A NEW ERA OF DISCOVERY

THE 2023 LONG RANGE PLAN FOR NUCLEAR SCIENCE

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Successful History of Long Range Planning in Nuclear Science

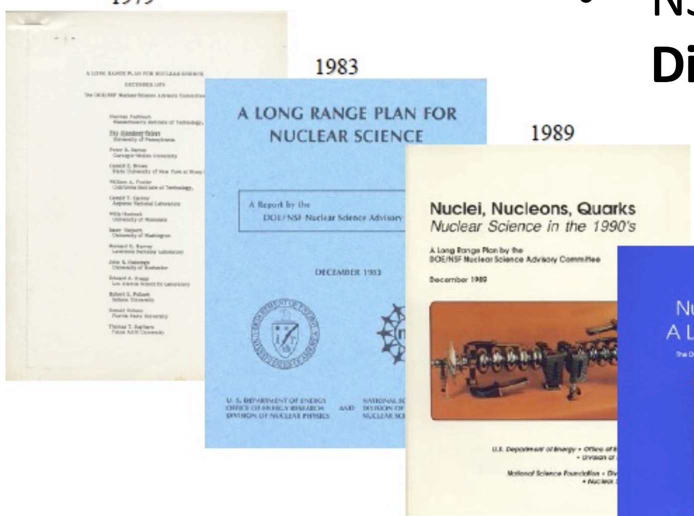
Since 1979 the Department of Energy Office of Science and the National Science Foundation periodically have charged the Nuclear Science Advisory Committee, NSAC, to provide a framework for coordinated advancement of the Nation's nuclear science research program.

- A consistent, strategic plan for investments was developed every 5 – 8 years
- NSAC engaged the community though town meetings organized by the **Division of Nuclear Physics of the American Physical Society**

1979

1983

1989

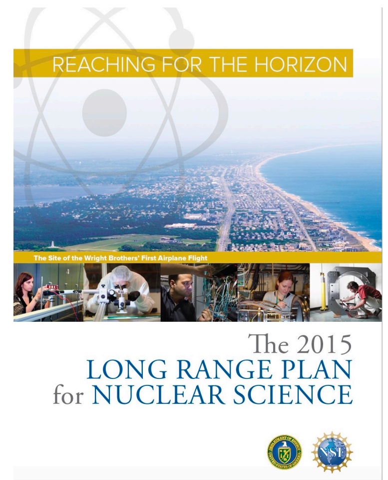


1996

2002

2007

2015



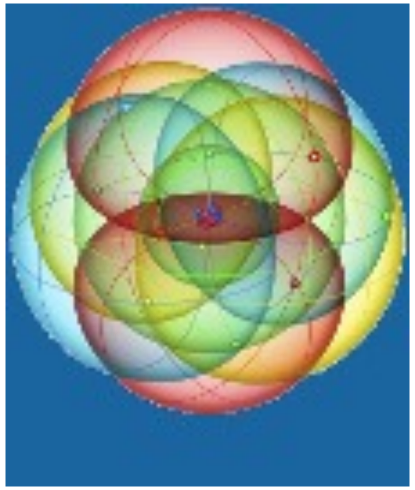
2023

The process is initiated by a charge to NSAC from DOE and NSF.

DNP organized town meetings

2022 Town Meeting on Hot & Cold QCD
Sept. 23 – 25, 2022
Massachusetts Institute of Technology

NSAC Long Range Plan Town Hall Meeting on Nuclear Structure, Reactions and Astrophysics
Nov 14 – 16, 2022
Argonne National Laboratory



Fundamental Symmetries, Neutrons, and Neutrinos Town Meeting
Dec 13 – 15, 2022
University of North Carolina – Chapel Hill

Thank you to the conveners of these town meetings!!

Whitepapers

Each town meeting as well as other collaborations or gatherings produced white papers.

Available on the open website: *NuclearScienceFuture.org*

These documents were invaluable input to the writing committee and serve as excellent summaries of the accomplishments in the field and opportunities for the future.

LRP Writing Committee

Thank you!!

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We formed 11 subcommittees to handle the writing and budget

Nuclear Science

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

The Recommendations

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 1 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.
- Continuing effective operation of the national user facilities ATLAS, CEBAF, and FRIB, and completing the RHIC science program, pushing the frontiers of human knowledge.
- Raising the compensation of graduate researchers to levels commensurate with their cost of living—without contraction of the workforce—lowering barriers and expanding opportunities in STEM for all, and so boosting national competitiveness.
- Expanding policy and resources to ensure a safe and respectful environment for everyone, realizing the full potential of the US nuclear workforce.

