Center for Frontiers in Nuclear Science

The Electron Ion Collider (EIC) moving forward….

EIC Workshop at JPARC

March 29, 2024

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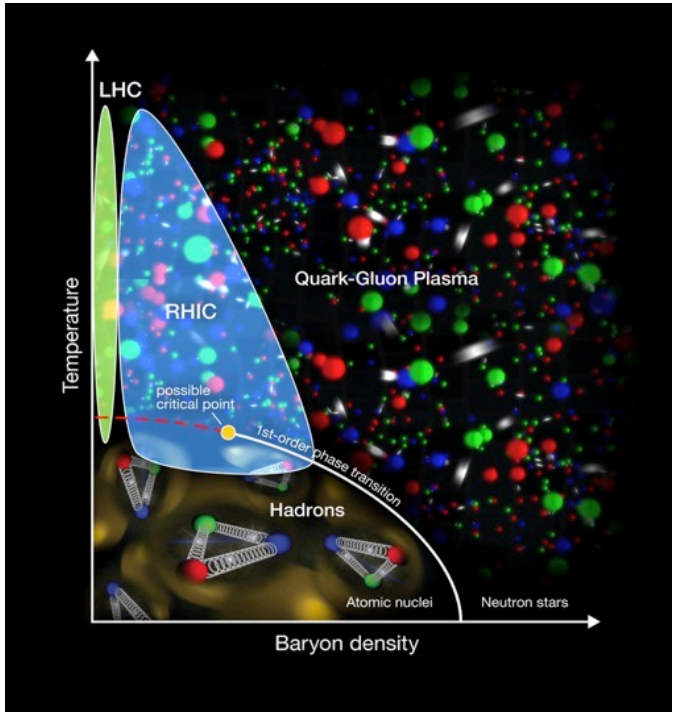
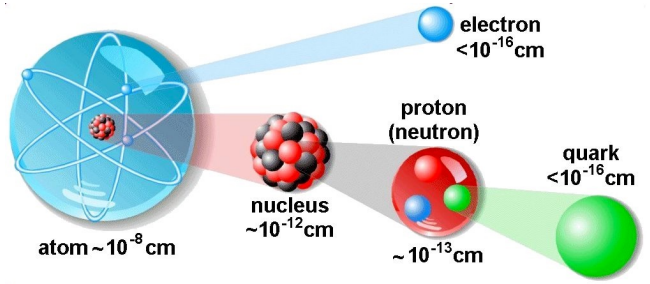
Stony Brook University

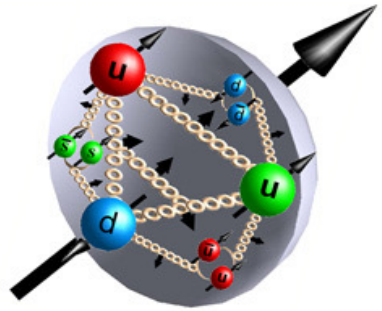
Brookhaven National Laboratory

RHIC – a Unique Research Tool

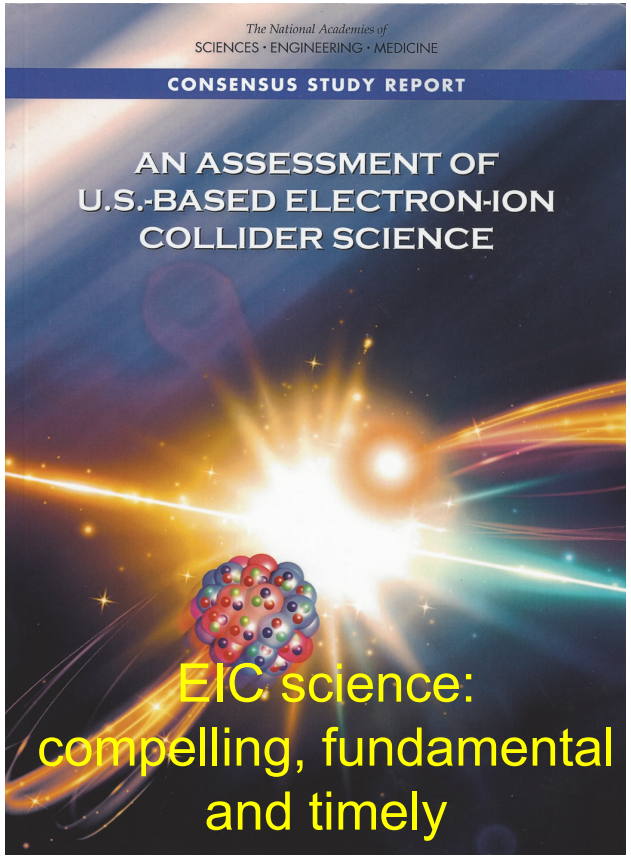
- Heavy ion collisions
  - Explore new state of matter: Quark Gluon Plasma
  - Highest collision rates and collide many different ion species
- Polarized proton collisions
  - Only collider of spin polarized protons to explore the internal spin structure of protons.
  - Gluons carry part of proton spin





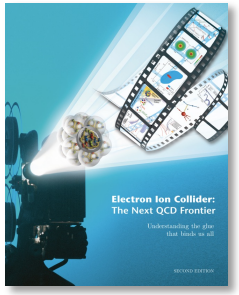


National Academy's Assessment, July 2018
Electron Ion Collider



Electron Ion Collider Science:

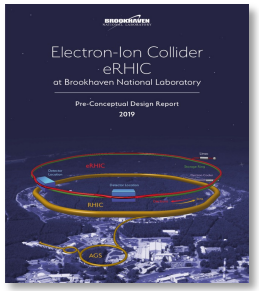
- Origin of nucleon spin
- Understanding the origin of mass
- Intense gluonic fields & novel gluonic matter



Machine Design Parameters:

