Status of the LBNE Neutrino Beamline

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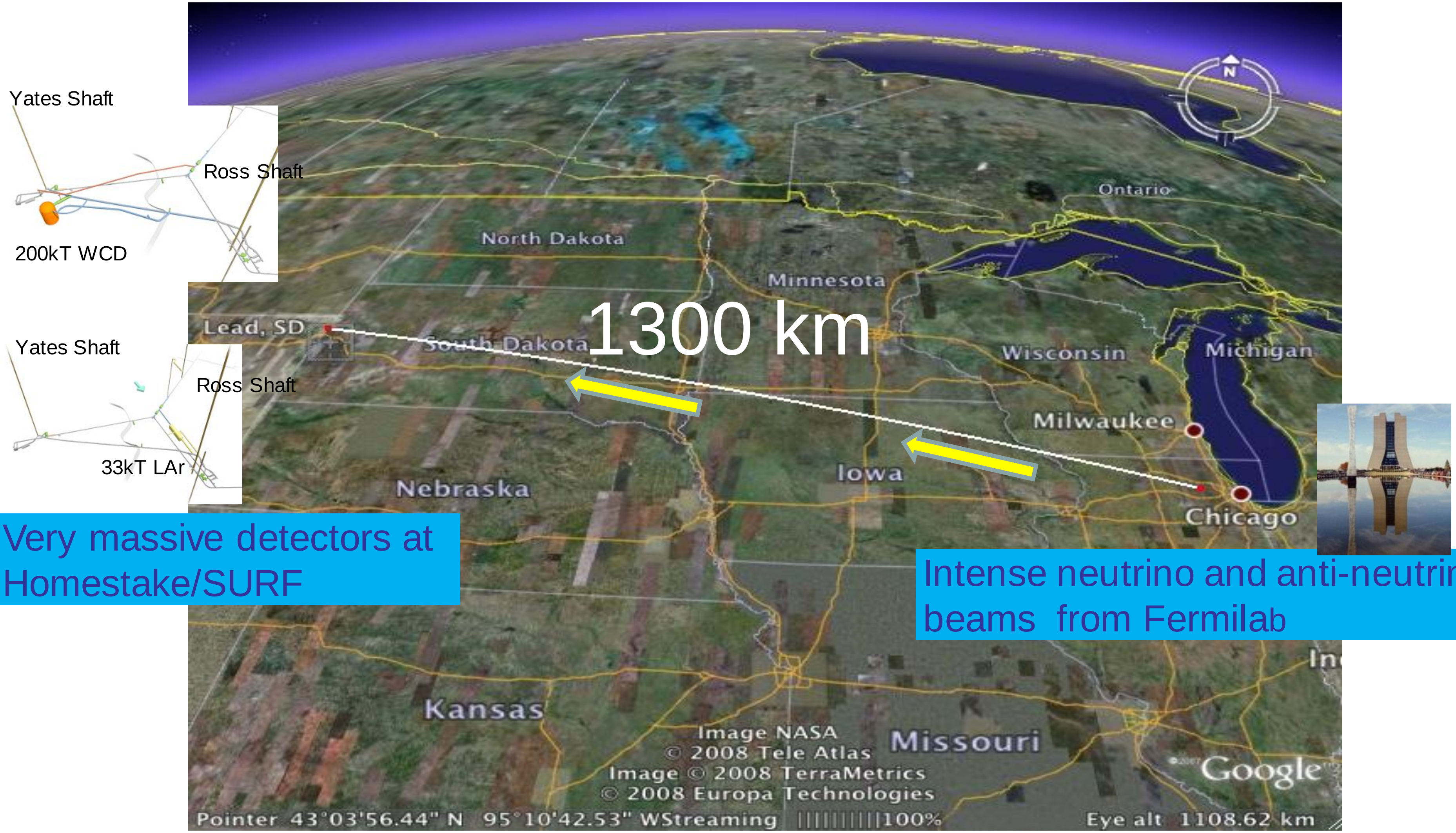
Outline

- Introduction
- Design considerations and requirements for the LBNE Neutrino Beamline
- Scope, Reference Designs
- Challenges (technical, radiological, spacial, financial,…)
- Status of the conceptual design
- Conclusion

Long Baseline Neutrino Experiment



Very massive detectors at Homestake/SURF

Intense neutrino and anti-neutrino beams from Fermilab

Critical Decision 0 (CD-0) approved on January 8, 2010
Aiming for CD-1 (conceptual design) review in Spring of 2012

Additional milestones

- NSF/DUSEL decoupling – February 2011
- "DOE Office of Science Review of Options for Underground Science" report available – June 2011
- National Rerearch Council assessment of DUSEL available – July 2011
- DUSEL changes scope – SURF (Sanford Underground Research Facility)
- Waiting for DOE/Office of Science Decision
- In the mean time LBNE is trying to reduce the overall cost – significant value engineering effort.
- CD-2 Review (baseline) expected in summer 2013

Beamline Plans

- For the Beamline (NuMI style conceptual design) we had 8 internal design and cost/ schedule reviews between April 2010 and September, 2010. CDR developed, September 2010.
- From October 2010 and on we entered in the 2nd/3rd phase of value engineering with the goal to reduce the cost significantly. We have evaluated ~15 Value Engineering proposals so far. A Technical Board was established in March 2011 to help review the proposals as well as provide recommendations and advice on important technical decisions . Two Reference Designs developed and being pursued aggressively towards CD-1.
- Aiming for a technical review of the LBNE Near Site in October/November 2011 and CD-1 Review in the Spring of 2012.

Beamline Design Drivers

- The driving physics considerations for the LBNE Neutrino Beamline are the long baseline neutrino oscillation analyses where the primary objectives are:
  - Search for, and precision measurements of, the parameters that govern ν_μ to ν_e oscillations (θ_{13}, and if large enough, CP violating phase δ and mass ordering)
  - Precision measurements of θ_{23} and $|\Delta m^2_{32}|$ in the ν_μ disappearance channel
- Wide band beam to cover the 1st and 2nd oscillation maxima. Optimizing for $E\nu$ in the range 0.5 – 5.0 GeV.
- Flexibility to operate in the proton beam energy range of 60-120 GeV.
- Start with a 708 kW beam (ANU/NOvA at 120 GeV), and then be prepared to take profit of the significantly increased beam power (~2.3 MW) available with Project X.

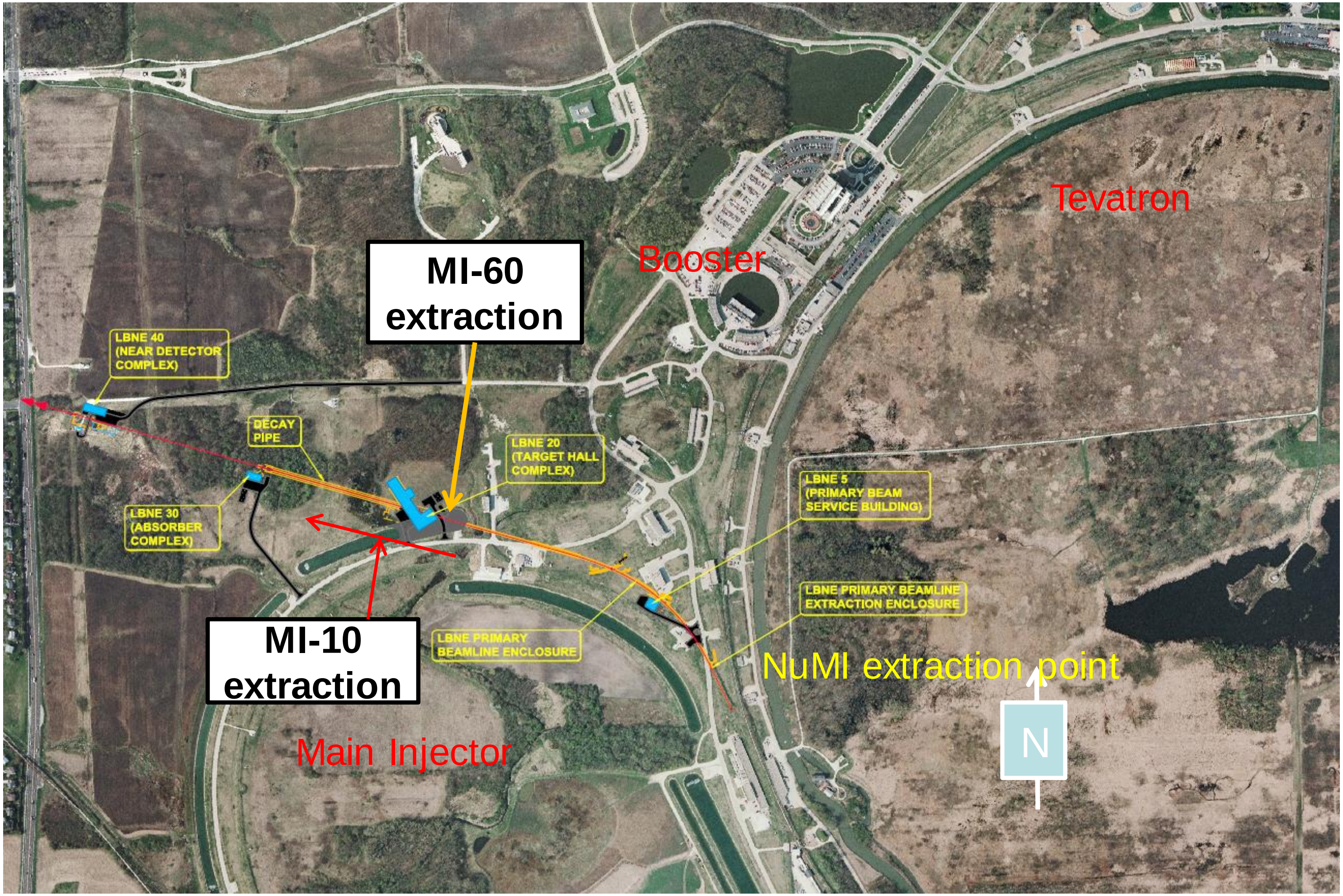
Beamline Design Drivers

- There are a few systems in the Neutrino Beamline (including underground spaces) that are conceptually designed for 2.3 MW in order to enable the facility to be upgraded in a cost efficient manner and run with an upgraded accelerator complex.
- The beam is aimed from Fermilab to the Homestake Mine in South Dakota (48/7 degree horizontal bend, 5.8 degree vertical bend).
- The Neutrino Beamline Facility will be contained within Fermilab property.
- Stringent limits on radiological protection of environment, members of public and workers.
- Maximize the distance between the target and the Near Detector and allow for a muon range-out distance (Absorber to Near Detector) of at least 210 m.

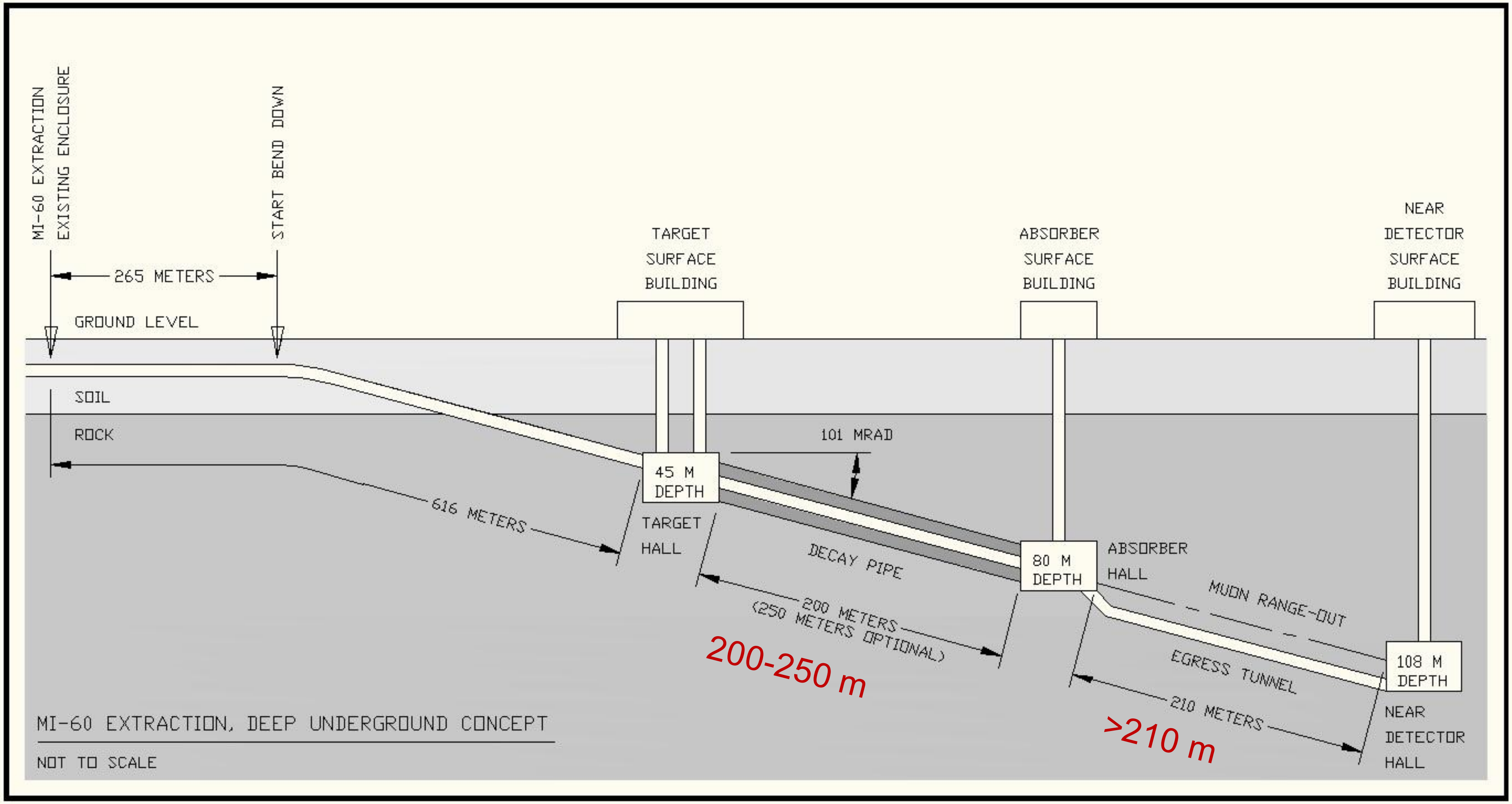
Configurations considered

- Four separate beamline / facility configurations have been defined with accompanying conceptual level cost estimates. These are (varying extraction points and beamline depth):
  - MI-60, Deep (similar to NuMI design) and MI-60, Shallow
  - MI-10, Deep and MI-10, Shallow
- Deep options feature excavations in soil and in rock.
- Shallow options feature a large berm into which facilities would be constructed. This is to minimize excavations in rock.
- We have two reference conceptual designs: MI-60, deep and MI-10, shallow
- Decay tunnel length varies between 200m and 250m (about 12% effect in # of Far Detector interactions). Diameter is 4m.

The LBNE Neutrino Beamline Facility at Fermilab

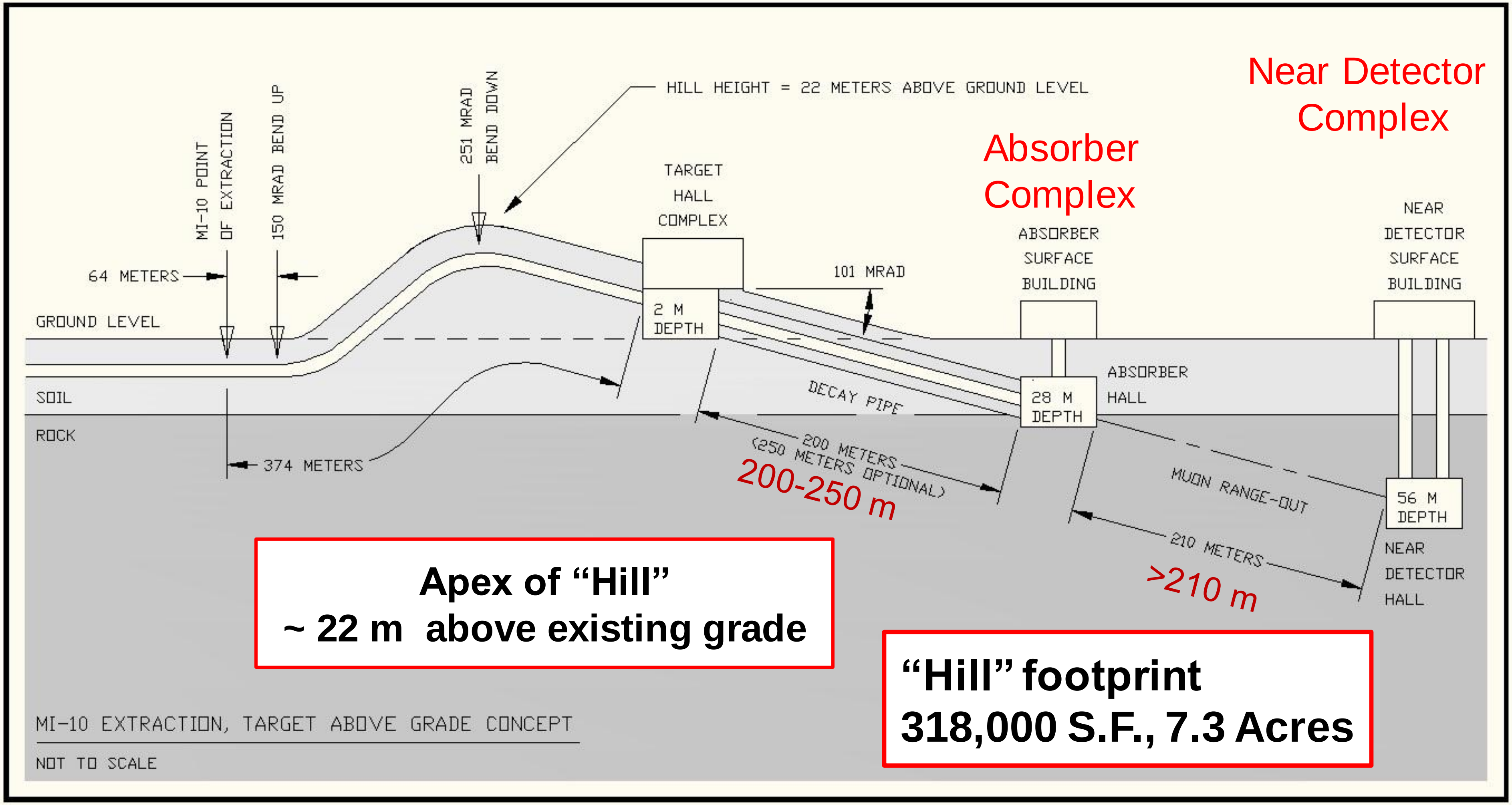


MI-60 Extraction, deep



Existing extraction point for NuMI
Sufficient space available to increase significantly decay pipe/muon range out distances

MI-10 Extraction, shallow



Apex of "Hill"
~ 22 m above existing grade

"Hill" footprint
318,000 S.F., 7.3 Acres

Introduce a drift tube to minimize the impact on MI and therefore cost and downtime.

Evaluating stability (deep foundations), impact on MI, muon-shine issues, position of decay pipe/absorber (geomembranes)

Radiological Requirements

- Design for 2.3 MW, 120 GeV proton beam.
- Member of the public at the Fermilab boundary should not receive more than 1 mrem in a year from all radiation sources originated from the LBNE beam line.
- Sheilding for protecting ground water:
  - For the deep underground design aim to stay below 10% of the drinking water limit and in the wells to be below the detection limit.
  - For the shallow design concentrations outside the aquifer will be below the detection limit.
- The current laboratory air emissions permit requires that the annual exposure of a member of the public off-site to radioactive air emissions from all sources should be less than 0.1 mrem. We are designing for LBNE contributions to be between 30-50% of this limit to allow room for other Laboratory projects.

