NP LOW ENERGY FACILITIES AND THE SBIR/STTR PROGRAM

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DOE NP SBIR/STTR Exchange Meeting
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OUTLINE

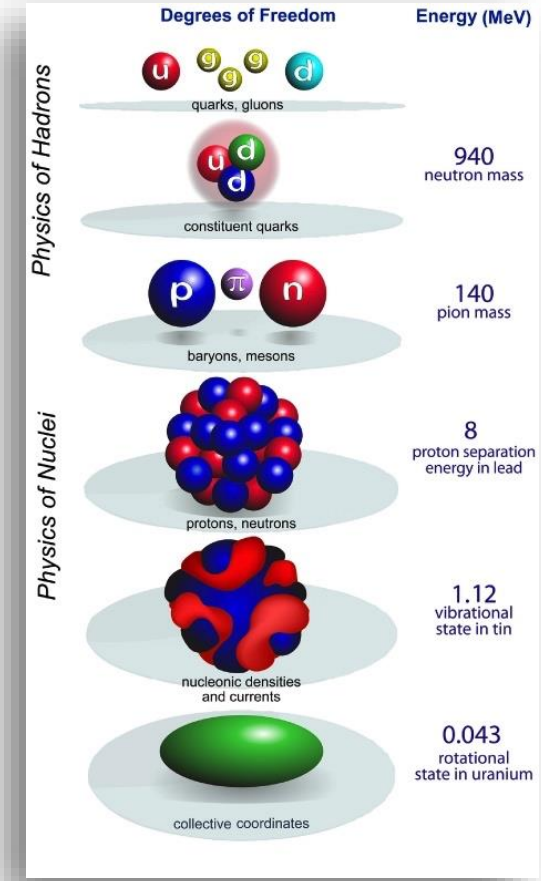
- Low energy nuclear physics
- DOE facilities
  - Overview
  - ATLAS/CARIBU
  - FRIB
- Instrumentation
- Summary

- Acknowledgements – information provided by
  - Georg Bollen, Thomas Glasmacher, Dave Morrissey, Greg Severin, Brad Sherrill (FRIB/MSU)
  - Heather Crawford, Paul Fallon, Jackie Gates, Augusto Macchiavelli (LBNL)
  - Guy Savard (ANL)

LOW ENERGY NUCLEAR PHYSICS

LOW ENERGY NUCLEAR PHYSICS

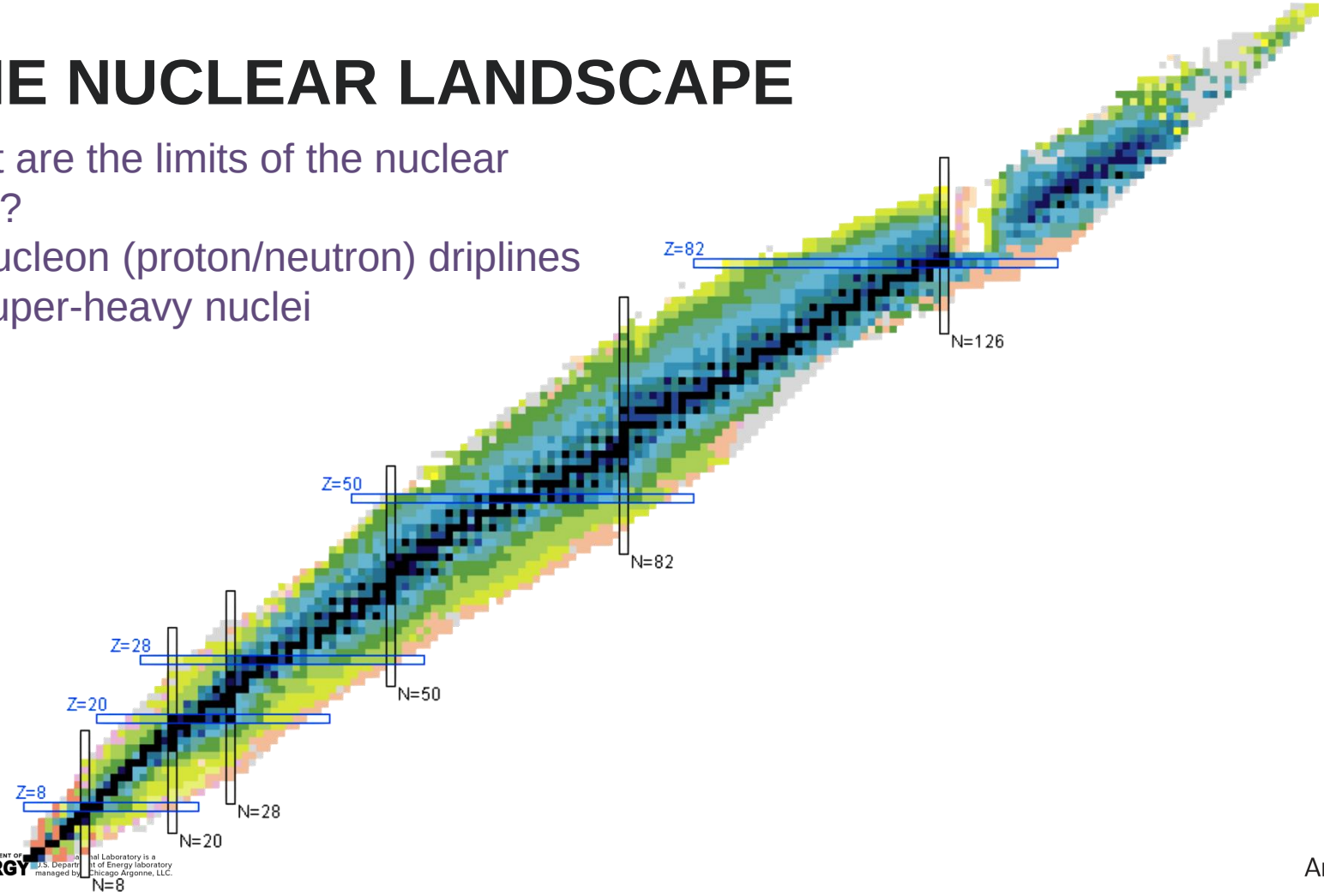
- Refers to the energy scale of the science
  - Of order few MeV (nuclear binding scale)
- Physics encompasses nuclear structure, decay, reactions and limits of nuclear chart
- Most direct impacts to our lives
  - Energy
  - Medicine
  - Security . . .



THE NUCLEAR LANDSCAPE

What are the limits of the nuclear chart?

- Nucleon (proton/neutron) driplines
- Super-heavy nuclei



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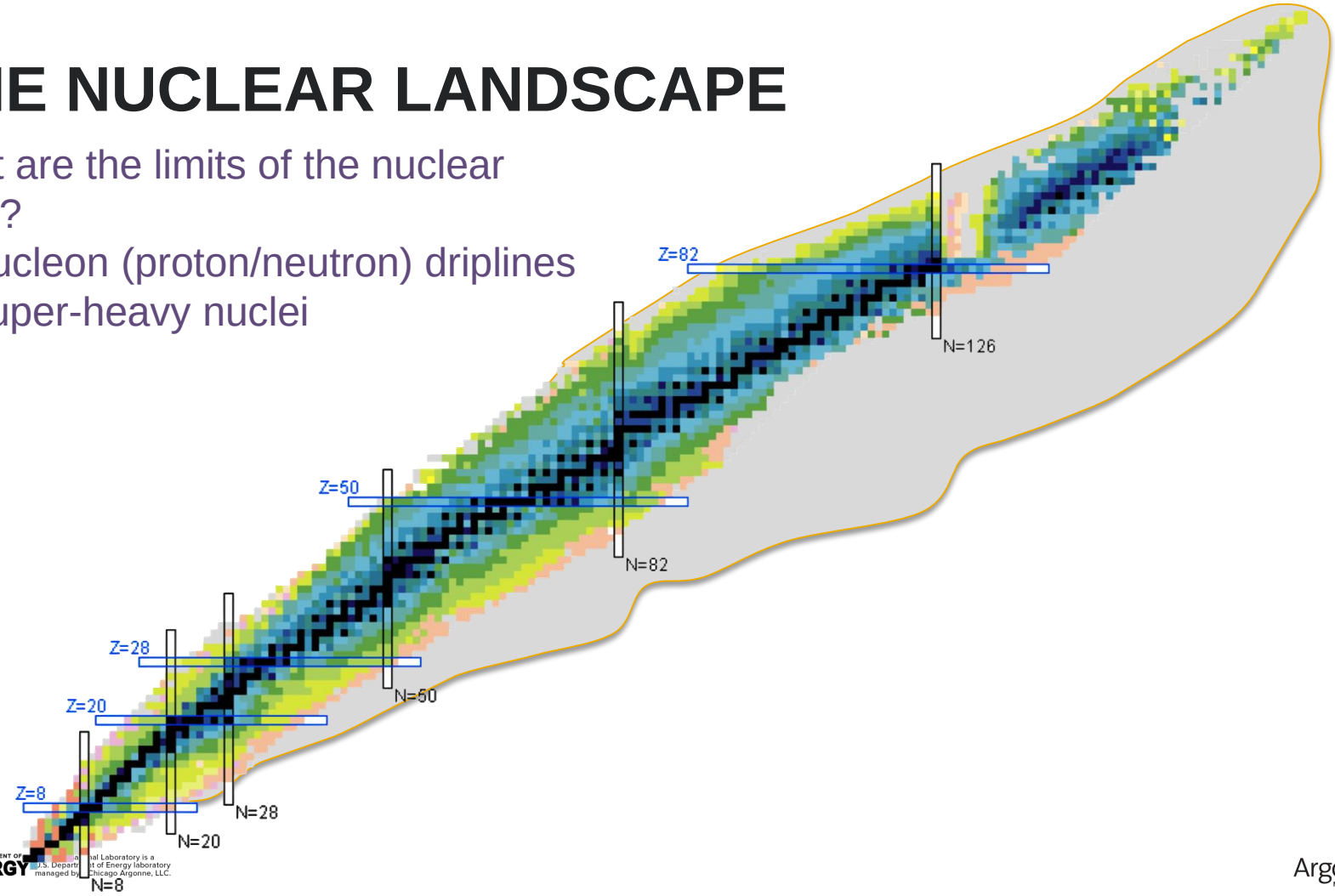

