

Nuclear Physics at a Glance

Nadia Fomin
DNP Chair
May 22, 2026



APS Division of Nuclear Physics



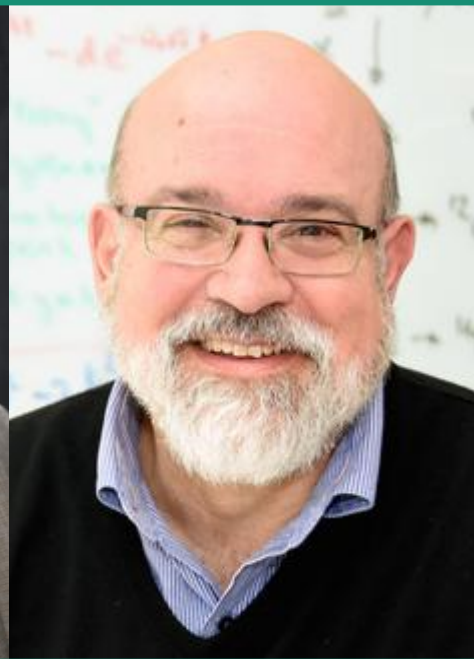
Nadia Fomin
Chair
University of
Tennessee



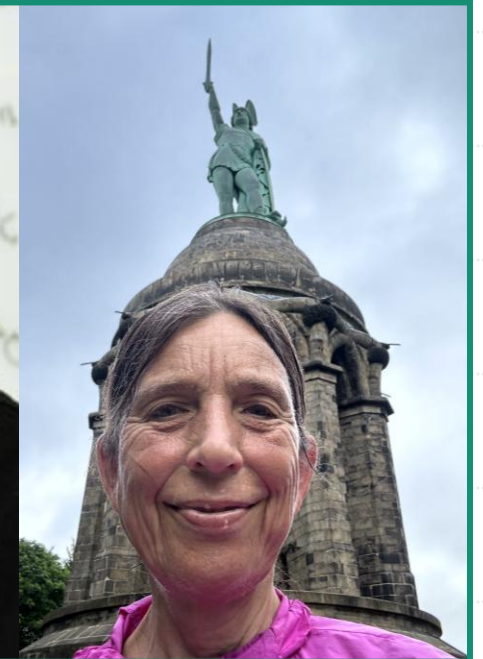
Helen Caines
Chair-elect
Yale University



Jeffery Blackmon
Vice Chair
LSU



Jim Napolitano
Past Chair
Temple University



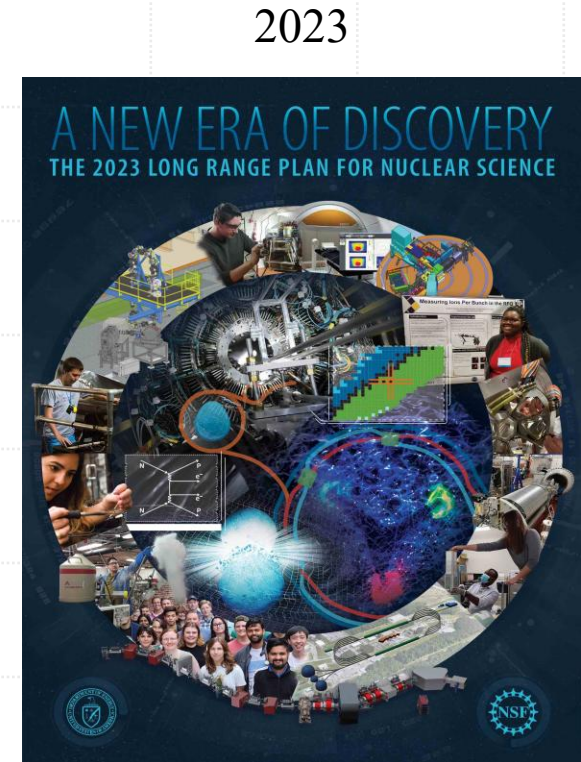
Ramona Vogt
Secretary/Treasurer
LLNL/UC Davis

Successful History of Long Range Planning in Nuclear Science

Since 1979 the Department of Energy Office of Science and the National Science Foundation periodically have charged the Nuclear Science Advisory Committee, NSAC, to provide a framework for coordinated advancement of the Nation's nuclear science research program.



LRPs consistently completed on budget



Slide from Gail Dodge

2023 LRP – Science Questions

1. How do quarks and gluons make up protons, neutrons, and ultimately, atomic nuclei?
2. How do the rich patterns observed in the structure and reactions of nuclei emerge from n-p interactions?
3. What are the nuclear processes that drive the birth, life, and death of stars?
4. How do we use atomic nuclei to uncover physics beyond the Standard Model?

2023 LRP – Selected Chapters*

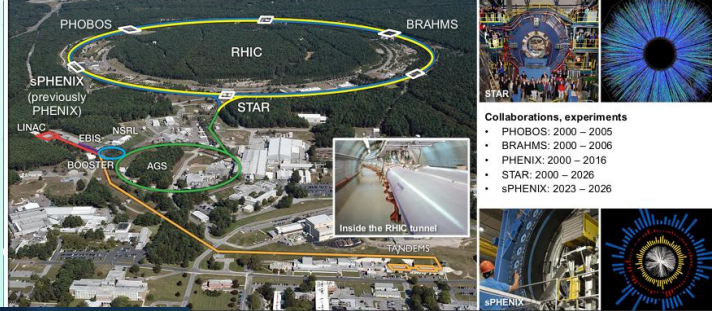
- Quarks and Gluons: Understanding the Strong Nuclear Force
- Nuclear Structure and Nuclear Reactions
- Nuclear Astrophysics
- Fundamental Symmetries, Neutrons, and Neutrinos
- Developing a Nuclear Workforce for the benefit of society
- Nuclear Science Applications (including Nuclear Data)

Facilities

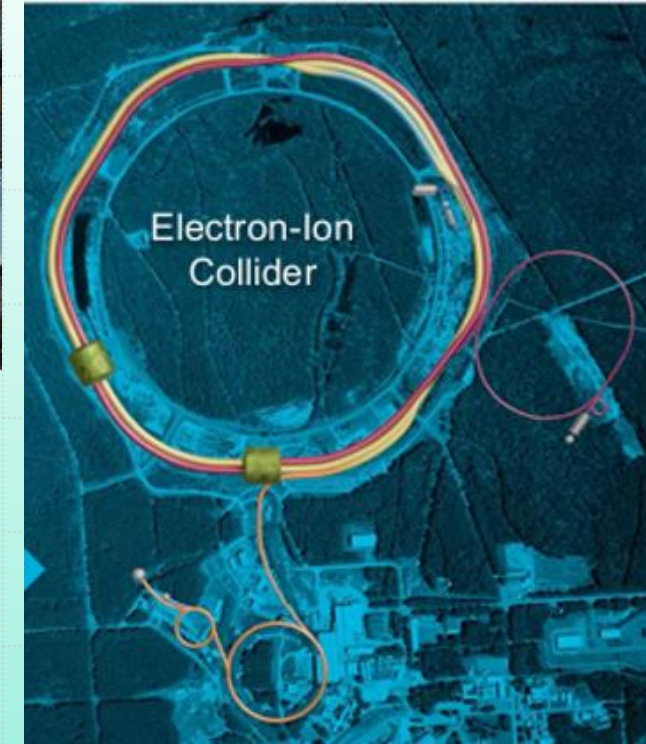
A glorious run from 2000-2026 : unparalleled scientific output: Quark Gluon Plasma and Nucleon Spin

The Relativistic Heavy Ion Collider

A machine built to explore fundamental matter at the dawn of time



- Collaborations, experiments
- PHOBOS: 2000 – 2005
 - BRAHMS: 2000 – 2006
 - PHENIX: 2000 – 2016
 - STAR: 2000 – 2026
 - sPHENIX: 2023 – 2026



ARUNA (Association for Research at University Nuclear Accelerators)



