Outline

- Why an EIC?
- The EIC - A unique facility
- EIC Users Group
- EIC Canada activities
Consider the proton, a baryon with $uud$ valence quarks

$$m_p \approx 938 \text{ MeV}/c^2,$$

$$m_u \approx 3 \text{ MeV}/c^2, m_d \approx 6 \text{ MeV}/c^2,$$

$$(2 \times 3) + 6 = 938?$$

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 \((10^{33} - 10^{34} \text{ cm}^{-2}\text{s}^{-1})\)
  - Both beams polarised
  - Different species (d, Pb, \(^3\)He, Au...)
  - Variable beam energies \((e^- 5 - 18 \text{ GeV}, \text{ Ion } 41 - 275 \text{ GeV})\)
  - Need to precisely image quarks, gluons and their interactions
The EIC - A Unique Facility

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- However, if we need:

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  - 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 ($p, d, ^3He$)
- Nuclear beams

Only the EIC ticks all of the boxes

EIC is unique
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

![Graph showing peak luminosity and annual integrated luminosity versus center of mass energy.](image)

Stephen Kay
University of Regina
11/02/2021
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)
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
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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

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!**
Potential to extend measurements of $F_\pi$ to very high $Q^2$

Note - $y$ positioning of points arbitrary

Higher $Q^2$ data on $F_\pi$ vital for our understanding of hadronic physics

Hoping to extend event generator used to investigate $F_K$ - Potential project!
Summary

- The US National Academy 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?

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

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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
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 $F_\pi$ vital for our understanding of hadronic physics
  - Pion properties connected to DCSB
  - $F_\pi$ is our best hope of observing QCD’s transition from confinement-dominated physics to perturbative QCD

- Measurement of $F_\pi$ at the EIC will be challenging
  - Conventional L-T separation not possible
  - Should be possible to use a model to separate $\sigma_L$ from the unseparated cross section
  - Can use $\pi^-/\pi^+$ 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!