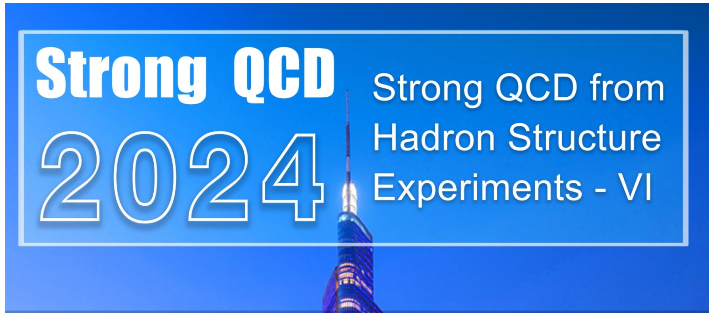
Center for Frontiers in Nuclear Science

The Electron Ion Collider (EIC) moving forward….



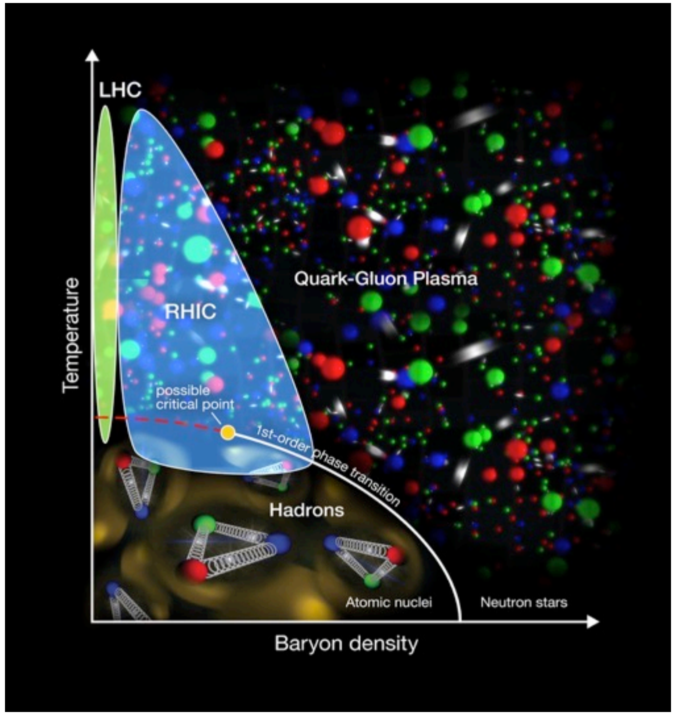
Abhay Deshpande

(remote presentation)

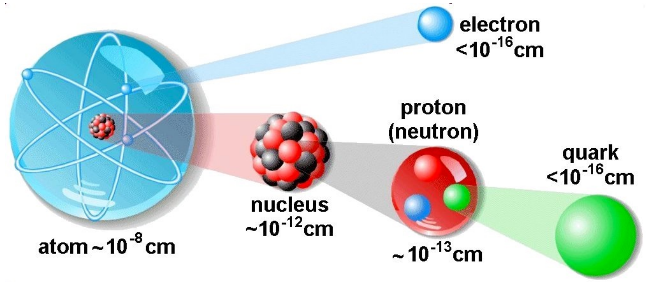
Stony Brook University

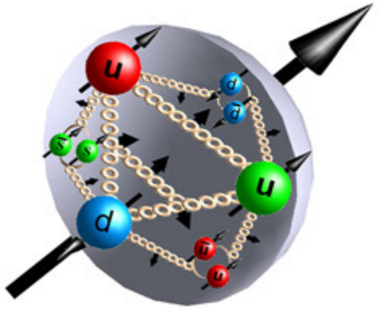
Brookhaven National Laboratory

RHIC – a Unique Research Tool



- Heavy ion collisions
  - Explore new state of matter: Quark Gluon Plasma
  - Highest collision rates and collide many different ion species
- Polarized proton collisions
  - Only collider of spin polarized protons to explore the internal spin structure of protons.
  - Gluons carry part of proton spin

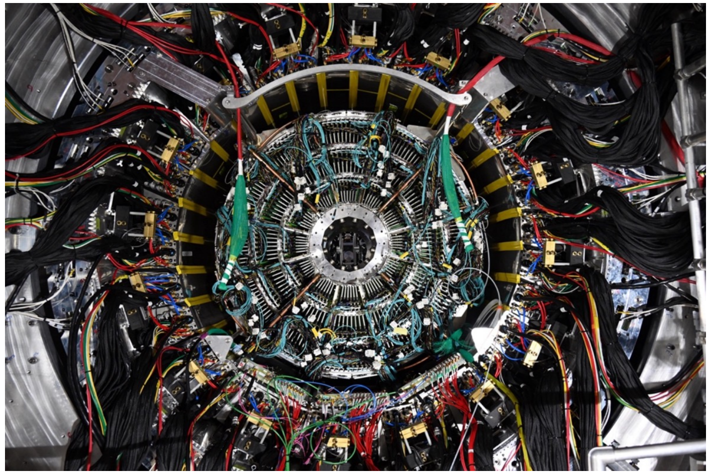


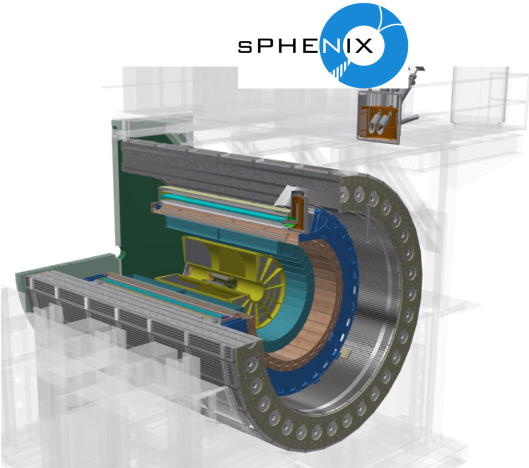


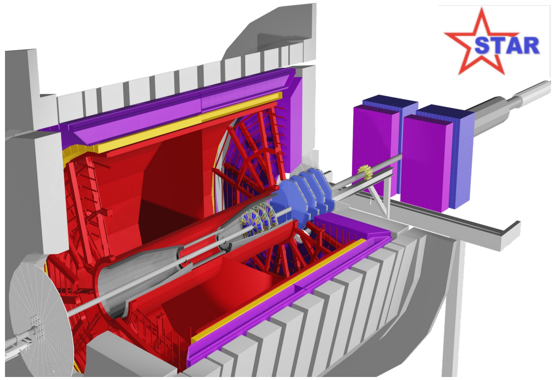
Completing the RHIC Mission with sPHENIX and STAR

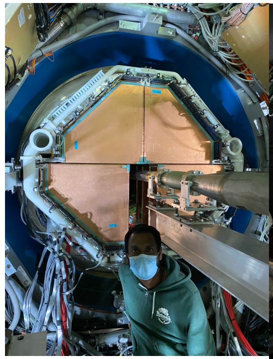
- sPHENIX will use energetic probes (jets, heavy quarks) to study quark-gluon plasma with unprecedented precision
  - How the structureless "perfect" fluid emerges from the underlying interactions of quarks and gluons at high temperature
- sPHENIX outer hadron calorimeter will be part of the EIC project detector

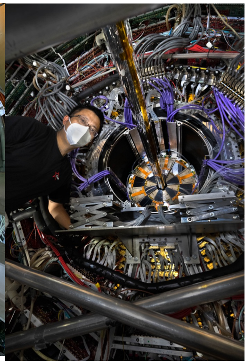
- STAR with forward upgraded detectors will understand the initial state of nucleon and nuclei from high to low x and the inner workings of QGP
- How are gluons and sea quarks distributed in space and momentum inside the nucleon?
- How does a dense nuclear environment affect quarks and gluons, their correlations, and their interactions and giving rise to non-linear effects?





