NP Low Energy Facilities and the SBIR/STTR Program

Presentation at the DOE NP SBIR/STTR Exchange Meeting

October 1-2, 2012

Birger B. Back

Chief, Low Energy Group

Overview

- Physics
- Facilities
- Equipment
- Wish lists

The Physics

Many recent reviews of our field have identified the key issues and summarized them in the form of four questions

- What binds protons and neutrons into stable nuclei and rare isotopes?
- What is the origin of collective motion in complex nuclei
- Where and how did the elements from iron to uranium originate?
- What causes stars to explode?

Techniques and measurements

Nuclear Structure and Reactions

- Coulomb excitation in regions of magic and doubly magic nuclei
- In-beam gamma-ray spectroscopy
- Decay spectroscopy (many kinds)
- The evolution of single-particle states and nuclear shells
- Synthesis and study of heavy elements

Nuclear Astrophysics

- Masses, decay properties, and reactions for r-process nuclei
- Direct reactions on rp-process nuclei
- Structure studies of specific states that affect reaction rates

Societal applications and benefits

- Surrogate reactions for astrophysics, energy, and stockpile stewardship
- Isotope production for medicine and industry
- Detection techniques for medicine, homeland security

DOE Low-energy nuclear physics facilities

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

Facilities for in-house 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

2012 – lost two facilities

- Holifield Radioactive Ion Beam Facility (HRIBF)

  Oak Ridge National Laboratory

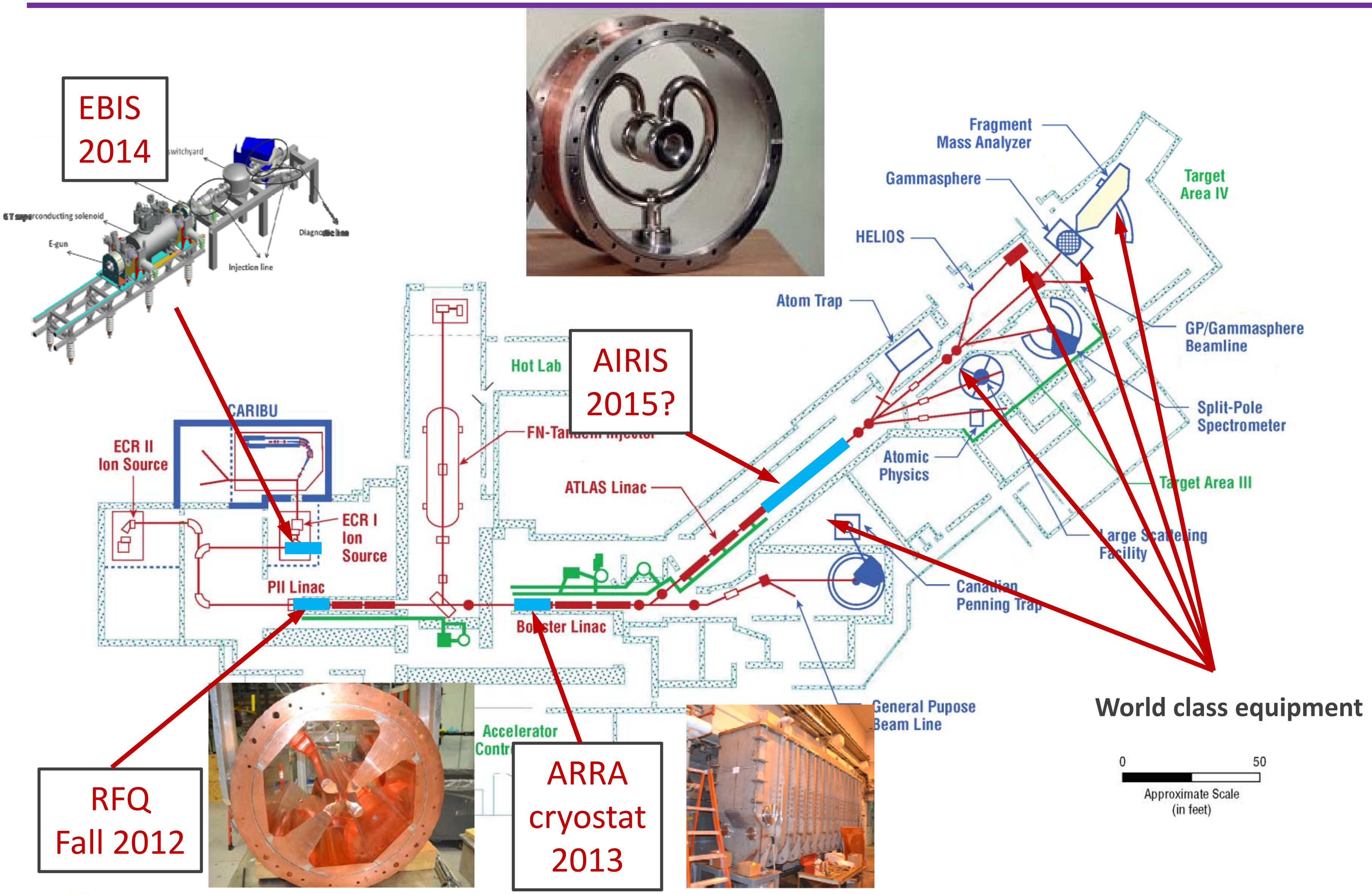
  - Re-accelerated fission fragments from uranium

