FRIB

Current Construction Status

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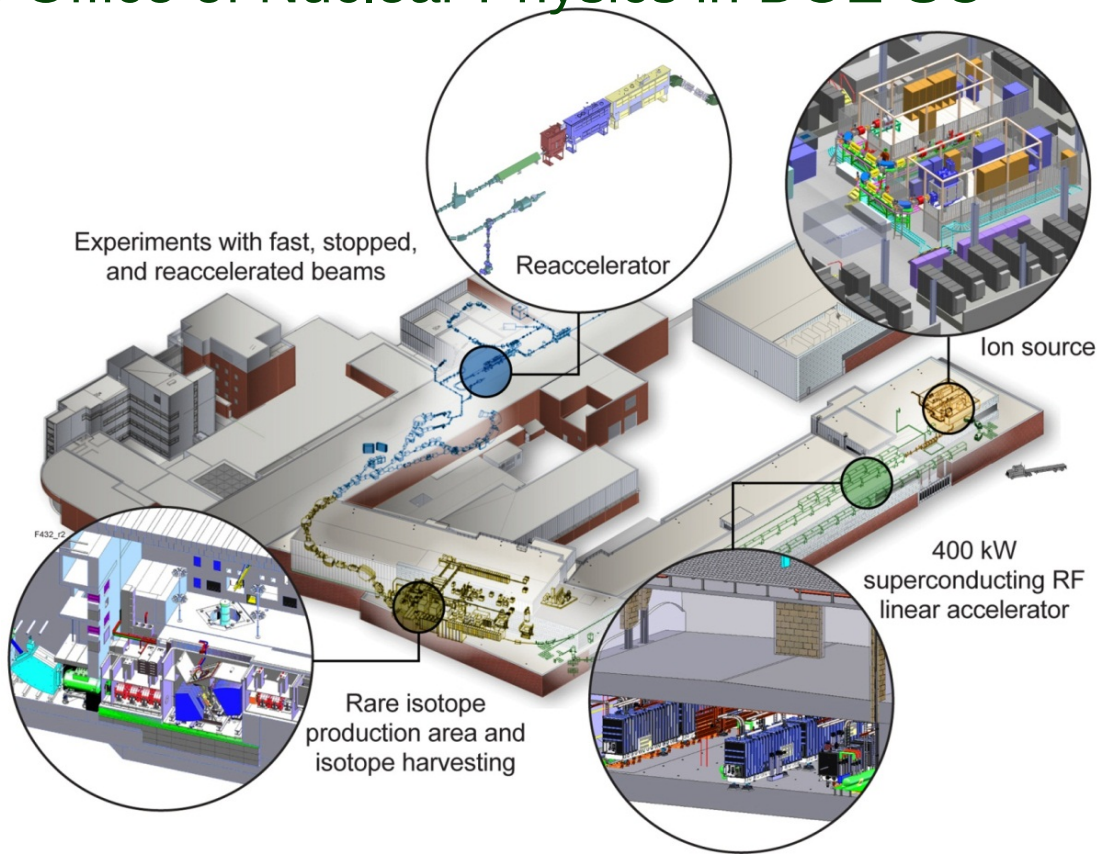
MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. 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.

Facility for Rare Isotope Beams
A Future DOE-SC Scientific User Facility for Nuclear Physics

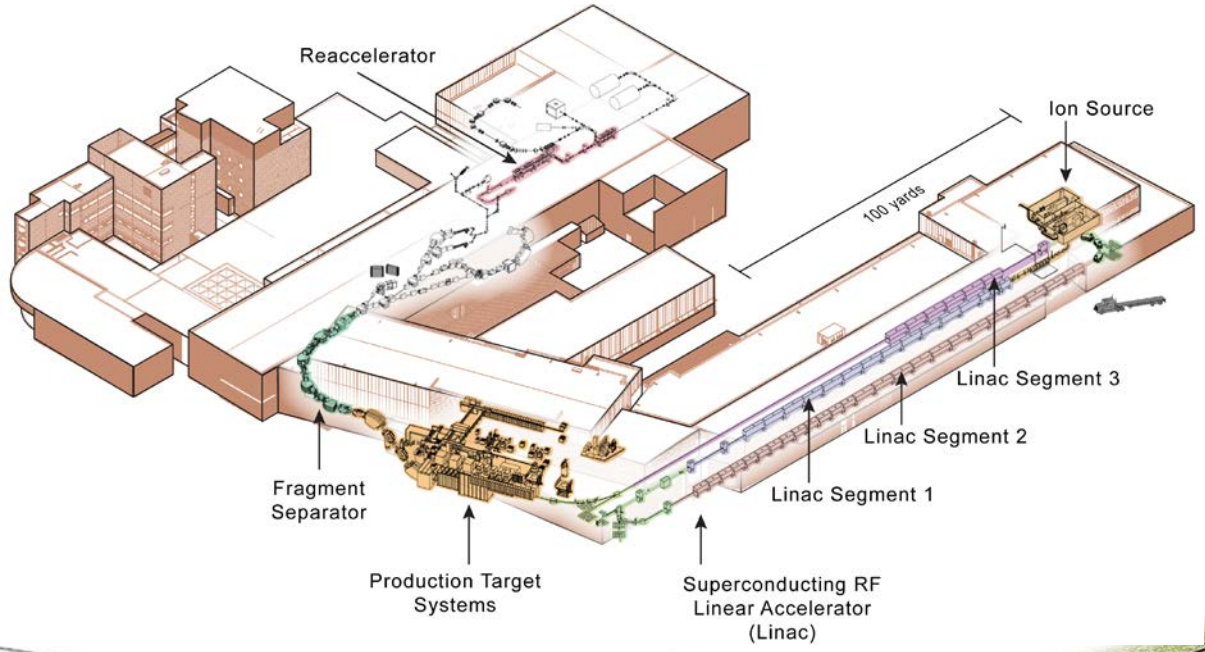
- Funded by U.S. Department of Energy Office of Science (DOE-SC) supporting the mission of the Office of Nuclear Physics in DOE-SC
- Serving over 1,350 users
- Key feature is 400 kW beam power for all ions (5×10^{13} ^{238}U/s)
- Separation of isotopes in-flight
  - Fast development time for any isotope
  - Suited for all elements and short half-lives
  - Fast, stopped, and reaccelerated beams