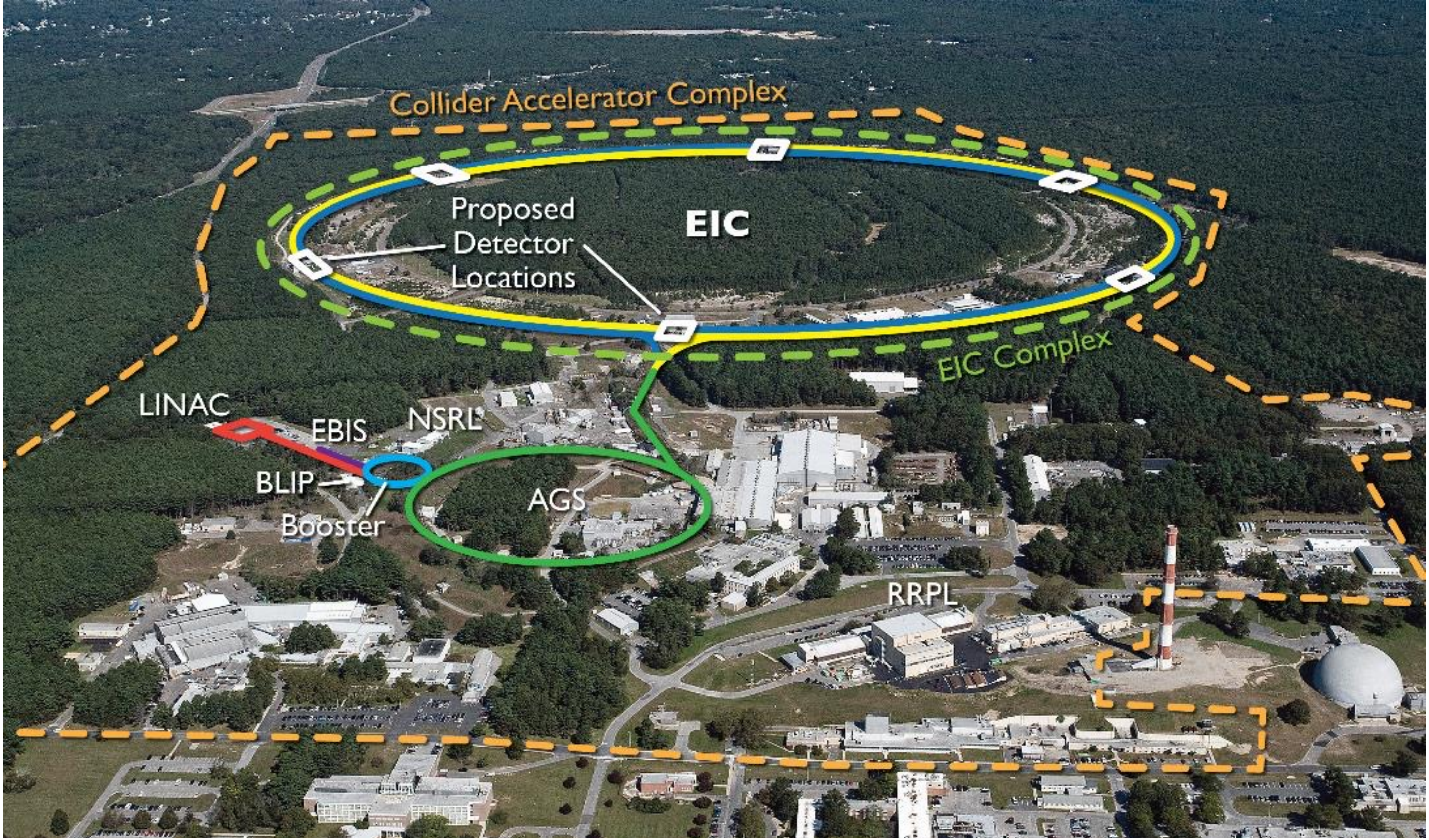






Synergies with the EIC science and contribute to EIC workforce development

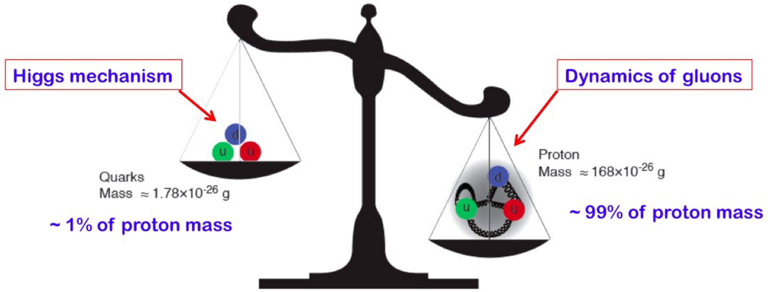
RHIC data taking scheduled for 2024–2025
sPHENIX and STAR with forward upgrade will fully utilize the enhanced (~50 times Au+Au design) luminosity of RHIC



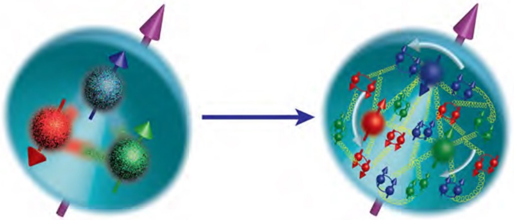
- EIC benefits from $B class investments at BNL and the highly successful RHIC program.
- RHIC will conclude operations in 2025. Electron Ion Collider installation will begin after RHIC ops concludes.

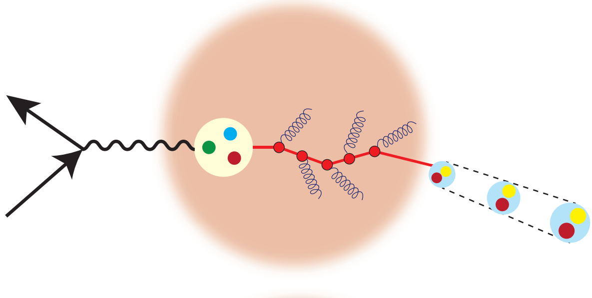
EIC Physics at-a-Glance

Eur. Phys. J. A 52 (2016) 9, 268 arXiv:1212.1701 (nucl-ex)



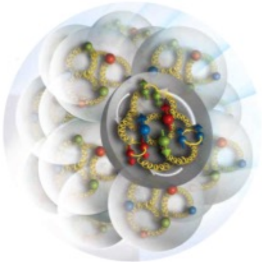
How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties (mass & spin) emerge from their interactions?

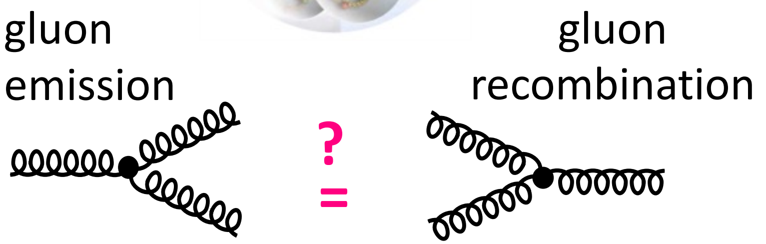




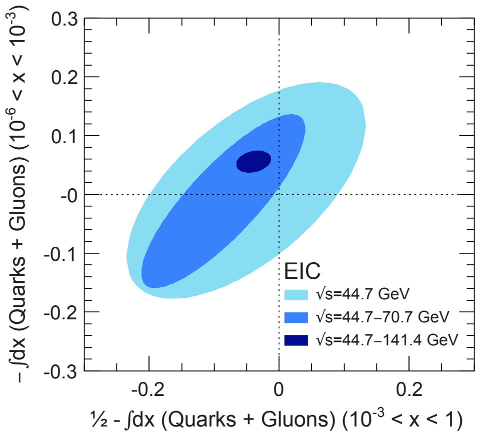
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

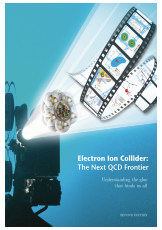
How does a dense nuclear environment affect the quark- and gluon- distributions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?

