Nuclear Physics Low Energy Facilities and the SBIR/STTR Program

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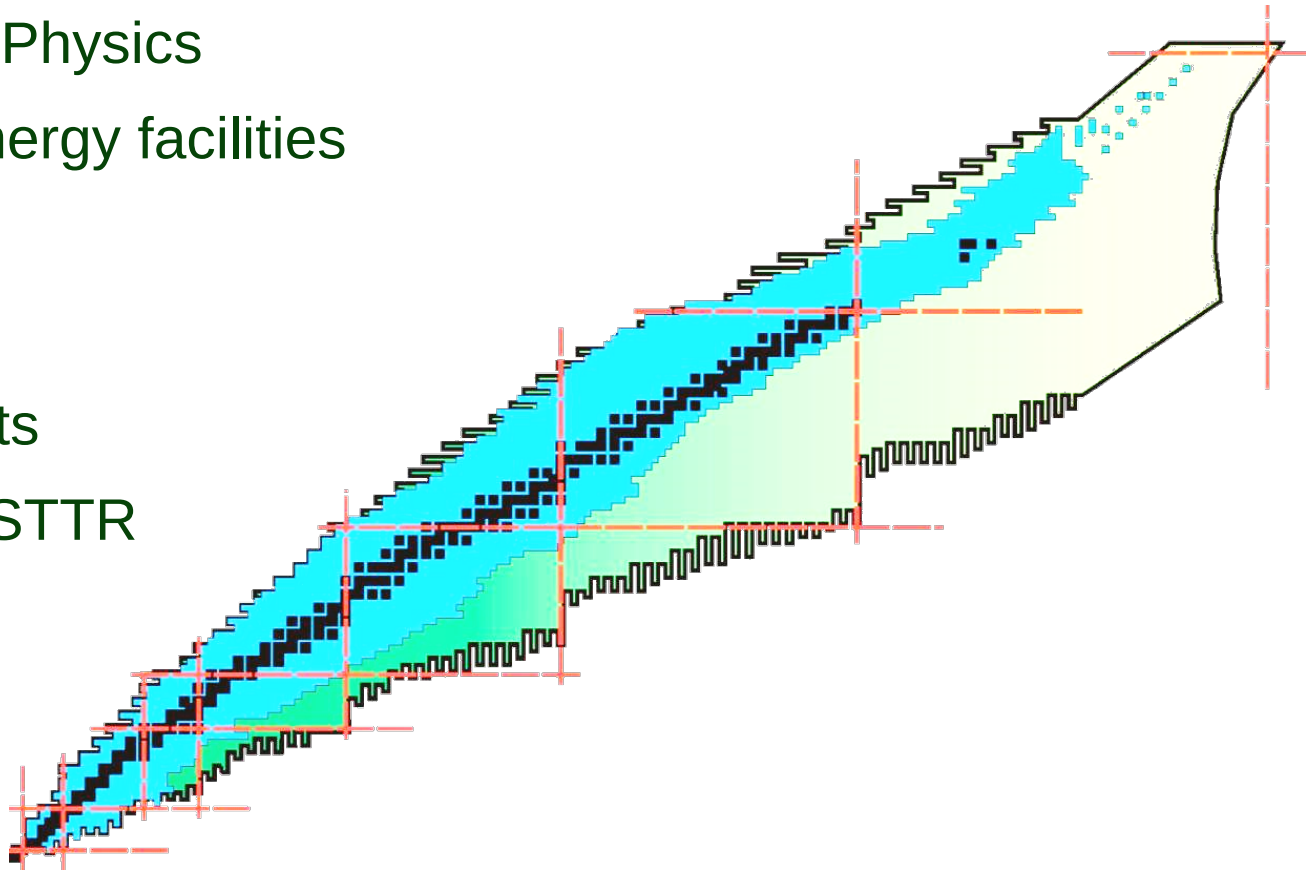
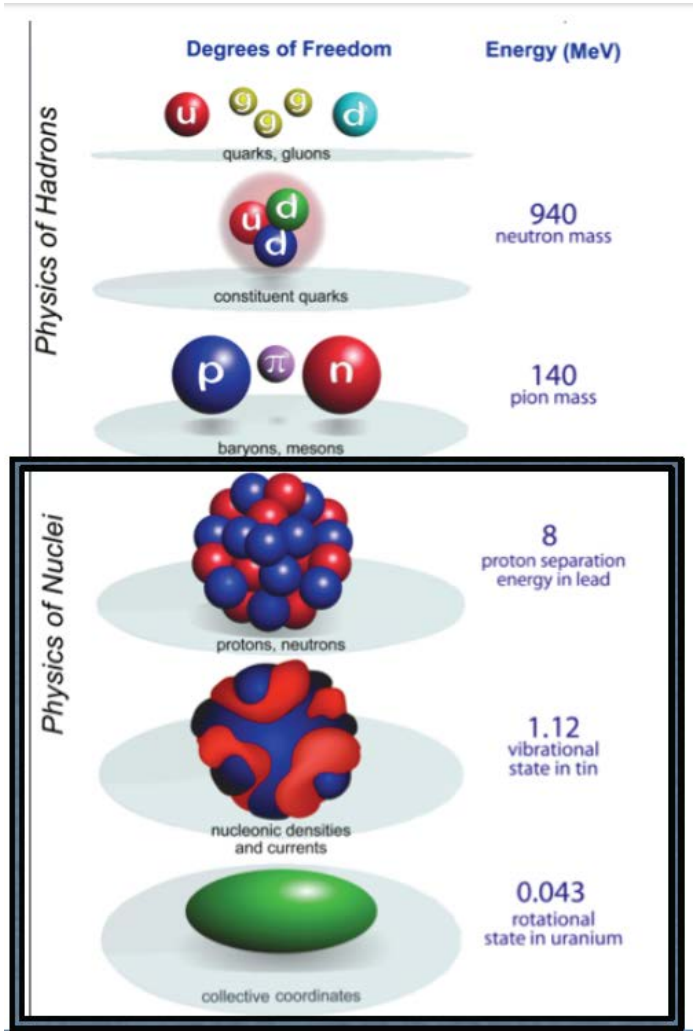
Outline

- Low Energy Nuclear Physics
- Context of NP low energy facilities
- ATLAS
- FRIB
- Advanced Instruments
- Importance of SBIR/STTR for LE NP program
- Summary



- *Acknowledgments*
  - *Materials provided by G. Savard, R. Janssen, P. Fallon, and others*

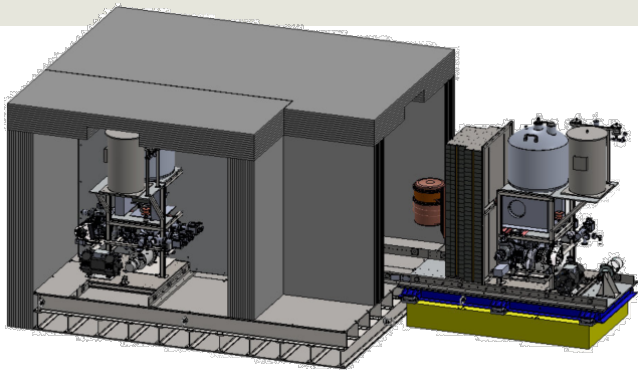
Low Energy Nuclear Physics

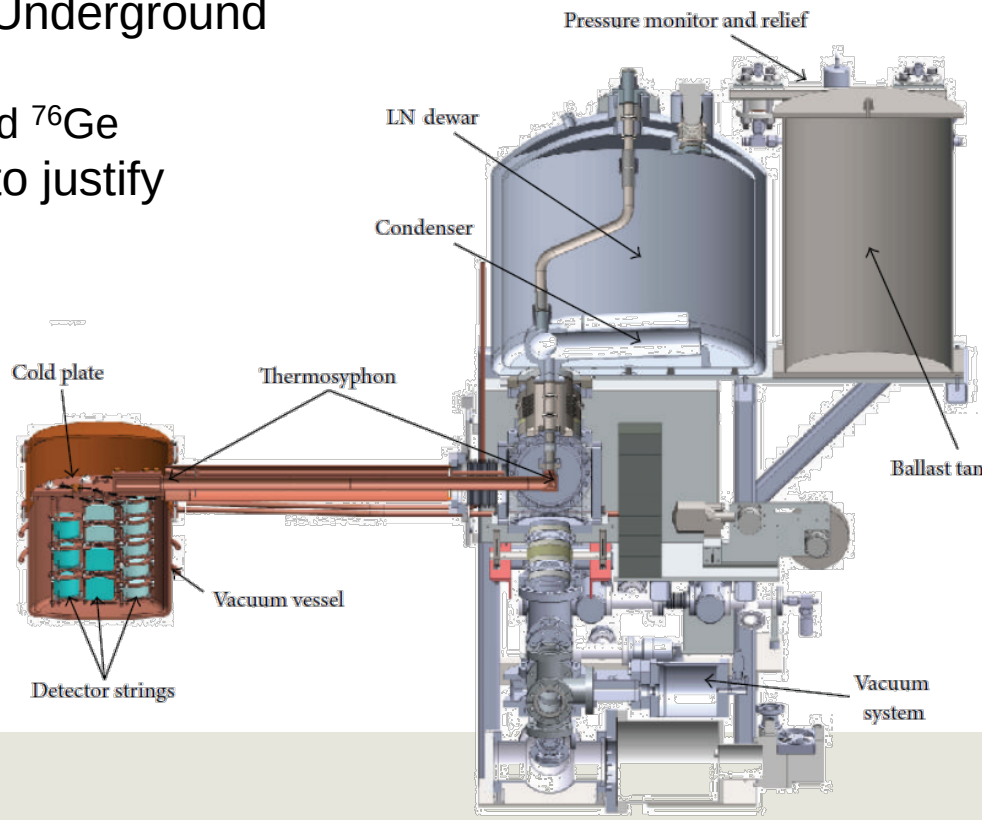


- Refers to the energy scale of the science
  - Of order few MeV (nuclear binding scale)
- Encompasses the physics governing nuclear decays and how nuclear matter combines to create elements.
- It is where our field most directly impacts and touches our lives (energy, medicine, security)
- Provides a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

