Facility for Rare Isotope Beams and National Superconducting Cyclotron Laboratory Overview

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MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

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FRIB Laboratory

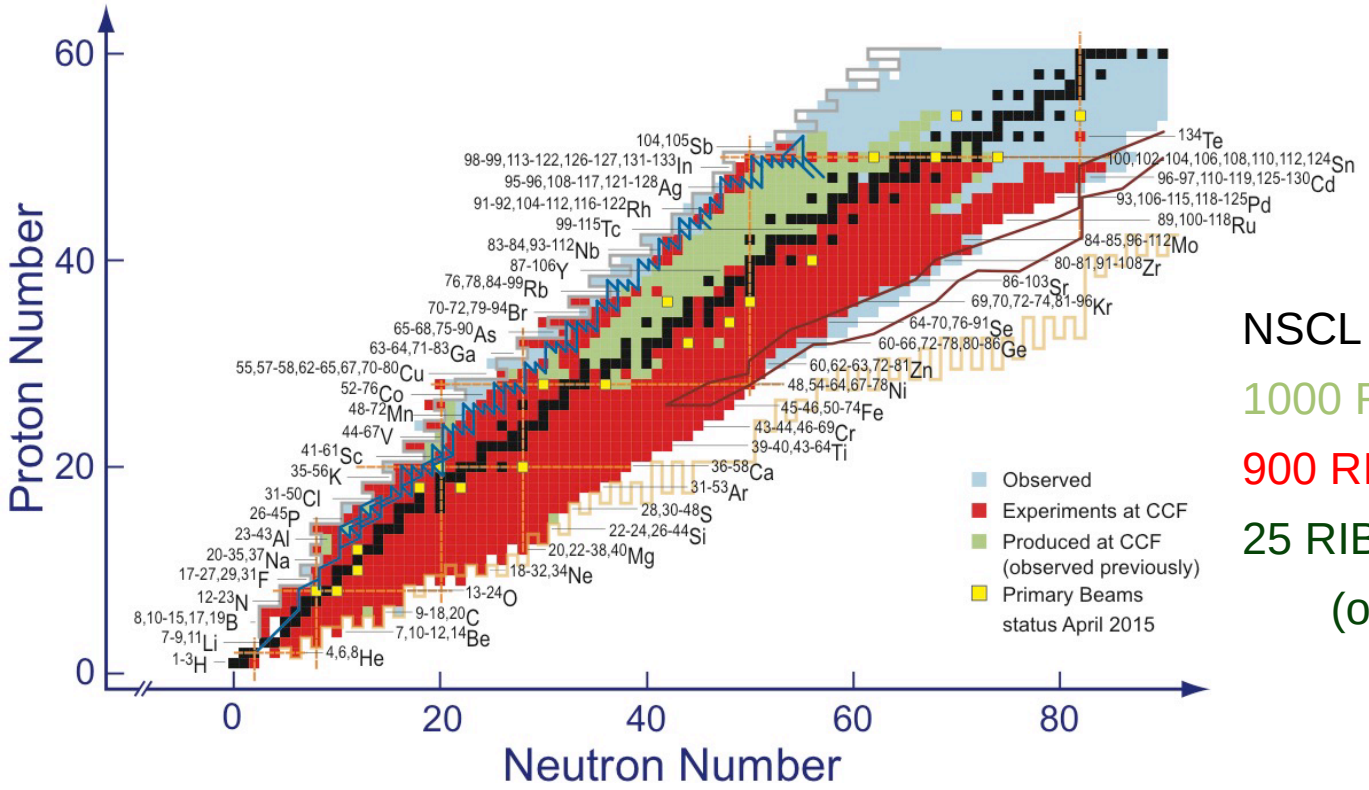
National Superconducting Cyclotron Laboratory
Facility for Rare Isotope Beams Project

- 43 Faculty
  - 22 Experimental
  - 11 Theory
  - 10 Accelerator Physics
- 90 Graduate Students
- 107 Undergraduate Students
- ~1400 member Users Group

- Operate the Coupled Cyclotron Facility (CCF) as a National User Facility
- Design, construct, and establish the Facility for Rare Isotope Beams (FRIB)

NSCL Operational Overview

- Since 2001, the CCF has delivered beams in excess of 4000 hours/year, at ~90% availability in support of the scientific program
- Secondary beams from projectile fragmentation and delivered within 24 hours of published schedule to experiments. [LISE++ provides excellent predictions]



NSCL Beams

1000 RIBs produced

900 RIBs used in experiments

25 RIBs stopped

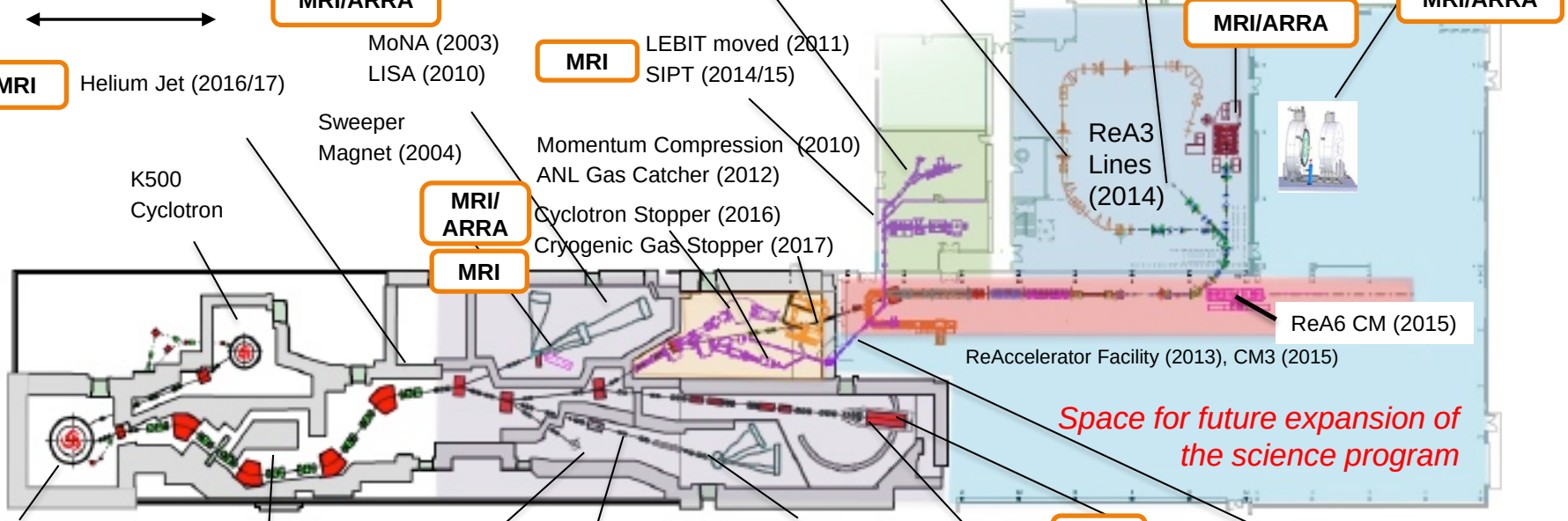
(of 19 chemical elements)

NSCL Developments

- Current NSF Cooperative Agreement ends 30 Sep 2016
  - MSU will submit a new proposal to NSF to operate NSCL for the period Oct 2016 to Oct 2021
  - Operating hours are a priority
  - Proposal preparation is in process
- Leadership changes
  - Thomas Glasmacher is FRIB Laboratory Director, effective 1 March
  - Effective 16 May Brad Sherrill took over as NSCL Director
  - Effective 1 June Michael Thoennessen is FRIB Laboratory Associate Director for Users
  - NSCL Leadership Team: Alexandra Gade (NSCL Chief Scientist), Richard Jacobson (Executive), Dave Morrissey (Operations), Filomena Nunes (Theory), Hendrik Schatz (JINA-CEE), Artemis Spyrou (Education and Outreach), Remco Zegers (Experimental Research)

