FRIB Instruments

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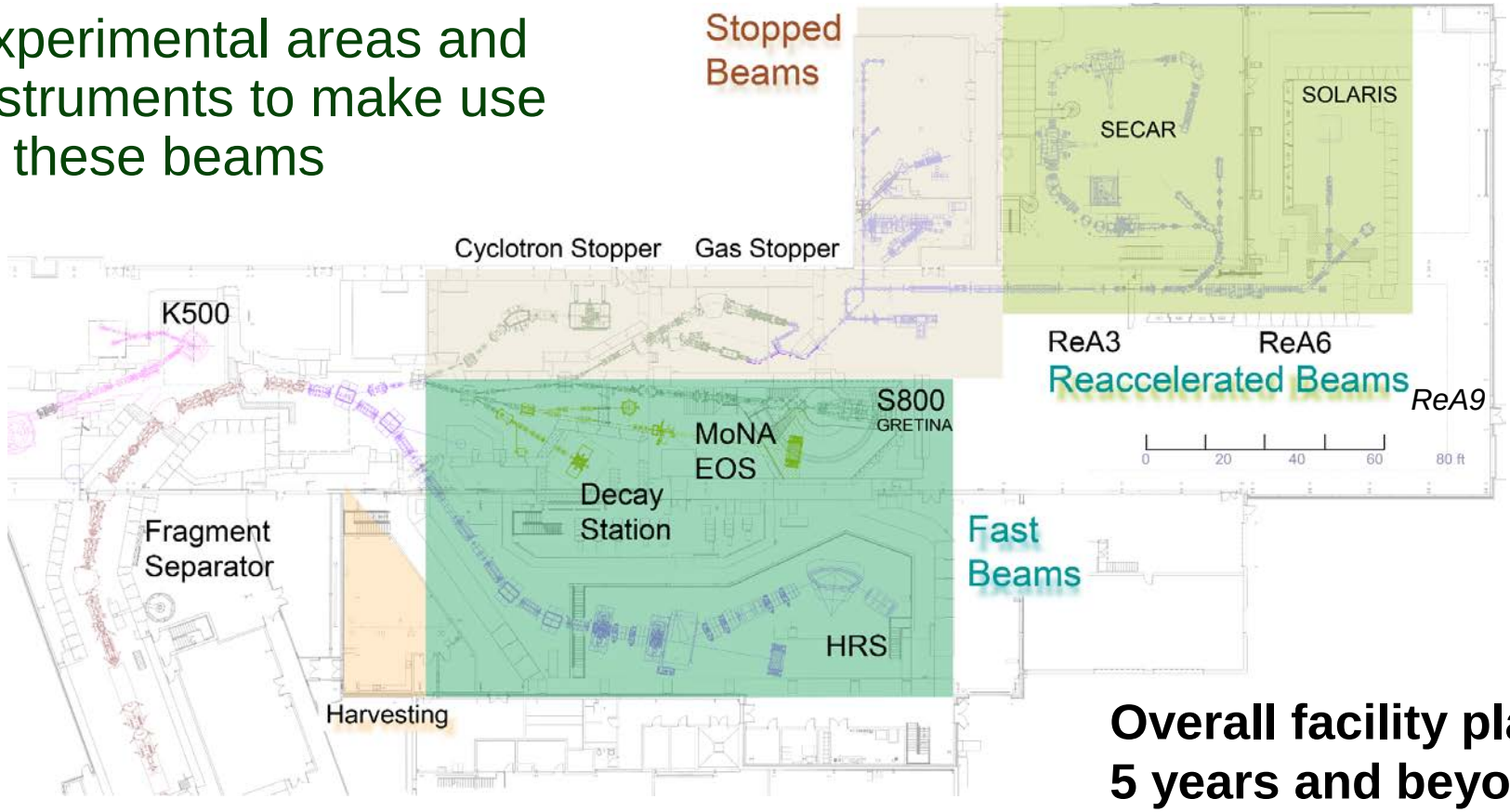
Outline

- FRIB has available fast, stopped, and reaccelerated beams from in-flight separation of projectile fragments
- Existing and plan for new scientific instruments and upgrades supports science strategy and long-term perspective
- Realization of new scientific instrumentation with community engagement and leadership
- Experimental area completion supports user experiment program
- Ideas and initiatives for new instruments welcome

