NP Low Energy Facilities and the SBIR/STTR Program

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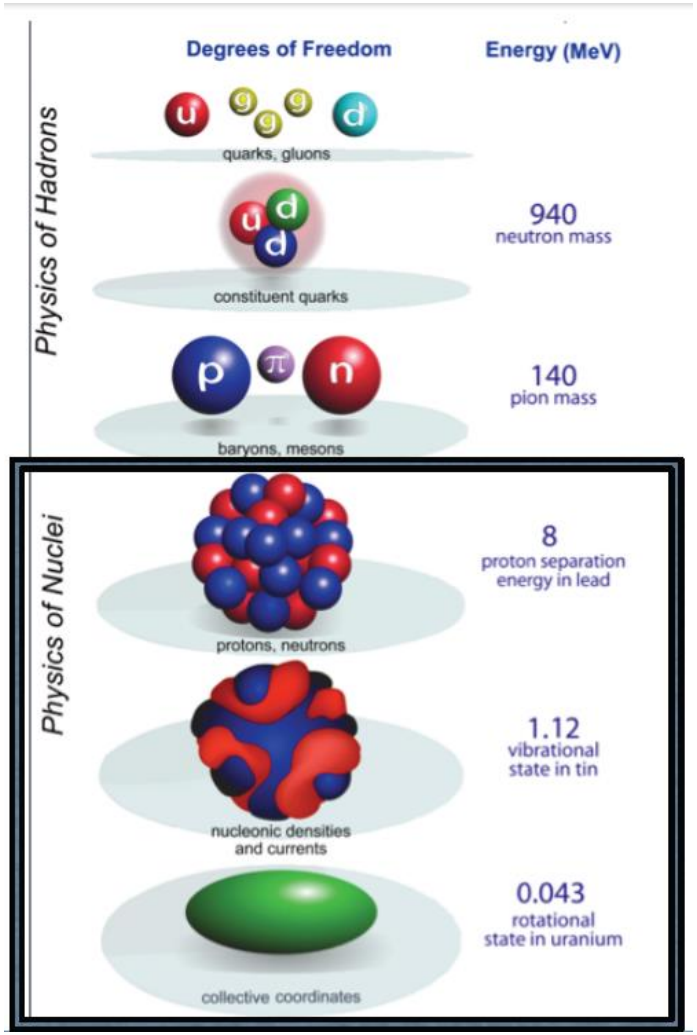
Outline

- Context
- Science
- Major Facilities
- Advanced Instrumentation

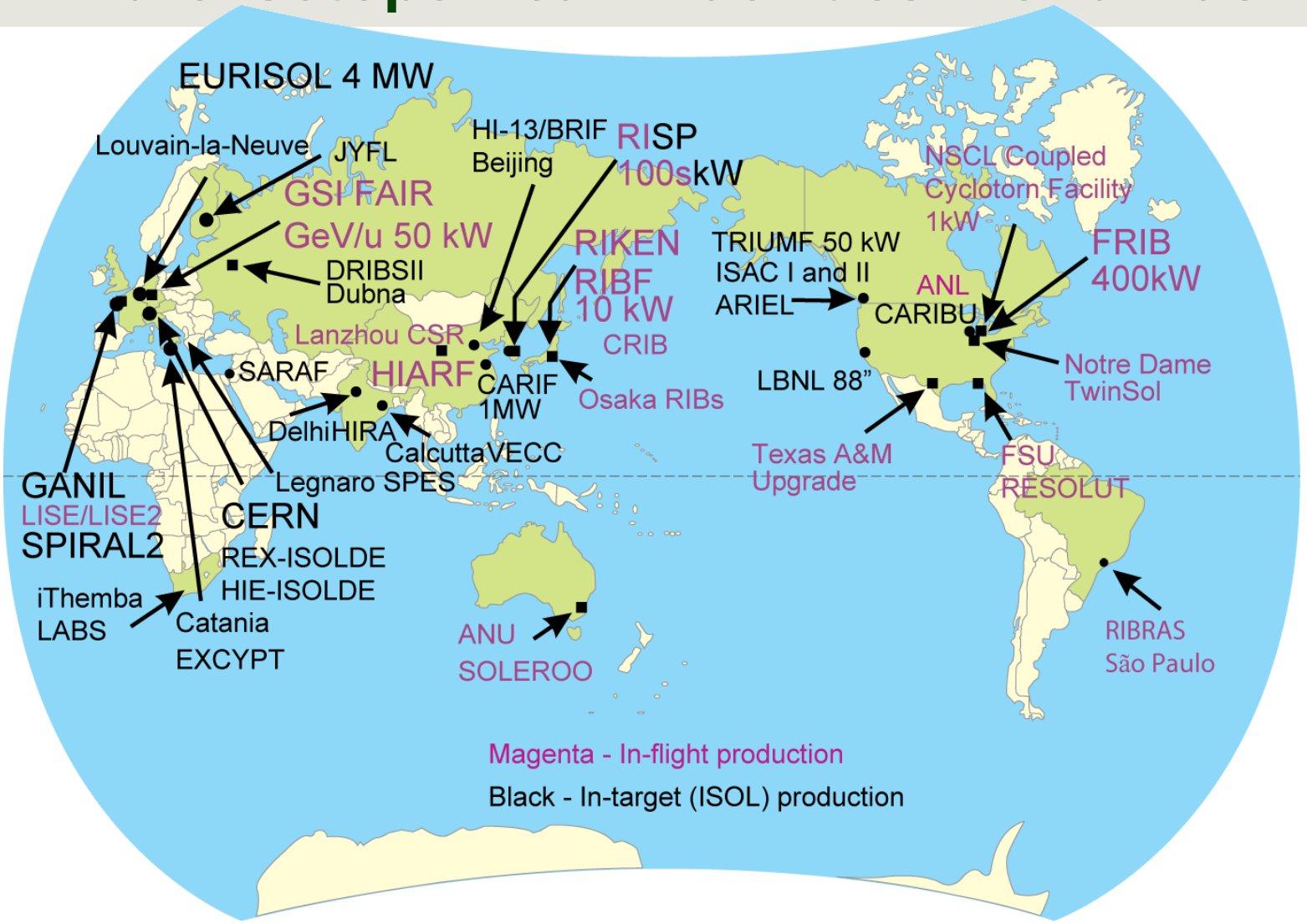
- Acknowledgment
  - Materials provided by G. Savard (ANL), A. Macchiavelli (LBNL), D. Radford (ORNL), and others

Low Energy Nuclear Physics



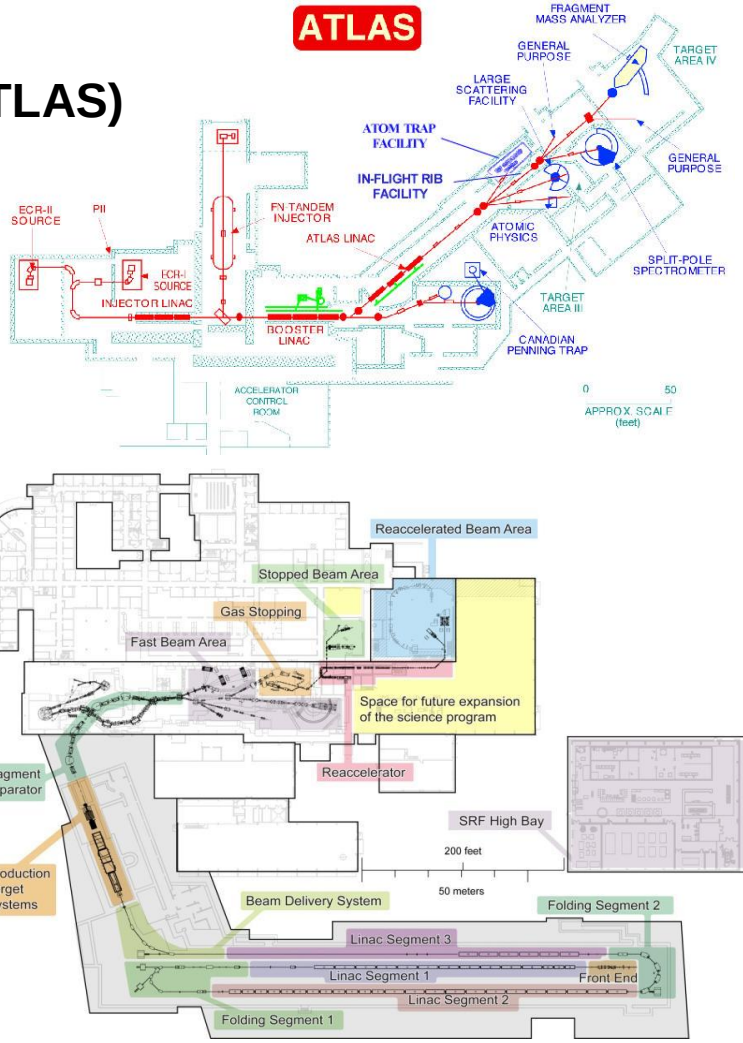
- Refers to the energy scale of the science
  - Of order few MeV (nuclear binding scale)
- Encompasses the physics governing nuclear decays and how they combine to create elements.
- It is where our field most directly impacts and touches our lives (energy, medicine, security)
- Provides a unique way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

