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Beamline Optimization
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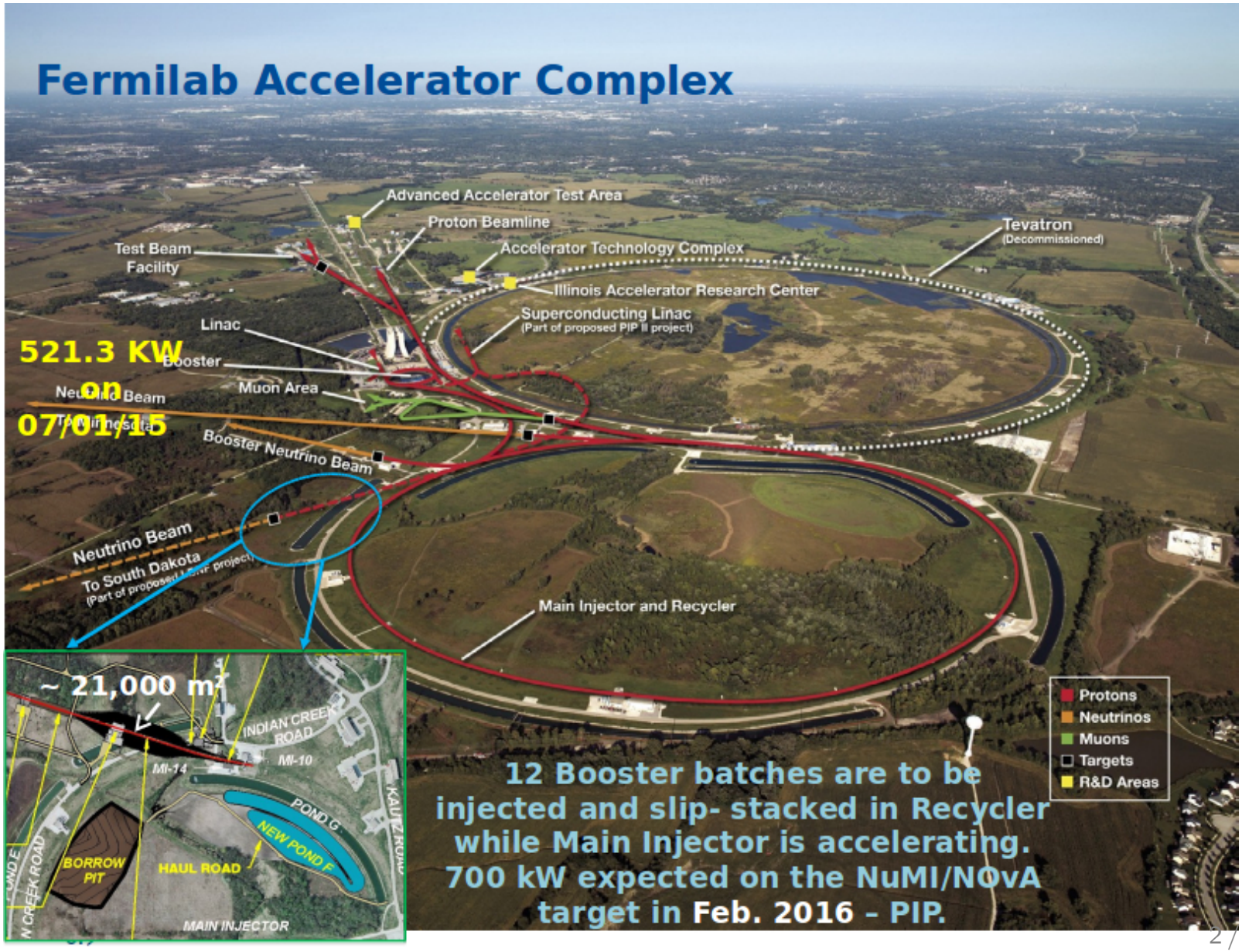
Fermilab Neutrino Beams: Present and Future

HINT 2015, J-PARC, Oct 13-15, 2015

Mary Bishai
Brookhaven National Laboratory

October 13, 2015

The Fermilab Accelerator Complex



Current Neutrino Beamlines at Fermilab

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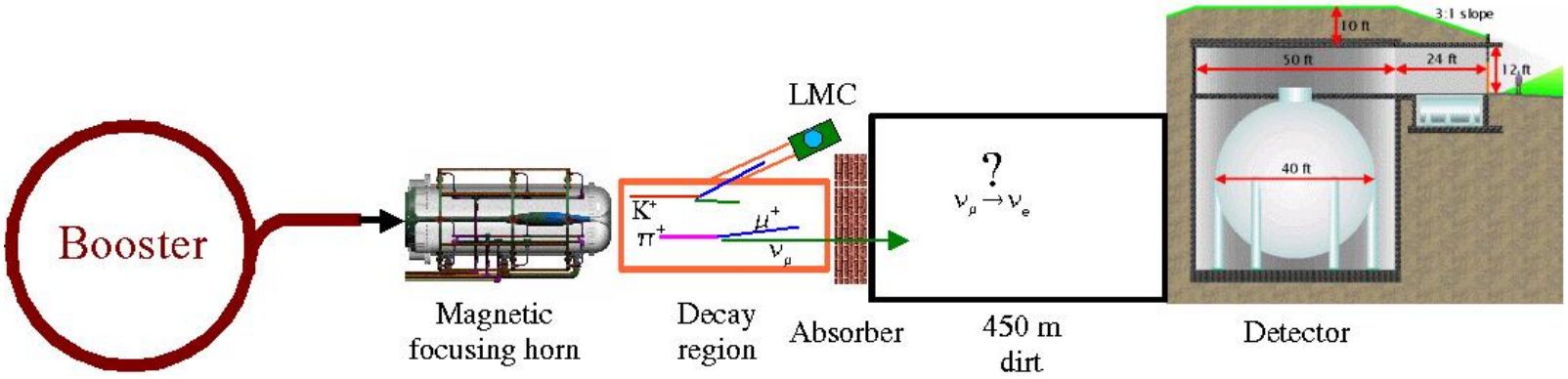
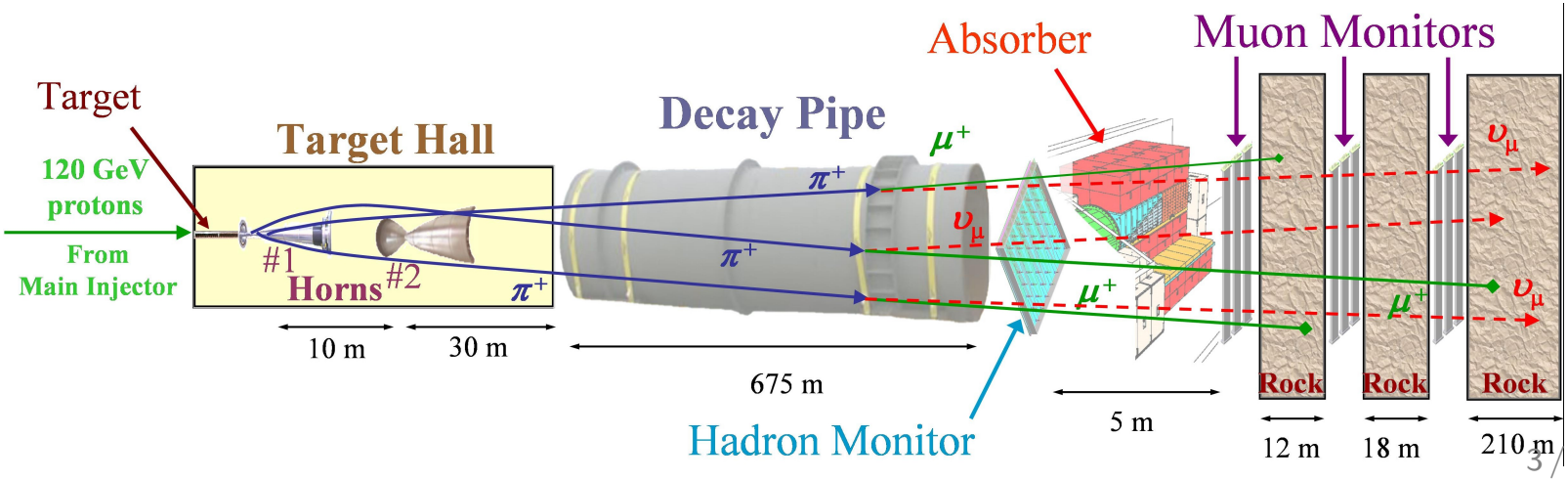
Booster Neutrino Beam (BNB)

E_p^+ = 8 GeV (10-30 kW), Be target l=71cm, 174 kA pulsed horn.



Neutrinos at the Main Injector (NuMI)

E_p^+ = 120 GeV (350-700kW), graphite target l=95cm
2 pulsed horns 185-200 kA, tunable focus



Current Neutrino Beam Spectra

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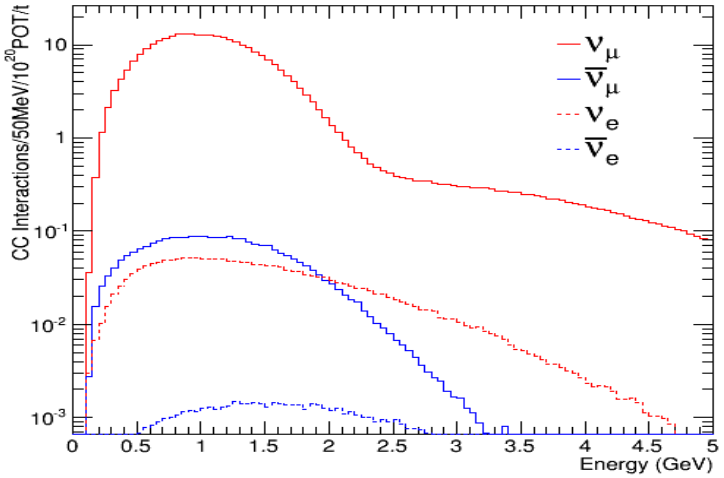
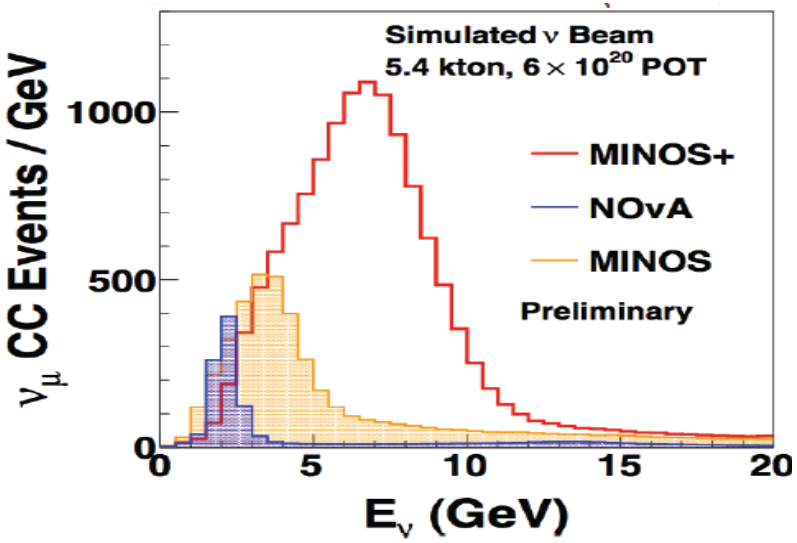
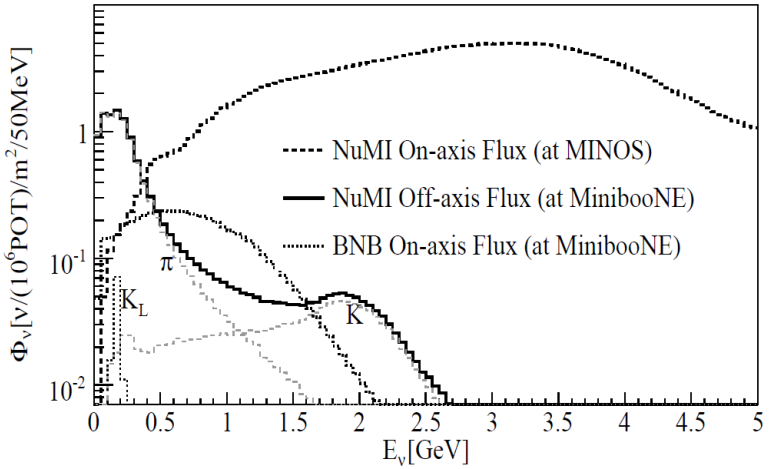
BNB-μBooNE (470m)



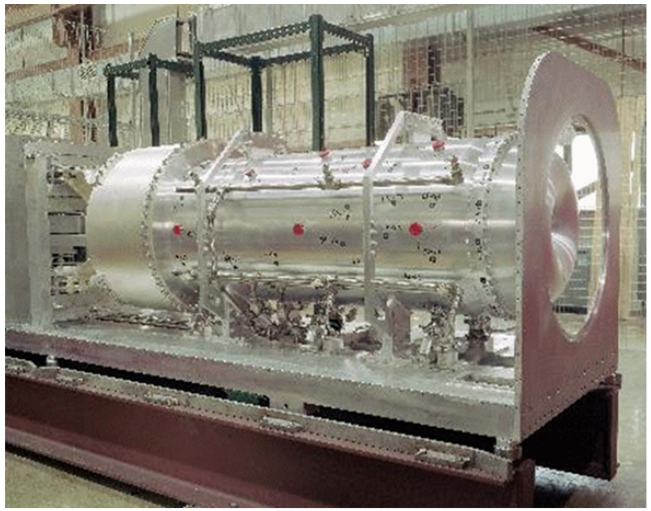
NuMI-MINOS/NOνA



NuMI beam in MiniBooNE

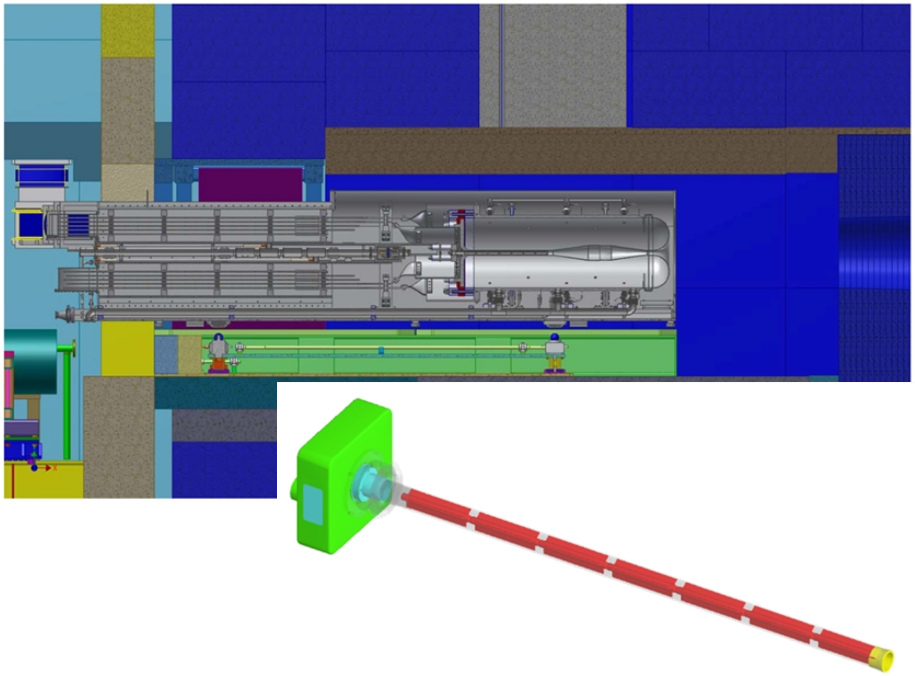


Current BNB Configuration



- 8 GeV protons, ~4.5×10^{12} protons/spill
- 70 cm Be target (1.7 λ_I), inserted in the horn neck
- 1.8 m long horn, pulsed at 172 kA, 6.1 kV, 145 μs pulse width
- max average rate of 5 Hz, up to 10 pulses in a row at 15 Hz

