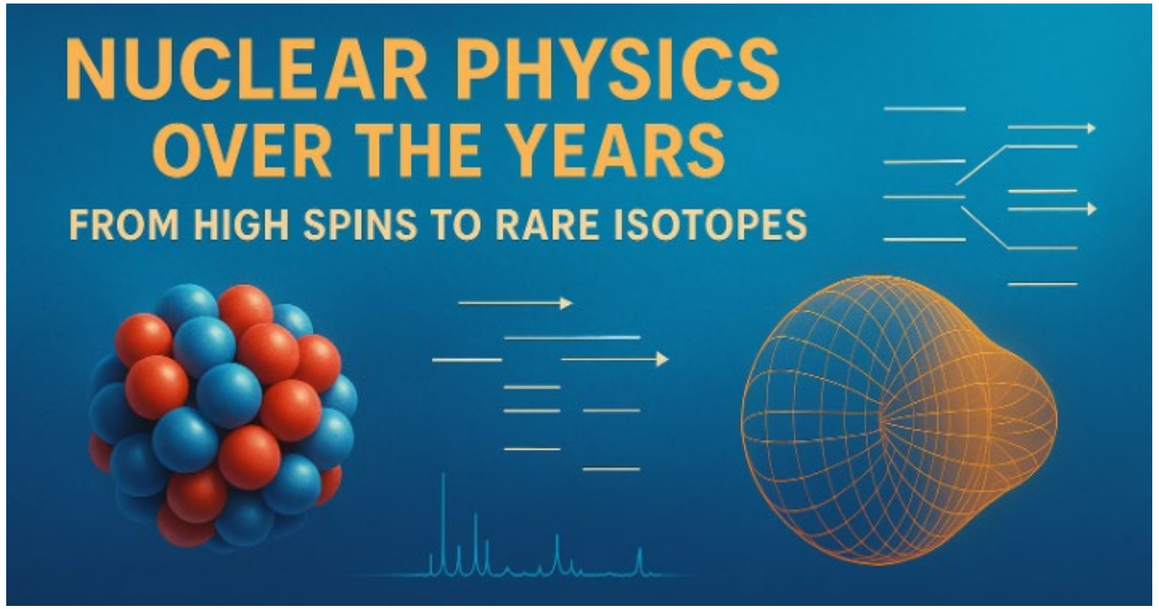


Celebrating the Career and Contributions of Robert V. F. Janssens

Building the Facility for Rare Isotope Beams

Thomas Glasmacher, FRIB Laboratory Director

19 September 2025

MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT of ENERGY | Office of Science

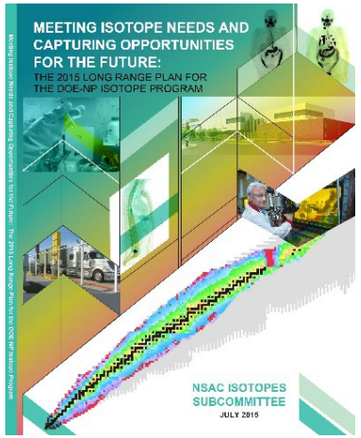
This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and used resources of the Facility for Rare Isotope Beams (FRIB) Operations, which is a DOE Office of Science User Facility under Award Number DE-SC0023633.

Facility for Rare Isotope Beams is Operating as a DOE-SC User Facility

- FRIB is a scientific user facility funded by the Department of Energy Office of Science (DOE-SC), Michigan State University, and the State of Michigan
  - FRIB Project started in 2008, delivered on budget, ahead of schedule in 2022
  - MSU operates FRIB for DOE-SC, with financial support from and furthering mission of DOE-SC Office of Nuclear Physics
- FRIB enables scientists to make discoveries about the properties of these rare isotopes in order to better understand the physics of nuclei, nuclear astrophysics, fundamental interactions, and applications for society
- As a community, we are privileged to have the public trust allowing us to build large science machines

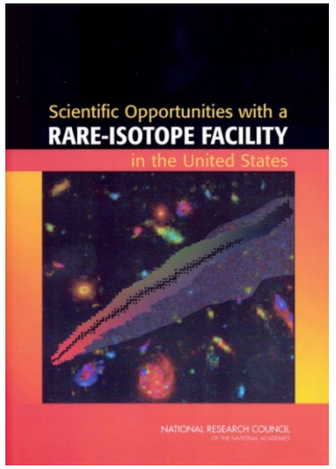
As a Community we Develop National Priorities and FRIB Needs to Deliver on National Priorities

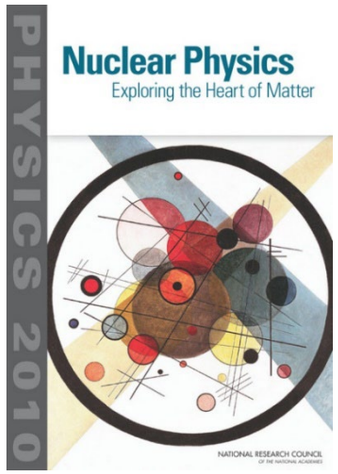
- DOE/NSF Nuclear Science Advisory Committee (NSAC)
  - *DOE-SC Isotope Long Range Plan* (2015)
    - » Recommendations related to FRIB include:
      - ✓ Implement isotope harvesting at FRIB

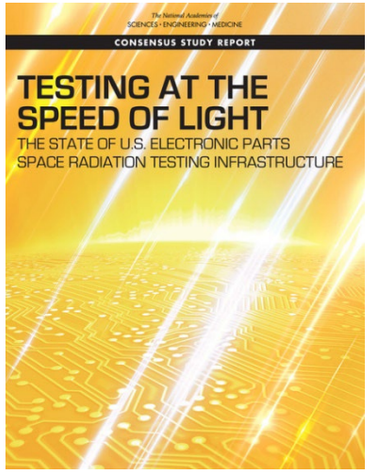


- *A New Era of Discovery: The 2023 Long Range Plan for Nuclear Science (2023)*
  - » Recommendations related to FRIB include:
    - High Rigidity Spectrometer (HRS)
    - FRIB400 energy upgrade
    - Support for core research

- National Academy Studies
  - *Scientific Opportunities with a Rare-Isotope Facility (2007)*
  - *Nuclear Physics (2013)*
  - *Testing at the Speed of Light (2019)*
    - ✓ FSEE beamline
    - ✓ K500 SEE beamline
    - Chip-testing capacity and capability





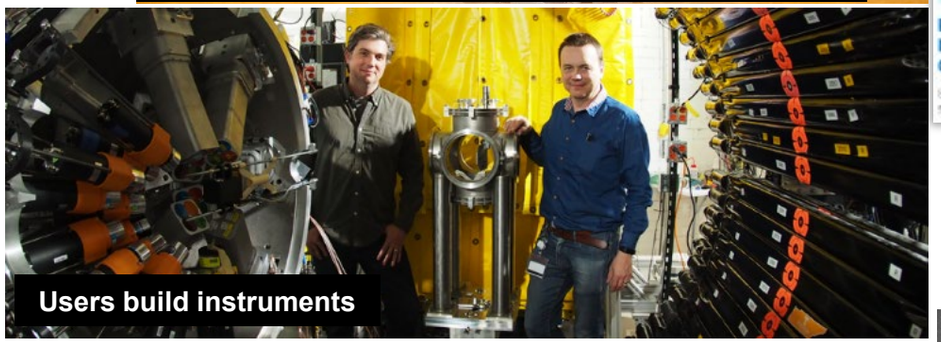


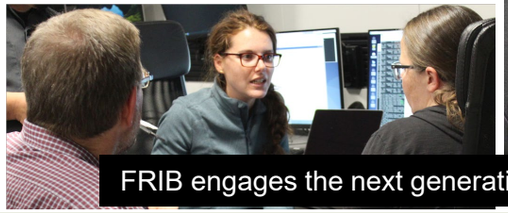
And we need to communicate how nuclear science is of benefit to the public who funds us

