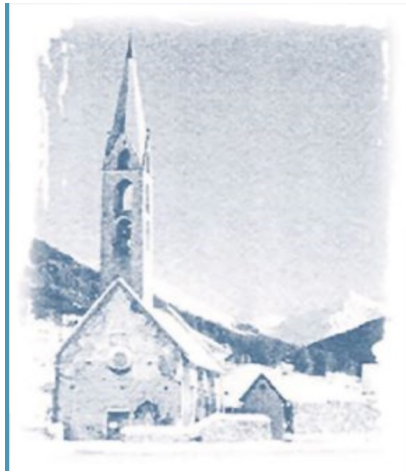


62nd International Winter Meeting on Nuclear Physics

19 - 23 January 2026

Bormio, Italy

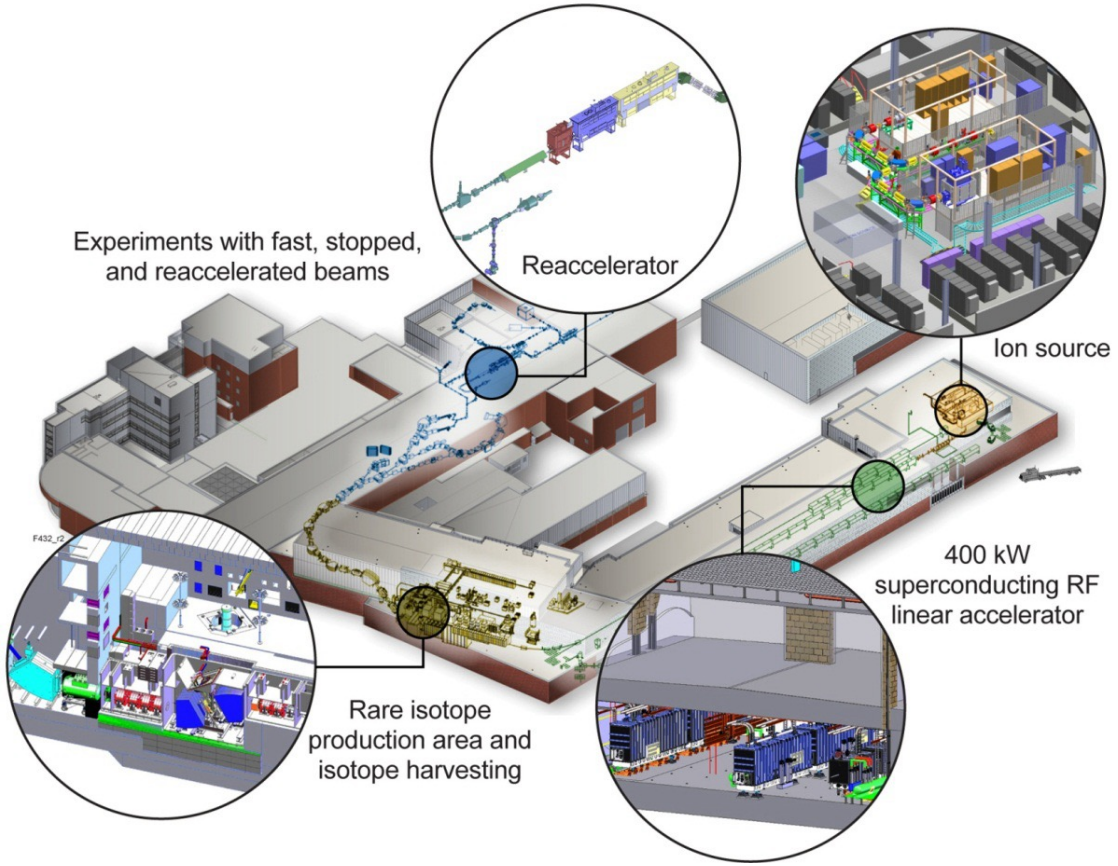
# Facility status and new results from FRIB

Artemis Spyrou
Michigan State University

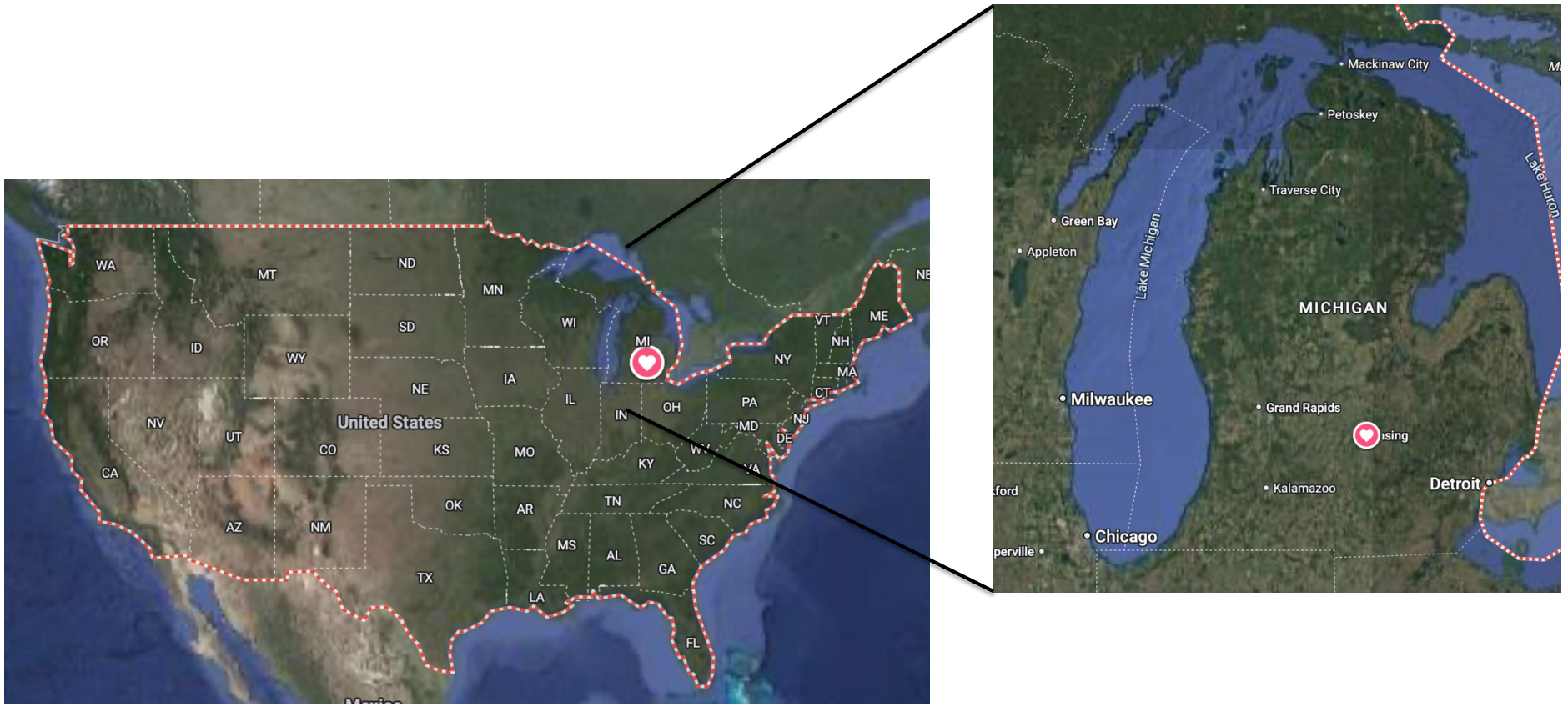
(thanks to Alex Gade for some of the slides)

*Supported by the U.S. Department of Energy (DOE), Office of Science and the National Science Foundation*

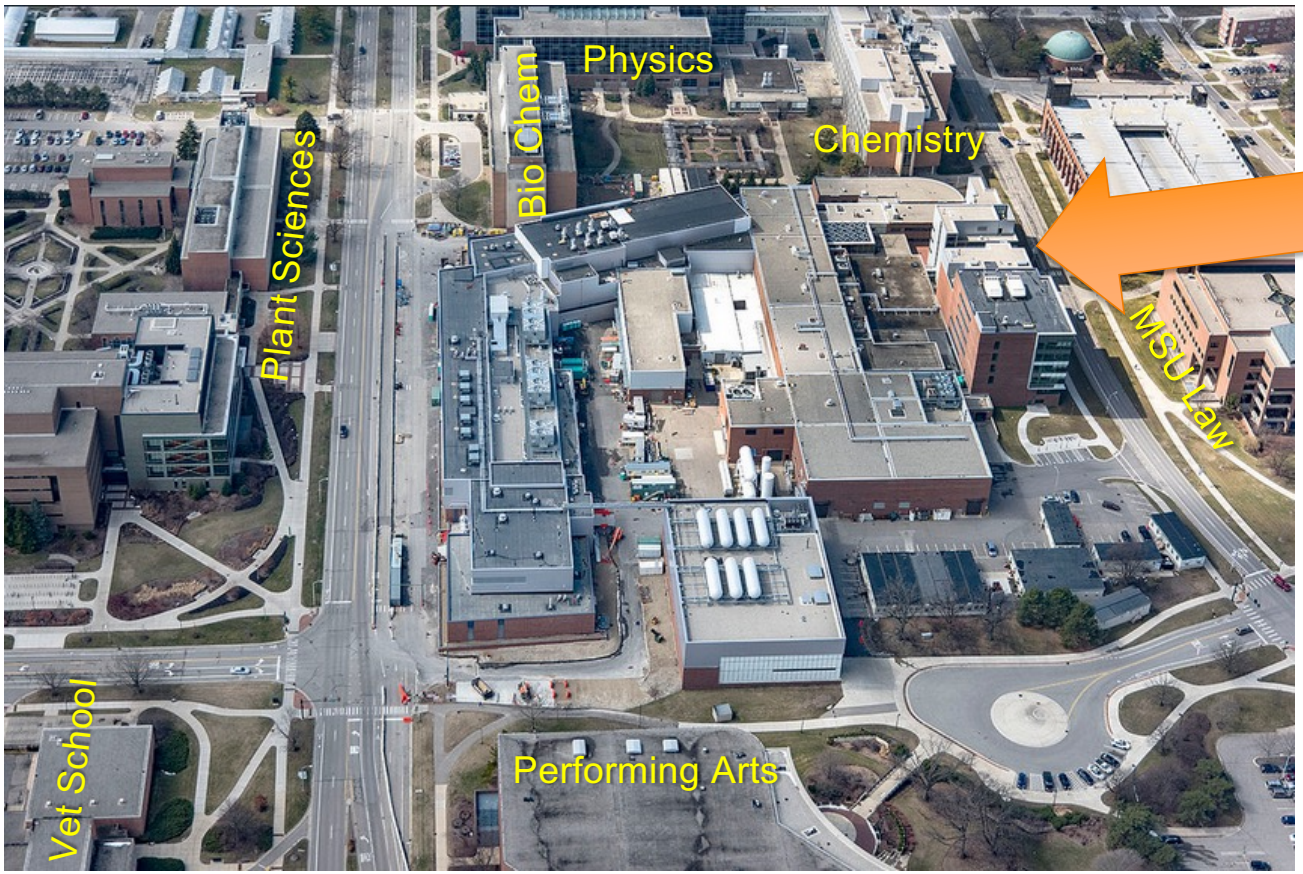
# Facility for Rare Isotope Beams (FRIB)

