NP Low Energy Facilities and the SBIR/STTR Program

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Facility for Rare Isotope Beams

Michigan State University

FRIB

DOE NP SBIR/STTR Exchange Meeting, August 7-8, 2018

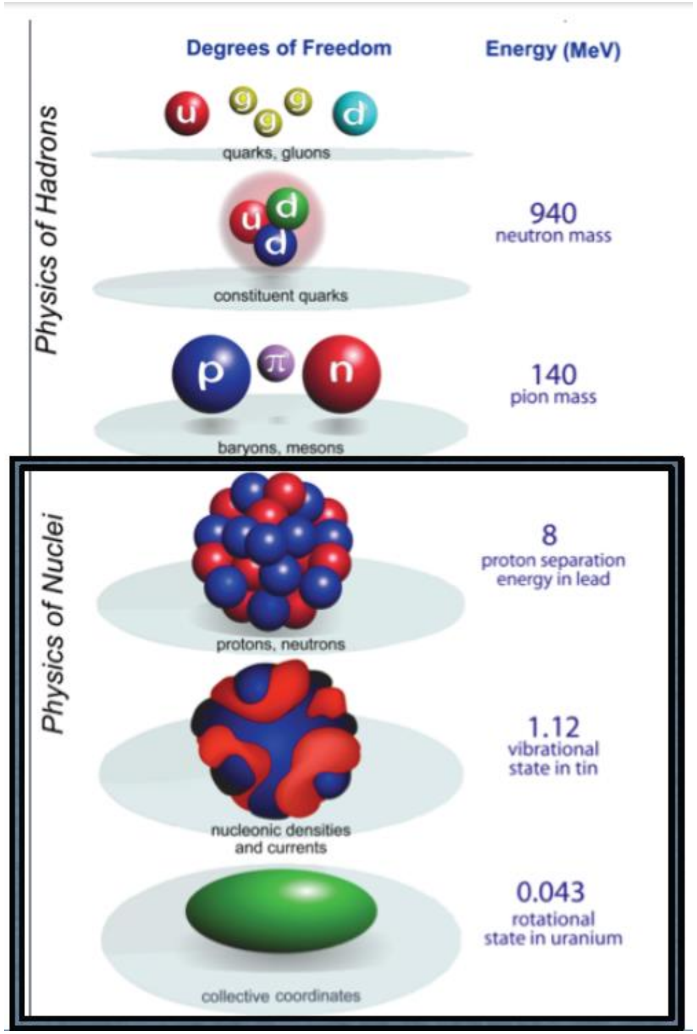
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Context
- Science
- Major Facilities
- Advanced Instrumentation

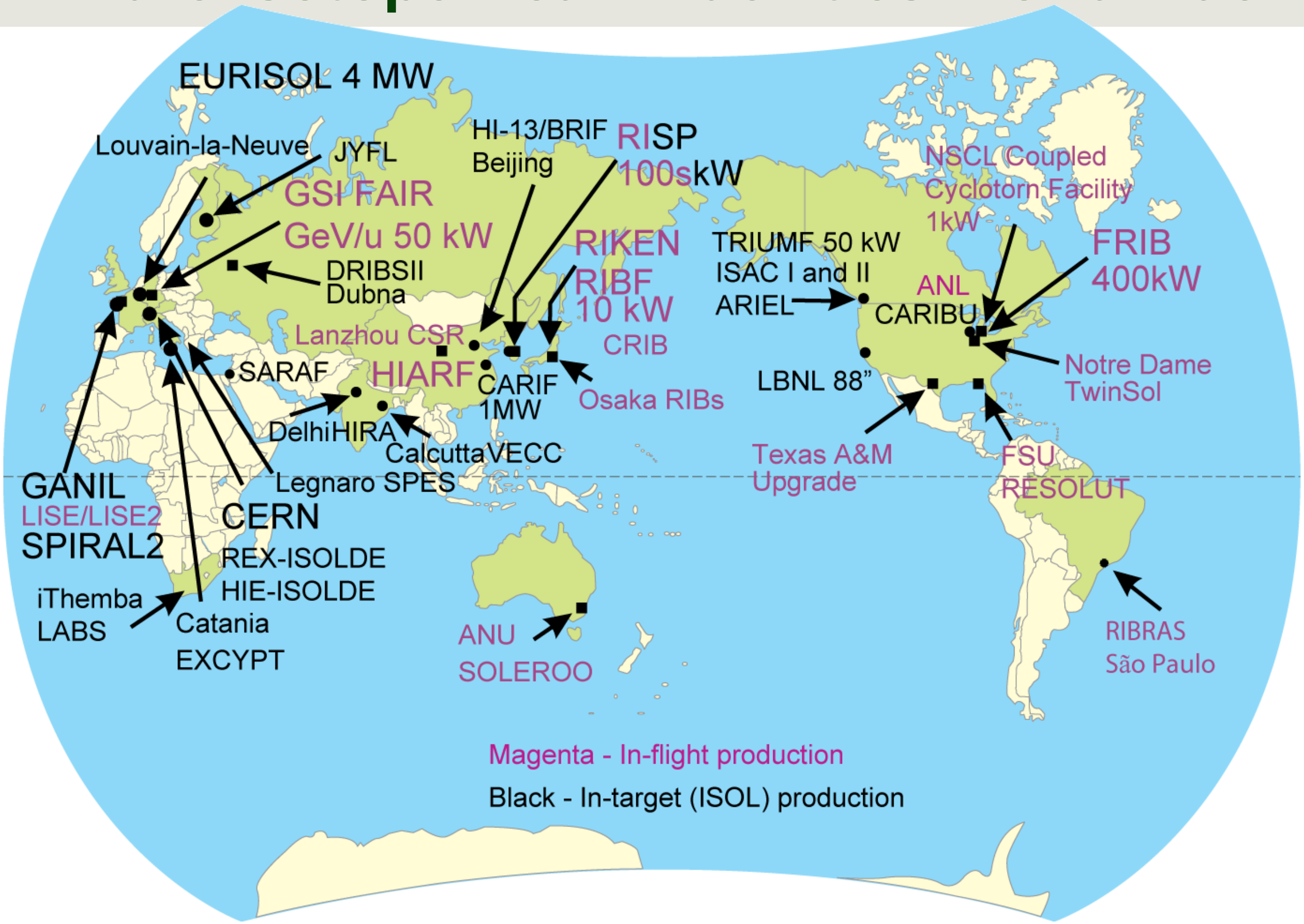
- Acknowledgment
  - Materials provided by G. Savard (ANL), H. Crawford (LBNL), and others

Low Energy Nuclear Physics



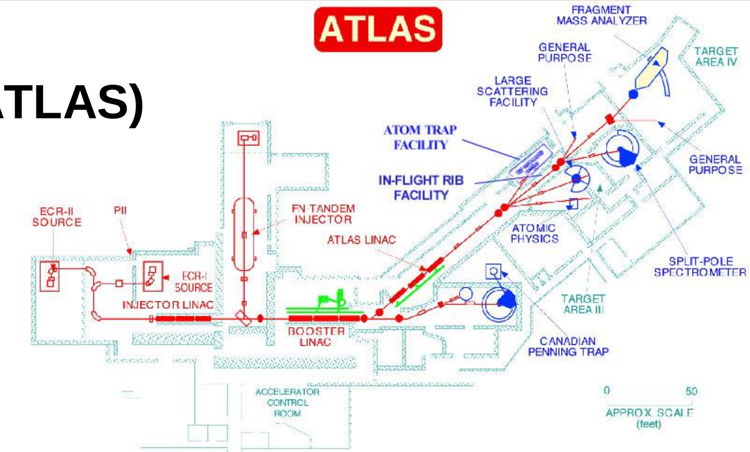
- Refers to the energy scale of the science
  - Of order few MeV (nuclear binding scale)
- Encompasses the physics governing nuclear decays and how they combine to create elements.
- It is where our field most directly impacts and touches our lives (energy, medicine, security)
- Provides a unique way to study fundamental properties of our universe (e.g. neutrinos)

Low Energy Nuclear Physics
Rare Isotope Beam Facilities Worldwide

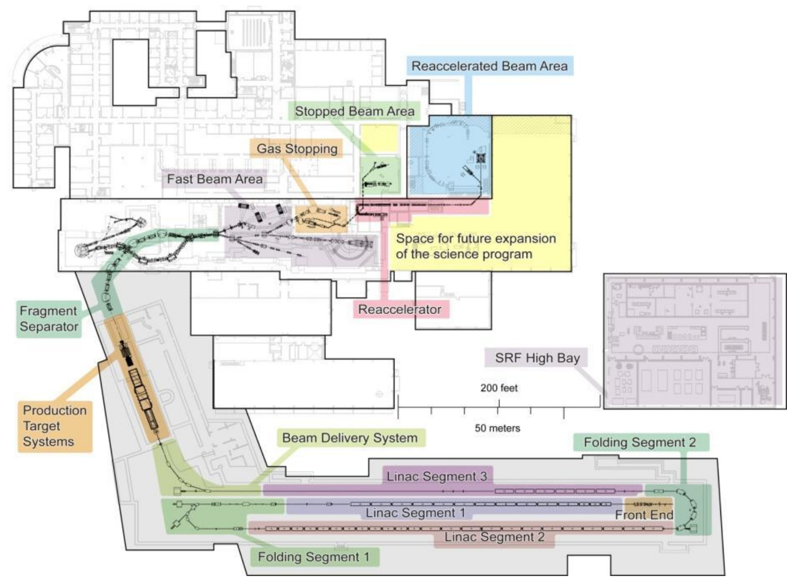


Low Energy Nuclear Physics Facilities

- DOE National User Facilities
  - **Argonne Tandem-Linac Accelerator System (ATLAS)** (http://www.phy.anl.gov/atlas/facility)
    - » High intensity stable beams
    - » Limited radioactive beam program with stopped, re-accelerated, and in-flight beams



