Facility for Rare Isotope Beams Overview

Bradley Sherrill

Director NSCL, FRIB Scientific Director

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.

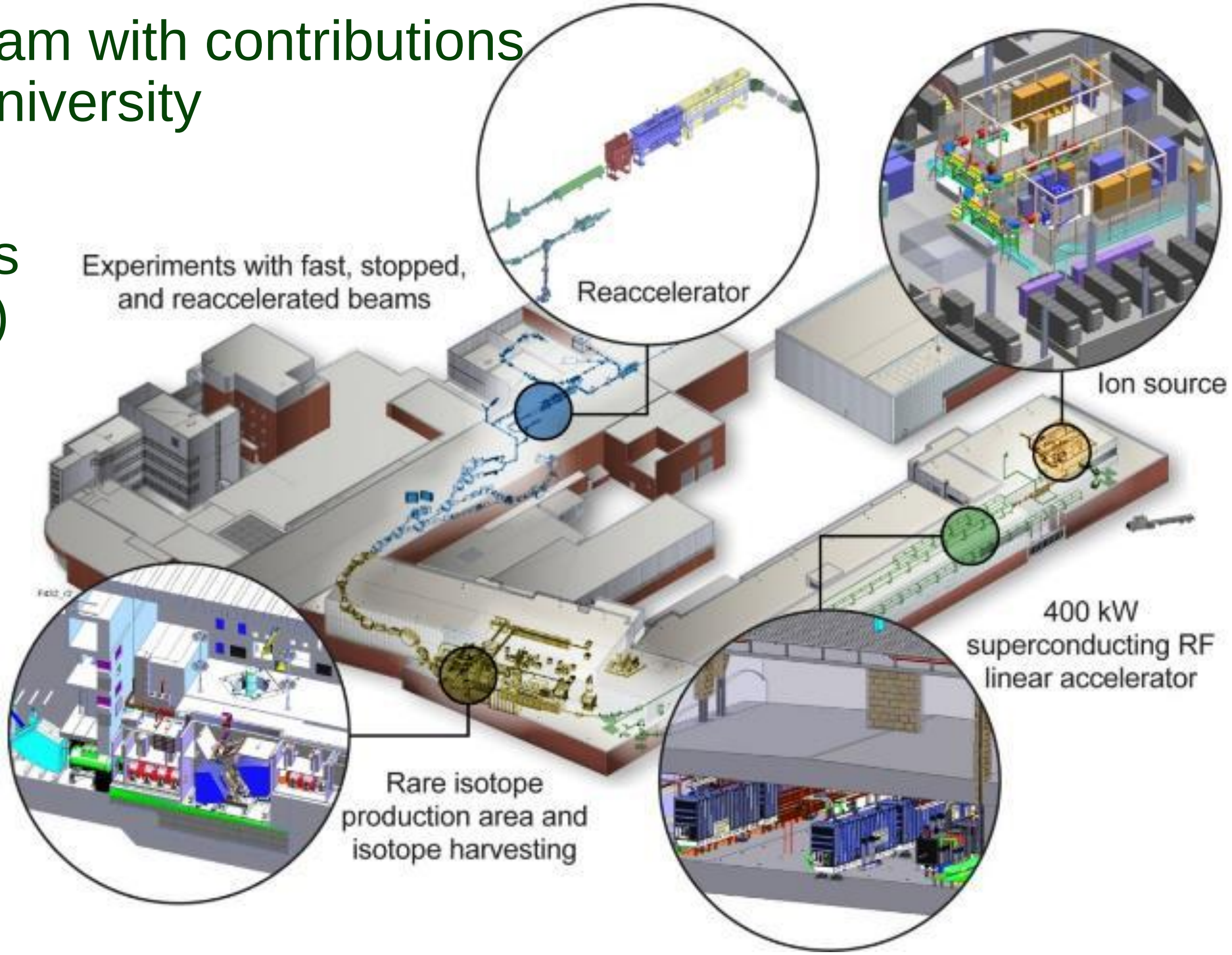
Outline

- Introduction – This workshop is a wonderful opportunity to discuss mutual goals, challenges, and collaboration
- Overview of FRIB
- Challenges
- Capabilities
- Experimental equipment
- Science program - harvesting

Facility for Rare Isotope Beams

Thomas Glasmacher, FRIB Laboratory Director

- Funded by the US DOE– Office of Science Nuclear Physics Program with contributions from Michigan State University
- Key feature is 400 kW beam power for all ions (8pμA or 5×10^{13} ^{238}U/s)
- Separation of isotopes in-flight provides
  - Fast development time for any isotope
  - Beams of all elements and short half-lives
  - Fast, stopped, and reaccelerated beams



FRIB Civil Construction Substantially Complete – Now Installing Accelerator

FRIB construction site March 2017

Web cameras at www.frib.msu.edu

FRIB Timeline

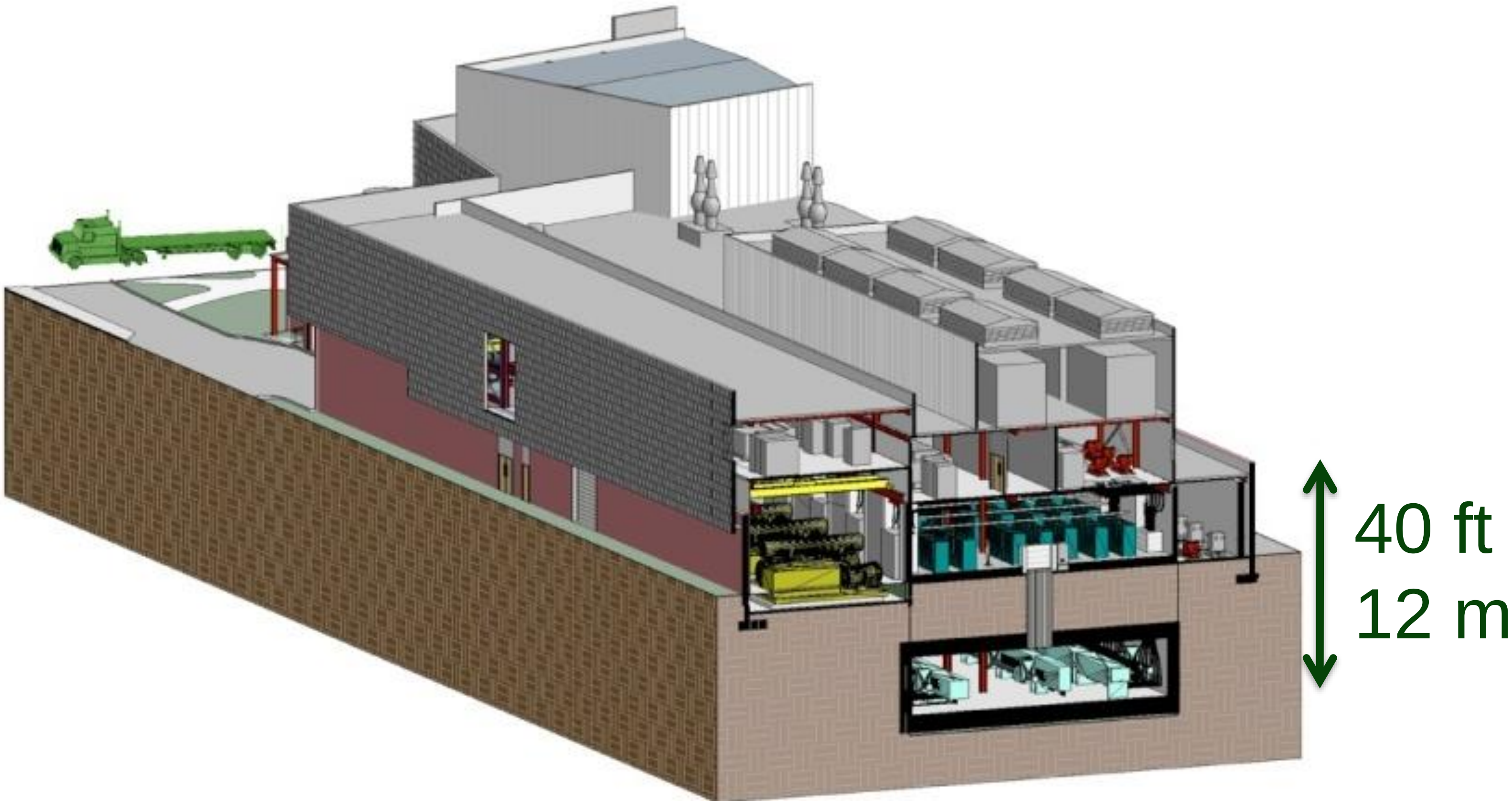
- Early 1990s – Community effort to push construction of a new rare isotope facility (ISOL)
- 2002 NSAC Long Range Plan endorsement
- 2007 NSAC Top priority for new construction
- September 2010 – CD-1 approved
- April 2012 – Lehman review, baseline and start of civil construction
- August 2013 – CD-2 approved (baseline), CD-3a approved (start civil construction pending FY2014 federal appropriation)
- **March 2014 – Start civil construction**
- August 2014 – CD-3b approved (technical construction)
- October 2017 – First accelerated beam in LINAC hall
- by December 2017 – Planned first liquid from FRIB cryoplant
- 2021 – End of NSCL operations
- 2021 – Early completion goal
- **June 2022 – CD-4 (scheduled project completion)**

