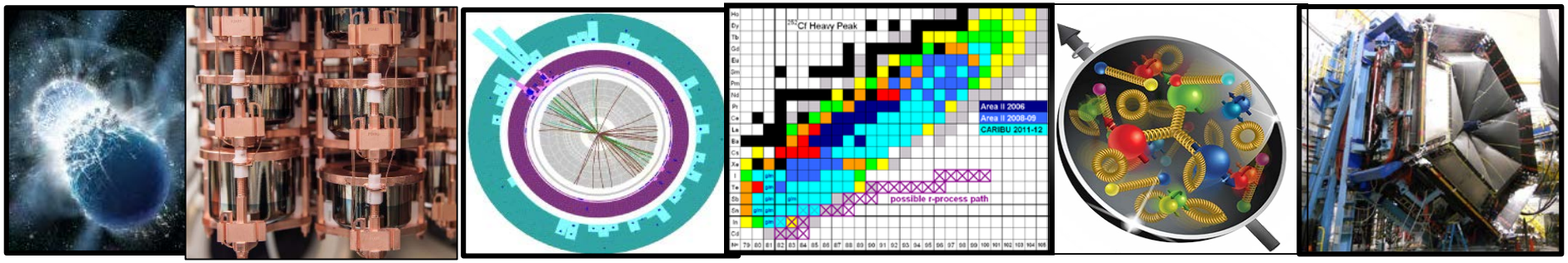
U.S. DEPARTMENT OF ENERGY | Office of Science

SEE Perspectives from DOE NP

(Why high energy heavy ion facilities exist and their future)

DHESEE 2021 High-Energy SEE Testing Users Meeting
April 13, 2021

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



The Mission of DOE NP:
Discovering, Exploring, and Understanding all Forms of Nuclear Matter

DOE NP Supports More than 95% of U.S. Basic Nuclear Physics Research

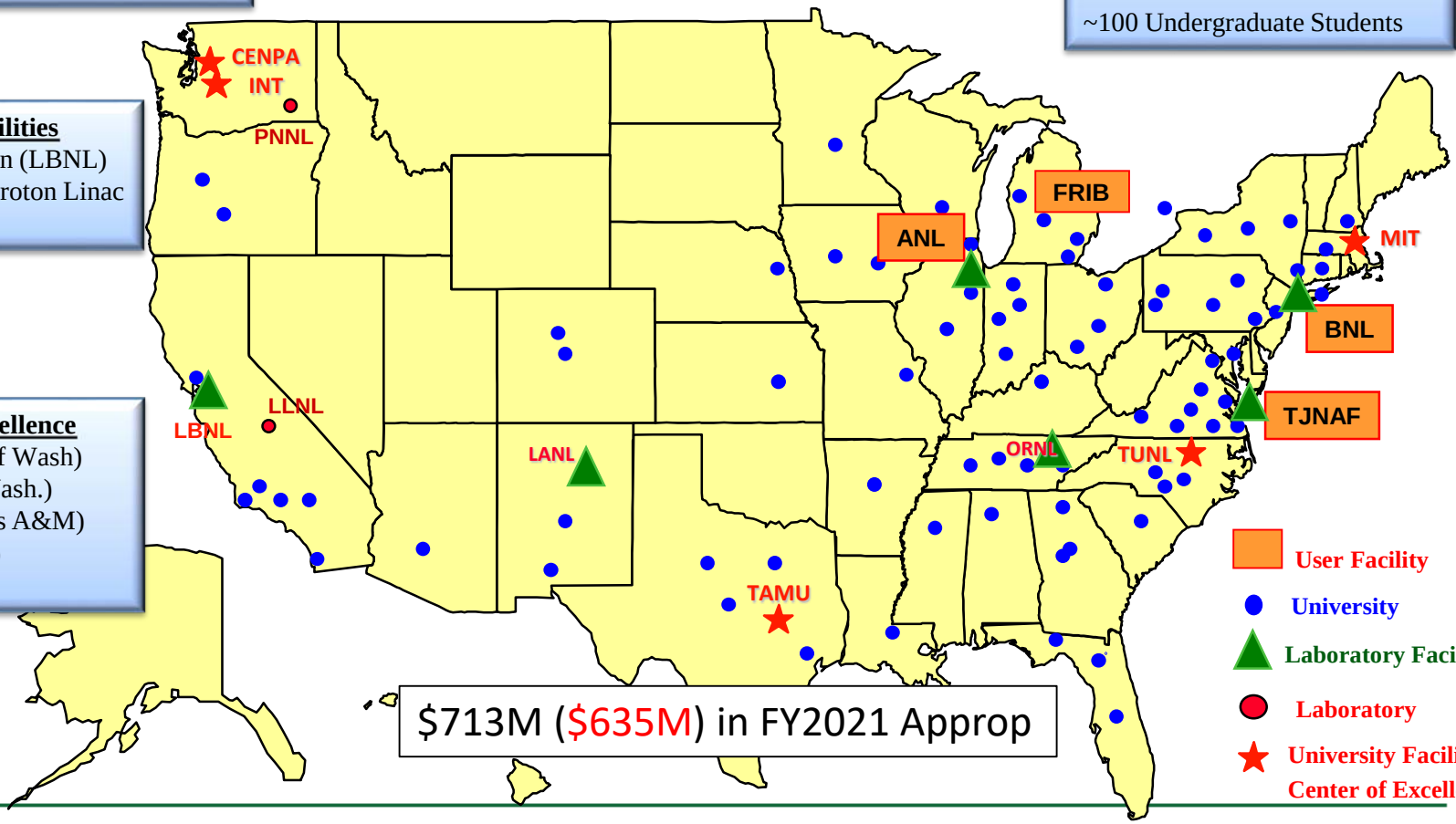
National User Facilities ~3,500 users
- RHIC (BNL)
- CEBAF (TJNAF)
- ATLAS (ANL)
- FRIB (MSU)

Research Groups
- 8 National Laboratories
- 93 Universities

NP Workforce
~840 Faculty & Lab Res Staff
~380 Post-docs
~500 Graduate Students
~900 Lab technical/admin
~100 Undergraduate Students

Other Lab. Facilities
- 88-Inch Cyclotron (LBNL)
- 200 MeV BNL Proton Linac (BNL)

Centers of Excellence
- CENPA (U. of Wash)
- INT (U. of Wash.)
- TAMU (Texas A&M)
- TUNL (Duke)
- REC (MIT)



$713M ($635M) in FY2021 Approp

Important to Know About DOE SC/NP:

Like all Federal Offices, SC/NP is very diligent about its mission both in terms of:

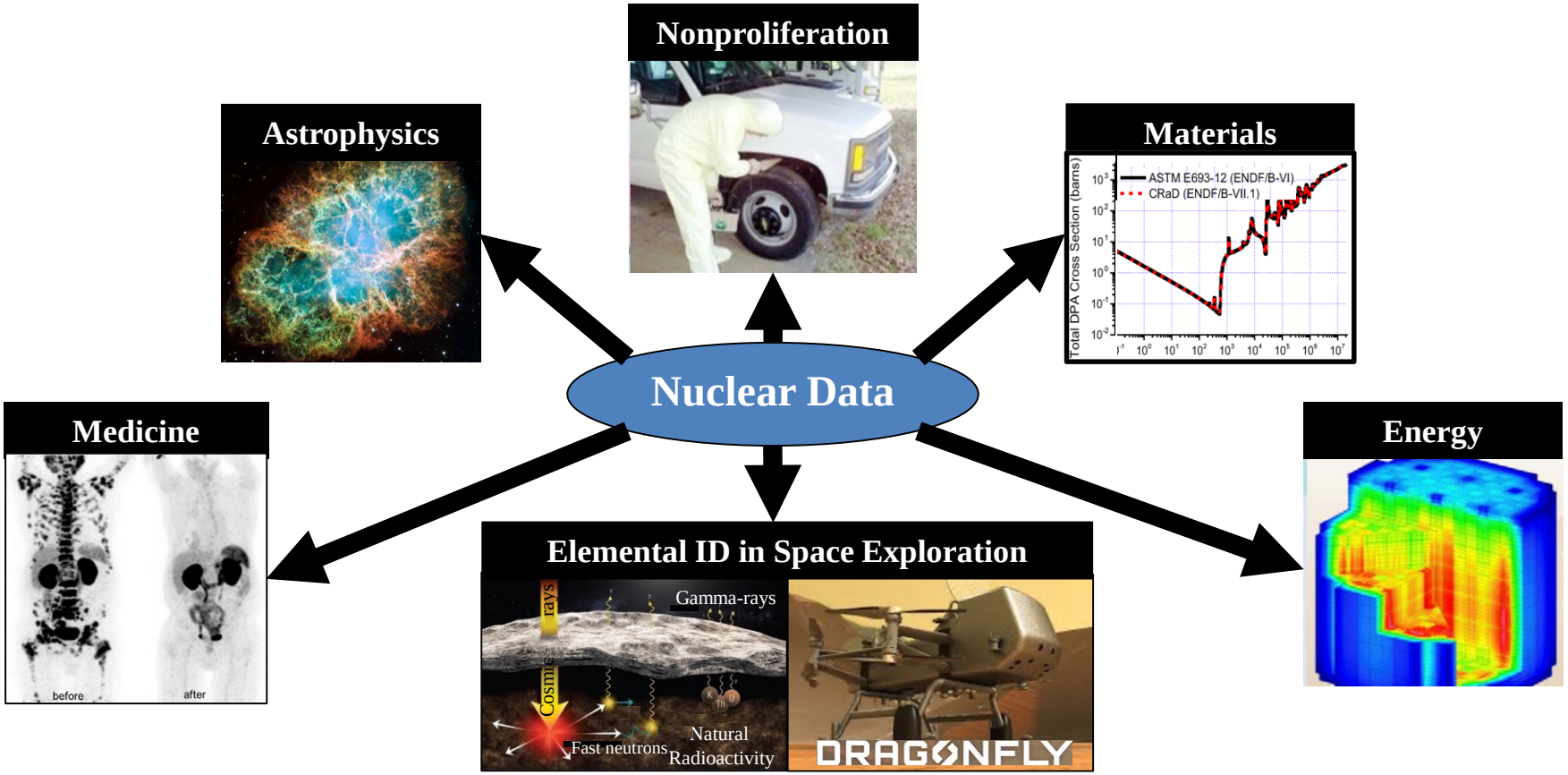
- Doing everything possible to ensure its success
- Staying in its lane

SC/NP is very appreciative when the knowledge it creates or capabilities it supports can be leveraged for applications with societal benefit

BUT, it can not directly fund applied R&D

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

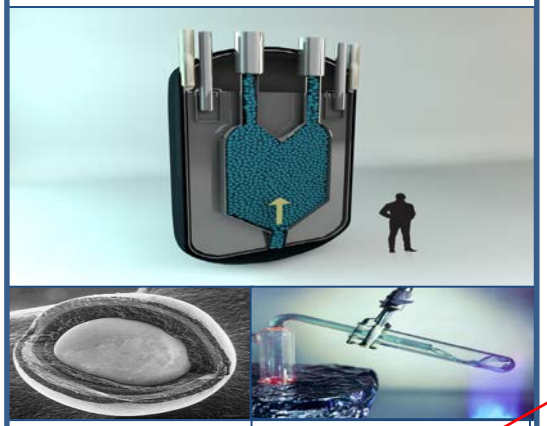
In Support of Clean Energy Goals

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

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

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

Kairos FHR

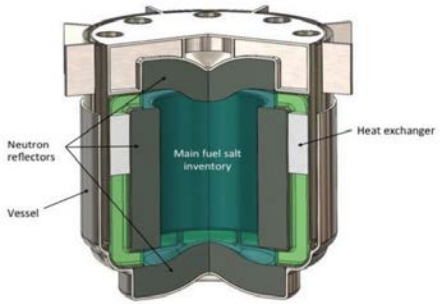


TRISO Pebble Fuel (U,C,Si)

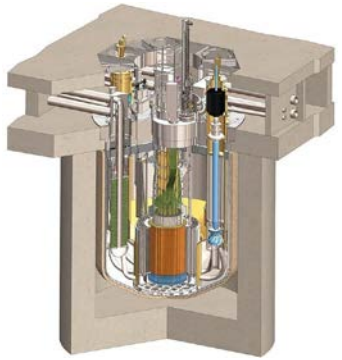
Molten Salt Coolant (Flibe)