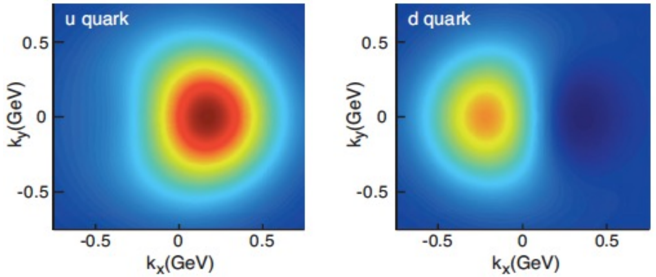


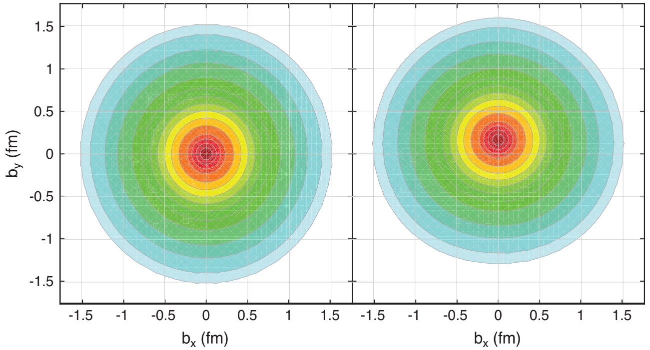


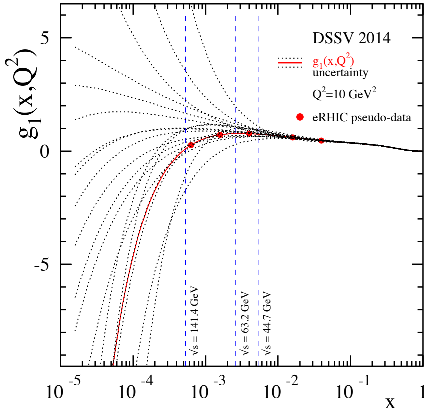
EIC science highlights

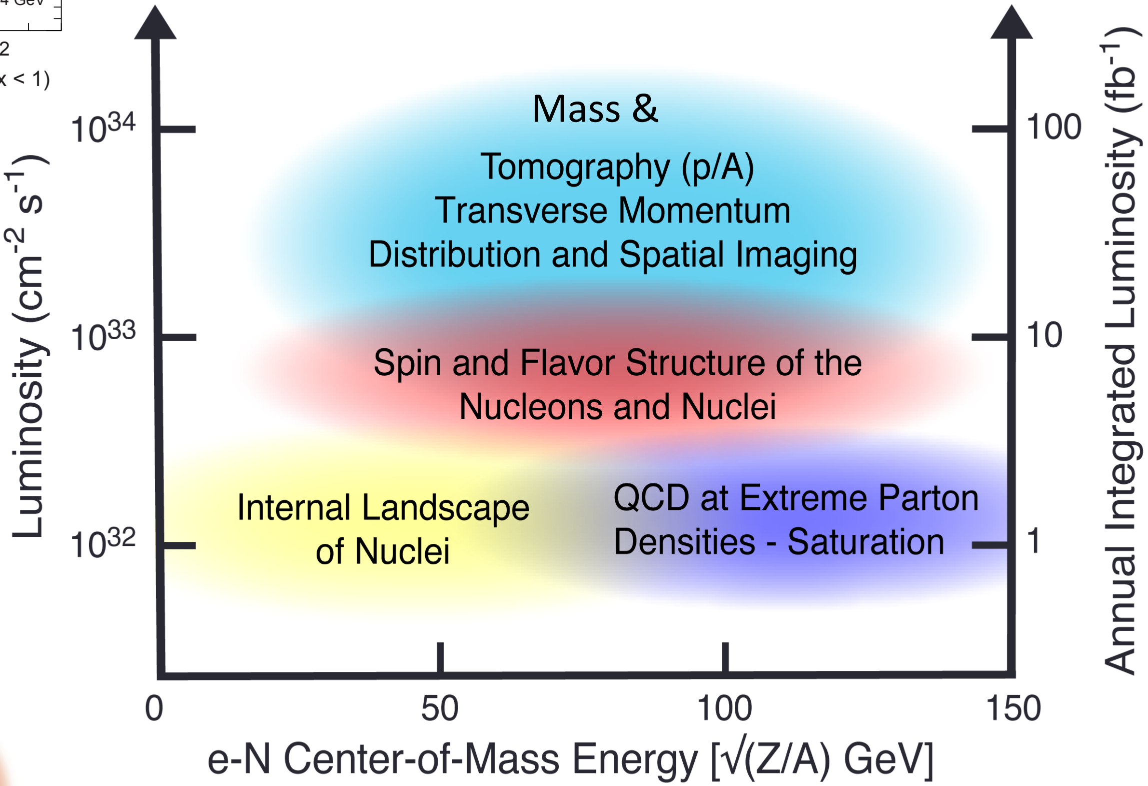


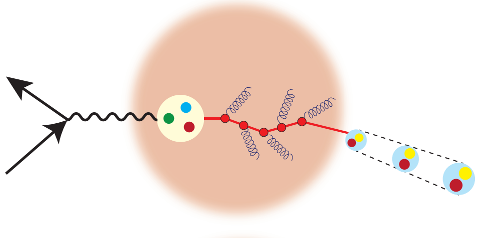


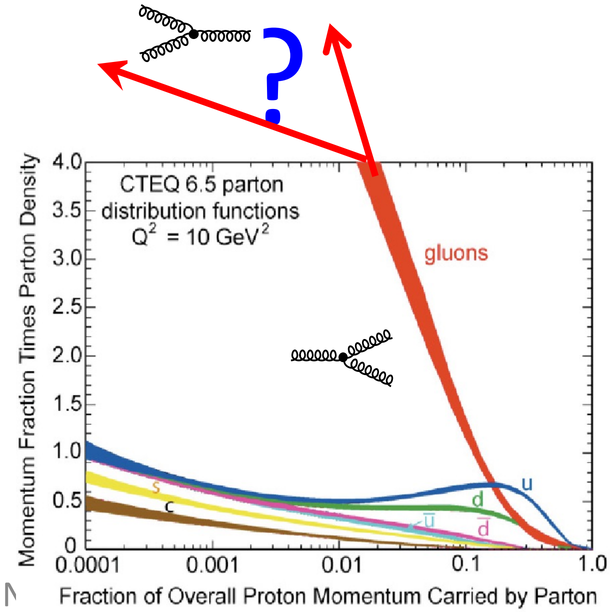


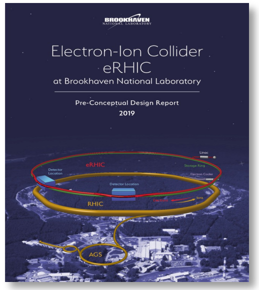






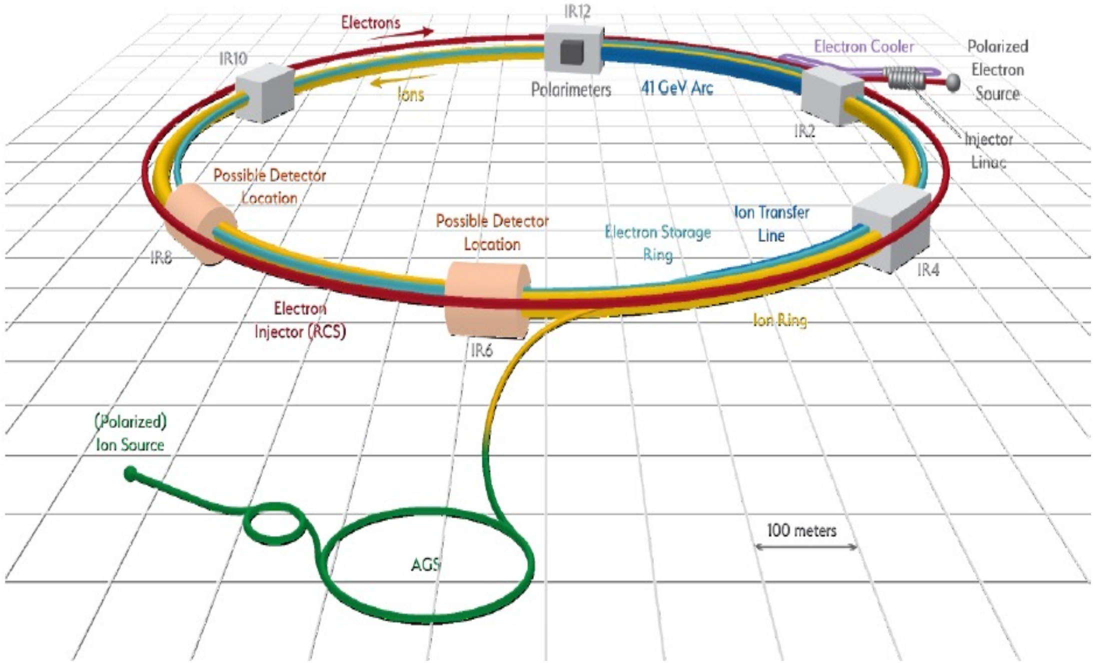






The US Electron Ion Collider

CD0: Dec. 2019, CD1 July 2021



- ❖ Electron storage ring with frequent injection of fresh polarized electron bunches
- ❖ Hadron storage ring with strong cooling or frequent injection of hadron bunches
- ❖ AI and ML surely will play a major role in optimizing this complex accelerator operation

Hadrons up to 275 GeV

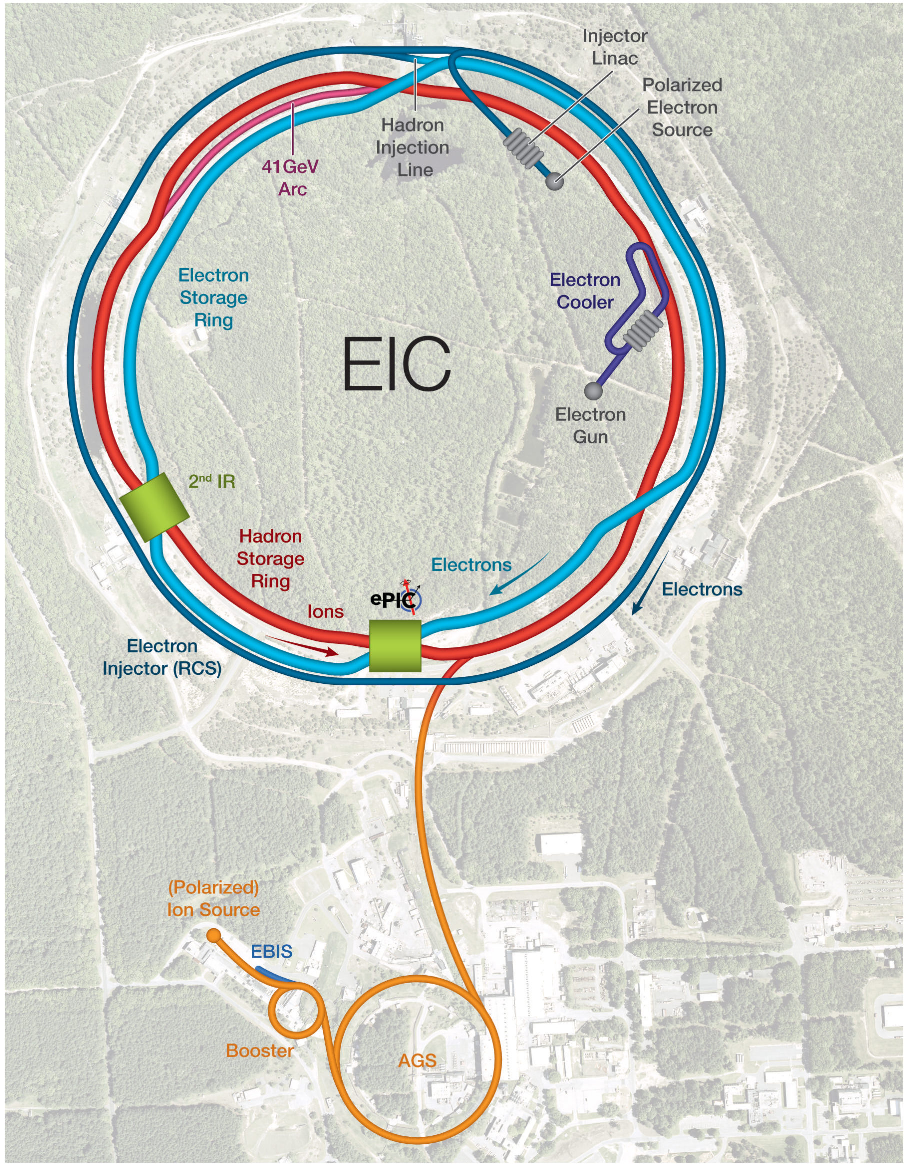
- ➢ Existing RHIC complex: Storage (Yellow), injectors (source, booster, AGS)
- ➢ Need few modifications
- ➢ RHIC beam parameters fairly close to those required for EIC@BNL