FRIB Partners

- Argonne National Laboratory
  - Liquid lithium charge stripper; Stopping of ions in gas; Fragment separator design; Beam dynamics; SRF
- Brookhaven National Laboratory
  - Radiation resistant magnets; Plasma charge stripper
- Fermilab
  - Diagnostics
- Jefferson Laboratory
  - Cryogenics; SRF
- Lawrence Berkeley National Laboratory
  - ECR ion source; Beam dynamics
- Oak Ridge National Laboratory
  - Target facility; Beam Dump R&D; Cryogenic Controls
- Stanford National Accelerator Lab
  - Cryogenics
- Sandia
  - Production target
- Budker Inst. of Nuclear Physics (Russia)
  - Production target
- GANIL (France)
  - Production target
- GSI (Germany)
  - Production target
- IMP of CAS (China)
  - Magnets
- INFN Legnaro (Italy)
  - SRF
- KEK (Japan)
  - SRF technology, SC solenoid magnets
- RIKEN (Japan)
  - Charge strippers
- Soreq (Israel)
  - Production target
- Tsinghua University (China)
  - RFQ
- TRIUMF (Canada)
  - SRF, beam dynamics

FRIB Accelerator Building

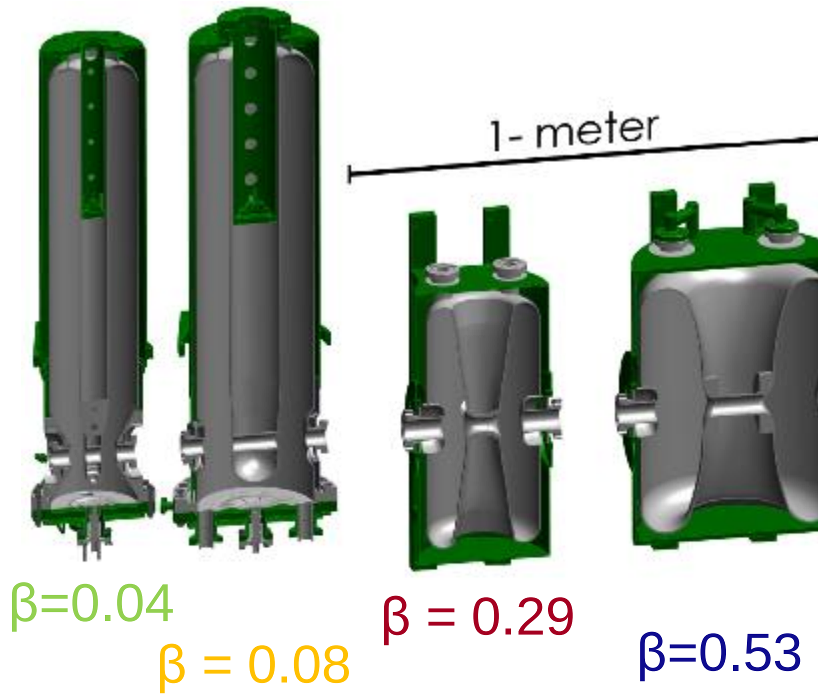
J. Wei (head of FRIB Accelerator Division), P. Ostroumov, J. Yamazaki, K. Saito, et al.

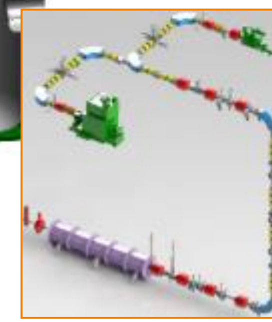


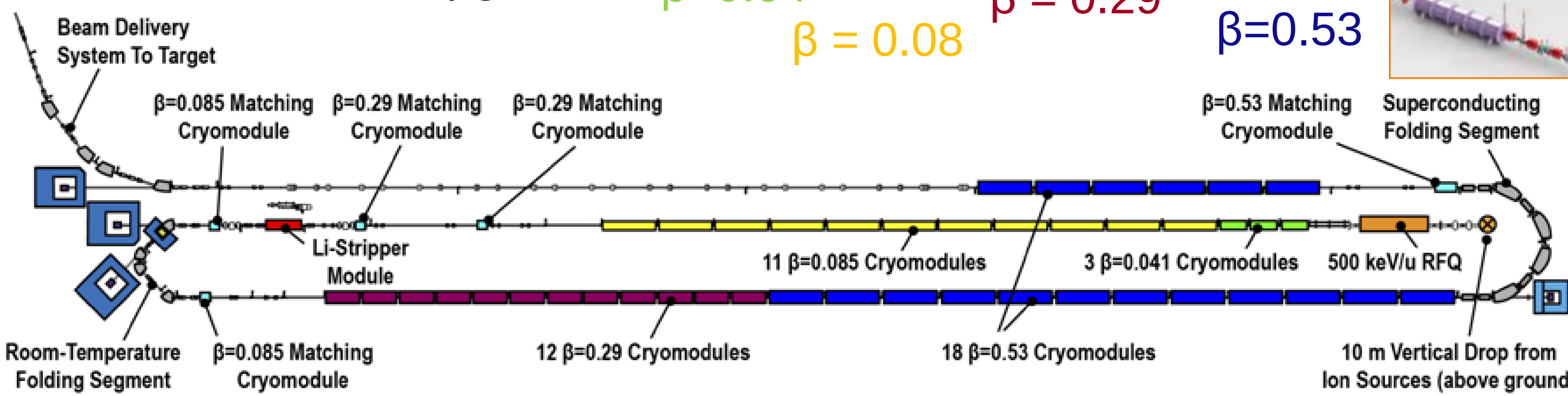
FRIB Superconducting LINAC

J. Wei (head of FRIB Accelerator Division), P. Ostroumov, J. Yamazaki, K. Saito, et al.

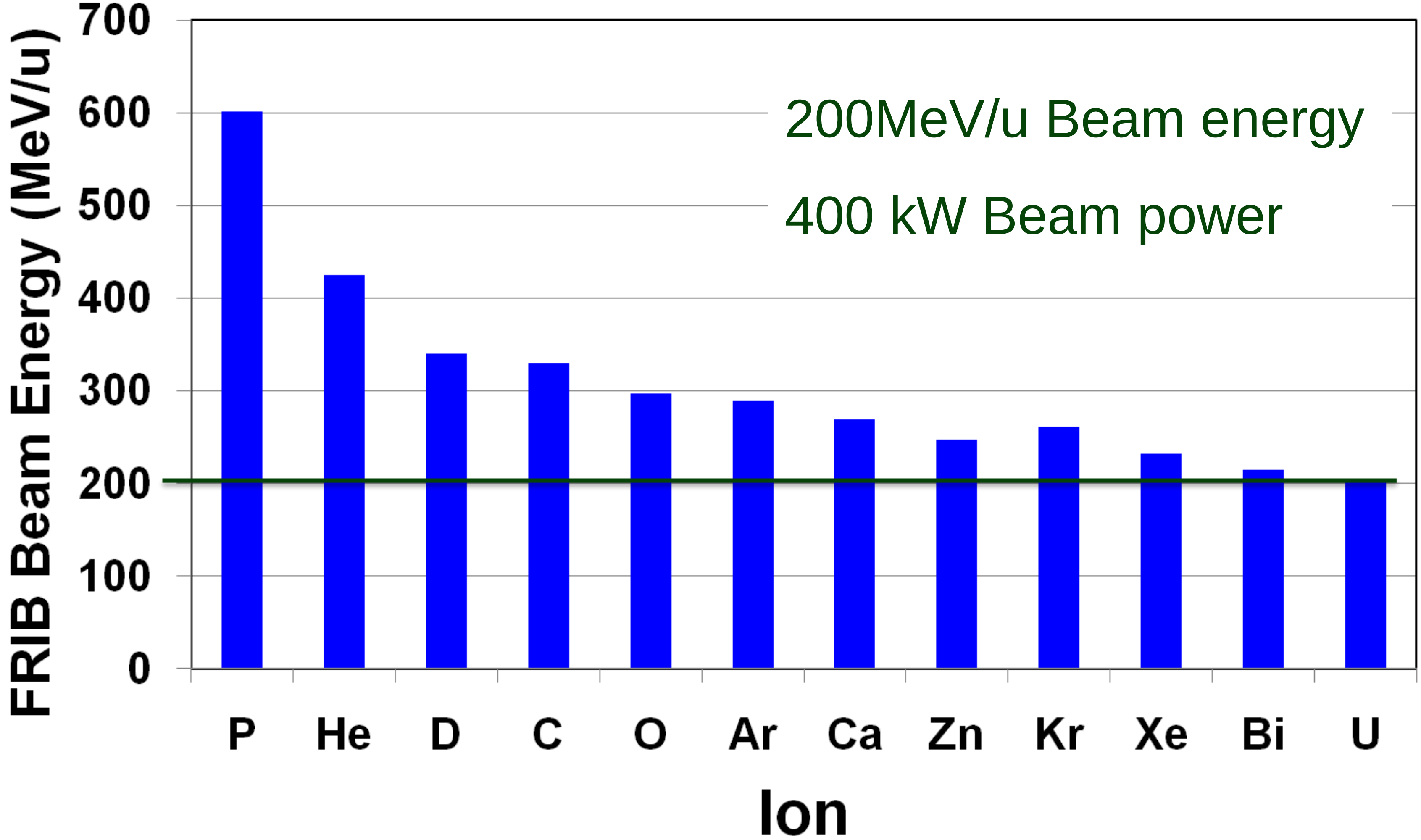
- Accelerate ion species up to ^{238}U with energies of at least 200 MeV/u
- Provide beam power up to 400kW
- Energy upgrade to 400 MeV/u for ^{238}U by filling vacant slots with 12 SRF cryomodules
- Provisions for ISOL upgrade