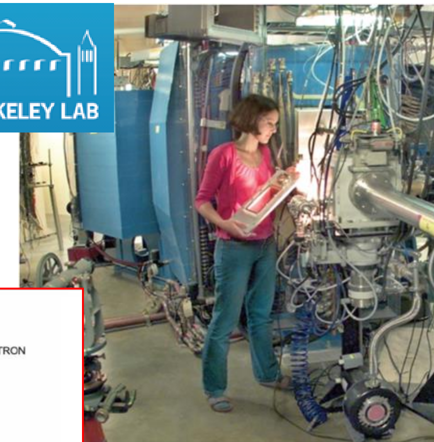
  - **Facility for Rare Isotope Beams (FRIB) at MSU** (http://frib.msu.edu)
    - » World-leading facility under construction at MSU
    - » 400 kW heavy-ion SRF linac; >200 MeV/u
    - » Rare isotopes beams produced by fragmentation and in-flight fission
    - » Fast, stopped, and reaccelerated beams

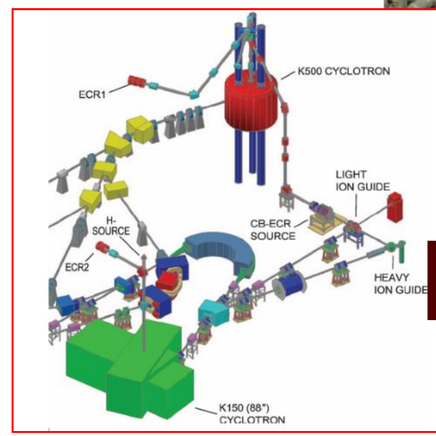


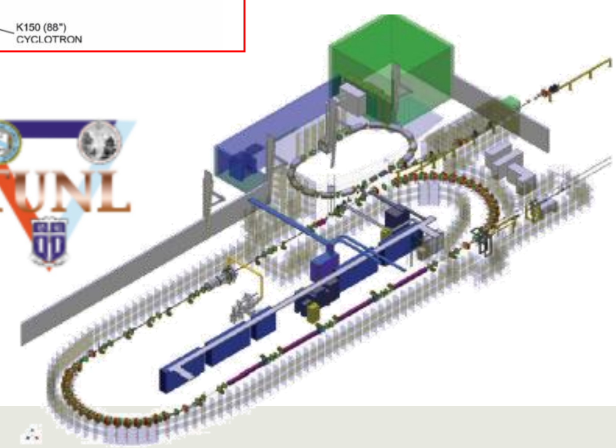
- NSF User Facility
  - National Superconducting Cyclotron Laboratory (NSCL) at MSU (http://nscl.msu.edu)
  - In-flight rare isotope beam production
  - Fast, stopped, and re-accelerated beams

Low Energy Nuclear Physics Facilities

- Other DOE facilities (local use)
  - **LBNL 88-Inch Cyclotron** (http://cyclotron.lbl.gov)
    - » Basic and applied research with stable beams
  - **Texas A&M Cyclotron Institute** (http://cyclotron.tamu.edu)
    - » Nuclear physics research with stable and radioactive re-accelerated beams
  - **Triangle-Universities Nuclear Laboratory** (TUNL) (http://www.tunl.duke.edu)
    - » High Intensity Gamma Source (HIGS)
    - » Laboratory for Experimental Nuclear Astrophysics
    - » Tandem Van de Graaff accelerator

