Status of the LBNE Beamline

Vaia Papadimitriou
Accelerator Division Headquarters, Fermilab
L2 Manager for the LBNE Neutrino Beamline

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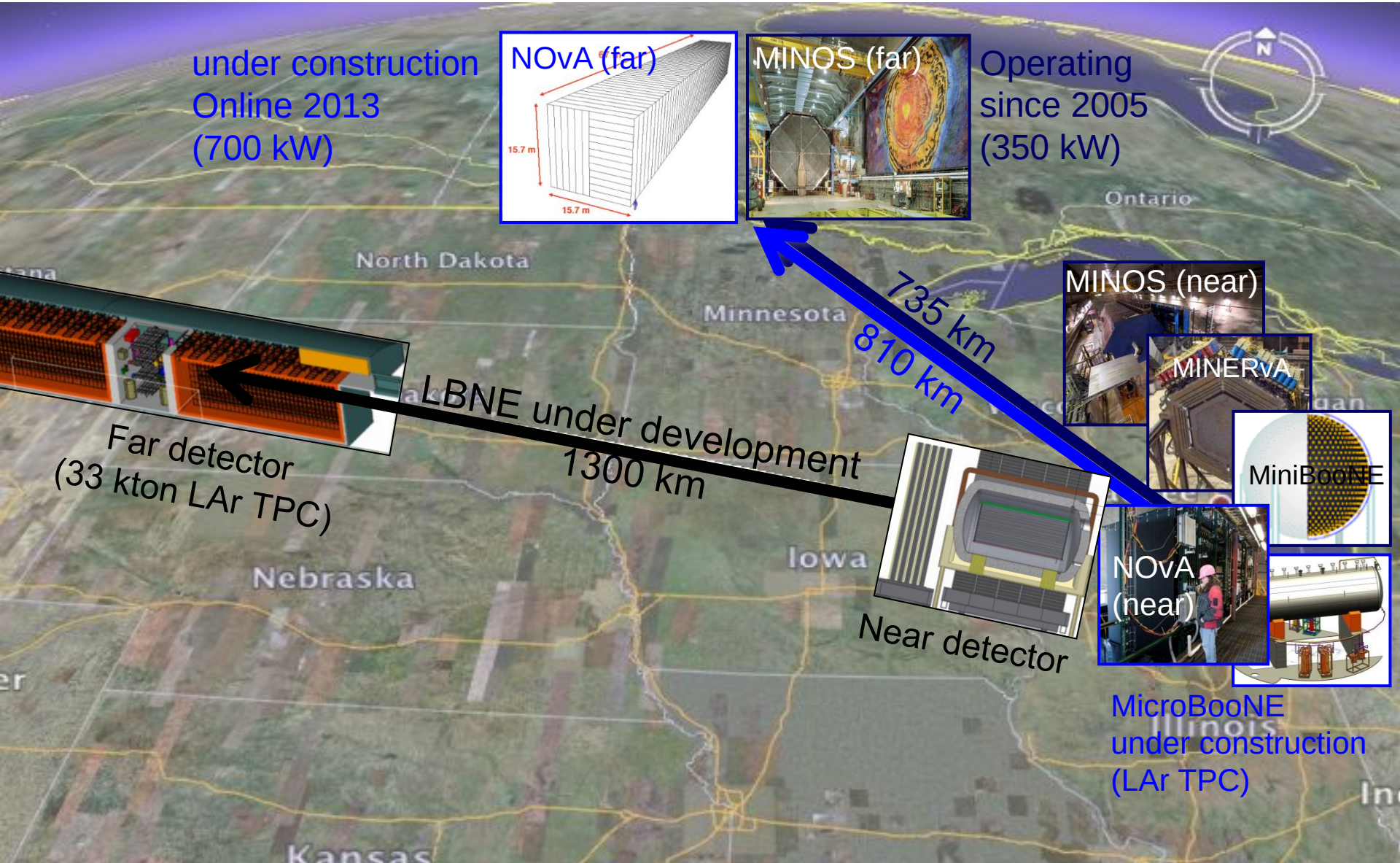
Outline

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

Neutrino Program at Fermilab



Milestones

- Critical Decision 0 (CD0) approved – January 2010
- Fermilab Director's Review towards CD1 – March 2012 (very successful)
- Letter from B.Brinkman (Director of Office of Science) to P. Oddone (Fermilab Director) asking Fermilab to lead the development of an affordable phased approach for LBNE since projected peak costs of reference design cannot be accommodated in current budget climate. Alternatives to be considered as well – March 2012
- Steering Committee and Working Groups established, LBNE reconfiguration workshop – April 2012
- Draft report of Steering Committee submitted; strong preference for Beamline to Homestake option – June 2012
- Pre-CD1 Fermilab Director's review for LBNE Phase 1 – September 25-27, 2012
- CD1-Lehman Review – Oct. 30 to Nov. 1, 2012
- CD-2 Review (baseline) expected by the end of 2014

Beamline Design Drivers

- The driving physics considerations for the LBNE Neutrino Beamline are the long baseline neutrino oscillation analyses.
  - Search for, and precision measurements of, the parameters that govern ν_μ to ν_e oscillations
  - 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 (2.3 GeV and 0.8 GeV respectively at 1300 km baseline). Optimizing for $E\nu$ in the range 0.5 – 5.0 GeV.
- The primary beam designed to transport high intensity protons in the energy range of 60-120 GeV to the LBNE target (focusing on 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 allowing for upgradeability of the facility.

Beamline Design Drivers

- There are a few systems in the Neutrino Beamline (e.g. shielding) 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 (7 degree horizontal bend, 5.8 degree vertical bend for extraction from the MI-10 straight section of the Main Injector).
- 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.

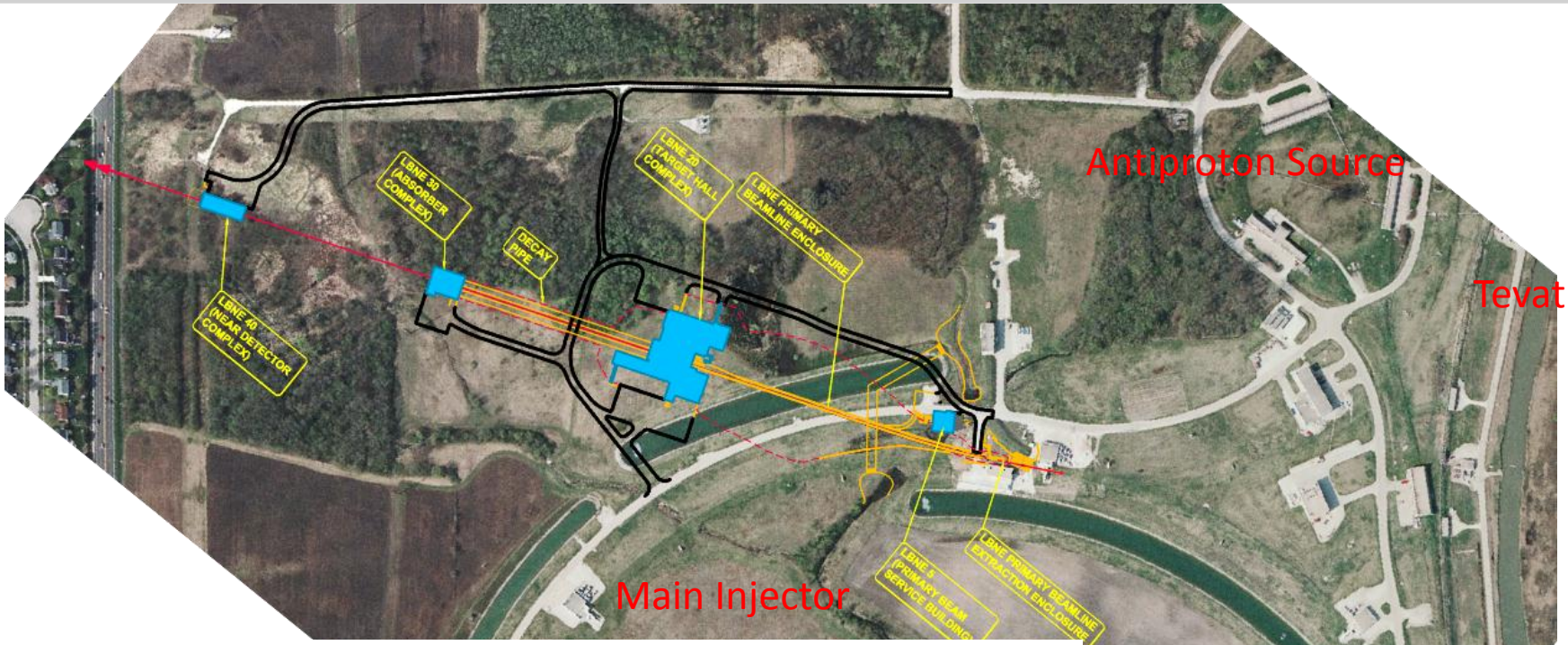
Radiological Requirements

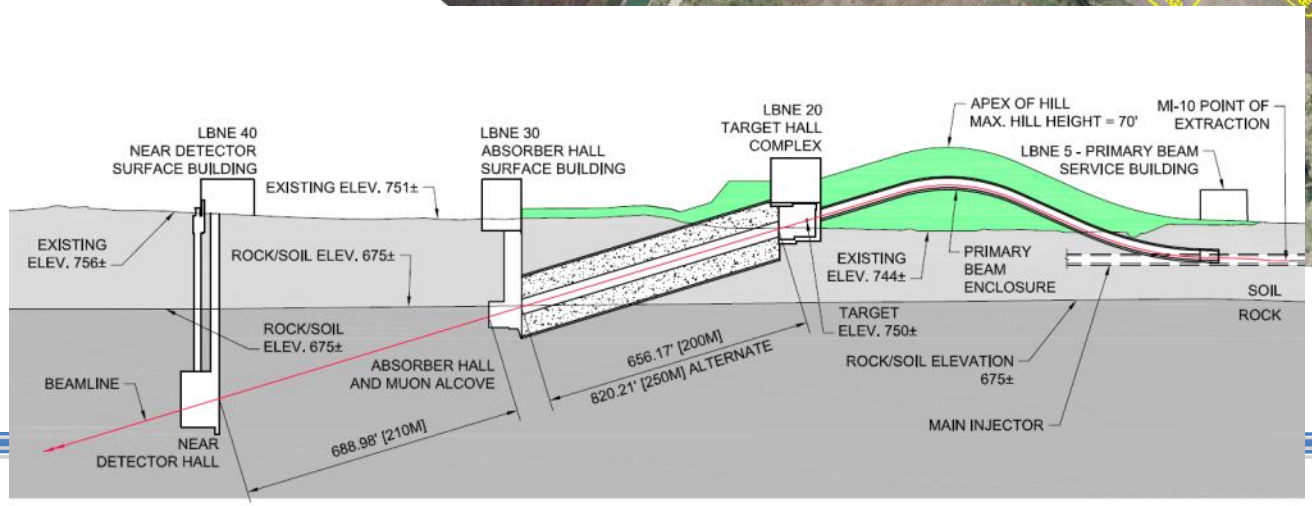
- Design for 2.3 MW, 120 GeV proton beam.
- Member of the public at the Fermilab boundary should not receive more than 1 mrem in a year from all radiation sources originated from the LBNE beam line.
- Sheilding for protecting ground water:
  - For the current shallow design concentrations outside the aquifer will be below 1 pCi/ml for tritium and below 0.04 pCi/ml for sodium-22.
- 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.

Beamline Reference Design

- After evaluation of four separate Beamline configurations - two deep and two shallow at two different extraction points from the Fermilab Main Injector – and after developing two CDRs for two of the four configurations, in November 2011 we selected as Reference Design the MI-10, Shallow option.
- This shallow option features a large berm into which Beamline facilities would be constructed. Primary beamline and Target Hall complex founded to bedrock with drilled concrete piers.

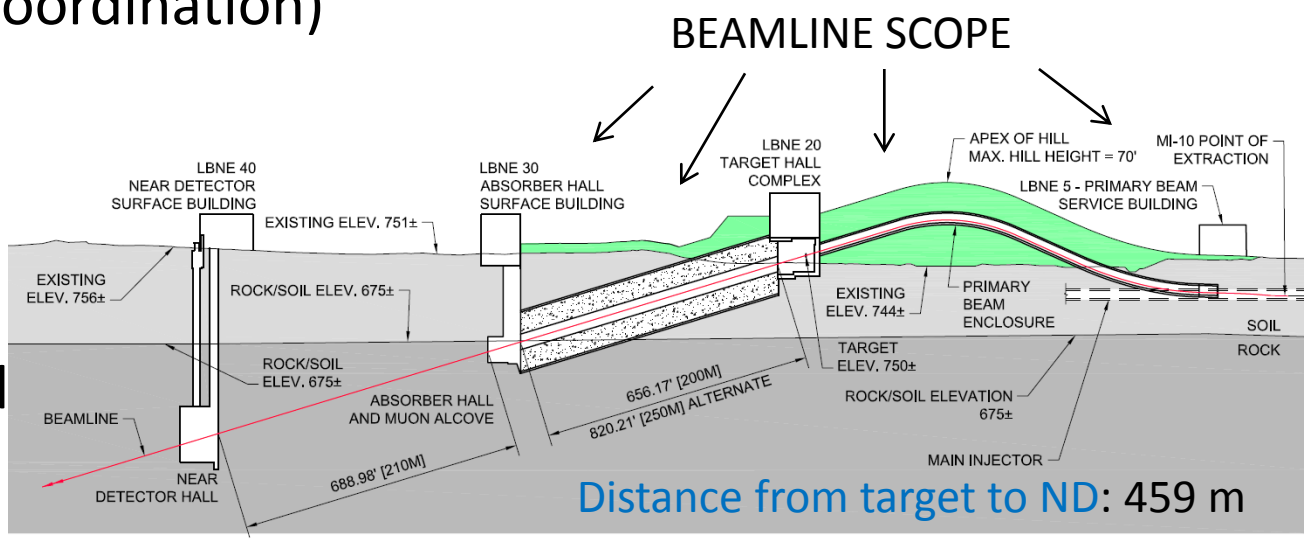
LBNE Beamline Reference Design: MI-10 Extraction, Shallow Beam





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 and coordination)
- Providing specs for Conventional facilities (hall sizes, shielding thicknesses, distance Between absorber and Near Detector, etc.)



Distance from target to ND: 459 m

The Beamline Team

- From Fermilab's Accelerator, Particle Physics and Technical Divisions, FESS and ES&H Sections and Accelerator Physics Center.
- Also Collaborators/Contractors from ANL, BNL, IHEP (Protvino, Russia), RAL (UK), ORNL, Bartoszek Eng., Design Inovations.
  - ANL, BNL, IHEP, RAL (Accords/MOUs on target)
  - RAL (Accord on primary beam window)
  - ORNL (Contract on Remote Handling)
  - Bartoszek Eng. (Contract on baffle and horn support modules)
  - Design Inovations (Contract on magnet installation equipment)
- A nineteen member Technical Board.

Primary Beam Design Parameters (Main Injector)

Beam Parameter	Value
Protons per cycle	4.9×10^{13}
Cycle time (120/60 GeV)	1.33/0.76 sec
Pulse duration	1.0×10^{-5} sec
Proton beam energy	60 to 120 GeV
Beam power at 120 GeV	708 kW
Operational efficiency	56%
Protons on target per year	6.5×10^{20}
Beam size at target	1.5 mm
Beam divergence x,y	17 μrad

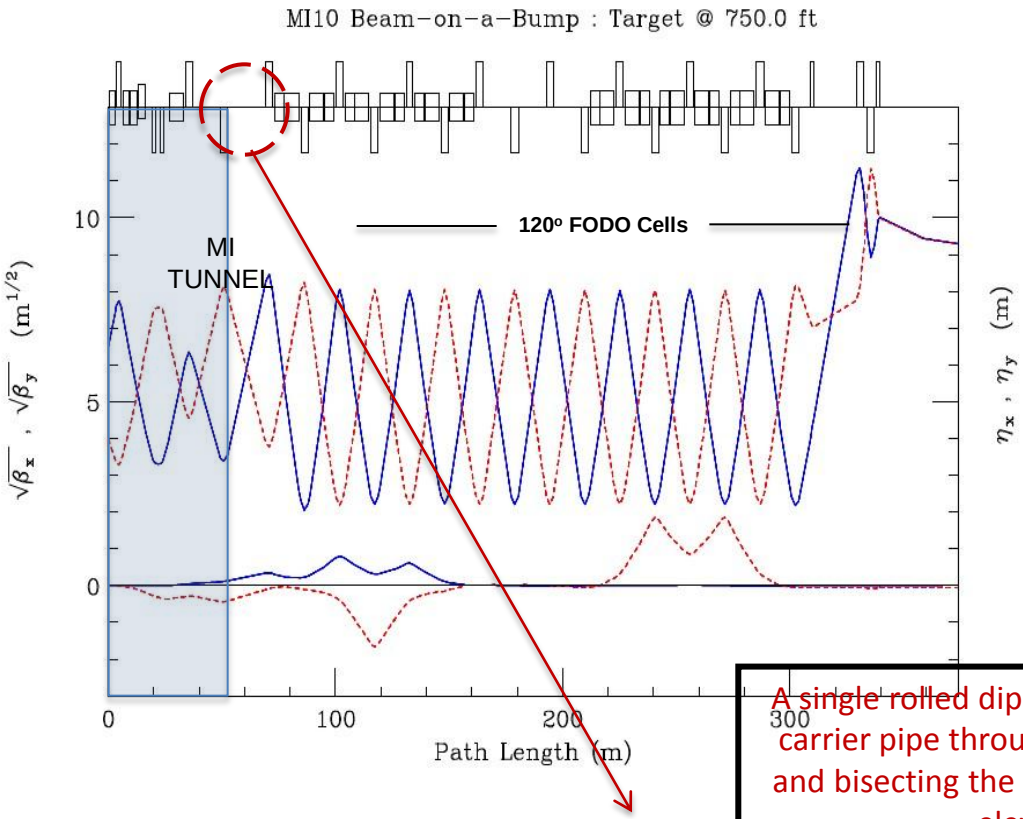
Constant beam power above ~80 GeV

Tunable between 1.0 to 4.0 mm

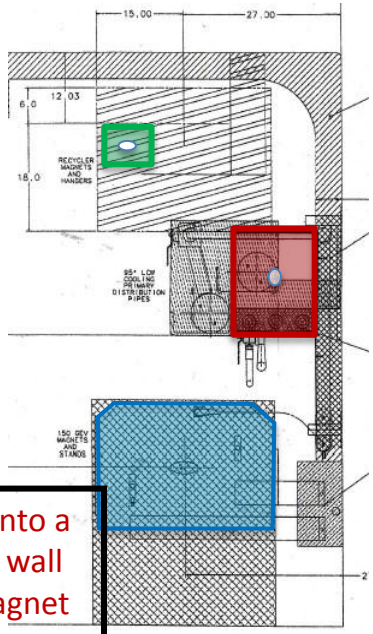
Beam stability requirements

Beam Parameter	Value
Position at target	±0.45 mm
Angle at target	±70 μrad
Size at target	10% of σ(x,y)

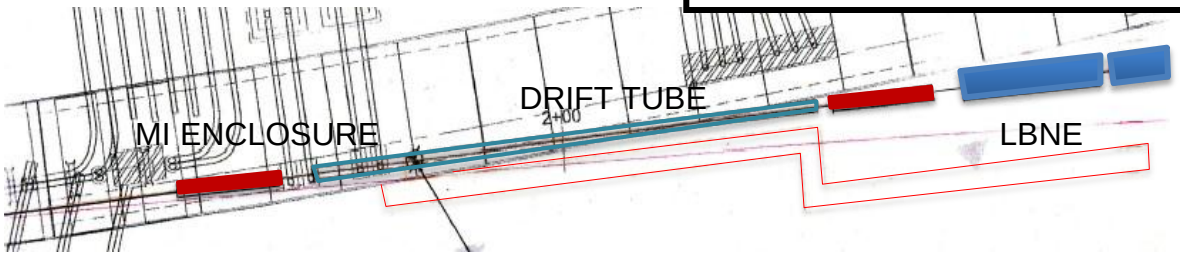
MI-10 extraction, Shallow (new extraction enclosure)



120º 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 and bisecting the MI & Recycler magnet elevations.