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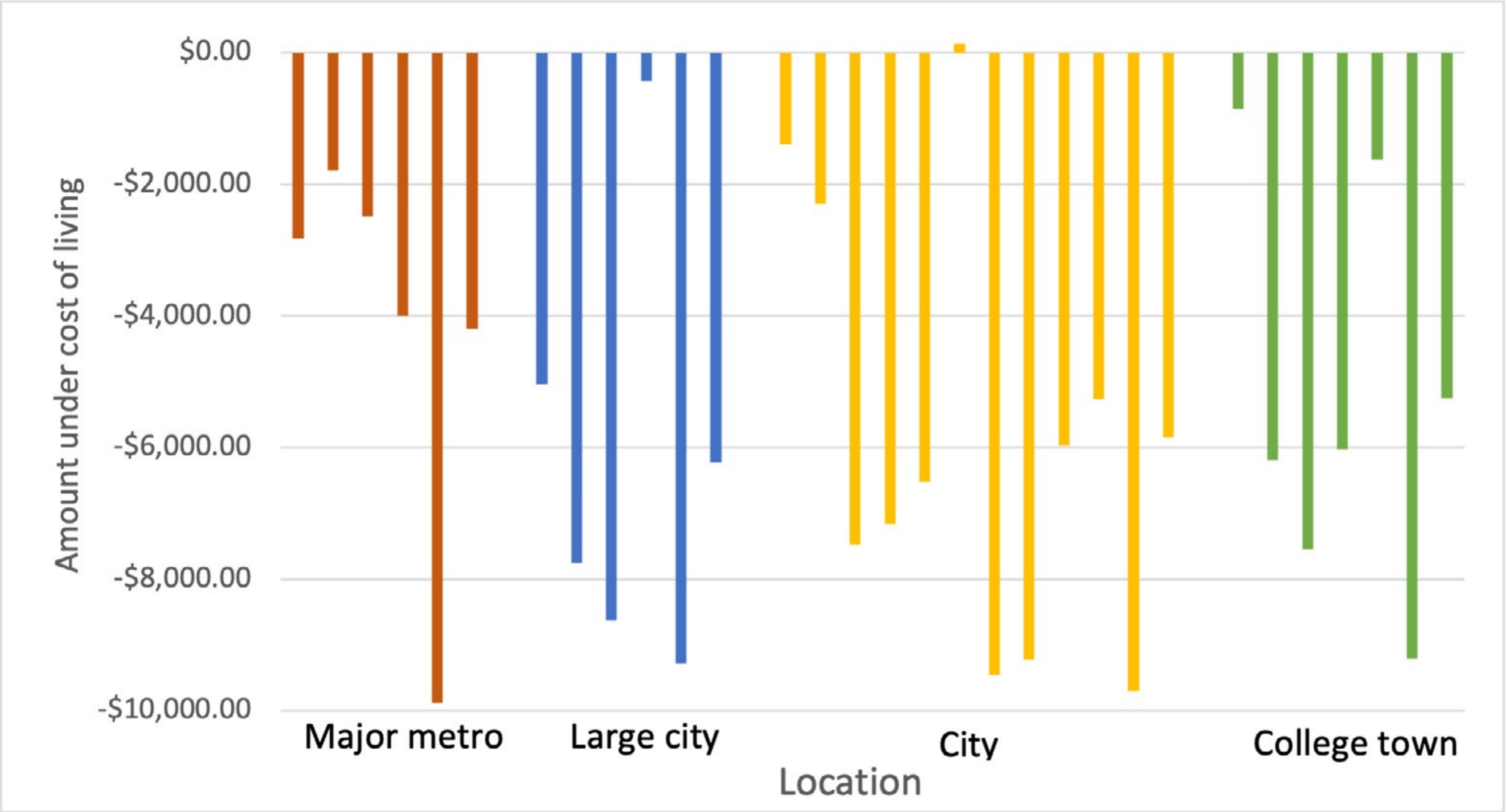
Compensation for Graduate Researchers

Compensation was compared to cost of living for 31 schools.

Survey of graduate researchers revealed that 65% struggle to meet basic costs.

Students cited family support as enabling them to make ends meet or deal with unexpected expenses.



Graduate researchers are paid an average of $5,460 per year less than the cost of living for their location. The institutions are grouped by population of the host city or town.

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RECOMMENDATIONS 2 and 3 are of Equal Priority

Electron–Ion Collider (EIC), to be built at Brookhaven National Lab, will elucidate the origin of visible matter in the universe and significantly advance accelerator technology as the first major new advanced collider to be constructed since the LHC.

Neutrinoless double beta decay experiments have the potential to dramatically change our understanding of the physical laws governing the universe.

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.

Neutrinoless Double Beta Decay ($0\nu\beta\beta$)

Observation of $0\nu\beta\beta$ would mean that the neutrino is its own antiparticle.

It would also mean that lepton number is not conserved.

It would mean that matter can be created and help explain why the universe has more matter than antimatter.

The rate of $0\nu\beta\beta$ has implications for neutrino masses.

