The NP Low-Energy User Facilities

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SBIR/STTR Meeting

Gaithersburg, MD

Sept 13, 2010

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Overview

- The physics
- The NP LE user facilities
  - The HRIBF (ORNL)
  - ATLAS (ANL)
  - The future FRIB (MSU)
- Examples of experimental equipment
- MAJORANA DEMONSTRATOR

The Physics

Nuclear Structure: Properties of nucleonic matter

- Many-body quantum problem (mesoscopic quantum science)
- Structure far from stability (neutron- or proton-rich; super-heavy)
- Structure at high excitation energy and/or high angular momentum
- Competition and interplay between collective & single-particle behaviors
- Exotic nuclear shapes

Nuclear Astrophysics: Nuclear processes in the universe

- Energy generation in stars
- Nucleosynthesis in stars, novae, and supernovae
- Properties of neutron stars; EOS of asymmetric nuclear matter

Tests of fundamental symmetries

- Effects of symmetry violations are amplified in certain nuclei

Societal applications and benefits

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

Examples of techniques & measurements

Nuclear Structure and Reactions

- Coulomb excitation in regions of magic and doubly magic nuclei
- In-beam gamma spectroscopy
- Decay spectroscopy (many kinds)
- Identification and detailed studies of crucial single-particle states
- Systematics: 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
- Accelerator Mass Spectrometry

What We Need for a typical experiment

An accelerator facility to provide a beam of ions

- Beam may be composed of unstable (radioactive) ions
- Beam energy can be low (~100 keV) or high (~ 3 to 100 MeV per nucleon)

A target (for higher-energy beams)

- A small fraction of the beam ions react with target nuclei to make something of interest

Detectors and associated electronics to study that "something"

- Gamma-rays, light charged particle, fragments, heavy residuals, …
  - HPGe detectors
  - Double-sided strip detectors (Si or Ge)
  - Scintillators, with either PMTs or photodiodes
  - Magnetic spectrometers
  - Gas counters
  - Ion traps
  - Many more

Computers, data storage, software

The Facilities

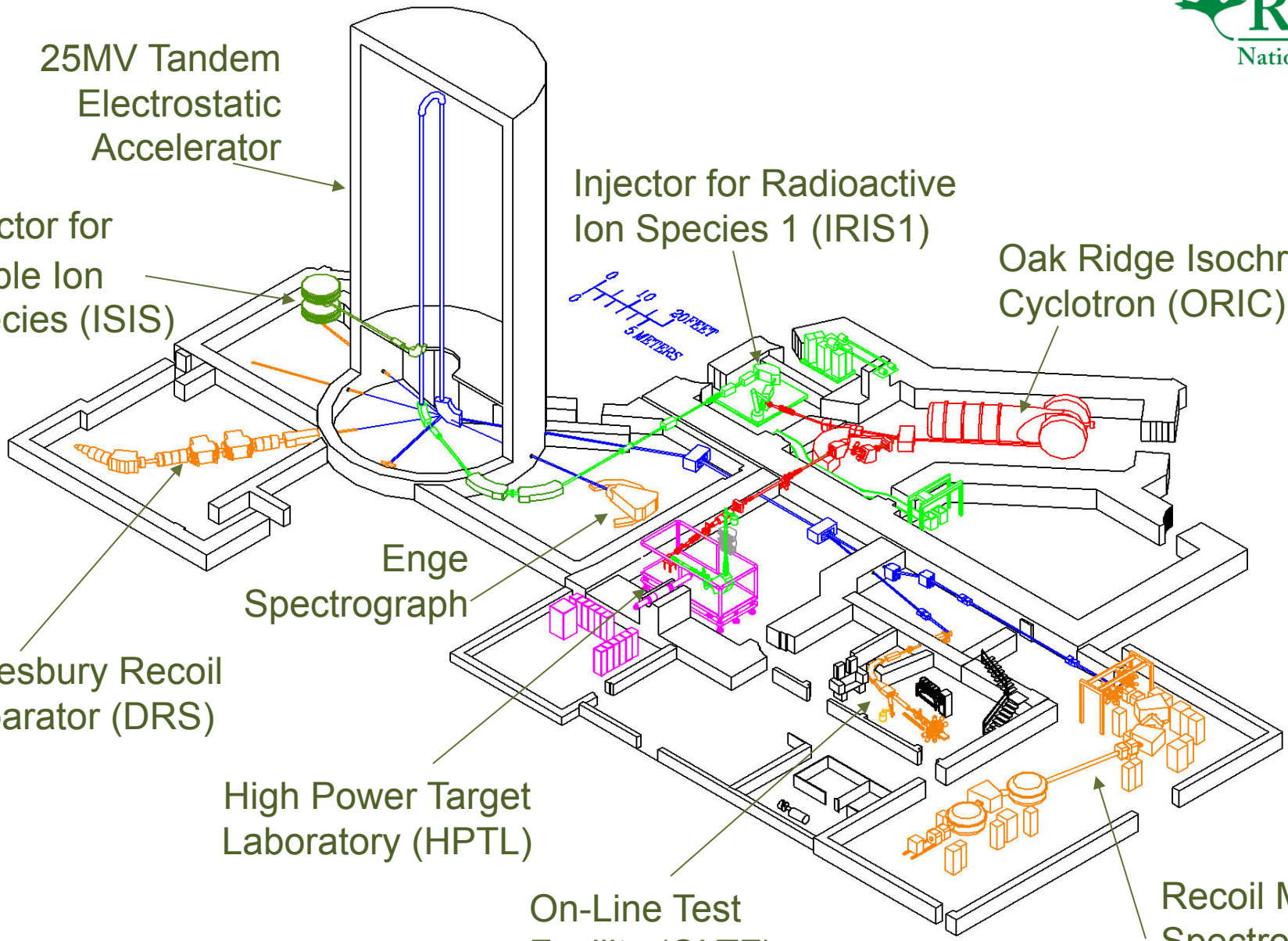
Three *User Facilities*

- Encourage and support experiments proposed by and/or involving outside users (labs, universities, international)
- Beam time is allocated based on proposals judged on scientific merit

- The Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory
- The Argonne Tandem-Linear Accelerator System (ATLAS) at Argonne National Laboratory
- The Facility for Rare Isotope Beams (FRIB) to be constructed at Michigan State University