1,800-Strong Engaged and Active User Community
fribusers.org

- Users organized and active in FRIB as part of independent FRIB Users Organization (FRIBUO)
  - Chartered organization with elected executive committee
  - As of 1 September 2025, FRIBUO has 1,813 members from 50 countries, including:
    - » 140 U.S. colleges and universities
    - » 13 national laboratories (over one-third of approved experiments include a national lab spokesperson)
    - » 38 U.S. states
  - 22 working groups engaging in FRIB science and instrumentation
- Published results at frib.msu.edu/publications
- Results receiving press coverage
  - DOE-SC maintains list of 'tier 1' media outlets of interest
  - FRIB uses Cision media monitoring service to track reach of media coverage
  - In last year, approximately $1.7B people potentially saw FRIB-related content, according to Cision.com

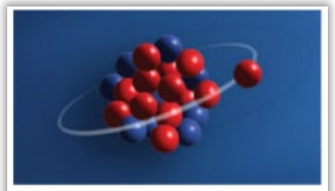

2025 Annual Community Meeting at Texas A&M University


Users build instruments

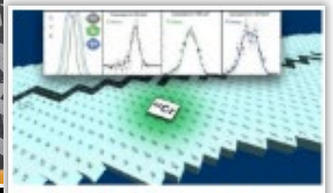

FRIB engages the next generation of scientists


First Science Results from FRIB Published

Researchers have published the results from the first experiment at the Facility for Rare Isotope Beams, measurement of 5 new half-lives, in Physical Review Letters.


Researchers Obtain the First High-Precision Mass Measurement of Aluminum-22

The Facility for Rare Isotope Beams enables a high-precision mass measurement at the edge of the nuclear chart.


Experiment Reveals Competing Nuclear Shapes in the Rare Isotope Chromium-62

Successfully modeling chromium-62 nuclei in an interesting structure for neutron-laden calcium-60.


nature physics

News & Views | Published: 12 December 2024

Radioisotopes

Into the islands of inversion

Anna Corsi

Nature Physics 21, 3–4 (2025) | Cite this article

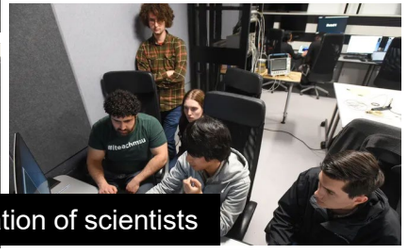
Tier 1 outlets cover results


FEBRUARY 27, 2024 | 5 MIN READ

Weird Lab-Made Atoms Hint at Heavy Metals' Cosmic Origins

Researchers have created ultraheavy versions of elements that have never existed before on Earth

SCIENTIFIC AMERICAN



Scientists with Experiments at FRIB Produce High-impact Results

Featured in Physics | Editors' Suggestion

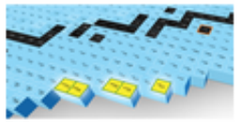
Phys. Rev. Lett. 132, 072501 (2024)

Observation of New Isotopes in the Fragmentation of ^{198}Pt at FRIB

O. B. Tarasov, A. Gade, K. Fukushima, M. Hausmann, E. Kwan, M. Portillo, M. Smith, D. S. Ahn, D. Bazin, R. Chyzh, S. Giraud, K. Haak, T. Kubo, D. J. Morrissey, P. N. Ostroumov, I. Richardson, B. M. Sherrill, A. Stolz, S. Watters, D. Weisshaar, and T. Zhang

Phys. Rev. Lett. **132**, 072501 (2024) – Published 15 February 2024

Physics: Five New Isotopes Is Just the Beginning



Less than a year after its opening, the Facility for Rare Isotope Beams produced five never-before-seen isotopes for observation, a success that researchers say highlights the discovery potential of the facility.

nature physics

Article

https://doi.org/10.1038/s41567-024-02680-0

In-beam spectroscopy reveals competing nuclear shapes in the rare isotope ^{62}Cr

Received: 17 March 2024

Accepted: 24 September 2024

Published online: 18 October 2024

Check for updates

Alexandra Gade[1,2] ✉, Brenden Longfellow[3], Robert V. F. Janssens[4,5], Duc D. Dao[6], Frédéric Nowacki[6], Jeffrey A. Tostevin[7], Akaa D. Ayangeakaa[4,5], Marshall J. Basson[1,2], Christopher M. Campbell[8], Michael P. Carpenter[9], Joseph Chung-Jung[1,2], Heather L. Crawford[8], Benjamin P. Crider[10], Peter Farris[1,2], Stephen Gillespie[1], Ava M. Hill[1,2], Silvia M. Lenzi[11], Shumpei Noji[1], Jorge Pereira[1], Carlotta Porzio[8], Alfredo Poves[12], Elizabeth Rubino[1] & Dirk Weisshaar[1]

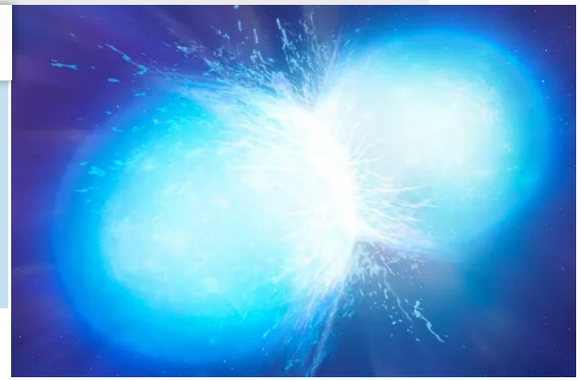
- Recent publication unravels unusual properties of rare isotopes and challenges traditional view of nuclei

FEBRUARY 27, 2024 | 5 MIN READ

Weird Lab-Made Atoms Hint at Heavy Metals' Cosmic Origins

Researchers have created ultraheavy versions of elements that have never existed before on Earth

SCIENTIFIC AMERICAN



FRIB made 5 never-before-seen isotopes of the elements thulium, ytterbium, lutetium

Includes researchers from RIKEN in **Japan**, IBS in **South Korea**, and MSU in the **U.S.**