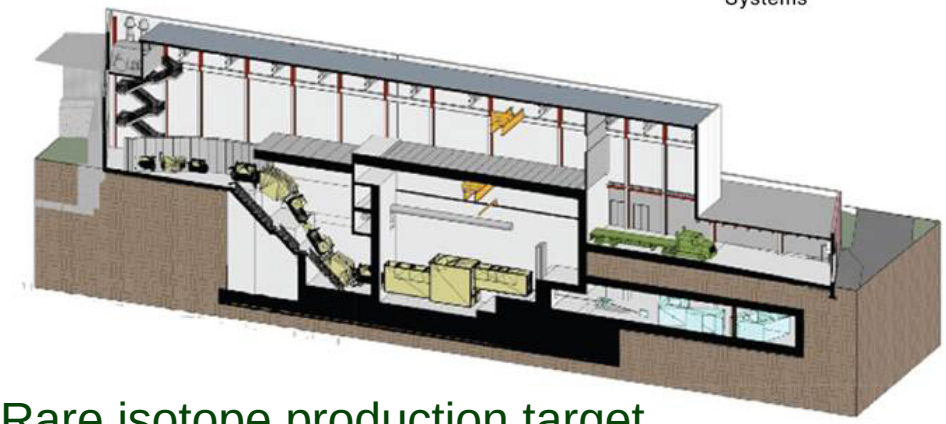


FRIB Project is on Track

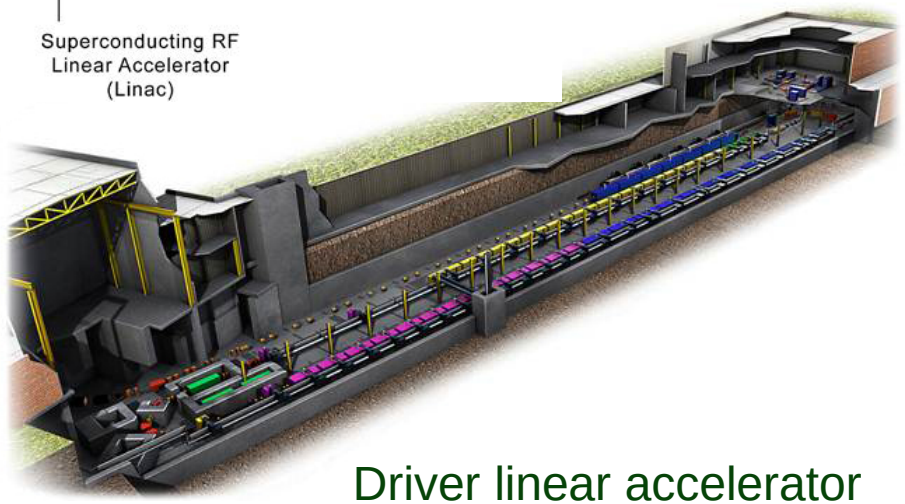
- 8 June 2009 – DOE-SC and MSU sign Cooperative Agreement
- September 2010 – CD-1 approved, DOE issues NEPA FONSI
- April 2012 – Lehman review, baseline and start of civil construction
- August 2013 – CD-2 approved (baseline), CD-3a approved (start civil construction pending FY2014 federal appropriation)
- March 2014 – Start civil construction
- August 2014 – CD-3b approved (technical construction)
- 12-14 Jan 2016 DOE Operations Cost Review
- 6-8 December 2016 DOE Office of Project Assessment Review
- June 2022 – CD-4, managing to early completion in FY21
  - »First beam from ECR in 2016
  - »Beneficial occupancy of FRIB building in March 2017

FRIB Facility Layout





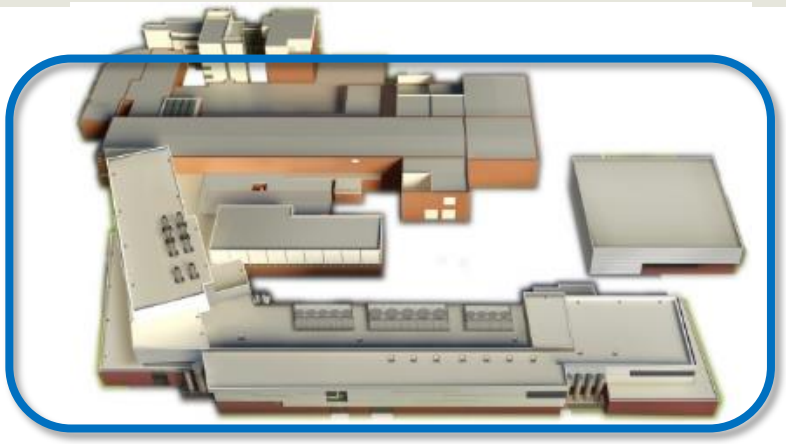
Rare isotope production target



Driver linear accelerator

FRIB Key Features

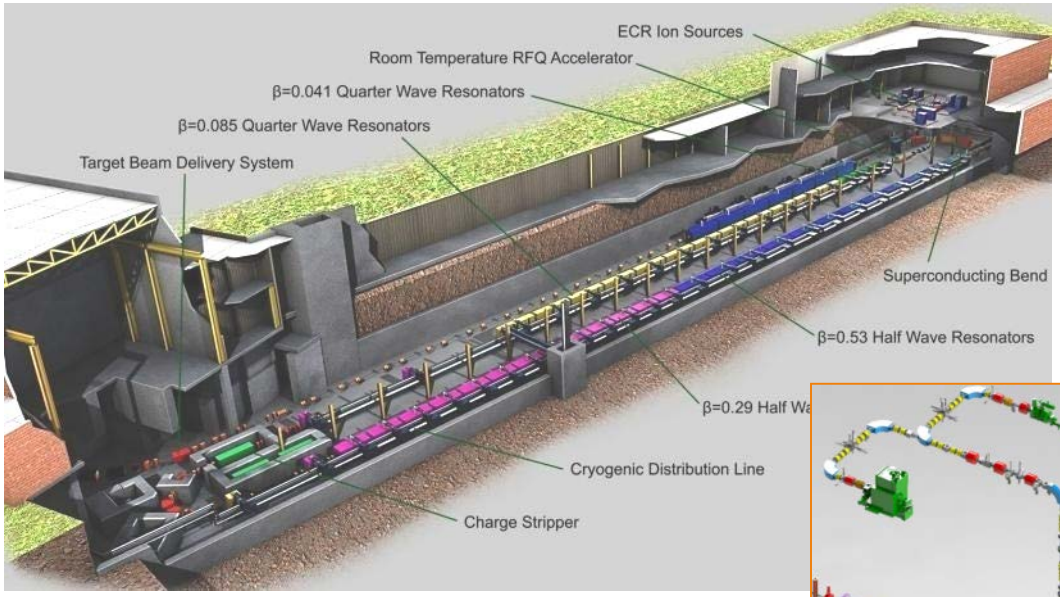
- High power accelerator [SNS, PSI, ISIS]
  - Path to full power (400 kW)
  - Configuration management
  - Machine protection
  - Root cause analysis of failure modes
- Heavy ion accelerator [RHIC]
  - Variety of primary beams
  - Dynamic range on diagnostics
- Full-scale Superconducting RF accelerator [SNS]
  - Cryoplant
  - SRF infrastructure for maintenance
- In-flight rare isotope beam production at high power [FAIR, RIBF]
  - Variable targets
  - Many secondary beams
  - Fast, stopped, and reaccelerated beams
  - Safety analysis for each beam, due to high production rates
- Remote handling [PSI, SNS, ESS, ISIS]
  - High radiation levels
  - Personnel protection
  - Waste handling and waste reduction
  - Non-conventional utilities
- Maintenance of physical infrastructure, including non-conventional utilities
  - All systems under one roof - interdependencies create complexity