- Wright Nuclear Structure Laboratory

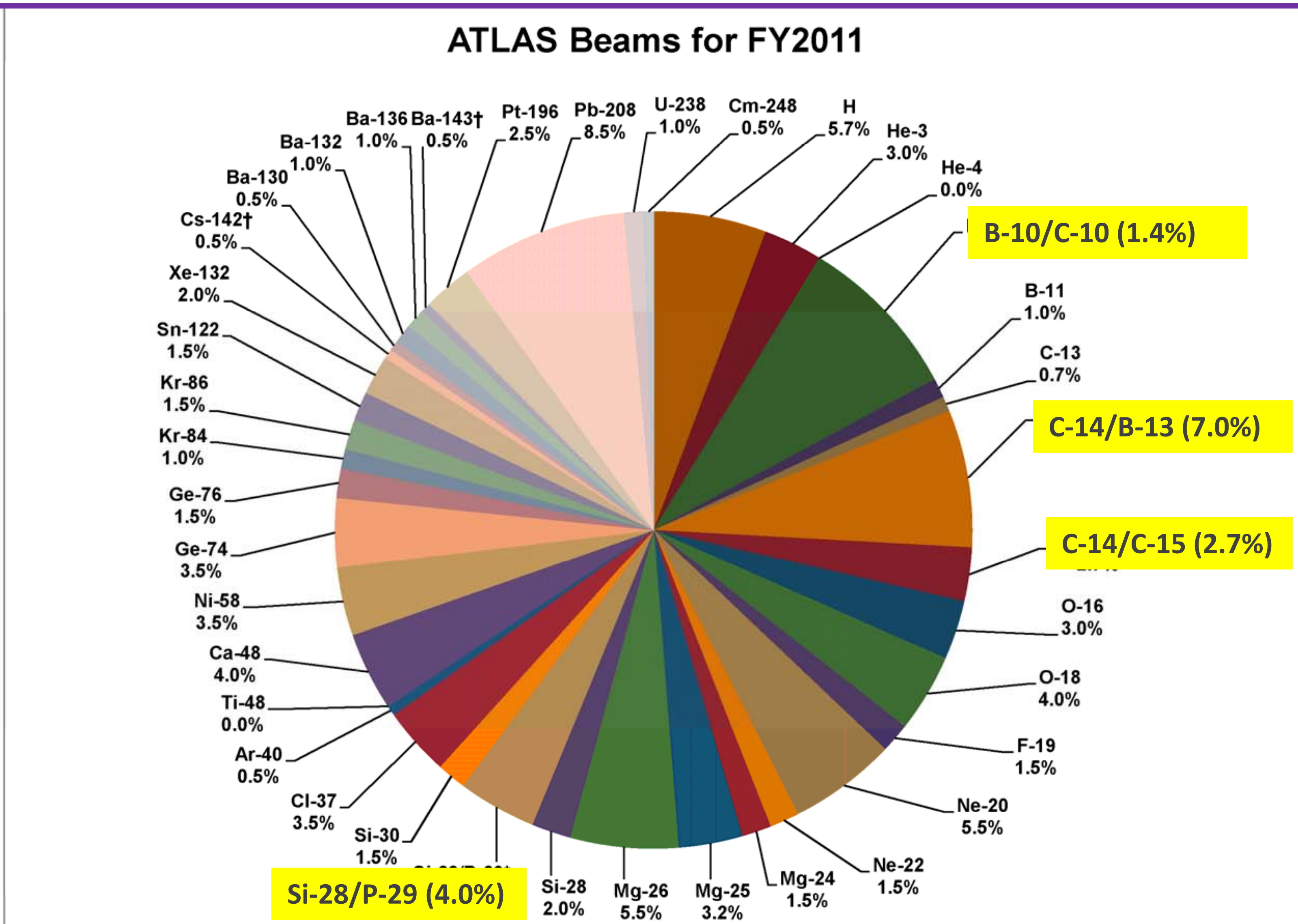
  Yale University

  - Light-ion and heavy-ion beams

ATLAS: The first SC ion accelerator in the world



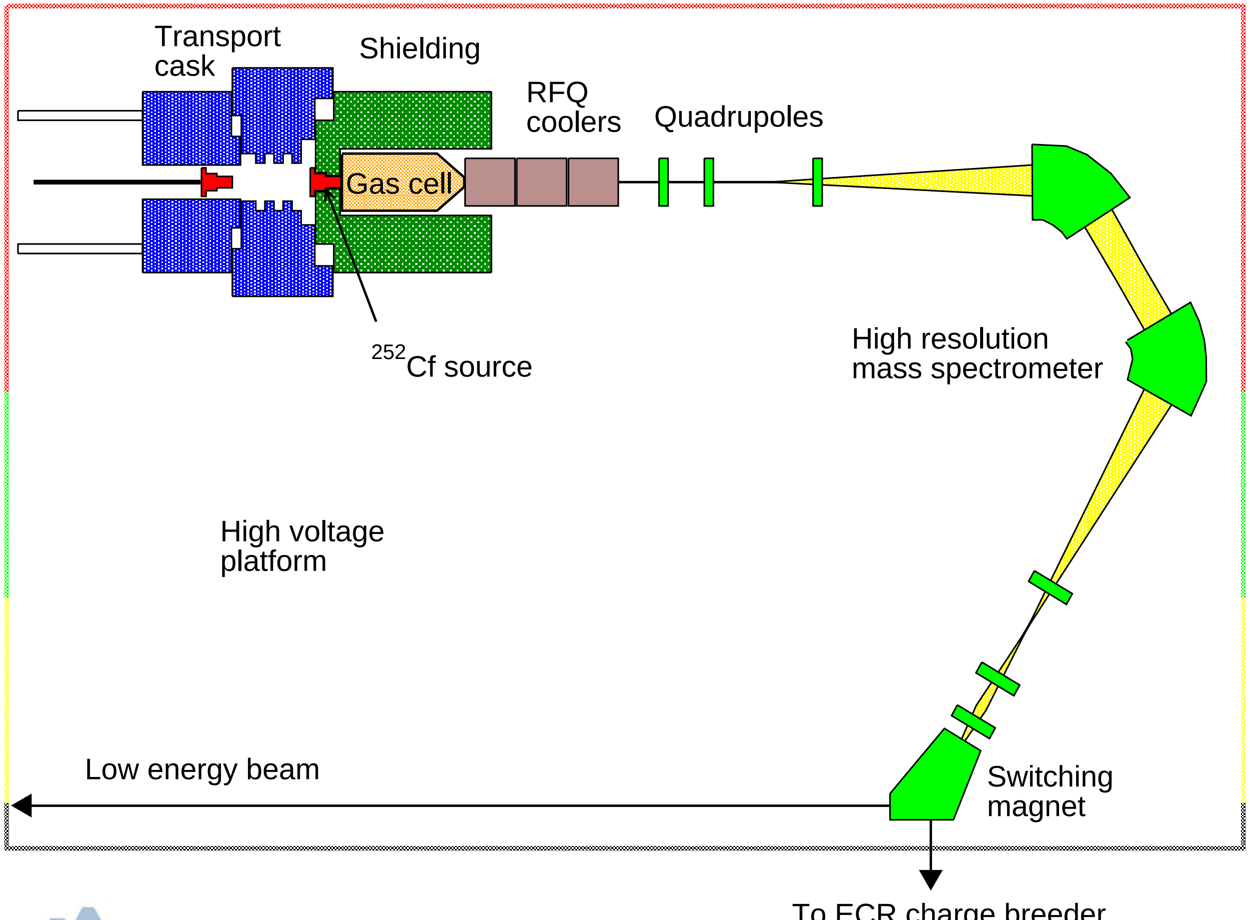
ATLAS Beams



39 different isotopes / ~15% beam time for radioactive beams

ATLAS: The CARIBU project

~1Ci ^{252}Cf fission fragments
Charge breeding and re-acceleration or stopped beams



Stopped beams:

- Precision mass measurement in CPT ~69 to date
- Decay studies
- Laser spectroscopy

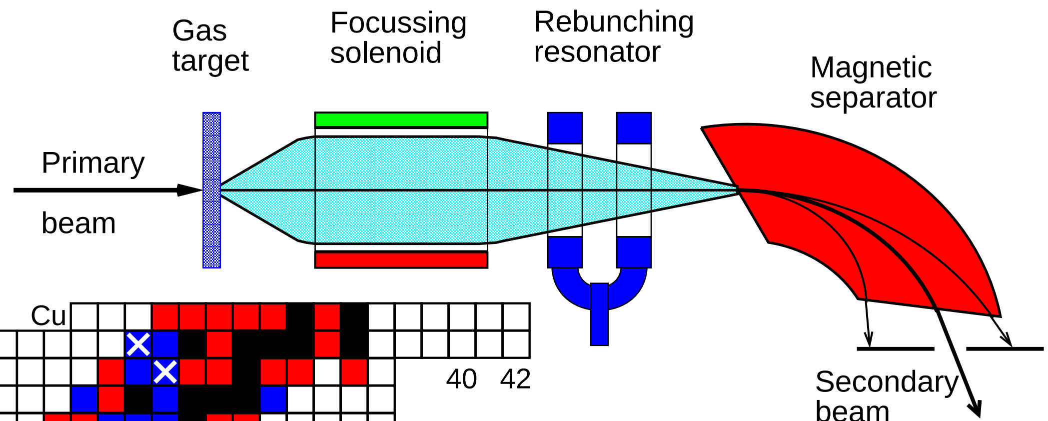
Re-accelerated beams:

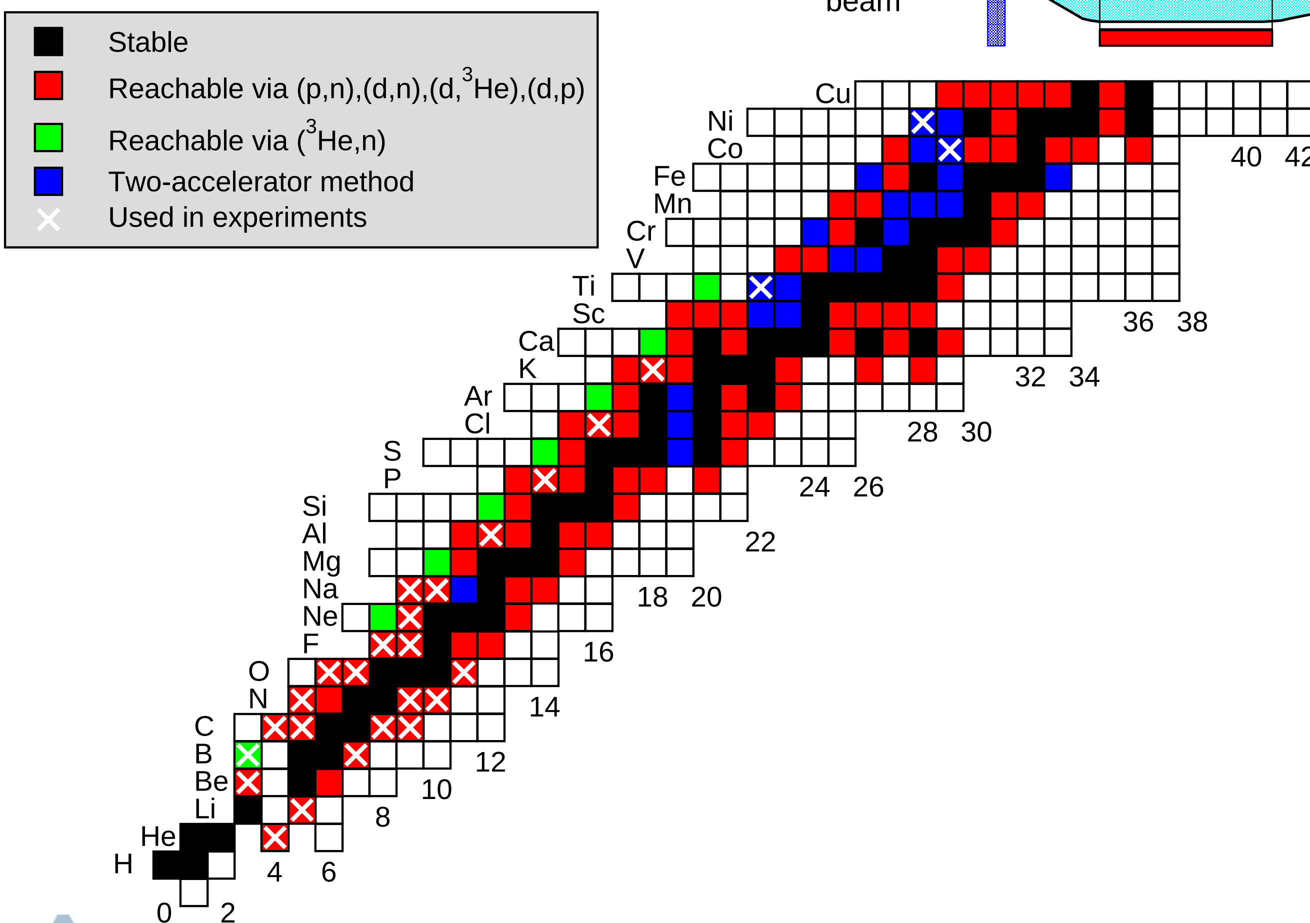
- Coulex in gammasphere (^{141}Cs)
- Transfer reactions in HELIOS
- Etc.

