FRIB Fragment Separator Design

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Facility for Rare Isotope Beams

Michigan State University

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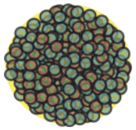
Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

Outline

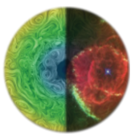
- Production of rare isotope beams for science at FRIB
- Fragment separator design
  - Design goals
  - Beam physics design
  - Production target
  - Fragment separator magnets
  - Beam dump
  - Mechanical design
  - Remote handling

FRIB – a DOE-SC National User Facility for Science with Rare Isotope Beams



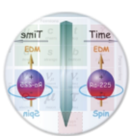
Properties of nuclei

- Develop a predictive model of nuclei and their interactions
- Many-body quantum problem: intellectual overlap to mesoscopic science, quantum dots, atomic clusters, etc.
- The limits of elements and isotopes



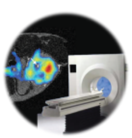
Astrophysical processes

- Origin of the elements in the cosmos
- Explosive environments: novae, supernovae, X-ray bursts …
- Properties of neutron stars



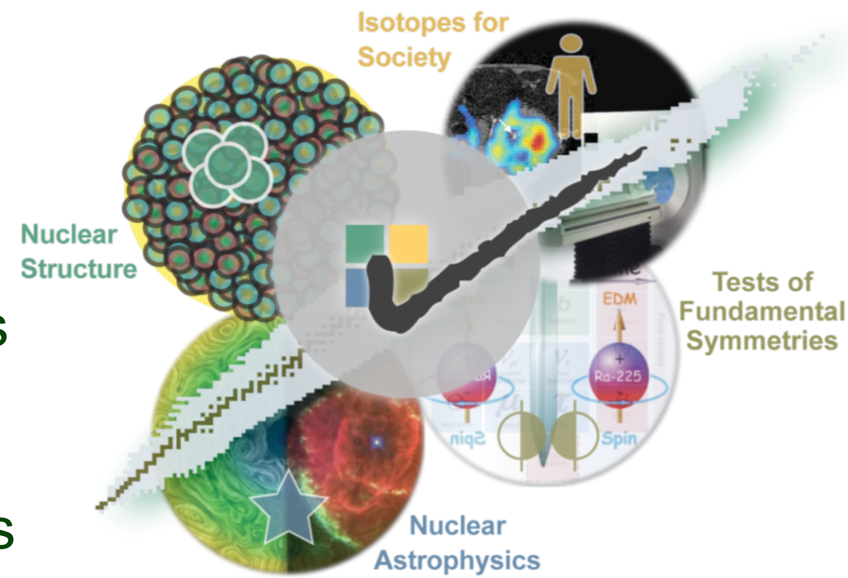
Tests of fundamental symmetries

- Effects of symmetry violations are amplified in certain nuclei



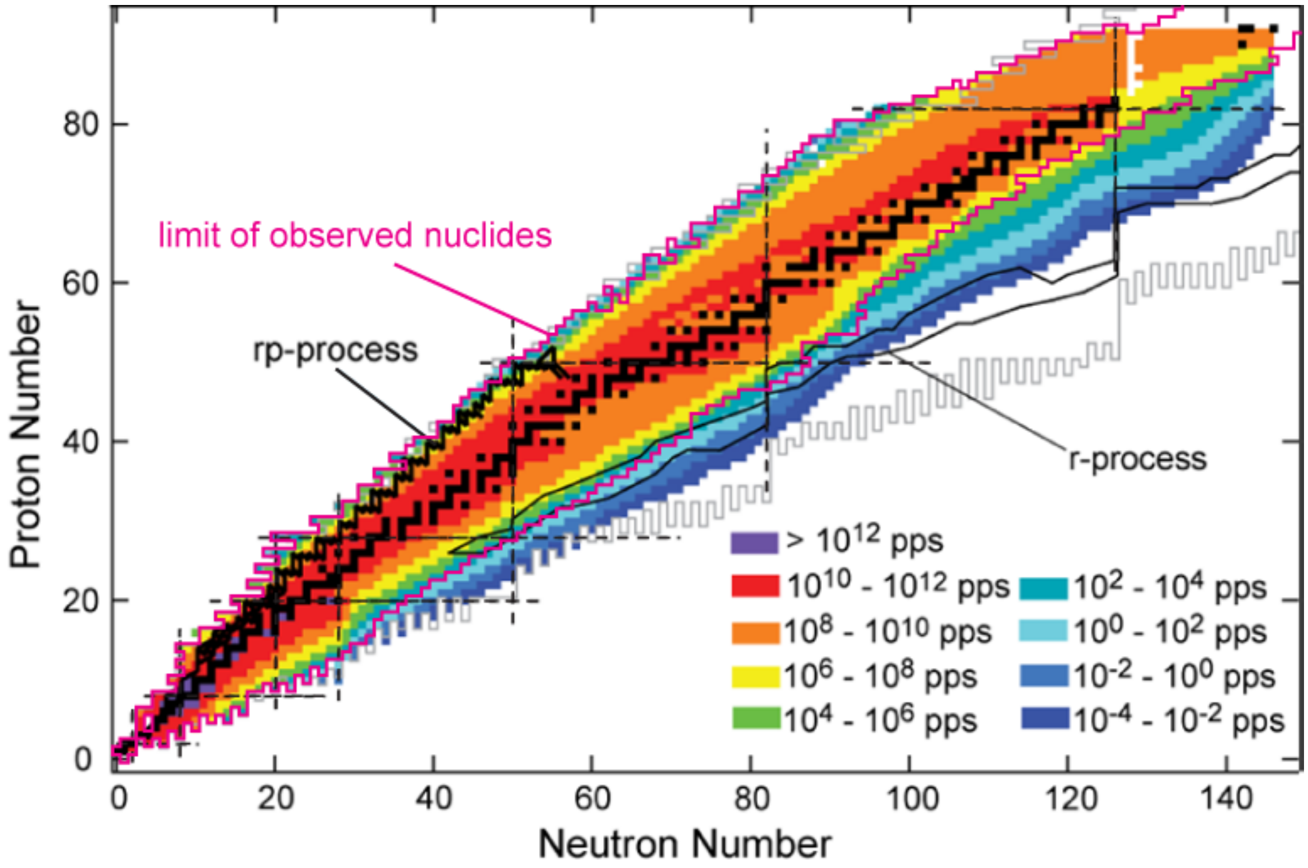
Societal applications and benefits

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



FRIB Rare Isotope Beam Reach

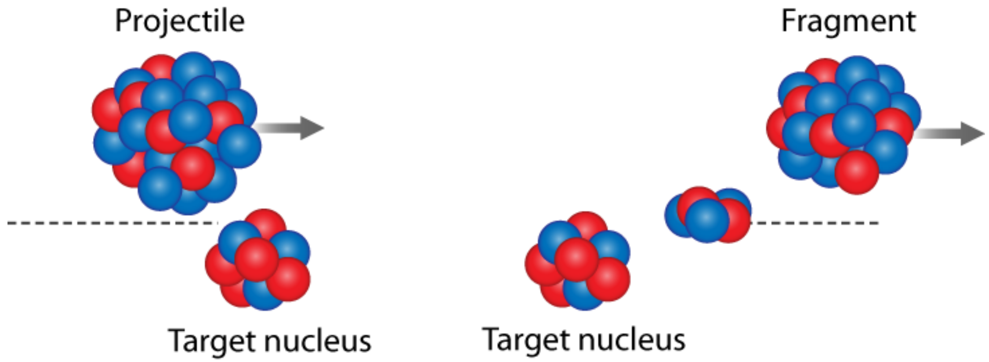
- FRIB is estimated to produce more than 1000 NEW isotopes at useful rates (4500 available for study; compared to 1900 now)
- Enabling studies of nuclei along the driplines
- Production of the most key nuclei for astrophysical modeling



