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Participation Opportunities on LBNF Neutrino Beamline

P. Hurh

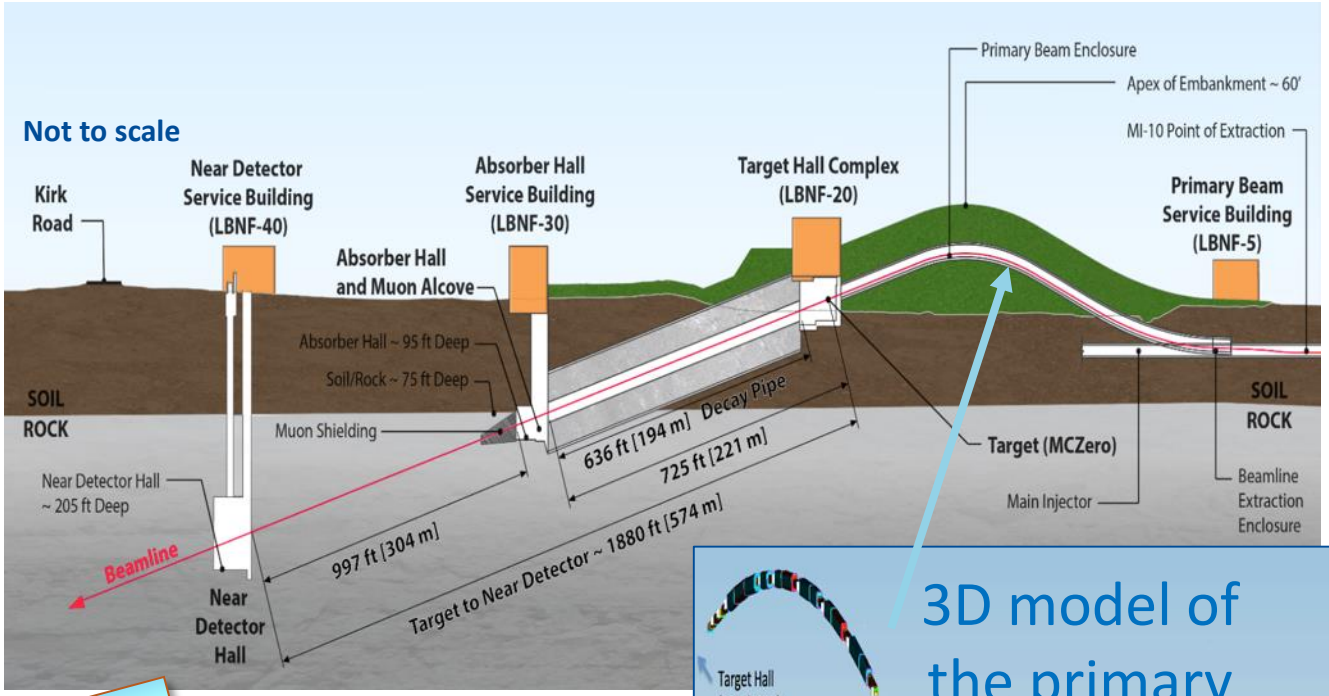
(on behalf of the Fermilab Neutrino Beam team)

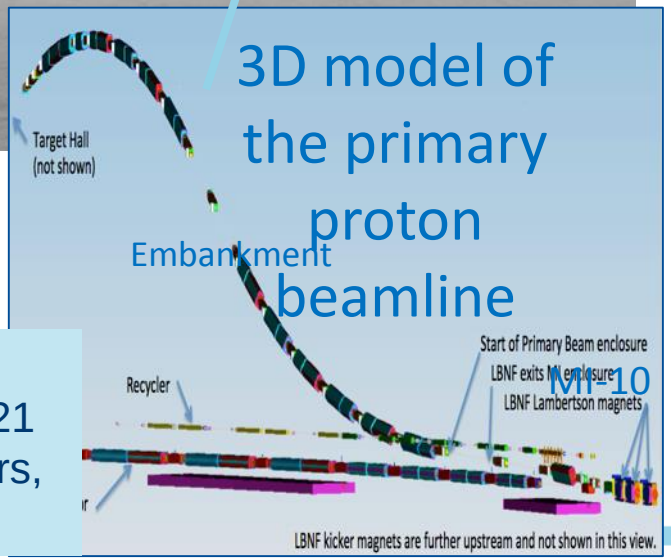
European Neutrino Meeting LBNF/DUNE

April 7-8, 2016

The LBNF Beamline (Reference Design)

Facility designed for initial beam power of 1.2 MW, upgradeable to 2.4 MW





3D model of the primary proton beamline

Proton beam extracted from Fermilab's Main Injector in the range of 60 – 120 GeV every 0.7 – 1.2 sec with pulse duration of 10 μs

Protons per cycle:
1.2 MW era: 7.5×10^{13}
2.4 MW era: $(1.5\text{-}2.0) \times 10^{14}$

Beam size at target tunable between 1.0-4.0 mm sigma

The beam lattice points to 79 conventional magnets: 25 dipoles, 21 quadrupoles, 23 correctors, 6 kickers, 3 Lambertsons and 1 C magnet

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Opportunities for collaboration

Primary Beam

- dipole & quadrupole magnets
- corrector magnets
- quadrupole power supplies
- primary beam monitoring

Neutrino Beam

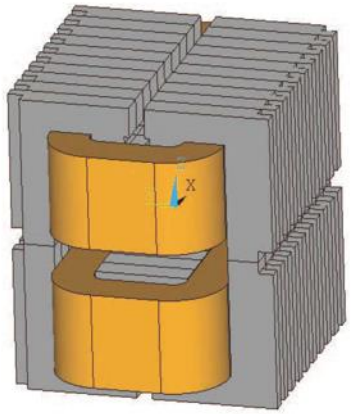
- primary beam window, baffle, target
- focusing horns, horns power supply
- instrumentation (beam profile on target, target health, alignment)
- support modules target/baffle/horns
- target chase shield covers and water cooling panels
- evaluation of alternative design for inert gas-cooled target chase & corrosion impacts
- hadron absorber
- remote handling equipment
- physics, energy deposition, and radiation transport simulations
- materials R&D

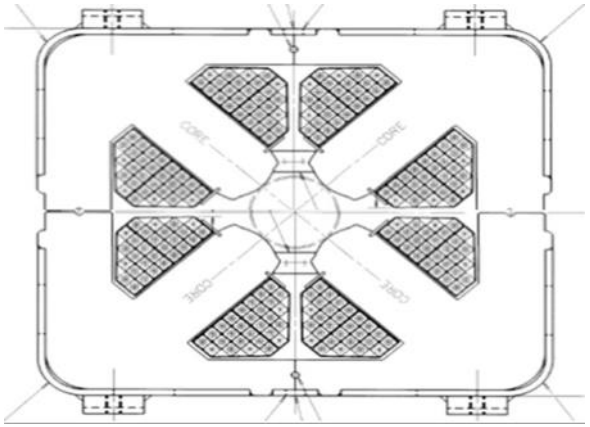
Magnets – Summary Table

Magnet	Common Name	Source	Nom. Strength at 120 GeV	Count
RKB type Kicker		new	0.058 T	6
ILA	MI Lambertson	Tev	0.532 / 1.000 T	3
ICA	MI C Magnet	Pbar	1.003 T	1
IDA	MI Dipole 6 m	new	1.003 - 1.604 T	13
IDD	MI Dipole 4 m	new	1.003 - 1.604 T	12
3Q120	120” quadrupole	4 from NUMI	9.189 - 16.546 T/m	17
3Q60	60” quadrupole	new	11.135 - 17.082 T/m	4
IDS	LBNF trim dipoles	new	Up to 0.365 T	23

<u>design</u>
dipoles/quads: built to existing design
correctors: modification of existing design (larger aperture/better cooling)
kicker: similar to existing design

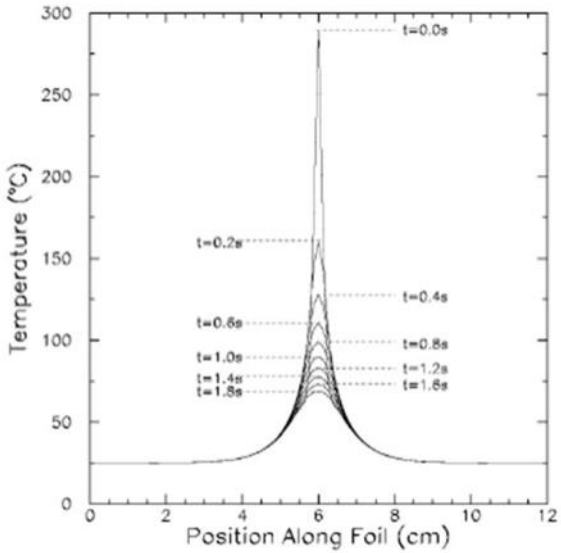
79 total (8 refurbished)