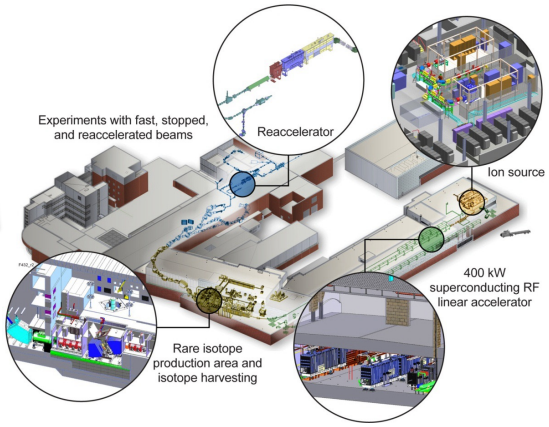


# FRIB is located in Michigan, US



# … located in the middle of the MSU Campus




Combining education and research experiences for students and faculty

# Who we are – Facility for Rare Isotope Beams

~800 employees

Including:

>45 faculty

>20 postdocs

>140 graduate

>90 undergraduate students

National User Facility

>1800 Users

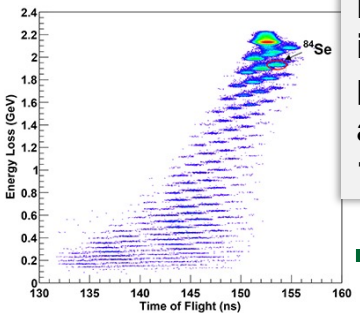
# Who we are – Facility for Rare Isotope Beams

- Michigan State University has a long history in nuclear science: First beam in 1965
- Operated the National Superconducting Cyclotron Lab (NSCL)
- FRIB is the next generation facility for rare isotope production.
- **Timeline:**

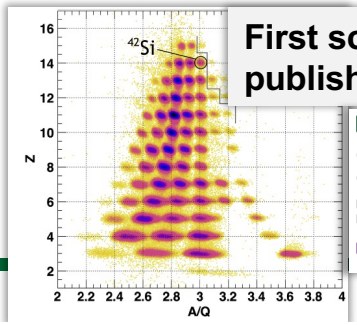
**Groundbreaking 03/2014**

**Beneficial occupancy 03/2017**

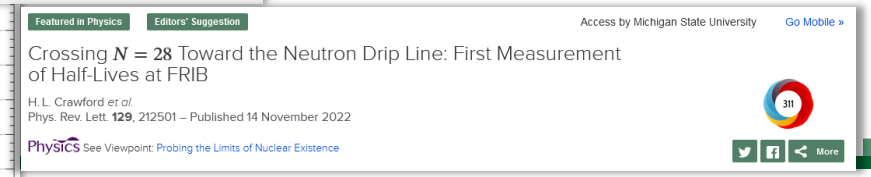
**Designated as DOE-SC User Facility 09/2020**




**First rare isotopes produced and identified 12/2021**




**First science results published 11/2022**



# FRIB Science

## Nuclear Structure

- How do the rich patterns observed in the structure and reactions of nuclei emerge from the interactions between neutrons and protons
- Limits of nuclear existence and new phenomena

## Nuclear Astrophysics

- Origin of the elements, r process
- Explosive environments: novae, supernovae, X-ray bursts
- Properties of neutron stars

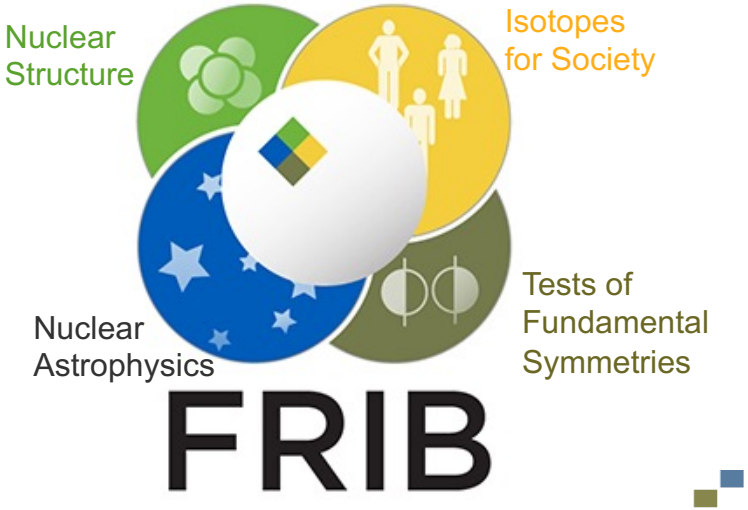
## Fundamental Symmetries

- High Precision Measurements
- Electric Dipole Moments

## Isotopes for Society

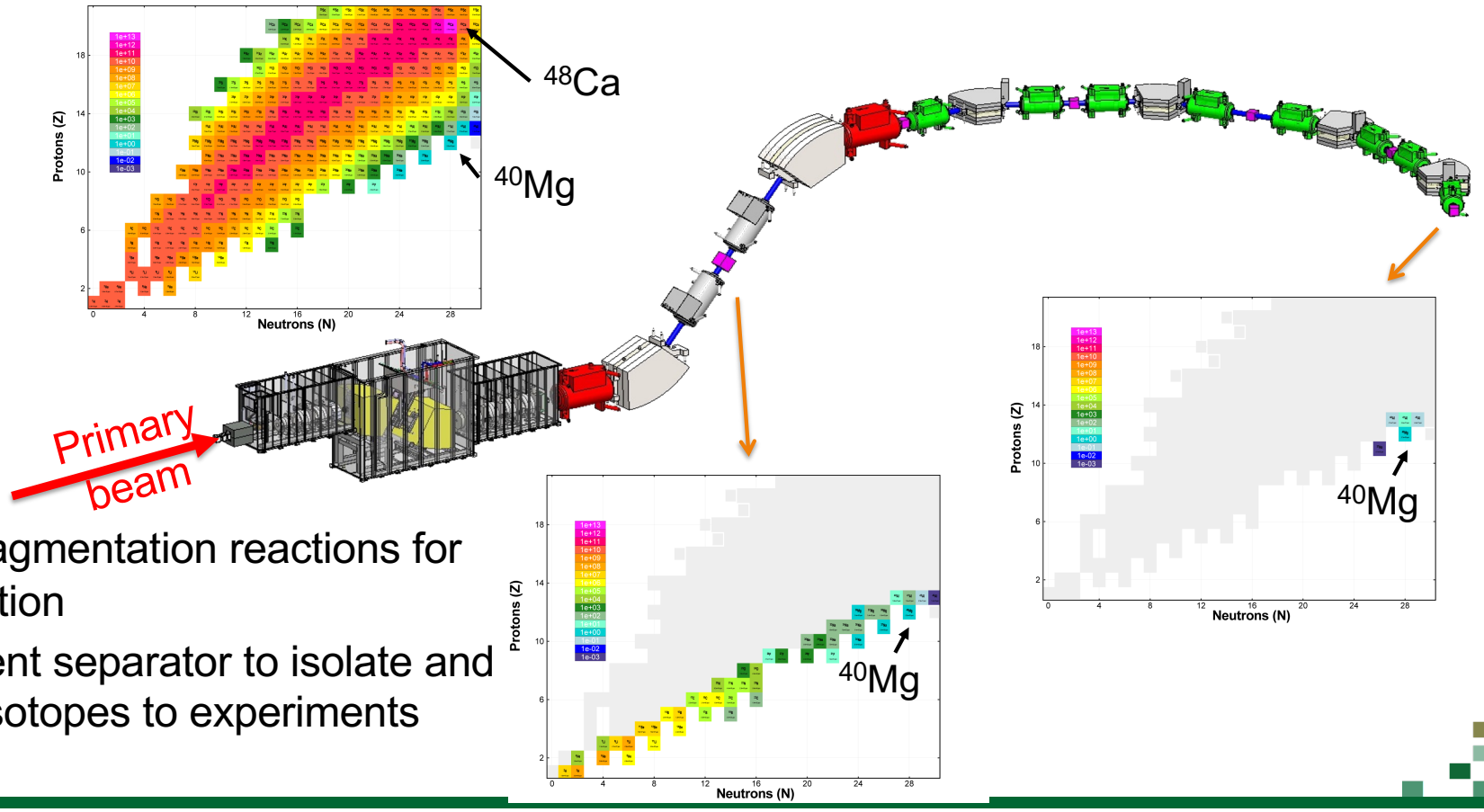
- Isotope Harvesting
- Medicine, energy, material sciences, national security

2023 US Long Range Plan


Experiment and theory working together to answer major questions in the field

# Beam Production at FRIB

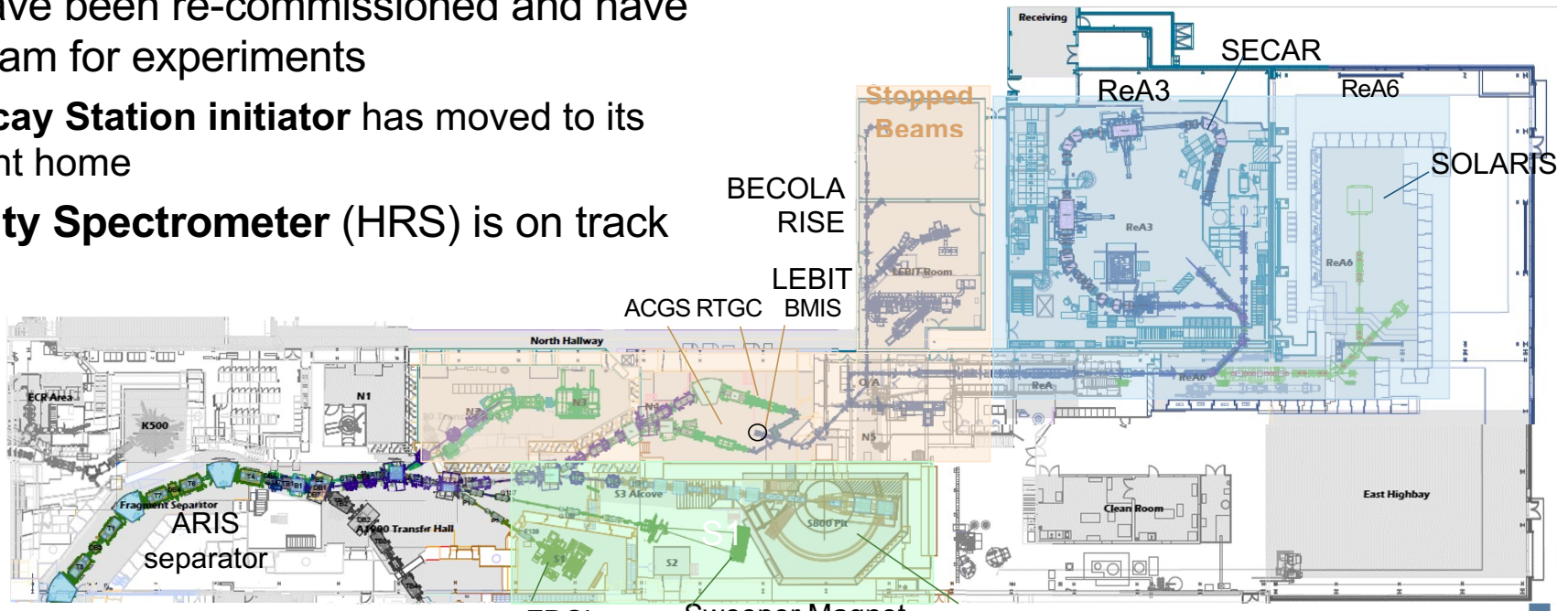



- FRIB uses fragmentation reactions for beam production
- **ARIS**: fragment separator to isolate and deliver rare isotopes to experiments

