LBNE Status

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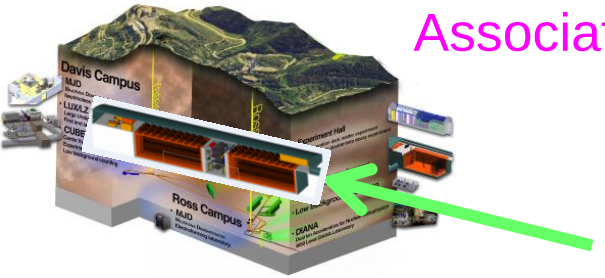

Lead, South Dakota

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Outline

- LBNE Scientific Goals
- LBNE History and Milestones
- LBNE Project Scope
- Scientific capabilities
- Recent Beamline Scope Changes
- Beamline Design Overview
- Summary and Conclusions

LBNE Science Goals

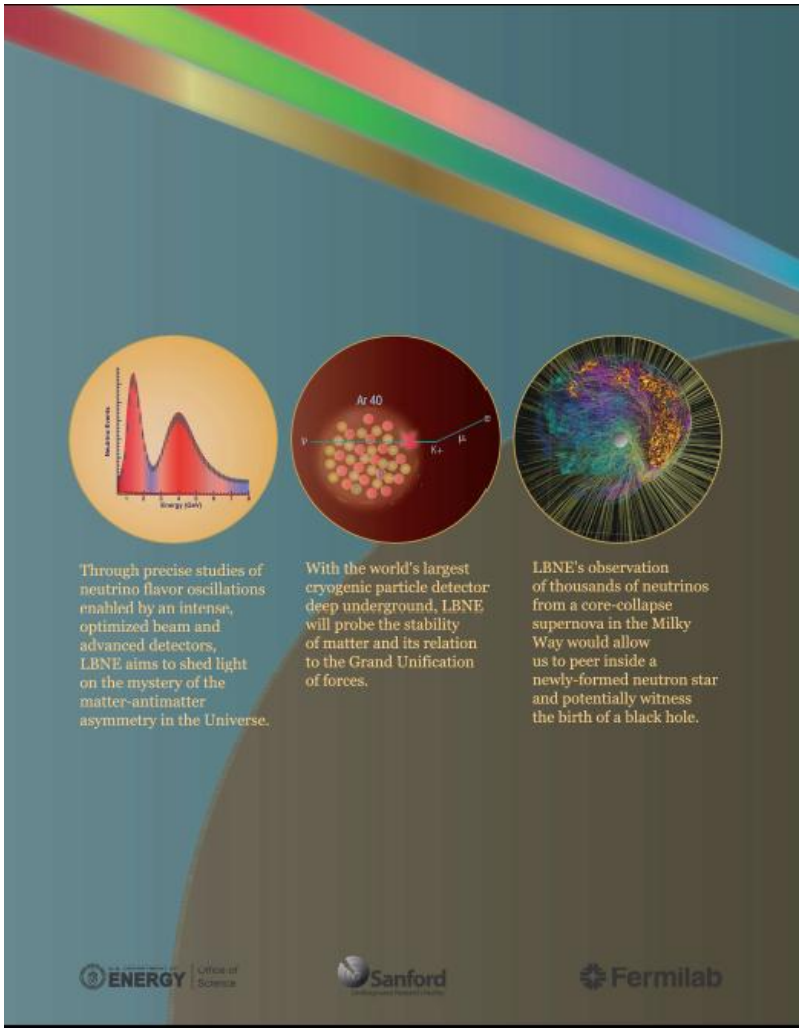
LBNE is a comprehensive program to:

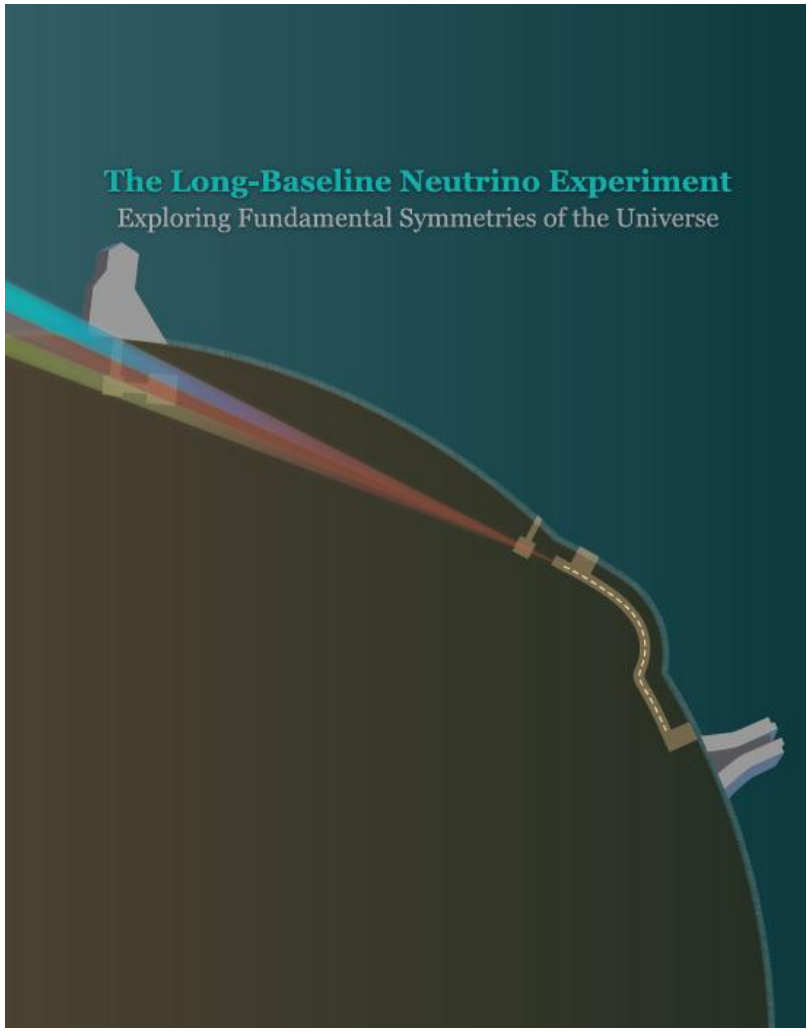
- Measure neutrino oscillations
  - Direct determination of CP violation in the leptonic sector
  - Precise measurement of the CP phase δ
  - Determination of the neutrino mass hierarchy
  - Precision measurement of the mixing angle θ_{23} including determination of its octant
  - Testing the 3-flavor mixing paradigm
  - Precision measurements of neutrino interactions with matter
  - Searching for new physics
- Study other fundamental physics enabled by a massive, underground detector
  - Search for nucleon decays
  - Measurement of neutrinos from core collapse supernovae
  - Measurements with atmospheric neutrinos
- Study the physics enabled by a precision near detector
  - Neutrino cross sections, EW precision measurements, nuclear physics in the transition region to QCD, etc.

LBNE Science Book

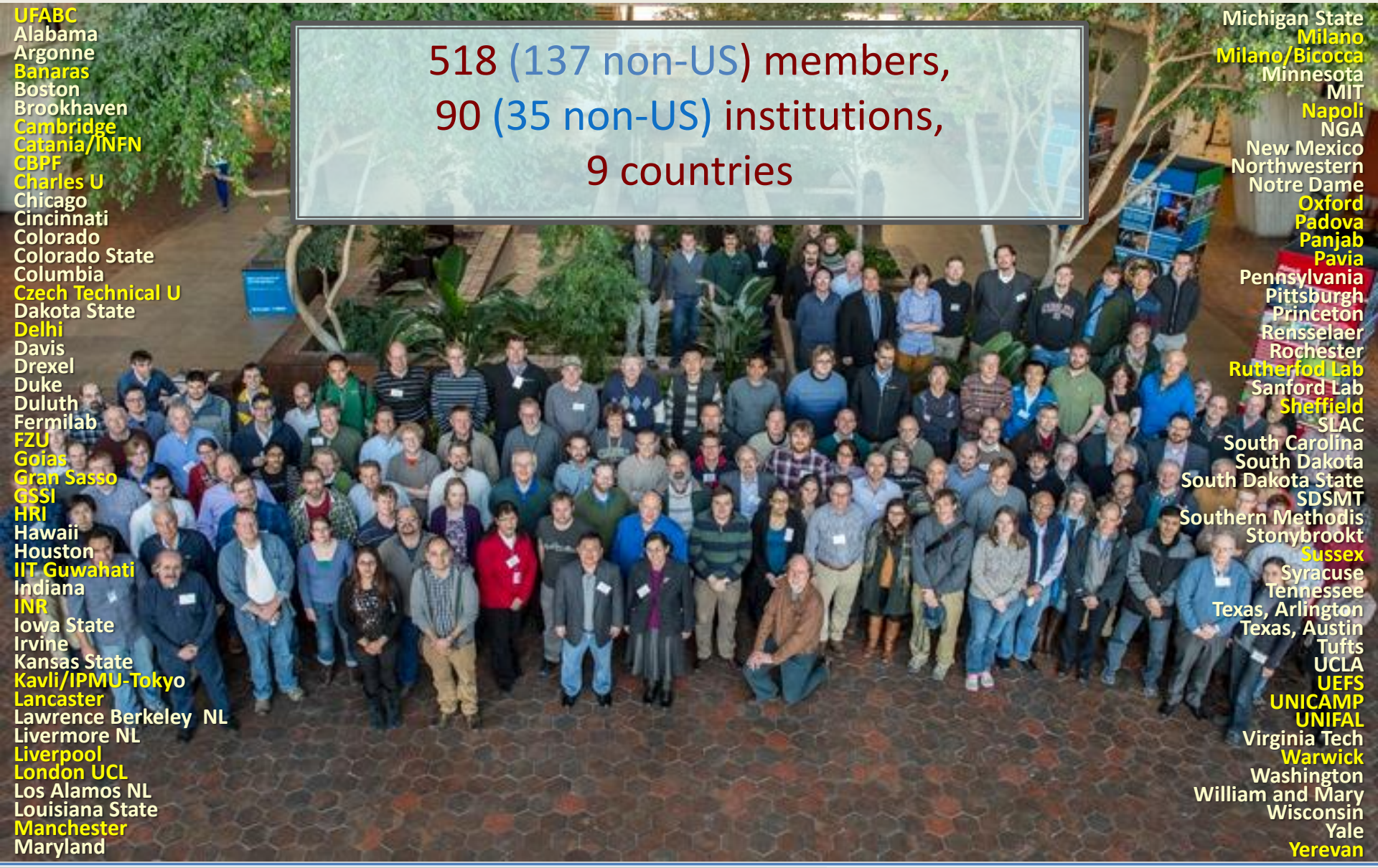
http://lbne.fnal.gov/

The LBNE science program is described in detail in: arXiv:1307.7335v3 [hep-ex], 22 Apr 2014





LBNE Collaboration



The Beamline Team and collaborative activities

- From Fermilab's Accelerator, Particle Physics and Technical Divisions, FESS (Facil. Eng.) and ES&H Sections and Accelerator Physics Center.
- A twenty five member Technical Board.
- University of Texas at Arlington (Hadron Monitor)
- STFC/RAL (target)
- Bartoszek Eng. (Contract on baffle/target and horn support modules)
- RADIATE Collaboration
- US-Japan Task force (radiation damage, non-interactive profile monitor, kicker magnets)
- IHEP(China)
- CERN
- Six contracts completed already with ANL, BNL, IHEP (Protvino, Russia), STFC/RAL, ORNL, Design Inovations.

Neutrino Program at Fermilab

LBNE History and Milestones

- The 2008 P5 (Particle Physics Project Prioritization Panel) recommends the Long Baseline Neutrino Experiment as "*core component of the US program*".
- DOE issues a Mission Need for a Long Baseline Neutrino Experiment in Sept. 2009 and Critical Decision-0 (CD-0) is approved on January 8, 2010.
- Successful Director's Review of the full-scope LBNE (26-30 Mar. 2012). This was for a 700 kW - 2.4 MW ν source at Fermilab and a 34 kton LAr TPC, 1,300 km away, at the 4,850-ft level of the Sanford Underground Research Facility (SURF) in the former Homestake Mine. (Alternative sites were considered and discarded).
- Office of Science in DOE asking that LBNE is staged (19 Mar. 2012).
- A three month "Reconfiguration" process and recommendation for a phased LBNE (Aug. 6, 2012).
- Successful Director's Review of the Phase 1 LBNE Project (Sept. 2012)
- Successful DOE CD-1 Independent Project/Cost Reviews (Oct.- Nov., 2012).

LBNE History and Milestones

- CD-1 approved, December 10, 2012, with initial funding of $867 M and with a surface 10 kton far detector.

Tailoring of the scope definition prior to CD-2 to enhance scientific capabilities may also be considered. The physics opportunities offered by the beam from Fermilab and the long baseline may attract the support of other agencies both domestic and international. Contributions from such other agencies offer alternative funding scenarios that could enhance the science capabilities of the Project. If additional domestic or international funding commitments are secured sufficiently prior to CD-2, the DOE LBNE Project baseline scope could be refined before CD-2 to include scope opportunities such as a Near Neutrino Detector complex at Fermilab or an underground location at SURF for the far detector.

- Summer 2013: After the Snowmass Meeting, surface option for the Far Detector is discarded. DOE funding to be applied to an initial phase project with a Near Detector and a 10 kton LAr TPC at SURF.
- May 2014: P5 report
- LBNF is now being formulated as a more ambitious long-baseline neutrino project, international from its conception, with the neutrino source at Fermilab.

Importance of LBNE Science and the P5 Report

The LBNE science has been recognized to be top priority:

- Report of the Snowmass 2013 summer study
- European strategy for Particle Physics (update of 2013)
- P5 report, May 2014

The Science Drivers:

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles

P5 Report, May 2014

- The U.S. should host a world-leading neutrino program.
  - An optimized set of short- and long-baseline neutrino oscillation experiments, with the long-term focus on the Long Baseline Neutrino Facility (LBNF).
  - The Proton Improvement Plan (PIP-II) project at Fermilab would provide the needed neutrino physics capability.

- **Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.**

Evolving Scope of the LBNE Project

- LBNE is developing as an international partnership, with the goal of delivering an initial project consisting of:
  - A broad band, sign-selected neutrino beamline, operating initially at 1.2 MW,
  - A highly-capable near detector system,
  - A ≥10 kt fiducial mass far detector underground at SURF, 4850 ft deep (1,300 km baseline)
  - Conventional facilities including a cavern at the far site for a ≥ 35 kt fiducial mass far detector system.
  - The designs of the near and far detectors and of the beam will incorporate concepts from new partners.
- The planned project allows for future upgrades:
  - The beamline is designed to be upgradeable up to 2.4 MW proton beam power.
  - Future far detector module(s) can be installed in the underground cavern.

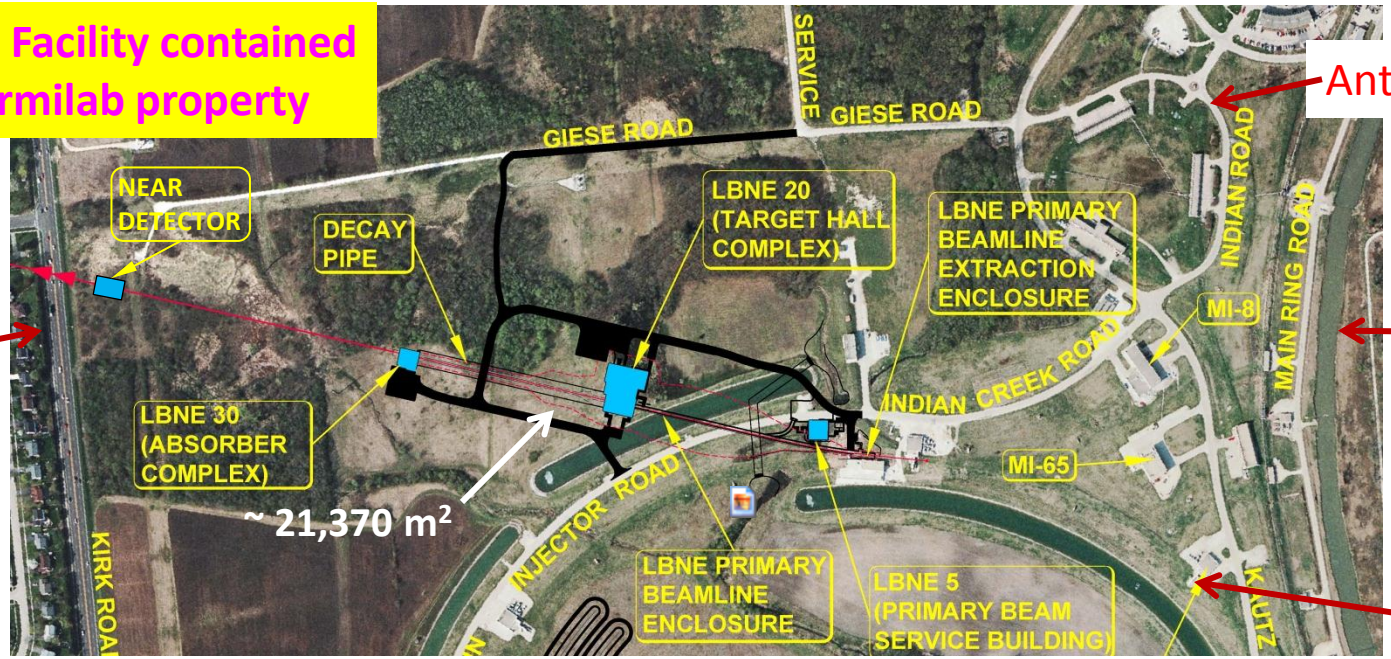
LBNE Since CD-1

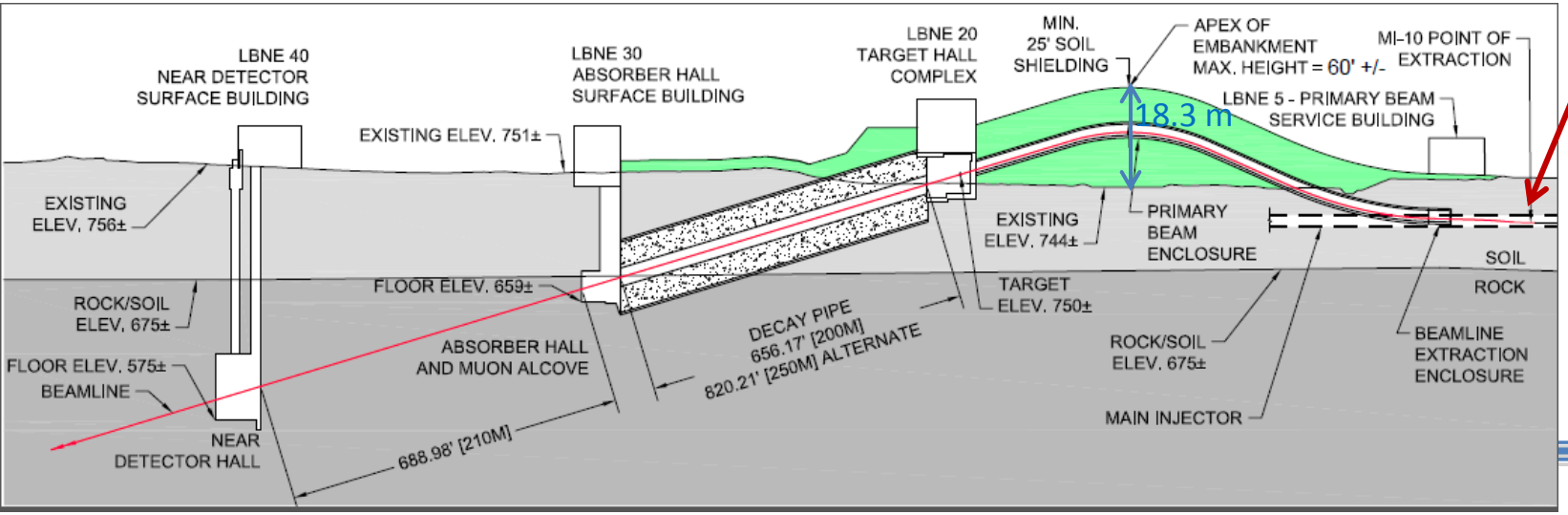
- We have evolved the project
  - To establish a reference scope for what might become an international project
  - To establish the associated cost/schedule/risk
  - Tracking through an internal change control process

CD-1 SCOPE		CURRENT REFERENCE SCOPE
10kt Surface detector	→	10kt underground detector, 4850 ft deep
No near neutrino detector or facility	→	Fine grain tracker and its Conv. Facility (CF)
700kW initial beam	→	1.2MW initial beam
CF FS for 10kt surface detector	→	Excavation for 34kt, outfitting for 10kt