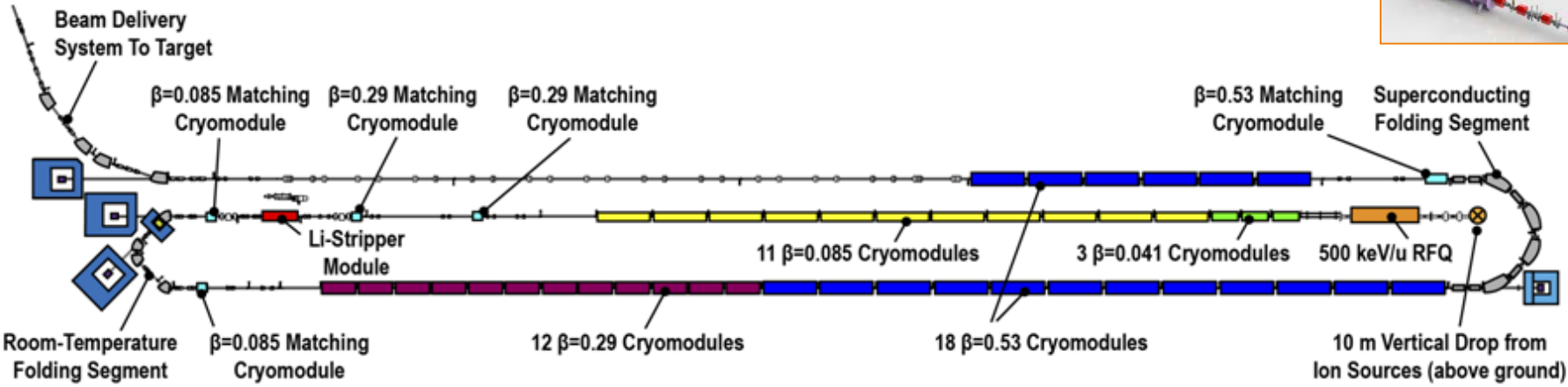


While there are facilities world-wide that have a subset of these key features, FRIB is the only facility that comprises such a level of complexity

FRIB Accelerator Systems
Superconducting RF Driver Linac

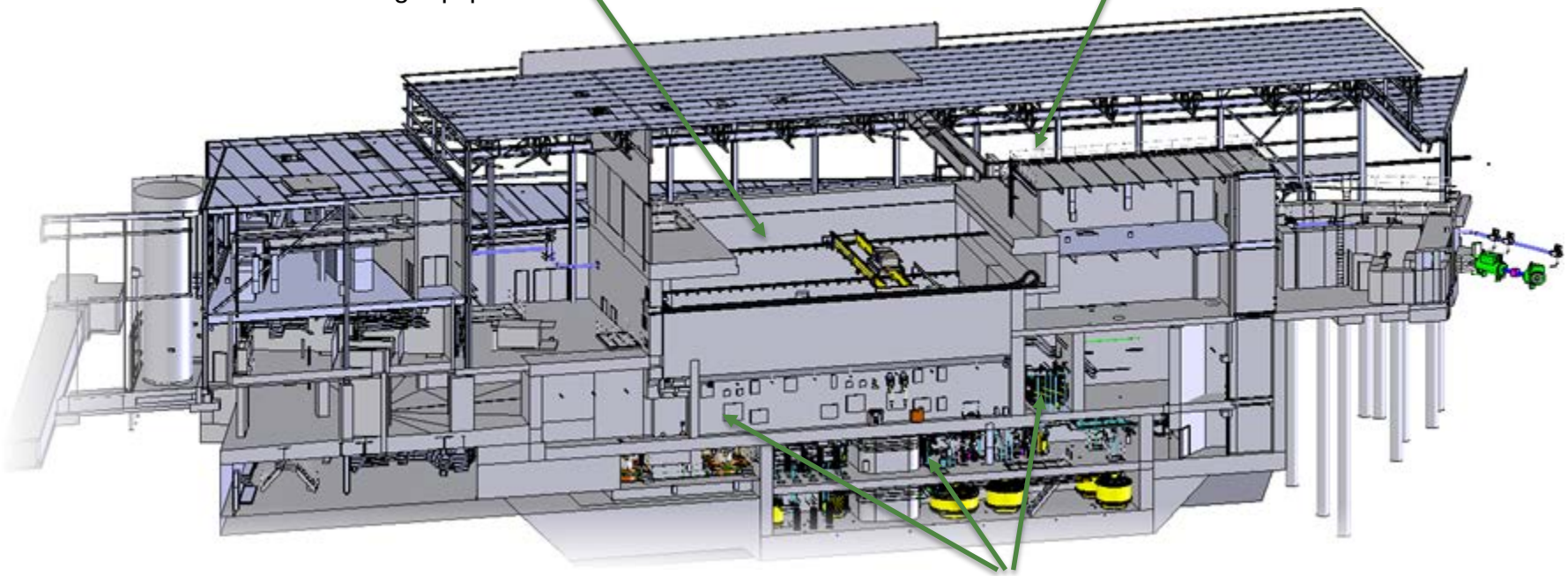
- Accelerate ion species up to ^{238}U with energies of no less than 200 MeV/u
- Provide beam power up to 400kW
- Energy upgrade to 400 MeV/u for ^{238}U by filling vacant slots with 12 SRF cryomodules
- Provisions for ISOL upgrade





Target Facility Overview
Equipment Installation Underway

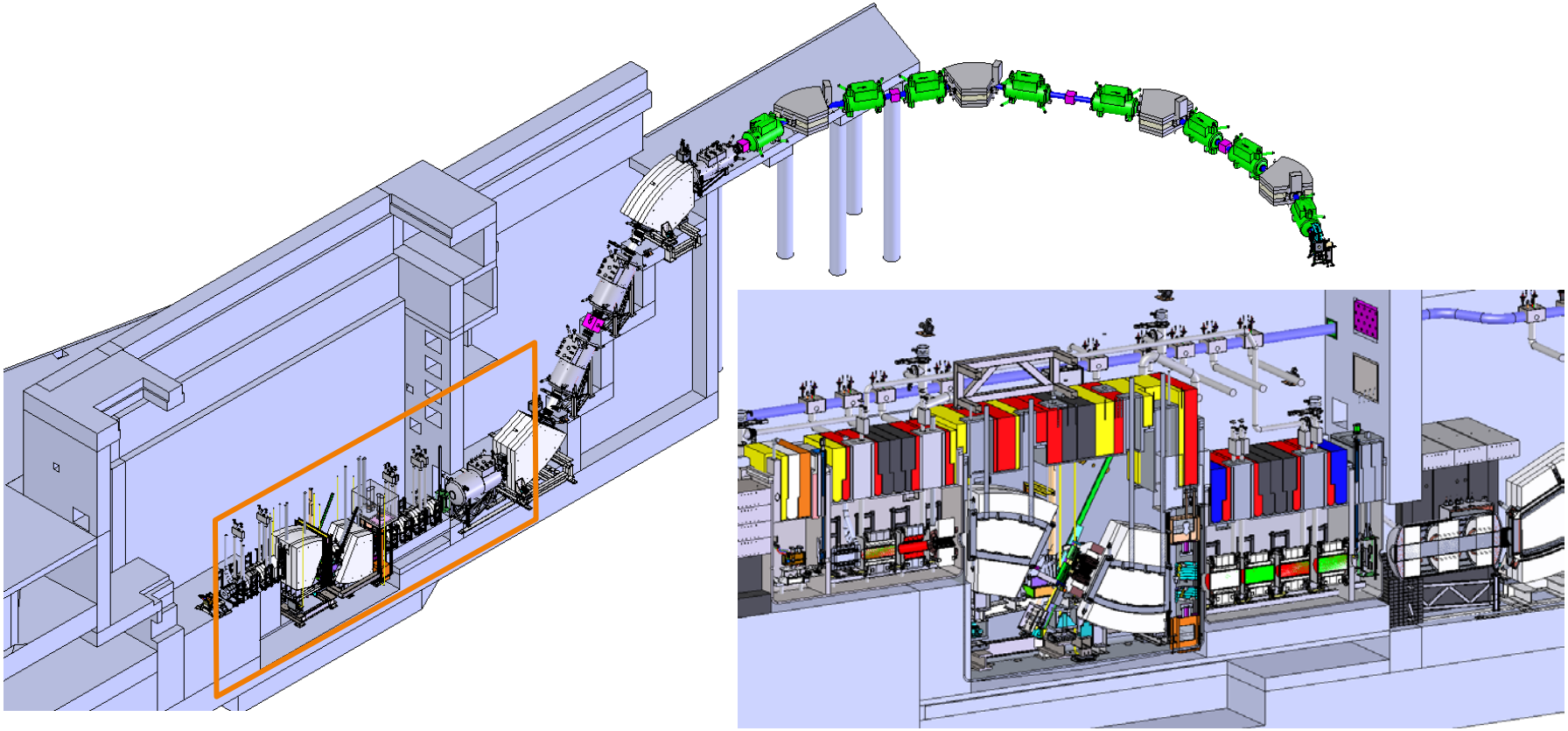
- Target hot cell, subterranean
  - Production target
  - Fragment preseparator
  - Primary beam dump
  - Remote handling equipment
- Target facility building high bay
  - Second and third stage of fragment separator
  - 50 ton bridge crane
  - Magnet power supplies