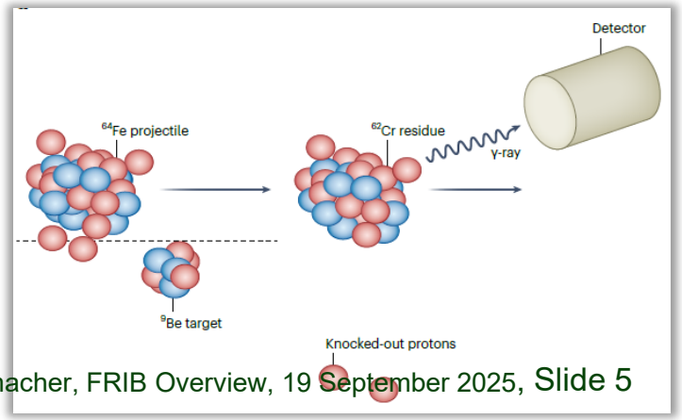
News & views

Radioisotopes

Into the islands of inversion

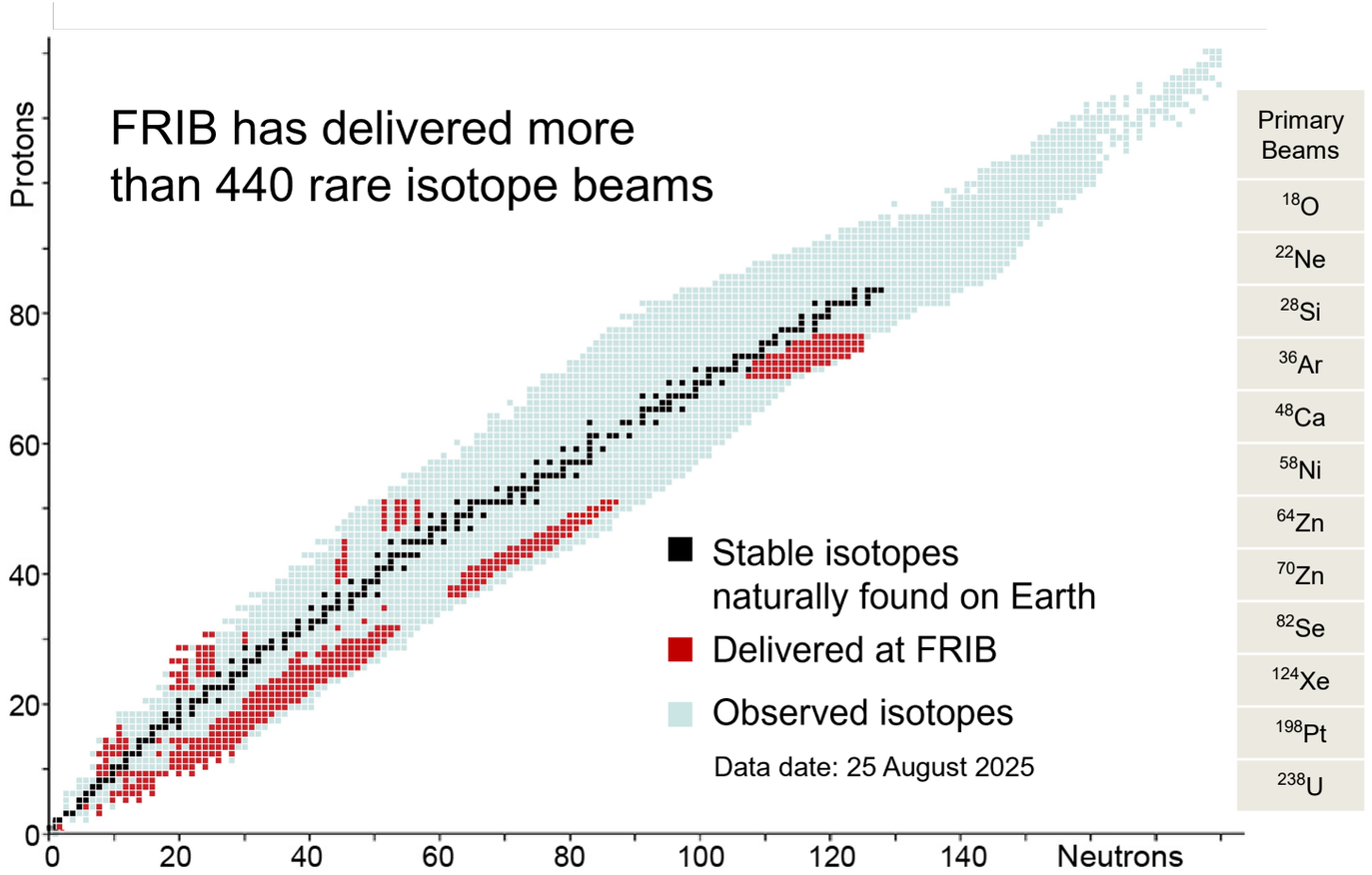
Anna Corsi

In systematic studies of radioactive isotopes, the so-called islands of inversion appear to be promising areas of the nuclear chart in which to look for phenomena that challenge the traditional description of the atomic nucleus.



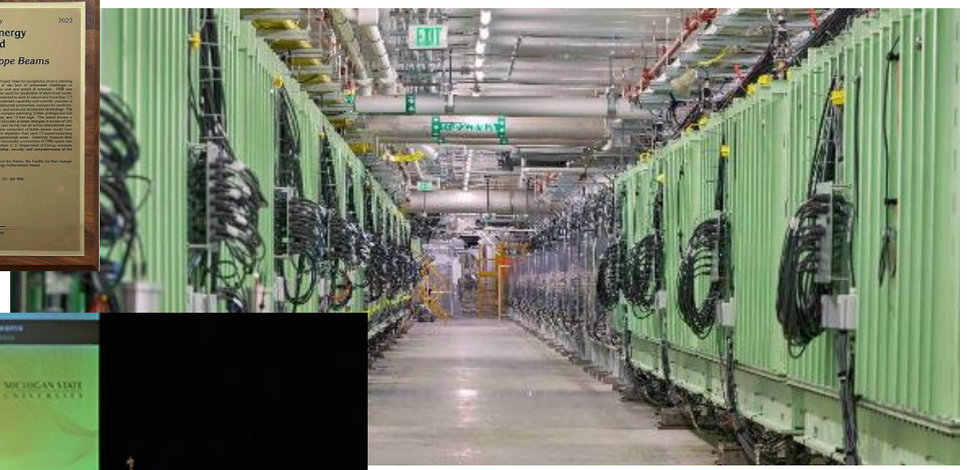
More than 440 Rare Isotope Beams Delivered and 931 Experimenters Supported

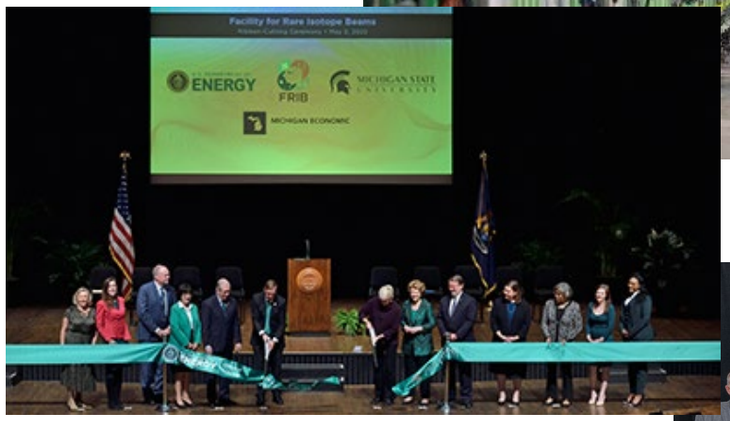
- Since the start of user operation in May 2022, FRIB has:
  - Delivered more than 440 rare isotope beams to experiments
  - Supported 931 participants, including 263 students, across 174 experiments and 23 countries from 166 institutions and companies
    - » Participants, institutions, and companies may take part in multiple experiments
- Published results are available at frib.msu.edu/publications
- 27 primary beams from 21 isotopes demonstrated and available, see frib.msu.edu/beams
- FRIB is oversubscribed and can only accommodate a third of all requested beam time due to the large interest
  - Since 2022, FRIB has received 251 proposals for beam time use



Keeping the Public Trust is Easier when we Deliver Projects On-Cost and On-Schedule

- 2024: U.S. Department of Energy's Secretary of Energy Achievement Award
  - "… recognize the Facility for Rare Isotope Beams—FRIB—for their exceptional project planning skills, discipline in project management, and resilience in the face of unforeseen challenges to successfully complete the 14-year construction of FRIB—on cost and ahead of schedule"
- 2022: Ribbon cutting of FRIB opening joined by government officials and MSU leaders
  - U.S. Department of Energy Secretary J. Granholm, Gov. G. Whitmer, U.S. Congressman T. Walberg, U.S. Sen. G. Peters, U.S. Sen. D. Stabenow, U.S. Congresswomen E. Slotkin and Congresswomen B. Lawrence
- 2020: U.S. Secretary of Energy Brouillette designates FRIB a DOE Office of Science user facility
  - Brouillette and Under Secretary Dabbar designated Michigan State University a DOE-SC user facility





Strategic Engagement with International Partners Extends FRIB's Global Impact

- French **Centre National de la Recherche Scientifique (CNRS)** established IRL NPA at FRIB
  - Leverages FRIB's unique research capabilities to address nuclear physics and astrophysics research questions
  - Three scientists stationed at FRIB
- Inauguration ceremony with agreement-signing held at FRIB in July 2023; inaugural science meeting in December 2023 at FRIB; French ambassador to U.S. visits FRIB in July 2024
- CNRS has nearly 80 international research laboratories worldwide; IRL NPA at FRIB is first dedicated to nuclear physics and astrophysics