# All experimental areas for user experiments ready

- FRIB offers **fast**, **stopped**, and **reaccelerated** experiments with rare isotopes
- All vaults have been re-commissioned and have received beam for experiments
  - **FRIB Decay Station initiator** has moved to its permanent home
- **High Rigidity Spectrometer** (HRS) is on track

HRS



# First results from FRIB

# First isotope discovery at FRIB

Featured in Physics | Editors' Suggestion

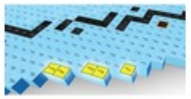
Phys. Rev. Lett. 132, 072501 (2024)

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

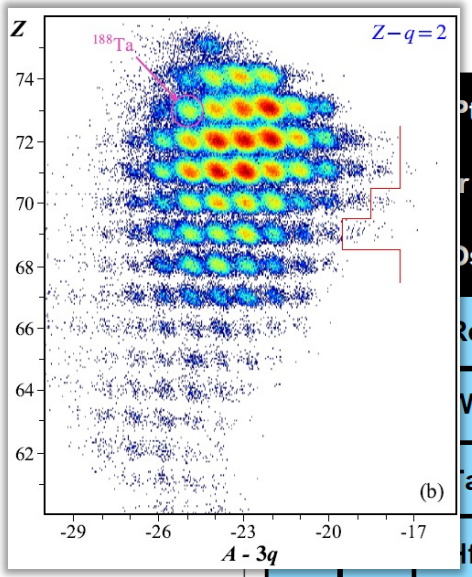
O. B. Tarasov, A. Gade, K. Fukushima, M. Hausmann, E. Kwan, M. Portillo, M. Smith, D. S. Ahn, D. Bazin, R. Chyzh, S. Giraud, K. Haak, T. Kubo, D. J. Morrissey, P. N. Ostroumov, I. Richardson, B. M. Sherrill, A. Stolz, S. Watters, D. Weisshaar, and T. Zhang

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.

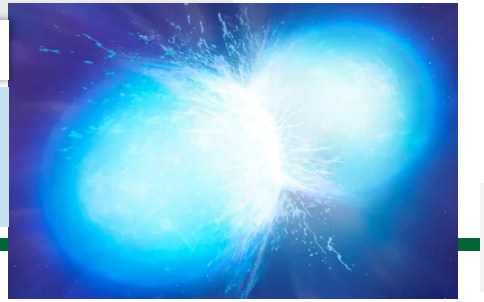


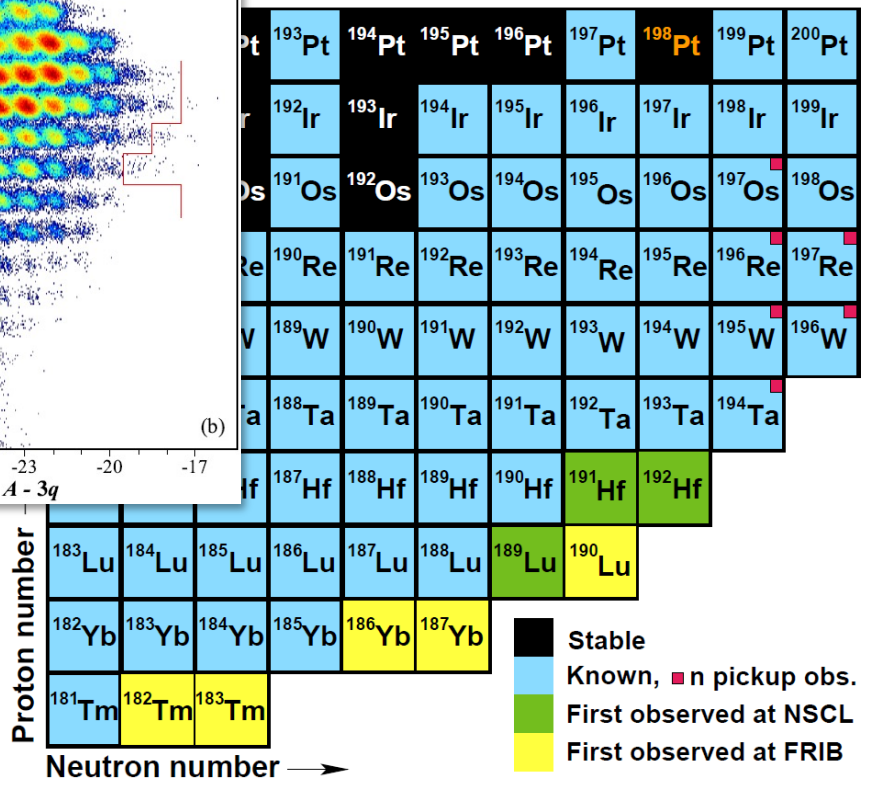

FEBRUARY 27, 2024 | 5 MIN READ

**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

The new isotopes were formed in the fragmentation of $^{198}$Pt on C at 1.5 kW → discovery potential!

# New isotopes discovered at FRIB

PHYSICAL REVIEW C **112**, 034604 (2025)

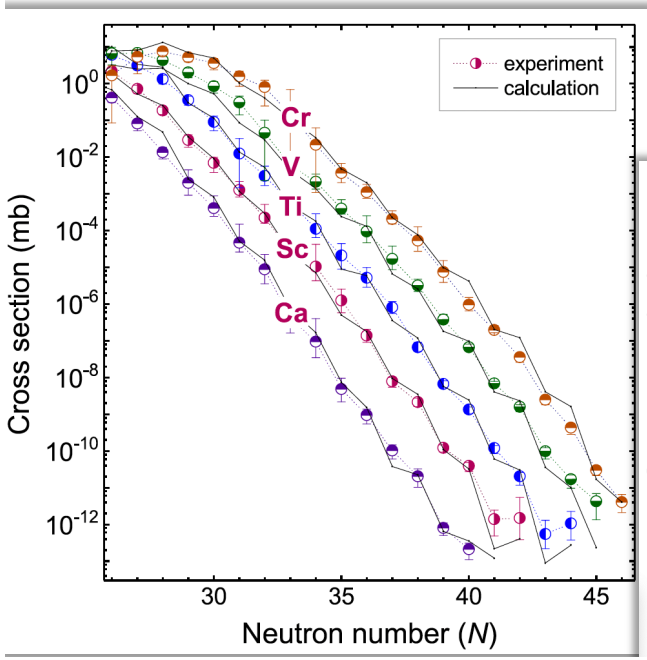
**Discovery of new isotopes in the fragmentation of $^{82}$Se and insights into their production**

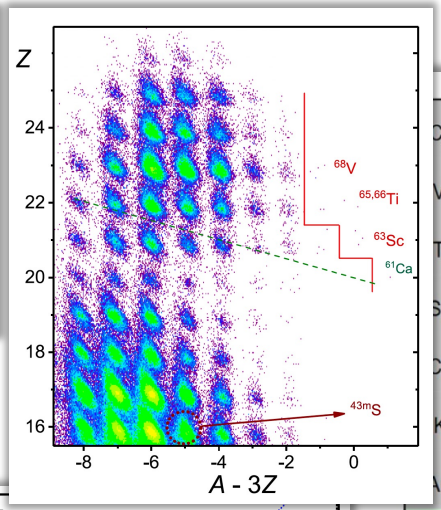
O. B. Tarasov,[1,*] B. M. Sherrill,[1,2] A. C. Dombos,[1] K. Fukushima,[1] A. Gade,[1,2] K. Haak,[1,2] M. Hausmann,[1] D. Kahl,[1] D. Kaloyanov,[1,2] E. Kwan,[1] H. K. Matthews,[1,2] P. N. Ostroumov,[1,2] M. Portillo,[1] I. Richardson,[1,2] M. K. Smith,[1] and S. Watters[1,2]

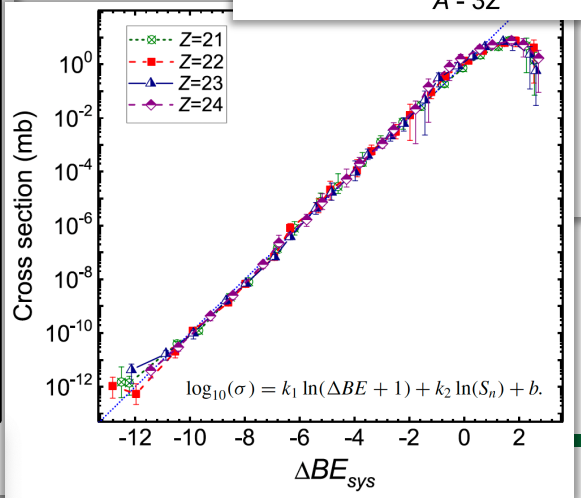
[1]*Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA*

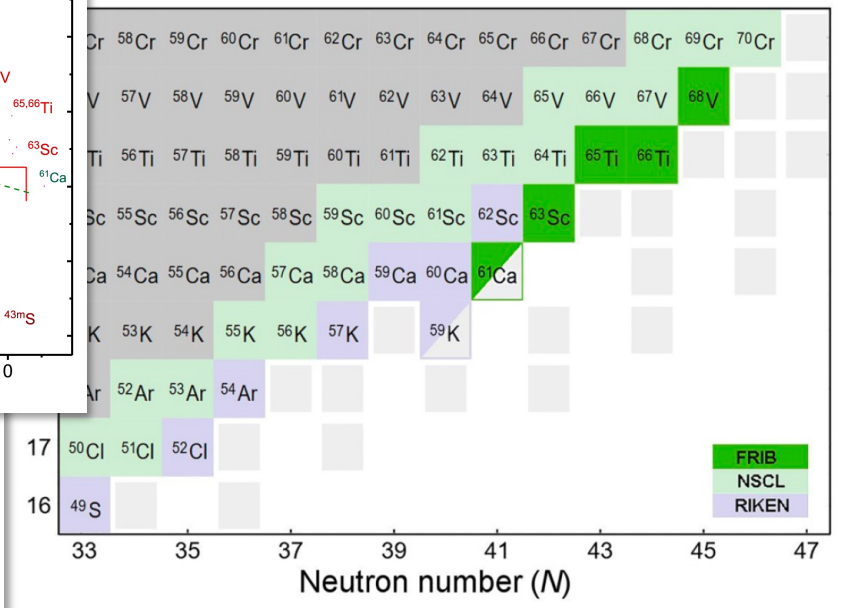
[2]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA*

(Received 19 January 2025; revised 16 July 2025; accepted 8 August 2025; published 4 September 2025)



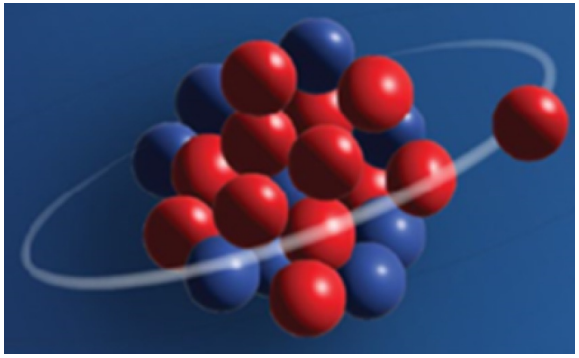



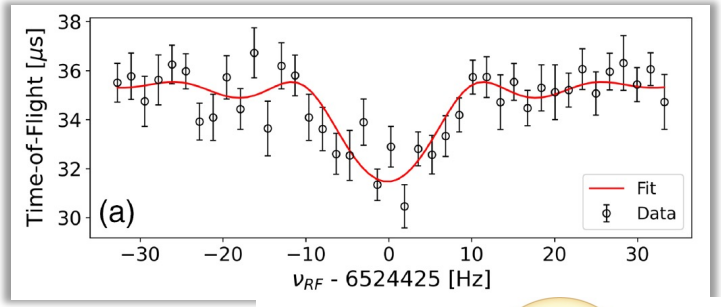
# FRIB: First results on weak binding from precision program

