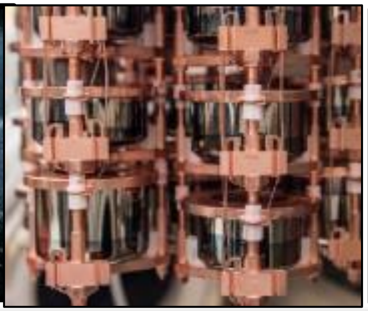
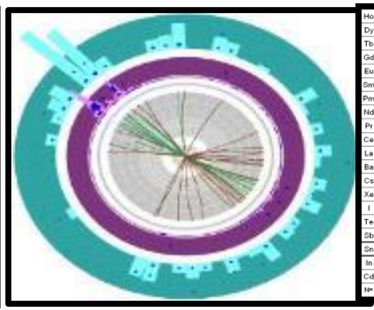
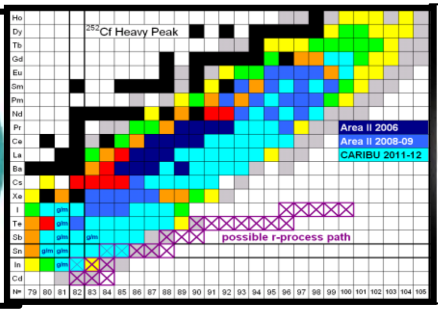
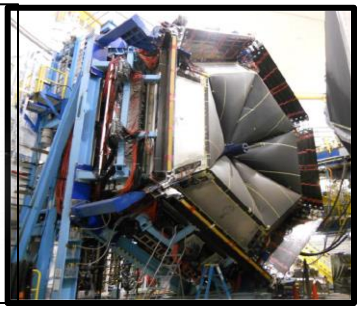
DOE Perspectives on the Electron-Ion Collider

EIC User Group Meeting

July 24, 2023

Dr. T. J. Hallman
Associate Director of the Office of Science
for Nuclear Physics

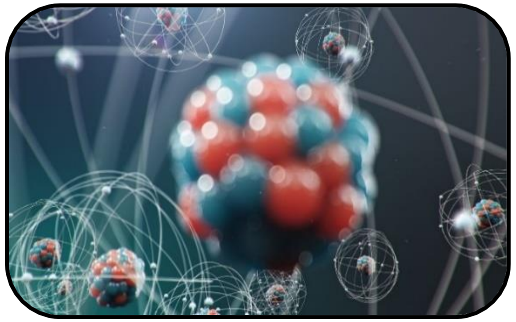





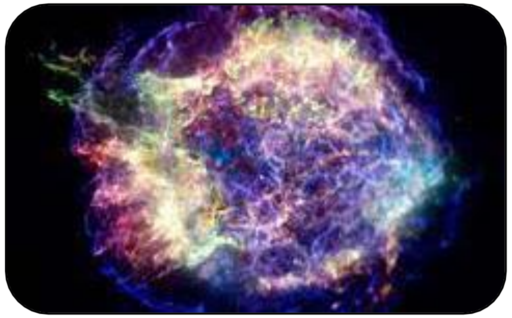
U.S. DEPARTMENT OF ENERGY | Office of Science

Prime NP Deliverable: New Knowledge & Tech Via Basic NP R&D

- Discovering and understanding new forms of nuclear matter
  - Quark-Gluon Plasma at RHIC
  - Four new Super-Heavy Nuclei
- New discoveries
  - Natural radiation frustrates quantum coherence times
  - Direct production of matter from an electro-magnetic field (e^+e^- pairs)
  - Neutron skins exist on heavy nuclei
- New technology important for future needs
  - First ever demonstration of accelerator bunched-beam cooling
  - FEL ERL development using LERF
- R&D integration that enables important applications (prospecting, isotopes)
- Nuclear data & knowledge for a suite of applications
  - Space exploration
  - Reactor design
  - Nuclear forensics / Nonproliferation
- A highly trained, "nuclear-literate", workforce with specialized skills



The Structure of the Atomic Nucleus



The Birth of Nuclei in Astronomical Processes

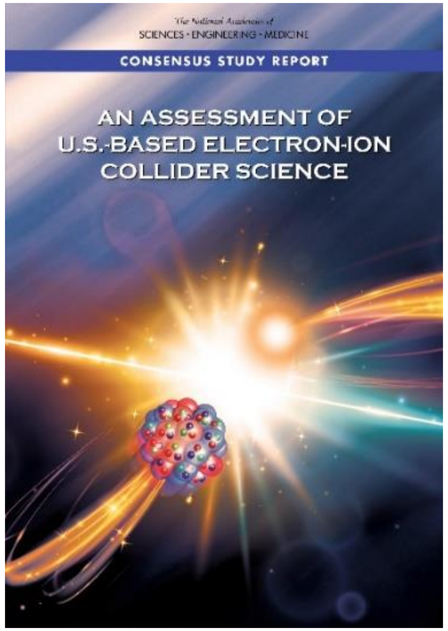
Probing Universal Laws in Nuclear Decays

Planned NP Research Horizons in FY24 and Beyond

- **Discovery of the origin of mass, proton spin, and comprehensive tomography of the proton**
- Search for anomalous atomic electric-dipole moments at FRIB as a signal of new physics using laser trapped isotopes
- Search for anomalous parity violation in electron scattering as a signal of new physics using MOLLER at JLAB
- Search for the next superheavy nucleus (A = 120) at the LBNL 88 inch cyclotron
- Understanding the equation of state of the quark-gluon plasma using sPHENIX at RHIC
- Expanding the boundary of present knowledge of how heavy elements are produced in the cosmos via never-before-produced heavy neutron-rich nuclei at FRIB
- Discovering ways to suppress the effects of natural radiation on quantum coherence times
- Quantum step forward in rare search capability via AI/ML pattern recognition software
- Significantly advancing imaging technology for the physical sciences.

The Next Super High Power, Polarized High Energy Microscope: The Electron-Ion Collider

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

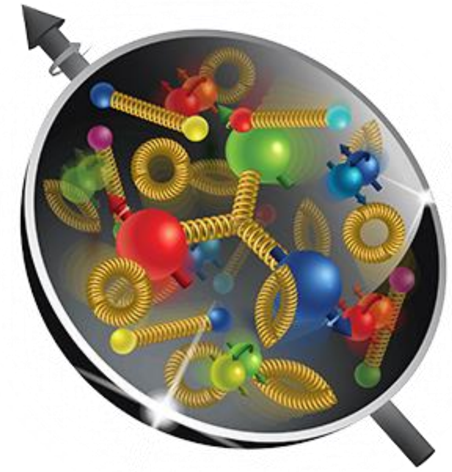


"An EIC can uniquely address three profound questions
About nucleons—neutrons and protons—and how they
are assembled to form the nuclei of atoms:

- **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?"**

The EIC would be a unique facility & maintain leadership in nuclear science

The EIC would continue to advance innovation in the science and technology of colliders



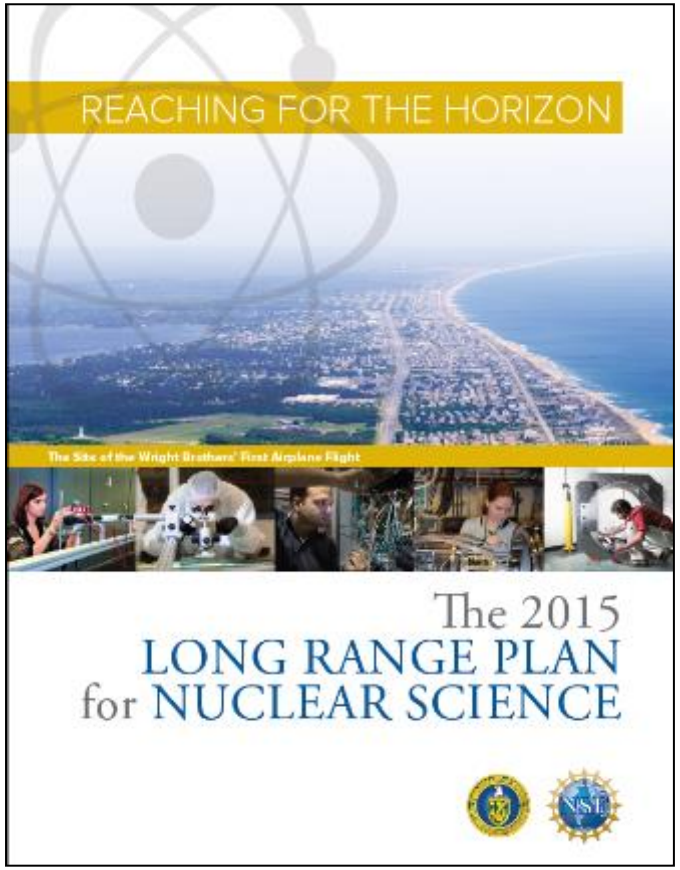
The DOE NP High-Level Work Plan

1. Operate and get science out from the Relativistic Heavy Ion Collider (RHIC),the Continuous Electron Beam Accelerator Facility (CEBAF), the Argonne Tandem Linac Accelerator System (ATLAS) and the Facility for Rare Isotope Beams (FRIB)