FRIB Accelerator Performance



Cryomodule Production, Testing, and Installation Underway

Chemical processing of cavities

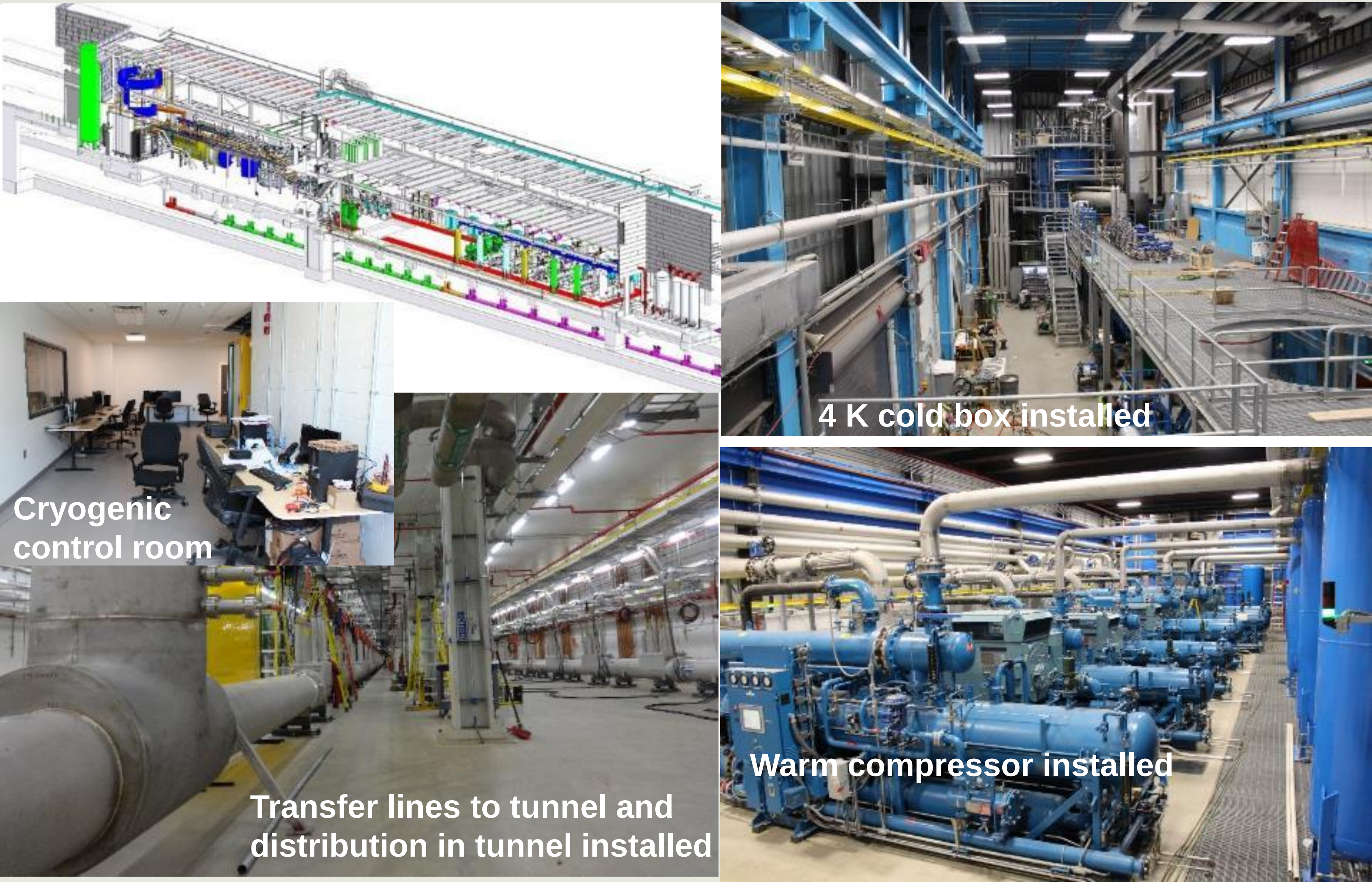
Coldmass assembly in clean room

Cryomodule assembly (four of five bays)

The three β=0.041 cryomodules installed and being cabled up in the FRIB tunnel

FRIB Cryoplant Overview

Scheduled to Make 4K Liquid in 2017, 50% larger than SNS Cryogenic Plant

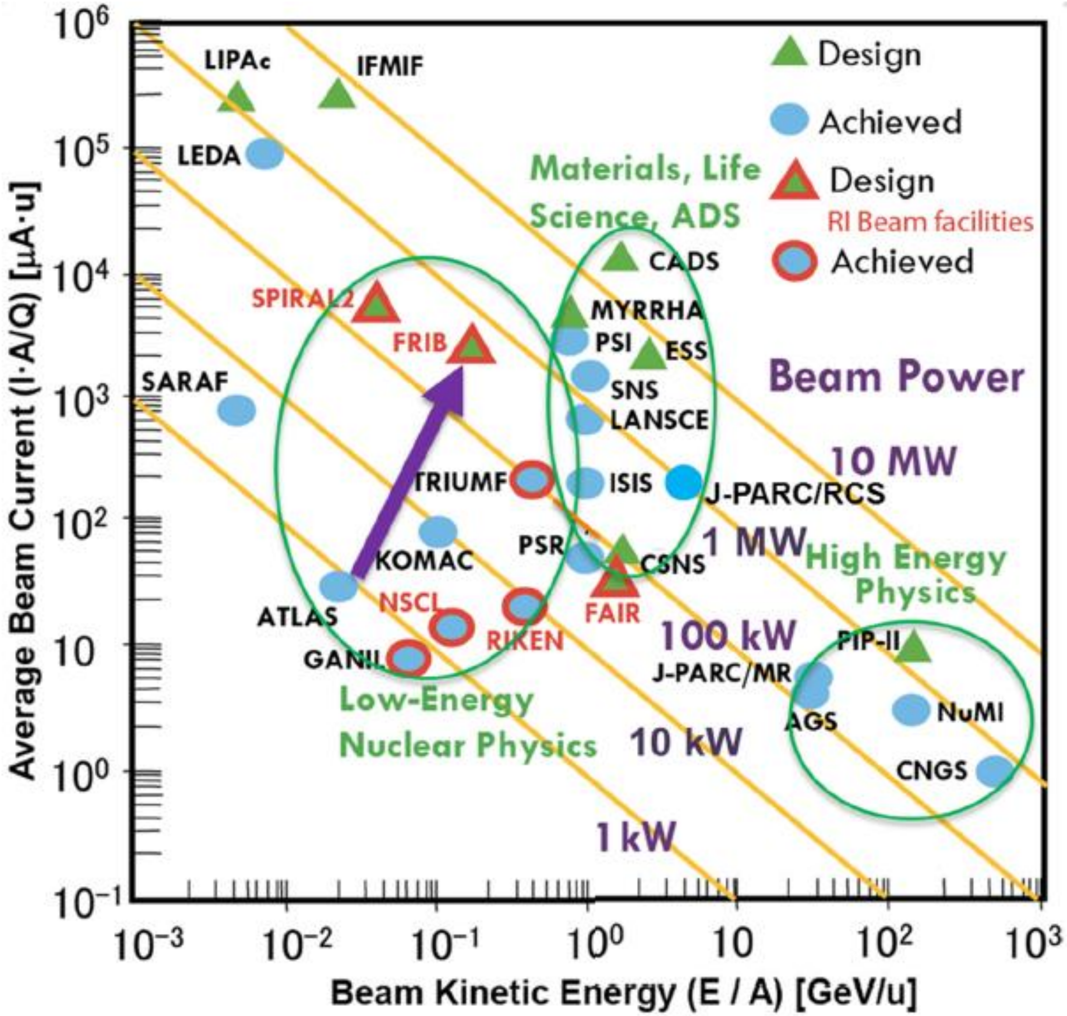


Challenge of FRIB – High Power Accelerators

- Beam Power

P[kW] = I [μA] x E [GeV/u] x A

- FRIB operation will be challenging like facilities such as SNS or JPARC
- FRIB will have multiple different beams
- FRIB may change beams every couple weeks



