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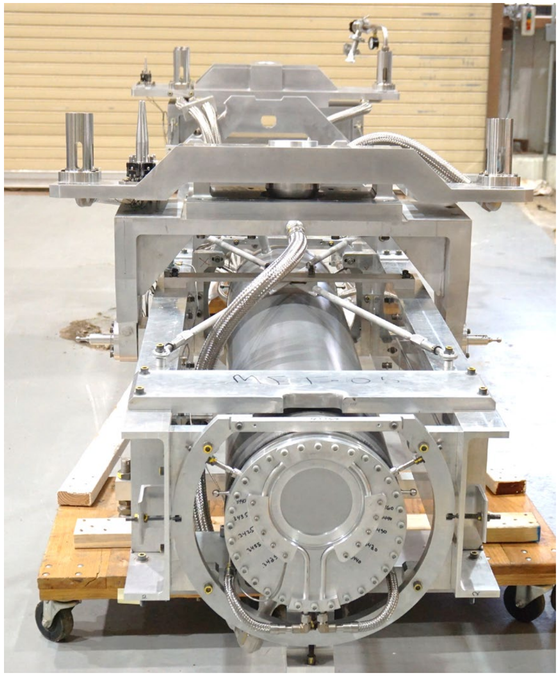
Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

NuMI Target System Megawatt Upgrade



Yun He
NBI 2019
October 22, 2019

Outline

Fermilab's NuMI (Neutrinos at the Main Injector)

provides an intense, high-energy flux of muon-neutrinos to the far detector in Ash River, MN

➔ NOvA experiment, with **700 -750 kW** beam operation

NuMI target system upgrade NuMI-TS-AIP (Accelerator Improvement Program)

➔ capability for beam power to **1 MW**, by April, 2021

2019 summer shutdown – Mid-term milestone

➢ Introduction

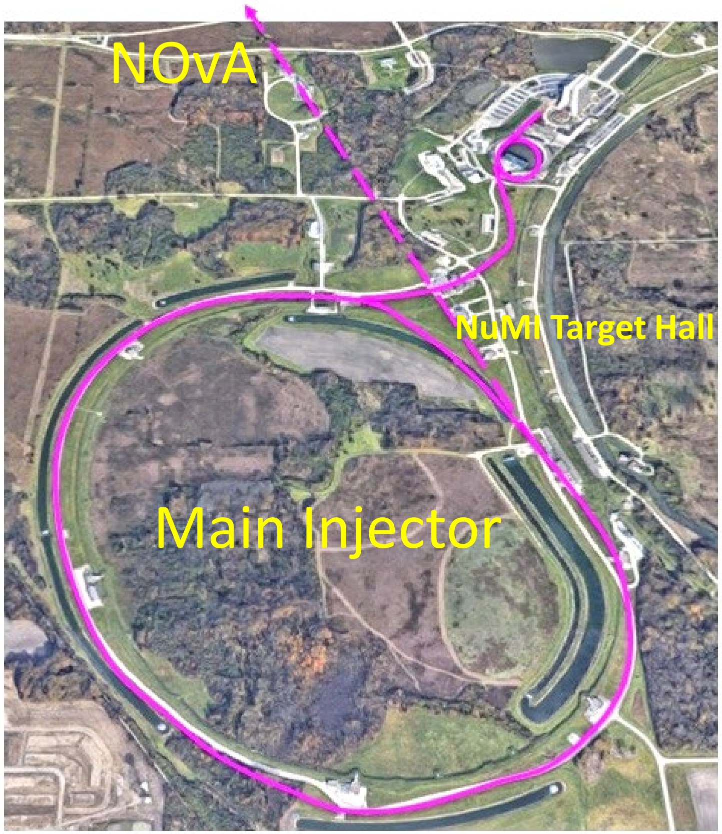
- NuMI neutrino beamline
- Megawatt project NuMI-TS-AIP scope and issues to be addressed
- Tasks and schedule
- Activities completed during 2019 summer shutdown
- Organization chart

➢ Technical descriptions

- Status overview
- 12 tasks
- Activities to be completed FY20

➢ Summary

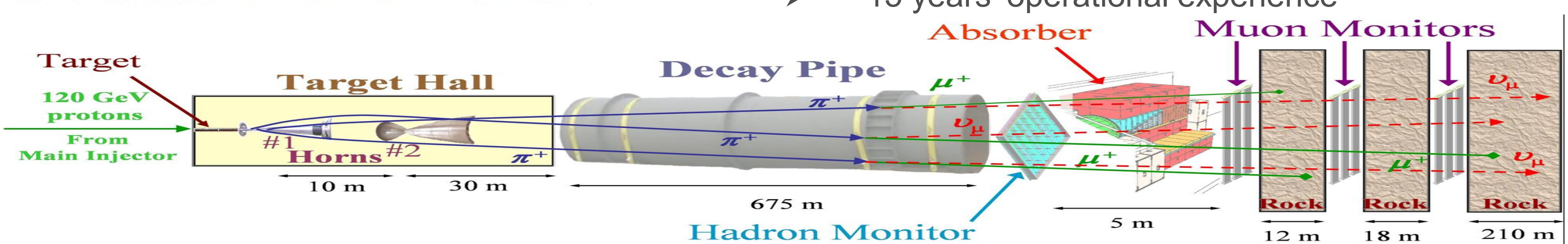
NuMI Neutrino Beamline



- Neutrinos at Main Injector
- 1st beam for MINOS experiments Spring 2005
- 2012 summer shutdown for NOvA 700 kW upgrade

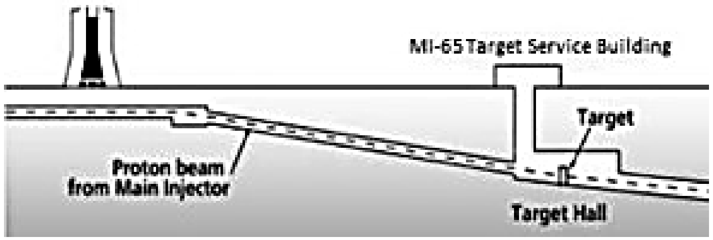
	NuMI Design	NOvA	1 MW upgrade
Proton beam energy	120 GeV		
Beam power (kW)	400	700	1 MW
Energy Spectrum	Low Energy	Medium Energy	
Cycle time (s)	1.87	1.33	1.2
Protons per spill	4.0×10^{13}	4.9×10^{13}	6.5×10^{13}
Spot Size (mm)	1.0	1.3	1.5
Beam pulse width	10 microsec		

- Facilities aging
- ~15 years' operational experience



Megawatt Project Scope and Issues to be Addressed

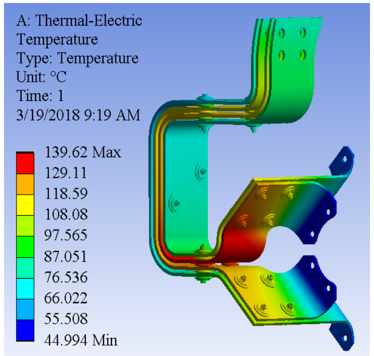
Beam acceptance capabilities	maximum beam power to target 1 MW
Reliability	maintain 85% availability for HEP at full proton delivery
Lifetime	minimally through 2025

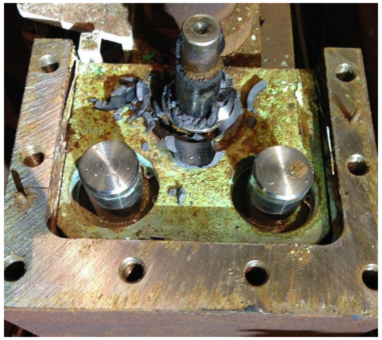


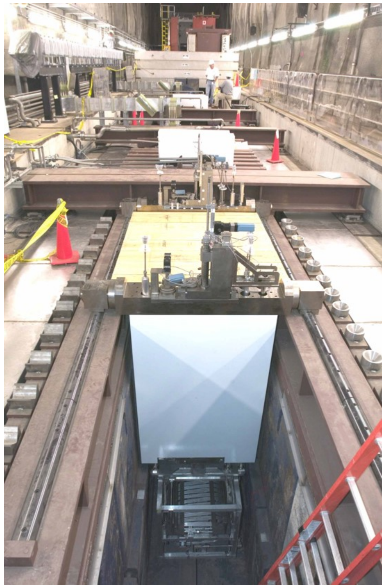
- 40m underground (MI-65 Service building)
- High radiation / corrosive environment
- Utility support systems (water & air cooling)