FRIB Scientific Instruments and Experimental Areas for User Experiments

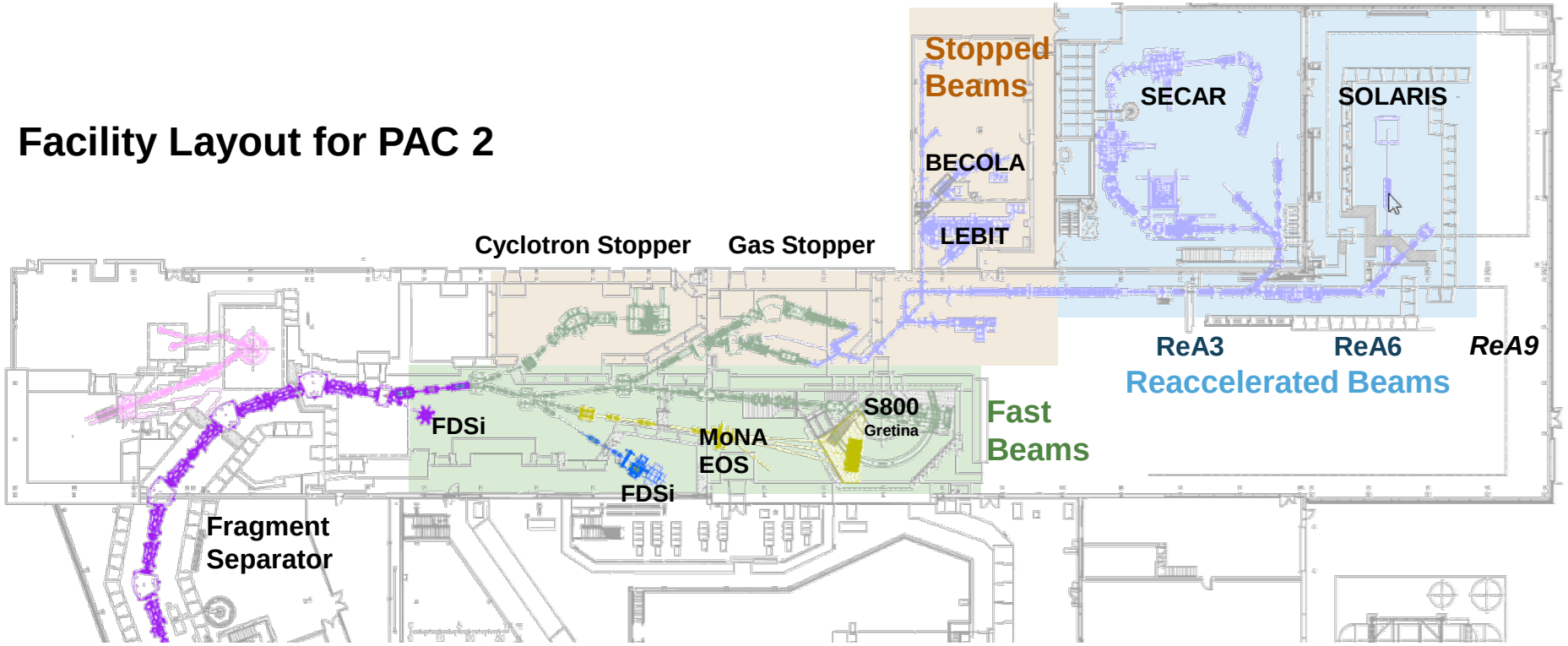
- FRIB has available fast, stopped, and reaccelerated beams from in-flight separation of projectile fragments
- Experimental areas and instruments to make use of these beams



Overall facility plan
5 years and beyond

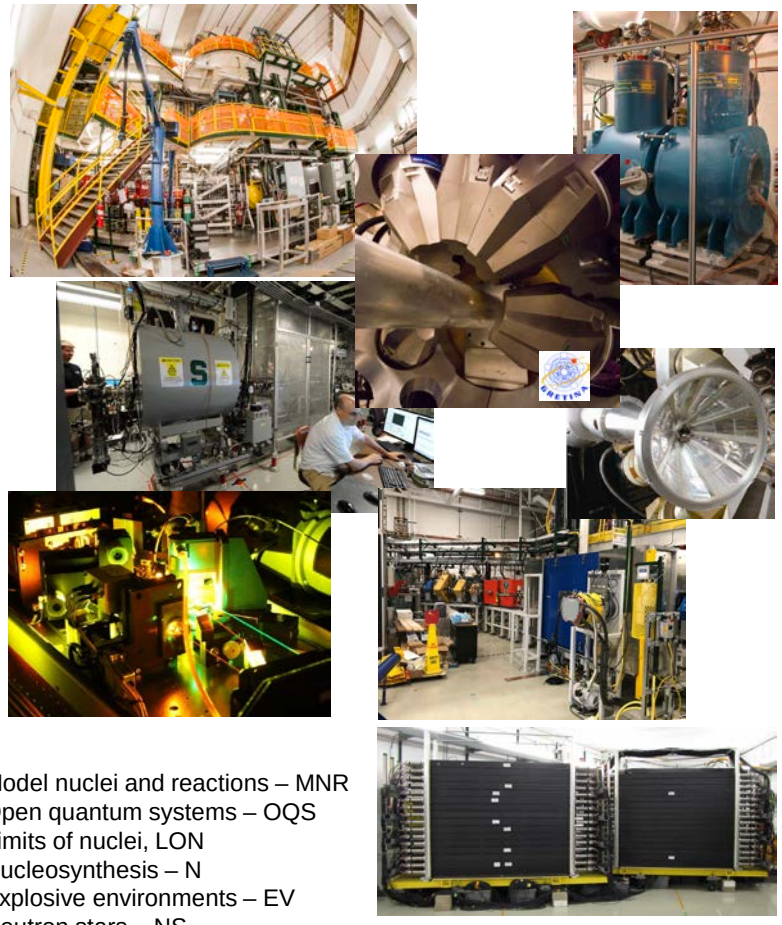
Experimental Instruments Integrated

- Roadmap for scientific instruments and experimental areas supports 5 year science strategy and 10 year perspective
- Experimental areas accommodate lab-supported and user-provided instruments
  - https://frib.msu.edu/users/instruments/index.html