Low Energy Nuclear Physics
Rare Isotope Beam Facilities Worldwide



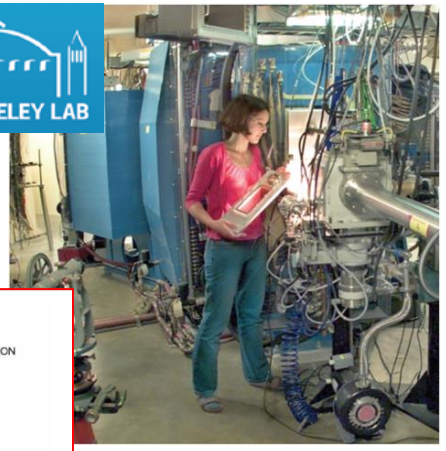
Low Energy Nuclear Physics Facilities

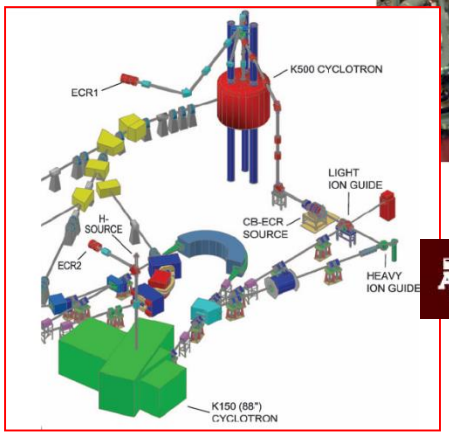
- DOE National User Facilities
  - **Argonne Tandem-Linac Accelerator System (ATLAS)** (http://www.phy.anl.gov/atlas/facility)
    - » High intensity stable beams
    - » Limited radioactive beam program with stopped, re-accelerated, and in-flight beams
  - **Facility for Rare Isotope Beams (FRIB) at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

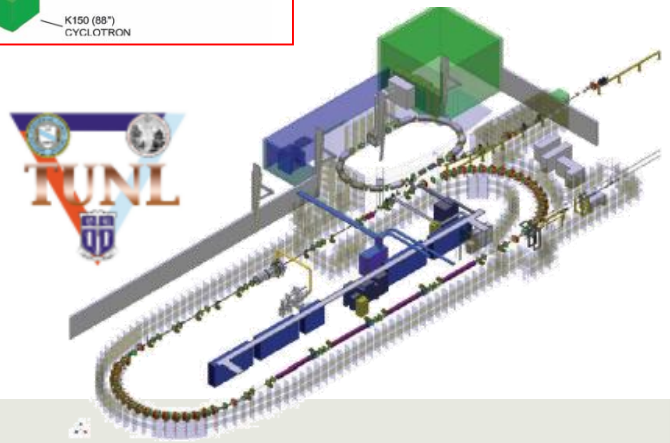


Low Energy Nuclear Physics Facilities

- Other DOE facilities (local use)
  - **LBNL 88---Inch Cyclotron** (http://cyclotron.lbl.gov)
    - » Basic and applied research with stable beams
  - **Texas A&M Cyclotron Insitute** (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

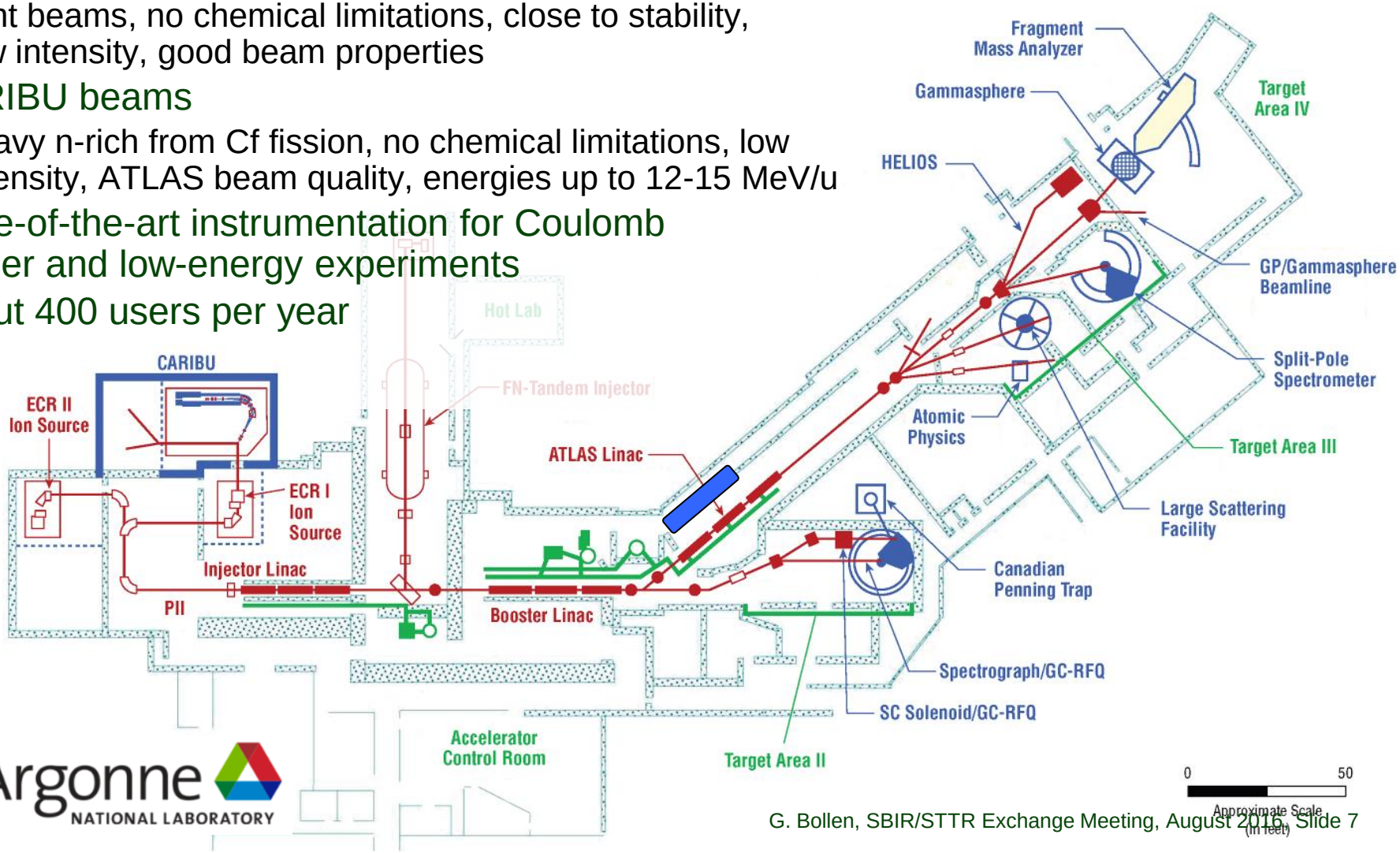






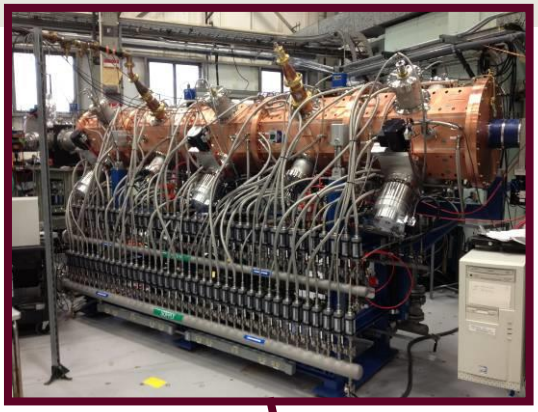
ATLAS/CARIBU Facility at Argonne National Laboratory

