Facility For Rare Isotope Beams

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Office of Science

This lecture

- Motivation for FRIB: Why are rare isotopes important to study?
- How can one produce rare isotopes?
- How does FRIB do it?
- Some project details and status

Next lectures:

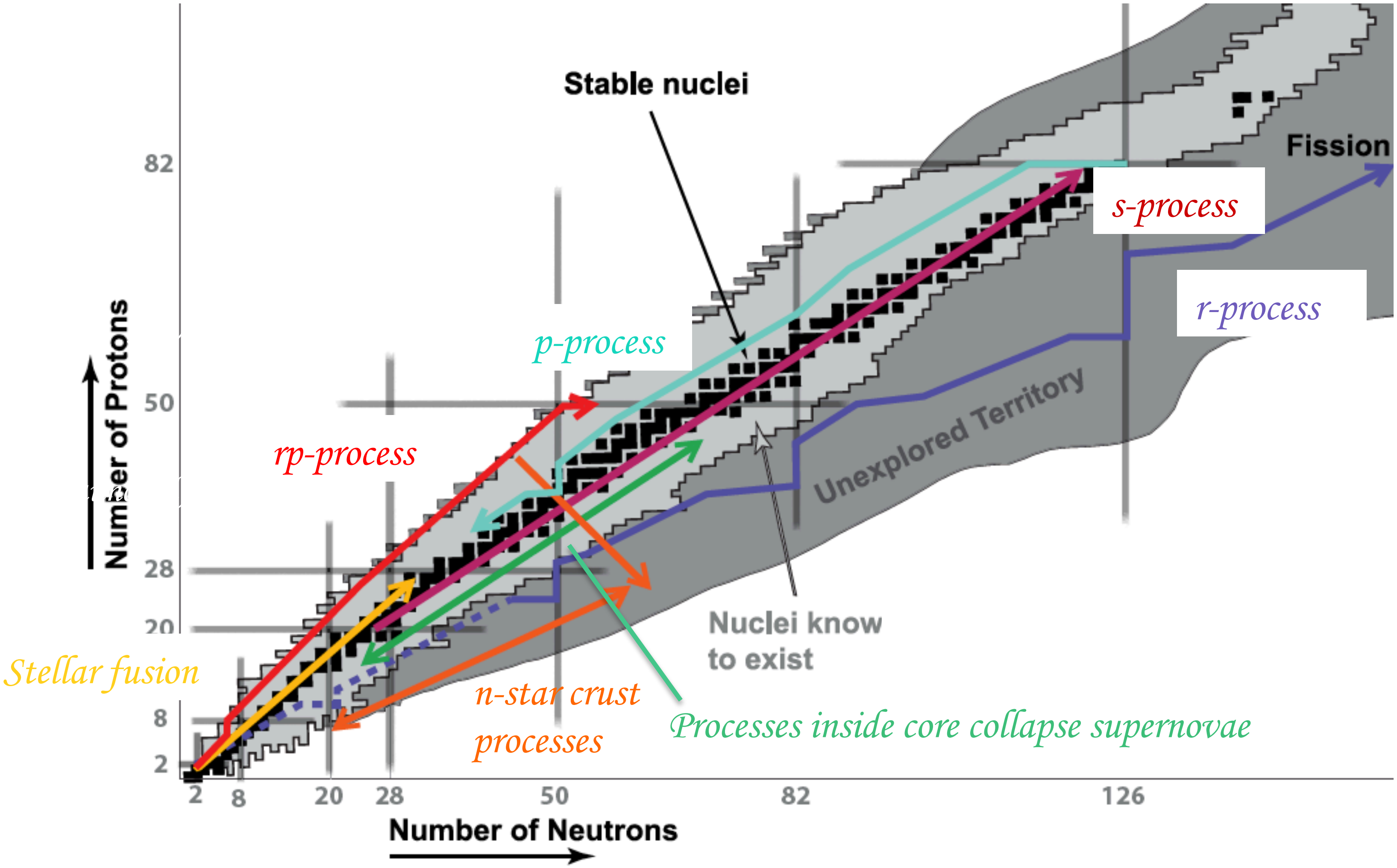
- Experiments with neutron rich isotopes
- Experiments with “proton rich” isotopes

(Mostly motivated by astrophysics questions)

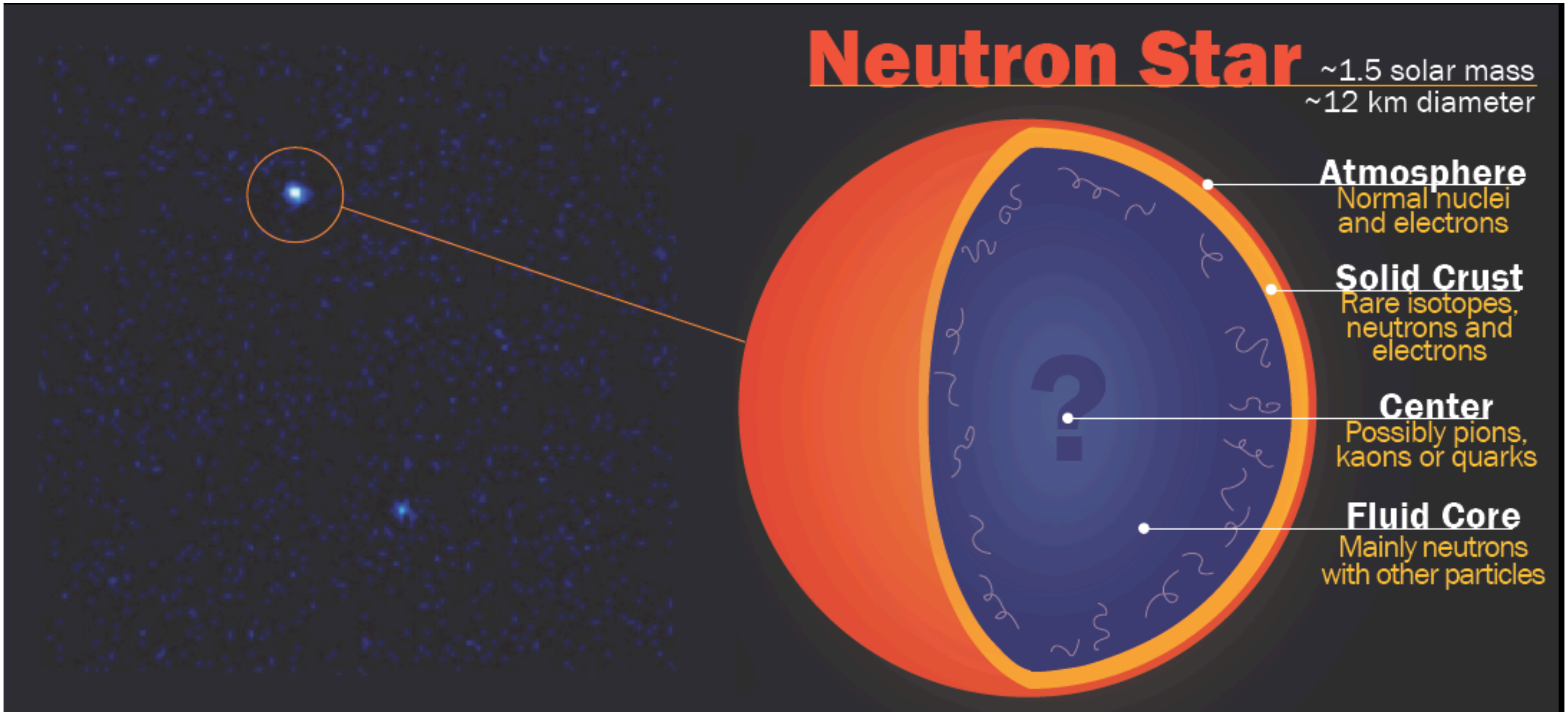
Why Rare Isotopes: The Science Drivers for FRIB

- Nuclear Astrophysics: Understand the nuclear processes that occur in nature
  - Make the same nuclei that nature makes to understand
    - » The origin of the heavy elements and of radioactive nuclei in space
    - » Stellar explosions powered by rare isotopes
    - » Composition of neutron star crusts
- Understand the atomic nucleus
  - Find new phenomena (shapes, collective behavior, skins)
  - Explore the limits of existence
  - What makes matter stable?
    - » Towards a predictive theory for nuclei – need isospin dependence
- Fundamental Symmetries: Use rare isotopes as optimized laboratories
  - Effects of symmetry violations are amplified in certain nuclei
- Other Scientific Applications
  - Stockpile stewardship, materials, medical, reactors

