Facility for Rare Isotope Beams at MSU

Georg Bollen

Facility of Rare Isotope Beams

Michigan State University

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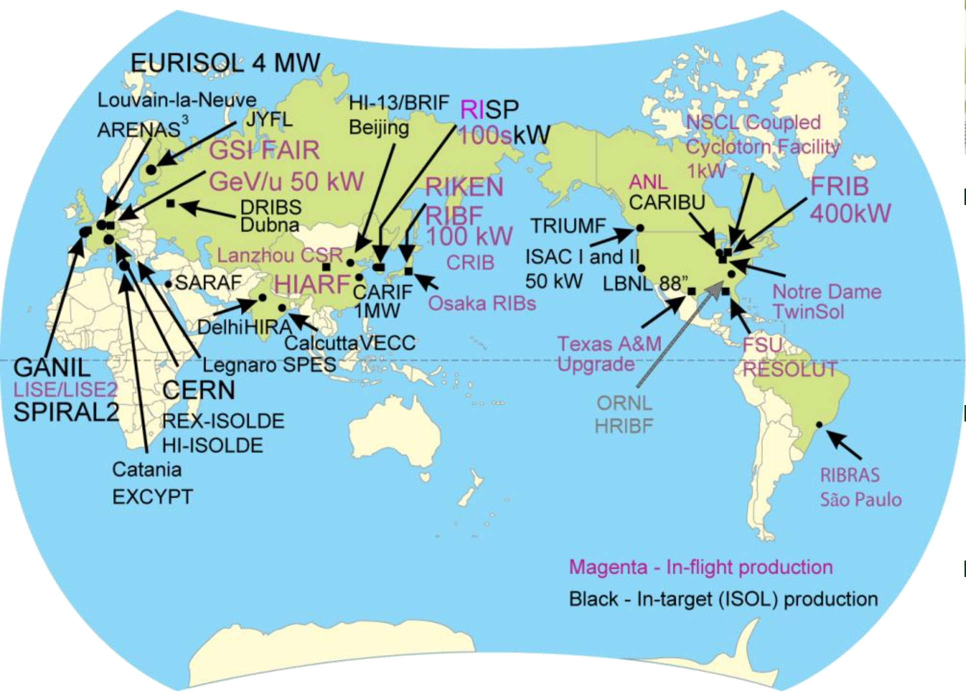
Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

Outline

- FRIB Overview
- Science themes
- FRIB beams for science
- FRIB Project status
- FRIB facility baseline design
- Upgrade options
- Users
- Summary

Facility for Rare Isotope Beams (FRIB) at Michigan State University

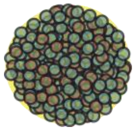
World-leading next-generation rare isotope beam facility



- Rare isotope production via in-flight technique with primary beams up to 400 kW, 200 MeV/u uranium
- Fast, stopped and reaccelerated beam capability
- Upgrade options
  - Energy 400 MeV/u for uranium
  - ISOL production – Multi-user capability

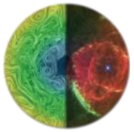
FRIB Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

FRIB –Four Science Themes



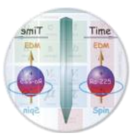
Properties of nuclei

- Develop a predictive model of nuclei and their interactions
- Many-body quantum problem: intellectual overlap to mesoscopic science, quantum dots, atomic clusters, etc.



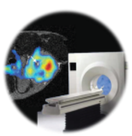
Astrophysical processes

- Origin of the elements in the cosmos
- Explosive environments: novae, supernovae, X-ray bursts …
- Properties of neutron stars



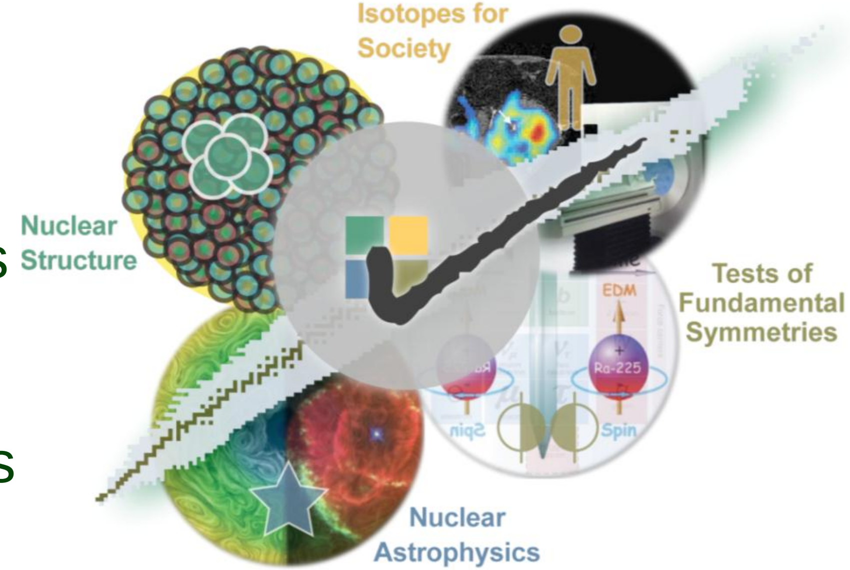
Tests of fundamental symmetries

- Effects of symmetry violations are amplified in certain nuclei



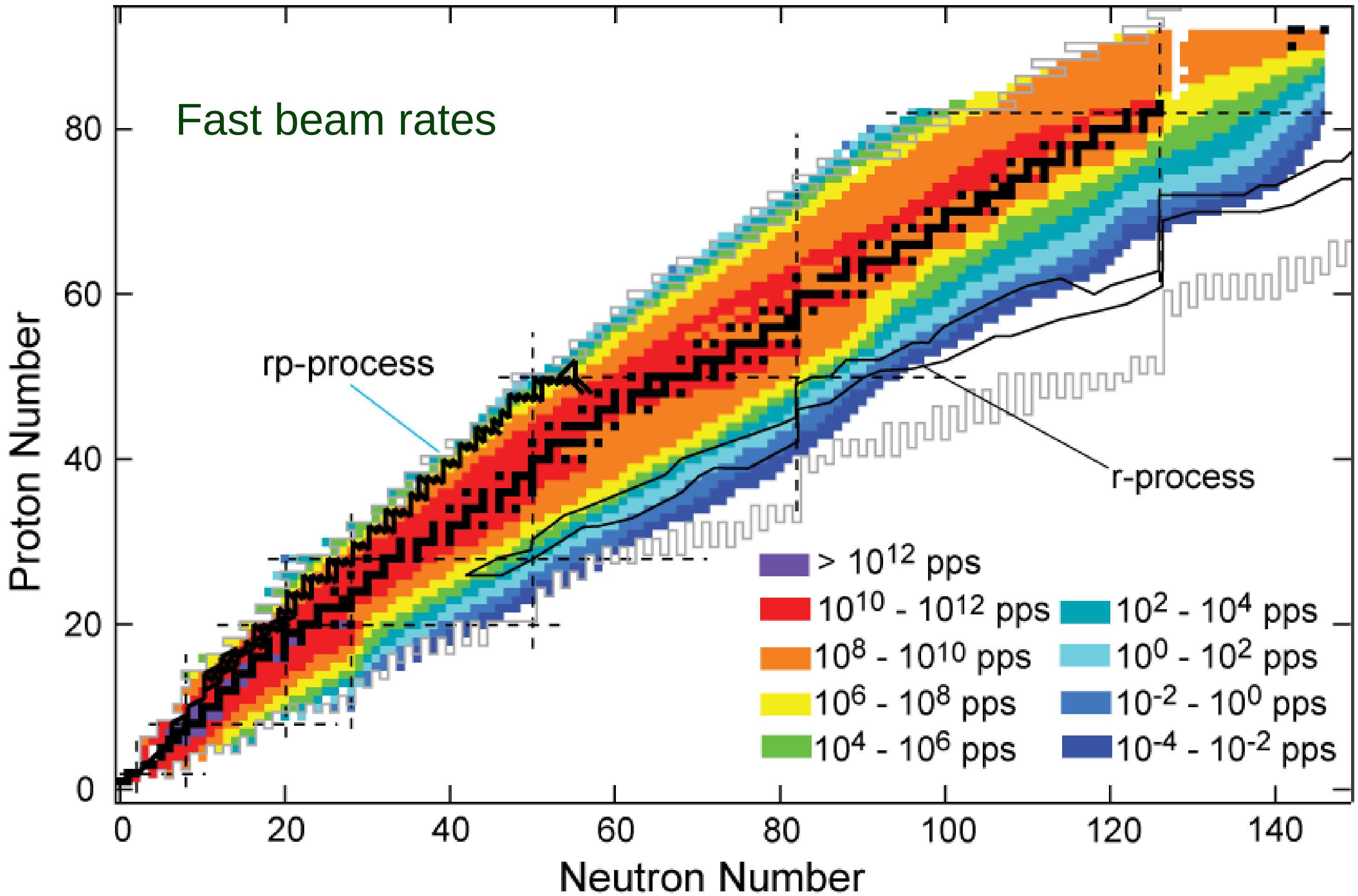
Societal applications and benefits

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



FRIB Rare Isotope Beam Rates

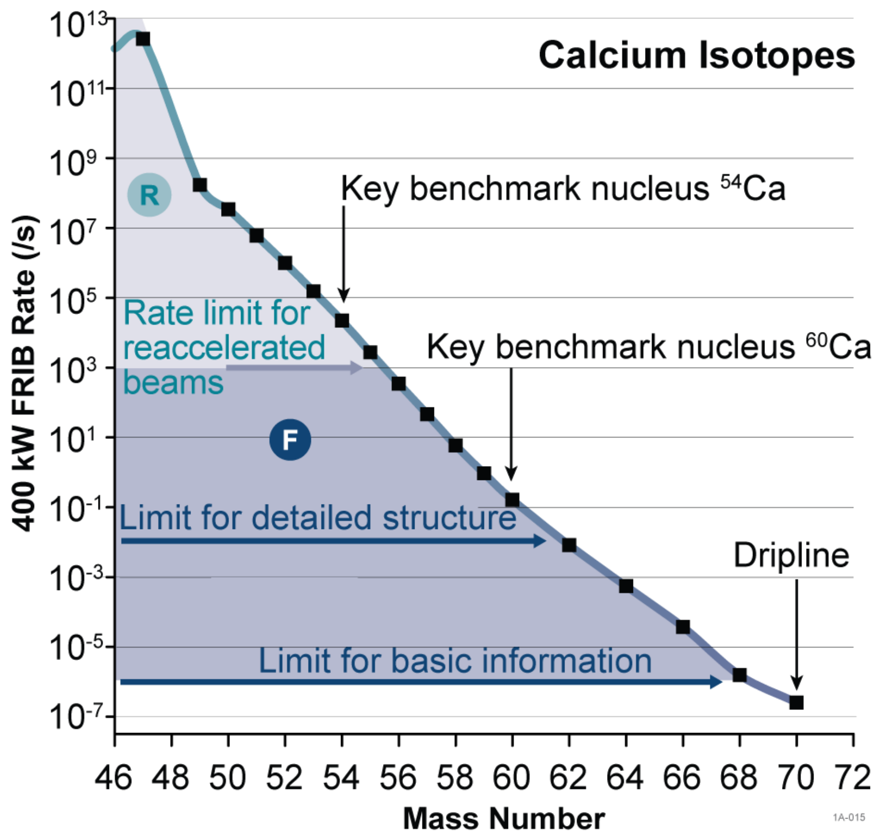
High beam rates to maximize science reach



