LBNF Neutrino Beam

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For the LBNF/DUNE Team

NuFact 2015

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Outline

- Overview of LBNF/DUNE
- Current and expected capabilities of the Main Injector complex
- Reference design of the LBNF Neutrino Beam
- Optimizing the focusing system for greater physics reach
- Summary

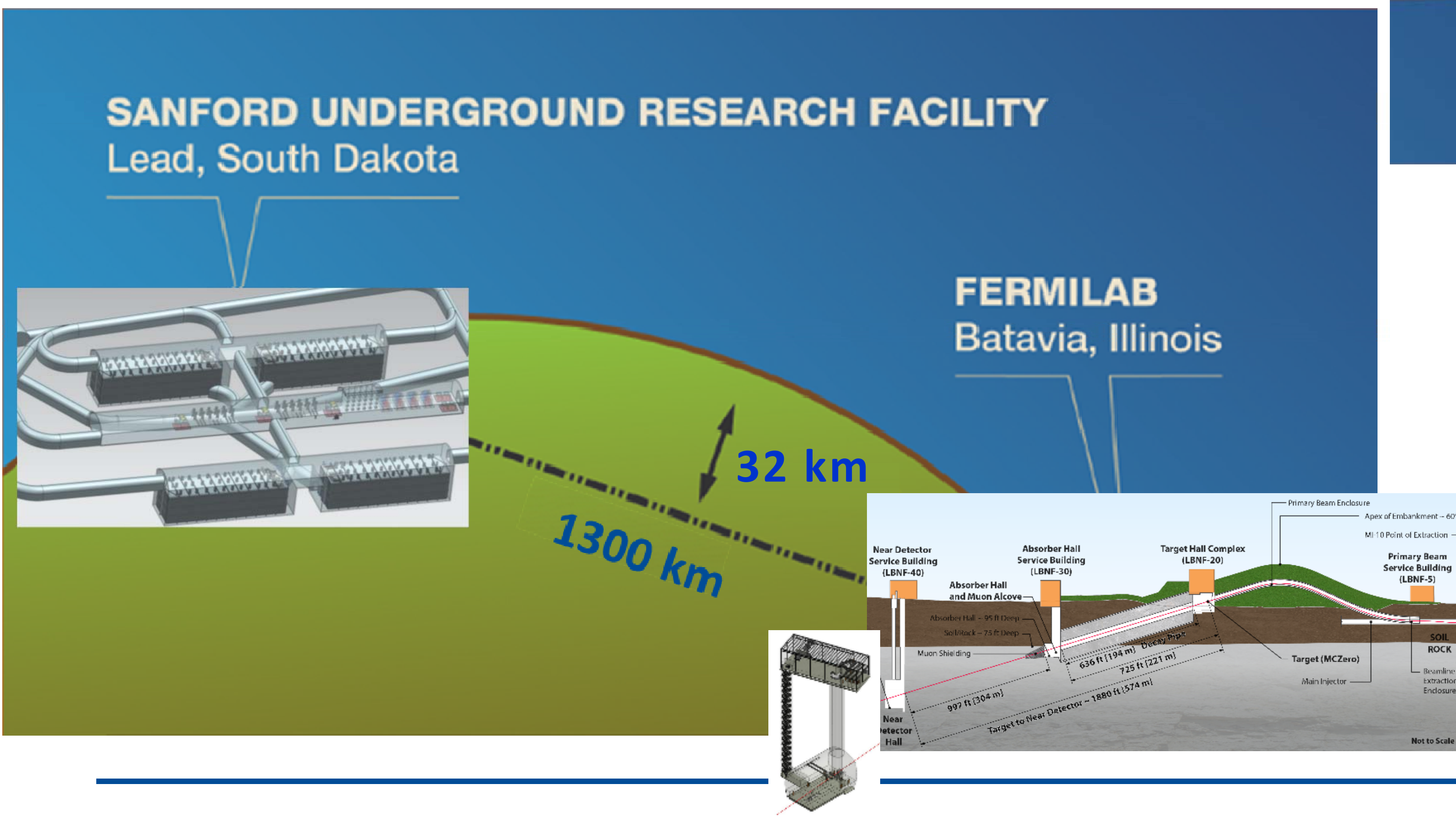
Long-Baseline Neutrino Facility

A facility to enable a world-leading experimental program in neutrino physics, nucleon decay, and astroparticle physics.
LBNF comprises:

- Underground and surface facilities at the Sanford Underground Research Facility capable of hosting a modular LAr TPC of fiducial mass ≥ 40 kt (~70 kt liquid mass)
- Cryostats, refrigeration and purification systems to operate the detectors
- A high-power, wide-band, tunable, ν beam at Fermilab
- Underground and surface facilities to host a highly-capable near detector at Fermilab … and potentially other non-oscillation neutrino experiments

LBNF/DUNE

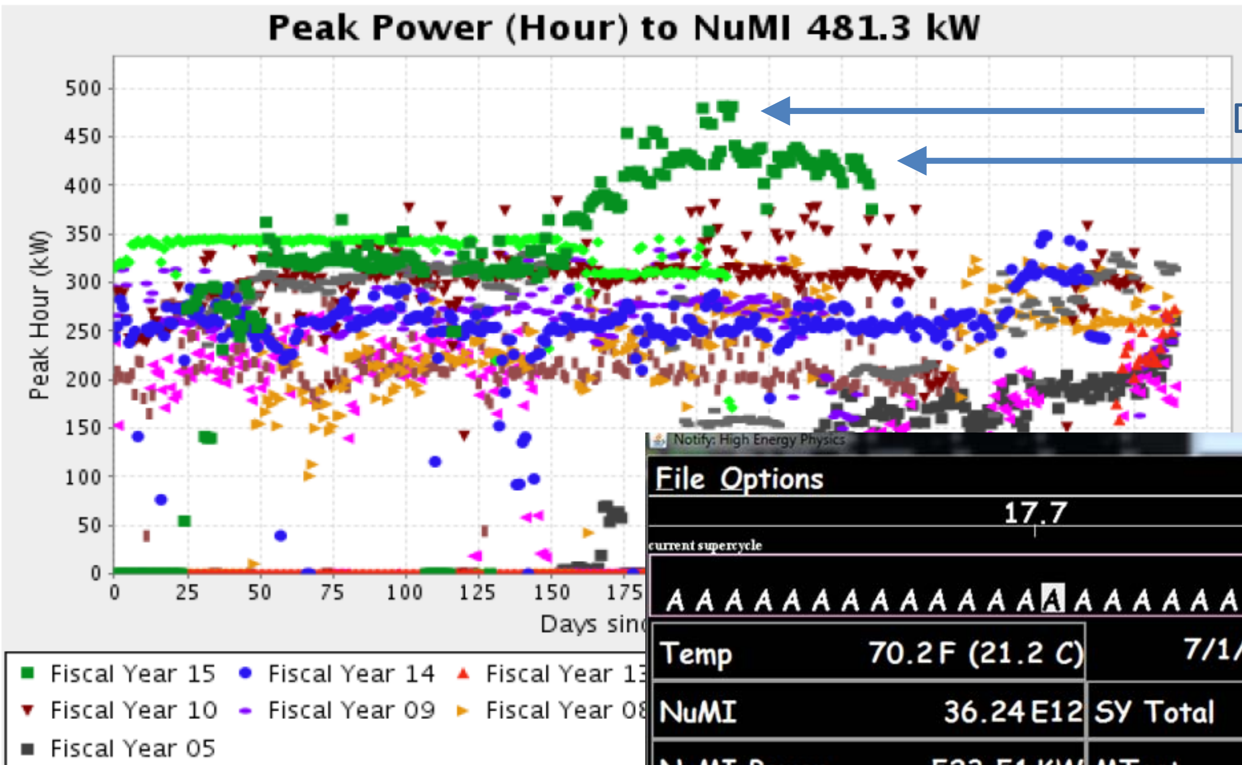
- LBNF is a DOE/Fermilab hosted project with international participation.
- Major partners include CERN and SURF.
- DUNE Collaboration will build and operate the experiment* in LBNF.

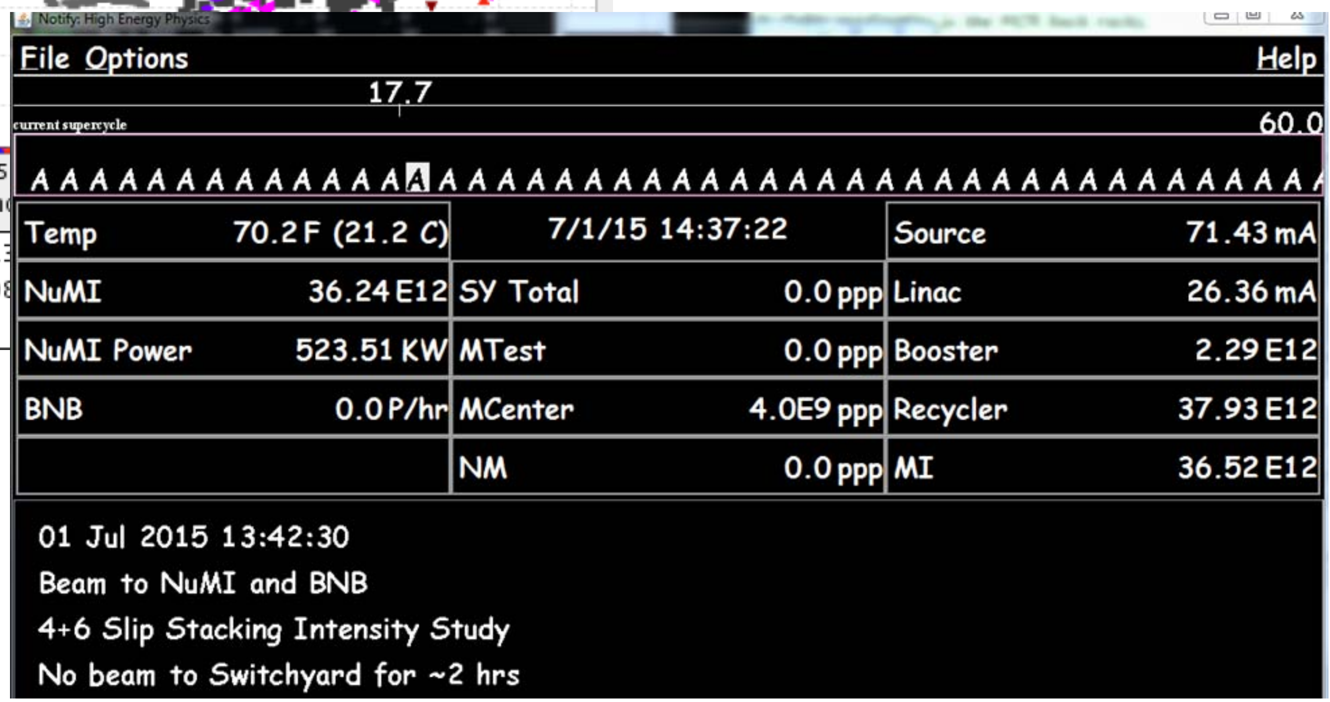


*See DUNE talks:
- DUNE Physics (WG1 Monday)
- DUNE Near Detector (WG1-2 Tuesday)
- DUNE Systematics (WG1-2-3 Thursday)

Fermilab Main Injector Capabilities

Routine operation >400 kW since March





Record beam power 520 kW just before summer shutdown.