The Neutrino Beamline Scope

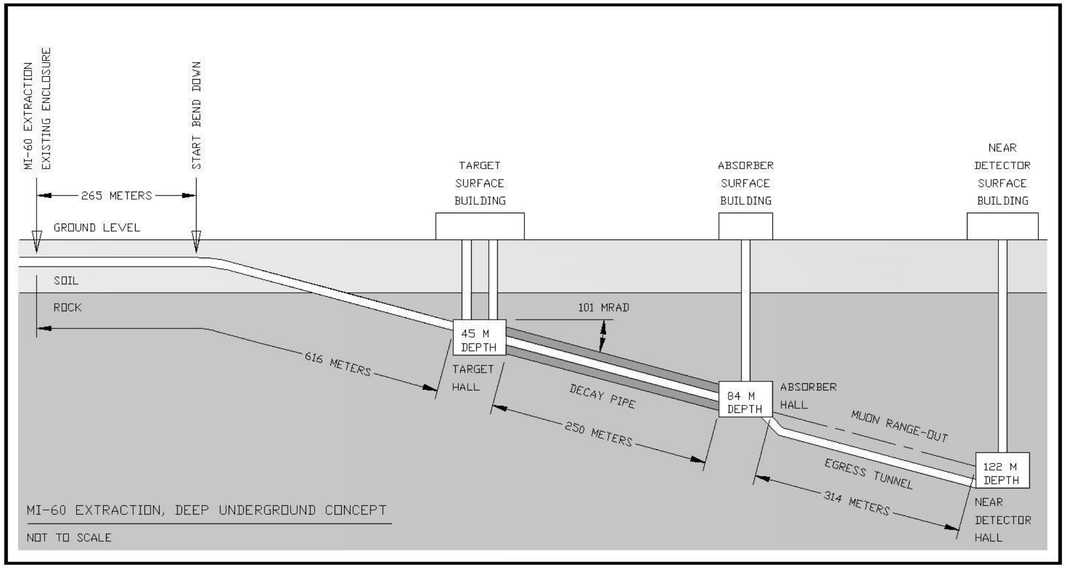
Primary Beam (magnets, magnet power supplies, LCW, vacuum, beam instrumentation, beam optics and beam loss calculations)

Neutrino Beam (primary beam window, baffle, target, 2 focusing horns, horn power supplies, target pile, decay pipe, absorber, RAW, tritium mitigation, remote handling, modeling, storage of radioactive components)

System Integration (controls, interlocks, alignment, installation infrastructure)

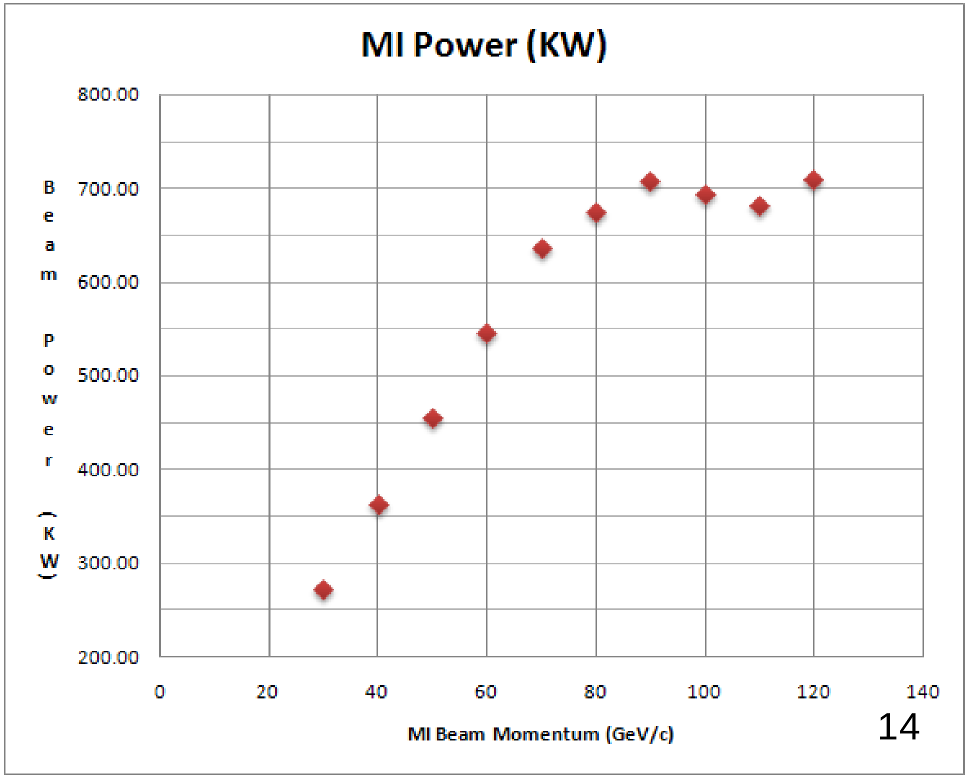
Conventional Facilities

Which systems are significantly different in the two reference designs



Primary Beam Design Parameters

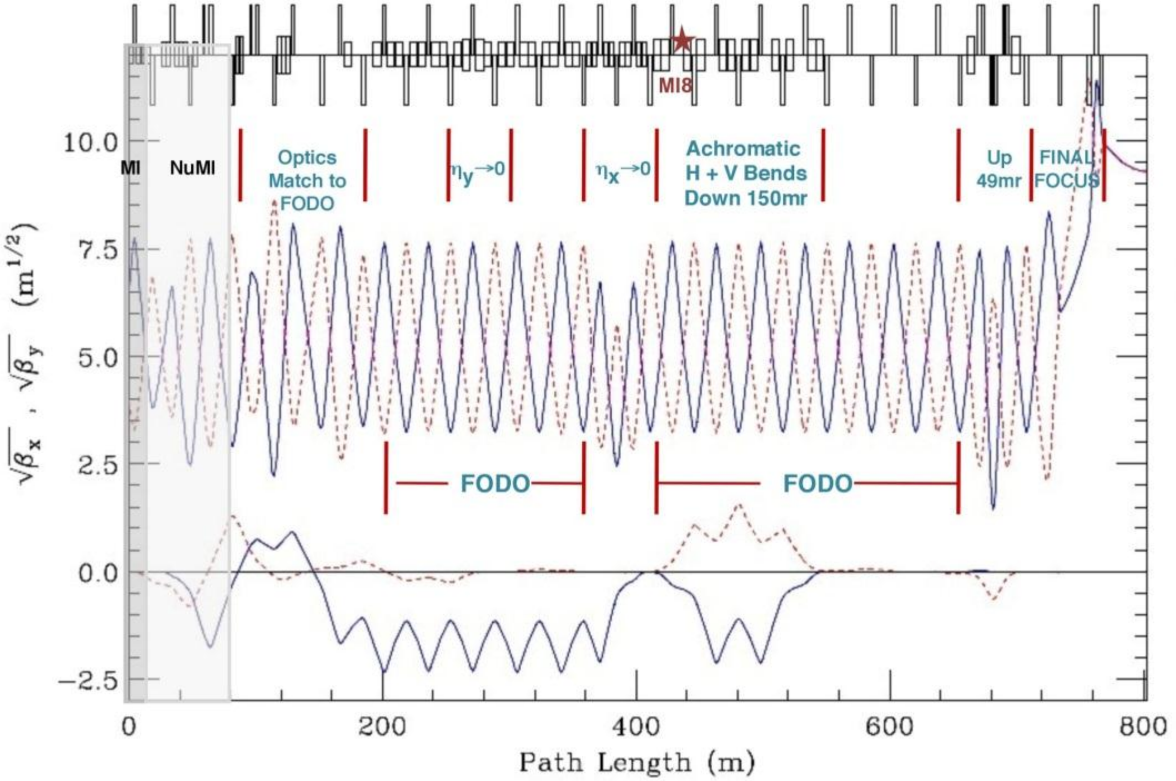
Beam Parameter	Value
Protons per cycle	4.9 x 10^{13}
Cycle time (120/60 GeV)	1.33/0.76 sec
Pulse duration	1.0 x 10^{-5} sec
Proton beam energy	60 to 120 GeV
Beam power at 120 GeV	708 kW
Operational efficiency	59%
Protons on target per year	6.8 x 10^{20}
Beam size at focus	1.5 mm
Beam divergence x,y	0.017 mrad



MI-60 extraction, deep

Beam optics

90^{o} FODO cells

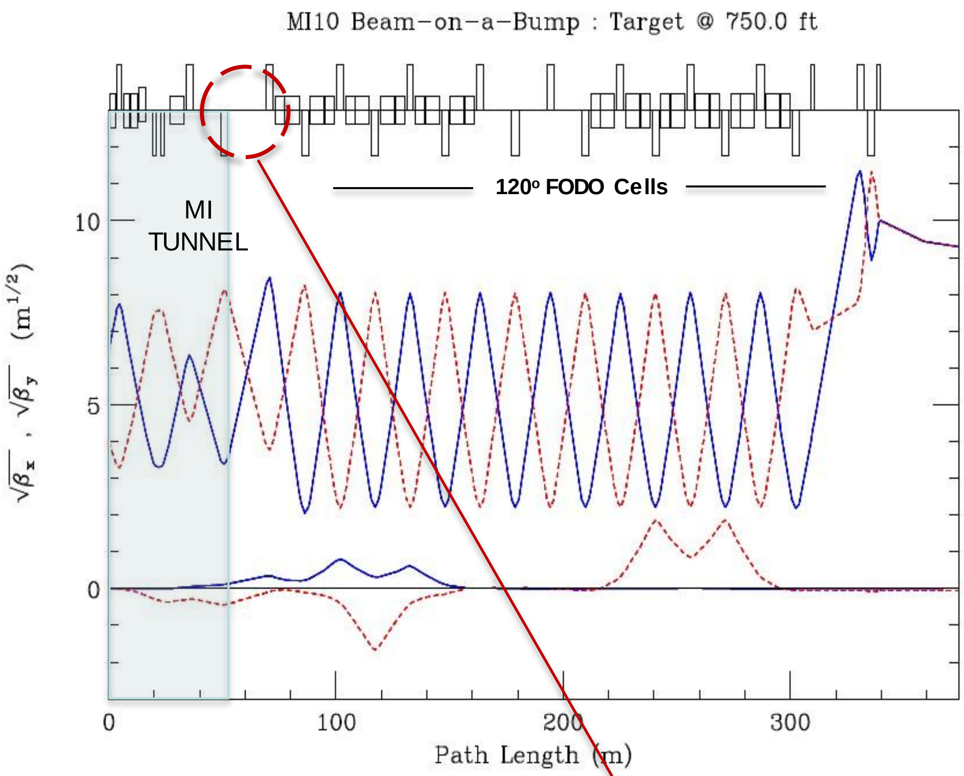


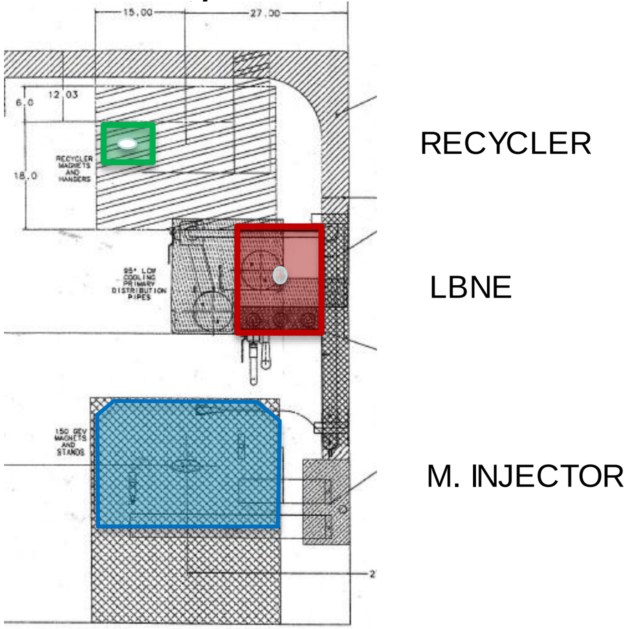
Horizontal (solid) and vertical (dashed) lattice function of the LBNE transfer line. The line is comprised of distinct optical modules & the final focus is tunable to produce a spot size of $\sigma = 1.00 \rightarrow 3.00$ mm over the range 60 → 120 GeV/c with $\varepsilon = 26\pi$ μm (98%, normalized).

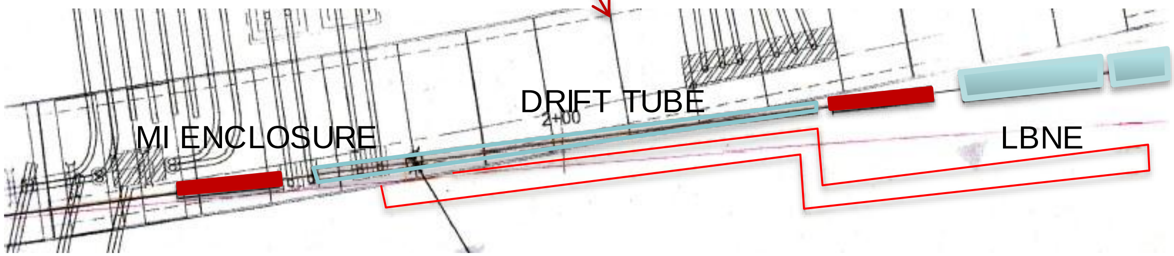
- Little rectangles : vertical bends
- Medium rectangles: horizontal bends
- Large rectangles: rolled dipoles
- Up and Down rectangles: quadrupoles (F&D respectively)

MI-10 extraction, shallow

120° FODO cells are chosen as the most efficient implementation of space in creating vertical achromats.



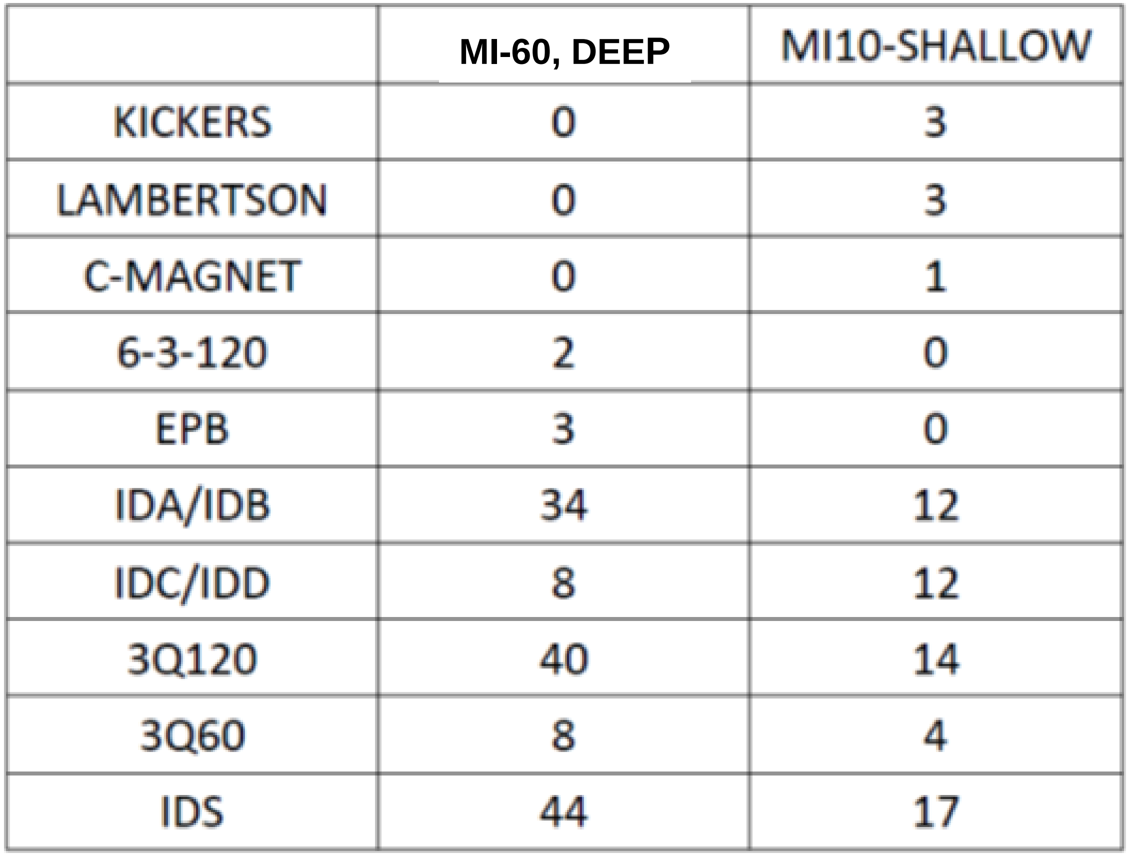




A single rolled dipole steers beam into a carrier pipe through the enclosure wall & bisects the MI & Recycler magnet elevations.

