DOE Office of Nuclear Physics Report

Sharon Stephenson
Division Director, Physics Research Division
Office of Nuclear Physics

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U.S. DEPARTMENT of ENERGY | Office of Science

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Office of Nuclear Physics at a Glance

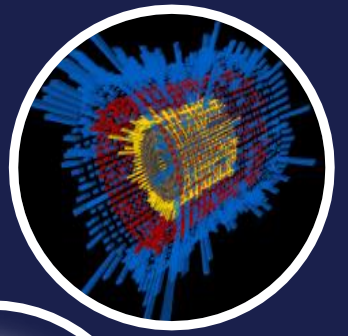
Our Mission:

Discover, explore, and understand all forms of nuclear matter.

Seek to understand **subatomic matter**, including exotic matter inside neutron stars and in the early days of the universe, **and how that knowledge can benefit society (critical technologies, medicine, and national security)**.

Largest supporter (>95%) of nuclear physics research
FY 2025 Enacted $825.6M

Supports over **1,400 Ph.D. staff** and **720 graduate students**
FY 2025 Research 29%



Stewardship of **4 SC User Facilities:** ATLAS, CEBAF, FRIB, RHIC
FY 2025 Operations 57%

Electron-Ion Collider will probe the inside of the proton
FY 2025 Projects 14%

NP Avenues for Discovery

Probing Proton Substructure

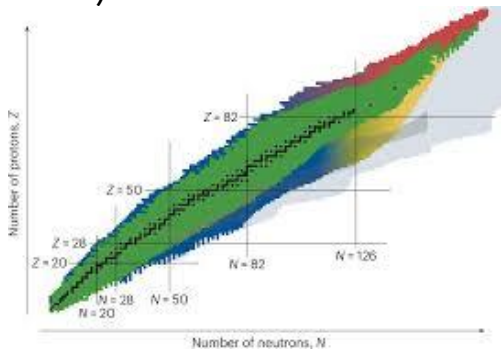
Reveals dynamics, structure, and spin for protons and neutrons

- Heavy ion collision data informs understanding of nuclear phenomena and the formation of the universe
- U.S. provides the world's highest intensity, polarized beams for this science

Exploring the Isotope Landscape

Enables element and isotope discovery

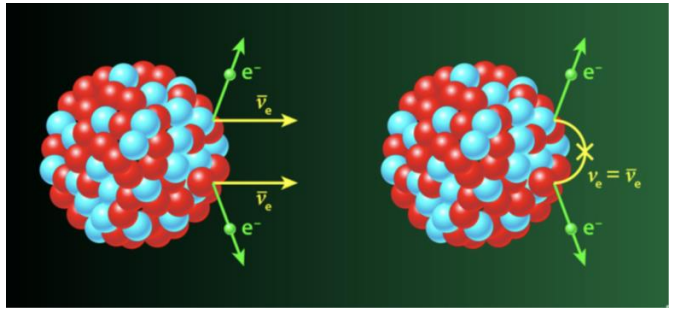
- Reaction rates and structure data for national priorities
- Superheavy elements provide a fertile ground for tests of theory
- Nuclear data and capabilities for characterization of electronics (e.g., defects, radiation-induced failures)



Studying Rare Decays

Targets natural processes that break conservation laws and symmetries

- Data-driven science to explain the matter-antimatter balance
- Extreme high-precision detectors translate to other applications
- Nuclear-science-based innovation for Quantum Information Science



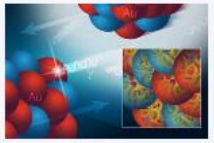
Crosscutting: Theory, AI, & Advanced Computing; Accelerator & Detector R&D

Probing Proton Substructure

Open questions:

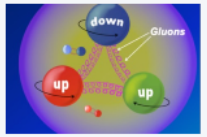
- How does nuclear matter evolve with temperature and density?
- How do quarks and gluons make up protons, neutrons, and atomic nuclei?
- Does gluon density saturate at high energy?

Highlights:



Gluons' Density Isn't the Same in Bound vs Unbound Protons and Neutrons

Data show the distribution of gluon "glue" in protons and neutrons changes when they are bound together in nuclei.