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

Terrapower

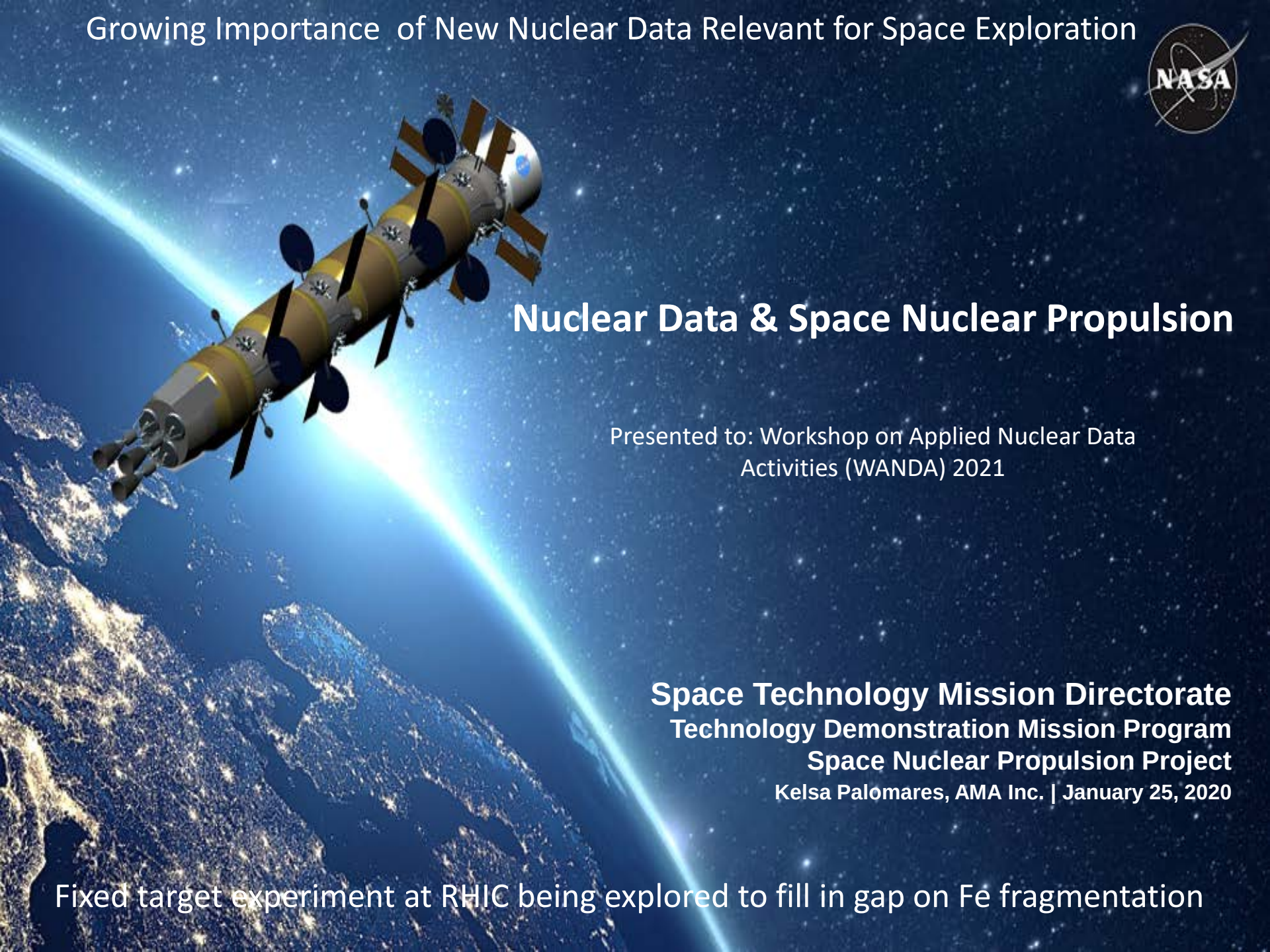


MCFR (Cl)



SMR (Na)

Growing Importance of New Nuclear Data Relevant for Space Exploration



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

Fixed target experiment at RHIC being explored to fill in gap on Fe fragmentation

In both cases, DOE NP creates new knowledge essential for other missions, but in neither case is it using appropriated funds for applied R&D outside its own mission

The Next Super High Current, "High" Energy Microscope: The Facility for Rare Isotope Beams (>96% Complete)

FRIB will increase the number of known isotopes from ~2,000 to ~5,000 and will enable world-leading research on:

Nuclear Structure

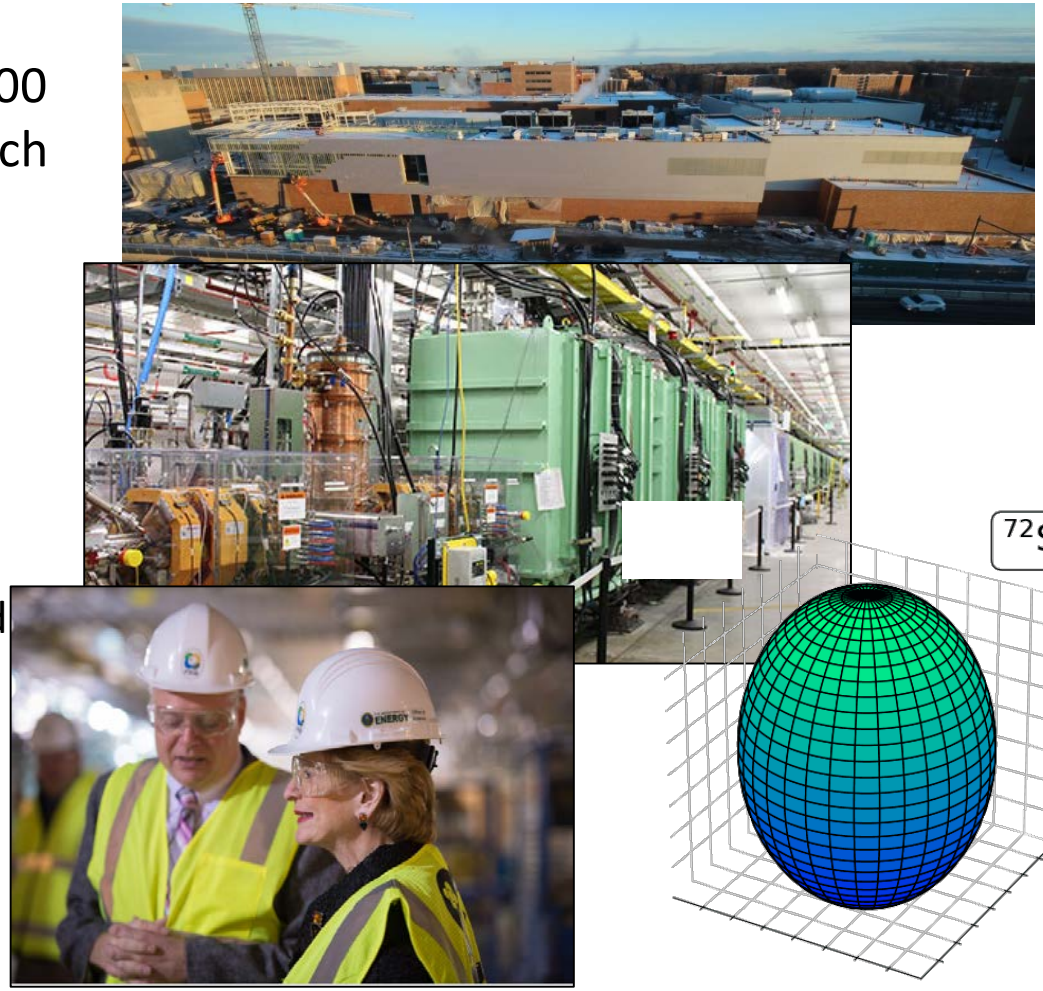
- The limits of existence for nuclei
- Nuclei that have neutron skins
- Synthesis of super heavy elements

Nuclear Astrophysics

- The origin of the heavy elements and explosive nucleo-synthesis
- Composition of neutron star crusts

Fundamental Symmetries

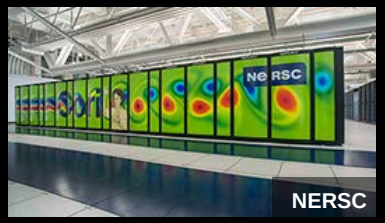
- Tests of fundamental symmetries, Atomic EDMs, Weak Charge

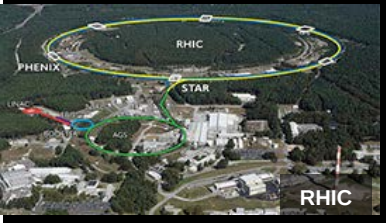


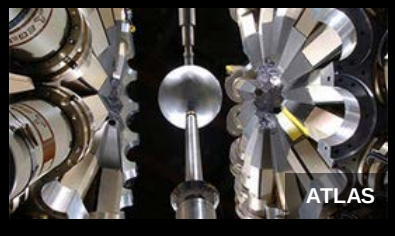
	PYs	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	DOE Total	MSU	TOTAL
FUNDING PROFILE	318,000	100,000	97,200	75,000	40,000	5,300	635,500	94,500	730,000

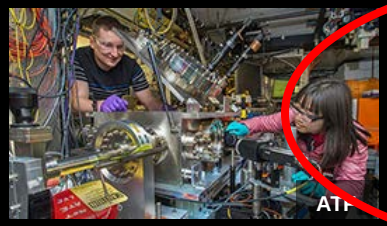
Office of Science User Facilities

Number of User Facilities
28









FRIB's (Already Busy) Status

- FRIB is approximately 96% complete and continues on cost and schedule, with a target early completion of December 2021.
- FRIB received its final construction funding of $5.3M in FY 2021
- The Gamma Ray Energy Tracking Array (GRETA) Major Item of Equipment (MIE) and the High Rigidity Spectrometer (HRS), both are included in the FY 2021 appropriation
- The FY2021 appropriation includes $50M for FRIB operations.
- In preparation for early science, the FRIB Directorate recently issued a call for proposals to its 1500 member user group.
- In response to the call, 82 proposals from 130 institutions in 30 countries were received requesting 9,784 hours of beam time
- A first FRIB Program Advisory Committee Meeting to advise on proposal selection will be held in May 2021.