Y. Yamazaki

FRIB Year-One Beams and Development Plan

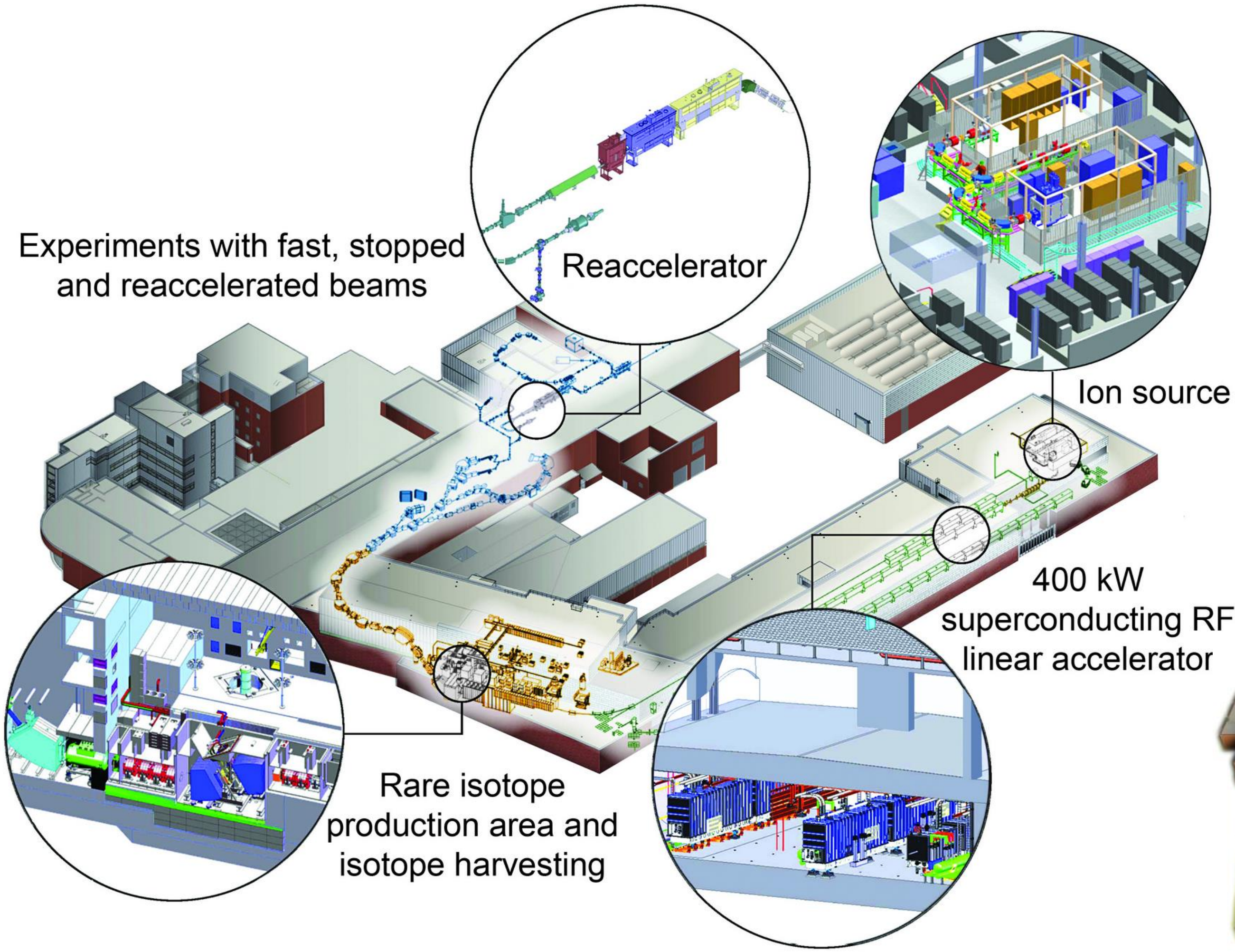
J. Wei, J. Yamazaki et al.

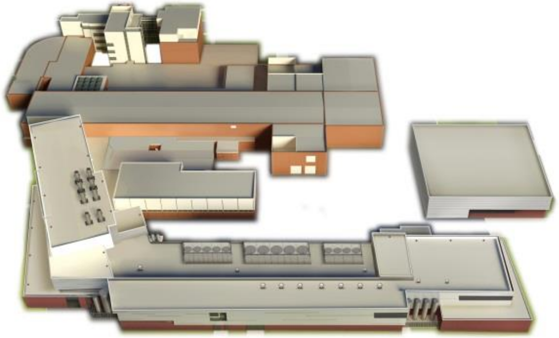
- ^{36}Ar and ^{86}Kr will be developed as part of FRIB Project, primary beams beyond ^{36}Ar and ^{86}Kr will be developed during early operations and operations
- **Additional beams will be added each year, power increased over 5 years**
- Proposal is to run 32 weeks/y for science, but will take time to reach that due to complexity of accelerating multiple charge states
- Beam losses will limit power ramp-up, mitigation takes time and experience
- Past experience for proton machines, SNS and J-PARC, indicates steep learning curve

Year 1 Beams	Notional Weeks Year 1
^{238}U	6
^{48}Ca	3
^{78}Kr	2
^{82}Se	3
^{124}Xe	1
^{18}O	-
^{86}Kr	4
^{16}O	-
^{36}Ar	-

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

FRIB Facility Overview

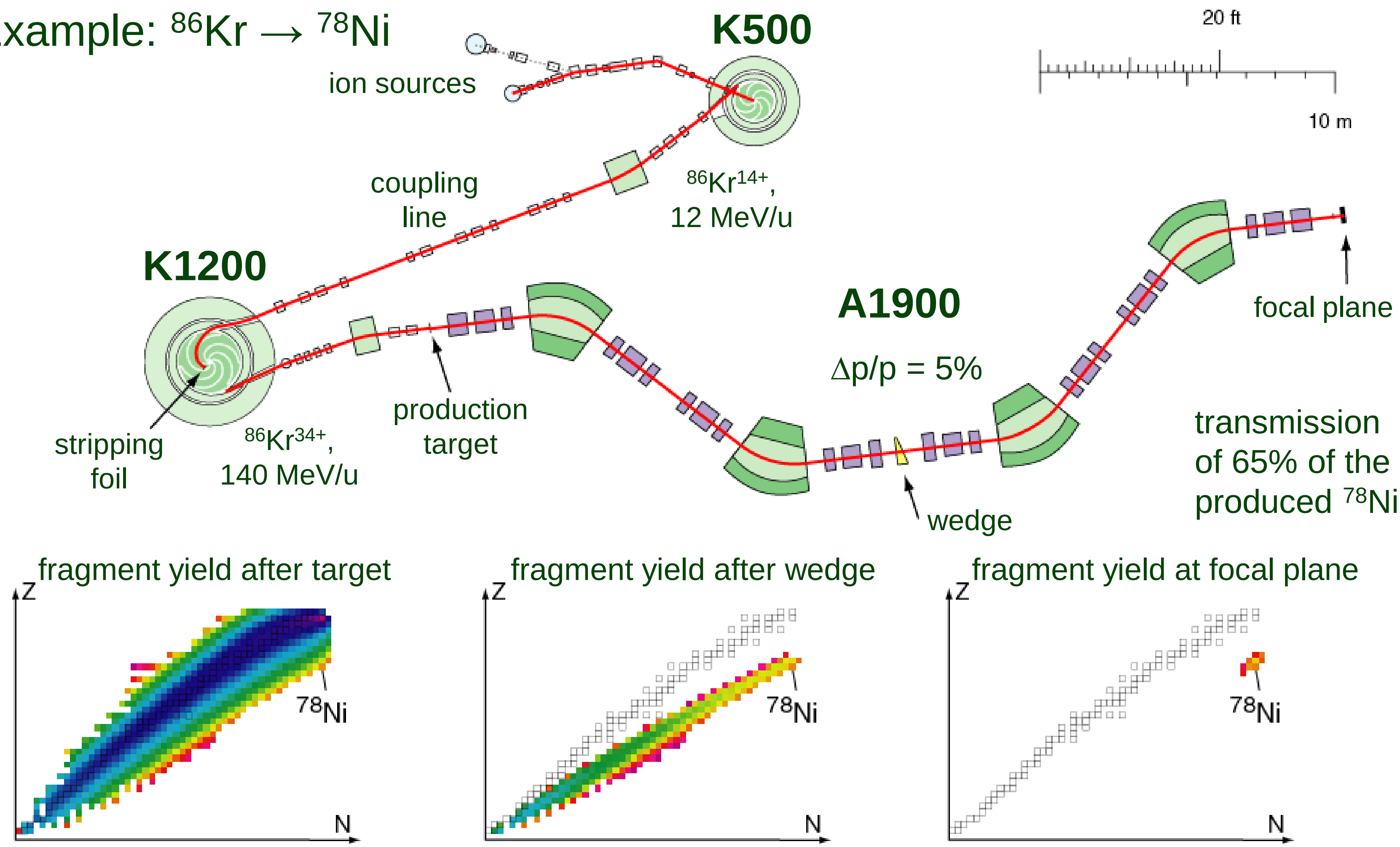




In-Flight Production of Rare Isotopes at NSCL

D.J. Morrissey, B.M. Sherrill, Philos. Trans. R. Soc. Lond. Ser. A. Math. Phys. Eng. Sci. 356 (1998) 1985.

