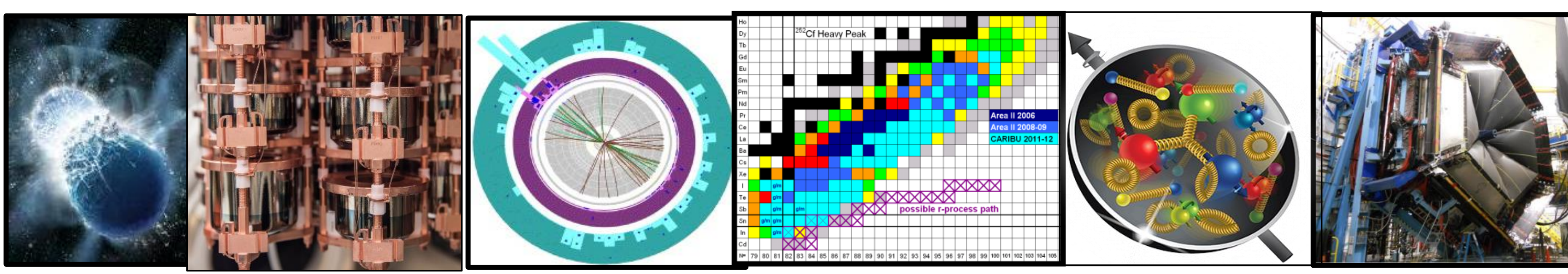
U.S. DEPARTMENT OF ENERGY | Office of Science

Perspectives from DOE Nuclear Physics

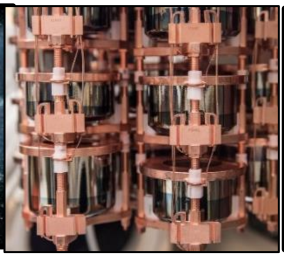
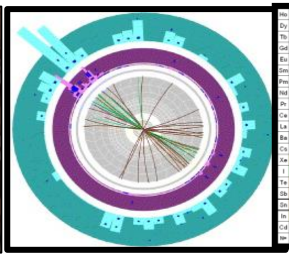
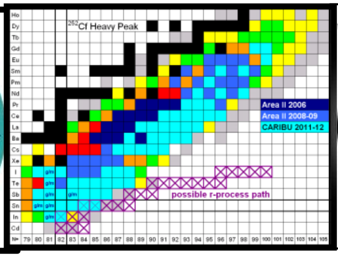
July 19, 2021

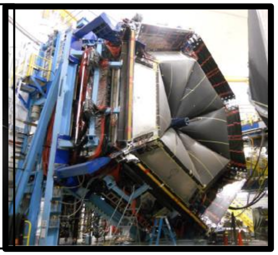
Dr. Timothy J. Hallman
Associate Director of the Office of Science
for Nuclear Physics



Nuclear Physics
Discovering, exploring, and understanding all forms of nuclear matter

- Understanding why matter takes on the specific forms observed in nature and how that knowledge can benefit energy, commerce, medicine, and national security, by discovering:
  - How mass is created from energy in the interior of the proton using the future Electron-Ion Collider?
  - What are the properties of the novel quark-gluon plasma discovered at RHIC?
  - What is the mechanism underlying the confinement of quarks and gluons via CEBAF and RHIC?
  - The search for new exotic particles and anomalous violations of nature's symmetries at CEBAF
  - The limits of nuclear existence? How are heavy elements made in the cosmos via FRIB and ATLAS?
  - Is the neutrino its own anti-particle? Do the neutron's precise properties point to new physics?
  - The nature of the strong force in many-body systems via SciDAC?
  - Advanced Nuclear Data for Space, Energy, and Research.

Budget Matters

Nuclear Physics – FY 2022 Highlights
Discovering, exploring, and understanding all forms of nuclear matter

Operations

- The Request supports operations of the NP scientific user facilities to enable world-class science:
  - **RHIC operates at 90 percent optimal utilization** and installs sPHENIX to study the Quark-Gluon Plasma.
  - **CEBAF operates at 90 percent of optimal utilization**, enabling highest priority 12 GeV experiments and critical maintenance activities and cryomodule refurbishments.
  - **ATLAS operates at 93 percent of optimal utilization** to enable the most compelling experiments in nuclear structure and astrophysics and invests in multi-user capabilities to increase utilization of the facility.
  - **FRIB** transitions from a construction project to a scientific user facility and **operates at 100% of optimal utilization** to support research, beam studies and commissioning.

Projects

- The Request also supports compelling major scientific investments:
  - Completion of the **super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) MIE**, to further RHIC's scientific mission by studying high-rate jet production
  - Continuation of the **Gamma-Ray Energy Tracking Array (GRETA) MIE**, to enable provision of advanced, high resolution gamma ray detection capabilities for FRIB.

Nuclear Physics – FY 2022 Highlights (cont.)
Discovering, exploring, and understanding all forms of nuclear matter

Projects (cont.)

- Continuation of the **Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIE** to measure the parity-violating asymmetry in polarized electron-electron scattering with the 12 GeV CEBAF.
- Continuation of the **Ton-scale Neutrinoless Double Beta Decay MIE** to determine whether the neutrino is its own antiparticle.
- Continuation of the **High Rigidity Spectrometer (HRS)** research project at FRIB to maximize the rate of rare neutron-rich nuclei of central importance for understanding the synthesis of heavy elements in cosmic events.

- The DOE Isotope Program is embedded in the Nuclear Physics budget in FY 2021 Enacted but is broken out as a Program separate from NP in the FY 2022 Request.
- The **Electron Ion Collider (EIC),** of critical importance to maintain world-leadership in nuclear physics and accelerator science, receives its third year of OPC and TEC funding. OPC funding supports conceptual design efforts and R&D, while the TEC funding supports design efforts, long lead procurements and Project Engineering Design (PED) activities.

Nuclear Physics – FY 2022 Highlights (cont.)
Discovering, exploring, and understanding all forms of nuclear matter

Research

- Funding is strengthened at national labs and universities conducting research in relativistic nuclear collisions, hadron physics, nuclear structure and nuclear astrophysics, fundamental symmetries and nuclear theory.
- NP participates in six crosscutting scientific initiatives:
  - **Accelerator Science and Technology Initiative** – strengthening U.S. supply chain robustness to steward key technologies such as electron ion source developments and advanced approaches in SRF technology
  - **Artificial Intelligence and Machine Learning** – R&D for automated optimization of accelerator performance and operation as well as algorithm development for data-analytics-driven discovery.
  - **Integrated Computational & Data Infrastructure** – Cross-cutting cloud solutions to Big Data storage challenges in Nuclear Physics
  - **Microelectronics** – R&D on detector materials, devices, advances in front-end electronics, and integrated sensor/processor architectures
  - **Quantum Information Science** – leveraging discovery opportunities in sensing, simulation, and computing at the intersections of nuclear physics and QIS
  - **Reaching a New Energy Sciences Workforce (RENEW)** - advancing a diverse, equitable, and inclusive research community

Summary of 2022 President's Request Changes Relative to FY 2021 Enacted

FY 2021 Enacted	FY 2022 President's Request
Core Research reduced 3.75% from FY20 Enacted (including COL, this is a 5.6% cut from constant effort in FY20). New ECA awards are made.	**Core research** in **Medium Energy, Heavy Ions, and Theory** is increased by 12% from FY21 Enacted. (After accounting for COL, this represents a ~10% increase over FY21 Enacted,.) **The Fundamental Symmetries and Nuclear Structure and Nuclear Astrophysics** portfolios are increased by 15% over FY21 Enacted.
LHC M&O commitments are met.	**LHC M&O** commitments are met.
FRIB Research flat with FY2020 and below the planned level.	**FRIB Research** is increased, but still below the planned level.
nEDM supported below planned profile.	**nEDM** supported significantly below planned profile, possibly impacting schedule.
SciDAC commitment are met.	**SciDAC** funding is increased to support SciDAC-5 (+$600k).
Nuclear Data slightly increased over FY20 Enacted.	**Nuclear Data** increased $3.5M from FY21 Enacted to support the expansion of experimental efforts.
Accelerator R&D subject to the 3.75% research reduction.	**Accelerator R&D** increased ~$1M over FY21 Enacted level.
QIS at $9.5M.	**QIS increased to** $10.5M.
NP ML/AI Initiative begins with $4M.	**AI/ML Initiative support flat** with FY21 Enacted ($4M).

Summary of 2022 President's Request Changes Relative to FY 2021 Enacted

FY 2021 Enacted	FY 2022 President's Request
	Four new initiatives are supported: • Reaching a New Energy Sciences Workforce (RENEW) - $3M • Accelerator Science and Technology - $2M • Integrated Computational & Data Infrastructure - $1M • Microelectronics - $500k
Facility operations funding reduced by 3.75%. - **RHIC** operates 24 weeks (100 % maximum) - **CEBAF** operates 7 weeks (41 % maximum) - **ATLAS** operates 39 weeks (93 % optimal)	**Facilities operations supported at >90% of optimal.** - **RHIC** operates 18 weeks (90 % maximum) - **CEBAF** operates 31 weeks (90 % optimal) - **ATLAS** operates 39 weeks (93 % optimal) - **FRIB** operates 12 weeks (100% of optimal)
FRIB operations supported at $50M.	**FRIB Operations increased,** but still slightly below planned levels ($77M in PR vs $82M planned)
FRIB construction at baselined $5.3M in final funding year.	
EIC construction at TEC of $5M and OPC of $24.65M	**EIC construction** at TEC of $20M and OPC of $10M
Major Items of Equipment: - **GRETA** reduced below planned levels ($6.6M) - **sPHENIX** at planned baseline level ($5.53M) - **MOLLER** at $5M TEC - **TSNLDBD** at $1.4M TEC - **HRS** at $3M TEC	**Ongoing Major Item of Equipment:** - **GRETA** below planned levels ($6.6M) - **sPHENIX** at baseline level ($0.2M) - **MOLLER** at $7M TEC - **TSNLDBD** at $1.44M TEC - **HRS** at $3M TEC
Isotope Program embedded within NP budget	**Isotope Program no longer embedded within NP budget**

NP - FY 2022 President's Request

(Dollars in thousands)

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted		FY 2022 Request vs FY 2020 Enacted	
Nuclear Physics								
Medium Energy, Research	66,800	65,479	41,110	54,083	12,973	31.56%	-11,396	-17.40%
Medium Energy, Operations	117,390	122,110	117,201	142,709	25,508	21.76%	20,599	16.87%
Medium Energy Physics	**184,190**	**187,589**	**158,311**	**196,792**	**38,481**	**24.31%**	**9,203**	**4.91%**
Heavy Ion, Research	37,354	37,661	36,313	48,059	11,746	32.35%	10,398	27.61%
Heavy Ion, Operations	187,465	187,131	181,625	183,943	2,318	1.28%	-3,188	-1.70%
Heavy Ion, Projects	5,660	19,520	30,180	10,213	-19,967	-66.16%	-9,307	-47.68%
Heavy Ion Physics	**230,479**	**244,312**	**248,118**	**242,215**	**-5,903**	**-2.38%**	**-2,097**	**-0.86%**
Theory, Research	55,327	51,862	61,129	60,781	-348	-0.57%	8,919	17.20%
Nuclear Theory	**55,327**	**51,862**	**61,129**	**60,781**	**-348**	**-0.57%**	**8,919**	**17.20%**
Low Energy, Research	63,690	60,398	61,763	74,341	12,578	20.36%	13,943	23.09%
Low Energy, Operations	30,215	55,739	79,379	107,831	28,452	35.84%	52,092	93.46%
Low Energy, Projects	6,840	10,600	16,000	18,040	2,040	12.75%	7,440	70.19%
Low Energy Physics	**100,745**	**126,737**	**157,142**	**200,212**	**43,070**	**27.41%**	**73,475**	**57.97%**
Isotopes Operations	22,451	34,400	36,340	---	-36,340	-100.00%	-34,400	-100.00%
Isotope - Research	9,808	11,500	26,660	---	-26,660	-100.00%	-11,500	-100.00%
Isotopes, Projects	12,000	3,600	3,000	---	-3,000	-100.00%	-3,600	-100.00%
Isotope Production and Applications	**44,259**	**49,500**	**66,000**	**...**	**-66,000**	**-100.00%**	**-49,500**	**-100.00%**
Program Subtotal	**615,000**	**660,000**	**690,700**	**700,000**	**9,300**	**1.35%**	**40,000**	**6.06%**
14-SC-50 Facility for Rare Isotope Beams FRIB	**75,000**	**40,000**	**5,300**	**...**	**-5,300**	**-100.00%**	**-40,000**	**-100.00%**
20-SC-51 Stable Isotope Production and Research Center SIPRC, ORNL	**...**	**12,000**	**12,000**	**...**	**-12,000**	**-100.00%**	**-12,000**	**-100.00%**
20-SC-52 Electron Ion Collider EIC, BNL	**...**	**1,000**	**5,000**	**20,000**	**15,000**	**300.00%**	**19,000**	**1,900.00%**
Construction Subtotal	**75,000**	**53,000**	**22,300**	**20,000**	**-2,300**	**-10.31%**	**-33,000**	**-62.26%**
Total Nuclear Physics	**690,000**	**713,000**	**713,000**	**720,000**	**7,000**	**0.98%**	**7,000**	**0.98%**