New Approach Merges Theoretical Fundamentals with Experimental Studies of the Proton's Structure

A new approach to applying quantum chromodynamics paves the way for a deeper understanding of the strong nuclear interaction.

Imaging Nuclear Shapes by Smashing Them to Smithereens

Scientists use high-energy heavy ion collisions in a new way to reveal subtleties of nuclear structure with implications for many areas of physics.

Tools of the trade:

National user facilities

- Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF)
- Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL)

Other facilities

- European Council for Nuclear Research (CERN) in Switzerland/France
- Triangle Universities Nuclear Laboratory (TUNL) in North Carolina

CEBAF@TJNAF

RHIC@BNL

Exploring the Isotope Landscape

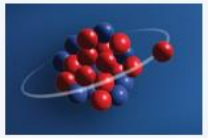
Open questions:

- What are the limits of nuclear existence?
- What are the nuclear processes that drive the birth, life, and death of stars?
- How does matter behave at the most extreme densities in the universe?

Highlights:

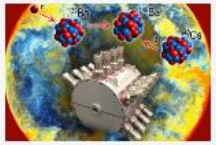
New Progress Toward the Discovery of New Elements

Scientists demonstrated a new way to produce the superheavy element livermorium (element 116) with titanium-50.



Researchers Obtain the First High-Precision Mass Measurement of Aluminum-22

The Facility for Rare Isotope Beams enables a high-precision mass measurement at the edge of the nuclear chart.



Nuclear Physics Experiment Helps Identify Conditions for a New Astrophysical Process

New nuclear physics measurements shed light on the synthesis of heavy elements in stars.

Tools of the trade:

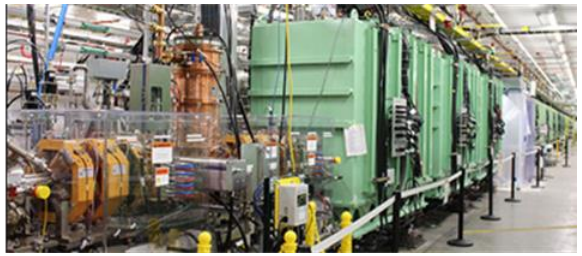
National user facilities

- Facility for Rare Isotope Beams (FRIB) at Michigan State University
- Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Lab

Other facilities

- 88-Inch Cyclotron at Lawrence Berkeley National Laboratory
- Cyclotron Institute at Texas A&M University
- Triangle-Universities Nuclear Laboratory (TUNL) in North Carolina

ATLAS@ANL

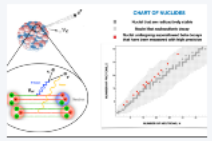


FRIB@MSU

Studying Rare Decays

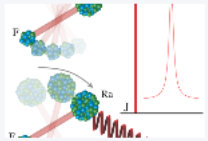
Open questions:
- What is the origin of the matter-antimatter imbalance in the universe?
- Are neutrinos their own antiparticles?
- Are there more forces than the four we know about?

Highlights:



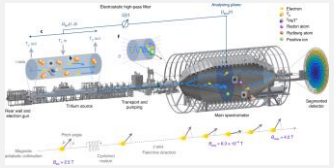
New Precise Calculation of Nuclear Beta Decays Paves the Way to Uncover Physics Beyond the Standard Model

Theorists identify new effects needed to compute the nuclear beta decay rate with a precision of a few parts in ten thousand.



Precision Measurements of Radioactive Molecules for Fundamental Physics

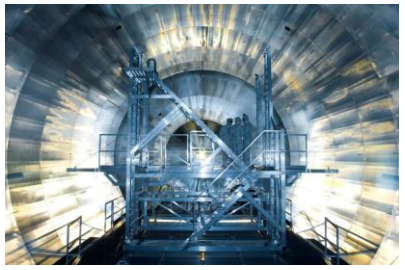
Pushing boundaries with radioactive molecules for future studies of nuclear structure and fundamental symmetry.