Example: $^{86}Kr \rightarrow {}^{78}Ni$

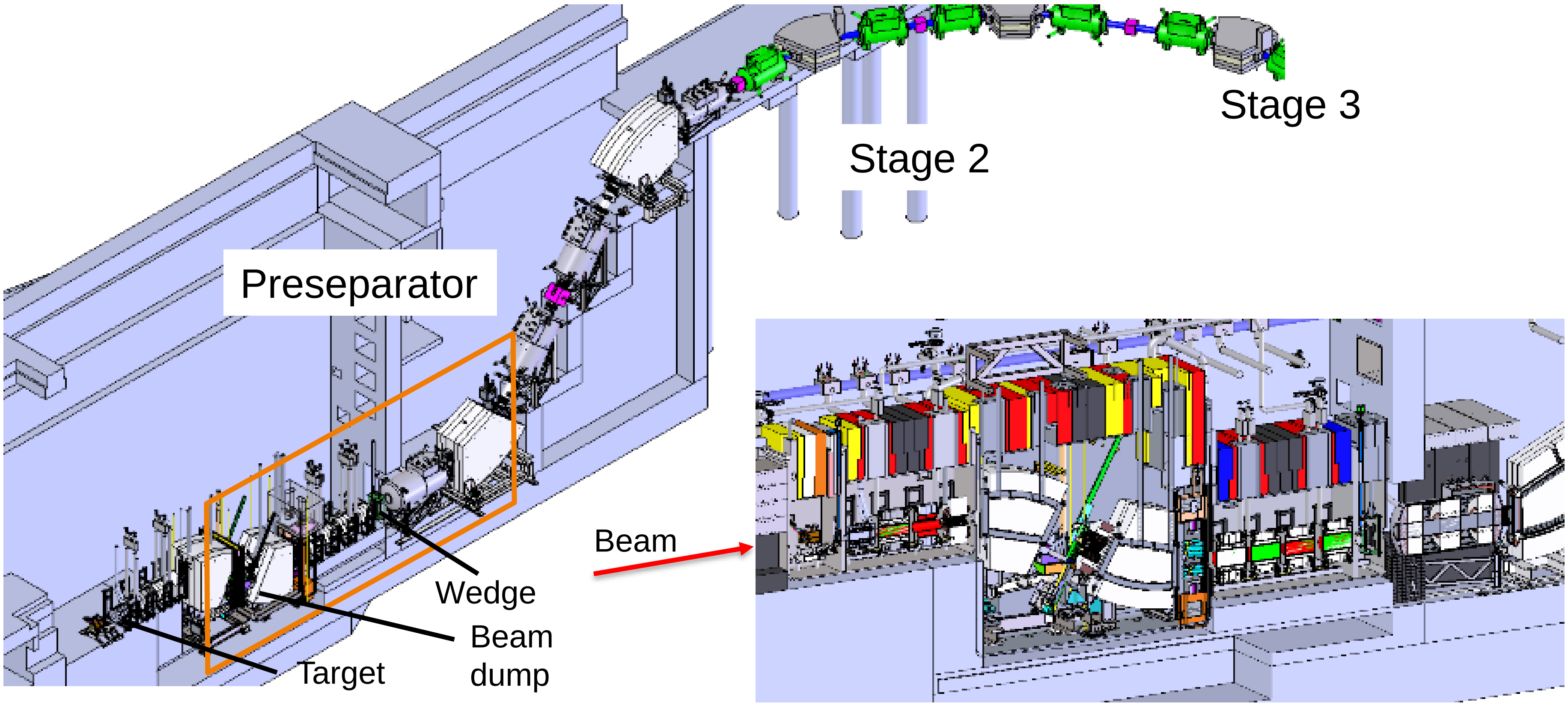


The same concept will be used at FRIB, but with a new LINAC and separator

FRIB Fragment Separator

M. Haussmann, G. Bollen (FRIB Experimental System Division), et al.

- Three stage fragment separator for production and delivery of rare isotope beams (high power preseparator and high resolution stage 2 and 3)
- Must be able to accommodate 400 kW and allow ion-by-ion ID

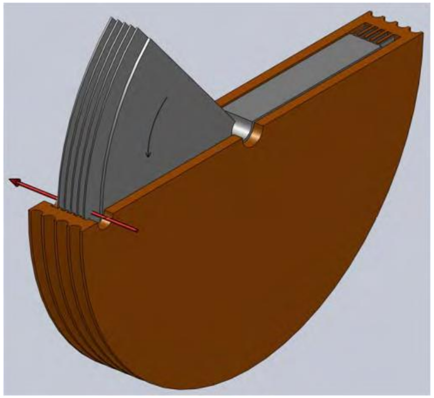


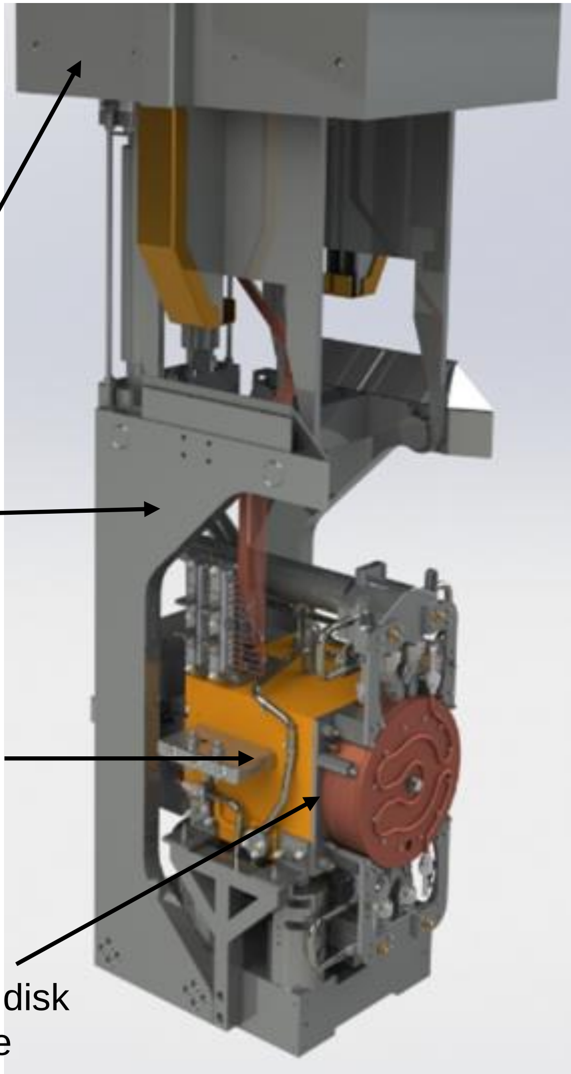
Vessels for Rare Isotope Production Fabricated, Installed and Leak Checked

Rotating Carbon Production Target

F. Pellemoine et al. (W. Mittig)

- Multi-slice rotating graphite disk target
  - Capable of withstanding 400 kW primary beam
  - 30 cm diameter disks rotating at 5000 rpm
  - High power density: ~ 20 - 60 MW/cm^3
- Target module on track for on-schedule completion
  - 99% of target module parts ordered - 65% received
- Additional early operations target will be developed
  - “Ladder” with multiple targets, blank, and viewer screen to be exchanged with rotating target disk module

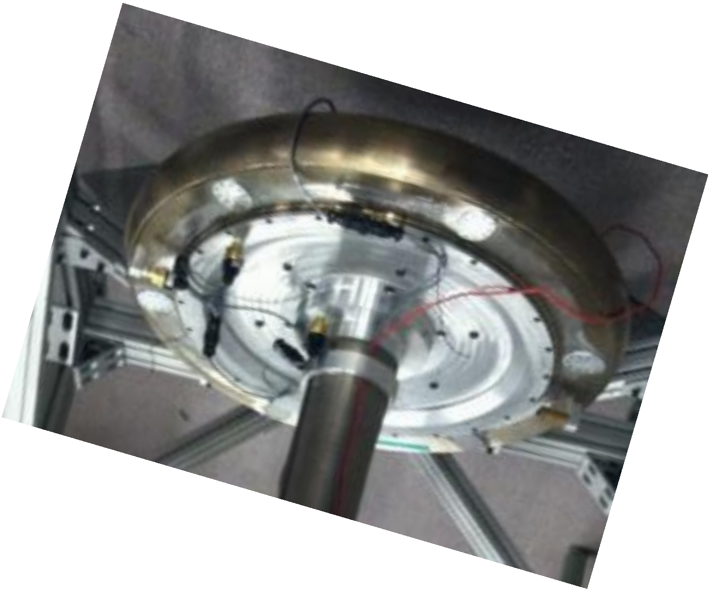




Beam Dump Status: Rotating Drum with Water

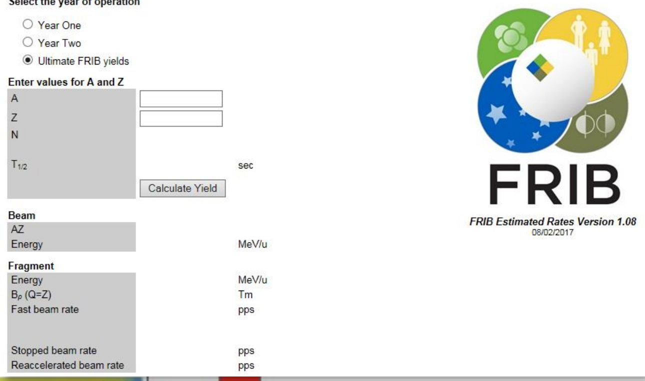
F. Pellemoine et al. (W. Mittig)