Goal is 700 kW for NOvA by next Spring

LBNF Beam Operating Parameters:

Main Injector Complex with PIP-II and PIP-III upgrades

Summary of key Beamline design parameters for $\leq$1.2 MW and $\leq$2.4 MW operation

Parameter	Protons per cycle	Cycle Time (sec)	Beam Power (MW)
≤ 1.2 MW Operation - Current Maximum Value for LBNF			
Proton Beam Energy (GeV):			
60	7.5E+13	0.7	1.03
80	7.5E+13	0.9	1.07
120	7.5E+13	1.2	1.20
≤ 2.4 MW Operation - Planned Maximum Value for LBNF 2nd Phase			
Proton Beam Energy (GeV):			
60	1.5E+14	0.7	2.06
80	1.5E+14	0.9	2.14
120	1.5E+14	1.2	2.40

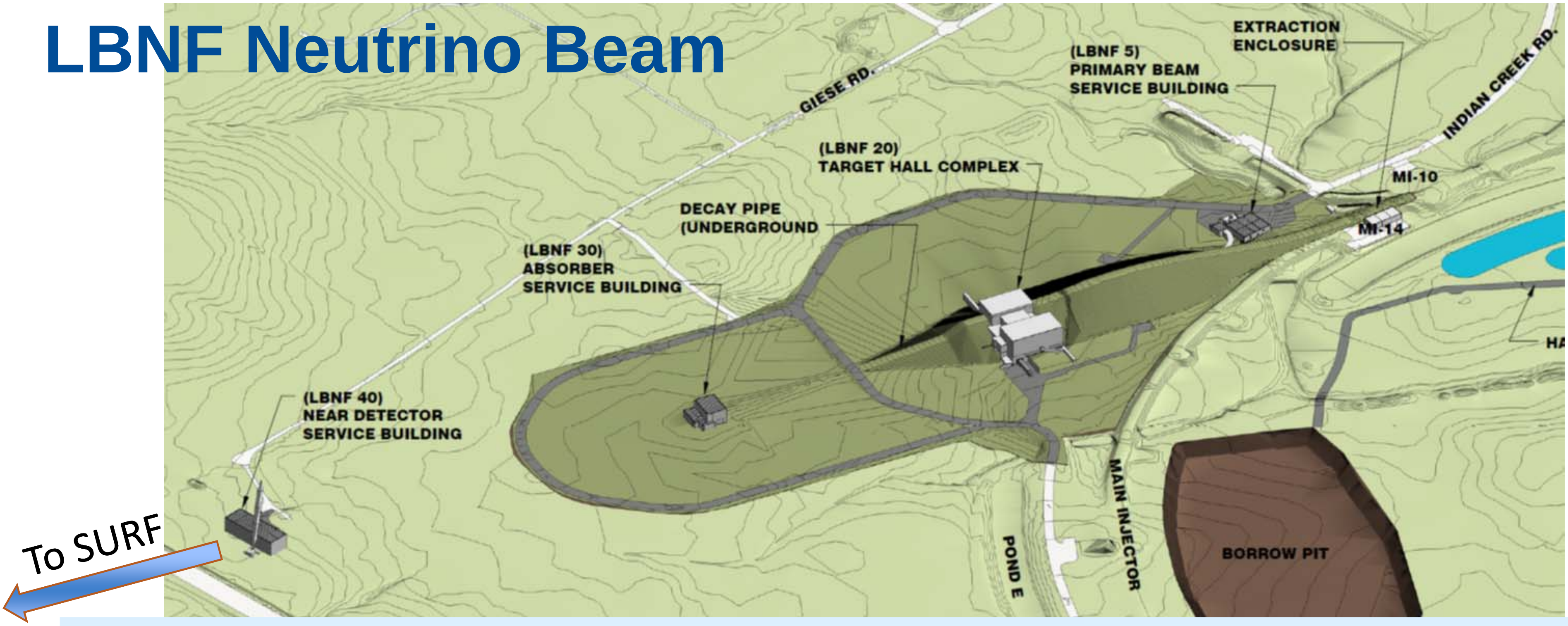
PIP-II

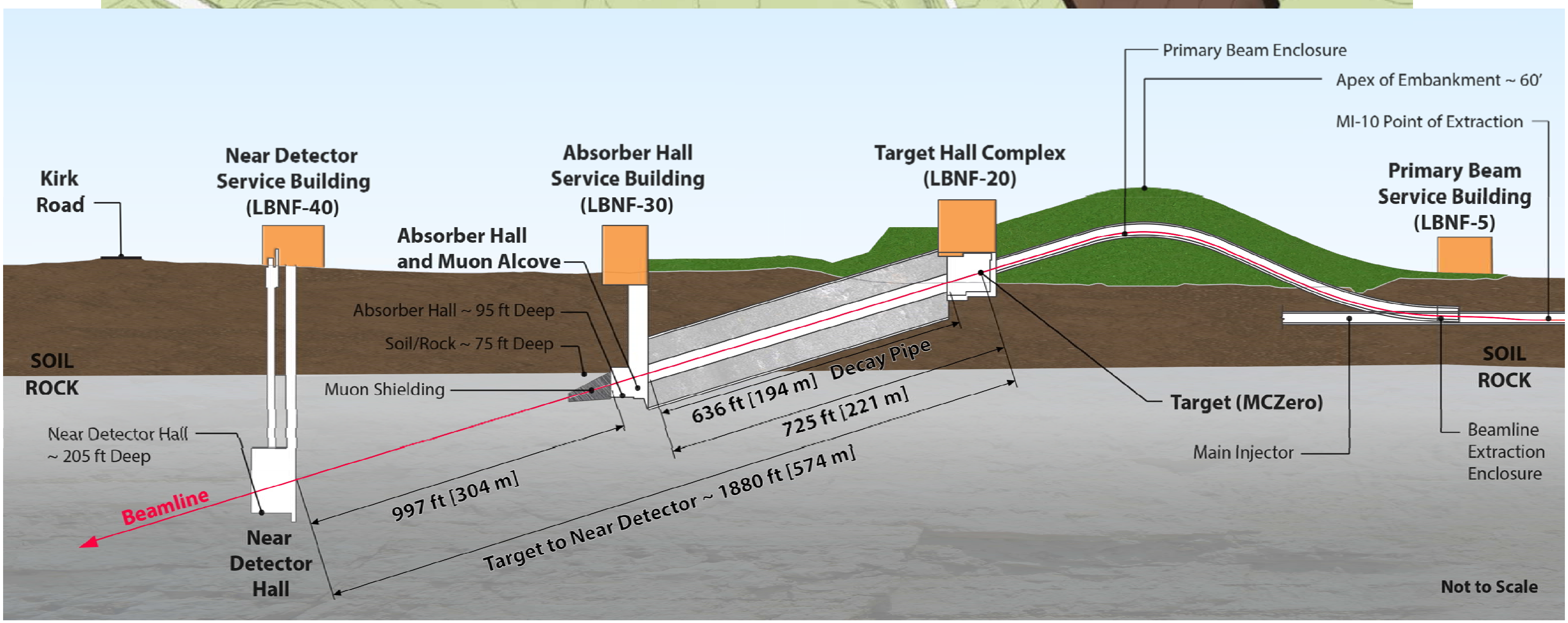
$(1.1 – 1.9)\times10^{21}$ POT/yr

PIP-III

Pulse duration: 10 μs
Beam size at target: tunable 1.0-4.0 mm

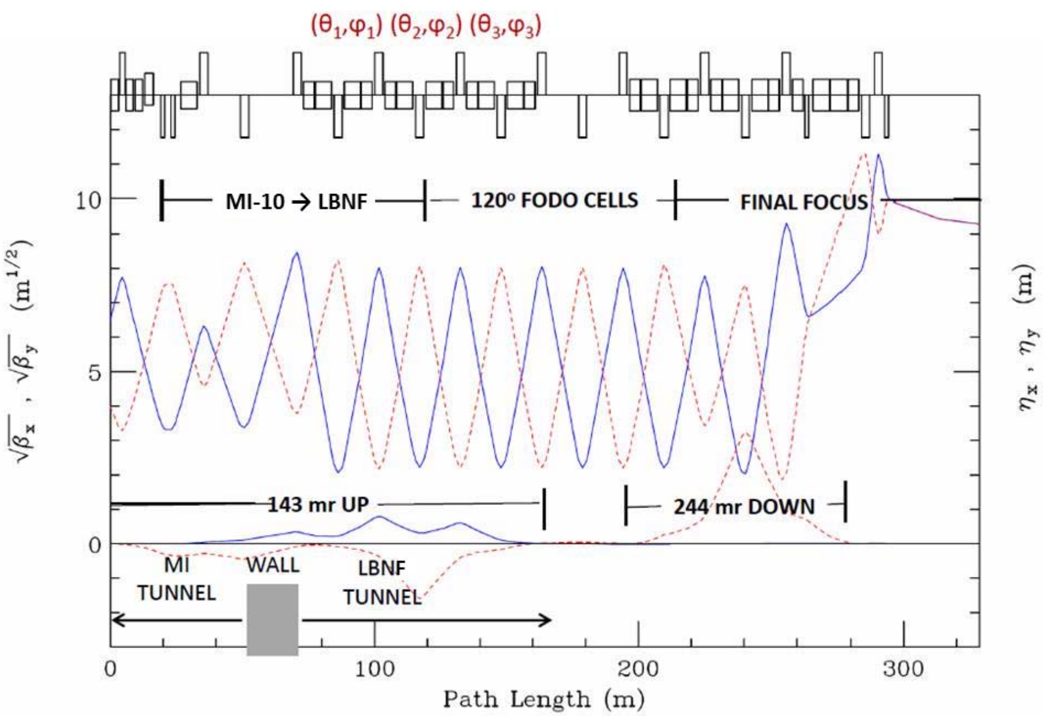
LBNF Neutrino Beam



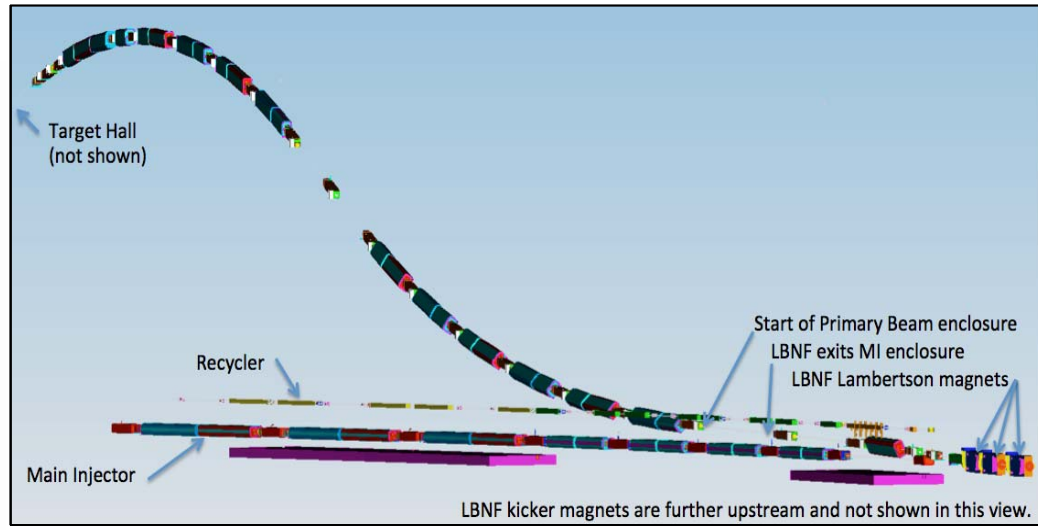


Primary Beam and Lattice Functions

- The LBNF Primary Beam will transport 60 - 120 GeV protons from MI-10 to the LBNF target to create a neutrino beam. The beam lattice points to 79 conventional magnets (25 dipoles, 21 quadrupoles, 23 correctors, 6 kickers, 3 Lambertsons and 1 C magnet).