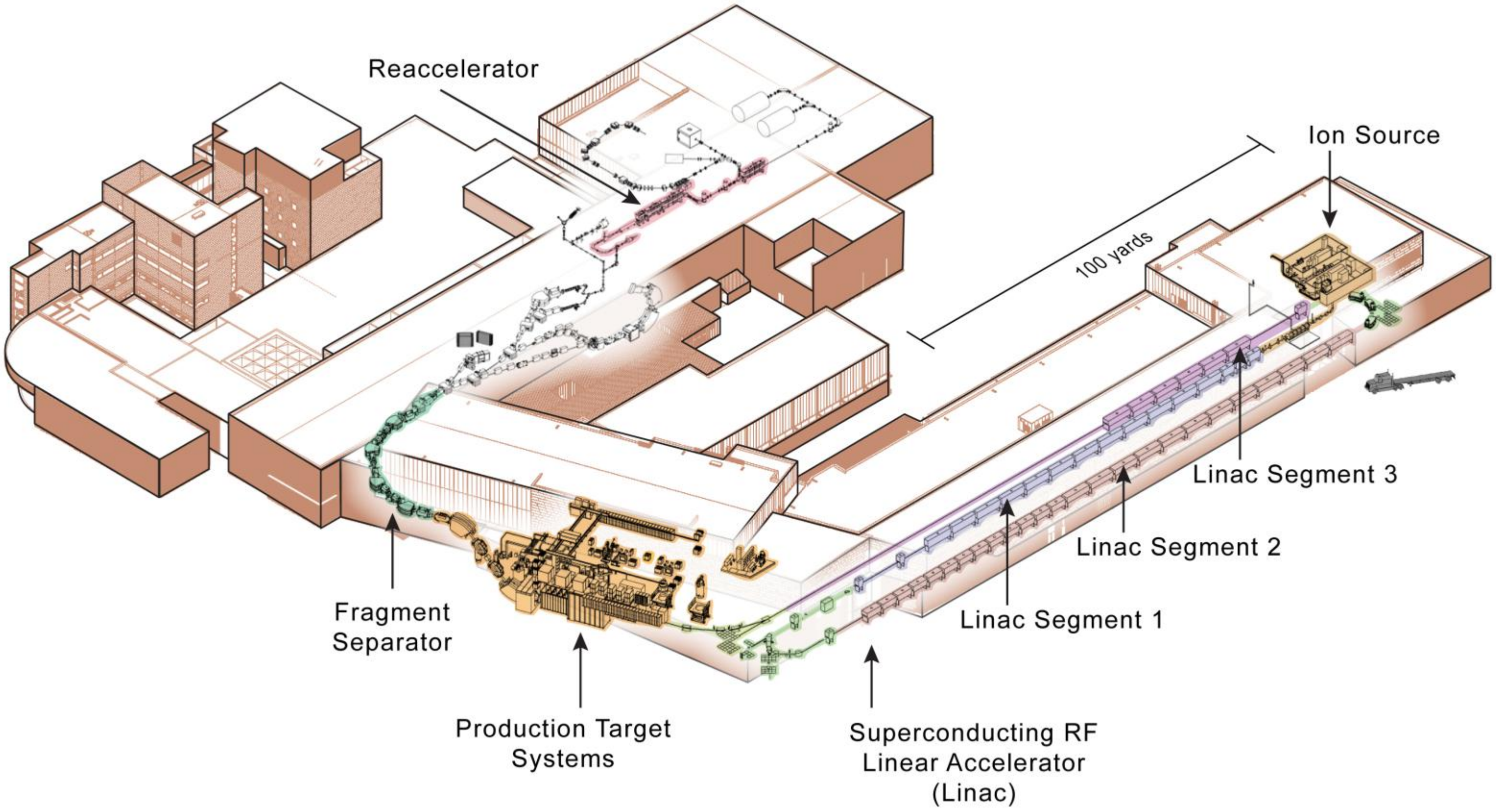
Rates are available at http://groups.nscl.msu.edu/frib/rates/

Fast, Stopped, and Reaccelerated Beams for Broad Science Opportunities

- Fast beams (>100 MeV/u)
  - Farthest reach from stability, nuclear structure, limits of existence, EOS of nuclear matter
- Stopped beams (0-100 keV)
  - Precision experiments – masses, moments, symmetries
- Reaccelerated beams (0.2-20 MeV/u)
  - Detailed nuclear structure studies, high-spin studies
  - Astrophysical reaction rates



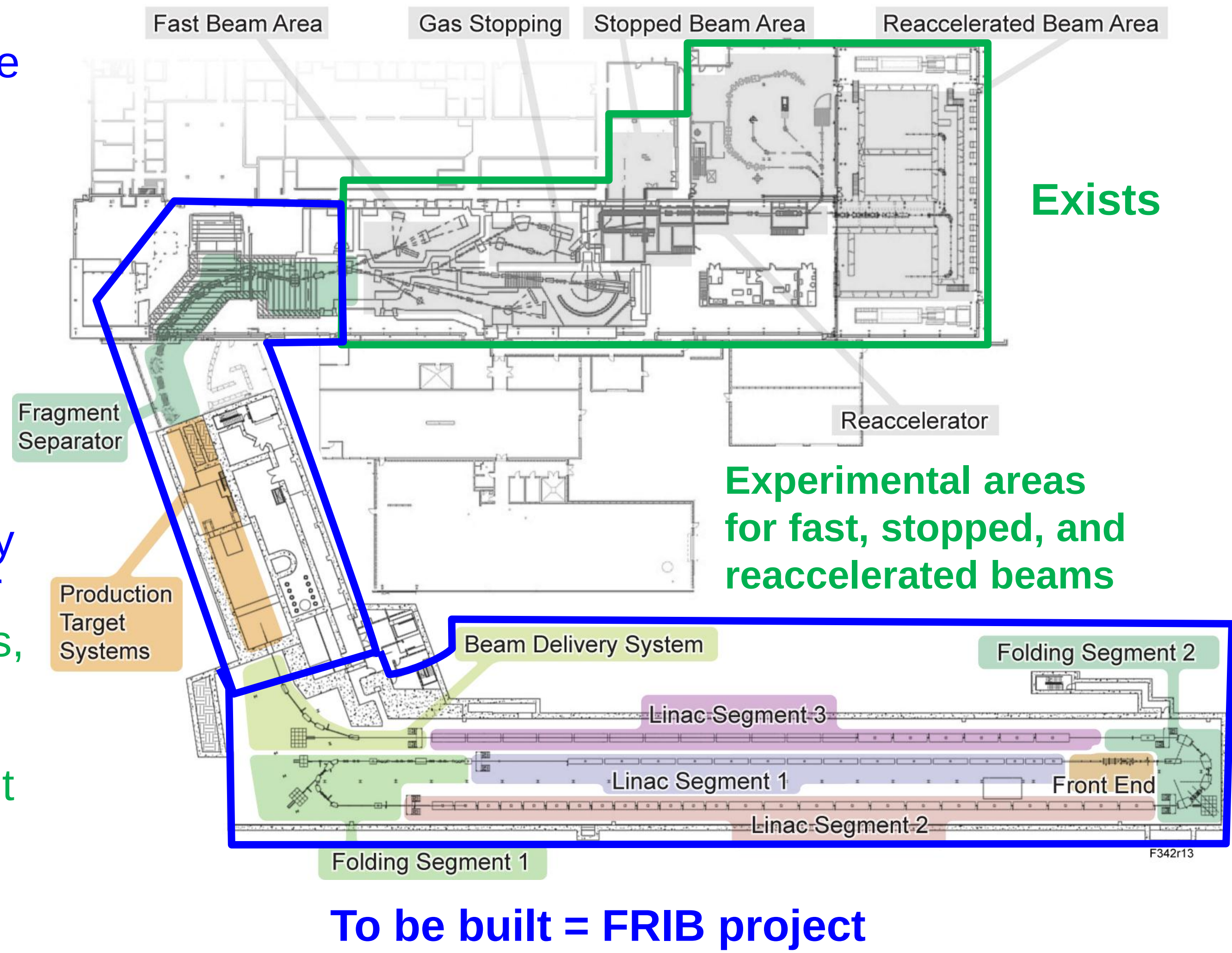
Facility for Rare Isotope Beams



- FRIB project scope: driver linac, target facility and fragment separator, conventional facilities
- FRIB facility will integrate and leverage existing NSCL– pre FRIB science – fast transition to full FRIB operation

Facility for Rare Isotope Beams

- Conventional Facilities
  - Linac tunnel and service building
  - Target building
- Accelerator Systems
  - Frontend
  - Linear Accelerator
  - Central Systems
- Experimental Systems
  - Production target facility and fragment separator
  - Beam stopping systems, reaccelerator, experimental areas, experimental equipment