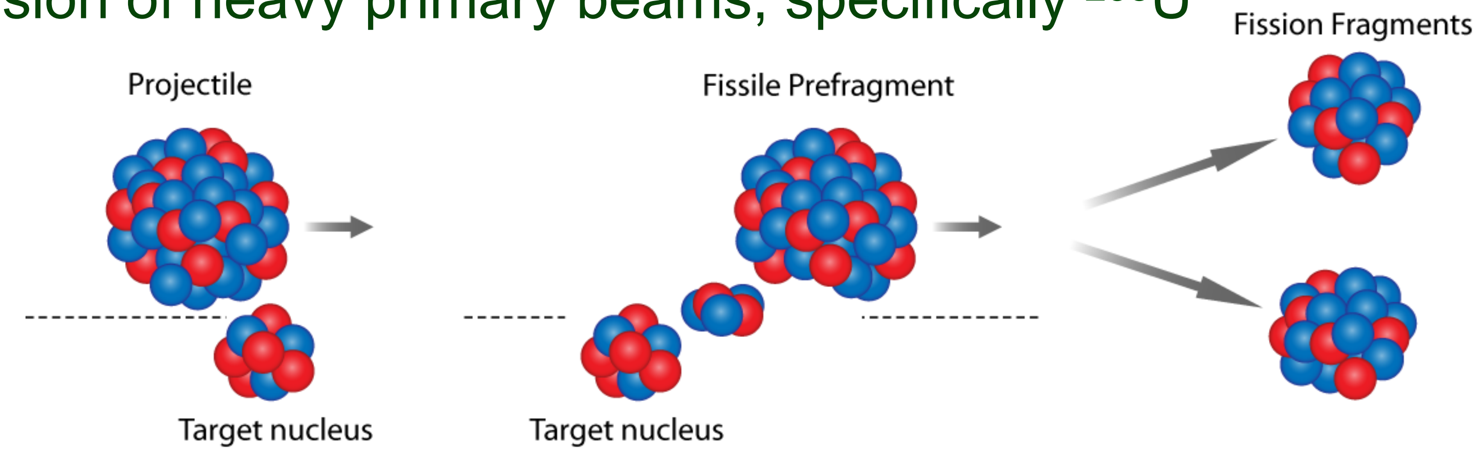
Rate estimates are available at https://groups.nscl.msu.edu/frib/rates/fribrates.html

Rare Isotope Production at FRIB

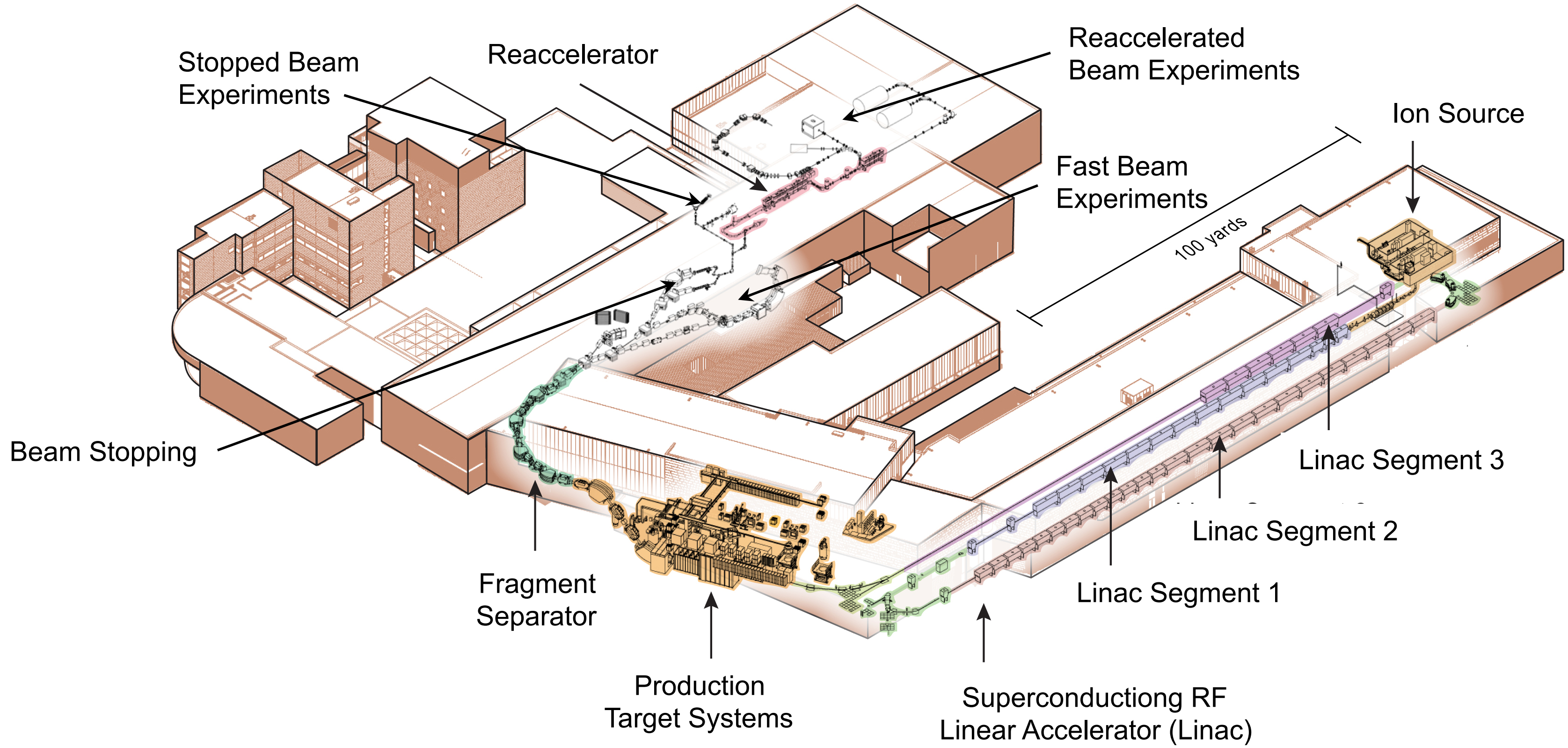
- In-flight production is fast and chemistry-independent
- Projectile fragmentation of all primary beams