Direct neutrino-mass measurement with sub-electronvolt sensitivity

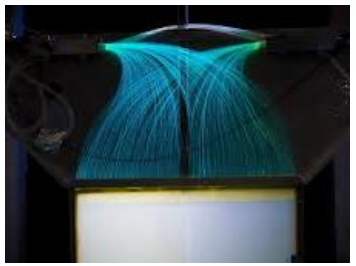
Tools of the trade:
- Karlsruhe Tritium Neutrino Experiment (KATRIN) in Germany
- Cryogenic Underground Observatory for Rare Events (CUORE) and Large Enriched Germanium Experiment for Neutrinoless Double Beta Decay (LEGEND-200) in Italy
- Ultra Cold Neutron Lifetime Measurement (UCNtau) at Los Alamos National Laboratory
- Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington
- Cyclotron Institute at Texas A&M University (TAMU)

+ other efforts at National Laboratories and Universities

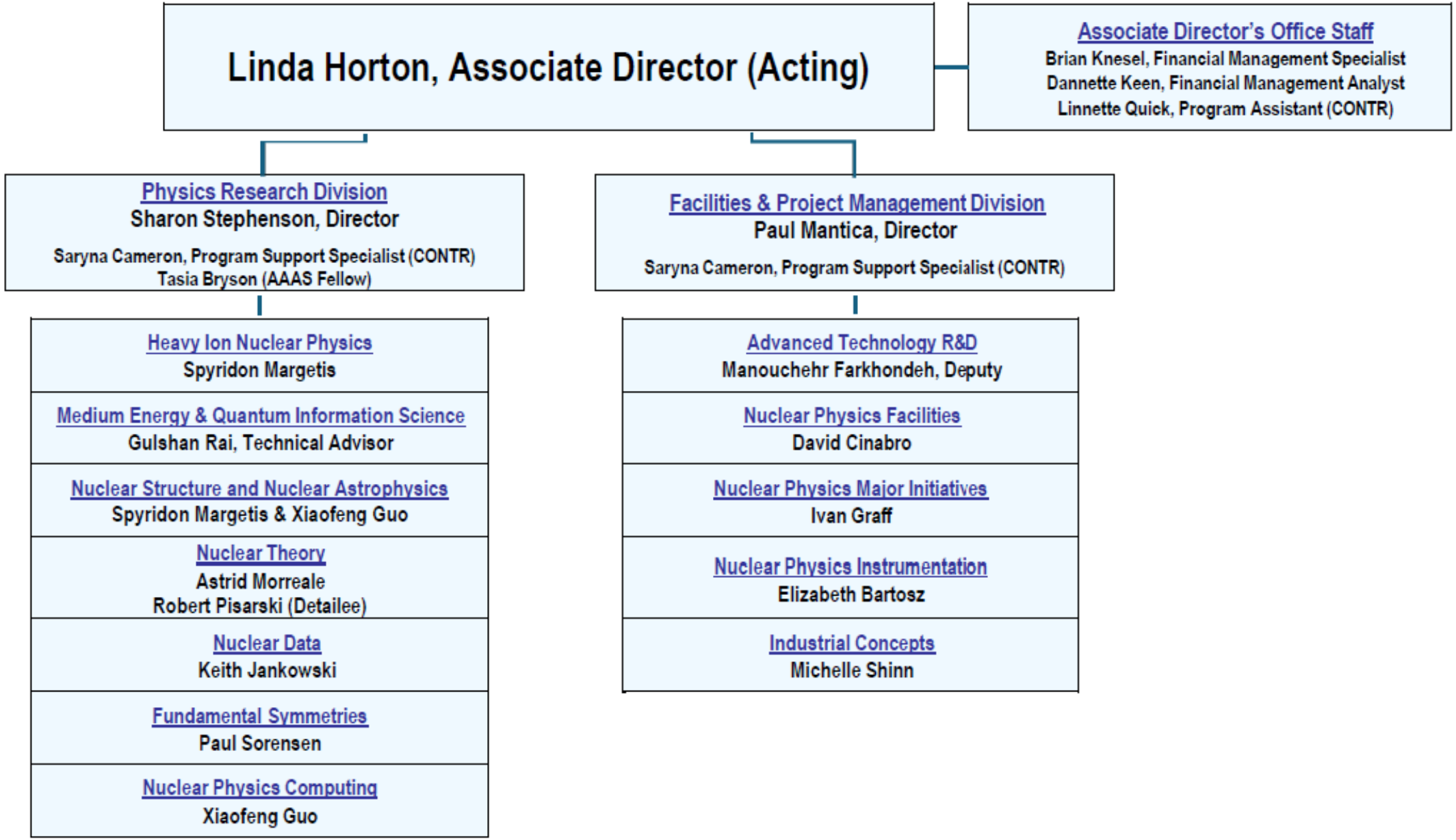


KATRIN@KIT

CUORE@LNGS



UCNtau@LANL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David Cinabro
Nuclear Physics Major Initiatives
Ivan Graff
Nuclear Physics Instrumentation
Elizabeth Bartosz
Industrial Concepts
Michelle Shinn

FY 2025 Initial Funding Opportunities/National Lab Calls
Notices of Funding Opportunities (NOFOs)

Title	Release Date
FY 2025 Continuation of Solicitation for the Office of Science Financial Assistance Program – OPEN	10/1/2024
Early Career Research Program	1/17/2025
EPSCoR Implementation Grants (DOE-SC)	9/12/2024
Nuclear Data Interagency Working Group Research Program	12/3/2024
Artificial Intelligence and Machine Learning Applied to Nuclear Science and Technology	10/15/2024
National Quantum Information Science Research Centers (DOE-SC)	1/15/2025