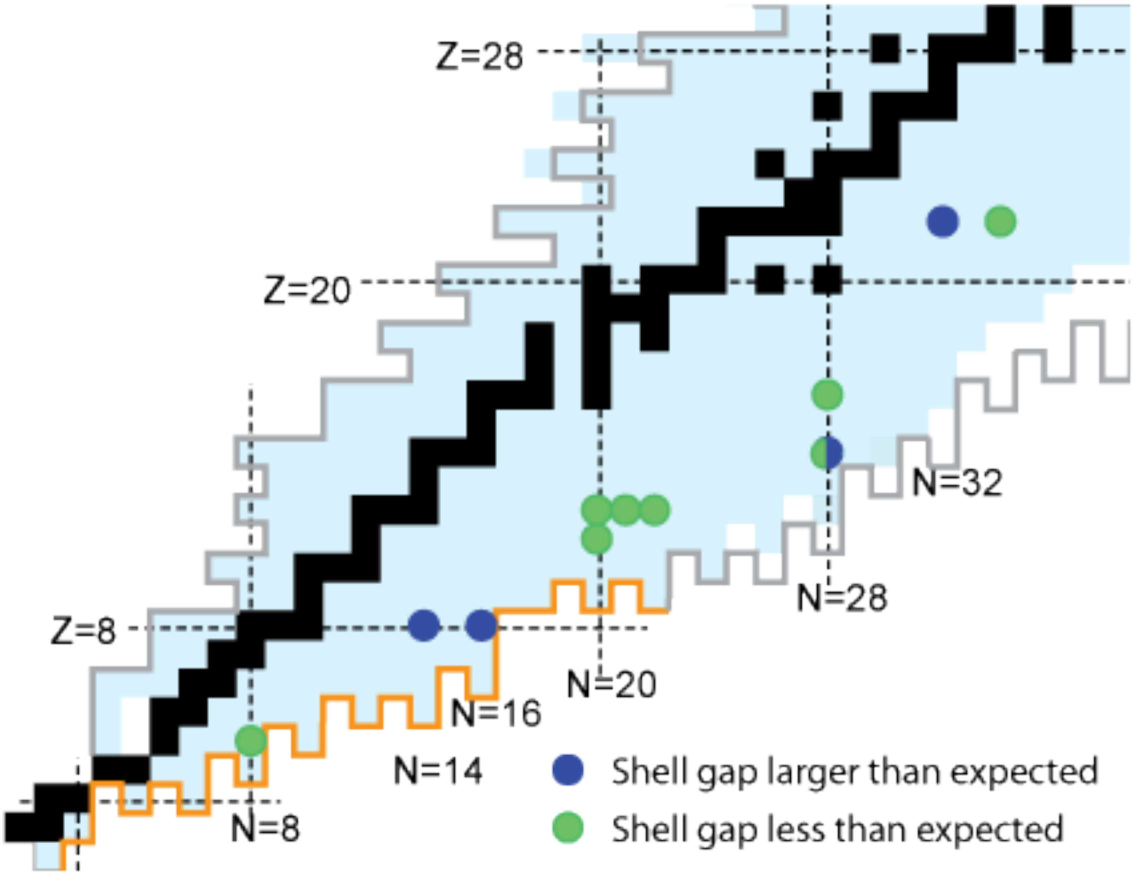
Nuclear processes in the cosmos



Neutron stars – wrapped in rare isotopes



Drip line and shell structure



Finding the drip line

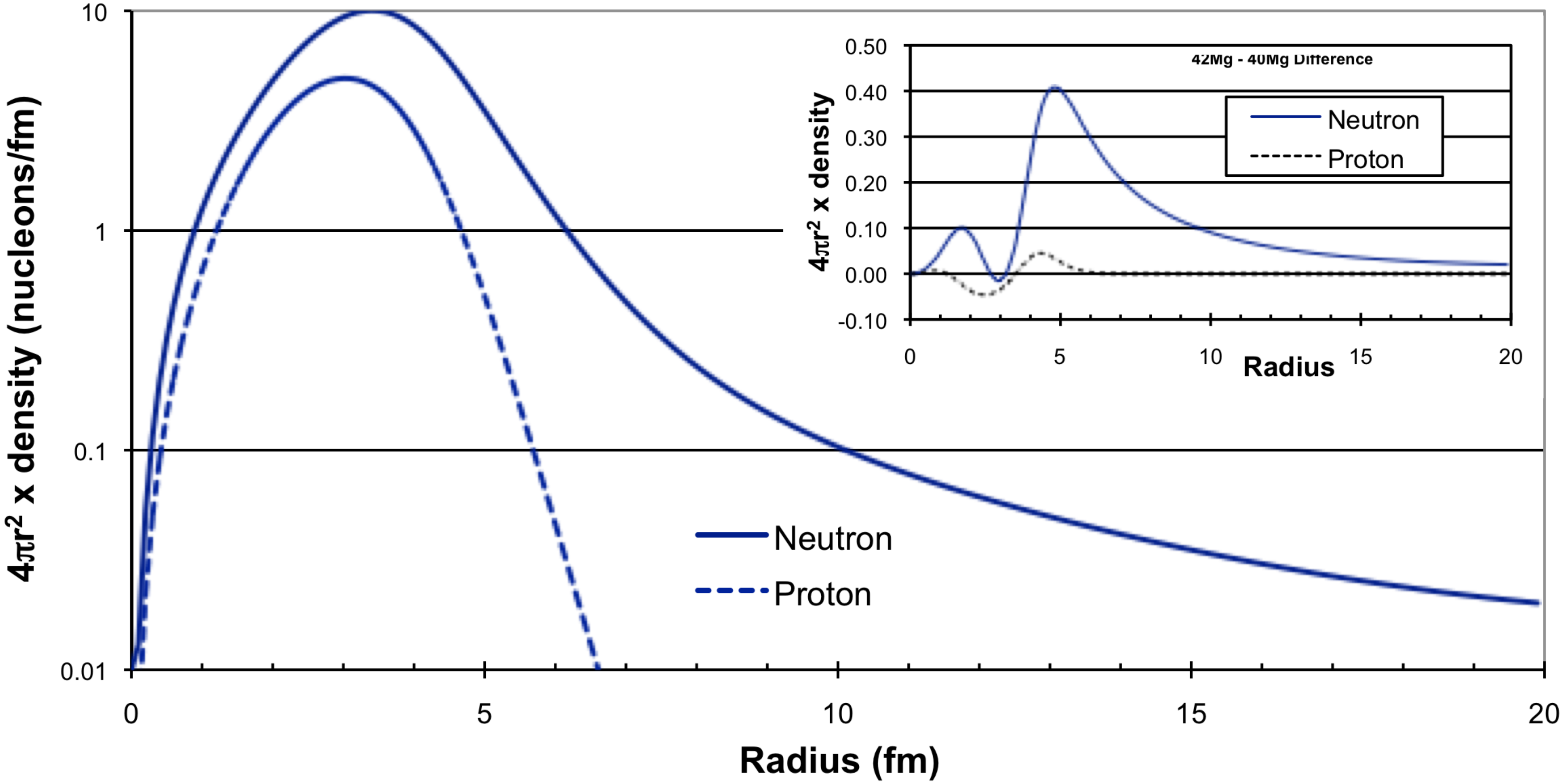
- Fundamental question: which nuclei can exist?
- Neutron star crust models
- Sensitive probe of mass models and nuclear force furthest from stability

Identifying shell structure

- Defines "chemistry" of nuclei (therefore affects astrophysical processes)
- Sensitive probe of nuclear forces

New Insight and Physics from Extreme Halos and Skins

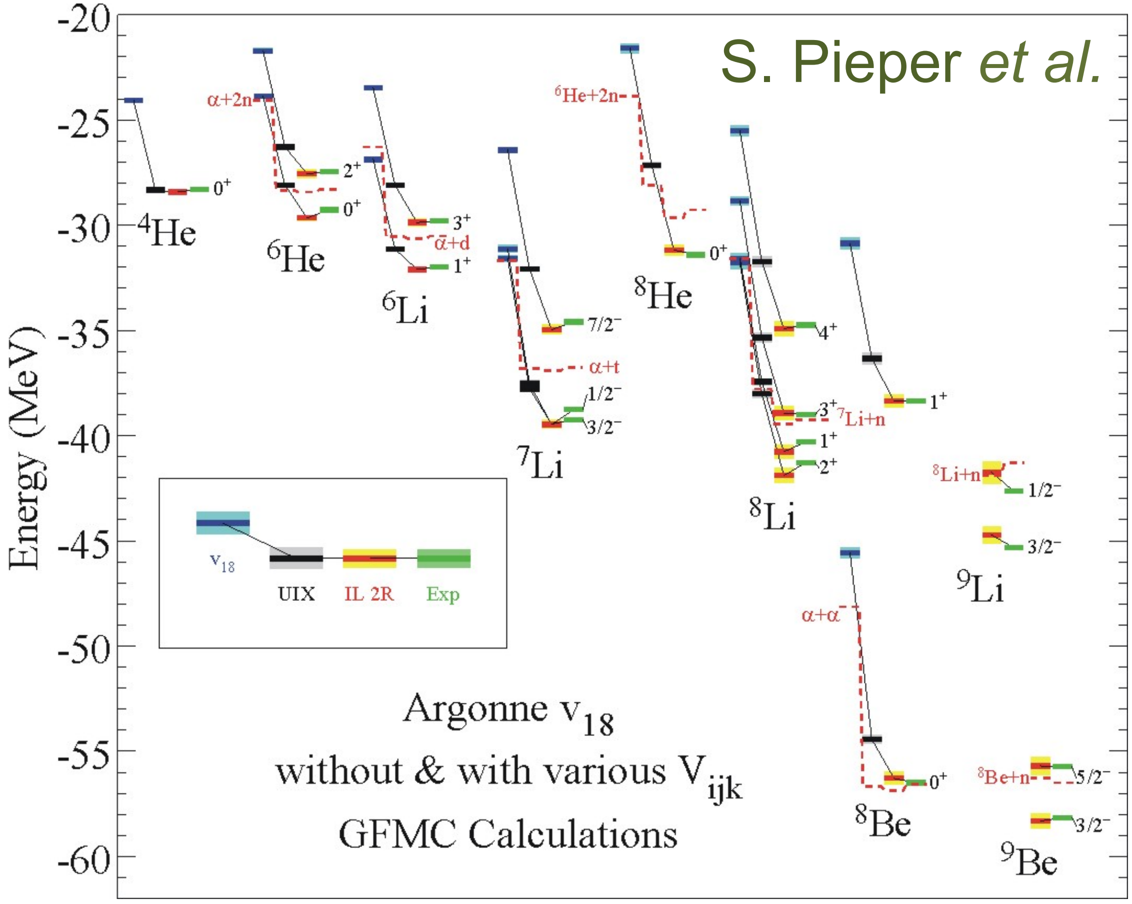
Example: ^{42}Mg (10 atoms/day) – Theory 100 keV S_n BA Brown



Science: Pairing in low-density material, new tests of nuclear models, Interaction with continuum states - Reactions

Step 1: Understand light nuclei in terms of NN interactions and connect to QCD

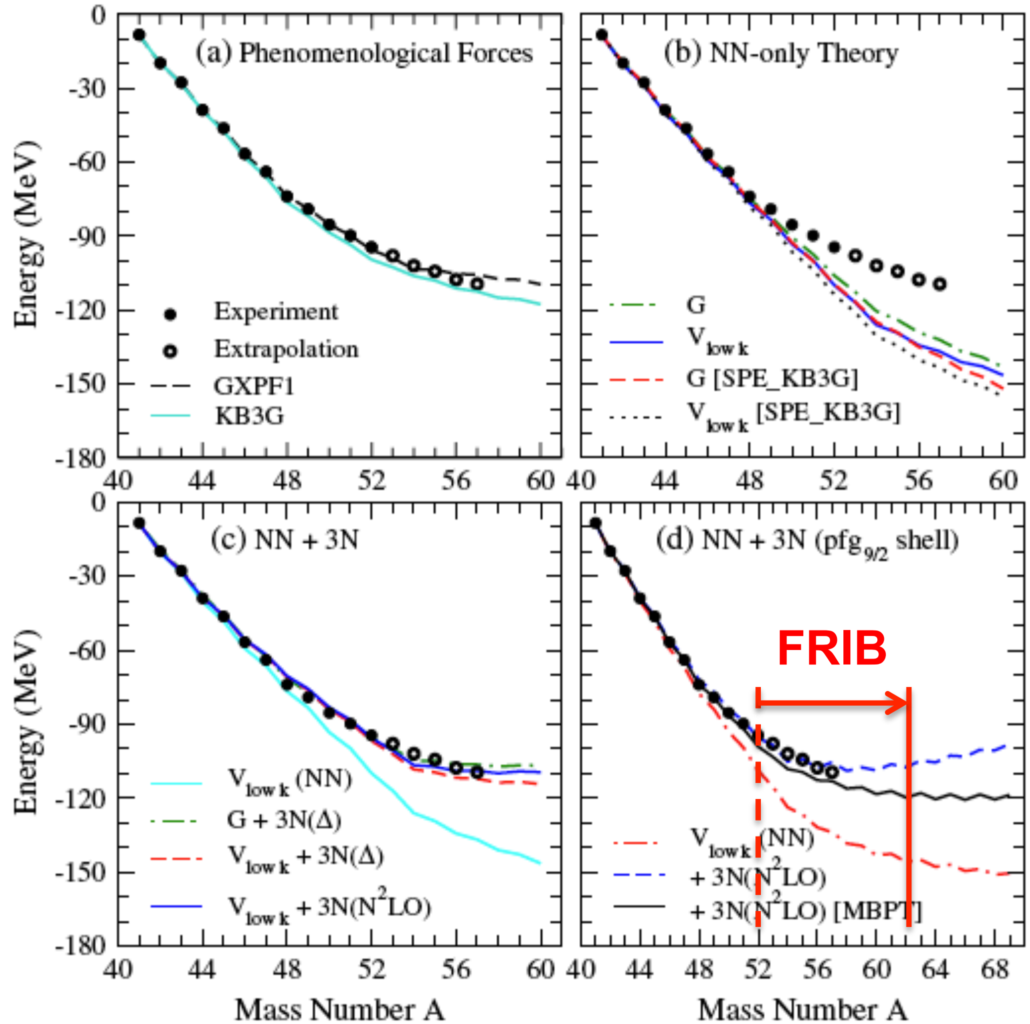
- Neutron rich nuclei were key in determining the isospin dependence of 3-body forces
- New data on exotic nuclei continues to lead to refinements in the interactions
- EFT developments are providing insight for *ab initio* theories, but they need grounding in data