2. Make progress on a U.S.-led ton-scale neutrino-less double beta decay experiment.

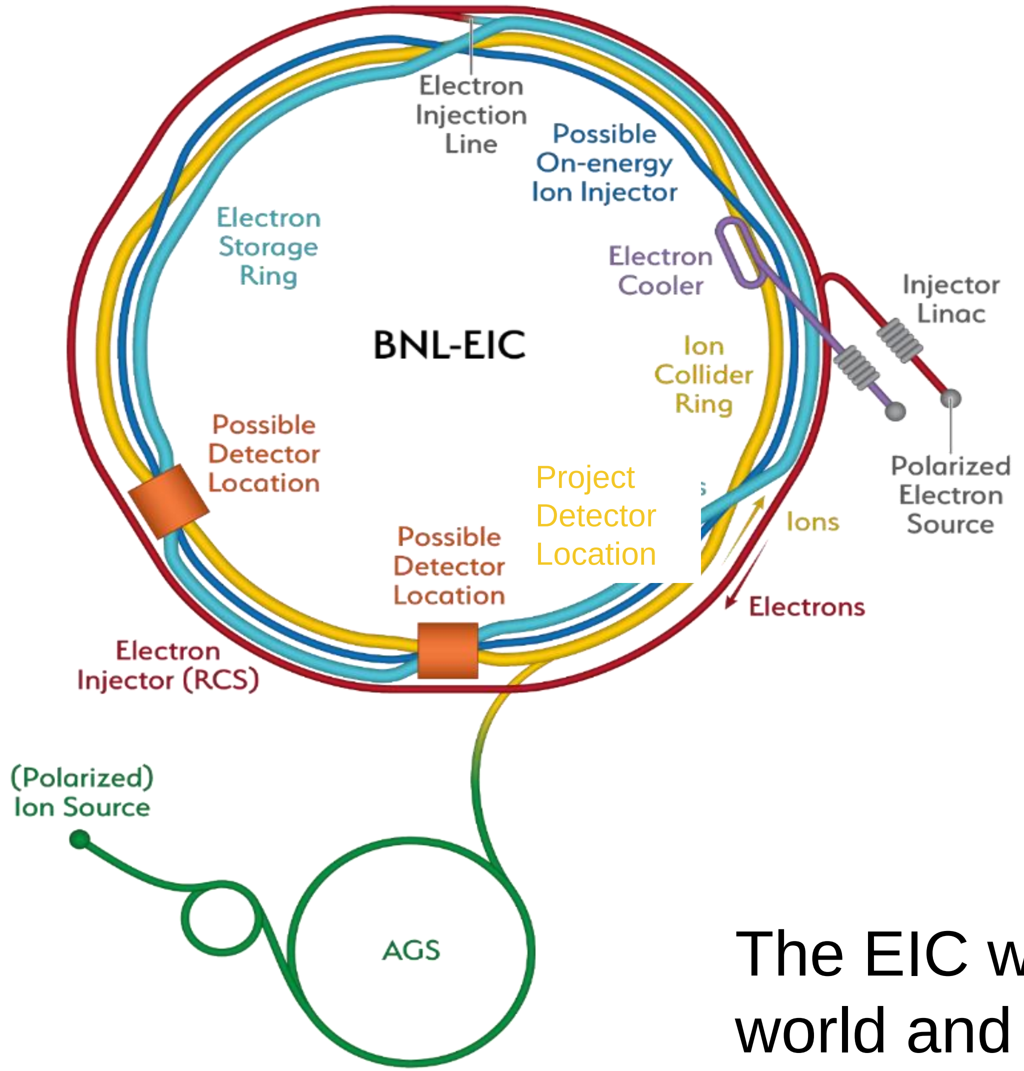
3. Start construction of a high-energy high-luminosity polarized electron-ion collider (EIC)

4. Implement smaller scale instrumentation to take advantage of facility capabilities



The work plan centers on NP’s mission to understand all forms of nuclear matter to benefit energy, commerce, medicine, and national security. A new Long Range Plan is in development by NSAC.

Constructing Capability to Advance Knowledge Throughout The Century: the Future Electron-Ion Collider



Recent Progress

Successful OPA Progress Review 1/ 2023

Significant Project staffing increases via IRA

Pursuing Long Lead (CD3a) followed by CD-2

- Hadron Storage Ring
- Hadron Injector Complex
- Electron Storage Ring
- Electron Injector Synchrotron
- Electron Cooler
- Possible On-energy Hadron Injector Ring

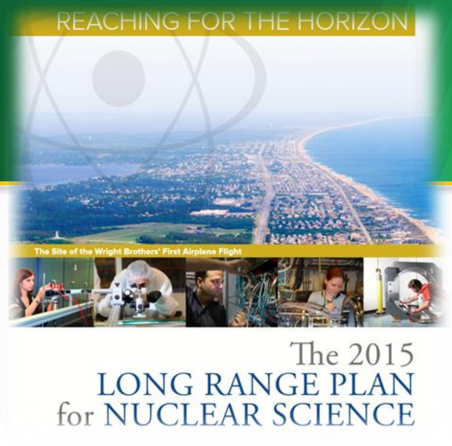
The EIC will be the most advanced accelerator in the world and the only new collider built for decades. It will keep capabilities in accelerators physics challenged

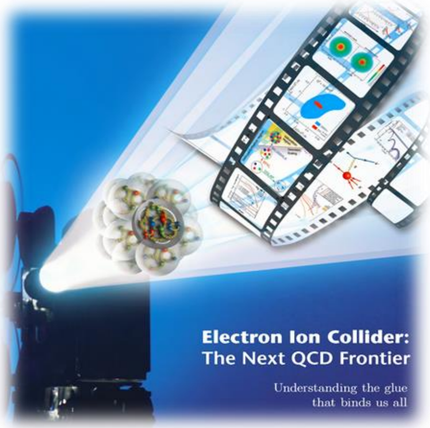
EIC Science-Driven Requirements

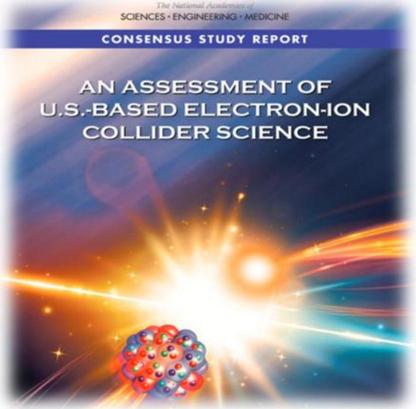
Project Design Goals

- High Luminosity: L= $10^{33} – 10^{34} cm^{-2} sec^{-1}$, 10 – 100 fb^{-1}/year
- 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
- Accommodate a Second Interaction Region (IR)

Conceptual design scope and expected performance meets or exceed NSAC Long Range Plan (2015) and the EIC White Paper requirements endorsed by NAS (2018)



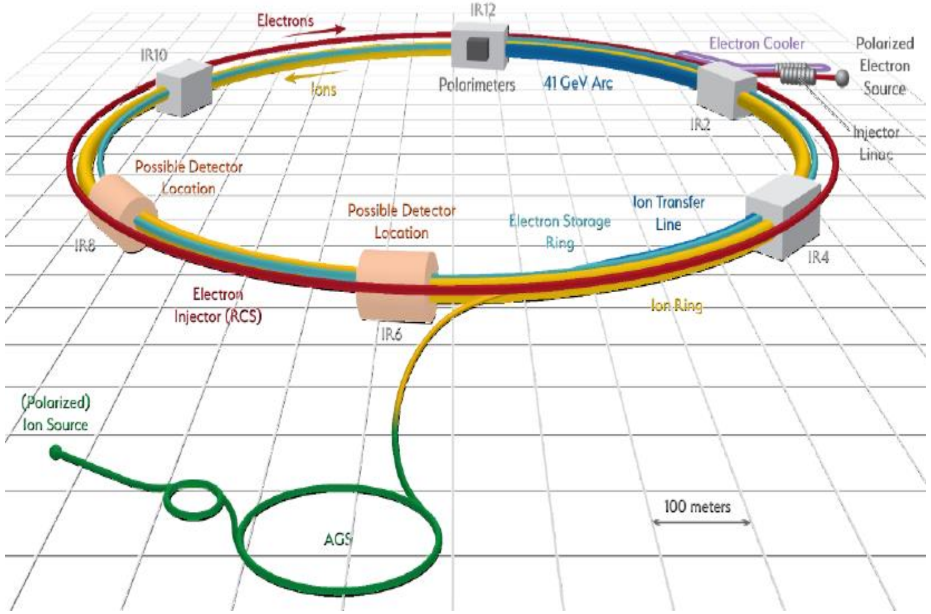




Progress Continues on the Electron-Ion Collider

CD-1 was attained in June 2021.

