FRIB

FRIB: A New Accelerator Facility for the Production of and Experiments with Rare Isotope Beams

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U.S. DEPARTMENT OF ENERGY

Office of Science

Facility for Rare Isotope Beams (FRIB) Historical Background

1999: ISOL Task Force Report – proposes Rare Isotope Accelerator (RIA) concept
- Based on 400 MeV/u 100 kW heavy-ion linac

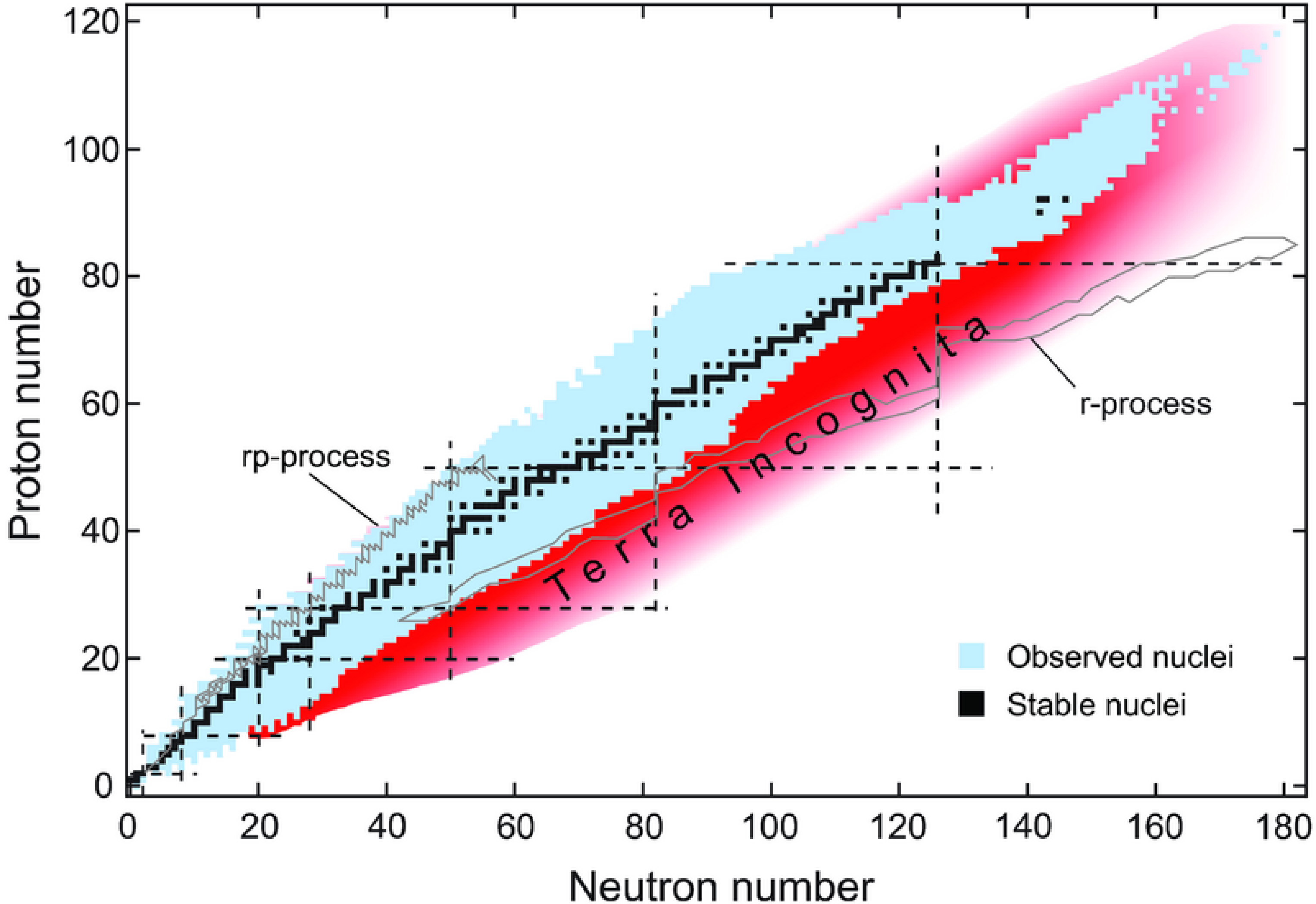
2003: RIA ranks 3rd in DOE 20-year Science Facility Plan

2006: Rare Isotope Science Assessment Committee (RISAC) of the Academies endorses construction of FRIB
- Based on less expensive 200 MeV/u 400 kW heavy-ion linac

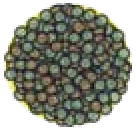
2007: NSAC makes construction of FRIB the second highest priority for nuclear science

2008: DOE issues a Financial Assistance Funding Opportunity Announcement (FOA) for FRIB (May 20 – application due date July 21) and selects the MSU application following a merit review and evaluation process (Dec. 11)

Domain of FRIB Research

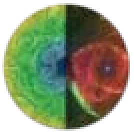


The Science of FRIB



Properties of nucleonic matter

- Classical domain of nuclear science
- Many-body quantum problem: intellectual overlap to mesoscopic science – how to understand the world from simple building blocks



Nuclear processes in the universe

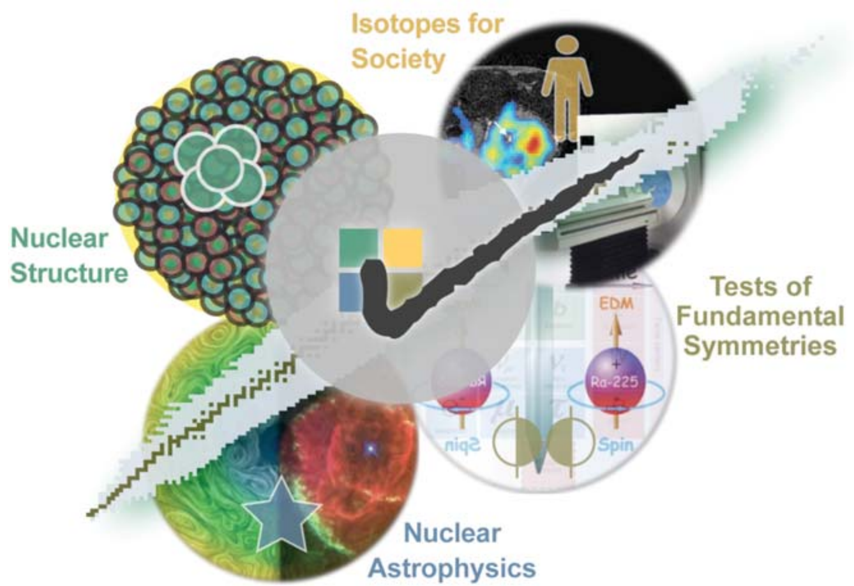
- Energy generation in stars, (explosive) nucleo-synthesis
- Properties of neutron stars, EOS of asymmetric nuclear matter

Tests of fundamental symmetries

- Effects of symmetry violations are amplified in certain nuclei

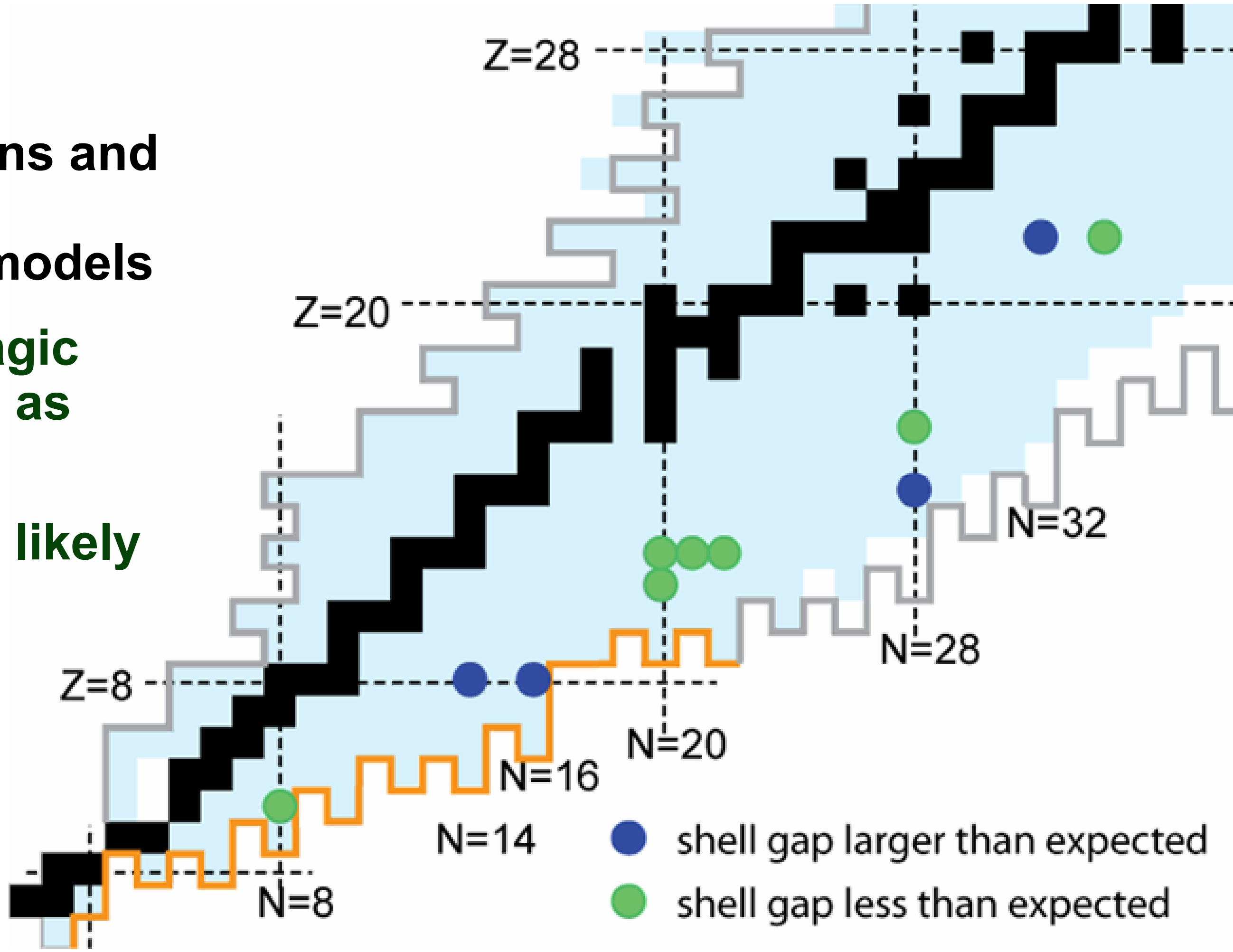
Societal applications and benefits

- Bio-medicine, energy, material sciences, national security



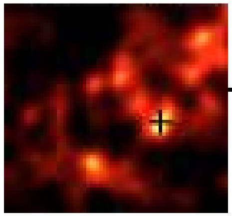
Example: Evolution of Shell Structure

- **Needed for an improved understanding of**
  - **the nature of the effective interactions and operators used in nuclear structure models**
- **Shell model – e.g. magic numbers break down as approach drip line**
- **Further surprises are likely**



Major Advance in Nuclear Astrophysics

FRIB is designed to address important scientific questions in nuclear astrophysics identified in NSAC's 2007 Long Range Plan



– **What is the origin of the elements in the cosmos**
  - » Synthesis of neutron-rich nuclei heavier than iron: r-process
  - » Gamma-ray emitters in supernovae
  - » Isotope harvesting for s-process studies – close to stability

– **What are the nuclear reactions that drive stellar explosions**
  - » Synthesis of proton-rich nuclei: rp-process
  - » Weak interactions in supernovae