NSCL Facility Layout

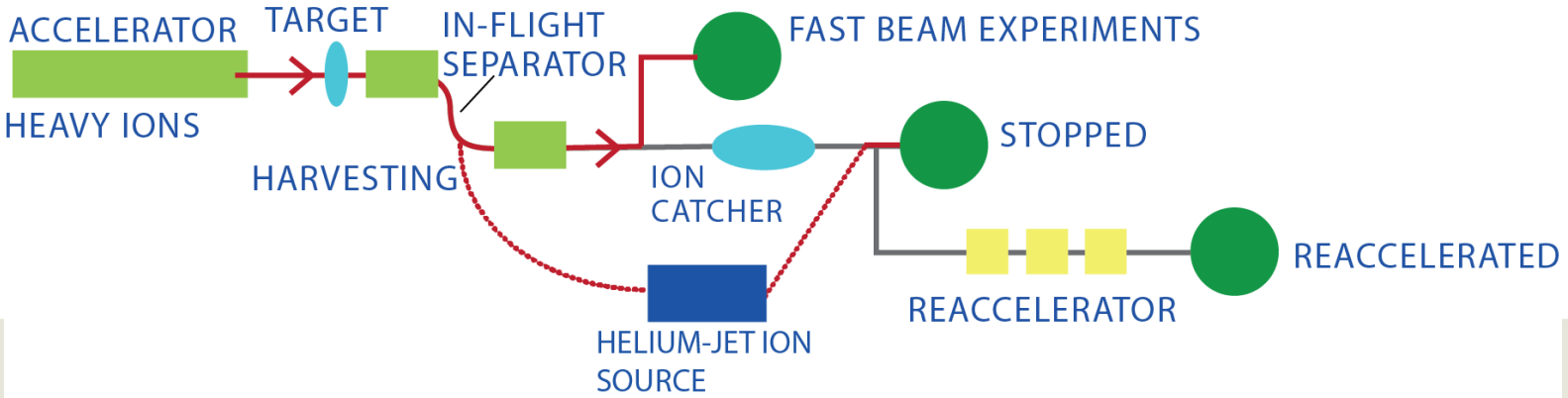
Developments and equipment enable forefront science and will be used at FRIB



Helium-Jet Ion-Guide System (HJ-IGS)
new capability for commensal operation

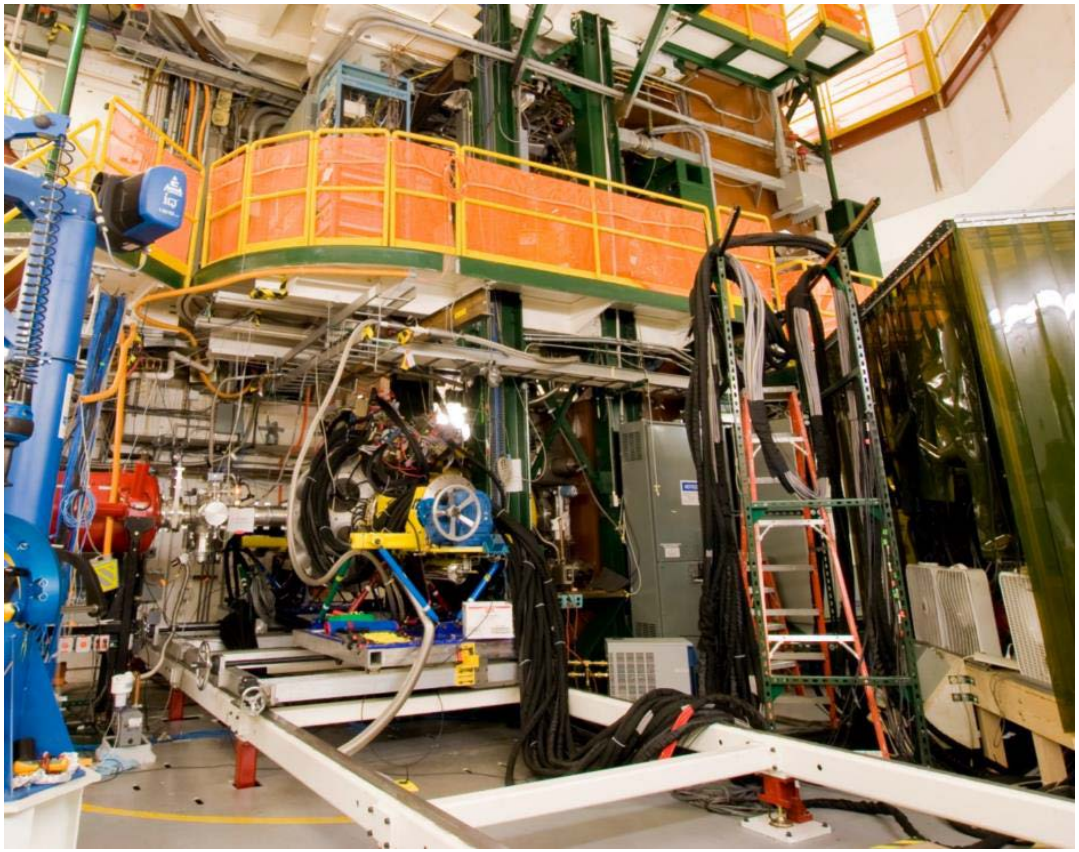
- Based on design by Chalk-River Nuclear laboratories; Reassembled and updated by ORNL, UNIRIB, Center for Radioactive Ion Beams for Stewardship Science; tests at ORNL completed with additional support from NSCL/FRIB
- NSF-MRI Proposal accepted for implementation of HJ-IGS for commensal operation at NSCL
  - Rare isotopes produced off-axis of the fragment separator are caught in a high-pressure cell filled with a helium-aerosol mixture
  - Harvested isotopes are transported through a capillary to the helium-jet ion source, where helium is pumped away and the rare isotopes are ionized
  - Rare isotopes are accelerated, purified and delivered to experimental stations in the stopped and reaccelerated beam areas