$^{22}$Al controversy: halo or no halo

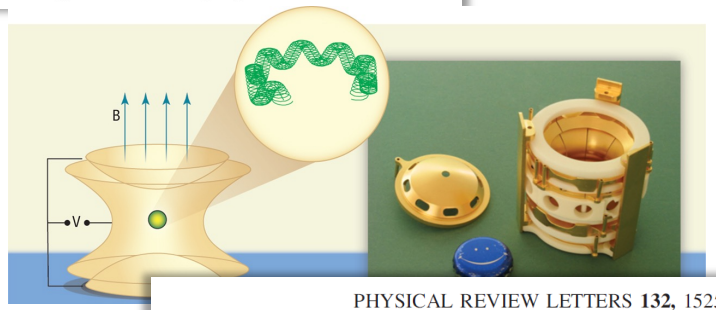


- New measurement of the ground state spin/parity: A ground state $^{22}$Al is unlikely
- (Jensen et al. arxiv 2026)
- The final precision answer will be given following a charge radius measurement (MIT-MSU collaboration – See talk by Roland Garcia Ruiz)

The necessary (not sufficient) condition is that the proton separation energy is low:




- Highest-precision mass of $^{22}$Al
- It only takes 100.4(8) keV to remove the last proton




PHYSICAL REVIEW LETTERS **132,** 152501 (2024)

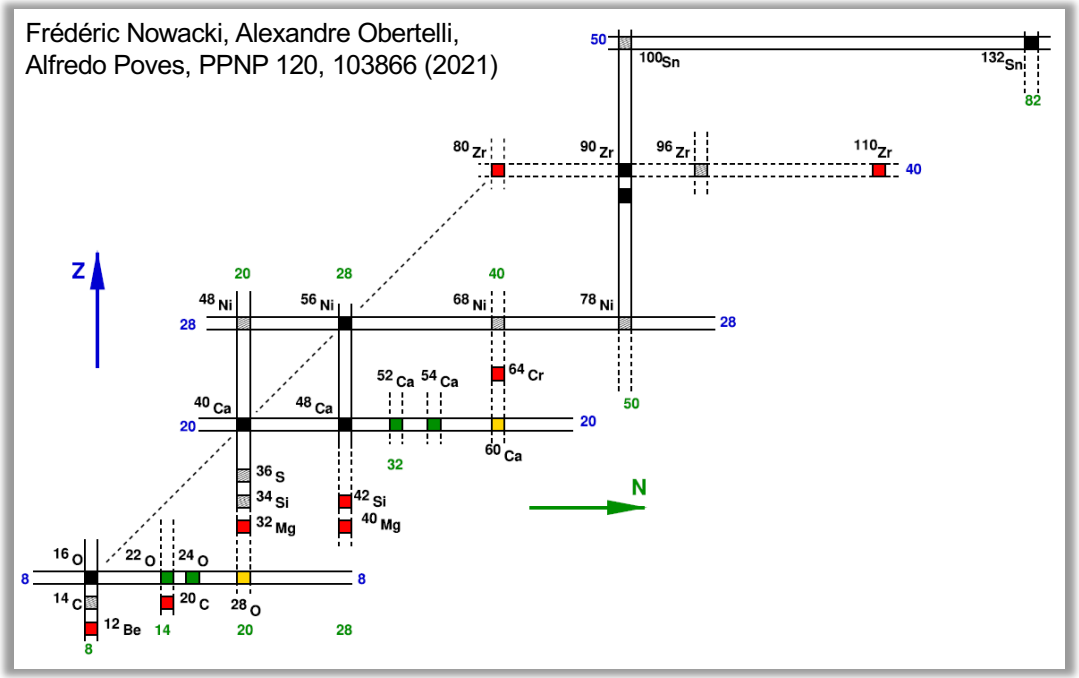
**Precision Mass Measurement of the Proton Dripline Halo Candidate $^{22}$Al**

S. E. Campbell,* G. Bollen, B. A. Brown, A. Dockery, C. M. Ireland, K. Minamisono, D. Puentes, B. J. Rickey, R. Ringle, and I. T. Yandow
*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA and Facility for Rare Isotope Beams, East Lansing, Michigan 48824, USA*

K. Fossez
*Department of Physics, Florida State University, Tallahassee, Florida 32306, USA and Physics Division, Argonne National Laboratory, Lemont, Illinois 60439, USA*

A. Ortiz-Cortes, S. Schwarz, C. S. Sumithrarachchi, and A. C. C. Villari
*Facility for Rare Isotope Beams, East Lansing, Michigan 48824, USA*

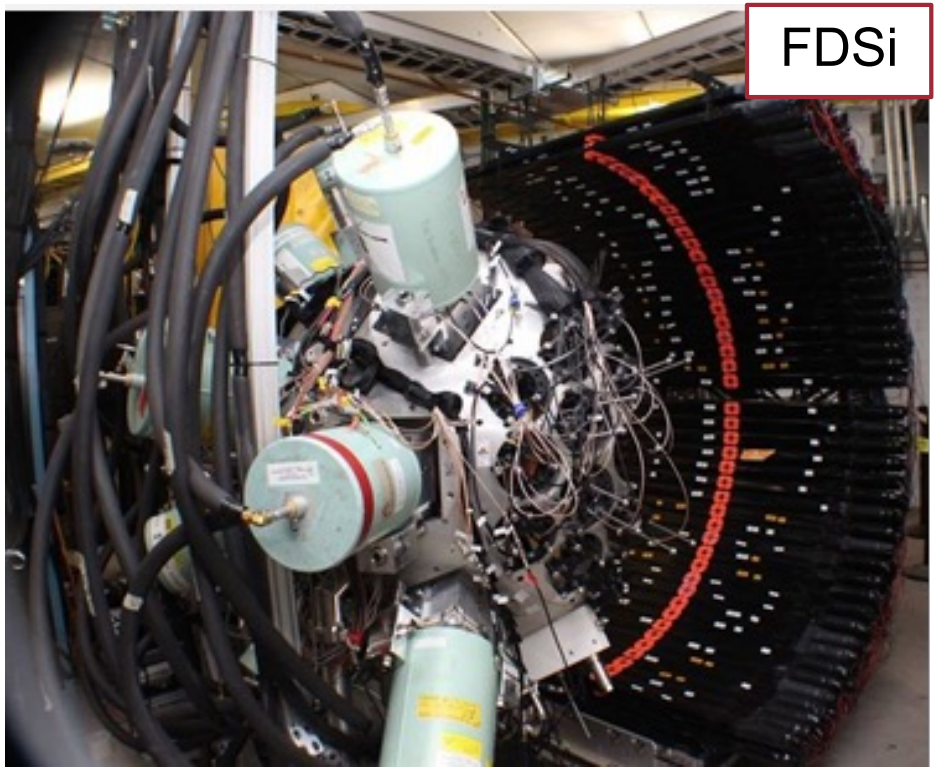
# Changing nuclear structure across the nuclear chart




- Classical doubly magic
- New local doubly magic
- New doubly magic
- Structure under debate
- Expected magic turned deformed

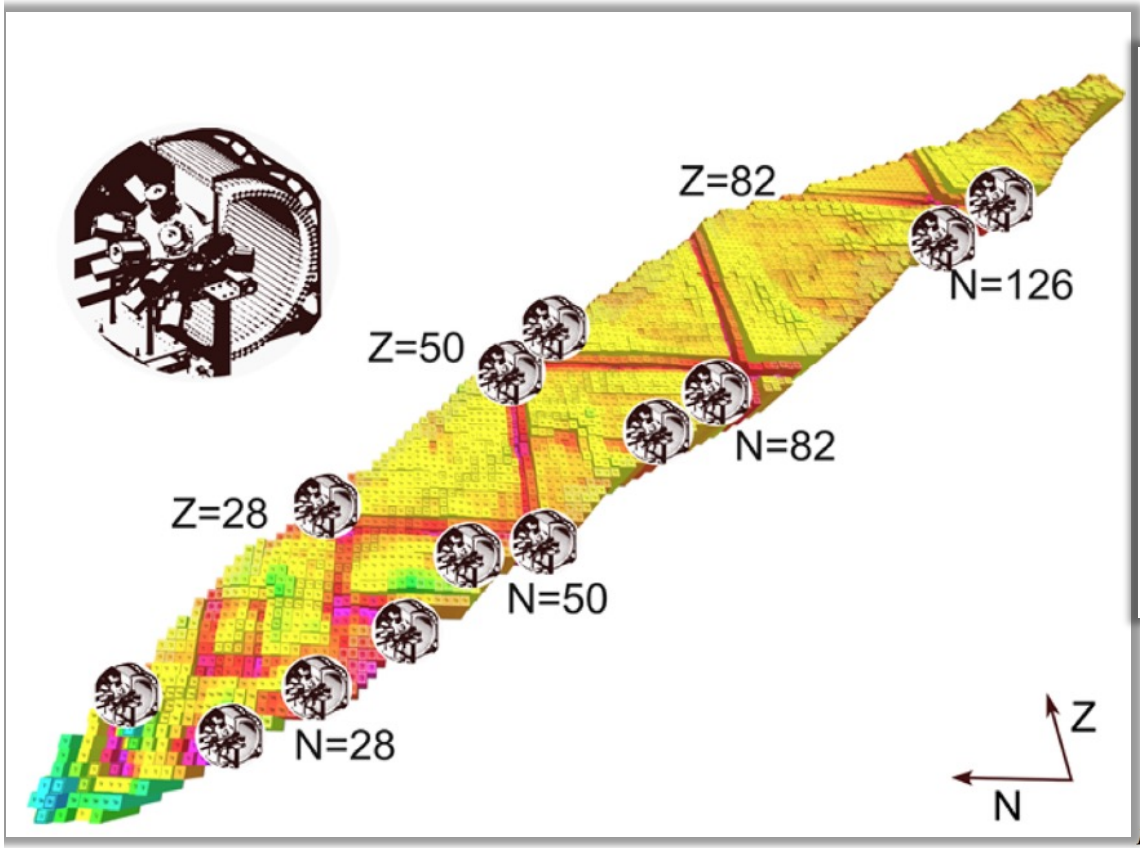
- Not all nuclei are equally important to constrain nuclear models
  - Nuclear theory, computational physics and experiment work in concert to identify key nuclei and properties
- The nuclear chart offers a rich playground to amplify the drivers of structural evolution
  - Access key nuclei and compare to theory to identify missing physics in models
  - Explore the chart and find surprises that lead to revisions of models
- Complementary techniques to probe the nuclear structure

# β decay studies at FRIB: Decay Station initiator (FDSi)

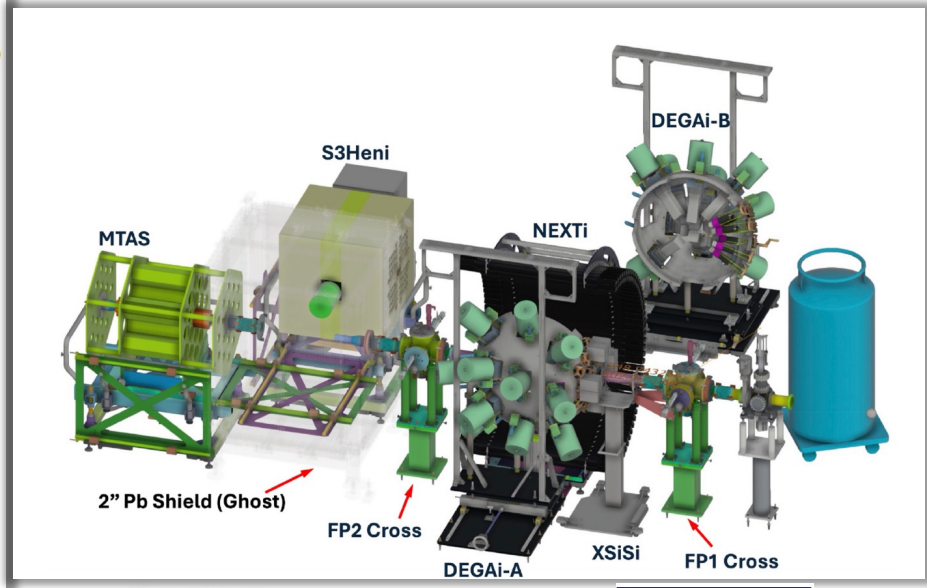



- Large community effort to put together a diverse set of detectors.
- Leadership at ORNL, ANL, Berkeley, MSU, and more.
- Ion implantation
- β-detection
- γ- detection – high resolution and TAS
- Neutron-detection
- Measuring decays across the nuclear chart for nuclear structure and astrophysics.