Users have Assembled a Suite of State-of-the-Art Instruments

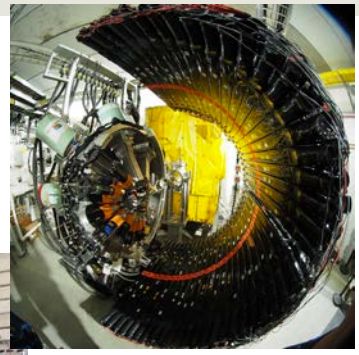
Scientific Instrument	Science Themes			
	Nucl. Structure	Nucl. Astrophysics	Fundamental Symmetries	Applications
SeGA	MNR	N		
FDSi	MNR, OQS	N, EV		
HiRA /LASSA		NS, MM	BSM	A
LEBIT	MNR, OQS	N	BSM	
MoNA-LISA	MNR, OQS	NS		
Neutron Walls		MM		
NERO/ 3HeN	MNR, OQS	NS		
S800	MNR, OQS, LON	N, EV, MM		A
Sweeper Magnet	MNR, OQS	EV		
TriPLEX	MNR			
BECOLA/ RiSE	MNR		EDM, BSM	
LENDA/ VANDLE	MNR	NS		
CAESAR	MNR, OQS			
AT-TPC	MNR, OQS	EV		
SuN/MTAS		N, EV		A
Liquid H-Target	MNR, OQS	EV		
CFFD	MNR			
JANUS	MNR		EDM	
JENSA		N		
ANASEN	MNR, OQS	N, EV		
GRETINA	MNR, OQS	EV	EDM	A
superORRUBA	MNR	N, EV		
superCHICO	MNR		EDM	
SOLARIS	MNR, OQS	N, EV	EDM	A
SECAR		N, EV		
ARIS	OQS, LON	N, MM		
Harvesting				A
Goddess	NSR	N		A
MUSIC		NS, EV		
GADGET		EV		
Polarimeter			BSM	
CloverShare	NSR			A

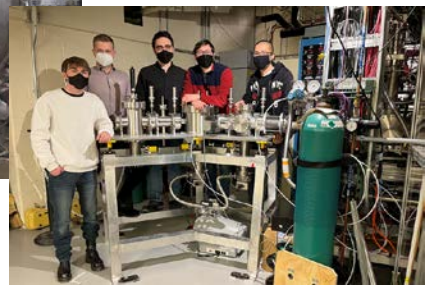
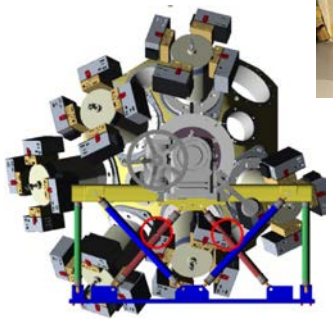
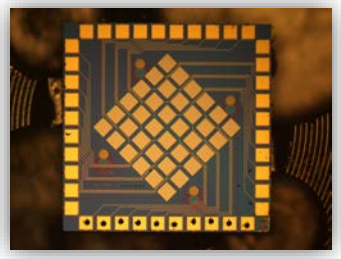


Model nuclei and reactions – MNR
Open quantum systems – OQS
Limits of nuclei, LON
Nucleosynthesis – N
Explosive environments – EV
Neutron stars – NS
Multi-messenger physics – MM
EDM searches – EDM
beyond Standard Model – BSM
Applications – A

New Scientific Instrumentation Realization with Community Engagement and Leadership

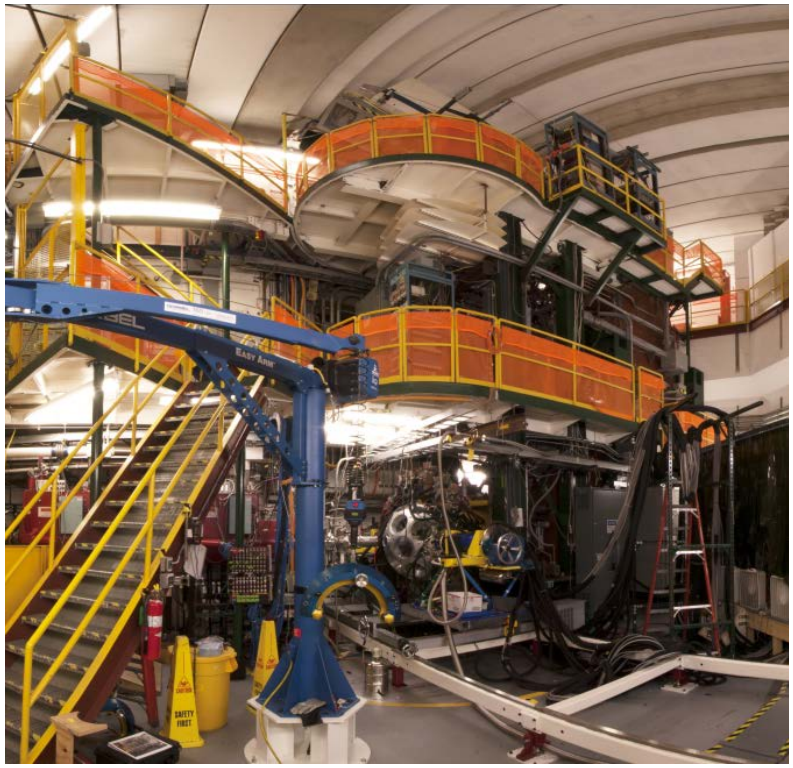
- **FRIB Decay Station initiator (FDSi)** - led by ORNL
  - Phase 1 completed, 2 FRIB experiments successful
- **SOLARIS**: SOLenoid spectrometer Apparatus for ReactIon Studies – led by ANL
  - Intermediate phase completed and first experiments at ReA6 successful
  - FSU collaborates on DAQ system
- **RiSE**: Collinear laser Resonance Ionization Spectroscopy at BECOLA – led by MIT
  - Beam line installed and stable beam test performed
- **GRETA detectors at S800 -** Gretina frame modification in collaboration with LBNL
- **SALER** – Superconducting Array for Low-Energy Radiation
  - New project led by Colorado School of Mines
- **EOS-TPC:** EOS active target time projection chamber under discussion
  - TAMU has taken on leadership in moving this forward