DNP Town Halls

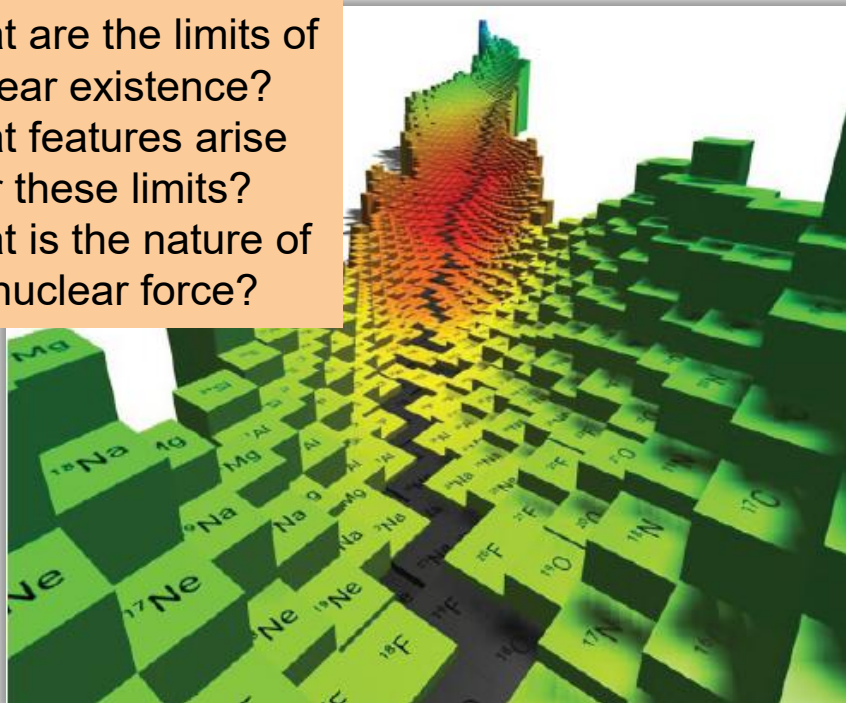
Jan 12 - <https://indico.phys.utk.edu/event/290>

Feb 13 - <https://indico.phys.utk.edu/event/297>



FRIB and FRIB users respond to national priorities that enable answers to fundamental questions posed by 2023 and earlier LRPs

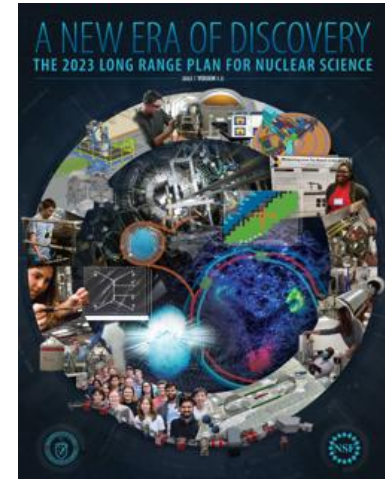
- What are the limits of nuclear existence?
- What features arise near these limits?
- What is the nature of the nuclear force?



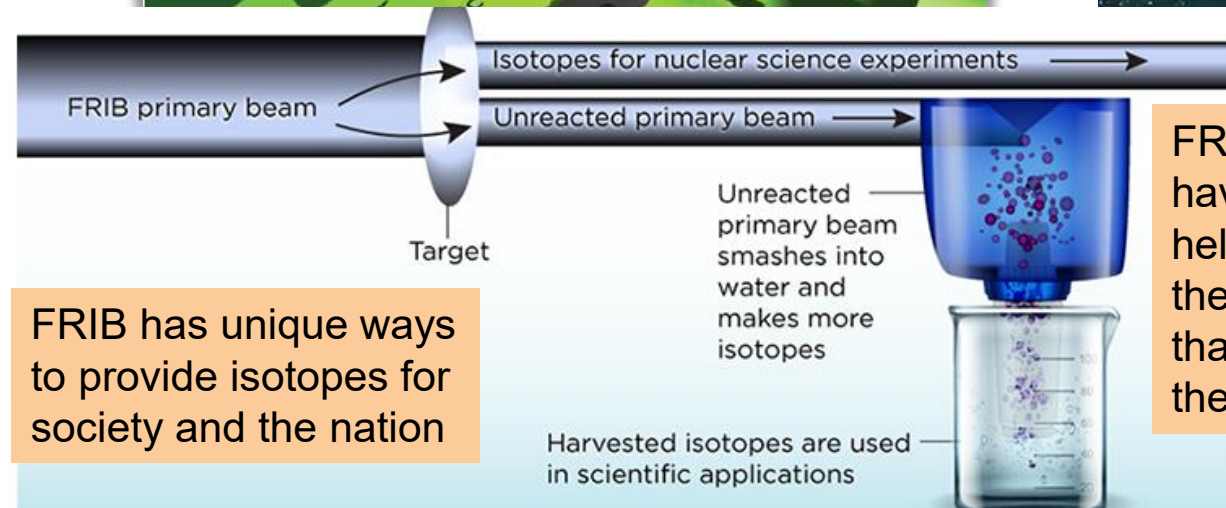
What are nuclear processes that drive the birth, life, and death of stars?



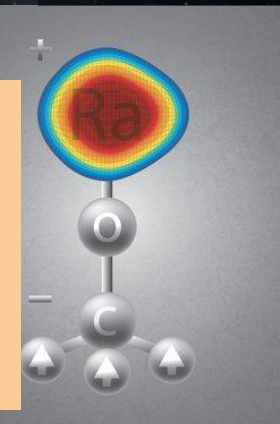
Observables in are isotopes connect FRIB with LIGO, NASA missions, and other international multi-messenger communities



"A New Era of Discovery: The 2023 Long Range Plan for Nuclear Science"



FRIB's isotopes can have properties to help answer why there is more matter than anti-matter in the universe

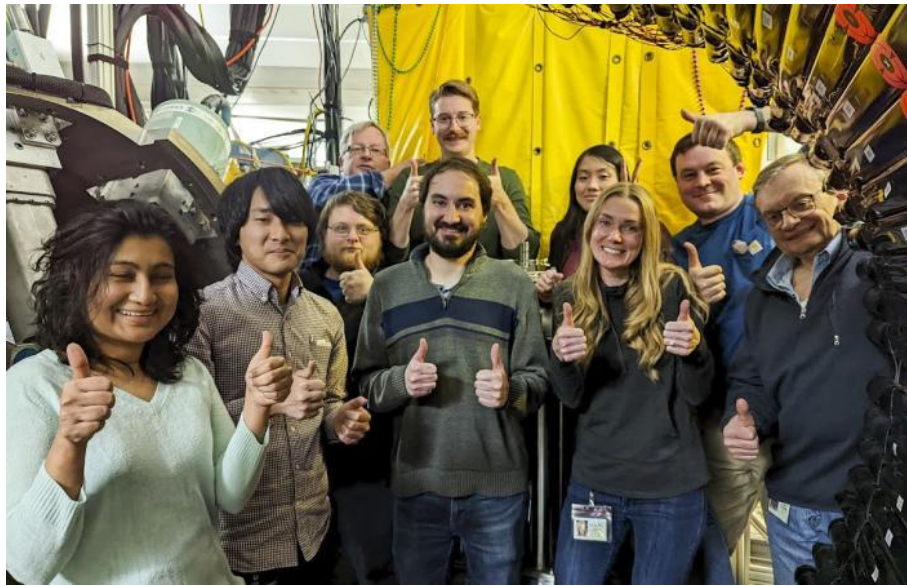


FRIB's science is interdisciplinary and connects to astronomical observations, atomic and molecular physics, and chemistry