- Projectile fission of heavy primary beams, specifically ^{238}U



FRIB Facility Overview
Rare Isotope Beams for Science



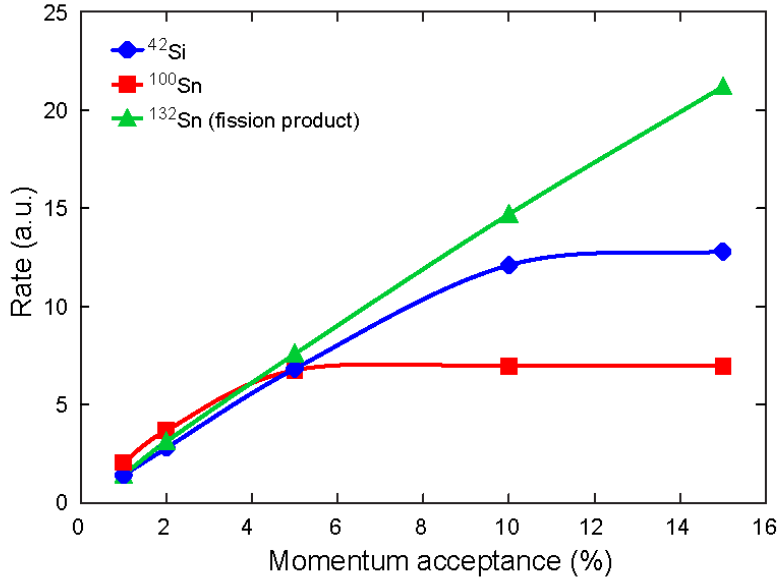
- Driver LINAC: accelerates all ion species to ≥ 200 MeV/u at power up to 400 kW
  - Upgradable to 400 MeV/u
- Fragment separator: in-flight production and separation of rare isotopes
- Science with fast, stopped, and reaccelerated rare isotope beams

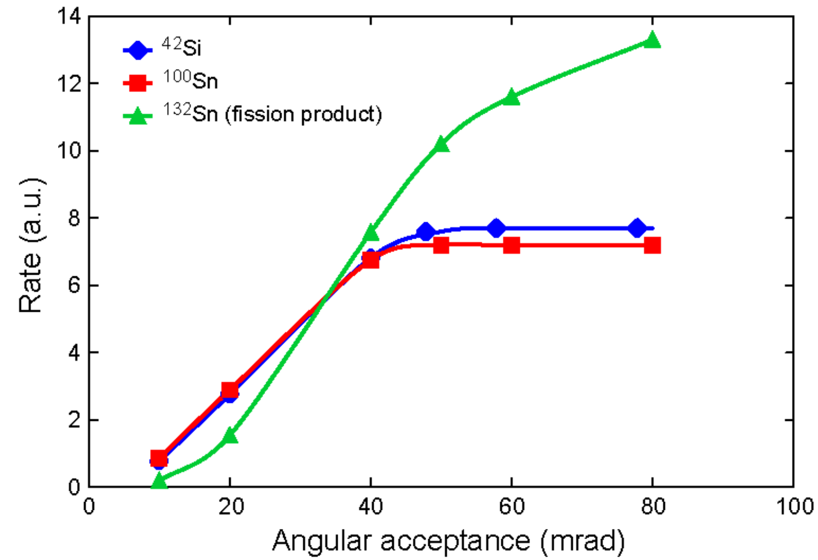
Fragment Separator Design Goals
Utilize 400 kW Primary Beam to Maximize Science Results

- Efficient collection of rare isotopes to leverage production at 400 kW
  - Angular acceptance of ± 40 mrad and momentum acceptance of ± 5 %
  - Projectile fragments and fission fragments to maximize FRIB facility reach
- Clean rare isotope beams to enable world-class experiments
  - Three stage separation overcomes contamination from secondary reactions
- Tunable to any rare isotope for maximum science reach
  - Design rigidity of 8 Tm covers essentially all possible nuclides
- Meeting challenges of operation at 400 kW
  - Advanced concepts for production target and beam dump to mitigate high-power density, radiation damage
  - Sufficient shielding to deal with high radiation fields
  - Use of radiation resistant components (magnets)
  - Remote handling of activated components
- Compatible with FRIB upgrade option of beam energies ≥ 400 MeV/u
  - Magnetic rigidity range up to 8 Tm covers > 2/3 of isotopes at upgrade energies

Fragment Separator Acceptance Goal

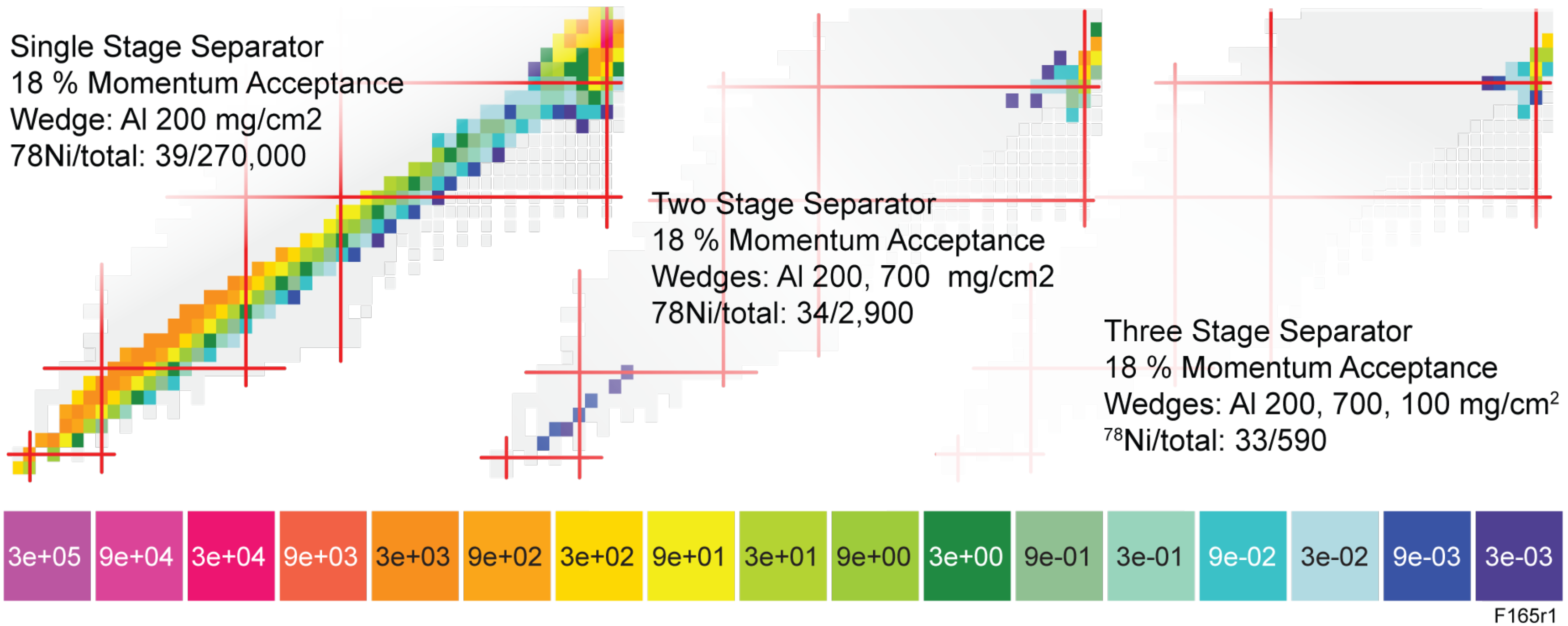
- Parametric study of particle rate at experiment as function of acceptance parameters
  - Studied ^{42}Si, ^{100}Sn, ^{132}Sn
  - At 200 MeV/u primary beam energy
- Acceptance of ±40 mrad in angles and ± 5 % in momentum
  - Effective collection of fragmentation product
  - Acceptable for fission fragments