Issues to be addressed

- Increased temperatures and stresses due to beam heating
  most vulnerable: target, horn 1
- Increased radio-activation
  radiation shielding, tritium mitigation, hadron monitor
- An aging infrastructure in radiative environment
  target / horn module drive mechanism

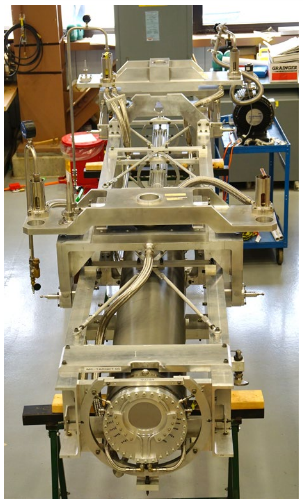


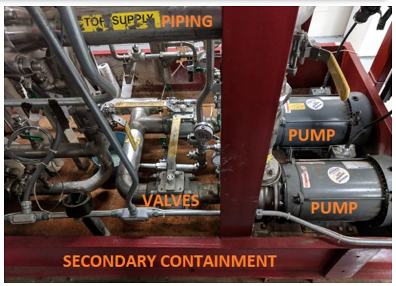


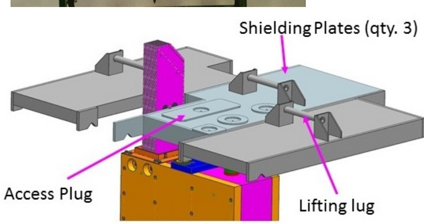


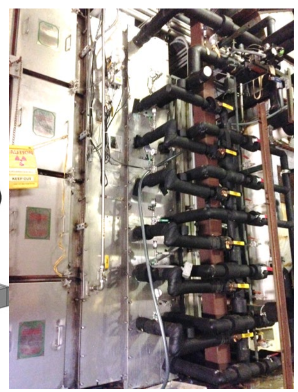
Tasks and Schedule

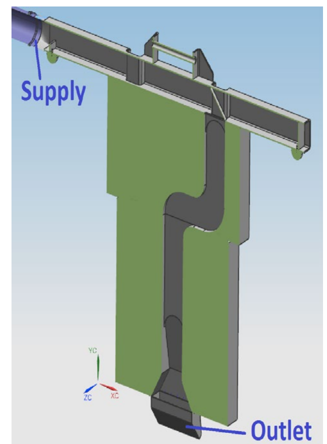
2019 summer shutdown Completed	2020 summer shutdown	Tasks not involving summer shutdowns
1 MW target installation	1 MW horn 1 installation	MARS simulations
Target & Horn 1 RAW upgrade	Stripline air diverter T-block	Pre-target Be window
Target chase cooling / air upgrade	Target and horn 1 module drives	Decay pipe Al window
Target chase supplemental shielding	Hadron beam monitor & absorber	Tritium mitigation

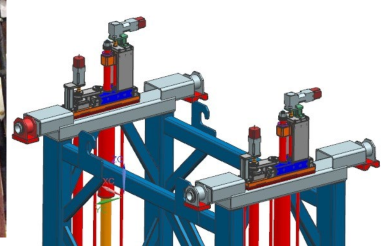


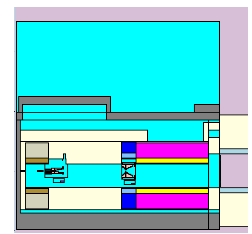


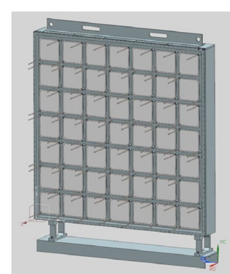


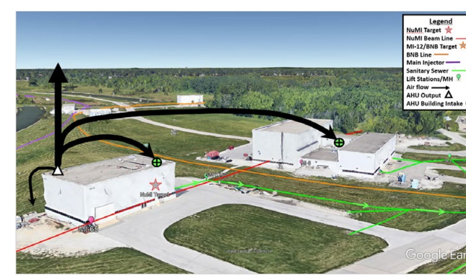






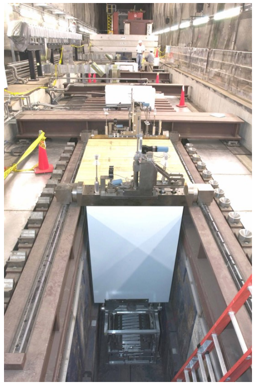


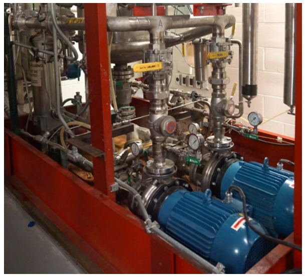


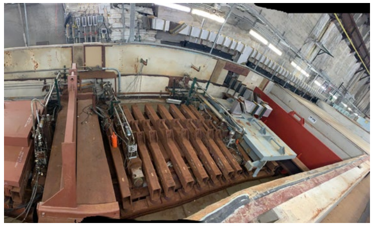


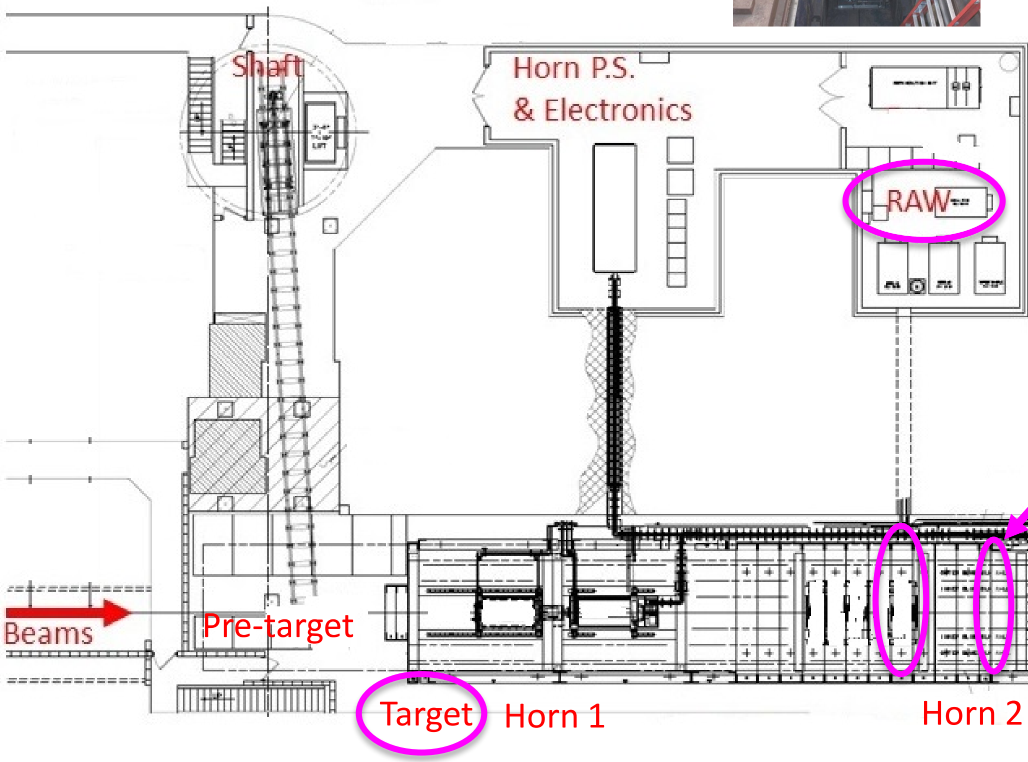
Activities been Completed during 2019 Summer Shutdown

2019 summer shutdown
1 MW target installation
Target & Horn 1 RAW upgrade
Target chase cooling / air upgrade
Target chase supplemental shielding