Regular beta decay:

$\mathrm{n} \rightarrow \mathrm{p} + e^{-} + \bar{\nu}_e$

Double beta decay (DBD):

$2\mathrm{n} \rightarrow 2\mathrm{p} + 2e^{-} + 2\bar{\nu}_e$

Neutrinoless DBD:

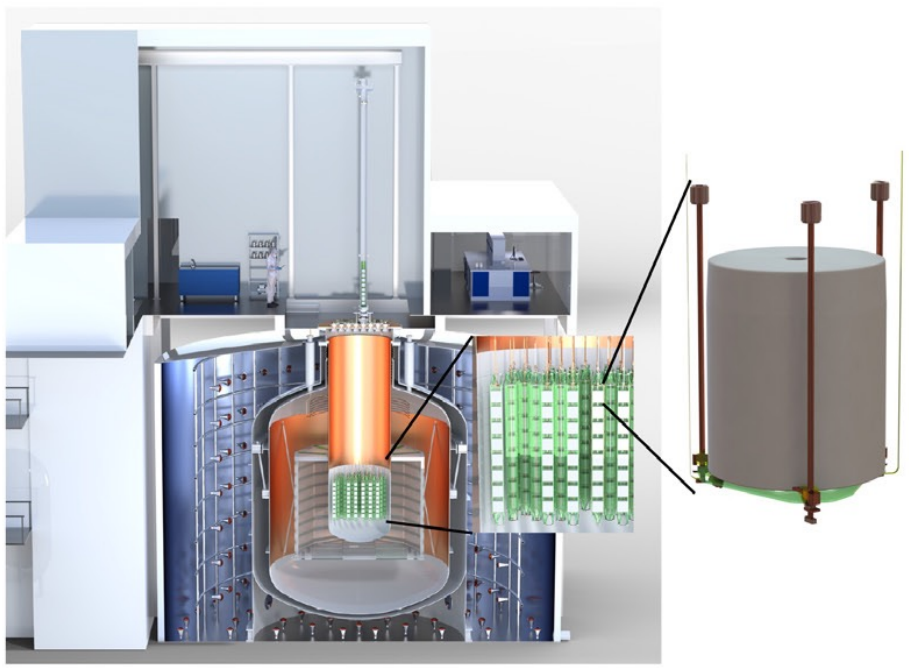
$2\mathrm{n} \rightarrow 2\mathrm{p} + 2e^{-}$

Major discovery potential!

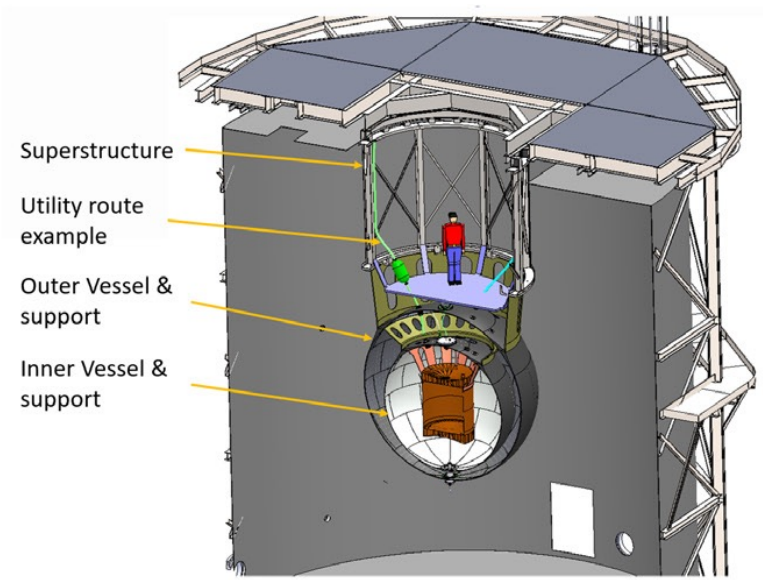
Neutrinoless Double Beta Decay ($0\nu\beta\beta$)

After extensive R&D since the last long range plan, three experiments are ready for construction.

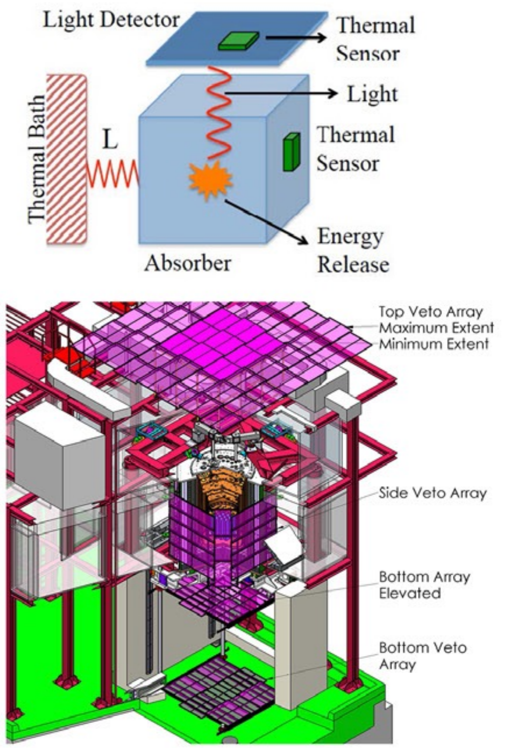
Different isotopes and different detector technologies are important to understand backgrounds and interpretation of the signal.