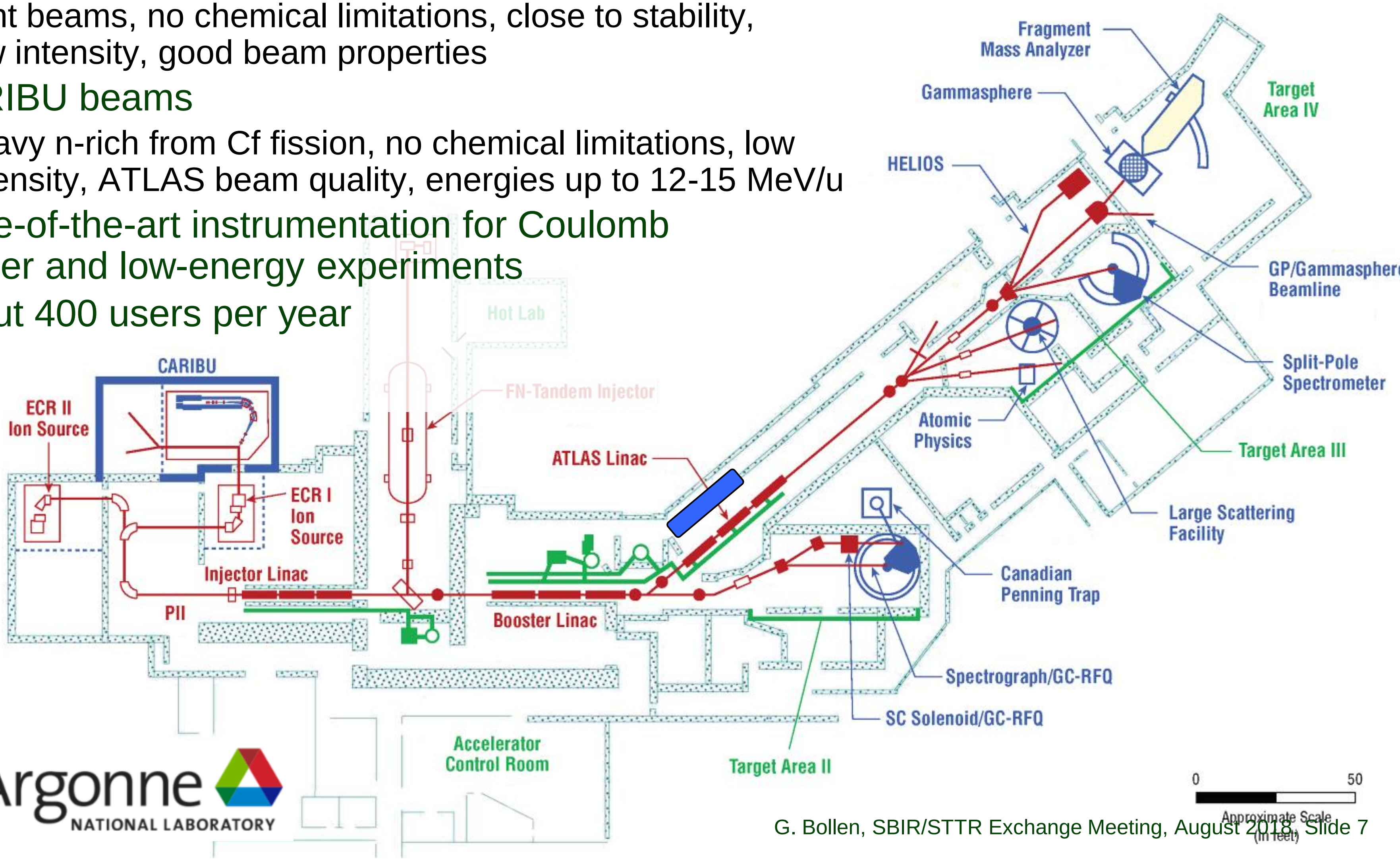




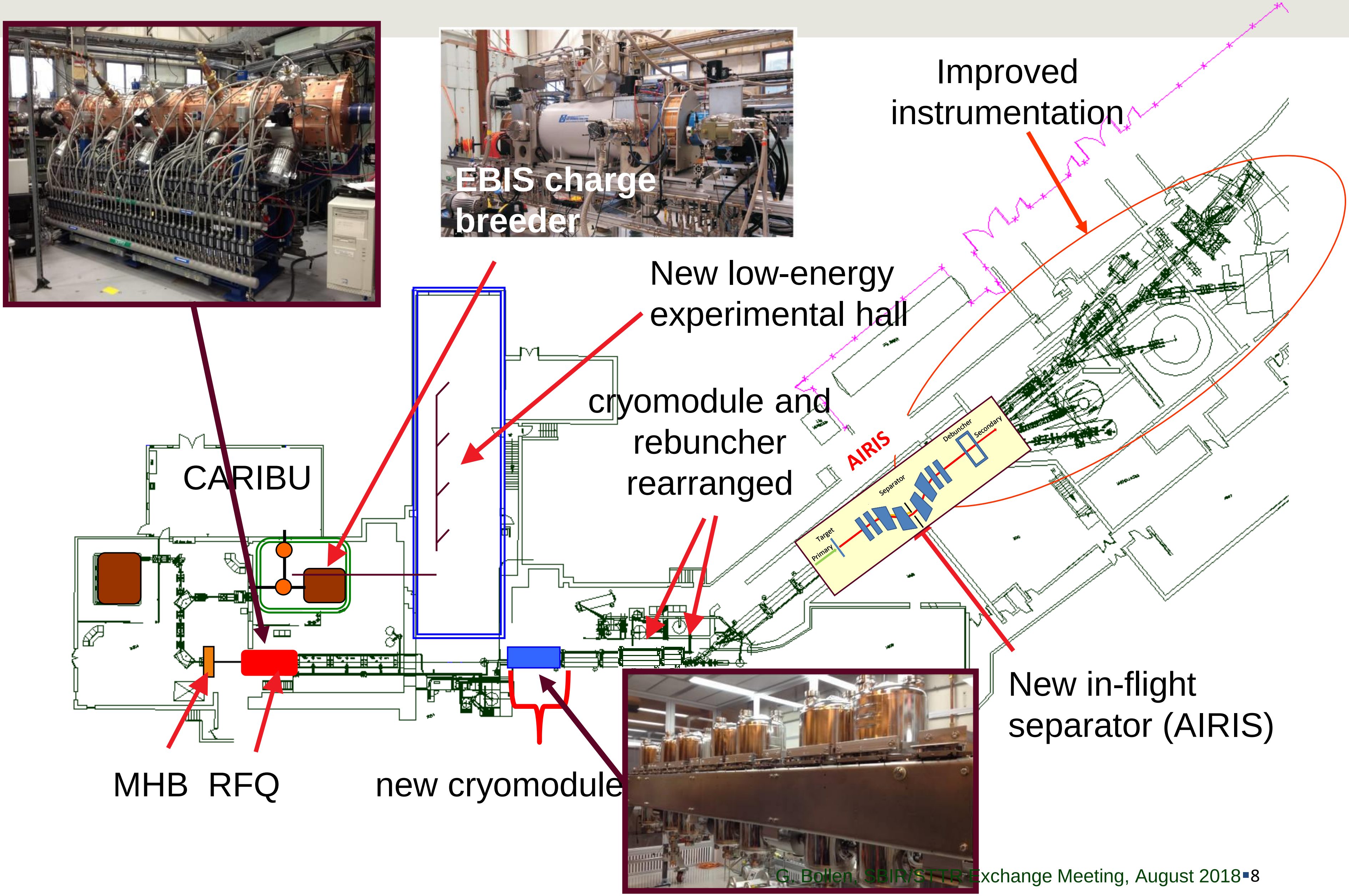


ATLAS/CARIBU Facility at Argonne National Laboratory

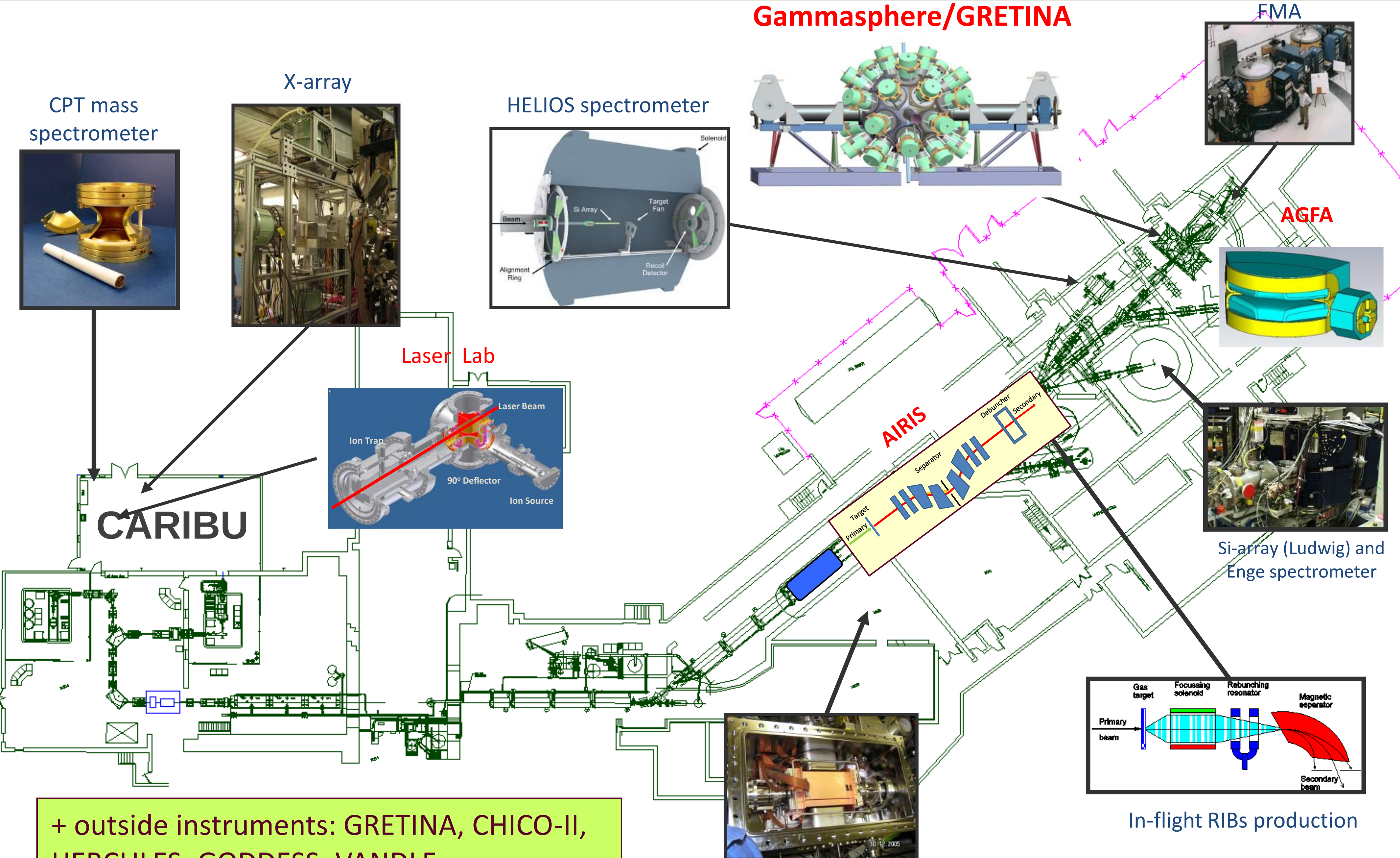
- Stable beams at medium intensity and energy up to 10-20 MeV/u
- In-flight radioactive beams
  - light beams, no chemical limitations, close to stability, low intensity, good beam properties
- CARIBU beams
  - heavy n-rich from Cf fission, no chemical limitations, low intensity, ATLAS beam quality, energies up to 12-15 MeV/u
- State-of-the-art instrumentation for Coulomb barrier and low-energy experiments
- About 400 users per year



ATLAS/CARIBU Facility at ANL



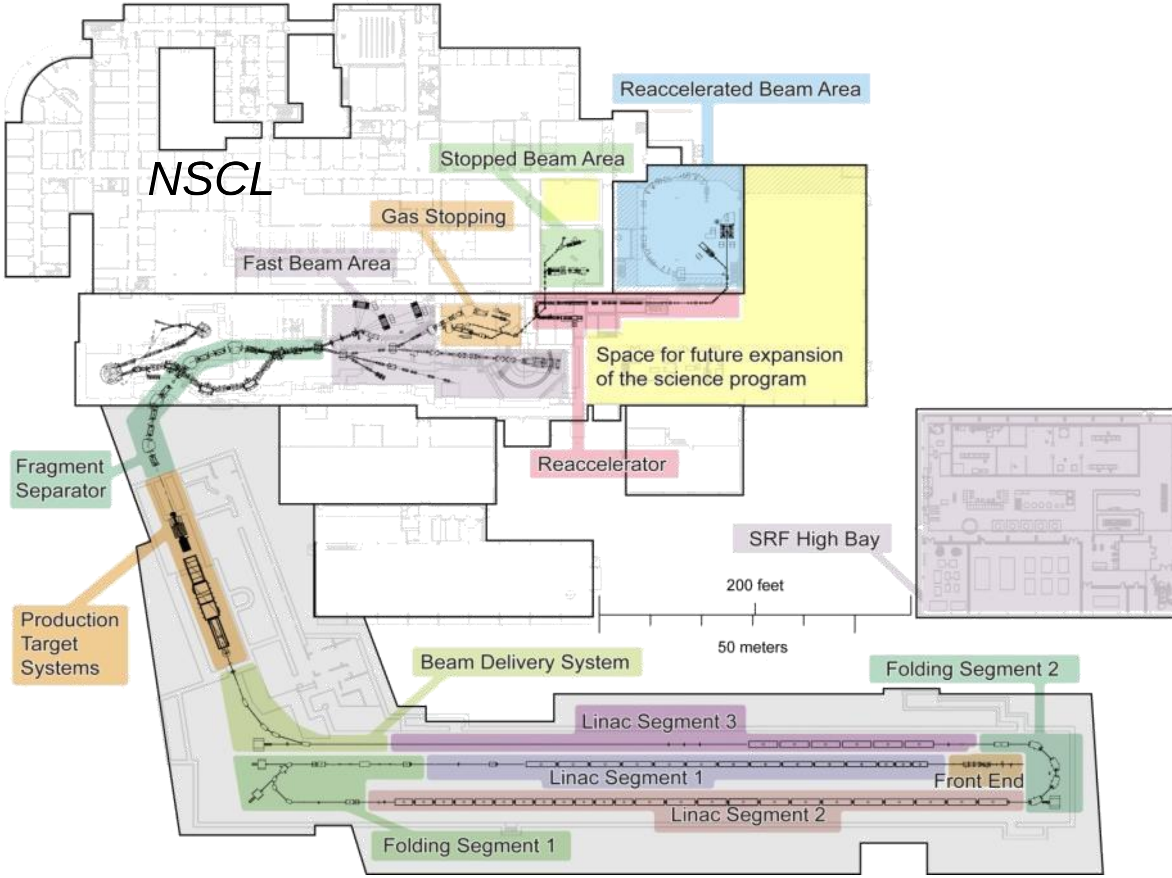
ATLAS Suite of Experimental Equipment



+ outside instruments: GRETINA, CHICO-II, HERCULES, GODDESS, VANDLE, …

FRIB - Facility for Rare Isotope Beams
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 re-accelerated beam capability
- Upgrade options
  - 400 MeV/u for uranium
  - ISOL production – multi-user capability