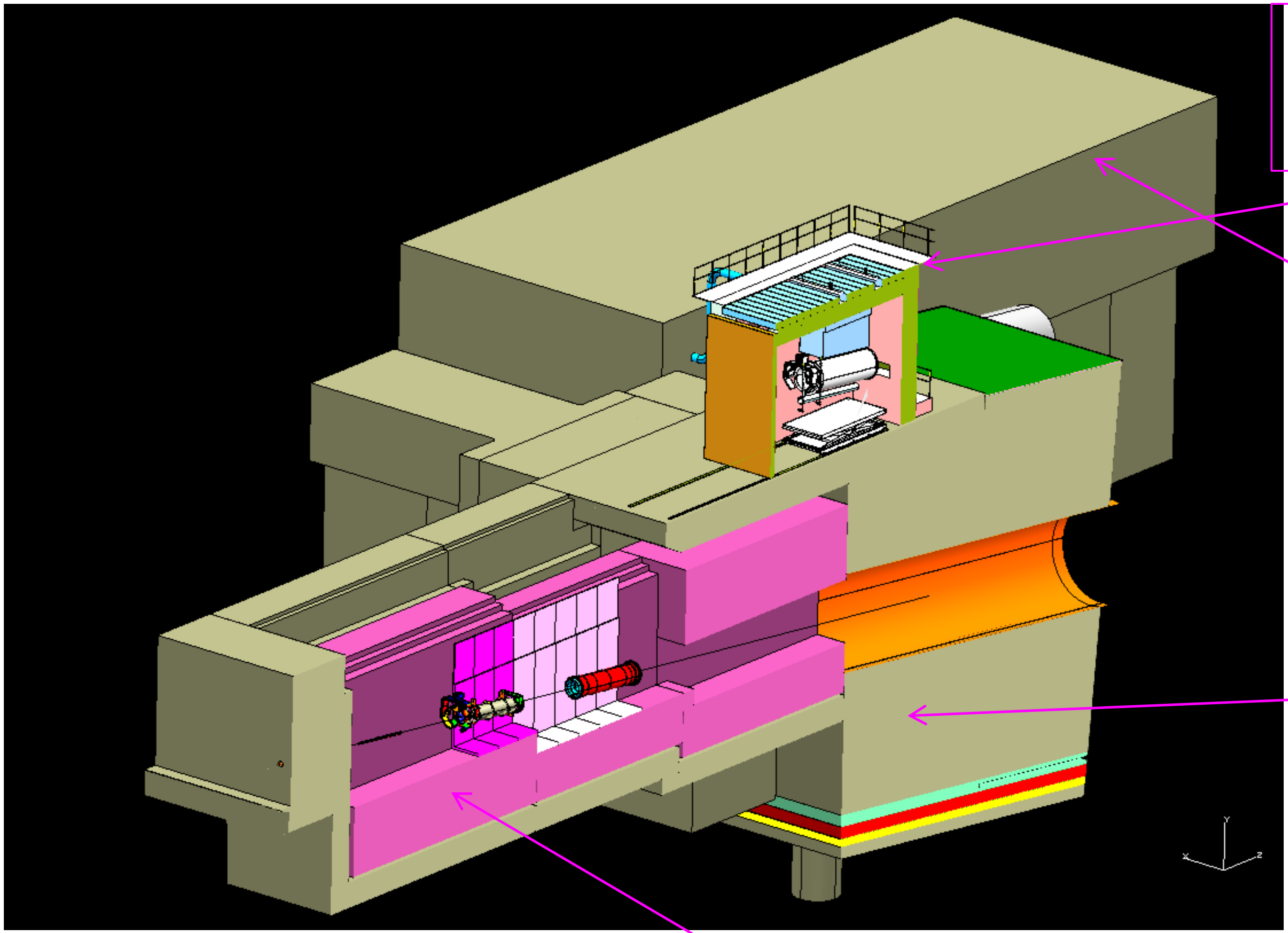
Magnet count comparison between MI-60, deep and MI-10, shallow

We are considering as default Main Injector type magnets although we have considered several alternatives



	MI-60, DEEP	MI10-SHALLOW
KICKERS	0	3
LAMBERTSON	0	3
C-MAGNET	0	1
6-3-120	2	0
EPB	3	0
IDA/IDB	34	12
IDC/IDD	8	12
3Q120	40	14
3Q60	8	4
IDS	44	17

Target Hall/Decay Pipe layout (MI-10, shallow)



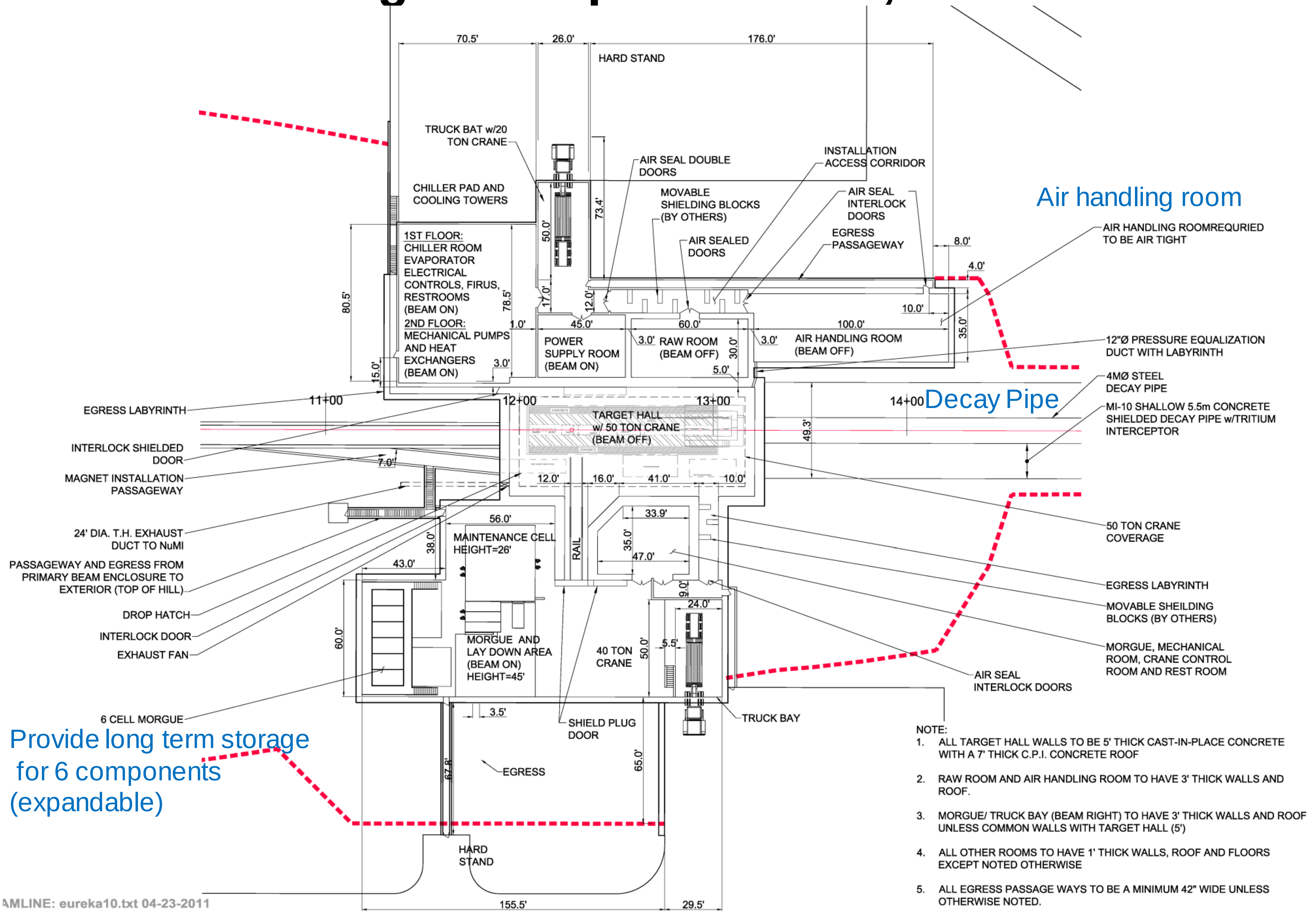
Work cell to be used for replacement of components, primarily horns

Air handling building (~3500 SQ Ft)

Decay Pipe concrete shielding (5.5 m)

Target Chase: 64” wide

Target Complex – MI-10, shallow



Air handling room

Decay Pipe

Provide long term storage
for 6 components
(expandable)

NOTE:
1. ALL TARGET HALL WALLS TO BE 5' THICK CAST-IN-PLACE CONCRETE WITH A 7' THICK C.P.I. CONCRETE ROOF
2. RAW ROOM AND AIR HANDLING ROOM TO HAVE 3' THICK WALLS AND ROOF.
3. MORGUE/ TRUCK BAY (BEAM RIGHT) TO HAVE 3' THICK WALLS AND ROOF UNLESS COMMON WALLS WITH TARGET HALL (5')
4. ALL OTHER ROOMS TO HAVE 1' THICK WALLS, ROOF AND FLOORS EXCEPT NOTED OTHERWISE
5. ALL EGRESS PASSAGE WAYS TO BE A MINIMUM 42" WIDE UNLESS OTHERWISE NOTED.

Reference Design of the target system with double layer cooling (IHEP/Protvino)

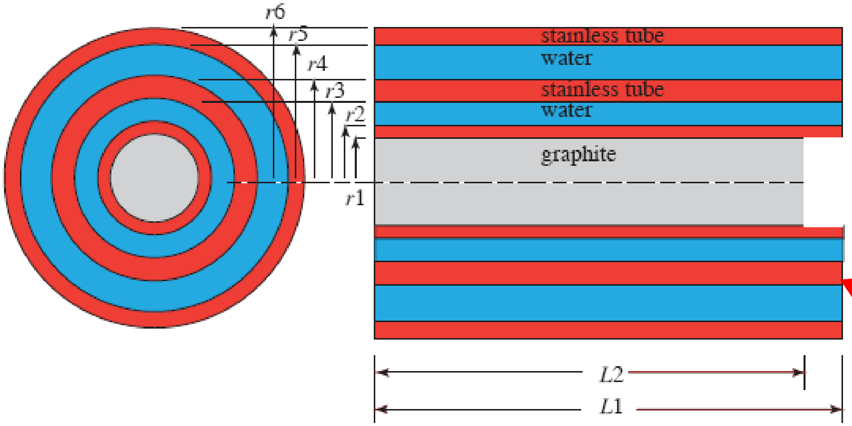
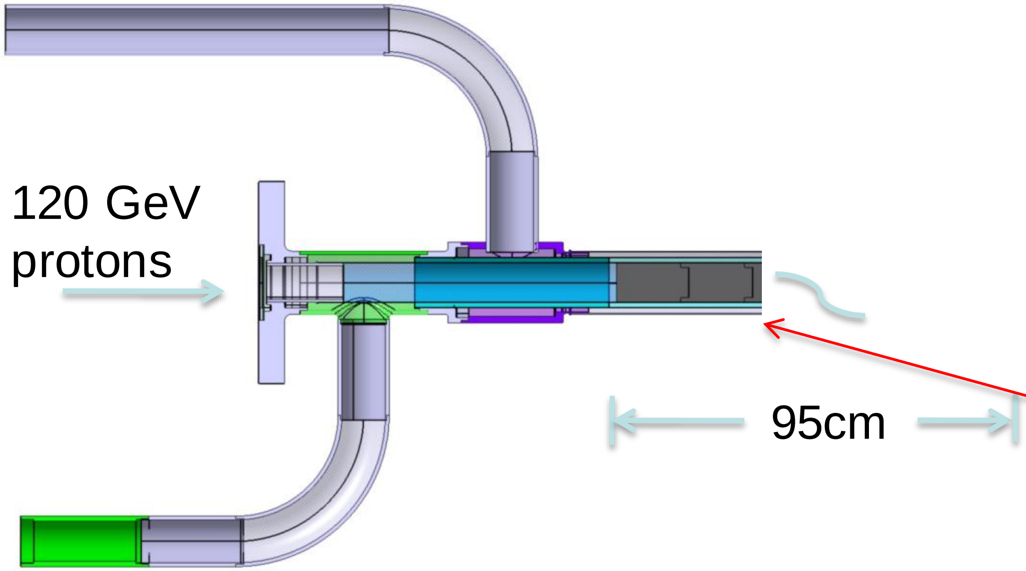


Figure 1. Target Assembly

Target material: POCO ZXF-50

Radial thickness (mm)	
IHEP design	
7.65	graphite
0.3	stainless
1.7	water
0.3	stainless
2.2	water
0.3	stainless
12.45	**Total**



120 GeV protons

95cm

A row of 15.3 mm diameter and 25 mm length graphite segments separated by 0.2 mm gaps.

Alternatives: Other graphites, C-C composite, HBN, Be or thinner targets.

BNL/BLIP irradiation study March-June, 2010
~ 9 weeks of beam

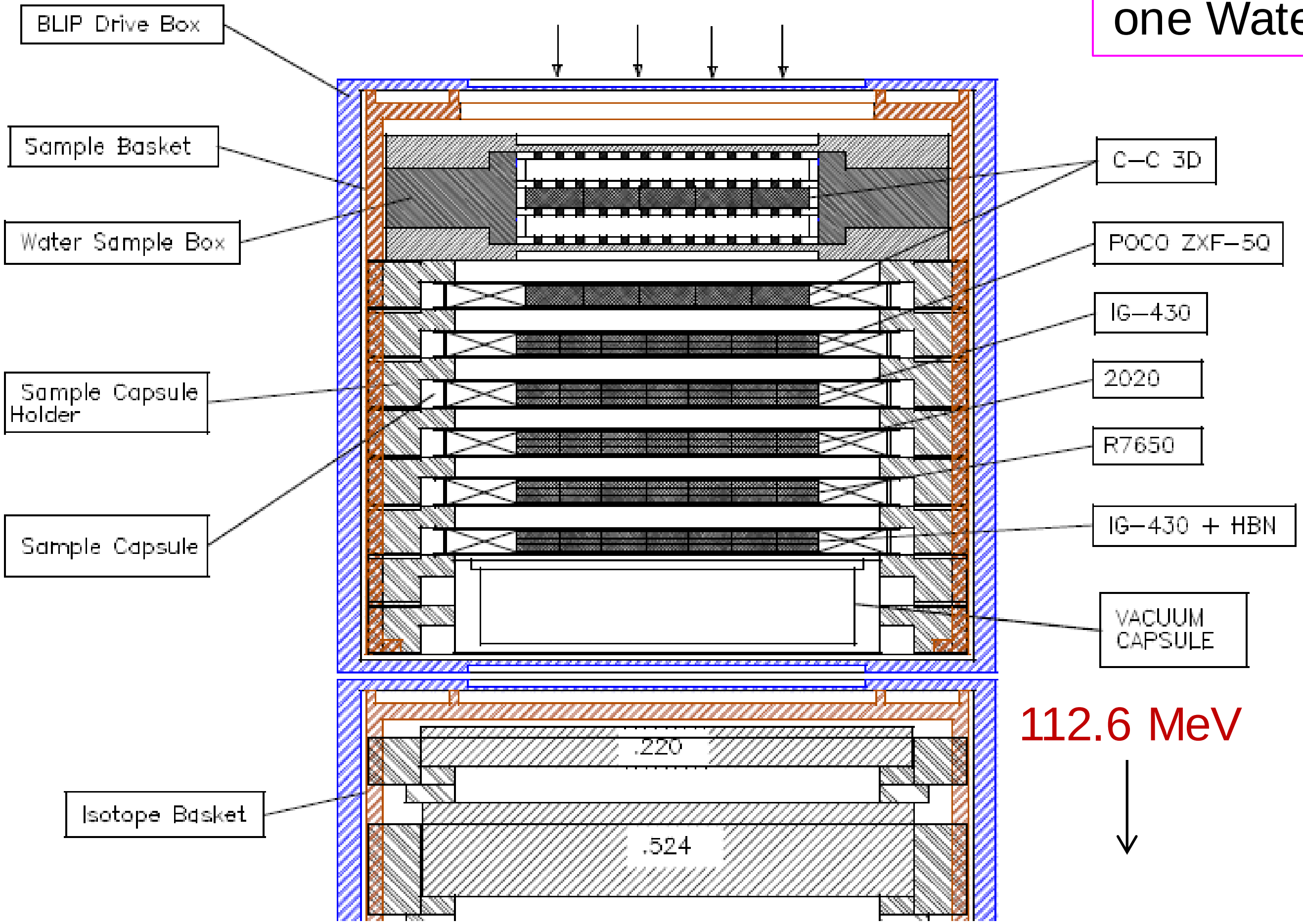
Beam in at 181 MeV, must reach isotope box at 112.65 MeV

Top View

BEAM

181 MeV

Six Argon capsules and one Water capsule



Carbon-carbon composite

NuMI target graphite

Japanese graphite

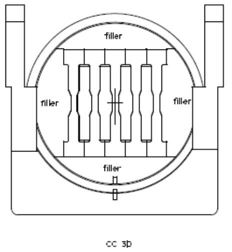
Another graphite, higher thermal shock metric

NuMI baffle graphite

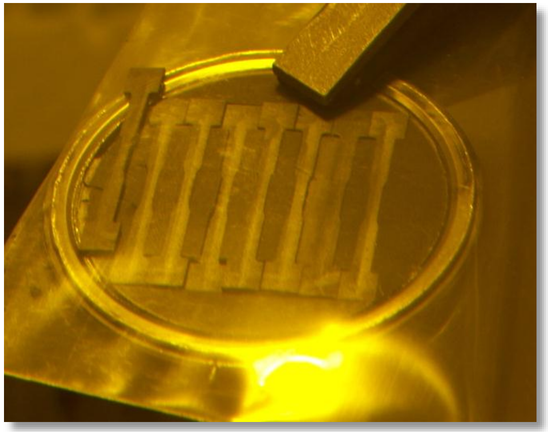
Highest therm. shock metric

112.6 MeV

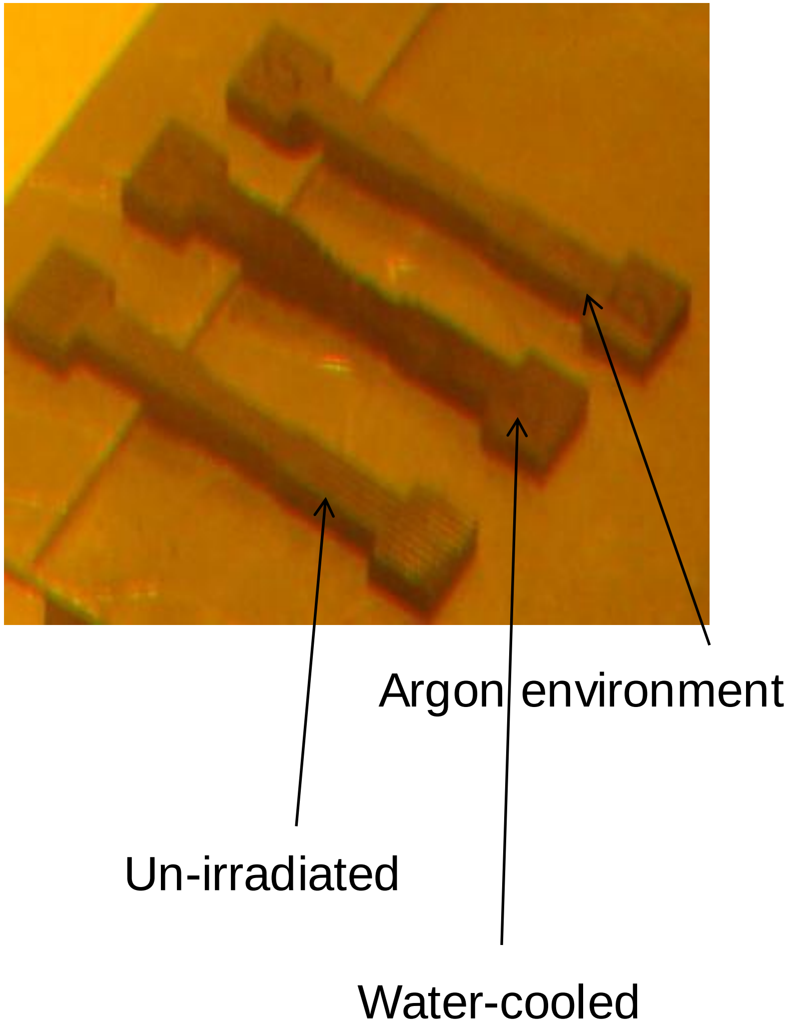
Beam View of Samples and Holder



Target Samples from BLIP test



Irradiation damage in water-cooled 3D carbon composite LBNE candidate target samples irradiated at BLIP.