ATLAS In-flight radioactive beam production

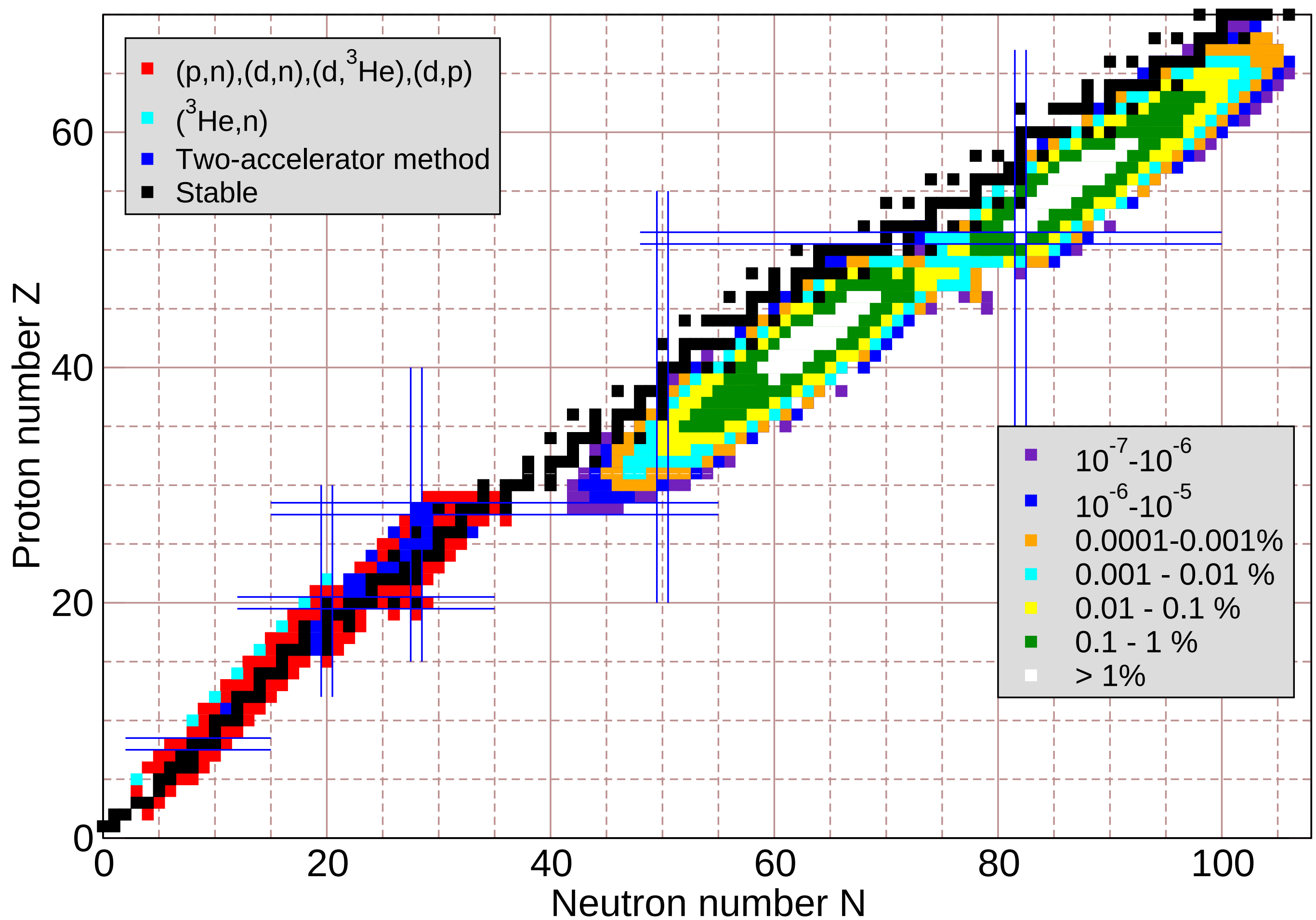
Few nucleon transfer reactions

Inverse kinematics





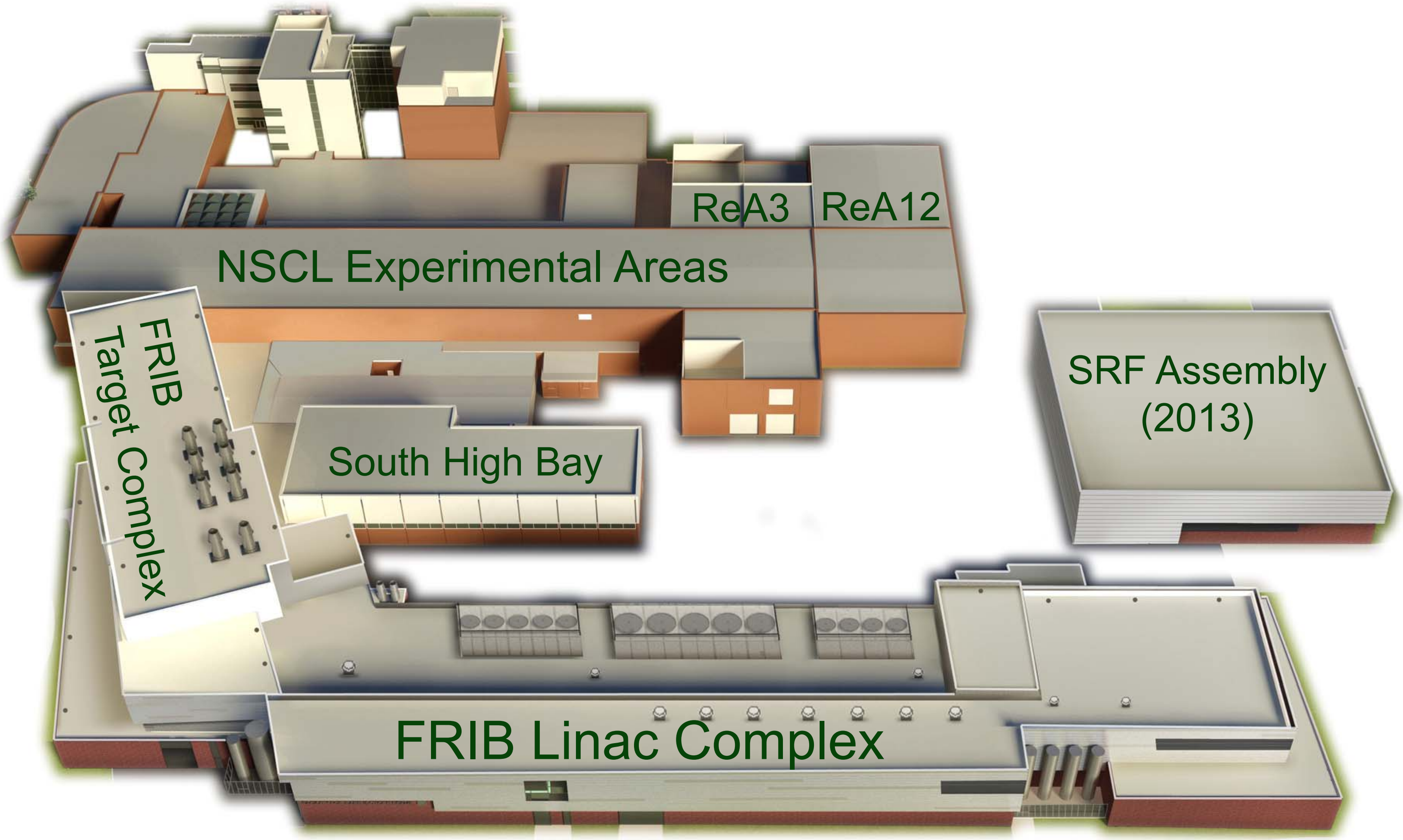
Radioactive beams from CARIBU and in-flight facility



Features of FRIB

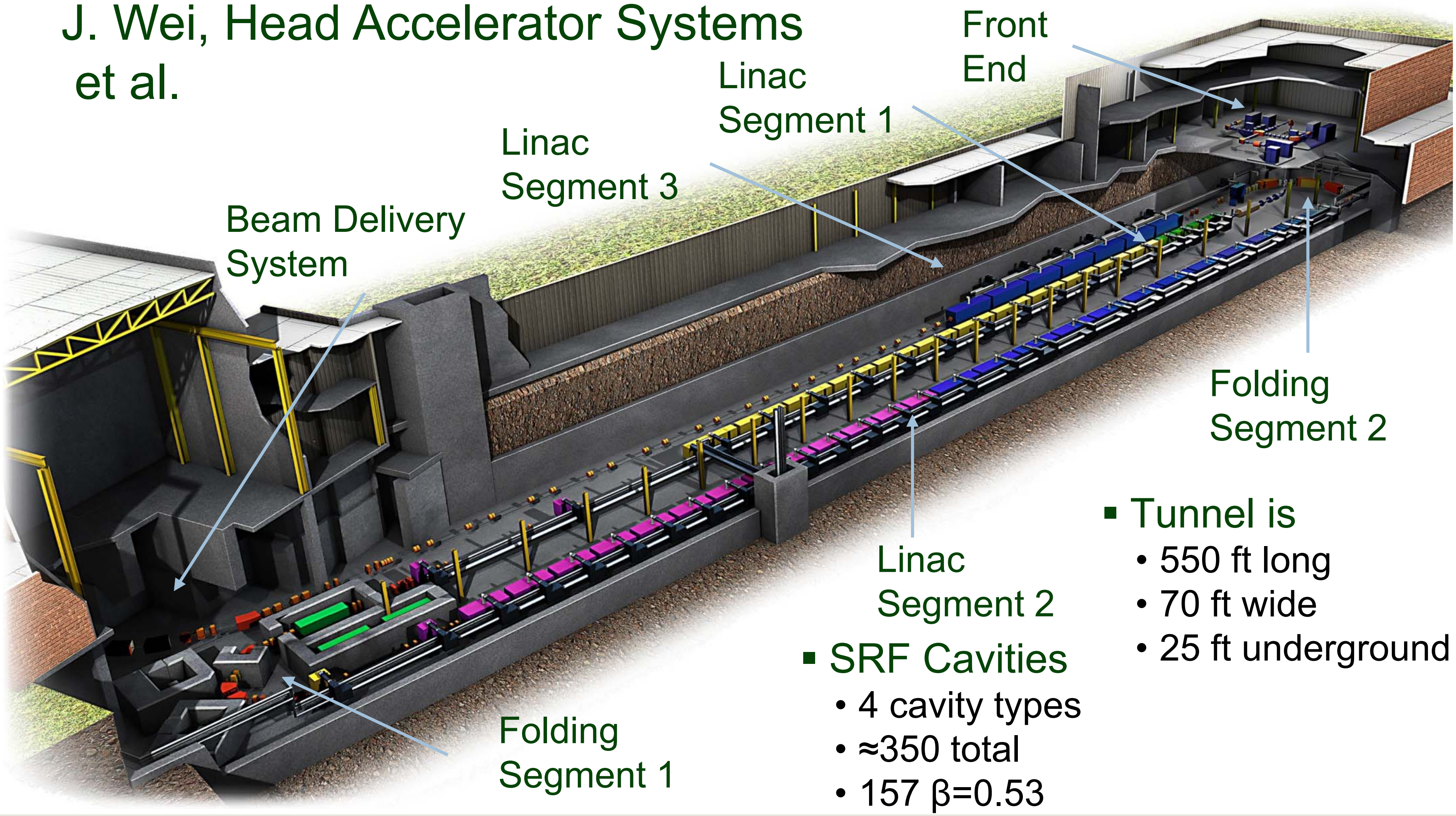
- Heavy Ion, superconducting linear accelerator with 400 kW beam power at 200 MeV/u
- 400kW corresponds to a ^{136}Xe beam of 8×10^{13} ion/s and a sensitivity to production cross sections as low as 2×10^{-6} pb.
- ^{238}U intensity of 5×10^{13} ion/s
- FRIB laboratory will have beams of rare isotopes at a wide range of energies
  - Thermalized beams for trapping, laser spectroscopy, etc.
  - Reaccelerated beams to 15 MeV/u (goal) with 15 – 22 MeV/u depending on A/Q)
  - Fast beams up to 250 MeV/u (used in-flight with no slowing)
- Multi-user capability