- 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



Argonne NATIONAL LABORATORY

ATLAS/CARIBU Facility at ANL



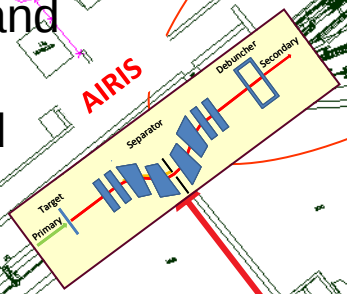
Improved
instrumentation

New low-energy
experimental hall

cryomodule and
rebuncher
rearranged

CARIBU

AIRIS



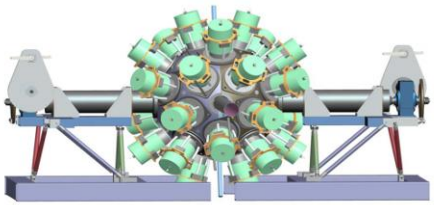
New in-flight
separator (AIRIS)

MHB RFQ

new cryomodule

ATLAS Suite of Experimental Equipment

Gammasphere/GRETINA

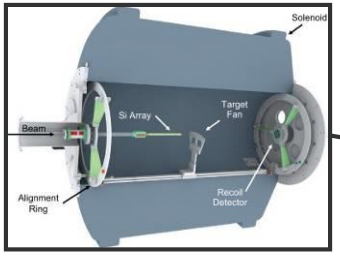


FMA

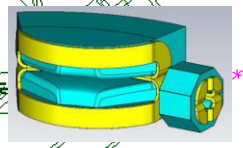
CPT mass spectrometer

X-array

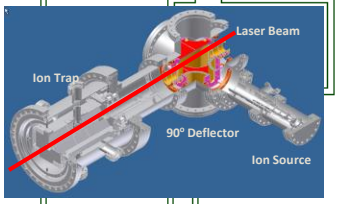
HELIOS spectrometer



AGFA

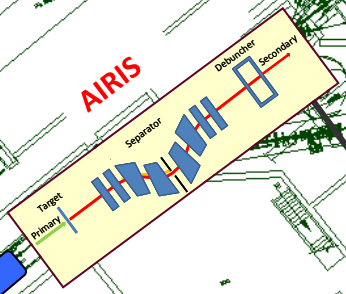


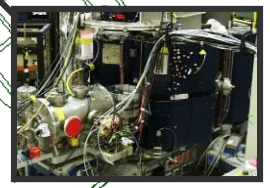
Laser Lab



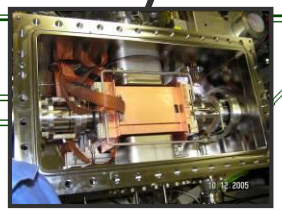
CARIBU

AIRIS

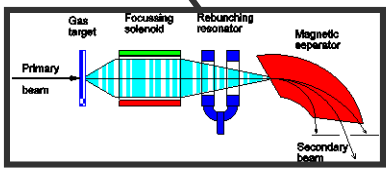




Si-array (Ludwig) and Enge spectrometer



Beta decay Paul trap



In-flight RIBs production

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

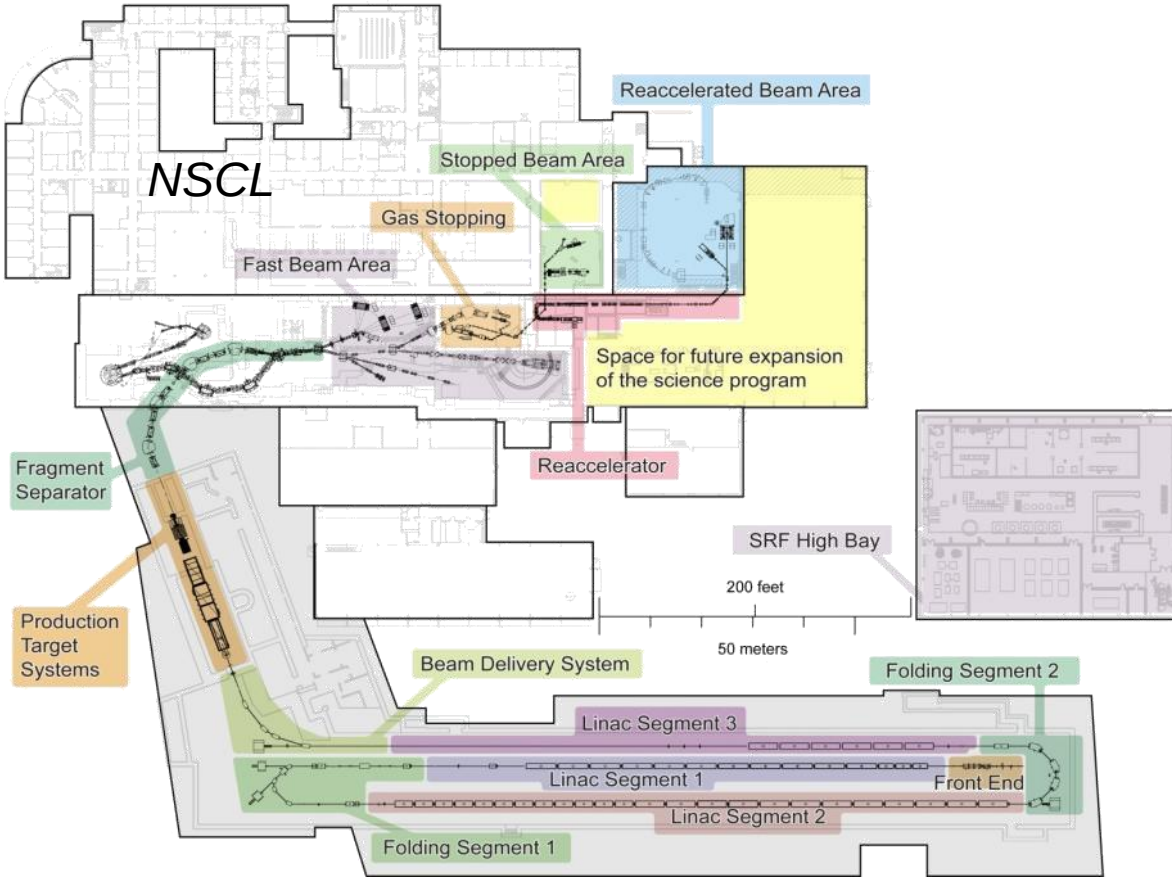
FRIB - Facility for Rare Isotope Beams

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

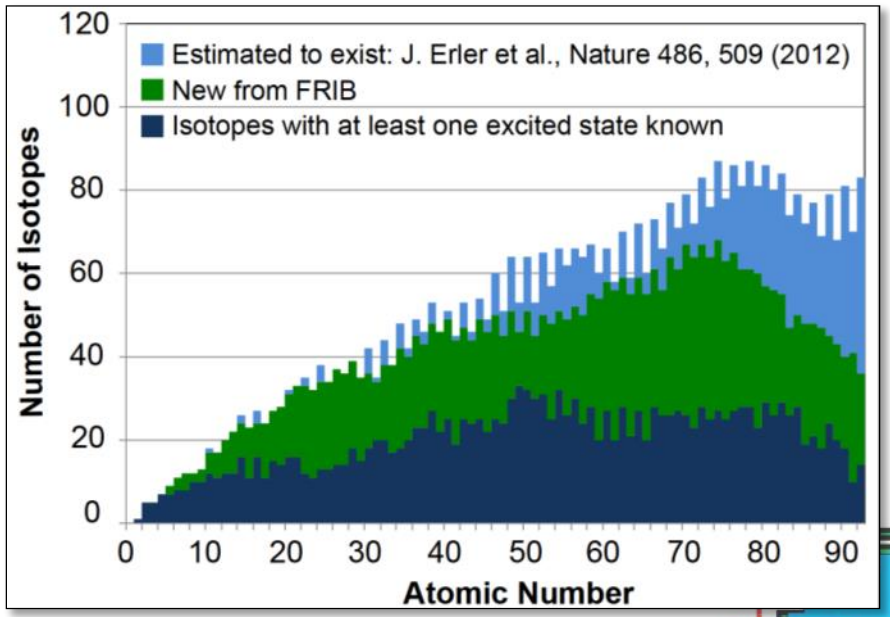
FRIB project start 6/2009
Civil construction started 3/2014
Technical construction started 10/2014
Managed to early completion FY 2021
CD-4 (project completion) 6/2022