- Located at BNL and with TJNAF as a major partner. Estimated cost between $1.7 and $2.8 billion.
- Utilizes existing RHIC assets; adds electron storage ring, & electron cooling



$ ~90M anticipated detector in-kind (~30%)

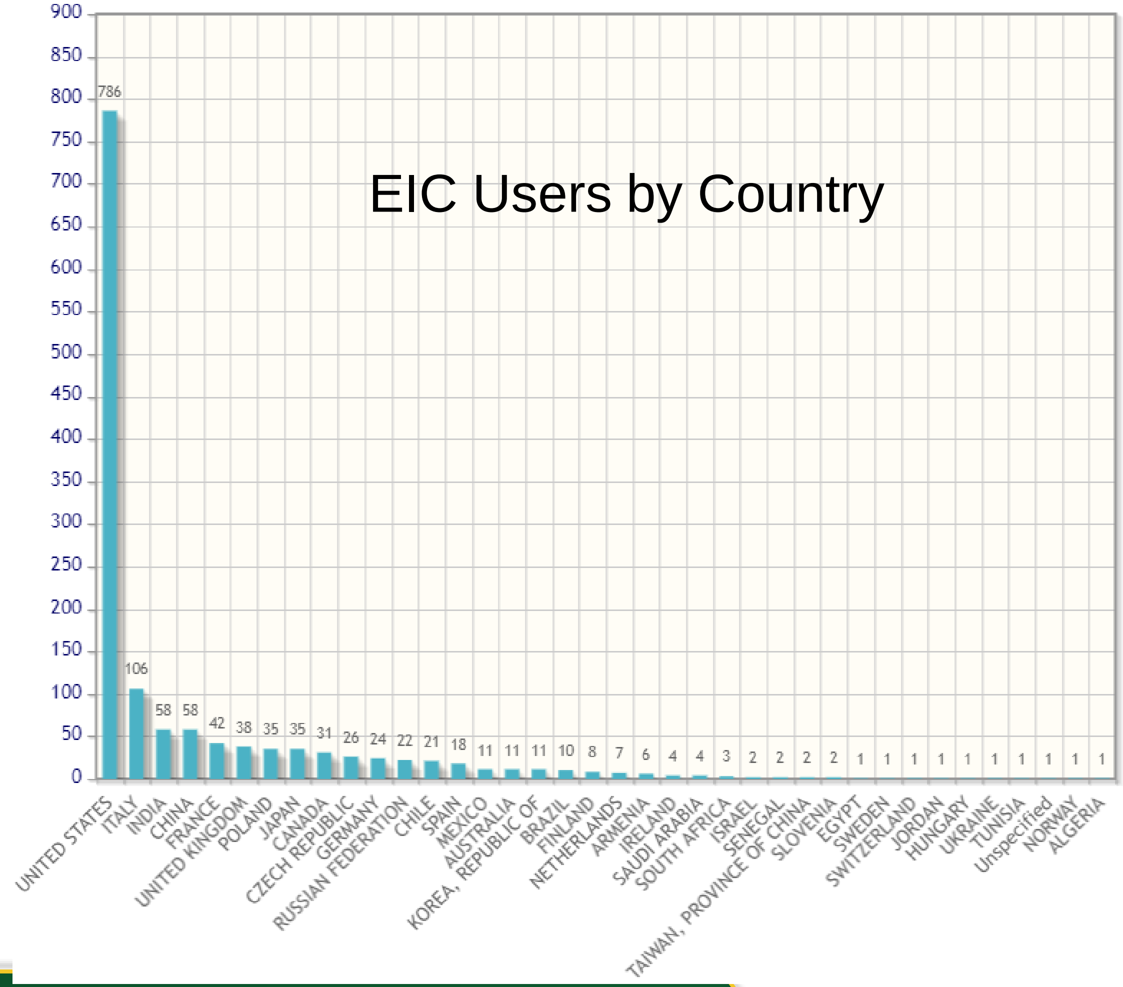
$ ~50M anticipated accelerator in-kind (~5%)

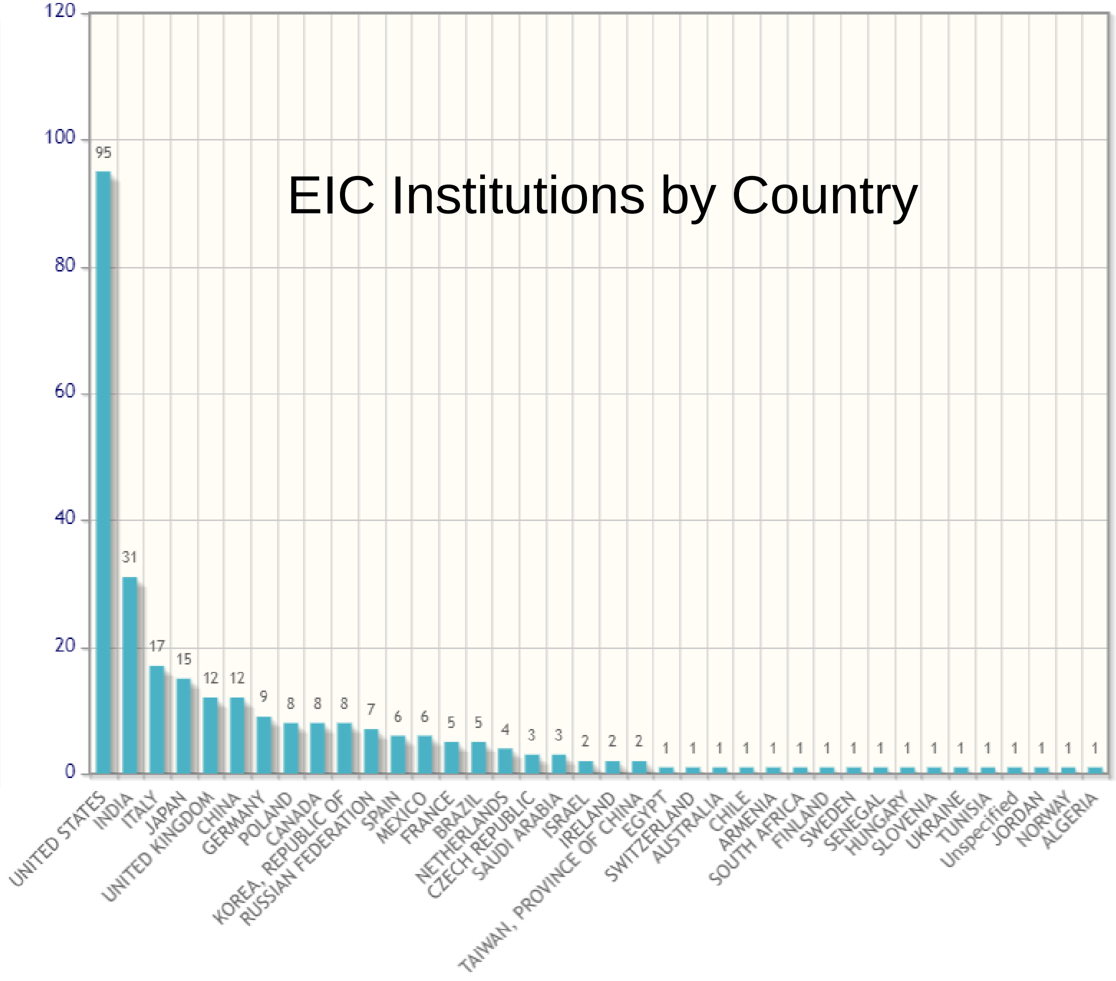
$ 100M grant from New York State

The EIC Project continues to target sufficient progress to be prepared for a CD-2 Review in the first half of FY 2025. The timing is important to attempt to match the RHIC timeline and avoid loss of needed skills in FY 2025.