FRIB Laboratory Building Plan



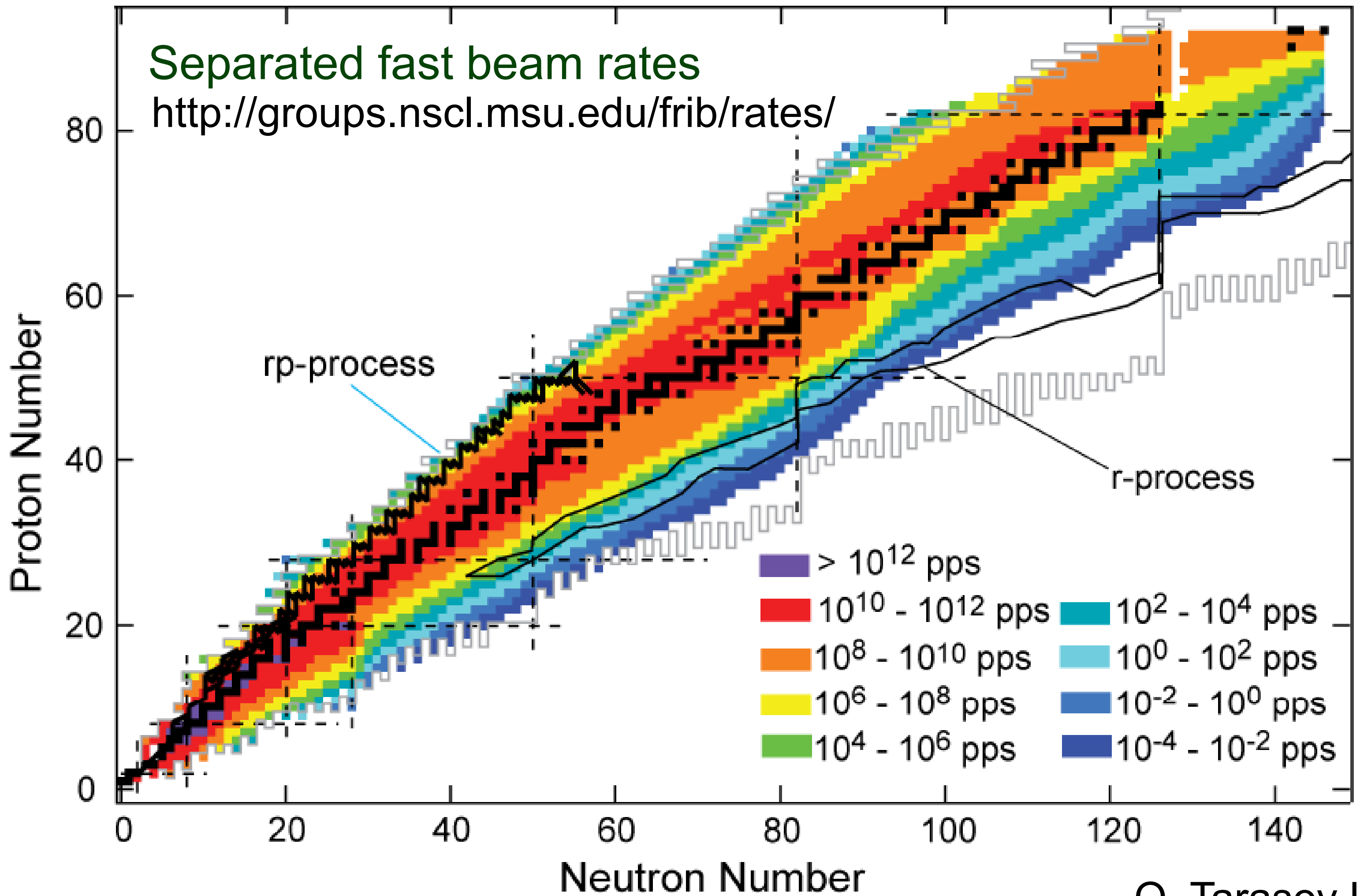
FRIB Driver Linear Accelerator

J. Wei, Head Accelerator Systems et al.



- Tunnel is
  - 550 ft long
  - 70 ft wide
  - 25 ft underground
- SRF Cavities
  - 4 cavity types
  - ≈350 total
  - 157 β=0.53

The Reach of FRIB



O. Tarasov LISE++

FRIB Users Organization Working Groups

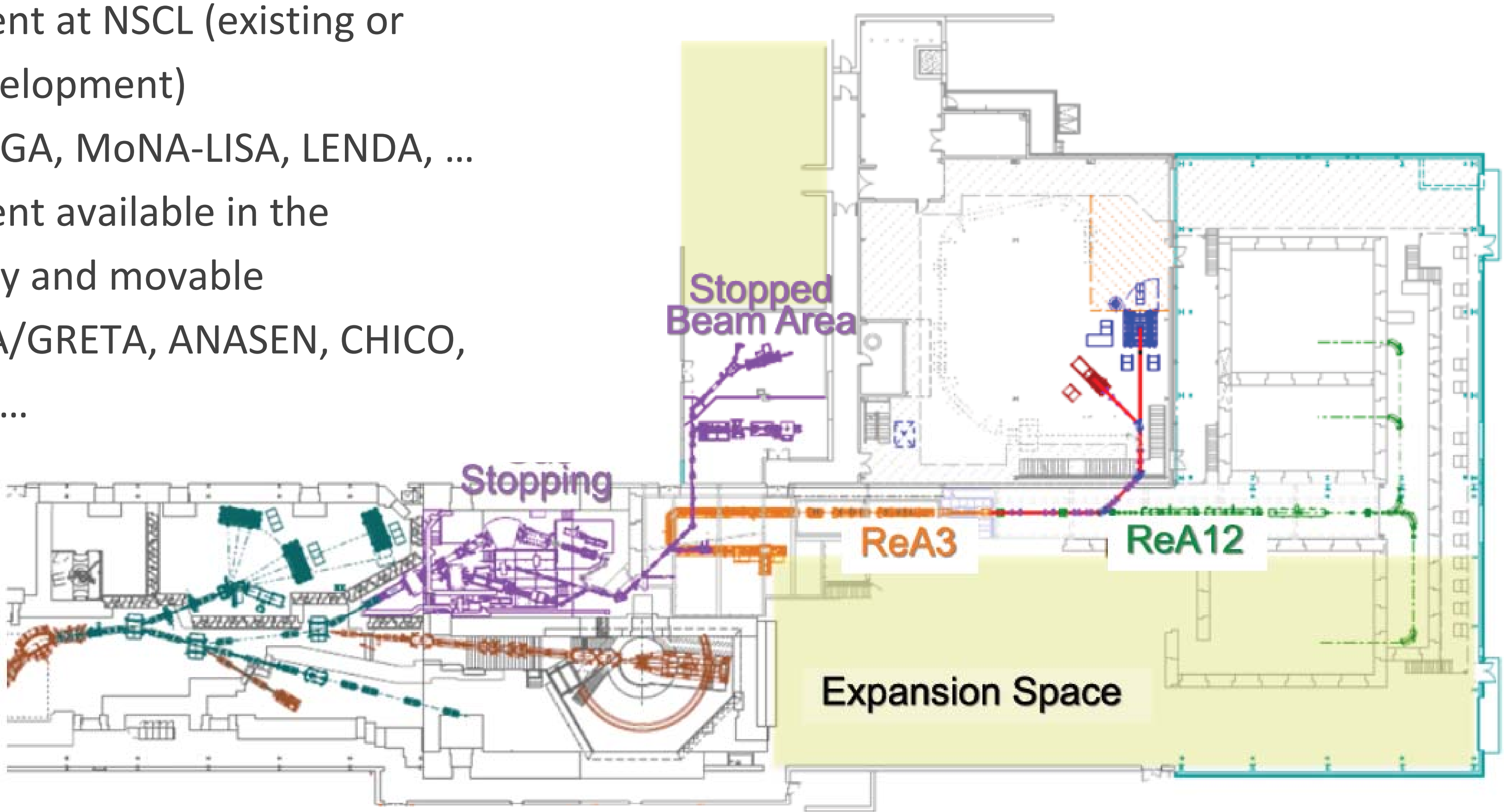
www.fribusers.org

- Theory (FRIB Theory Users Group, FRIB Theory Fellow)
- Astrophysics (SECAR)
- Data Acquisition (incl. digital data acq.)
- Decay Station (α, β, γ, electron counting)
- EoS physics
- GRETINA (+GRETA/Digital Gammasphere)
- Isotopes (and Applications)
- Jet Target
- Lasers (Laser Spectroscopy / Neutral Atom Traps)
- MoNA-Lisa
- Neutron Detection (incl. ^{3}He, plastic, liquid scintillators, MoNA-Lisa)
- Scintillators (Super Scintillator Arrays, new high resolution materials, high energy γ-rays)
- ReA12 Separator – merger of
  - Gas filled separator (BGS or RITU-like)
  - High Efficiency Spectrometer (ISLA- or VAMOS-like)
  - Separator 3 MeV/u
- Silicon Arrays
- Solenoid Detector (Helios-like)
- High Rigidity Spectrometer
- Target Laboratory (thin films and windows, special radioactive sources …)
- Technology (new technologies in detectors and electronics)
- TPC (Time Projection Chamber / Active Target)
- Traps (Penning and Paul Ion Traps)

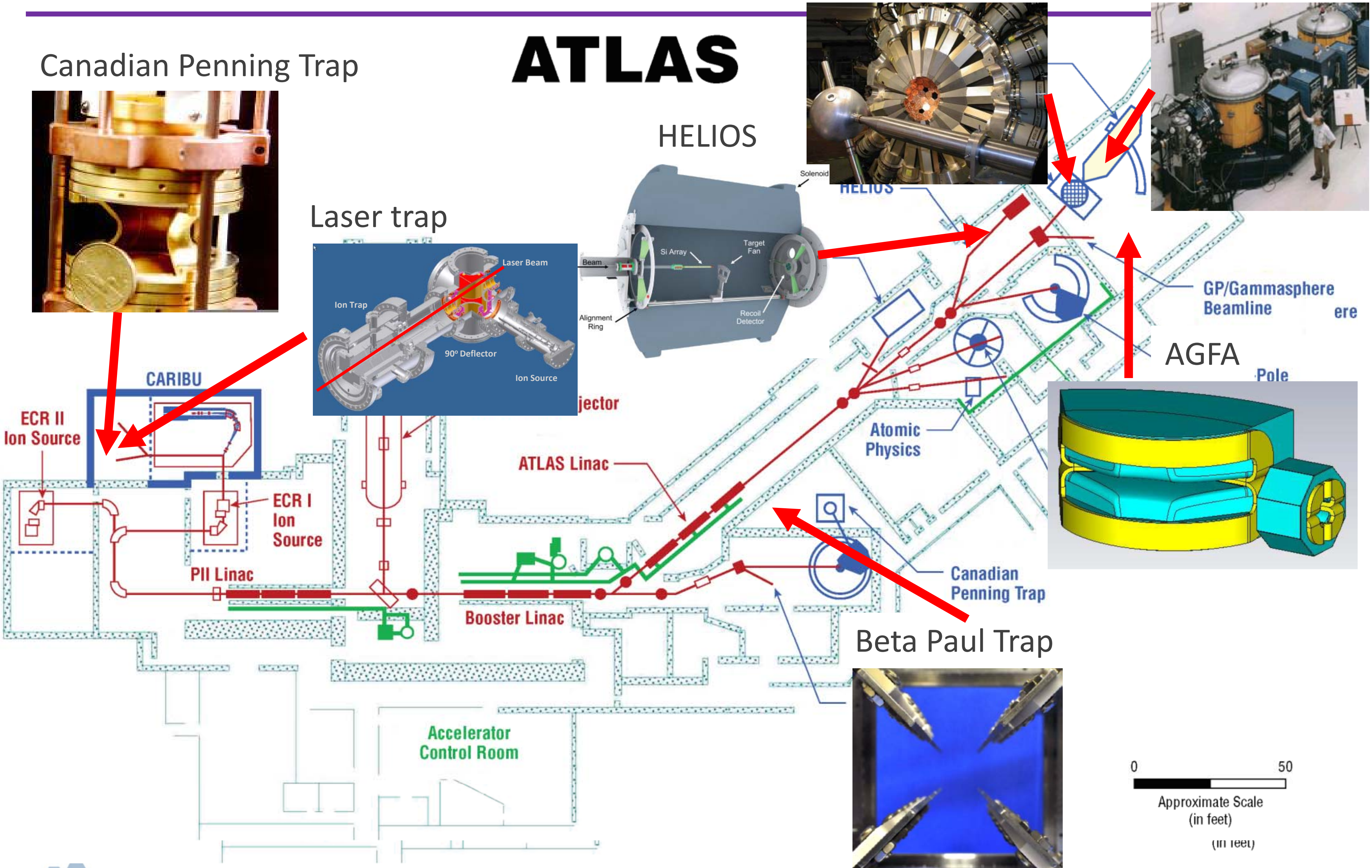
- Users are fully engaged in working groups in preparation for FRIB science