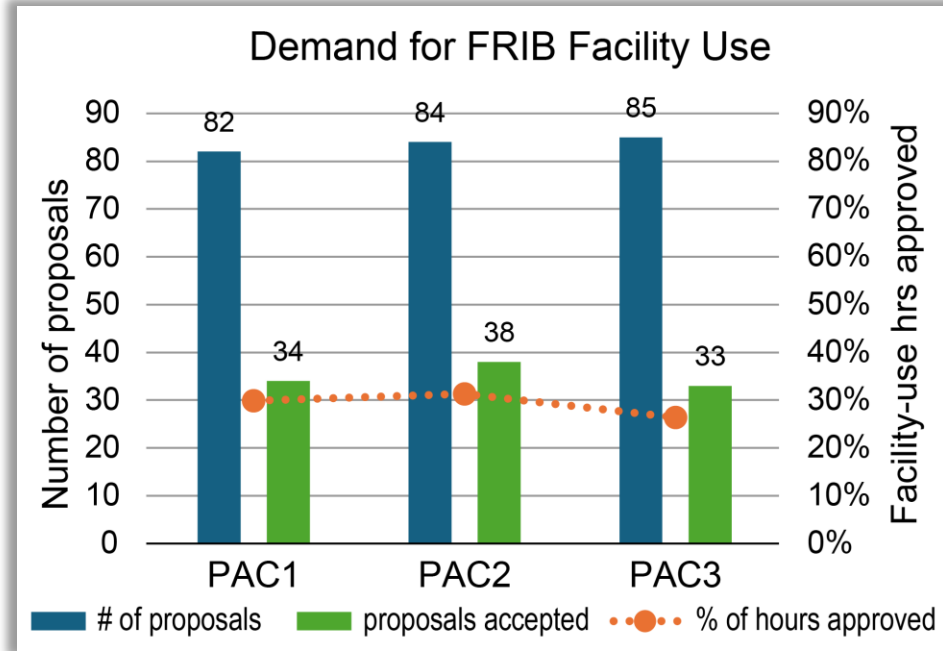
<https://www.caltech.edu/about/news/radioactive-molecules-may-help-solve-mystery-of-missing-antimatter>

The user community embraces the opportunities afforded by FRIB

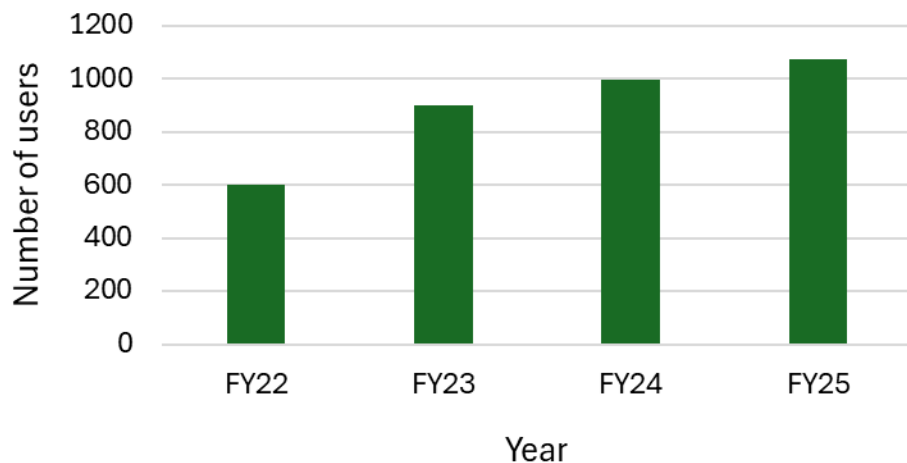
Facility is oversubscribed, only about 1/3 of requested facility-use time can be awarded



- High demand for facility-use time at FRIB
- All vaults and beam lines are in commission and have received beam, serving laboratory- and user-supported instruments
- Users are engaged and
 - bring instruments for campaigns and support them
 - build dedicated instruments
 - base PhD theses on FRIB experiments



DOE Annual User Statistics for FRIB



FRIB as international partner of choice

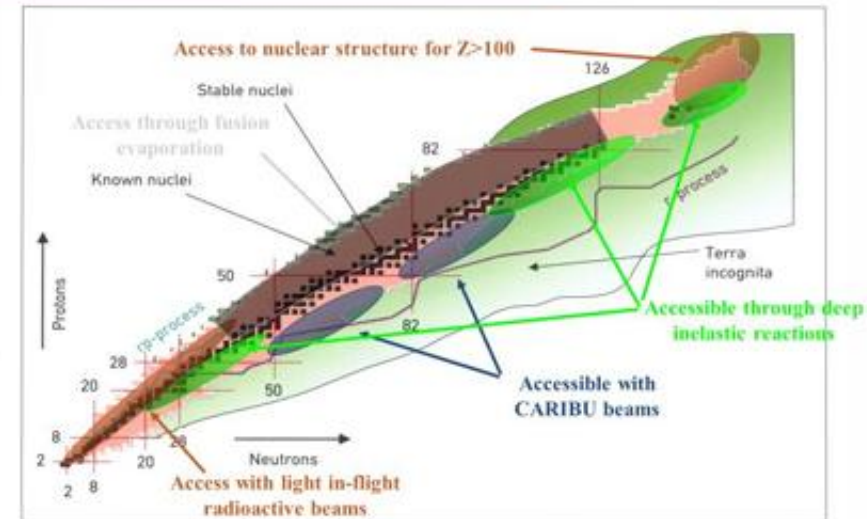
- FRIB attracted the International Research Laboratory on Nuclear Physics and Astrophysics:
 - CNRS (France) and MSU established at FRIB the International Research Laboratory on Nuclear Physics and Astrophysics (IRL NPA)
- FRIB attracted £3M UK investment for detector
 - FAUST is a UK-funded instrumentation project based at the University of Surrey, focused on developing a charged-particle detection system for GRETA@S800
- FRIB and INFN (Italy) have memorialized collaboration

ATLAS

- *ATLAS is a DOE low-energy nuclear physics national user facility*
- It provide beams and facilities enabling world leading research at around Coulomb barrier energy, answering key questions in the fields of:
 - nuclear structure
 - nuclear astrophysics
 - low-energy tests of the Standard Model
 - applications of low-energy nuclear physics

Research goals are guided by the Nuclear Science Long-Range plan, the relevant DOE performance milestones and the ATLAS Strategic plan.

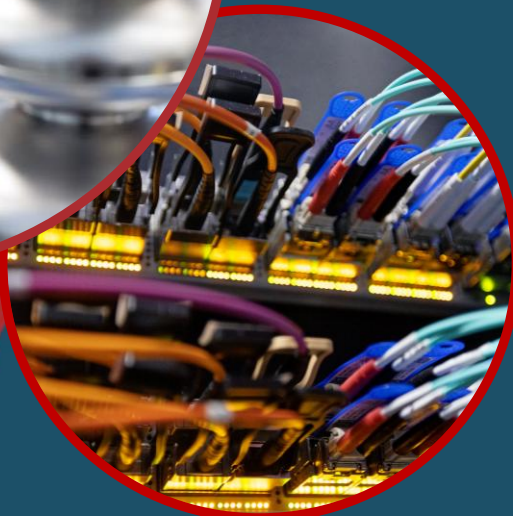
- This is done through:
 - providing beamtime for research programs
 - any stable beam from proton to uranium
 - some in-flight radioactive beams
 - low-energy and reaccelerated (nu)CARIBU beams
 - developing new experimental equipment and accelerator capabilities to address evolving needs of the field



- ATLAS continues serving the community, delivering a large number of highly sought-after beamtime hours, while implementing an upgrade plan developed in collaboration with the users that will keep it at the forefront of the field.

