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Opportunities to create an optimal beam design for the 40kt experiment

Vaia Papadimitriou
Accelerator Division Headquarters – Fermilab

ELBNF proto-collaboration meeting at Fermilab

22-23 January, 2015

Outline

- Recent upgrades to the Fermilab Accelerator Complex
- Future plans for the Accelerator Complex
- Where we are with the beamline design for ELBNF
- Opportunities to create an optimal beam design
- Summary and conclusions
- A few facts and discussion on:
  - Do we need 700 kW prior to 2024 pointing to SURF?

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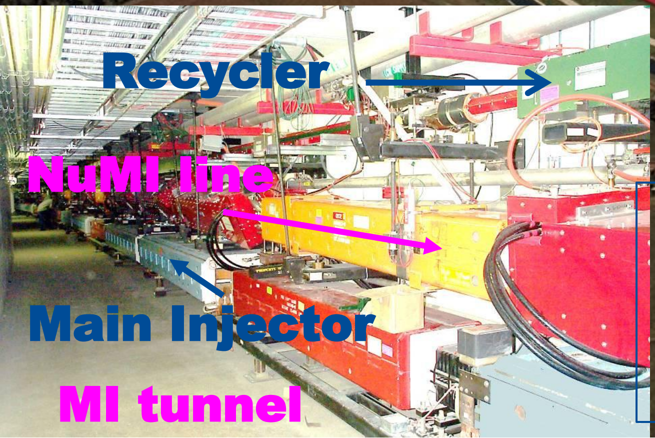
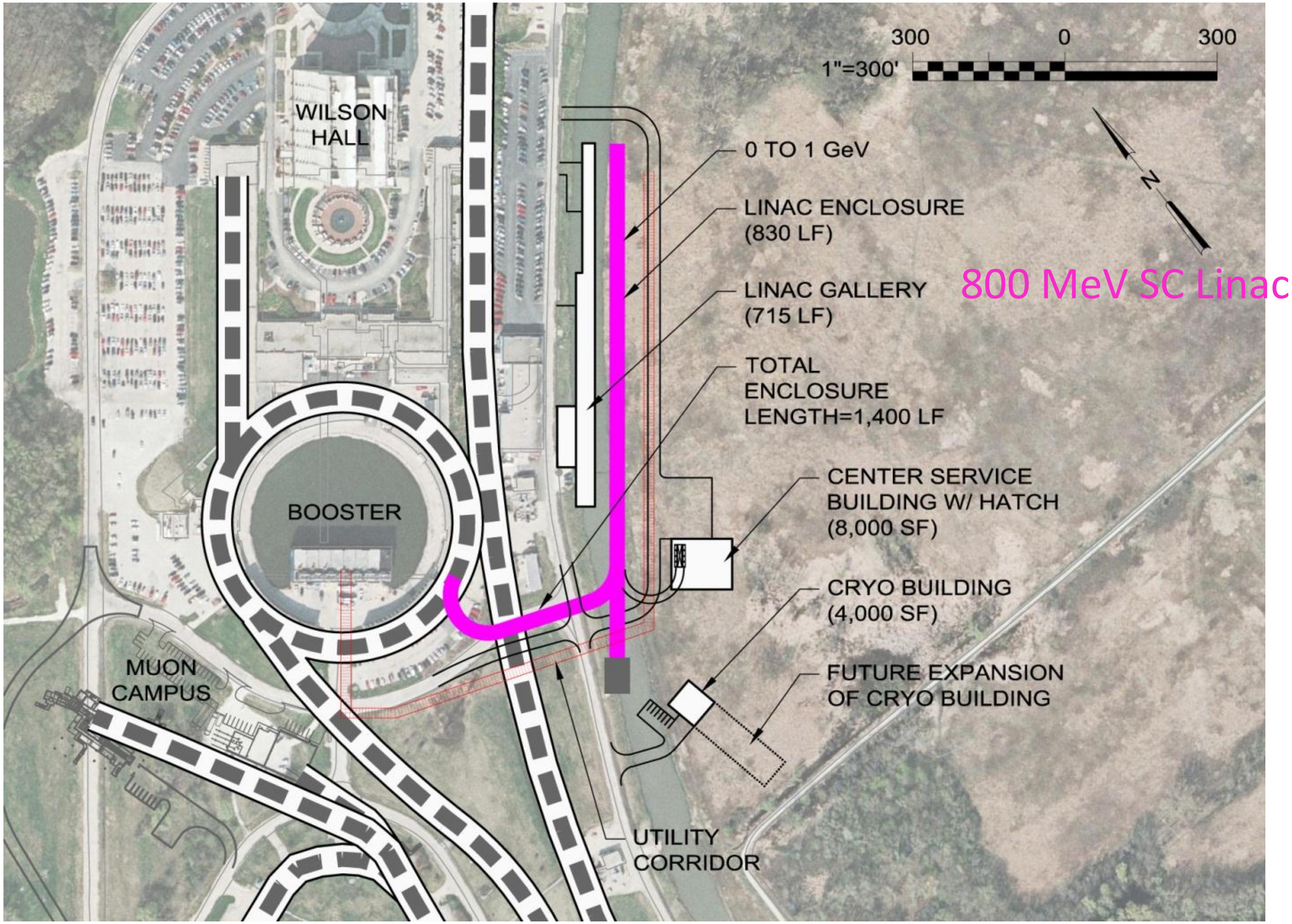
Fermilab Accelerator Complex



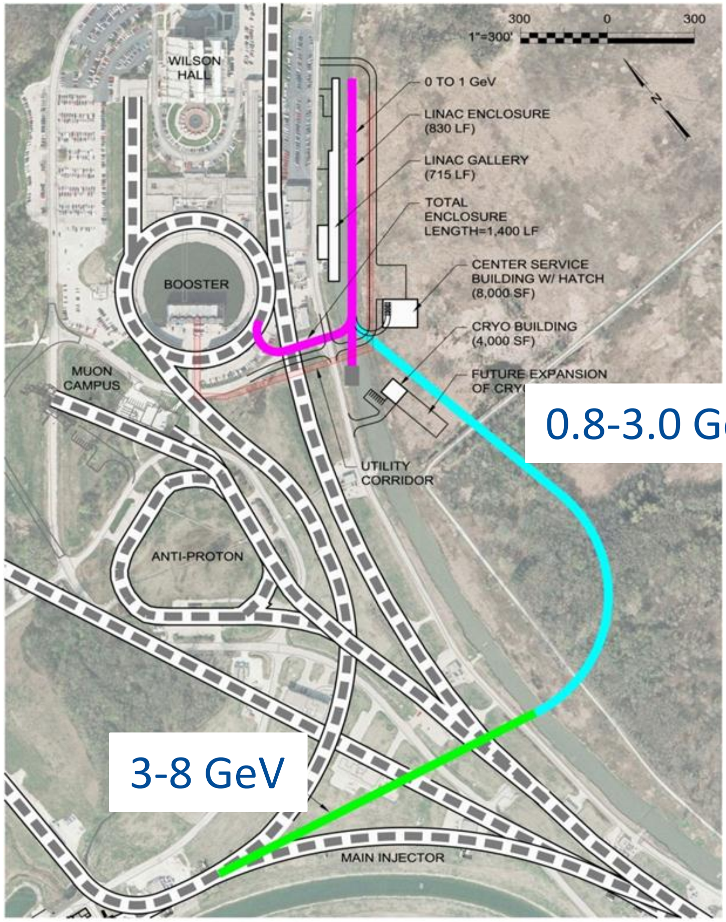
12 Booster batches are injected and slipped stacked in Recycler while MI is accelerating, thus saving injection time. This and a few more upgrades will allow 700 kW on the NuMI/NOvA target

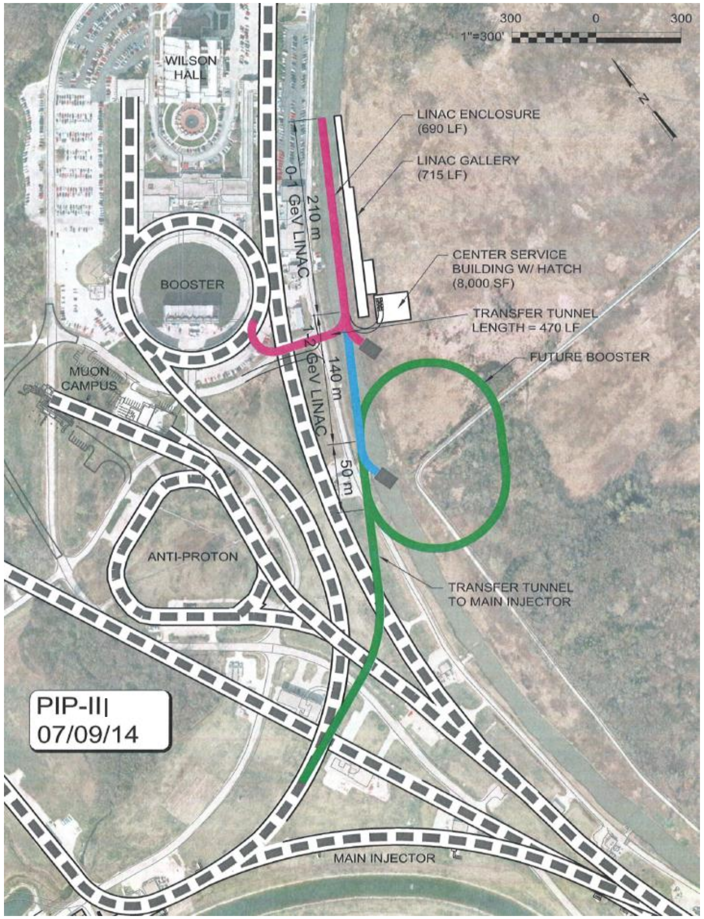
Proton Improvement Plan-II (PIP-II) Site Layout (provisional)



Flexible Platform for the Future (PIP-III)

- Opportunities for expansion include full energy (8 GeV) linac or RCS





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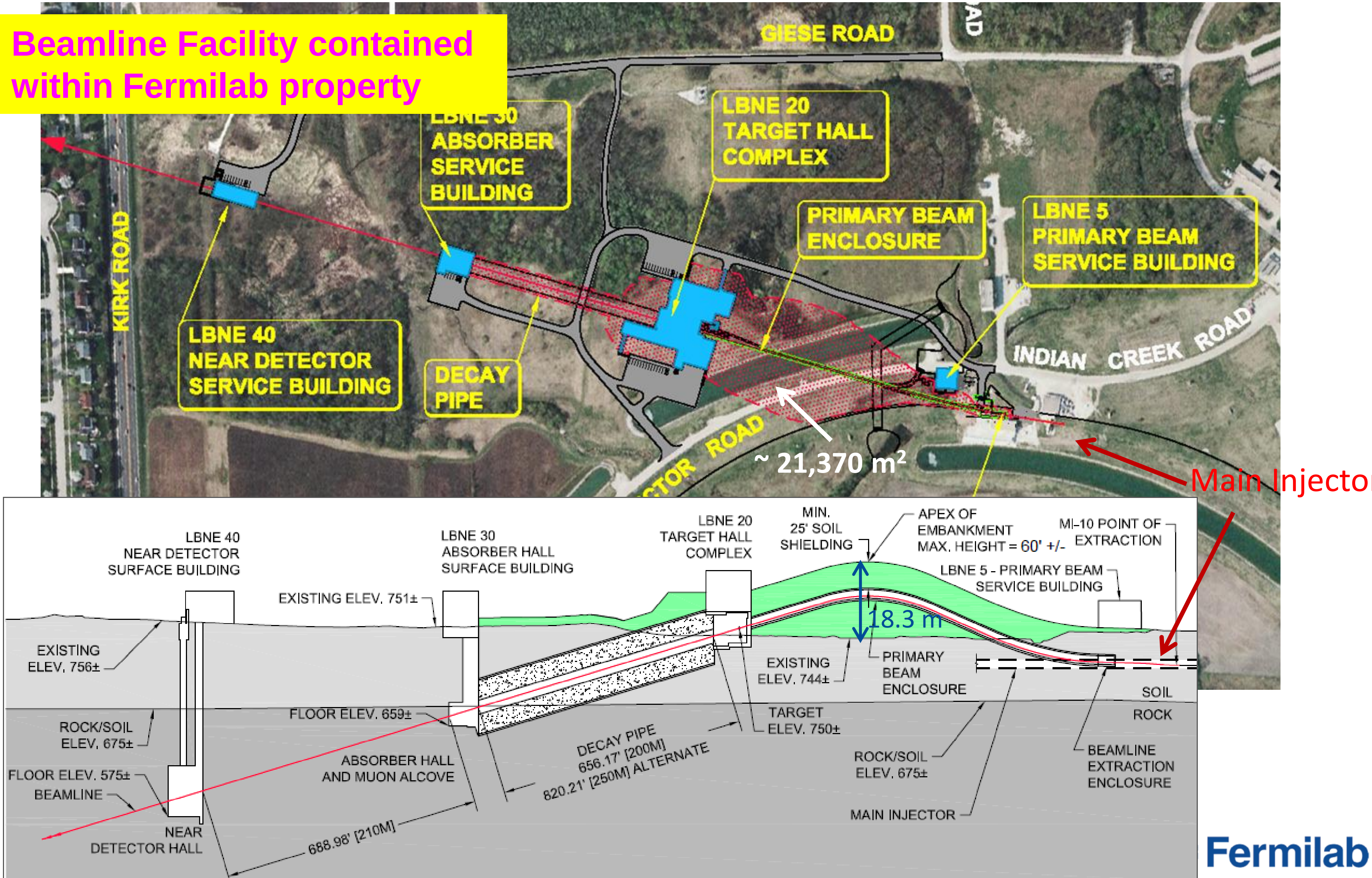
Beamline for the new Long-Baseline Neutrino Facility

A design for a new Beamline at Fermilab is under development, based on work done for the LBNE Project, which will support the new Long-Baseline Neutrino Facility.

- Directed towards the Sanford Underground Research Facility (SURF) in Lead, South Dakota, 1300 km from Fermilab.
- The primary beam designed to transport high intensity protons in the energy range of 60-120 GeV to the LBNF target.
- A broad band, sign selected neutrino beam with its spectrum to cover the 1st (2.4 GeV) and 2nd (0.8 GeV) oscillation maxima => Covering 0.5 ~ 5.0 GeV
- All systems designed for 1.2 MW initial proton beam power (PIP-II, ~2024). (Were planning to start at 700 kW a year ago).
- Facility is upgradeable to 2.4 MW proton beam power (PIP-III).
- We are currently assuming 20 year operation of the Beamline, where for the first 5 years we operate at 1.2 MW and for another 15 years at 2.4 MW.
- The lifetime of the Beamline Facility including the shielding is assumed to be 30 years.