# Accepted FDSi experiments across the nuclear chart




FDSi in 2025

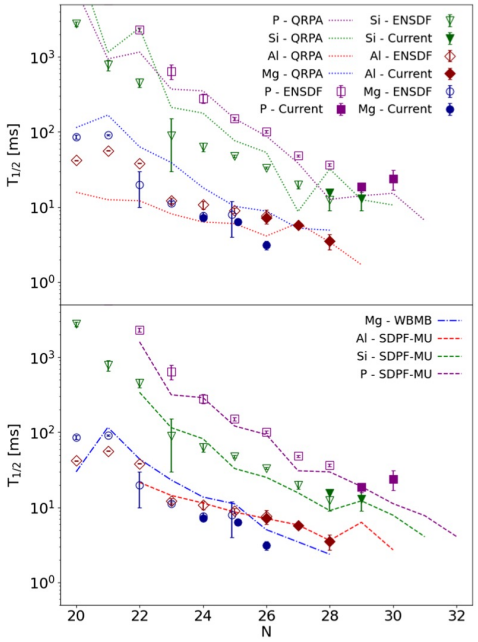



J. M. Allmond
*Physics Division, Oak Ridge National Laboratory*

R. Grzywacz
*Department of Physics and Astronomy, University of Tennessee*

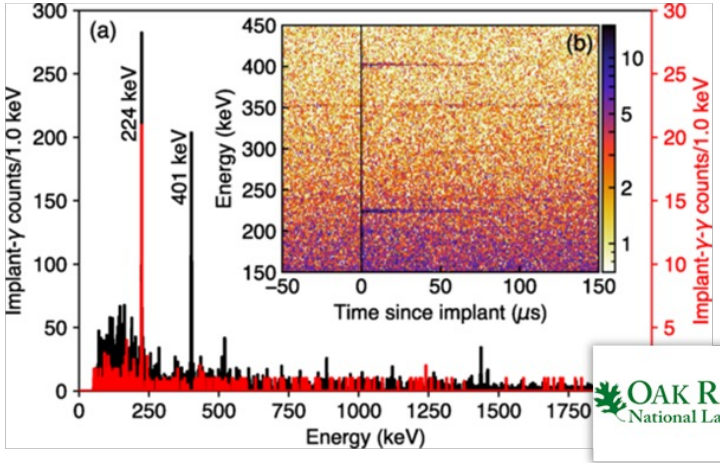
# First results from the FDSi at FRIB

First FRIB experiment: New half lives



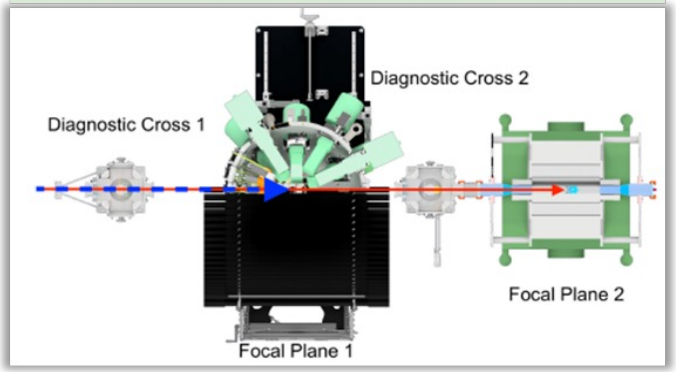

Crawford et al. PRL 129, 212501 (2022)

Discovery of unusually long-lived isomer in $^{32}$Na (24 μs) indicates onset of spherical-to-deformed shape inversion.




Gray et al. PRL 130, 242501 (2023)

First complete spectroscopy of $^{45}$Cl β-decay strength distribution – a new approach to probe proton shell structure in neutron-rich nuclei




Cox et al. PRL 132, 152503 (2024)

- Half-lives
- High-resolution γ-ray spectroscopy
- Total Absorption Spectroscopy
- β-delayed neutron emission
- Isomers

# Knocking into yet another region of structural change

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

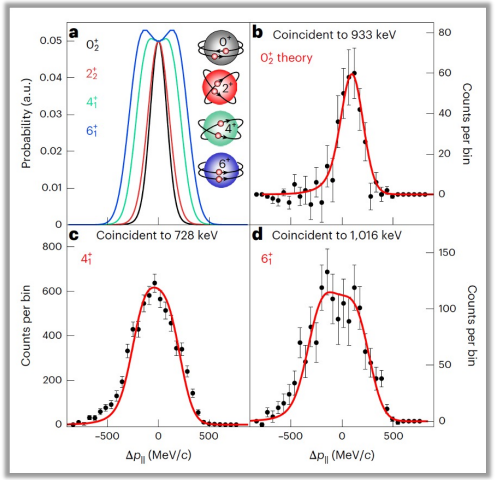
Received: 17 March 2024

Accepted: 24 September 2024

Published online: 18 October 2024

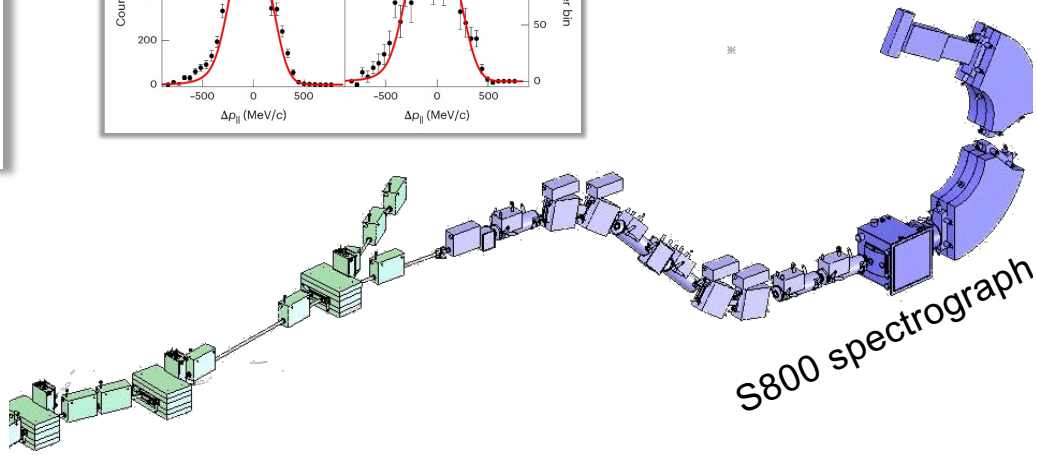
Check for updates

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]



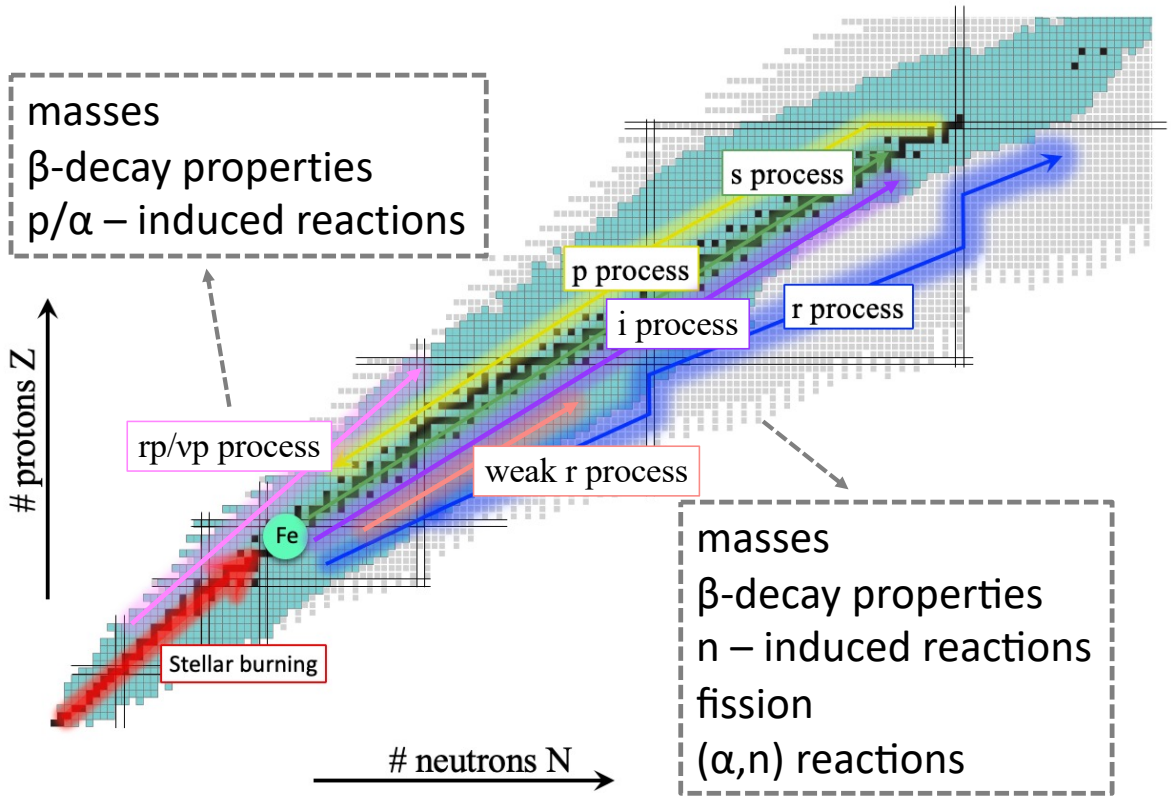


- $^{62}$Cr: member of the island of inversion
- 2p knockout from $^{64}$Fe to populate $^{62}$Cr
- Shape coexistence
- Rich ground for state-of-the-art theoretical models