Jefferson Lab

Thomas Jefferson National Accelerator Facility



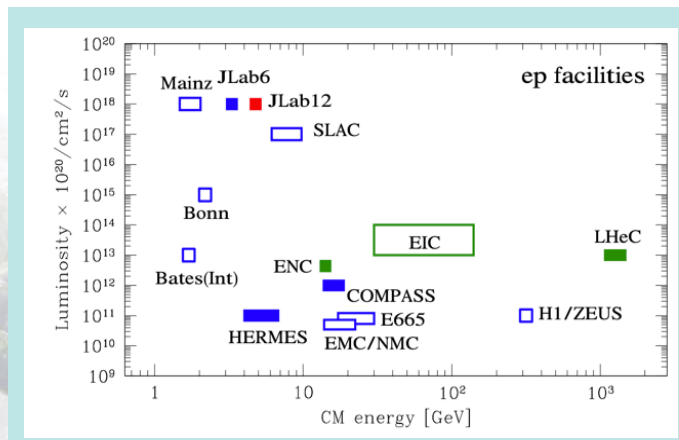
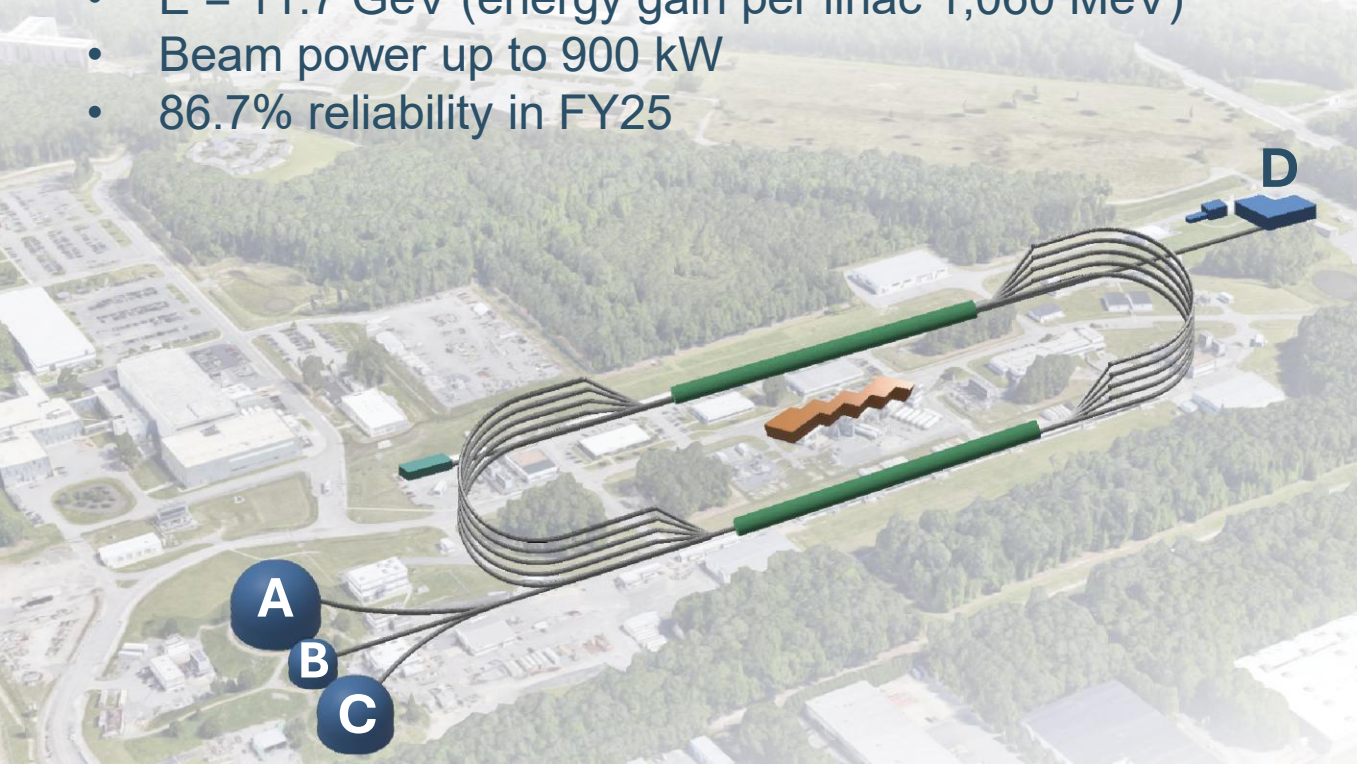
U.S. DEPARTMENT
of ENERGY

Jefferson Lab

Continuous Electron Beam Accelerator Facility (CEBAF)

FY26 CEBAF Operations Plan

- 24 weeks of Physics
- E = 11.7 GeV (energy gain per linac 1,060 MeV)
- Beam power up to 900 kW
- 86.7% reliability in FY25



CEBAF is the only electron accelerator in the world capable of probing nucleon and nuclear structure at the fundamental quark and gluon level.

World leadership:

luminosity (up to $10^{39} \text{ e/cm}^2/\text{s}$),
 polarization (up to 95%)
 with energy up to 12 GeV

Experiments in four halls – A, B, C and D

- 2 high current, spectrometers, multipurpose
- 1 low current, nearly full acceptance
- 1 for direct photon interactions (exotic spectroscopy, J/Ψ , etc.)



CEBAF: High-Impact Science Programs

The CEBAF user facility runs up to four experimental halls simultaneously provided polarized electrons and total beam power of over 1MW. The scientific program, which completes several experiments a year, has six main categories:

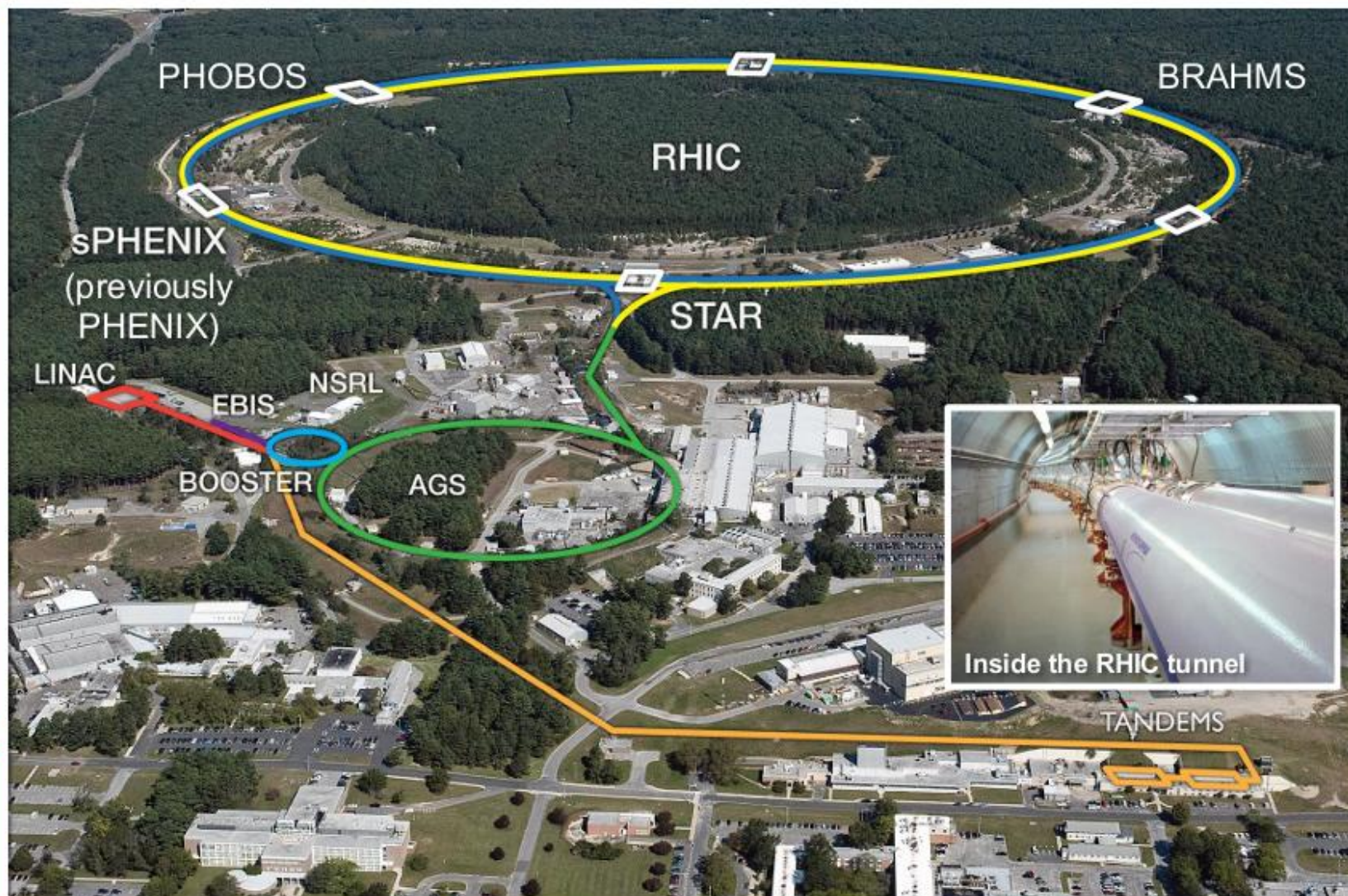
- **Nucleon structure:** Precision measurements of form factors and parton distributions reveal how quarks and gluons are arranged and bound.
- **Excited states & resonances:** Mapping the baryon spectrum tests how QCD confinement generates mass and structure.
- **3D imaging of quarks:** Generalized Parton Distributions (GPDs) from Deeply Virtual Compton Scattering and meson production give a “tomographic” picture of the nucleon.
- **Short-range nuclear forces:** Studies of correlated nucleon pairs show how QCD at the quark level translates into the nuclear force.
- **Exotic matter:** Searches for hybrid mesons and gluonic excitations test predictions of QCD beyond the simple quark model.
- **Tests of the Standard Model and Fundamental Symmetries:** Precision measurement such as MOLLER making ultra-precise measurements of the electron's weak charge and the weak mixing angle to search for physics beyond the standard model.