The EIC User Group Continues to Have an Enormous Impact

There are now >1391 EIC Highly Active Users from 277 Institutions in 37 countries



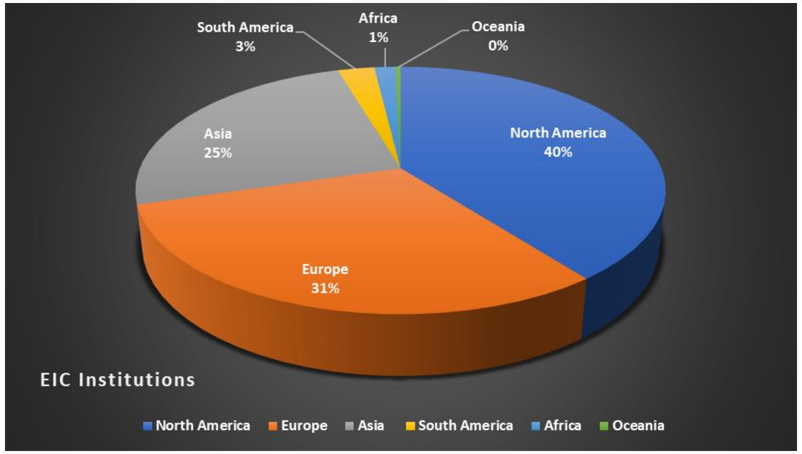


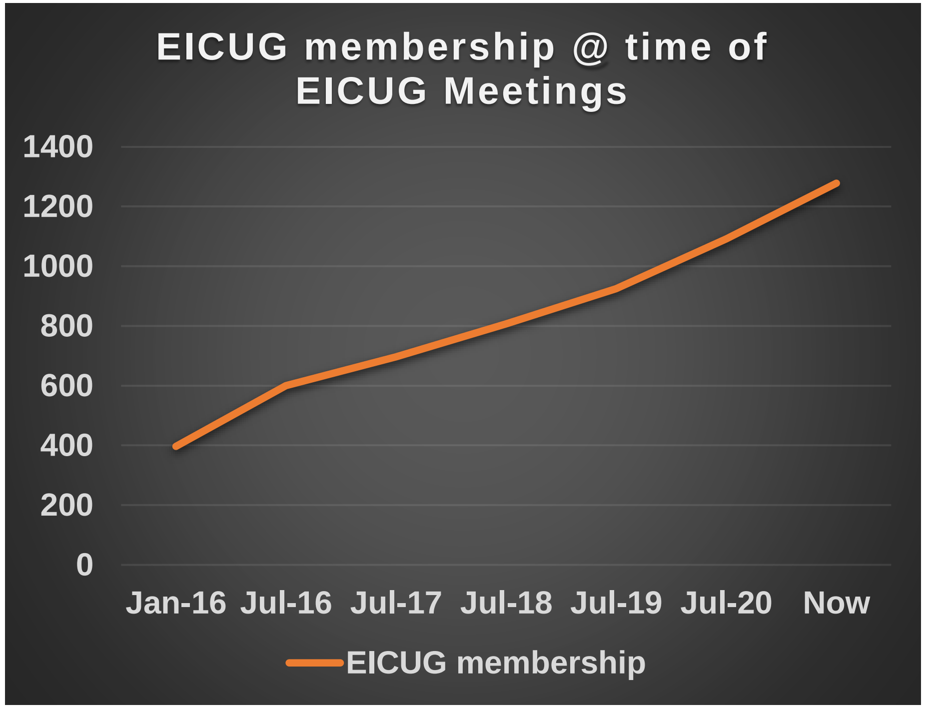
The EIC is International At Its Core

EIC Users Group Formed in 2016
EICUG.ORG

Status January 2023:

- Collaborators 1391
- Institutions 277
- Countries 37





As Is The Vision for It’s Governance

The EIC Advisory Board

Name	Affiliation
Stuart Henderson, Chair	TJNAF, USA
Diego Bettoni	INFN, Italy
Paul Kearns	ANL, USA
Mike Lamont	CERN, Switzerland
Lia Merminga	FNAL, USA
Reynald Pain	IN2P3/CNRS, France
Franck Sabatié	CEA, France
Nigel Smith	TRIUMF, Canada
Mark Thomson	STFC, United Kingdom
Mike Witherell	LBNL, USA
Maria Chamizo-Llatas, Scientific Secretary	BNL, USA

Laboratory and National Program Leaders from Around the World

Current EIC Resource Review Board To Discuss International Contributions

Name (Members)	Affiliation	Country	Funding Agency/PI
Samson, Claire	Canada Foundation for Innovation (CFI)	Canada	Funding Agency
Vyšinka ,Marek	Ministry of Education, Youth and Sports	Czech Republic	Funding Agency
Sabatie, Franck	Institut de Recherche sur les Lois Fondamentales de l'Univers (Irfu-SPhN), CEA-Saclay	France	Funding Agency
Grasso, Marcella	IN2P3/CNRS	France	Funding Agency
Lucotte, Arnaud	IN2P3/CNRS	France	Funding Agency
Bettoni, Diego	Instituto Nazionale de Fisica Nucleare (INFN)	Italy	Funding Agency
Nania, Rosario	Instituto Nazionale de Fisica Nucleare (INFN)	Italy	Funding Agency
Moon, Young Kun	Research Promotion Division at the Ministry of Science and ICT	Korea	Funding Agency
Gaczyński, Mateusz	Department of Innovation and Development, Ministry of Science and Higher Education	Poland	Funding Agency
Blaire, Grahme	UK Science and Technology Facilities Council (STFC)	United Kingdom	Funding Agency
Hiscock, Jenny	UK Science and Technology Facilities Council (STFC)	United Kingdom	Funding Agency
Hallman, Timothy	DOE Office of Nuclear Physics	United States	Funding Agency
Name (Observers)	**Affiliation**	**Country**	**Funding Agency/PI**
Hayotsyan, Sargis	State Science Committee of Armenia	Armenia	Funding Agency
Mohanty, Bedanga	NISER	India	Funding Agency
Nxomani, Clifford	National Research Foundation	South Africa	Funding Agency

PIs participating in the Resource Review Board To Discuss International Contributions

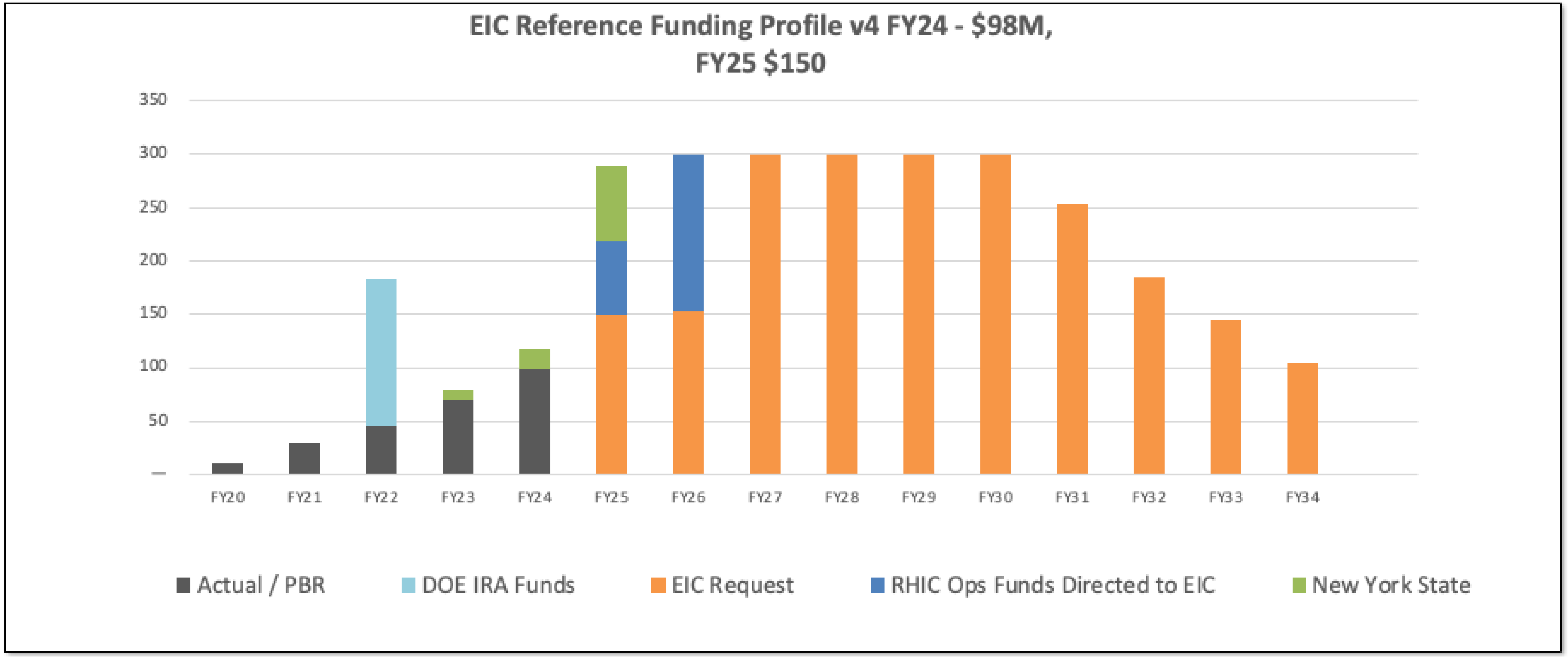
Name (PI)	Affiliation	Country
Machado, Ana Amelia	UNICAMP	Brazil
Huber, Garth	University of Regina	Canada
Bielčík, Jaroslav	Czech Technical University, Prague	Czech Republic
Munoz Camacho, Carlos	IJCLab	France
Antonioli, Pietro	INFN Bologna	Italy
Goto, Yuji	RIKEN	Japan
Gunji, Taku	Center for Nuclear Study, University of Tokyo	Japan
Ka, Oumar	Cheikh Anta Diop University	Senegal
Jones, Pete	iThemba Labs	South Africa
Joo, Kyungseon	University of Connecticut	South Korea
Oh, Yongseok	Kyungpook National University	South Korea
Yang, Yi	National Cheng Kung University	Taiwan
Jones, Peter	University of Birmingham	UK

