Overview and Preparations for the FRIB Scientific Program

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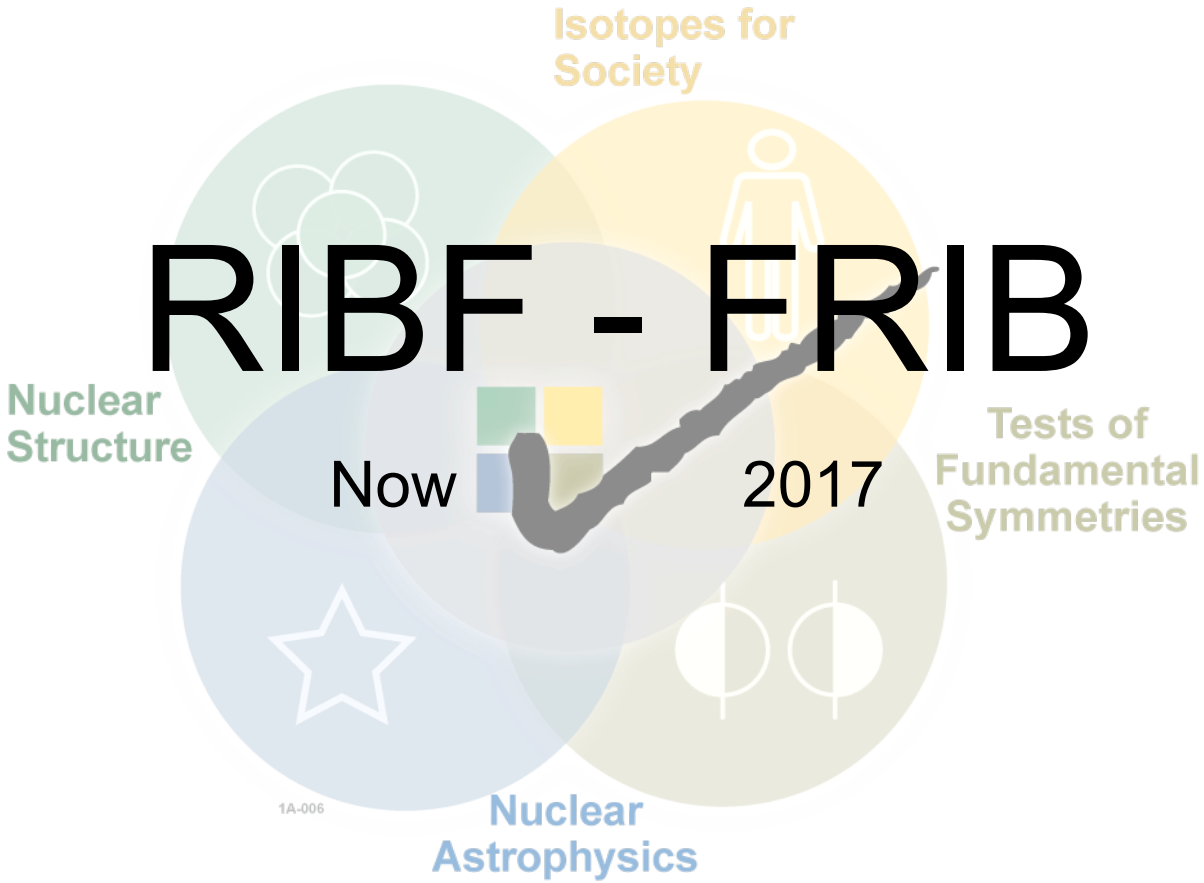
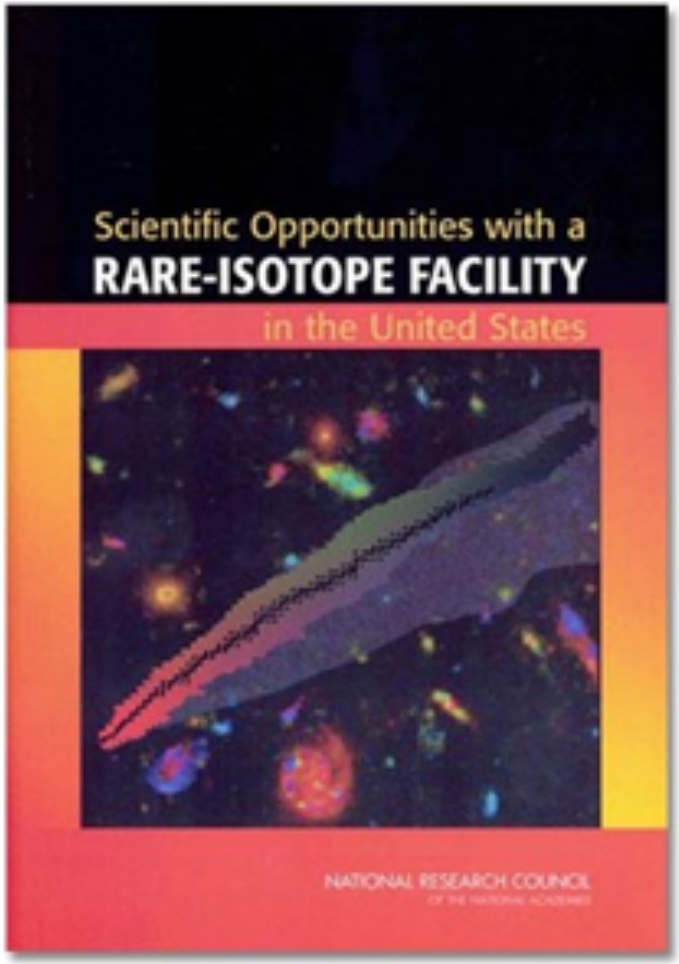
Office of Science

Close Collaboration Makes Sense



NRC Rare Isotope Science Assessment Committee, RISAC

"The committee concludes that the science addressed by a rare-isotope facility, most likely based on a heavy ion linac driver, should be a high priority for the United States."



"The committee concludes that nuclear structure and nuclear astrophysics constitute a vital component of the nuclear science portfolio in the United States. Moreover, nuclear structure-related research provides the scientific basis for important advances in medical research, national security, energy production, and industrial processing."

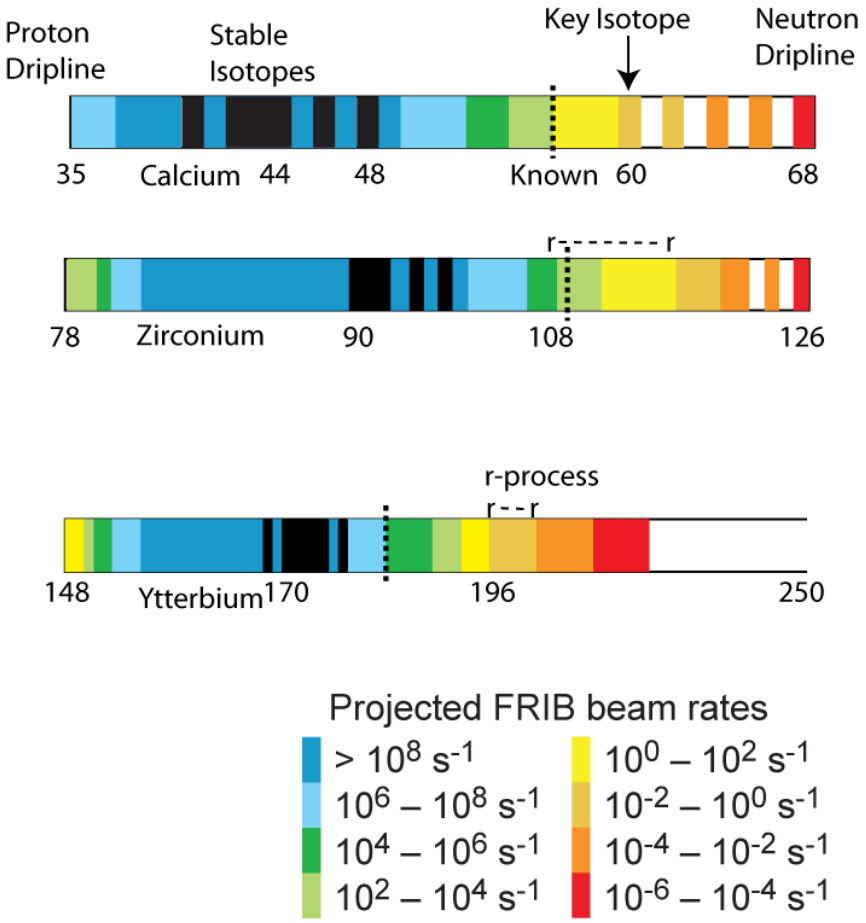
"The Gathering Storm report argued that strong public support of basic research can help fuel the national economic engine… While it is nearly impossible to argue that any one specific investment is critically necessary to maintain the future health of the enterprise, the committee does recognize the value of a U.S. FRIB as one element of a much broader portfolio in the physical sciences."