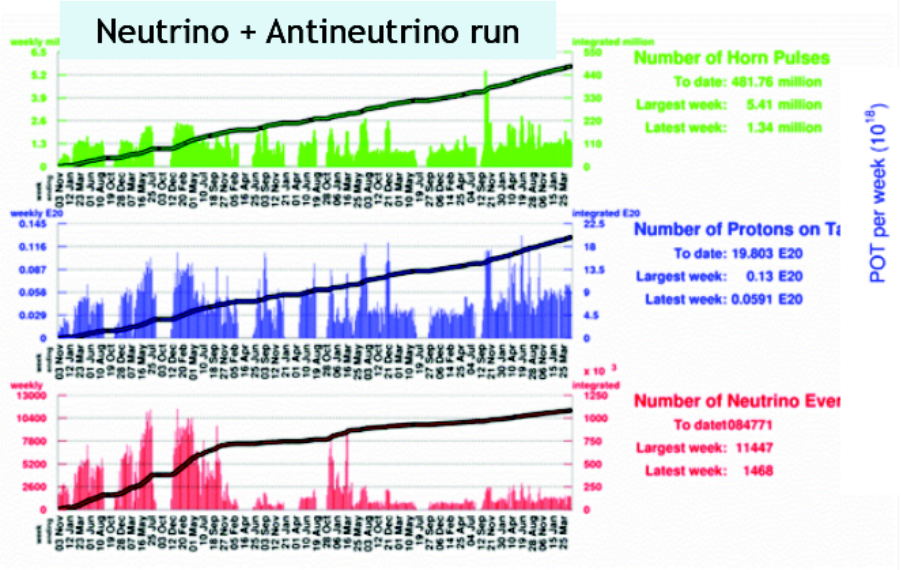
- Horn inserted in an opening inside shielding blocks
- downstream collimator with 60 cm diameter opening
- stripline designed for 250 kA, 10 kV

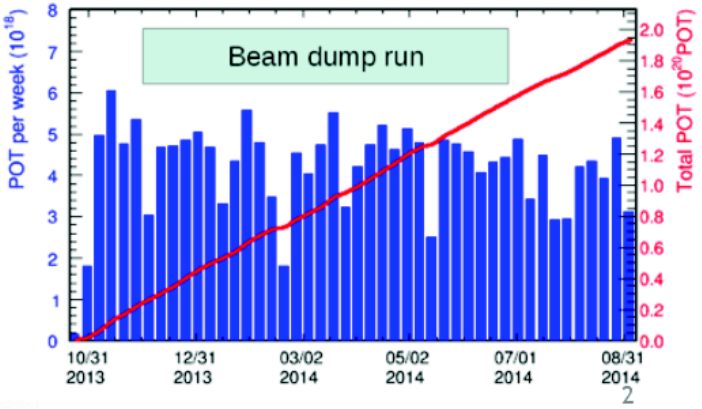


BNB operations 2002-2014

12 years of running

- BNB delivered more than 2e21 POT since turning on
- Two target/horn assemblies
  - 1st horn 2002-2004 - 97 million pulses
  - 2nd horn 2004-2014 - 375 million pulses

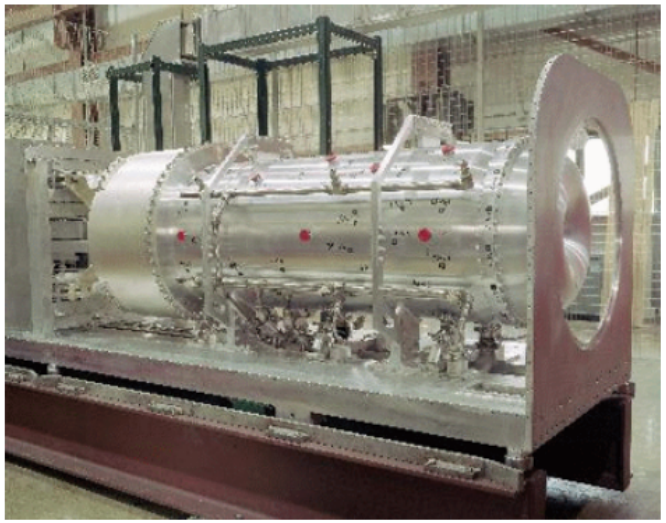


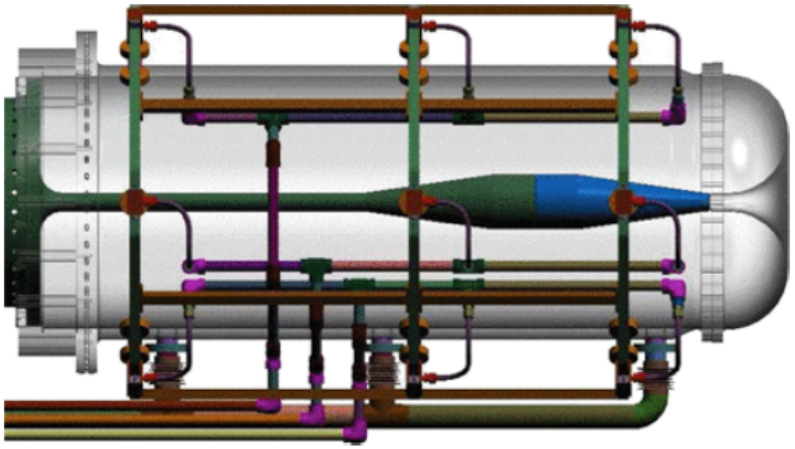


BNB Horn Experience

- Both horns had water system failure
  - 1st horn developed leak and short to ground (late 2004) due to stagnant water
  - 2nd horn had plugged cooling lines
- Third horn installed spring 2015
  - tested in June 2015
  - starting MicroBooNE run October 2015

Horn	Pulses	POT
1	97M	3.7E+20
2	375M	1.6E+21





3

Fermilab BNB Short Baseline Program (SBN)

Z. Djurcic

presentation

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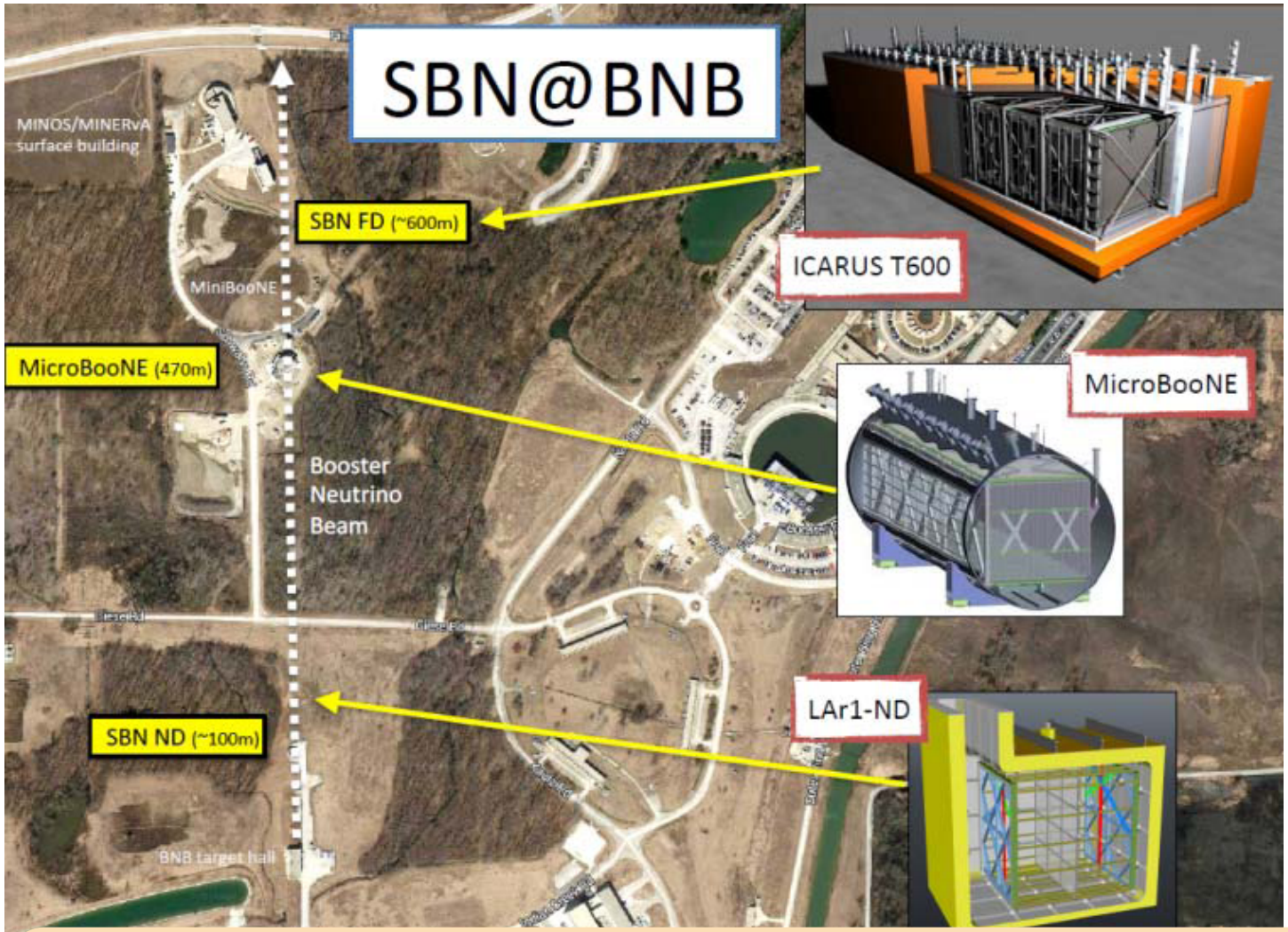
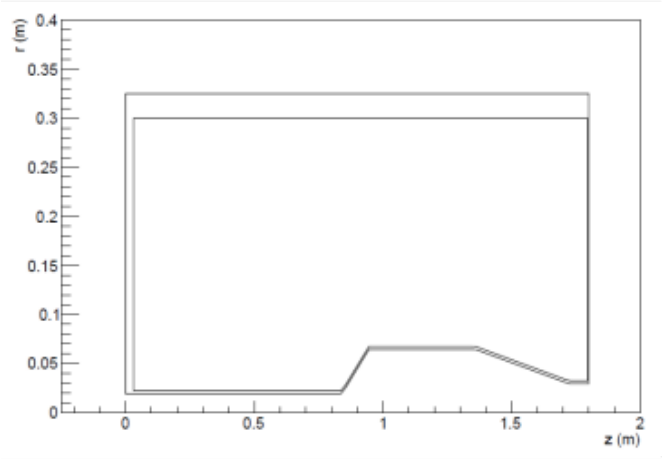
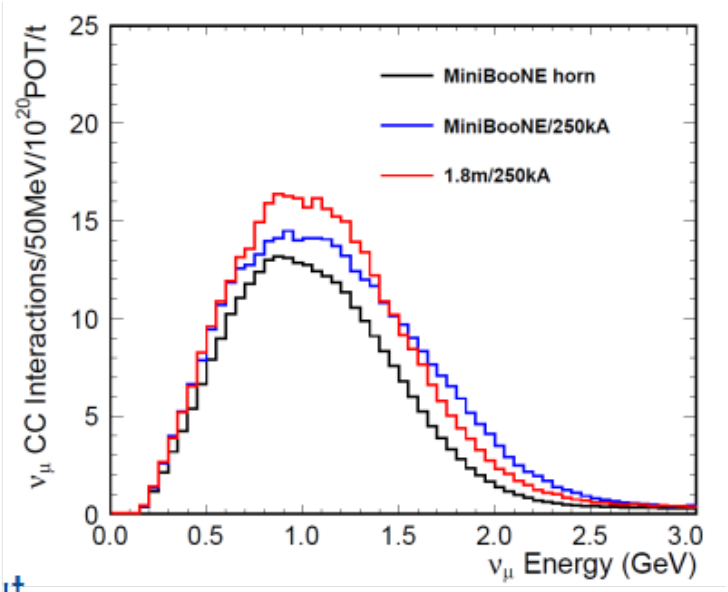


MicroBooNE beam starts NOW! Approved for 6.6×10^{20} p.o.t. SB ND and FD (T600) by 2018 - additional 6.6×10^{20} p.o.t.