Experimental Areas and Equipment

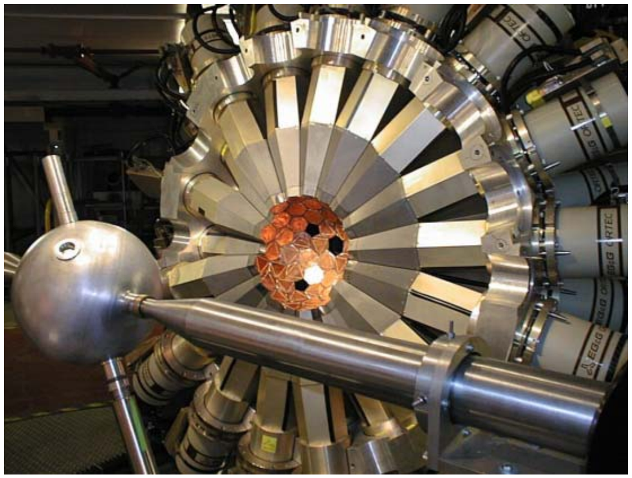
- Experimental Equipment
- • None in FRIB scope
- • Equipment at NSCL (existing or
- under development)
- » S800, SeGA, MoNA-LISA, LENDA, …
- • Equipment available in the
- community and movable
- » GRETINA/GRETA, ANASEN, CHICO,
- Nanoball, …



ATLAS instrumenation



GammaSphere

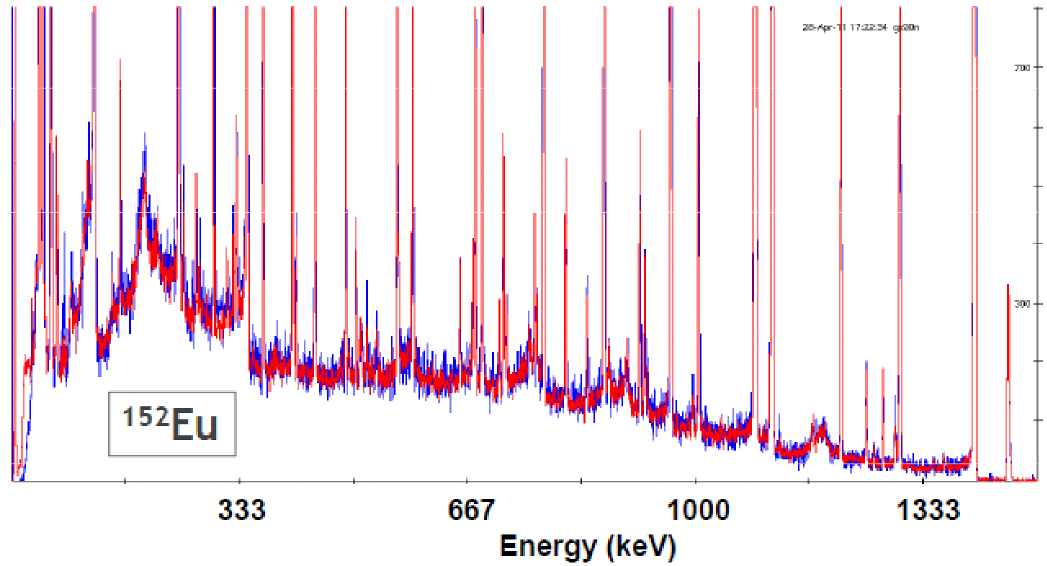


Upgrades:

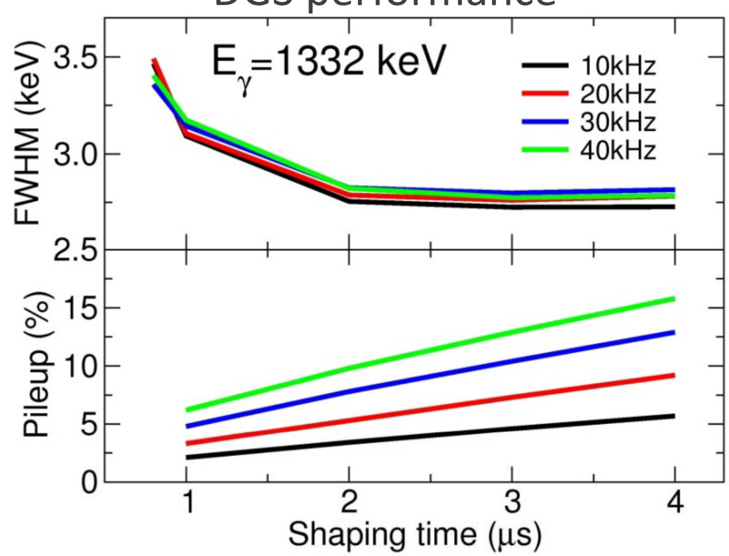
- Goal: Increase rates x 4-12
- Digitized HPGe energy signals
  - High resolution & high count rate
  - Digital @ 40kHz 1μs shaping = analog @ 10kHz 10μs
- FY2012: Digitize BGO, trigger, nearest neighbor Compton suppression

Analog Gammasphere vs Digital Gammasphere

Red is DGS and Blue is GS – (spectra normalized to 1408 peak intensity)



DGS performance



Fragment Mass Analyzer

Installation of new ED1 tank February 2012

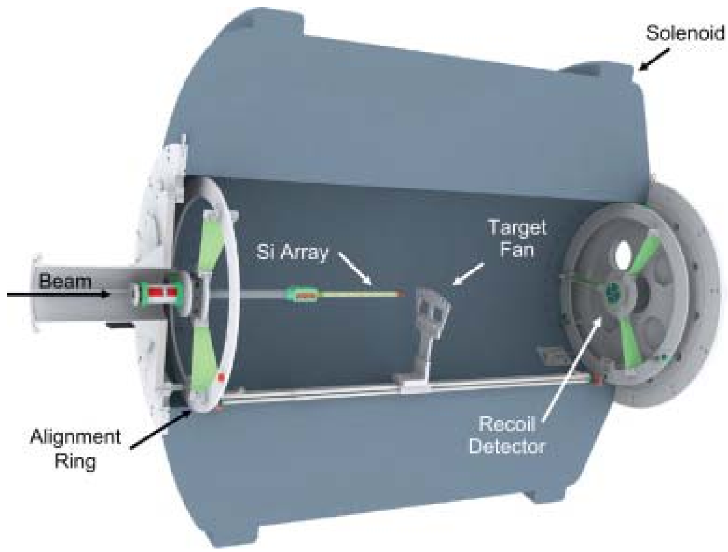
Physics motivation

- High rates for focal plane physics
- Intense beams + external F.C + m/q separation => high selectivity, weak channels *e.g.* K-isomers in heavy nuclei

Upgrades

- Goal: Increase rates x10
- Replace 1st anode tank (complete)
  - External Faraday cup
- Digitize DSSD & other focal plane detectors (complete)
- High acceptance 1st quadrupole
- Status: Ongoing
- Completion: FY 2014

HELIOS (ANL, WMU, Manchester collaboration)



Current status

- World-leading spectrometer for inverse kinematics reactions
- Superconducting solenoid (3T)+ Si detector array
- Commissioned 2008
- First physics publication, April 2010

History

- LDRD funding FY2006-FY2008
- MRI solenoid – minimal cost Dec 2006
- Proposed implementations
  - HIE Isolde, FRIB

Upgrades

- PPAC + Bragg recoil detection
  Initial tests done (Manchester Univ.)
- High-rate recoil IC (LSU)
  Under construction – test fall 2012
- Gas target for $^{3,4}He$
  Initial tests done
- Si detector upgrade
  Testing prototypes
- $LaBr_3$ array (LANL LDRD project)
- Completion: FY2013

Canadian Penning Trap - Beta Paul Trap

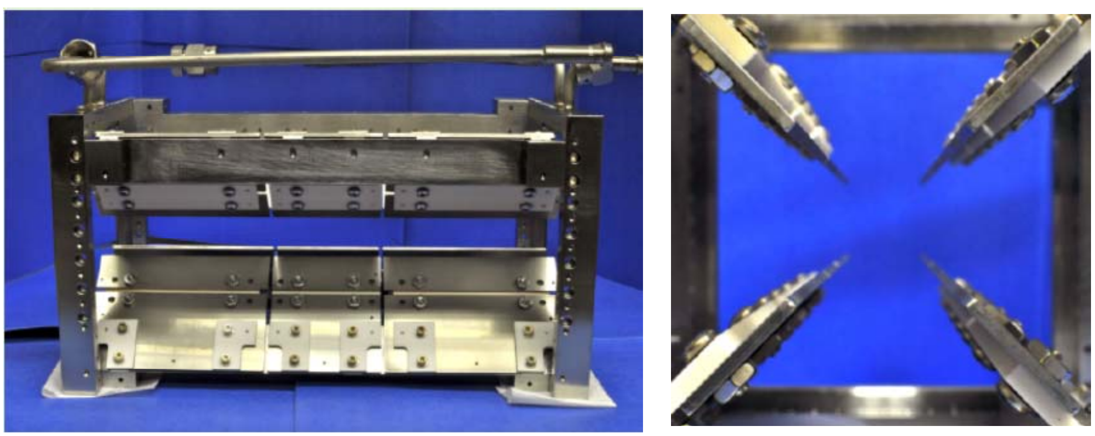
Upgrade

- Move CPT to Area III, DIC gas cell after 1Ci ^{252}Cf program done

Status

- World-leading mass measurements
- CPT presently installed at CARIBU
- BPT ready for ^{8}B $\nu\beta$ precision correlation measurements
- β –delayed neutron emission