—Scientific Opportunites with a Rare Isotope Facility, December 2006

1A QB-002

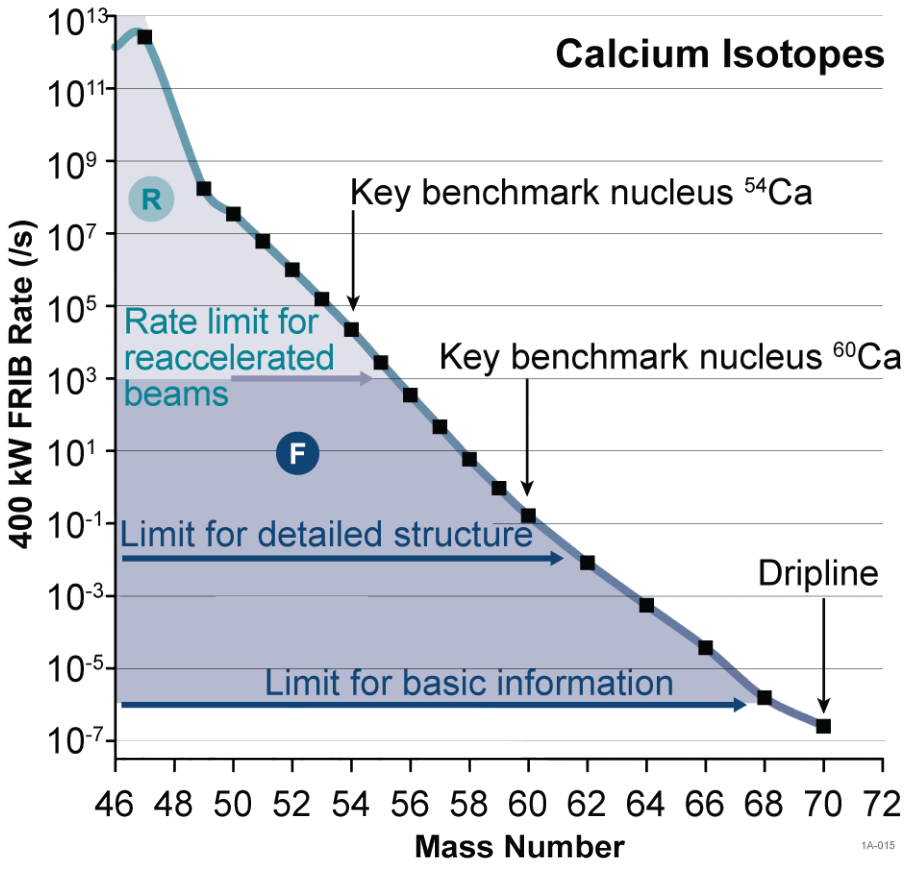
RISAC Science Drivers

- Nuclear Structure
  - Explore the limits of existence and study new phenomena
  - Possibility of a broadly applicable model of nuclei
  - Probing neutron skins
  - Synthesis of superheavy elements
- Nuclear Astrophysics
  - The origin of the heavy elements
  - Explosive nucleosynthesis
  - Composition of neutron star crusts
- Fundamental Symmetries
  - Tests of fundamental symmetries
- Other Scientific Applications
  - Stockpile stewardship, materials, medical, reactors



Examples of Scientific Goals of FRIB that Drive Specifications

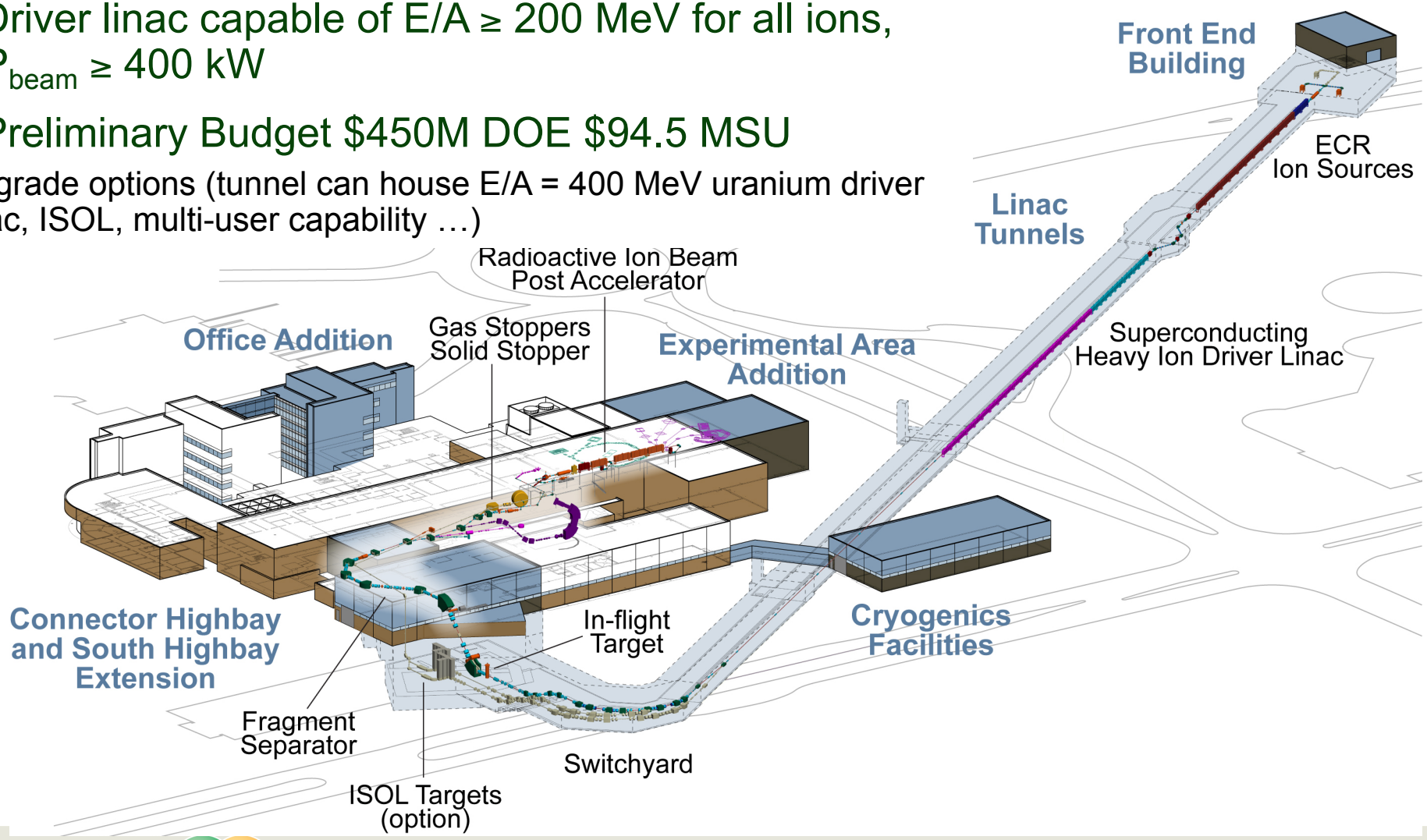
- Produce and study nuclei along the drip lines at A≈100
- Produce and study nuclei in the r-process including at N=126
- Provide reaccelerated beams capabilities (fusion, transfer, COULEX, etc.)
- Superheavy element studies and fundamental symmetries experiments require that ISOL production by 600 MeV protons be an option
- Example: FRIB intensity will allow the key benchmark nuclei ^{54}Ca (reaccelerated beams) and ^{60}Ca (fast beams) to be studied



FRIB Broad Overview

- Driver linac capable of E/A ≥ 200 MeV for all ions, P_{beam} ≥ 400 kW
- Preliminary Budget $450M DOE $94.5 MSU

