BNB upgrade

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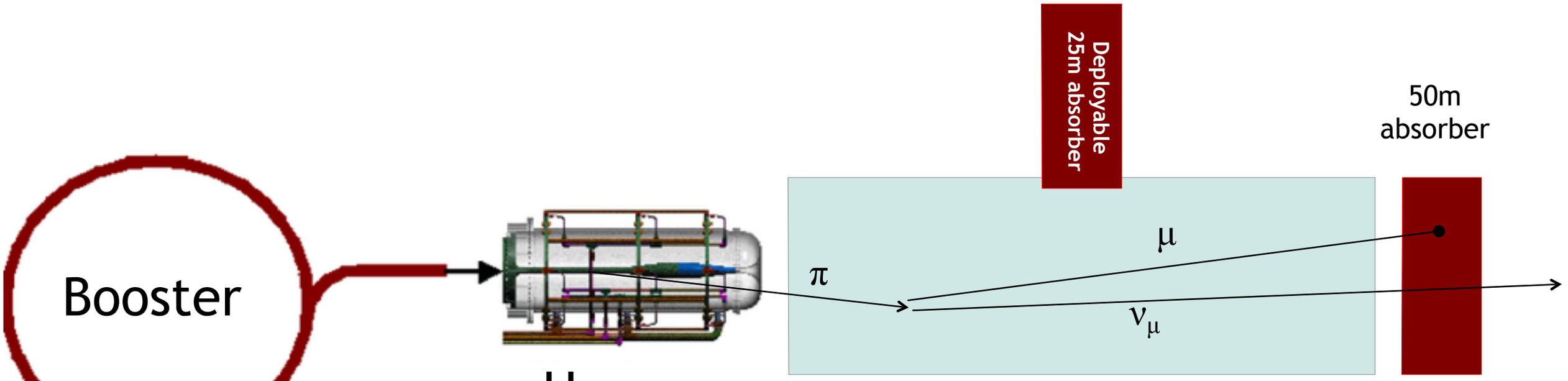
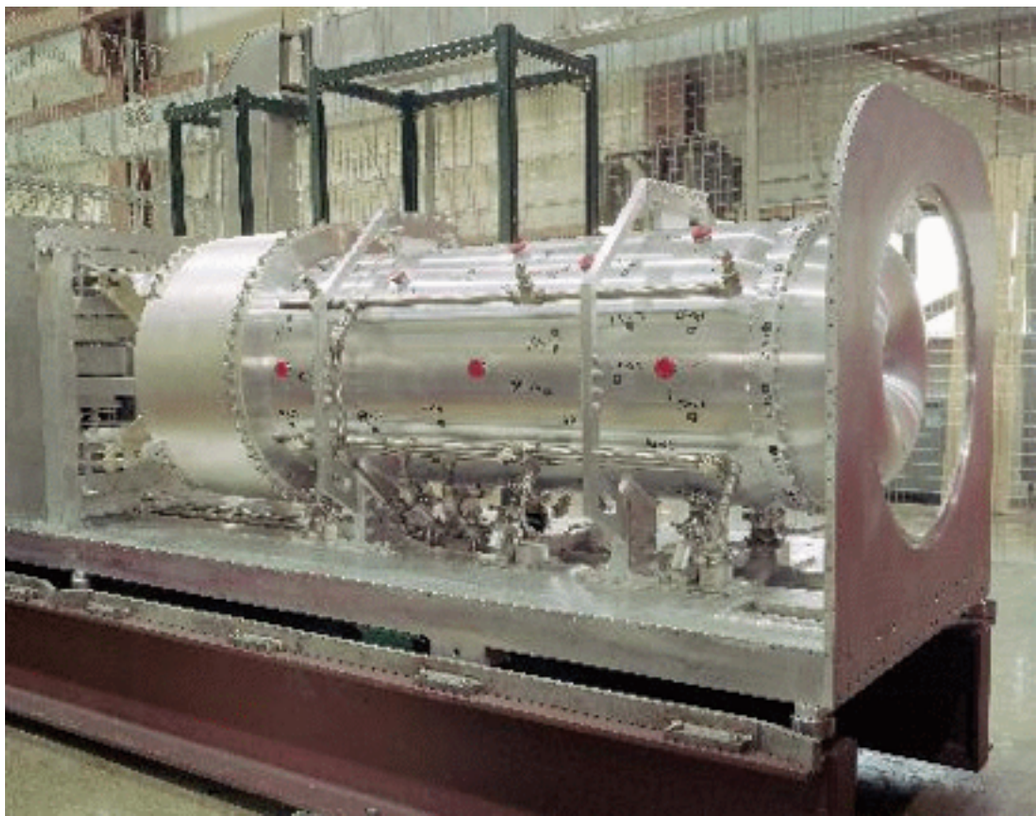
Booster Neutrino Beamline