Primary Beam Instrumentation

- Beam Position Monitors
  - “button style” prototype installed and tested in NUMI
- Beam Loss Monitors
  - Re-purpose existing NuMI loss monitors
- Four argon filled Heliax total loss monitors to span entire beamline
  - NuMI read-out system will be re-purposed
- Beam Intensity Monitors
  - Re-purpose NuMI toroid transformers
- Beam profile monitors
  - NUMI type, wire plane material TBD (based on NUMI 700kW experience)
- ***Non-interacting beam profile monitor***
  - ***Downstream end of the line for spot size on every pulse.***



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Quad Magnet Power Supplies

Magnet Loop Name	Number of Magnets	Power Supply Location	Power Supply Type	Power Supply Voltage	Peak Magnet Current	RMS Current	RMS Power
E:Q201/2	2-3Q60	LBNF-5	75 kW	150	234	110	2.6 kW
E:Q203	1 -3Q120	LBNF 5	75 kW	150	263	125	3.3 kW
E:Q204	1 -3Q120	LBNF 5	75 kW	150	194	96	1.9 kW
E:Q205	1 -3Q120	LBNF 5	75 kW	150	275	132	3.7 kW
E:Q206	1 -3Q120	LBNF 5	75 kW	150	285	138	4.0 kW
E:Q207	1 -3Q120	LBNF 5	75 kW	150	340	173	6.3 kW
E:Q208	1 -3Q120	LBNF 5	75 kW	150	333	158	3.9 kW
E:Q209	1 -3Q120	LBNF 5	75 kW	150	333	158	3.9 kW
E:Q210	1 -3Q120	LBNF 5	75 kW	150	333	158	3.9 kW
E:Q211	3-3Q120	LBNF 5	150 kW	150	333	180	18.7 kW
E:Q214	1 -3Q120	LBNF 5	75 kW	150	293	135	2.9 kW
E:Q215	1 -3Q120	LBNF 5	75 kW	150	293	117	2.1 kW
E:Q216	1 -3Q120	LBNF 5	75 kW	150	348	164	4.2 kW
E:Q217	1 -3Q120	LBNF 5	75 kW	150	261	152	1.9 kW
E:Q218	1 -3Q60	LBNF 5	75 kW	150	282	140	4.7 kW
E:Q219	1 -3Q120	LBNF 5	75 kW	150	223	179	7.6 kW
E:Q220	1 -3Q120	LBNF 5	75 kW	150	339	173	6.3 kW
E:Q221	1 -3Q60	LBNF 5	75 kW	150	288	110	1.6 kW

- re-use 5 supplies from NUMI
- 10 new 75 kW supplies (same design)
- 1 new 150kW supply (new design)

- Actively looking for contributor on these quad magnet power supplies

Primary Beam Window, Target & Target/Beam Instrumentation

Primary Beam Window

- Ref design: Be, passive air cooled for 1.2 MW
- May have to water cool for 2.4 MW
- Alternative ideas welcome (Densham talk)

Baffle

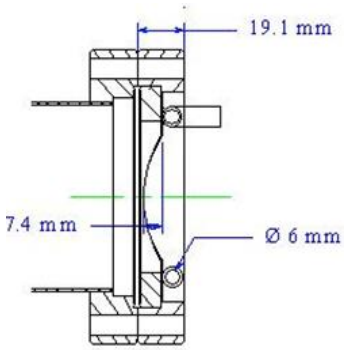
- Protects target cooling lines and horns from errant beam pulses

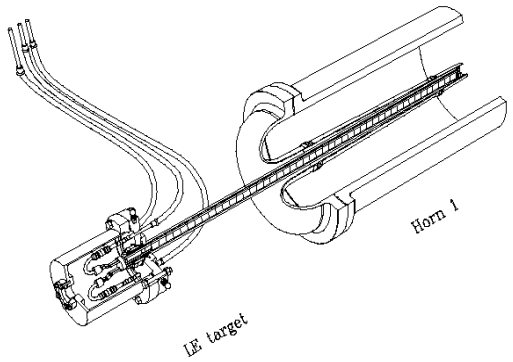
Target

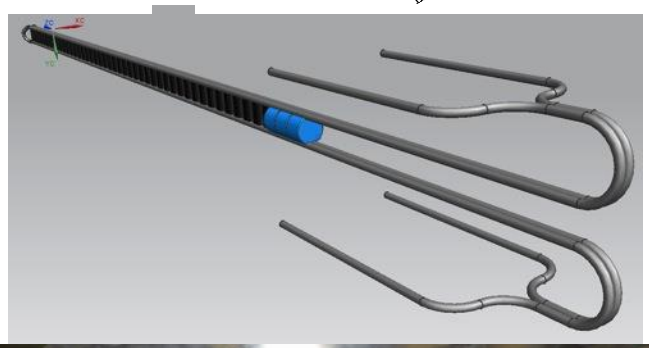
- Ref design is similar to NuMI-MINOS LE target
- 47 graphite segments, 2 cm long each
- 2 interaction lengths ~94 cm
- Alternatives ideas being pursued (Densham short talk)

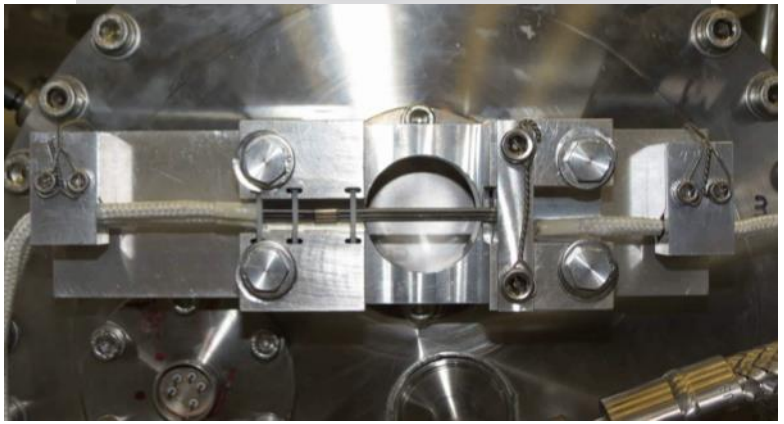
Target/Beam Instrumentation

- Current NuMI facility uses “Hylen device” to monitor beam position and profile on the target (uses Be bars & thermocouples)
- Beam scans utilizing hadron monitor are used for alignment and target health monitoring
- Alternative ideas are welcome
  - Radiation “hard”
  - Passive cooling desired

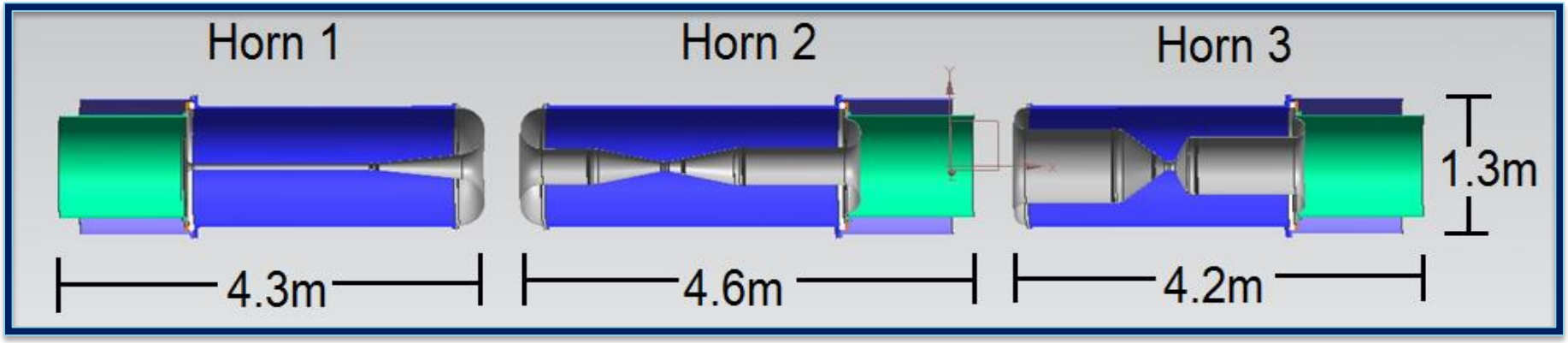




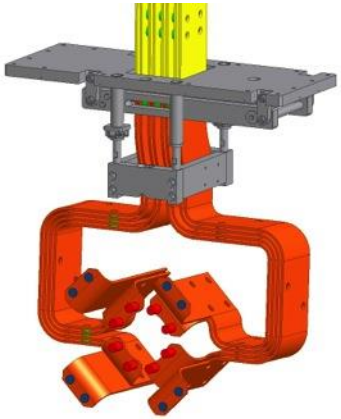




Optimized Focusing Horn System & Power Supply



- Constructed from 75% 6061-T6 aluminum forgings, balance is 316 SS / Gr. 5 Ti / Ceramics.
- Contributing institutions must have high purity critical welding expertise, in addition to knowledge of alumina and zirconia ceramic structural / electrical applications.
- Required alignment tolerance & mechanical stability on straightness, concentricity, & circularity of all conductor components along beam axis is ± .25mm.
- Minimum fatigue life requirements of 100 million pulses for each design at any energy range from 60 – 120 GeV.
- Power supply design and electrical bus must be integrated with horns for balanced pulse width & magnetic field.