First GRETINA experiment at FRIB

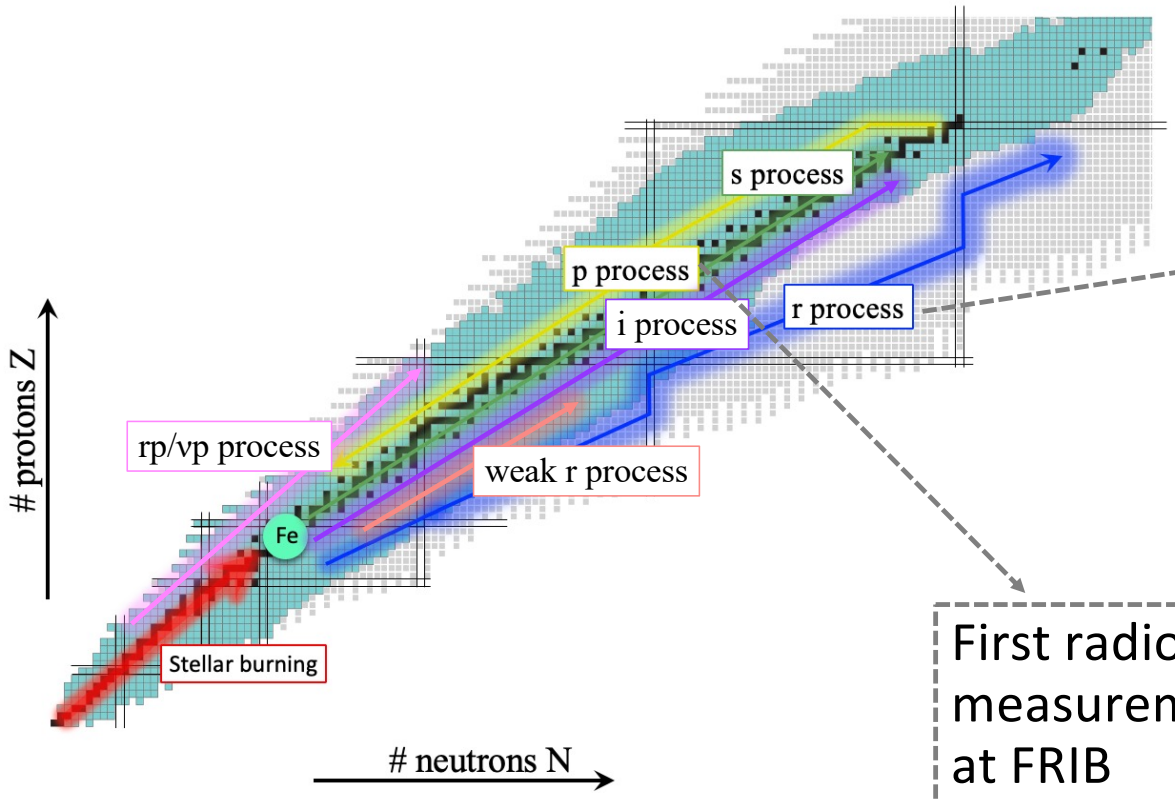
# Astrophysical Processes




Nucleosynthesis picture more complex than previously thought

- Each process has different **nuclear physics needs**
- Majority of processes involve **radioactive nuclei**
- Efforts in **nuclear experiment** to access and study these nuclei
- Efforts in **nuclear theory** to predict relevant quantities

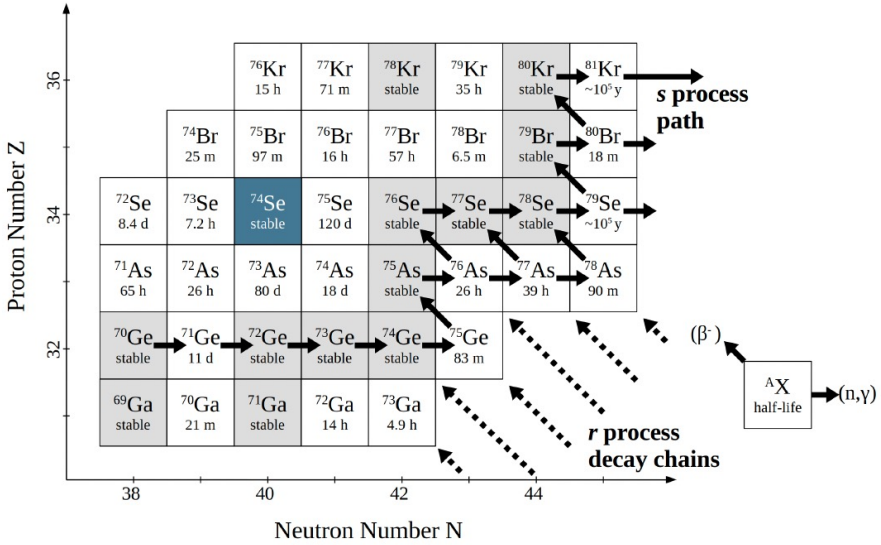
# Outline




Status and future of **r process** measurements at FRIB

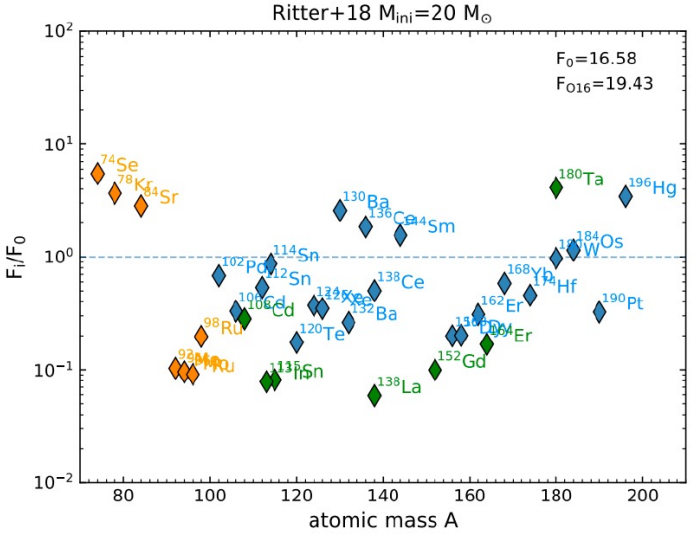
First radioactive beam measurement for the p process at FRIB

# Nucleosynthesis of proton-rich isotopes




- @ FRIB
- ReA standalone experiments: Long-lived radioisotopes used directly into the ion source

- 35 p nuclei
- Produced by photodisintegration reactions
- Astrophysical site: core-collapse or Type Ia SN
- Involve reactions on radioactive isotopes
- Abundances not well reproduced by models

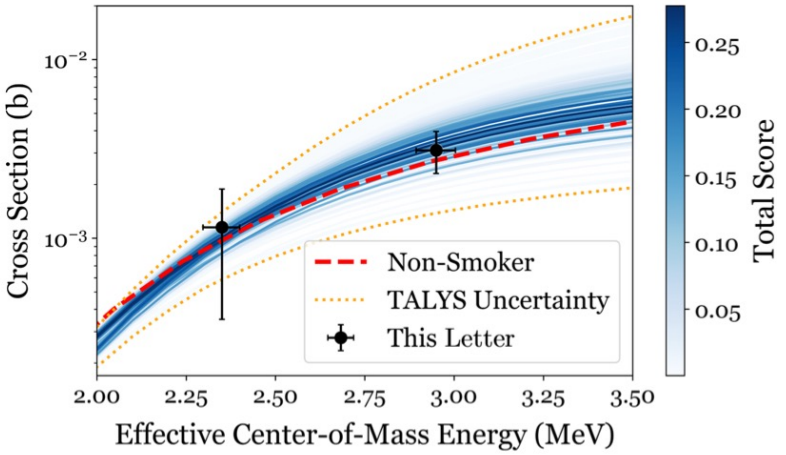


# Nucleosynthesis of proton-rich isotopes

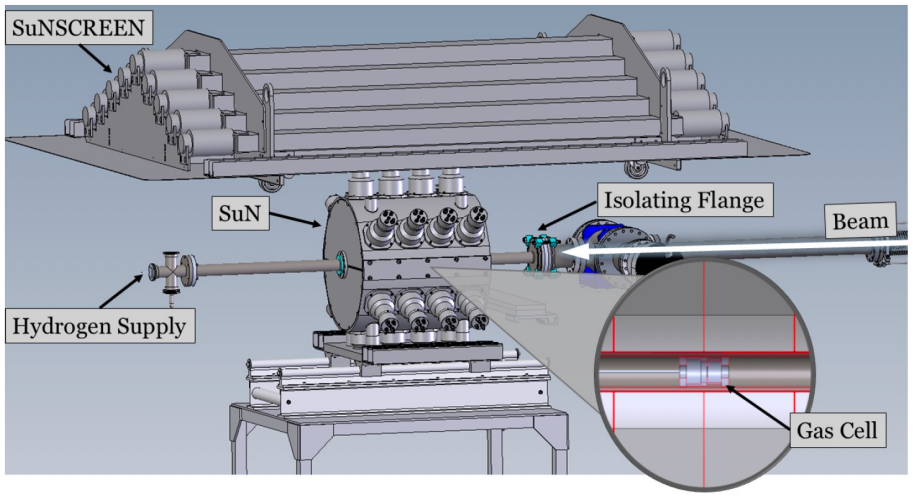
PHYSICAL REVIEW LETTERS **135,** 212701 (2025)

**Constraining the Synthesis of the Lightest *p* Nucleus $^{74}$Se**

A. Tsantiri,[1,2,3,*,†,††] A. Spyrou,[1,2,‡] E. C. Good,[1,§] K. Bosmpotinis,[1,2] P. Giuliani,[1] H. Arora,[4] G. Balk,[5] L. Balliet,[1,2] H. C. Berg,[1,2] J. M. Berkman,[1,6] C. Dembski,[7] P. DeYoung,[5] Pavel A. Denissenkov,[8,9,3,††,‡‡] N. Dimitrakopoulos,[4] A. Doetsch,[1,2] T. Gaballah,[10] R. Garg,[1] A. Henriques,[1] R. Jain,[1,2,‖] S. N. Liddick,[1,6] S. Lyons,[11] R. S. Lubna,[1] B. Monteagudo Godoy,[5] F. Montes,[1] S. Nash,[1] G. U. Ogudoro,[5] J. Owens-Fryar,[1,2] A. Palmisano-Kyle,[12] J. Pereira,[1] A. Psaltis,[13,14,3,††] A. L. Richard,[15,1] L. Roberti,[16,17,18,19,3,††] E. K. Ronning,[1,6] H. Schatz,[1,2] A. Sebastian,[1,2] M. Smith,[1,2] M. K. Smith,[1] C. S. Sumithrarachchi,[1] C. Tinson,[1,2] P. Tsintari,[4,¶] N. Ţubaro,[1,2,**] S. Uthayakumaar,[1] A. C. C. Villari,[1] E. Weissling,[5] and R. G. T. Zegers[1,2]




- Long standing question:
  Over and under production of lightest p nuclei
- Driving reactions involve radioactive nuclei
- Measured for the first time the $^{73}$As(p,γ)$^{74}$Se
- Overproduction of $^{74}$Se not caused by nuclear physics