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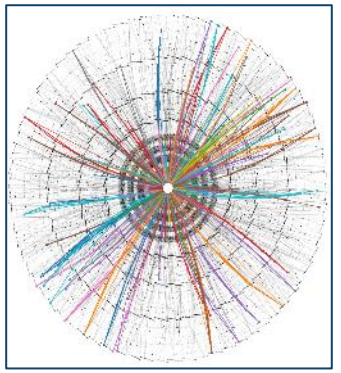
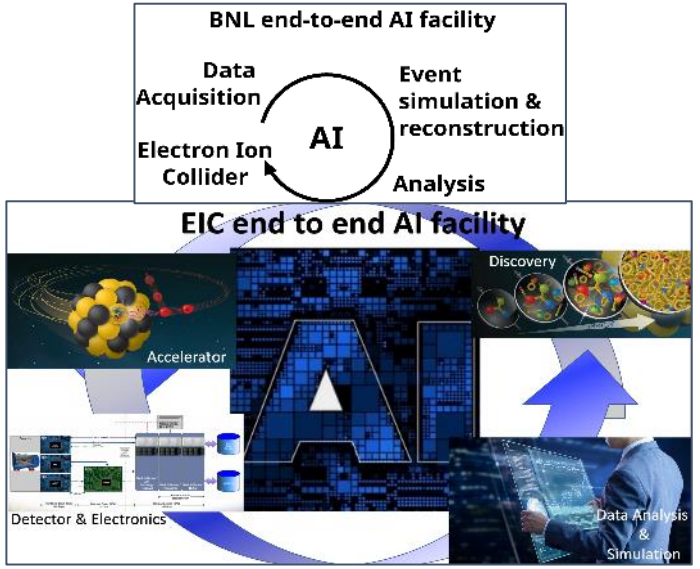
Artificial Intelligence and Machine Learning in Nuclear Physics

- **AI for efficient accelerator operations**. NP supports efforts to improve machine performance, increasing the available beam hours for scientific research. This includes enabling automated beam tuning at FRIB and ATLAS, ion production optimization at the 88-Inch Cyclotron, and reducing the impact of radiofrequency trips at CEBAF.
- **AI/ML for advancing scientific discovery.** Both experimentalists and theorists are applying AI/ML techniques to accelerate the pace of science outcomes. For example, artificial neural networks were recently used by theorists to explore the inner crust of a neutron star and the onset of neutron superfluidity.
- **AI/ML driven experiment Calibration and Control**. Scientists at JLab have reduced the time needed for controlling and calibrating complex detector systems at CEBAF, which using conventional methods range from months to years, shortening the time to realize science output from these nuclear physics experiments.
- **AI for the Electron-Ion Collider (EIC)**. The EIC will be the only new particle collider built in the next decade. Making AI an integral part of the EIC in these early stages of the project is key to ensuring the accelerator and detectors are AI ready when the facility begins its science program.



