Science and Status of the Facility for Rare Isotope Beams

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for the FRIB Laboratory and Project Team

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MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

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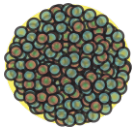
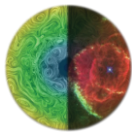
Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

FRIB Scientific Program



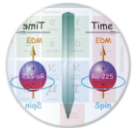
Properties of nuclei

- Develop a predictive model of nuclei and their interactions
- Rare isotopes to guide *ab Initio*, Configuration Space, DFT models
- Define the limits of elements and isotopes
- Many new cases of halo and large neutron-skin nuclei for study



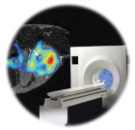
Astrophysical processes

- Origin of the elements in the cosmos
- Use element abundances for stellar history
- Modeling explosive environments: novae, supernovae, X-ray bursts …
- Properties of neutron stars



Tests of fundamental symmetries

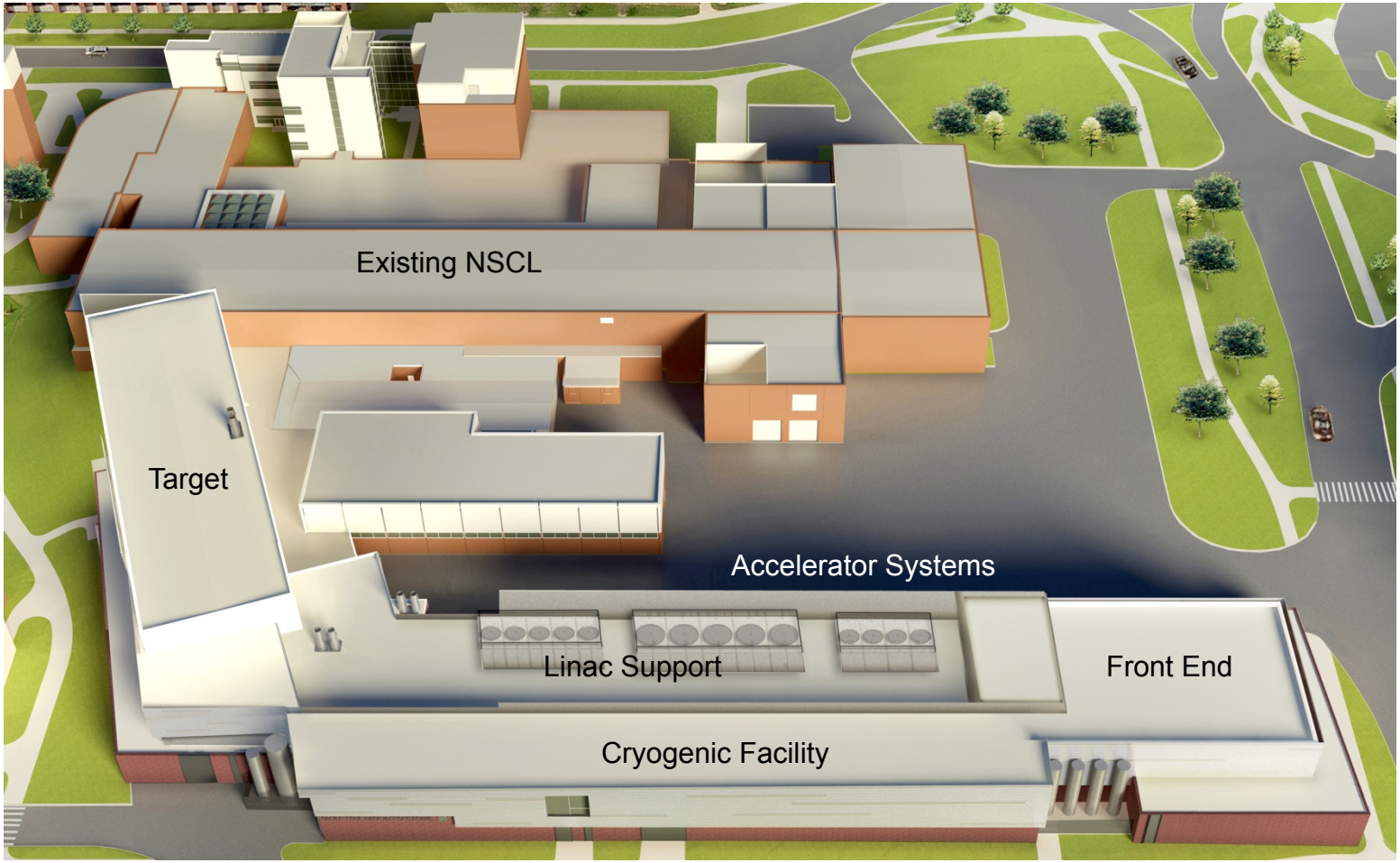
- Effects of symmetry violations are amplified in certain nuclei, e.g., EDM



