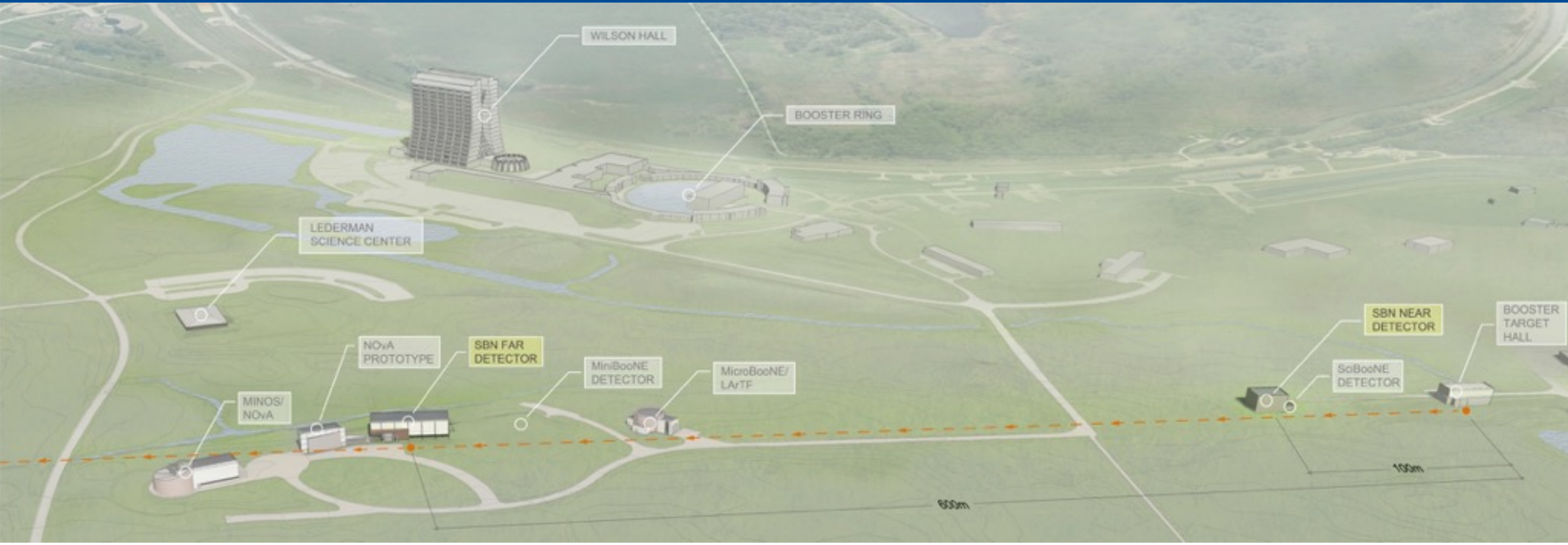


BNB Upgrade

Zarko Pavlovic for the BNB upgrade group

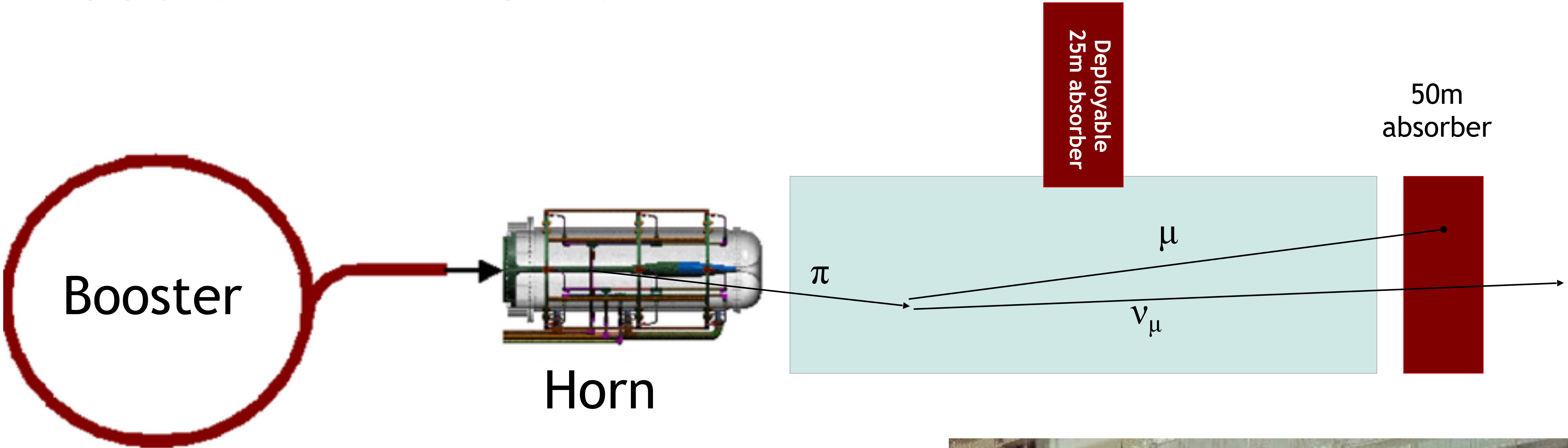
Director's Progress Review of SBN

15-17 December 2015

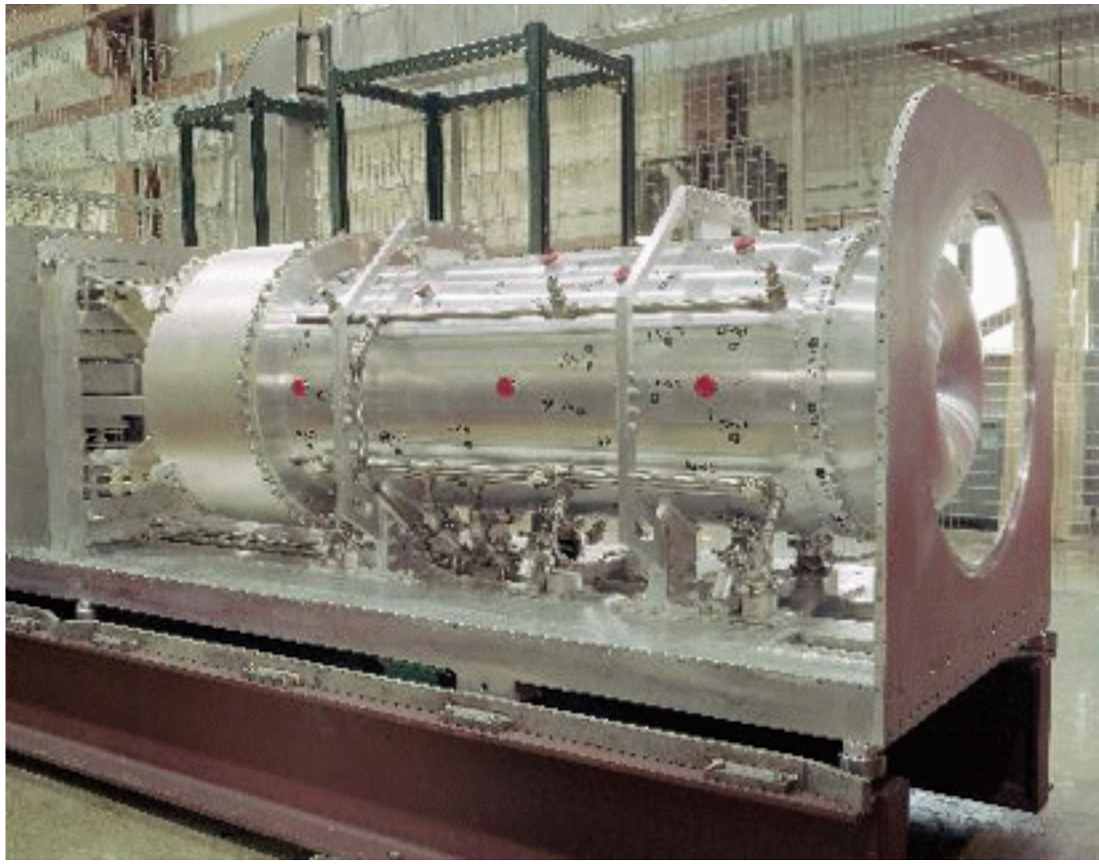
Outline

- Overview of BNB
- Optimization strategy
- Resources
- Optimization procedure
- Status of design
- Conclusion

Booster Neutrino Beam



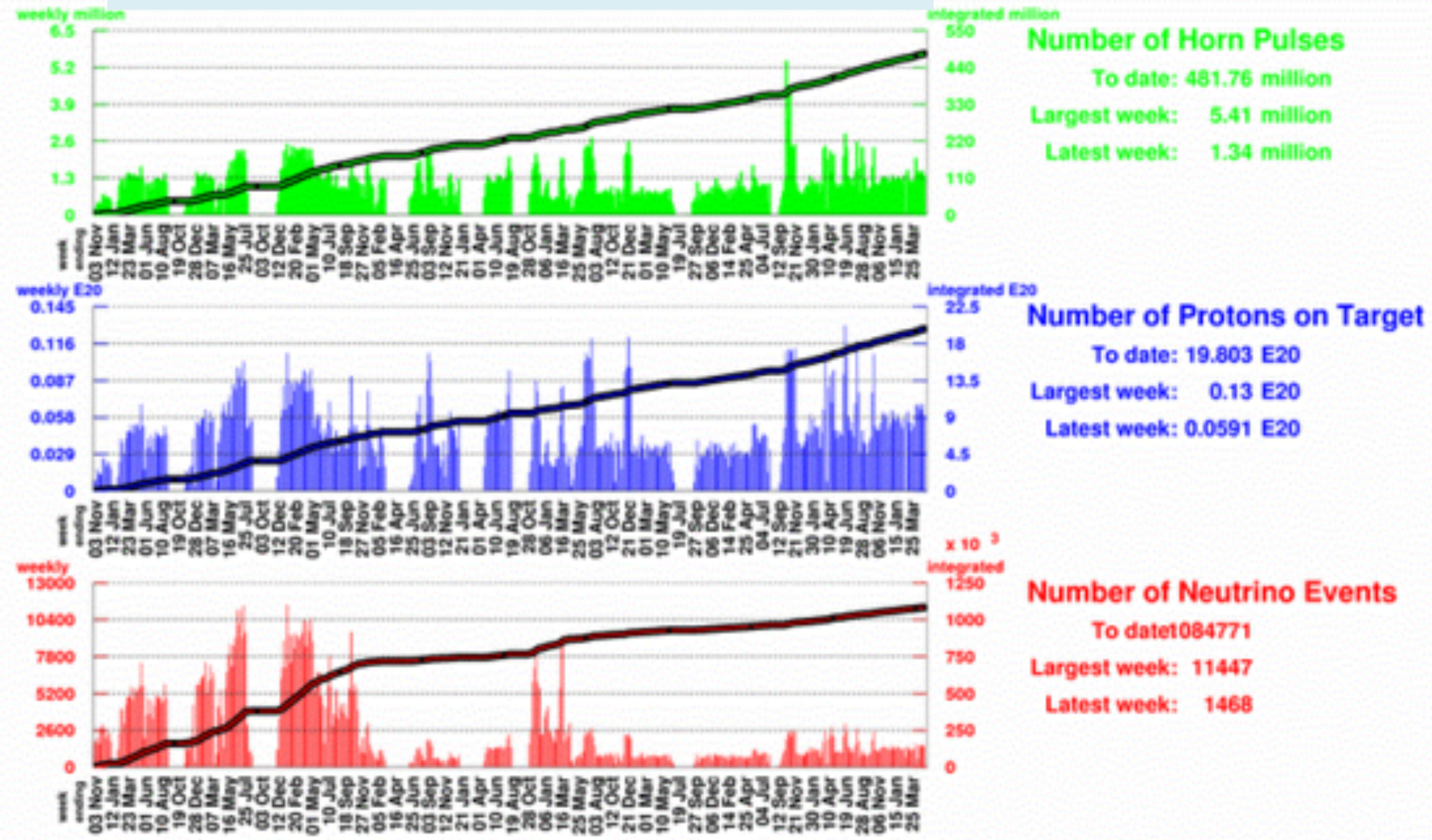
- 8GeV protons from Booster
- 4-5e12 protons per pulse
- Up to 5Hz average rate (10 pulses in a row)
- 1.7 interaction lengths Beryllium target
- Horn ±174kA (neutrino or antineutrino running)
- 50m long decay pipe

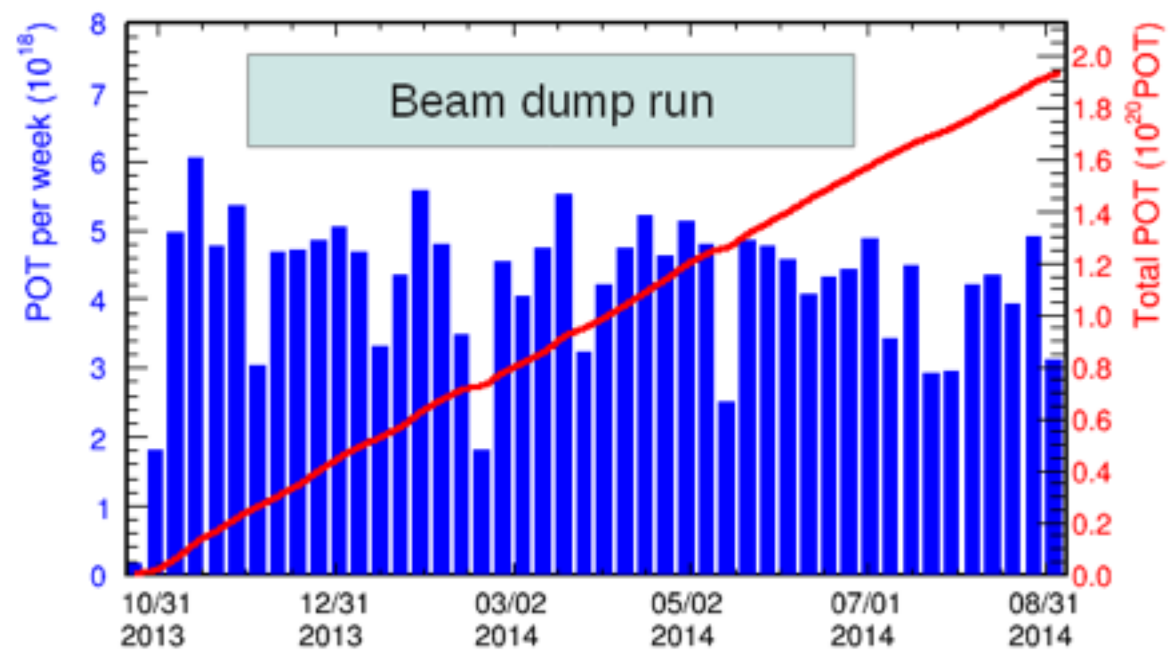


12 years of running

- BNB delivered more than 2e21 protons on target
- Two target/horn assemblies
  - 1st horn 2002-2004: 97 million pulses
  - 2nd horn 2004-2015: 375 million pulses