Potential BNB upgrades

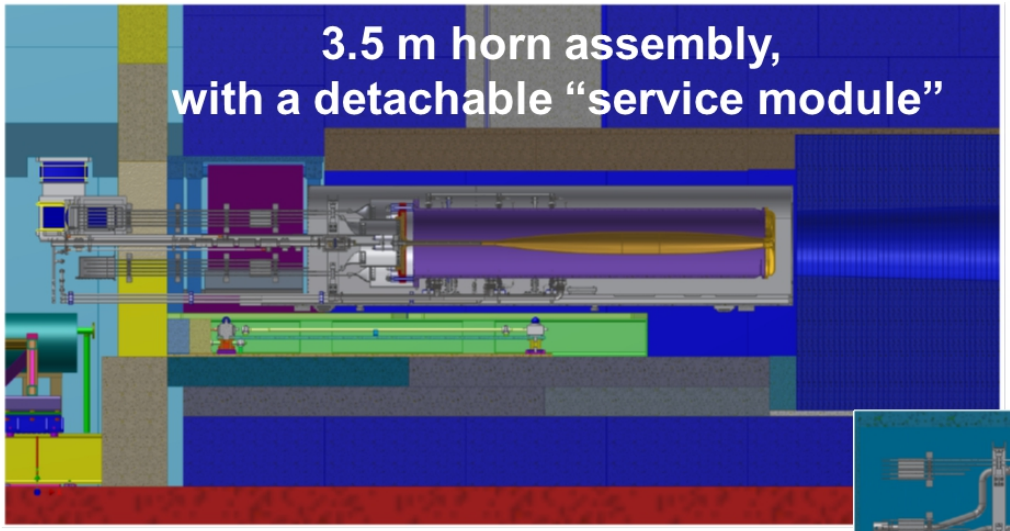




Install an improved inner conductor, but maintain the current horn length (180 cm)

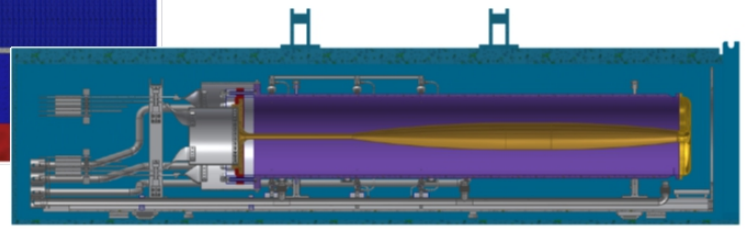
Option	Current (kA)	Relative Yield	Rel. Peak Yield
MiniBooNE (nominal)	172	1.00	1.00
MiniBooNE	250	1.28	1.08
Opt 1	250	1.30	1.24

Potential BNB upgrades

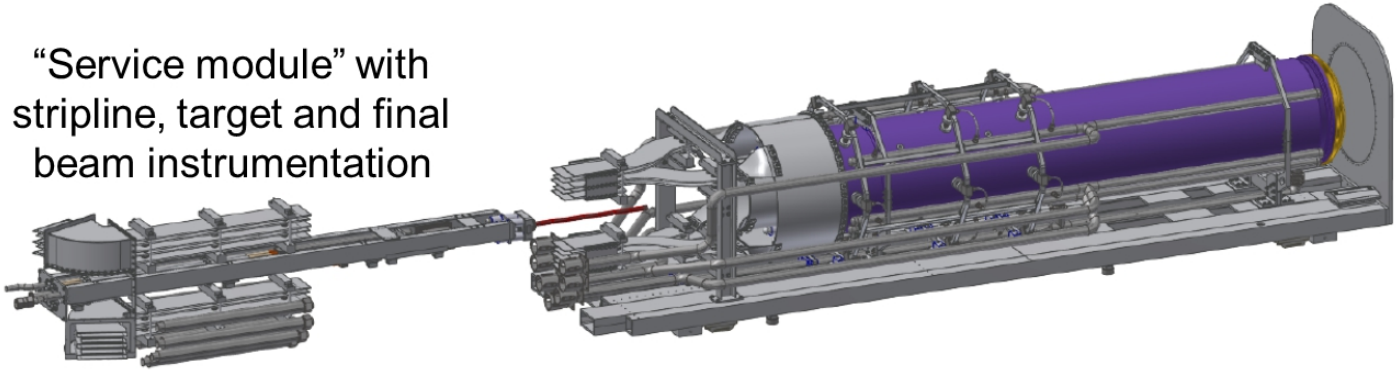


Target position moves upstream 44 cm relative to MiniBooNE horn

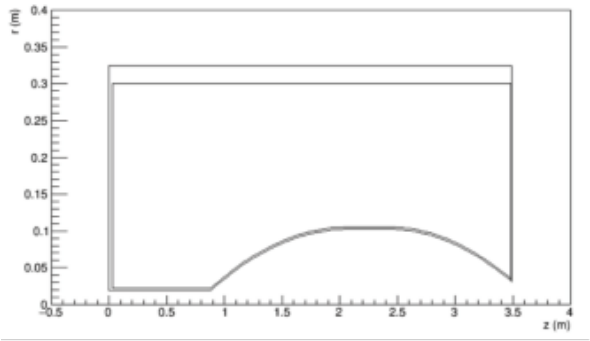
Horn with stripline connection inside the shielded coffin

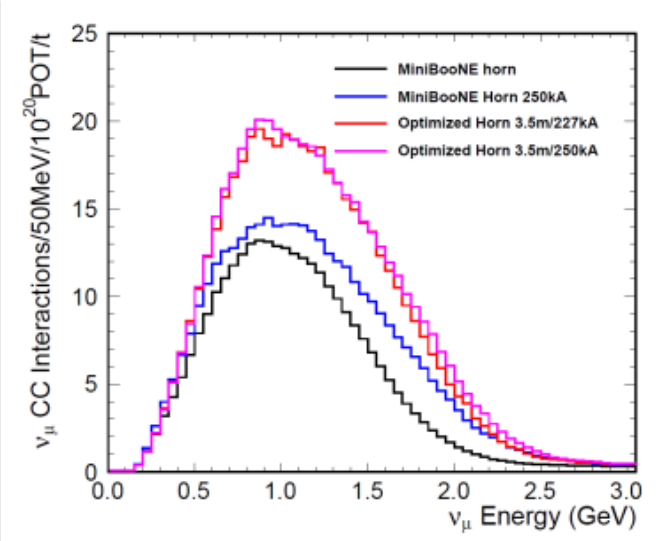


"Service module" with stripline, target and final beam instrumentation



Potential BNB upgrades

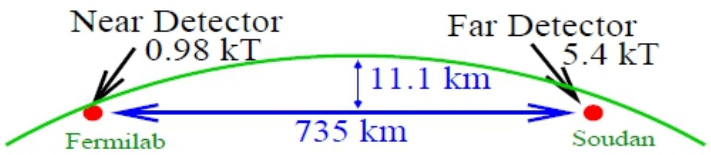




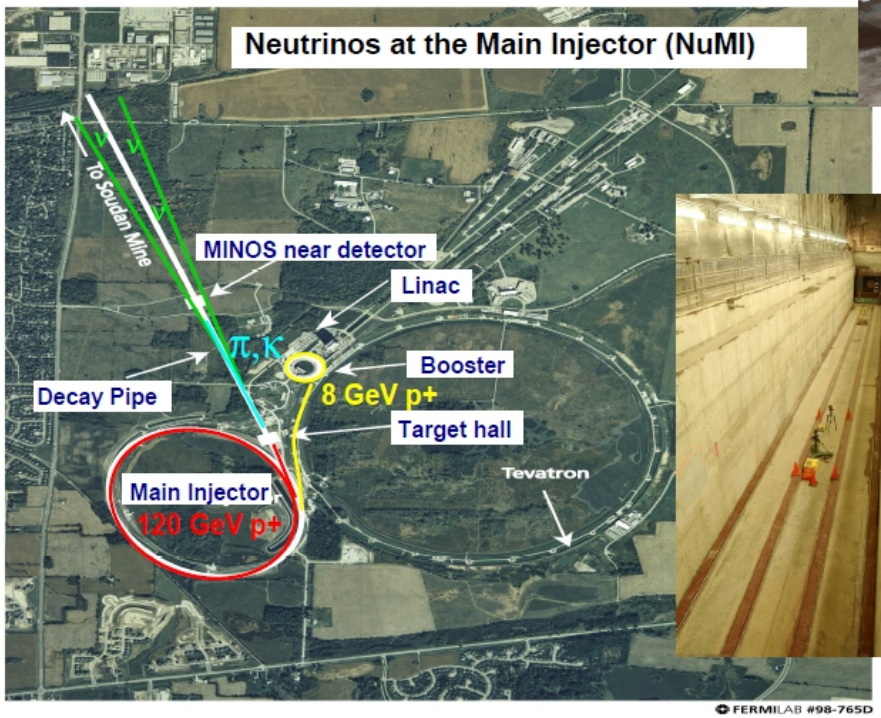
3.5 m long horn with the inner conductor optimized for each specific current

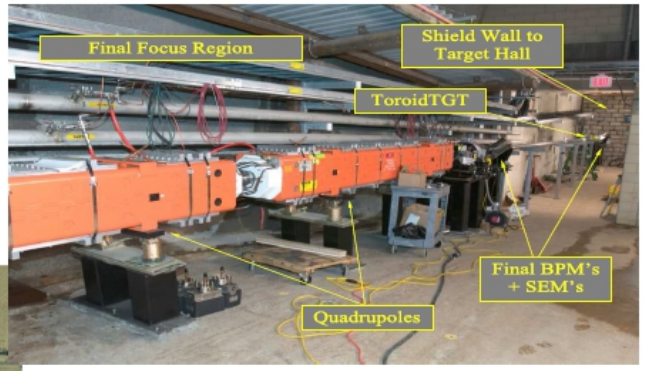
Option	Current (kA)	Relative Yield	Rel. Peak Yield
MiniBooNE	178	1.00	1.00
Opt 2	180	1.48	1.29
Opt 2	200	1.55	1.38
Opt 2	220	1.62	1.45
Opt 2	240	1.68	1.52
Opt 2	250	1.71	1.52

NuMI/MINOS

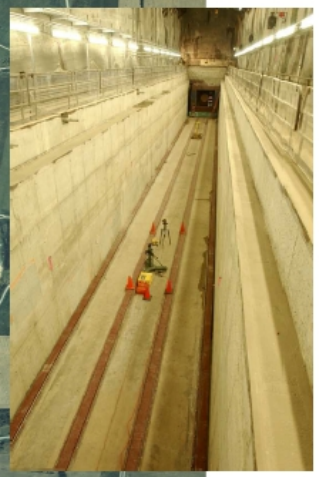


Fermi Natl. Lab., IL Soudan Underground Lab, MN





Pretarget region



Target hall

Decay pipe

Description of NuMI neutrino beam: arXiv:1507.06690 (to be published in Nucl. Instrum. Meth. A, 2015)

NuMI/MINOS Targetry/Horns

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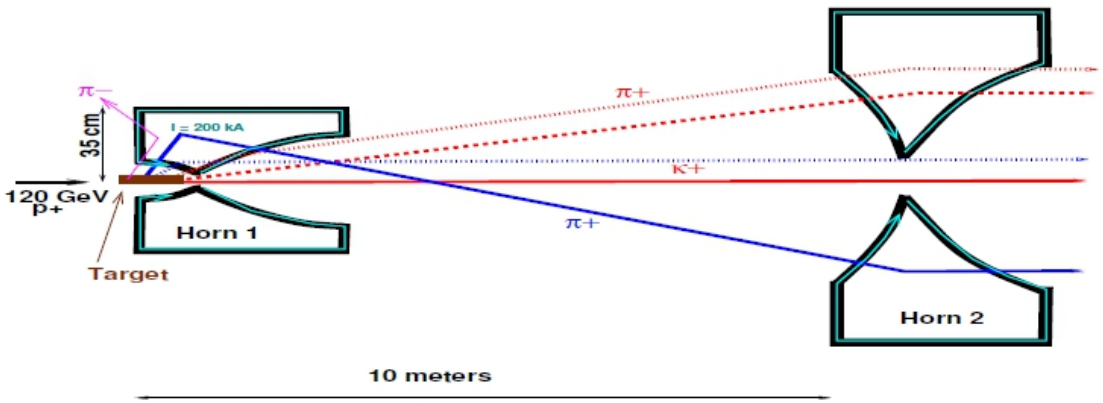


NuMI Target

6.4 x 15 mm^2 graphite segments.

1m long = 1.9 interaction lengths.

$\mathcal{O}(10)$ KW beam power at 1 mm beam width.

Water cooled.

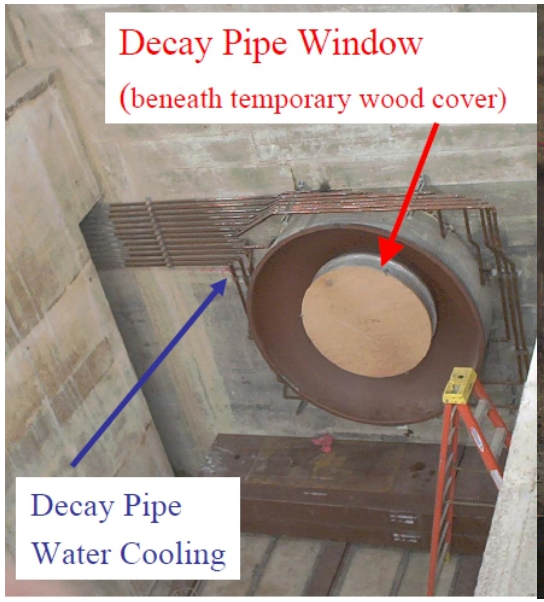
Horn 1

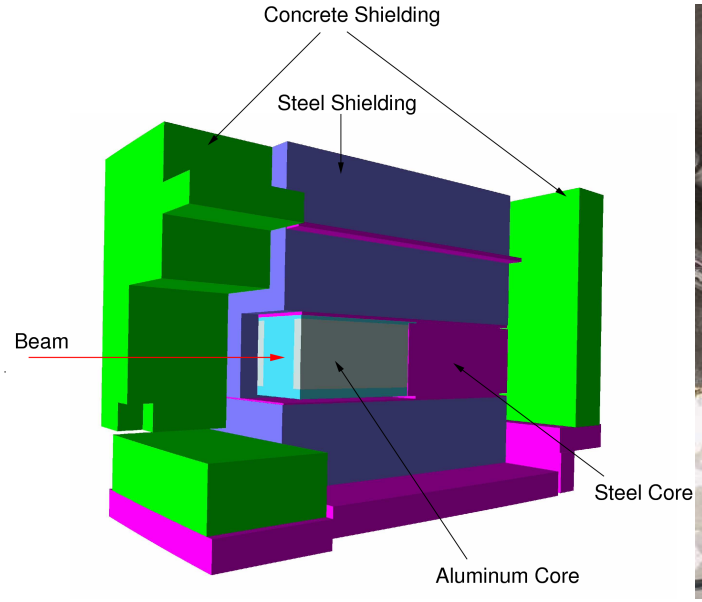
Horn 2

Parabolic magnetic lens.