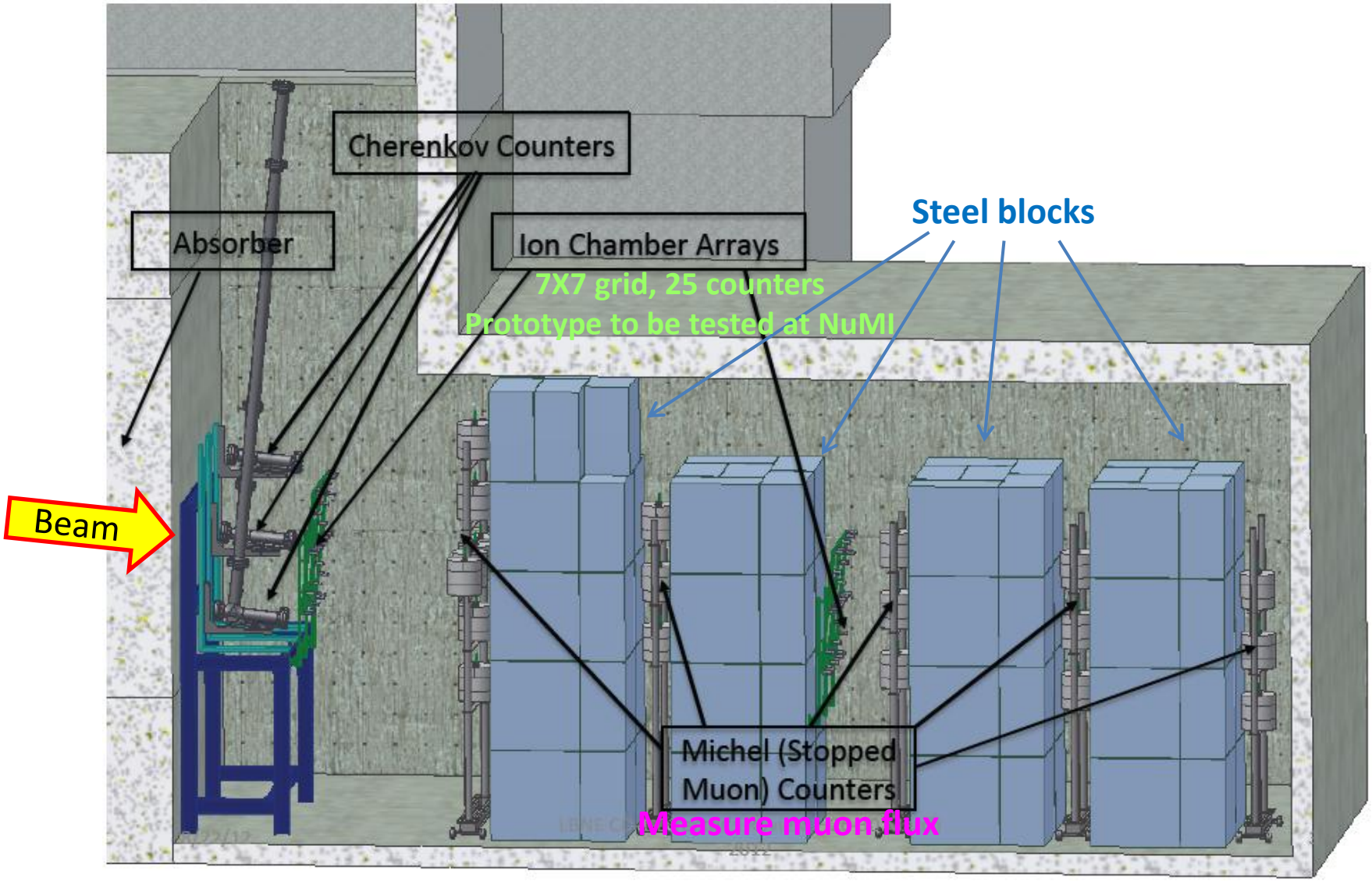
LBNE Beamline Reference Design: MI-10 Extraction, Shallow Beam

Beamline Facility contained within Fermilab property



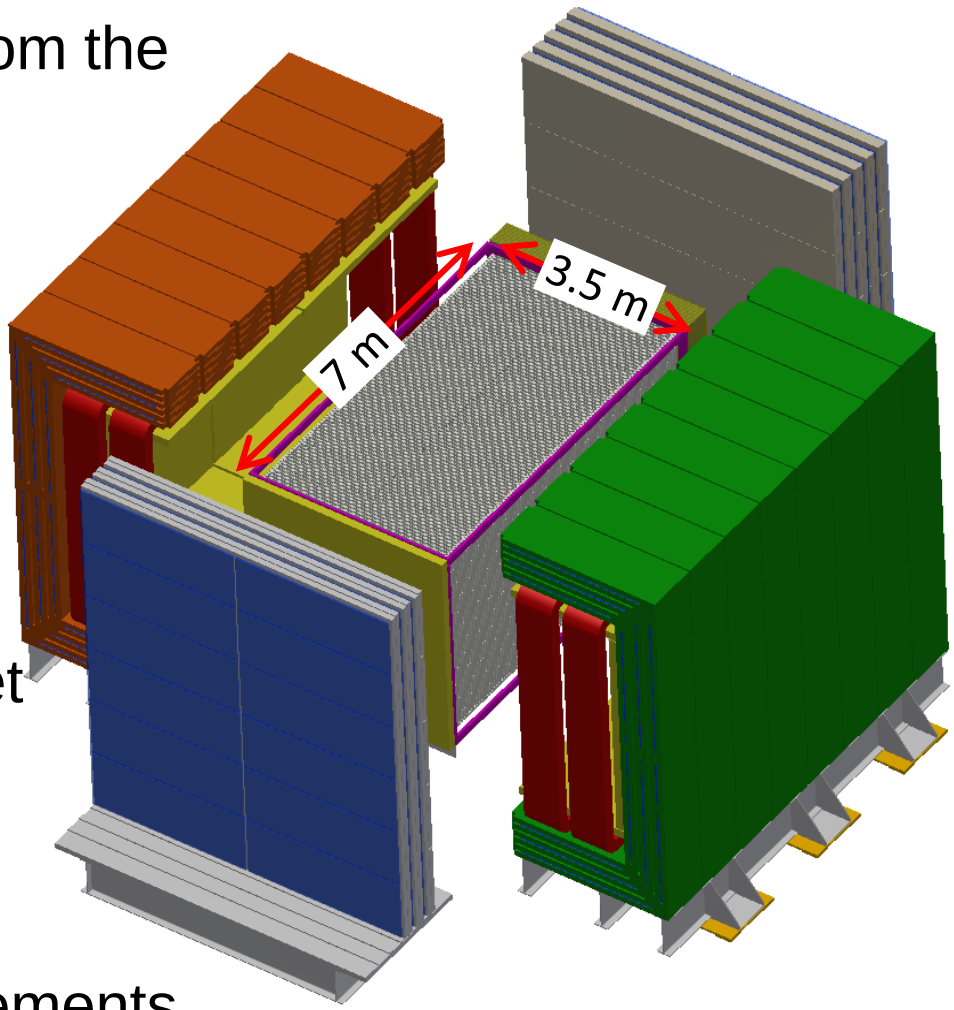


Near Detector Complex: Tertiary Muon Monitor System



Near Detector

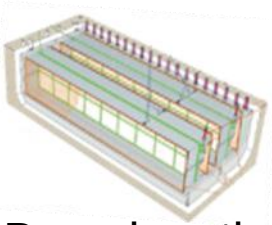
- Proposed by collaborators from the Indian institutions
- High precision straw-tube tracker with embedded high-pressure argon gas targets
- 4π electromagnetic calorimeter and muon identification systems
- Large-aperture dipole magnet
- Considering addition of LAr TPC or GAr TPC "active target"
- Design and potential improvements considered in an open workshop 28-29 July, 2014



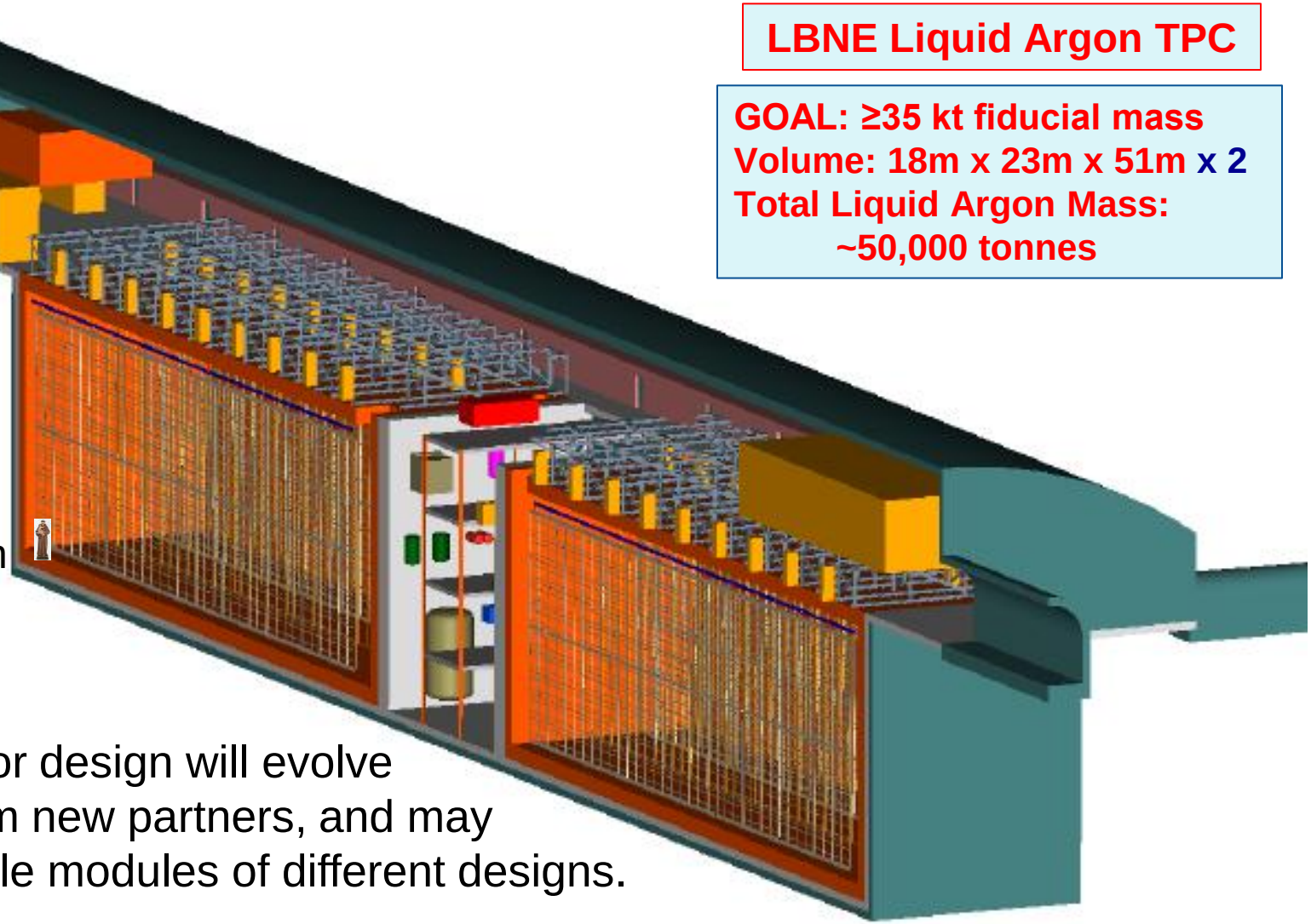
Far Detector

LBNE Liquid Argon TPC

GOAL: ≥35 kt fiducial mass
Volume: 18m x 23m x 51m x 2
Total Liquid Argon Mass:
~50,000 tonnes

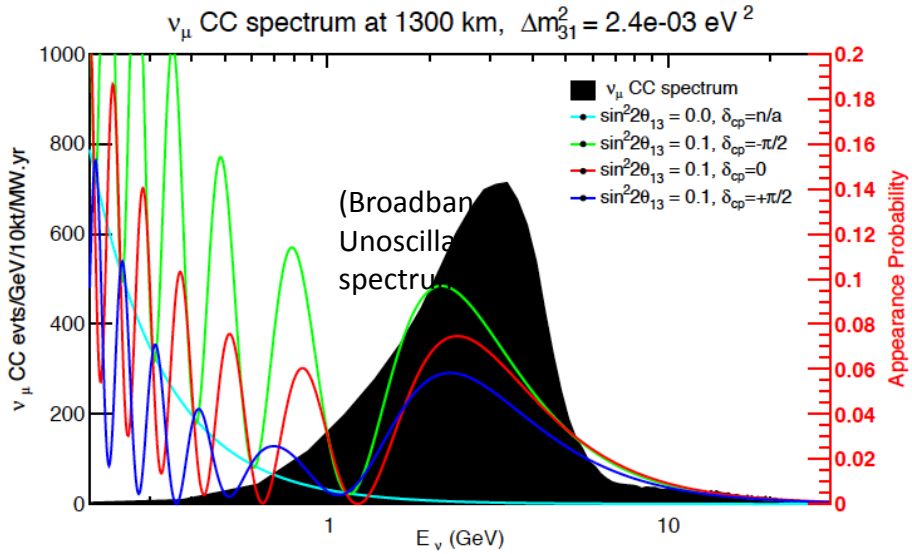


Based on the ICARUS design



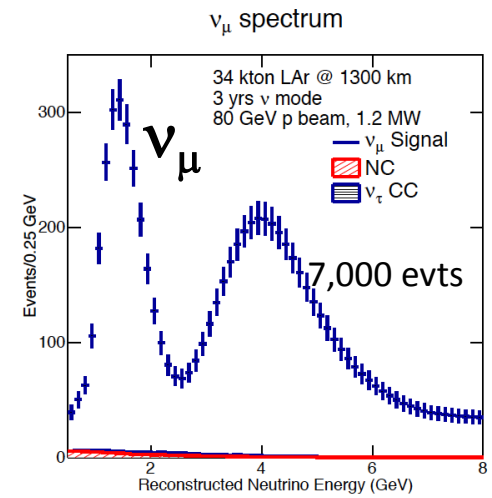
Actual detector design will evolve with input from new partners, and may involve multiple modules of different designs.

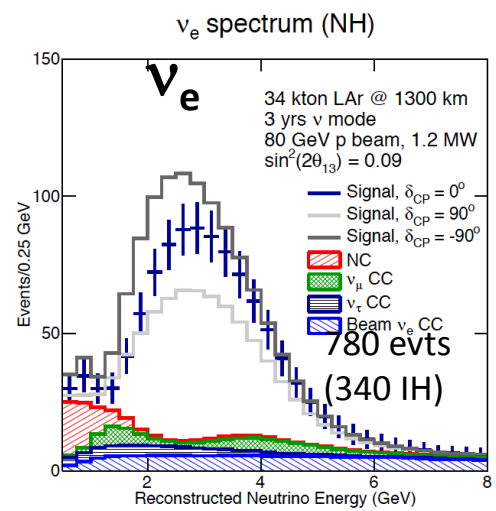
Essential Experimental Technique



disappearance

appearance





- Produce a pure ν_μ muon-neutrino beam with energy spectrum matched to oscillation pattern at the chosen distance
- Measure spectrum of ν_μ and ν_e at a distant detector
- **LBNE is a near optimal choice of beam and distance for sensitivity to CP violation, CP phase, neutrino mass hierarchy and other oscillation parameters *<u>in same experiment</u>***

Mass Hierarchy and CP Violation Sensitivity

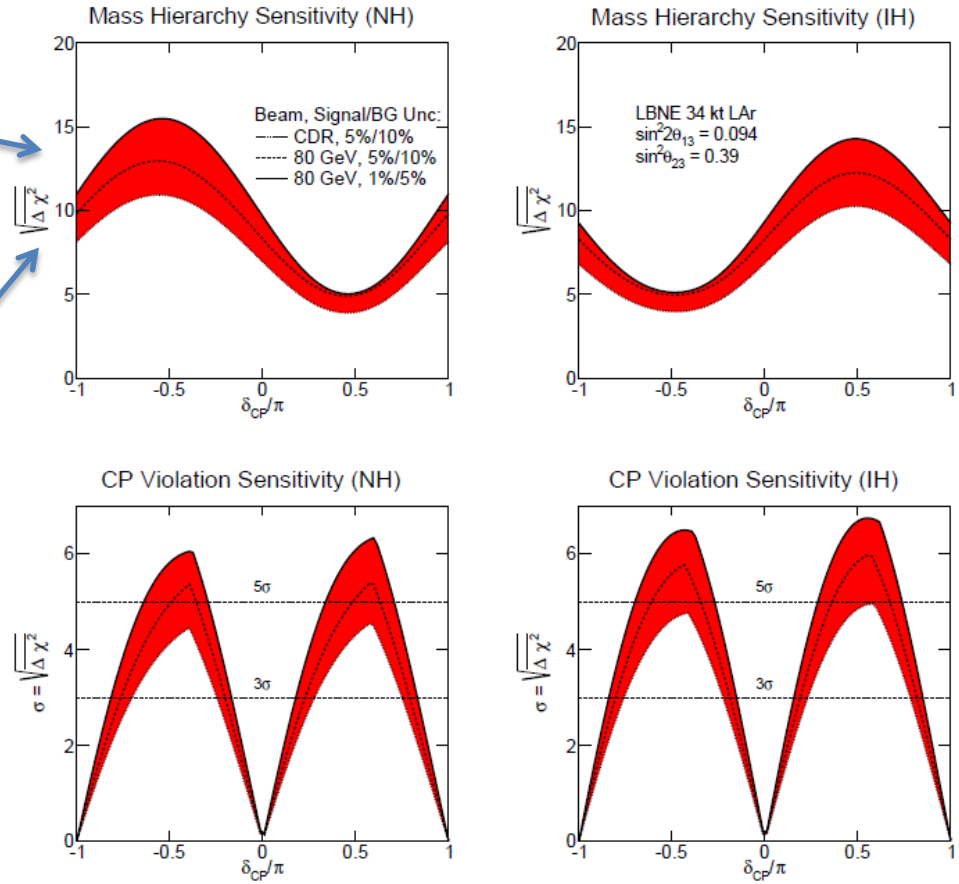
Exposure 245 kt.MW.yr

34 kt x 1.2 MW x (3$\bar{\nu}$+3ν) yr

Optimized beam & systematics goal

Band is range of beam and systematics assumptions

Unoptimized beam & poor systematics



- Mass hierarchy is very well determined over most of δ_{CP} range
- CPV > 3σ over most of range and > 5σ for maximal CPV
- Atmospheric neutrinos in LBNE provide ~1σ increased CPV sensitivity if combined with beam

LBNE Beam Operating Parameters

LBNE Beamline Design Parameters Spreadsheet

LBNE-doc -9277

Summary of Key Beamline Design Parameters for ≤1.2 MW and ≤2.4 MW Operation

This spreadsheet summarizes the key design parameters for the LBNE Beamline at ≤1.2MW and ≤2.4MW Operation

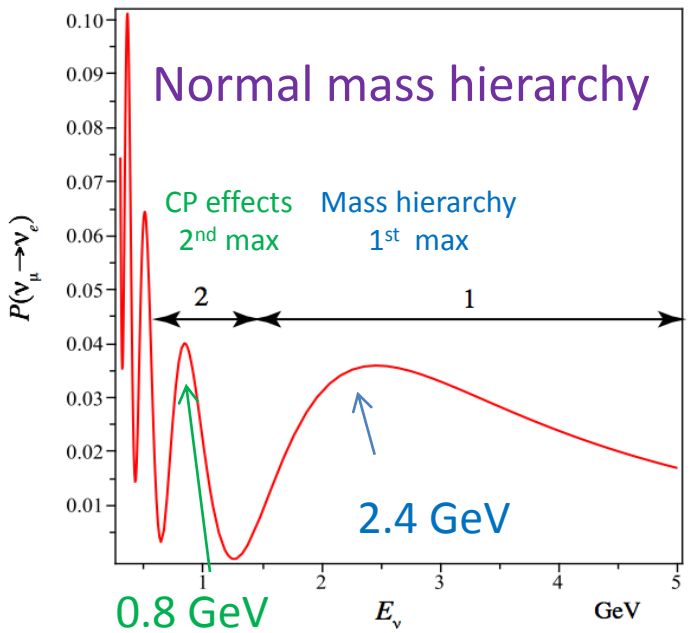
Pulse duration: 1x 10^{-5} sec

Beam size at target: tunable 1.0-4.0 mm

Parameter	Protons per cycle	Cycle Time (sec)	Beam Power (MW)	Source/Ref	Notes
≤ 1.2 MW Operation - Current Maximum Value for CD4					
Proton Beam Energy (GeV):					
60	7.5E+13	0.7	1.03	Project X-doc-1232 (PIP-II Report)	Input assumptions are 7.5e13 protons/cycle and 12 batch slip stacking (Recycler-MI) with a minimum 0.6s cycle time at 60GeV assuming Booster operation at 20 Hz. The 0.6s becomes 0.7s with a realistic MI ramp. The 80 GeV cycle time also incorporates a realistic MI ramp as shown in Project X-doc-1295. (Document 1232 is expected to be updated in October 2014 and that will reflect Booster operation at 20 Hz).
80	7.5E+13	0.9	1.07		
120	7.5E+13	1.2	1.20	Project X-doc-1295 (POT vs Energy and cycle time for high power operation)	
≤ 2.4 MW Operation - Ultimate Maximum Value LBNE Final Phase					
Proton Beam Energy (GeV):					
60	1.5E+14	0.7	2.06	Project X-doc-1295 (POT vs Energy and cycle time for high power operation)	Input assumptions are 15e13 protons/cycle and a 1.2s cycle for a 120GeV extraction energy. Slip stacking is not feasible at these intensities and a 8GeV source providing the required intensity is assumed to be in operation.
80	1.5E+14	0.9	2.14		
120	1.5E+14	1.2	2.40		

Beamline Requirements driven by the physics

- The driving physics considerations for the LBNE Beamline are the long-baseline neutrino oscillation analyses.
- Wide band, sign selected beam to cover the 1st and 2nd oscillation maxima. Optimizing for Eν 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.