Beamline for a new Long-Baseline Neutrino Facility
MI-10 Extraction, Shallow Beam

Beamline Facility contained within Fermilab property



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LBNF Beam Operating Parameters

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

Parameter	Protons per cycle	Cycle Time (sec)	Beam Power (MW)
≤ 1.2 MW Operation - Current Maximum Value for CD4			
Proton Beam Energy (GeV):			
60	7.5E+13	0.7	1.03
80	7.5E+13	0.9	1.07
120	7.5E+13	1.2	1.20

≤ 2.4 MW Operation - Ultimate Maximum Value LBNE Final Phase			
Proton Beam Energy (GeV):			
60	1.5E+14	0.7	2.06
80	1.5E+14	0.9	2.14
120	1.5E+14	1.2	2.40

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

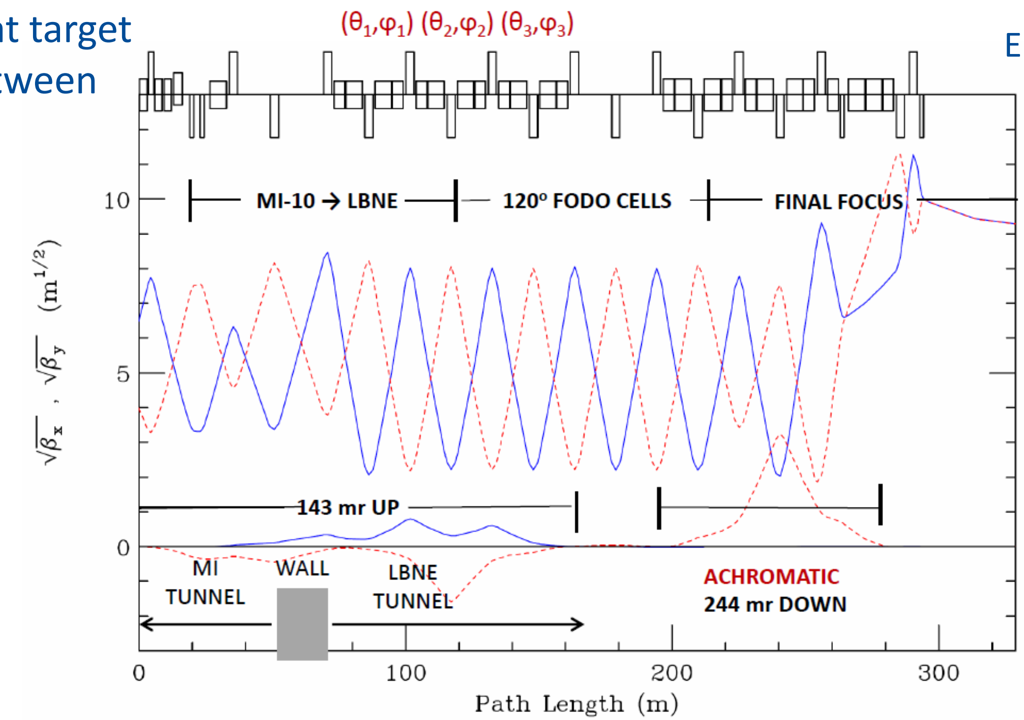
What is being designed for 2.4 MW

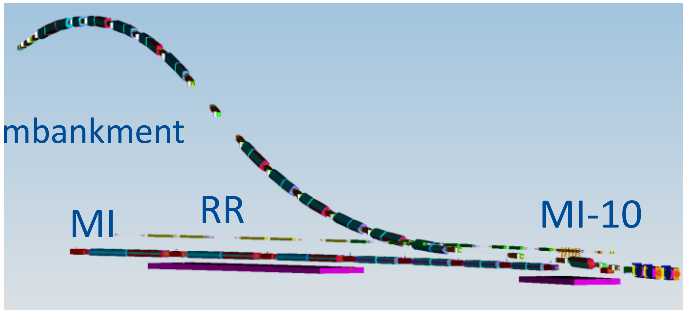
- Designed for 2.4 MW, to allow for an upgrade in a cost efficient manner:
  - Primary beamline
  - the radiological shielding of enclosures (primary beam enclosure, the target shield pile and target hall except from the roof of the target hall, the decay pipe shielding and the absorber hall) and size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

Primary Beam and Lattice Functions

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

Beam size at target tunable between 1.0-4.0 mm



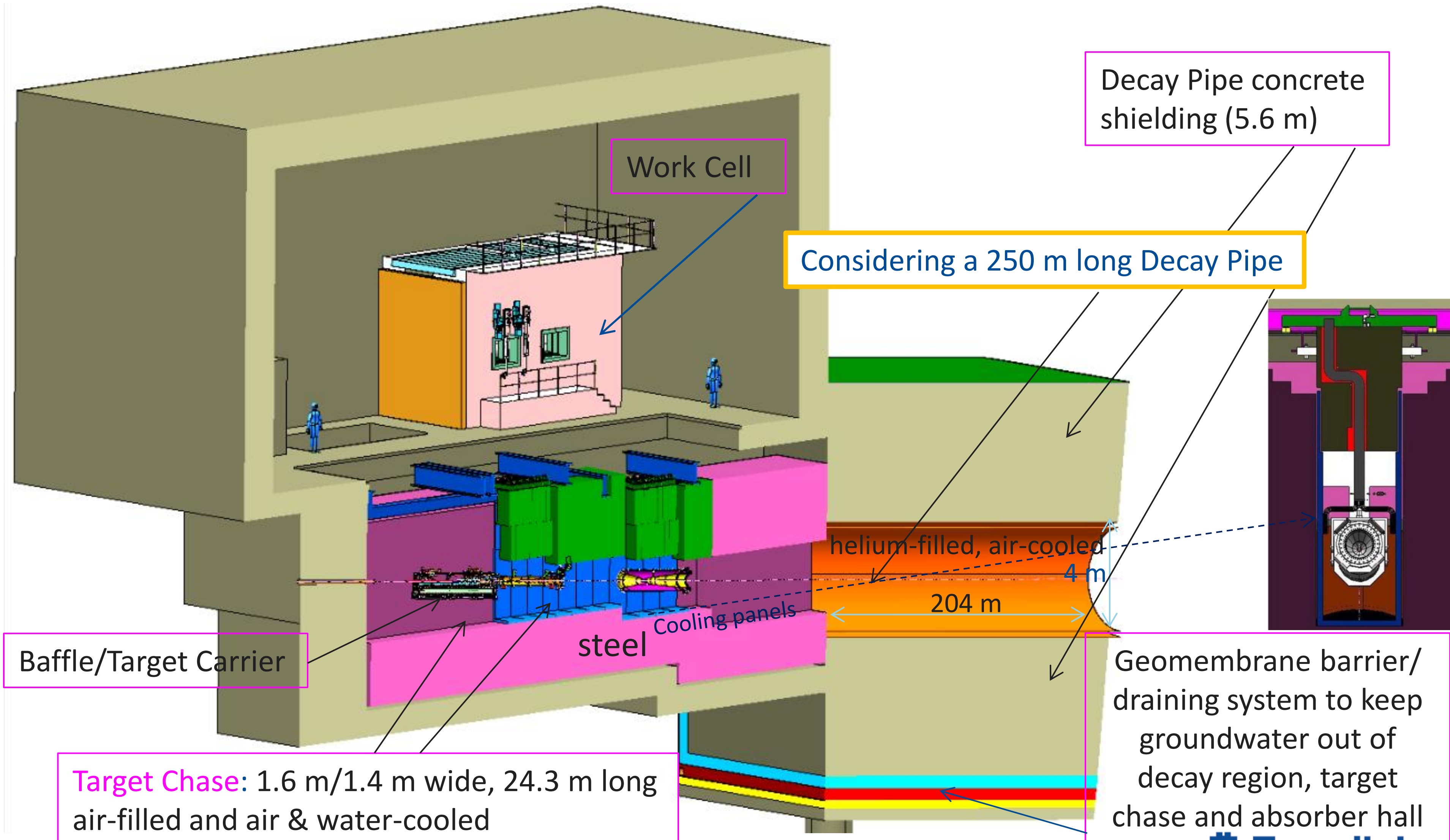


STRUCT/MARS simulations have shown that highest beam loss rate takes place right at the apex of the beamline

Horizontal (solid) and vertical (dashed) lattice functions of the LBNF 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 & $\Delta p_{99}/p = 11\times10^{-4}$

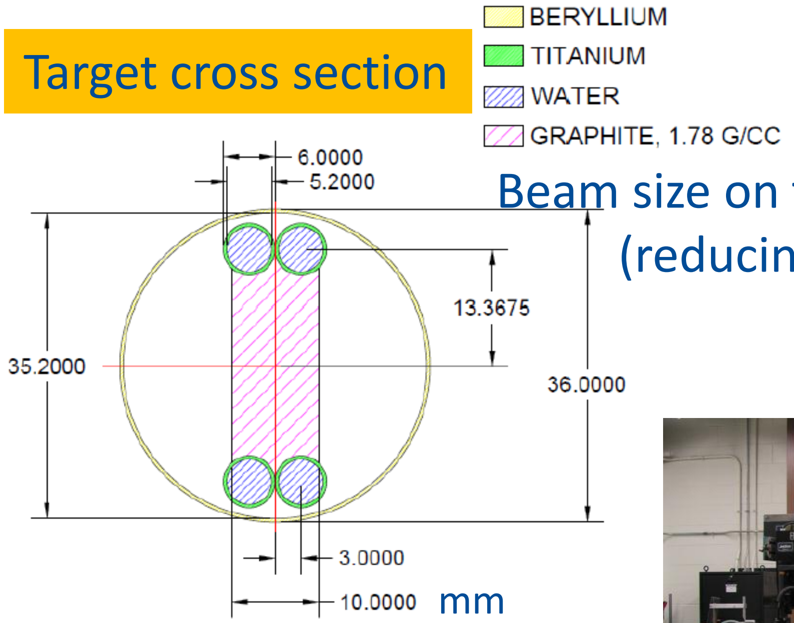
Target Hall/Decay Pipe Layout



1.2 MW components inside the target chase

47 graphite target segments, each 2 cm long

Target cross section

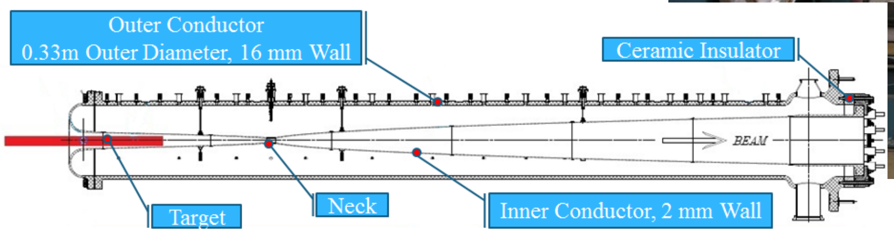


mm

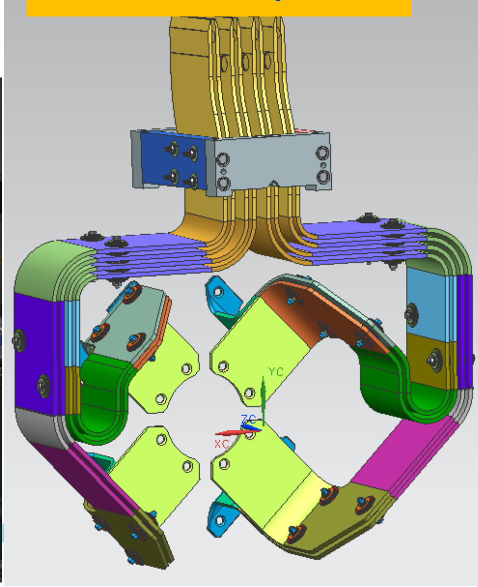
Beam size on target 1.7 mm (reducing stress)

Baffle

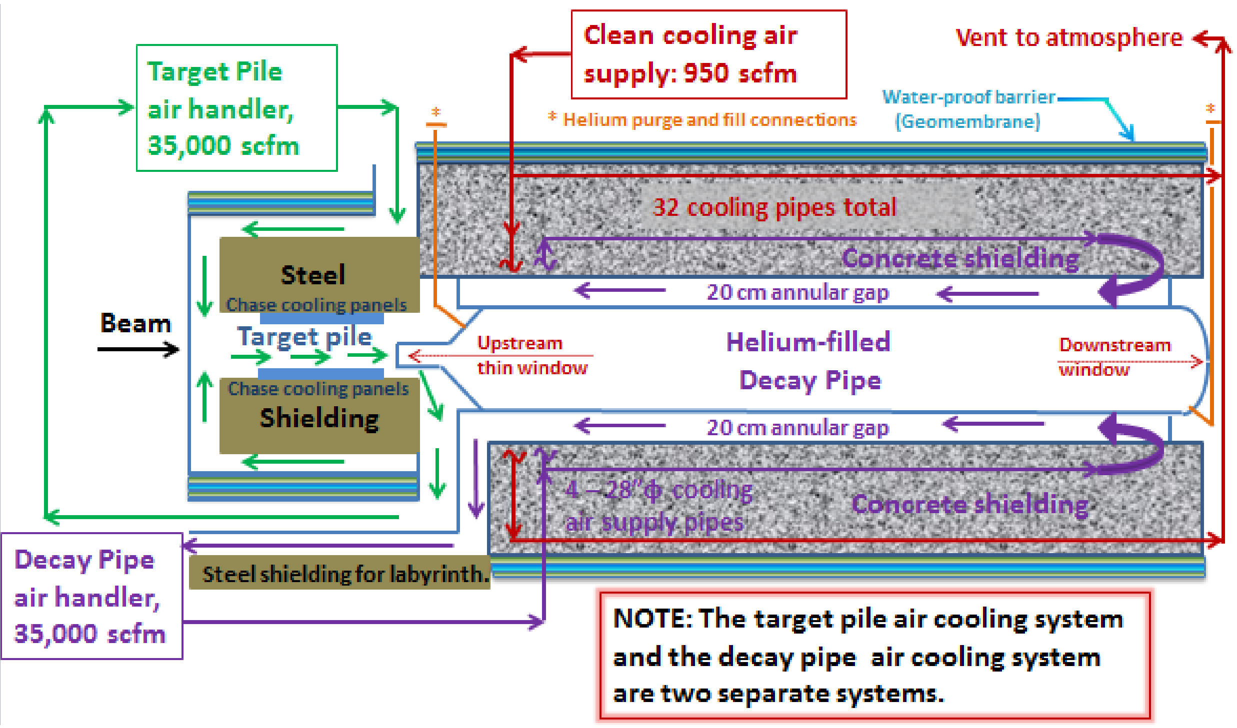
Horn

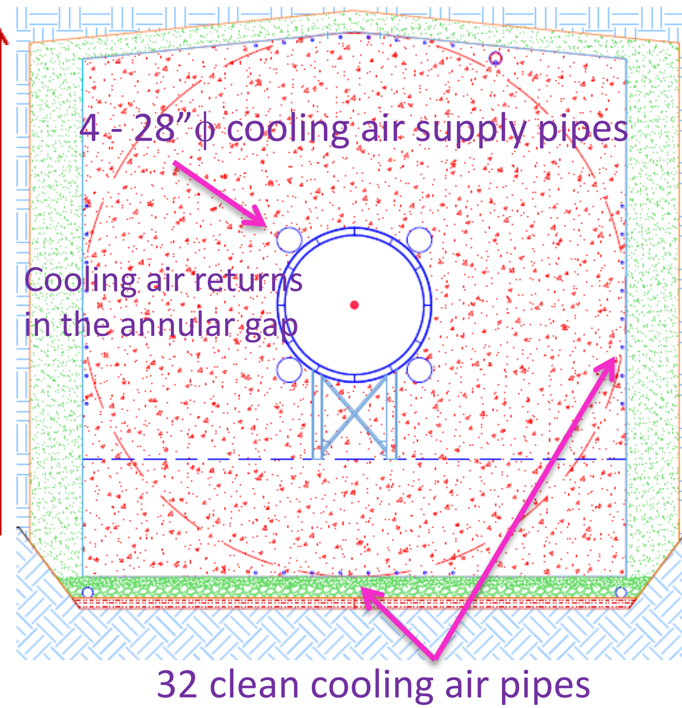


Horn Stripline

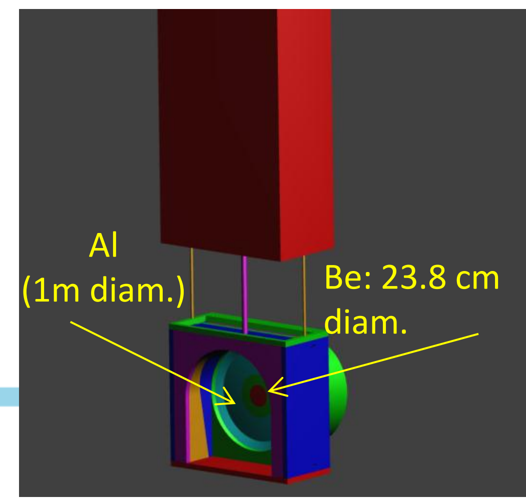


Helium-filled/Air-cooled Decay Pipe (Helium increases the ν flux by ~10%)





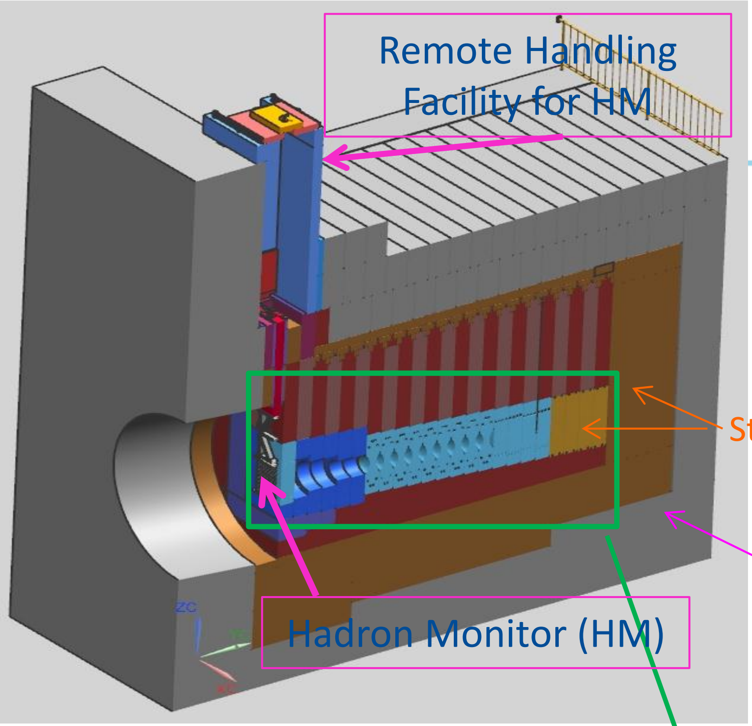
- Concentric Decay Pipe. Both pipes are ½" thick carbon steel
- Decay pipe cooling air supply flows in four, 28" diam. pipes and the annular gap is the return path (purple flow path)
- The helium-filled decay pipe requires that a replaceable, thin, metallic window be added on the upstream end of the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