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

Primary Beam

- The LBNE Primary Beam will transport protons of 60 - 120 GeV from the MI-10 extraction point of the Main Injector (MI) to the target in the LBNE Target Hall to create a neutrino beam. The fractional beam loss design goal is $5E^{-7}$ for 708 kW operation.
- The primary beam elements necessary for transport include vacuum pipes, dipole, quadrupole and corrector magnets and beam monitoring equipment (BPMs, BLMs, Beam Profile Monitors, etc.).

The lattice design points to ~80 conventional magnets:

Almost all of the conceptual design effort at Fermilab

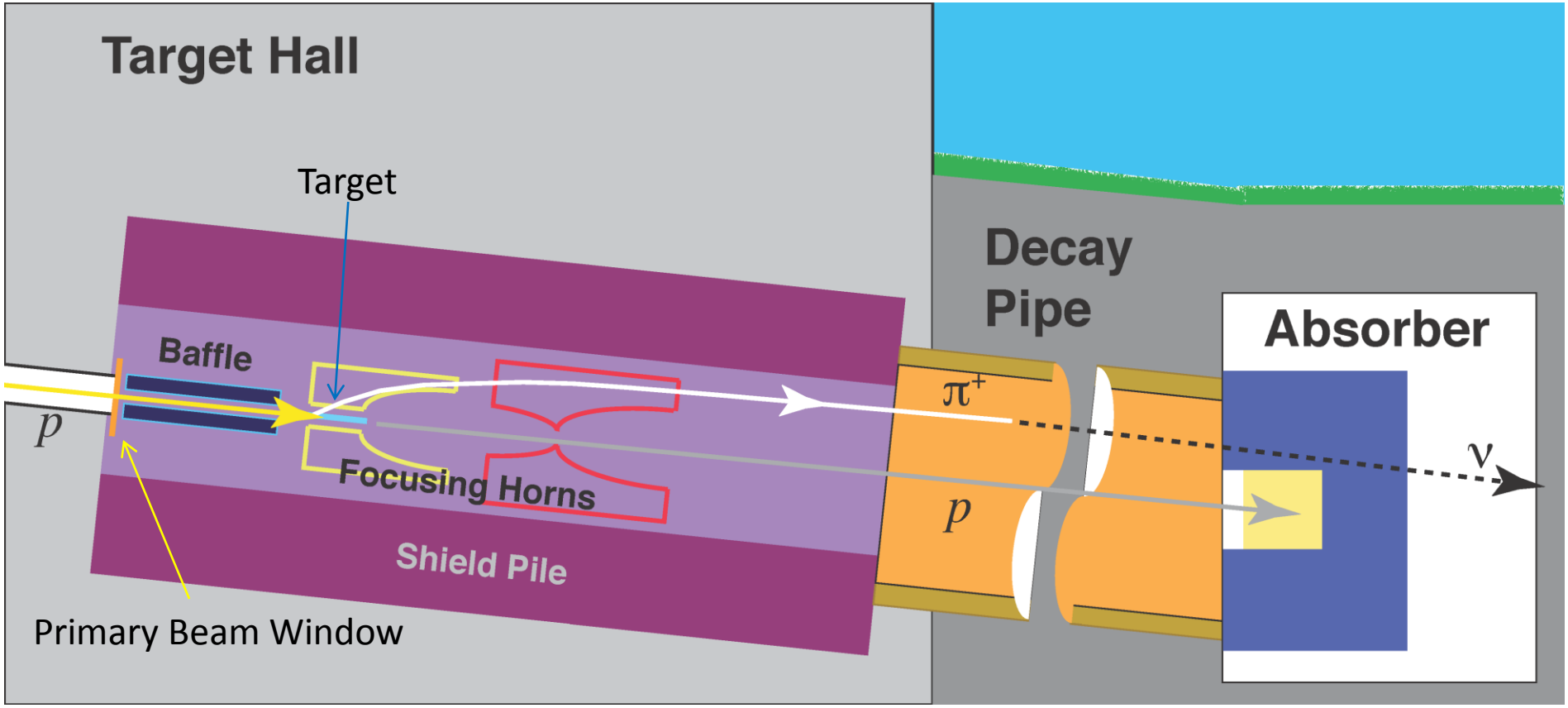
Magnets	Name	Steel Length (m)	Nominal Strength @ 120 GeV	Count
Kickers	NOvA extractr. type	~1.700	0.017 T	5
ILA	MI Lambertson	2.800	0.53-1.00 T	3
ILC	MI C Magnet	3.353	1.00 T	1
IDA/IDB	Main injector dipole	6.100	1.43-1.65 T	13 (7/6)
IDC/IDD	MI short dipole	4.067	1.43-1.65 T	12 (6/6)
QQB	MI 3Q120 quadrupole	3.048	5.52-15.68 T/m	20
QQC	LBNE 3Q60 quads	1.524	13.61-16.85 T/m	4
IDS	LBNE trim dipoles	0.305	0.548 T	24

Neutrino Beam

- The neutrino beam will be created by the interaction of high energy protons from the primary beam in a three step process.
  - First, the primary beam strikes the neutrino production target in the Target Hall. (Target will interact with ~ 85% of primary protons at full intensity).
  - Second, the charged products of these interactions (mostly π and K) are collected in the Target Hall and focused in the direction of the far detectors.
  - Third, the pions and kaons that are aimed correctly enter the long pipe of the decay volume, where they decay into neutrinos.
- Primary Beam Window, Baffle, Target, two focusing Horns, Target Shield Pile, Decay Pipe, Absorber.
  - Need remote handling, tritium mitigation, a lot of modeling, storing of spent radioactive components, etc.

Conceptual design effort at Fermilab and several Accords, MOUs, Contracts in place

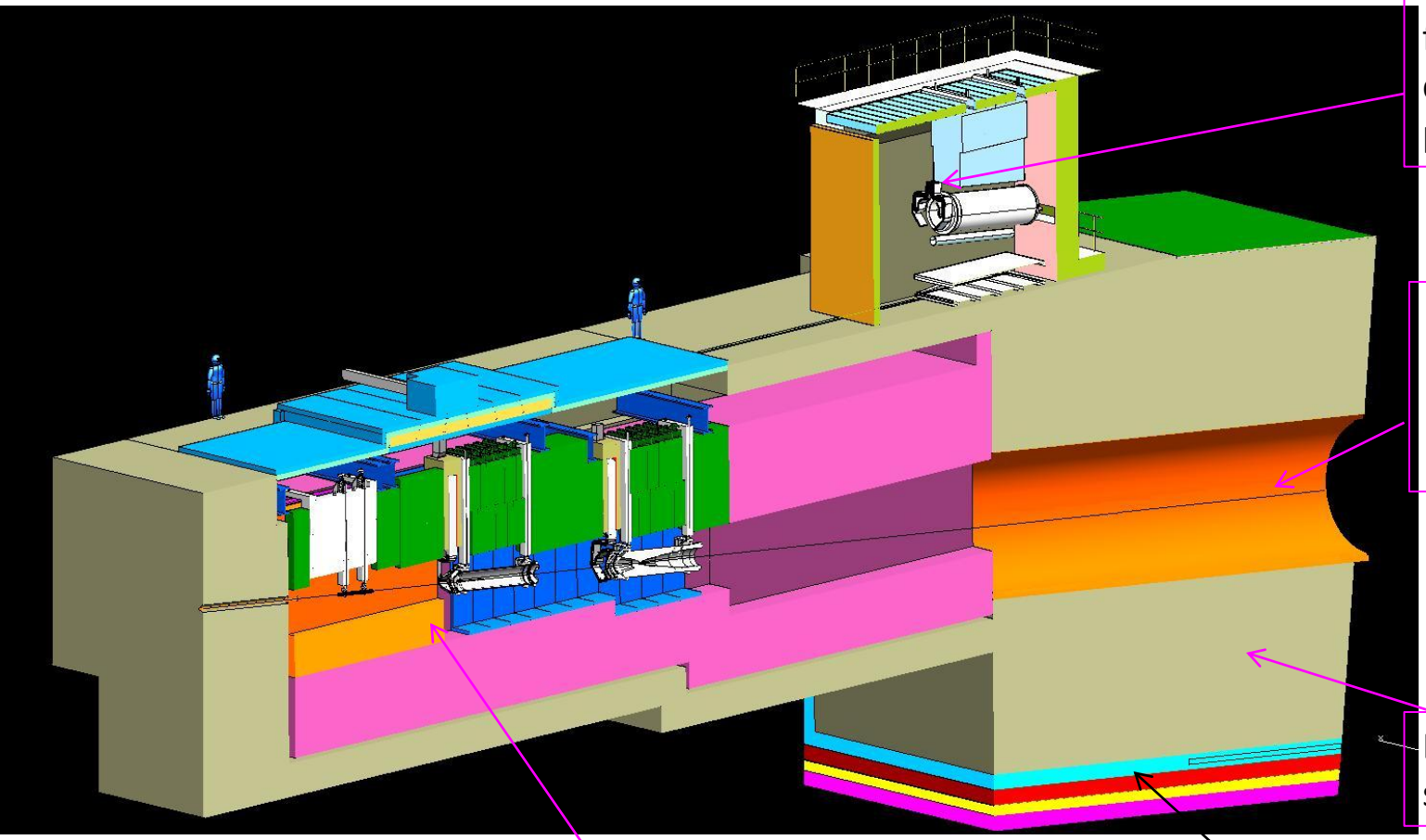
Major Components of the Neutrino Beam



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

- Horn 1
  - Radius outer conductor: 30 cm
  - Radius inner conductor: 2.0 cm (neck), then parabolic
  - Length: 330 cm, neck: 100 cm

Target Hall/Decay Pipe Layout



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

Decay Pipe: air-filled, air-cooled
Radius: 2m
Length: 200 m

Decay Pipe concrete shielding (5.5 m)

Target Chase: 64” wide, 29 m long

Geomembrane barrier system to keep groundwater out of decay region

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

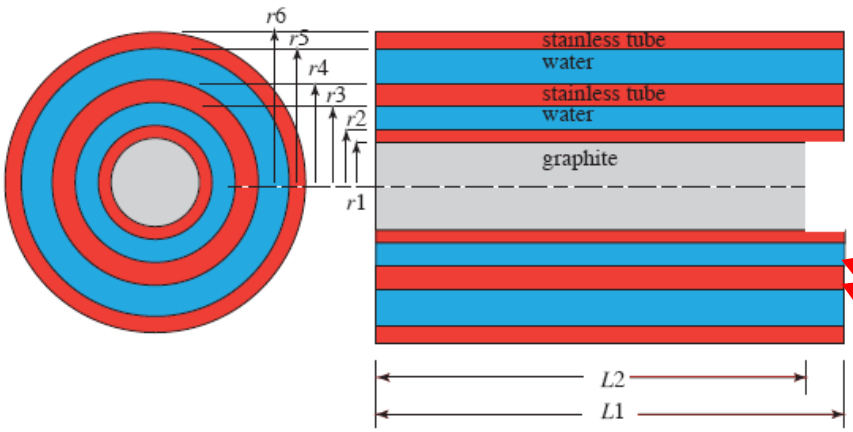
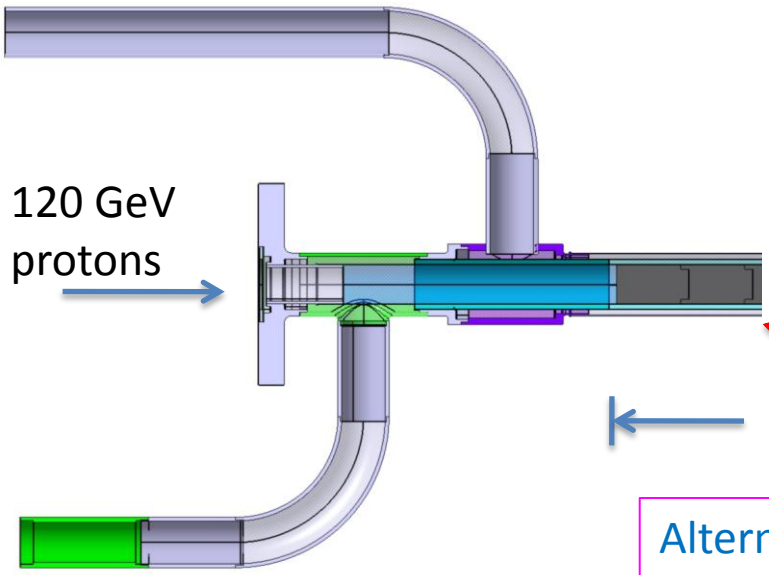


Figure 1. Target Assembly

Target material: POCO ZXF-50 graphite

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**



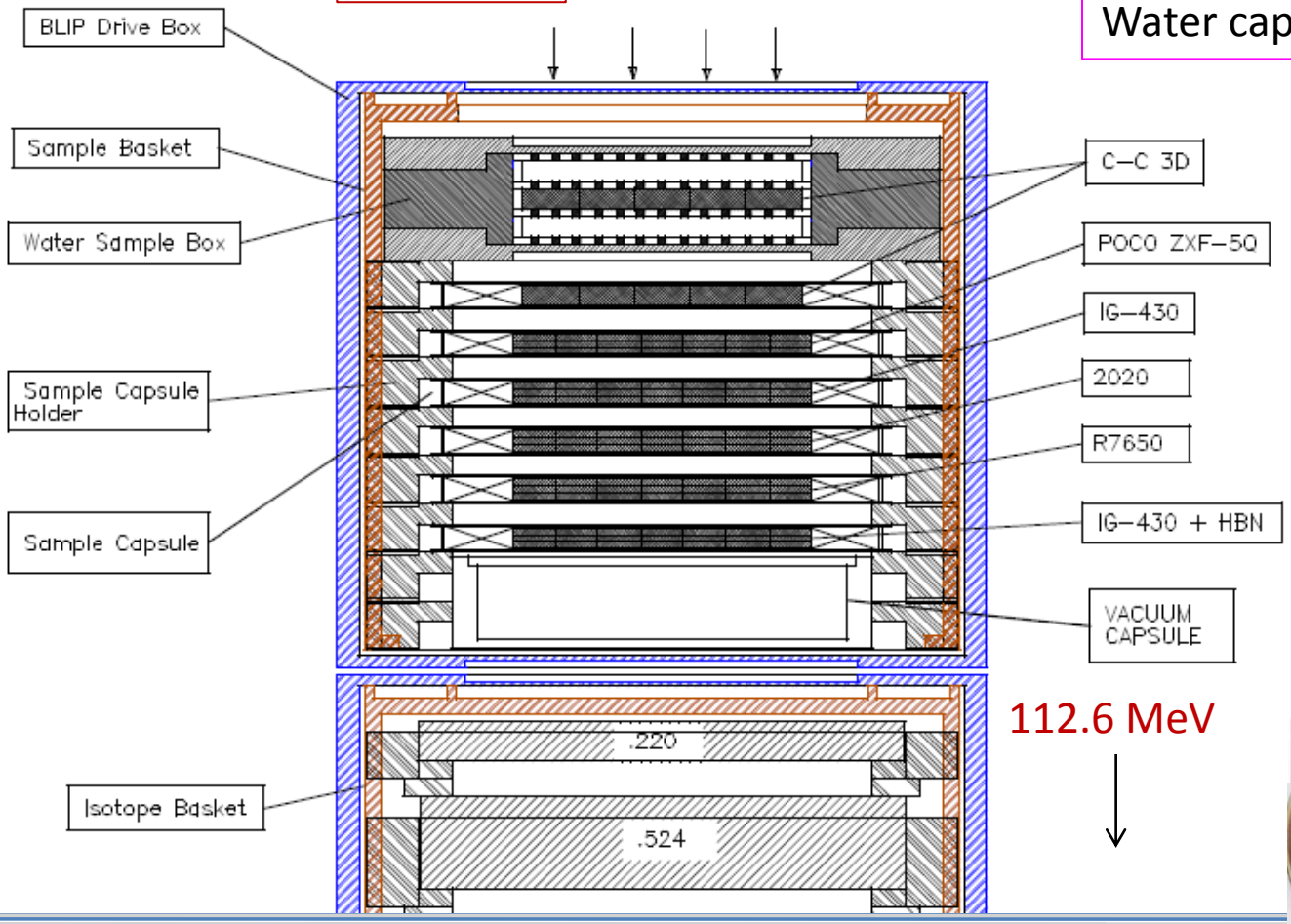
A row of 15.3 mm diameter and 25 mm length graphite segments separated by 0.2 mm gaps.