Total, NP FY21 – FY20	**651,500**	**635,000**	**-16,500**
FY21 NP Appropriation	**713,000**	**713,000**	**-**

FY 22 House Mark $665

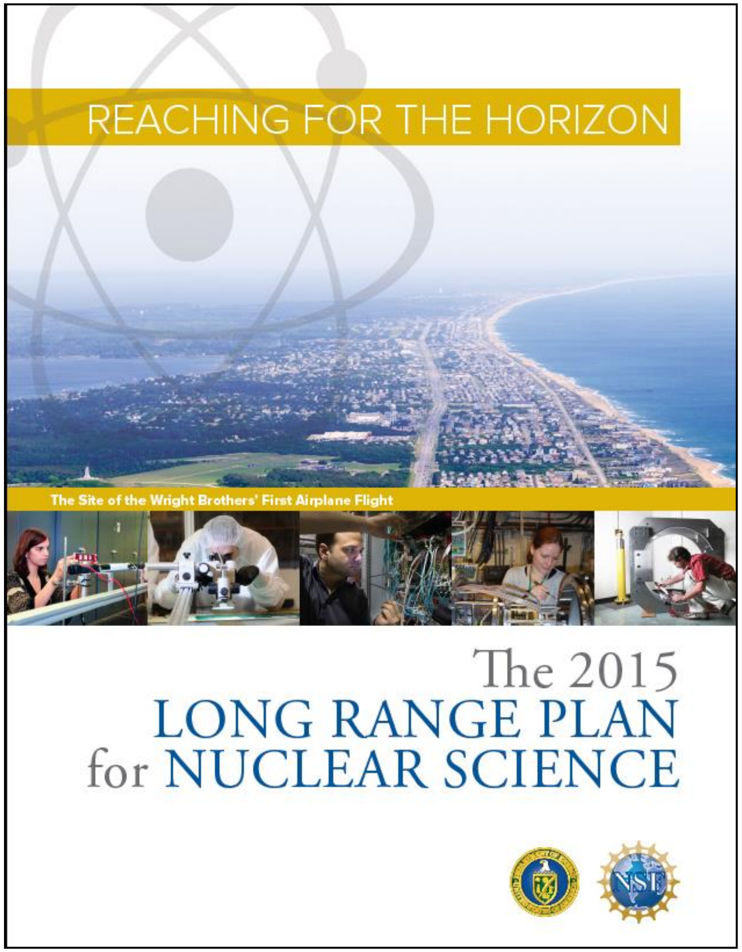
General Outlook

- The budget uncertainty continues.
- We need to stay focused and continue to deliver important outcomes for the nation.
- Delivering exciting discoveries, important scientific knowledge, technological advances, and workforce training is what we do.
- We need to keep up the good work!

The 2015 Long Range Plan for Nuclear Science

Recommendations:

1. Capitalize on investments made to maintain U.S. leadership in nuclear science.
2. Develop and deploy a U.S.-led ton-scale neutrino-less double beta decay experiment.
3. Construct a high-energy high-luminosity polarized electron-ion collider (EIC) as the highest priority for new construction following the completion of FRIB.
4. Increase investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.



NP continues to execute on the 2015 LRP Vision

Upcoming Decisions

Three Front-Runner Technologies

- Scintillating bolometry (**CUPID**, ^{100}Mo enriched Li_2Mo_4 crystals)
- Enriched ^{76}Ge crystals (**LEGEND-1000**, drifted charge, point contact detectors)
- Liquid Xenon TPC (**nEXO**, light via APD, drifted ionization)

Background constraints are exceptionally challenging < 1 count/ton of material/year

Also, there are three possible sites

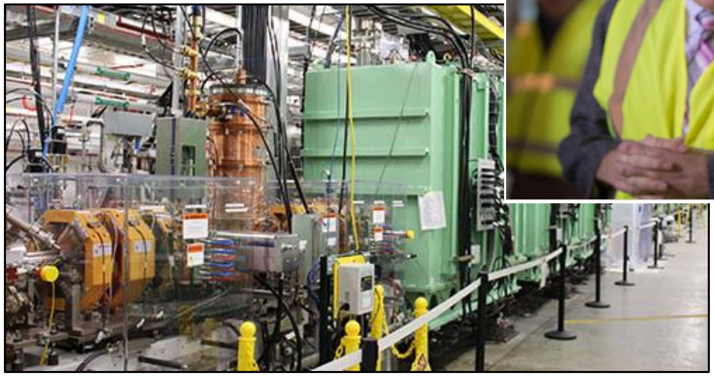
- SURF (SD)
- SnoLab (Canada)
- Gran Sasso (Italy)

$0\nu\beta\beta$ Progression

- Ongoing interactions with potential international collaborators to introduce U.S. perspectives, hear European perspectives, and suggest a global approach to investment in DBD science
- DBD Portfolio Review was held July 13-16, 2021 to inform U.S. investment strategy. Instructions published by April 15, 2021.
- North American – European Summit will be held September 29 to October 1, 2021 to see if common ground exists for an international approach to DBD investment
- Funding for ton-scale $0\nu\beta\beta$ is going to be challenging

The Fourth, Newest Microscope: Facility for Rare Isotope Beams (FRIB)

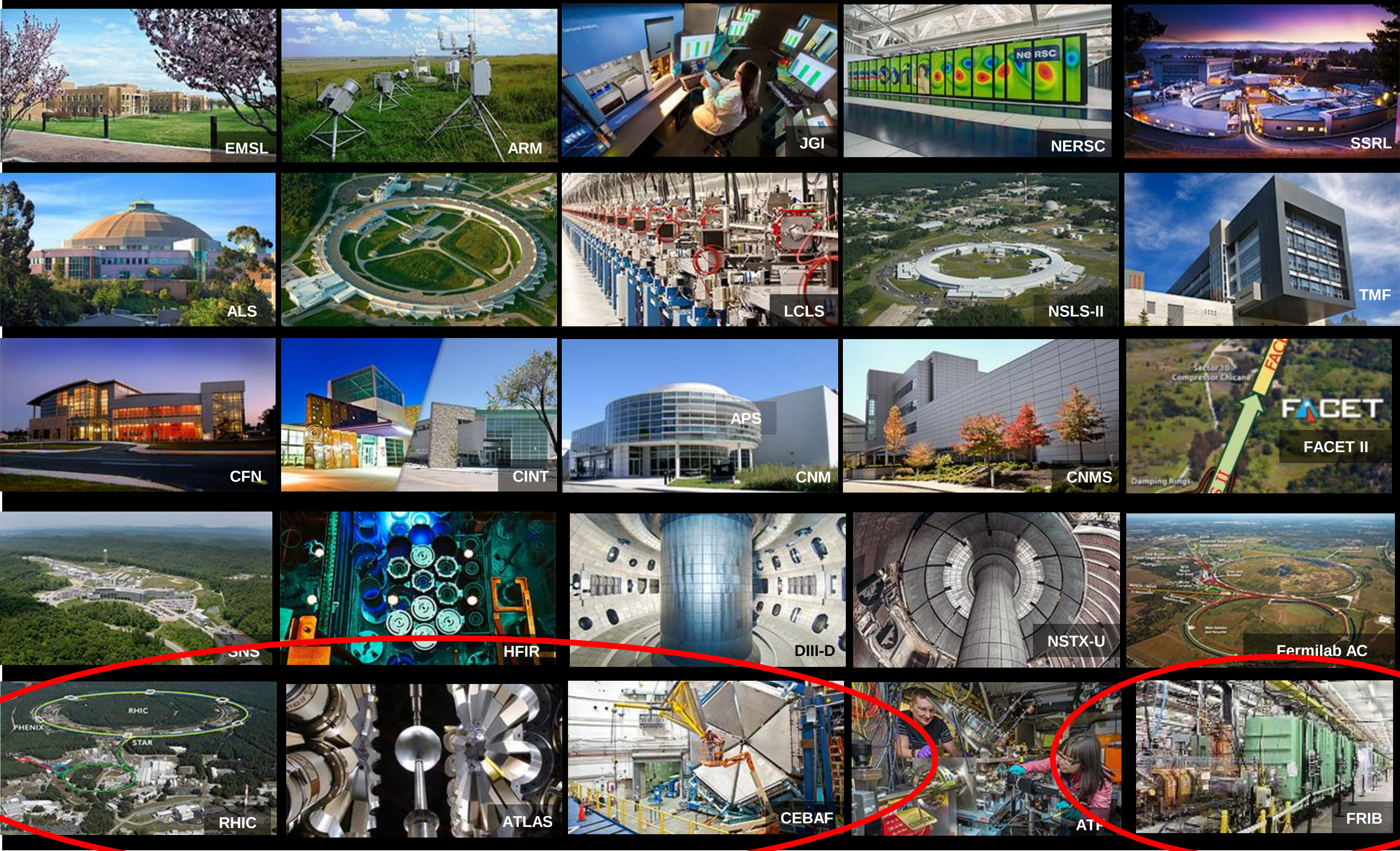
- FRIB issued a call for proposals to its 1500 member user group.
- 82 proposals received from 130 institutions in 30 countries requesting 9,784 hours of beam time
- FRIB Program Advisory Committee Meeting held in May 2021.
- First science in spring of 2022



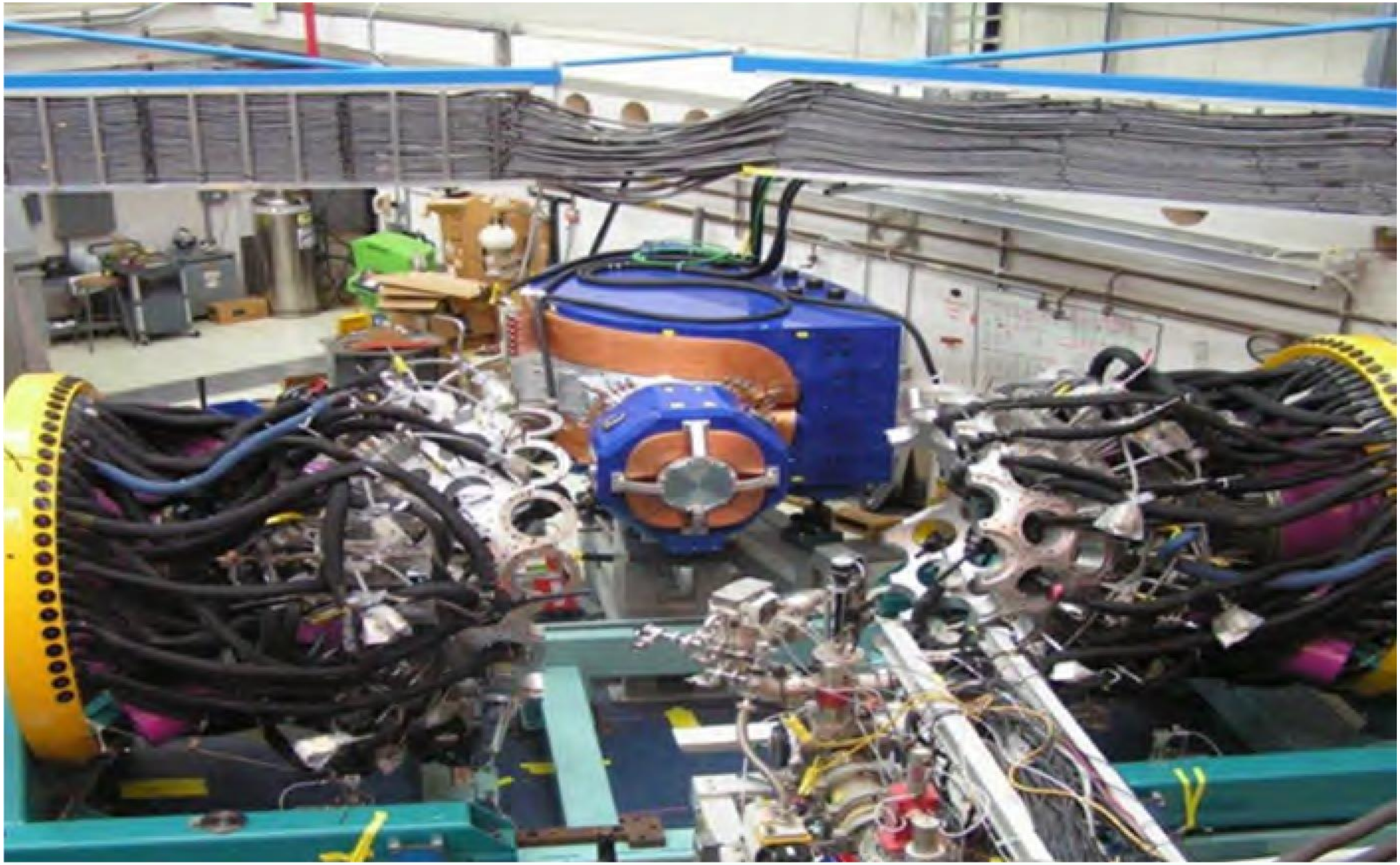
World Leadership in Nuclear Structure & Nuclear Astrophysics Research