Neutrino Physics
MAJORANA Demonstrator

- MAJORANA is a proposed experiment to search for neutrinoless double-beta decay (0νββ) in ^{76}Ge
  - Is neutrino a Majorana particle? What is neutrino mass scale?
- MAJORANA Demonstrator
  - Located underground at 4850' Sanford Underground Research Facility
  - 40-kg of Ge detectors: 30 kg 87% enriched ^{76}Ge
  - Demonstrate backgrounds low enough to justify building a tonne scale experiment.
  - Establish feasibility of modular arrays of Ge detectors.
  - Searches for additional physics beyond the Standard Model





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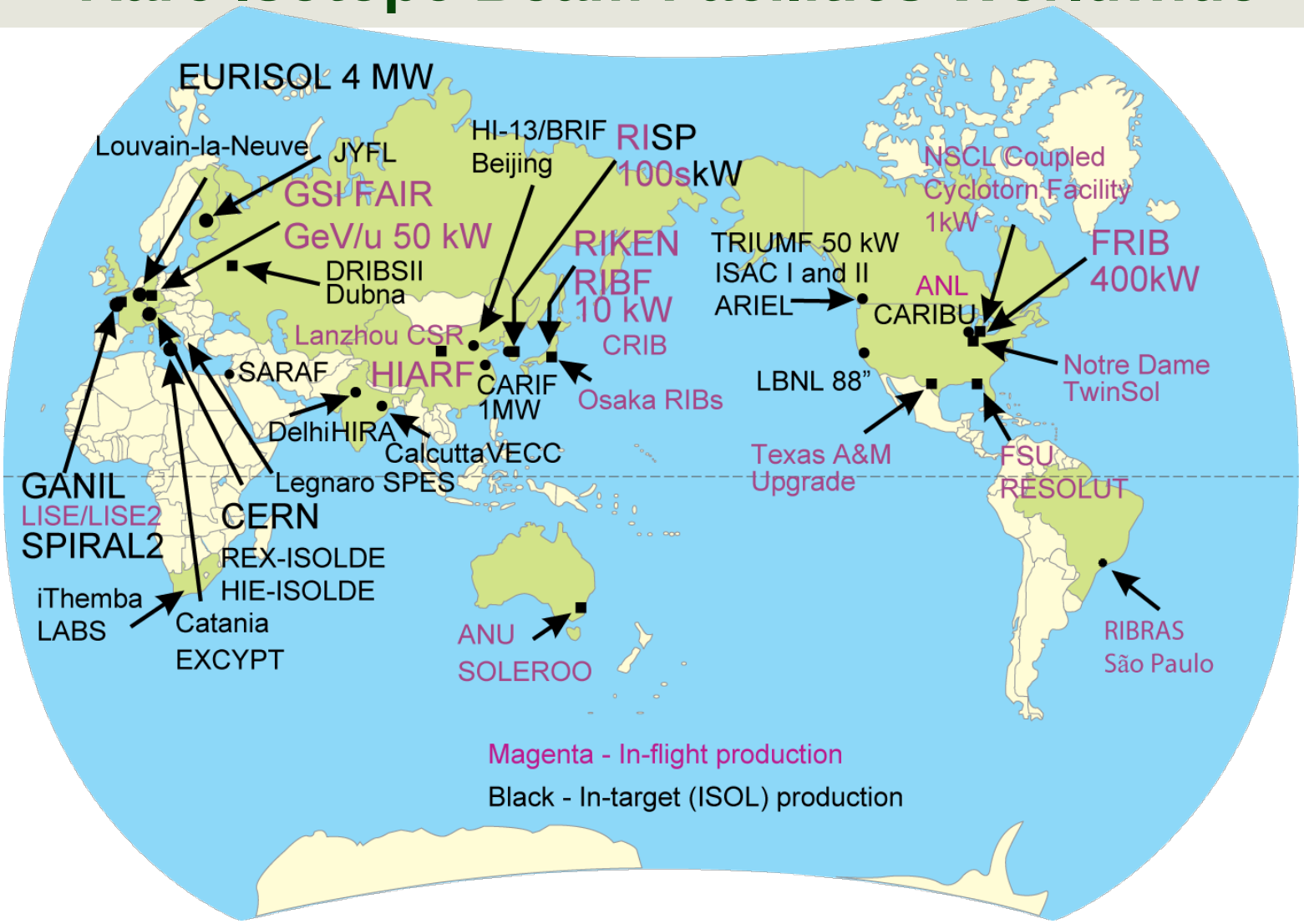
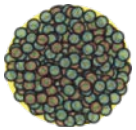
Low Energy Nuclear Physics
Rare Isotope Beam Facilities Worldwide

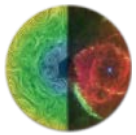


Low Energy Nuclear Science Themes



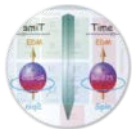
Properties of nuclei

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



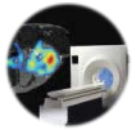
Astrophysical processes

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



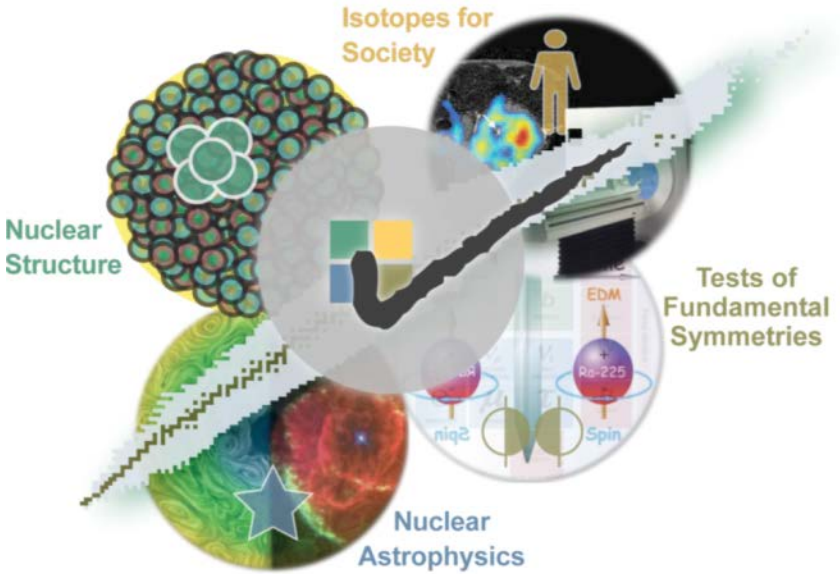
Tests of fundamental symmetries

- Effects of symmetry violations are amplified in certain nuclei



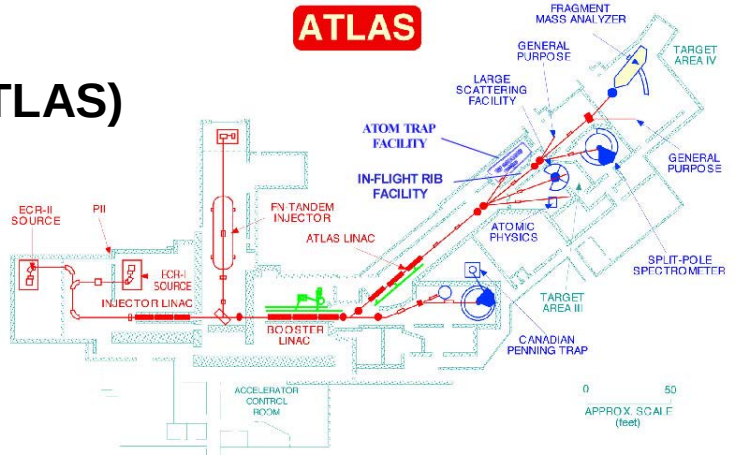
Societal applications and benefits

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

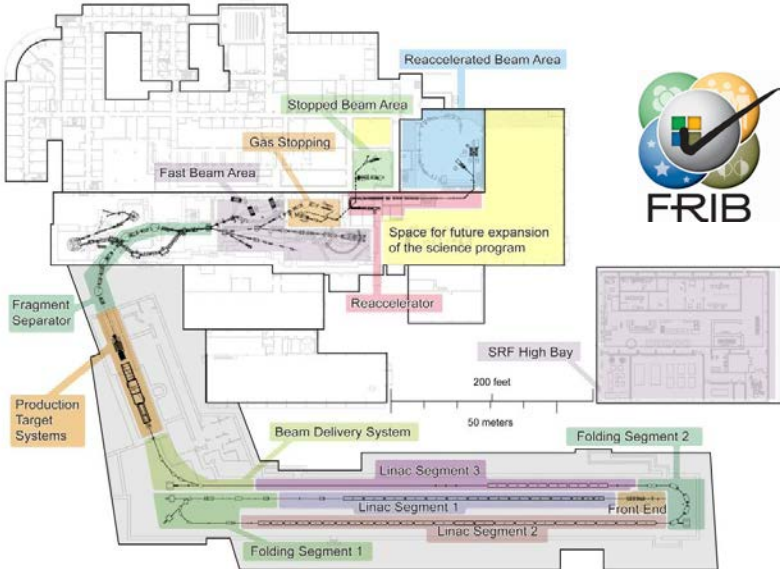


Low Energy Nuclear Physics Facilities

- 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



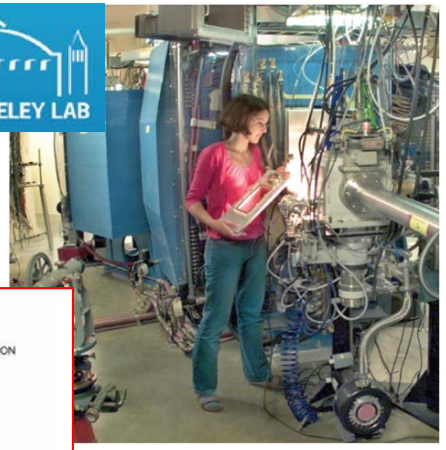
  - **Facility for Rare Isotope Beams (FRIB) at MSU** (http://frib.msu.edu)
    - » World-leading facility under construction at MSU
    - » 400 kW heavy-ion SRF linac; >200 MeV/u
    - » Rare isotopes beams produced by fragmentation and in-flight fission
    - » Fast, stopped, and reaccelerated beams