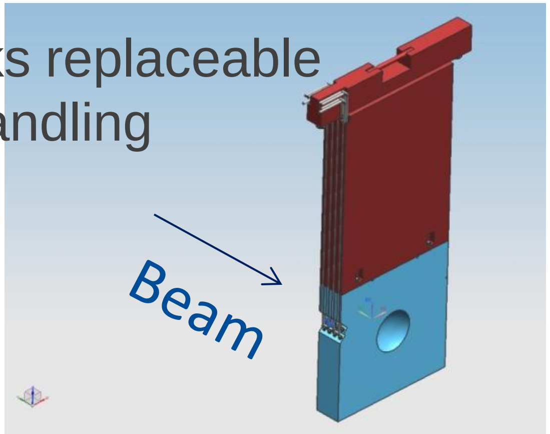


Current Configuration of Hadron Absorber

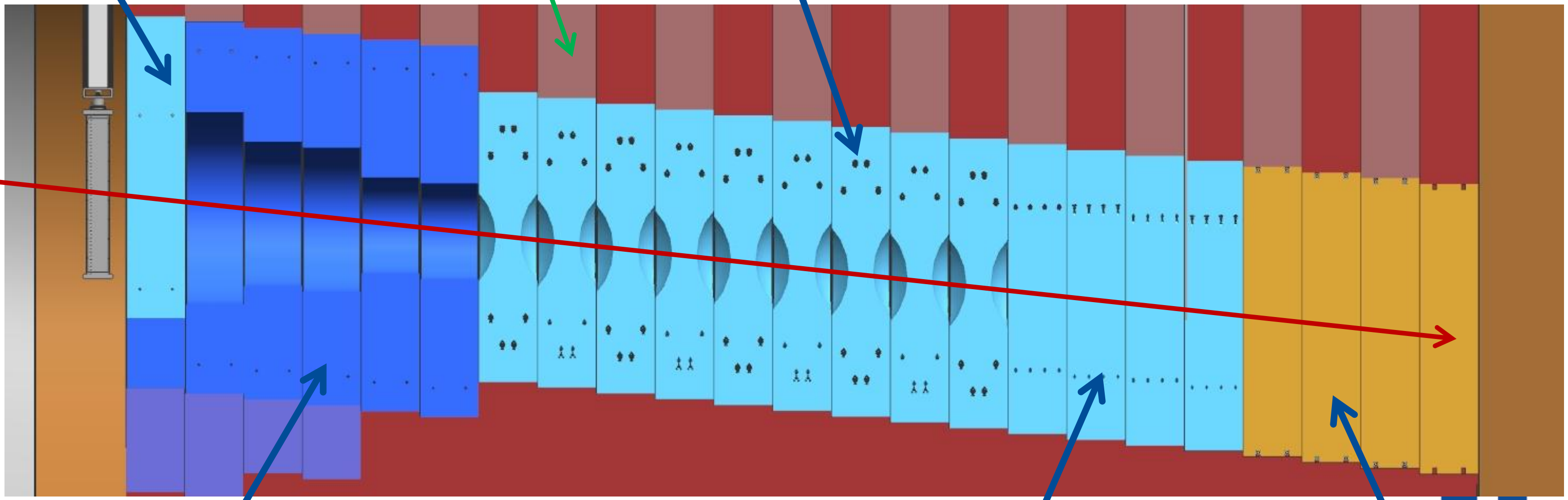
The Absorber is designed for 2.4 MW

- All core blocks replaceable via remote handling





Sculpted Al block



Review Committee (Absorber Core Review)

- Curtis Baffes (CHAIR) – FNAL
- Chris Densham – RAL
- Ilias Efthymiopoulos – CERN
- Peter Kasper – FNAL
- Ang Lee – FNAL
- Antonio Marcone – CERN
- Andy Stefanik – FNAL

January 20-22, 2015

Just had closeout

Very successful – “clear pass”

Opportunities for an optimal beam design - physics

- Proton energy choice in the range 60-120 GeV (some programmatic consequences).
- Choice of Decay Pipe length (and width). Current length 204 m. Real estate allows for up to 250 m.
- Horns
  - Shape of inner conductor
  - current (power supply up to 300 kA, need new design)
- Target (currently two interaction lengths)
  - Size/shape
  - Material(s) (higher longevity can increase up time)
- Vertically adjustable beam (run off-axis at ~23 mrad for 2nd oscillation maximum)

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Possible improvements in the focusing system

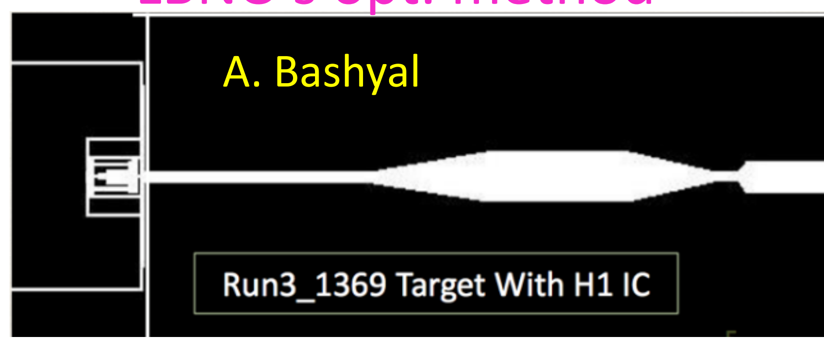
- When LBNE was reconfigured in 2012, in order to save money we abandoned our LBNE optimized target and horn designs and opted for NuMI designs with small modifications. (e.g.we were able to verify the NuMI horns up to 230 kA instead of their 200 kA design value).

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

Horn 1 simulation using LBNO's opt. method

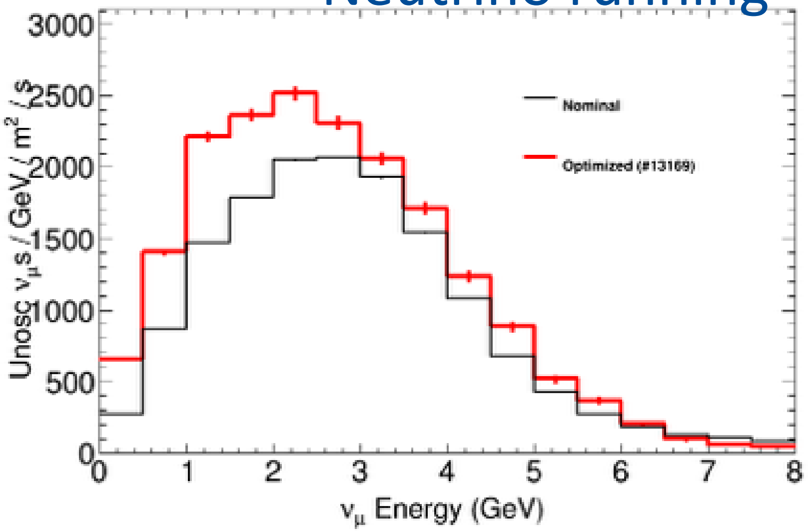


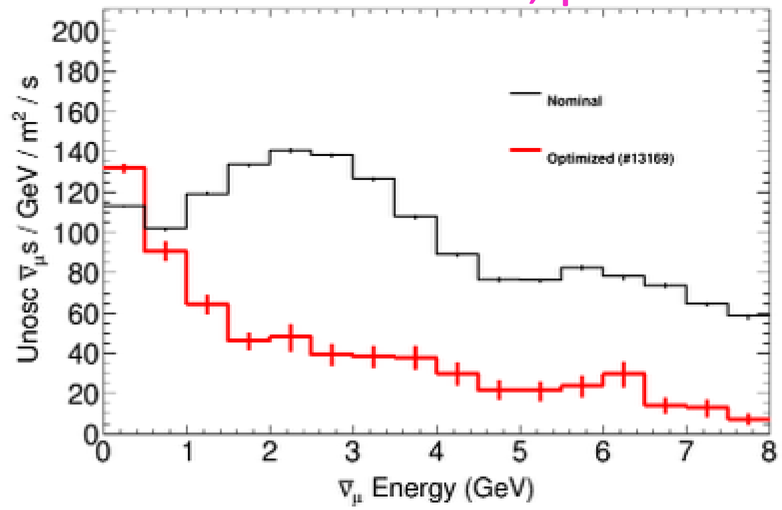
Tunable E_ν spectrum

Neutrino Flux of best configuration compared with nominal (Optimized for 19 beam parameters)

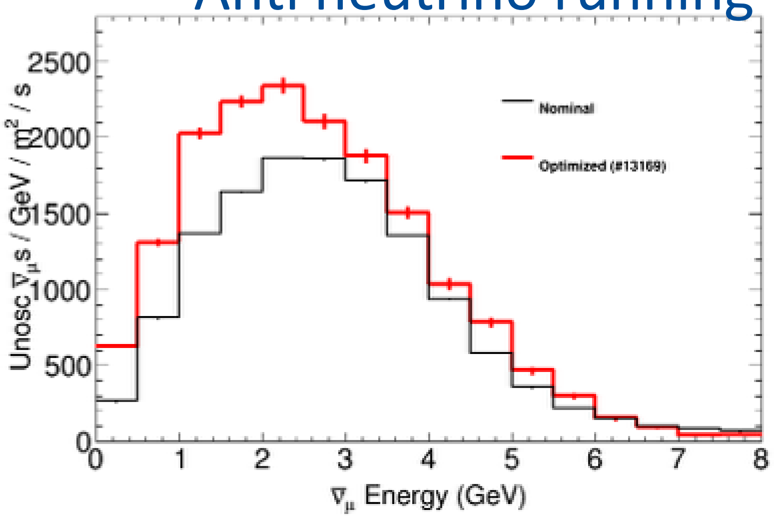
Laura Fields, parallel session

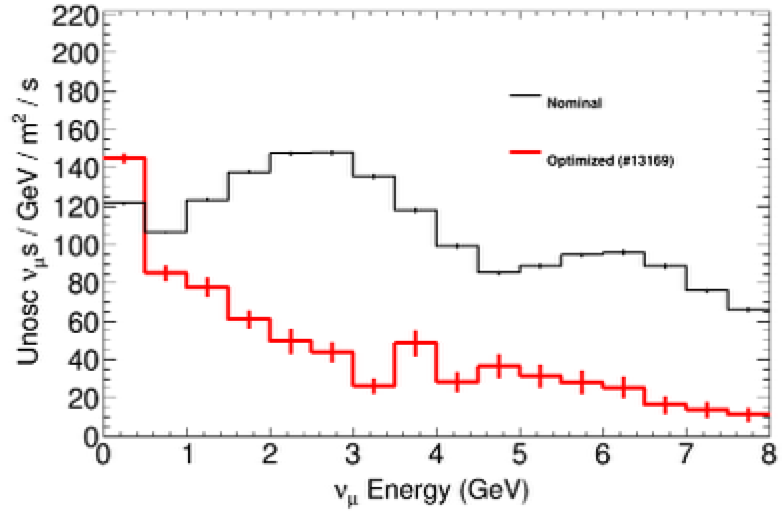
Neutrino running





Anti neutrino running





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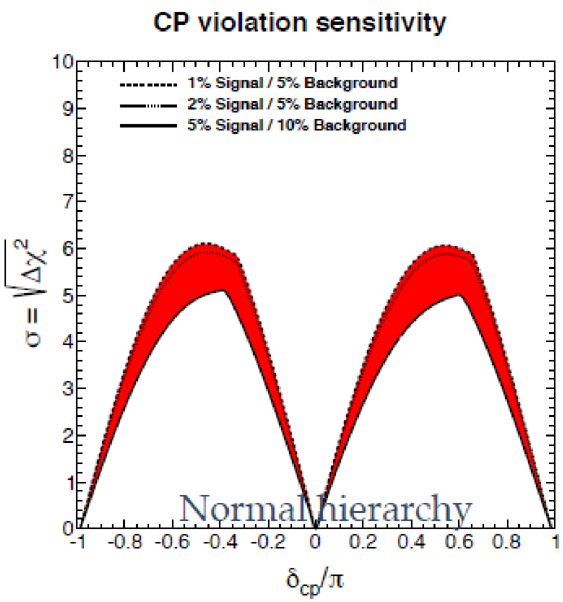
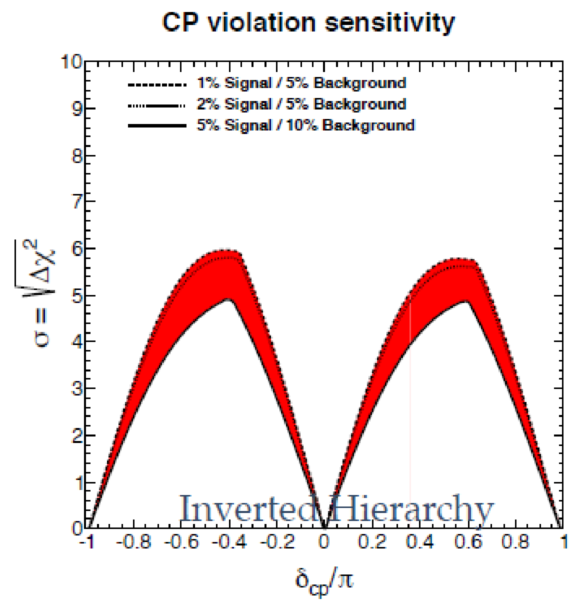
CP violation sensitivity: Nominal and recently re-optimized





Nominal

Horns 12.6 m apart (was 6.6 m)

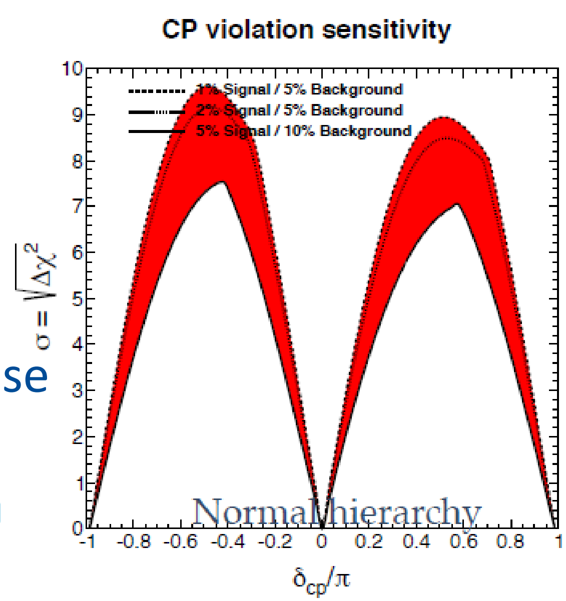
Horn2 long. scale: 1.28

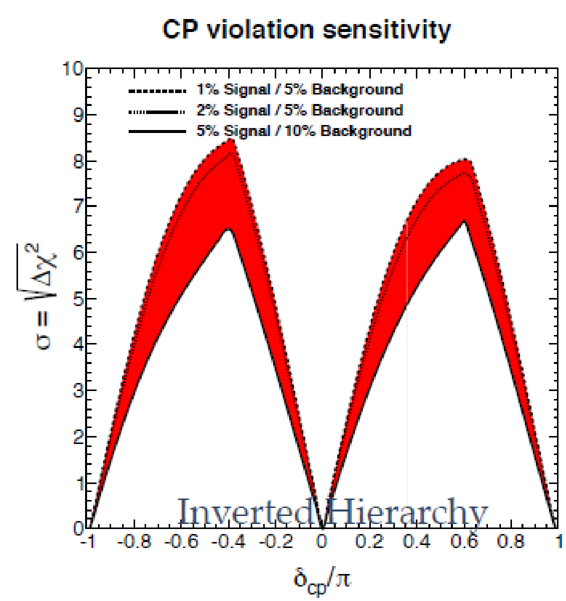
Horn2 radial scale: 1.67

……….

Points to 8-9 m longer target chase

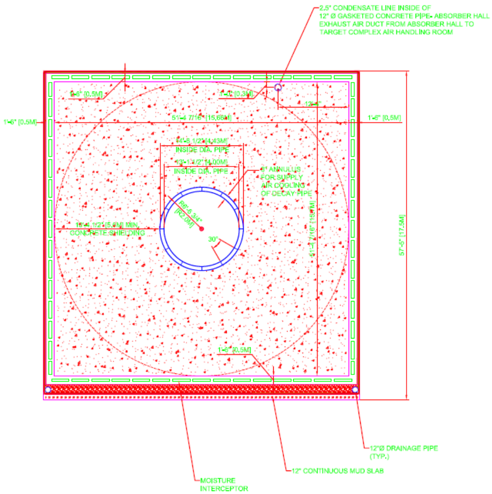
No engineering evaluation yet



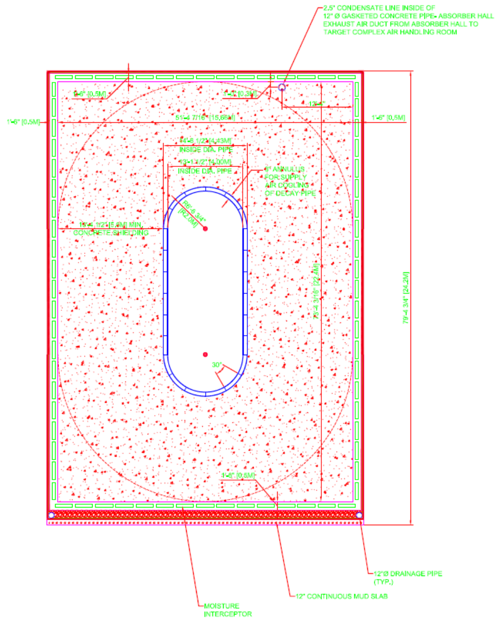


Adjustable beam

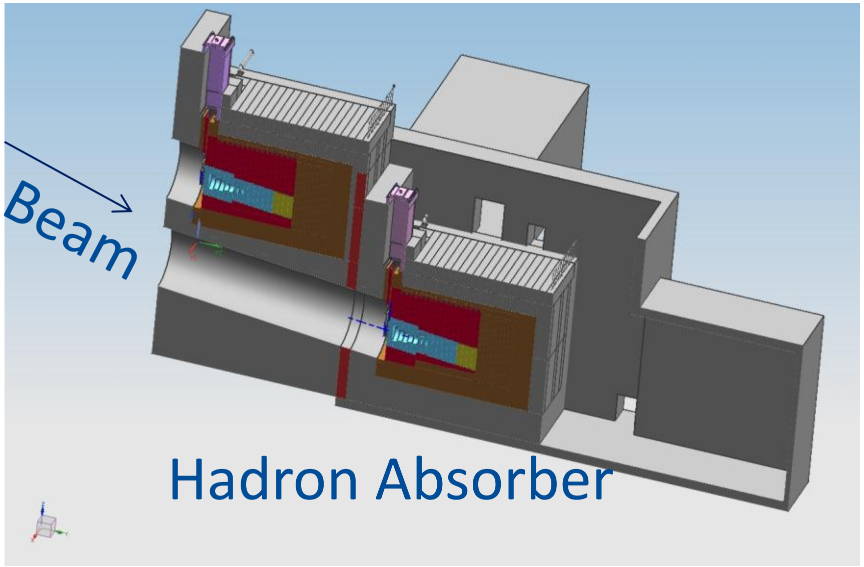
Run off-axis at ~23 mrad (1.3 deg) to access the 2nd oscillation maximum.



