NP Low Energy Facilities and the SBIR/STTR Program

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Nuclear Science Division
Lawrence Berkeley National Laboratory

DOE NP SBIR/STTR Exchange Meeting
November 6-7, 2013

Community (User) Meeting (Aug. 23-24)

A great place to start to get

- facility descriptions and status
- instrumentation initiatives and projects
- who to contact

http://meetings.nscl.msu.edu/CommunityMeeting2013/program.htm

- **FRIB/NSCL** Status and Overview – Georg Bollen/Daniela Leitner
- **ATLAS** Status and Overview – Guy Savard
- Agency Comments
  - Brad Keister - NSF
  - Tim Hallman – **DOE**

14 Working Groups

Super-heavy Elements, Theory, Precision Measurements, High Rigidity Spectrograph, Astrophysics and Astrophysics Equipment, In-Flight Gamma-ray Detection, Neutron Detectors, HELIOS, Recoil Separator, Decay Spectroscopy, EOS, Data Acquisition, Applications

Acknowledgments

Brazen “use” of material, input, and the effort of others

slides from

Birger Back, Guy Savard (ANL)

Georg Bollen, Thomas Glasmacher, Brad Sherrill (MSU)

Augusto Macchiavelli (LBNL)

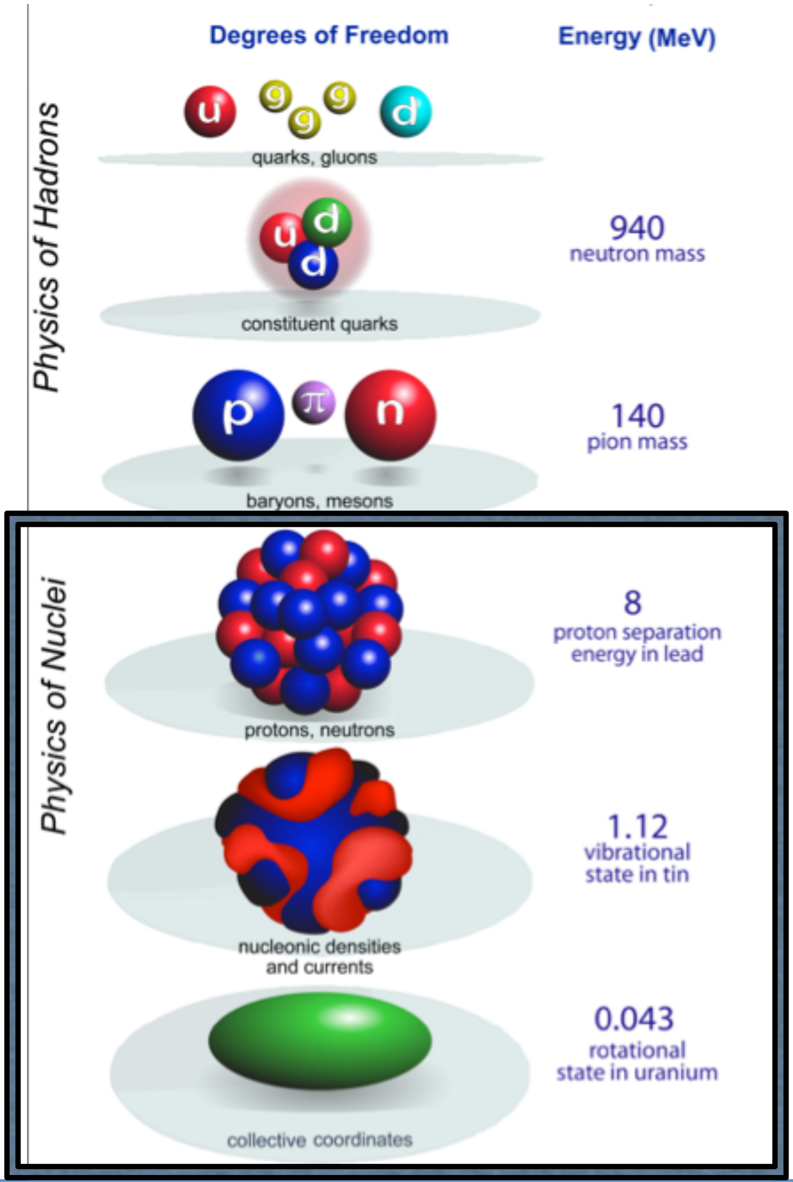
DOE NP office

Thank you

Outline

- Context
- Science
- Major Facilities
- Advanced Instruments

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)

Context

much activity, exciting time…

• New facilities to create and accelerate beams of exotic, radioactive ions are under construction in the US (FRIB at Michigan State University) and word-wide.

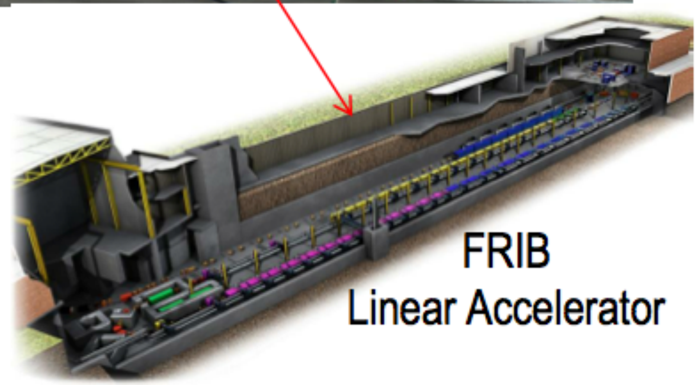
• New innovative instruments are being developed (e.g. gamma-ray tracking arrays).

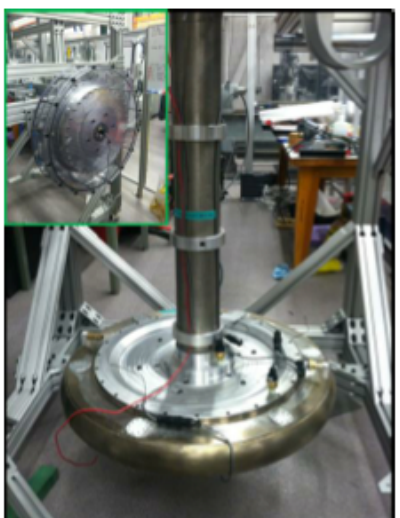
• A new generation of measurements in heavy element science is underway.

• Pursuing ultra-sensitive measurements for neutrino science.

Facility for Rare Isotope Beams

FRIB Site February 2013





Left: Titanium-shell beam dump prototype in final preparation for testing under rotation, a capability essential to handle very high power FRIB beams

FRIB will increase the number of isotopes with known properties from ~2,000 observed over the last century to ~5,000 and will provide world-leading capabilities for research on:

Nuclear Structure

- The ultimate limits of existence for nuclei
- Nuclei which have neutron skins
- The synthesis of super heavy elements

Nuclear Astrophysics

- The origin of the heavy elements and explosive nucleo-synthesis
- Composition of neutron star crusts

Fundamental Symmetries

- Tests of fundamental symmetries, Atomic EDMs, Weak Charge

This research will provide the basis for a model of nuclei and how they interact.

The “FRIB Era”

Major new facility for low energy nuclear science in the US.
August 2013, CD-2/CD-3a approval

Sets the context:

- Science (weakly-bound exotic nuclei, nuclear astrophysics)
- Priorities for our field (current number 1 for new construction)
- Timeframe(s)

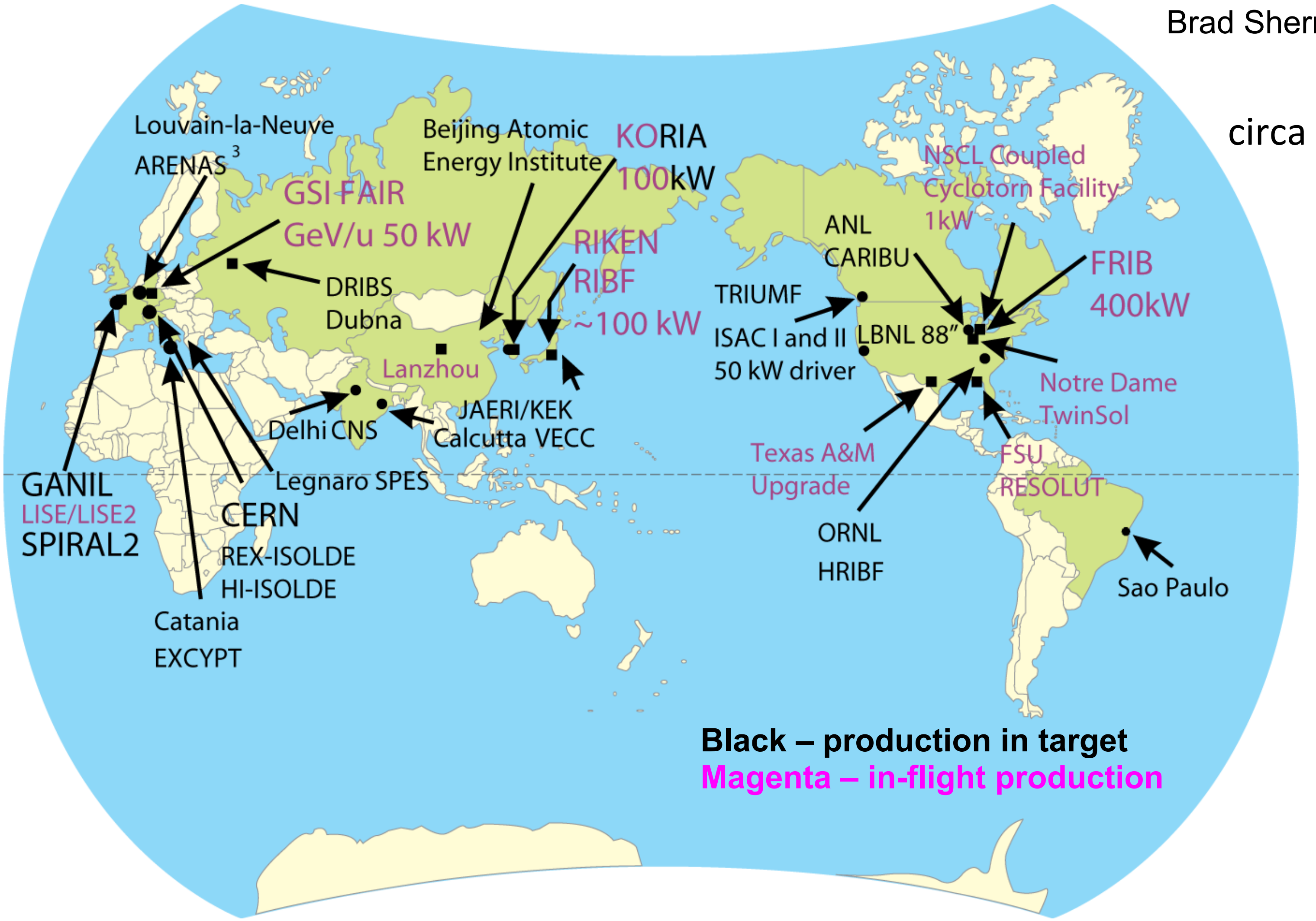
2014	2022	2022+
Start construction	FRIB CD4 (early date 2020)	Science (upgrades)

Rare Isotope Beams are part of a major world-wide effort: RIKEN(RIBF), TRIUMF(ISAC), GANIL(SPIRAL), GSI(FAIR), CERN(ISOLDE) … others planned.

