DOE LENP User Facilities and the SBIR/STTR Program

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Outline:

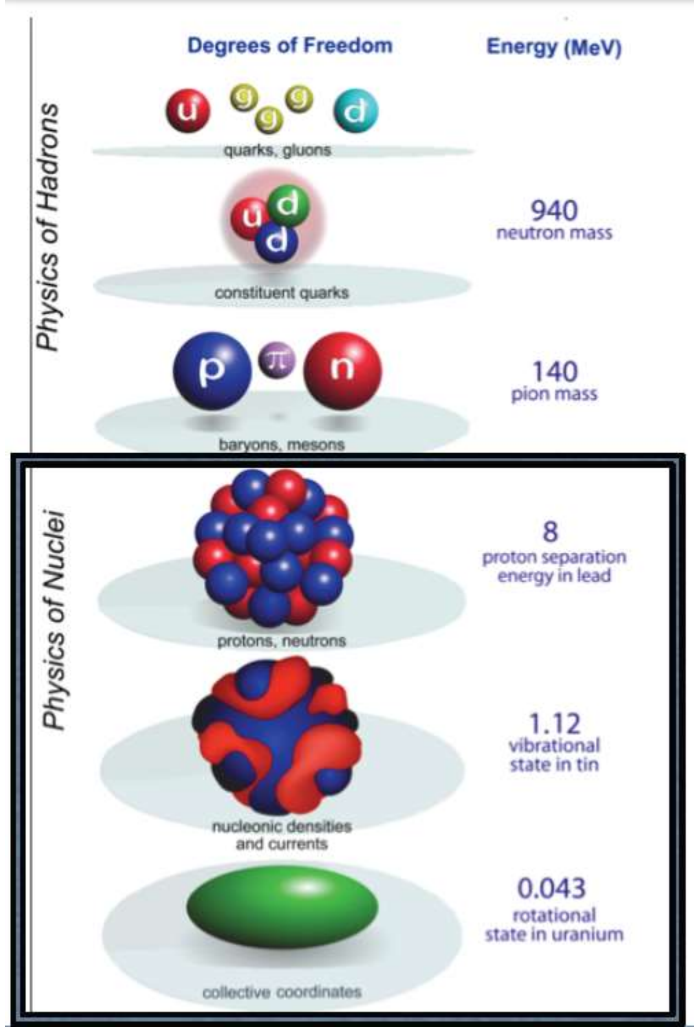
- Scope of Low Energy Nuclear Physics
- DOE LE NP User Facilities
- DOE LE NP Advanced Instrumentation

Thanks to Georg Bollen (FRIB), Clayton Dickerson (ANL), Aaron Couture (LANL), Andrew Rogers (UMass), and many others

Scope of Low Energy Nuclear Physics

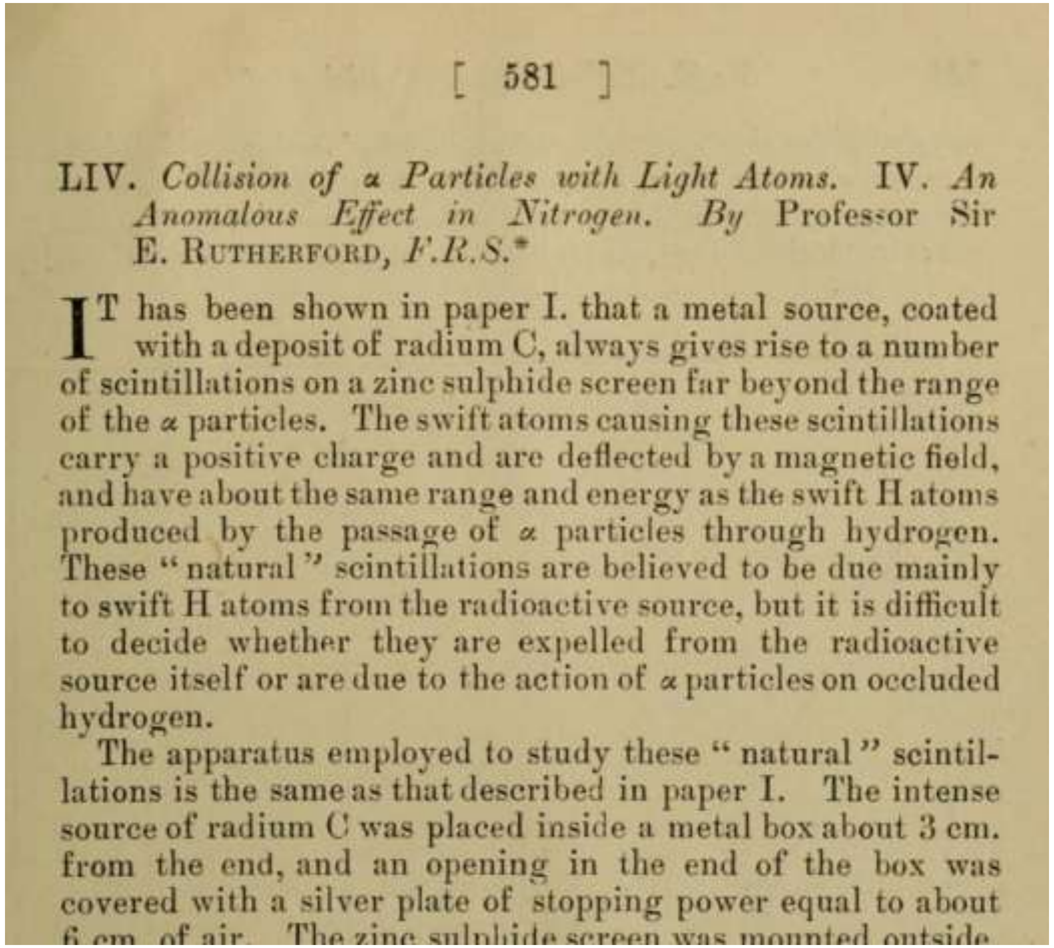
Low Energy Nuclear Physics

- When we say "low energy," we mean the energy scale of the physics – here, it's fractions of a keV to multiple MeV
- Encompasses the physics governing nuclear decay (eg beta decay) and nuclear reactions (eg neutron-induced fission in reactors, reactions driving the synthesis of the elements in stars)
- This scale is where the broader field of nuclear physics most impacts our day-to-day lives (eg nuclear energy, security, medicine)
- This scale also provides a unique window into more fundamental properties of nature (eg neutrinos, EDM) and overlaps with other fields (eg QIS, AI/ML)



Low Energy Nuclear Physics

- Well-established field, but still making amazing new discoveries!



[581]

LIV. *Collision of α Particles with Light Atoms.* IV. *An Anomalous Effect in Nitrogen.* *By* Professor Sir E. Rutherford, *F.R.S.**

IT has been shown in paper I. that a metal source, coated with a deposit of radium C, always gives rise to a number of scintillations on a zinc sulphide screen far beyond the range of the α particles. The swift atoms causing these scintillations carry a positive charge and are deflected by a magnetic field, and have about the same range and energy as the swift H atoms produced by the passage of α particles through hydrogen. These "natural" scintillations are believed to be due mainly to swift H atoms from the radioactive source, but it is difficult to decide whether they are expelled from the radioactive source itself or are due to the action of α particles on occluded hydrogen.

The apparatus employed to study these "natural" scintillations is the same as that described in paper I. The intense source of radium C was placed inside a metal box about 3 cm. from the end, and an opening in the end of the box was covered with a silver plate of stopping power equal to about 6 cm. of air. The zinc sulphide screen was mounted outside

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Article | Published: 01 May 2019

^{78}Ni revealed as a doubly magic stronghold against nuclear deformation

R. Taniuchi, C. Santamaria, [...] Z. Y. Xu

Nature **569**, 53–58(2019) | Cite this article

6960 Accesses | **23** Citations | **122** Altmetric | Metrics

Abstract

Nuclear magic numbers correspond to fully occupied energy shells of protons or neutrons inside atomic nuclei. Doubly magic nuclei, with magic numbers for both protons and neutrons, are spherical and extremely rare across the nuclear landscape. Although the sequence of