Requirements and assumptions

- We have been planning so far to start with a 700 kW beam (NuMI/NOvA at 120 GeV) and then be prepared to take significantly increased beam power (~2.4 MW) allowing for an upgradeability of the facility when more beam power becomes available.
- Fermilab is now planning to raise the beam power to 1.2 MW by the time LBNE starts operation (PIP-II).
  - We are currently assuming operation of the Beamline for the first 5 years at 1.2 MW and for 15 years at 2.4 MW.
- Stringent limits on radiological protection of environment, members of public and workers.
- The lifetime of the Beamline Facility including the shielding is assumed to be 30 years.

What is being designed for 2.4 MW

- Designed for 2.4 MW, to allow for an upgrade in a cost efficient manner:
  - Primary beamline
  - the radiological shielding of enclosures (primary beam enclosure, the target shield pile and target hall except from the roof of the target hall, the decay pipe shielding and the absorber hall) and size of enclosures
  - beam absorber
  - decay pipe cooling
  - remote handling
  - radioactive water system piping (in penetrations)

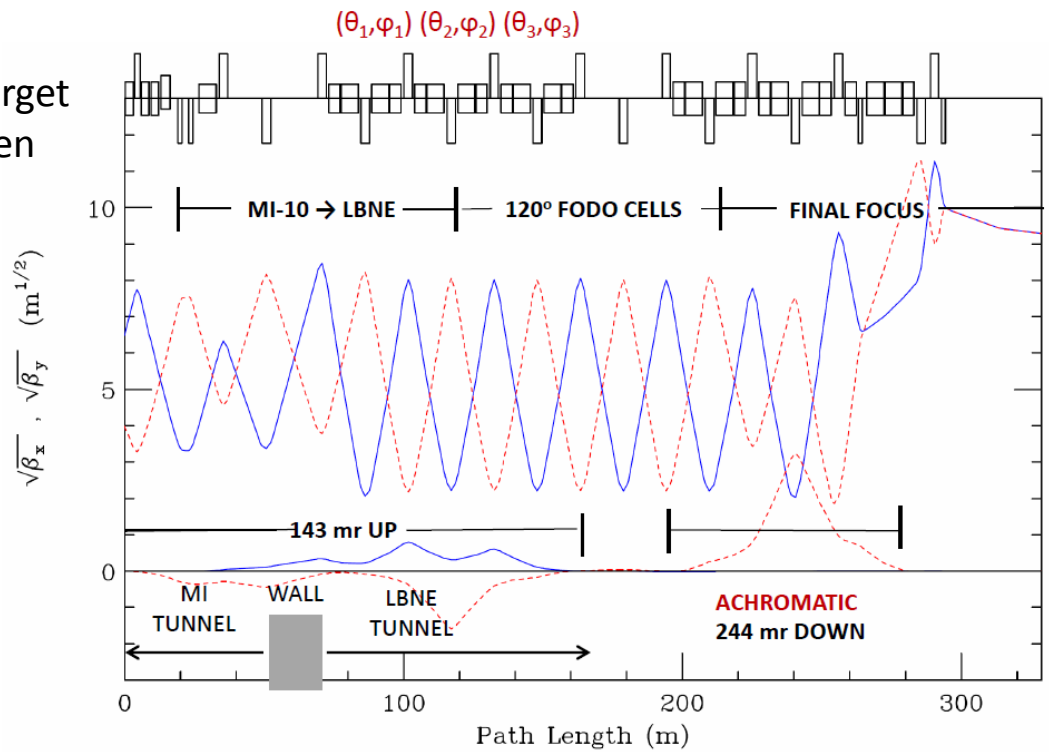
Recent scope changes/challenges

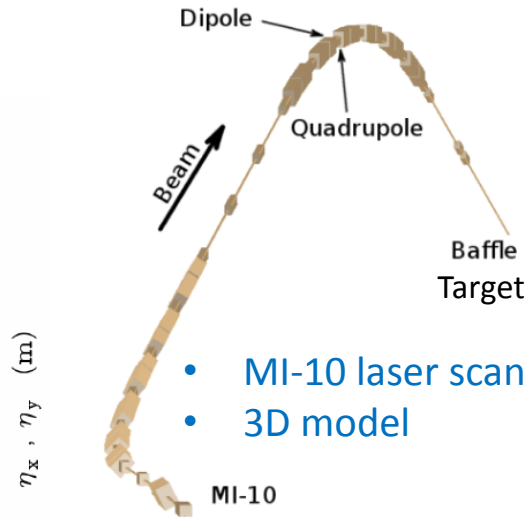
- Be ready for 1.2 MW at day one (changes required in many components of the neutrino beamline).
- Helium instead of air in the decay pipe to increase the neutrino flux and reduce the systematics (an upstream decay pipe window is required and more sophisticated air cooling).
- The helium in the decay pipe makes the design of the hadron absorber more challenging. We had to reduce temperatures and increase the safety factor even with air in the decay pipe.
- Understanding corrosion better for the decay pipe, target chase and absorber cooling lines.
  - Beamline corrosion working group
  - Corrosion consultant
  - Consulting with CERN and other HEP facilities

Primary Beam and Lattice Functions

- The LBNE Primary Beam will transport 60 - 120 GeV protons from MI-10 to the LBNE 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).

Beam size at target tunable between 1.0-4.0 mm





- MI-10 laser scan
- 3D model

STRUCT/MARS simulations have shown that highest beam loss rate takes place right at the apex of beamline

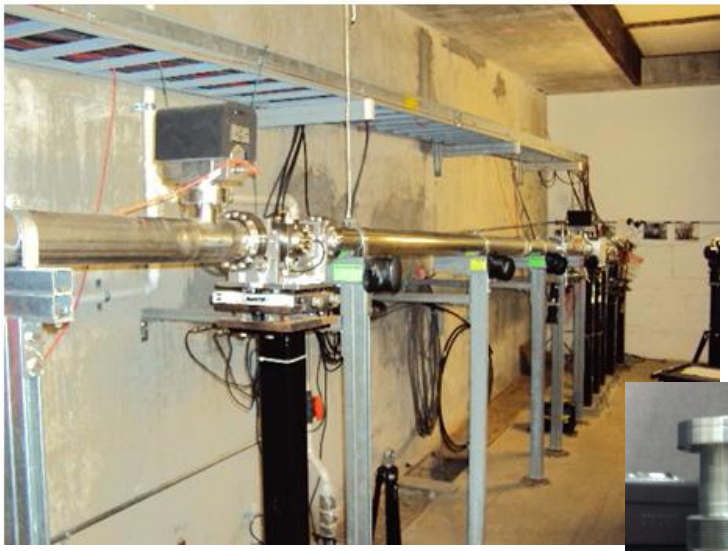
Horizontal (solid) and vertical (dashed) lattice functions of the LBNE transfer line

The final focus is tuned for $\sigma_x = \sigma_y = 1.50$ mm at 120 GeV/c with $\beta^* = 86.33$ m and nominal MI beam parameters $\varepsilon_{99} = 30\pi$ μm & $\Delta p_{99}/p = 11\times10^{-4}$

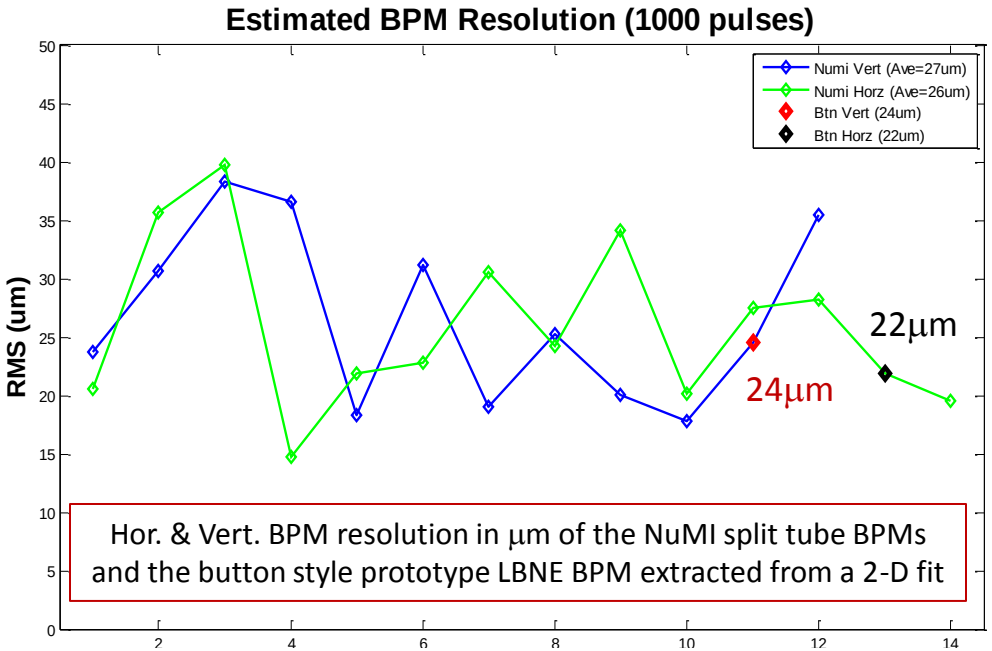
Primary Beam Instrumentation

- Beam-Position Monitors, Beam-Loss Monitors, Total-Loss Monitors, Beam-Intensity Monitors, Beam-Profile Monitors
  - Prototype Beam Position Monitors (already operational in NuMI). Getting simultaneously x and y information.

Button BPM operational in NuMI



~10”

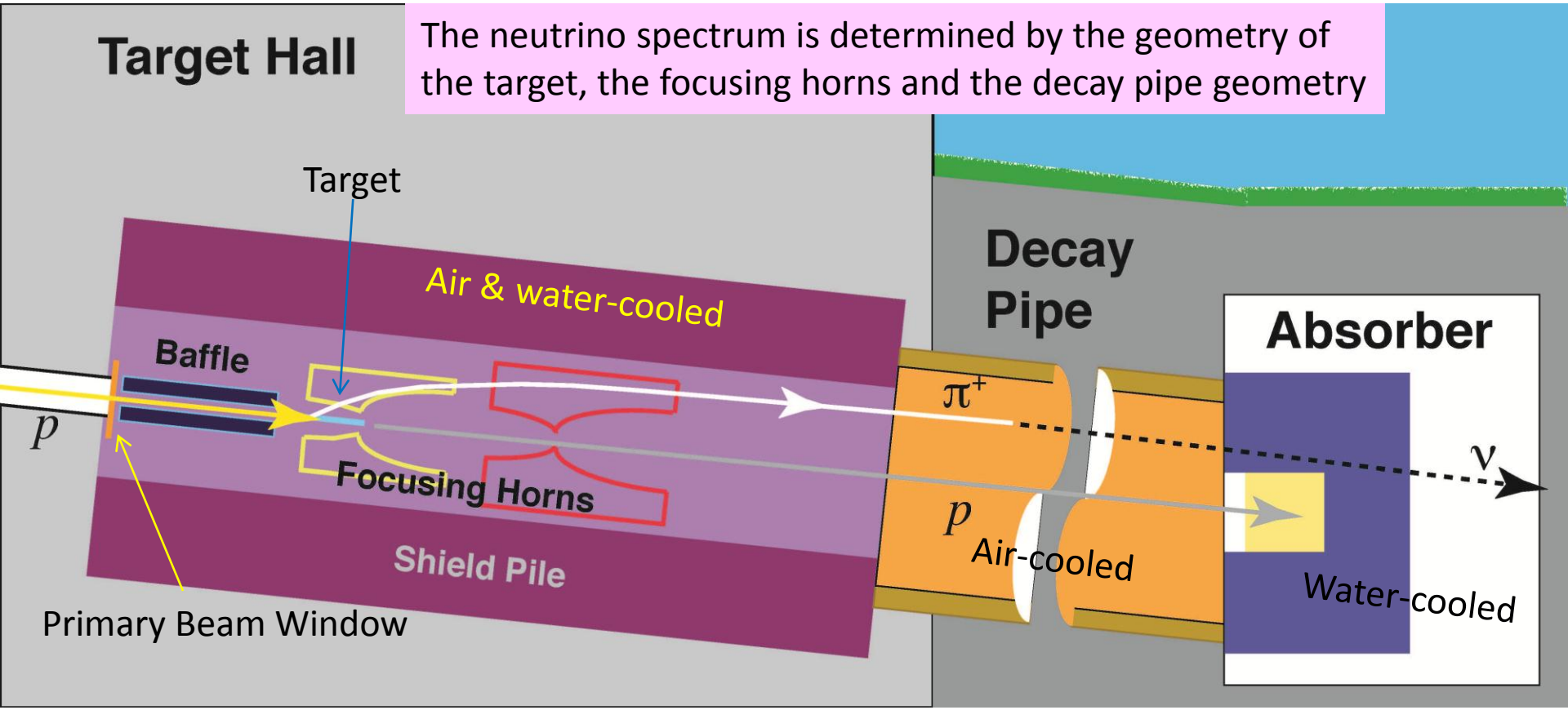


Hor. & Vert. BPM resolution in μm of the NuMI split tube BPMs and the button style prototype LBNE BPM extracted from a 2-D fit

BPM # along the NuMI primary line from US to DS

Major Components of the Neutrino Beam

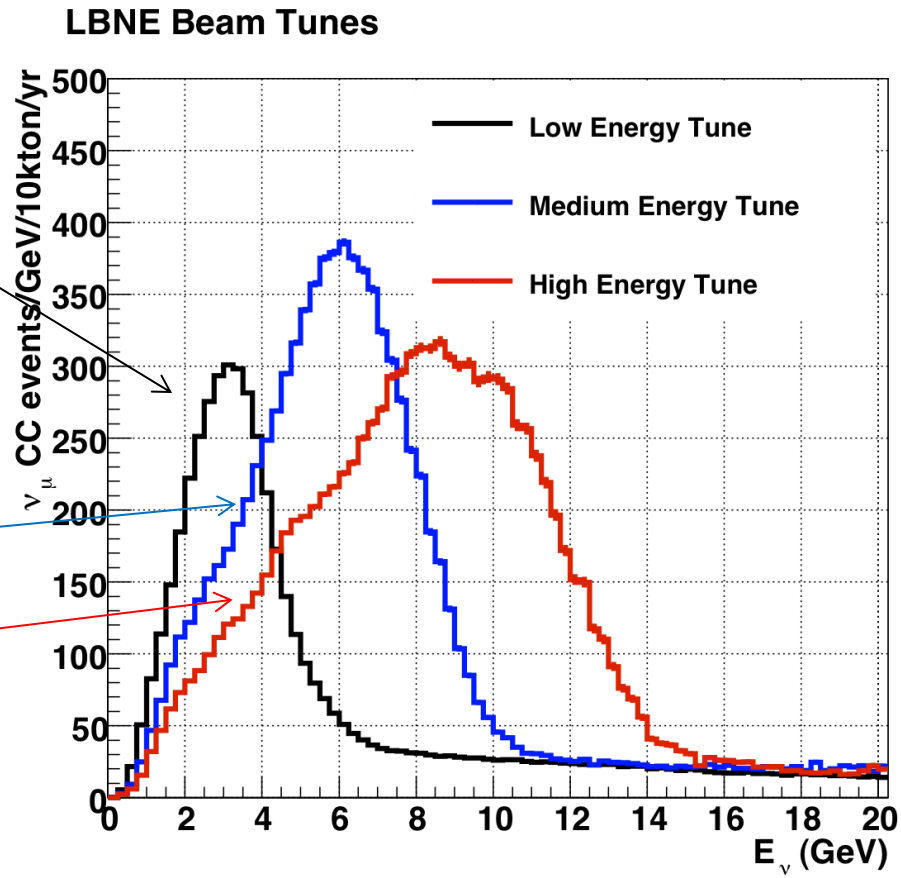
The neutrino spectrum is determined by the geometry of the target, the focusing horns and the decay pipe geometry



NuMI-like low energy target & NuMI design horns with some modifications for 1.2 MW operation

Tunable neutrino energy spectrum

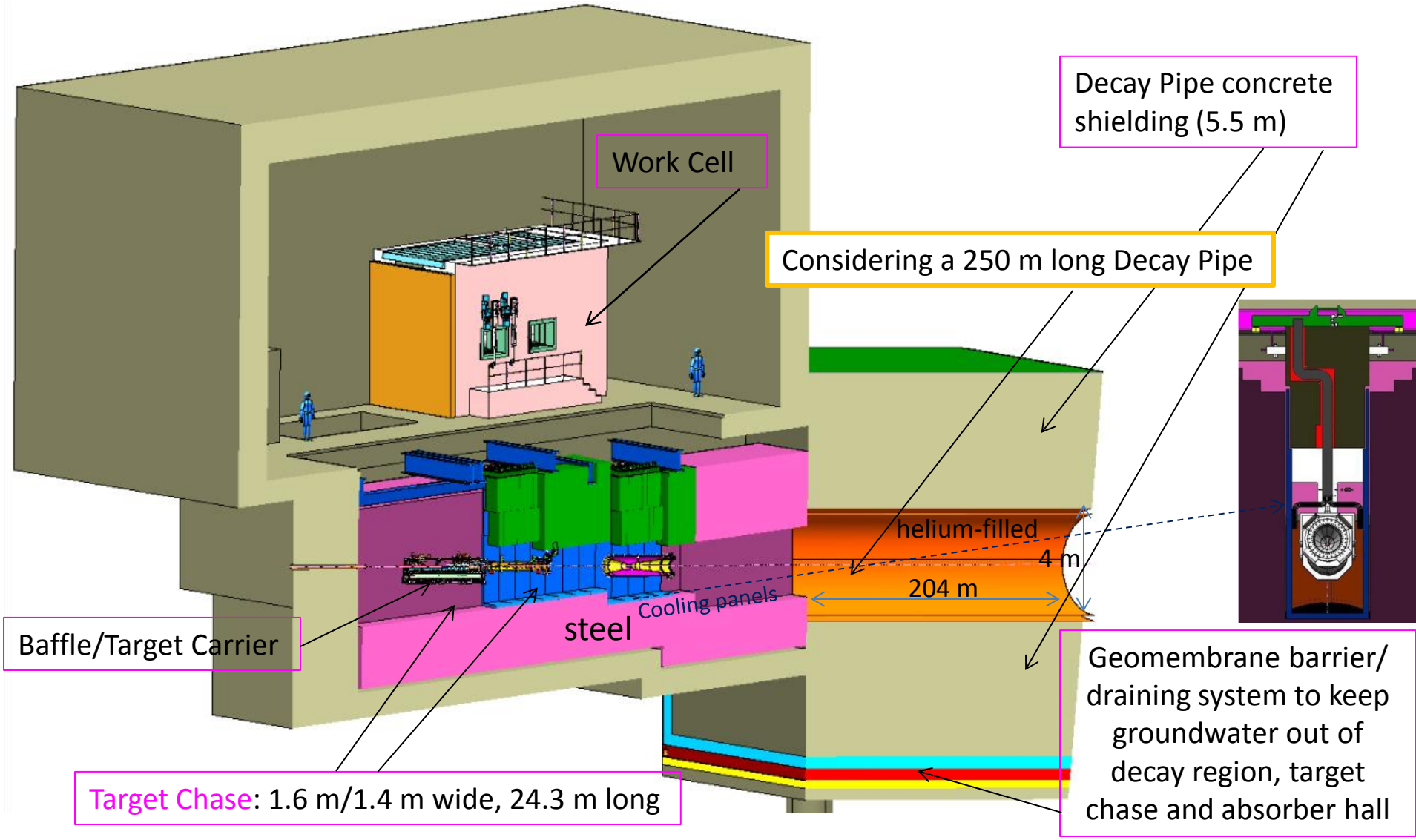
LBNE Beam Tunes: Moving the target with respect to Horn 1



Move target 1.5 m upstream of Horn 1

Move target 2.5 m upstream of Horn 1

Target Hall/Decay Pipe Layout

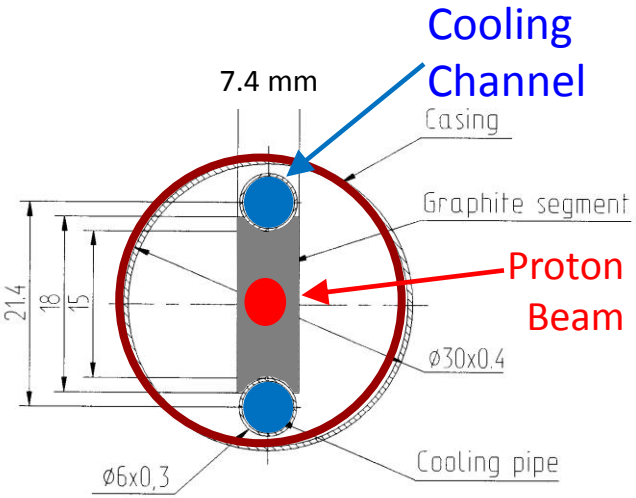


LBNE Target Design for 700 kW (CD-1)