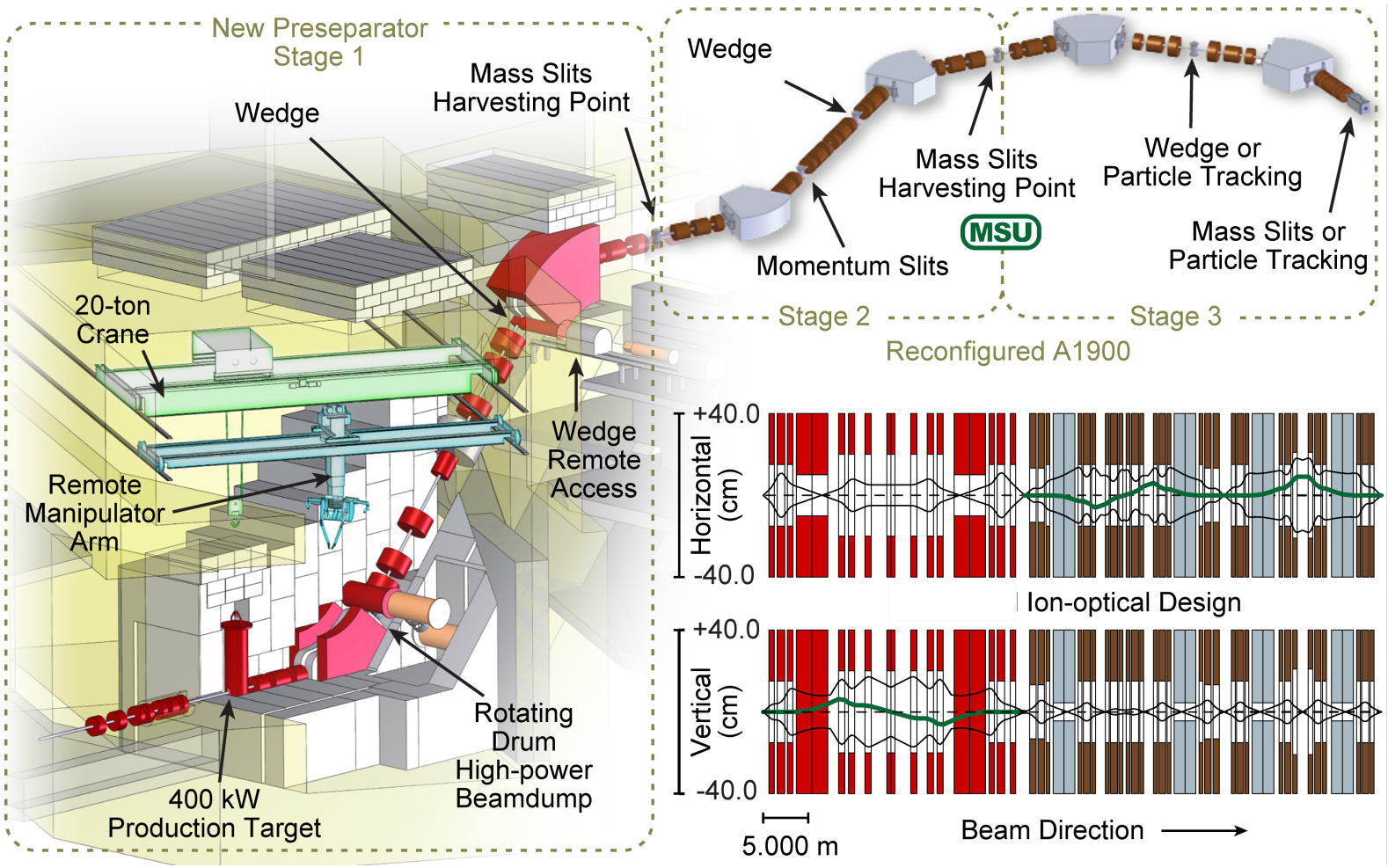
Upgrade options (tunnel can house E/A = 400 MeV uranium driver linac, ISOL, multi-user capability …)



Key Aspects of the Design

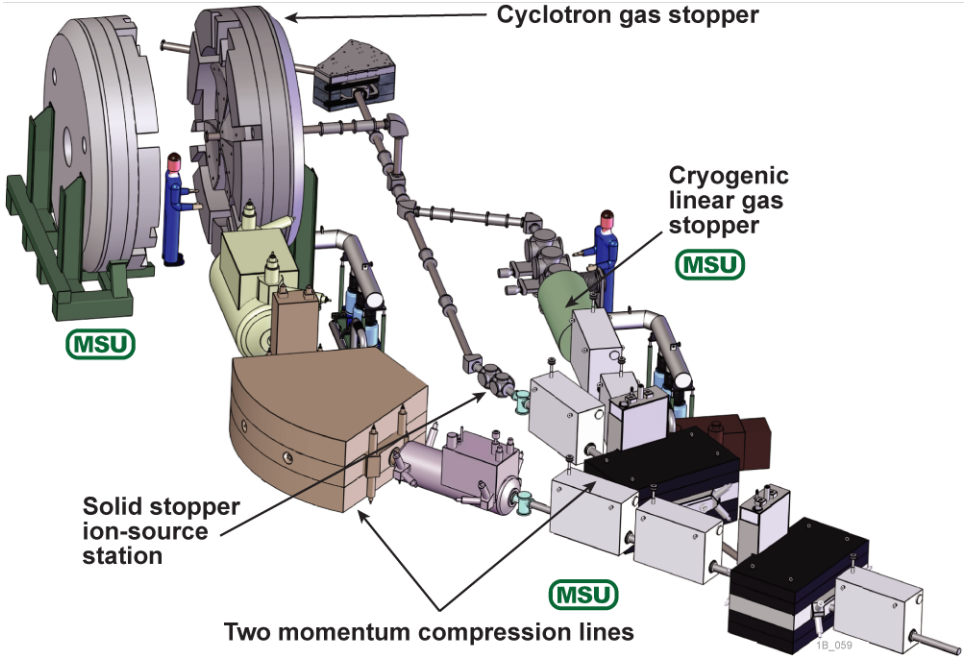
- Efficient acceleration allowing 400 kW beam power for all beams
  - 2.4×10^{13} uranium ions/s
  - 1.2×10^{14} ^{48}Ca ions/s (20 pnA)
- One stripping section, and acceleration of 5 charge states of uranium while maintaining 1 mm beam spot on target
- Target and beam dump area designed to allow 400 kW operation with beams of 500 MeV/u ^{48}Ca or 1 GeV protons
- Comparison to RIBF
  - Reaccelerated beams
  - 400 kW operation
  - ISOL