NP - FY 2024 President's Request

Office of Science Program Details - Category FY 2024 Senate Mark - Nuclear Physics (B/A in thousands)	FY 2022 Enacted		FY 2023 Enacted	FY 2024 Request	FY 2024		FY 2024 Senate Mark vs FY 2024 Request		FY 2024 Senate Mark vs FY 2023 Enacted	
	Regular	IRA Supp.	Regular	Regular	House Mark (Regular)	Senate Mark (Regular)				
Nuclear Physics										
Medium Energy, Research	53,404	...	59,083	55,555	51,724	55,555	...	...	-3,528	-5.97%
Medium Energy, Operations	142,709	...	149,834	141,930	150,000	143,430	1,500	1.06%	-6,404	-4.27%
Medium Energy Physics	196,113	...	208,917	197,485	201,724	198,985	1,500	0.76%	-9,932	-4.75%
Heavy Ion, Research	46,505	...	46,149	47,454	46,704	47,454	...	...	1,305	2.83%
Heavy Ion, Operations	183,943	...	182,087	176,195	166,684	178,695	2,500	1.42%	-3,392	-1.86%
Heavy Ion, Projects	25,013	10,000	20,000	2,850	2,850	2,850	...	...	-17,150	-85.75%
Heavy Ion Physics	255,461	10,000	248,236	226,499	216,238	228,999	2,500	1.10%	-19,237	-7.75%
Low Energy, Research	73,935	...	77,651	78,409	76,909	78,409	...	...	758	0.98%
Low Energy, Operations	107,831	...	128,579	127,624	132,487	130,624	3,000	2.35%	2,045	1.59%
Low Energy, Projects	17,400	78,760	23,940	9,259	18,000	9,259	...	...	-14,681	-61.32%
Low Energy Physics	199,166	78,760	230,170	215,292	227,396	218,292	3,000	1.39%	-11,878	-5.16%
Theory, Research	57,260	...	67,873	77,142	59,642	77,142	...	...	9,269	13.66%
Nuclear Theory	57,260	...	67,873	77,142	59,642	77,142	...	...	9,269	13.66%
Program Subtotal	708,000	88,760	755,196	716,418	705,000	723,418	7,000	0.98%	-31,778	-4.21%
20-SC-52, Electron Ion Collider EIC, BNL	20,000	128,240	50,000	95,000	95,000	95,000	...	...	45,000	90.00%
Construction Subtotal	20,000	128,240	50,000	95,000	95,000	95,000	...	...	45,000	90.00%
Total Nuclear Physics	728,000	217,000	805,196	811,418	800,000	818,418	7,000	0.86%	13,222	1.64%

- The TEC funding appropriated for EIC in FY 2023 is $70M. In addition, the EIC received $138M in Inflation Reduction Act Funding

EIC Reference Funding Plan

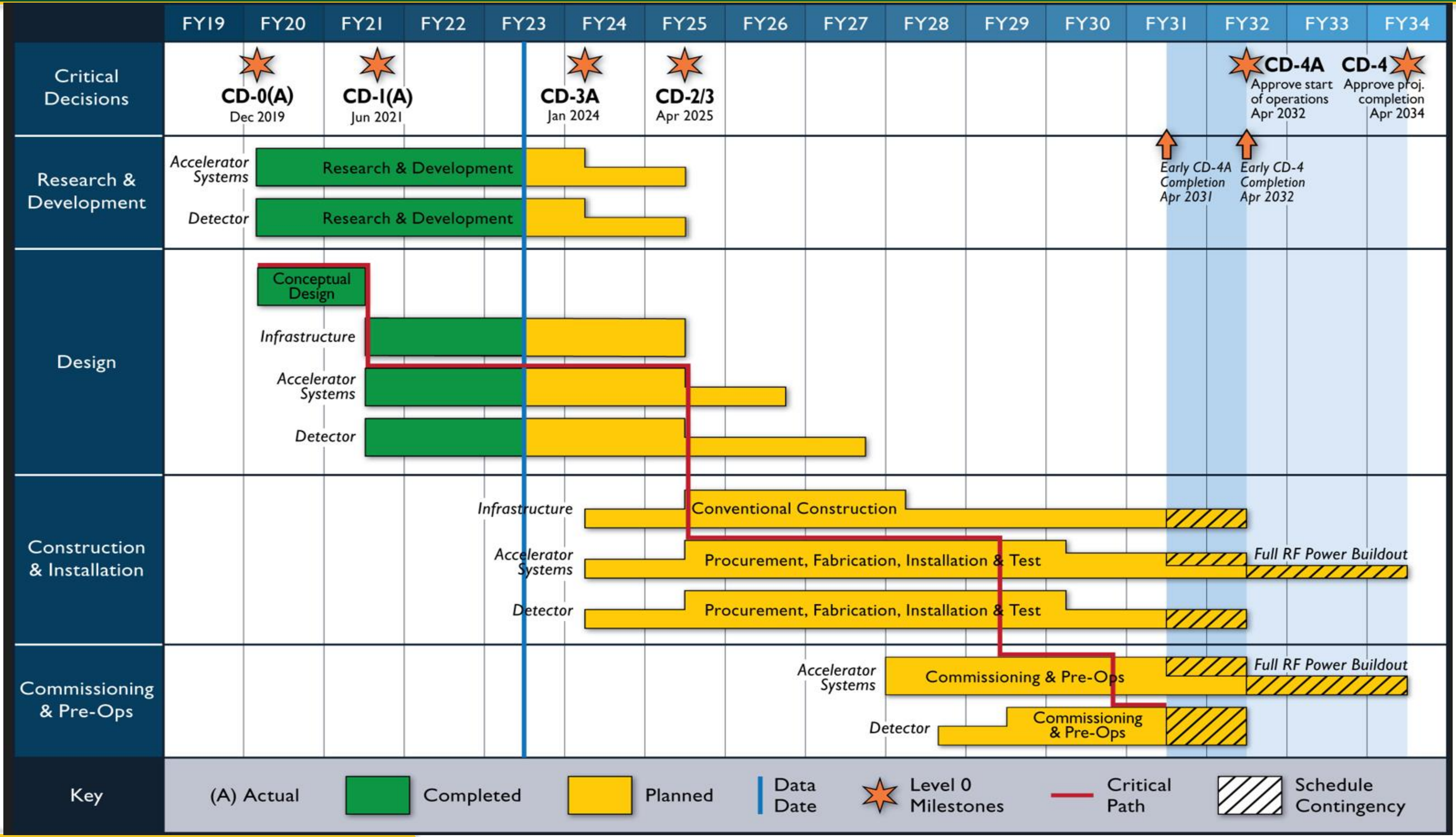


- DOE Inflation Reduction Act funding of $138M allocated at very end of FY2022. FY2023 funding is $70M. DOE request and U.S. House Mark for FY2024 is $98M.
- RHIC shut down planned for end of June 2025. Significant RHIC Operations funding will be redirected to EIC construction starting in FY2025 and reaching ~$150M/year in FY2026.
- Current funding request supports DOE CD-3A, Long Lead Procurement Approval (LLP), in January 2024. LLP items mitigate risks: technical, supply chain, inflation, and schedule.
- FY2025 request is a major challenge given the Fiscal Responsibility Act signed earlier this month.