1,500 Users Engaged and Ready for Science
fribusers.org

- Users organized as part of independent FRIB Users Organization (FRIBUO)
  - Chartered organization with an elected executive committee
  - 1,500 members (121 U.S. colleges and universities, 13 national laboratories, 53 countries) as of 31 August 2020
  - 19 working groups on instruments

- On track for first experiments
  - May 2020: FRIB First Experiments - Proposal Preparation workshop (1)
  - Nov 2020: FRIB First Experiments - Proposal Preparation workshop (2)
  - Dec 2020: Call for Proposals
  - May 2021: FRIB Program Advisory Committee (PAC 1)
  - Early 2022: first user experiments

- User needs and high user satisfaction are important to FRIB
  - ISO 9001 quality systems to assess user satisfaction
- Annual meetings
  - User meeting (three days with 200-300 participants)
    - » Most recent meeting August 2020 (online)

First Physics Spring of 2022

Report Coming from Andreas Stoltz at This Meeting

SEE Efforts at the FRIB Laboratory

- FRIB Linac Segment (LS) 1 SEE Beamline (<45 MeV/u)
  - Addition a SEE beamline to the FRIB DOE-SC user facility, supporting the mission of DTRA and the SEE community without adverse impact on the DOE-SC mission for FRIB
  - Contract discussions underway – can technically be operational in 2021
- FRIB Linac Segment 3 SEE Beamline (>100 MeV/u)
  - Possibility to provide High-Energy SEE testing
  - Could move LS1 SEE Beamline to LS3, or duplicate LS1 beamline
- K500 Cyclotron (<70 MeV/u)
  - K500 was completely refurbished for CCF project (2001)
  - Starting to plan SEE beamline – can be operational in 2022/23, depending on scope and contract instrument
- K1200 Cyclotron (>100 MeV/u)
  - Needs to be refurbished after technical evaluation
  - Cost effectiveness evaluation needed – 2023

FRIB Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

A. Stolz, 2021 High-Energy SEE Testing User Meeting, Slide 3

SEE Testing at FRIB

From FRIB Management: FRIB has responded to an RFP to add a beamline to FRIB LS1 (open to all FRIB users, full cost recovery for proprietary users such as SEE)

NP is pleased that the capabilities provided for basic research at FRIB can be leveraged for other missions

BUT, aside from ensuring FRIB operates within the envelope for a DOE National User Facility:

- NP's only official role related to SEE testing at FRIB is to stay informed and ensure the core NP mission is not compromised.
- All other SEE considerations are the remit of Michigan State University

The Texas Cyclotron Institute at Texas A&M

Is not an NP National User Facility

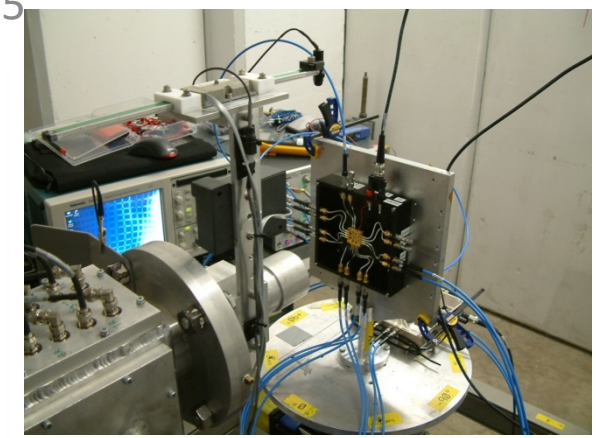
Is an NP Center of Excellence which gets significant funding from NP for nuclear science research, as well as funding from Texas and the Welch Foundation

NP is pleased that the capabilities provided for basic research at TAMU can be leveraged for other missions

BUT, aside from ensuring TAMU operates safely and effectively:

- NP's only official role related to SEE testing at TAMU is to stay informed and ensure the core NP mission is not compromised.
- All other SEE considerations are the remit of Texas A&M University

Texas A&M Cyclotron Institute



SEE Testing at TAMU

K500
15 MeV/u

TEXAS A&M UNIVERSITY

K150
15 MeV/u

Ion	Mass (amu)	A MeV	Total Energy (MeV)	Range in Si (μm)	Range to Bragg Peak (μm)	Initial LET (vac)	Initial LET (air)	LET at Bragg Peak
^{4}He	4.003	15	60	1449	1446	0.10	0.10	1.4
^{14}N	14.003	15	210	422	418	1.3	1.3	6.1
^{20}Ne	19.992	15	300	311	302	2.5	2.6	9.0
^{40}Ar	39.962	15	599	231	217	7.6	7.9	13.6
^{63}Cu	62.930	15	944	174	151	17.1	18.0	34.0
^{84}Kr	83.912	15	1259	170	149	25.4	26.6	41.4
^{109}Ag	108.905	15	1634	149	113	40.0	42.3	59.4
^{129}Xe	128.905	15	1934	146	107	50.4	53.1	69.3
^{141}Pr	140.908	15	2114	154	99	55.8	58.4	70.8
^{165}Ho	164.930	15	2474	151	102	67.0	69.6	82.3
^{181}Ta	180.948	15	2714	159	111	72.3	74.8	87.7
^{197}Au	196.967	15	2954	159	108	78.0	80.5	94.4

He – Xe (LETs 1 – 69)

Most Requested

~2800 hrs of 4000 hrs Annually

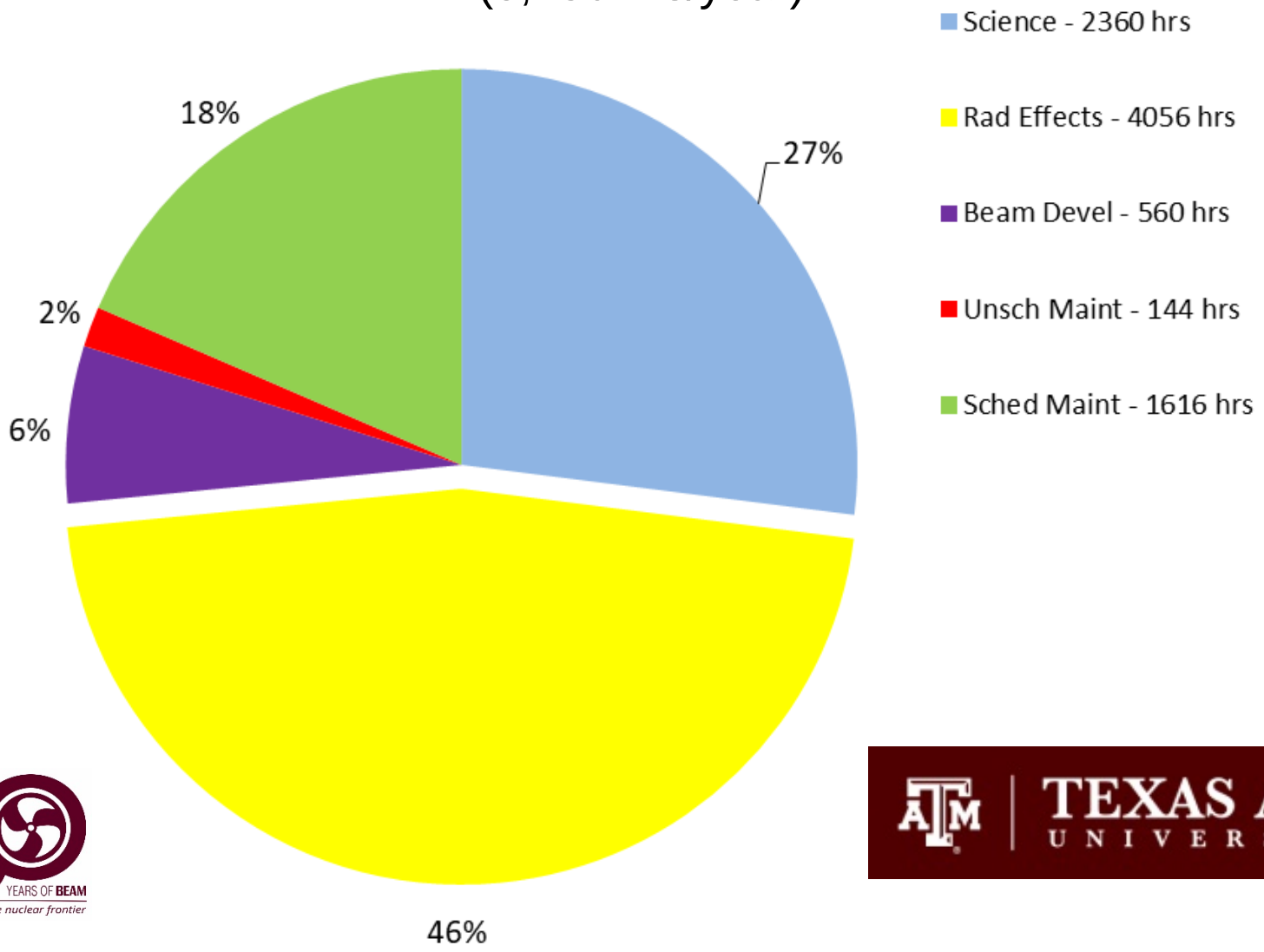
Can Currently Provide He – Kr (LETs 1 – 41)