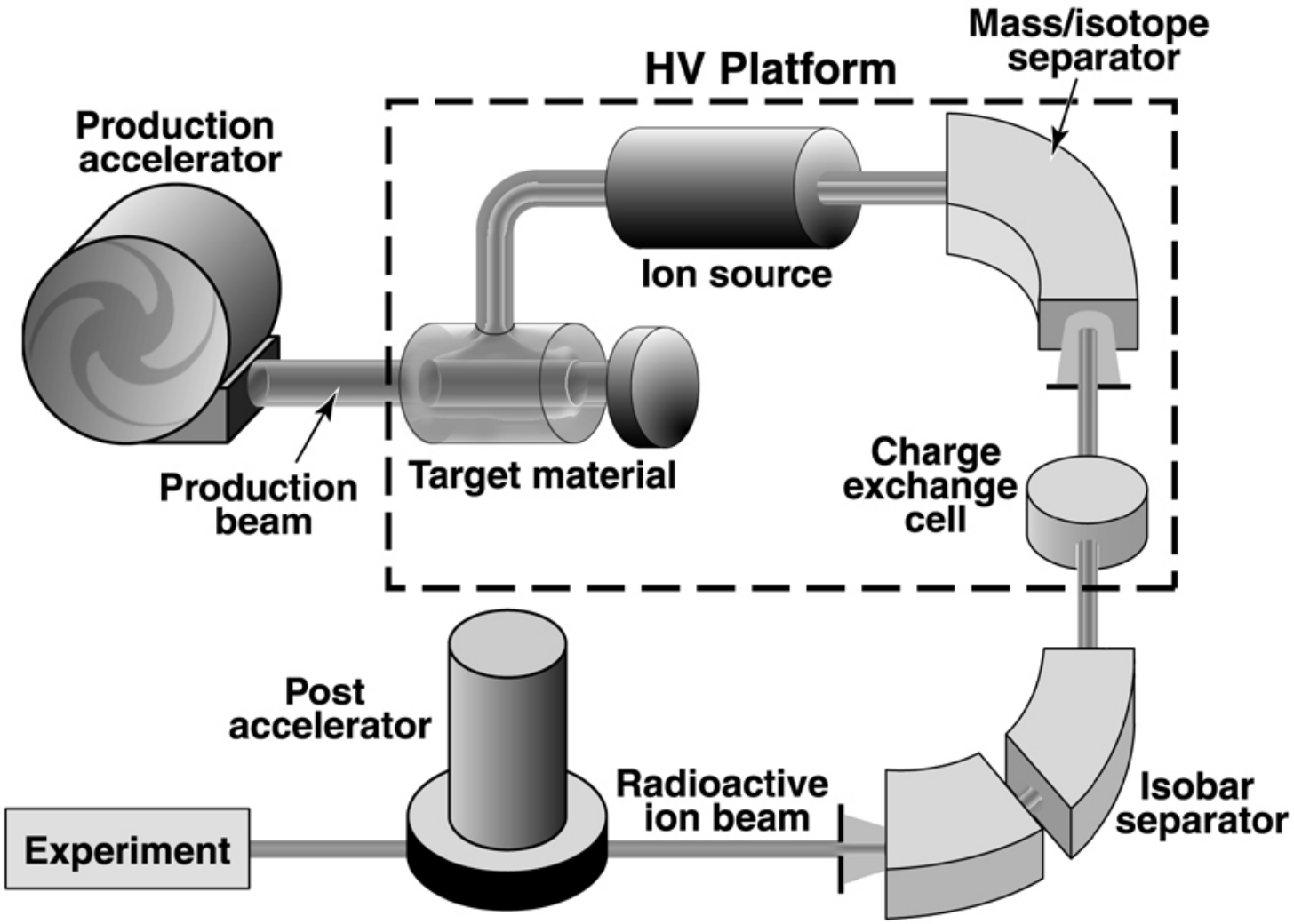
HRIBF

OAK RIDGE National Laboratory



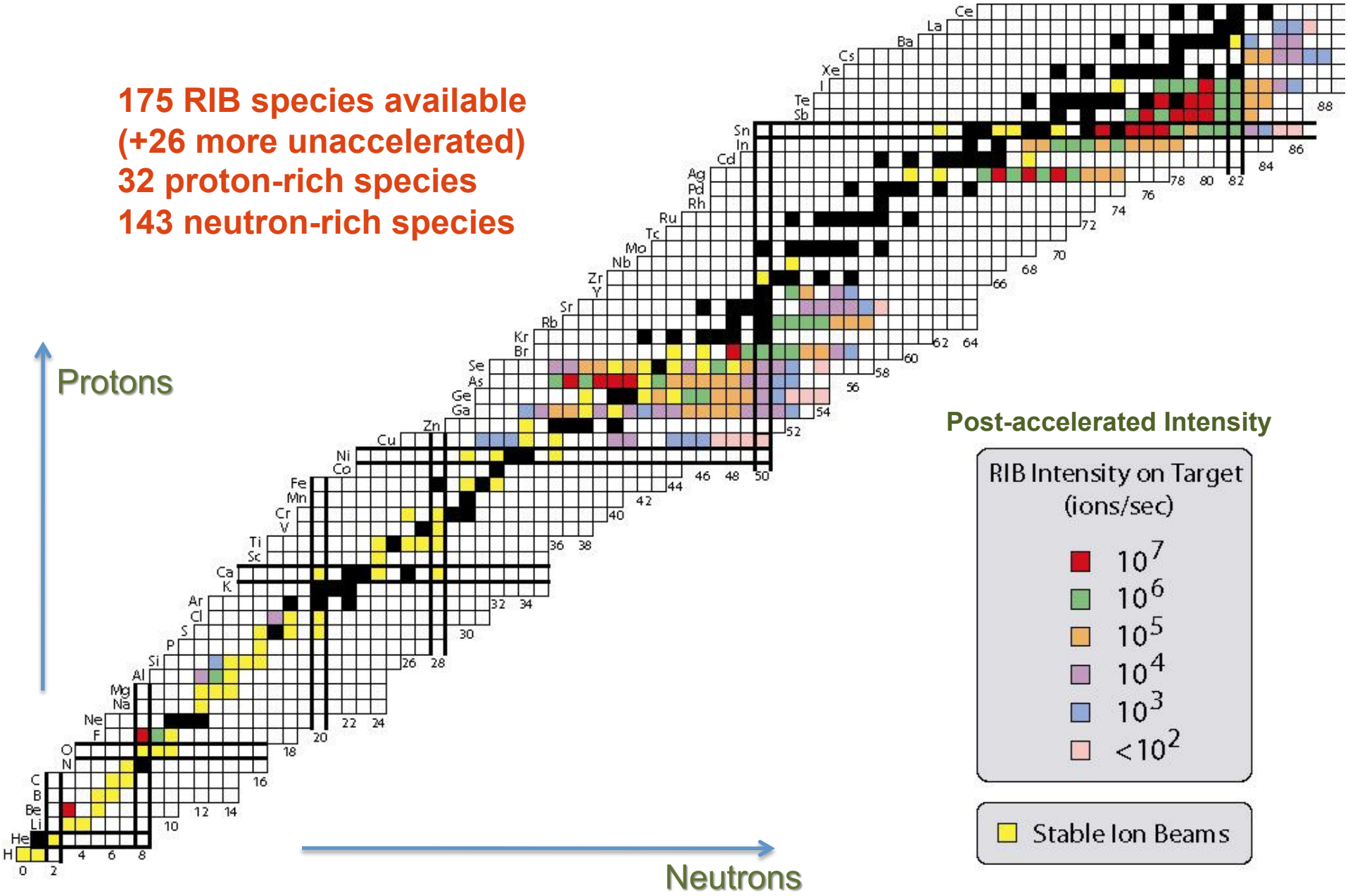
hribf
Holifield Radioactive Ion Beam Facility
Oak Ridge National Laboratory

Schematic of RIB Production at the HRIBF



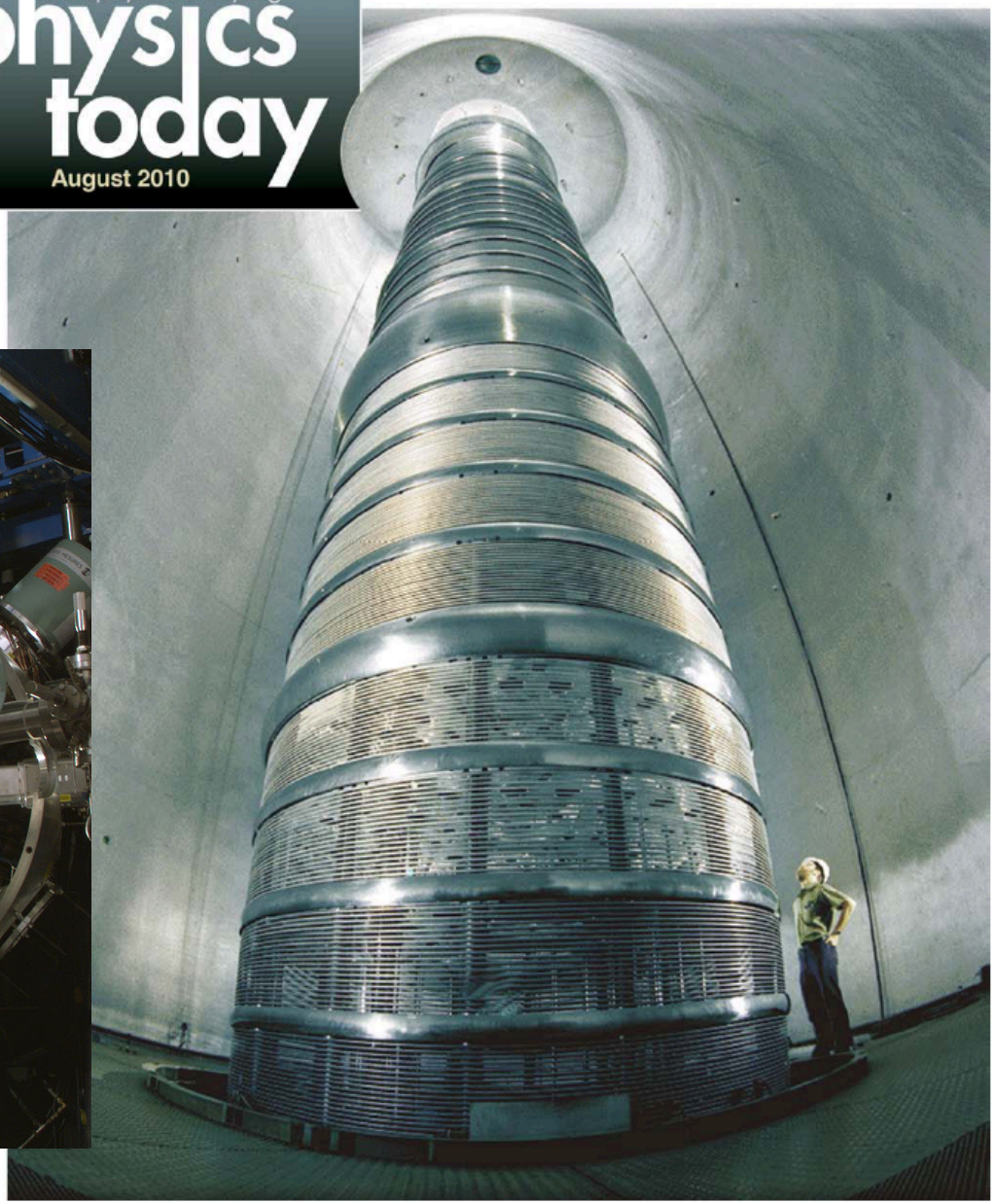
HRIBF Post-accelerated Beams

175 RIB species available
(+26 more unaccelerated)
32 proton-rich species
143 neutron-rich species



CLARION
(HPGe Clover array)

