FRIB

Facility for Rare Isotope Beams: Never the Same Beam Twice

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Overview

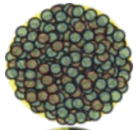
The Facility for Rare-Isotope Beams: Never the Same Beam Twice

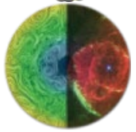
- Introduction to FRIB
  - Radiological environments
  - The many beams at FRIB
  - Shielding and shielding analysis
- Recent radiation transport case studies from the fragment separator
  - Canyon shielding reevaluated in detail for power ramp up
  - Measured vs calculated rates
  - Employing stable heavy ion as surrogate for its rare isotopes
  - Understanding which beams leave the Target Hall

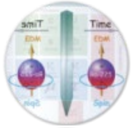
Work in collaboration with FRIB team: Georg Bollen, Rajarshi Pal Chowdhury, Juan Zamora

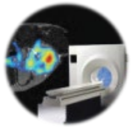
FRIB - Facility for Rare Isotope Beams
World-leading Next-generation Rare Isotope Beam Facility

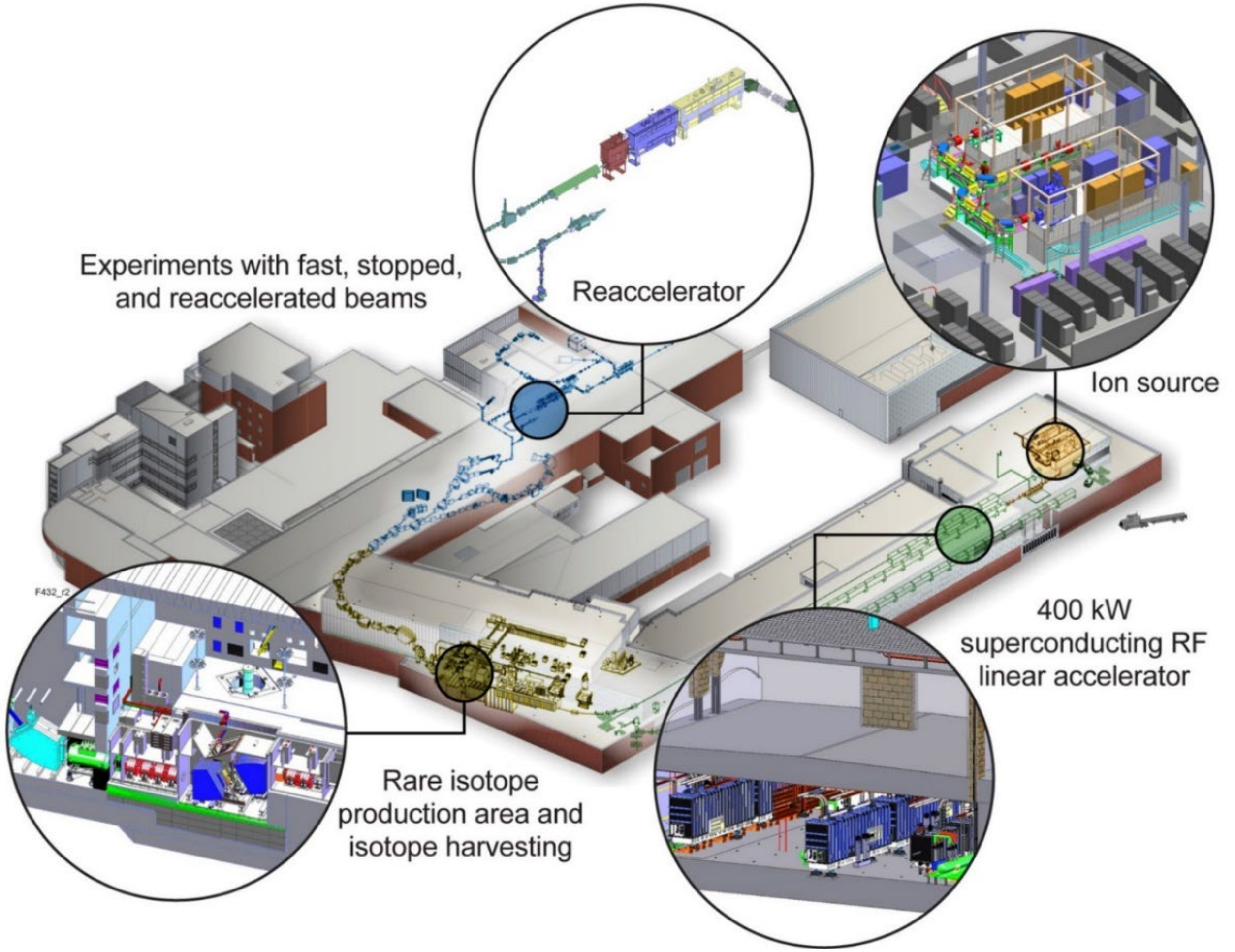
- Rare isotope production via in-flight technique with primary beams up to 400 kW, 200 MeV/u uranium
- Fast, stopped, and re-accelerated beam capability
- Experimental areas and equipment for science with fast, stopped, and reaccelerated beams
- FRIB started operation in May 2022
- Broad science addressed


Properties of nuclei


Astrophysical processes

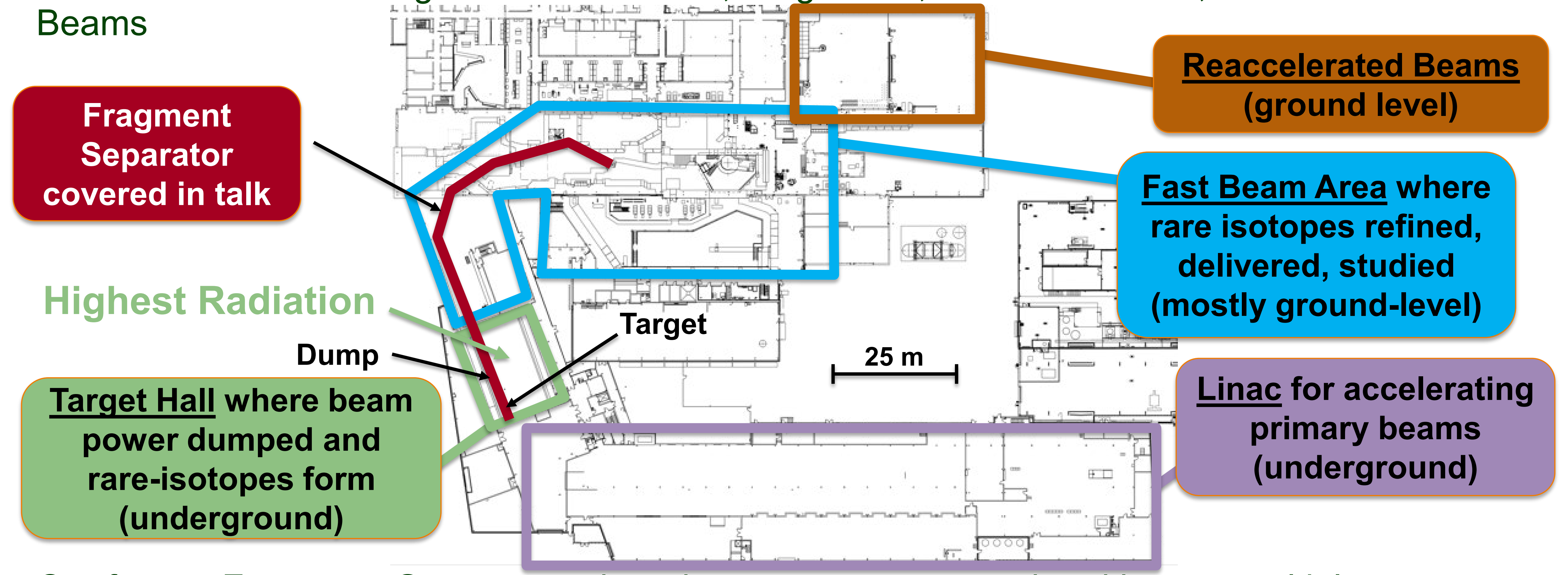

Tests of fundamental symmetries


Societal applications and benefits



FRIB's Different Radiological Areas
Highest Radiation in Target Hall Section of Fragment Separator