Office of Science User Facilities

Number of User Facilities
28

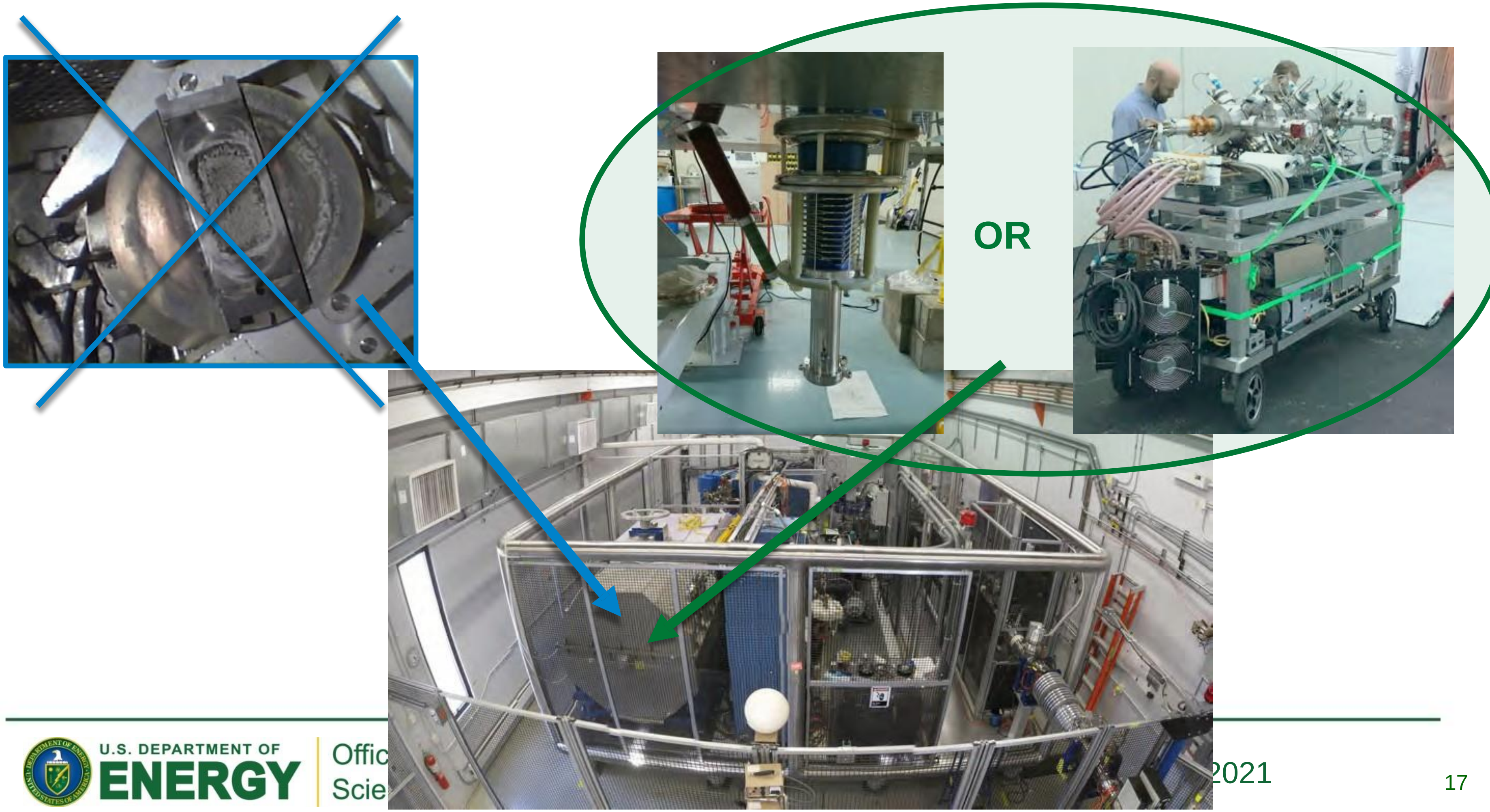


ATLAS Continues as a Premier Stable Beam Facility



NEUTRON GENERATOR UPGRADE

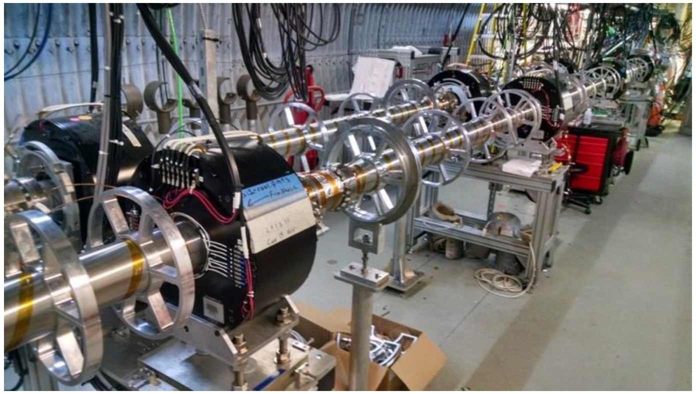
- Replace ^{252}Cf source by neutron-induced fission on actinide foils
  - More reliable source of fission products
  - Operationally easier to maintain and operate
  - Higher fission yield feeding in the ^{132}Sn region



RHIC Machine Performance Continues to Set New Records

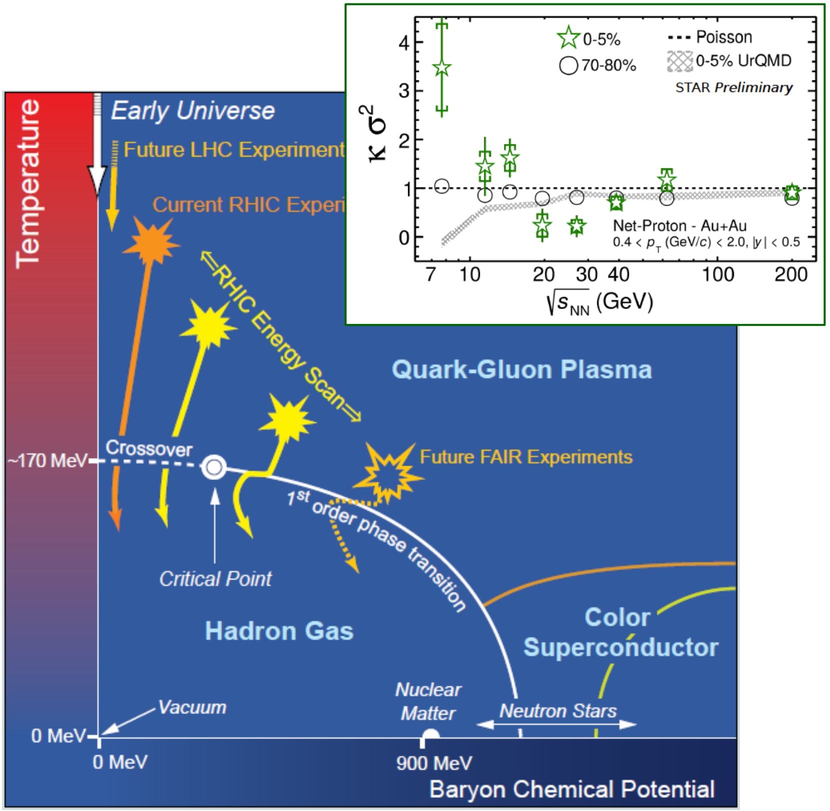
- The continued focus at RHIC: search for a critical point between the phases of nuclear matter

LEReC



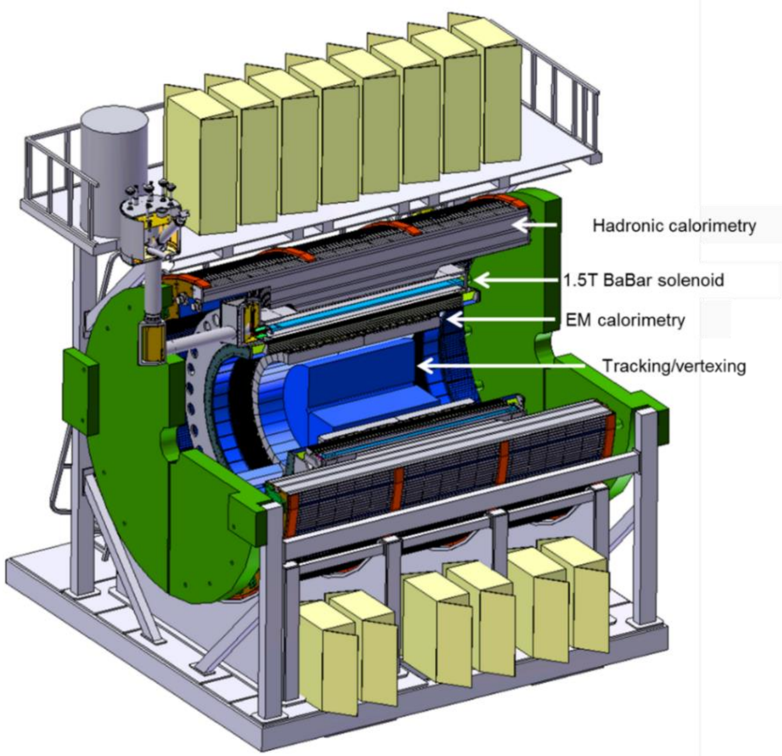
Cooling of low energy, bunched heavy ion beams (3.85–5.75 GeV/n) to increase luminosity

Project on track for use in low-energy RHIC runs



- Consistently high facility availability (~85%)
- No other facility worldwide, existing or planned, rivals RHIC in science reach and versatility as a heavy ion collider. It is the only polarized proton collider in the world.

The sPHENIX Upgrade is Continued



- mapping the character of the hadronic matter under extreme conditions by varying the temperature of the medium, the virtuality of the probe, and the length scale within the medium.
- understanding the parton–medium interactions by studying heavy-flavor jets.
- probing the effect of the quark–gluon plasma on the Upsilon states by comparing the p-p (proton-proton), p-A (proton-nucleus), and A-A (nucleus-nucleus) collisions.

Elsewhere in Heavy Ion:

CMS MTD Science Review Ongoing

ALICE Forward Upgrade Review Anticipated

implemented from within RHIC base by limiting operations to one detector and periodically not operating facility.