DECAY PIPE SECTION AT TARGET HALL



DECAY PIPE SECTION NEAR ABSORBER

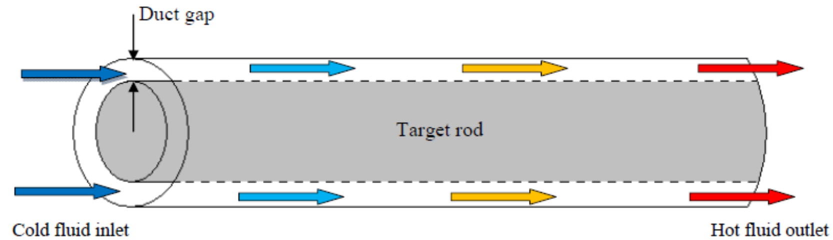


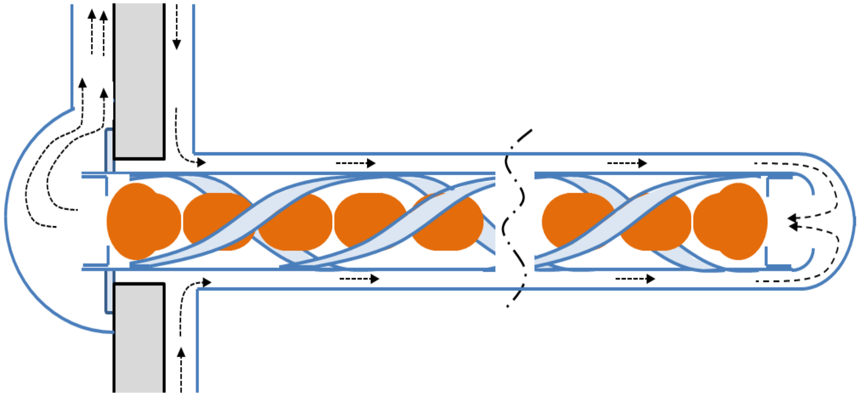
For a 204 m long Decay Pipe

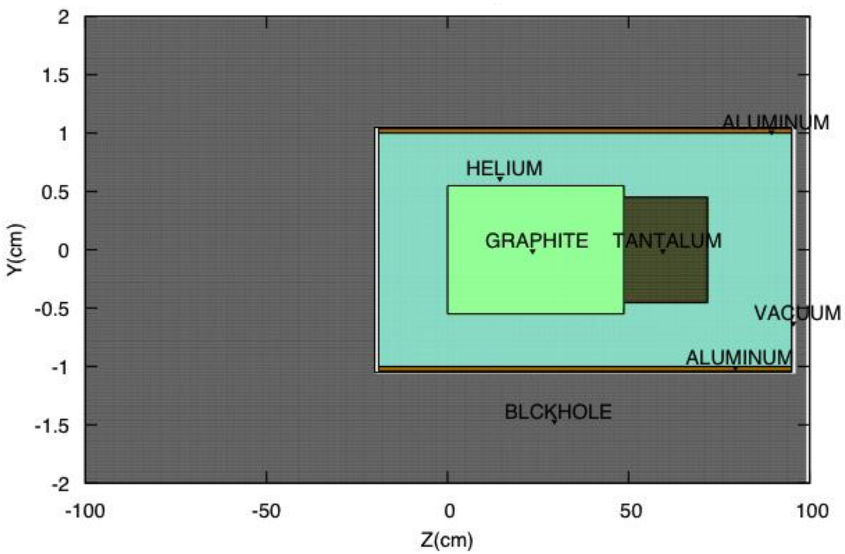
- Preliminary investigation indicates that the cost impact is expected to be in the $49M-$55M range and that an at least 6 month shutdown is required to switch between on and off-axis positions.

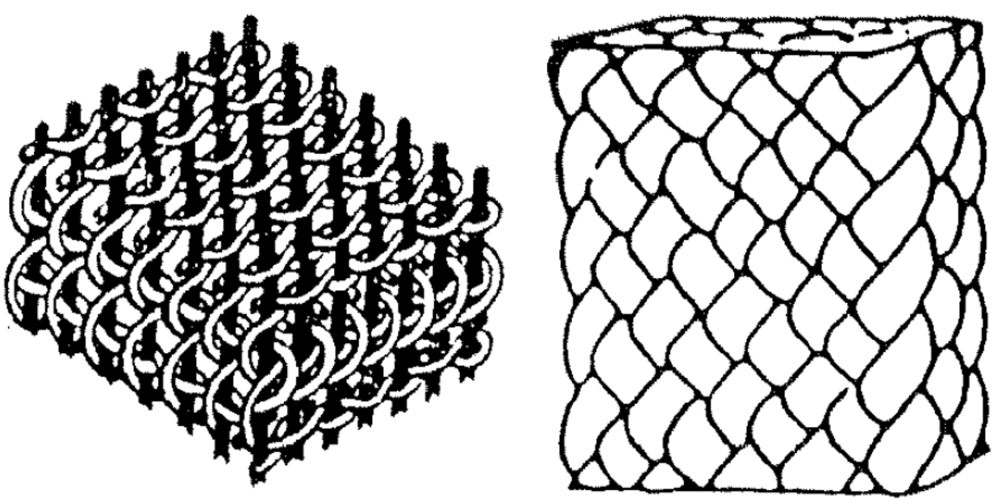
Novel Target Designs

- High heat-flux coolants
  - Elimination of water
- Composite targets
- Segmentation
- Robust materials and assemblies







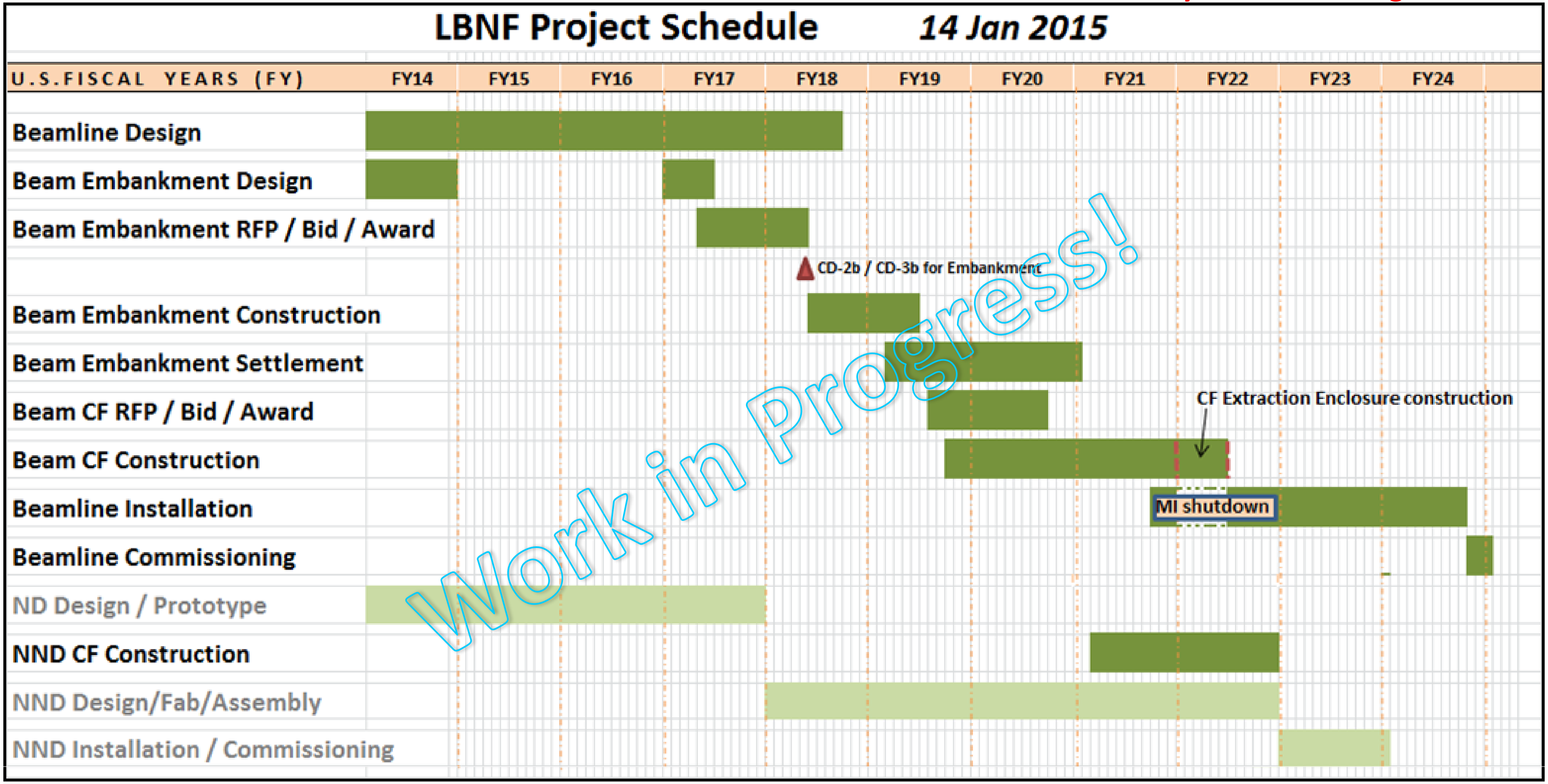


Summary/Conclusions

- **Advanced conceptual design of the Beamline available for 1.2 MW operation using NuMI-like target and horns**
- **Several opportunities available to further optimize the beam design**
- **Before CD-1 we had an engineering evaluation of a more optimized horn but had to abandon that work in order to reduce cost. We are now at the early simulation stage – using the LBNO approach - of evaluating more optimal for the physics target/horn designs but no significant engineering has been done for those.**
- **We have early indications that we will need to increase the size (especially the length) of the target chase to fit those.**
- **As far as we have a target chase of sufficient size we can always switch to more optimized components later.**

Near Site Schedule: Beamline and Near Detector Cavern

Work is technically-limited starting Oct 2015



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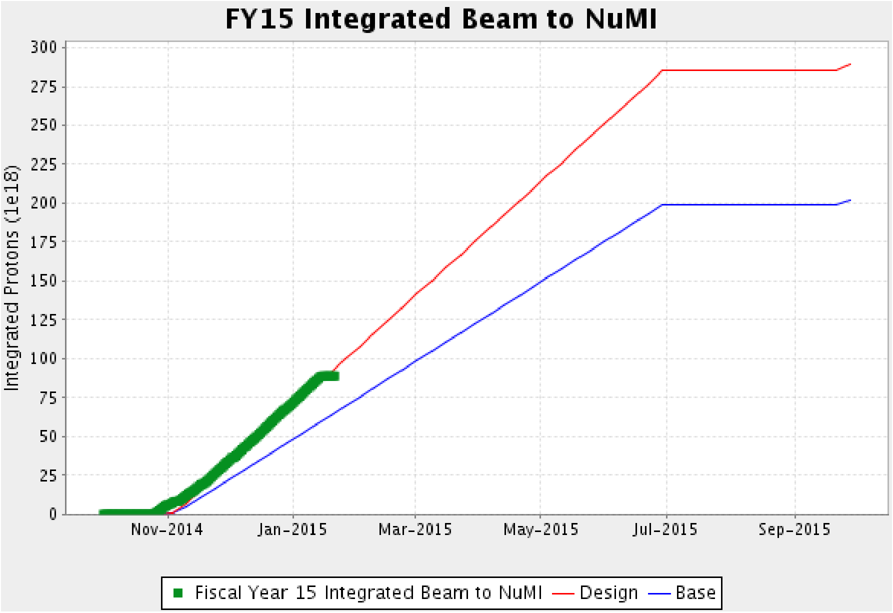
POT Projections: FY16 & FY17

	NuMI (e20)	BNB (e20)	g-2 (e20)
FY16 Range	4.2 – 6.0	1.4 – 2.1	0
FY16 Target	4.8	1.7	
FY17 Range	4.7 – 6.8	2.7 – 3.9	0.72 – 0.85
FY17 Target	5.4	3.1	0.76

Range: lower to upper bound

Target: (2 * lower + upper)/3



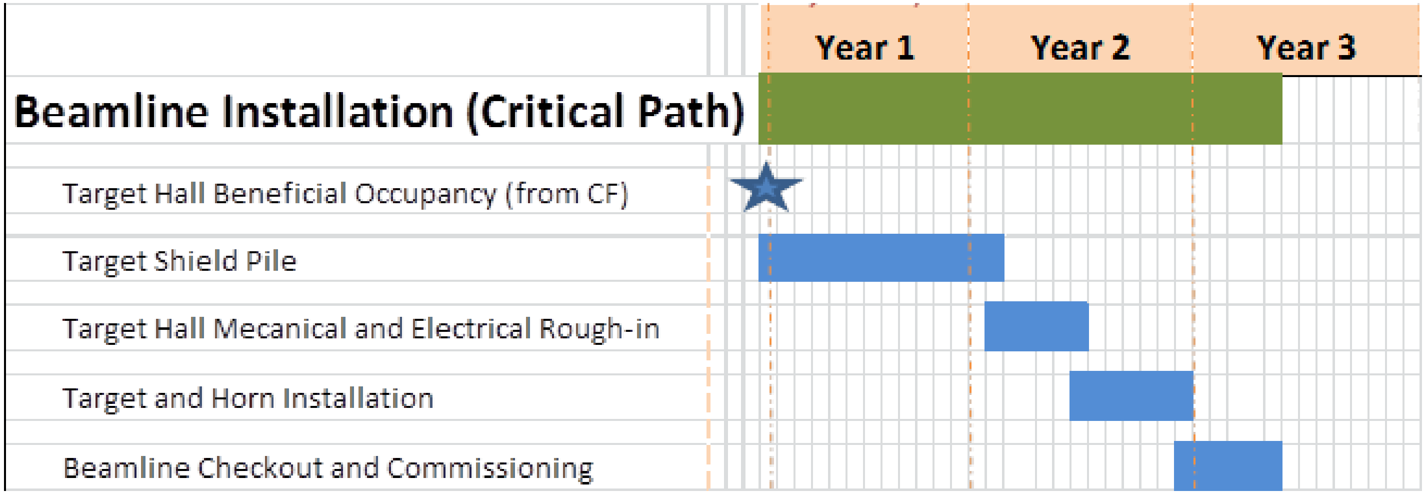
Do we need 700 kW prior to 2024 pointing to SURF?

