FRIB Fragment Separator

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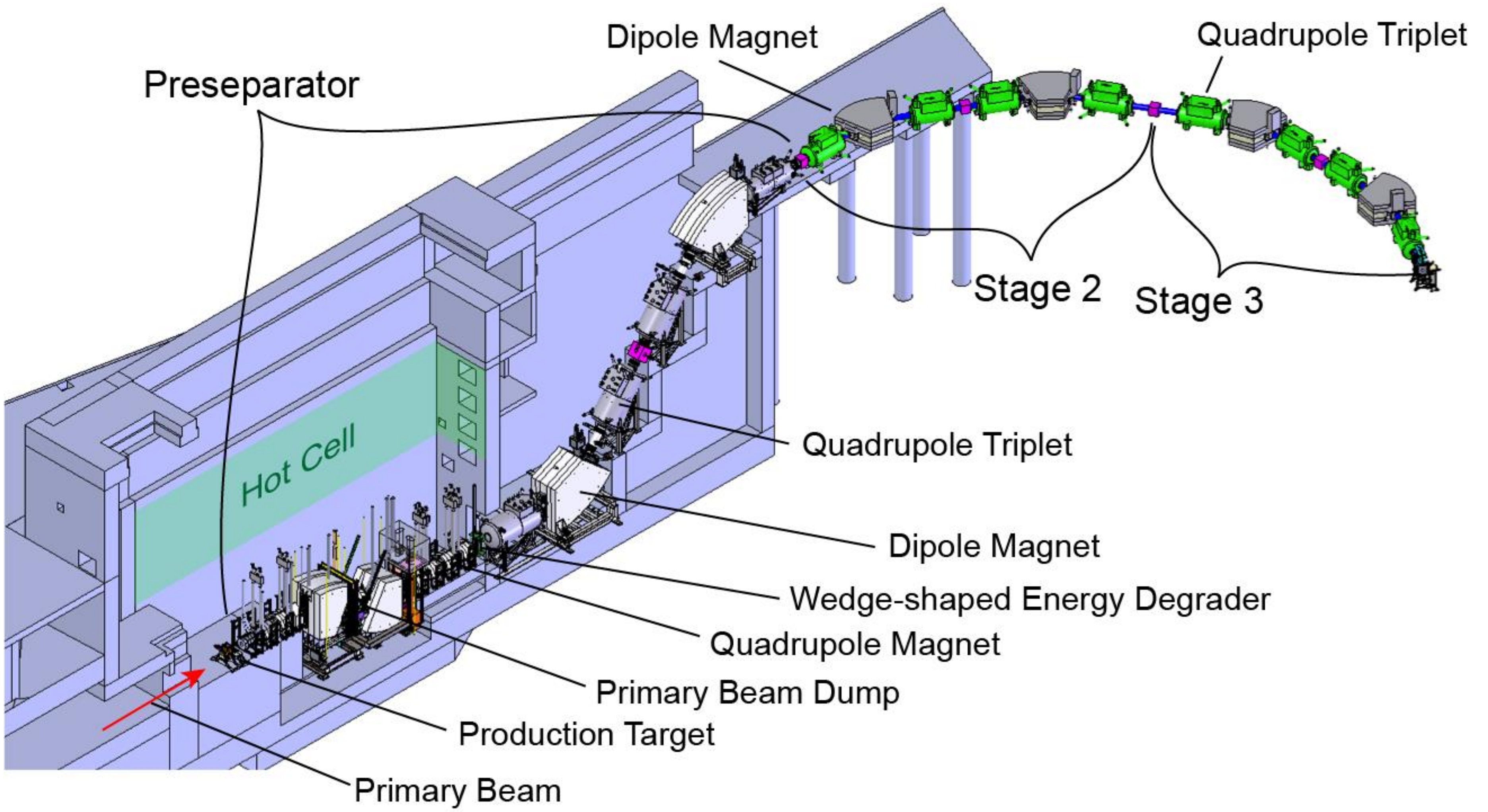
Fragment Separator Expert Meeting 2016

30 August 2016, Grand Rapids

This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. 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.

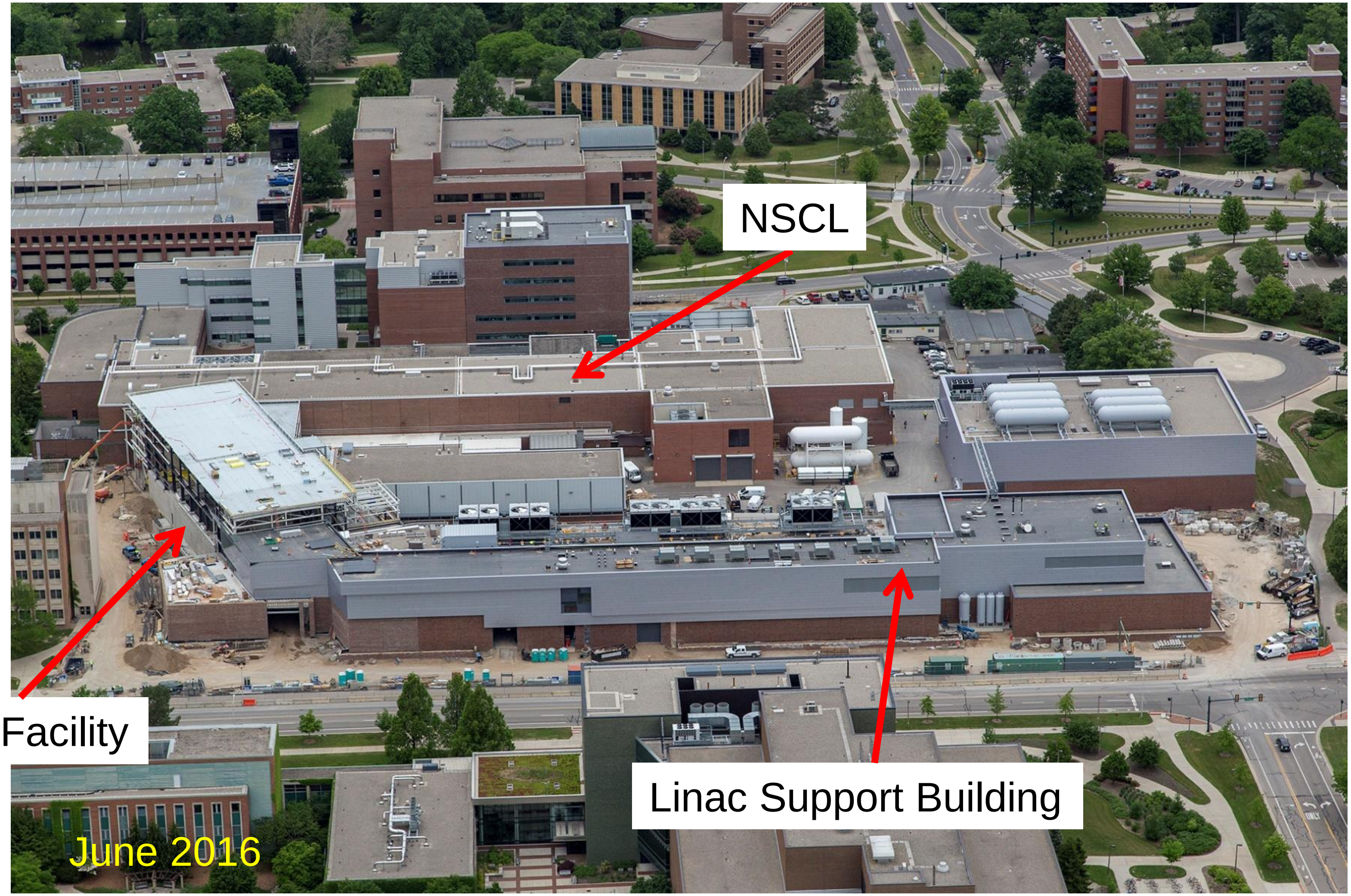
FRIB Fragment Separator Overview
Layout Unchanged from 2013 Expert Meeting



Construction has Started

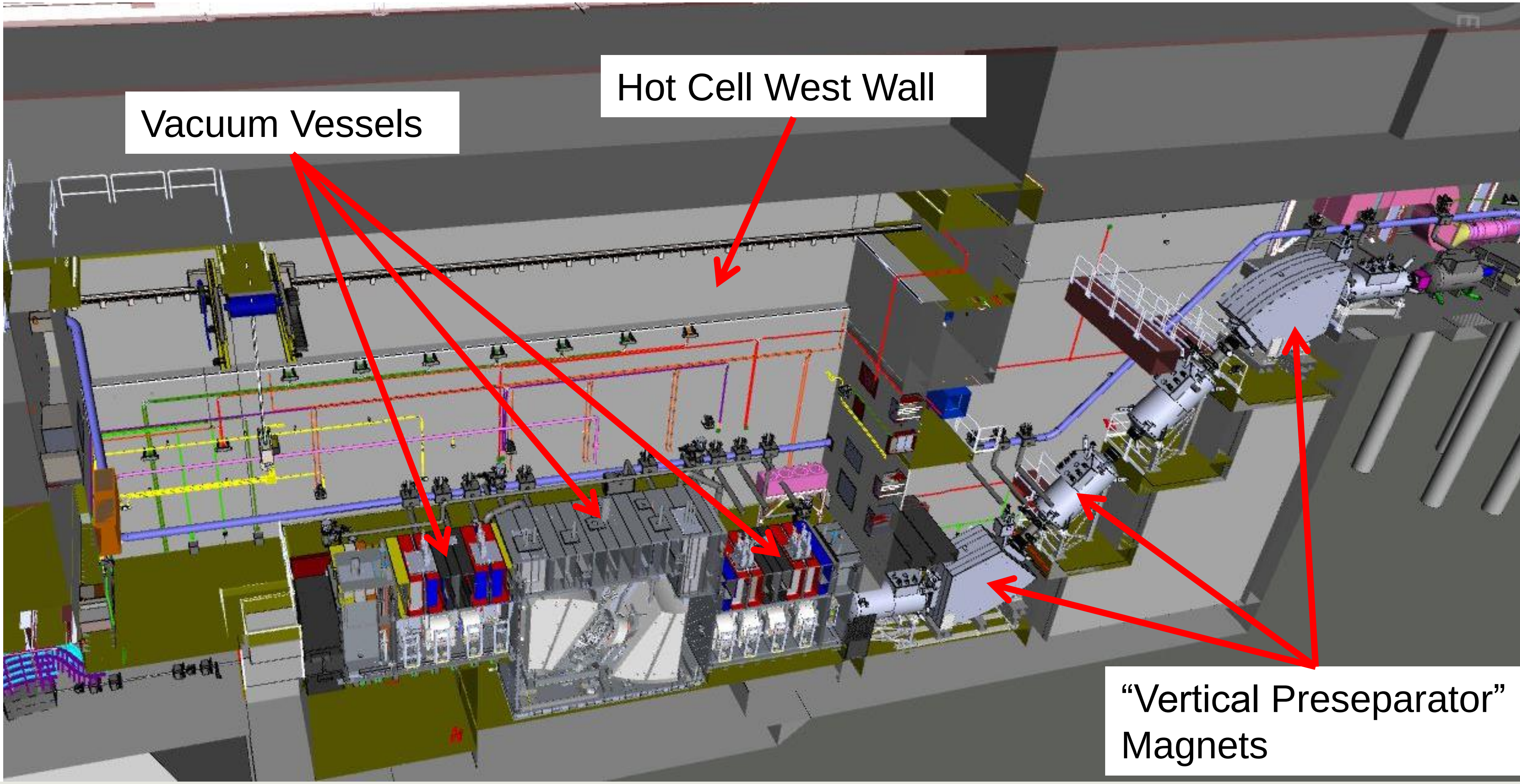
- Ground breaking in Spring 2014 (shortly after last expert meeting)
- Hole in the ground by summer 2014