Total project cost $730 million



NSCL enables pre-FRIB science

FRIB Beams Will Enable New Discoveries

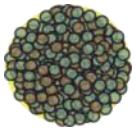


Available today

New territory to be explored with FRIB

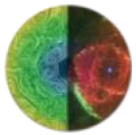
about 3000 known isotopes

FRIB – Four Science Themes



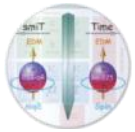
Properties of nuclei

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



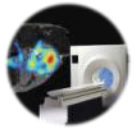
Astrophysical processes

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



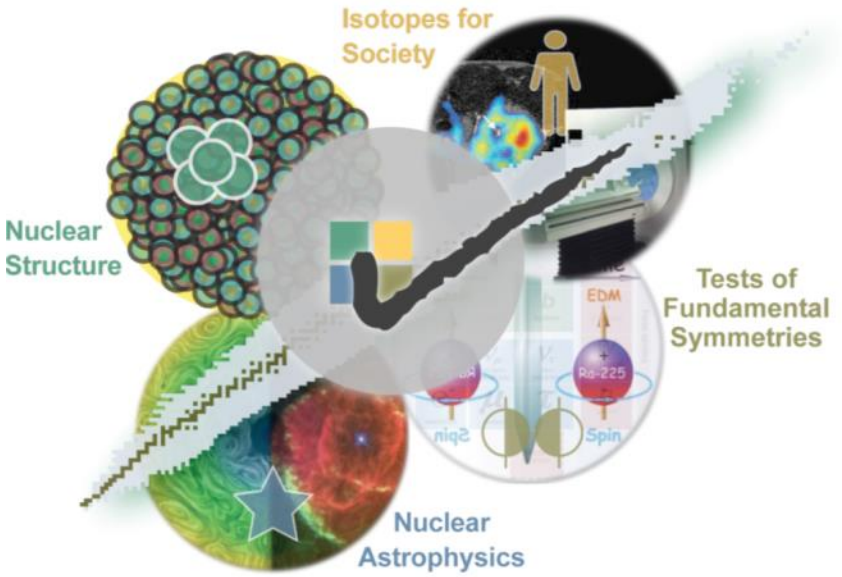
Tests of fundamental symmetries

- Effects of symmetry violations are amplified in certain nuclei

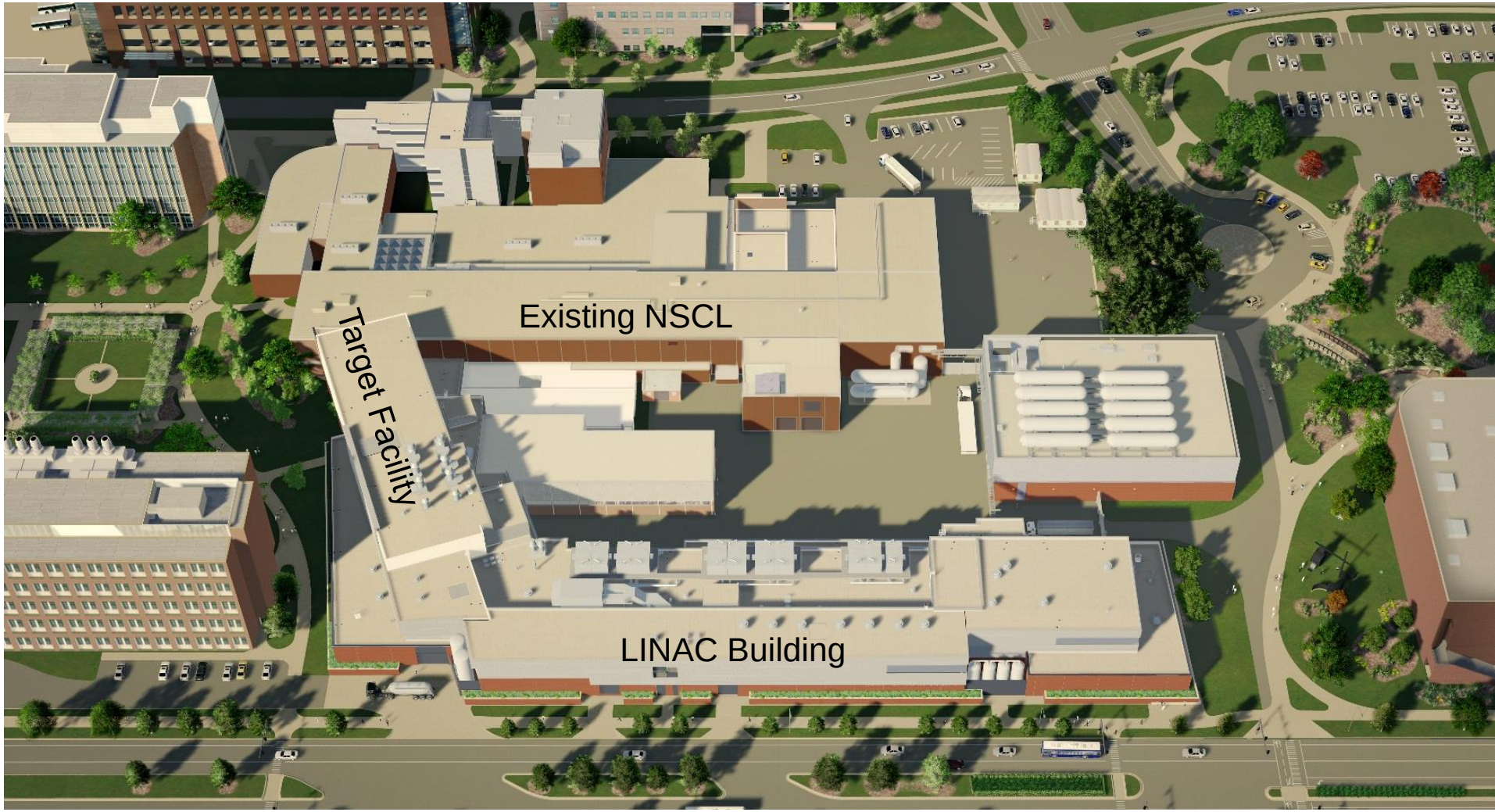


Societal applications and benefits

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



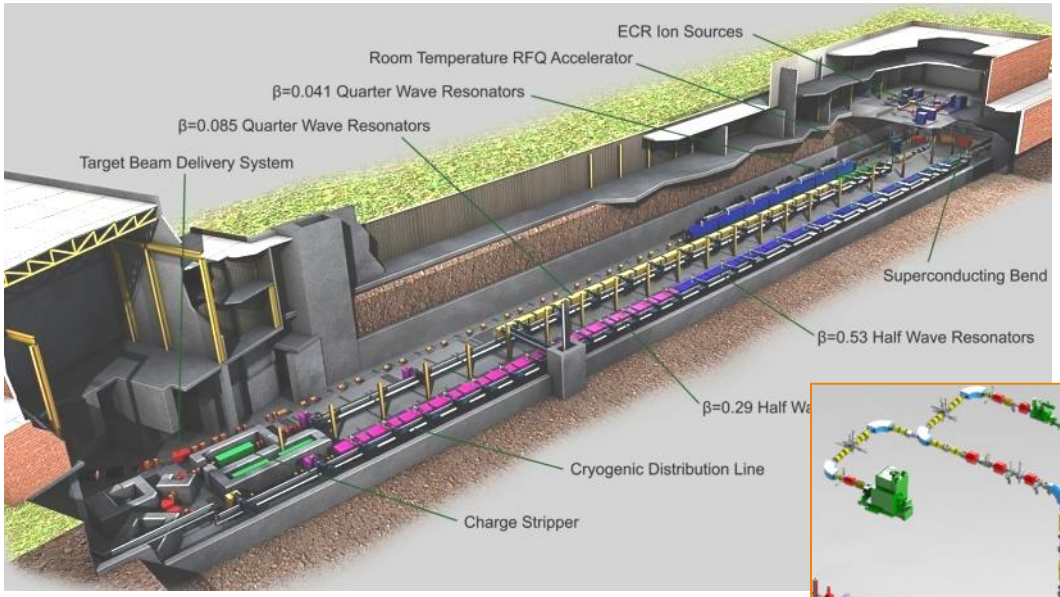
Facility for Rare Isotope Beams

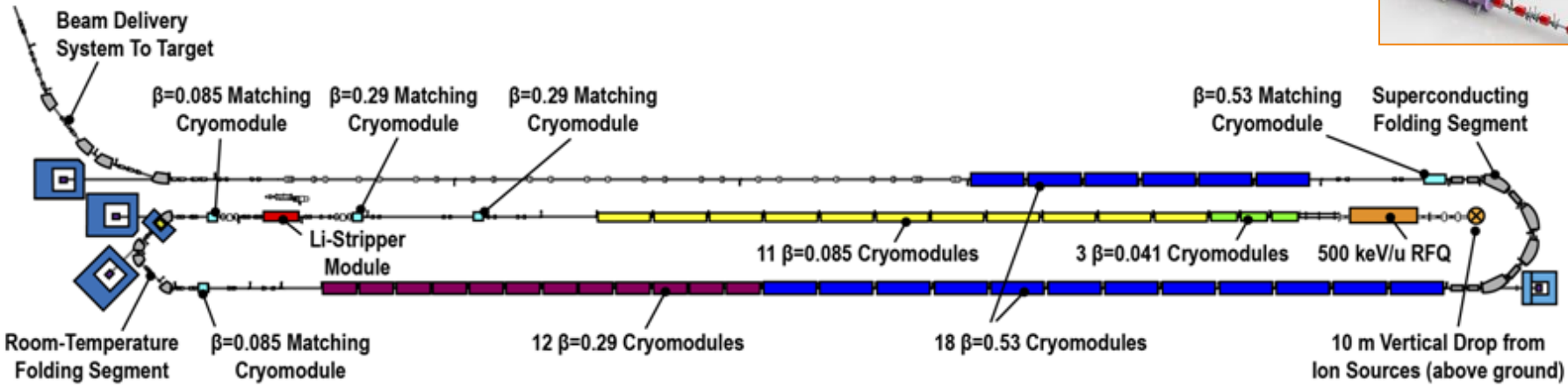


Civil Construction Nears Completion

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





Installation of Accelerator Equipment Underway

- Cryomodule fabrication underway
- Installation of equipment in surface building and linac tunnel started
- Commissioning of linac front end (ion source, low-energy transport, RFQ) to start in Jan/Feb 2017