Societal applications and benefits

- National security, environment, energy, material sciences, …

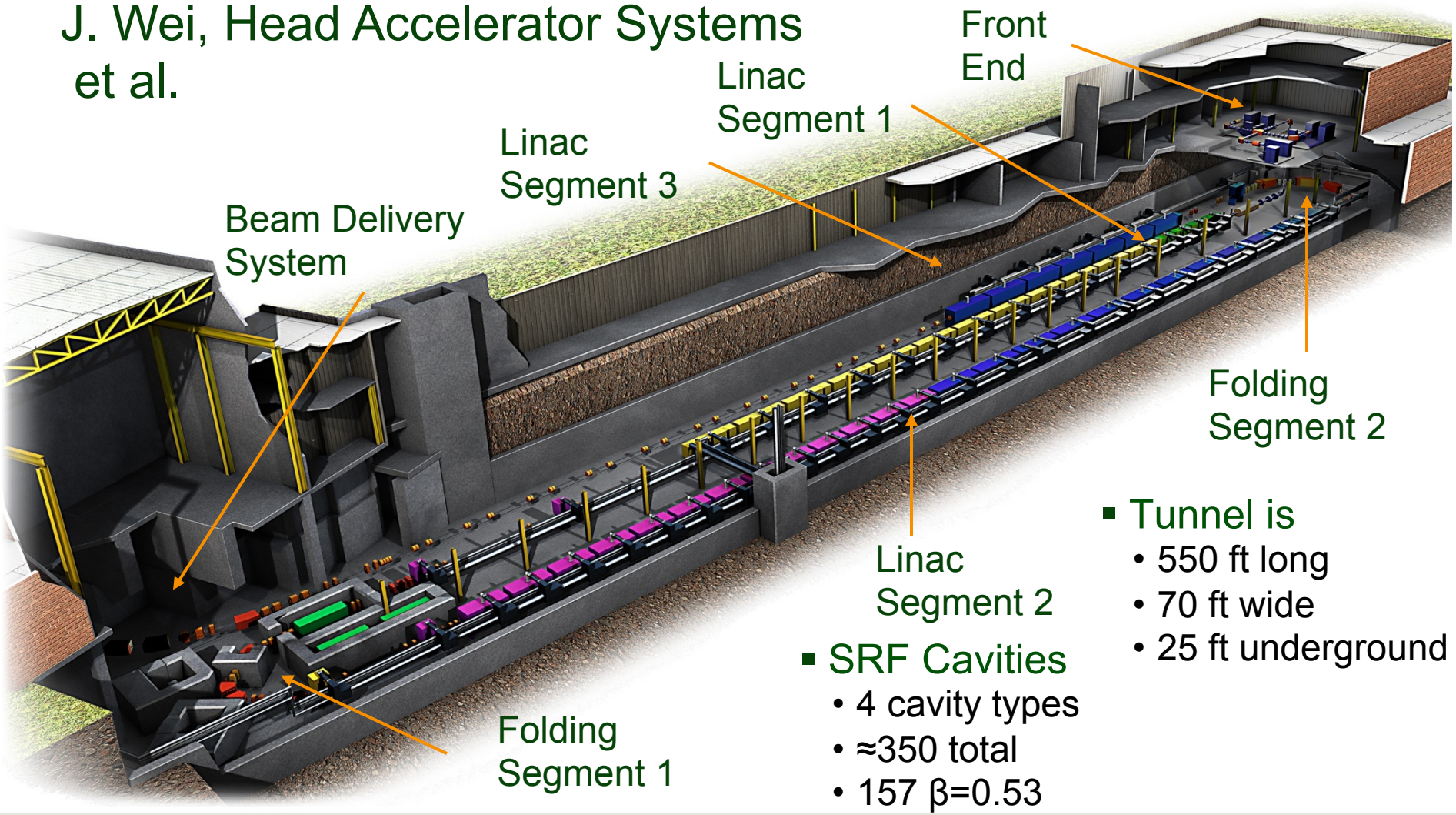
Overview of the FRIB Facility



T. Glasmacher, Project Leader C.K. Gelbke, Laboratory Director

FRIB Driver Linear Accelerator

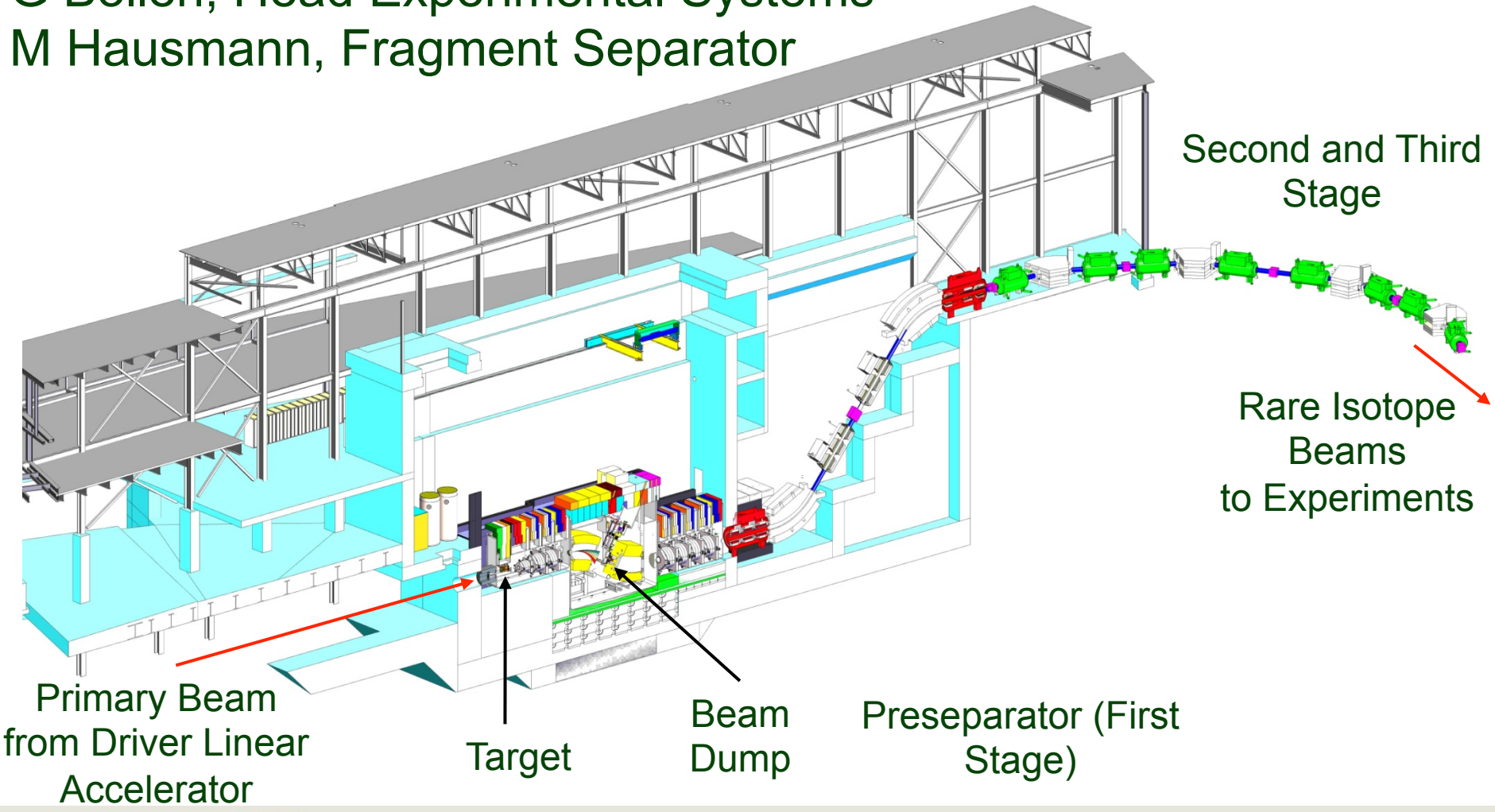
J. Wei, Head Accelerator Systems et al.



