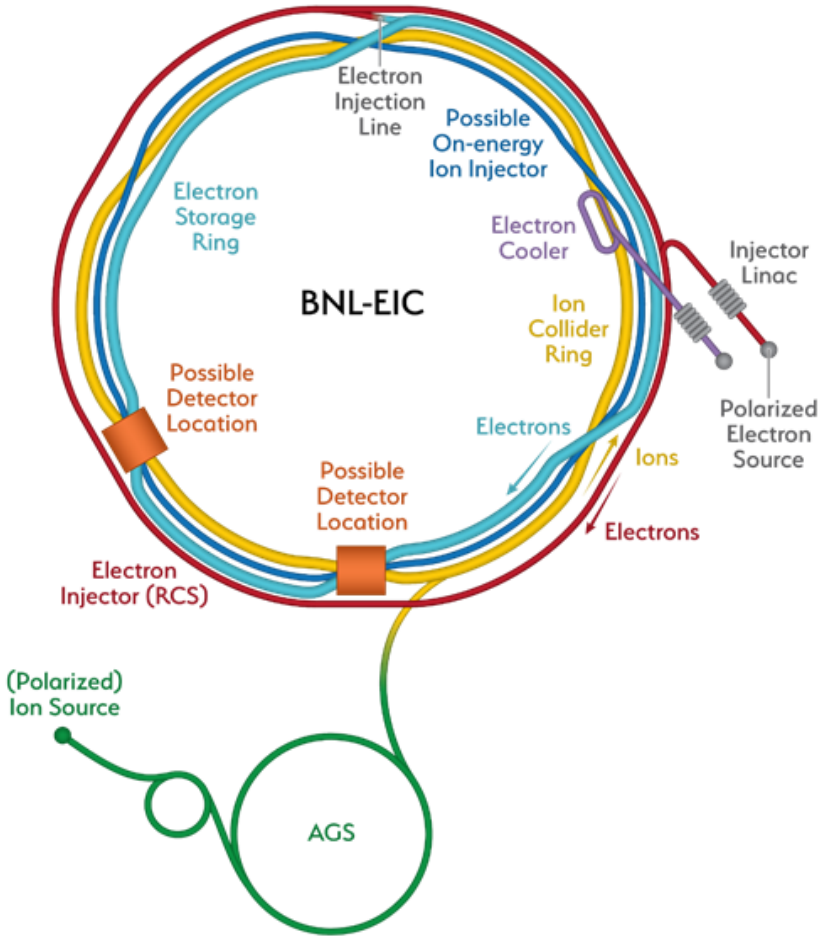


eRHIC



- Use existing RHIC
  - Up to 275 *GeV* polarised proton beams
  - Existing tunnel, detector halls, hadron injector complex (AGS)
- New 18 *GeV* electron linac
  - New high intensity electron storage ring in existing tunnel
- Achieve high $\mathcal{L}$, high E e-p/A collisions with full acceptance detectors
- High $\mathcal{L}$ achieved by state of the art beam cooling techniques

eRHIC



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EIC Users Group

- 1247 members from 250 institutions spread across 34 countries (as of Feb 2021)
- 23 members from 7 Canadian institutions