Neutrino + Antineutrino run

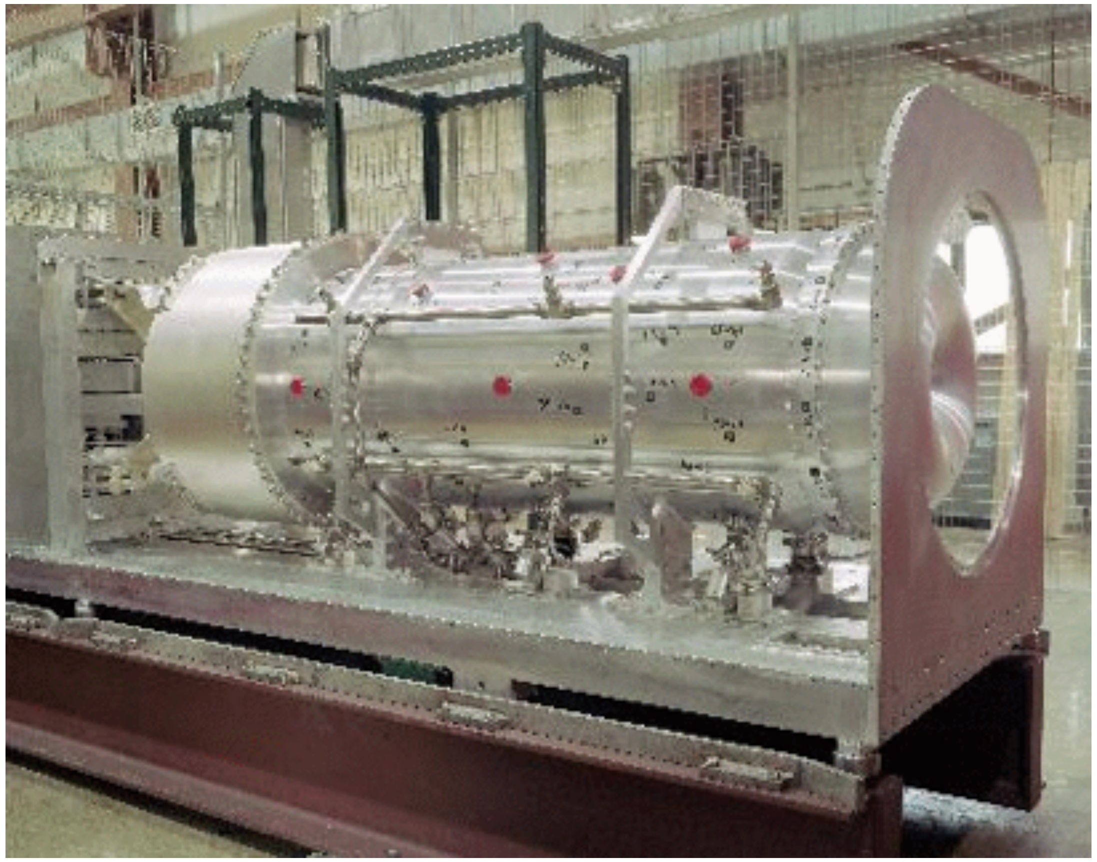


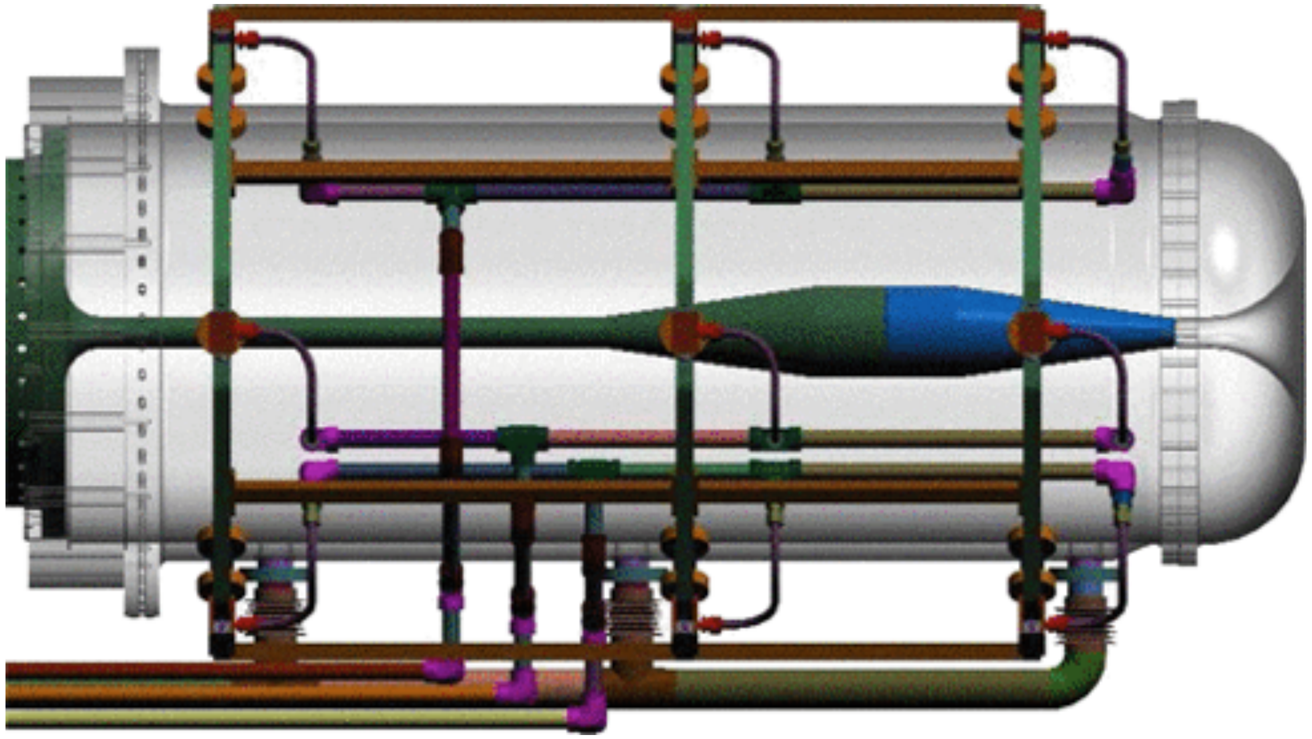


BNB horns

- Both horns suffered water system failure
  - 1st horn developed leak and short to ground due to stagnant water (late 2004)
  - 2nd horn had plugged cooling lines
- 3rd horn installed in spring 2015
  - Tested in June 2015
  - Started MicroBooNE run in October 2015
- 4th horn under construction
- Horns designed to last >200M pulses

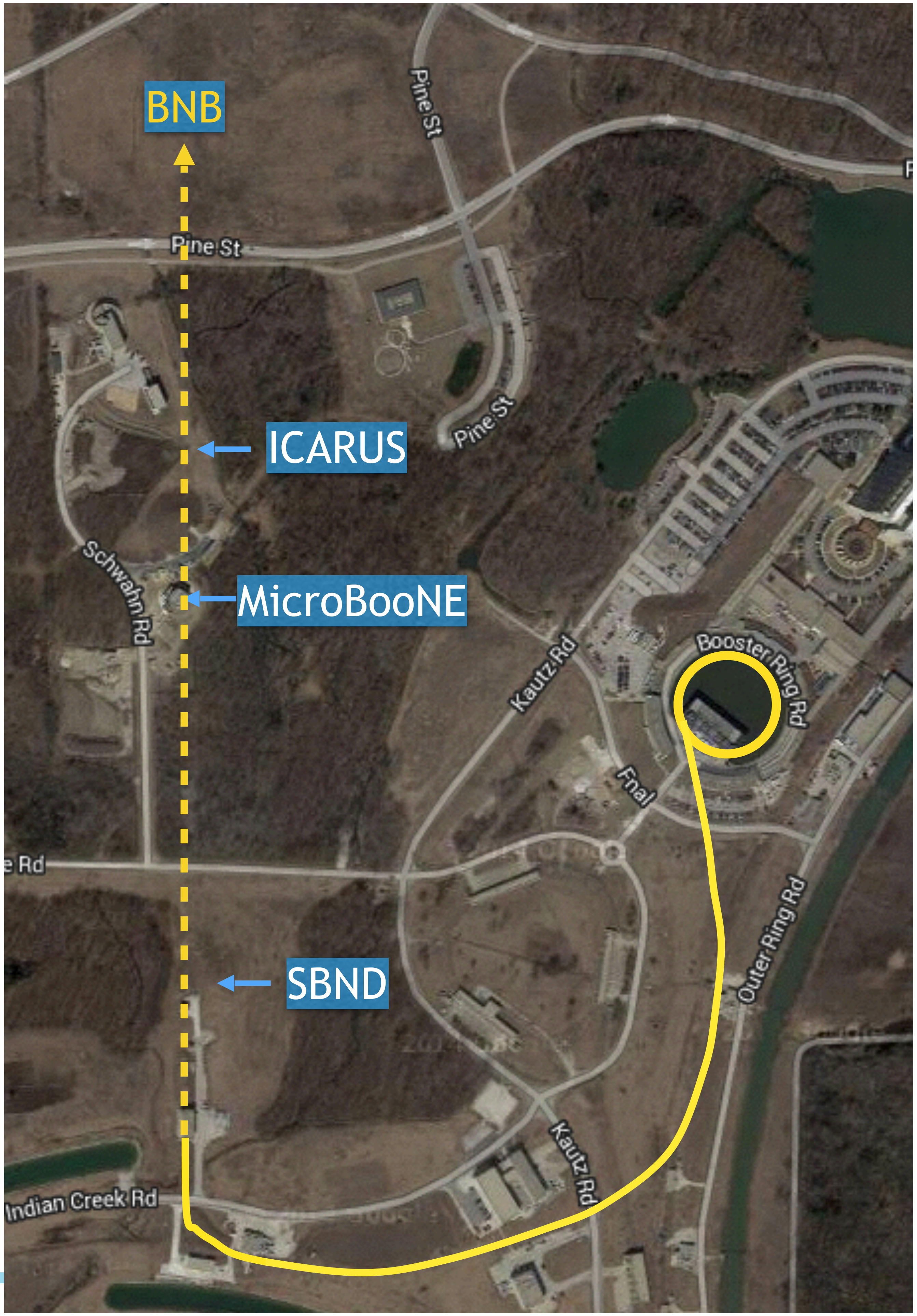
Horn	Pulses	POT
1	97M	3.7E+20
2	375M	1.6E+21





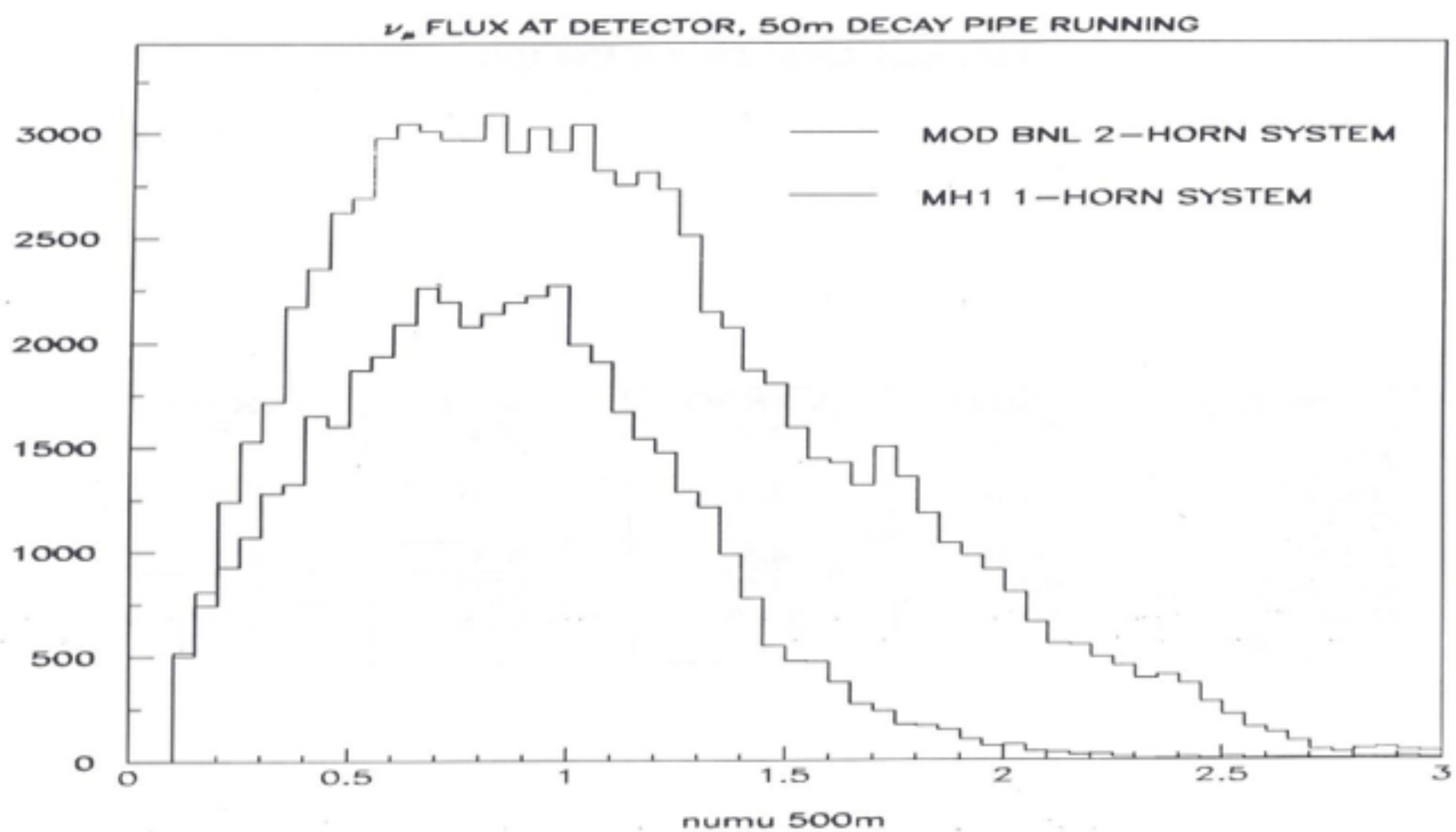
Future running

- MicroBooNE running starting October 2015
  - 6.6e20 POT to be delivered
- MITPC, ANNIE, SciBath
- Short baseline program (SBND + ICARUS) 2018-
  - Additional 6.6e20 POT
- BNB upgrades considered for SBN program and future running to maximize physics reach
  - Better focusing with new longer horn capable of running at higher rate and current



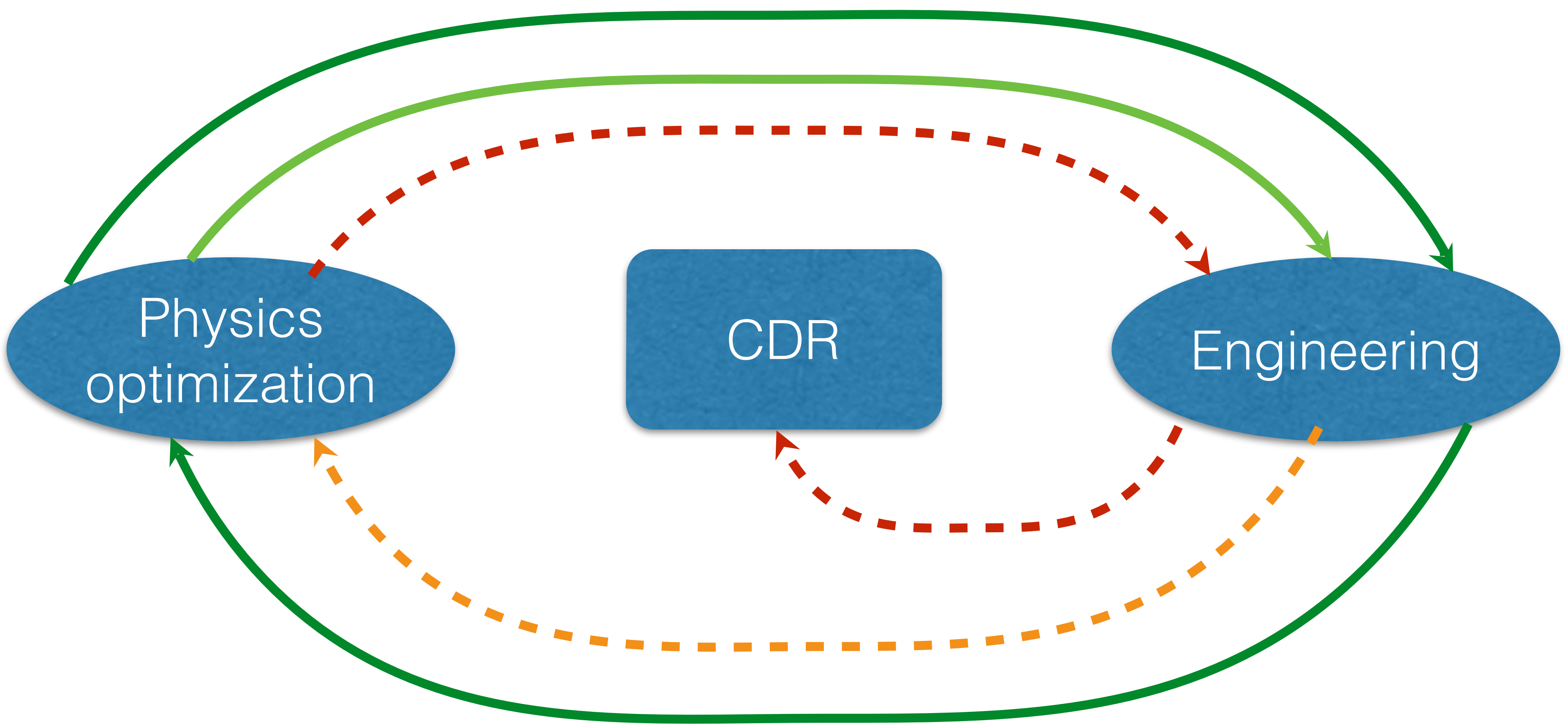
MiniBooNE design

- BNB optimization for MiniBooNE started from BNB 2-horn design
- Final design with single horn
  - Significant loss of signal, however in Cherenkov detector higher energy neutrinos create π^0 background so S/B remained similar