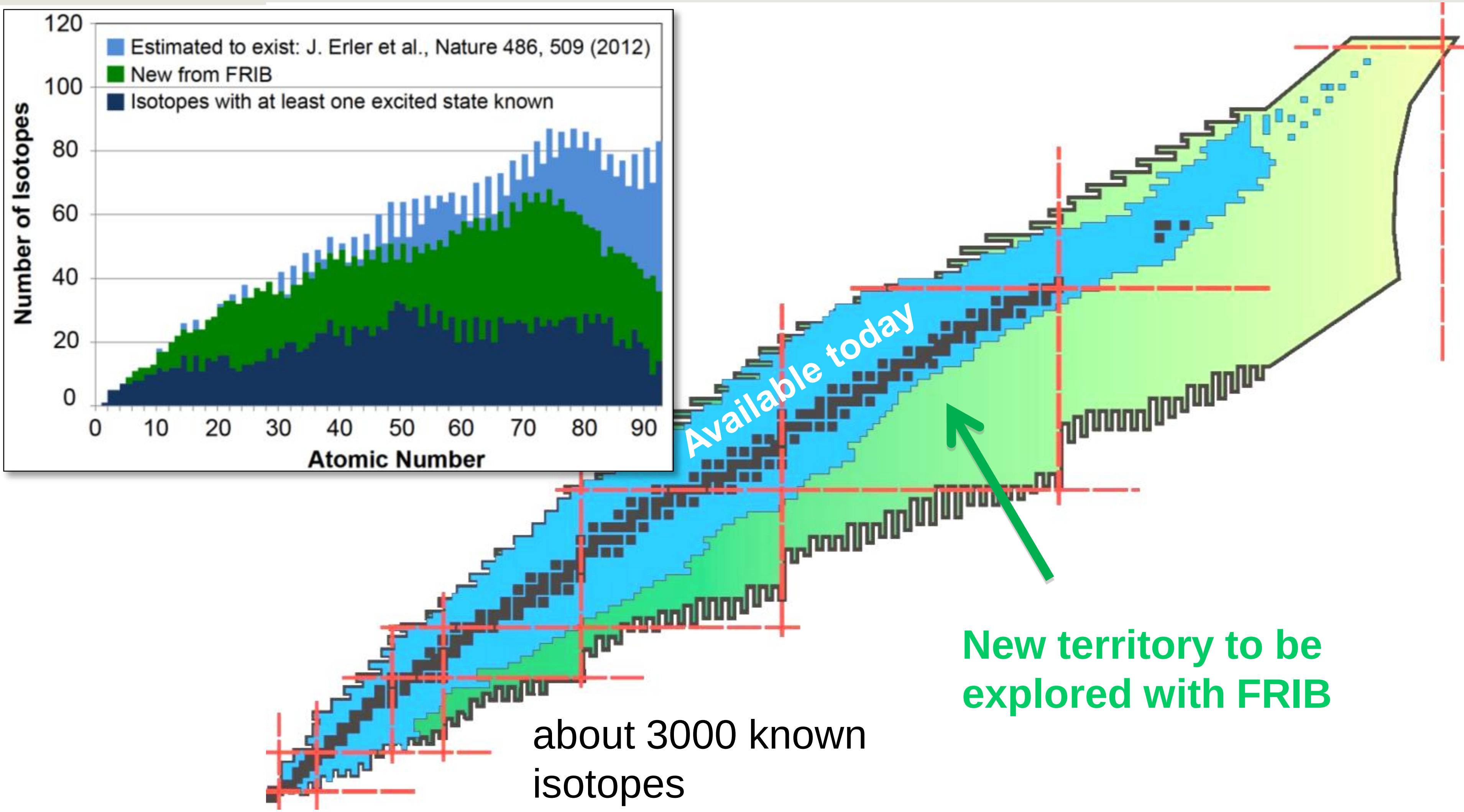


NSCL enables pre-FRIB science

FRIB project start 6/2009
Civil construction started 3/2014
Technical construction started 10/2014
Managed to early completion FY 2021
CD-4 (project completion) 6/2022

Total project cost $730 million

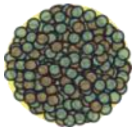
FRIB Beams Will Enable New Discoveries



about 3000 known isotopes

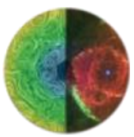
New territory to be explored with FRIB

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.