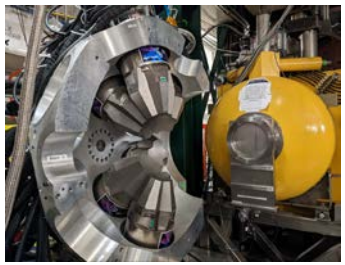


Fast Beam Instruments
S800 Spectrograph Remains to be Key Instrument

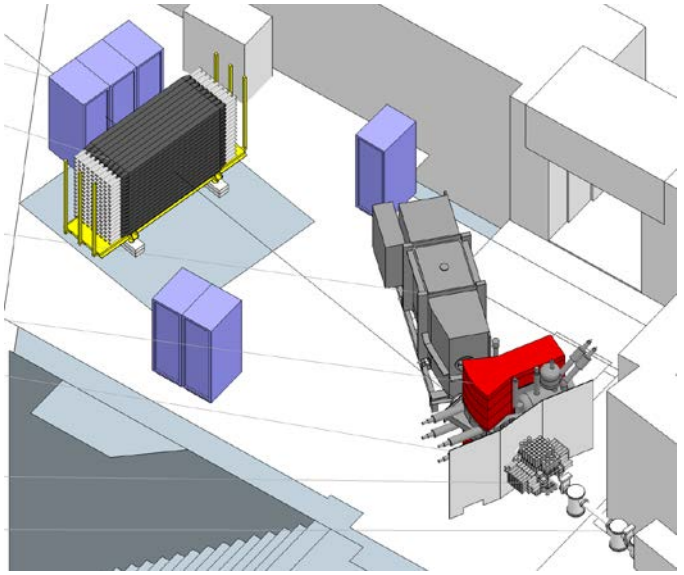
- S800 is main workhorse for nuclear structure and reactions studies with fast beams until High-Rigidity Spectrometer (HRS) is complete
- Accommodates a variety of target and detector systems
  - Liquid-hydrogen target, Plunger, SeGA, GRETINA, HiRA
- Improvements implemented to assure continued high level of reliability and performance for FRIB operation
  - Magnet power supplies replaced, controls, diagnostics, detector gas handling systems, vacuum
  - Further improvements planned include focal plane detector upgrades (resolution, rate capability)
- **First FRIB experiment with GRETINA at S800 successful – July 2022**