Civil Construction Status in Summer 2016



Evolution Tracked in Building Integration Model

- View onto preseparator from above: design mixed with “as built”

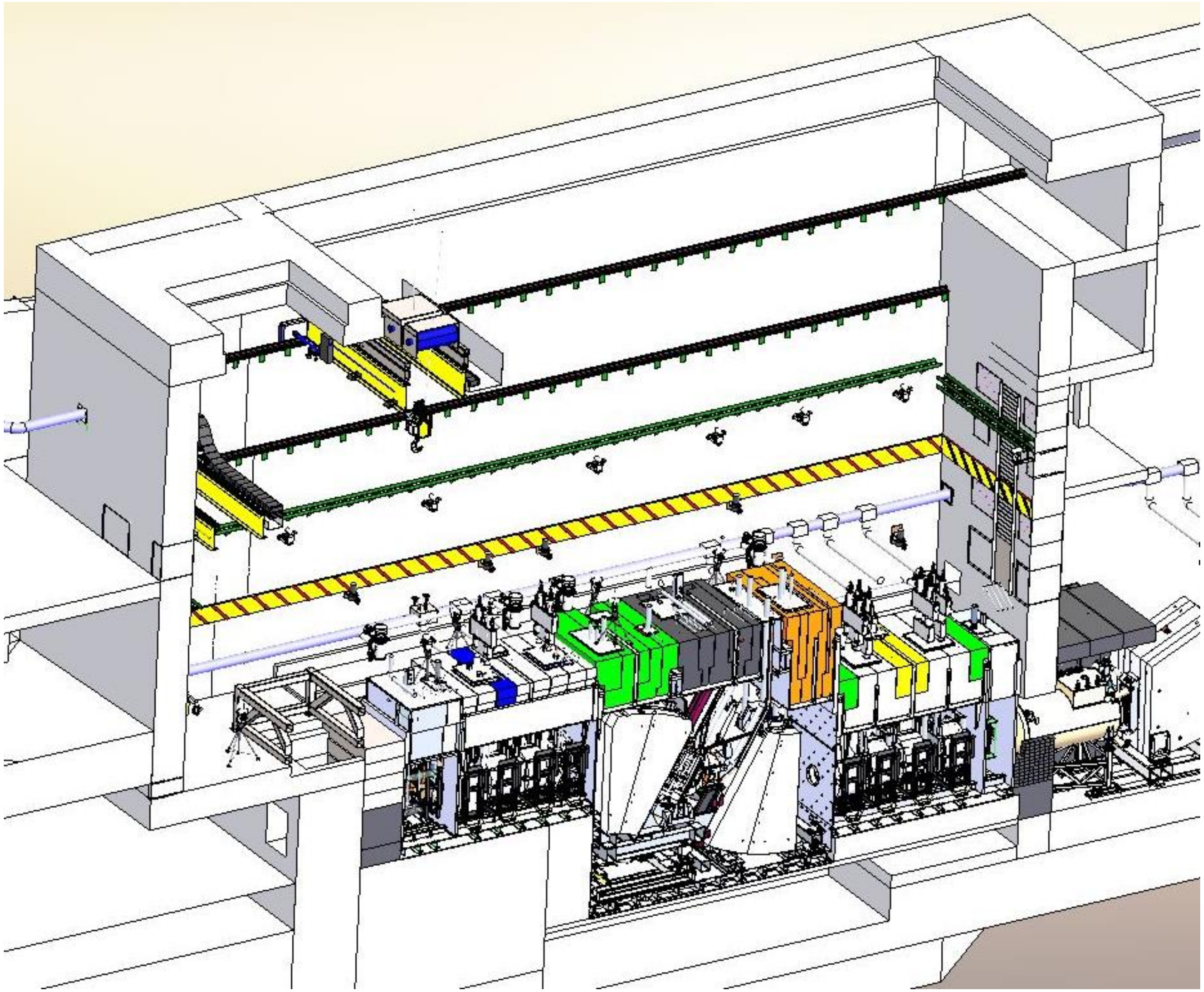


Key Parameters of the FRIB Fragment Separator

- Reminder from 2013 expert meeting
- Rare isotopes production
  - Primary beams of stable isotopes from ~ oxygen to uranium
    - » Beam power: 400 kW (cw, no pulsed beams)
    - » Beam energy: 200 MeV/u for uranium, higher for lower Z elements
  - Projectile fragmentation
  - In-flight fission (predominantly abrasion-fission)
- Large acceptance for efficient collection of rare isotopes
  - Angular acceptance of ± 40 mrad and momentum acceptance of ± 5 %
  - Preseparator compresses momentum width by factor three (standard mode)
- Three separator stages provide versatility
  - Multiple combinations of Bρ – δE – Bρ separation and beam tagging
- Maximum magnetic rigidity: 8 Tm (preseparator)
  - Stages 2 and 3 maximum magnetic rigidity: 7 Tm

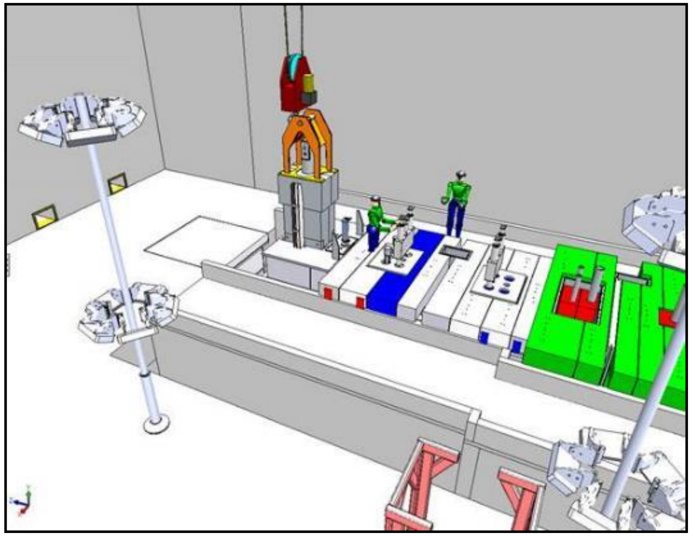
Preseparator Front End in Hot Cell

- Hot cell contains major radiation fields
  - Production target
  - Beam dump
- All components in three large vacuum vessels
- Maintenance largely via remote handling
- Hands-on access above shielding when beam is off
- New designs and developments

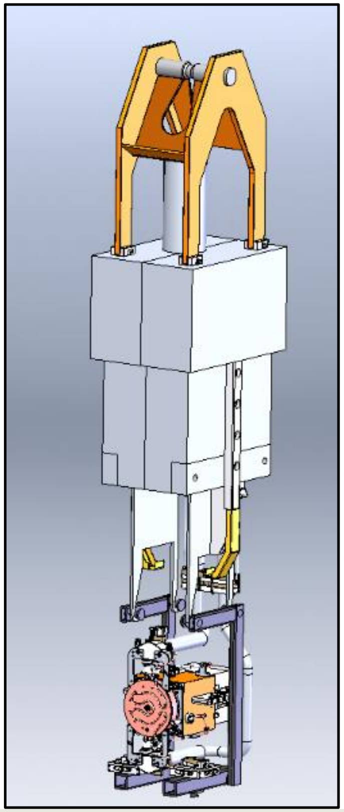


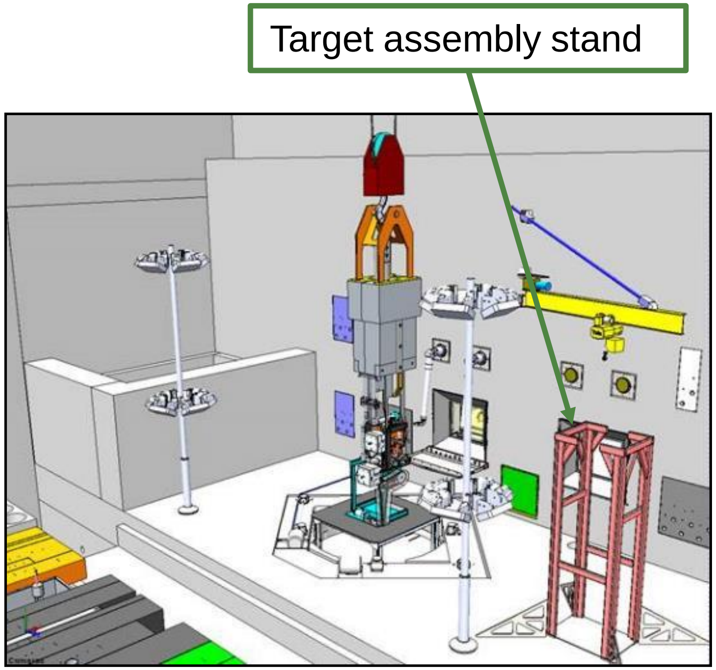
Target Replacement

- Target lasts about 2 weeks at full beam power
- Target assembly and shielding designed for fast replacement with remote handling



