Hadronic Physics, Accelerators, and Detectors

Lecture 4: Electron-Ion Collider

Physics Motivation and Project Status

Douglas W. Higinbotham

14 July 2022

Conference Opportunities for Ph.D. students

EIC Early Career Workshop
July 24-25, Stonybrook / Center for Frontier in Nuclear Science, NY
https://indico.jlab.org/event/485/

EICUG 2022 Annual Meeting
July 26–30, Stonybrook, NY
https://indico.bnl.gov/event/15342/overview

Frontiers and Careers Workshop (for students & postdocs)
August 5-6, Meeting at MIT with Boston University housing (intended as a premeeting for Gordon and near the Gordon bus pickup)

Photonuclear Gordon Research Conference
August 7–12, Holderness School, NH.
https://www.grc.org/photonuclear-reactions-conference/2022/

Fixed Target and Collider Beam Electron Scattering Facilities

- CEBAF at Jefferson Lab
  - Decade long physics program with 12GeV beams
    - Lots of exciting new results and fantastic new experiments
    - Outstanding new ideas still being developed!
    - PAC50 was held this week (results today 14 July 2022)
  - Positron Experiments for 12GeV Being Developed
    - Topical Collection of Papers: https://link.springer.com/journal/10050/topicalCollection/AC_e1e21fcfbc06a710672e7faf53314693
    - First positron experiments conditionally approved at PAC48
  - Very exciting ideas for increasing Jefferson Lab's energy https://indico.jlab.org/event/503/contributions/9273/attachments/7474/10393/FFA_Hall_A_mtg_11Feb_rev2.pdf
- Focus of this lecture will be on what science the EIC can do and what questions will it address.

HERA

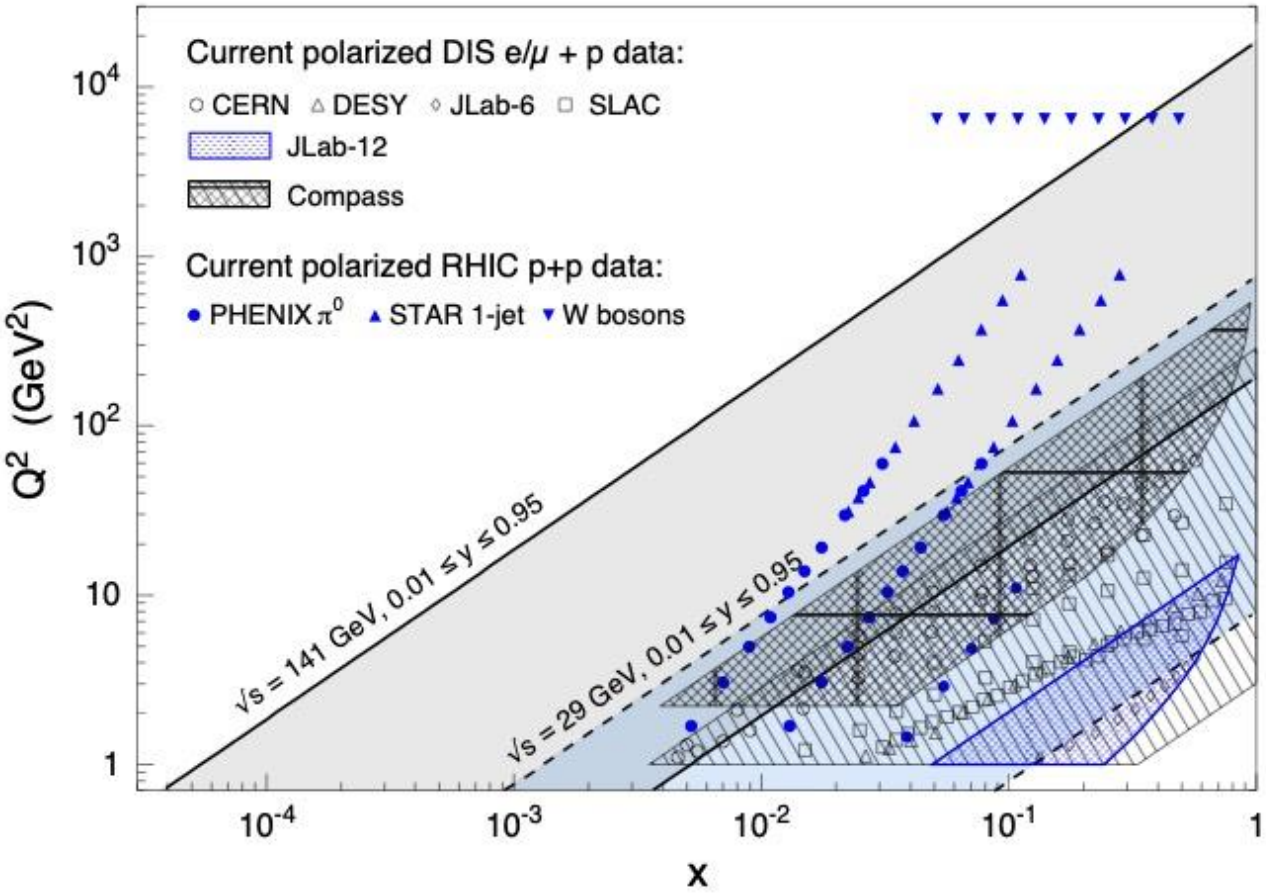
- HERA (German: Hadron-Elektron-Ringanlage, English: Hadron-Electron Ring Accelerator) was a particle accelerator at DESY in Hamburg.
- 318 GeV center of mass energies: 27.5 GeV e, 920 GeV p
- Electron-proton collider ran from 1992 – 2007
- Electron polarization by Sokolov – Ternov effect.
- Amazing machine and publications are still coming out from the data.
- Luminosity and some design choices limited the physics reach which now naturally lead to next generation machine: the EIC.

Key Science Questions For The EIC To Answer

- How do the nucleonic properties such as mass and spin emerge from partons and their underlying interactions?
- How are partons inside the nucleon distributed in both momentum and position space?
- How do color-charged quarks and gluons, and jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?
- How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei and even nucleons?

- https://www.nap.edu/login.php?record_id=25171&page=https%3A%2F%2Fwww.nap.edu%2Fdownload%2F25171 and download as guest for a free copy of the National Academy of Science pdf

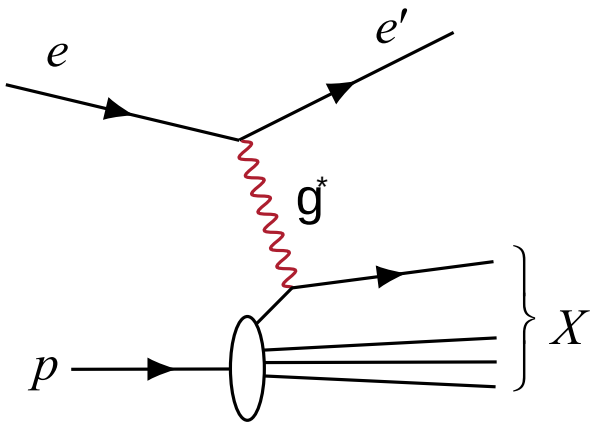
Kinematic Coverage Of The Electron Ion Collider



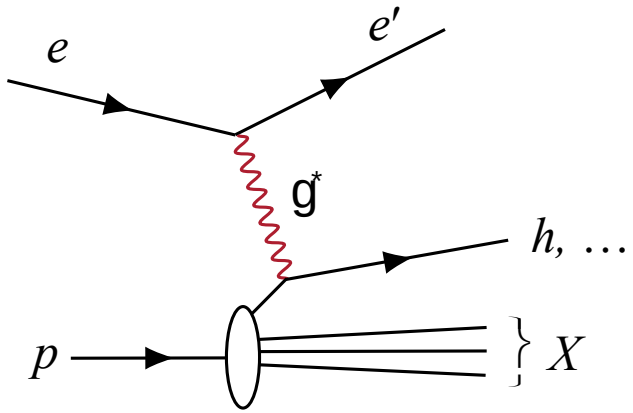
Q^2 is the Lorentz invariant four-momentum transfer and $x = Q^2/(2m(E-E'))$

NOTE: Jefferson Lab is also very high luminosity $>10^{38}$ $cm^{-2}s^{-1}$ while the proposed EIC would be ~10^{33} to 10^{34} $cm^{-2}s^{-1}$ so kinematic coverage alone isn't the whole story!

