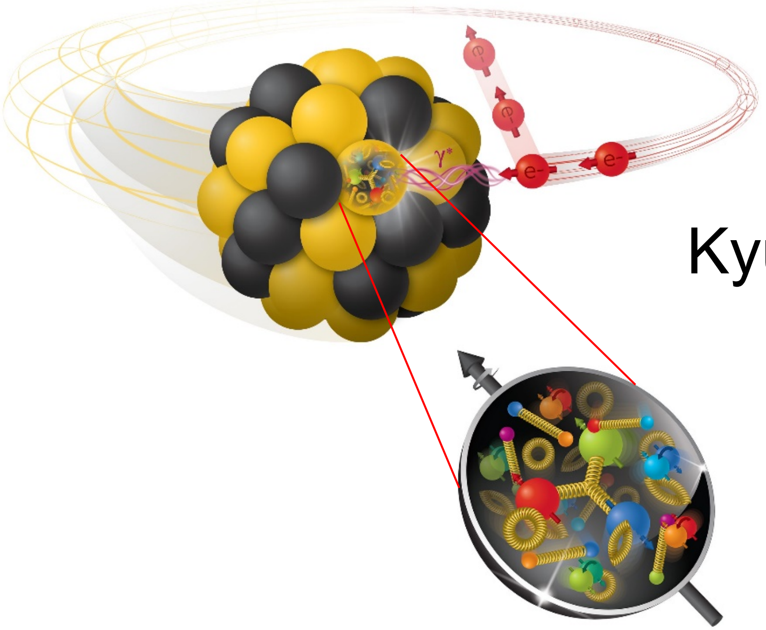
Electron-Ion Collider(EIC)의 소개 및 건설 로드맵



Hyon-Suk Jo

Kyungpook National University

KSHEP 2024 Spring Meeting

서울대학교 – 2024.05.23

Science of the Electron-Ion Collider (EIC)

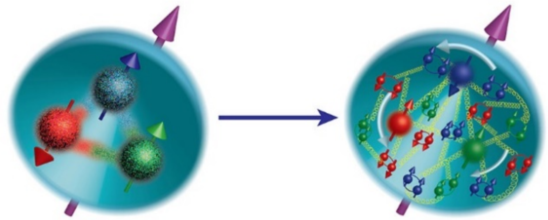
- The Electron-Ion Collider will further improve our understanding of the structure of the nucleon (proton and neutron) and nuclei by studying the **sea quarks** and the **gluons**.

- How are the (sea) quarks and gluons distributed in **space** and **momentum** inside the nucleon?

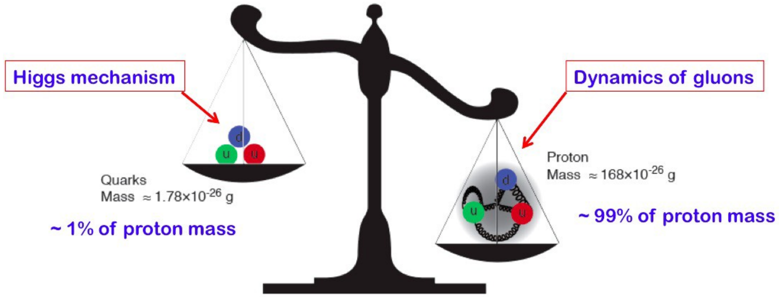
- Massless gluons and almost massless quarks, **through their interactions**, generate most of the mass of the nucleons and hence the entire visible world. How?

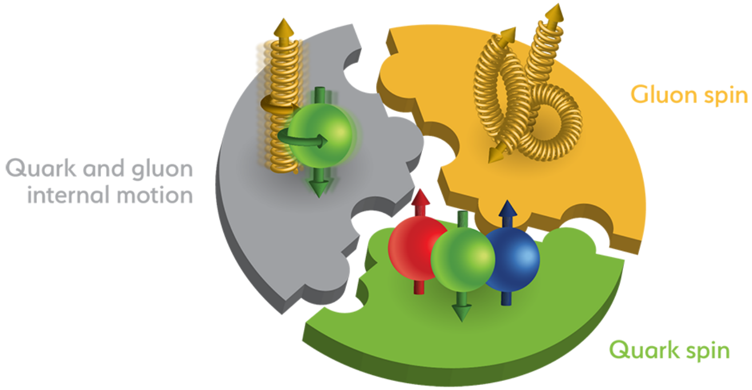
- What are the emergent properties of high-density systems of gluons?

- What is the origin of the **proton spin**?

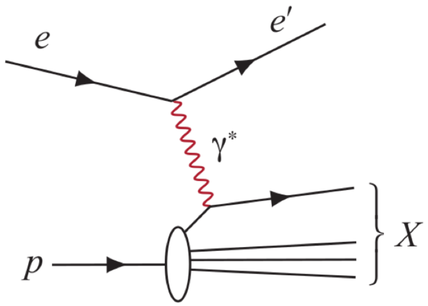


valence quarks **sea quarks and gluons**





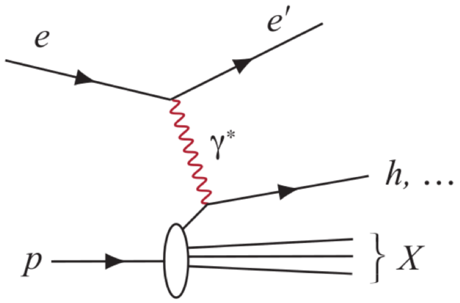
Experimental Processes to Access EIC Physics



Inclusive Deep Inelastic Scattering (DIS)

- Detection of scattered electron

Parton Distributions in nucleons and nuclei

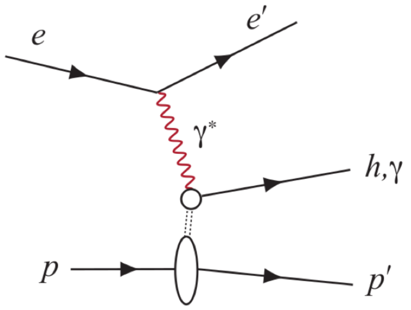


Semi-Inclusive DIS

- Detection of scattered electron in coincidence with at least 1 hadron

Spin and Flavor structure of nucleons and nuclei

Tomography Transverse Momentum Dist.



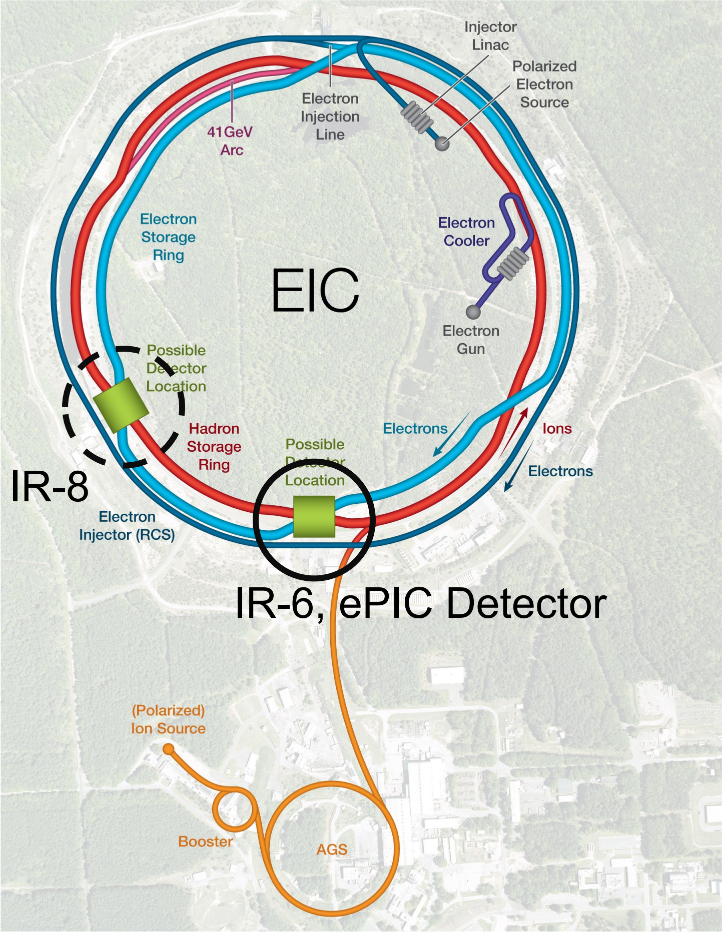
Deep Exclusive Processes

- Detection of all particles

QCD at Extreme Parton Densities - Saturation

Tomography Spatial Imaging

The Electron-Ion Collider (EIC) at Brookhaven National Laboratory (BNL)



Brookhaven National Laboratory (BNL)

EIC Project Design Goals

- High Luminosity: L=10^{33} – 10^{34} $cm^{-2}sec^{-1}$, 10 – 100 fb^{-1}/year

The EIC luminosity will be a factor 100 to 1000 higher than at HERA

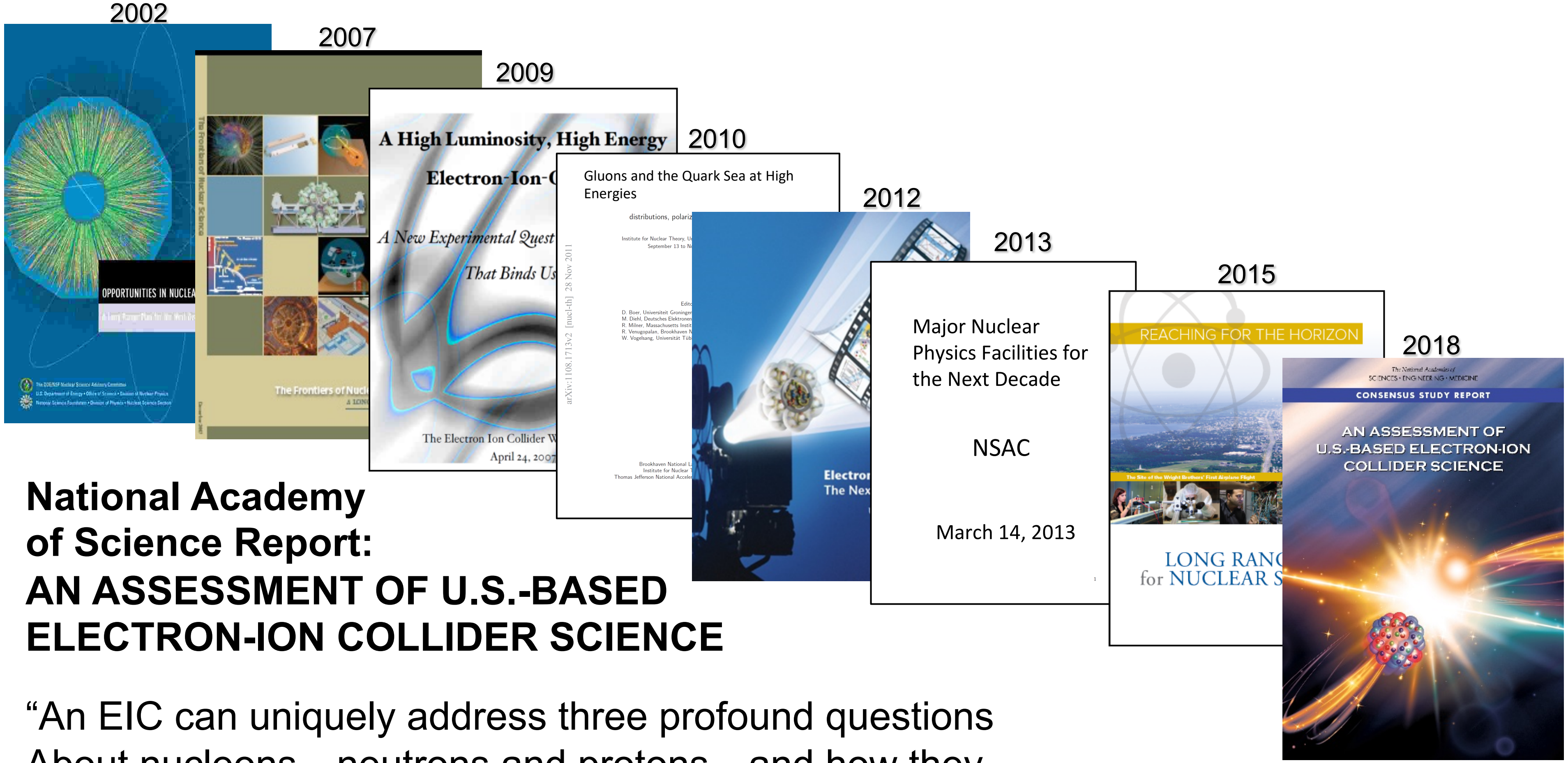
- Highly Polarized Beams: 70%
- Large Center of Mass Energy Range: E_{cm} = 20 - 140 GeV
- Large Ion Species Range: protons - Uranium
- Large Detector Acceptance and Good Background Conditions
- Possibility of a Second Interaction Region (IR)

p/A beam → ← e beam

p: 41 GeV, 100 to 275 GeV

e: 5 GeV to 18 GeV

Building the EIC Scientific Foundation Over Two Decades



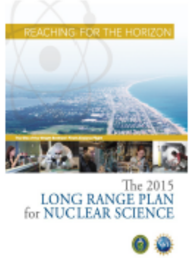
National Academy of Science Report:
AN ASSESSMENT OF U.S.-BASED ELECTRON-ION COLLIDER SCIENCE