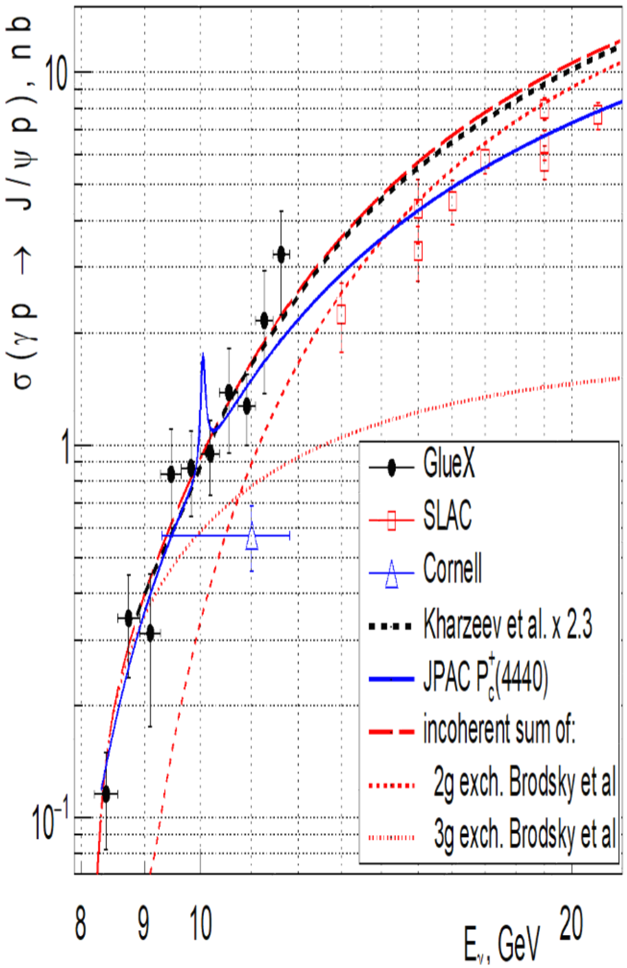
12 GeV CEBAF Science Program Continues

CEBAF Weeks Capped by CHL Install in FY21

New results from GlueX illuminate the mechanism of threshold J/Psi production and the upper limit on the pentaquark. The latter provides constraints on the structure of the LHCb pentaquark, favoring a molecular description.

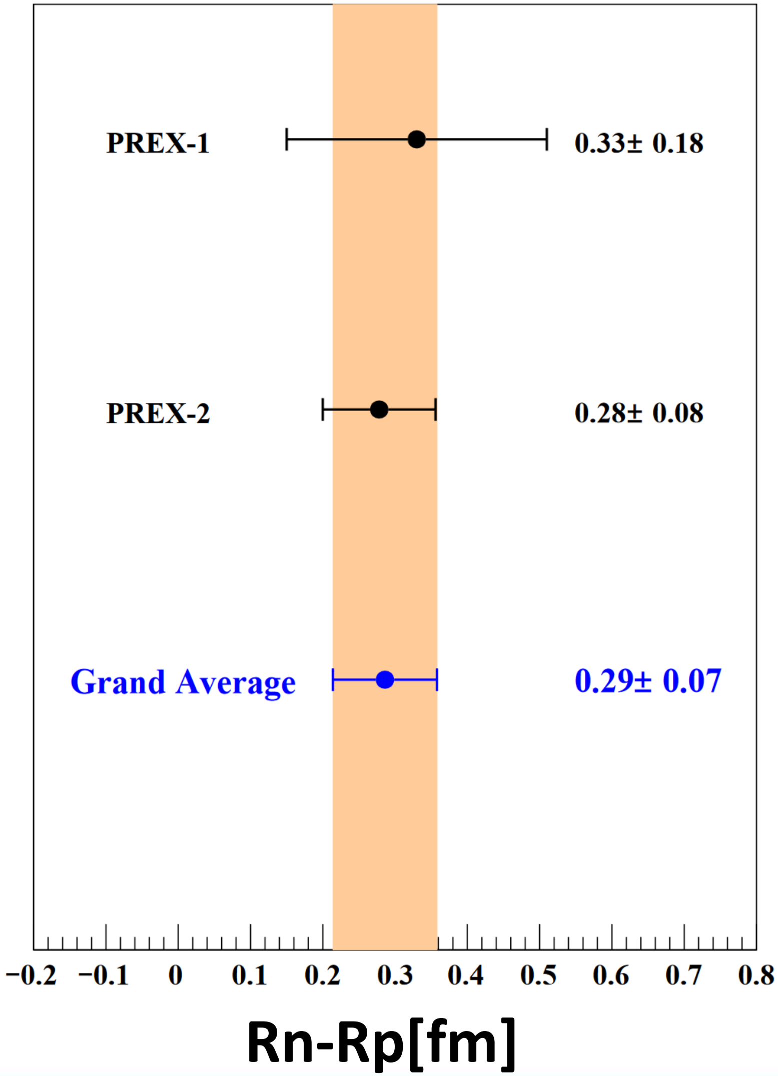
Phys. Rev. Lett. 123, 072001(2019)

$$\gamma p \to pJ/\psi \to pe^+e^-$$



(Based on ~25% of collected data.)

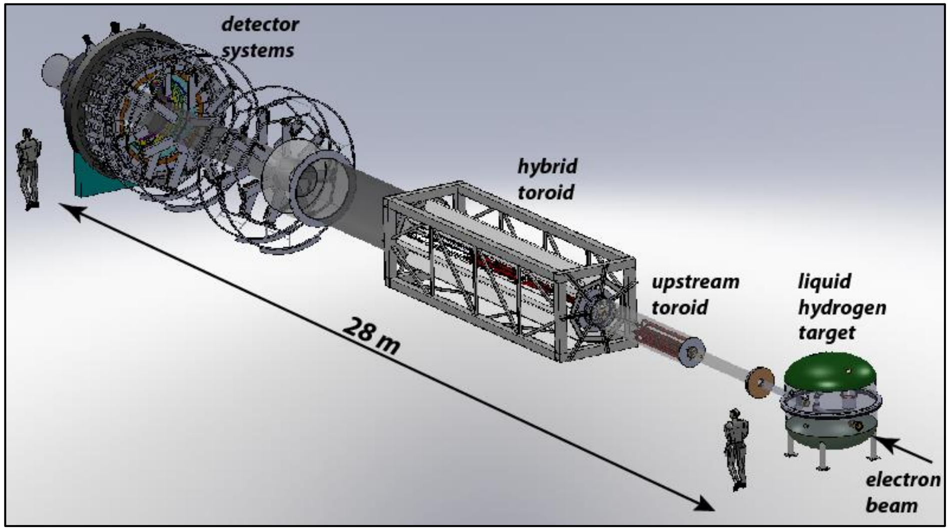
New P-REX Results Unblinded !



- The weak radius can be combined with the well-known charge density to obtain the baryon density of 208Pb
- This is the first clean determination of the central baryon density of a heavy nucleus and is accurate to 2%
- Provides an important benchmark to chiral EFT calculations that is closely related to nuclear saturation density
- Result has direct relevance for bounding the radius of neutron stars in concert with neutron star merger data from LIGO

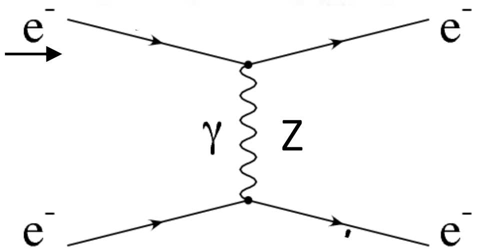
MOLLER: a "Must Do" Experiment To Point the Way to New Science

The scientific world rather desperately needs additional markers due to the consistency thus far of LHC data with Standard Model Predictions. Due to the technical challenge of constructing a next generation accelerator with very high accelerating gradients, those markers will have to come from "indirect" discovery experiments like MOLLER.



parity-violating Moller scattering

$\vec{e} + e \rightarrow e + e$



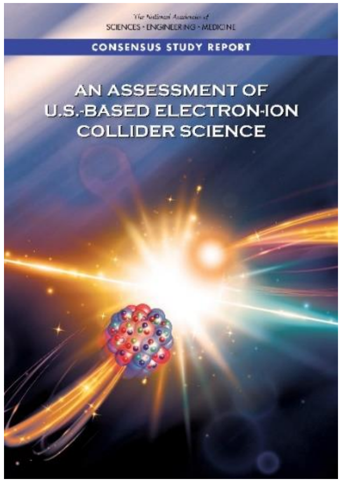
In MOLLER, polarized electrons are scattered of unpolarized electrons. The amount of parity violation due to interference of the two possible exchange mechanisms (γ or Z) is <u>precisely</u> predictable in QED. (No messy quarks or color charge, or QCD to worry about, only quantum electrodynamics). The theory is so "clean" that like the g-2 approach, If the level of parity violation is greater than expected, a new particle must be the source of the discrepancy.

Project at CD-1, FY 2021 Enacted: $5M

Solid Science Review Report in Preparation

The Next Super High Power, High Energy Microscope: The Electron-Ion Collider

National Academy of Science Report: AN ASSESSMENT OF U.S.-BASED ELECTRON-ION COLLIDER SCIENCE



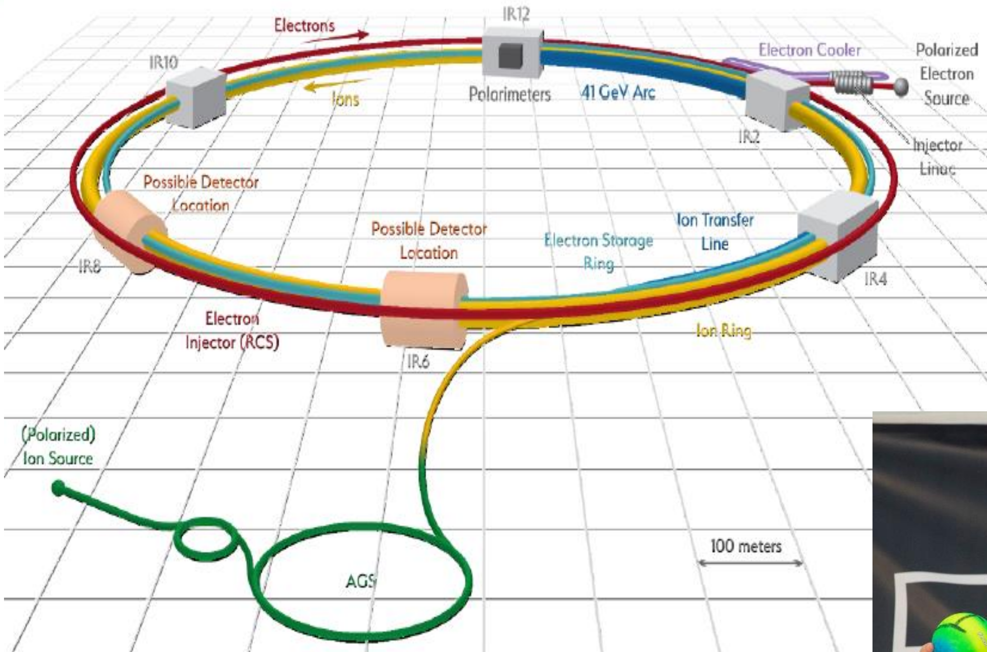
"An EIC can uniquely address three profound questions About nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:

- **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?"**

The EIC would be a unique facility & maintain leadership in nuclear science

The EIC would maintain leadership in the accelerator science and technology of colliders

EIC CD-0, Site Selection, Project Start & Dedication in FY20



The EIC will be located at BNL and with TJNAF as a major partner. The realization of the EIC will be accomplished over the next decade at an estimated cost between $1.7 and $2.8 billion.

Utilize existing operational hadron collider; add electron storage ring, cooling in existing RHIC tunnel and electron injector.

