A NEW ERA OF DISCOVERY

THE 2023 LONG RANGE PLAN FOR NUCLEAR SCIENCE

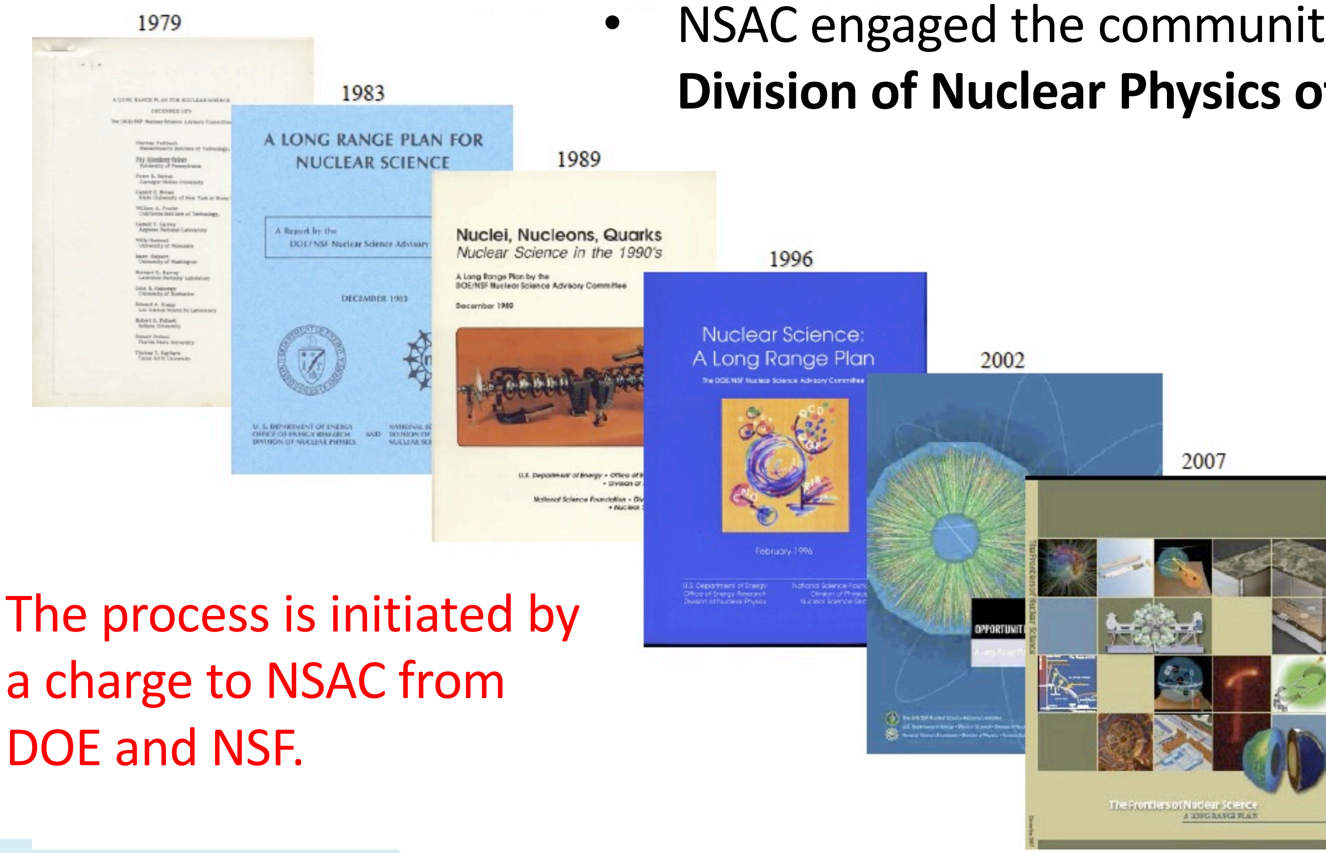
Gail Dodge
Chair, NSAC
Old Dominion University