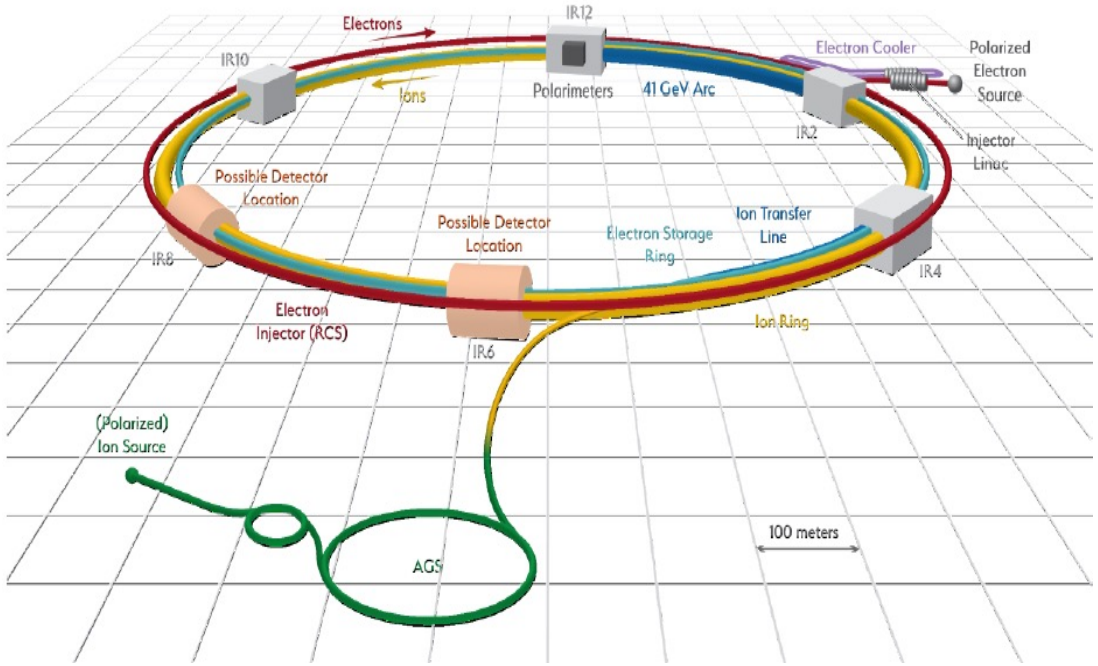
- High luminosity: up to 10^{33}-10^{34} $cm^{-2}sec^{-1}$
  - a factor ~100-1000 times HERA
- Broad range in center-of-mass energy: ~20-100 GeV upgradable to 140 GeV
- Polarized beams e-, p, and light ion beams with flexible spin patterns/orientation
- Broad range in hadron species: protons…. Uranium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

Use of AI and ML in both operation, optimization of machine and data acquisition (triggerless data collections)



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

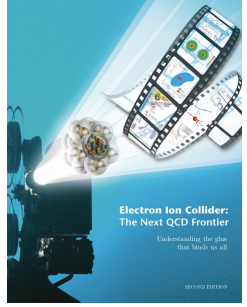
Hadrons up to 275 GeV

- 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

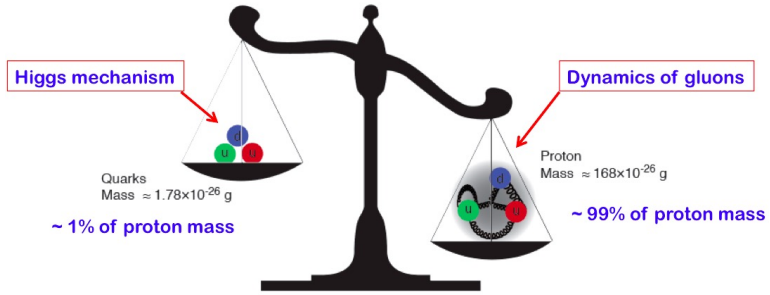
- Storage ring, provides the range sqrt(s) = 20-140 GeV. Beam current limited by RF power of 10 MW
- Electron beam with variable spin pattern (s) accelerated in on-energy, spin transparent injector (Rapid-Cycling-Synchrotron) with 1-2 Hz cycle frequency
- Polarized e-source and a 400 MeV s-band injector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

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

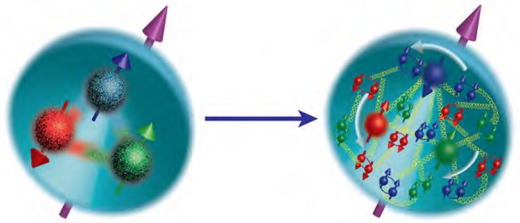


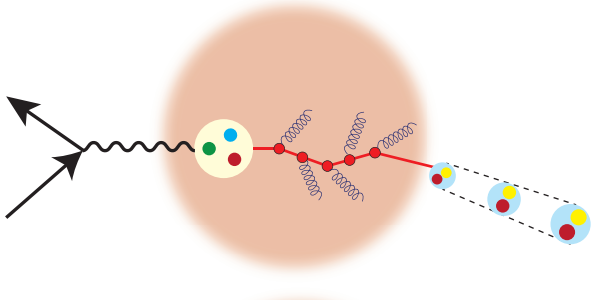
EIC Physics at-a-Glance

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



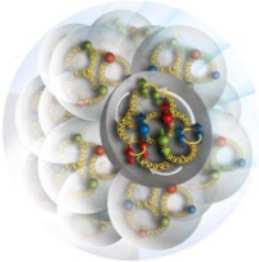
How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties (mass & spin) emerge from their interactions?

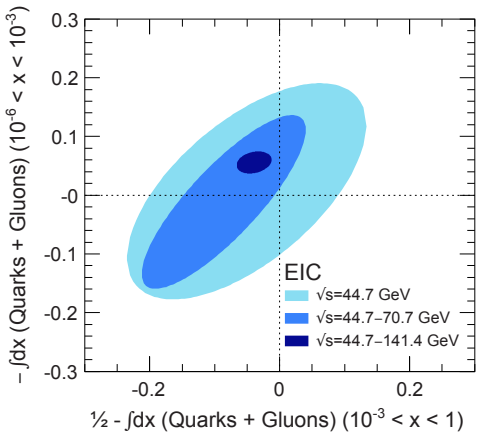


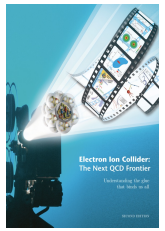


How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

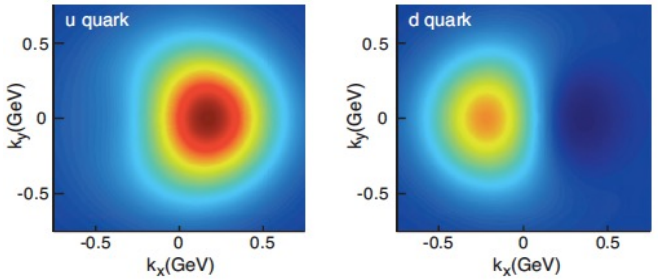
How does a dense nuclear environment affect the quark- and gluon- distributions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?