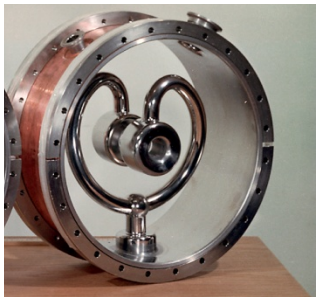
Inside the Tandem



Doubly magic shell game

ATLAS: The world's first superconducting ion accelerator

Dedicated in 1985



8.5-MV Tandem Injector

Important for:

Beams of A<58

Long-lived RIB's

2 ECR Ion Sources on HV platform

12-MV Positive Ion Injector (PII)

Required for:

Beams with A>58

Noble gases

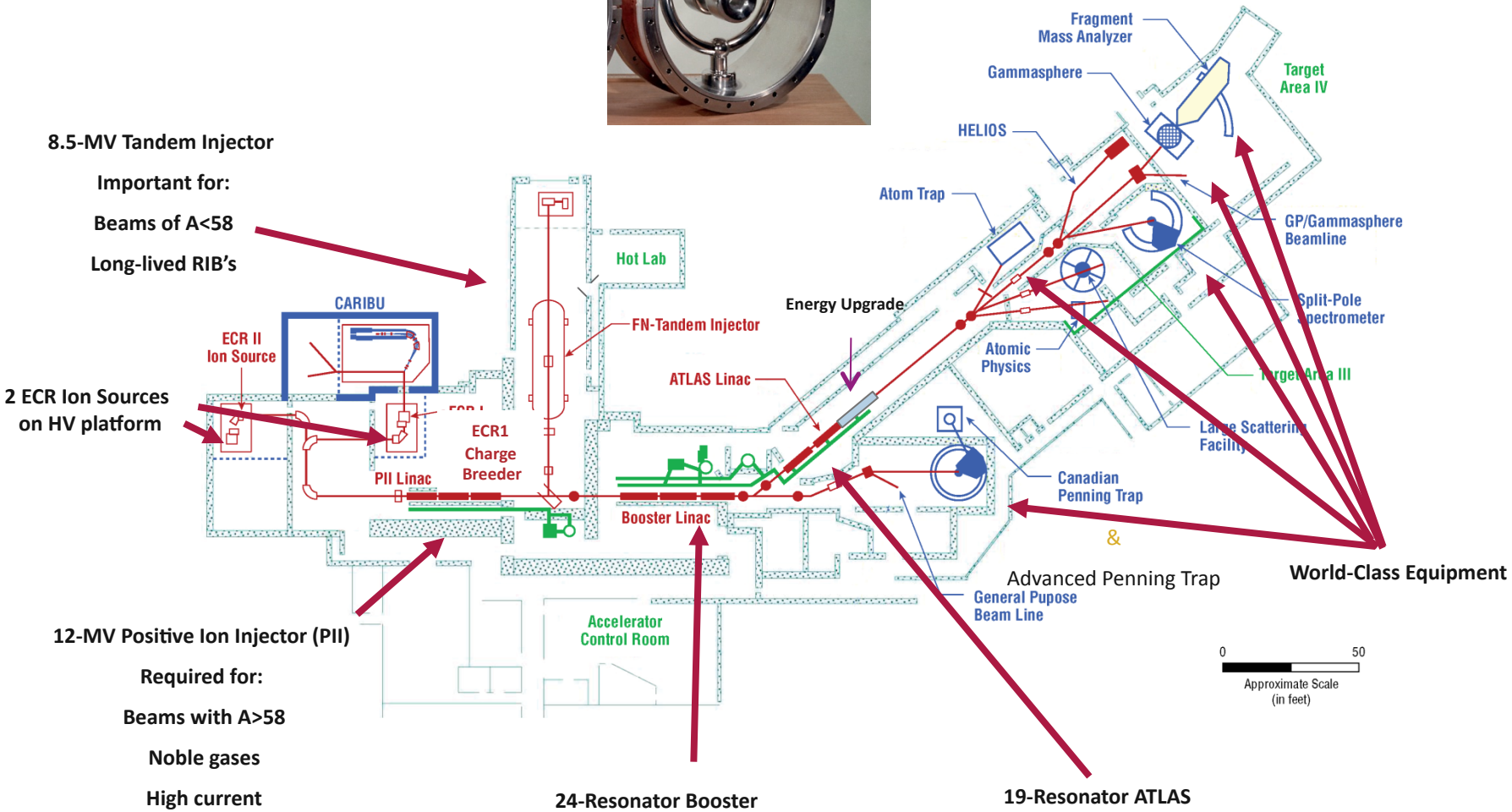
High current

18 Quarter-wave SC resonators

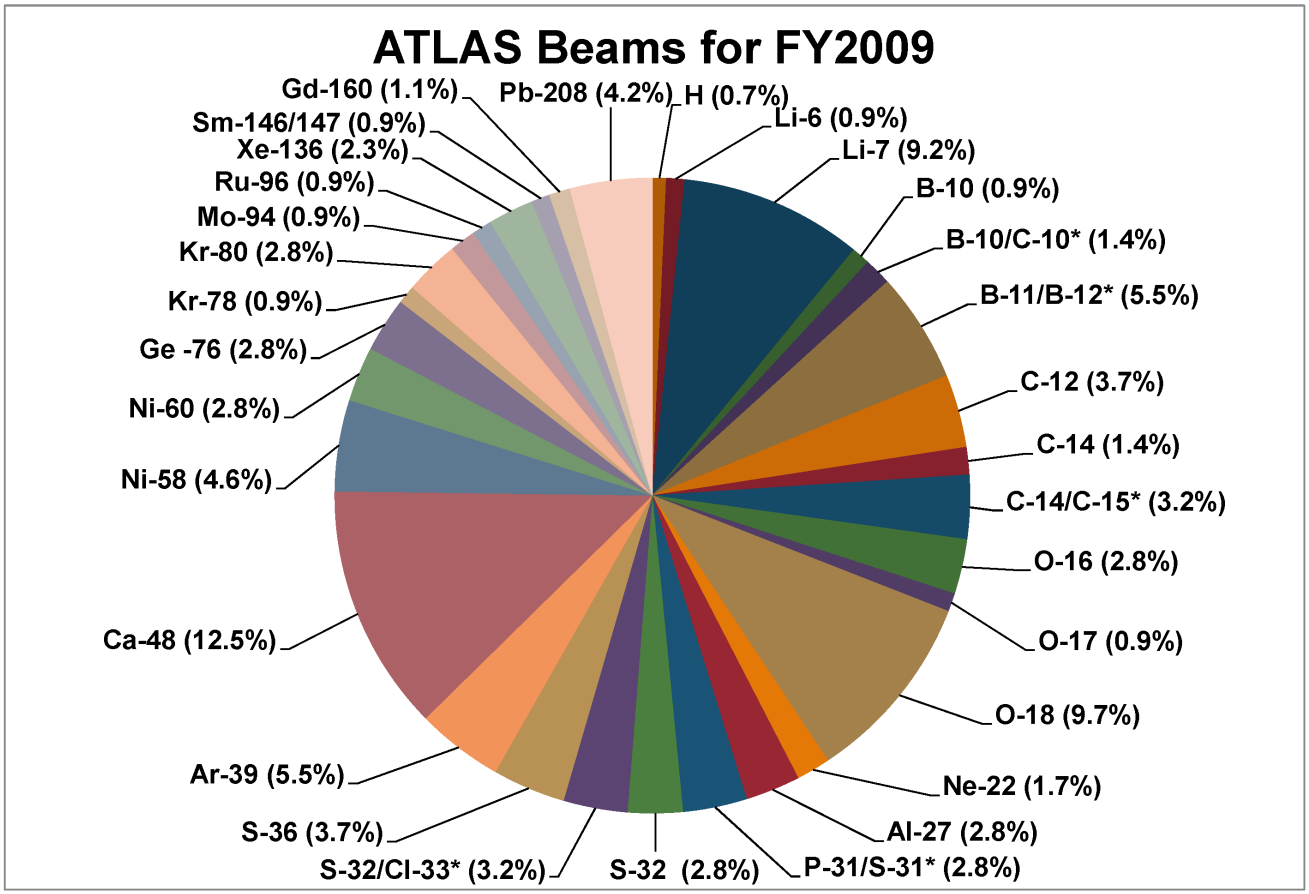
24-Resonator Booster

19-Resonator ATLAS

World-Class Equipment



ATLAS Beams



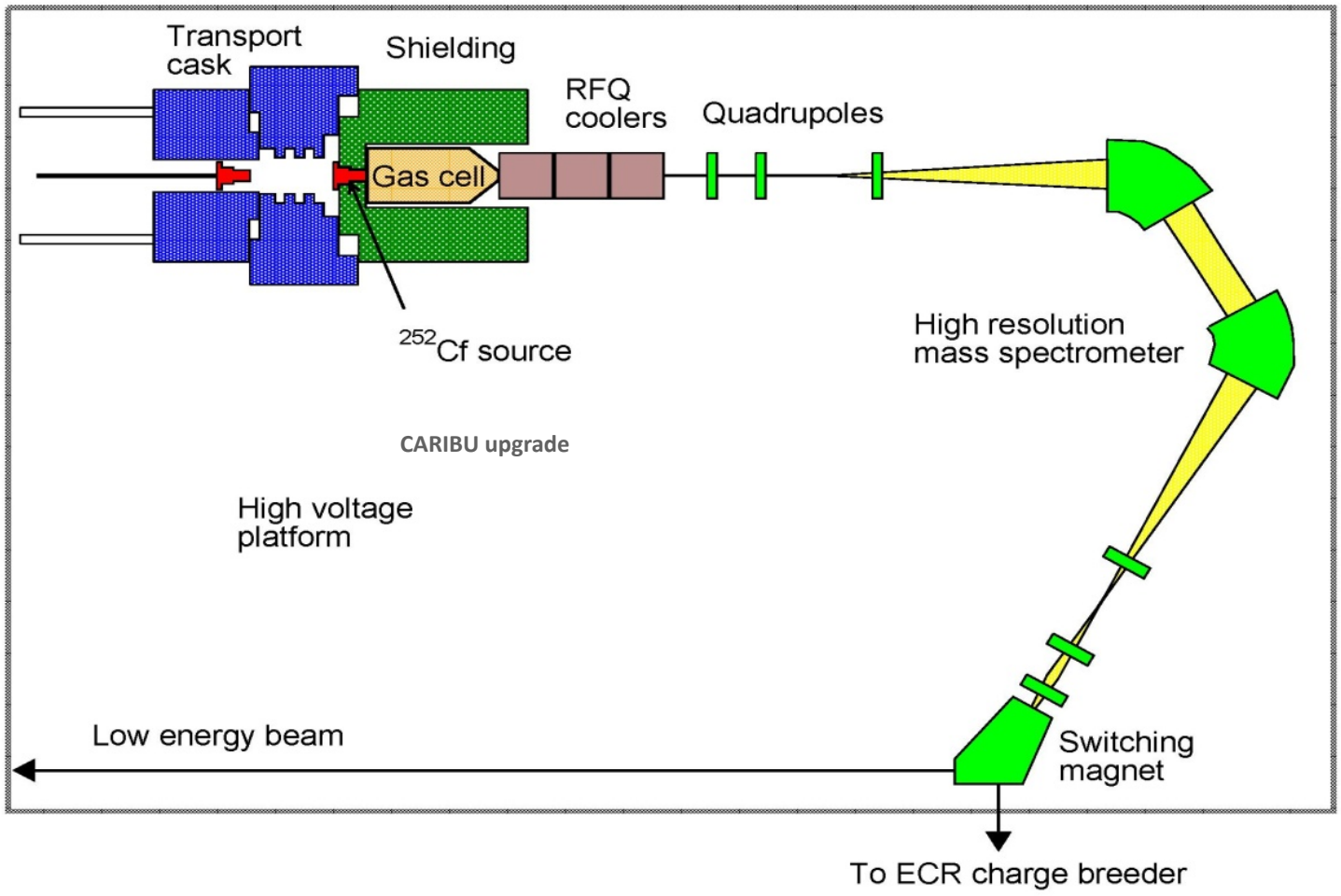
31 Different Isotopes

~ 18% beam time for Radioactive Beams

ATLAS: The CARIBU project

Californium Rare Ion Breeder Upgrade

- Will provide beams of neutron-rich radioactive ions (fission fragments)