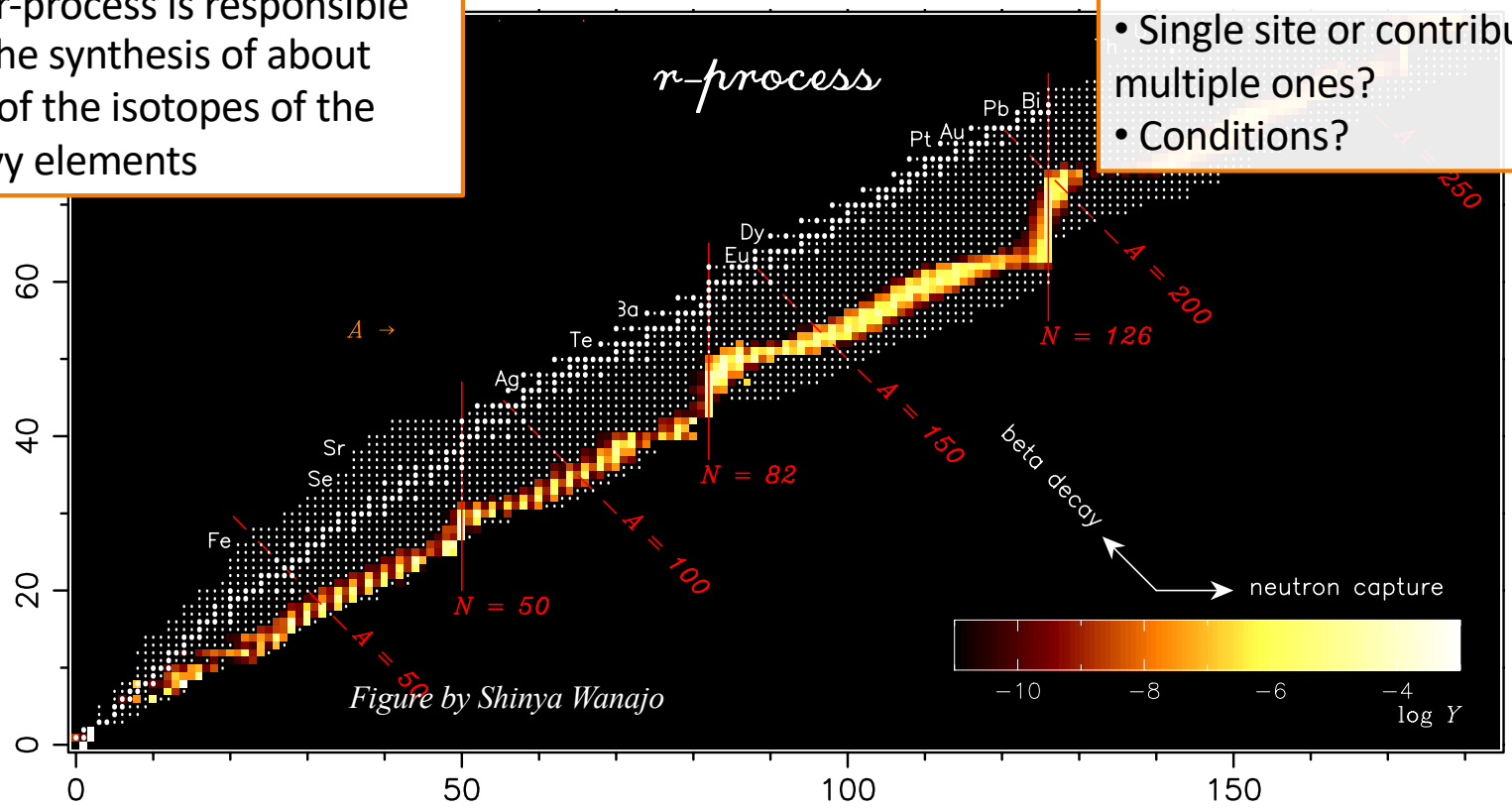



*Artemis Tsantiri*

# Astrophysical r process

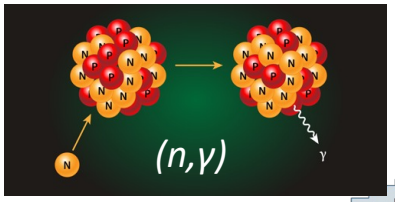
The r-process is responsible for the synthesis of about half of the isotopes of the heavy elements

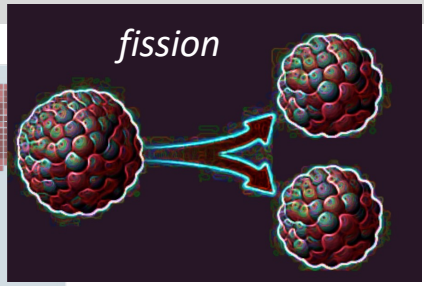
- What is the site of the r process?
- Single site or contributions from multiple ones?
- Conditions?



# r-process input: What's known?

- masses
- beta-decay rates
- beta-delayed neutron emission probabilities
- neutron capture rates

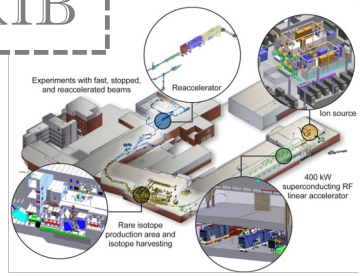



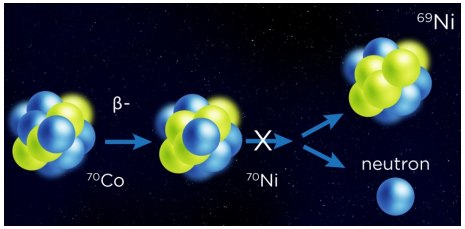







FRIB

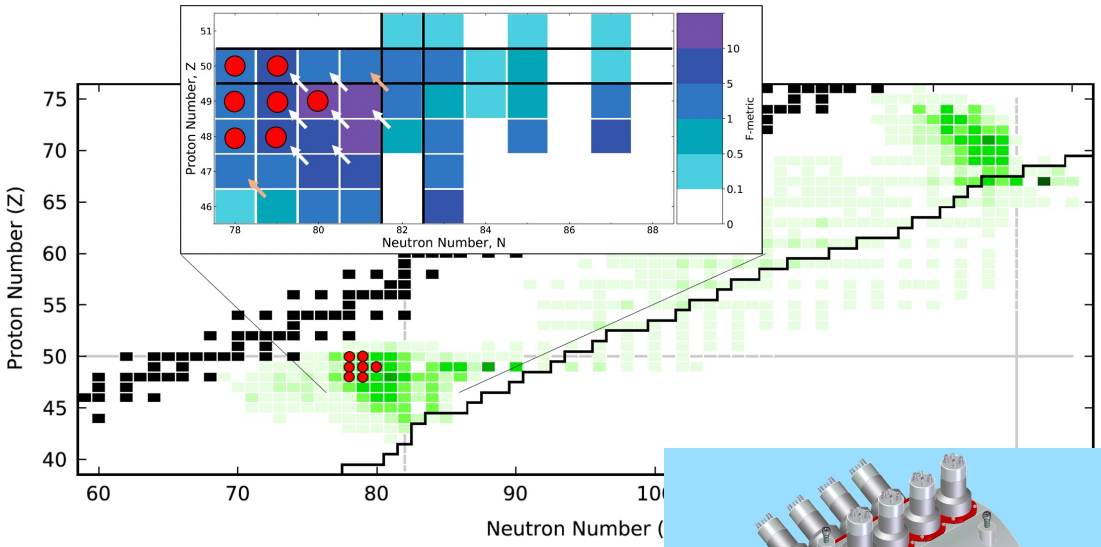



- fission rates
- fission product distributions
- neutrino interaction rates
- Equation of state

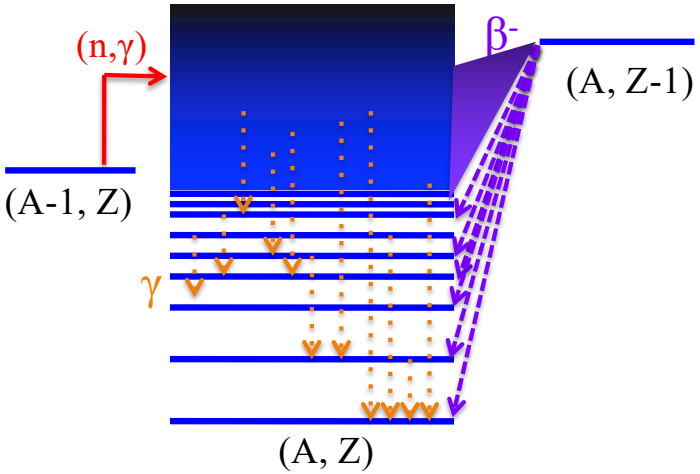
# Neutron Captures @ FRIB: β-Oslo method

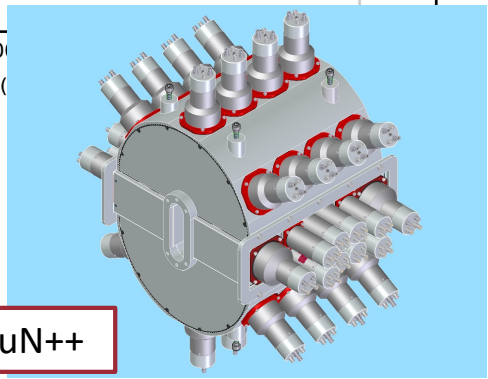
*Proposal: Spyrou & Muecher*




Experiment completed in June 2025

*Spyrou, Liddick, Larsen, Guttormsen, et al, PRL2014*



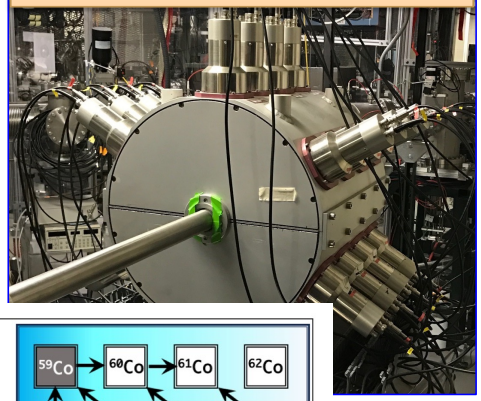
SuN++

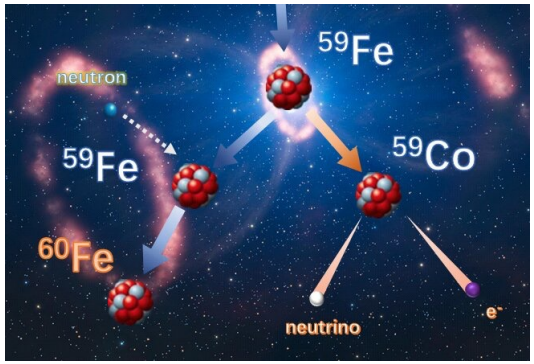
- Populating compound nucleus of interest
- Measuring γ rays and excitation energy
- Extracting statistical properties of the nucleus
- Experimentally constrained neutron-capture reaction rates

# Enhanced Production of $^{60}$Fe in Massive Stars

- $^{60}$Fe/$^{26}$Al γ-ray observations: models overpredict ratio
- Could the discrepancy come from uncertain nuclear reactions?
- $^{59}$Fe(n,γ)$^{60}$Fe reaction: dominates production of $^{60}$Fe
- Results: Higher production of $^{60}$Fe, Discrepancy persists