Removal of target assembly from beamline

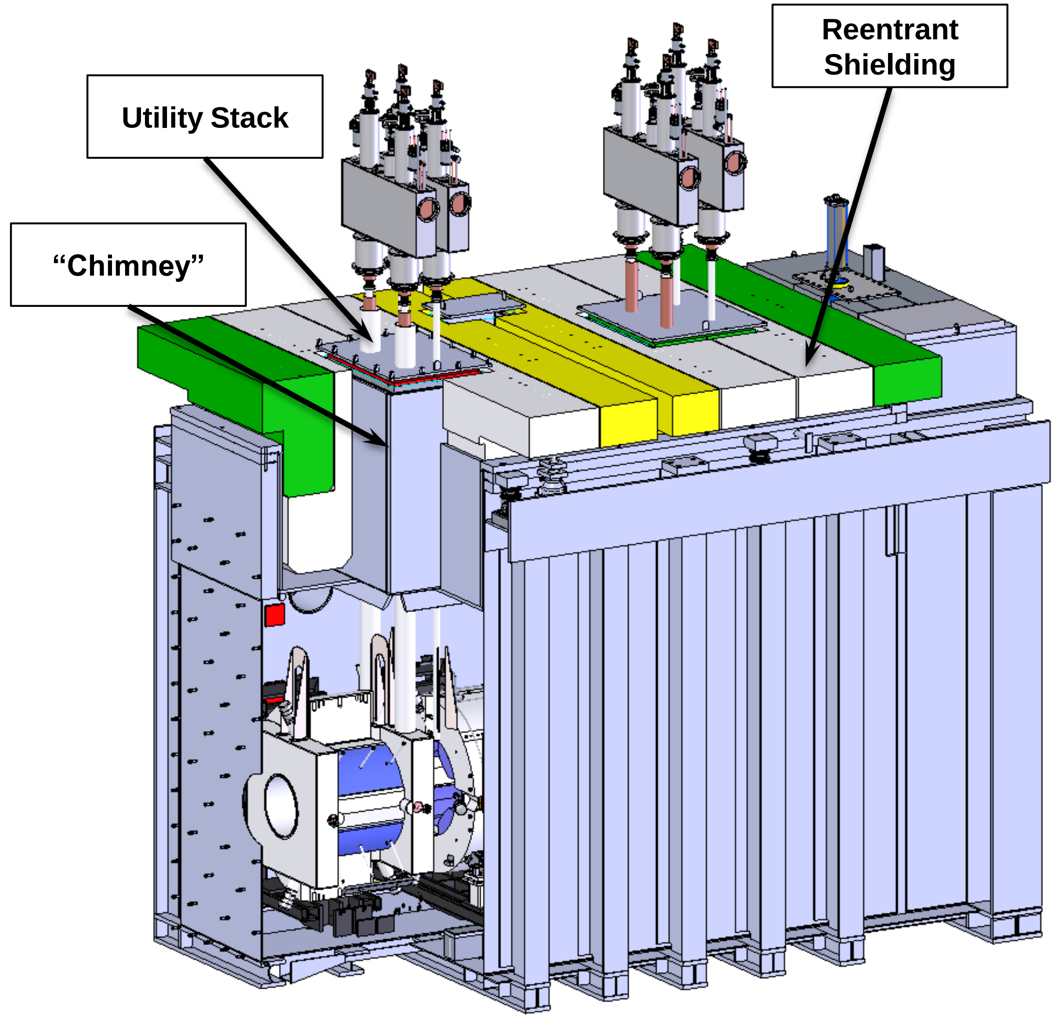




Target assembly at window workstation

Vacuum Vessels (1)

- Three large vacuum vessels house all equipment in hot cell
- Reentrant lids with shielding contain radiation
  - Hands-on access above shielding when beam is off
- Concept also reduces air activation
- Shielded “chimneys” contain utility lines for equipment
- Vacuum pumping with five turbo pumps plus cold panels for water (outgassing)

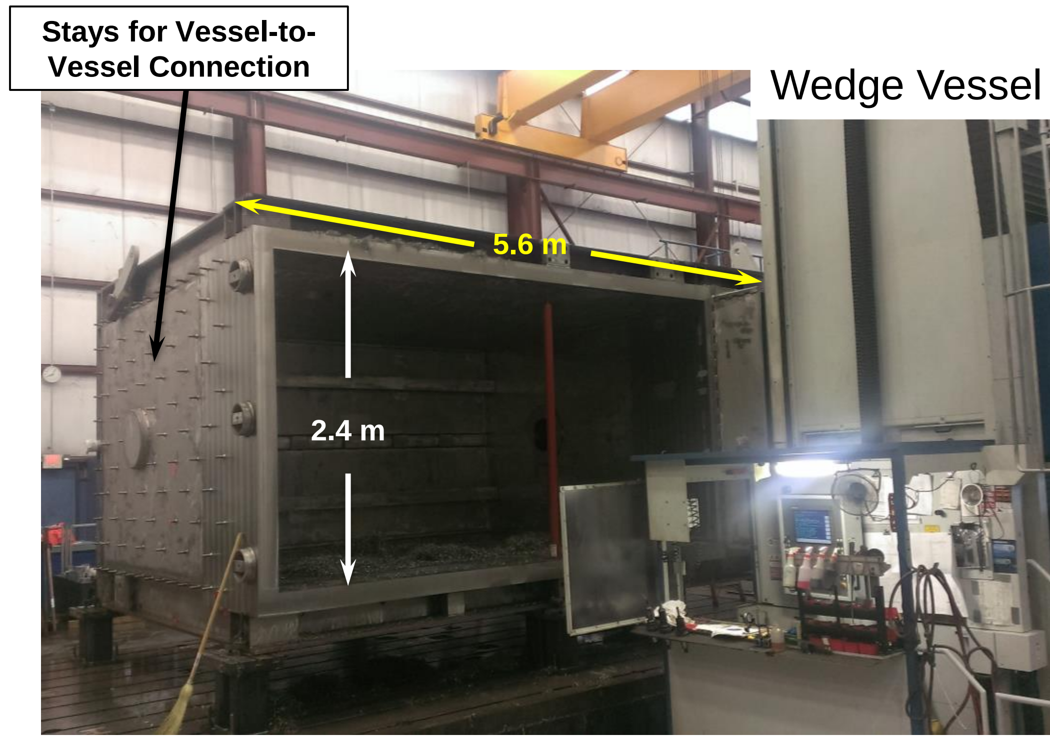


Wedge Vacuum Vessel

Vacuum Vessels (2)

- Two vessel completely assembled
- Final machining for one vessel complete, vacuum testing in early September

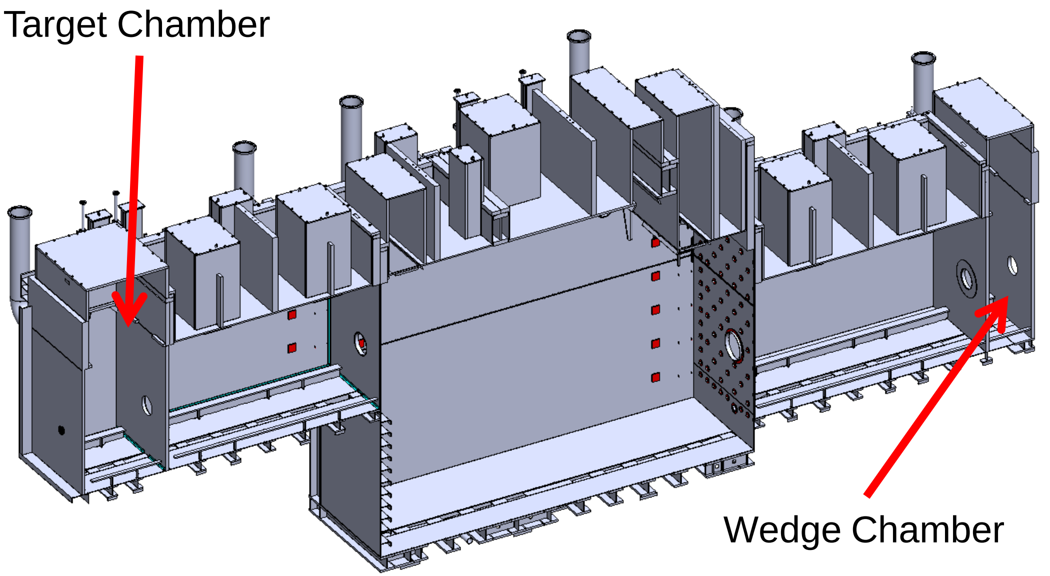
Target vessel



Wedge Vessel

Vacuum Vessels (3)