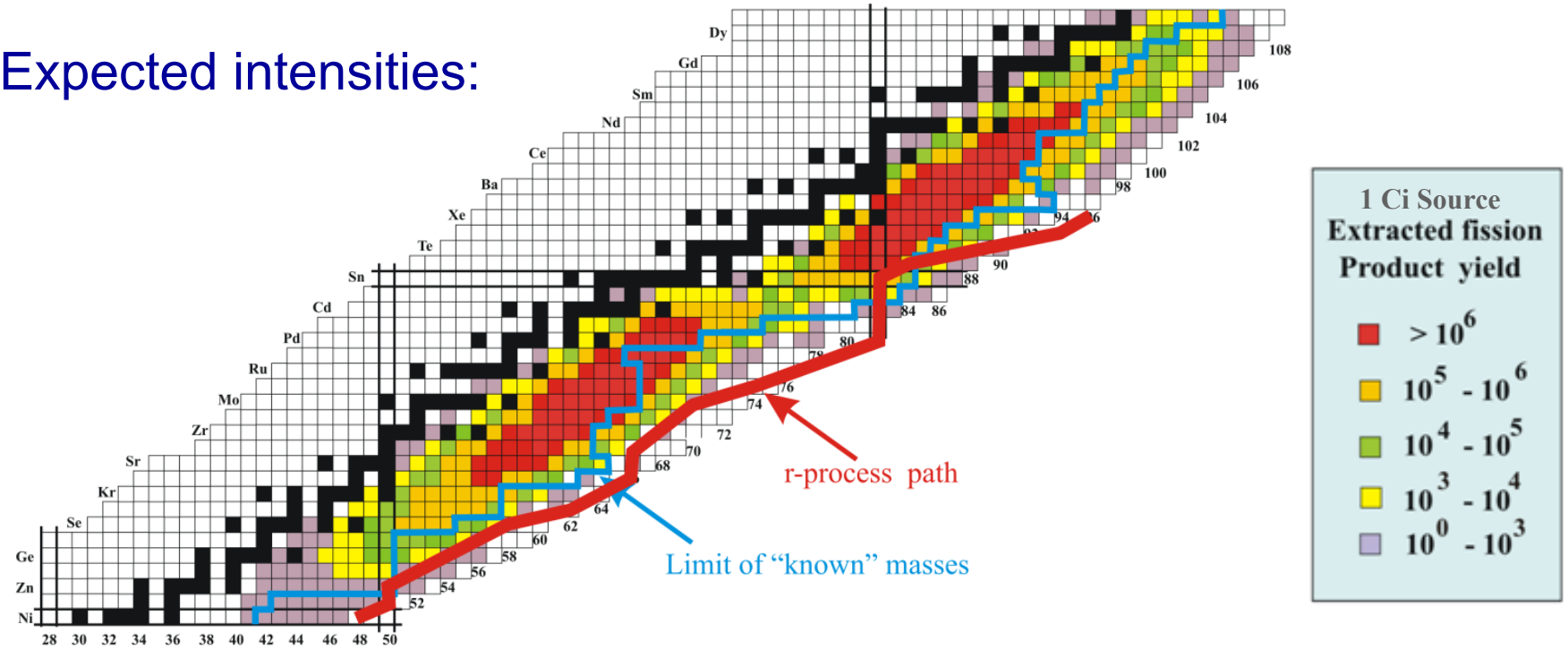


CARIBU:
A Californium Fission Source for ATLAS

^{252}Cf spontaneous fission

$T_{1/2}$ = 2.6 years 3.1% fission branch

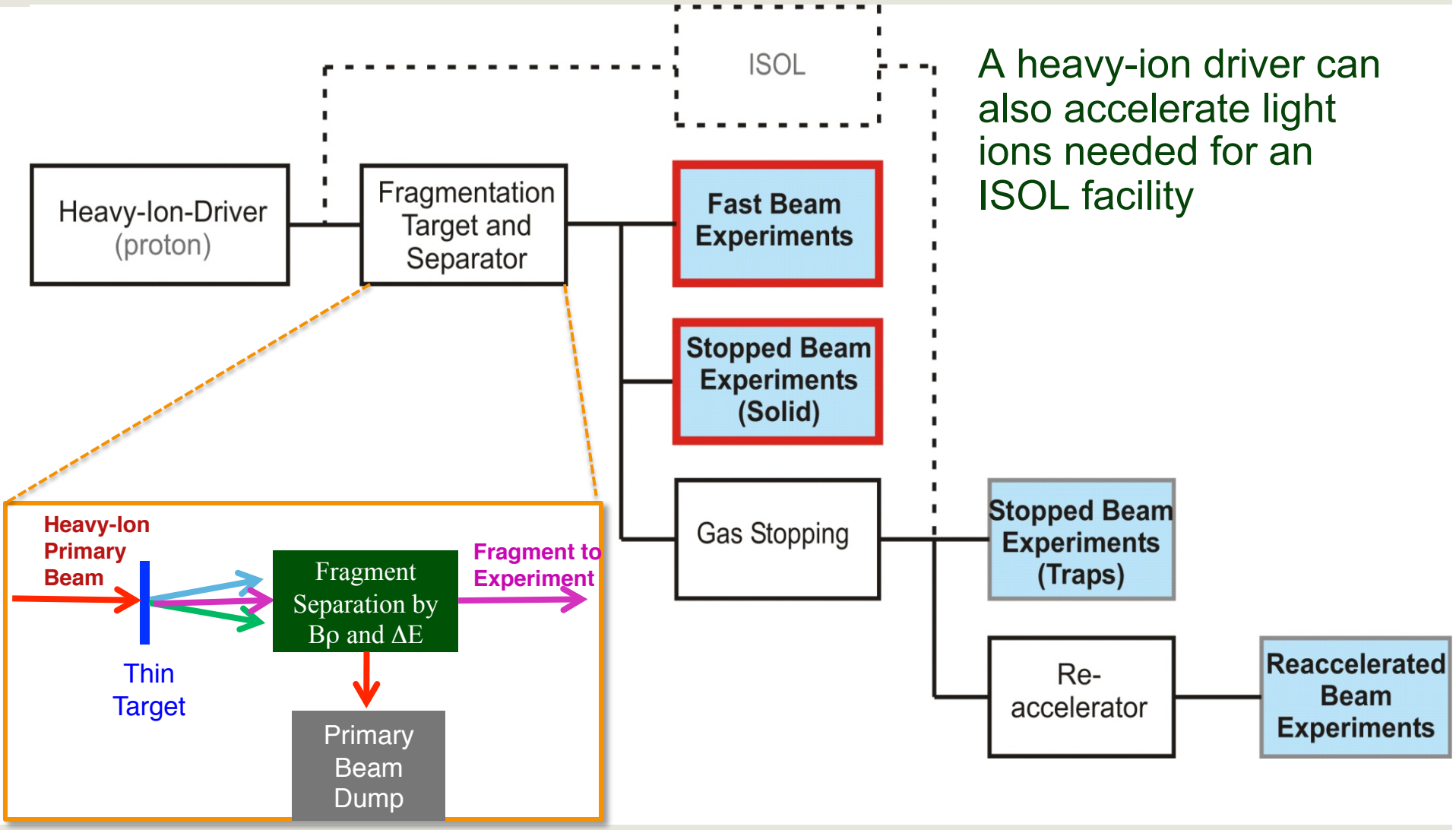
Expected intensities:



Facility for Rare Isotope Beams (FRIB)

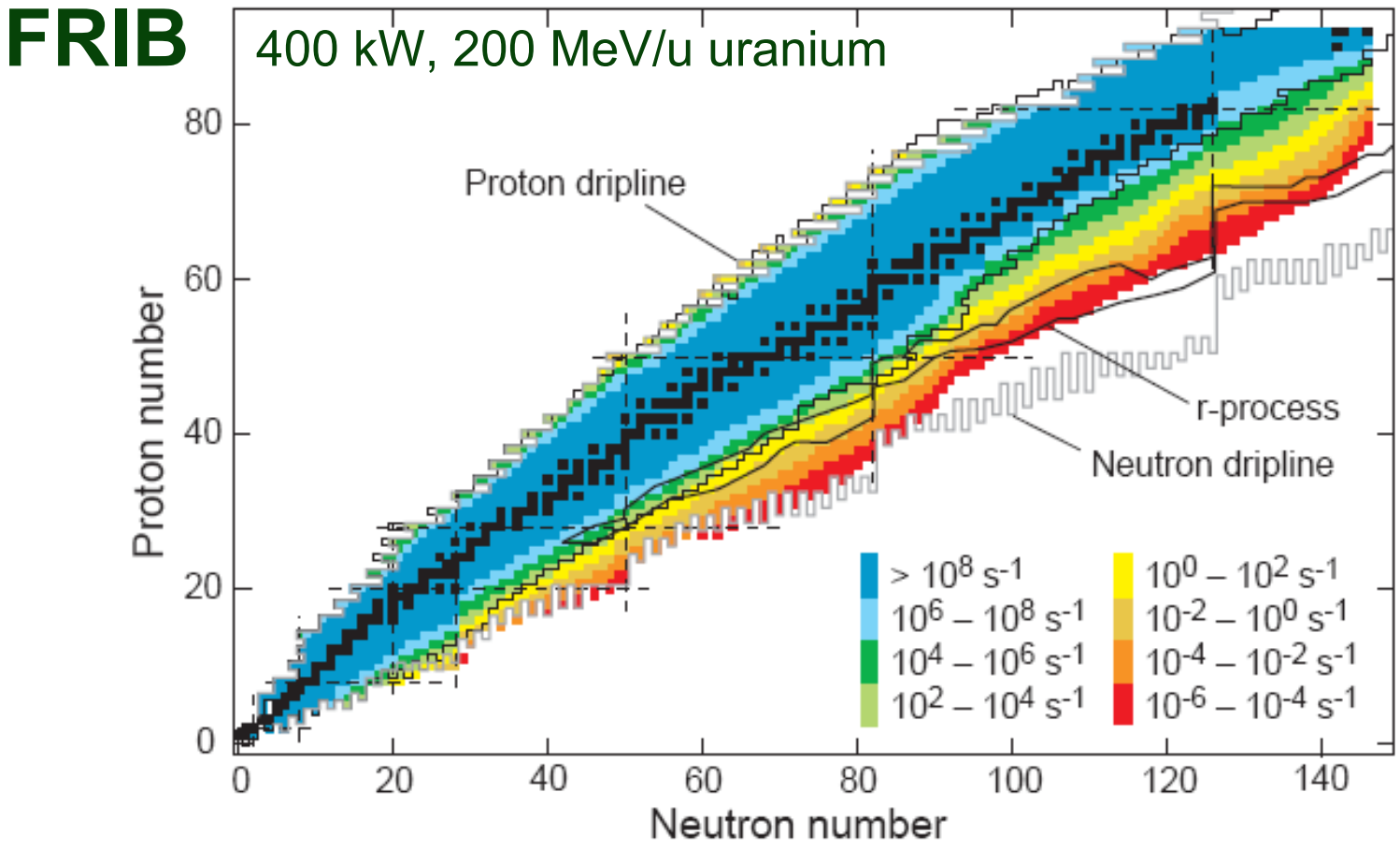
- A DOE-SC National User Facility to be built at MSU
- Scheduled for construction starting in 2013,
  completion in 2018-2020
- Rare isotope production via projectile fragmentation and in-flight fission
- Driver accelerator: Heavy-ion linac
  - E/A ≥ 200 MeV for all ions
  - Beam power = 400 kW
  - Use of existing NSCL; enables pre-term science, fast start of FRIB science
- Fast, stopped, and reaccelerated beams