Power Supply Parameters	60-120 GeV Operation
Horn Current	300 kA
Current Pulse Width	0.8 ms
Repetition Rate	0.7 s – 1.2 s

Pictures of NuMI Horn Systems & Power Supply

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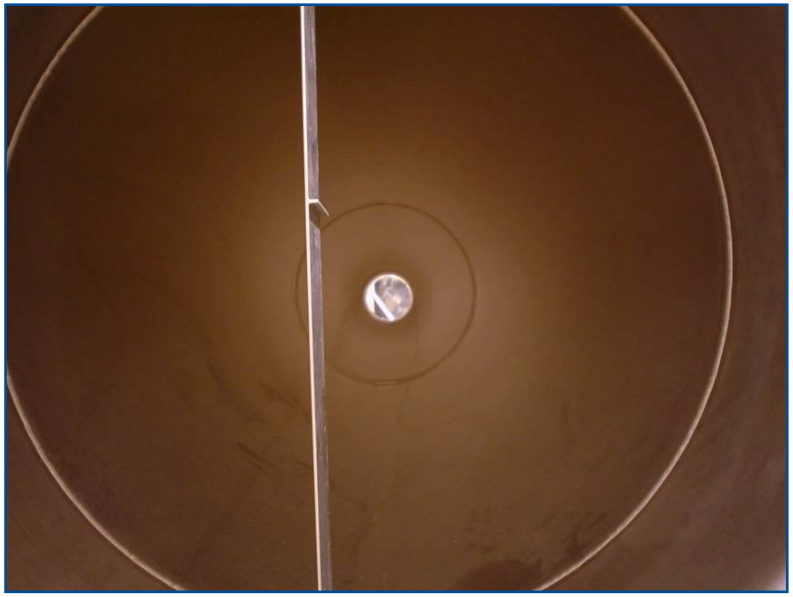
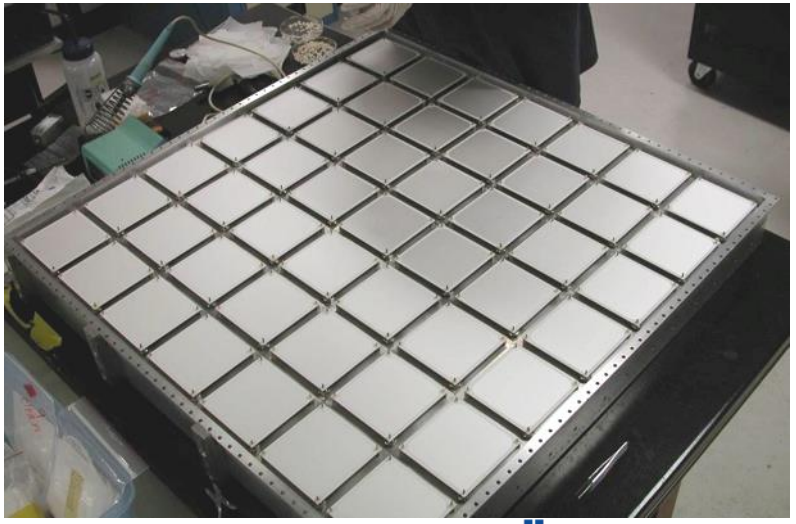
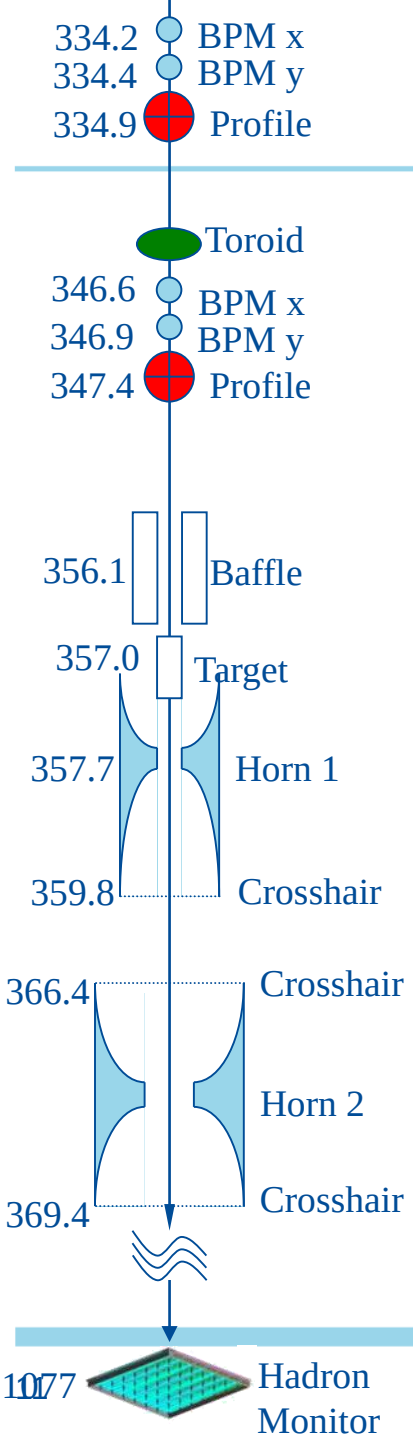
Target & Horns Instrumentation (THI)

- Additional instrumentation in and near target hall to support beam operation
  - Commissioning
  - Beam-Based Alignment
  - Beam Permit
  - Long-Term Monitoring
- Interfaces with other instrumentation systems
  - Primary beam
  - Systems (RAW, air, temps)
  - Neutrino beam monitors
- Detector systems and integrative software
  - Crosshair monitors: align the horns
  - Hadron Monitor: measures remnant proton and secondary beam just upstream of the absorber
  - Muon Beam Permit measures muons just downstream of absorber
  - Software correlates data between instrumentation in a real-time manner that is useful for operations
- Target Decay Monitor was a previously conceived device whose functionality is now being provided by detectors from the ND group



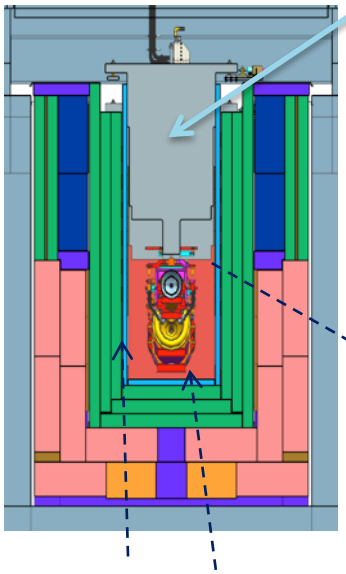


Beam-Based Alignment



- Needs for alignment
  - Target & Baffle
    - Meson production varies with amount of material traversed
    - Position of production important for other optics
  - Horns
    - Focusing depends on positioning and angle
- Procedure
  - Scan proton beam across known features of beamline components
    - Target & Baffle material
    - Horn neck and cross-hairs
  - Use instrumentation to correlate measured proton beam position with component features
    - Target budal Monitors
    - Loss Monitors in the target hall
    - Hadron and Muon Monitors