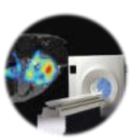


Astrophysical processes

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

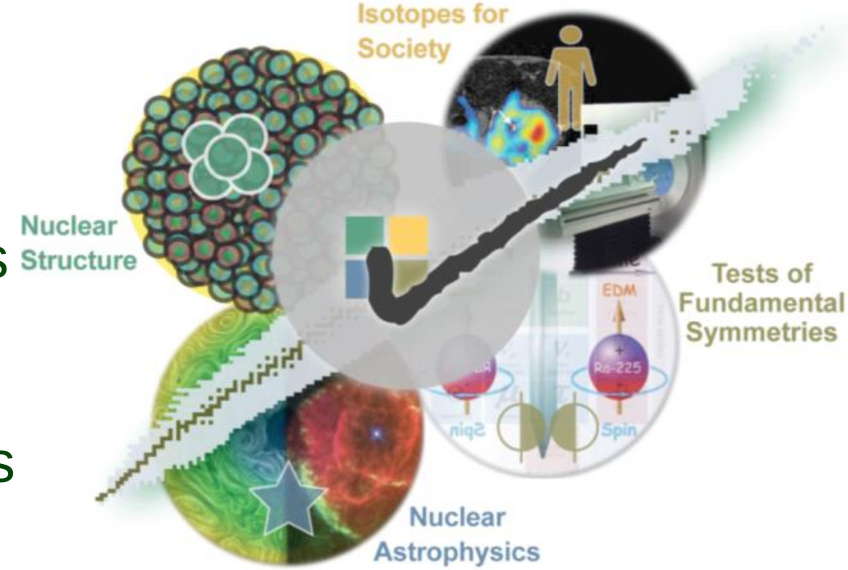
Tests of fundamental symmetries

- Effects of symmetry violations are amplified in certain nuclei

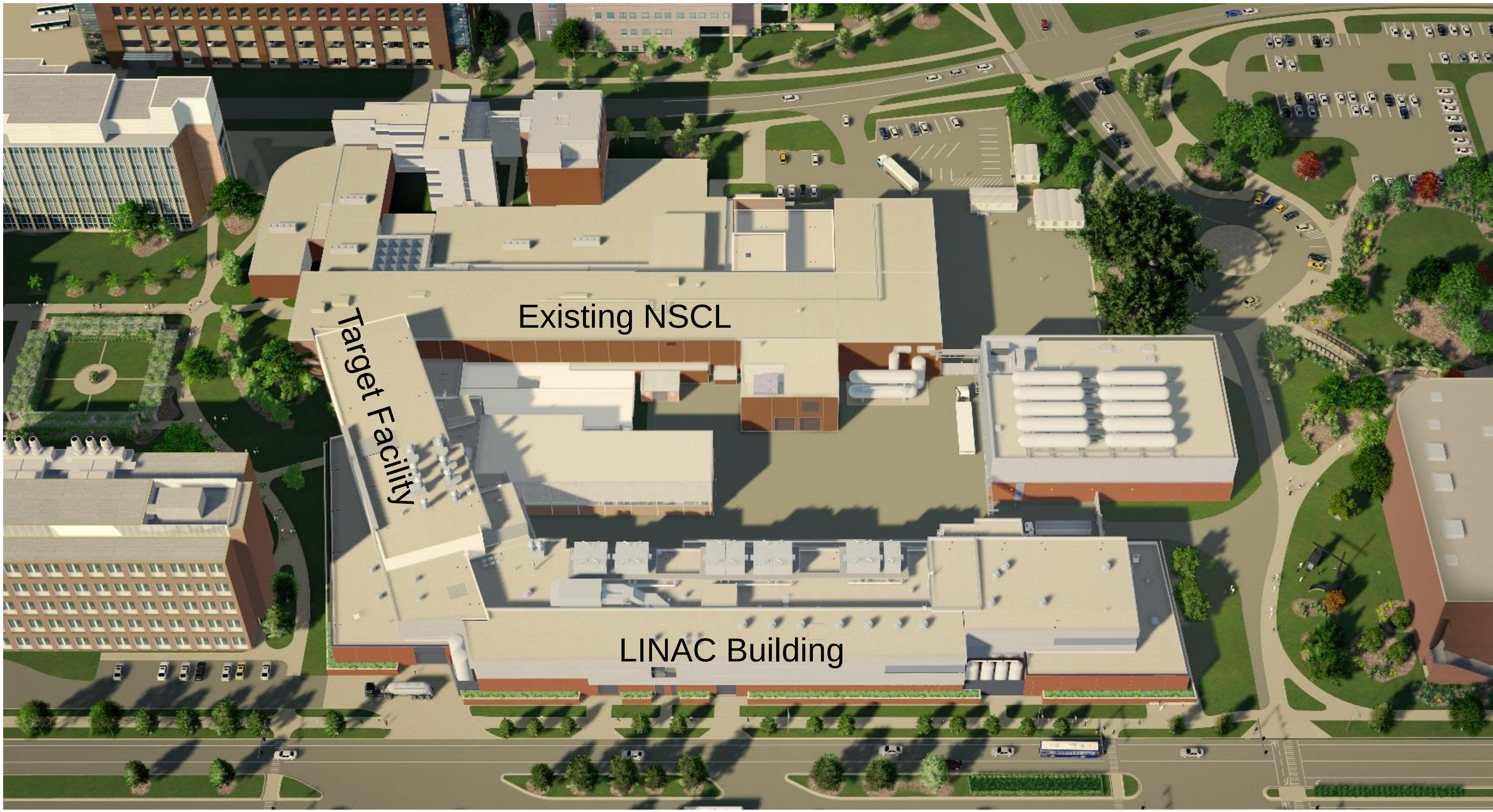


Societal applications and benefits

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



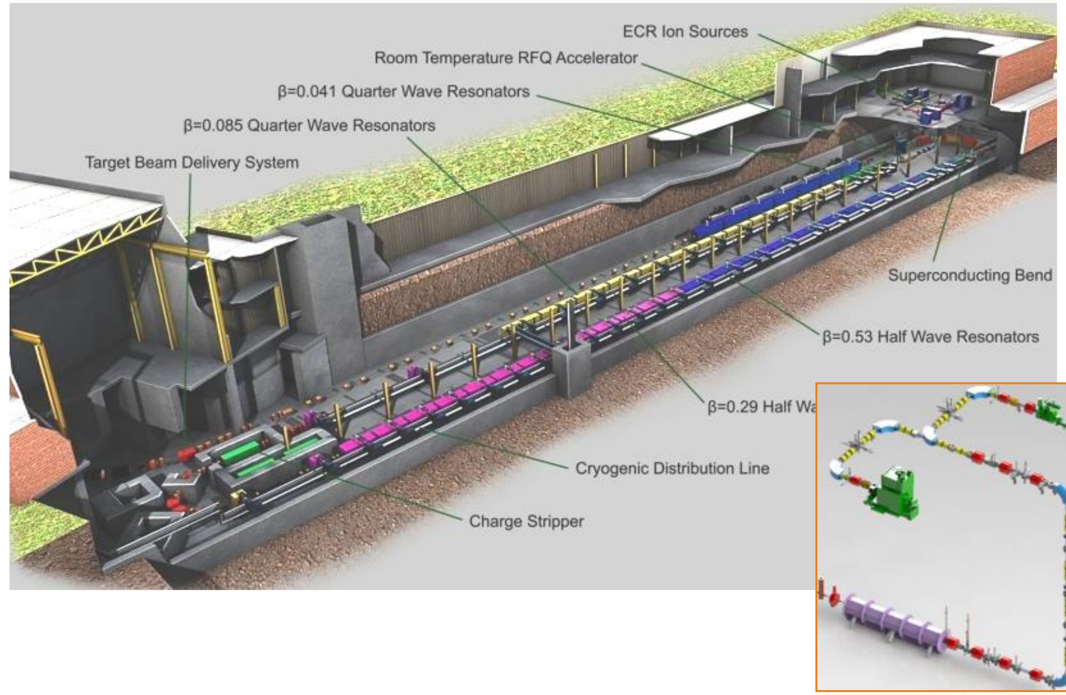
Facility for Rare Isotope Beams

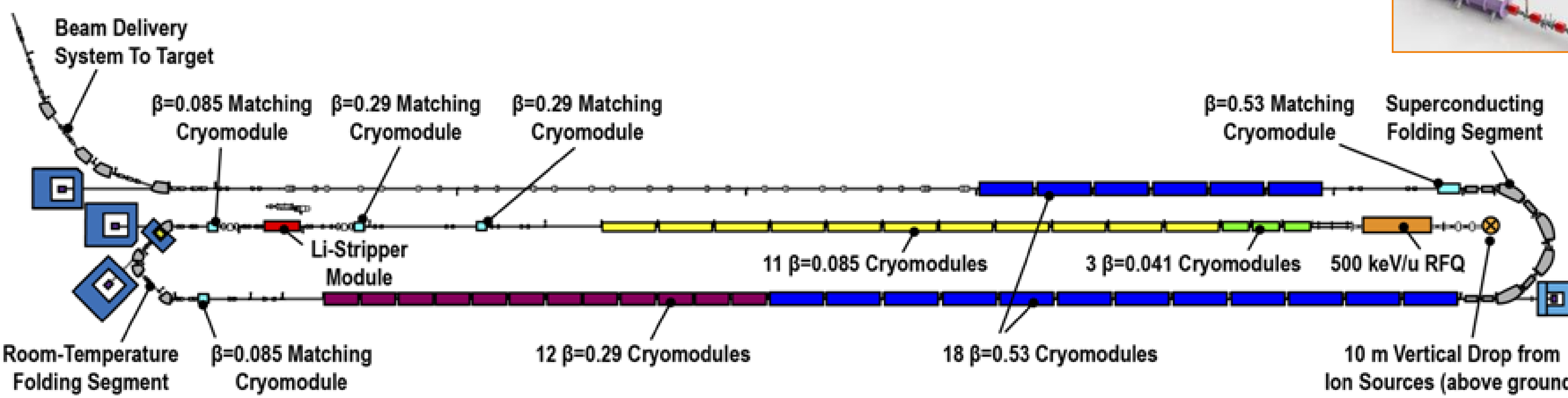


Civil Construction Complete, Installation Advanced, First Beams Accelerated

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 uranium by filling vacant slots with 12 SRF cryomodules
  - MSU has funded β=0.65 cavity prototype development



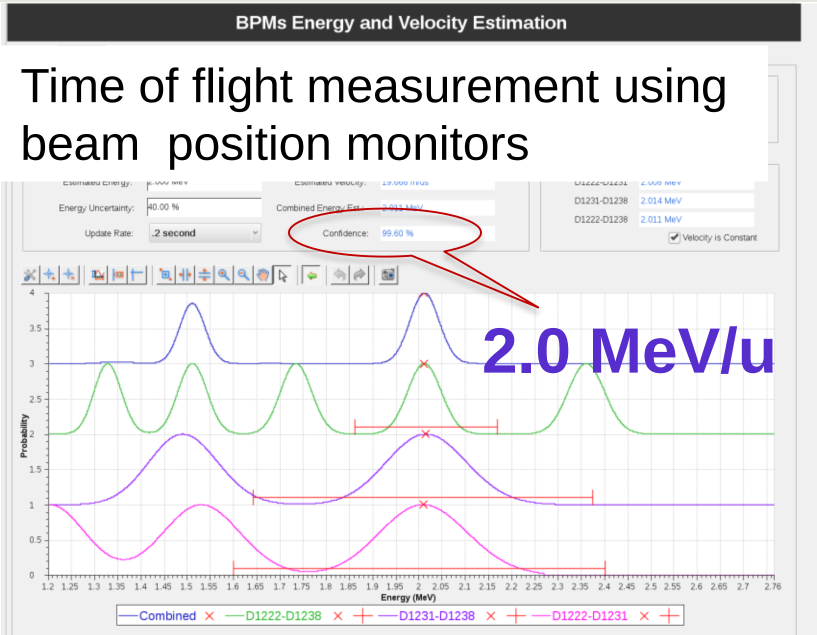


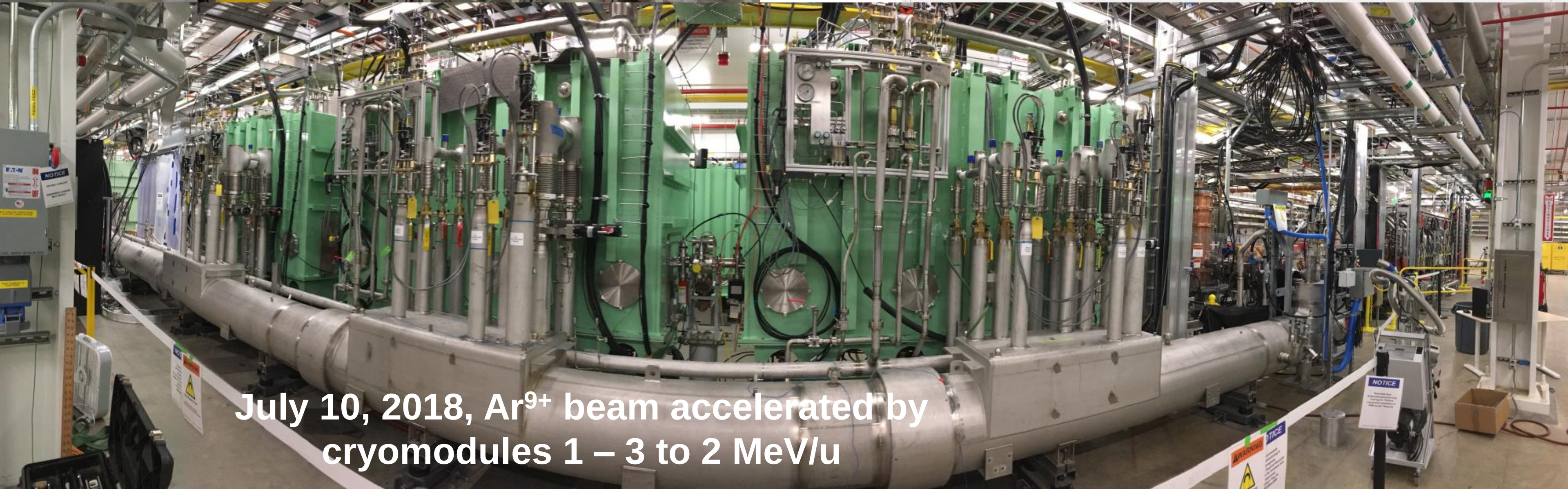
Front End and Cryomodules in FRIB Tunnel
Beam Commissioning in Parallel with Accelerator Installation

- Front-end of accelerator commissioned
  - > 40 μA $^{40}Ar^{9+}$ and > 25 μA $^{86}Kr^{17+}$ beams accelerated through RFQ, exceeding key performance parameters
- >50% of cryomodules installed