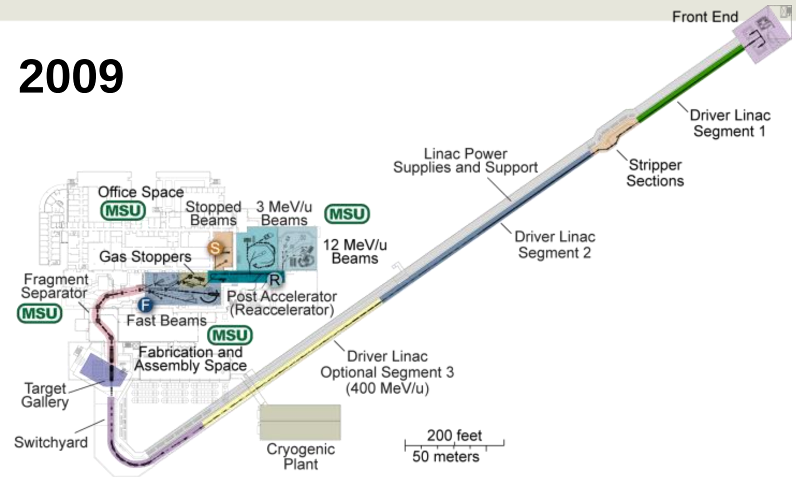


FRIB Project Status and Highlights

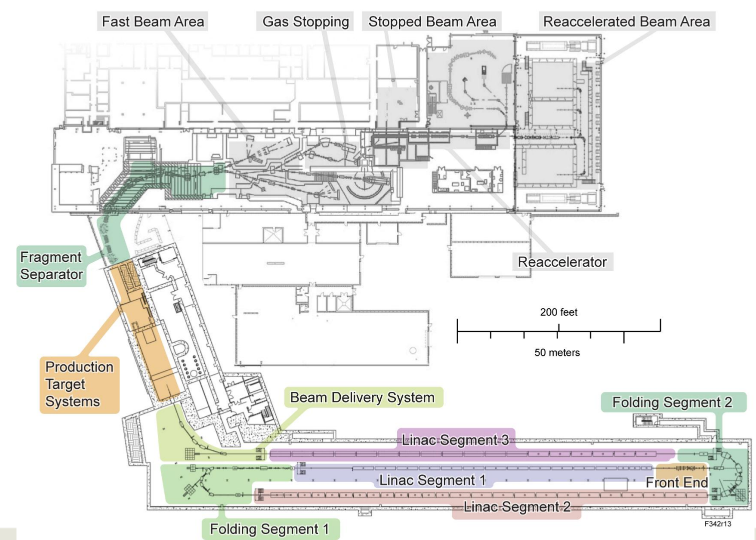
- 8 June 2009 – DOE Office of Science and MSU sign Cooperative Agreement
- Start of Conceptual Design, R&D
- Sept 2010 – Critical Decision 1
- Start of Preliminary Design
- June 2011 - Technical system layouts frozen
- Technical systems preliminary design completed
- R&D to retire technical risks completed
- Civil design 100% completed
- 24-26 April 2012 – DOE Review, baseline and start of civil construction
- Final design under way

Project start 2009
Planned start of civil construction 2012
Early completion date 2019

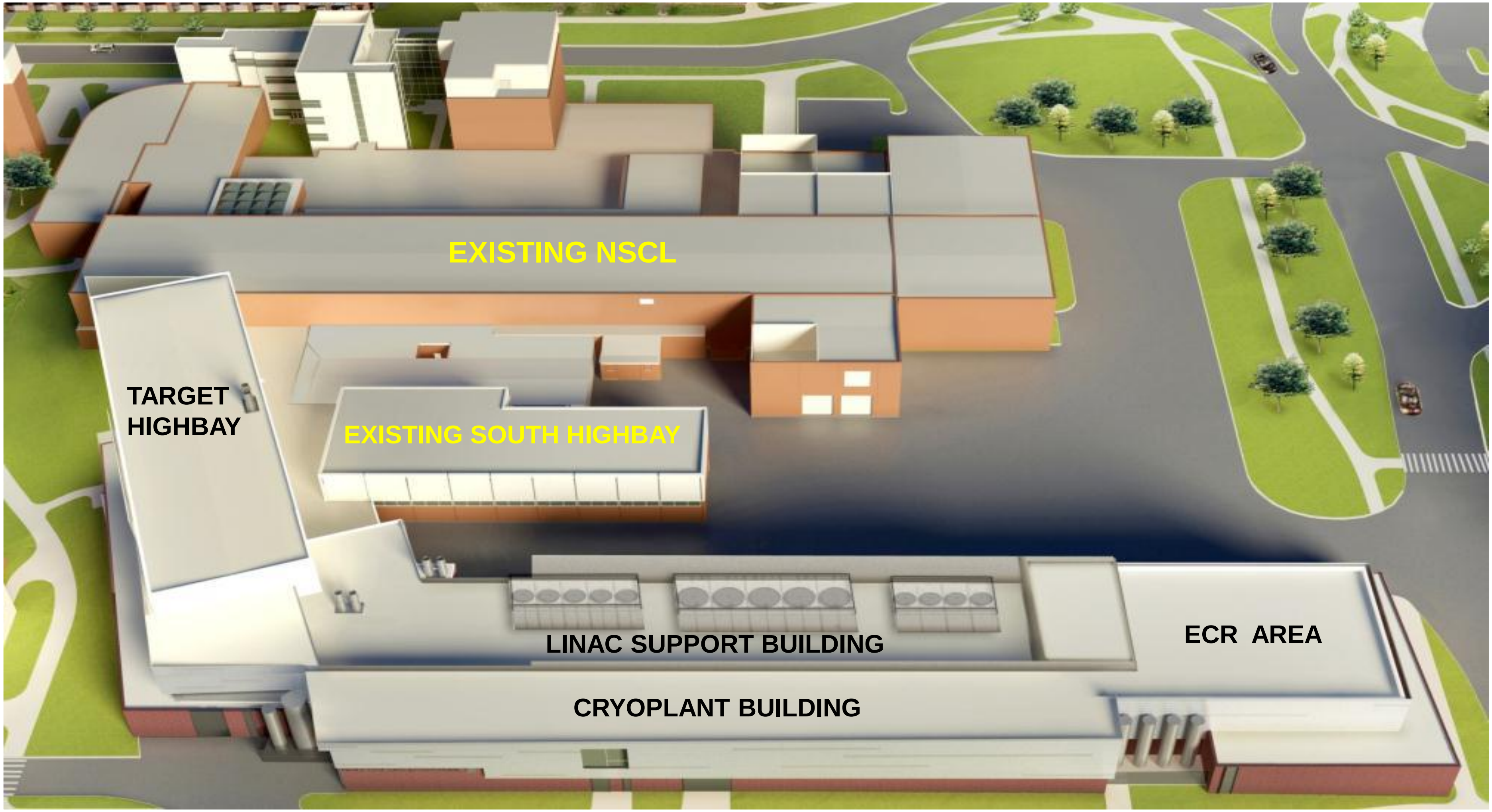
2009



2012



Facility for Rare Isotope Beams
Civil Design Completed



Facility for Rare Isotope Beams
Southwest View

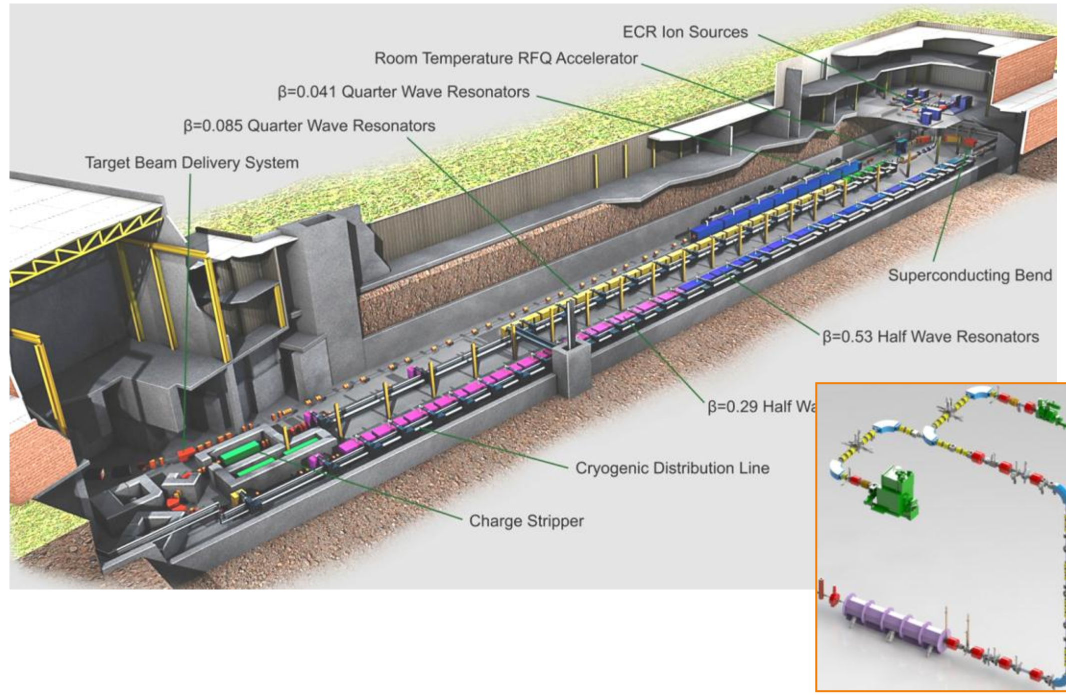
Site Preparation
Getting Ready for Civil Construction