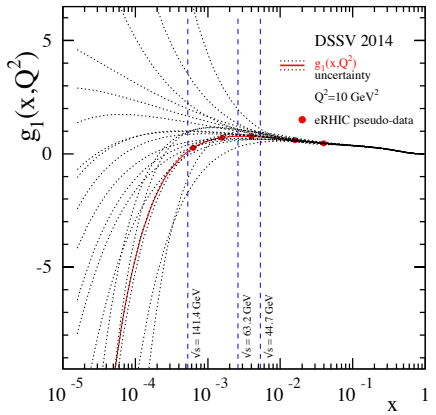


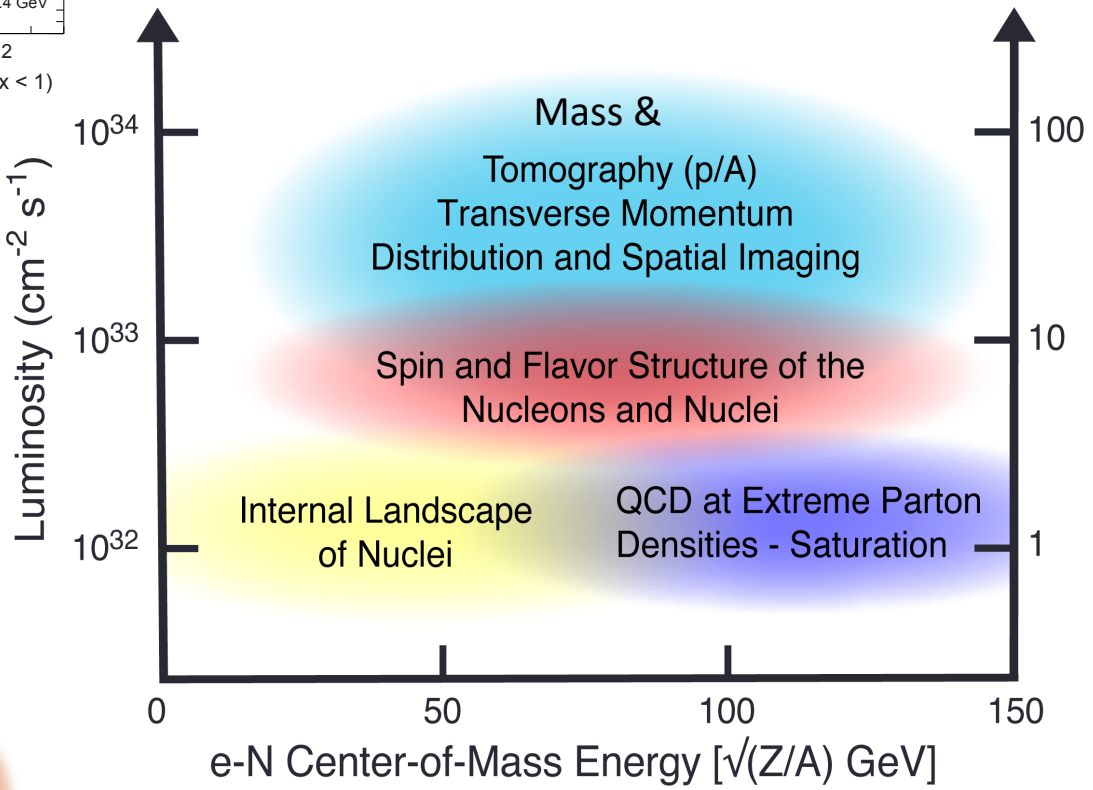


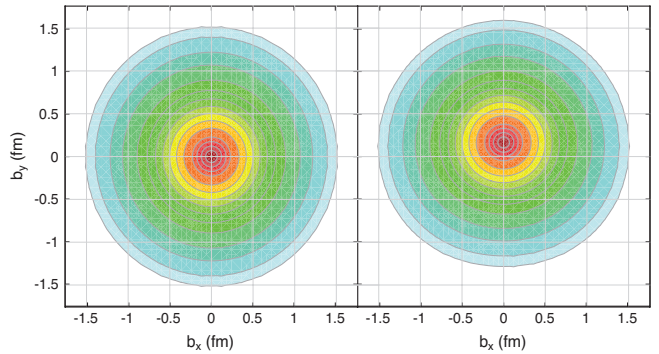


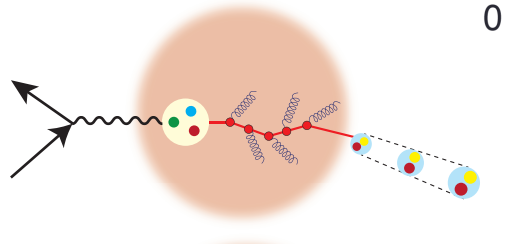
EIC science highlights

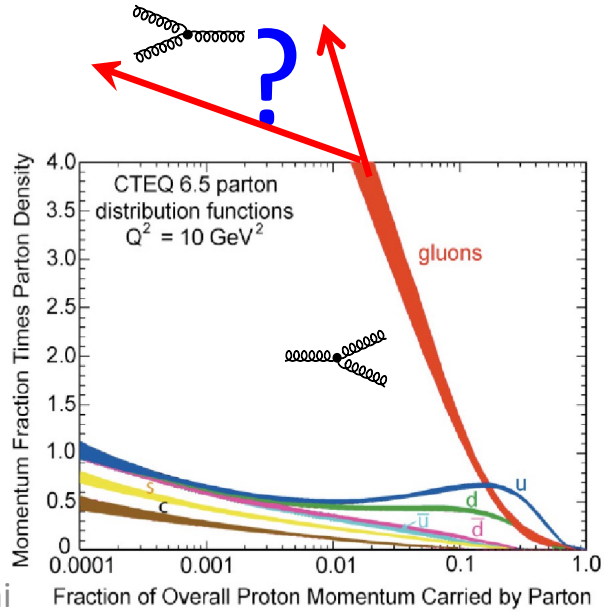




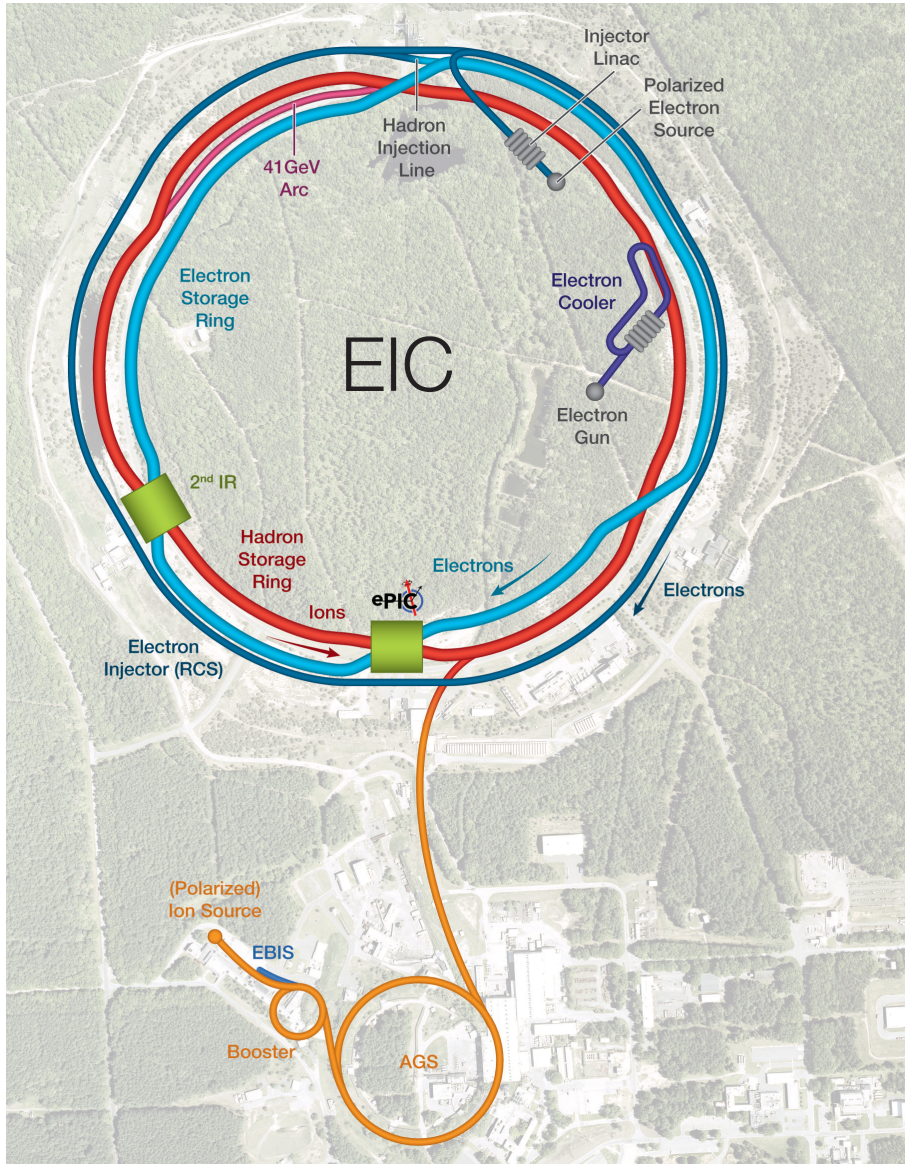




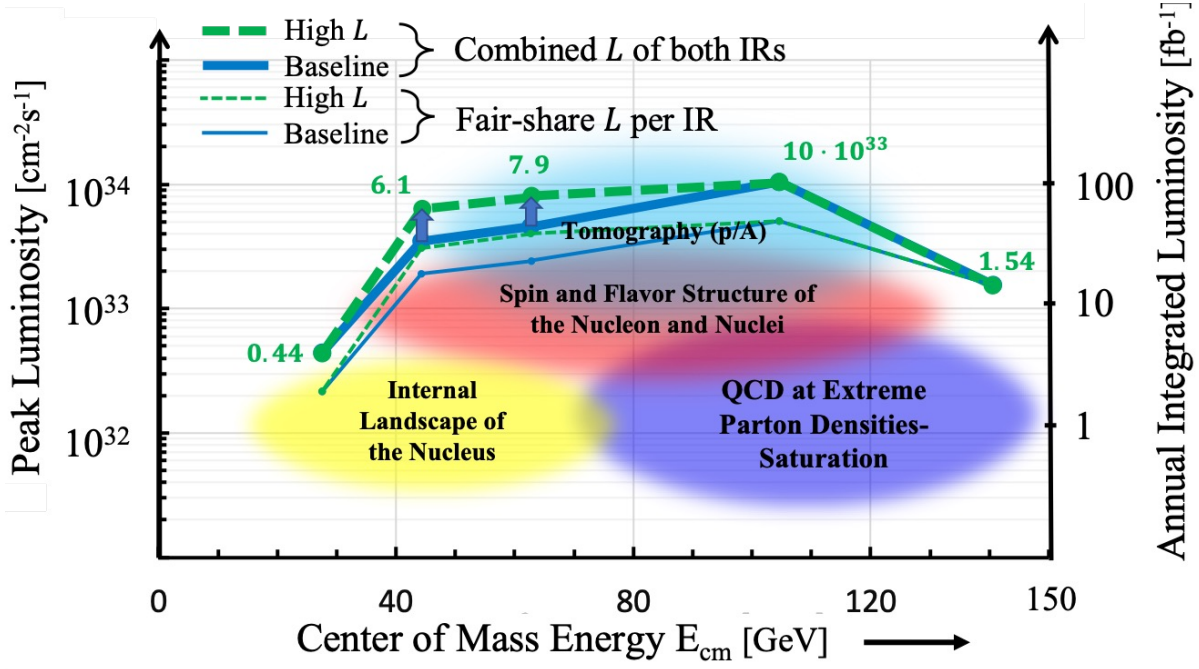




EIC Accelerator Design