BNB reoptimization

- Reoptimize beamline for SBN program, maximize physics reach of the Liquid argon based program
- Iterative process
  - Cross dependency between optimization parameters
  - Went through few physics reoptimizations and engineering checks
- Converging toward conceptual design



Upgrade paths

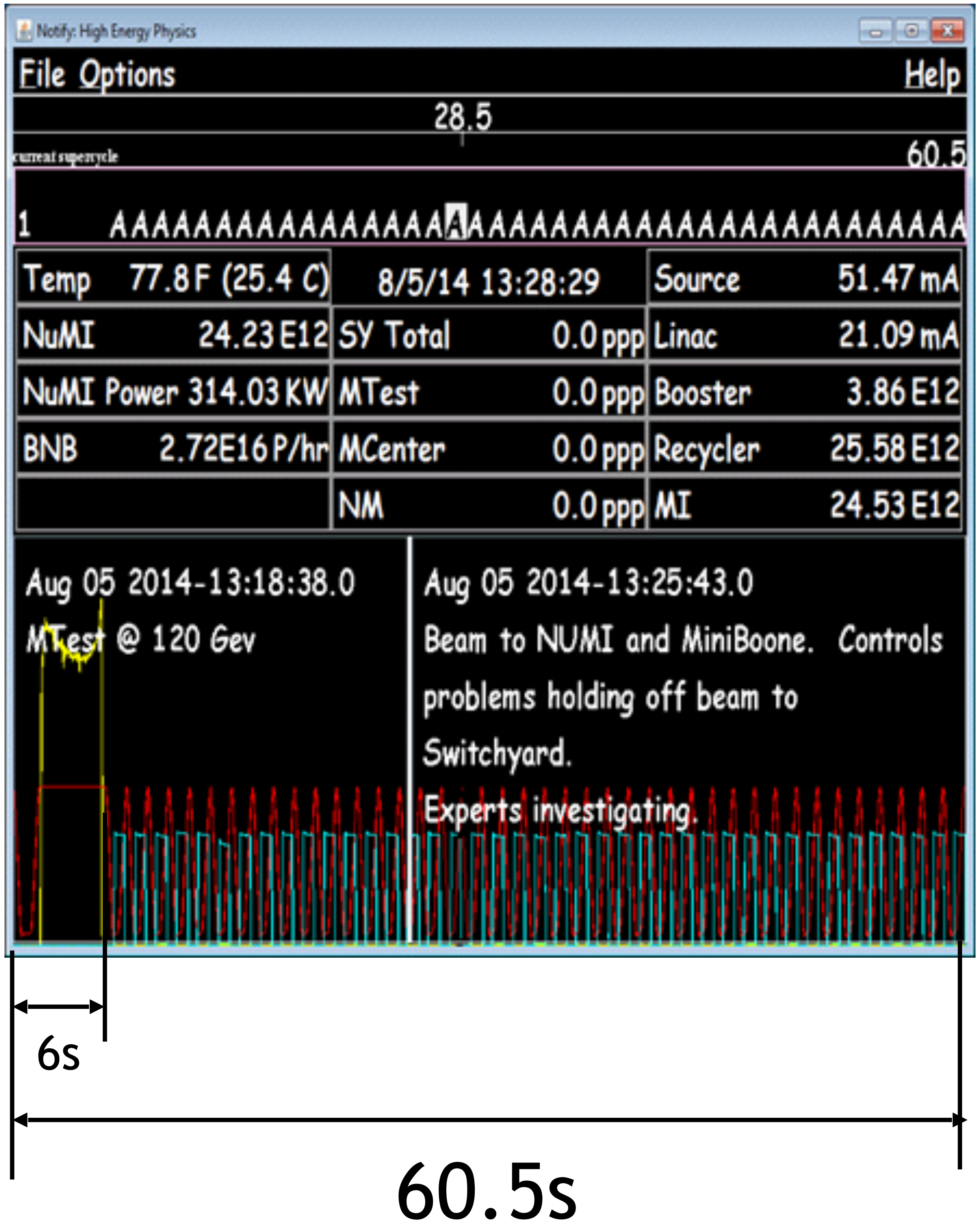
1. Increase focusing efficiency of target/horn system
   - optimized horn length, inner conductor, and current
   - take into account physical constraints of present target hall, stripline limitations, and power supply capability
2. Increase rate at which horn system is capable running
   - Booster will operate at 15Hz
   - Maximize use of available cycles (beyond those sent to NuMI and muon program)
   - Requires improvement in horn power supply, mechanical integrity of horn (both depend on horn current)

- Account for coupling between paths, i.e. higher focusing efficiency with higher current, but mechanical integrity and power supply push maximal rate down
- Optimize cost/benefit with potentially affordable solutions

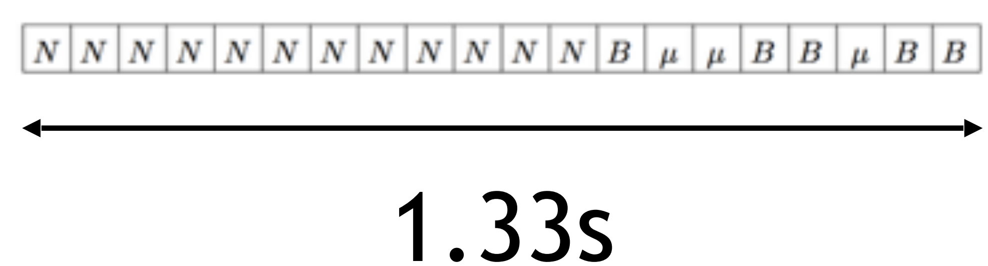
Resources

- Bartoszek Engineering - Larry Bartoszek
  - Horn Design
- Fermilab:
  - AD: Keith Gollwitzer, Tom Kobilarcik, Valerie Lebedev, Craig Moore, Sergei Striganov
  - AD - engineering: Salman Tariq, Howie Pfeffer, Dan Wolff
  - ND: Steve Brice, Cat James, Doug Jensen, Paul Lebrun, Byron Lundberg, Alberto Marchionni, Peter Wilson, Zarko Pavlovic
  - PPD - engineering: Zhijing Tang, Erik Voirin
  - BNB expertise, MARS modeling, neutrino flux optimization, power supply refurbishment, FE analysis, instrumentation upgrades
- University of Chicago - Joseph Zennamo
  - SBN sensitivity
- Yale - Corey Adams
  - SBN sensitivity

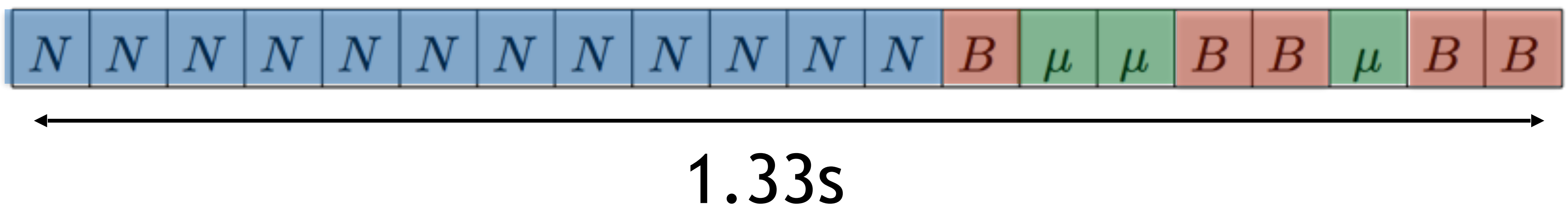
Proton delivery



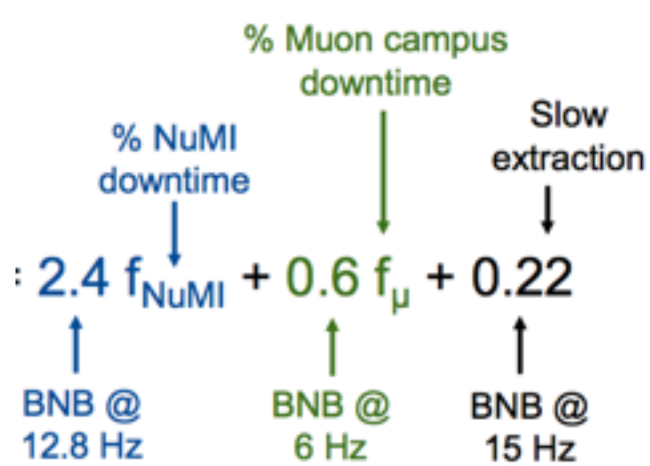
- Supercycle 60.5 sec long
- 1 MI slow extraction (6 sec)
  - beam to BNB
- 41 NuMI cycles each 1.33sec (54.5 sec)
  - beam to BNB, NuMI and muon campus



Proton delivery (cont'd)



- Booster runs at 15Hz => 20 booster cycles within 1.33s
- Protons shared between **NuMI (N)**, **muon program (μ)** and **BNB (B)**
- 5 proton beam batches to BNB over 1.33s long cycle (corresponds to 3.76Hz average rate)
- Additional rate if capable running at 15Hz:



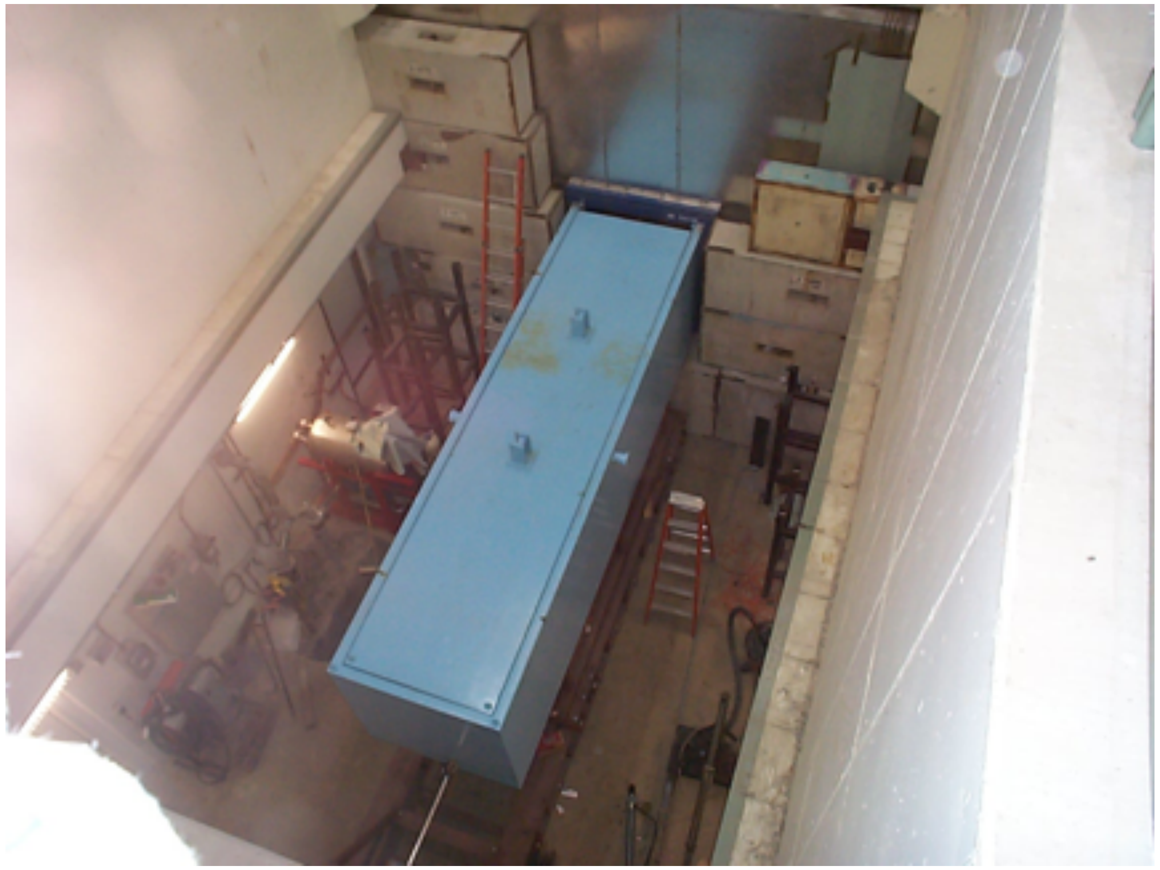
Annual proton delivery

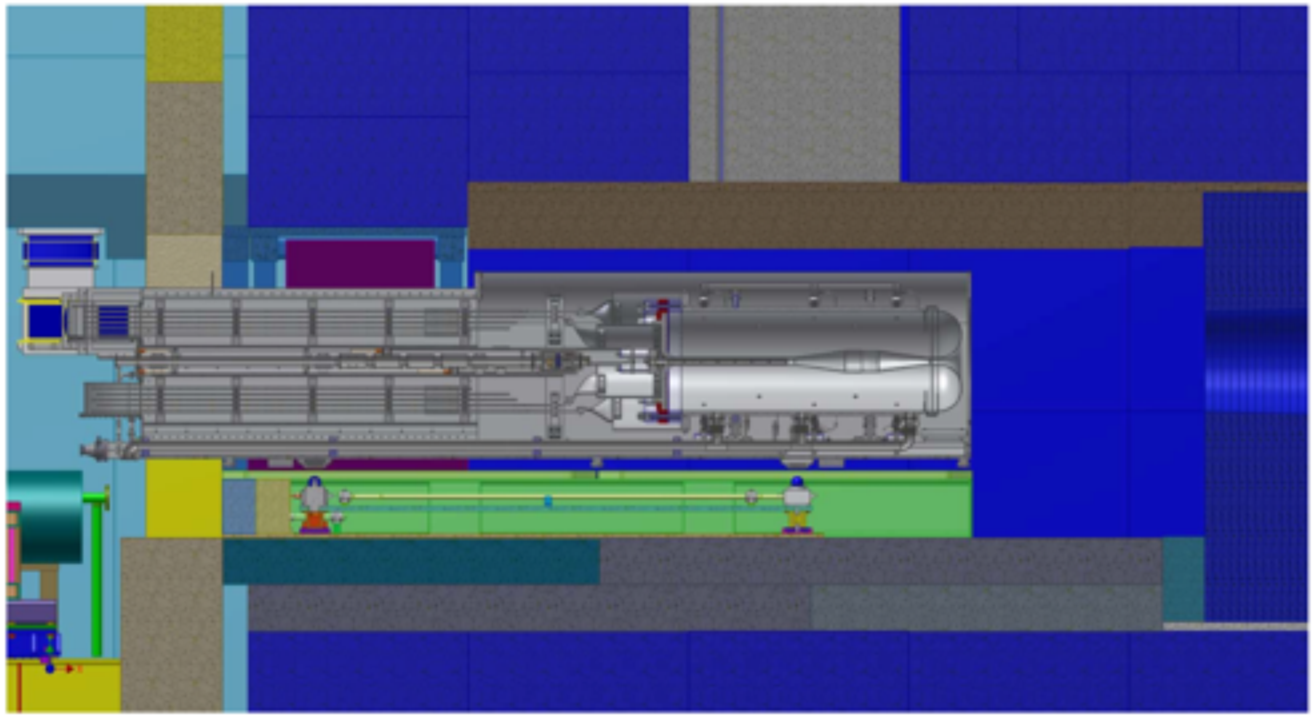
- Assuming 71.4% uptime
  - Historical proton source/linac/booster uptime 85%
  - Two months annual shutdown (uptime 84%)