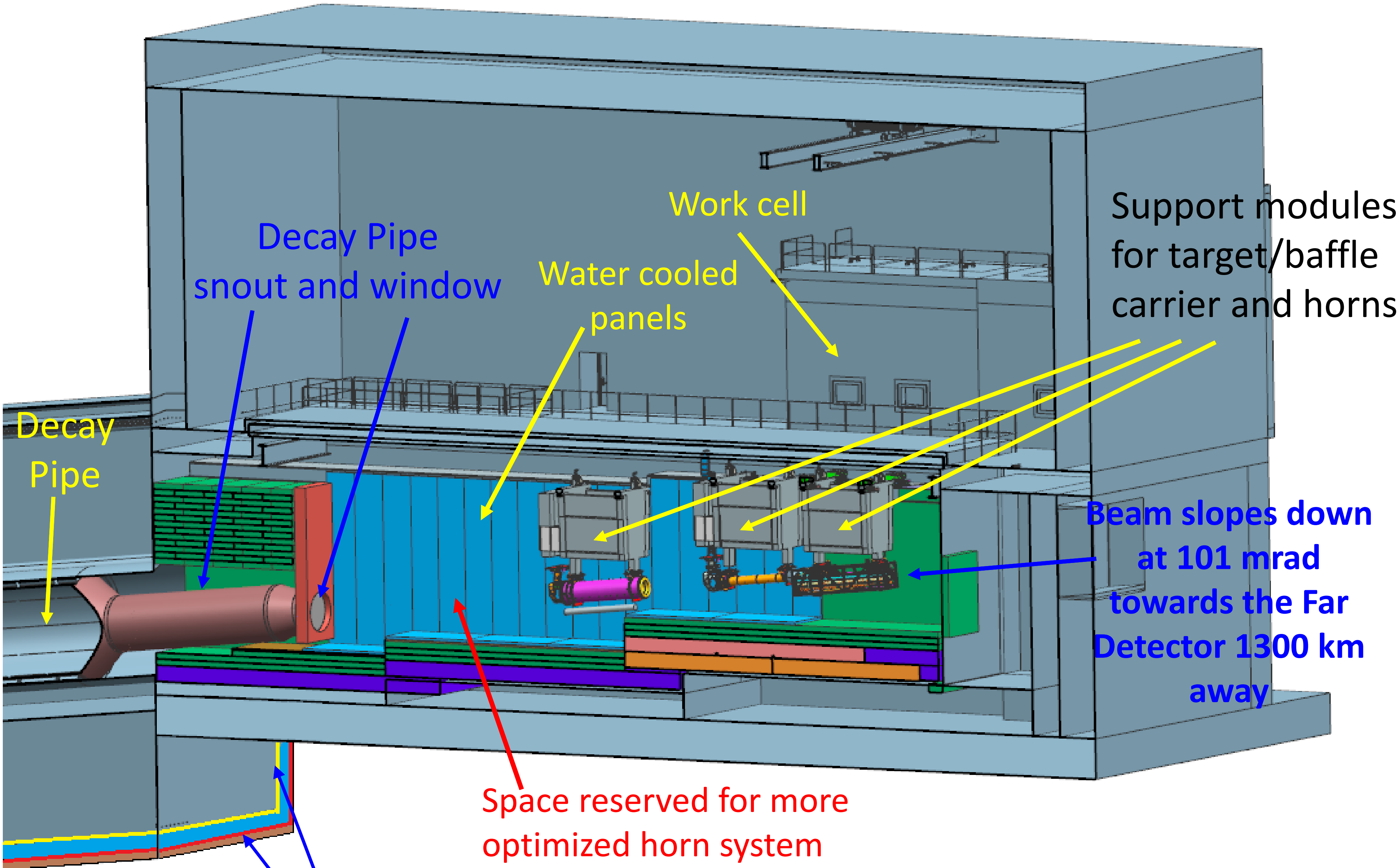


Horizontal (solid) and vertical (dashed) lattice functions of the LBNF transfer line



Beam size at target tunable between 1.0-4.0 mm

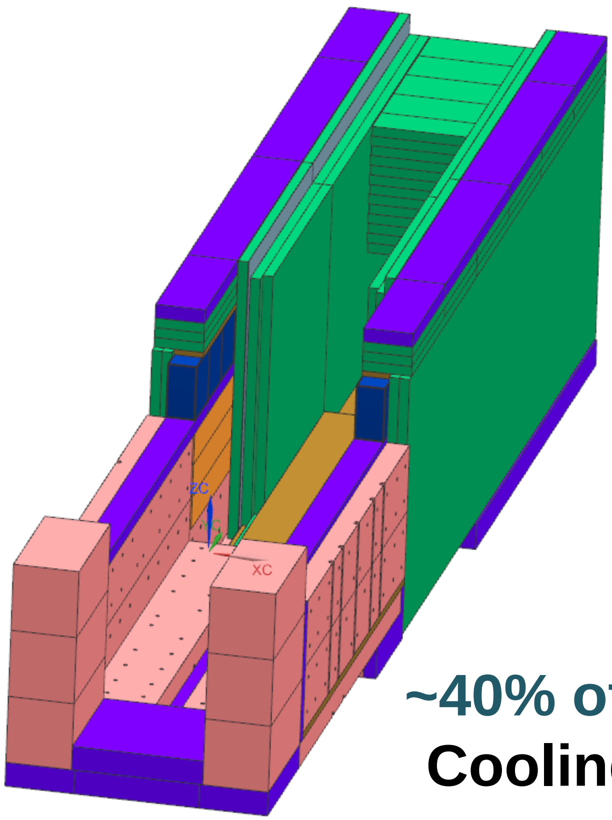
Neutrino Beam Configuration

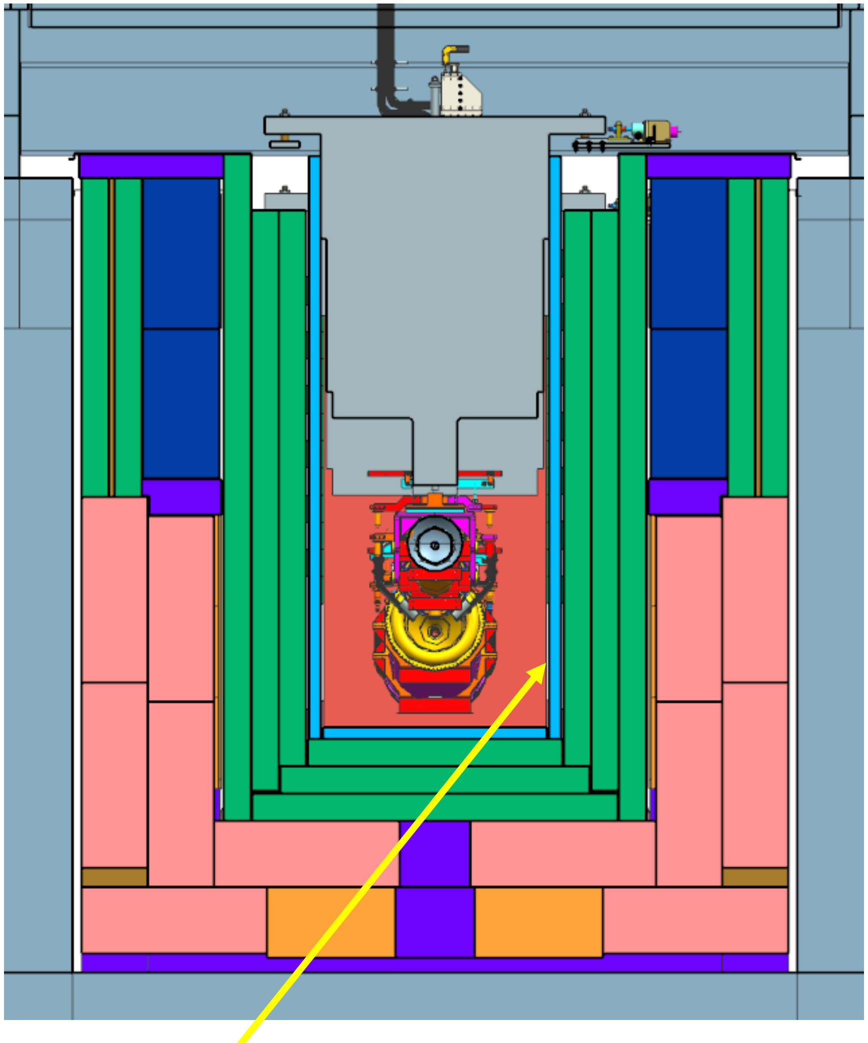


multi-ply geosynthetic barriers, separated by a drainage layer

Target Shield Pile

steel shielding surrounds the beamline components (baffle, target, Horn 1, Horn 2, and the decay pipe upstream window) installed in the target chase

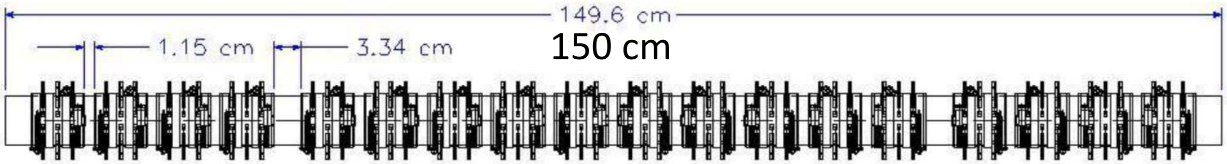




~40% of the beam energy deposited in the target chase

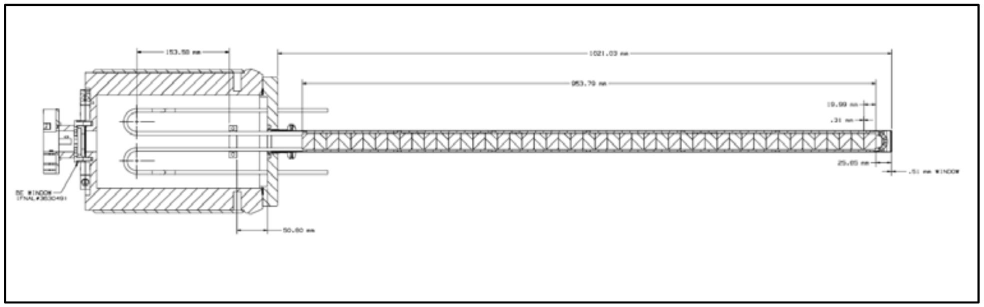
Cooling: combination of forced air & water-cooled panels

Target and Focusing System – Reference Design



Protection Baffle

Ten graphite cores, 17 mm Ø hole, enclosed by an aluminum tube

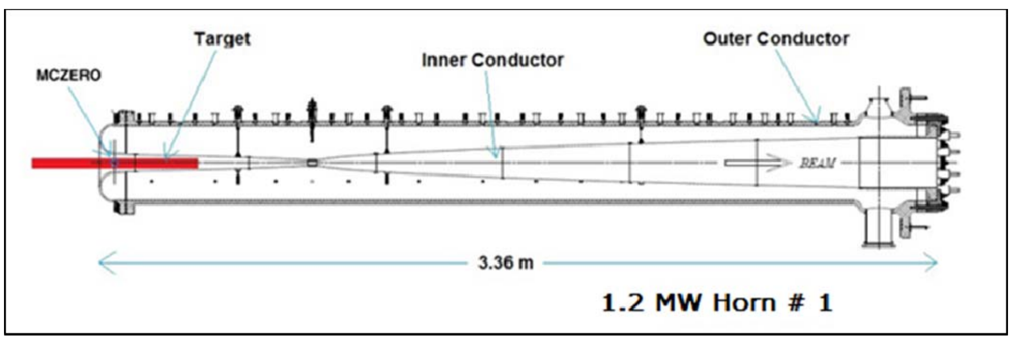


Target

NuMI-style target: 47 graphite segments, each 2 cm long and spaced 0.2 mm apart, for a total target core length of 95 cm, 2 λ_I. Viable for 1.2 MW beam power.