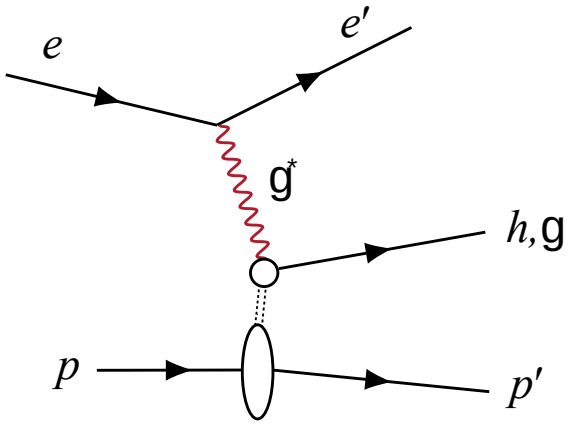
Deep Inelastic Electron Scattering



Inclusive DIS

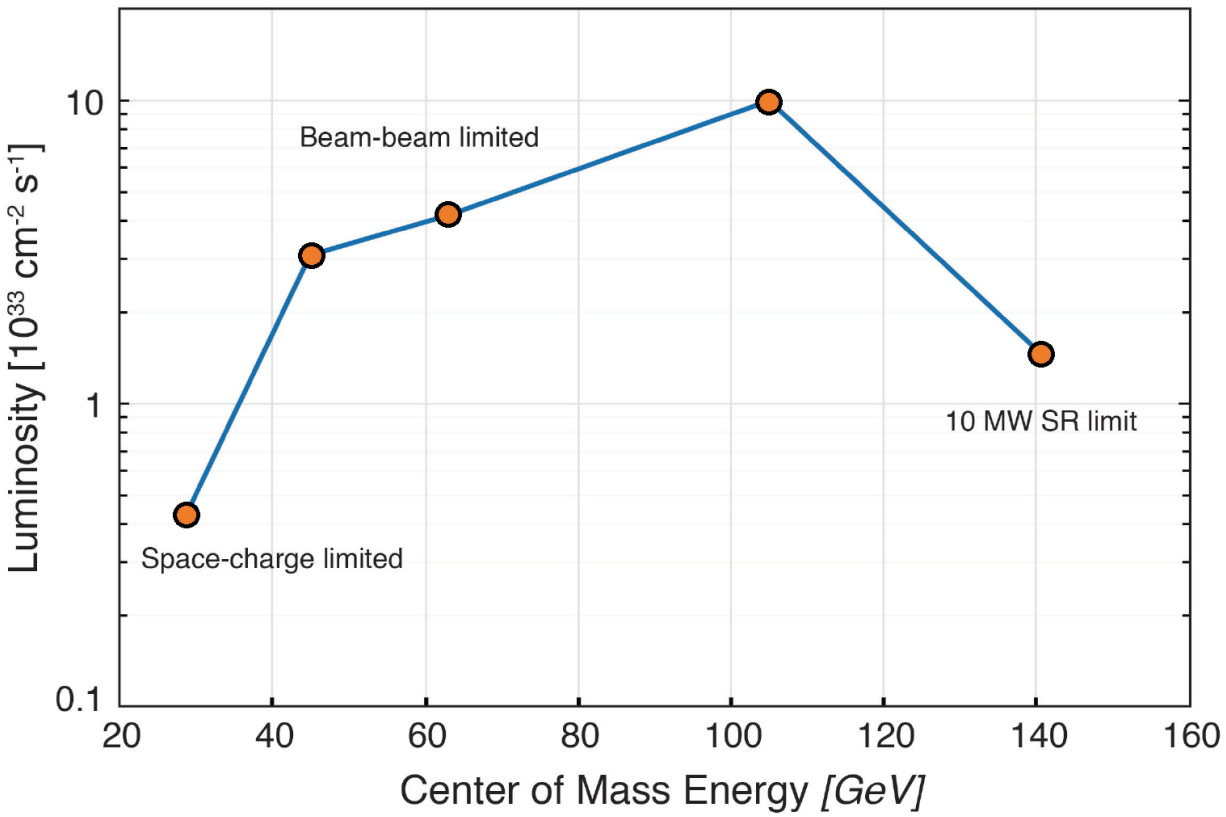


Semi-Inclusive DIS



Exclusive DIS

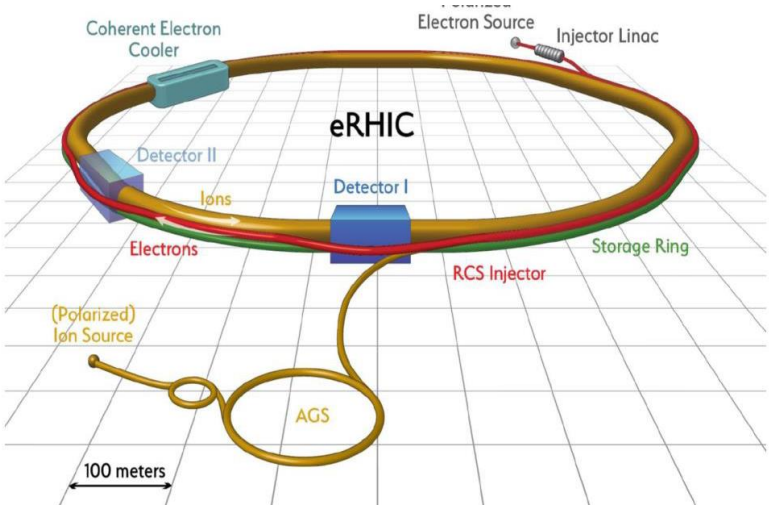
Luminosity vs Center of Mass Energy at the EIC

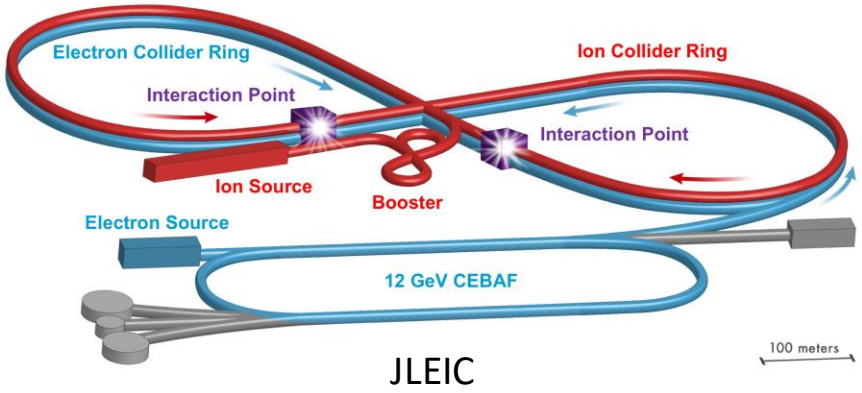


- Parameter and IR optimization at 105 GeV center-of-mass energy
- Optimization yields $10^{34} cm^{-2} sec^{-1}$ luminosity at 105 GeV
- NOTE: At a collider, it nominally takes years to reach the maximum luminosity with rapid luminosity improvements at first and then a long slow multi-year rise to