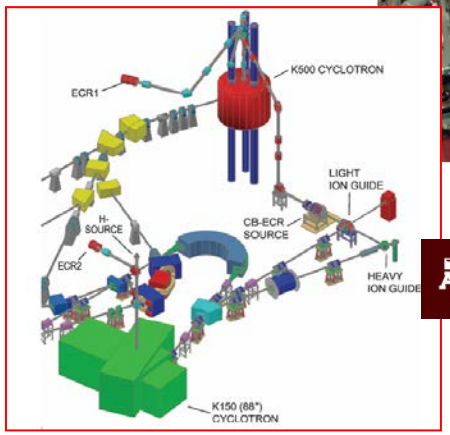


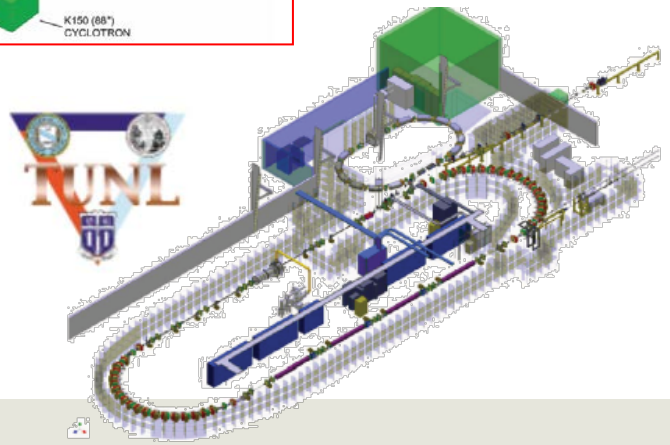
- NSF User Facility
  - National Superconducting Cyclotron Laboratory (NSCL) at MSU (http://nscl.msu.edu)
  - In-flight rare isotope beam production
  - Fast, stopped, and re-accelerated beams

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 Ins1tute** (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
    - » Neutrons

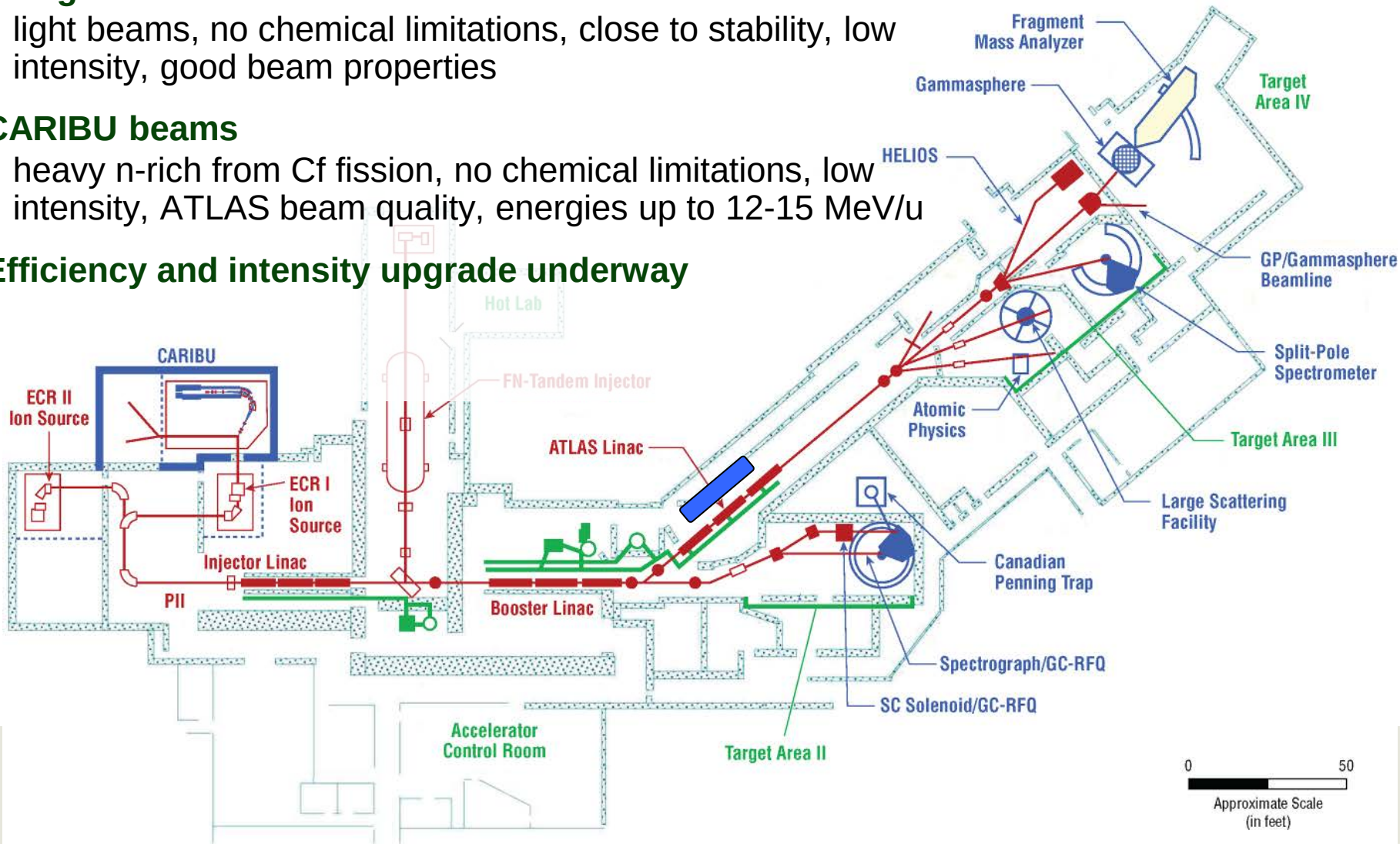






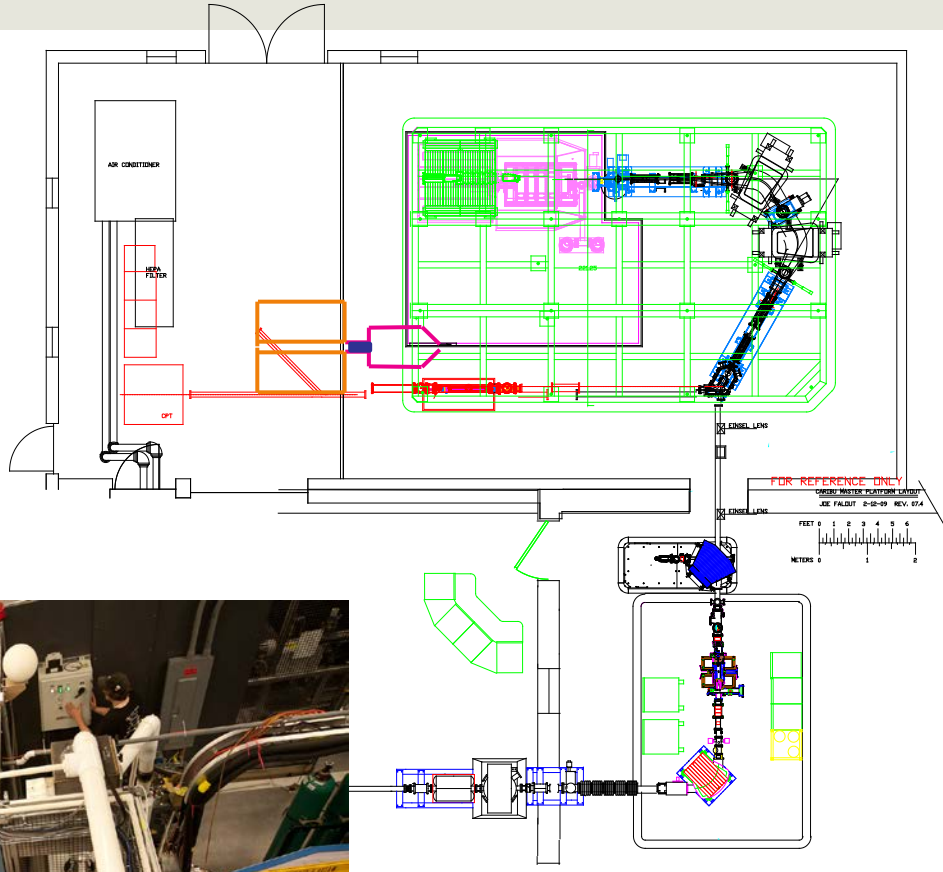
ATLAS Facility at Argonne National Laboratory