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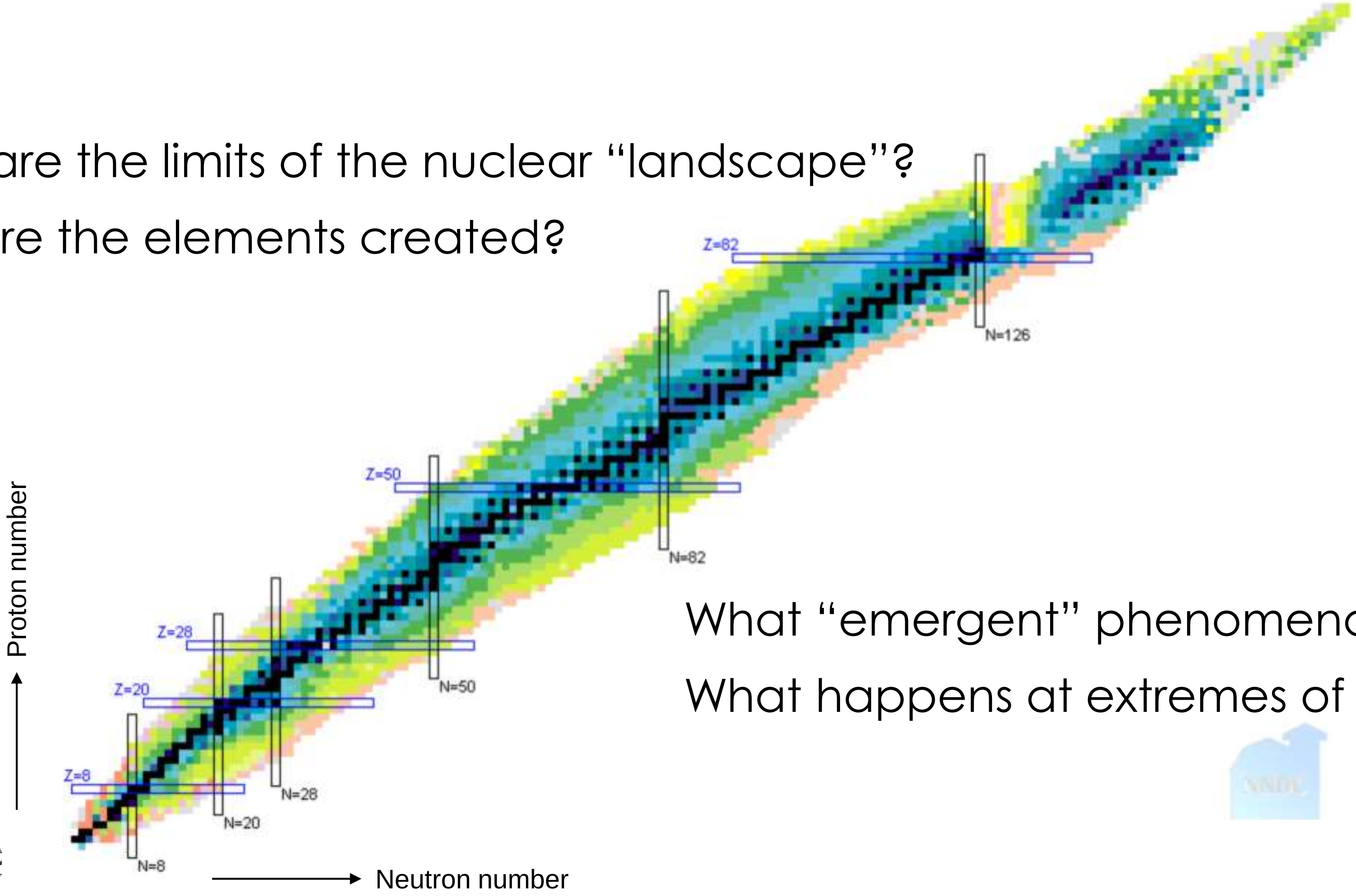
Low Energy Nuclear Physics – Open Questions

What are the limits of the nuclear "landscape"?

How are the elements created?



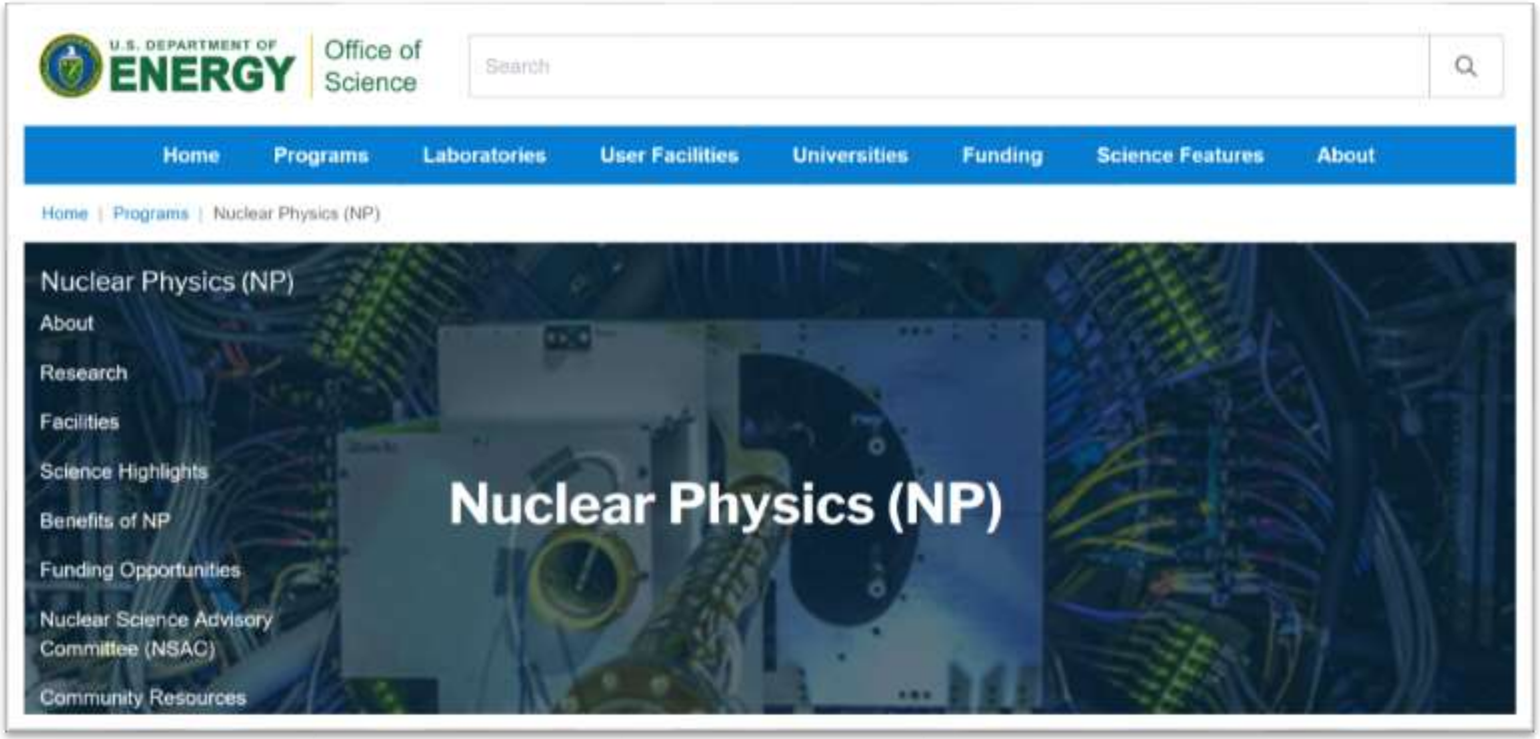
What "emergent" phenomena arise?

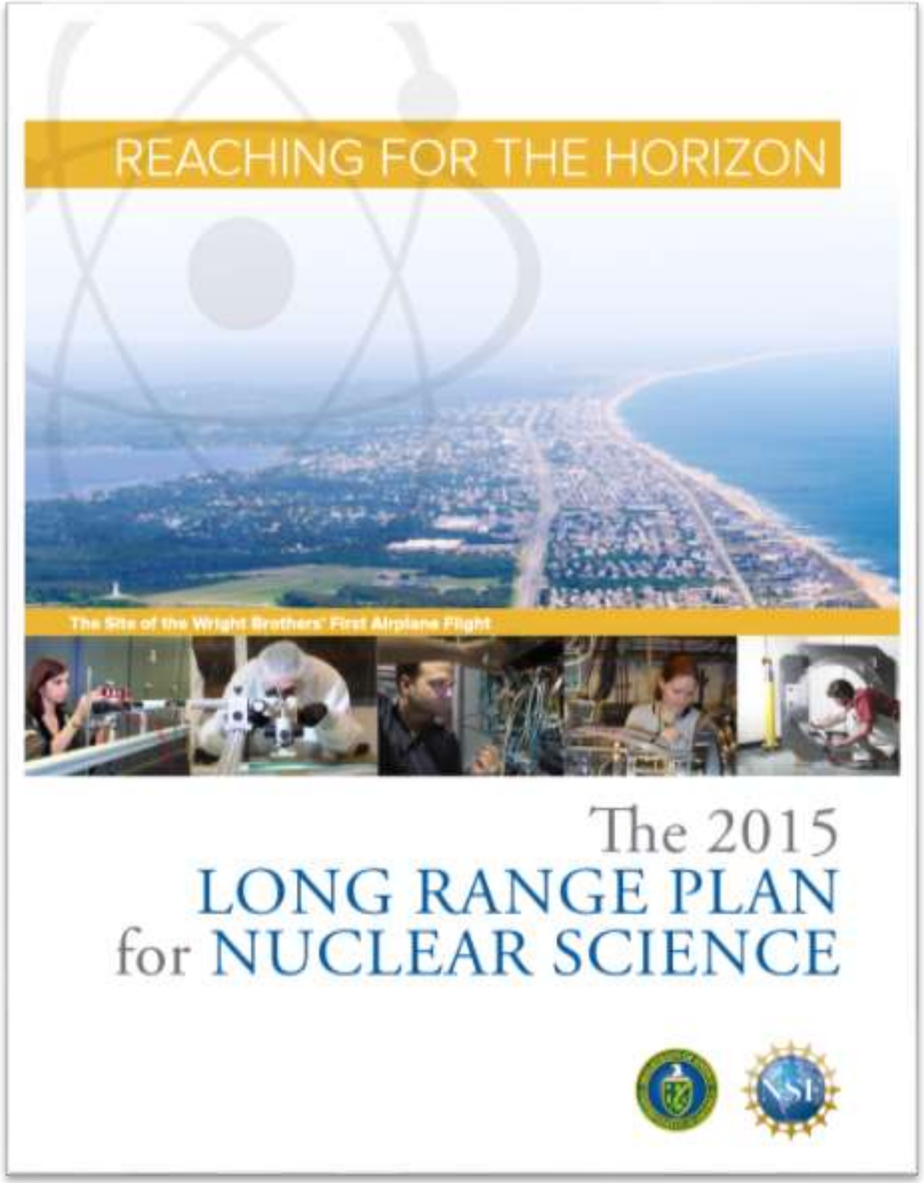
What happens at extremes of N/Z?