October 2019 Review of Two Competing EIC Designs

- For e-N collisions:
  - Polarized beams: e, p, d/^{3}He (effective neutron)
  - e beam 5-10(20) GeV
  - Luminosity ~ $10^{33\text{-}34}$ cm^{-2}sec^{-1}
  - 100-1000 times HERA
  - 20-100 (140) GeV variable center of mass energy
- For e-A collisions:
  - Wide range in nuclei
  - Luminosity per nucleon same as e-p
  - Variable center of mass energy
- Key Supporting Documents
  - EIC White Paper
  - National Academy of Science Report





JLEIC

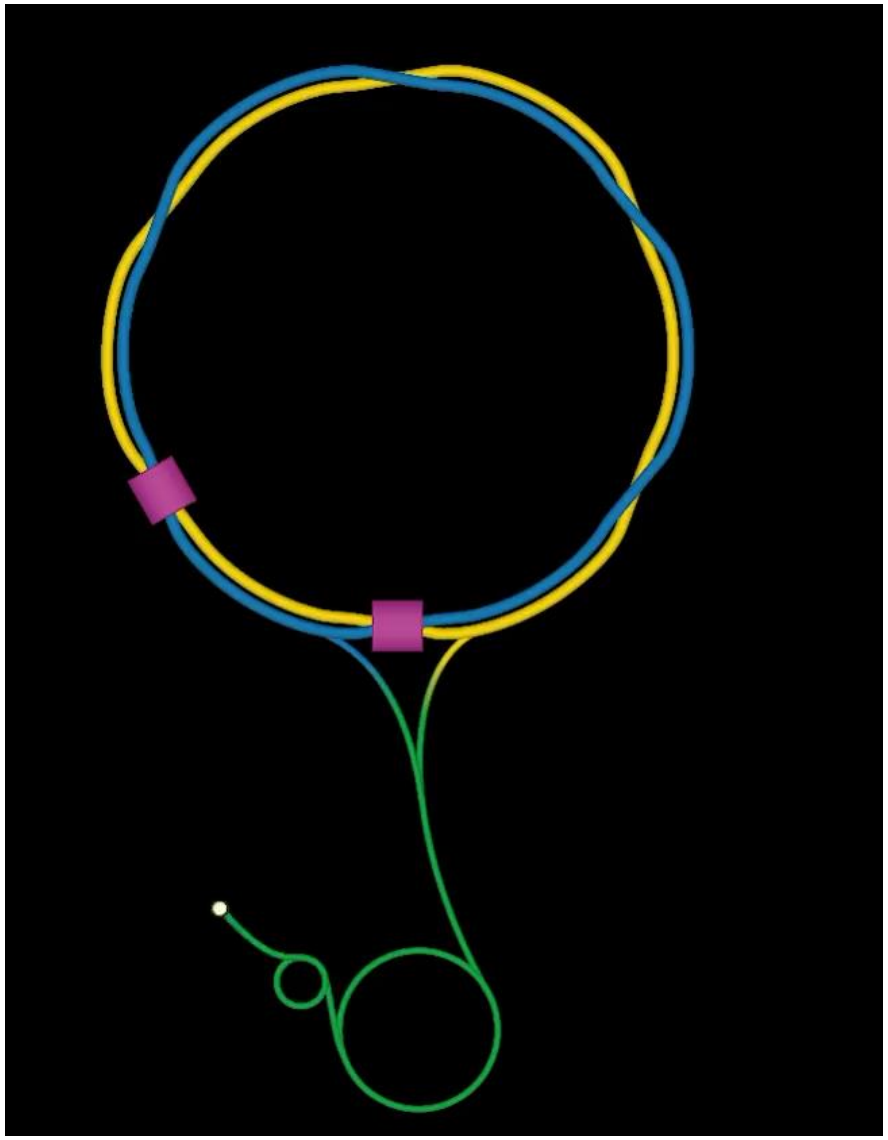
Site Selection & Intellectual Ownership of the Physics

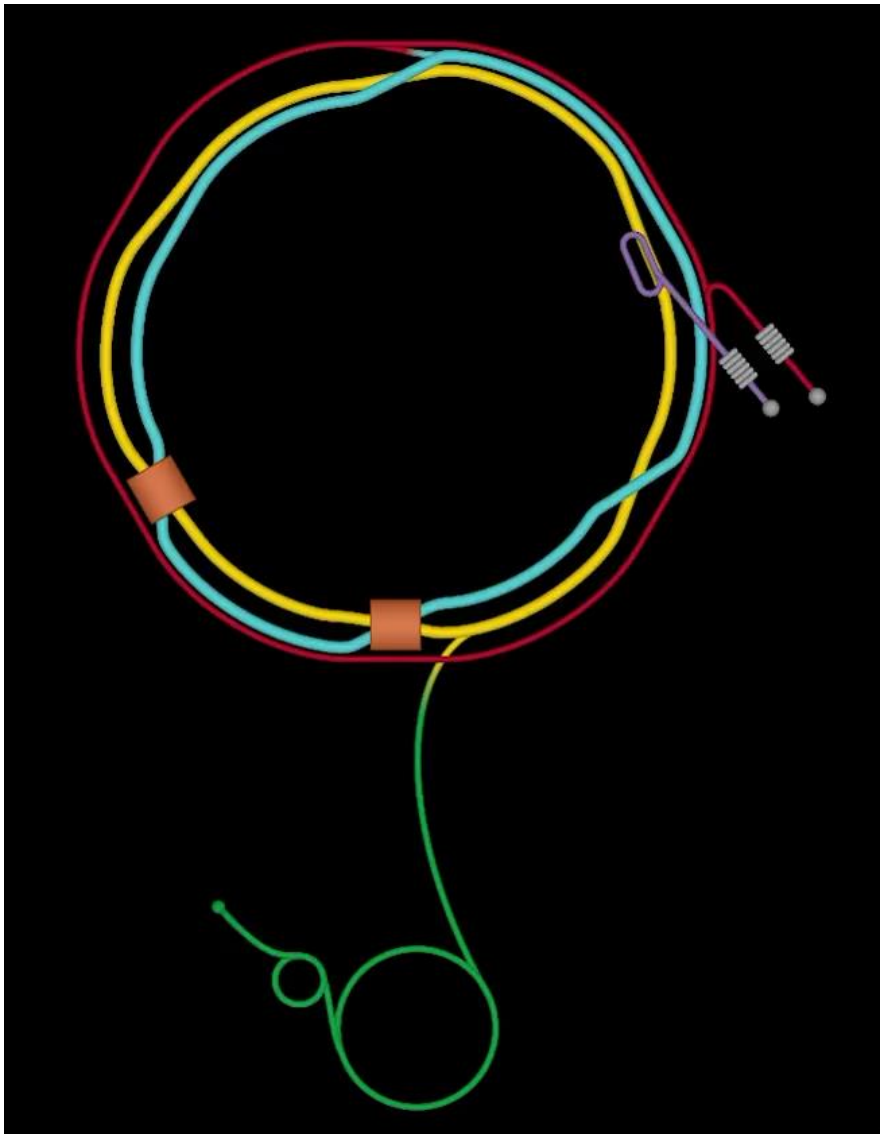
- CD0 was approved 19 Dec. 2019 with an announcement from the DOE department of energy on 9 Jan. 2020 https://www.energy.gov/articles/us-department-energy-selects-brookhaven-national-laboratory-host-major-new-nuclear-physics
- While JLab scientists were understandably disappointed, Tim Hallman came here after site selection and encouraged us to continue to develop our intellectual ownership of the physics.
- This idea really resonated with many of us and a very positive partnership and commitment to the EIC has taken root.
- This commitment to the EIC was formalized with the BNL-JLAB Partnering Agreement, signed May 7, 2020.
- Informally, this flourishing partnership can be seen online almost day of the week at the numerous EIC meetings, workshops, and discussions.