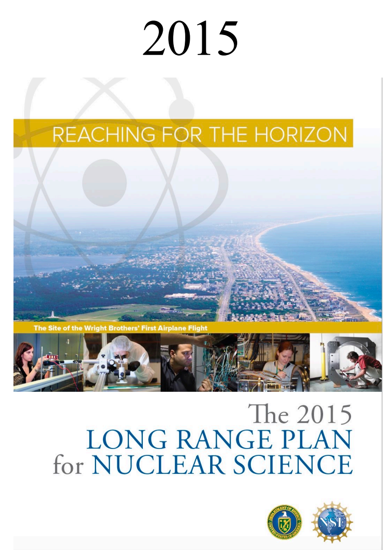
IUPAP: June 21, 2024

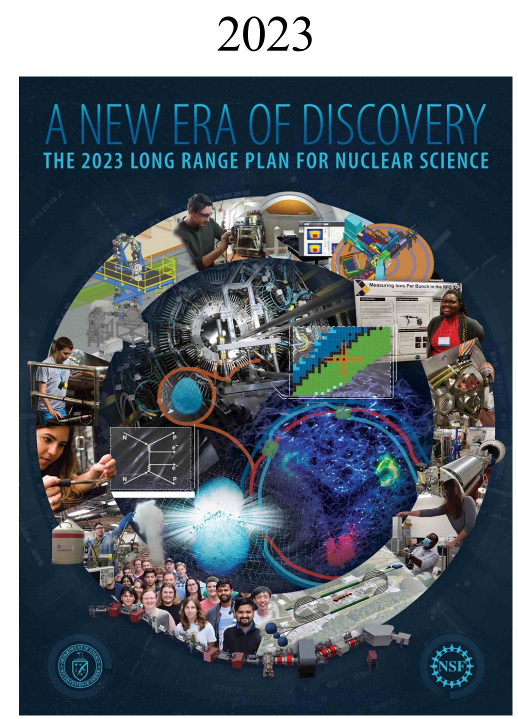
Successful History of Long Range Planning in Nuclear Science

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**







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

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.

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.

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:

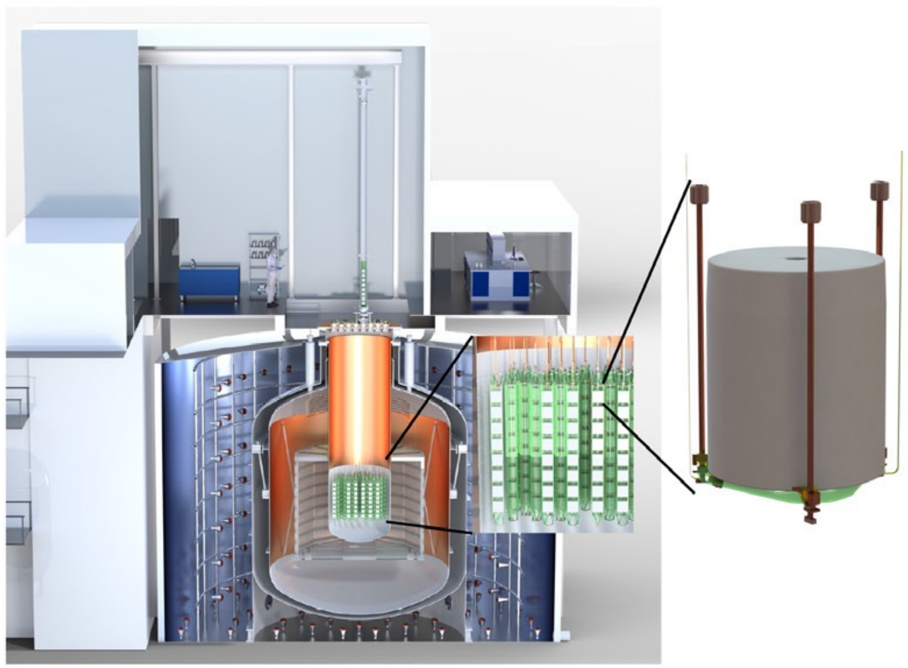
$$2\mathrm{n} \rightarrow 2\mathrm{p} + 2e^{-}$$

Major discovery potential!