LEGEND



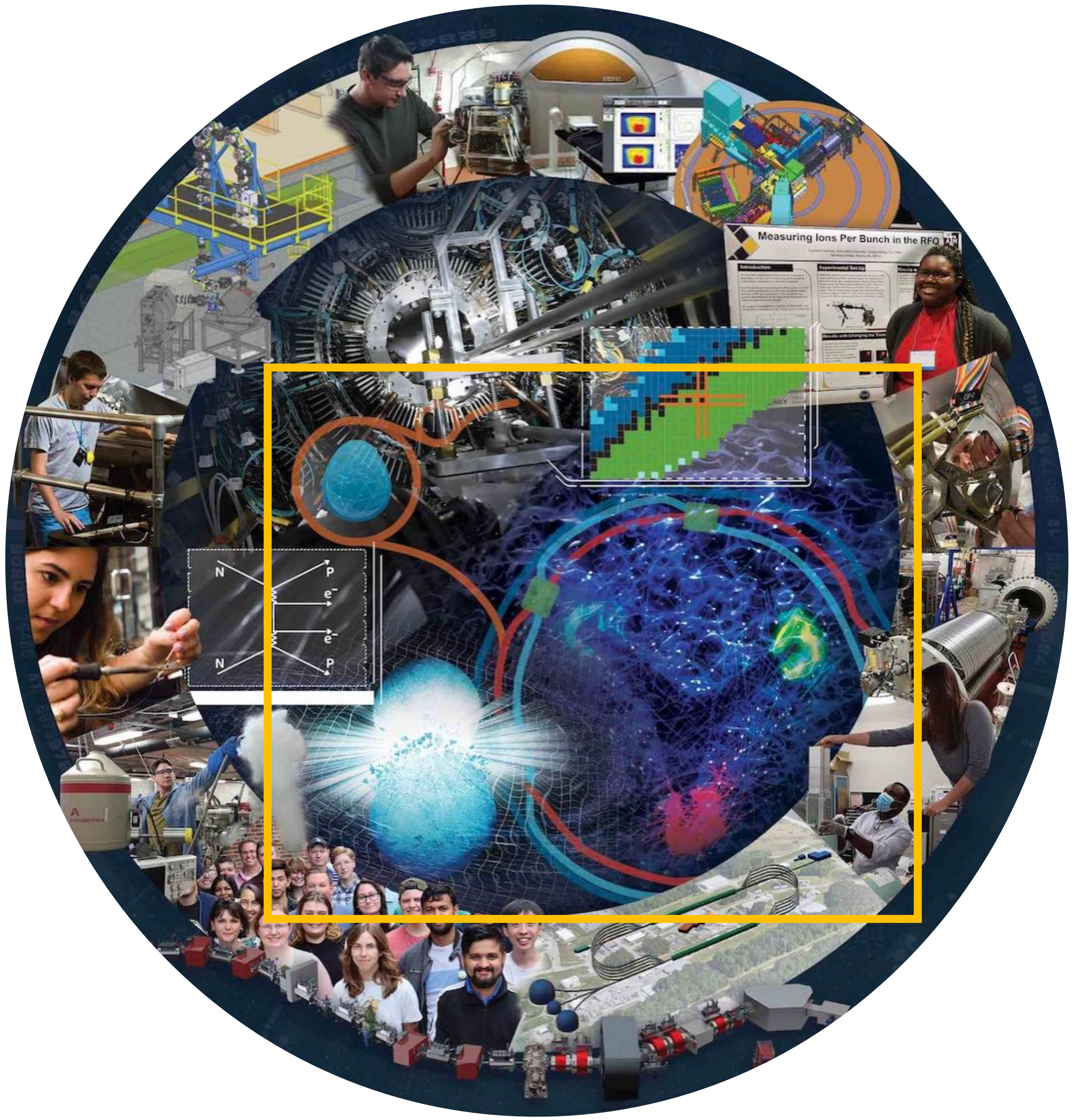
nEXO



CUPID

RECOMMENDATION 3

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



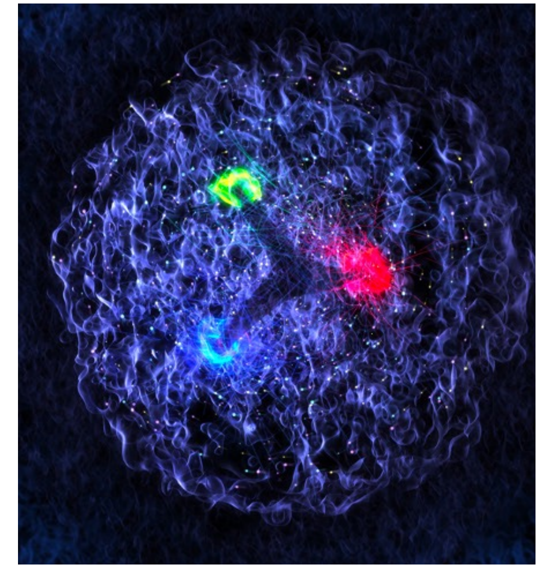
The Electron-Ion Collider

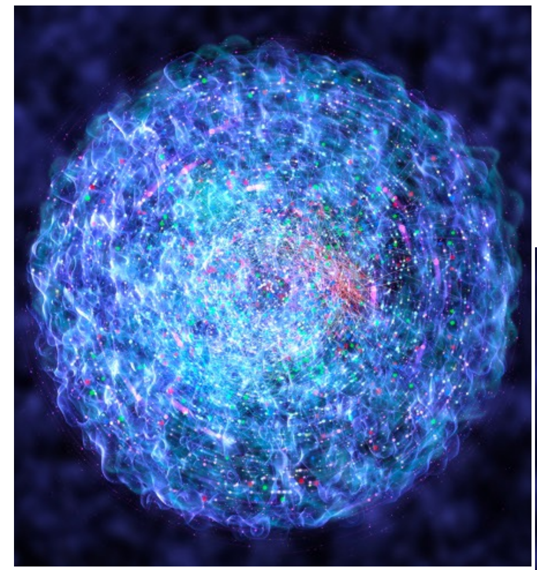
Polarized electrons colliding with polarized protons, polarized light ions, and heavy ions will allow us to study sea-quarks and gluons to understand:

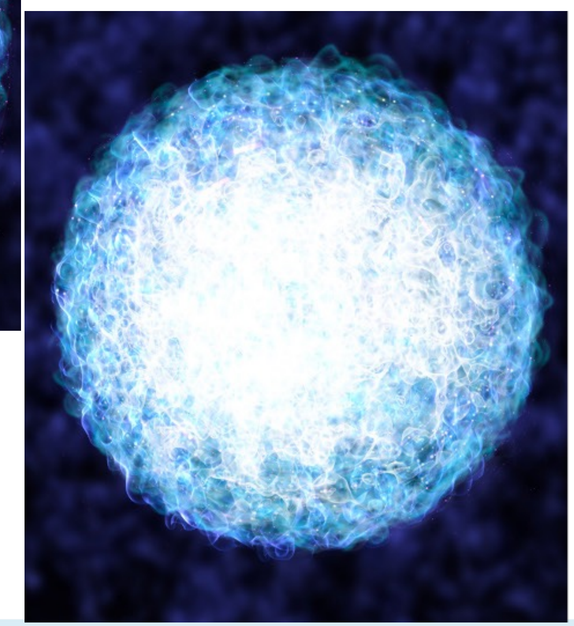
- mass and spin of the proton.
- spatial and momentum distribution of low-x partons
- Possible gluon saturation
- modifications of parton distribution functions when a nucleon is embedded in a nucleus
- hadron formation

Major discovery potential!

Artistic renderings of the nucleon: James LaPlante, Sputnik Animation in collaboration with the MIT Center for Art, Science & Technology and Jefferson Lab