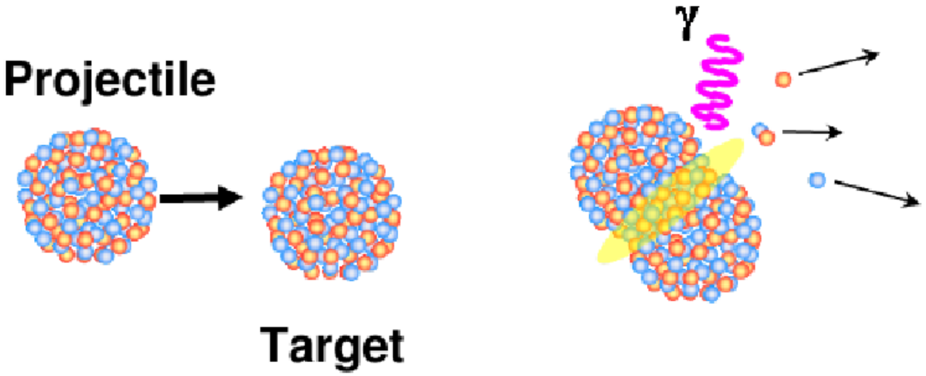
- FRIB's 4 distinct radiological realms: Linac; Target Hall; Fast Beam Area; Reaccelerated Beams

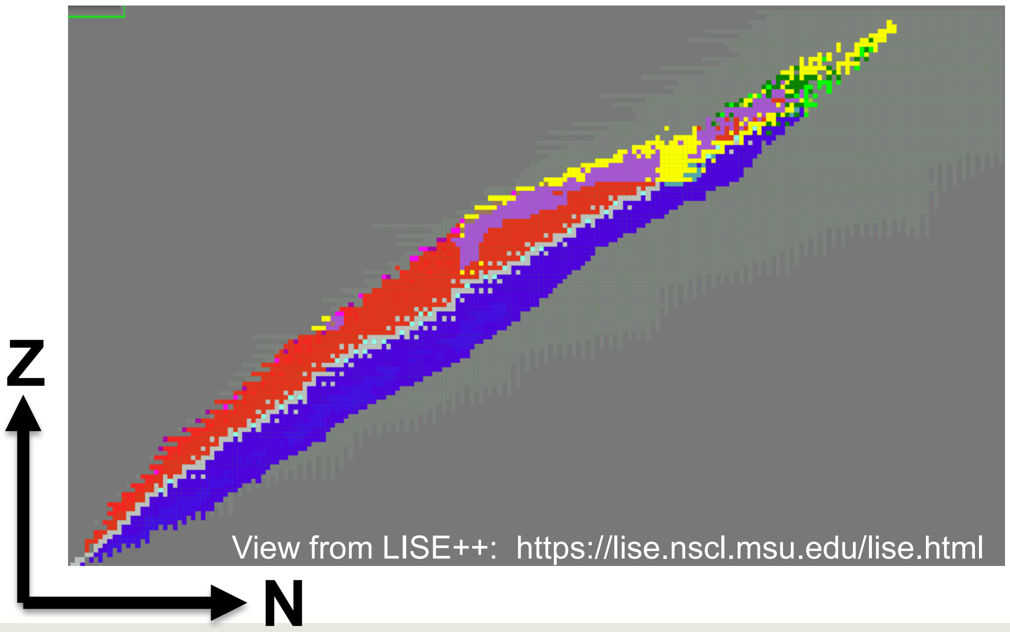


- Our focus: **Fragment Separator** where beam power managed and beams multiply

The Many Beams of FRIB
Heavy Ion Primary and Secondary Beams Change Frequently

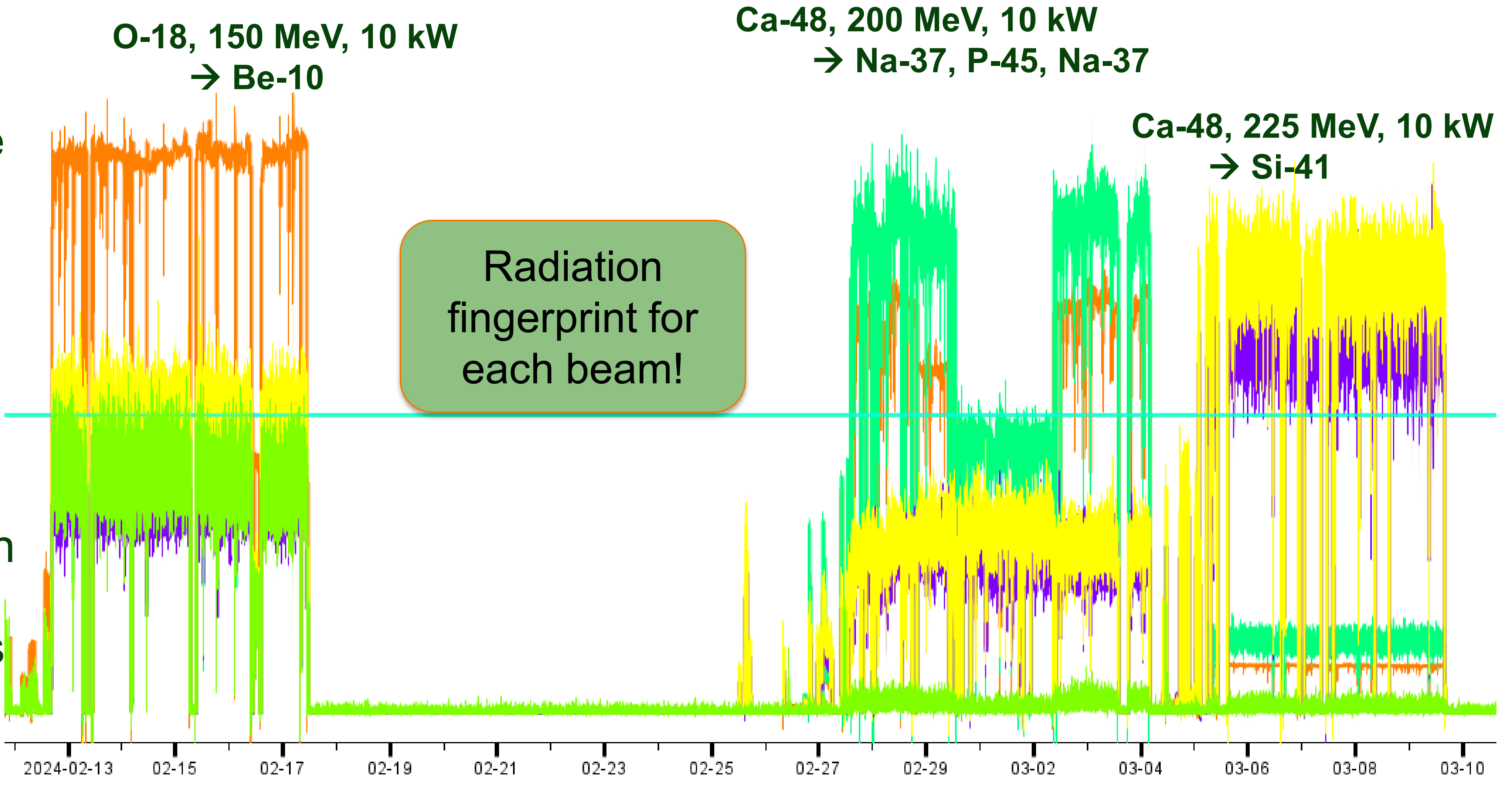
- FRIB accelerates not just one primary beam, but many heavy ions (stable isotopes) to produce rare isotopes: O-18, Ne-22, Si-28, Ar-36, Ar-40, Ca-48, …, U-238
  - Energy: Reaching 200 MeV/u for all beams, higher for lower masses
    - » World-leading linac for heavy ions
  - Power: 1 kw (start) → 10 kW (now) → 20 kW (this year) → 400 kW (ultimate)
    - » World-leading for uranium
- Rare-isotopes produced as secondary beams by in-flight fragmentation/fission of heavy ions
  - Rare-isotope beam power on order of 1 W but can be higher
- Experimental science program demands different beams every few days, if not every few hours