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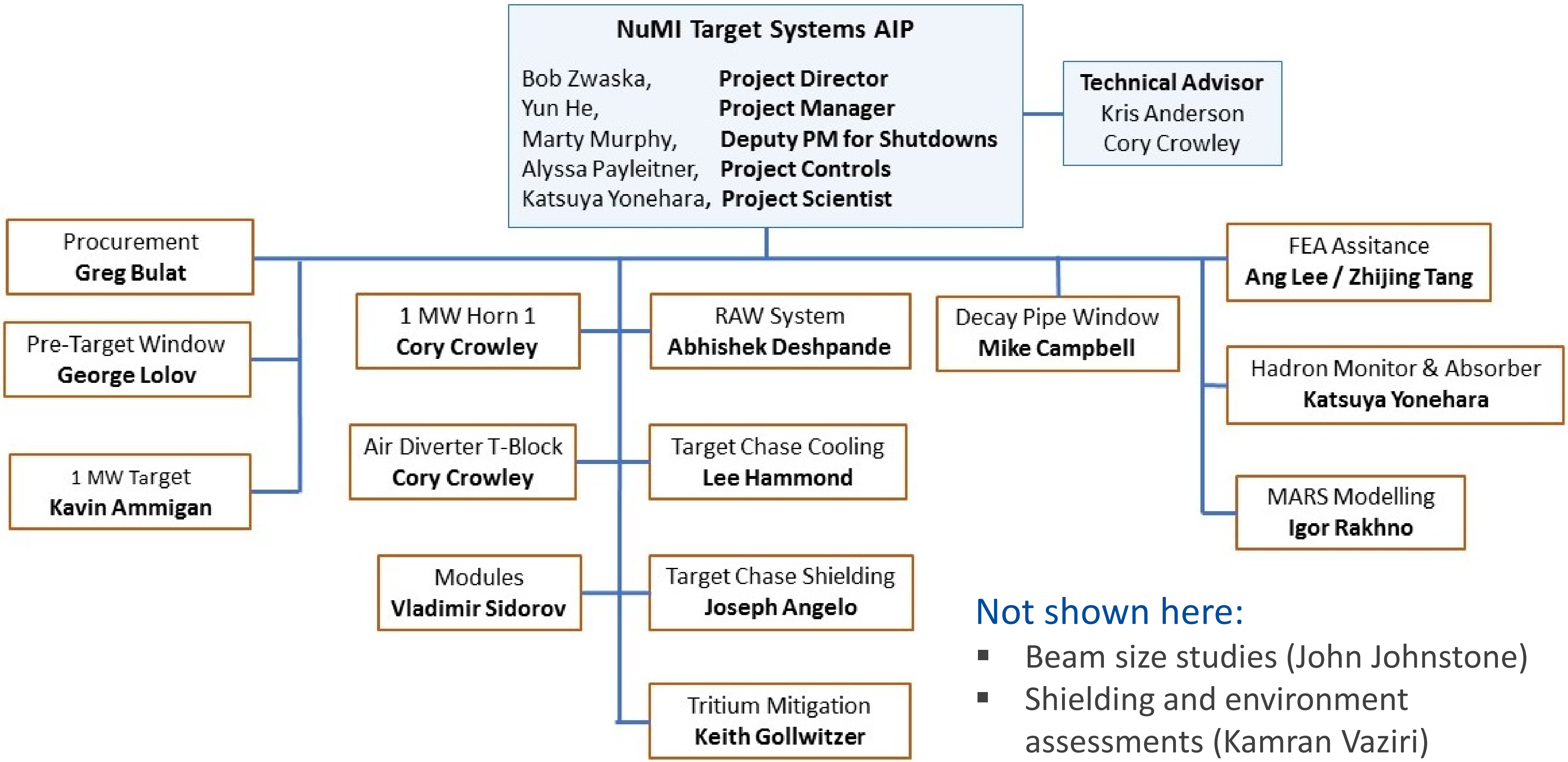
Project Organization Chart



Not shown here:

- Beam size studies (John Johnstone)
- Shielding and environment assessments (Kamran Vaziri)

Some of the task managers are giving talks at this workshop
(though the topics may not be NuMI-TS-AIP specific)

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  - Tasks and schedule
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Status Overview

Activities been completed
Design / FEA / procurement / fabrication

FY20
Fabrication/ installation / add new activities

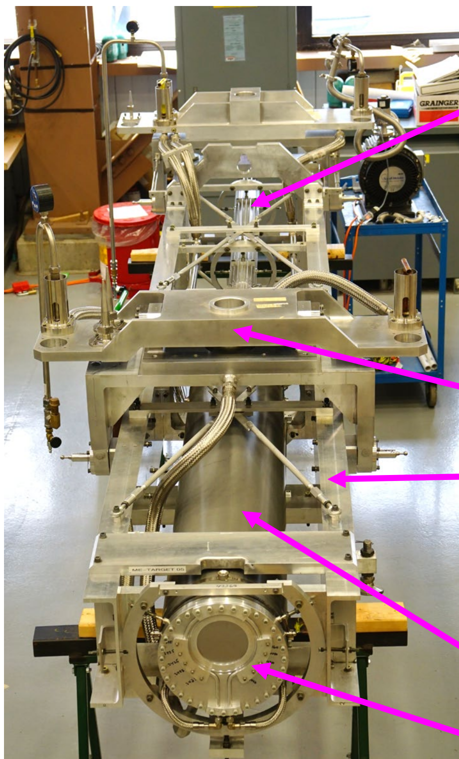
Tasks	50%	80%	100%	Remaining work
MARS simulations				MARS for horn 1 stripline air diverter T-block
Pre-target Be window				final welding
1 MW Target				installation after beam scans
1 MW Horn 1				Stripline final machining
Stripline air diverter T-block				Delivery
Target / horn 1 module drives				Fabrication / procurement
RAW skids				Add new activities
Target hall chiller/air handling				Add new activities
Target chase shielding				-----
Tritium mitigation				Instrumentation design & implementation
Decay pipe window				Drawings generation
Hadron monitor & absorber				Update design by U of Texas

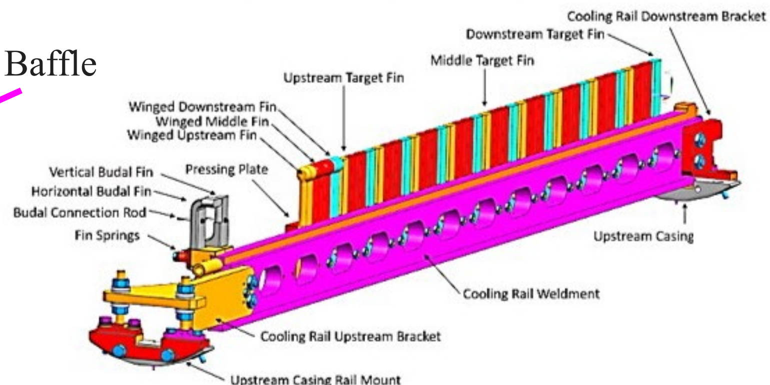
1). 1 MW Target (Kavin Ammigan / Kris Anderson / Cory Crowley / George Lolov / Mike Stiemann) see George Lolov's talk

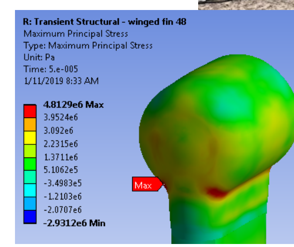
Redesigned target core (for larger fins 9.0 mm from 7.4 mm) and baffle per increased beam size Φ1.5 mm (from Φ1.3 mm) for stress reduction in graphite (POCO ZXF-5Q)

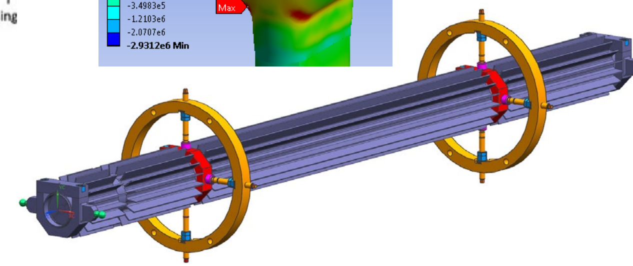
Design, FEA , modifications

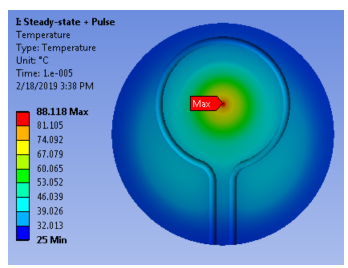
- Addition of U.S. winged fins: protection per mis-steered beam
- Extensive thermo-structural FEA
- Additional cooling Ω-loop to DS Be window