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

Fragment Separator

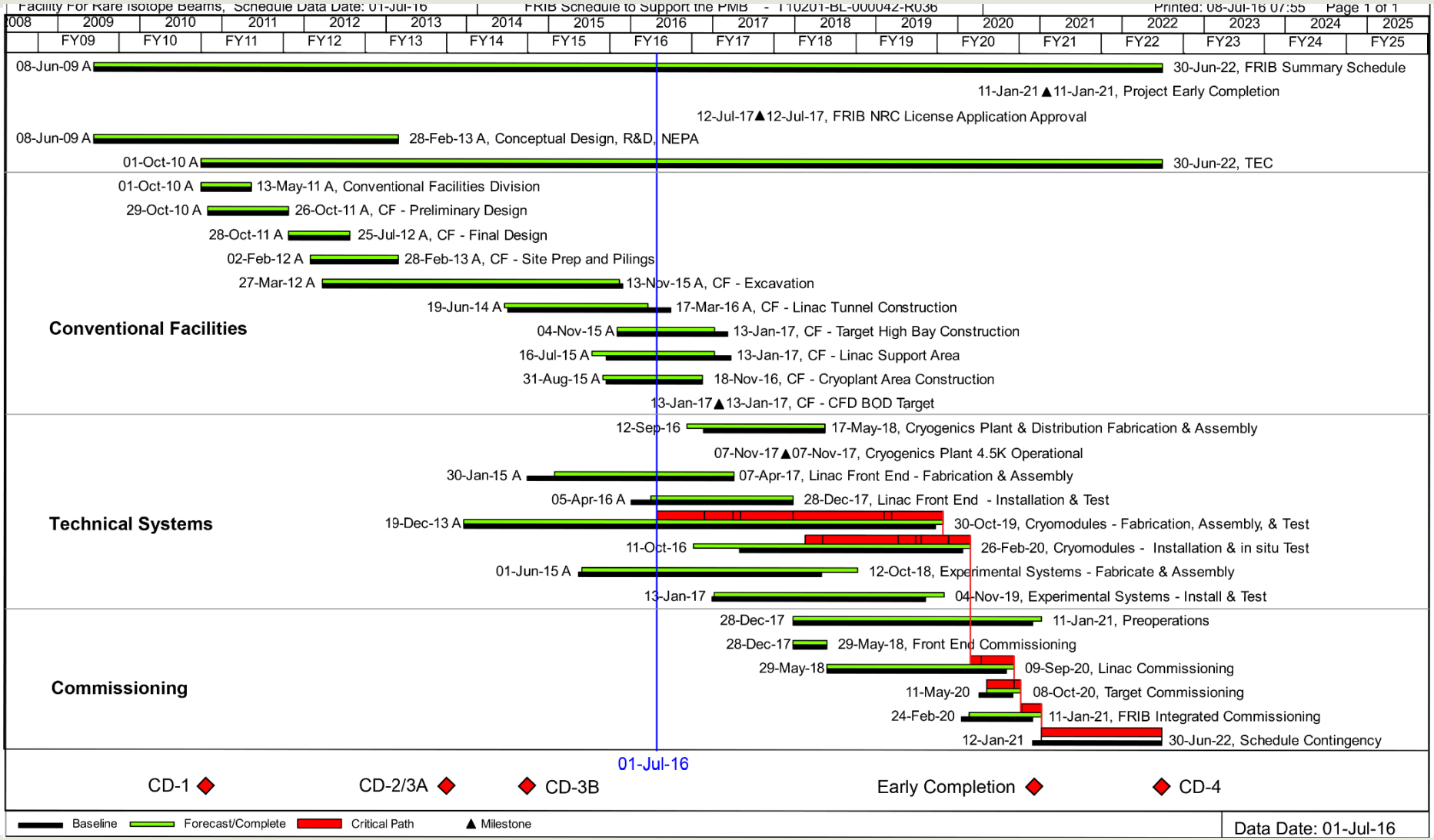
- Three-stage fragment separator for production and delivery of rare isotope with high rates and high purities to maximize FRIB science reach
- Primary beam power of 400 kW and beam energies of ≥ 200 MeV/u



Facility for Rare Isotope Beams in 2021

Aerial View - Progress to Date

FRIB Schedule Summary
Technical and Civil Construction Proceeding Well



Target Facility Civil Construction Progress
Ahead of Schedule

Hot-cell north view

Remote handling gallery

Hot-cell south view

Experimental Systems Division
Vacuum Vessel Fabrication Progressing Well

- Fabrication is making good progress
  - Target: Final assembly complete, final machining underway
  - Beam dump: Assembly 48% complete
  - Wedge: Wedge vessel shipped to machine shop in Cincinnati, OH, final machining completed
- Vessel seals procured and in house
- First vacuum test of Wedge vessel underway


Wedge Vessel Seal Retainer


Wedge vessel arrival in Cincinnati, OH


Wedge Vessel loaded on Truck in Camden, NJ

Cryoplant Construction on Schedule
4 K Cold Box; Warm Compressors; Cold Compressors

- Warm compressor installed
- 4 K cold box installation underway
  - Started in July 2016 with upper coldbox
  - Lower coldbox delivery in September
- Cold compressor
  - Delivery expected January 2017