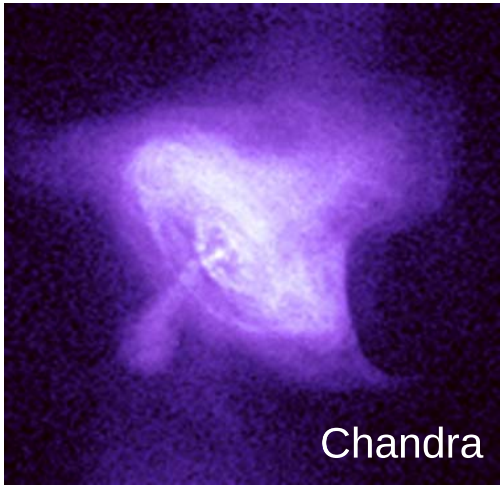
– **What is the nature of neutron stars and dense nuclear matter**
  - » Nuclear processes in the crusts of neutron stars
  - » Symmetry energy term of equation of state of nuclear matter – neutron rich

The Rapid Neutron Capture Process
(r-process)

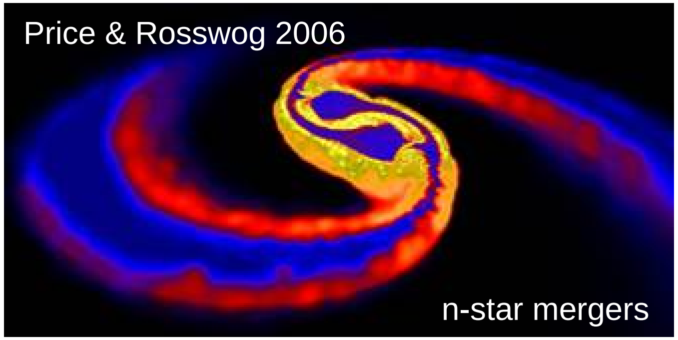
Occurs at $T > 10^9$ K, $\rho_{neutron} > 10^{20}$ cm^{-3}

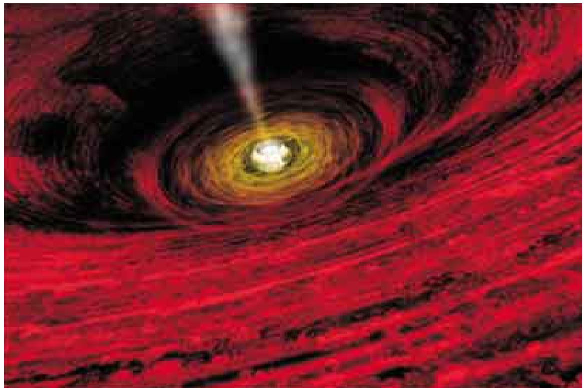
- **Open questions:**
  - Where does nature produce about half of the heavy elements beyond Fe?
  - What is the actual nuclear reaction sequence?
  - What does the abundance pattern tell us about the astrophysical environment?
- **Needed: Data**
  - Nuclear experimental data (masses, half-lives) plus improved nuclear theory
  - Precision observations of abundance patterns produced by the r-process in nature

Crab Nebula



Supernovae: Neutrino-driven wind? Prompt explosions? Shocked O-Ne-Mg cores?

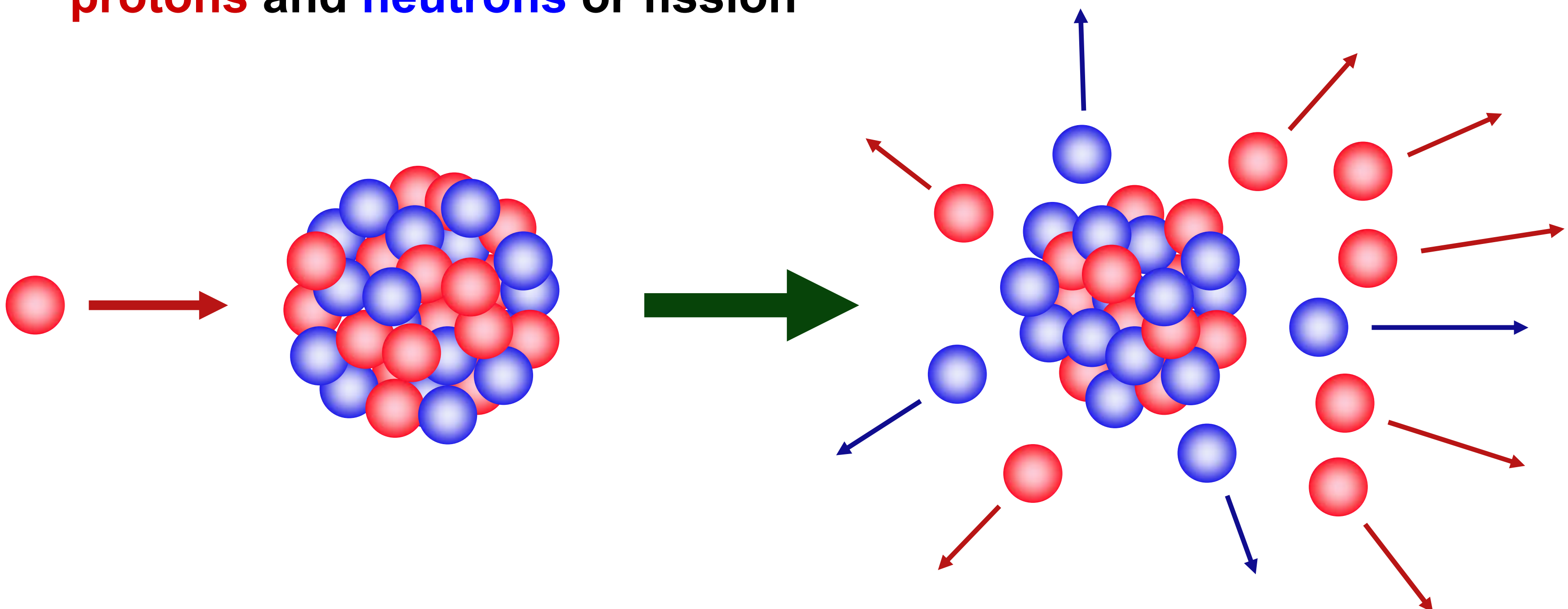




Nucleosynthesis in gamma ray burst accretion disks?

Production of Rare Isotopes at Rest
Isotope Separation On Line (ISOL technique)

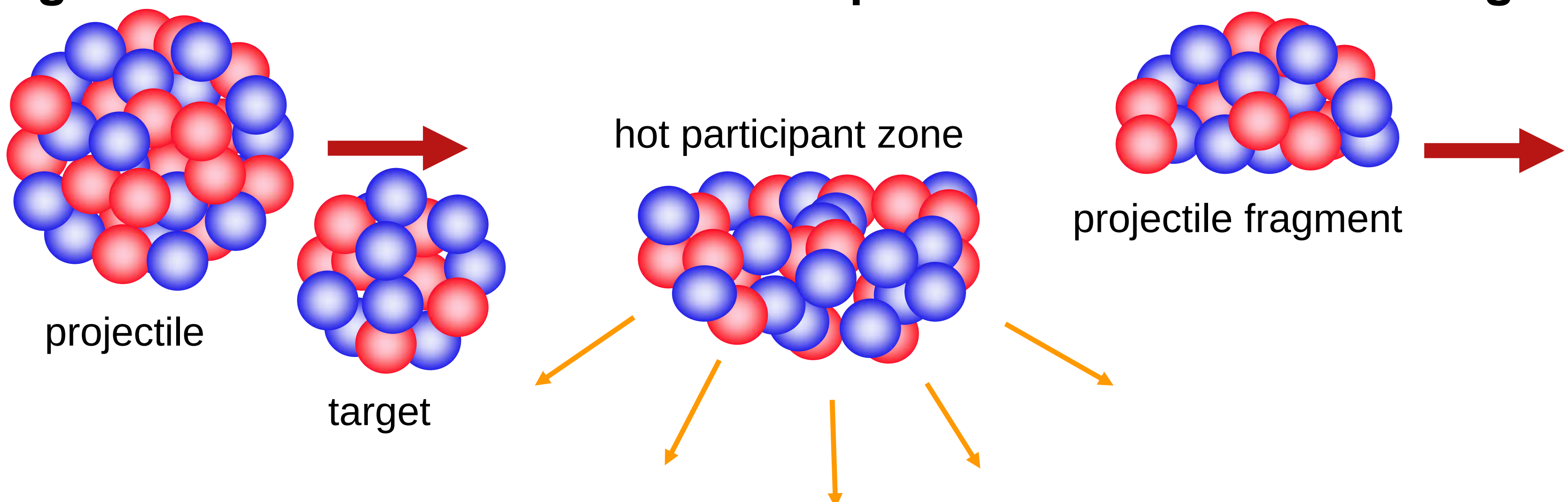
1. Bombard a thick target of heavy nuclei with energetic light particles, e.g. 1 GeV protons, to achieve random removal of protons and neutrons or fission



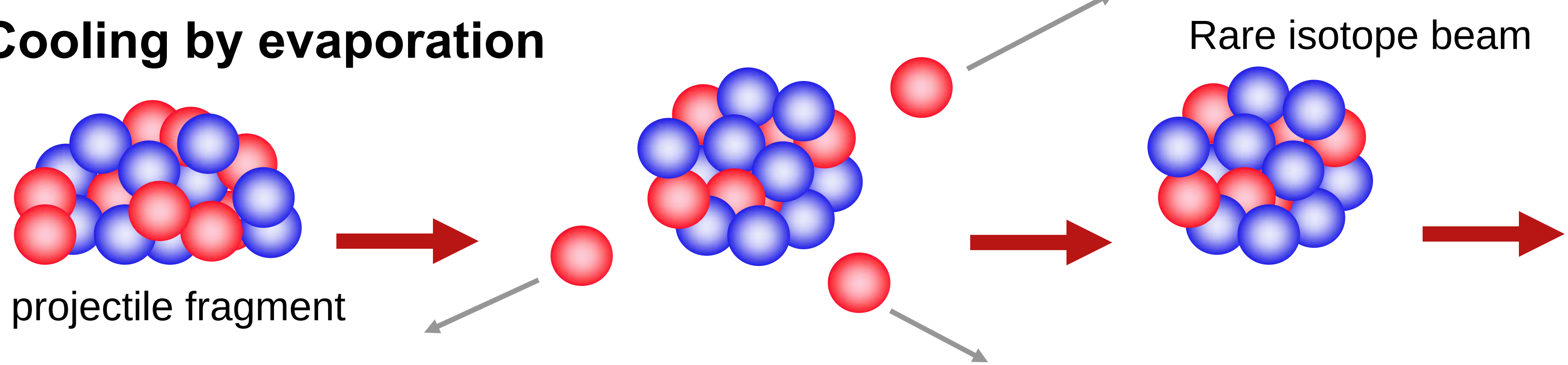
2. Extract rare isotopes from the target material by diffusion or effusion; ionize and accelerate them to the desired energy $\rightarrow$ beam of high quality

Production of Rare Isotopes in Flight

1. **Accelerate heavy ion beam to high energy and pass through a thin target to achieve random removal of protons and neutrons in flight**