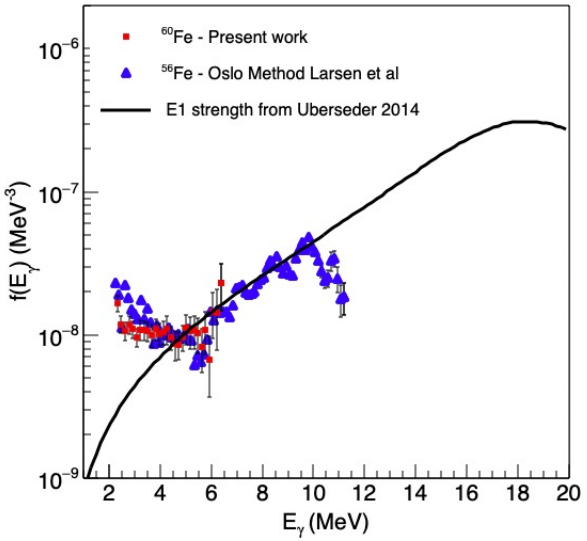
SuN
γ-Total Absorption Spectrometer

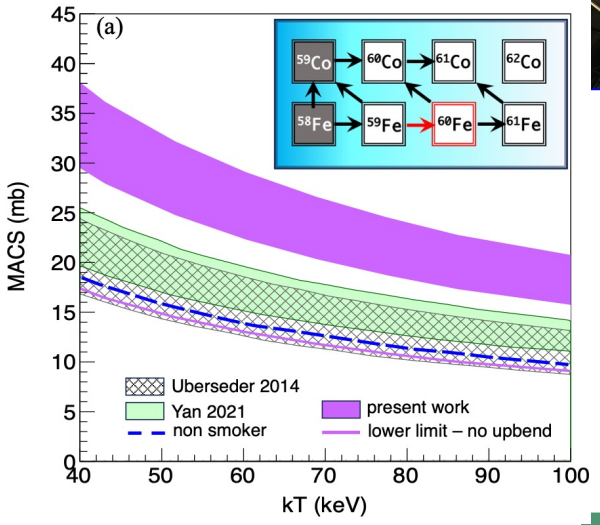





**Hauser – Feshbach (Statistical Model)**
- Nuclear Level Density (NLD)
- γ-ray strength function (γSF)
- Optical model potential

γ-ray Strength Function

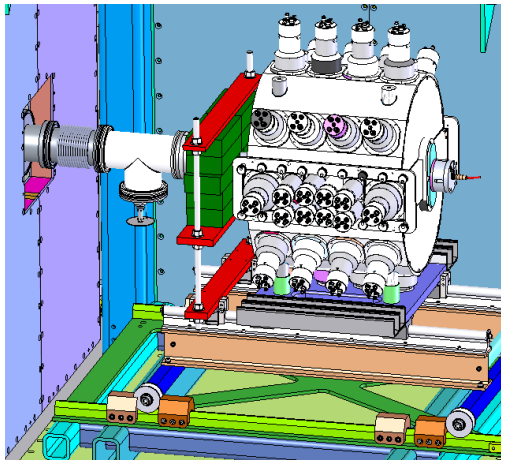


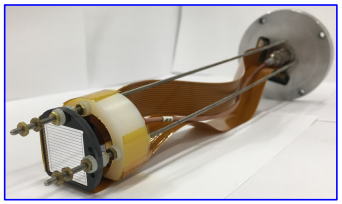






*Spyrou et al. Nature Com. (2024)*

# Online results





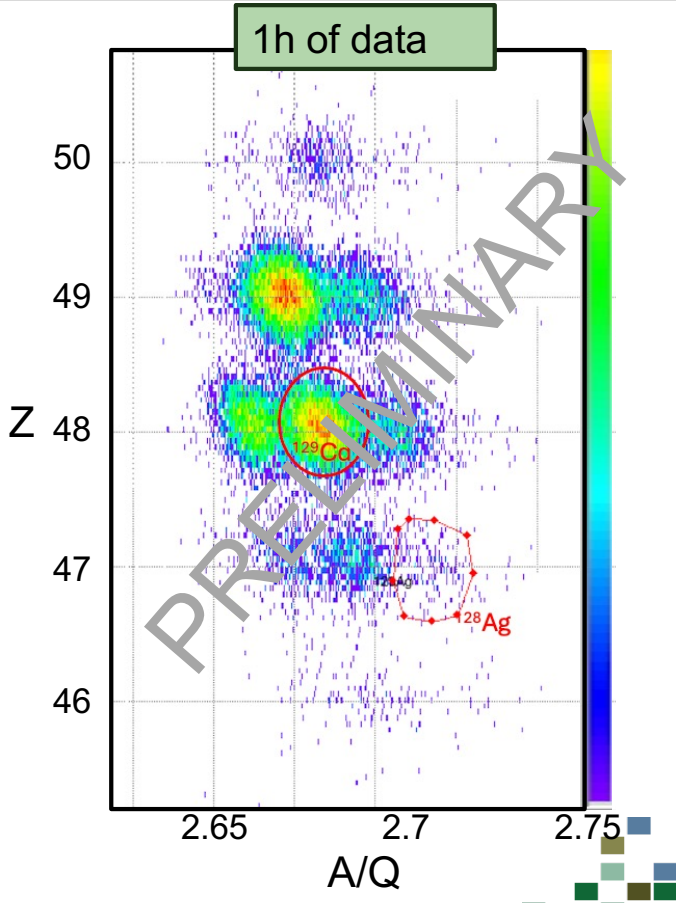
Setup

- Beam implanted in mini DSSD
- γ-rays measured by SuN++

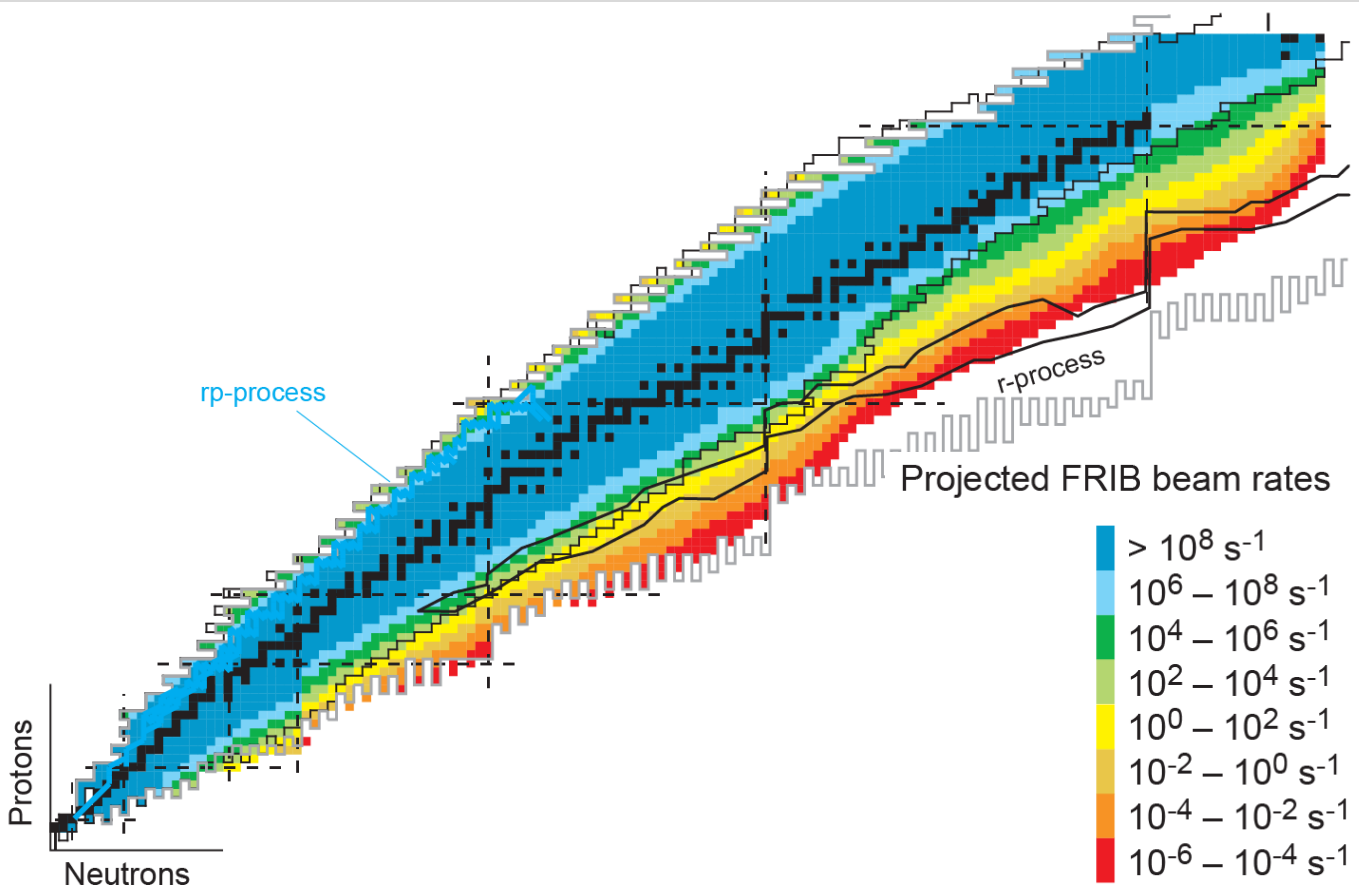
Jessica Berkman
(Liddick group)
MSU

Kostas Bosmpotinis
(Spyrou group)
MSU

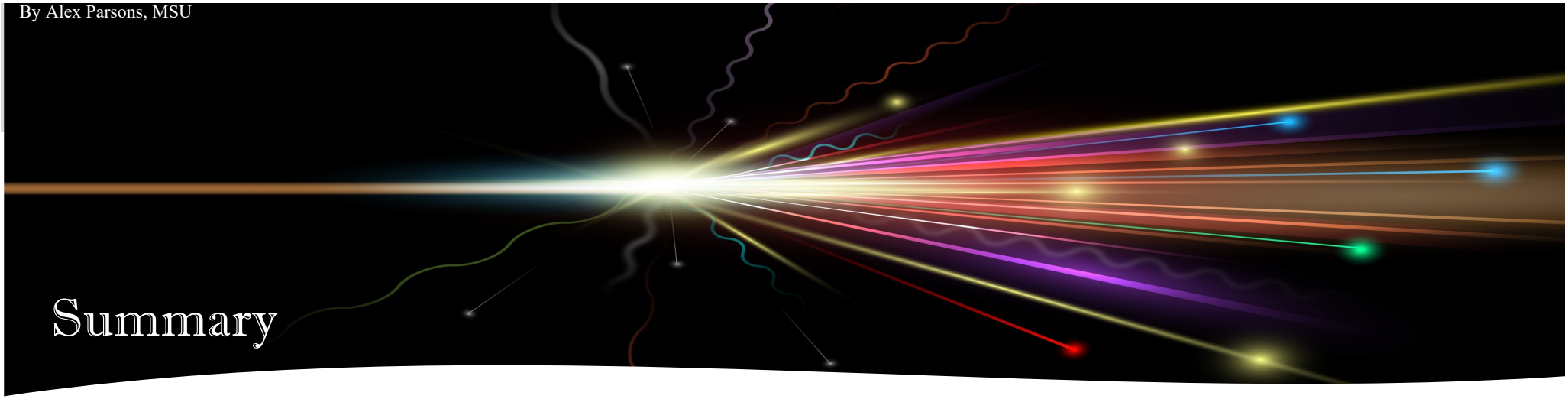
Chris Schlaier
(Muecher group)
Univ. Cologne



# Beam rates for a broad range of applications



By Alex Parsons, MSU



# Summary

- FRIB is up and running, providing beam to all areas, and ramping up capabilities
- Broad science program including
  - nuclear structure
  - nuclear astrophysics
  - fundamental symmetries
  - applications

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and by the National Science Foundation