Rare isotopes guiding theory
role of 3 body forces

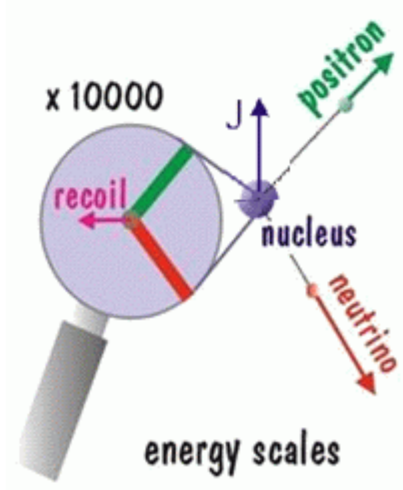
Ground state energies relative to ^{40}Ca from Theory and experiment

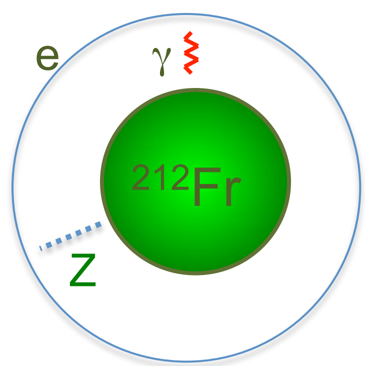
(Holt et al. 2012)

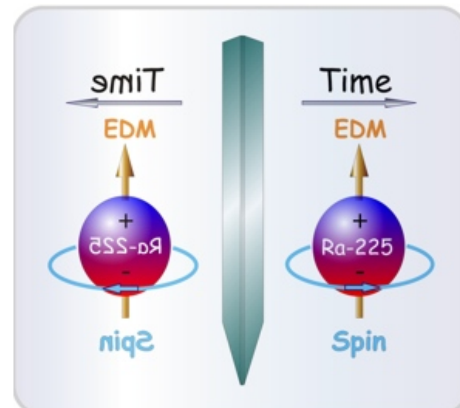


Tests of Nature's Fundamental Symmetries

- Angular correlations in β-decay and search for scalar currents
  - Mass scale for new particle comparable with LHC
  - ^{6}He and ^{18}Ne at 10^{12}/s
- Electric Dipole Moments
  - ^{225}Ac, ^{223}Rn, ^{229}Pa (30,000 more sensitive than ^{199}Hg; > 10^{9}/s)
- Parity Non-Conservation in atoms
  - weak charge in the nucleus (francium isotopes; 10^{9}/s)
- Unitarity of CKM matrix
  - V_{ud} by super allowed Fermi decay
  - Probe the validity of nuclear corrections







$$\begin{vmatrix} \mathbf{V_{ud}} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix}$$

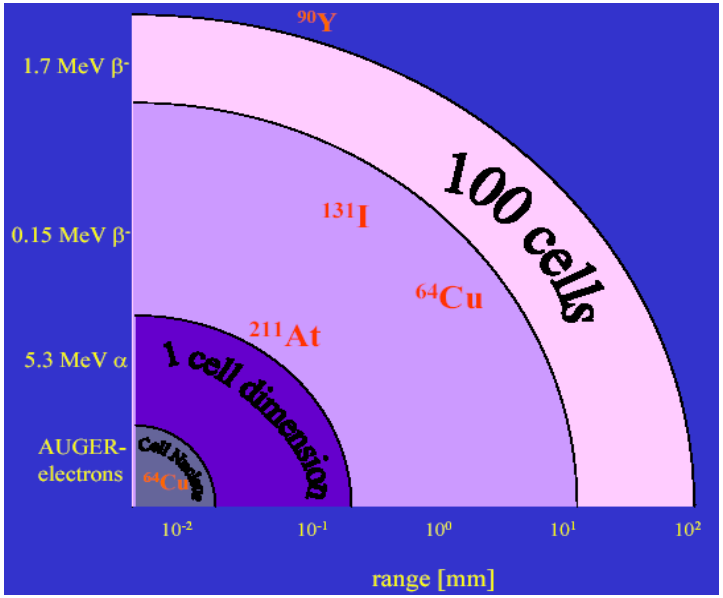
Rare Isotopes For Society

- Isotopes for medical research
  - Examples: ^{47}Sc, ^{62}Zn, ^{64}Cu, ^{67}Cu, ^{68}Ge, ^{149}Tb, ^{153}Gd, ^{168}Ho, ^{177}Lu, ^{188}Re, ^{211}At, ^{212}Bi, ^{213}Bi, ^{223}Ra (DOE Isotope Workshop)
  - α-emitters ^{149}Tb, ^{211}At: potential treatment of metastatic cancer
- Reaction rates important for stockpile stewardship – non-classified research
  - Determination of extremely high neutron fluxes by activation analysis
  - Rare isotope samples for (n,γ), (n,n'), (n,2n), (n,f) e.g. ^{88,89}Zr
    - » Same technique important for astrophysics
  - More difficult cases studied via surrogate reactions (d,p), (^{3}He,α xn) …
- Tracers for Geology, Condensed Matter (^{8}Li), material studies, …

Isotope harvesting is included in the FRIB scope

Example: Targeted Cancer Therapy

- Modern targeted therapies in medicine take advantage of knowledge of the biology of cancer and the specific biomolecules that are important in causing or maintaining the abnormal proliferation of cells
- These radionuclides have been relatively difficult to get in sufficient quantities[1]. The short-lived alpha emitters are particularly in demand, especially ^{225}Ac, ^{213}Bi, and ^{211}At.
- Pairs, e.g., ^{67}Cu (treatment) and ^{64}Cu (dosimetry) are particularly interesting
- FRIB can parasitically supply demand for many isotopes



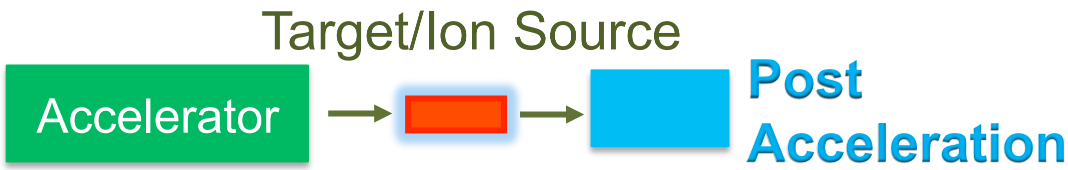
[1]Isotopes for the Nation's Future:
A Long Range Plan , NSACIS 2009

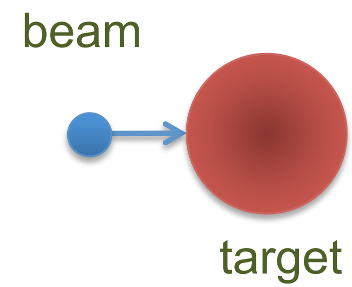
Question

How can one produce rare isotopes?

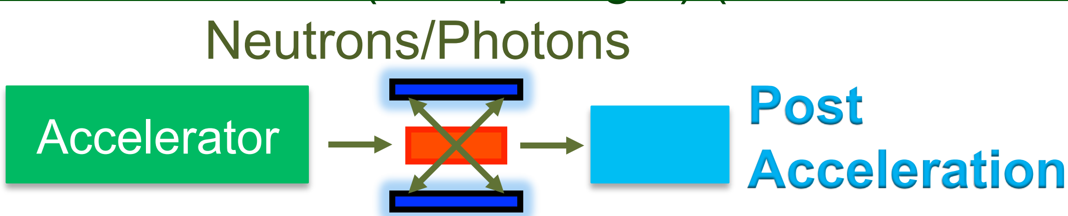
Rare Isotope Production Techniques: Uniqueness of FRIB

- Target spallation and fragmentation by light ions (ISOLDE/HRIBF/TRIUMF)

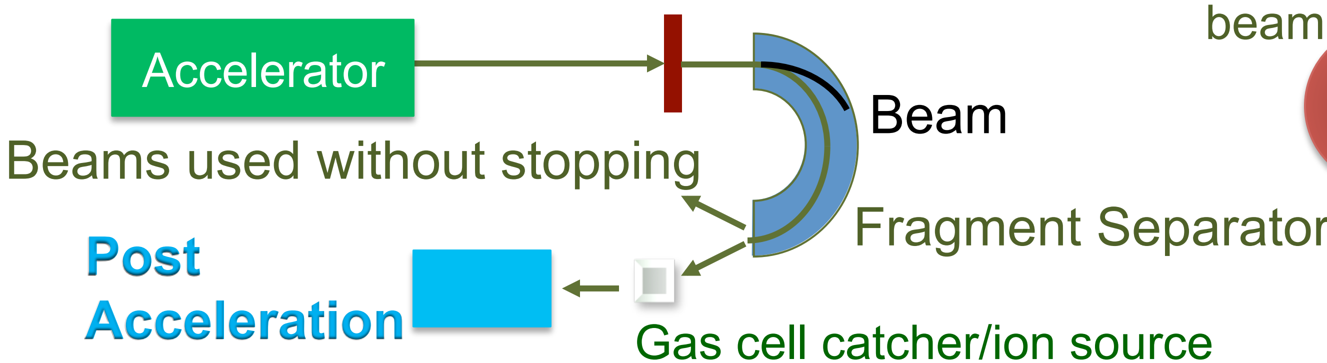


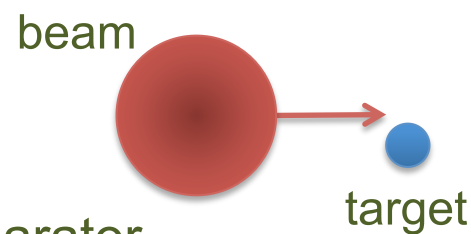


- Neutron induced fission (2-step target) (SPIRAL2/TRIUMF)



- In-flight Separation following projectile fragmentation/fission (RIKEN,FAIR,FRIB)