Rare Isotope Facilities – World View

Brad Sherrill

circa 2010



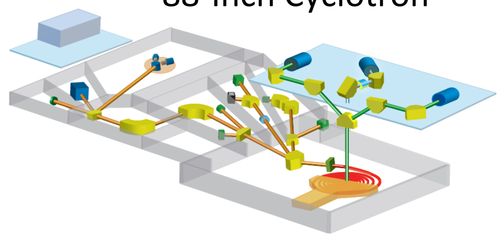
Black – production in target

Magenta – in-flight production

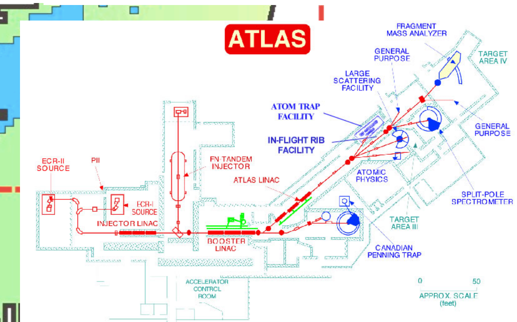
Pushing the Limits

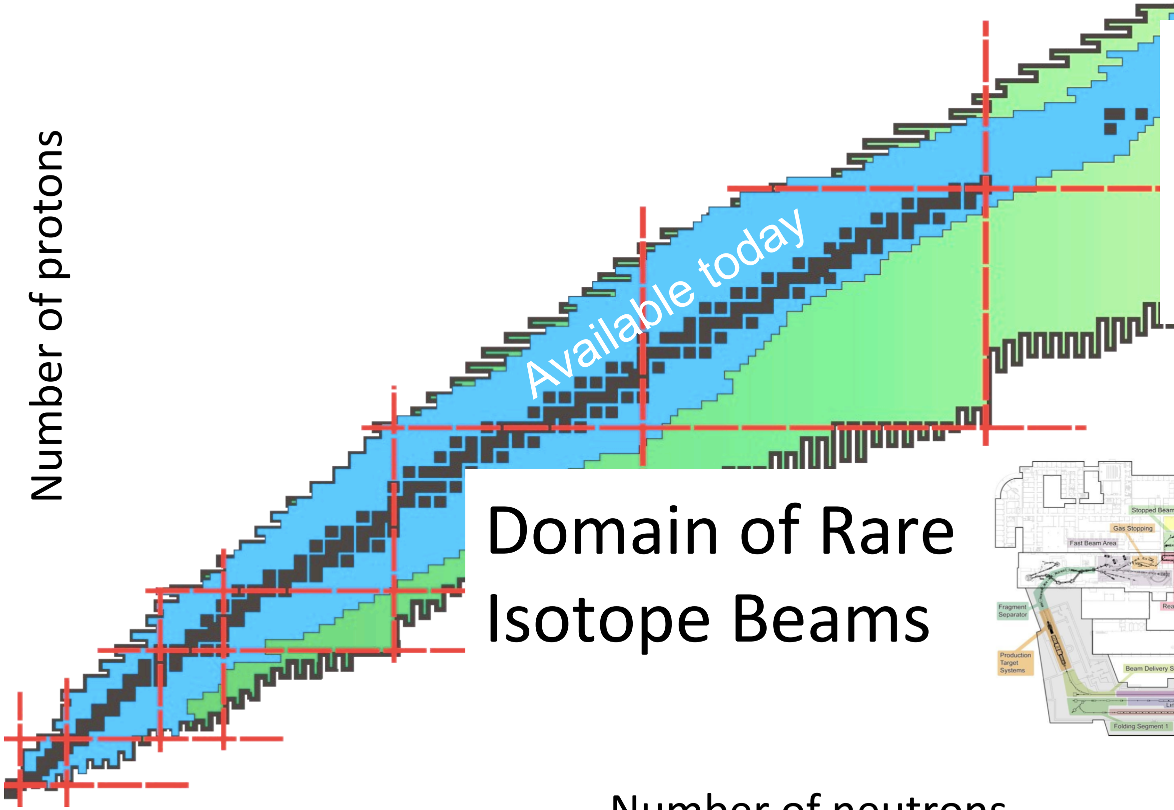
Chart of Nuclei

88-Inch Cyclotron

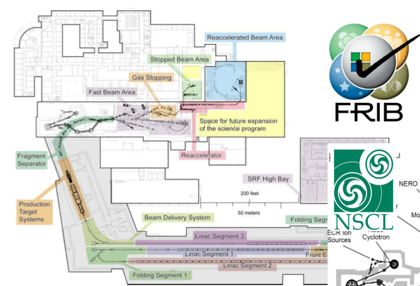


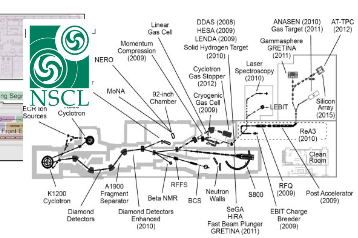
Domain of Stable Beams



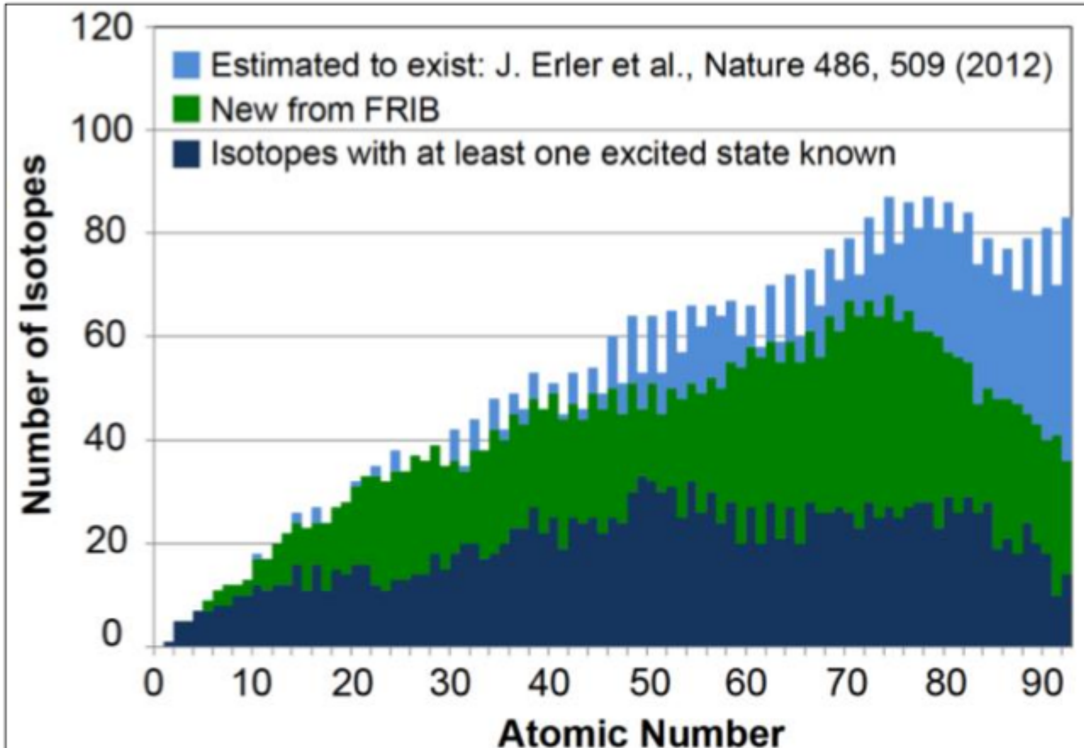


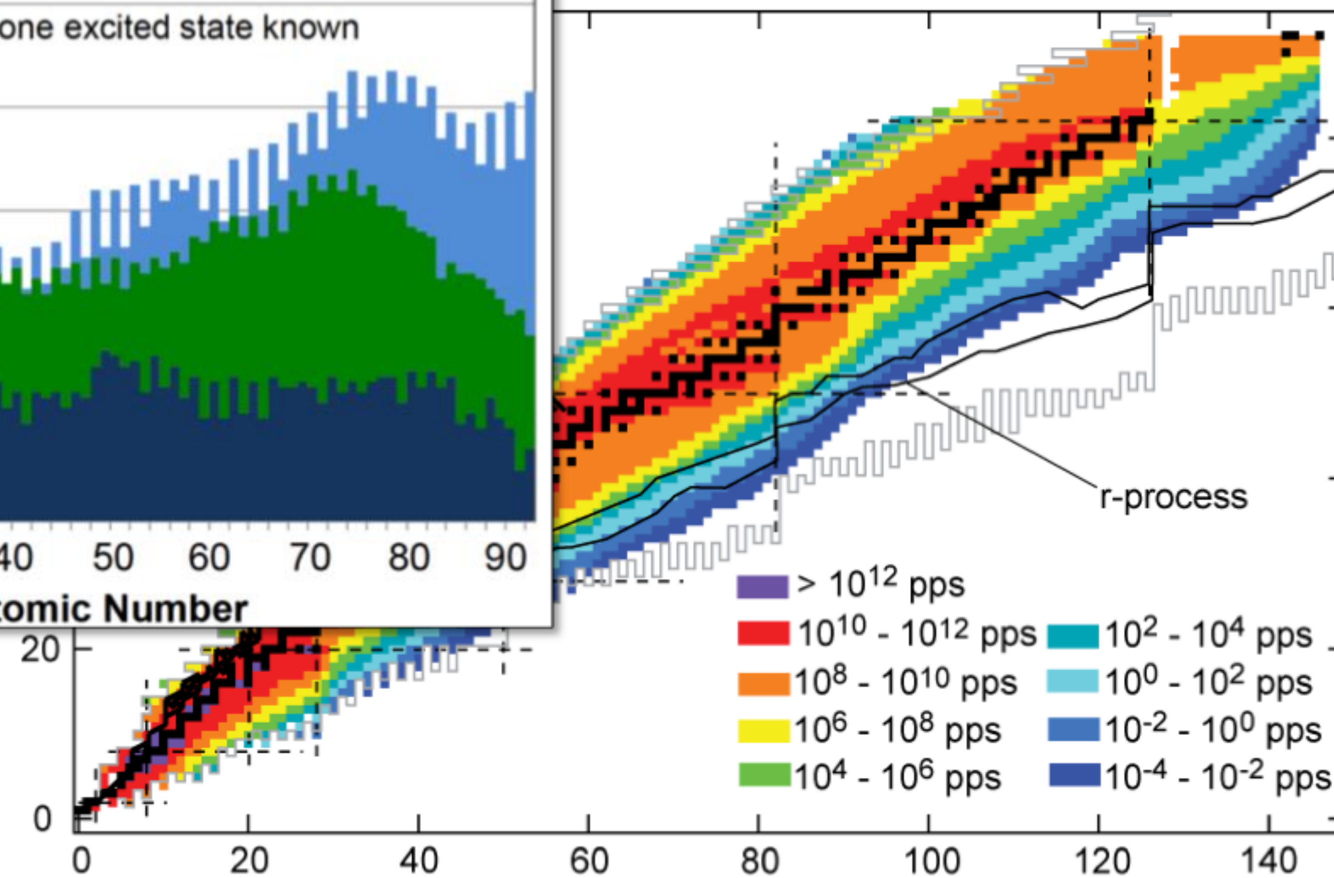
Domain of Rare Isotope Beams





Enabling New Discoveries



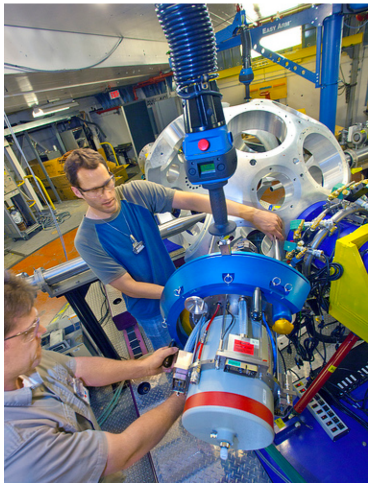


FRIB will increase the number of isotopes with known properties from ~2,000 observed over the last century to ~5,000