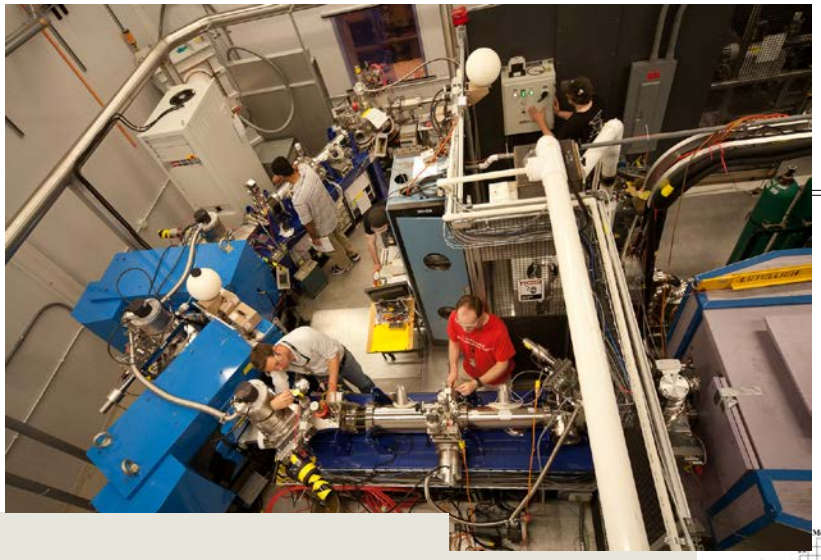
- **Stable beams** at medium intensity and energy up to 10-20 MeV/u
- **In-flight radioactive beams**
  - light beams, no chemical limitations, close to stability, low intensity, good beam properties
- **CARIBU beams**
  - heavy n-rich from Cf fission, no chemical limitations, low intensity, ATLAS beam quality, energies up to 12-15 MeV/u
- **Efficiency and intensity upgrade underway**

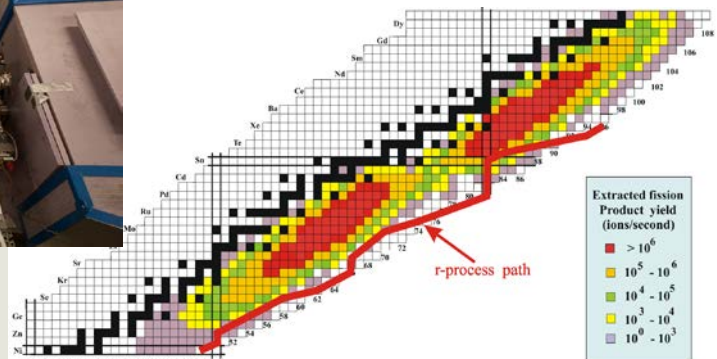


CARIBU – Californium Rare Ion Breeder Upgrade
Neutron-rich beam source

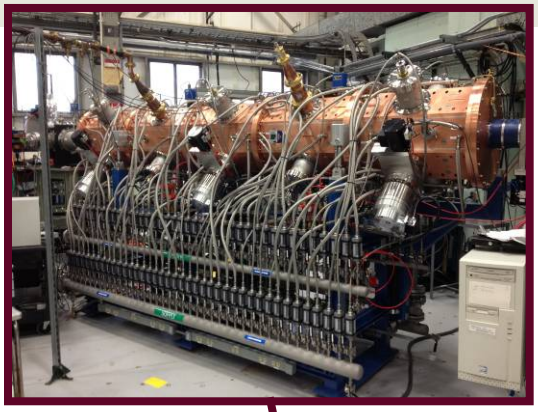
- **PRODUCTION**: ^{252}Cf source inside gas catcher (up to 1 Ci)
  - Thermalizes fission fragments
  - Extracts all species quickly
  - Forms low emittance beam
- **SELECTION**: Isobar separator
  - Purifies beam
- **DELIVERY**: beamlines and preparation
  - Switchyard
  - Low-energy buncher
  - Charge breeder
  - Post-accelerator ATLAS







ATLAS Layout After Recent Upgrades



Improved
instrumentation

New low-energy
experimental hall

- **ATLAS now capable of running up to 10 pμA at greater than 80% transmission**
- **As a post-accelerator with ECR charge breeder, provides up to 10% total efficiency for CARIBU beams**

CARIBU

MHB RFQ

new cryomodule

New in-flight
separator (AIRIS)

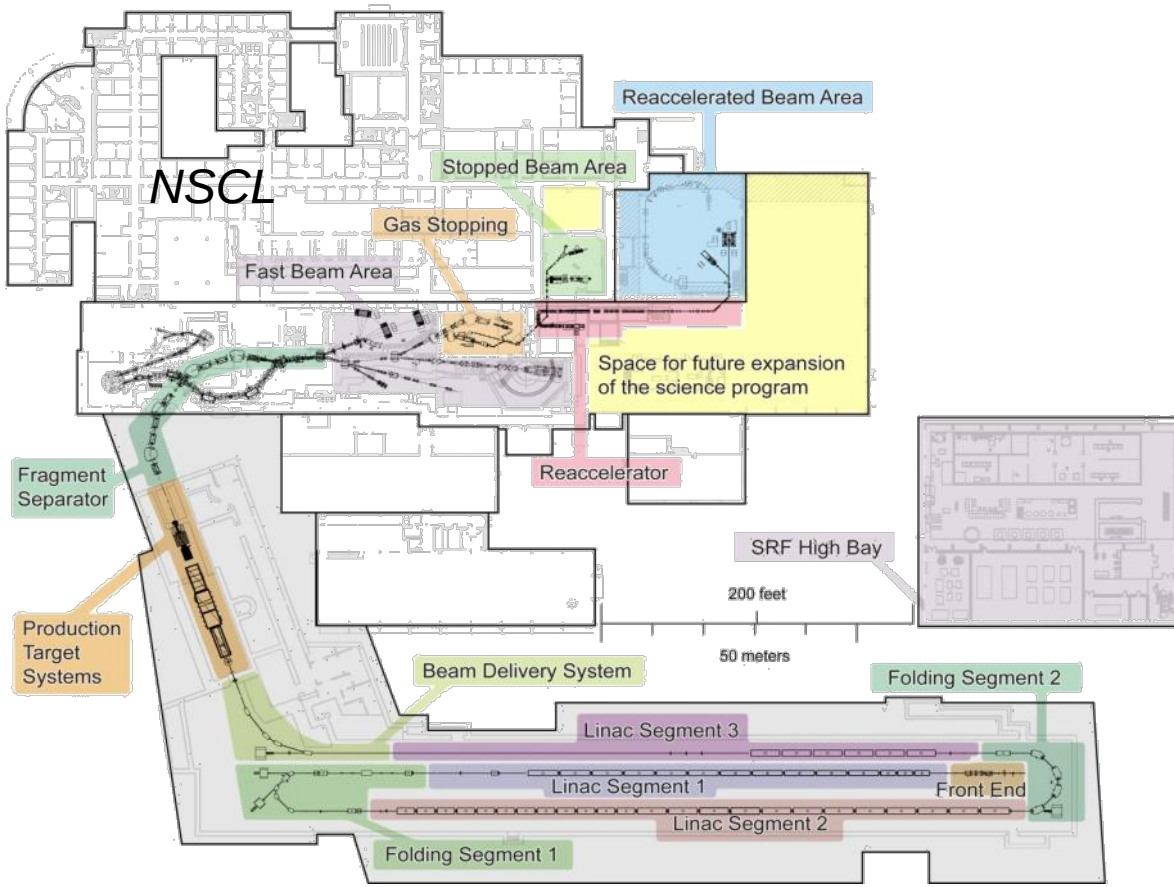
FRIB - Facility for Rare Isotope Beams

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 to start 10/2014
Managed to early completion 12/2020
CD-4 (project completion) 6/2022