EIC Detector Project – joint JLab and BNL responsibility

- Co-associate directors for Experimental Program:
  Rolf Ent (JLab) and Elke Aschenauer (BNL)
  - 6.10 Detectors
  - 6.10.01 Detector Management
  - 6.10.13 Detector #2 Development
- We also heavily utilize Walt Akers (Jlab) who is a Systems Engineer
- R&D scope has both a BNL and JLab person
  - 6.10.02 Detector R&D — Thomas Ullrich (BNL), Patrizia Rossi (JLab)
- Some scope has a BNL person
  - 6.10.05 EM Calorimetry — Alexander Bazilevsky (BNL)
  - 6.10.06 Hadronic Calorimetry — Alexander Kiselev (BNL)
  - 6.10.10 Detector Infrastructure — Rahul Sharma (BNL)
  - 6.10.12 Detector Pre-Ops — Elke Aschenauer – acting (BNL)
  - 6.10.14 Polarimetry & Luminosity — Oleg Eyser (BNL)
    (L4 electron polarimetry is David Gaskell (JLab))
- Some scope has a JLab person
  - 6.10.03 Tracking — Brian Eng (JLab)
  - 6.10.04 Particle Identification — Beni Zihlmann (JLab)
  - 6.10.07 Magnets — Renuka Rajput-Ghoshal (JLab)
  - 6.10.08 Electronics — Fernando Barbosa (JLab)
  - 6.10.09 DAQ/Computing — David Abbott (JLab)
  - 6.10.11 IR Integration, Aux. Detectors — Yulia Furletova (JLab)

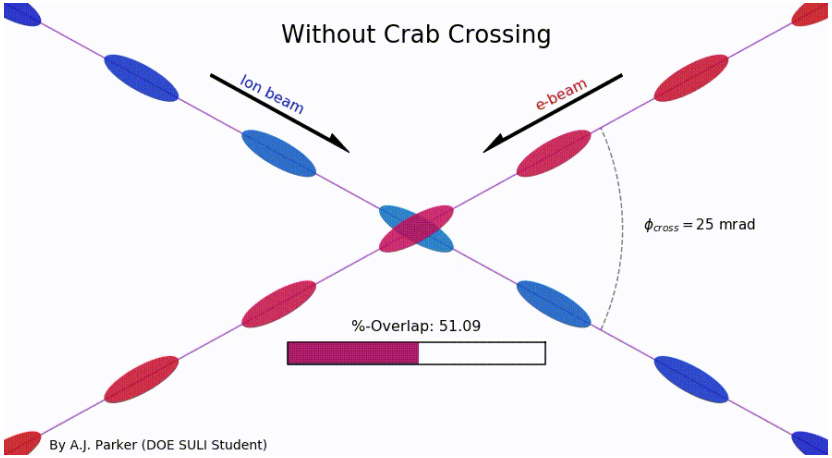
From RHIC to Electron Ion Collider @ BNL

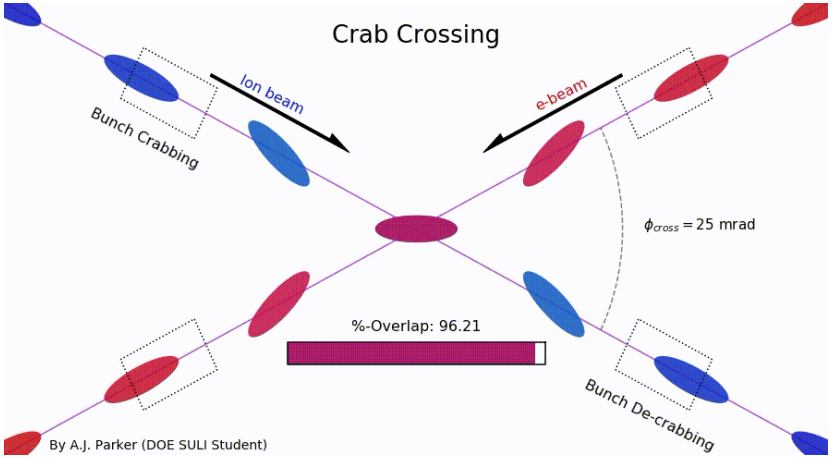




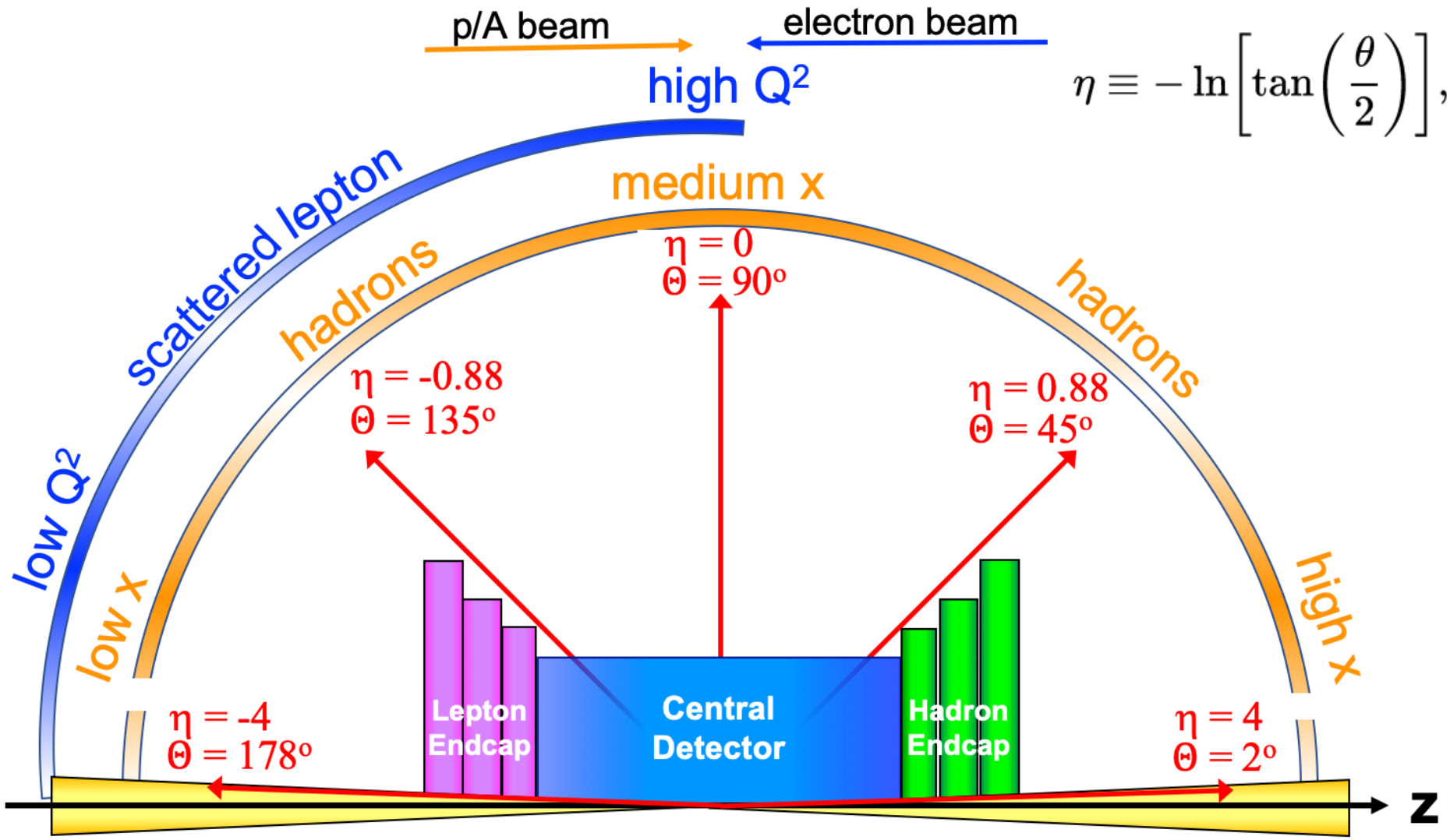
SULI Student Project To Visualize The Colliding Beams