COMMENSAL OPERATION AT NSCL

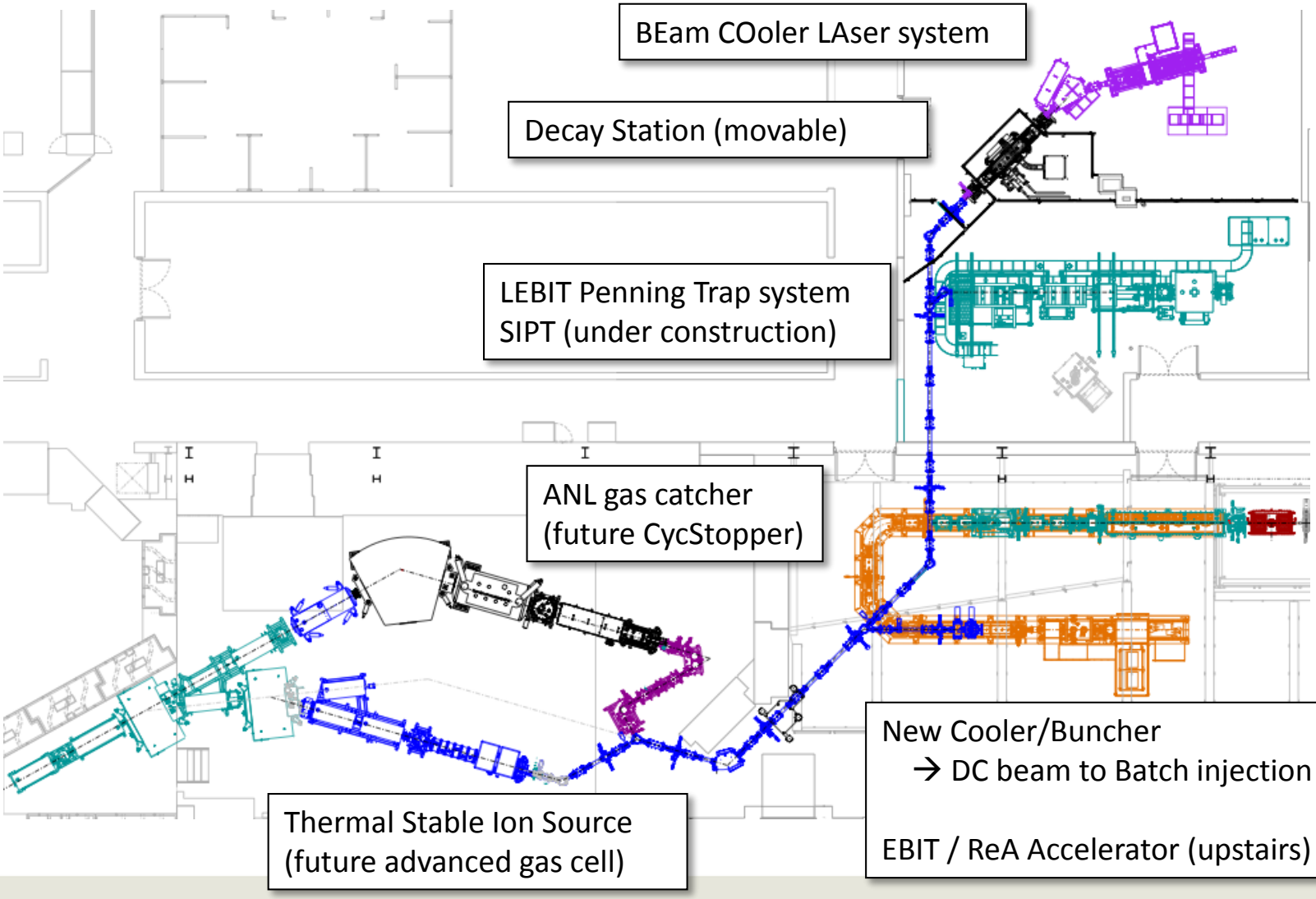


GRETINA with S800
major success of the science program

- First GRETINA Campaign at NSCL - June 2012 to July 2013: 24 experiments
- Status of science results:
  - 4 PRLs
  - 4 PRC Rapids
  - 3 PRCs
  - 5+ Ph.D. Theses
  - More to come….
- GRETINA has returned to NSCL; arrived July 2015 for an approximately 1.5 year campaign
- 11 GRETINA experiments approved at PAC39, PAC40 in 2016

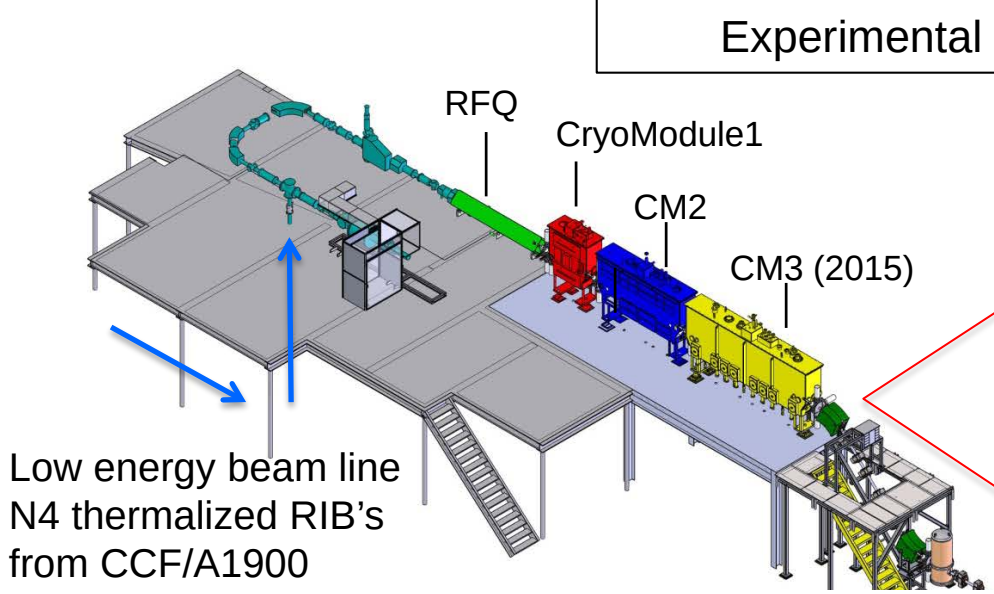


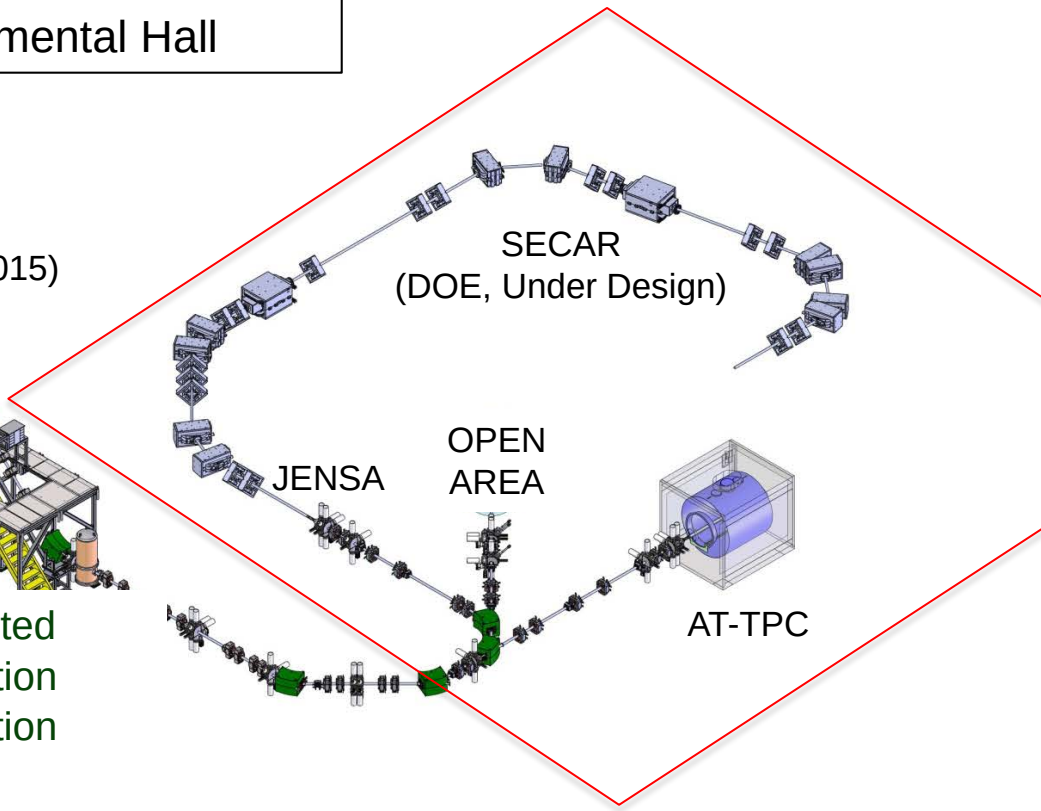
NSCL Stopped Beam Area
feeds ReA and precision experiments



ReA3 Ready for Science
commissioning completed in 2015

ReA3 Accelerator and Experimental Hall





2010/10: RFQ commissioning started
2011/04: CM1 first beam acceleration
2011/06: CM2 first beam acceleration
2012/04: first $1^+ \rightarrow n^+$ acceleration
2013/06: First experimental hall beam line
2013/08: First rare isotope experiment
2014/01: EBIT coil fails ☹
2014/12: ReA3 Beam Lines complete
2014/04: EBIT magnet returns ☺
2015/05: CM3 full energy acceleration
2015/09 ReA RIB program starts