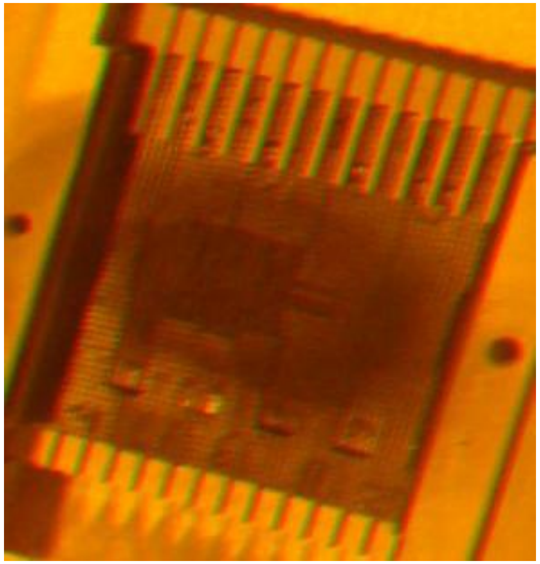


Argon environment

Un-irradiated

Water-cooled

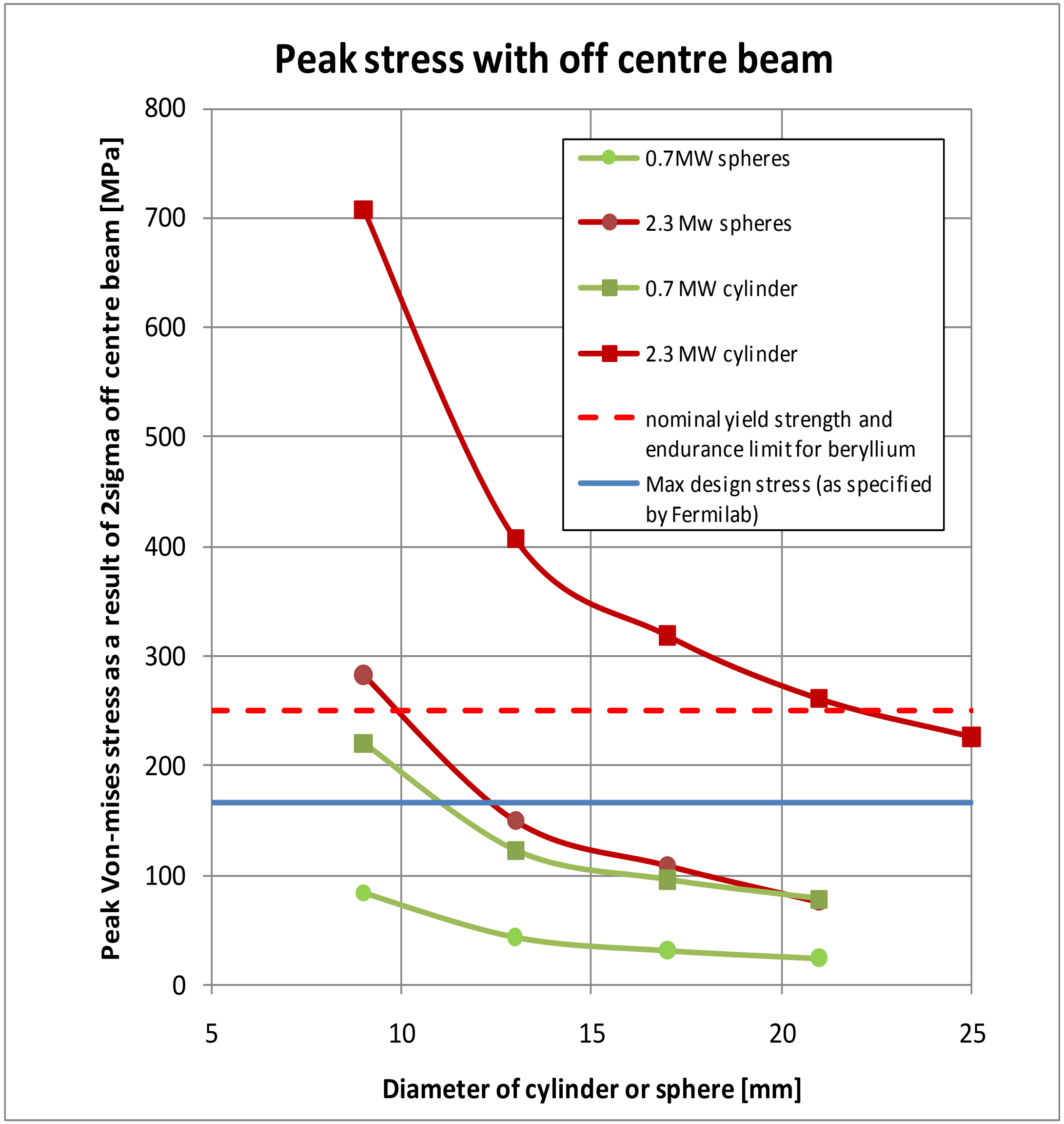
- Peak integrated flux about 5.9e20 proton/cm^2
- Average over 1 sigma area about 4.6e20 proton/cm^2



HBN “used up”

Effects of accidental 2σ off-centre beam on stress waves in simply supported target rod

Be target R&D



C. Densham et al. RAL report, LBNE docs 2400/3247, Nov. 2010

For 700 kW operation of a 13 mm diameter 1 m long beryllium cylinder falls inside the chosen design point stress. A series of spheres could be fit even better

For 2.3 MW operation, a cylindrical rod beryllium target would have to be well above 21 mm in diameter in order to bring the peak dynamic stresses below the yield strength. The stress in a series of spheres can be kept below the design point with spheres of 13 mm diameter - advantage of longitudinal segmentation

Reference Design for the Focusing Horns

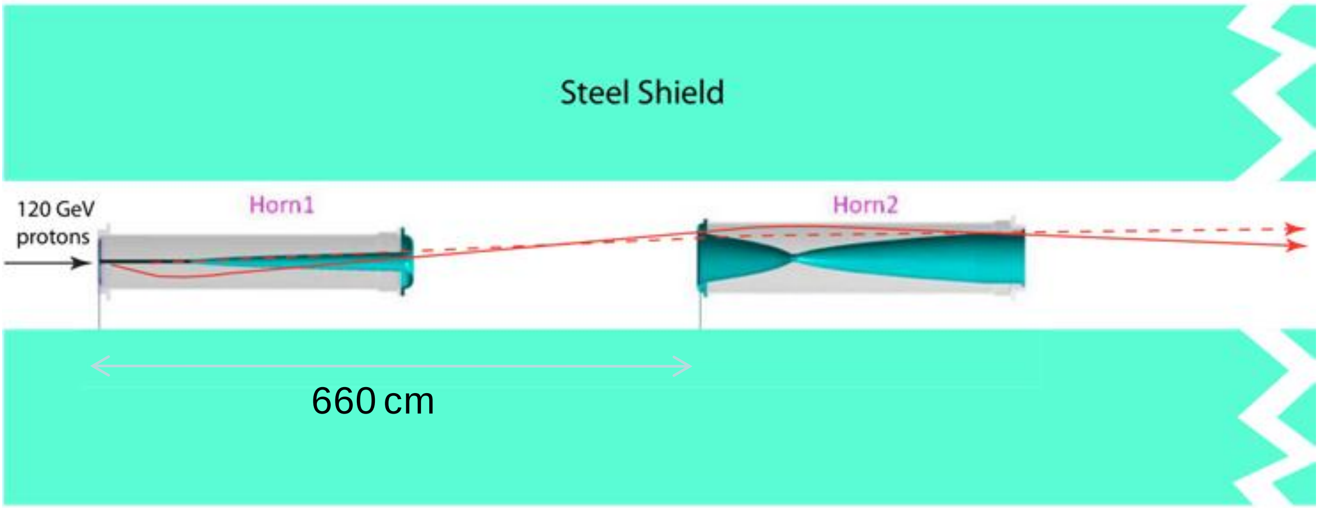
- Horn 1
  - Radius outer conductor: 30 cm
  - Radius inner conductor: 2.0 cm (neck), then parabolic
  - Length: 330 cm, neck: 100 cm
  - Current: 300 kA
- Horn 2
  - Radius outer conductor: 38 cm
  - Double paraboloid inner conductor
  - Length 353 cm
  - Current: 300 kA

Material: Al as default.
Be considered as well.

NUMI Horn 2

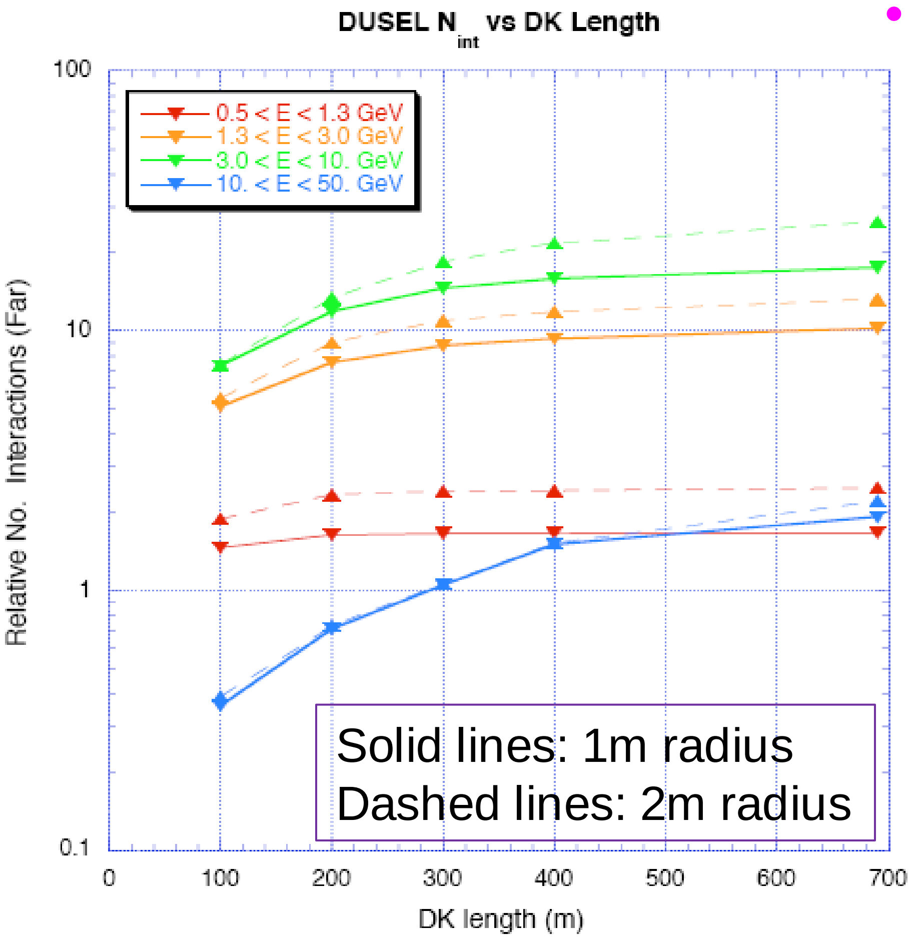
Target inserted/mounted into Horn 1.
Upstream end of target at -5 cm relative to the upstream face of Horn 1.

Plan View



Decay Pipe Considerations

Far Detector Neutrino Interactions vs Decay Pipe Length



Solid lines: 1m radius
Dashed lines: 2m radius

- Dimensions: Radius of 2m. Length of 200-250 meters.
- Filling-Cooling : Air – filled and air-cooled pipe is the default. Helium-filled pipe which is water cooled and sealed-off from the target hall is an alternative.

- ➢ In the deep option the decay region is within a tunnel excavated in rock.
- ➢ In the shallow option a substantial part of the decay region is in soil with limited rock excavation required.

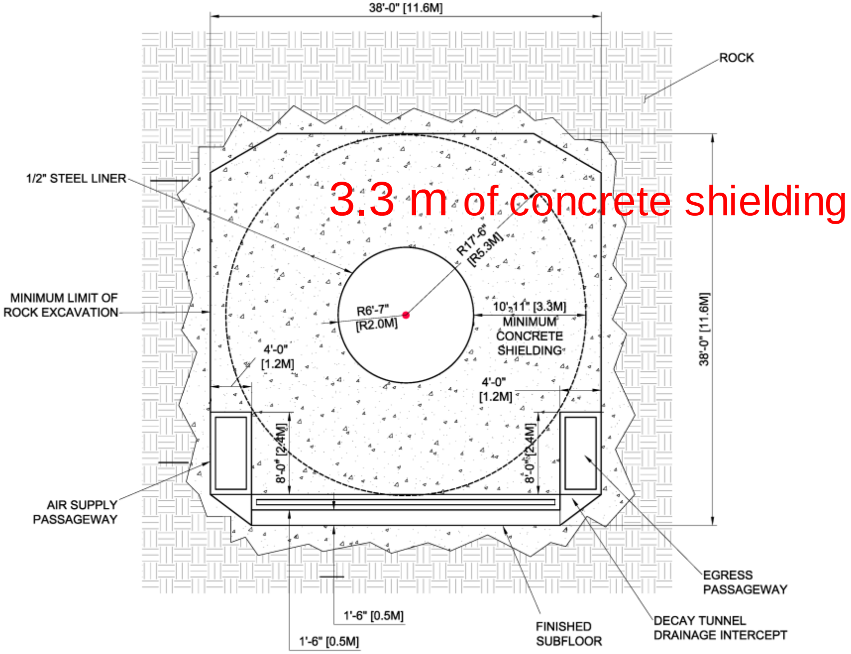
Two Radiological Models

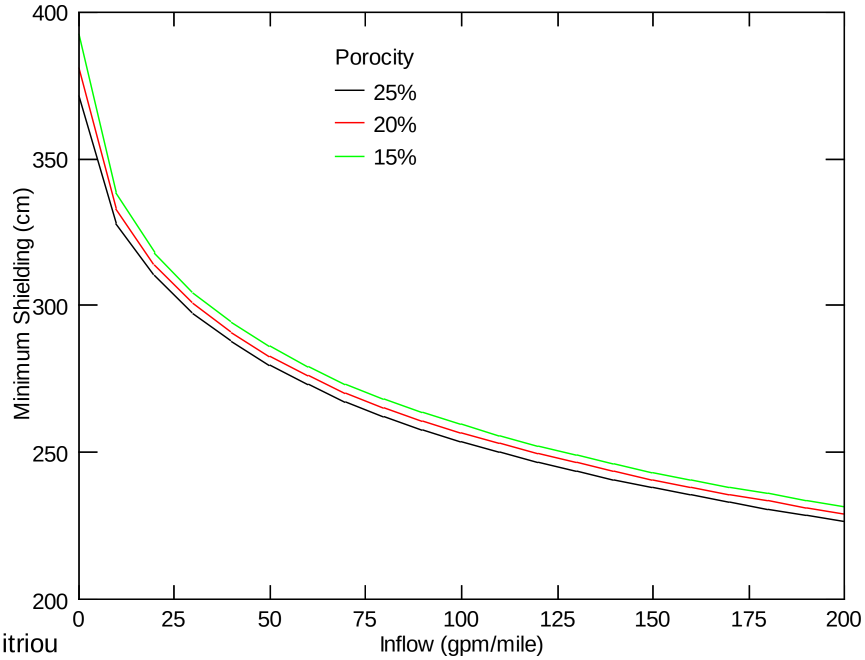
- In the deep design (NuMI like) groundwater is encouraged to migrate through the rock mass toward and into the decay region where it can be collected and transported away.
- In the shallow design, because of the presence of a local aquifer at and near the top of rock surface we cannot encourage groundwater to migrate toward and into the decay region (significant daily collection) and therefore we have to provide a hard barrier.

MI-60 Extraction, deep (Decay Pipe shield thickness)

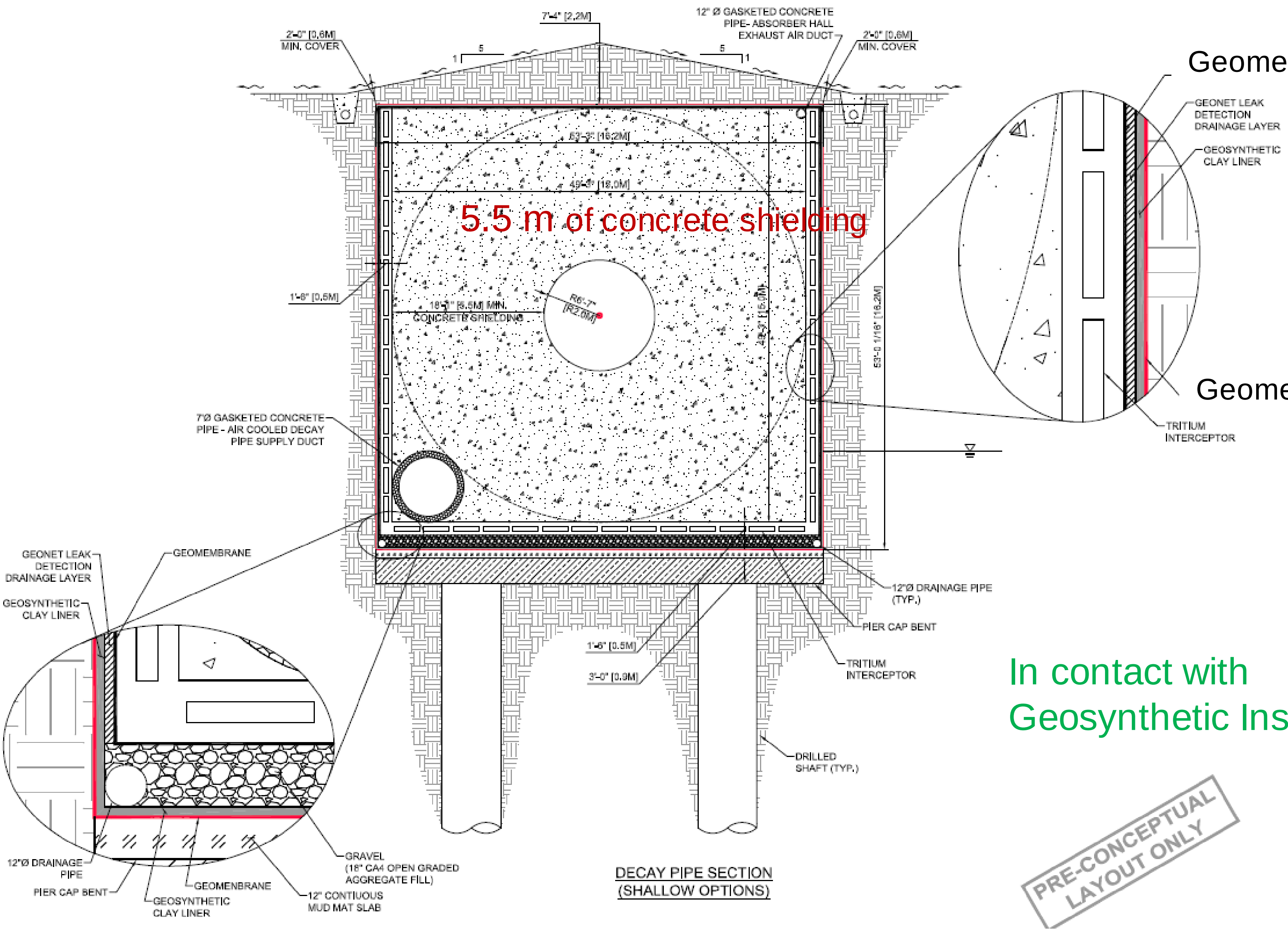
Inflow (gpm/mile)	15% (m)	20% (m)	25% (m)
0	3.93	3.81	3.72
10	3.38	3.33	3.28
30	3.04	3.01	2.97
130	2.49	2.47	2.44

Minimum shield thickness as a function of rock porocity and water inflow


3.3 m of concrete shielding



MI-10 Extraction, shallow (Decay Pipe Cross Section)