"An EIC can uniquely address three profound questions About nucleons—neutrons and protons—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?"**

Electron-Ion Collider (EIC) Milestones

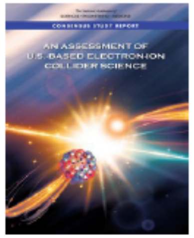
2012-14: EIC White Paper



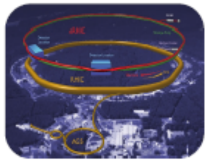
2015: NSAC Long-Range Plan

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

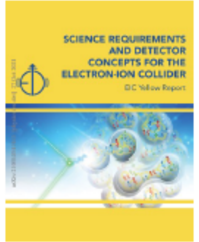
2016: EICUG Formation



2018: NAS Study & Report

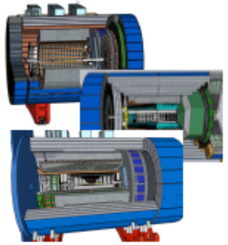


2020: Site Selection



2021: Yellow Report

2021: CDR & CD-0

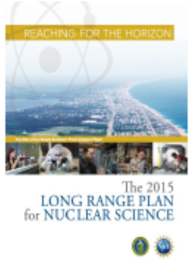


2022: DPAP Reference Design

2022: ePIC Collaboration!

Electron-Ion Collider (EIC) Milestones

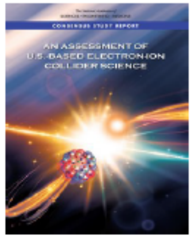
2012-14: EIC White Paper



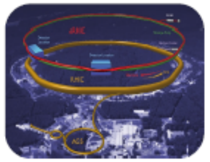
2015: NSAC Long-Range Plan

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

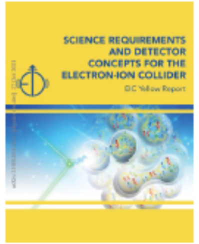
2016: EICUG Formation



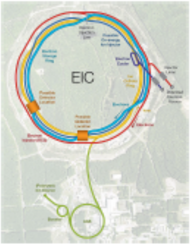
2018: NAS Study & Report



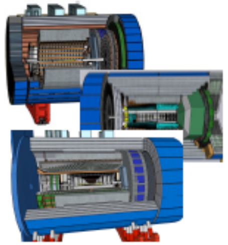
2020: Site Selection



2021: Yellow Report



2021: CDR & CD-0



2022: DPAP Reference Design

2022: ePIC Collaboration!

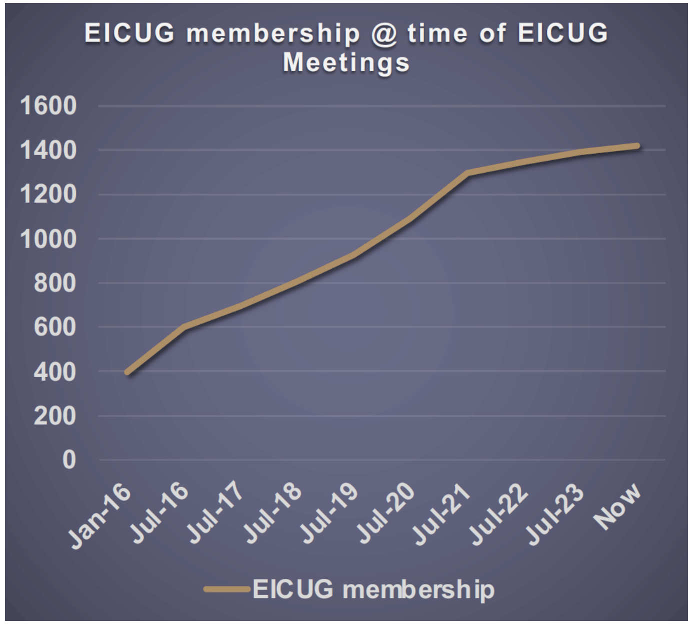
The Electron-Ion Collider User Group (EICUG)

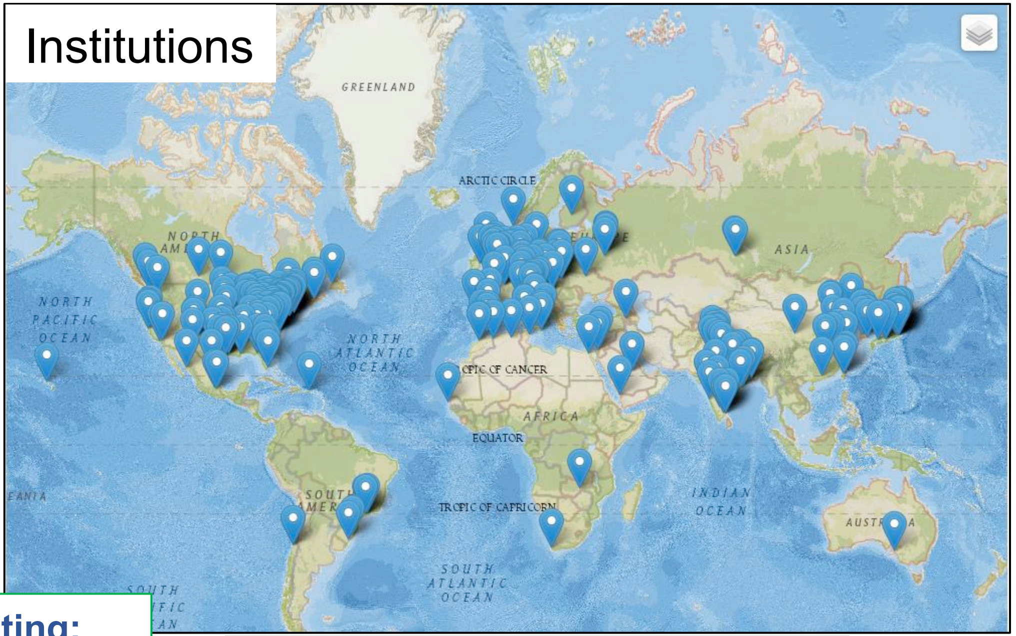
The EIC User Group:

EIC User Group formed in 2016

Status in April 2024:
- 1491 collaborators
- 40 countries
- 291 institutions

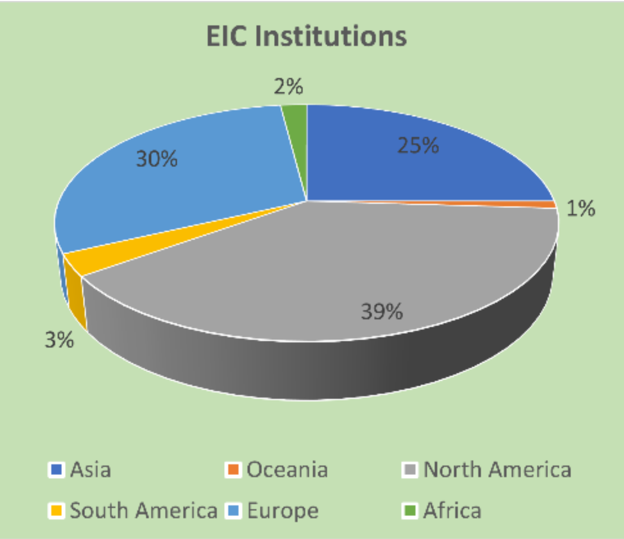
International participation still growing





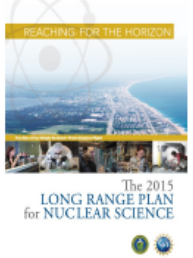
Annual EICUG meeting:

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



Electron-Ion Collider (EIC) Milestones

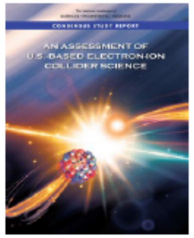
2012-14: EIC White Paper



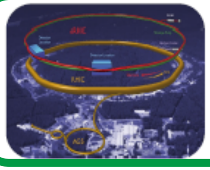
2015: NSAC Long-Range Plan

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

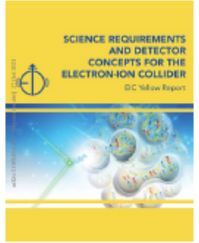
2016: EICUG Formation



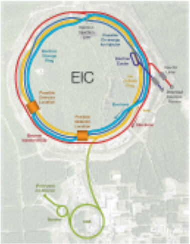
2018: NAS Study & Report



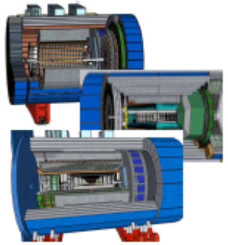
2020: Site Selection



2021: Yellow Report



2021: CDR & CD-0

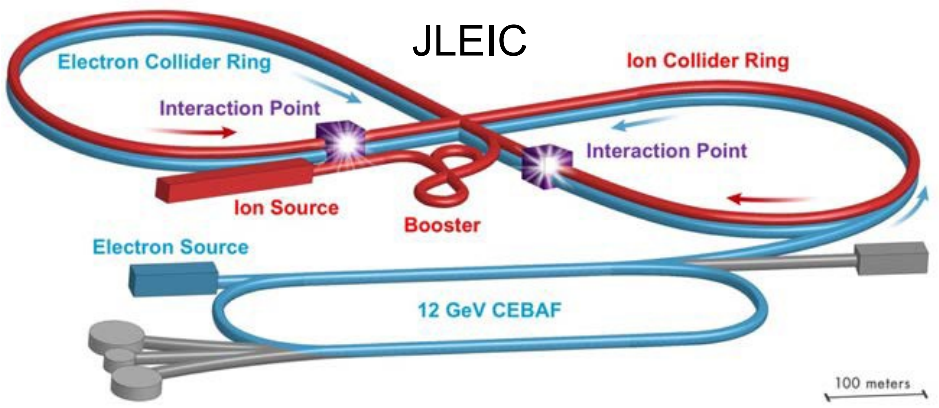


2022: DPAP Reference Design

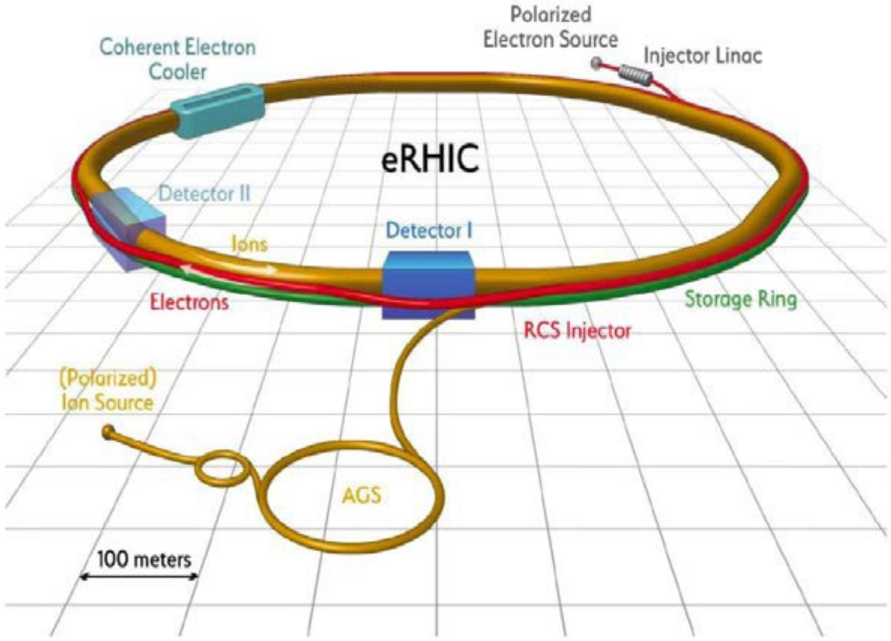
2022: ePIC Collaboration!