Beam Changes → Radiation Level Changes
Neutron Monitor Readings

- Plot shows readings from neutron monitors in and around the Fast Beam Area in response to different beams over a few weeks
- Labels show the various primary and rare-isotope beams being run
- Every beam is unique in terms of radiation rankings and intensities at each location

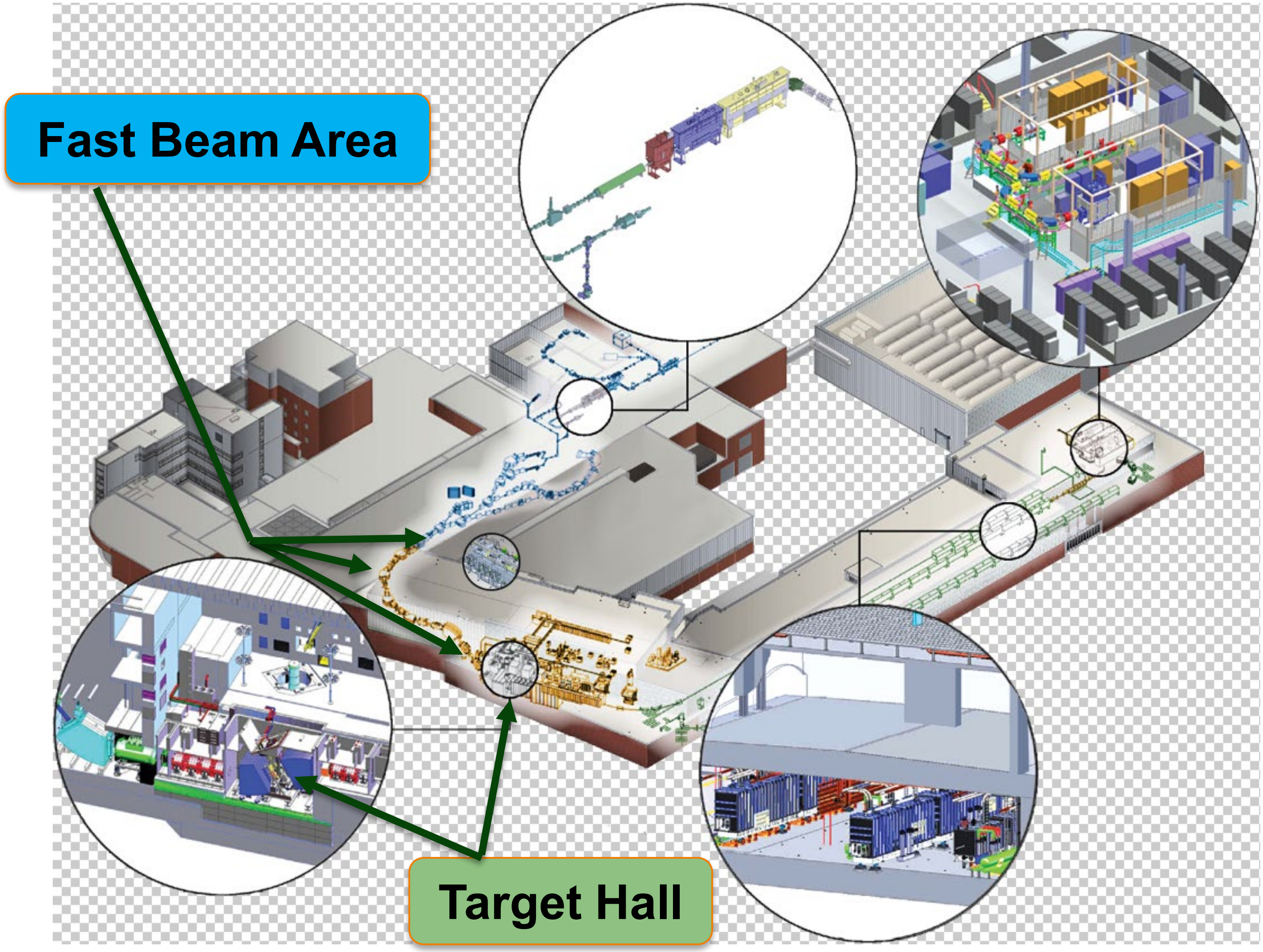


Wide Range of Beams in Different Facility Areas Requires Adequate Shielding as FRIB Power Ramps Up