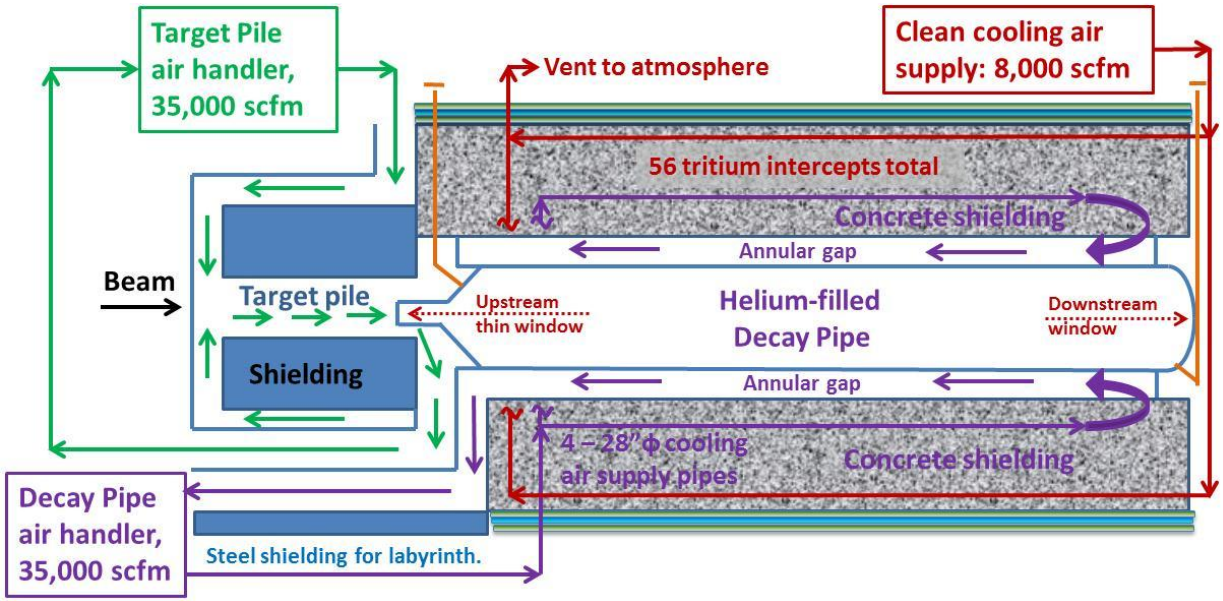
- Developed from the NuMI Low-Energy Target
  - Same overall geometry and material (POCO Graphite)
- Key change 1: Cooling lines made from continuous titanium tubing instead of stainless steel with welded junctions
- Key change 2: Outer containment can be made out of beryllium alloy instead of aluminum
  - Be generates less heat load and is stronger at higher temperatures
  - An all Be construction eliminates brazing joint to the DS Be window
  - Titanium alloys also being investigated

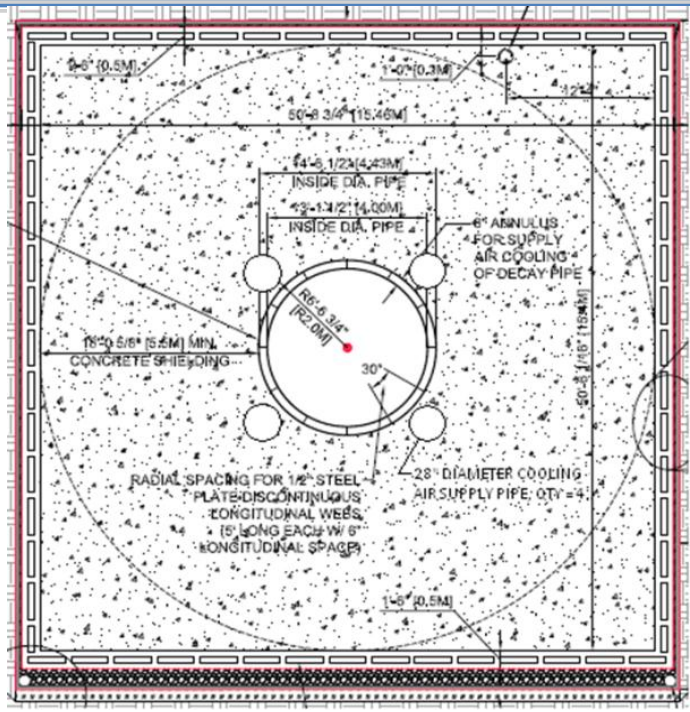
- Expect to change target ~twice a year for 700 kW operation
  - Limited lifetime due to radiation damage of graphite
  - Annealing? (subject of RADIATE R&D)
- Option remains for Be as target material pending validation.
  - Radiation damage a factor of 10 less than graphite (subject of RADIATE R&D)

47 graphite segments, each 2 cm long

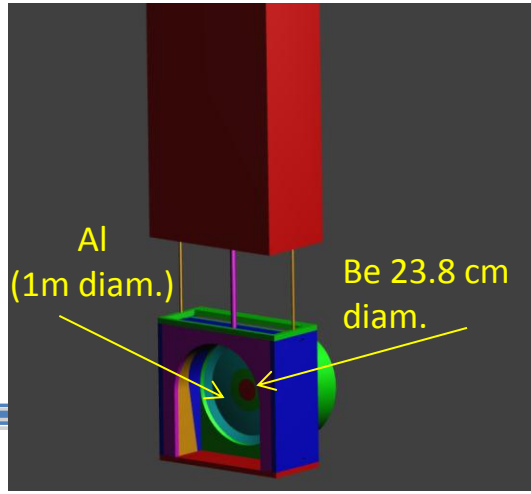


Helium-filled/Air-cooled Decay Pipe
(Helium increases the ν flux by ~10%)

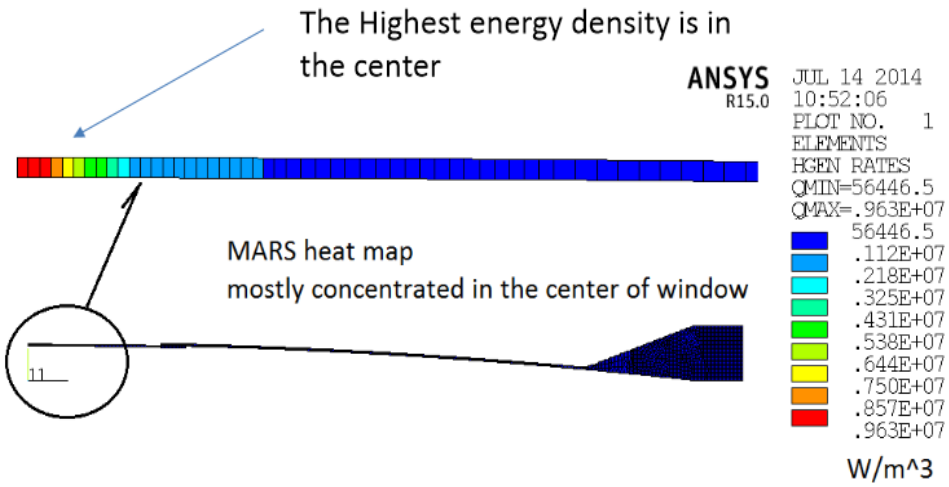




- Concentric Decay Pipe. Both pipes are ½" thick carbon steel
- Decay pipe cooling air supply flows in four, 28-inch diam. pipes and the annular gap is the return path (purple flow path)
- The helium-filled decay pipe requires that a replaceable, thin, metallic window be added on the upstream end of the decay pipe



Upstream Decay Pipe Window



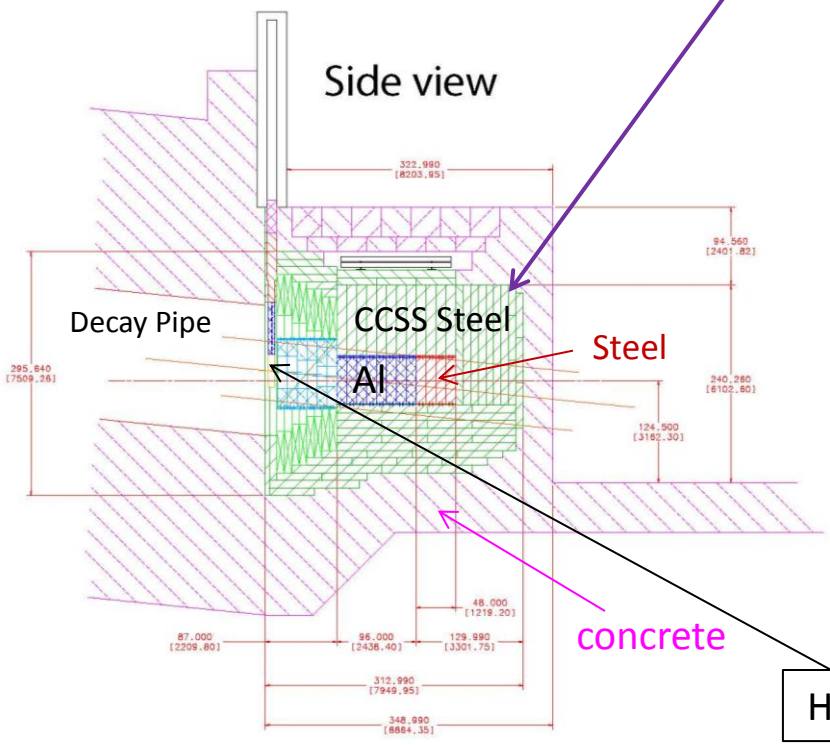
	The center of the window_ Be alloy section				flange	
	Tave(Steady state)_C	Tmax_C	Tmin_C	ΔT _C	Tmax_C	ΔT _C
120Gev_ 2.4 MW	85	87.75	84.25	3.5	115	0
120Gev_ 1.2 MW	63.5	65	63.25	1.75	78	0
80 Gev _ 2.14 MW	*79*	*80.6*	*78.73*	*1.87*	*105*	*0*
80 Gev _ 1.07 MW	*60.67*	*61.34*	*60.41*	*0.93*	*72.6*	*0*

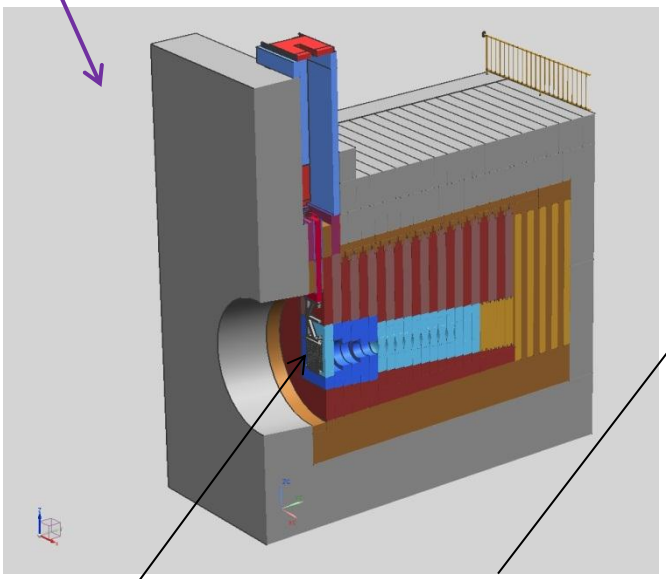
LBNE Absorber Complex – Longitudinal Section

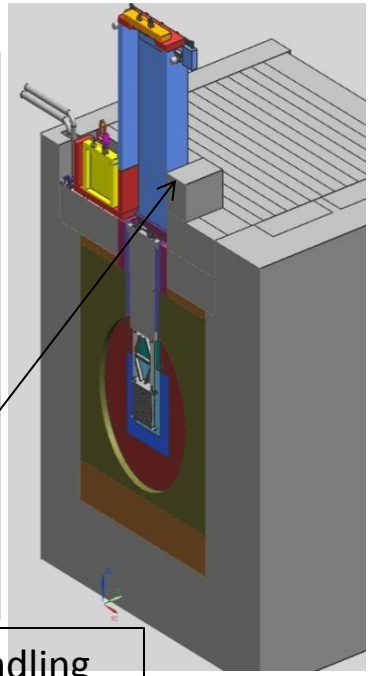
The Absorber is designed for 2.4 MW

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.

Thermal, structural, mechanical engineering development in progress







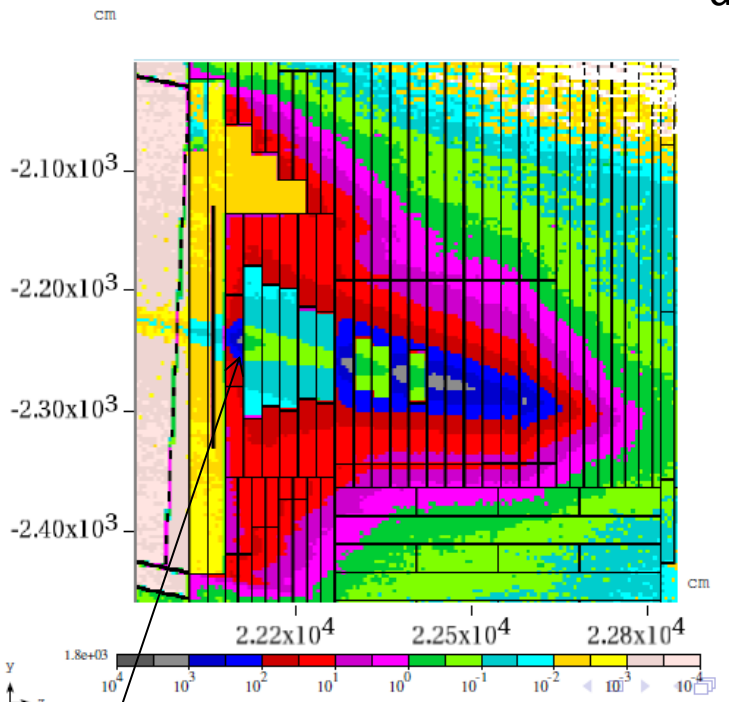
Hadron Monitor (HM)

Remote Handling Facility for HM

Absorber design

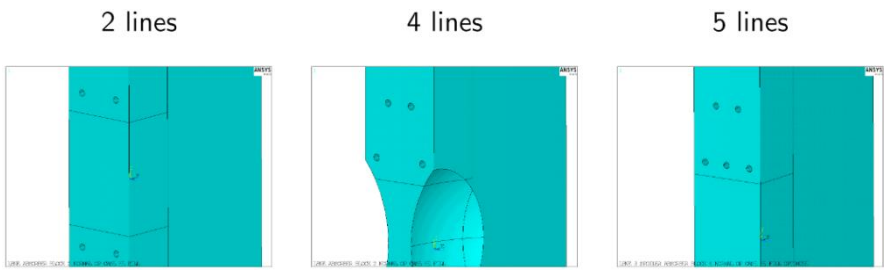
Al core temperatures reduced significantly since November 2013 (were about 170^{0}C)

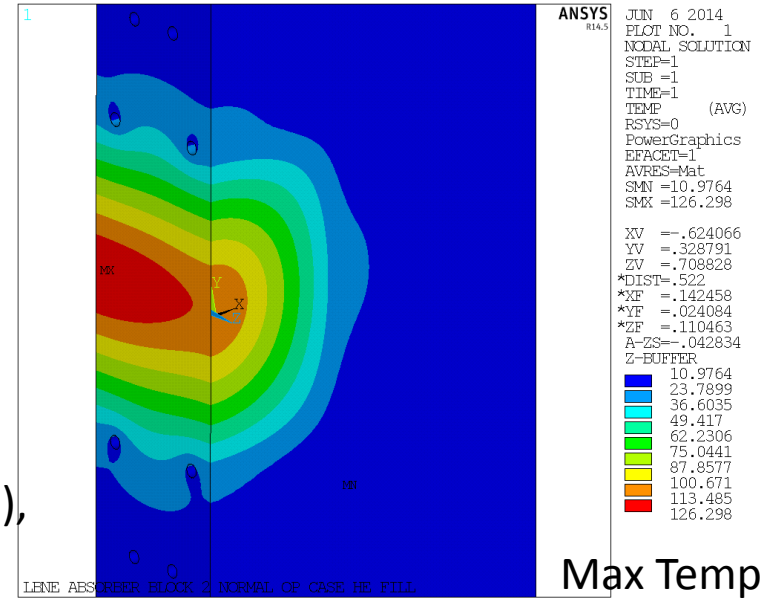
Introducing one to three Al spoilers, thinner or sculpted blocks, different number & location of cooling lines, different water temperatures, different water flow rates,…



Power density distribution

Spoiler: 1 ft thick Al



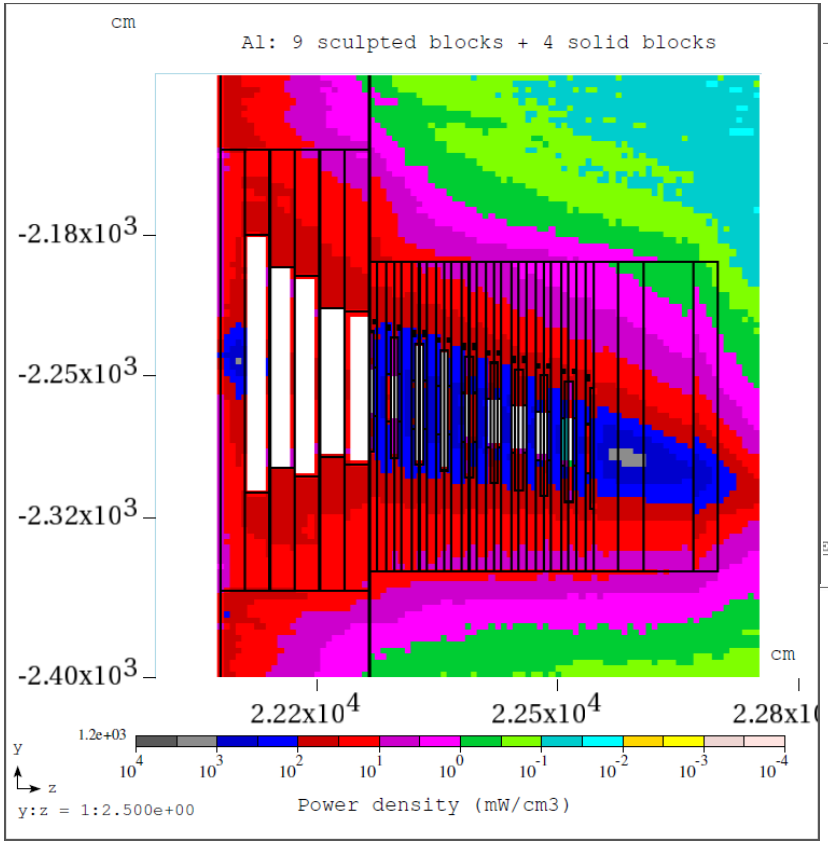


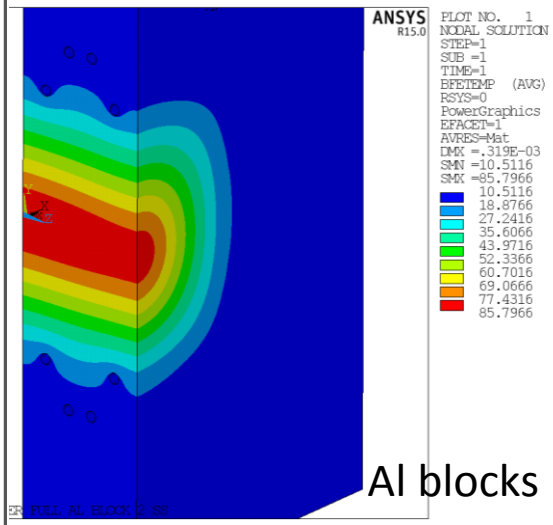
Block 4, 4 water lines(30cm/50cm), 3 spoilers, 20 gpm flow rate

Max Temp 126^{0}C

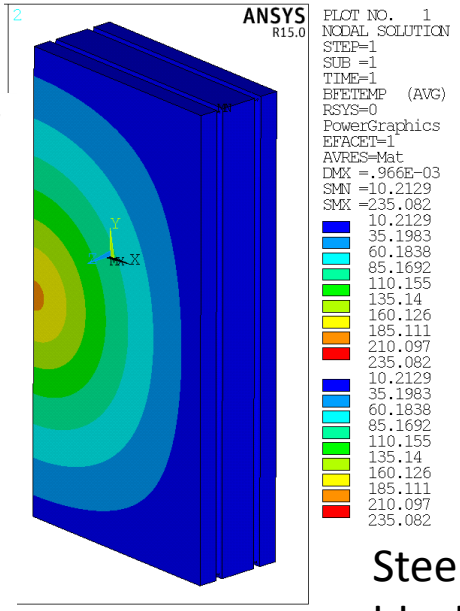
Absorber Design/MARS Simulations (single spoiler)