Jefferson Lab

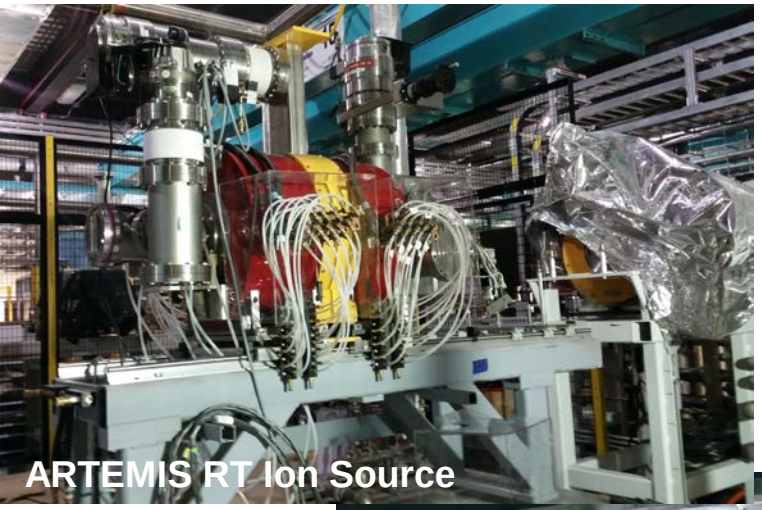

4 K upper cold box transported to FRIB on a 140’ flatbed truck


Warm compressors installed at FRIB


4 K upper cold box installed at FRIB

FRIB Construction Progress

Front End Technical Work Underway – Area Controlled by Technical Staff



ARTEMIS RT Ion Source

RFQ cold test assembly at vendor

High voltage platforms in the Front End

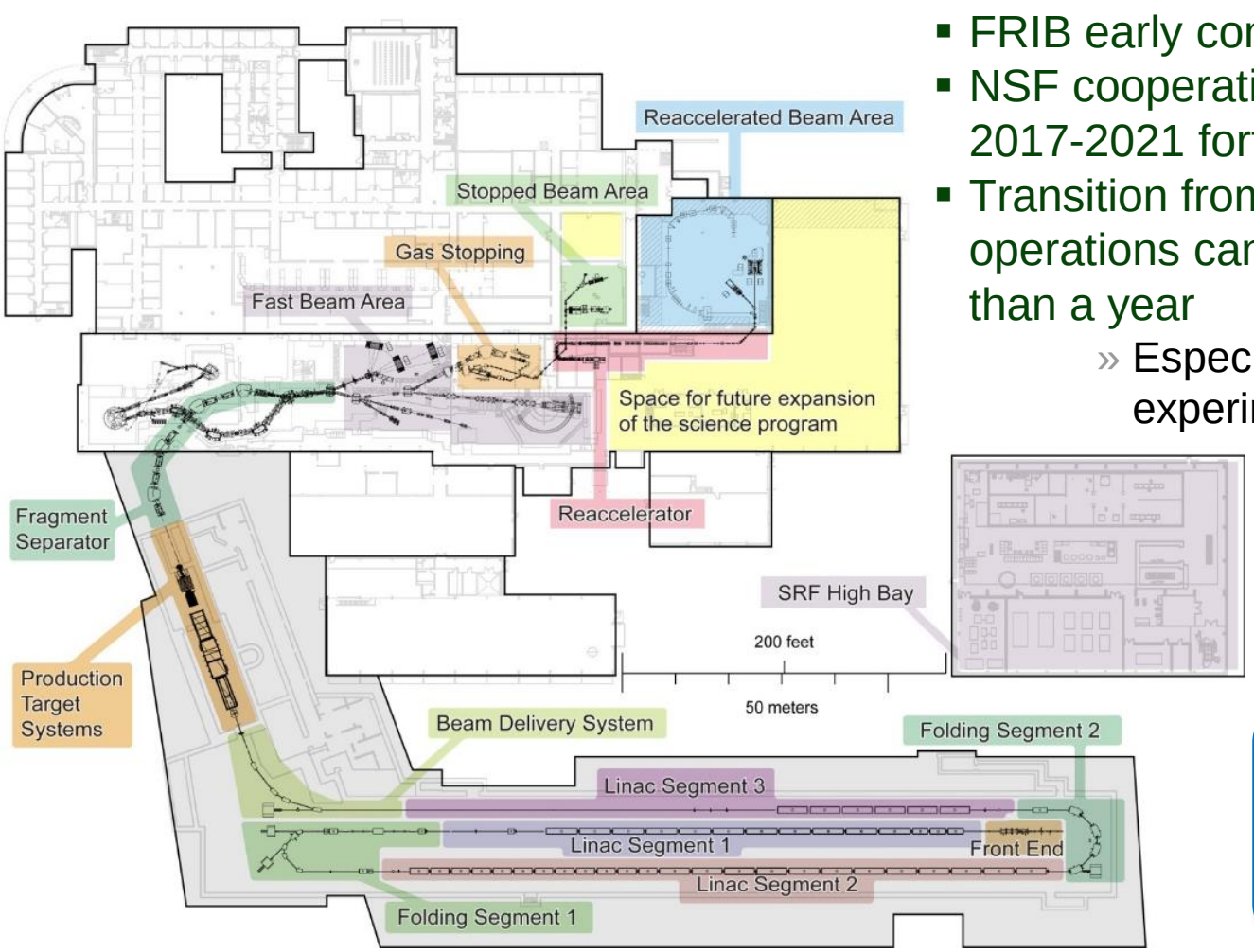
Production Cryomodules Being Assembled
Four Assembly Lines Proceeding in Parallel; Five at Peak


β=0.041 cryomodule #1
being assembled at MSU


β=0.085 cryomodule #3
being assembled at MSU

NSCL-FRIB Integration Plan

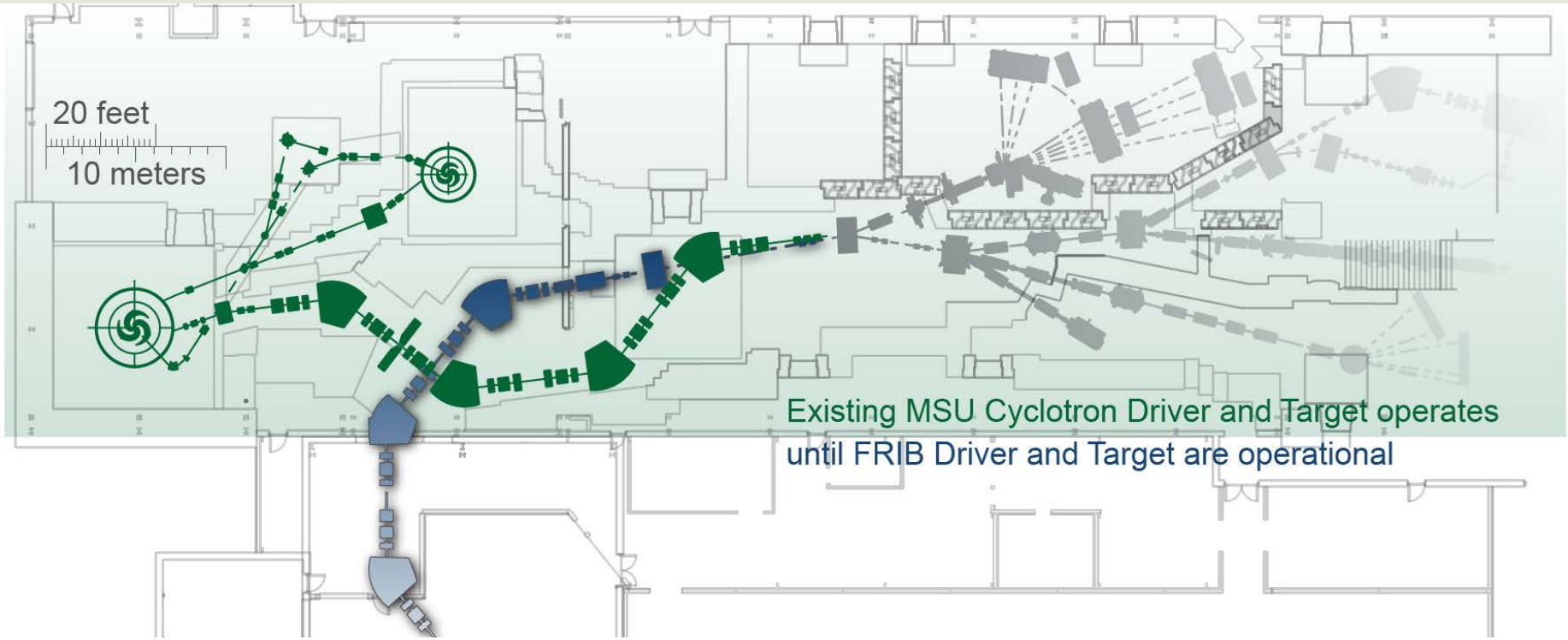
Minimal disruption of world-leading science and education program