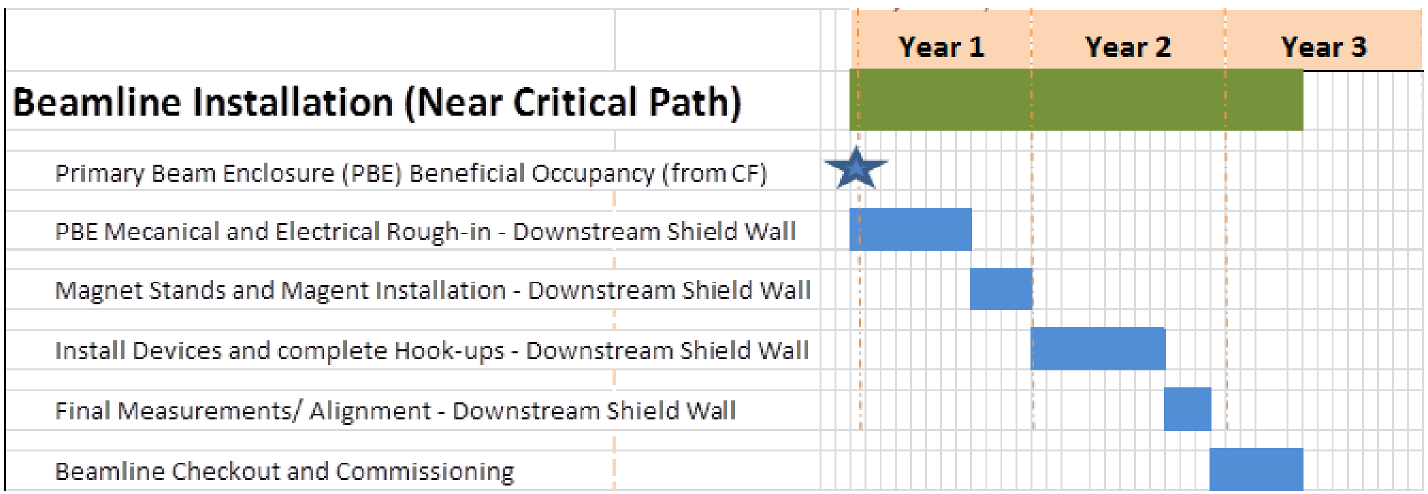
- It would be very useful to start data taking with beam as soon as possible to commission beamline and detectors and start understanding the data. In that respect it would be great to start data taking with 700 kW on the target and continue with 1.2 MW as soon as it is available.
- NOvA expects to run 6 years at 700 kW and accumulate $6x10^{20}$ POT per year for a total of $3.6x10^{21}$ POT.
- The expectation is to reach 700 kW within FY16 and taking into account the current operational scenario NOvA will reach its goal by the end of FY2021.
- A ~13 month long shutdown is needed to connect the LBNF Beamline with MI. In the mean time a ~ 8 month shutdown is needed to connect the PIP-II injector with the Booster and it would be helpful to have them take place at the same time.

Do we need 700 kW prior to 2024 pointing to SURF?

- If the long shutdown takes place after NOvA data taking is complete it means that it will take the entire FY22 and part of FY23.
- After the Beamline has beneficial occupancy it requires about 2 years of installation in a technically driven schedule implying that the Beamline will not be ready to take data before FY25.
- PIP-II is expected to deliver 1.2 MW in ~2024, so this does not allow any time for 700 kW data taking for LBNF unless we find ways to speed up the installation time.
- On the other hand, if the shutdown takes place before FY22, it could speed up the possibility to start as soon as possible data taking with 1.2 MW and can maximize 700 kW data taking for NOvA.
- That would imply though a gap in data taking for NOvA, would not allow for LBNF Beamline to use NOvA components and would imply sufficient resources to have both PIP-II and LBNF to be ready for a shutdown before FY22.

Beamline Installation Critical path





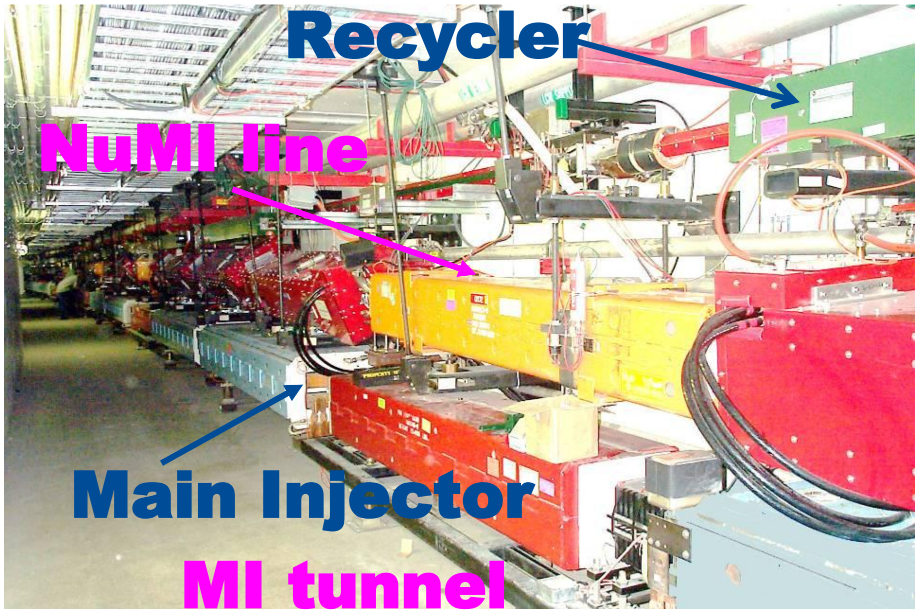
Supplemental Material

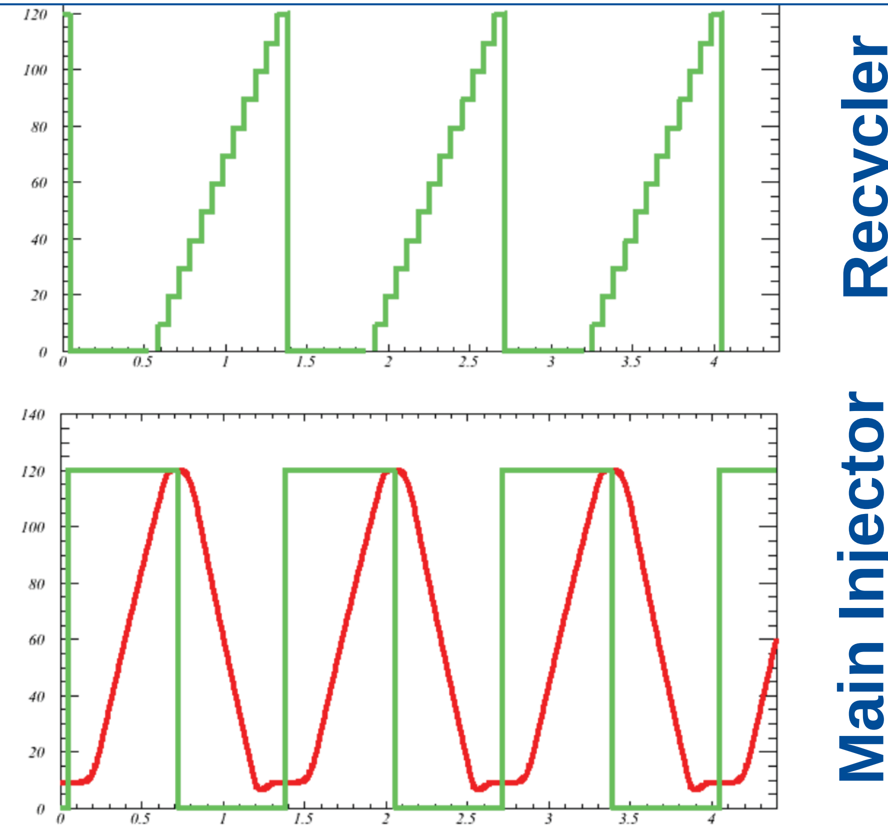
Current Status of High Power Target R&D Activities

- Although focus on the High Power Targetry R&D Program is relatively recent, good progress has already been made
  - **RaDIATE collaboration (possibility for an additional irradiation run at BNL's BLIP facility in 2016)**
  - **HiRadMat (In-beam thermal shock test) experiment (Beam time at CERN in November 2015)**
  - Fatigue testing machine (hot-cell compatible) design
  - Simulation (Monte-Carlos, Thermo-mechanical) efforts to support above activities
  - Autopsy of NuMI graphite targets

Recent Accelerator Complex reconfiguration

12 Booster batches injected and slipped stacked in RR while MI is accelerating

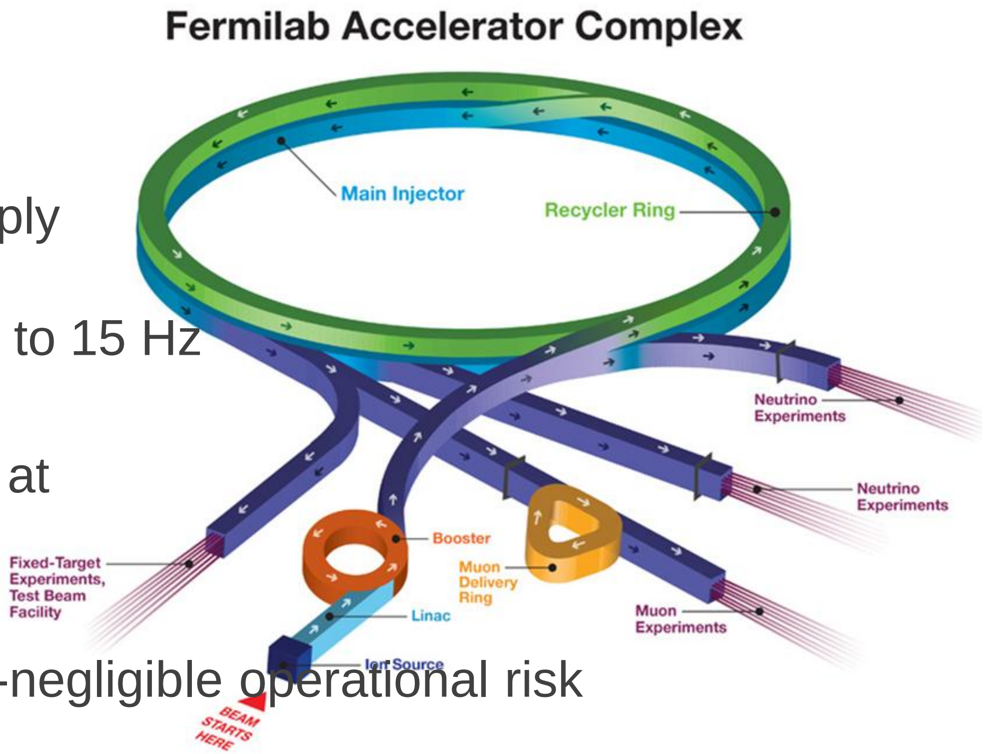




- **With the conclusion of the Tevatron program, the Recycler can be used to pre-inject to MI and stack the Booster protons, thus saving injection time**
- A 15 month shutdown to reconfigure the accelerator complex and to upgrade the NuMI beamline was completed in August 2013.
- **The upgrades will allow 700 kW on the NuMI target**

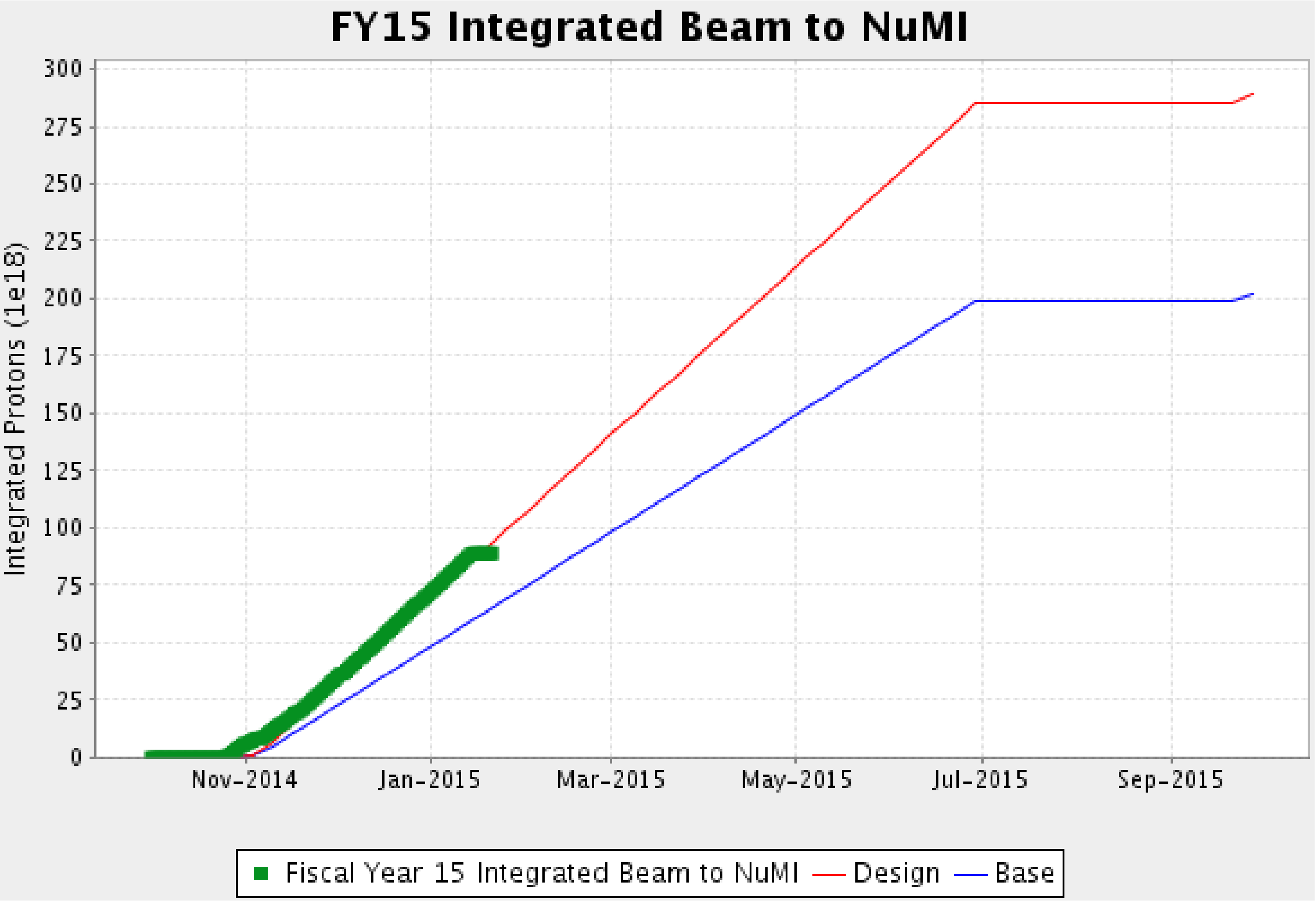
The Fermilab Accelerator Complex Today

- The Fermilab complex delivers protons for neutrino production at both 8 and 120 GeV, with a capability following PIP completion:
  – Booster: 4.2×10^{12} protons @ 8 GeV @ 15 Hz = 80 kW
  – MI: 4.9×10^{13} protons @ 120 GeV @ 0.75 Hz = 700 kW



- Present limitations
  – Booster pulses per second
    - The Booster magnet/power supply system operates at 15 Hz
    - PIP is upgrading the RF system to 15 Hz
  – Booster protons per pulse
    - Limited by space-charge forces at Booster injection
  – Reliability
    - Linac/Booster represent a non-negligible operational risk
  – Target systems capacity
    - Limited to ~700 kW by a large number of factors

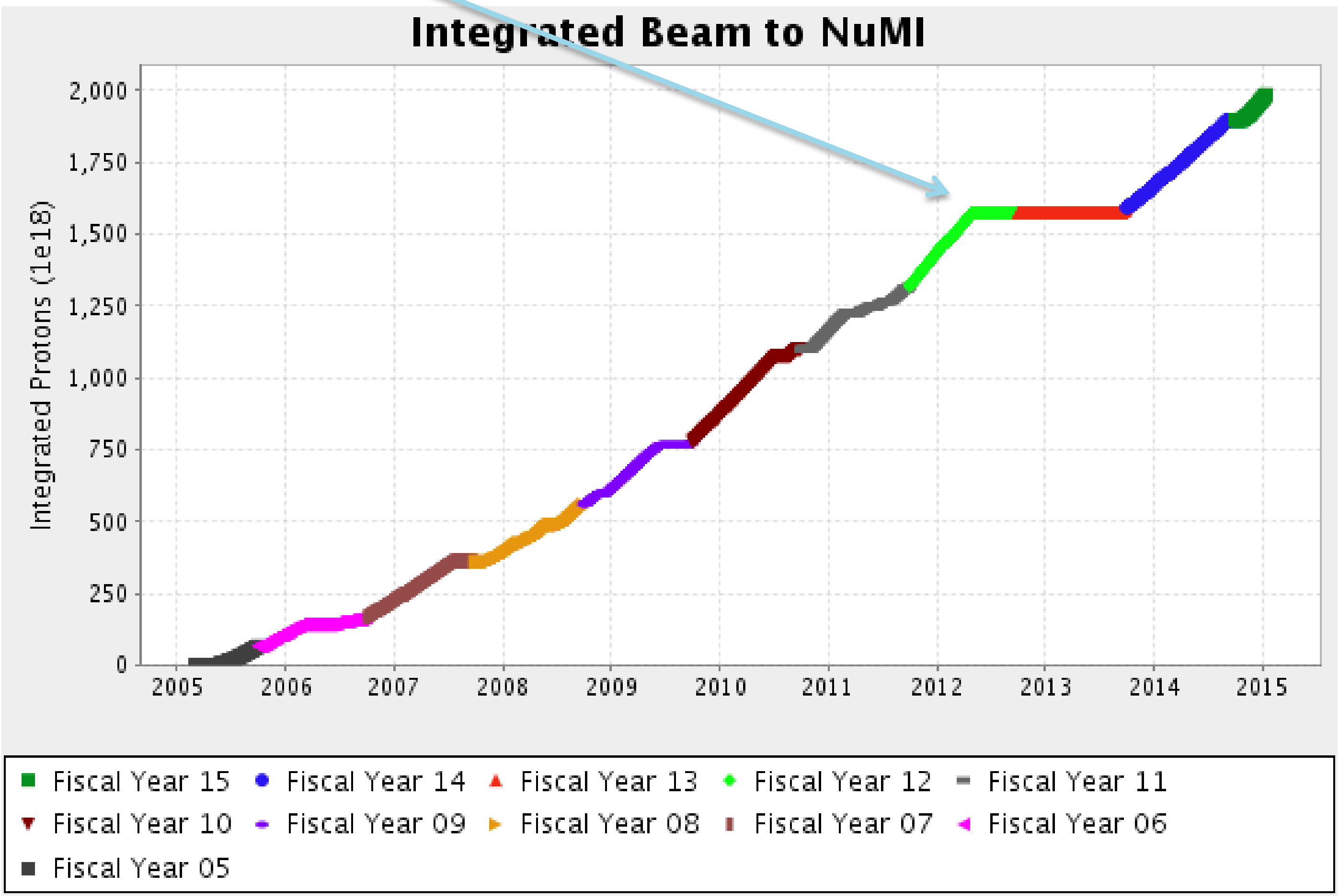
FY15 performance



By the end of FY15, NOvA expects to have at best about 3×10^{20} POT

Accelerator Performance for NuMI

- Started delivering protons to NuMI in 2005
  - ~1.55e21 in 7 years; NOvA goal is 3.6e21
  - Most intense high energy neutrino beam in the world