Target Chase Shielding Components

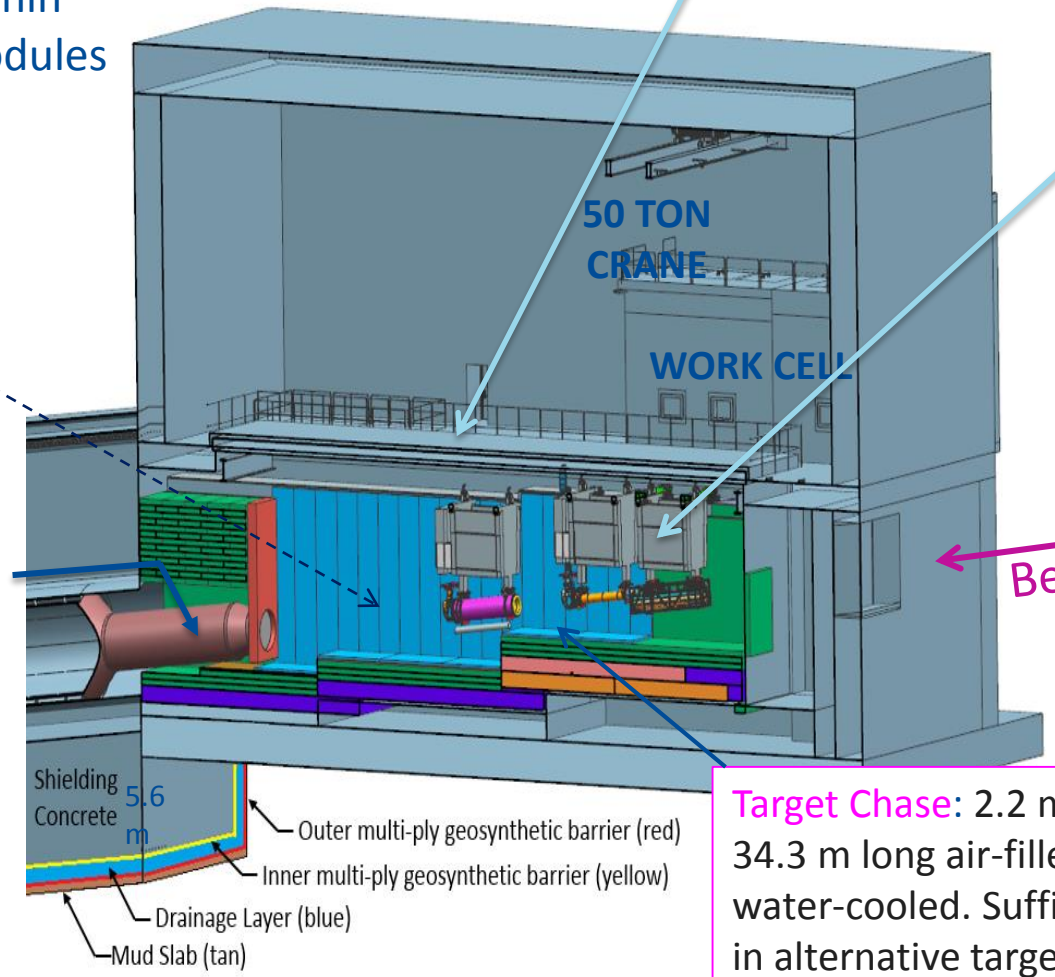


T-blocks within modules

Cooling panels

Shielding Covers

Support modules with utility penetrations



Target Chase: 2.2 m/2.0 m wide, 34.3 m long air-filled and air & water-cooled. Sufficiently big to fit in alternative target/horns.

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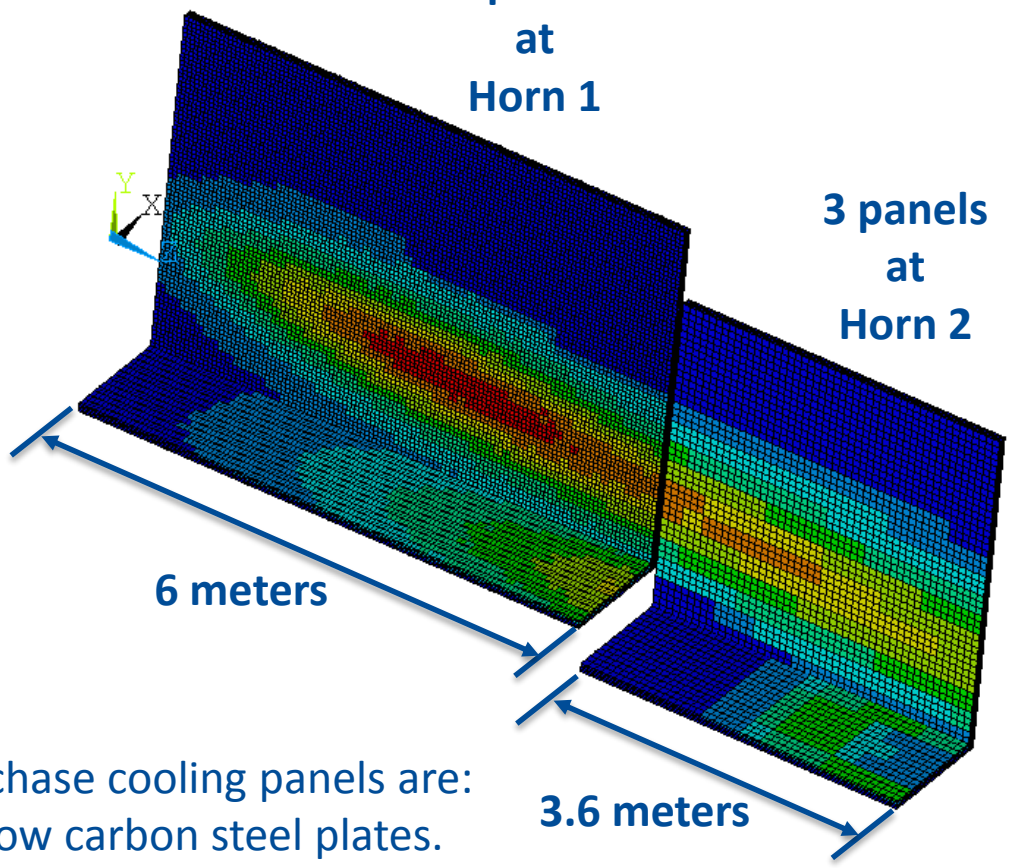
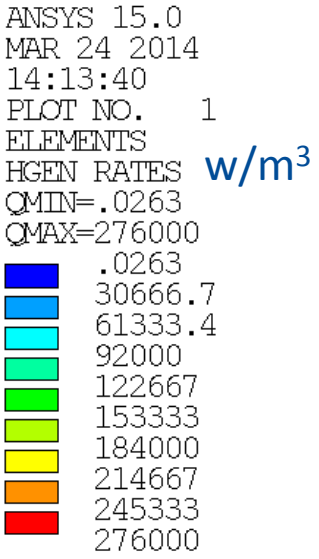
Chase Cooling Panels, cooled with RAW

- 5 panels at Horn 1

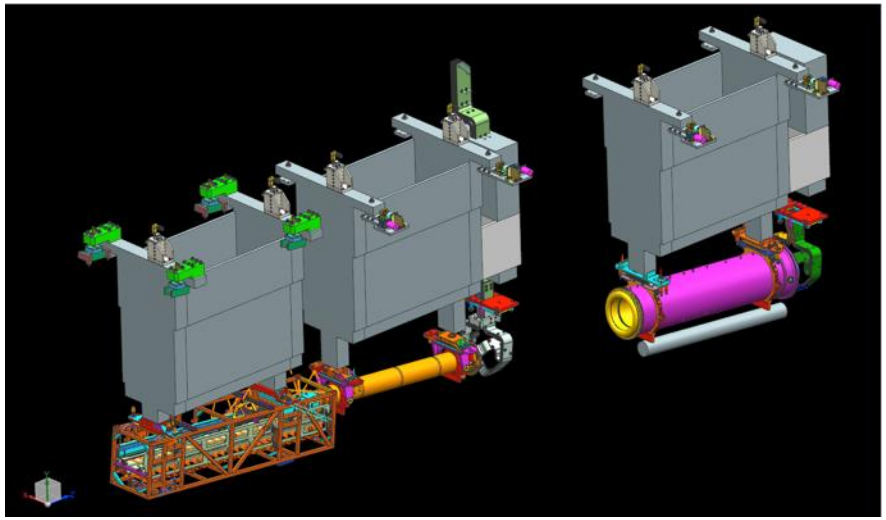


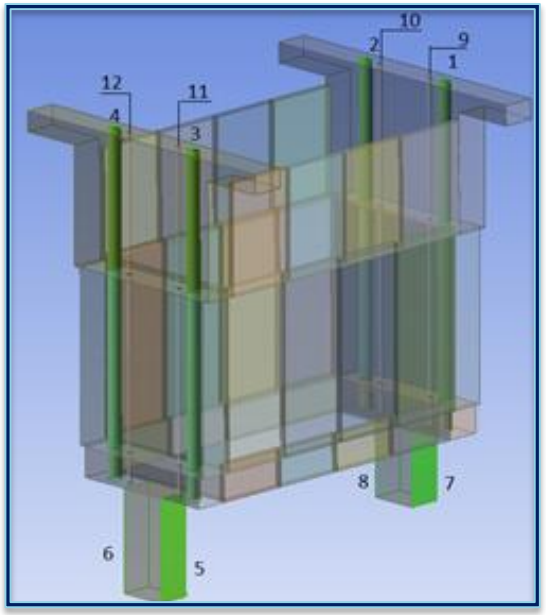


The chase cooling panels are:
(1) Low carbon steel plates.
(2) Replaceable.

Target / Horn Support Modules

- Life of facility components that must survive at all beam energies for 20 years.
- Constructed from 90% A36 or equivalent steel, balance 316 SS / 6061-T6 aluminum. Weight approaching 40 tons.
- Serves as the remote handling and utility supply interface between target, horns, and conventional facilities.





- Required alignment tolerances are within +/- .5mm regardless of operating temperature.
- Design must allow flexibility for evolving horn conductor shapes / lengths.
- Must incorporate forced cooling throughout structure for reliability and stability.
- Conceptual model is at an early stage, and presents an attractive opportunity for fresh or unique designs from a contributing institution.