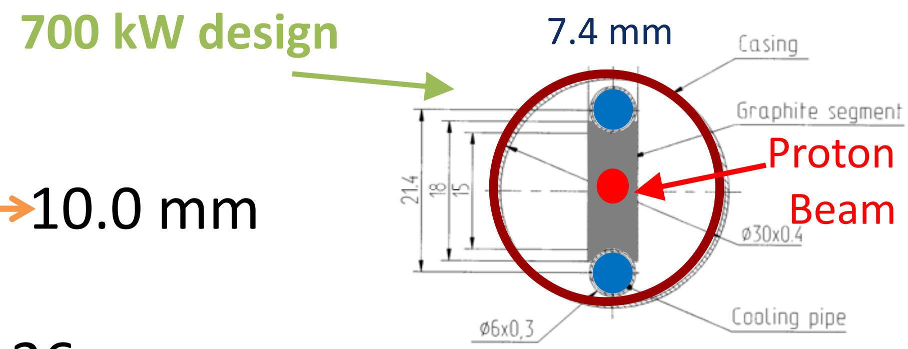
Horns: identical to NuMI, but operated at 230 kA current and subjected to a maximum beam power of 1.2 MW

- new Horn Power Supply necessary to reduce pulse width to 0.8 ms



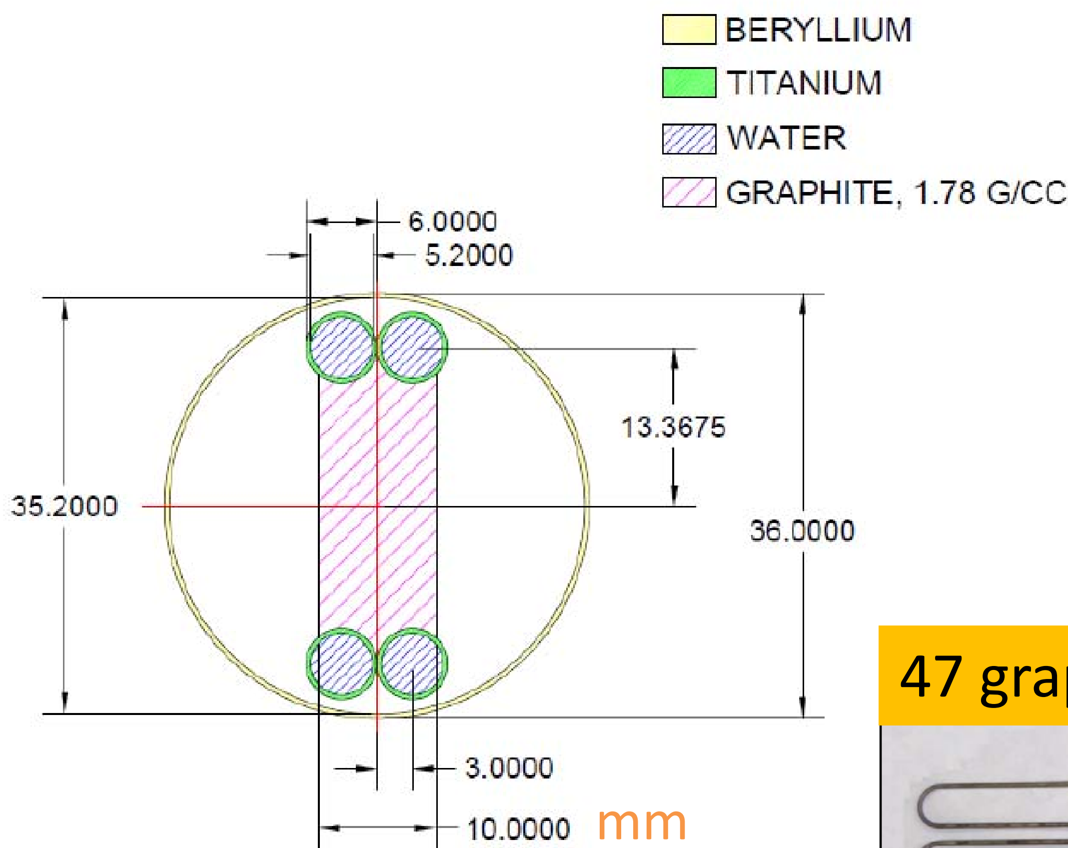
Target starting 45 cm upstream of MCZERO

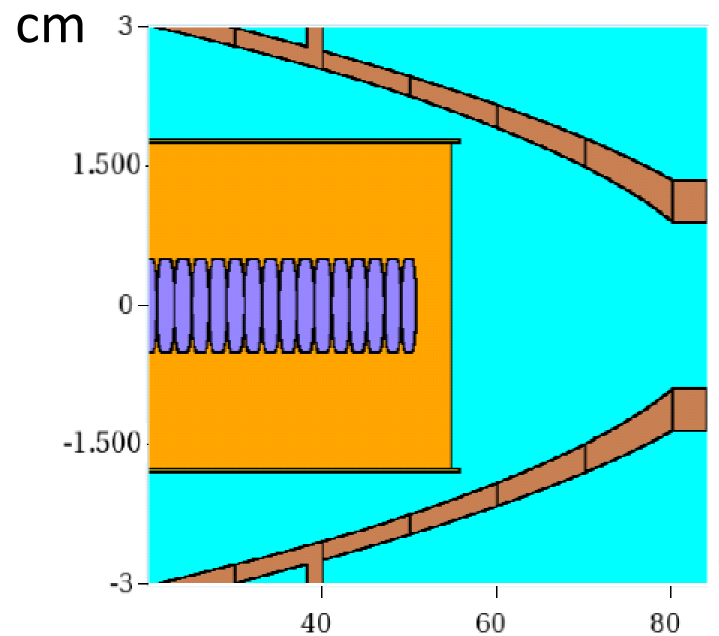
Initial Modifications for 1.2 MW



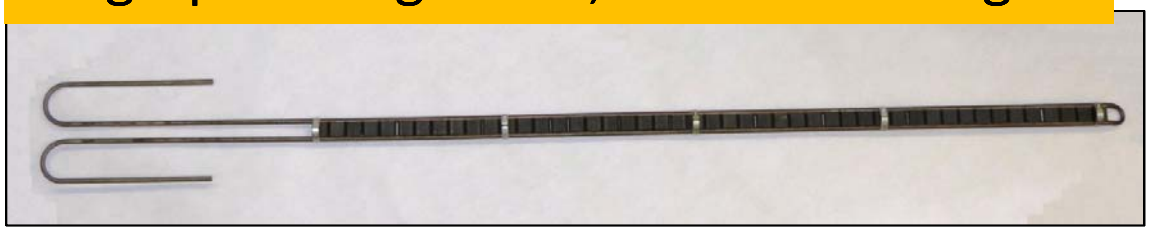
- Wider target material (still graphite): 7.4→10.0 mm
- Dual cooling pipes – greater surface area
- Slightly larger outer vessel diameter: 30→36 mm

(Move target upstream 10 cm from horn)