9 sculpted Al blocks and 4 solid Al blocks in the core

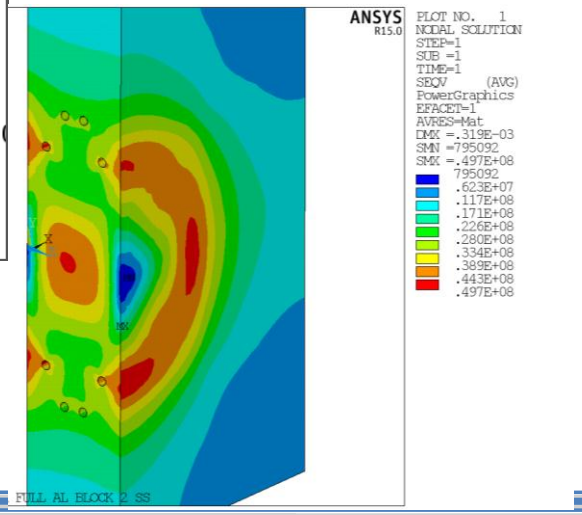


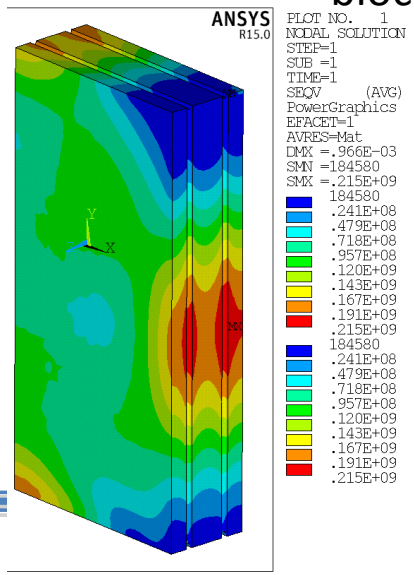


Al blocks



Steel blocks





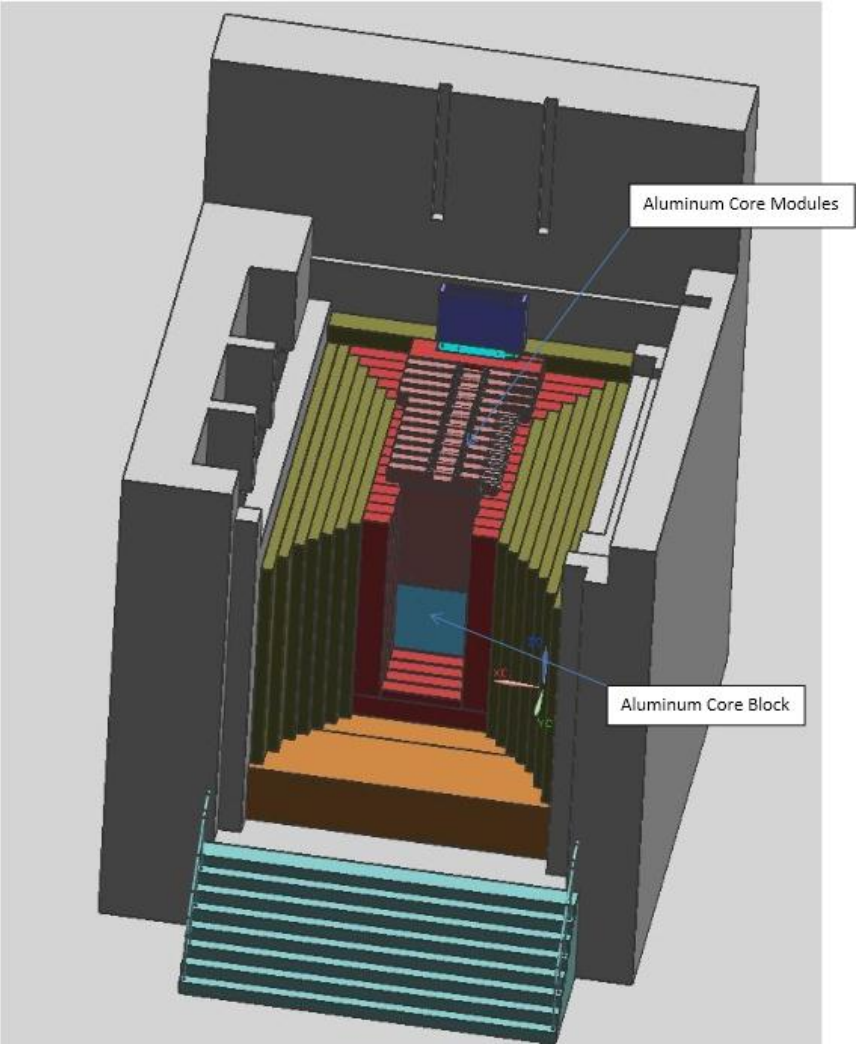
Max Temp Al: 86^{0}C

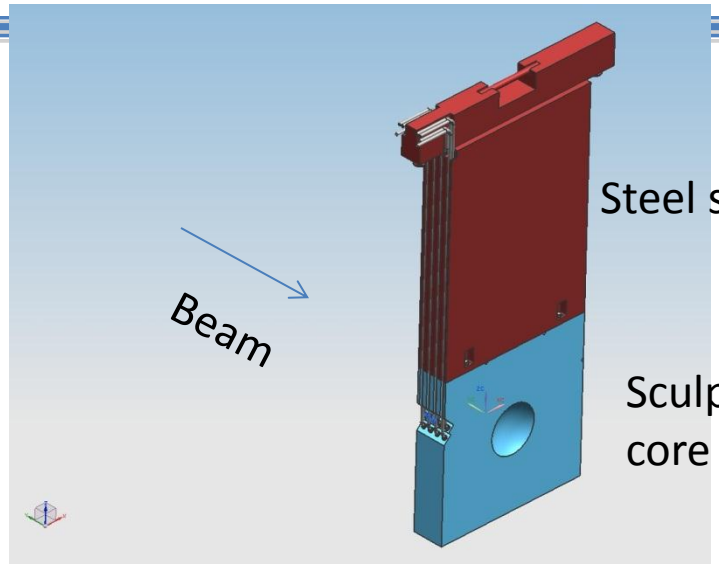
Max VM stress Al: 50 MPa at water line

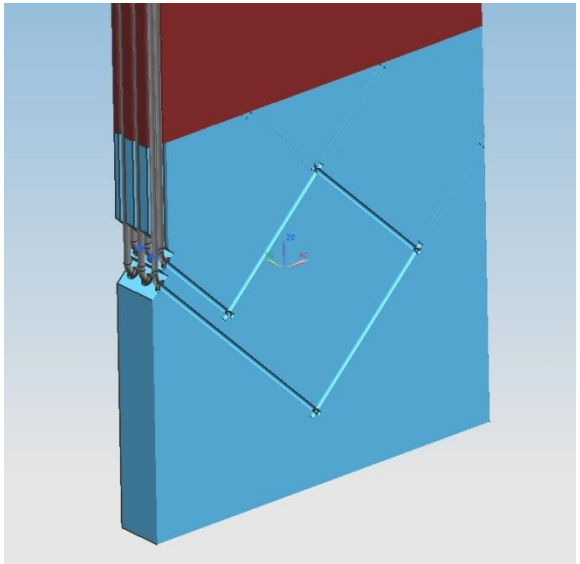
Max Temp steel: 235^{0}C

Max VM stress Al: 215 MPa

Absorber Mechanical Design





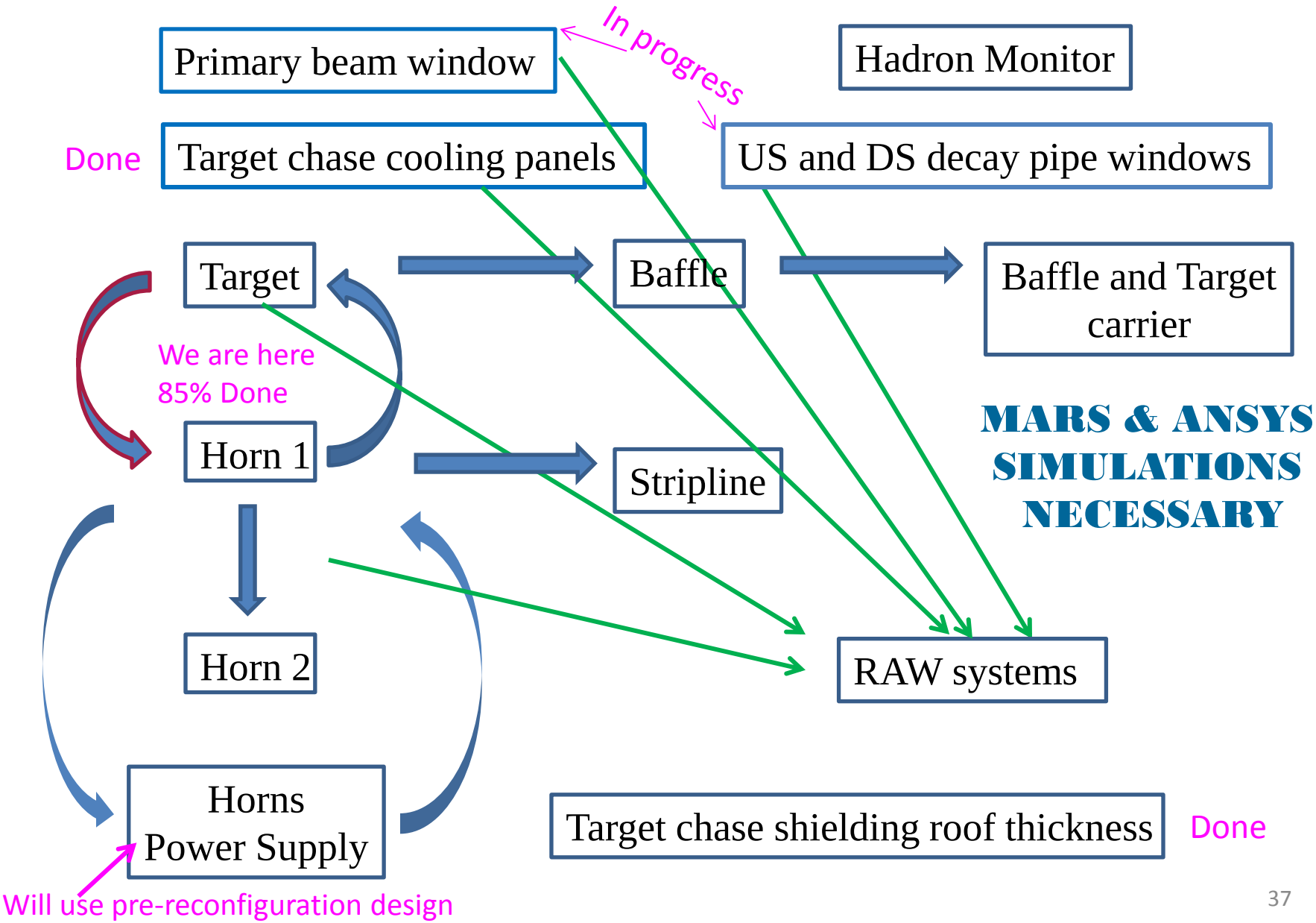


Aluminum core gun drilled holes

What will need to be re-evaluated or replaced at 1.2 MW
Increased collaboration opportunities

- Primary beam window
- Baffle and target, and their carrier
- Horns
- Horn power supply (we were using the NuMI one)
- Horn stripline
- Cooling panels for target chase
- Water cooling at the bottom of support modules for target/baffle and horns
- Upstream decay pipe window in the Helium filled decay pipe
- Raw systems (Target, Horns, Cooling Chase Panels, Absorber, Decay Pipe windows)
- Chillers for air handling and RAW Water systems
- Water evaporators
- Hadron Monitor
- Additional interlock system in the Absorber Hall (on top of thermocouples) to protect from primary beam accident
- Target chase shielding roof thickness
- Radioactive air releases

Sequence of work needed for designing for 1.2 MW



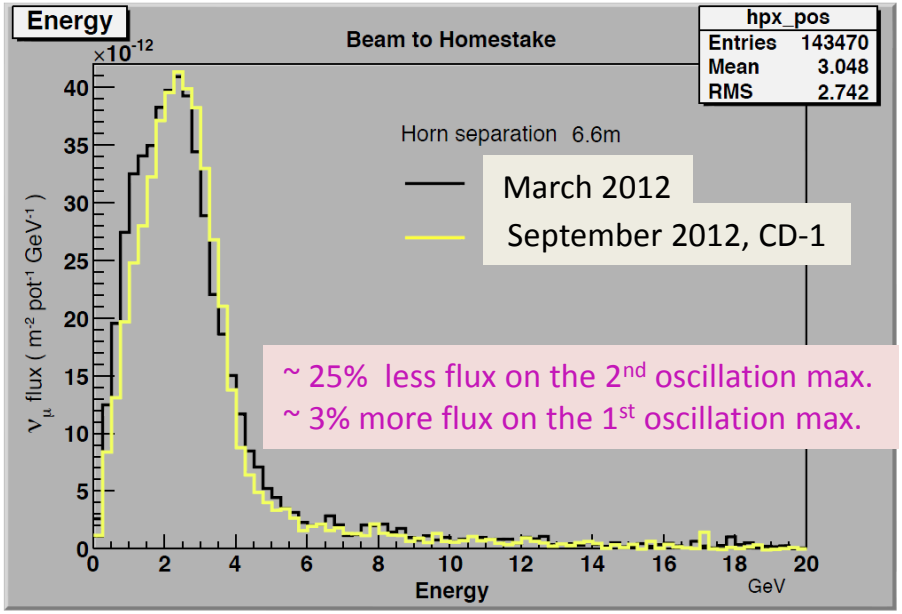
1.2 MW Target/Horn Considerations

- When LBNE was reconfigured in 2012, in order to save money we abandoned our LBNE optimized target and horn designs and opted for NuMI designs with small modifications. (e.g.we were able to verify the NuMI horns up to 230 kA instead of their 200 kA design value).

LBNE CD-1 – NuMI like horn 1

LBNE prereconfiguration horn 1

	LBNE Sept. 2012 CD-1	LBNE March 2012
Beam Power	708 kW	708 kW
Horn 1 shape	Double Parabolic	Cylindrical/Parabolic
Horn current	200 kA	300 kA
Target	Modified MINOS (fins)	IHEP cylindrical
Target "Carrier"	NuMI-style baffle/ target carrier	New handler, target attaches to Horn 1

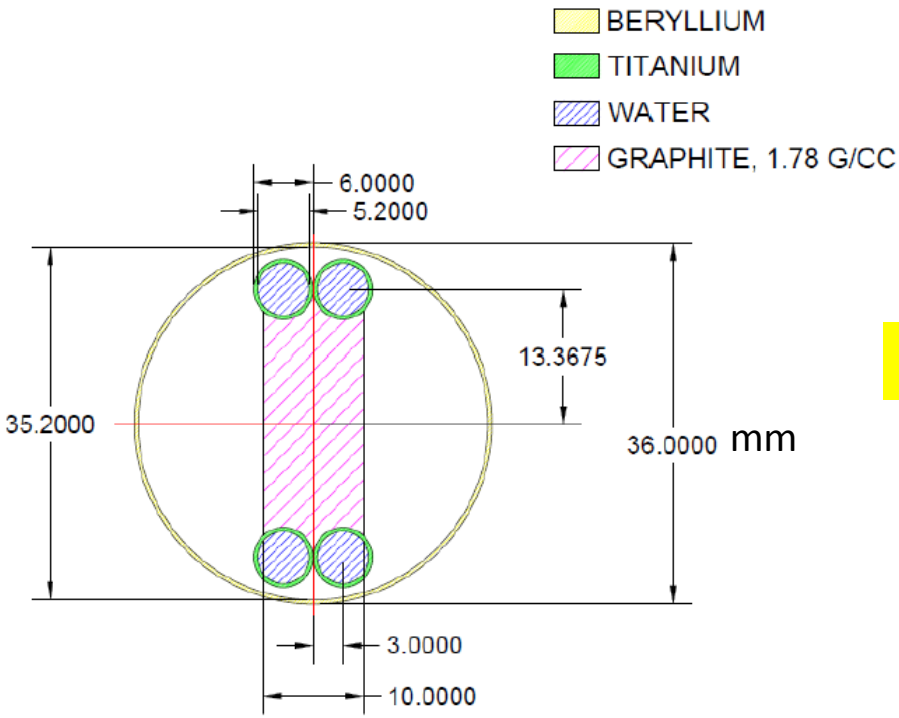


Tunable E_ν spectrum

1.2 MW Target/Horn Considerations

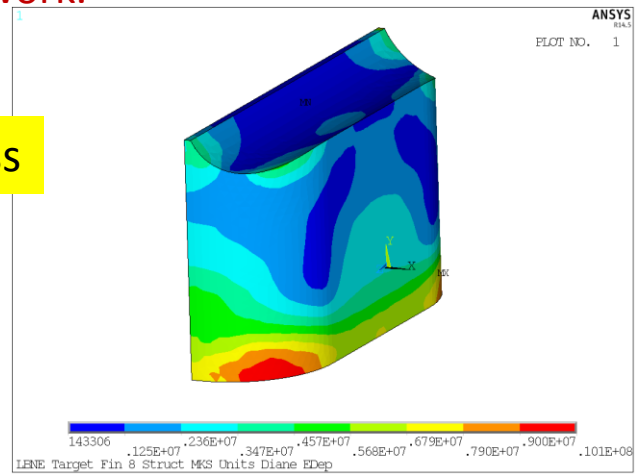
- Our current plan is to check if modest modifications to the CD-1 (NuMI-like) designs can get us to 1.2 MW, minimizing the redesign effort and the increase in cost.(Targets and horns are consumables).
- As a first attempt reduce stress by increasing beam spot size. Use NuMI target as a base but increase the fin width to 10mm and beam sigmas to 1.7mm.
- For the horns try to reduce the joule heating to make room for more beam heating (shorter pulse – cannot use the NuMI power supply).

Preliminary target design for 1.2 MW



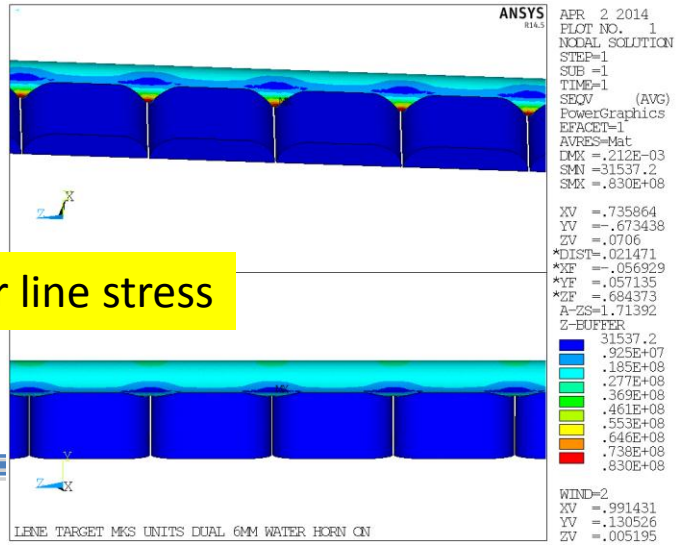
We are simulating this target design and the NuMI horns with MARS and GEANT. It will take a couple more iterations but we see no show stoppers for this design to work.

Graphite fin stress



47 graphite segments, each 2 cm long

Water line stress



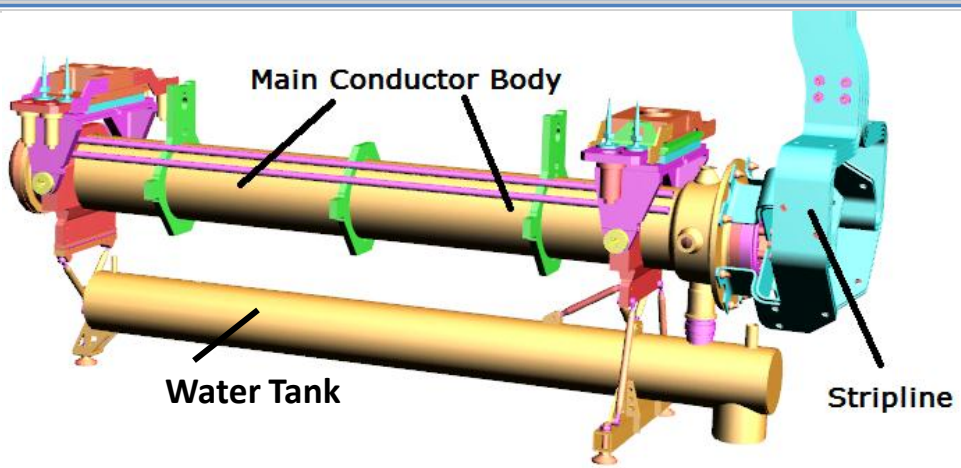
Preliminary target design for 1.2 MW

Target critical safety factors

Location	Material	Stress	Criteria	Safety Factor
Worst Case Fin	Graphite	10.5 MPa	UTS - 80MPa	7.6
Fin, Off-Center Pulse	Graphite	10.1 MPa	UTS - 80MPa	7.9
Water Line, Static	Ti grade 2	83 MPa	Fatigue - 270MPa @ 1e5 cycles, 150C	3.3
Water Line, Pulsed	Ti grade 2	M-126MPa, Alt- 32MPa	Goodman @ 90C (mean temp)	3.2
Can	Beryllium	25.9 MPa	Yield - 218 MPa @ 185C	8.4
Window	Beryllium	27.2 MPa	Yield - 218 MPa @ 185C	8.0

UK/RAL and CERN colleagues interested in collaborating on the target design (in addition to R&D)

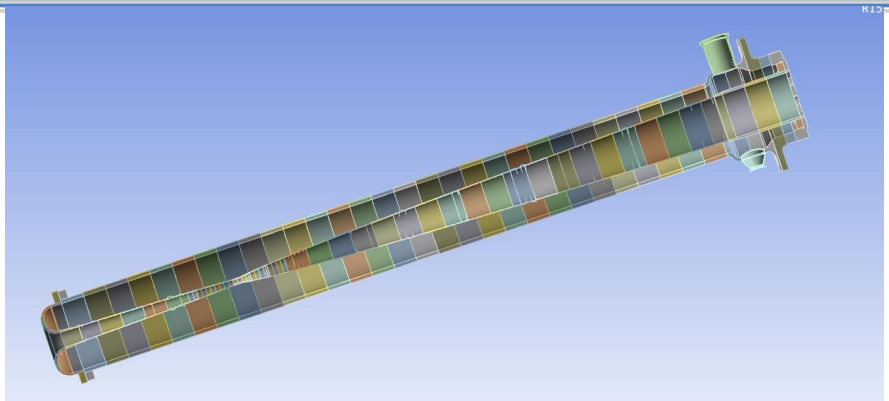
Horn Operation at 1.2MW

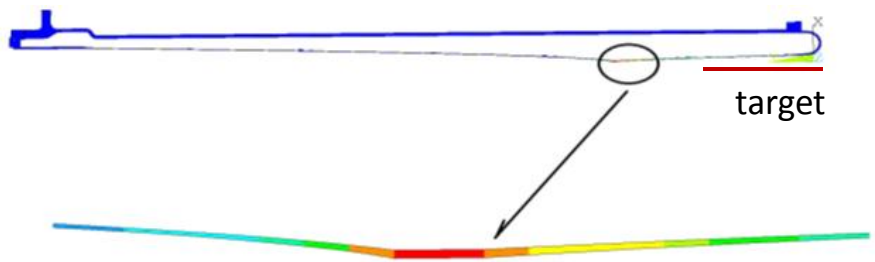


Parameters	700 kW	1.2 MW
Current Pulse Width	2.1ms	0.8ms
Cycle Time	1.33s	1.20s
Horn Current	230kA	230kA
Target Width	7.4mm	10mm
Protons Per Spill	4.9×10^{13}	7.5×10^{13}

- Beam heating and joule heating on horn 1 generate unacceptable power input into the horn inner conductor with the new target design and the NuMI horn power supply (2.1ms pulse width).
- Higher energy depositions from the target can be offset by reducing the current pulse width to 0.8ms (requires a new horn power supply).
- These changes allow the design current to remain at 230kA which is the upper current limit for a NuMI conductor design.