Rates are available at http://groups.nscl.msu.edu/frib/rates/

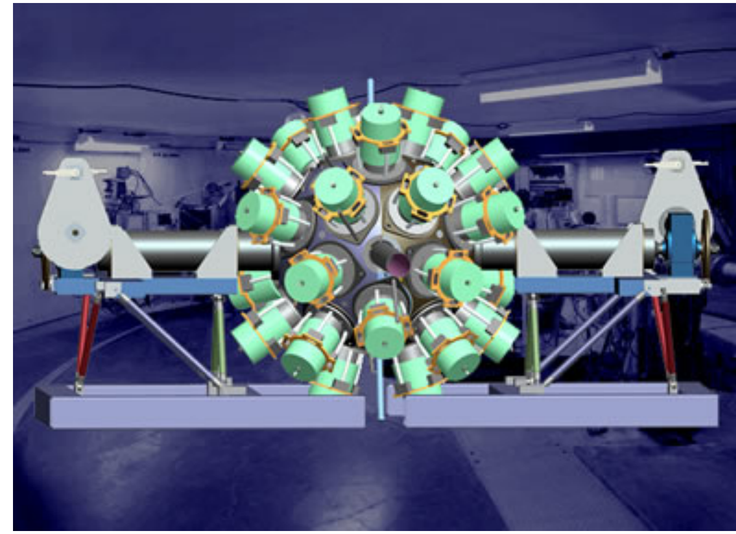
Advanced Instruments Optimize Science Reach

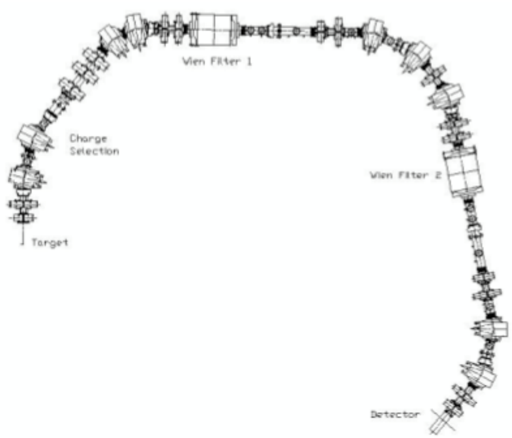
New detectors are being discussed to optimally exploit FRIB



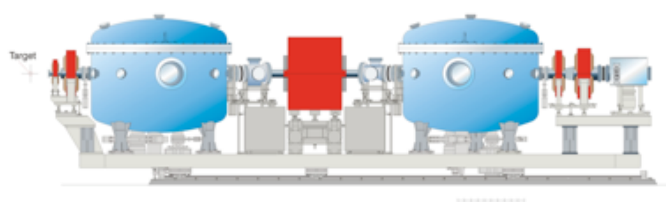
GRETINA (used at NSCL/ANL)

GRETA 4π array for FRIB





Other Instruments



NSAC Subcommittee, Sept 8, 2012

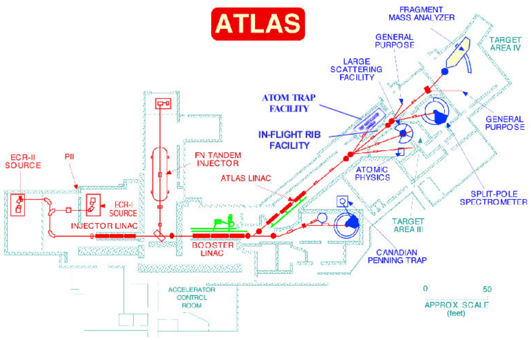
Slide by David Dean

The Facilities in more detail

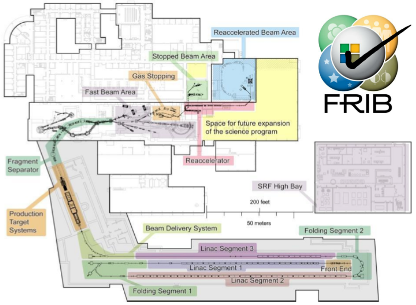
Low Energy Nuclear Physics Facilities

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

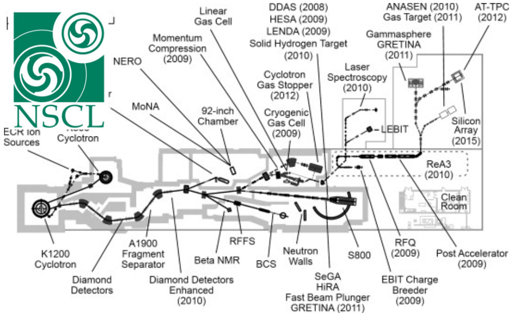


- Facility for Radioactive Ion Beams (FRIB)
  - being constructed at MSU
  - Fast radioactive beams produced by fragmentation and in-flight fission
  - Stopped beams
  - Re-accelerated beams at near Coulomb barrier energies



NSF User Facility

- National Superconducting Cyclotron at MSU (http://nscl.msu.edu)
  - Fast radioactive beams produced by fragmentation (re-accelerated beams coming online)



Low Energy Nuclear Physics Facilities

Other DOE facilities (local use)

- LBNL 88-Inch Cyclotron (http://cyclotron.lbl.gov)
  - Basic and applied research w. stable beams

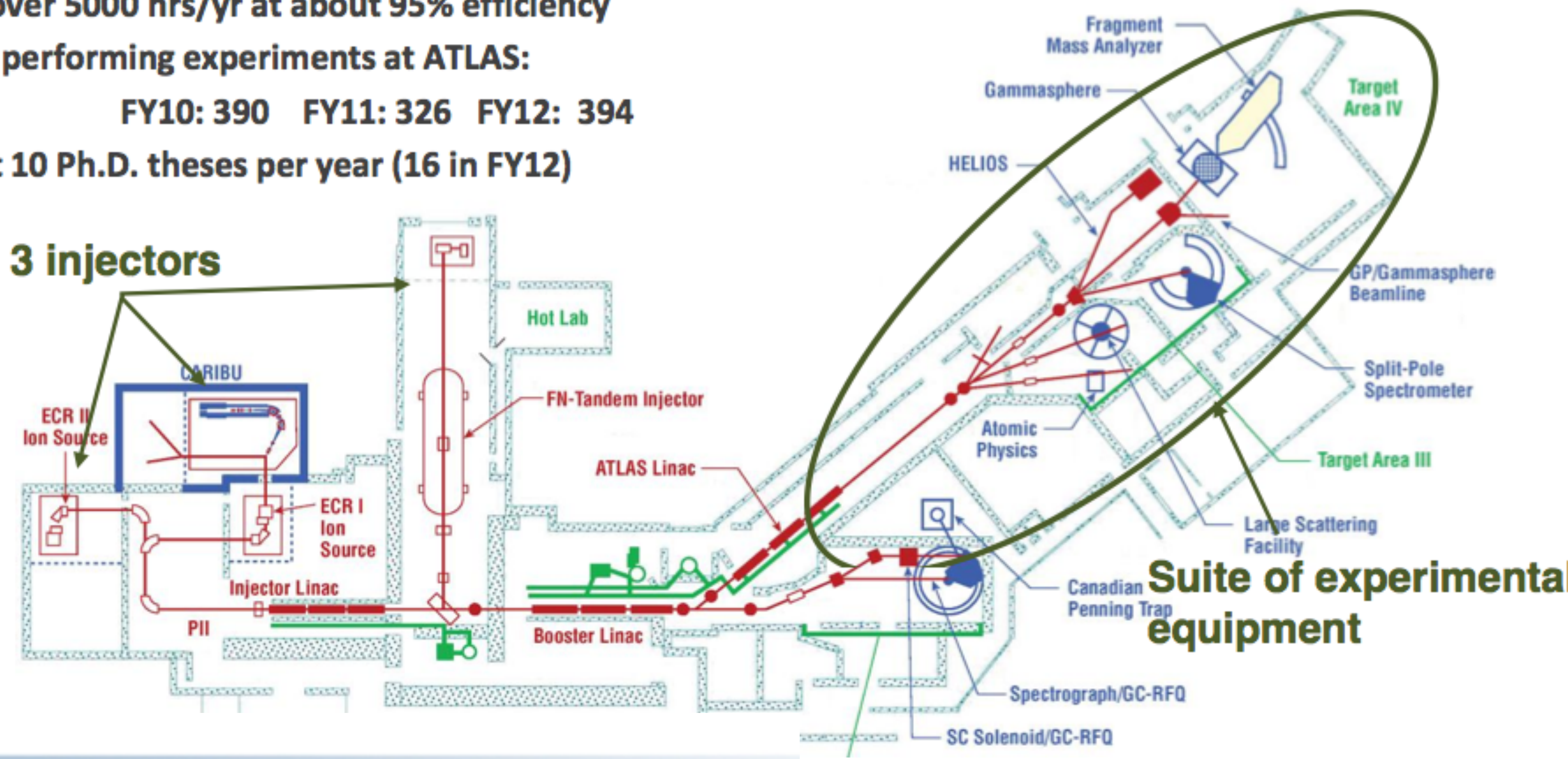
- Texas A&M Cyclotron Institute (http://cyclotron.tamu.edu)
  - Nuclear physics research with stable and radioactive re-accelerated beams

- 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 - neutrons

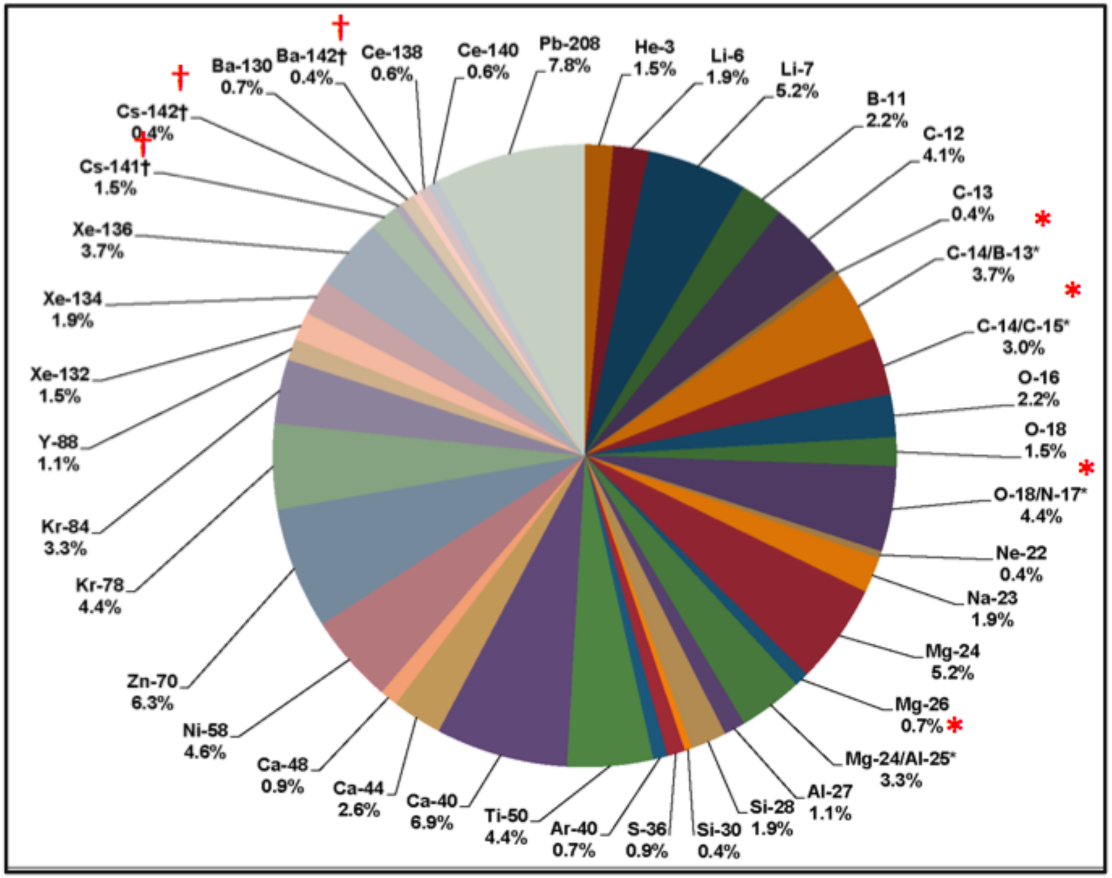
The ATLAS Facility

- **Stable beams at high intensity and energy up to 10-20 MeV/u**
- **Light in-flight radioactive beams**
  - ***light beams, no chemical limitations, close to stability, acceptable beam properties***
- **CARIBU beams**
  - ***heavy n-rich from Cf fission, no chemical limitations, low intensity, ATLAS beam quality, energies up to 15 MeV/u***
- **State-of-the-art instrumentation for Coulomb barrier and low-energy experiments**
- **Operating over 5000 hrs/yr at about 95% efficiency**
  - **Users performing experiments at ATLAS:**