FRIB concept



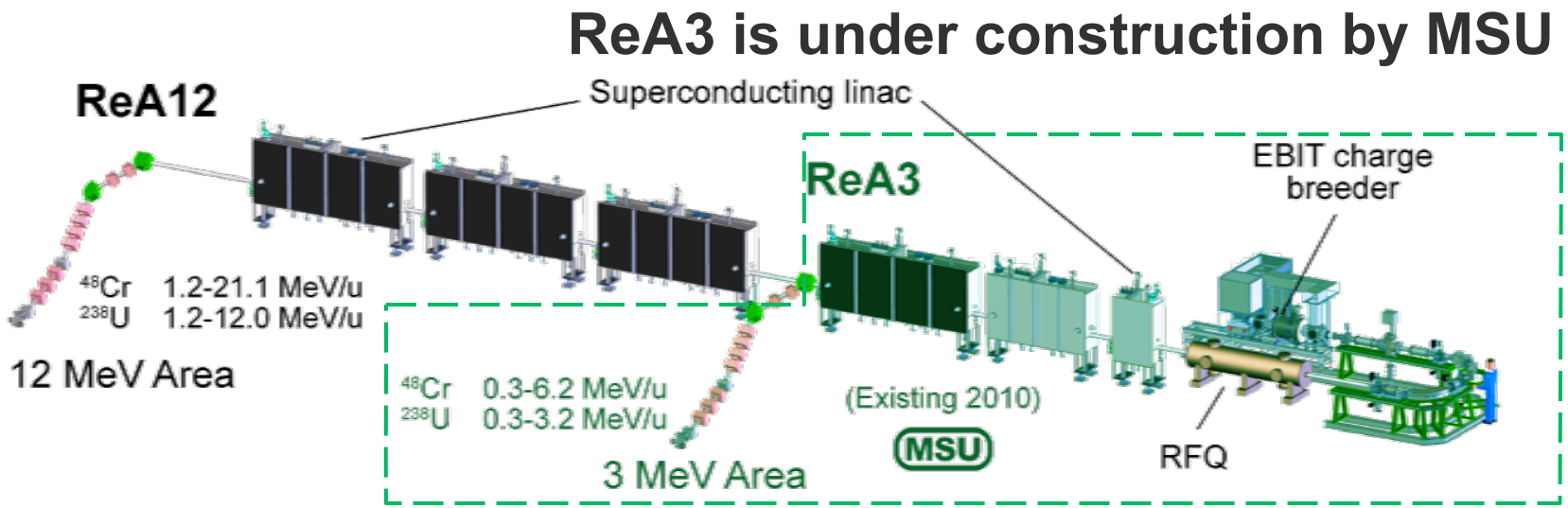
A heavy-ion driver can also accelerate light ions needed for an ISOL facility

FRIB Beams



Gain factors of 10-10000 over operational facilities

Reaccelerated Beams at FRIB



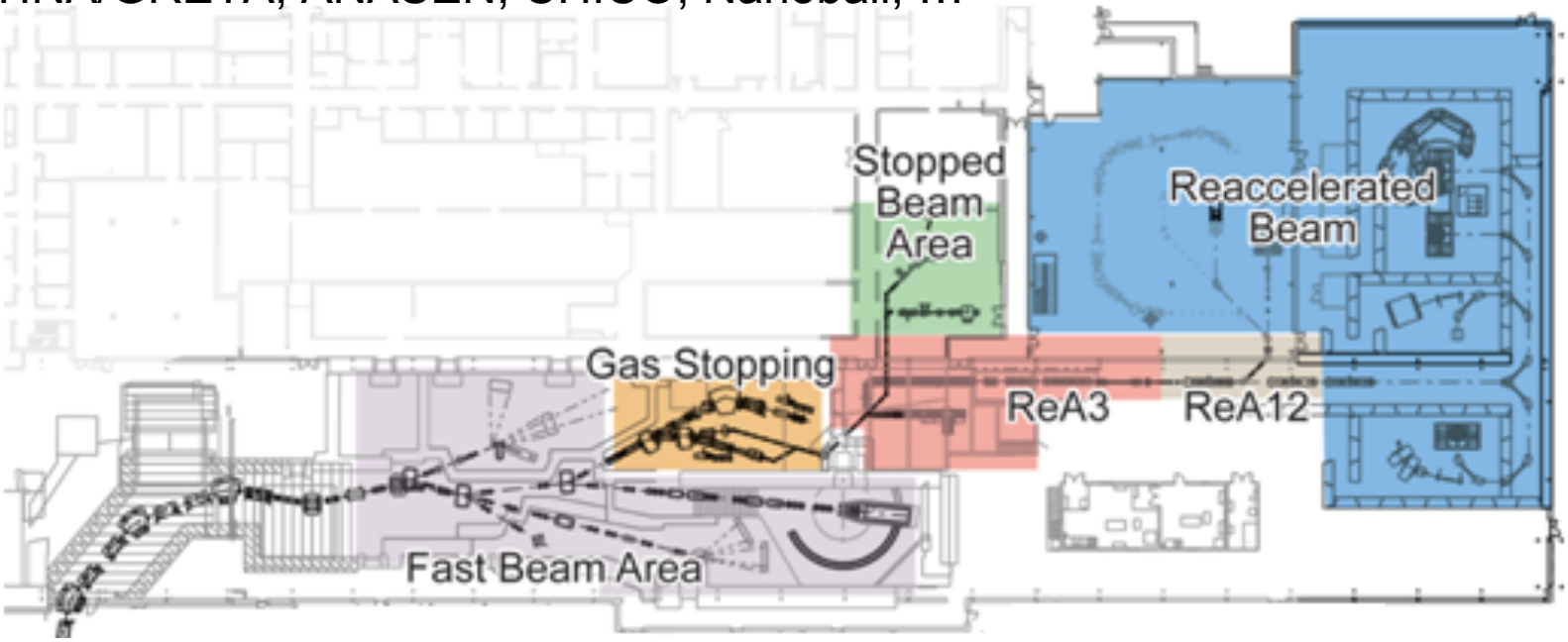
ReA3 in operation by 2011

- 0.3-3.2 MeV/u for uranium
- 0.6-6.2 MeV/u for ^{48}Cr
- Option to upgrade to 12 MeV/u for uranium, >20 MeV/u for light ions

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, …



Examples of Experimental Equipment

Gamma detectors

- Usually *arrays* of HPGe detectors or scintillators
- *In-beam* or *out-of-beam*

Recoil and light-ion detectors

- Magnetic spectrometers and separators
- Gas counters
- Si detectors (usually DSSD or position-sensitive)
- Scintillators

Electronics

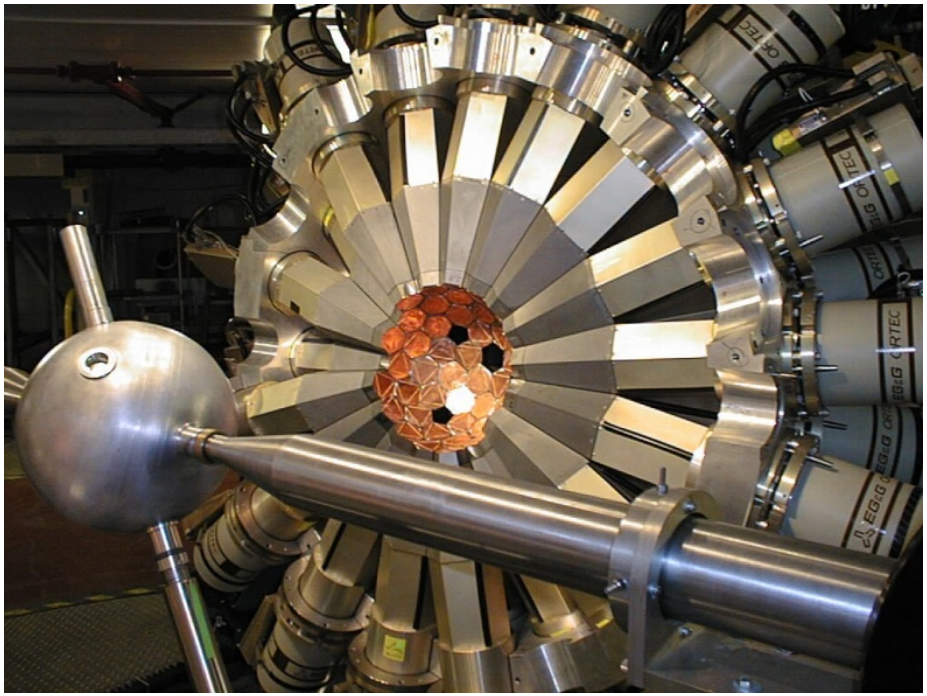
- Waveform digitizers, ASICs, preamps
- Digital pulse processing

All of these have benefitted greatly from DOE-SC SBIR/STTR program. Improvements in instrumentation can greatly extend the physics reach of the facilities.