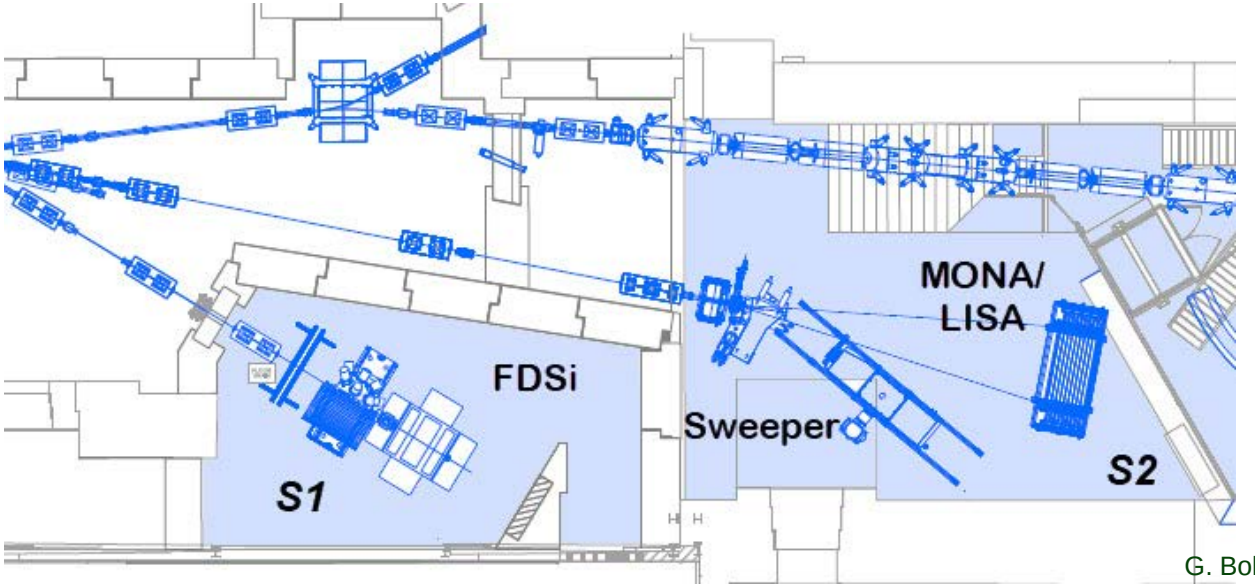




Fast Beam Instruments
New Fast Beam Vaults for FDSi and Sweeper

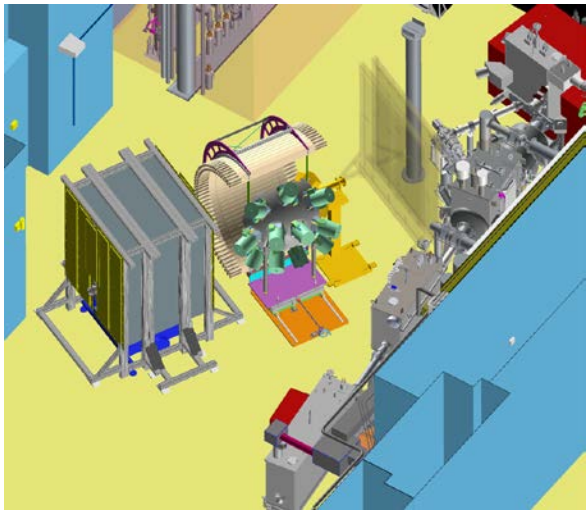
- Beam lines to new S1 vault and to S2 vaults planned to be completed by October 2023
- FDSi to move into S1 in summer 2023
- Sweeper to be installed in S2 in 2023 to support experiments with MONA/LISA and others
  - Sweeper modified to allow beam to pass through for experiments installed behind it

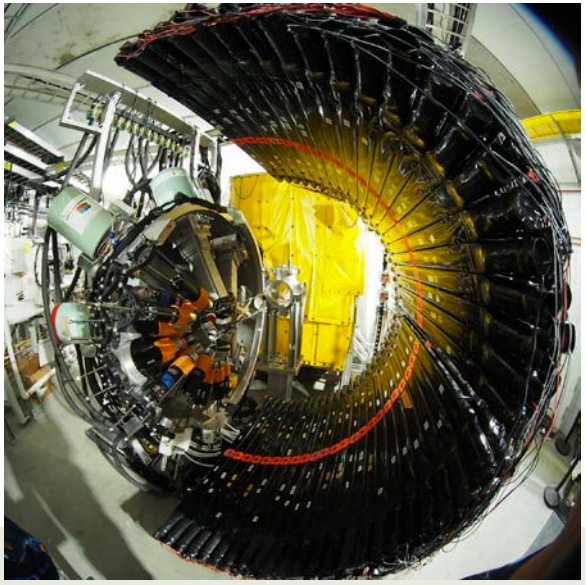




FRIB Decay Station initiator (FDSi)
First Step Towards FRIB Decay Station (FDS)

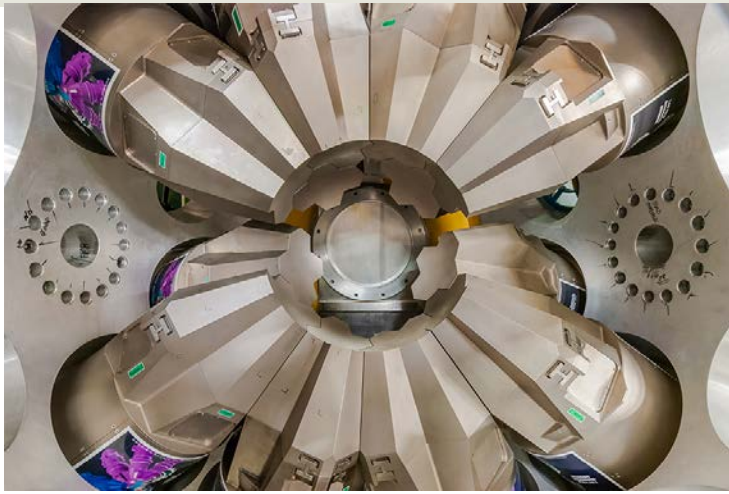
- **FRIB Decay Station initiator (FDSi)** provides increased discovery potential of FRIB in strategic areas
  - Access the most exotic nuclei
  - Measure several nuclei simultaneously
  - Measure and resolve all decay paths in the same experiment
- FDSi accommodates community-owned detectors
  - MTAS, VANDLE, SUN, CLARION, and others
  - Additional new detectors + electronics
- Multi-institutional effort (ORNL, UT, ANL, FRIB)
  - ORNL leads FDSi project
- **Phase I completed and 2 successful experiments performed**
- FDSi to move into S1 vault by fall 2023
- **FRIB Decay Station (FDS) can build on FDSi**
  - *see Mitch Allmond's talk*





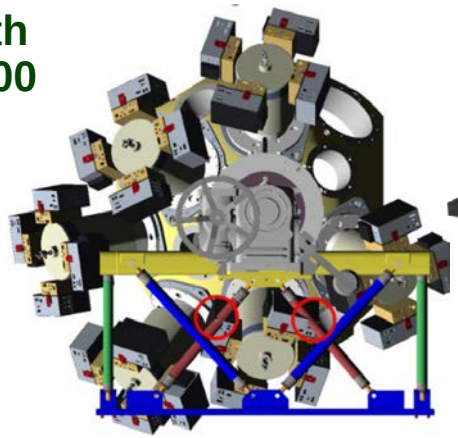
GRETINA and GRETA
Early Use of GRETA Detectors at S800