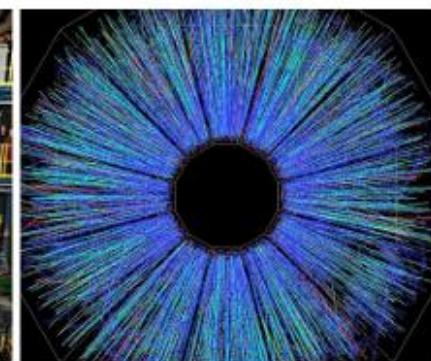
A glorious run from 2000-2026 : unparalleled scientific output: Quark Gluon Plasma and Nucleon Spin

The Relativistic Heavy Ion Collider

A machine built to explore fundamental matter at the dawn of time



STAR

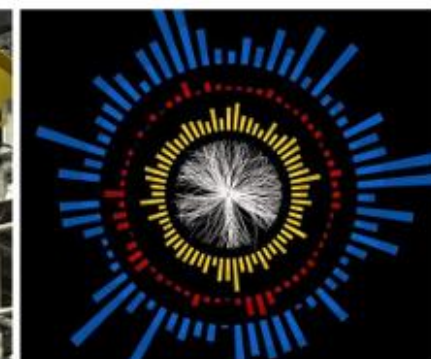


Collaborations, experiments

- PHOBOS: 2000 – 2005
- BRAHMS: 2000 – 2006
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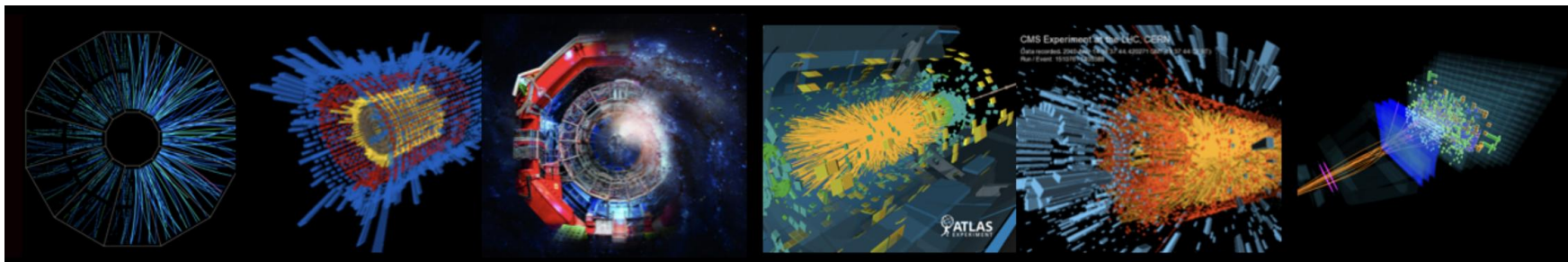


sPHENIX



Discovery Science at RHIC and the LHC

Combined complementary programs have demonstrated that the quark gluon plasma (QGP) is a strongly coupled, near perfect, highly vortical, fluid of deconfined quarks and gluons



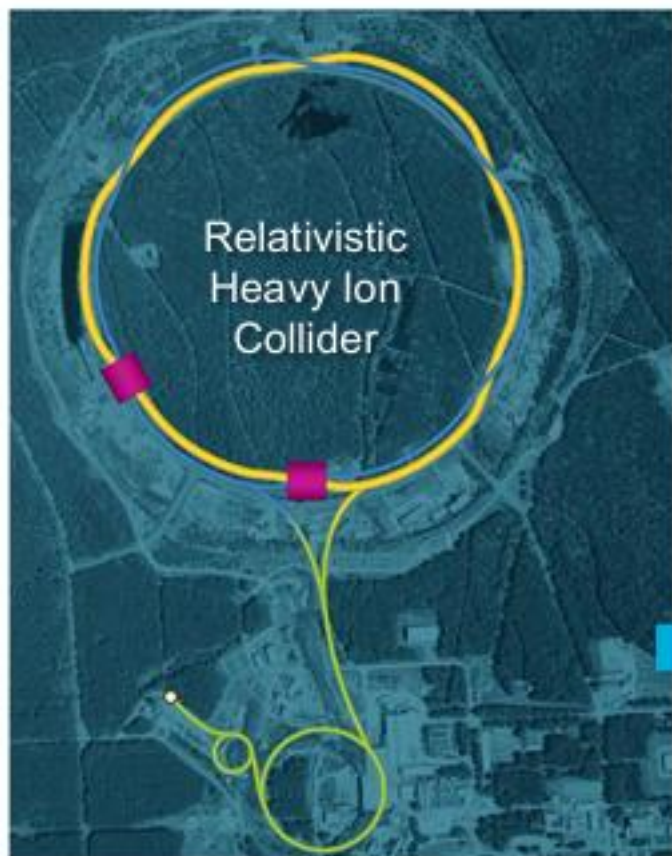
Open questions remain:

- What are the QGP's microscopic properties?
- How does this strongly interacting matter thermalize and exhibit collective fluid-like behavior?
- Is there a Critical Point in the QCD phase diagram?
- How do quarks and gluons lose energy and propagate through hot nuclear matter?
- Can we understand the emergence of hadrons, confinement, and the structure of matter?
- What are the connections between heavy-ions collisions and neutron stars?