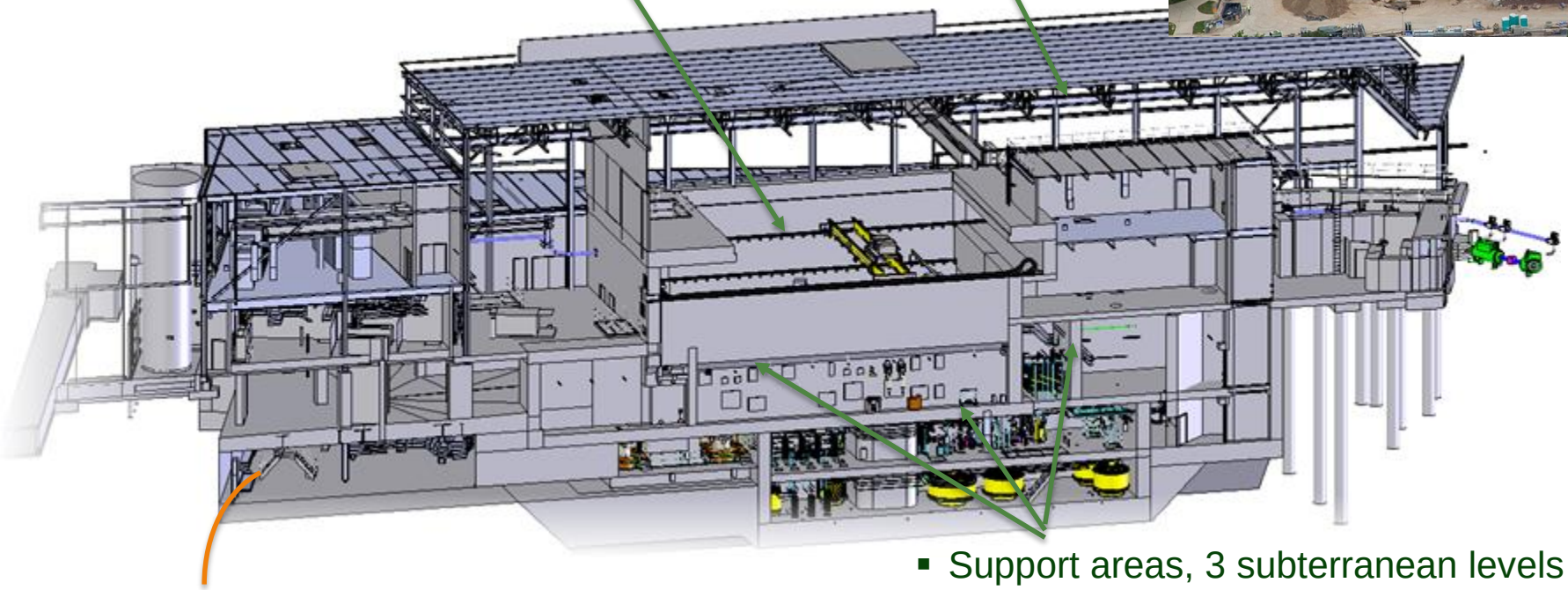

ARTEMIS 14 GHz ECR ion source on HV platform


Cryo transfer line in the Linac Tunnel


β=0.53 preproduction cryomodule being assembled at MSU

FRIB Rare Isotope Production Facility

- 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

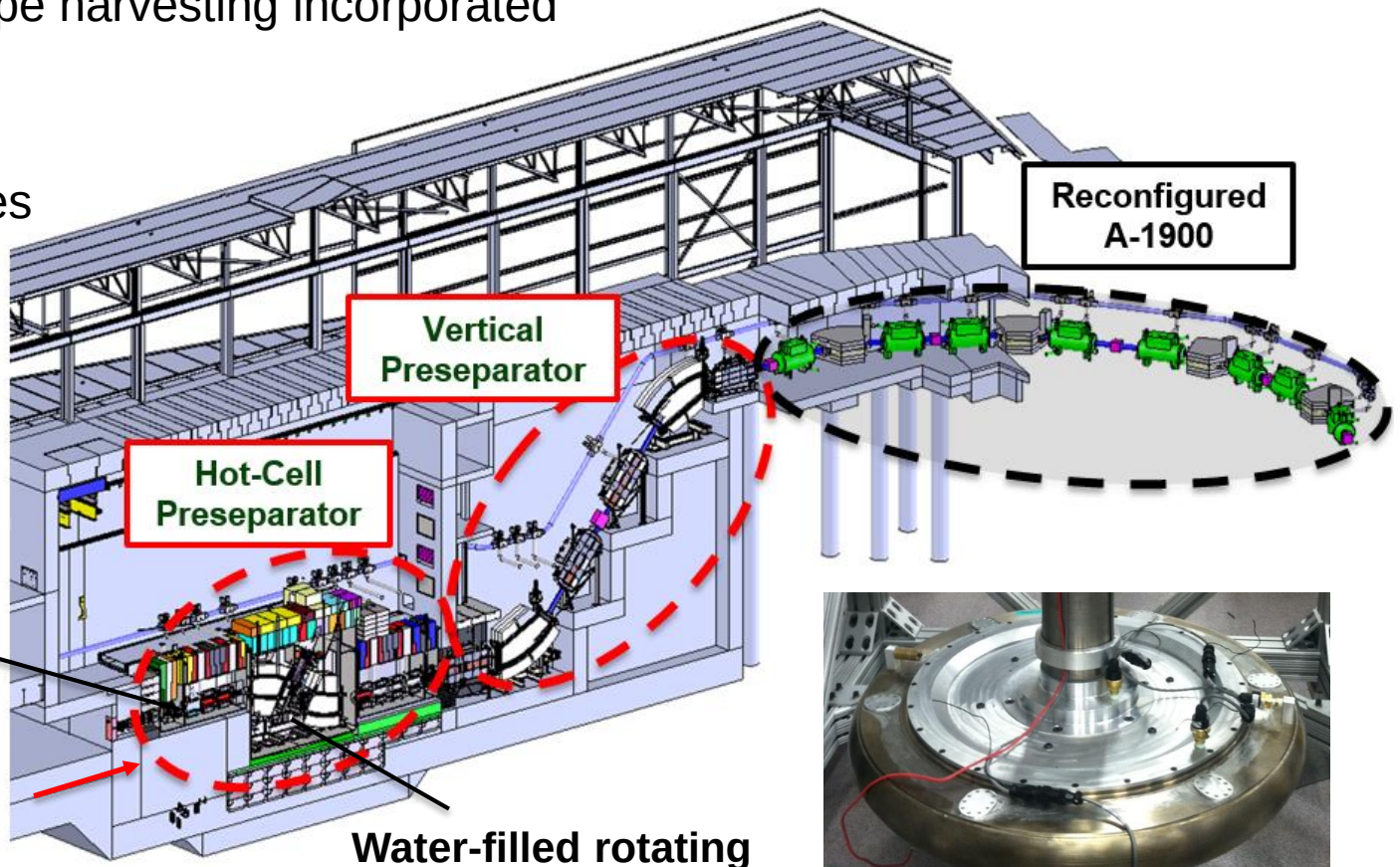


400 kW beam from linac

- 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

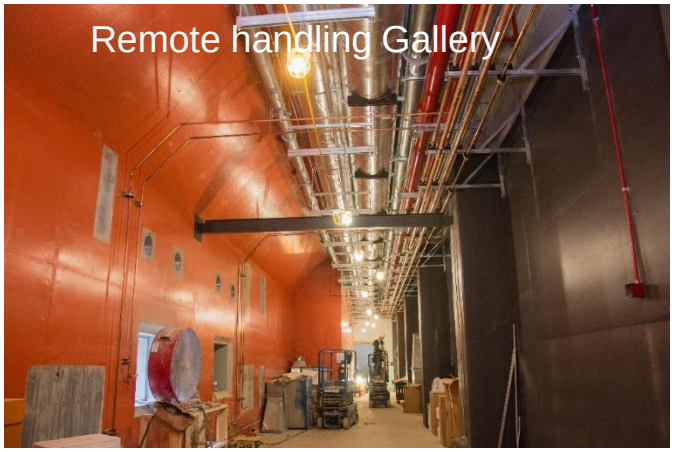


Multi-slice rotating graphite target

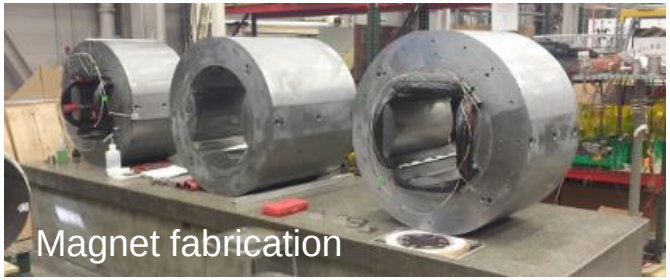
Water-filled rotating beam dump

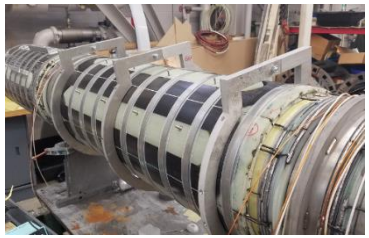
FRIB Rare Isotope Production Facilities
Target Facility and Fragment Separator

- Target Facility BOD is January 2017