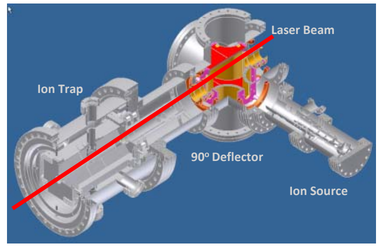
Beta-Paul Trap

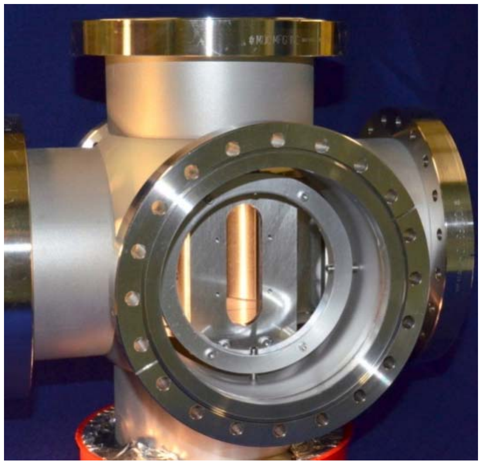


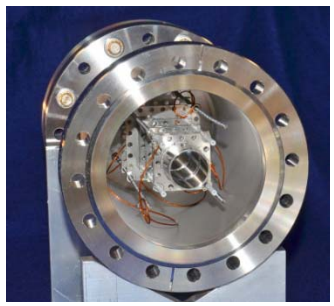
Canadian Penning Trap

Laser laboratory

In-trap spectroscopy





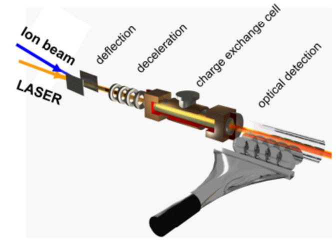


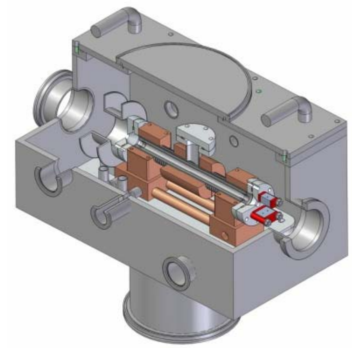
90 ° deflector *Ion source*

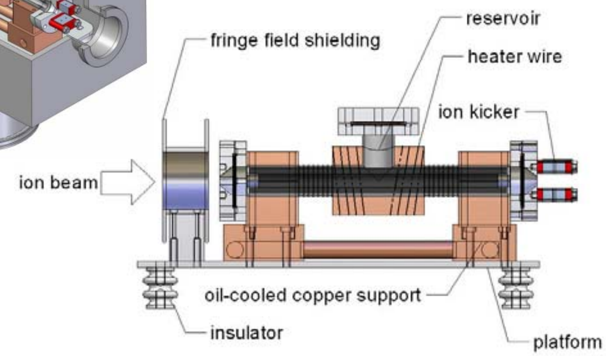
- Ion optics elements under construction
- Off-line tests with Ba^+ starting in fall 2012
- Installation @ CARIBU end of 2013

- High sensitivity: few to single ion
- Open geometry, LN_2 cooled linear Paul trap
- Buffer gas cooling

Collinear spectroscopy







Technical design of charge exchange cell (Mainz Univ.)

- Ion beam line elements under design (in collaboration with Mainz University)
- DFG proposal for postdoc position
- Construction in 2013, Installation in 2014
- High spectroscopic resolution
- High sensitivity through bunched beams
- Extend isotopic chains: Y, Zr, Nb, Mo
- Measure for the first time: Sb, Rh, Ru

Developments: Argonne Gas-Filled Analyzer (AGFA)

Purpose:

- High efficiency separation
  - Gammasphere at target position
  - Evaporation residues
    - Superheavy nuclei
    - ~^{100}Sn region
  - Deep-inelastic products
    - N-rich nuclei e.g. N~126

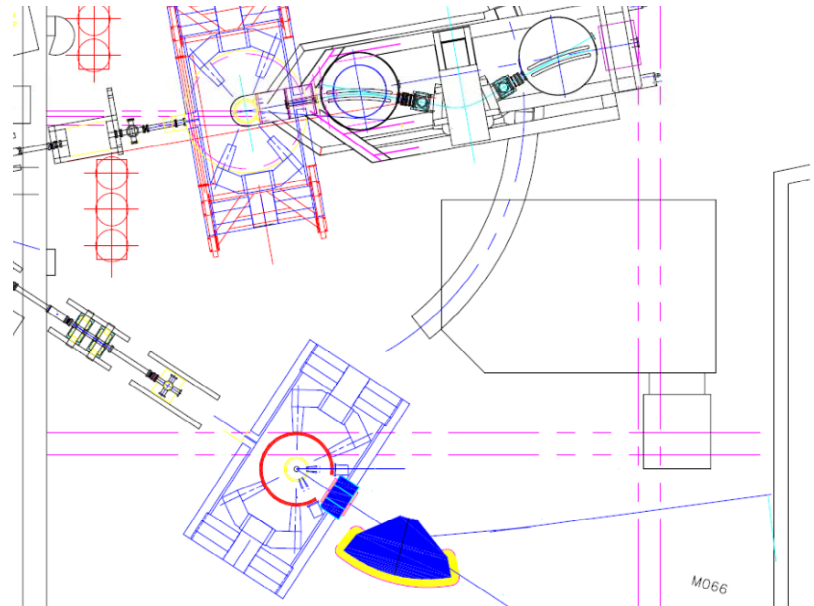
Status:

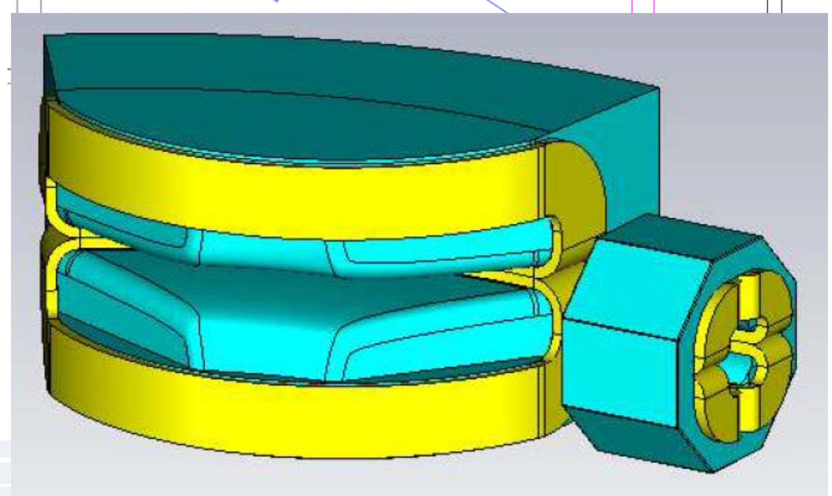
- Conceptual design done

→With Digital Gammasphere this is a unique capability

AGFA: 30-50% Efficiency

FMA: Less efficiency, m/q measurement





Other instruments

- Gretina
- Majorana
- Bubble chamber

Gretina

Background: Community built instrument

Multi electrode digital readout

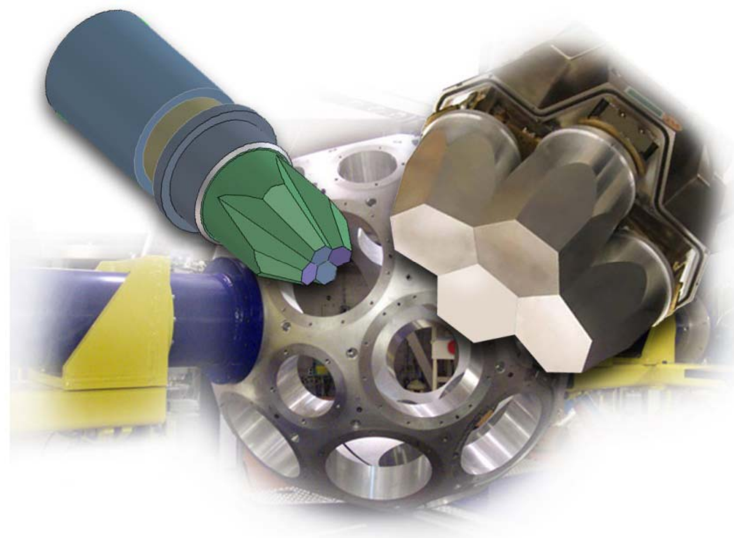
- Commissioned at LBNL 2011
- Residing at NSCL/MSU 2012
- Move to ATLAS 2013

Purpose:

- Precise location of γ-ray interactions – important for Doppler shift corrections
- Recover Compton-scattered events
- With Greta – higher detection efficiency

ANL Gretina contributions:
Management: Lister, Carpenter
Tracking software: Lauritsen
Trigger: Anderson, HEP

Physics opportunities:
Coulex of CARIBU beams
Precision lifetime studies
Neutron-rich nuclei w. D.I.C.



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

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

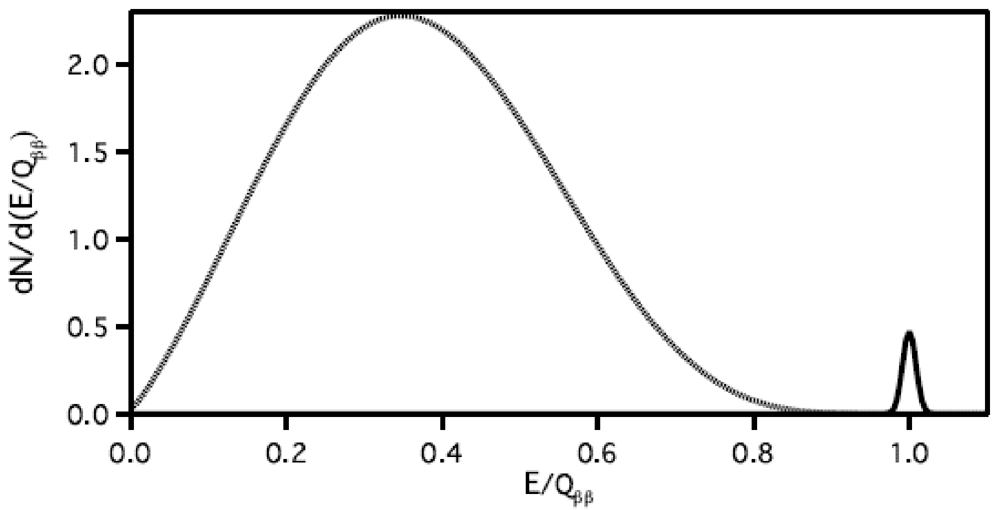


Fig. from arXiv:0708.1033

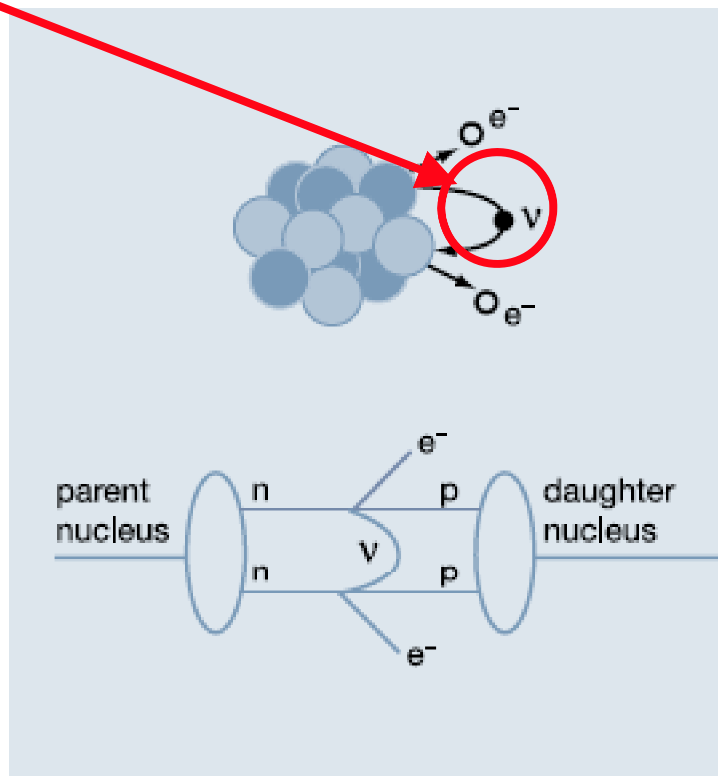


Fig. from Deep Science

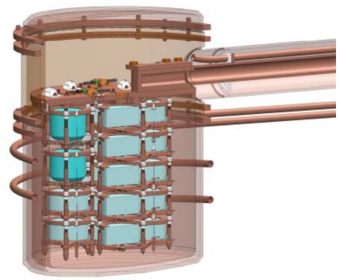
MAJORANA DEMONSTRATOR R&D Goals

- Technical goals:
  - Demonstrate backgrounds low enough to justify building a tonne scale Ge experiment.
  - Establish feasibility to construct & field modular arrays of Ge detectors.
  - Minimize costs, optimize the schedule, and retire risks for a future 1-tonne experiment.
- Science goals:
  - Although we are driven by technical goals, we also aim to extract the maximum science from the DEMONSTRATOR prototype,
    - Test the recent claim of an observation of $0\nu\beta\beta$ in ^{76}Ge.
    - Exploit the low-energy sensitivity to perform searches for dark matter, axions.
- Work cooperatively with GERDA Collaboration toward a single international tonne-scale Ge experiment that combines the best features of MAJORANA and GERDA.