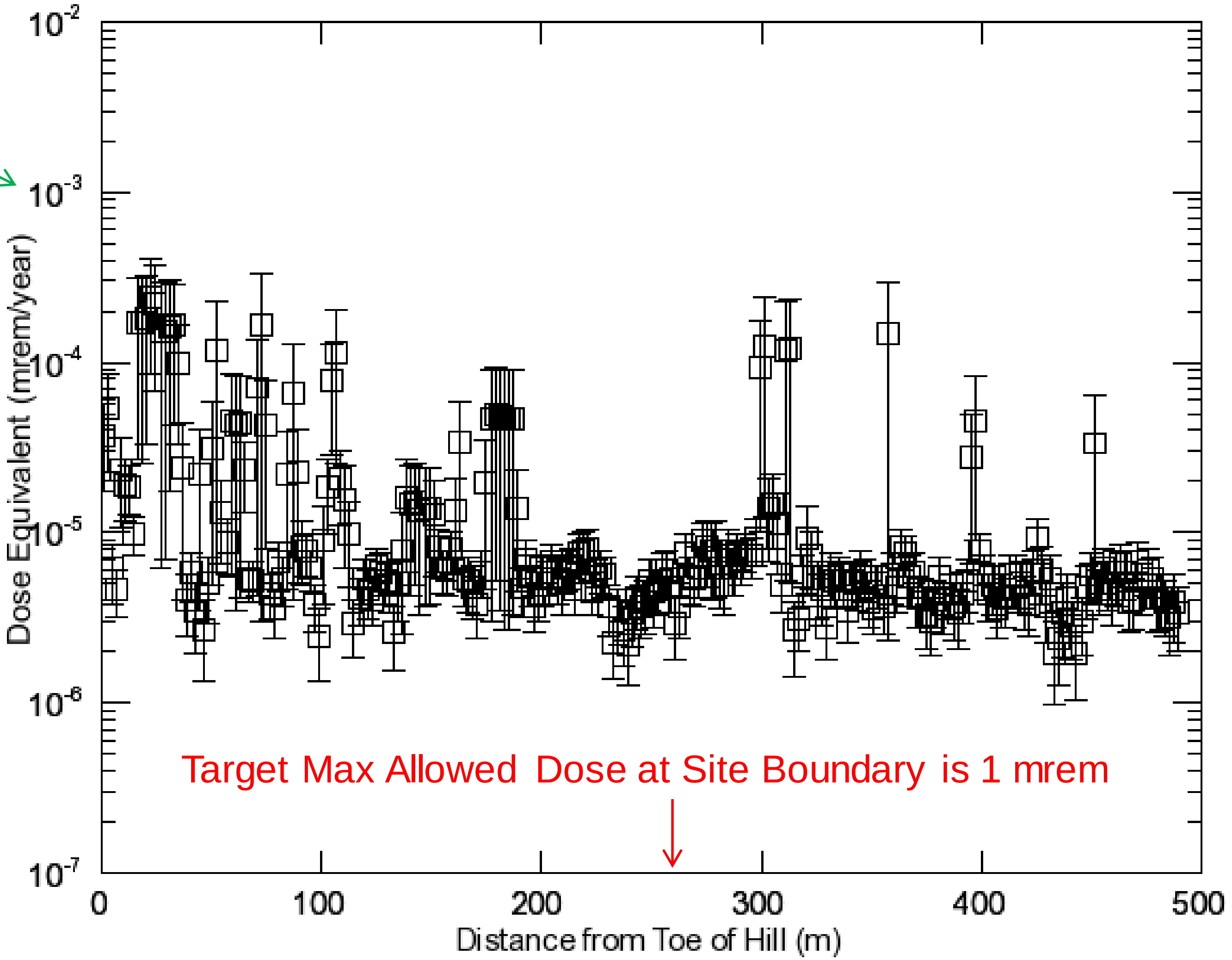
5.5 m of concrete shielding

DECAY PIPE SECTION
(SHALLOW OPTIONS)

In contact with Geosynthetic Institute

Direct Total Dose On-Axis from Decay Pipe MI-10 Extraction, Target above grade

1μrem



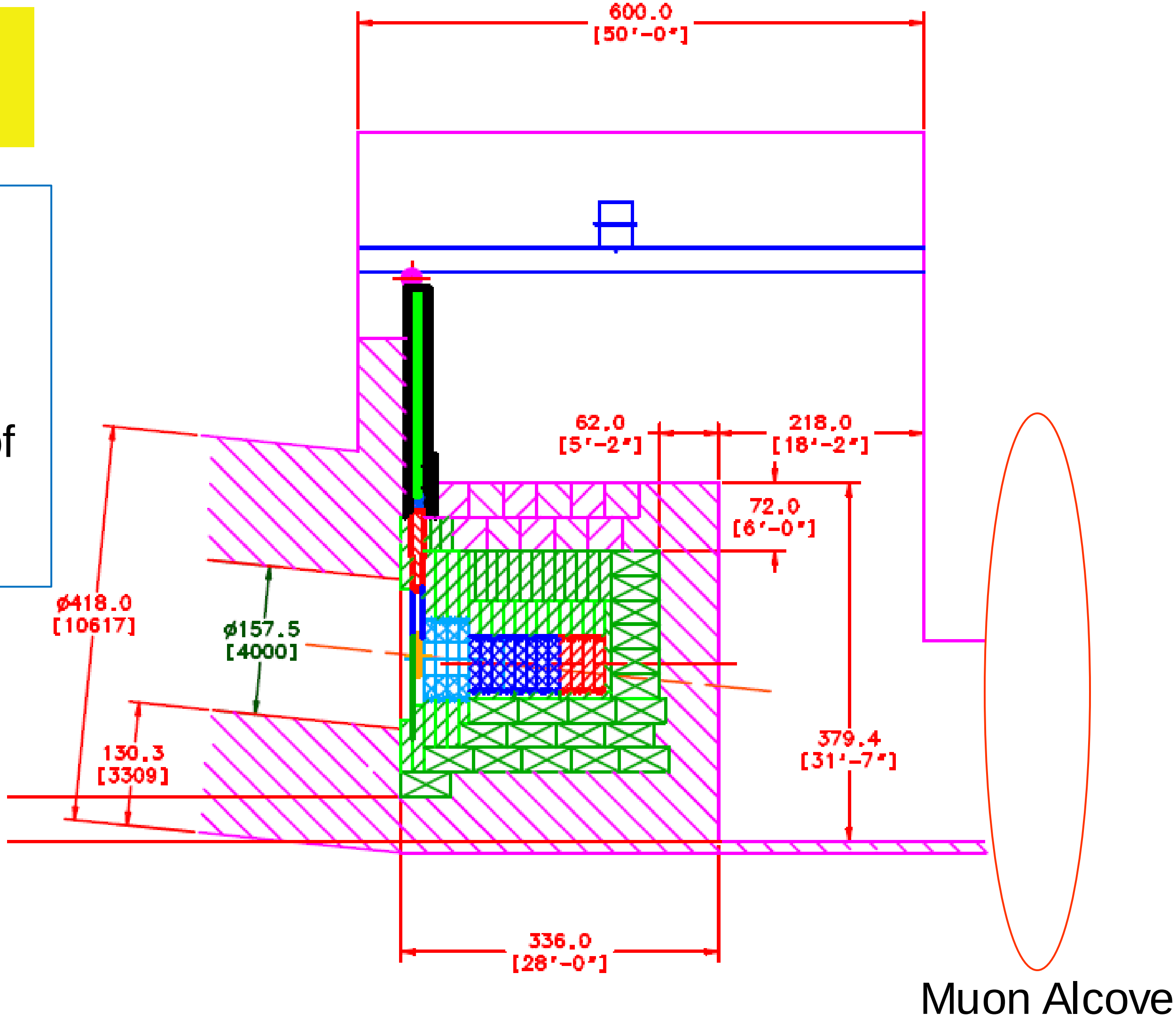
Target Max Allowed Dose at Site Boundary is 1 mrem

“0” = Downstream end of decay pipe

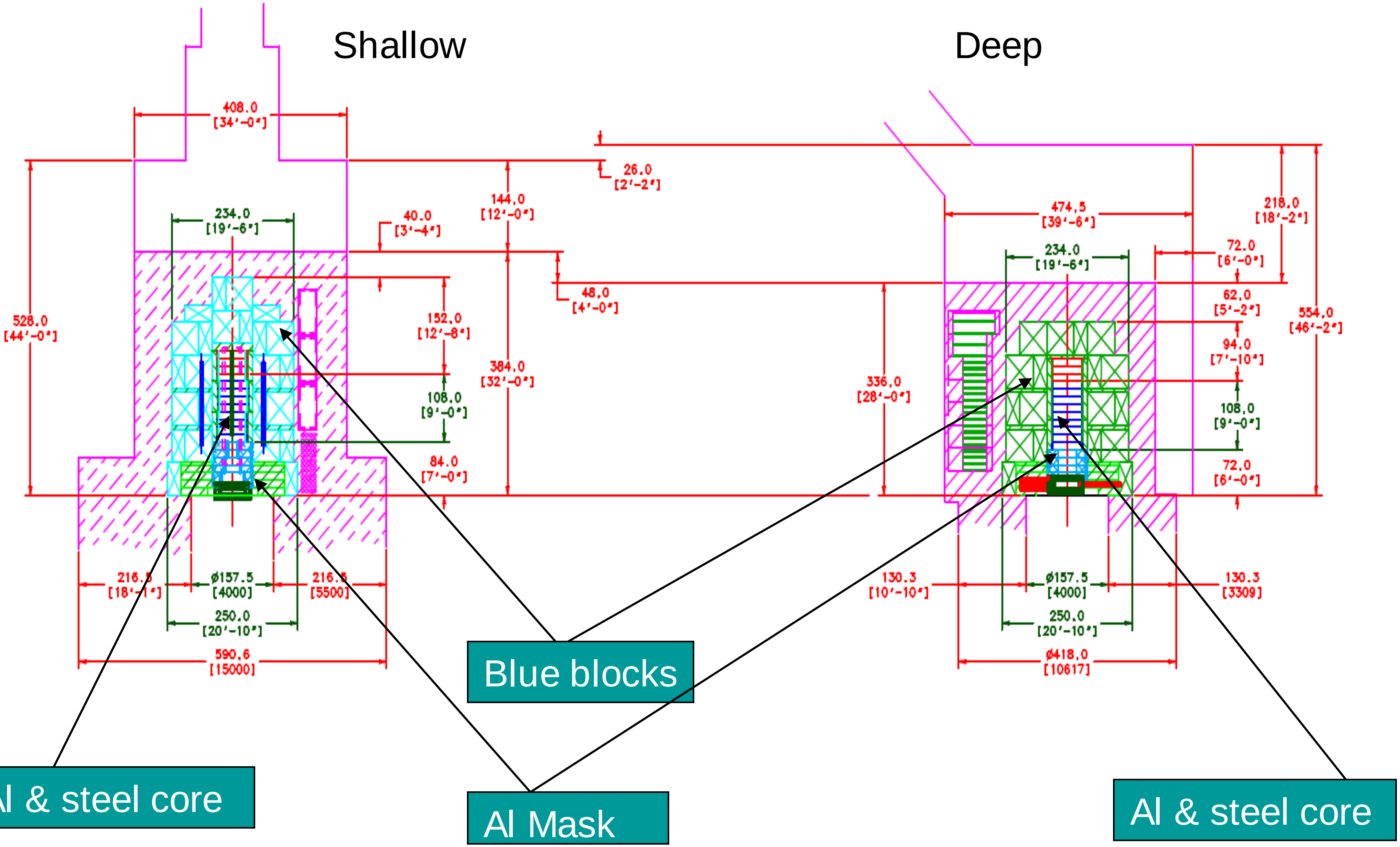
LBNE Absorber Hall (longitudinal section)

Conceptually designed for 2.3 MW

A specially designed pile of aluminum, steel and concrete blocks, some of them water cooled which must contain the energy of the particles that exit the Decay Pipe.



Comparison shallow vs deep



Shallow

Deep

Blue blocks

Al & steel core

Al Mask

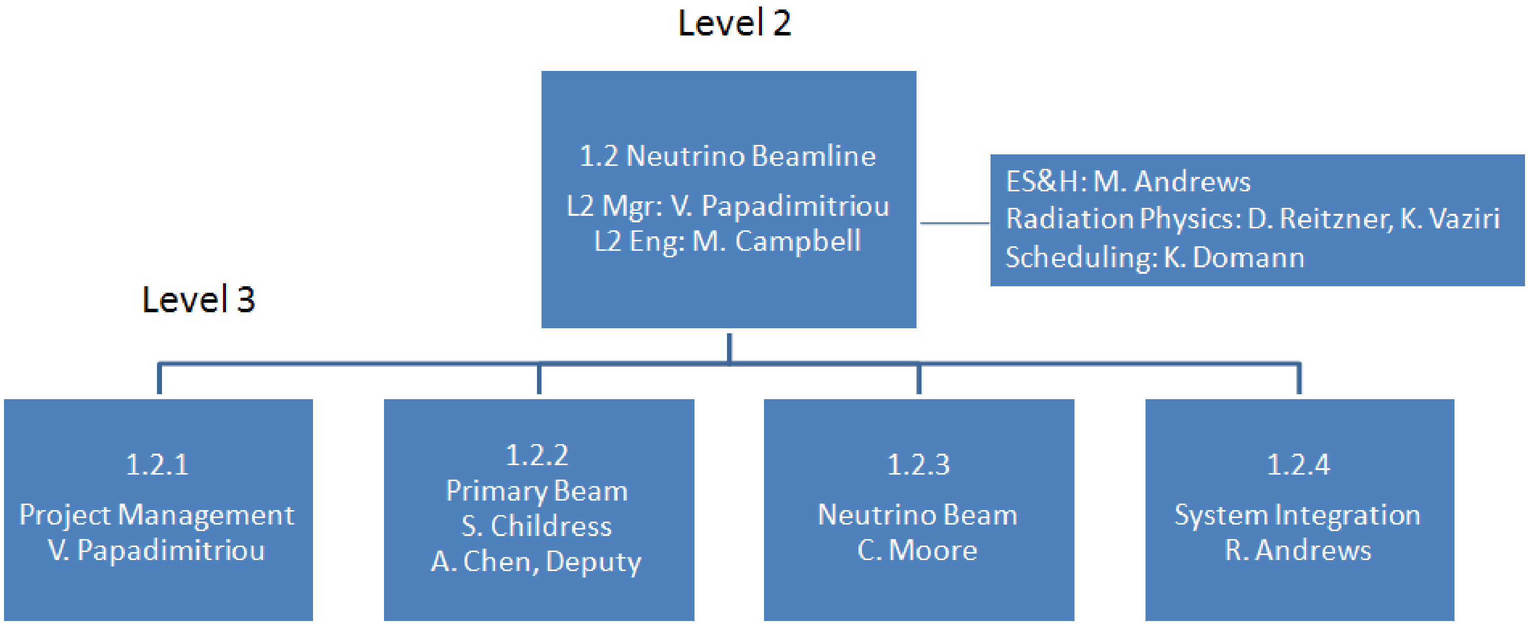
Al & steel core

Conclusion

- The LBNE Neutrino Beamline had a CDR and has been at a technical status suitable for CD-1 review since September 2010.
- Since then we developed and reviewed several value engineering proposals with the goal of reducing the beamline facility cost further.
- We have considered four “big picture” configurations and have developed two (new) reference designs.
- We are making very good progress in developing them towards CD-1 (Spring 2012).

Backup

Organization WBS 1.2



Level 2

1.2 Neutrino Beamline
L2 Mgr: V. Papadimitriou
L2 Eng: M. Campbell

ES&H: M. Andrews
Radiation Physics: D. Reitzner, K. Vaziri
Scheduling: K. Domann

Level 3

1.2.1
Project Management
V. Papadimitriou

1.2.2
Primary Beam
S. Childress
A. Chen, Deputy

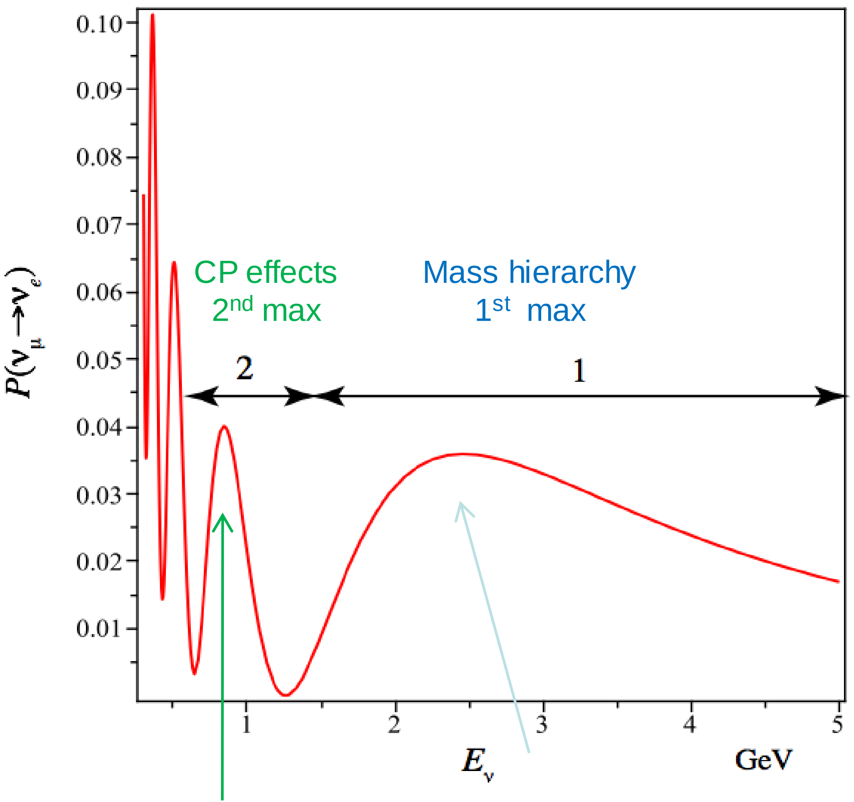
1.2.3
Neutrino Beam
C. Moore

1.2.4
System Integration
R. Andrews

The Neutrino Beamline Team

- From Fermilab's Accelerator, Particle Physics and Technical Divisions, FESS and Accelerator Physics Center.
- Also Collaborators/Contractors from ANL, BNL, IHEP (Protvino), RAL (UK), ORNL, Bartoszek Eng., Design Inovations, U. of Colorado