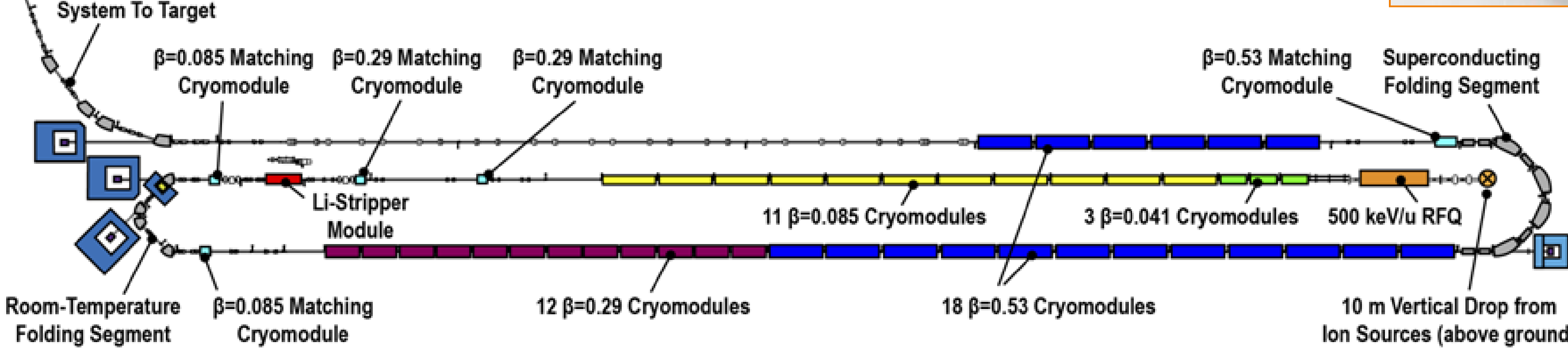
- FRIB site preparations on track for starting civil construction in 2012



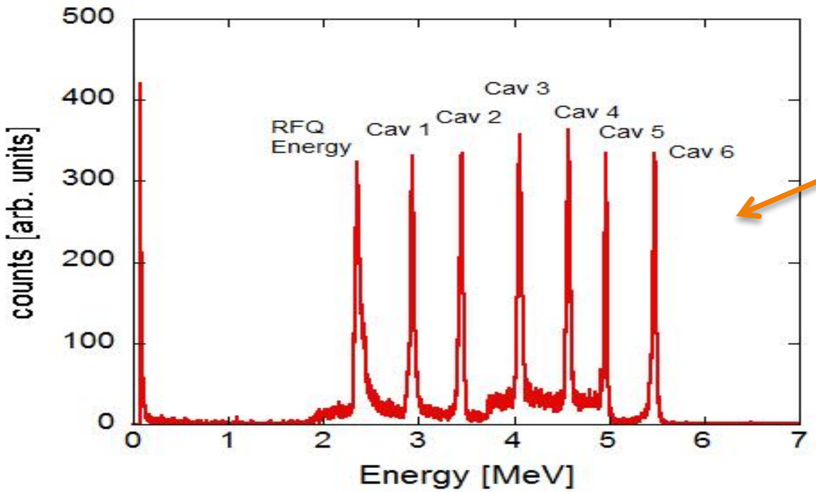
Accelerator Systems
FRIB SRF Driver Linac

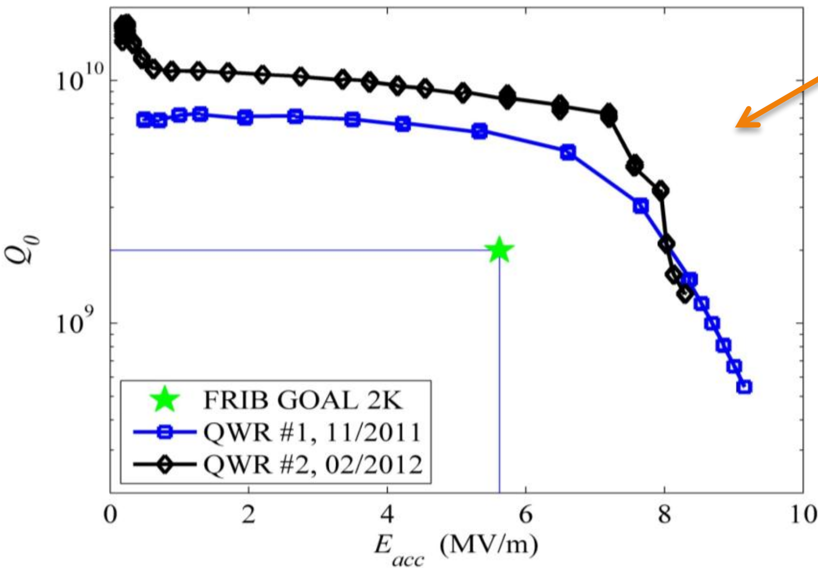
- Accelerate ion species up to ^{238}U with energies of no less than 200 MeV/u
- Provide beam power up to 400kW
- Energy upgrade to 400 MeV/u for uranium by filling vacant slots with 12 SRF cryomodules





FRIB Driver SRF LINAC
SRF Cavity and Cryomodule Development

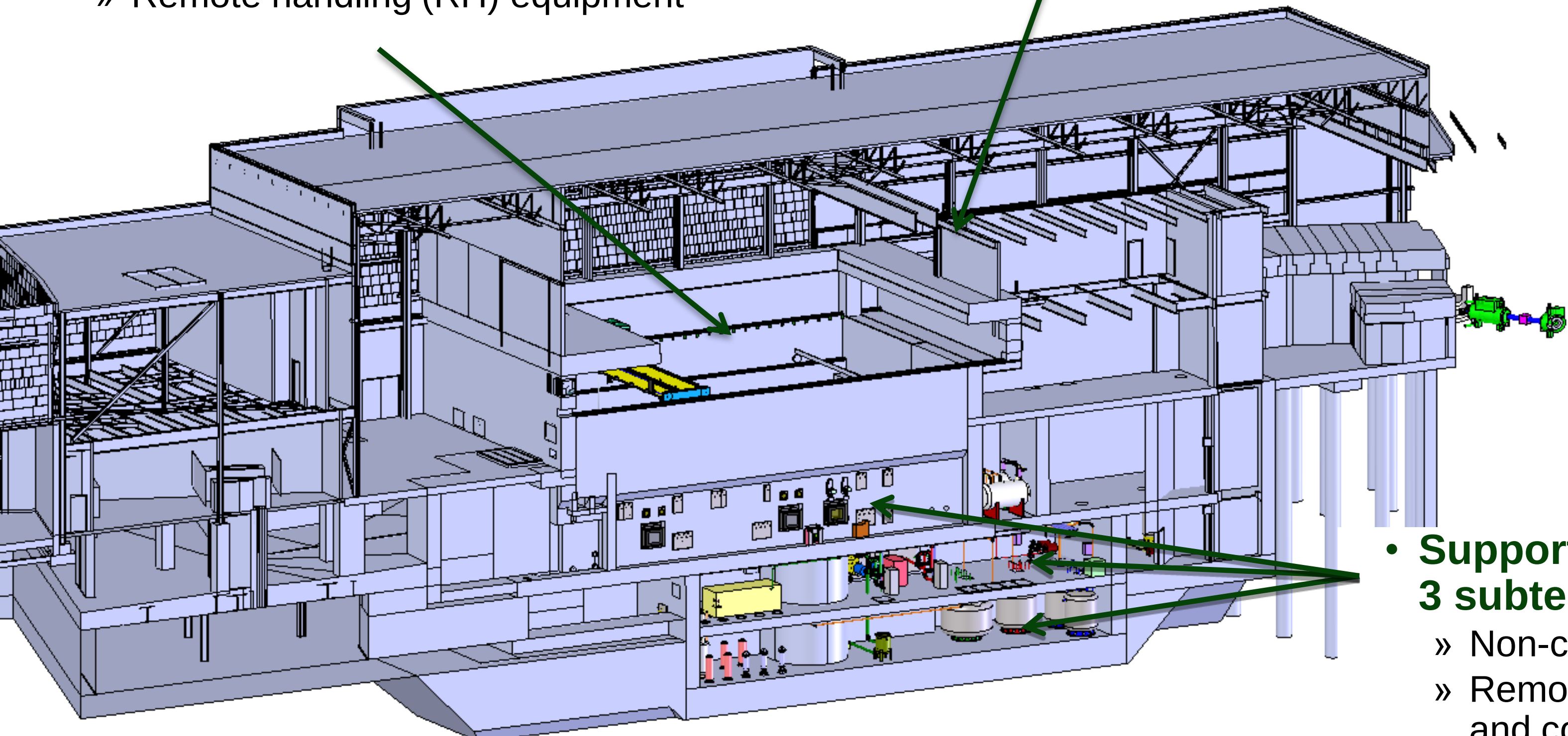




- β=0.041 Cryomodules
  - Accelerate Beam at ReA3
    - » H^{2+}, He^{+}, He^{2+}, Ne^{8+} at design energies
  - Some cavity performing at world record accelerating gradient at Dewar tests
- β=0.085 QWR SRF Cavities
  - Exceed FRIB requirements by significant margin
  - Allowed 10% design gradient increase
- β=0.53 HWR Test Cryomodule
  - Operates stably at 2K temperature
  - Cavities continually locked to design frequency; excellent low-level RF control
  - Fundamental power coupler operates at full FRIB design power (4.5 kW CW)