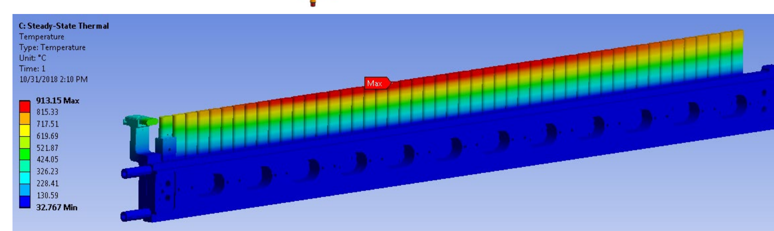












2) MARS Simulations (Igor Rakhno)

Calculated energy deposition, distributions of star density, hadron flux, prompt and residual dose for:

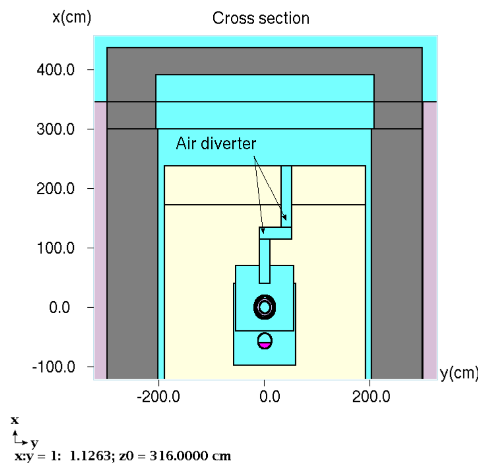
- Target chase, Decay pipe, Absorber Hall and Muon Alcoves
- Shielding and environmental assessments

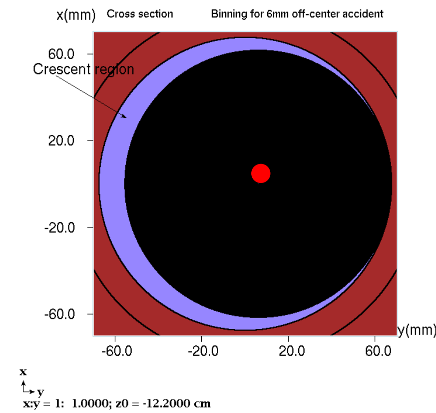
Two scenarios:

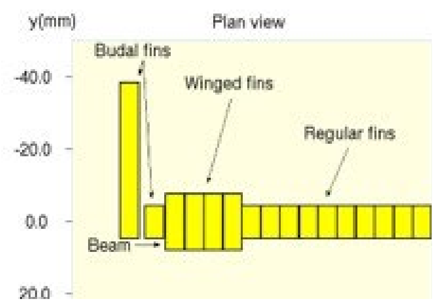
- Beam normal operation
- Beam 6mm off-center accident condition

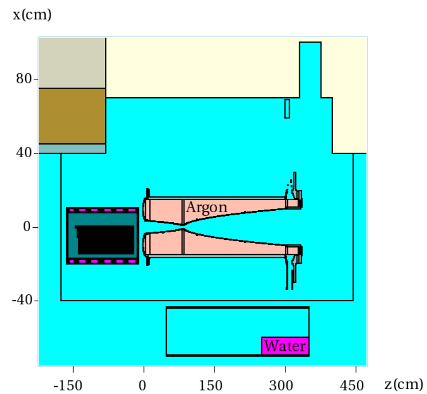
MARS re-run for energy deposition data for

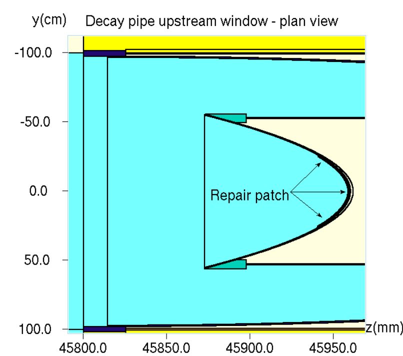
- Target DS beryllium window:
  - With target 4 winged fins placed upstream
  - With cooling loop on the DS Be window
- Decay pipe US window
- Beam absorber
- Horn 1 stripline air diverter T-block

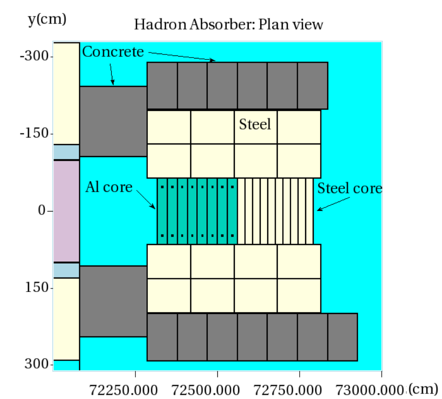




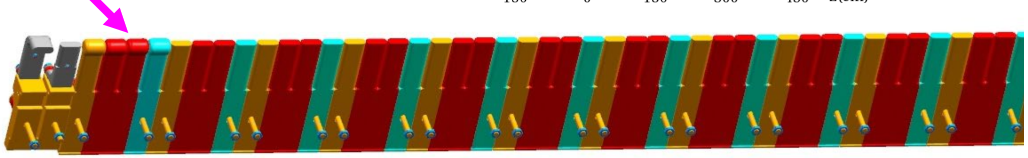






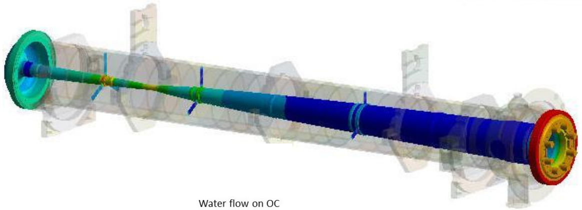


Winged fins



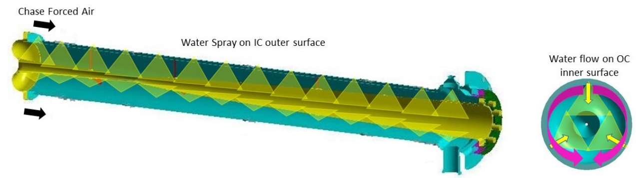
3) 1 MW Horn 1 (Cory Crowley / George Lolov)

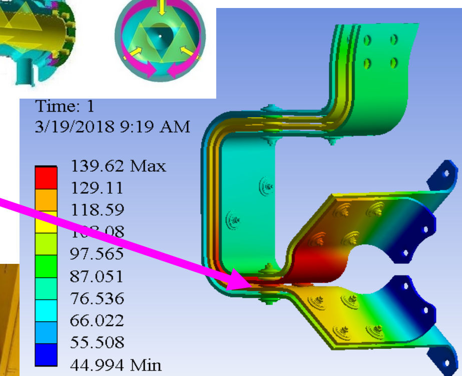
Cooling improvement to Horn 1 inner conductor & stripline