The Gammasphere Array

108 Compton suppressed HPGe spectrometers

Dedicated Dec 1995

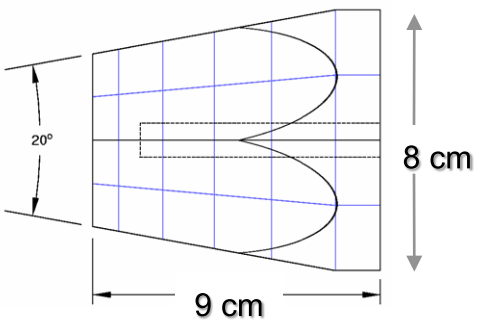


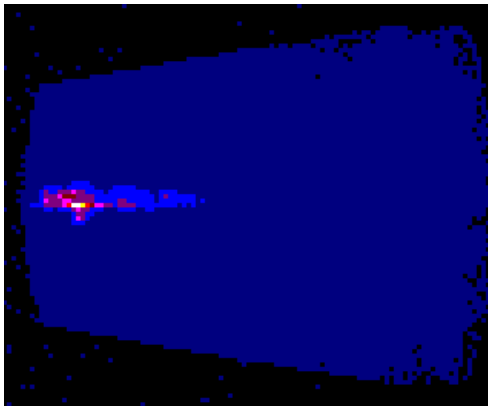
Absolute photopeak efficiency ~ 0.09 at 1.33 MeV

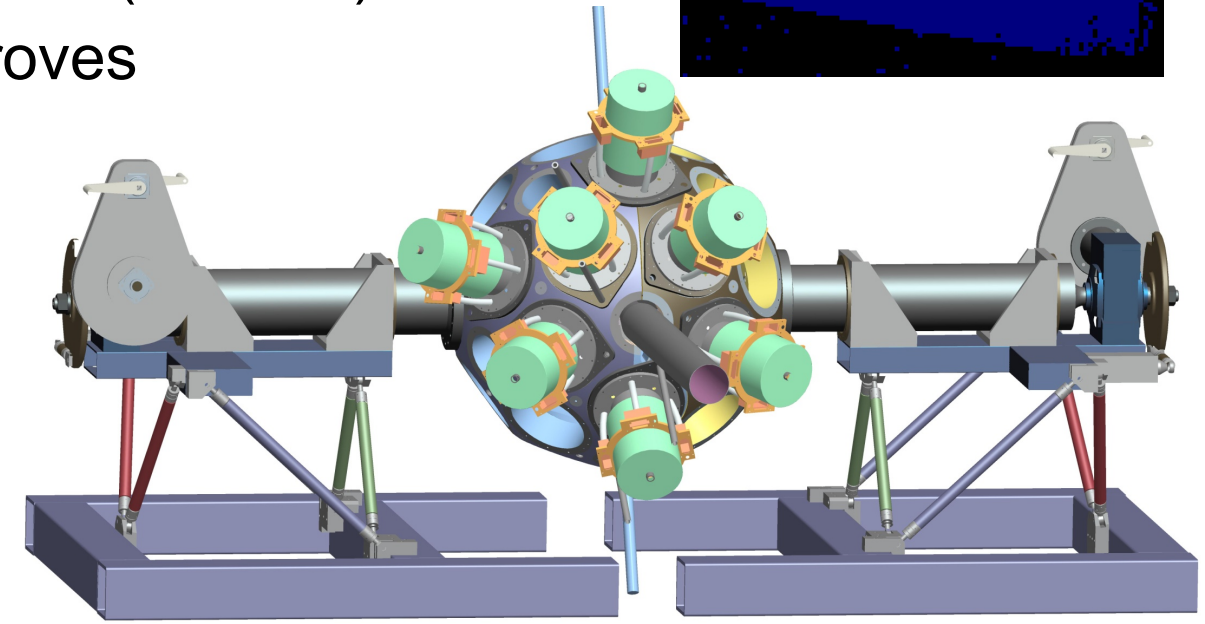
Peak-to-total ratio ~ 0.55

GRETINA: Gamma-ray tracking detector array

- For in-beam nuclear structure studies
- 28 highly segmented Ge detectors
  - 36-fold segmentation
  - Tapered irregular hexagons
  - 2mm position resolution (RMS)
- Under construction at LBNL
- Scheduled for completion in March 2011
- One-fourth of full sphere (GRETA)
- Tracking greatly improves
  - efficiency
  - resolution
  - overall sensitivity