FRIB Experimental Systems
Target Facility

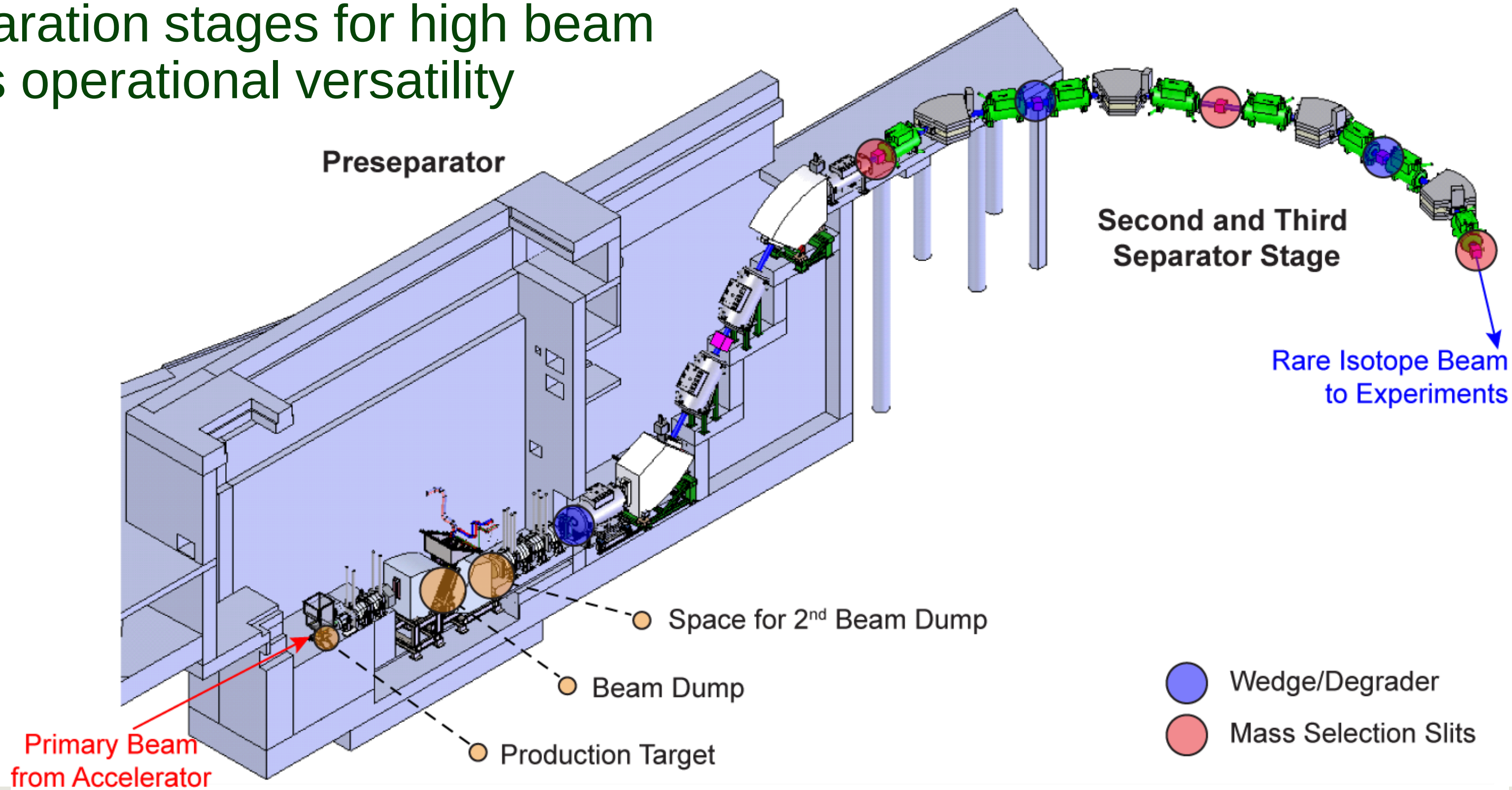
- **Target hot cell, subterranean**
  - » Production target
  - » Fragment preseparator
  - » Primary beam dump(s)
  - » Remote handling (RH) equipment
- **Target facility building high bay**
  - » Second and third stage of fragment separator
  - » 50 ton bridge crane
  - » Fragment separator power supplies



- **Support areas, 3 subterranean levels**
  - » Non-conventional utilities
  - » Remote handling gallery and control room
  - » Waste handling

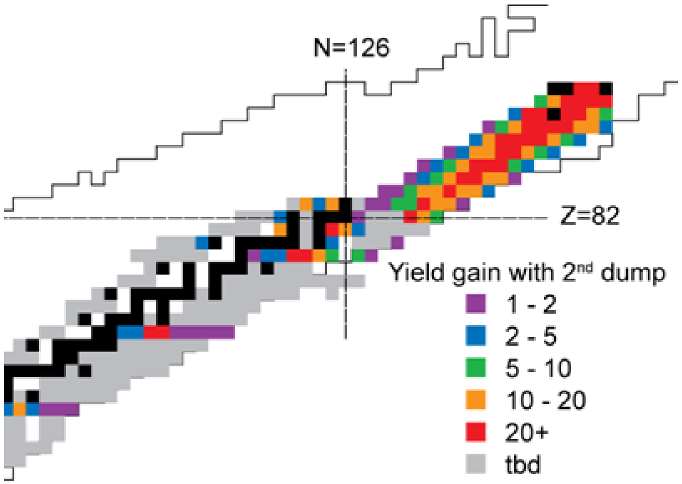
FRIB Experimental Systems
Fragment Separator

- Production of rare isotope beams with 400 kW beam power using light to heavy ions up to ^{238}U with energy ≥ 200 MeV/u
  - Large acceptance: ± 40 mrad (angular) and ± 5% (momentum)
  - High magnetic rigidity: 8 Tm after target
- Three separation stages for high beam purity plus operational versatility

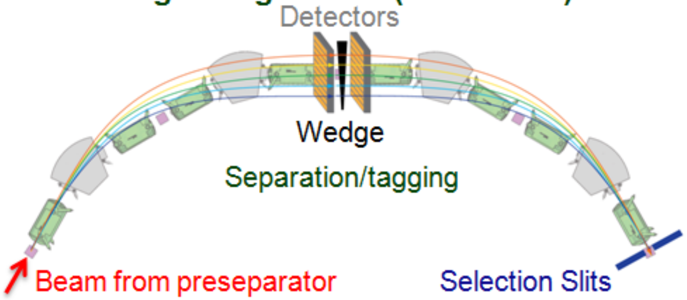


Fragment Separator Beam Optics
Multiple Optical Modes Maximize Performance

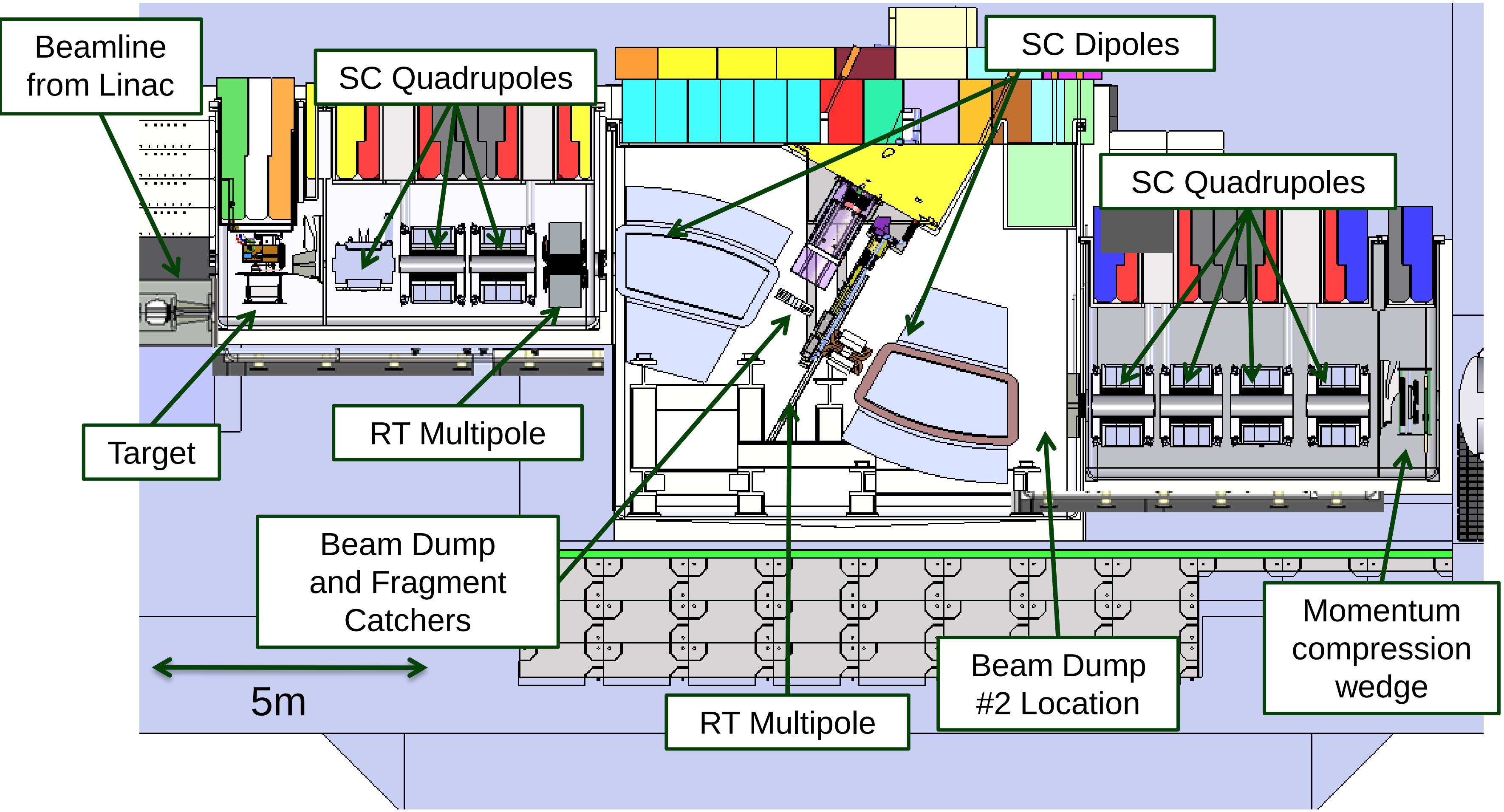
- Preseparator
  - Dump 1 mode: Optimized for rare isotopes far from stability
    - » Maximum acceptance
    - » Maximum magnetic rigidity of 8 Tm
  - Dump 2 mode (future upgrade): Optimized for heavy rare isotopes near stability
    - » Selection of rare isotope beam between primary beam charge states



- 2nd and 3rd separator stage
  - Emphasizing resolving power, acceptance or momentum tagging
    - » Two horizontal separator stages mode
    - » Single horizontal separator stage mode



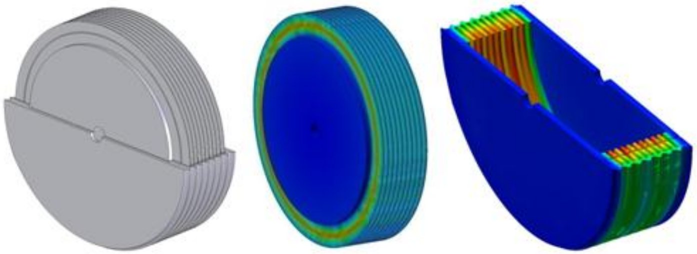
FRIB Preseparator
Meets 400 kW Beam Power Requirement