  - Non-conventional utility equipment and remote-handling being installed
- Fragment separator construction
  - Target first-article construction started
  - Beam dump design completion on track
  - Large vacuum vessels being fabricated
  - Superconducting magnet fabrication underway


Remote handling Gallery


Fragment Separator
Vacuum Vessels


Magnet fabrication

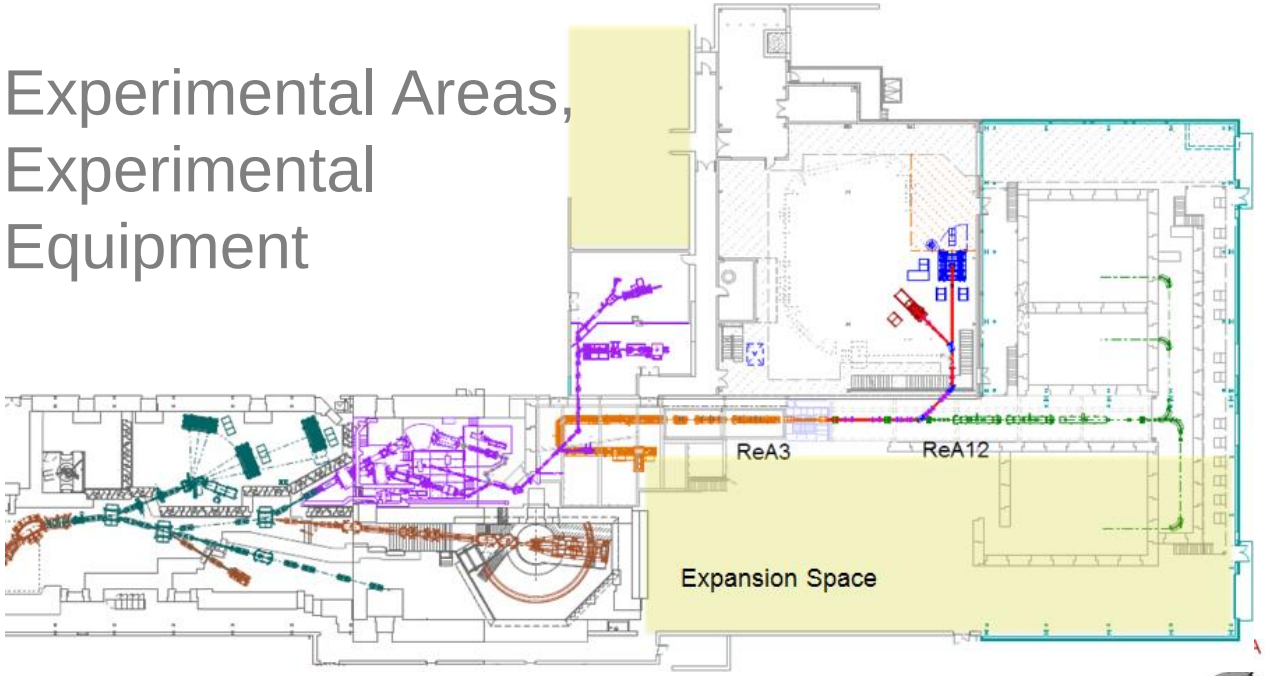



Non-conventional utilities


Target Facility Hot-cell

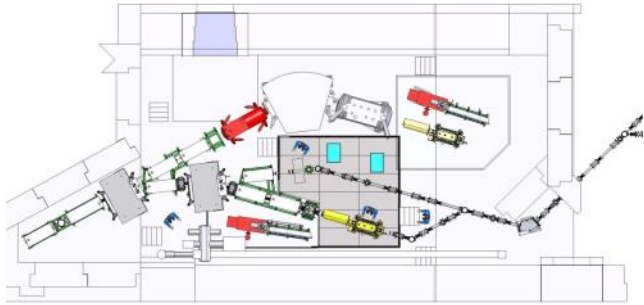
Fast, Stopped, and Reaccelerated Beam Experimental Areas and Equipment

Experimental Areas, Experimental Equipment



Fast Beams

Stopped Beams



Reaccelerated Beams

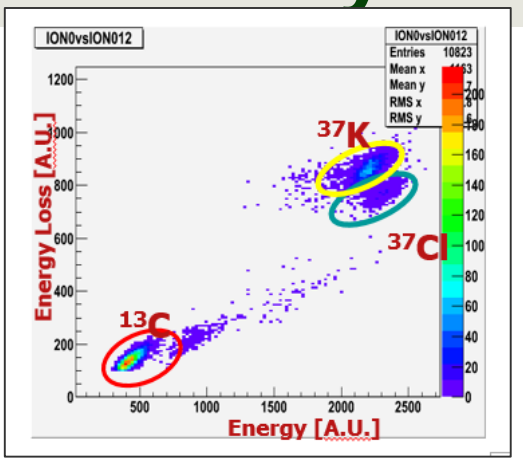
NSCL enables pre-FRIB science while FRIB construction is underway