Low Energy Nuclear Physics – Answering Those Questions

LENP accelerator facilities

LENP advanced detectors and
instrumentation





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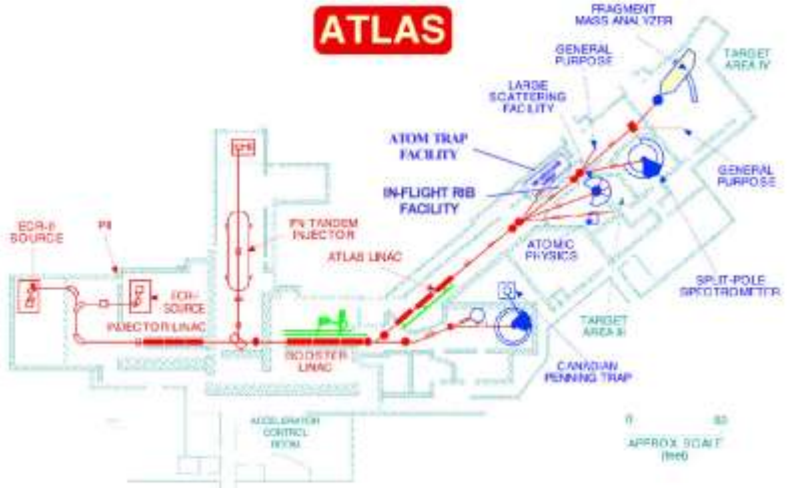
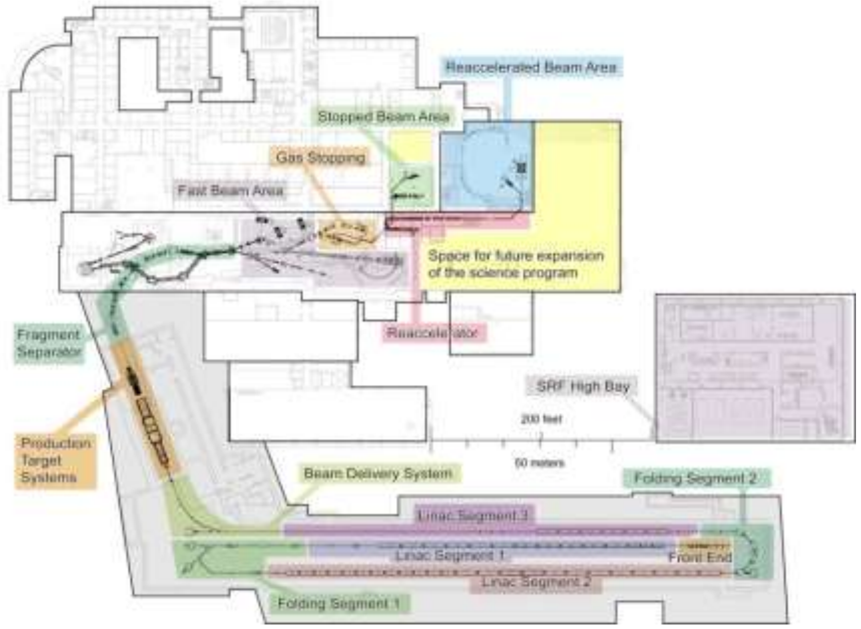
DOE LE NP User Facilities

US Low Energy Nuclear Physics Facilities

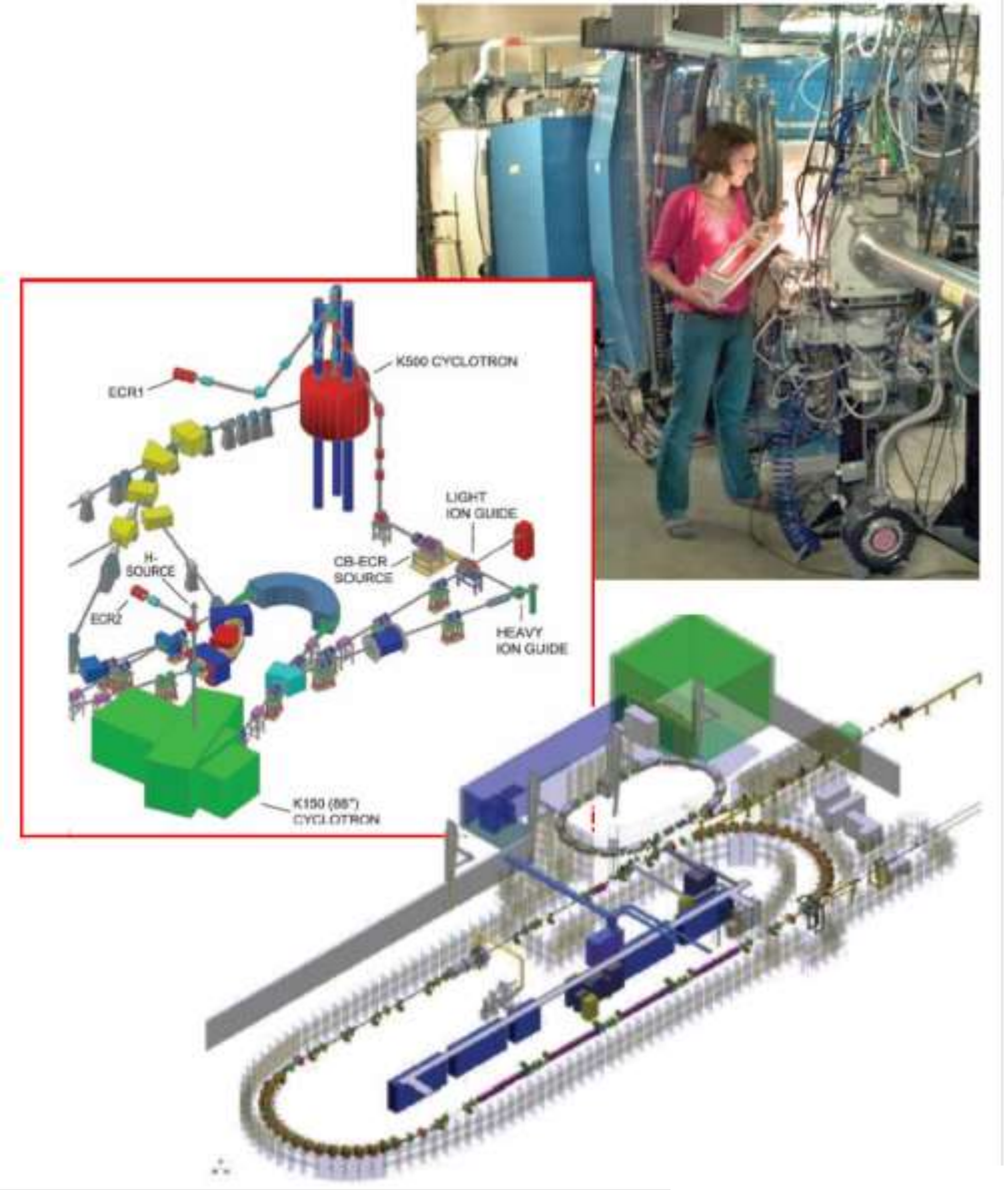
- DOE National User Facilities
  - **Argonne Tandem-Linac Accelerator System (ATLAS)** (http://www.anl.gov/atlas)
    - » High intensity stable beams
    - » Limited radioactive beam program with stopped, re-accelerated, and in-flight beams
  - **Facility for Rare Isotope Beams (FRIB) at MSU** (http://frib.msu.edu)
    - » 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





US Low Energy Nuclear Physics Facilities

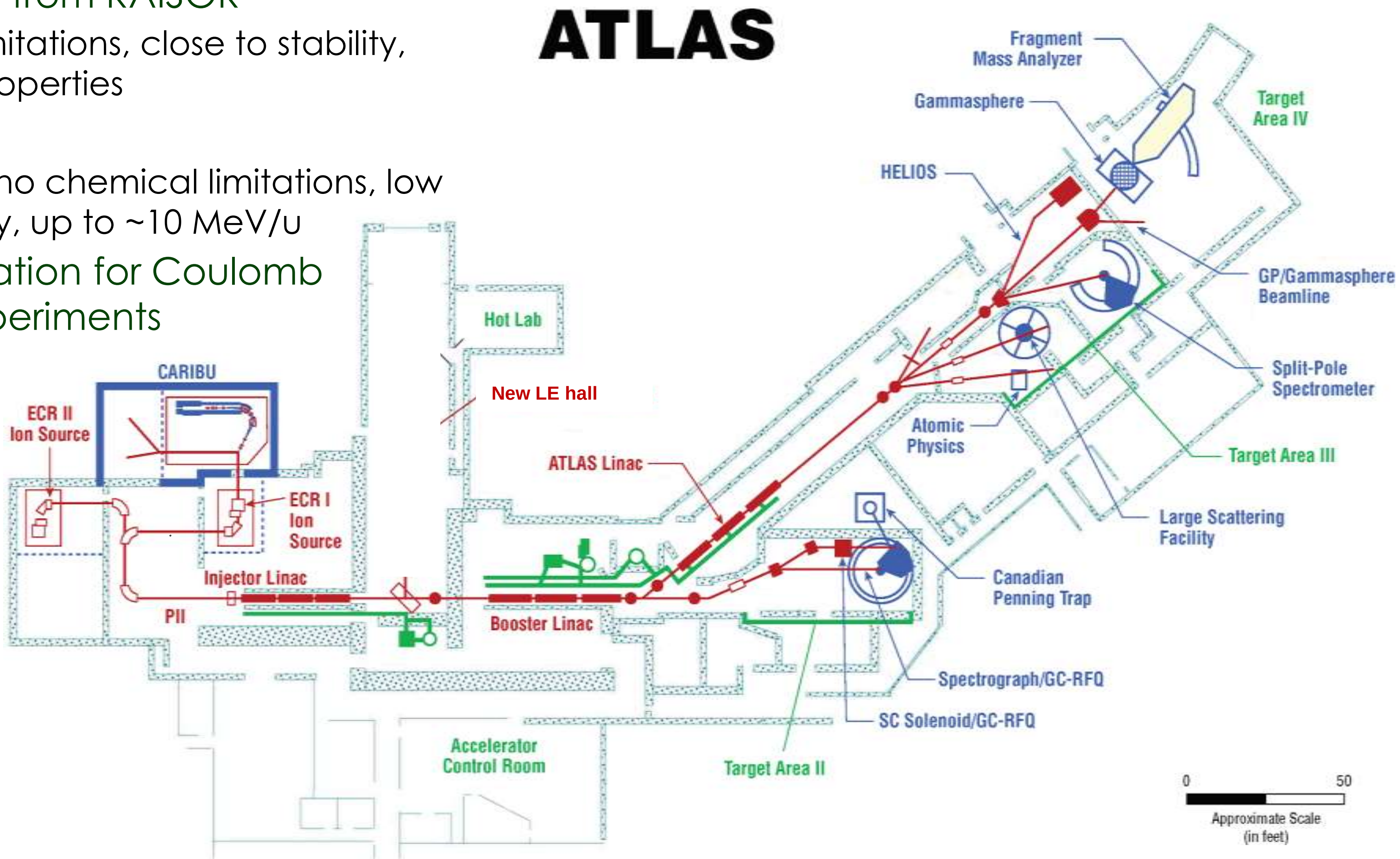
- Other DOE Facilities (university labs/local use)
  - **LBNL 88-inch Cyclotron** (http://cyclotron.lbl.gov)
    - » Stable beams
    - » Basic and applied research
    - » FIONA super-heavy element spectrometer
  - **Texas A&M Cyclotron Institute** (http://cyclotron.tamu.edu)
    - » Stable beams and a few in-flight beams
    - » Basic and applied research
    - » MDM spectrometer
    - » Stewardship science
  - **Triangle Universities National Laboratory** (http://tunl.duke.edu)
    - » High Intensity Gamma Source (HIgS) user facility
    - » Laboratory for Experimental Nuclear Astrophysics (LENA)
    - » Tandem accelerator stable beams