    FY10: 390 FY11: 326 FY12: 394
  - **About 10 Ph.D. theses per year (16 in FY12)**



ATLAS Beams (2012)

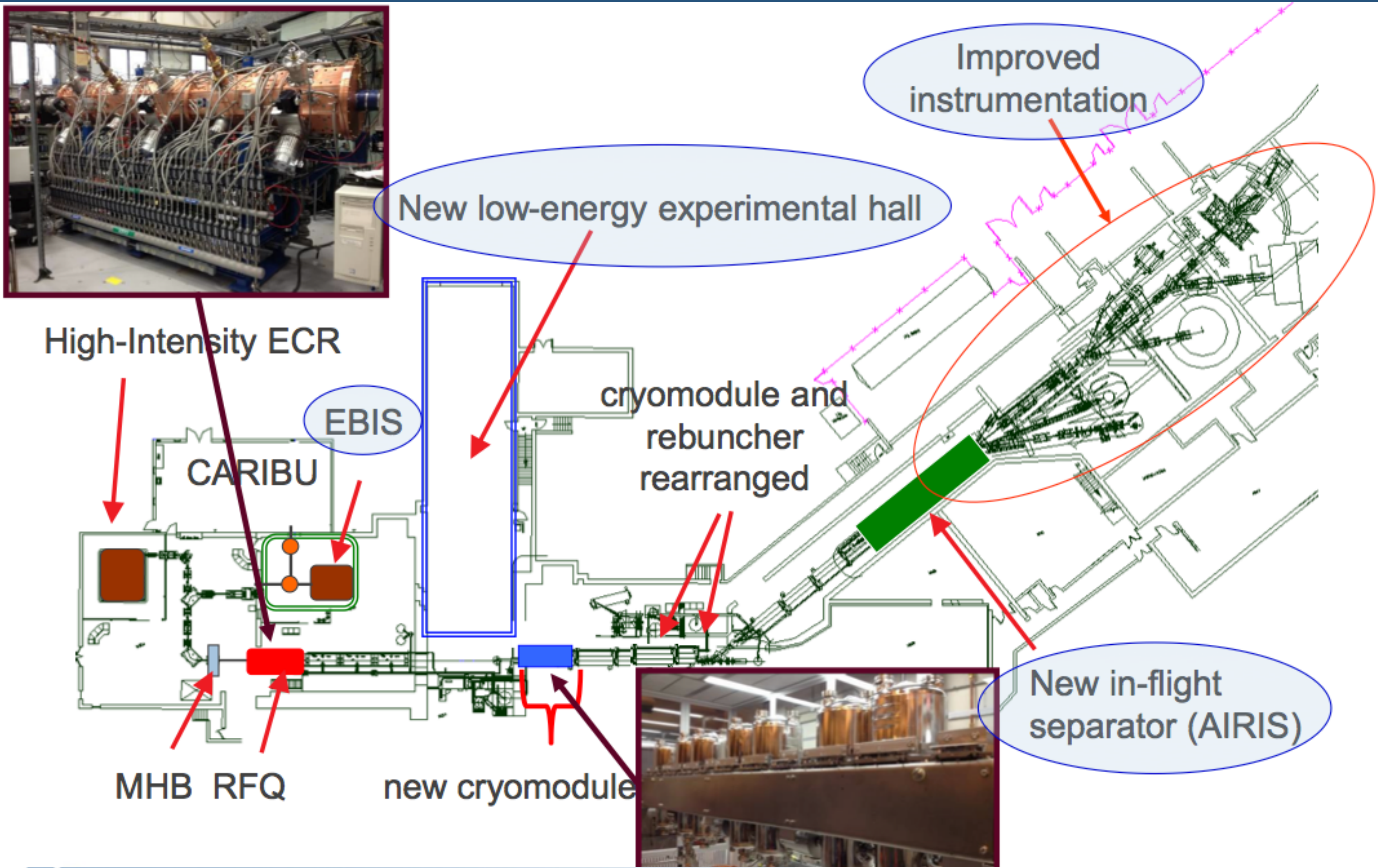


40 Different Isotopes (a record)

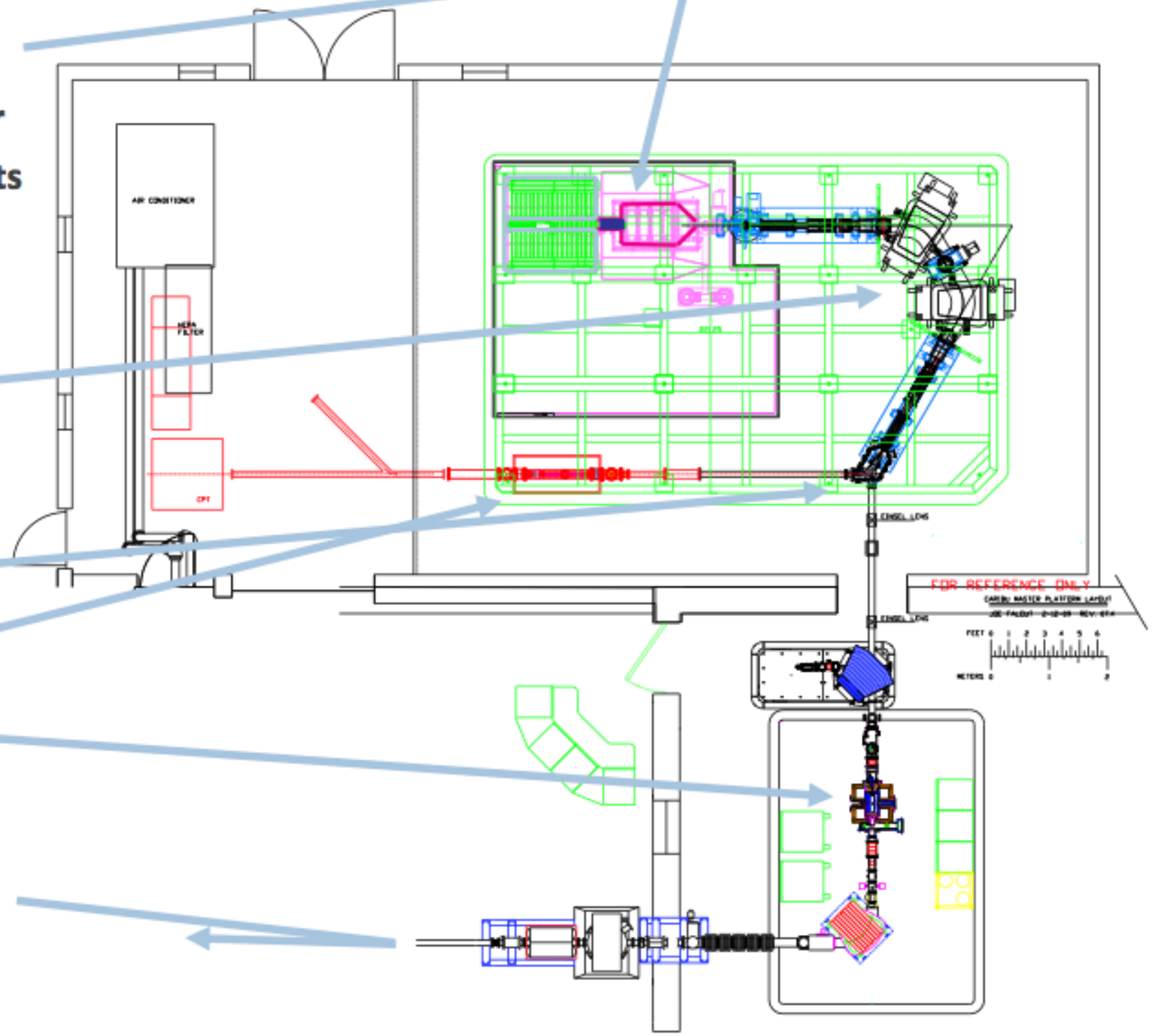
*14.4% of beam time for Radioactive Beams

†2.3% of beam time for accelerated CARIBU runs (not incl. Develop.)