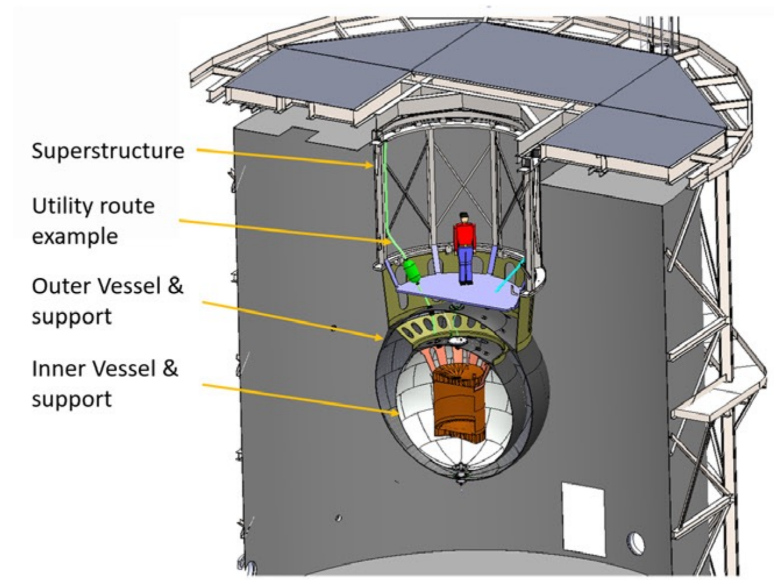
Neutrinoless Double Beta Decay ($0\nu\beta\beta$)

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

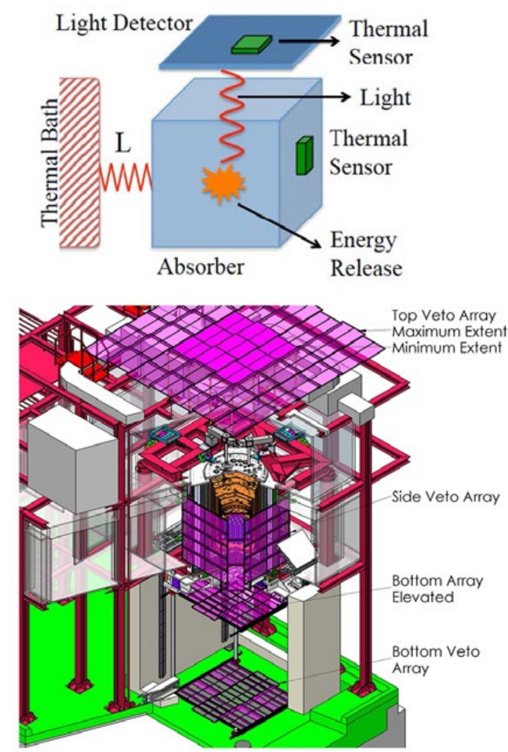
Different isotopes and different detector technologies are important to understand backgrounds and interpretation of the signal.