EIC scope includes the machine upgrade to RHIC asset and two interactions regions with one of the interaction regions outfitted with a major detector. Working towards CD-1 in Q3 FY 2021

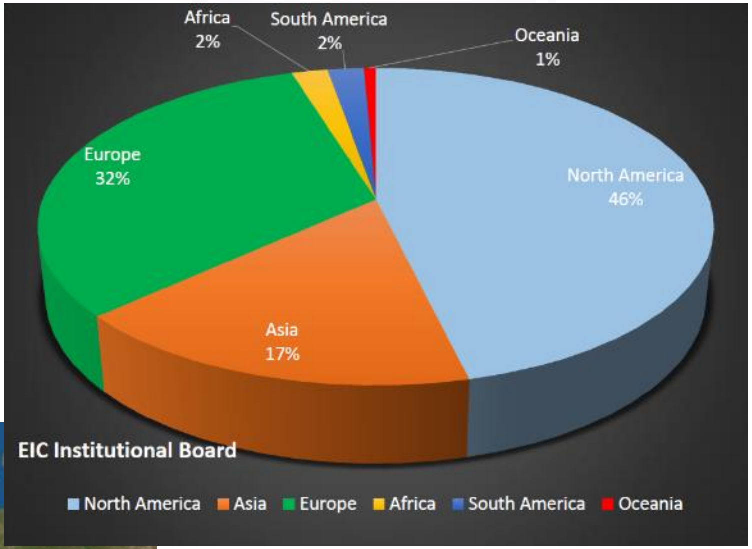
EIC Dedication September 18, 2020

<u>The EIC will be a game-changing resource for the international nuclear physics community.</u> *DOE looks forward to engaging with the international community and the international funding agencies about potential collaborations and contributions to the EIC effort, in nuclear, accelerator and computer science.*

EIC User Community

EIC Users Group Formed in 2016
EICUG.ORG

Status February 2021:
- Collaborators 1259
- Institutions 252
- Countries 34



Annual EICUG meeting
2016 UC Berkeley, CA
2016 Argonne, IL
2017 Trieste, Italy
2018 Washington, DC
2019 Paris, France
2020 Miami, FL
2021 Warsaw, Poland

Office of Science ESAAB Equivalent Board Critical Decision Approval

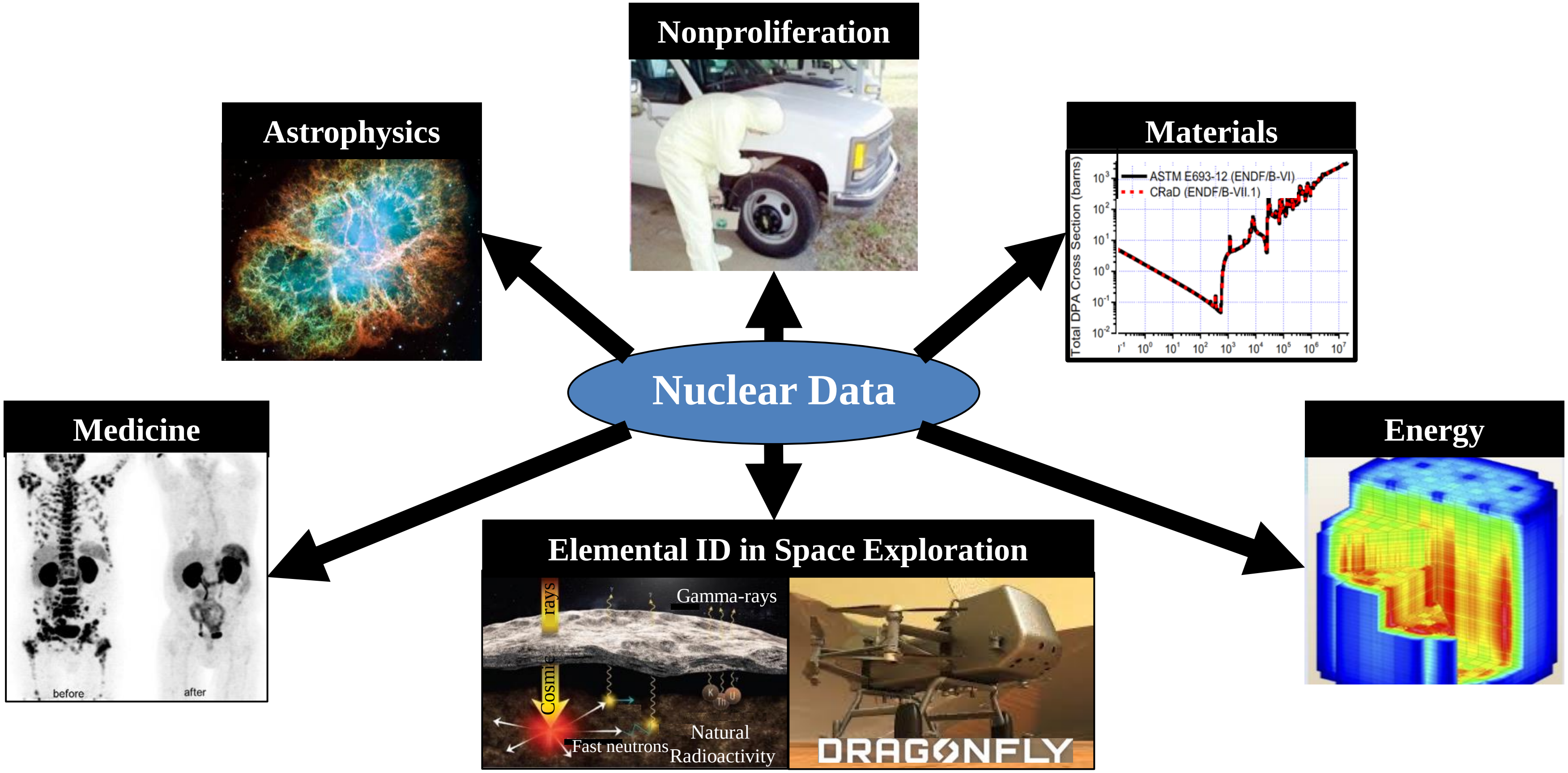
Kurt W. Fisher, Director
Office of Project Assessment, SC-23
Office of Science, U.S. Department of Energy
https://science.osti.gov/opa

June 25, 2021

EIC CD-1 is Approved

New & Traditional Frontiers Requiring Accurate Nuclear Data

Many types of nuclear data are "crosscutting" to numerous applications



NP Leads a Nuclear Data Interagency Working Group (NDIAWG) that has published 4 FOAs

Active Participants in WANDA and/or NDIAWG

NNSA
National Nuclear Security Administration

NASA

NATIONAL NUCLEAR LABORATORY

NEA
Nuclear Energy Agency

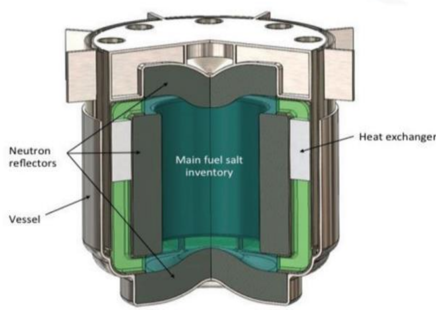
In Support of Clean Energy Goals

Next generation reactors use faster neutrons, different fuels, and coolants to achieve greater safety and modularity

$$k = \eta f p \varepsilon P_{FNL} P_{TNL}$$

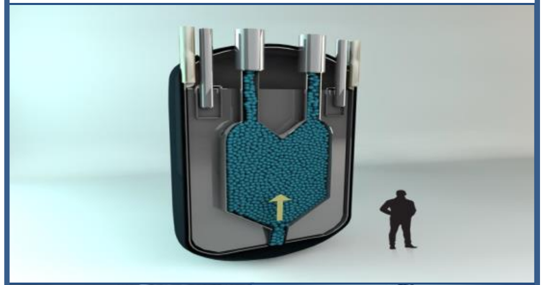
- *neutron multiplication factor* → k
- *Thermal fission factor* → η
- *Thermal utilization factor* → f
- *Resonance escape factor* → p
- *Fast fission factor* → ε
- *Fast Non-leakage factor* → P_{FNL}
- *Thermal Non-leakage factor* → P_{TNL}

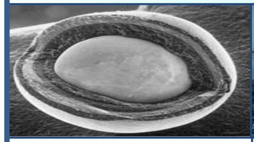
Terrapower



MCFR (Cl)

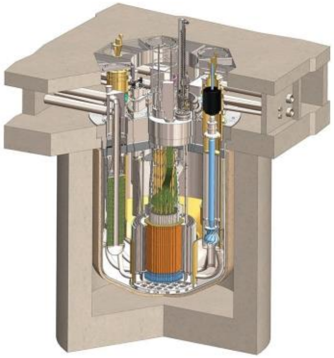
Kairos FHR





TRISO Pebble Fuel (U,C,Si)	Molten Salt Coolant (Flibe)

Non-existent or uncertain Nuclear Data needs to be redressed for new materials and fuels in order to correctly understand/model the neutronics in new designs at a high level of confidence



SMR (Na)

Nuclear Data & Space Nuclear Propulsion

Presented to: Workshop on Applied Nuclear Data Activities (WANDA) 2021

Space Technology Mission Directorate
Technology Demonstration Mission Program
Space Nuclear Propulsion Project

Kelsa Palomares, AMA Inc. | January 25, 2020

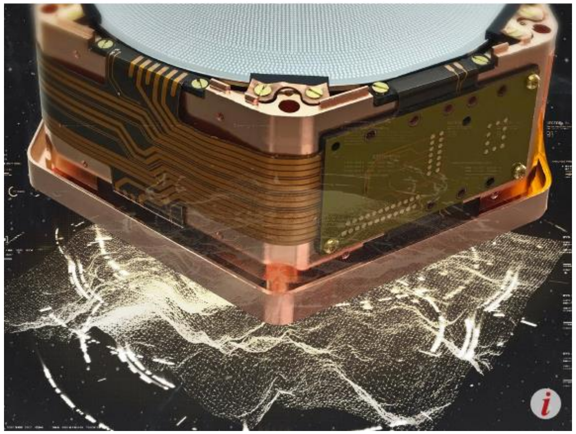
A Landmark Study Published in Journal Nature

Article

Impact of ionizing radiation on superconducting qubit coherence

https://doi.org/10.1038/s41586-020-2619-8
Received: 25 January 2020
Accepted: 5 June 2020
Published online: 26 August 2020

Antti P. Vepsäläinen[1✉], Amir H. Karamlou[1], John L. Orrell[2✉], Akshunna S. Dogra[1,4], Ben Loer[2], Francisca Vasconcelos[1], David K. Kim[3], Alexander J. Melville[3], Bethany M. Niedzielski[3], Jonilyn L. Yoder[3], Simon Gustavsson[1], Joseph A. Formaggio[1], Brent A. VanDevender[2] & William D. Oliver[1,3]



Naturally occurring radiation produced by environmental radioactive materials and cosmic rays is enough to limit the useful lifetime of superconducting qubit state to just a few milliseconds… Identifying ionizing radiation as a dominant source of excess quasiparticles… is a first step towards developing to mitigate its impact on superconducting circuits, including those used for quantum computation and quantum sensing.

Popular press coverage: ***PNNL "Natural Radiation Can Interfere with Quantum Computers "and MIT Technology Review "Cosmic rays could pose a problem for future quantum computers "*** https://www.pnnl.gov/news-media/natural-radiation-can-interfere-quantum-computers
https://www.technologyreview.com/2020/08/26/1007688/cosmic-rays-could-pose-a-problem-for-future-quantum-computers/

***Independent*, Future of Quantum Computing Could Be Disrupted by Space**
https://www.independent.co.uk/life-style/gadgets-and-tech/news/quantum-computer-cosmic-rays-radiation-space-a9689946.html

***The Vice*, Particles From Space Are Messing With Our Quantum Computers, Scientists Discover**
https://www.vice.com/en_us/article/wxqy5x/particles-from-space-are-messing-with-our-quantum-computers-scientists-discover

New Scientist, Quantum computers may be destroyed by high-energy particles from space
https://www.newscientist.com/article/2252933-quantum-computers-may-be-destroyed-by-high-energy-particles-from-space/

"Natural Radiation Can Interfere with Quantum Computers"

An FY 2021 NP/SC DEI Pilot Has Garnered Strong Interest

- NP received 36 proposals requesting funding to support over 200 traineeships across the country.

- The proposed collaborations involve 91 potential participating institutions including
  - 9 National Labs,
  - 44 MSIs of which 18 are HBCUs and 2 are PBIs,
  - 9 Community Colleges, and
  - 2 Women's Colleges.