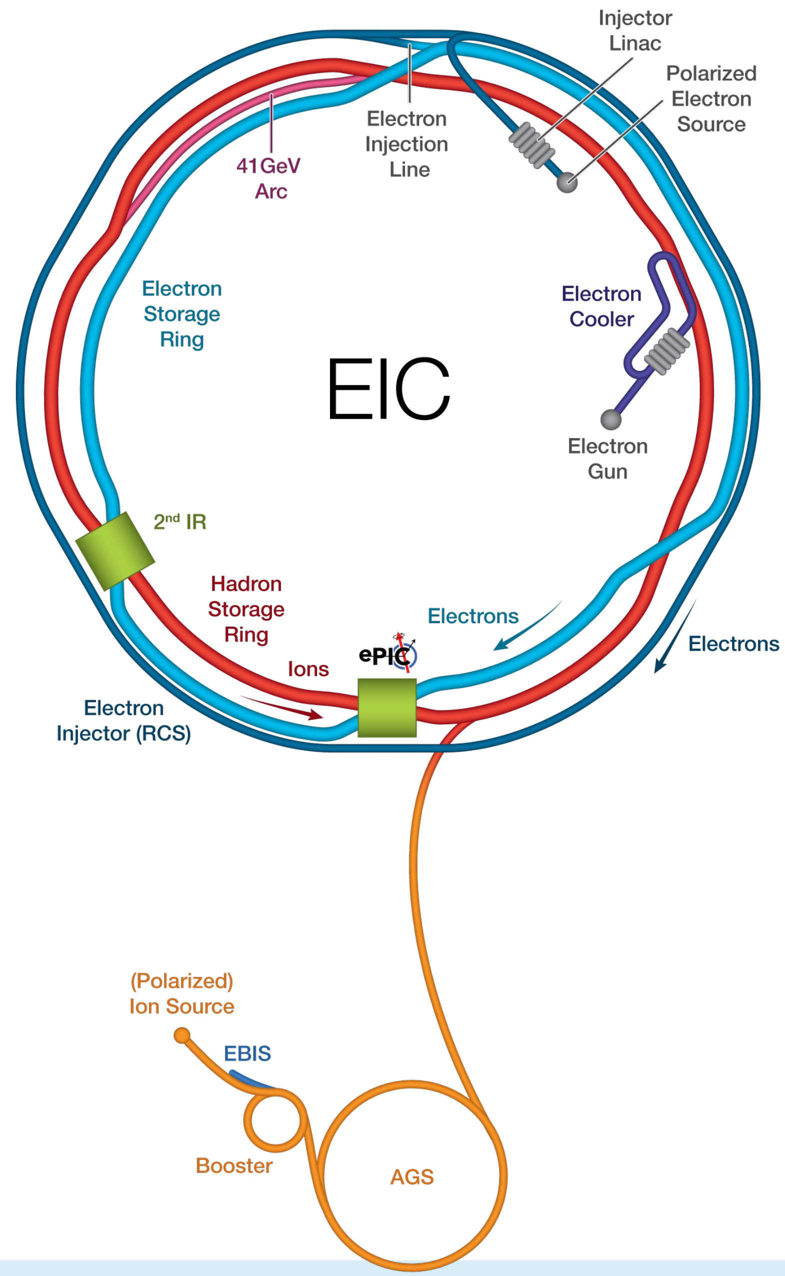






The Electron-Ion Collider

- The EIC is a partnership between Brookhaven and Jefferson Lab.
- The ePIC detector design is advanced (6 o’clock)
- Significant international support and participation (User Group has 1440 members from 40 countries).
- Accelerator physics advances are critical
- CD-3A is approved; CD-2 is expected in 2025



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.

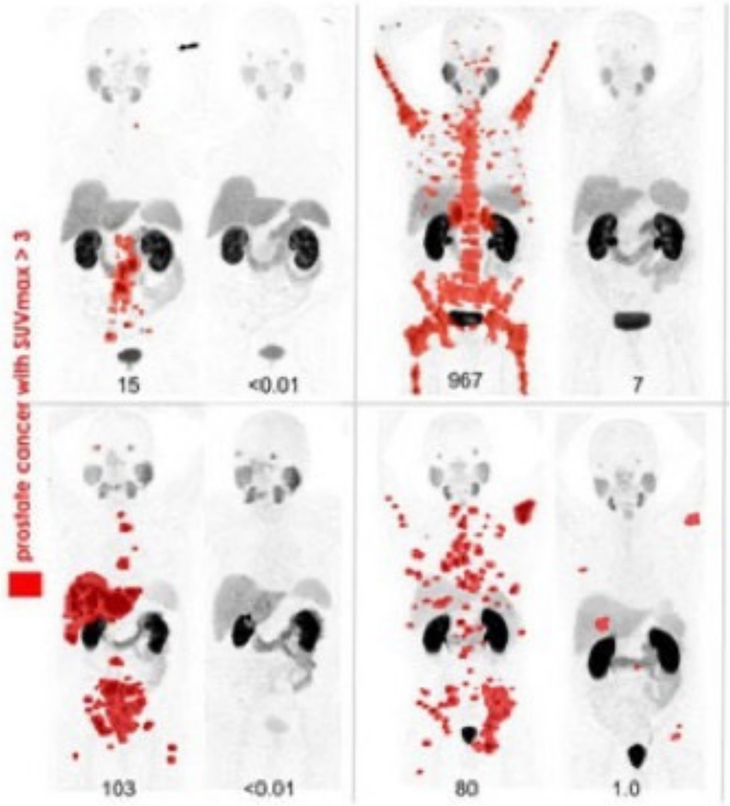
Strategic Opportunities

- Projects that lay the foundation for the discovery science of tomorrow
  - Examples: FRIB400, SoLID, LHC upgrades, EDM experiments, ν mass measurements
- Detector and accelerator R&D
- Emerging technologies: computing and sensing
  - Quantum information science and technology
  - Artificial intelligence and machine learning
  - High performance computing
- Multidisciplinary centers