LEGEND



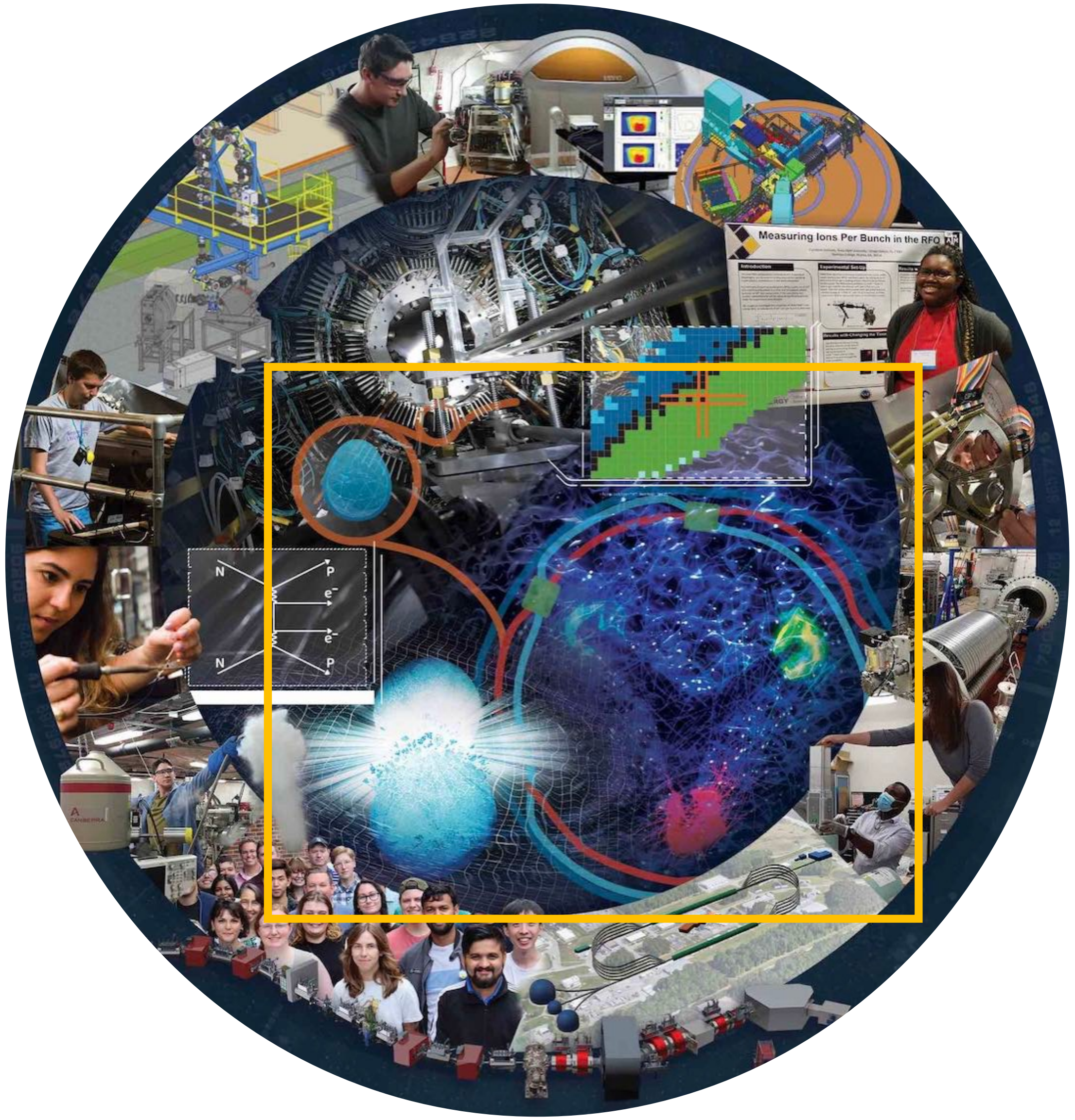
nEXO



CUPID

RECOMMENDATION 3

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



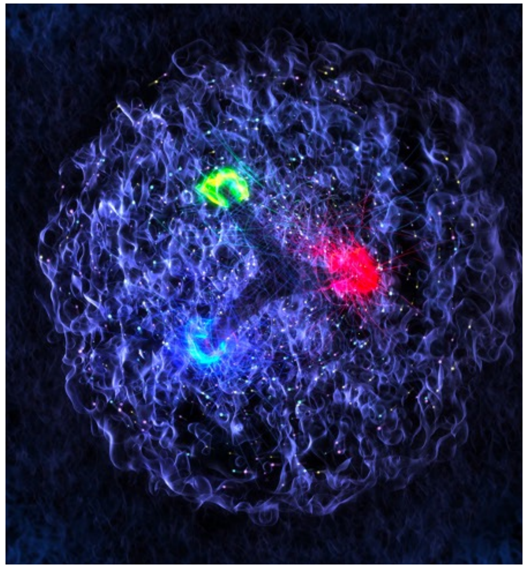
The Electron-Ion Collider

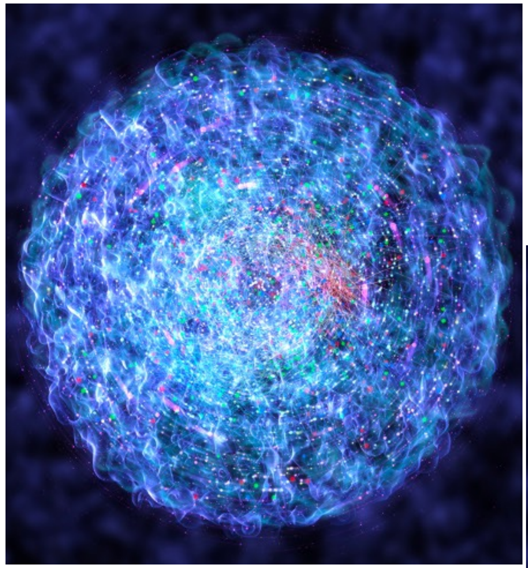
Polarized electrons colliding with polarized protons, polarized light ions, and