- Tunnel is
  - 550 ft long
  - 70 ft wide
  - 25 ft underground
- SRF Cavities
  - 4 cavity types
  - ≈350 total
  - 157 β=0.53

Isotope Production Area
Target and Fragment Separator

G Bollen, Head Experimental Systems
M Hausmann, Fragment Separator



Working with many labs in US and Worldwide
13 Active Work-for-Others Agreements and 14 Active MOUs

- Argonne National Laboratory (3+1*)
  - Liquid lithium charge stripper; Stopping of ions in gas; Fragment separator design; Beam dynamics; SRF; gas cell
- Brookhaven National Laboratory (3)
  - Radiation resistant magnets; Plasma charge stripper*
- Fermilab (1)
  - Diagnostics
- Jefferson Laboratory (4)
  - Cryogenics; SRF
- Lawrence Berkeley National Laboratory (2*)
  - ECR ion source; Beam dynamics*
- Oak Ridge National Laboratory (2)
  - Target facility; Beam Dump R&D
- Stanford National Accelerator Lab. (2*)
  - SRF multipacting*
- Budker Inst. of Nuclear Physics (Russia)
  - Production target
- GANIL (France)
  - Production target
- GSI (Germany)
  - Production target
- Legnaro (Italy)
  - SRF
- RIKEN (Japan)
  - Charge strippers
- Sandia
  - Production target*
- Soreq (Israel)
  - Production target*
- TRIUMF (Canada)
  - SRF

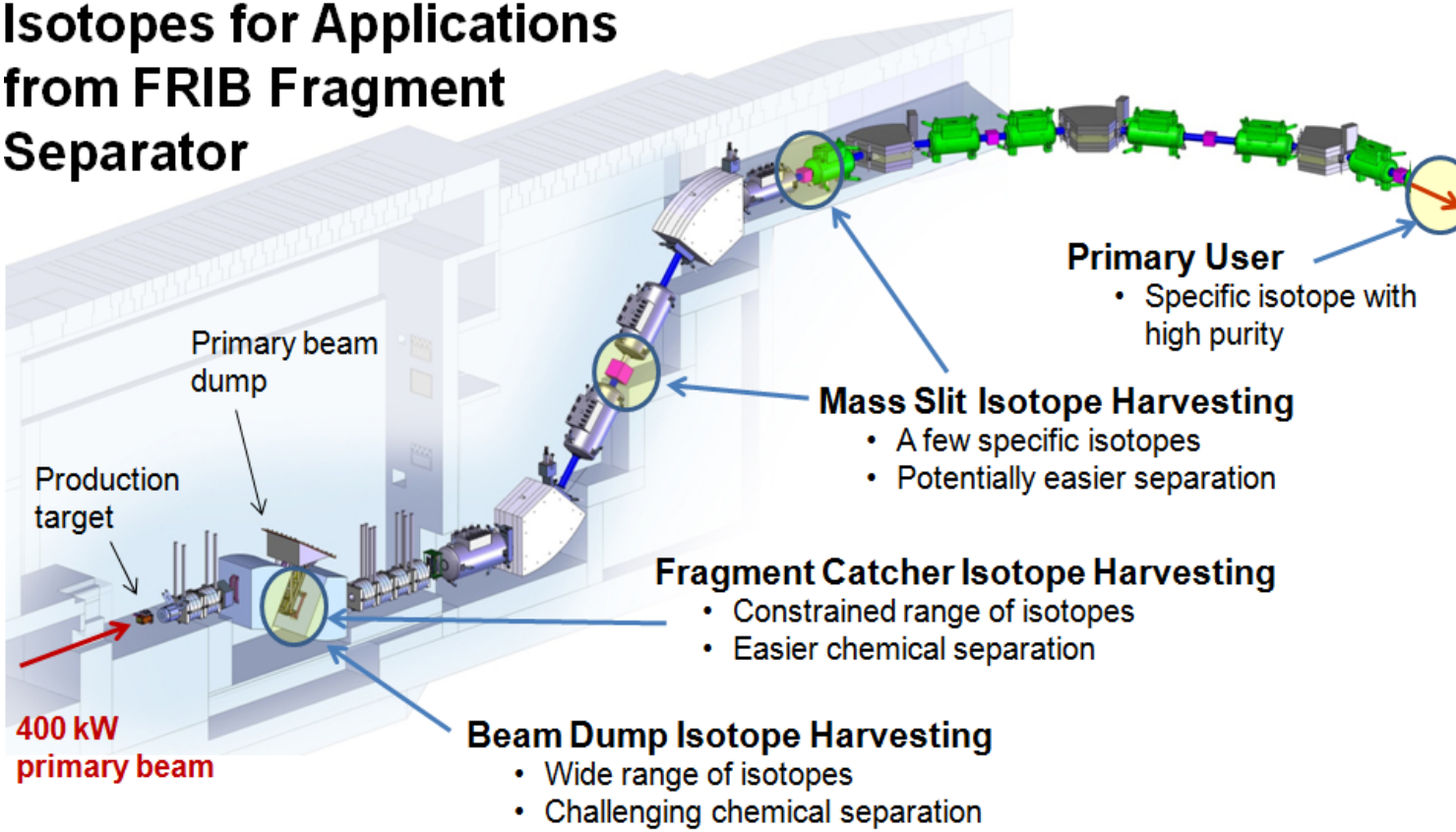
* completed

Features of FRIB

- Heavy Ion, superconducting linear accelerator with 400 kW beam power at 200 MeV/u
- 400kW corresponds to a ^{136}Xe beam of 8×10^{13} ion/s and a sensitivity to production cross sections as low as 2×10^{-6} pb.
- ^{238}U intensity of 5×10^{13} ion/s
- FRIB laboratory will have beams of rare isotopes at a wide range of energies
  - Thermalized beams for trapping, laser spectroscopy, etc.
  - Reaccelerated beams to 15 MeV/u (goal) with 15 – 22 MeV/u depending on A/Q)
  - Fast beams up to 250 MeV/u (used in-flight with no slowing)
- Multi-user capability