Total project cost $730 million

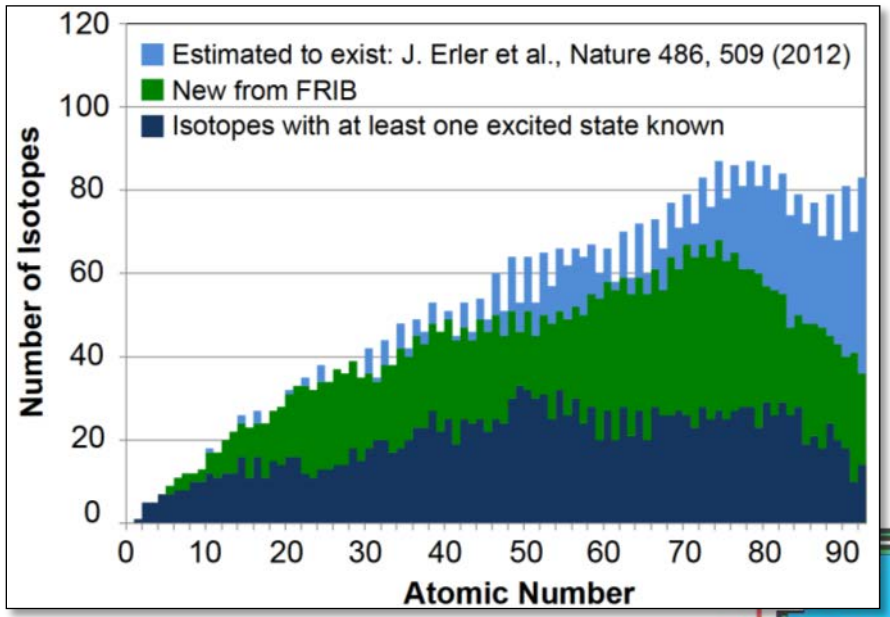


NSCL enables pre-FRIB science

MICHIGAN STATE UNIVERSITY

U.S. DEPARTMENT OF ENERGY | Office of Science

FRIB Beams Will Enable New Discoveries

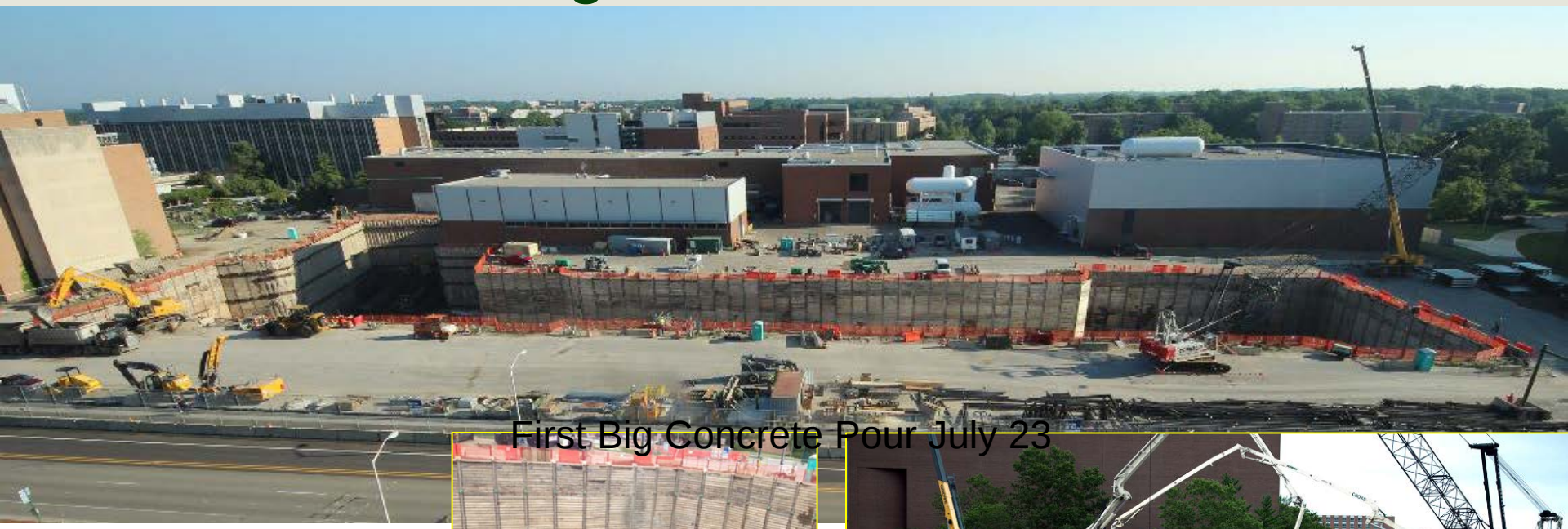


Available today

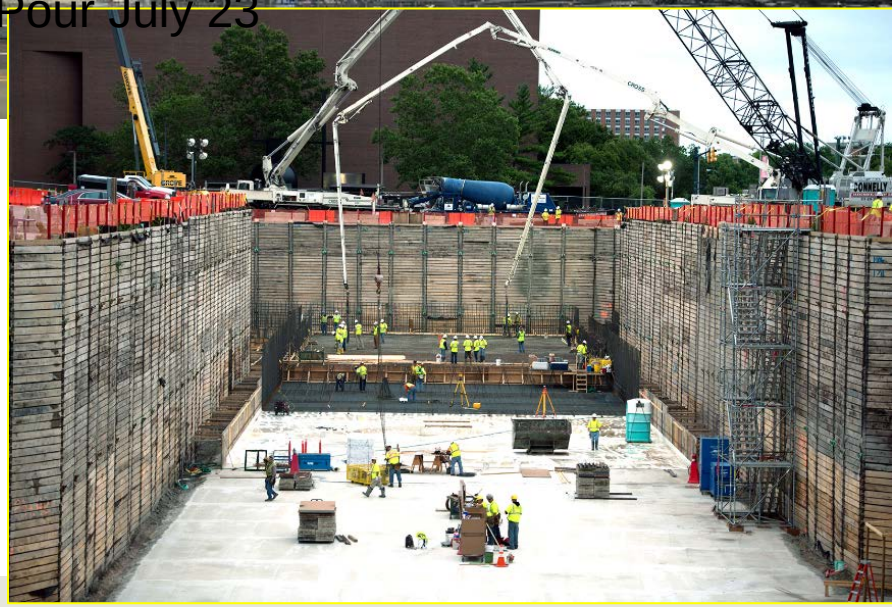
New territory to be explored with FRIB

about 3000 known isotopes

FRIB Civil Construction Underway
Began 3 March 2014

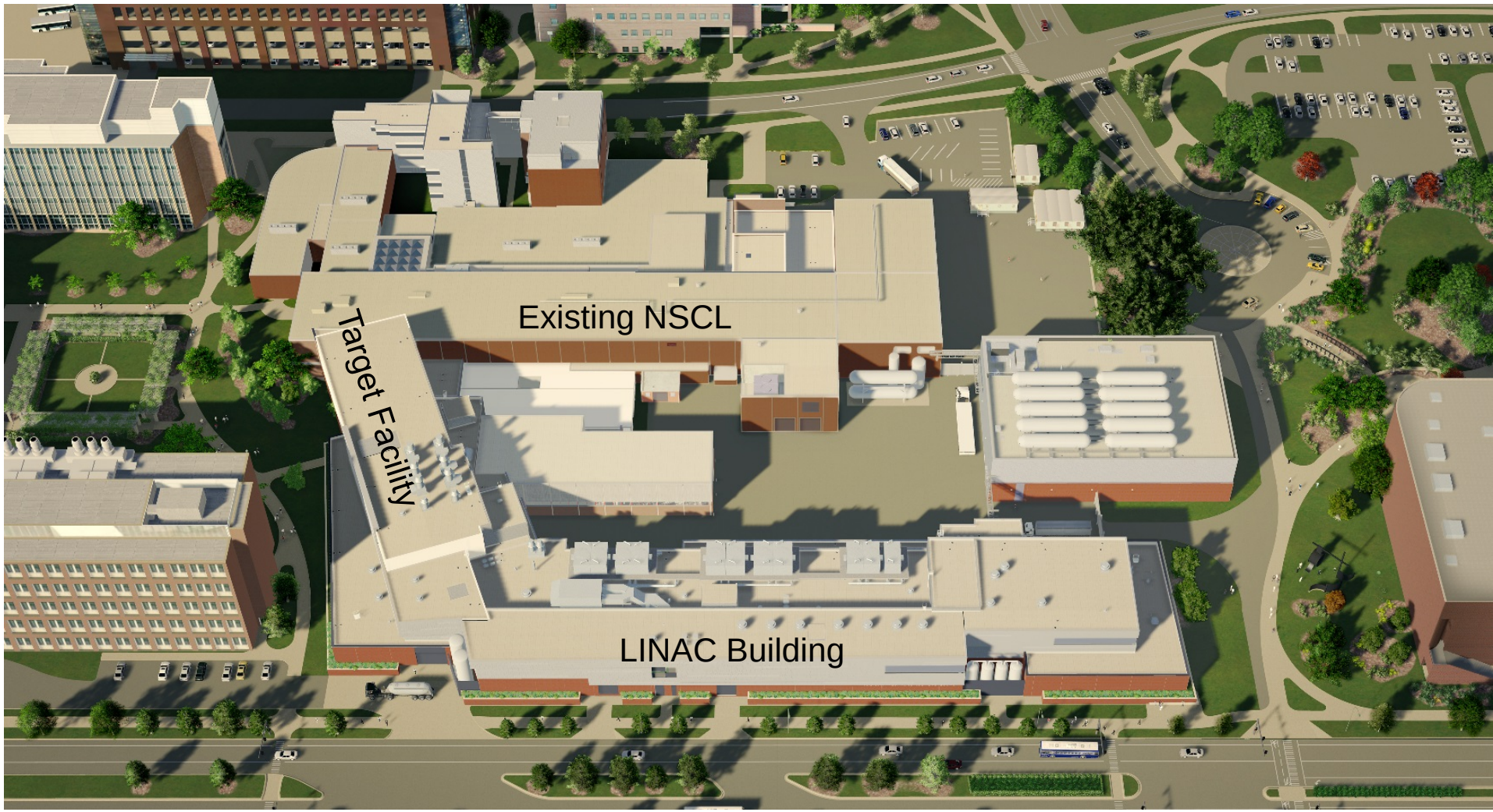


First Big Concrete Pour July 23



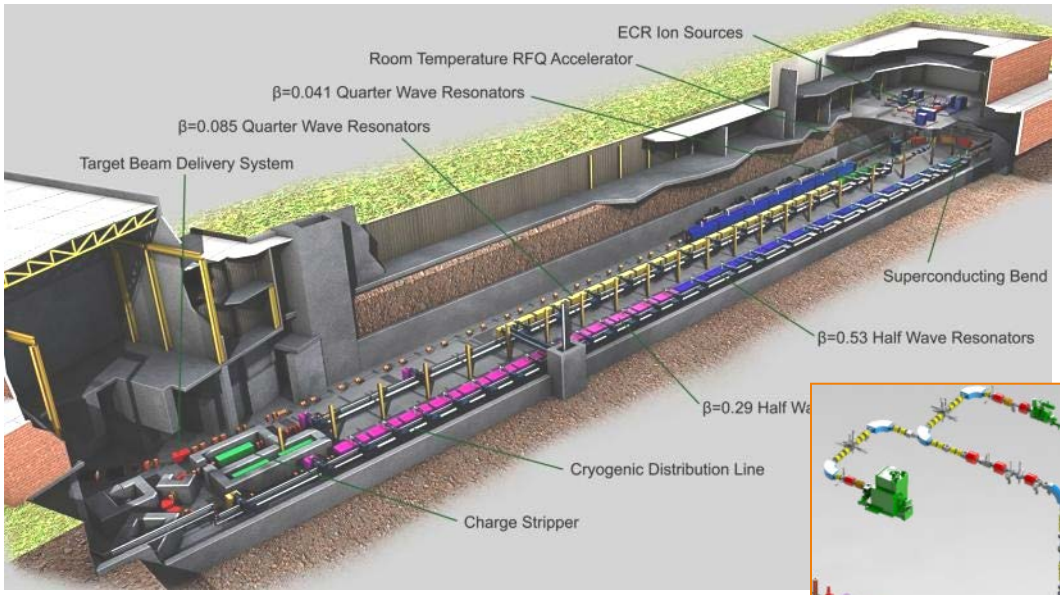
First big concrete pour July 23, 2014

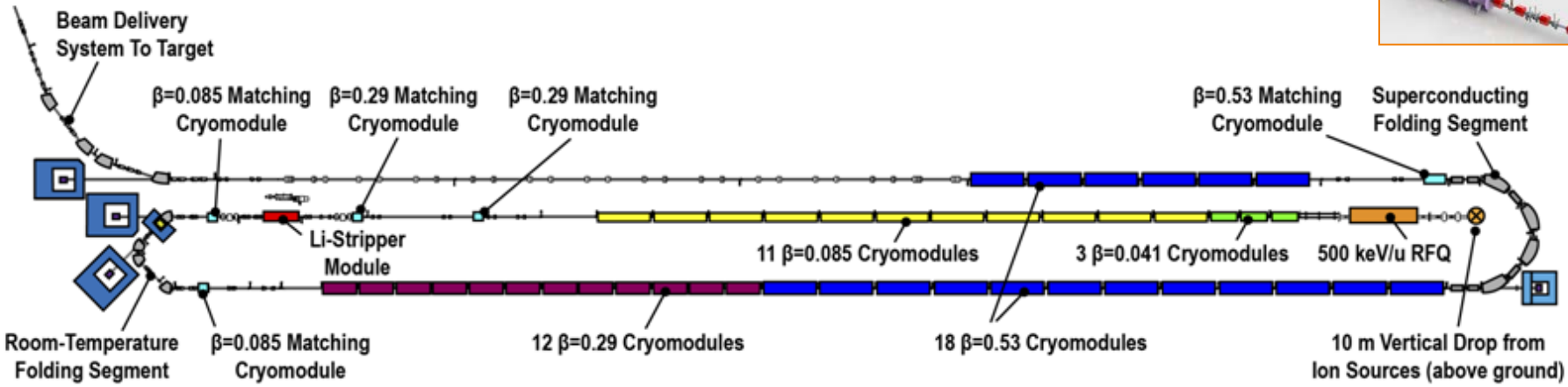