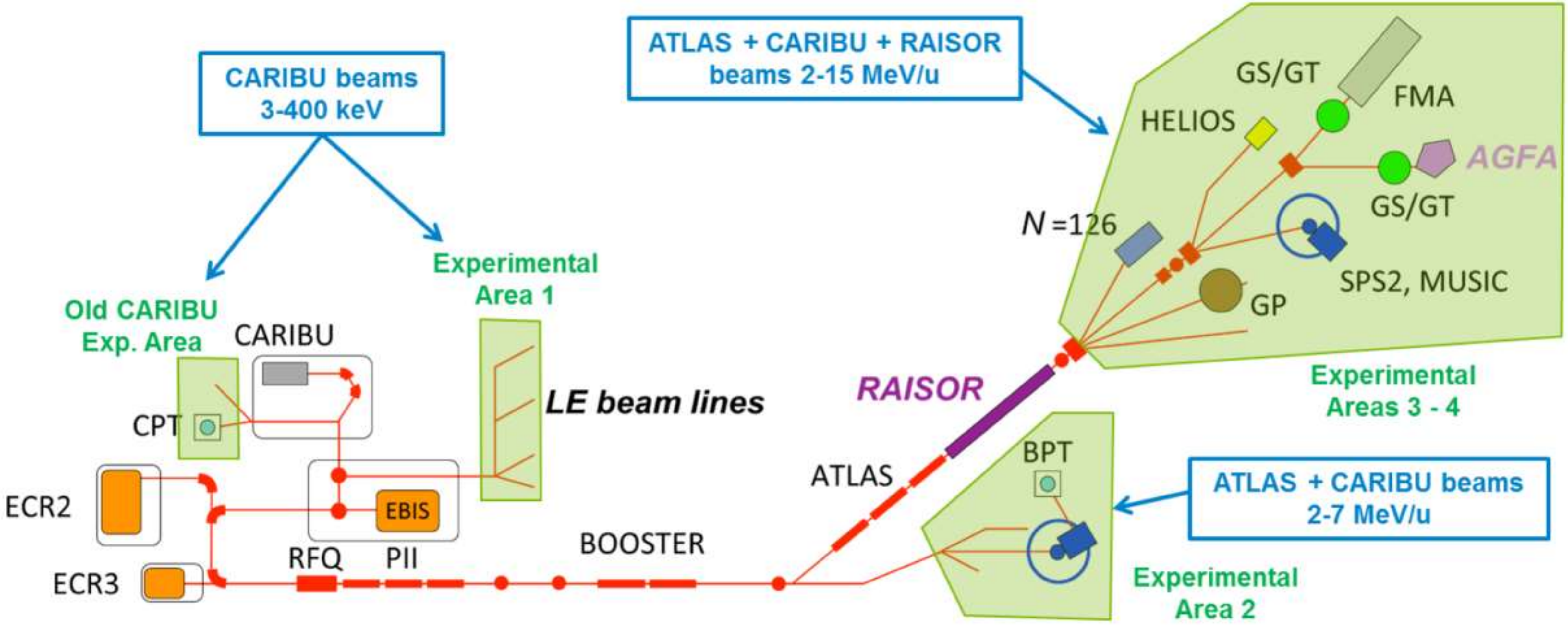
DOE LE NP User Facilities: ATLAS

ATLAS and CARIBU Facilities, Argonne National Lab

- Stable beams at medium intensity and energy up to 10-20 MeV/u
- In-flight radioactive beams from RAISOR
  - 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, up to ~10 MeV/u
- State-of-the-art instrumentation for Coulomb barrier and low-energy experiments
- About 400 users per year
- ~6000 operating hours per year, with another ~2000 from CARIBU (not accel.)

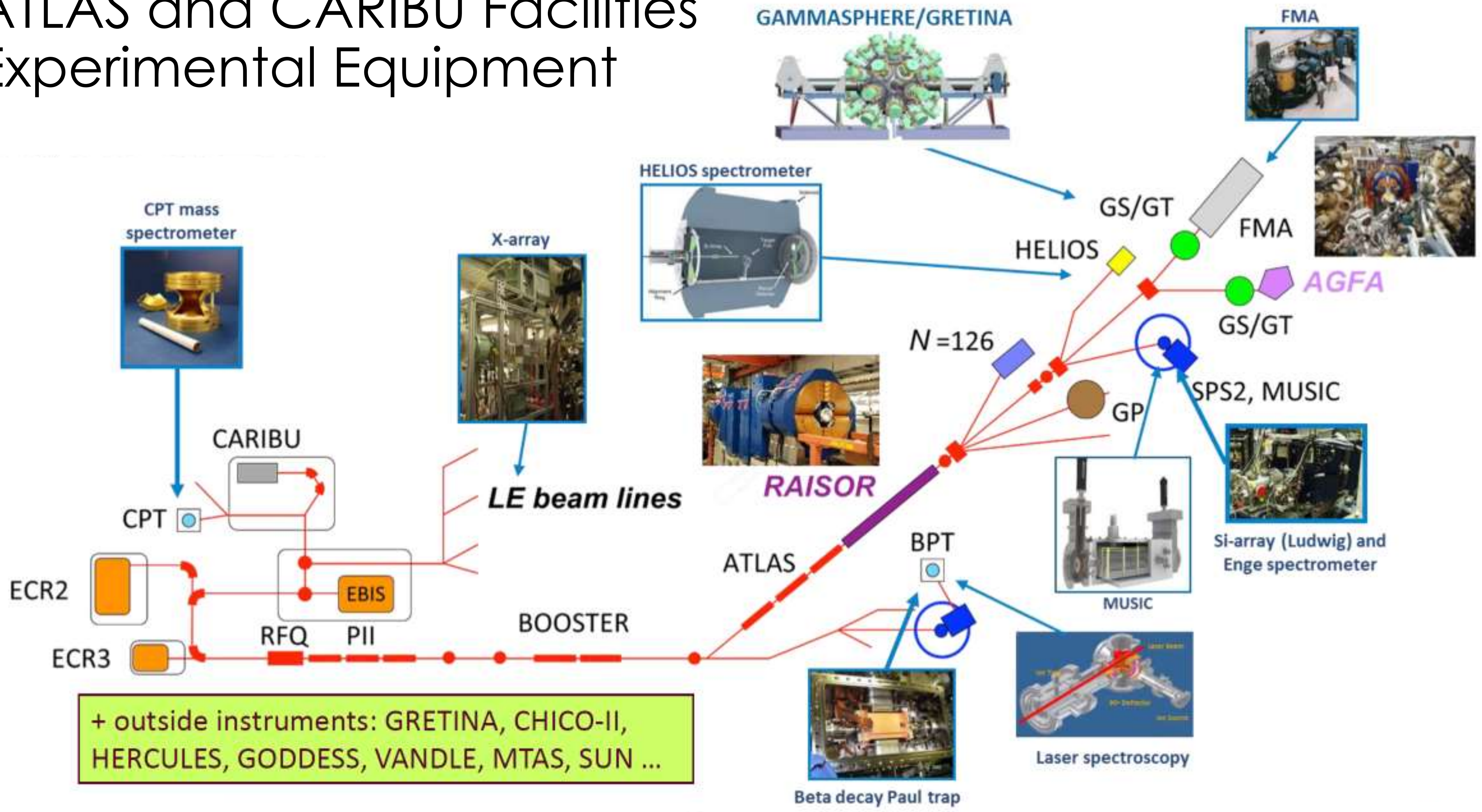


ATLAS and CARIBU Facilities, Argonne National Lab



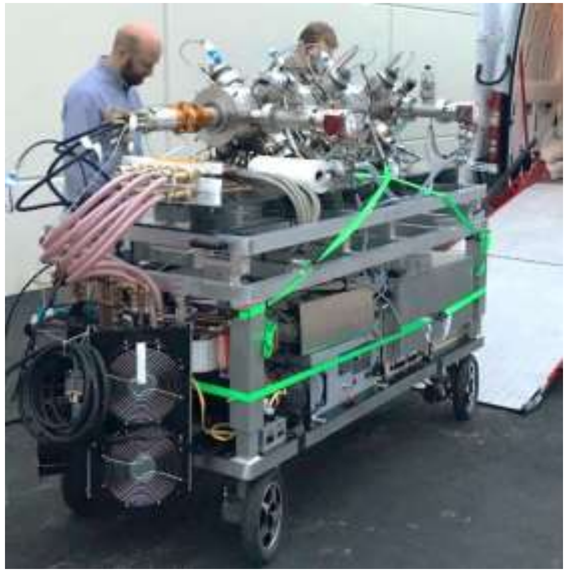
Argonne NATIONAL LABORATORY

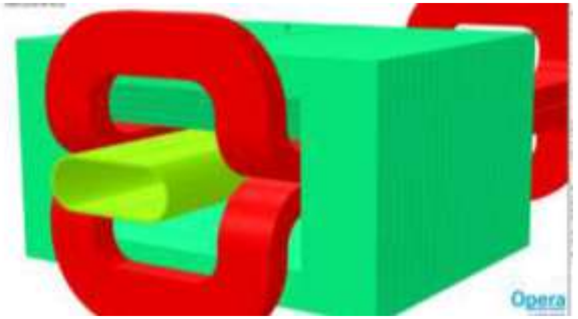
ATLAS and CARIBU Facilities Experimental Equipment