Congressional interest garnered as well

U.S. DEPARTMENT OF ENERGY | Office of Science

Additional NP DOE FOAs

FOA/Lab Call	Nuclear Data Interagency Working Group Research Program
FOA/Lab Call	Quantum Horizons: QIS Research and Innovation for Nuclear Science
FOA/Lab Call	Pilot Program for Traineeships to Broaden and Diversify the NP Workforce
FOA/Lab Call	Data Analytic for Autonomous Optimization and Control of Accelerators and Detectors

Other News Items

- New Staff in DOE NP
  - Xiaofeng Guo — Nuclear Physics Computing
  - Ivan Graff — Nuclear Physics Major Initiatives
  - Kenneth Hicks (IPA) — Heavy Ion
  - Paul Mantica (IPA) — Technical Advisory/Facilities & Project Management Division
  - Melissa Emerson (CONTR) — Administrative Specialist
  - Saryna Cameron (CONTR) — Program Support Specialist
- John Yates has joined as a DOE Intern
- Kiara Fenner has joined as a DOE Intern
- NP has solicitations out for Theory PM and Heavy Ion PM; Soliciation for International PM coming soon

Office of Nuclear Physics

Timothy J. Hallman, Associate Director

Melissa Emerson, Administrative Specialist (CONTR)

Associate Director's Office Staff

Brian Knesel, Financial Management Specialist
VACANT, Financial Management Analyst
Linnette Quick, Program Assistant (CONTR)
Brenda May, Program Analyst
VACANT, International Cooperation and Outreach

Physics Research Division

VACANT, Director

Christine Izzo, Program Support Specialist

- **Medium Energy & Quantum Information Science** — Gulshan Rai, Technical Advisor
- **Heavy Ion Nuclear Physics** — VACANT; Kenneth Hicks (IPA)
- **Nuclear Structure and Astrophysics** — Sharon Stephenson
- **Nuclear Theory** — VACANT
- **Nuclear Data** — Keith Jankowski
- **Fundamental Symmetries** — Paul Sorensen
- **Nuclear Physics Computing** — Xiaofeng Guo

Facilities & Project Management Division

Jehanne Gillo, Director

Saryna Cameron, Program Support Specialist (CONTR)
Paul Mantica (IPA), Technical Advisor
Latifa Elouadrhiri (Detailee)

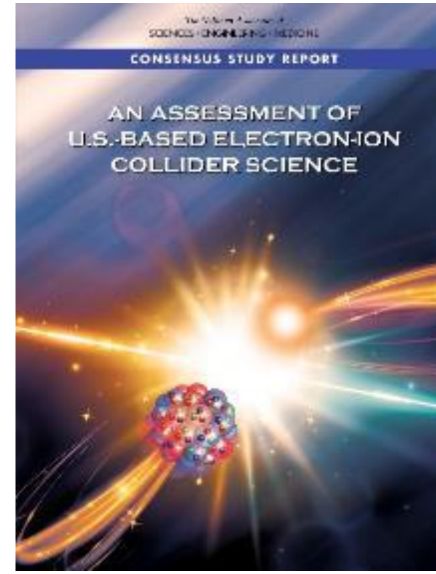
- **Advanced Technology R&D** — Manouchehr Farkhondeh, Deputy
- **Nuclear Physics Facilities** — James Sowinski
- **Nuclear Physics Major Initiatives** — Ivan Graff
- **Nuclear Physics Instrumentation** — Elizabeth Bartosz
- **Industrial Concepts** — Michelle Shinn

(IPA) – Intergovernmental Personnel Act

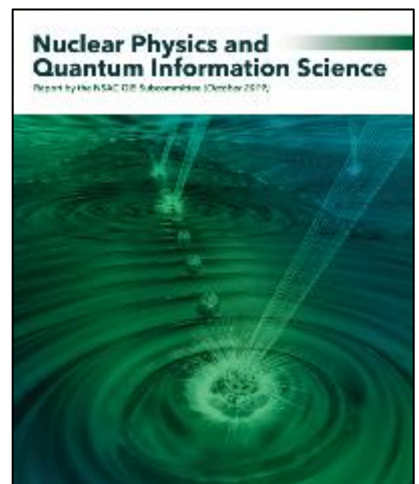
Overall, Progress in Implementing the LRP Has Been Good

World leading research supported at state-of-the-art NP National User Facilities

The vision to maintain U.S. leadership continues to be implemented: EIC construction; FRIB construction



Pioneering experiments and research tools (MIEs) are created



Groundbreaking contributions to national cross-cutting priorities continue

A Long Tradition of Partnership and Stewardship

There has been a long tradition in Nuclear Science of effective partnership between the community and the agencies in charting compelling scientific visions for the future of nuclear science.

Key factors:

1) Informed scientific knowledge as the basis for recommendations and next steps
2) Mutual respect among scientific sub-disciplines
3) Commitment to the greater good of nuclear science as a discipline
4) Meticulously level playing field leading to respect for process and outcomes
5) Deep appreciation for the wisdom of Ben Franklin

Staying united we can accomplish great things together

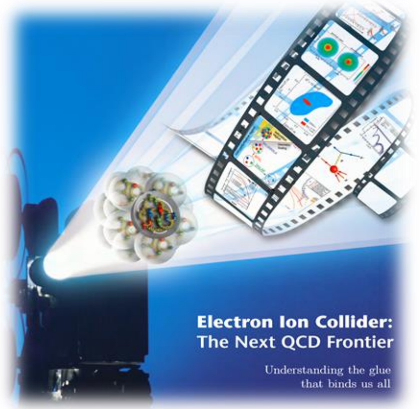
Division will setback the entire field and is the last thing needed right now

Additional Information

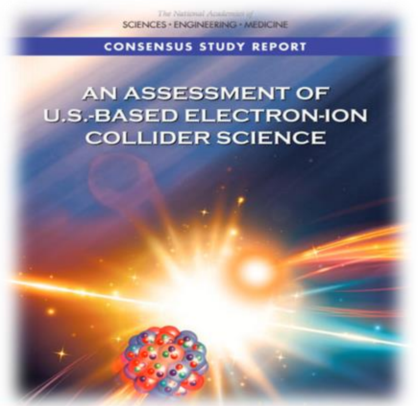
Science-Driven Project Requirements

<u>Project Design Goals</u>

- High Luminosity: $L = 10^{33} – 10^{34} cm^{-2} sec^{-1}$, 10 – 100 fb^{-1}/year
- Highly Polarized Beams: 70%
- Large Center of Mass Energy Range: E_{cm} = 20 – 140 GeV
- Large Ion Species Range: protons – Uranium
- Large Detector Acceptance and Good Background Conditions
- Accommodate a Second Interaction Region (IR)



Conceptual design scope and expected performance meets or exceed NSAC Long Range Plan (2015) and the EIC White Paper requirements endorsed by NAS (2018)

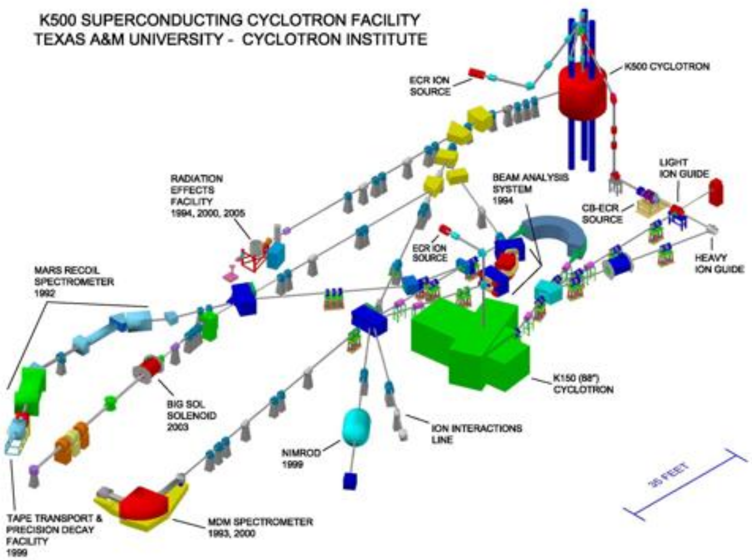


These challenging performance goals require a machine that is state-of-the-art

Two NP Centers of Excellence at TUNL and Texas A&M

1967 - 2017 50 YEARS OF BEAM exploring the nuclear frontier

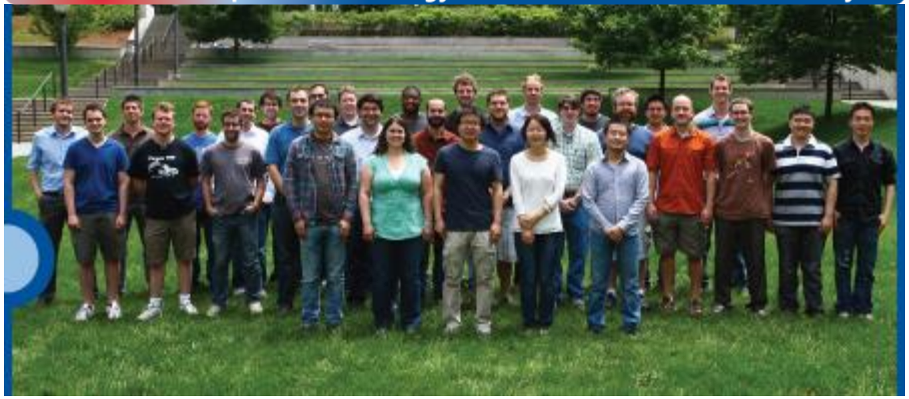
CYCLOTRON INSTITUTE
TEXAS A&M UNIVERSITY



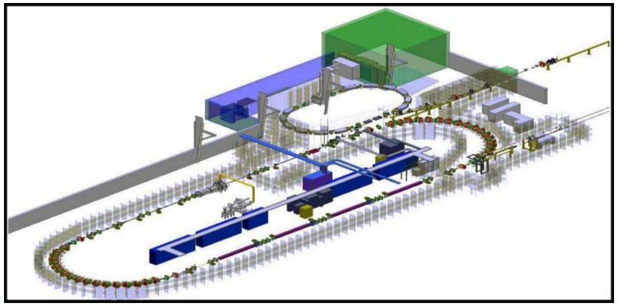
The Texas A&M University Cyclotron Institute jointly supported by DOE and the State of Texas focuses on conducting basic research, educating students in accelerator-based science and technology, and providing technical capabilities for a wide variety of applications in space science, materials science, analytical procedures and nuclear medicine.

The 88 inch cyclotron also plays a crucial role in space radiation effects chip testing for the Air Force

TUNL TRIANGLE UNIVERSITIES NUCLEAR LABORATORY
Durham, North Carolina
A US Department of Energy Center of Excellence in Nuclear Physics



The Triangle Universities Nuclear Laboratory (TUNL) is Center of Excellence that focuses on low-energy nuclear physics research. TUNL is a consortium Duke University, North Carolina State University, and the University of North Carolina at Chapel Hill comprising about 30 faculty members, 20 postdocs and research scientists, and 50 graduate students.