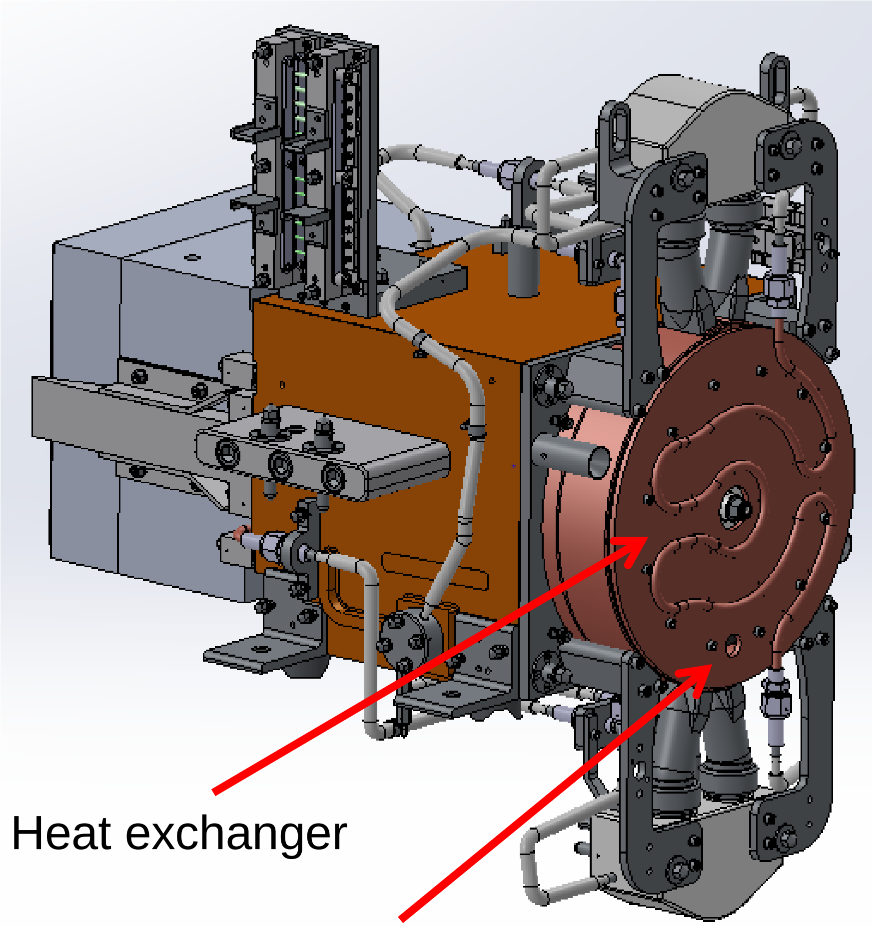
- Complete individual vessels will be installed in hot cell and joined using stay welds distributed over adjacent surfaces
- End chambers for target and wedge can be closed off by isolation valves
- Vessels will be pumped with several turbo pumps and with cold panels



Production Target (1)

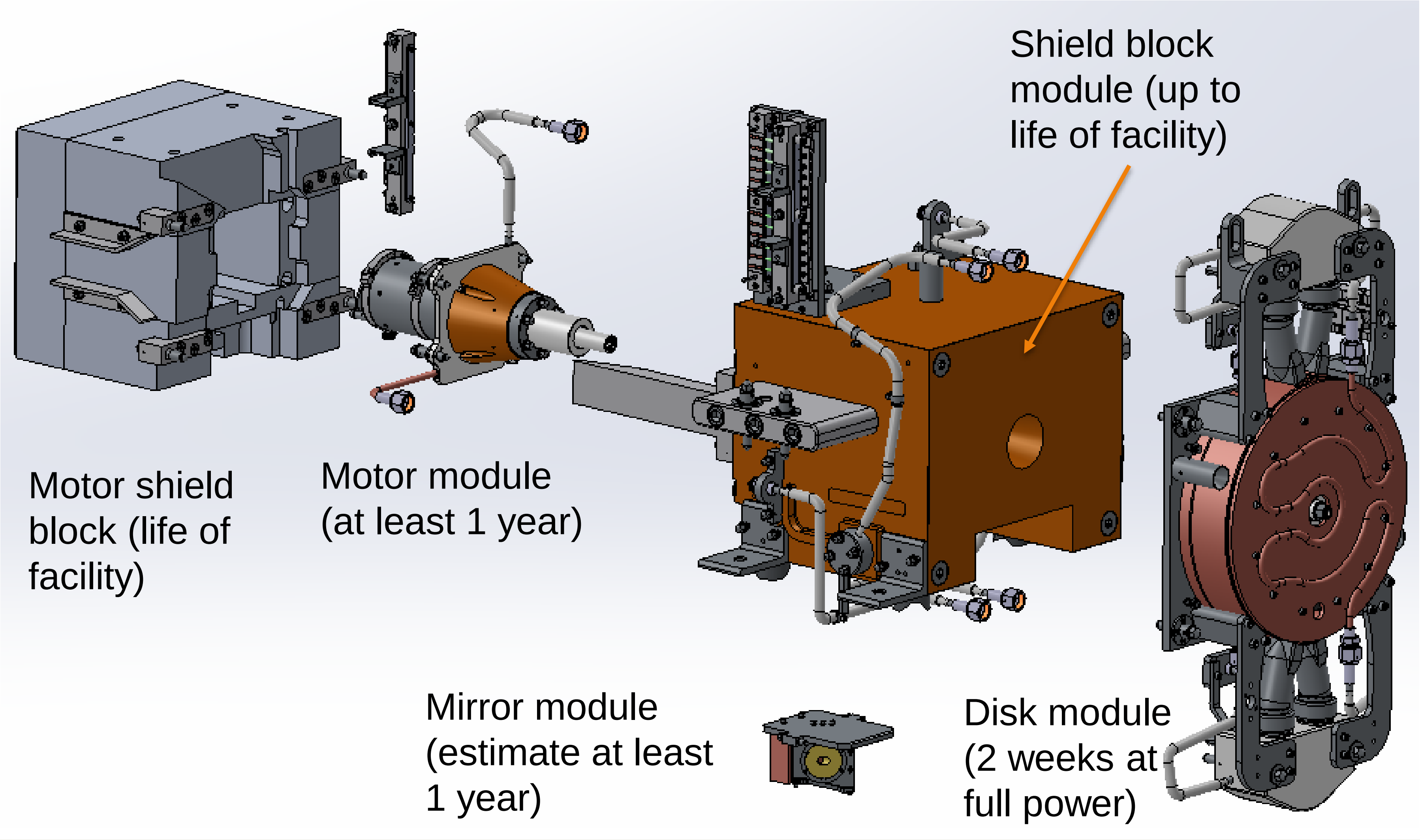
- Multi-slice rotating graphite target
  - 30 cm diameter, 5000 rpm, up to 9 disks
  - About 100 kW deposited in 1 mm dia. beam spot
  - Radiative cooling to copper heat exchanger
- Driven by radiation tolerant in-vacuum motor
- Design essentially complete, including remote handling features
- Parts are being procured

Target design



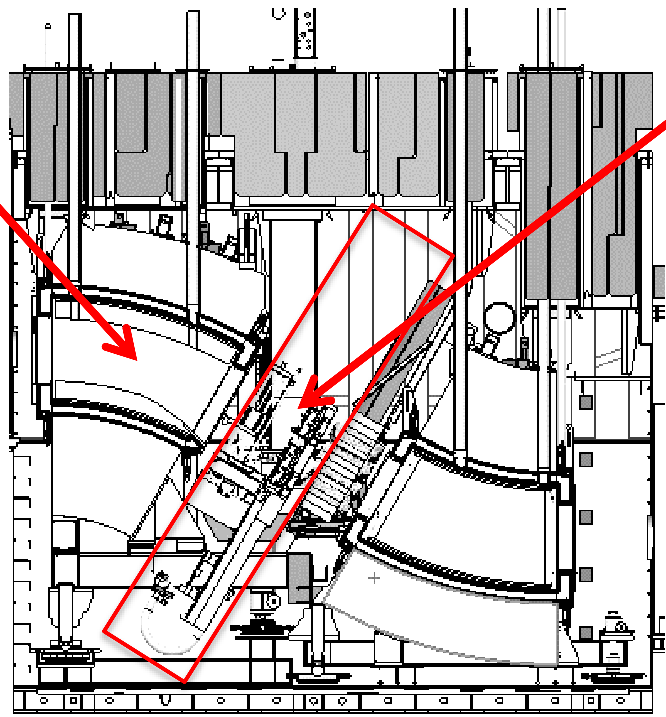
Prototype target with five disks

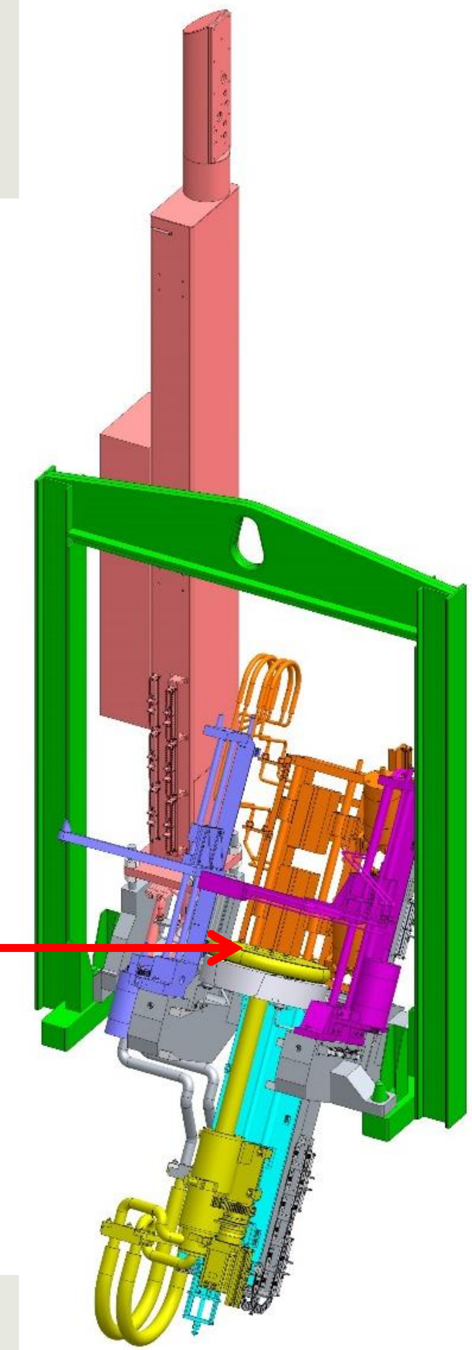
Production Target (2)
Waste Stream Reduced: All but Disk Module Reusable



Beam Dump (1)