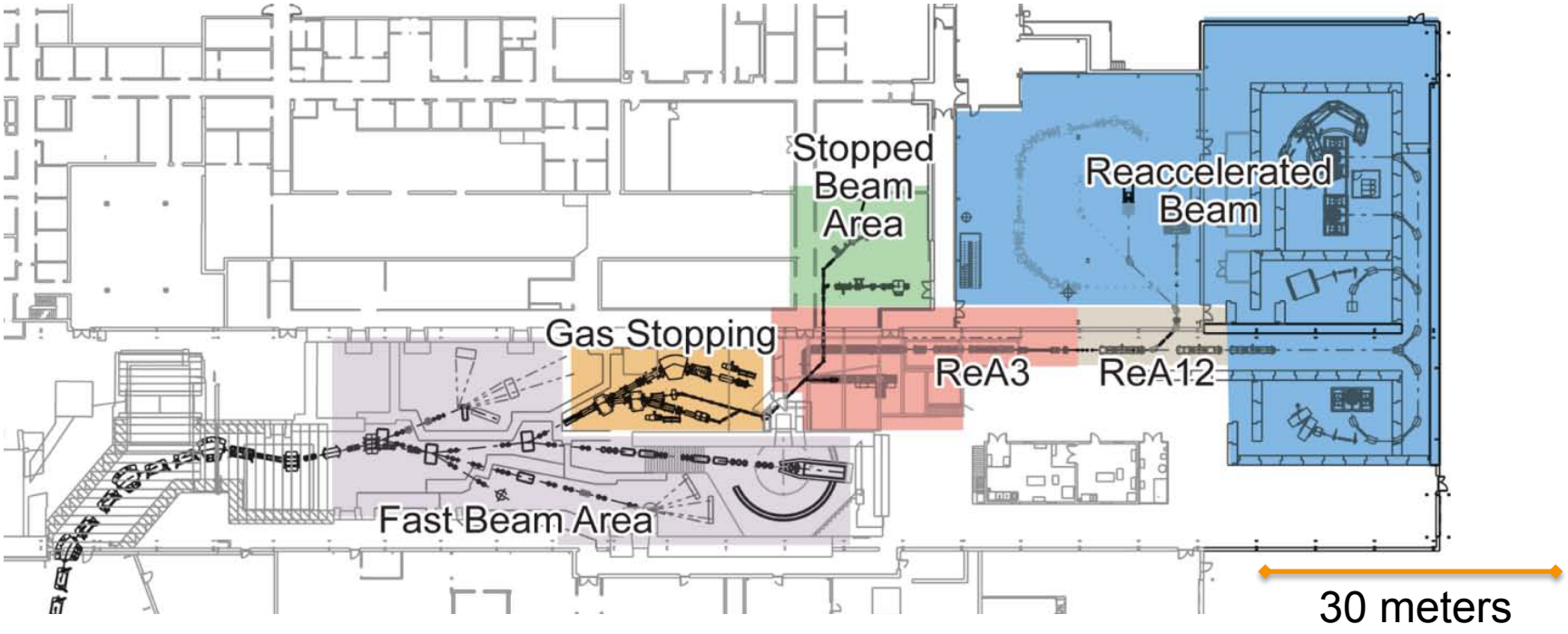
Multi-User Options at FRIB

- Stopped beam experiments using material from the beam dump and slits
- Targets, Ion Source material for other labs
- Transport of material to ReAX
- New hire at NSCL to begin development

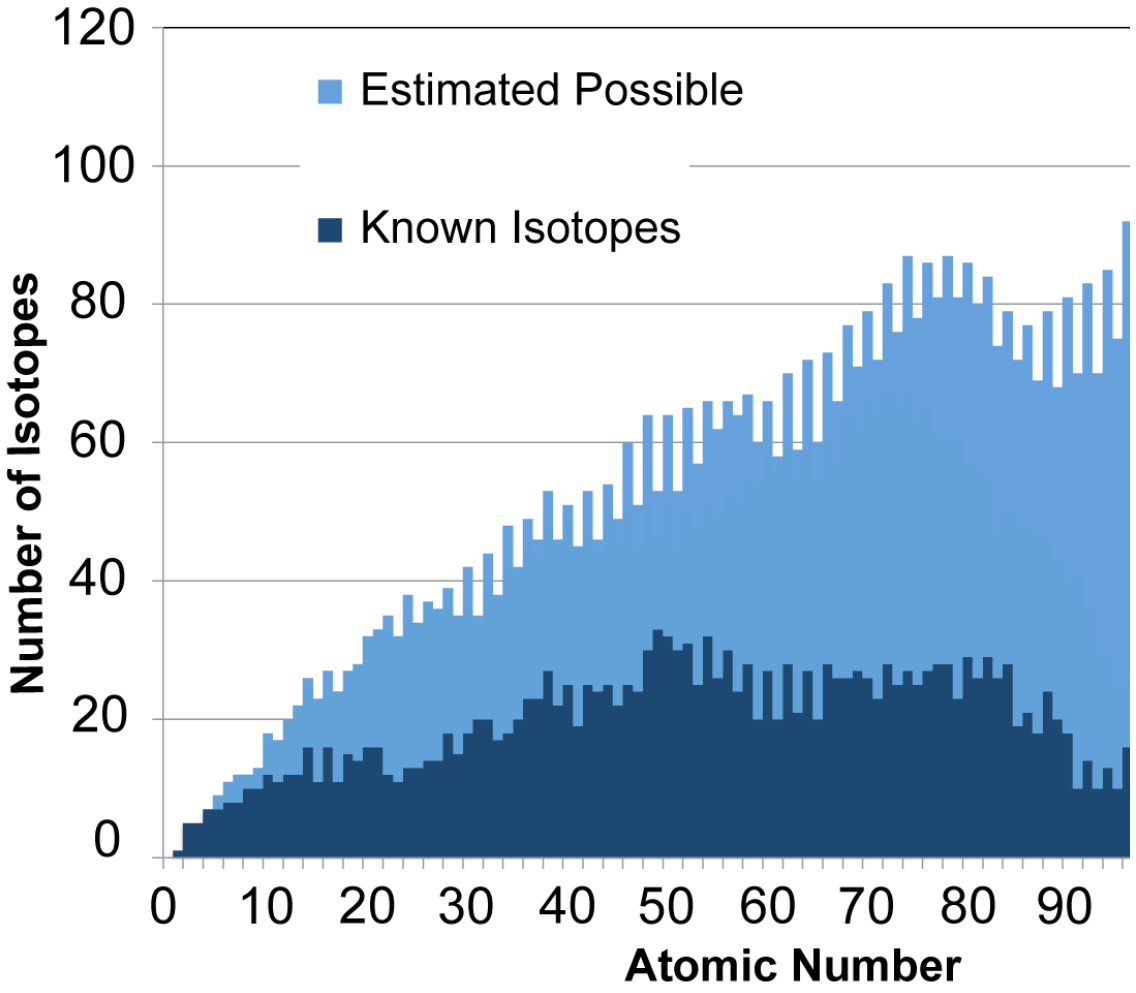


Overview FRIB Reaccelerators, and Experimental Stations

- Fast, stopped, and reaccelerated beam capabilities
- ReA12 experimental hall is ready for occupancy
- ReA12 is not fully funded but was well reviewed by NSF, MSU will move forward with ReA6
- Room for 3-4x expansion of the experimental areas