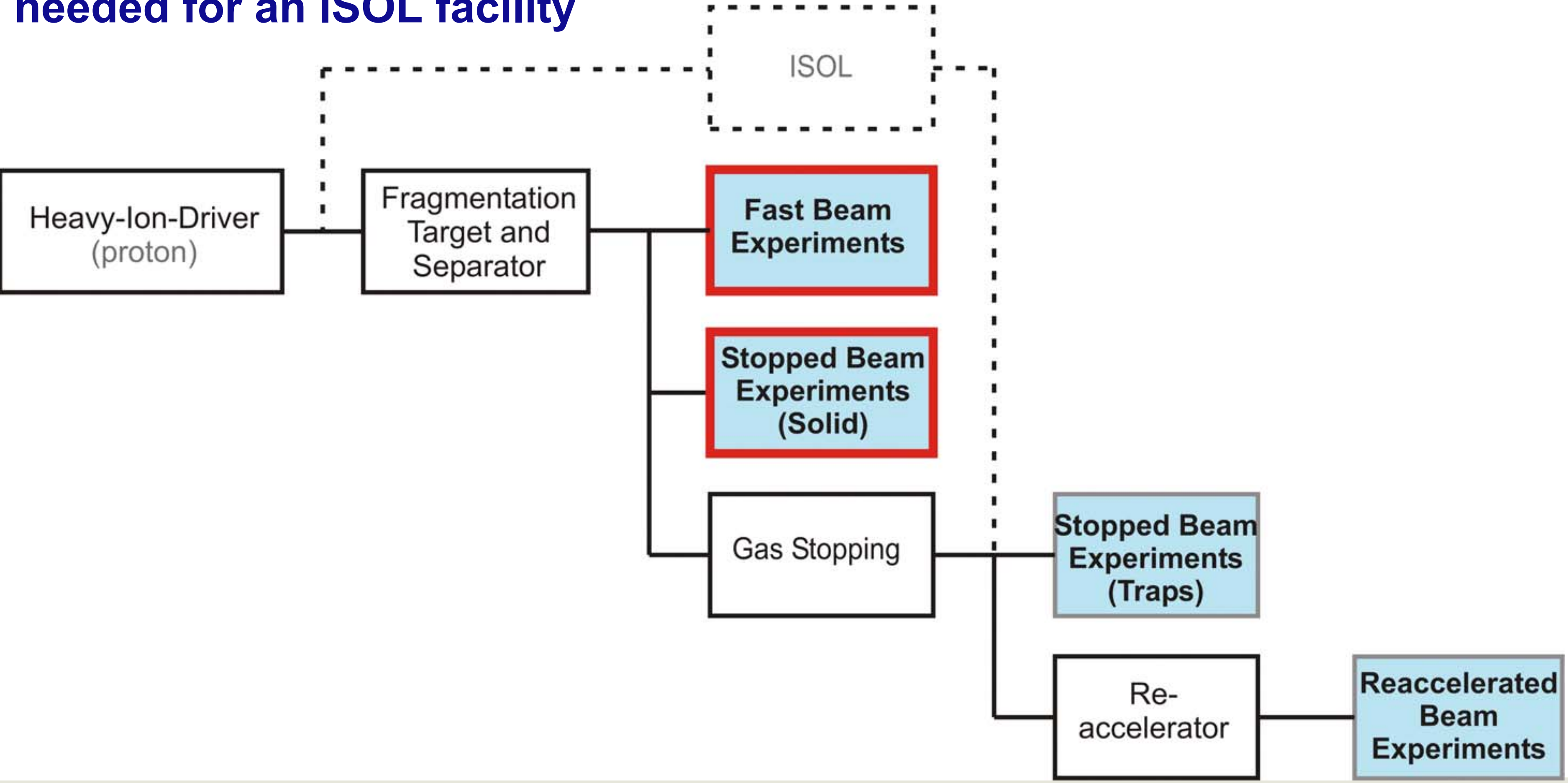


2. **Cooling by evaporation**

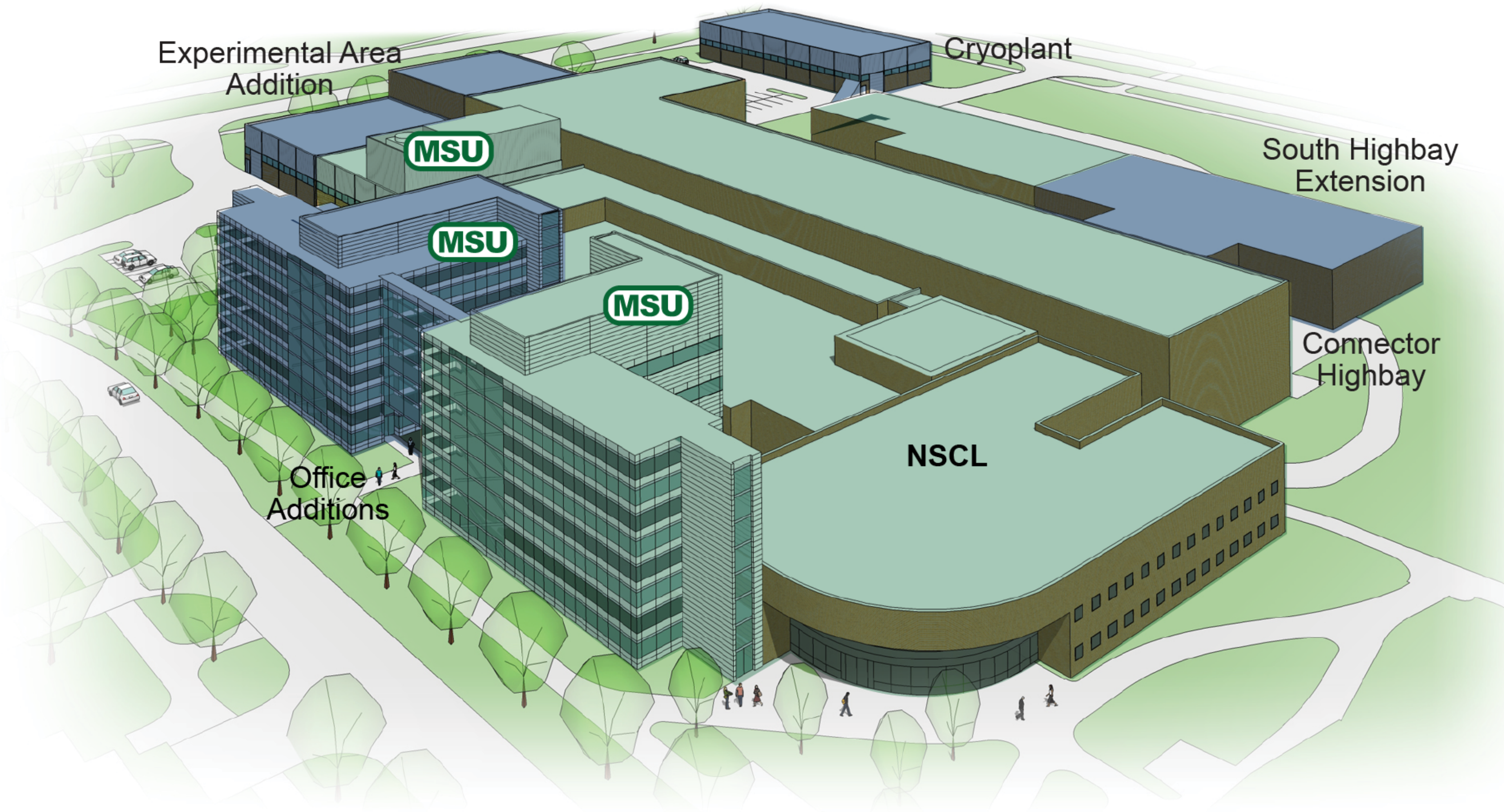


Building Blocks of a Rare Isotope Beam Facility

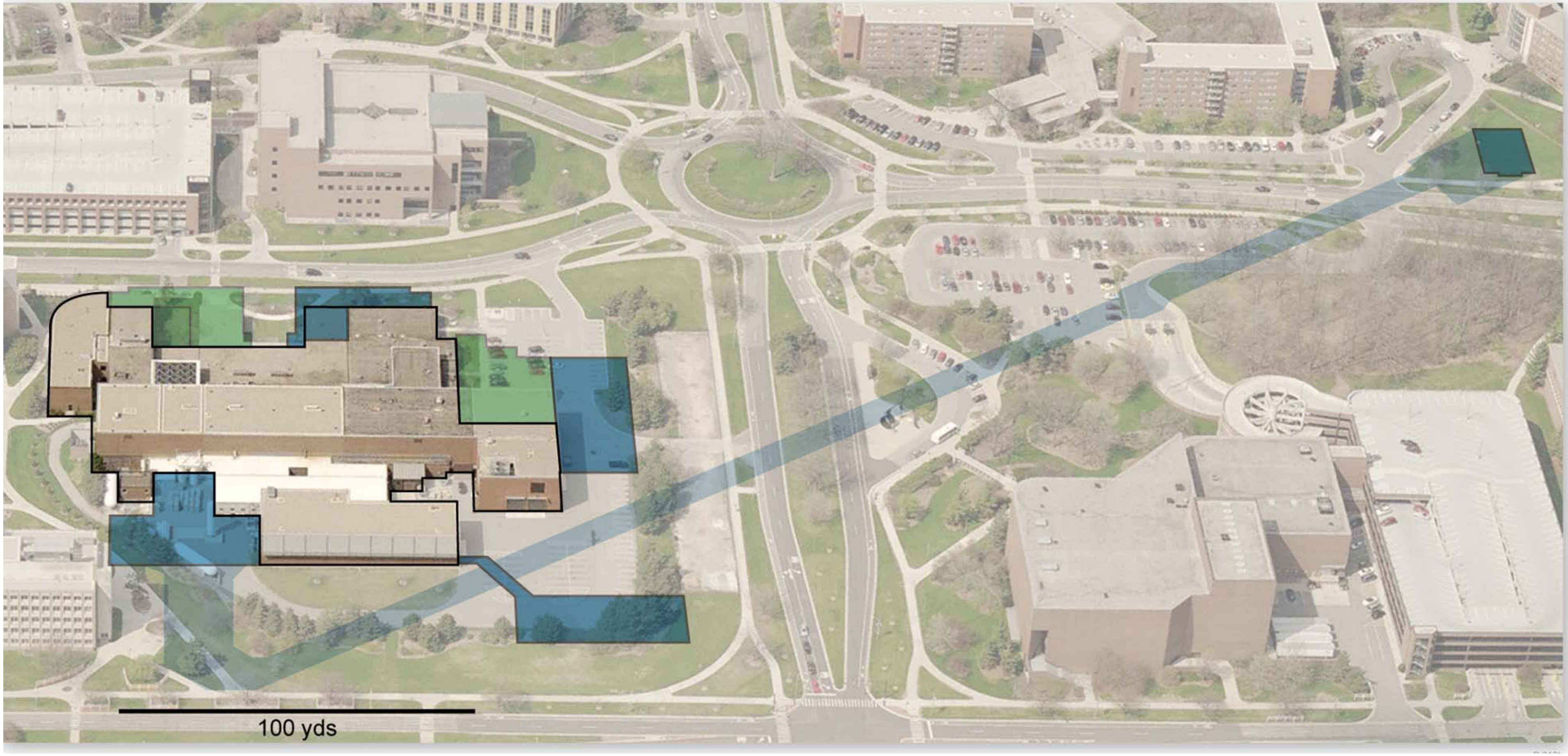
A heavy-ion driver can also accelerate light ions needed for an ISOL facility