Cooling gas selection for target chase - alternative

- There are a few studies in progress that could eventually affect which gas is selected for use in the target pile cooling system (the reference design assumes air):
- (1) LBNF Corrosion Working Group studies
  - Airborne corrosive chemicals (ozone, nitric acid, NxOx) are being measured at NuMI
  - Could motivate reduction/elimination of Oxygen
- (2) LBNF Air Releases to the Atmosphere
  - Air-born radioisotopes (Ar-41, C-11, /N-13, O-15)
  - Could motivate reduction/elimination of Argon
- Nitrogen or Helium are possible alternatives
- (3) High level study in progress for using Nitrogen
- (4) Investigative work begun for using Helium

Target Chase Gas Atmosphere – N_2

Will need to reduce the leak rate by a couple of orders of magnitude and we need a better sealed system. We need:

- Energy deposition into the concrete and follow-up FEA.
- Stainless steel liner for the concrete bathtub.
- Upgraded, air-sealed hatch covers.
- Sealing around the air-system (ductwork, air-handler, etc.)
- Upgraded condensate system.
- Larger Target Hall building space to allow for hatch cover seal.
- Better sealing at penetrations (horn striplines, utilities, etc.)
- Nitrogen filling and monitoring (instrumentation, etc.)
- Oxygen Deficiency Hazard considerations.
- Air cooling of bathtub concrete for thermal stability (if needed).

Most of the additional costs are associated with the larger building, the stainless steel liner and the possibly needed air-cooling of concrete bath tab

The LBNF Neutrino Beamline – Hadron Absorber (Reference Design)

Absorber Hall and Service Building

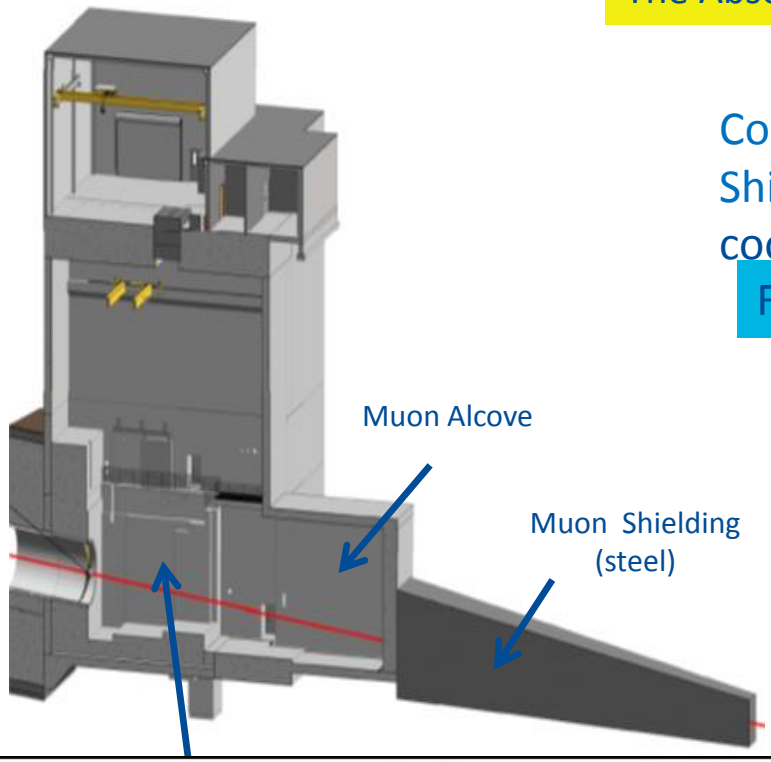
The Absorber is designed for 2.4 MW

Absorber Cooling

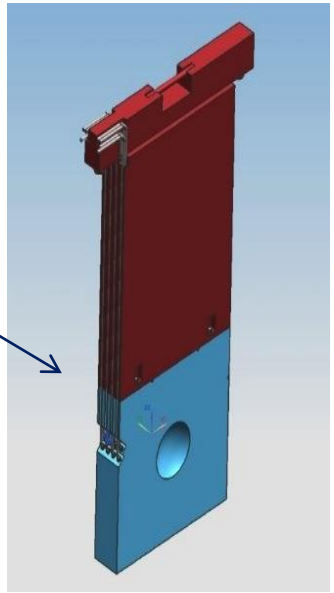
Core: water-cooled

Shielding: forced air-cooled

Flexible, modular design

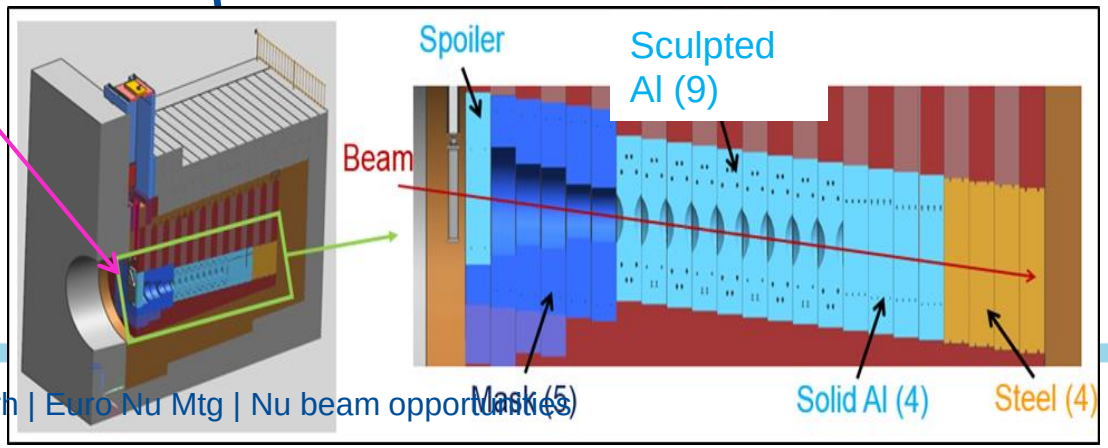


Core blocks replaceable (each 1 ft thick)



Beam

Hadron Monitor



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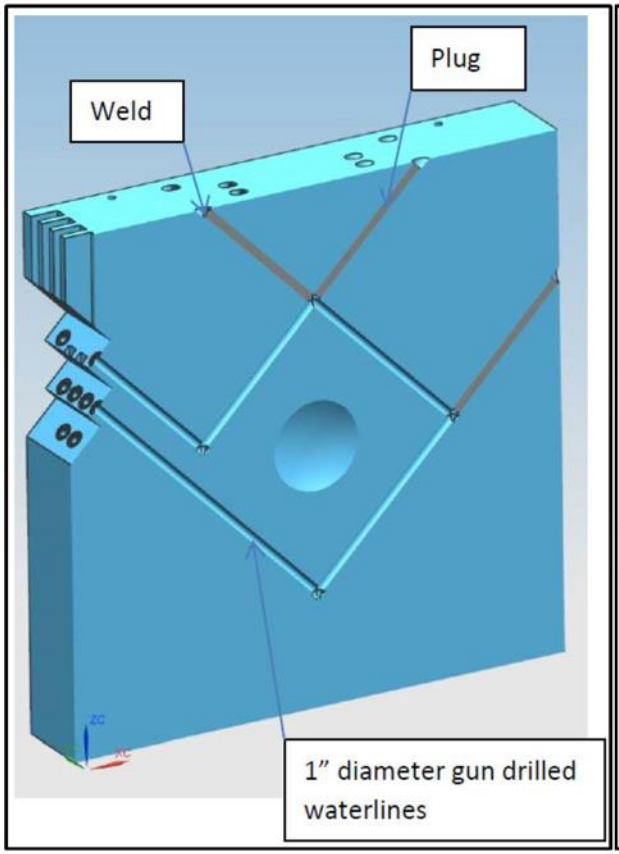
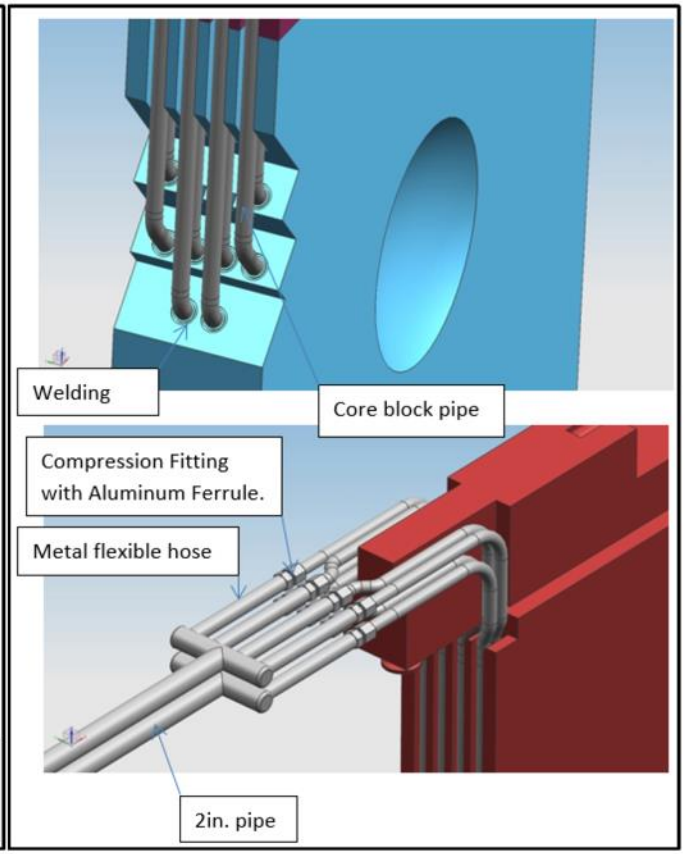
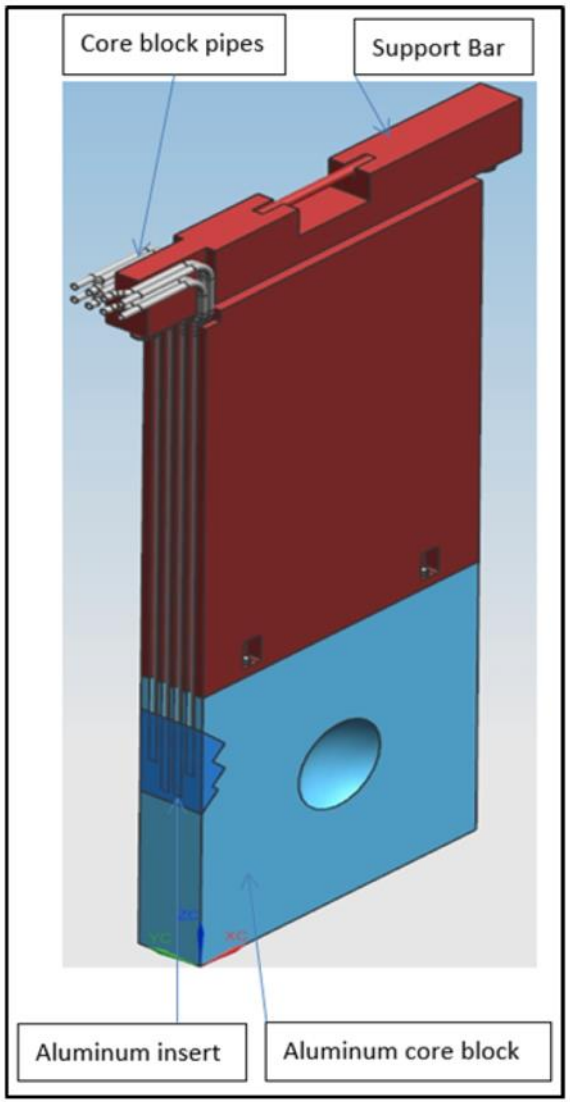
Absorber core module design