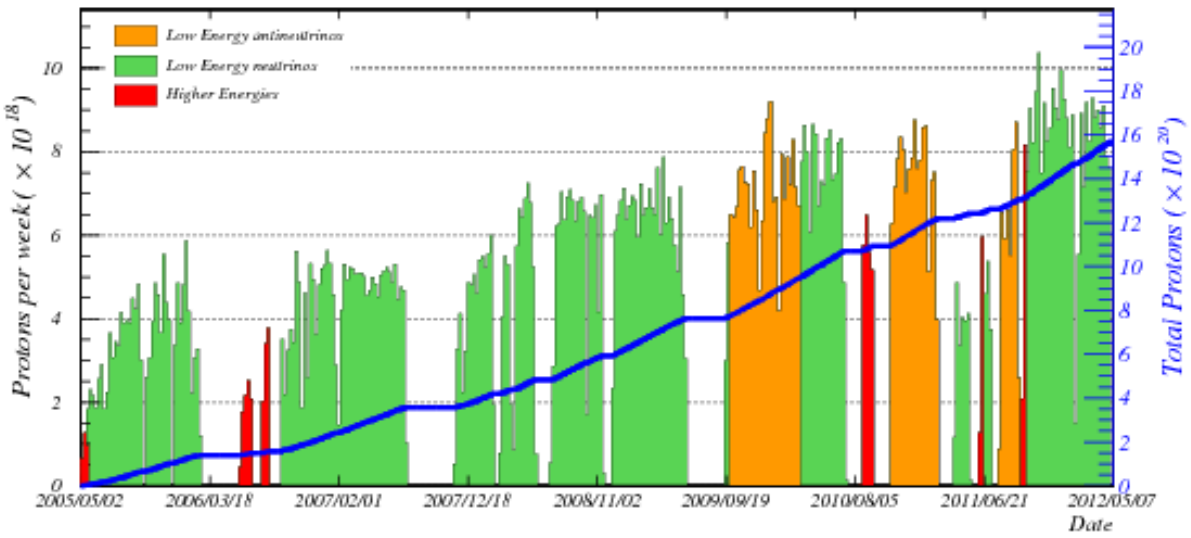
3T at 200 kA

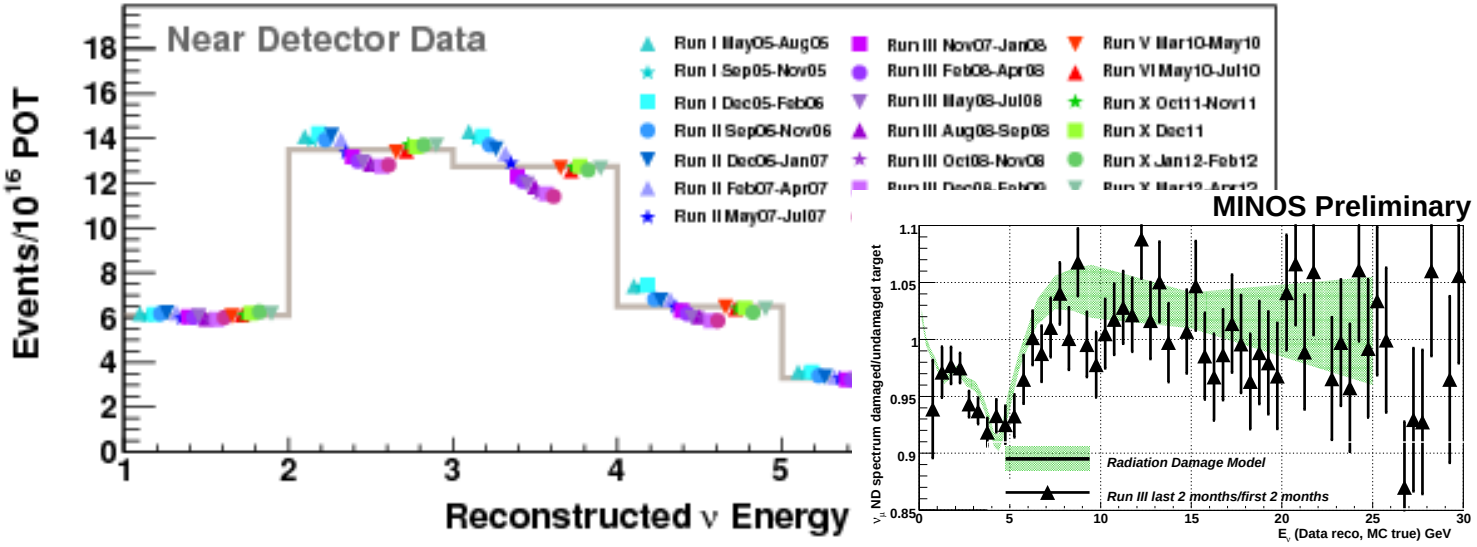
NuMI Decay Pipe and Hadron Absorber



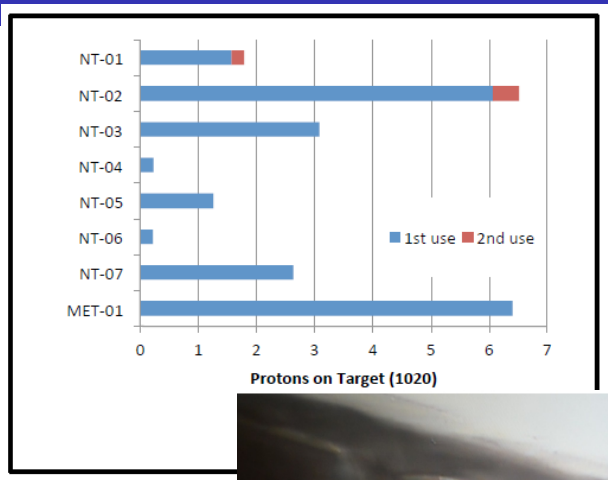


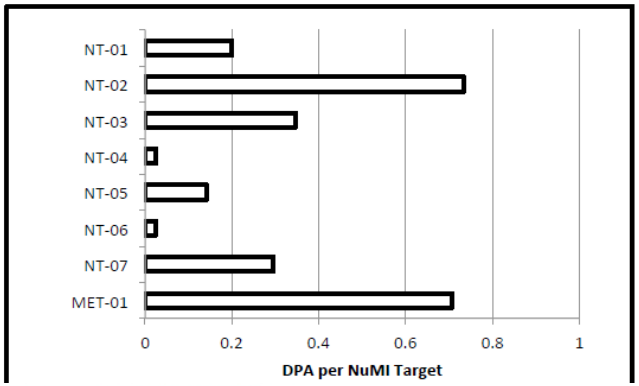
NuMI/MINOS Operation 2005-2012

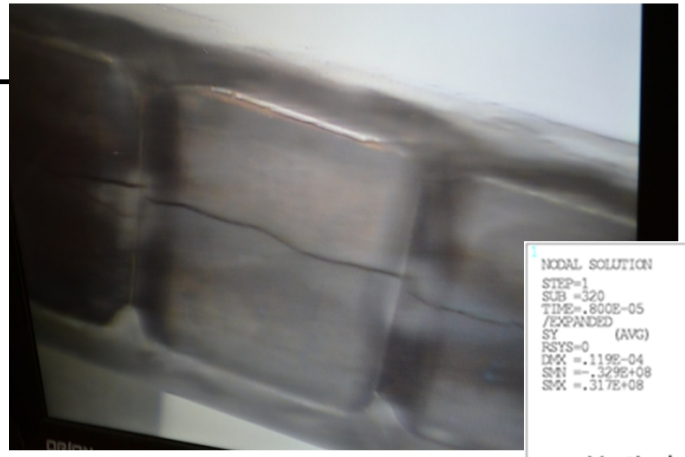




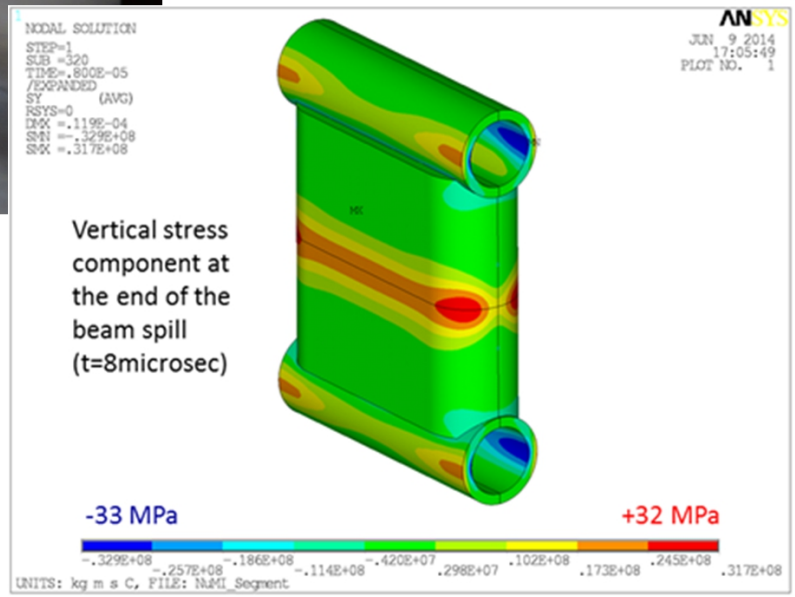
NuMI/MINOS Operation 2005-2012







Autopsy of NT-02 (photo courtesy of V. Sidarov)



Possible explanation: high tensile stress after beam pulse 400 kW beam (T. Davenne/P. Loveridge)

NuMI/MINOS Operation 2005-2012

Horns	Status	# Pulses	Location	Comments
PH1-01	Very Used, Water Leak	24.2M	C0 Bay	9 R/hr @ 1 ft. on 5/12/14
PH1-02	Used, Still Operational 400kW "Spare"	45.9M	C0 Bay	35 R/hr @ 1 ft. on 9/10/14
PH1-03	400kW Spare, Upgraded Cooling for higher beam power	0	MI-8	
PH1-04	700 kW Horn Stripline Fracture	27M	NuMI Target Pile	Must be replaced Very Radioactive
PH2-01	Used, Stripline Fracture	28.1M	C0 Bay	Intend to ship off-site FY16
PH2-02	In operation	65.1M Pulses 4/13/2015	NuMI TH Beamline	

NuMI/NOνA

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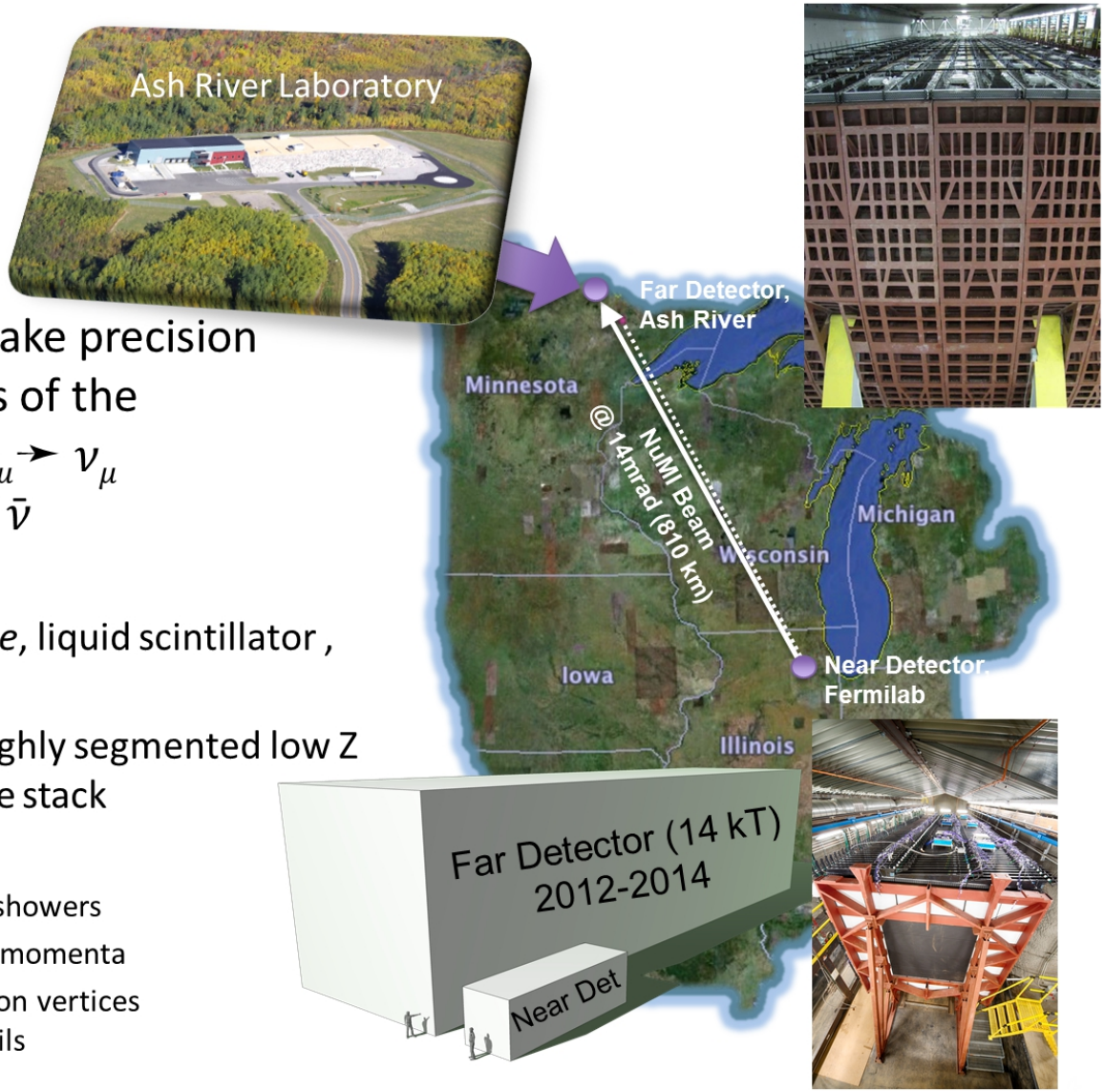
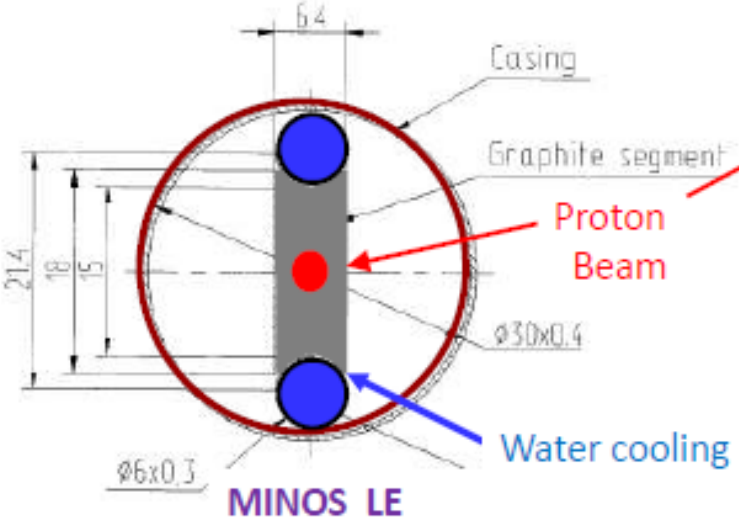
- Designed to make precision measurements of the $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_\mu$ for both ν and $\bar{\nu}$
- 14 kt *totally active*, liquid scintillator , surface detector
- Optimized as a highly segmented low Z calorimeter/range stack
- Tuned to:
  - Reconstruct EM showers
  - Measure μ track momenta
  - Identify interaction vertices and nuclear recoils



NuMI/NOνA Modifications

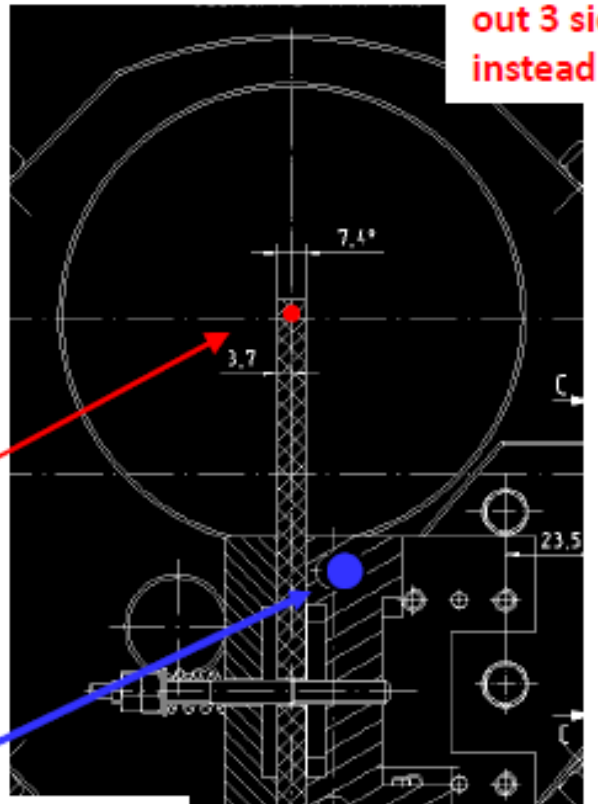
MINOS beam spot size of 1.1 mm RMS is increasing to 1.3 mm for NOVA, increasing 6.4 mm target width to ~ 7.4 mm
- reduces the neutrino flux ~ 1%, but eases alignment tolerance.