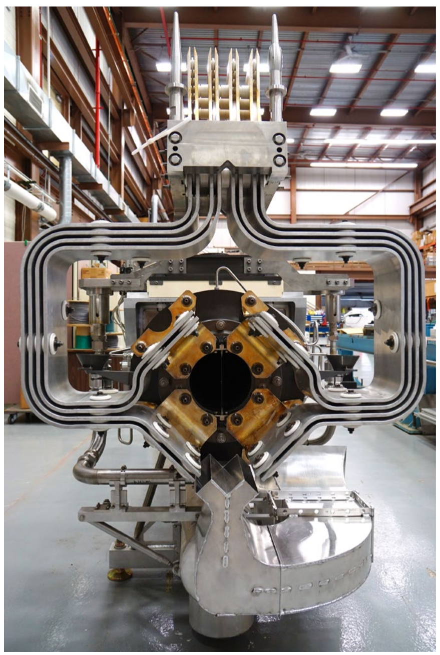
Modifications & FEA

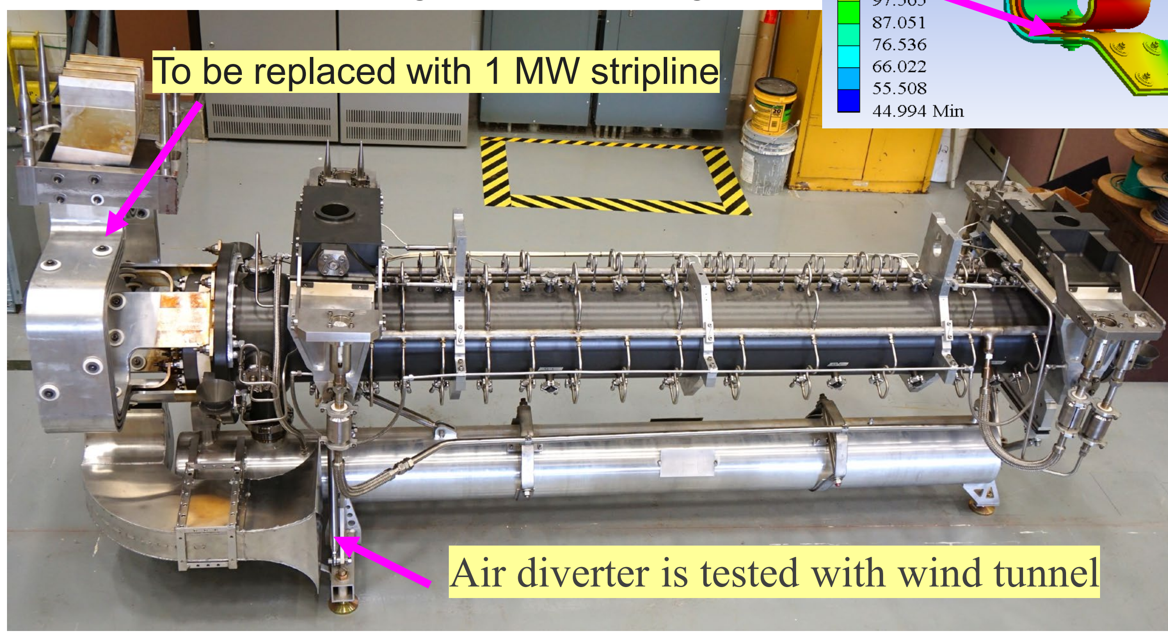
- Increased cooling water flow to inner conductor (RAW system upgrade)
- Stripline w/ air diverter, see George Lolov's talk
- Extensive thermo-structural FEA
- Wind tunnel test





Segment replaced w/ Al 6013-T6
High heat/stress region





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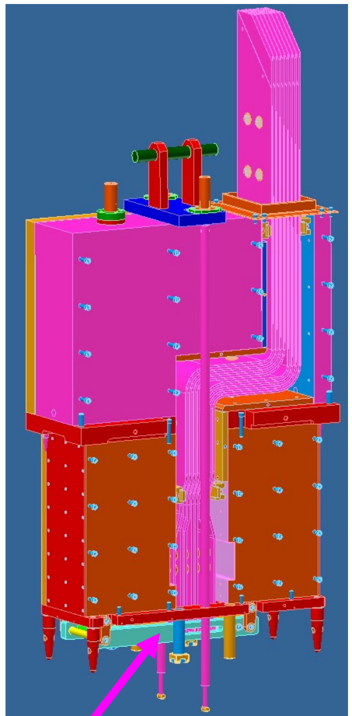
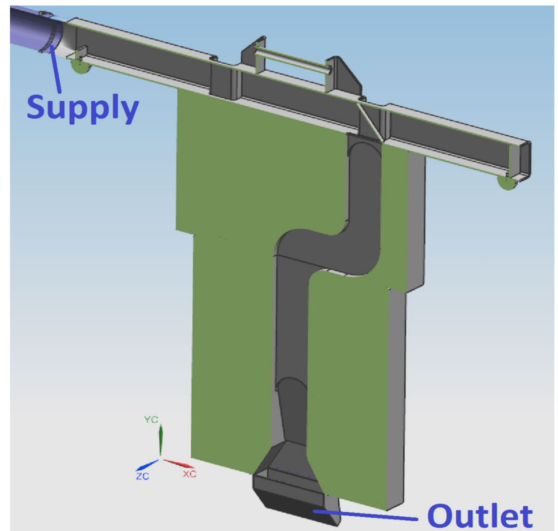
4). Stripline Air Diverter T-block (Cory Crowley)

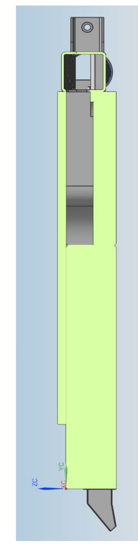
Provide dedicated air cooling to Horn 1 electrical bus stripline

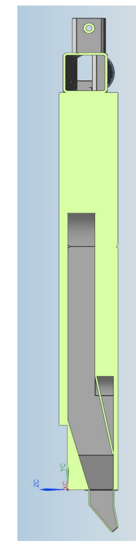
Design	Shielding study in progress
• Through an adjacent shielding block with new air supply installation through battlement	• MARS simulation, shielding assessment



Heating sources:
1. energy deposition from beam
2. joule heating from current pulse







Outlet

5) Target /Horn 1 Module Drive Mechanism (Vladimir Sidorov)

Module are corroded, motion control on Target & Horn 1 is failing

- Redesigned drives and linkages with corrosion resistant materials SS
- Challenging: changeout procedure
- Remote handling tools, training, practice on module assembly stand

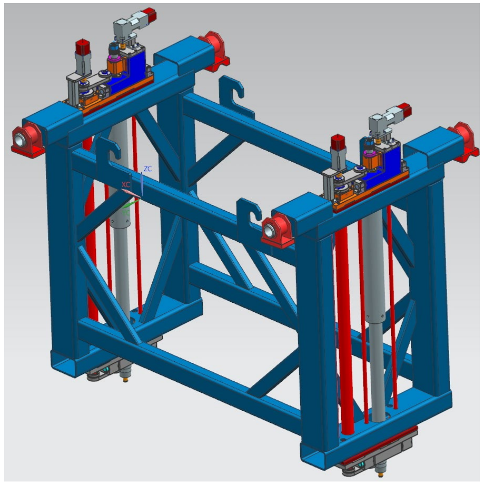
Kinetic interfaces are frozen

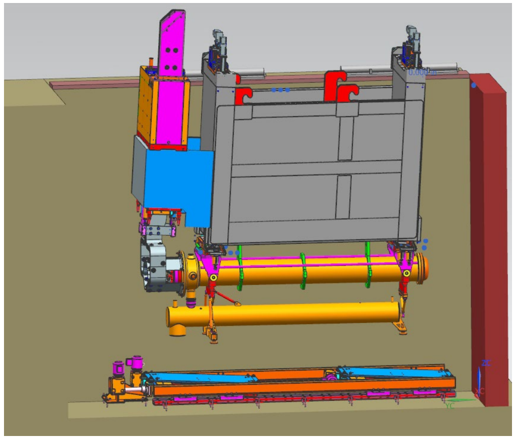
Design modifications

- Graphalloy bushings and washers
- More powerful motors with stainless steel gear box
- Al anodized bushings in lower linear block
- Transverse link shaft design
- Vertical shaft support block
- Module mock-up frame

Modules	Vertical motion	Horizontal motion
Target	+8 mm to -200 mm	+/- 8mm
Horn 1	+/- 3 mm	+/- 3 mm

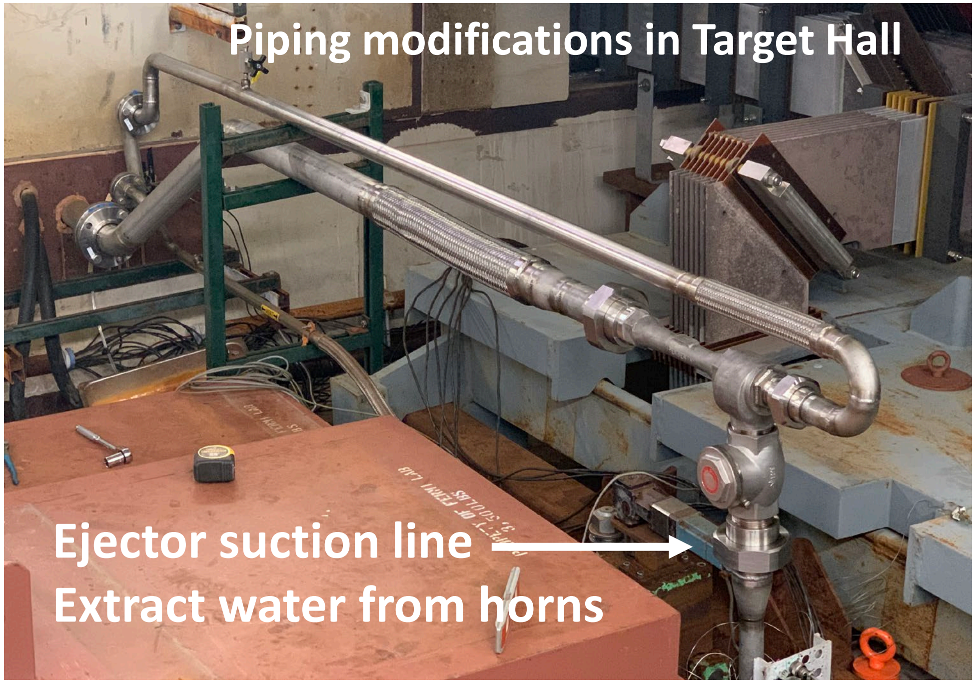
Mock-up frame





6). Target & Horn 1 RadioActive Water System(Abhishek Deshpande)