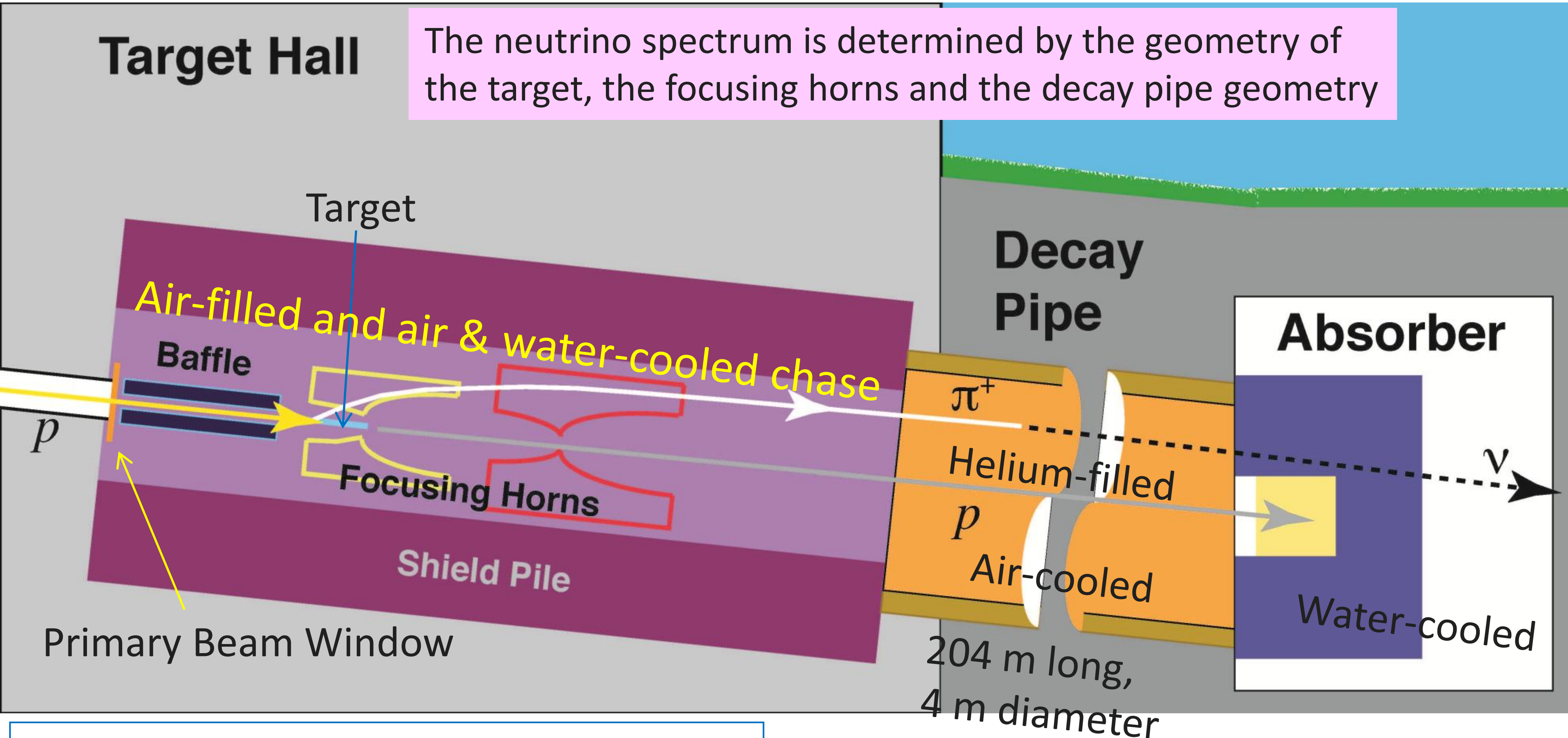
PIP/PIP-II Performance Goals

Performance Parameter	PIP	PIP-II	
Linac Beam Energy	400	800	MeV
Linac Beam Current	25	2	mA
Linac Beam Pulse Length	0.03	0.5	msec
Linac Pulse Repetition Rate	15	20	Hz
Linac Beam Power to Booster	4	13	kW
Linac Beam Power Capability (@>10% Duty Factor)	4	~200	kW
Mu2e Upgrade Potential (800 MeV)	NA	>100	kW
Booster Protons per Pulse	4.2×10^{12}	6.4×10^{12}	
Booster Pulse Repetition Rate	15	20	Hz
Booster Beam Power @ 8 GeV	80	160	kW
Beam Power to 8 GeV Program (max)	32	80	kW
Main Injector Protons per Pulse	4.9×10^{13}	7.5×10^{13}	
Main Injector Cycle Time @ 120 GeV	1.33	1.2	sec
LBNF Beam Power @ 120 GeV	0.7	1.2	MW
LBNF Upgrade Potential @ 60-120 GeV	NA	>2	MW

Future Directions

- The strategy for next step(s) beyond PIP-II will be developed in consideration of the following:
  - Slip-stacking in the Recycler is not possible at intensities beyond PIP-II
  - The Booster cannot be upgraded to support intensities beyond ~7×10^{12} ppp, no matter what the injection energy
  - A new 8-GeV rapid cycling synchrotron (RCS) could meet the needs of the neutrino program
    - Beam power @ 8 GeV ~600kW
    - Injection energy ~2 GeV
  - Construction of an RCS would require long-term utilization of the Recycler for proton accumulation
  - An extension of the PIP-II linac to 6-8 GeV would be required to remove the Recycler from service and/or to achieve the 1-4 MW required to support a muon-based facility
- The strategy will likely be determined on the basis of programmatic choices once PIP-II construction is underway
- In all scenarios it will be necessary to extend the PIP-II linac to at least 2 GeV and to retire the existing Booster
  - Unless realization of “smart RCS” with lower (800 MeV) injection energy

Major Components of the Neutrino Beam



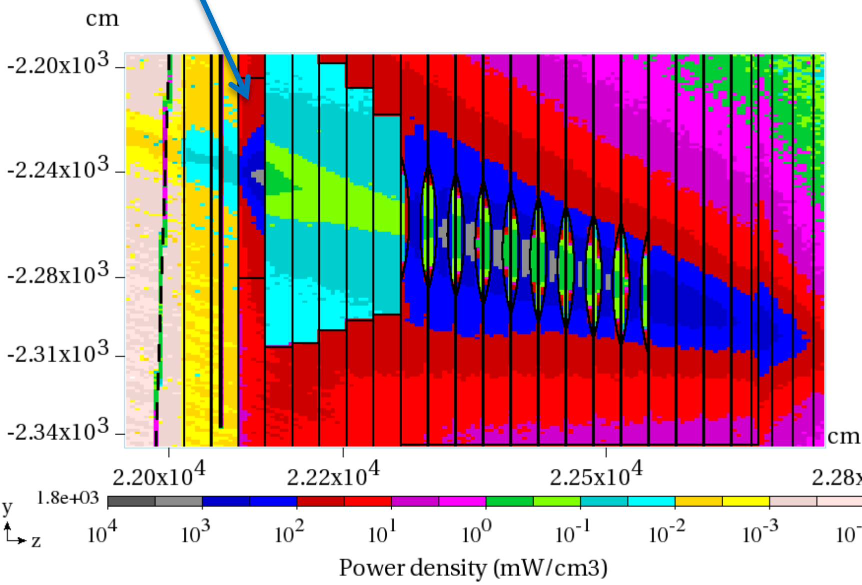
For now, NuMI-like low energy target (two interaction lengths) & NuMI design horns with some needed modifications for 1.2 MW operation

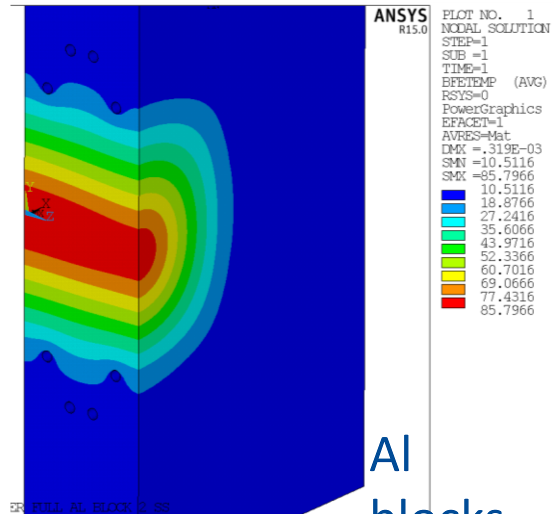
Tunable neutrino energy spectrum

Absorber Design/MARS Simulations (single spoiler)

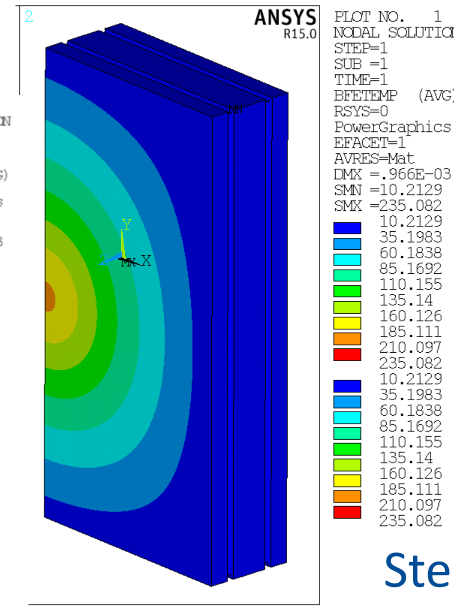
9 sculpted Al blocks and 4 solid Al blocks in the core

Al spoiler

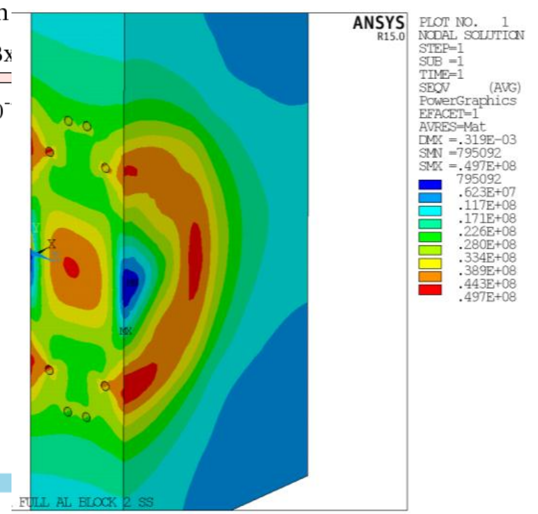


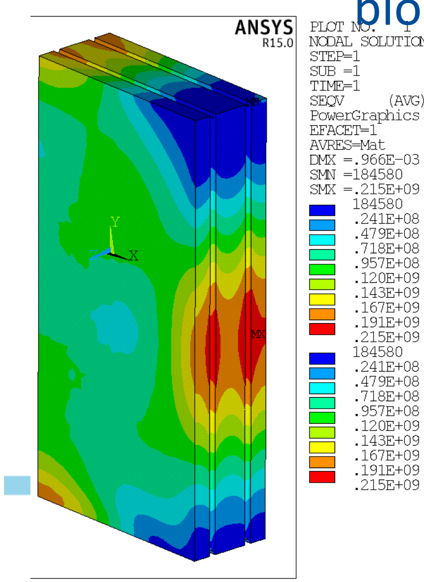


Al blocks



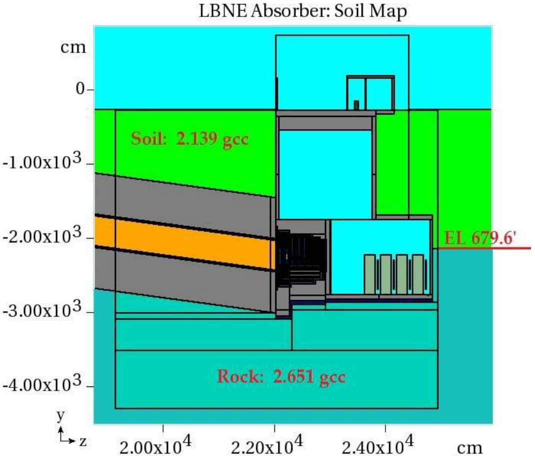
Steel blocks

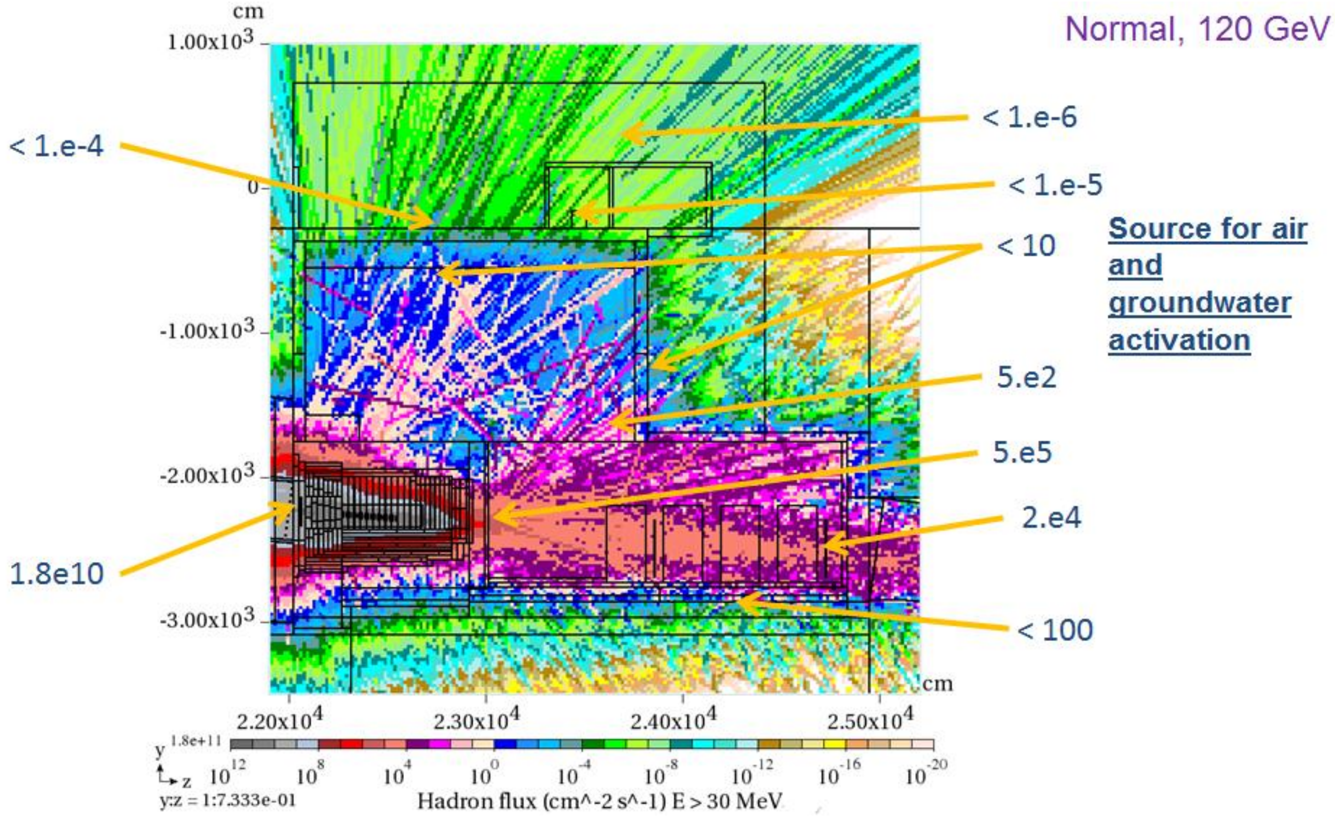




- Max Temp Al: 86^{0}C
- Max VM stress Al: 50 MPa at water line
- Max Temp steel: 235^{0}C
- Max VM stress Al: 215 MPa

Hadron Flux (cm^{-2} s^{-1}) at E > 30 MeV





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RaDIATE Collaboration

Radiation Damage In Accelerator Target Environments

Broad aims are threefold:

www-radiate.fnal.gov

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

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Pacific Northwest NATIONAL LABORATORY