K150 Needs Improvements in order to make Ag, Xe for LETs to 69

1967 - 2017 50 YEARS OF BEAM exploring the nuclear frontier

Year 2019 K500 Operational Hours

(8,736 hrs/year)

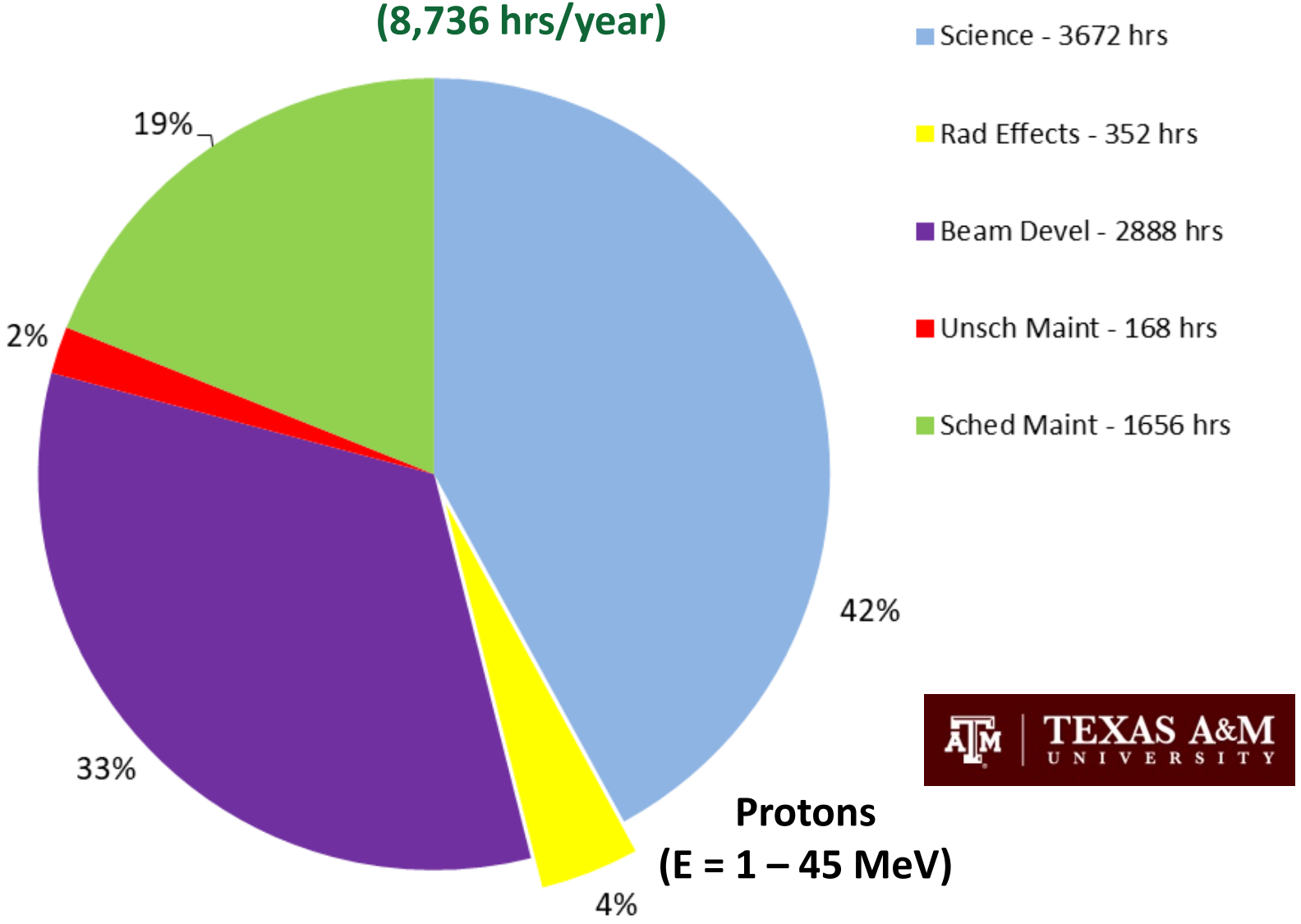


1967 - 2017 50 YEARS OF BEAM exploring the nuclear frontier

TEXAS A&M UNIVERSITY

Year 2019 K150 Operational Hours

(8,736 hrs/year)



Protons
(E = 1 – 45 MeV)

1967 - 2017 50 YEARS OF BEAM exploring the nuclear frontier

TEXAS A&M UNIVERSITY

TAMU 2020 Retrospective

- 2020 was a challenging year for Cyclotron operations,
- The cyclotron was granted an exception as an essential service which enabled running and delivering SEE beams even though the science program was paused
- Operations were challenged by key senior staff needing to work remotely which slowed recovery from glitches
- The 25+ year old ECR on the K500 sprung a fatal leak late in the fall so that SEE beams available for the end of 2020 were limited. In the end TAMU delivered > 3500 hours of SEE beams in 2020.