SRF Cryomodule 1 – 3 Beam Commissioned

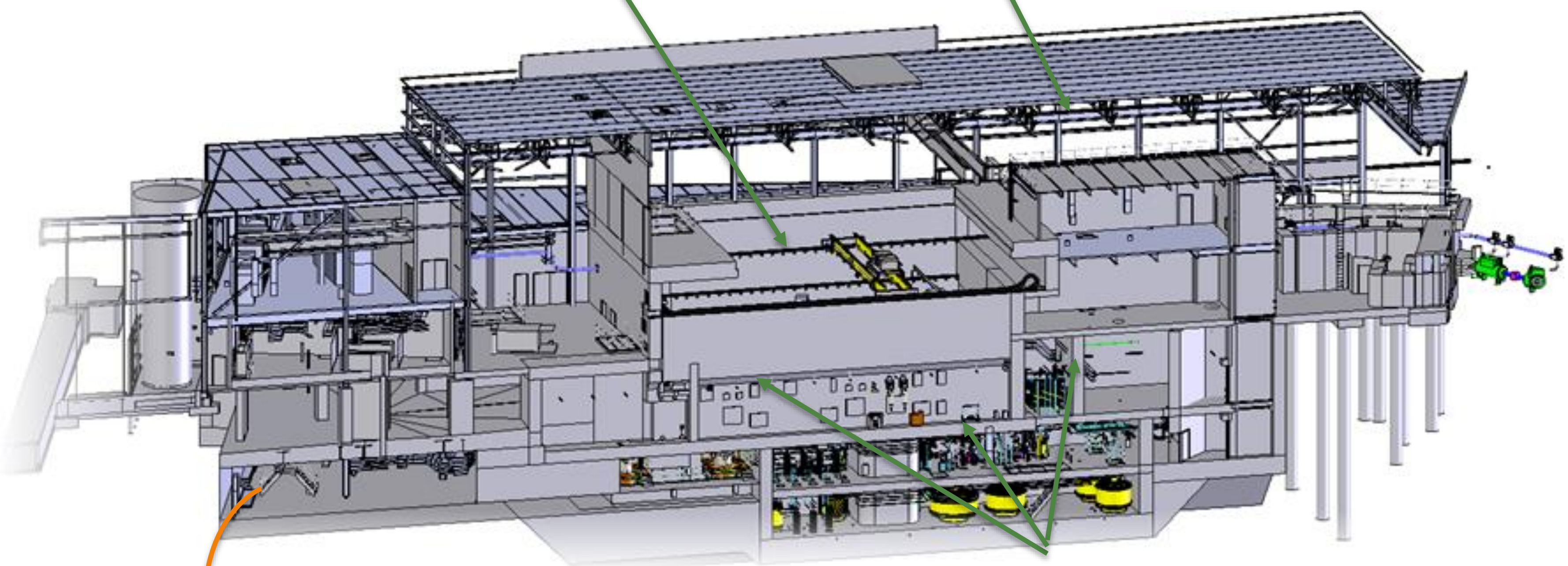
Met Key Performance Parameters in 2 Days upon Authorization





FRIB Rare Isotope Production Facility 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

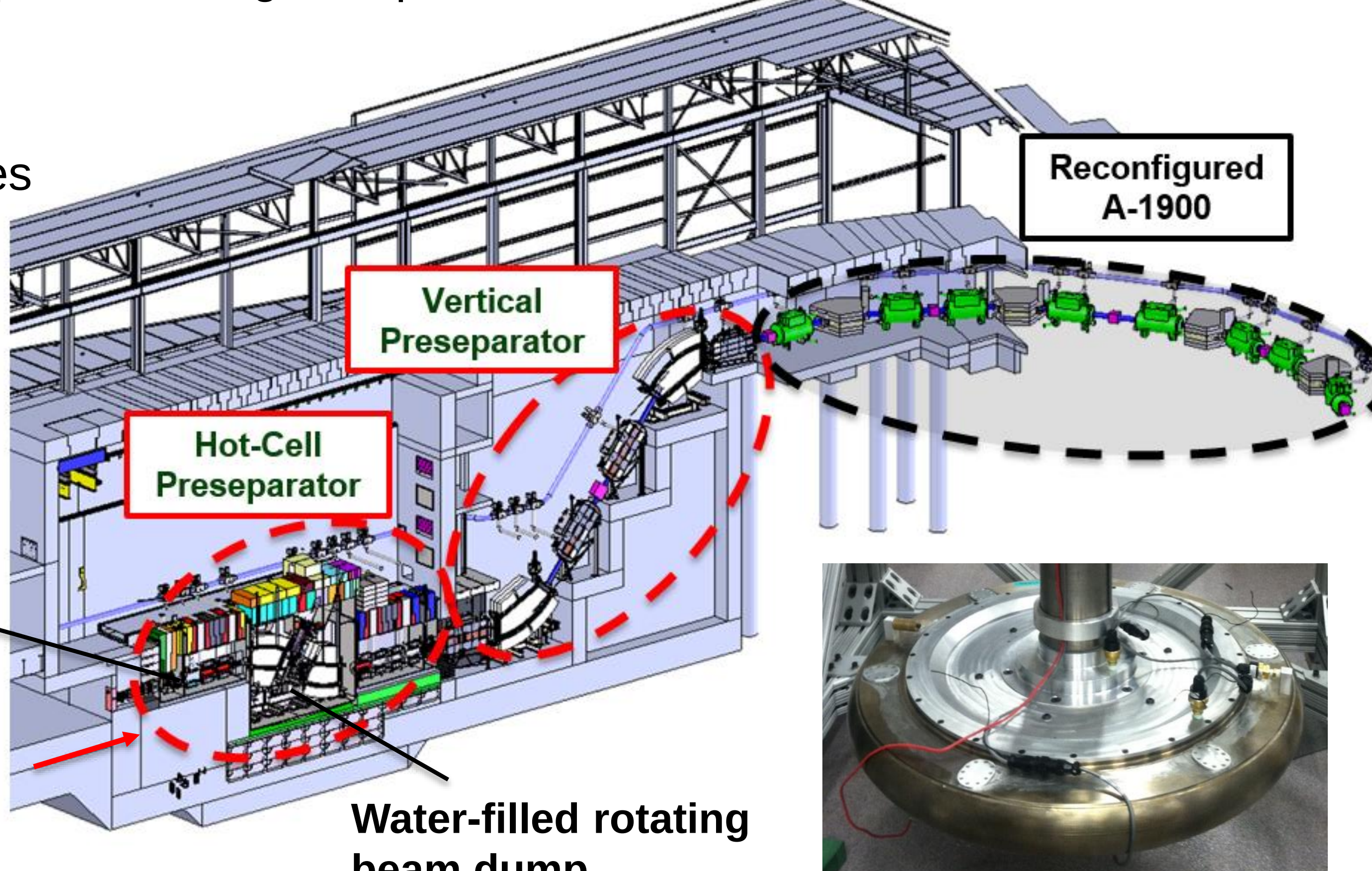


400 kW beam from linac

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

FRIB Rare Isotope Production Facilities
Fragment Separator

- Three stage magnetic fragment separator
  - High acceptance, high resolution to maximize science
  - Provisions for isotope harvesting incorporated in the design
- Challenges
  - High power densities
  - High radiation

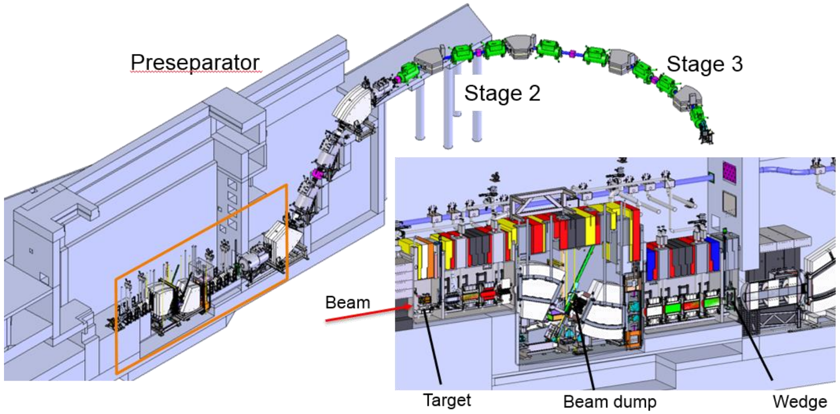


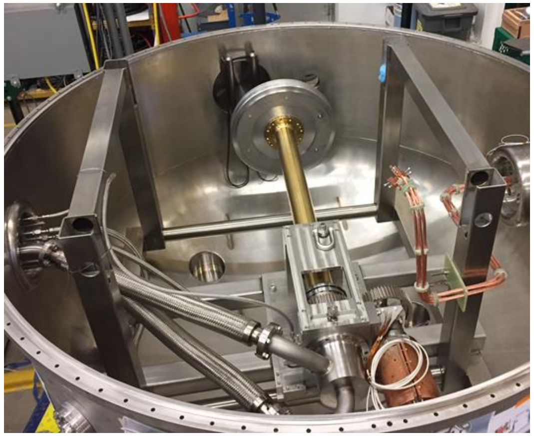
Multi-slice rotating graphite target

Water-filled rotating beam dump

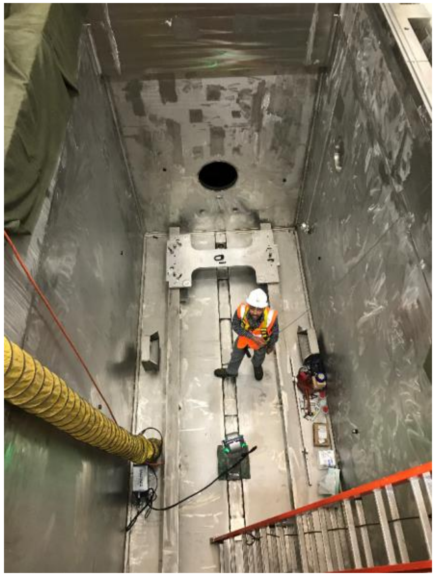
FRIB Rare Isotope Production Facilities
Fragment Separator