- Nuclear data

Benefits to the nation

- Synergy and impact on other fields, such as high energy physics, astrophysics and cosmology, accelerator science, atomic physics, condensed matter physics …
- Trained nuclear workforce, affects many fields, including nuclear nonproliferation and security, isotope production for medical and other needs
- Applications: energy, health care, environmental issues, radiation hardening for electronics, improved particle detection for homeland security
- Development of computational techniques

Nuclear science provides opportunity for students who want to make a difference



PET images using gallium-68 before (left) and after (right) treatment of prostate cancer with lutetium-177-PSMA-617

Workforce

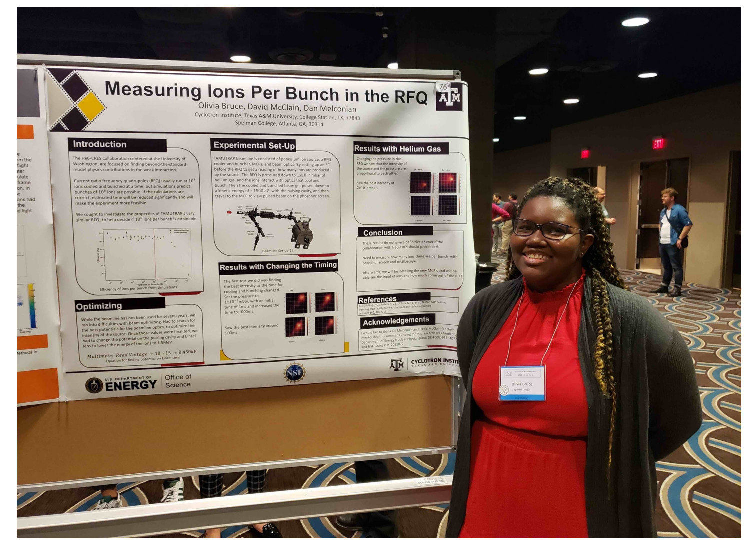
People are essential to accomplishing the goals in all areas of physics described in the Long Range Plan.