Alternatives: Other graphites, C-C composite, HBN, Be, etc. (BLIP test at BNL)

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



Six Argon capsules and one Water capsule

Carbon-carbon composite

NuMI target graphite

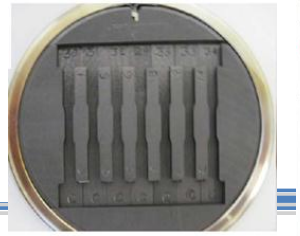
Japanese graphite

Another graphite, higher thermal shock metric

NuMI baffle graphite

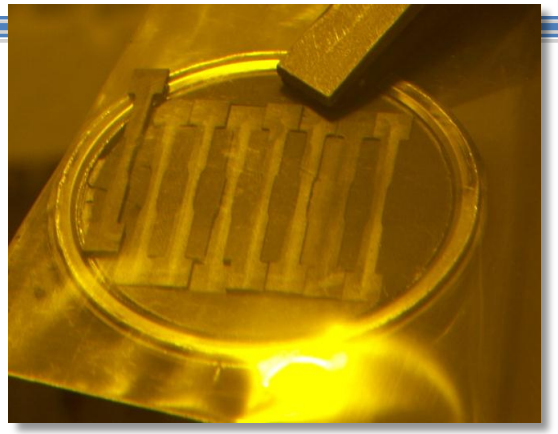
Highest therm. shock metric

Beam View of Samples and Holder

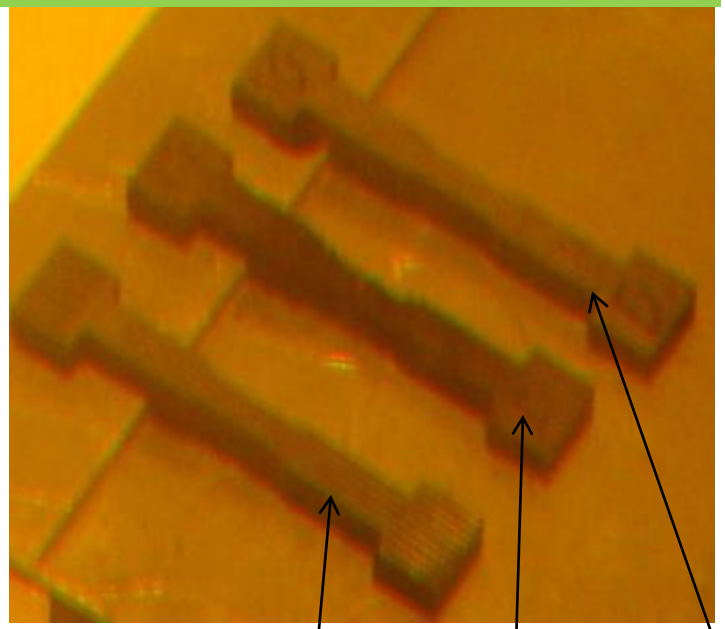


Target Samples from BLIP test

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



- Peak integrated flux about 5.9e20 proton/cm^2
- Average over 1 sigma area about 4.6e20 proton/cm^2
- ~ 150 tensile samples tested

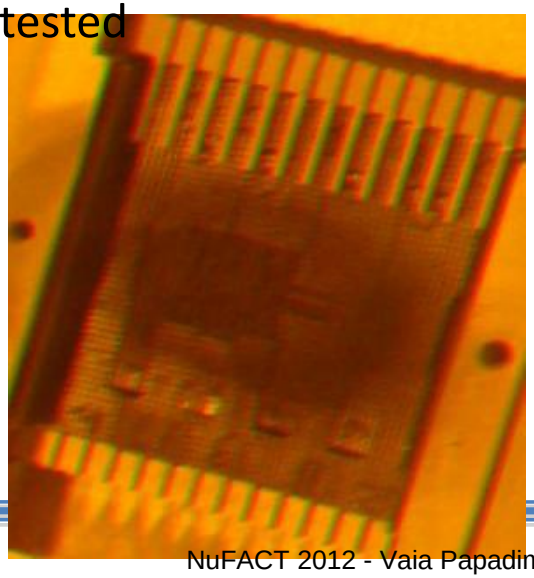


Argon environment

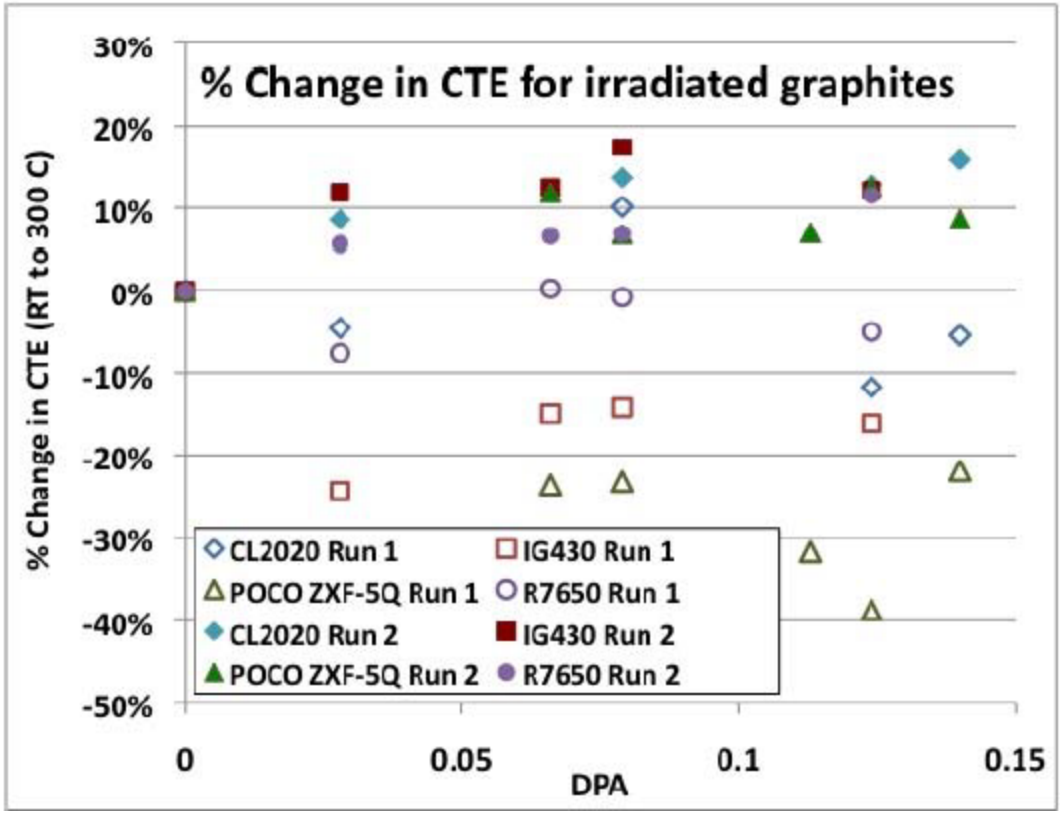
Un-irradiated

Water-cooled

HBN "used up"



BLIP test results and recommendations



Comparison of change in coefficient of thermal expansion (20-300°C) for graphite samples during two consecutive thermal cycles after irradiation. Open symbols: first cycle; Filled symbols: second cycle

Recommended candidate materials for LBNE out of the ones studied are 3D C/C, POCO and R7650 graphites and they should be exposed to higher fluences.

Expect to do single pulse beam tests of prototype Be fins and other target materials at CERN's High-Rad-Mat Facility as well.

Reconfiguring LBNE as a Phased Program

- Reconfiguration process led by Fermilab Directorate, who formed a Steering Committee and two Working Groups
- Enormous amount of work done during ~2 month period to develop viable options for a reconfigured LBNE.
- Effort led by Steering Committee; a lot of the detailed work was done through the two Working Groups in collaboration with the LBNE Project and the LBNE Collaboration.
- The work was based as much as possible on the LBNE Conceptual Design, cost and schedule estimates developed for the pre-CD1 Fermilab Director's review in March 2012.
- About 20 Value Engineering proposals affecting Beamline technical components and its conventional facilities were evaluated by the Beamline Team between mid April and mid July 2012.

The LBNE Reconfiguration Steering Committee

Membership	
Young-Kee Kim, FNAL (Chair)	LBNE LOG (Lab Oversight Group) member
James Symons, LBNL	LBNE LOG (Lab Oversight Group) member
Steve Vigdor, BNL	LBNE LOG (Lab Oversight Group) member
Bob Svoboda, UC Davis	LBNE co-spokesperson
Kevin Lesko, LBNL	SURF (Sanford Underground Research Facility) head
Gary Feldman, Harvard	NOvA co-spokesperson
Mel Shochet, U.Chicago	Physics working group chair, Former HEPAP chair
Mark Reichanadter, SLAC	Engineering/Cost working group chair DOE DUSEL review committee co-chair
Charlie Baltay, Yale	P5 chair
Jon Bagger, JHU	Former HEPAP deputy chair
Ann Nelson, UW, Seattle	HEPAP member

Ex-officio group

Membership	
Andy Lankford, UC Irvine	HEPAP chair, DUSEL NRC study chair
Steve Ritz, UC Santa Cruz	PASAG (Particle Astrophysics Scientific Assessment Group) chair, Fermilab PAC member (chair from Fall 2012)
Jay Marx, Caltech	DOE DUSEL review committee co-chair
Pierre Ramond, U. Florida	DPF chair
Harry Weerts, ANL	DOE Intensity Frontier Workshop co-chair
JoAnne Hewett, SLAC	DOE Intensity Frontier Workshop co-chair
Jim Strait, FNAL	LBNE Project Manager Engineering/Cost working group deputy chair
Pier Oddone, FNAL	Director, Fermilab
Susan Seestrom, LANL	LBNE LOG (Lab Oversight Group) member

Physics Working Group	Engineering / Cost Working Group
Mel Shochet, U.Chicago (chair) Mary Bishai, BNL Ed Blucher, UChicago Steve Brice, FNAL Milind Diwan, BNL Bonnie Fleming, Yale Gil Gilchriese, LBNL Bill Marciano, BNL Mark Messier, Indiana Stephen Parke, FNAL Gina Rameika, FNAL Kate Scholberg, Duke Jenny Thomas, UCL Charlie Young, SLAC Sam Zeller, FNAL	Mark Reichanadter, SLAC (chair) Jim Strait, FNAL (deputy chair) Bruce Baller, FNAL Mike Headley, SURF Marvin Marshak, U. Minnesota Chris Mauger, LANL Elaine McCluskey, FNAL Vaia Papadimitriou, FNAL Bob O'Sullivan, FNAL Jeff Sims, ANL Additional invitation to Tracy Lundin (FNAL) Jeff Dolph (BNL) Jim Stewart (BNL) Joel Sefcovic (FNAL)

Steering Committee Report
Interim Conclusions

- These options are (not priority ordered):
  - Using the existing NuMI beamline in the low energy configuration with a 30 kton LAr-TPC surface detector 14 mrad off-axis at Ash River in Minnesota, 810 km from Fermilab.
  - Using the existing NuMI beamline in the low energy configuration with a 15 kton LAr-TPC underground (at the 2,340 ft level) detector on-axis at the Soudan Lab in Minnesota, 735 km from Fermilab.
  - Constructing a new low energy LBNE beamline with a 10 kton LAr-TPC surface detector on-axis at Homestake in South Dakota, 1,300 km from Fermilab.

Prefered option ★

While each of these first-phase options is more sensitive than the others in some particular physics domain, the Steering Committee in its discussions strongly favored the option to build a new beamline to Homestake with an initial 10 kton LAr-TPC detector on the surface.

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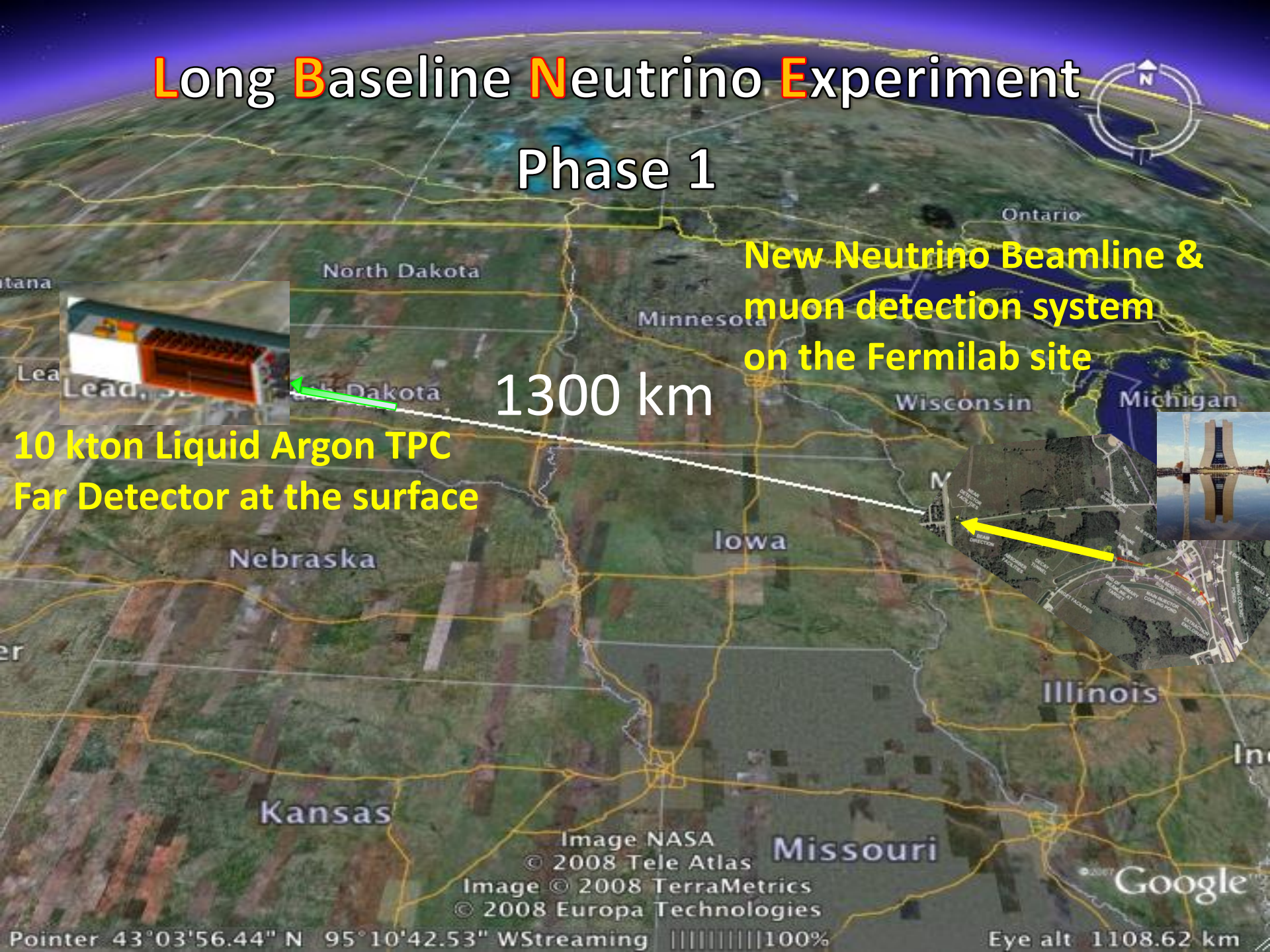
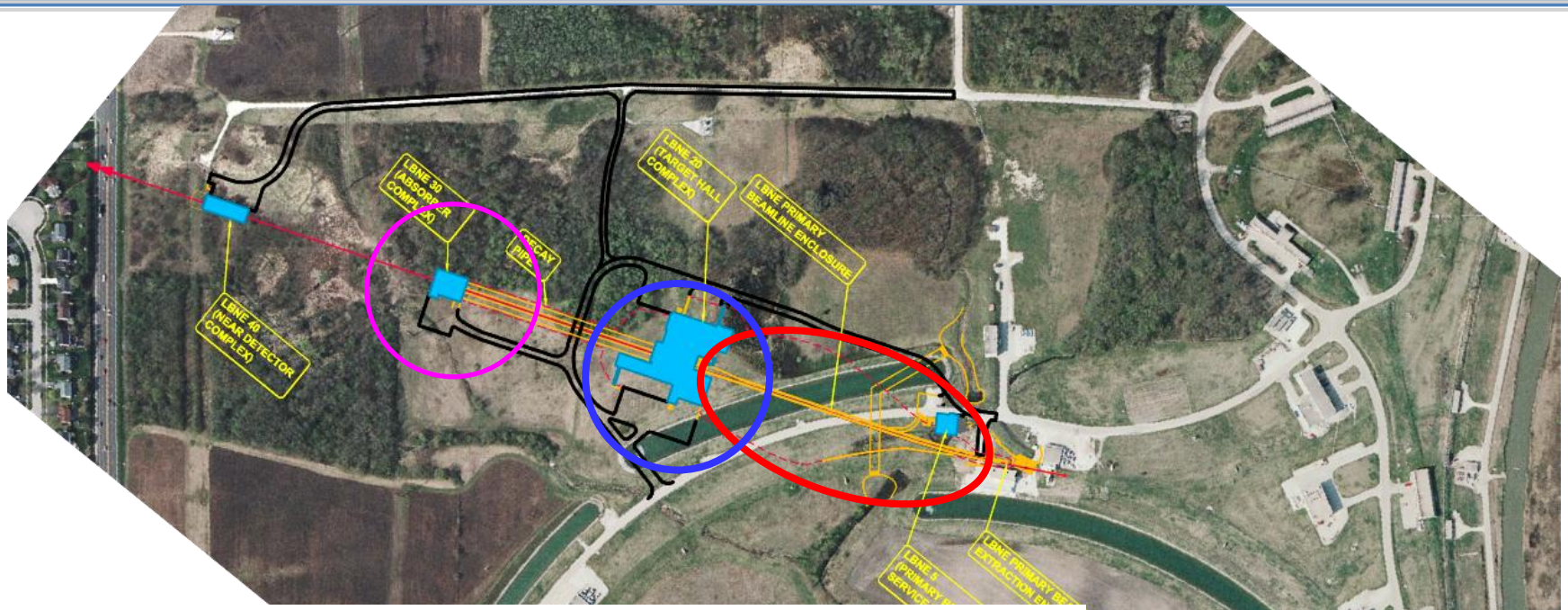
Long Baseline Neutrino Experiment

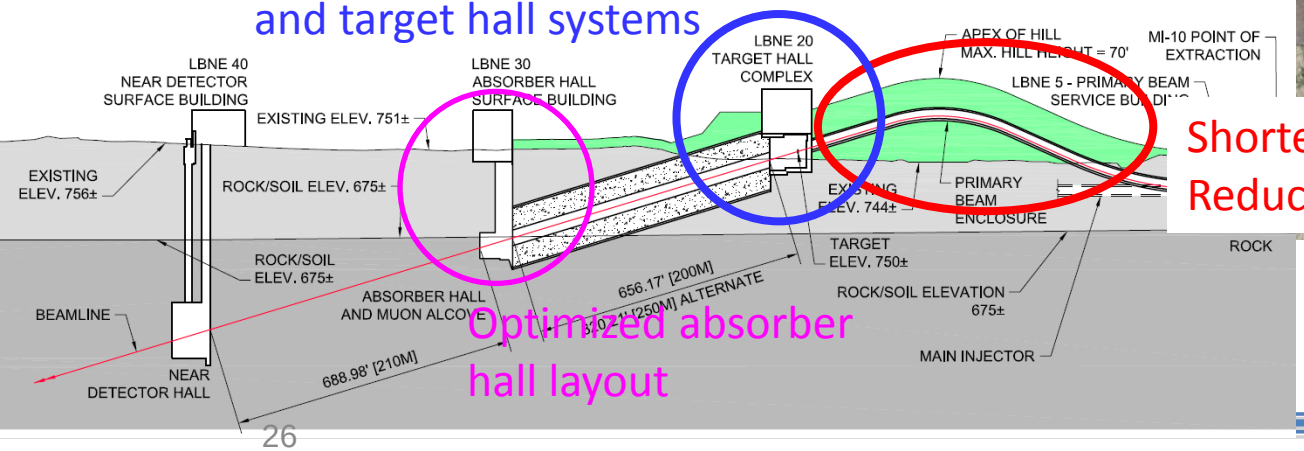
Phase 1



LBNE Beamline Facility



Simplified target hall
and target hall systems



Shorten primary beamline,
Reduce hill height

Optimized absorber
hall layout

LBNE Beam Cost Reductions
(FY2010 $M, estimate uncertainty contingency)

