The *2023 NSAC Long Range Plan for Nuclear Science*

Haiyan Gao

ALD, Nuclear and Particle Physics

EIC RRB Meeting, December 7-8, 2023

@BrookhavenLab

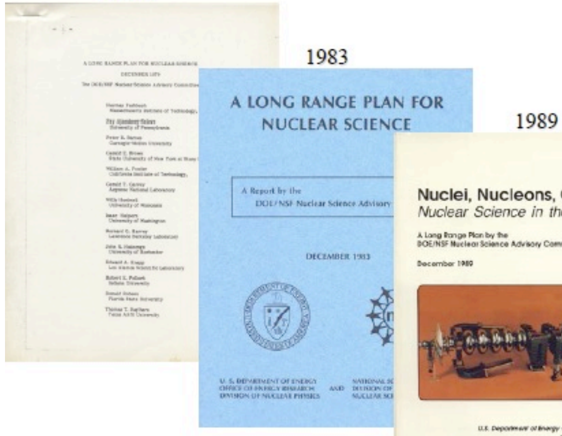
Successful History of Long Range Planning in Nuclear Science

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 – 7 years
- NSAC engaged the community though town meetings organized by the Division of Nuclear Physics of the American Physical Society

1979

1983



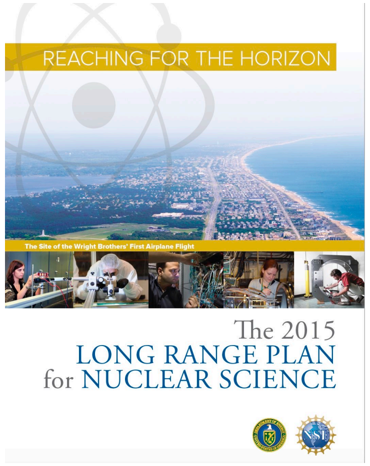
1989

1996

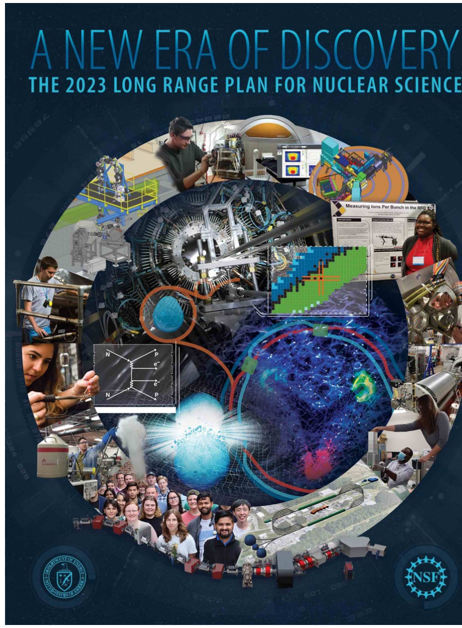
2002

2007

2015



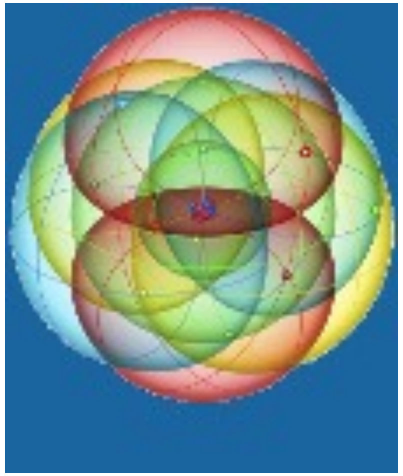
2023



American Physical Society/Division of Nuclear Physics 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

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

Available on the open website: *NuclearScienceFuture.org*

LRP Writing Committee

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)

Subcommittees (Chairs)

- QCD (Richard Milner)
- Fundamental Symmetries (Brent VanDevender)
- Nuclear Structure & Nuclear Astrophysics (Ani Aprahamian)
- Workforce (Shelly Lesher)
- Applications (Calvin Howell and Mike Carpenter)
- Theory (Filomena Nunes)
- Crosscutting/interdisciplinary (Ian Cloët)
- Impact and synergies with other fields (Jorge Piekarewicz)
- Facilities (Haiyan Gao)
- International Context (Krishna Kumar)
- Budget (Sherry Yennello)

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.

https://science.osti.gov/-/media/np/nsac/pdf/202310/NSAC_LRP_2023.pdf

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

Next, we reaffirm the exceptionally high priority of the following two investments in new capabilities for nuclear physics. The Electron–Ion Collider (EIC), to be built in the United States, will elucidate the origin of visible matter in the universe and significantly advance accelerator technology as the first new particle 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:

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

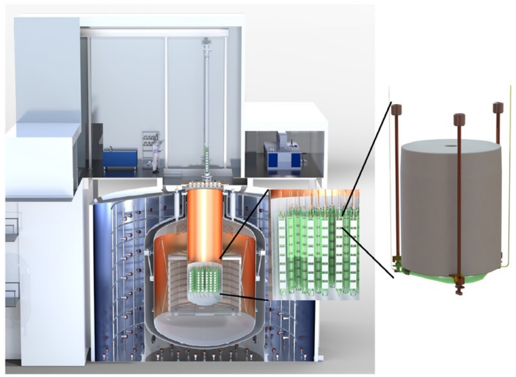
Double beta decay (DBD):

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

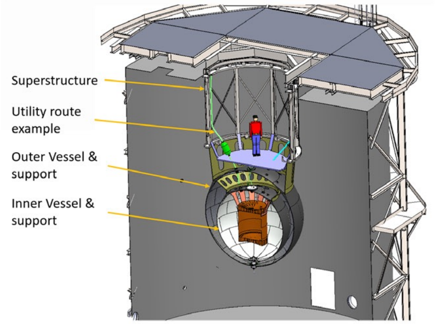
Neutrinoless DBD:

$$2n \to 2p + 2e^-$$

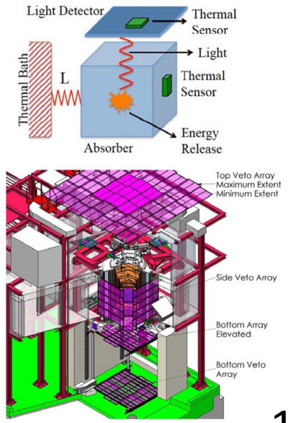
Major discovery potential!



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:

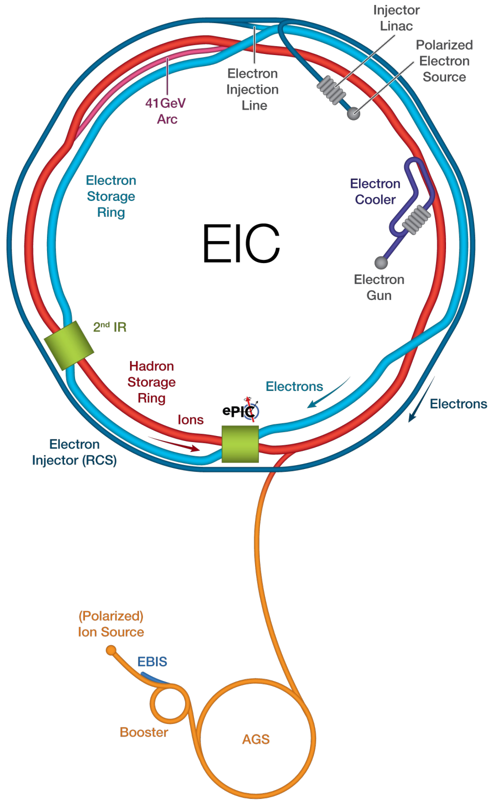
- mass and spin of the proton.
- spatial and momentum distribution of low-x partons
- Possible gluon saturation
- modifications of parton distribution functions when a nucleon is embedded in a nucleus
- hadron formation

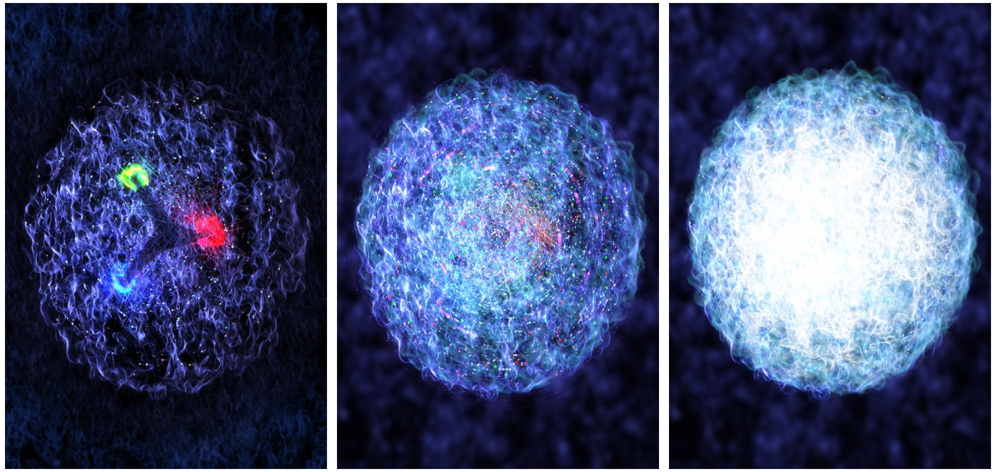
The EIC is a partnership between BNL and Jefferson Lab.