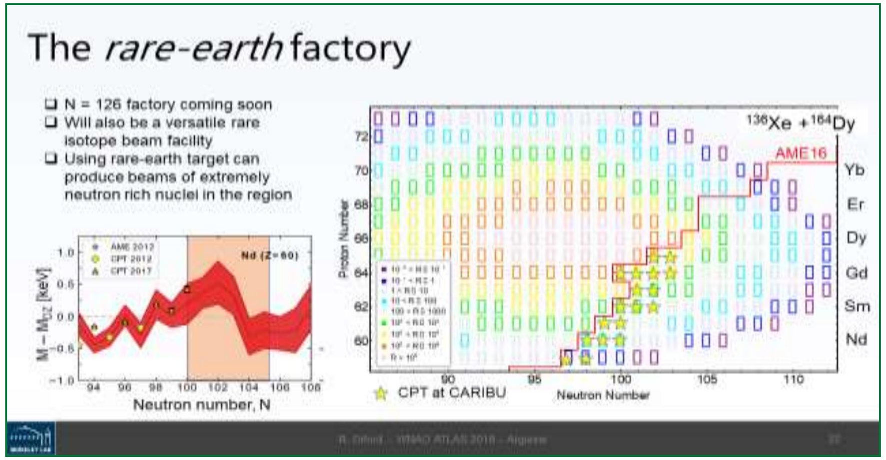


+ outside instruments: GRETINA, CHICO-II, HERCULES, GODDESS, VANDLE, MTAS, SUN …

ATLAS and CARIBU Facilities
Facility Upgrades







NuCARIBU upgrade:
Neutron generator for neutron-induced fission, replace Cf source. Back end hardware remains the same. Improved yields and up-time.

Multi-User upgrade:
Mix beams with same A/q but different duty cycle, then reseparate prior to 2nd stage acceleration. Allows two end stations to run simultaneously.

N=126 Factory upgrade:
Utilize heavy beam/heavy target transfer reactions to produce elements in rare earth peak. Higher yields than fragmentation. Measure completely unknown masses/decays.

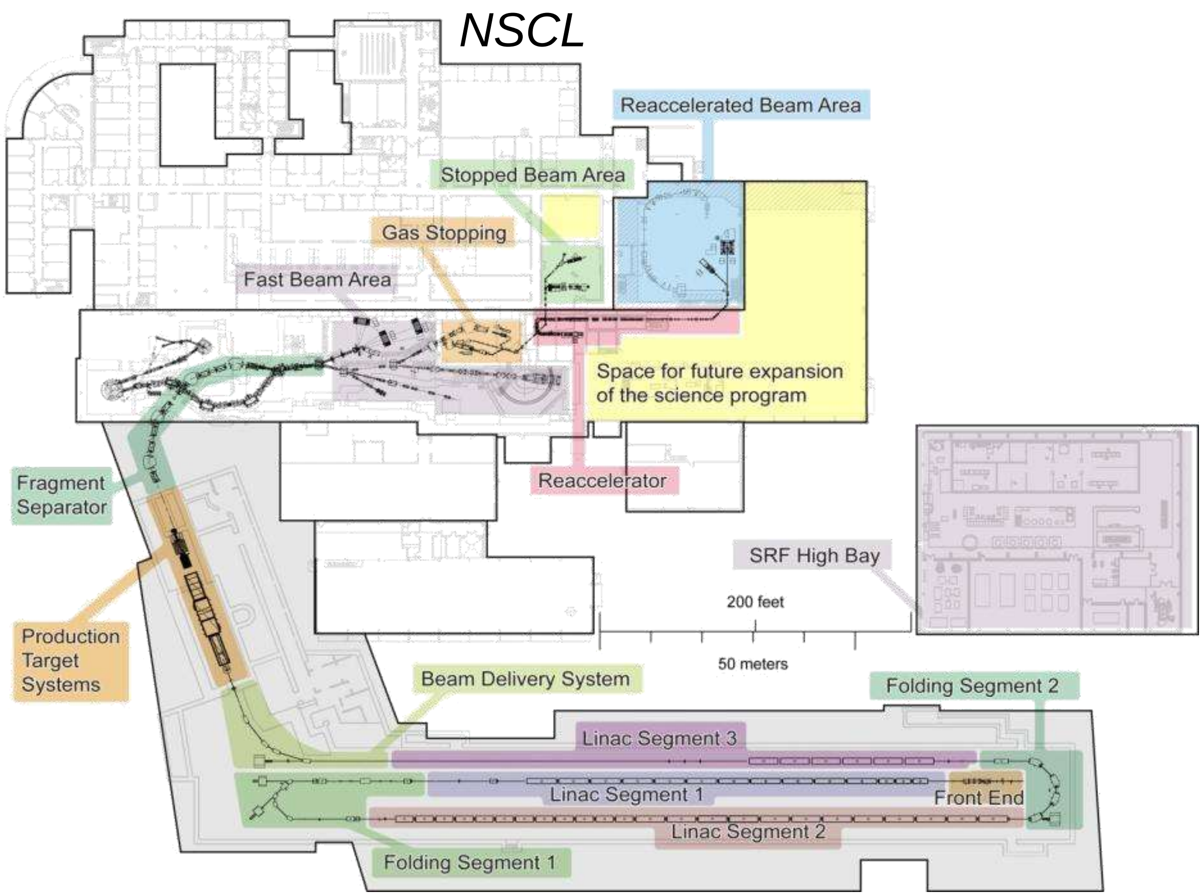
DOE LE NP User Facilities: FRIB

Facility for Rare Isotope Beams (FRIB)

- Rare isotope production via in-flight fragmentation 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

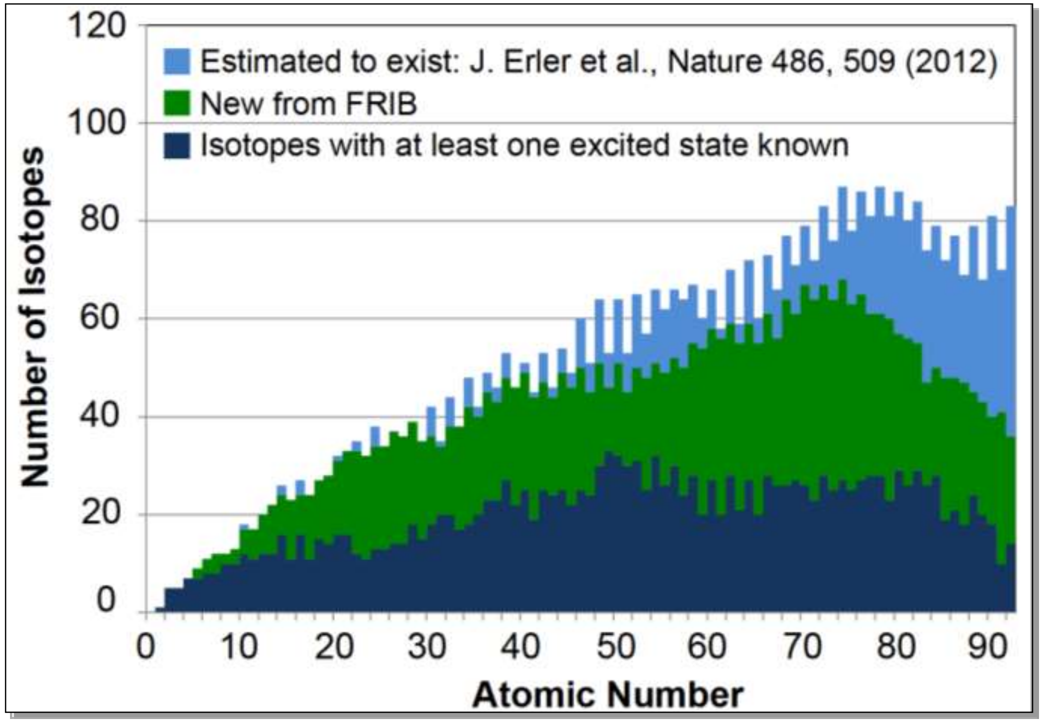
FRIB project start 6/2009
Civil construction started 3/2014
Technical construction started 10/2014
Managed to early completion FY 2021
CD-4 (project completion) 6/2022