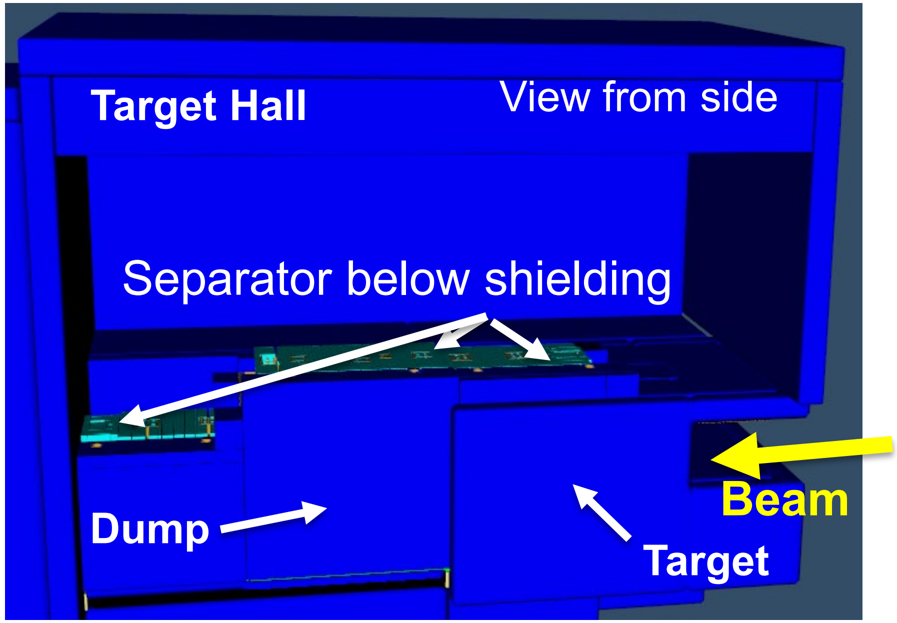
- FRIB approach to shielding
  - **Design basis enables what will be needed at full power**
    - » Shielding that can't be added later was already addressed during facility construction
      - Enough underground shielding for Linac Tunnel and Target Hall to protect ground water
      - Planning focused on limiting, worst-case scenarios
    - » Enough shielding in place at end of construction for early years of operation
  - During power ramp-up add shielding based on measurements and further simulations
    - » Only as needed
    - » As informed by operational experience
    - » To address new facility additions
- Current shielding analysis approach
  - Evaluate dynamically and with a more granular view
  - **Still a powerful tool:** use worst cases to cover the many-beam scenario

Case Studies from the Fragment Separator

- In Target Hall
  - Canyon shielding reevaluated in detail for power ramp up
  - Measured vs calculated rates
- In Fast Beam Area
  - Employing stable heavy ion as surrogate for its rare isotopes
  - Understanding which beams leave the Target Hall



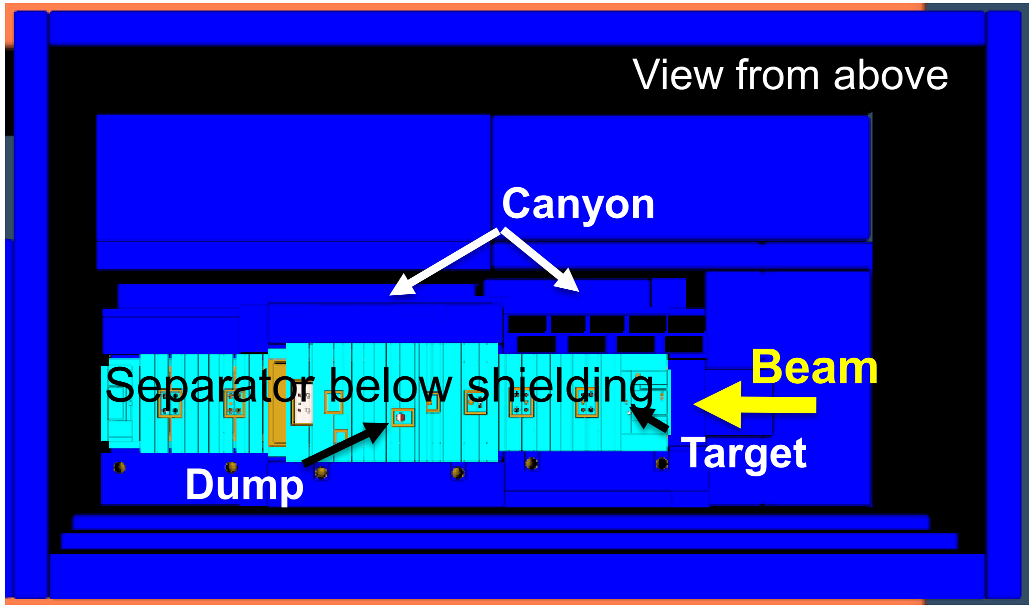
Target Hall Environment
Access Needed When Beam is Off



- When beam is on (most of the time) intense prompt fields from dumping multiple kW of beam in separator
- Strong residual fields from highly activated separator parts undergoing remote maintenance

Target Hall generally not a nice place!

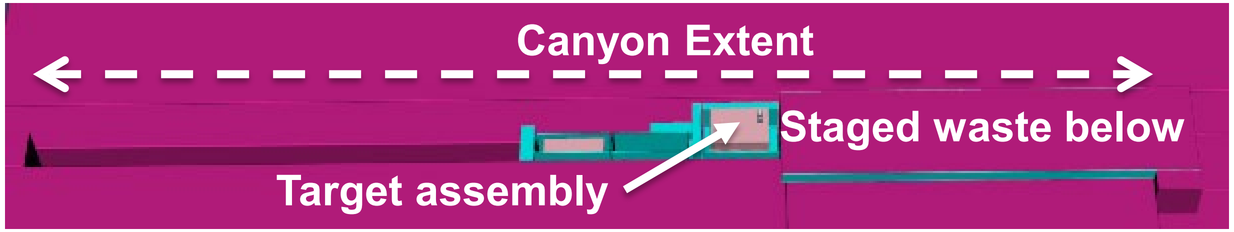
- Canyon
  - A place to hide activated parts and waste to allow access when beam is off
  - Requires adequate shielding on top



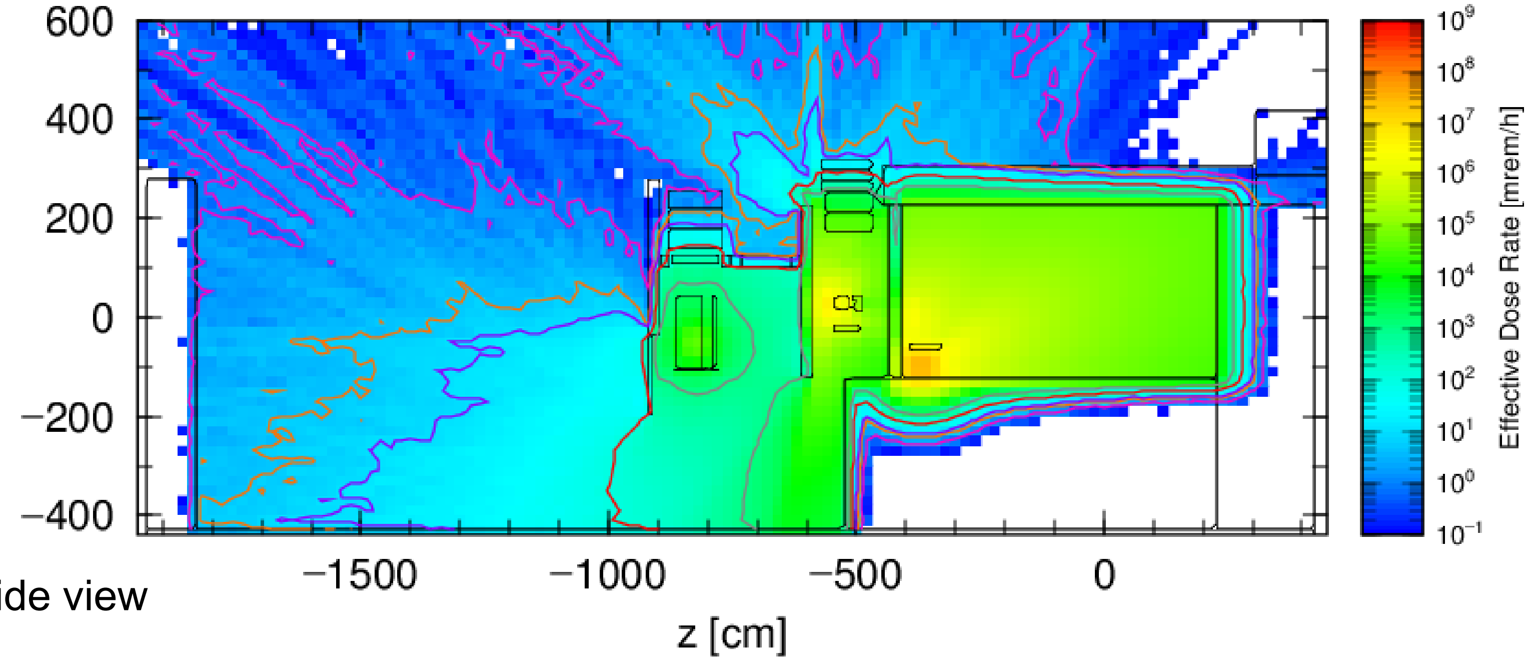
Views from radiation transport model of Target Hall