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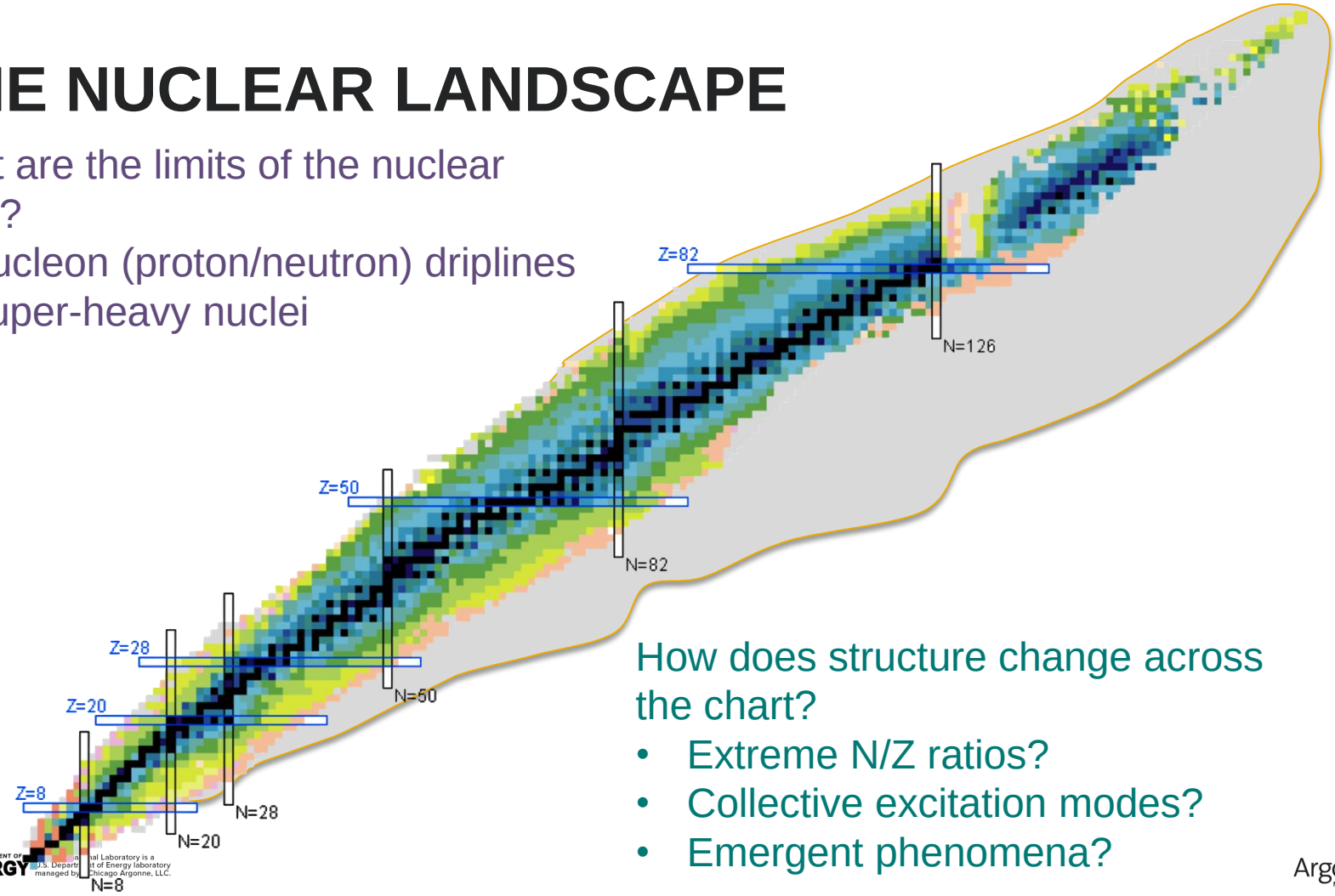


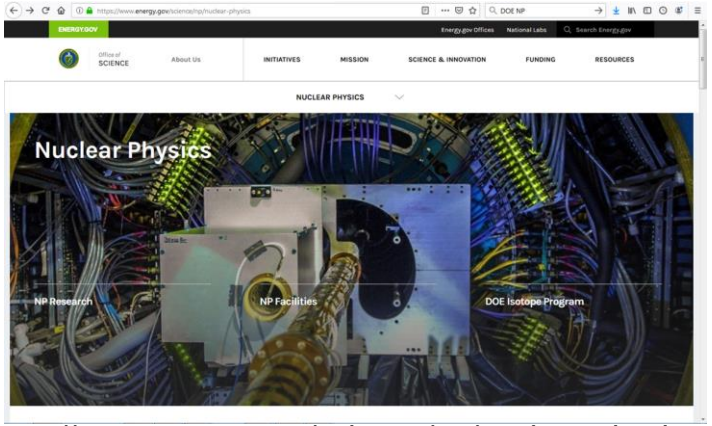
How does structure change across the chart?

- Extreme N/Z ratios?
- Collective excitation modes?
- Emergent phenomena?

ANSWERING THESE QUESTIONS

1. Accelerator facilities
   - Diverse capabilities to deliver beams of stable and radioactive ions, at energies ranging from ~ 100 keV to GeV
2. Advanced Detectors and Instrumentation
   - High efficiency, high resolution detection systems for:
     - Light charged particles
     - Heavy charged fragments
     - Gamma-rays
     - Neutrons
   - Data acquisition, software and data storage

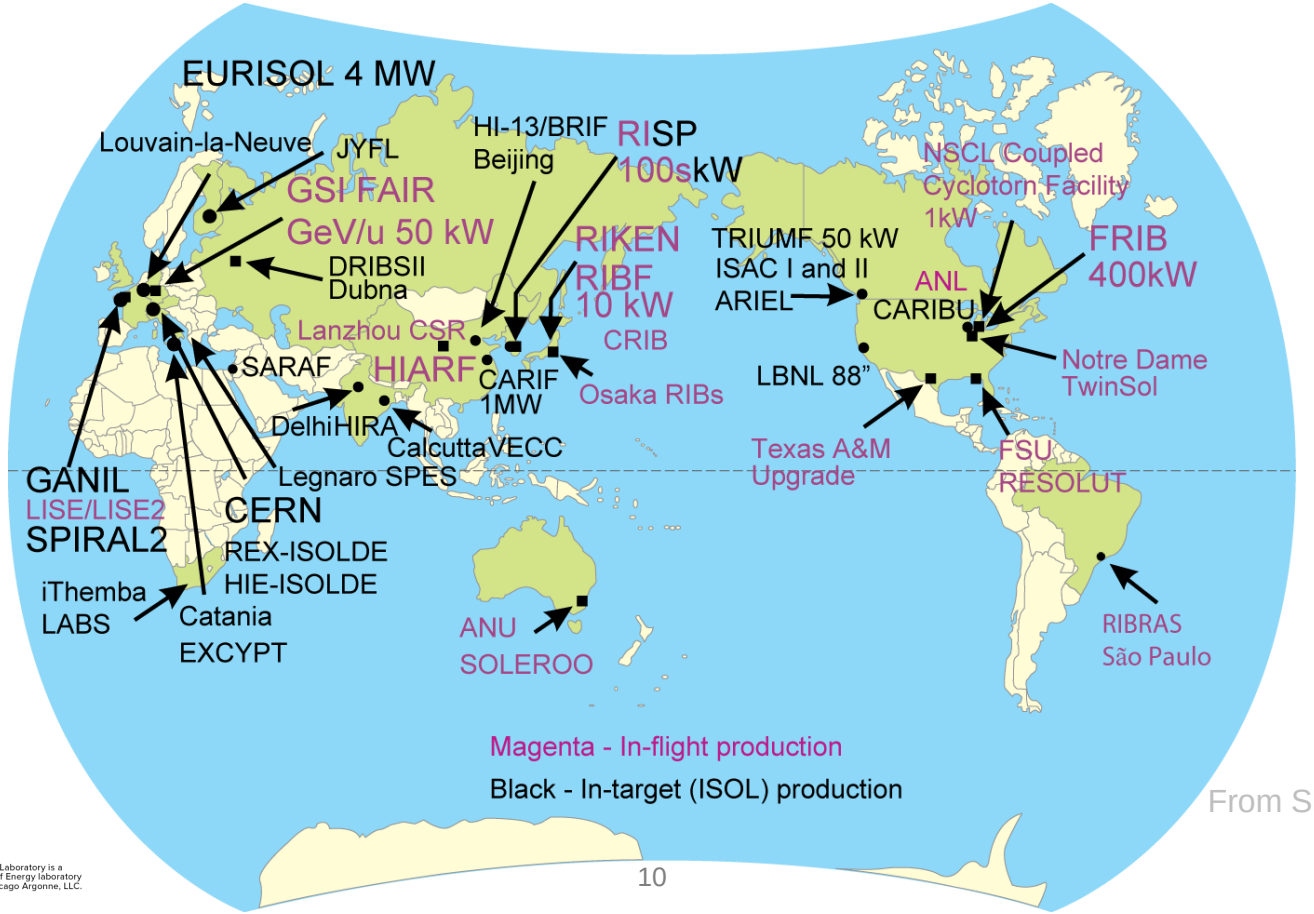
The 2015
LONG RANGE PLAN
for NUCLEAR SCIENCE



https://www.energy.gov/science/np/nuclear-physics

ACCELERATOR FACILITIES

RARE ISOTOPE BEAM FACILITIES WORLDWIDE



From Sherrill/Bollen - MSU

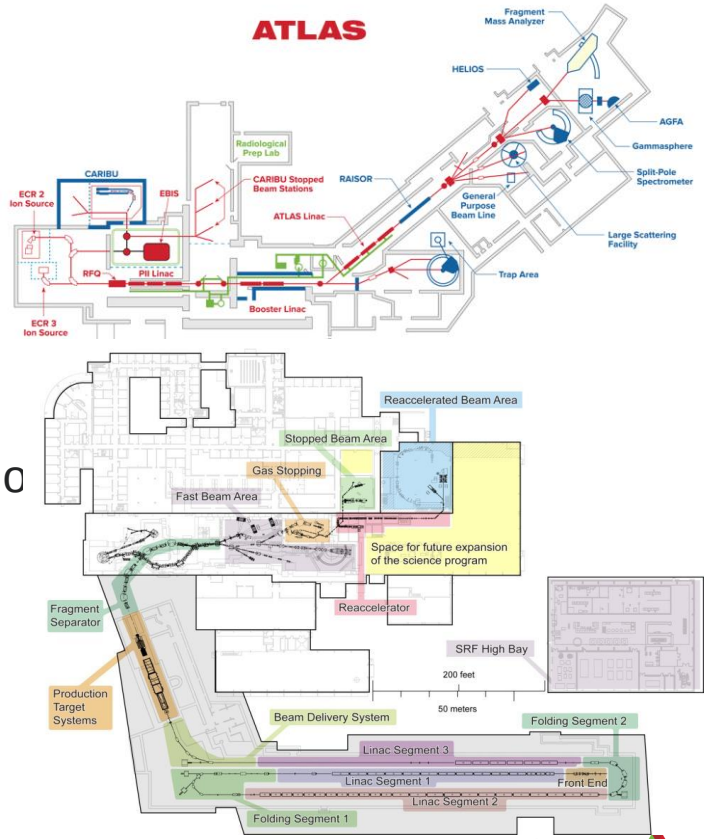
LOW ENERGY NUCLEAR PHYSICS FACILITIES

DOE National User Facilities

- **Argonne Tandem-Linear Accelerator System (ATLAS) –** https://www.anl.gov/atlas
  - High-intensity stable beams
  - Radioactive beam program with stopped and re-accelerated fission products and in-flight beams
- **Facility for Rare Isotope Beams (FRIB)** – http://frib.msu.edu
  - World-leading facility under construction at MSU
  - 400 kW heavy-ion SRF line; > 200 MeV/u
  - Rare isotopes via fragmentation and in-flight fissio
  - Fast, stopped, and reaccelerated beams