- As an exercise to learn Python, SULI summer student Asia Parker (Duquesne University) took a static image of the EIC's crab crossing and made an animation.
- https://github.com/sherwberry/SULI2020_CrabCrossingAnimation



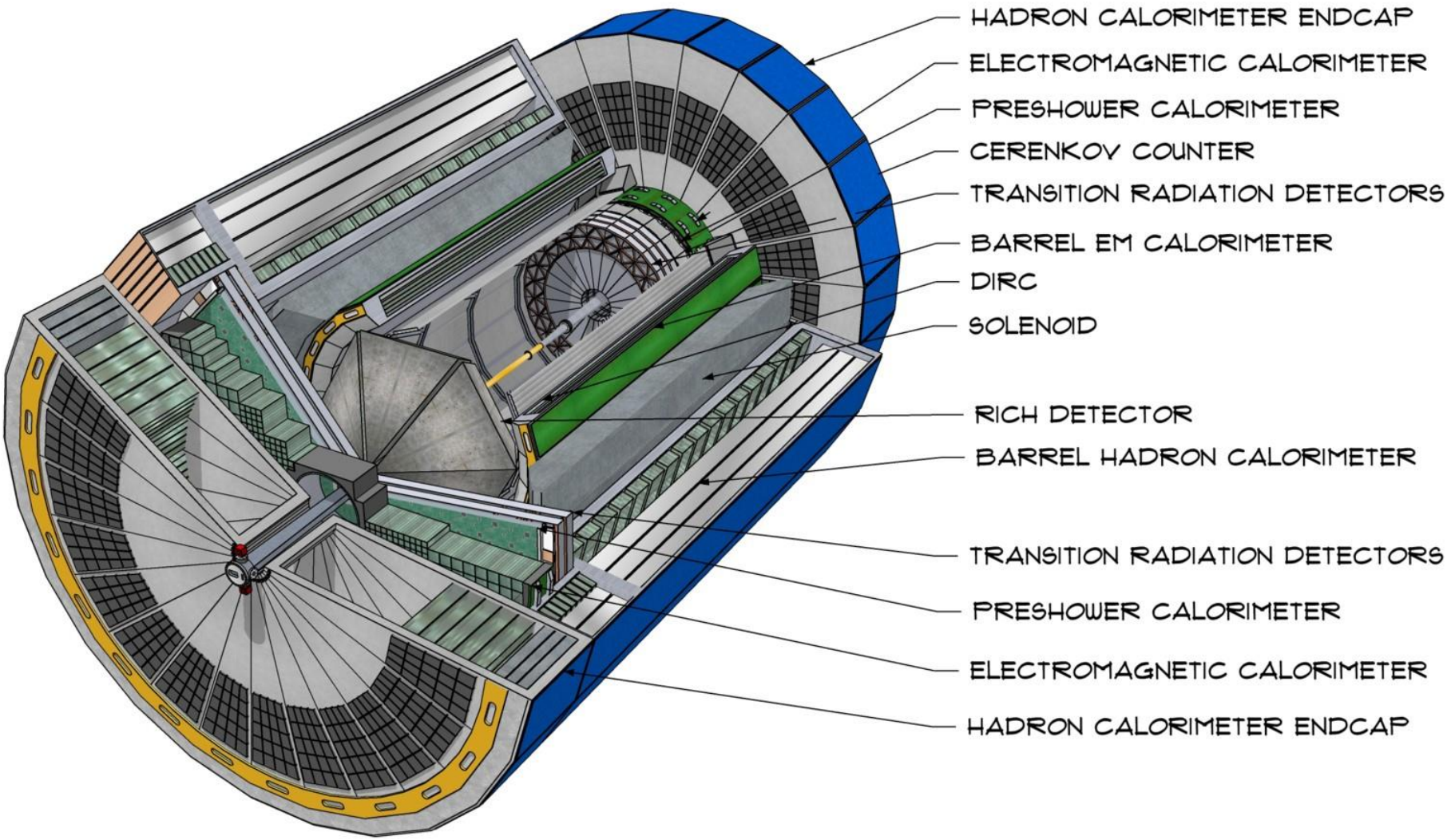


Detector polar angle / pseudo-rapidity coverage



$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$

CAD Model of Generic EIC Detector



Size and Planned Location of the First EIC Detector

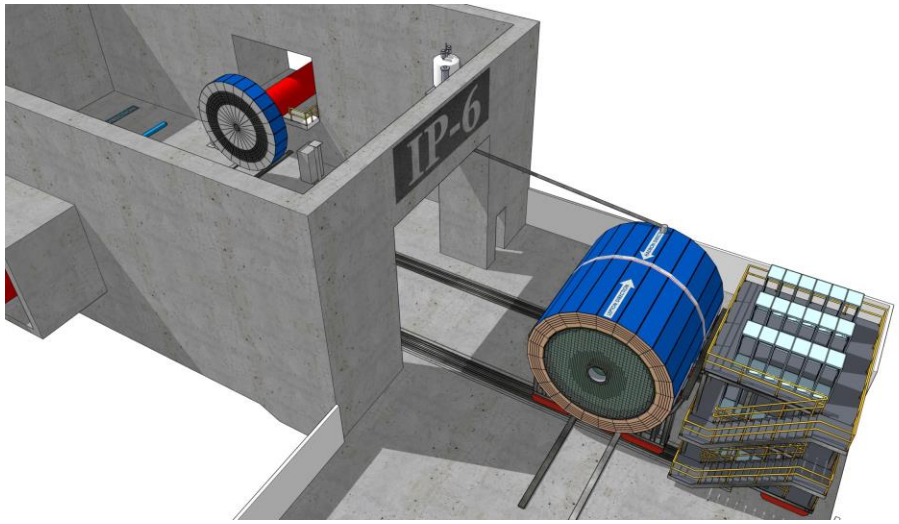
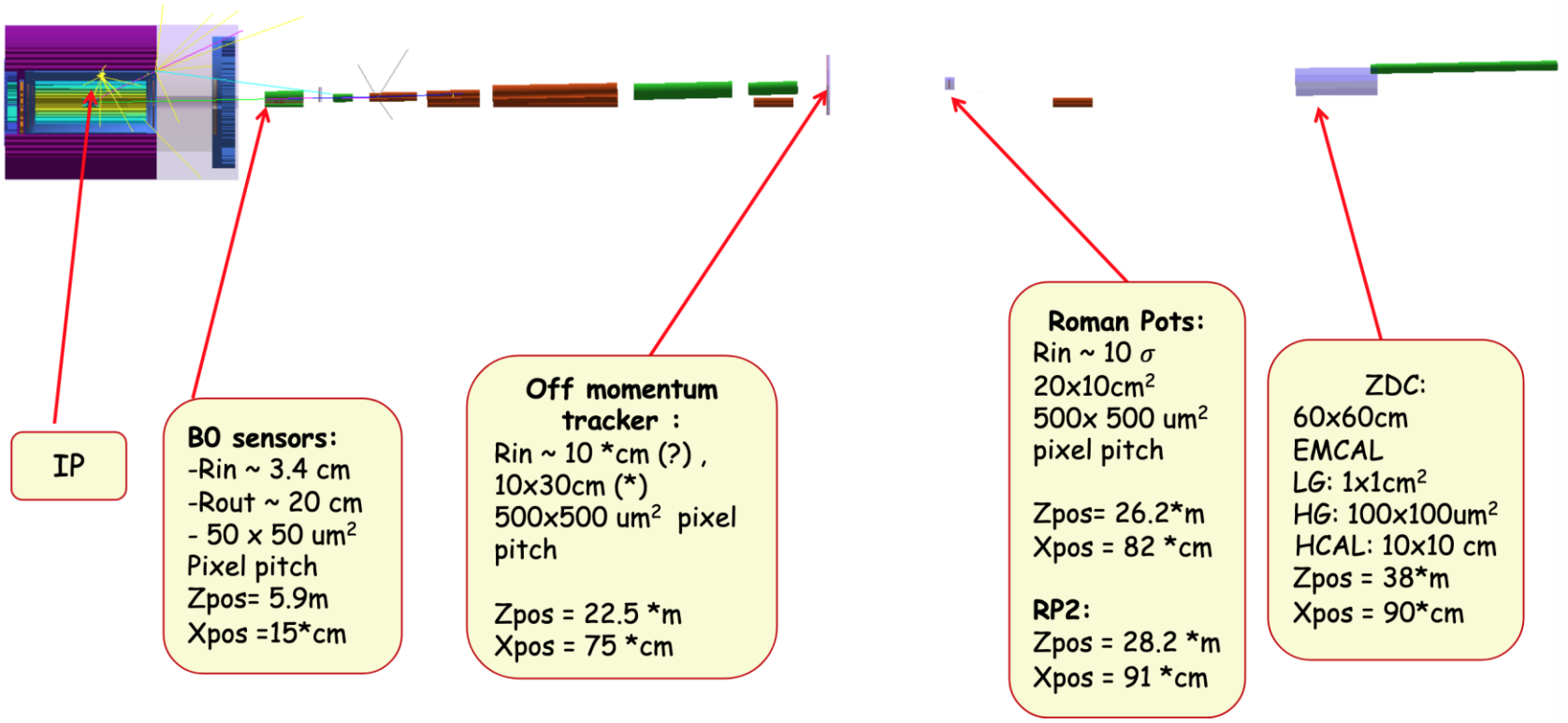