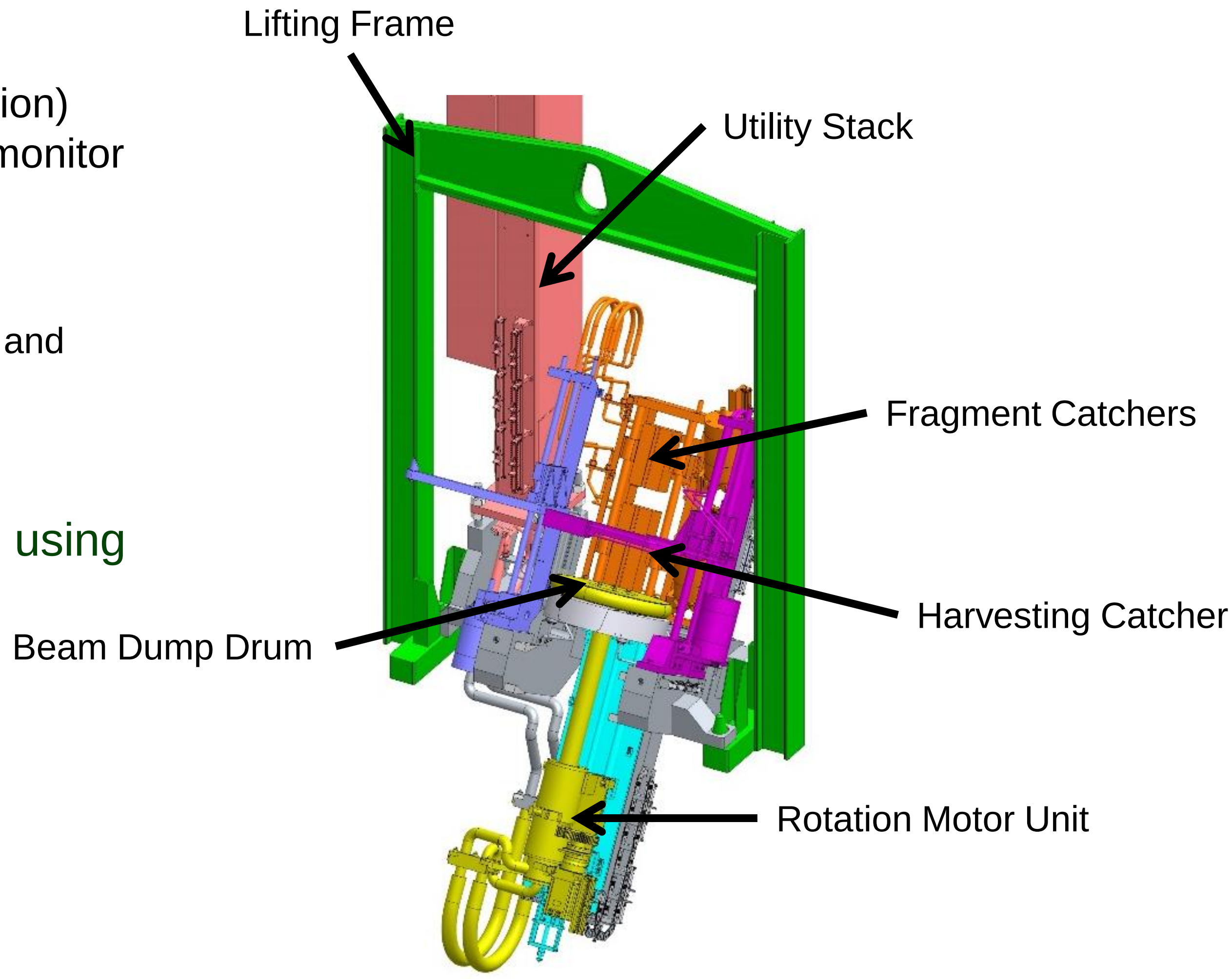
- Water filled rotating drum
  - Intercepts up to 325 kW primary beam right after first dipole
    - » Position adjustment in “vertical” direction required
  - 70 cm diameter, 600 rpm, thin titanium shell
  - Water stops beam and cools shell → W. Mittig (tomorrow morning)





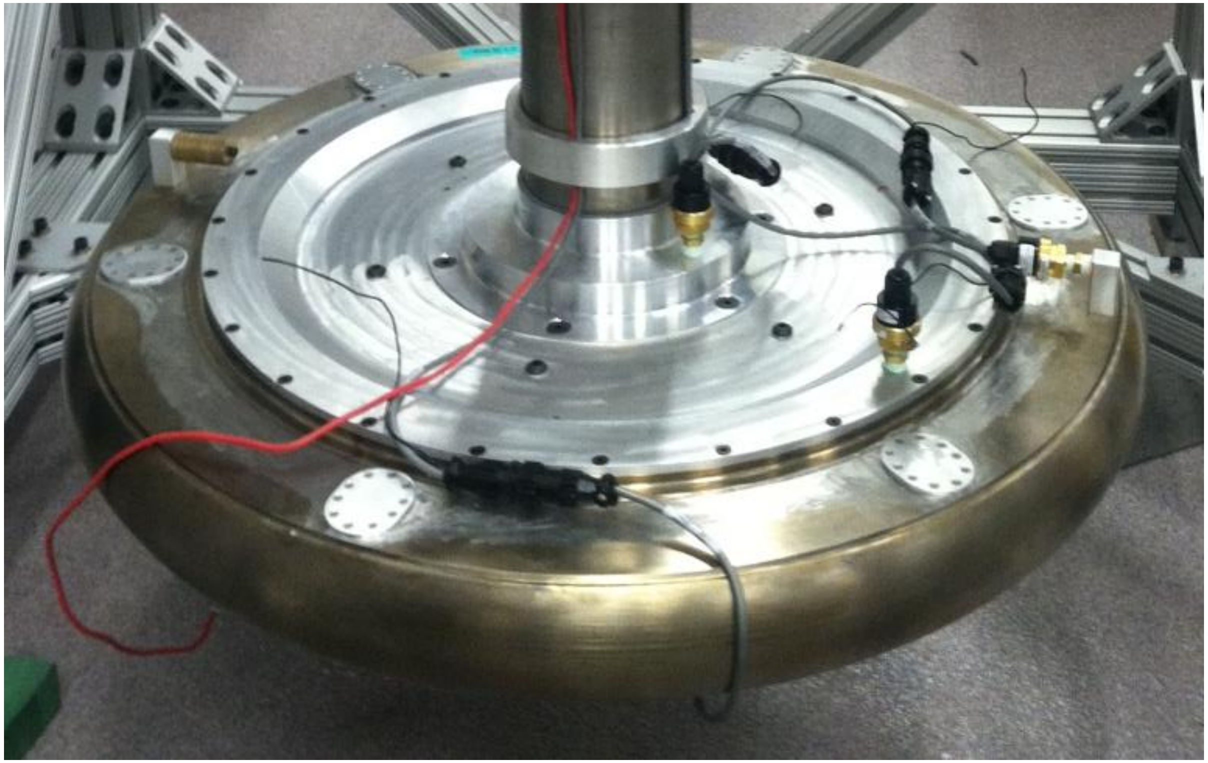
Beam Dump (2)

- Beam dump assembly also contains:
  - Fragment catchers (slit function)
  - Thermal imaging system to monitor beam position on drum
  - Drive system for harvesting catcher/viewer plate
    - Viewer during commissioning and early operation
    - Harvesting catcher to access additional fragment off-axis
- Entire assembly removable using one lifting frame



Beam Dump (3)

- Drum for 1st years of operation will use conventionally machined Ti-6AL-4V shell with 1-mm wall thickness
  - Prototype successfully tested at ORNL
  - Good for first 2 years of operation

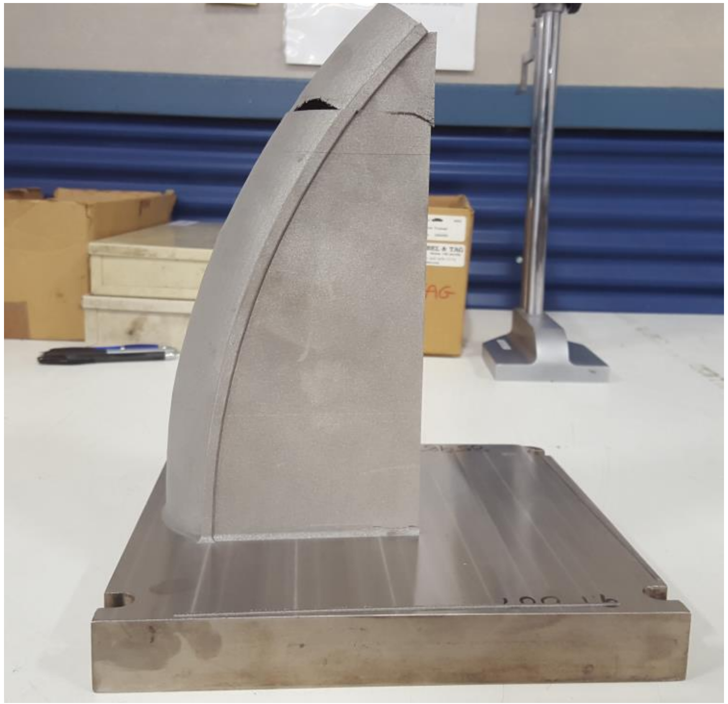


Conventional machined drum with 1 mm wall thickness

Beam Dump (4)

- Development of 0.5 mm drum using 3D printing
  - 0.5 mm wall thickness needed for 400 kW ^{238}U beam
  - 3D printing is preferred production method
  - Industry developments are expected to reduce the number of segments required

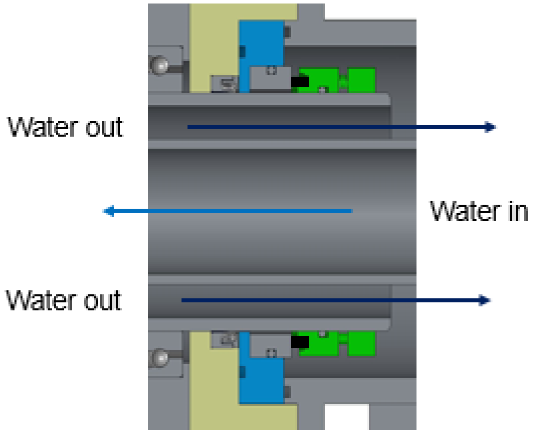
30 degree segment with 0.75 mm wall thickness