Simplify Technical Systems Design	Cost Savings
Shorten primary beam 148'	0.8
Eliminate OTR profile monitor	0.2
Re-optimize beam loss calculation labor	0.5
Reduced target shield pile	4.4
Recycle old shielding steel	1.3
No target chase water-cooling panels in phase 1	3.7
NuMI design horns (200 kA)	13.0
NuMI style target and reduced R&D in phase 1	3.0
NuMI design target hall instrumentation	2.3
Combined target-baffle module	0.7
No in-chase target handler	7.7
Reduce and combine vision systems	0.7
Total - technical systems	**38.2**

Re-use NuMI beamline components	Cost Savings
NuMI horn PS + stripline	3.6
Beamline Magnets	1.3
Magnet power supplies	0.5
Primary beam instrumentation	1.0
Target	0.8
Target hall instrumentation	1.9
Remote handling equipment	0.4
Total - reusing NuMI components	**9.5**

Simplify Conventional Facilities Design	Cost Savings
Target Hall Complex Reconfiguration (partial)	30.2
Shorten primary beam 148'	6.6
Reduced tritium interceptor	1.4
Total - Conventional Facilities	**38.2**

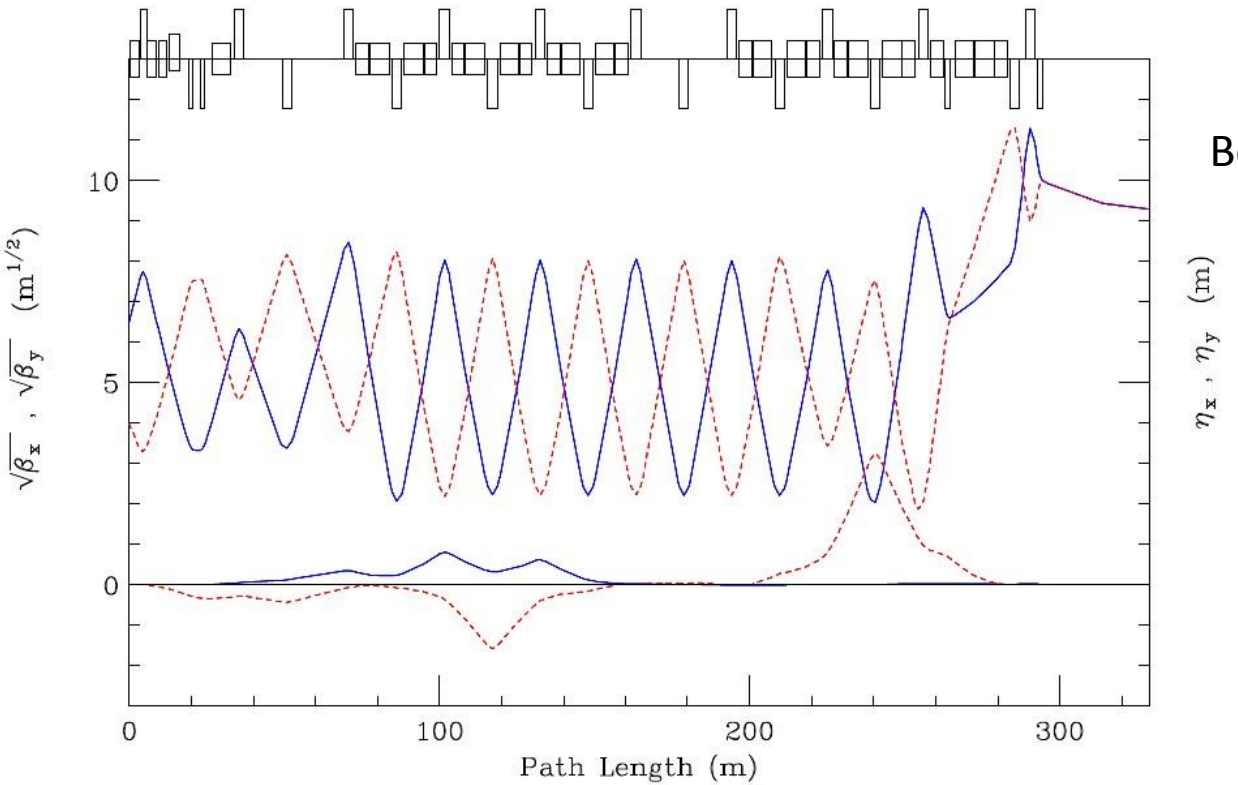
Grand Total	**85.9**

Out of ~ $400 M

Including <u>all</u> contingency and escalation *$110M*

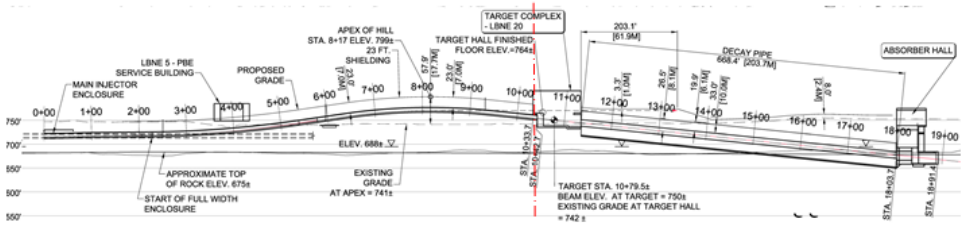
In the mean time we have performed additional VE work optimizing the Target Hall and Absorber Hall complexes further

New Beam Optics & shortening of the Primary Beamline



Beam tunability up to 3.2 mm

- **Shortened Primary Beamline by 148'**
- **Lowered Apex of "Hill" by 12'**
- **Decreased Soil Shielding from 25' to 23'**
- **Steepened Side Slopes to from 22 to 30 degrees**
- **Decreased Max. Width of "Hill" from 365' to 207'**

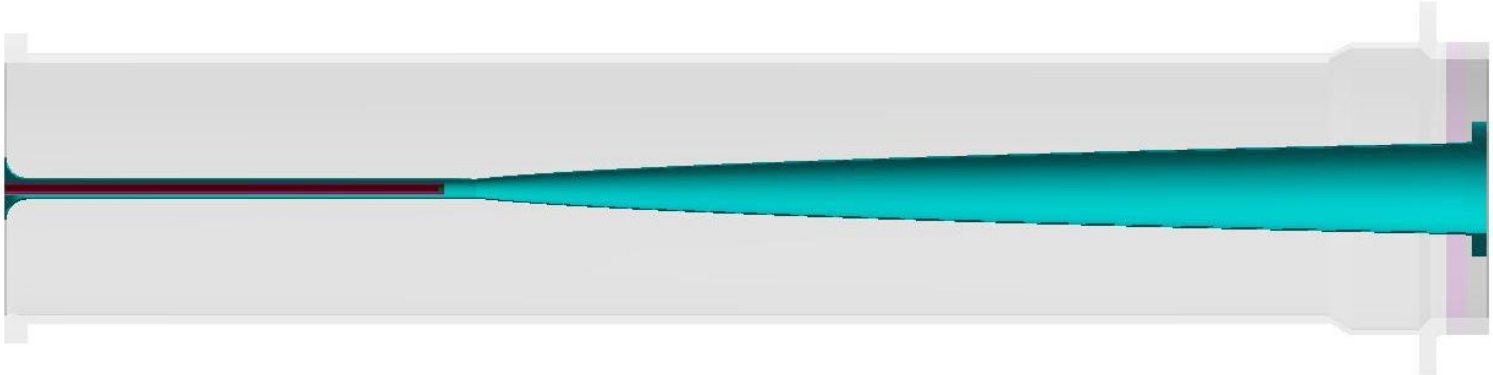


July 2012 Reconfig. Design

Horn 1 Shapes for NuMI/LBNE

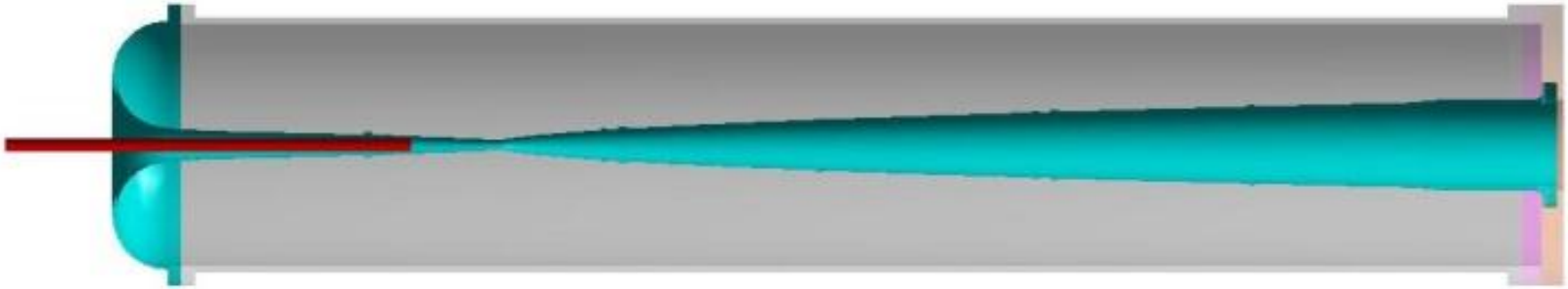
LBNE CDR – straight cylindrical upstream section

optimized for lowest energy neutrino spectrum



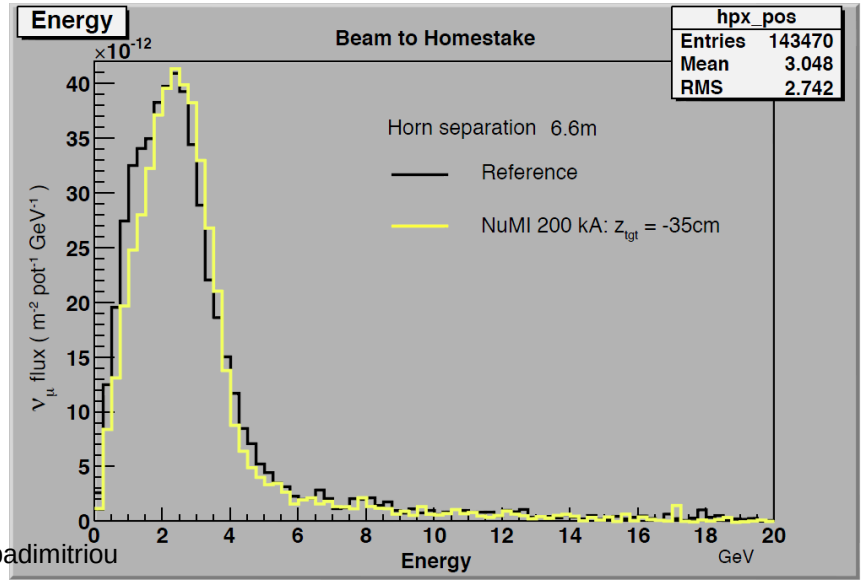
NUMI – parabolic upstream section

optimized for tune-ability of neutrino energy spectrum



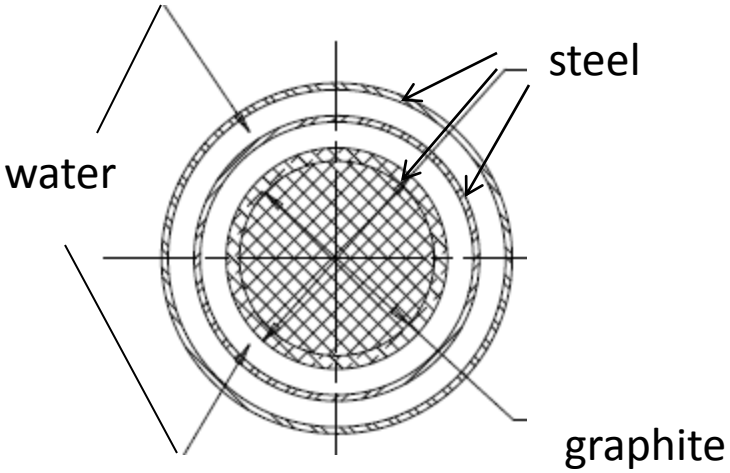
Use by LBNE at 700 kW of NuMI Horn1 and NuMI Style target

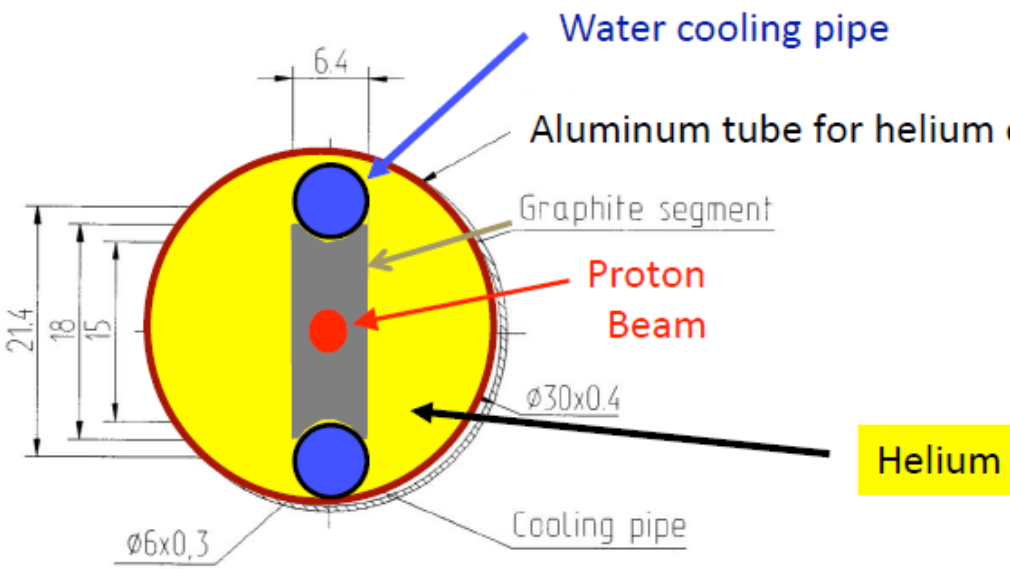
	LBNE CDR	LBNE new beam-line but NUMI horns
Beam power	700 kW	700 kW
Horn 1 shape	Cylindrical/parabolic	Double parabolic
Horn current	300 kA	200 kA
Distance between two horns	6.6 m	10 m (but could instead do 6.6 m)
Target	IHEP cylindrical	Modified MINOS
Horn power supply	New	Re-use NUMI P.S.
Target "carrier"	New handler, target attaches to horn	Re-use NT-08 target carrier



~ 25% effect on the 2nd oscillation max.

LBNE CDR target versus NUMI LE target





- LBNE CDR target design is on a path to a 2.3 MW target
- LBNE target traps the graphite, so may last longer in beam against radiation
- NUMI target has less material
- Monte Carlo shows NUMI target deposits only half as much beam energy in horn inner conductor
- NUMI target as-is will not take 700 kW beam

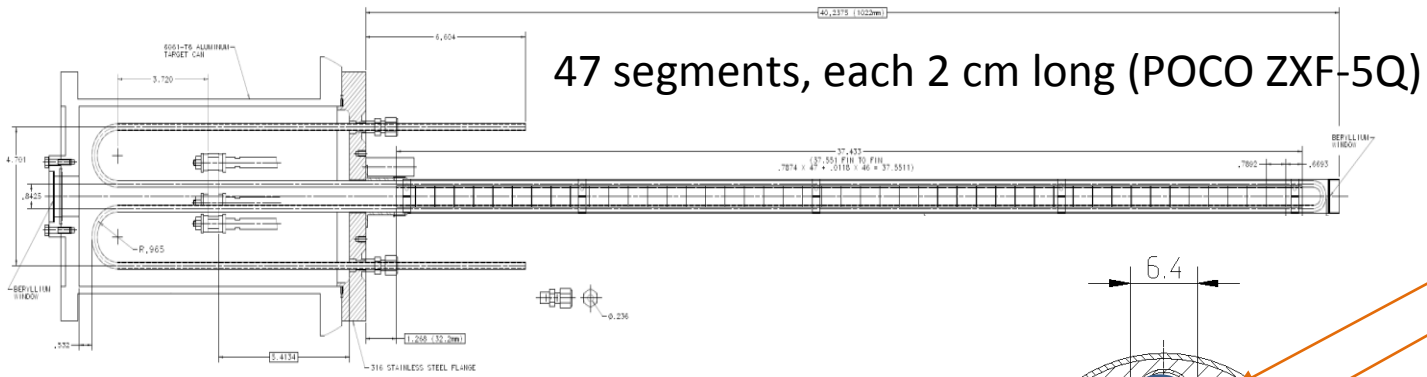
Problem of NUMI horn + LBNE target at 700 kW

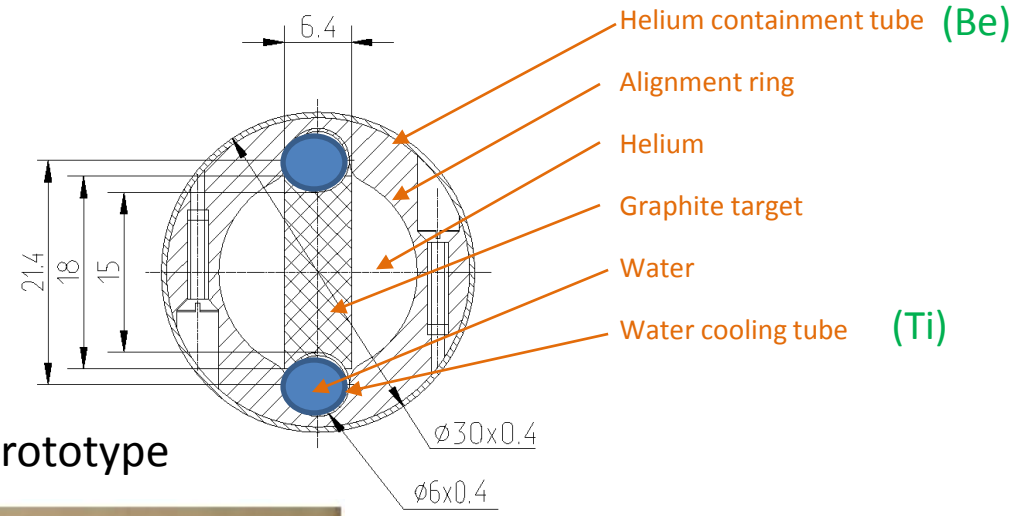
- Beam energy over-heats horn inner conductor, Aluminum creep problematic
- Combination of 300 kA joule heating, magnetic loading and beam heating give stress that is on edge for fatigue lifetime of 1 year