Rare Isotope Beam Purity

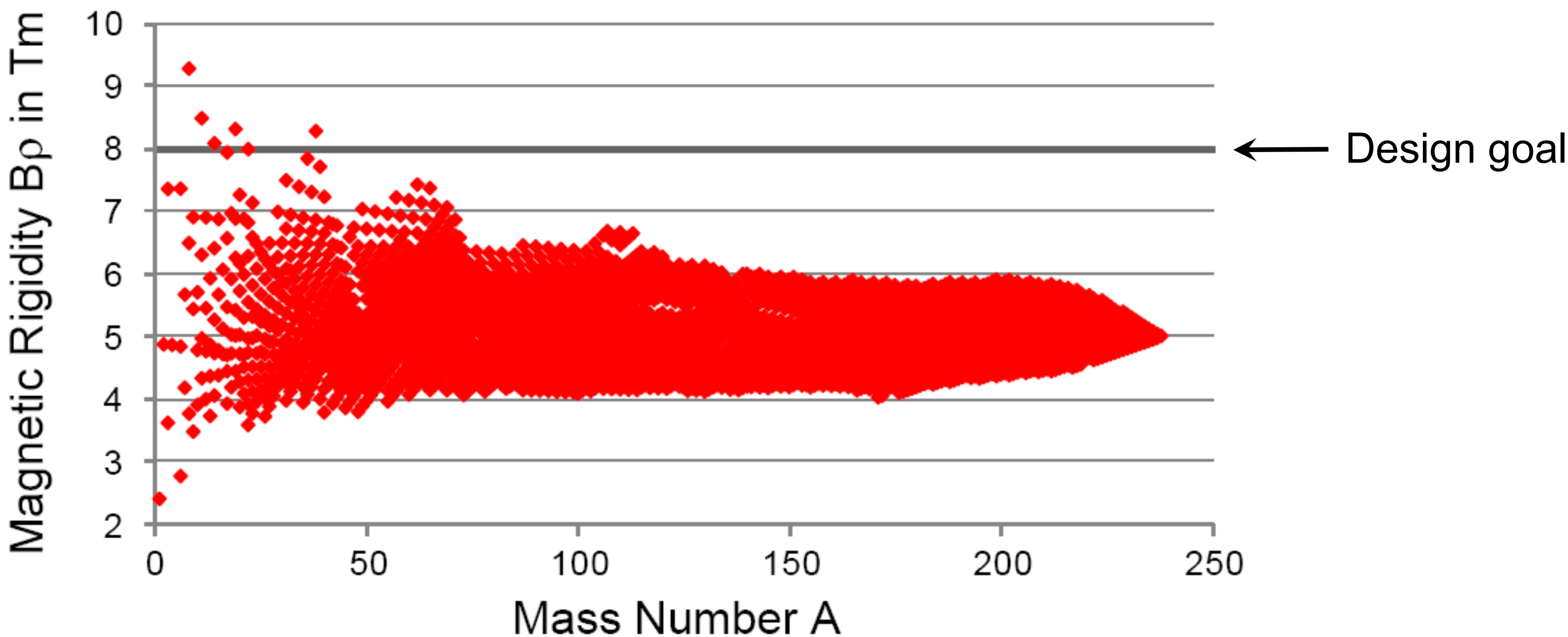
- Three stage separator for optimum beam purity
  - Example: ^{78}Ni from 253 MeV/u ^{86}Kr (calculated w/ LISE++ version 8)



- Second stage overcomes most of secondary reaction induced contamination
- Third stage in case of thick 2^{nd} wedge or for momentum tagging