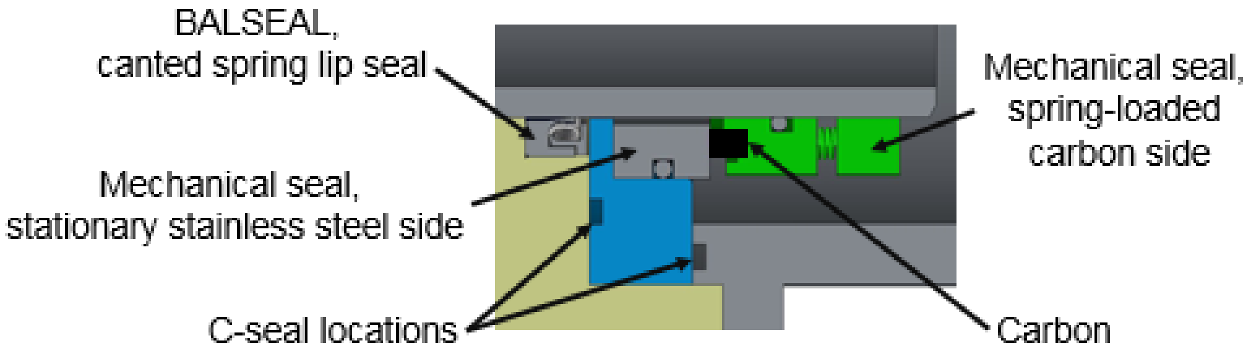
Stress cracks in 3D printed test piece

Beam Dump (5)

- Beam dump drum ¼ scale prototype test with high-energy electron beam → W. Mittig
- Material studies in support of beam dump → F. Pellemoine
- Obtained vacuum vessel for testing of beam dump rotation setup
  - Primary focus on rotating water seal



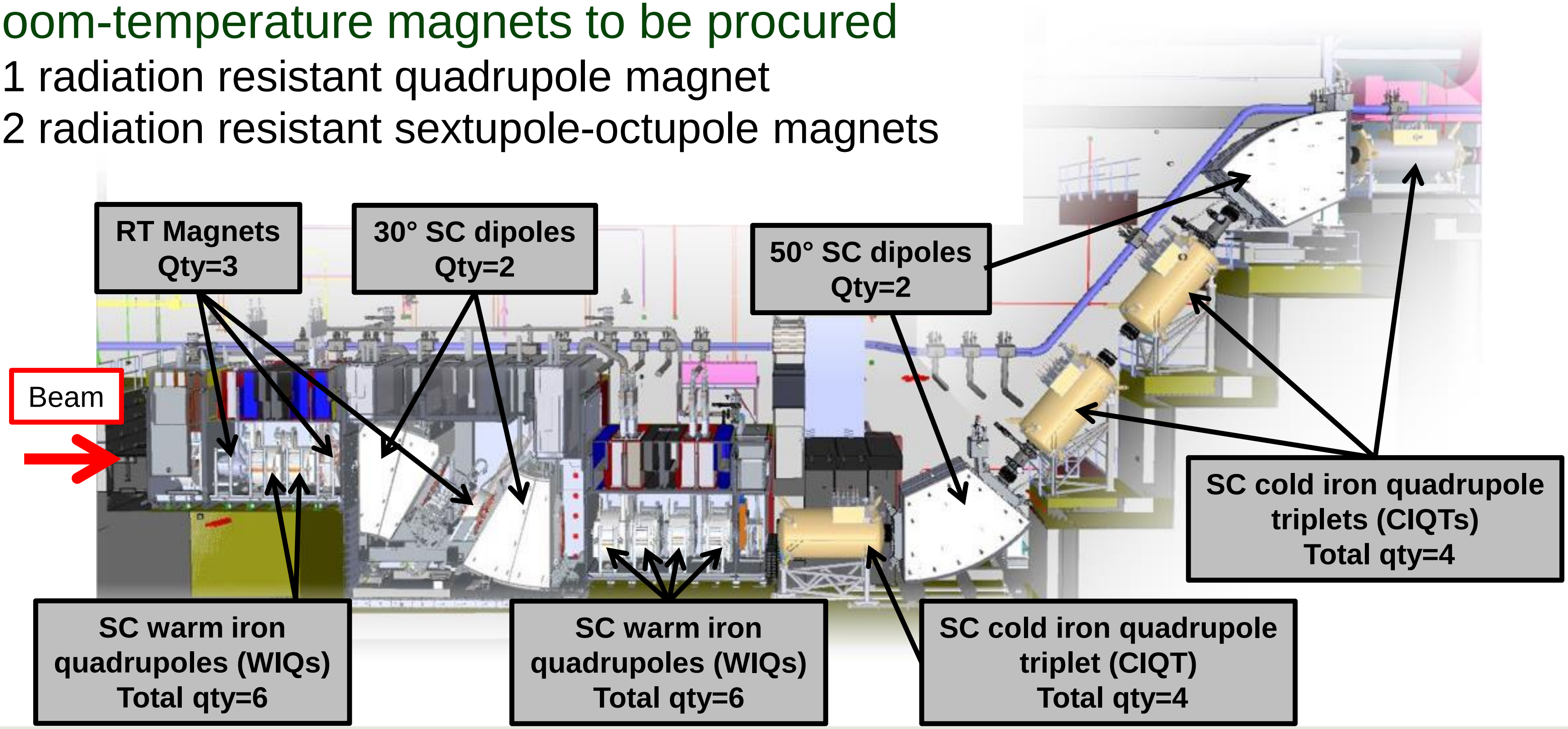
Beam dump rotation module mechanical seal



Detail view of mechanical seal

Preseparator Magnets Overview

- Superconducting magnets to be fabricated in-house
  - 4 superconducting dipoles (two radiation tolerant 30º dipoles and two 50º dipoles)
  - 4 superconducting cold-iron quadrupole triplets
  - 6 superconducting warm-iron quadrupole singlets (radiation tolerant)
- Room-temperature magnets to be procured
  - 1 radiation resistant quadrupole magnet
  - 2 radiation resistant sextupole-octupole magnets



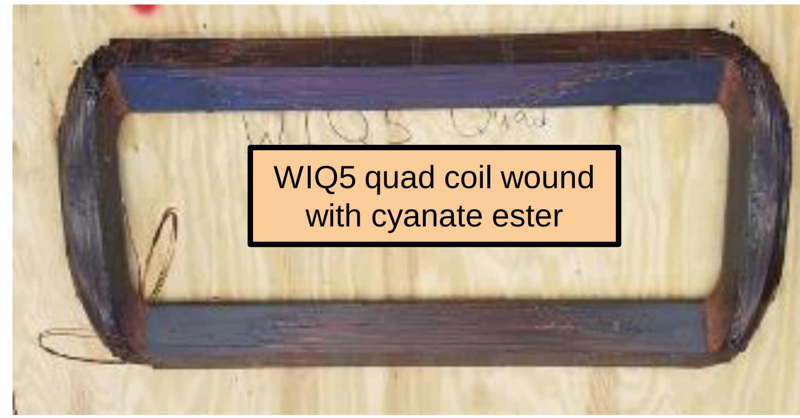
Magnet Technologies

- Magnets in hot cell radiation tolerant
  - Superconducting magnets “warm” iron (not at cryogenic temperature) and with cyanate ester epoxy
  - Room temperature magnets with mineral-insulated conductor or with standard conductor and cyanate ester
- Magnets in “vertical preseparator” using standard superconducting magnet technology
  - Quadrupole triplets with iron at cryogenic temperature
  - Dipoles with “warm” iron
  - Standard epoxy for insulation
- Magnets for horizontal separator exist already
  - Rearrangement of A1900 magnets with minor change of dipoles

Magnet Construction: Coil Winding (1)

- Superconducting magnet coil winding complete except for 30˚ dipoles
  - All quadrupole coils wound

WIQ5 Quad Winding

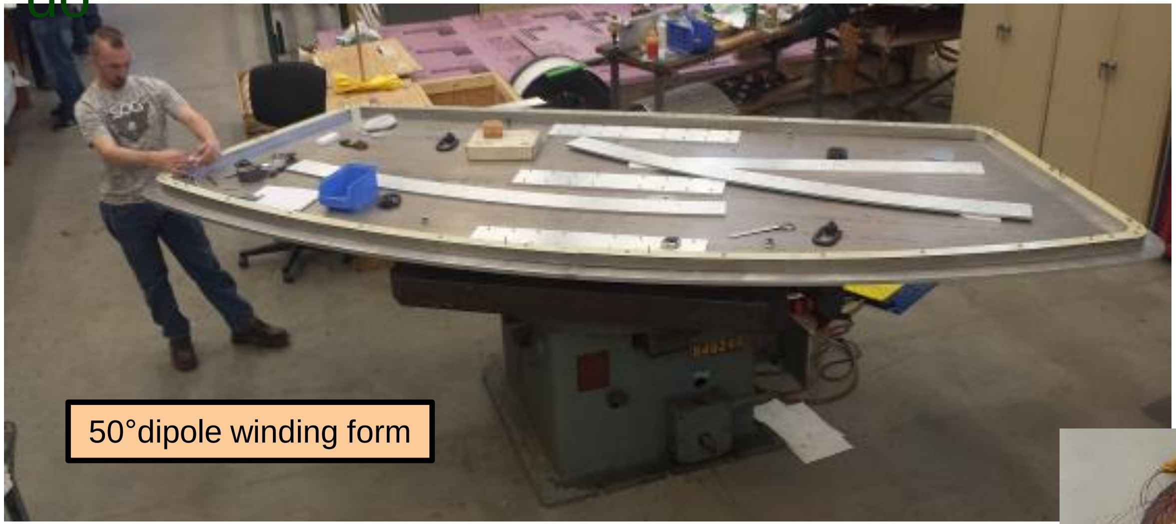


WIQ5 quad coil wound with cyanate ester

Quadrupole coil with controlled end build and total length

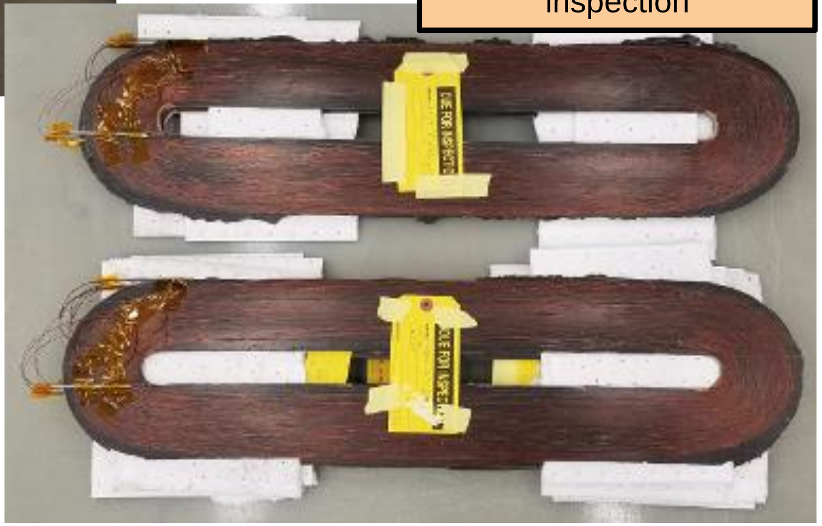
Magnet Construction: Coil Winding (2)