Electrons up to 18 GeV

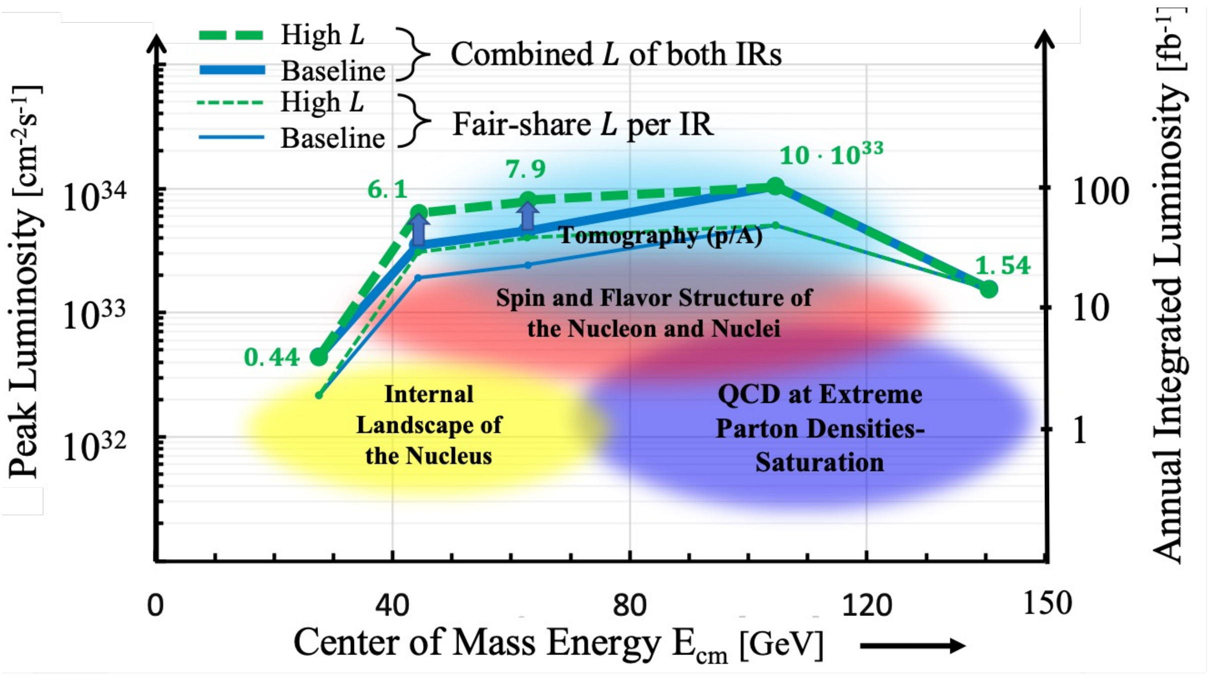
- ➢ Storage ring, provides the range sqrt(s) = 20-140 GeV. Beam current limited by RF power of 10 MW
- ➢ Electron beam with variable spin pattern (s) accelerated in on-energy, spin transparent injector (Rapid-Cycling-Synchrotron) with 1-2 Hz cycle frequency
- ➢ Polarized e-source and a 400 MeV s-band injector LINAC in the existing tunnel

Design optimized to reach 10^{34} $cm^{-2}sec^{-1}$

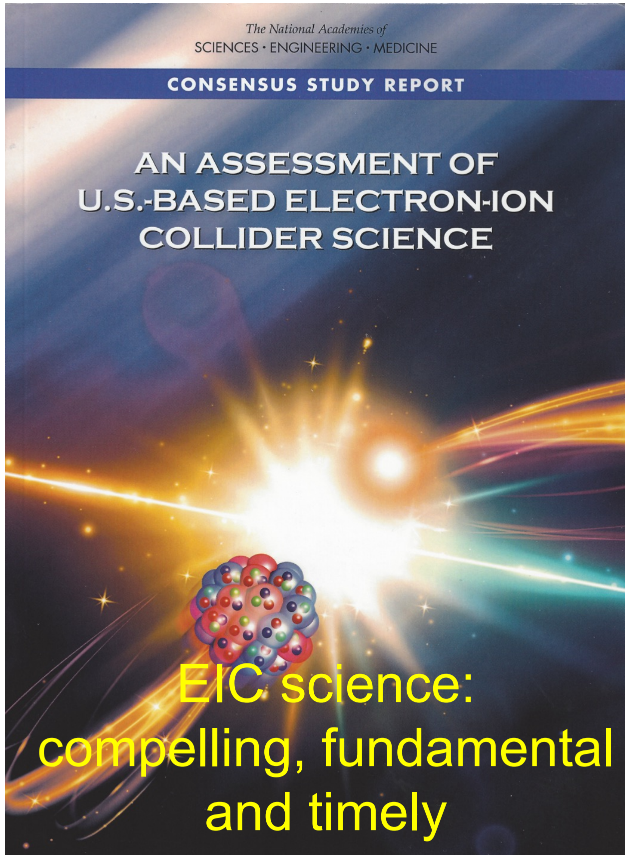
EIC Accelerator Design



Center of Mass Energies:	20GeV - 140GeV
Luminosity:	10^{33} - 10^{34} $cm^{-2}s^{-1}$ / 10-100fb^{-1} / year
Highly Polarized Beams:	70%
Large Ion Species Range:	p to U
Number of Interaction Regions:	Up to 2!

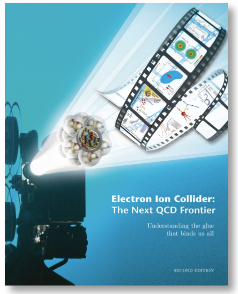


National Academy’s Assessment, July 2018
Electron Ion Collider



Electron Ion Collider Science:

- Origin of nucleon spin
- Understanding the origin of mass
- Intense gluonic fields & novel gluonic matter



Machine Design Parameters:

- High luminosity: up to 10^{33}-10^{34} $cm^{-2}sec^{-1}$
  - a factor ~100-1000 times HERA
- Broad range in center-of-mass energy: ~20-100 GeV upgradable to 140 GeV
- Polarized beams e-, p, and light ion beams with flexible spin patterns/orientation
- Broad range in hadron species: protons…. Uranium
- Up to two detectors well-integrated detector(s) into the machine lattice

Use of AI and ML in

- Operation, optimization of machine and
- Data acquisition (triggerless data collections)

Worldwide Interest in EIC

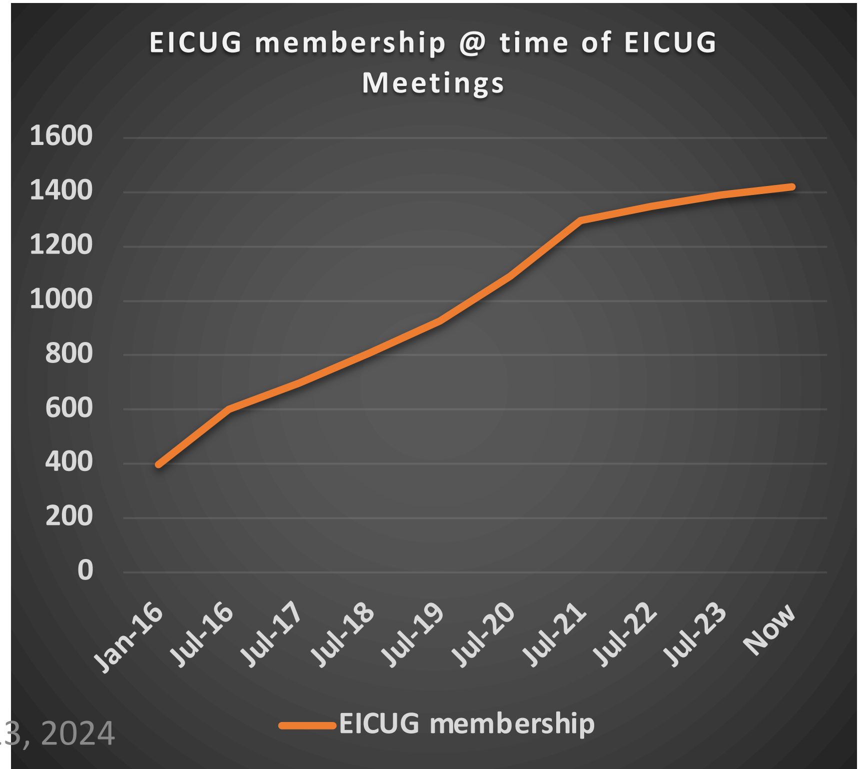
The EIC User Group:
https://eicug.github.io/

Formed 2016 – (with 700 enthusiasts)

- **1450+ collaborators,**
- **40+ countries,**
- **290+ institutions**

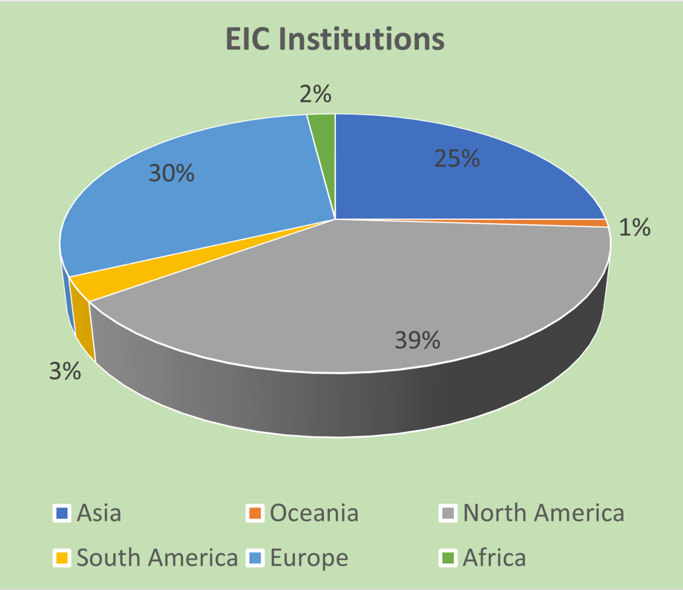
as of May, 2024.