RHIC : 7-10 years of analyses and publications necessary to complete science mission

LHC : Final HI collisions of Run-3 starting soon. Preparing for HL Run-4 and beyond

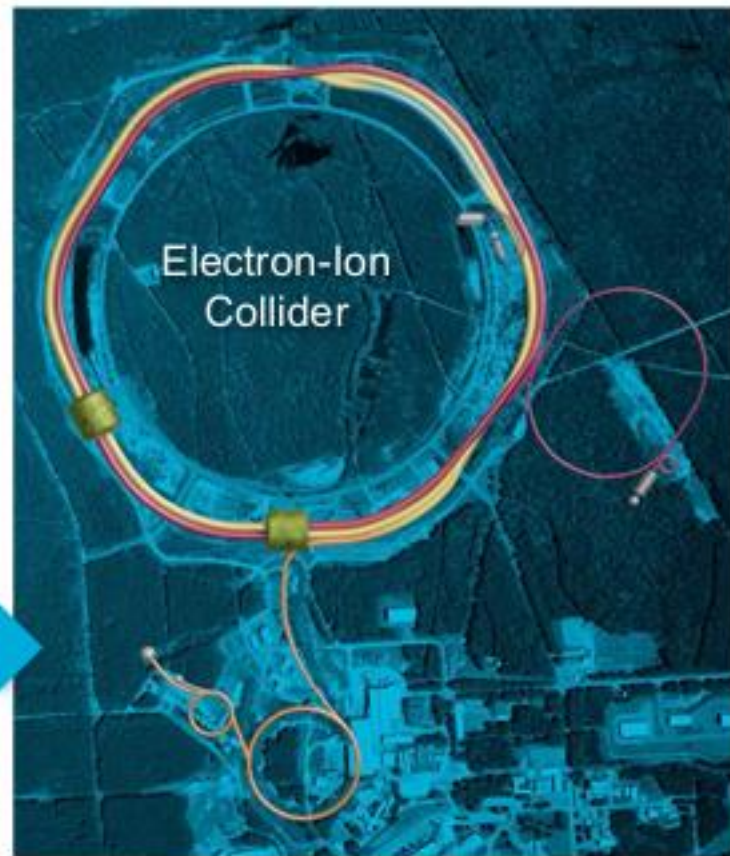
A New Era of Discovery: From RHIC to the Electron-Ion Collider (EIC)



Building on the ~\$2 billion+ investment in RHIC:

- Re-use existing tunnel
- Minimal modification to ion beam complex (yellow)
- New electron beam facility

Partnership between U.S. Department of Energy, Brookhaven Lab, Thomas Jefferson National Accelerator Facility, New York State, and collaborators around the world.



Compelling EIC Science Case



How do quarks, gluons, and orbital angular momentum contribute to proton spin?

Spin is a fundamental property of matter.

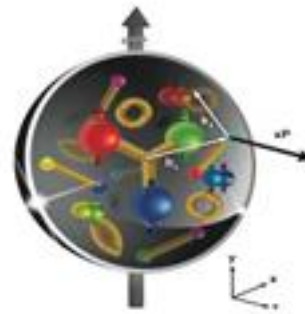
All elementary particles, but the Higgs, carry spin. Spin cannot be explained by a static picture, rather the interplay between the properties and interactions of quarks and gluons inside the proton.



Does the mass of visible matter emerge from quark-gluon interactions?

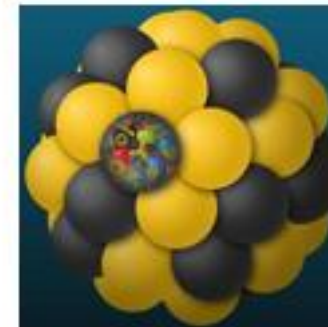
Atom: Binding/Mass = 0.00000001
Nucleus: Binding/Mass = 0.01
Proton: Binding/Mass = 100

The EIC will determine an important term contributing to the proton mass, the so-called quantum chromodynamics (QCD) trace anomaly.



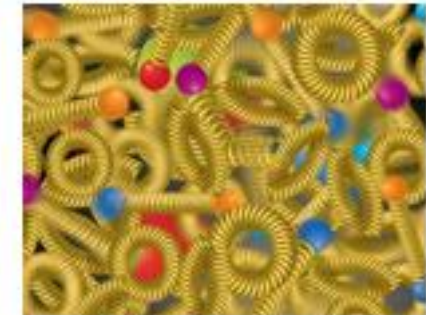
How can we understand QCD dynamics and the relation to confinement?

EIC will image quarks and gluons in 3D in space and momentum inside the nucleon and nuclei and uncover how the nucleon properties emerge from quarks and gluons and their interactions.



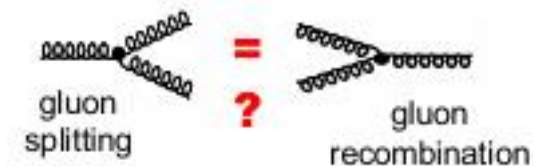
How do quark-gluon interactions create nuclear binding?

Is the structure of a free and bound nucleon the same?
How do quarks and gluons, interact with a nuclear medium?
How do the confined hadronic states emerge from these quarks and gluons?



Does gluon density in nuclei saturate at high energy?

How many gluons can fit in a proton?
How does a dense nuclear environment affect the quarks and gluons, their correlations and interactions?



A NEW ERA OF DISCOVERY

THE 2023 LONG RANGE
PLAN FOR NUCLEAR SCIENCE



RECOMMENDATION 1

The highest priority of the nuclear science community is to capitalize on the extraordinary opportunities for scientific discovery made possible by the substantial and sustained investments of the United States. We must draw on the talents of all in the nation to achieve this goal.

RECOMMENDATION 2

As the highest priority for new experiment construction, we recommend that the United States lead an international consortium that will undertake a neutrinoless double beta decay campaign, featuring the expeditious construction of ton-scale experiments, using different isotopes and complementary techniques.

RECOMMENDATION 3

We recommend the expeditious completion of the EIC as the highest priority for facility construction.

RECOMMENDATION 4

We recommend capitalizing on the unique ways in which nuclear physics can advance discovery science and applications for society by investing in additional projects and new strategic opportunities.

Complete initiated
scientific programs

International Collaboration

New Construction

Applications

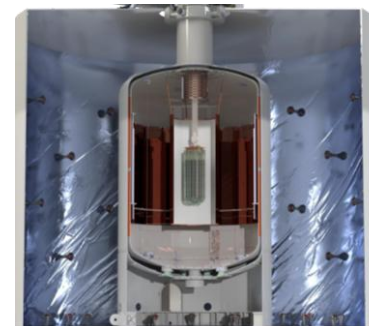
~350 researchers from about ~60 institutions from around the world

Combines the technological expertise and experience from the predecessor experiments GERDA and the MAJORANA DEMONSTRATOR

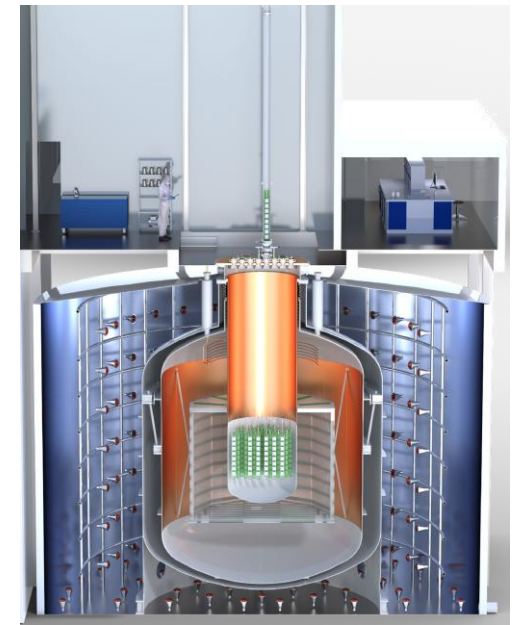
LEGEND aims to improve the half-life discovery sensitivity for $^{76}\text{Ge } 0\nu\beta\beta$ by two orders of magnitude, with discovery sensitivity of

$$T_{1/2} > 1.3 \times 10^{28} \text{ yrs } (3\sigma) \quad m_{\beta\beta} \sim 10\text{-}25 \text{ meV}$$

- **LEGEND-200**: up to 200 kg of 90%-enriched Ge detectors deployed in the GERDA liquid argon (LAr) cryostat, running at LNGS. [PRL 136, 022701, \(2026\)](#)
- **LEGEND-1000**: 1 ton of 90%-enriched Ge detectors deployed in a new experimental infrastructure at LNGS, start of data taking in the 2033-2035 timeframe.