FRIB 3-Stage Fragment Separator and Optics



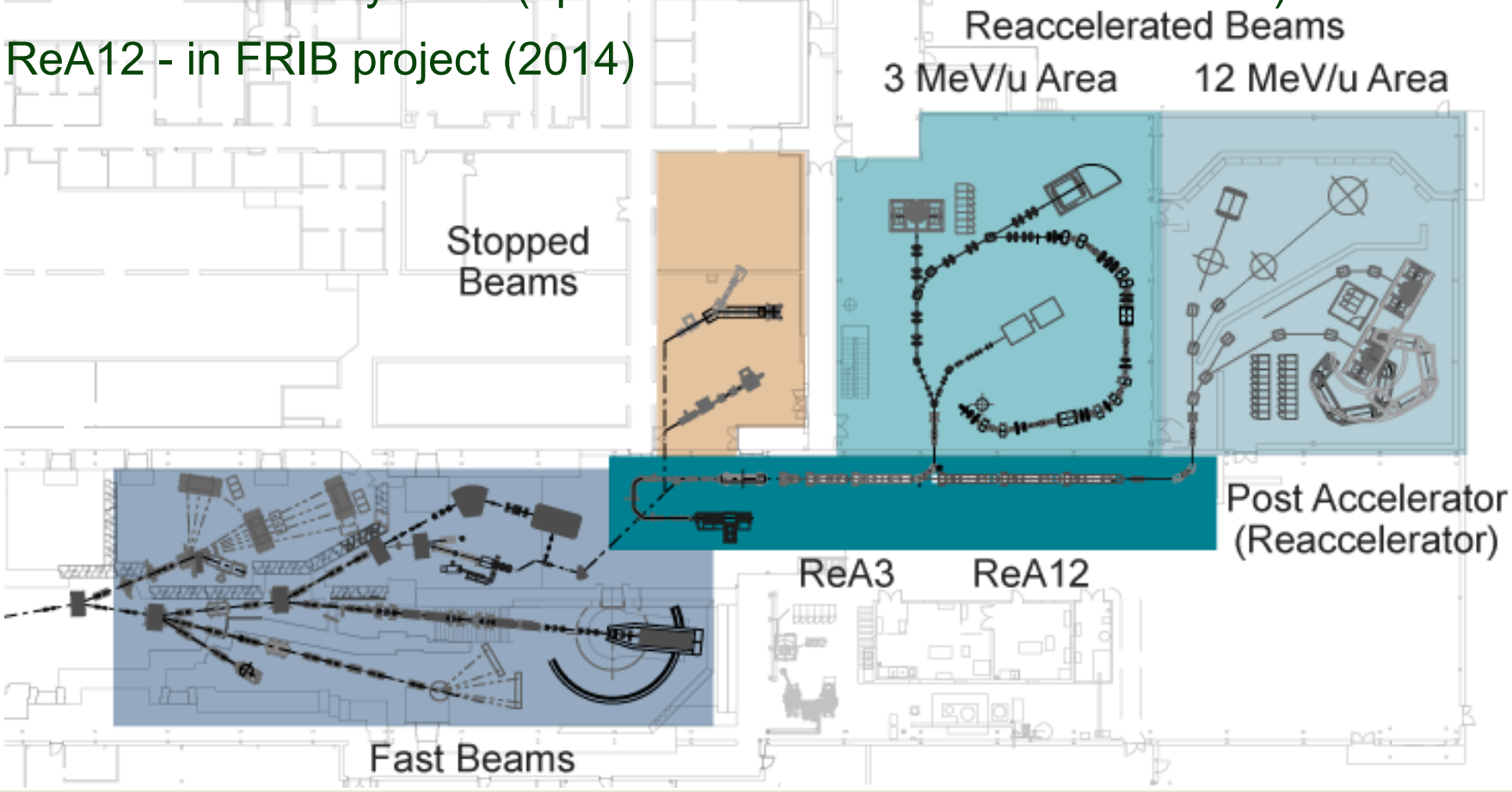
Gas Stopper

- R&D Program ANL/MSU
- Technical Specifications
  - 3 complementary stopping stations and 2 momentum compression lines specifically optimized
  - **Cyclotron gas stopper** for light and medium heavy isotopes
    - » B_{max} = 2.3T, r_{inj} = 0.95, p_{He} = 50-250 mbar
    - » I > 10^8/s, $T_{1/2}$ < 50ms
  - **Linear gas stopper** for heavy isotopes
    - » L = 1.5 m, p < 300 mbar
    - » I < 10^7/s, $T^{1/2}$ > 100ms
  - **Solid stopper** for special elements and high beam rates
    - » Example: ^{15}O, I >10^{10}/s



Stopped and Reaccelerated Beams

- Stopped beam area
- ReA3 – Funded by MSU (operational in 2010 for stable beams)
- ReA12 - in FRIB project (2014)

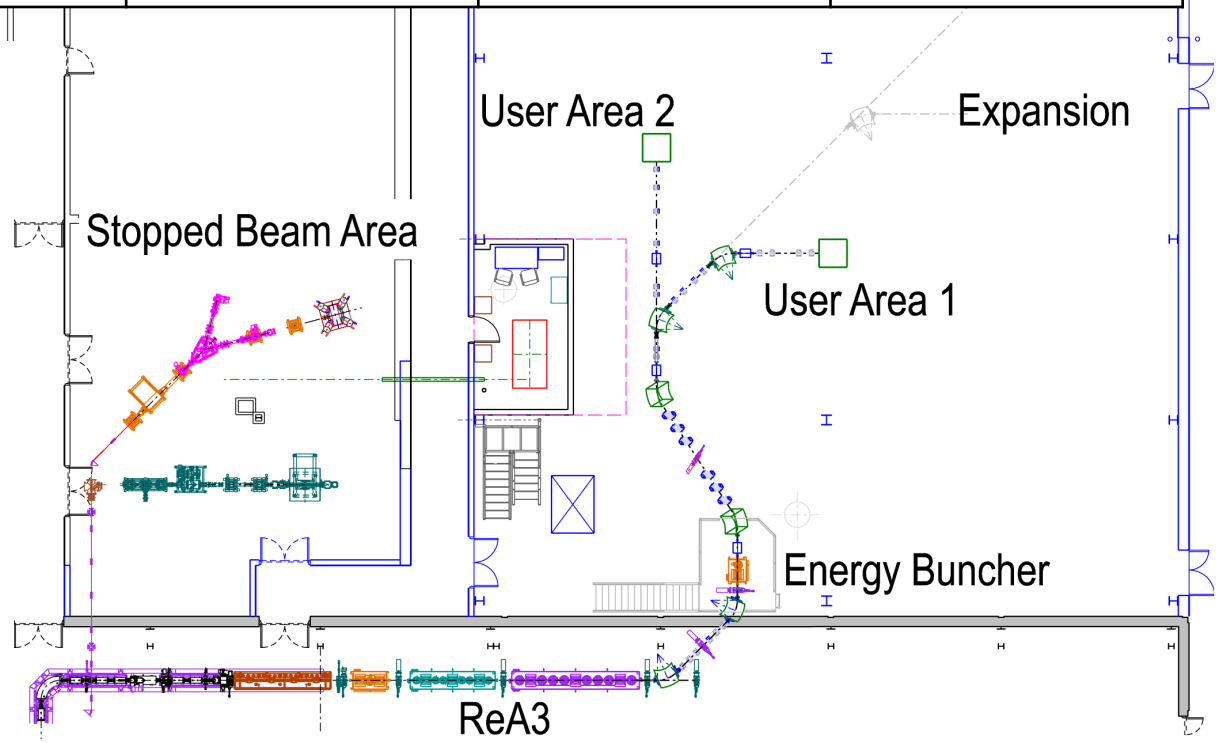


Stopped and Reaccelerated Beams Areas

available by the end of 2010 with first experiments in 2011

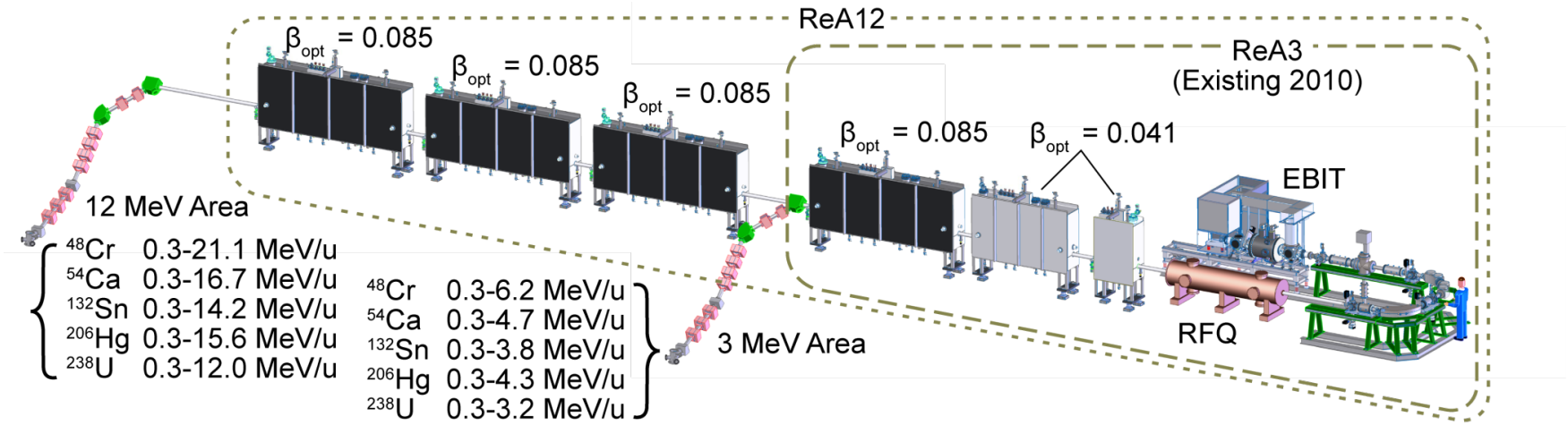
Q/A	Final Energy (MeV/u)		
	Deceleration	Acceleration (Design gradient)	Acceleration (FRIB gradient)
0.20	0.3	2.4	3.8
0.25	0.3	3.0	4.6
0.50	0.3	6.0	9.4

- Initial layout with 2 beam lines; expandable to 6.
- Initial equipment
  - ANASEN (LSU/FSU)
  - AT-TPC (MSU/LLNL/LBL/St Mary's/Catania/GANIL/
  - Coulex
  - LENDA
  - Etc.
- 18 Letters of intent at last PAC



FRIB ReA12 Accelerator

- The proposed FRIB project schedule calls for operations in 2015
- The User community has endorsed trying to accelerate completion to 2013; this may be difficult to accommodate and will have to rely on existing facilities such as ATLAS and TAMU.
- Funded by the FRIB Project