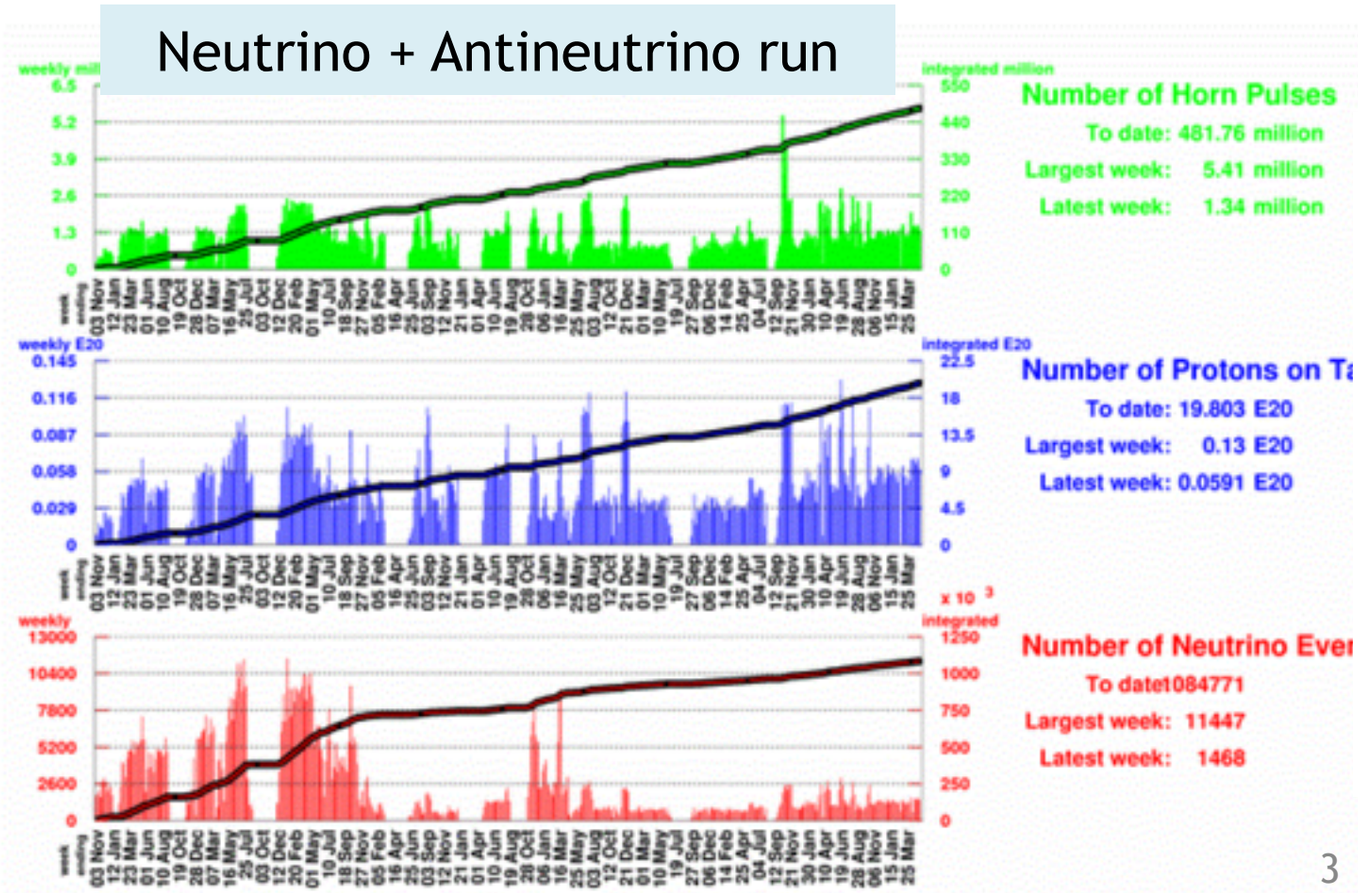


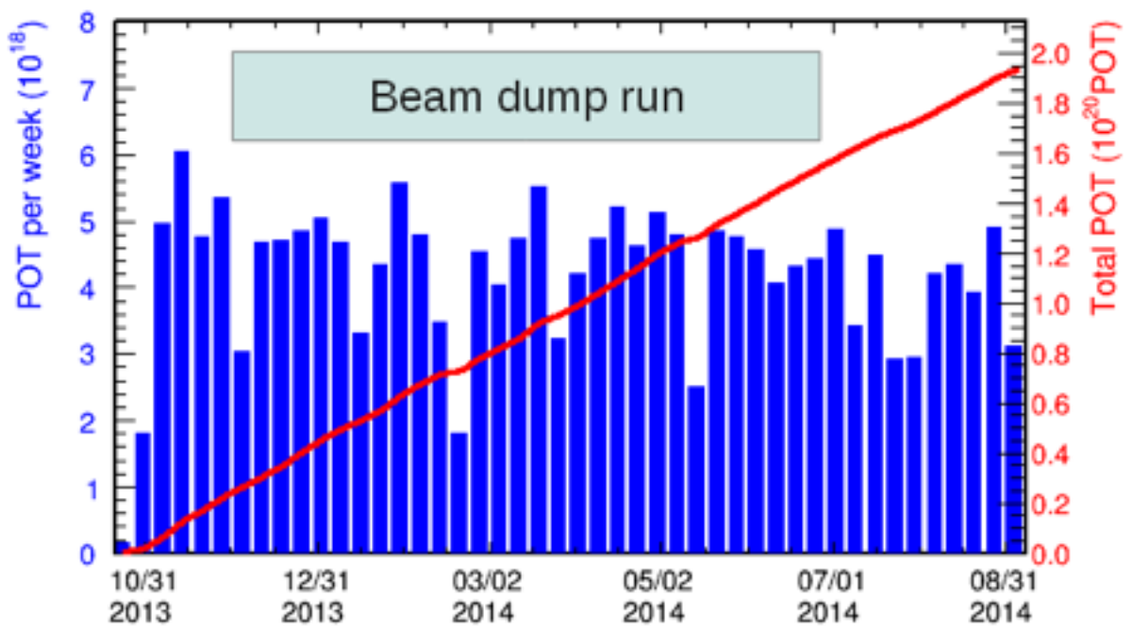
- 8 GeV protons from Booster
  - 4-5e12 PPP
  - Up to 5Hz average rate, 10 pulses in a row
- 1.7 int. length Be target
- Horn
  - Neutrino & Antineutrino mode ±170kA
- 50m long decay pipe