Total project cost $730 million

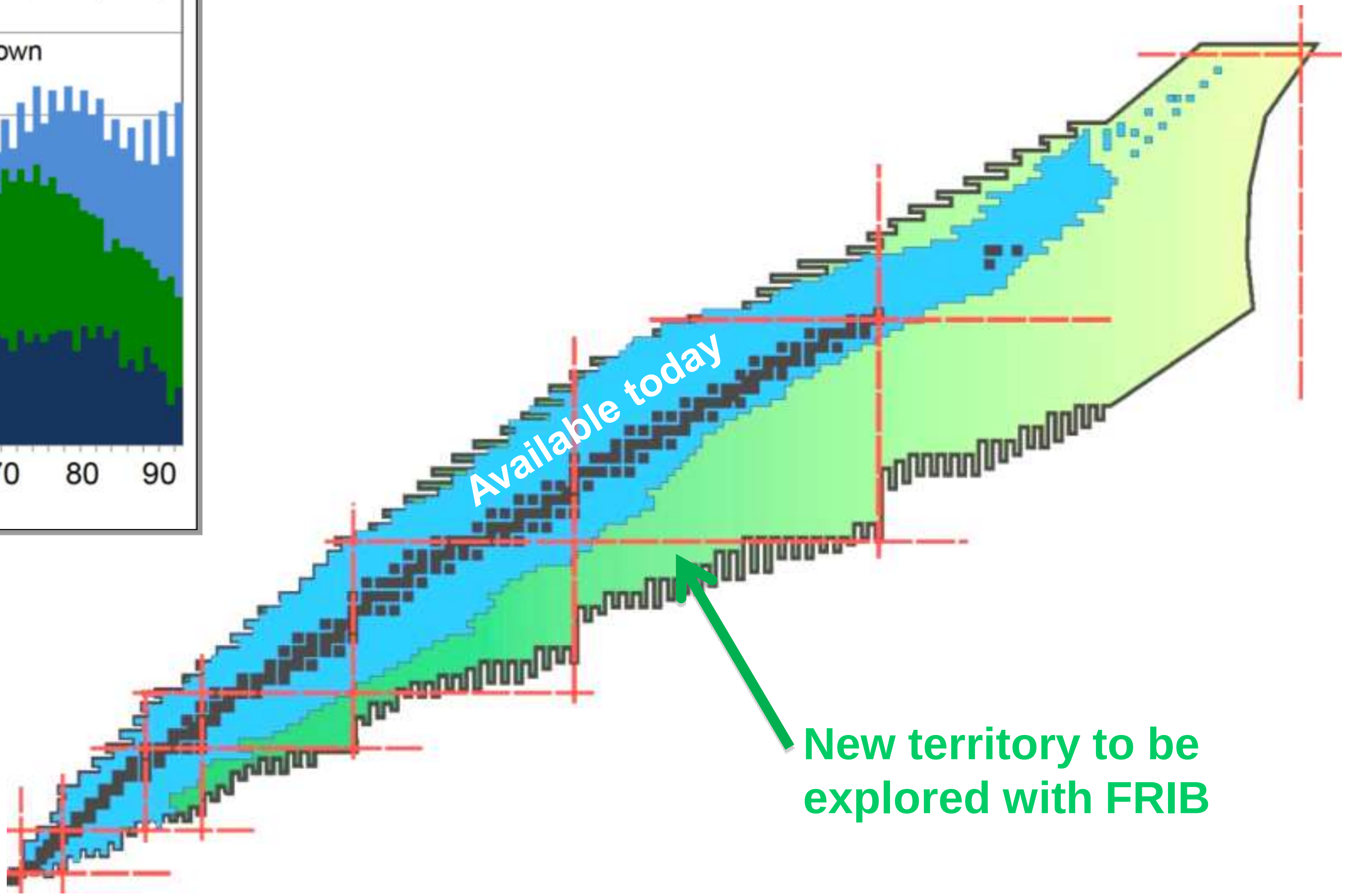


NSCL enables pre-FRIB science

FRIB Beams Will Enable New Discoveries



about 3000 known isotopes



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Facility for Rare Isotope Beams – Civil Construction

> 94% completion

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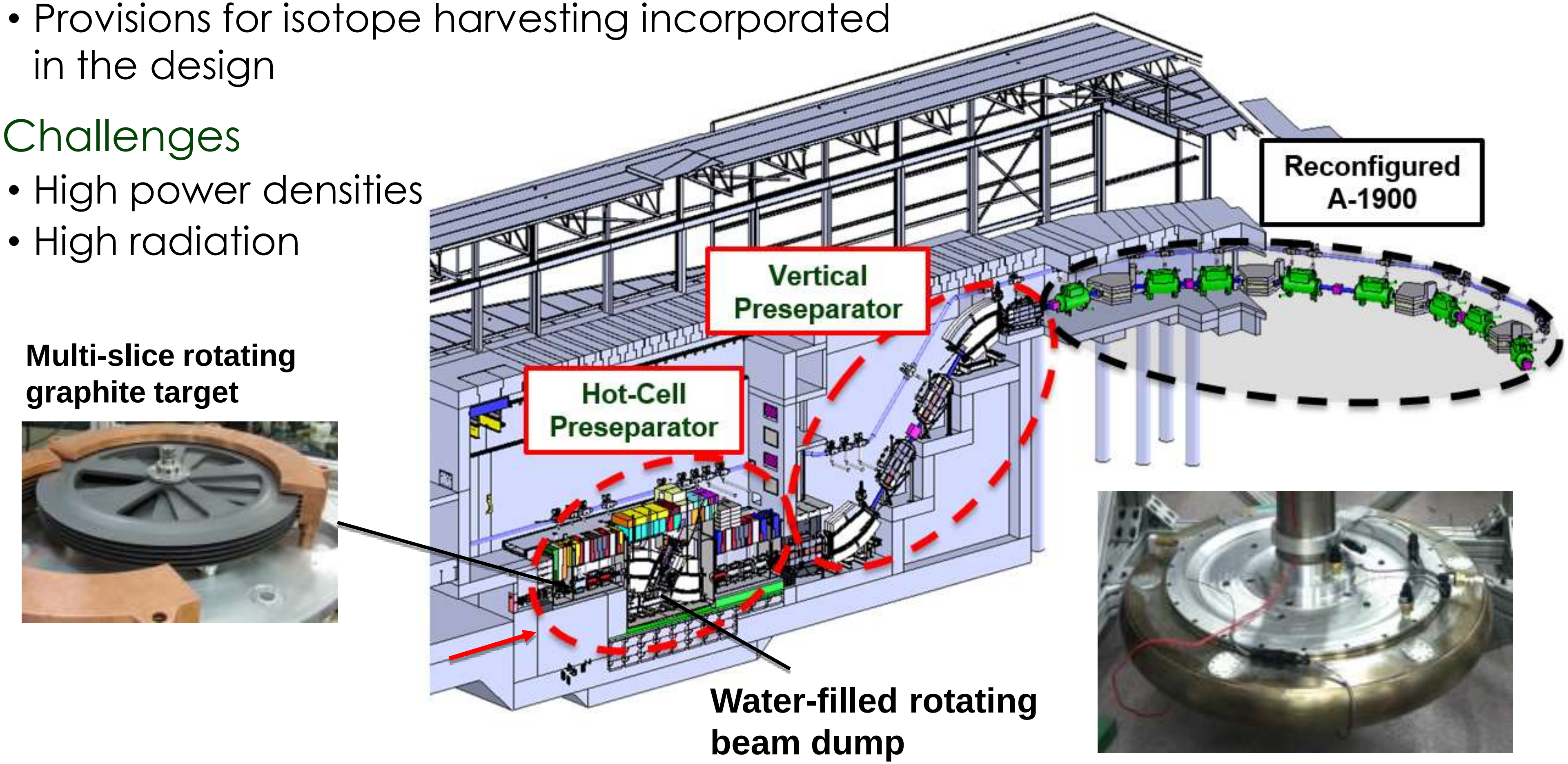
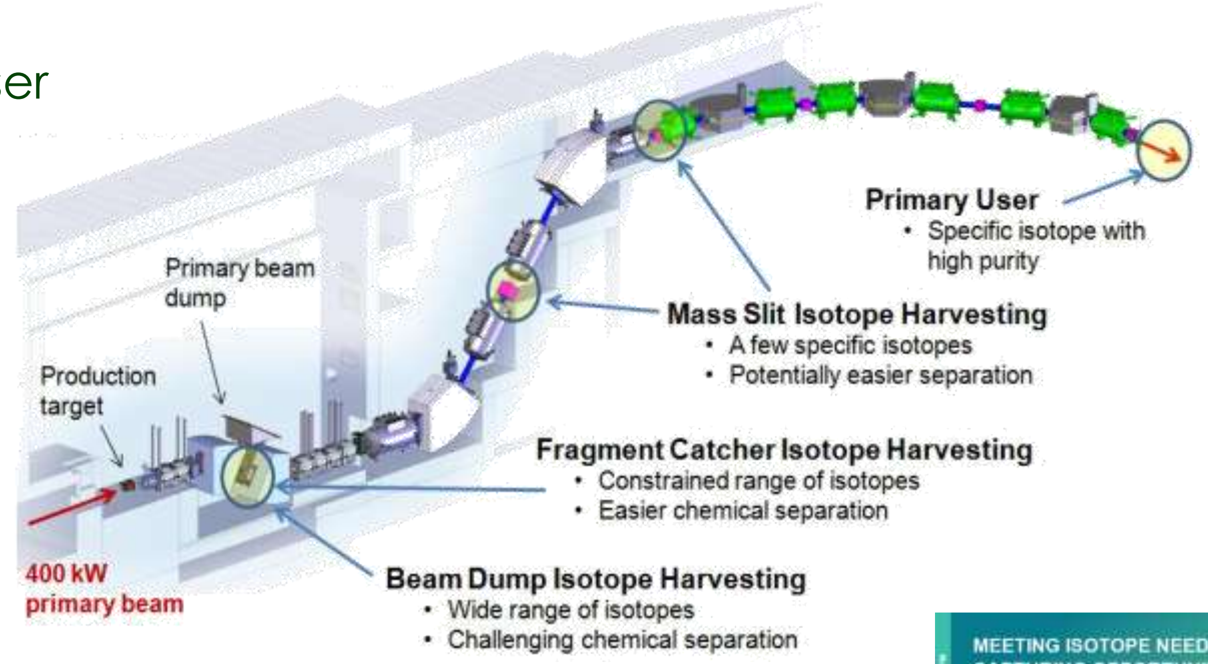
FRIB Production Facility/Beam Delivery