Possible solution

- Use lower mass NUMI style target to cut beam energy deposition in horn
  - Reducing peak temperature from 124 deg C to 85 deg C
  - Also reducing beam-heating induced stress in horn
- Use NUMI-style 200 kA beam current to reduce magnetic loading

Conceptual design of a NuMI-LE like target for LBNE for 700 kW operation



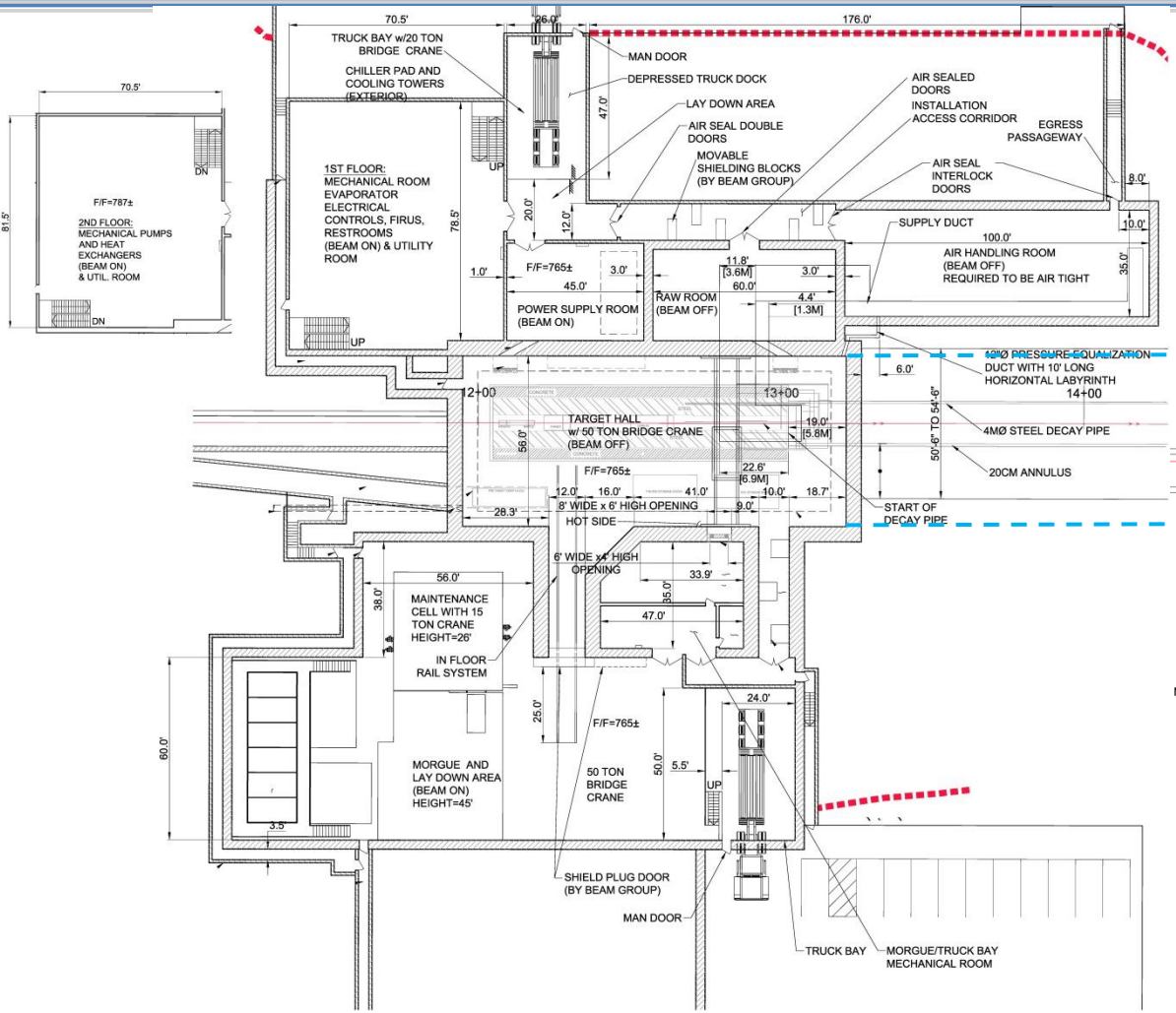


The first Titanium-tube water cooling line prototype

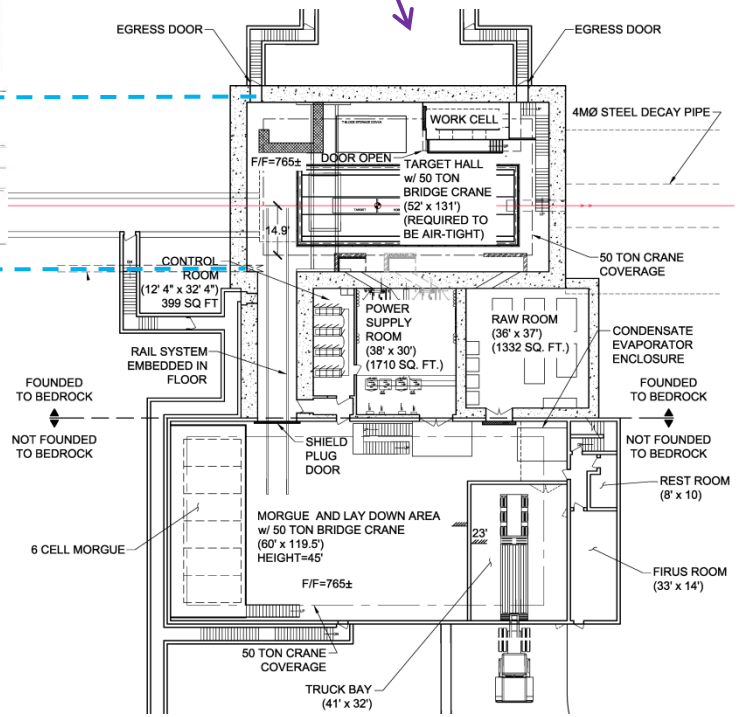
Taking advantage of work done for the:

- 700 kW ANU-NOvA medium energy target
- R&D towards making the NuMI-MINOS low energy target more robust

Target Complex – Ref. Design vs. Reconfig. Design



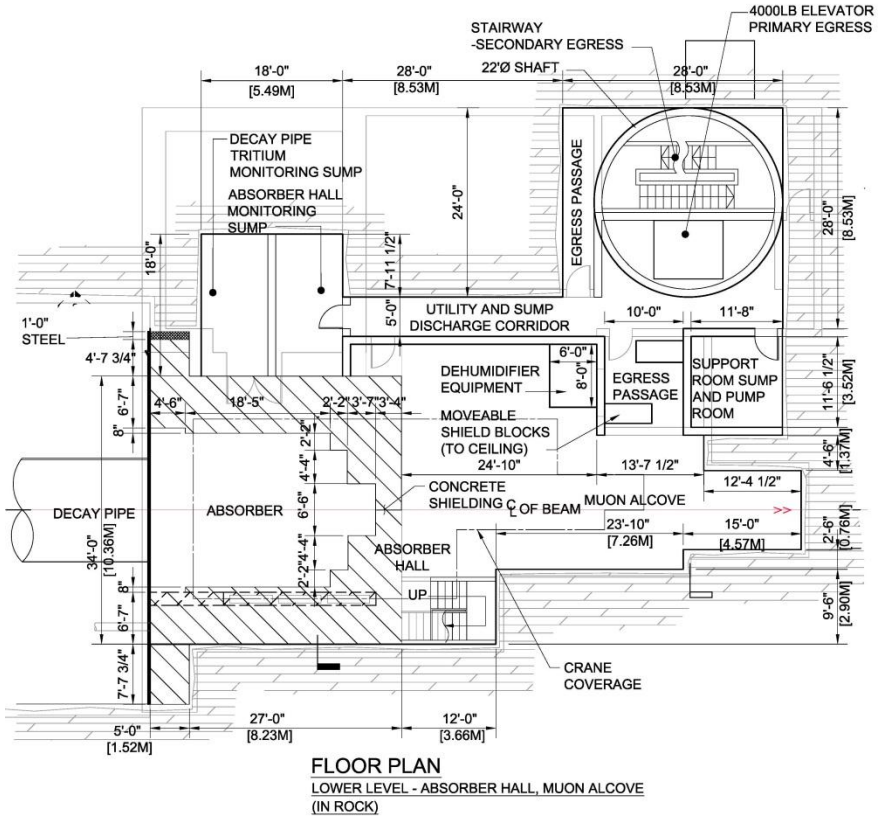
3 story structure
Fewers drilled piers

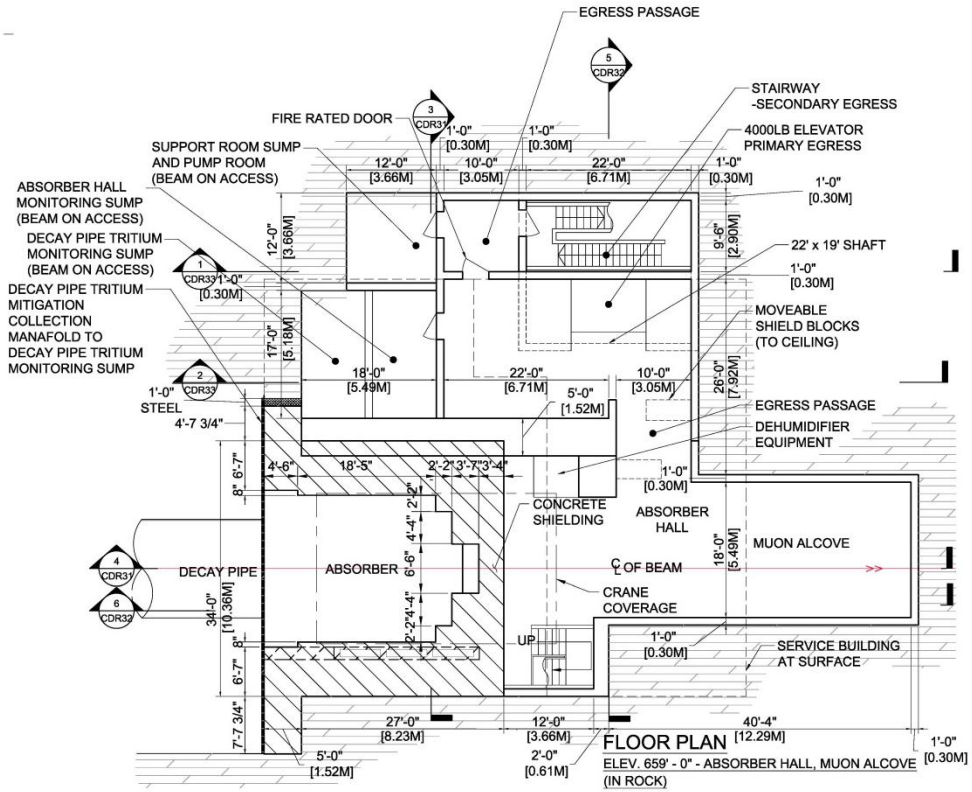


March 2012
Reference Design

July 2012
Reconfig. Design

Absorber Hall / MUON Alcove





March 2012, Reference Design

July 2012, Reconfiguration Design

Absorber Hall Service building footprint reduced as well from 6900 SF to 3850 SF

Summary - 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 Beamline configurations and value engineering proposals with the goal of reducing the Beamline Facility cost further.
- The conceptual design has been reviewed at the pre-CD1 Fermilab Director's Review in March 2012. The design is complete and in some systems beyond the conceptual design level since we are following closely the design from NuMI.
- LBNE reconfiguration effort, developing a phase 1 LBNE, complete in mid July 2012.
- Fermilab Director's review in September 2012 and CD-1 review in the end of October 2012.

Backup Slides

BACKUP SLIDES

What is conceptually designed for 2.3 MW

- There are a few systems in the LBNE Beamline that are conceptually designed for 2.3 MW in order to enable the facility to run with an upgraded accelerator complex that will provide higher beam power. These systems include:
  - the shielding of the primary beam enclosure, the target shield pile, the decay pipe shielding and the absorber. Upgrading these systems after beam exposure is inconsistent with ALARA considerations, technically impractical and cost inefficient. (Shielding design specifications within LBNE doc # 4080)
  - The Conventional Facilities space requirements for the Beamline Facility are sized for 2.3 MW as the overheads for upgrading the construction are large.
  - Remote handling is conceptually designed for 2.3 MW as well since much of the remote handling infrastructure cannot be upgraded or replaced after commissioning with beam.

What is conceptually designed for 2.3 MW

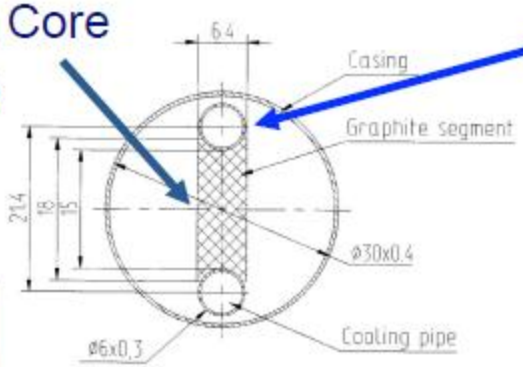
- These systems include:
  - the air cooling for the decay pipe is designed for 2.3 MW capability.
  - The air cooling for the target shield pile is designed for 708 kW but will become capable of 2.3 MW when panels installed for shielding purposes during 708 kW operation become eventually water cooled.
  - The RAW system piping is sized for 2.3 MW.

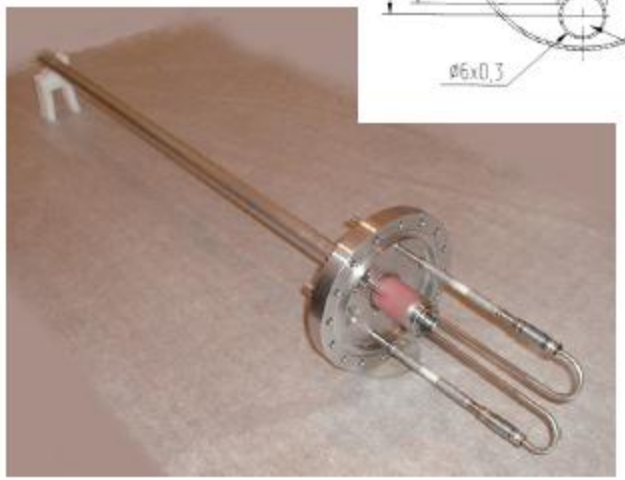
NuMI/MINOS target

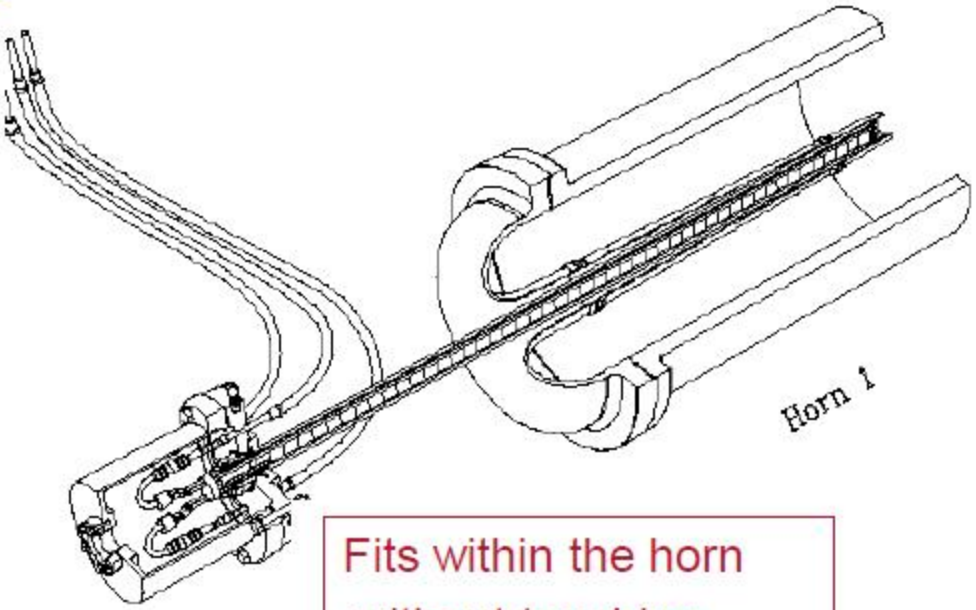
2 int. length long; narrow so pions get out sides without re-interacting