Review of Two Competing EIC Designs in 2019

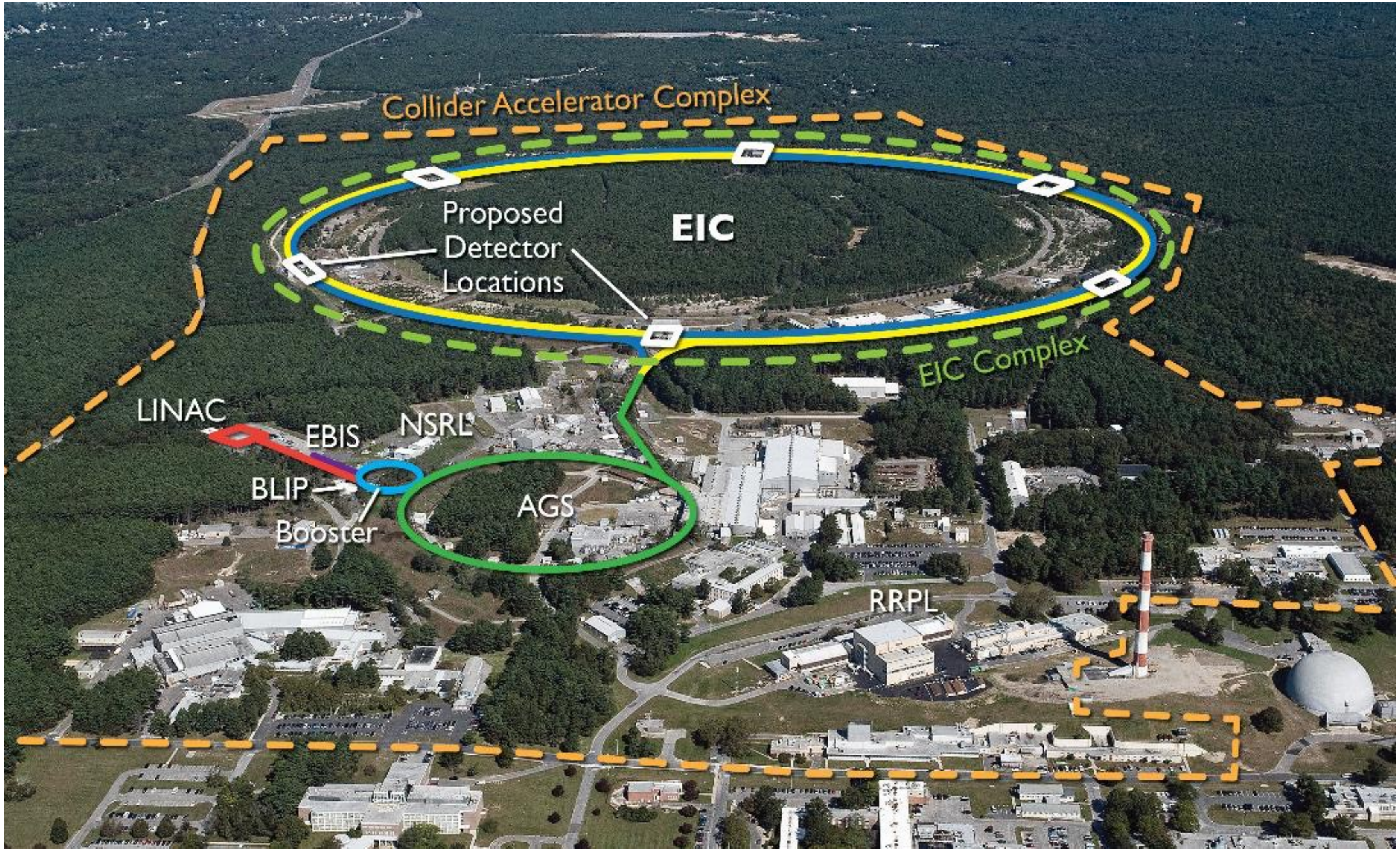
JLEIC (JLab):
- Upgrade to CEBAF 12 GeV electron beam
- New hadron injector



eRHIC (BNL):
- Upgrade to RHIC hadron beam
- New electron injector

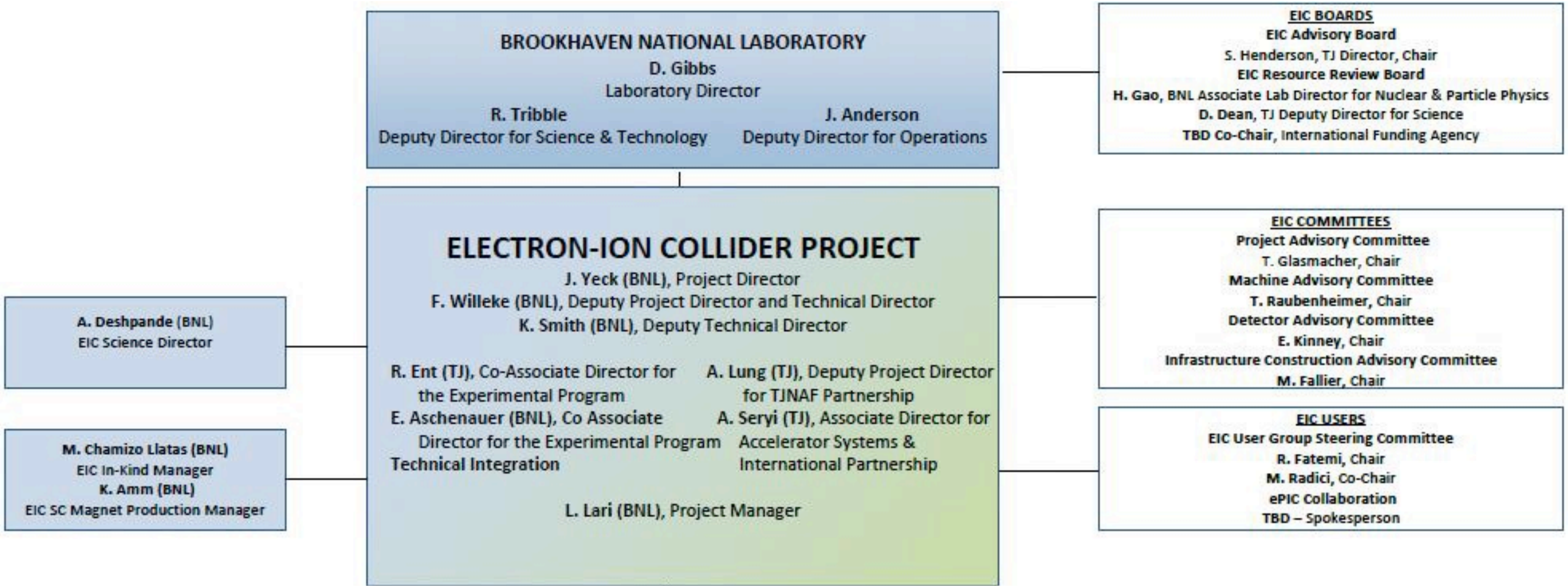


EIC Design from BNL Based on Existing RHIC Facility



EIC Project led by a BNL/JLab partnership

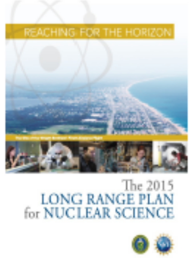
- BNL/JLab partnership established in early 2020
- BNL and JLab serve together as hosts for the EIC experimental program



TJ = Thomas Jefferson National Accelerator Facility (JLab)