	Average rate	Spills/year (M)	POT (10^20)	Spills/year (w/ uptime) (M)	POT (w/ uptime) (10^20)
3.76Hz	3.8	119	5.3	85	3.8
3.76Hz+(5Hz slow spill)	3.9	122	5.5	87	3.9
3.76Hz+5Hz(slow spill) +5Hz(NuMI/muon down 10%)	4.0	126	5.7	90	4.0
3.76Hz+10Hz(slow spill)	4.3	137	6.1	98	4.4
3.76Hz+10Hz(slow spill) +10Hz(NuMI/muon down 10%)	4.9	154	7.0	110	5.0

Physical constraints

- Target pile shielding
  - Rebuilding prohibitively expensive (~$15M) and would require long downtime (12-18 months)
- Hatch size matched to the coffin length
- Collimator at the entrance to decay pipe (r=30cm)
  - Matched horn outer conductor radius

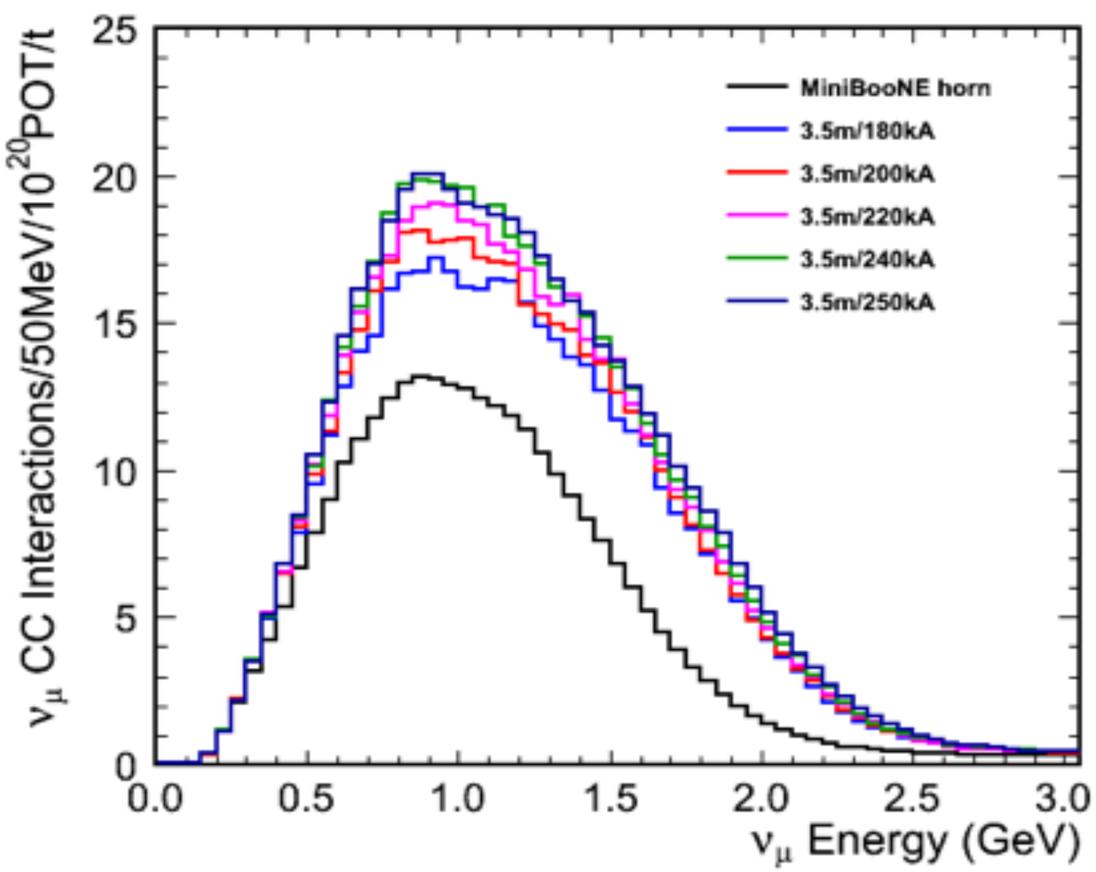


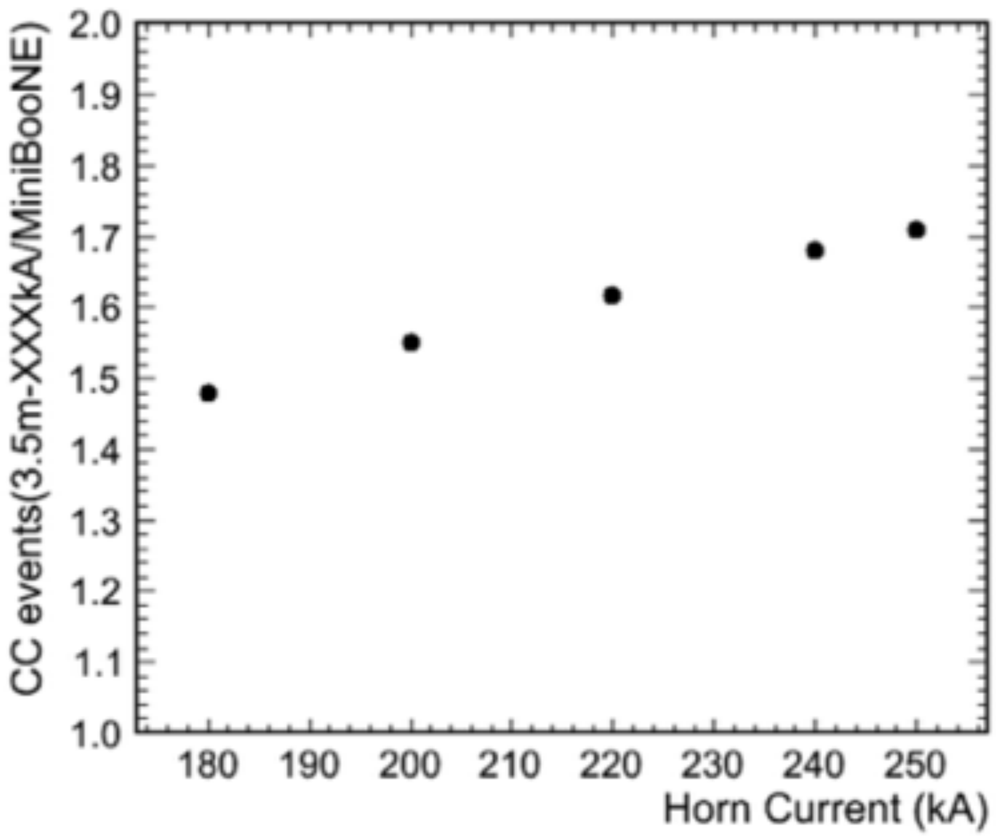


Optimization

- Vary inner conductor shape, horn length,horn current
- Optimization prefers longer horns and higher current
- Longest horn that can fit 3.5m
- Power supply capable running up to 250kA

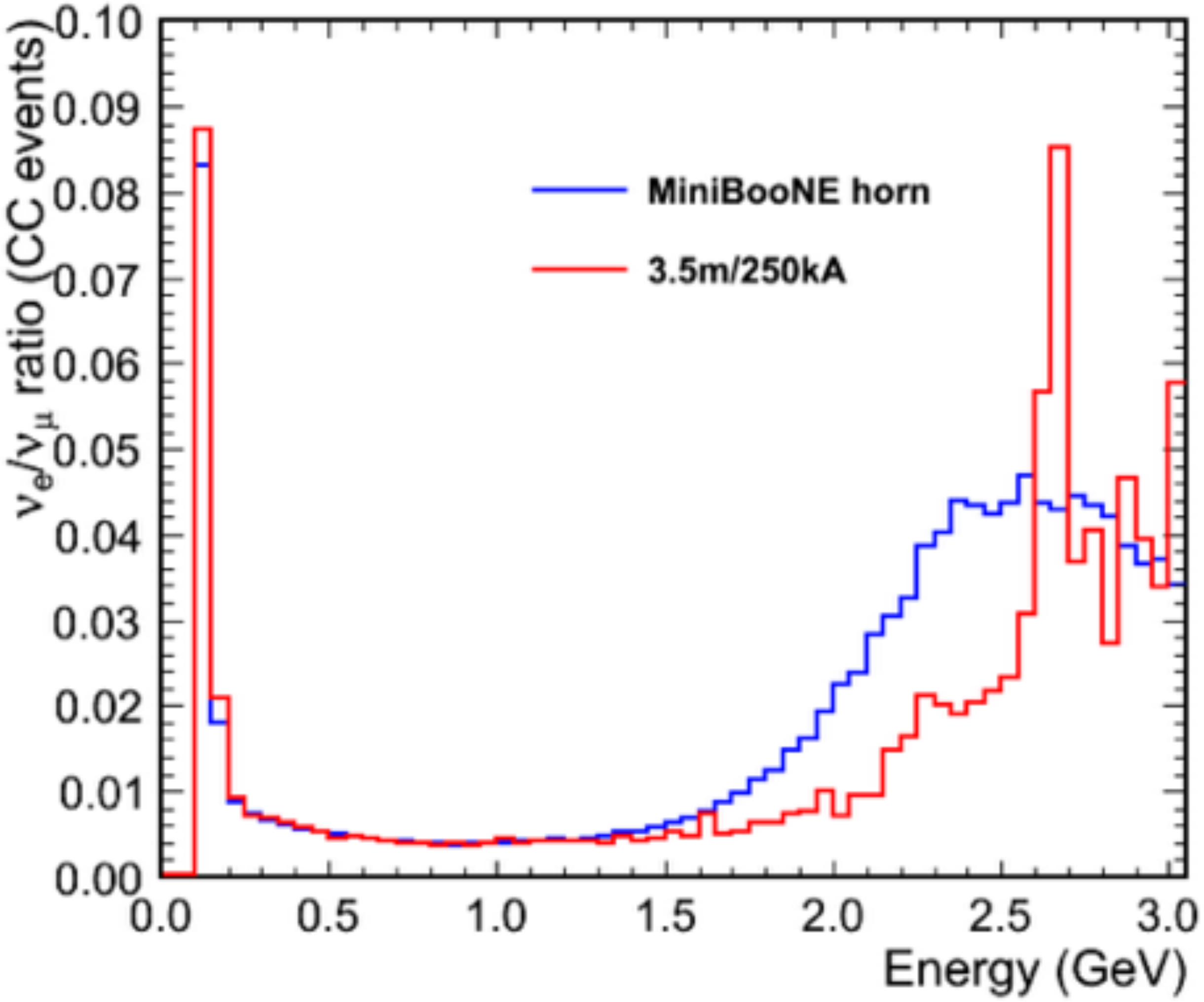
	Overall rate/ MiniBooNE
MiniBooNE	1
3.5m/180kA	1.48
3.5m/200kA	1.55
3.5m/220kA	1.62
3.5m/240kA	1.68
3.5m/250kA	1.71





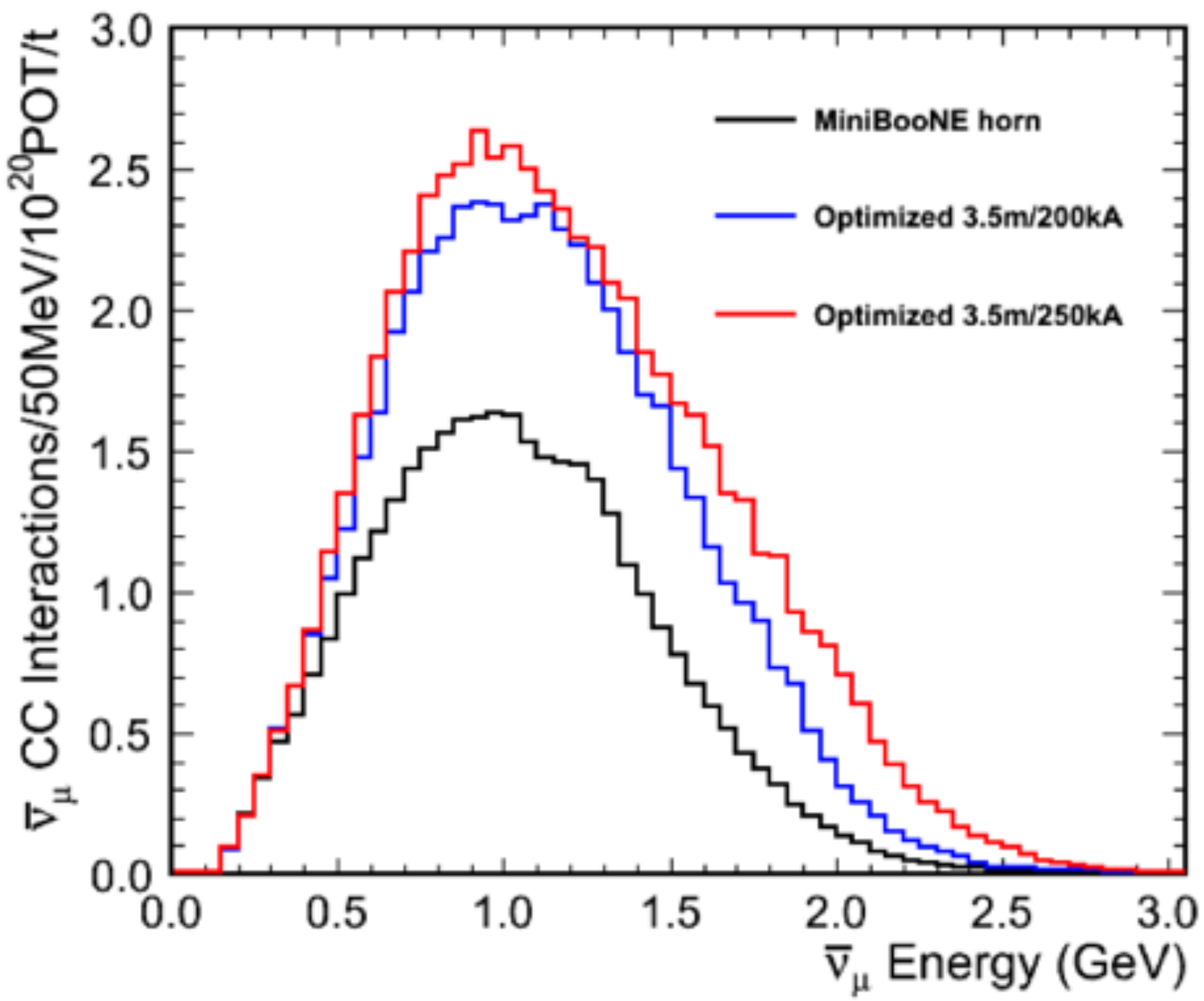
Backgrounds - Electron neutrinos

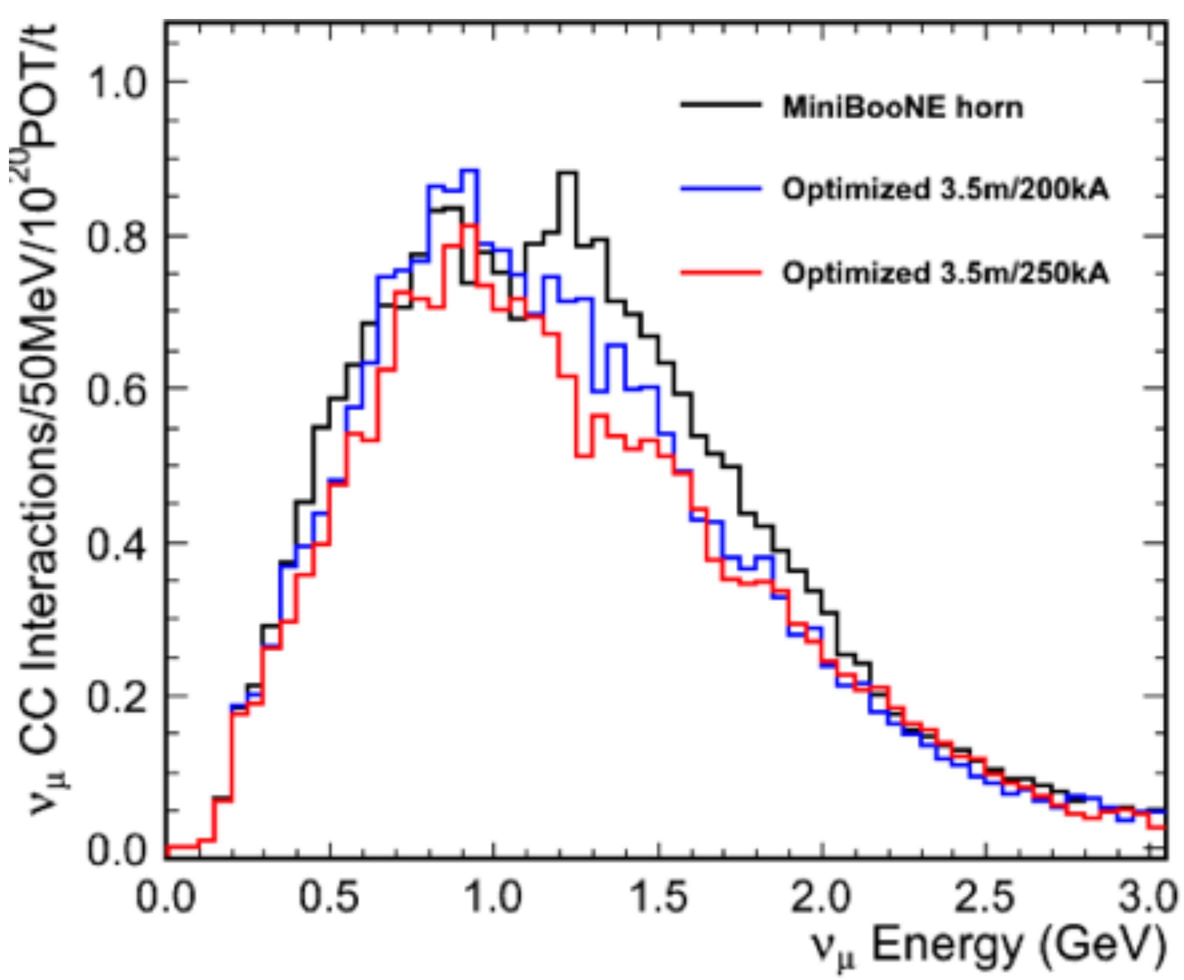
- Intrinsic electron neutrino component fractionally similar to MiniBooNE horn
  - Lower at higher energies