Event Reconstruction with Geometric Deep Learning



NP in Quantum Information Science: Quantum Horizons

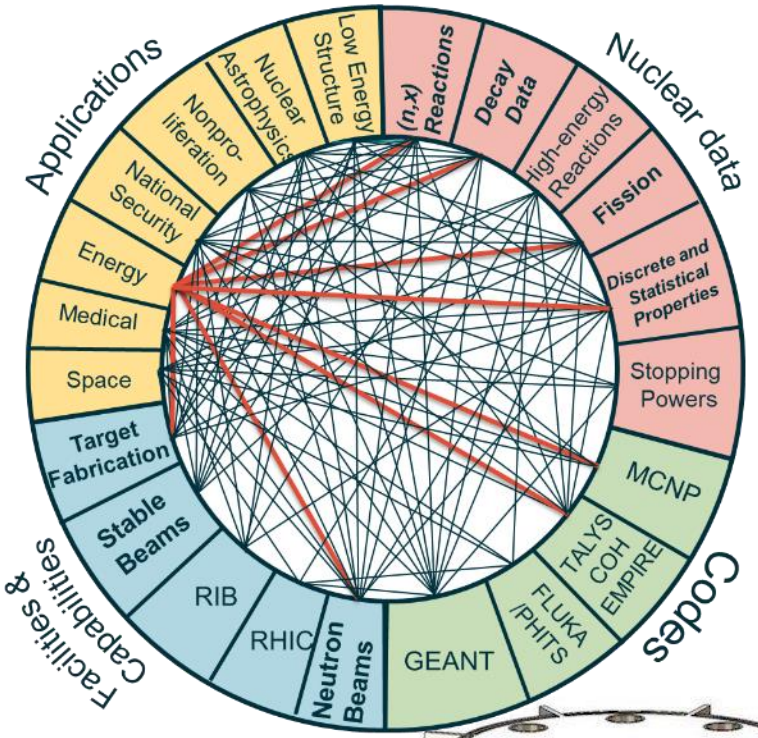
- Support for one of SC's National QIS Research Centers
- Led by BNL, partners with IBM, PNNL and 25 other institutions to build tools for scalable fault-tolerant quantum systems.
- >350 team members, 5 subject inventions, 11 open-source packages, 173 publications.

NP QIS Highlights:

- **Quantifying background radiation on qubits**. Scientists used a thermal kinetic inductance detector to measure disruptive events that were consistent with know terrestrial and cosmic sources of radiation. Such measurements are crucial to deduce the impact on coherence times of qubits that are subject to naturally occurring radiations.
- **Scalable quantum circuits**. Scientists at the InQubator for Quantum Simulations performed the one of the largest quantum simulations to date (more than 100 qubits) using IBM's quantum computers. The results from the quantum computer address the need for complex simulations of pre-collisional protons and heavy nuclei.
- **Detecting the decay of individual nuclei**. Scientists detected the decay of radiative lead-212 embedded in helium by measuring the recoil of the helium atom. This was identified as a 2024 top 10 breakthrough by Physics World and demonstrates that very small forces (10^{-20} N) and accelerations (10^{-7} g) are in the realm of detection.

NP Nuclear Data Research Aligns with NNSA, Nuclear Energy, Fusion Energy, and Other Agencies

- Leverage resources for new and updated nuclear data
  - Data for next generation molten salt reactors with DOE/NE, ARPA-E; Advanced reactors (ARPA-E, NASA)
  - Electronics protection (NASA, Missile Defense Agency, Federal Aviation Administration)
  - NASA [spaceflight], NIH [ion beam therapy]
  - Fusion energy – FY 2025 NOFO