LBNL BASE Facility Layout & Capabilities

Heavy Ions, Low Energy Protons, Microbeams

Cave 4B

Standard Cocktail Beams:
4.5, 10, 16, & 20 AMeV — available in air

Low Energy Protons:
1-10 MeV

88 BASE Facility Beams:

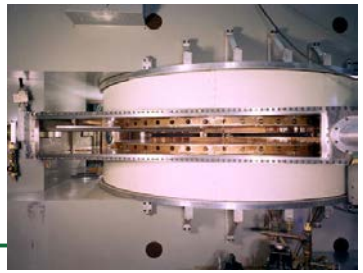
- Heavy Ions
- Light Ions
- Protons
- Low Energy Protons
- Neutrons
- Microbeams

available in-air

Cave 0

Neutrons:
8-30 MeV

Cyclotron



Light Ions, Protons

Cave 4A

Standard Proton Beams:
10-60 MeV

Light Ion Cocktails:
30 and 32.5 AMeV — available in-air

SEE Testing at LBNL

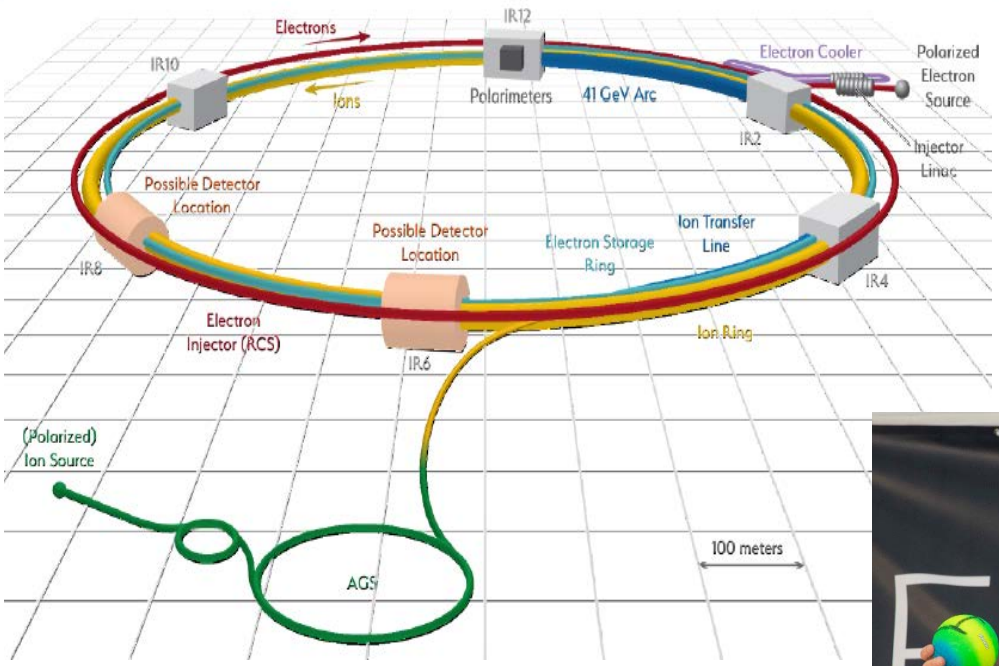
- 2020 was a challenging year for operations at the 88 inch cyclotron at LBNL due to COVID, CA wildfires, and a failed cooling tower
- Fixing the cooling tower was made an Laboratory "Notable Outcome"
- The interruption is regrettable but should not be taken as an indication of general reliability which has typically been good.
- NP is exploring possibilities with LBNL to recoup as many of the lost hours as possible
- LBNL staff have to be paid regardless

Other Remarks

One thing that NP brings to the table is the ability, developed over the last century, to design, build, and operate the most advanced accelerators in the world

A case in point: the Electron-Ion Collider

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.

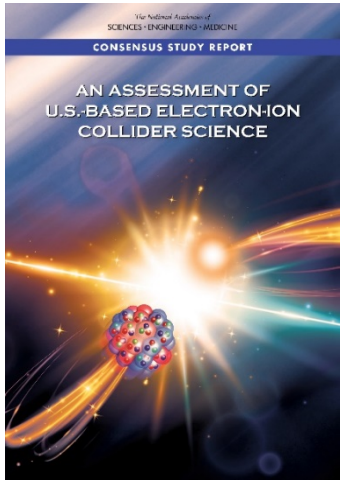
EIC scope includes the machine upgrade to RHIC asset and two interactions regions with one of the interaction regions outfitted with a major detector. Working towards CD-1 in Q3 FY 2021

EIC Dedication September 18, 2020

The EIC will be a game-changing resource for the international nuclear physics community. *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.*

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

The Discovery Horizon in Nuclear Science

Neutron-rich Nuclei;
Structure Of Nuclei;

Reactions in Core Collapse Super Novae;

Super Heavy Element 117
Heavy Nuclei Formation;
Density Effects in Nuclei;
Neutron Skins;

Nuclear-Reactions;

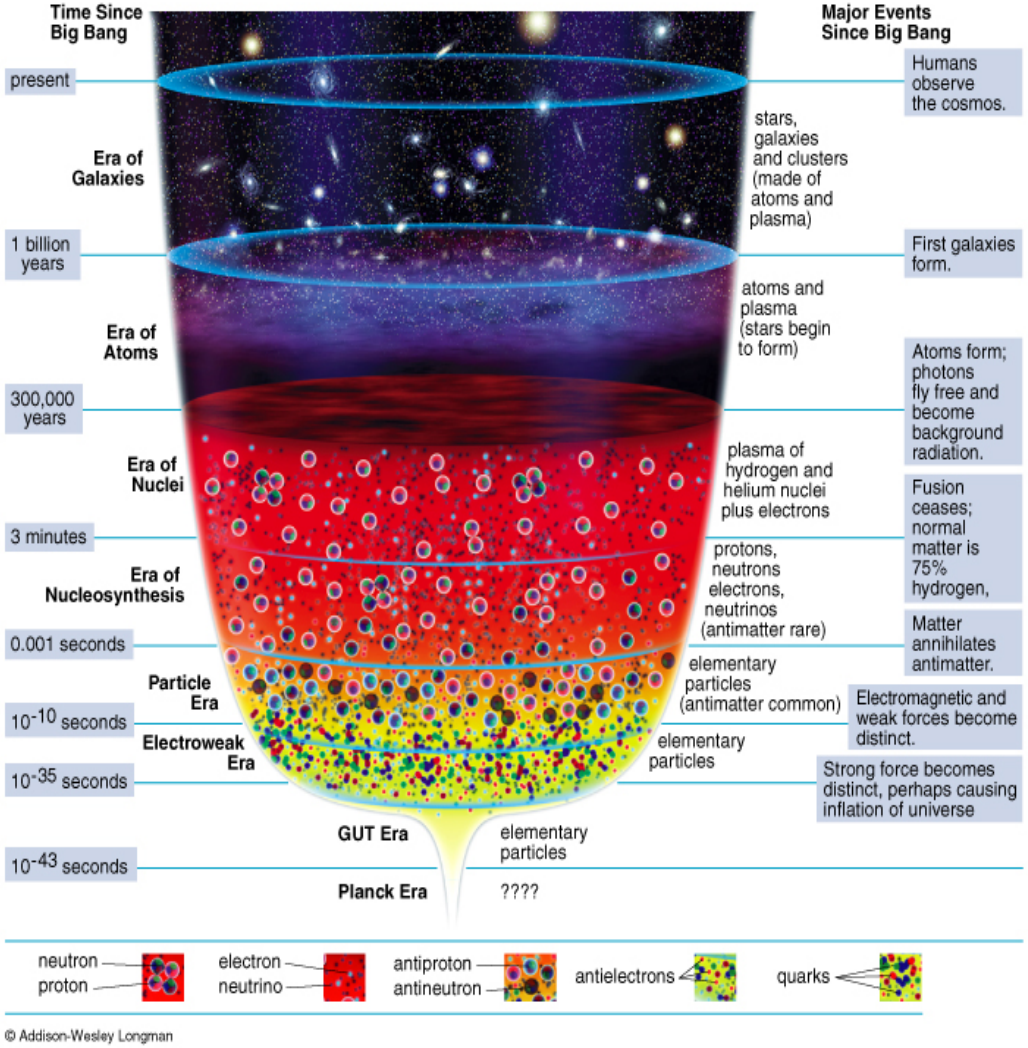
NP Discovery Horizon

Anti-Helium 4;
Proton Spin
Majorana/DIRAC Neutrino;
Perfect QGP Liquid

Neutron Beta Decay;
Neutron EDM;
Parity Violation
Searches;