ATLAS layout with ongoing and planned upgrades



Neutron-rich beam source for ATLAS: CARIBU



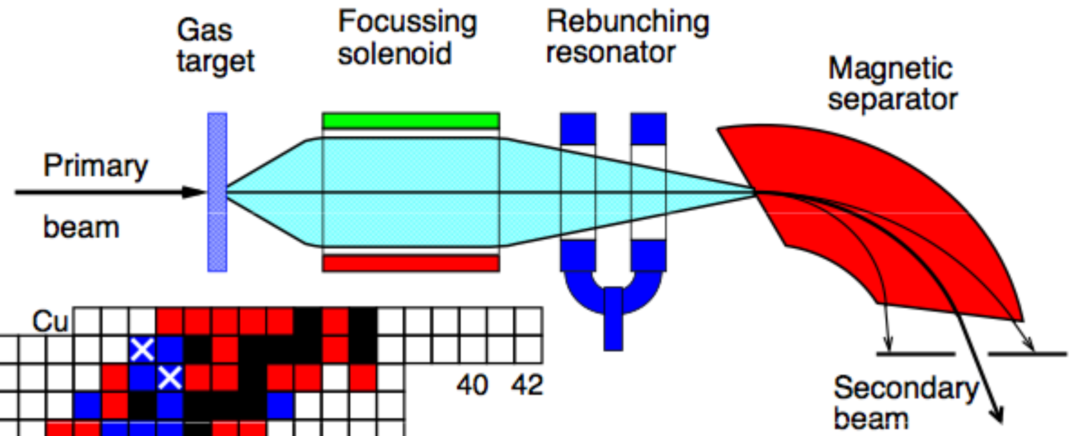
Main components of CARIBU

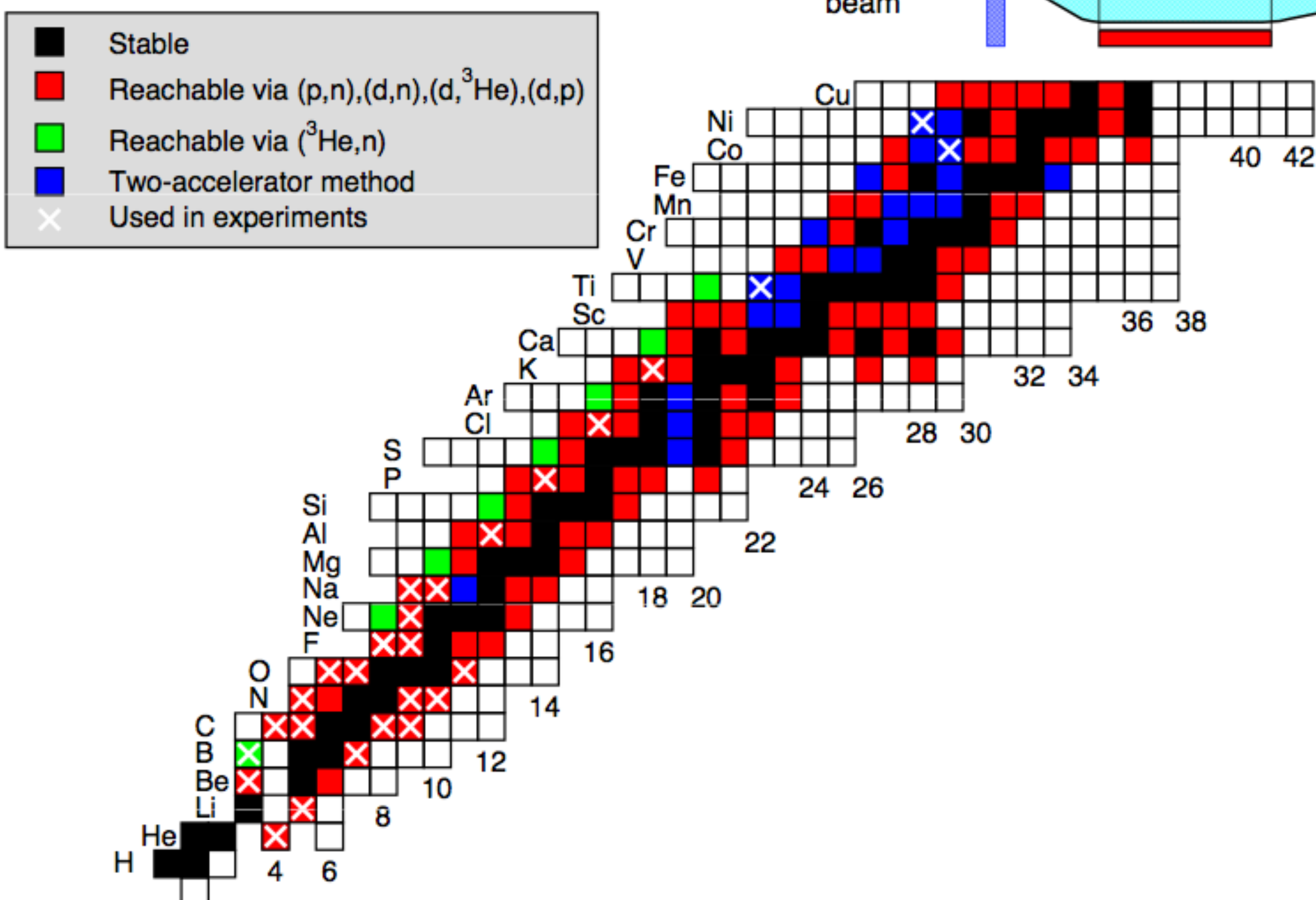
- **PRODUCTION**: "ion source" is ^{252}Cf source inside gas catcher
  - Thermalizes fission fragments
  - Extracts all species quickly
  - Forms low emittance beam
- **SELECTION**: Isobar separator
  - Purifies beam
- **DELIVERY**: beamlines and preparation
  - Switchyard
  - Low-energy buncher and beamlines
  - Charge breeder to Increase charge state for post-acceleration
  - Post-accelerator ATLAS and weak-beam diagnostics

ATLAS In-flight radioactive beam production (AIRIS)

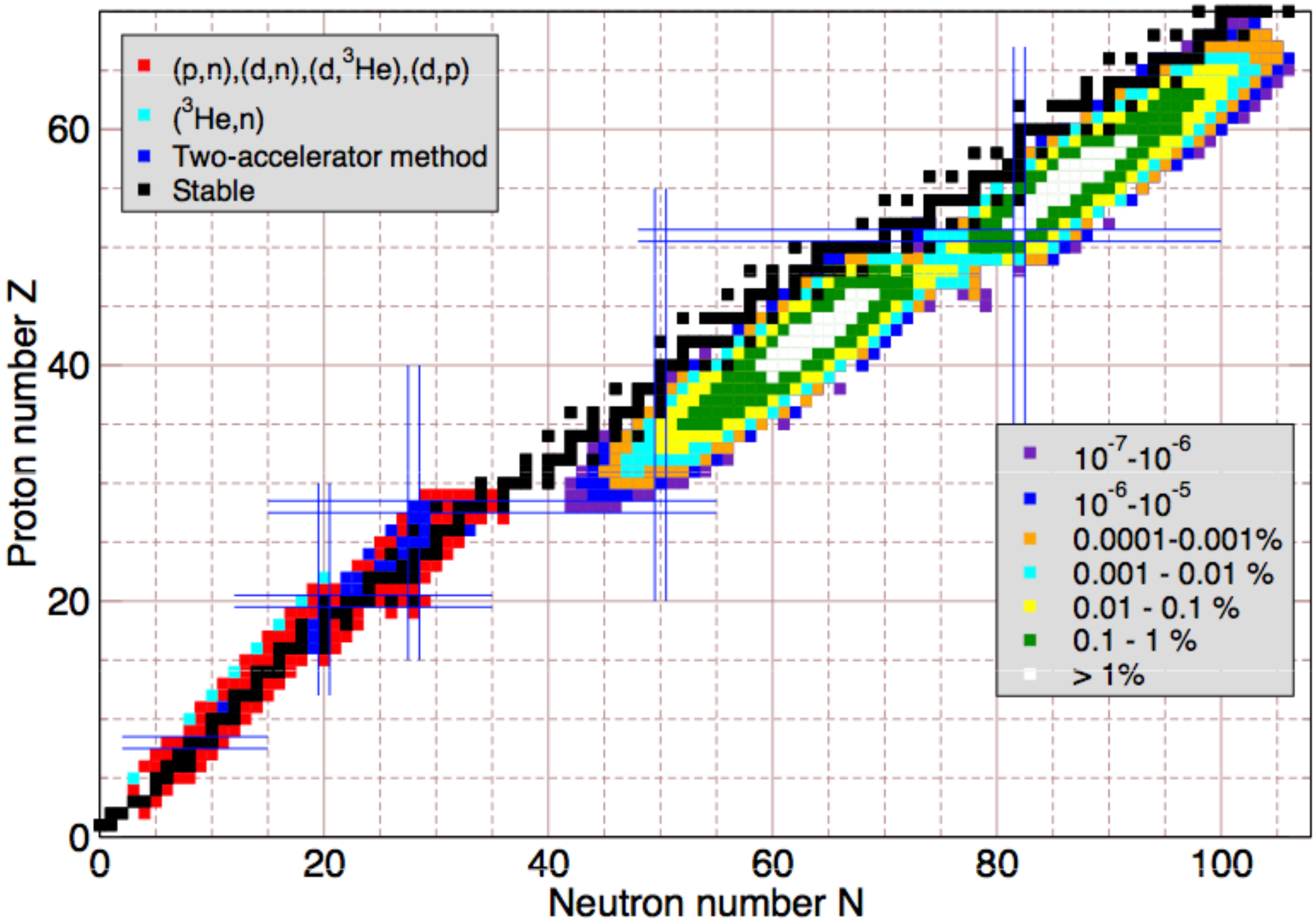
Few nucleon transfer reactions

Inverse kinematics



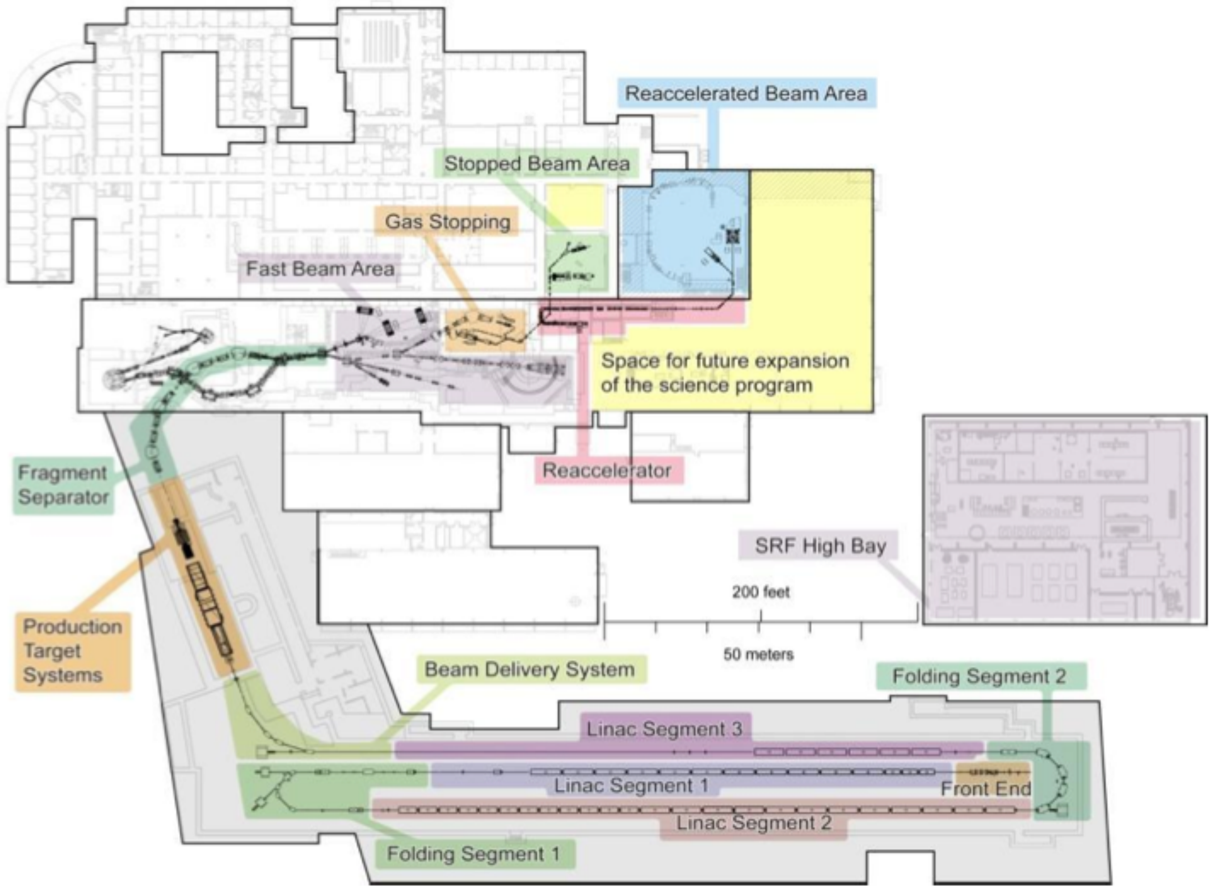


Radioactive beams from CARIBU and AIRIS



FRIB - Facility for Rare Isotope Beams

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

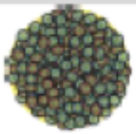


World-leading next-generation rare isotope beam facility

FRIB Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

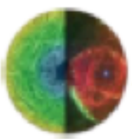
FRIB Science

Articulated by National Research Council RISAC Report (2006), NSAC LRP (2007), NRC Decadal Survey of Nuclear Physics (2012)



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.