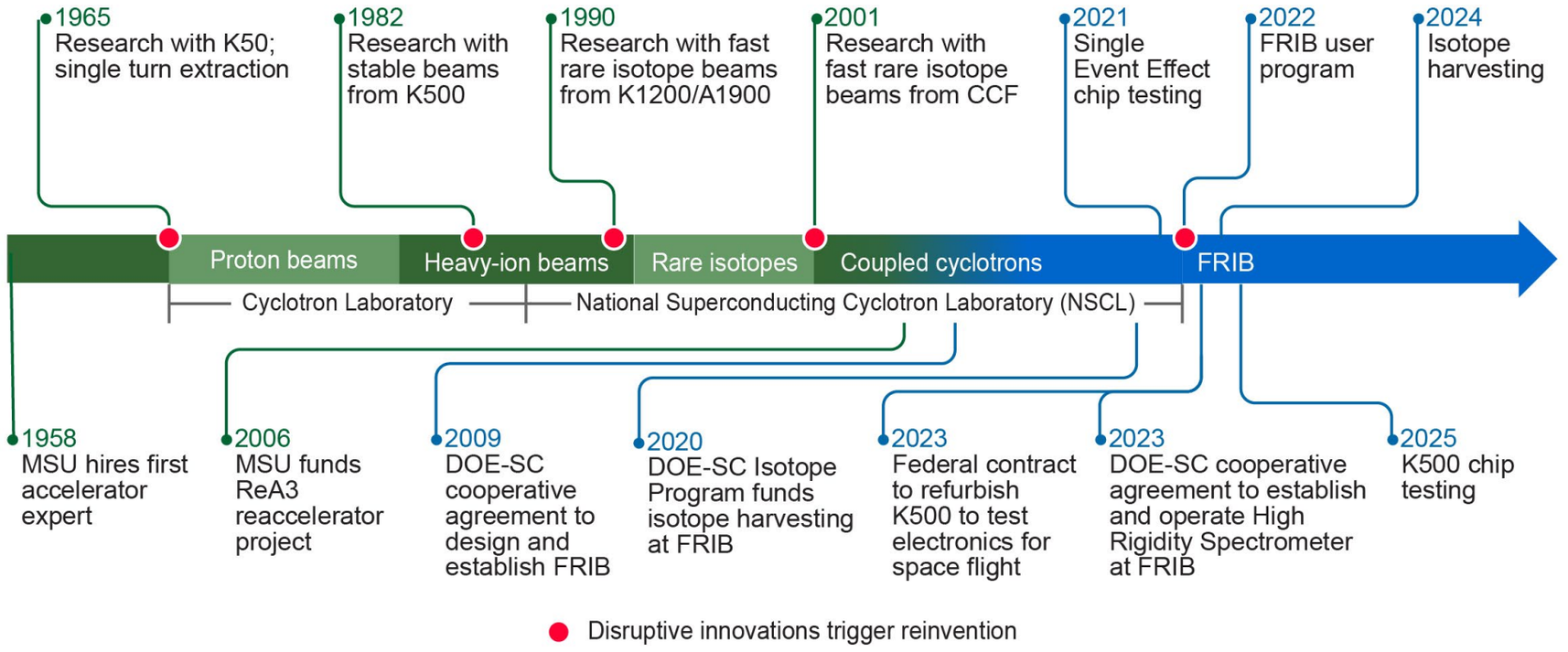
- **UKRI/Science and Technology Facilities Council (STFC)** funds FAUST (FRIB Accelerated-beams for Understanding Science and Technology) instrument which will enable new experiments at FRIB
- This is £3.2M investment benefiting FRIB and its user community
- The UK team visited FRIB in January 2024 and March 2025.
- The first FAUST Science Workshop was held on 14-15 April 2025 at the Institute of Physics in London, UK.

Science and Technology Facilities Council

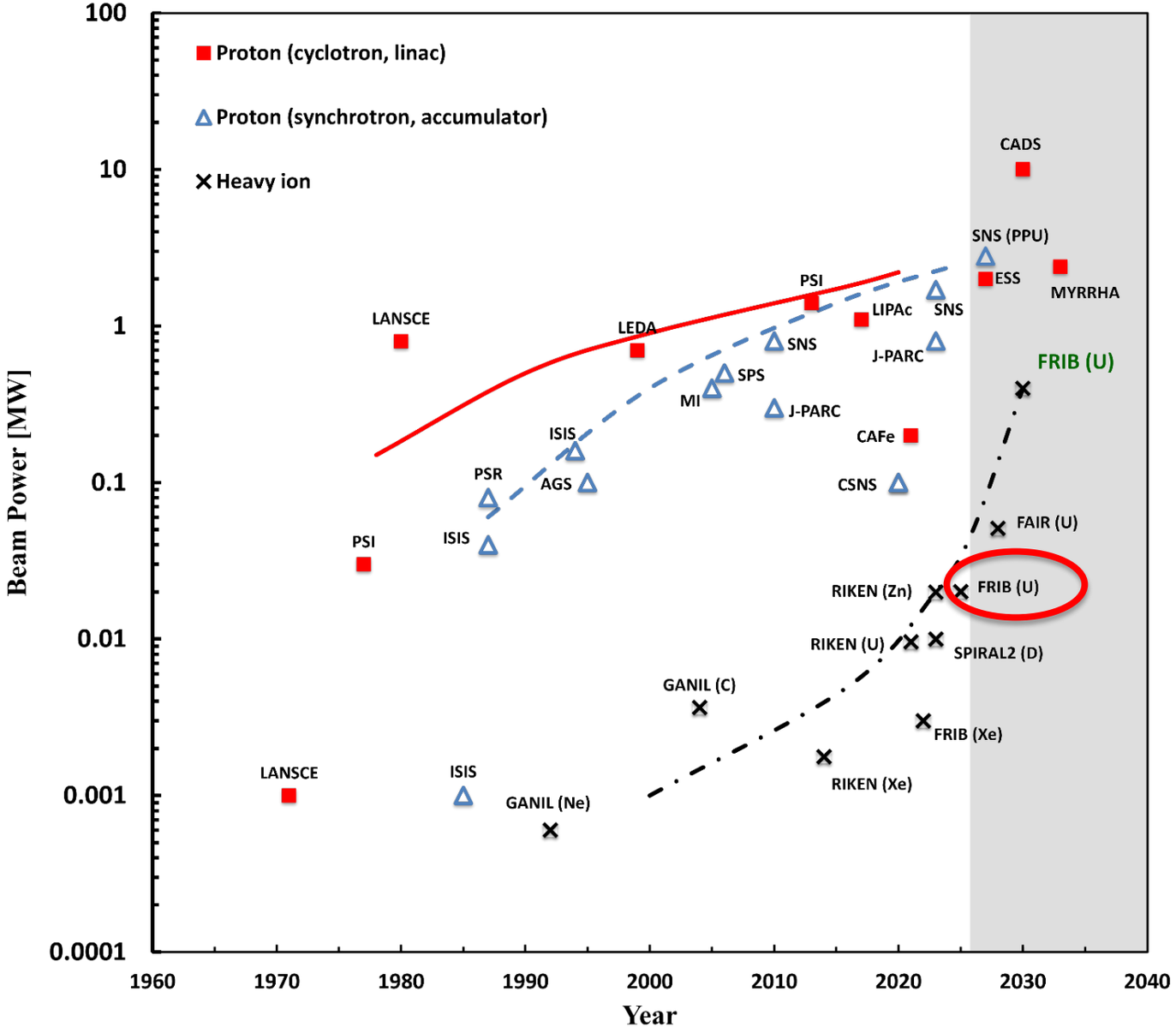
- Discussion with **Italian National Institute for Nuclear Physics (INFN)** exploring Nuclear Structure, Dynamics, and Astrophysics project at FRIB (INFN-NUSDAF)
- Involves five INFN collaborations with multi-purpose experiment setups

Attracting, Retaining, and Sustaining a Highly Qualified Workforce is Key to Delivering and Operating FRIB

- FRIB Laboratory and predecessors have 60-year history in accelerator-based science
  - Cyclotron Laboratory (1965 - 1985)
  - NSCL, National Superconducting Cyclotron Laboratory (1985 - 2021)
  - FRIB (2008 - present)
- Major reinventions leveraged assets and kept laboratory at cutting edge
  - 1965 proton beams, 1982 heavy ion beams, 1990 rare isotopes, 2001 coupled cyclotrons, 2022 FRIB, 2025 chip testing
- FRIB history
  - **2008** FRIB awarded to MSU after competitive procurements
  - **2021** Single Event Effect testing (chip testing) starts
  - **2022** FRIB in-beam user program starts
- FRIB expertise addresses national need
  - **2021** Single Event Effect testing (chip testing)
  - **2024** Isotope harvesting
  - **2025** K500 chip testing