Comparison of different methods

ISOL: light beam into thick target

- Xxx
- Xxx

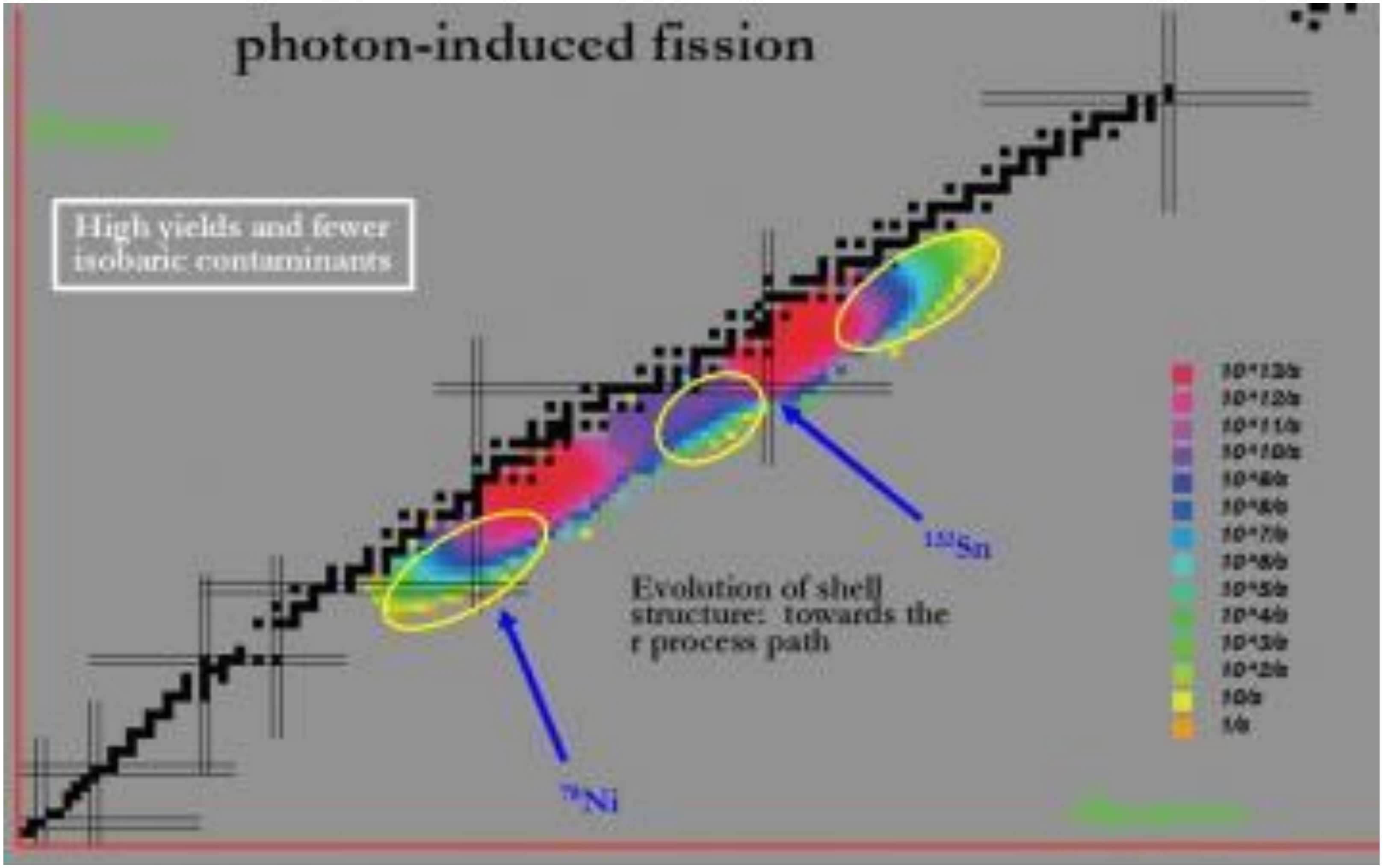
n/gamma induced fission

- Xxx
- Xxx

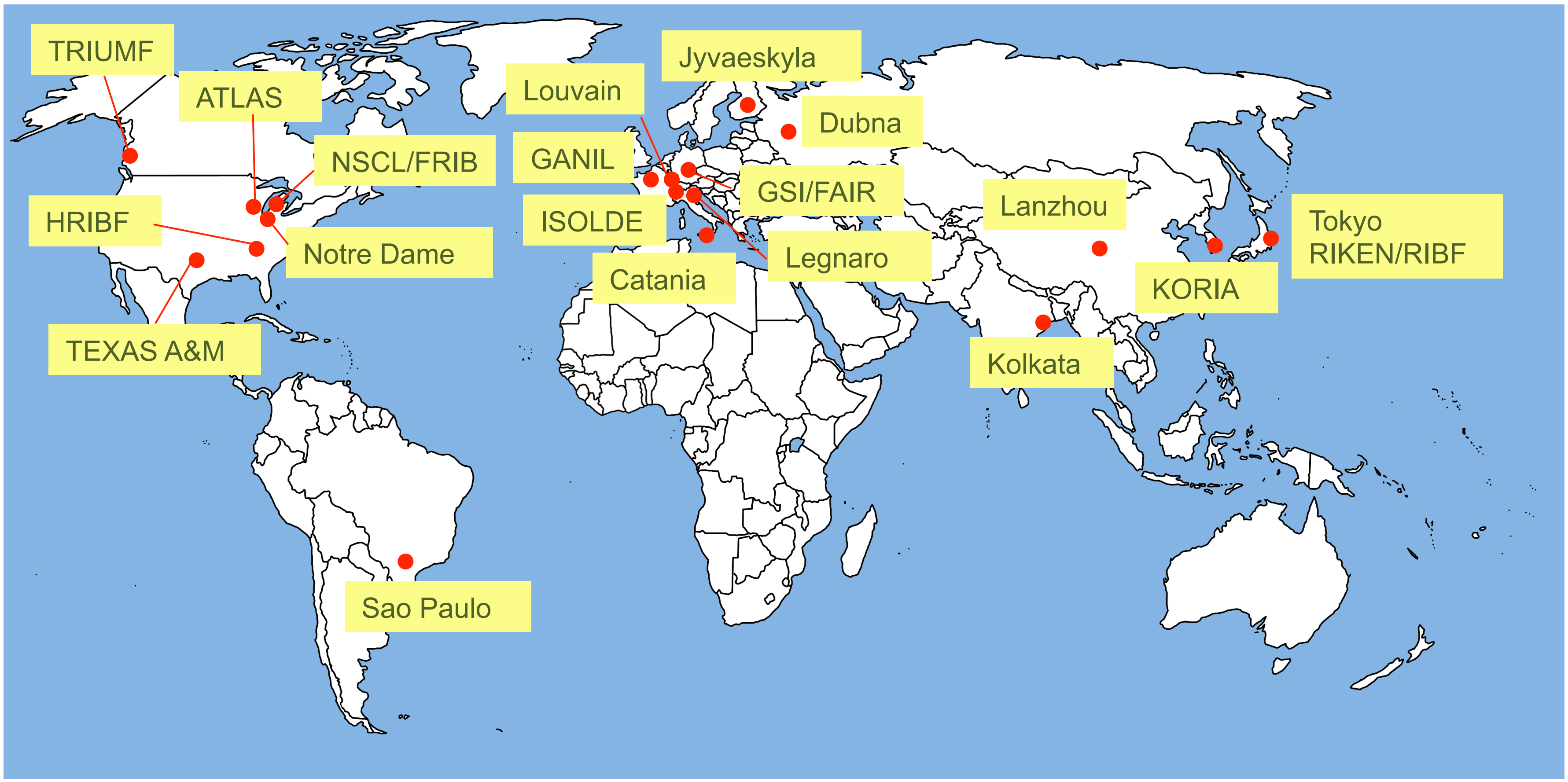
Fragmentation fast and reaccelerated beams