EIC History and Plans

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**

EIC Schedule

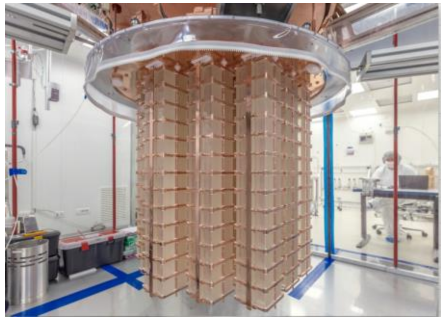


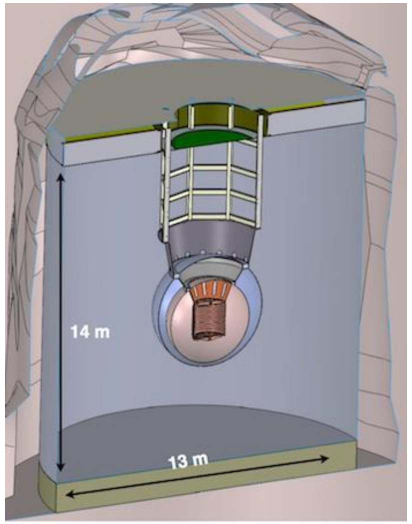
The Other Priority of the 2015 Long Range Plan for Nuclear Science: Neutrinoless Double Beta Decay

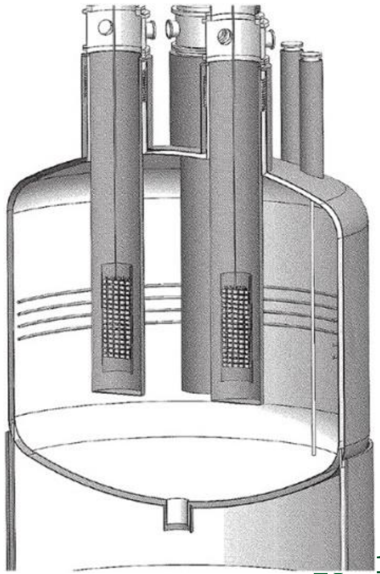
- Between IRA funding and NP Program Funding, approximately $12.8 M allocated to the three technologies being explored LEGEND 1000, nEXO, and CUPID since FY 2020.
- Additional resources provided by international partners
- Inability to procure isotopes from Russia is creating serious challenges
- The next DBD international occurred on April 27, 2023 at SNOLab in Canada. A Virtual Global DBD Observatory is being established.
- NP is thinking about options to demonstrate a proof-of-principle isotope procurement test

Three Proposed Technologies

- Scintillating bolometry (**CUPID**, ^{100}Mo enriched Li_2Mo_4 crystals)
- Enriched ^{76}Ge crystals (**LEGEND-1000**, drifted charge, point contact detectors)
- Liquid Xenon TPC (**nEXO**, light via SiPM, drifted ionization)







Potential Partners:
Italy, Canada, and Germany

Snapshot of the Status of NP Projects

Project	Location	Status	Cost	CPI	SPI	CD-4	Operation cost plan
Construction Projects							
Facility for Rare Isotope Beams (FRIB) *	MSU	CD-4	$730M	1.00	1.00	6/2022	Included in NP budget formulation
Electron-Ion Collider (EIC)	BNL	CD-1	$1.7B to $2.8B			Q4 FY33	RHIC operations funds redirected to EIC project recovered for EIC operations
Major Items of Equipment							
Gamma Ray Energy Tracking Array (GRETA) [FF]	LBNL	CD-2/3	$58.3M	0.97	0.93	4/2028	Mostly covered by host laboratory operations experimental support
Super Pioneering High Energy Nuclear Interaction Experiment (sPHENIX) *	BNL	PD-4	$26.5M	1.00	1.00	12/2022	Covered by RHIC operations experimental support
Measurement of Lepton-Lepton Electroweak Reactions (MOLLER) [FF]	TJNAF	CD-3A	$45.8M to $56.6M			Q4 FY27	Covered by TJNAF operations experimental support
High Rigidity Spectrometer (HRS)	*MSU*	*CD-1*	*$85.0M to $111.4M*			*Q2 FY29*	*Covered by FRIB operations experimental support*
Ton Scale Neutrinoless Double Beta Decay (TS-NLDBD)	TBD	CD-0	$215M to $250M			TBD	TBD

Blue (*) indicates "Completed", green ([FF]) "Fully Funded", *and purple italic "Substantially Funded"*

Smaller NP Projects are being "cleared off the books"

NP - Research Initiatives

(dollars in thousands)

	FY 2022 Enacted	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted		FY 2024 Request vs FY 2022 Enacted	
Nuclear Physics (NP)							
Accelerate Innovations in Emerging Technologies	–	4,000	4,000	–	–	+4,000	–
Accelerator Science and Technology Initiative	1,037	–	–	–	–	-1,037	-100.00%
Artificial Intelligence and Machine Learning	4,000	8,000	8,000	–	–	+4,000	+100.00%
Funding for Accelerated, Inclusive Research (FAIR)	–	2,000	5,000	+3,000	+150.00%	+5,000	–
Microelectronics	518	518	518	–	–	–	–
Quantum Information Science	10,866	10,866	10,866	–	–	–	–
Reaching a New Energy Sciences Workforce (RENEW)	3,000	6,000	11,500	+5,500	+91.67%	+8,500	+283.33%
Total, Research Initiatives	**19,421**	**31,384**	**39,884**	**+8,500**	**+27.08%**	**+20,463**	**+105.37%**

Which Raises a Thought

The Hallman Challenge:

Consider creating a dedicated WBS activity, with a budget, a CAM, etc.to integrate/build AI into the operational controls for the EIC machine “from the beginning”.

DOE NP Outlook On The EIC

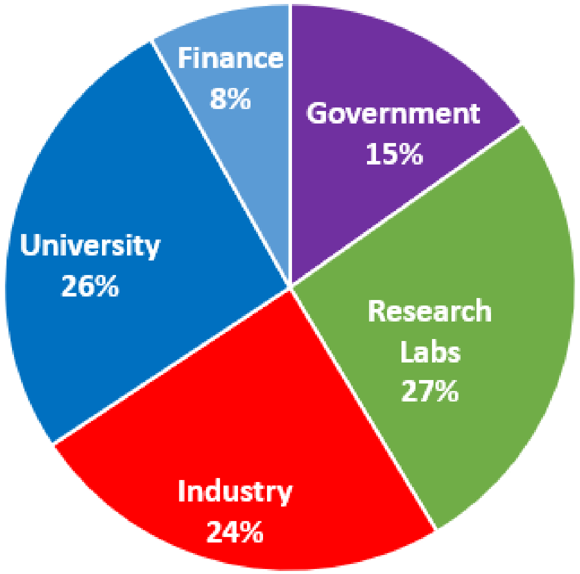
- The EIC Project is making steady progress, towards CD3a (Long Lead Procurement), and the next DOE gateway CD-2 (Approve Performance Baseline).
- The EIC is intended to be fully international in character. For those countries interested in collaborating, now is a good time to become involved and express your interest. All are welcome at any time, but the pace of the project will require clear understanding of "who will do what" in time to baseline the project in FY 2025.
- Although not yet baselined, increased support from annual appropriations will continue to be important to enable timely progress and a smooth transition of workforce from the Relativistic Heavy Ion Collider in FY 2025.
- International contributions and very careful Project Management will be crucial to contain cost growth and maintain schedule.

A Second Very High priority: Training in Nuclear Science

- Highly Specialized Technical skills
- Creative problem analysis/solving ability
- Scientific communication skills
- Resilience/perseverance despite set-backs
- Self confidence
- Time management ability
- Project planning skills
- Ability to work within a large collaboration
- Leadership development

The result is an essential national core competency useful not only for "things nuclear", but for a variety of other challenging pursuits as

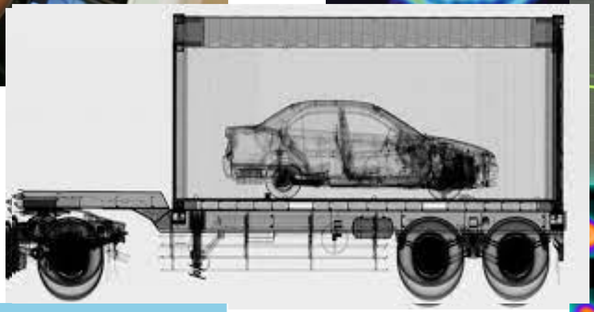
Where NP PhDs go

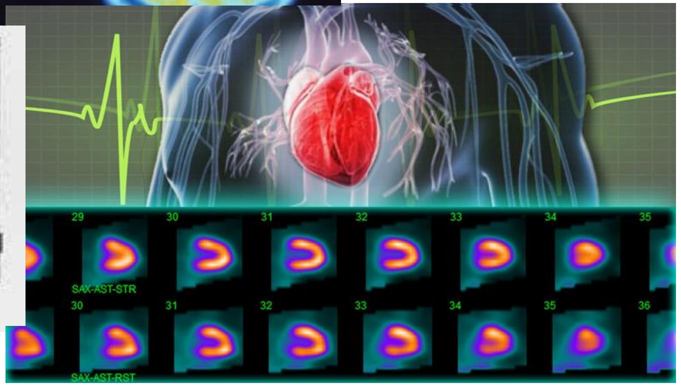


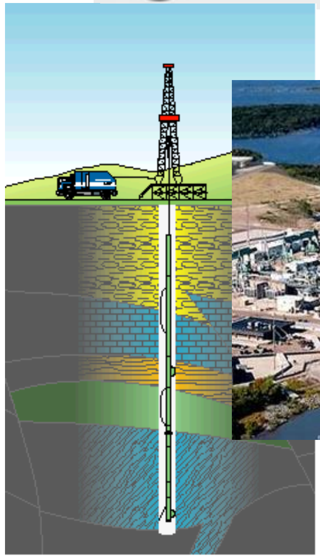
U.S. science, commerce, medicine, defense —all benefit, in part, from a stable level of sustained competence, capability, capacity, and leadership in nuclear physics;