High Power Heavy Ion Facility Complexity and Challenges
In Comparison with Proton Facilities



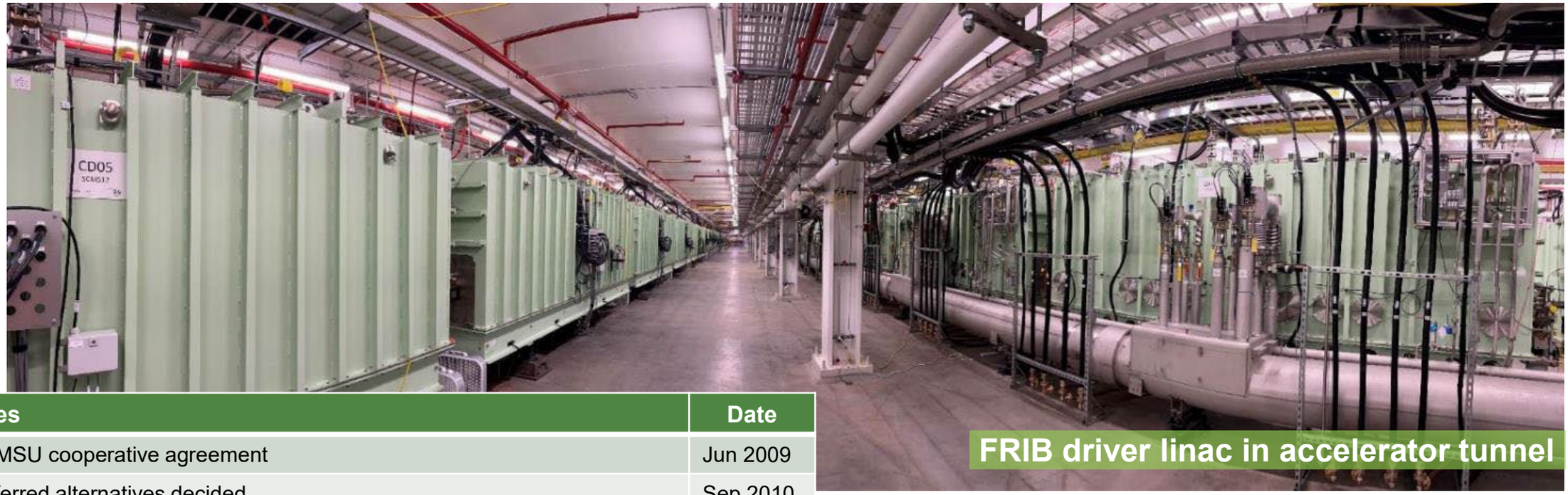
- Source intensity is lower
- Acceleration efficiency is lower $\propto q/A$
- Stripping efficiency is low unless multiple charge states can be accelerated
- Heavy ion beams have high stopping power and short range, demanding fast response time for machine protection

$$S_p \propto Z_{P,\mathrm{eff}}^2 \qquad R \propto \frac{E_{K,P}^{1.74}}{A_P^{0.76} Z_{P,\mathrm{eff}}^2} \qquad t_{\mathrm{mps}} \propto Z_{P,\mathrm{eff}}^{-2}$$

- High power targetry systems (i.e. beam intercepting devices) are challenging
- Operational complexity with frequent change of different beams

FRIB Project Construction 2014 – 2022

Highest Energy Heavy Ion Linac / CW Hadron Linac



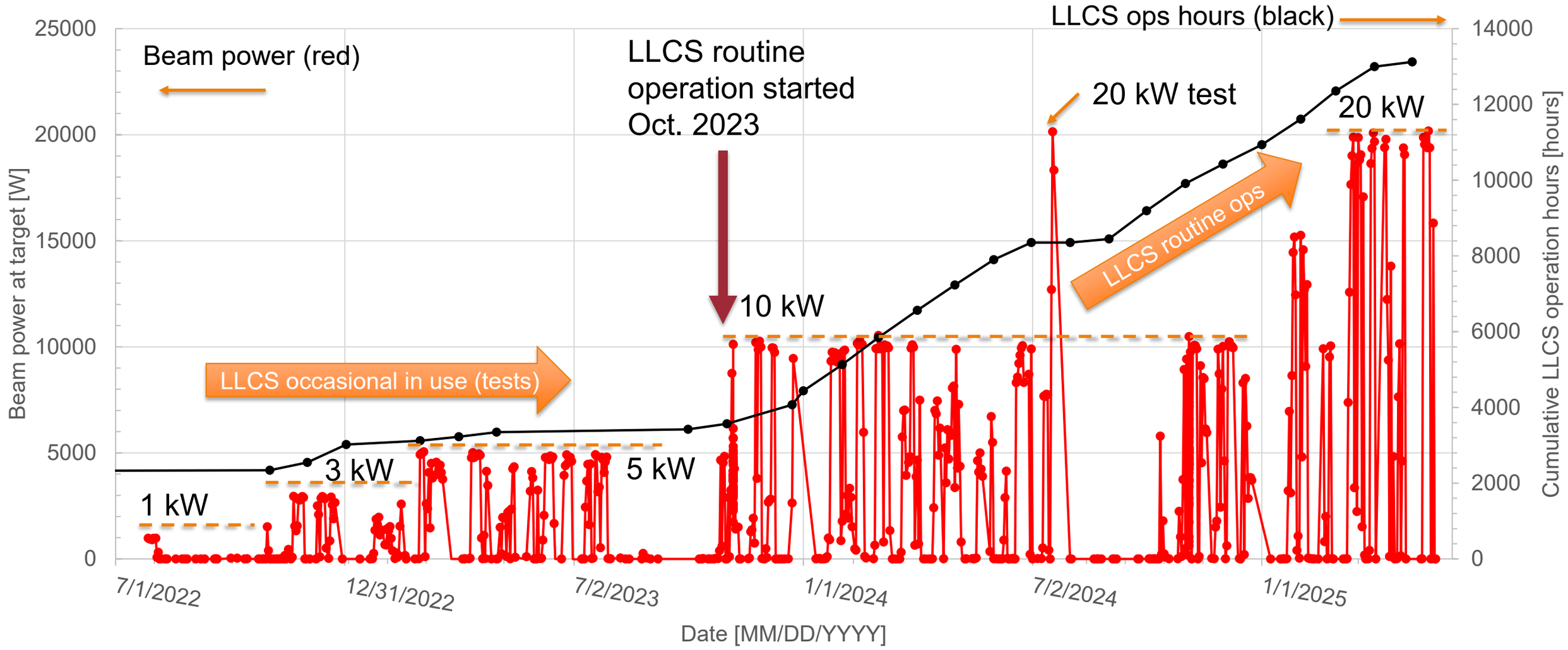
FRIB driver linac in accelerator tunnel

Milestones	Date
DOE and MSU cooperative agreement	Jun 2009
CD-1: preferred alternatives decided	Sep 2010
CD-2/3a: performance baseline, start of civil construction & long lead procurement	Aug 2013
CD-3b: start of technical construction	Aug 2014
FRIB linac construction completion	May 2021
Project technical construction completion	Jan 2022
CD-4: project completion	Apr 2022
Start of PAC1 user experiments at 1 kW primary beam power	May 2022
User experiments at 10 kW primary beam power	Oct 2023
User experiments at 30 kW primary beam power	Oct 2025

- Linac includes front end and 46 SRF cryomodules
  - ECR ion sources; RFQ; 324 SRF cavities in 46 cryomodules with velocity β from 0.041 to 0.53
  - 208 cold magnets, 350 warm magnets
- Liquid helium for 2 K, 4 K operations
- Liquid lithium charge stripping
- Capable of accelerating all stable ions > 200 MeV/u