Facility for Rare Isotope Beams



FRIB Accelerator Systems
Superconducting RF Driver Linac

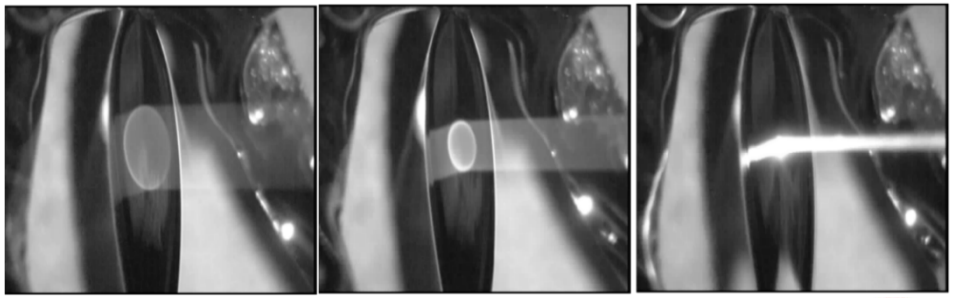
- Accelerate ion species up to ^{238}U with energies of no less than 200 MeV/u
- Provide beam power up to 400kW
- Energy upgrade to 400 MeV/u for uranium by filling vacant slots with 12 SRF cryomodules

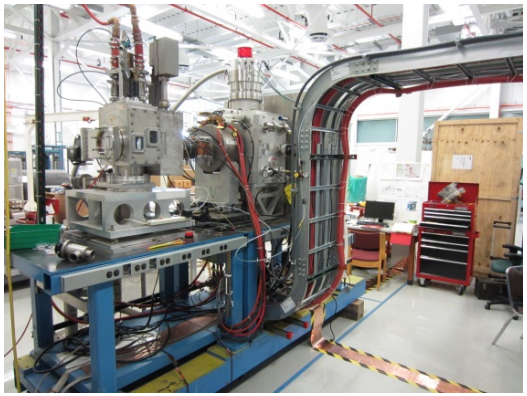




FRIB Accelerator Systems

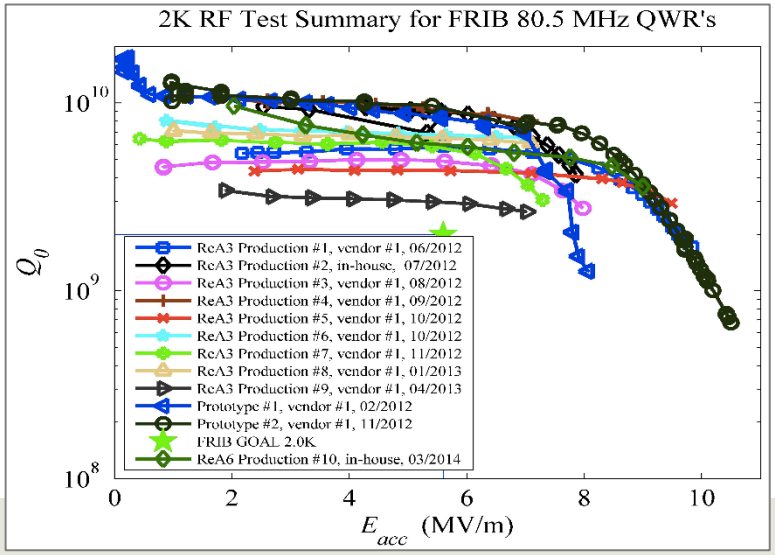
- Cavity preproduction and cryomodule prototyping underway
- Cavities exceed FRIB performance goals
- Liquid lithium charge stripping scheme validated