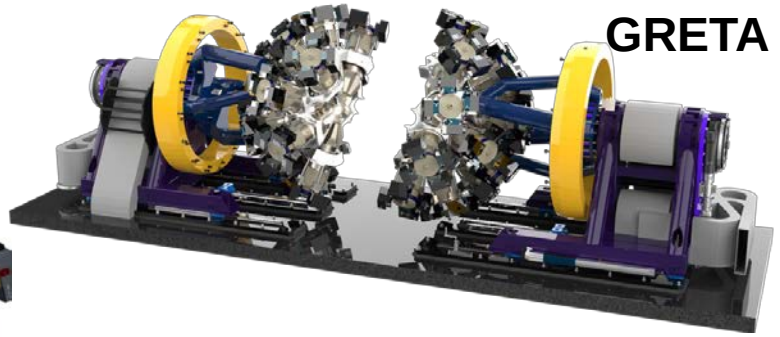
- **GRETINA**: advanced gamma-ray detector arrays for nuclear science
- GRETINA successfully used for first FRIB experiment with S800 in July 2022
- **GRETA** will be a key instrument for the FRIB science program (*see Paul Fallon's talk*)
  - GRETINA is the first phase of GRETA
  - Coupling with HRS will provide unprecedented science reach for the most exotic isotopes made available by FRIB
- **GRETA Phase 1 to be delivered to FRIB in 2025**
  - ≥ 6 detector modules, all other systems
- **GRETA detectors to be used with GRETINA for experiments at S800**
  - Modification of GRETINA frame to accommodate additional GRETA detectors for S800 experiments in process
  - More science per beam time



GRETINA

BERKELEY LAB





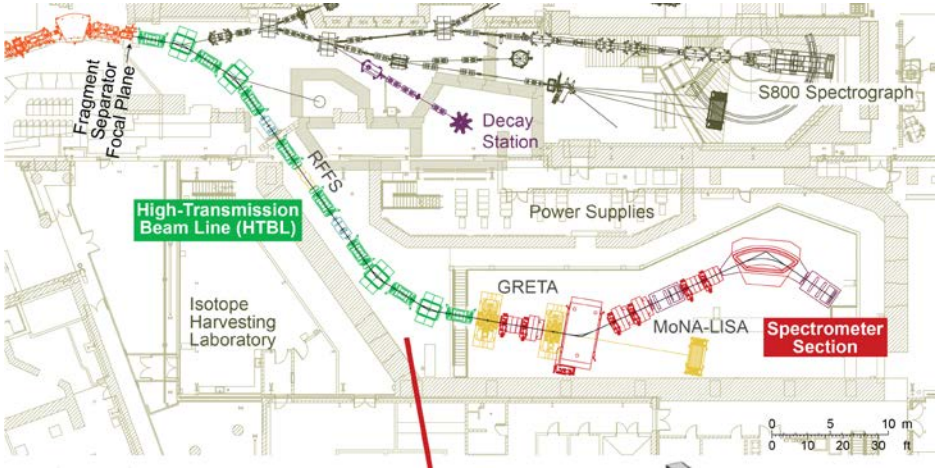
GRETA

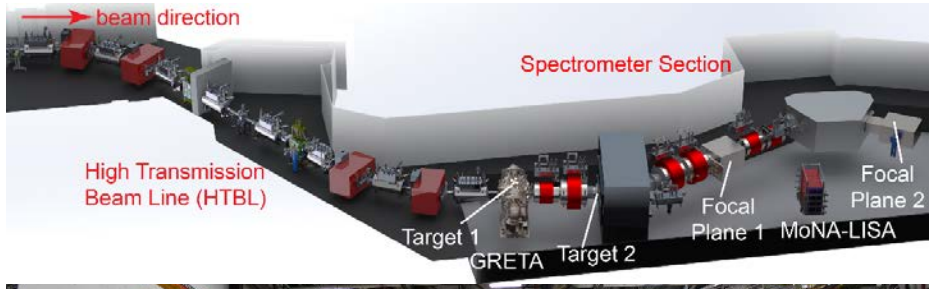
http://greta.lbl.gov/

High Rigidity Spectrometer (HRS)
Project Moves Forward with Funding Received

- The **High Rigidity Spectrometer (HRS) will make best use of FRIB's high rigidity rare isotope beams** for in-flight reaction experiments, such as:
  - In-beam γ-ray spectroscopy near the dripline
  - Invariant-mass spectroscopy with neutrons
  - Knock-out experiments in inverse kinematics
  - Time-of-flight mass measurements
  - In-flight fission measurements
- Multiple ion-optical modes optimize different experiments
- Can accommodate wide range of auxiliary detectors
- **CD1 received – preparing for CD2/3a in 2023**
- Next 5 years provide ample opportunity for community to define new opportunities and contribute