Image show how such a detector could be moved out of IP-6 at the EIC.

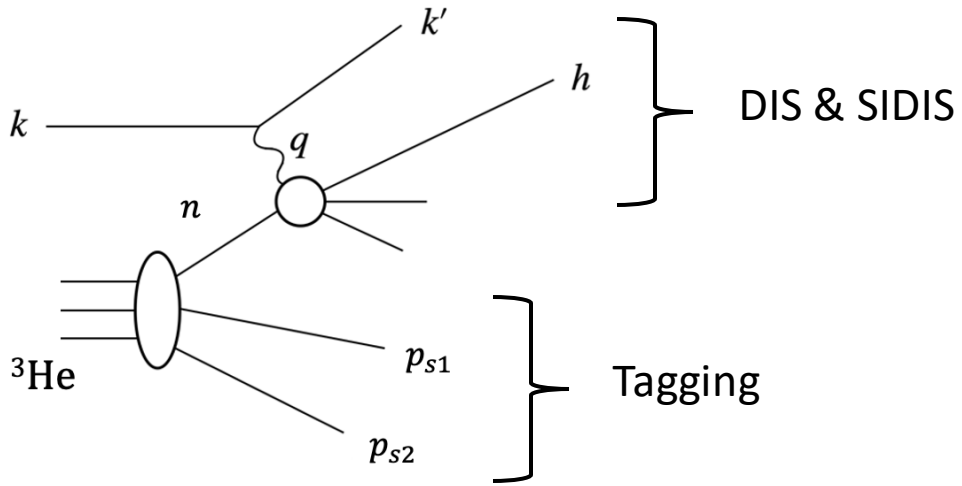
Far Forward Detection Systems (my favorite part of the EIC)

Detectors located tens of meters from the main EIC detector and are small in size.



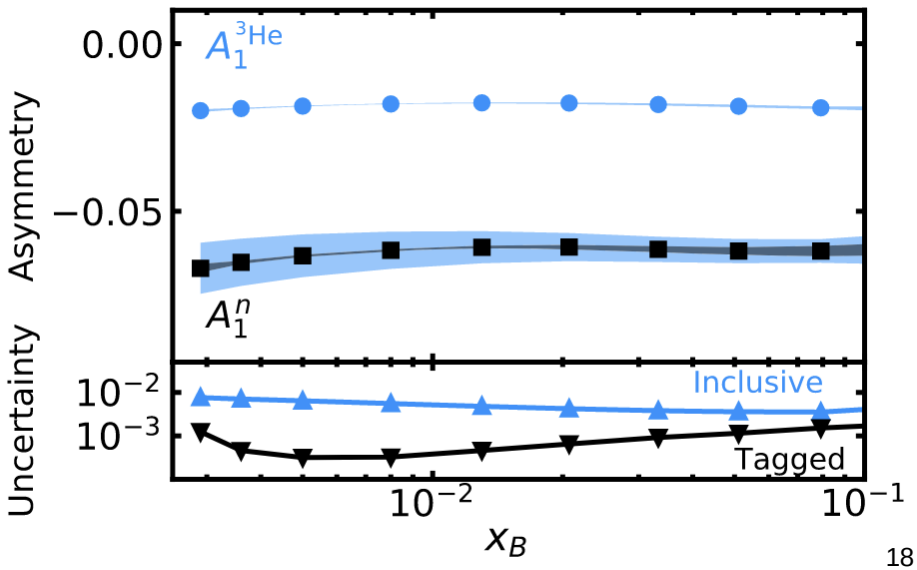
EIC ^{3}He Physics with Tagging

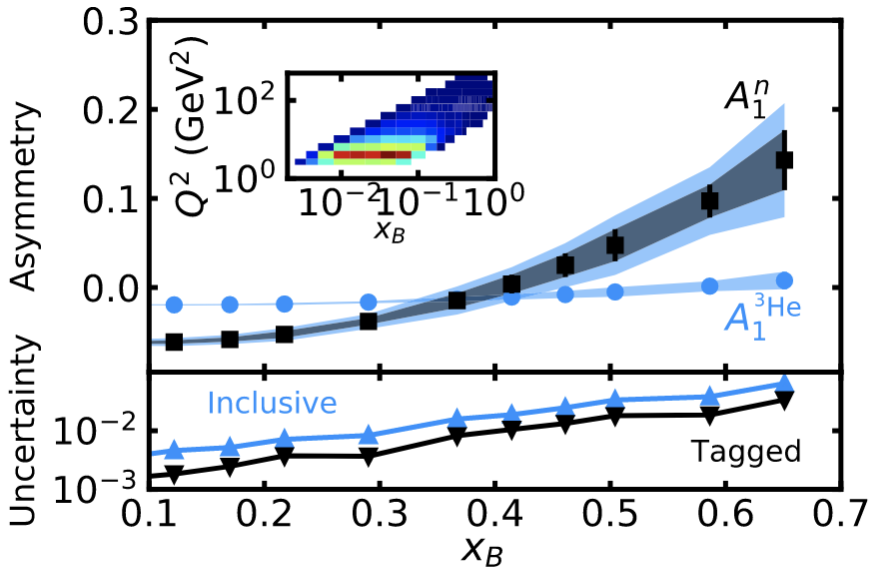
Frišcic, D. Nguyen, J.R. Pybus, A. Jentsch, E.P. Segarra, M.D. Baker, O. Hen, D.W.H., R. Milner, **A.S. Tadepalli, Z. Tu, J. Rittenhouse West,** Phys. Lett. B (2021) 136726 https://doi.org/10.1016/j.physletb.2021.136726