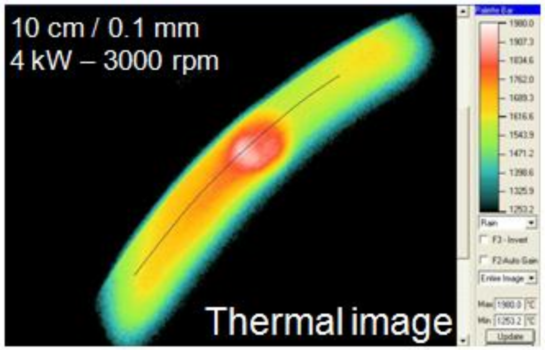


- Challenges: beam power densities, radiation damage, activation, …

FRIB Production Target
Rotating multi-slice graphite target concept

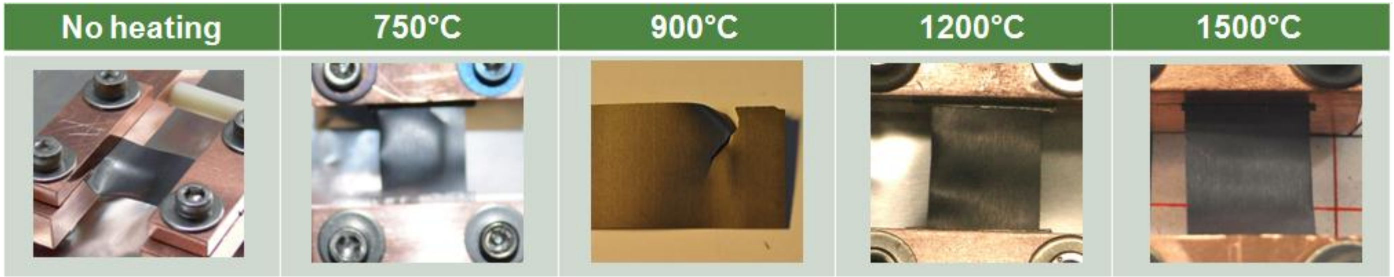
- Requirements
  - 400 kW beam power requirement
    - » 100 kW power loss in a ~ 0.3 - 8 g/cm2 target
  - Optics requirements
    - » 1 mm diameter beam spot
    - » Maximum extension of 50 mm in beam direction
  - Target lifetime of 2 weeks





- Rotating multi-slice graphite target chosen for FRIB
  - R&D retired radiation damage and high-power density risk
    - » Electron beam tests at SARAF and SANDIA
    - » Heavy ion irradiations at GSI (UNILAC)

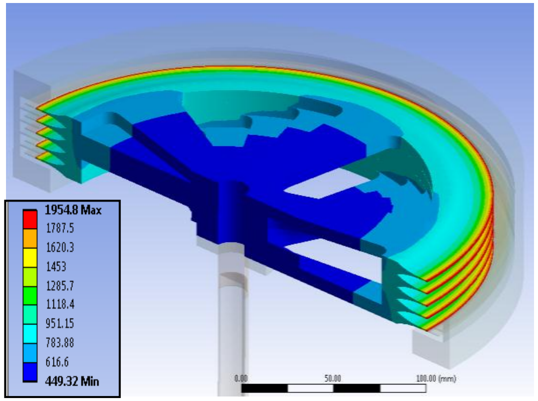
Annealing of Damage at High Temperature (> 1200^{o}C)

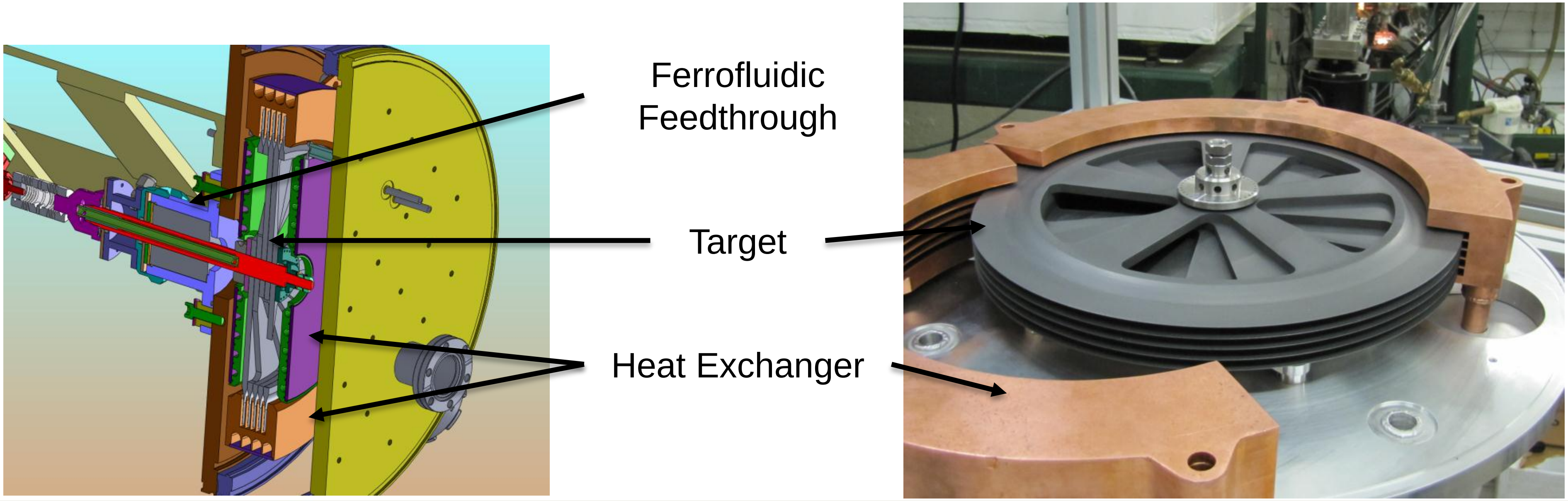


➔ Talk by M. Tomut

FRIB Production Target
Multi-slice 50 kW Target Prototype

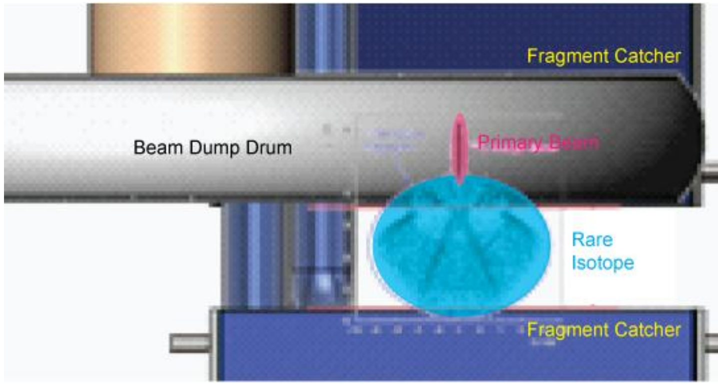
- Prototype for FRIB production target; design and construction completed and tests started
  - 5 slices - 5000 rpm - 30 cm diameter
  - Cooling system designed for 70 kW dissipated power capability
- Electron beam tests scheduled at BINP (Russia)

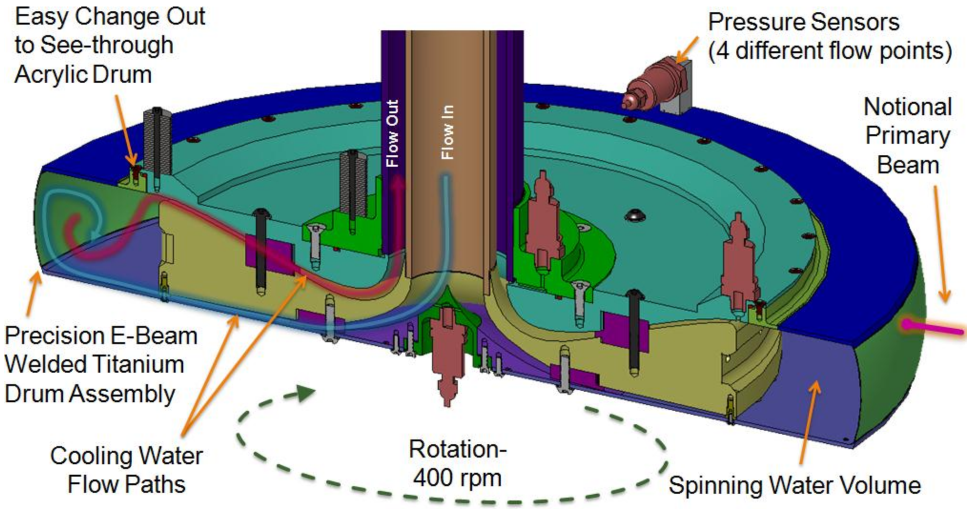




Primary Beam Dump
Water-filled rotating drum concept

- Requirements
  - High power capability up to 325 kW
  - Efficient replacement
    - » 1 year lifetime desirable
    - » Remotely maintainable
- Water-filled rotating drum beam dump
  - 400 rpm, 70 cm diameter, <100 gpm
  - Bulk of beam power absorbed by water
  - Downstream fragment catchers provide slit function
- Risks mitigated by successful R&D
  - High power density
  - Material radiation damage
- Prototype under construction
  - Flow mockup tests in summer 2012