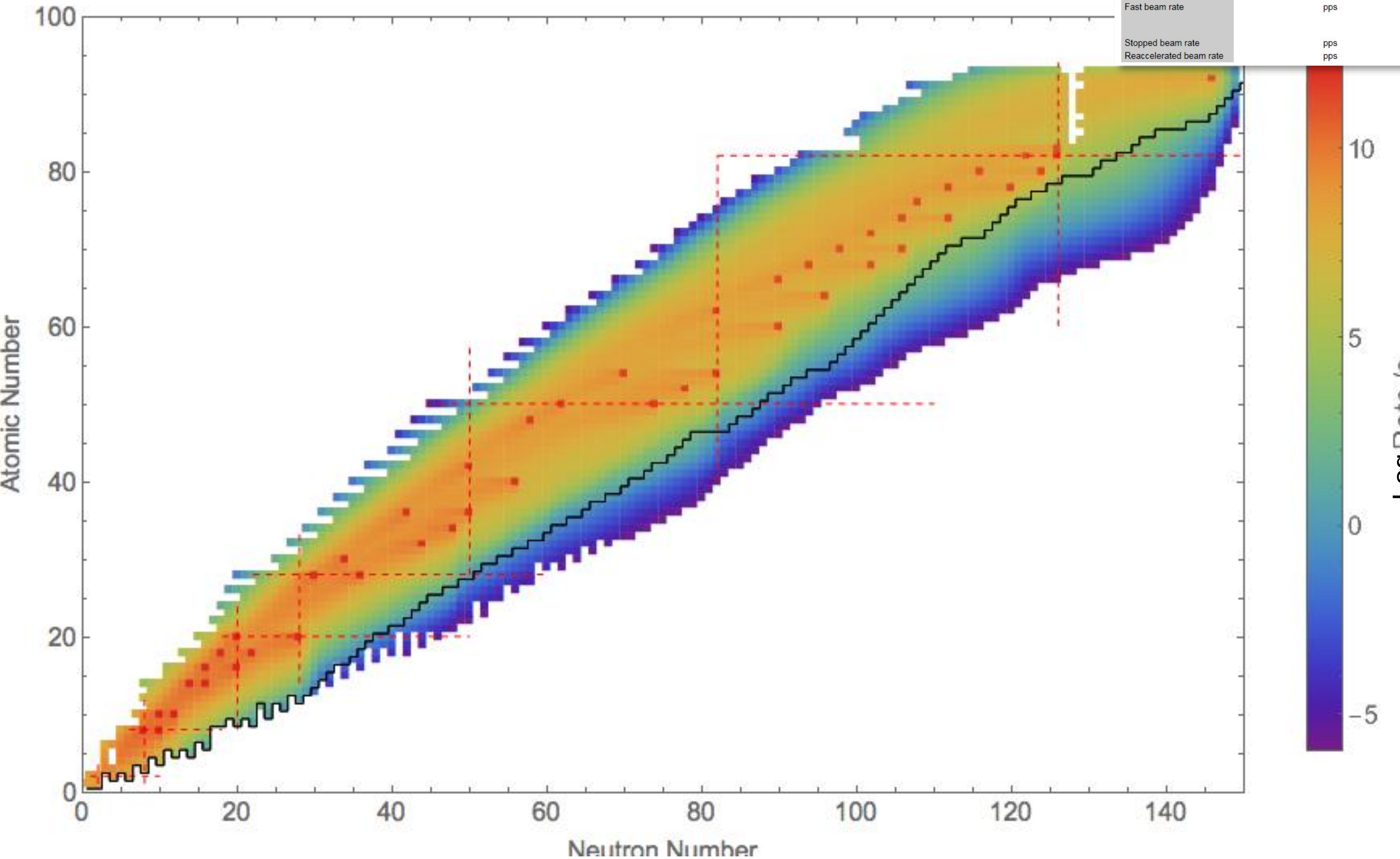
- Thin-walled water-filled rotating drum
  - Water cools drum shell and absorbs up to 325 kW of beam power
- Additional static beam dump for commissioning and first years of operation to be developed
- Working on harvesting of isotopes from the water – White Paper in preparation (G. Severin et al.)



FRIB Estimated Beam Rates

https://groups.nscl.msu.edu/frib/rates/fribrates.html





O. Tarasov, et al. EPAX 2.15

Note: Possibility to collect unused isotopes for target material for (n,γ) studies

Users Engaged and Ready for Science

www.fribusers.org

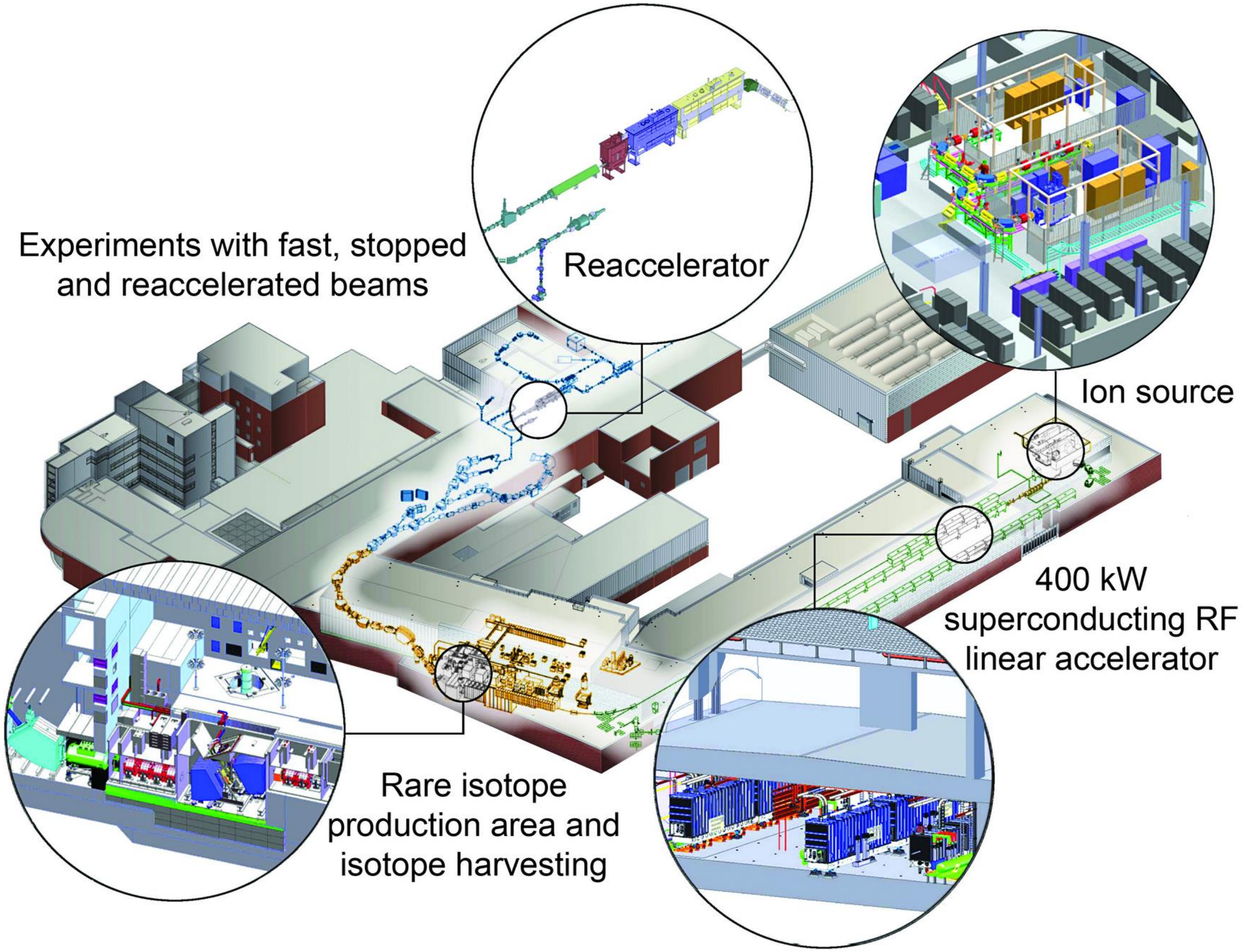
- Users are organized as part of the independent FRIB Users Organization (FRIBUO)
  - Chartered organization with an elected executive committee
  - Approximately 1,400 members (250 Institutions world wide, 51 countries) as of September 2017
  - 19 working groups on instruments
- Yearly User Meeting
- Science Advisory Committee Advice on User Initiatives
  - 2011 Review of equipment initiatives
  - 2012 Review of FRIB design
  - 2013 Review of equipment working group progress
  - 2015 Review of equipment priorities
  - 2016 Reviewed day-1 science program and major equipment status
  - Next SAC meeting 2018 (Equipment)
  - First PAC about one year prior to operation