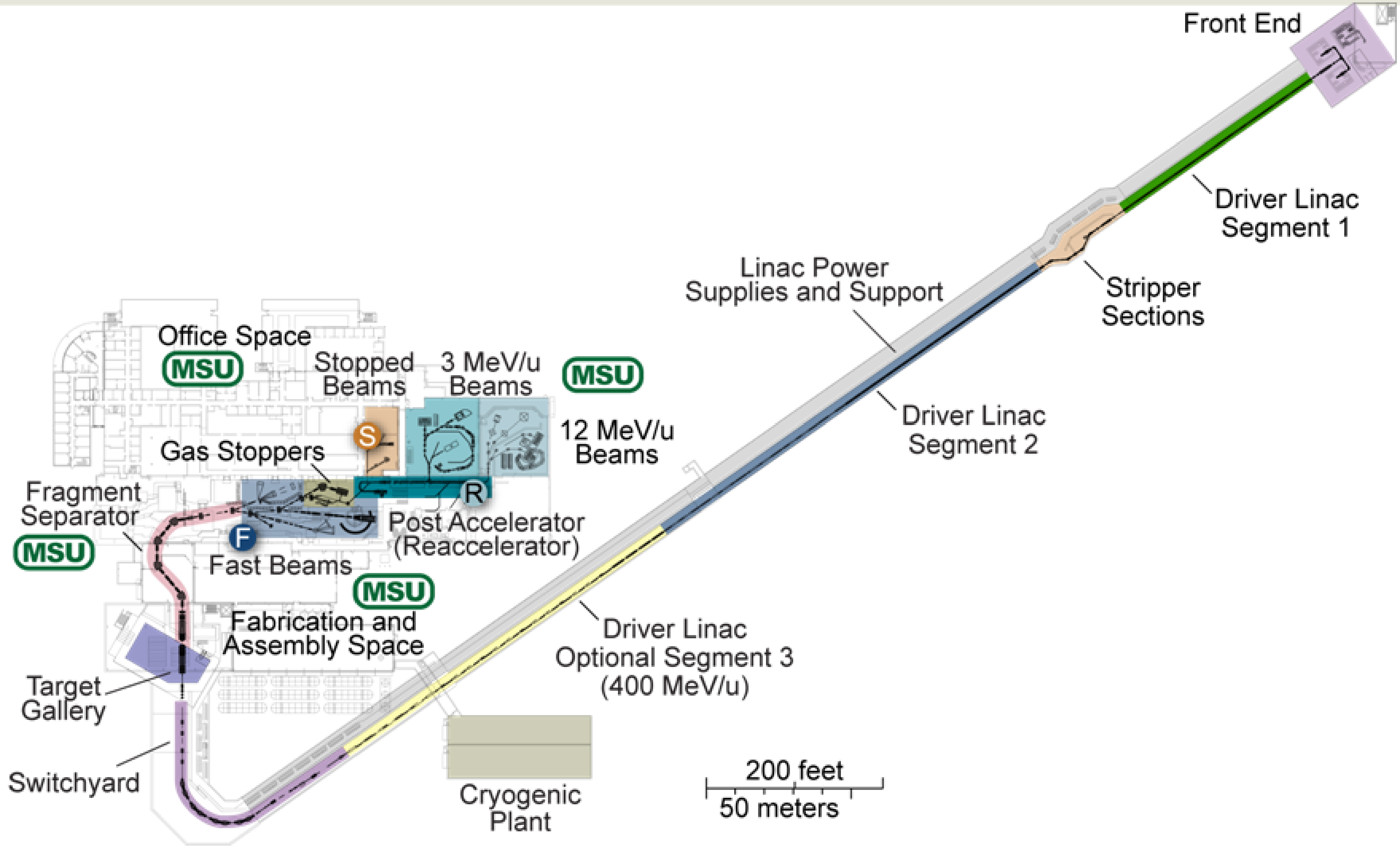
FRIB Surface Structures



FRIB Location on the MSU Campus

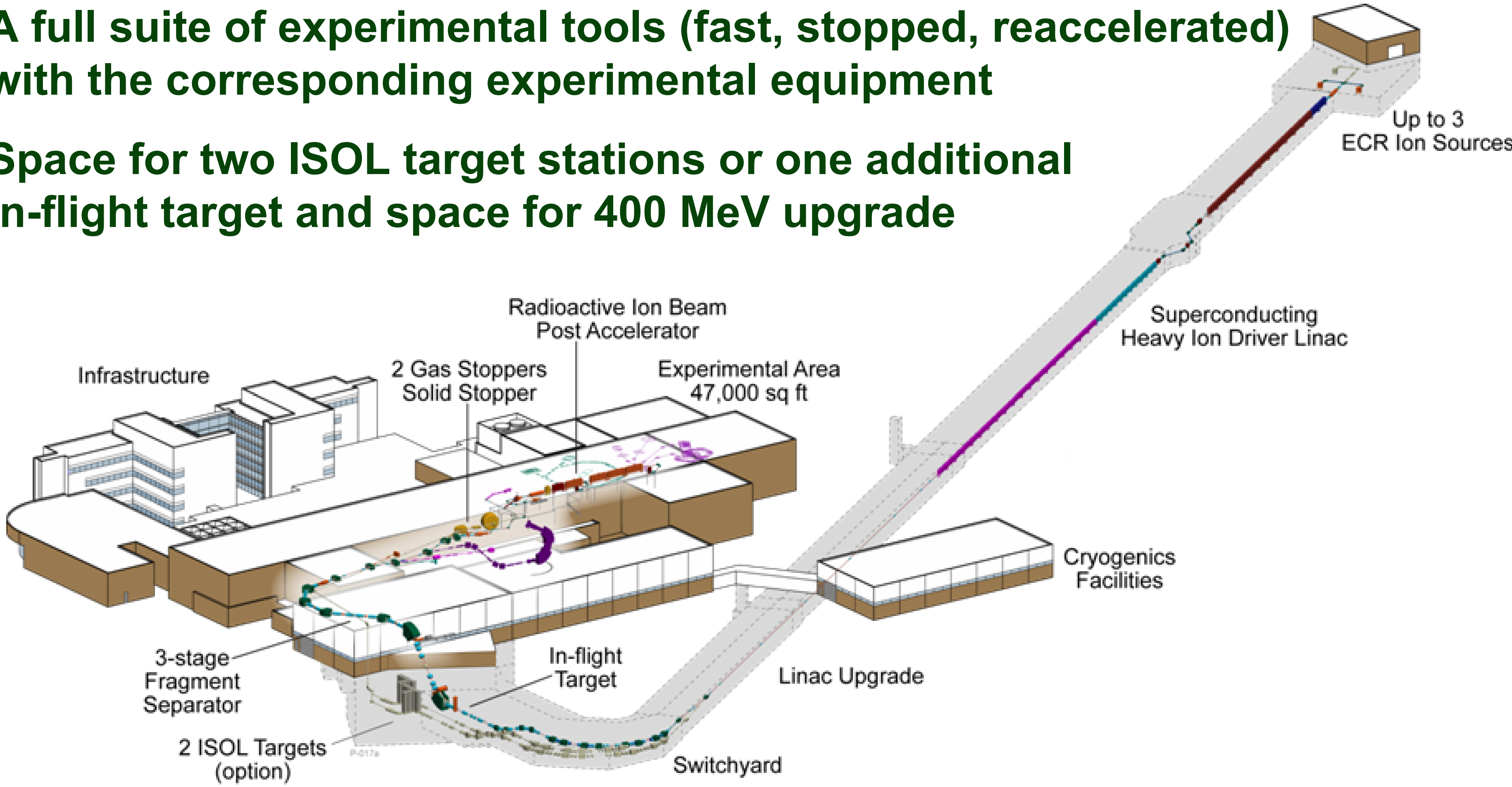


FRIB Configuration



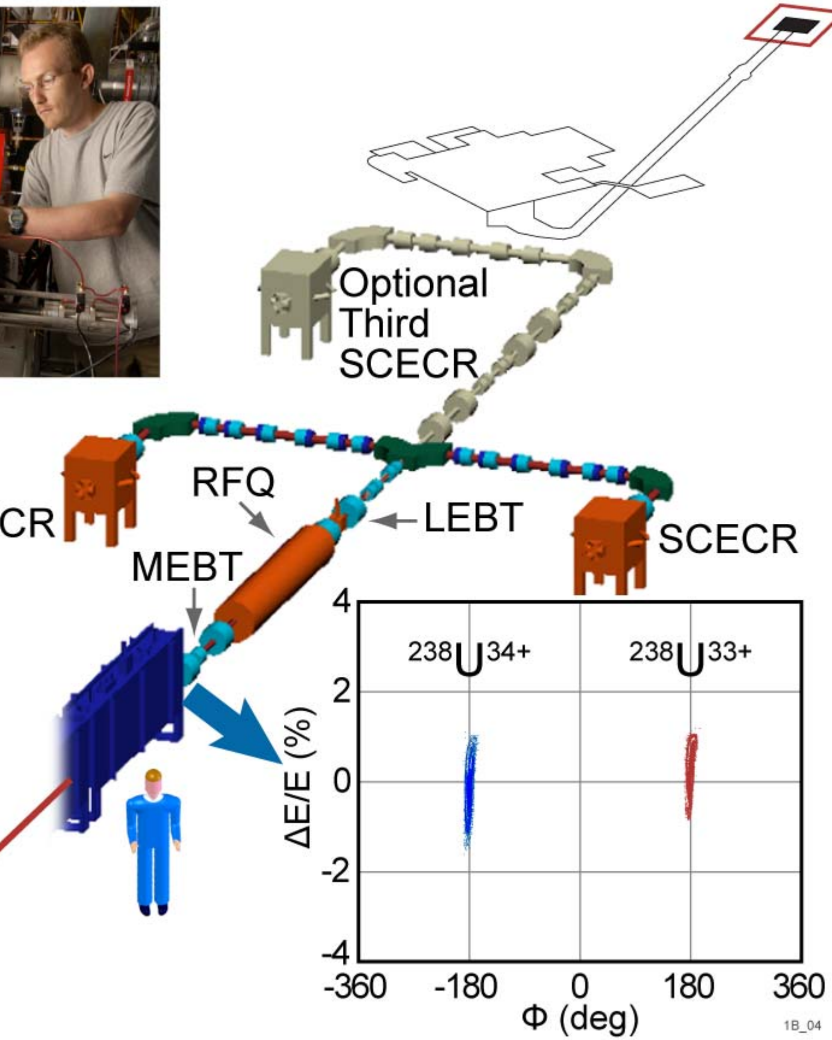
FRIB General Features

- **Driver linac with 400 kW and greater than 200 MeV/u for all ions**
- **A full suite of experimental tools (fast, stopped, reaccelerated) with the corresponding experimental equipment**
- **Space for two ISOL target stations or one additional in-flight target and space for 400 MeV upgrade**