Strong International Participation.



Annual EICUG meeting

2016 UC Berkeley, CA
2016 Argonne, IL
2017 Trieste, Italy
2018 CUA, Washington, DC
2019 Paris, France
2020 FIU, Miami, FL
2021 VUU, VA & UCR, CA
2022 Stony Brook U, NY
2023 Warsaw, Poland
2024 Lehigh U, PA



Physics @ the EIC: Connections to High Energy Physics

Of HEP/LHC-HI interest to Snowmass 2021 (EF 05, 06, and 07 and possibly also EF 04)

New Studies with proton or neutron target:

- Impact of precision measurements of unpolarized PDFs at high x/Q^2, on LHC-Upgrade results(?)
- Precision calculation of α_S : higher order pQCD calculations, twist 3
- Heavy quark and quarkonia (c, b quarks) studies with **100-1000 times lumi of HERA and with polarization**
- Polarized light nuclei in the EIC

Physics with nucleons and nuclear targets:

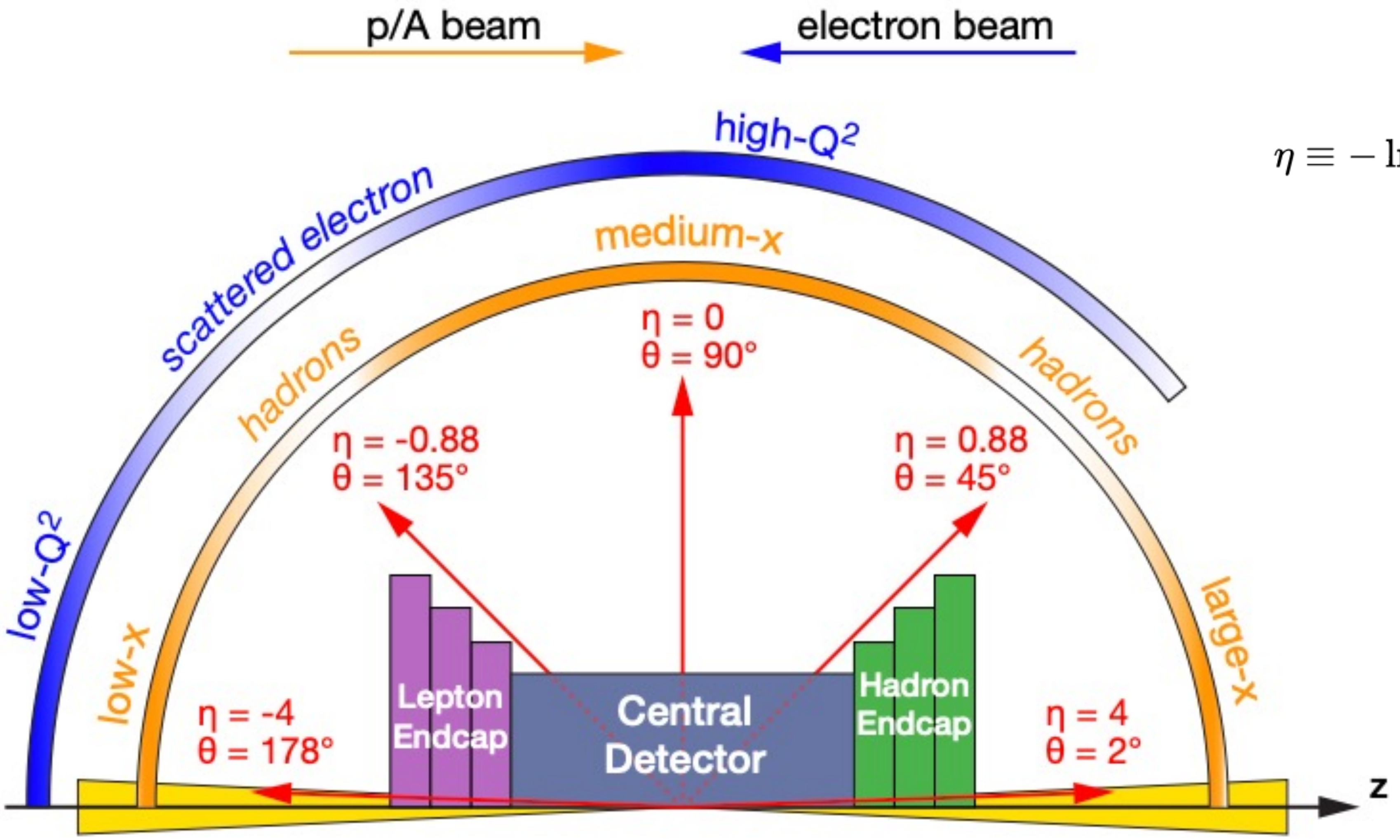
- Quark Exotica: 4,5,6 quark systems…? Much interest after recent **LHCb** led results.
- Physic of and with jets with EIC as a precision QCD machine:
  - Jets as probe of nuclear matter & Internal structure of jets : novel new observables, energy variability
  - Entanglement, entropy, connections to fragmentation, hadronization and confinement

Precision electroweak and BSM physics:

- Electroweak physics & searches beyond the SM: Parity, charge symmetry, lepton flavor violation
- LHC-EIC Synergies & complementarity

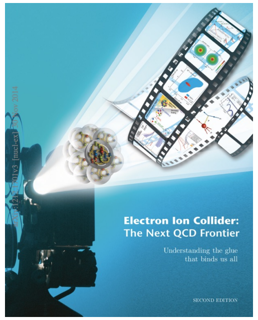
Study of universality: e-p/A vs. p-A, d-A, A-A at RHIC and LHC