Science & Technology Facilities Council

RaDIATE Collaboration

Radiation Damage In Accelerator Target Environments

www-radiate.fnal.gov

MOU Revision to add Institutions:

- Oak Ridge National Laboratory
- Michigan State University
- European Spallation Source
- Los Alamos National Laboratory
- Argonne National Laboratory
- Helmholtz Center For Heavy Ion Research – GSI
- Center of Energy, Environmental and Technological Research - CIEMAT

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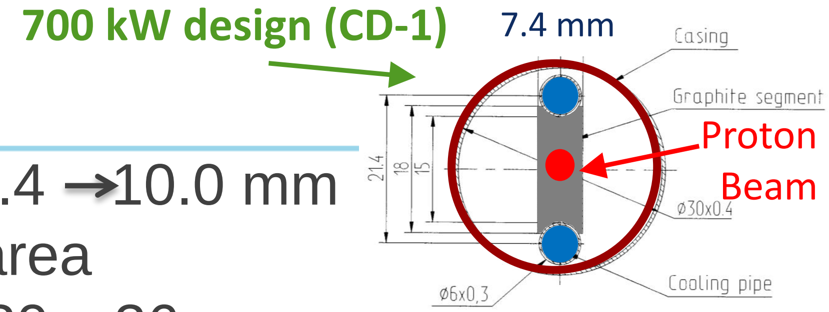
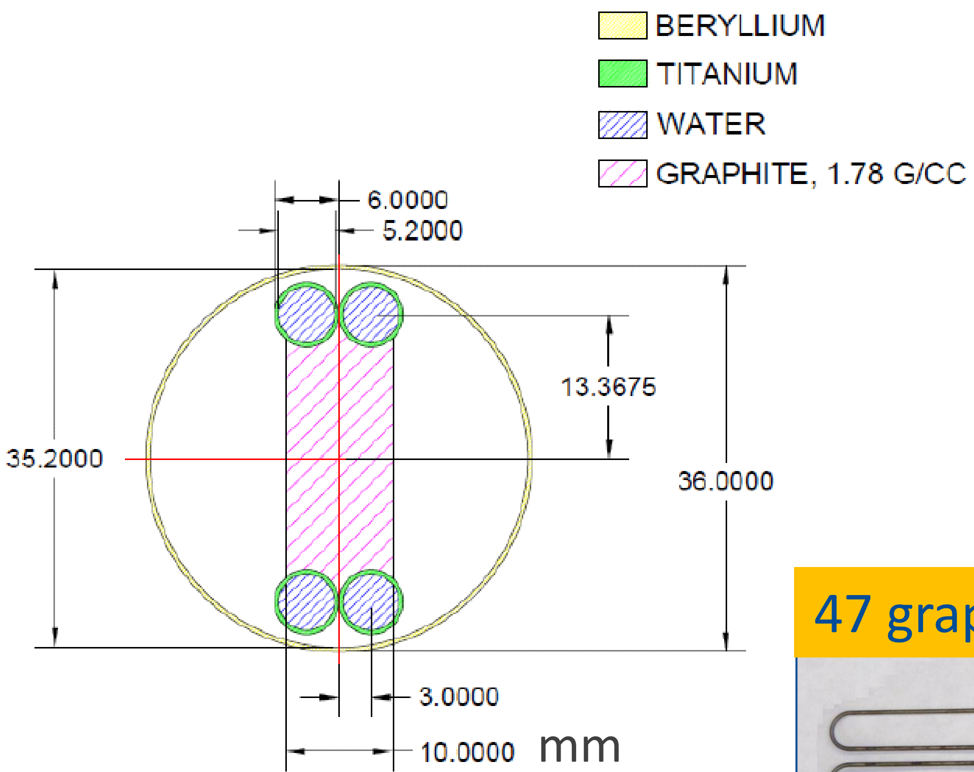
Science & Technology Facilities Council

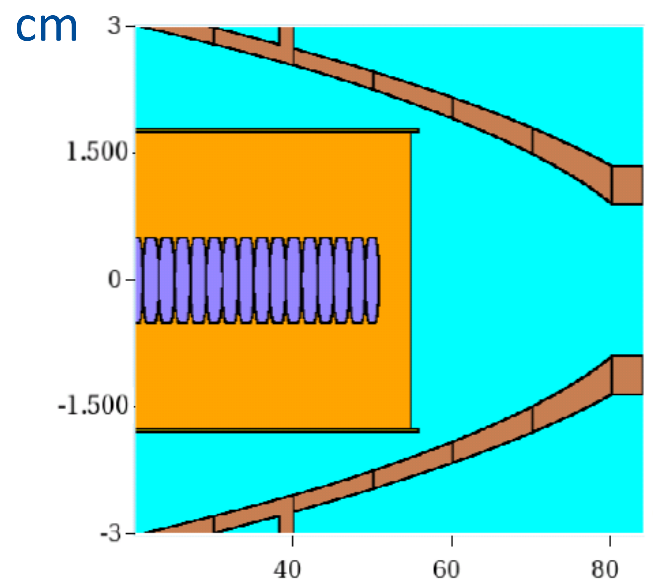
Initial Modifications for 1.2 MW



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

(Move target back 10 cm from horn)





47 graphite segments, each 2 cm long

Preliminary target design for 1.2 MW

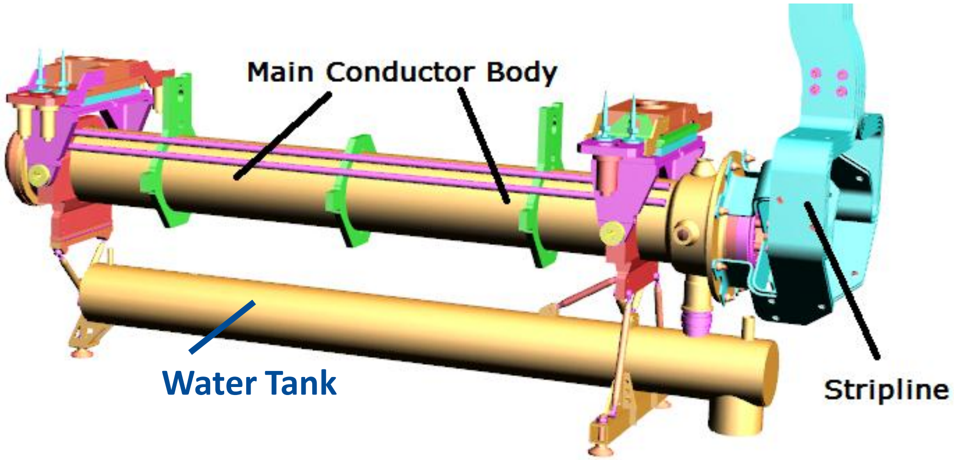
Target critical safety factors

Location	Material	Stress	Criteria	Safety Factor
Worst Case Fin	Graphite ZXF-5Q	10.5 MPa	UTS - 80MPa	7.6
Fin, Off-Center Pulse	Graphite ZXF-5Q	10.1 MPa	UTS - 80MPa	7.9
Water Line	Titanium Grade 2	83 MPa	Fatigue - 270MPa @ 1e5 cycles, 150C	3.3
Can	Beryllium	25.9 MPa	Yield - 218 MPa @ 185C	8.4
Window	Beryllium	27.2 MPa	Yield - 218 MPa @ 185C	8.0

- Target evolved from NuMI
  - Target/horn system efficiency somewhat compromised from optimal – mostly horns
- Expect to change graphite target ~2-3 a year for 1.2 MW operation
  - Limited lifetime due to radiation damage of graphite
    - Based on limited in-beam experience
- Option remains for Be as target material pending validation.

No showstoppers identified at this point

Horn Operation at 1.2MW



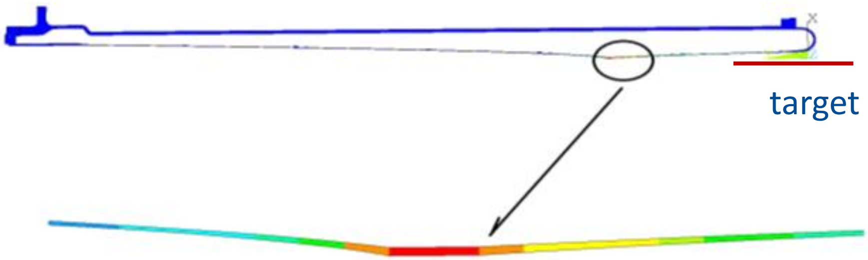
Parameters	700 kW	1.2 MW
Current Pulse Width	2.1ms	0.8ms
Cycle Time	1.33s	1.20s
Horn Current	230kA	230kA
Target Width	7.4mm	10mm
Protons Per Spill	4.9×10^{13}	7.5×10^{13}

- 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.

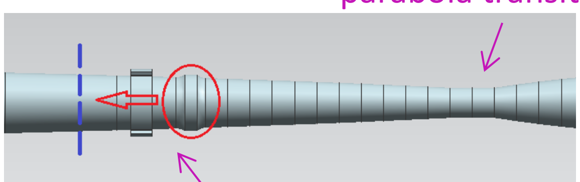
Horn Current Analysis Results



- 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.

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.

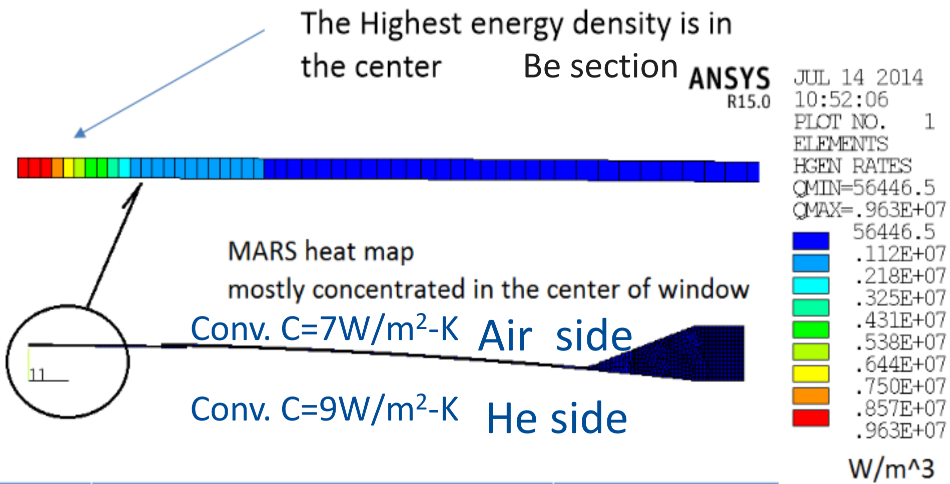


Safety Factors for 120 GeV Operation

	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

Upstream Decay Pipe Window – Thermal Results (normal operation)

Power density along the radius of the US window



No active cooling of 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*

Increase convection coeff.

	hc_air side (W/m^2*K)	The center of the window_ Be alloy section				flange	
		Tave(Steady state)_C	Tmax_C	Tmin_C	ΔT _C	Tmax_C	ΔT _C
120 Gev 2.4 MW	7	85	87.75	84.25	3.5	115	0
120Gev 2.4 MW	14	68	70.69	67.27	3.42	86.8	0
80 Gev_ 2.14 MW	***7***	***79***	***80.6***	***78.73***	***1.87***	***105***	***0***
80 Gev 2.14 MW	***14***	***64.05***	***65.4***	***63.53***	***1.87***	***80.4***	***0***

The Beamline Team so far and collaborative activities

- From Fermilab's Accelerator, Particle Physics and Technical Divisions, FESS (Facil. Eng.) and ES&H Sections.
- University of Texas at Arlington (Hadron Monitor)
- STFC/RAL (target R&D and target design)
- Bartoszek Eng. (Contract on baffle/target and horn support modules)
- RADIATE Collaboration (radiation damage for target and windows)
- CERN (target R&D, corrosion, Beamline monitoring,…)
- US-Japan Task force (radiation damage, non-interactive profile monitor, kicker magnets)
- IHEP/China (simulations, beam window, special alloys)
- Six contracts completed already with ANL, BNL, IHEP (Protvino, Russia), STFC/RAL, ORNL, Design Innovations.

Adjustable beam

- We considered both horizontal and vertical steering options.
- Most promising: Vertical steering of beam pivoting around the target.
- Two discrete positions for on- and off-axis – will require reconfiguration of beamline (with a significant shutdown of at least 6 months) to switch between on-axis and off-axis.
- Run off-axis at ~23 mrad (1.3 deg) to access the 2nd oscillation maximum.
- Near Detector does not move from default position & sees the same off-axis beam as the Far Detector.
- Complete optics design has been fleshed out.
- Gradually increasing vertical cross section of the decay pipe (9.4 m at the end of the 204 m pipe) and significantly bigger absorber (we considered two staggered absorbers).

Upstream Decay Pipe Window – Stresses (Accident Case)

Air side: p=1.5 psi; Conv. Coeff.= 7 W/m^2-K

acc	Tmax	ΔT=203 C	σ (eqv) ksi	σ (x) ksi
120 Gev_ 2.4 MW	Tmax=293 C	ΔT=203 C	53.3	-55.56
120 Gev_ 1.2 MW	Tmax=168 C	ΔT=102 C	21.28	-22.22
80 Gev_ 2.14 MW	Tmax=257 C	ΔT=170 C	43.4	-44.7
80 Gev_ 1.07 MW	Tmax=150.2	ΔT=85 C	17.1	-17.7

Temperature (c)	UTS AlMet162	UTS/2_FERMI window standard
21 C	55 ksi	27.5 ksi
200 C	41 ksi	20.5 ksi
300 C	31 ksi	15.5 ksi
500 C	12.1 ksi	6.05 ksi

The window will not be able to survive the accident condition under a 2.14 or 2.4 MW beam power but it can survive a few accident pulses at 1.2 MW.

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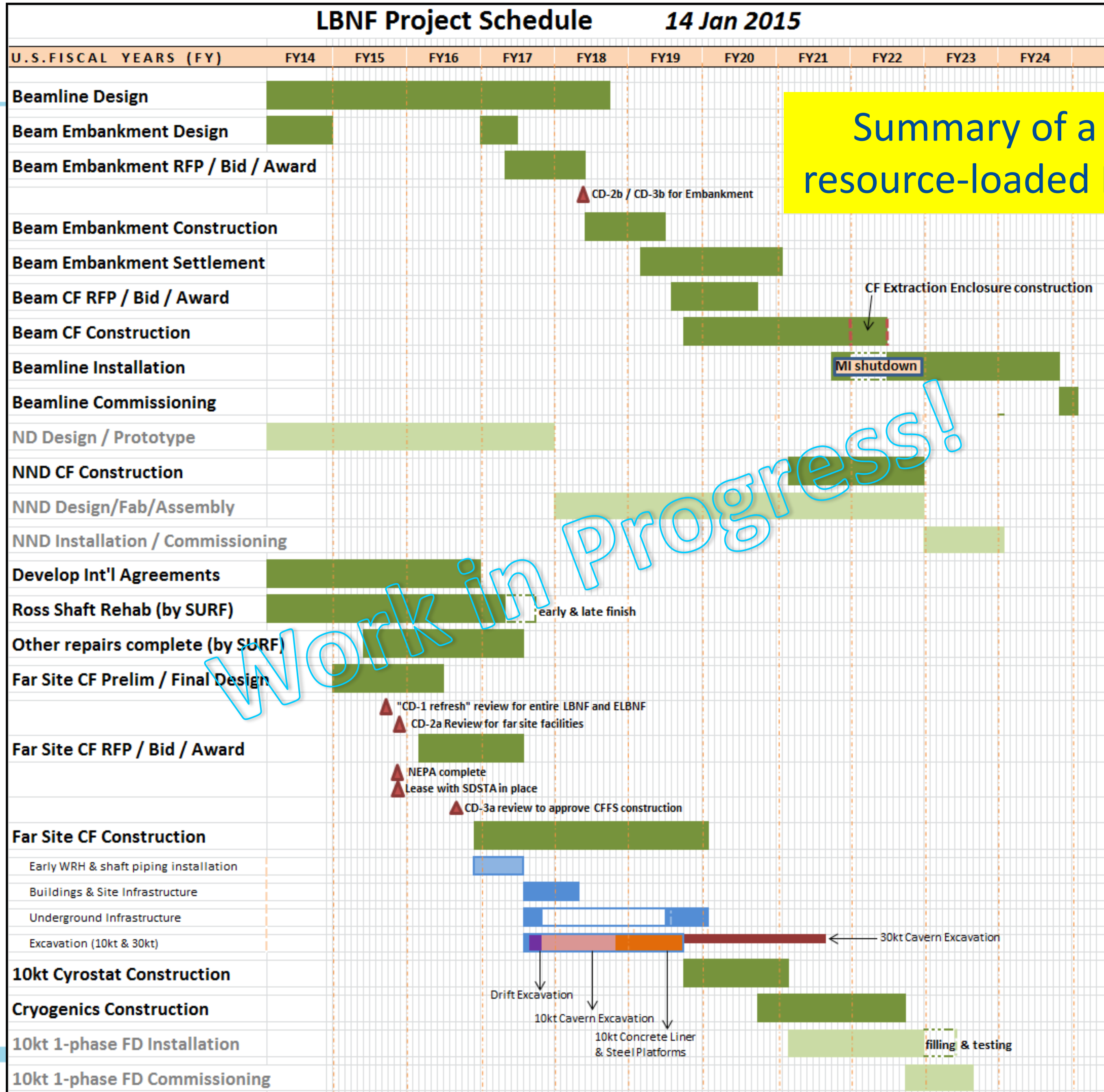