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!



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

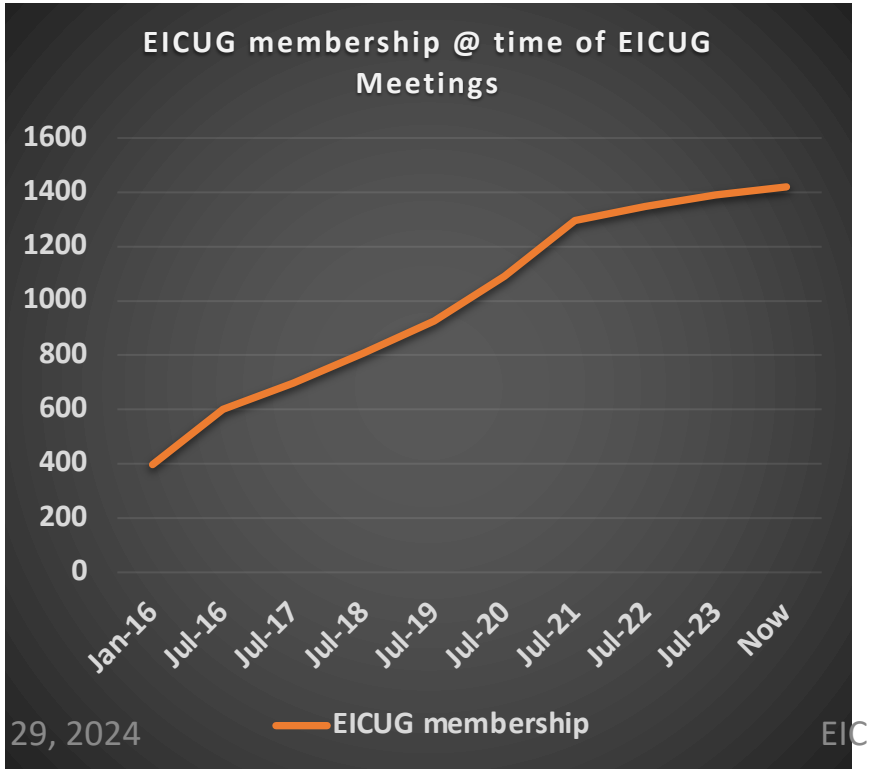
Worldwide Interest in EIC

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

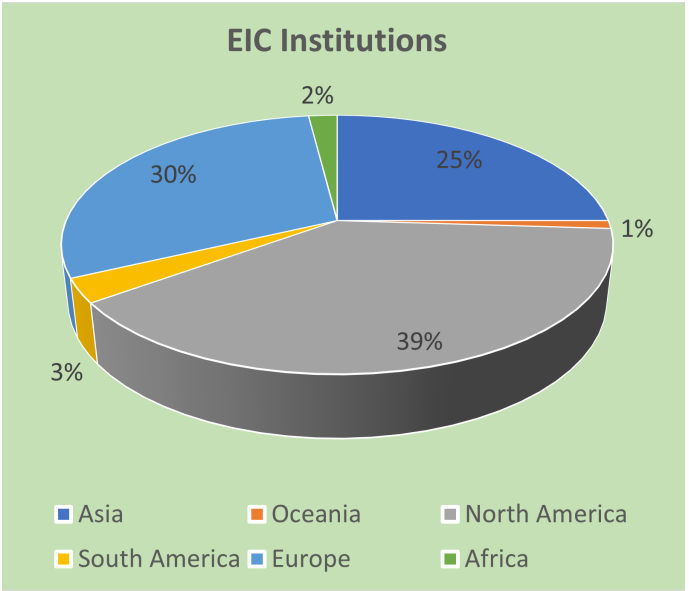
Formed 2016 –
- **1417 collaborators,**
- **37 countries,**
- **285 institutions**

as of October 02, 2023.