Canyon Shielding Revaluated in Detail for Power Ramp Up
1st Target Hall Example

- Original analysis
  - Completed 9 years ago
  - Established shielding thickness, not details
- Recent analysis
  - Confirms early results in context of present plans
  - Supports **detailed design** of shielding and equipment support stands **based on recent experience managing work in the Target Hall**
  - Assumed worst-case scenarios for Target Hall use



top view

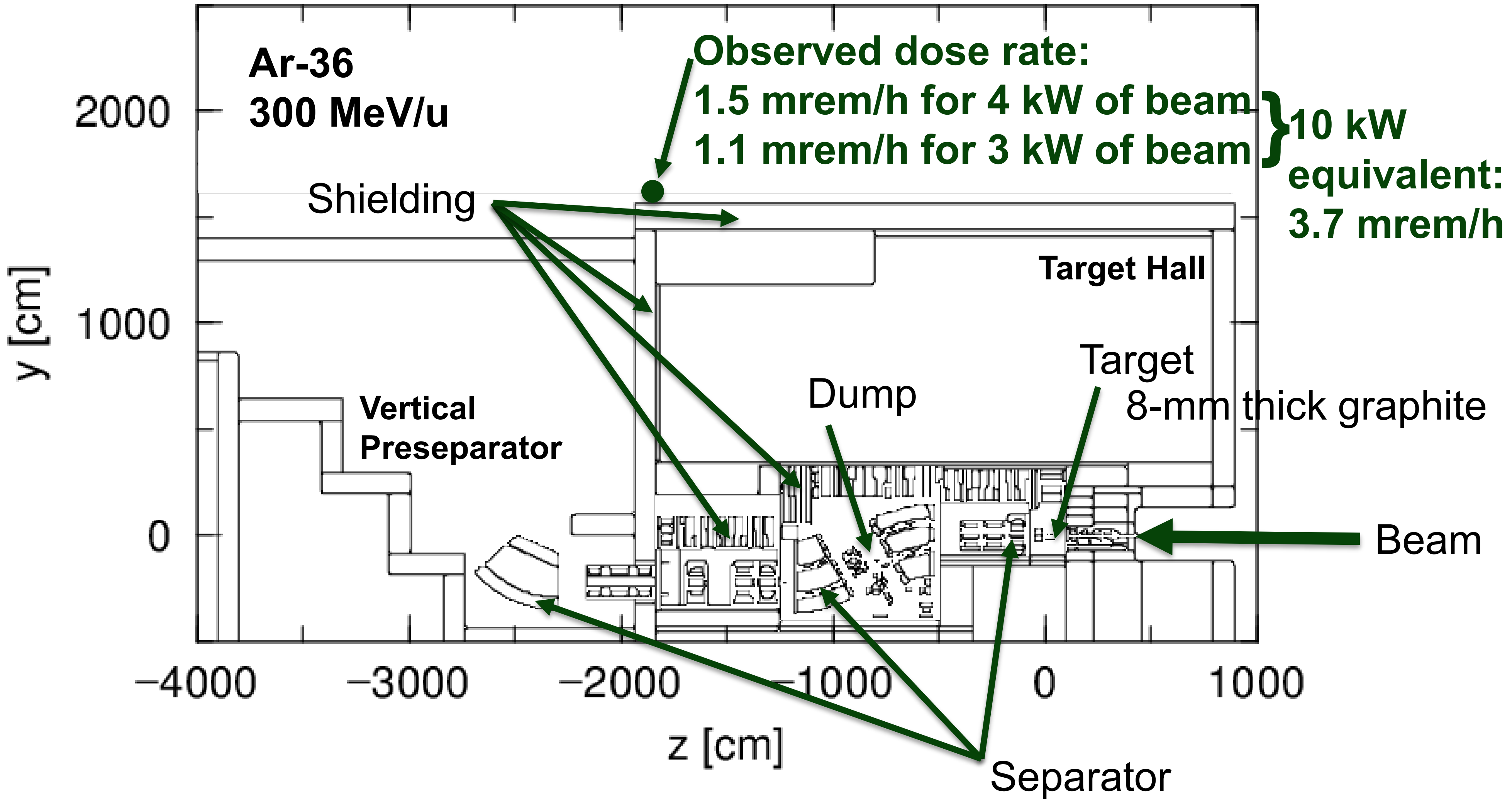


side view

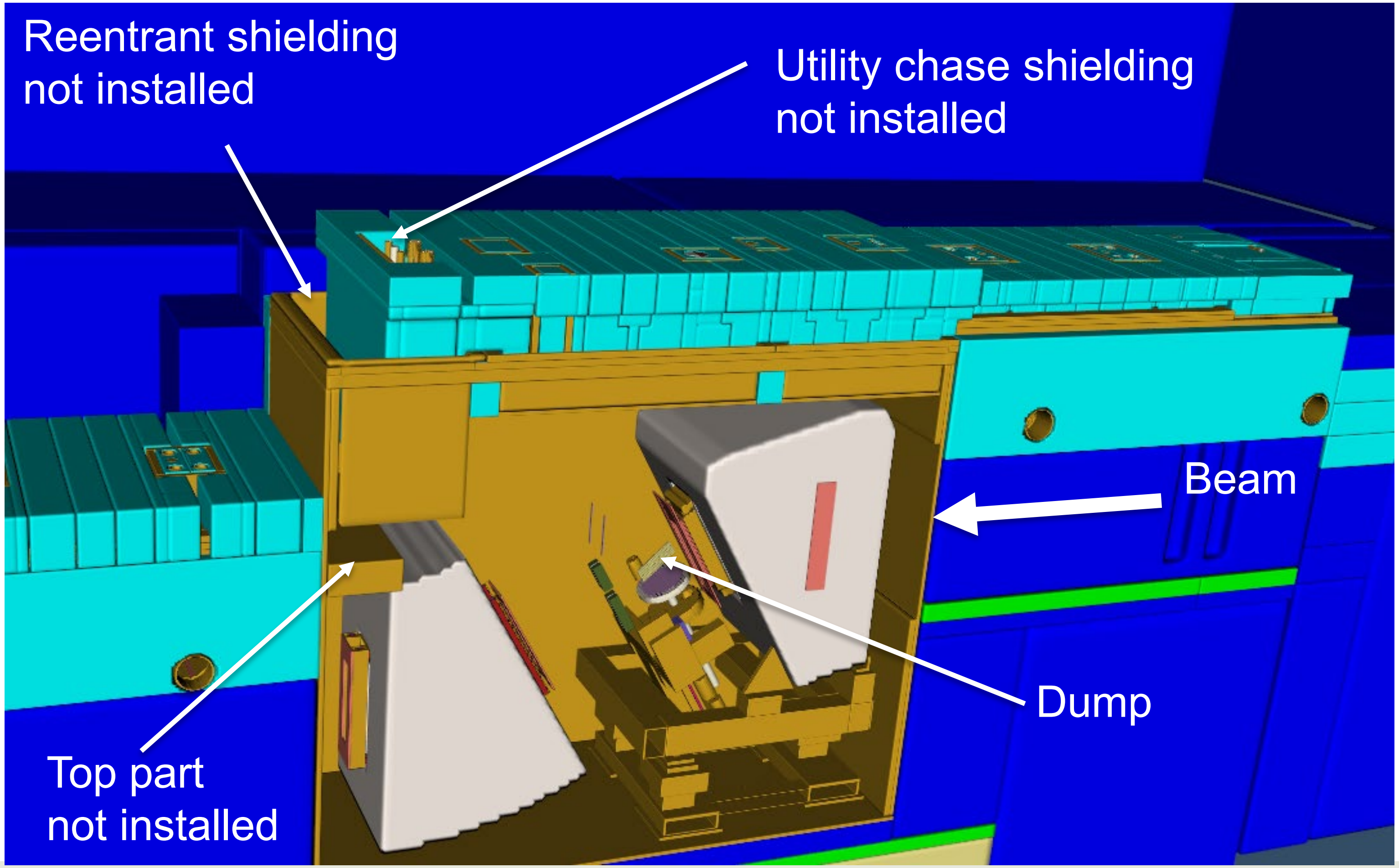
Must anticipate wide range of beams and resulting part activation over the next 30 years