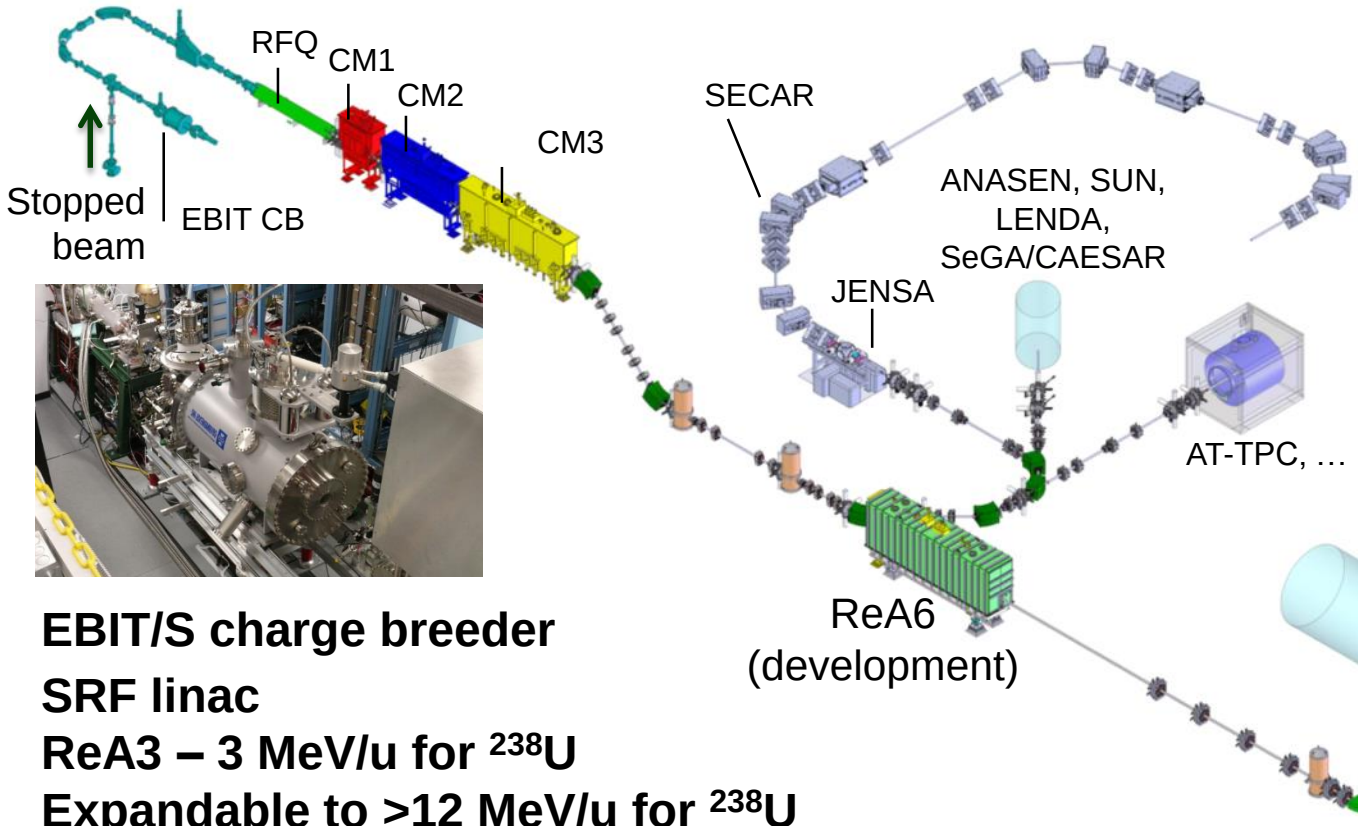
MSU

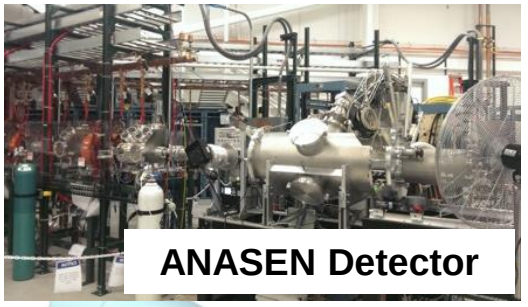
Reaccelerated Beams at NSCL and FRIB with ReA Facility

First rare isotope beam experiment with ReA3 August 2013

5 PAC approved rare isotope beam experiments since then







EBIT/S charge breeder

SRF linac

ReA3 – 3 MeV/u for ^{238}U

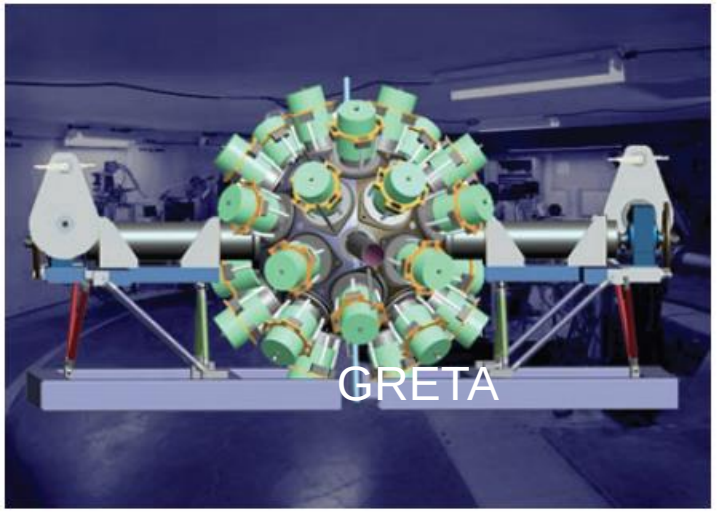
Expandable to >12 MeV/u for ^{238}U

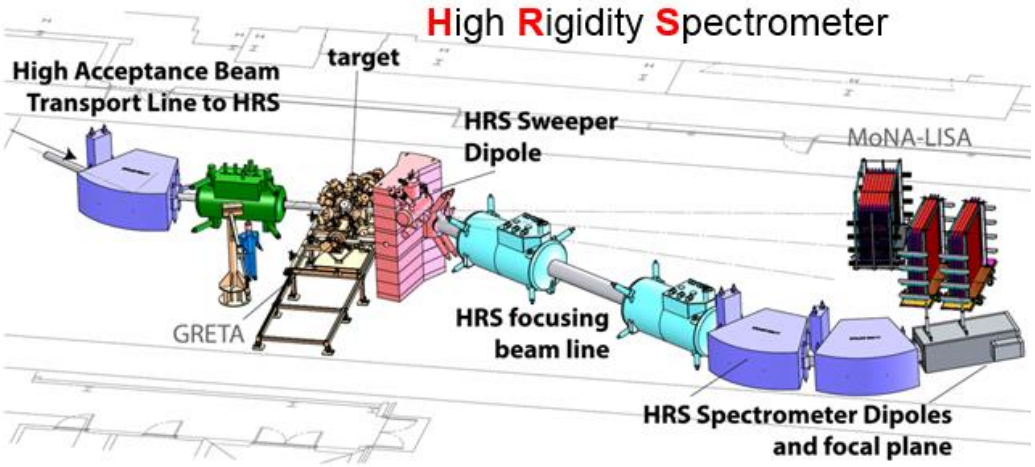
Instrumentation for Low Energy Nuclear Physics

- 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: Example GRETINA and GRETA

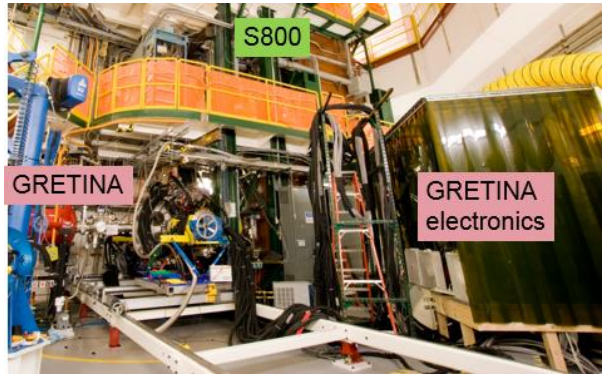
- GRETINA is one of the most advanced gamma-ray detector array for nuclear science uses highly segmented detectors to track and reconstruct gamma-rays
  - Science campaigns successful
  - GRETINA is the first phase of the larger Gamma Ray Energy Tracking Array (GRETA).
- GRETA has received CD-0 in 2015
- GRETA will benefit from High Rigidity Spectrometer (HRS) at FRIB
  - Design study funded by DOE-NP underway