Graphite Fin Core
6.4 mm wide

Water cooling tube





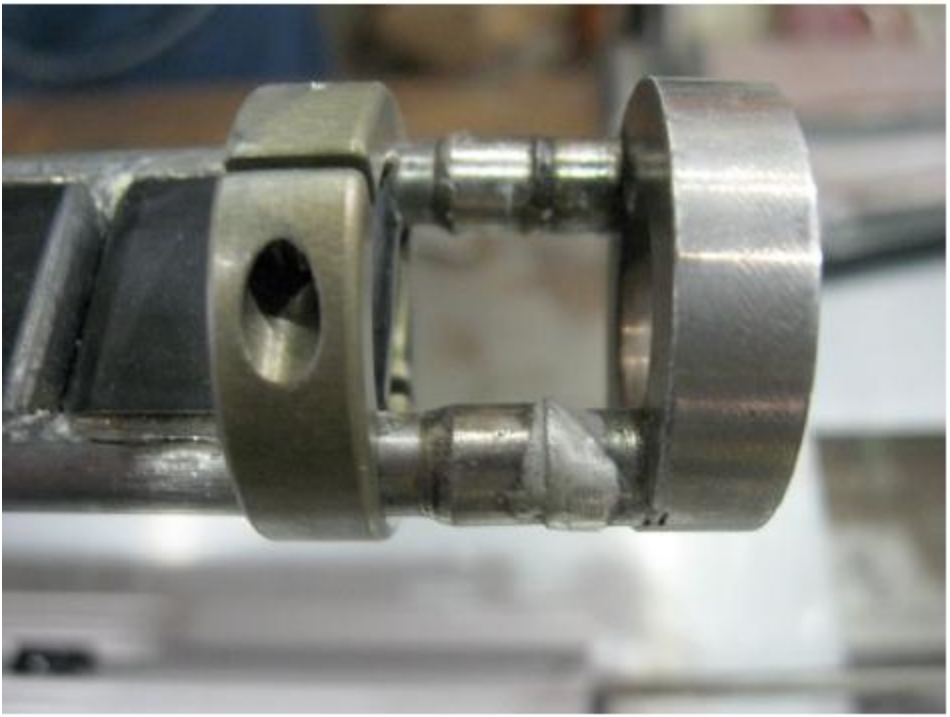


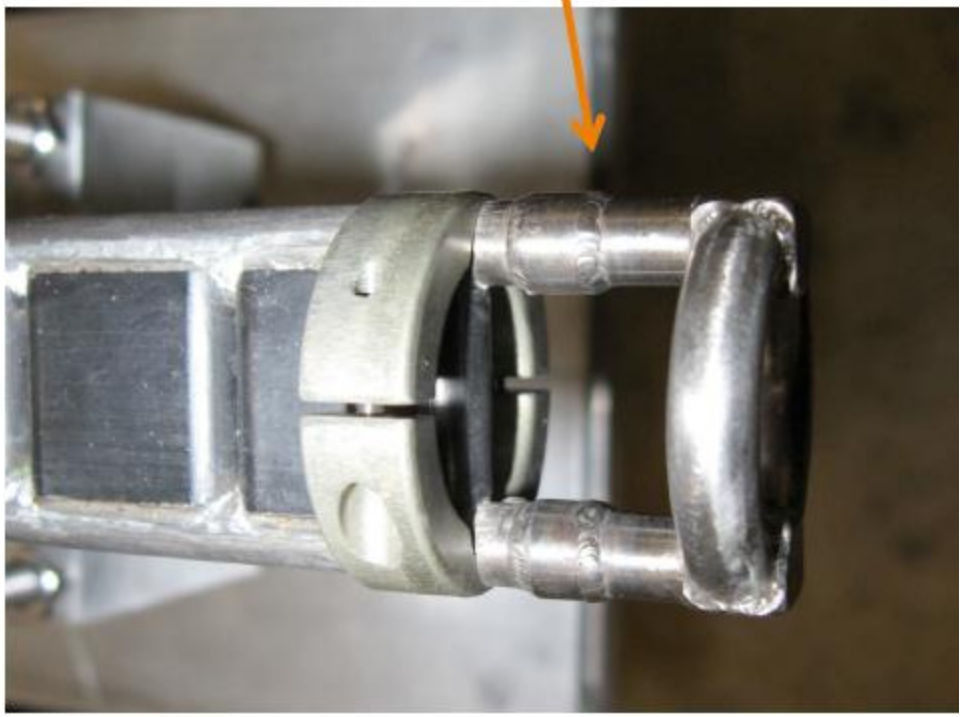
Fits within the horn without touching.

NuMI/MINOS target

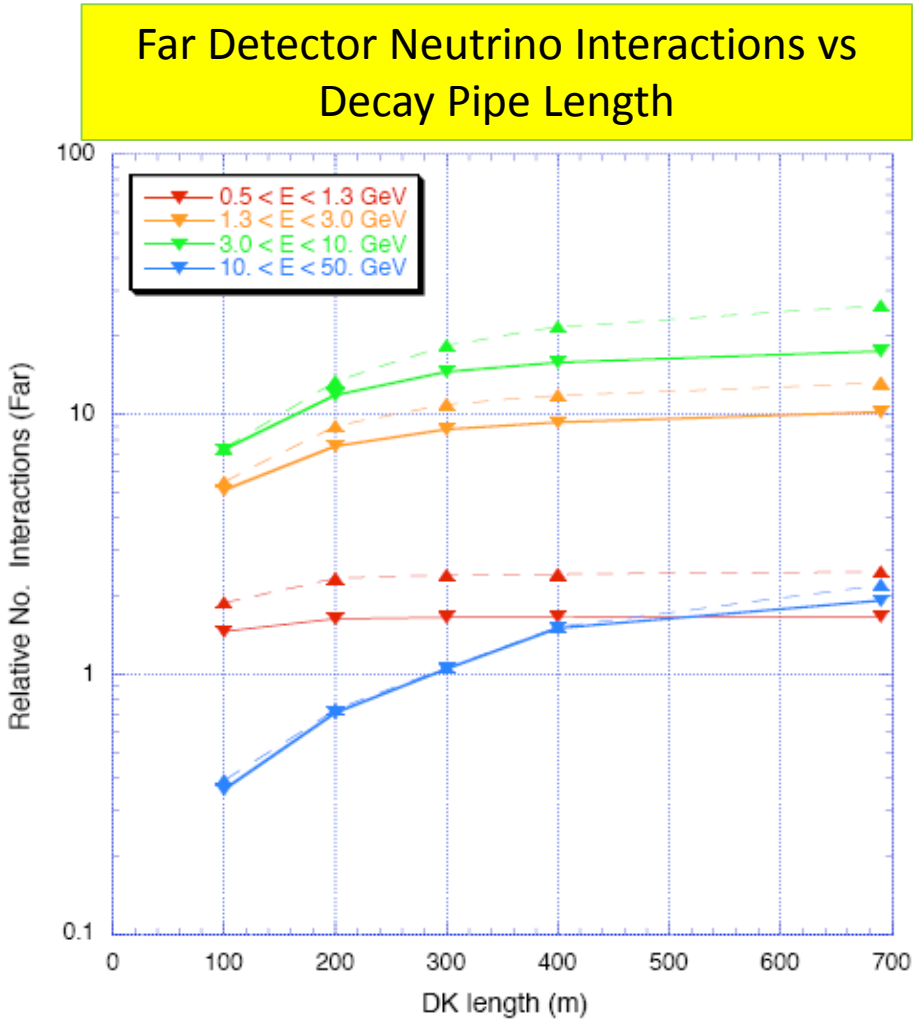
NuMI/MINOS target

Ream old weld of water-feed-through at base (not shown)
Wire EDM off old water-turn around (minimal vibration)
Clean up and make room for new connection tube (made special tool)
Micro-tig-weld new tip on
Re-weld water feed-through
Pressure leak test





Decay Pipe Considerations and Reference Design



- Dimensions: Radius of 2m. Length of 200 meters.

Real estate allows up to 250 m.

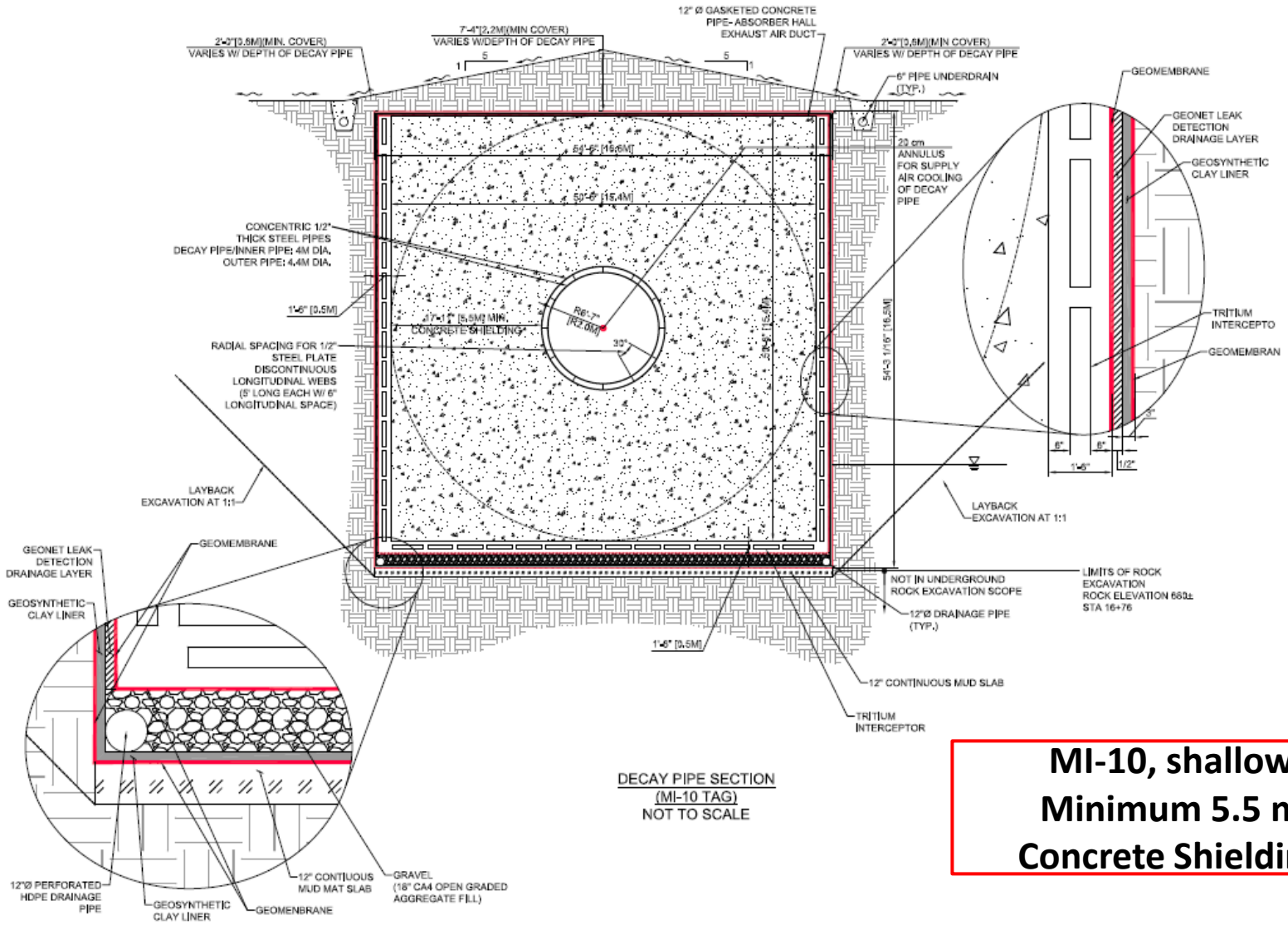
- Filling-Cooling: Air – filled and air-cooled pipe is the default.

Helium-filled pipe which is air OR water cooled and sealed-off from the target hall is an alternative.

➢ A substantial part of the decay region is in soil with limited rock excavation required.

Shielding: 5.5 m of concrete

Inflowing water collection system

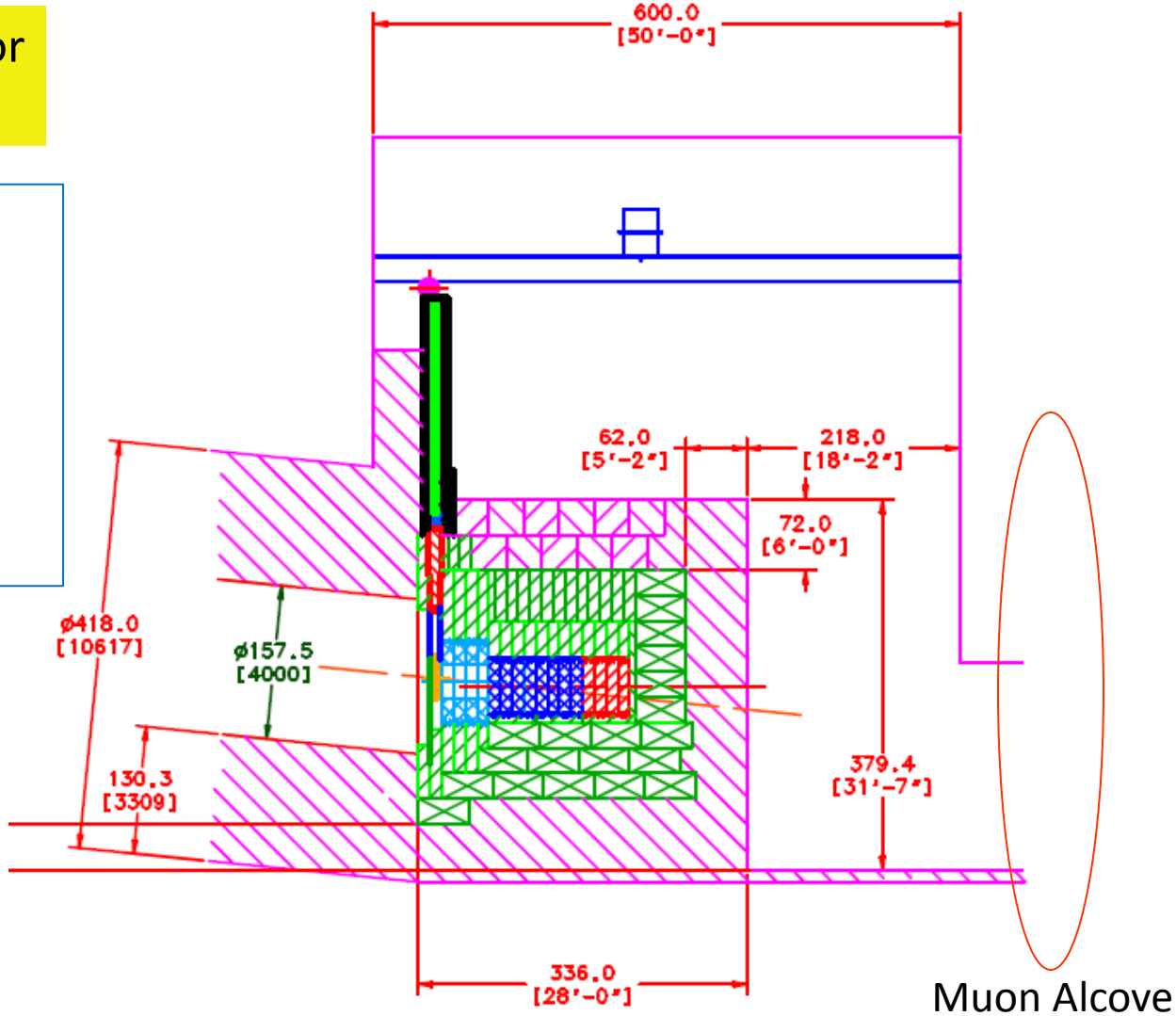


MI-10, shallow
Minimum 5.5 m
Concrete Shielding

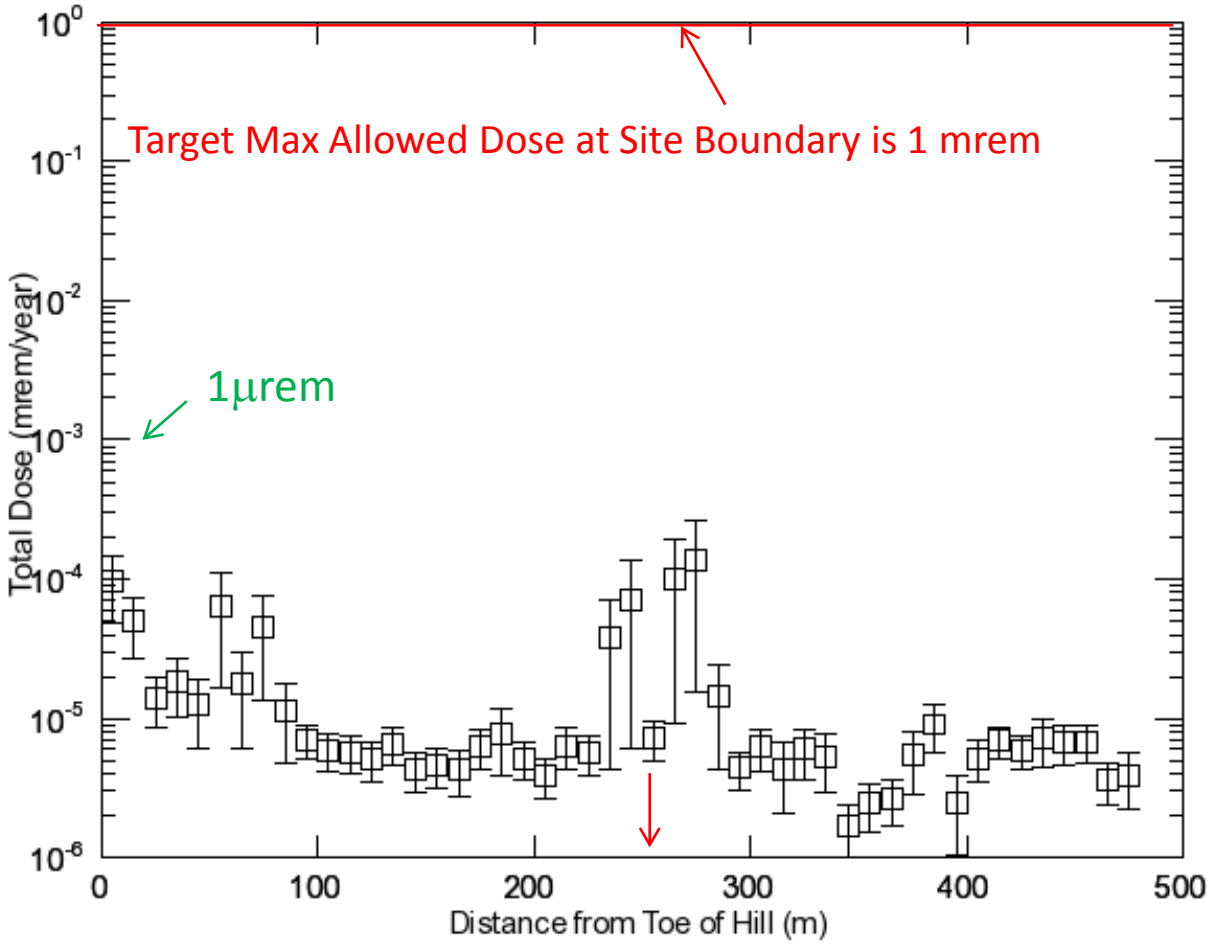
LBNE Absorber Hall (longitudinal section)

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.



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



"0" = Downstream end of decay pipe

Shielding: 5.5 m of Concrete

Interim Conclusions

While each of these first-phase options is more sensitive than the others in some particular physics domain, the Steering Committee in its discussions strongly favored the option to build a new beamline to Homestake with an initial 10 kton LAr-TPC detector on the surface.