Strong International Participation.

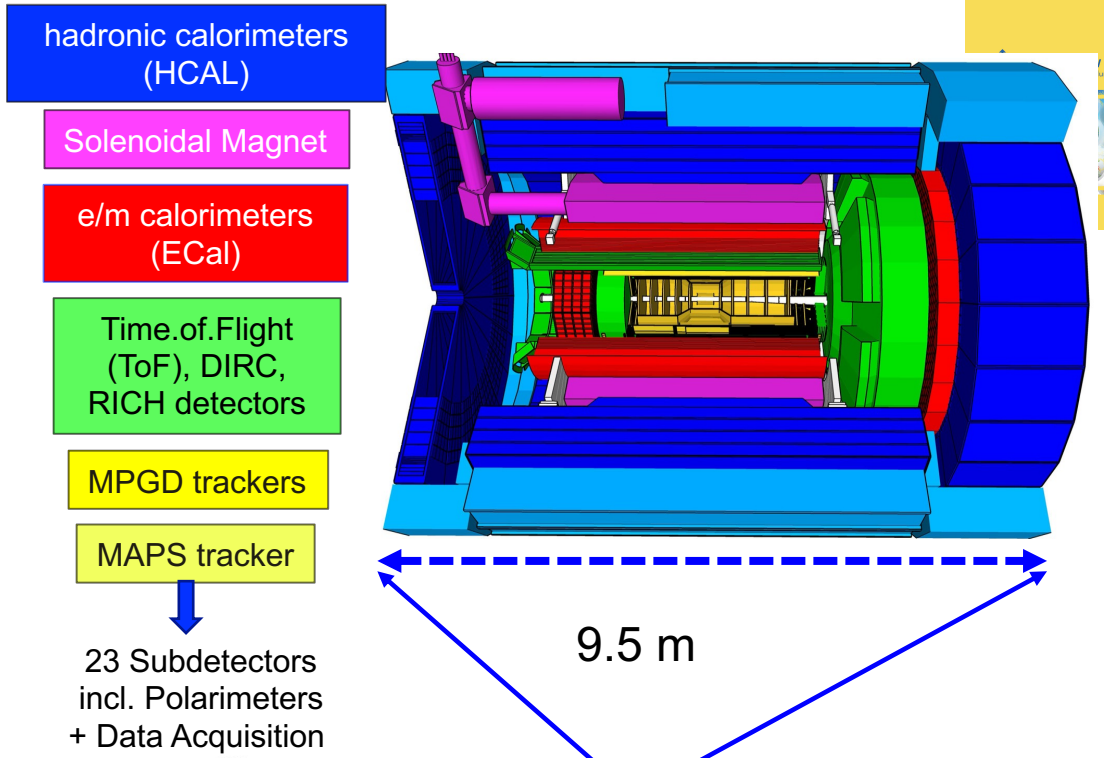


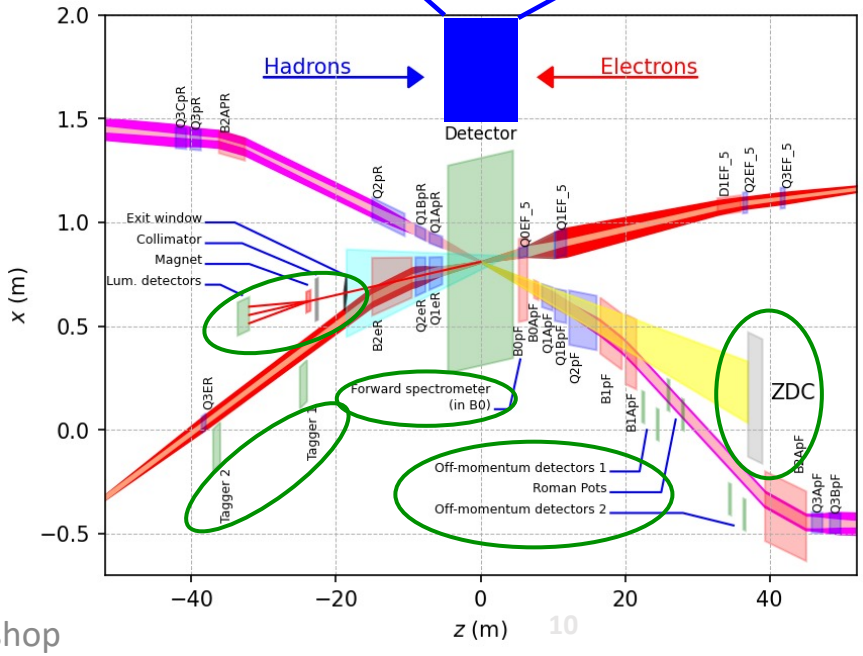
Annual EICUG meeting
2016 UC Berkeley, CA
2016 Argonne, IL
2017 Trieste, Italy
2018 CUA, Washington, DC
2019 Paris, France
2020 FIU, Miami, FL
2021 VUU, VA & UCR, CA
2022 Stony Brook U, NY
2023 Warsaw, Poland
2024 Lehigh U, PA