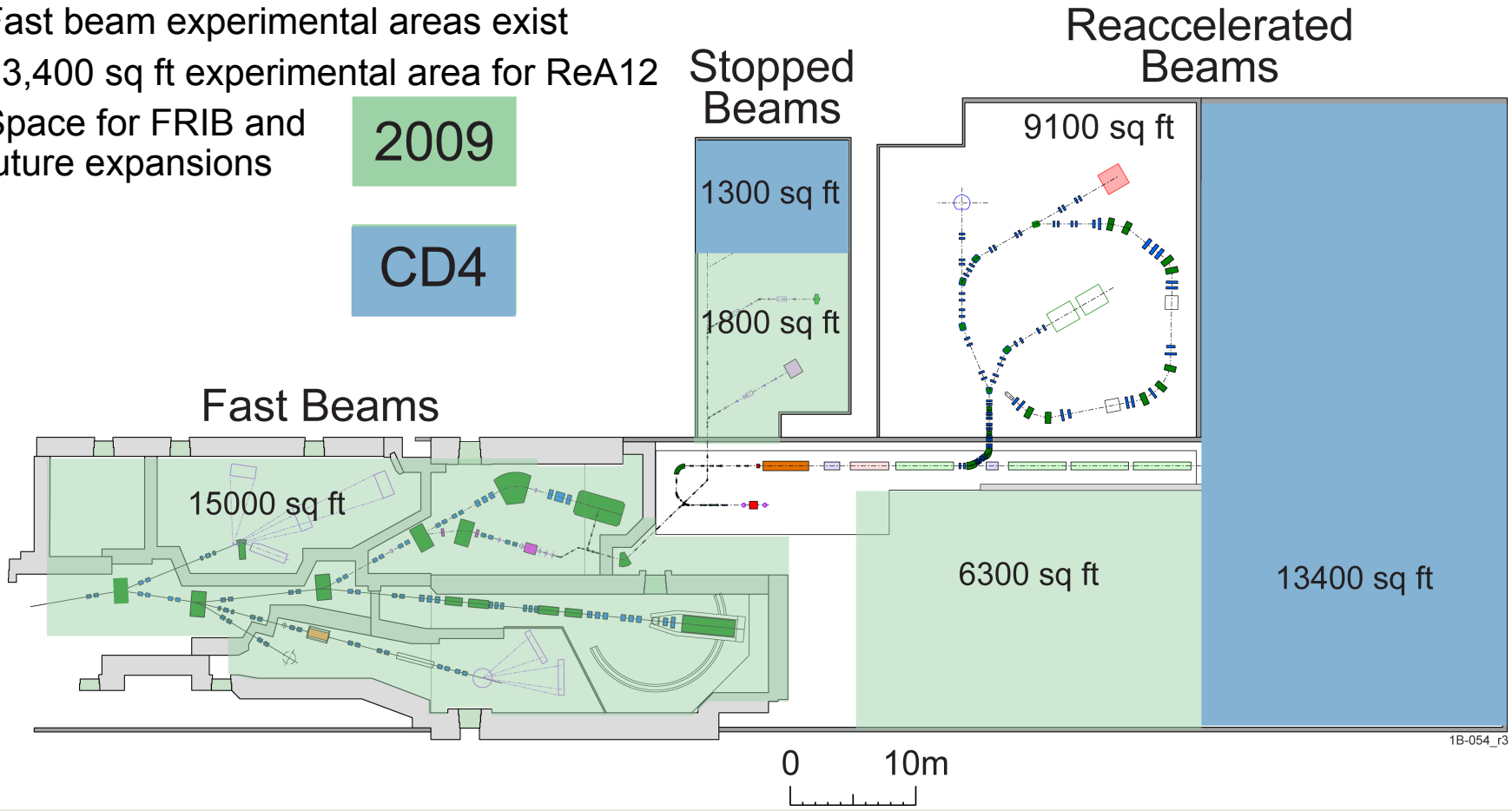
Energy upgrade of reaccelerated beams from 3-6 MeV/u to 12-21 MeV/u

Experimental Areas

- FRIB experimental areas will use existing NSCL augmented by a new ReA12 experimental area
  - Fast beam experimental areas exist
  - 13,400 sq ft experimental area for ReA12
  - Space for FRIB and future expansions