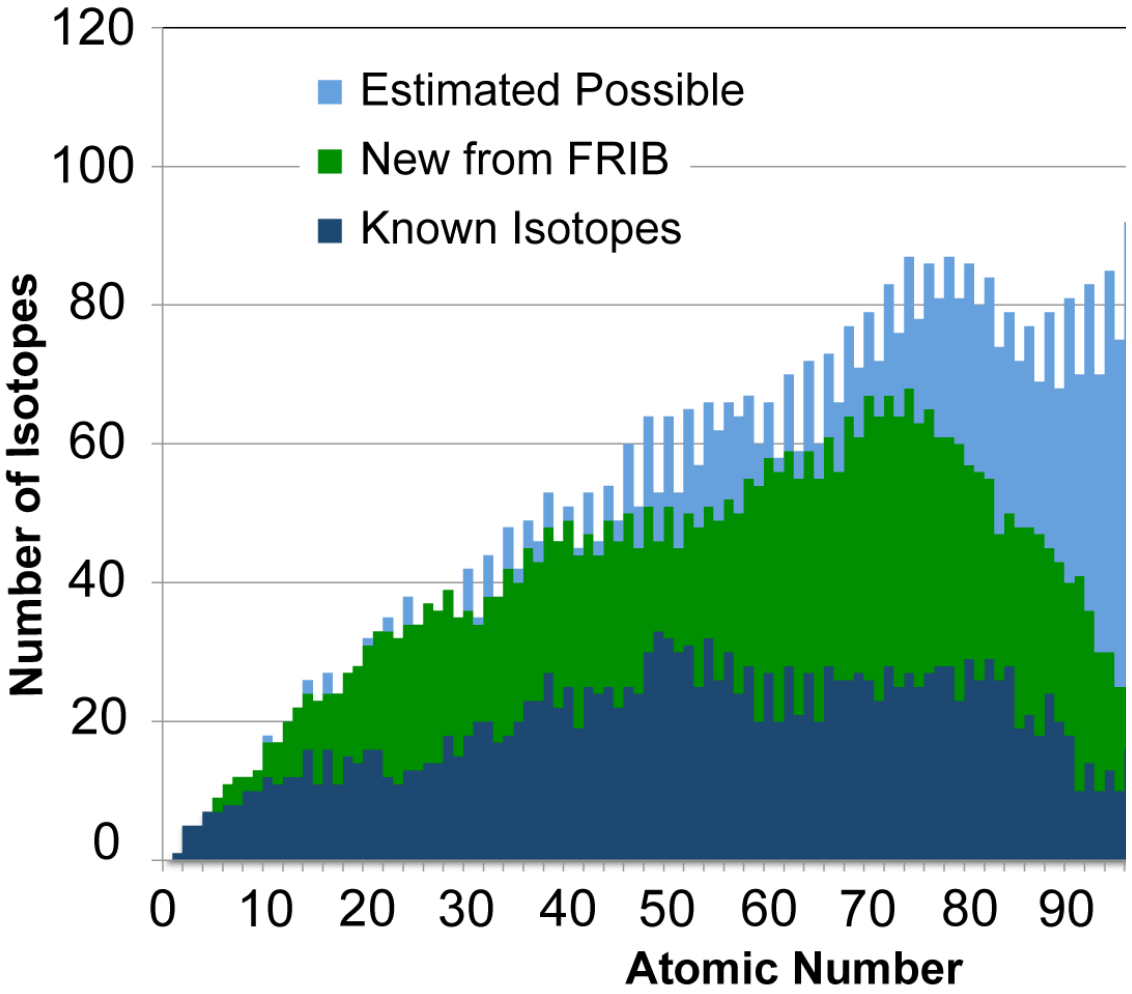


How many isotopes might exist?



- Estimated Possible: Erler, Birge, Kortelainen, Nazarewicz, Olsen, Stoitsov, Nature 486, 509–512 (28 June 2012) , based on a study of EDF models
- “Known” defined as isotopes with at least one excited state known (1900 isotopes from NNDC database)
- The neutron drip line has only been determined to oxygen

The Number of Isotopes Available for Study at FRIB



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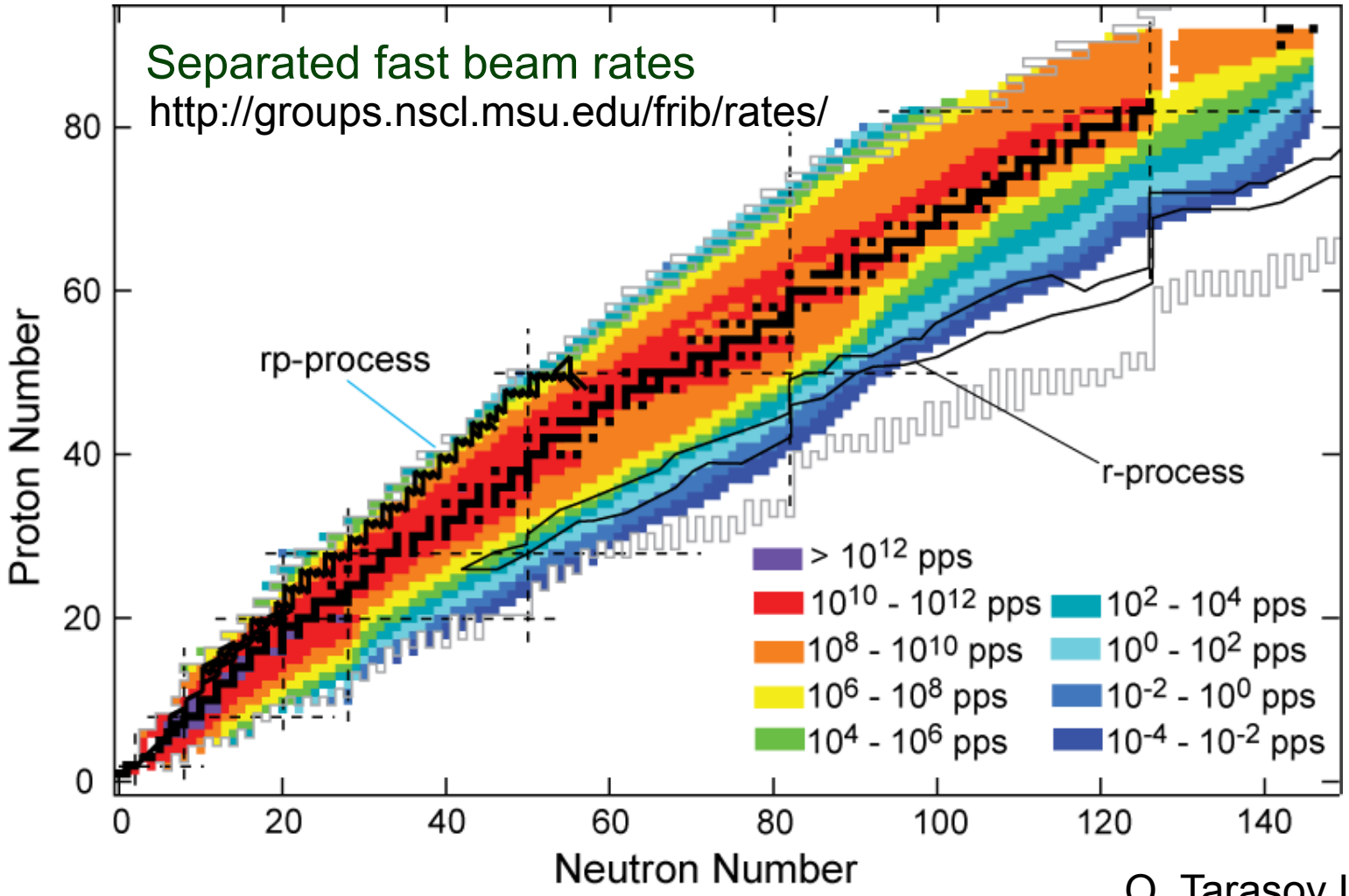
- “Known” defined as isotopes with at least one excited state known (1900 isotopes from NNDC database)
- For Z<90 FRIB is predicted to make > 80% of all possible isotopes