A. Villari, ReA3 Dept. Head

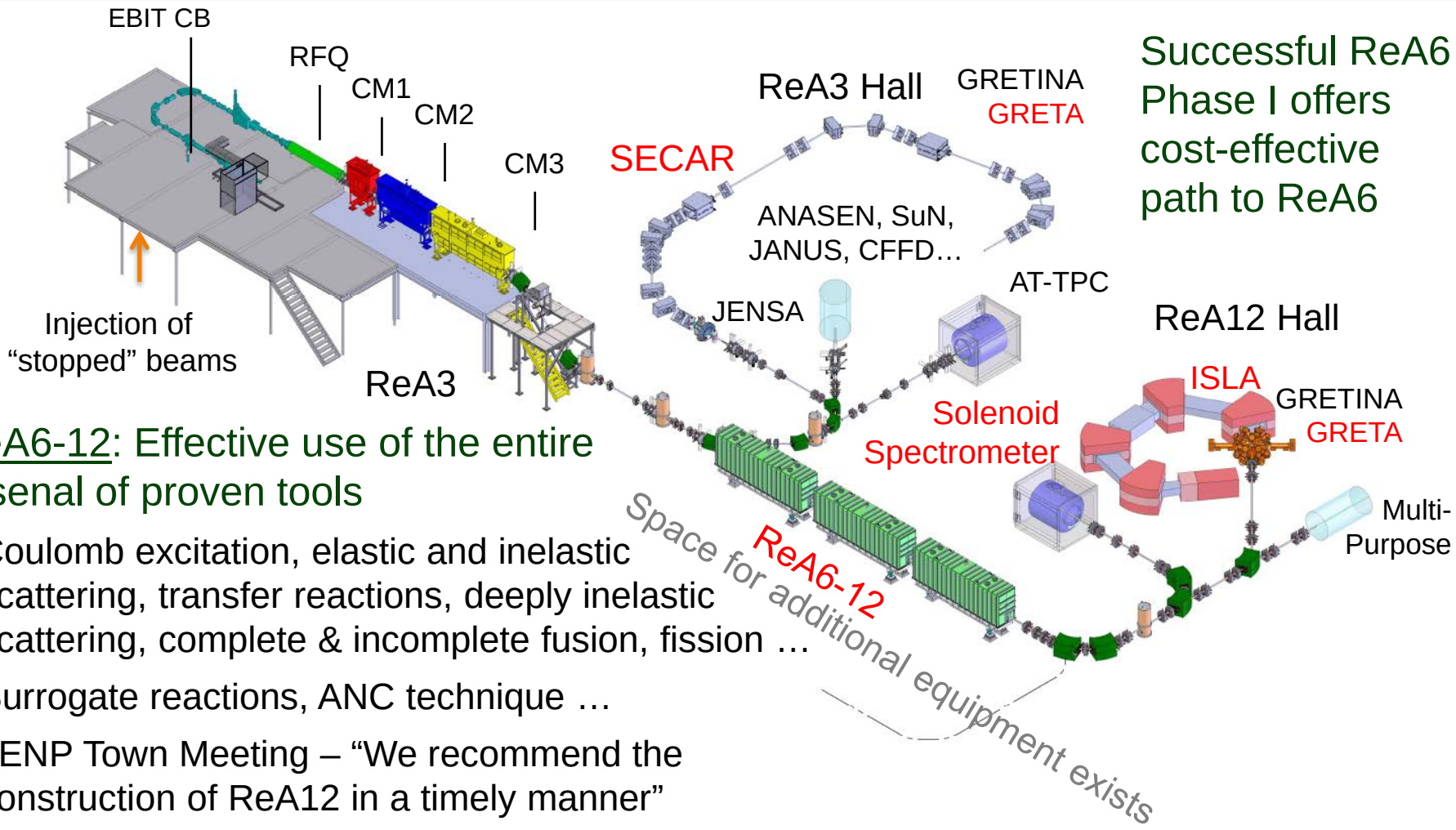
ReA3 Beam List
includes isotopes from 11 elements

- Demonstrated ReA3 beams can be found at the link below – used for the calls for proposal (next call Spring 2016)
- 94 beams on the list; elements Mg, P, S, Cl, Ar, K, Fe, Co, Ga, Br, Kr
- Development continues - have since PAC39 call developed C, O, Si

Br **ReA3 BEAM LIST** http://www.nscl.msu.edu/users/beams.html

A	Element	Isomer	T 1/2	Maximum ReA3 Energy (MeV/u)	Projected ReA3 Rate (pps)
71	Br	g	2.14 sec	5.4	2.70E+02
*72	Br	g+i	78.6 sec	5.3	3.46E+03
73	Br	g	3.4 min	5.3	2.45E+04
74	Br	g+i	25.4 min	5.2	9.43E+04
75	Br	g	96.7 min	5.1	1.49E+05
76	Br	g+i	16.2 hr	5.1	1.50E+05

ReA6-12: Significant Scientific Opportunity
proposal to be submitted to NSF

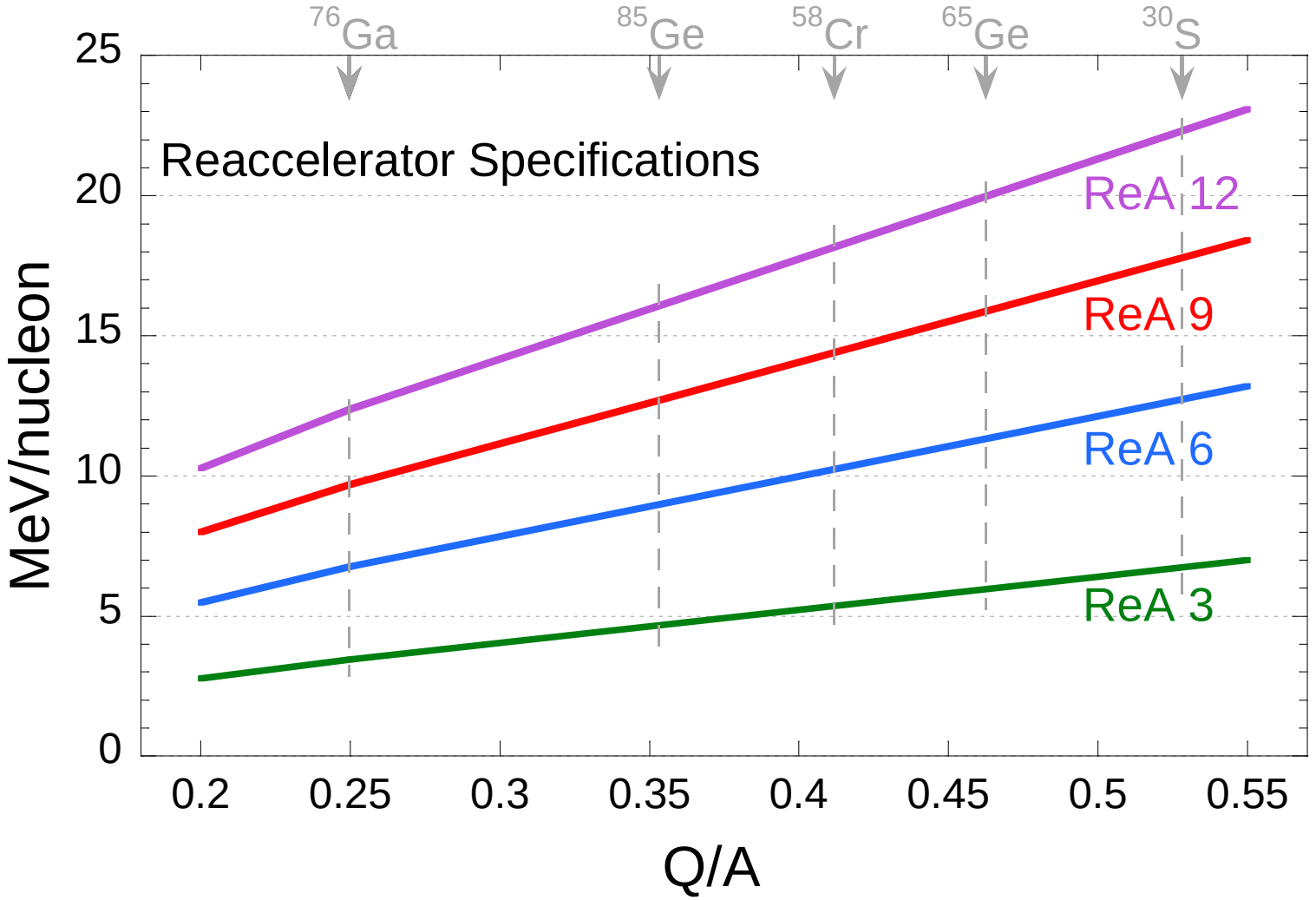


Successful ReA6 Phase I offers cost-effective path to ReA6

ReA6-12: Effective use of the entire arsenal of proven tools

- Coulomb excitation, elastic and inelastic scattering, transfer reactions, deeply inelastic scattering, complete & incomplete fusion, fission …
- Surrogate reactions, ANC technique …
- LENP Town Meeting – “We recommend the construction of ReA12 in a timely manner”
- Proposal kickoff workshop held Thursday 20 Aug (Iwasaki)

Reaccelerator Performance Specifications



Single Particle Structure

Collective Nuclear Properties

Astrophysical Energies

ReA6 Phase-1 Cryomodule
Successfully Tested

- The prototype contains two β = 0.085 cavities and one superconducting focusing solenoid, built to validate both the unique bottom-up assembly of the cold mass and the FRIB cryogenic cooling system

- A FRIB-style cryoline was also constructed and connected to the cryomodule
- The device was installed in a concrete shielded area in the position that would be used later for operation with beam but NOT connected to the ReA3 beamline
- Successful testing was completed in May 2015
  - Validation of the FRIB cryomodule design
  - First step in a cost-effective path towards ReA12