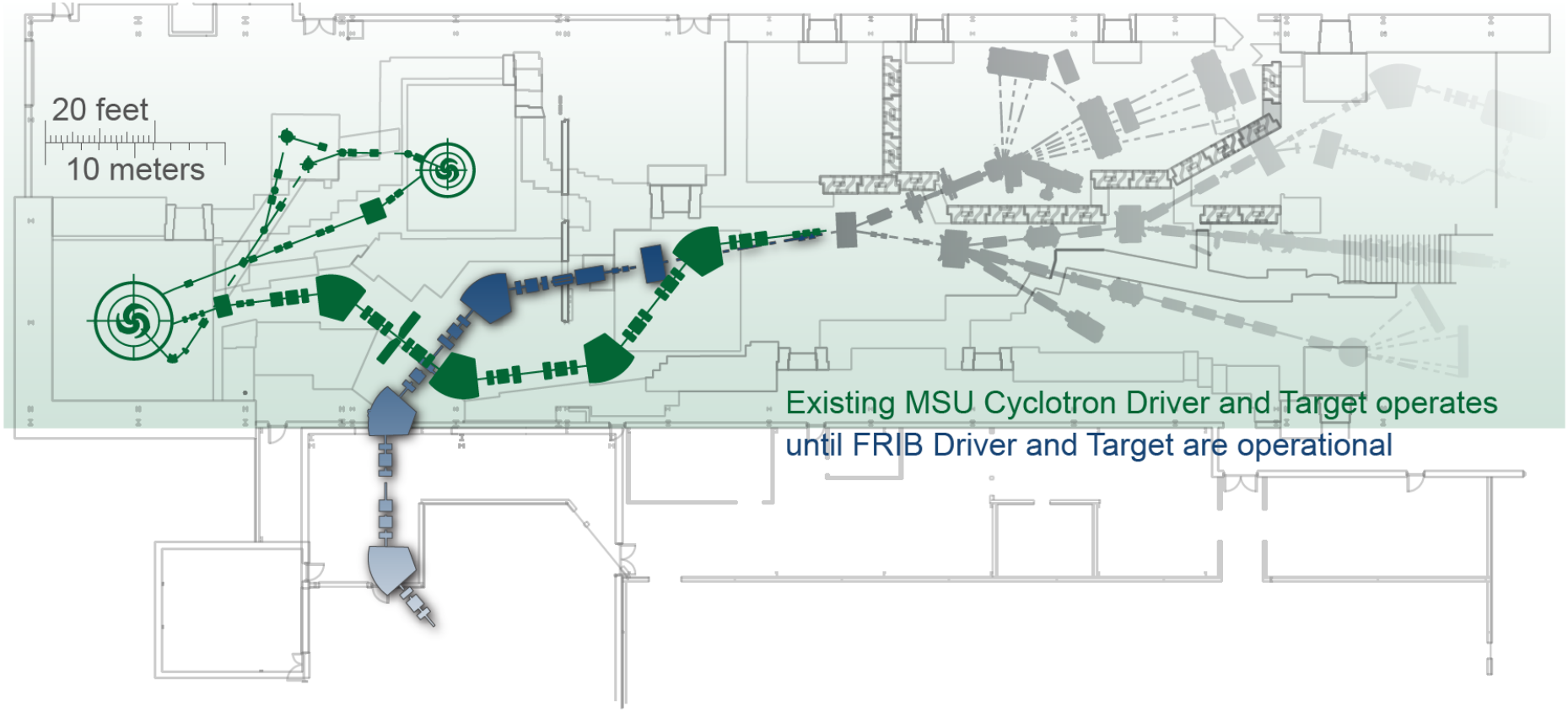
2009

CD4



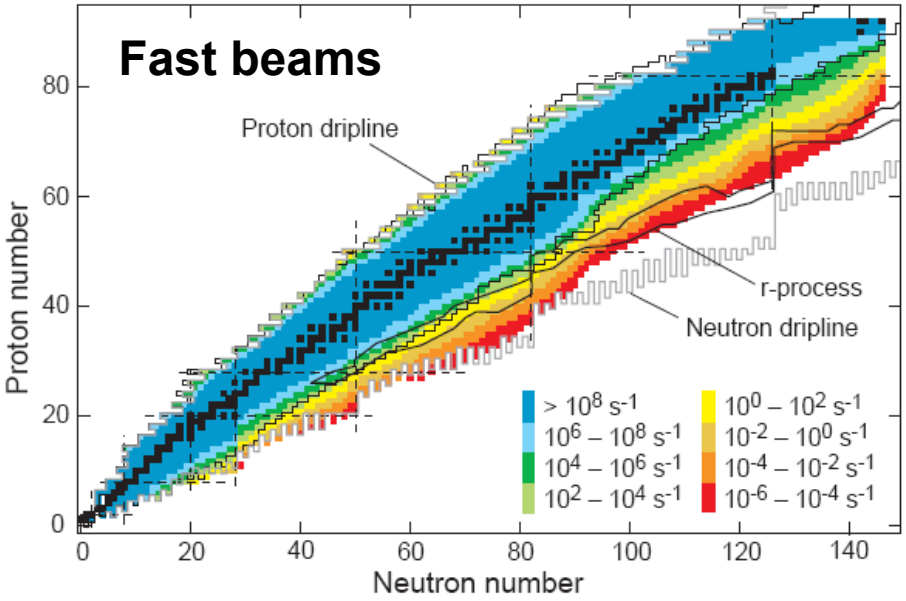
Transition from NSCL to FRIB Operations

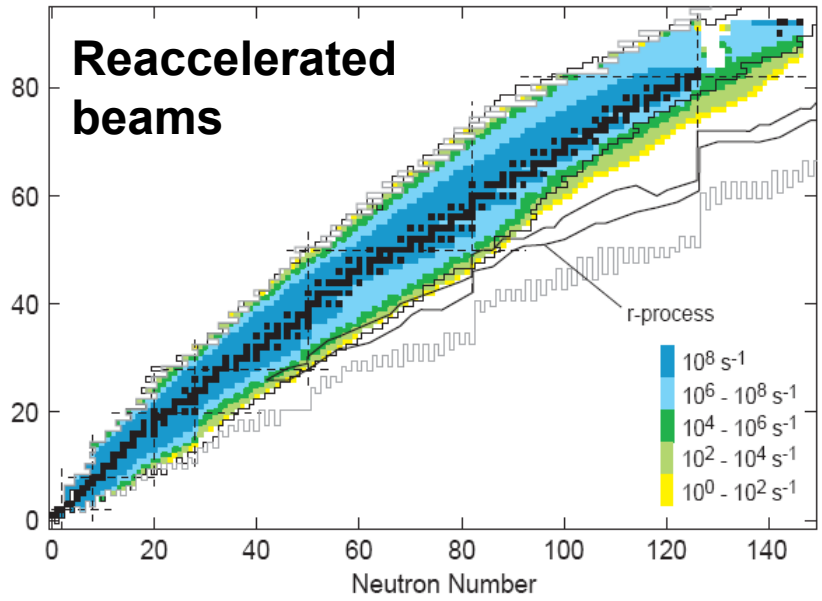
- Minimal perturbation of the experimental area when transitioning from CCF to FRIB operations (goal is six months down time)



FRIB Rare Isotope Projected Beam Rates

- Fast beams: rate calculations (LISE++), 400 kW, carbon target, optimized primary beam, target thickness and separator parameters
- Stopping efficiencies 10-50% + extraction efficiency 1-50% (beam rate and mass dependent), decay losses due to extraction times (30-50 ms, mass dependent), breeding and acceleration efficiency 20-50%
- Rates are available at http://groups.nscl.msu.edu/frib/rates/

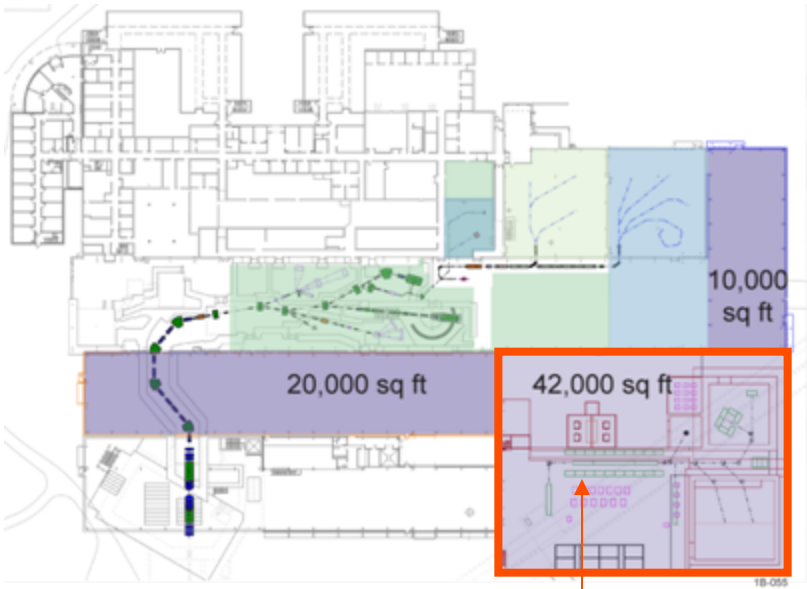




Rare Isotopes For Society

- Isotopes for medical research
  - 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
- Reaction rates important for stockpile stewardship – non-classified research
  - 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) …

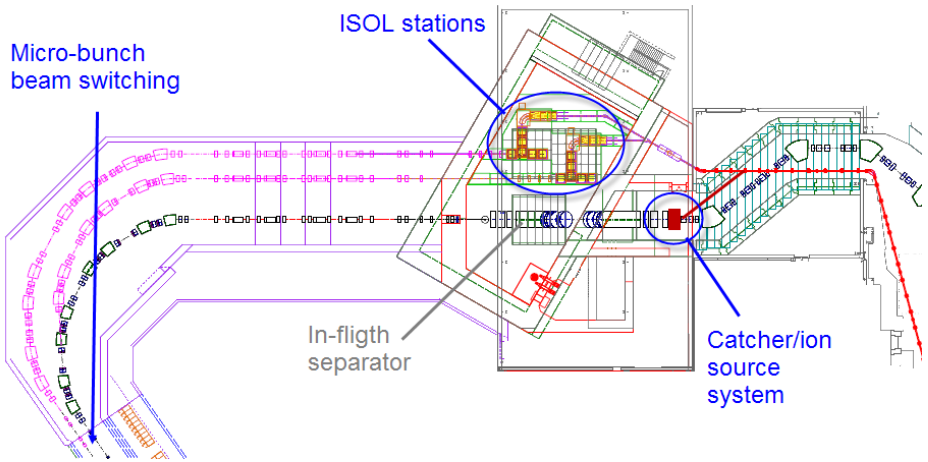
Expansion options (beyond FRIB scope)