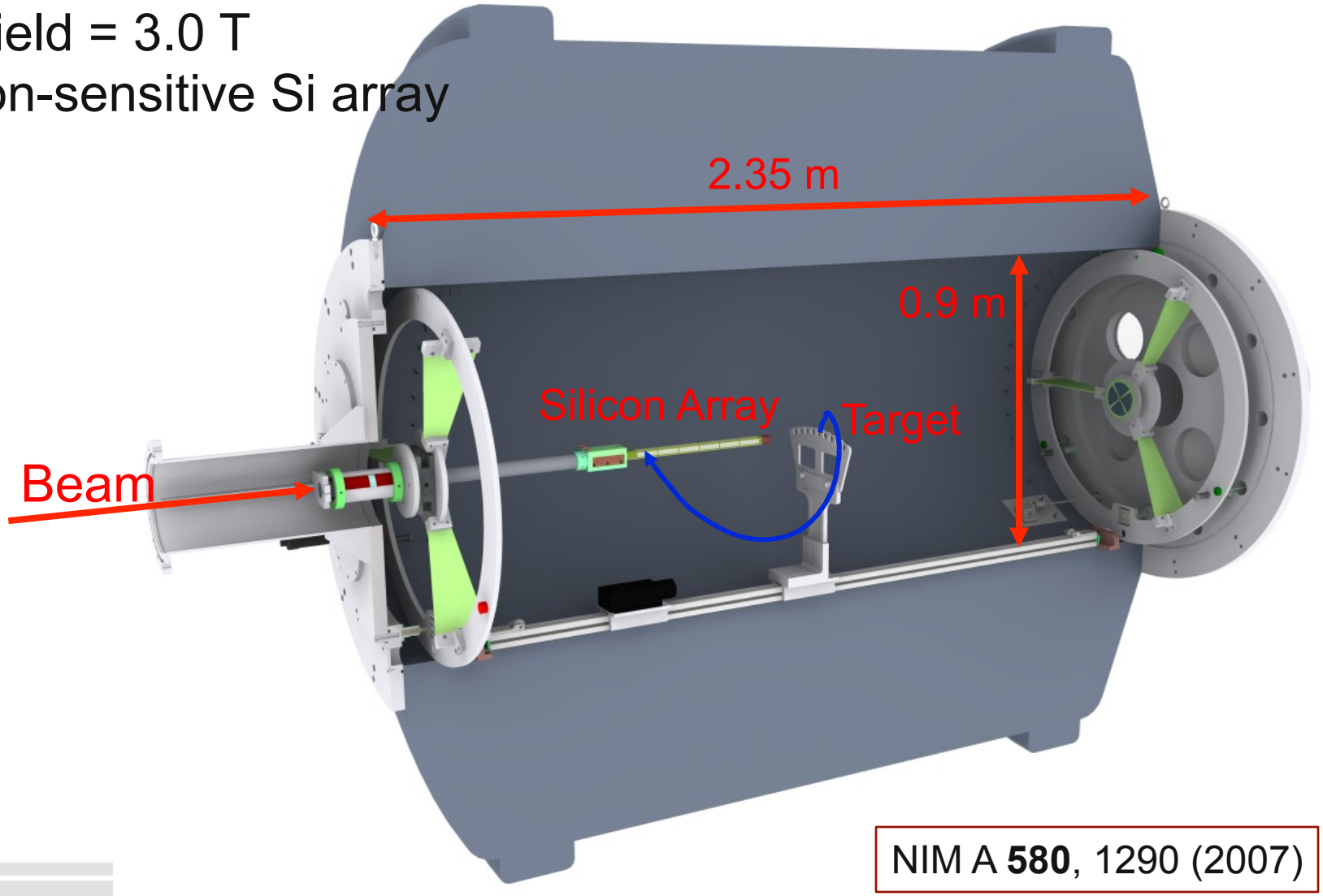






The HELIOS spectrometer for light-ion reactions

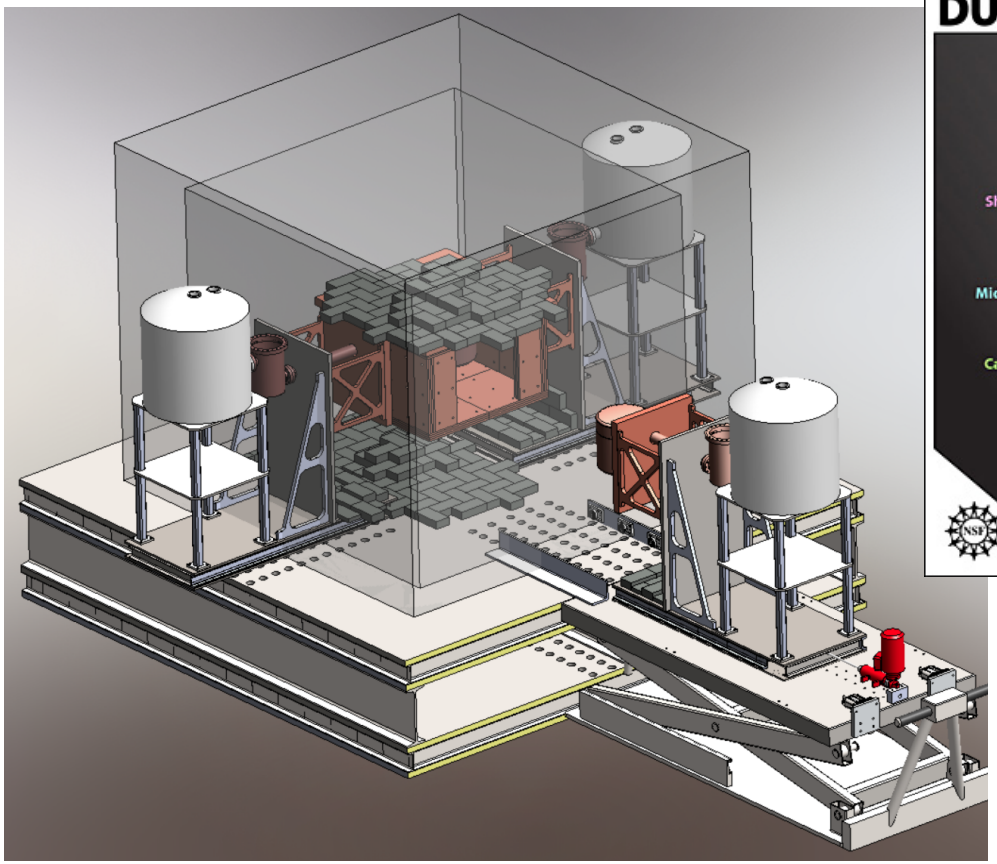
Novel spectrometer design, recently completed at ANL
Superconducting solenoid with on-axis Si detectors
Max. field = 3.0 T
Position-sensitive Si array

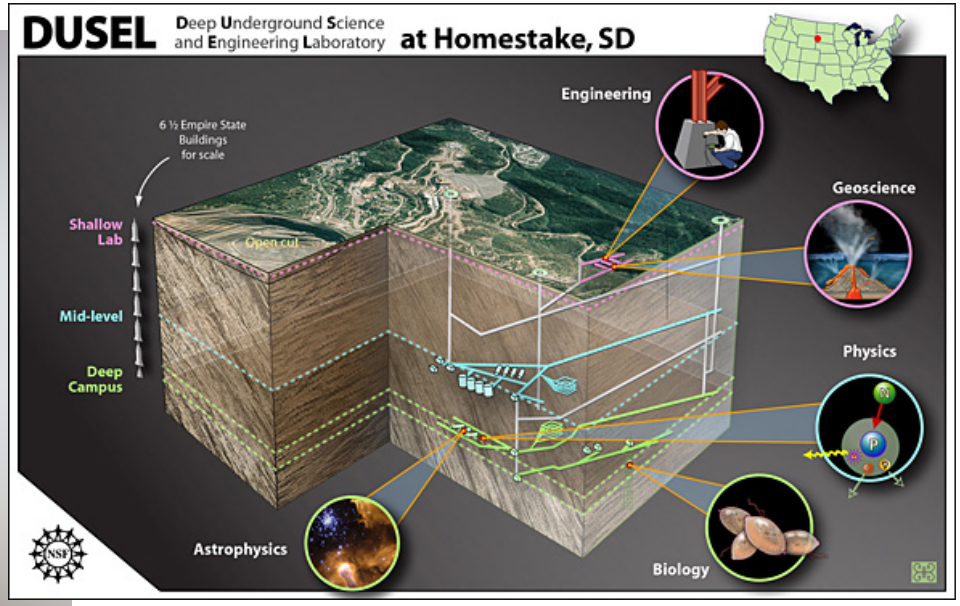


NIM A **580**, 1290 (2007)

MAJORANA DEMONSTRATOR

- An R&D project aimed at a ~1 tonne scale ^{76}Ge neutrinoless double beta decay ($0\nu\beta\beta$) experiment
- To be sited at DUSEL at the Homestake mine in SD





MAJORANA Science and Challenges

Science goals include:

- Determine the nature of the neutrino : Majorana or Dirac particle?
- Test the fundamental symmetry of lepton number conservation
- Probe the absolute neutrino mass scale

Some of the many challenges:

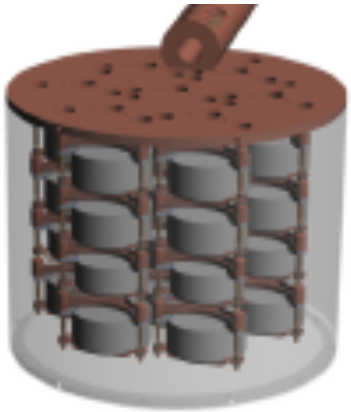
- Enriched ^{76}Ge detectors; requires large quantity of enriched material
- Background goal of 1 count/tonne-year in a 4-kev ROI

  ➔ *Extreme radio-purity requirements* for all materials.