- Xxx
- Xxx

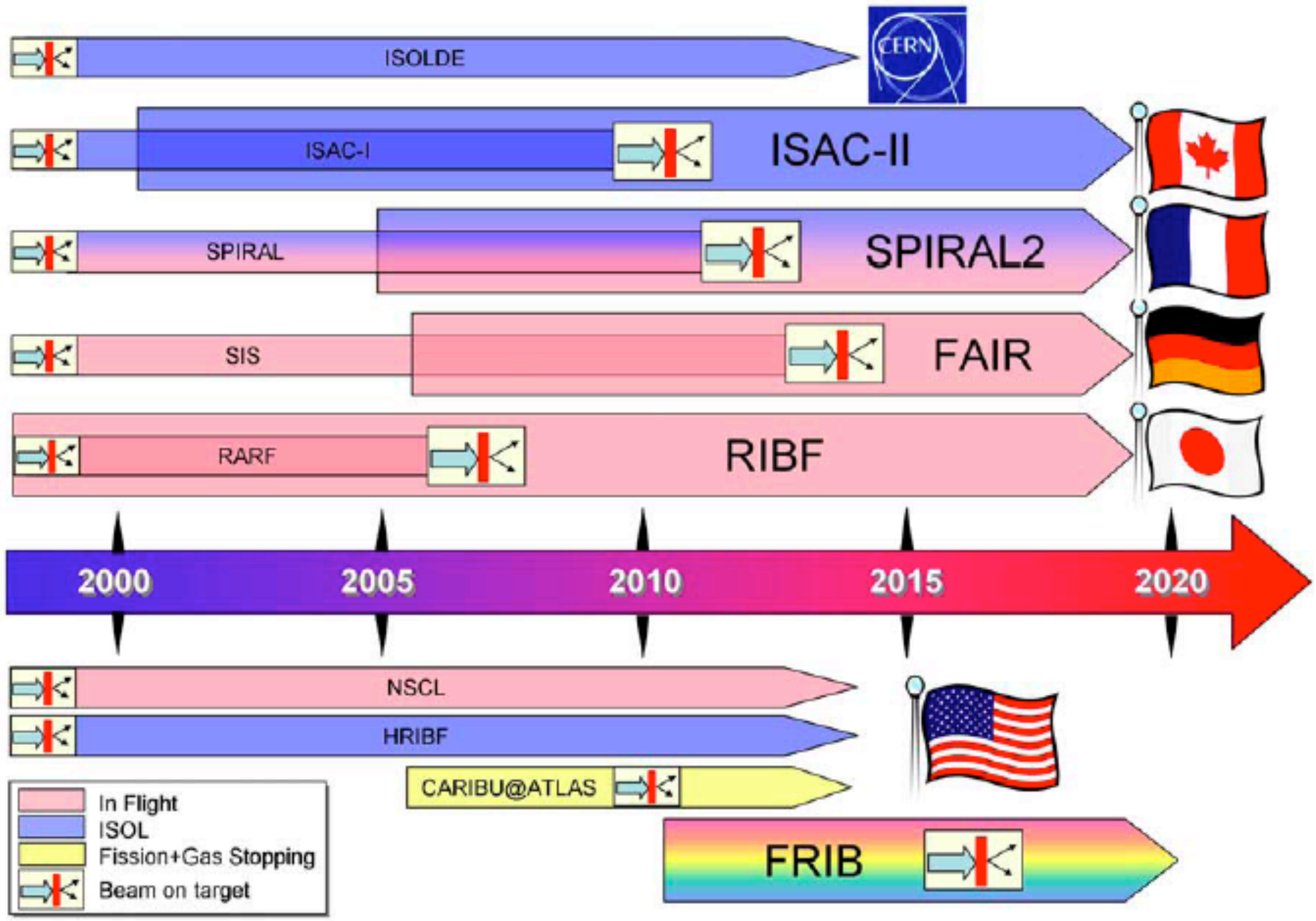
Photo fission yields



Rare Isotope Facilities Around the World



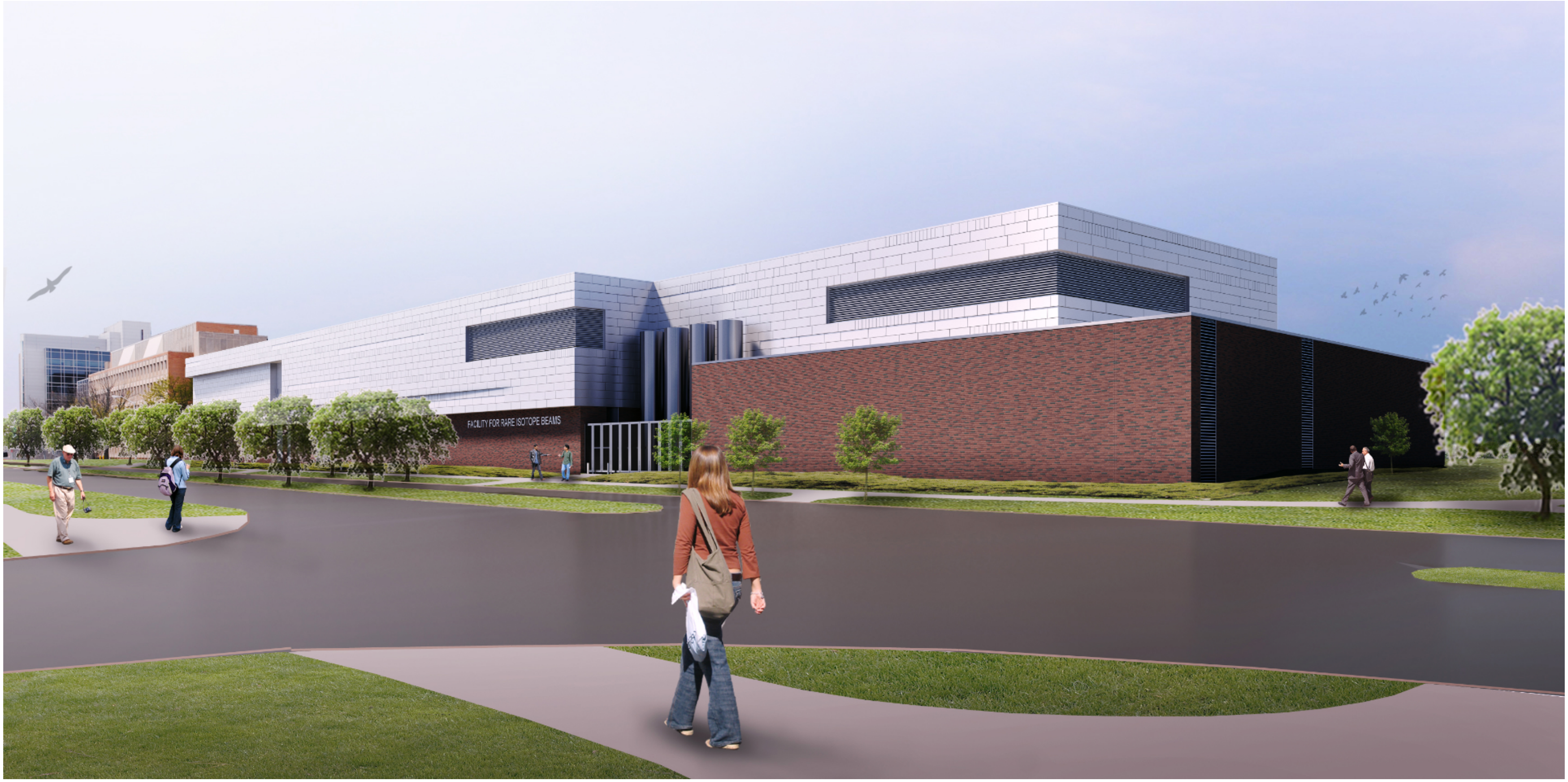
Timelines for major facilities



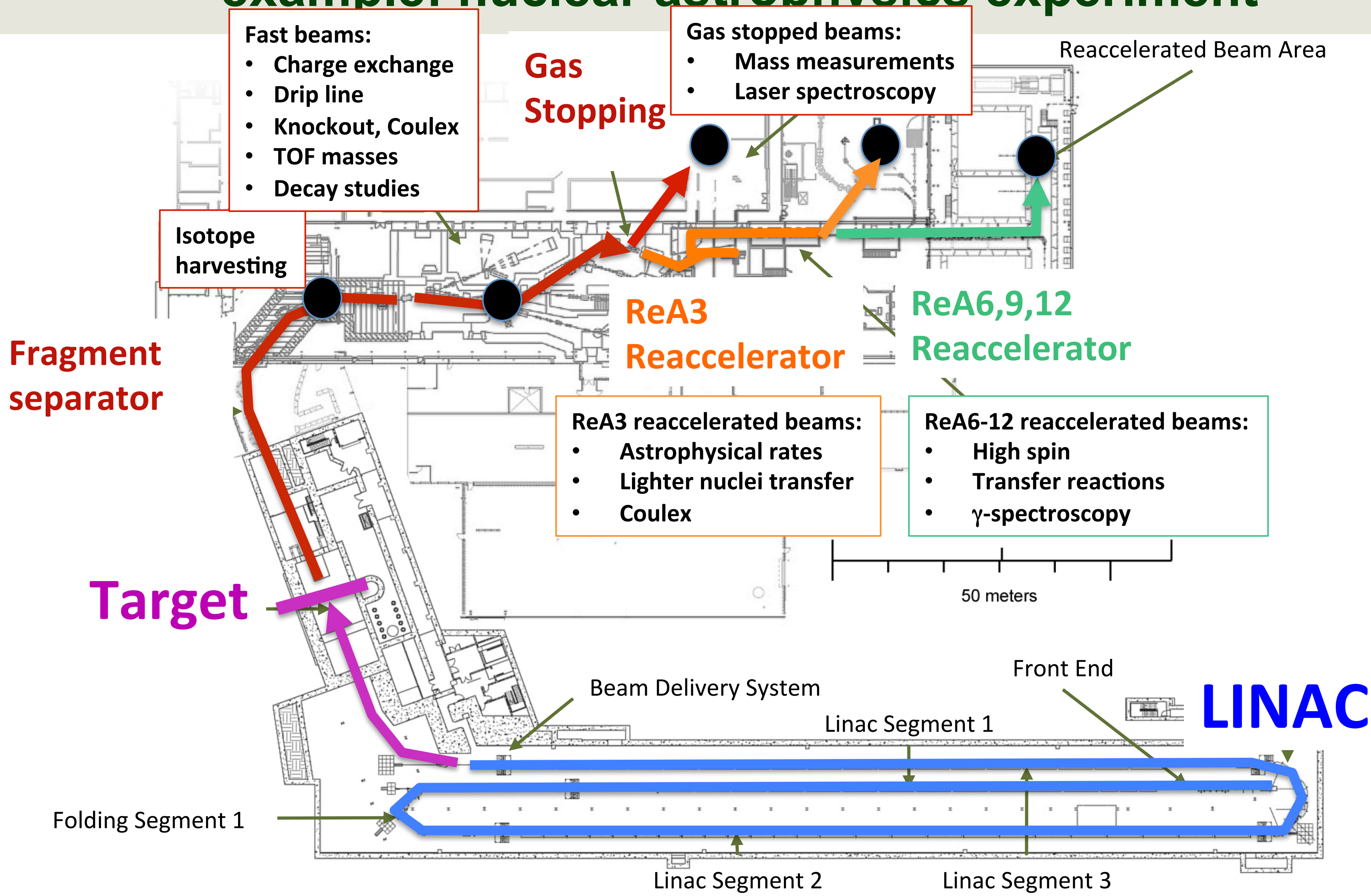
Rare Isotope Assessment Committee, NRC/NAS study 2006

Overview of the FRIB Facility

Rendered Perspective
Southeast View

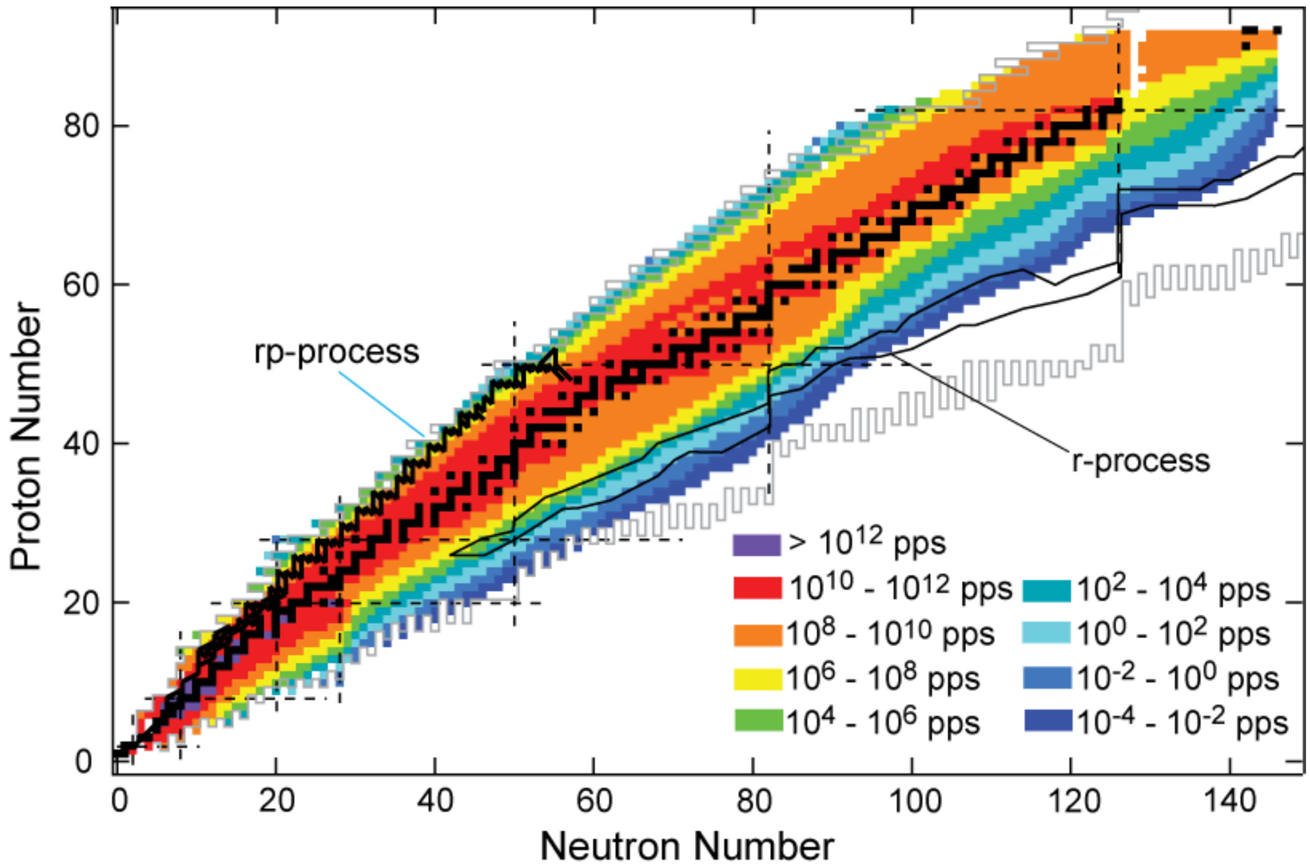


FRIB Layout
example: nuclear astrophysics experiment



The Reach of FRIB

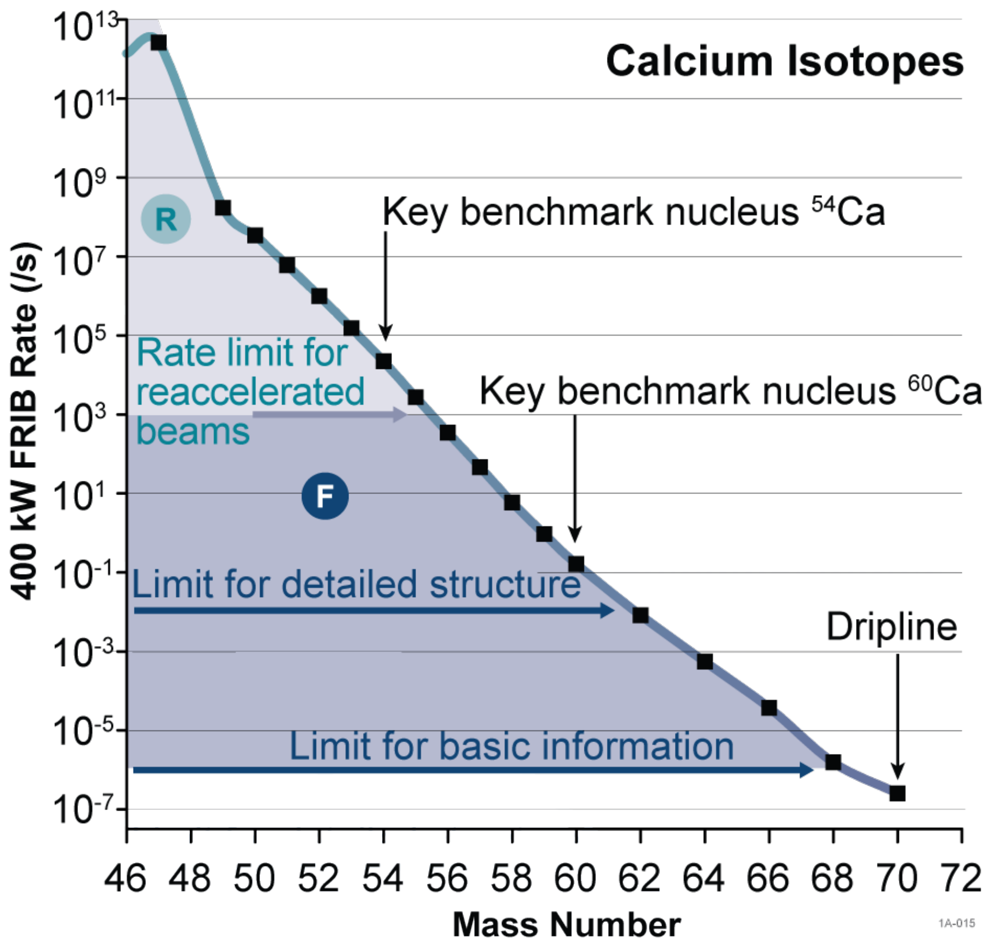
- FRIB is estimated to produce more than 1000 NEW isotopes at useful rates (4500 available for study; compared to 1900 now)
- Exciting prospects for study of nuclei along the drip line to A=120(compared to A=24)
- Production of most of the key nuclei for astrophysical modeling
- Theory is key to making the right measurements and interpreting them