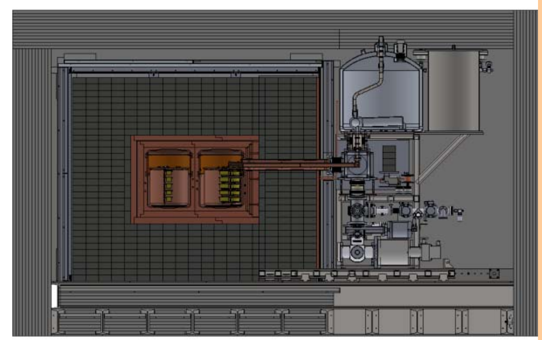
The MAJORANA DEMONSTRATOR Module

^{76}Ge offers an excellent combination of capabilities & sensitivities.

(Excellent energy resolution, intrinsically clean detectors, commercial technologies, best $0\nu\beta\beta$ sensitivity to date)



- **40-kg of Ge detectors**
  - 30-kg of 86% enriched ^{76}Ge crystals required for science and background goals
  - Point-contact detectors for DEMONSTRATOR
- **Low-background Cryostats & Shield**
  - ultra-clean, electroformed Cu
  - naturally scalable
  - Compact low-background passive Cu and Pb shield with active muon veto

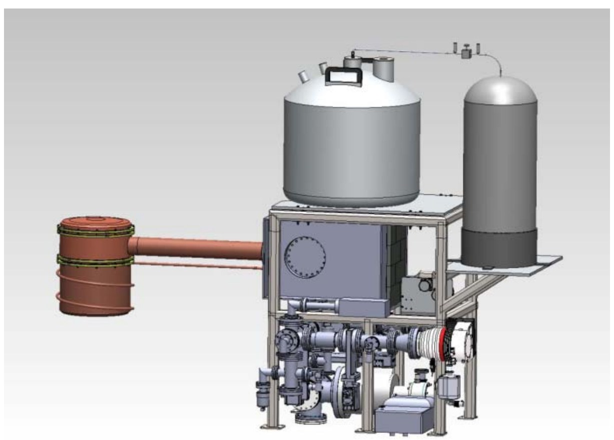


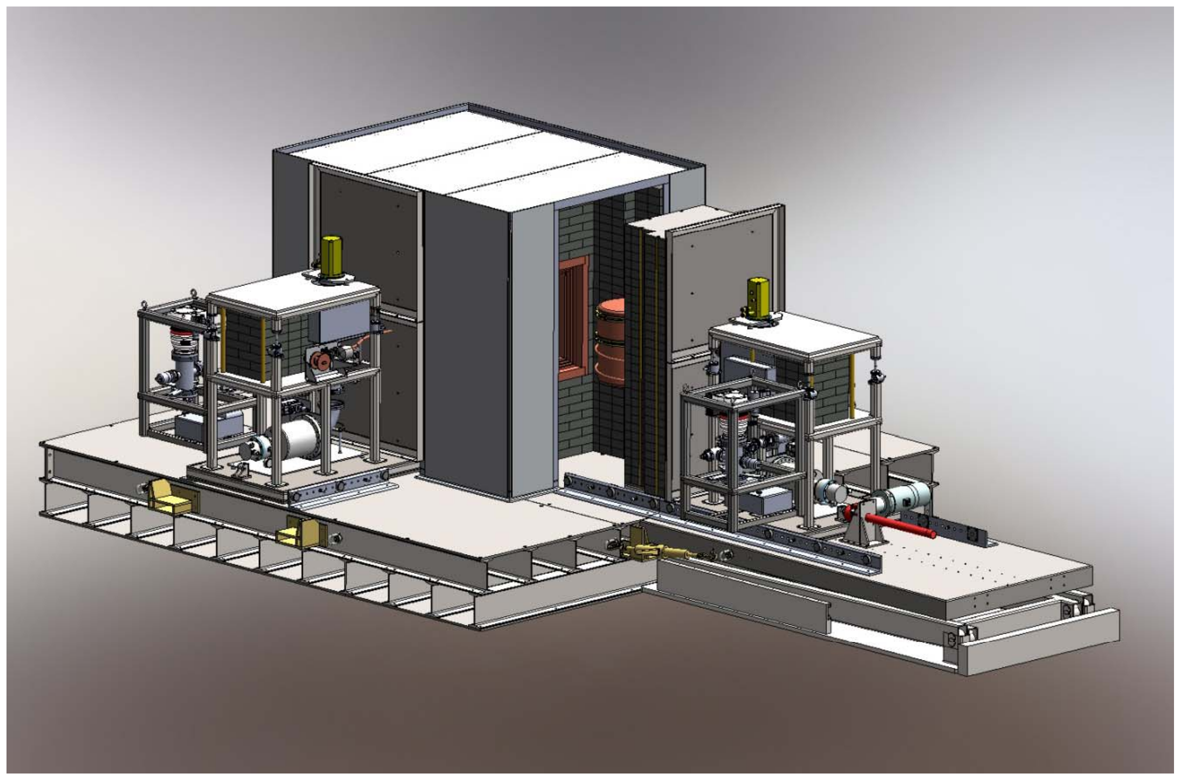
- **Located at 4850' level at Sanford Lab**
- **Background Goal in the $0\nu\beta\beta$ peak ROI(4 keV at 2039 keV)**

~ 3 count/ROI/t-y (after analysis cuts) (scales to 1 count/ROI/t-y for tonne expt.)

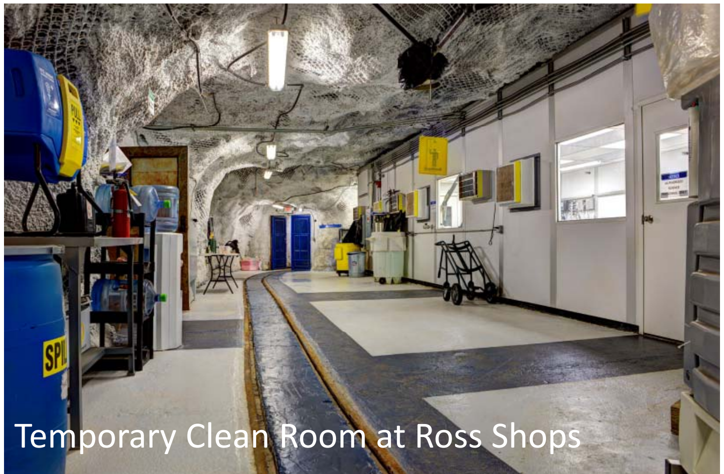
MJD Implementation

- Three Phases
  - Prototype cryostat (2 strings, ^{nat}Ge) **(Fall 2012)**
  - Cryostat 1 (3 strings ^{enr}Ge & 4 strings ^{nat}Ge) **(Fall 2013)**
  - Cryostat 2 (up to 7 strings ^{enr}Ge) **(Fall 2014)**





Underground Lab - Status



Temporary Clean Room at Ross Shops

- Eforming lab operational since summer 2011
- Davis Campus lab outfitting finished
- Shield floor, LN system, assembly table,
- Air bearing system, glove boxes, localized clean space all installed

Glove Box

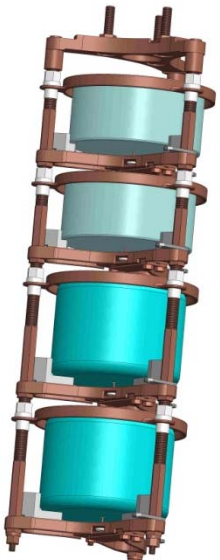
Assembly table, Overfloor, Air Bearing

Enriched Ge

- 20 kg ^{enr}Ge received as oxide and stored UG in Oak Ridge
- Additional 22.5 kg ordered, Fall delivery
- 4-5 kg Russian contribution by end 2012

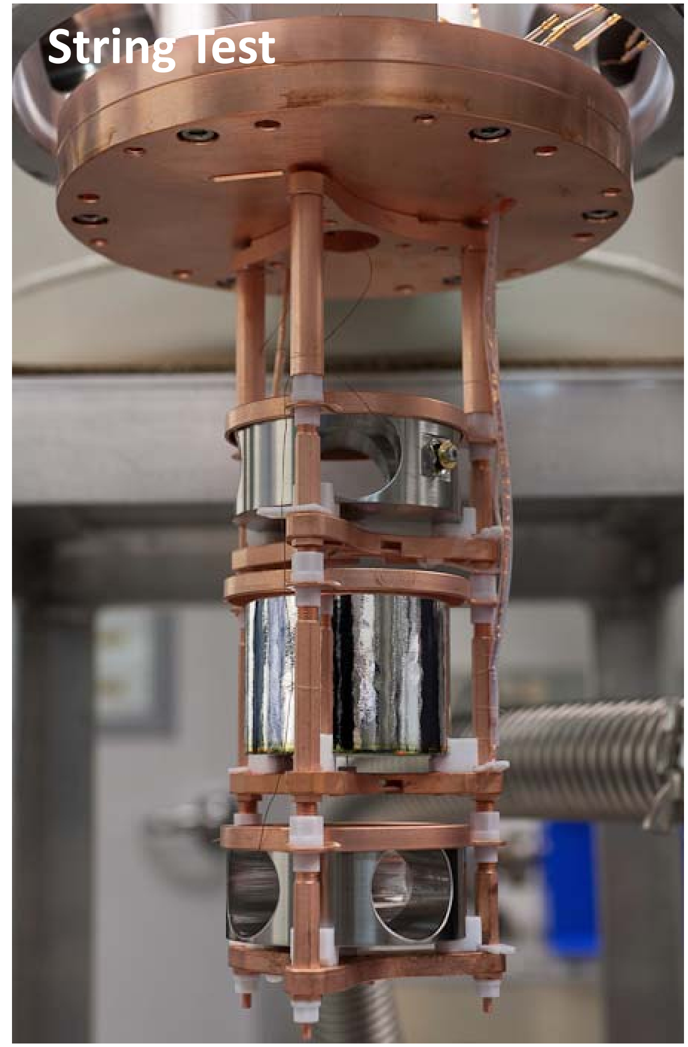
	Specs	ECP	ORNL Physics (Sample 1)	ORNL CSD (sample 2)	PNNL (Sample 3)
^{76}Ge	≥86.0	87.67	86.9 (2)	87.9 (9)	88.2 (3)
^{74}Ge		12.16	12.5 (1)	12.0 (1)	11.8 (3)
^{73}Ge		0.07	< 0.2	0.052 (1)	0.04 (2)
^{72}Ge		0.05	<0.2	0.0058 (3)	0.02 (1)
^{70}Ge	≤0.07	0.05	<0.2	0.0157 (3)	0.005 (4)