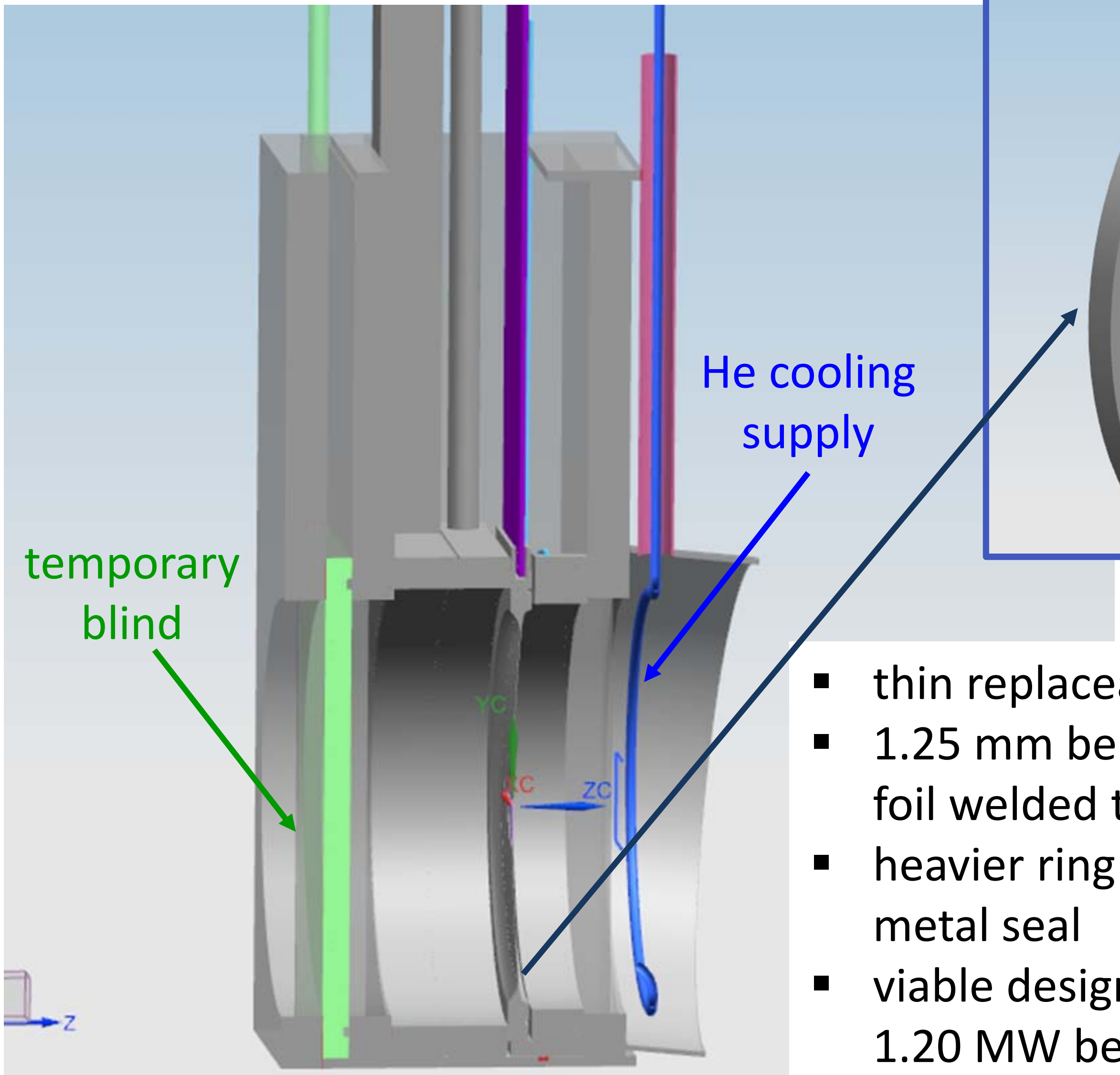


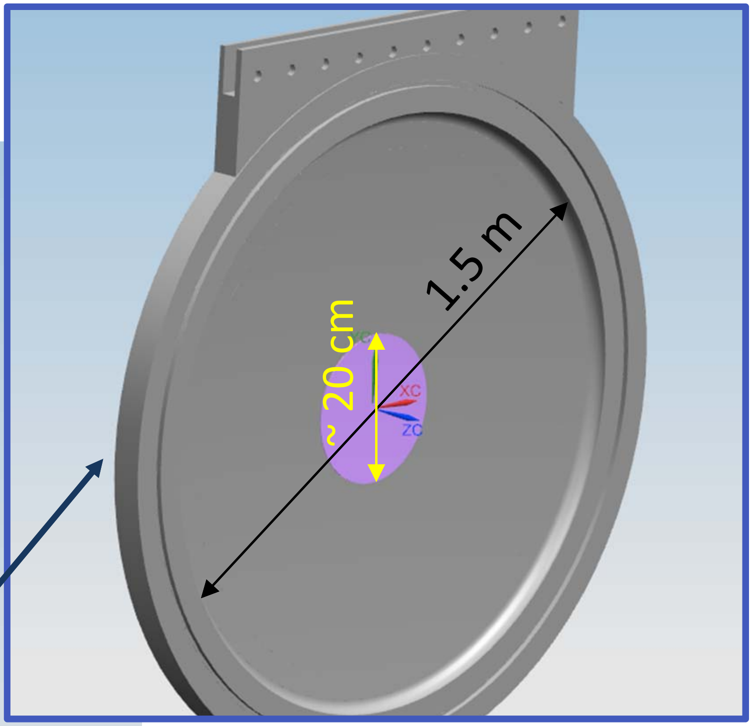


47 graphite segments, each 2 cm long



Upstream Decay Pipe Window

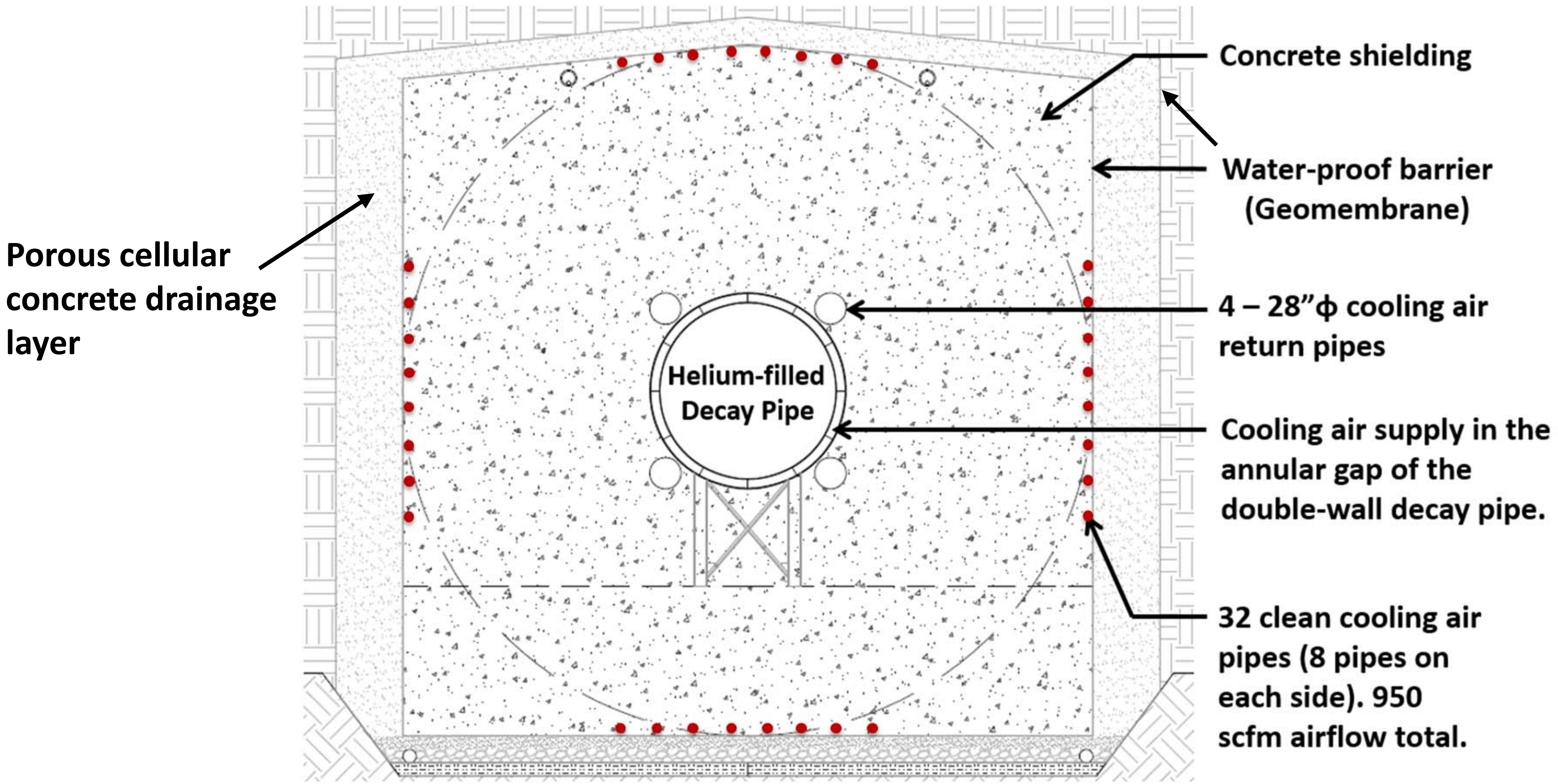




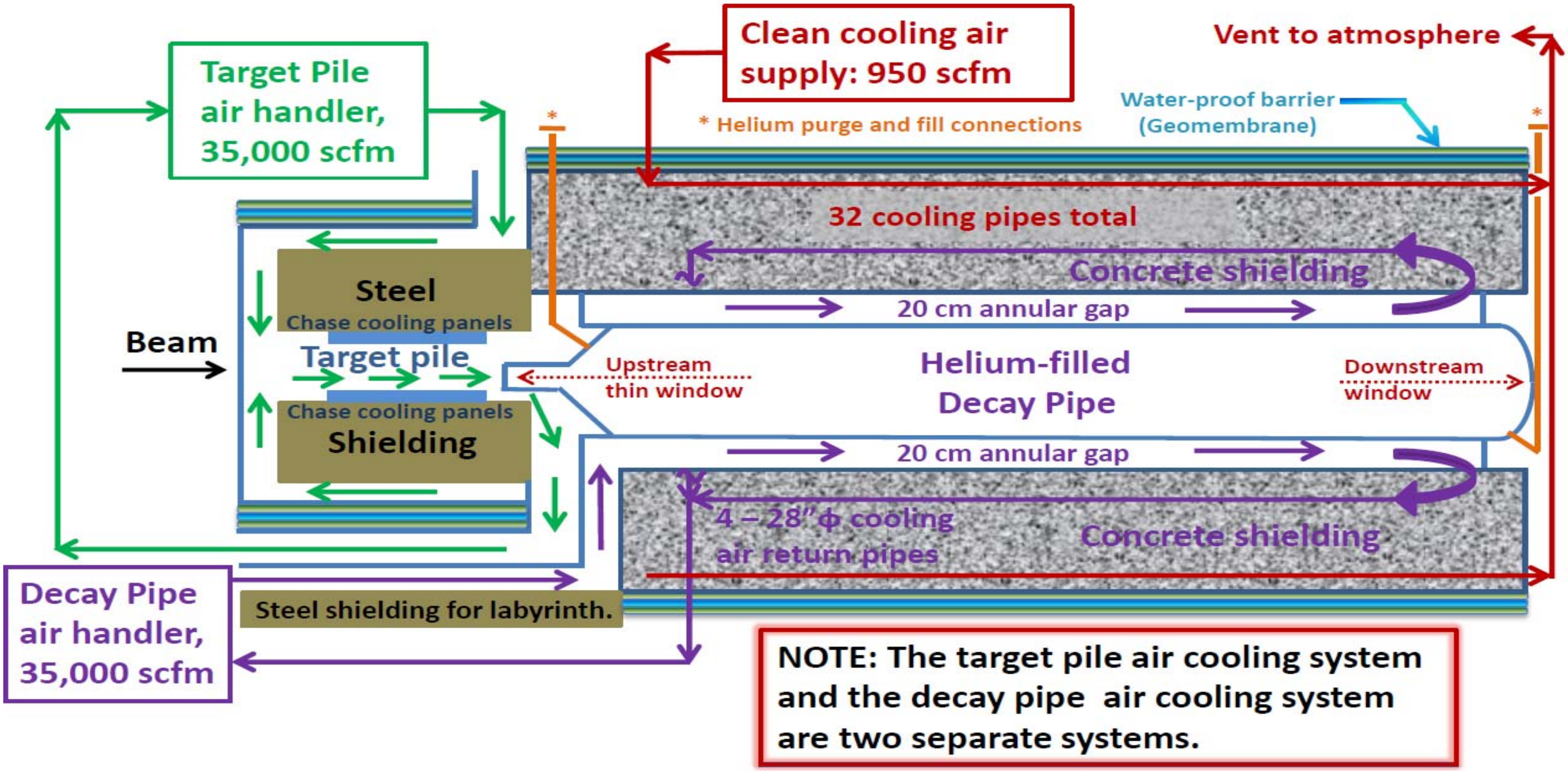
- thin replaceable window
- 1.25 mm beryllium or beryllium-aluminum alloy foil welded to a heavier aluminum ring
- heavier ring includes a seal groove for an all metal seal
- viable design for 60-120 GeV/c protons, 1.03-1.20 MW beam power

Decay Pipe

- 194 m long, 4 m inside diameter
- Helium filled
- double-wall decay pipe, 20 cm annular gap
- 5.6 m thick concrete shielding
- It collects ~30% of the beam power, removed by an air cooling system