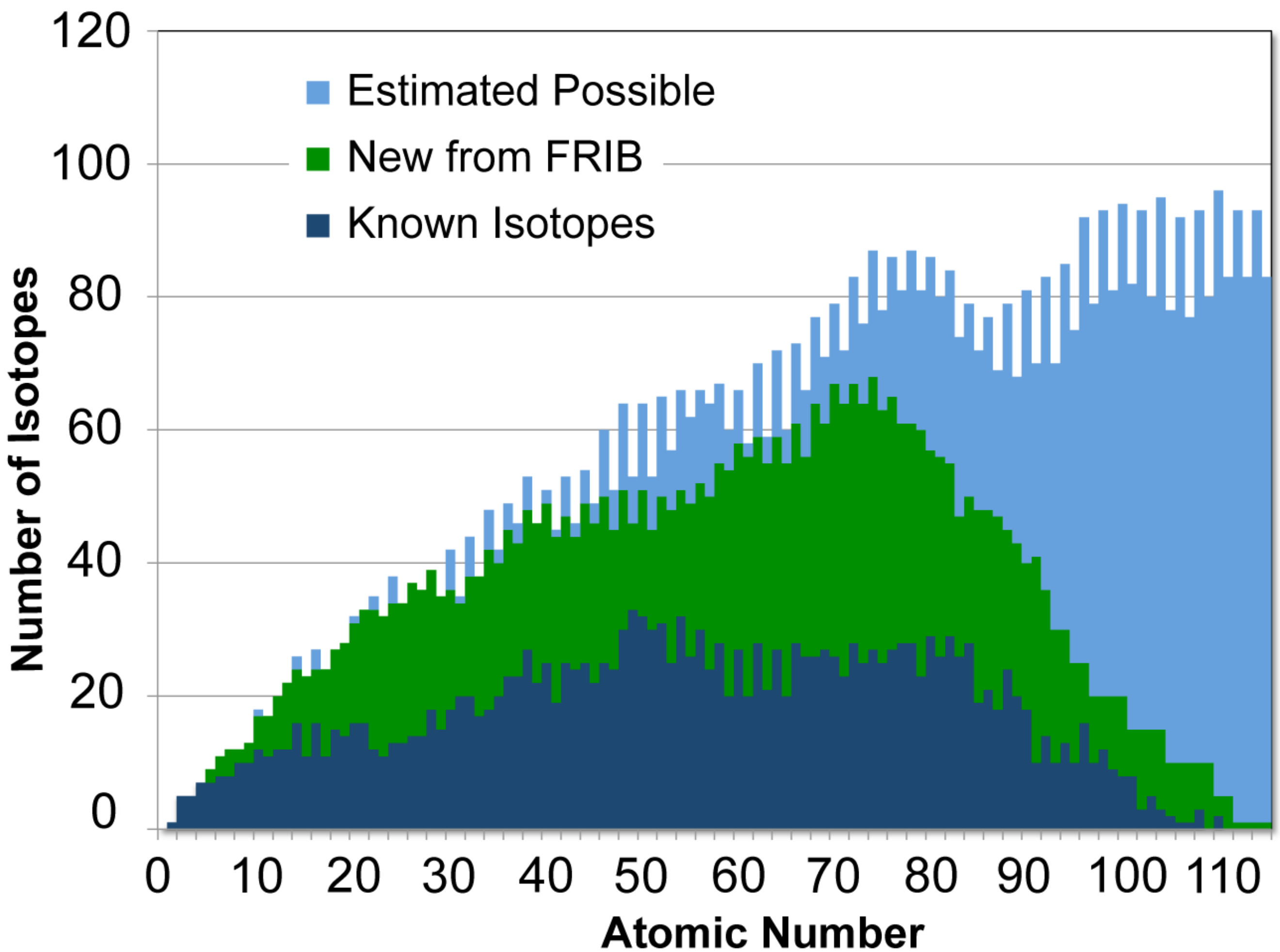
Rates are available at http://groups.nscl.msu.edu/frib/rates/

Fast, Stopped, and Reaccelerated Beams for Broad Science Opportunities

- Fast beams (>100 MeV/u)
  - Farthest reach from stability, knockout, Coulomb exictation, nuclear structure, limits of existence, EOS of
    nuclear matter
- Stopped beams (0-100 keV)
  - Precision experiments – masses, moments, atomic structure, symmetries
- Reaccelerated beams (0.2-20 MeV/u)
  - Detailed nuclear structure studies, high-spin studies
  - Astrophysical reaction rates



The Reach of FRIB



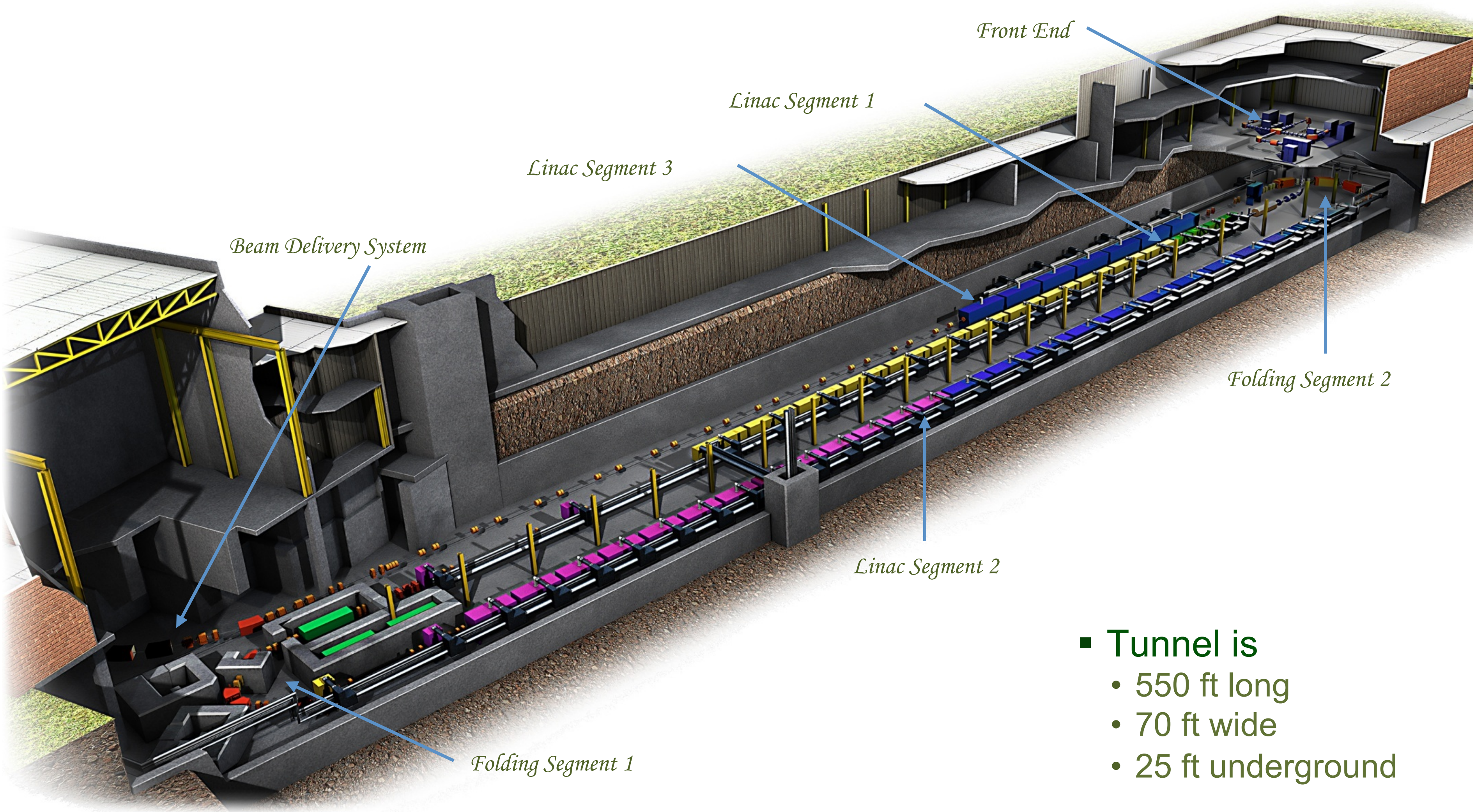
Estimated Possible: Erler, Birge, Kortelainen, Nazarewicz, Olsen, Stoitsov, to be published