Summary of a detailed, resource-loaded P6 schedule

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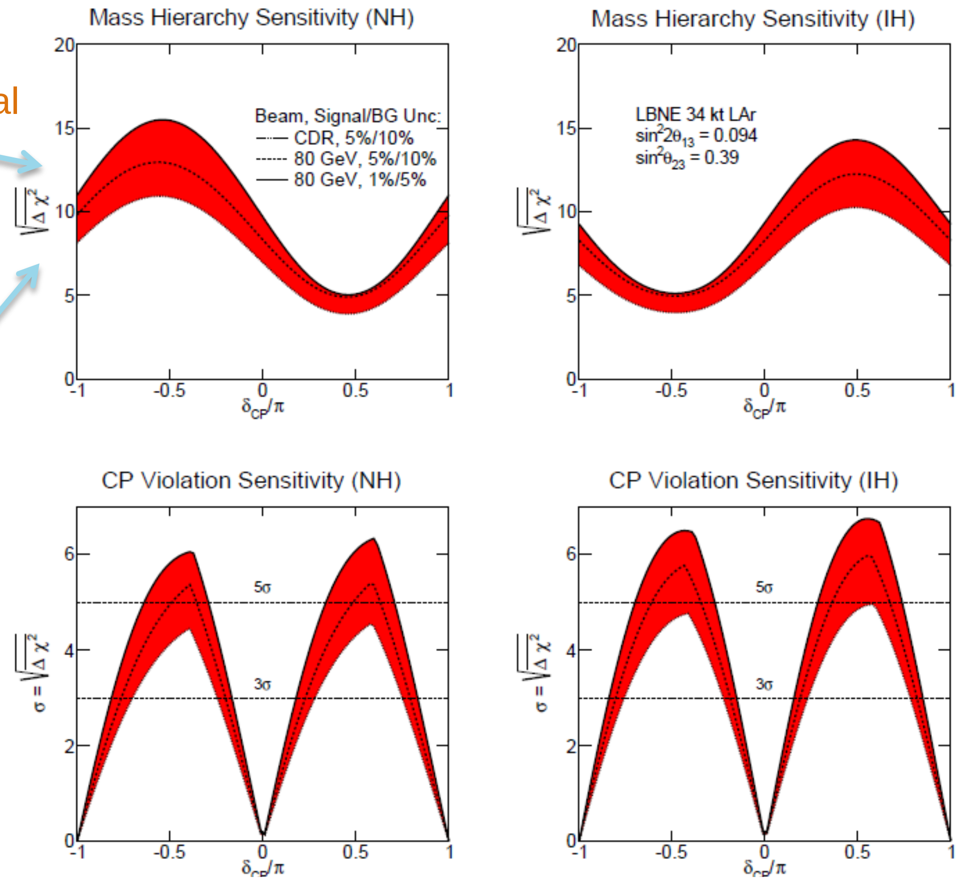
Mass Hierarchy and CP Violation Sensitivity

Exposure 245 kt.MW.yr
34 kt x 1.2 MW x (3ν+3νbar) yr

Optimized beam
& systematics goal

Band is range of beam and
systematics assumptions

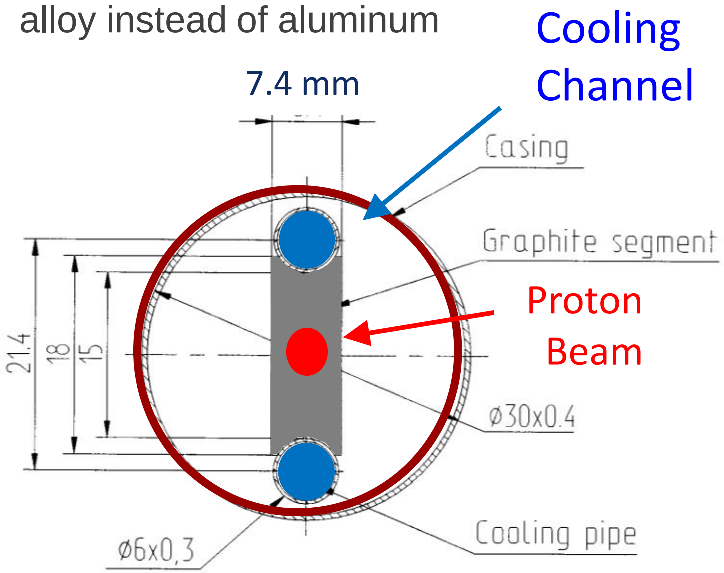
Unoptimized beam
& poor systematics

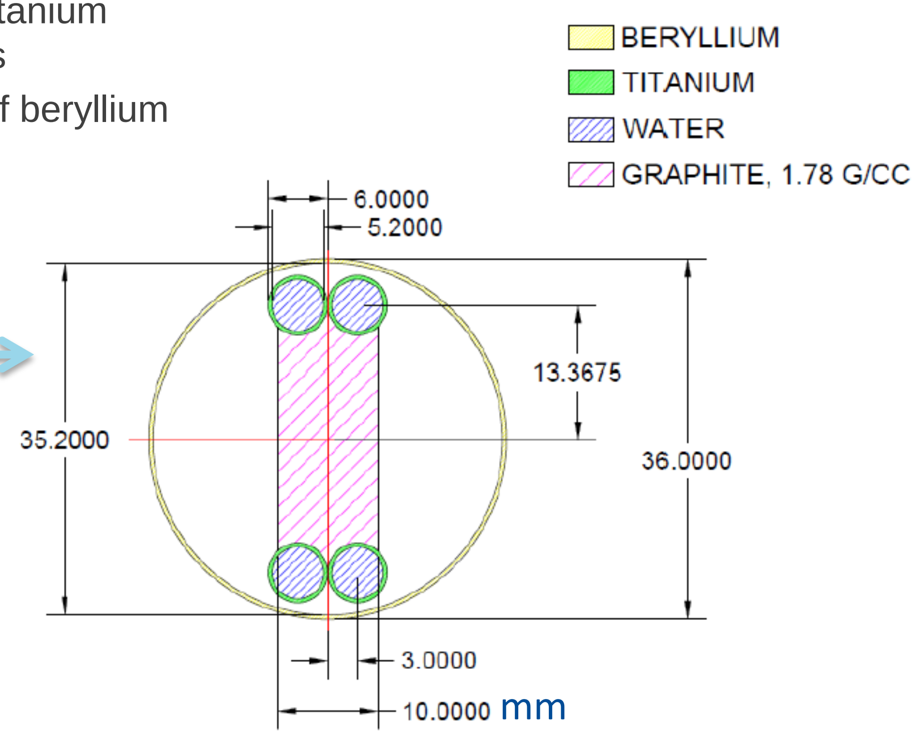


- Mass hierarchy is very well determined over most of δ_{CP} range
- CPV > 3σ over most of range and > 5σ for maximal CPV
- Atmospheric neutrinos in LBNE provide ~1σ increased CPV sensitivity if combined with beam

LBNE Target Design: 700 kW (CD-1) to 1.2 MW

- 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



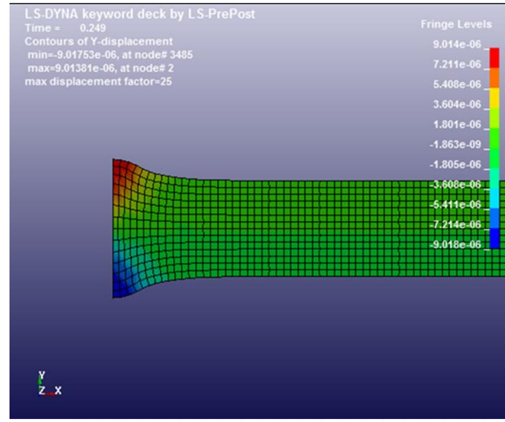


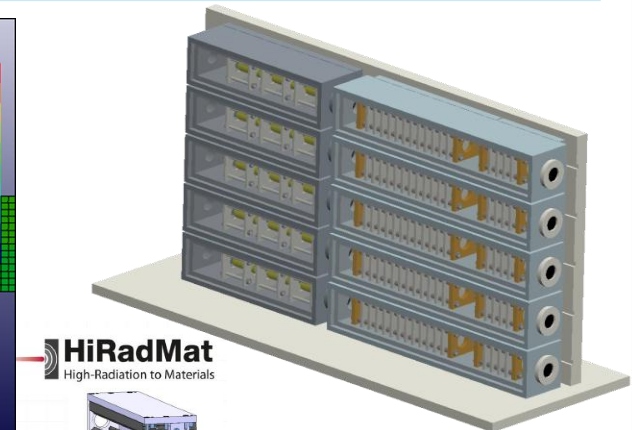
R&D ongoing for Be target

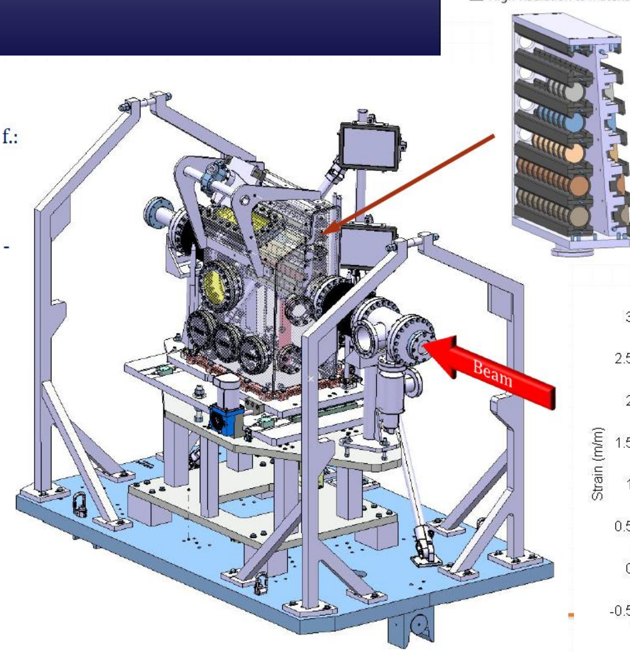
Safety factors for 1.2 MW target vary from 3.2 (water line) to 7.6 (graphite fin) to 8.4 (Be can), all acceptable and some quite generous.

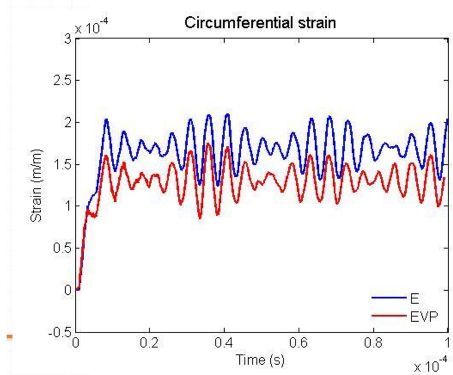
“BeGrid” High Intensity Beam Pulse Test

- Proton beam capabilities:
  - up to 4.9e13 ppp
  - 440 GeV
  - 0.1 mm – 2.0 mm sigma radius
- Test on Be samples to detect:
  - Onset of plastic deformation (LDV, SG)
  - Fracture (EBSD)
  - Micro-structural damage mechanisms (EBSD)
  - Differences between grades and forms (texture) of Beryllium
- Verify simulations









HRMT-14 Collimator materials test rig
(image courtesy of A. Fabich, CERN)

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ANSYS Result Summary

Safety Factors 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 Factors for 80 GeV Operation

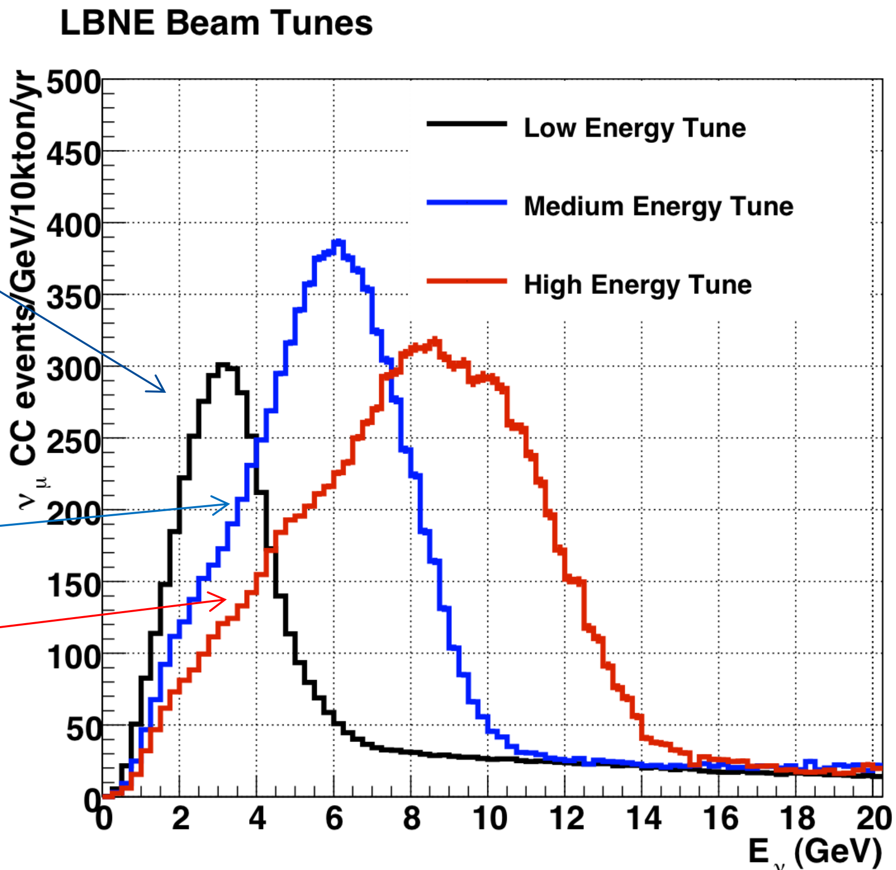
	Safety Factor			
Operation Condition	Up-stream Weld	Neck	Down-stream Weld	Transition
Normal Operation	**2.55**	**3.6**	4.65	10.3
Test Operation	3.4	5.1	4.6	10.3
Horn-off Operation	9.4	15	13	25.9
On-off Operation	2.55	3.6	4.65	10.3

- 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.

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

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

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

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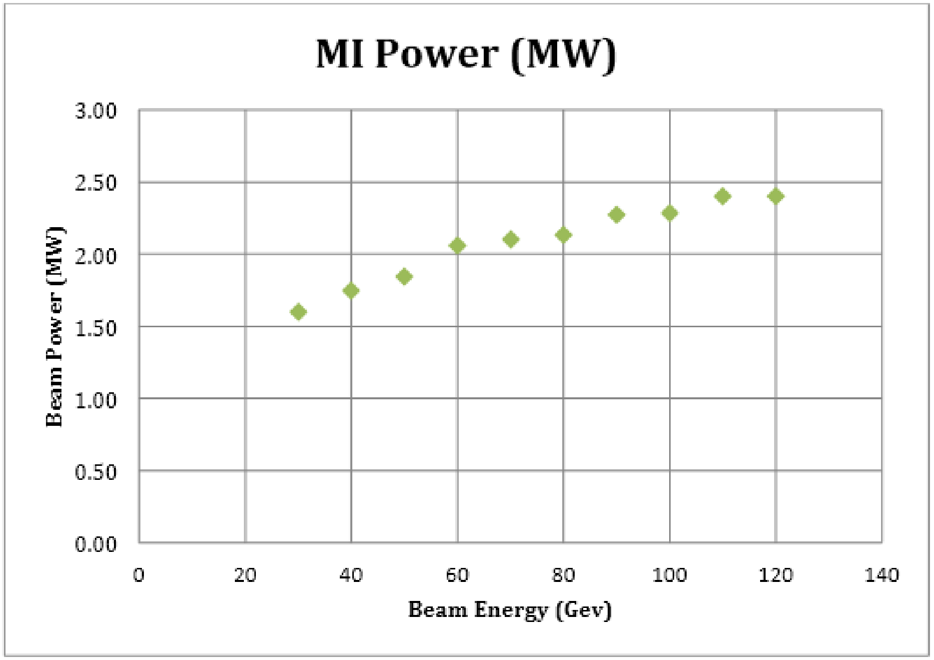
Proton Improvement Plan-III
Performance Goals

Energy (GeV)	Intensity (1e13)	Cycle Time (sec)	Power (MW)
120	15	1.2	2.4
110	15	1.1	2.4
100	15	1.05	2.29
90	15	0.95	2.13
80	15	0.9	2.13
70	15	0.8	2.1
60	15	0.7	2.06
50	15	0.65	1.85
40	15	0.55	1.75
30	15	0.45	1.6

P. Derwent, S. Holmes, I. Kourbanis, V. Lebedev

http://projectx-docdb.fnal.gov/cgibin/ShowDocument?docid=1295

Building on:
http://projectx-docdb.fnal.gov/cgibin/ShowDocument?docid=1232



Updated Proton Delivery Scenario (approximate - no shutdowns shown)