Beam Design Considerations



0.8 GeV

2.7 GeV

- Need a wide band beam to cover the 1st and 2nd oscillation maxima

Normal mass hierarchy

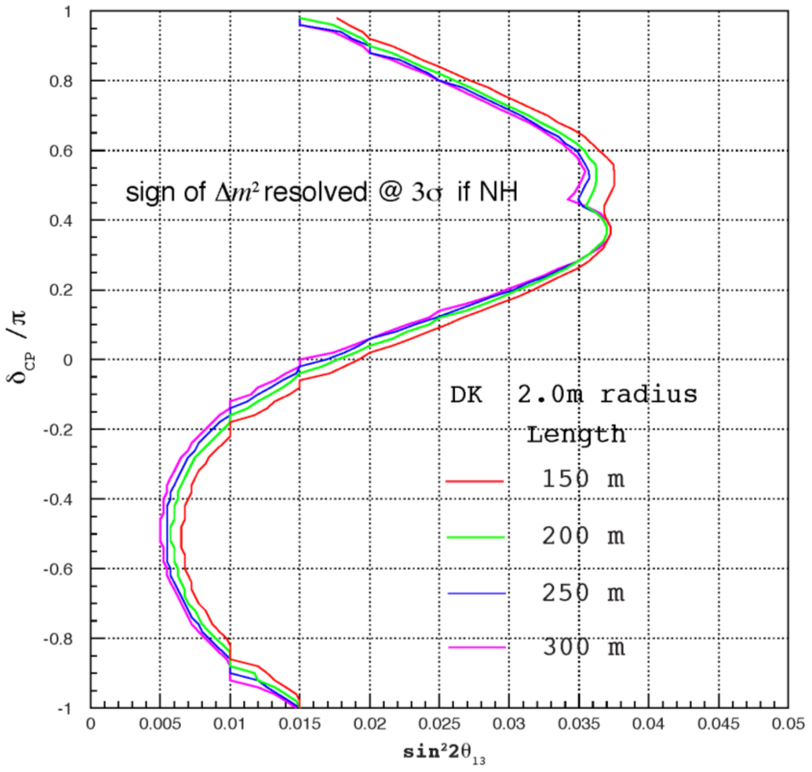
- Energies above 10 GeV not very useful

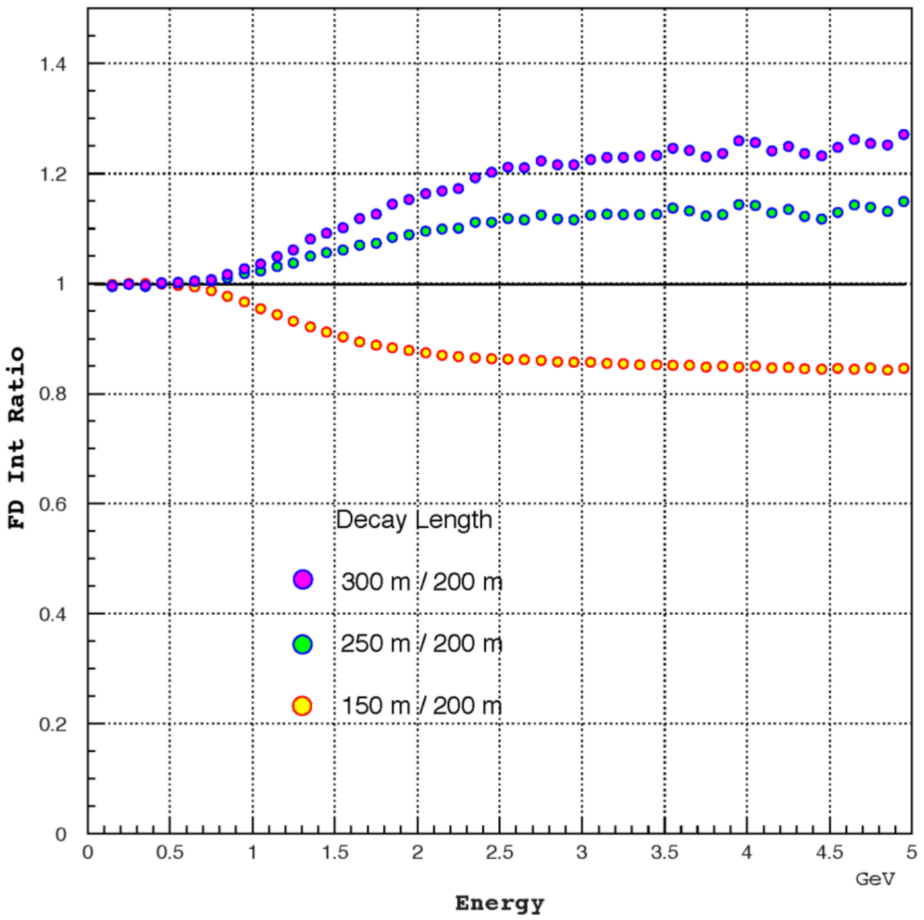
MI-60, deep

MI-60 deep is the original CDR design as modified by several VE proposals that include:

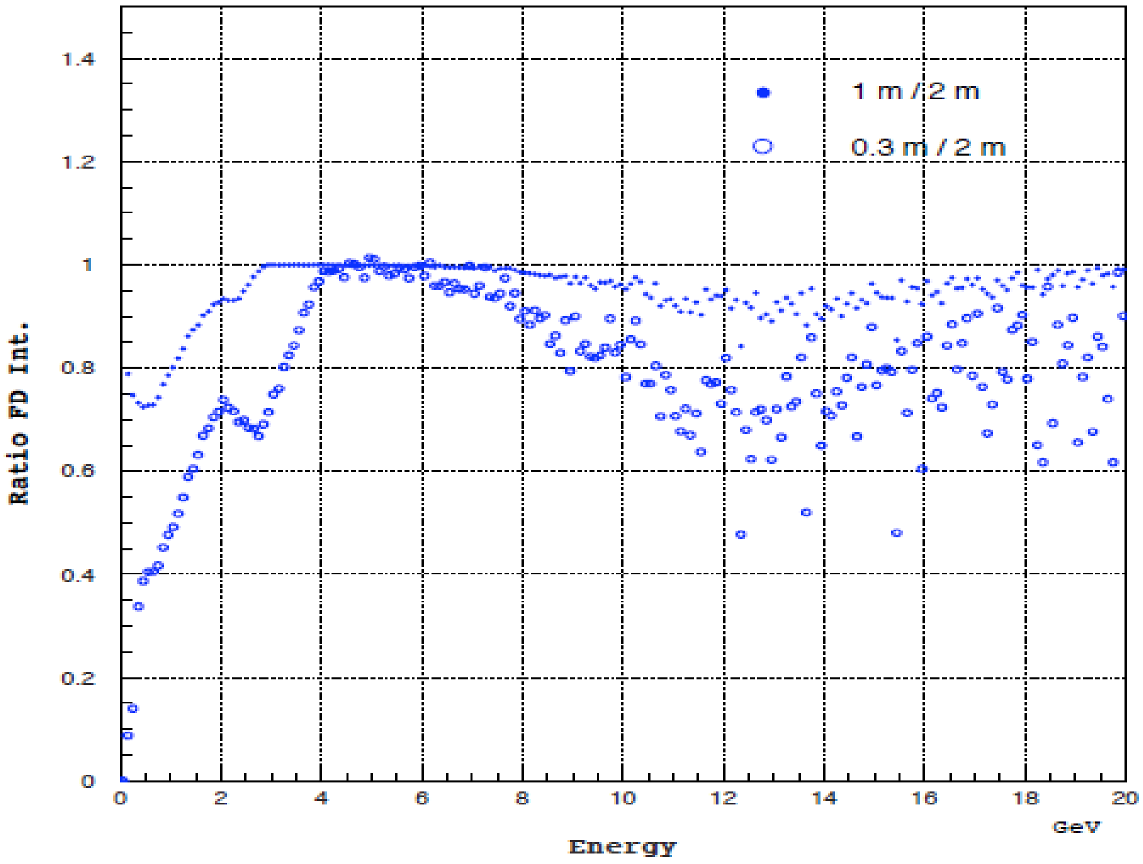
- Near detector hall and support room(s) size reduction and surface building size reduction
- Depth of ND shallower due to reduction of muon range out distance from 320m to 210m and due to reducing Decay Pipe length from 250m to 200m
- Omit a ND shaft and add a small diameter egress tunnel to the absorber hall
- Remote handling crane radiation hardened crane features reduced
- Reduce shaft diameters in target, absorber, and near detector complexes
- Eliminate Project X crossing enclosure
- Omit master substation upgrade
- Use Tevatron power supplies for the primary beam magnets

FD interactions vs Decay Pipe Length





FD interactions vs Decay Pipe radius



Accords, MOUs, SOWs, Contracts

- We established collaborations with ANL, BNL, IHEP (Russia), ORNL, RAL(UK), Bartoszek Eng., Design Inovations and made sure we have sufficient supervision and integration effort at Fermilab.

  - ✓ Accord with IHEP for the conceptual design of a 700 kW graphite target.
    - ○ Complete
  - ✓ MOU with ANL (2 MW target R&D) to investigate hydraulic shock in the cooling water (water hammer effect).
    - ○ Complete
  - ✓ MOU with BNL for a 9-week irradiation study at BLIP to investigate candidate target materials (started in March 2010).
    - ○ Run complete. Analysis in progress.

Accords, MOUs, SOWs, Contracts

- ✓Accord with RAL (700 kW/2 MW R&D) to: investigate Be as possible target material; cooling concepts; conceptual design for a beam window.
  - ○ Complete
- ✓ SOW with ORNL on remote handling issues.
  - ○ Complete
- ✓ SOW with Bartoszek Eng. on Baffle and Horn support structures.
  - ○ In progress.
- ✓ Contract with Design Inovations on magnet installation equipment.
  - ○ In progress.
- ✓ Expect to have MOU with University group(s) on target hall instrumentation after CD-1.

Be target R&D

700 kW Beam Power Target Summary

For 700 kW operation of a 13 mm diameter 1 m long beryllium cylinder fixed at one end and constrained radially at the other end with a 2.16 mm beam sigma falls inside the chosen design point stress. The maximum deflection for this case has been calculated as 0.6 mm near the centre of the target. A series of spheres could be significantly smaller at the 700 kW power level.

2.3 MW Beam Power target summary

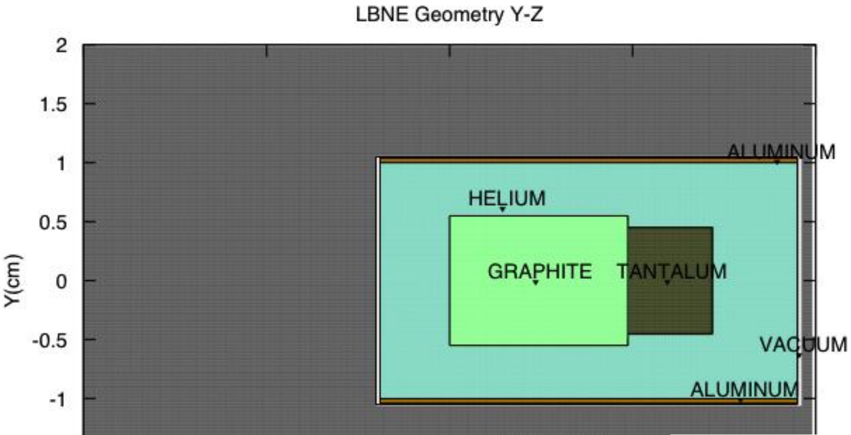
For 2.3 MW operation, a cylindrical rod beryllium target would have to be well above 21 mm in diameter in order to bring the peak dynamic stresses below the yield strength. The stress levels in the 2.3 MW cylinder are dominated by inertial effects in the form of both longitudinally stress waves and bending stresses induced by an off centre beam. The figure shows that the stress in a series of spheres with the 2.3 MW beam can be kept below the design point with spheres of 13 mm diameter. This result indicates the advantage of longitudinally segmenting the target.

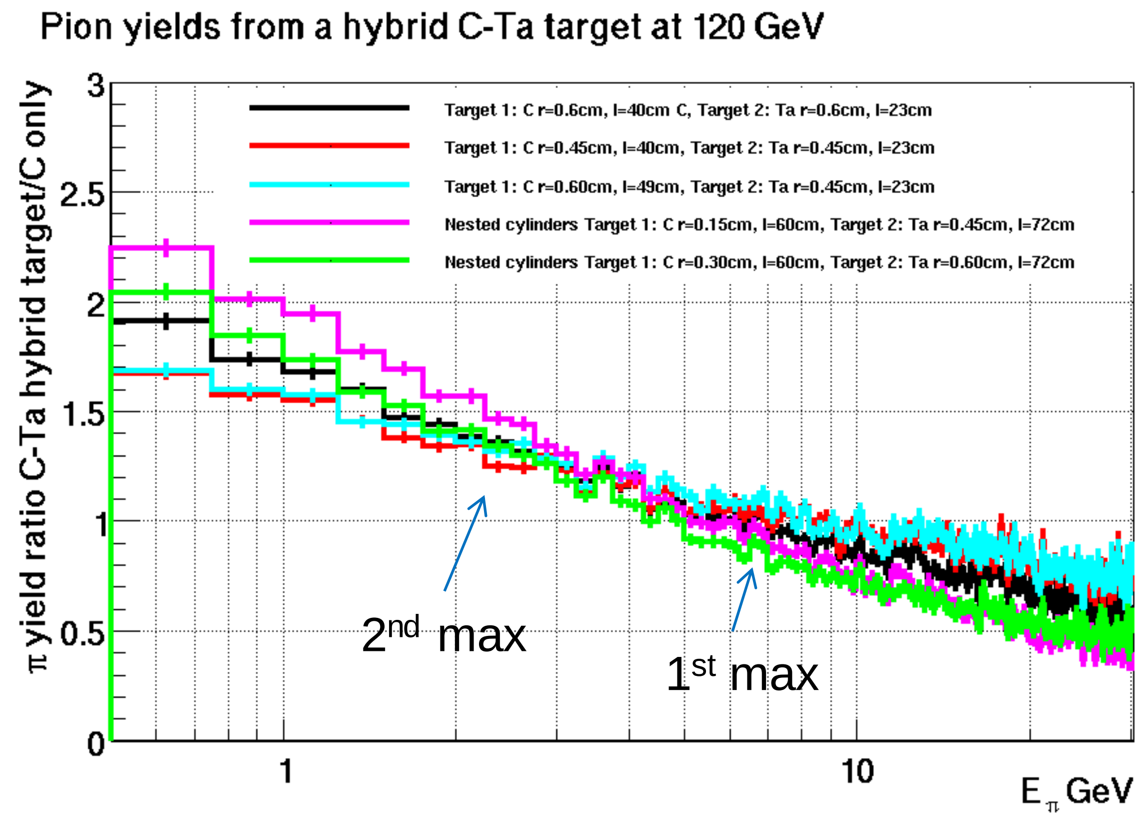
Graphite R&D

- Why Graphite?
  - – Excellent for thermal shock effects (lower Cp, lower CTE, very low E, high strength at high temperatures)
  - – Not toxic
  - – Not dual-use (normal/nuclear) technology (not export controlled)
  - – Readily available in many grades and forms
- Why not Graphite?
  - – Rapid oxidation at high temperatures
  - – Radiation damage

Hybrid Targets

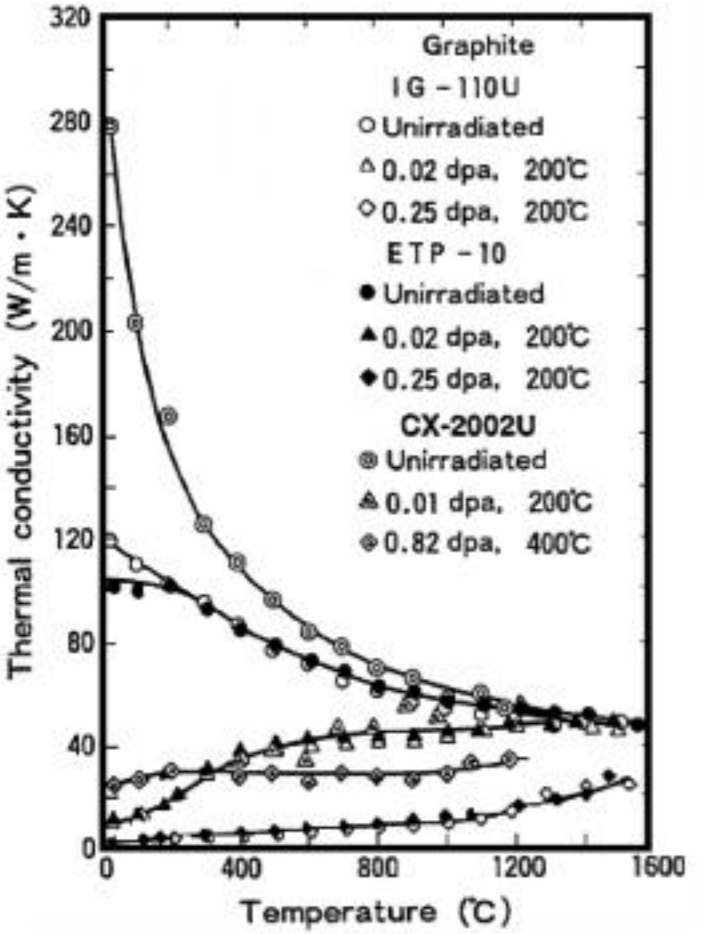
M. Bishai, Yi Lu (Highschool)



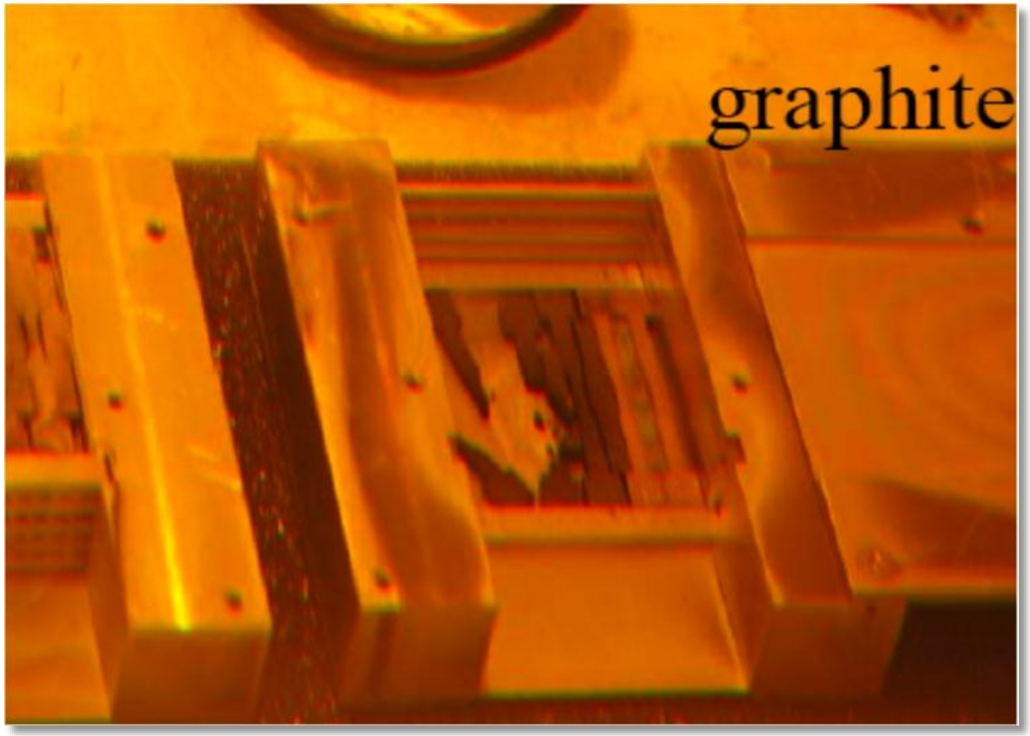


Using hybrid targets, the pion yield at the 2nd maximum can be increased by 50% without changing the pion yield at the 1st maximum. The high energy pion yield can be also reduced by > 50%.