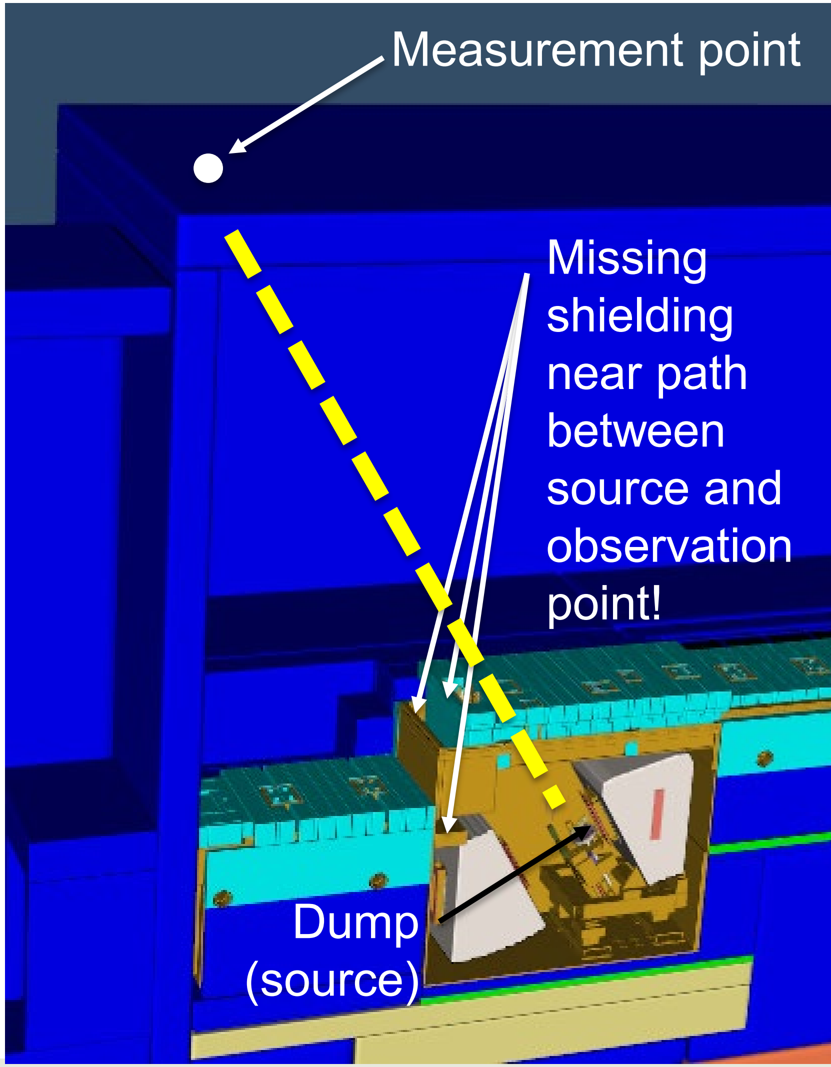
Measured Rates Compared to Simulation
2nd Target Hall Example

- This beam caught our attention – potent combination of low-Z, high energy
- Measured rates on shielding roof 5x higher than expected based on simulations with full shielding in place



Measured vs Calculated Rates
Full Initial Shielding Not Yet Installed!





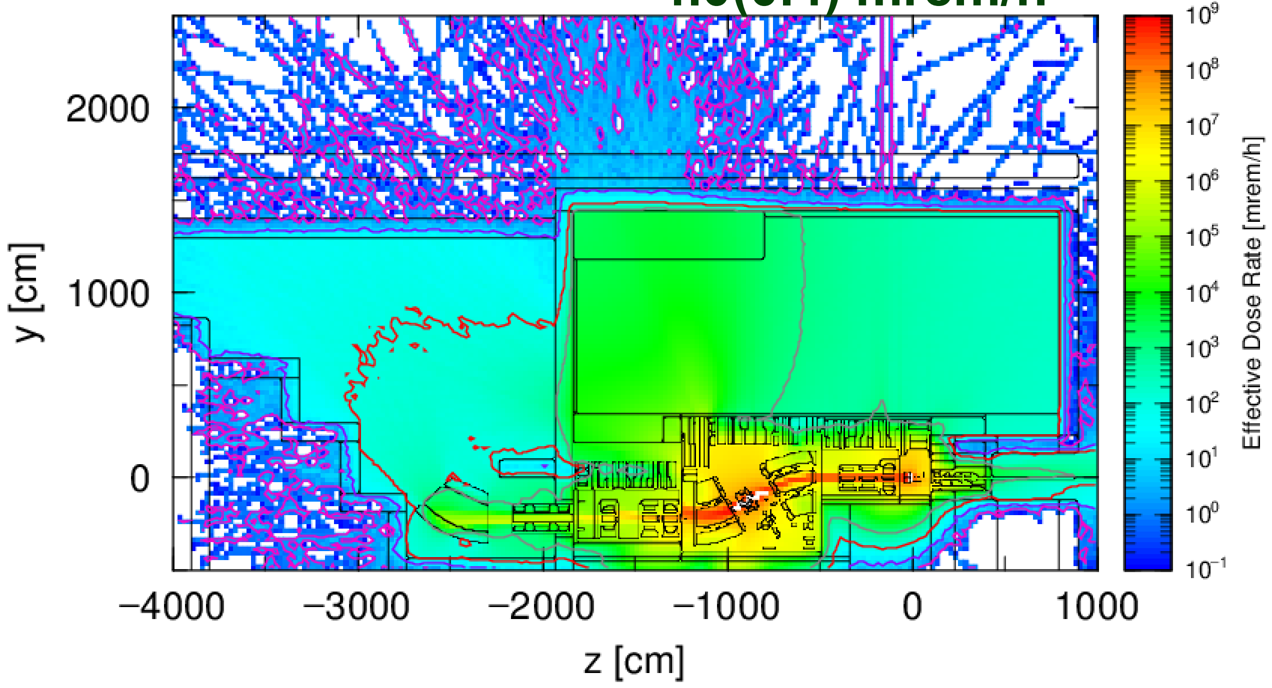
Measured vs Calculated Rates
Corrected Model → Good Agreement

Simulate again!