NSCL Operations and Infrastructure
Summary and Issues

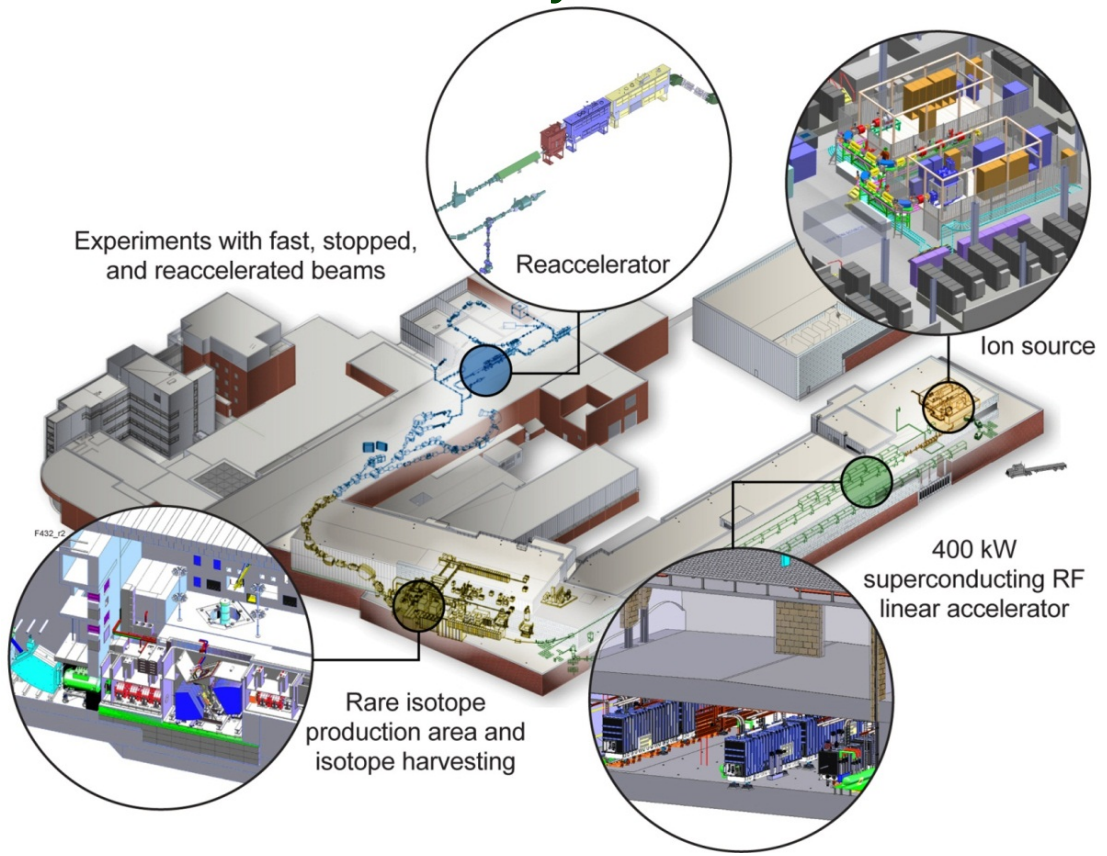
- High demand for beam time is accentuated by world-wide shortage and closure of ORNL facility
  - PAC39 – less than 50% of requested hours approved
- Current operating funds not sufficient to support historical operating hours
  - Typically 4500 hrs annually
  - MSU support in recent years has been used to supplement operations
  - ReA3 operations outside of funding scope
- Additional funds from NSF will be requested in the new operating grant proposal.
  - Additional operators and scientific staff needed to run a ReA3 user program.
  - Maintain equipment in a ready state for FRIB
  - Support commensurate to realize 4500 hrs of operations
- ReA6-12 could be possible after 2016 by upgrading proof-of-principle CM4.1 to fully instrumented CM4 – a huge scientific opportunity
  - Upgrade of ReA3 will be initiated by a white paper and proposal based on the 20 Aug workshop
  - Essential for future science at FRIB

Major Facility Equipment Requests
next five-year funding cycle

- Major facility improvements to be included in the operating grant proposal
  - A1900 improvements for higher-efficiency collection + better tracking detectors
  - ECR upgrades
  - Energy buncher for ReA3 beam lines
  - Heavy-ion ion source for ReA3
  - 2nd EBIT for ReA3
  - Improvements in data storage and backup
  - Expanded stopped beam area
  - Resonant LASER Ionization beam line for spectroscopy of weak beams
- Input from the user community on these initiatives and other priorities is welcomed

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

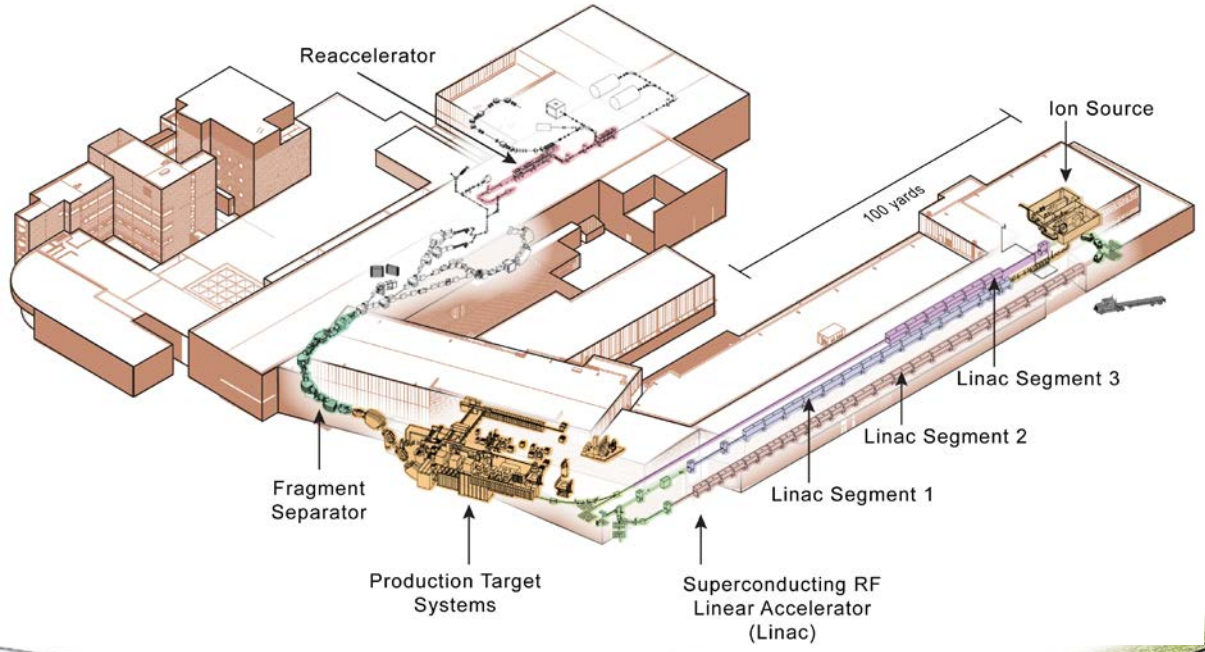
- Funded by U.S. Department of Energy Office of Science (DOE-SC) supporting the mission of the Office of Nuclear Physics in DOE-SC
- Serving over 1,400 users
- Key feature is 400 kW beam power for all ions ($5x10^{13}$ $^{238}U/s$)
- Separation of isotopes in-flight
  - Fast development time for any isotope
  - Suited for all elements and short half-lives
  - Fast, stopped, and reaccelerated beams