HRS Working group: https://hrs.lbl.gov/
HRS Preliminary Design Report



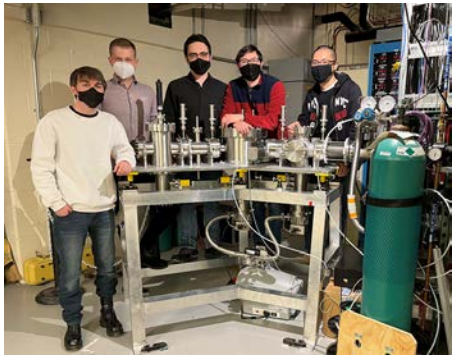


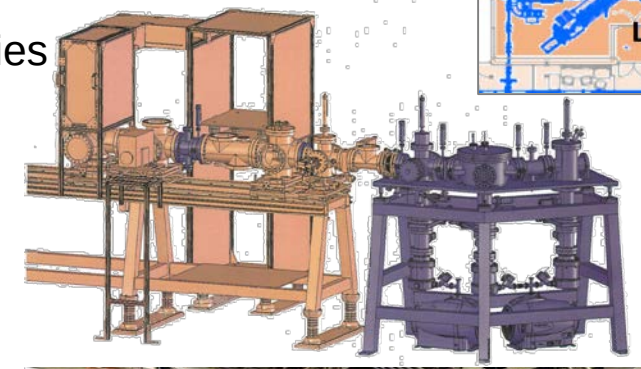

Highbay for High Rigidity Spectrometer

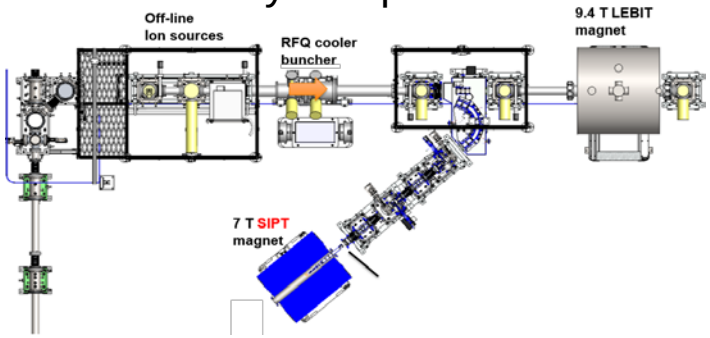
Stopped Beam Instruments

BECOLA/RiSE and LEBIT – Instruments for Precision Experiments

- **BECOLA** - Laser spectroscopy facility
  - Static properties of ground and isomeric states using laser techniques: nuclear spins, moments, charge radii
- New: **RiSE**: Collinear laser Resonance Ionization Spectroscopy at BECOLA (MIT-Led project)
  - Factor 50 sensitivity gain due to charged-particle detection
  - Study of exotic molecules for fundamental symmetry studies
  - RiSE beam line installed and commissioned
- **LEBIT** – Penning Trap Mass Spectrometer Facility
  - Highest sensitivity with added Single-Ion Penning Trap (SIPT)
  - Phase-Imaging Ion-Cyclotron Resonance (PI-ICR) for improved sensitivity and precision





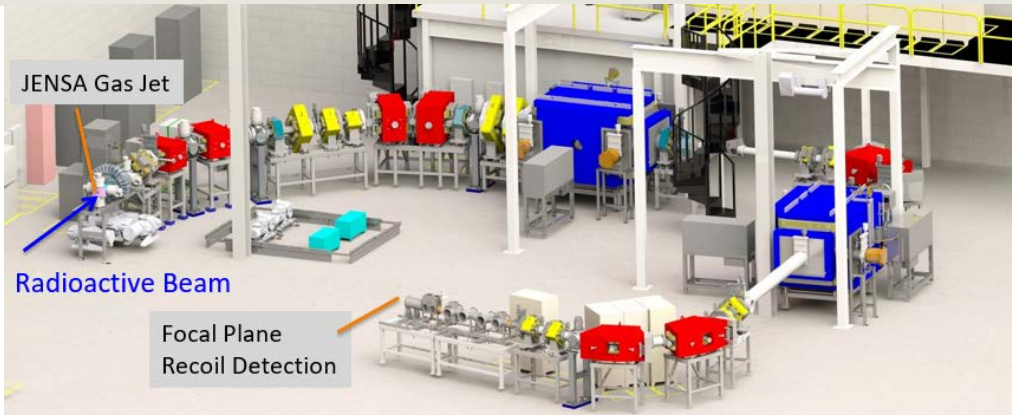


- **Two general purpose beam lines available for stopped beam experiments**

Reaccelerated Beam Instruments at ReA3
SECAR - Ready for User Experiments

SECAR
Separator for
Capture Reactions

- SECAR recoil separator enables direct measurements of astrophysical p- and α-capture reactions
  - Multi-institutional effort (FRIB + 12 institutions)
- **Project completed with demonstration of KPPs – August 2022**
  - Direct measurement of resonance strength of $^{16}O(\alpha,\gamma)^{20}Ne$ reaction
  - Demonstration of beam rejection of $>10^{13}$
- First experiments with (α,n) and (p,n) reactions performed
- SECAR is installed in ReA3 experimental area -
  2 general purpose beam lines available



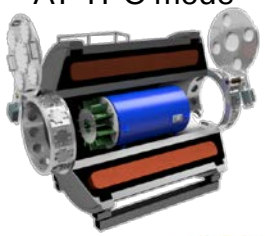
Reaccelerated Beam Instruments at ReA6

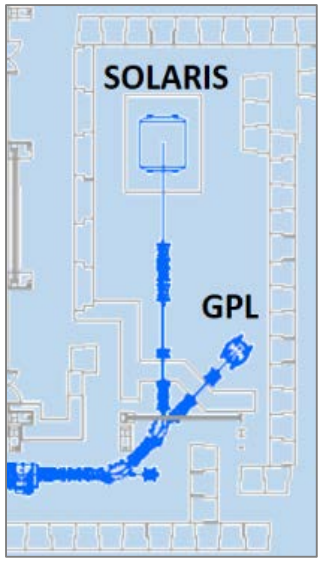
SOLARIS – Ready for FRIB Science in Nuclear Reaction Studies

- **SOLARIS**: SOLenoid spectrometer Apparatus for ReactIon Studies
  - Single-particle structure of nuclei, collective features in complex nuclei, explosive nucleosynthesis, fundamental symmetries
- Two modes of operation of SOLARIS
  - Si-array mode and AT-TPC mode
- Multi-institutional effort (ANL, U Connecticut, and others)
  - Strategic Partnership Project with ANL, collaboration with FSU on data acquisition
- Ready for experiments
  - First stand-alone experiments with AT-TPC and ANL HELIOS Si array successful
  - Dedicated Si-array on track to be completed in 2024
- ReA6 vault has one **general purpose beam line and space for setups** in front of SOLARIS