Designed to be life of facility, but replaceable

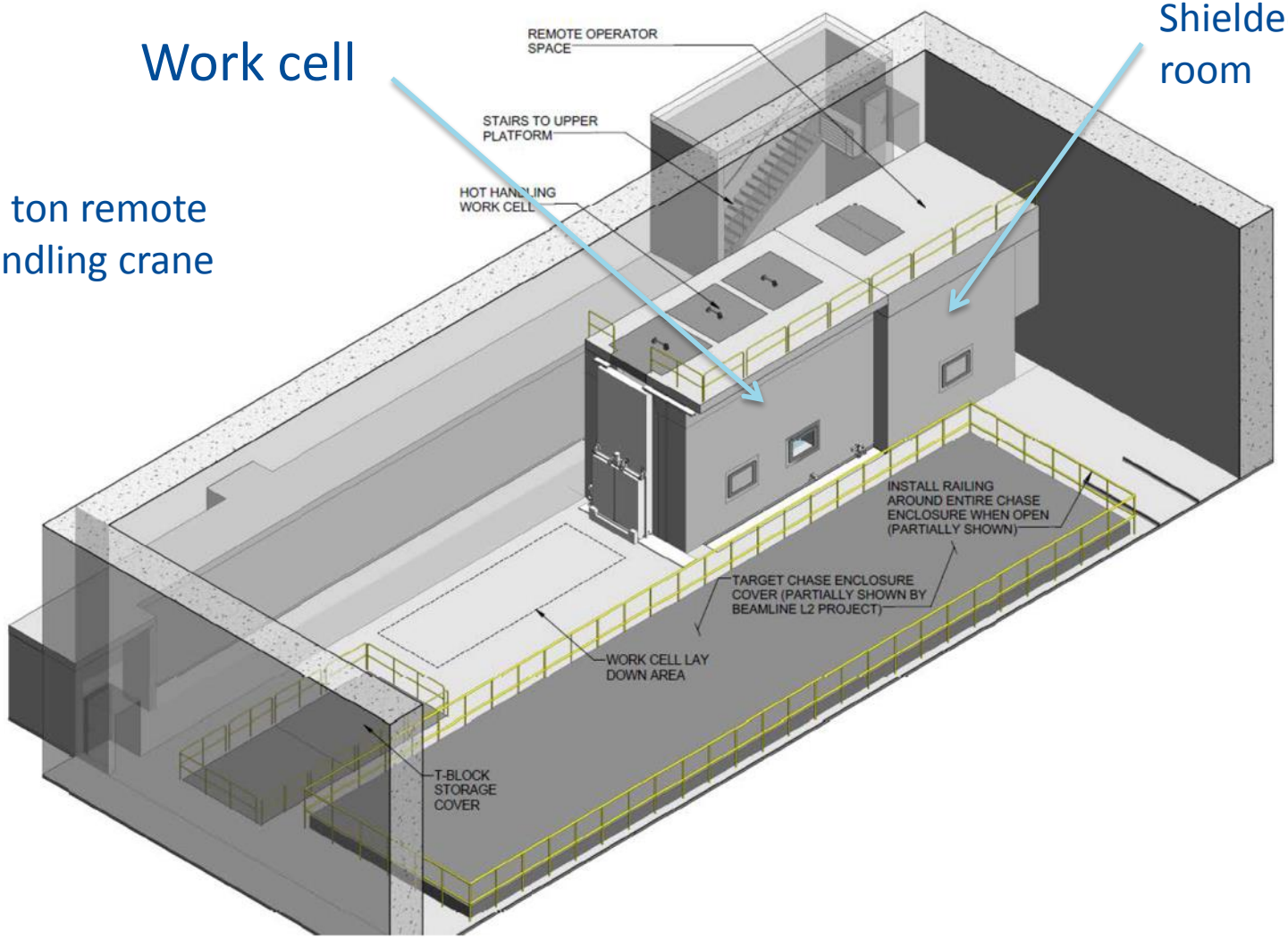
- Redundant water circuits
- Remote handling features

Remote Handling

Work cell

Shielded control room

50 ton remote handling crane



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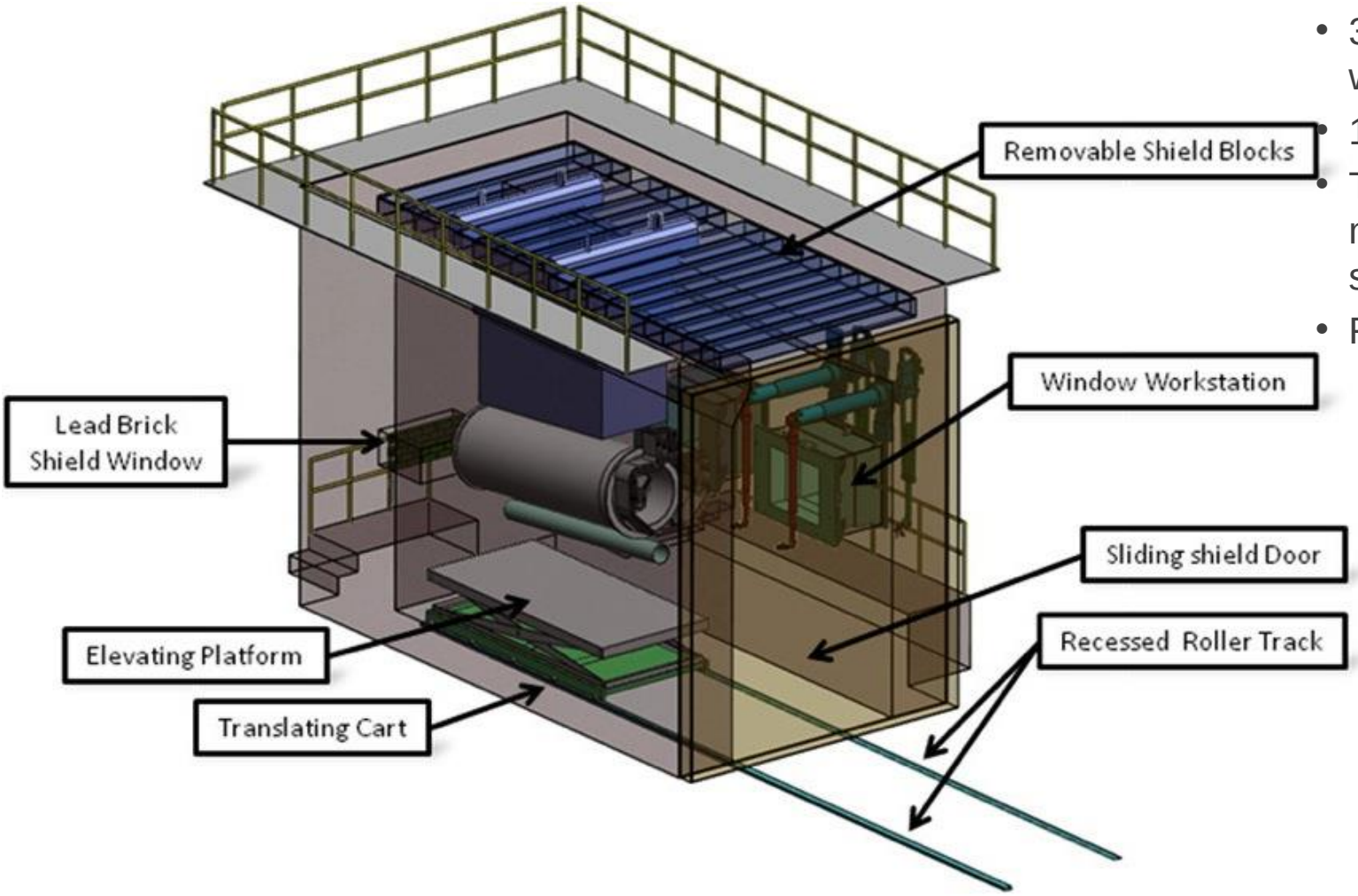
Work-cell Concept