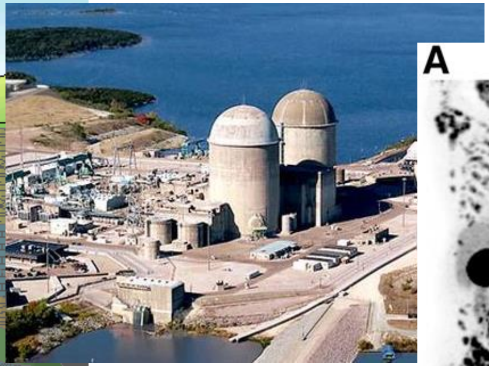
A Third Priority: Better Living Through Apps of Nuclear Physics

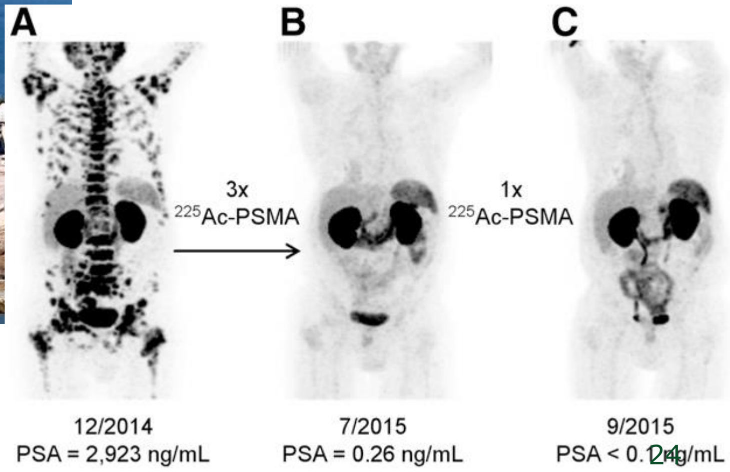
- Fire safety in your house
- Heart Health
- Food safety
- Medical Diagnosis
- Carbon free electricity generation
- Port of entry security
- Metastasized cancer treatment
- Oil and gas prospecting
- Deep space exploration
- Lasting joint replacements
- National Security







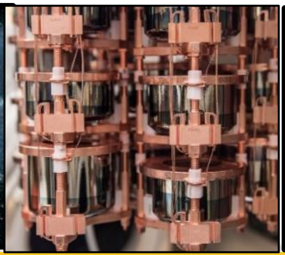
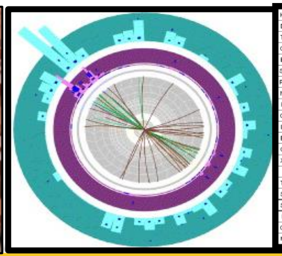
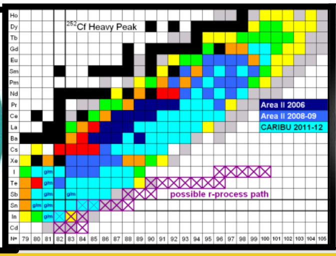


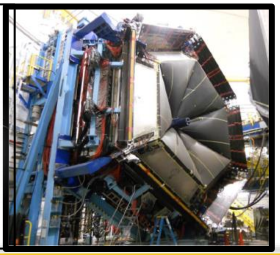


Nuclear Physics
Discovering, exploring, and understanding all forms of nuclear matter

Understanding why matter takes on the specific forms observed in nature and how that knowledge can benefit energy, commerce, medicine, and security, by:

- Mapping the quantum cosmos inside the proton using the future Electron-Ion Collider
- Discovering the properties of the novel quark-gluon plasma RHIC, LHC
- Exploring the mechanism underlying the confinement of quarks and gluons via CEBAF and RHIC
- Searching for new exotic particles and violations of nature's symmetries at CEBAF, FRIB, ATLAS
- Determining the limits of nuclear existence and how are heavy elements made via FRIB and ATLAS
- Discovering if the neutrino its own anti-particle or if the neutron's precise properties point to new physics via Neutrino-less Double Beta Decay and Neutron Electric dipole Moment
- Exploring the strong force in many-body systems via SciDAC, Core Research, QIS/QC, AI/ML
- Advancing Nuclear Data for Space, Energy, and Research through Nuclear Data and AI/ML

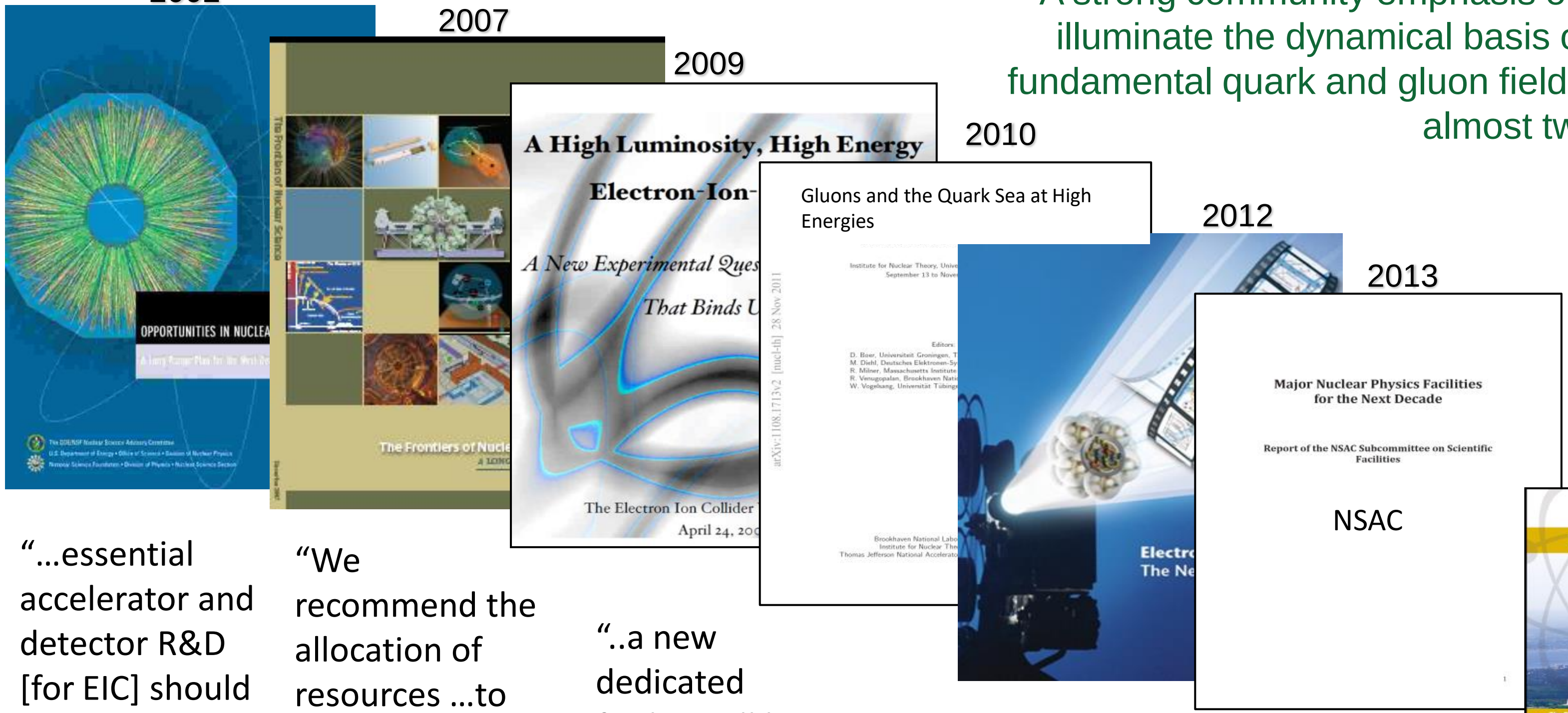





Developing the EIC Science Case

A strong community emphasis on the urgent need for a machine to illuminate the dynamical basis of hadron structure in terms of the fundamental quark and gluon fields has been a persistent message for almost two decades

2002 2007 2009 2010 2012 2013



"…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."