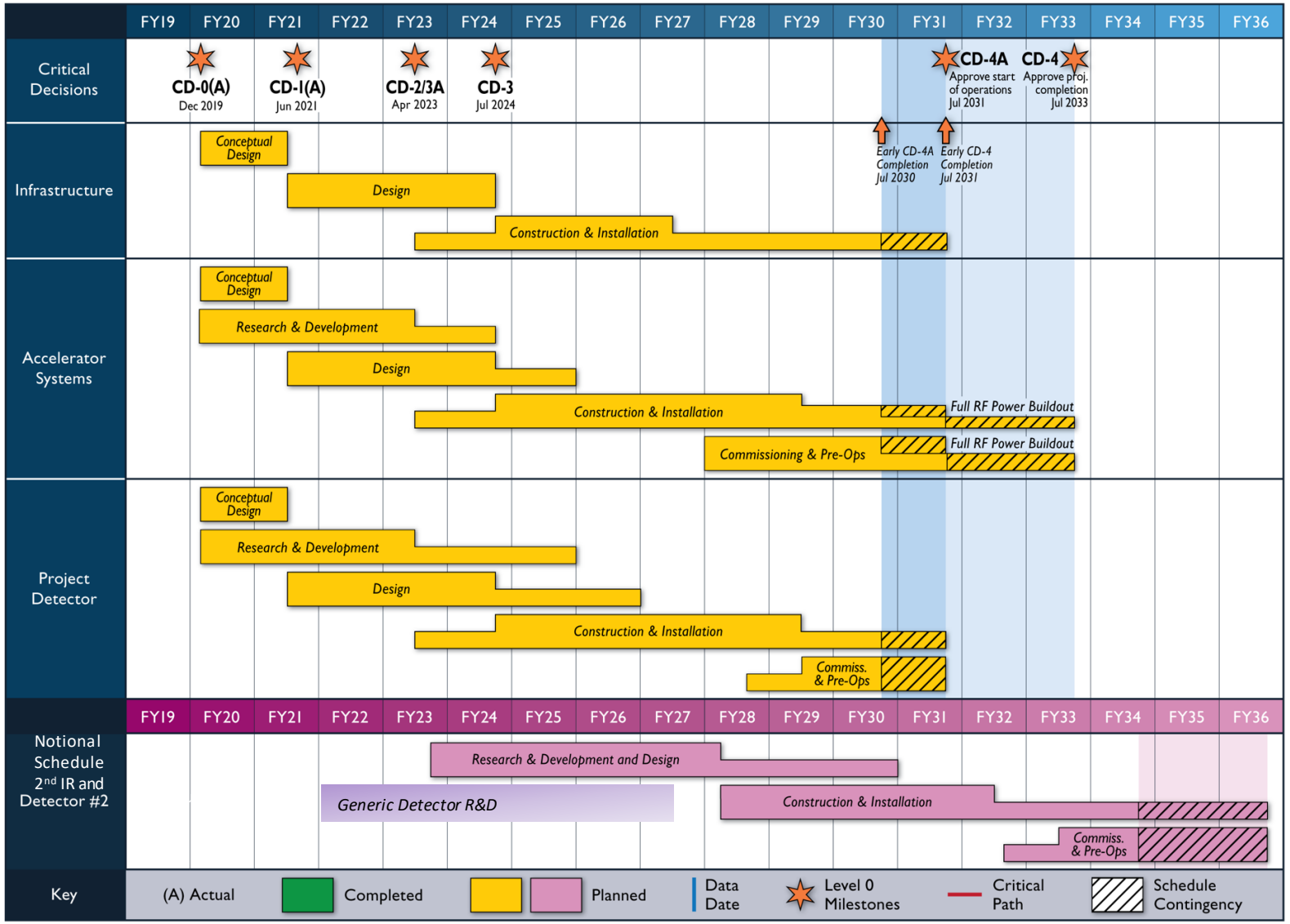
Physics Goals:

- Nucleon structure function F_2^n, F_2^p and study medium modifications
- Neutron spin structure study on A_1^n, g_1^n for polarized PDFs
- TMD measurements: Flavor and spin dependence of the Transverse Momentum Distribution.





Reference Schedule (Oct. 2021)



EIC Yellow Report

Posted to the arXiv on 8 March 2021:
https://arxiv.org/abs/2103.05419

902 pages, 415 authors, and 151 institutions

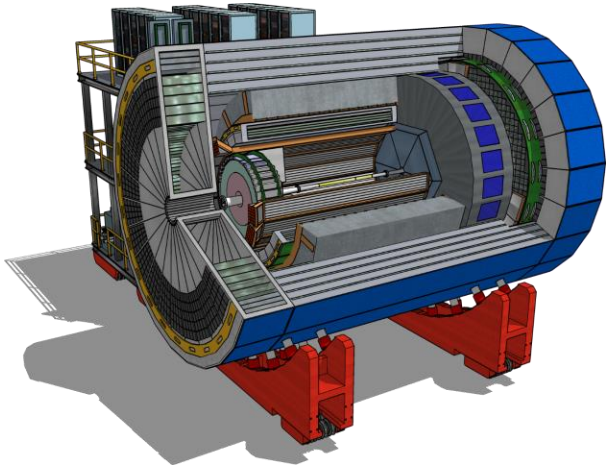
LaTeX Source Code On The arXiv

As of 17 June 2022 has 297 citations.

The document is broken into three volumes:
Executive Summary
Physics
Detectors

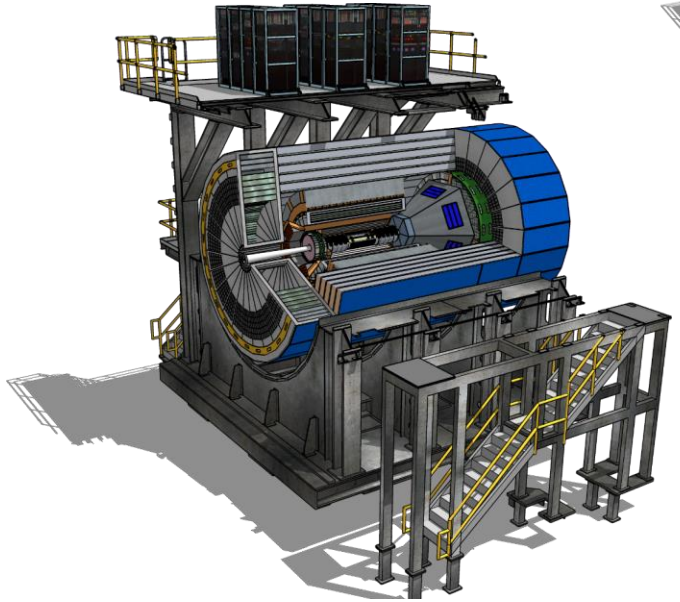
ATHENA, ECCE, and CORE Proto-Collaborations