Spacing between fins
0.5 mm / 24 mm versus 0.2 mm / 20 mm

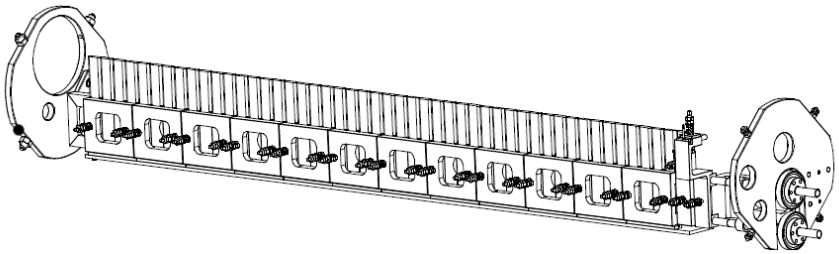


4/15/2011

Pions come out 3 sides instead of 2

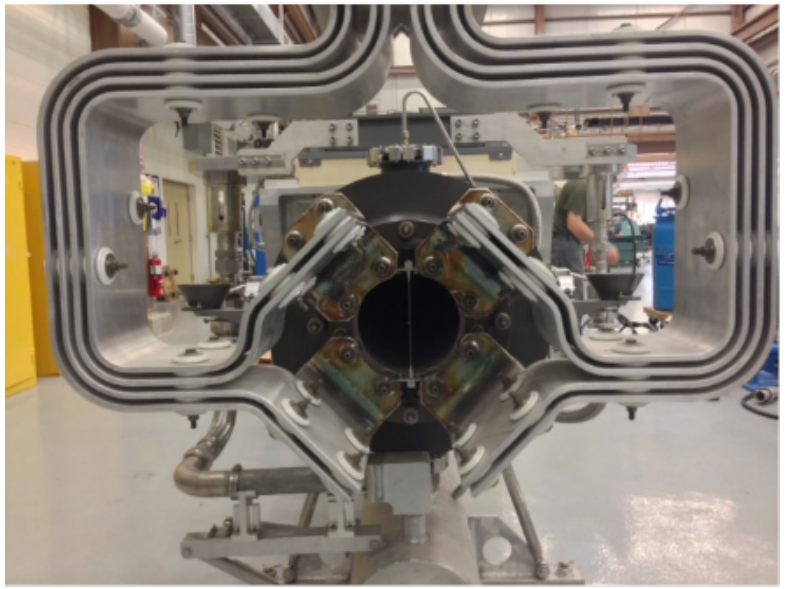


All units

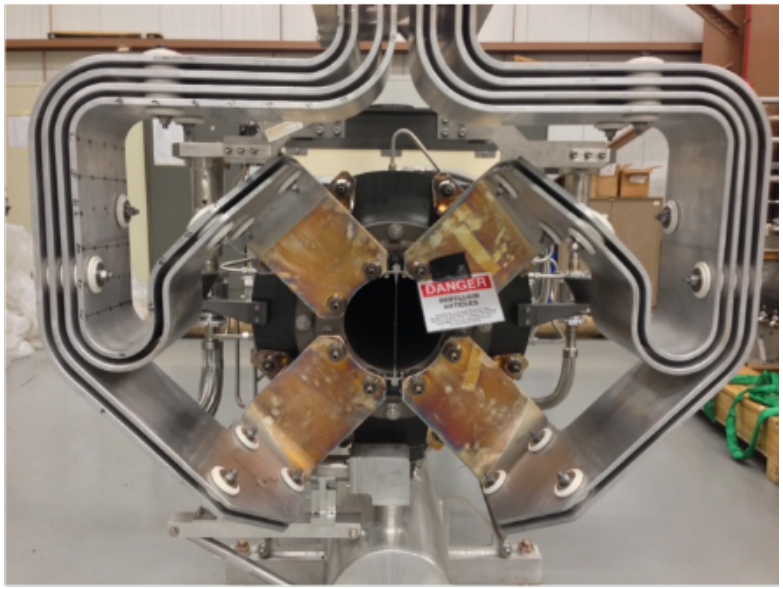


NuMI/NOνA Modifications

PH1-03

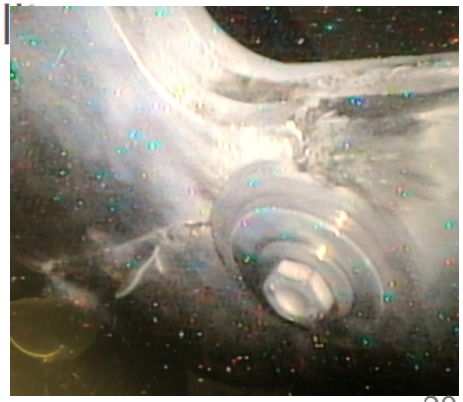


PH1-05



- Stripline shape changed for higher power
- Crosshair changed from Aluminum to Beryl

PH04 first 700 W capable horn in service since Sept 2013 accumulated $\approx$ 27 million pulses - stripline fractured and is being replaced $\Rightarrow$



NuMI/NOνA Operations

B. Zwaska presentation

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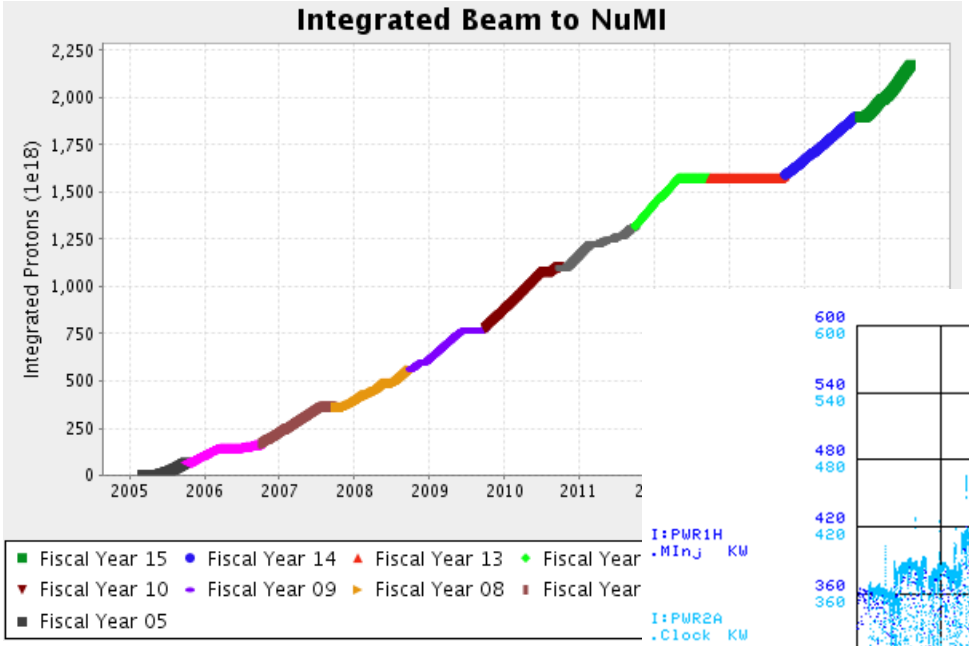

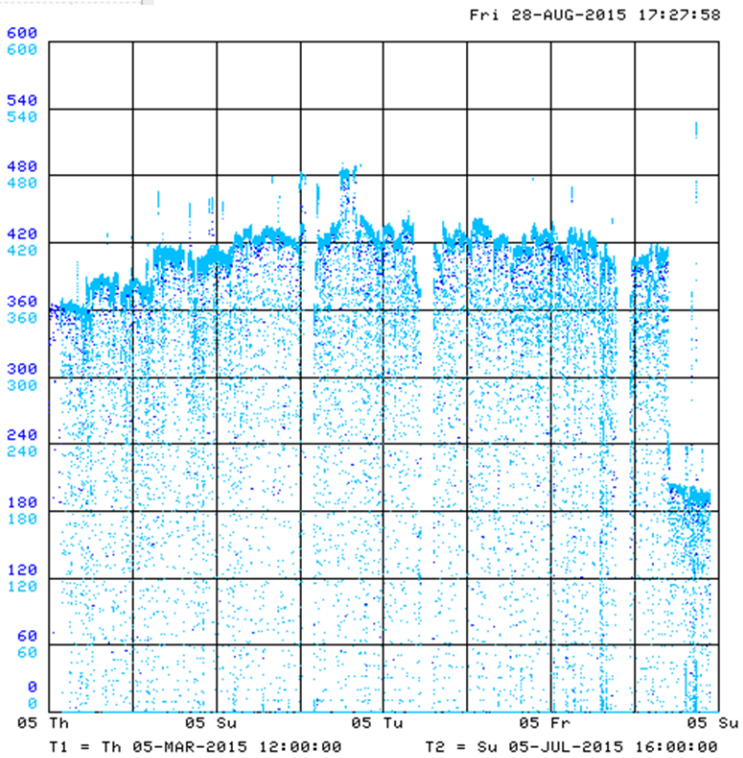

Achieved on July 1st 2015: 521 kW for 1hr !

NuMI/NOνA Operations

B. Zwaska presentation

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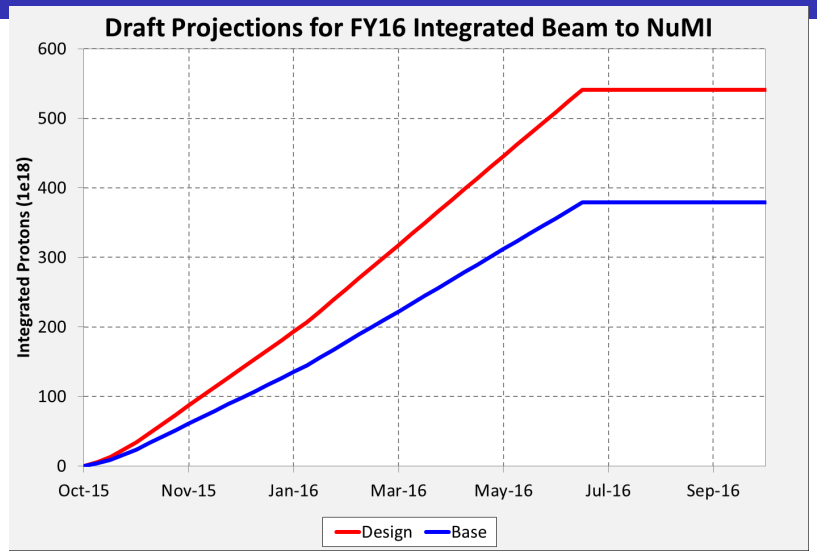

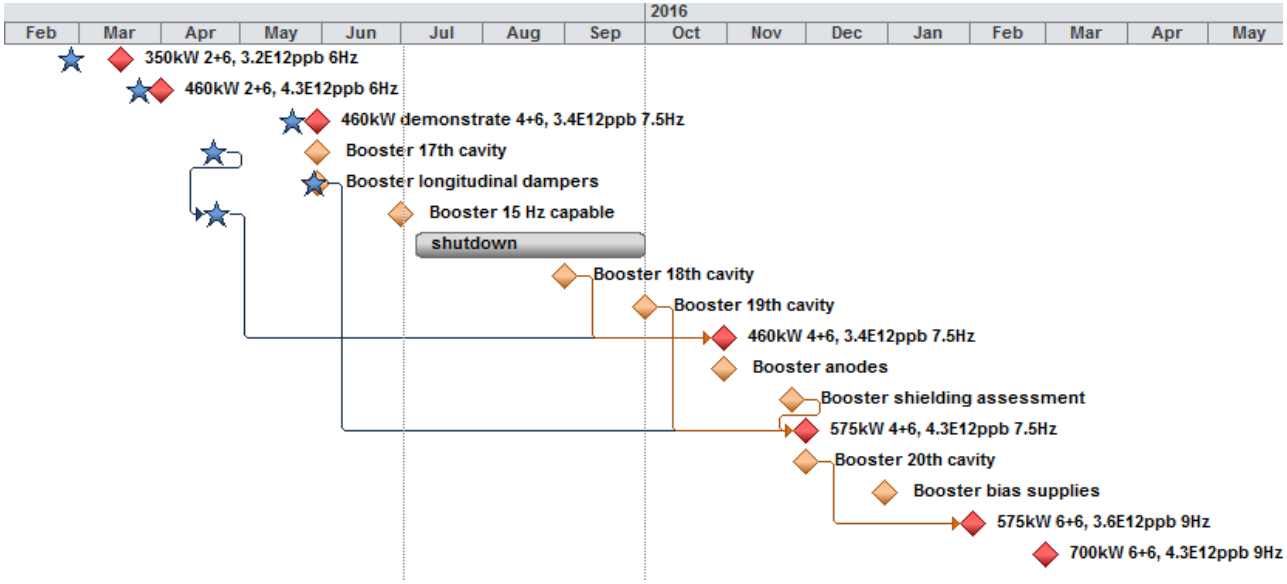

The LBNF/DUNE Experiment

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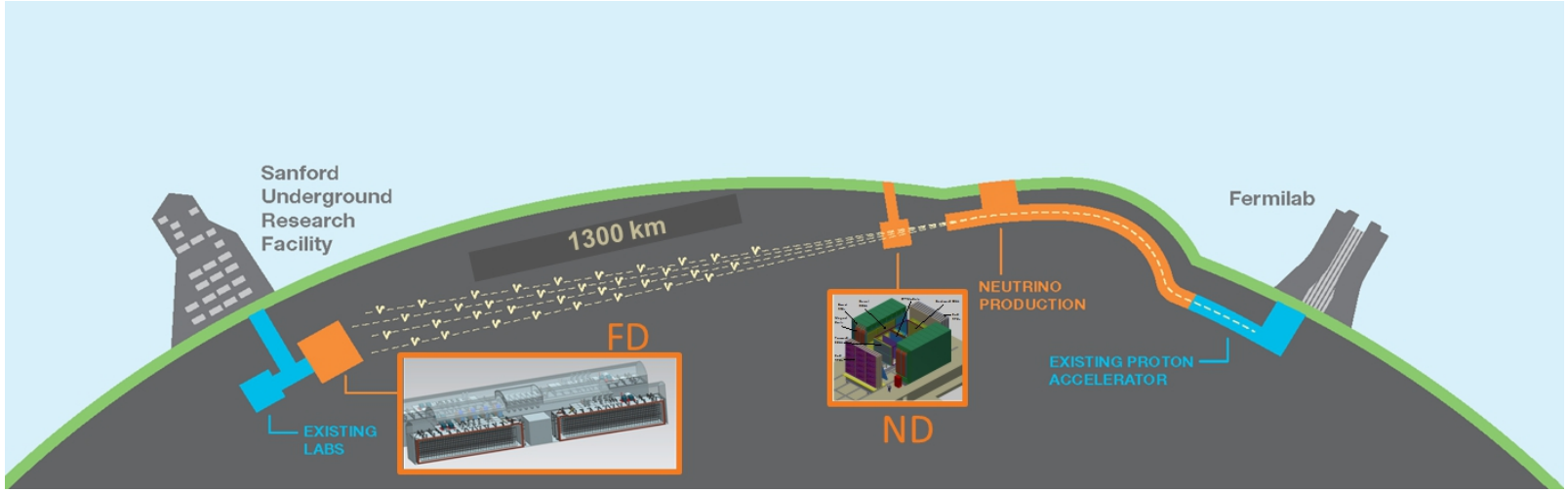