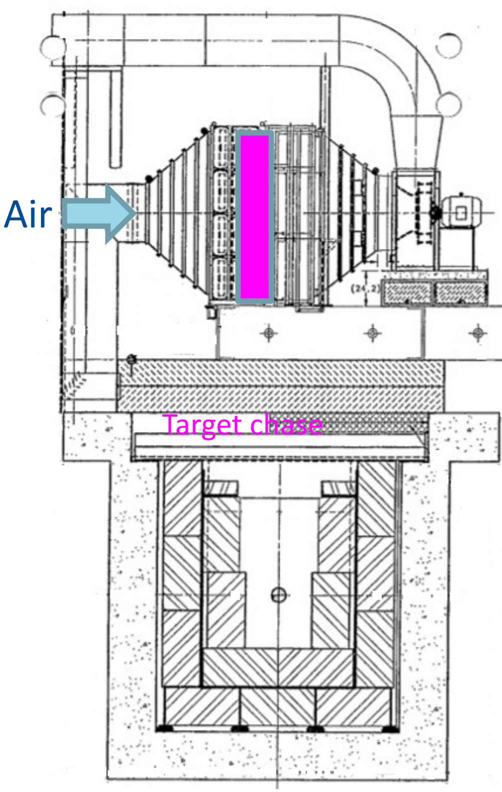
Upgrade with higher capacity: pumps, ejector pump, heat exchangers, piping, PEEK sealed valves and instrumentation, to handle extra cooling needed



7) Target Chase Cooling & Air Handling System (Lee Hammond / Cory Crowley)

Upgrade target chase cooling and air handling system
removes heat from target chase and dehumidification system.

Pumps replaced and piping installed in Multi-stack chiller system	Additional cooling coils installed in heat exchanger bank
pressure test, electrical installation, insulation	Custom channels, field fits are made for directing air to coils Upgrade instrumentation for pressures and temperatures



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8) Tritium Mitigation (Keith Gollwitzer / Lee Hammond)

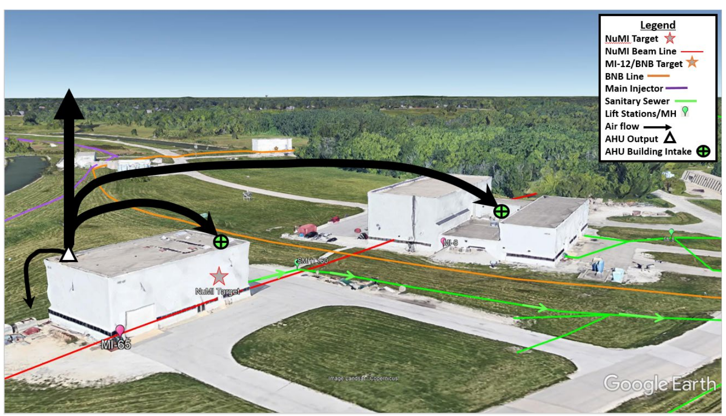
Tritium mitigation plan – to separate the target hall sanitary plumbing from the dehumidifier drains for capture, holding and pumping condensed tritium to the evaporation system.

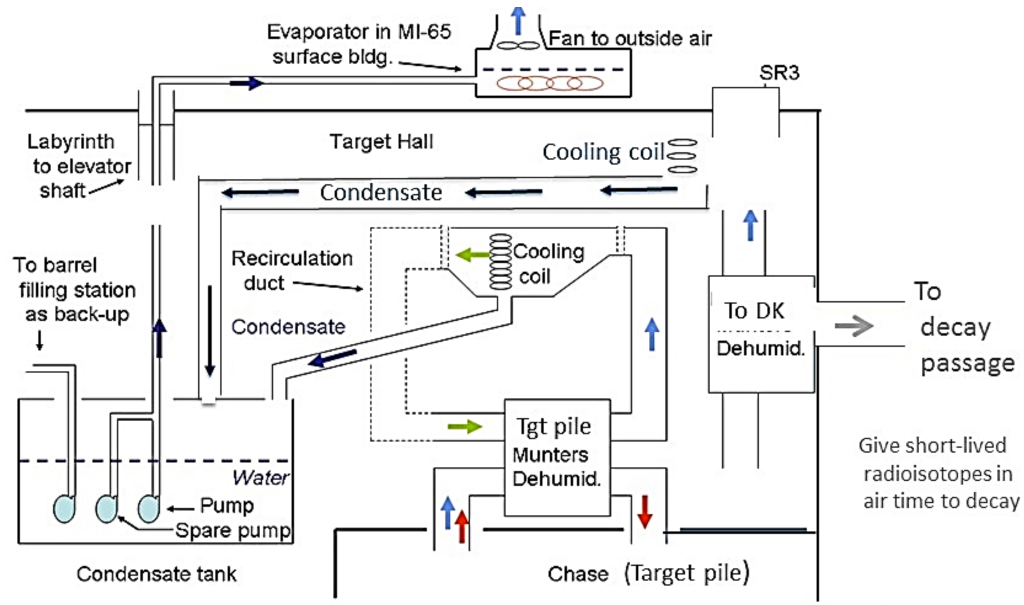
See Jim Hylen's talk

Tritium task force has been investigating various sources of tritium at MI65 (NuMI).

- soil samples
- sanitary sewer samples
- condensate tank samples
- precipitation samples

has learned that blow down from the evaporator stacks contributes a tritium load onto the roof of the building.





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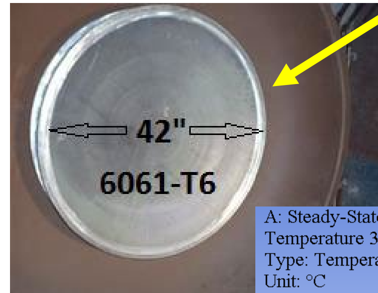
9) Decay Pipe Upstream Window (Mike Campbell / Zhijing Tang)

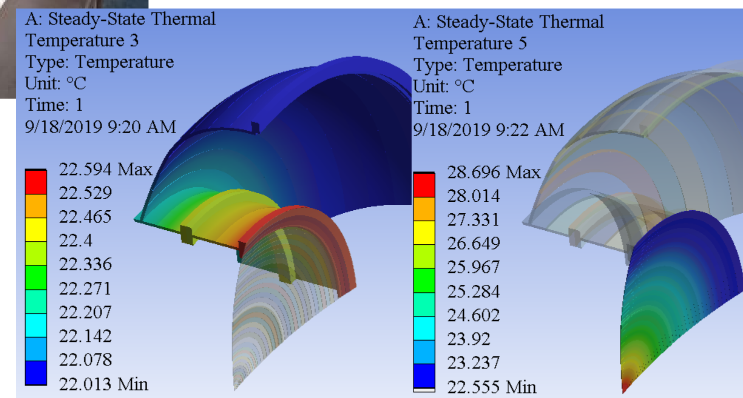
Evaluate possible solutions in event window needs to be repaired