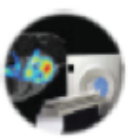


Astrophysical processes

- 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

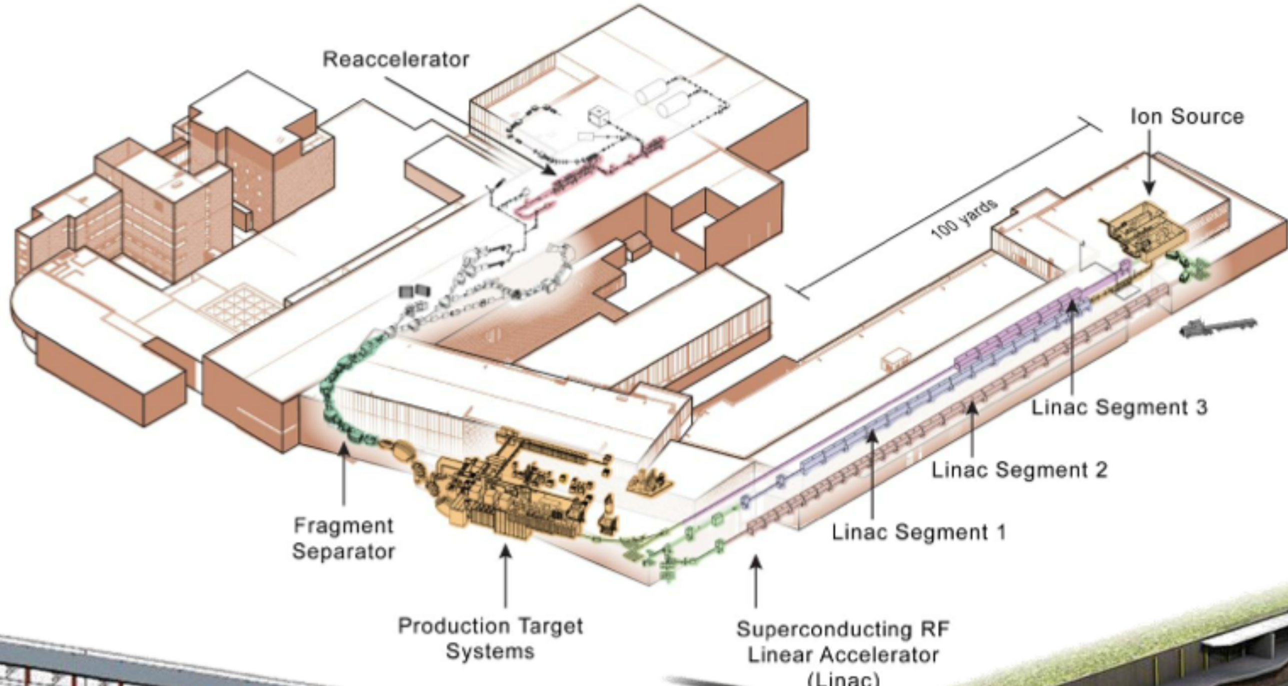


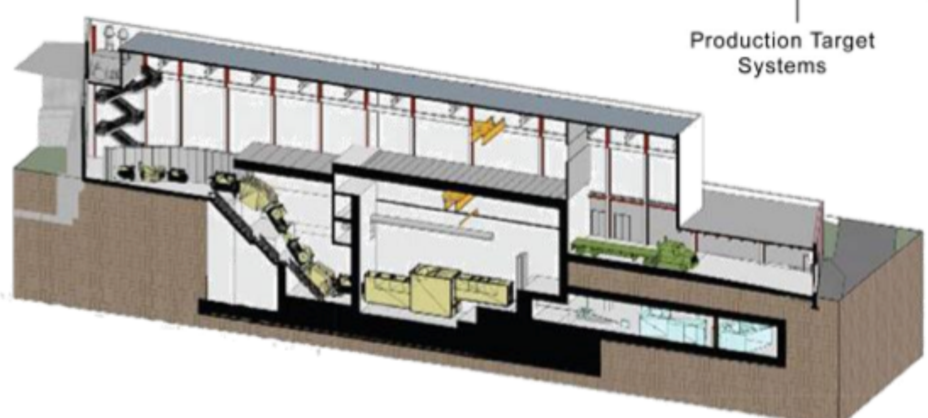
Societal applications and benefits

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

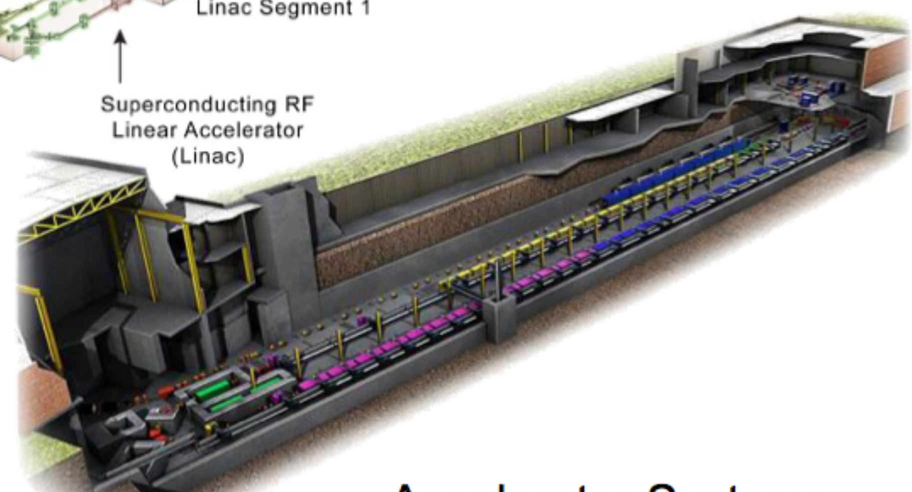
> *"Data to date on exotic nuclei are already beginning to revolutionize our understanding of the structure of atomic nuclei. FRIB will enable experiments in uncharted territory at the limits of nuclear stability. FRIB will provide new isotopes for research related to societal applications, address long-standing questions about the astrophysical origin of the elements and the fundamental symmetries of nature."*
>
> 2012 NRC Decadal Study

FRIB Major Systems





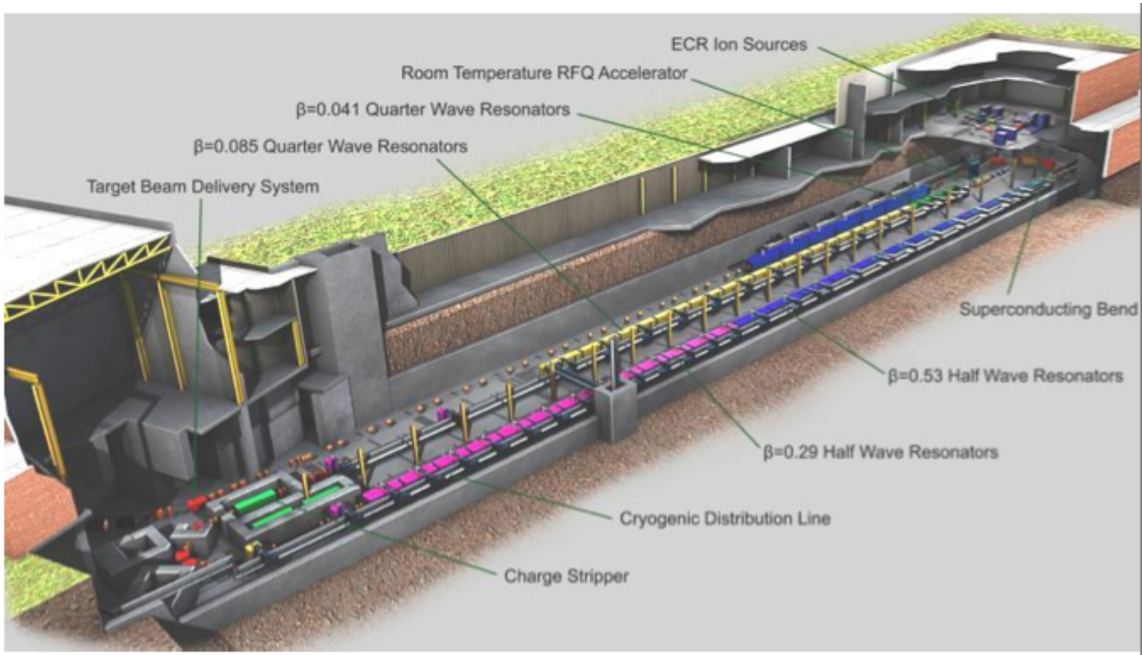
Experimental Systems

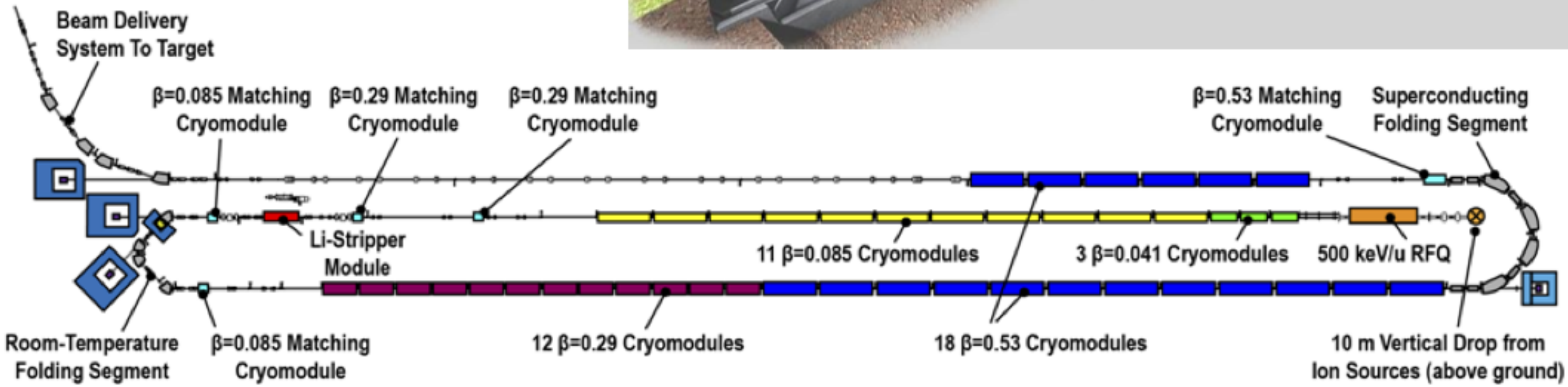


Accelerator Systems

FRIB Accelerator Systems: SRF Driver Linac

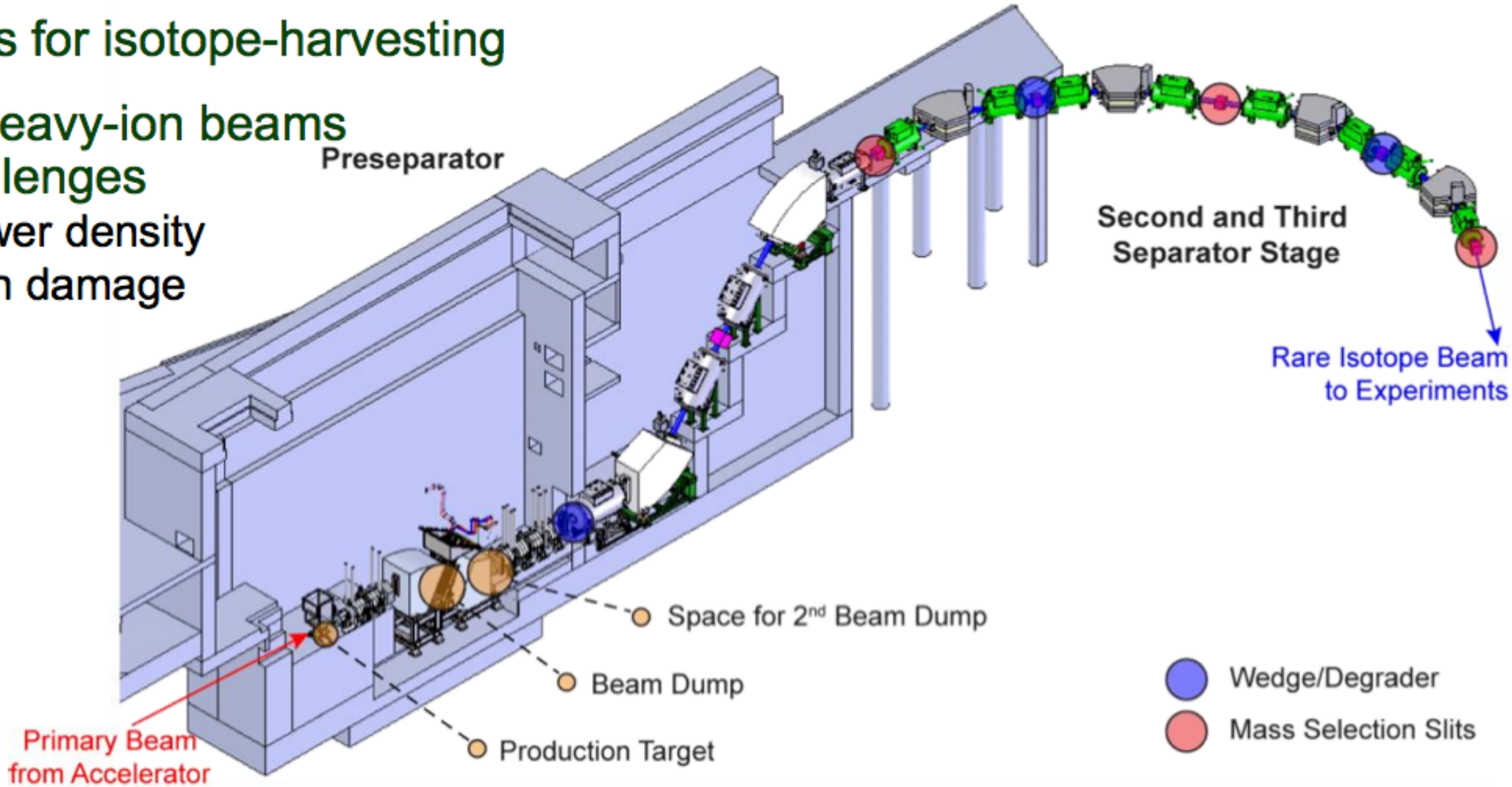
- Accelerate ion species up to ^{238}U with energies of no less than 200 MeV/u
- Provide beam power up to 400kW
    - Highest power heavy ion accelerator in the world