heavy ions will allow us to study sea-quarks and gluons to understand:

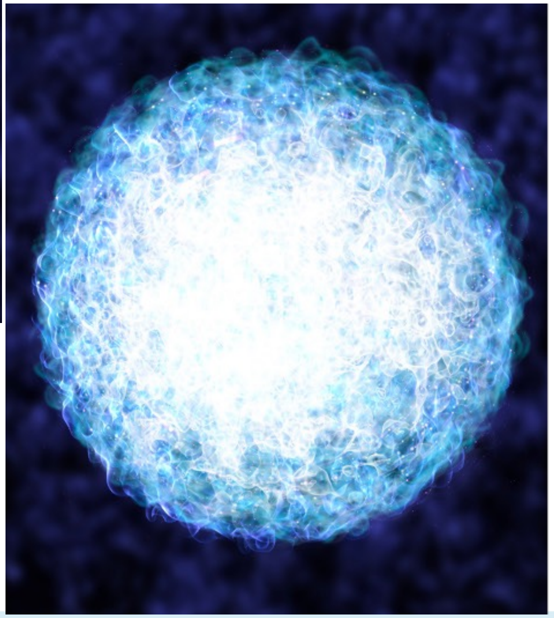
- mass and spin of the proton.
- spatial and momentum distribution of low-x partons
- Possible gluon saturation
- modifications of parton distribution functions when a nucleon is embedded in a nucleus
- hadron formation