Antineutrino running

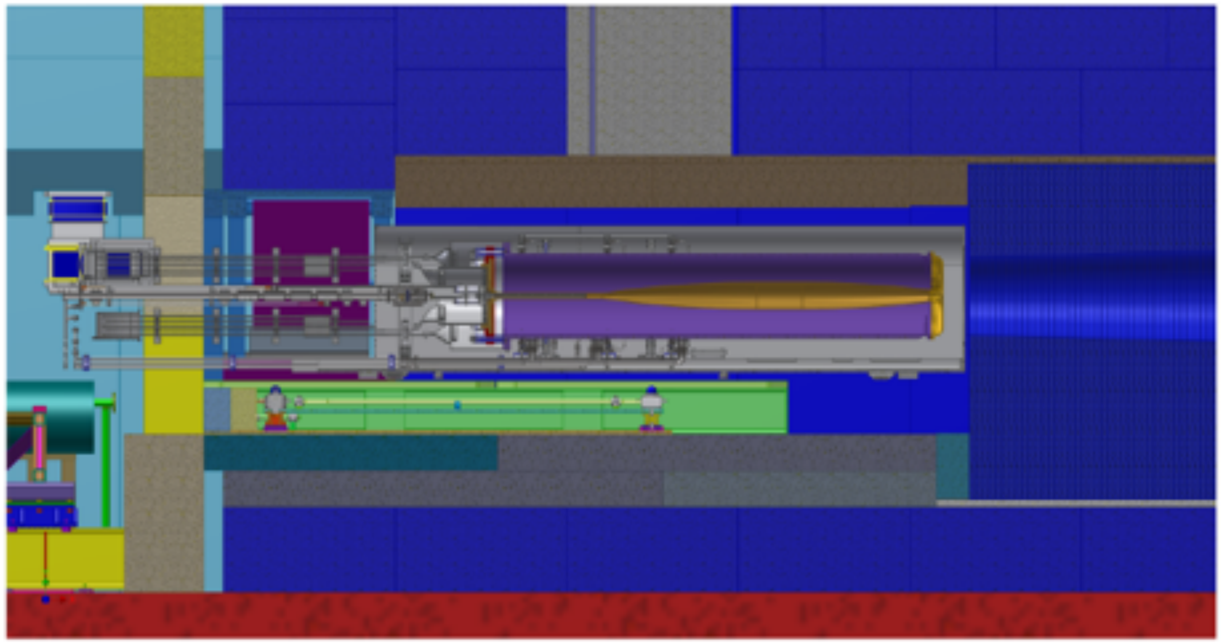
- Even better improvement expected in ν_μ rate in anti-neutrino mode
  - Gain 1.8@250kA and 1.56@200kA
- Wrong signs fractionally much smaller

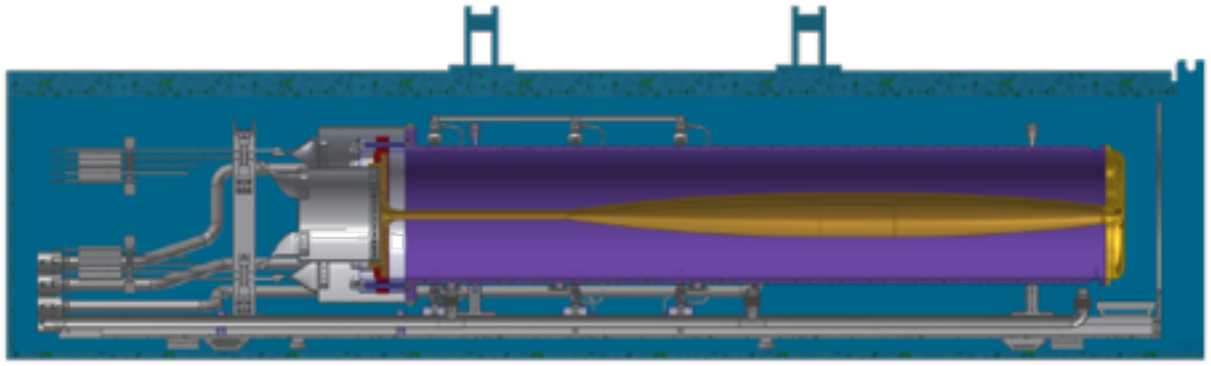


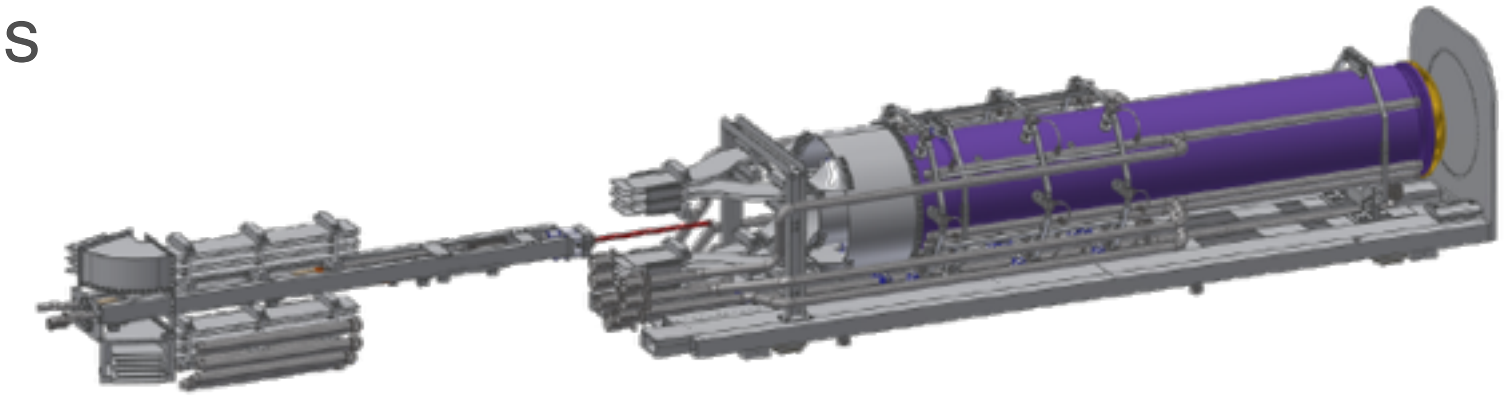


Horn engineering

- Larry Bartoszek built a model for 3.5m horn
- Target needs to be pulled about 50cm upstream
- Study stresses due to heat loads and magnetic forces
  - Heat load predominantly from joule heating
  - BNB rapid cycling, so need to sustain ~10^8 cycles/year
- Preliminary finite element studies of optimized horn
- Feedback to design options