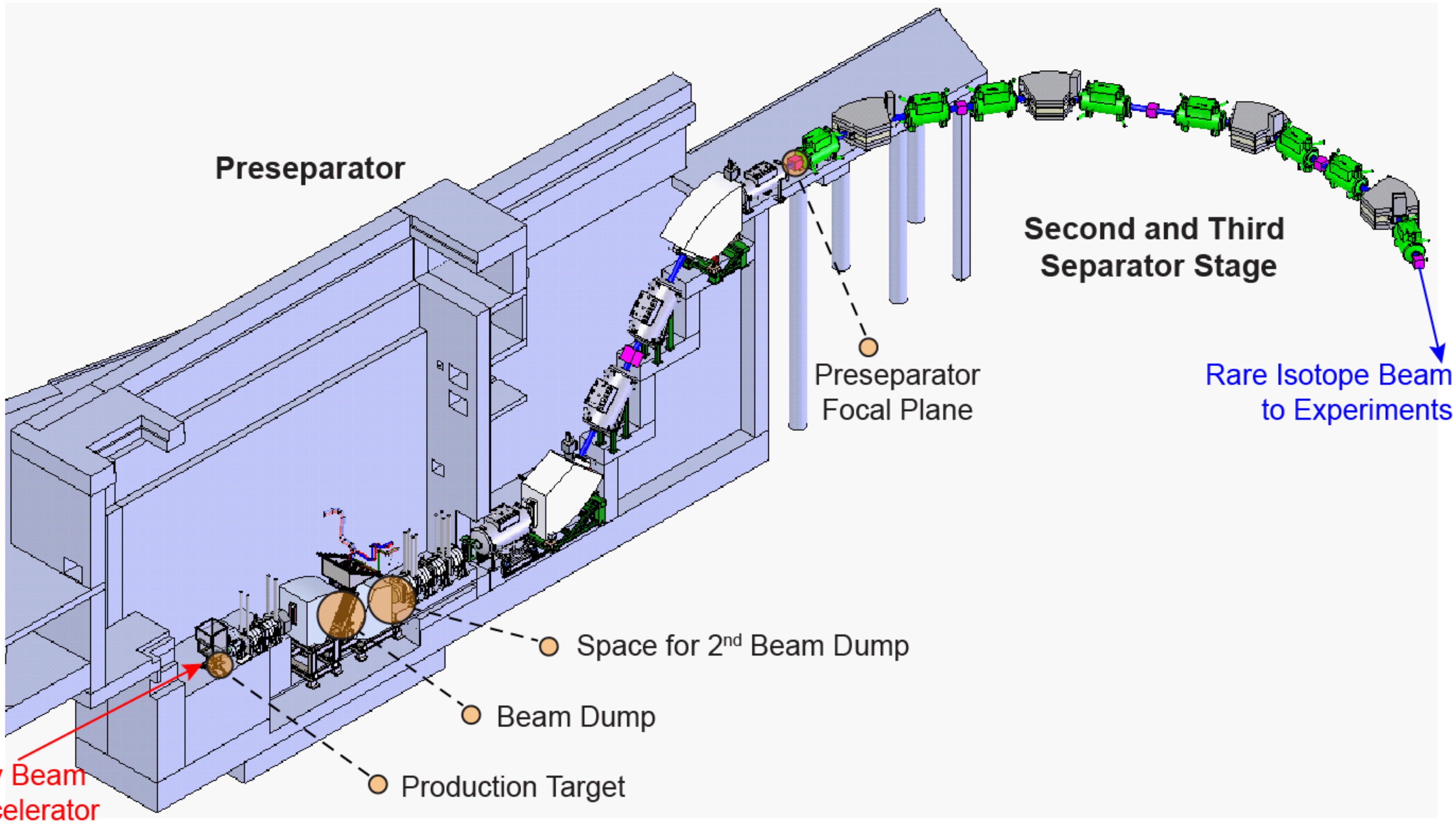
Magnetic Rigidity Requirement

- Design rigidity $B\rho_{max}$ = 8 Tm covers basically all beams at optimum conditions
  - Assuming typical target thickness: 30% of range of primary beam (d/R = 0.3)
  - Compatible with energy upgrade to 400 MeV/u
    - » 8 Tm covers around 80% for high-Z beams and more than 2/3 of isotopes overall



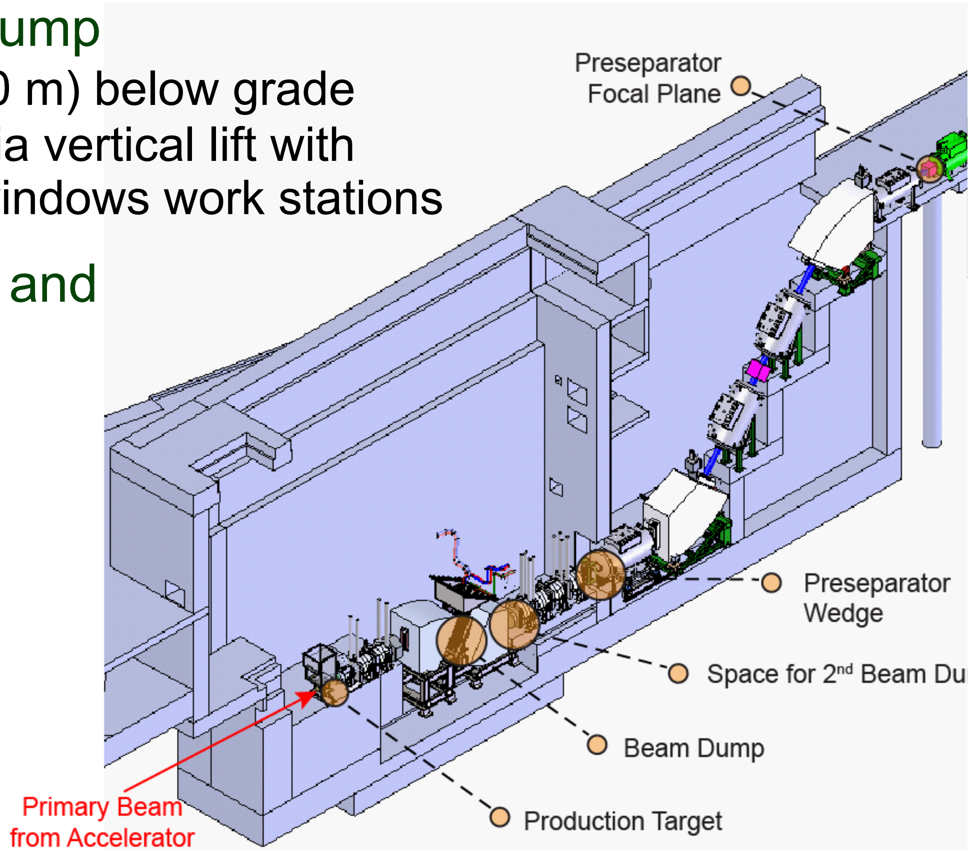
FRIB Fragment Separator Design Overview

- Vertical preseparator followed by two horizontal separator stages



FRIB Preseparator

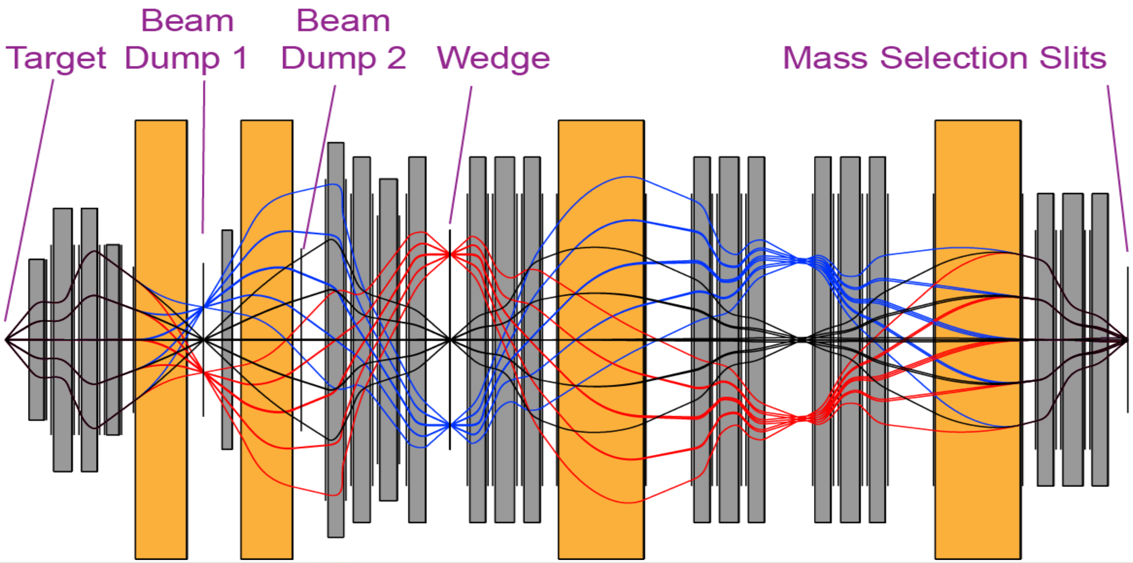
- Provides first separation of rare isotopes and stops primary beam
  - Intercepts the primary beam
  - Momentum cut and first mass separation of rare isotopes
- Houses production target and beam dump
  - Major radiation sources located 30 ft. (10 m) below grade
  - Component maintenance/replacement via vertical lift with remote controlled overhead crane and windows work stations
- Connects to separator stages 2 and 3 and existing grade level beam distribution system
- Is momentum compressing achromat
  - Matches 10% momentum acceptance to following separator stages and NSCL beam lines
  - Momentum compression in vertical plane preserves horizontal emittance for efficient gas stopping