NSF User Facilities

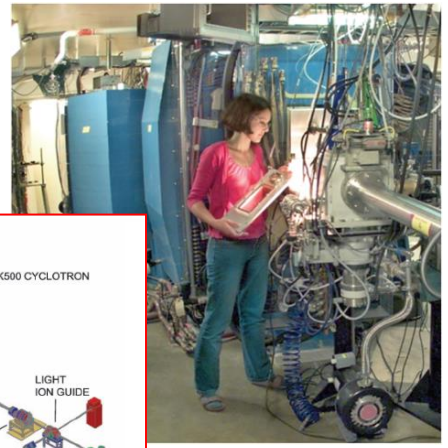
- **National Superconducting Cyclotron Laboratory (NSCL)** – http://nscl.msu.edu
  - In-flight rare isotope beam production
  - Fast, stopped, and reaccelerated beams

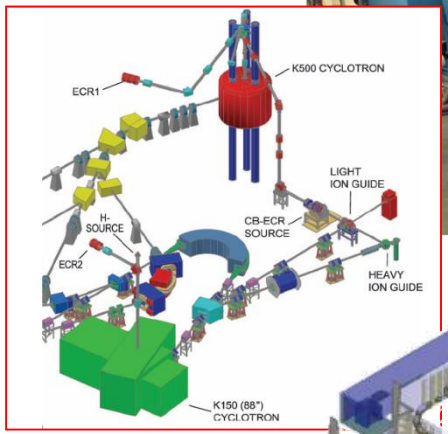


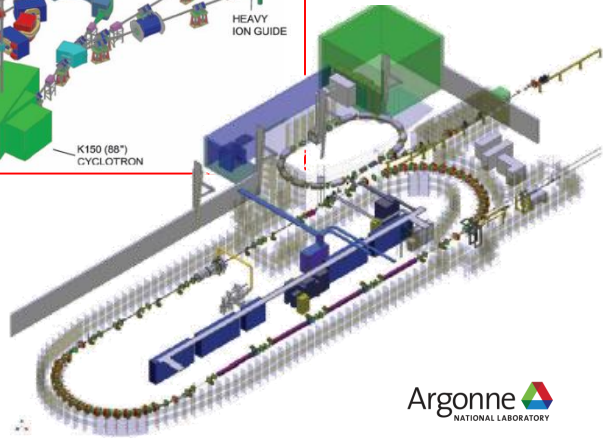
LOW ENERGY NUCLEAR PHYSICS FACILITIES

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



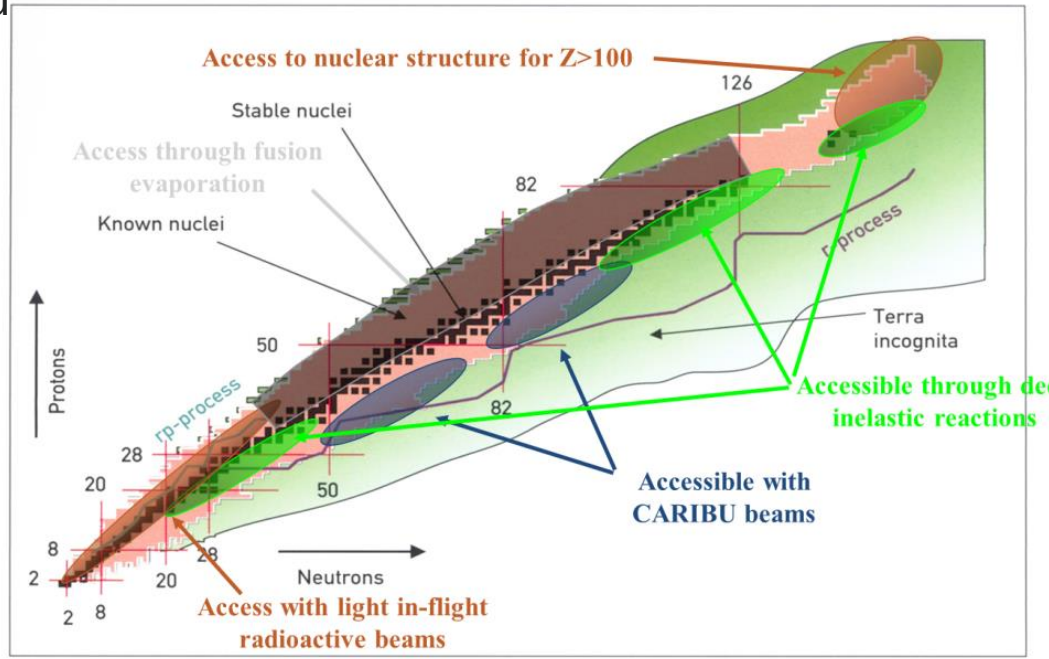




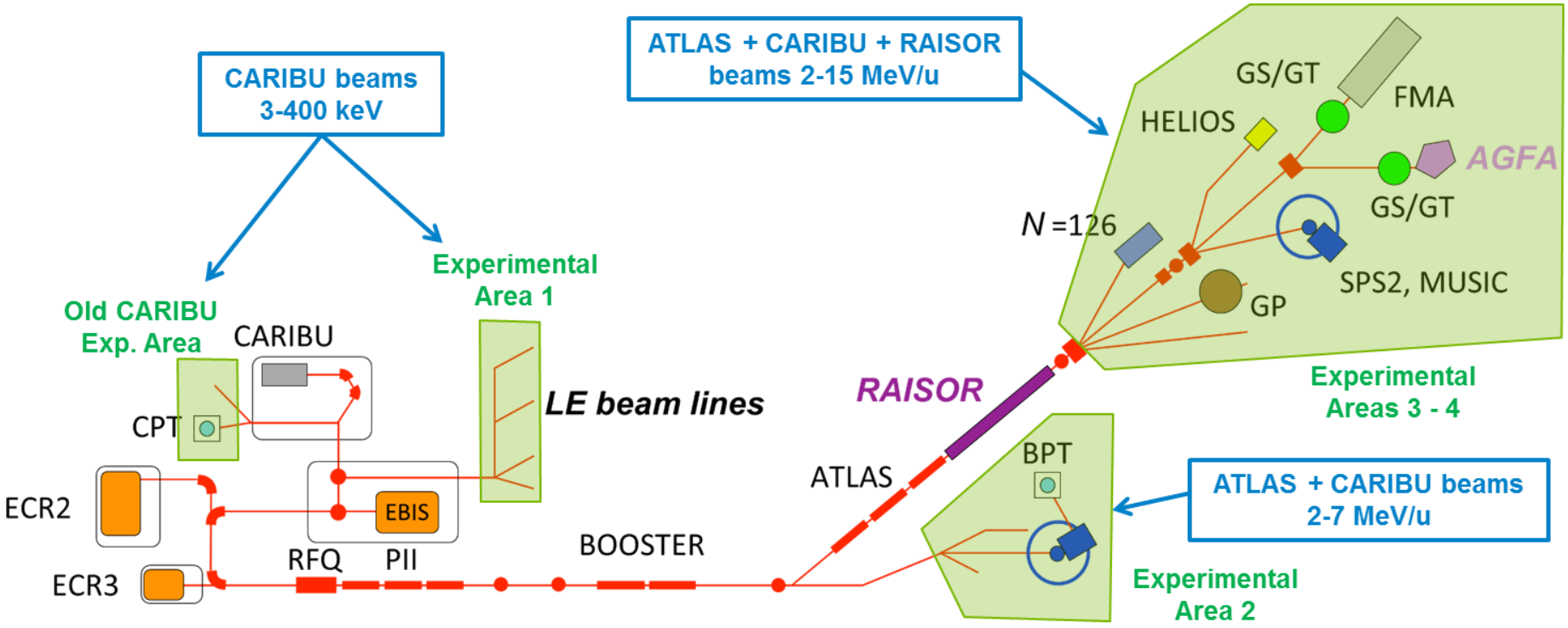
ARGONNE TANDEM LINEAR ACCELERATOR SYSTEM – ATLAS

ATLAS/CARIBU FACILITY

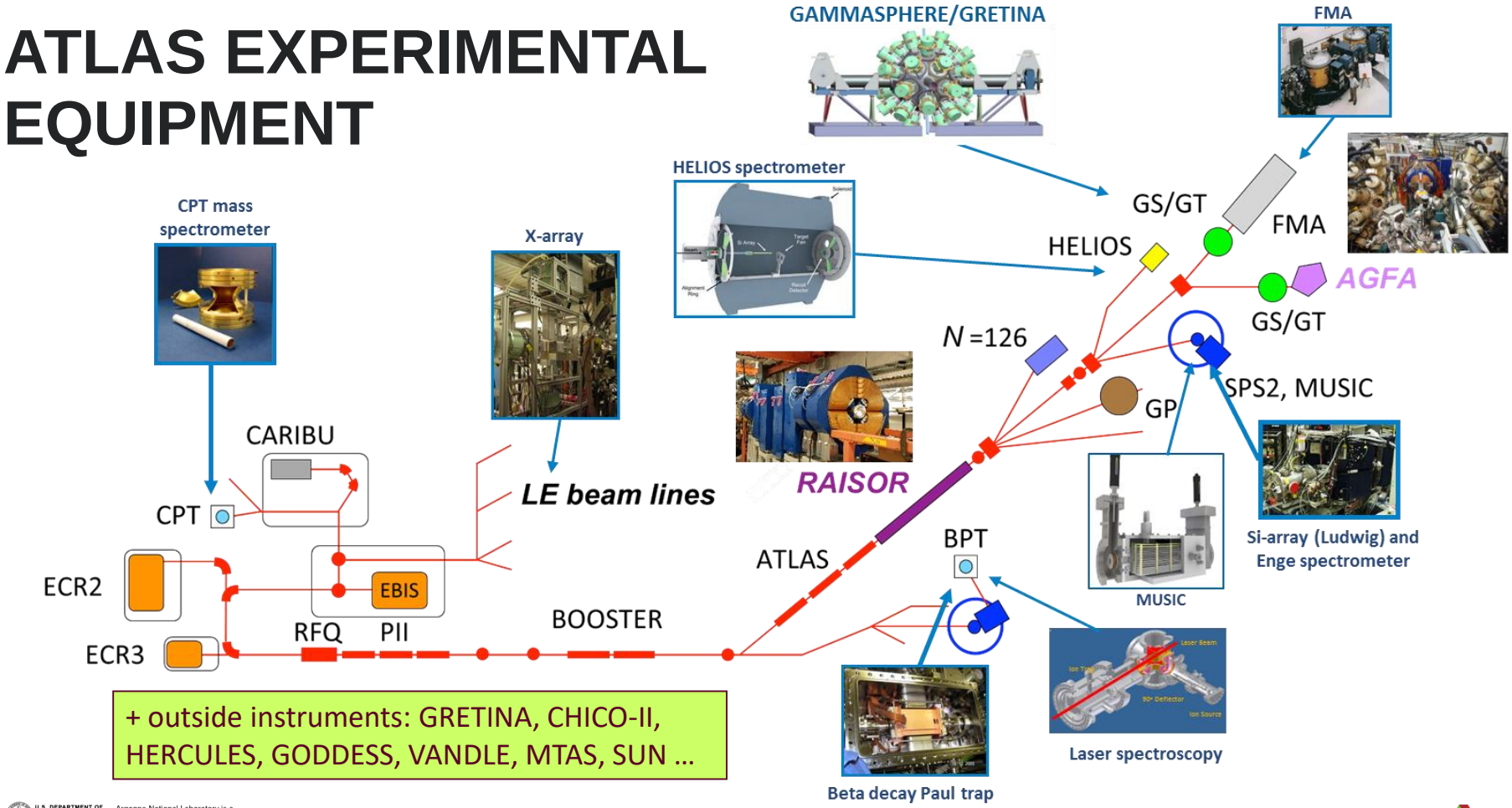
- Stable beams at high intensity, ~10pμA, and energy from ~0.5 to 10-20 MeV/u
- CARIBU (CAlifornium Rare Isotope Breeder Upgrade) beams
  - heavy n-rich from Cf fission, no chemical limitations, low intensity, ATLAS beam quality, energies up to 10 MeV/u
- In-flight radioactive beams with RAISOR