- Target facility fragment separator vessels installed
  - Preparing for magnet installation
- High-power target module assembly complete
- High-power beam dump testing and fabrication underway




High-power target beam dump

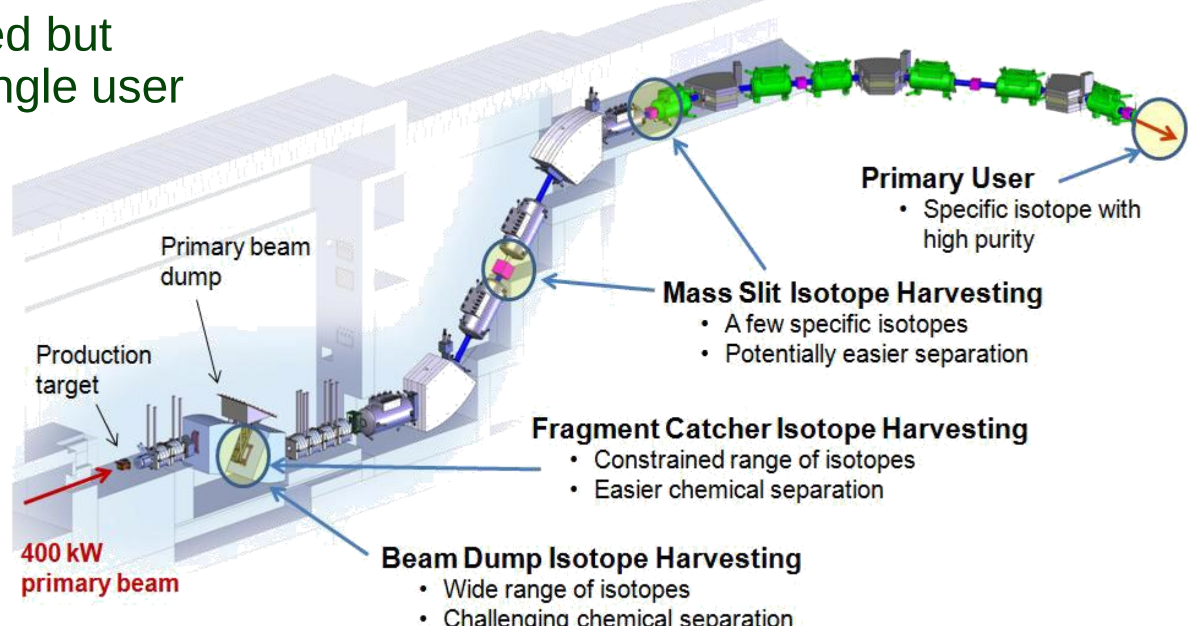

High-power target module



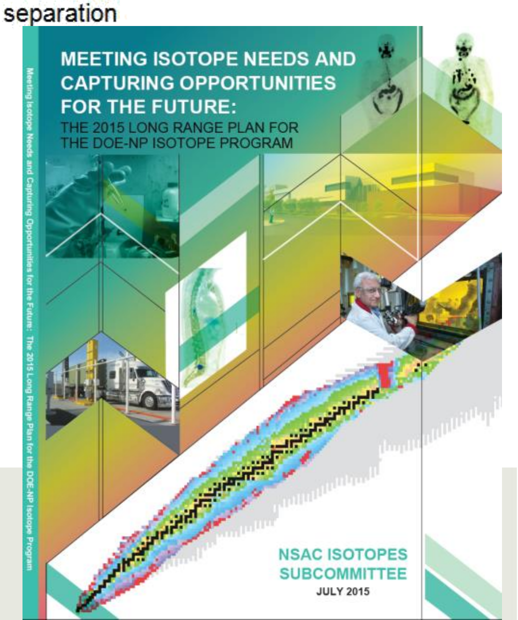
Vacuum vessels accommodate separator front end with target and beam dump

Leveraging FRIB Capabilities
Isotope Harvesting for Broad Benefit

- Many rare isotopes are produced but only one isotope delivered to single user
  - Often 1000 other isotopes are produced that could be harvested and used for experiments or applications
- FRIB has provisions for isotope harvesting incorporated in the design
  - NCU water-cooling and off-gas system prepared for harvesting upgrade

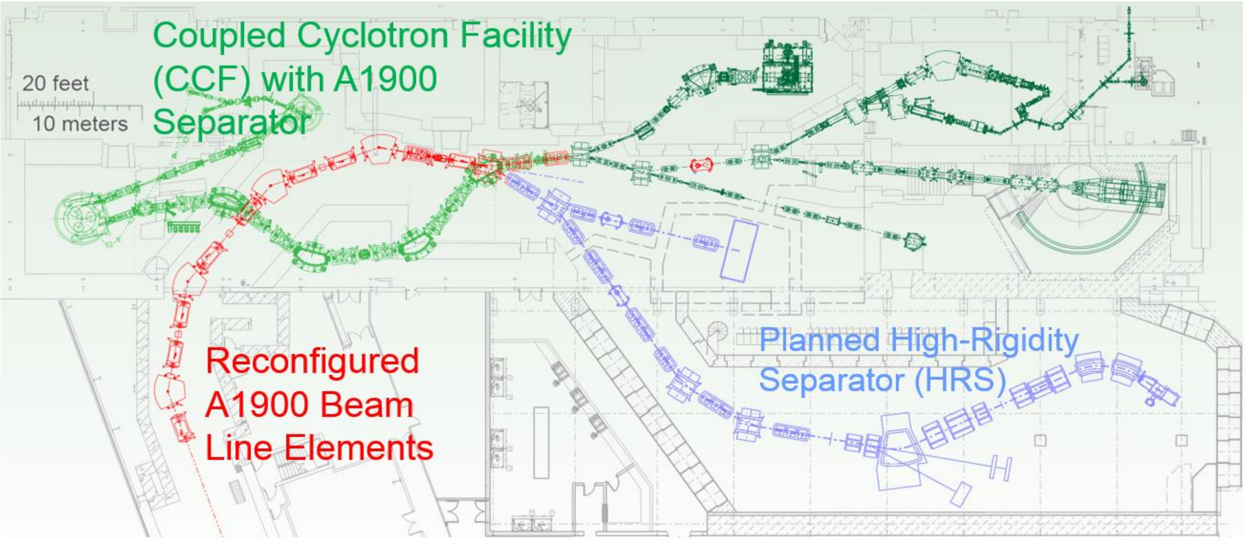


- 2015 Long Range Plan for the NP-DOE Isotope Program recognizes FRIB importance and recommends investment in infrastructure for isotope harvesting at FRIB
- Whitepaper on Isotope Harvesting prepared



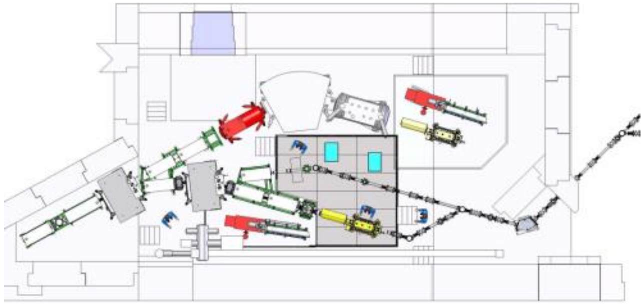
Fast, Stopped, and Reaccelerated Beam Experimental Areas and Equipment