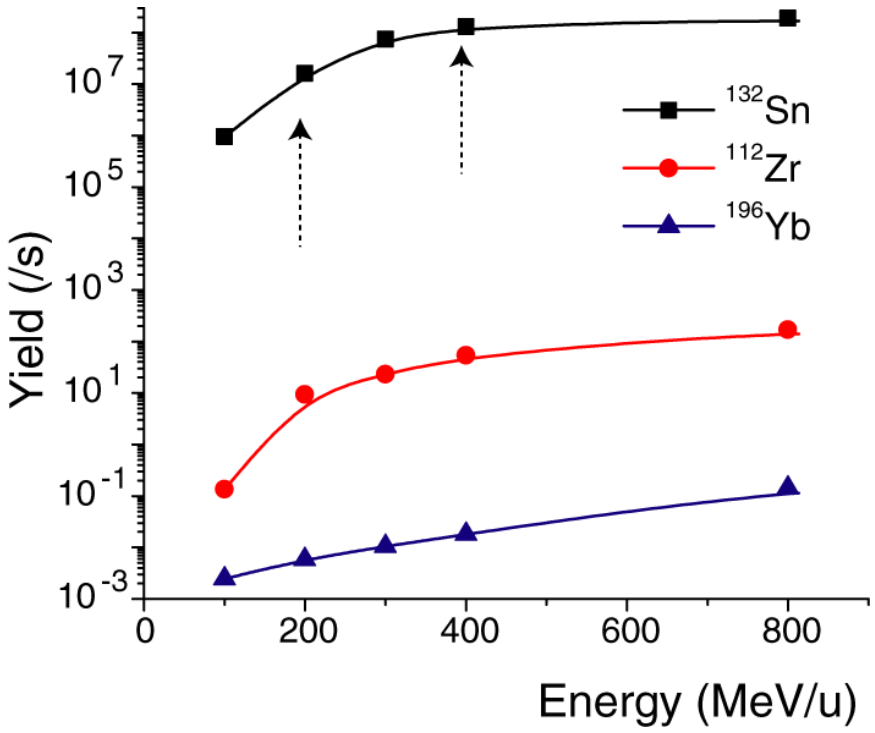


Example:
NNSA Neutron Facility as proposed by LLNL

Flexibility for Science Driven Upgrades

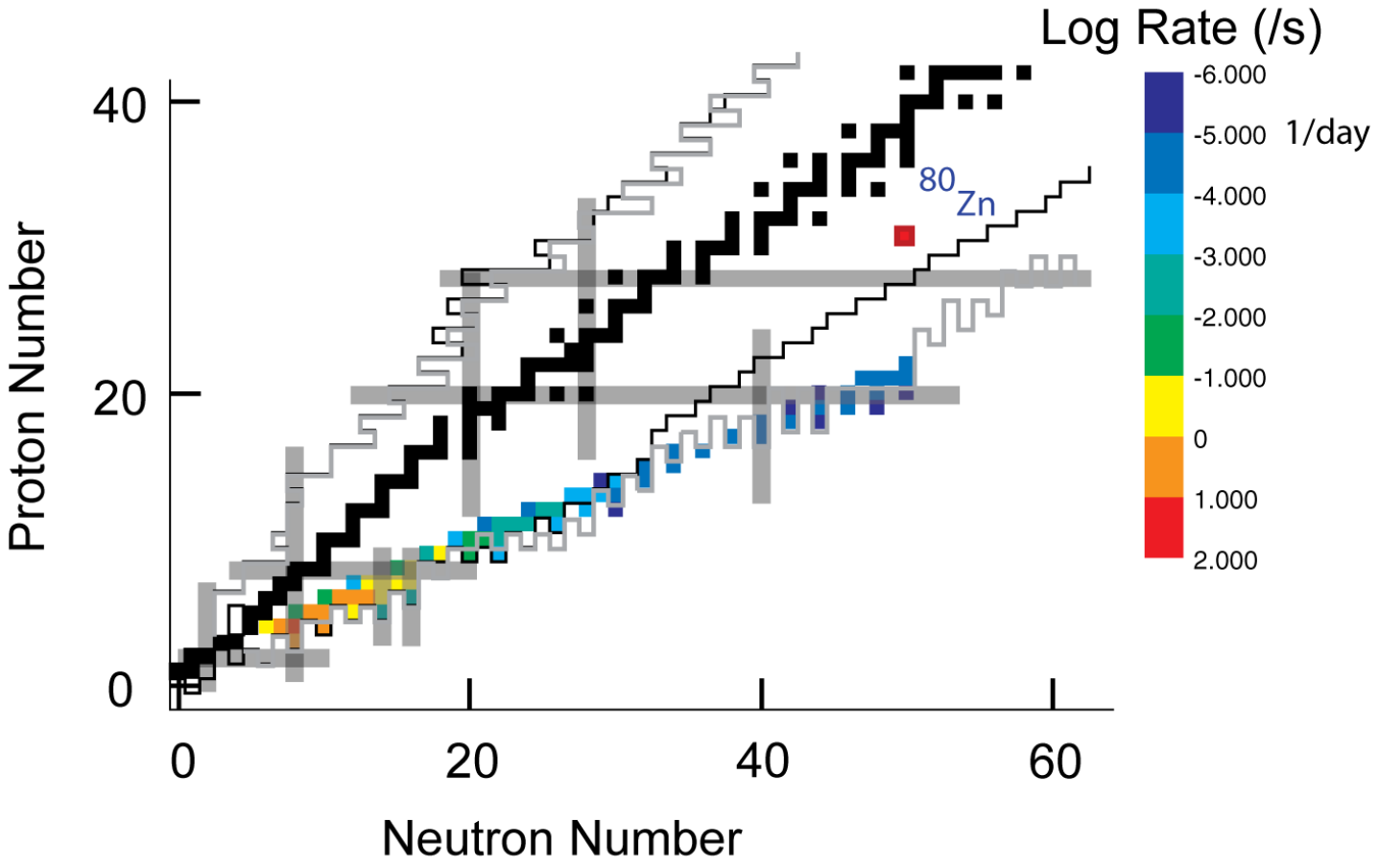
- Possible future expansion for FRIB
  - ISOL capability – full infrastructure is included in the design, targets could be added when appropriate
  - Upgrade of Heavy-ion Linac Driver to 400 MeV/u for Uranium – space in tunnel included
  - Reacceleration of Rare Isotopes to 200 MeV/u Using the Existing K1200 Cyclotron





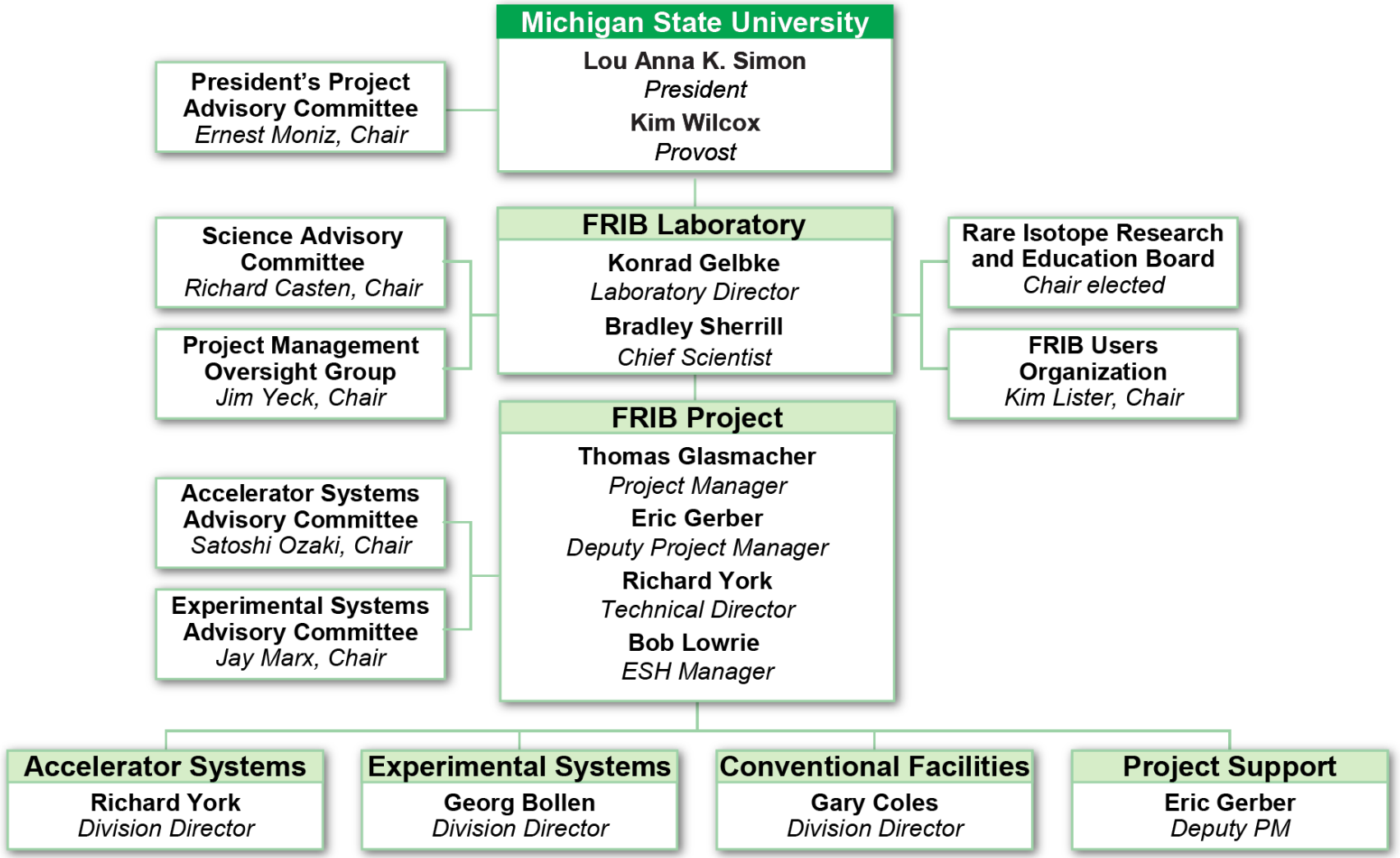
Future Prospects for Drip Line Study

- Use neutron induced fission of ^{238}U with 400 kW 600 MeV protons from FRIB
- ISOL Production of 5×10^{8}/s ^{80}Zn
- Acceleration to 160 MeV/u with the K1200 Cyclotron (200 MeV/u maximum energy)
- Production of nuclei along the drip line up to ^{70}Ca