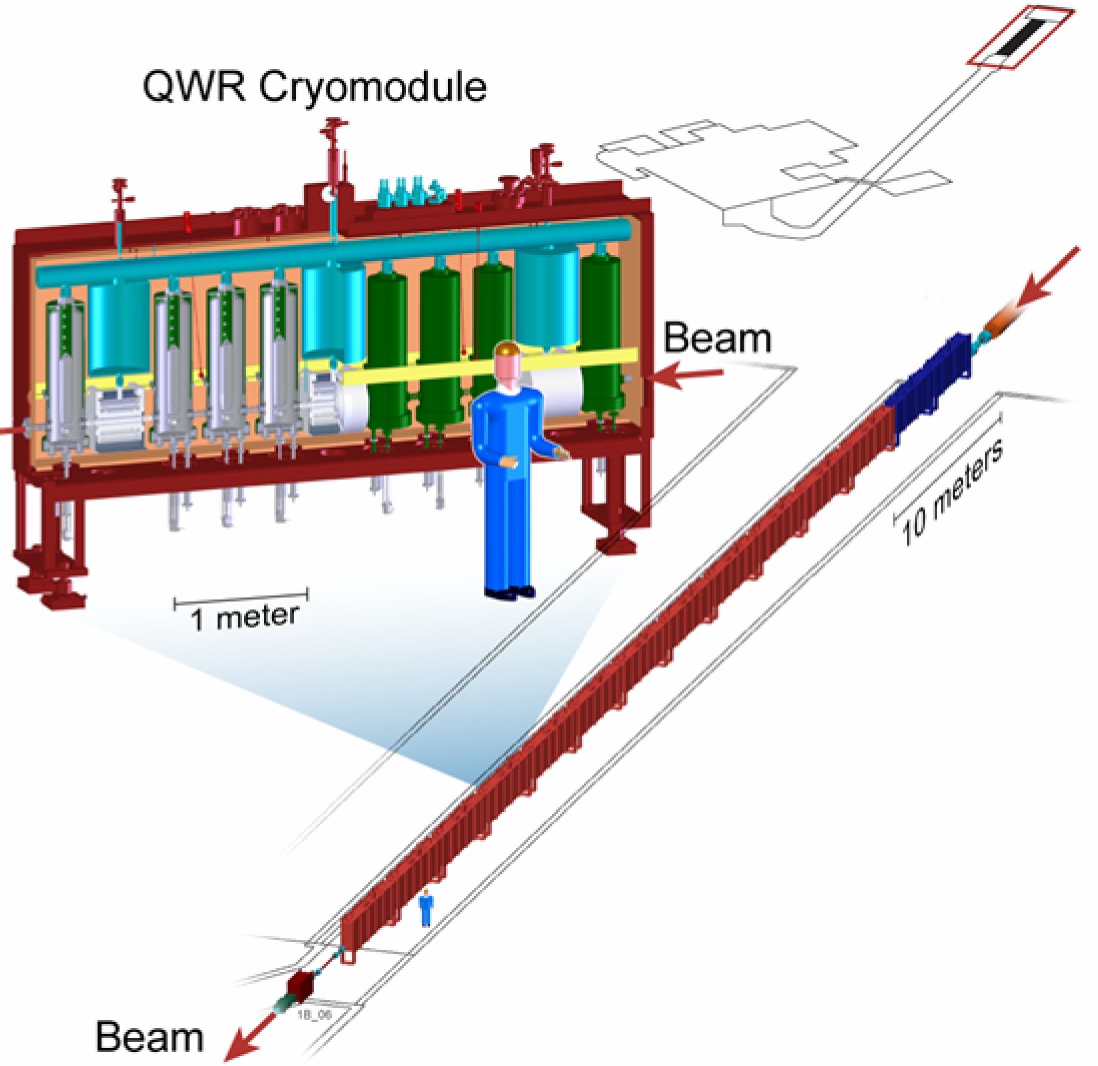
Driver Linac – Front End

- **Two superconducting ECR ion sources**
  - **Option for 3rd ECR**
- **Low Energy Beam Transport (LEBT)**
- **Radio Frequency Quadrupole (RFQ)**
- **Medium Energy Beam Transport (MEBT)**
- **Output for 400 kW uranium on target**
  - **Two charge states (33+ & 34+)**
  - **6 pμA per charge state**



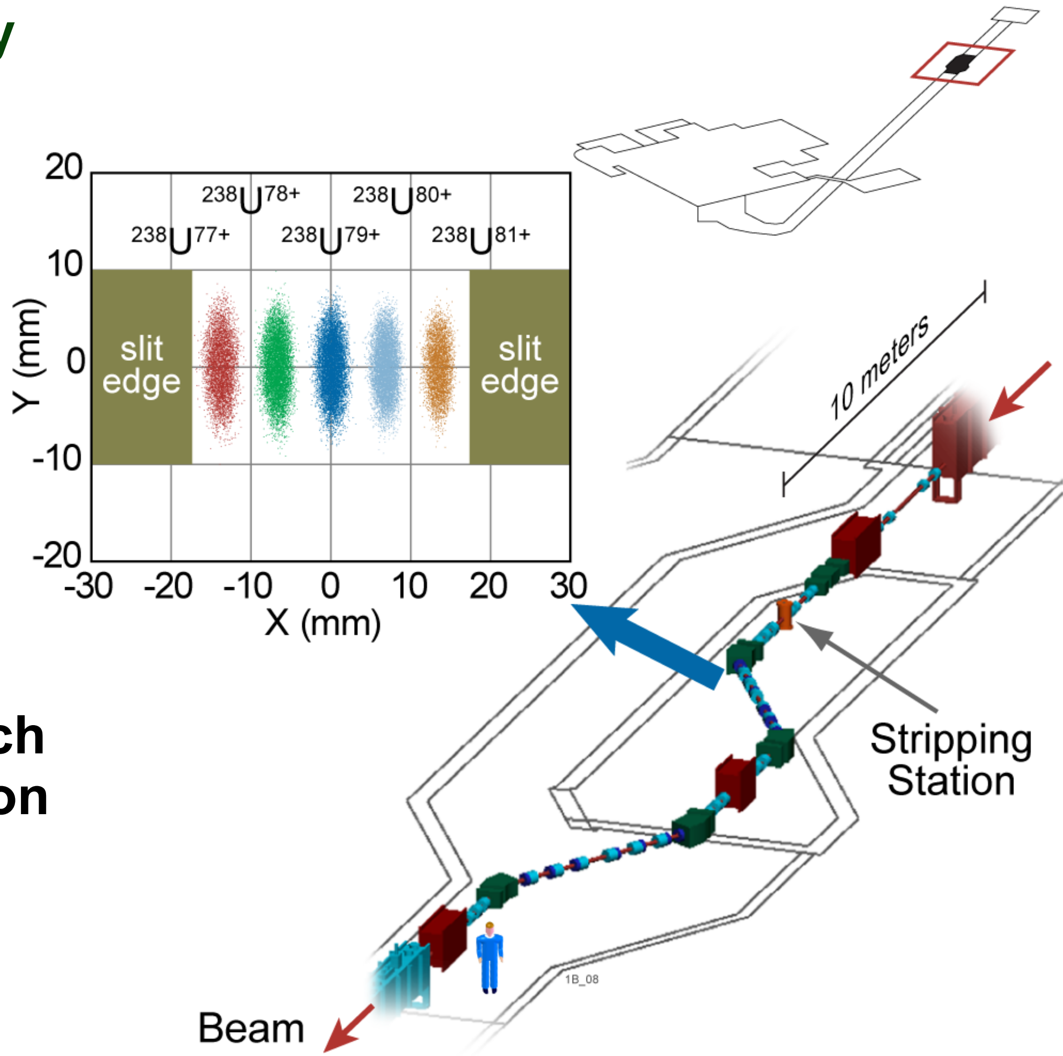
Driver Linac – Linac Segment 1

- Output beam
  - 17.5 MeV/u
  - 10 pμA (uranium)
- Two types of Quarter Wave Resonators (QWRs) at 80.5 MHz
  - Beta = 0.041 & 0.085
- 9T superconducting solenoids
- 14 cryomodules



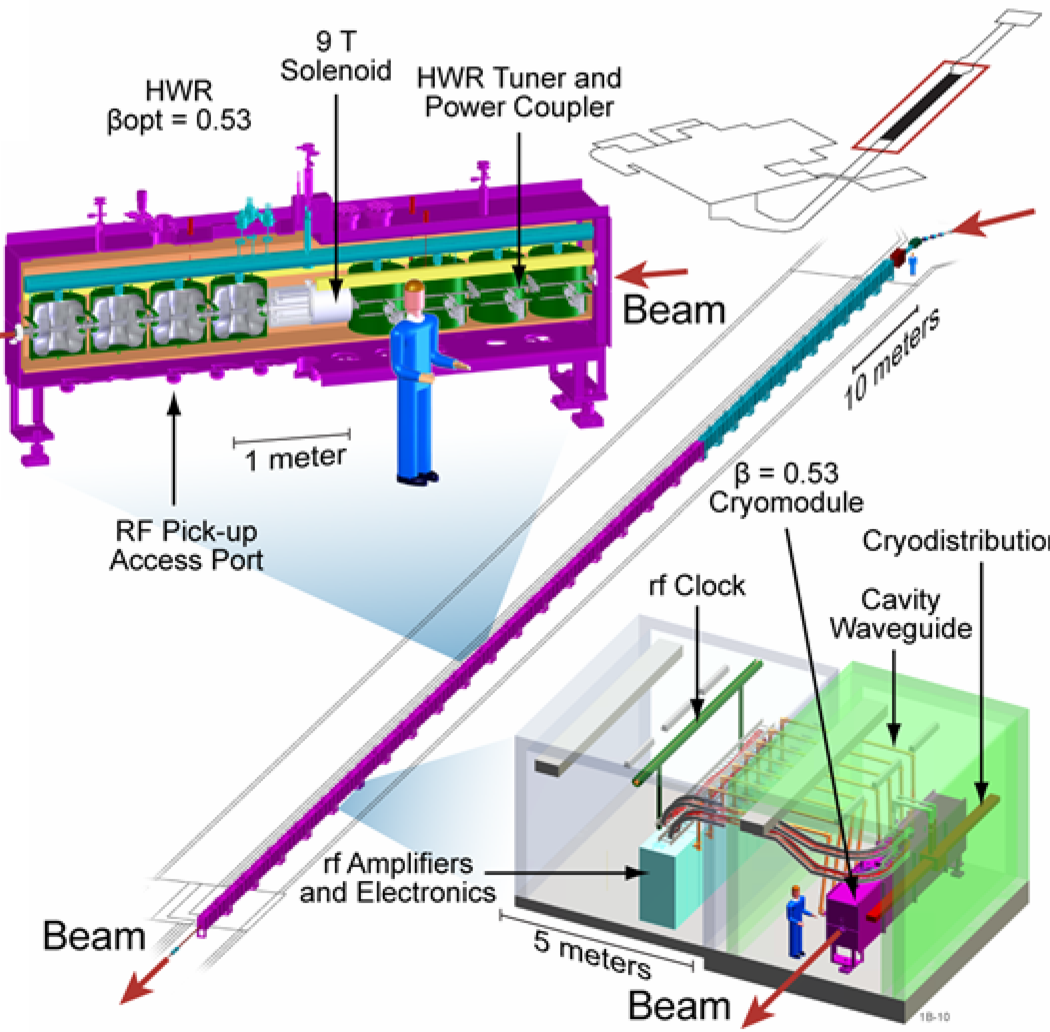
Driver Linac – Stripping Section

- **Increase acceleration efficiency by**
  - Focus input beam (up to 2 charge states) in space and time onto stripper
  - Strip and collimate beam
  - Match beam (up to 5 charge states) into next linac segment (Segment 2)
- **Technical Challenge**
  - Reliable solution for stripper at beam power of 40 kW which provides 400 kW at production target



Driver Linac – Segment 2

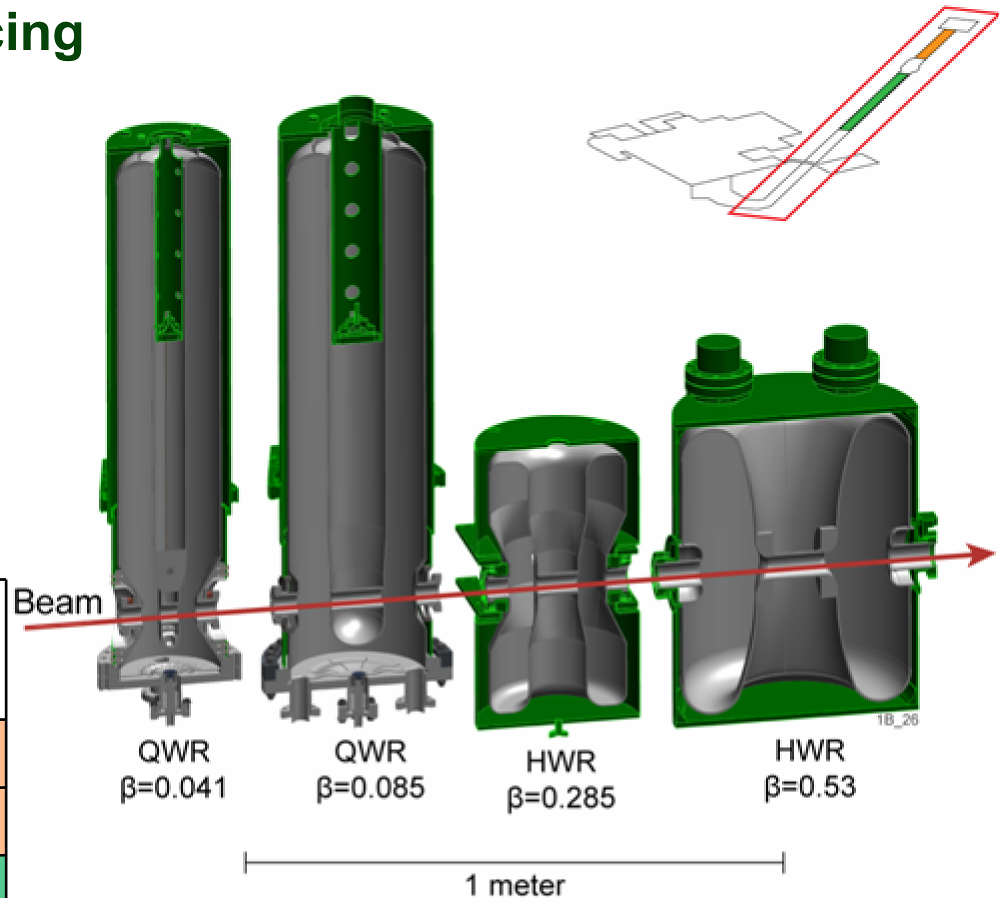
- **Final baseline acceleration segment**
- **Output Beam Energy**
  - **>400 kW beam power**
  - **200 MeV/u uranium**
  - **265 MeV/u mid-mass (^{86}Kr)**
  - **610 MeV/u protons**
- **Two types of Half-wave Resonators (HWRs) at 322 MHz**
  - **Beta = 0.285 & 0.53**
  - **9 T superconducting solenoids**
- **31 Cryomodules**
- **Undisturbed surface with both accelerator and electronic gallery subterranean**