Electron-Ion Collider (EIC) Milestones

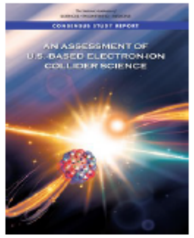
2012-14: EIC White Paper



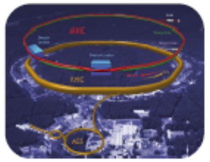
2015: NSAC Long-Range Plan

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

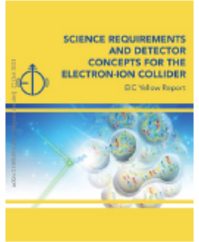
2016: EICUG Formation



2018: NAS Study & Report

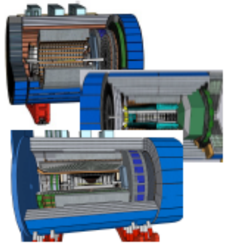


2020: Site Selection



2021: Yellow Report

2021: CDR & CD-0

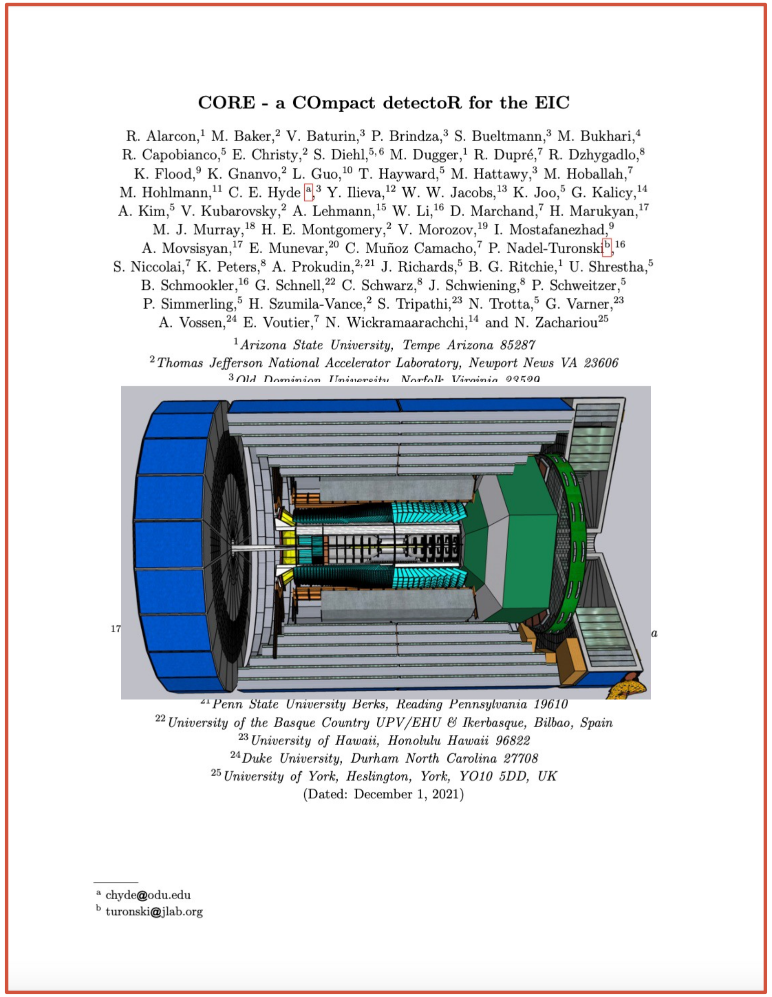


2022: DPAP Reference Design

ePIC **2022: ePIC Collaboration!**

ATHENA, ECCE, and CORE Proposals reviewed by an external panel

EIC Advisory Panel’s recommendation in April 2022



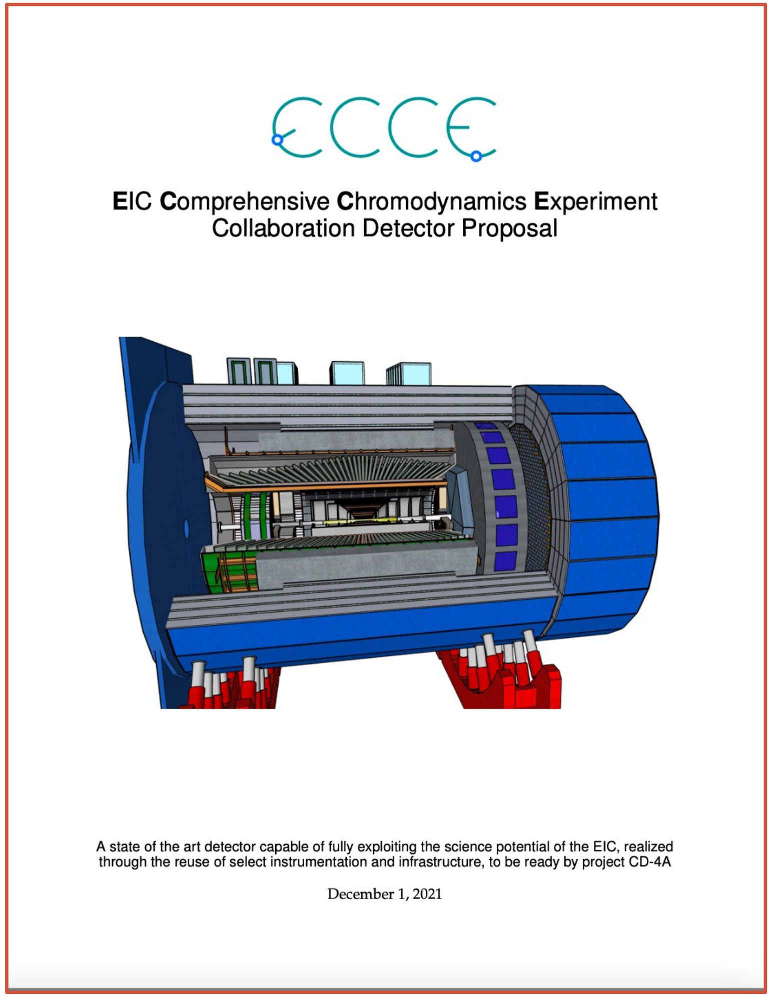
CORE - a COmpact detectoR for the EIC

R. Alarcon,[1] M. Baker,[2] V. Baturin,[3] P. Brindza,[3] S. Bueltmann,[3] M. Bukhari,[4] R. Capobianco,[5] E. Christy,[2] S. Diehl,[5,6] M. Dugger,[1] R. Dupré,[7] R. Dzhygadlo,[8] K. Flood,[9] K. Gnanvo,[2] L. Guo,[10] T. Hayward,[5] M. Hattawy,[3] M. Hoballah,[7] M. Hohlmann,[11] C. E. Hyde [a],[3] Y. Ilieva,[12] W. W. Jacobs,[13] K. Joo,[5] G. Kalicy,[14] A. Kim,[5] V. Kubarovsky,[2] A. Lehmann,[15] W. Li,[16] D. Marchand,[7] H. Marukyan,[17] M. J. Murray,[18] H. E. Montgomery,[2] V. Morozov,[19] I. Mostafanezhad,[9] A. Movsisyan,[17] E. Munevar,[20] C. Muñoz Camacho,[7] P. Nadel-Turonski [b],[16] S. Niccolai,[7] K. Peters,[8] A. Prokudin,[2,21] J. Richards,[5] B. G. Ritchie,[1] U. Shrestha,[5] B. Schmookler,[16] G. Schnell,[22] C. Schwarz,[8] J. Schwiening,[8] P. Schweitzer,[5] P. Simmerling,[5] H. Szumila-Vance,[2] S. Tripathi,[23] N. Trotta,[5] G. Varner,[23] A. Vossen,[24] E. Voutier,[7] N. Wickramaarachchi,[14] and N. Zachariou[25]

[1] *Arizona State University, Tempe Arizona 85287*
[2] *Thomas Jefferson National Accelerator Laboratory, Newport News VA 23606*
[3] *Old Dominion University, Norfolk Virginia 23529*

[21] *Penn State University Berks, Reading Pennsylvania 19610*
[22] *University of the Basque Country UPV/EHU & Ikerbasque, Bilbao, Spain*
[23] *University of Hawaii, Honolulu Hawaii 96822*
[24] *Duke University, Durham North Carolina 27708*
[25] *University of York, Heslington, York, YO10 5DD, UK*
(Dated: December 1, 2021)

[a] chyde@odu.edu
[b] turonski@jlab.org



ATHENA, ECCE, and CORE Proposals reviewed by an external panel

All three proposals received high marks

Concluded that both ATHENA and ECCE satisfied the requirements

Congratulated CORE for some good ideas but too small overall

Recommended ECCE as the “reference design”: lower risk and cost

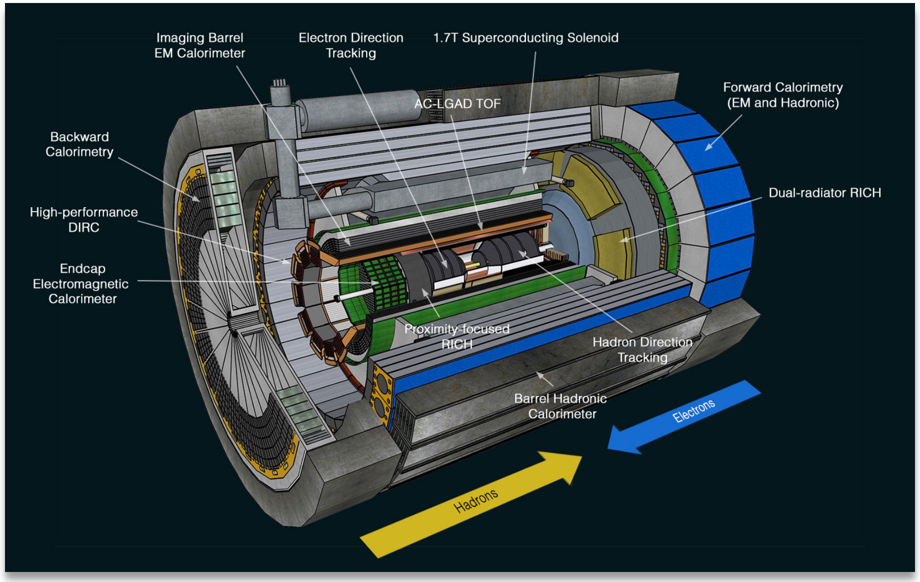
- ATHENA, ECCE – collaborator overlap – neither large enough to become Detector 1
- Strongly encouraged the two collaborations to merge and build the **Project Detector** starting from ECCE‘s reference design

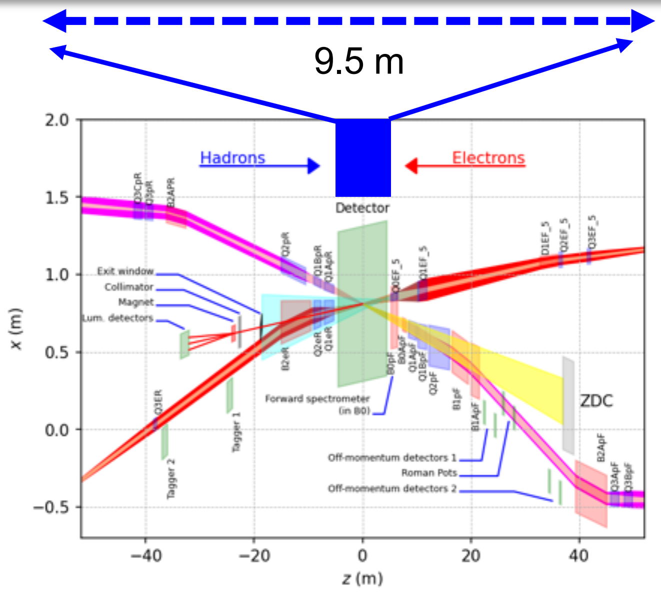
July 2022: (ATHENA + ECCE) : electron Proton Ion Collider (**ePIC**) Detector Collaboration formed

➔ working together to realize the EIC science

Enthusiastically supported the idea of a **second detector for the 2nd IR**

The ePIC Detector (Central Detector)





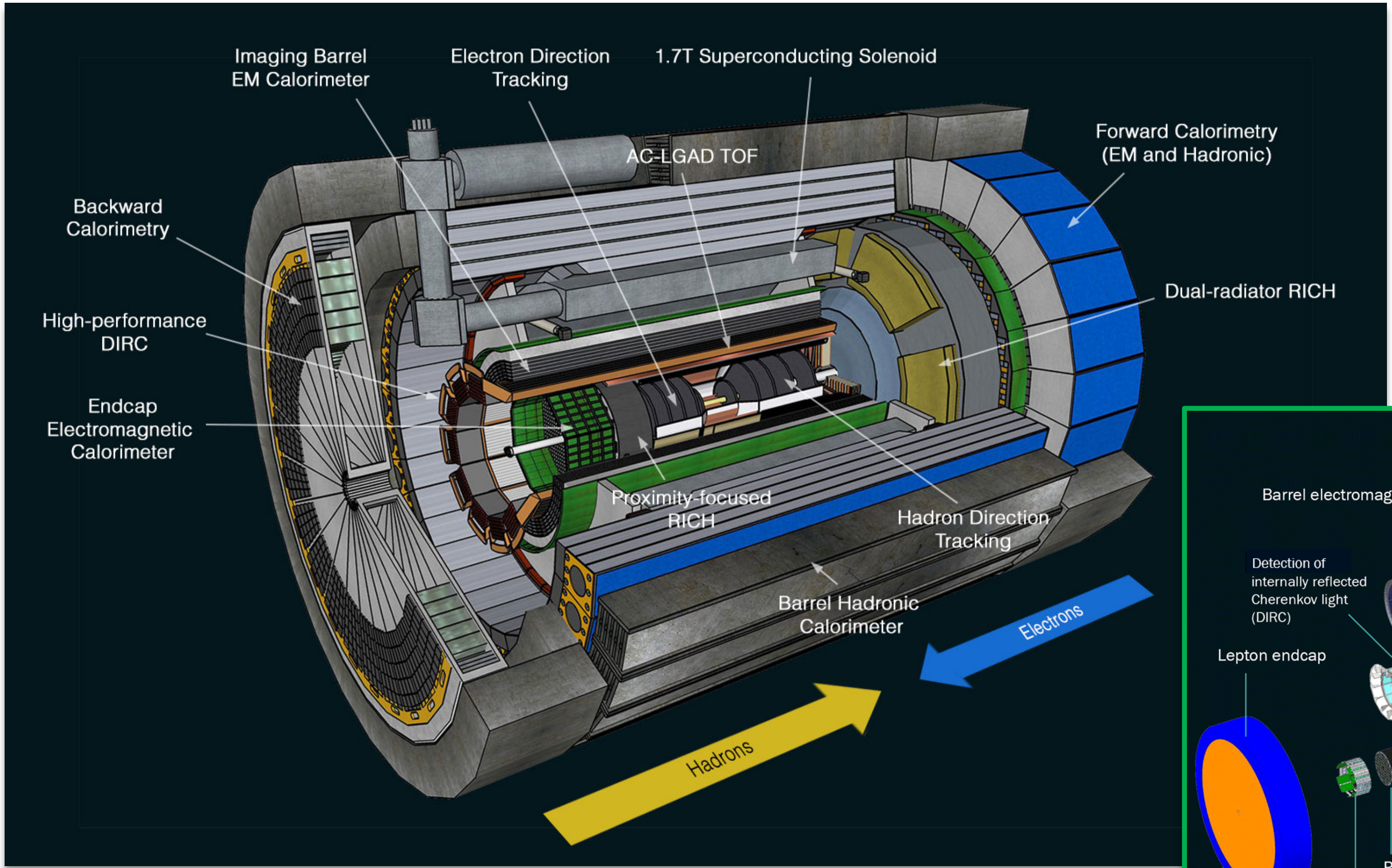
ePIC = electron Proton Ion Collider

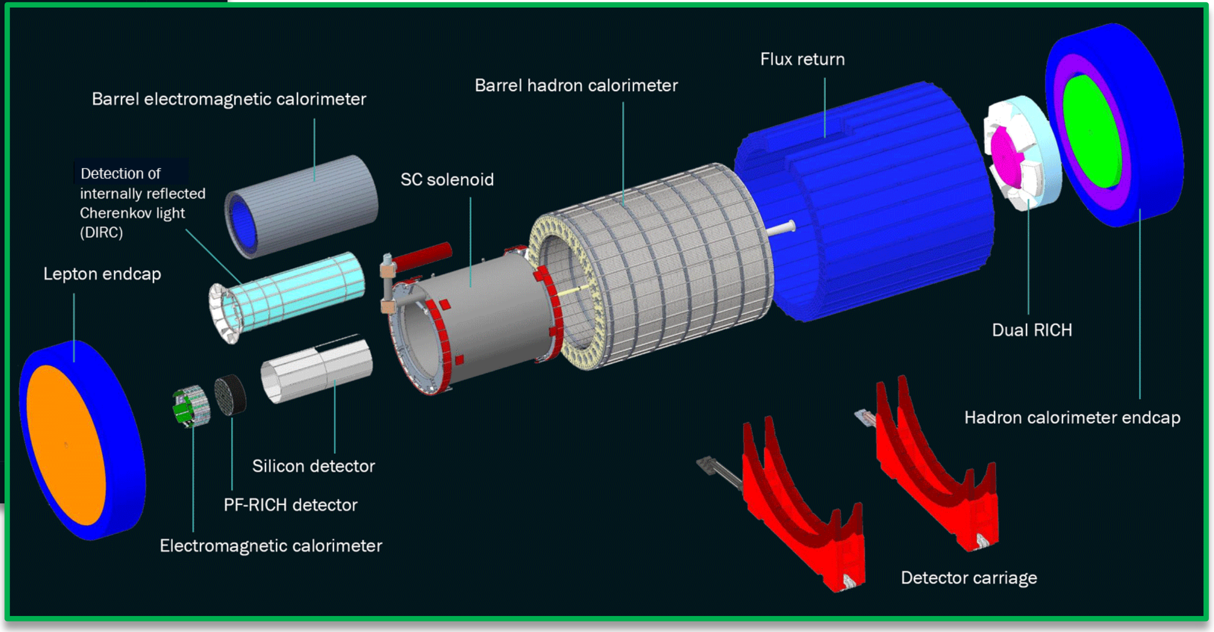
The ePIC Detector will include:

- A 1.7 Tesla superconducting magnet for curving the trajectories of charged particles created in these collisions
- High-precision silicon detectors for tracking particle trajectories in the magnetic field
- Precise calorimeters for measuring the energy of electromagnetic particles with exquisite precision
- A suite of particle identification technologies for determining the quark content of particles over a wide range of energies
- Dense calorimetric detectors at the outer radius of the cylindrical detector to allow the measurement of “jets”

The ePIC Detector (Central Detector)

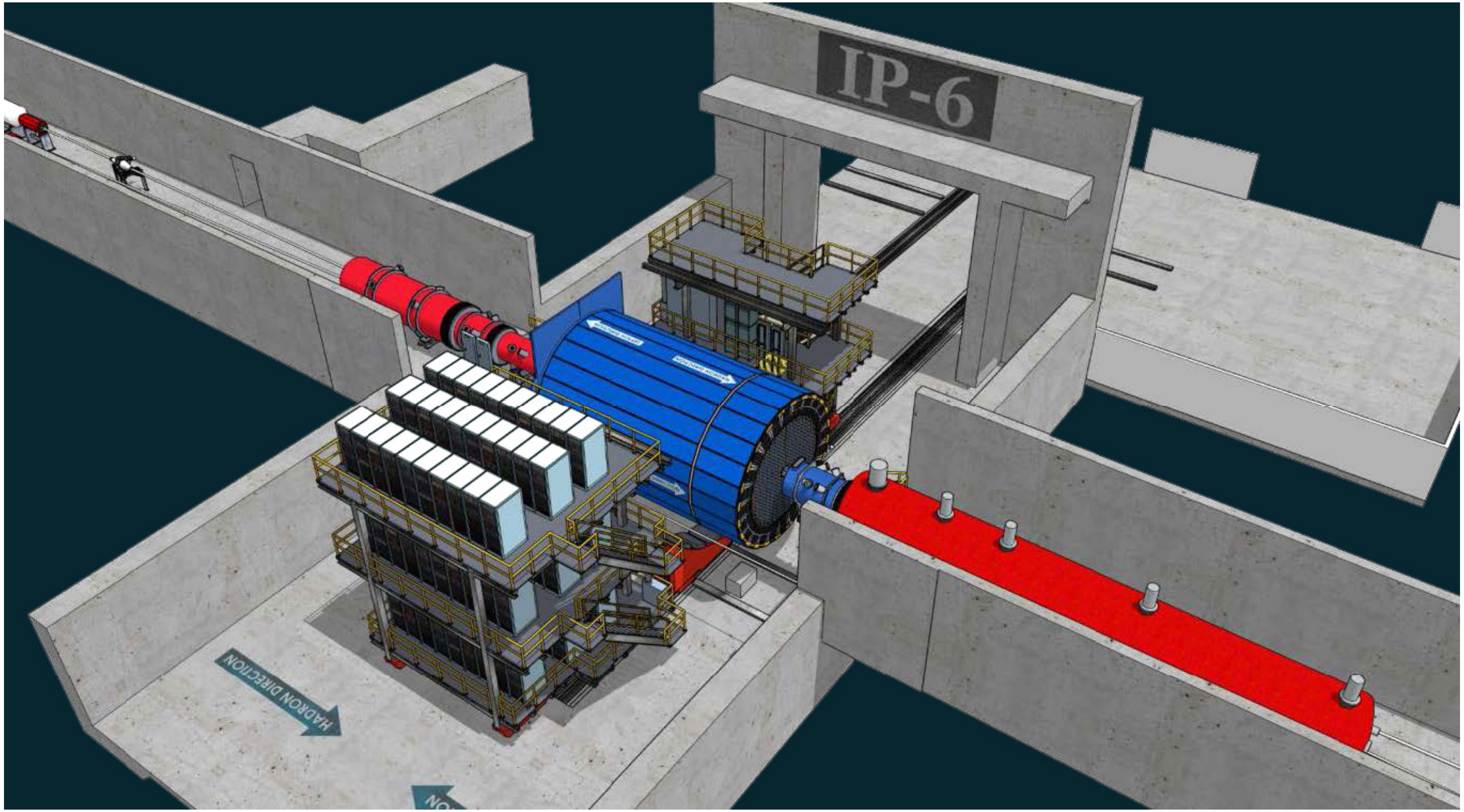
ePIC = electron Proton Ion Collider



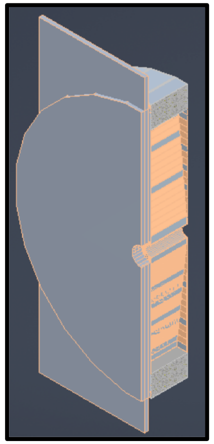


The ePIC Detector (Central Detector) at IP-6

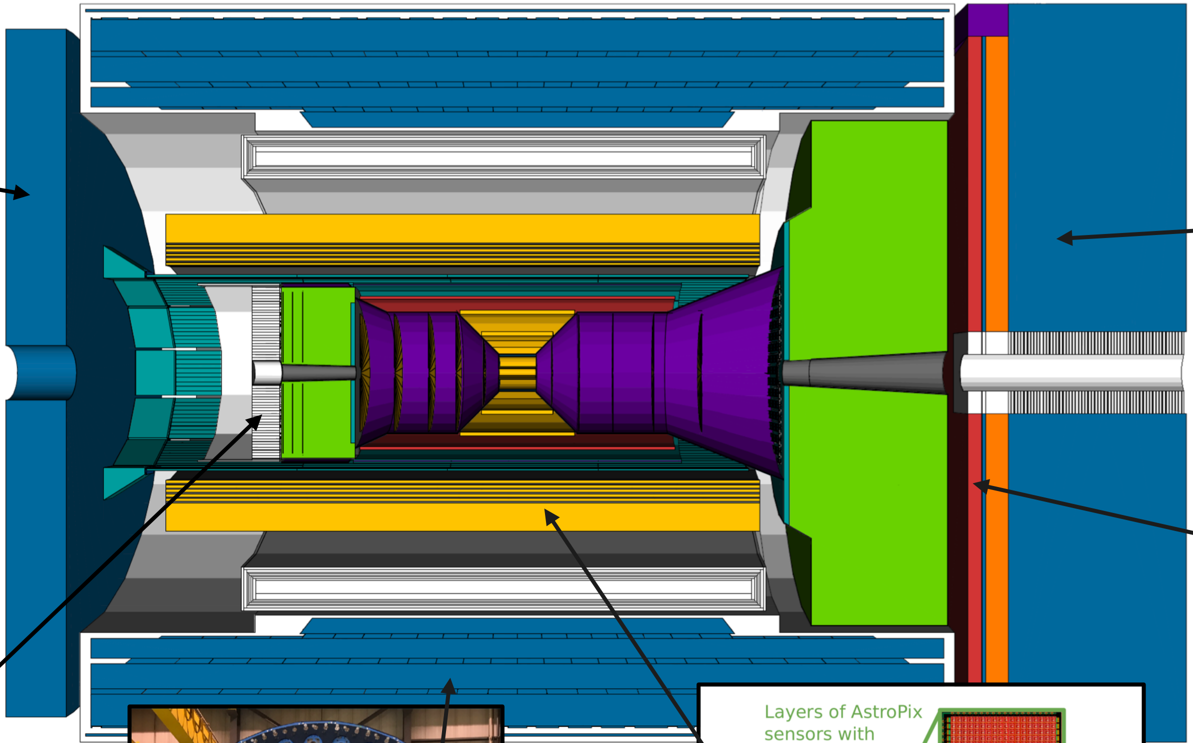
ePIC = electron Proton Ion Collider

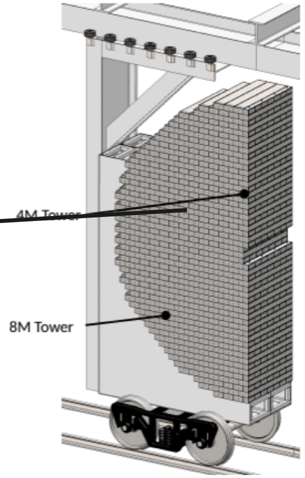


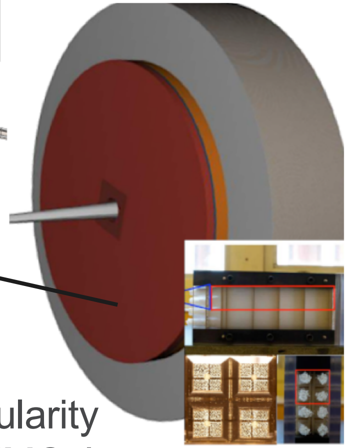
Calorimeters of the ePIC Detector



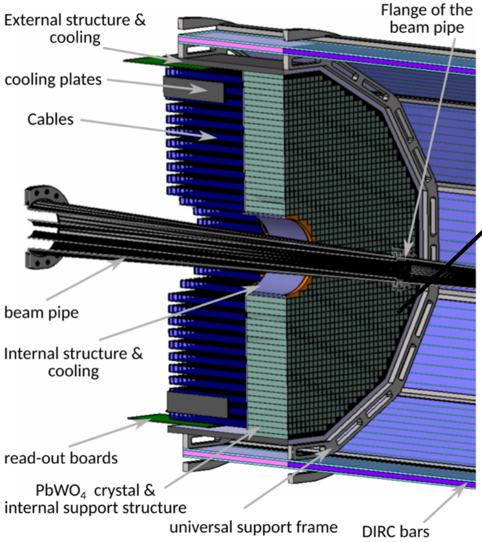
Backwards HCal Steel/Sc Sandwich tail catcher



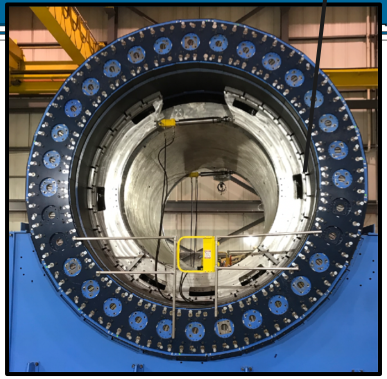




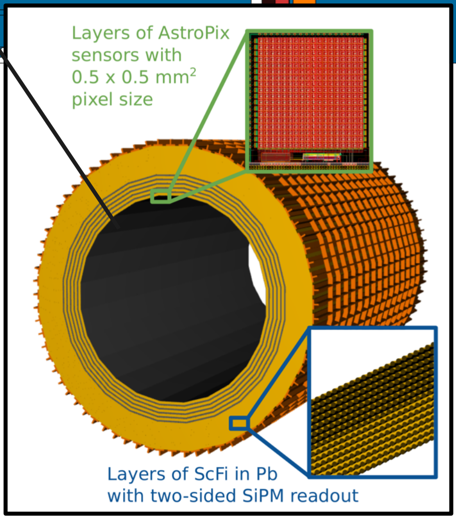
High granularity W/SciFi EMCal Longitudinally separated HCAL with high-η insert



Backwards EMCal $PbWO_4$ crystals

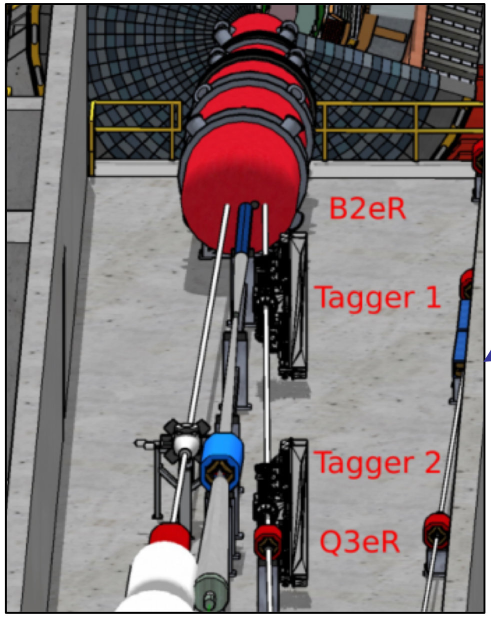


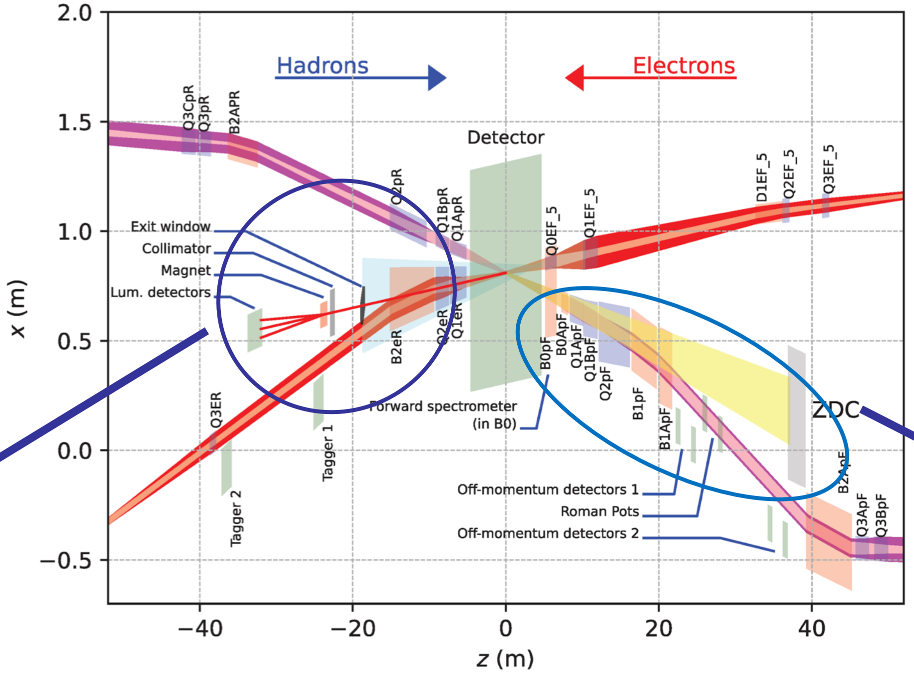
Barrel HCAL (sPHENIX re-use)