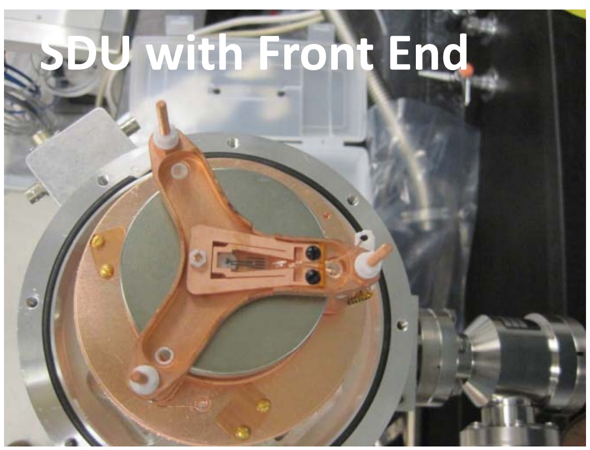
Detectors

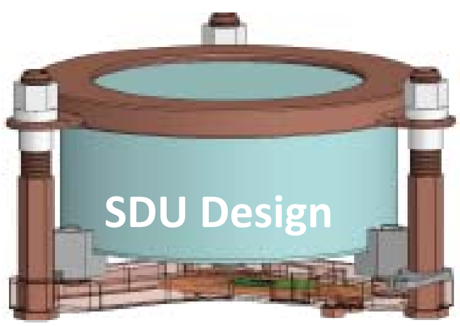


String Design

- 20 kg of modified BEGe (Canberra)
- natGe detectors in hand (33 UG).
- ORTEC selected to produce enriched detectors. Excellent projected yield.
- First enriched detectors delivered UG in Spring 2013.



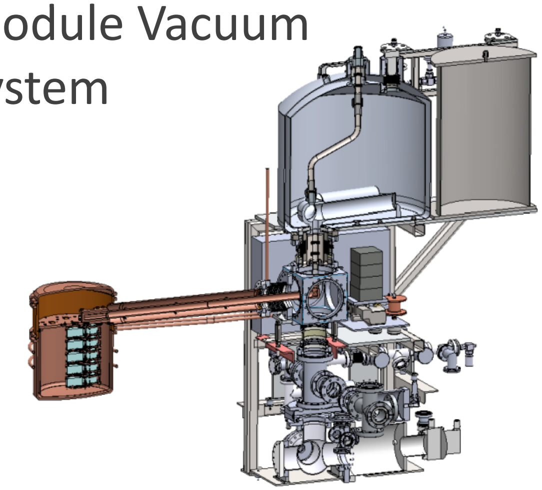




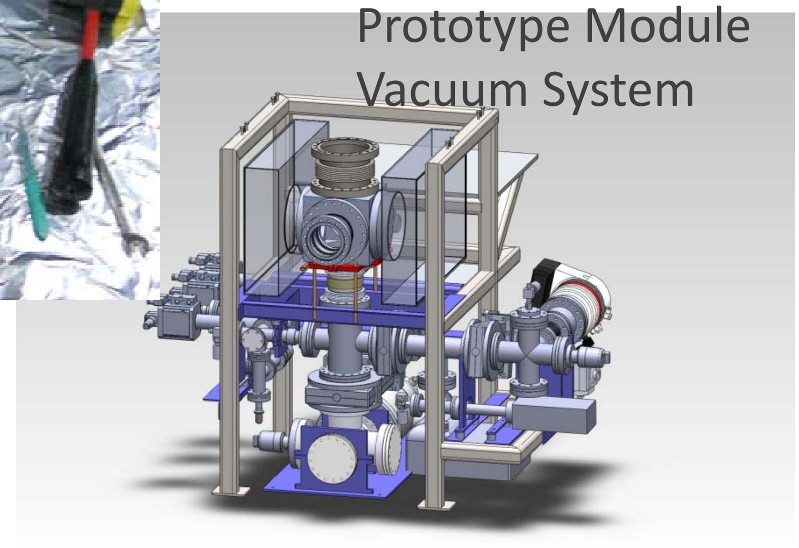
Modules

- Prototype cryostat being fabricated and assembled. E-beam welds completed
- Thermosyphon design validated. Fabricated and tested.
- Prototype vacuum system designed, reviewed, assembled, and being operated.
- First two string test cryostats built.
- Parts and material tracking in place.
- Clean machining implemented underground.

Module Vacuum System



Prototype Module Vacuum System

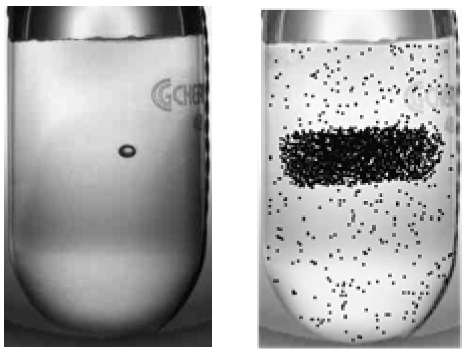


Bubble chamber - initially LDRD funded Rehm, DiGiovine

New technique to measure $^{12}C(\alpha,\gamma)$ via $^{16}O(\gamma,\alpha)$ x1000 more efficient than competitors

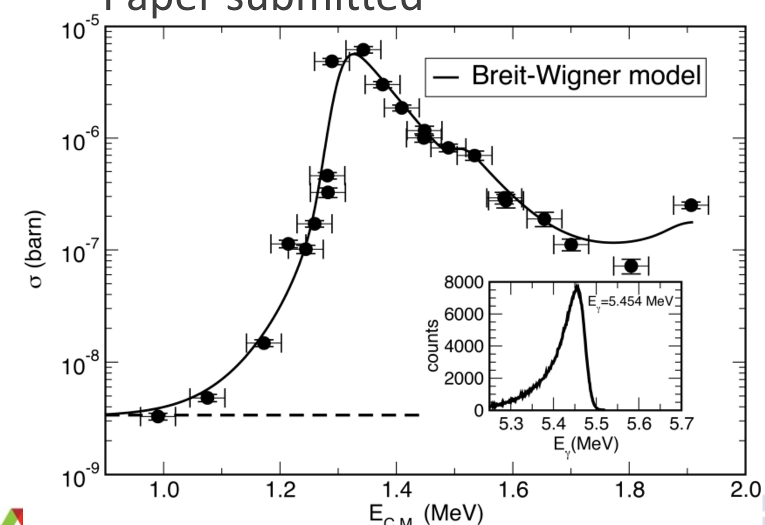
First version with R134a refrigerant

Single bubble 24hr exposure

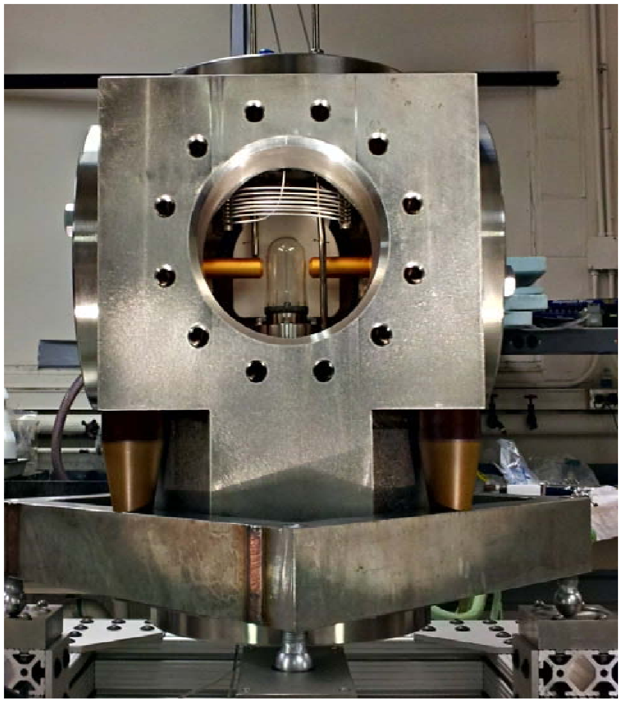


$^{19}F(\gamma,\alpha)^{15}N$ measurement

Paper submitted



Superheated **T**arget for **A**strophysics **R**esearch (**STAR**) P=100 ATM T=250^{o}C



My wish list

- High strength, thin foils for gas cells (In-flight beams and H,D,T, He gas targets)
- Weak beam diagnostics (t, x, y, ΔE) – rates up to $10^6 – 10^7$ Hz
- Custom Si detector fabrication in US
- High power liquid or solid targets for in-flight RIB production
- High rate recoil detector with good Z resolution (t, x, y, ΔE) – rates up to 10^6 Hz
- Large area diamond detectors
- . . .

Examples of FRIB related SBIR topics (NP3+ NP4) – Georg Bollen, MSU

- High-rate, position sensitive particle tracking detectors and timing detectors for high-energy heavy-ions, (for example diamond detectors)
- Technologies and sub-systems for the targets required at high-power, rare isotope beam facilities that use heavy ion drivers for rare isotope production.
- Radiation resistant (high-speed) rotating vacuum seals and multiple-use vacuum seals.
- Tilted solenoids for high-acceptance spectrometers
- Radiation resistant magnetic field probes for 0.2-5 Tesla and a precision of dB/B<1E-4.
- Radiation tolerant or resistant multipole inserts in large-aperture superconducting quadrupoles
- Radiation resistant thermal isolation systems for superconducting magnets
- RF techniques and devices for efficient ion transport in gas for the thermalization of fast beams
- Techniques for charge breeding of rare isotopes in Electron Beam Ion Sources or Traps (EBIS/T)
- Polarized high-density gas or solid targets; frozen-spin active targets; windowless gas targets and supersonic jet targets; targets capable of high power dissipation; thin windows for gaseous detectors
- Fast-release solid catcher materials for realizing high-intensity low-energy beams and for enabling parasitic use of rare isotopes produced by projectile fragmentation
- Techniques for efficient rare isotope extraction from water. Water-filled beam dumps or reaction product catchers at FRIB could provide a source for the harvesting heavy-ion reaction products
- Advancement of radiation transport codes by inclusion of charge state distributions of initial and produced ions including distribution changes when passing through material and magnetic fields

Thanks for your attention