Scientific goals of LBNF/DUNE:

- **Comprehensive experimental program to defintively determine CP violation, mass hierarchy, and make precision measurements of oscillation parameters.**
- **Search for unique signatures of proton decay and precision detection of the ν_e signal from a core-collapse Supernova should one occur.**
- **Precision tests of the Standard Model using neutrino scattering measurements with the Near Detector.**

Proton Improvement Plan (PIP)-II

B. Zwaska presentation

Fermilab Neutrino Beams: Present and Future

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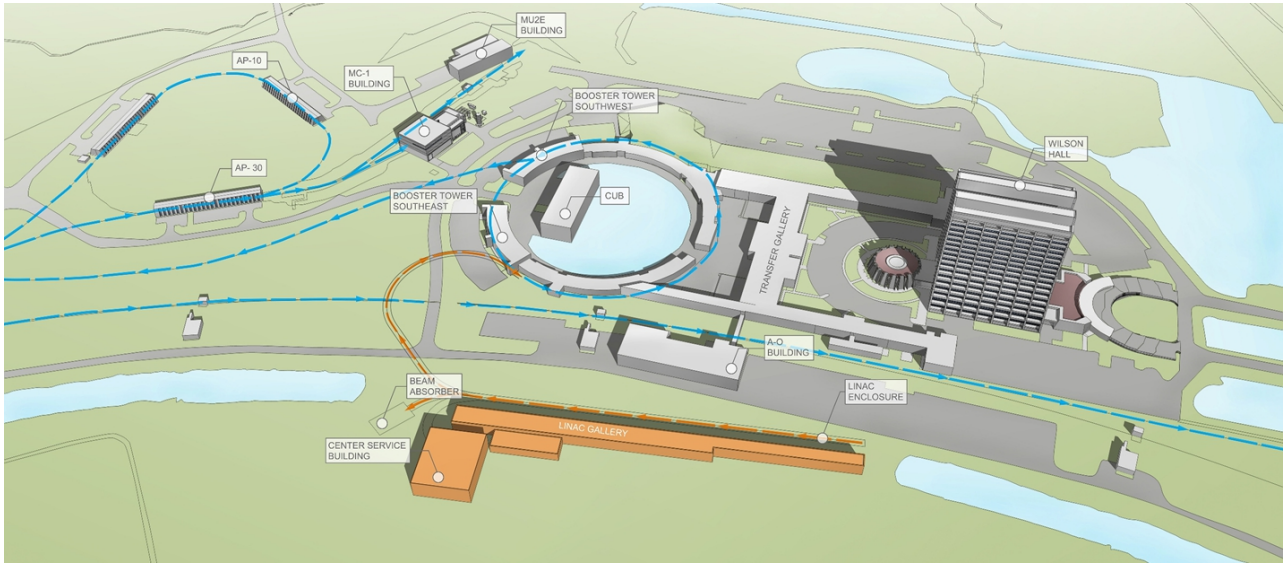
Planned upgrades to the Fermilab complex to increase proton intensity:



PIP-II replaces upstream portion of linac feeding into 8 GeV Booster:
1.03 MW at 60 GeV
1.07 MW at 80 GeV
1.20 MW at 120 GeV

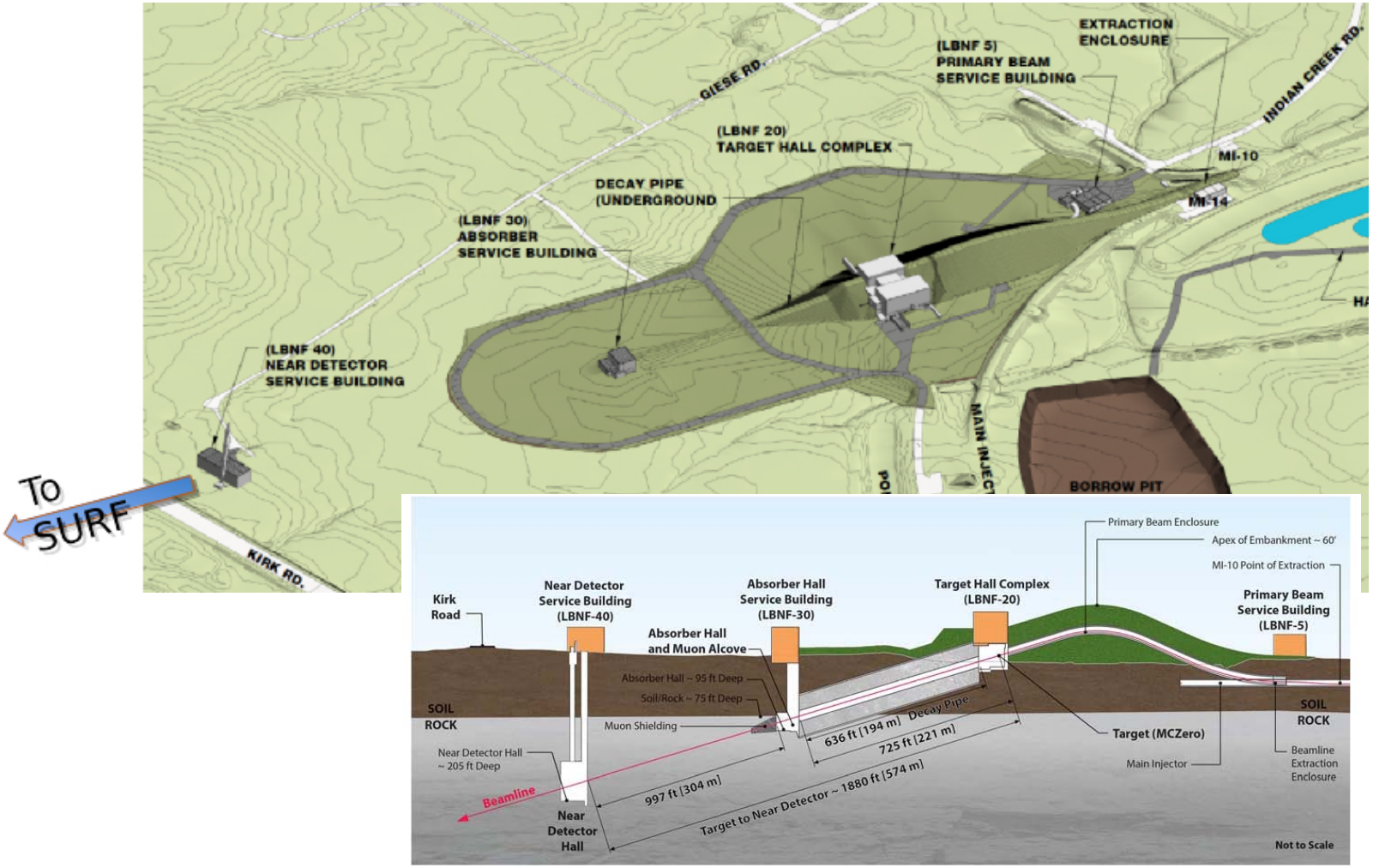
Ready by 2025

Further upgrades (PIP-III) would replace booster with Rapid Cycling Synchrotron (RCS) or SC Linac. Currently in R&D stage.

$\geq$ 2.0 MW at 60 GeV
$\geq$ 2.3 MW at 120 GeV

The LBNF Beamline

Novel concept beam-on-a-hill reduces cost.



Primary proton beamline: extracts 60-120 GeV designed for 1.2MW upgradable to 2.3MW

The LBNF Beamline

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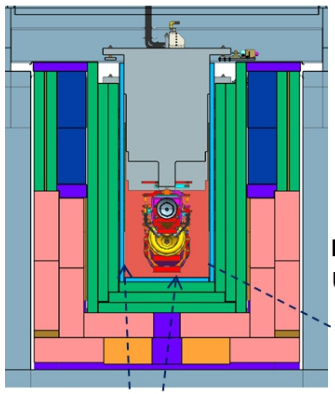
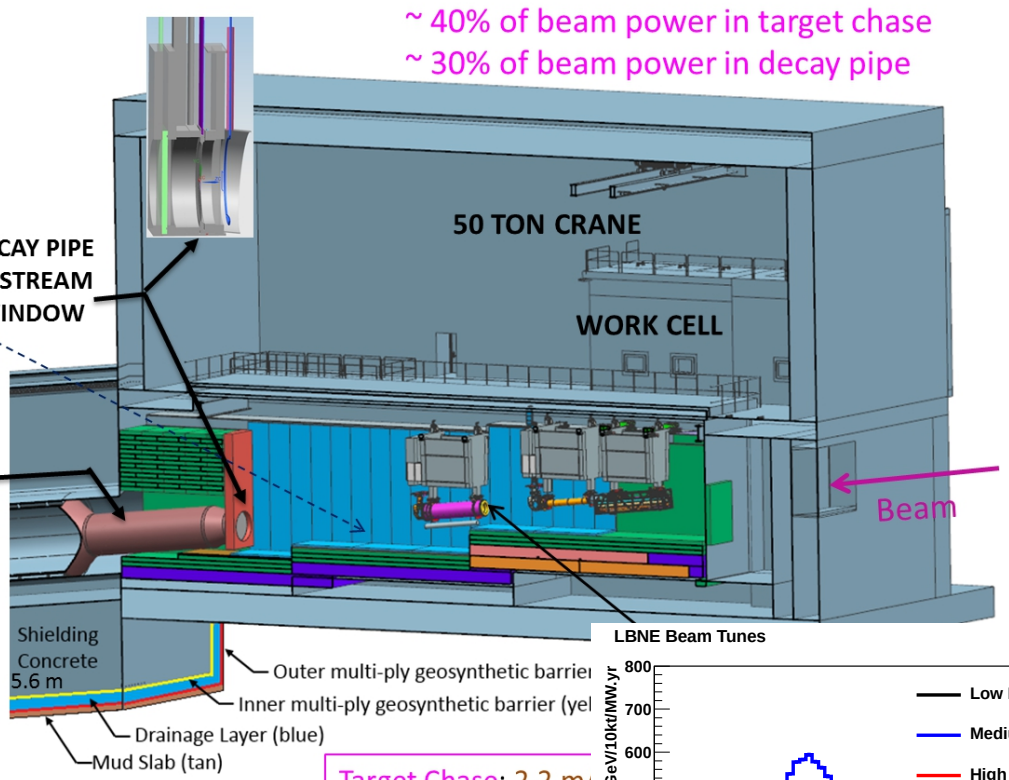
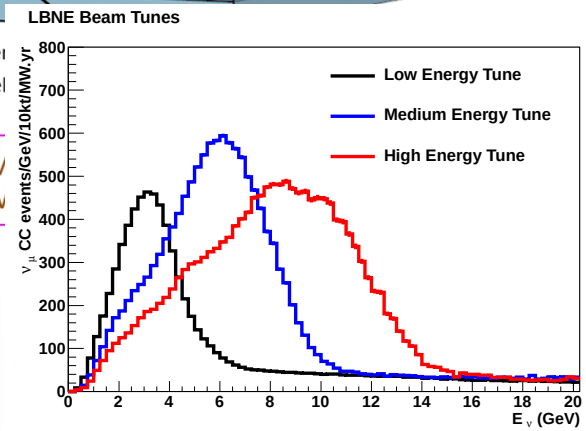
Advanced conceptual design with upgraded tunable NuMI focusing:

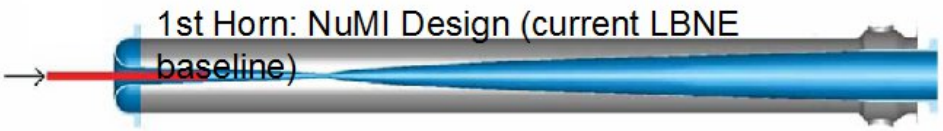




Decay Pipe: 194 m long, 4 m in diameter, double – wall carbon steel, helium filled, air-cooled.

Target Chase: 2.2 m/ air-filled and air & w

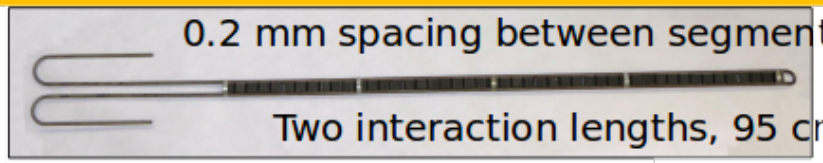




LBNF Beamline Targetry/Focusing

1.2 MW target and horns inside the target chase

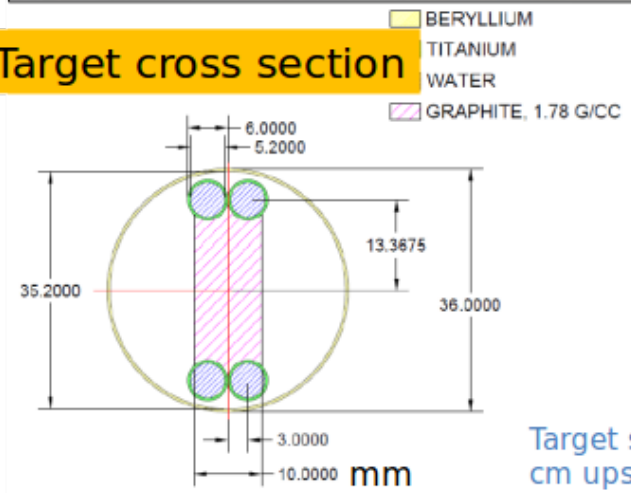
47 graphite target segments, each 2 cm long



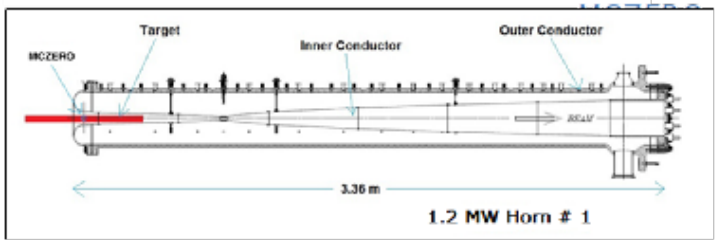
NuMI-like target and horns with modest modifications