MSU 2011

ANL 2017

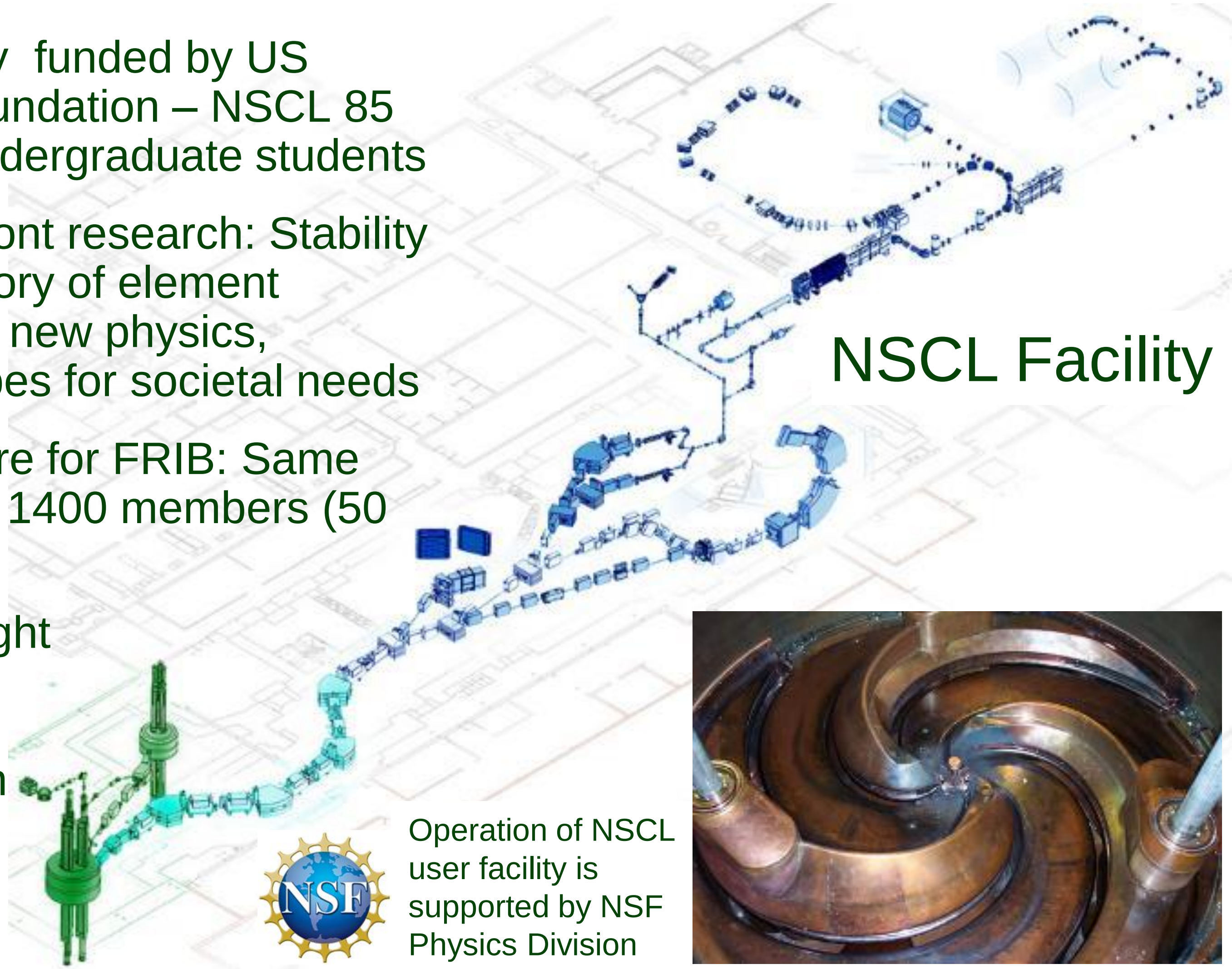
Notre Dame 2016

FRIB Facility Overview



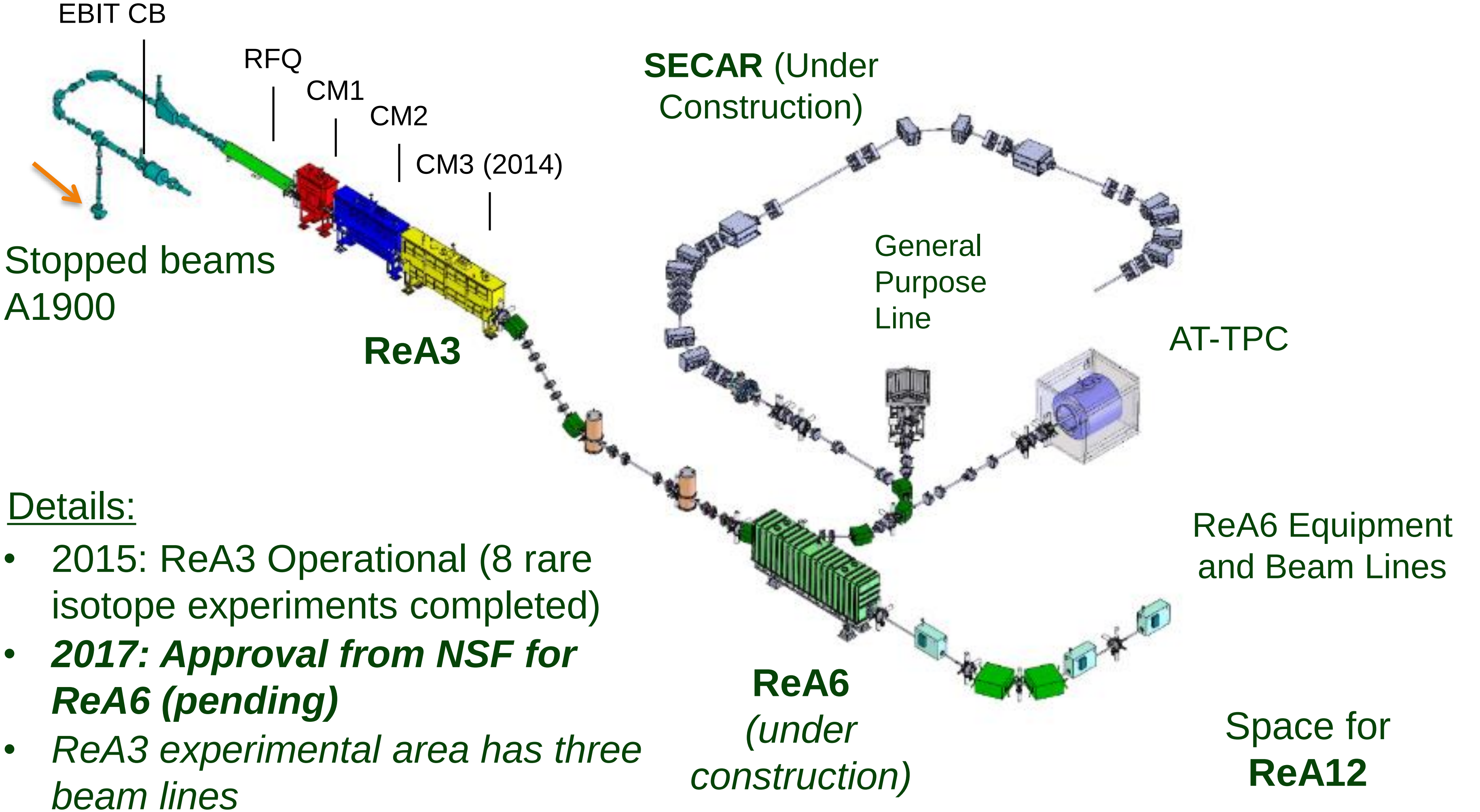
Current Facility – National Superconducting Cyclotron Laboratory (NSCL)

- National User Facility funded by US National Science Foundation – NSCL 85 graduate and 120 undergraduate students
- NSCL enables forefront research: Stability of atomic nuclei, history of element formation, search for new physics, applications of isotopes for societal needs
- Opportunity to prepare for FRIB: Same user group FRIBUO, 1400 members (50 nations involved)
- First system for in-flight separation and reacceleration of rare isotopes ReA3, which became operational in 2015



Operation of NSCL user facility is supported by NSF Physics Division

ReA3 (soon ReA6) at NSCL



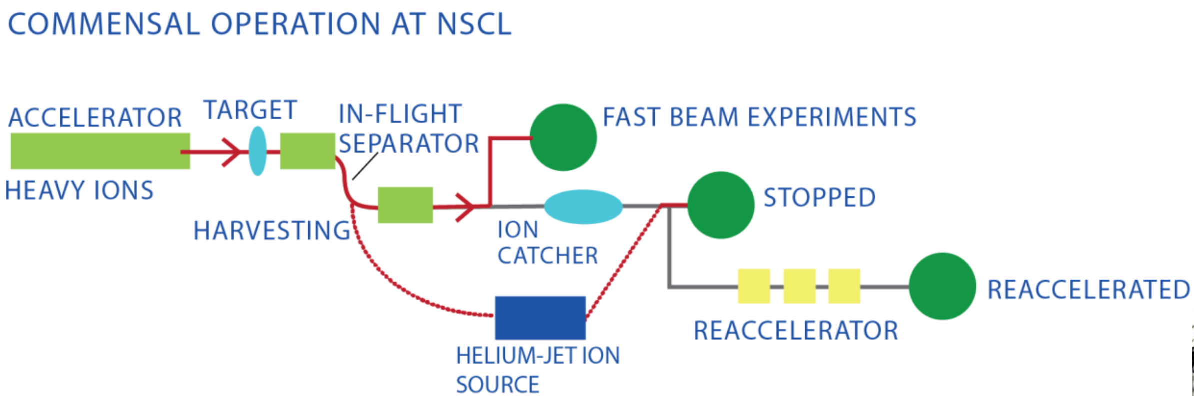
Details:

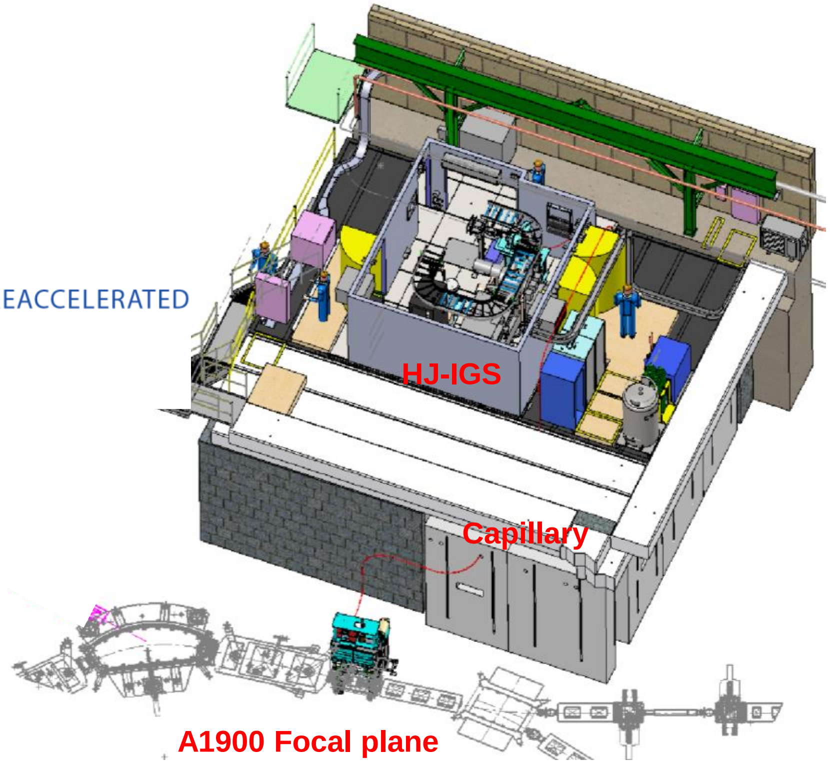
- 2015: ReA3 Operational (8 rare isotope experiments completed)
- ***2017: Approval from NSF for ReA6 (pending)***
- *ReA3 experimental area has three beam lines*

Helium-Jet Ion-Guide System (HJ-IGS) for commensal (multi-user) operation at NSCL

MRI

- Rare isotopes that would otherwise be lost are caught in a high-pressure cell filled with a helium-aerosol mixture placed off-axis in the fragment separator
- Collected 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 can be used in the stopped and reaccelerated experimental areas

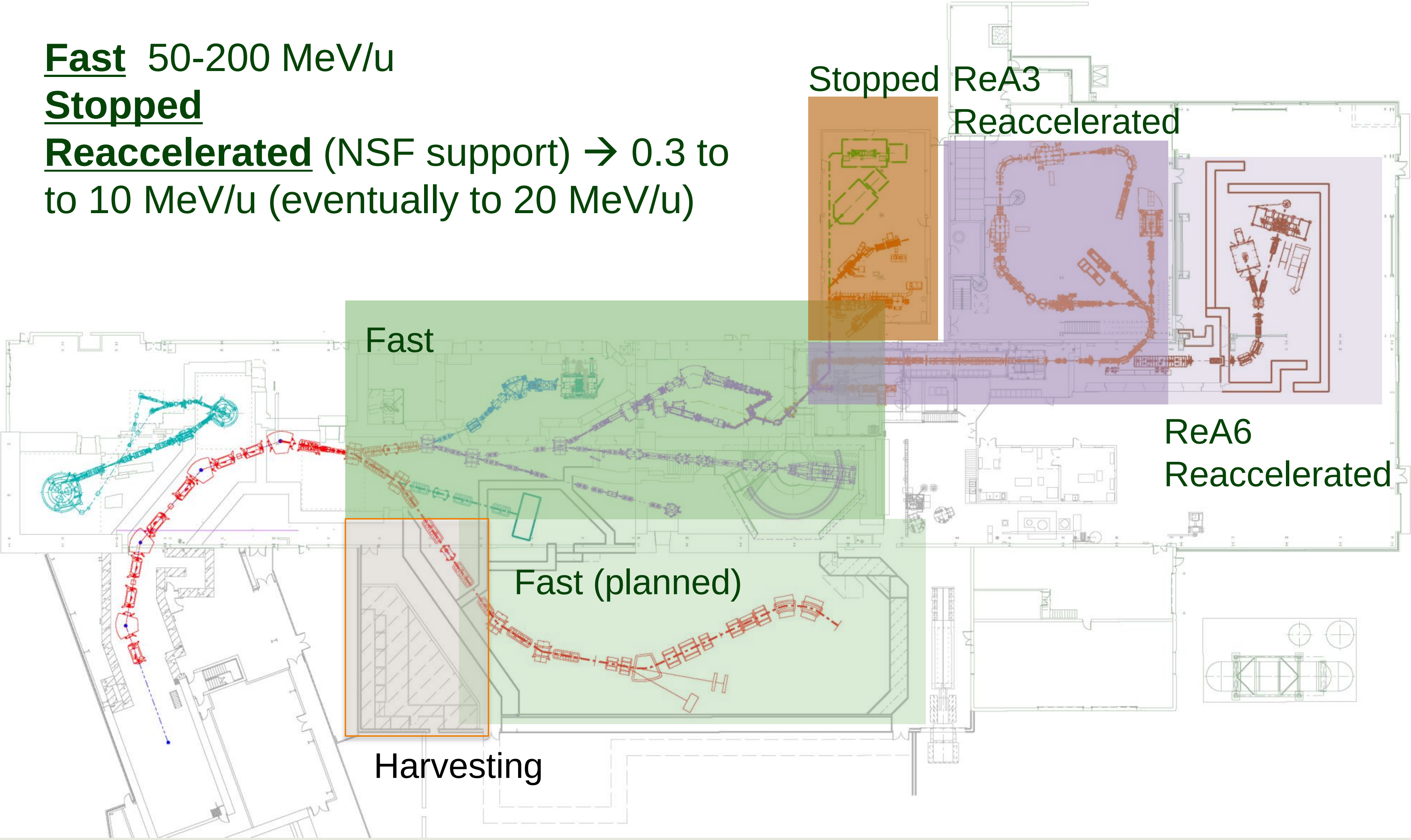




FRIB Experimental Capabilities

Radioactive Ion Beams are needed/available in three energy domains

Fast 50-200 MeV/u
Stopped
Reaccelerated (NSF support) → 0.3 to to 10 MeV/u (eventually to 20 MeV/u)



FRIB Equipment Status – Not Complete

Bold Funded, Blue FRIB SAC priority

Item	Status	Item	Status
GRETINA	**Operational**	**Penning Traps**	**Operational**
GRETA	CD1 2017	Scintillator Arrays	Conceptual stage
SECAR	**Completed 2020**	Silicon Arrays	**Operational** and Conceptual stage
Recoil Separator ReA12	White paper in 2014	SiEFUS	NSF MRI
High Rigidity Spectrograph	Preliminary design and white paper 2014	Atom Traps	Under development at ANL/TRIUMF
SOLARIS	DOE ANL, Planning	Harvesting	White Paper 2017
MONA/LISA	**Operational**	**AT-TPC**	**Operation in 2015**
Decay Station	**Existing Equipment**; White paper 2017	**ANASEN**	**Operational**
BECOLA	**Operational**	**SUN**	**Operational**
CRIS	NSF MRI	**CAESER**	**Operational**
VANDLE/LENDA	**Operational**	**ReA3 (3-6 MeV/u)**	**Operation in 2015**
EOS Detector	**TPC at RIKEN;** conceptual	**ReA6 (6-10 MeV/u)**	**NSF Approved 2017**

Future Equipment Opportunities

- Fundamental symmetries traps
- Storage Rings
- TPC for EOS studies
- Active target for high energy
- …

Blue/Green NSCL
Red FRIB
Light Green - Expansion

FRIB Scientific Program

Structure

Applications

Nuclear Astrophysics

Fundamental Symmetries

FRIB

Application of FRIB Isotopes

- FRIB offers fast development for 1000s of isotopes (via harvesting in parallel to normal operation)
- Isotopes extracted from the water of the beam dump or in catchers located along the fragment separator (offers parallel operation)
- 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
  - Cancer therapy of hypoxic tumors based on ^{67}Cu treatment/^{64}Cu dosimetry
- Tracers for Marine Studies (^{32}Si), Condensed Matter (^{8}Li), industrial tracers (^{7}Be, ^{210}Pb, ^{137}Cs, etc.), …
- Data for advance reactor design and destruction of nuclear waste

Summary

- FRIB construction is going well and is scheduled to be completed by 2022 (Early completion in 2021)
- Key features of FRIB include 400 kW primary beams, fast-stopped-reaccelerated beams of rare isotopes
- Described FRIB LINAC, cryoplant, target, beam dump, separator, experimental areas and equipment
- FRIB will enable a broad science program: Structure, Nuclear Astrophysics, Fundamental Symmetries, and Applications of Isotopes