Repair mechanism concept developed

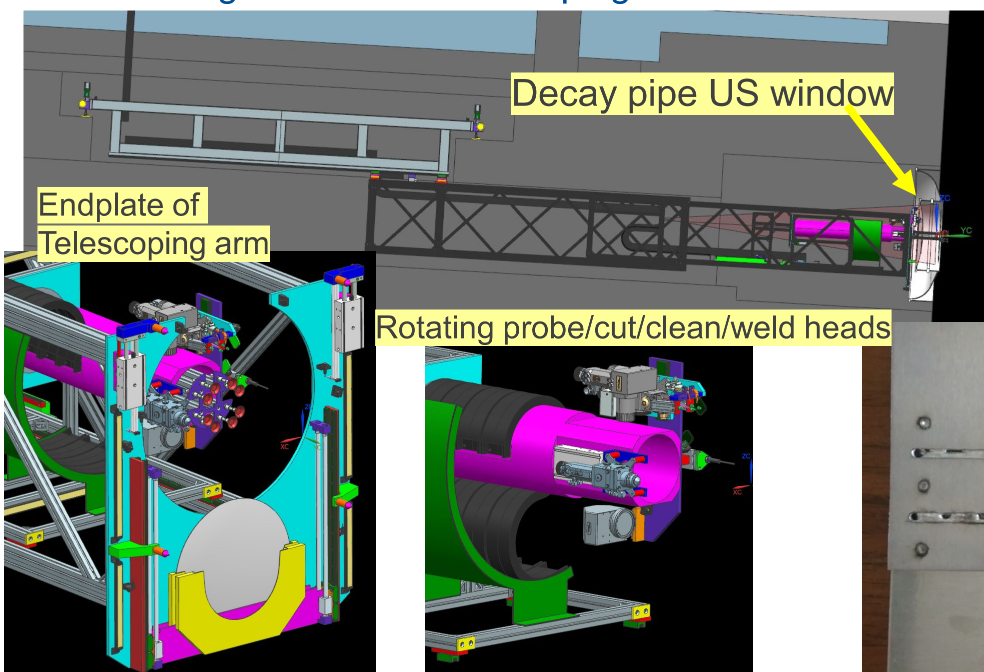
- ➢ Repair mechanism concept developed
- ➢ Robot laser ablation welding testing
- Weld repair patch (Al 5083 or 5052) over failed section (Al 6061)
- Samples, welding, testing & characterize properties
- ➢ FEA thermo-structural analysis

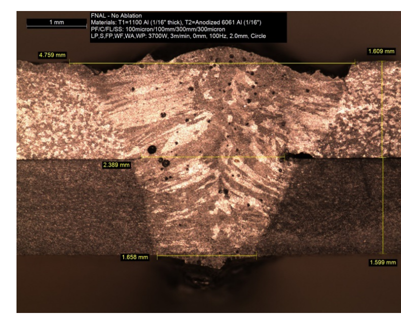


- Suspected corrosion was found on the window at beam spot center in 2007
- Since then, decay pipe was filled helium gas



Uses a 2-stage motorized telescoping arm to reach out 23.5'





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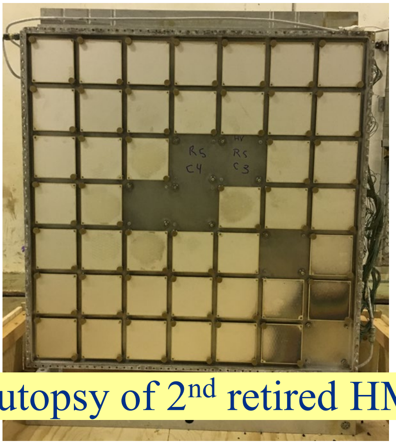
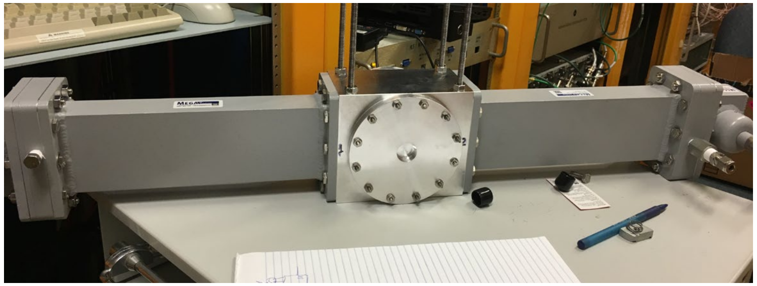
10) Hadron Beam Monitor (Katsuya Yonehara)

- Present hadron monitor shows low gain due to radiation damage
  - Central pixel still useful for aligning beam elements (baffle, target, horns)
- U. of Texas at Austin to produce Hadron beam monitors
  - Using radiation hard materials
  - Design options: number of pixels, number of layers per pixel, pixel size, electrode gap, ionization medium, feedthrough geometry, rad-hard cables, chamber seal, etc
- Studies for hadron monitor design improvements
  - Pressure analysis
  - Electrode surface study
  - Study electron-ion dynamics in ion chamber (mitigate recombination process)
- Upgrade gas handling system

  To avoid corrosion caused by ionization gas impurities
  - Mass flow controlled device,
  - add bubbler (gas trap) on exhaust gas line
  - Operate through PLC
- Upgrade high voltage power supply
  - Apply individual pixel
  - Remote control through ACNET
    - Voltage can be changed
    - Leakage current monitoring
- R&D alternative detectors (gas-filled RF detector, SEM)



Autopsy of 2nd retired HM



See Katsuya Yonehara's talk

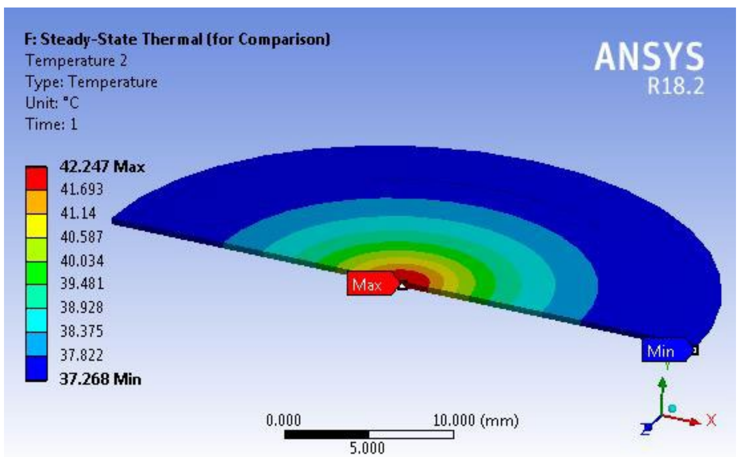
- 2.4 GHz gas-filled RF resonator
- made of aluminum for rad-hard
- Beam ionizing gas and form plasma in the cavity
- RF power consumption is proportional to the amount of incident beam
- tested with beam at MI-40

11) Pre-target Vacuum Pipe with Be window (George Lolov)

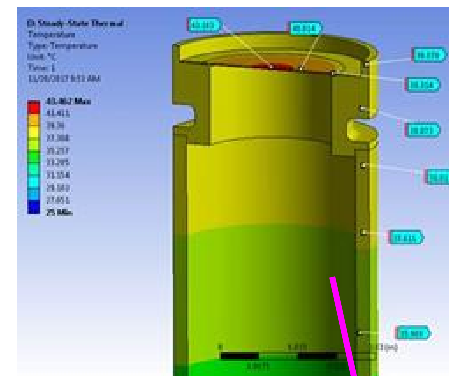
Interface juncture between primary beamline and target station
Improved design and fabrication techniques to address increased heating

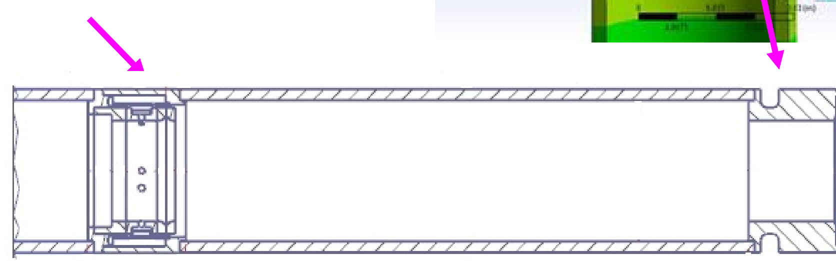
Design & FEA completed

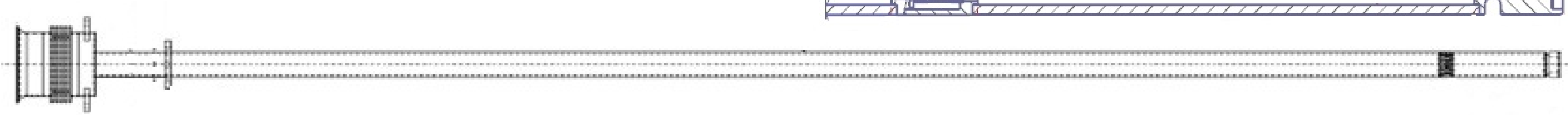
- Slightly domed and thicker
- Improved brazing joint design
- FEA Thermal-structural analysis