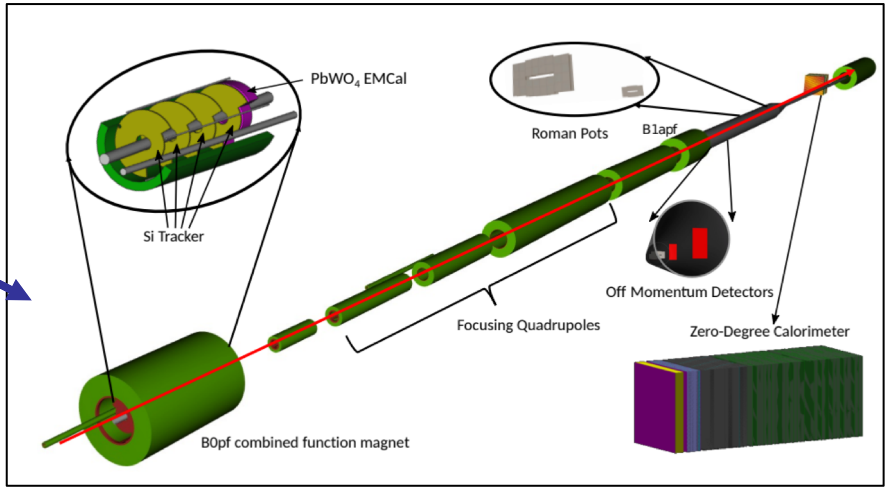


Imaging Barrel ECAL

Far-Forward and Far-Backward Detectors







Far-Backward Detectors

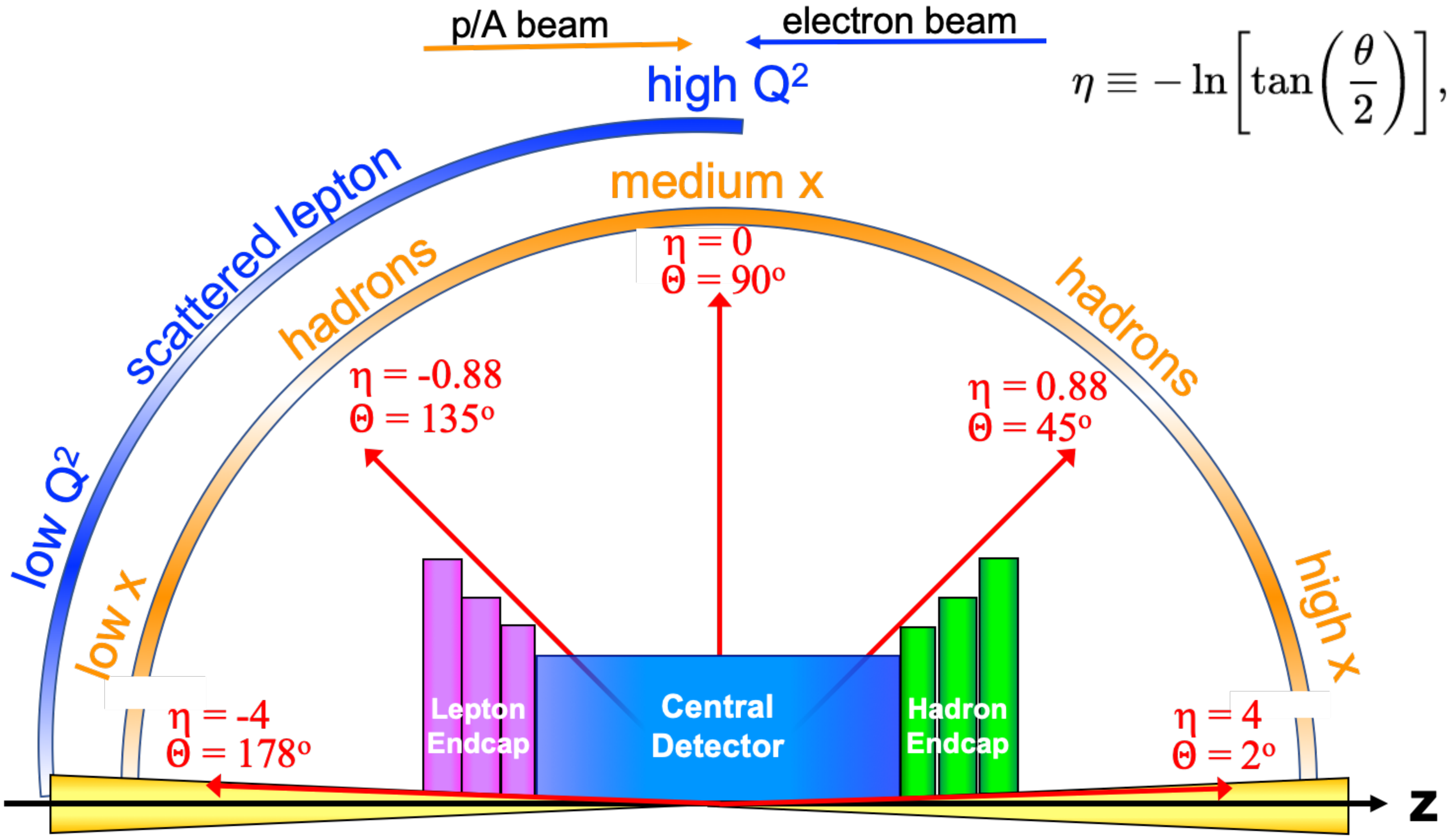
- Luminosity monitor
- Low-Q^2 Tagging Detectors

Far-Forward Detectors

- B0 Tracking and Photon Detection
- Roman Pots and Off-Momentum Detectors
- Zero-Degree Calorimeter

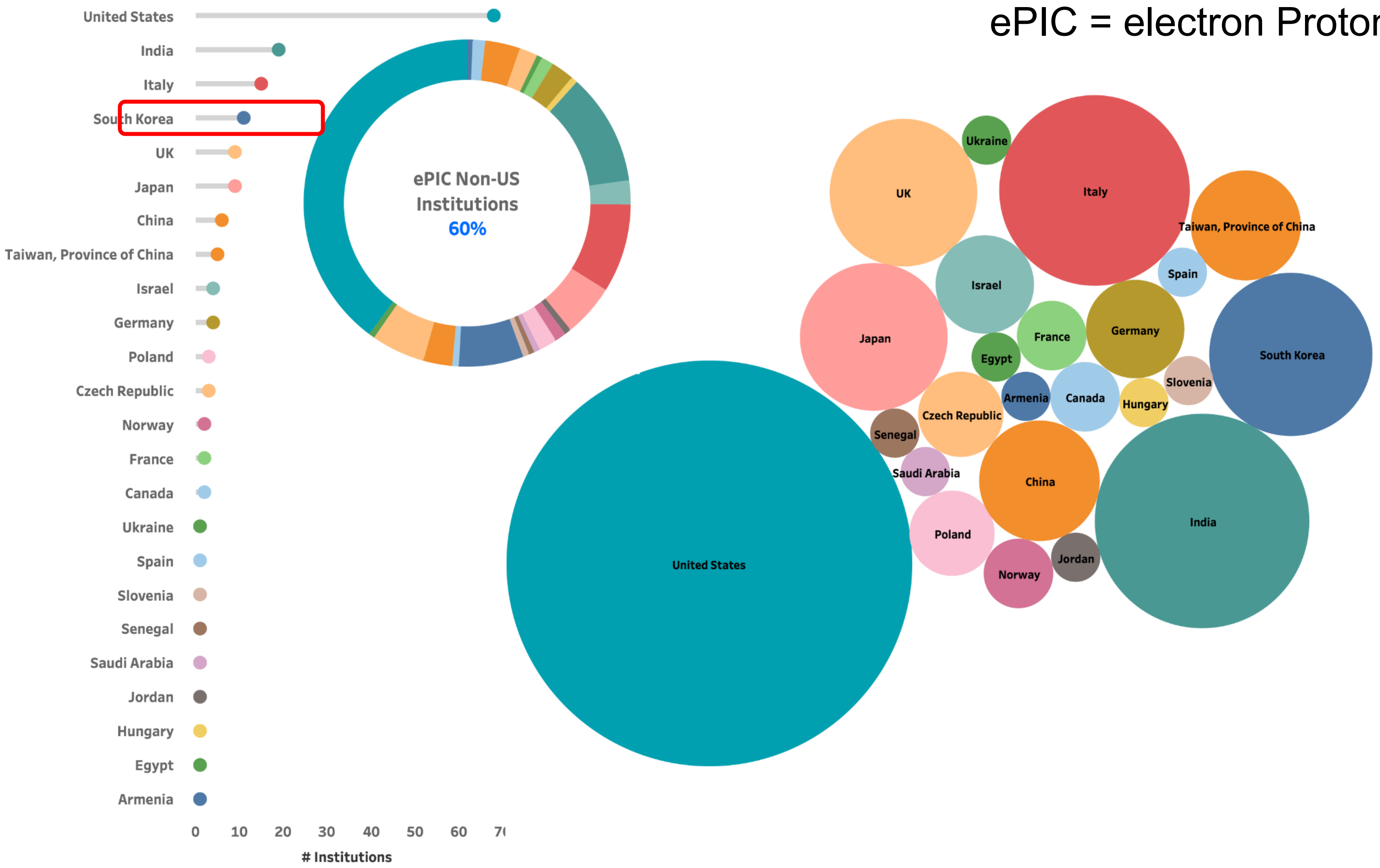
Detector polar angle / pseudo-rapidity coverage

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



The ePIC Collaboration (updated in October 2023)