Project is aiming for CD2/3 in 2025

ePIC detector design is advanced. Significant international support and participation (160+ institutions, 24 countries).

Major discovery potential!





RECOMMENDATION 4

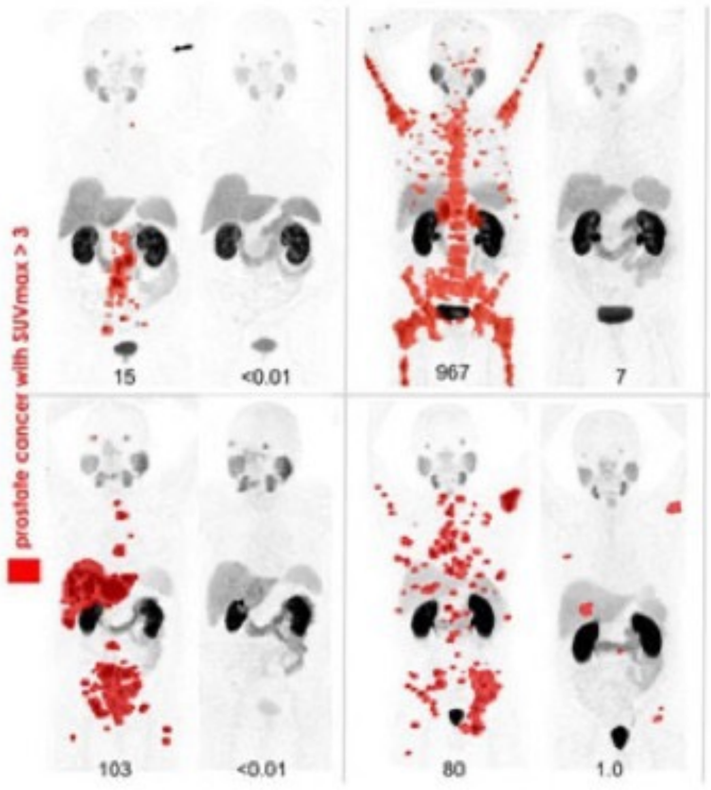
We recommend capitalizing on the unique ways in which nuclear physics can advance discovery science and applications for society by investing in additional projects and new strategic opportunities.

Strategic Opportunities

- Projects that lay the foundation for the discovery science of tomorrow
  - Examples: FRIB400, SoLID, LHC upgrades, EDM, 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 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



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

Workforce

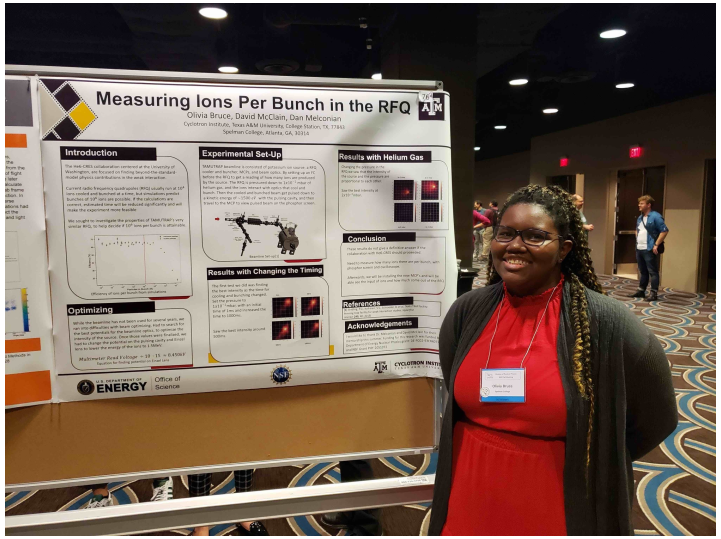
People are essential to accomplishing the goals in all areas of physics described in the Long Range Plan.

Programs such as the NSF REU and DOE SULI are essential to attracting talented students to nuclear science.

Central to our proposals is the necessity to reduce barriers to participation in nuclear science.

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

The training our students receive is very valuable in industry, national labs, and in critical areas of national need, such as nuclear nonproliferation and security



EIC Network for Discovery Science and Workforce Development

An EIC network would empower discovery science at the EIC while strengthening and building nuclear physics research at U.S institutions, especially those with limited research capacities, and supporting training of a STEM workforce for the nation from a broad pool of talent.

The network promotes partnerships between U.S. national labs and universities and supports students and postdoctoral fellows. The network would promote collaborations between experimentalists and theorists, organize traineeships, and provide mentoring and career development programs for students and postdocs.

In addition to discovery science, the nation benefits from a highly skilled STEM workforce for advances in fields such as energy, environment, health, and national security.