- All multipole and 50° dipole coils wound; only 30° dipole coils left to do



50°dipole winding form

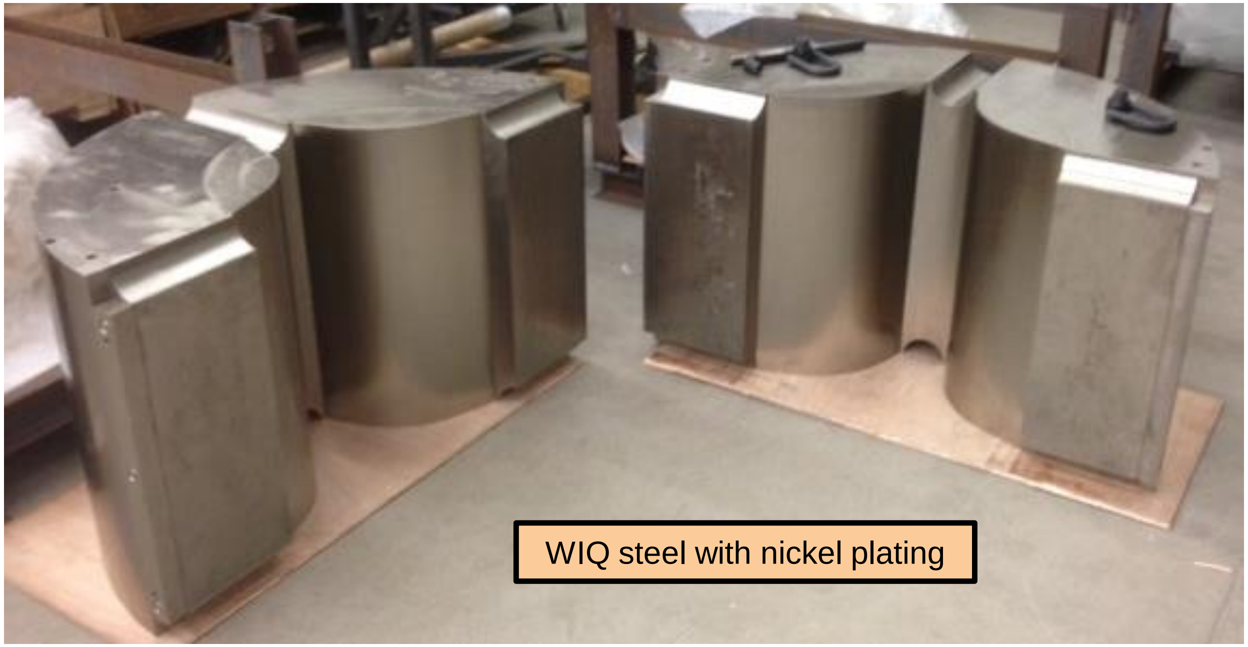
Accepted CIQT multipole coil



WIQ multipoles ready for inspection

Magnet Assembly (1)

- Iron for all SC quadrupoles in house and inspected
- Cold-iron quad yokes in one piece
- Warm-iron quad yokes in two halves and nickel plated to control outgassing
  - Iron for 30° dipole also nickel plated



WIQ steel with nickel plating

CIQT steel inspection

Magnet Assembly (2)

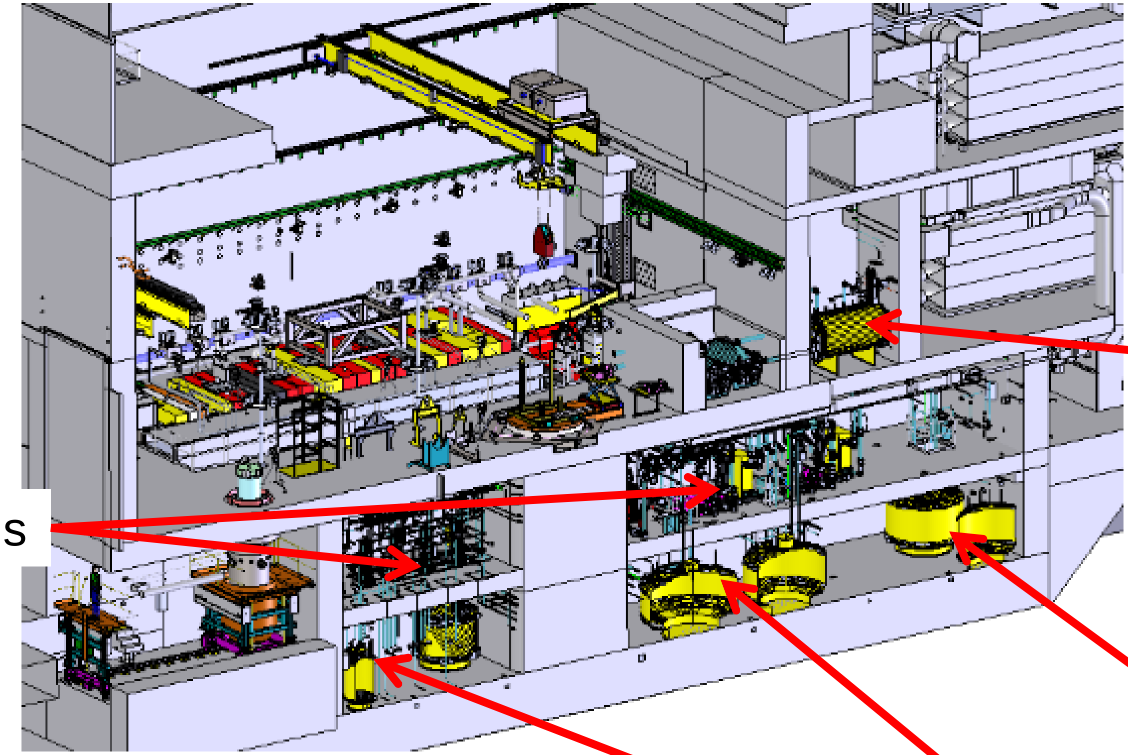
- First triplet bore-tube assembly with multipole coils complete and cold shocked
- Quadrupoles for first triplet assembled, wired, and tested in dewar
  - Preliminary excitation curve matches TOSCA simulation within about 0.3%

CIQT4 Quad Assembly

Cold-shock trough for multipole assemblies

Non-Conventional Utilities (NCU)
Being Installed in Target Facility Now

- Target, beam dump, magnet yokes, RT magnet coils, and all other equipment in vacuum vessels are cooled by water from NCU system
  - One cooling loop for water directly exposed to beam (beam dump, etc.)
  - One cooling loop for all other cooling water needs

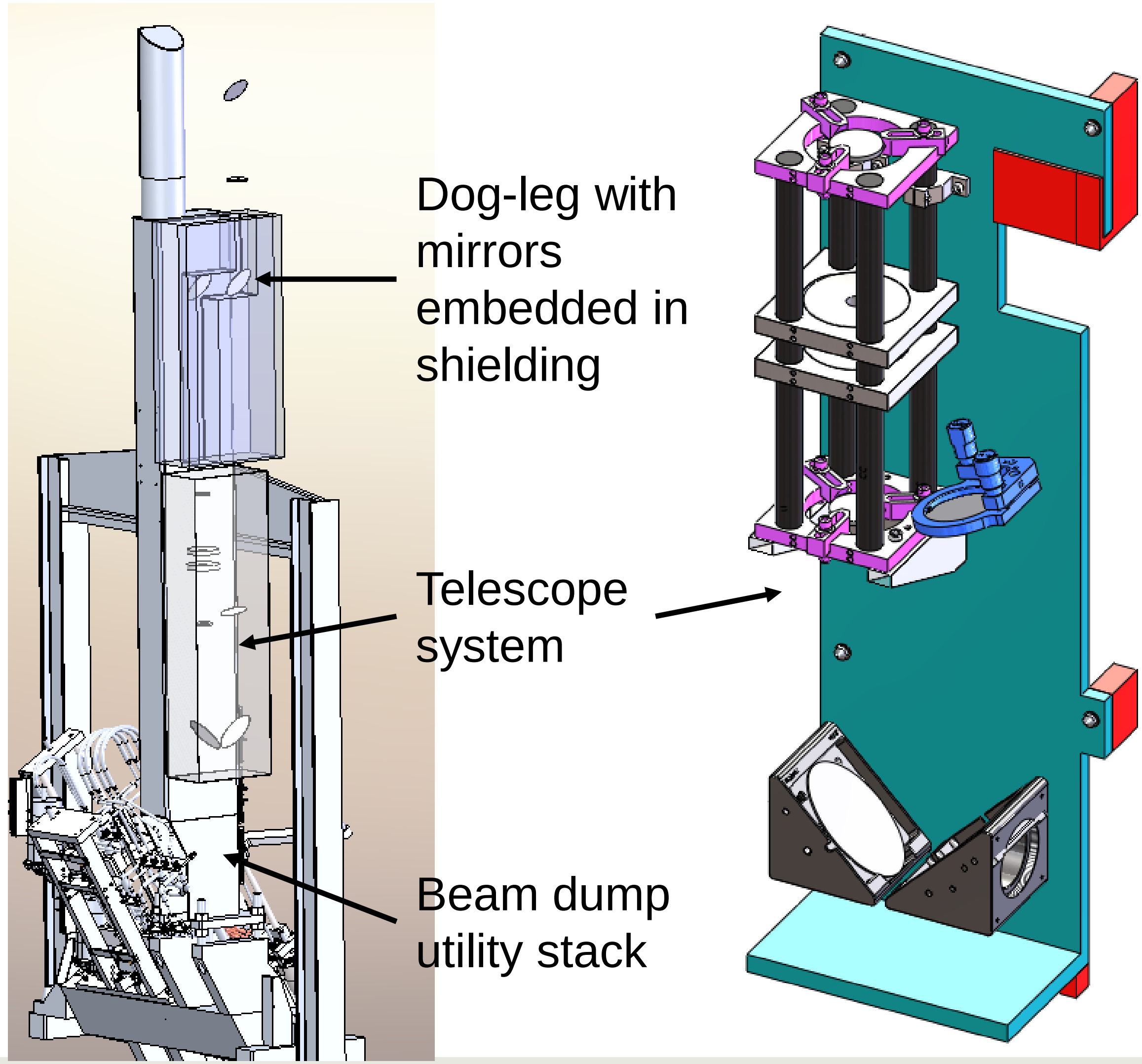


Diagnostics (1)