THE WHITE HOUSE

Administration Priorities The Record Briefing Room Espa

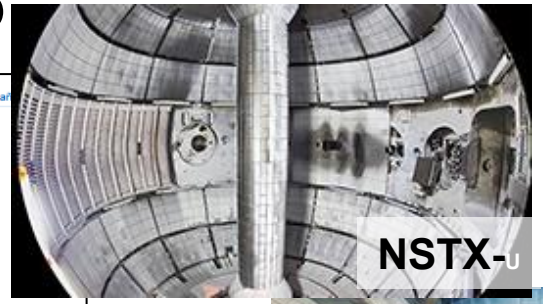
APRIL 19, 2022

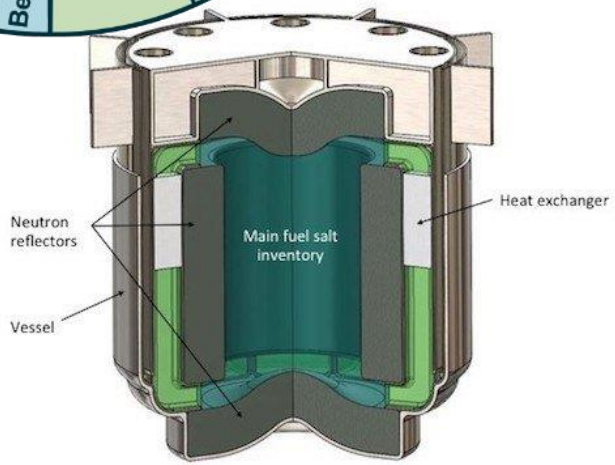
Readout of the White House Summit on Developing a Bold Decadal Vision for Commercial Fusion Energy

OSTP › NEWS & UPDATES › PRESS RELEASES

Executive Summary

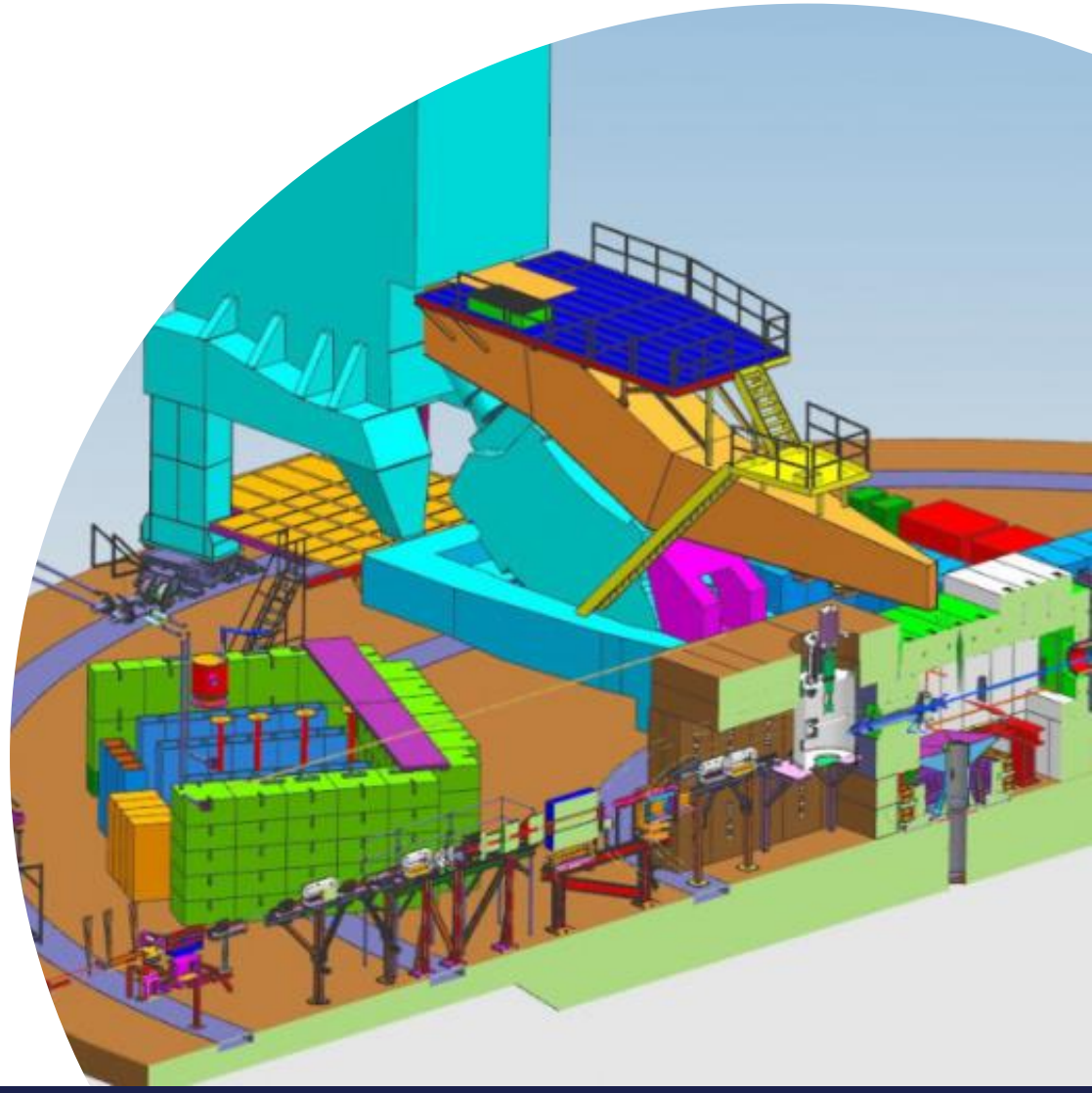
The Biden-Harris Administration is developing a strategy to accelerate fusion energy– a clean energy technology that uses the same reaction that powers the Sun and stars. On March 17, 2022, the White House Office of