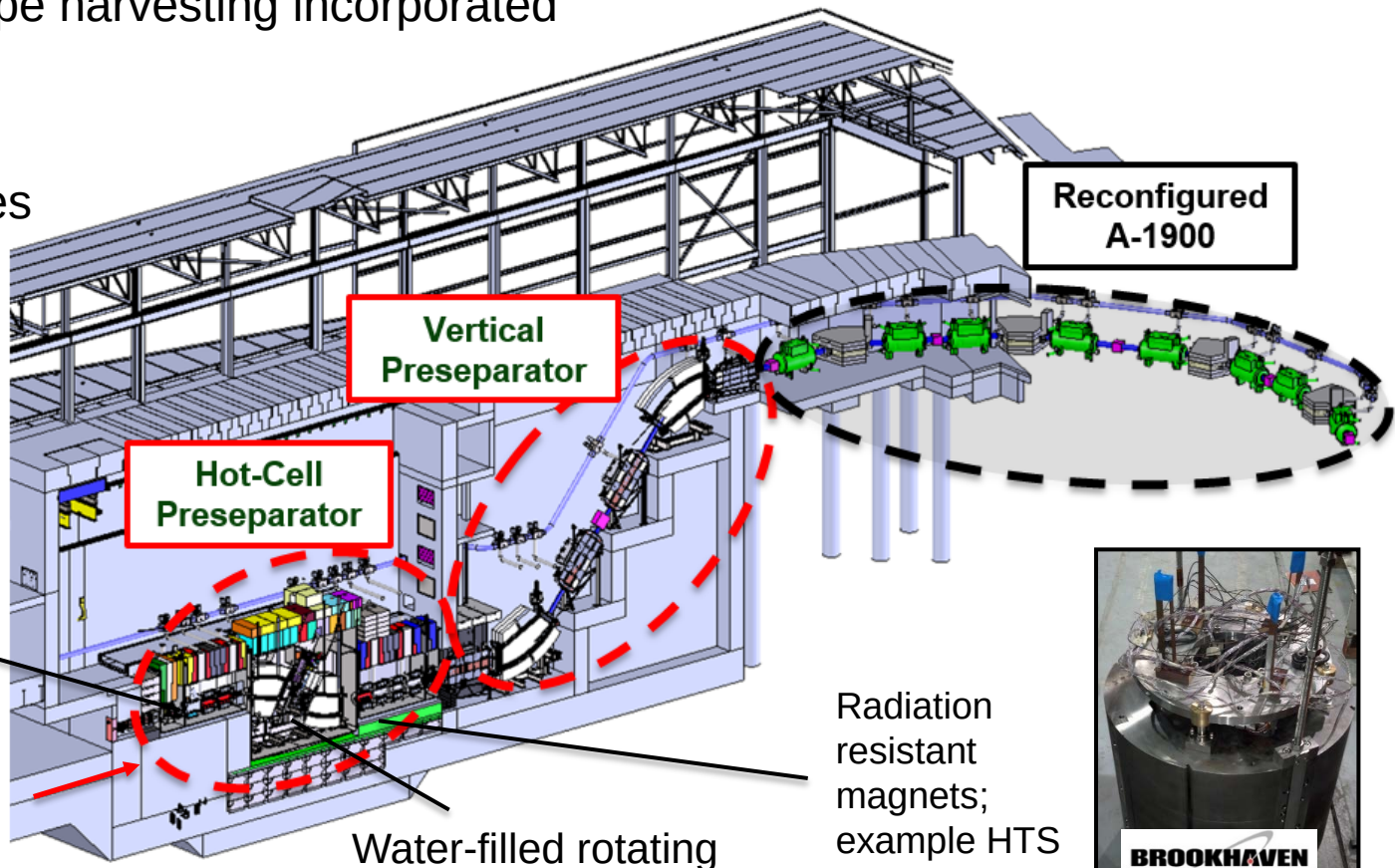
Argonne NATIONAL LABORATORY

Los Alamos NATIONAL LABORATORY EST.1943



FRIB Fragment Separator
Three Separation Stages

- 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



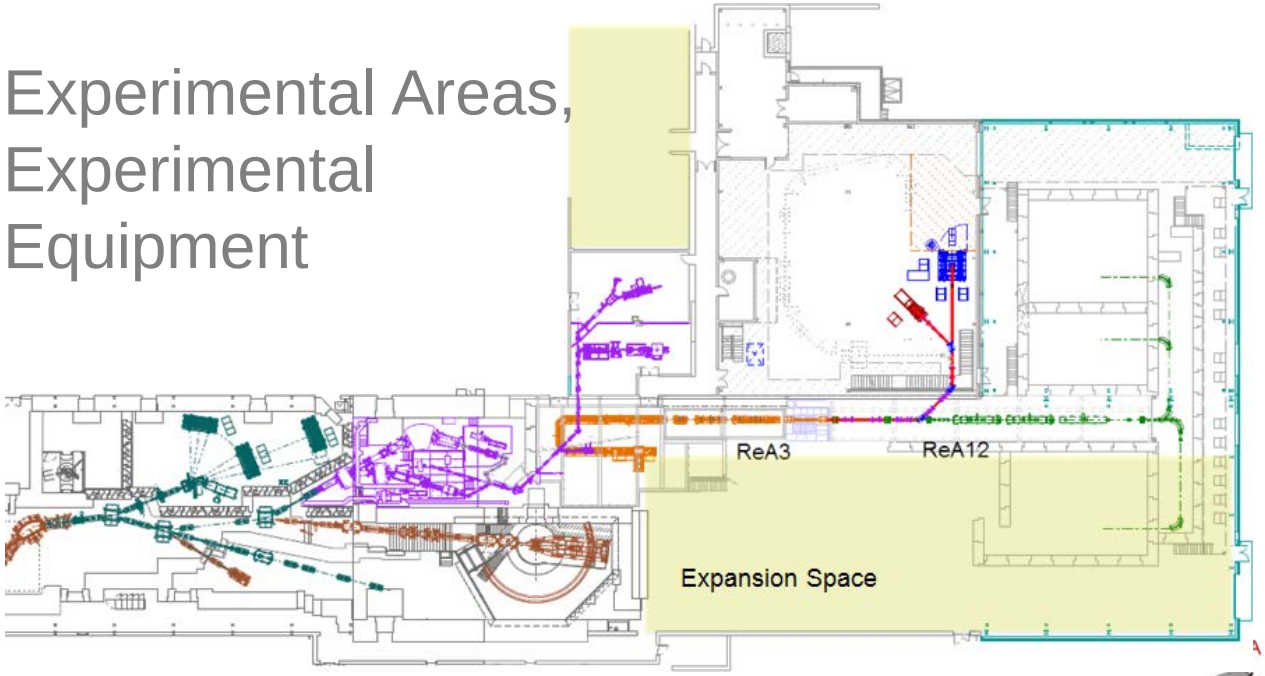
Multi-slice rotating graphite target

Water-filled rotating beam dump

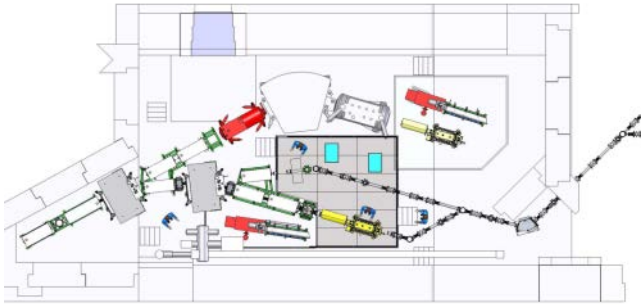
Radiation resistant magnets; example HTS quad

Fast, Stopped, and Reaccelerated Beam Experimental Areas and Equipment

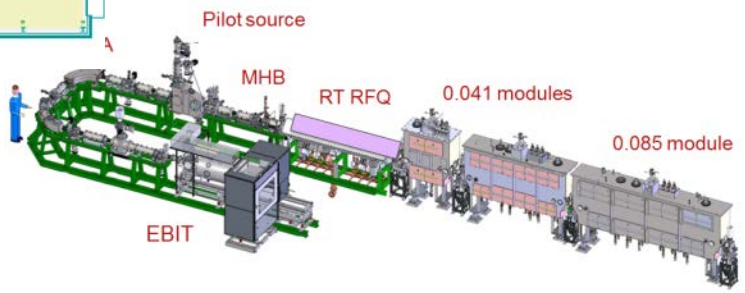
Experimental Areas, Experimental Equipment



Beam Stopping



Reacceleration

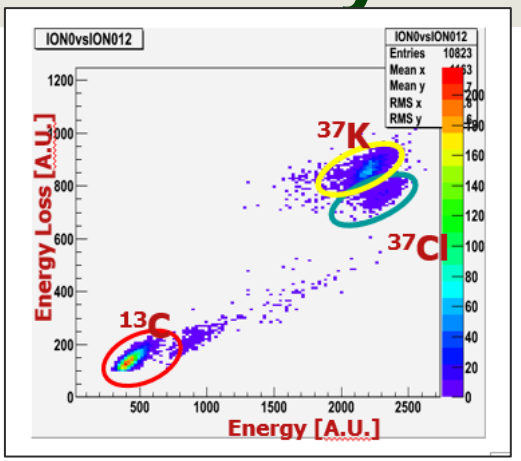


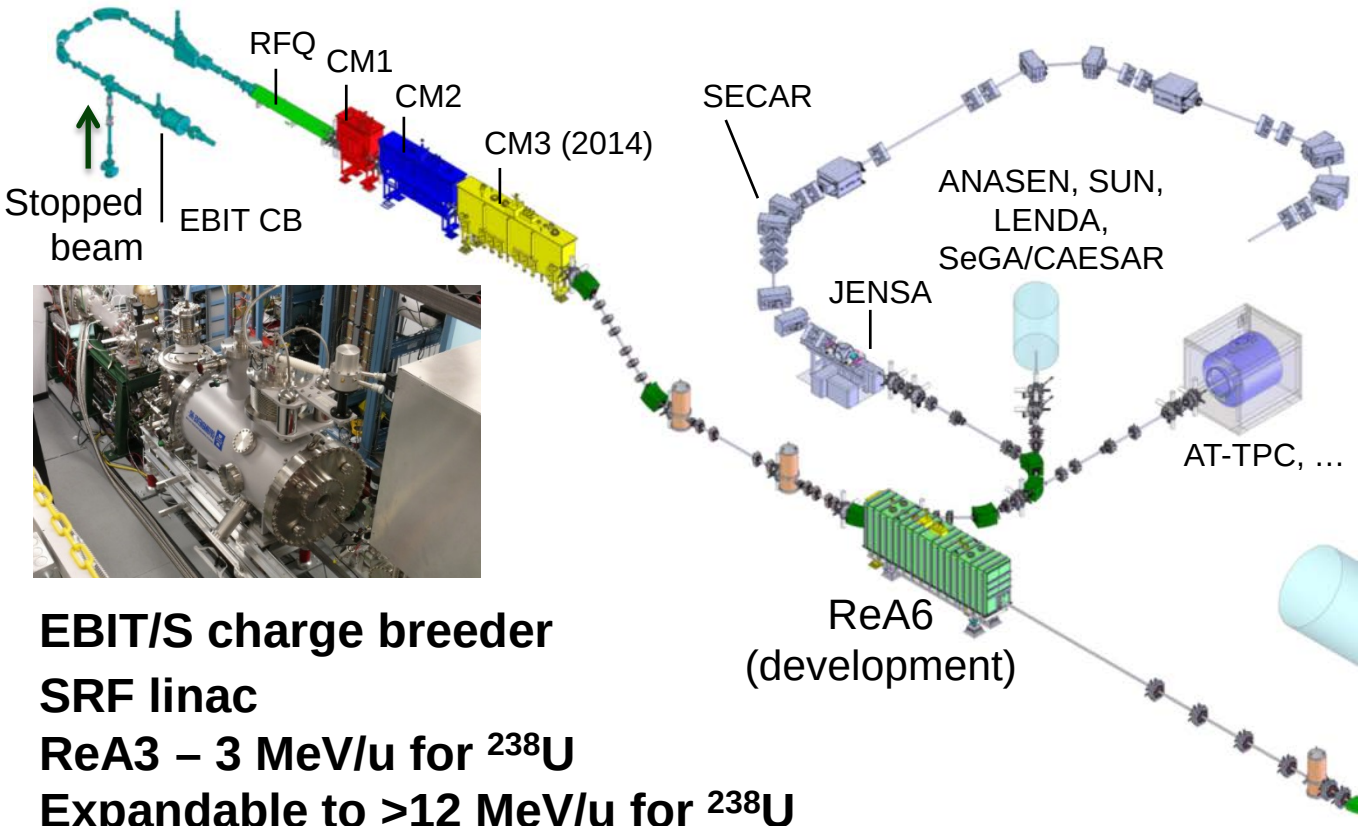
- NSCL enables pre-FRIB science with fast, stopped, and reaccelerated beams

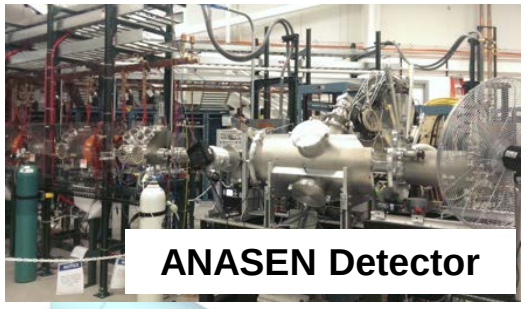
MSU

Reaccelerated Beams at NSCL and FRIB with ReA Facility

First radioactive beam experiment with ReA3 August 2013







EBIT/S charge breeder

SRF linac

ReA3 – 3 MeV/u for ^{238}U

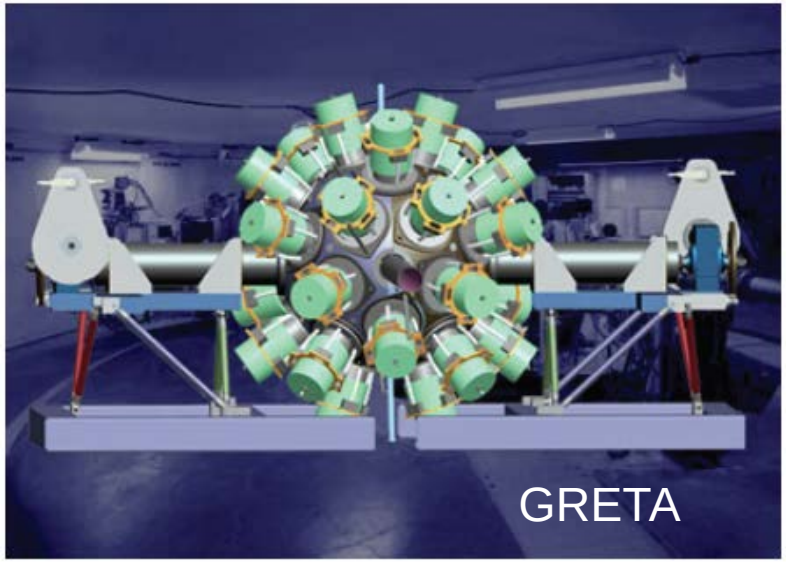
Expandable to >12 MeV/u for ^{238}U

Instrumentation for Low Energy Nuclear Physics

- A variety of instrumentation is required to make use of 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 acquisition
- 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