Based on a study of EDF parameters

Known – isotopes with at least one excited state known

Up to Z=90 FRIB will be able to make >80% of all possible isotopes

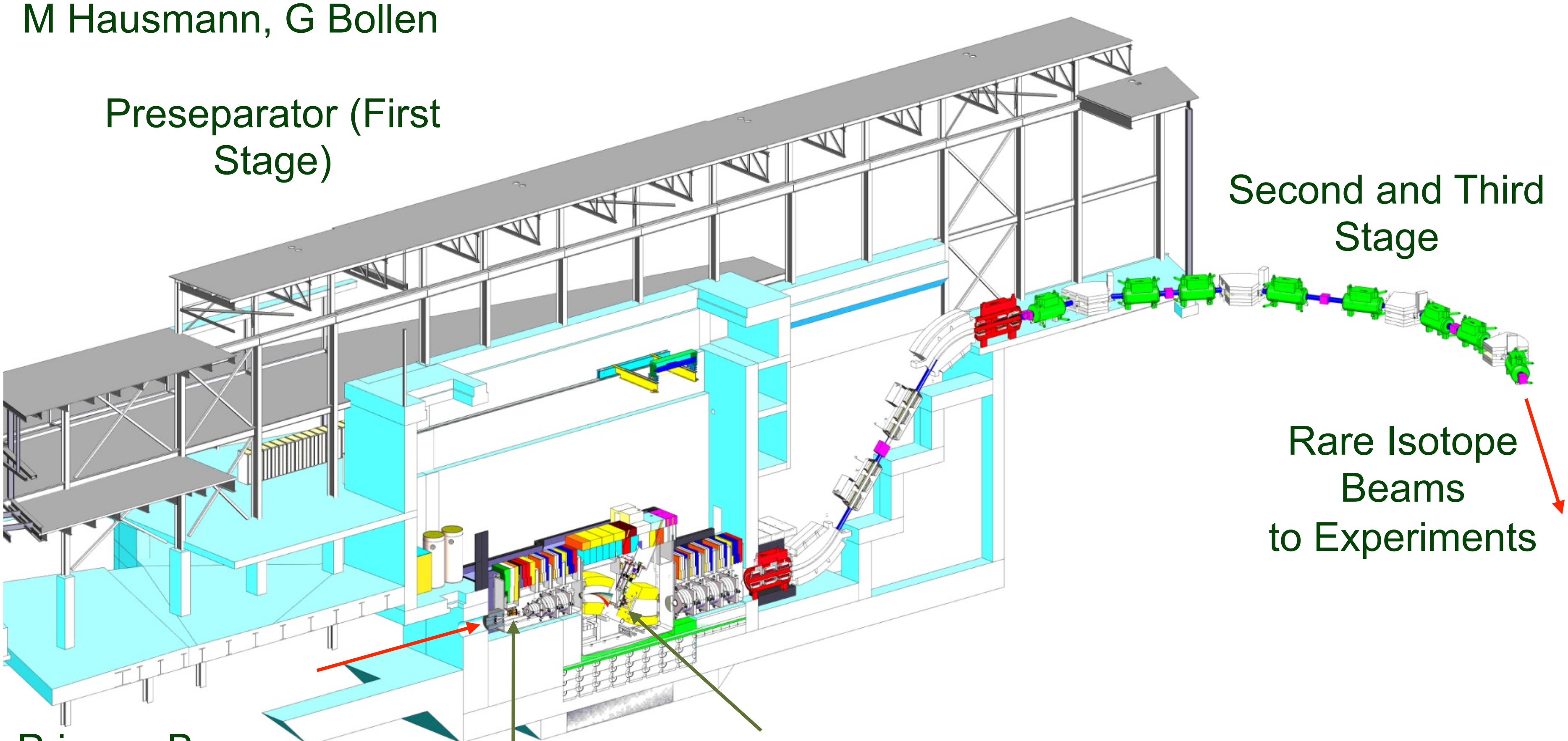
Driver Linear Accelerator



- Tunnel is
  - 550 ft long
  - 70 ft wide
  - 25 ft underground

Isotope Production Area
Target and Fragment Separator

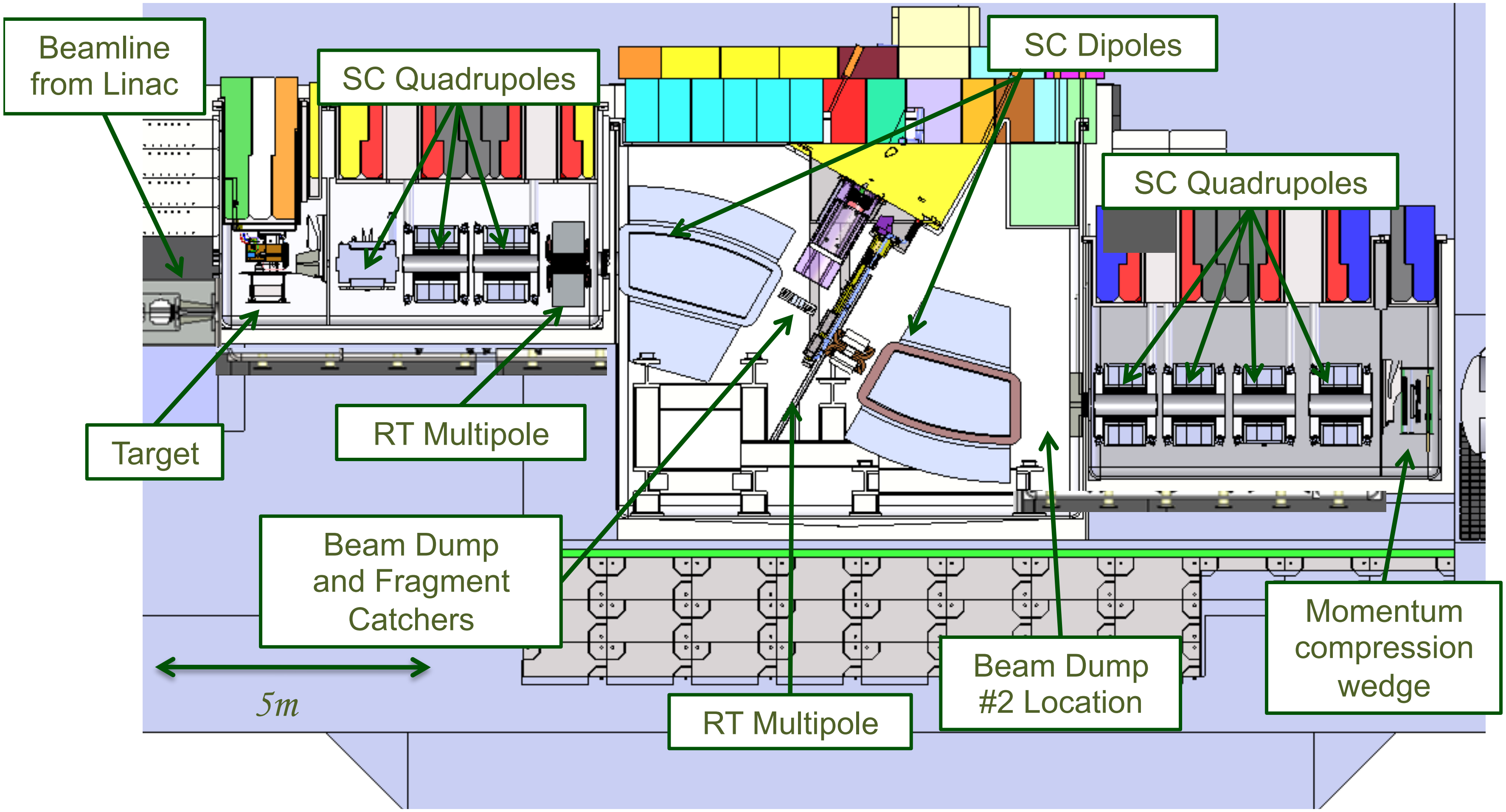
M Hausmann, G Bollen



Separator Length 96 m

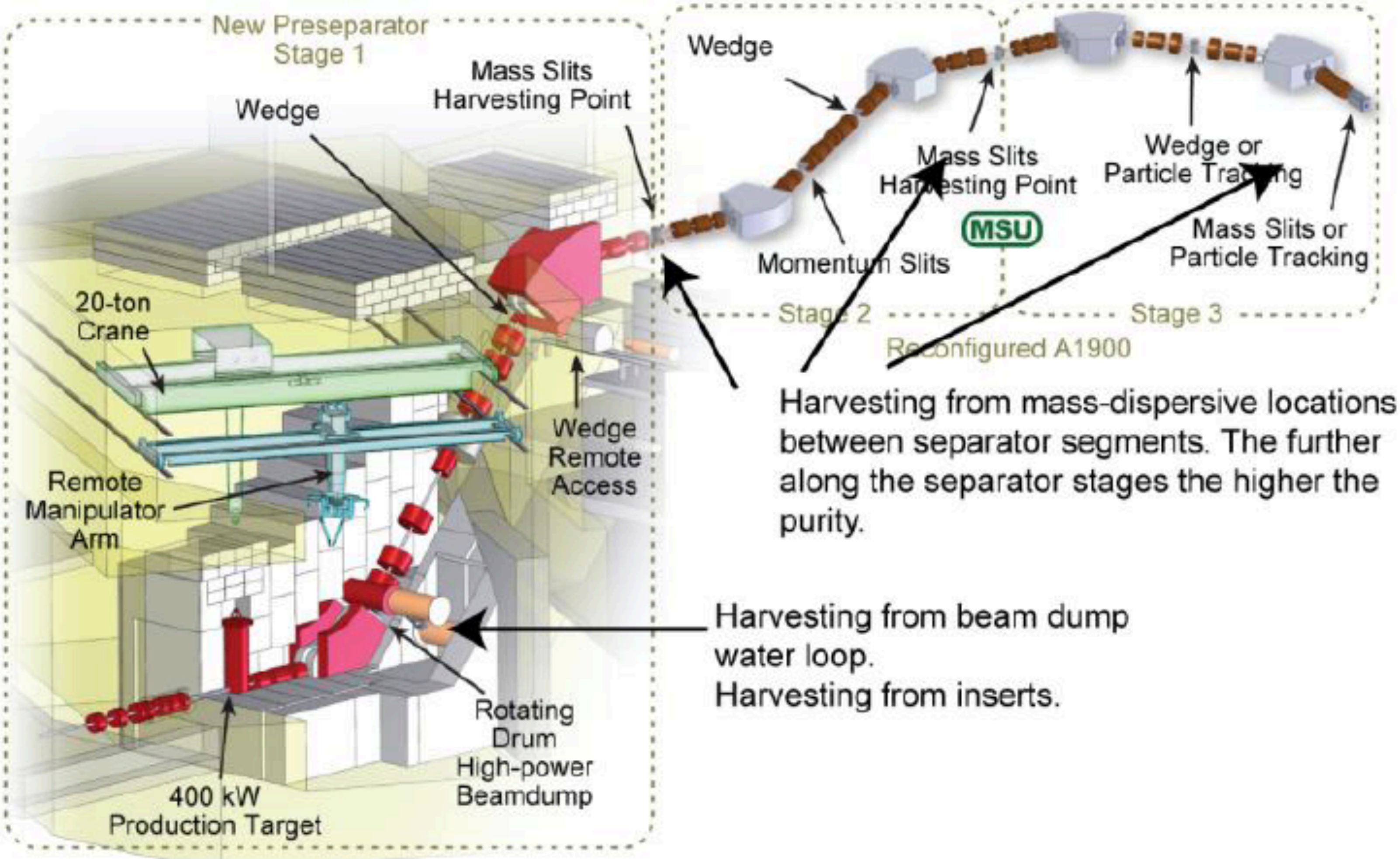
FRIB Preseparator
400 kW Beam Power Requirement

G Bollen



- Challenges: beam power densities, radiation damage, activation, …

Isotope harvesting points

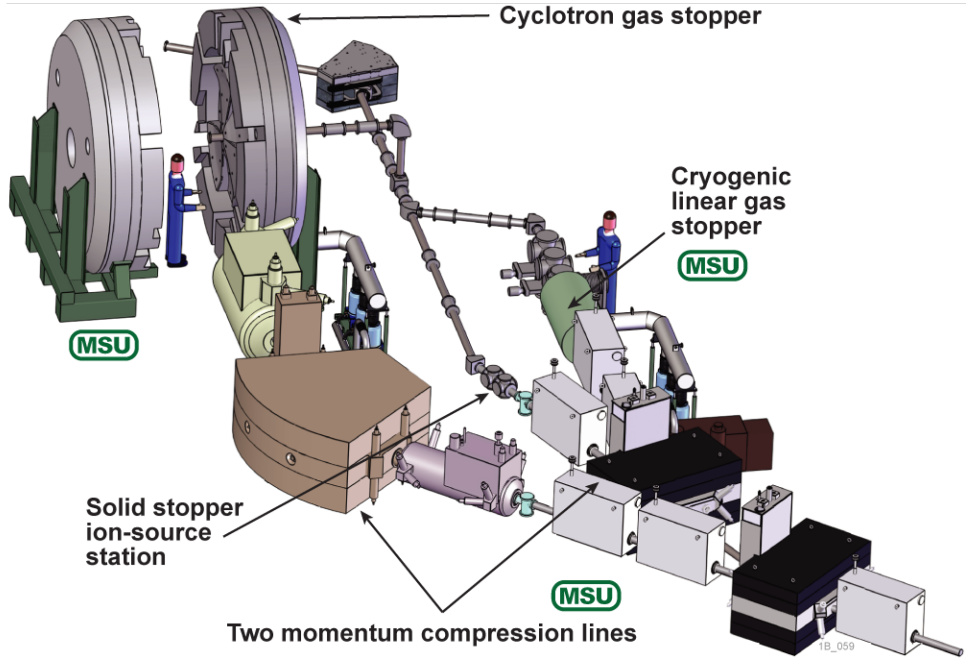


Harvesting from mass-dispersive locations between separator segments. The further along the separator stages the higher the purity.