  - light beams (A<50), no chemical limitations, close to stability, acceptable beam properties
- State-of-the-art instrumentation for Coulomb barrier and low-energy experiments
- Operating 5500-6500 hrs/yr (+ 2000 hrs/yr CARIBU low energy)



ATLAS FACILITY LAYOUT



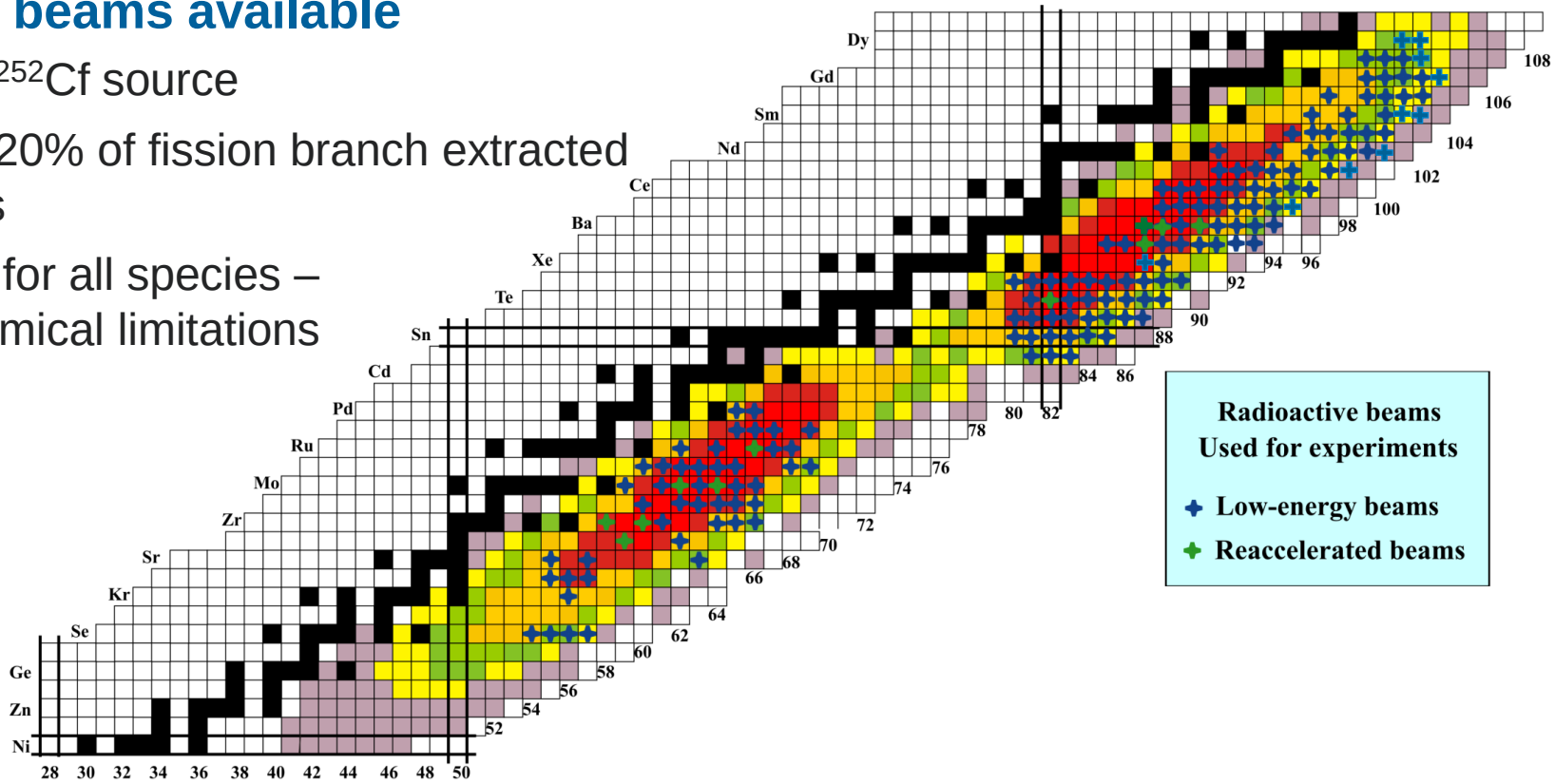
ATLAS EXPERIMENTAL EQUIPMENT



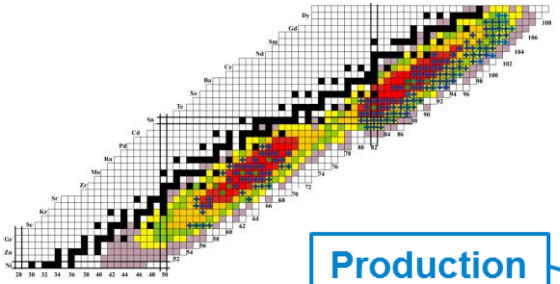
CARIBU BEAMS FOR ATLAS

Unique beams available

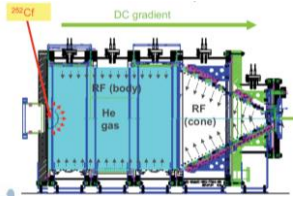
- "Thin" ^{252}Cf source
- About 20% of fission branch extracted as ions
- Works for all species – no chemical limitations



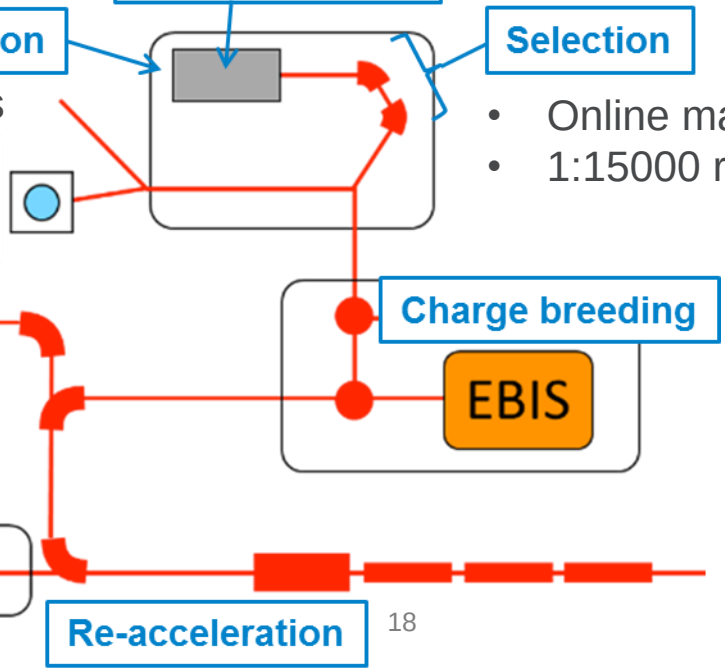
REACCELERATED CARIBU BEAMS



- ^{252}Cf fission fragments
- ≤ 10^6 ions/s
- 80 ≤ A ≤ 160
- q = +1 or +2



- High purity He gas catcher
- Thermalizes fission fragments
- RF electrodes form beam



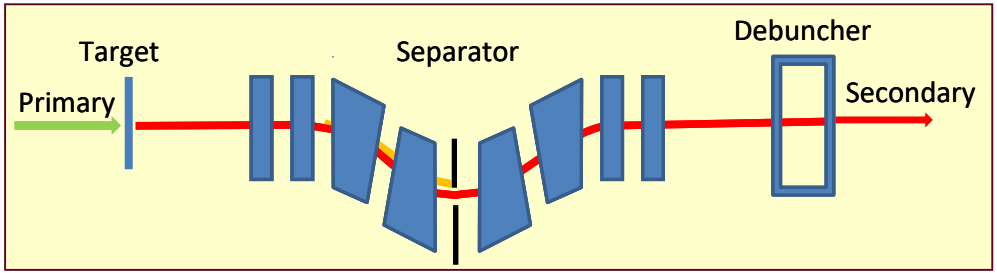
- Online magnetic separation
- 1:15000 resolution