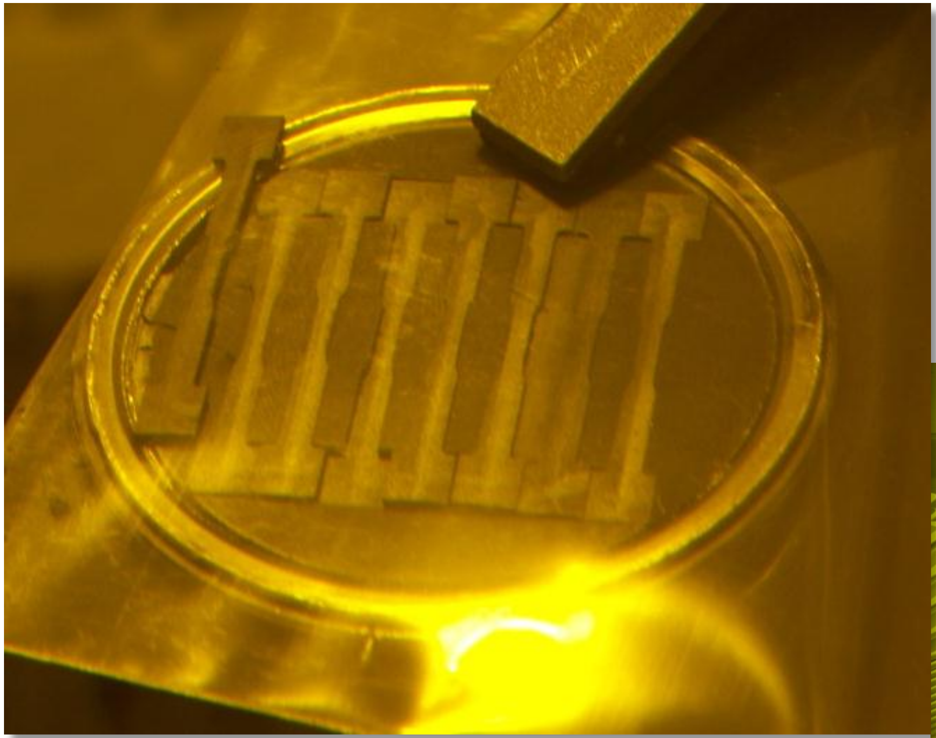
Graphite R&D: Radiation Damage



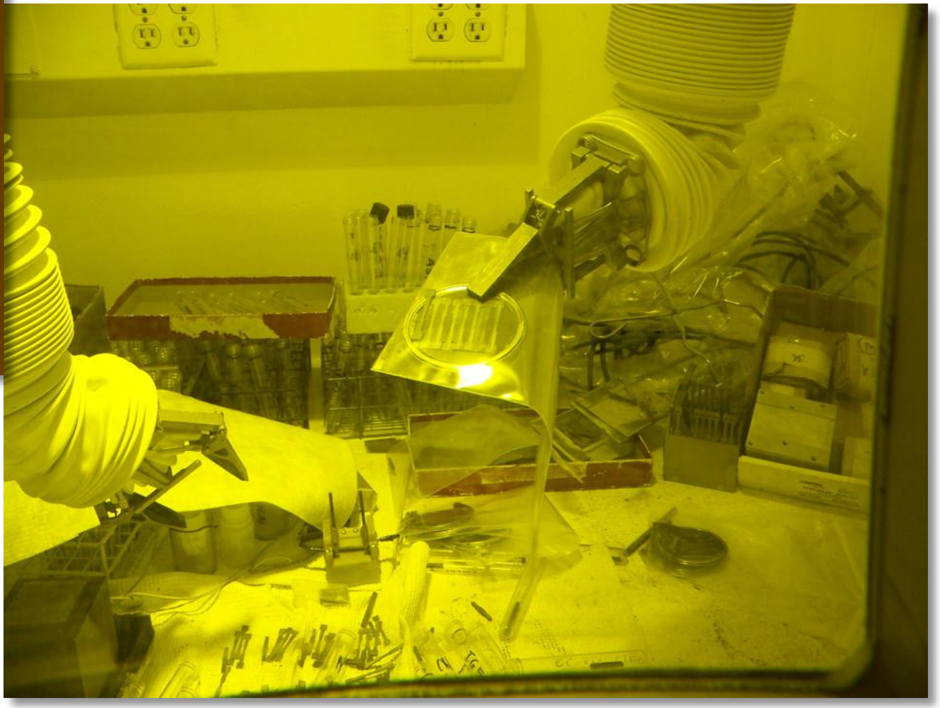
- Rapid degradation of properties at relatively low levels of DPA
- Evidence of complete structural failure at 1e21 p/cm^2 (BLIP test)



Irradiation Testing at BLIP



- About 150 samples in total
- Tensile samples have gauge width of 3 mm and thickness of 1 mm



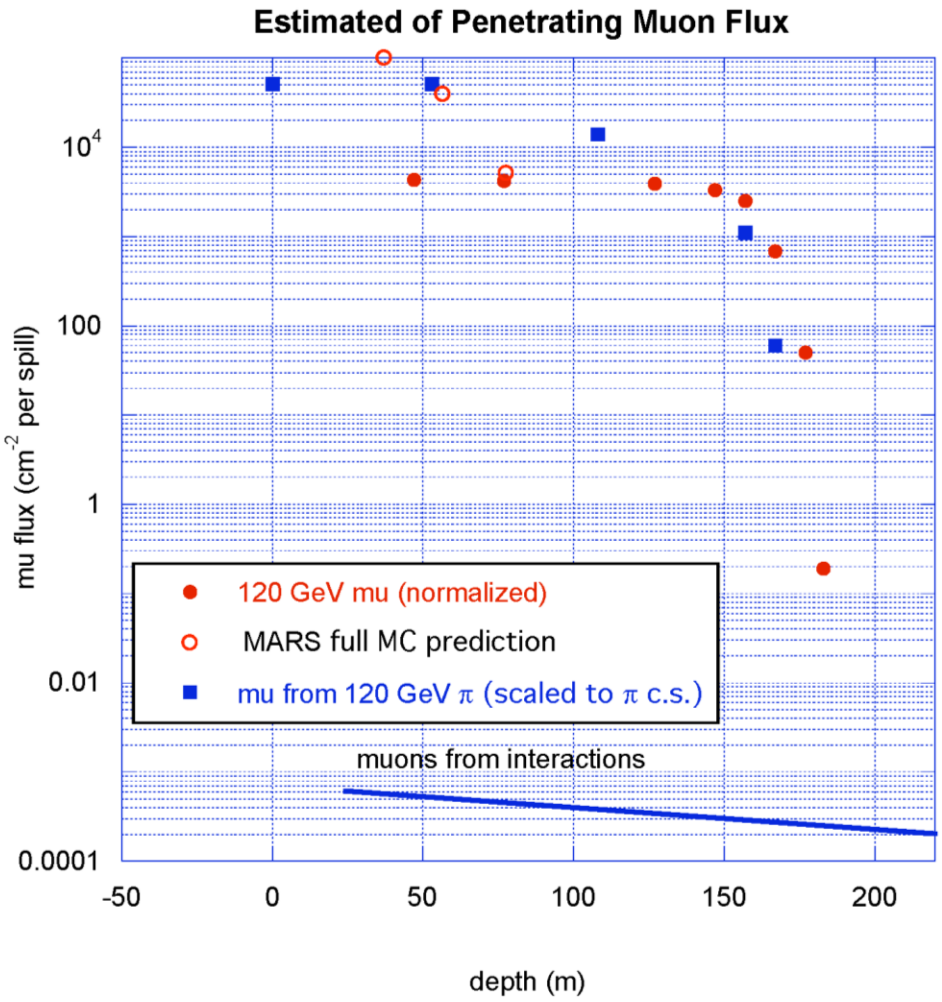
- ☐ 181 MeV proton beam
- ☐ Peak integrated flux about 5.9e20 proton/cm^2
- ☐ Average over 1 sigma area about 4.6e20 proton/cm^2

Absorber Requirements

- Absorber requirements - short list
  - Designed for 2.3 MW beam power, 20 years
  - Normal operation: 540 kW in absorber
  - Dealing with 2.3-MW (~3-MJ for accident) beam energy deposition in the absorber components.
  - Water and air radiation protection
- Absorber Configurations (4 configurations):
  - MI60 deep
  - MI10 target above grade (shallow)
  - Decay Pipe length:
    - 250 m – normal operation
    - 200 m - energy deposition increases by ~ 8-10%
  - Practically two options of the absorber mask & core, deep (250 m DP) and shallow (200 m DP)

Muon range out

B. Lundberg

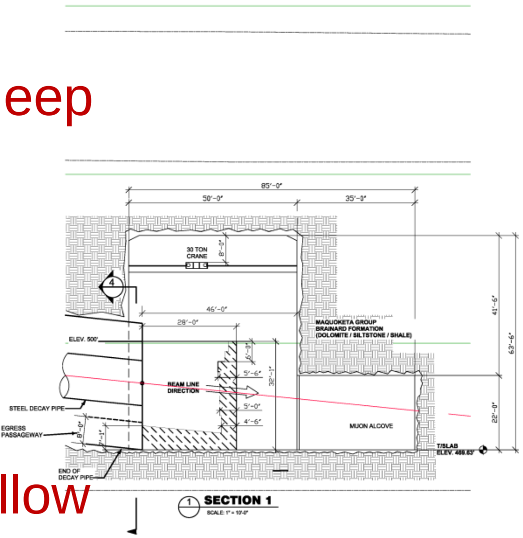


Trend (rapid fall-off) is clear, but need to extrapolate orders of magnitude to reach intrinsic background of neutrino-rock interactions

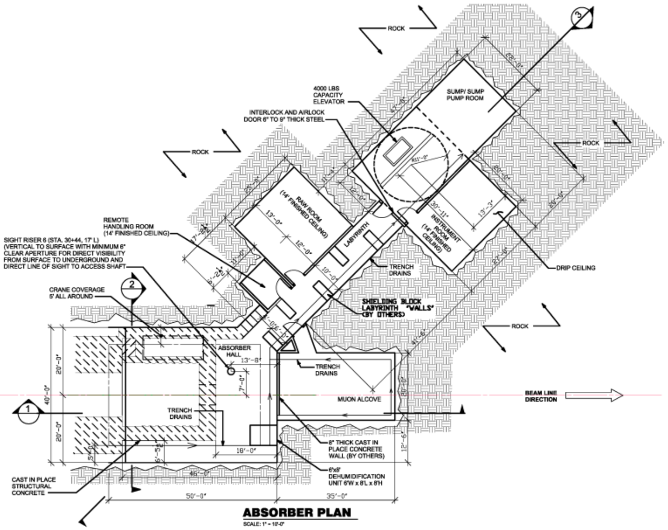
> 200 m of rock required between End of absorber and ND at 120 GeV

Absorber Hall configuration

MI-60, deep

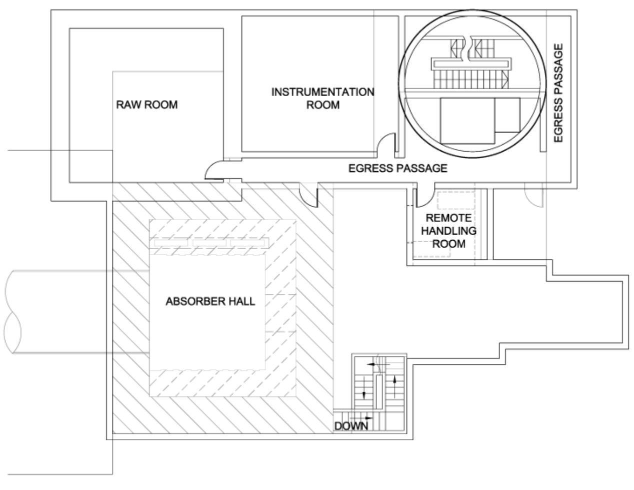


SECTION 1
SCALE: 1" = 10'-0"

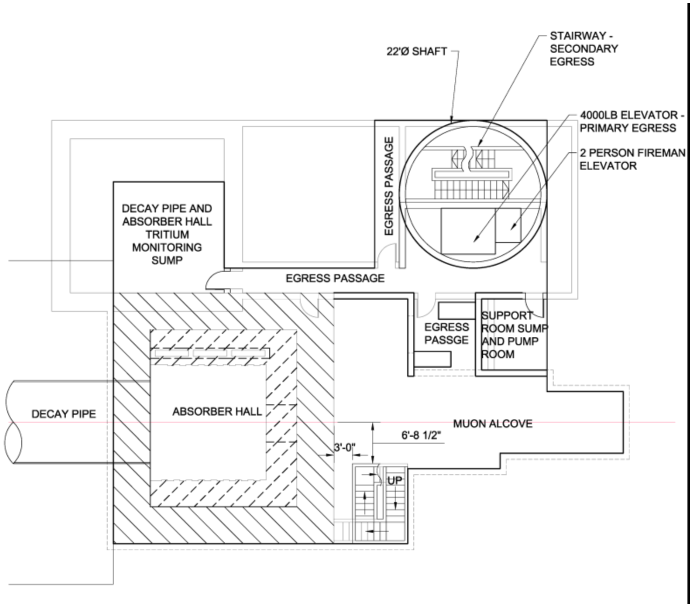


ABSORBER PLAN
SCALE: 1" = 10'-0"

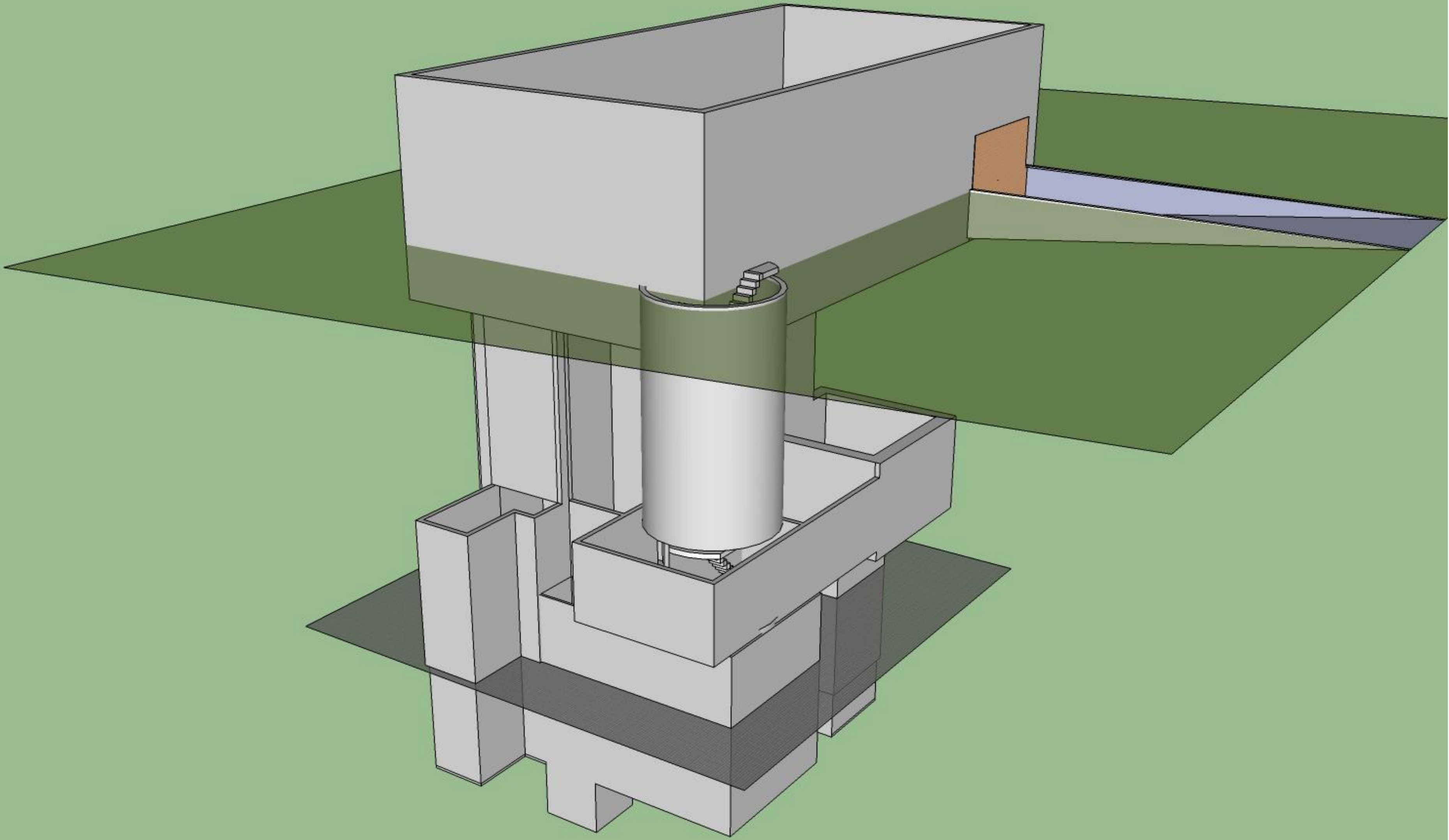
MI-10, shallow



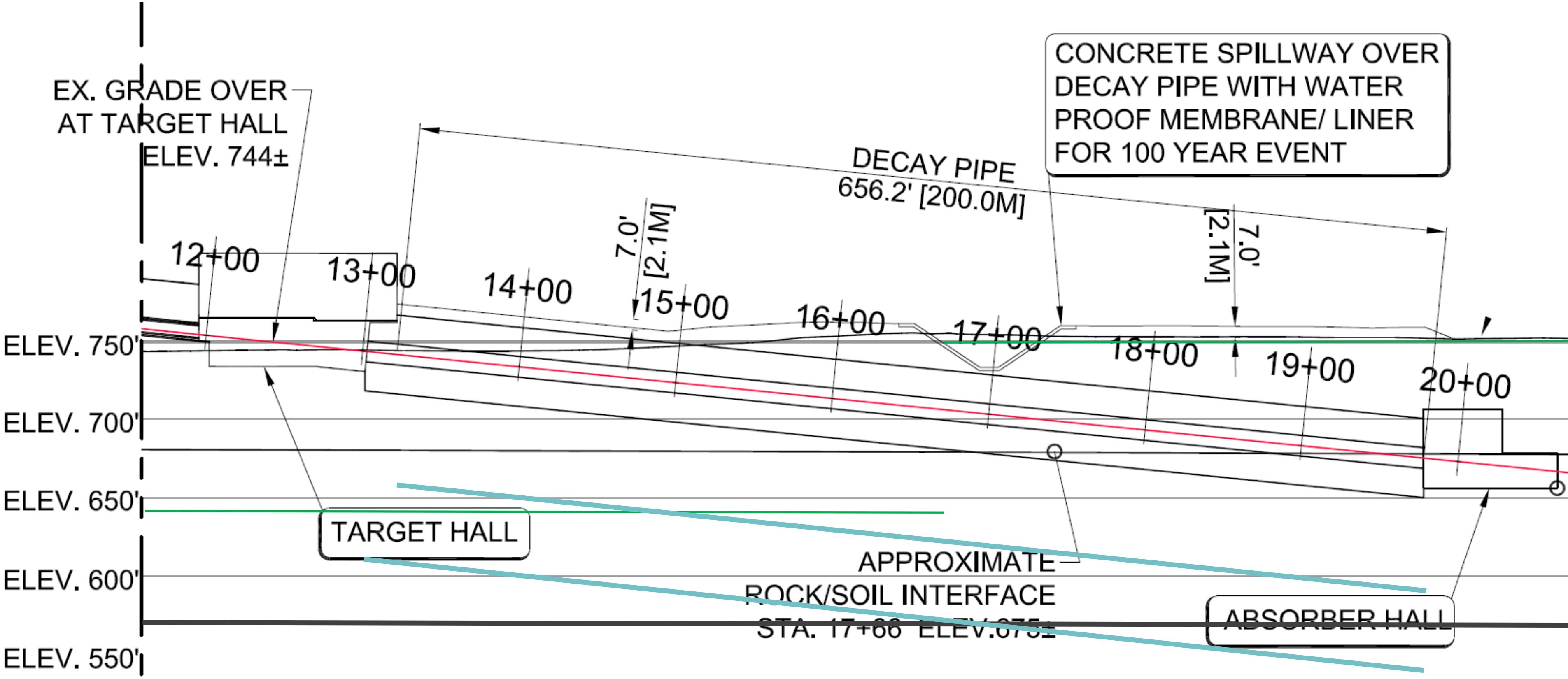
FLOOR PLAN
UPPER LEVEL - SUPPORT ROOM
(IN GLACIAL TILL)



FLOOR PLAN
LOWER LEVEL - ABSORBER HALL, MUON ALCOVE
(IN ROCK)