Superconducting Cavities

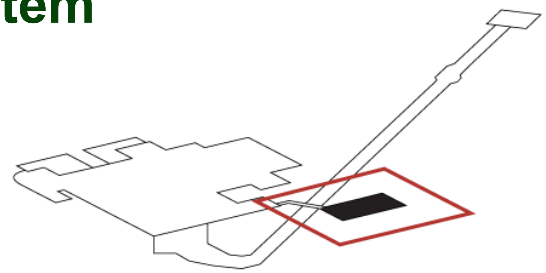
- **Only 4 cavity types required reducing**
  - **R&D**
  - **Design**
  - **Fabrication**
  - **Spare parts inventory**
- **Only 1 frequency change**
  - **Preserves beam quality**

Type	β	# per Cryomodule		# Cryomodules
		Cavities	Solenoids	
QWR	0.041	8	7	2
	0.085	8	3	12
HWR	0.285	6	1	12
	0.53	8	1	19
Totals		336	81	45



Cryogenic Facility

- Cryogenic systems include plant & distribution system
  - Plant from commercial vendor
  - Distribution self performed



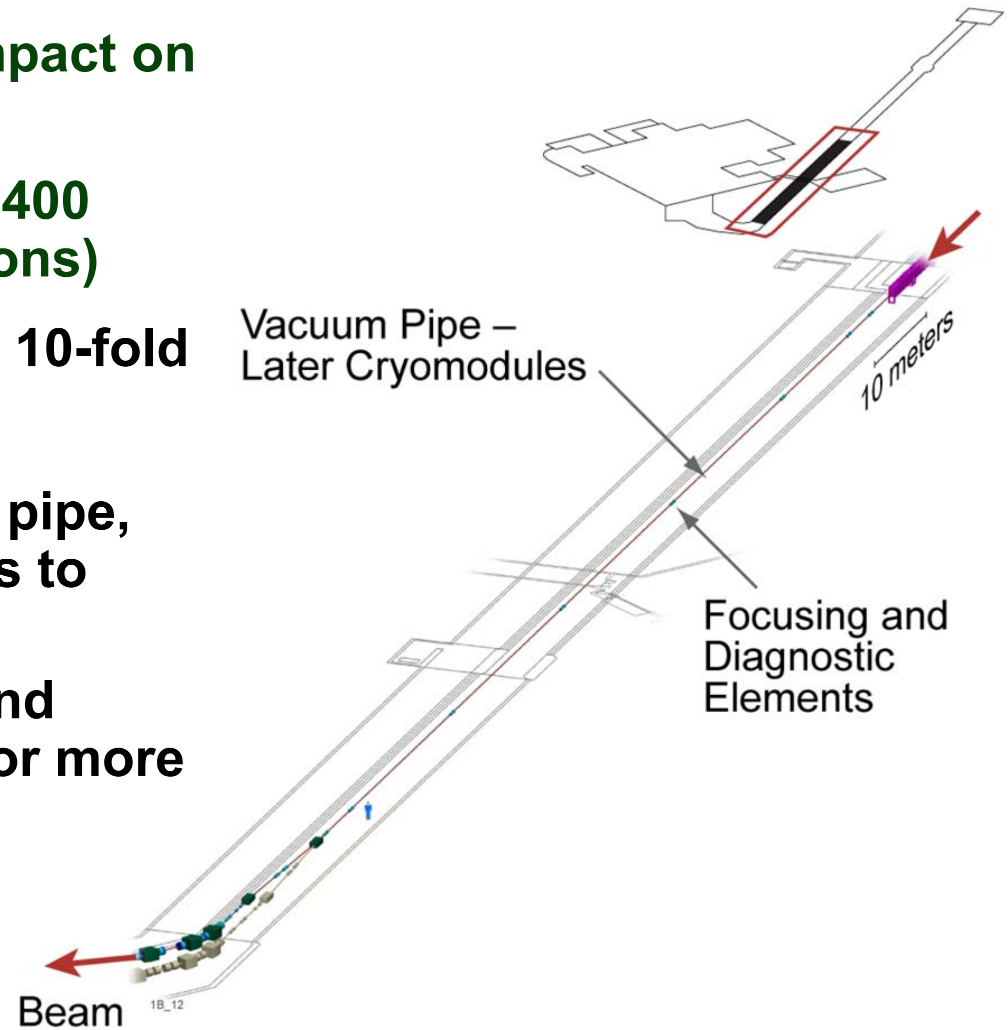
- Capacity of 10.7 kW at 4.5K
  - 50% excess capacity
  - Dynamic (rf driven) – 6.4 kW, Static – 4.3 kW
  - Loads at 4.5K (magnets and QWRs) and 2K (HWRs)

Driver Linac – Segment 3

- **Upgrade option with minimum impact on operations**
- **Space appropriate for more than 400 MeV/u uranium (1000 MeV/u protons)**
  - **Increase RIB production about 10-fold**
- **Approach**

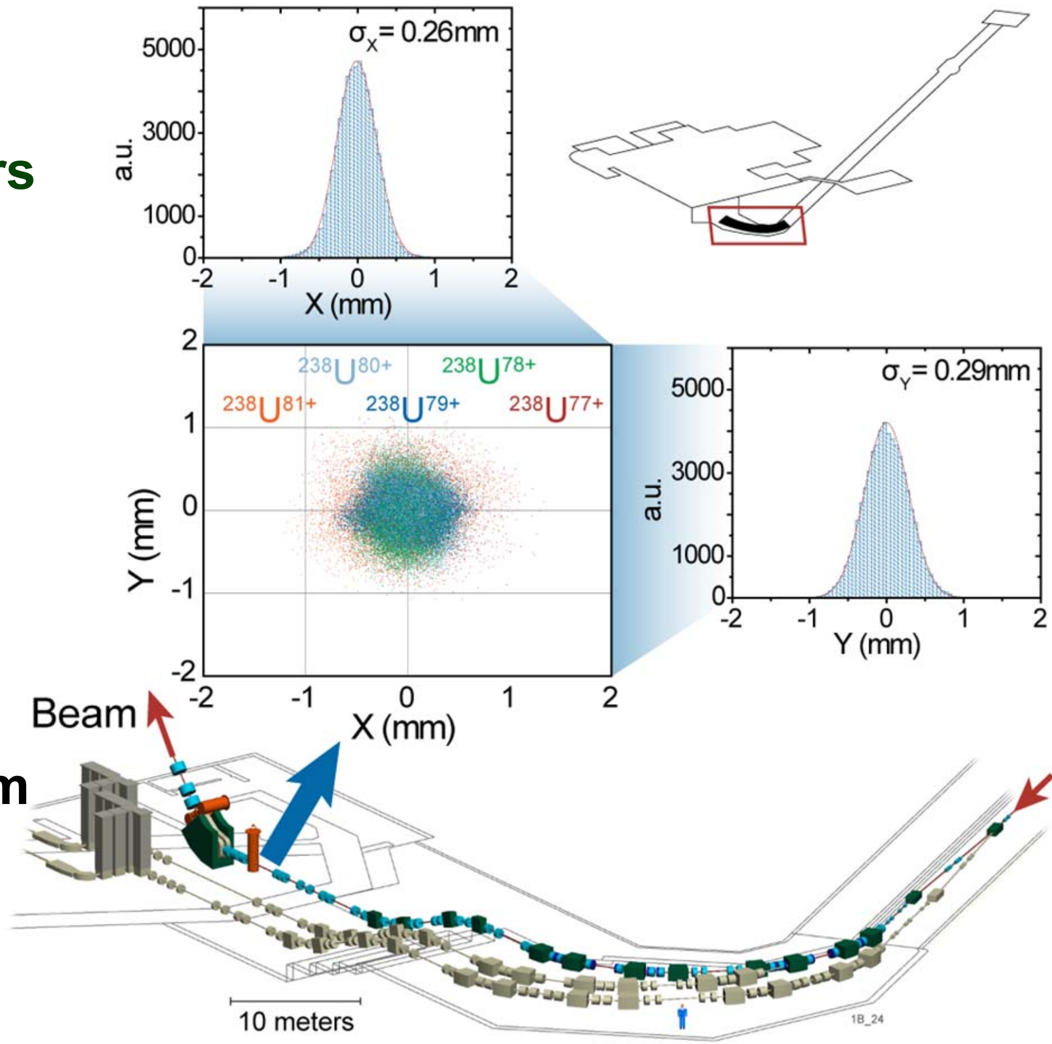
– **Initial implementation of vacuum pipe, focusing and diagnostic elements to deliver beam to switch yard**

– **Later can remove vacuum pipe and replace with cryomodules – one or more at a time**