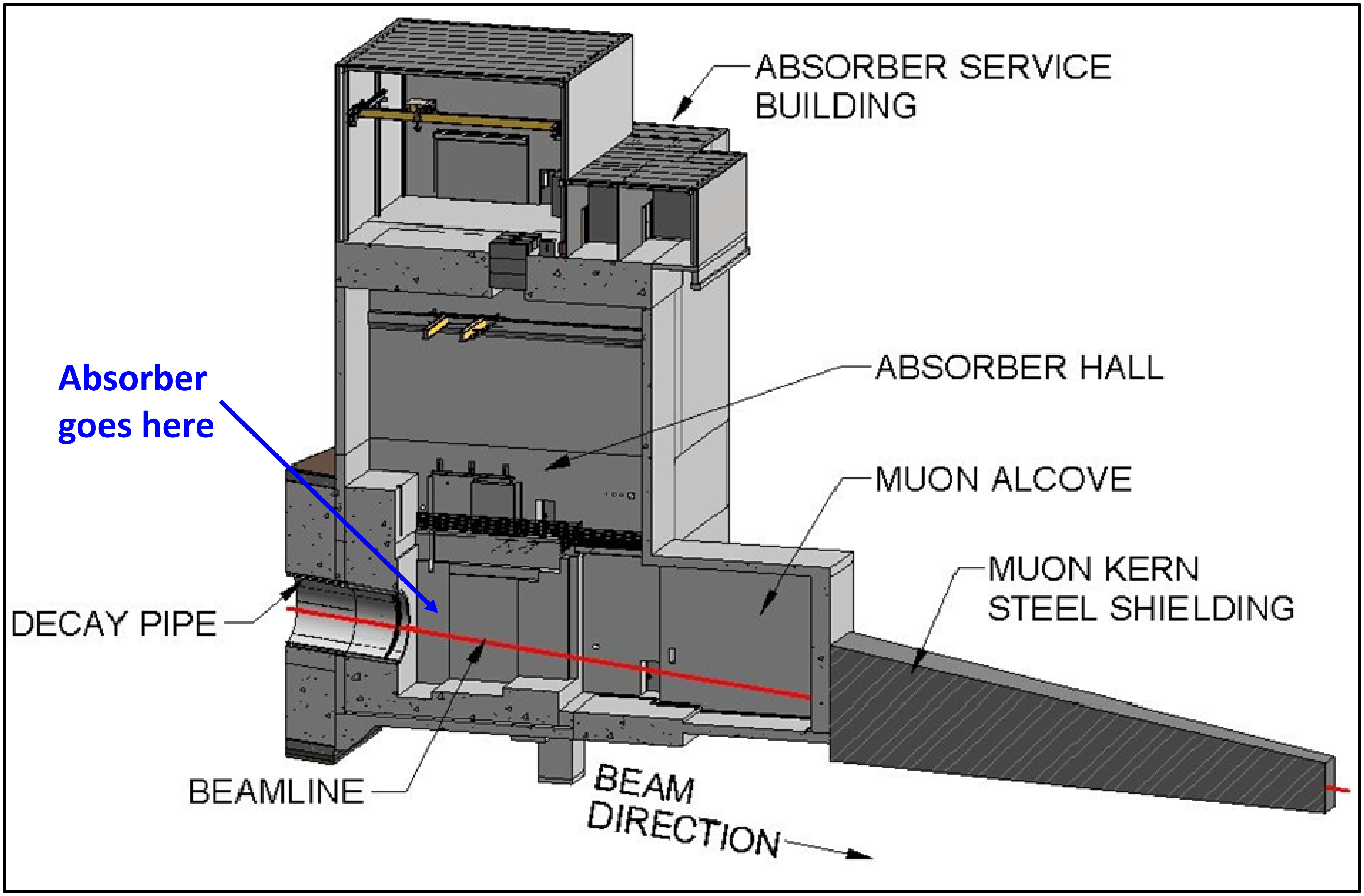


Target Chase & Decay Pipe Cooling

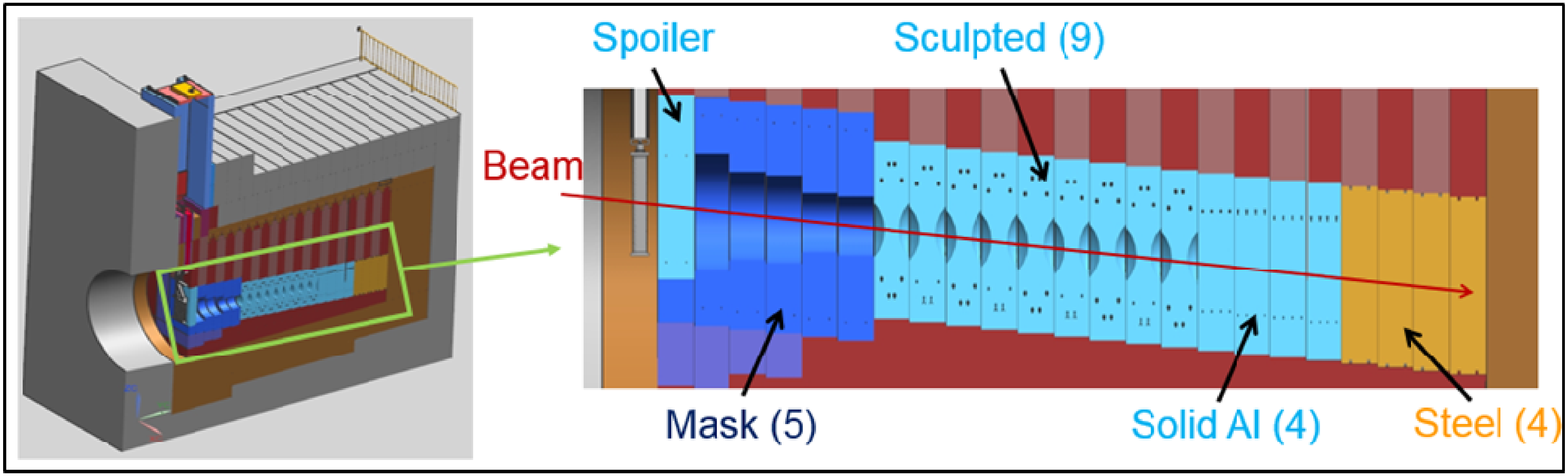


- Combination of forced air & water cooling panels for Target Shield Pile
- Air-cooled Decay pipe
- 2 separate air systems for target Chase and Decay Pipe
- Possible need to replace air in the target chase with N2 or He under study

Absorber building



Beam Absorber Configuration



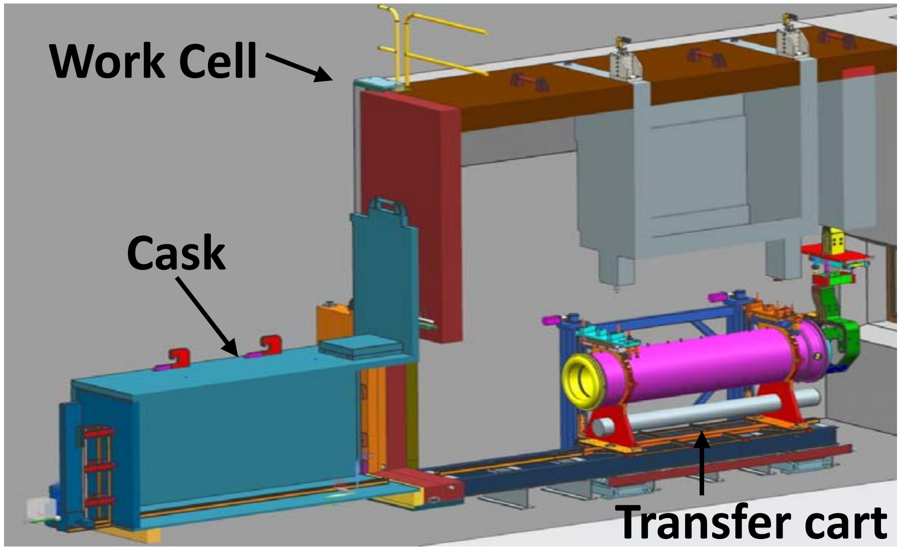
- ~30% of the beam energy deposited in the Absorber

- Core: replaceable water-cooled blocks, each 1 foot thick
- Outside of the core is forced-air cooled steel and concrete shielding

- Viable for 60-120 GeV/c protons, 2.06-2.4 MW beam power, including both steady-state operations and accident conditions

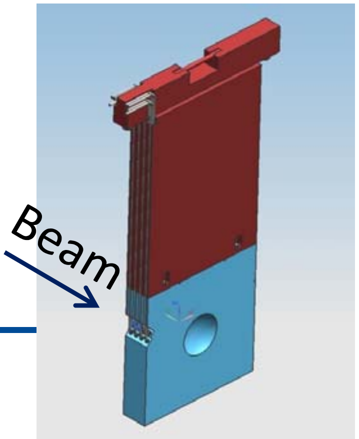
Remote Handling

- Remote Handling systems are integrated into the infrastructure of the Target complex, they must be designed to be sufficient for 2.4-MW beam power
  - Shield doors (will incorporate air seals)
  - Lifting fixtures, vision system
  - Morgue/Maintenance areas, Rail System
  - Hot Storage Rack and Work Cell



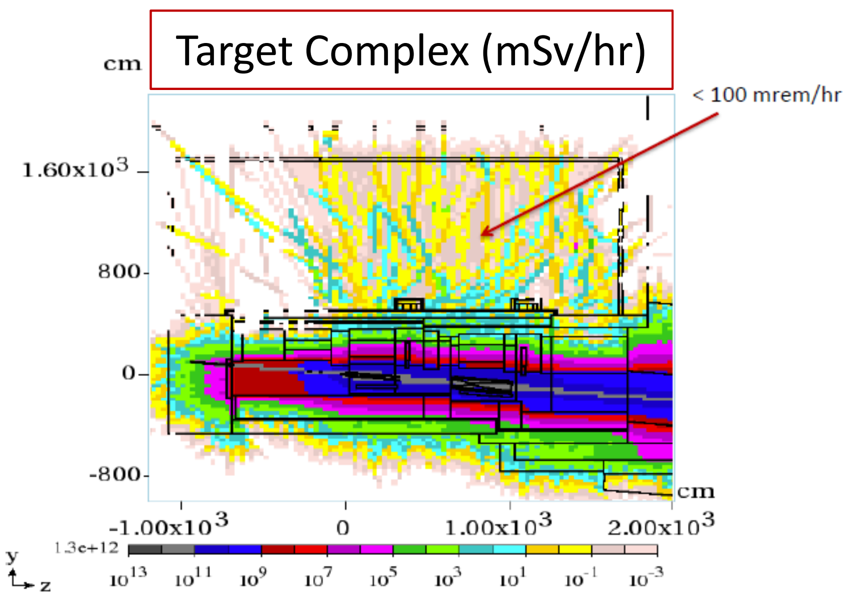
- Absorber Hall components and shielding allow future replacement
  - Low probability of complete failure, final design and construction of remote handling equipment not included in the LBNF project
  - No Work Cell needed in Absorber Hall

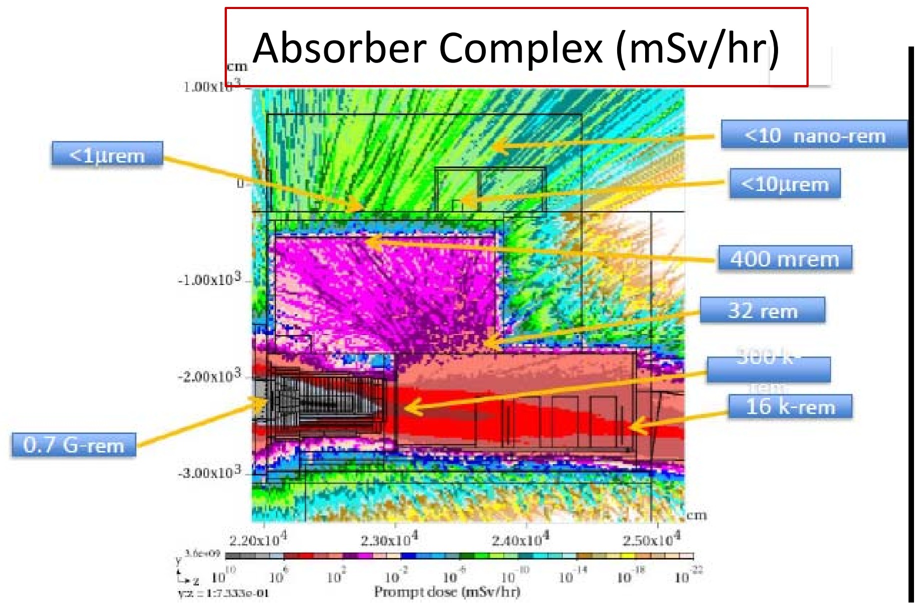
Replaceable core blocks



Beam Simulation

- Extensive MARS simulations for energy deposition and radiological studies as well as for Beamline configuration optimization studies.
  - ~40% of the beam power is deposited to the Target Hall Complex, 30% to the Decay Pipe region and 30% to the Absorber Hall complex.
- GEANT simulations for Beamline configuration optimization studies, neutrino fluxes, sensitivity and systematic studies.