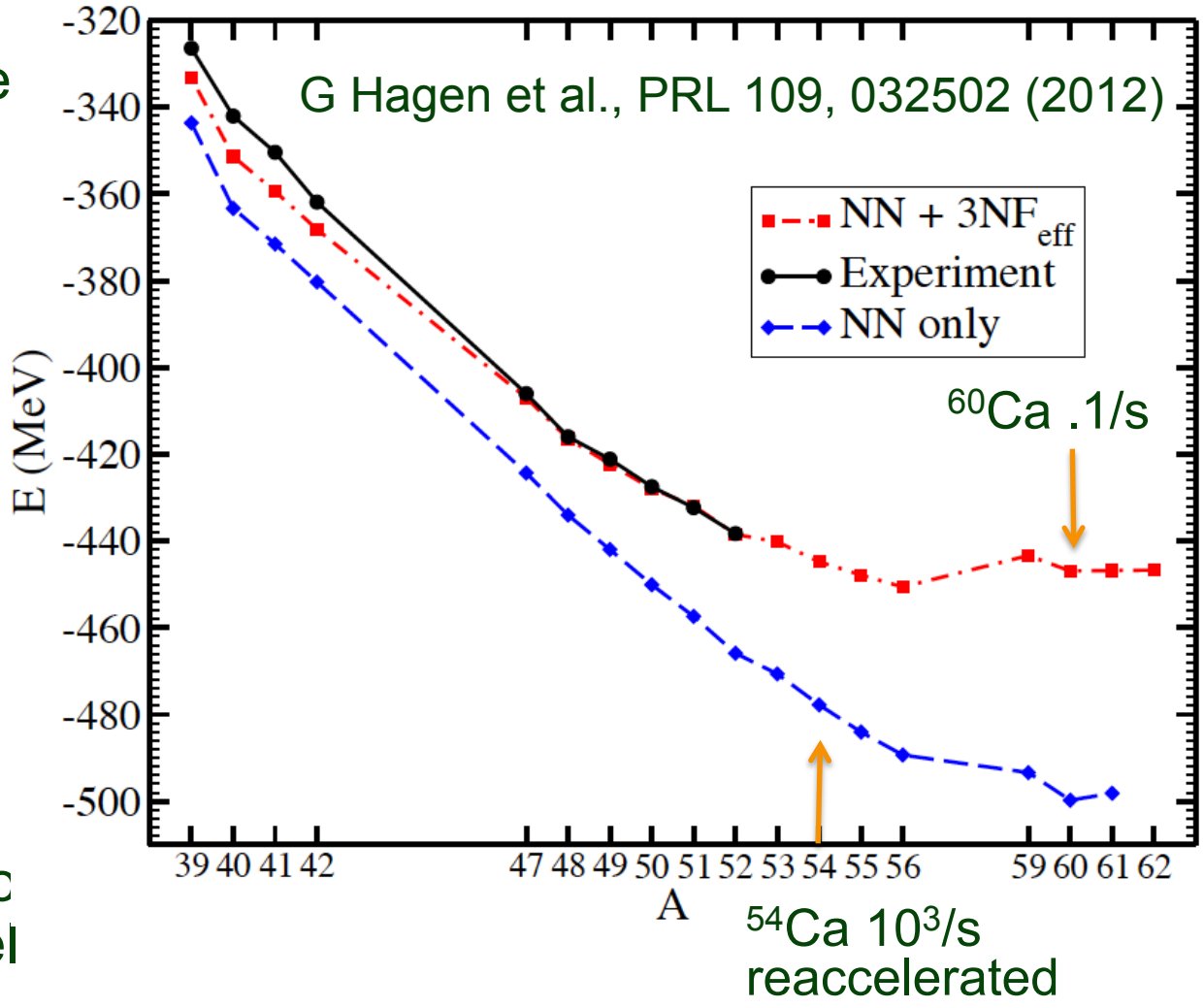
The Reach of FRIB



O. Tarasov LISE++

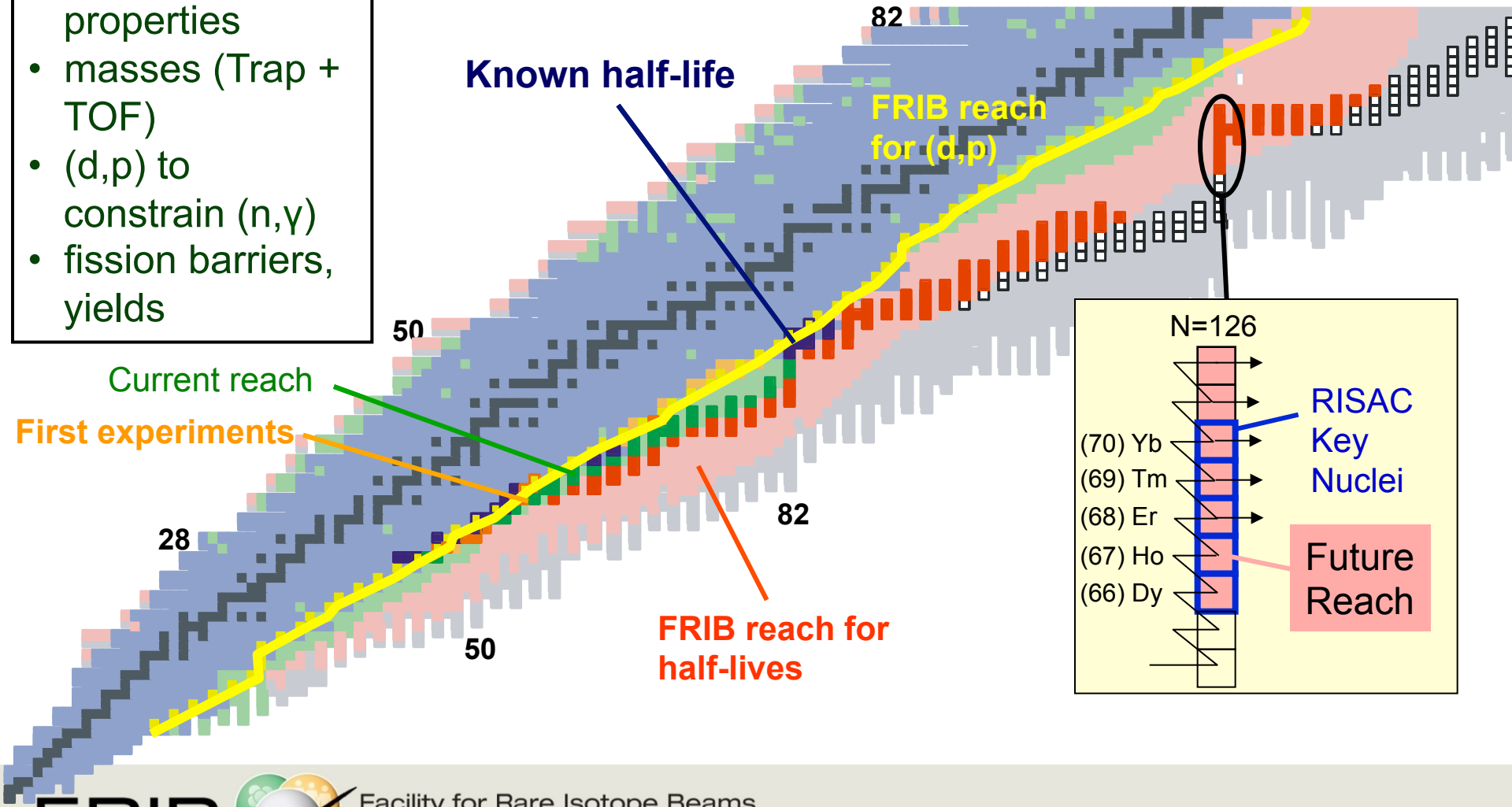
Example: Heavy Calcium Isotopes

- Chiral effective field theory and compute the binding energies and low-lying excitations of calcium isotopes with the coupled-cluster method.
- 3NF tends to reduce the binding