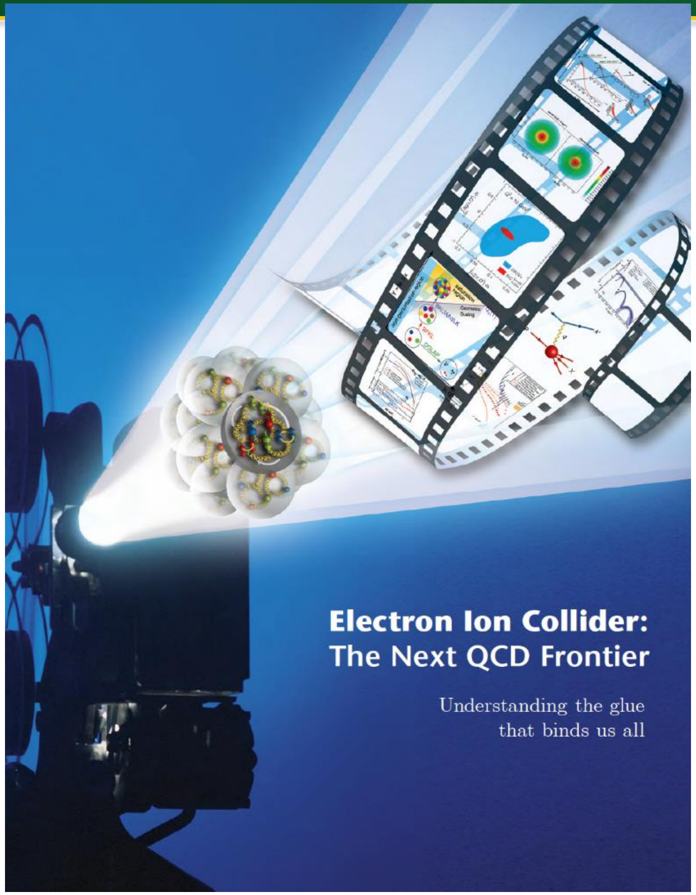
Electron-Ion Collider *absolutely central* to the nuclear science program of the next decade.

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

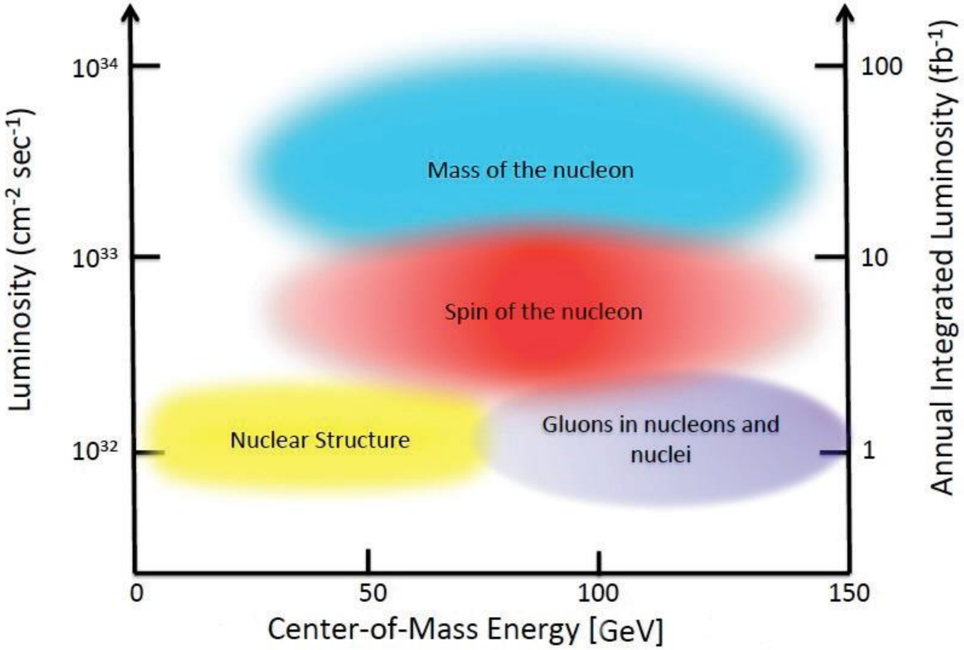
2015 2018

U.S. DEPARTMENT OF ENERGY | Office of Science

NSAC 2015 LRP Performance Parameters

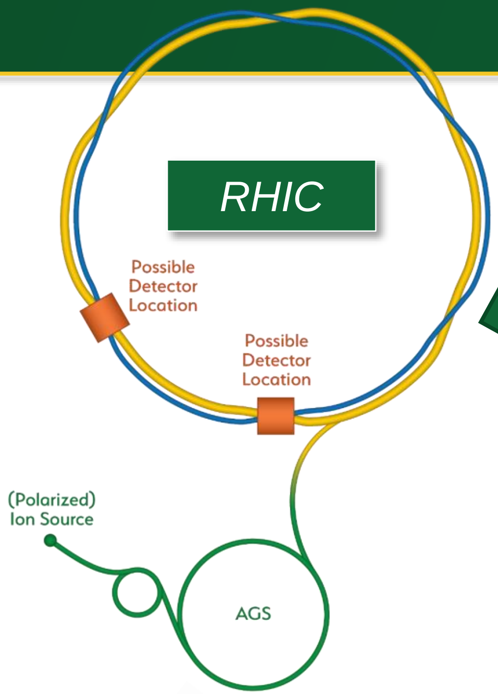


Community and NSAC defined the parameters of machine needed to address the science.

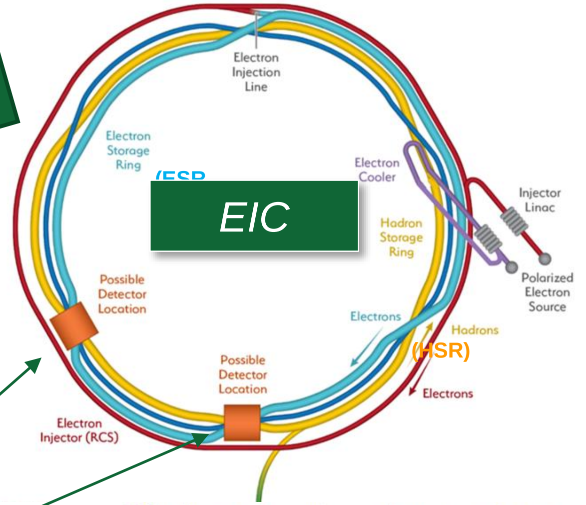


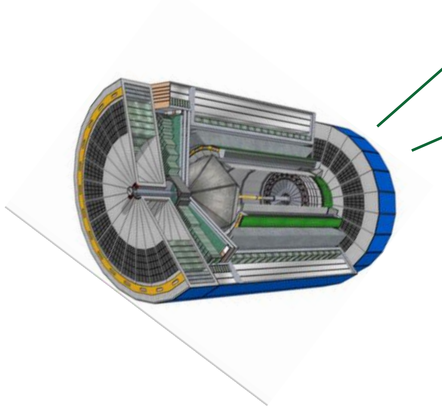
NSAC Performance Parameters:
A - Polarized e, p, light nuclei
B - Ion beam from deuterons to the heaviest table stable nuclei
C - Center of Mass energy 20-100 GeV
D - Capable of future Center of Mass upgrade to 140 GeV
E - High collision luminosity ~10^{33}-10^{34} cm^{-2} S^{-1}
F - More than one Interaction Region

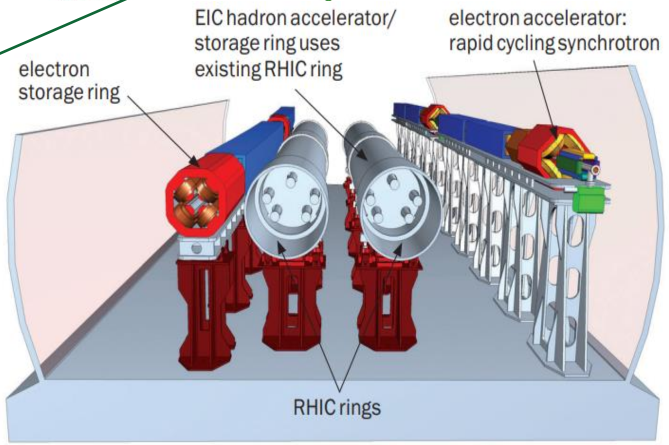
Preliminary Scope Overview



Current plan has the RHIC facility shutting down in 2025 and being modified for the EIC.







New systems include:

- Polarized electron source,
- Injector linac,
- Electron cooler complex,
- Rapid Cycling Synchrotron(RCS)
- Electron storage ring (ESR),
- Interaction region (IR) with 1 detector,
- Capability for implementing 2 IRs
- Infrastructure improvements.