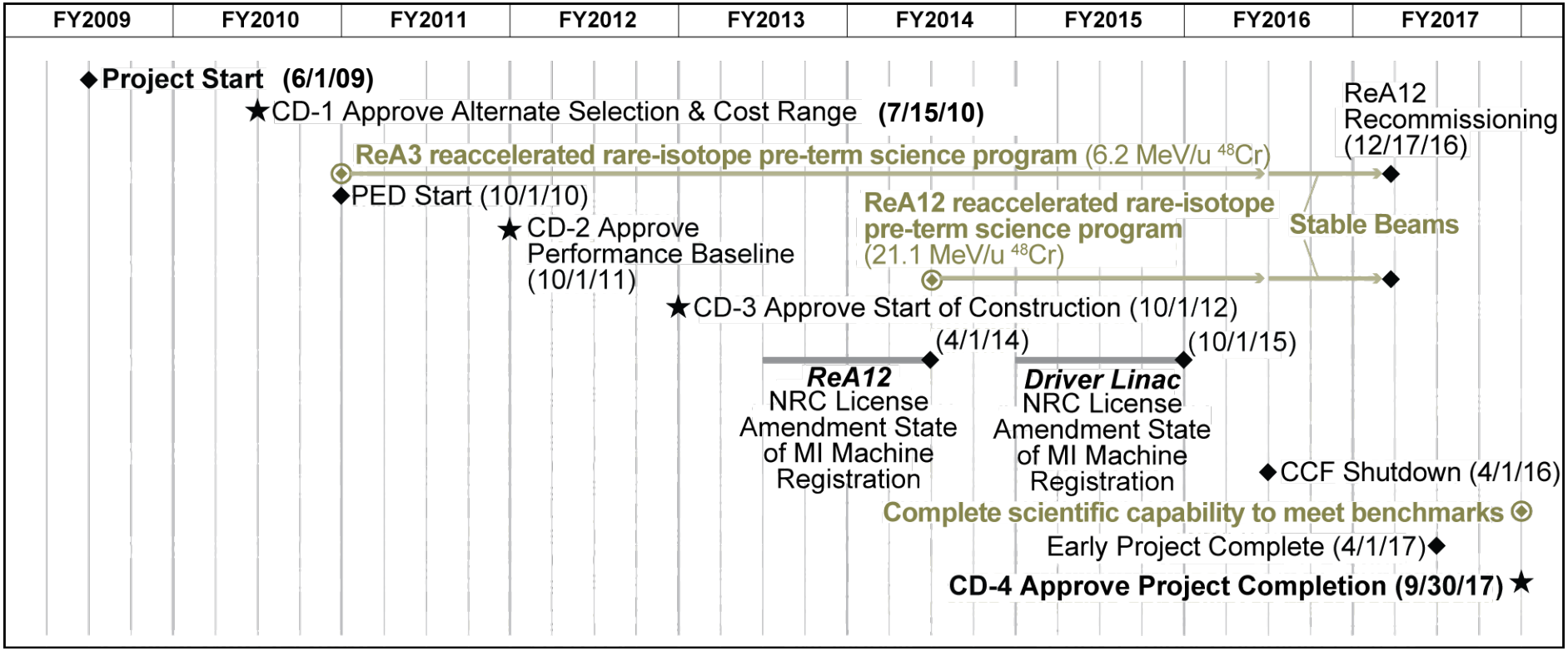
FRIB Organization

Chief Scientist serves as point of contact for users



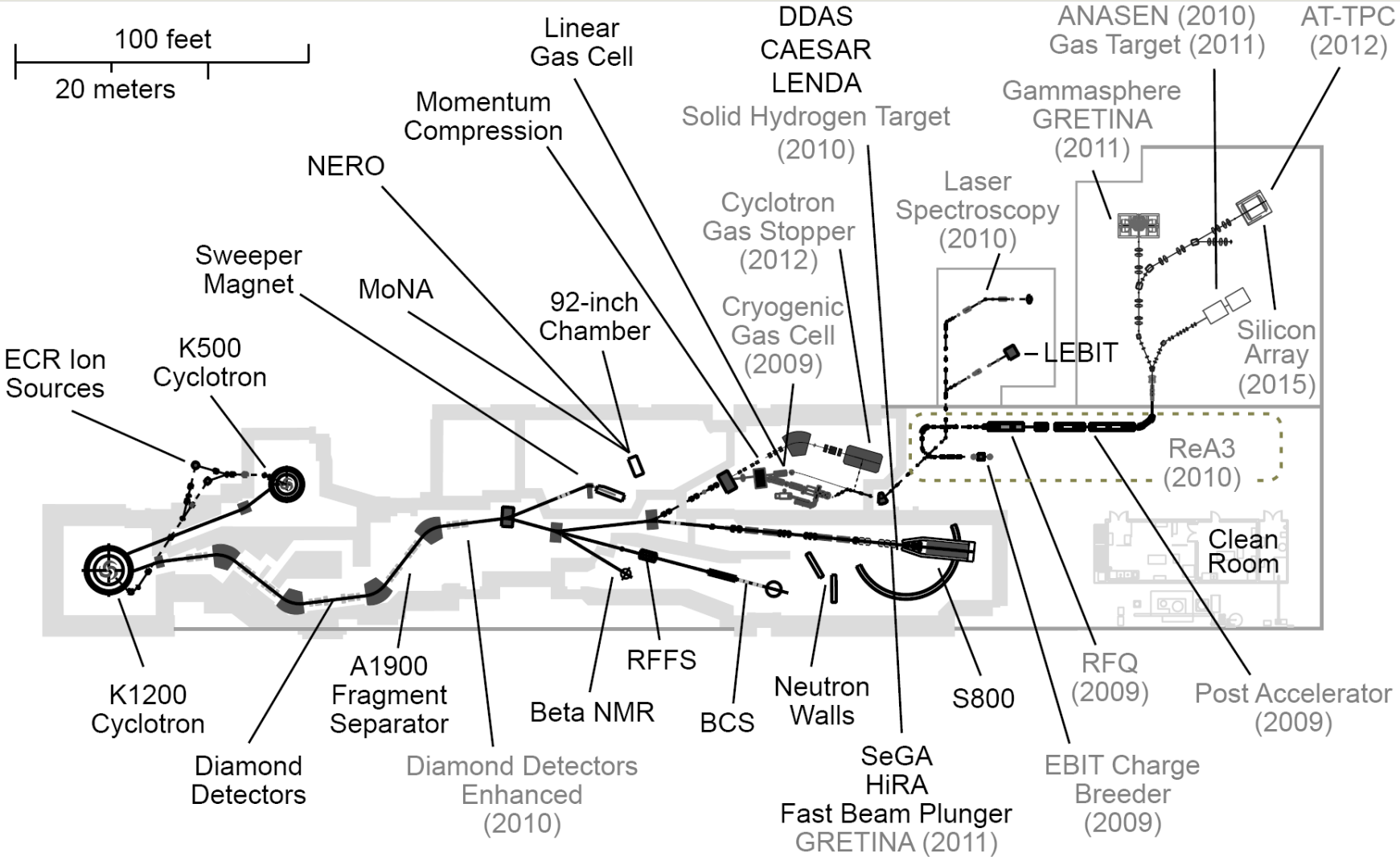
Notional Timeline for FRIB Development

- The timeline for FRIB is dependent on funding by congress and approval by DOE
- A possible schedule is:



Pre-FRIB Equipment

Opportunities for user-provided equipment



Equipment Initiatives

- Future equipment needs were identified at workshops in Washington (2002), Oak Ridge (2003), MSU (2005)
- The FRIB SAC has reviewed the needs and identified several items (next slide)
- Key infrastructure: Target making, digital electronics, ASIC, Data Acquisition …
- The equipment aspirations are driven by the user community
- Process forward
  - Targeted workshops
  - General workshop
- Funding can come from multiple sources
  - Project ($15M)
  - DOE
  - NSF (yearly MRI proposals; ANASEN, AT-TPC, Hydrogen Target, CAESAR, HIRA,...)
  - Other government agencies

User Identified and SAC Commented Equipment

Note: (1) New ideas may change or replace items on this list. (2) Equipment could be moveable to maximize it scientific benefit. FRIB may not run before 2017.

- GRETA
- Gamma and charged particle array for decay spectroscopy (clovers or possibly part of GAMMASPHERE)
- Gas Filled Separator
- Recoil Separator 10-15 MeV/u (money in the project)
- Astrophysics Separator
- Gas target
- MOTs and ion traps for fundamental symmetries studies (EDM)
- Solenoid Spectrometer (money in the project)
- Zero degree spectrograph (extends S800 capabilities)
- High energy gamma detector

User Input

- Workshops
  - ANL May 21 with 212 participants
  - Collaboration meetings Aug 10th at NSCL (150 participants)
  - …
- FRIB Users Organization [http://www.orau.org/RIA/]
- Rare Isotope Science and Education Board (Universities and National Laboratories)
- International Collaborations
  - MOU with University of Tokyo
  - MOU with RIKEN (Fragment separators, gas targets, etc.)

Summary

- FRIB will allow production of a wide range of isotopes
  - Extend our searches for the limits to nuclear stability
  - Answer key questions on the nature of the universe (chemical history, mechanisms of stellar explosions)
  - Significant opportunities for the tests of fundamental symmetries
  - Potential for important societal applications
- 200 MeV/u, 400 kW driver linac
- Experimental capability for fast, stopped and reaccelerated beams