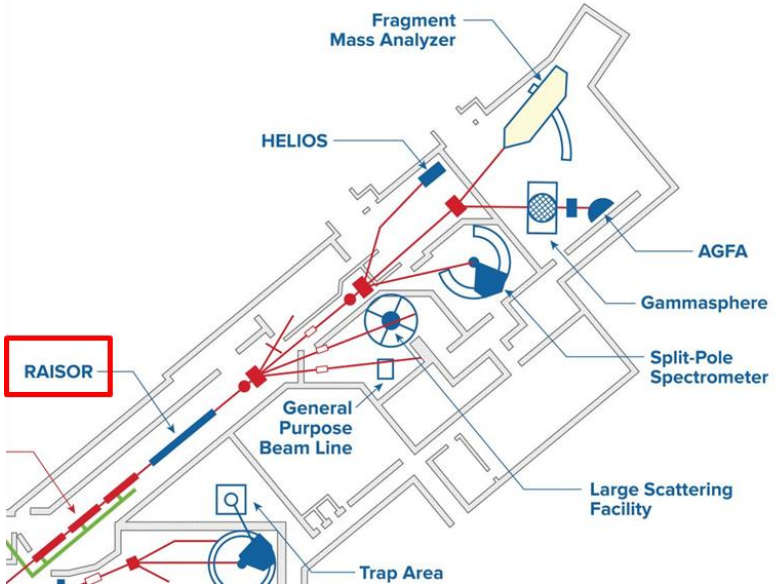
- Fast breeding
- High efficiency
- Low contamination

ATLAS IN-FLIGHT RADIOACTIVE BEAMS

Argonne In-flight Radioactive Ion Separator (RAISOR)

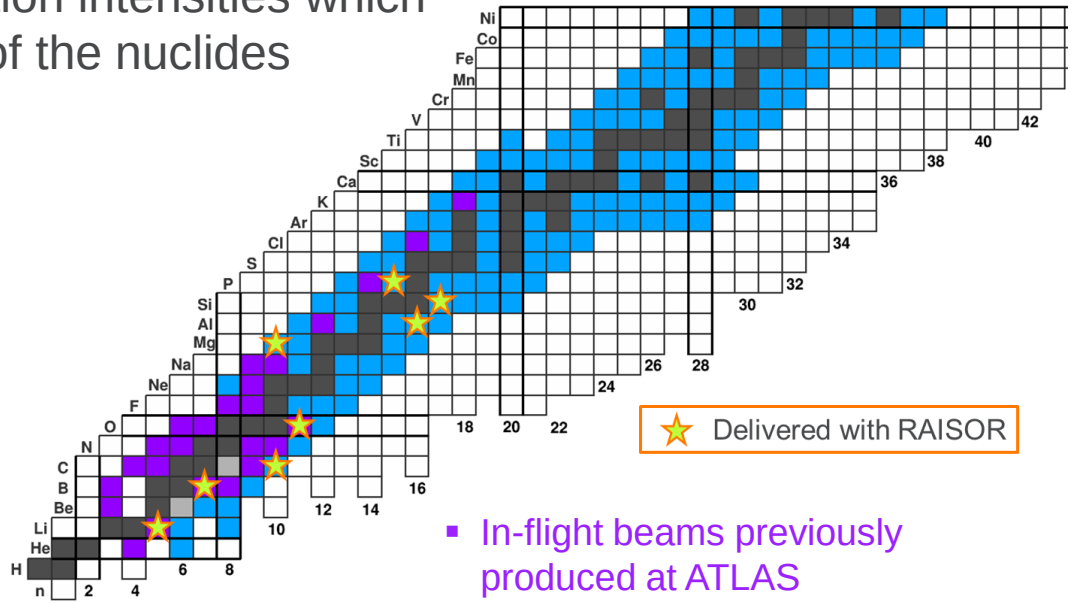
- Magnetic chicane couple with an RF sweeper
- 1-2 nucleon transfer reactions
- In-flight RIBs used to study
  - Single particle structure
  - Pairing in nuclei
  - Nuclear astrophysics





ATLAS IN-FLIGHT RADIOACTIVE BEAMS

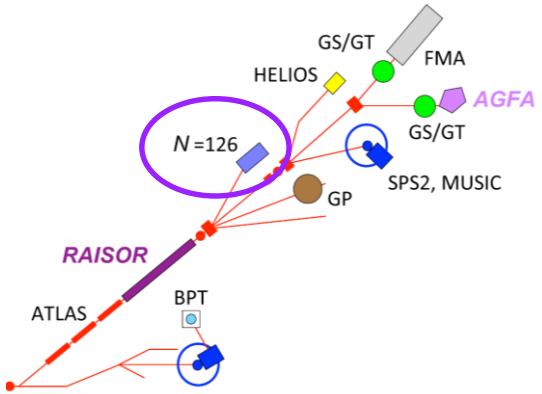
- RAISOR enables higher production intensities which will expand access to the chart of the nuclides
- Improvements
  - Selectivity
  - Purity
  - Target accessibility

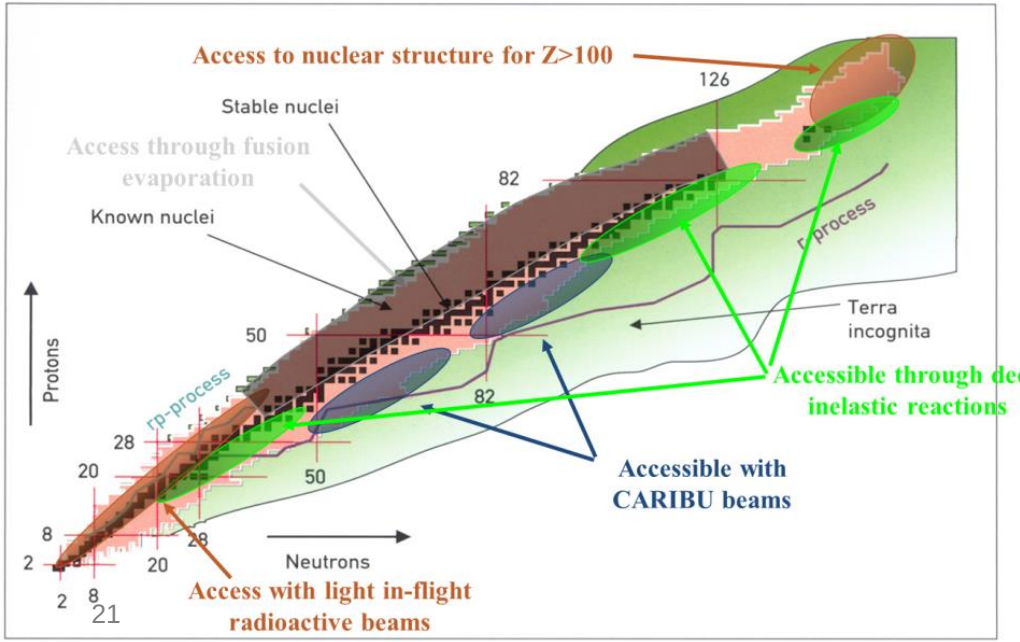


- In-flight beams previously produced at ATLAS
- Estimated secondary beams with >10^3 pps with RAISOR

N=126 FACTORY

- Access to nuclides in the last r-process abundance peak, the N=126 peak
- High intensity heavy ions at 8-10 MeV/u
- Multi-nucleon transfer (MNT) reactions
- ^{136}Xe + ^{198}Pt at 10 MeV/u for N=126
- Similar ion manipulation as CARIBU low energy
  - Gas catcher – RFQ ion guide – separation – MRTOF – trap

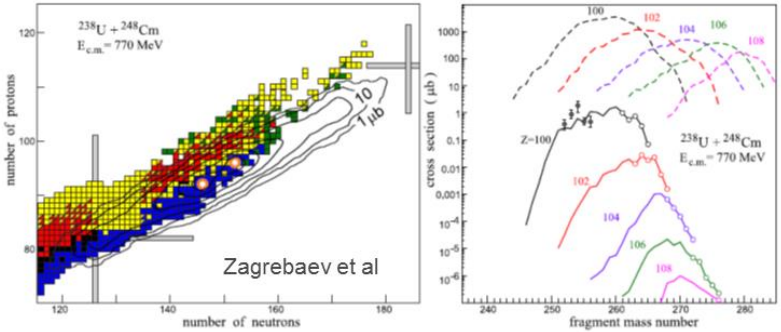




ATLAS MULTI-USER UPGRADE

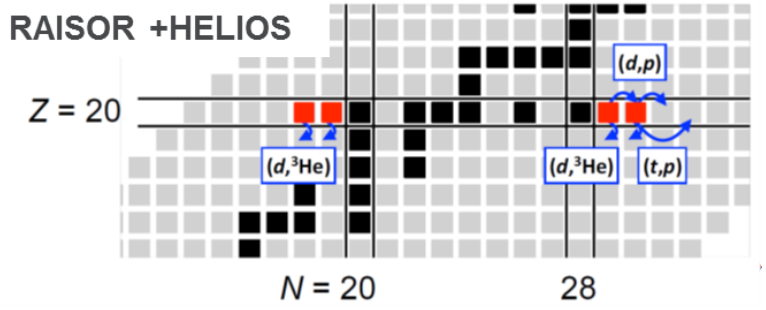
Responding to user needs

- **Spectroscopy of the heaviest isotopes**
  - Recoil and gamma efficiencies are now optimized, beam intensity limited by rate in Ge detectors . . . The main knob left is running longer



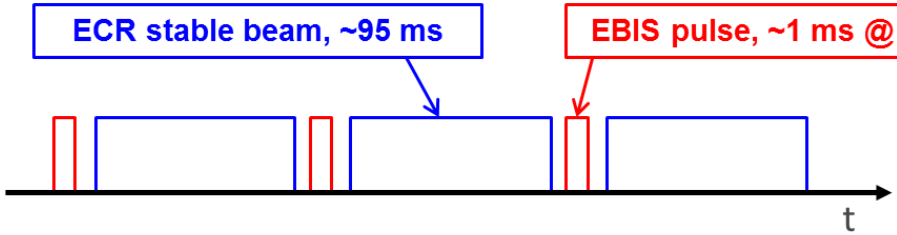
- **Production of new neutron-rich isotopes of the heaviest elements**
  - Small cross-section and long running time