Strong R&D program in place

Target cross section



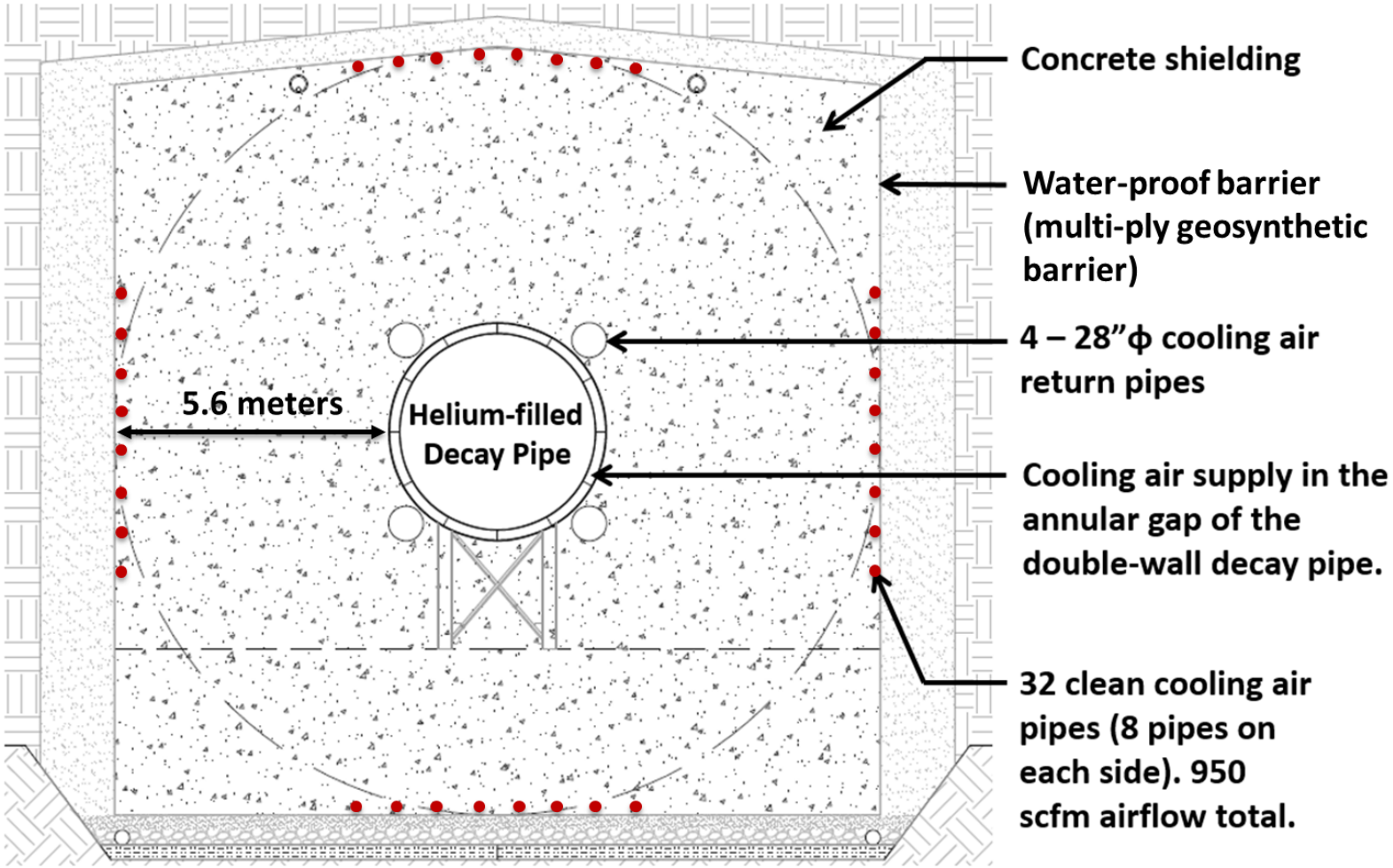
Target starts 45 cm upstream of



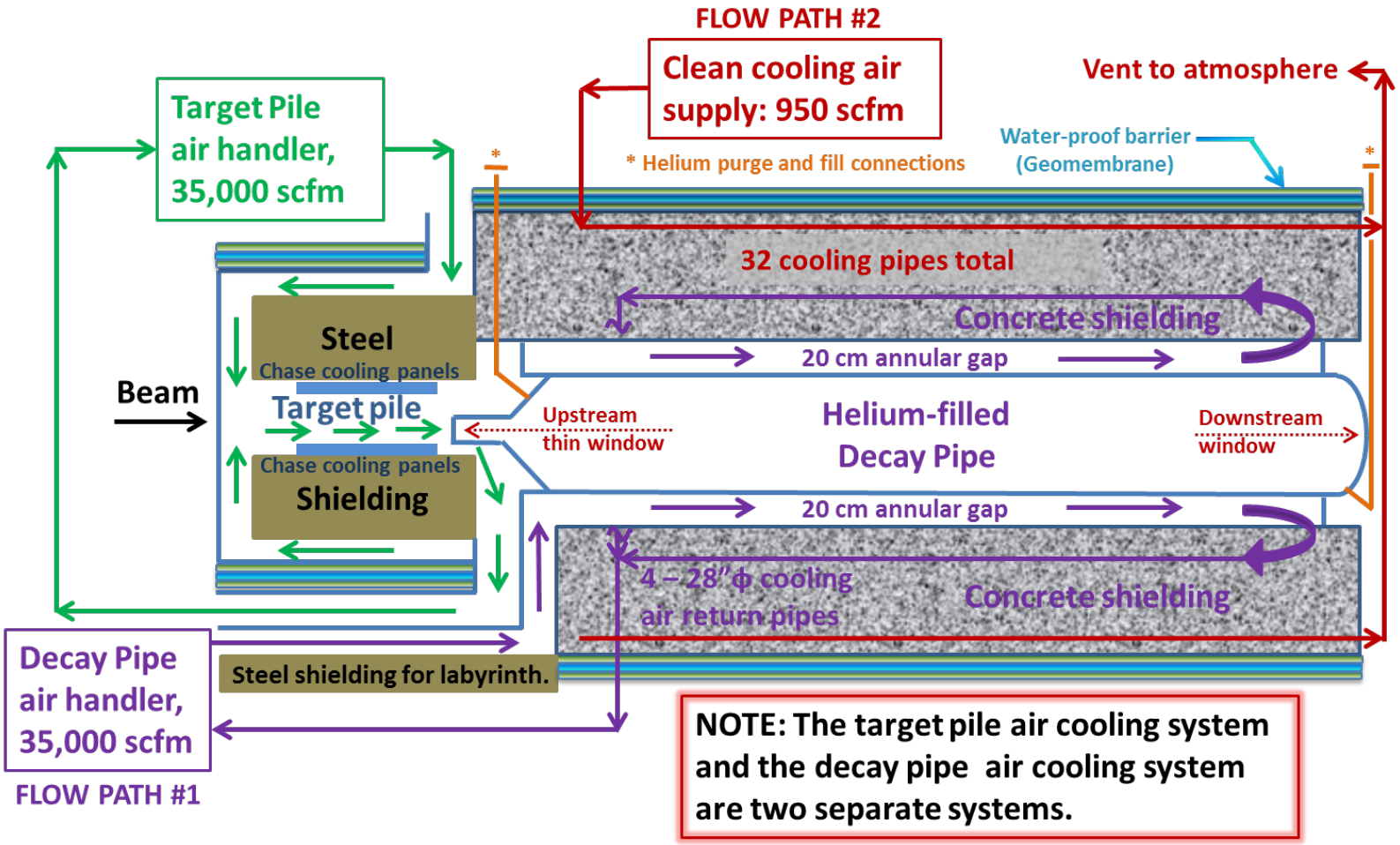
Inner Conductor of NuMI Horn

New Horn power supply needed to reduce the pulse width to 0.8 ms.

LBNF Decay Pipe



LBNF Decay Pipe



LBNF Absorber

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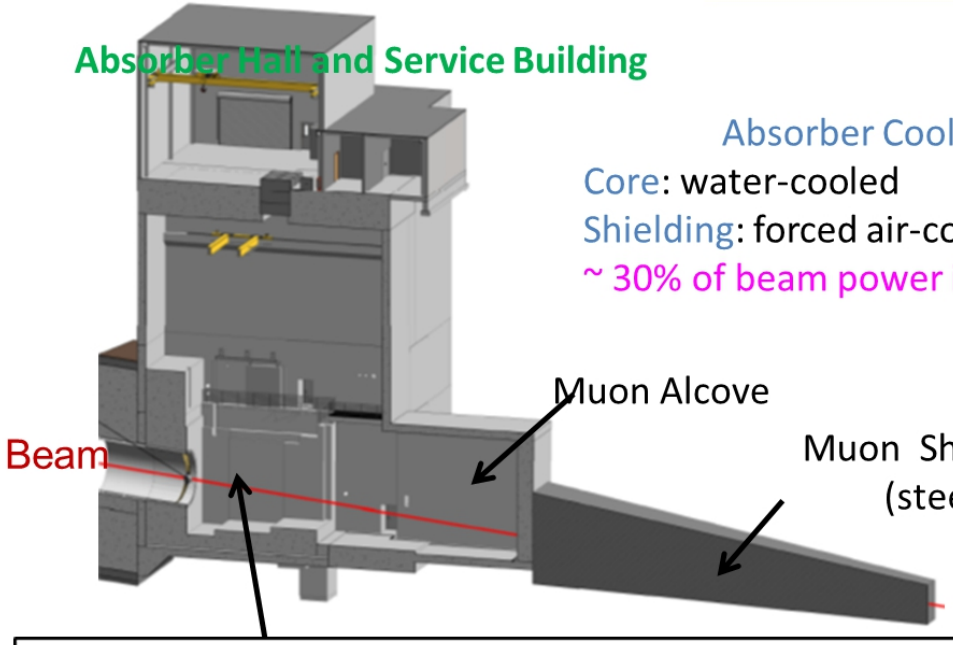
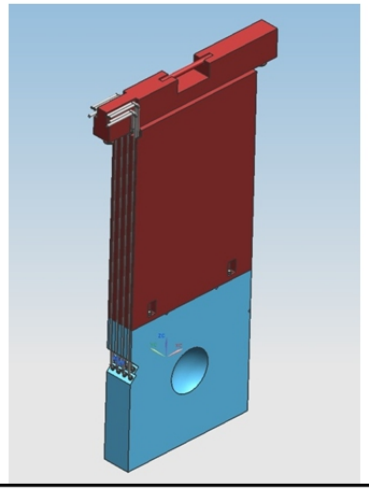
Hadron Absorber

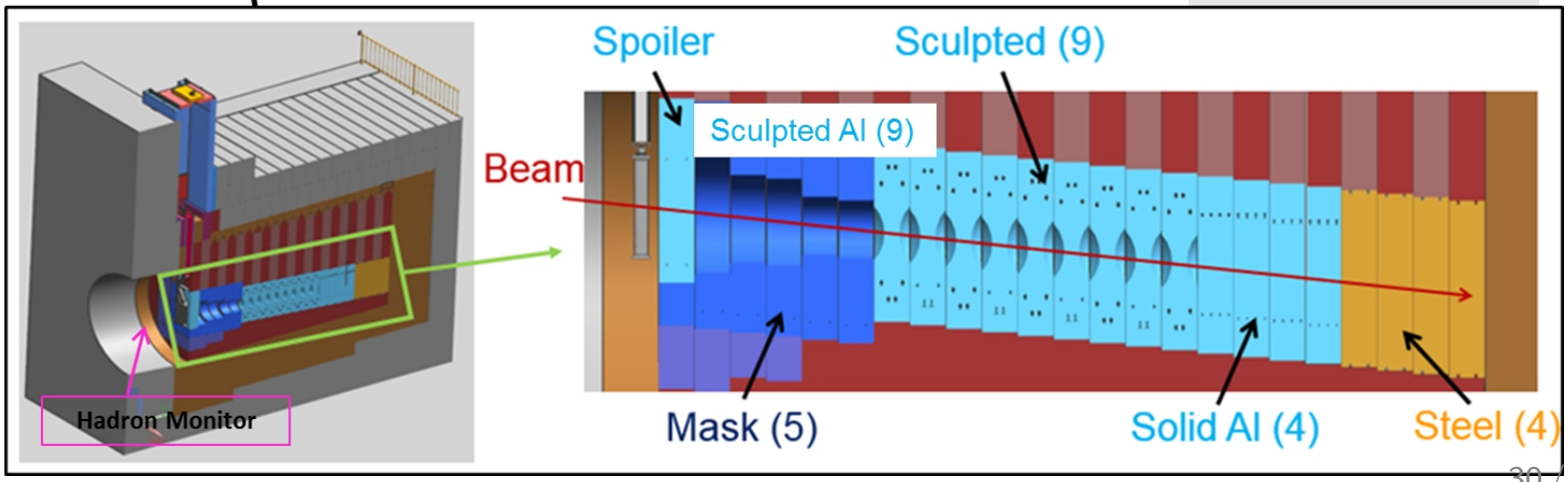
The Absorber is designed for 2.4 MW



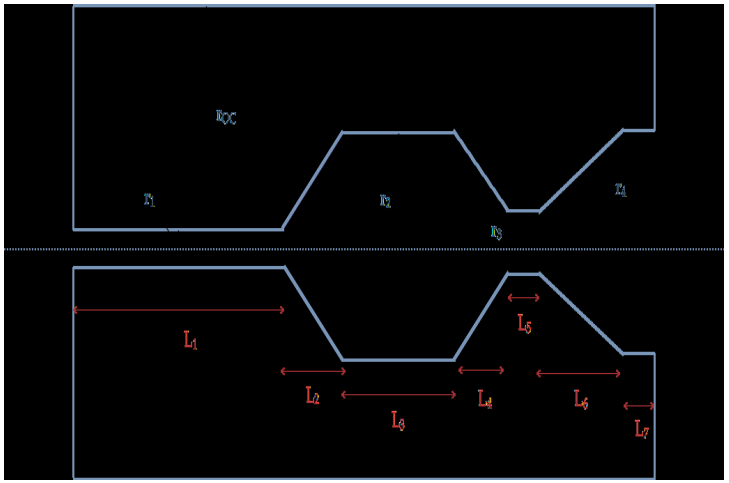
Absorber Cooling
Core: water-cooled
Shielding: forced air-cooled
~ 30% of beam power in Absorber

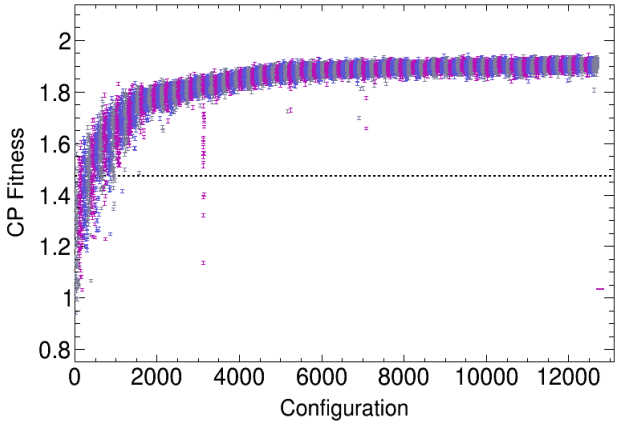
Core blocks replaceable (each 1 ft thick)