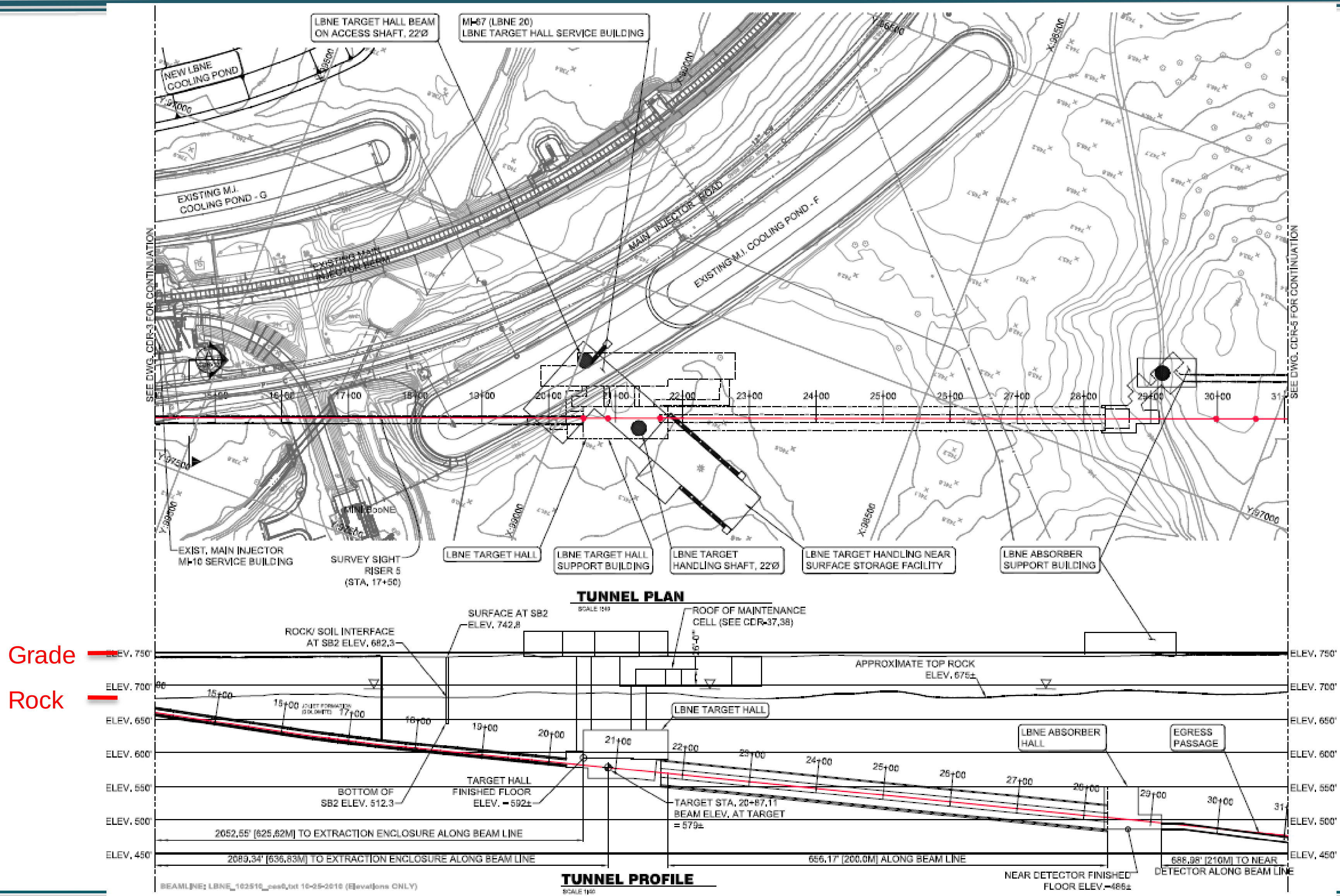
Decay Pipe Location (MI-10, shallow)



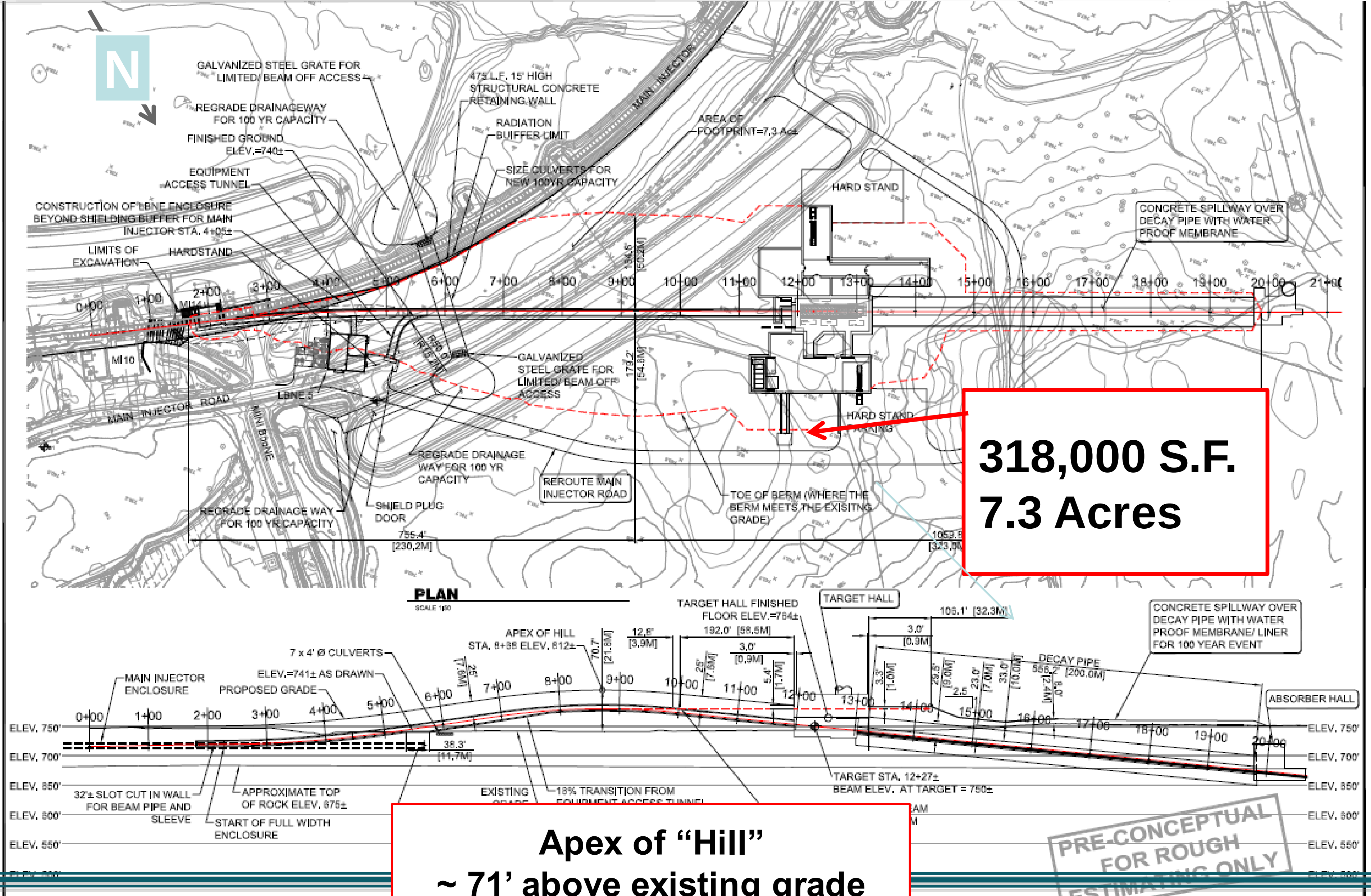
Weathered rock/aquifer/radiological issues (geomebranes, etc.).

Some of the tritium mitigation aspects less complicated, nevertheless no previous experience like in the NuMI case

Conventional Facilities Overview
Beamline MI-60 deep



MI-10 Extraction, shallow (top and elevation views)



318,000 S.F.

7.3 Acres

Apex of "Hill"

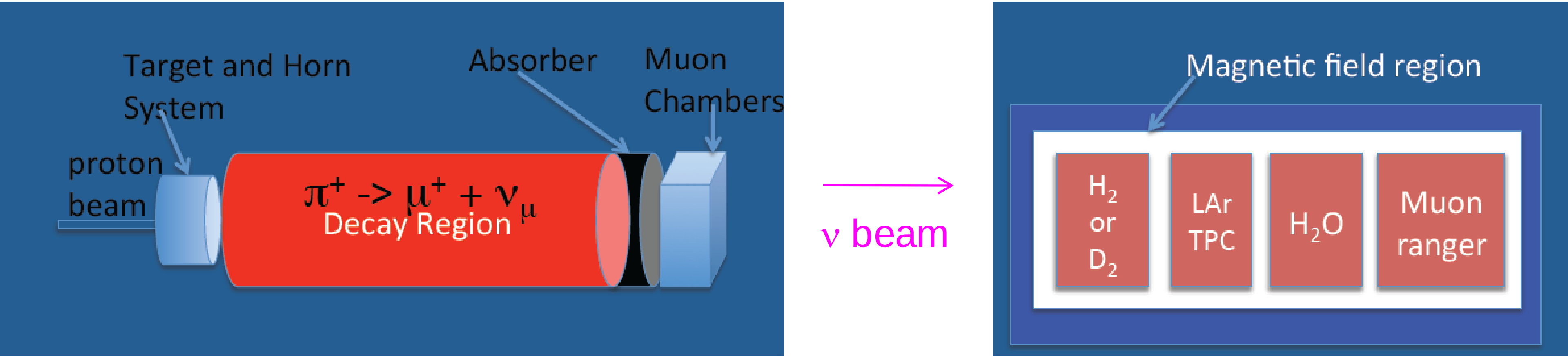
~ 71' above existing grade

Near Detector

Goal of Near Detector

- Measure neutrino flux (ν_e, $\bar{\nu}_e$, ν_μ, $\bar{\nu}_\mu$) vs energy
- Measure neutrino cross sections vs energy (CC, NCπ^0, NCγ, NC DIS, etc.) in H2O and Ar
- Determine extrapolation of events from near detector to far detector
- Make physics measurements of interest in their own right (e.g. $\sin^2\theta_W$, Δs, sterile ν decay, high Δm^2 oscillations, etc.)

Near Detector Hall: ~ 400 ft underground, ~ 112 ft long x 44 ft wide x 45 ft high



Evaluating

Main Options

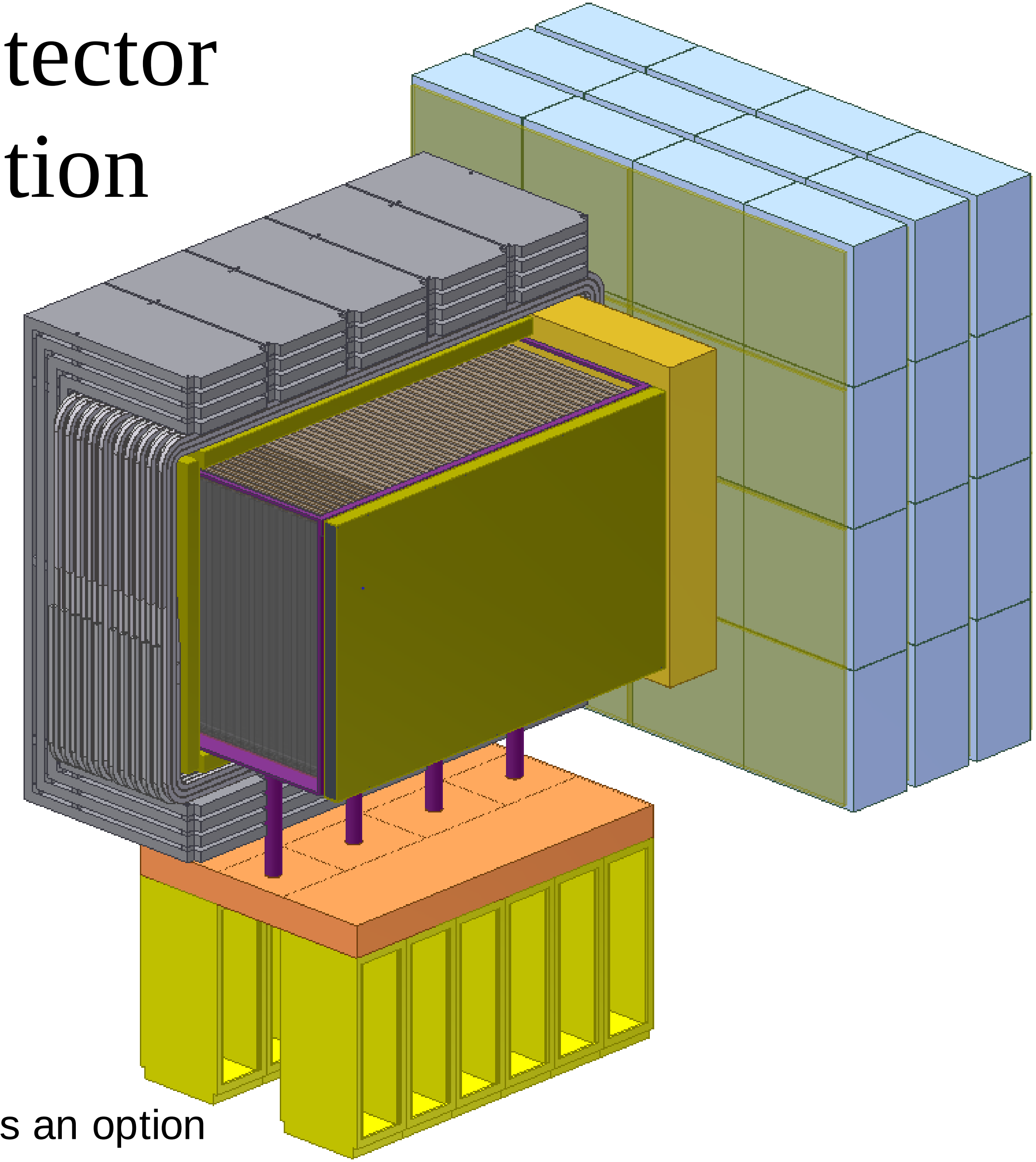
- H2 or D2 Bubble Chamber or Target (Measure events at Q^2~0 and determine ν flux)
- LAr Detector (MicroBooNE or ArgoNeuT or LANNDD Design)
- Fine-Grained H2O Tracker (MINERvA/MINOS or HiResMν)

Alternative Options

- Small H2O Cherenkov Detector (flat PMTs)?
- Large Offsite H2O Cherenkov Detector (~1 kton)?

Neutrino Detector – water option

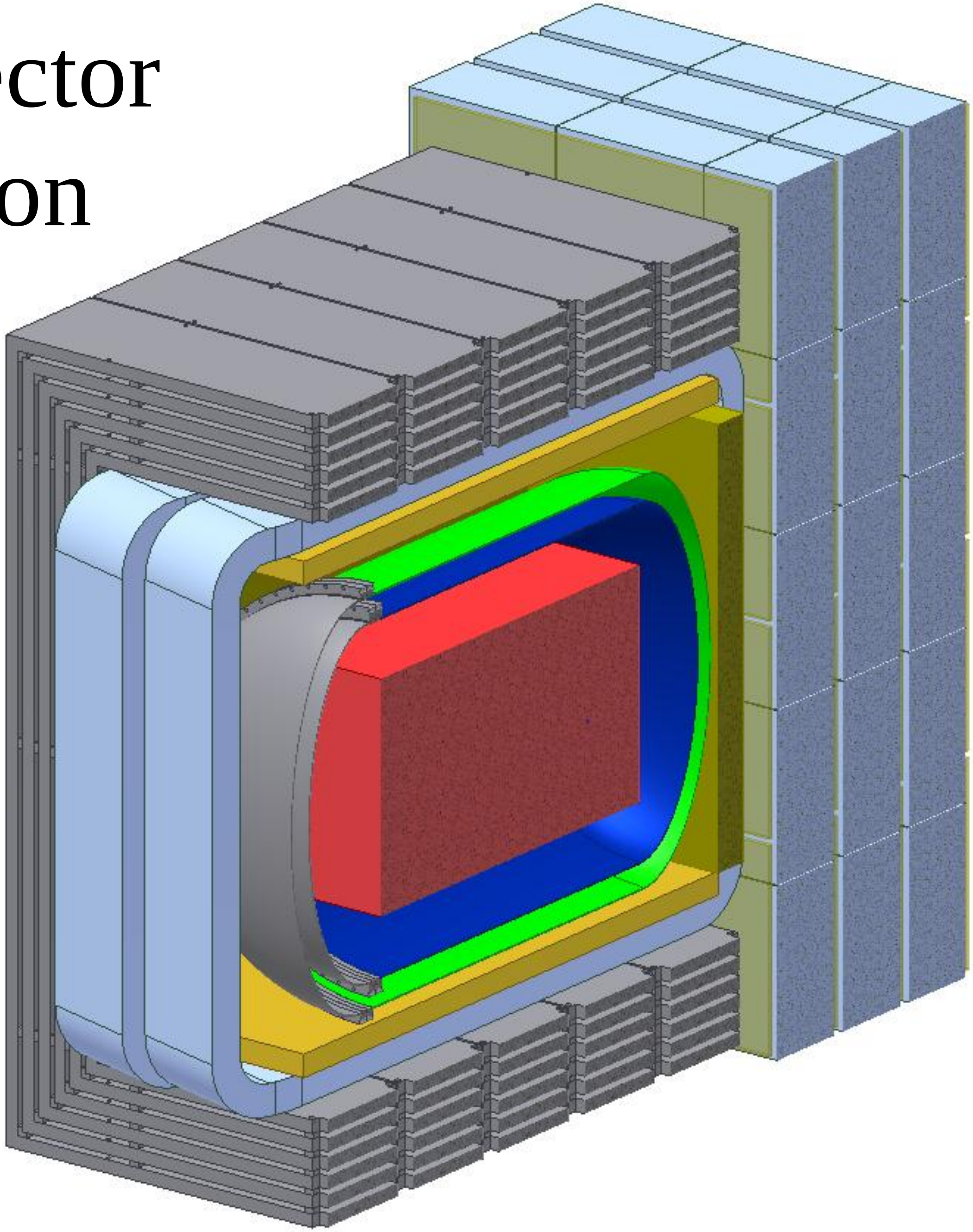
- Magnet
  - 3m x 3m x 5m volume
  - 0.4 Tesla
- Tracker
  - 2cm straws
  - 237cm length
  - 30 XY modules
    - 20 with water targets
- ECal
  - Scintillator
    - 5mm x 50mm profile
    - arranged x and y
  - Lead sheets barrel/upstream
    - 3mm thick
    - 16 sheets
  - Lead sheets downstream
    - 1.75 mm thick
    - 60 sheets
- Muon ID
  - RPCs interleaved in magnet barrel
  - Downstream muon identifier RPCs and ``blue blocks''



Scintillator tracker is kept as an option

Neutrino Detector – argon option

- Magnet
  - 4m x 4m x 5m volume
  - 0.4 Tesla
- Tracker
  - MicroBooNE-like
  - 1.8m x 1.8m x 3.0m TPC
- ECal
  - Scintillator
    - 5mm x 50mm profile
    - arranged x and y
  - Lead sheets barrel
    - 3mm thick
    - 16 sheets
  - Lead sheets downstream
    - 1.75 mm thick
    - 60 sheets
- Muon ID
  - RPCs interleaved in magnet barrel
  - Downstream muon identifier RPCs and ``blue blocks''



Beam Line Muon Measurements

From G. Mills

- Provide pulse-by-pulse monitoring of tertiary muon beam to check beam line performance

- Measure muon spectrum after the absorber pile in an effort to constrain neutrino flux

- Separation of positive and negative muons

- Would like to measure muons coming from the decay region down to ~ 2-4 GeV/c or lower

Three-fold Strategy

- Muon Ion Chamber Array
  - spatial distribution of muon flux for primary beam monitoring and flux cross checks
  - Pulse-by-pulse muon rate measurements
- Stopped muon detectors
  - Uses range of muons to measure spectrum and separation of positive and negative muons
  - Detect muon decays via Cherenkov light (positive muons)
  - Detect negative muon captures via ^{12}B ground state decays
- Pressurized threshold Cherenkov counters
  - Measure spectrum down 2-4 GeV (??) (decay pipe)
  - Could be used in a few locations where the absorber is modified for this purpose (absorber design still in flux)