FRIB Experimental Systems: FRIB Rare Isotope Production

- Production of rare isotope beams with 400 kW beam power using light to heavy ions up to ^{238}U with energy ≥ 200 MeV/u
- Three separation stages for high beam purity
- Provisions for isotope-harvesting
- 400 kW heavy-ion beams pose challenges
  - High-power density
  - Radiation damage



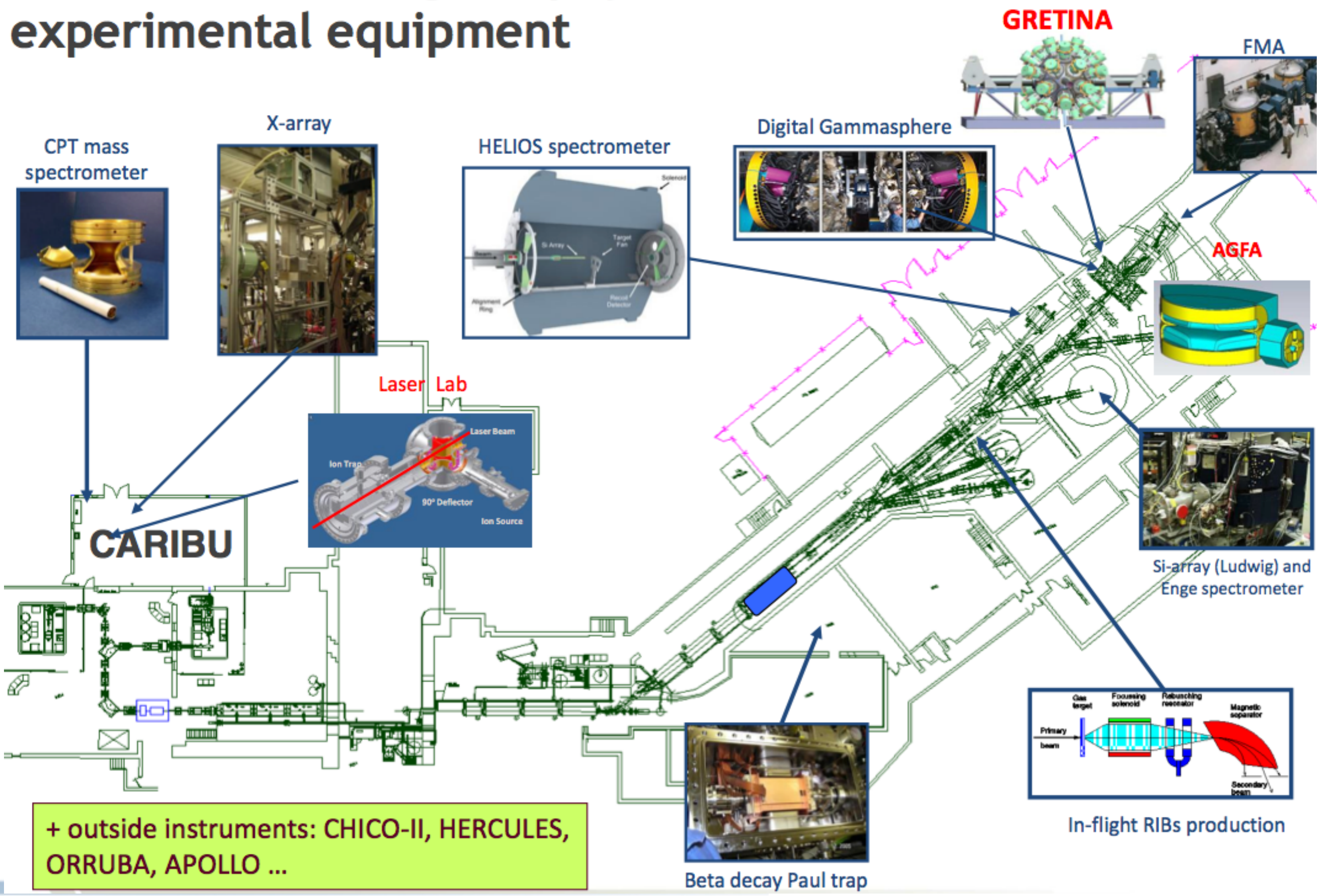
FRIB Timeline

- 8 June 2009 – DOE-SC and MSU sign Cooperative Agreement
- Sept 2010 – Critical Decision 1 (CD-1) approved
- April 2012 – Lehman review, baseline and start of civil construction
  - Project is ready *"to establish the performance baseline when funding profile guidance from DOE is provided"*
- Start of detailed design
- June 2013 – Successful Lehman Review
- **August 1, 2013 DOE Office of Science Approves CD-2 and CD-3a**
  - Baseline for FRIB established
  - Civil construction expected to start by April 2014
- Summer 2014 – CD-3b (technical construction)
- June 2022 - CD-4 (project complete)
  - Project managed for early completion in Dec 2020

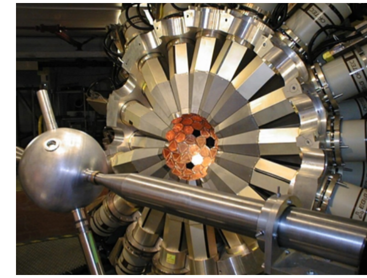
The Instruments

ATLAS Instrumentation

Main tools enabling the physics: ATLAS suite of experimental equipment

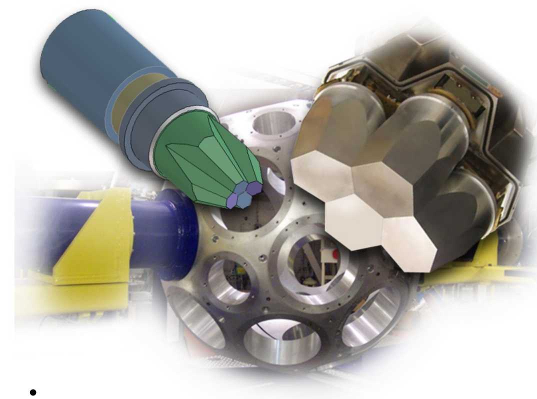


Advanced Instrumentation – an example



Gamma-ray Spectroscopy has played a major role in our current understanding of the structure of atomic nuclei.

It will continue to be a unique tool in the experimental studies of the nuclear structure as we push the limits of A (size), (N-Z) (Isospin), I (rotational frequency), and E* (Temperature)



Ingredients:

"Effective" Energy resolution (δE), Efficiency (ε), Peak-to-Total (P/T) plus auxiliary devices

} Resolving power

The calculated resolving power is a measure of the ability to observe faint emissions from rare and exotic nuclear states.

Towards the “Ultimate” Ge Array

ELSEVIER
Nuclear Instruments and Methods in Physics Research A 422 (1999) 195–200

Gamma-ray tracking detectors

I.Y. Lee

Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

ELSEVIER
Nuclear Instruments and Methods in Physics Research A 430 (1999) 292–310
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.nl/locate/nima

GRETA: utilizing new concepts in γ-ray detection☆

M.A. Deleplanque*, I.Y. Lee, K. Vetter, G.J. Schmid[1], F.S. Stephens, R.M. Clark, R.M. Diamond, P. Fallon, A.O. Macchiavelli

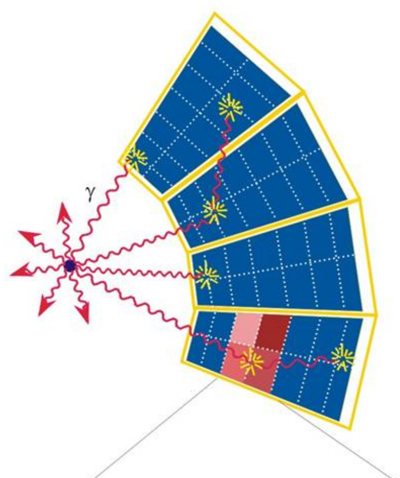
Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