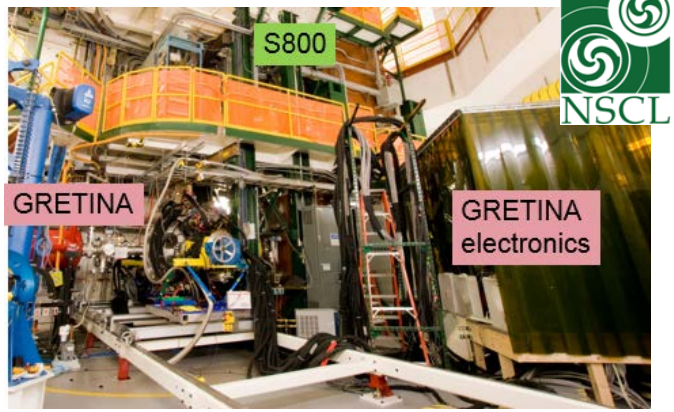
Instrumentation for Low Energy Nuclear Physics: Example GRETINA

- 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).



Instrumentation for Low Energy Nuclear Physics: Example GRETINA

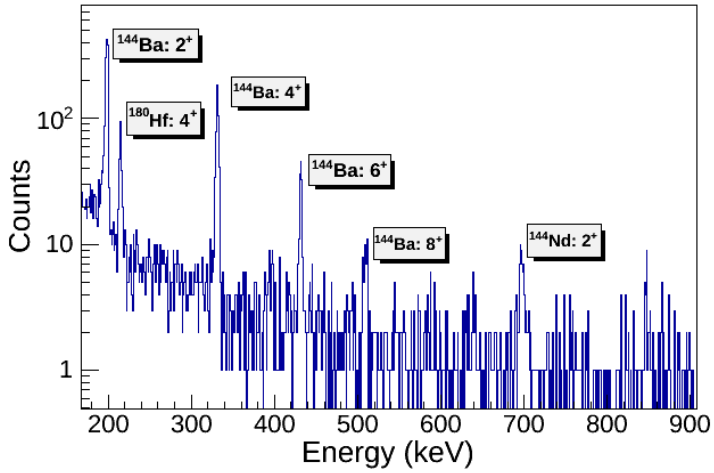
- First campaign successfully completed at NSCL/MSU
  - Over 3000 hrs of beam-time and 200 users in the first year
  - Nuclear Shell Evolution, Nuclear Astrophysics, Collective Phenomena
- New GRETINA science campaign at ATLAS Argonne National Laboratory successfully started



GRETINA at NSCL's S800 spectrograph

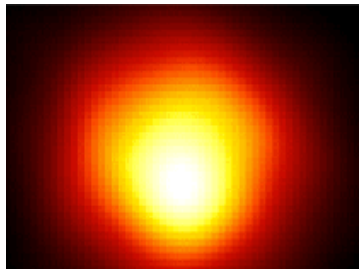
Coulomb excitation of ^{144}Ba GRETINA + CHICO2 + CARIBU/ATLAS

Argonne NATIONAL LABORATORY



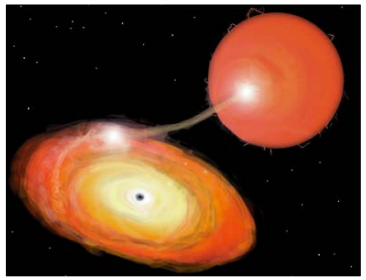
Instrumentation for Low Energy Nuclear Physics: Example SECAR

- Proposed **SECAR** recoil separator to directly measure astrophysical reaction rate
- Multi-institutional collaboration includes most experimental nuclear astrophysicists in US



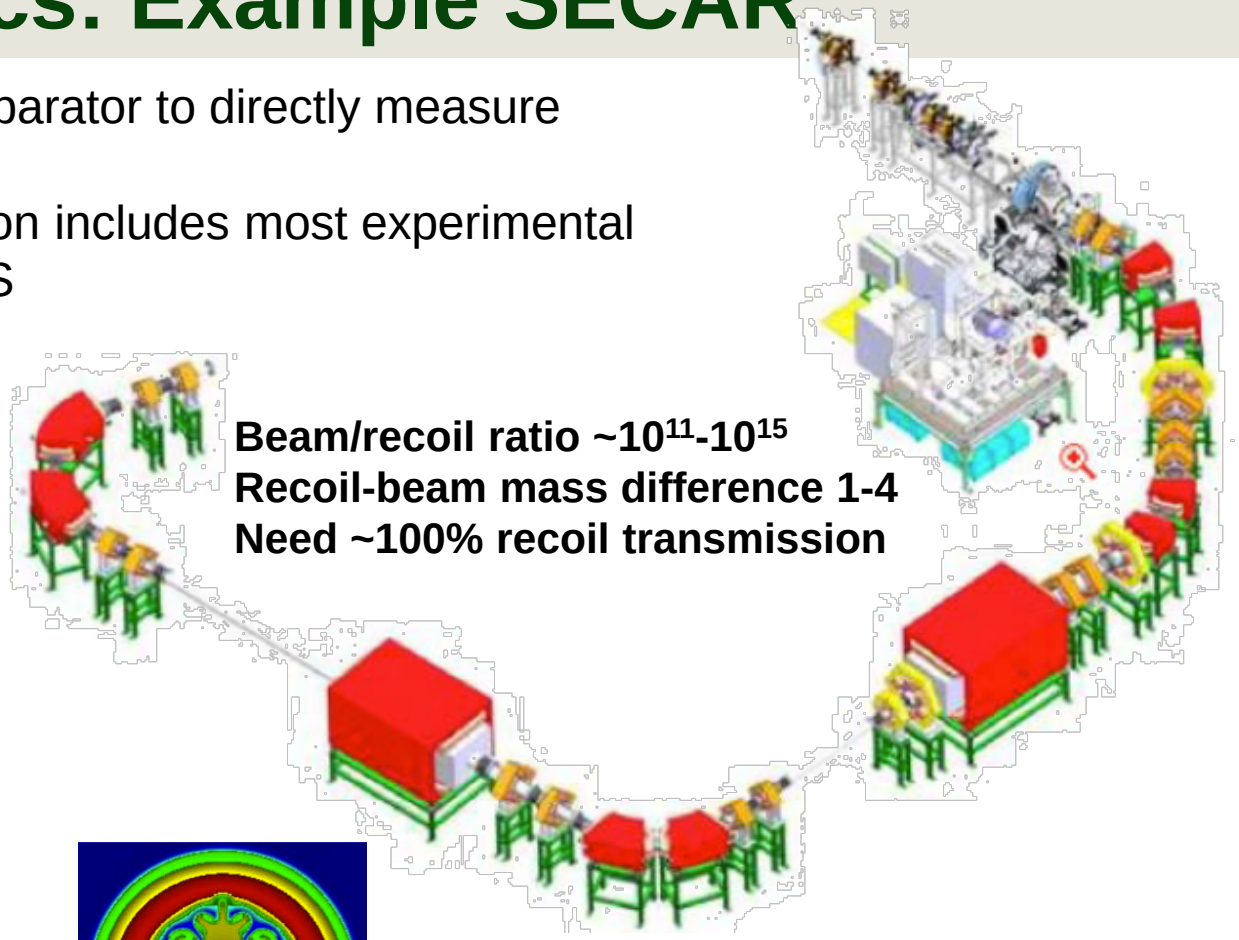
Extreme Stars

- Thorne Zytkov objects?
- Massive first stars

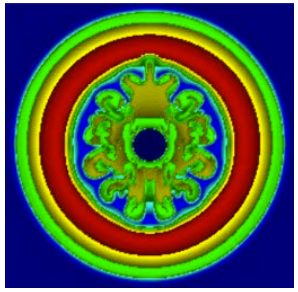


Accreting compact objects

- X-ray bursts
- Novae



Beam/recoil ratio ~10^{11}-10^{15}
Recoil-beam mass difference 1-4
Need ~100% recoil transmission



Supernovae

- νp-process, p-process
- Explosive burn

FRIB

Over 1300 Users Engaged and Ready for Science

- Users are organized as part of the independent FRIB Users Organization (FRIBUO) www.fribusers.org
- FRIBUO has 1350 members (92 U.S. colleges and universities, 10 national laboratories, 55 countries) as of April 2014
- FRIBUO has 19 working groups on experimental equipment
- 21-23 August 2014, Low Energy Community Meeting, Texas A&M University

August 2013 Low-Energy Community Meeting 274 participants

Low Energy NP User Facilities and the SBIR/STTR Program

- SBIR/STTR program is important for the DOE Low Energy NP facilities
  - Development needs for new techniques, instrumentation, and supporting system 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 (high current sources, charge breeders), beam catcher/release systems
  - Radiation resistant magnets (HTS, thermal insulation)
  - Radiation resistant precision magnetic field probes
  - Other accelerator related developments

Summary

- There are exciting times ahead for 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 (>1300 members)
- Existing LE radioactive beam facilities in the US provide world-class research opportunities prior to FRIB and beyond.
- The DOE NP SBIR/STTR program contributes to making Low Energy Nuclear Physics in the US successful