Experimental Areas, Experimental Equipment

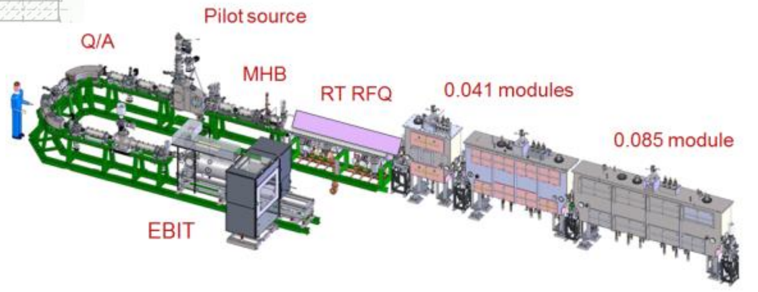


Fast Beams

Stopped Beams

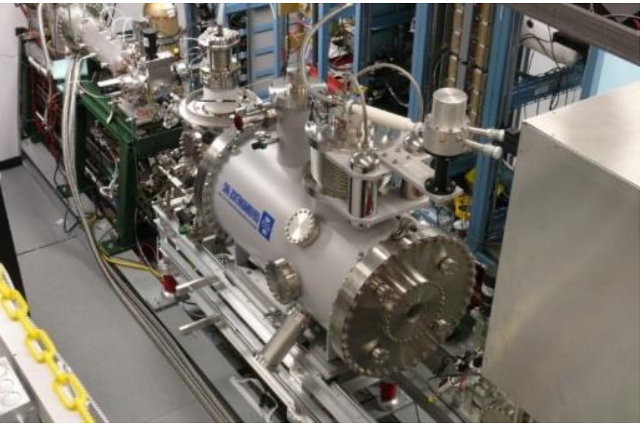


Reaccelerated Beams

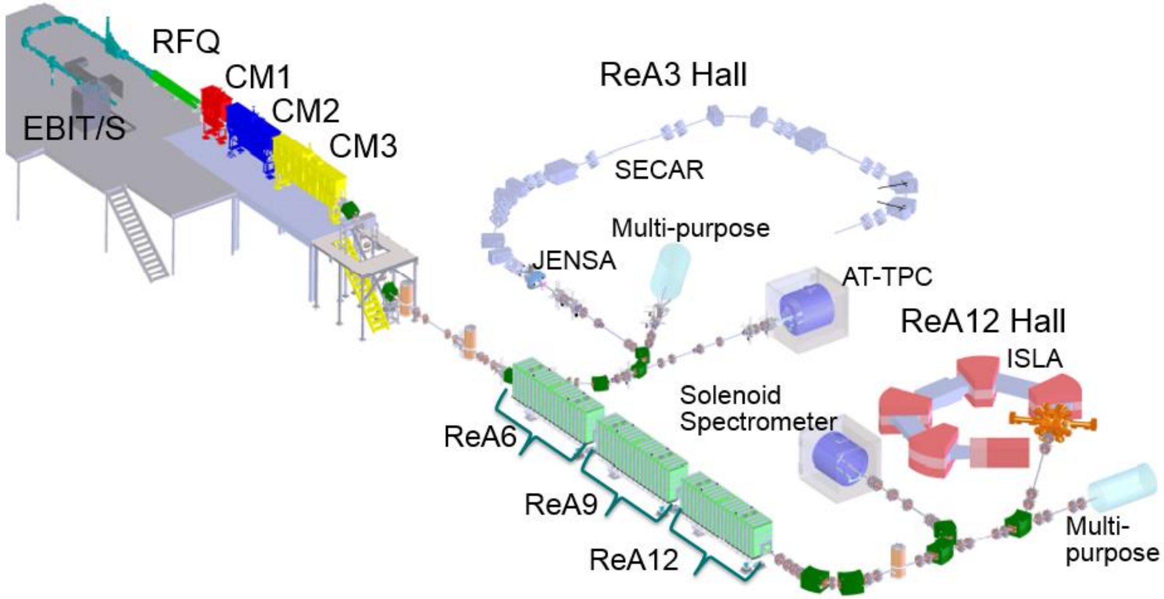


NSCL enables pre-FRIB science while FRIB construction is underway

Reaccelerated Beams at NSCL and FRIB with ReA Facility



First rare isotope beam experiment with ReA3 in 2013
10 PAC approved rare isotope beam experiments since then



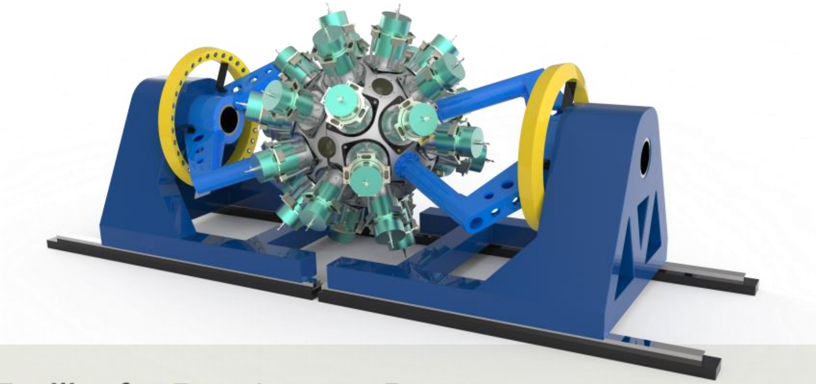
EBIT/S charge breeder
Superconducting RF linac
ReA3 – 3 MeV/u for ^{238}U, ReA6 – 6 MeV/u for ^{238}U (under construction) expandable to >12 MeV/u for ^{238}U

Advanced Instrumentation for Low Energy Nuclear Physics

- State-of-the art instrumentation is required to maximize science opportunities with rare isotope beams
  - Detectors
    - High efficiency, high resolution
  - Spectrometers
    - Large acceptance, high rigidity
  - Ions and atom traps, lasers
    - High-precision experiments
  - Control systems and data acquisitions
- High-power facilities like FRIB have challenges that provide basis for needed developments – higher beam rates need to be met with high performance instrumentation
  - High beam rates (event rates)
  - Radiation damage mitigation
  - High-power density mitigation

Instrumentation for Low Energy Nuclear Physics: GRETINA and GRETA

- GRETINA is one of the most advanced gamma-ray detector array for nuclear science - uses highly segmented detectors to track and reconstruct gamma-rays
  - GRETINA is the first phase of the larger Gamma Ray Energy Tracking Array (GRETA).
- GRETA will be the most advanced gamma-ray detector array for nuclear science
  - GRETA will benefit from High Rigidity Spectrometer (HRS) at FRIB
  - Design study funded by DOE-NP underway
  - HRS building addition underway at MSU



Advanced Instrumentation for Low Energy Nuclear Physics: GRETA

- GRETA will be the most advanced gamma-ray detector array for nuclear science
  - Uses highly segmented detectors to track and reconstruct γ-rays
  - The GRETA project will add 18 detector modules and new electronics, computing and mechanical systems to instrument the full array
  - The completed array will cover ~ 80% of the full solid angle, and be key in the physics programs at ATLAS and FRIB with fast and reaccelerated beams

- GRETA will benefit from High Rigidity Spectrometer (HRS) at FRIB
  - Design study funded by DOE-NP underway
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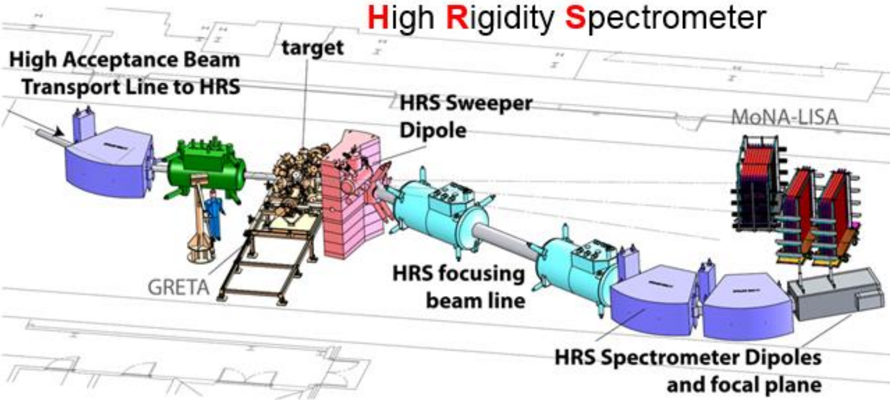
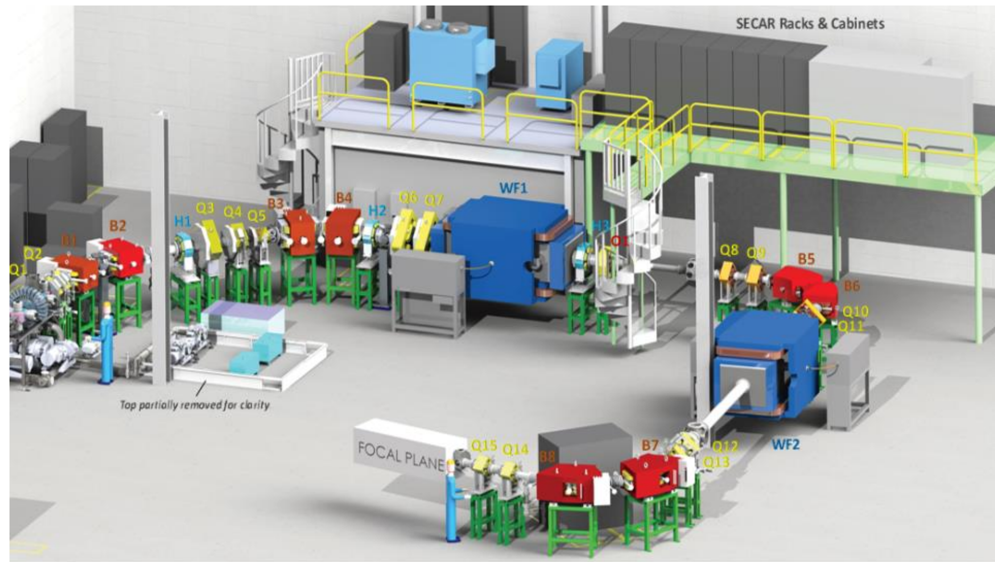


Advanced Instrumentation for Low Energy Nuclear Physics: Example SECAR

- SECAR (Separator for Capture Reactions) will enable use of FRIB’s unique low energy RIB production capabilities to directly measure astrophysical reaction rates
  - DOE-SC/NSF project, multi-institutional collaboration
  - Construction underway
- Extreme Stars
  - Thorne Zytkov objects?
  - Massive first stars
- Accreting compact objects
  - X-ray bursts
  - Novae
- Supernovae
  - np-process, p-process
  - Explosive burning



Low Energy NP User Facilities and the SBIR/STTR Program

- SBIR/STTR program is important for the DOE Low Energy NP facilities
  - Development of new techniques, instrumentation and supporting systems are suitable SBIR/STTR projects
  - New, higher power facilities are being built worldwide and existing facilities are being upgraded. Many low energy NP facilities exist worldwide
- Examples of possible areas for SBIR/STTR activities are
  - High-rate, position sensitive particle tracking detectors and timing detectors for high-energy heavy-ions
  - Fast data acquisition electronic
  - Target technology (high-power targets, thin targets, windows, strippers, …)
  - Ion source technology
  - Beam catcher/release systems
  - Radiation resistant precision magnetic field probes
  - Radiation resistant actuator systems
  - Real time data visualization framework
  - Other accelerator related developments

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Summary

- There are exciting times ahead in the area of low energy nuclear physics in the US
- FRIB under construction at MSU will be a world-leading rare isotope facility that will enable new discoveries
  - A strong user community exists (FRIB user organization has more than 1700 members)
- Existing low-energy rare isotope beam facilities in the US provide forefront research opportunities today
- DOE NP SBIR/STTR program plays important role in making low energy nuclear physics program successful