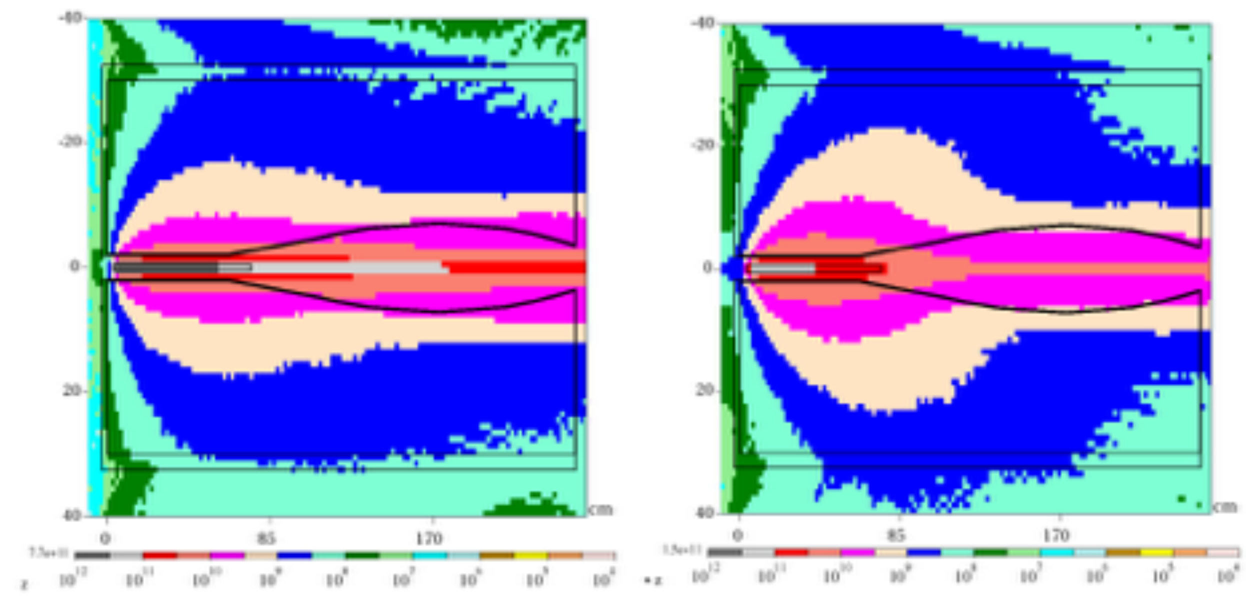


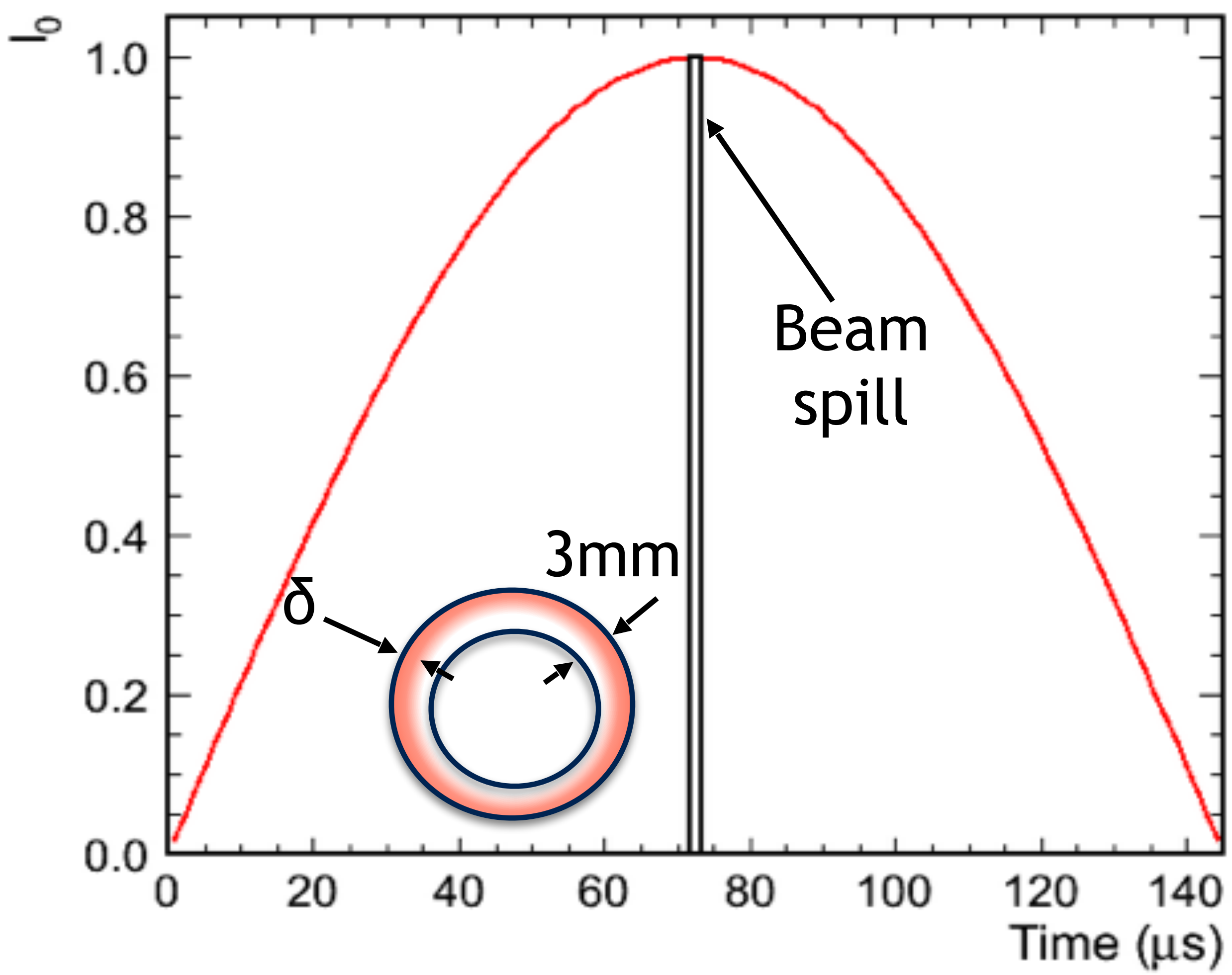


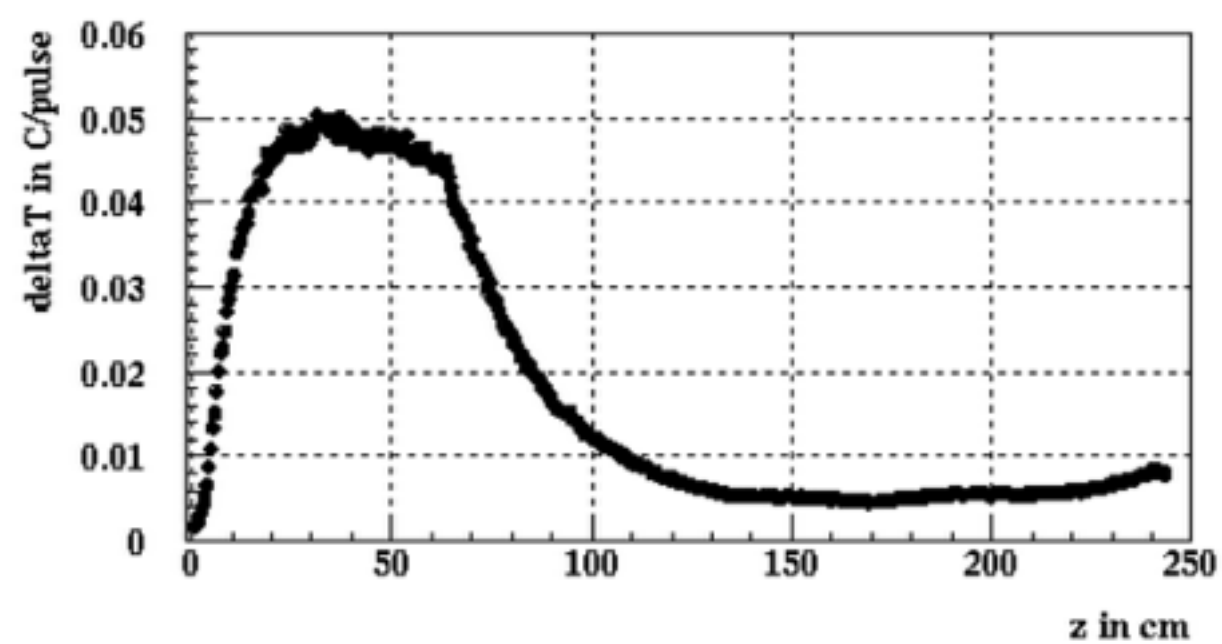
Bartoszek engineering

Heat load

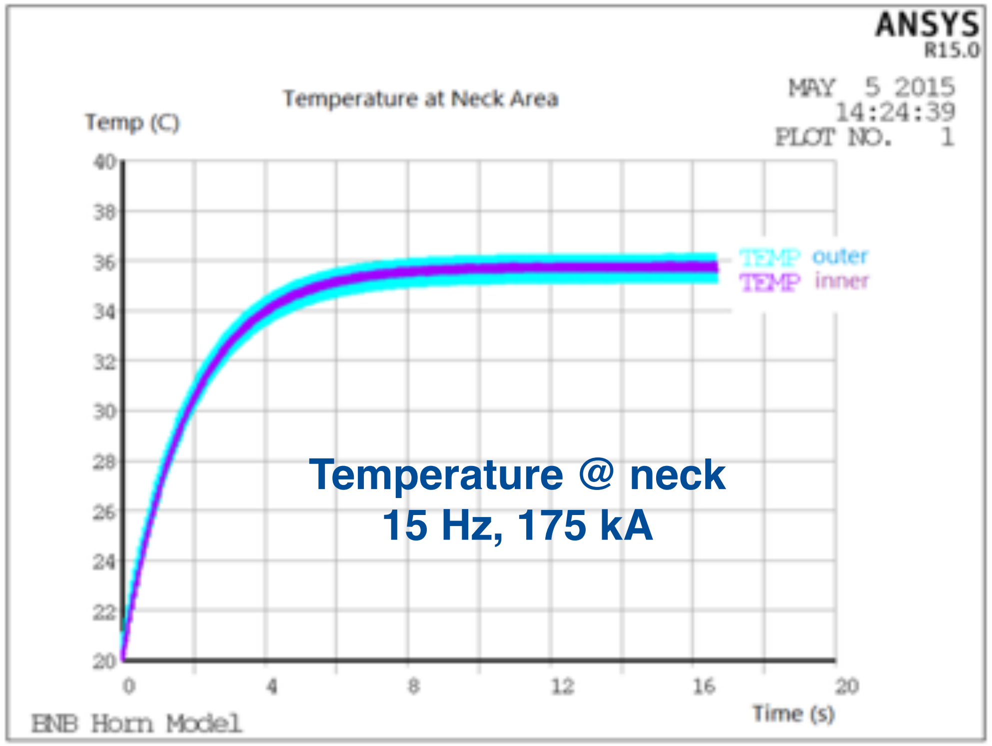
- Main contribution from Joule heating
- Beam heating contributes less than 10% at 175kA
- Skin depth is δ=1.4mm for BNB horn

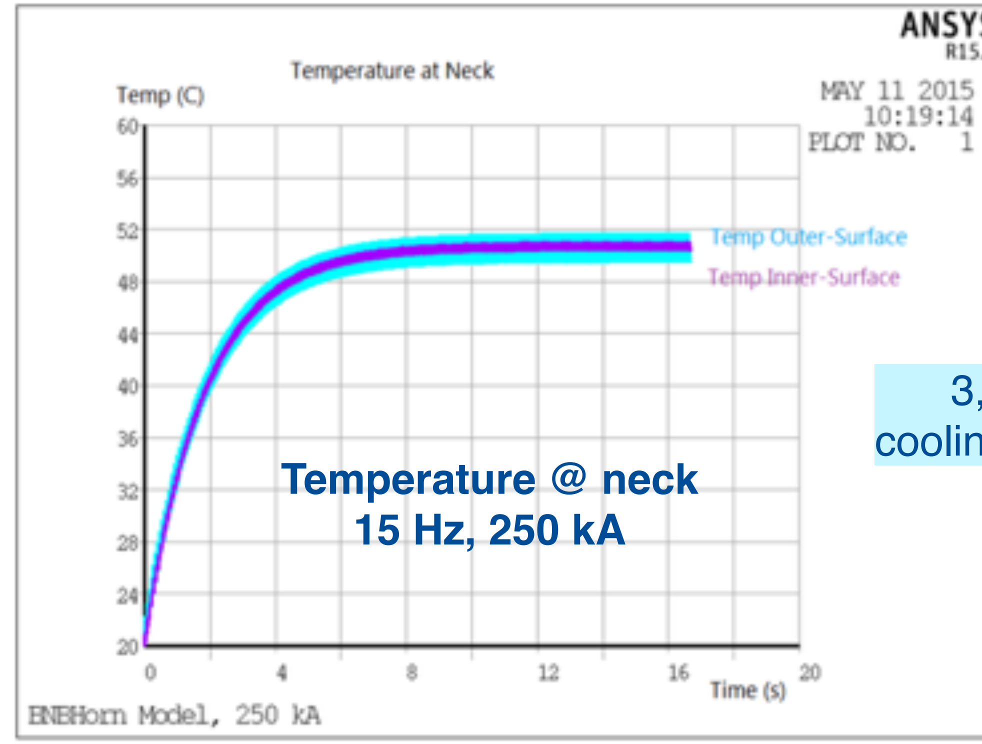




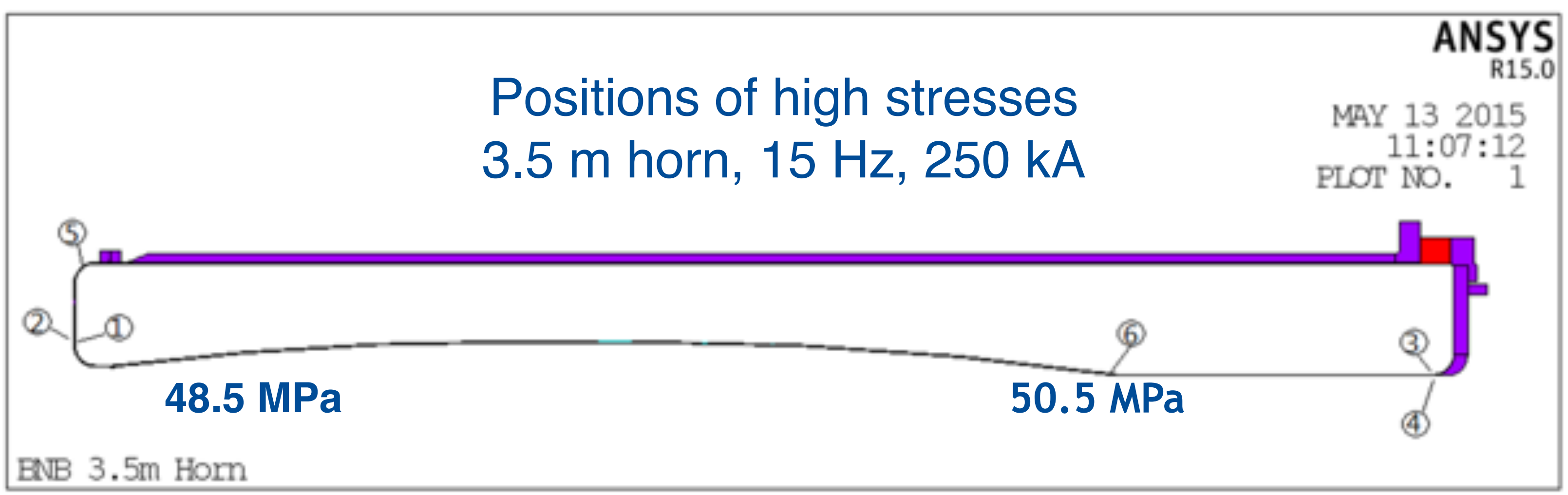


FE analysis





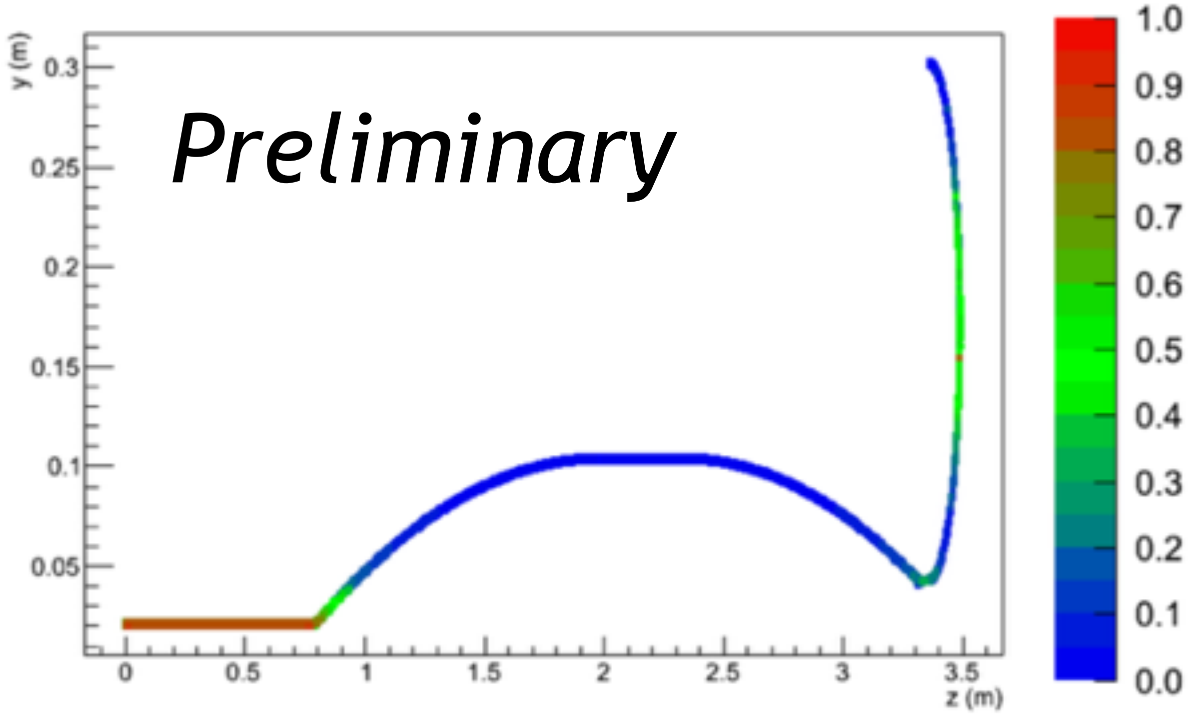
3,750 W/m² C cooling film coefficient

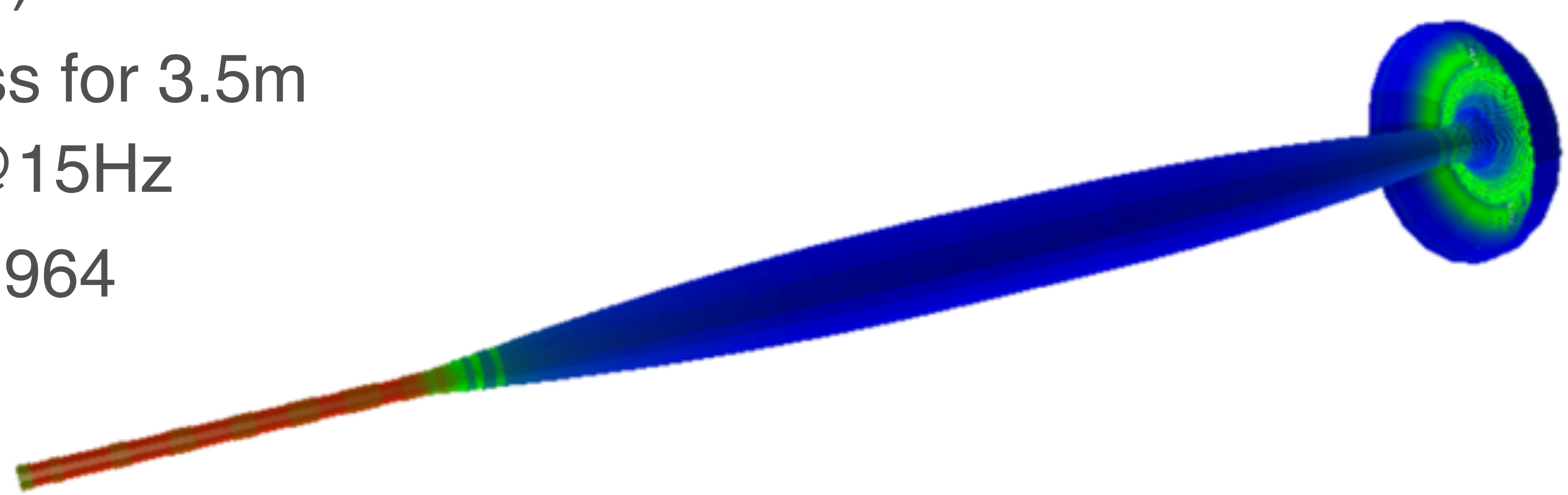


- Identify high stress points, use full stress history for each element in fatigue analysis

Fatigue limit

- Fatigue limit analysis based on stresses calculated in FE analysis
- Based on analysis originally done for MiniBooNE horn
- Comparing with allowable stress for >200 million pulses lifetime
- Using available stress/cycle data
- Takes into account environmental factors (wetness, welds)
- Ratio to allowable stress for 3.5m horn pulsed at 210kA@15Hz
- Highest ratio point at 0.964





Horn power supply

Parameter	Limit	Present Horn	Max. Rep.	Max. Current
Cap Bank RMS (kA)	6.4	3.6	5.6	5.7
Recover choke (A)	132	84	130	132
Max. Peak (kA)	250	172	172	250
Max. Voltage (kV)	10.5	6.1	6.1	8.9
Ave. Power (kW)	168	27	65	57.3
Charge Time (ms)		33	33	44
Energy $pulse^{-1}$ (kJ)		5.4	5.4	9.2
Max. Avg. cycle (Hz)		5	12	6.25
Max. cycles in 1 sec		31 (16)	31 (16)	18.3 (9.2)

MiniBooNE horn load

- Consider upgrades that maintain the basic structure of power supply (enclosure, internal connections, SCR,…)
- Cooling to the recovery choke to increase the max current by 20-30%
- Add charging supplies to decrease charge time/increase power

Power supply upgrade (cont'd)

- Power supply capable of driving 3.5m long horn
- Improved rate and/or peak current with modest upgrades

	Max current (kA)	Max rate (Hz)
No mods	250	4.3
	130	15
4 new charging supplies	250	5.1
	140	15
Recovery choke + Charging supplies	250	6.4
	160	15