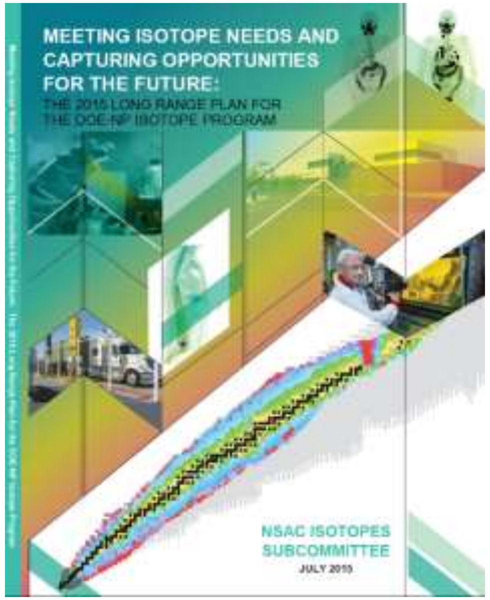
- Three stage magnetic fragment separator
  - High acceptance, high resolution to maximize science
  - Provisions for isotope harvesting incorporated in the design
- Challenges
  - High power densities
  - High radiation



Leveraging FRIB Capabilities – Isotope Harvesting

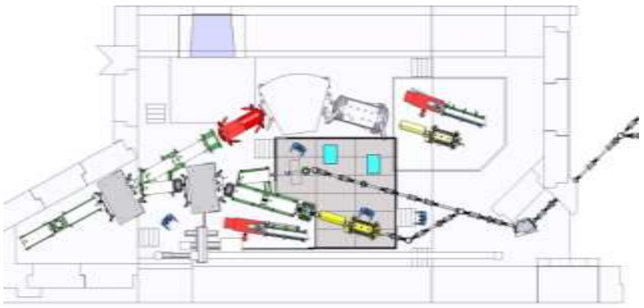
- Many rare isotopes are produced but only one isotope delivered to single user
  - Often 1000 other isotopes are produced that could be harvested and used for experiments or applications
- FRIB has provisions for isotope harvesting incorporated in the design
  - Water-cooling and off-gas system prepared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

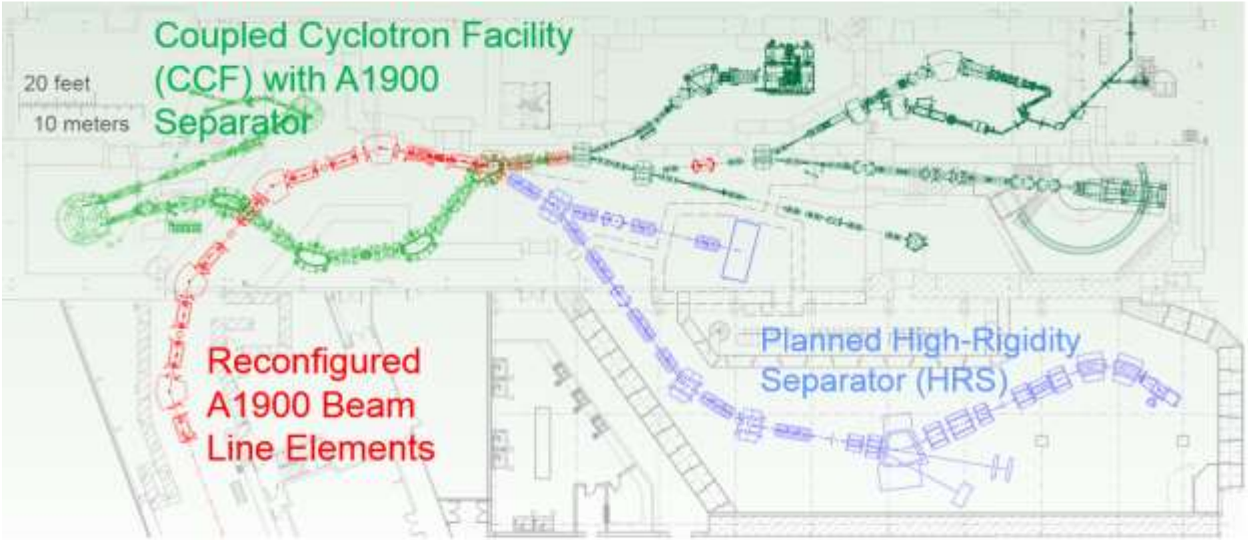




Three Main Beam Areas: Fast, Stopped, Reaccelerated; Experimental Equipment

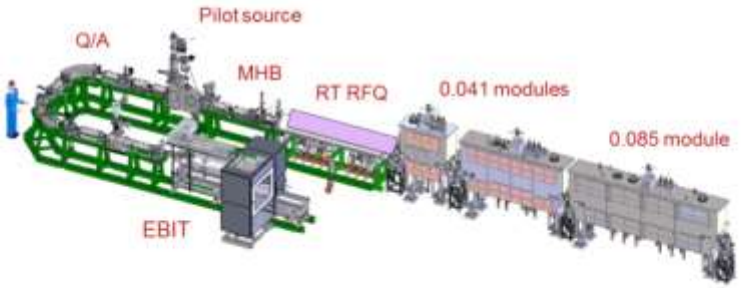
Stopped Beams





Fast Beams

Reaccelerated Beams



Large suite of experimental equipment: will focus on a few cases
>> GRETA (fast beams)
>> Decay Station (stopped beams/fast beams)
>> SECAR (reaccelerated beams)
>> SOLARIS (reaccelerated beams)

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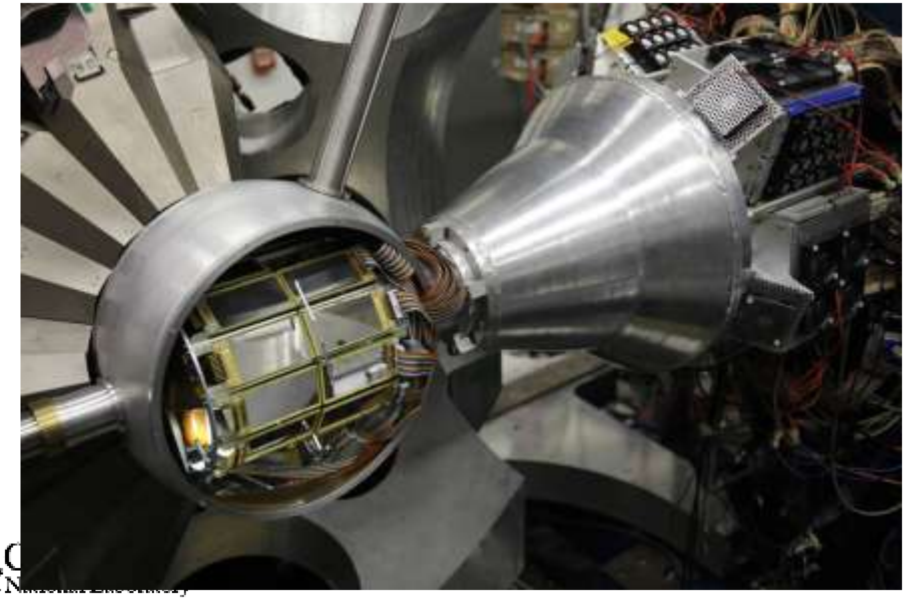
DOE LE NP Advanced Instrumentation

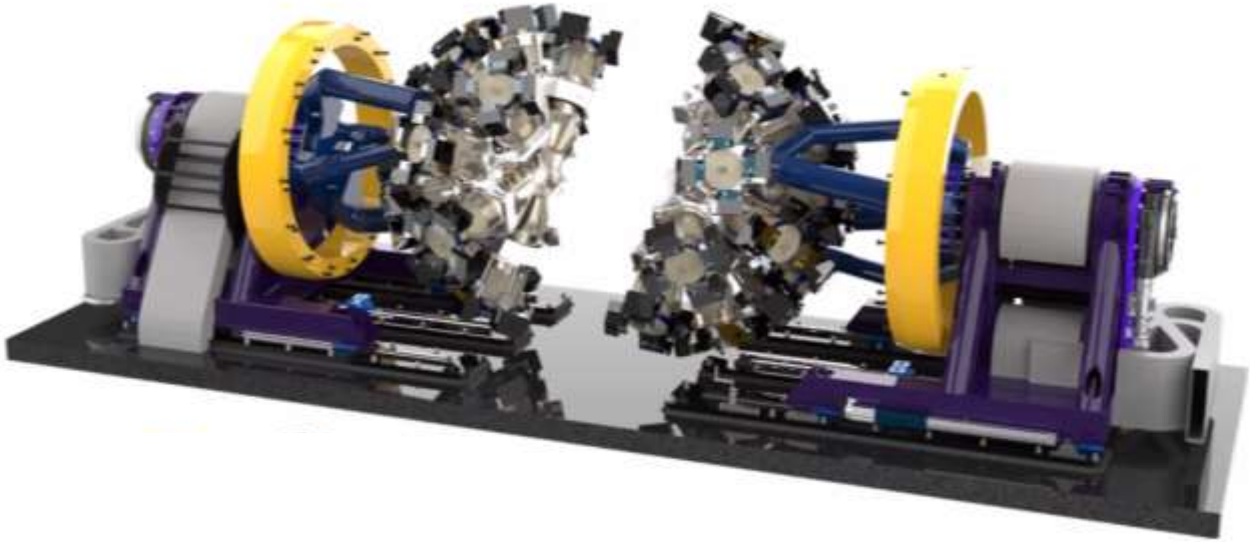
Advanced Instrumentation for LE Nuclear Physics

- Broad range of technologies and solutions are needed for the broad range of experiments, beams, and physics goals
  - Detectors: high efficiency, high resolution, particle identification
  - Spectrometers: large acceptance, high rigidity
  - Ions and atom traps, lasers: high-precision experiments, high sensitivity
  - Control systems and data acquisition: large range of energies, rates
- High-power facilities like FRIB or N=126 Factory at ATLAS 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