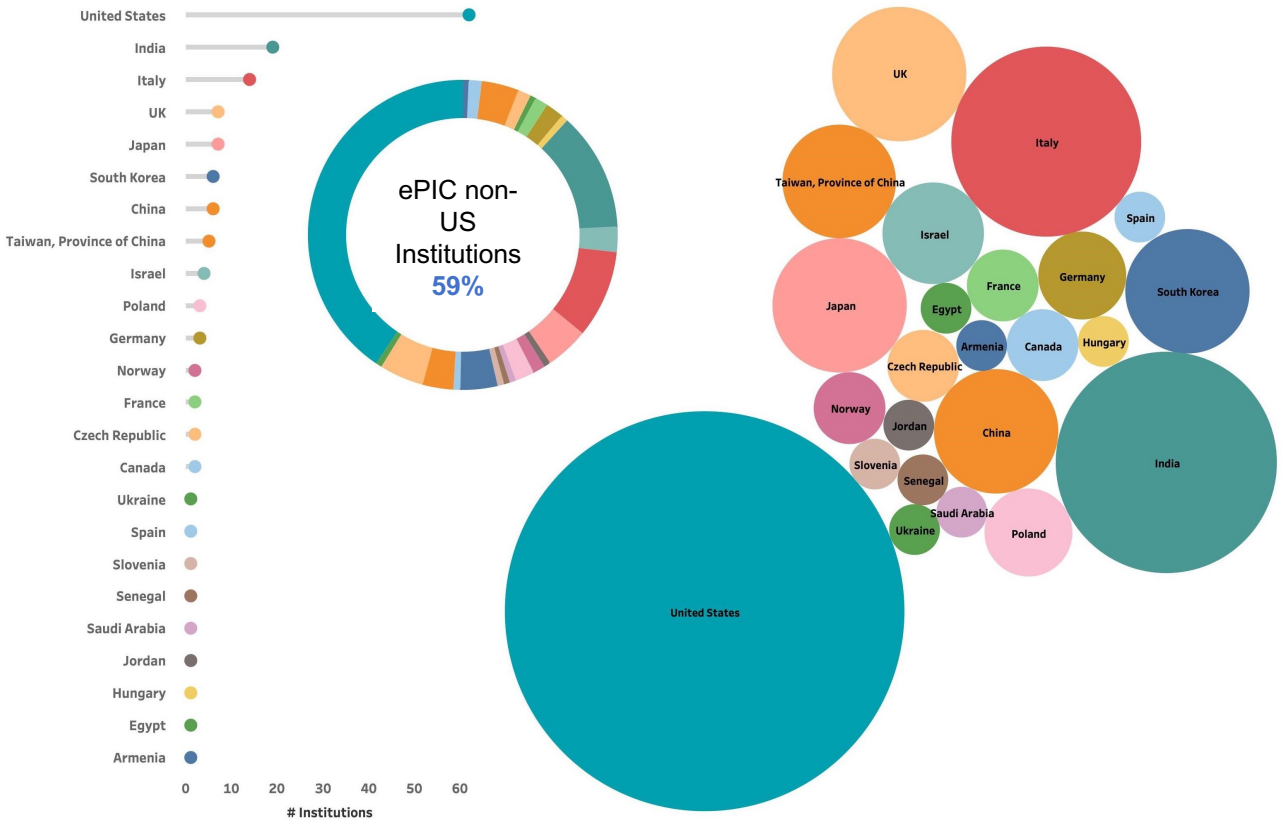
The ePIC Detector

- 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





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

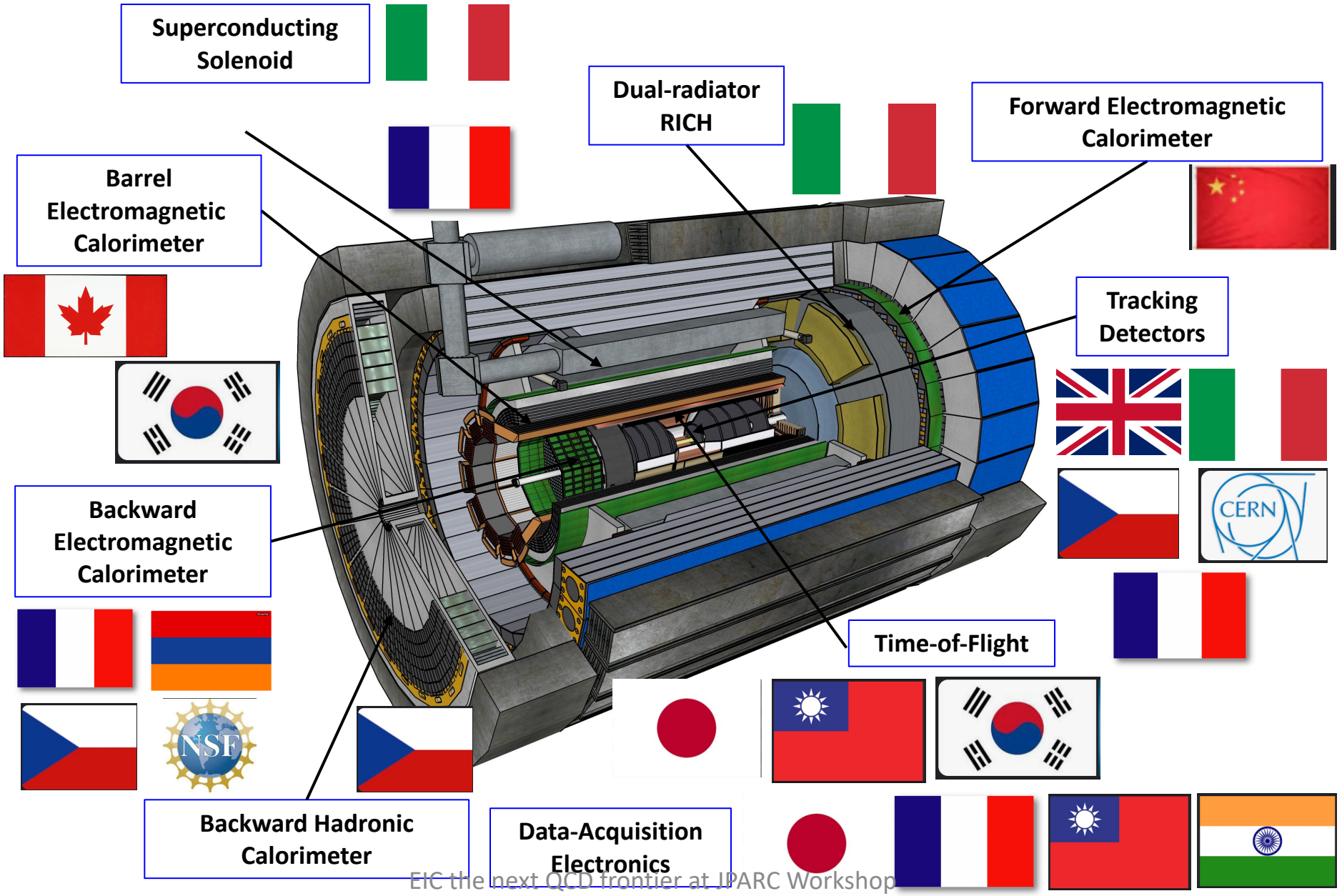
500+ participants

A global pursuit for a new experiment at the EIC!

ePIC Spokesperson:
John Lajoie (ORNL)

ePIC Deputy Spokesperson:
Silvia Dalla Torre (INFN Trieste)