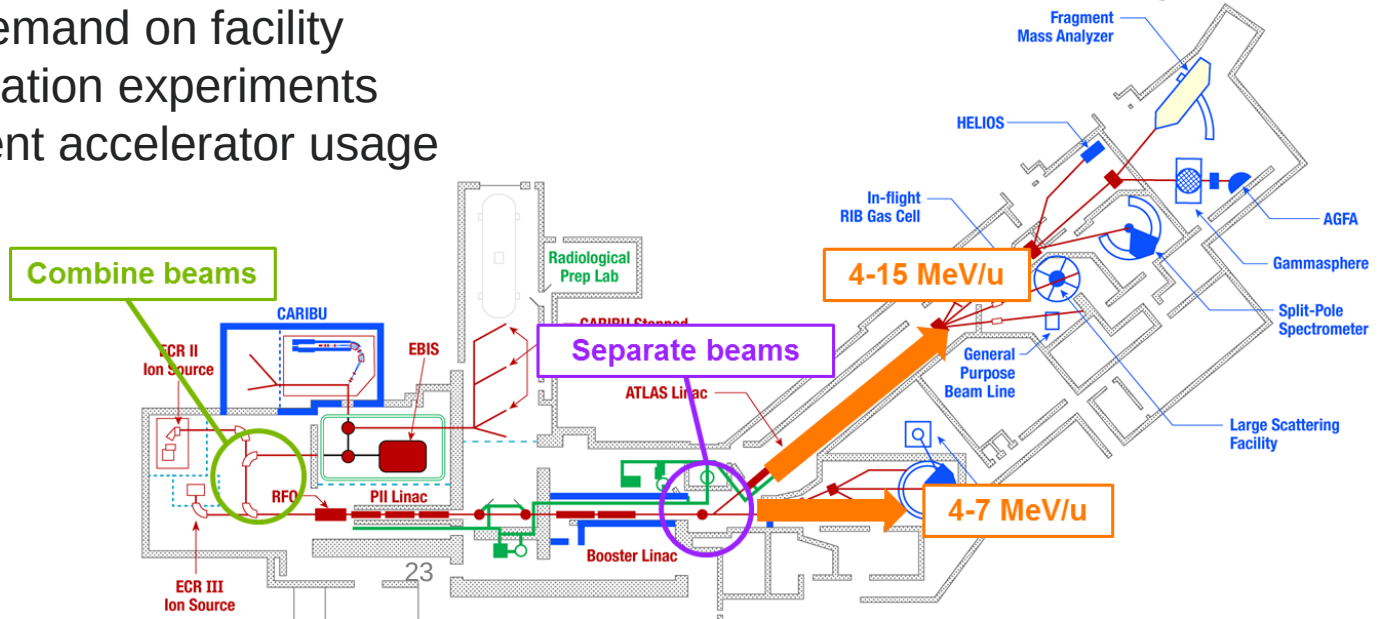
- **Detailed single-particle spectroscopy in the medium mass region**
  - Low production rates and intensities



ATLAS MULTI-USER UPGRADE

- EBIS beams represents 1-3% duty factor
- Combine pulsed EBIS beam with stable ECR beam
  - Address high demand on facility
  - Enable long duration experiments
  - Maximize efficient accelerator usage





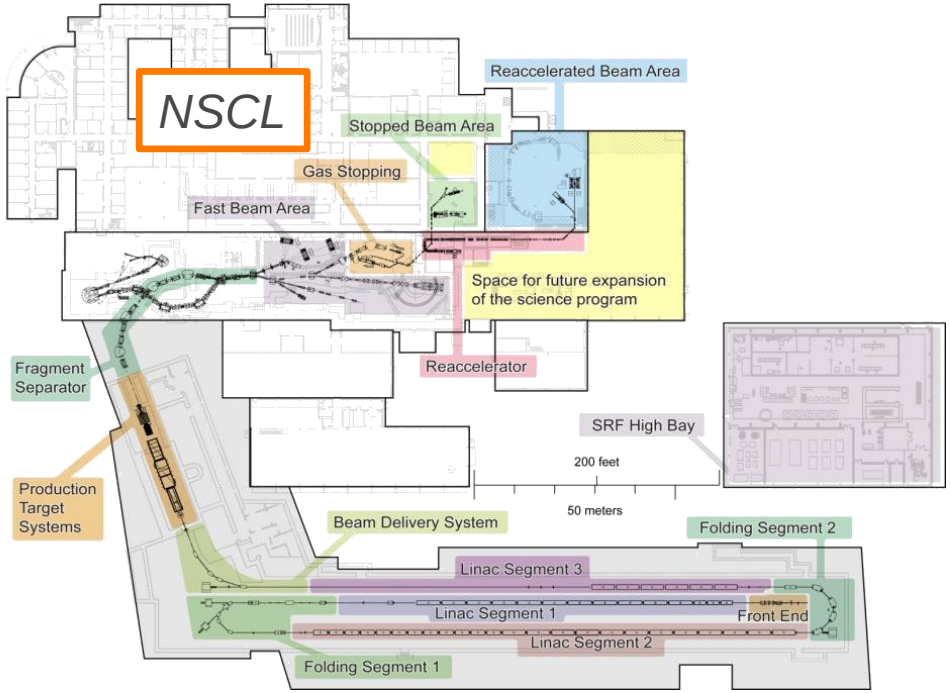
FACILITY FOR RARE ISOTOPE BEAMS – FRIB

FRIB – FACILITY FOR RARE ISOTOPE BEAMS

World-leading Next-generation Rare Isotope Beam Facility

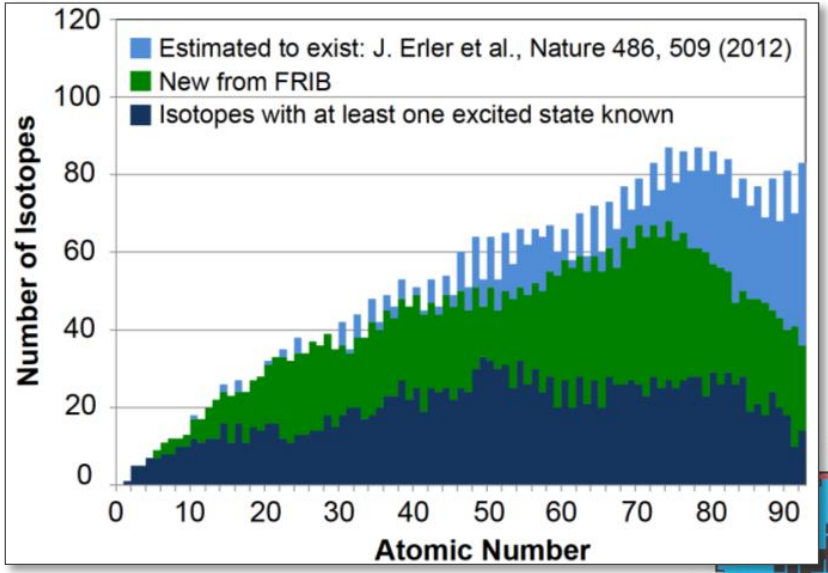
- Rare isotope production via in-flight technique with primary beams up to 400 kW, 200 MeV/u uranium
- Fast, stopped and re-accelerated beam capability
- Upgrade options
  - 400 MeV/u for uranium
  - ISOL production – multi-user capability

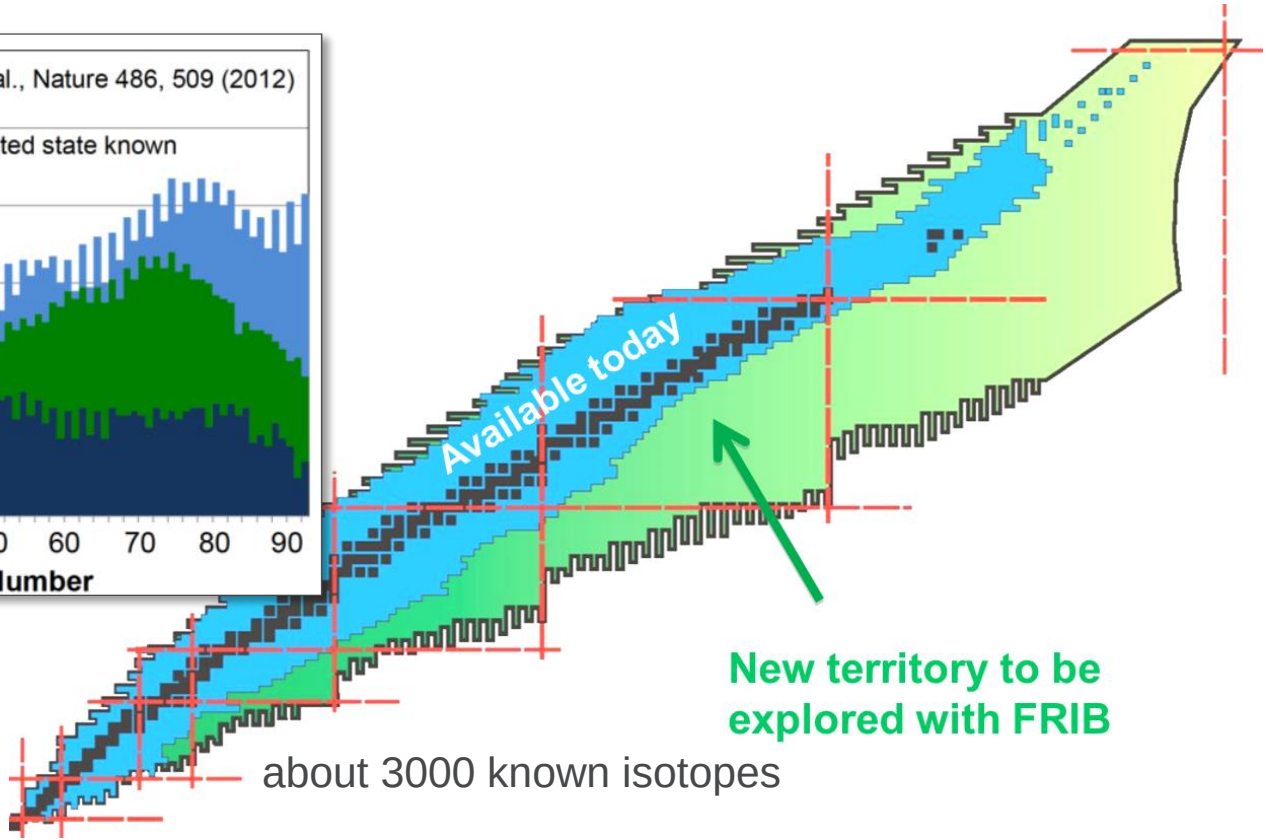
FRIB project start 6/2009
Civil construction started 3/2014
Technical construction started 10/2014
Managed to early completion FY 2021
CD-4 (project completion) 6/2022
Total project cost $730 million



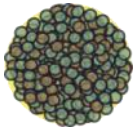
NSCL enables pre-FRIB science

FRIB BEAMS WILL ENABLE NEW DISCOVERIES



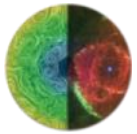


FRIB – FOUR SCIENCE THEMES



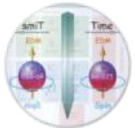
Properties of nuclei

- Develop a predictive model of nuclei and their interactions
- Many-body quantum problem: intellectual overlap to mesoscopic science, quantum dots, atomic clusters, etc.