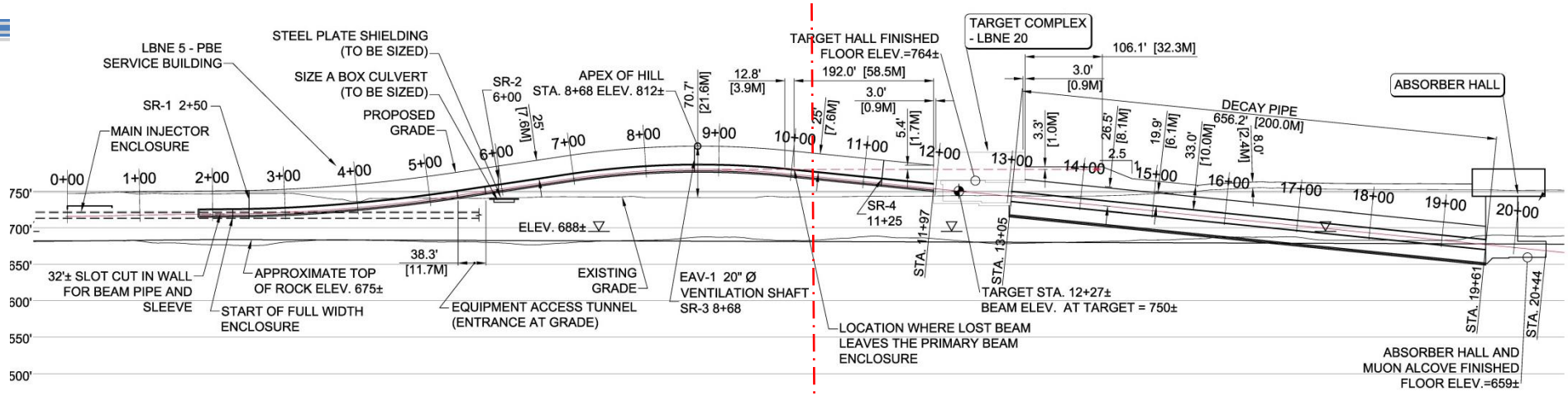
The physics reach of this first phase is very strong; more over this option is seen by the Steering Committee as a start of a long-term world-leading program that would achieve the full goals of LBNE in time and allow probing the Standard Model most incisively beyond its current state. Ultimately this option would exploit the full power provided by Project X. At the present level of cost estimation, it appears that this preferred option may be ~10% more expensive than the other two options, but cost evaluations and value engineering exercises are continuing.

Interim Conclusions

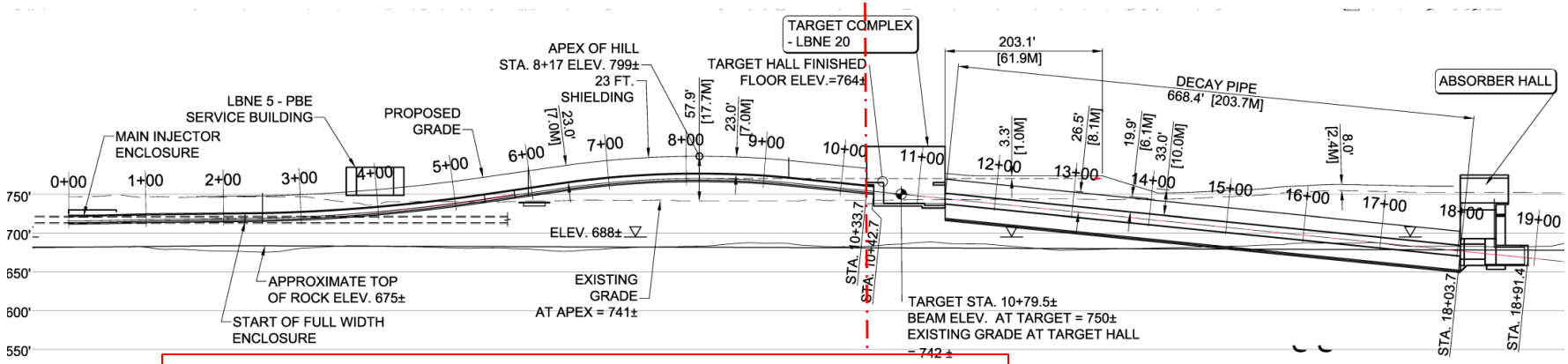
Although the preferred option has the required very long baseline, its major limitation of the preferred option is that the underground physics program including proton decay and supernova collapse cannot start until later phases of the project. Placing a 10 kton detector underground instead of the surface in the first phase would allow such a start, and increase the cost by about $135M.

Fermilab

Profile View – Ref. Design vs. Reconfig. Design



March 2012
Reference Design



- Shortened PBE by 148’
- Lowered Apex of “Hill” by 12’
- Decreased Soil Shielding from 25’ to 23’
- Steepened Side Slopes to from 22 to 30 degrees
- Decreased Max. Width of “Hill” from 365’ to 207’

July 2012
Reconfig. Design

List of Changes to Target Complex

Opportunities for cost savings - LBNE beamline conventional facilities:

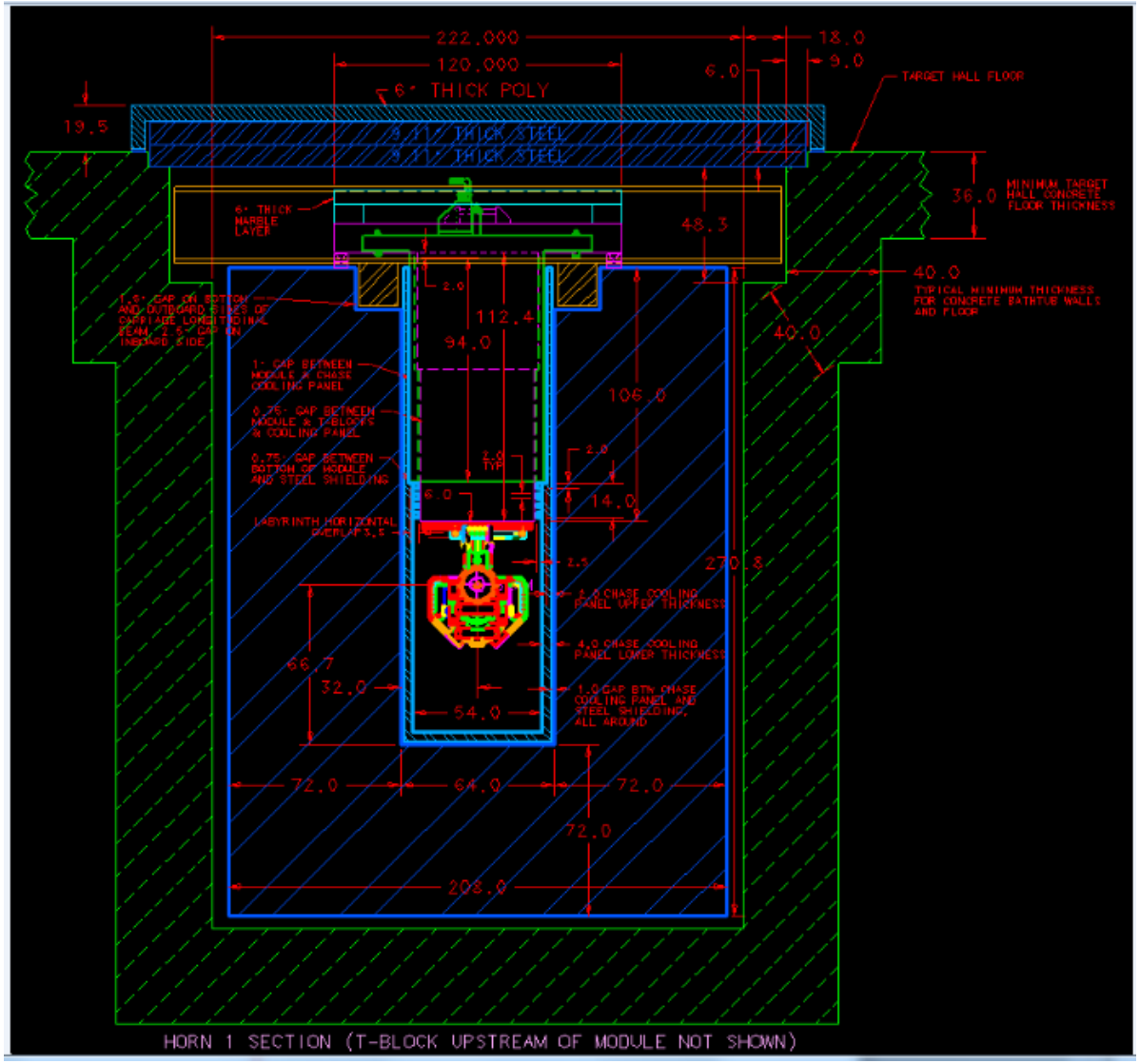
1) reduce length of TH by 35’ with respect to the CDR (from 126’ interior length of hall in the CDR to 91’ now – the length was 131’ for the Steering Committee report).
2) reduce width of TH by 5’ with respect to the CDR (the width was 56’ in the CDR and it is 51’ now – it was 52’ for the Steering Committee report).
3) reduce width of concrete bathtub that holds the target shield pile by 4’. (new)
4) omit pre-target access hatch and associated magnet transport tunnel.
5) omit module storage rack/pit. (new)
6) relocate T-block storage pit.
7) relocate work cell to beam-left side. (new)
8) decrease size of work cell (CF portion, orig size = 9’x 24’, new size = 6’x 22’). This allows no space for telemanipulators to be added later. (new)
9) reconfigured the personnel access corridor to consolidate it with the large access corridor. (new)
10) omit Remote Handling (RH) crane control room, provide space inside TH for temporary shielded RH control area. The cost of this temporary shielding will be taken care by RH technical components.
11) move all TH complex support rooms to beam-right side. (new)
12) decrease size of staging area between truck bay & morgue (orig size = 140’x 60’, new size = 90’x 60’), retain the same size 6 cell morgue. (new)

List of Changes to Target Complex

13) decrease size of RAW room (orig size = 60’x 30’, new size = 37’x 36’). (new)
14) decrease size of horn power supply room (orig size = 45’x 30’, new size = 30’x 38’). (new)
15) decrease size of CF electrical/mechanical rooms (orig size = 81’x 70’ [x2, in two floors], new size = 55’x 38’ [x1, in one floor])
16) omit maintenance cell (CF portion) & associated 15 ton crane
17) reduce thickness of TH concrete roof by 1.5’, from 7’ to 5.5’. This is appropriate for 700 kW only. We will still need 7’ of concrete for 2.3 MW operation.
18) reduce thickness for some of the support room concrete walls by 2’, from 3’ to 1’.
19) add target chase bathtub waterproof liner.
20) minimize footprint of TH complex that is founded to bedrock. (additional reduction in this version)
21) reduce size of air-handling unit & associated ducting from 125k cfm to 85k cfm. (new)
22) decrease cast-in-place bulk steel shielding near downstream end of target chase. The M&S for this is under Shield Pile in technical components and the installation cost under CF. (new)
23) redesign TH complex into 3 story structure:
(1 = Air Handling room, 2 = RAW & Horn Power Supply rooms, 3 = Mechanical/Electrical room). (new)

Possible CF TPC Cost Savings (FY 2010 $): at least $30.0 M [2, 3]

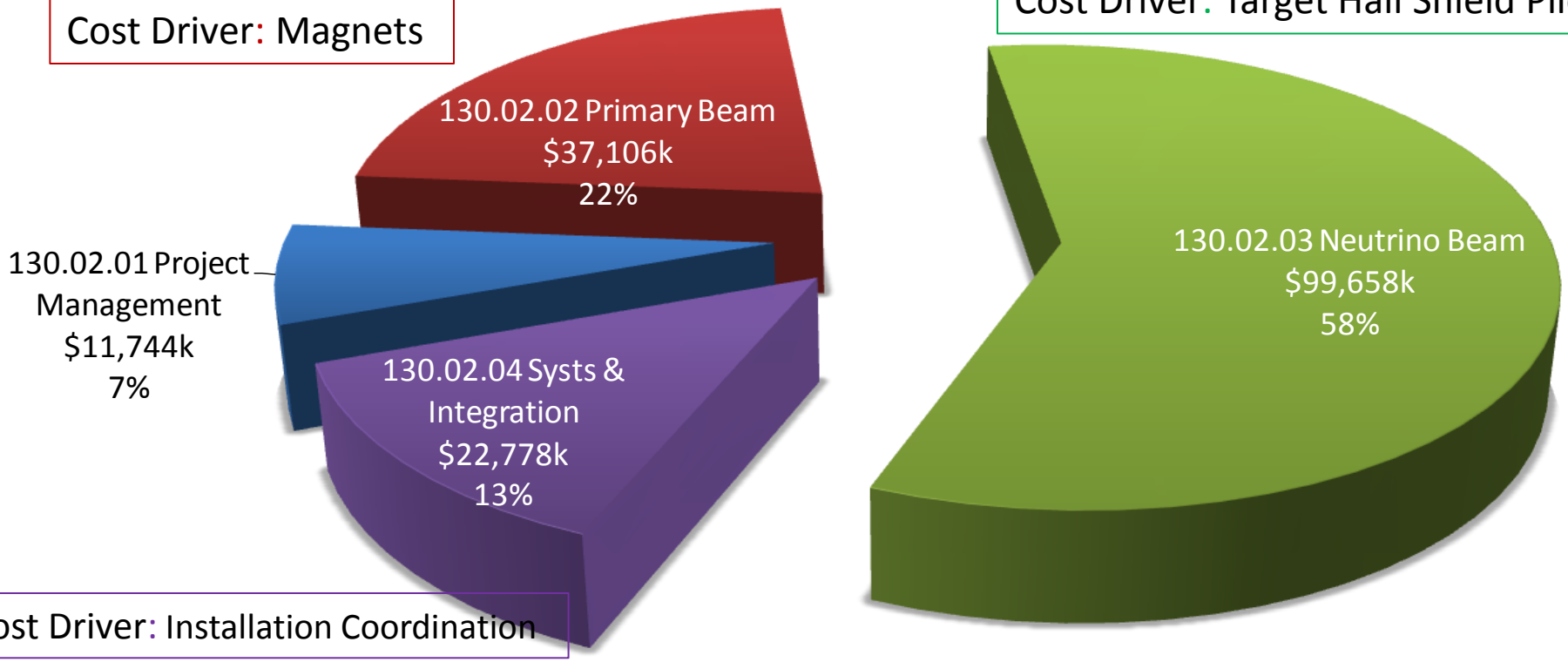
The LBNE target chase – Horn 1 cross section



Beamline Cost Summary Chart

Cost Driver: Magnets

Cost Driver: Target Hall Shield Pile



Cost Driver: Installation Coordination

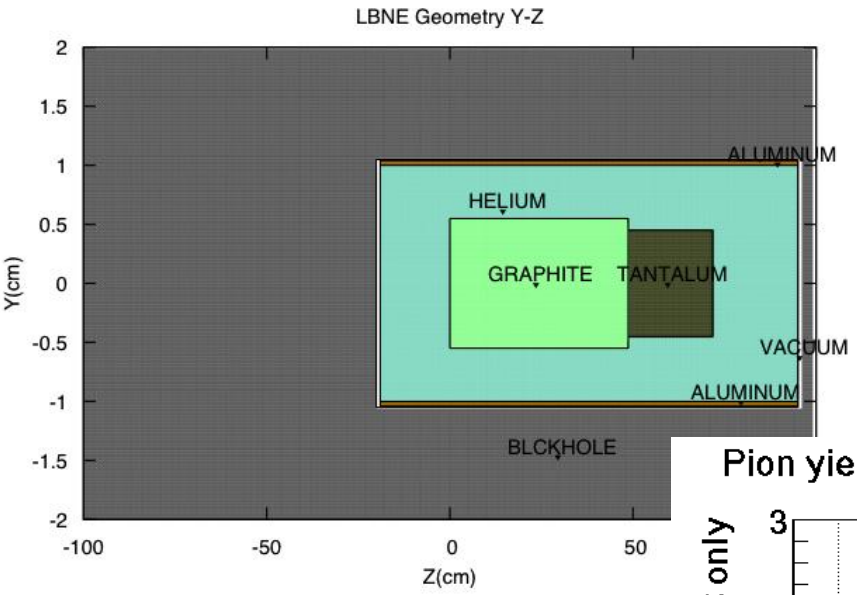
WBS - Level 3	Labor (inc. cont.)	M&S (inc. cont.)	TPC	E.U. Contingency %
130.02.01 Project Management	11,354	390	11,744	16.4%
130.02.02 Primary Beam	16,729	20,378	37,106	21.1%
130.02.03 Neutrino Beam	51,601	48,057	99,658	35.4%
130.02.04 Systs & Integration	17,945	4,833	22,778	22.8%
Total Project Cost (k$)	**97,629**	**73,658**	**171,286**	**28.9%**

TPC as shown is in k$, FY10

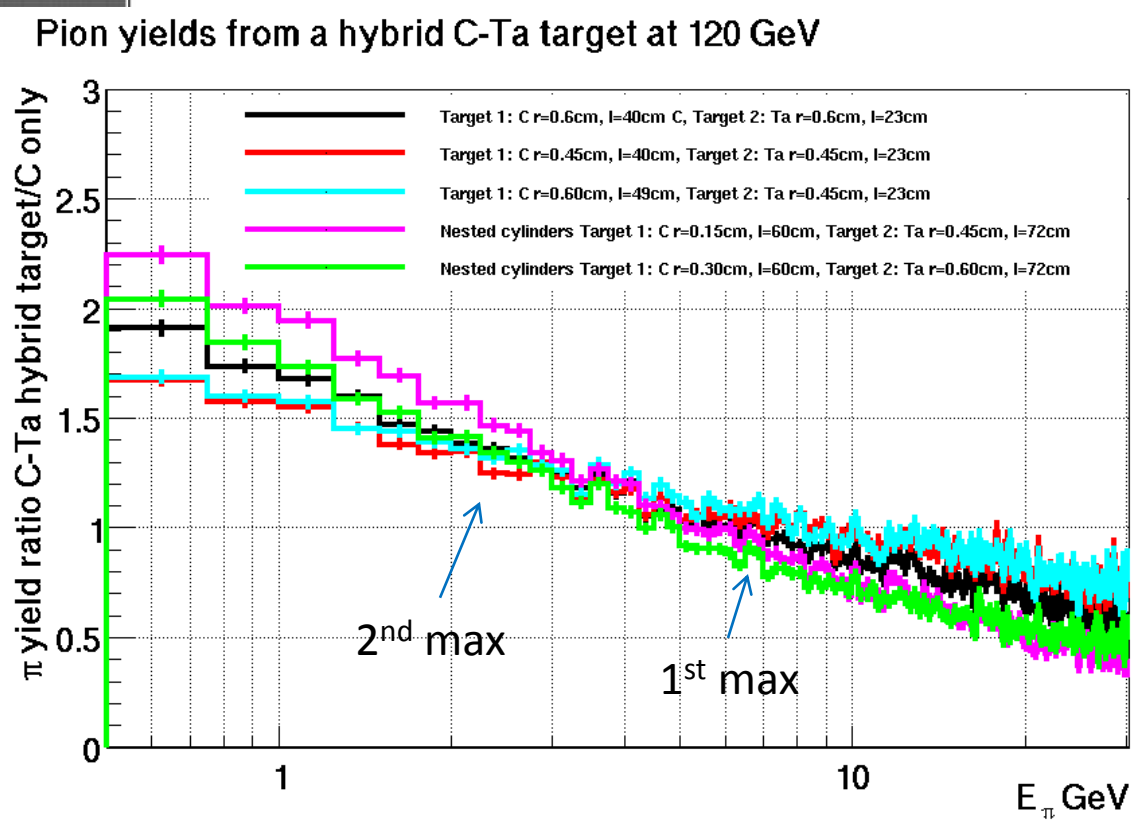
Graphite R&D

- 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%.