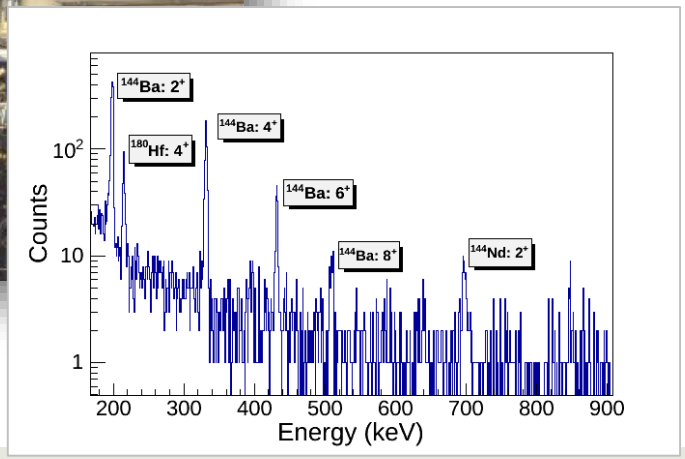
Instrumentation for Low Energy Nuclear Physics: Example GRETINA

- First campaigns at NSCL/MSU and ATLAS/ANL successfully completed
  - Over 6000 hrs of beam-time and >200 users
  - Nuclear Shell Evolution, Nuclear Astrophysics, Collective Phenomena
- Preparation for next GRETINA science campaign at NSCL started



GRETINA at NSCL's S800 spectrograph

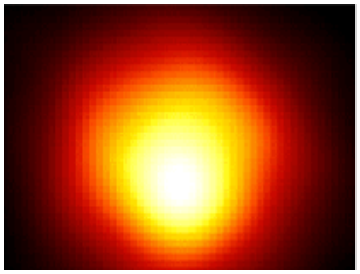
GRETINA at ATLAS



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

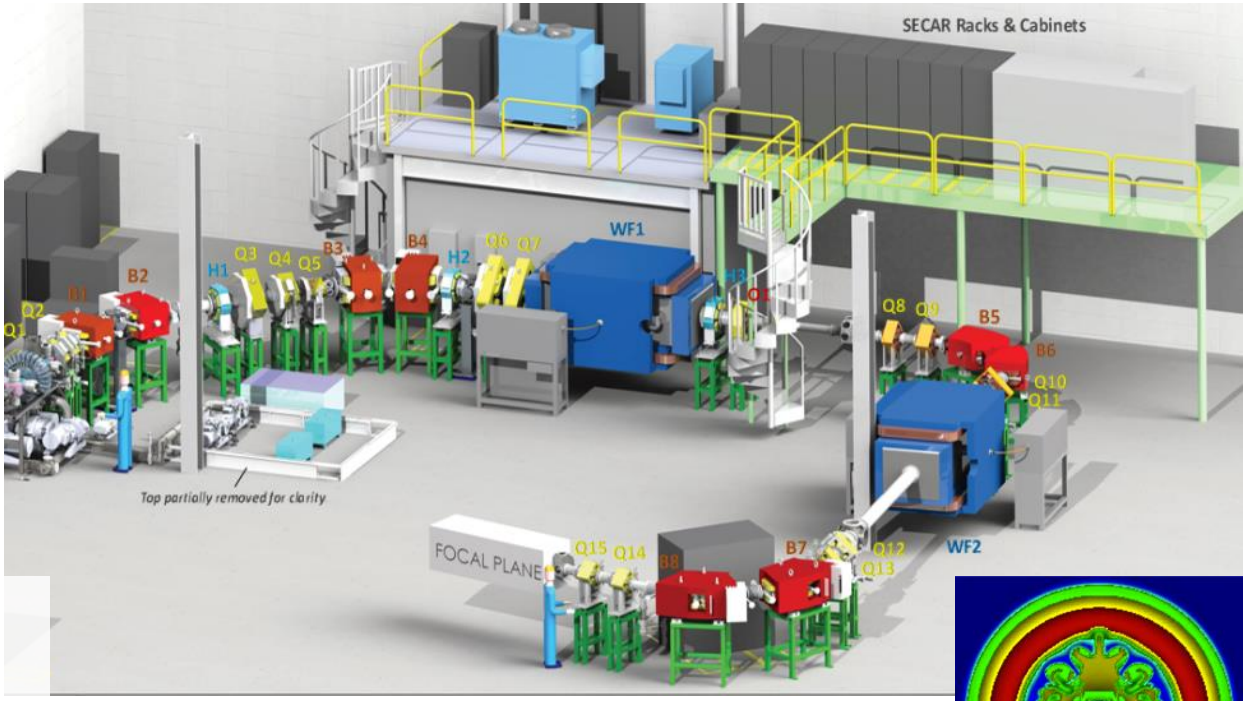
Instrumentation for Low Energy Nuclear Physics: Example SECAR

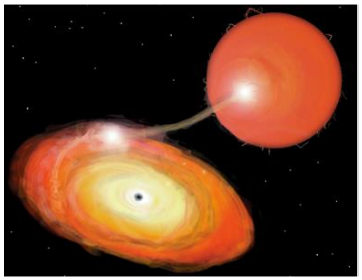
- **SECAR** will enable use of FRIB's unique low energy RIB production capabilities to directly measure astrophysical reaction rates
- DOE-SC/NSF project to establish SECAR underway, multi-institutional collaboration



Extreme Stars

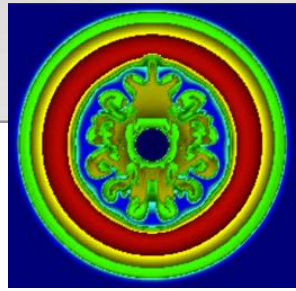
- Thorne Zytkov objects?
- Massive first stars





Accreting compact objects

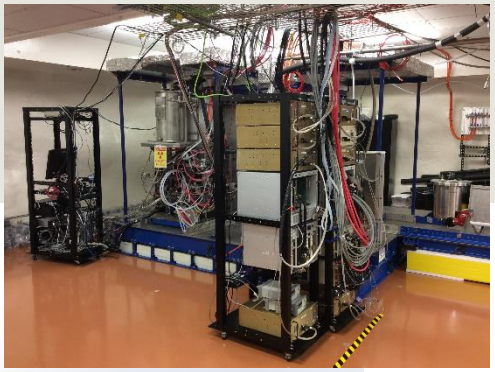
- X-ray bursts
- Novae



Supernovae

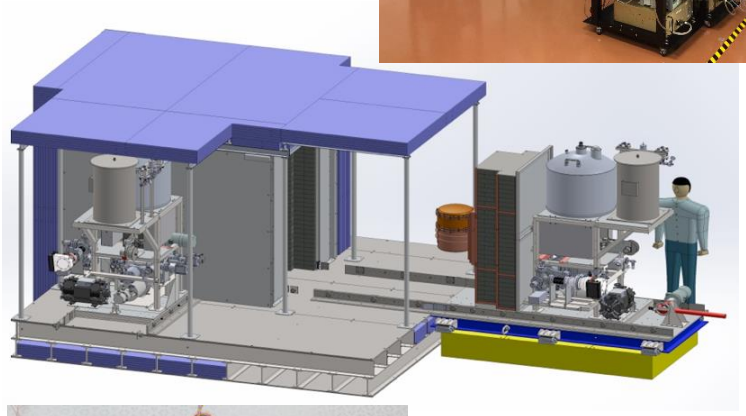
- νp-process, p-process
- Explosive burn

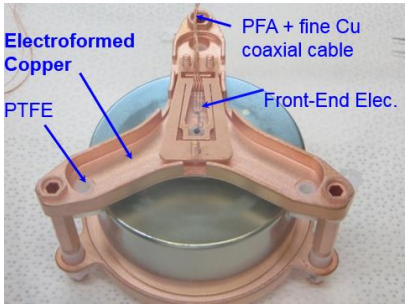
Other Major DOE NP Projects: MAJORANA Demonstrator



- MAJORANA is a proposed experiment to search for neutrinoless double-beta decay (0νββ).
  - Is neutrino a Majorana particle? What is neutrino mass scale?
- MAJORANA Demonstrator
  - Demonstrate backgrounds low enough to justify building a tonne scale experiment.
    - » Background goal in the 0νββ peak region of interest 3 counts/t/y (after analysis cuts)
  - Establish feasibility of modular arrays of Ge detectors.
  - Searches for additional physics beyond the standard model
  - Located underground at 4850' Sanford Underground Research Facility
  - 40-kg of Ge detectors
    - » 30 kg of 87% enriched ^{76}Ge
- Data taking underway

  N. Abgrall et al. Nuclear Instruments and Methods in Physics Research A 828 (2016) 22–36





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 (high current ECR ion sources, charge breeders)
  - Beam catcher/release systems
  - Radiation resistant magnets
  - Radiation resistant precision magnetic field probes
  - 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