Si-array mode

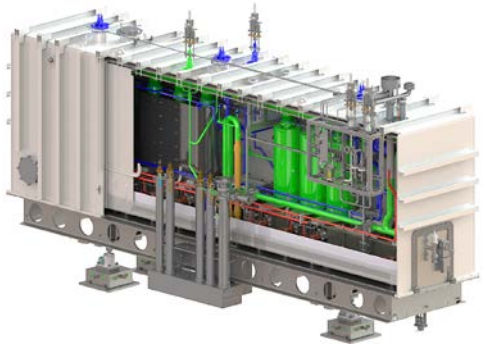
AT-TPC mode

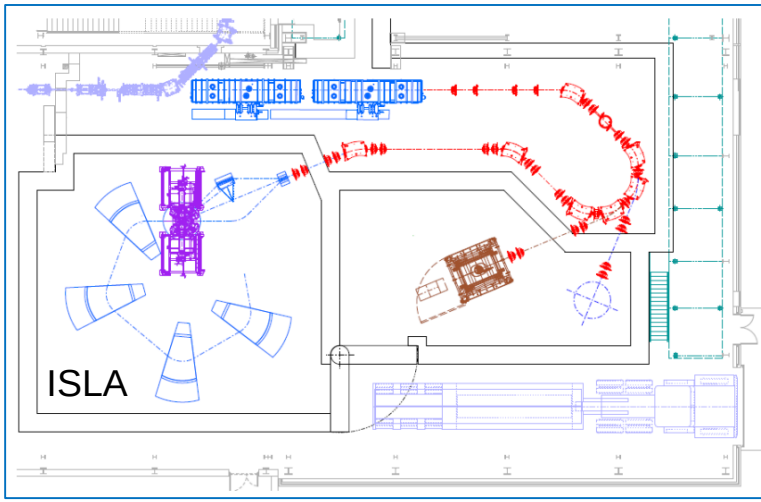




Stopped and Reaccelerated Beams
Opportunities and Plans

- **Batch Mode Ion Source (BMIS)** to provide beams of stable and long-lived isotopes – operational since 2021
  - **Enabled pre-FRIB science after shutdown of CCF**
- **Cyclotron stopper** for light ions commissioned in 2020
  - Beam line connection to stopped beam experimental area and ReA still needed (2025)
- **ReA9** included in FRIB operations proposal to DOE
  - Beam energies >12 MeV/u for light ions
  - **ISLA recoil separator** needed to tag reaction channels and extend the reaccelerated beam science program (*see D. Bazin talk*)





Pre-conceptual layout of an experimental vault for a ReA9 energy upgrade

Summary

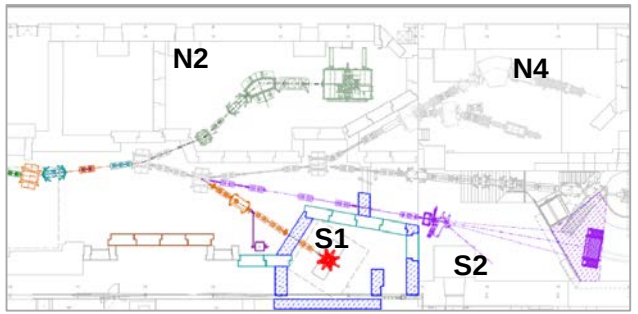
- FRIB enables science with unique availability of fast, stopped, and reaccelerated beams
- Existing and plan for new scientific instruments and upgrades supports science strategy and long-term perspective
- Realization of new scientific instrumentation with community engagement and leadership
- Experimental area completion supports user experiment program

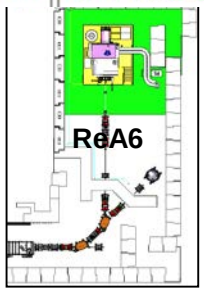
Expect the community to have new ideas, small and large. Space is available and FRIB is open to new initiates.

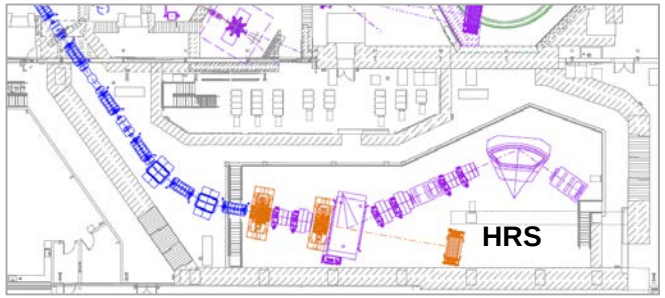
Backup Slide

Experimental Area Readiness Supports Science with Fast, Stopped, and Reaccelerated Beams

- **Early 2022** - ready for very first round of fast-beam user experiments
  - FDSi temporary location in transfer hall – 2 experiments in May and June 2022
  - S3 vault - First S800 and GRETINA experiment in July 2022
- **Early 2023** – ready for stopped and reaccelerated beam experiments
  - N4 vault – First beam delivery to gas stoppers planned in Dec 2022
  - Stopped beam area is ready – LEBIT, BECOLA
  - ReA3 and ReA6 vaults are ready – SECAR and SOLARIS and general purpose beam lines
- **Fall 2023** - S1 and S2 vaults ready for instruments
  - High-energy beam line completed
  - FDSi and Sweeper/Mona Lisa installed
- **5-year perspective** - N2/3 vault
  - Connection of cyclotron gas stopper to stopped beam area and reaccelerator
- **10-year perspective** - HRS
  - High resolution spectrometer building - HRS installed







Instrument Realization and Upgrades
Collaboration Leverages External Expertise