ePIC = electron Proton Ion Collider

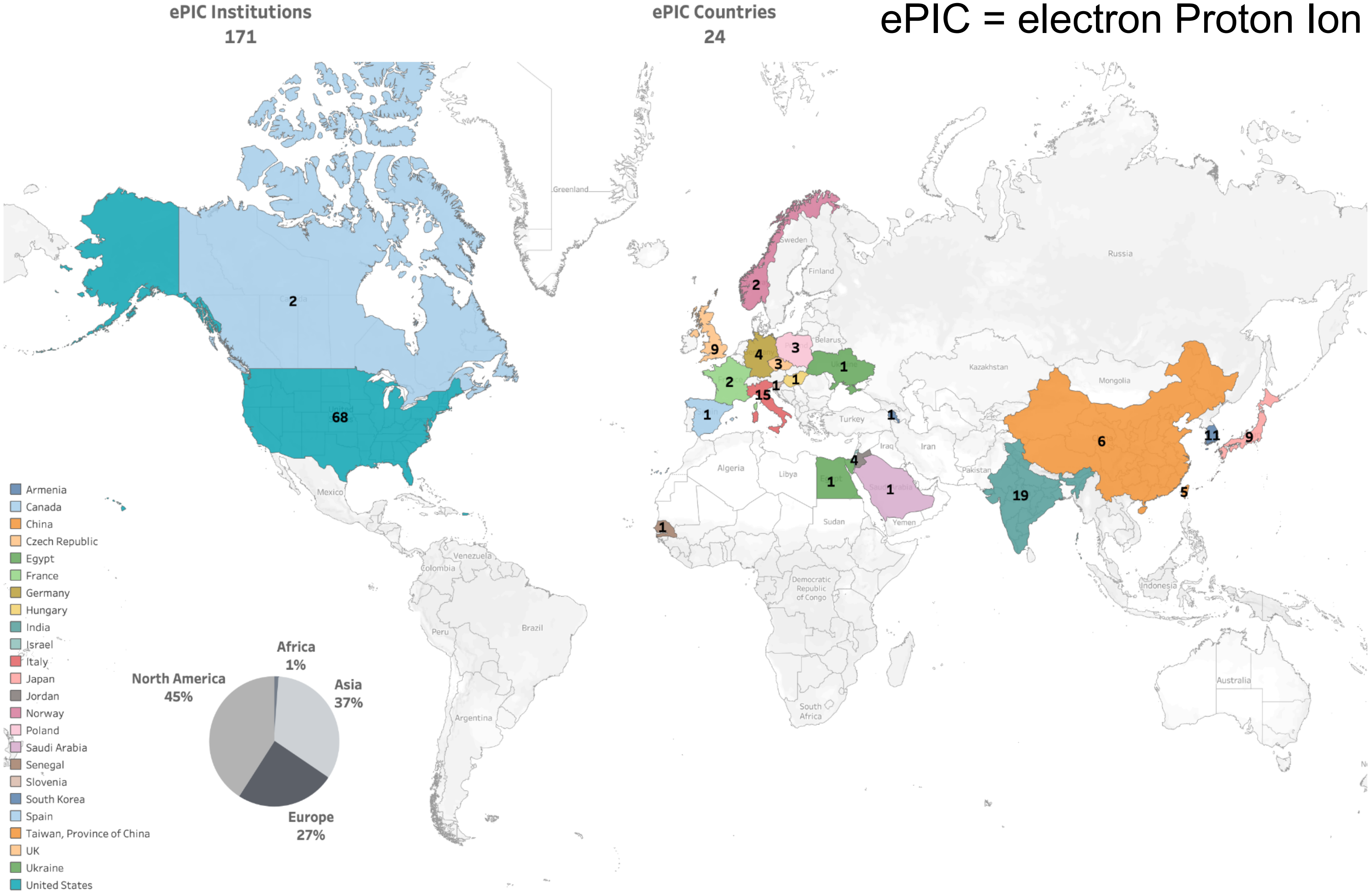


171 institutions

24 countries

The ePIC Collaboration (updated in October 2023)

ePIC = electron Proton Ion Collider

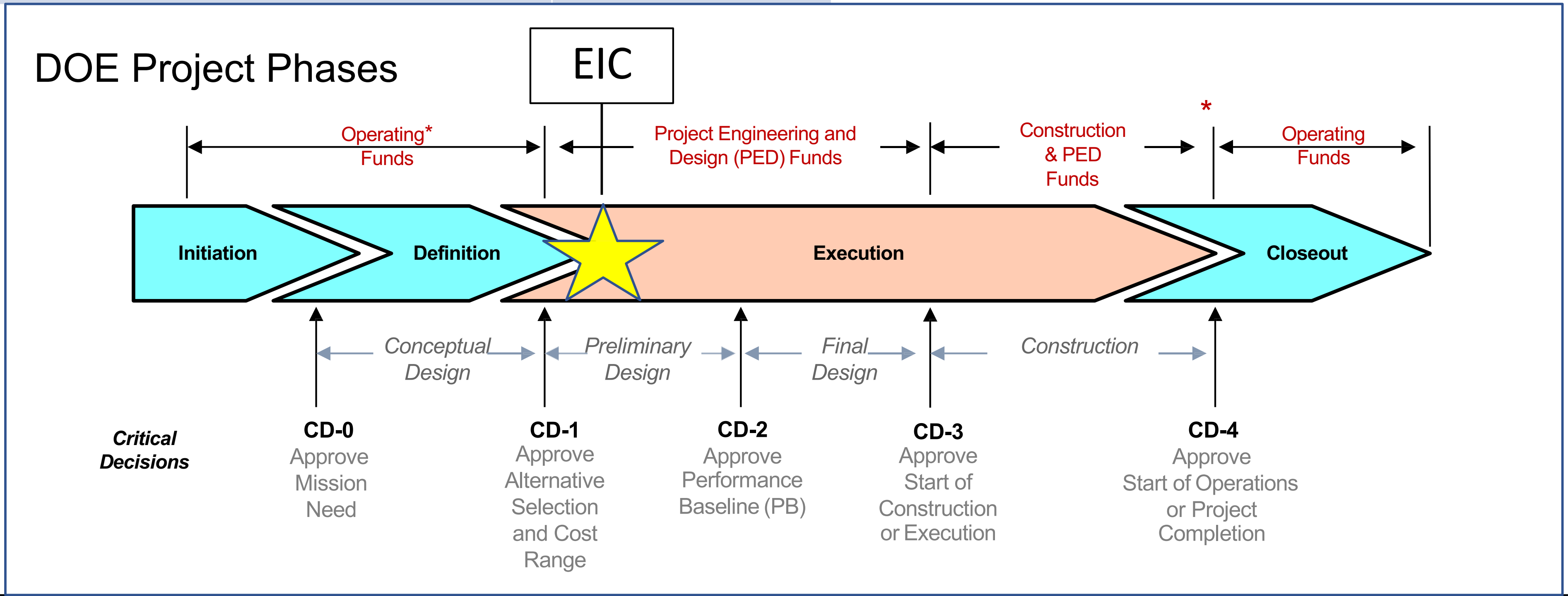


EIC Project History and Phases

Event	Date
CD-0, Mission Need Approved	December 2019
DOE Site Selection Announced	January 2020
BNL - TJNAF Partnership Agreement Established	May 2020
CD-1, Alternative Selection and Cost Range Approved	June 2021
CD-3A, Long Lead Procurement	**January 2024**
CD-2/3, Performance Baseline/Construction Start	**April 2025**
RHIC Shut Down	**June 2025**

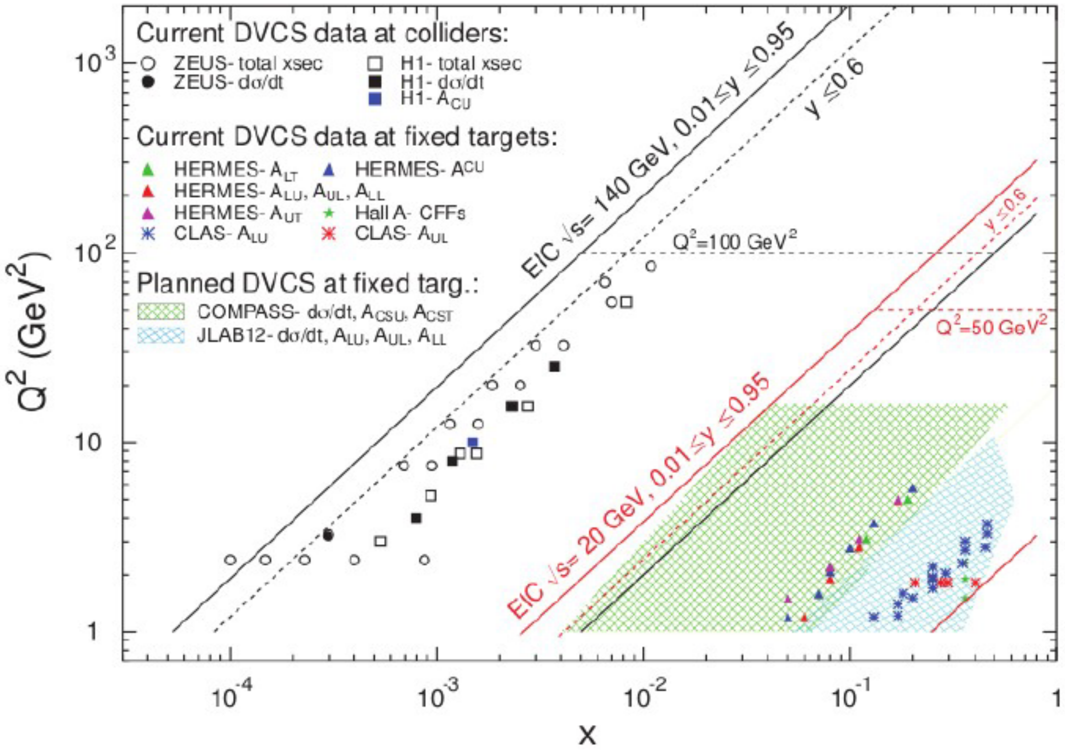
Process of DOE Reviews (Critical Decision)

- CD-0, Approve Mission Need ✓
- CD-1, Approve Alternative Selection and Cost Range ✓
- CD-3a, Approve Long Lead Procurement (Equipment, services and/or materials that must be procured well in advance of the need because of long delivery times)
- CD-2, Approve Performance Baseline
- CD-3, Approve Start of Construction
- CD-4, Approve Start of Operations or Project Completion