Horn Current Analysis Results

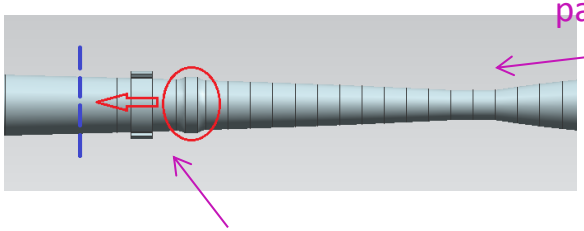




Temperatures	700 kW	1.2 MW
Maximum	61 C	77.5 C
Minimum	37 C	44.5 C
ΔT C	24 C	32 C
Average (Steady State)	48 C	59.4 C

- Increase in temperature range contributes to an increase in stresses.
- These higher stresses affect the Safety Factor (S.F.) of the horn.

- Two common high stress areas are the Neck and U.S. Weld.
- There are fabrication steps and geometrical changes that can regain lost strength due to higher loading.



ANSYS Result Summary

Safety Factor for 120 GeV Operation

	Safety Factor			
Operation Condition	Up-stream Weld	Neck	Down-stream Weld	Transition
Normal Operation	2.5	3.5	4.5	9.2
Test Operation	2.9	4.65	5.3	12.7
Horn-off Operation	7.5	12.7	10.9	36.8
On-off Operation	2.5	3.5	4.5	9.2

Safety Factor for 80 GeV Operation

	Safety Factor			
Operation Condition	Up-stream Weld	Neck	Down-stream Weld	Transition
Normal Operation	2.55	3.6	4.65	10.3
Test Operation	3.4	5.1	4.6	10.3
Horn-off Operation	9.4	15	13	25.9
On-off Operation	2.55	3.6	4.65	10.3

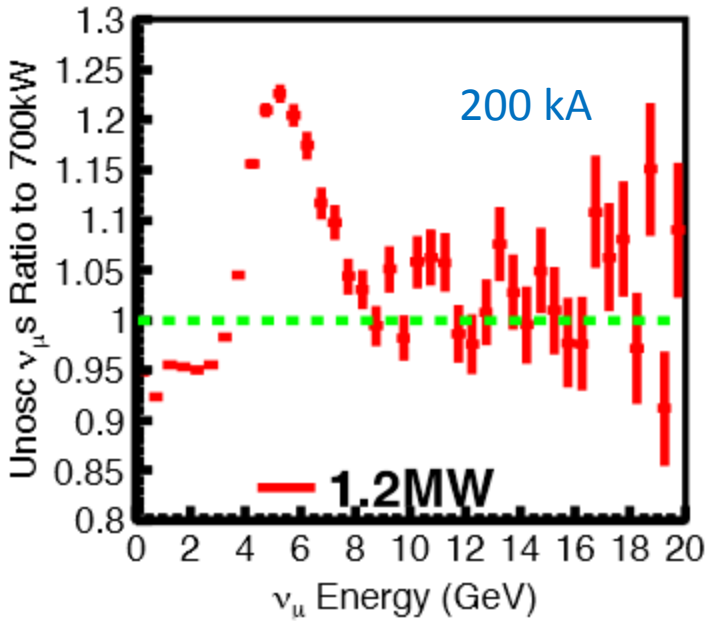
- 120 GeV operation will be the most demanding due to beam energy deposition.
- Minimum Safety Factor (S.F.) of 2.5 is acceptable with stringent quality control.
- Minor changes will be needed in conductor fabrication to accomplish this, such as weld relocation, but this can be absorbed by the current schedule and activity lists.

1.2 MW Target/Horn Considerations (Simulations)

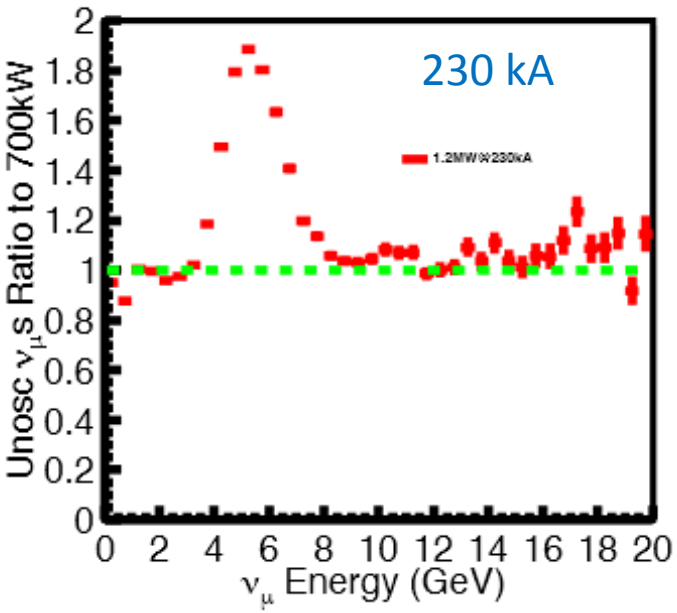
A lot of simulation effort needed

Energy Depositions, radiological:MARS

Physics oriented Beamline optimization: GEANT(MARS cross check)



Retrack target by 10 cm



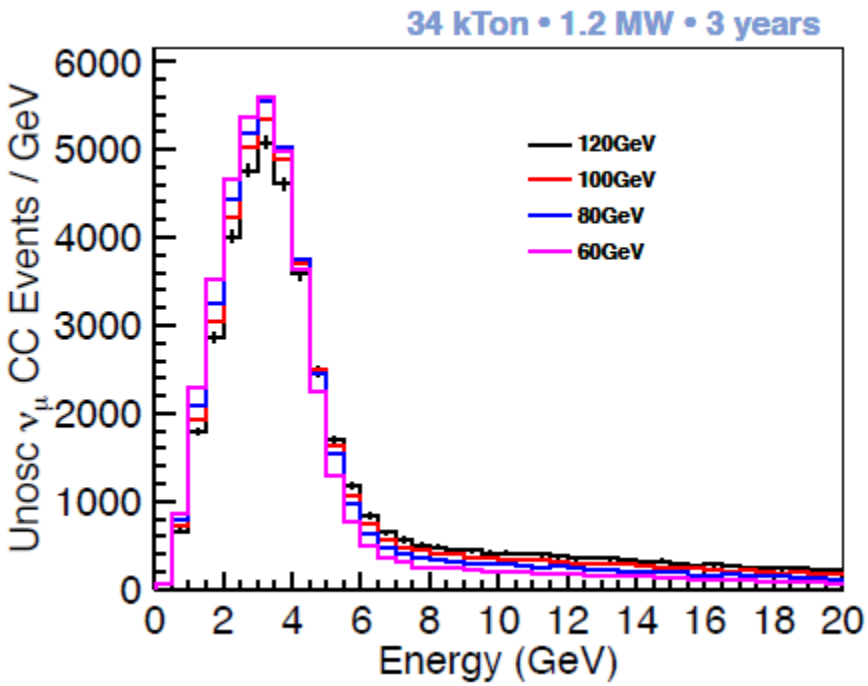
Increasing the horn current from 200 kA to 230 kA almost cancels the reduction of flux due to retracted target

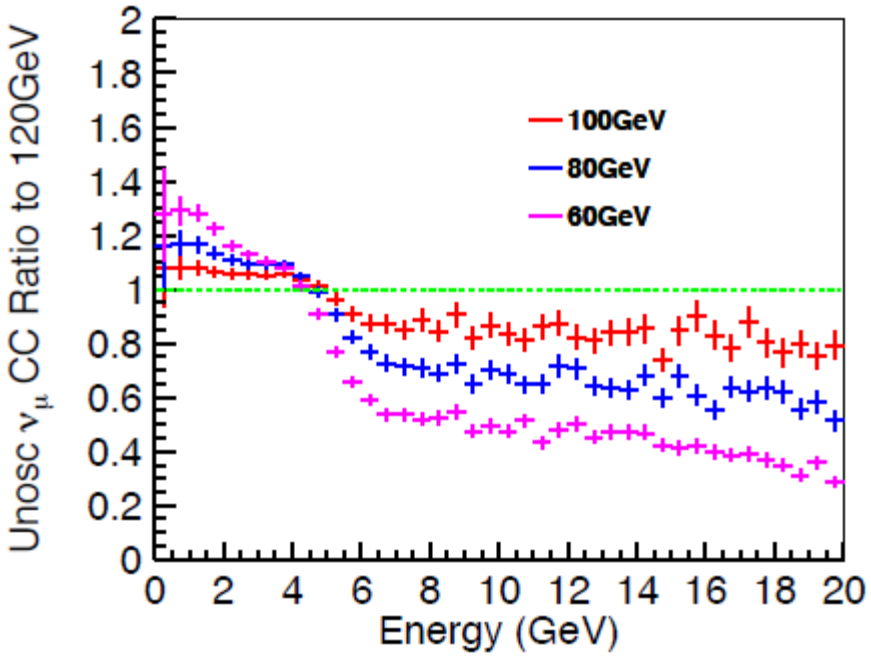
1.2 MW Target/Horn Considerations (Simulations)

A lot of simulation effort needed

Energy Depositions, radiological:MARS

Physics oriented Beamline optimization: GEANT(MARS cross check)





Retrack target by 10 cm

Considered design changes that increase the physics potential

Ratio of $\nu_\mu \rightarrow \nu_e$ CC appearance rates at the far detector

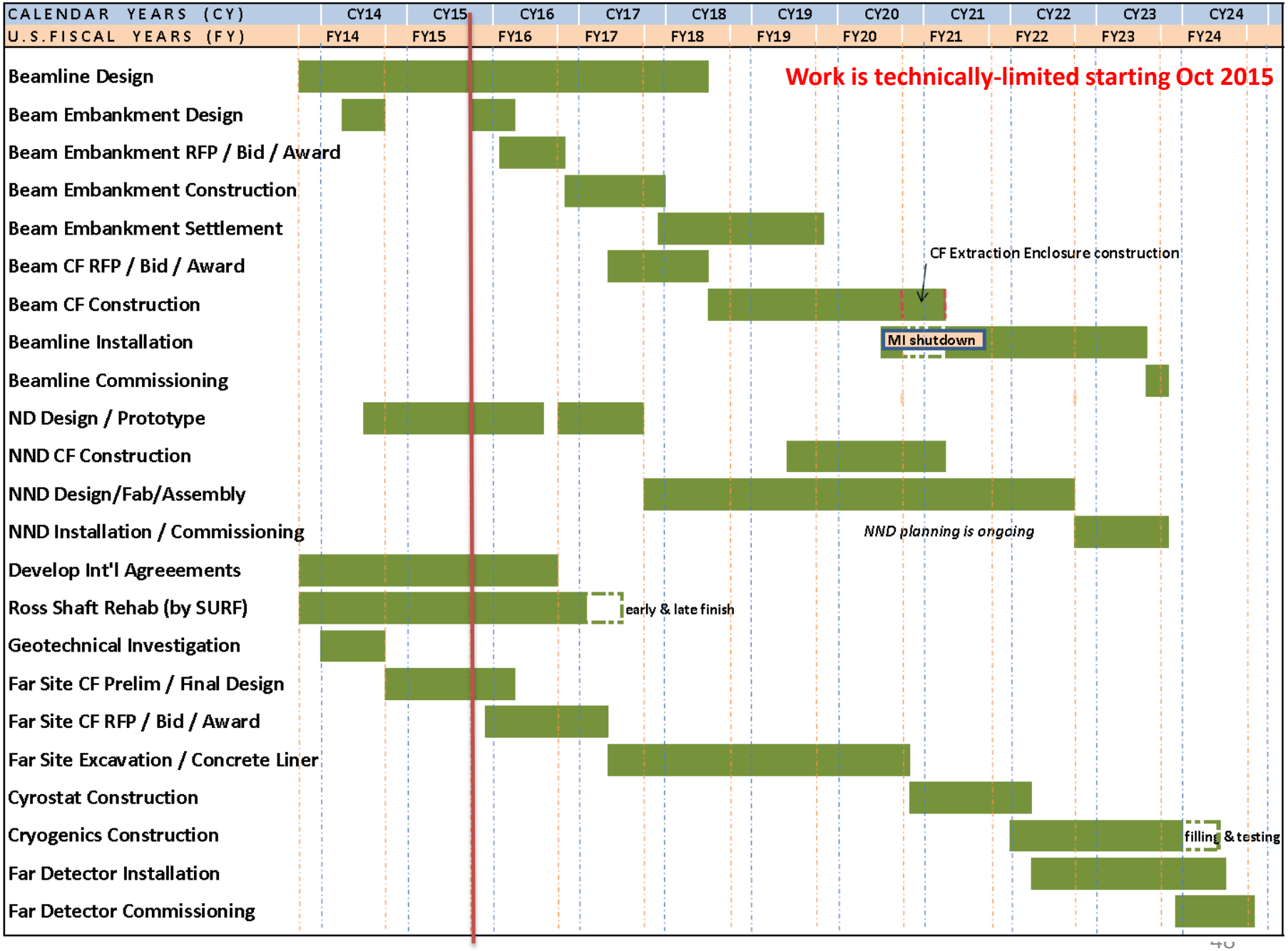
Change	0.5-2.0 GeV	2.0-5.0 GeV	Impact
DK pipe Air → He *	1.07	1.11	~$ 9 M
DK pipe length 200 m → 250 m (4m D)	1.04	1.12	~$ 30 M
DK pipe diameter 4 m → 6 m (200m L)	1.06	1.02	~ $17 M
Horn current 200 kA → 230 kA	1.00	1.12	small
Proton beam 120 → 80 GeV, 700 kW	1.14	1.05	Programmatic impact
Target graphite fins → Be fins Subject of R&D	1.03	1.02	Increase target lifetime
Total	1.39	1.52	

If both $55 M

- Simplifies the handling of systematics as well
- Recently approved

Potential Technically-Limited Schedule for International LBNE

19 Sep 2014



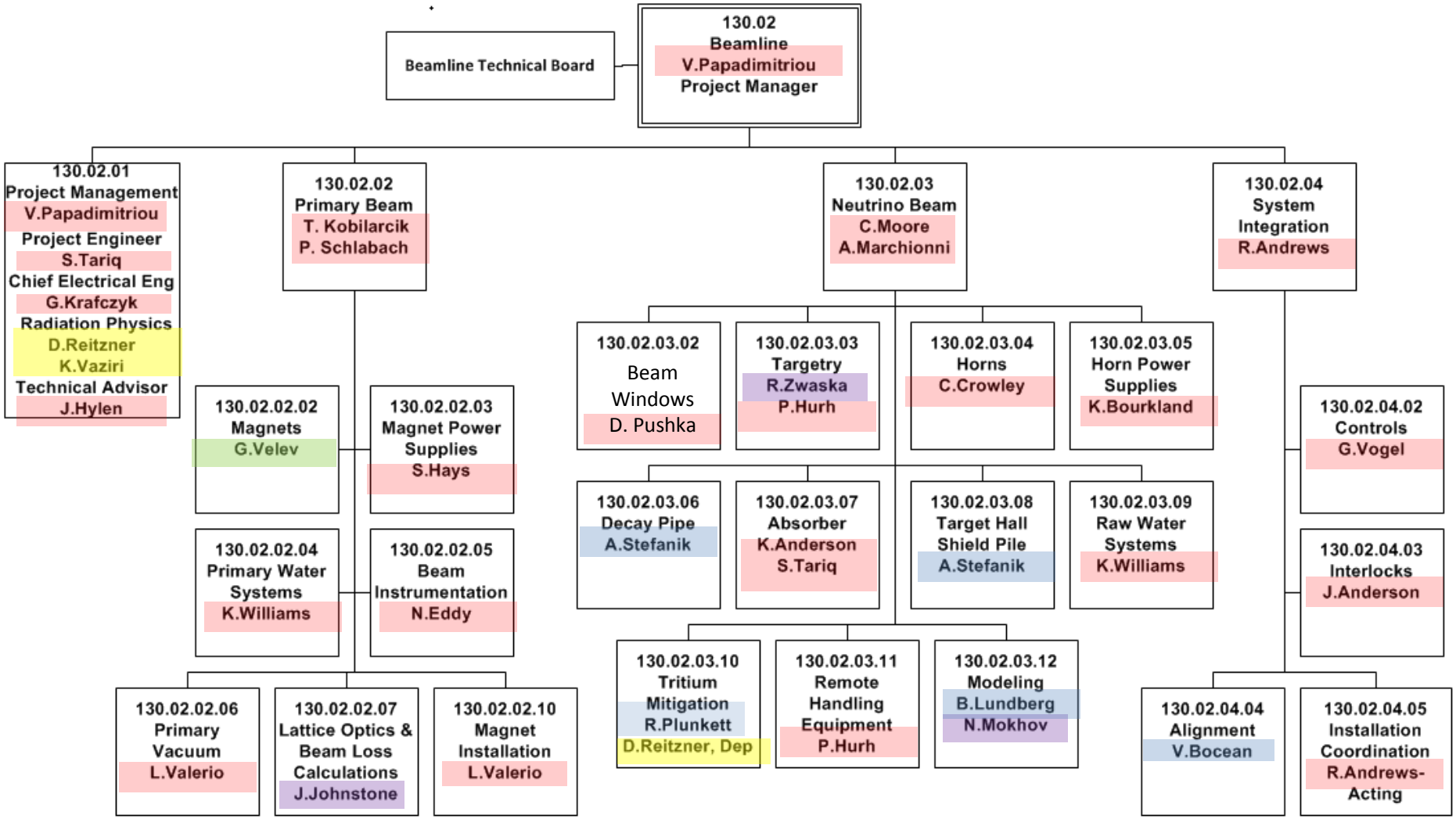
Summary/Conclusions

- The LBNE and emerging LBNF Project will enable a world-leading program that will address profound questions about nature.
- CD-1 approved in December 2012.
- Significant progress with the LBNE preliminary design effort in many Beamline systems including systems that have to accommodate new scope.
- Lots of opportunities for collaboration on the design of specific Beamline components as well as on beam simulations and R&D efforts.
- We are excited and looking forward to design and build this Beamline working together with all our international partners!!