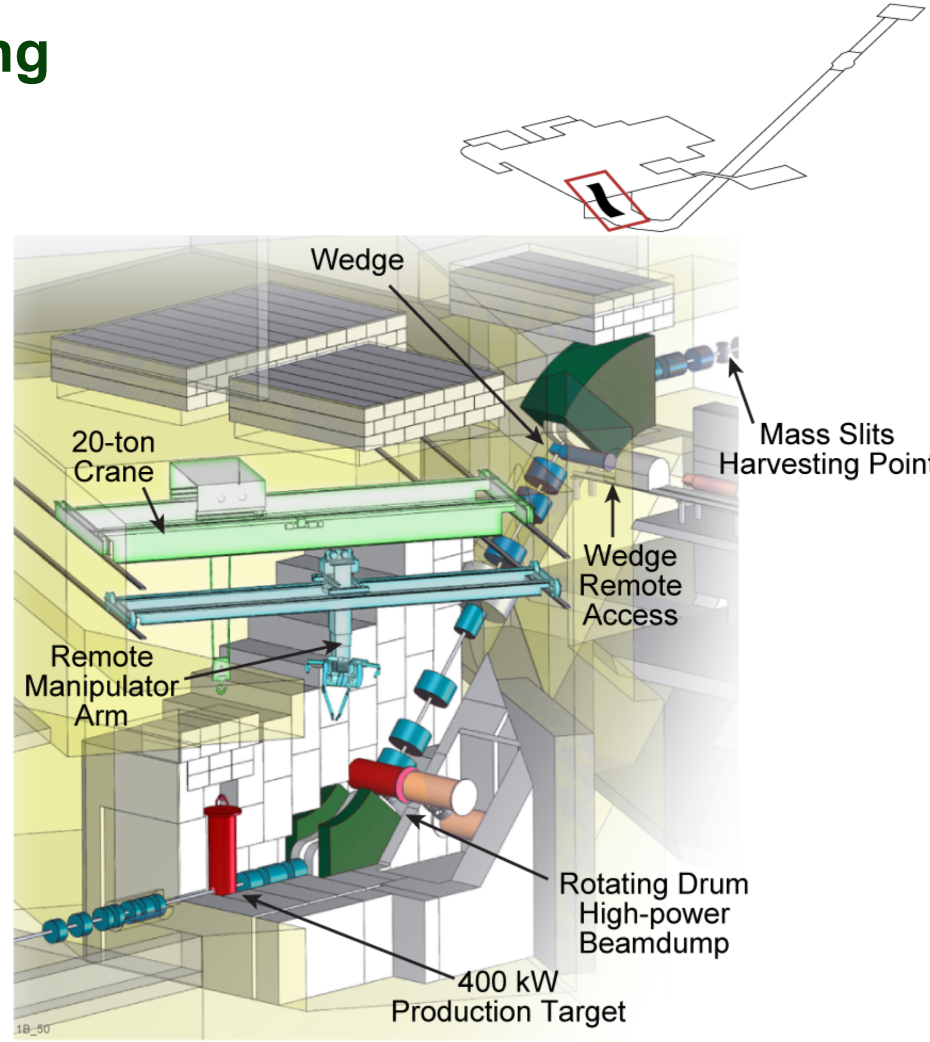
Switchyard

- **Deliver beam to RIB production target**
- **High-order optics design delivers high-quality beam on target**
- **High quality, multi-charge-state beam of small size on RIB production target**
- **Flexible approach for enhancements**
  - **Appropriate for up to 400 MeV/u uranium**
  - **Multiple user simultaneous beam capability obtained by simple addition of hardware**



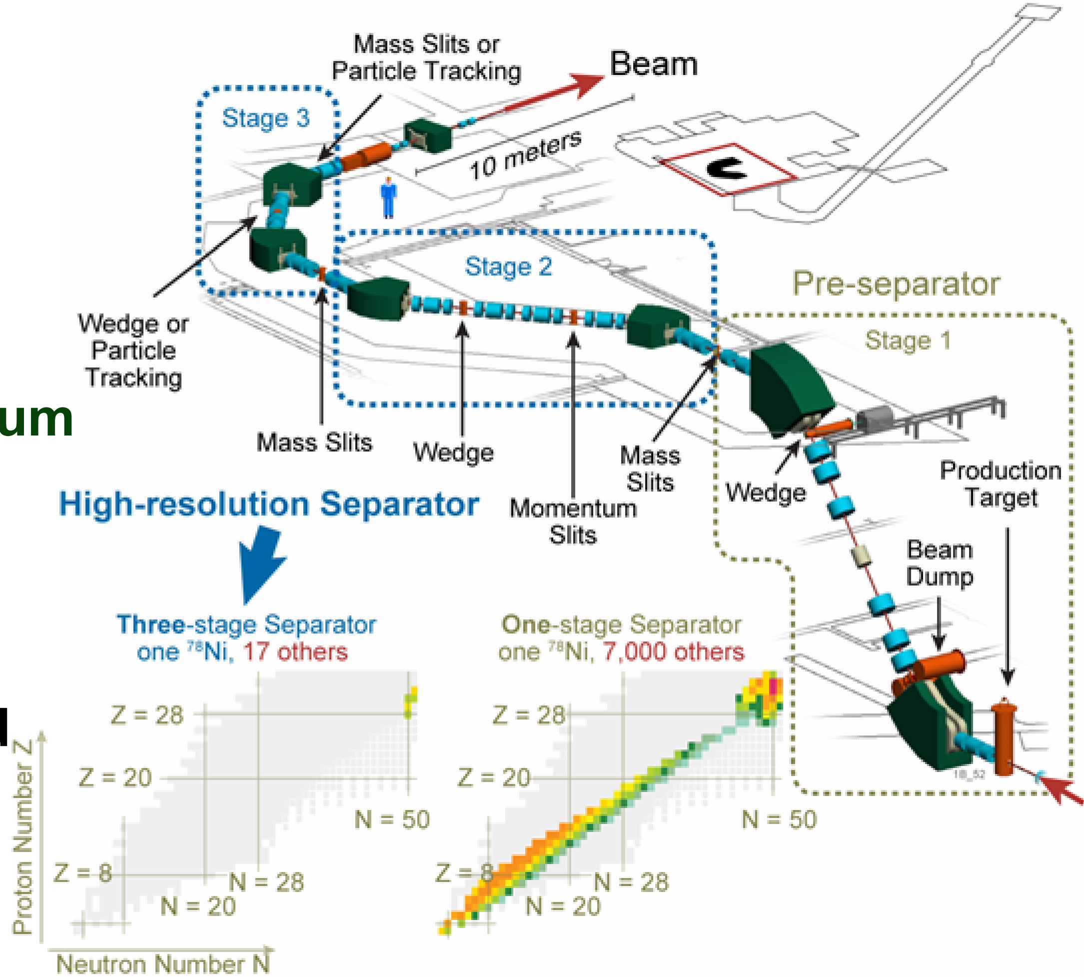
Target Facilities

- **Self-contained new target building with space for upgrade**
- **State-of-the-art full remote-handling to maximize efficiency**
- **Fast, cost-effective, flexible upgrades**
  - **2 ISOL stations or 2nd fragment separator**
  - **Designed for 400 kW 400 MeV/u uranium**

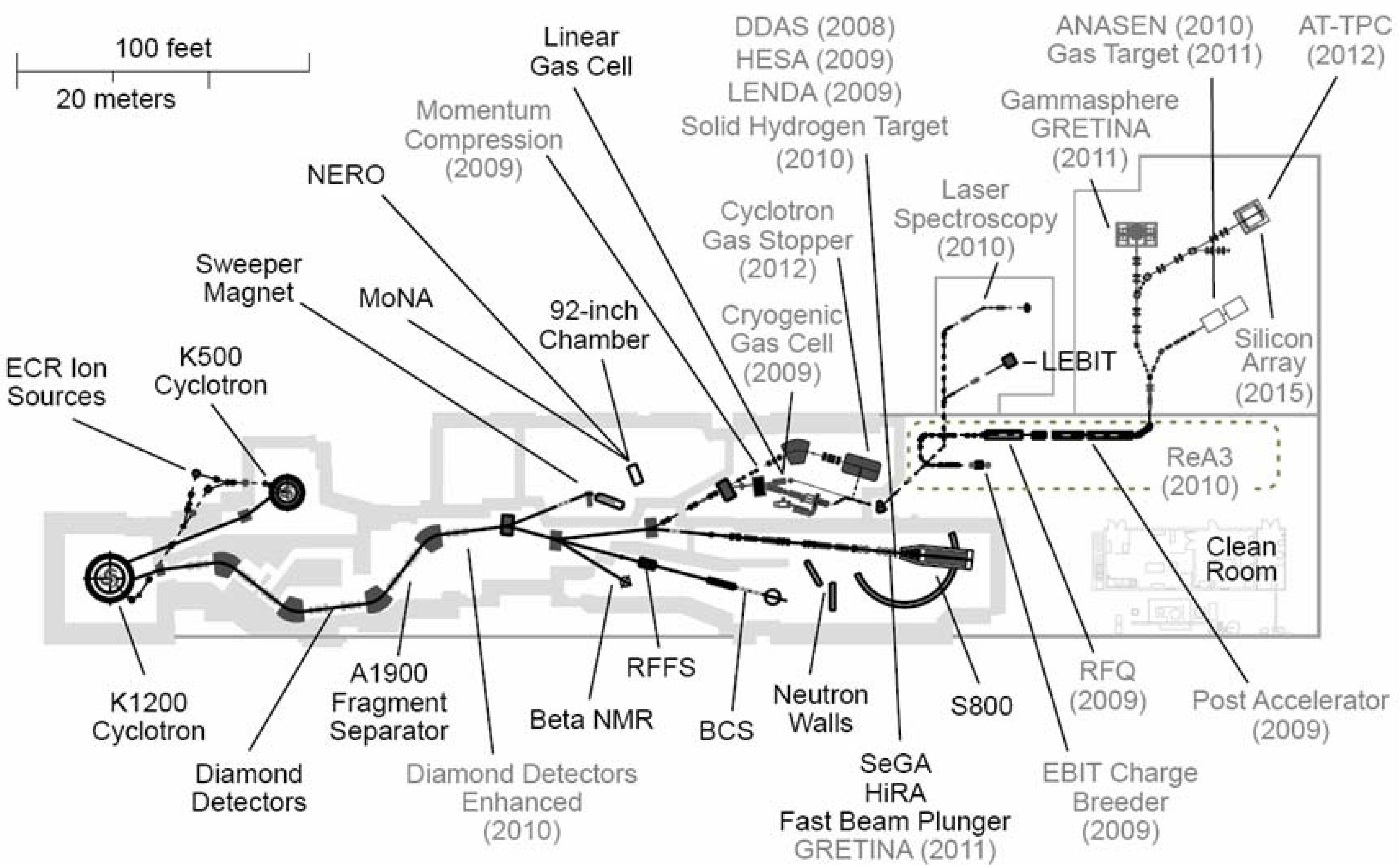


Fragment Separator

- **In-flight separation of rare isotopes with high acceptance and high resolution**
- **Provide purest-possible rare isotopes from 200 MeV/u uranium to maximize science reach**
- **3-stage separation**
  - **Heavy ions not fully stripped**
  - **Beam purity critical to new discoveries**
  - **Beam purity critical to gas stopping**