(Observed: 3.7 mrem/h)

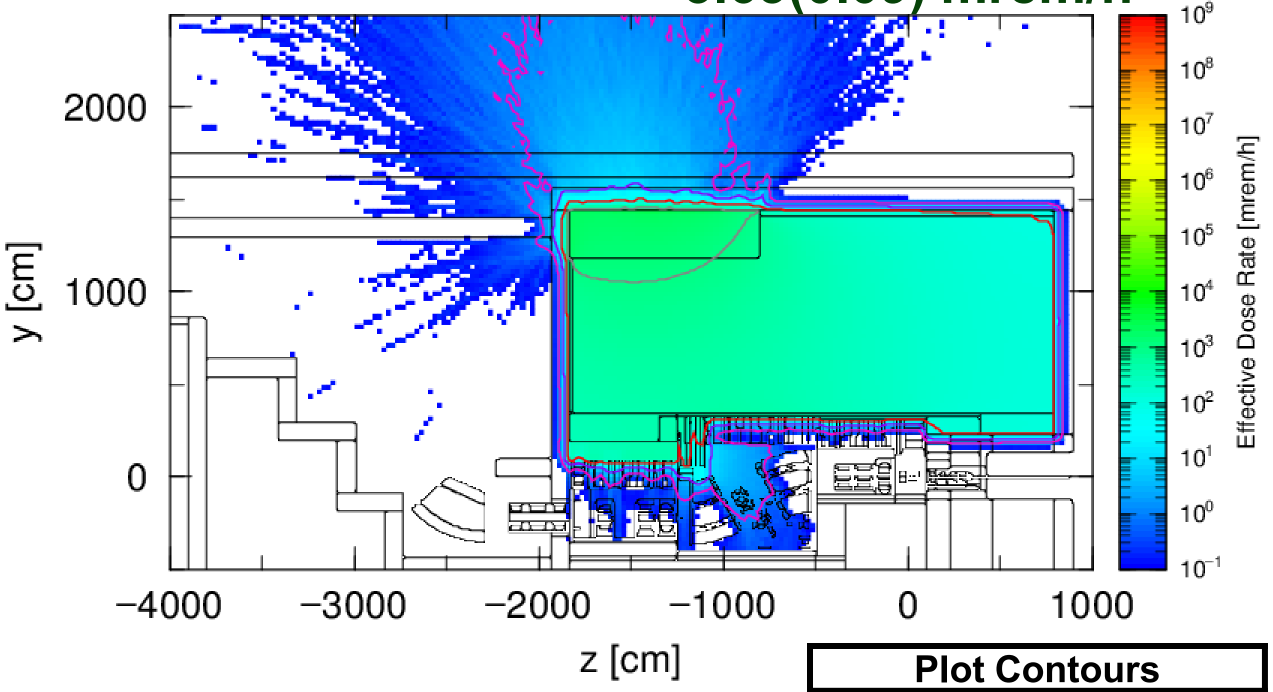
1-Step Simulation (Run for High Statistics)

4.0(0.4) mrem/h



2-Step Simulation

3.63(0.09) mrem/h

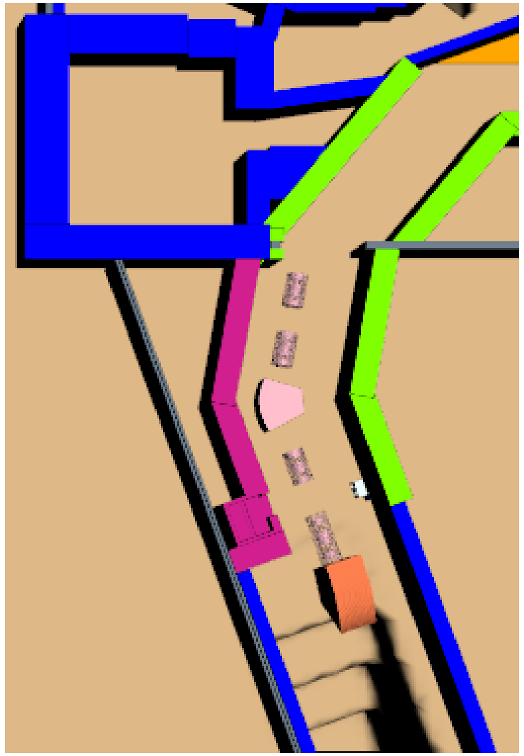


White areas in maps are >100,000 or <0.1 mrem/h

Plot Contours	
1 mrem/h	Magenta
10 mrem/h	Violet
100 mrem/h	Red
1000 mrem/h	Gray

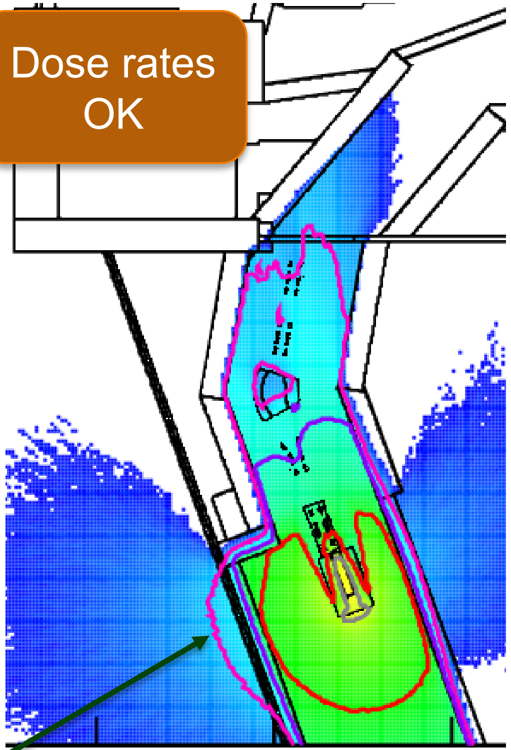
Primary Beam as Surrogate for Its Rare Isotops