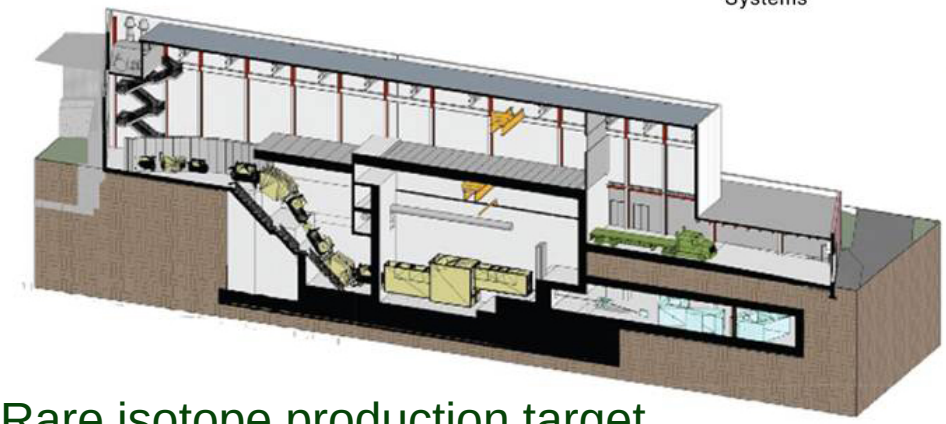


Facility for Rare Isotope Beams in 2021

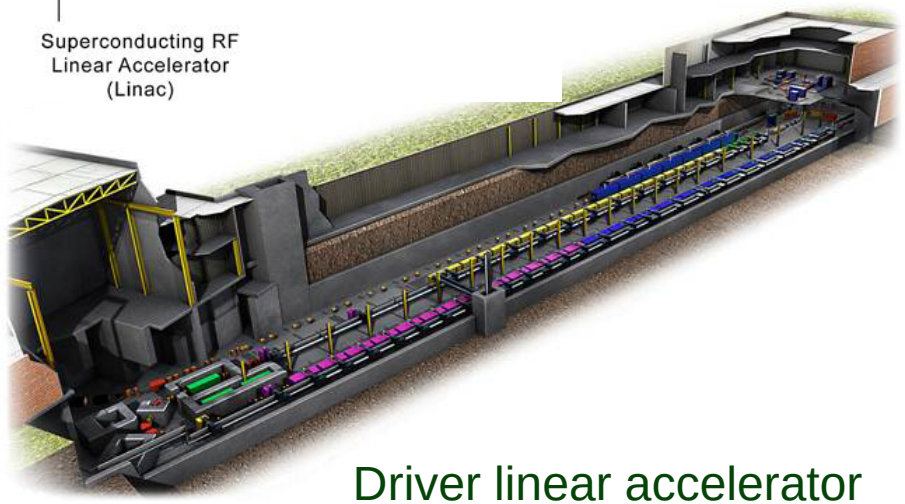
Civil Construction Progressing Well
9 weeks ahead of schedule