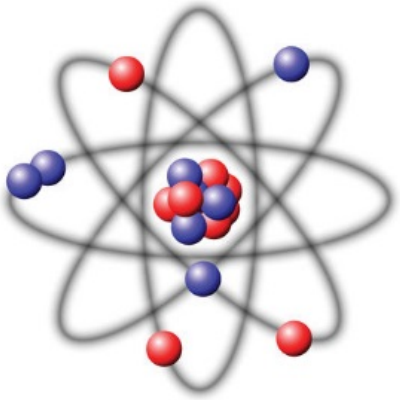
HEP Focus

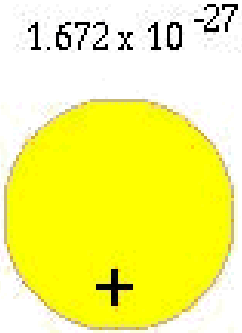
Evolution of the Universe

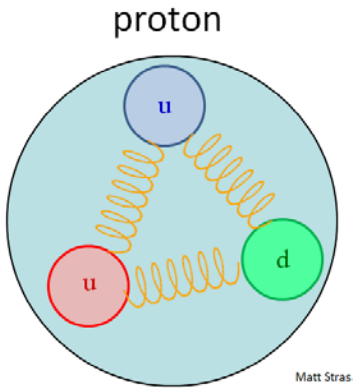


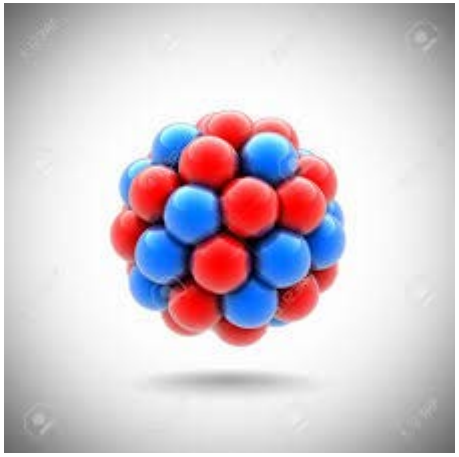
Addressing the Broad Focus of Nuclear Physics

What you "see" depends on the "power" of your microscope

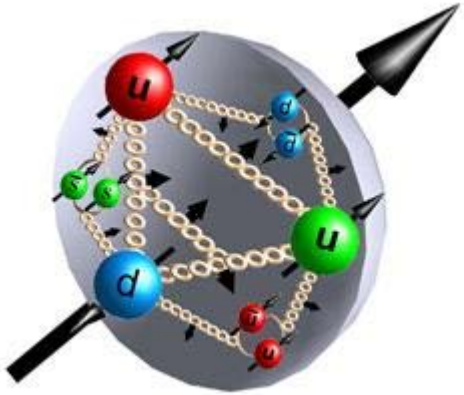




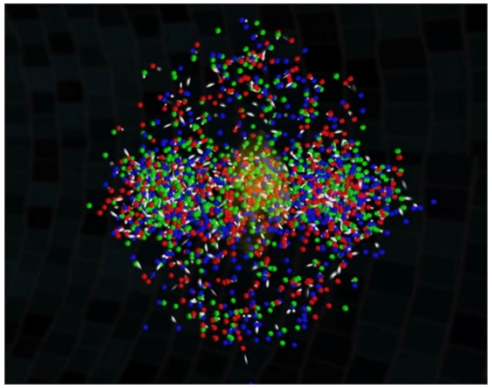




What combinations are possible and how are they made?

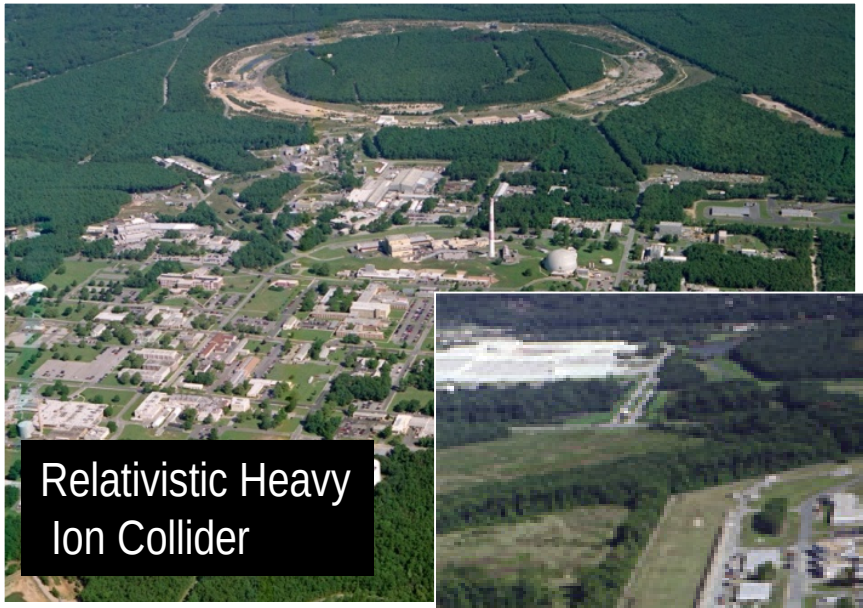


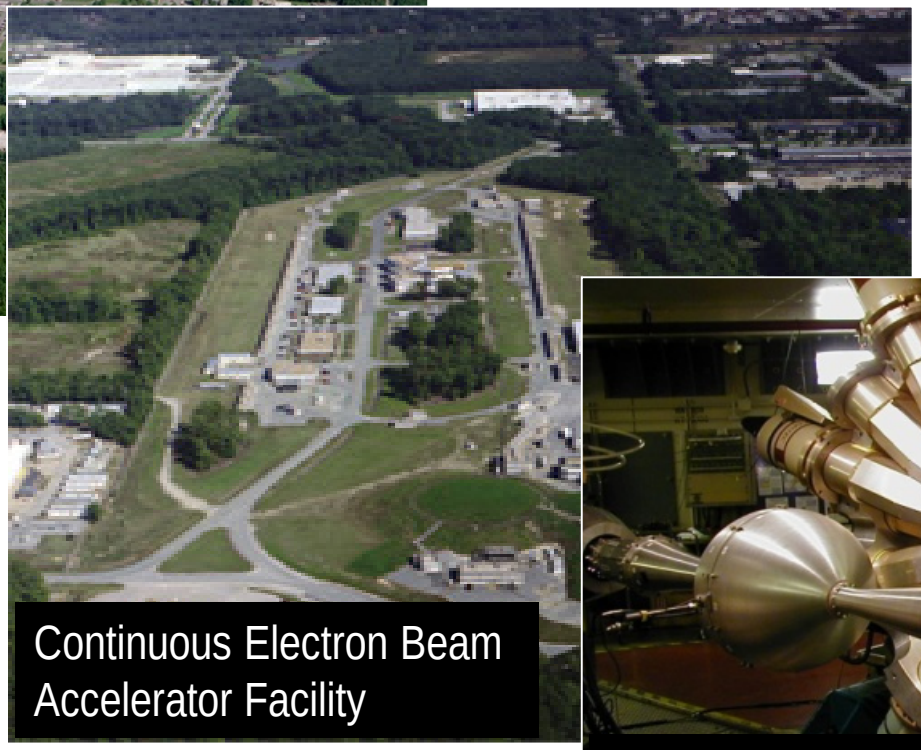
What's Inside the proton?