FRIB Power Ramp-up since Start of User Operations

LLCS Plays a Key Role to Push Heavy Ion Beam Power Frontier > 10 kW



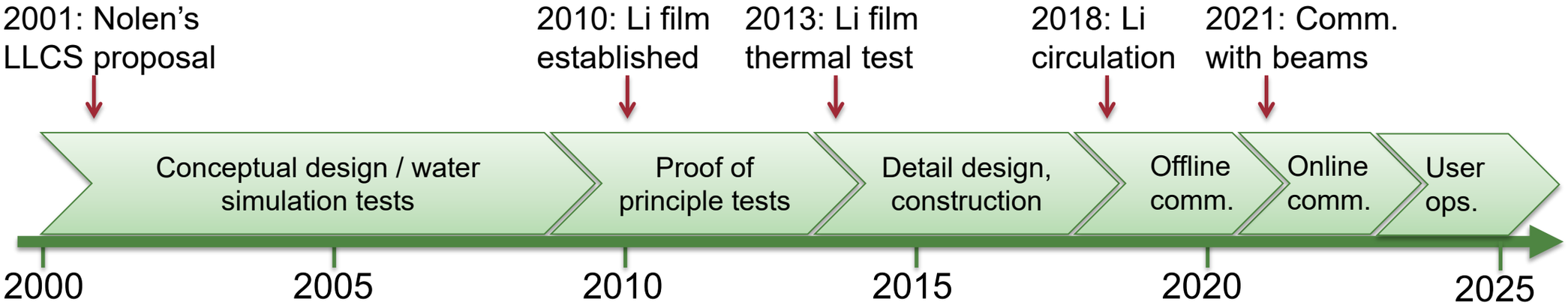
Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science | Michigan State University
640 South Shaw Lane • East Lansing, MI 48824, USA
frib.msu.edu

Liquid Lithium Charge Stripper Development for FRIB Based on Jerry Nolen's Idea

- The following process was taken to develop FRIB LLCS
  - Conceptual design
    - » R&D tests for selected critical performance with water as a simulant of liquid lithium
  - Proof of principle test (part of conceptual design stage)
    - » Small-scale liquid lithium system, or system with limited functions
  - Detail design and construction
    - » Liquid lithium system with full functions
  - Offline commissioning
    - » Stand-alone commissioning without ion beams
  - Online commissioning
    - » Commissioning with ion beams

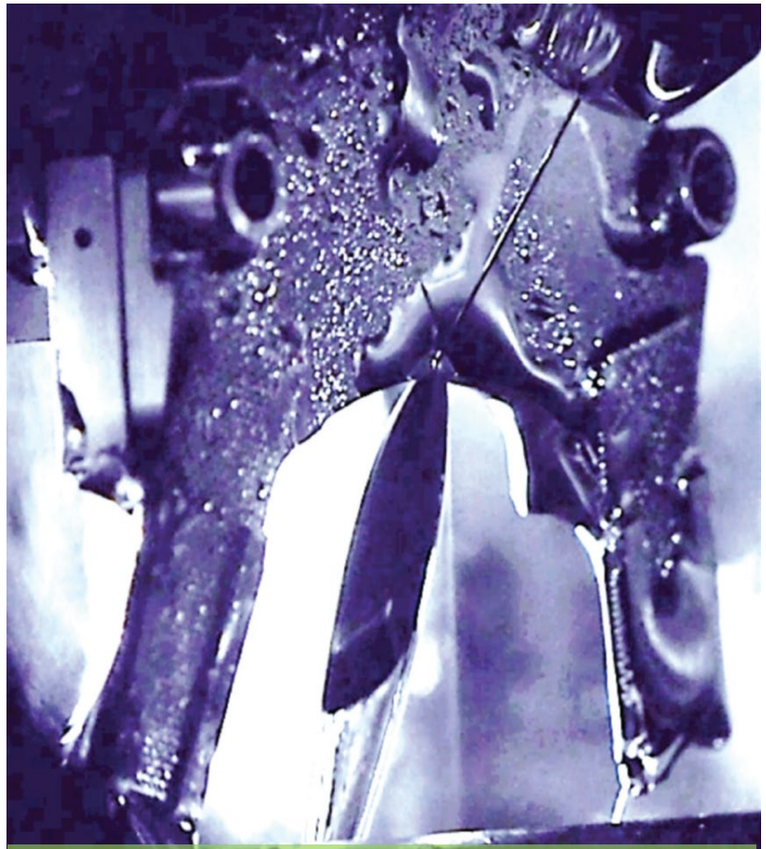
J. A. Nolen *et al.*, ANL-01/19, 2001

- In general, this approach can apply to other similar systems

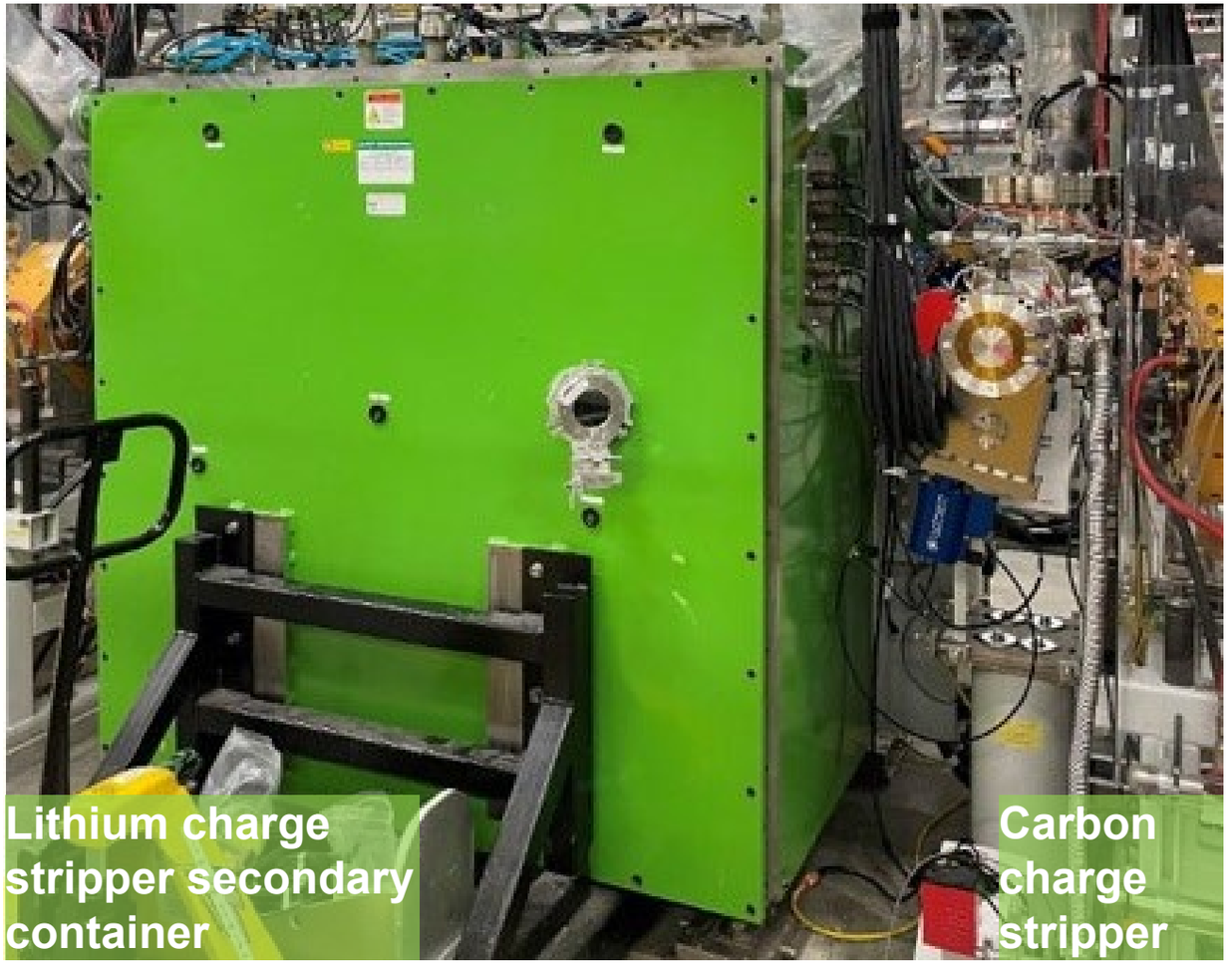


Liquid lithium Charge Stripping Vital for High Power Beams

- Operating with charge strippers of either liquid-lithium film (LLCS) or rotating carbon foil (for light ions)