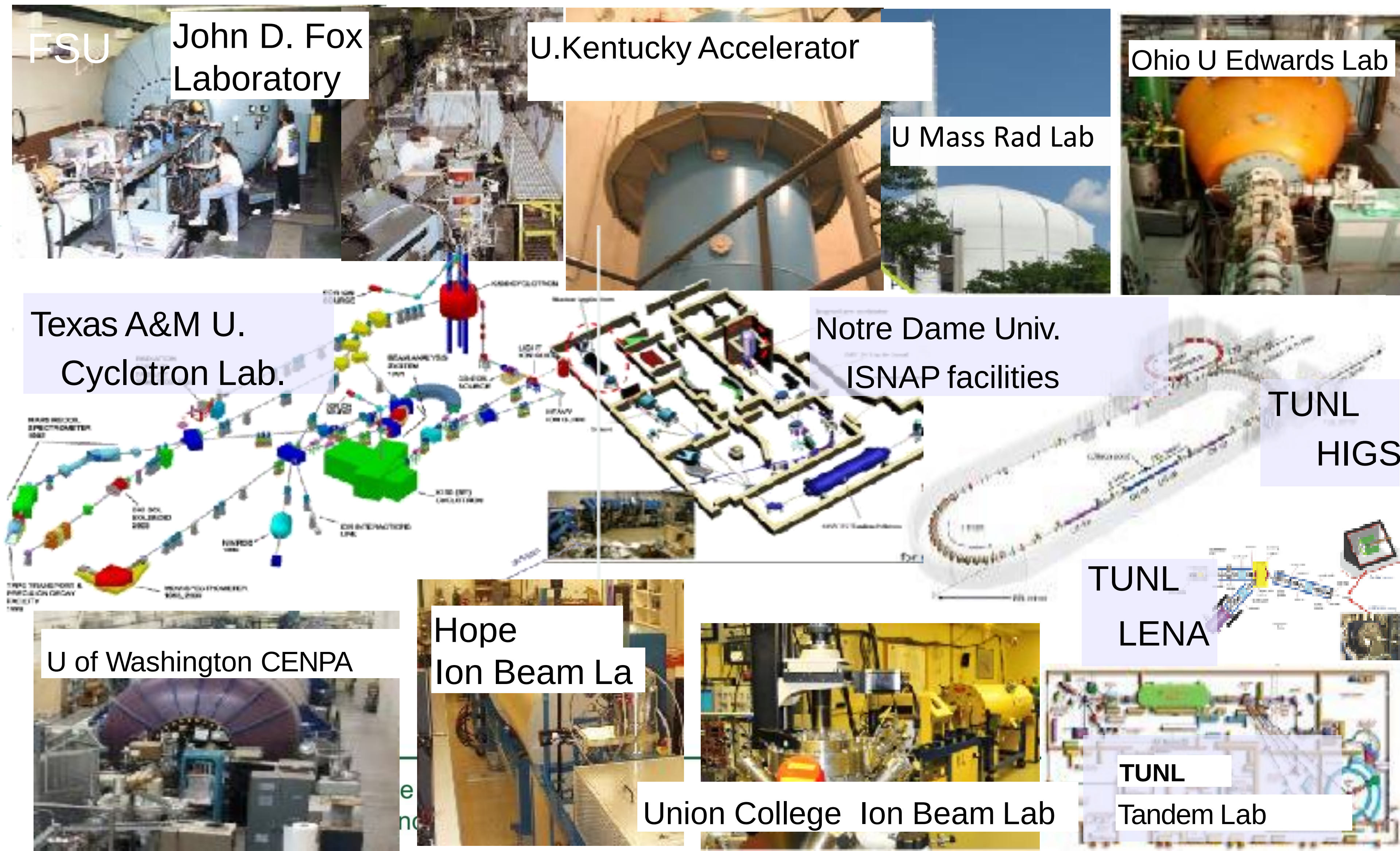


http://aruna.physics.fsu.edu

10 members

~200 users

ARUNA- Association for Research at University Nuclear Accelerators



Mo-99 Charge Letter

This letter is to request that, in accordance with direction given to the DOE in the National Defense Authorization Act (NDAA) for FY2013, the Nuclear Science Advisory Committee (NSAC) standing Subcommittee on Mo-99 conduct its annual assessment of the effectiveness of the National Nuclear Security Administration, Office of Material Management and Minimization (NNSA-MMM) Domestic Molybdenum-99 (Mo-99) Program (formerly known as the Global Threat Reduction Initiative).

The American Medical Isotopes Production Act of 2012 (Act), formerly known as S. 99 and H.R. 3276, was incorporated into the National Defense Authorization Act (NDAA) for FY2013. On January 2, 2013, President Obama signed the NDAA into law, enacting this legislation. A stipulation of the NDAA under section 3173 – *IMPROVING THE RELIABILITY OF DOMESTIC MEDICAL ISOTOPE SUPPLY* is that:

"…the Secretary [of Energy] shall…use the Nuclear Science Advisory Committee to conduct annual reviews of the progress made in achieving the [NNSA MMM] program goals and make recommendations to improve effectiveness."

The Department of Energy (DOE) and National Science Foundation (NSF) very much appreciate NSAC's six previous assessments as described in reports transmitted to the agencies on May 8, 2014, July 30, 2015, November 3, 2016, March 19, 2018, April 17, 2019, and March 16, 2020.

Mo-99 Charge Letter

We request that NSAC provide a seventh annual assessment addressing the following charge elements:

- What is the current status of implementing the goals of the NNSA-MMM Mo-99 Program? What progress has been made since the 6th NSAC assessment?
- Is the strategy for continuing to implement the NNSA goals complete and feasible, within an international context?
- Are the risks identified in implementing those goals being appropriately managed?
- Has the NNSA-MMM Program addressed concerns and/or recommendations articulated in the 2019/2020 NSAC assessment of the Mo-99 Program appropriately and adequately?
- What steps should be taken to further improve NNSA program effectiveness in establishing a domestic supply of Mo-99?

It is requested that this assessment be submitted spring of 2021.

Mo-99 Charge Letter

We are aware that this charge represents an additional burden on your time. However, the involvement of NSAC is essential to inform the Agency regarding the effectiveness of efforts to steward Mo-99, and isotope essential for the health and well-being of the Nation.

Sincerely,

J. Stephen Binkley
Acting Director
Office of Science

Sean Jones
Assistant Director
Directorate for Mathematical
and Physical Sciences
National Science Foundation

Benefits of Training in Nuclear Science

- Highly Specialized Technical skills
- Creative problem analysis/solving ability
- Scientific communication skills
- Resilience despite frustration / perseverance
- Self confidence
- Time management ability
- Project planning skills
- Ability to team and working within a large collaboration
- Leadership development

The result is an essential national core competency useful not only for "things nuclear", but for a variety of other challenge pursuits as well

Space Nuclear Propulsion: NTP Nuclear Data Needs

1. **HALEU Fuel Enrichment**
   - *Use of HALEU may drive the desire to thermalize the neutron spectrum compared to historic fast and epithermal designs*

2. **Unique Operating Regime –** NTP operating temperatures vary from cryogenic to ultrahigh temperature (> 2750 K)
   - *Cross section temperature dependence*

3. **High Temperature Moderators and Materials** – space reactors may benefit from high temperature moderator candidates (metallic hydrides and beryllium compounds) and refractory metals / ceramics
   - *Previous benchmarks and historic testing do exist for reference but spectrum may differ (possible need resolution of unresolved resonances over energy range)*

4. **Unique Working Fluids** – Scattering in hydrogen can play a role in reactor control and reactivity
   - *Scattering in hydrogen non-negligible contribution to overall reactivity*

5. **Prototypic Environment** - The use of a nuclear reactor in space must consider background radiation and probabilities for interaction with the reactor
   - *High energy photonuclear reactions and photon sources should be characterized to understand any impact to the reactor during idle, start up, or nominal operation*
   - *Different backgrounds expected for in-space or surface operation*

6. **Testing Infrastructure** – Space reactor technologies could benefit from pre-existing or new infrastructure for experimental testing and evaluation of nuclear data

7. **Uncertainty data** – updated covariance data will allow for more accurate characterization of reactor uncertainty / sensitivities

Safe nuclear energy is almost certainly part of a U.S. clean energy future. Accurate, reliable nuclear data is central to realizing that vision, terrestrially or "out of this world".

In Support of Clean Energy Goals

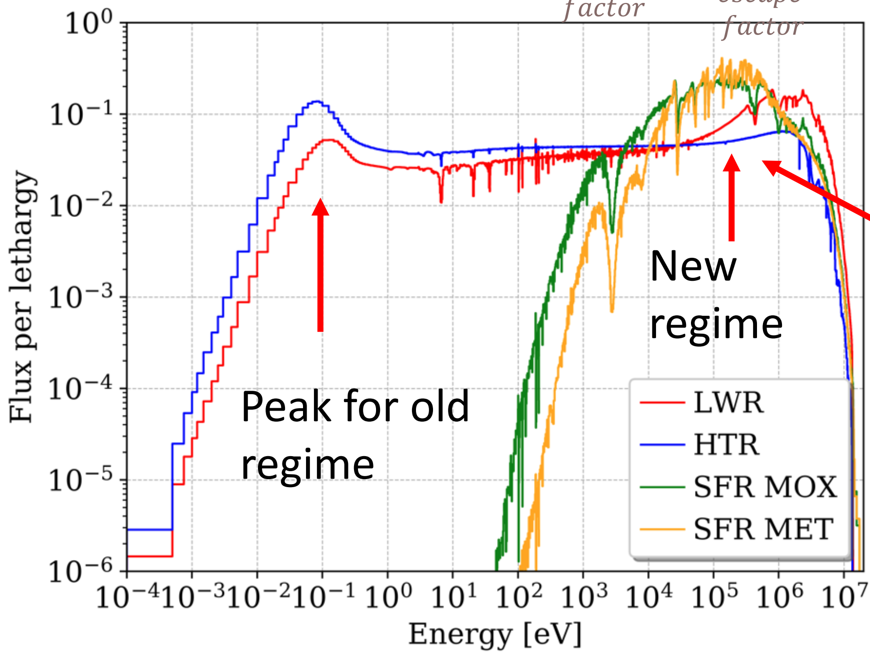
Next generation reactors use faster neutrons, different fuels, and coolants to achieve greater safety and modularity

$$k = \eta f p \varepsilon P_{FNL} P_{TNL}$$

- *neutron multiplication factor* → k
- *Thermal fision factor* → η
- *Thermal utilization factor* → f
- *Resonance escape factor* → p
- *Fast fission factor* → ε
- *Fast Non − leakage factor* → P_{FNL}
- *Thermal Non − leakage factor* → P_{TNL}

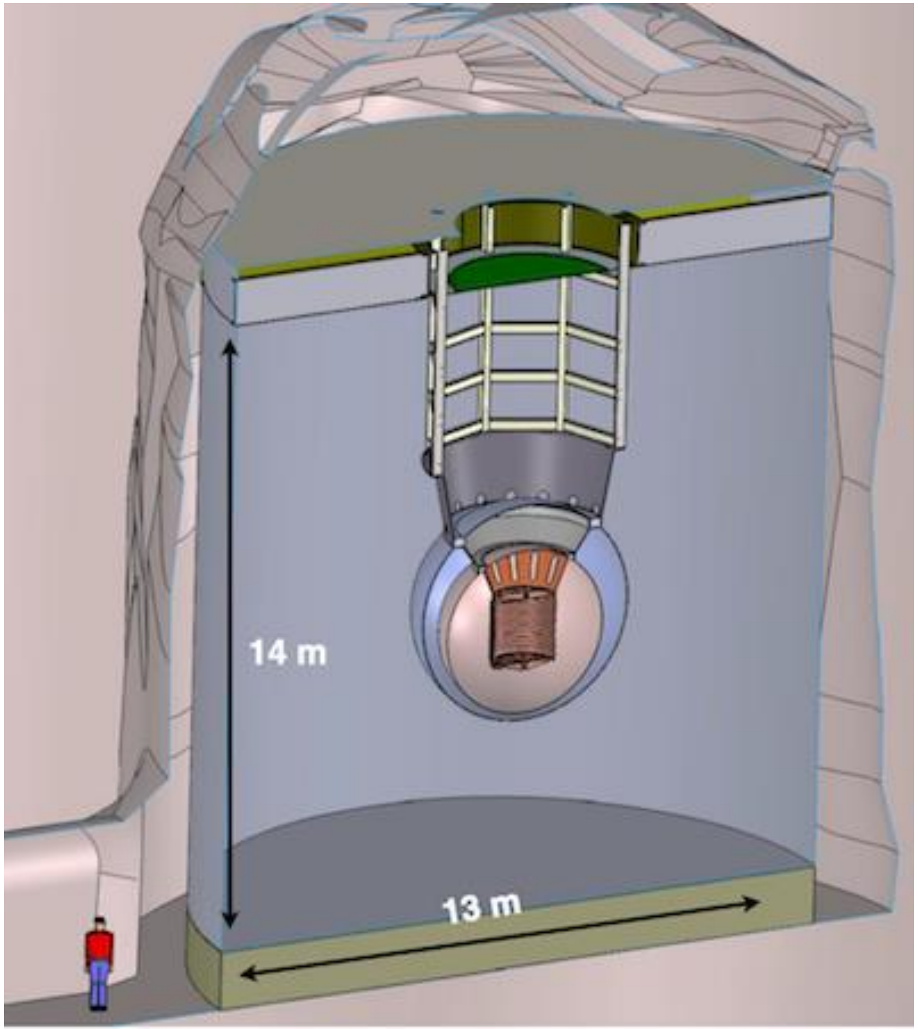
The harder neutron spectrum and different fuel introduce a dependence on types of nuclear data not explored