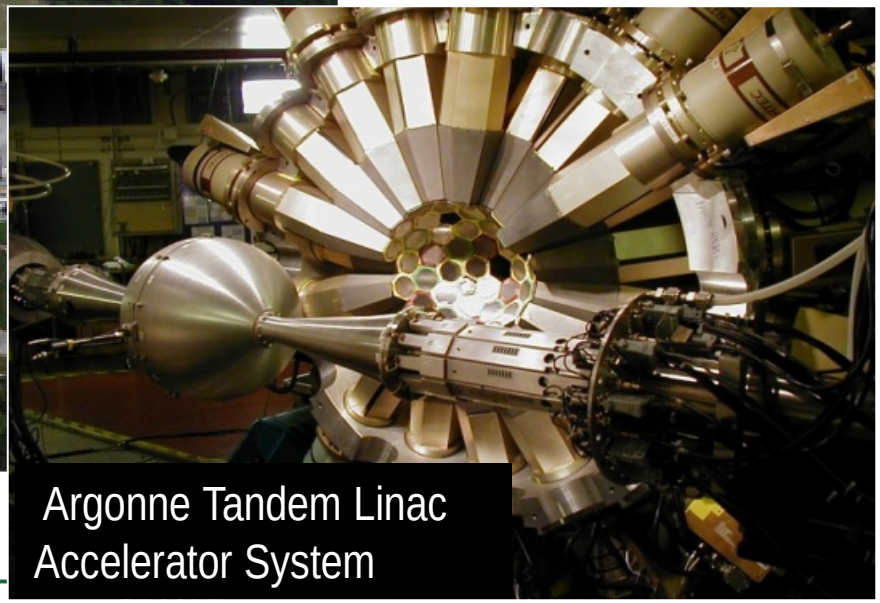


How did protons condense from the quarks/gluons in the early universe?

Additional NP National User Facilities







"Microscopes" pursuing groundbreaking research

Should the SEE community decide at some point that a dedicated facility is needed, and its requirements can not be achieved with off-the-shelf solutions, leveraging the experience in SC in building and operating state-of-the-art accelerators would prove useful.

- Progress is ongoing in NP in Quantum Information Science (QIS) which is also of prime interest for Quantum Computing (electronics) and Quantum Communications.

- The next slide is about a discovery NP made that naturally occurring radiation (e.g. cosmic rays from space) are detrimental to efforts to make electronics for quantum computing

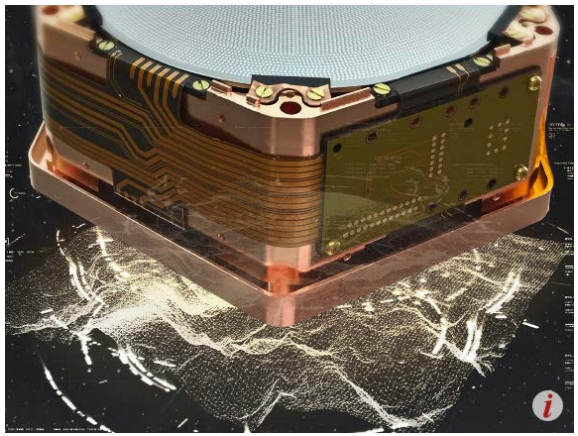
A Landmark Study Published in Journal Nature

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"

Additional Remark

- A long-standing personal belief (also an NAS recommendation):
  - ➢ That SEE testing activity would benefit greatly from increased simulation and modeling of components in extreme environments
- HEP and NP do this kind of activity a lot for electronics that has to reside in extreme radiation environments
- The fleet of SC leadership computers as well as an anticipated SC initiative on microelectronics will provide exciting opportunities in this regard.

A Recognized Challenge

COMMITTEE ON SPACE RADIATION EFFECTS TESTING INFRASTRUCTURE FOR THE U.S. SPACE PROGRAM

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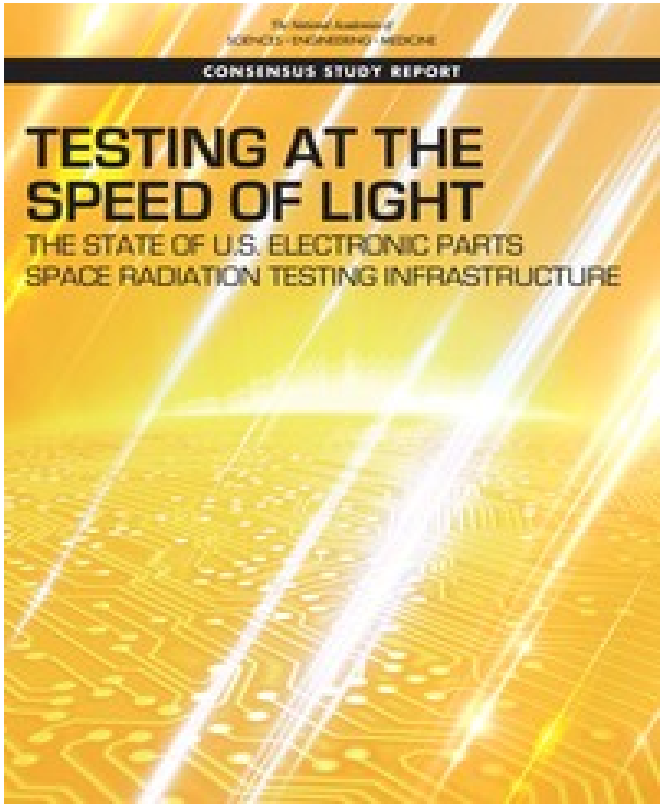
LEONARD ROCKETT, Technology Metrics, LLC RON TURNER, Analytic Services



There is still very considerable work to do to claim any progress on four of the five NAS recommendations

Among the challenges…..

- Different cultures
- Competing internal and external priorities
- Different funding mechanisms
- Different business models
- Different missions
- ……..

Even so, it is in all of our interest to figure things out ourselves, together

Final Observations

The “restaurant problem in a pandemic” continues…

“Restaurant chains are dying…”

- There is a fixed cost to setting the table for a banquet of opportunities—whether the customers come out or not
- If the amount of business does not justify/cover the fixed cost, maintaining the opportunity is not sustainable

Additional Information

NB: Costs at National Labs are greater than at universities in order to maintain mission readiness for complex infrastructure. For example, the multiplier on fully loaded labor at labs is generally in the vicinity of 2.5 versus 1.5 at a university.

Outlook at Relevant DOE Sites

BNL RHIC/NSRL/BLIP	Continued Operation: Mission QCD Research; Isotopes; Space Radiation Effects (Human and SEE) RHIC & BLIP Operations Primarily DOE Funded NSRL: Full Cost Recovery from NASA
LBNL 88 Inch Cyclotron	Continued Operation: Mission Super-Heavy Elements; SEE testing DOE support; MDA, NASA Fee for Service Funding
Texas A&M	Continued Operation: Mission NP Research SEE testing DOE Base funding, Welsh Foundation Funding, NNSA funding, Texas Funding, SEE Fee for Service Funding
LANL IPF	Continued Operation: Mission Isotopes DOE Base Funding
HFIR ORNL	Continued Operation: Mission Neutron Science & Isotopes DOE base Funding

Additional Facilities:

JLAB	Continued Operation: Mission QCD Research; Primarily DOE Funded
Facility for Rare Isotope Beams	Continued Operation: Mission QCD Research; Isotopes; Primarily DOE Funded

Short Summary: All operating Facilities will continue to operate for as far as the eye can currently see, although it is possible over time the scope of operations at some facilities may potentially be tailored depending evolving mission needs