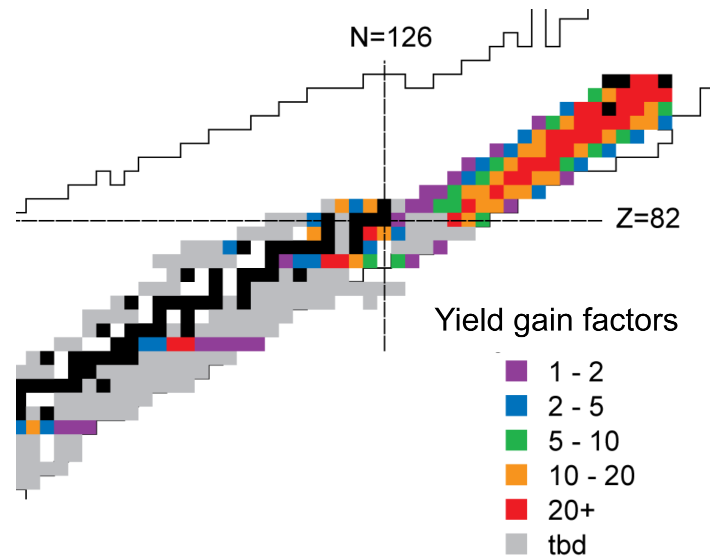
Preseparator Beam Physics Design
Versatile allows optimization for different rare isotopes

- Image and beam dump after 1st dipole → large acceptance for isotopes far from stability
- Image and beam dump after 2nd dipole → upgrade option for heavy rare isotopes near stability
- Aberration correction for entire fragment separator (typically 76 parameters)
  - Optimization using particle swarm optimizer

Beam dump 1 ion optics: trajectories (1st order) for angles of ±40 mrad and momentum $\delta_P = +5\%, 0, -5\%$



Yield gain for specific isotopes with 2nd beam dump



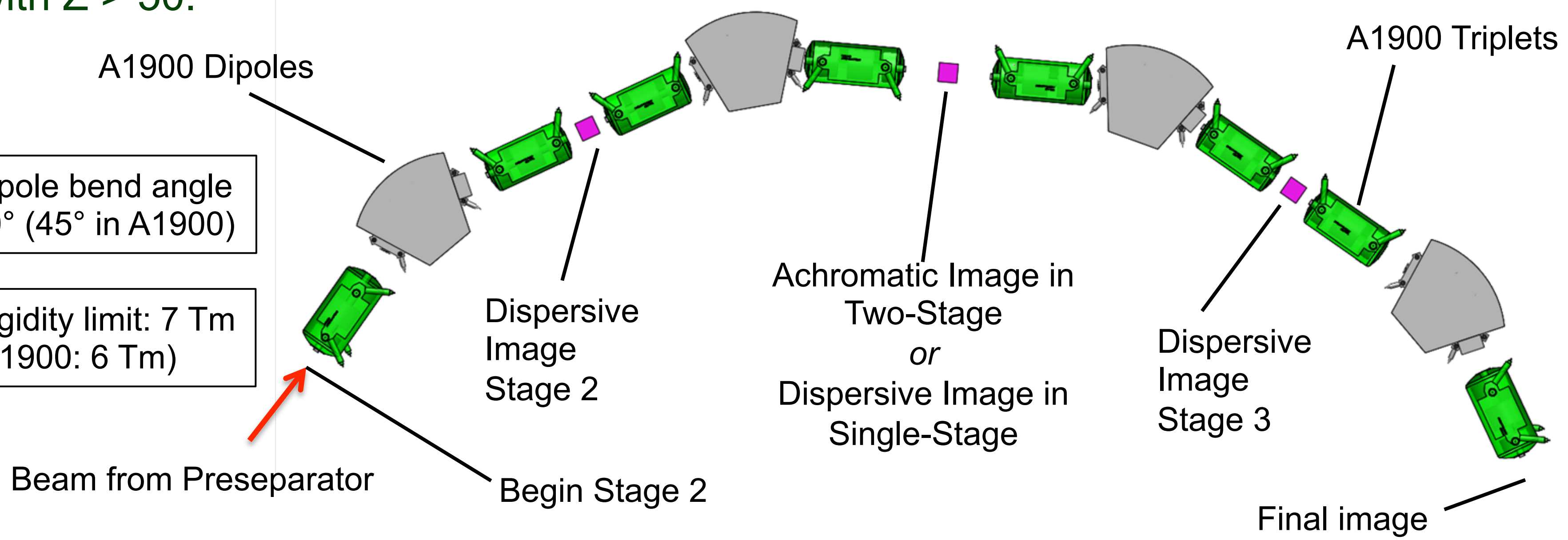
Versatile Operation of Separator Stages 2 and 3

Multiple operational modes allow optimization for different types of experiments

- Two-stage separation: beam purity for very exotic nuclei
  - Cleanup of contamination from secondary reactions in upstream wedges
- Momentum/phase space tagging in 3rd stage: improved gamma ray Doppler correction and in-flight particle – ID for experiments on multiple isotopes in cocktail beams
- Single stage separation: in-flight identification of atomic charge state for rare isotopes with Z > 50.

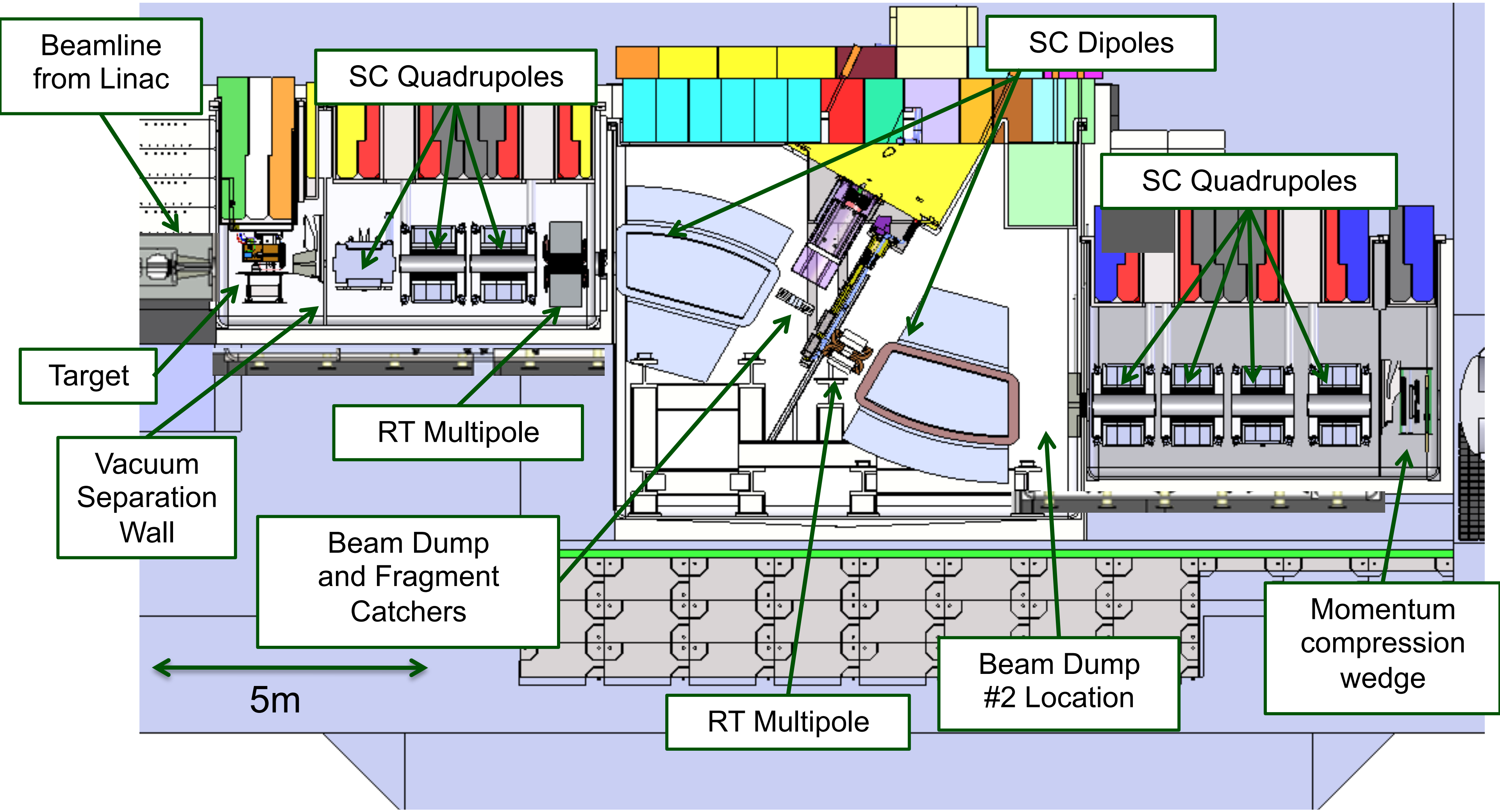
Dipole bend angle
30° (45° in A1900)