- What is the nature of heavy Ca isotopes?
- Need for GRETA
- FRIB will produce out to ^{68}Ca at the atom/w level



Reach of FRIB – Will Allow Modeling of the r-Process

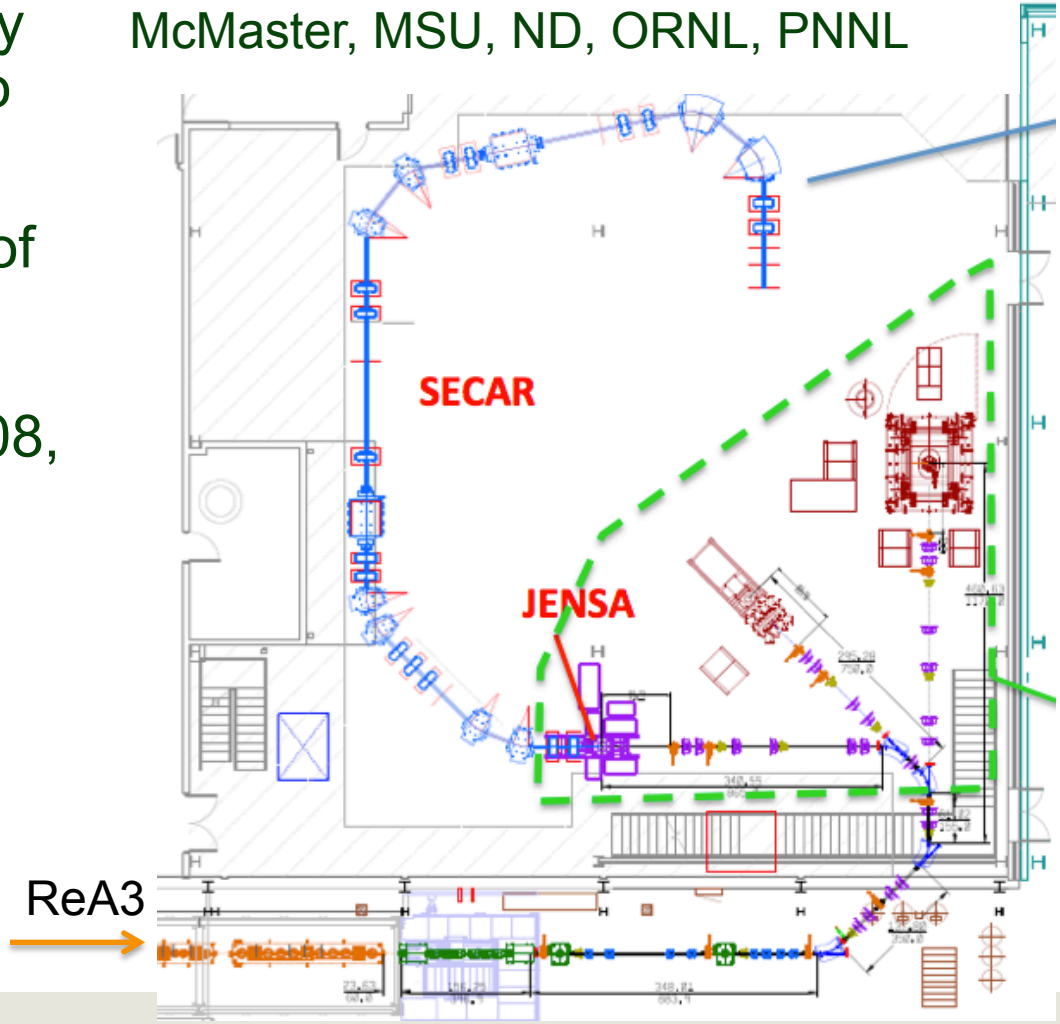
- β-decay properties
- masses (Trap + TOF)
- (d,p) to constrain (n,γ)
- fission barriers, yields