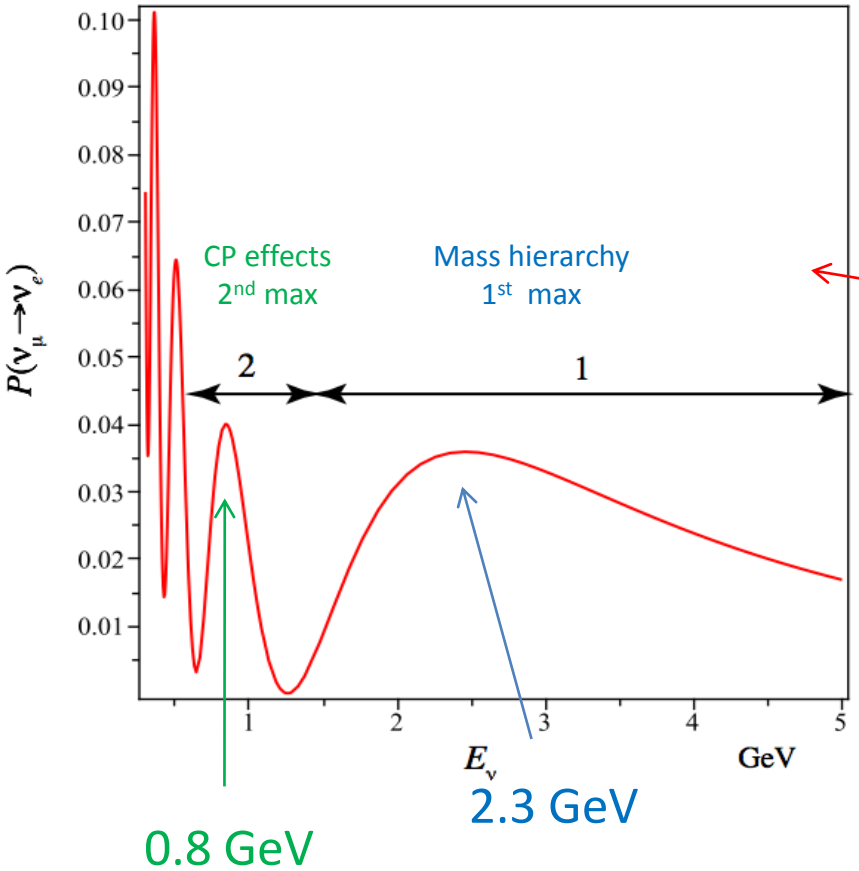
Backup Slides

BACKUP SLIDES

Beamline Organization



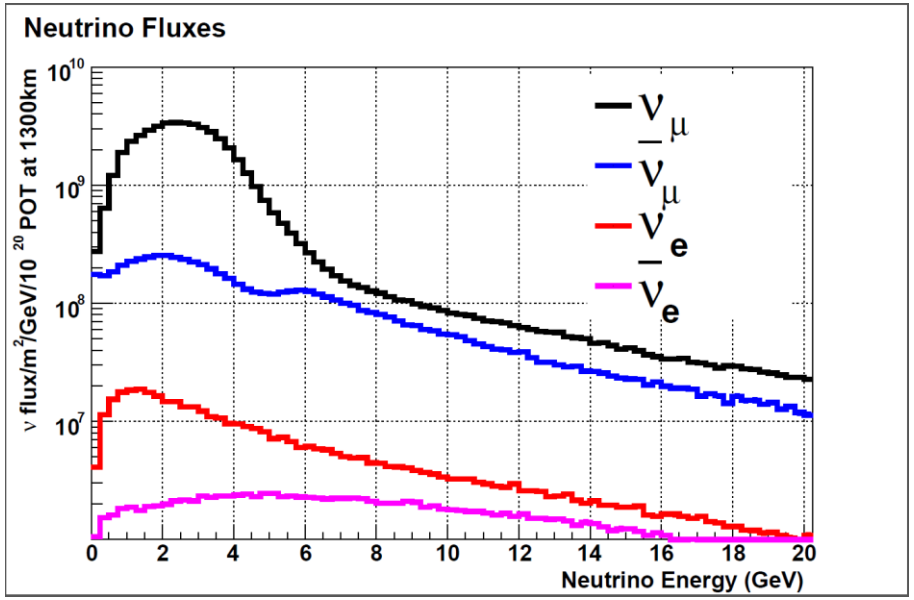
Beamline Requirements & Assumptions



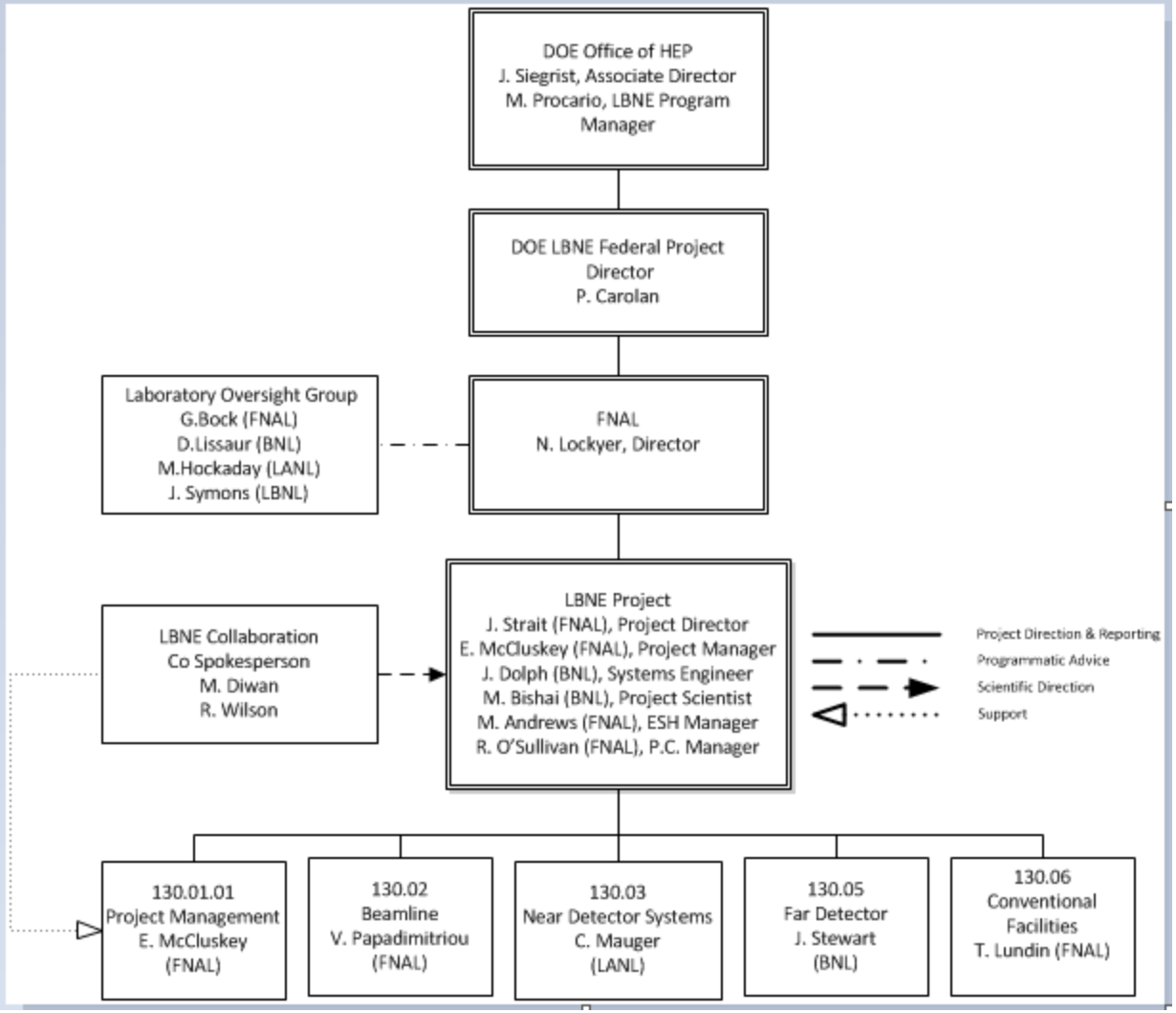
- Need a wide band beam to cover the 1st and 2nd oscillation maxima

Normal mass hierarchy

Neutrino flux at Far Detector



LBNE Project Organization



Primary Beam Design Parameters (Main Injector)

Beam Parameter	Value
Protons per cycle	4.9×10^{13}
Cycle time (120 GeV)	1.33 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	1.3 – 1.5 mm
Beam divergence x,y	17 μrad

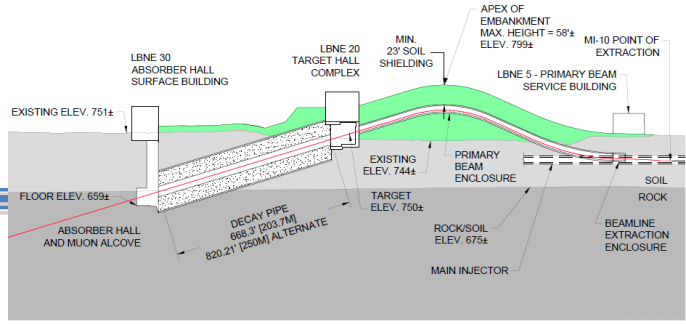
Constant beam power above ~80 GeV

Tunable between 1.0 to 3.2 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)

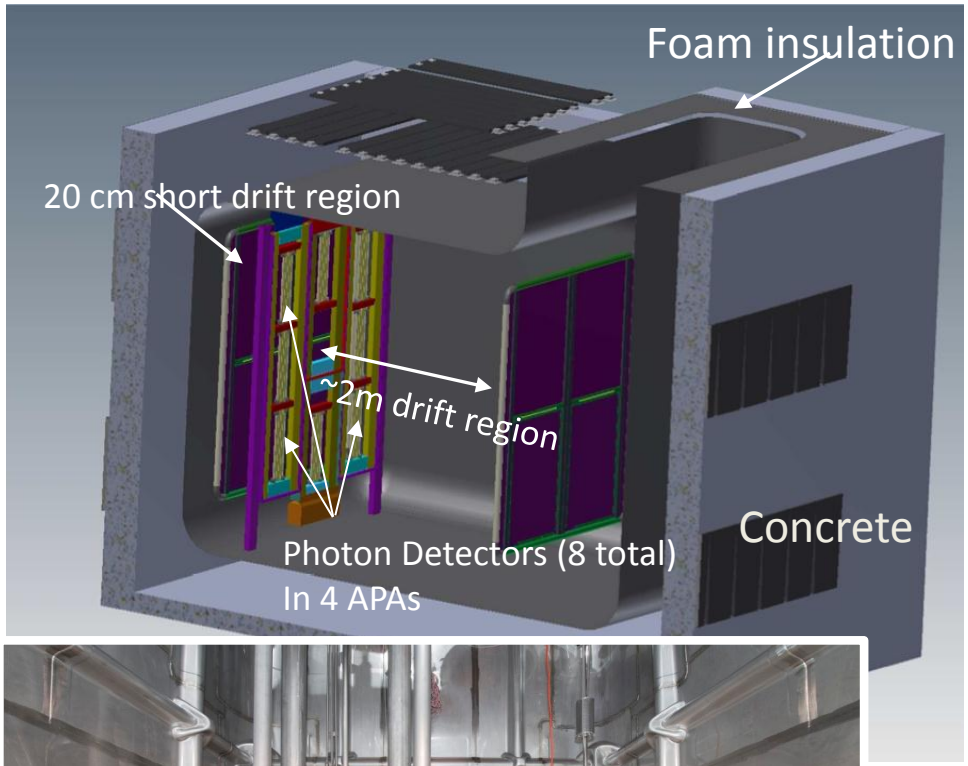
Choosing the Beamline Configuration

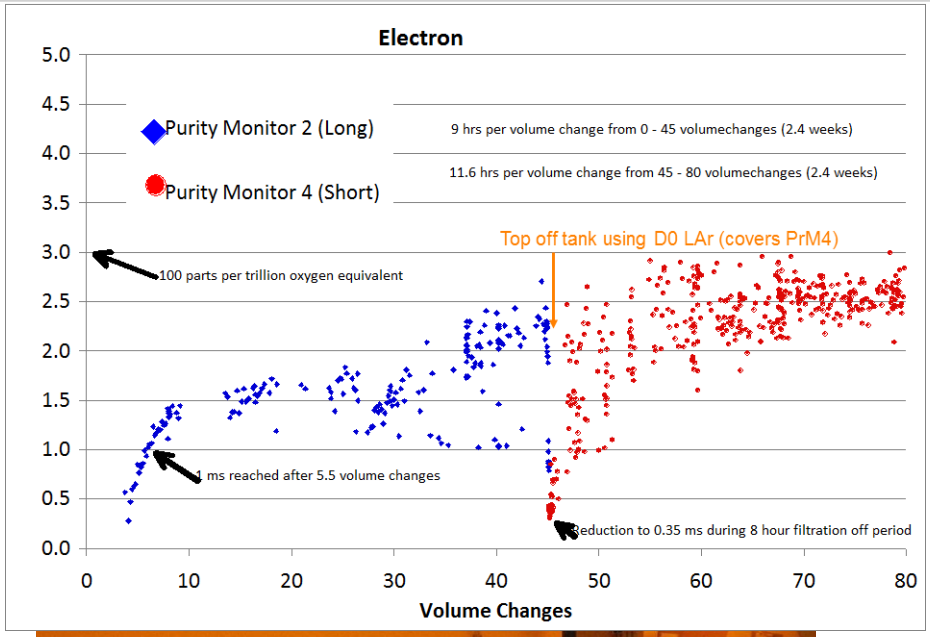


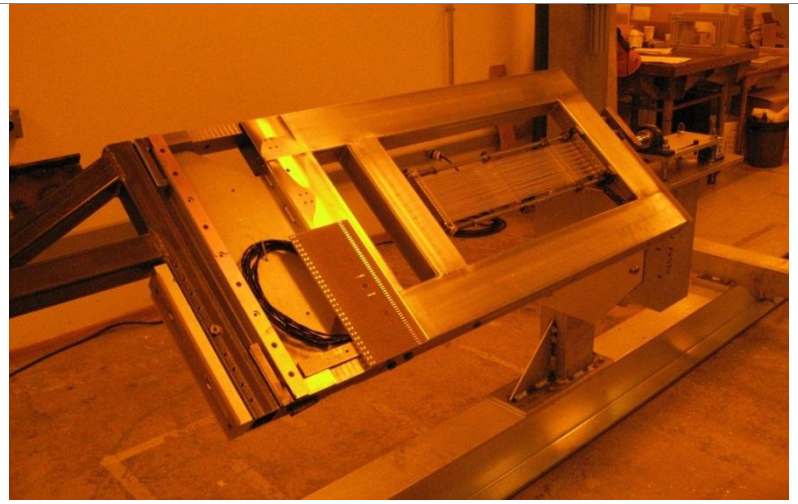
In the shallow option:

- The target hall is above grade and therefore the humidity is reduced, reducing the amount of tritium produced in the target hall which can be released.
- It is more affordable to build a 5.5 m thick concrete shielding around the decay pipe and therefore make the radioisotope levels outside the shielding below the standard detection limits.
- Since the beamline facility is closer to grade, it is more accessible and makes it easier to address possible radiological issues.
- Water inflow fluctuations are not a major risk.
- Easier construction of conventional facilities and installation of components.
- Quality Assurance and Quality Control for the design, construction and installation of the geomembrane barrier system & for the shielding for prompt radiation are very important.

35 t Prototype Cryostat and Prototype TPC Detector

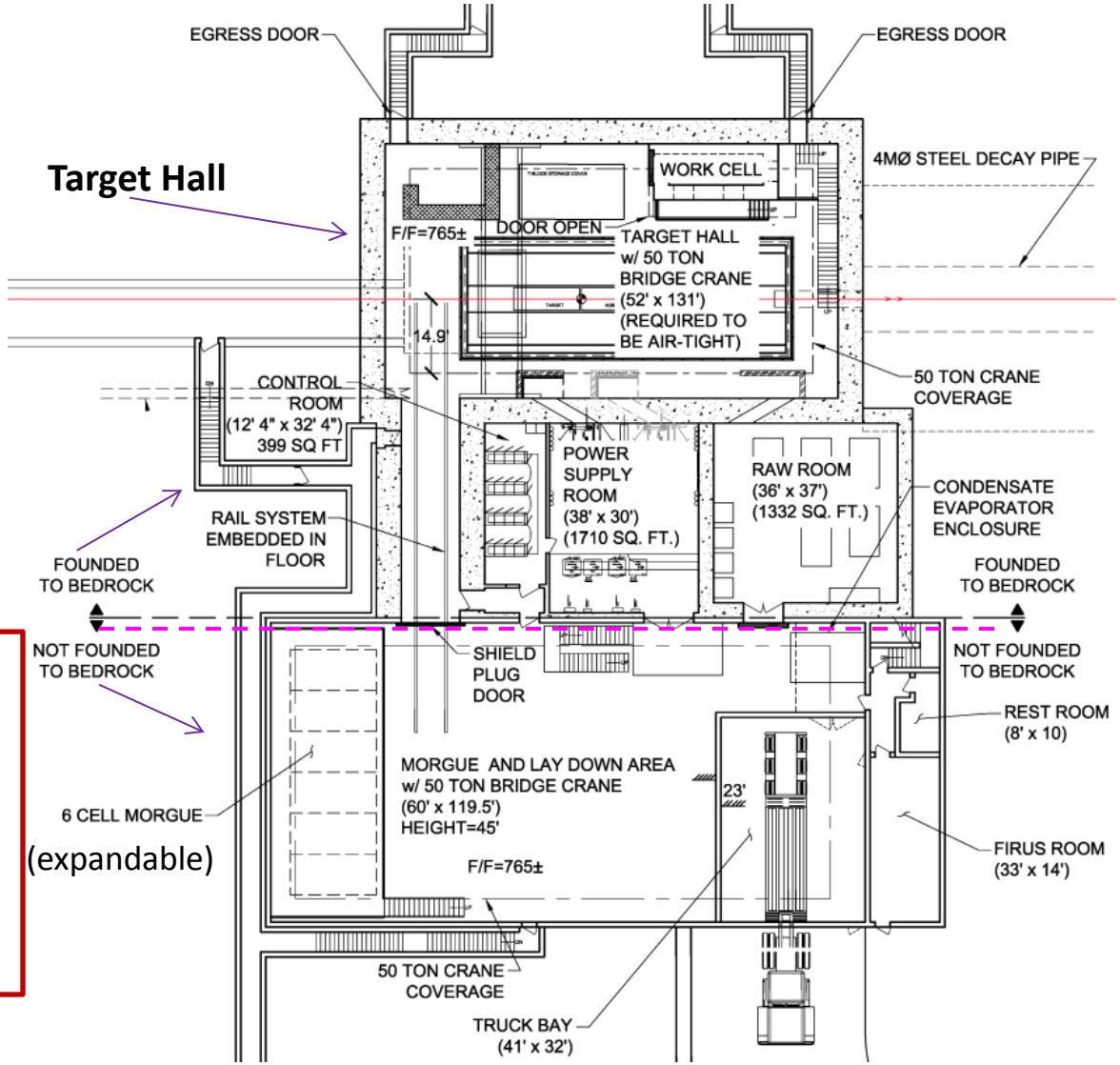






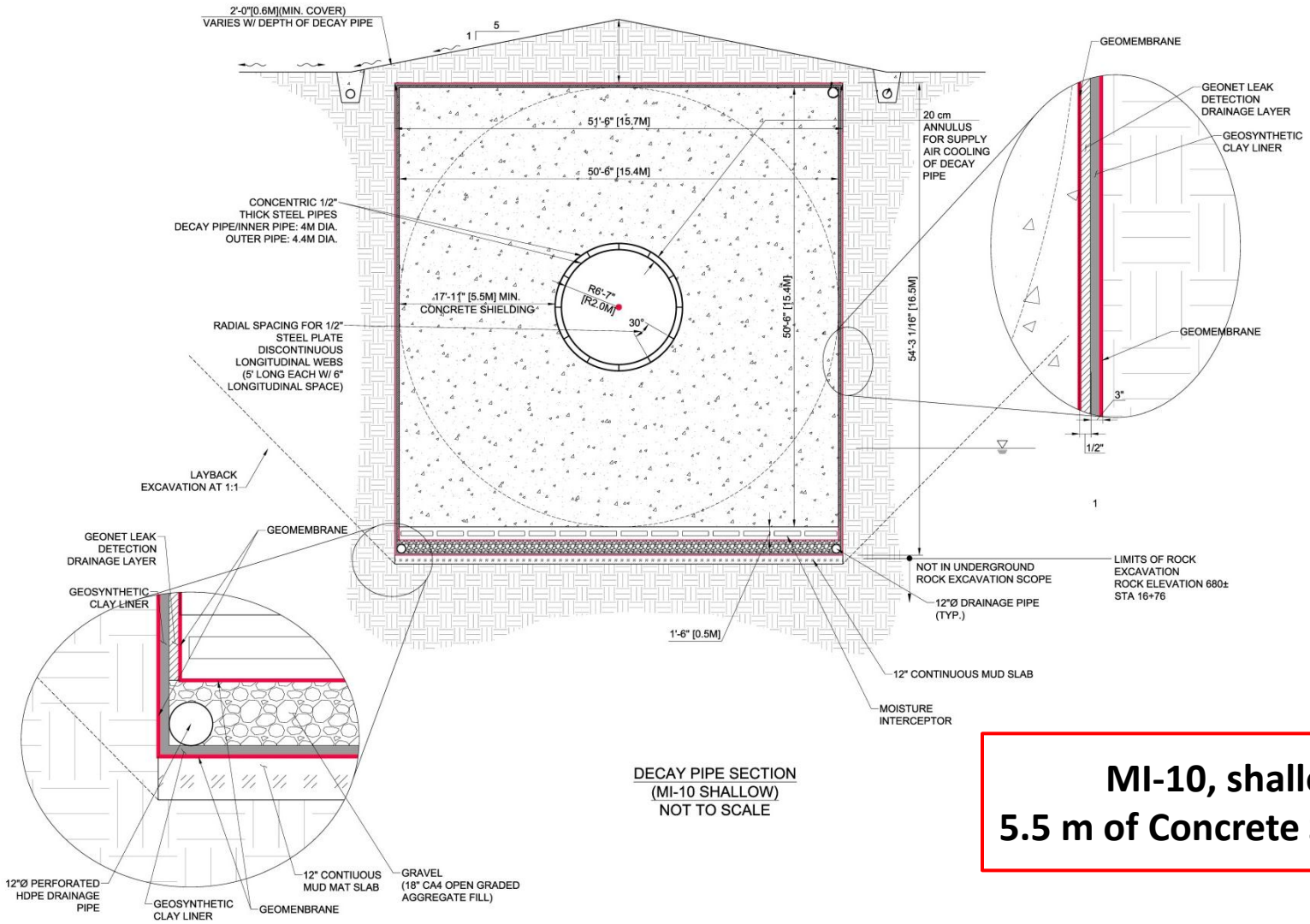
Target Hall Complex

3 story structure
Gross floor area
22,200 SF



6-cell radioactive component storage morgue has sufficient space for 2 years of operation at 708 kW. Fermilab assumed to provide any additional storage needed