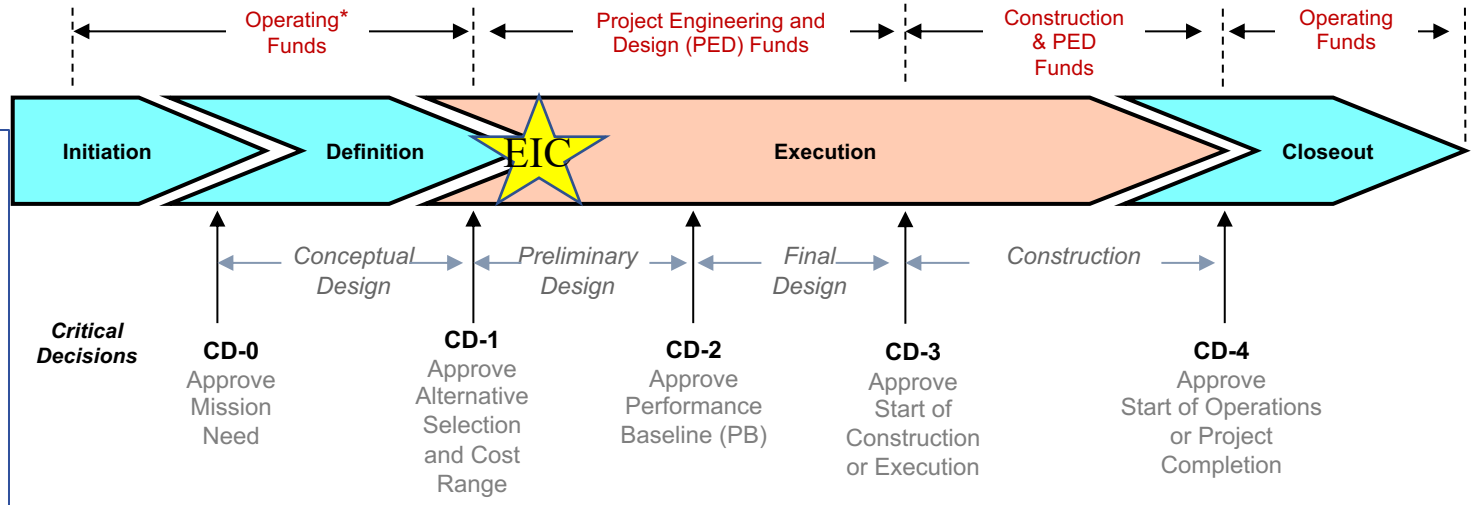
Central Detector Non-DOE Interest & In-Kind

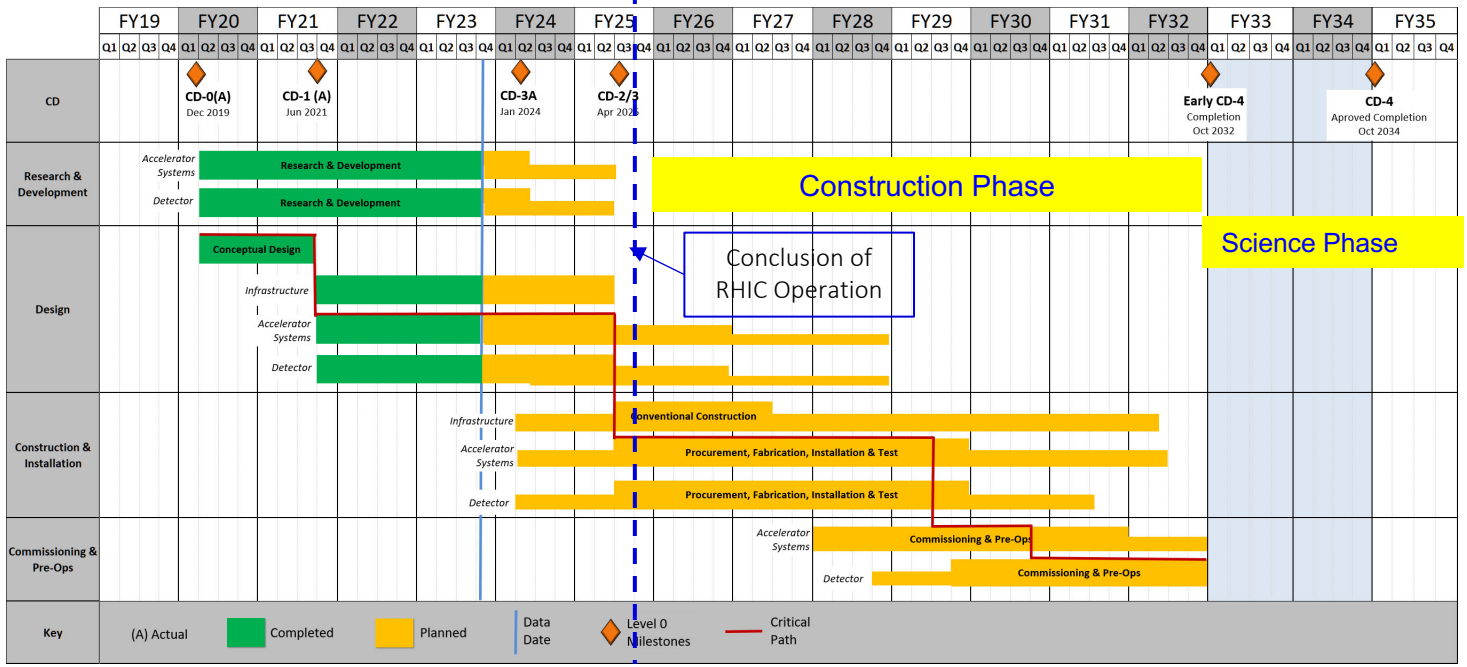


Timeline:

EIC Critical Decision Plan

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





CD-3A: (review mid-November)

Define Baseline:

technologies, Scope, Cost & Schedule

Long Lead Procurement (LLP) items

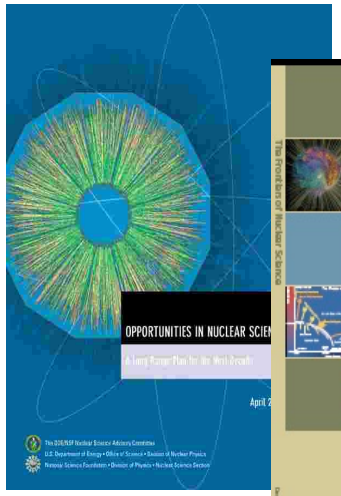
Design Maturity: ~90%

Plan is tracked through EVMS & Change control process

Start of construction for LLPs

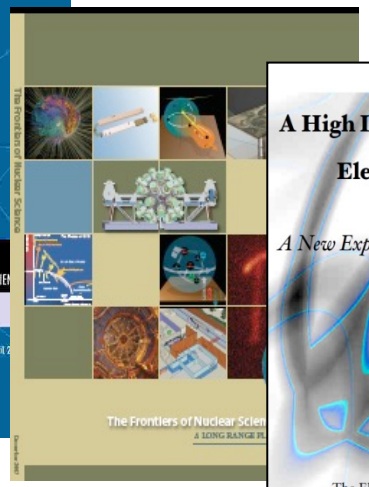
The Scientific Foundation for an EIC was Built Over Two Decades

2002



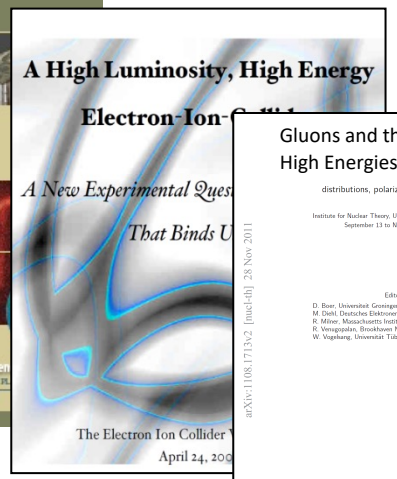
"…essential accelerator and detector R&D [for EIC] should be given very high priority in the short term."