Be target R&D

700 kW Beam Power Target Summary

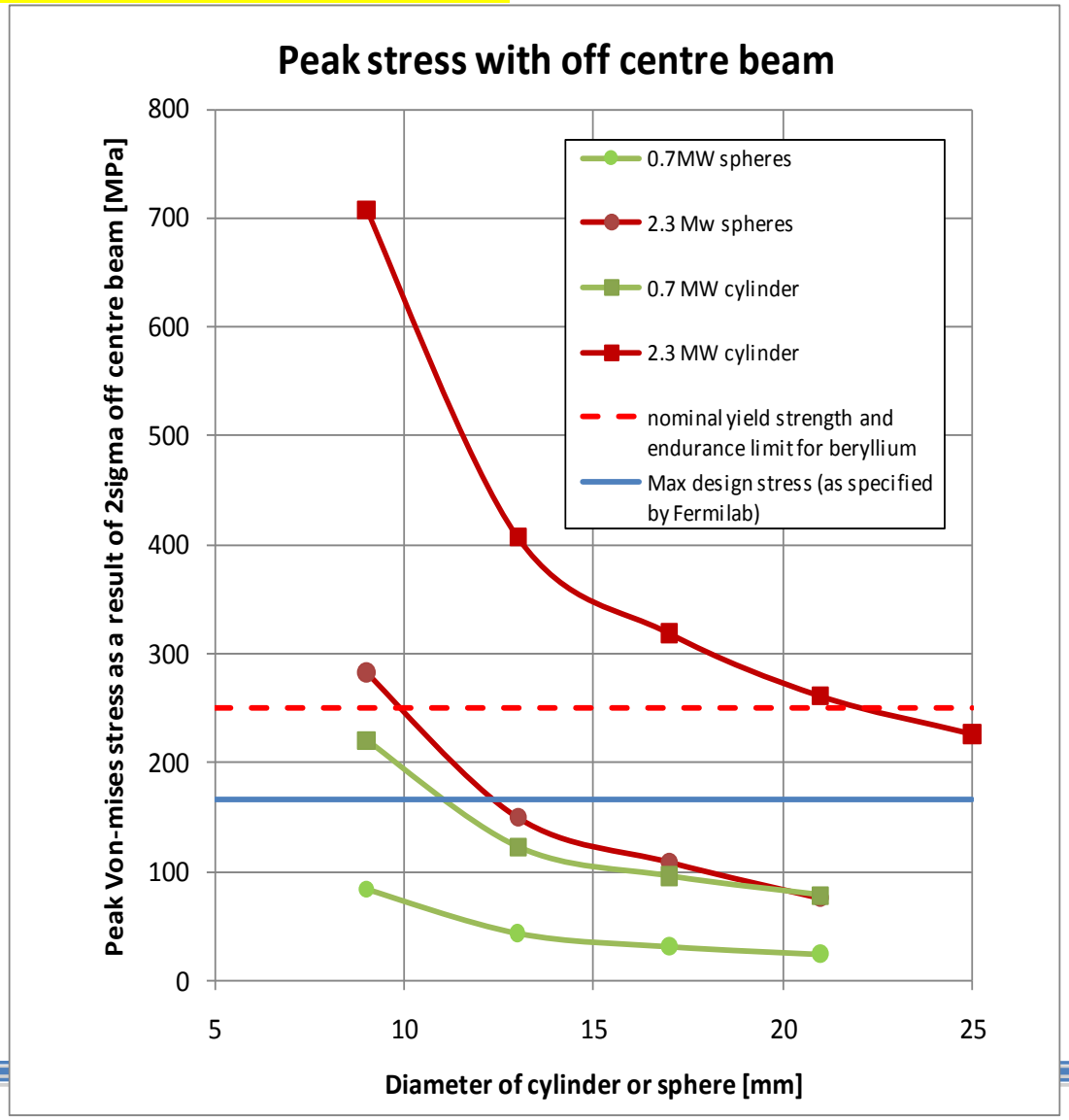
For 700 kW operation of a 13 mm diameter 1 m long beryllium cylinder fixed at one end and constrained radially at the other end with a 2.16 mm beam sigma falls inside the chosen design point stress. The maximum deflection for this case has been calculated as 0.6 mm near the centre of the target. A series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

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

Be target R&D

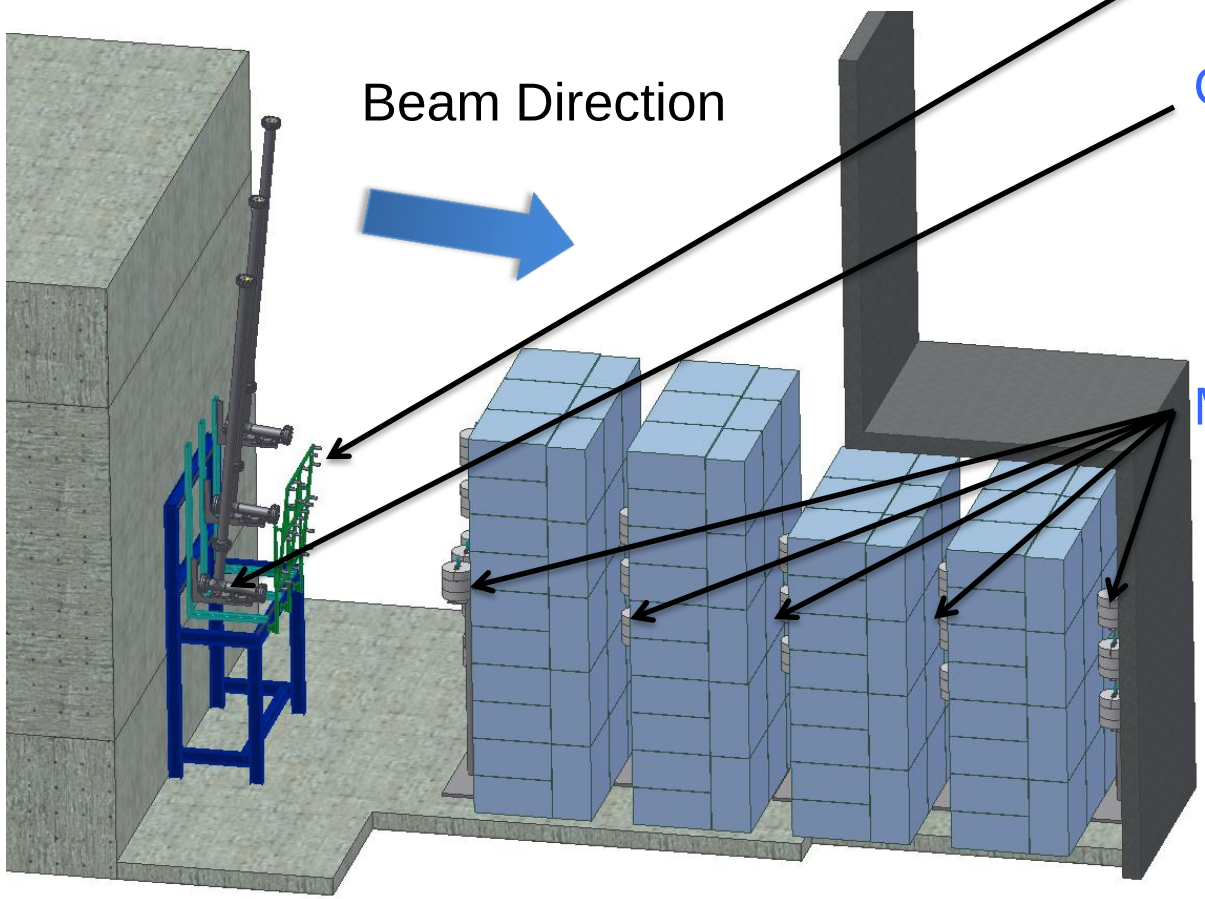


C. Densham et al. RAL report, LBNE docs 2400/3247, Nov. 2010

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

Three Beamline Measurement Systems



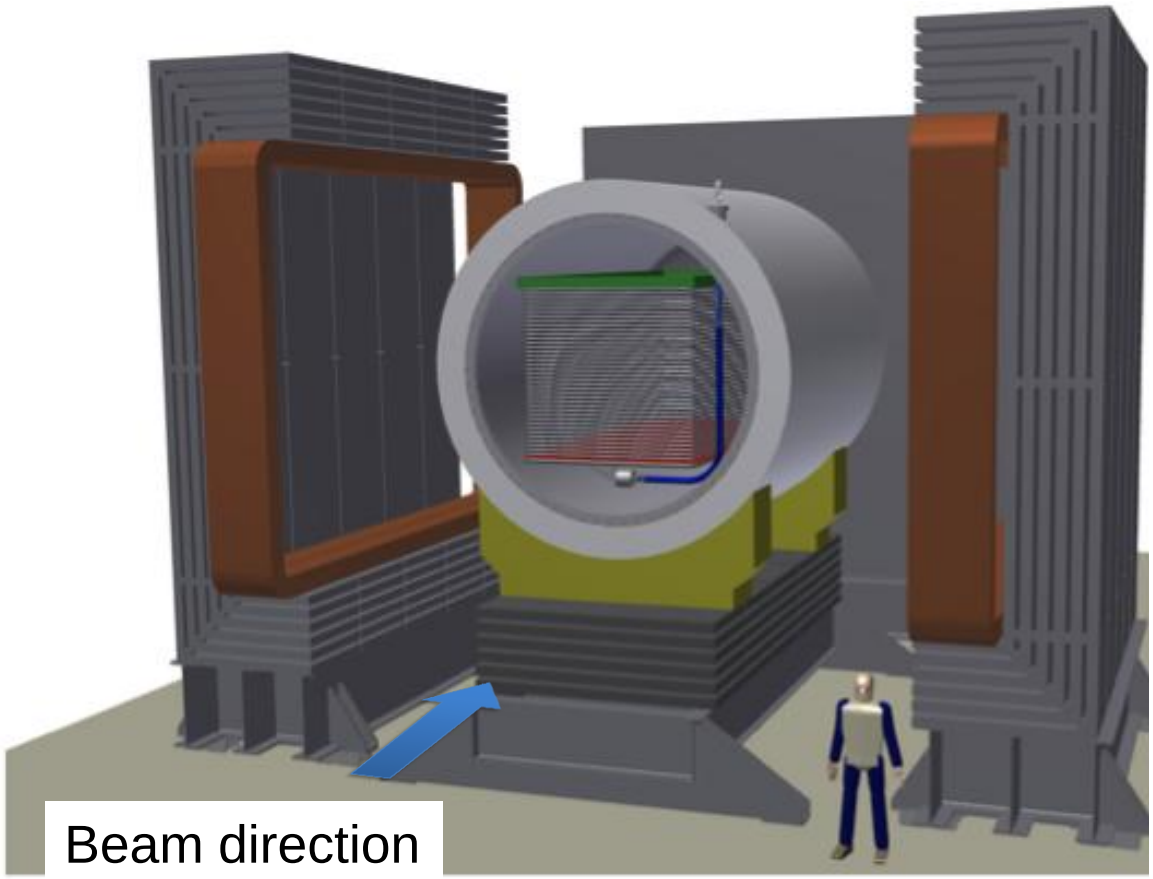
Ionization Chambers:
- spill-by-spill beam profile

Cherenkov Detectors:
- measure all muons above a variable threshold
- constrains muon spectrum (correlated with E_ν)

Michel Decay Detectors:
- measure muons that stop at a given depth in material
- constrains muon spectrum
- may give absolute flux constraint

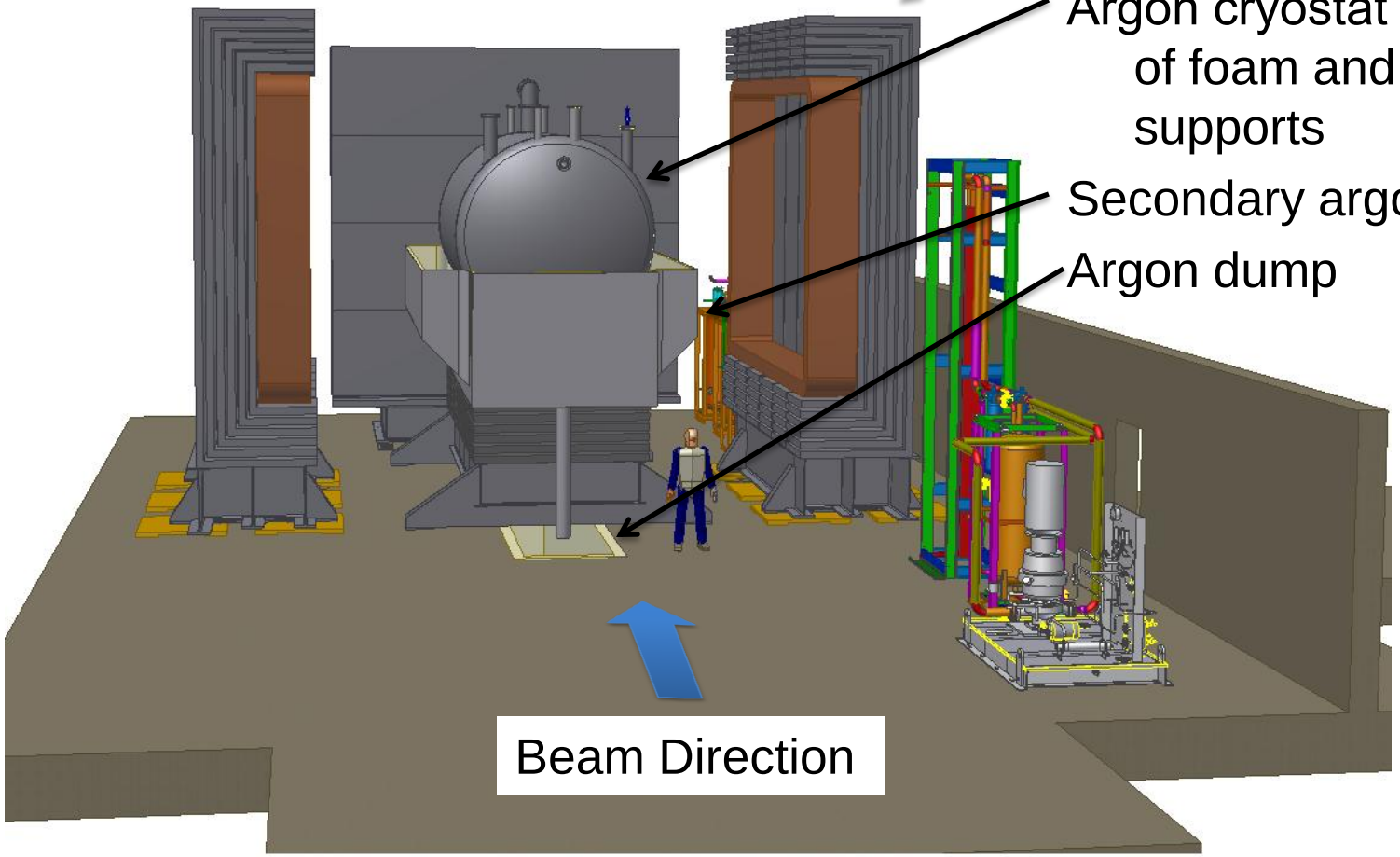
Includes planning measurements of hadron production on materials from which the target and horns are composed in external beamlines

Magnetized Liquid Argon TPC



- Based on MicroBooNE design
- 4.0m x 1.8m x 1.8m active volume – 18 tons of liquid argon
- Tracks charged particles
- Electromagnetic calorimetry
- 0.4 Tesla field
- Sign of muons, momentum for long tracks
- Downstream/side detectors in steel layers for muon/pion separation

Liquid Argon TPC in the Hall



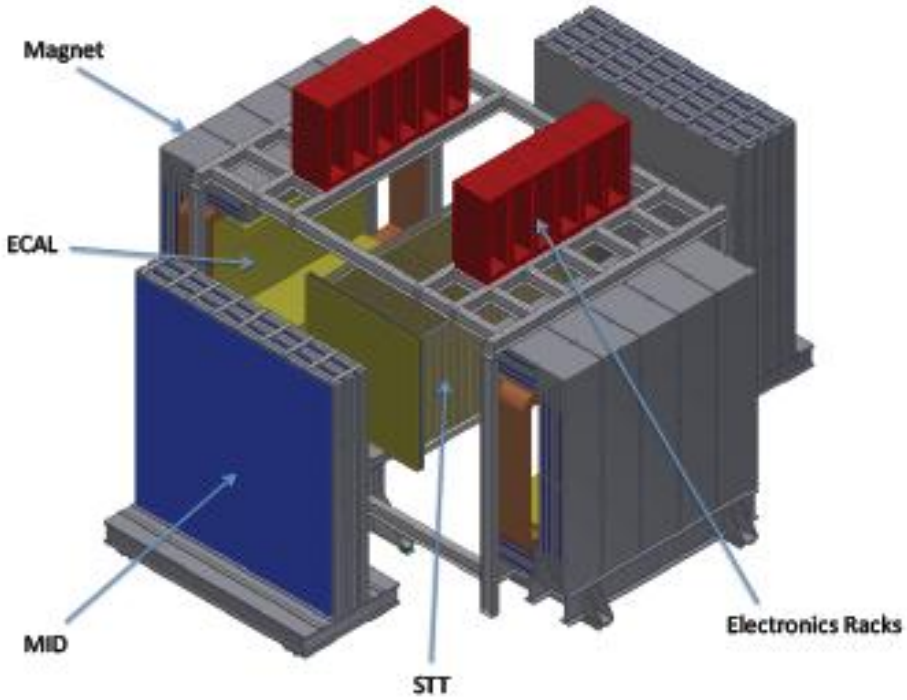
Magnet design based on the UA1 magnet

Argon cryostat encased in 16” of foam and sits on foam supports

Secondary argon containment

Argon dump

Alternative Design Near Detector (FGT)



Fine Grained Tracker

Inside a large 0.4 T dipole magnet