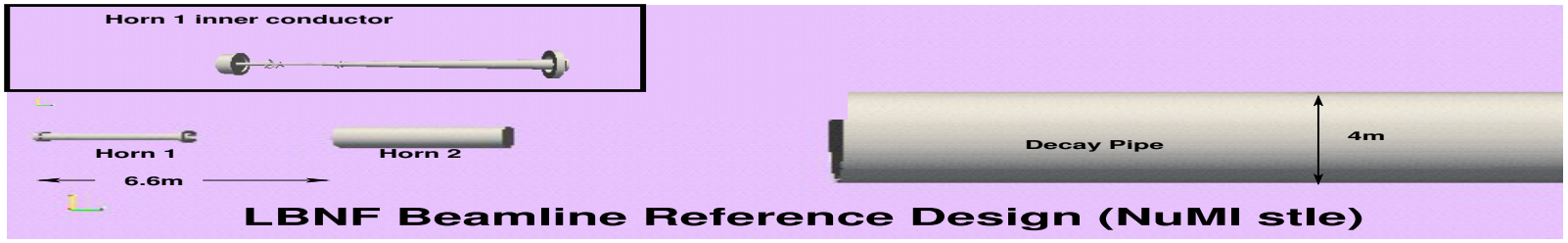


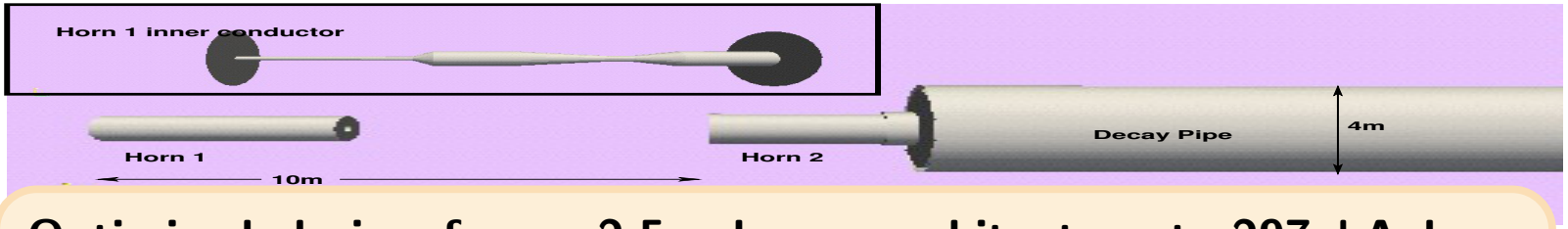
Optimization of Focusing System Geometry





Optimized focusing design obtained from genetic algorithim:





Optimized design favors 2.5m long graphite target, 297 kA horn current, Horn 1 r=0.6m, l = 5.75m, E_p = 110 GeV.

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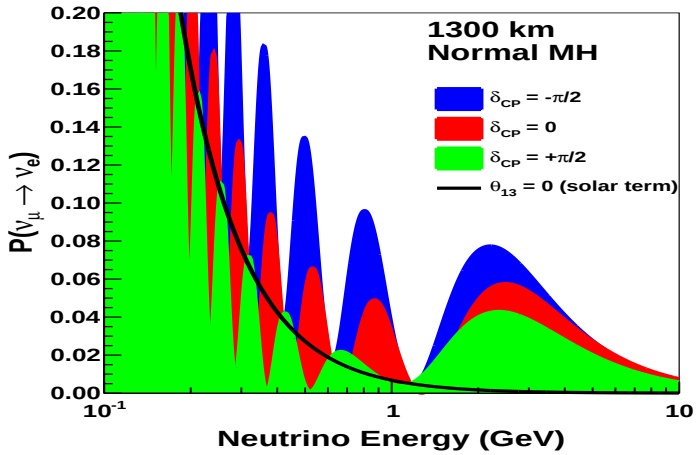

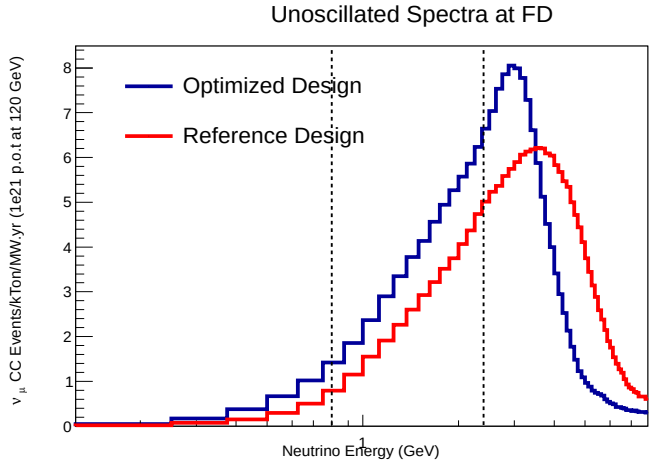

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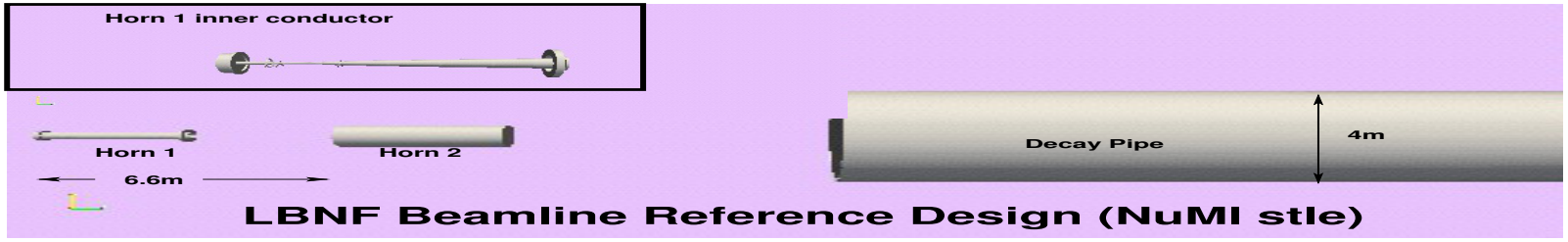

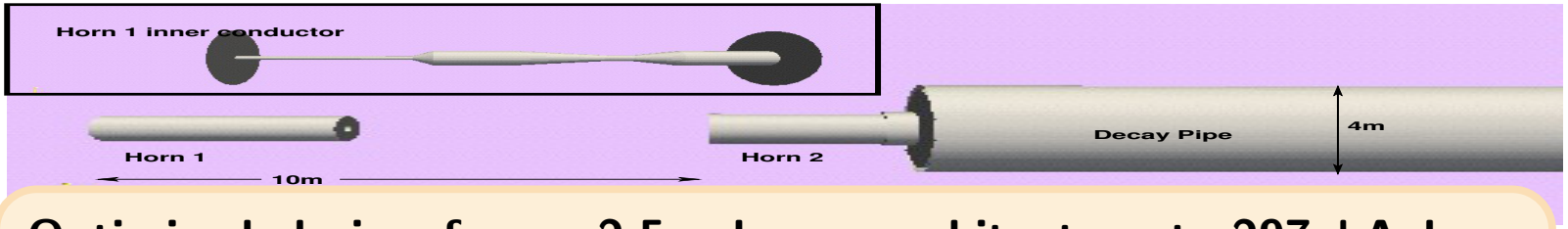

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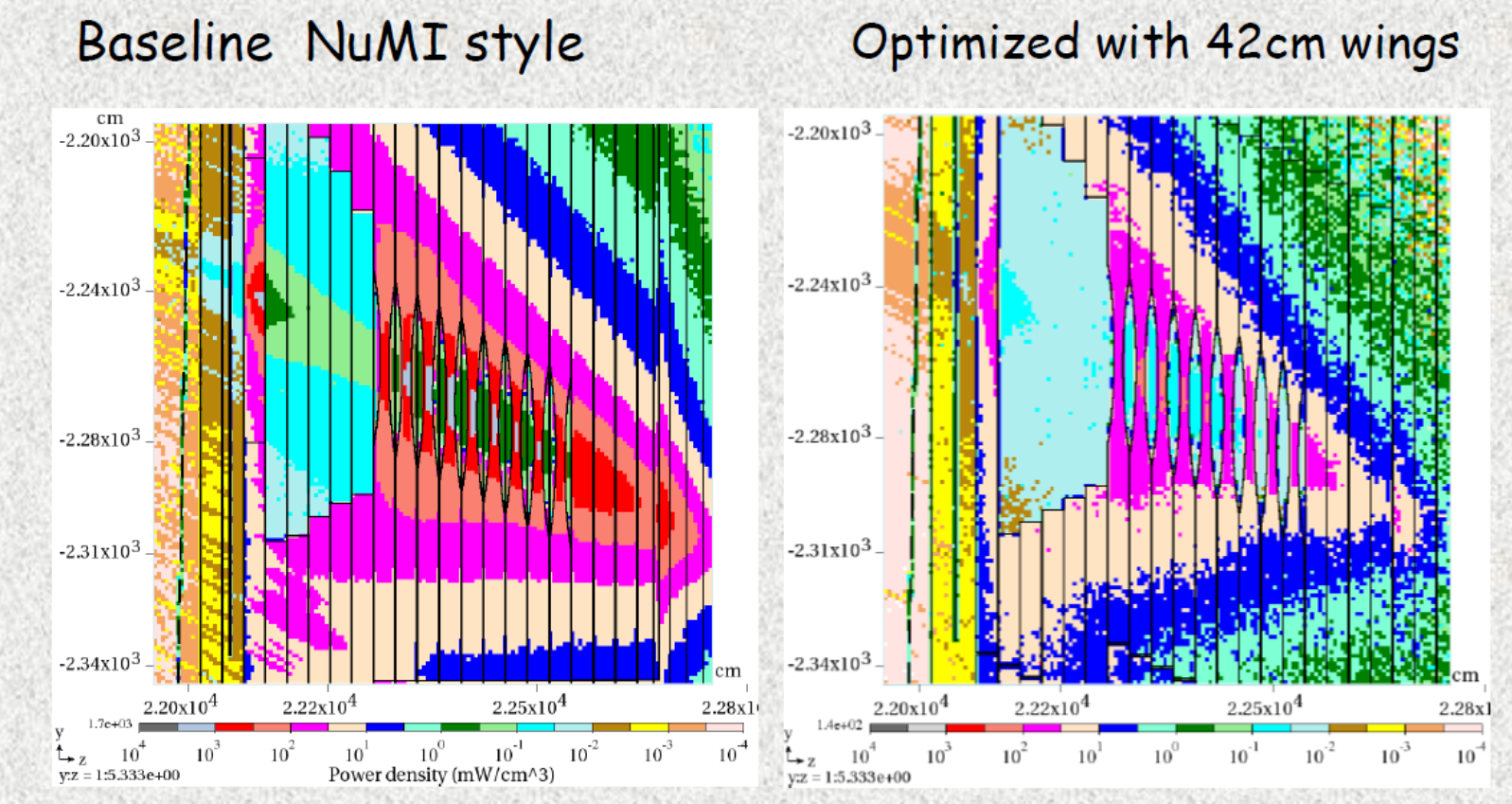
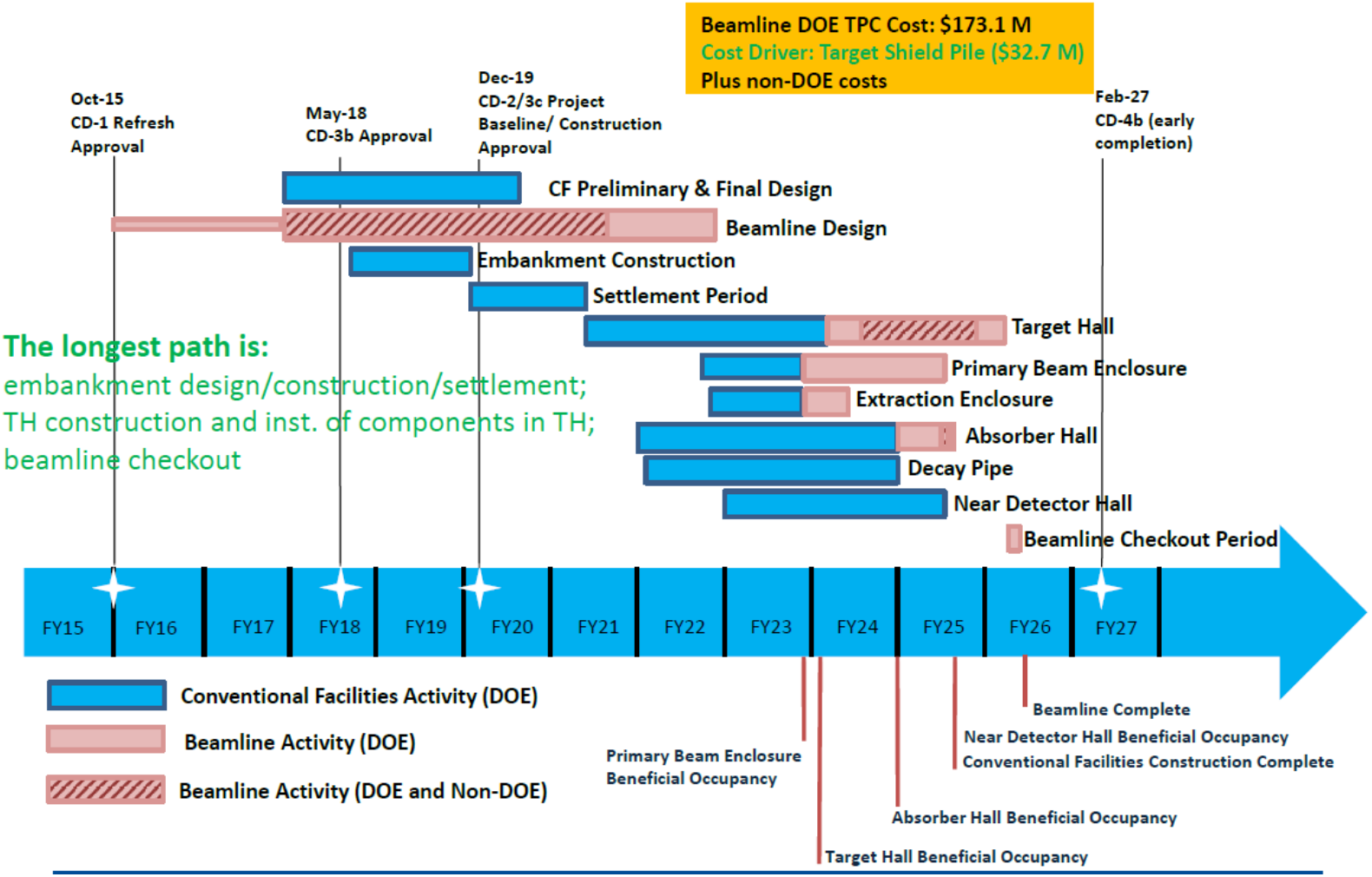
Absorber Energy Deposition



PRELIMINARY: Optimized focusing design and possible wings added to target could reduce peak energy deposition in absorber 8-12 $\times$.

LBNF Near Site Schedule



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THANK YOU

Special thanks to: Bob Zwaska, Zarko Pavlovich, Alberto Marchionni, Vaia Papadimitriou, Nikolai Mokhov, Andy Stefanic, Andrew Norman, Mary Convery, Chris Densham