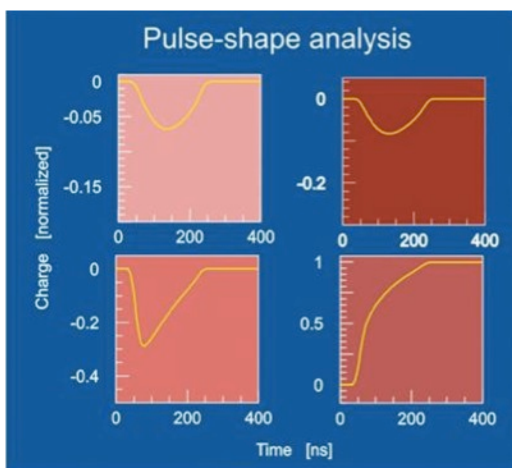
Pulse shape analysis in segments

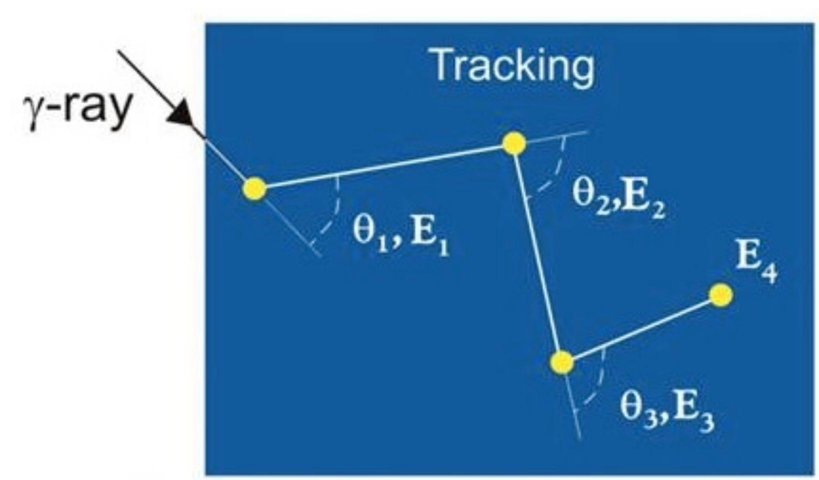
➔ 3D position of interaction points

Tracking of photon interaction points

➔ energy and position of γ-ray







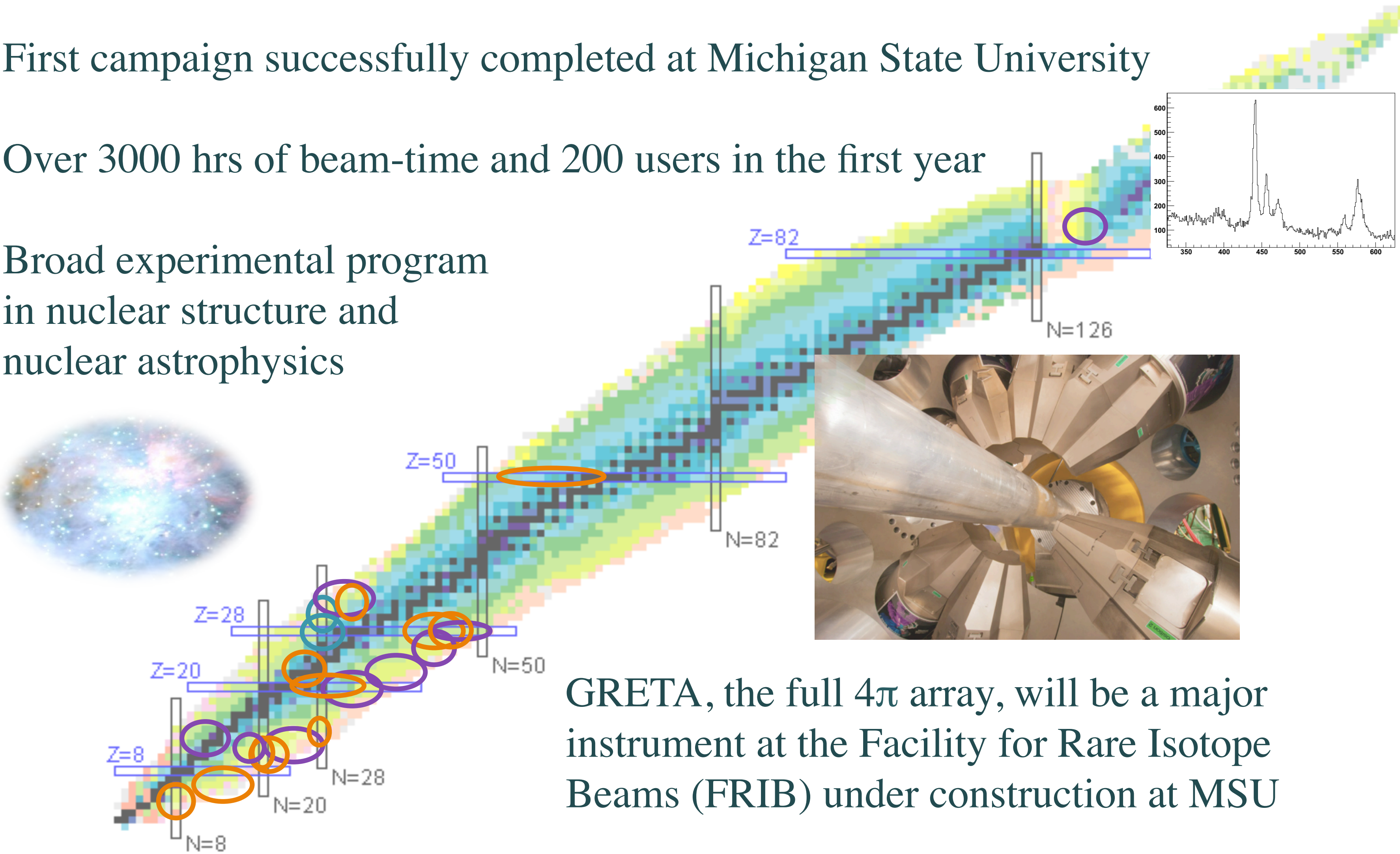
The Gamma-ray Tracking Array GRETINA

One of the most advanced gamma-ray detector array for nuclear science – uses highly segmented detectors to track and reconstruct gamma-rays.

First campaign successfully completed at Michigan State University

Over 3000 hrs of beam-time and 200 users in the first year

Broad experimental program in nuclear structure and nuclear astrophysics



GRETA, the full 4π array, will be a major instrument at the Facility for Rare Isotope Beams (FRIB) under construction at MSU

Majorana - search for ^{76}Ge 0ν2β decay

$$n \Rightarrow p + e^- + \bar{\nu}_e \qquad \nu_e + n \Rightarrow p + e^-$$

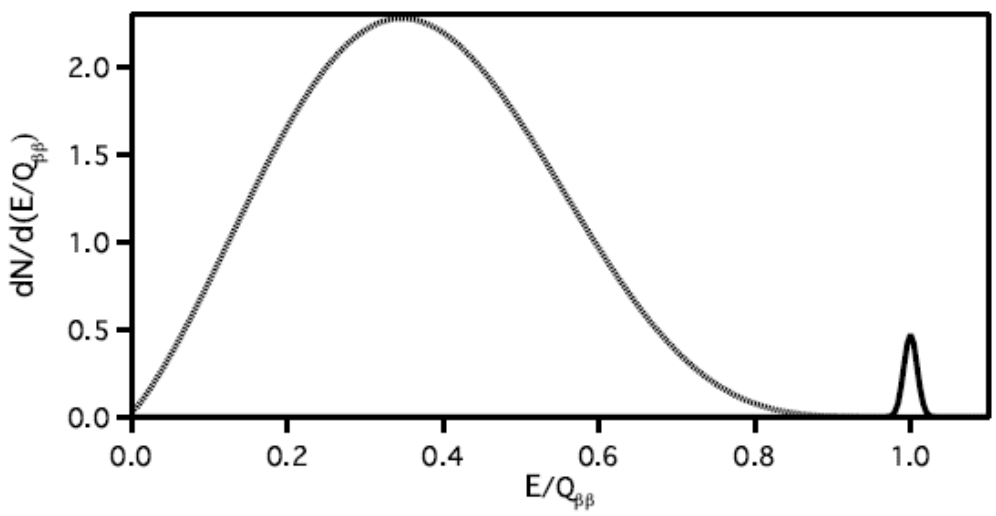


Fig. from arXiv:0708.1033

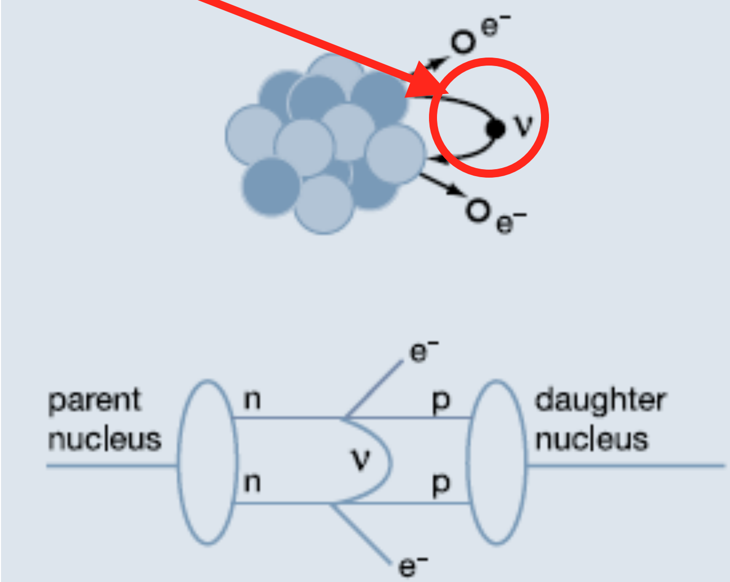
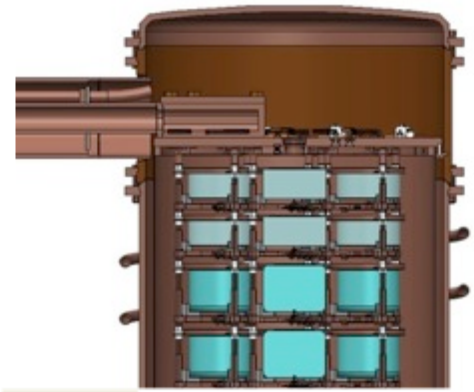


Fig. from Deep Science

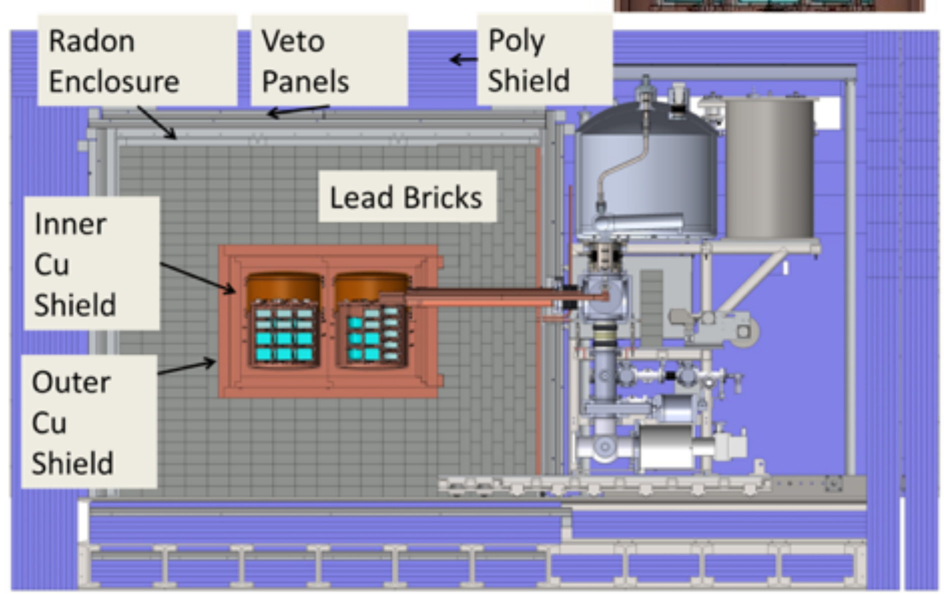
The Majorana Demonstrator

Funded by DOE Office of Nuclear Physics and NSF Particle Astrophysics,
with additional contributions from international collaborators.

Goals:
- Demonstrate backgrounds low enough to justify building a tonne scale experiment.
- Establish feasibility to construct & field modular arrays of Ge detectors.
- Test Klapdor-Kleingrothaus claim.
- Searches for additional physics beyond the standard model.



- Located underground at 4850’ Sanford Underground Research Facility
- Background Goal in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV)
  3 counts/ROI/t/y (after analysis cuts)
  scales to 1 count/ROI/t/y for a tonne experiment
- 40-kg of Ge detectors
  - 30 kg of 86% enriched ^{76}Ge crystals
  - 10 kg of ^{nat}Ge
  - Detector Technology: P-type, point-contact.
- 2 independent cryostats
  - ultra-clean, electroformed Cu
  - 20 kg of detectors per cryostat
  - naturally scalable
- Compact Shield
  - low-background passive Cu and Pb shield with active muon veto



Next Generation $0\nu\beta\beta$ Experiment

Within NP, and in preliminary discussion with HEP, there has begun to be some rumination about how to carry out a possible down-select process if the science “demands” that a ton-scale $0\nu\beta\beta$ experiment be carried out, and resources are available.

Discussion with HEP suggests that one approach could be an NSAC subpanel with members from NP and HEP to consider DBD R&D and downselect criteria. The subpanel could consider U.S. (pre-conceptual) R&D proposals for next generation experiments, in the context of related international planning efforts and report on:

- Merit of U.S. pursuing a next generation double beta decay experiment in current international landscape
- Identify potential candidates of next generation experiments – description, Status of R&D, remaining risks, priorities for future R&D
- Down select criteria for an internationally competitive experiment, including a sensitivity goal

Charge related to $0\nu\beta\beta$ and Mo^{99} direction from Congress planned to be given to NSAC

SBIR/STTR Program is relevant to our science

Many examples of SBIR projects that have direct relevance to the LE program

- Several discussed here
- From personal interest : gamma-ray tracking (GRETINA), Majorana.
- FRIB related developments

Research community welcomes collaboration

Continued opportunities and needs

One thought

high rate and data throughput capabilities: from intense beams AND the desire/need to collect “full” data information (digital data streaming mode – “rate independent”)

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Thank you