Rigidity limit: 7 Tm
(A1900: 6 Tm)



- Constructed from existing A1900 magnets with sextupole and octupole correction coils
  - Improved field description based on mapping of spare A1900 triplet → poster by M. Portillo

Preseparator Mechanical Design
Side View of Front End



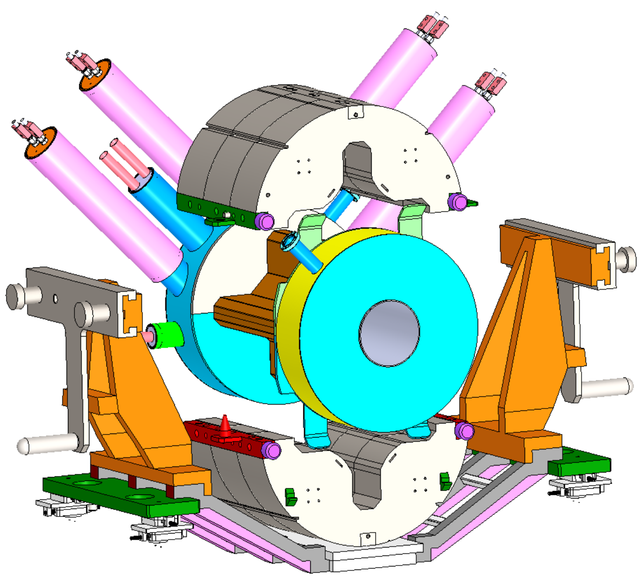
FRIB Production Target
Rotating Multi-slice Graphite Target for 400 kW Operation

- 400 kW beam focused to 1 mm diameter spot size
  - Deposited power ~ 100 kW, power density 20 - 60 MW/cm^3
  - Power density and multi-slice operation demonstrated through electron beam tests at SARAF, SANDIA, and BINP
- Annealing of radiation damage at operating temperature (1200 - 1900 ºC) verified with heavy ion irradiation at GSI
  - See talk by F. Pellemoine (Thursday, session VI, 9:00 am)

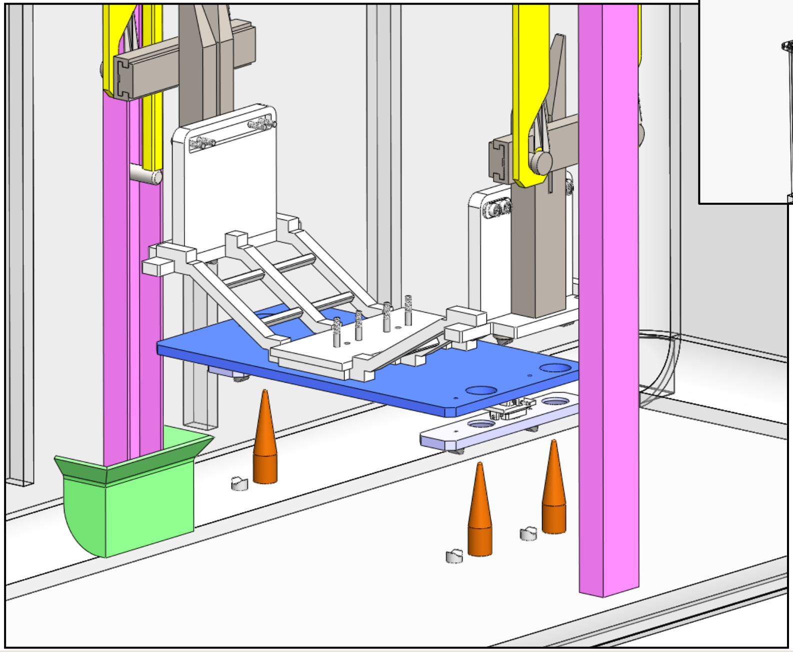
Fragment Separator Magnets

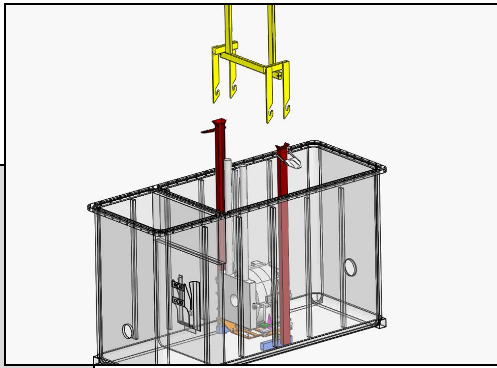
Radiation tolerant magnets in frontend crucial for efficient operation

- High temperature superconductor (HTS) and low temperature superconductor (LTS) with radiation tolerant epoxy
  - HTS radiation hardness verified at Brookhaven National Laboratory.
  - Expected HTS magnets lifetime ~ facility lifetime
- Remote handling design in collaboration with ORNL