Facility Layout Unchanged Since June 2011





Rare isotope production target



Driver linear accelerator

FRIB Technical Construction on Track

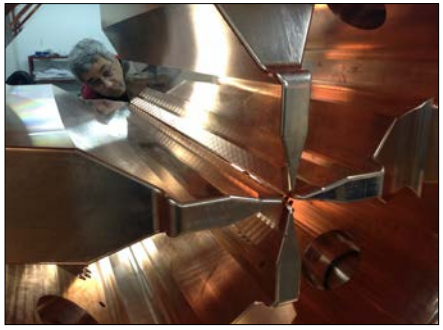
4.5 K cold box like Jlab 12 GeV

Master slave manipulators

Cryomodule

Bottom loading port

Non-conventional utilities tanks



RFQ

SRF half-wave cavity

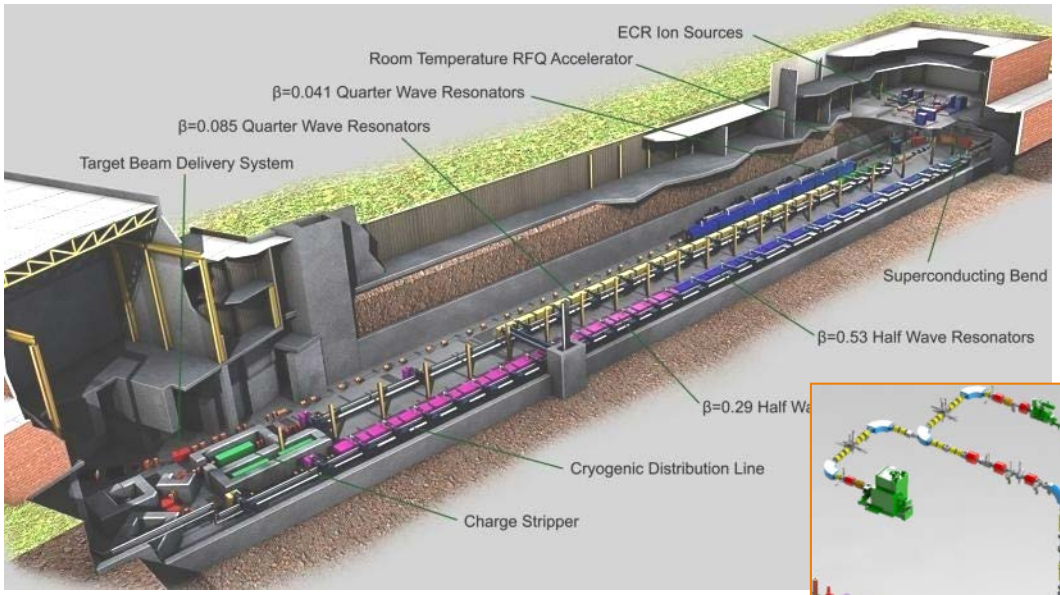
Cold beam-position monitor

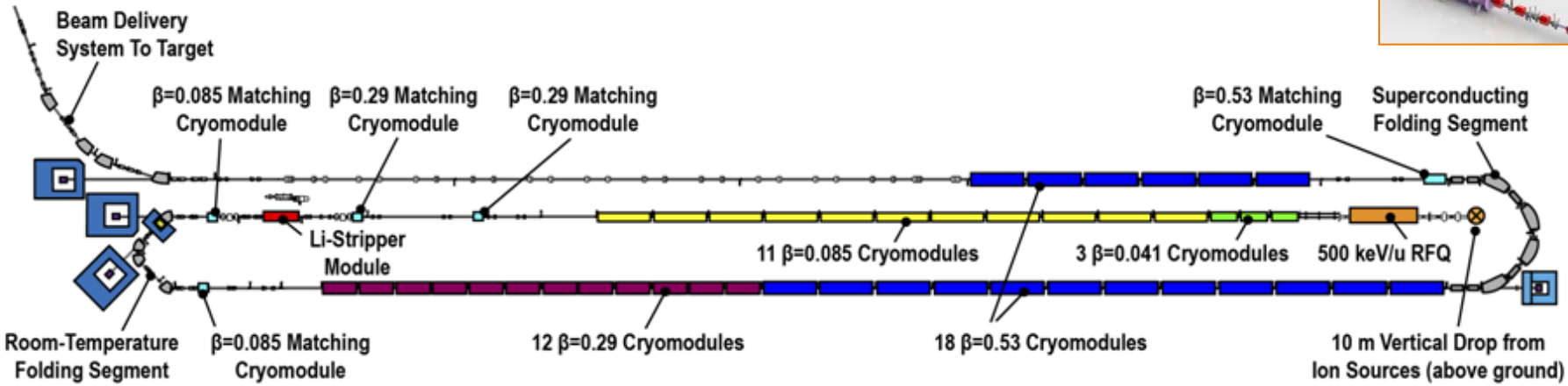
Superconducting magnet fabrication

SRF quarter-wave cavity processing

FRIB Accelerator Systems
Superconducting RF Driver Linac

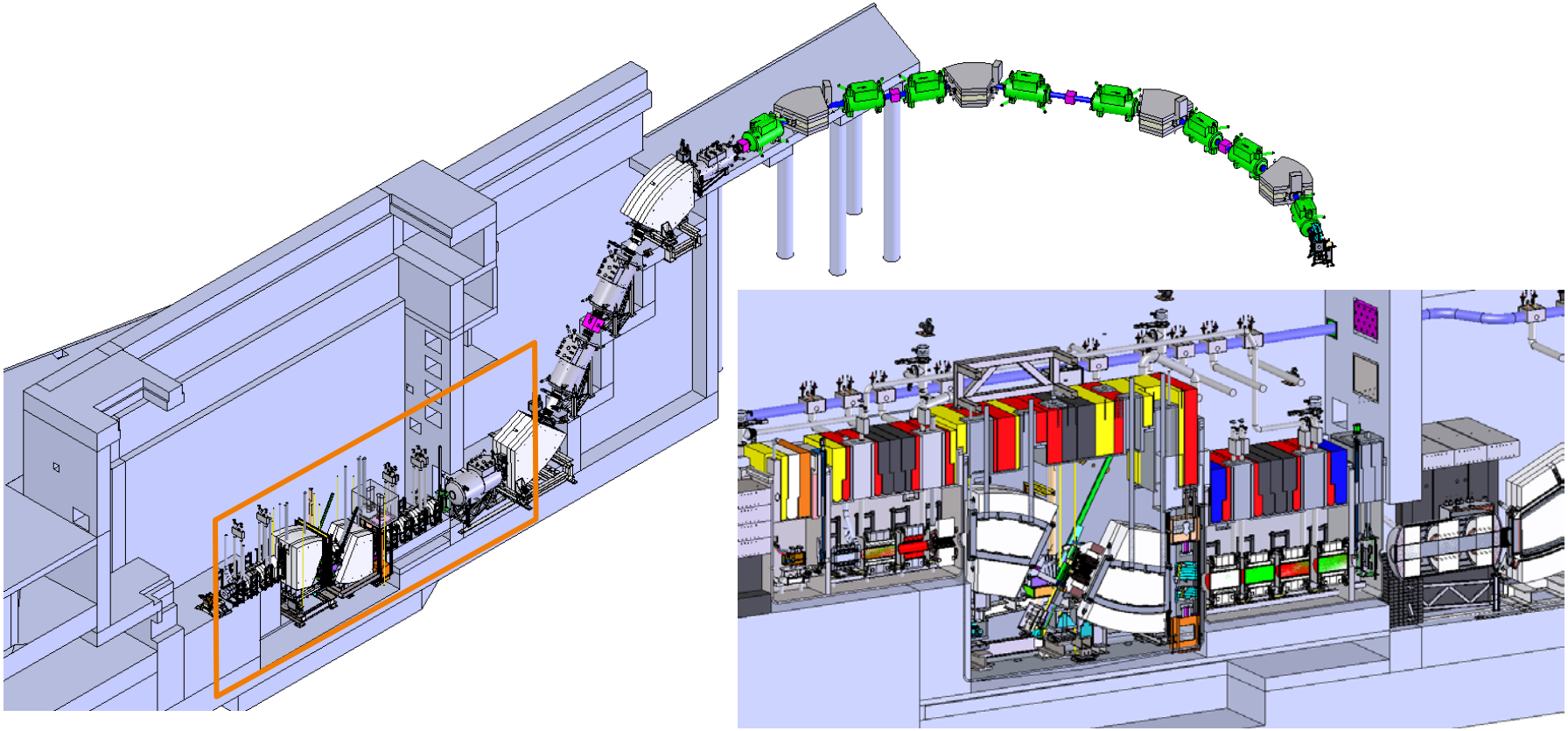
- Accelerate ion species up to ^{238}U with energies of no less than 200 MeV/u
- Provide beam power up to 400kW
- Energy upgrade to 400 MeV/u for ^{238}U by filling vacant slots with 12 SRF cryomodules
- Provisions for ISOL upgrade





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



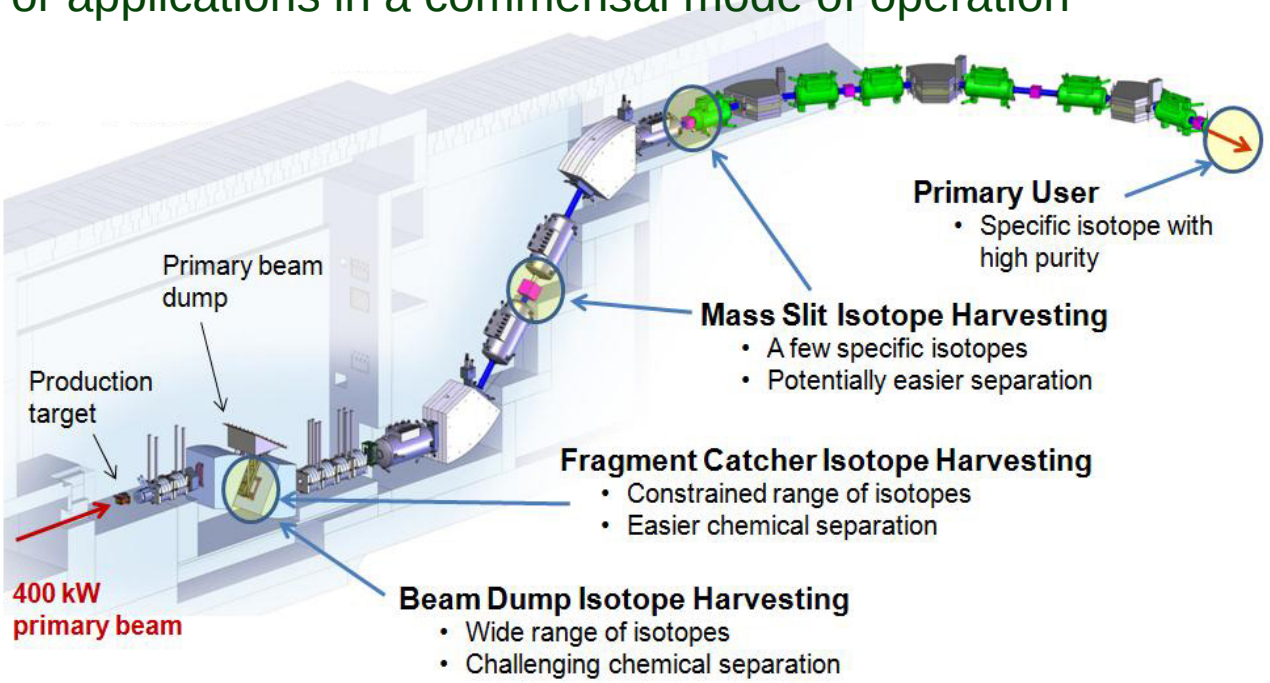
Isotope Harvesting Opportunity at FRIB
Make Best Use of Rare Isotopes Produced

- Produce a rare isotope beam for a primary user, for example ^{200}W from a ^{238}U primary beam
- At the same time up to 1000 other isotopes are produced that could be harvested and used for other experiments or applications in a commensal mode of operation