Detector polar angle / pseudo-rapidity coverage

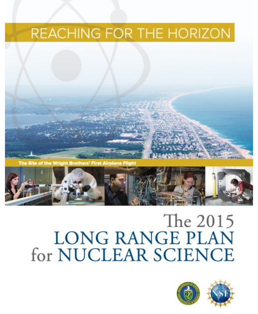


$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$

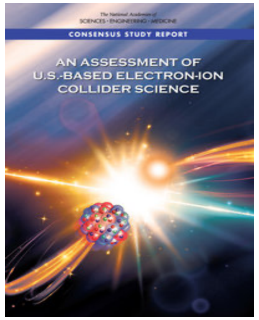
Detector Design Process Timeline



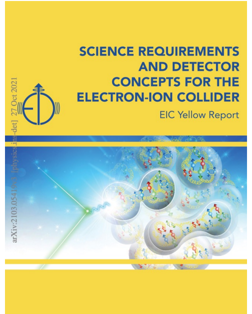
2012



2015



2018

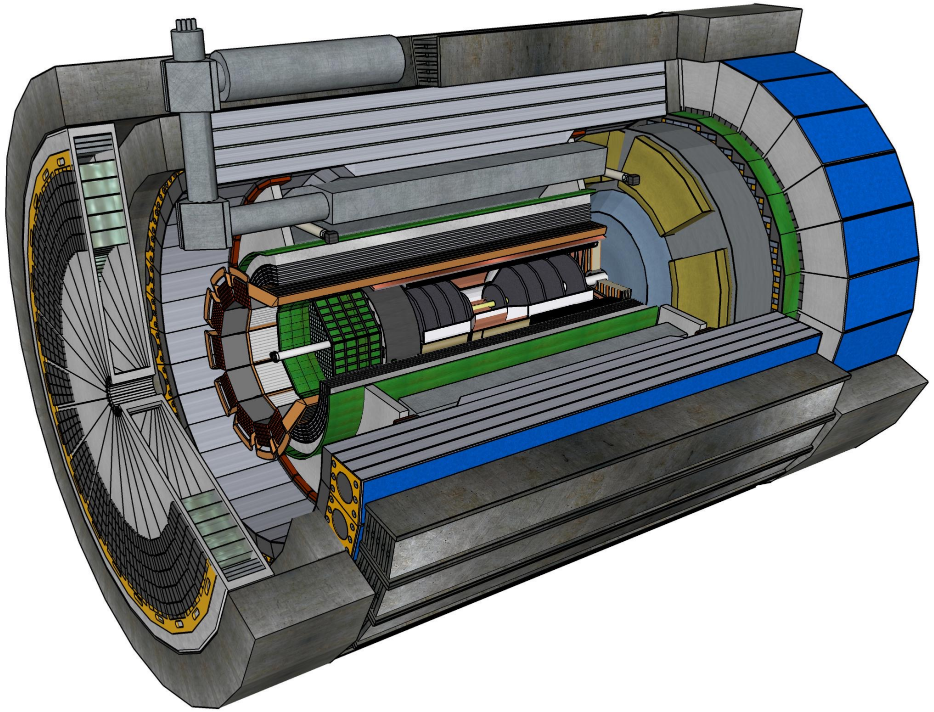


2020

2023

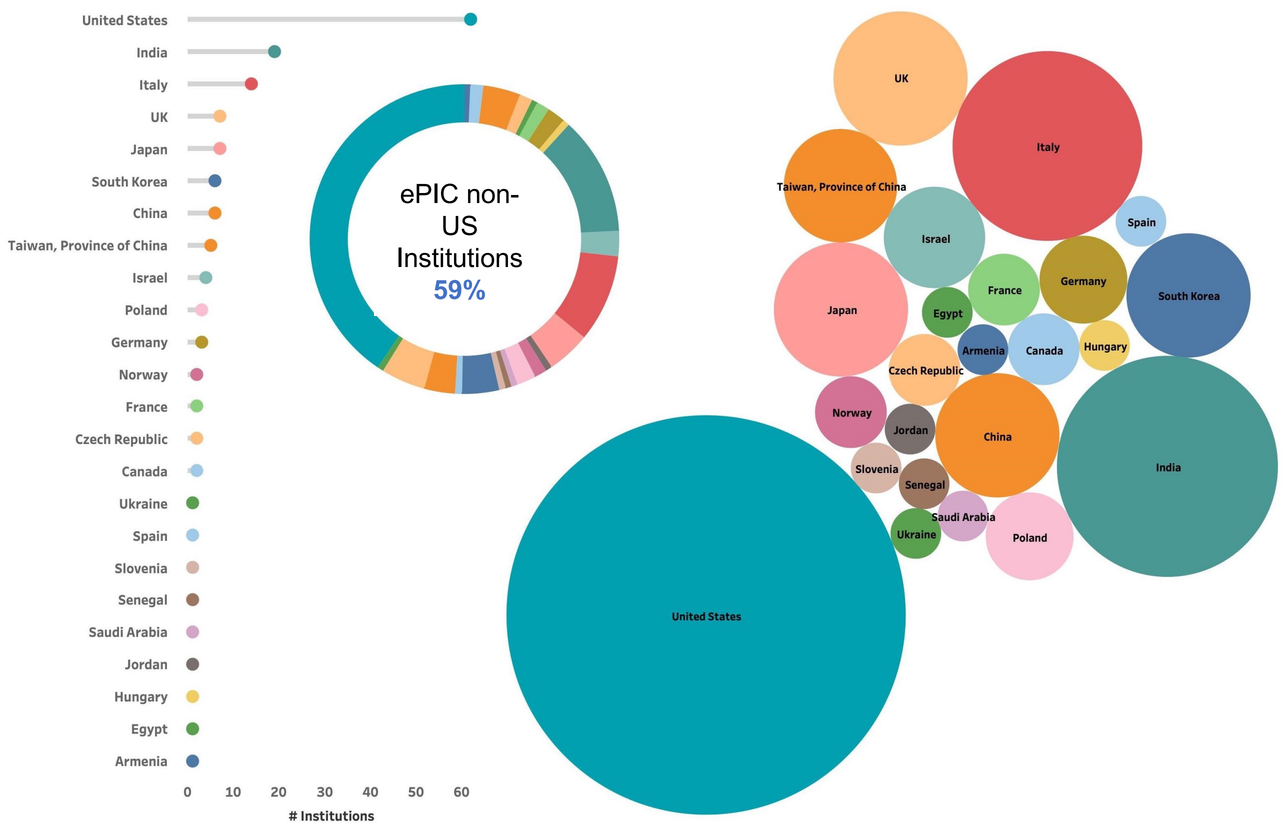
Detector and machine design parameters driven by physics objectives

- Call for proposals issued jointly by BNL and JLab in **March 2021** (Due Dec 2021)
  - ATHENA, CORE and ECCE proposals submitted
- DPAP review **Dec 2021 – Jan 2022**, closeout **March 2022**
  - ECCE proposal chosen as basis for first EIC detector reference design
- **Spring/Summer 2022** – ATHENA and ECCE form joint leadership team
  - Joint WG's formed and consolidation process undertaken
  - Coordination with EIC project on development of technical design
- Collaboration formation process started **July 2022**
- Charter ratified & elected ePIC Leadership Team **February 2023**
- **EIC/ePIC endorsed as highest priority for new facility construction in 2023 LRP.**
- **Working towards TDR and CD-3A (review Nov. 2023) and CD-2/3 (2025)**



John Lajoie

The ePIC Collaboration



ePIC formed a year ago.

ePIC is now 171 institutions including 11 new institutions that joined this July 2023.

Representing 24 countries

500+ participants

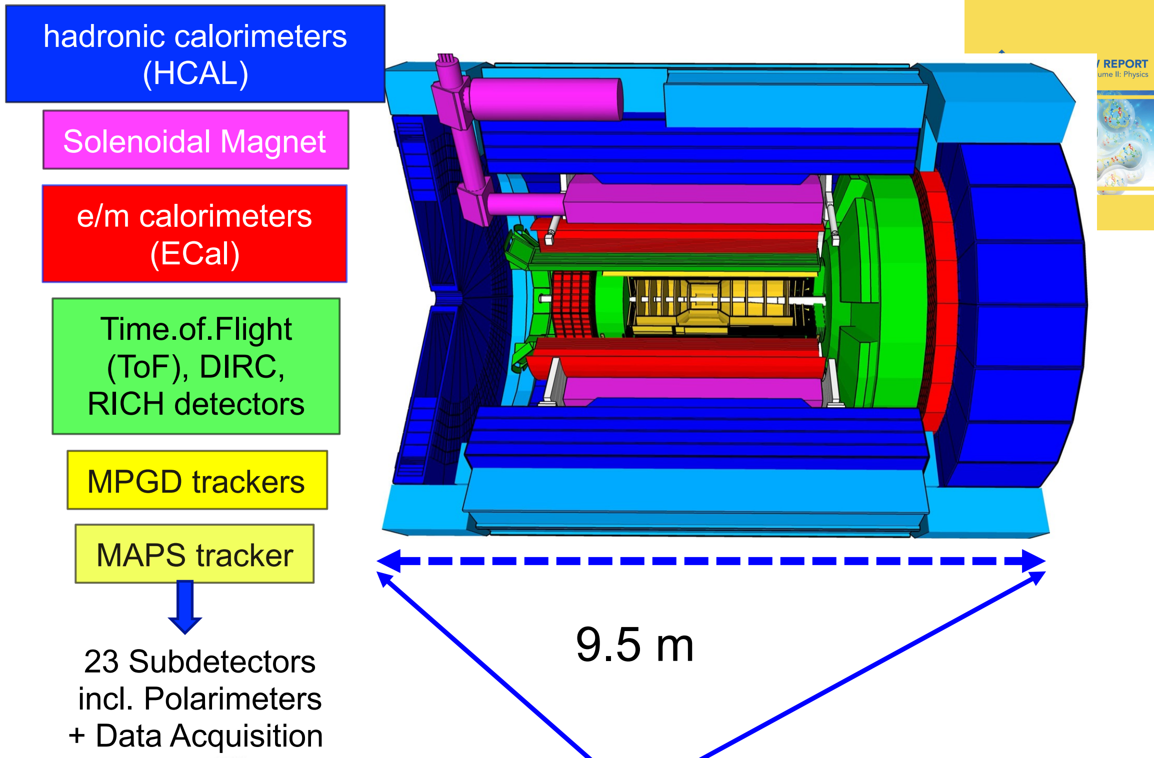
A global pursuit for a new experiment at the EIC!

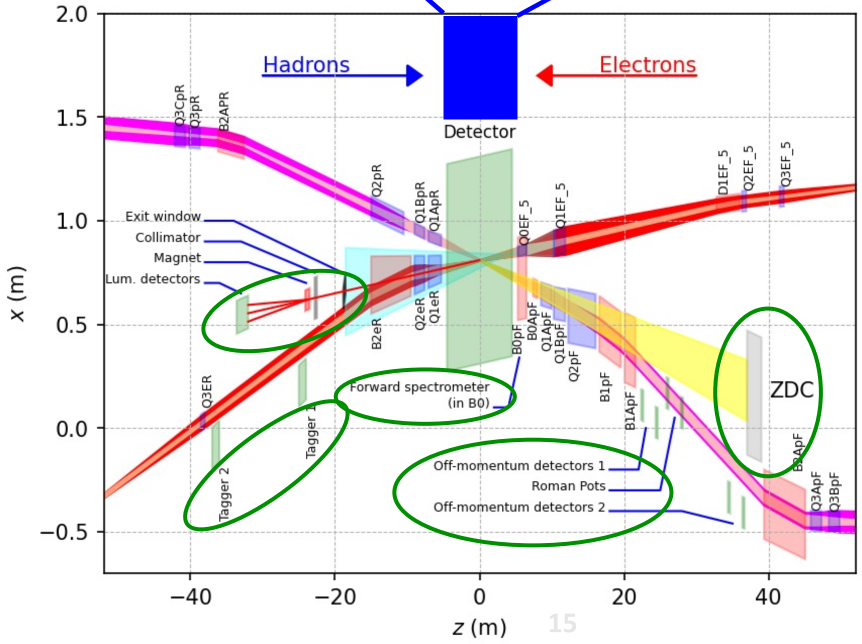
ePIC Spokesperson:
John Lajoie (ORNL)

ePIC Deputy Spokesperson & Interim Technical Director
Silvia Dalla Torre (INFN Trieste)