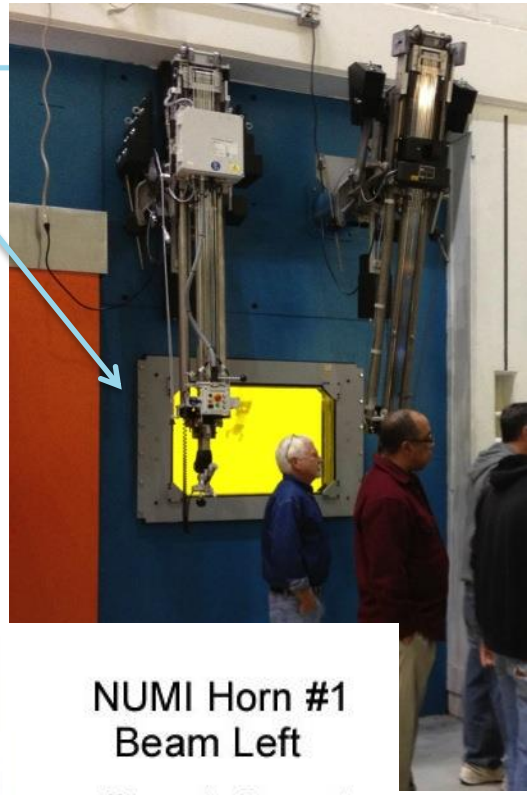


- 3 ft thick concrete walls
- 1 ft thick steel door
- Through-wall manipulator (MSM) station
- For replacement of:
  - Horns
  - Baffle
  - Target
  - Beam Windows

Remote Handling Equipment

Transport Casks

Lead glass windows and through wall manipulators



Remote Viewing

Horn on Module

NUMI Horn #1 Beam Left

Point	Doserate @ 1 foot (mr/hour)	Doserate On Contact (mr/hour)
1	70000	N/A
2	70000	N/A
3	80000	N/A

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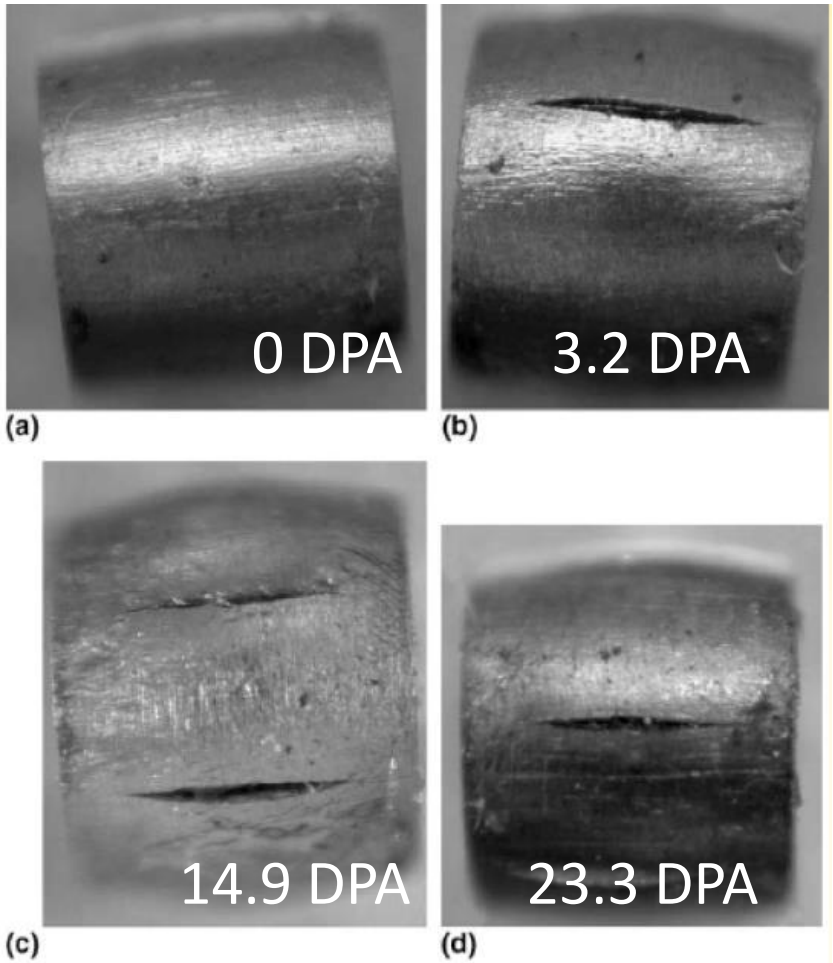
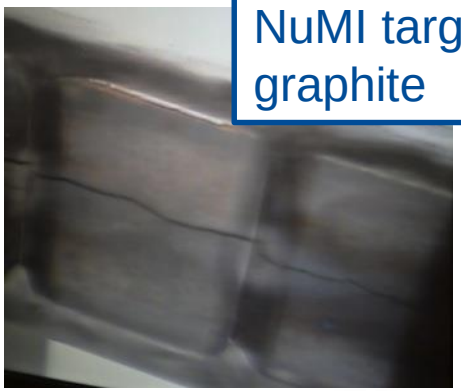
R&D: Radiation Damage

- Displacements in crystal lattice
  (expressed as Displacements Per Atom, DPA)
  - Embrittlement
  - Creep
  - Swelling
  - Fracture toughness reduction
  - Thermal/electrical conductivity reduction
  - Coefficient of thermal expansion
  - Modulus of Elasticity
  - Fatigue response
  - Accelerated corrosion
  - Transmutation products
    - H, He gas production can cause void formation and embrittlement (expressed as atomic parts per million per DPA, appm/DPA)
- Very dependent upon material condition and irradiation conditions (e.g. temp, dose rate)

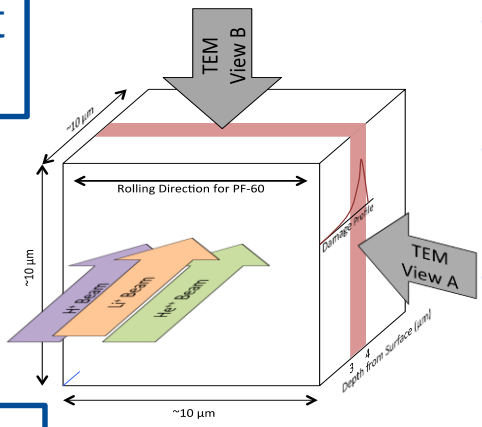


S. A. Malloy, et al., Journal of Nuclear Material, 2005. (LANSCE irradiations)

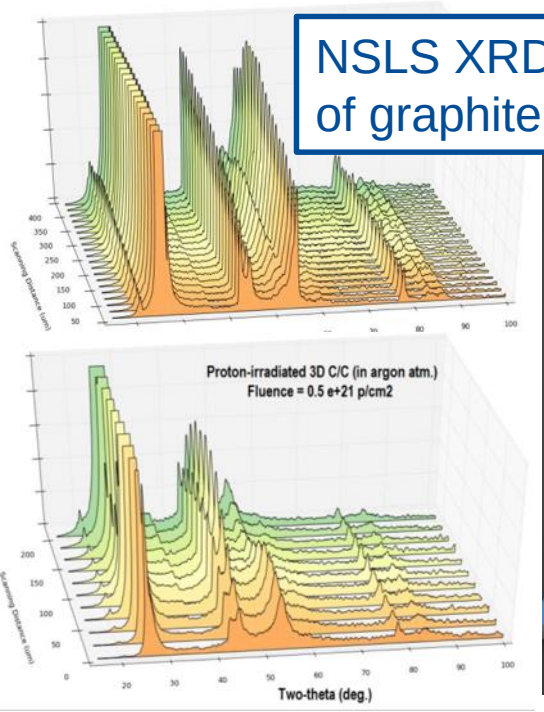
Low-energy ion irradiations of graphite to 2 DPA needed