LEGEND-200



LEGEND-1000

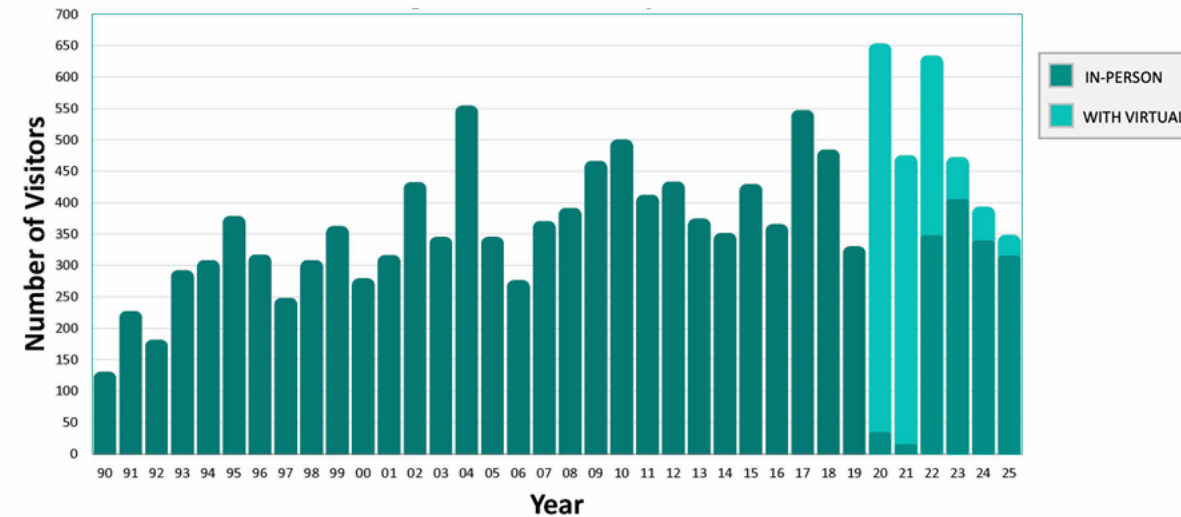
INT – A Theory “Facility”

Report of the
Nuclear Science Advisory Committee
Subcommittee on Nuclear Theory
May 11, 1988
“Koonin Report”

Recommendation: We recommend the creation of one or more nuclear theory centers. Such centers must be truly national in character, must have a significant interdisciplinary component, and must be viewed and funded as an important complement to the strengthened individual programs discussed in our Principal Recommendation.



- Founded in 1990, the INT has thrived for more than three decades due to the continued funding from the Department of Energy’s Office of Nuclear Physics and support from the University of Washington.
- Over this period, leadership and the program office within DOE Nuclear Physics, the University of Washington, the INT, and its National Advisory Committee have focused on shared objectives and demonstrated an outstanding record of communication and collaboration.



Nuclear Science Workforce

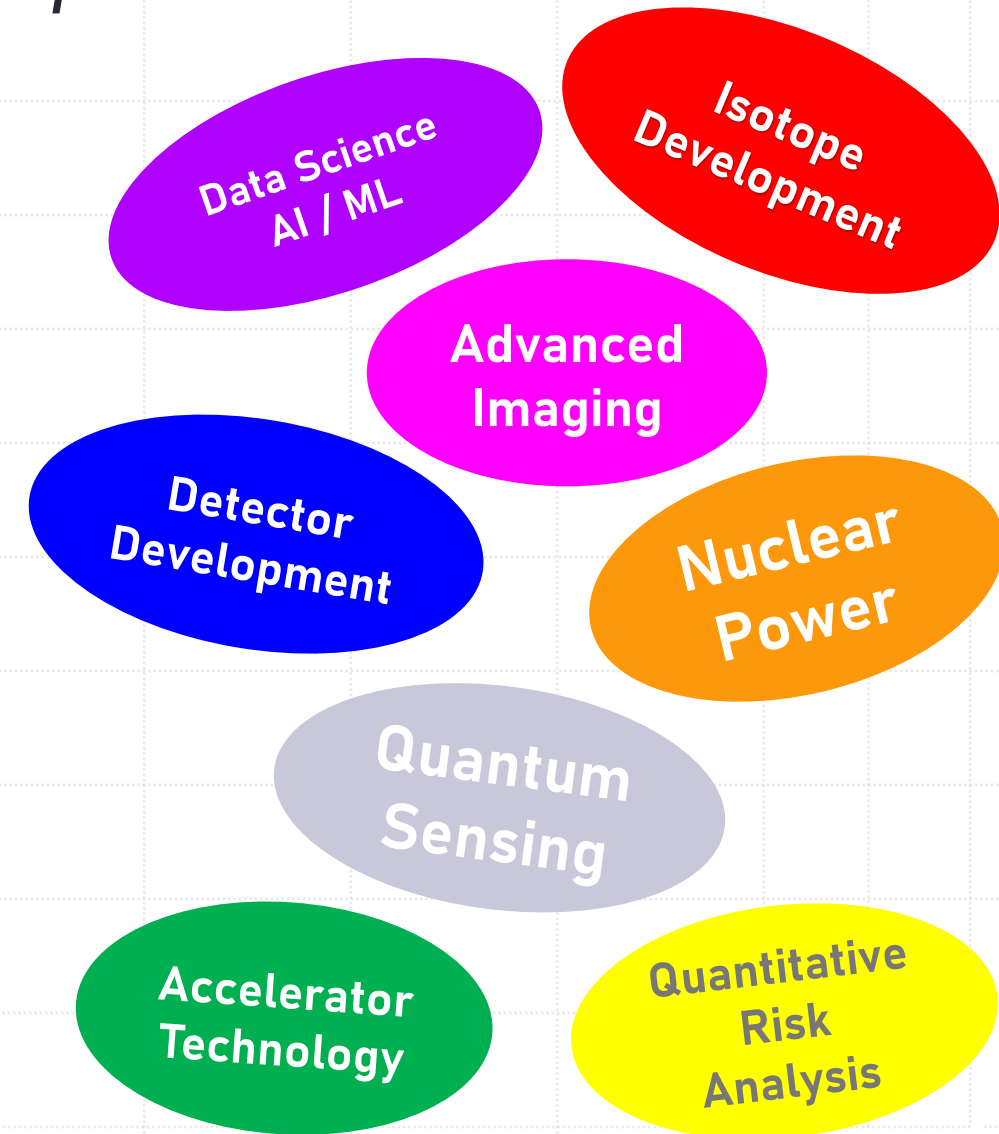
People are central to the scientific enterprise

2023 LRP recommendation 1 (of 4)

The highest priority of the nuclear science community is to capitalize on the extraordinary opportunities for scientific discovery made possible by the substantial and sustained investments of the United States. We must draw on the talents of all in the nation to achieve this goal.

This recommendation requires:

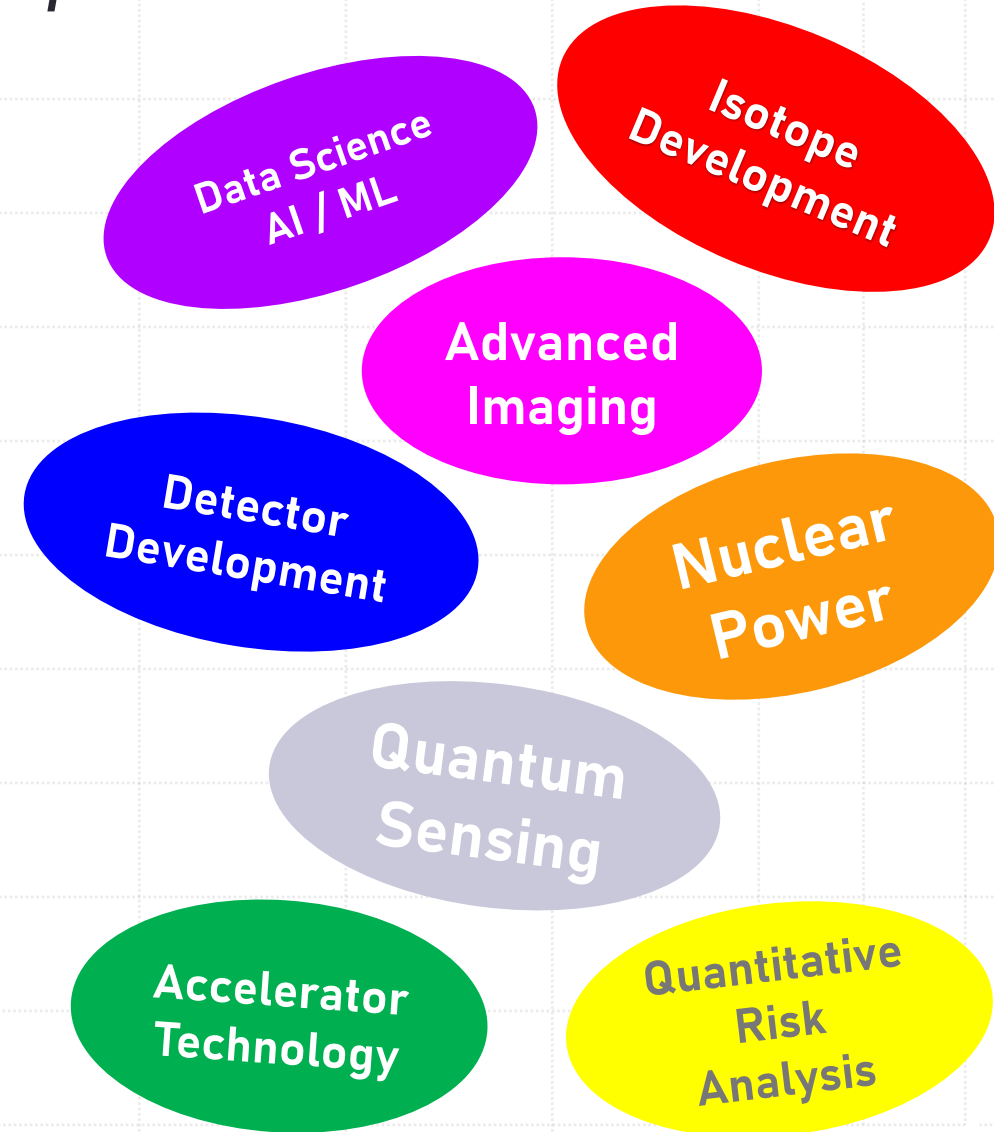
Increasing the research budget that advances the science program through support of theoretical and experimental research across the country, thereby expanding discovery potential, technological innovation and workforce development to the benefit of society.



Nuclear Science Workforce

People are central to the scientific enterprise

- **Analysis of CEU participants (2011 - 2021)**
- Traceable NP PhD Recipients: Industry, National Labs, Academia
- Using skills developed in PhD to support:
 - ✓ National Security
 - ✓ Non-proliferation
 - ✓ Healthcare Improvement
 - ✓ Financial / Health / Security Risk Analysis
 - ✓ Energy Security / Nuclear Power
 - ✓ Advanced Detectors / Accelerator Development
 - ✓ Crucial role in driving physics at FRIB, JLab, EIC, Theory etc.



2023 LRP Funding Profile

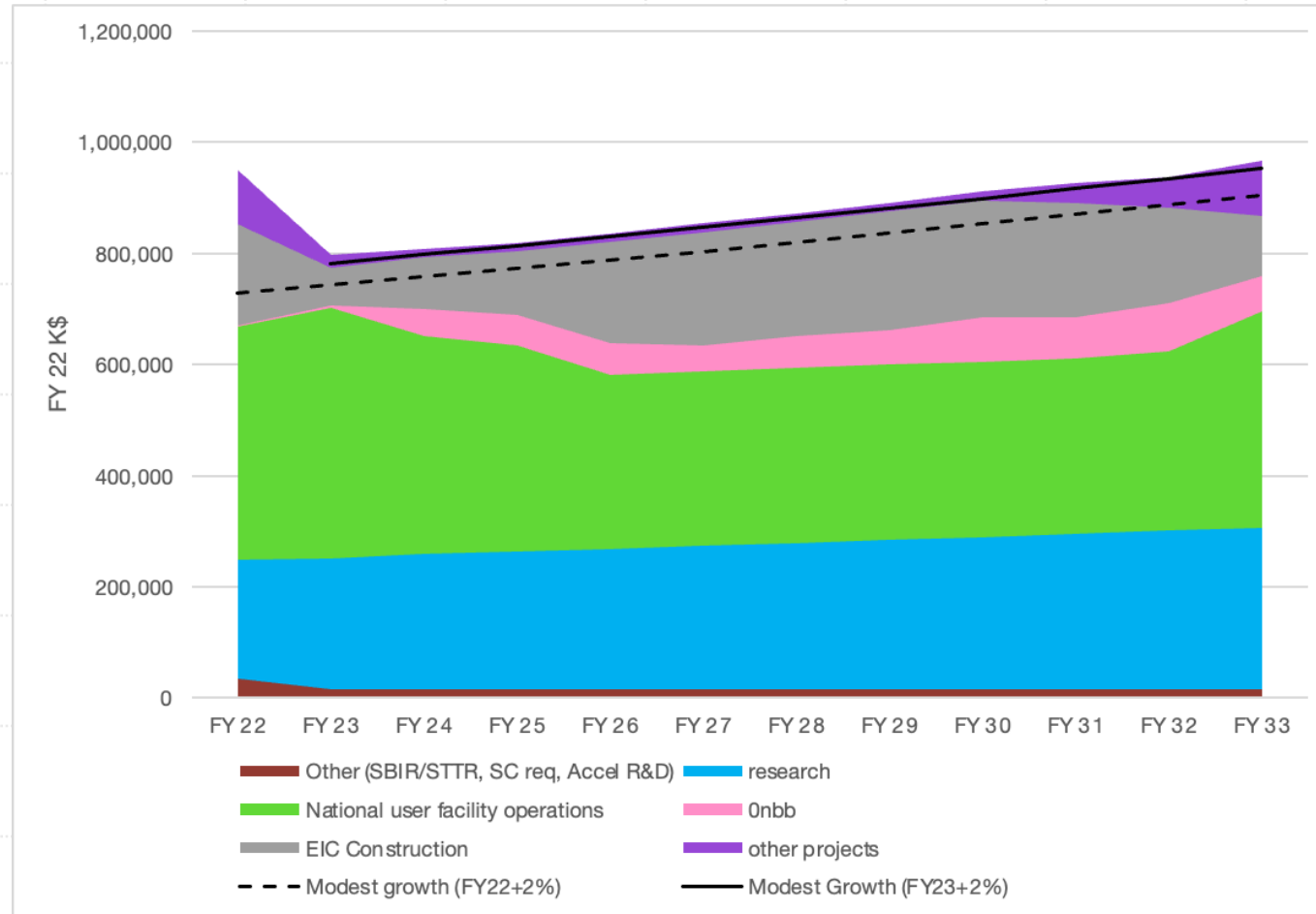


Figure 12.5. Modest growth funding profile.

This funding profile includes the required DOE contributions (e.g., to SBIR/STTR, Accelerator R&D) (brown), funding for a research program at the level of 32% of the enacted FY22 budget (without IRA funds), increasing annually by 2% over inflation (blue), funding for operations of national user facilities at 85% optimal operations (green), funding for the US portion of an international campaign of three ton-scale neutrinoless double beta decay experiments (pink), funding for EIC construction (gray), and funding for other projects (purple). All numbers are in FY22 \$K. The solid black line represents modest growth (2% real growth over inflation) anchored in FY23 dollars. The dashed black line represents modest growth (2% real growth over inflation) anchored in FY22 dollars.

Nuclear Physics is a vibrant and diverse field with well established international leadership in multiple areas

We look forward to a new era of collaboration and scientific discovery with our DPF colleagues

Thank you for input in various forms:

Abhay Deshpande, Jens Dilling, Thomas Glassmacher, Alex Gade, Sanjay Reddy, Evangeline Downie, John Wilkerson, Guy Savard, Helen Caines, and many many more

Abstract submission for the **Fall 2026 DNP Meeting** is now open (until July 21):

<https://www.aps.org/events/2026/dnp-2026>

Philadelphia, PA – Oct 11-14, 2026