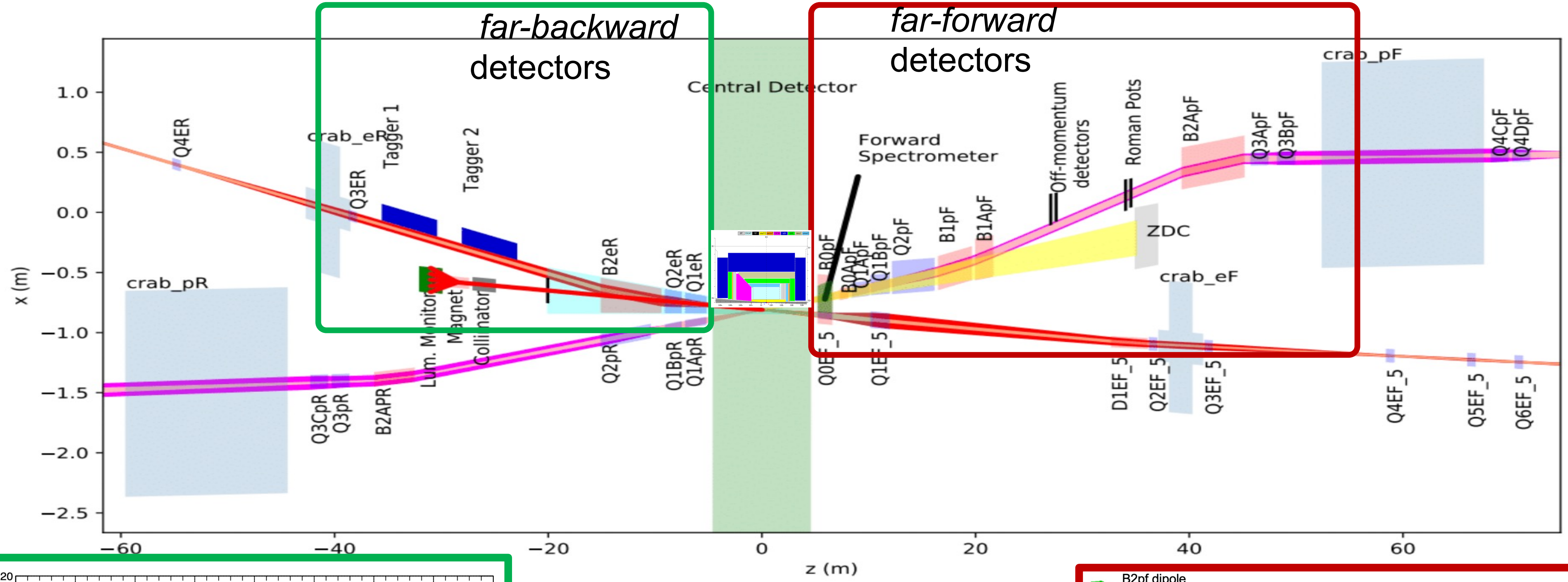
The ePIC Detector

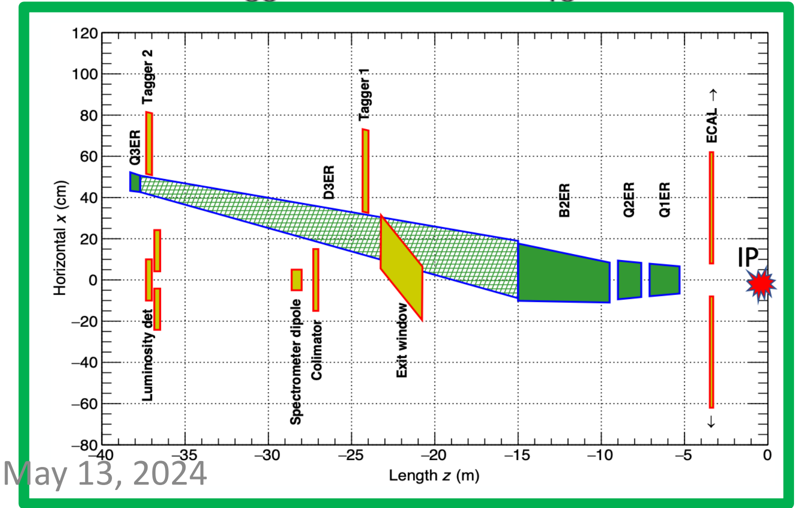
- ❑ Asymmetric beam energies
  - ➢ requires an asymmetric detector with electron and hadron endcap
  - ➢ tracking, particle identification, EM calorimetry and hadronic calorimetry functionality in all directions
  - ➢ very compact Detector, **Integration** will be key
- ❑ Imaging science program with protons and nuclei
  - ➢ requires specialized detectors integrated in the IR over 80 m
- ❑ Momentum resolution for EIC science requires a large bore 2T magnet
- ❑ Highest scientific flexibility
  - ➢ requires Streaming Readout electronics model



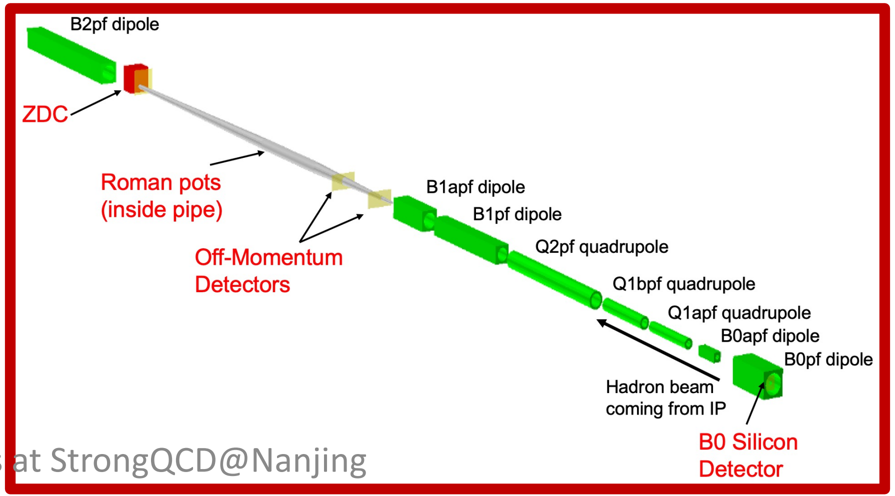


Reference Detector – Backward/Forward Detectors





Extensive integration of forward and backward detector elements into the accelerator lattice



Project Organization

- BNL/JLab Partnership
- Science & Collaboration Advice and Input
- International Governance
- Technical and Project Support

BROOKHAVEN NATIONAL LABORATORY
J. Hewett
LABORATORY DIRECTOR

J. Hill
DEPUTY DIRECTOR FOR SCIENCE & TECHNOLOGY

A. Emrick
DEPUTY DIRECTOR FOR OPERATIONS

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	S. Dalla Torre (INFN)
EIC ACCELERATOR COLLABORATION	**C. Welsch (Liverpool)**
	A. Seryi (JLAB)

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PROJECT DIRECTOR
A. Petrone
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D. Nassar, Deputy L2 Manager

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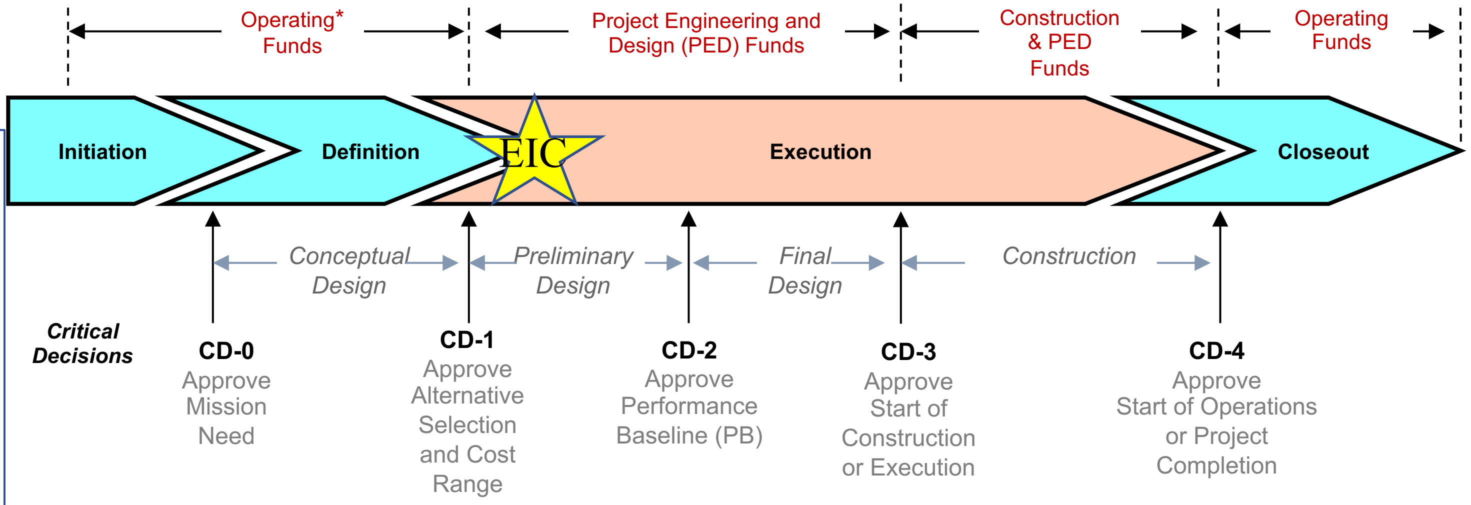
T. Satogata (JLAB), Deputy Level 2 Manager

Exciting news within these couple of months:

- State of NY gave EIC Project $100M for infrastructure building for the EIC
- EIC received CD3A – long lead procurement items ~$90M can now be bought.
- UK's science ministry announced a ~$75M contribution to accelerator and detector components for the EIC – first non-US in-kind contribution formalized

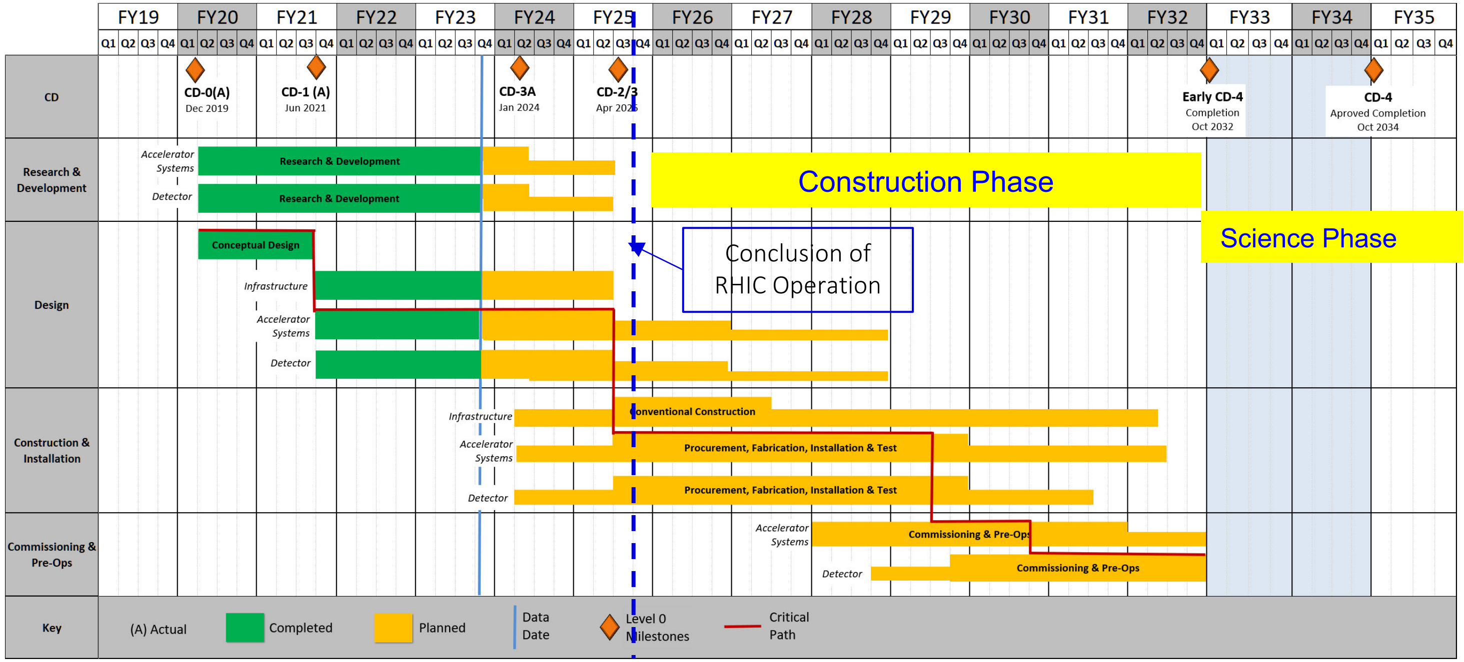
Timeline:



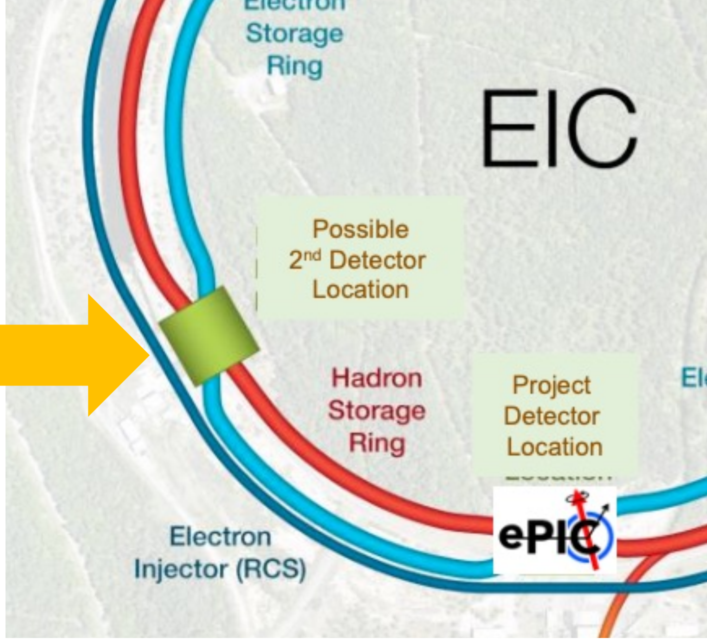
EIC Critical Decision Plan

CD-0/Site Selection	December 2019 ✓
CD-1	June 2021 ✓
CD-3A	March 2024 ✅
CD-3B	**March 2025**
CD-2/3	**End of 2025**
CD-4A	October 2032
CD-4	**October 2034**

CD-3A: (Approved)
Define Baseline:
technologies, Scope, Cost & Schedule
Long Lead Procurement (LLP) items
Design Maturity: ~90%
Plan is tracked through EVMS
& Change control process
Start of construction for LLPs



The 2nd detector
Not in the EIC Project



EIC would be incomplete without the 2nd IR and 2nd detector

Plans: set of workshops led by EIC Users Group starting this year (stay tuned for further information)

Two documents: with overlapping arguments

Ent and Milner et al for the EICUG SC

JLAB-PHY-23-3761

Motivation for Two Detectors at a Particle Physics Collider

Paul D. Grannis* and Hugh E. Montgomery†
(Dated: March 27, 2023)

It is generally accepted that it is preferable to build two general purpose detectors at any given collider facility. We reinforce this point by discussing a number of aspects and particular instances in which this has been important. The examples are taken mainly, but not exclusively, from experience at the Tevatron collider.

arXiv: 2303.08228v2 March 24, 20234

Case for two detectors being made from **Nuclear** and **Particle** Physics

Complementary detectors : 1 + 1 > 2

More than one detectors with different acceptances, optimizations and technologies: **Redundancy, cross-calibration and independent validation** of important results

- Complementary acceptance: confirming/refuting discoveries – studying from different "point of views"
- Complementary Technologies – multiple examples of systematic uncertainties improvement due to different Particle ID, Calorimetry, Tracking, magnetic field strengths and orientations.
  - H1/ZEUS, PHENIX/STAR, CDF/D0 and ATLAS/CMS vs. LHCb
  - Very important because most measurements at the EIC expected to be systematics limited
- Impact of different perspectives that different collaborators bring to the same problem.
  - Complementary analyses strategies build confidence in conclusions
- Complementary Science: add significant weight to the argument for the 2nd detector

Vision for the 2nd detector: C2C

Realize ~5-7 years after ePIC without impacting ePIC's realization

- Complementary (IR, detector technologies & design)
  - Continue to explore complementary ready and not-yet-ready technologies
  - Generic detector R&D program
- Complementary (physics)
  - A significant list of physics topics exists (some-exclusive to 2nd IR, some-overlapping): drill down and see which of those can ***develop into strong pillars of science for the 2nd detector.***
  - New physics developing around the world: we need to monitor constantly
- Complementary (people)
  - New non-US/outside groups who may bring new interests & funding in future
  - New US groups – other than those with significant responsibilities in ePIC

The Scientific Foundation for an EIC was Built Over Two Decades

2002

2007

2009

2010

2012

“…essential accelerator and detector R&D [for EIC] should be given very high priority in the short term.”

“We recommend the allocation of resources …to lay the foundation for a polarized Electron-Ion Collider…”

“..a new dedicated facility will be essential for answering some of the most central questions.”

“The quantitative study of matter in this new regime [where abundant gluons dominate] requires a new experimental facility: an Electron Ion Collider..”

Electron-Ion Collider *absolutely central* to the nuclear science program of the next decade.

2013

2015

2018

2021

2023

“a high-energy high-luminosity polarized EIC [is] the highest priority for new facility construction following the completion of FRIB.”

The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today.”

Build expeditiously

Science Requirements and Detector Concepts for the EIC – Drives the requirements of EIC detectors

Summary & Outlook

- Electron Ion Collider, a high-energy **high-luminosity polarized e-p, e-A collider**, funded by the DOE will be built in this decade and operate in 2030's.
  - Will address the most profound unanswered questions in QCD
- Up to two hermetic (full acceptance(?) and complementary) detectors under consideration, although **EIC project has funds for 1 detector**.
  - Experimental collaboration EPIC formed
    - A world-wide accelerator collaboration (also) being formed
  - An aggressive timeline : first collisions by ~2032; physics start by ~2033/34
  - High interest in having international partners both on detector and accelerator
  - A second detector a few years later

- *For all early career scientists, graduate and undergraduate students: This machine is for you! Ample opportunity to contribute to machine, detector & physics of the EIC.*


"New directions in science are launched by new tools much more often than by new concepts."
Freeman Dyson

Is QCD theory ready for EIC?

"A Case for an EIC Theory Alliance: Theoretical Challenges of the EIC", R. Abir et al. arXiv: 2305.14572v1

CFNS/Stony Brook & CFNS/MIT Workshops in 2022, 2023 and in 2024 for example (there are many more…. Also being organized and promoted)

1) Precision QCD for e-p at the EIC
2) Theory for EIC in the Next Decade