Neutron Spectra

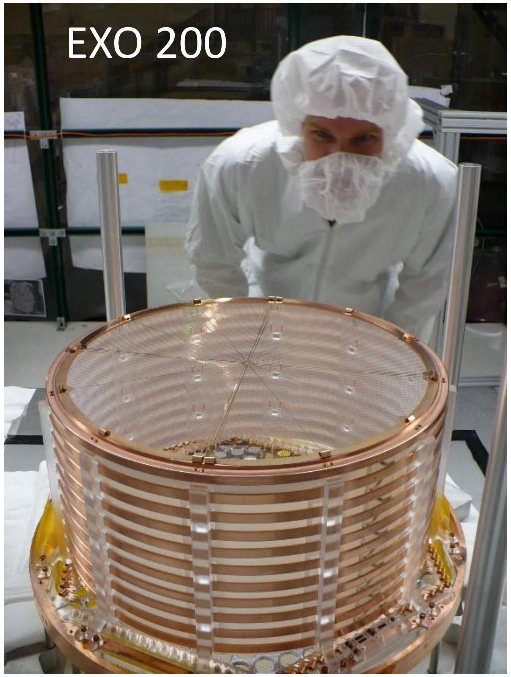


Non-existent or sparse Nuclear Data needs to be redressed for new neutron energy regime to correctly understand/model the neutronics

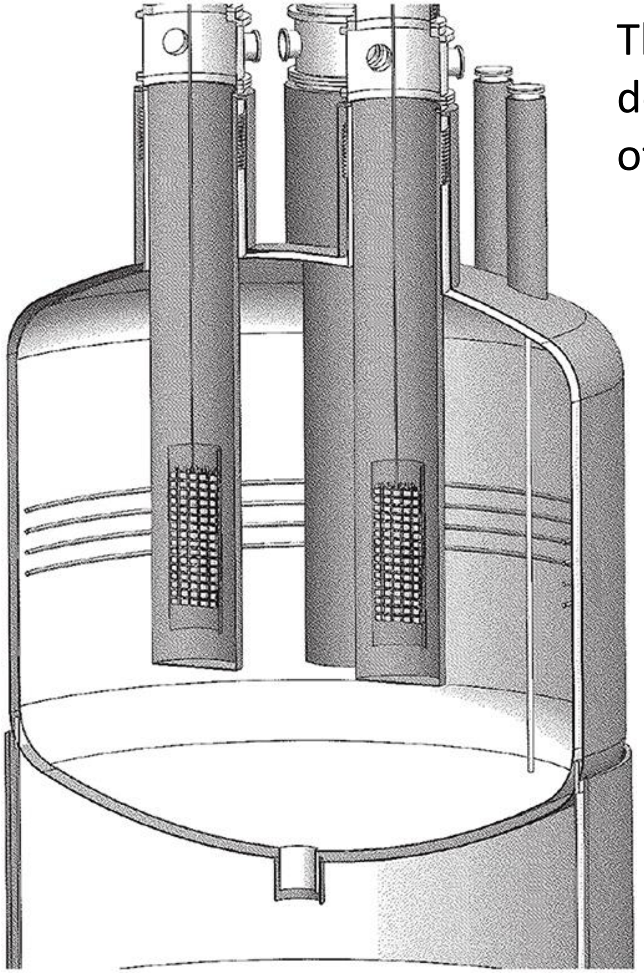
nEXO Concept



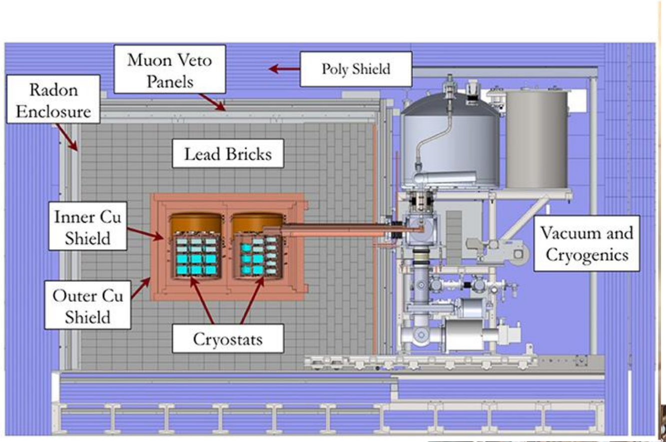
Artist rendering of the nEXO TPC (left) and its installation at the SNOLAB cryopit (left).
The cryostat is submerged in a water tank which acts as active shielding.
SiPMs will be mounted between field shaping rings and detector wall.



LEGEND-1000



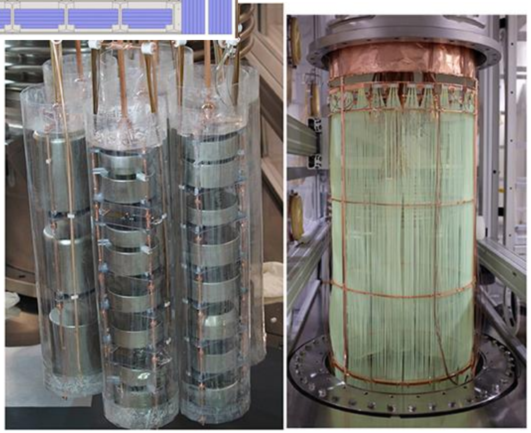
The concept for LEGEND-1000 showing a number of the deployments Ge detectors. This cut-away view shows three of five 200-kg groupings of Ge.



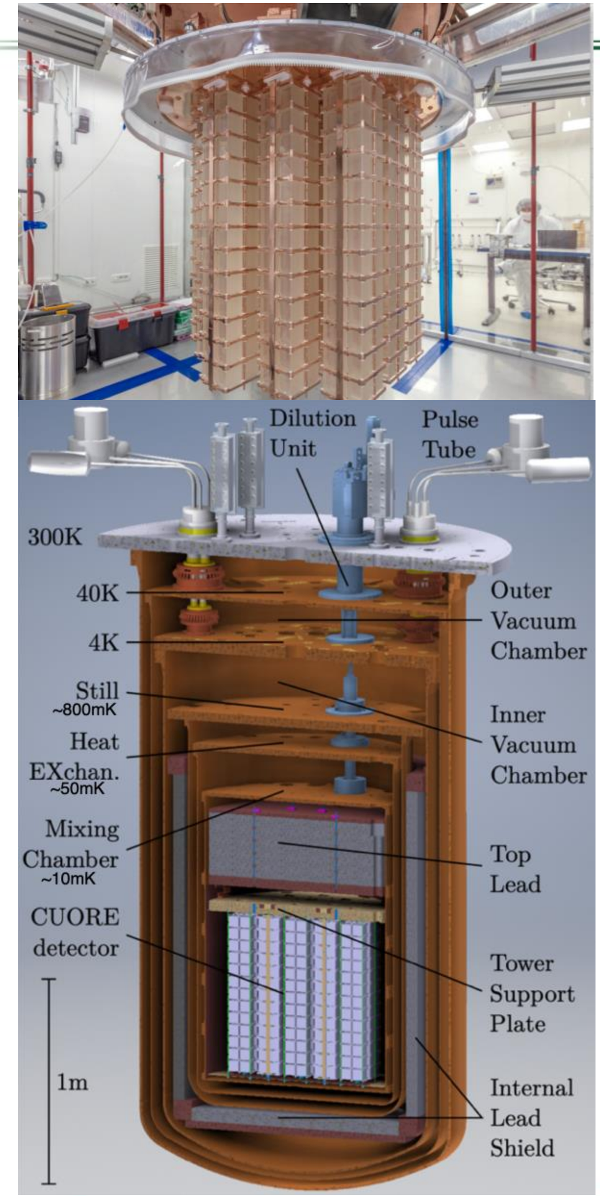
Majorana Demonstrator

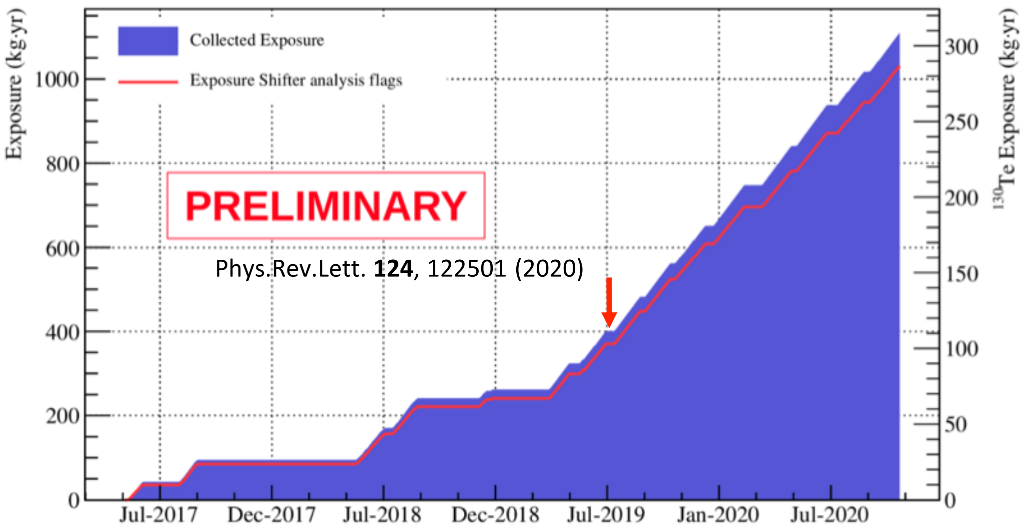
+

GERDA



CUORE: Towards Ton-scale NLDBD Search





Collected TeO_2 exposure: 1110 kg*year
Analyzable exposure: 1031 kg*year (*as of Oct 26, 2020)

>1 ton*year analyzable exposure
Largest dataset ever collected by a solid-state double-beta decay experiment
Continuous operations at 11mK since March 2019
Demonstrates readiness for a ton-scale bolometric double-beta decay experiment
CUPID proceeding to technical design

Summary of 2021 Enacted Relative to FY 2020

FY 2020 Enacted	FY 2021 Enacted
Facility operations at constant effort - **RHIC** operates 28 weeks (100 % optimal) - **CEBAF** operates 22.5 weeks (100 % maximum) - **ATLAS** operates 41 weeks (90 % optimal)	**Facilities operations** funding is reduced by 3.75%. Estimated run times are: - **RHIC** operates 24 weeks (100 % maximum) - **CEBAF** operates 7 weeks (41 % maximum) - **ATLAS** operates 39 weeks (92.6 % optimal)
FRIB operations supported at planned level $28.5M	**FRIB ops** supported slightly below planned levels ($50M vs $59.8M)
FRIB construction at baselined $40M	**FRIB construction** at baselined $5.3M
EIC construction at TEC of $1M and OPC of $10M	**EIC construction** at TEC of $5M and OPC of $24.65M
Ongoing Major Item of Equipment: - **GRETA** reduced below planned levels ($6.6M) - **sPHENIX** at planned baseline level ($9.52M) - **SIPF** at planned baseline level ($1.5M)	**Ongoing Major Item of Equipment:** - **GRETA** flat with FY2020, below baselined level ($6.6M) - **sPHENIX** at baseline level ($5.53M)
New Major Items of Equipment initiated - **MOLLER** at $2M TEC - **TSNLDBD** at $1M TEC - **HRS** at $1M TEC	**Major Items of Equipment initiated in FY 2020** - **MOLLER** increased to $5M, but below planned level - **TSNLDBD** at $1.4M TEC - **HRS** at $3M TEC
Isotope Program at $60.5M	**Isotope Program** at $78M

Summary of 2021 Enacted Relative to FY 2020

Total, NP	**651,500**	**635,000**	**-16,500**
Total, NP Appropriation	**713,000**	**713,000**	**-**

FY 2020 Enacted	FY 2021 Enacted
Core Research reduced 5.5% from FY19 Enacted (including COL, this is a 7.4% cut from constant effort in FY19). New ECA awards were made.	**Core research** reduced 3.75% from FY20 Enacted. This reduction also includes a reduced number of new ECA awards in FY21.
LHC M&O commitments were met.	**LHC M&O** commitments met but subject to the research cut.
FRIB Research was supported as planned.	**FRIB Research** is reduced by 3.75% from FY20; planned ramp-up is not supported.
nEDM supported modestly below planned profile.	**nEDM** supported below planned profile, possibly impacting schedule.
SciDAC maintained relative to FY 2019	**SciDAC** supported but subject to the research cut.
Nuclear Data held flat with FY19 Enacted	**Nuclear Data** research funds subject to the research cut. Experimental commitments met, but limited funding is available for new awards.
NP QIS at $6.8M (NP QIS flat with FY2019)	**NP QIS** at $9.5M, an increase of $2.7M from FY2020
Accelerator R&D was increased	**Accelerator R&D** is reduced by $1M beyond 3.75% cut.
Machine Learning/Artificial Intelligence awards were initiated through the SC ML/AI FOA.	**The new ML/AI Initiative** is supported with $4M of dedicated funds.