- FRIB early completion in FY2021
- NSF cooperative agreement for period 2017-2021 forthcoming
- Transition from NSCL to FRIB operations can be accomplished in less than a year
  - » Especially important for experimental nuclear science

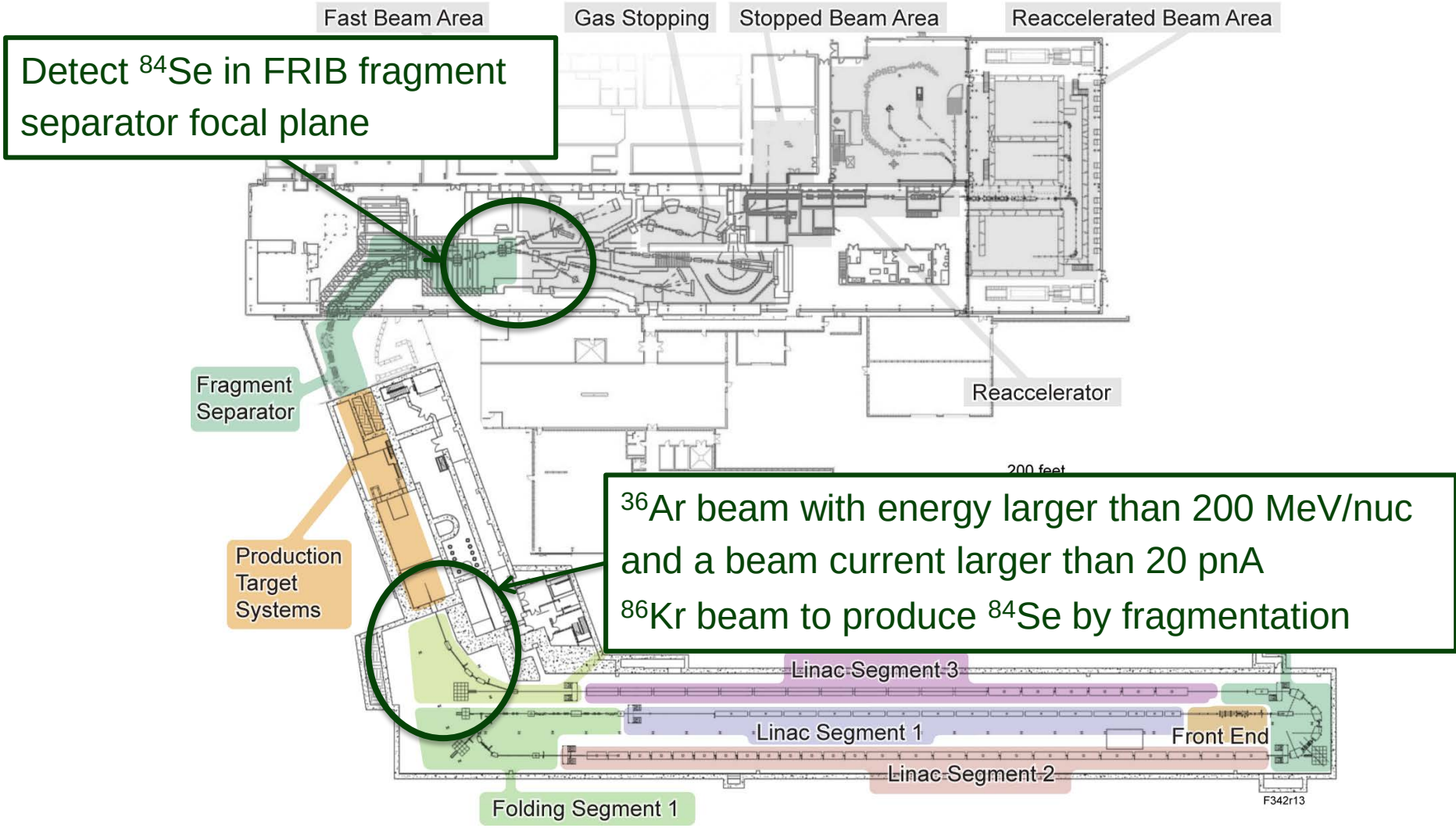
Plan enables continued world-class science for LE Community

Transition to Operations Plan



- Users form collaborations, commission detectors and do science with NSCL beams
- FRIB is commissioned through target before NSCL shutdown
- Transition from NSCL to FRIB operations in less than a year
  - Reconfigure fragment separator
  - Complete FRIB commissioning

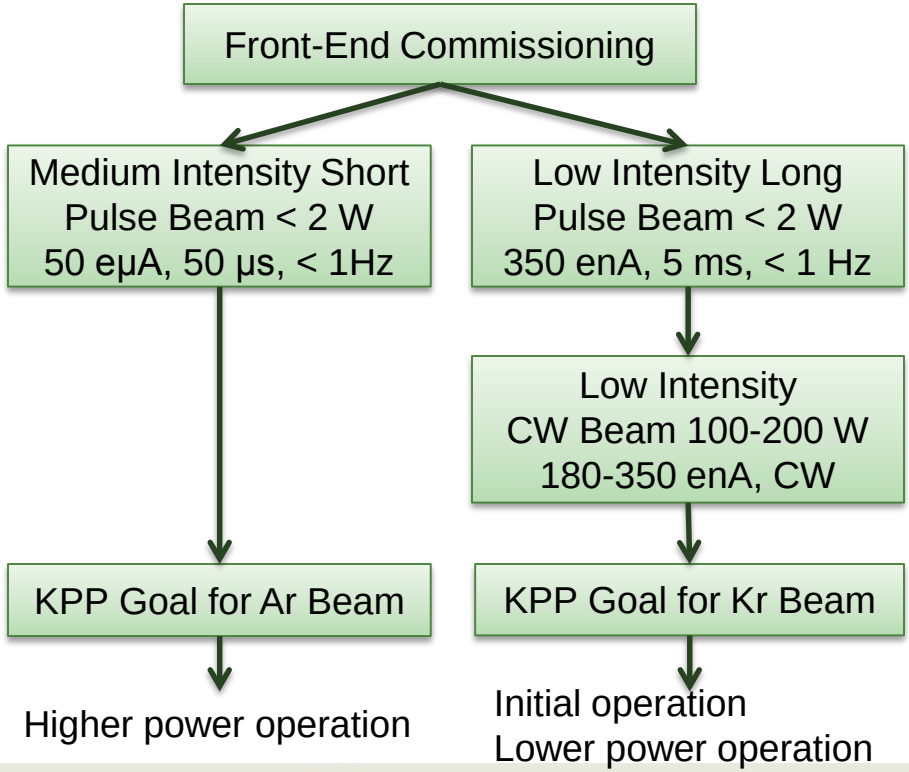
Commissioning Performance Requirements Defined by FRIB Key Performance Parameters for CD-4



Course of Beam Development Identified

Two-course Beam Development Supports Achievement of Two KPP Goals

- Commissioning beams defined (^{36}Ar and ^{86}Kr)
- Use single charge state beams for commissioning
- Two courses of beam development identified to achieve KPP goals