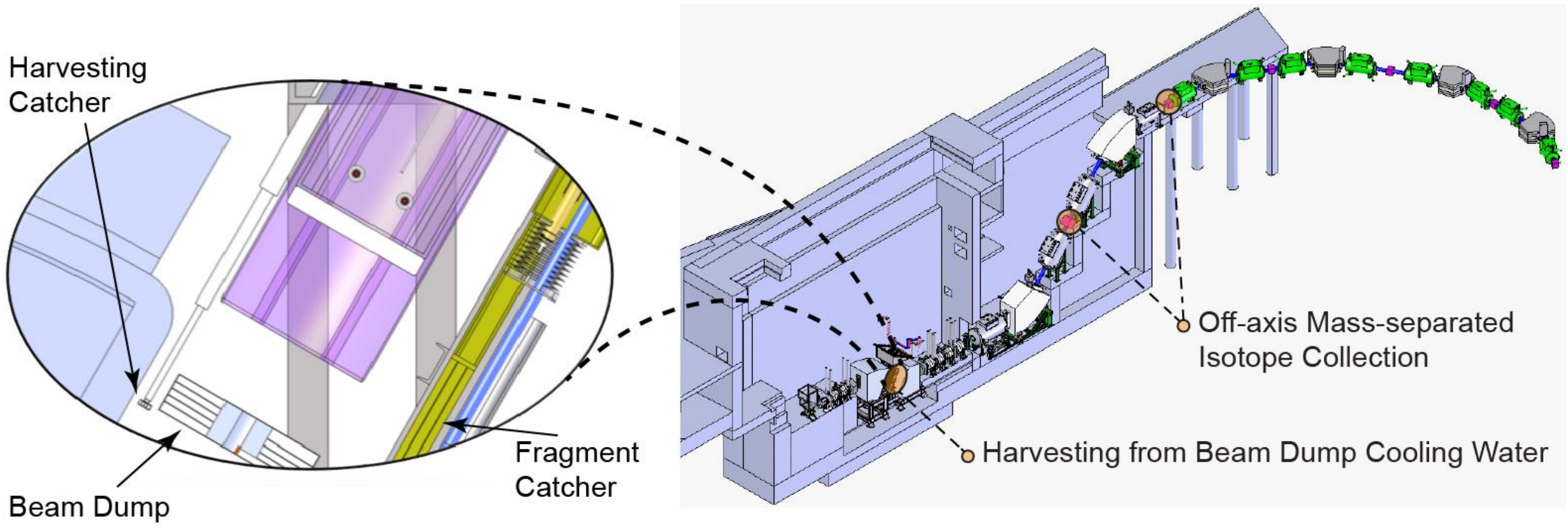




Future Isotope Harvesting
Provisions Included in Baseline Design

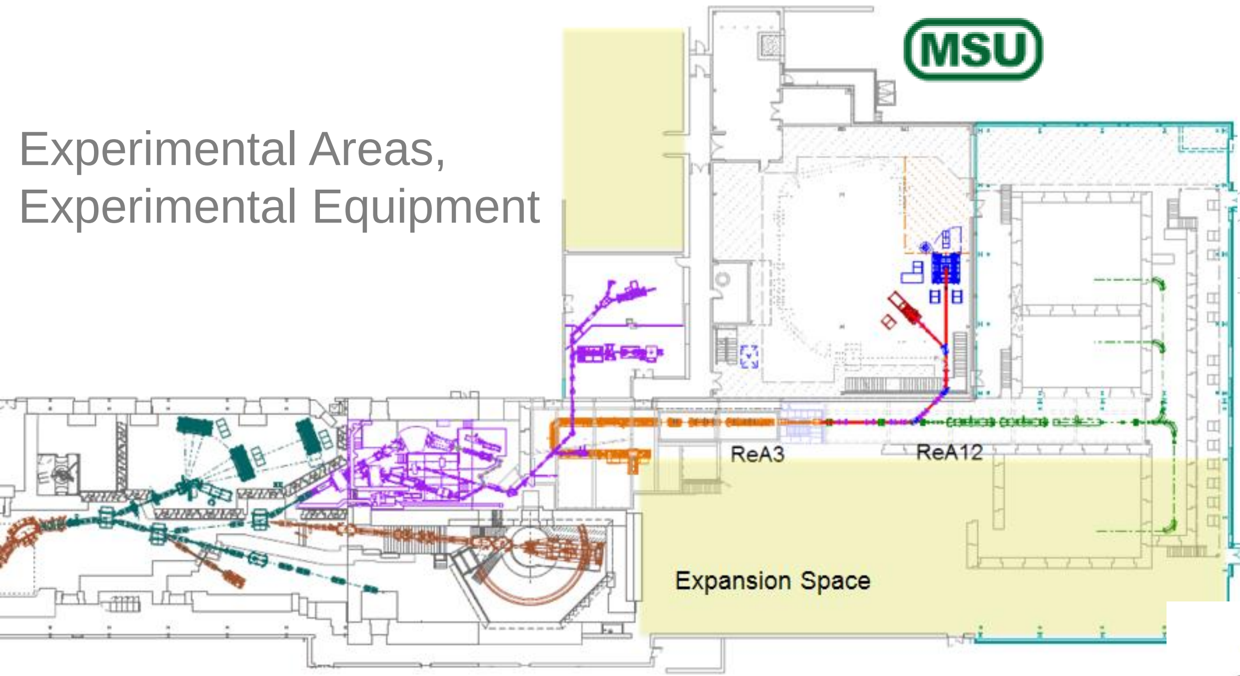
- Preseparator design includes provisions for future isotope harvesting
  - Isotope harvesting from cooling water of beam dump or fragment catcher or harvesting catcher
    - » Workshop on Harvesting Radioactive Isotopes from FRIB. Sep. 29 – Oct. 1, 2010, Santa Fe
  - Off-axis collection of mass separated isotopes at downstream focal planes
    - » Generation of 2^{nd} beam with off-axis catcher/ionizer possible

- Provides additional science opportunities and enhanced facility productivity in the future (limited multi-user capability)

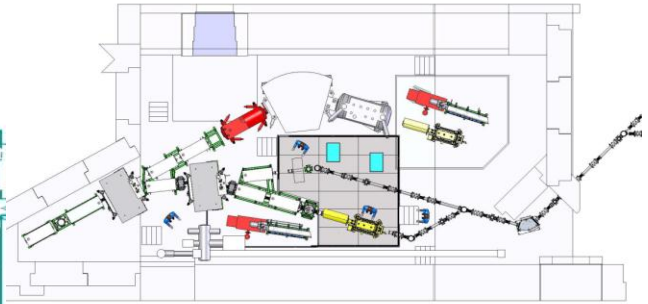


Fast, Stopped, and Reaccelerated Beam Experimental Areas and Equipment

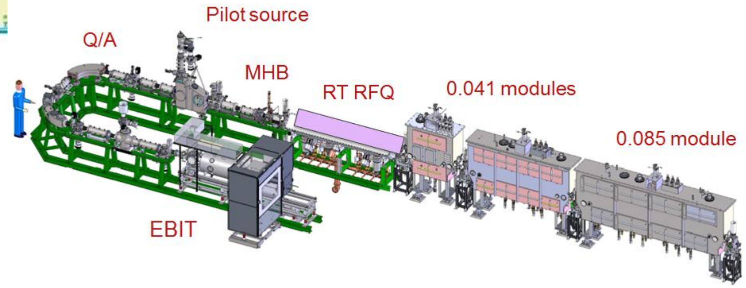
Experimental Areas,
Experimental Equipment



Beam Stopping

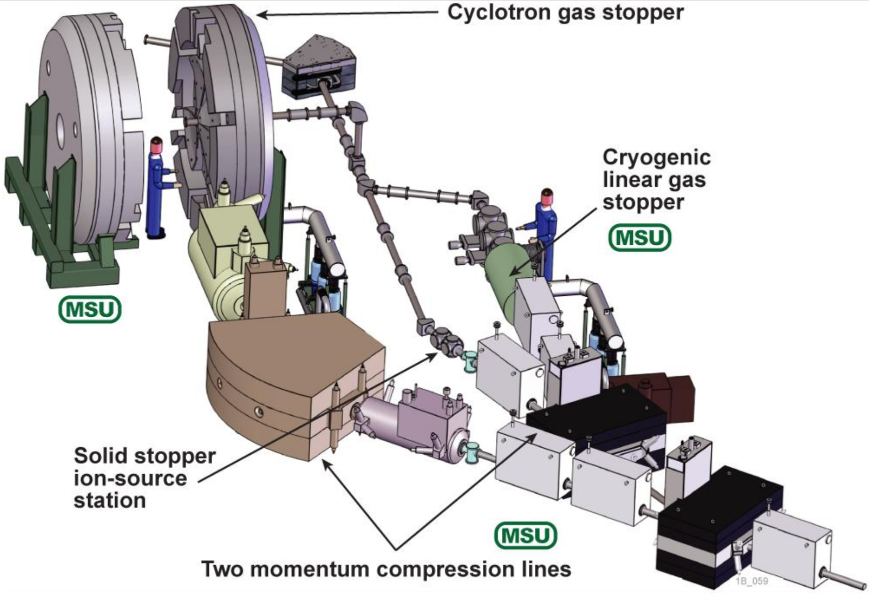


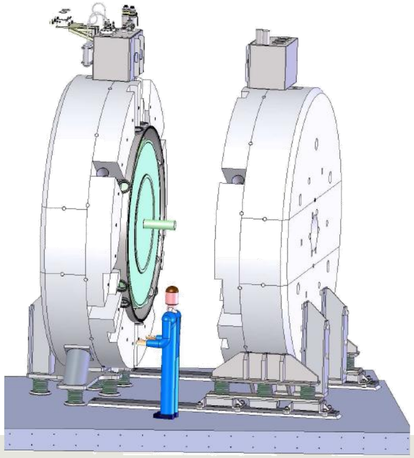
Reacceleration

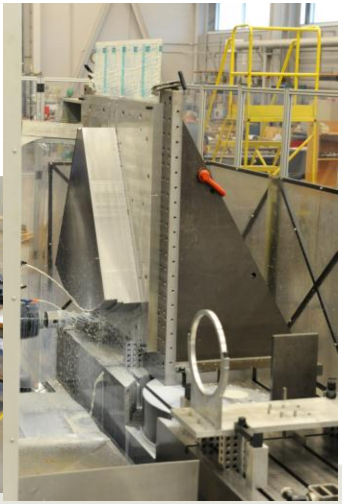


Stopped Beams at FRIB

- Multifaceted approach reduces technical risk and maximizes science reach
  - Linear gas stopper (heavier and medium mass beams)
  - Cyclotron gas stopper (light beams)
  - Solid stopper (certain elements, highest intensity)
- Status
  - Momentum compression beam lines completed
  - Linear gas catcher (ANL) from FRIB R&D delivered and in place
  - Cyclotron gas stopper (NSF-MRI) under design and construction