EIC UG - https://phonebook.sdcc.bnl.gov/eic/client/

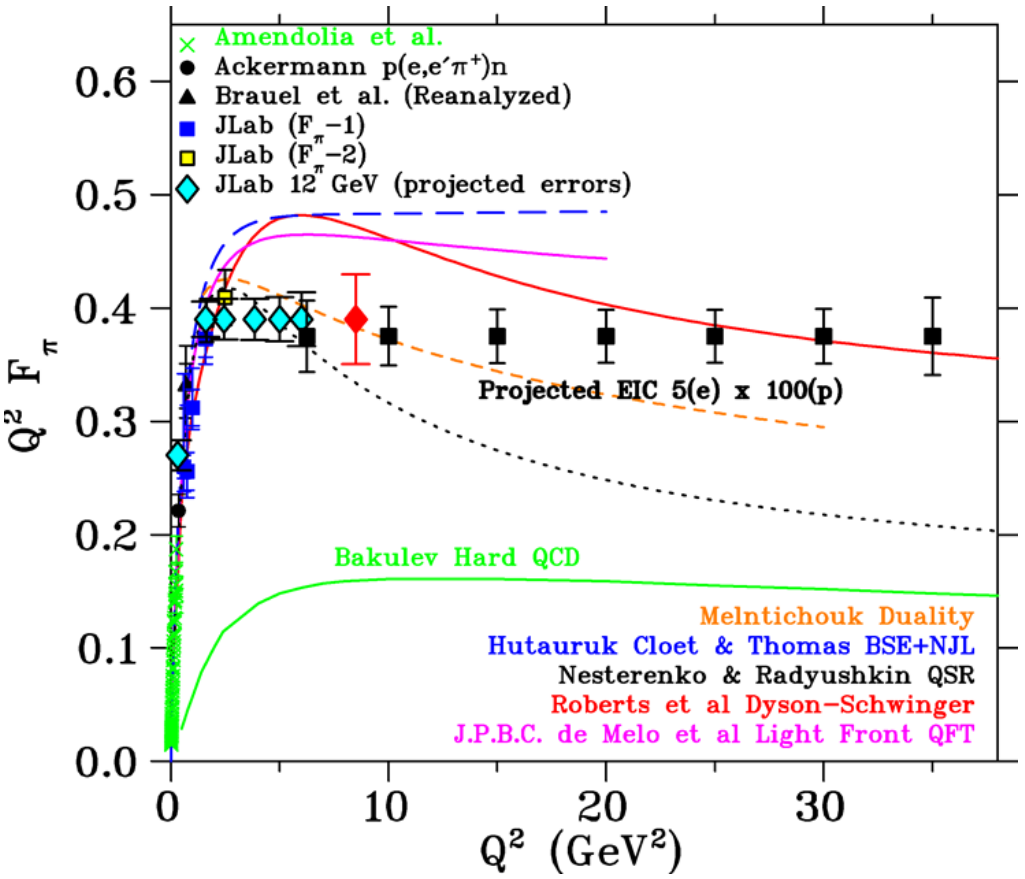
EIC Canada

- Canadian subatomic physicists involved in the planning and development of the EIC for many years
- EIC Canada collaboration formed to co-ordinate participation
- Investigators and researchers from three institutions currently
  - University of Manitoba
  - Mount Allison University
  - University of Regina
- Current opportunities for MSc and undergraduate projects
- More and more opportunities expected as the project develops!
- `https://eic-canada.org/` for more information
- More Canadian members of the user group or the EIC Canada collaboration always welcome!

EIC Canada - Potential Projects

- EIC Canada interested in a range of topics at the EIC
- Various potential projects planned
- University of Manitoba
  - Electroweak mixing angle studies with projected EIC detector performance
  - Lepton polarimetry detector design and development for the EIC
- Mount Allison University
  - Software development for parity violation and electroweak mixing angle studies
- University of Regina
  - Simulations of K^+ form factor (F_K) measurements at the EIC
  - Hadron spectroscopy and calorimetry evaluations
- New ideas and projects are also always welcome!

UoR - Meson Form Factors at the EIC



- Potential to extend measurements of F_π to very high Q^2
- Note - y positioning of points arbitrary
- Higher Q^2 data on F_π vital for our understanding of hadronic physics
- Hoping to extend event generator used to investigate F_K - Potential project!

Summary

- The US National Accademy of Sciences, in their 2018 study, summarise the EIC better than I can!
- *An EIC can uniquely address three profound questions about nucleons 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?*
- *the science it will achieve is unique and world leading*
- The EIC is an exciting opportunity for our generation of physicists - Expected program: 2030-2060
- Canada is well positioned to contribute to this program
- Projects already available, opportunities to contribute only going to grow from here!