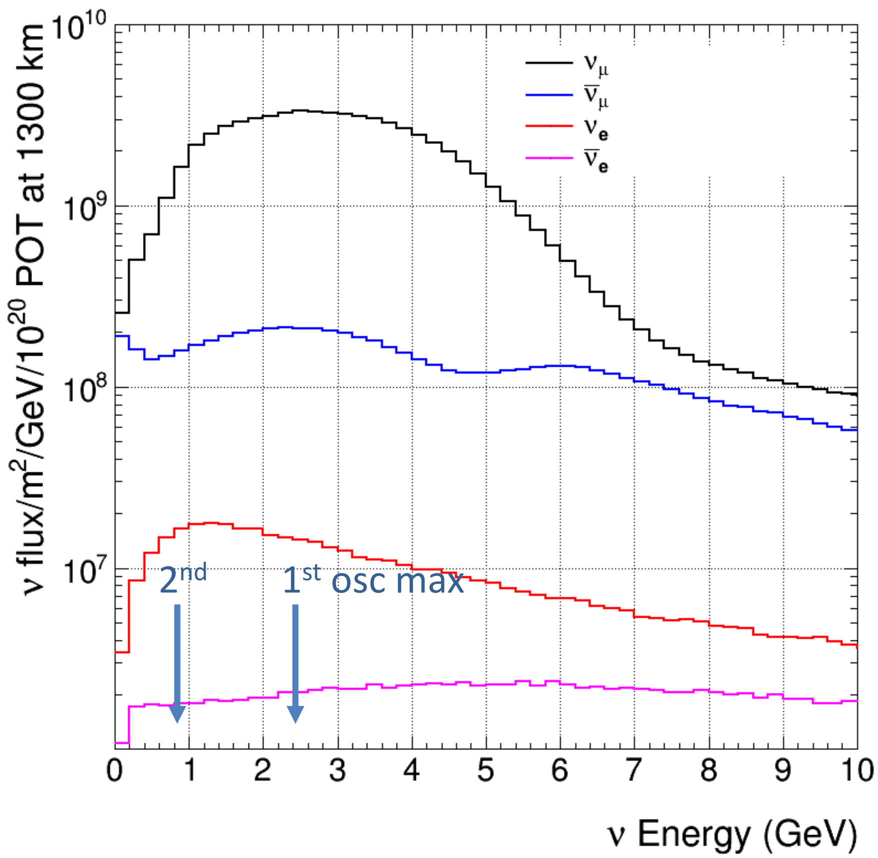
What is being designed for 2.4 MW

- Designed for 2.4 MW, since upgrading later would be prohibitively expensive and inconsistent with ALARA:
  - Size of enclosures (primary proton beamline, target chase, target hall, decay pipe, absorber hall)
  - Radiological shielding of enclosures (except from the roof of the target hall, that can be easily upgraded for 2.4 MW when needed)
  - Primary Beamline components
  - The water cooled target chase cooling panels
  - The decay pipe and its cooling and the decay pipe downstream window
  - beam absorber
  - remote handling equipment
  - radioactive water system piping
  - horn support structures are designed to last for the lifetime of the Facility

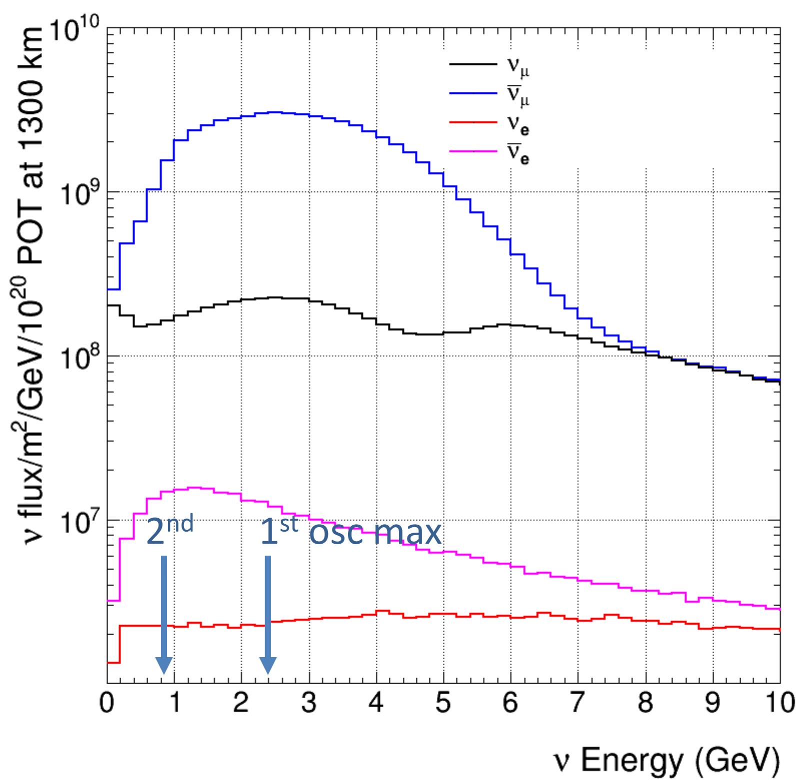
Neutrino Flux – Reference Configuration

Focusing positive particles (ν_μ beam)

120 GeV protons
230 kA horn current



Focusing negative particles ($\bar{\nu}_\mu$ beam)

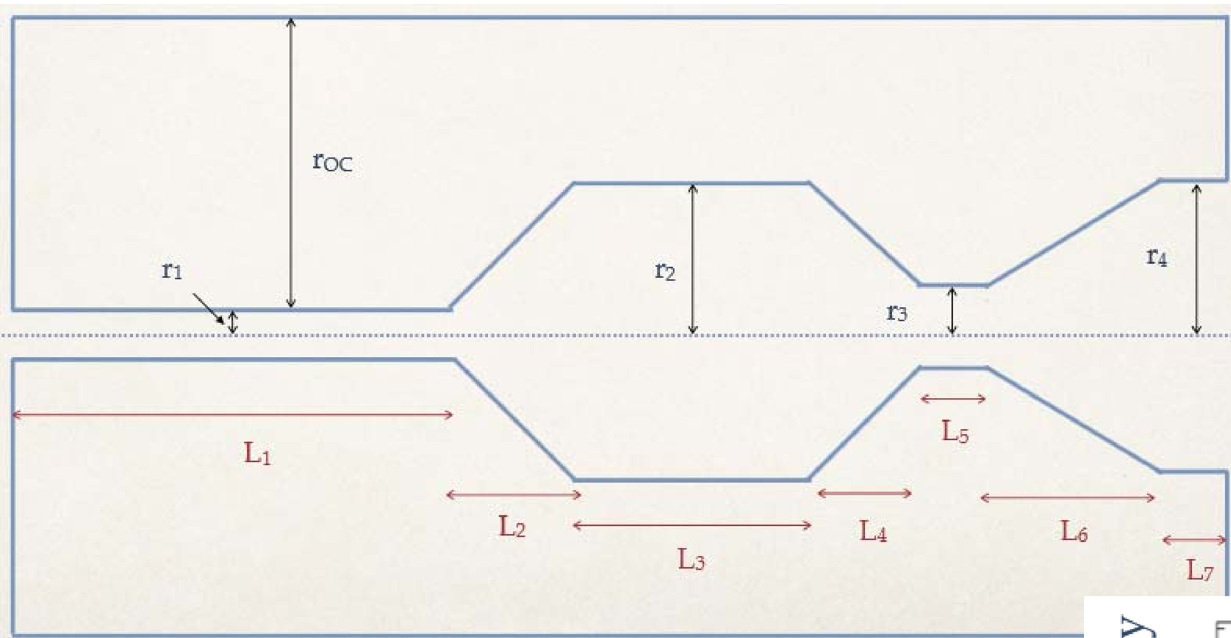


Studies for an optimal beam design - Physics

- Proton energy choice in the range 60-120 GeV (some programmatic consequences).
- Horns
  - Shape/size
  - current (power supply up to 300 kA, just completed new conceptual design)
- Target (currently two interaction lengths)
  - Size/shape/position with respect to Horn 1
  - Material(s) (higher longevity can increase up time - ongoing R&D)
- Studied Decay Pipe length and diameter. Current length 194 m (studied 170 m - 250 m). Current diameter 4 m (studied 2-6 m). *Recently fixed at 194 m long x 4 m diameter.*

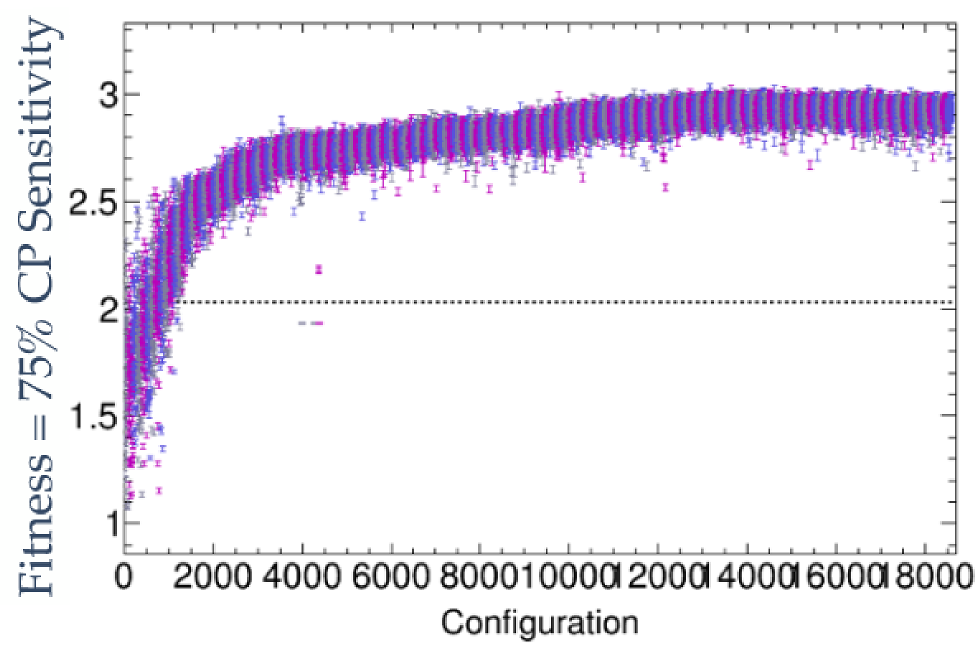
Optimizing the focusing system for greater physics reach

Genetic algorithm, inspired by work done by LBNO Collaboration
to optimize for CP Violation sensitivity



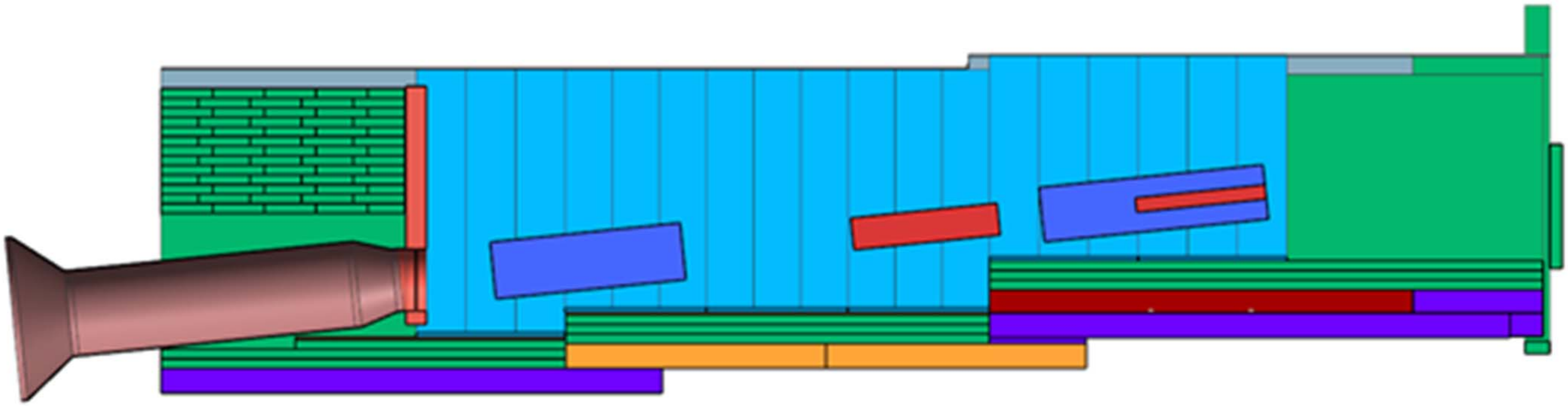
Genetic algorithm and new shape of Horn 1