Ti shard arrestor



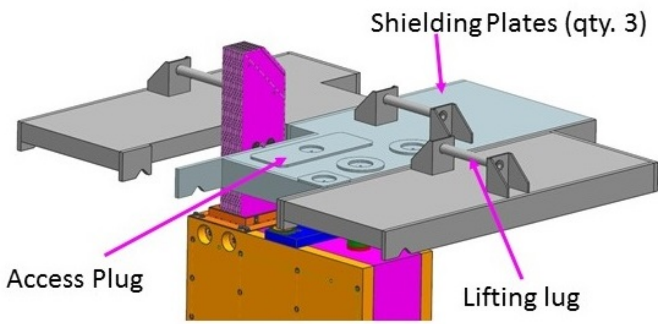




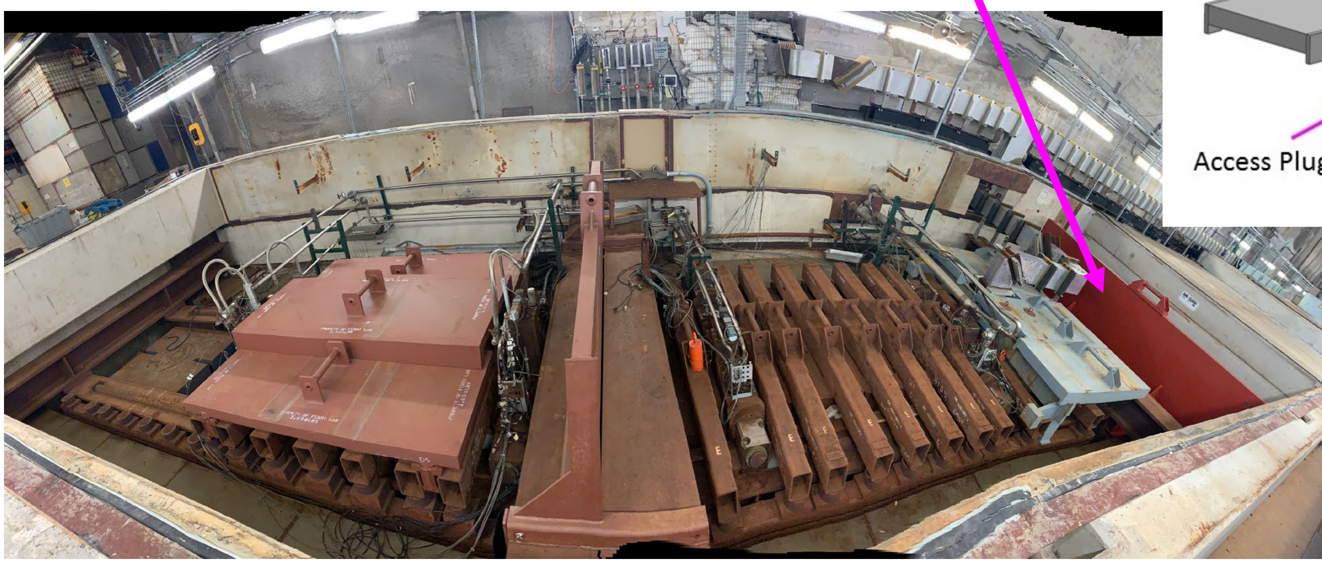
Fermilab

12) Target Chase Supplemental Shielding (Joseph Angelo)

- Protect personnel during maintenance and beamline components changeout activities
- Reduce cool-down time needed

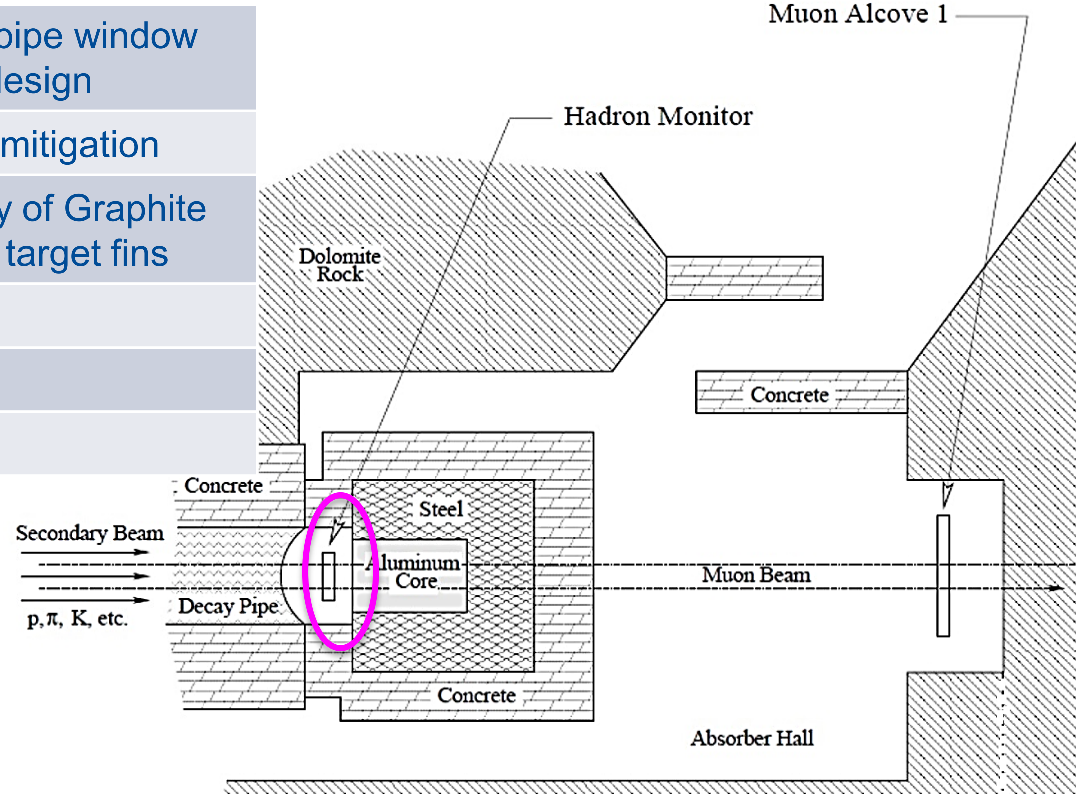


Horn 2 stripline



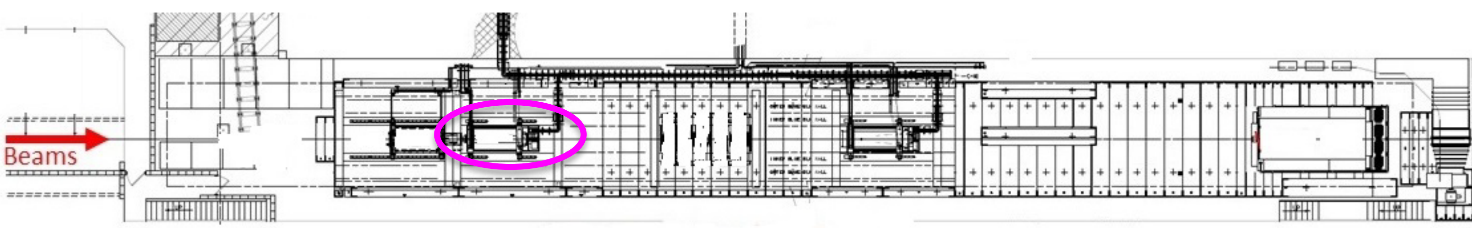
Activities to be Completed FY20

2020 summer shutdown	Other tasks
1 MW horn 1 installation	Decay pipe window repair design
Stripline air diverter T-block	Tritium mitigation
Target and horn 1 module drives	Autopsy of Graphite and Be target fins
Hadron beam monitor & absorber	
Beam absorber intermediate RAW	
MINOS surface chiller upgrade	



Beams from Target Hall

Horn 1, w/ new module drives, w/ Stripline air diverter T-block



Decay pipe window

To hadron beam monitor

Summary

- Megawatt target TA-05 installation in October 2019, but the horn limitations will not be superseded until the installation of PH1-05 next summer;
- Maximum operational beam power is set for 777 kW;
- By end of FY20, NuMI neutrino beamline system will be able to accept beam power up to 1 MW;
- Accelerator beam power roadmap:
  - -- Operational cycle time will be 1.2 sec after 2019 summer shutdown;
  - -- Spacing between cycles remains at 1.4 sec for Muon campus operation
  - -- Will be ready for 900 kW operation in 2022
- Will gain operation experiences for LBNF (initial 1.2 MW)

NuMi-TS-AIP Team