Our community is committed to establishing and maintaining an environment where all feel welcome and are treated with respect and dignity.

- Conference Experience for Undergraduates (CEU)
- DNP Allies program
- Gender Minorities in Science Social (GeMSS)

We can do more

- Compensate graduate students at levels commensurate with the cost of living
- Establish funding agency policies on areas such as medical and family leave
- Support appropriate skills development and training at conferences and meetings
- Provide resources to help establish and maintain enforceable Community Agreements.



Undergraduate research is critical

Summary

NuclearScienceFuture.org

- The nuclear science community has come together to consider our progress since the last Long Range Plan and the compelling opportunities over the next ten years.
- The science that we will undertake in the next decade is incredibly exciting. We have identified the Electron-Ion Collider and Neutrinoless Double Beta Decay as major opportunities to address some of the key, fundamental questions of our time.
- Maintaining our world-leading position in nuclear science requires investment – in people, in facilities, and in projects/experiments.
- We must realize the promise of a welcoming and respectful environment, removing barriers for all people to participate in the scientific enterprise
- We are on the threshold of

A New Era of Discovery

Thank you!

The LRP Writing Committee

APS Division of Nuclear Physics

NSF and DOE leadership and staff

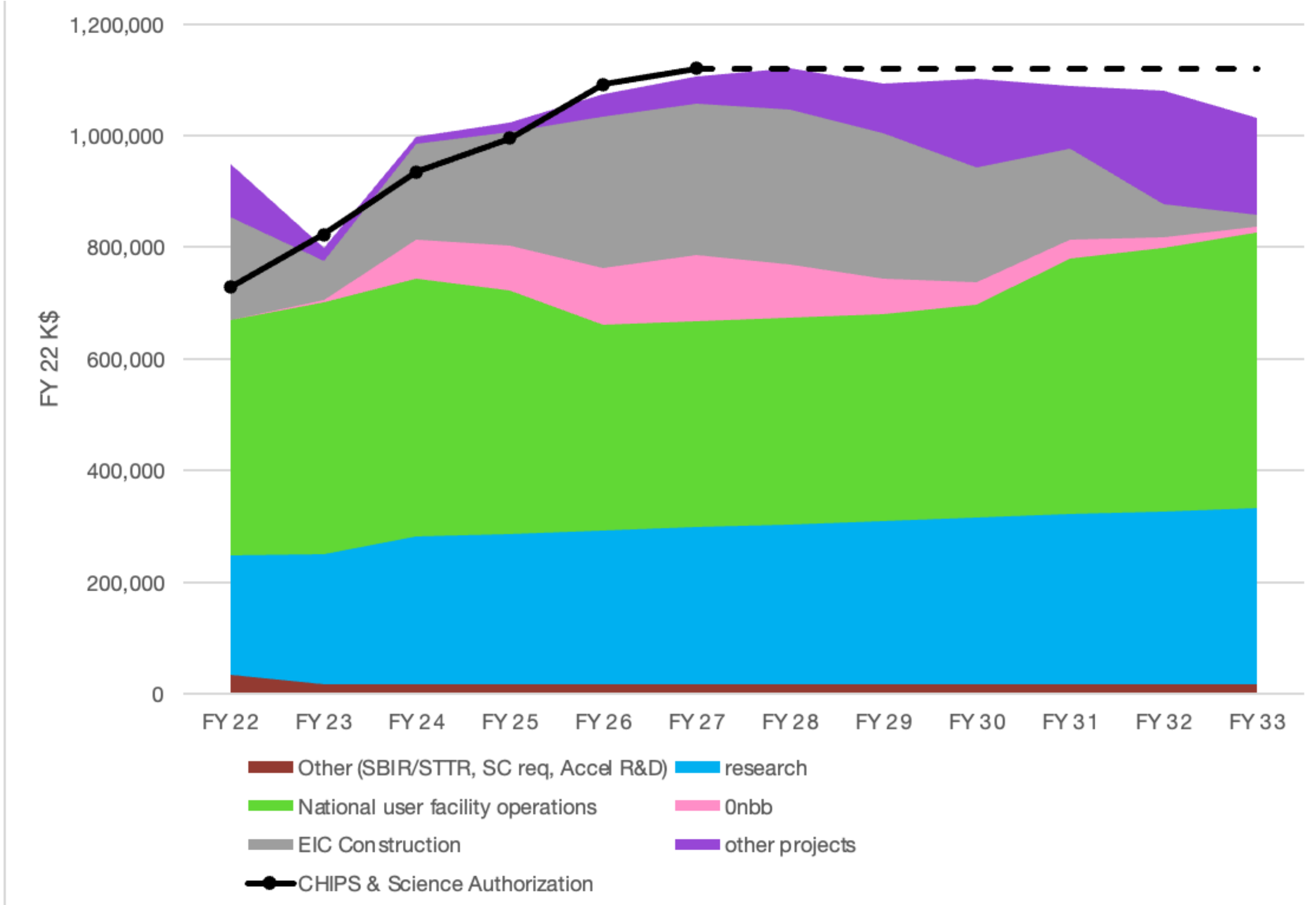
ORNL Communications Team

NuclearScienceFuture.org

CHIPS and Science Act Authorization

Research at 35% of FY22 enacted (w/o IRA funds)

Optimal operations of user facilities



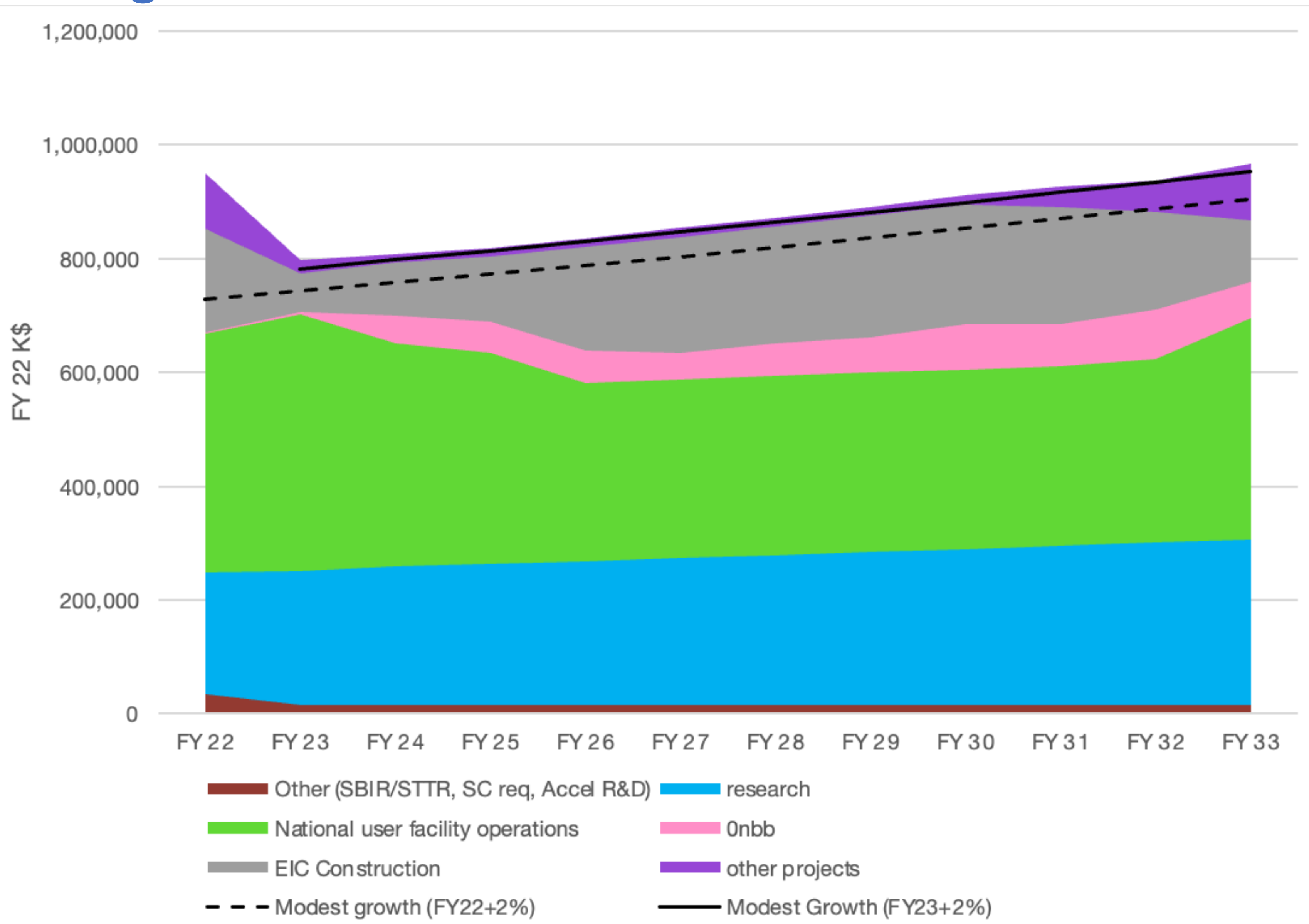
Modest Growth Budget Scenarios

Research at 32% of FY22 enacted (w/o IRA funds)

Reduced operations of user facilities

EIC stretched out

$0\nu\beta\beta$ reduced



U.S. is currently in a position of leadership within an increasingly competitive nuclear physics landscape