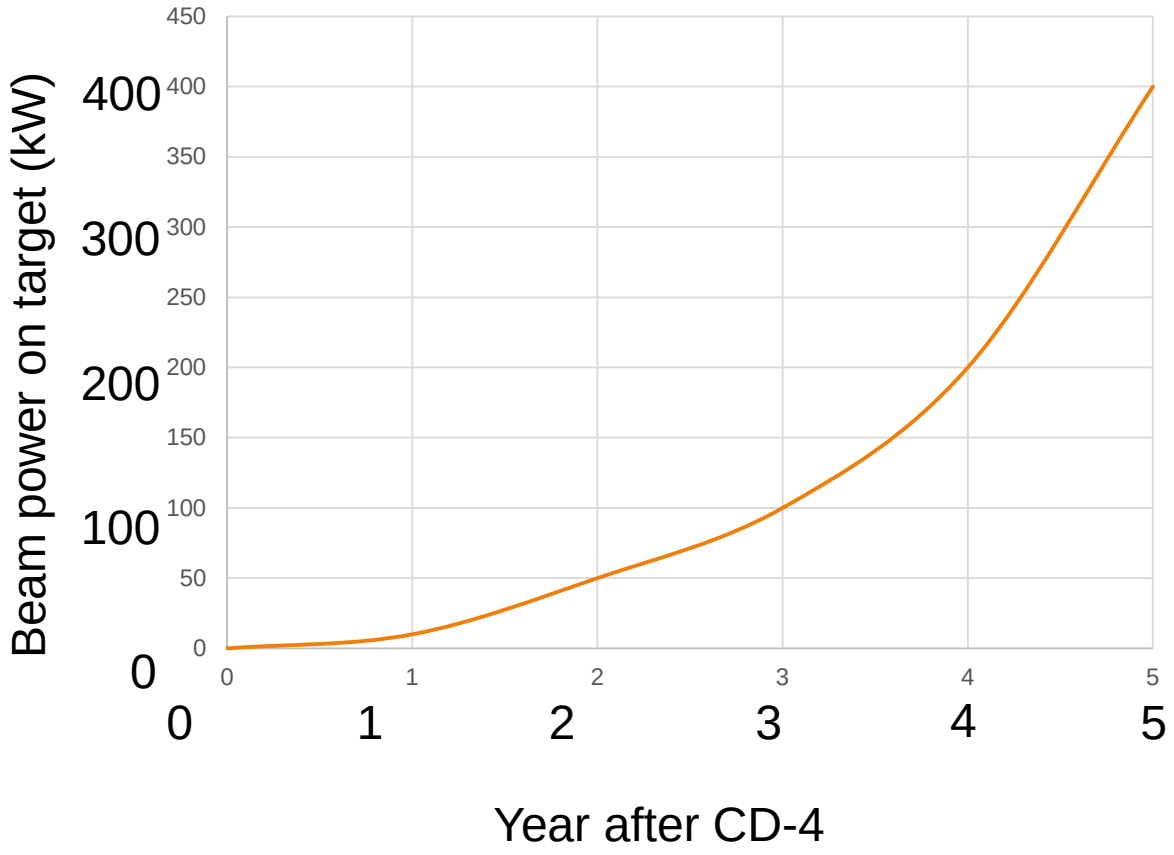


	^{36}Ar	^{86}Kr	Energy (MeV/u)
ECR IS	10+	17+	0.012
RFQ	10+	17+	0.5
LS1	10+	17+	>15
Stripper, FS1	18+	35+	>15
LS2, FS2	18+	35+	>140
LS3	18+	35+	>200

ECR IS: Electron Cyclotron Resonance Ion Sourse
RFQ: Radio Frequency Quadrupole linac
LS: Linac Segment, FS: Folding Segment

Approach to Full Beam Power Developed

- Year-by-year beam power ramp-up plan has been identified



Year after CD-4	Beam power on target (kW)
1	10
2	50
3	100
4	200
5	400

Accelerator Operations on Day-one

- Primary beams
  - See tables to right
- Beam power
  - Year One – 10 kW
  - Year Two – 50 kW
- Secondary beams
  - See reference to scientific benchmarks
  - Initial studies for all benchmarks enabled by year two
- Experimental end stations
  - Existing NSCL instruments
  - GRETA
  - SECAR
- Early operations funding ensures that key staff are available to deliver primary and secondary beams for science

Year One

Beam	Notional Weeks/ Year	Bench-marks
^{238}U	12	7,10,12,15
^{48}Ca	6.34	2,14
^{78}Kr	2.21	3,8,9,16,17
^{124}Xe	1.3	1,11,17
^{18}O	0.86	2,8
^{86}Kr	0.63	1,3,4,6, 14,15
^{16}O	0.44	2,8
^{36}Ar	-	8
Total	23.8	

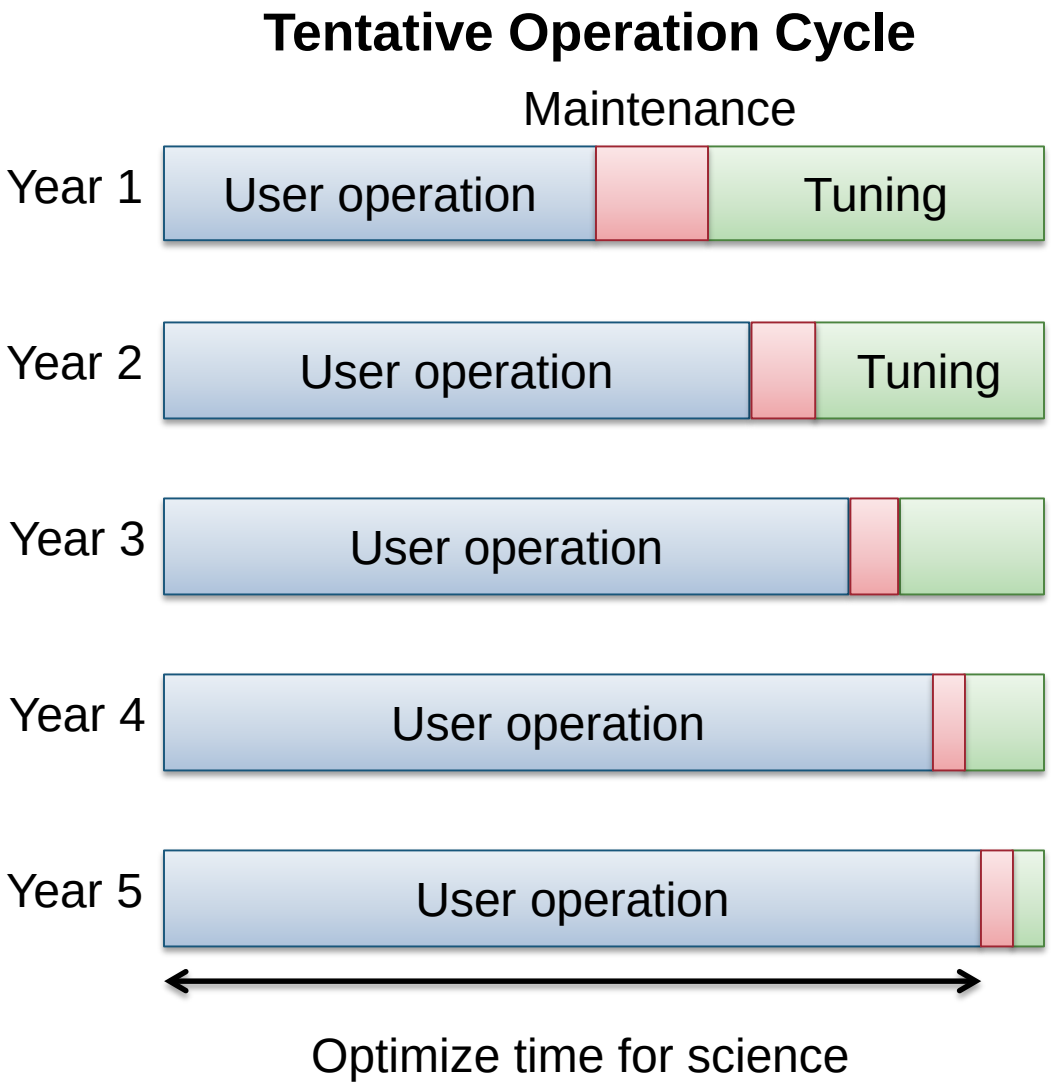
^{86}Kr and ^{36}Ar used to demonstrate FRIB Project's Key Performance Parameters