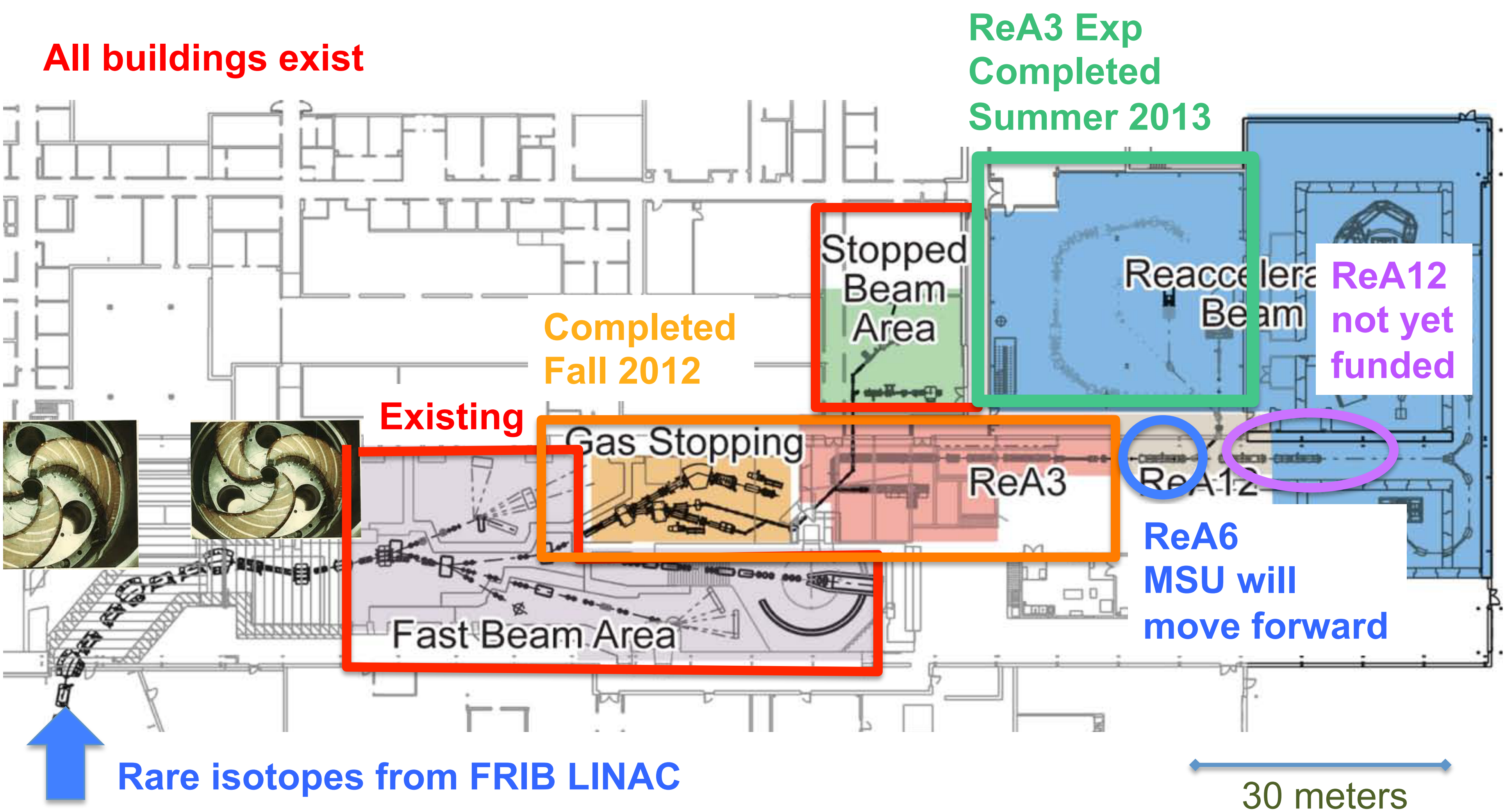
Harvesting from beam dump water loop.
Harvesting from inserts.

Gas Stopper

- R&D Program lead by ANL and MSU
- Technical Specifications
  - 3 complementary stopping stations and 2 momentum compression lines specifically optimized
  - **Two Linear gas stoppers** (ANL, MSU)
    - » L = 1.5 m, p < 300 mbar
    - » I < 10^8/s, $T^{1/2}$ > 100ms
  - **Cyclotron gas stopper** for light and medium heavy isotopes (NSF Funded)
    - » B_{max} = 2.3T, r_{inj} = 0.95, p_{He} = 50-250 mbar
    - » I > 10^8/s, $T_{1/2}$ < 50ms
  - **Solid stopper** for special elements and high beam rates
    - » Example: ^{15}O, I >10^{10}/s



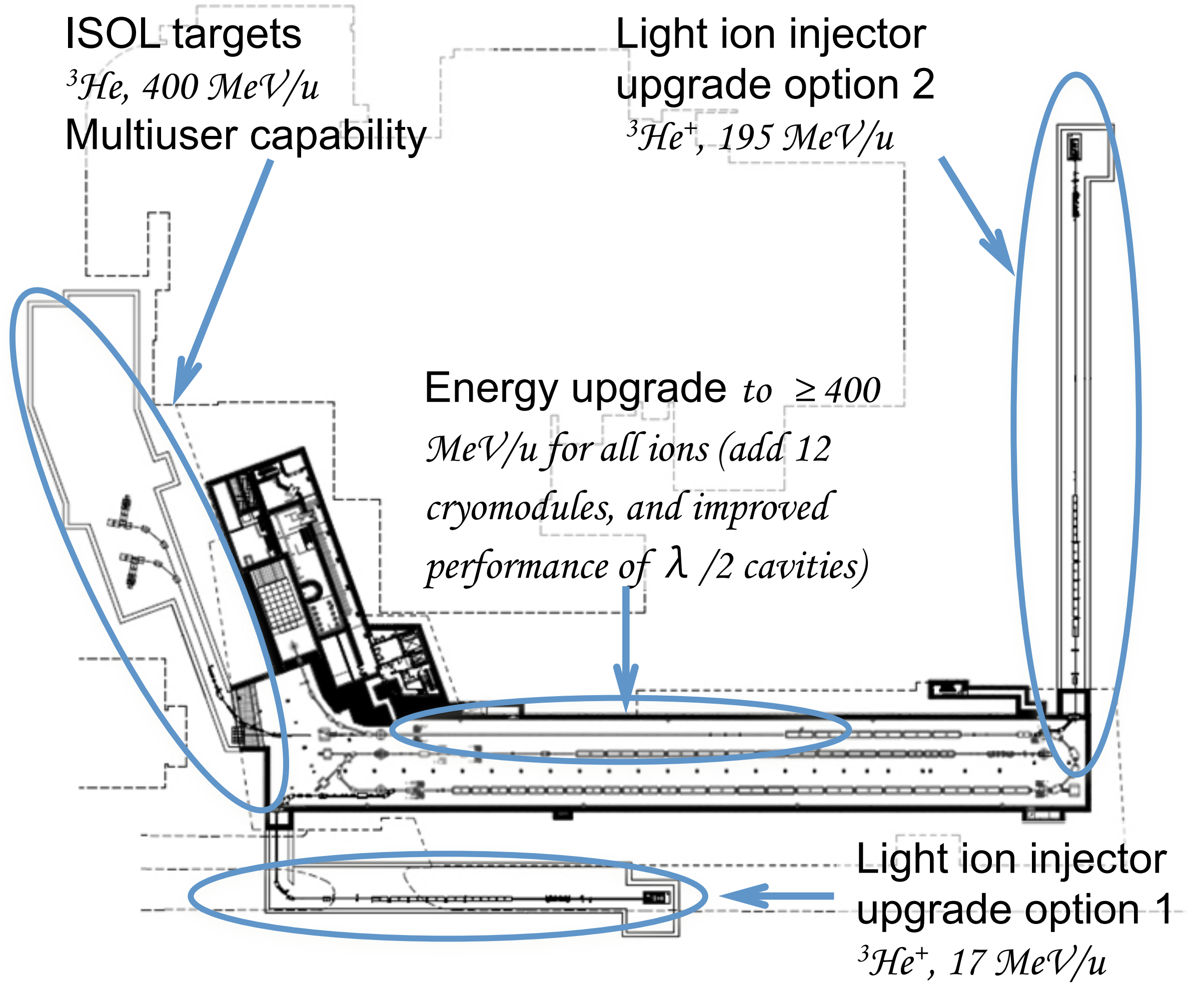
Overview FRIB Reaccelerators, and Experimental Stations



Science-driven Upgrade Opportunities

B13-Yamazaki

- Space available for various upgrade options
  - Higher energy
  - ISOL targets
  - Light ion injector (17 or 200 MeV/u)
  - Multi-user simultaneous operation
- Tunnel penetration locations identified in facility design



FRIB On Track, Moving Toward Construction

• Conceptual design	completed 9/2010 (CD-1)
• Preliminary design	2010-2012
– CD-2/3A (civil) review in April 2012	
• Civil construction begins	2012
– Pending DOE approval	
• Final design	2012-2013
– CD-3B (technical) review in 2013	
• Technical construction begins	2013
• Early project completion	2019
• Project completion	2021
• Total project cost	$680M ($585 Federal)

FRIB Site Ready for Civil Construction to Begin

- Utility relocation and site preparation continue on schedule; substantially completed in April, final completion in December 2012
- Pictured above, installation of underground electrical and communication concrete-encased duct bank including new vaults (left), and installation of class II sand backfill at new steam tunnel (right)

FRIB Users Organization

- Users are organized as part of the independent FRIB Users Organization
  - FRIBUO has 1227 members (92 US Colleges and Universities, 10 National Laboratories, 53 countries) as of 16 April 2012
  - Chartered organization with an elected executive committee (Chair is Michael Smith, ORNL)
  - FRIBUO has 20 working groups on experimental equipment
- Science Advisory Committee
  - Review of equipment initiatives (Feb. 2011)
  - Review of FRIB Integrated Design (March 2012)
- Low-Energy Community Meeting with NS2012 at ANL 17-18 Aug.

Join at fribusers.org (and fribastro.org)

August 2011
Joint Users Meeting
284 participants

fribusers.org

Why is it called FRIB ???

1. frib 17 up, 6 down

birf spelled backwards

2. frib 4 up, 12 down

A word that can be used to describe happiness, joy etc. Commonly replaces 'wow', 'cool' or 'great'.

Summary

- FRIB will allow production of a wide range of isotopes
  - Extend our searches for the limits to nuclear stability
  - Answer key questions on the nature of the universe (chemical history, mechanisms of stellar explosions)
  - Opportunities for the tests of fundamental symmetries
  - Potential for important societal applications
- The unique features of FRIB
  - High power linear accelerator 400 kW
  - In-flight production and separation providing stopped and reaccelerated beams of elements difficulty to get from ISOL techniques