Horn 2 is NuMI shape in this case but rescaled radially and longitudinally



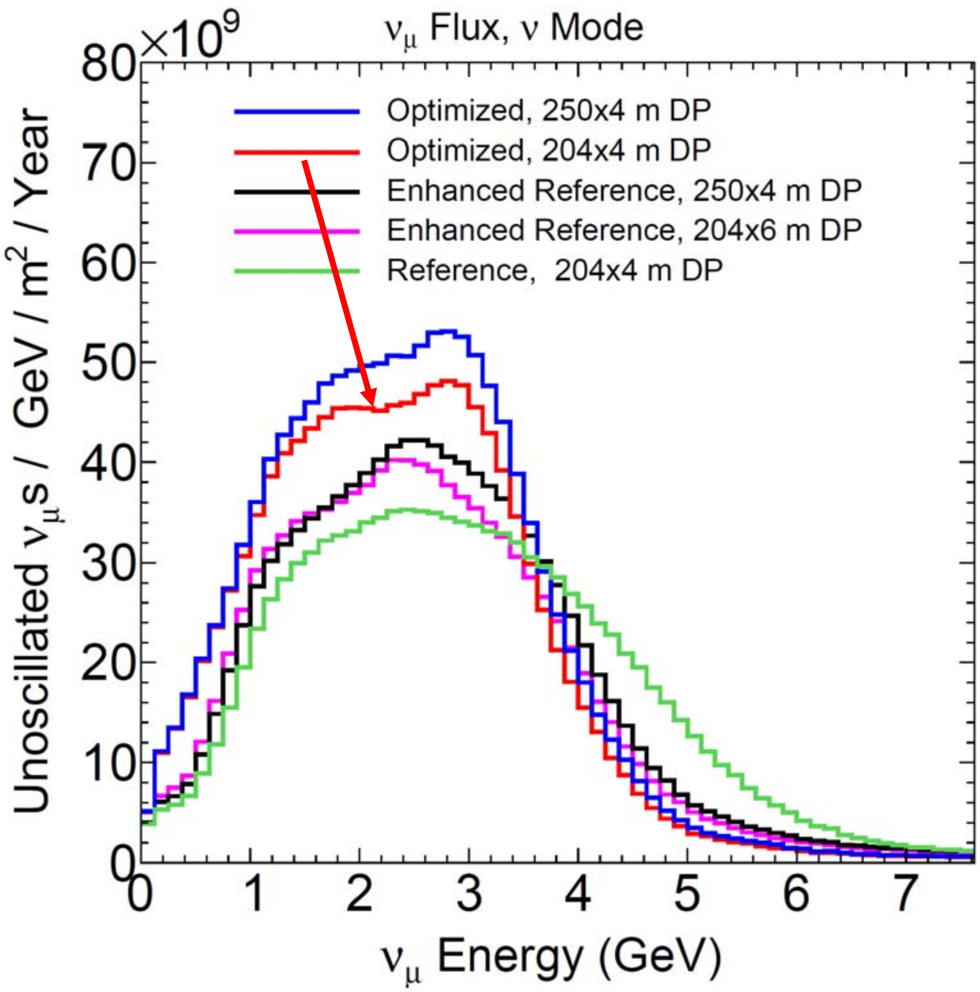
Target chase allows for optimized focusing systems

Reference Design Target Chase indicating the positions of the reference design horns (in red) and the optimized horns (in blue)



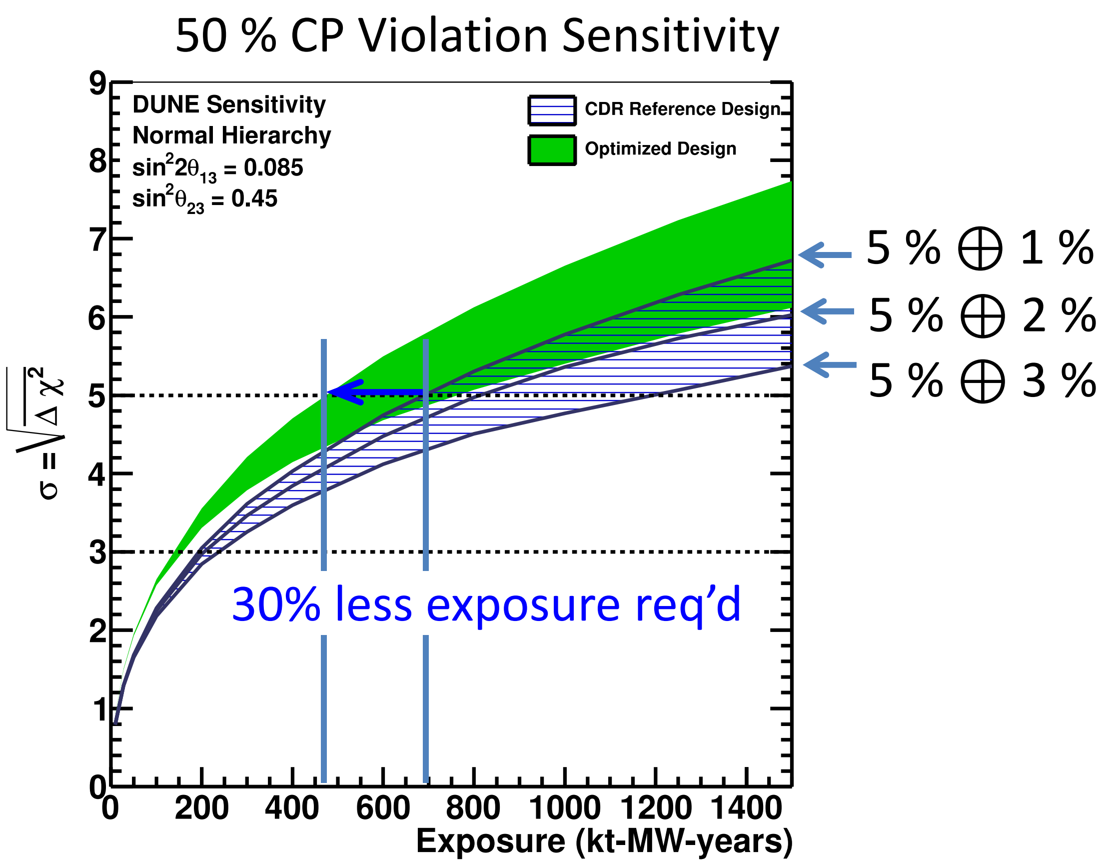
Neutrino Flux of best configurations compared with Reference Design

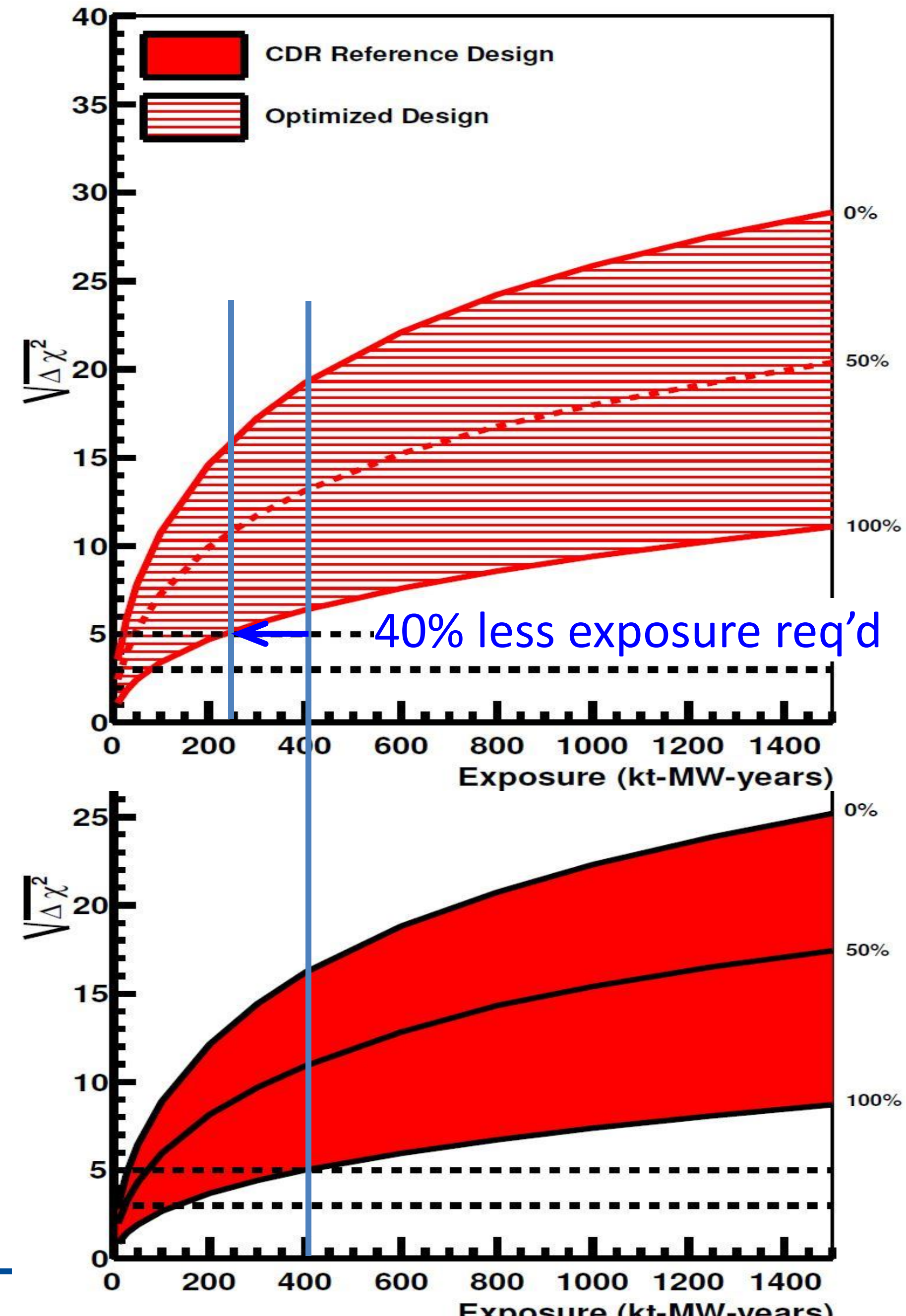
80 GeV protons



Enhanced: thinner and shorter cylindrical Be target, 25 cm upstream of 1st horn

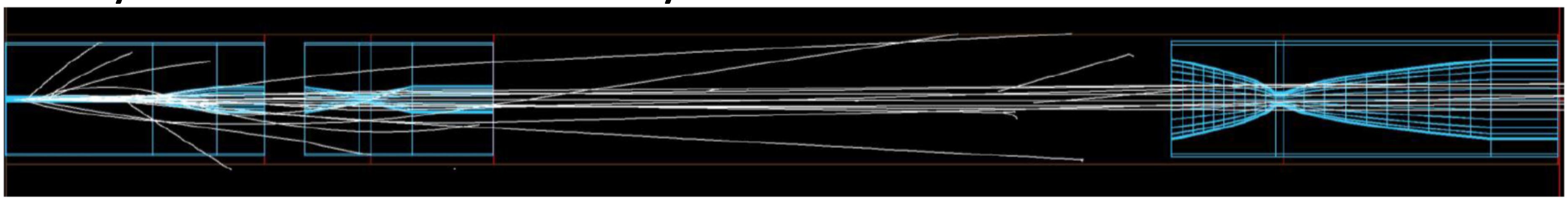
CPV and MH sensitivity improvement with optimized beam





Further work required on optimized target-horn system

- Engineering needed to determine feasibility of horn designs selected by genetic algorithm
- Study effect of 2 -> 3 horn system



- Search phase-space of horn design more broadly, and consider other optimization criteria, e.g. for ν_τ appearance.
- Alternate target designs and materials
- Target and horn R&D towards 2.4 MW operation
- Alternate ideas to “classical” horn focusing?

=> Ideas from new collaborators are needed!

Summary

- The Fermilab Main Injector is delivering the world's highest beam power for neutrinos ... 0.5 MW now, 0.7 MW next year, 1.2 MW -> 2.4 MW with PIP-II and eventually PIP-III
- The LBNF beamline design is well developed, based on NuMI experience
  - All systems designed for 1.2 MW
  - All elements that cannot be replaced later are designed for 2.4 MW
- Further optimization can have a big impact on the physics reach of DUNE … new ideas and new collaborators are needed **now** to realize this potential.