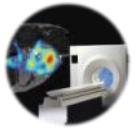
Astrophysical processes

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



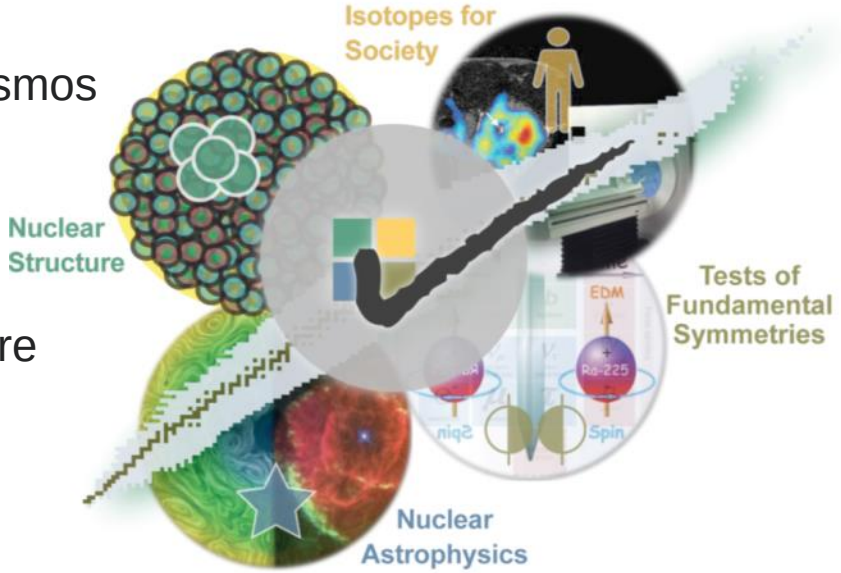
Tests of fundamental symmetries

- Effects of symmetry violations are amplified in certain nuclei

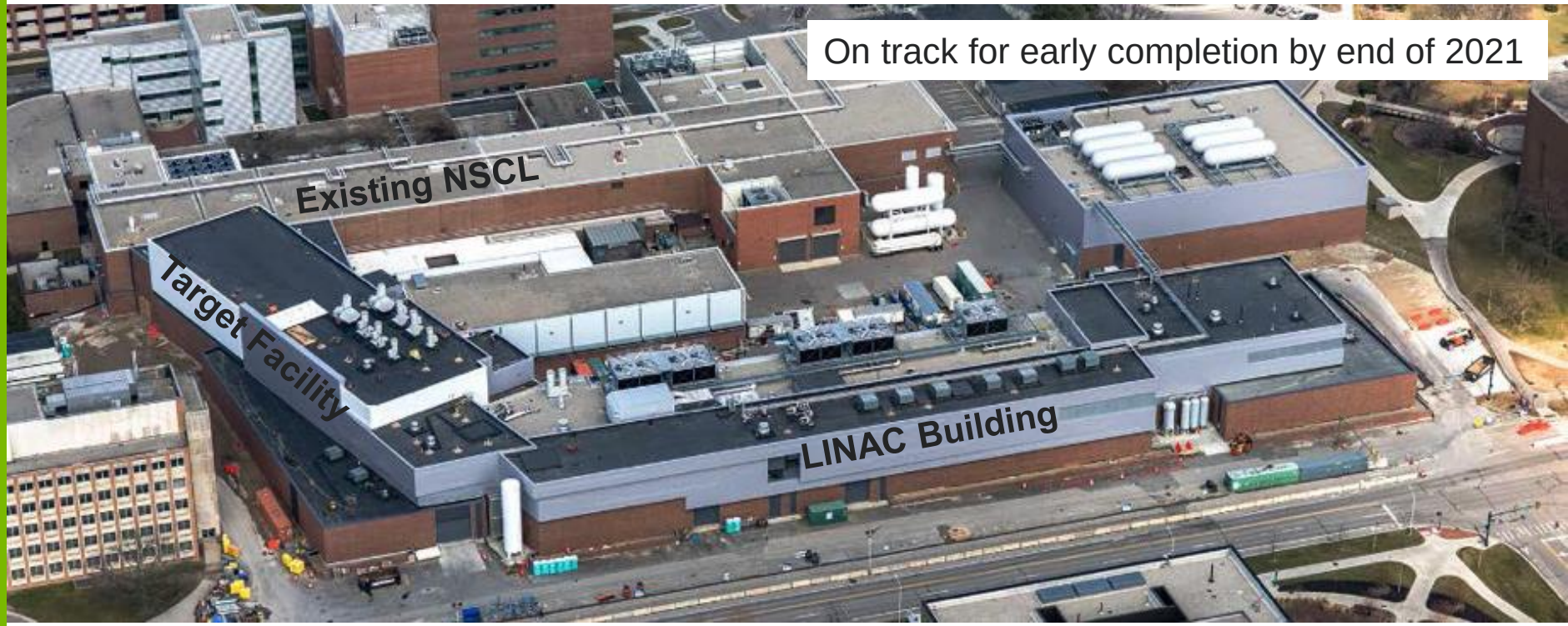


Societal applications and benefits

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

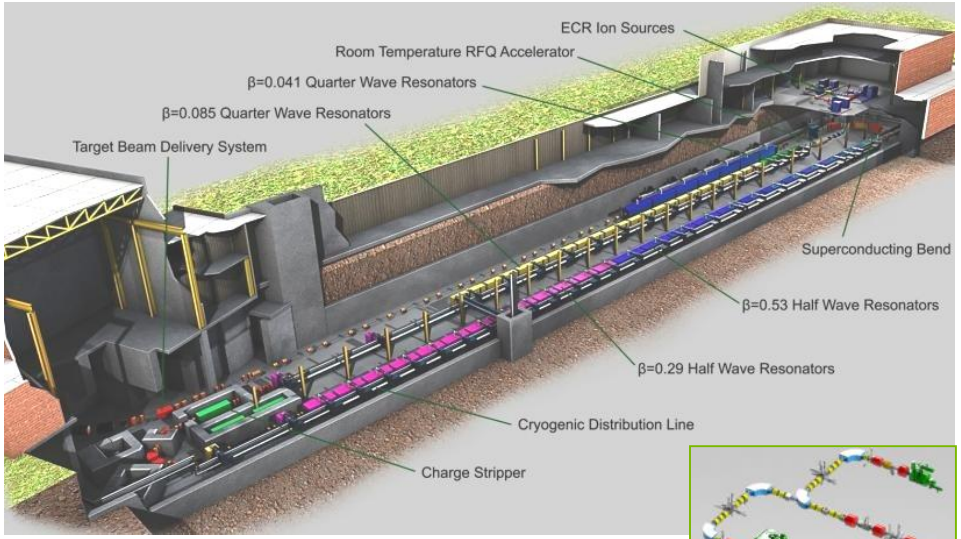


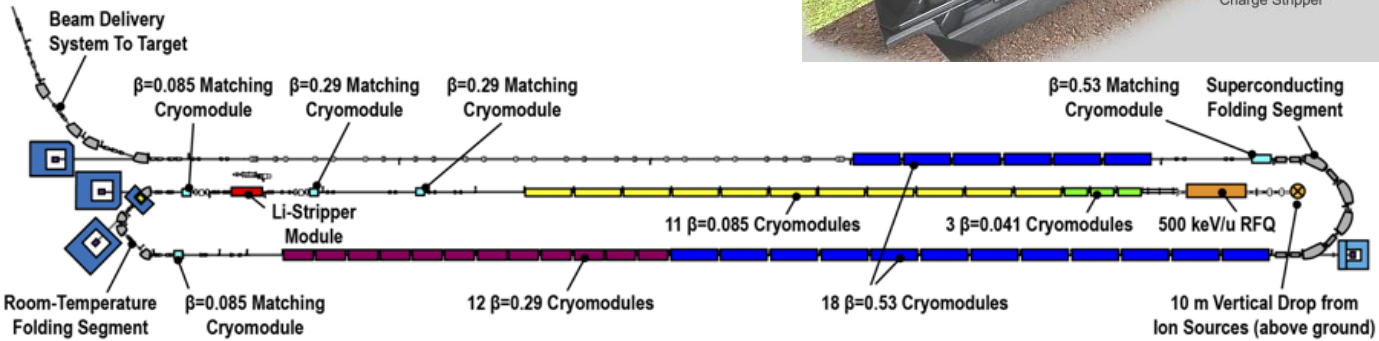
FRIB – INSTALLATION ADVANCED, FIRST BEAMS ACCELERATED

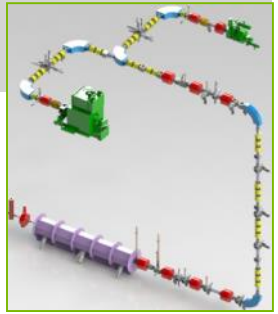


FRIB ACCELERATOR SYSTEMS
SUPERCONDUCTING RF DRIVER LINAC

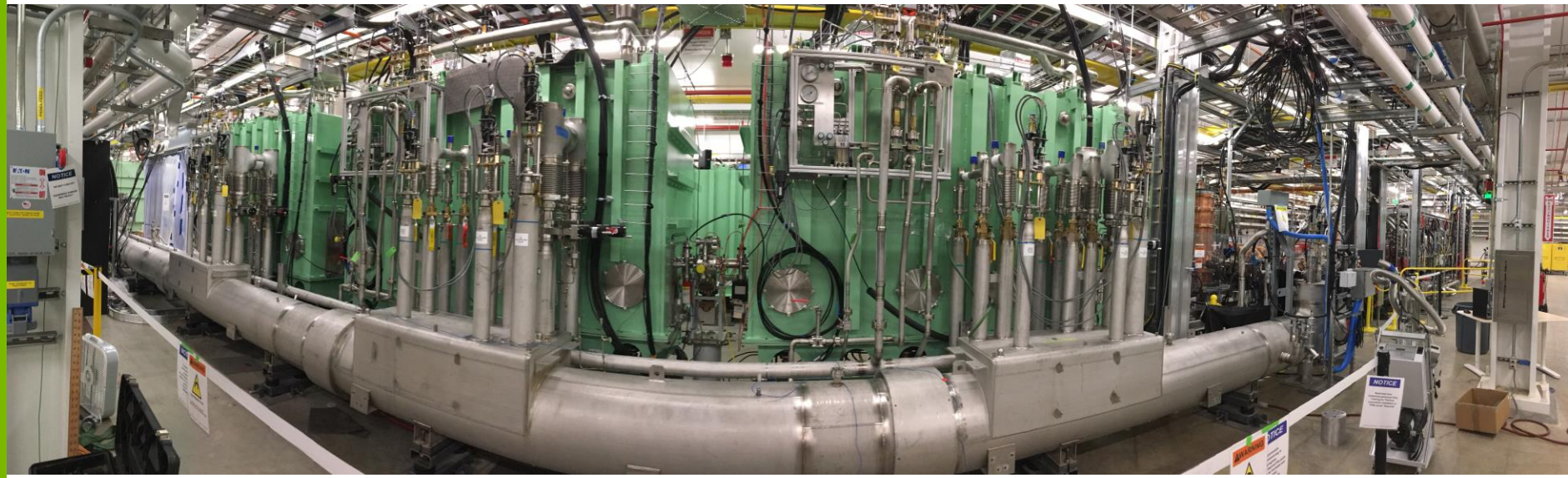
- Accelerate ion species up to ^{238}U with energies of no less than 200 MeV/u
- Provide beam power up to 400 kW
- Energy upgrade to 400 MeV/u for uranium by filling vacant slots with 12 SRF cryomodules
- MSU has funded β=0.65 cavity prototype development