1st Fast Beam Area Example – A Strategy for Dealing with Many Beams



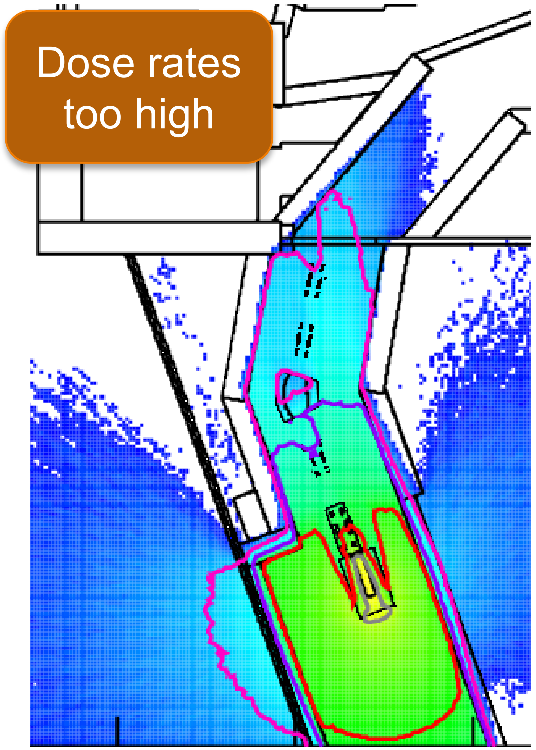
Location used for Matching contours

Ca-48, 257 MeV/u, 1 W



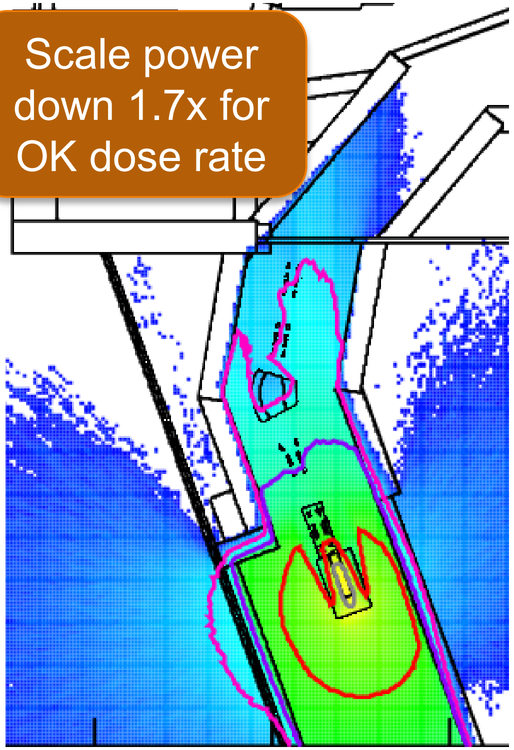
Plot Contours	
1 mrem/h	Magenta
10 mrem/h	Violet
100 mrem/h	Red
1000 mrem/h	Gray

Si-28, 320 MeV/u, 1 W

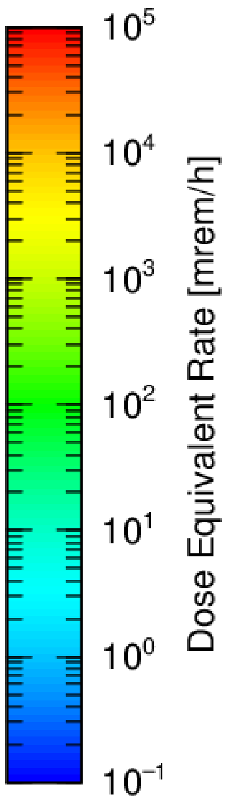


Plot Contours	
1 mrem/h	Magenta
10 mrem/h	Violet
100 mrem/h	Red
1000 mrem/h	Gray

Si-28, 320 MeV/u, 1 W



Plot Contours	
1.7 mrem/h	Magenta
17 mrem/h	Violet
170 mrem/h	Red
1700 mrem/h	Gray



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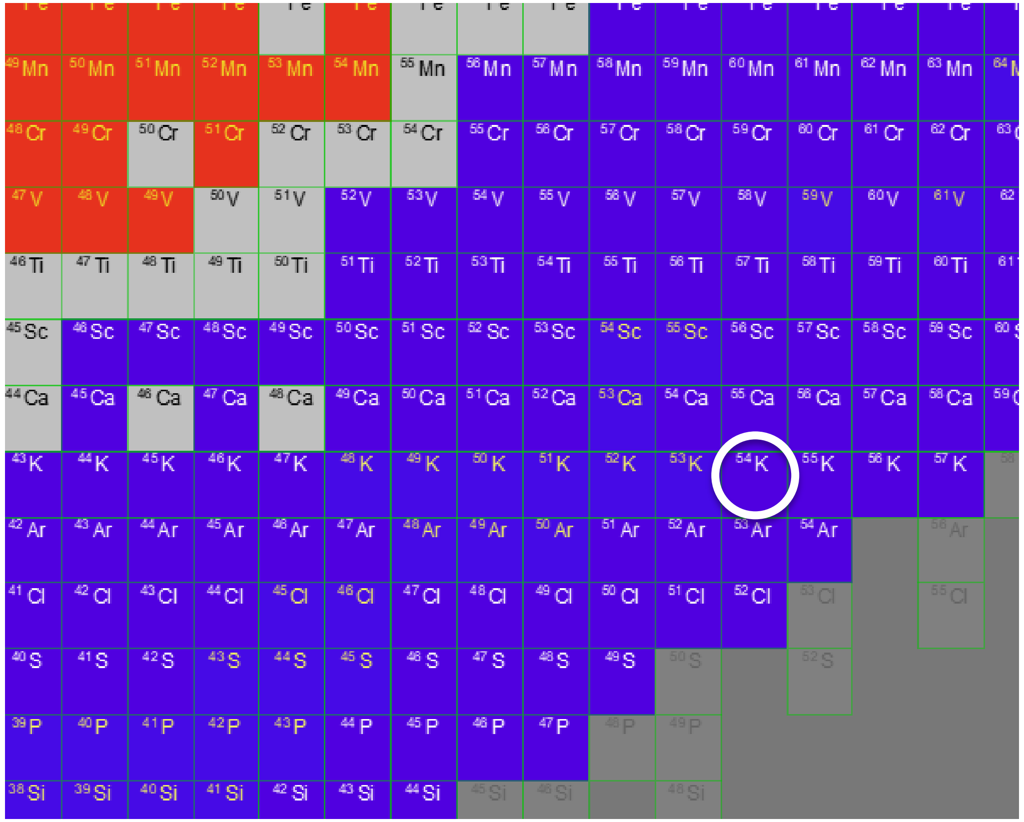
Caveat: Understand Which Beams Enter Fast Beam Area

2nd Fast Beam Area Example

- Primary beam: Se-82, 215 MeV/u, 10 kW used to produce the rare isotope K-54, 170 MeV/u
  - Rate **<1.5 particles/s**, Exotic!!!
- Higher radiation observed than expected from surrogate
- Reason: in addition to K-54, other fragments left the Target Hall and stopped at the point of reference
  - Had almost same rigidity as K-54
  - ~50% H-3 at 150 MeV/u
  - ~50% H-2 at 310 MeV/u
  - Beam power of 0.2 W!
- These H isotopes significantly worse than Se-82 surrogate at same power in terms of radiation impact
  - Higher average specific energy
  - More chances for nuclear interactions
    - » ~10x higher particle rate and higher range



Conclusion

- Radiation transport work at FRIB takes place in the context of beam conditions that almost never repeat
- These examples show that – while it is good to use simplifications wherever possible to address the complexity of many beams – we must understand the limitations
- Other SATIF-16 work from FRIB to address the many-beam challenge
  - Talk "Bayesian Uncertainty Quantification for Radiation Transport Calculations at FRIB" by Juan Zamora (this afternoon)
  - Poster "Applications of Machine Learning in Radiation Shielding at FRIB" by Rajarshi Pal Chowdhury

Thanks for your attention!