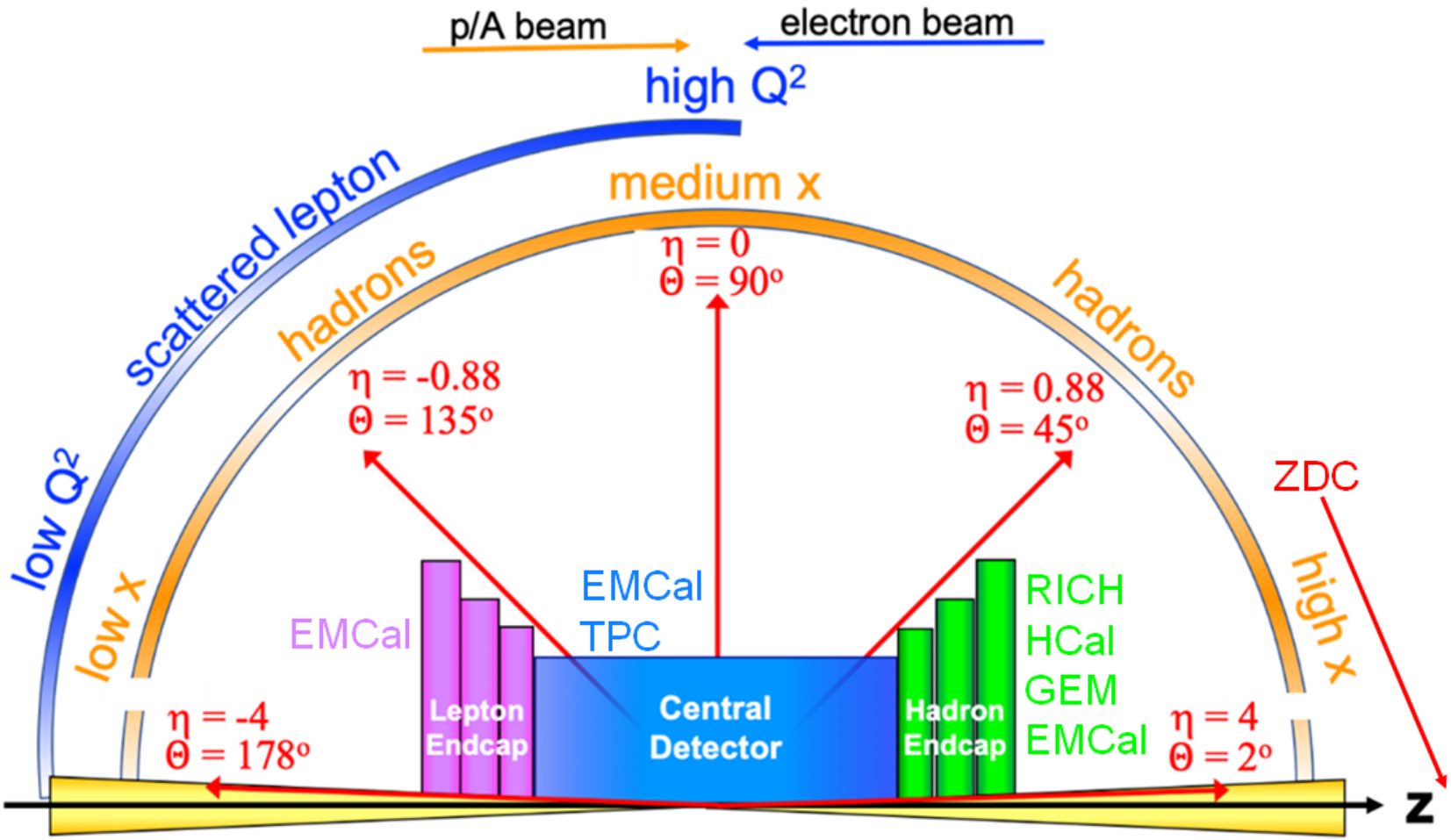
Thanks for listening, any questions?

University of Regina

S.J.D. Kay, G.M. Huber, Z. Ahmed and the EIC Canada collaboration

This research was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC), FRN: SAPIN-2016-00031

General Detector Concept



Context - Recent Activity

- Work so far has been focused on feasibility studies of pion form factor measurements at the EIC
- Utilising pion event generator created by Z. Ahmed
- Work straddles two different working groups
  - Exclusive reactions working group
  - Meson structure working group
- Regular meetings (fortnightly) with the meson structure group
- Progress on pion studies included in the yellow report
- Also presented progress at the CFNS workshop in June 2020
  - https://indico.bnl.gov/event/8315/contributions/37023/attachments/28561/44027/Kay_Stephen_CFNS2020.pdf

Context - Current Activities and Future Direction

- Finalising some improvements to the pion event generator
  - Improvements to efficiency and flexibility
- Aiming to write a paper on the pion generator once improvements have been made
- Also planning to investigate the feasibility of creating a kaon event generator
  - Project for new EIC Canada MSc student at UoR
- If successful, also aim to write a paper on the kaon event generator

Outlook and Future Plans

- Higher Q^2 data on F_π vital for our understanding of hadronic physics
  - Pion properties connected to DCSB
  - F_π is our best hope of observing QCD's transition from confinement-dominated physics to perturbative QCD
- Measurement of F_π at the EIC will be challenging
  - Conventional L-T separation not possible
  - Should be possible to use a model to separate σ_L from the unseparated cross section
  - Can use π^-/π^+ ratio in $e+d$ collisions to validate model
  - Replicate and improve upon previous smearing studies, process files through full geant simulation, process other beam energy combinations
- Building on our current event generator, new MSc student will build a Kaon event generator based on VR model
  - Will attempt to measure F_K in a similar manner
  - Further challenges to address for such a study!