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

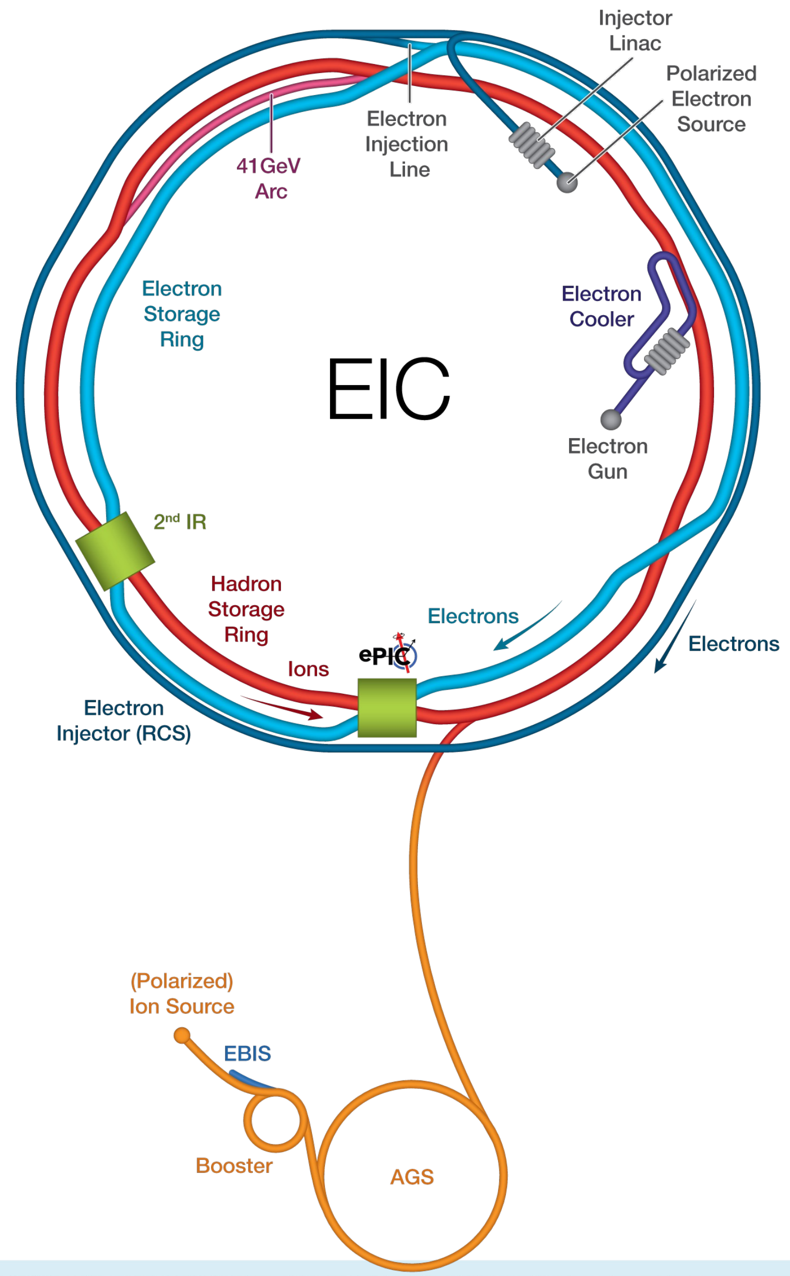






The Electron-Ion Collider

- 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

Summary

NuclearScienceFuture.org

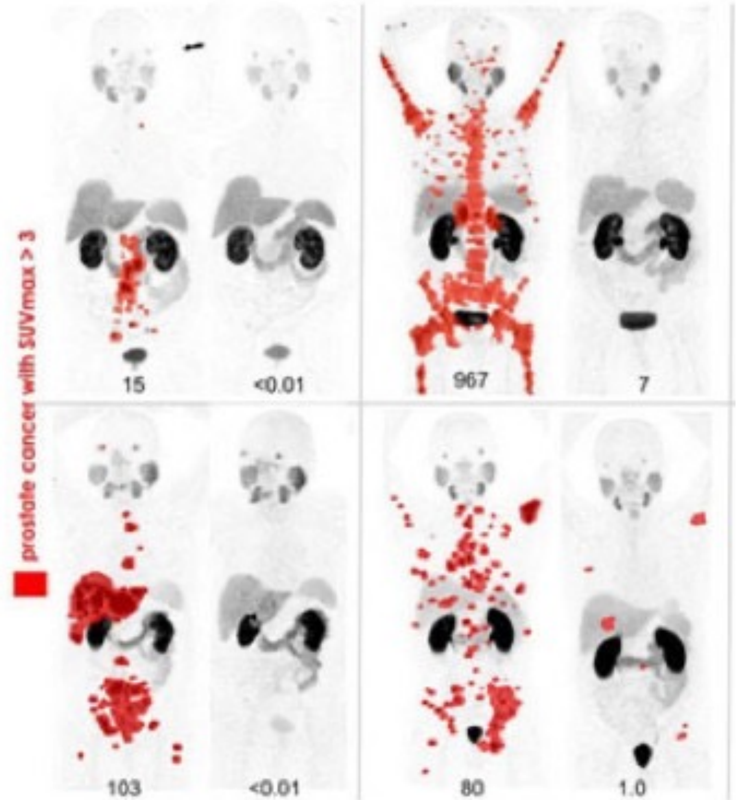
- The US nuclear science community has come together to consider our progress since the last Long Range Plan and the compelling opportunities over the next ten years.
- The science that we will undertake in the next decade is incredibly exciting. We have identified the Electron-Ion Collider and Neutrinoless Double Beta Decay as major opportunities to address some of the key, fundamental questions of our time.
- Maintaining our strength 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