BNL HTS quadrupole in handling cradle



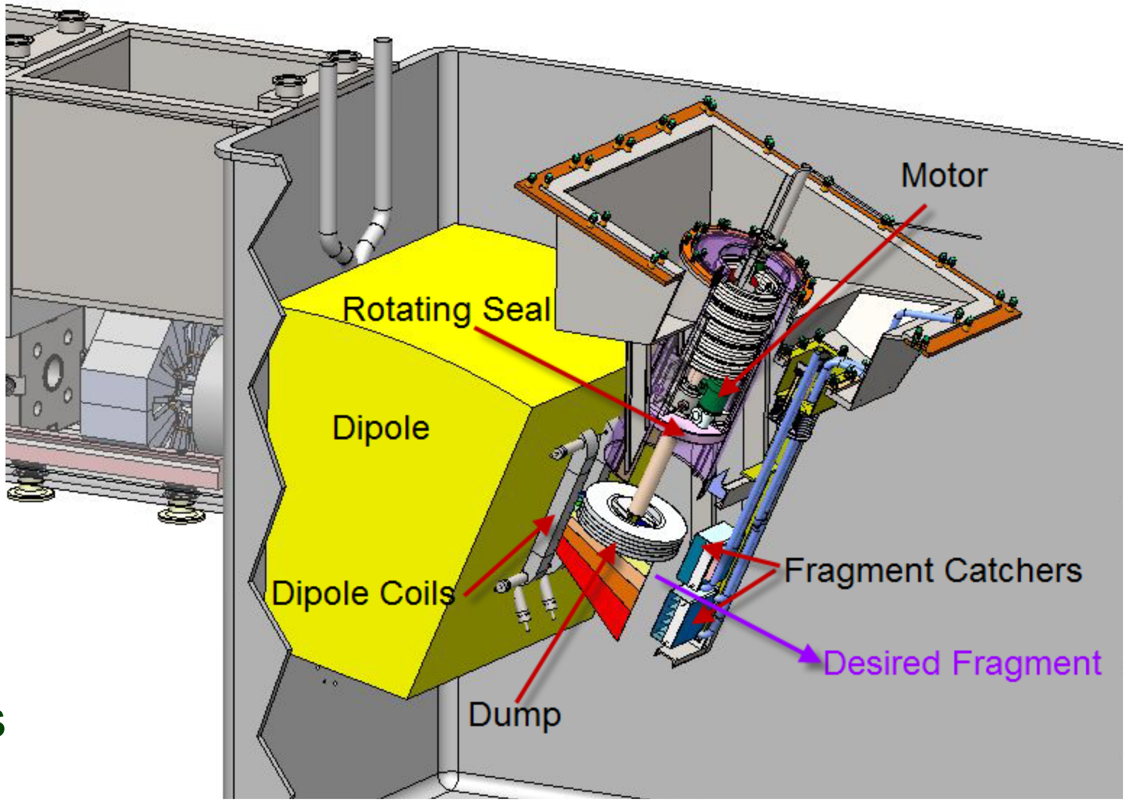


Lifting fixture directed by removable guides

Lifting fixture engages handling cradle

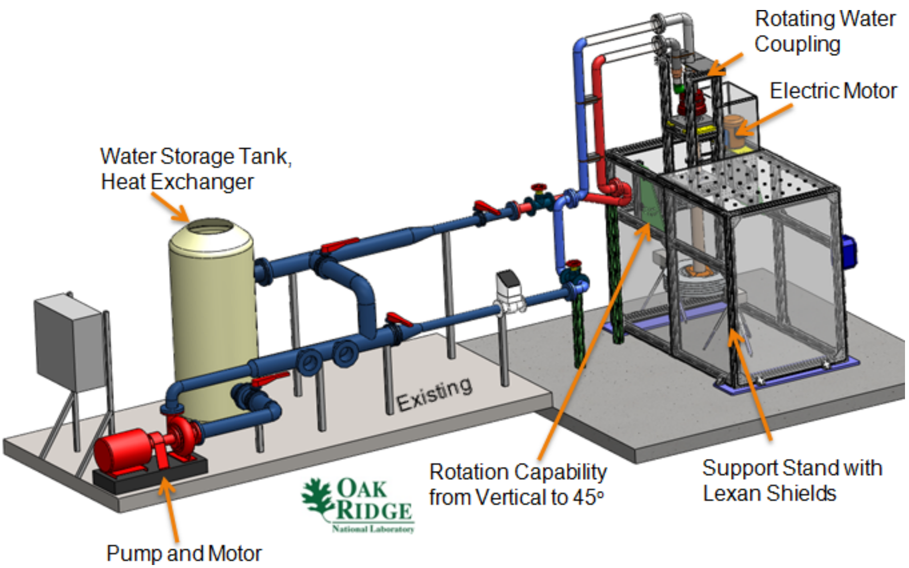
Primary Beam Dump
Water-filled Rotating Drum for 400 kW operation

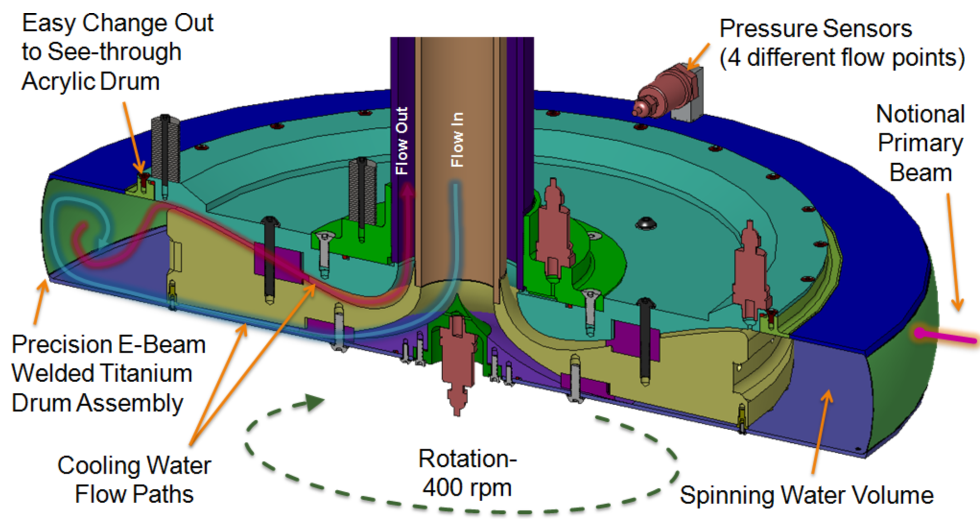
- Stop all primary beams with up to 325 kW absorbed beam power
  - Major challenges: high power density and radiation damage
    - » Efficient replacement/maintenance required,1 year lifetime desirable
- Water-filled rotating drum beam dump is concept chosen
  - Thin wall limits shell heat load
    - » 0.5 mm Titanium
  - Rotation spreads heat and radiation damage
    - » 400 rpm, 70 cm diameter
  - Water absorbs bulk of power and cools the shell
    - » Flow ~60 gpm
    - » **Also allows harvesting of rare isotopes from cooling water**
- Slit function provided by downstream fragment catchers



Primary Beam Dump Prototype

- Design verification program: flow mockup tests with prototype beam dump
  - Rotation speed, flow rates, pressure, bubble formation, cavitation, prototypic operation
- Prototype beam dump currently being assembled
  - Titanium shell drum for flow mockup tests
  - See-through acrylic drum for visual study of bubble formation, etc.
- Tests in spring 2013





Summary

- Fragment separator design for FRIB leverages rare isotope production with 400 kW primary beam
  - Efficient collection and separation of rare isotopes with large acceptance, three stage fragment separator
  - Versatile layout allows tailoring of separator settings to specific experiments
  - Isotope harvesting provisions included in fragment separator design
- Radiation transport and remote handling aspects are integrated parts of the fragment separator design
- Risks from beam power and radiation mitigated by successful R&D programs
  - Power density and radiation damage in production target
  - Power density and radiation damage in beam dump
  - Radiation tolerance of high temperature superconductor demonstrated
- FRIB fragment separator advanced design will maximize science