1st workshop on "Isotope Harvesting at FRIB", Santa Fe, 2010

2nd workshop on "Isotope Harvesting at FRIB", East Lansing, 2012

3rd workshop on "Isotope Harvesting at FRIB", St Louis, 2014

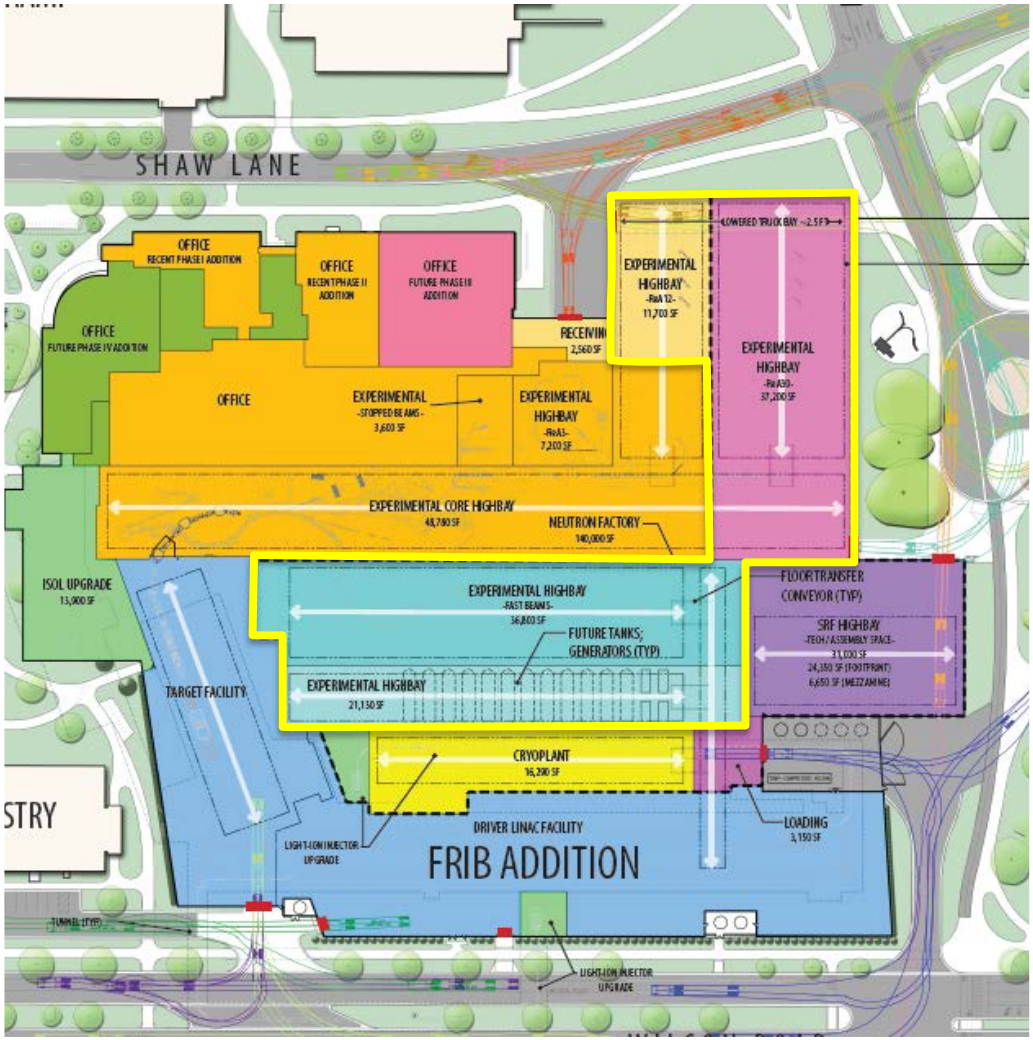


Meeting Isotope Needs and Capturing Opportunities For The Future
NSAC-I Report July 2015

"We recommend … Infrastructure for isotope harvesting at FRIB"

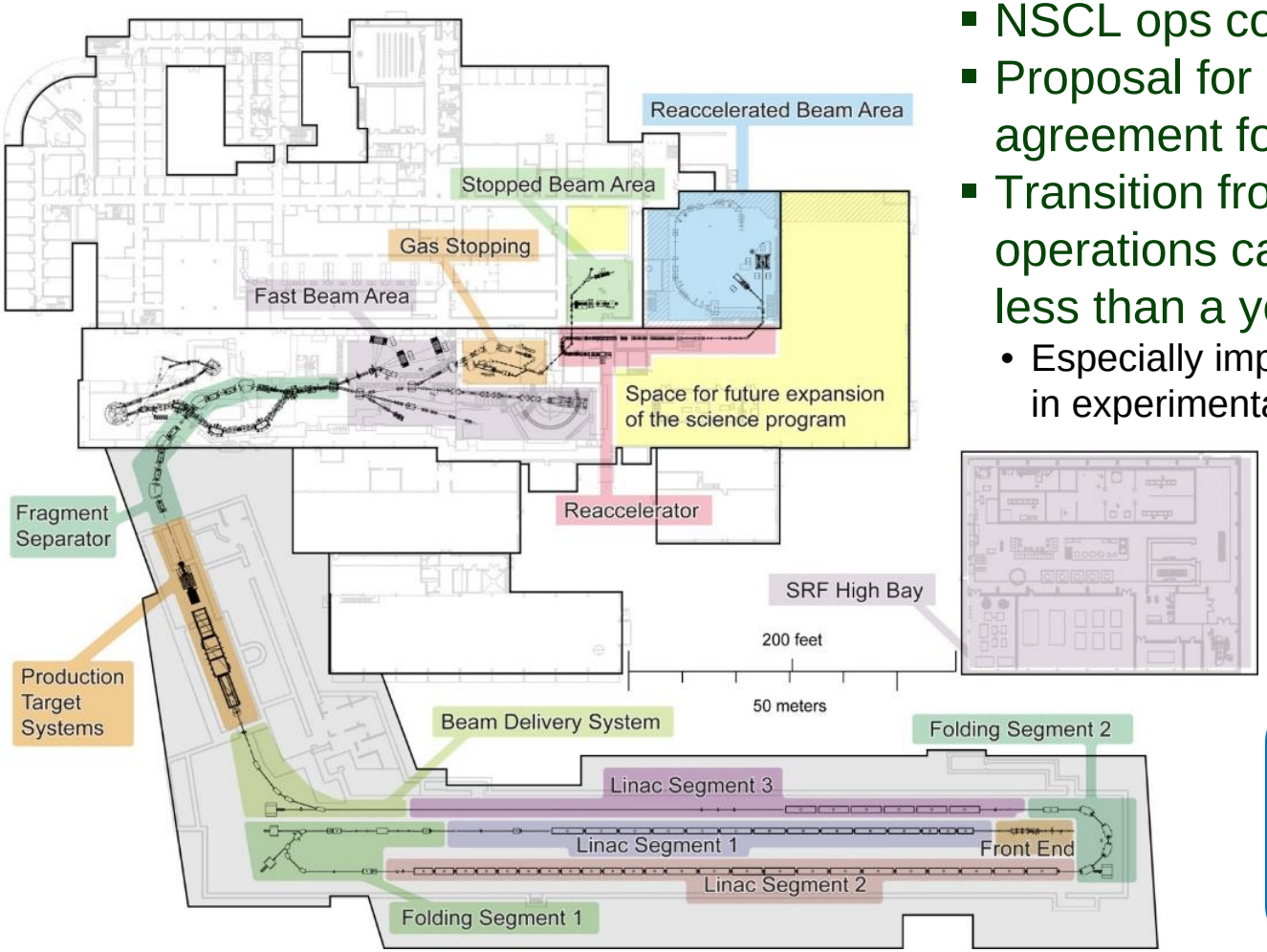
Experimental Area Expansion and New Experimental Equipment

- 47,000 sq ft operational when FRIB starts, 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, CAESAR, SUN, ...
  - Equipment available in the community and movable (existing, under development, or planned): GRETINA, ANASEN, CHICO, Nanoball, ORRUBA, JANUS, …
  - Science driven new equipment developed by FRIB user community: SECAR, GRETA, HRS, Decay Station, ISLA, …



NSCL-FRIB Integration Plan

Minimal disruption of world-leading science and education program



- NSCL ops complete by end of 2021
- Proposal for new NSF cooperative agreement for period 2017-2021
- Transition from CCF to FRIB operations can be accomplished in less than a year
  - Especially important for graduate program in experimental nuclear science

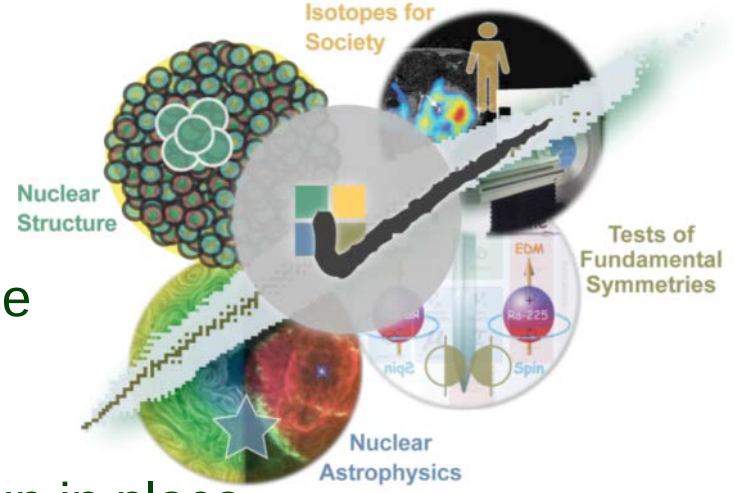
Plan enables continued world-class science for LE Community

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)
- 17-18 Nov 2015 DOE progress review
- 12-14 Jan 2016 DOE operations review
- June 2022 – CD-4, managing to early completion in FY21
  - Tunnel and first surface buildings (ECR and frontend) complete in 2015
    - »First beam from ECR in 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
- NSCL continues to deliver world-leading science
  - Reaccelerated beams ready for users
  - GRETINA second fast-beam science campaign



- Strong, growing, and committed FRIB user group in place
  - NSCL enables pre-FRIB science now
  - Opportunity to test and optimize experimental equipment
  - Working groups serve important role as advocates for new capabilities
    - » GRETA, SECAR, HRS, Decay Station, ISLA, etc.
- Facility operations will eventually transfer from NSF (CCF) to DOE (FRIB)
  - Submission of new 5-year proposal for CCF operations to NSF by 1 October
  - FRIB Operations Review in Jan 2016
  - NSF/DOE Joint Oversight Group (JOG) facilitating transfer