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

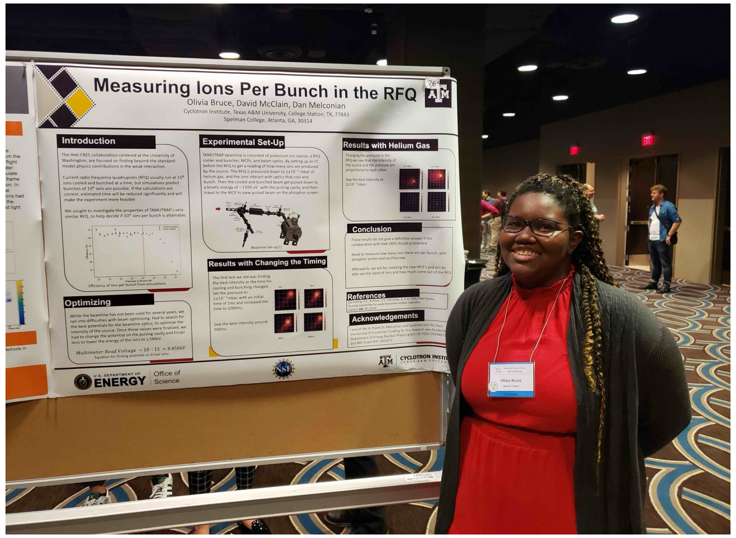
People are essential to accomplishing the goals in all areas of physics described in the Long Range Plan.

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

LRP Writing Committee

Thank you!!

Christine Aidala
Ani Aprahamian
Sonia Bacca
Paulo Bedaque
Lee Bernstein
Joe Carlson
Michael Carpenter
Kelly Chipps
Vincenzo Cirigliano
Ian Cloët
Andre de Gouvea
Romualdo DeSouza
Gail Dodge
Evie Downie
Jo Dudek
Renee Fatemi
Alexandre Gade
Haiyan Gao

Susan Gardner
Vicki Greene
Auston Harton
Raph Hix
Tanja Horn
Calvin Howell
Yordanka Ilieva
Barbara Jacak
Thia Keppel
Oliver Kester
Josh Klein
Krishna Kumar
Kyle Leach
Dean Lee
Shelly Lesher
Chen-Yu Liu
Jorge Lopez
Cecilia Lunardini

Richard Milner
Filomena Nunes
Dan Phillips
Jorge Piekarewicz
Dinko Počanić
Jianwei Qiu
Sofia Quaglioni
David Radford
Rosi Reed
Lijuan Ruan
Martin Savage
Carol Scarlett
Bjoern Schenke
Daniel Tapia Takaki
Derek Teaney
Brent VanDevender
Ramona Vogt
Nathalie Wall

Fred Wietfeldt
John Wilkerson
Richard Wilson
Lindley Winslow
Sherry Yennello
Xiaochao Zheng

International Observers:
Marek Lewitowicz (NuPECC)
Byungsik Hong (ANPhA)

We formed 11 subcommittees to handle the writing and budget