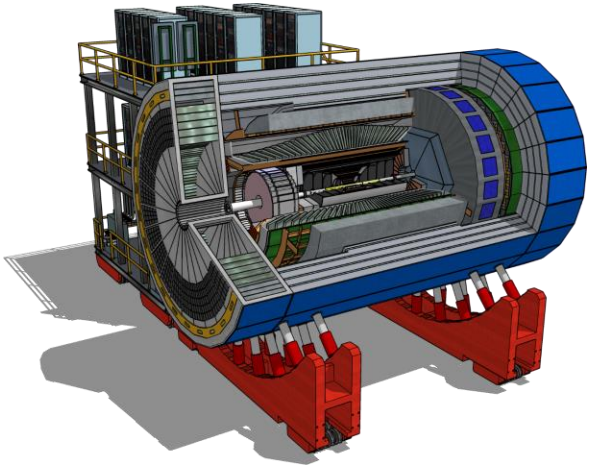
https://www.bnl.gov/dpapanelmeeting/



ATHENA
A Totally Hermetic Electron-Nucleus Apparatus

CORE
COmpact detectoR for the EIC





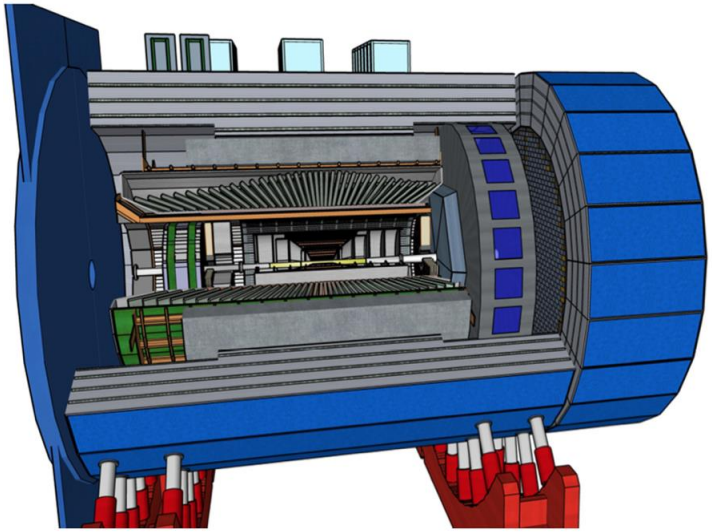
ECCE
EIC Comprehensive Chromodynamics Experiment

21 March 2022 the ECCE concept was selected to be the baseline and now we are coming back together to take those ideas (improve them) into what is presently called detector one.

Path to EIC Project Detector Collaboration

Silvia Dalla Torre, Or Hen, Tanja Horn, John Lejoie, Bernd Surrow

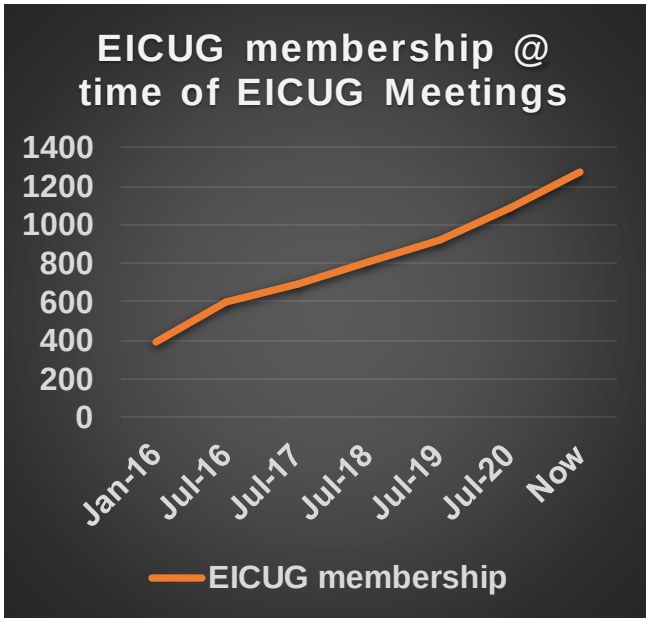
- Consolidation of ATHENA and ECCE and formation of a new scientific collaboration for the first EIC detector is in full swing
- While the road to a new collaboration may take a while, we have tasks that require immediate attention:
  - Evolution of the ECCE reference design to a Detector-1 technical design
  - Formation of joint Working Groups
    - Take advantage of the strength in both the ATHENA and ECCE collaborations
  - Prepare for CD-2/3A



International Interest in EIC Science

The EIC User Group:
EICUG.ORG, Formed 2016

16 March 2022:
- **1331 collaborators**
- **266 institutions**
- **36 countries**



You are all welcome to join the EICUG by contacting your institutional representative:
https://phonebook.sdcc.bnl.gov/eic/client/

(or email me and I will help you!)

Jefferson Lab EIC Center Fellowships

Fellowships will be awarded for a period of one year to fund EIC related research, including innovations to maximize scientific output of the EIC and studies to expedite both scientific and experimental readiness for EIC operations. The areas of research include theory, simulations, detectors, and computing.

Each graduate fellowship provides the awardee's home institution with a $13,000 stipend and for postdoctoral fellows $36,000 will be provided. Fellows will typically be expected to spend half their time at Jefferson Lab.

The applications will be evaluated by a committee according to the following criteria:

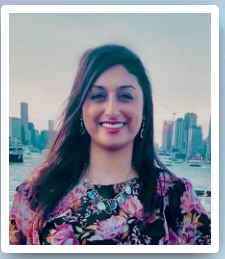
- Merit and quality of proposed research
- Relevance of the proposed research to the Electron-Ion Collider and Jefferson Lab
- Likelihood that the proposed research can be successfully accomplished within the fellowship period.
- Letters of recommendation.

Applications are accepted once a year.

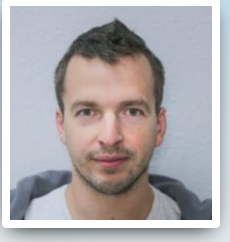
See web site for details: https://www.eiccenter.org/jefferson-lab-eic-center-fellowships

2021/22 RESEARCH FELLOWS

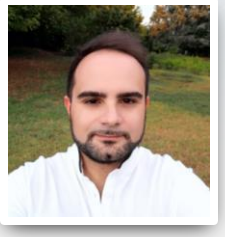
Postdoctoral Research Fellows



Salina Ali
University of Virginia
Assist with construction of a prototype micro-RWELL, a new micro-pattern gaseous detector technology that could be ideal for the EIC, and to conduct parasitic tests of the detector's performance at JLab.

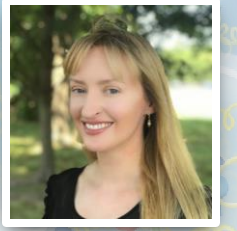


Alexander 'Sasha' Bylinkin
University of Kansas
Optimization of the proton and photon detectors in the EIC far forward regions and further development of the physics case for these systems.



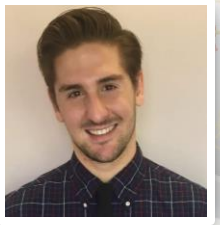
Francesco Celiberto
European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*)
Twist-two calculations for extracting transverse momentum distributions and study of phenomenological applications of the research to spin-dependent observables.

Graduate Student Fellows



Christine Ploen
Old Dominion University
Background reduction in the EIC detector beamline by first characterizing the expected background caused by synchrotron photons and then evaluating mitigation schemes.

Jackson Pybus
Massachusetts Institute of Technology
Studies of tagged semi-inclusive deep inelastic scattering from polarized helium-3 nuclei and determination of the requirements of the far-forward detectors for these measurements.



Richard Trotta
Catholic University of America
Optimization of the second far forward EIC beamline for the extraction of pion and kaon structure functions.

Detector Testing Program

- Jefferson Lab users have a long history of its users setting up small parasitic detector tests in the experimental halls to ensure successful experiments.
- With a focus on detectors for the EIC, the EIC center coordinates between outside groups and the experimental Halls to facilitate testing.
- Presently Four Parasitic Testing Areas On Site
  - High Luminosity Tests: Hall A and Hall C
  - Low Luminosity Tests: Hall B and Hall D
- Presently One Area For Dedicated Testing
  - 10 MeV Upgraded Injector Test Facility
- Testing will require approval by hall leader and work coordinator as well as appropriate training and safety documentation
- More details found at: https://www.eiccenter.org/detector-testing

Summary

- Due to a very strong overlap in the physics interests, the EIC project has turned into a very nice joint project with BNL and JLab.
- Just as the two labs were able to come together after site selection, now the detector teams ECCE, CORE, ATHENA are coming together to build what is presently known as detector one.
- The future will most likely have two detectors, but the project funding only has funds for one.