Relevant NP priorities

- Efficient and reliable operations of CEBAF.
- Successful independent project review of the Measurement of a Lepton-Lepton Electron Electroweak Reaction (MOLLER) to measure parity violation in electron-electron scattering to unprecedented precision in Hall A at CEBAF@TJNAF.
- Critical Decision-2 Approve Performance Baseline and Critical Decision-3 Approve Start of Construction attained May 28, 2024.
- Maintaining a strong safety culture for all activities at TJNAF.

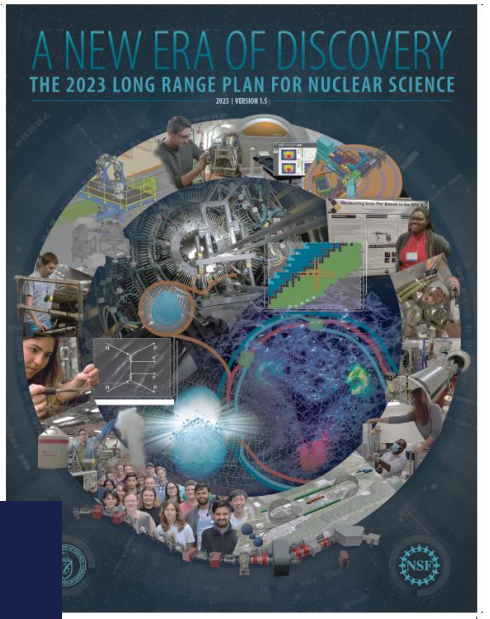


The NP Strategic Plan: A New Era of Discovery

The DOE-NSF Nuclear Science Advisory Committee brought the community together to plan the future of Nuclear Physics Research for the Nation. Recommendations:

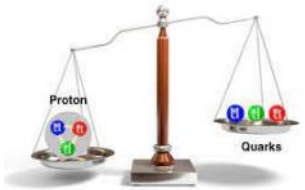
- **Increase research** and expand the workforce to capitalize on the extraordinary opportunities for scientific discovery made possible by the substantial and sustained investments of the United States.

- Reaffirmed the exceptionally high priority of the following two investments in new capabilities for nuclear physics.
  - The **Electron–Ion Collider (EIC)** …will elucidate the origin of visible matter in the universe and significantly advance accelerator technology…
  - **Neutrinoless double beta decay experiments** have the potential to dramatically change our understanding of the physical laws governing the universe (shown: LEGEND-1000).