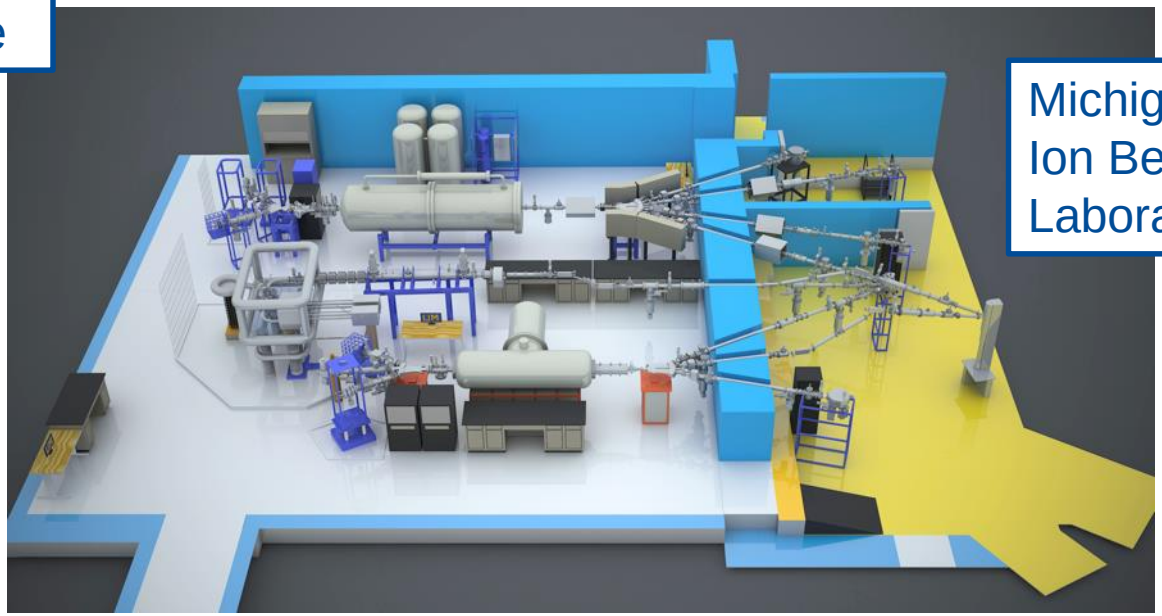
NuMI target graphite



- Current HE proton irradiations of graphite limited to 0.2 DPA
- LE ion irradiations can achieve 10 DPA in 1 day in small volumes
- Looking for partner to conduct studies at dual or triple beam facility in Europe (JANNUS, Saclay)



NSLS XRD of graphite



Michigan Ion Beam Laboratory

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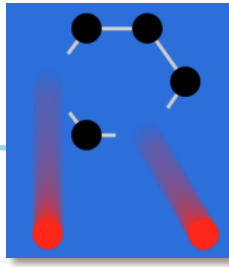

RaDIATE Collaboration

Radiation Damage In Accelerator Target Environments

Broad aims are threefold:

www-radiate.fnal.gov

- to generate new and useful materials data for application within the **accelerator** and **fission/fusion** communities
- to recruit and develop new scientific and engineering experts who can **cross the boundaries** between these communities
- to initiate and coordinate a **continuing synergy** between research in these communities, benefitting both **proton accelerator applications** in science and industry and **carbon-free energy technologies**

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University of Oxford

Brookhaven National Laboratory

ESS European Spallation Source

Argonne National Laboratory

Science & Technology Facilities Council

FRIB

Pacific Northwest National Laboratory

Oak Ridge National Laboratory

Los Alamos National Laboratory EST. 1943

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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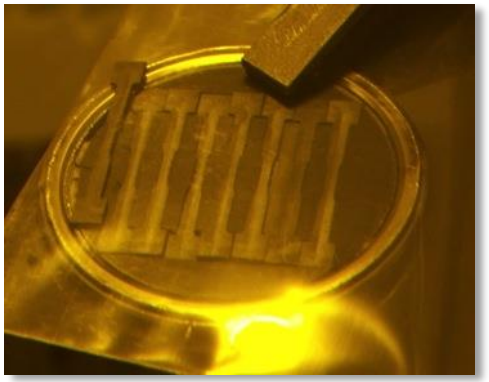
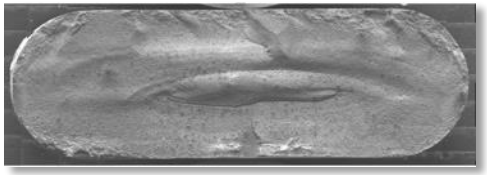
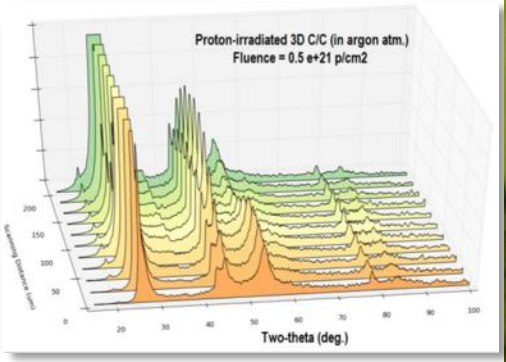
Plans to add CERN and J-PARC/KEK this year!

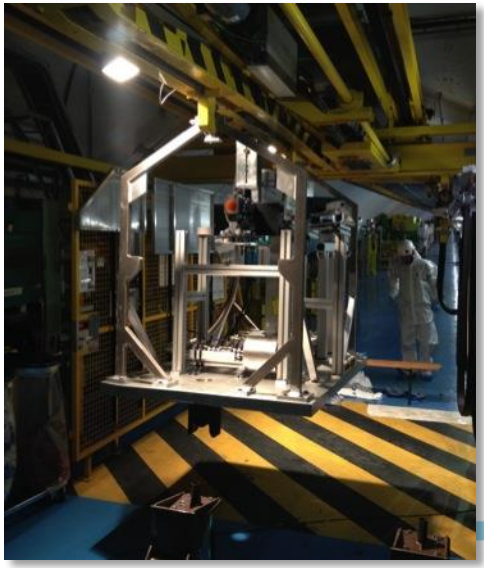
RaDIATE Current Activities

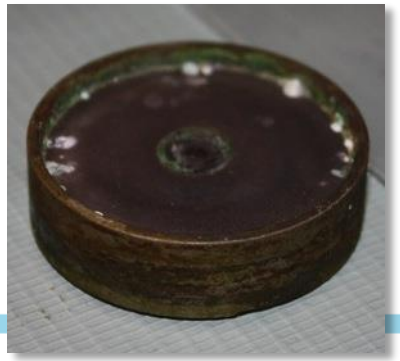
- **HE proton irradiations & Post-Irradiation Examinations (PIE)**
  - **Many materials of interest from Be to Ir!**
- **LE ion irradiations & PIE**
  - **Utilize advanced techniques to correlate damage to HE proton regime**
- **PIE of spent targets/windows**
- **Thermal Shock studies**
  - **HiRadMat beamline at CERN**

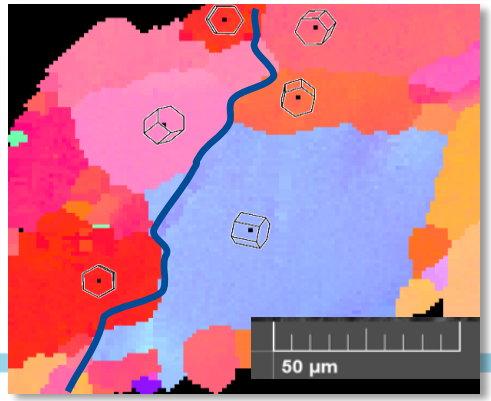


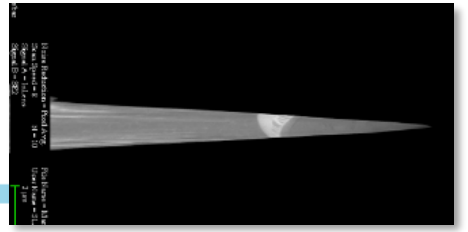












Opportunities for collaboration

Primary Beam

- dipole & quadrupole magnets
- ***corrector magnets***
- ***quadrupole power supplies***
- primary beam monitoring (***non-interacting profile monitor***)

Neutrino Beam

- ***primary beam window, baffle***, target
- focusing horns, ***horns power supply***
- instrumentation (***hadron monitor***)
- ***support modules target/baffle/horns***
- ***target chase shield covers and water cooling panels***
- ***evaluation of alternative design for inert gas-cooled target chase & corrosion impacts***
- hadron absorber
- remote handling equipment (***lead glass windows, manipulators***, etc)
- ***physics, energy deposition, and radiation transport simulations***
- materials R&D (***LE ion irradiation/implantation of graphite***)

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