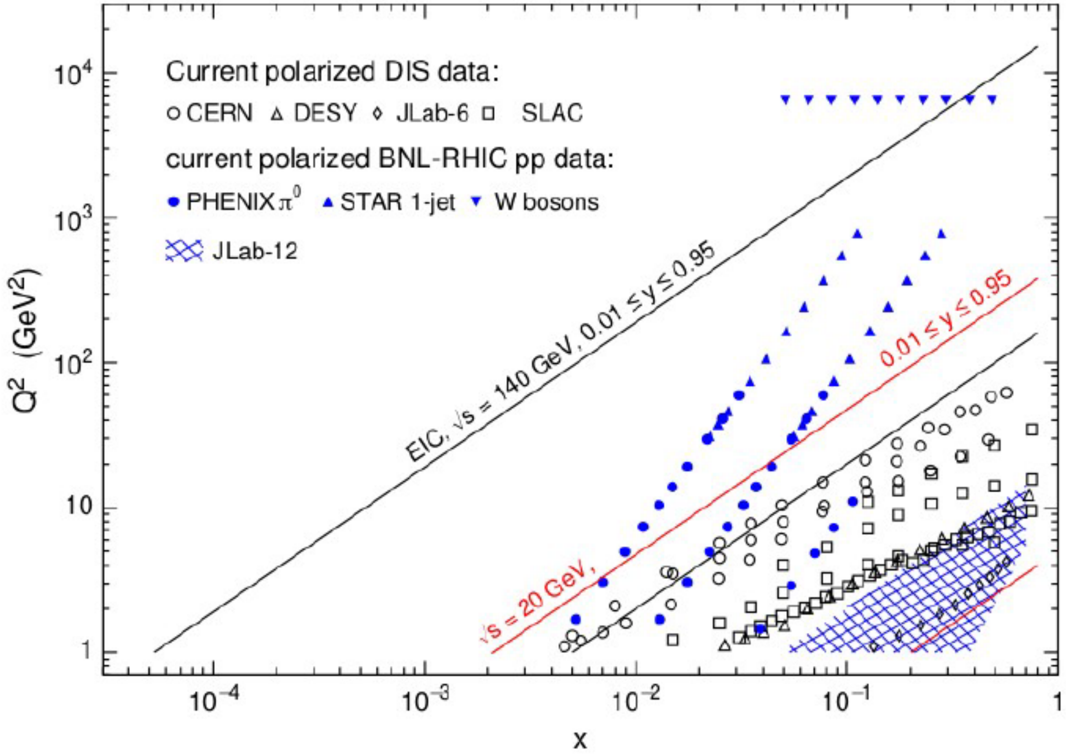


Overlap of EIC kinematic coverage with other experiments

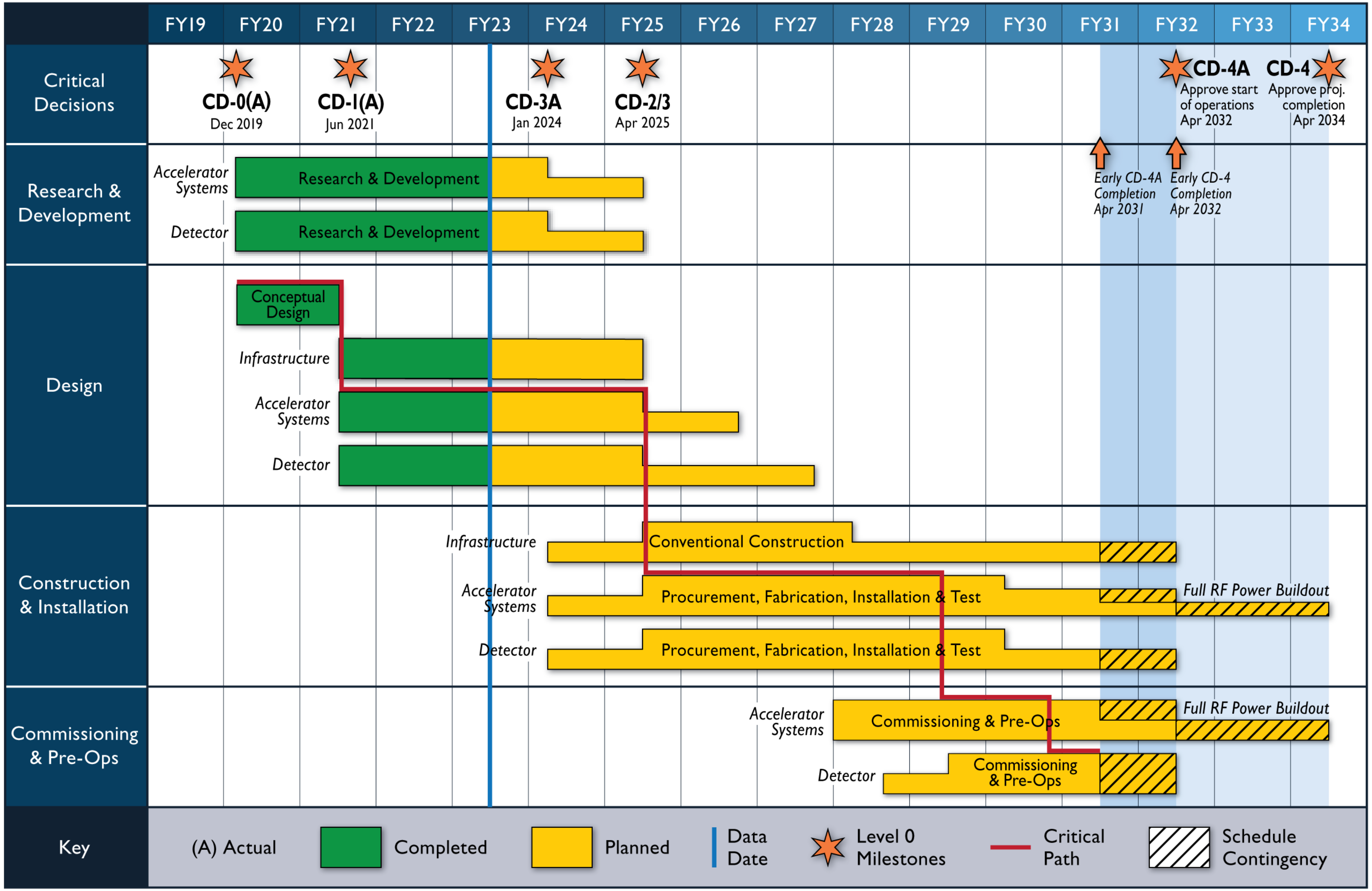
DVCS



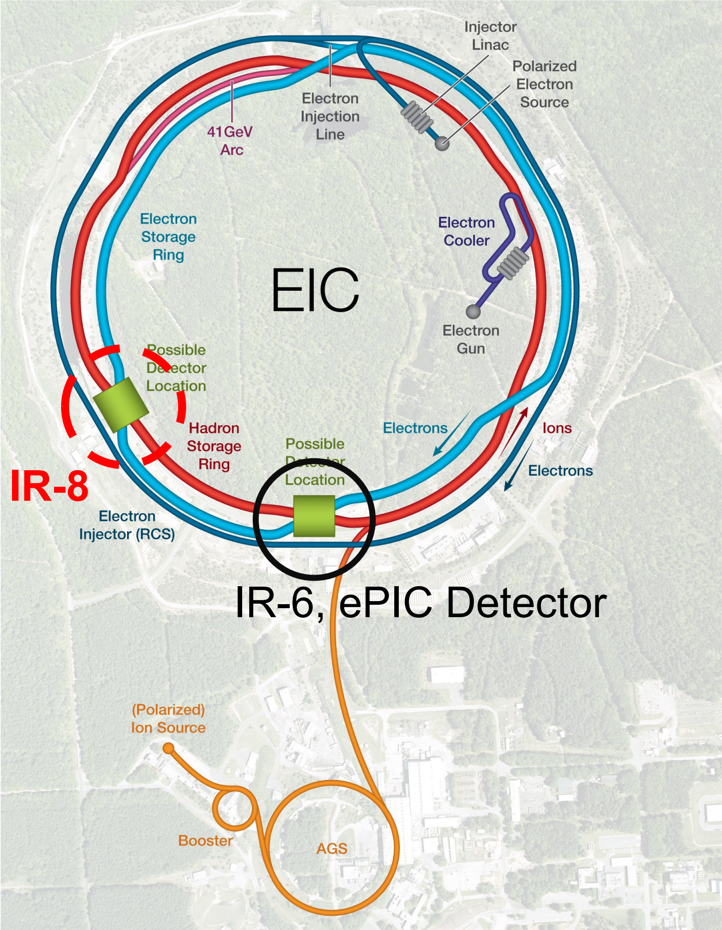
Polarized DIS (Proton Spin)



EIC Project Schedule

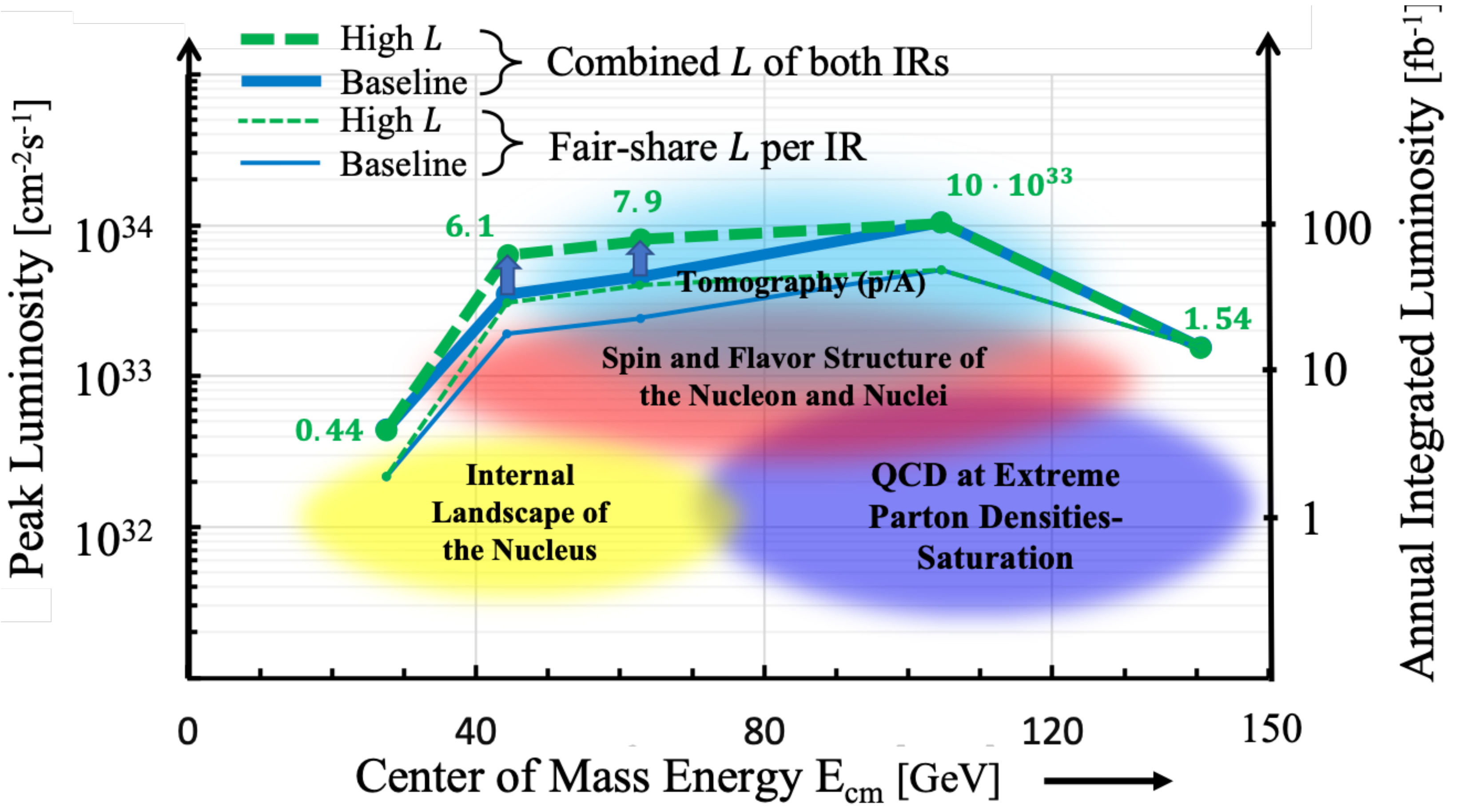


Second detector for the 2nd IR (IR-8)

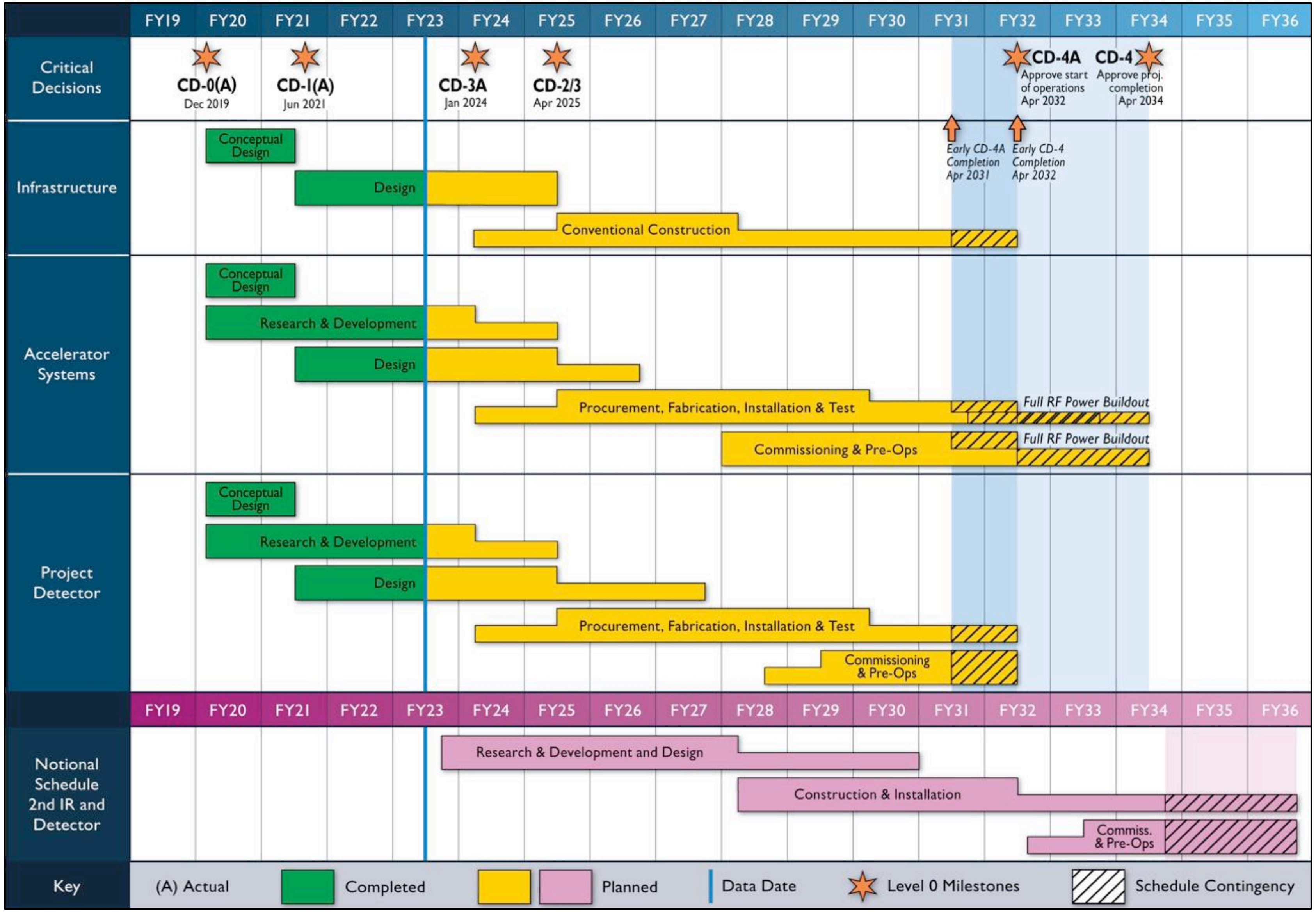


Brookhaven National Laboratory (BNL)

With a second IR, the luminosity gets shared



Reference Schedule for 2nd IR and Detector



Overview

- EIC will be a unique facility in terms of science capabilities due to its high-luminosity high energy polarized beams.

- EIC will allow us to finally solve many fundamental questions about the structure of the nucleon and nuclei.

- The DOE EIC project has funds for only 1 detector. The costs of a second detector from non-DOE sources need to be determined.

- A difficult schedule : First beam collisions by ~2031/32 and physics runs start by ~2033

Thank you