Reaccelerated Beam Example: Direct Determination of Key Reaction Rates

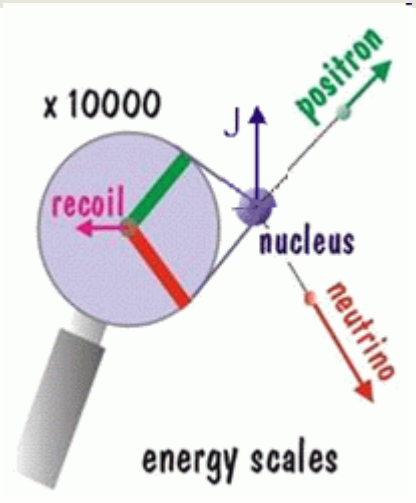
- ONe novae outbursts are enhanced in elements as heavy as Ca; Si isotope ratios used to identify nova meteoritic grains.
- Key reaction for the synthesis of these elements is $^{30}P(p,\gamma)^{31}S$ reaction. Recent experimental work DT Doherty et al., PRL 108, 262502 (2012)
- FRIB rate of ^{30}P $1x10^{9}$ /s
- Other reactions: If interesting $^{15}O(\alpha,\gamma)^{19}Ne$
- FRIB rate of ^{15}O is $1x10^{12}$/s

Collaboration: ANL, CSM, JINA, LSU, McMaster, MSU, ND, ORNL, PNNL

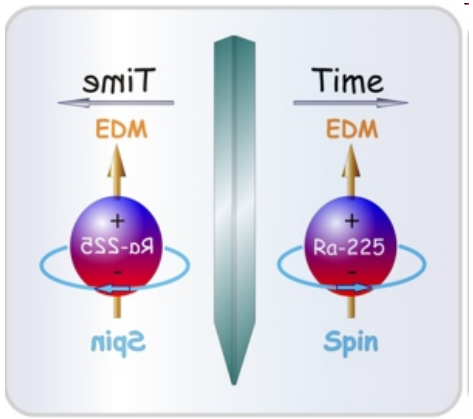


Are the fundamental interactions that are basic to the structure of matter fully understood?

- Angular correlations in β-decay and search for scalar currents
  - Mass scale for new particle comparable with LHC
  - ^{6}He and ^{18}Ne at 10^{12}/s
- Electric Dipole Moments
  - ^{225}Ra, ^{223}Rn, ^{229}Pa (10,000x more sensitive than ^{199}Hg; ^{229}Pa > 10^{10}/s)
- Anapole moment in Fr atoms
  - Understanding of weak interactions in nuclei (francium isotopes; 10^{10}/s)
- Unitarity of CKM matrix
  - V_{ud} by super allowed Fermi decay
  - Probe the validity of nuclear corrections



Savard et al.



$$\begin{vmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix}$$

How can the knowledge and technological progress provided by nuclear physics benefit society?

- Reaction rates important for stockpile stewardship and nuclear power – related to astrophysics network calculations
  - Determination of extremely high neutron fluxes by activation analysis
  - Rare isotope samples for (n,γ), (n,n'), (n,2n), (n,f) e.g. ^{88,89}Zr
    - » Same technique important for astrophysics
  - More difficult cases studied via surrogate reactions (d,p), (^{3}He,α xn) …
- Isotopes for medical research (commensal collection)
  - Examples: ^{47}Sc, ^{62}Zn, ^{64}Cu, ^{67}Cu, ^{68}Ge, ^{149}Tb, ^{153}Gd, ^{168}Ho, ^{177}Lu, ^{188}Re, ^{211}At, ^{212}Bi, ^{213}Bi, ^{223}Ra (DOE Isotope Workshop)
  - α-emitters ^{149}Tb, ^{211}At: potential treatment of metastatic cancer
  - Cancer therapy of hypoxic tumors based on ^{67}Cu treatment/^{64}Cu dosimetery
- Tracers for Marine Studies (^{32}Si), Spin probes for advanced materials (^{8}Li), industrial tracers (^{7}Be, ^{210}Pb, ^{137}Cs, etc.), …

FRIB Users Organization

FRIB Users Organization
FACILITY FOR RARE ISOTOPE BEAMS

- Users are organized as part of the independent FRIB Users Organization
  - FRIBUO has 1240 members (92 US Colleges and Universities, 10 National Laboratories, 53 countries) as of 16 August 2012
  - Chartered organization with an elected executive committee (Chair is Michael Smith, ORNL)
  - FRIBUO has a Theory organization + 20 working groups on experimental equipment
- Science Advisory Committee
  - Review of equipment initiatives (Feb. 2011)
  - Review of FRIB Integrated Design (March 2012)
- Low-Energy Community Meeting with NS2012 at ANL 17-18 Aug.

August 2011
Joint Users Meeting
284 participants

fribusers.org

FRIB On Track, Moving Toward Construction

- Conceptual design — completed 9/2010 (CD-1)
- Preliminary design — 2010-2012
  - Cost and schedule reviewed in April 2012 "…the FRIB design is technically sound; the cost estimate and project schedule are complete and reasonable; and the requirements for a Critical Decision (CD) 2 and 3a (Approve Performance Baseline and Start of Conventional Facilities Construction) have been appropriately addressed within the context of the draft Project Execution Plan (PEP)."
- Site preparation continues — 2012 ($51M federal spent)
  - Civil construction pending DOE approval
- Final design — 2012-2013
  - CD-3B (technical) review in 2013
- NSAC LRP Implementation Subcommittee Report Jan. 2013
- Technical construction begins — 2013 (expect $80M federal spent, 16%)
- Early project completion — 2019
- Project completion — 2021
- Total project cost — $680M ($585 Federal)

FRIB Site Ready for Civil Construction

- Ready to begin civil construction upon approval from DOE
- Site preparation is substantially complete; placement of pilings for the earth retention system is underway
- Live web cameras are linked from frib.msu.edu

Summary

- FRIB will be a next-generation high-power RIB facility for new science opportunities with rare isotopes
  - Properties of nucleonic matter
  - Nuclear processes in the universe
  - Tests of fundamental symmetries
  - Societal applications and benefits
- Key features of FRIB
  - 400 kW Heavy Ion beams
  - Fast/Stopped/Reaccelerated Beams
  - ReA6 (6-9 MeV/u) is on the way
  - Goal is ReA15
- FRIB is progressing well; site prep underway, ready for construction
- User community large and involved in the project

Backup Material

Re-accelerator Timeline