2007



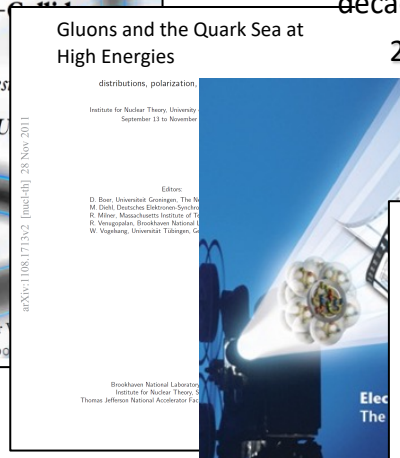
"We recommend the allocation of resources …to lay the foundation for a polarized Electron-Ion Collider…"

2009

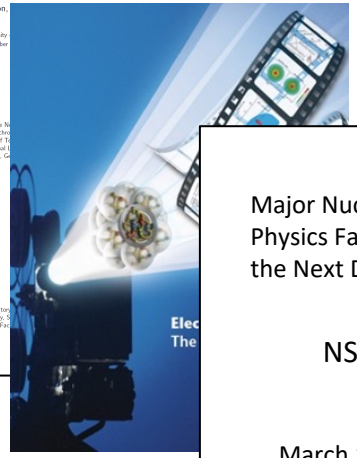


"..a new dedicated facility will be essential for answering some of the most central questions."

2010



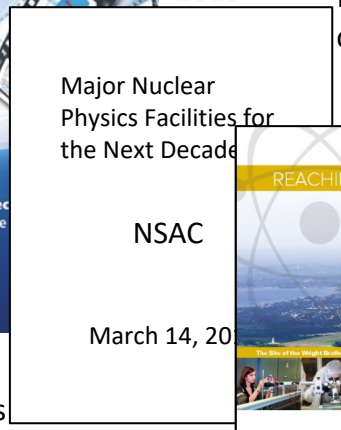
2012



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

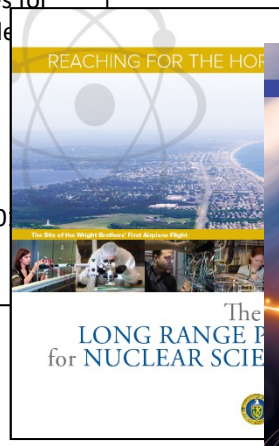
Electron-Ion Collider..*absolutely central* to the nuclear science program of the next decade.

2013



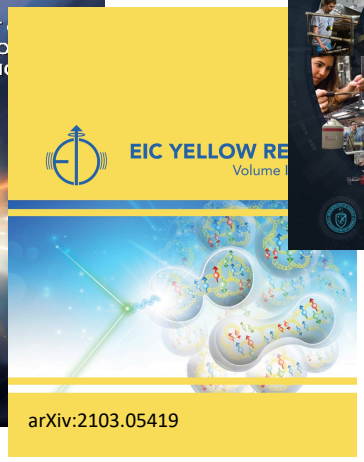
"a high-energy high-luminosity polarized EIC [is] the highest priority for new facility construction following the completion of FRIB."

2015



2018

2021



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

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."

2023

Build expeditiously

Exciting news this week:

- 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

There is exciting time ahead

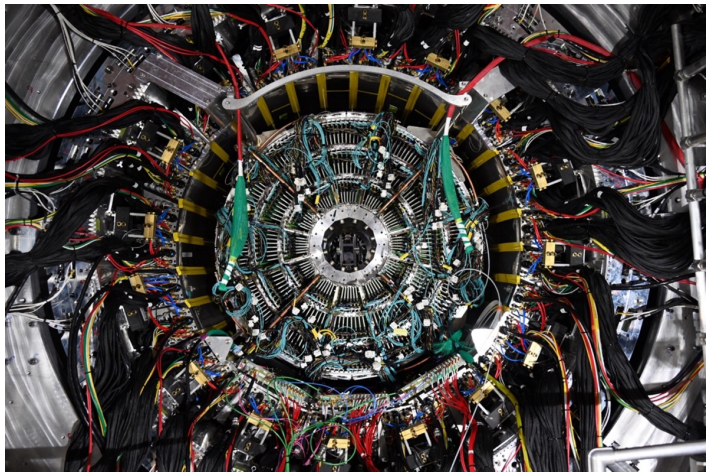
- New polarized collider, new ion collider, new challenges
- New detector, new physics program
- Opportunities for new physics limited only by the imagination of early career scientists, postdocs and students

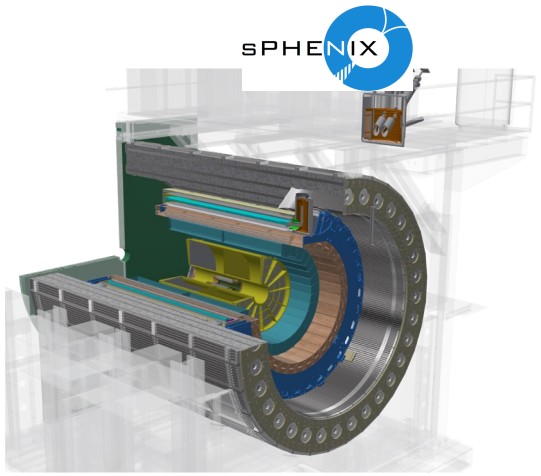
- Japan has a great history of collaboration at BNL : US-Japan Collaboration in HEP, RIKEN BNL Research Center for NP/RHIC
- It behooves us not to explore possibilities for the future on EIC; We look forward to continuing that tradition

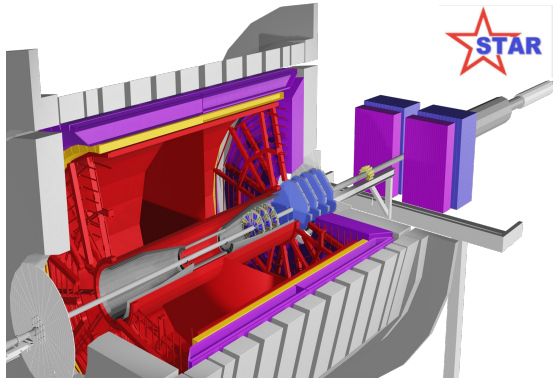
Completing the RHIC Mission with sPHENIX and STAR

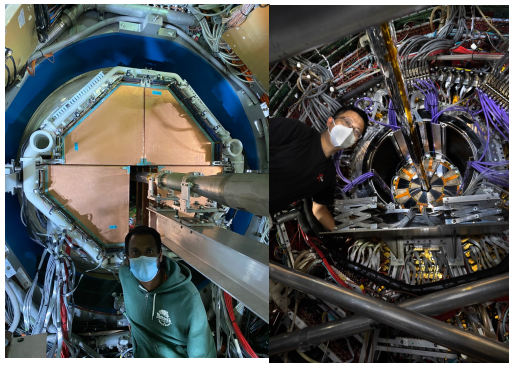
- sPHENIX will use energetic probes (jets, heavy quarks) to study quark-gluon plasma with unprecedented precision
  - How the structureless "perfect" fluid emerges from the underlying interactions of quarks and gluons at high temperature
- sPHENIX outer hadron calorimeter will be part of the EIC project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