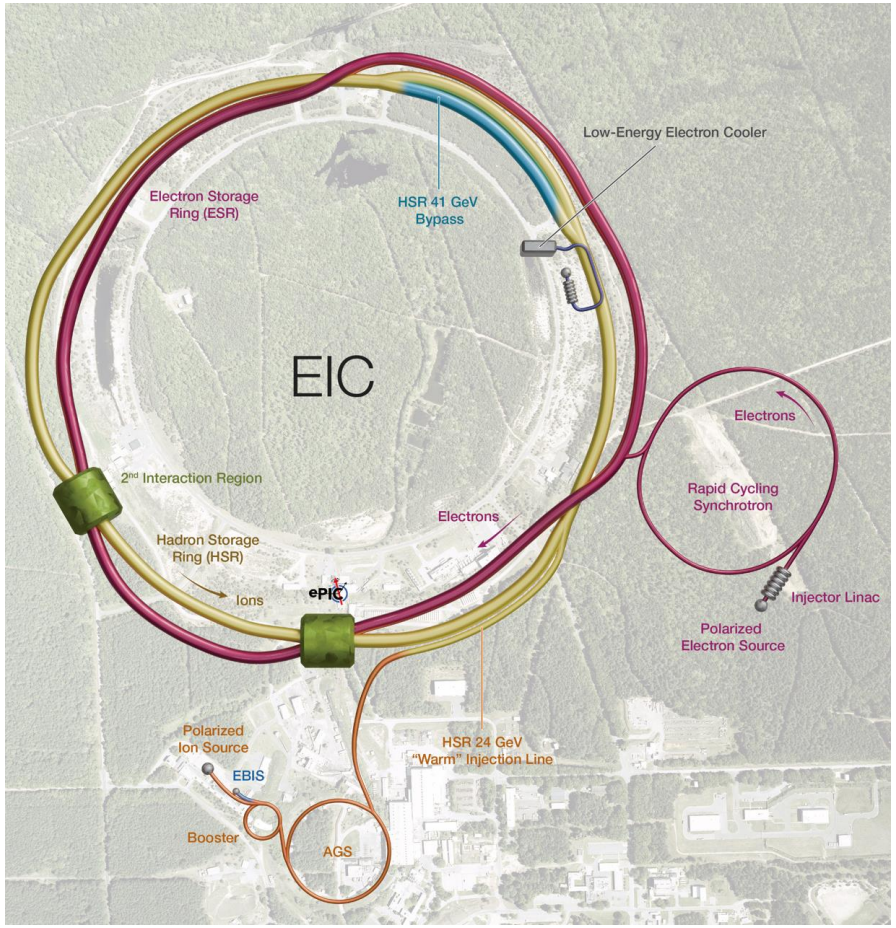


Electron-Ion Collider: Top Priority for New Facility Construction in the 2023 Long Range Plan for Nuclear Science

- National Academies Report: A US- based EIC will uniquely answer
  - 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?



- Located at BNL with Jefferson Lab as a major partner
- Estimated cost rage $1.7 and $2.8 billion
- Utilizes existing RHIC assets
  - adds electron storage ring, electron cooling
- In-kind contributions:
  - $100M grant from New York State in place to support civil construction
  - ~$90M anticipated for the project detector ePIC (~30% of full scope)
  - ~$50M anticipated accelerator scope (~5% of full scope)
- Critical Decision-3A (long lead procurement) attained in March 2024.
- The EIC project remains a priority for new facility construction; work with the project team to advance the EIC project with available and anticipated funds a high NP priority.



Summary

- NP delivers world-leading science and discoveries; operates unique, world-class user facilities; and contributes to impactful applications.
- NP supports innovative, priority research in nuclear science, AI/ML, quantum information science, and microelectronics.
- NP user facilities operate to support DOE's nuclear physics mission.
  - Serves ~4,200 users per year and delivers impactful research.
- Community strategic planning serves as a framework for prioritization of new NP capabilities.
  - The EIC Project is making steady progress towards CD-3B (Long-Lead Procurement) and the next DOE gateway CD-2 (Approve Performance Baseline).
  - NP has established a priority for new experiment construction, focusing on LEGEND-1000 to search for neutrinoless double beta decay.