Liquid lithium film for charge stripping



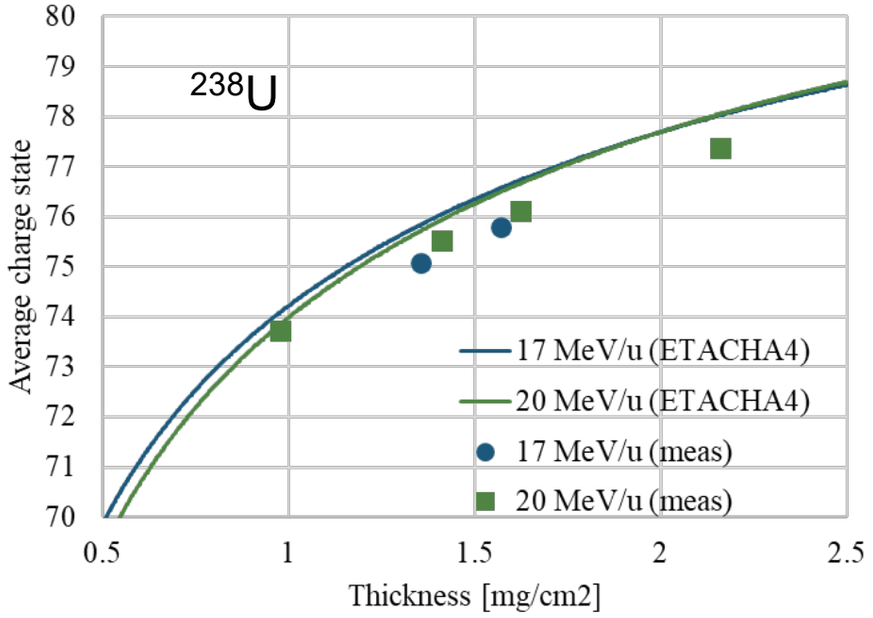
Lithium charge stripper secondary container

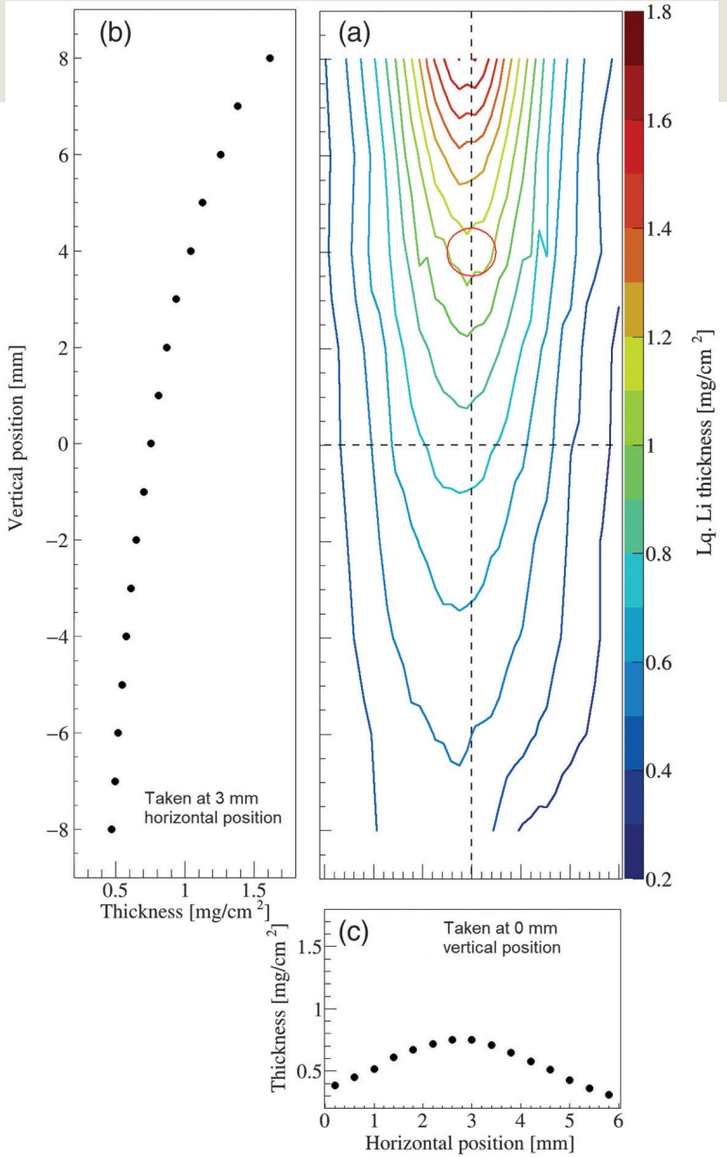
Carbon charge stripper

T. Kanemura, *et al., Phys. Rev. Lett.* **128**, 212301 (2022)

Liquid Lithium Charge Stripper Perspective

- Measurement data of U beam charge stripping with lithium showed that a 1 mg/cm^2 thick film gives an average charge state of 74+
  - Accelerator designed with 78+
  - Thicker part of film is too steep to use (beam RMS radius 0.5 mm)
- R&Ds to improve film uniformity and to make a thicker film for U beam stripping
  - Starting with water test
  - Our goal: 1.5 mg/cm^2





T. Kanemura

Designed and Built Helium Liquefaction at 4K and 2K

- FRIB designed, built, and operates one of the nation's largest, most energy-efficient helium liquefaction plants to meet its need
  - Operates at 4 K and 2 K
  - Has operated without interruption since 2018
- FRIB grad student developed as thesis project helium recovery system to capture and purify helium, reducing waste and improving energy efficiency
- Integrated design of cryogenic refrigeration, distribution, helium recovery and cryomodule systems is leading-edge and key to energy-efficient and reliable operations
- Operates on patented Ganni Floating-Pressure Process Cycle to stably regulate cooling capacity down to 30 percent of maximum capacity
  - Significant power and utility (liquid nitrogen cooling water) savings relative to other plants
- Applies to hydrogen liquefaction
- MSU invests: Cryogenic engineering faculty and MSU Cryogenic Initiative to train students

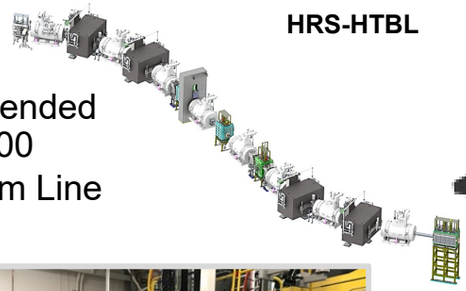
Superconducting Radio Frequency for Heavy-Ion Acceleration

- Superconducting radio frequency (SRF) technology saves energy and makes heavy-ion acceleration affordable
- FRIB established world-class program to design and produce SRF resonators, cold masses, and cryomodules for heavy-ion accelerators
  - Designed and prototyped SRF resonators to accelerate FRIB's heavy-ion beam that were then produced by industry (most domestically)
  - FRIB produced largest, fastest domestic construction of SRF cryomodules with best quality
- DOE-SC selected FRIB to develop superconducting RF injector at SLAC's Linac Coherent Light Source (LCLS-II-HE)
- FRIB SRF capabilities enable single-event effects testing

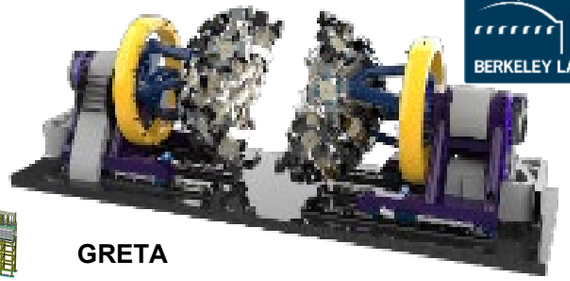
Instruments for FRIB Science
Community Engaged, Instruments Delivering Science

- Large instruments for FRIB science underway
  - **HRS-High Transmission Beam Line (HRS-HTBL)**
    - » Evolution of shell structure, single particle structure of rare isotopes, limits of stability - extended scientific reach by a combined production-rate and luminosity increase by up to a factor 100
    - » In February 2025, DOE-SC approved the start of execution of the High Transmission Beam Line (HTBL), one of the two segments of the High Rigidity Spectrometer (HRS).
  - **GRETA gamma detector array (Berkeley Lab)**
    - » Structure of new nuclei with maximum resolving power and acceptance
    - » CD4 received in June 2025, installation commencing at FRIB in fall 2025