Total gains

Max rate depending on PS capabilities and horn load

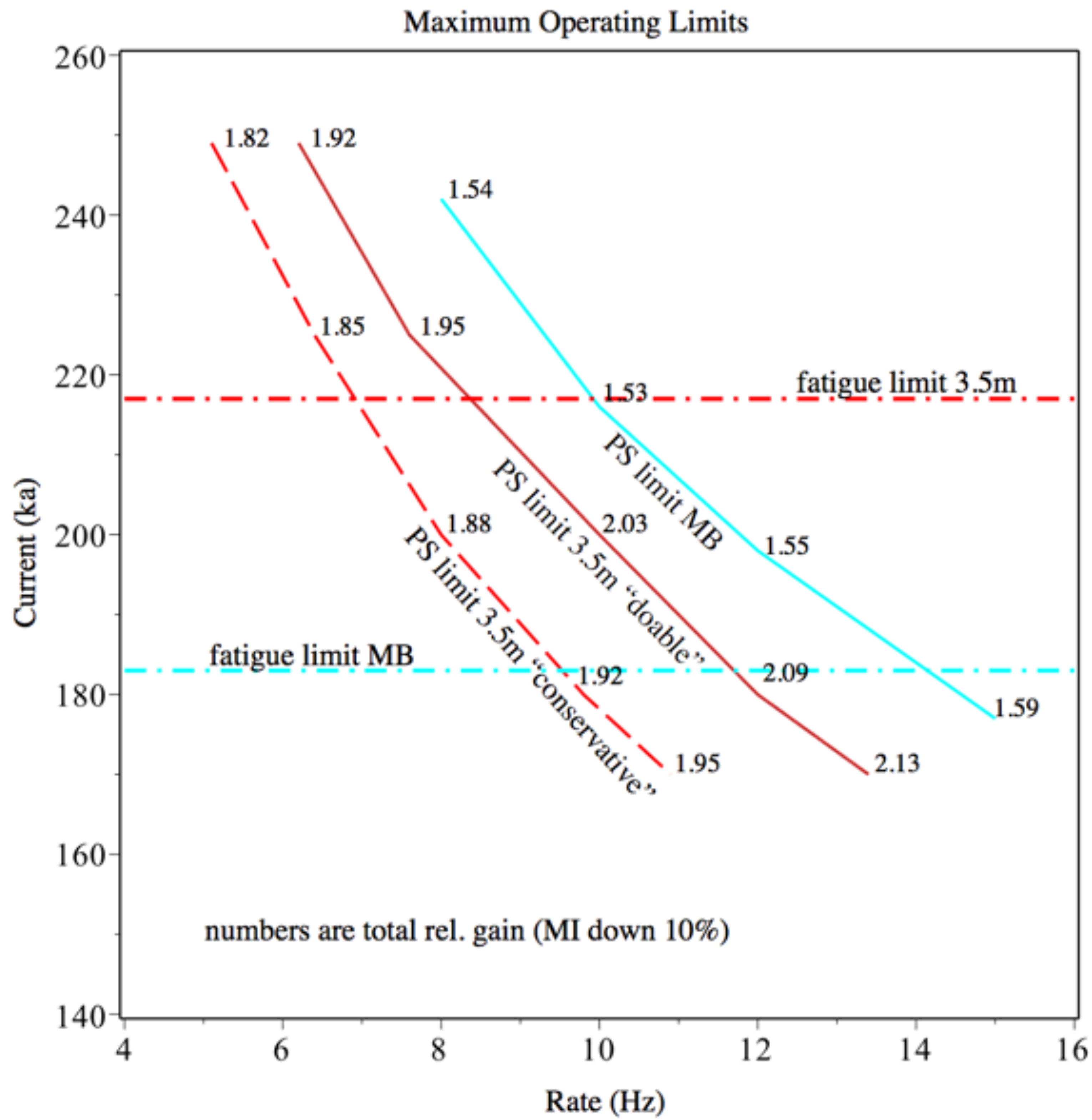
Gain from better focusing

Total gain from better focusing and using available cycles up to max rate

Total gain if 10% downtime assumed for NuMI and muon program

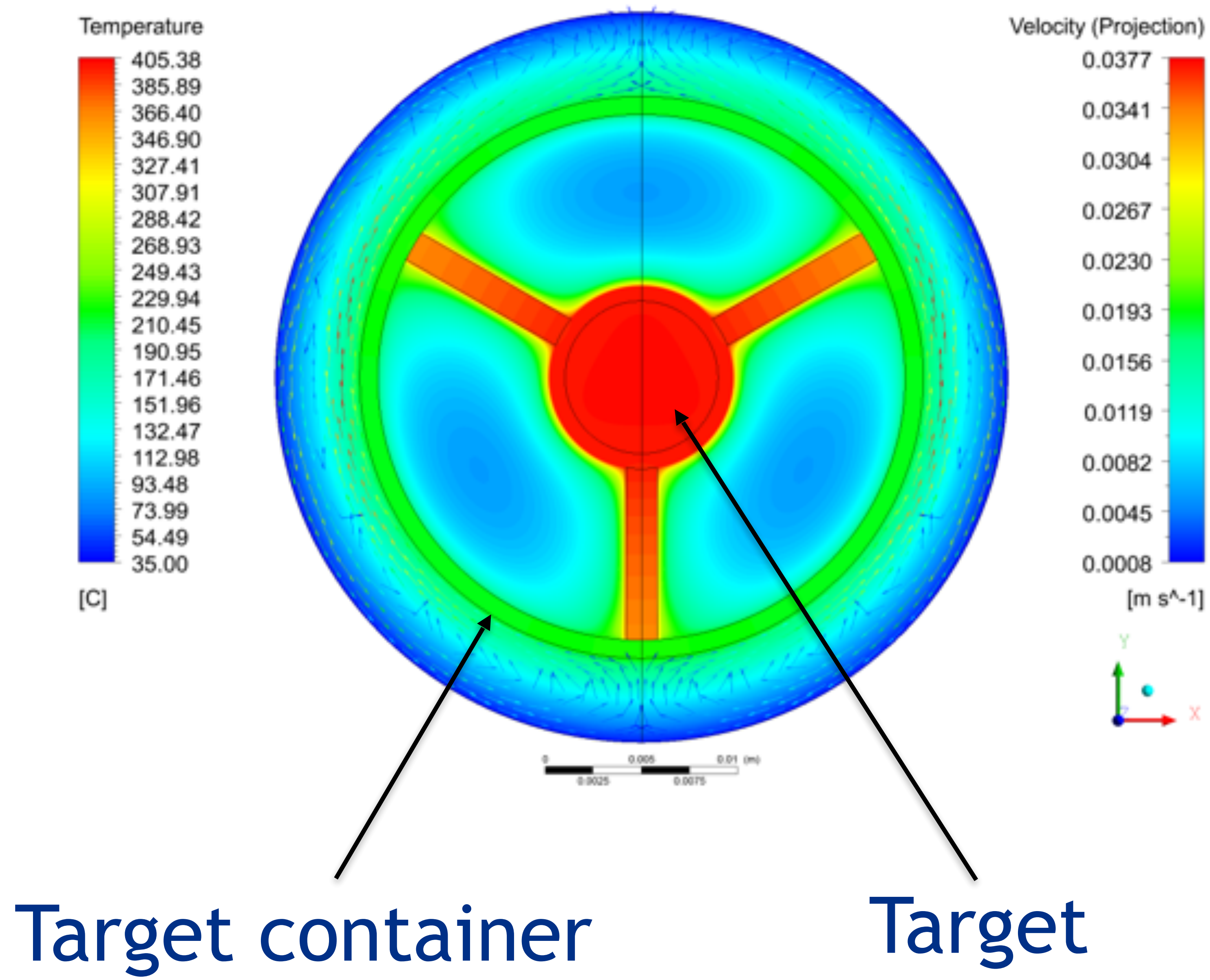
Horn current	Max rate (Hz)	Gain (focusing)	Total Gain (focusing*rate)	Total Gain (10% BNB only)
180kA	12.3	1.48	1.77	2.11
200kA	10	1.55	1.77	2.03
210kA	9	1.58	1.78	2.01
220kA	8.2	1.62	1.78	1.97
250kA	6.4	1.71	1.81	1.93

Total gains (cont'd)



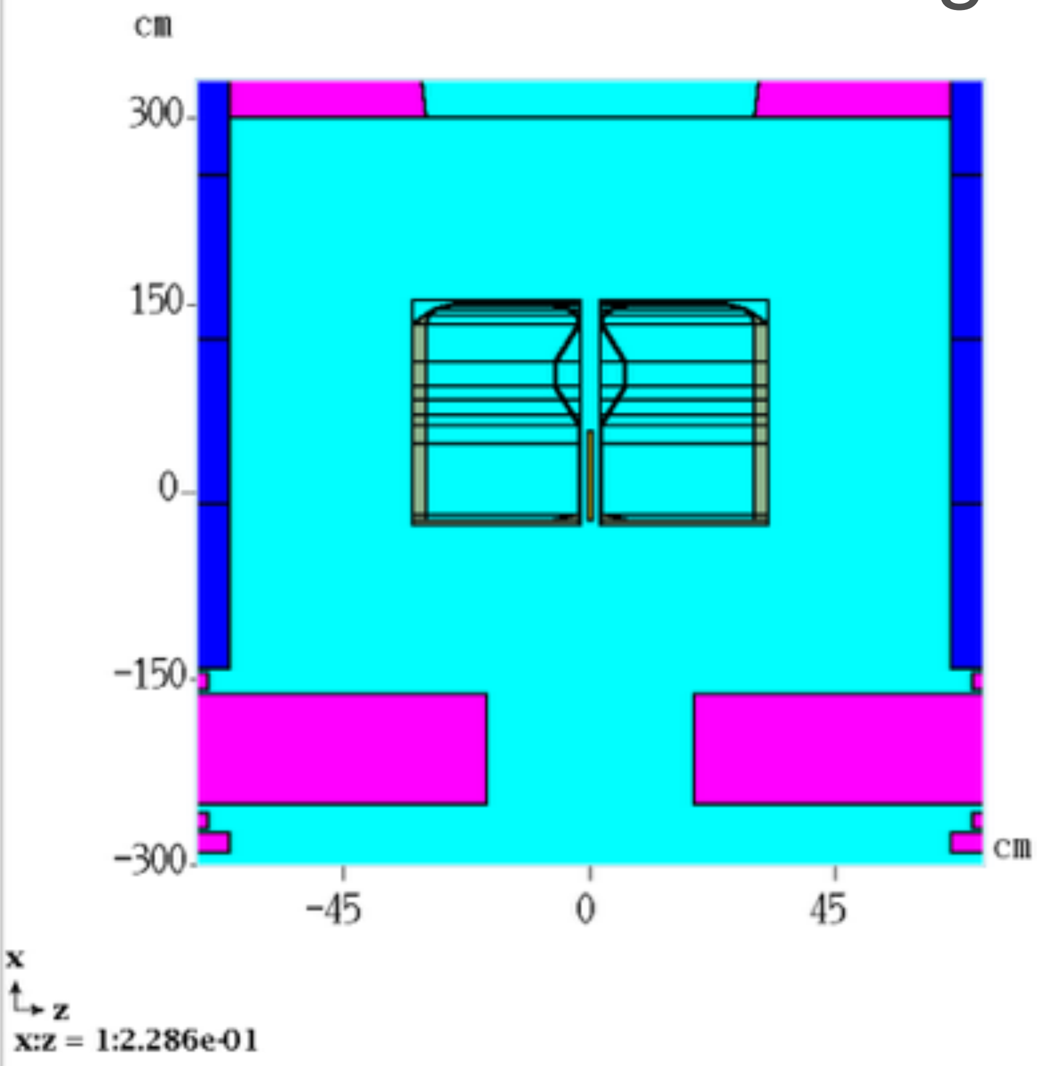
Target heating

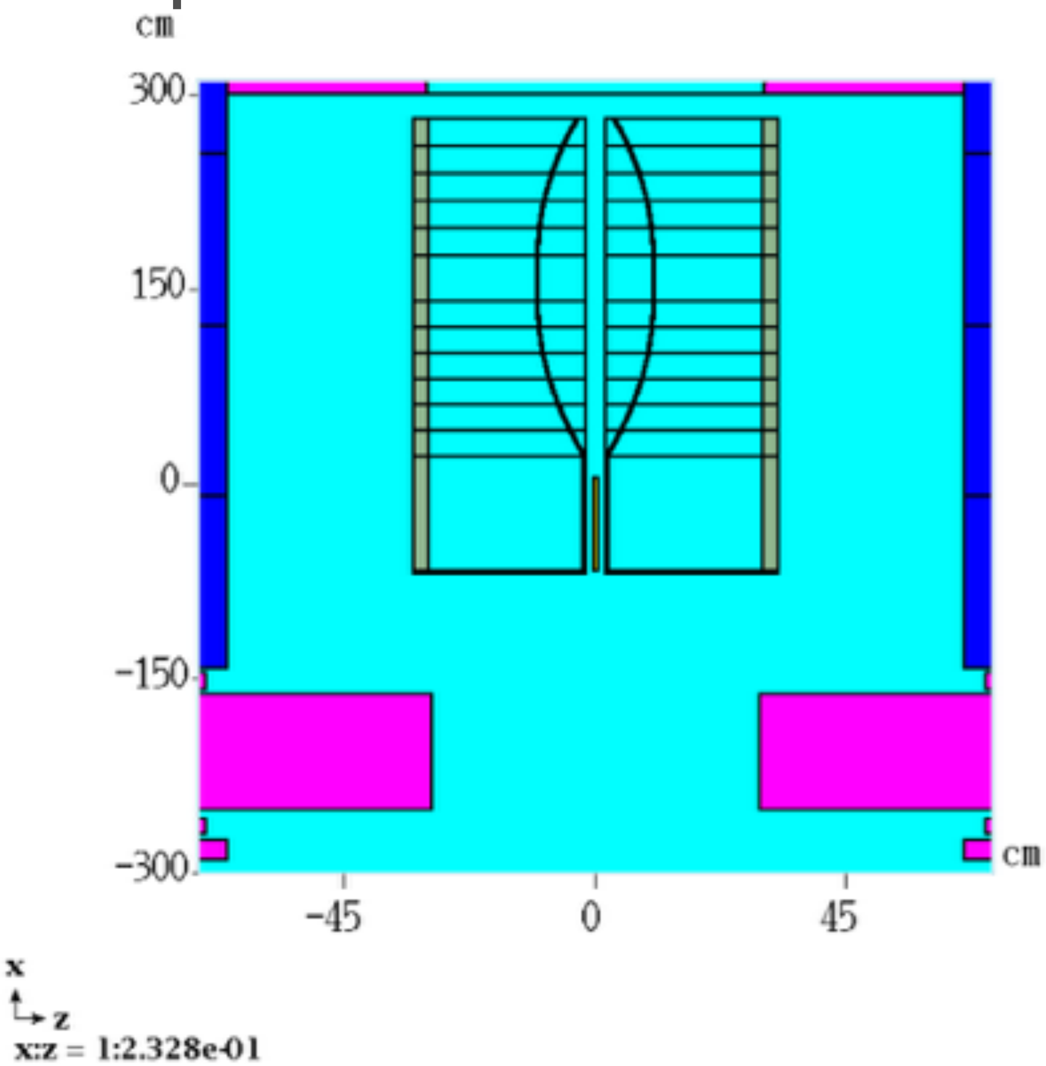
- Air cooled target
- ~600W deposited energy assuming 5e12@5HZ
- Preliminary studies predict manageable target temperature assuming 5e12@10Hz
  - Energy deposition (MARS)
  - Full FE analysis