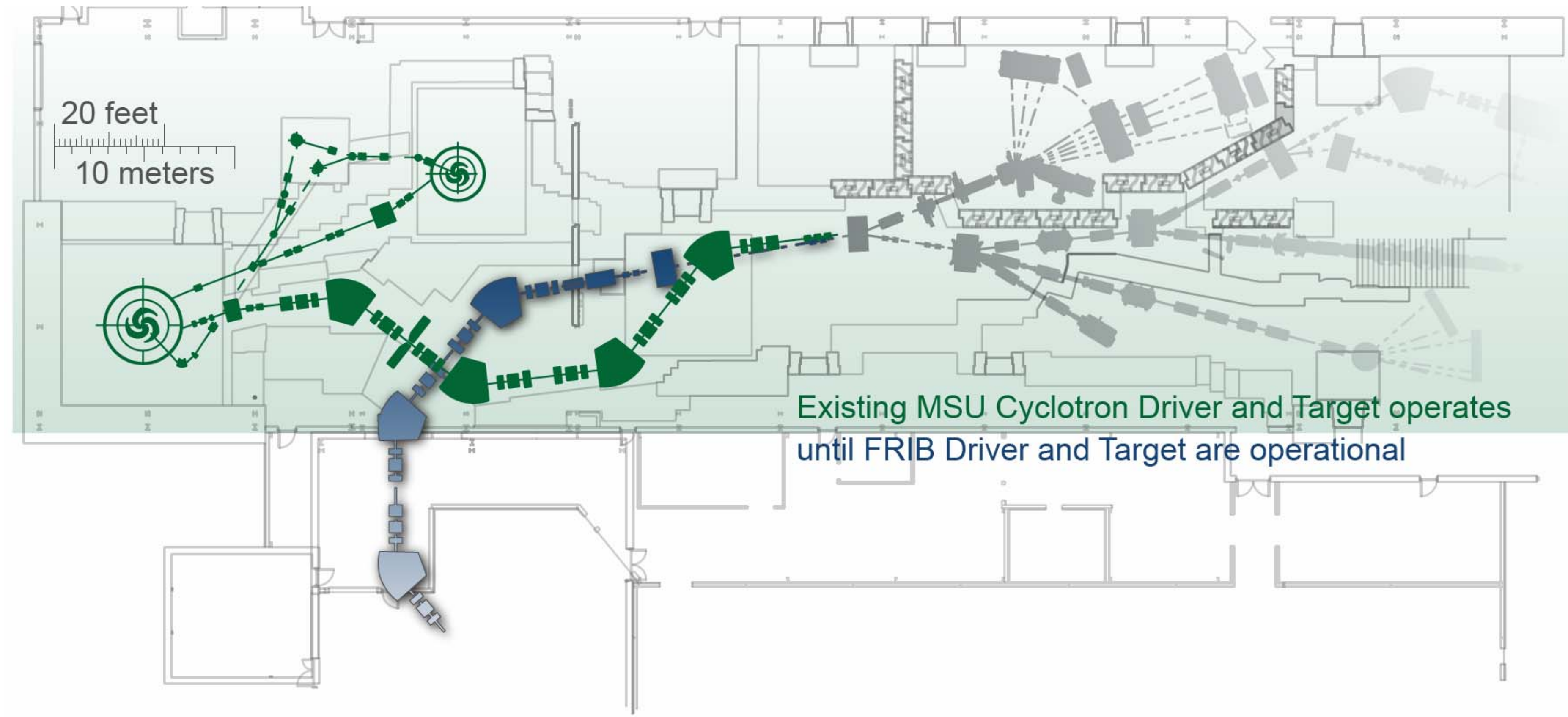


Pre- FRIB Equipment



Transition from NSCL to FRIB Operations

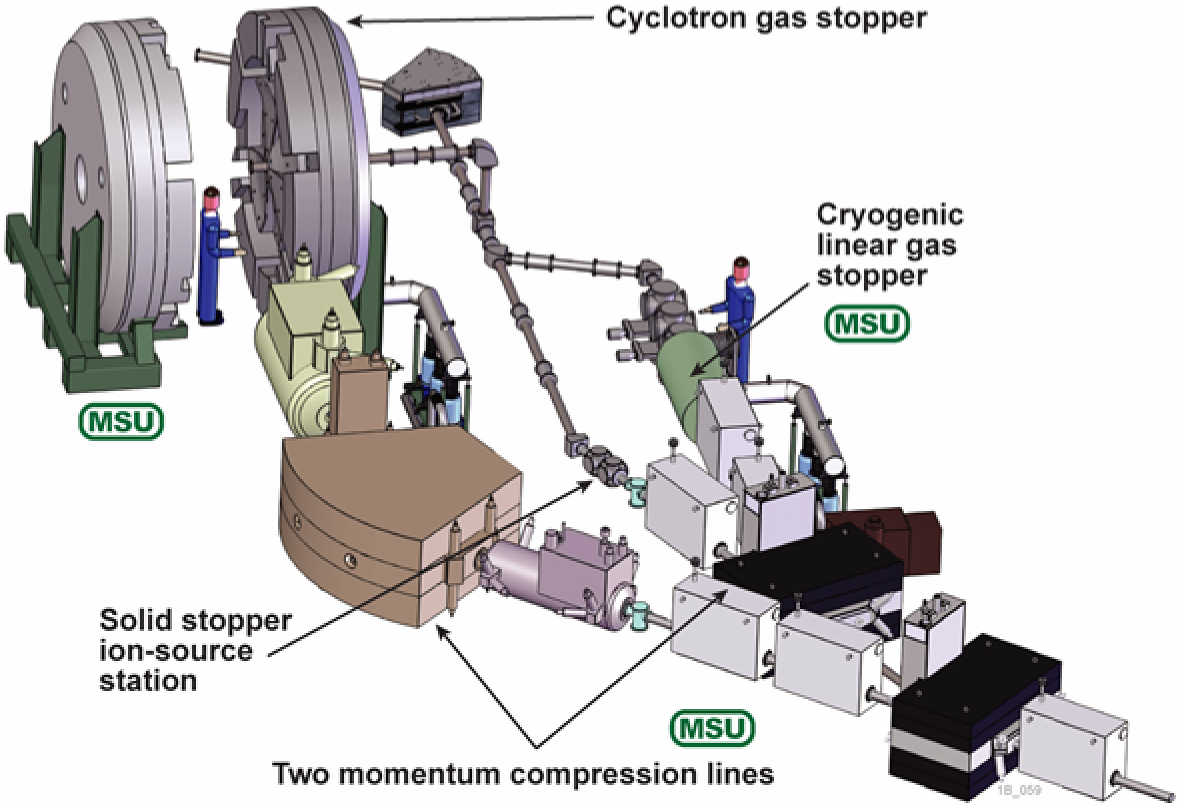
- **Minimal perturbation of the experimental area when transitioning from NSCL to FRIB operations**



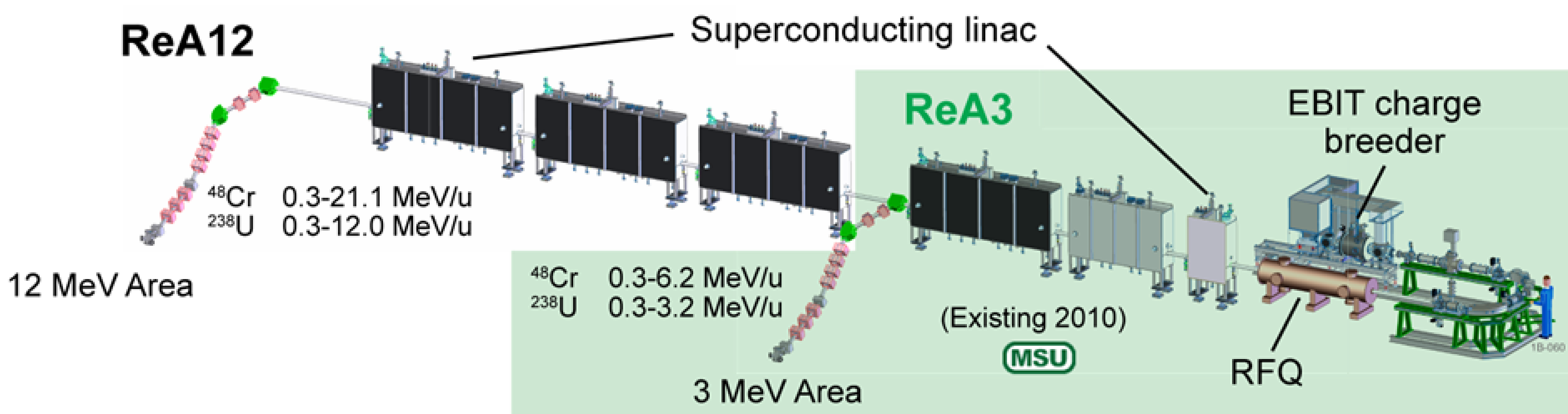
Beam Stopping

- Rare Isotopes brought to rest by 3 complementary stopping stations
- Cyclotron gas stopper for light and medium heavy isotopes
- Cryogenic linear gas stopper for heavy isotopes
- Solid stopper for special elements and high beam rates

MSU's multi-station approach



Radioactive Ion-beam Reaccelerator



ReA3 - MSU

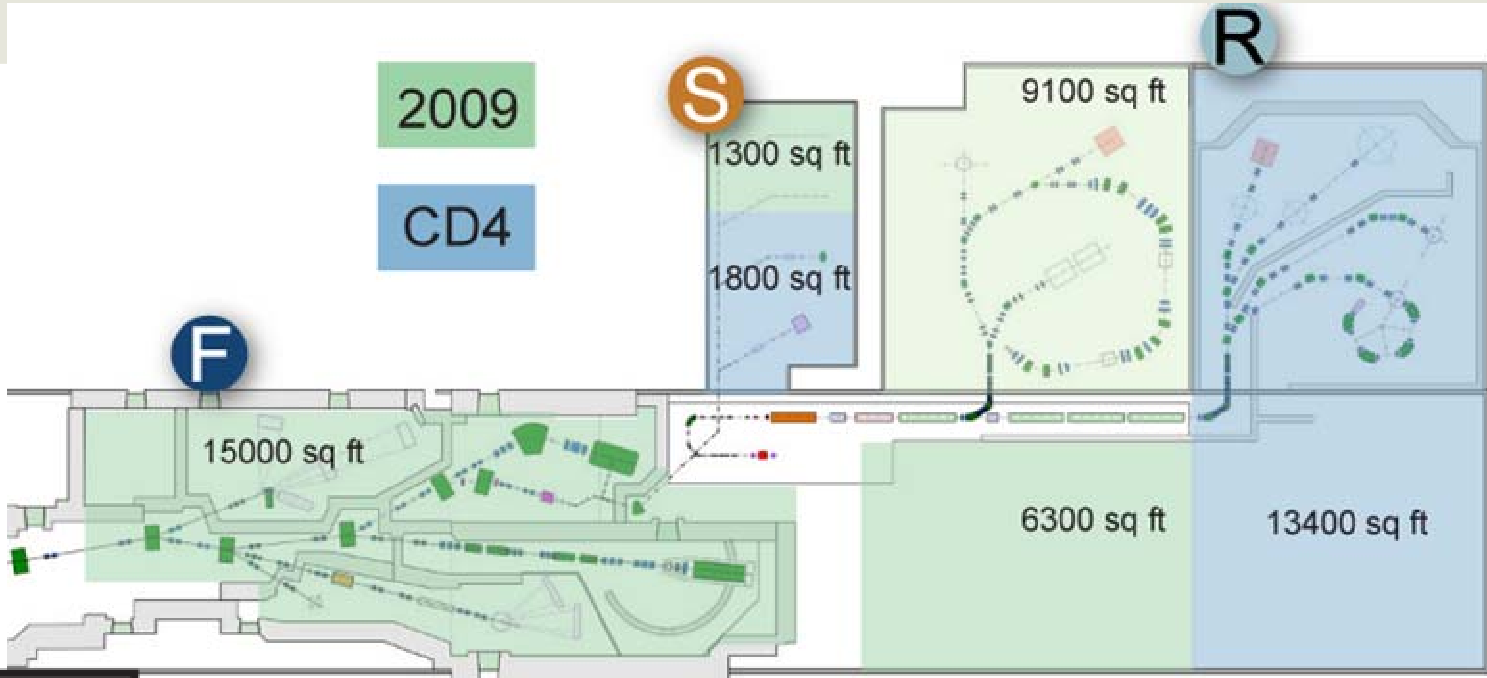
- **High-intensity EBIT as $1^{+} \rightarrow n^{+}$ charge breeder**
- **RT RFQ and SRF QWR cavities and cryomodules**
- **Energies 0.3 to 3 MeV/u**

ReA12 – FRIB

- **Energies 0.3 to 12 MeV/u**

Experimental Areas

- **47,000 sq ft operational areas by CD4**
- **Space to more than double sq ft**



F		15,000 sq ft
S		3,100 sq ft
R	3 MeV/u	15,400 sq ft
	12 MeV/u	13,400 sq ft
Total at CD4: 46,900 sq ft Expandable to >100,000 sq ft		

FRIB Project

- Total Project Cost ~$550M
- Initial Activities
  - Continuation of R&D program
  - National Environmental Policy Act (NEPA) evaluations
  - Development of Conceptual Design Report
- Subject to availability of funds – operational ~2017.

Summary

- FRIB will allow major advances in nuclear science and nuclear astro-physics
  - Significant opportunities for the tests of fundamental symmetries
  - Potential for important societal applications
  - Campus-based location offers important educational and collaboration benefits
- 200 MeV/u, 400 kW driver linac
- Experimental capability for fast, stopped and reaccelerated beams
- Attractive upgrade options make the facility viable far beyond 2030