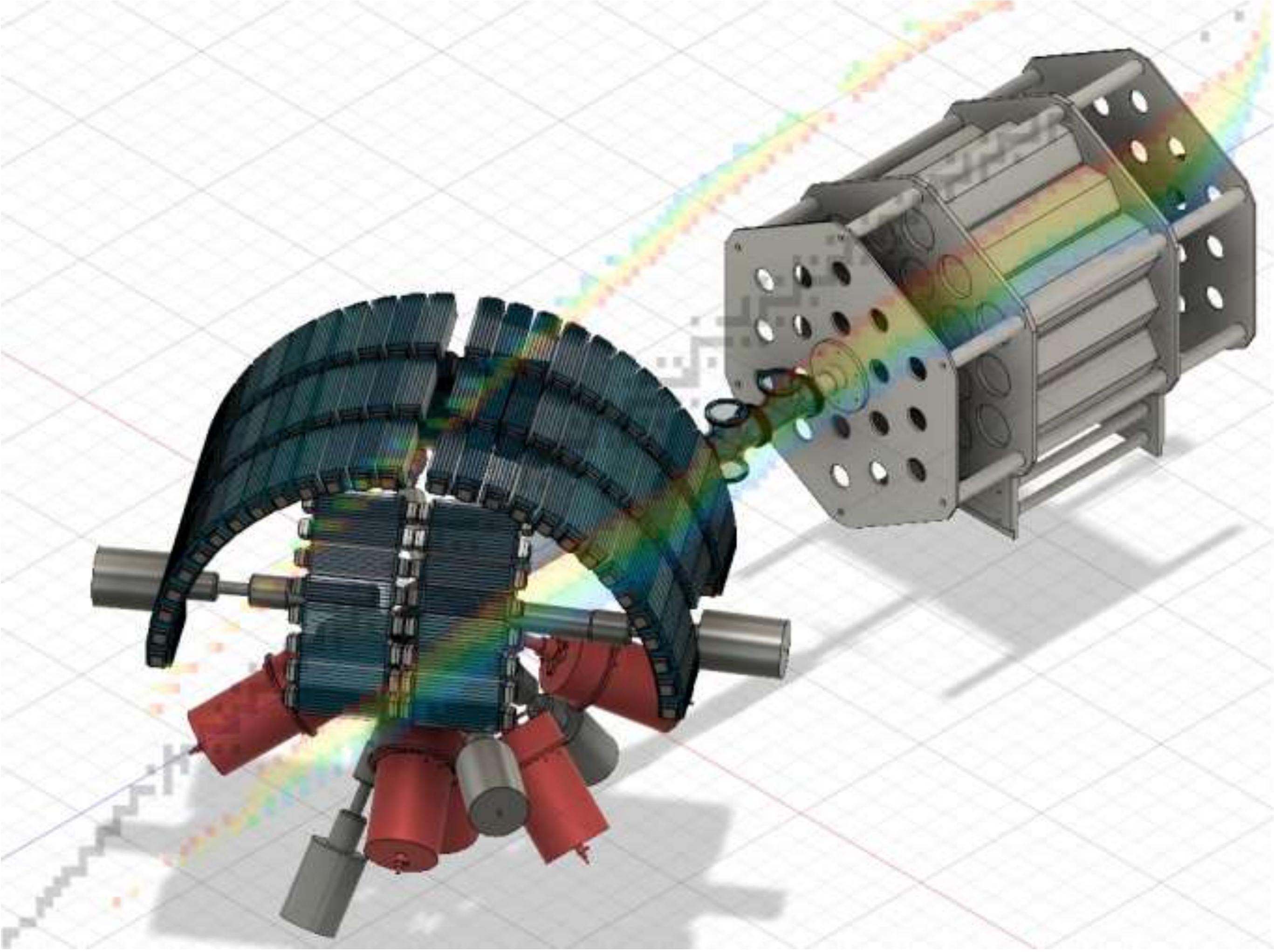
Advanced Instrumentation: GRETA

- GRETA will be the most advanced gamma-ray detector array for nuclear science, coupled to the High Rigidity Spectrometer (under development)
- GRETINA is the first “phase” of GRETA: Gamma Ray Energy Tracking Array
  - Uses highly segmented, highly purified Ge detectors to track and reconstruct gamma rays from nuclear reactions
  - Digitized signals (unique system), complicated reconstruction algorithms, extensive hardware, combinations with other devices eg GODDESS





Advanced Instrumentation: Decay Station



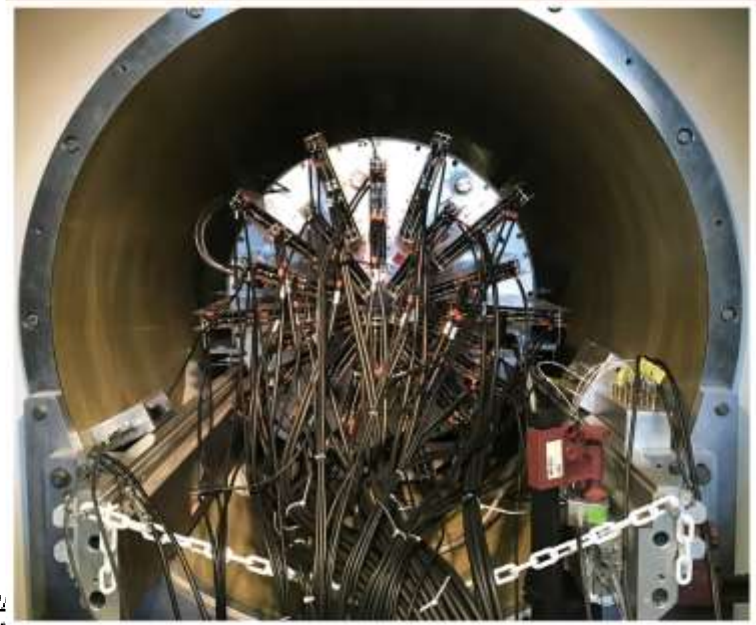
- The FRIB Decay Station will provide a suite of instrumentation to take advantage of "day one" discovery opportunities
  - Efficient, granular, and modular multi-detector system designed under a common infrastructure
  - Multiple complementary detection modes together in a framework capable of performing spectroscopy with multiple radiation types over a range of beam production rates spanning ten orders of magnitude
  - HPGe array for gammas, time-of-flight scintillators for neutrons, Si implantation array for decay lifetimes, digital signals, large bandwidth data

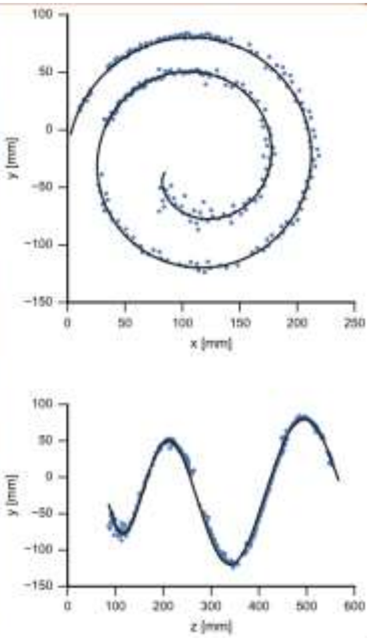
Advanced Instrumentation: SECAR

- Highly specialized SEparator for CApture Reactions
- Joint DOE/NSF funded project
- Targets the proton and alpha capture reactions powering stars and stellar explosions
  - Reject $10^{13} – 10^{17}$ particles for every one from the reaction of interest
  - Recirculating high-pressure gas target presents unique hazards
  - Digitized signals from multiple devices, slow controls, data merging, interlocks, mobile clean room

Advanced Instrumentation: SOLARIS

- SOLARIS is a next-generation solenoidal spectrometer for nuclear reactions studies
  - Large-bore solenoid magnet, LHe cooled, under vacuum
  - Dual-mode usage planned: highly segmented silicon detector array or a large gas-filled TPC
  - Digitized signals, TPC has high channel density, all equipment must operate either in or near 4 Tesla magnet





SBIR and STTR Involvement

How can SBIR/STTR impact LE NP?
There are myriad opportunities for collaborative work

- (35) Software and Data Management
- (36) Electronics Design and Fabrication
- (37) Accelerator Technology
- (38) Instrumentation, Detection Systems and Techniques

How can SBIR/STTR impact LE NP?

- (35) Software and Data Management
  - High bandwidth/high rate data collection
  - Novel digitization filters
  - Fast algorithms/parallelization
  - Real-time data visualization
- (36) Electronics Design and Fabrication
  - High channel density preamplifiers and onboard logic
  - Radiation-hard or magnetic-field-resistant electronics
  - Ultra-low-noise devices
  - Onboard slow controls/readback

How can SBIR/STTR impact LE NP?

- (37) Accelerator Technology
  - Radiation hard beamline components (actuators, motors, seals)
  - High power fragmentation targets
  - PLC/smart slow controls/interlocks
  - High efficiency/low contamination charge breeders
- (38) Instrumentation, Detection Systems and Techniques
  - Beam monitoring/tracking (event-by-event over wide range of rates)
  - Ultra-thin charged particle detectors
  - Gamma-blind neutron detectors
  - New detection techniques incorporating quantum sensing

Some additional "real world" examples

- Development of large volume stilbene scintillation detectors (LANL)
- Development of coupled silicon photomultiplier + scintillator readout (LANL)
- Development of doped/loaded scintillation detectors (UMass Lowell)
- Development of mitigation techniques for neutron damage effects in HPGe detectors (UMass Lowell)

Many more opportunities exist!

A good place to start is the FRIB Users website:

https://fribusers.org/workingGroups/index.html

I am also available to put you in touch with the right person:

chippska@ornl.gov

Thank you for your attention!