Radiological limits

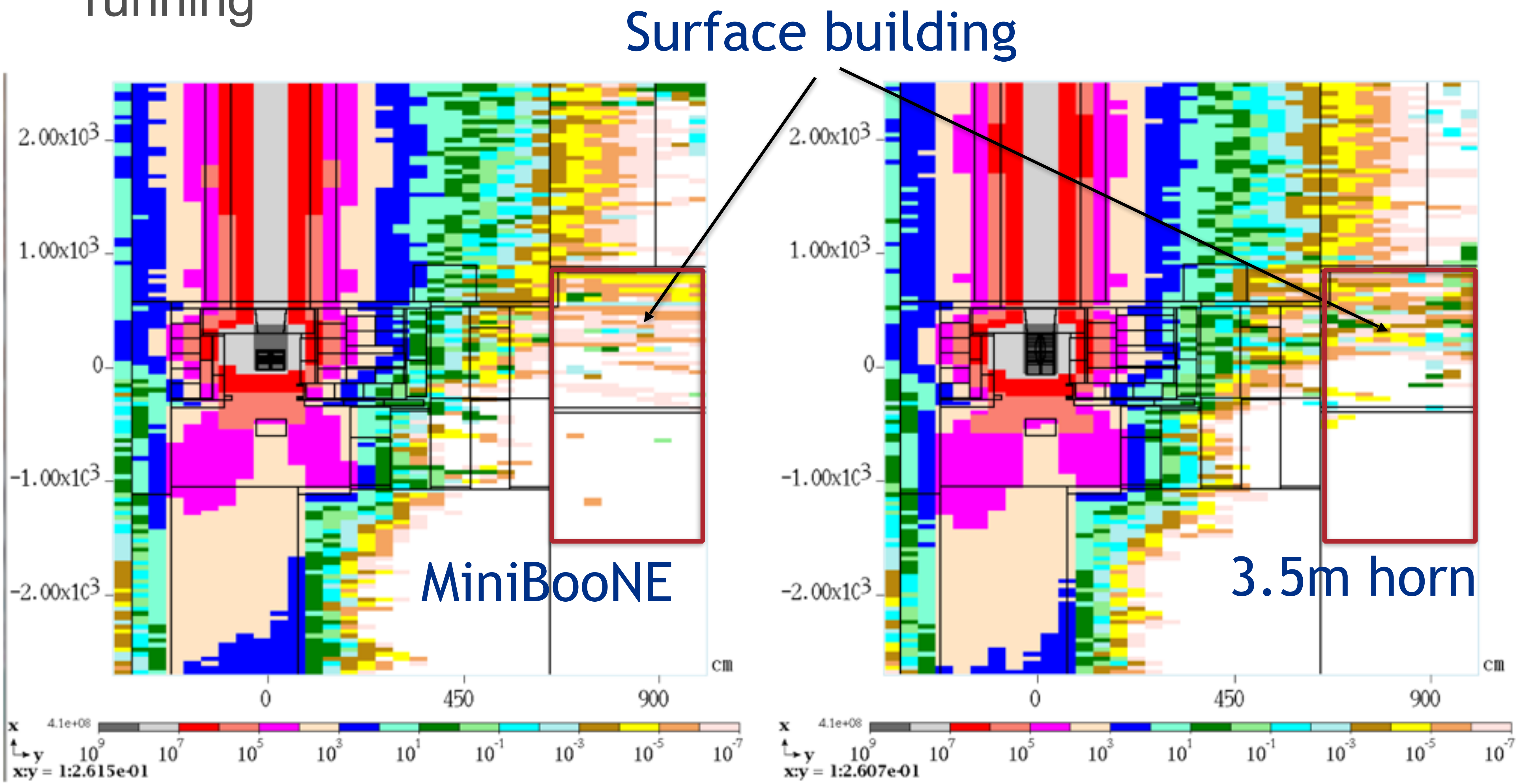
- 3.5m long horn requires target to be pulled 50cm upstream
- Service module and cooling pipes might require additional opening of shield doors
- These could have radiological impact





Radiological limits (preliminary)

- Similar dose on surface with MiniBooNE and optimized horn running



Cost

- Estimated cost based on experience with BNB/NuMI horns $6.5M
  - $1.5M horn power supply
    - Includes new components and labor
  - $5M reoptimized and redesigned horn
    - Includes design of horn and stripline, procurement, fabrication, and installation

Next steps

- Nearly complete with conceptual design
  - Finalize radiological studies
  - Finalize horn fatigue analysis, target analysis
  - Horn design, service module, coffins
  - Full conceptual design (Jan/Feb 2016)
- A better cost and schedule for upgraded power supply and new horn (spring 2016)
- Technical review of conceptual design (spring 2016)

- Ready for AIP funds starting FY2017 for final engineering and production

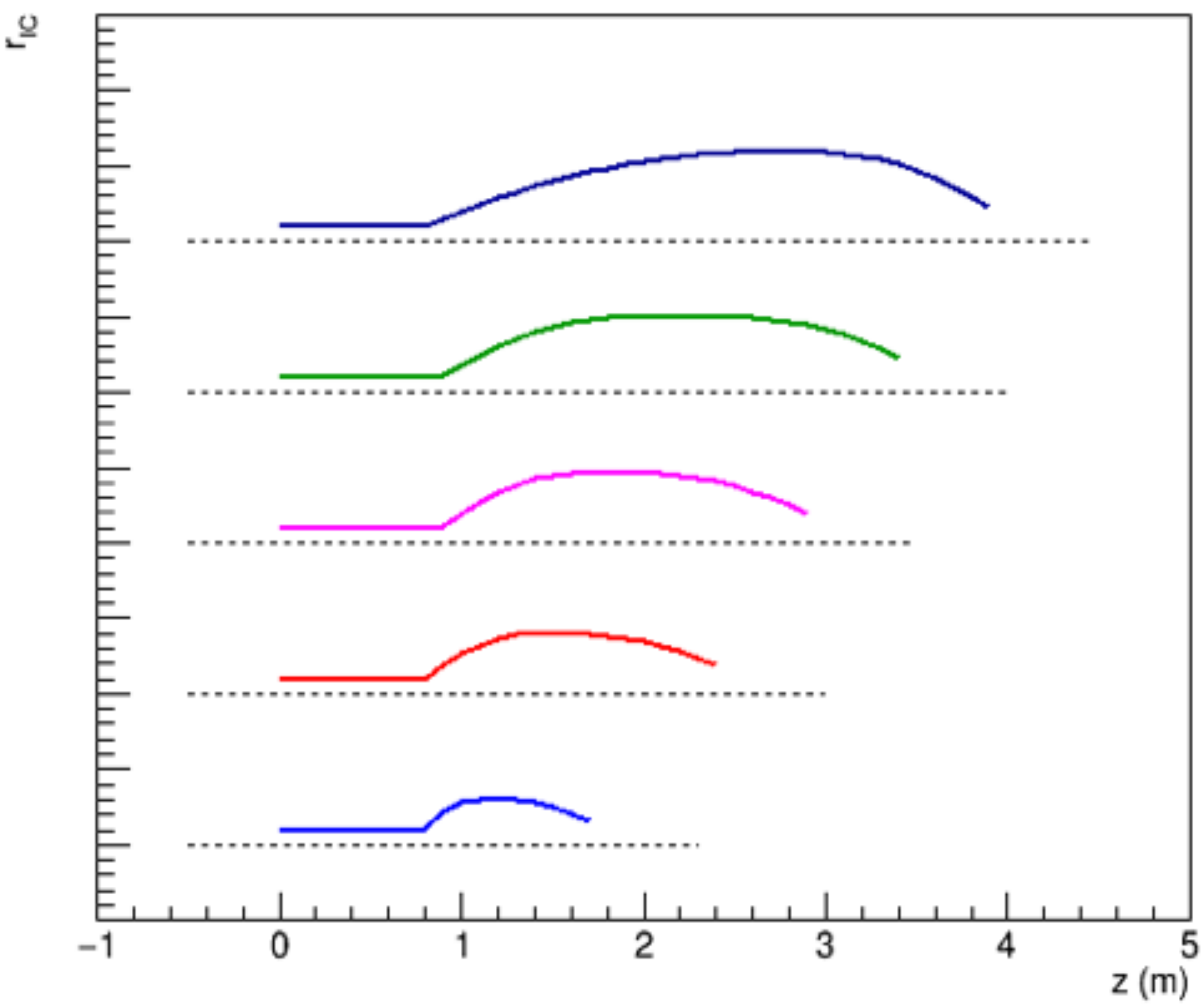
Conclusion

- BNB has provided stable and reliable beam
- Possible significant gains with upgraded horn system (~1.8x)
  - New longer horn and upgraded power supply
  - Reusing existing target hall and power supply basic structure
- Upgraded beam at modest cost ($6.5M)
  - Includes first horn
- Seamless transition to new horn design with minimal downtime
  - Horns designed as wear parts and are expected to be replaced (next horn always under construction)
- Full conceptual design in 2016, new horn ready to use in 2019

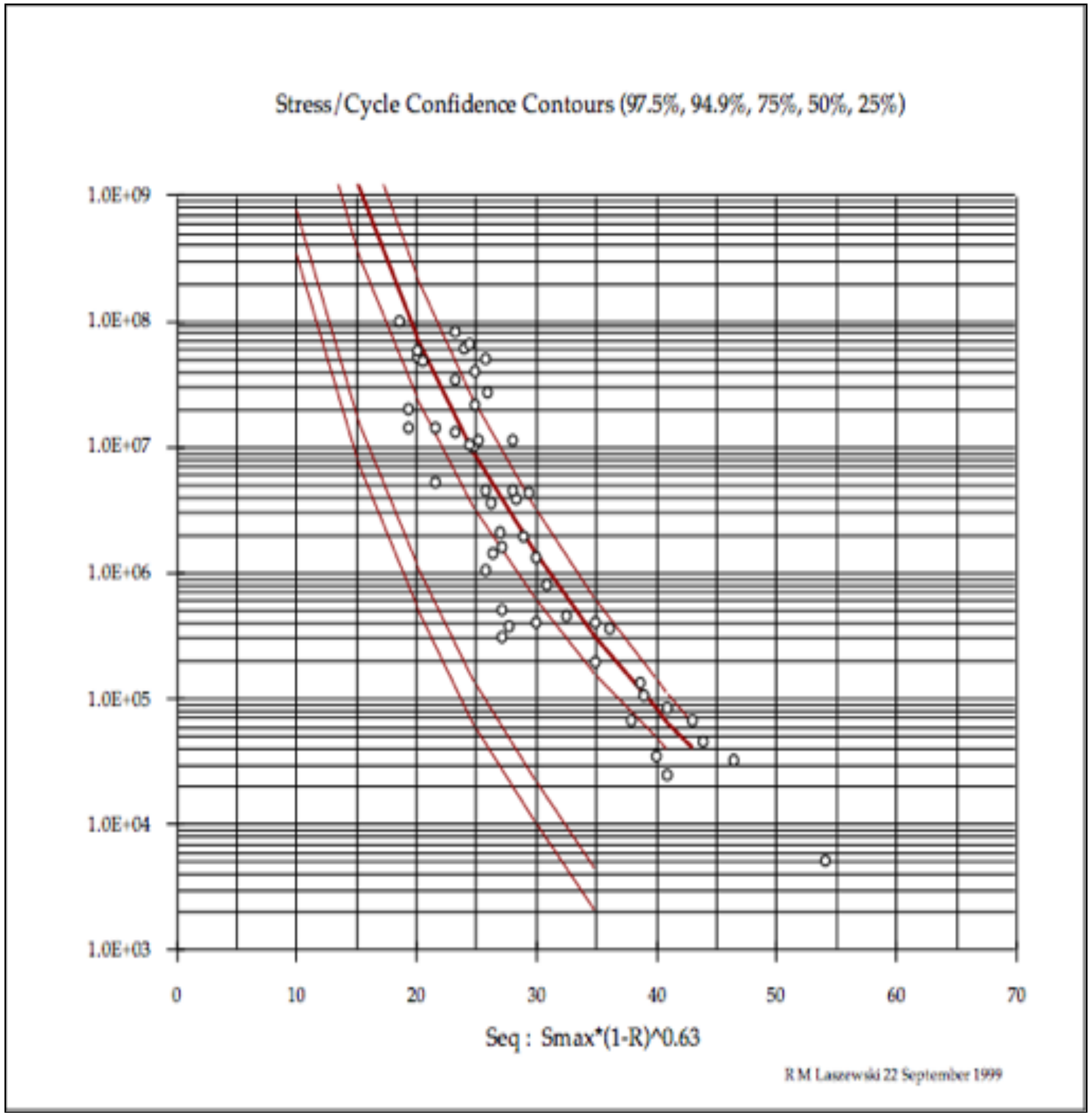
Backup

Optimization

- Fast MC used for fitting
  - Genetic algorithm
  - 7 inner conductor shape parameters, horn current
- Optimized for most neutrino events
- Regenerate neutrino fluxes with full BNB MC with optimized horn to calculate real gain
  - Real beamline geometry
  - HARP pion production cross sections



Allowable stress

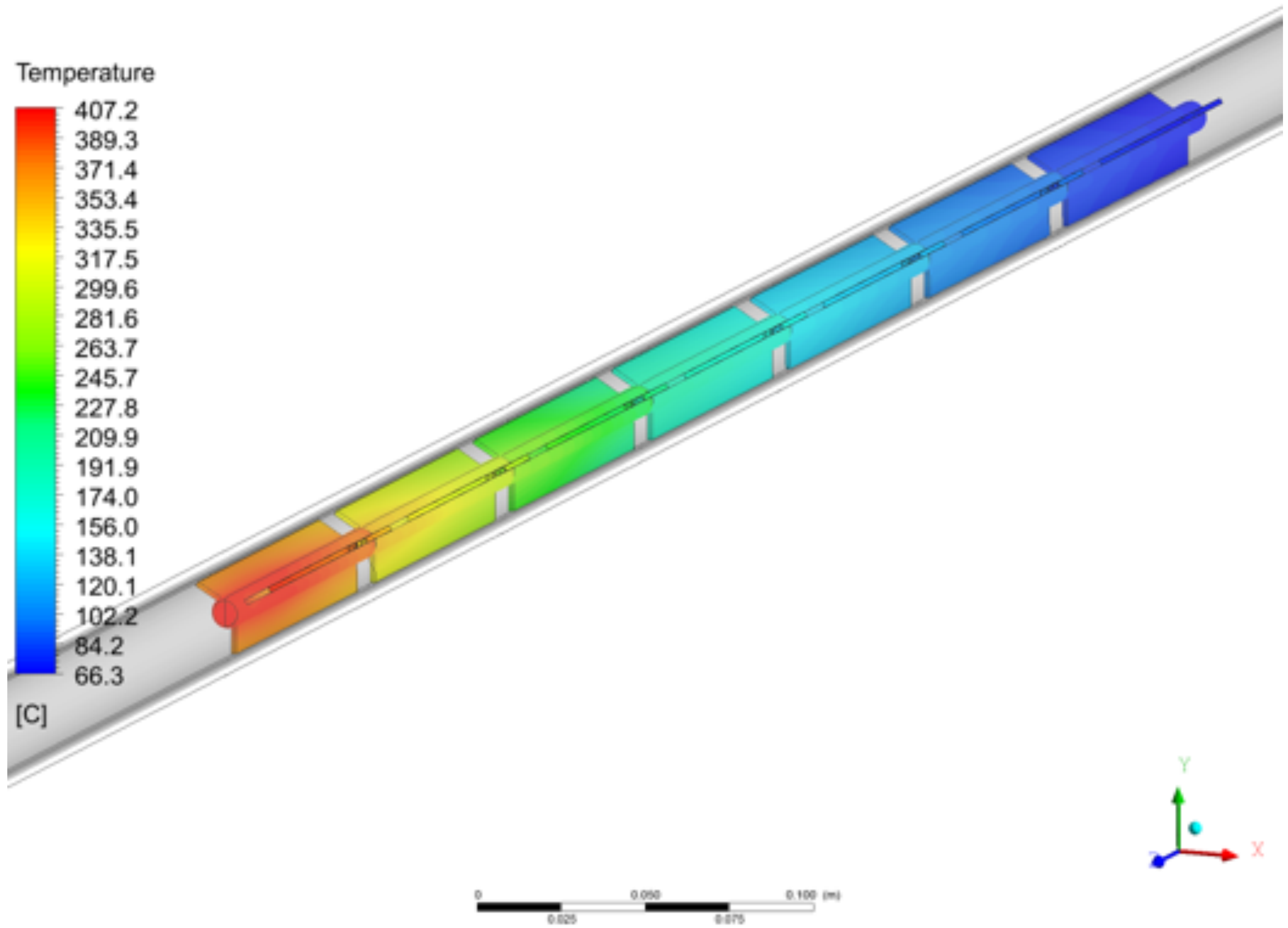


Radiological limits

	Limit	Reason
Booster & 8 GeV Line up to cell 803	1.8e17/hr	Overburden
8 GeV Line (cell 803 to cell 850)	2.84e17/hr	Overburden
8 Gev Line (cell 850 to BNB target station)	1.62e17/hr	Dose at stripline penetration
BNB Target Station	7.5e20/year	Groundwater

- 1.62e17POT/hr assuming 4.5e12 protons per pulse corresponds to maximum average rate of 10Hz

Target temperature



Target cooling

- Air cooled
- Simple heat transfer model taking into account energy deposition (~600W@5Hz/5e12) and air flow describes observed data well