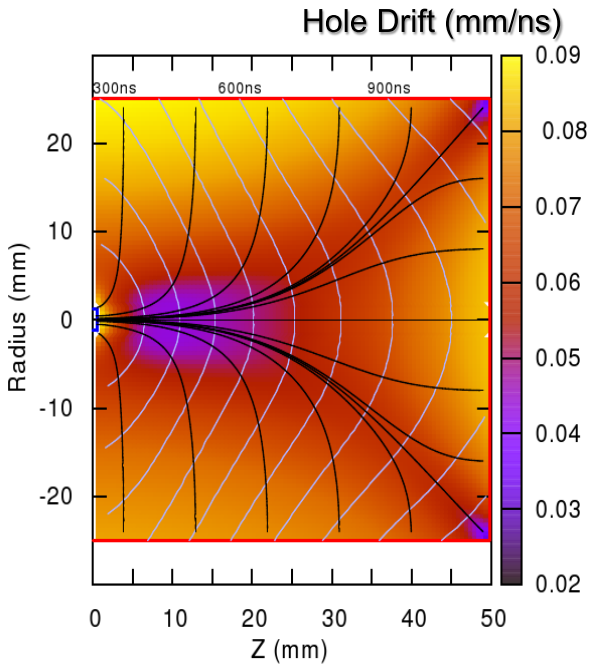
  Cryostats and small parts made from underground electro-formed copper, ~ 10^{-7} Bq/kg

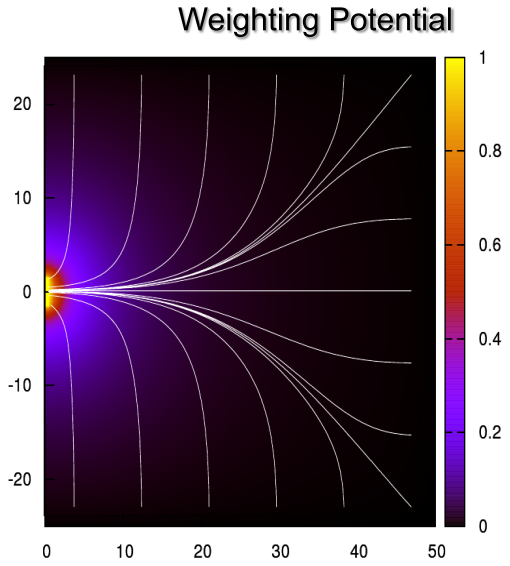
MAJORANA DEMONSTRATOR Detectors

P-type Point Contact detectors



- Superb pulse-shape sensitivity
  - Distinguish single-/multi-site events
- Very low capacitance (~1pF)
  - Gives excellent low-energy resolution, low threshold
- Thick (~0.5 mm) outer Li contact absorbs alpha background





SBIR/STTR Program

Some of the many crucial contributions of the SBIR/STTR program to low-energy user facilities are illustrated by talks at this meeting:

- Accelerator Technology
  - Niowave, Innosense, Far-Tech
- Instrumentation, Detection Systems and Techniques
  - RMD, PHDs, Tech-X, Integrated Sensors
- Electronics Design and Fabrication
  - XIA
- Software and Data Management
  - Tech-X

Acknowledgements

Material or slides were provided by

- Michael Carpenter, Richard Pardo (ANL)
- Georg Bollen, Thomas Glasmacher, Brad Sherill (MSU)
- Jim Beene, Dan Stracener, Carl Gross (ORNL)