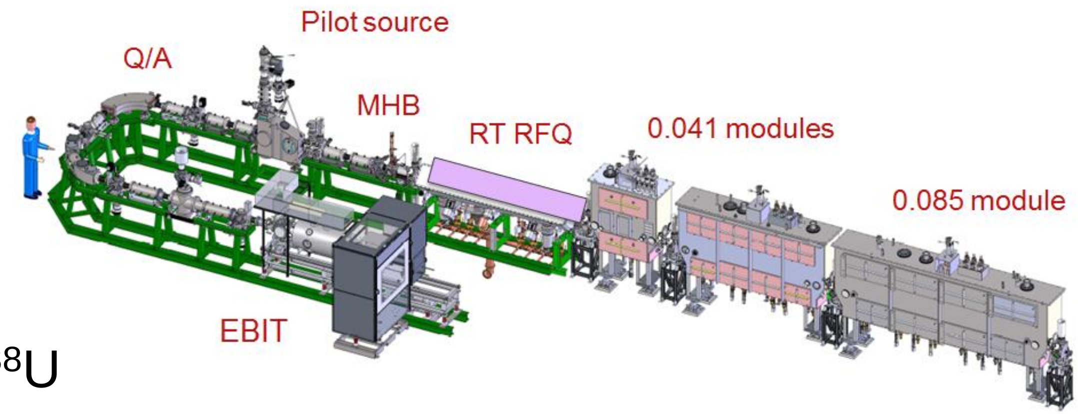






Reaccelerated Beams at FRIB with ReAx

- ReAx
  - EBIT/S charge breeder
    - ➔ Talk by P. Delahaye
  - SRF linac
  - ReA3 – 3 MeV/u for ^{238}U
  - Expandable to >12 MeV/u for ^{238}U

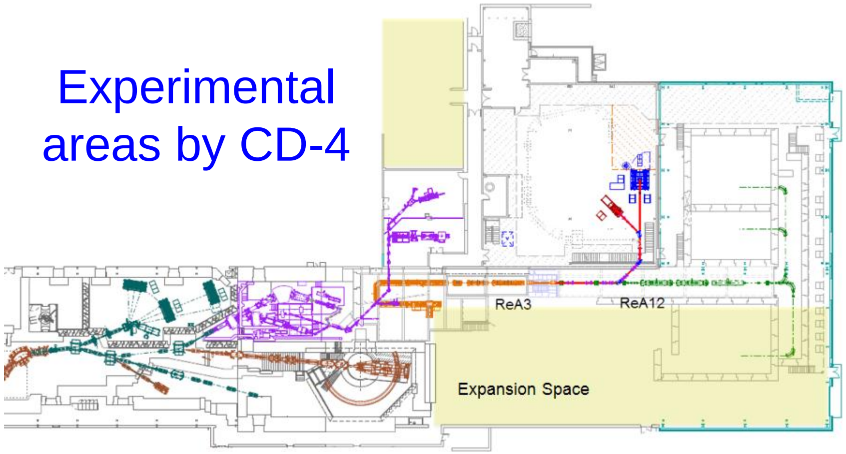


- Status
  - Commissioning underway
  - Ions from EBIT including $^{39}K^{19+}$ accelerated with RFQ and first cryo-module
  - Last ReA3 cryo-module being completed
  - First reaccelerated beams planned for 2013

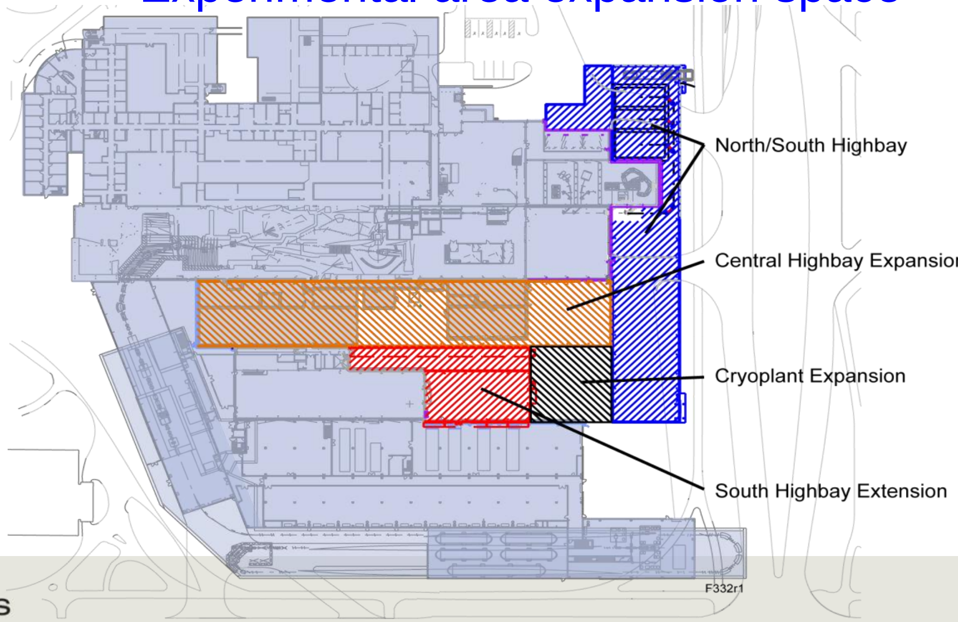
Experimental Areas and Equipment at FRIB
Flexible Layouts and Expandable

- Reconfigurable areas for fast, stopped and reaccelerated beam experiments
  - 47,000 sq ft operational at CD-4
  - Additional upgrade space of more than 60,000 sq ft
- Experimental Equipment
  - Equipment at NSCL (existing or under development)
    - » S800, SeGA, MoNA, MoNA-LISA, LENDA, NSCL-BCS, LEBIT, BECOLA, AT-TPC, SECAR, CAESAR, …
  - Equipment available in the community and movable (existing or under development)
    - » GRETINA, GRETA, ANASEN, CHICO, Nanoball, …

Experimental areas by CD-4

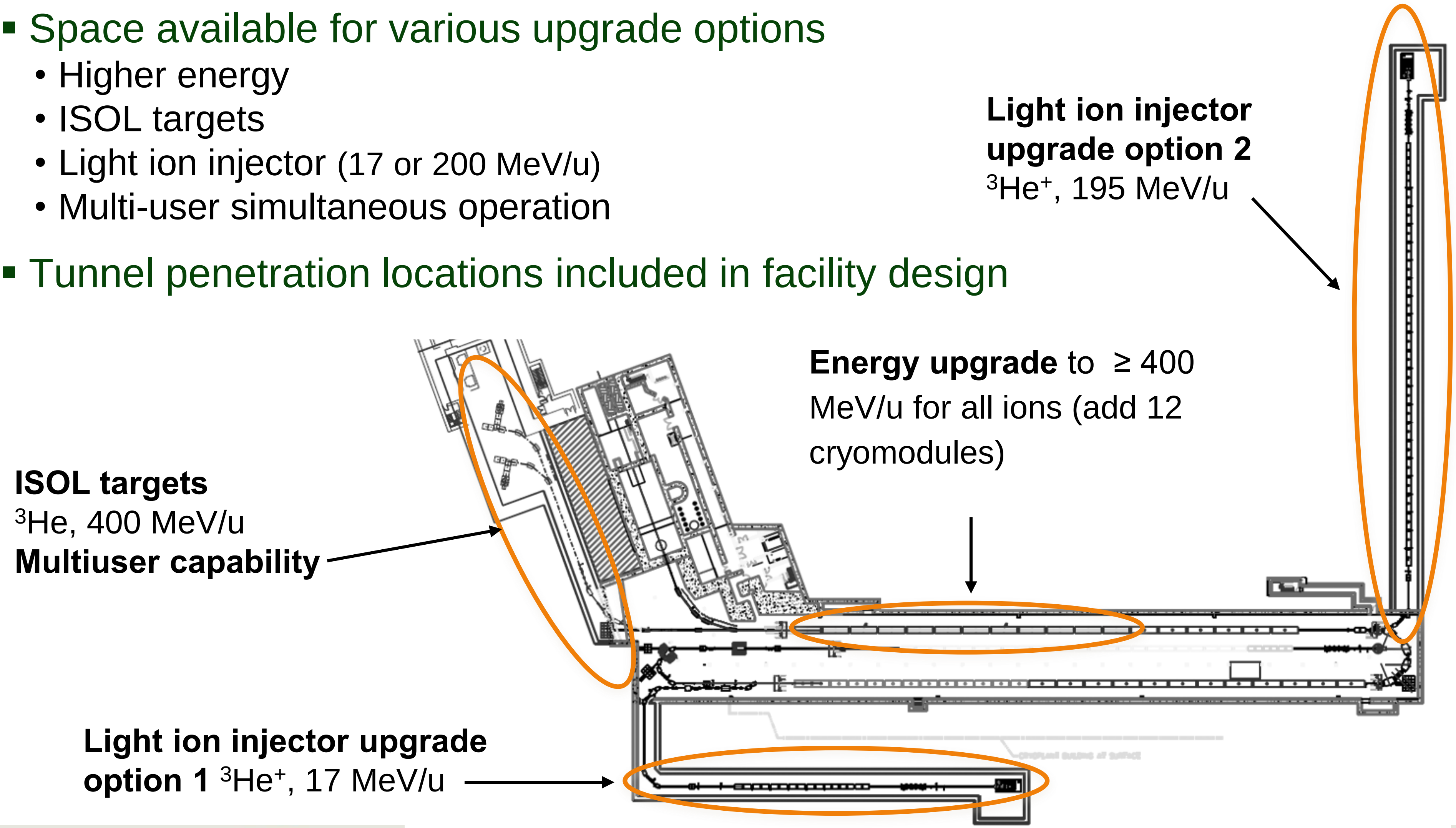


Experimental area expansion space



Upgrade Opportunities Provided in FRIB Design

- Space available for various upgrade options
  - Higher energy
  - ISOL targets
  - Light ion injector (17 or 200 MeV/u)
  - Multi-user simultaneous operation
- Tunnel penetration locations included in facility design



FRIB Users Organization
Over 1200 Users Ready for Science

- Users are organized as part of the independent FRIB Users Organization
  - FRIBUO has 1227 members (92 US Colleges and Universities, 10 National Laboratories, 53 countries) as of 16 April 2012
  - Chartered organization with an elected executive committee (Chair is Michael Smith, ORNL)
  - FRIBUO has 20 working groups on experimental equipment

August 2011
Joint Users Meeting
284 participants

fribusers.org

Next meeting will be held at ANL in connection with the NS2012 meeting

Summary

- FRIB 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
- FRIB to become the world's next flagship facility for rare isotope science -
  - Highest-power heavy ion linac worldwide
  - High-performance fragment separator
  - Provisions for isotope harvesting and multi-user capability
- FRIB project ready to start civil construction and prepared to baseline
  - Plan for starting civil construction in 2012
- MSU contributions enable pre-FRIB science and well tested and optimized systems by CD-4
- Strong FRIB user group in place