Year Two

Beam	Notional Weeks/ Year	Bench-marks
^{82}Se	5.25	1,3,4,5,6, 13,14,15
^{92}Mo	2.45	1,3,9,11,16, 17
^{58}Ni	1.64	1,3
^{22}Ne	0.54	2
^{64}Ni	0.5	1,13,14
Total	10.4	

Prepared to Allocate Time to Properly Address Integration Challenges

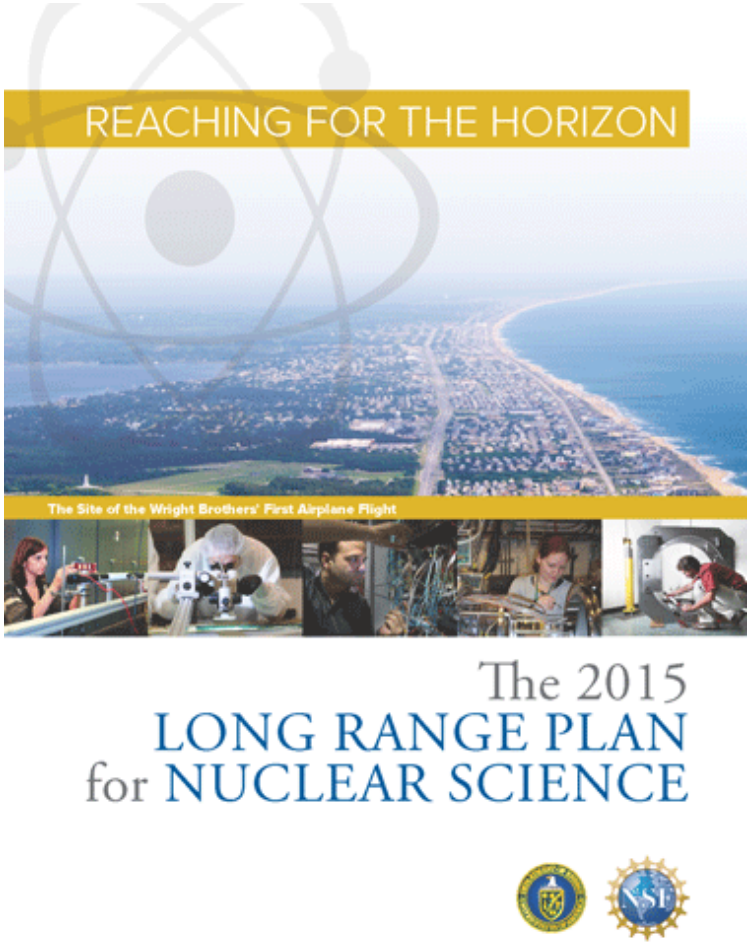
- After CD-4, adequate time allocated for maintenance and tuning to assure machine integrity and path towards mission goal while enabling world-class science
- Time allocation optimized for efficient integration assuming more extensive maintenance/ tuning for early years
- Detailed operation cycle is under discussion, trade-offs will be discussed with *Accelerator Systems Advisory Committee* (*Machine Advisory Committee* once FRIB in operation) and *Science Advisory Committee* (*Program Advisory Committee* once FRIB in operation)



Operations Requirements Assumptions

- Operate a world-class DOE-SC national user facility
  - Goal 5,500 hrs/year
  - Operate 24 hrs/day
  - Goal of > 90% availability
- Cryogenic plant
  - Operates 6,000 hrs/year at 15 kilowatt (kW) at 4 K
  - Operates remaining time at lower cooling power
- Provide users with
  - Rare isotope beams characterized on an event-by-event basis
  - Support to operate permanently-installed experimental equipment
  - Support to install non-permanently-installed experimental equipment
  - MSU Department of Environmental Health and Safety (EHS) support
  - Support for research is not included
- Cost estimation developed by FRIB project team and was vetted by United States Department of Energy Office of Nuclear Physics in the Operations Cost Review held 12-14 January 2016

Community Works Together to Define National Priorities



Long Range Plan for Nuclear Science completed October 2015

"*Expeditiously completing the Facility for Rare Isotope Beams (FRIB) construction is essential. Initiating its scientific program will revolutionize our understanding of nuclei and their role in the cosmos.*" (Recommendation I, Sec. 1)

Over 1,300 Users Engaged and Ready for Science

FRIB Users Organization
FACILITY FOR RARE ISOTOPE BEAMS

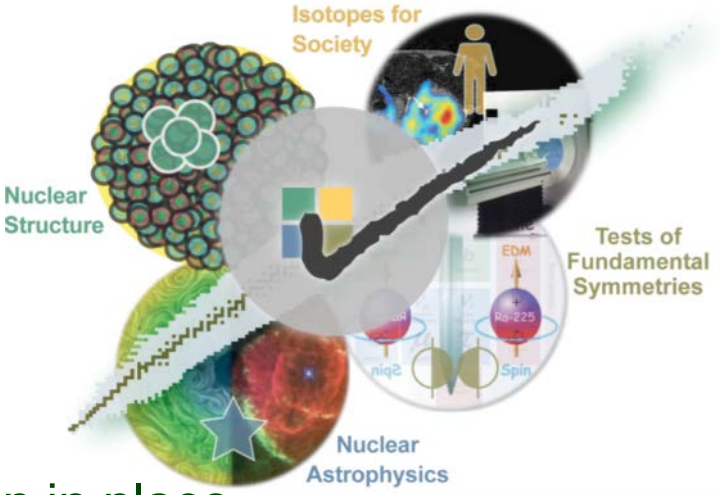
- Users are organized as part of the independent FRIB Users Organization (FRIBUO) www.fribusers.org
  - Chartered organization with an elected executive committee
  - 1,348 members (98 U.S. colleges and universities, 12 national laboratories, 52 countries) as of 31 August 2016
  - 19 working groups on instruments
  - 12-13 August 2016, Low Energy Community Meeting, U Notre Dame

    "FRIB remains our top priority. The community eagerly anticipates the completion of FRIB and the forefront science this facility will enable"

- Science Advisory Committee
  - Considerations for initial science program (8-9 December 2016)

Summary

- FRIB to become a world-leading DOE-SC scientific user facility for rare isotope science
  - Highest-power heavy ion linac worldwide
  - High-performance fragment separator
  - Fast, stopped, and reaccelerated beams
- FRIB project making appropriate progress
  - Civil construction ahead of schedule
  - Technical construction advancing well



- Strong, growing, and committed FRIB user group in place
  - Experimental equipment used now at NSCL, ready for FRIB science
  - New equipment investments will enable FRIB to optimize science outcomes
  - Initial science experiments under discussion