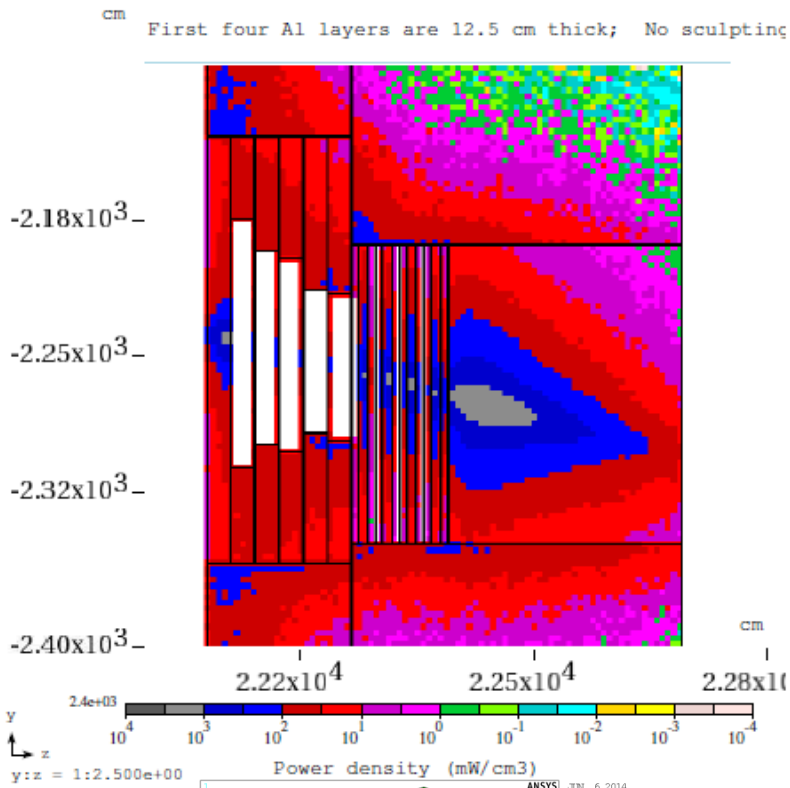
Decay Pipe - Inflowing water collection system



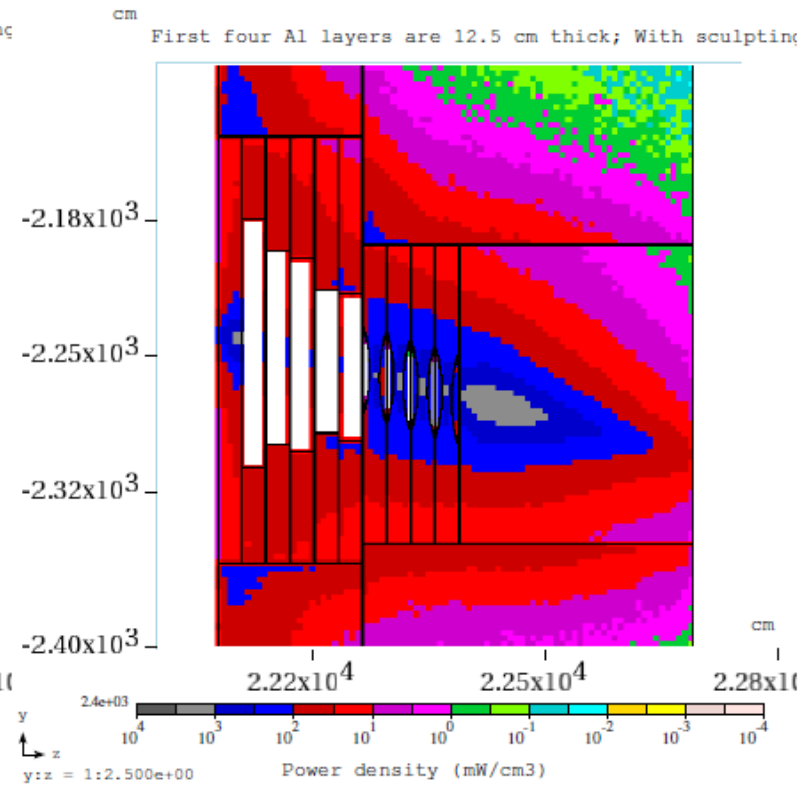
MI-10, shallow
5.5 m of Concrete Shielding

Absorber Design/MARS Simulations (single spoiler)

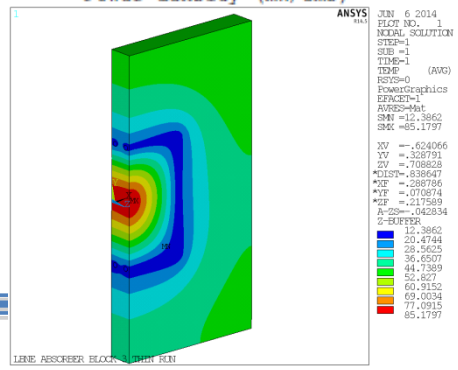
Thin (12.5 cm) Al blocks



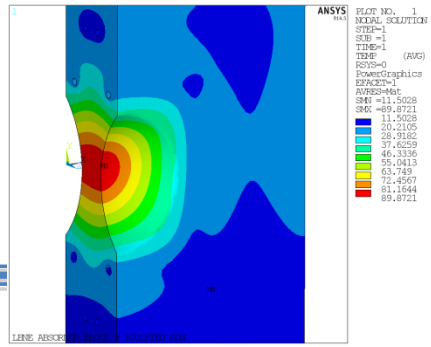
Sculpted Al blocks



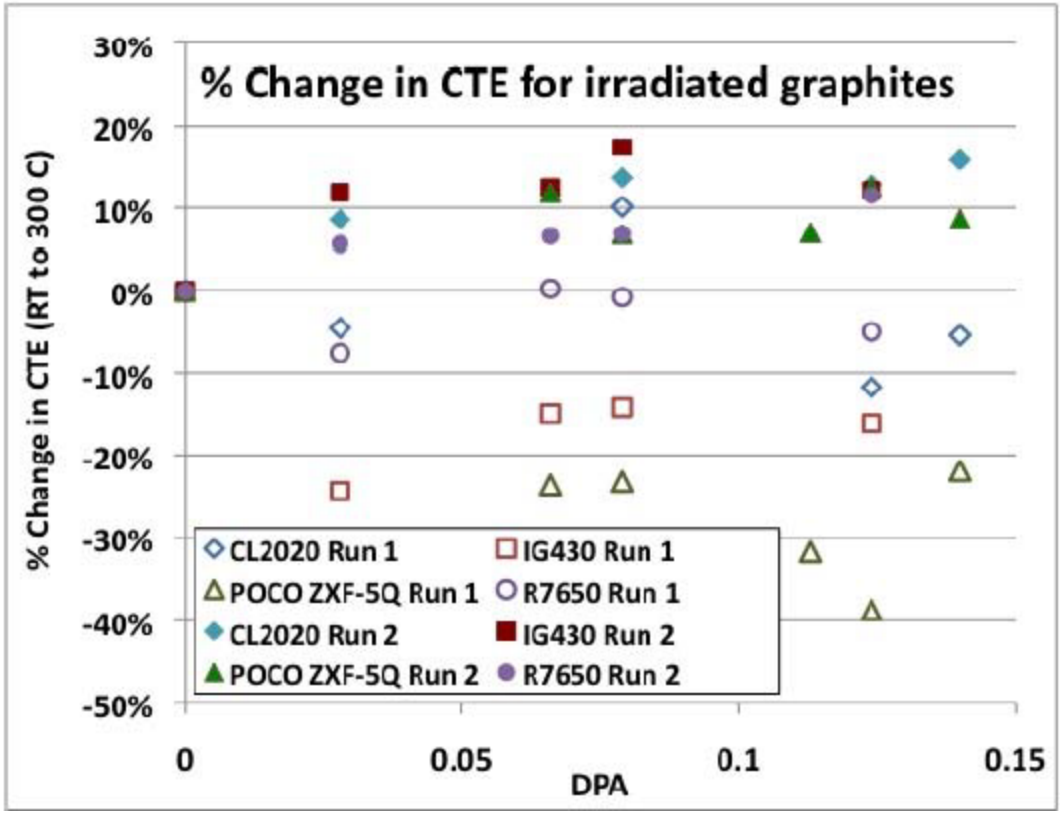
Max Temp 85^{0}C



Max Temp 90^{0}C



BLIP test results and recommendations



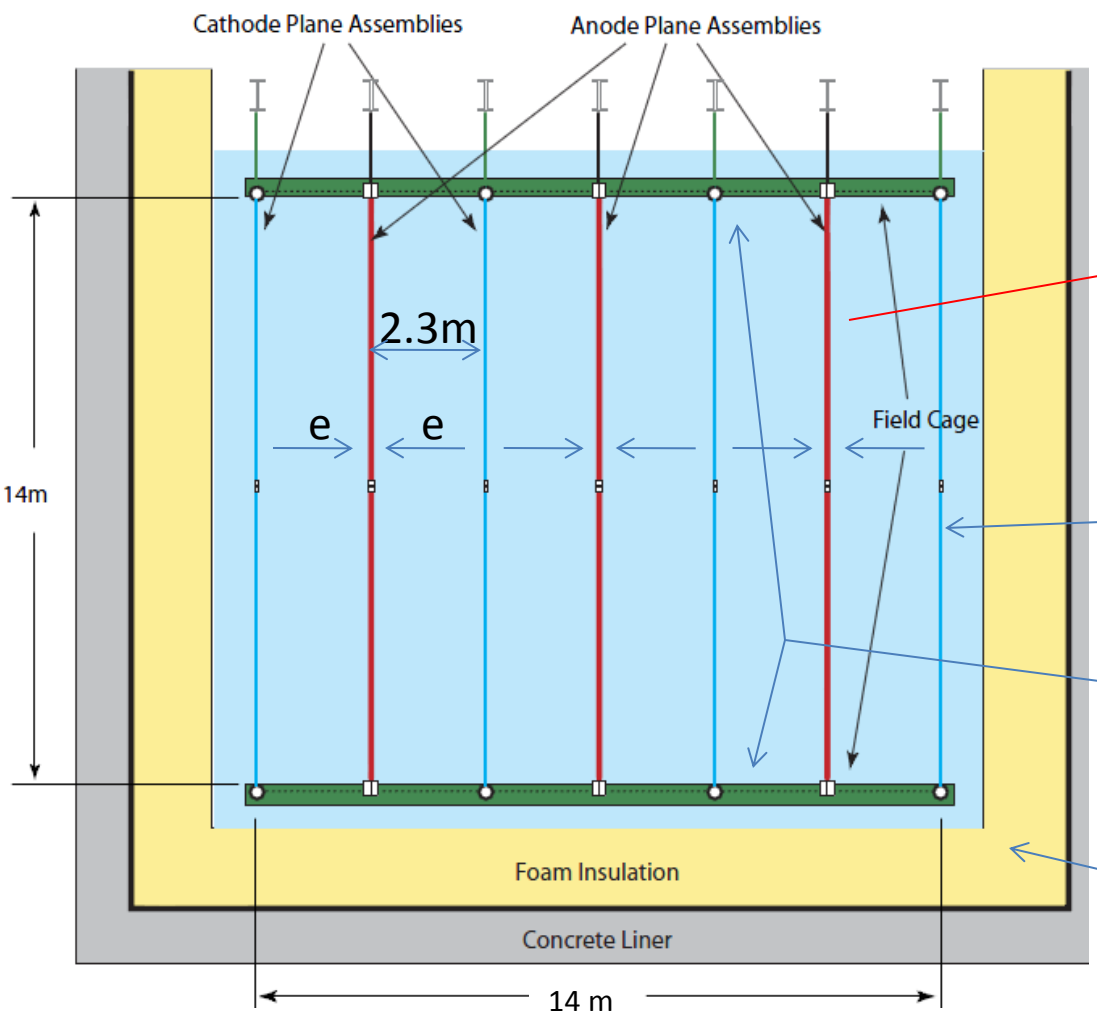
Comparison of change in coefficient of thermal expansion (20-300°C) for graphite samples during two consecutive thermal cycles after irradiation. Open symbols: first cycle; Filled symbols: second cycle

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.

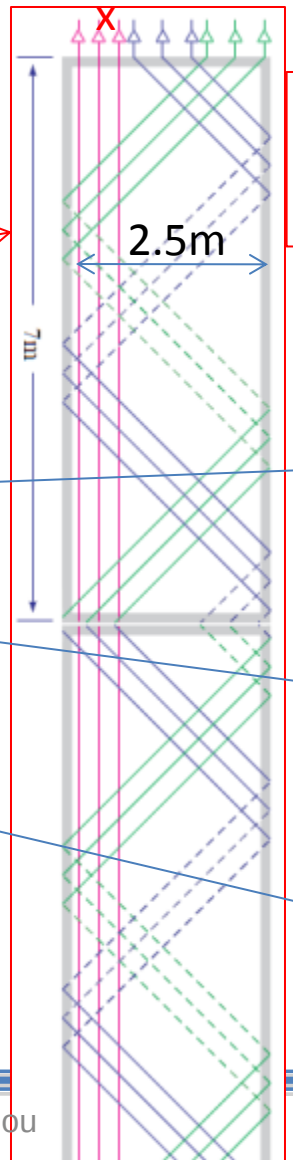
Detector Design – TPC cross section

Beam's Eye View



2 modules x 3 wide x 2 high x 10 long = 120 APA planes

Side View



Anode Plane Ass'y (APA) - Standard wire chamber construction

Cathode Plane Ass'y (CPA) – Stn Stl sheet

Field cage wraps detector

Membrane cryostat

Far Site Surface Detector Location: Sanford Underground Research Facility (SURF)

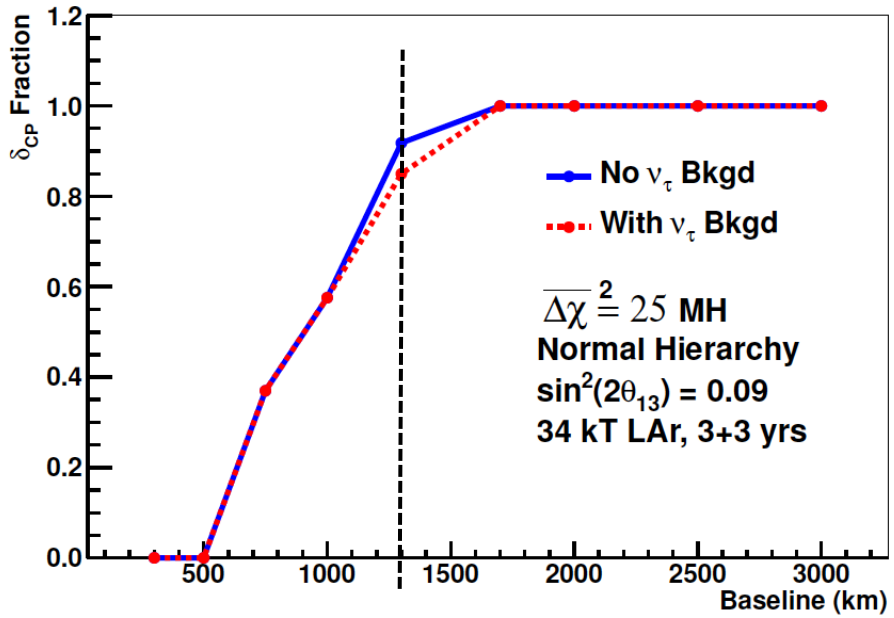
News on Collaborations

- Chinese colleagues (IHEP) visited to discuss collaboration on specific Beamline activities April 21-24.
- US-Japan Task Force proposal approved and work started. Focus on targetry, non-interactive profile monitors and kicker magnets.
- Several meetings with CERN colleagues in 2014. Lists of items of common interest exchanged and discussions are on-going.
- Collaboration with UTA colleagues started on the Hadron Monitor.

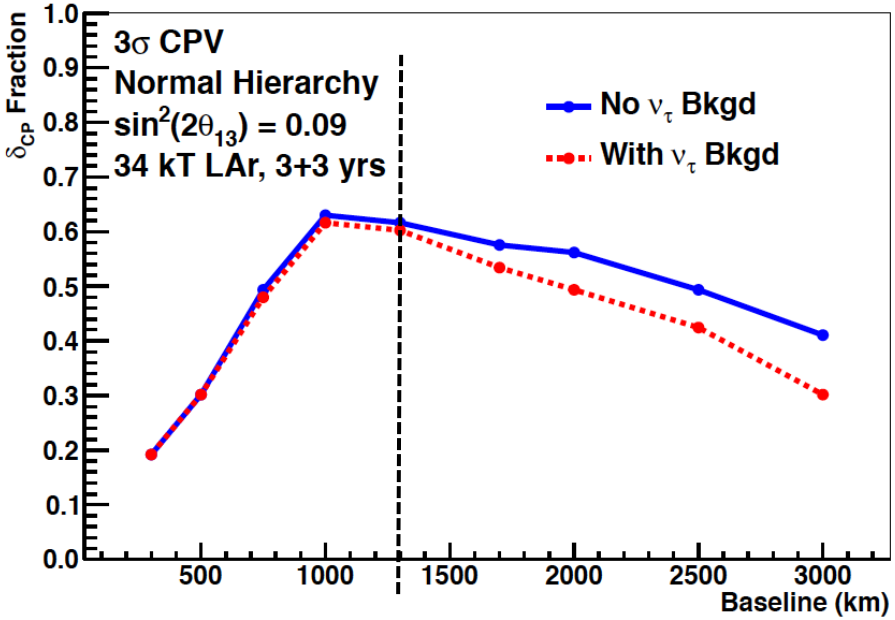
arXiv:1311.0212

Baseline Optimization

Mass Hierarchy



CP Violation



- **Based on simulations for Fermilab NuMI 120-GeV, 1.2 MW proton beam**
  - Target-1st horn distance tuned to cover 1st oscillation node + part of 2nd
  - Decay pipe length tuned (280-580 m)
  - For short baselines (<1000 km) use off-axis beam simulation to produce most flux
- **Baselines 1000-1300 km near optimal**
- For very long baselines event rate suppression in one of beam polarities makes observation of explicit CP-violation asymmetry difficult

LBNE Beamline: Primary Beam and System Integration Accomplishments

- Dipole, Quadrupole, Corrector magnets: Drawings released in NX
- Kicker magnets: Determined that we need 6 magnets; specifications completed and currently in the design phase
  - Ceramic tube - completed req for a sample vendor coated beam tube
- "Button-style" BPM prototype complete and tested at NuMI
- 3-D CAD model of the full PB developed (incorporating MI-10 laser scanning data) – helped identify interferences with MI & Recycler
- Successful Primary Beam shielding review held in March 2014
  - Some additional Muon plume MARS calculations in progress
- Studied (with CF) the effects of removing a portion of the MI-10 enclosure & constructing a new extraction enclosure (vs. adapting to existing structure)
- Worked with CF on systems to protect MI from LBNE embankment (e.g. slurry trench) and on an alternative to replacing pond F that offers potential broad improvements to ICW and pond systems

LBNE Beamline: Neutrino Beam Accomplishments

- Developed the design for a 1.2 MW (NuMI-like) graphite target for 120GeV; in the process of verifying this design for 80GeV
- Showed that the LBNE Horn 1 can work at 1.2 MW (& up to 230kA) at 80GeV & 120GeV, with small modifications to the CD-1 design
  - Demonstrated that we will need a new Horn Power Supply at 1.2MW
- Showed that we need to cool the target chase cooling panels at 1.2 MW
- After detailed evaluation changed from Air-filled, Air-cooled to Helium-filled, Air-cooled Decay Pipe and started making progress with new design
- Improved the Decay Pipe shielding & drainage design (with CF)
- Absorber core review in Nov. 2013. Since then core temps were reduced from 170^0C to 86^0C by implementing an Al spoiler & sculpted Al blocks; mechanical design and radiological shielding design advanced as well
- Progress on Target Hall Remote Handling and Shield pile design – focus on value engineering and optimization of the base design
- Advanced the design for beam windows for 1.2 MW
- Corrosion WG; Contract with ESI; Preparing to measure corrosion rates

LBNE Beamline: General Accomplishments

- In order to improve the physics reach of LBNE developed at a high level the full design concept and approximate cost for a discretely adjustable (steerable) beam with a ~23 mrad off-axis angle – e.g. run both on-axis and off-axis
- ANU-LBNE Working group: Completed a series of 14 meetings for lessons learned
- Developed collaborations:
  - China/IHEP (MOMENT) – funding approved
  - US-Japan Task Force proposal approved and work started
  - CERN (Several meetings so far and discussions on-going)
  - RAL/UK (target R&D and LBNE target)
  - UT-Arlington (Hadron Monitor work)