HRS-HTBL



BERKELEY LAB



GRETA

SECAR

FLORIDA STATE UNIVERSITY 1851

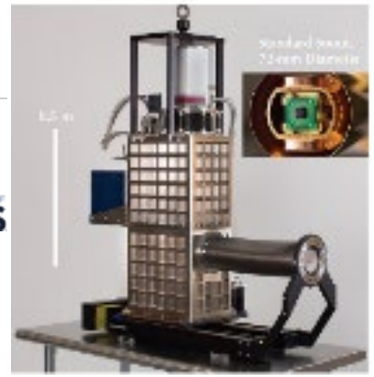
SOLARIS

Argonne NATIONAL LABORATORY

- Additional instruments installed and first experiments performed – new community driven projects underway
  - **SECAR** recoil separator for measurement of thermonuclear reactions in exploding and exotic stars
  - **SOLARIS** spectrometer (FSU, ANL) for nuclear reaction studies with reaccelerated beams
  - **FDSi** advanced decay station (UTK, ORNL) for complete decay spectroscopy at the limits
  - **RiSE** (MIT) for high-sensitivity laser spectroscopy via collinear resonance ionization for nuclear radius and moment measurements
  - **SALER** (Colorado School of Mines, LLNL) for the Test of Standard model via detection of sub-keV nuclear recoils
  - **EOS Active Target Time Projection Chamber** (TAMU) for the study of the equation of state of neutron matter – whitepaper complete

MIT

COLORADO SCHOOL OF MINES



OAK RIDGE National Laboratory

THE UNIVERSITY OF TENNESSEE KNOXVILLE

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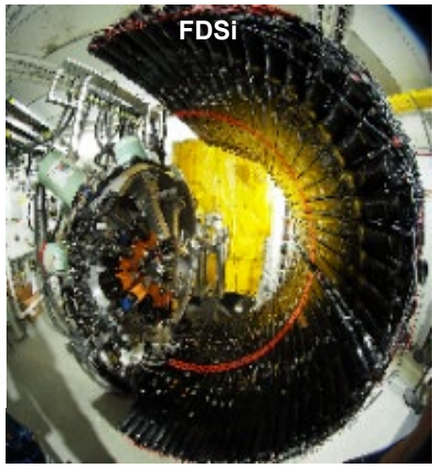
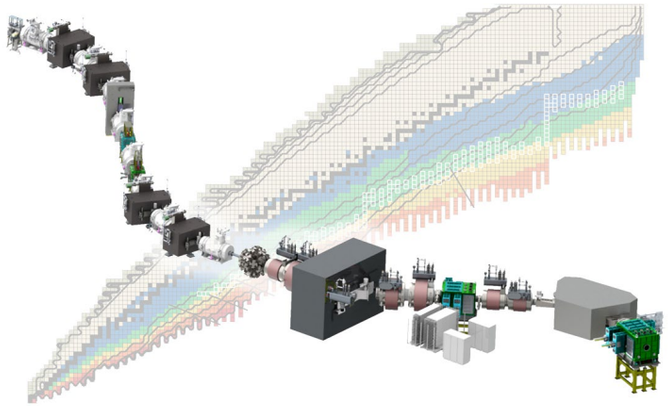
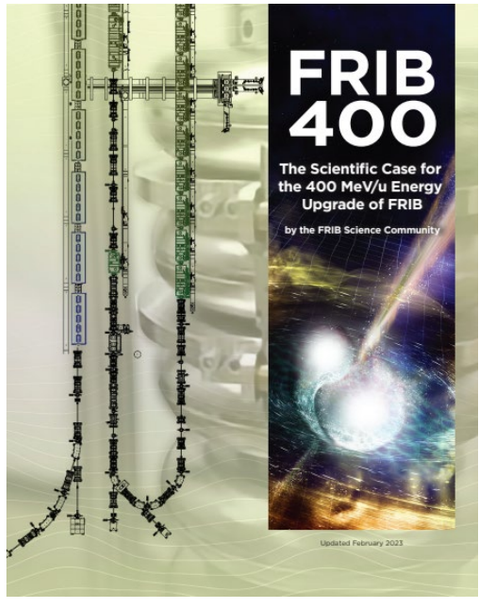


Community-driven Upgrade Projects to Optimize FRIB Discovery Potential: HRS and FRIB400

- High Rigidity Spectrometer (HRS) (in construction)
  - HRS (hrs.lbl.gov) will extend FRIB's scientific reach to neutron-rich isotopes by a combined production-rate and luminosity increase of up to a factor of more than 100
  - Project underway; user community of over 500 scientists
  - Status
    - » February 2025: DOE-SC approved start of execution of High Transmission Beam Line (HTBL)
    - » Pending: HRS SPS construction



- FRIB400 energy upgrade (planned)
  - FRIB400 (frib.msu.edu/frib400) will double beam energy to 400 MeV/nucleon
  - Expands scientific impact by increasing tenfold yield for many rare isotopes
  - Science community laid out opportunities in FRIB400 whitepaper (frib.msu.edu/frib400paper)
  - FRIB400 opportunity: World leadership in light of ambitious RIKEN (Japan) plans



*Finally, a **timely energy upgrade of the recently completed Facility for Rare Isotope Beams (FRIB400)** offers a golden opportunity to use the collision of heavy ions to probe the equation of state in regions of critical importance for multi-messenger astronomy.*

Sidebar 5.2 Neutron Star Inspired Density Ladder, 2023 LRP

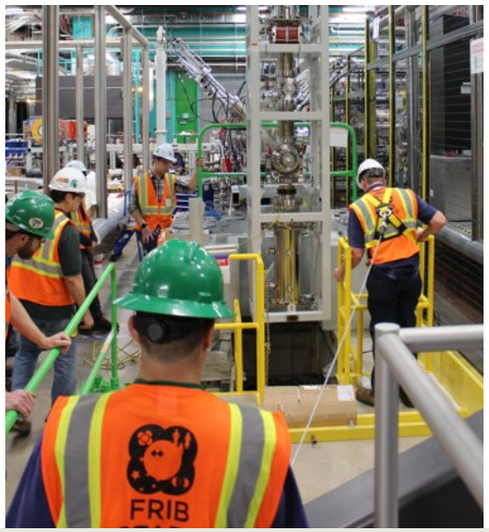
*The **FRIB400** project's doubling of the energy available at FRIB **would not only increase reaction rates by employing higher luminosities but also would enable new reaction mechanisms to be used***

4.6 What Happens When Nuclei Collide?, 2023 LRP

Keeping the Public Trust: Approach to Environment, Safety, Health & Quality

- FRIB operates under well-defined regulatory framework
  - U.S. Nuclear Regulatory Commission
  - FBI for export control
  - Michigan Department of Licensing and Regulatory Affairs
  - State of Michigan OSHA
  - Michigan Department of Environmental Quality
  - MSU Environmental, Health and Safety

- FRIB externally-registered management systems
  - ISO 14001 – Environment, since 2006
  - ISO 45001 – Safety, since 2007
  - ISO 9001 – Quality, since 2008
  - ISO 27001 – Information Security Management Systems, since 2018
- ISO fosters internal and external engagement
- External ESH Advisory Committee with experts from national laboratories
- We strive to be a good host to scientists and a good member of the MSU community



Facility for Rare Isotope Beams
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frib.msu.edu

Today we celebrate Robert Janssens

- Scientists make discoveries and discoveries drive ideas for new one-of-a-kind machines
- Bringing an idea for a new machine to realization takes a decade or more
  - And many hurdles have to be overcome
- Building a new machine takes a decade or more
  - And many hurdles have to be overcome
- Bringing a machine to its full potential takes a decade or more
  - And many hurdles have to be overcome
- All along we advance the state-of-the-art through technological development
- We need to remain aligned with national priorities, keep the public trust, and articulate public benefits
  - Chip testing, radioisotopes harvested, and cryogenic engineering
- Science-driven enhancements further advance discovery potential for scientific discoveries
  - High-Rigidity Spectrometer
  - FRIB 400