- Reminder from 2013 expert meeting
- Rare isotope diagnostics based on A1900 diagnostics
  - In fact planning to take over A1900 diagnostics along with magnets
- Single particle detectors for rare isotopes
  - Tracking detectors e.g. PPAC → particle position and angle (w/ 2 detectors)
  - Particle ID detectors:
    - » Energy loss detectors, e.g. PiN diodes
    - » Timing detectors, e.g. scintillator and diamond detectors as upgrade
- Detailed design of diagnostics planned later
  - Design details don't impact other systems, fit-form-function defined
- Simulations of rare isotope beam separation with detector responses → M. Portillo (this afternoon)

Diagnostics (2)

- Recently started mechanical design of thermal imaging systems
- Preliminarily identified mirror mounts
- Currently optimizing mounting of telescope secondary mirrors

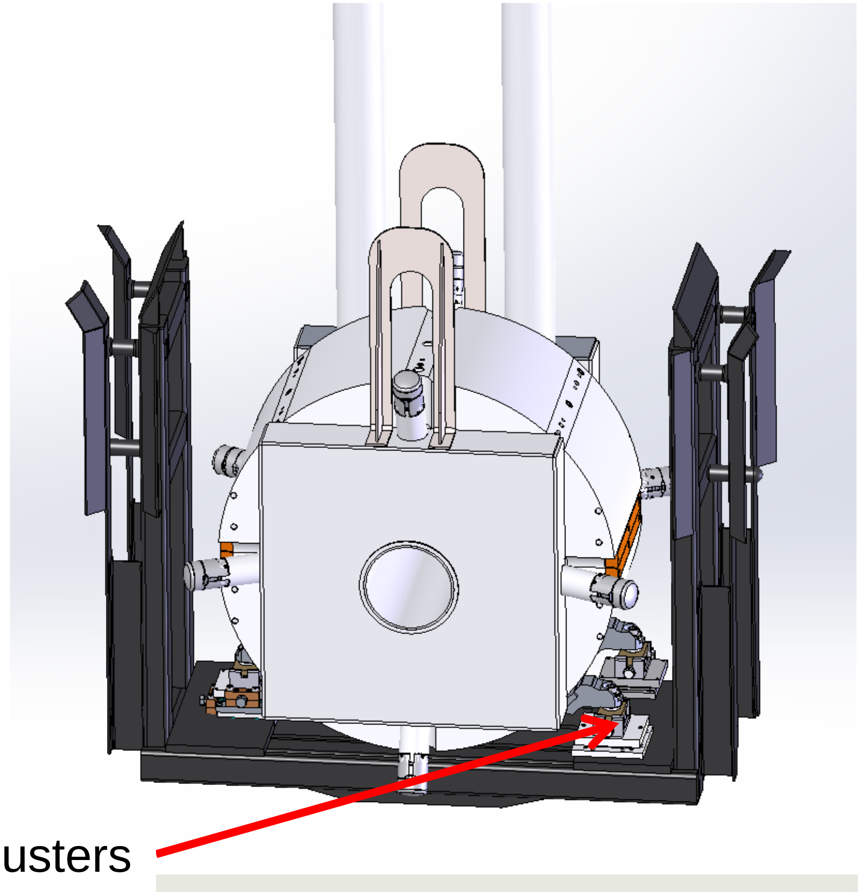


Beam Optics

- Preseparator optics slightly changed due to incorporation of actual magnet designs
  - Momentum compression factor increased from 3.0 to 3.5
  - Need dedicated optics for some fragments
    - Control component heating from beam losses, e.g. due to strong overfocusing in settings for very neutron-rich fragments
    - Control spot size on beam dump if primary beam gets focused right on the shell
  - Option to add second beam dump after second dipole maintained
- Versatility of multiple modes in horizontal separator stages maintained
- End-to-end simulations including beam transport to experiment stations → M. Portillo (this afternoon)

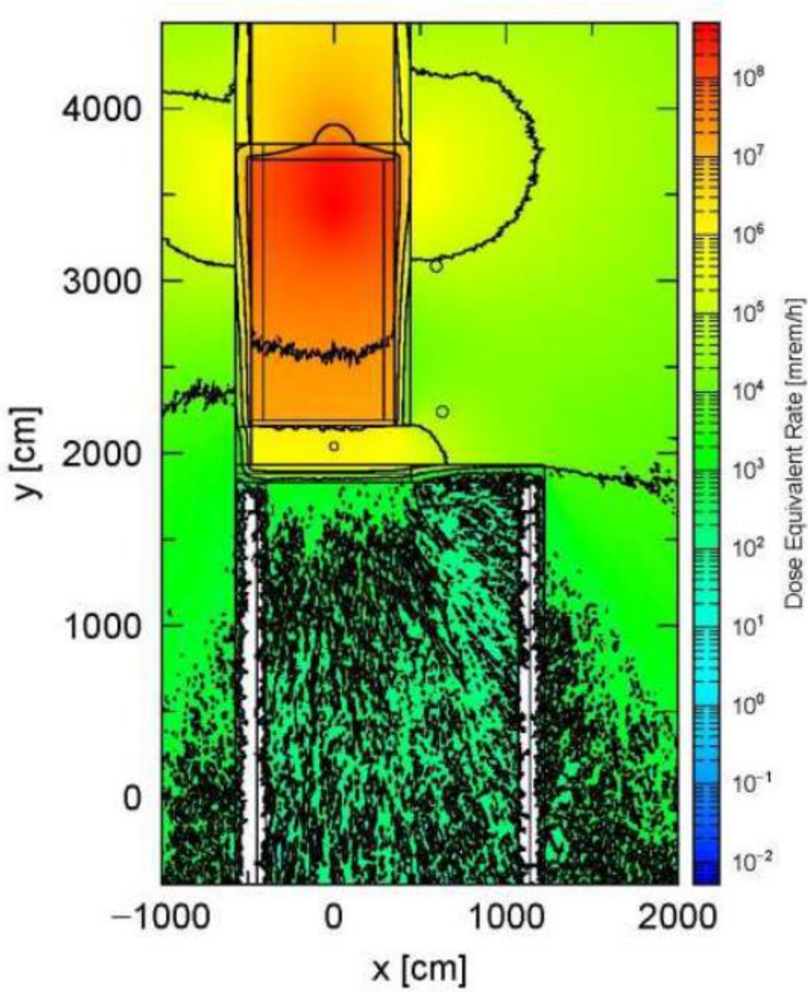
Alignment

- Established alignment requirements based on beam optics simulations
  - Statistical approach for misalignments
  - Tracked particles of three species: fragment of interest and two contaminants
  - Accepted 5% probability to reduce either transmission of purity by 5%
- Resulting requirements deemed challenging
  - In particular for quadrupoles:
    - » Transverse offset: 100 µm (rms)
    - » Rotation: 0.25 mrad
- Alignment group currently evaluating best methods to achieve alignment goals
  - Challenges include viewing angle from above for equipment in hot-cell vacuum vessels
- Likely switching from orthogonal adjusters to custom “shims” for equipment in hot cell vacuum vessels
  - Adjusters difficult to reach with remote handling Master-Slave Manipulators (MSMs)



Diagnostics as Mitigation for Primary Beam Being Transported Beyond the Hot Cell [1]

- Transporting full primary beam beyond hot cell leads to hazard
  - Complete or partial loss of target could match primary beam rigidity to magnet setting, resulting in primary beam being transported up the vertical preseparator
  - Shielding past the hot cell not designed for radiation fields from full primary beam
  - Analysis of settings for about 4000 different rare isotopes shows that such a scenario can be constructed
- Radiation transport calculations
  - Dose rate outside of shielding depends on location
  - Worst case leads to dose rate of 1000 rem/h
  - If not mitigated, limit of 2 mrem in any given hour reached in 0.007 seconds for worst case scenario
- Workshop on detection/mitigation of this hazard 21-22 September 2016



Diagnostics as Mitigation for Primary Beam Being Transported Beyond the Hot Cell [2]

- Requires reliable and fast detection
  - Preferred detection approach is to monitor radiation generated by beam on wedge with beam loss monitor
    - » Ion-chambers used at CERN for many years; ~4000 at LHC; sampled at 40 μs intervals
    - » Detectors also used at FAIR
  - Two alternative detection approaches identified
    - » Monitor secondary electrons from wedge
    - » Detect primary beam going through beam pipe with electromagnetic pickup

CERN beam loss monitors

Beam loss monitors at the LHC

- Supporting measures as defense-in-depth
  - Monitoring of primary beam heat signature on beam dump and target with thermal imaging system is planned, but not planned to be credited
- Proving system reliability could be a challenge

- It’s a pleasure to acknowledge the work of the entire FRIB team that went into getting us to this point.

- Thank you for your attention.