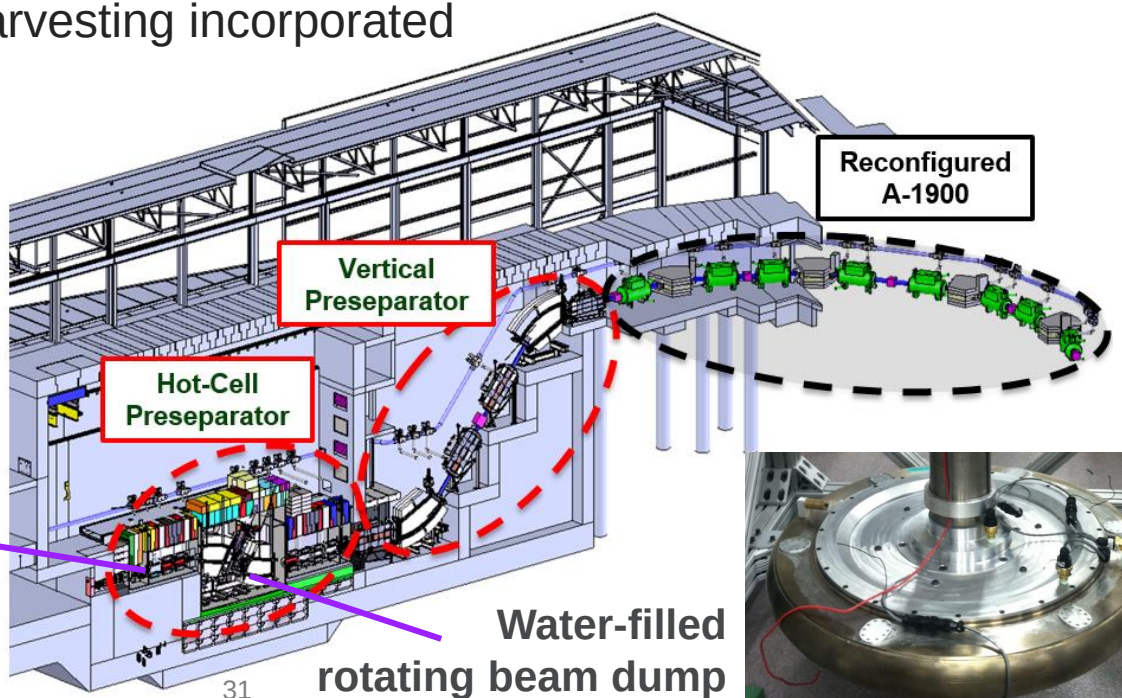
LINEAR ACCELERATOR IN FRIB TUNNEL



- First section of superconducting linac commissioned
  - $^{40}Ar^{9+}$ beam accelerated to >20 MeV/u
- >80% of cryomodules installed
- Helium refrigeration system commissioned at 2K

FRIB 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

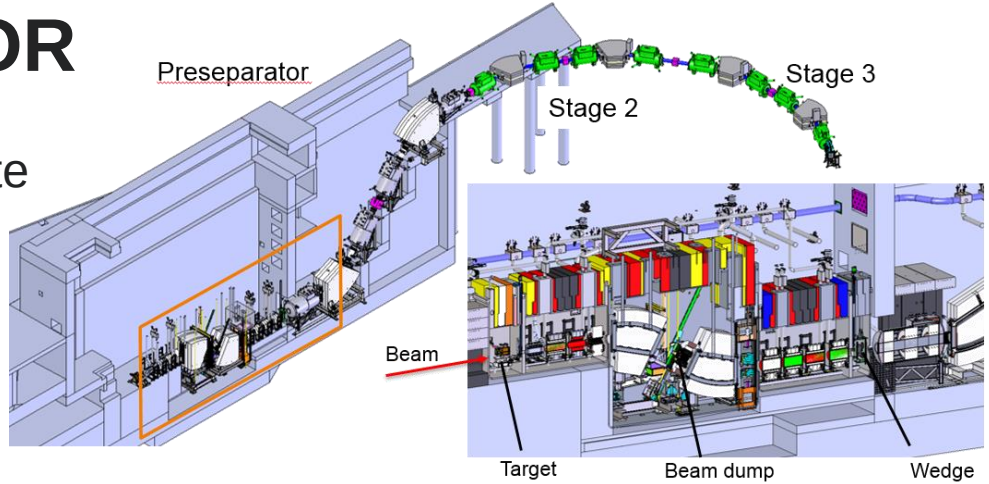


Multi-slice rotating graphite target

Water-filled rotating beam dump

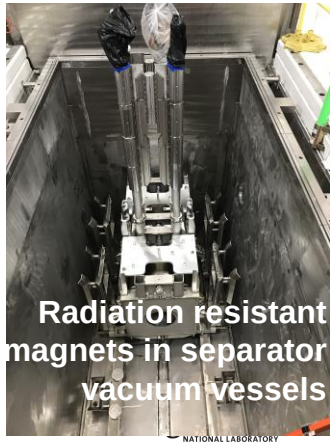
FRIB PRODUCTION FACILITIES FRAGMENT SEPARATOR

- High-power target module for rare isotope production assembly complete
  - Multi-slice rotating graphite disks
- High-power beam dump module fabricated
  - Water filled rotating drum to absorb up to 300 kW primary beam
- Radiation resistant super-conducting quadrupole magnets
  - Installation of magnets in fragment separator front-end underway




Target module on cradle

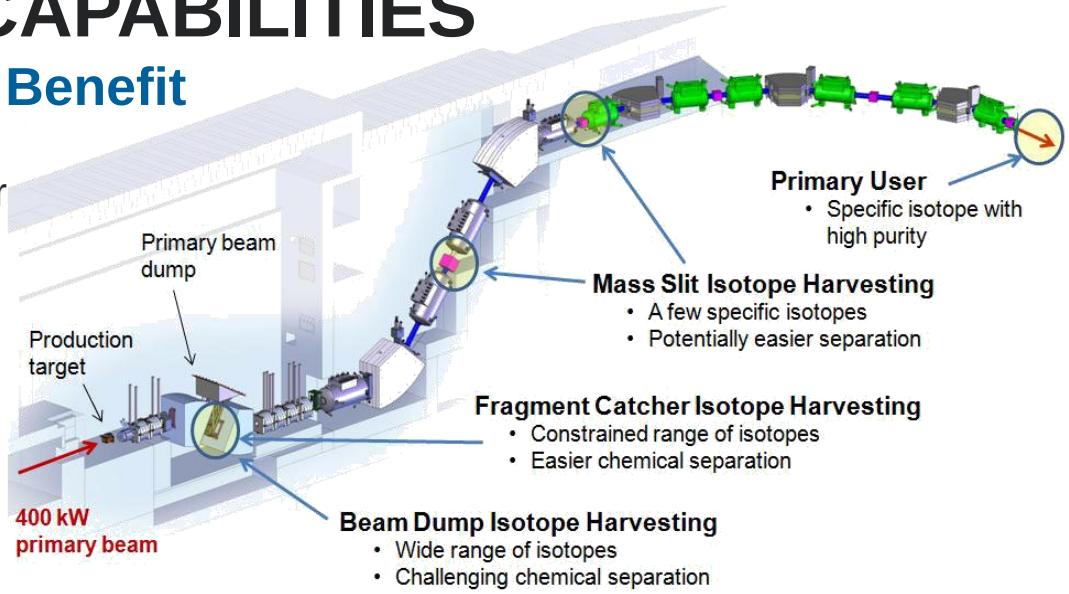

Beam dump assembly


Radiation resistant magnets in separator vacuum vessels

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:
  - **Isotope Harvesting at FRIB: Additional opportunities for scientific discovery**, E. Paige Abel et al 2019 J. Phys. G: Nucl. Part. Phys. in press https://doi.org/10.1088/1361-6471/ab26cc

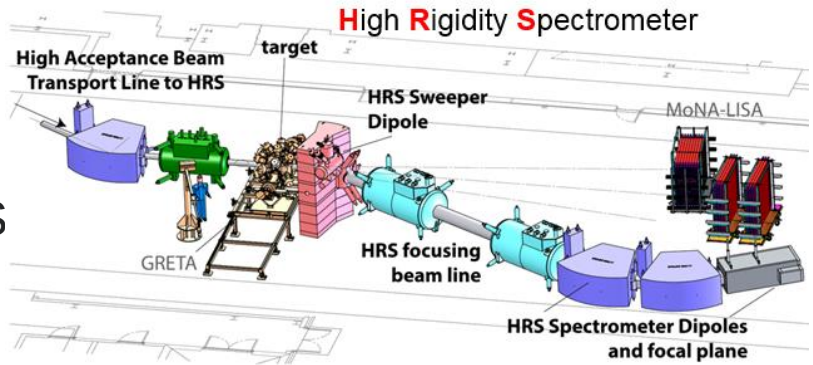
INSTRUMENTATION

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
  - Ion and atom traps, laser facilities
    - High-precision experiments
  - Control systems and data acquisitions
- Unique challenges in cutting-edge facilities
  - High beam rates / very low beam rates
  - Radiation hard equipment
  - Complex measurements with multiple systems

INSTRUMENTATION FOR LOW ENERGY NUCLEAR PHYSICS: GRETINA AND GRETA

- GRETINA – highly segmented Ge detectors to track and reconstruct gamma-rays is the first phase of the larger . . .
- GRETA (Gamma Ray Energy Tracking Array) will be the most advanced gamma-ray detector array for nuclear science
  - 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
    - HRS building addition underway at MS



http://greta.lbl.gov

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
- 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 electronics
  - Target technology (high-power targets, thin targets, windows, strippers, …)
  - Ion source technology
  - Beam catcher/release systems
  - Radiation hard precision magnetic field probes
  - Radiation hard actuator systems
  - Real time data visualization framework
  - Other accelerator related developments

SUMMARY

- The US low energy nuclear physics community is strong with exciting opportunities on the horizon
- DOE NP facilities are pushing the limits of technology to enable this science
  - Existing low-energy rare isotope beam facilities in the US provide forefront research opportunities today
  - FRIB will be a world-leading rare isotope facility that will enable new discoveries
- DOE NP SBIR/STTR program plays an important role in making the low energy nuclear physics program successful and will be critical moving in the FRIB era