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

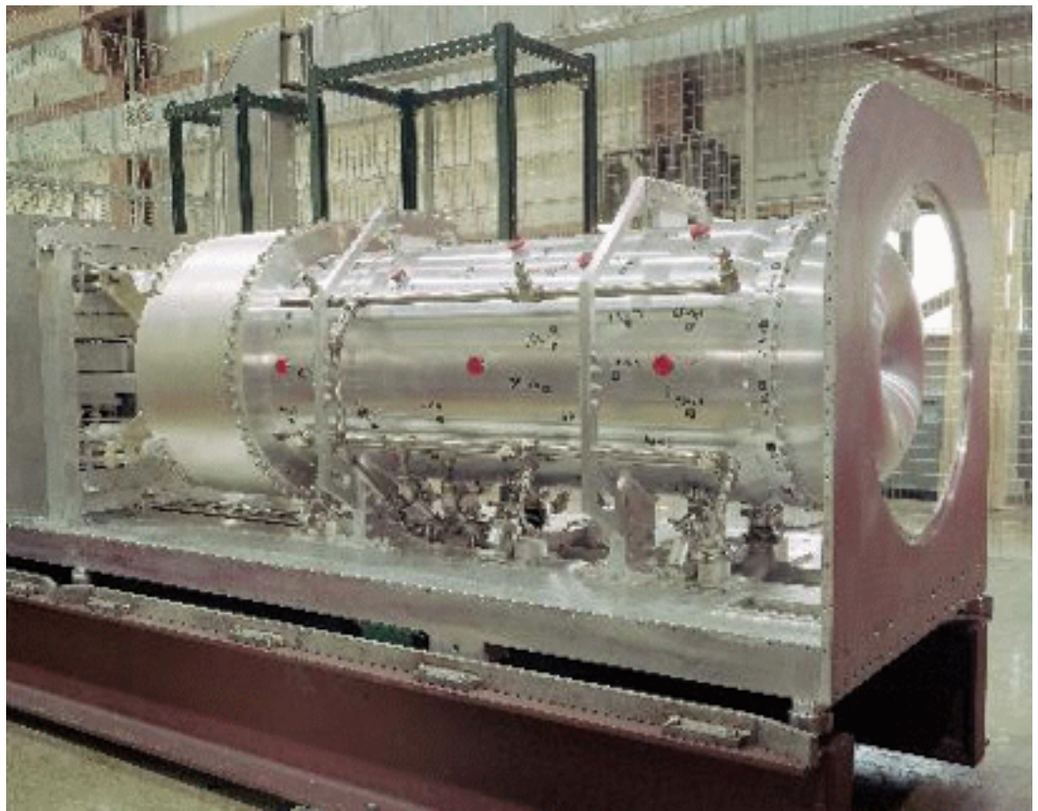


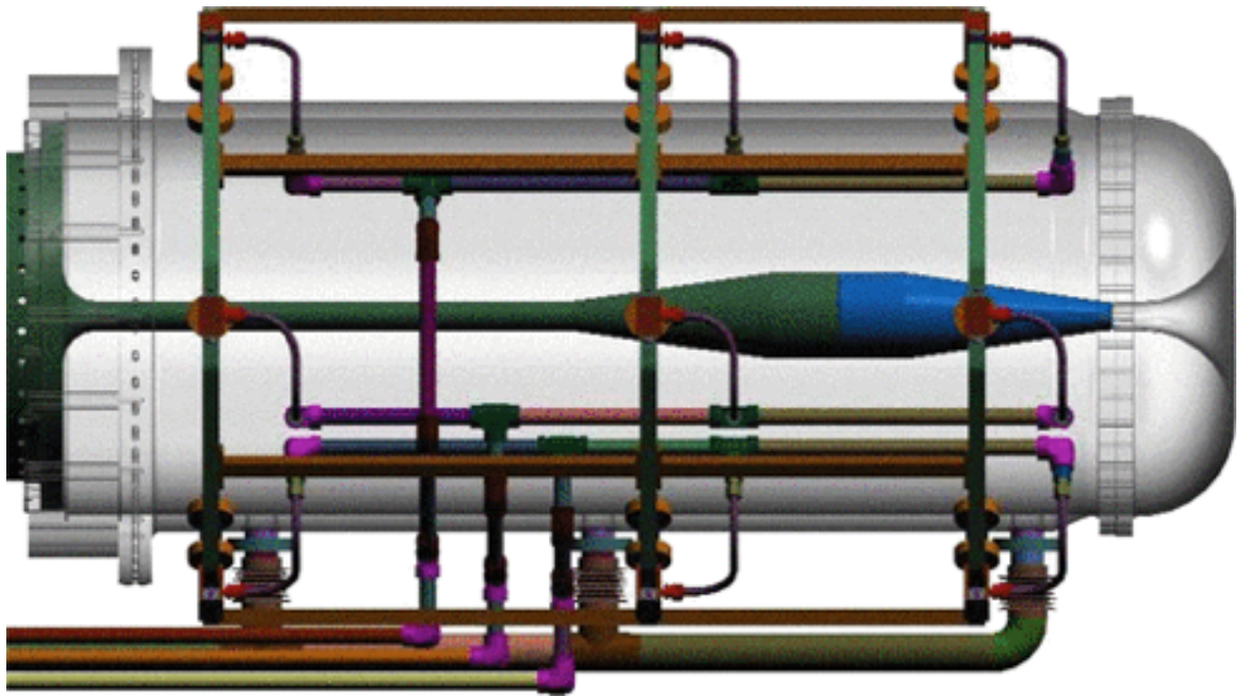


BNB horns

- 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
  - Started MicroBooNE run October 2015

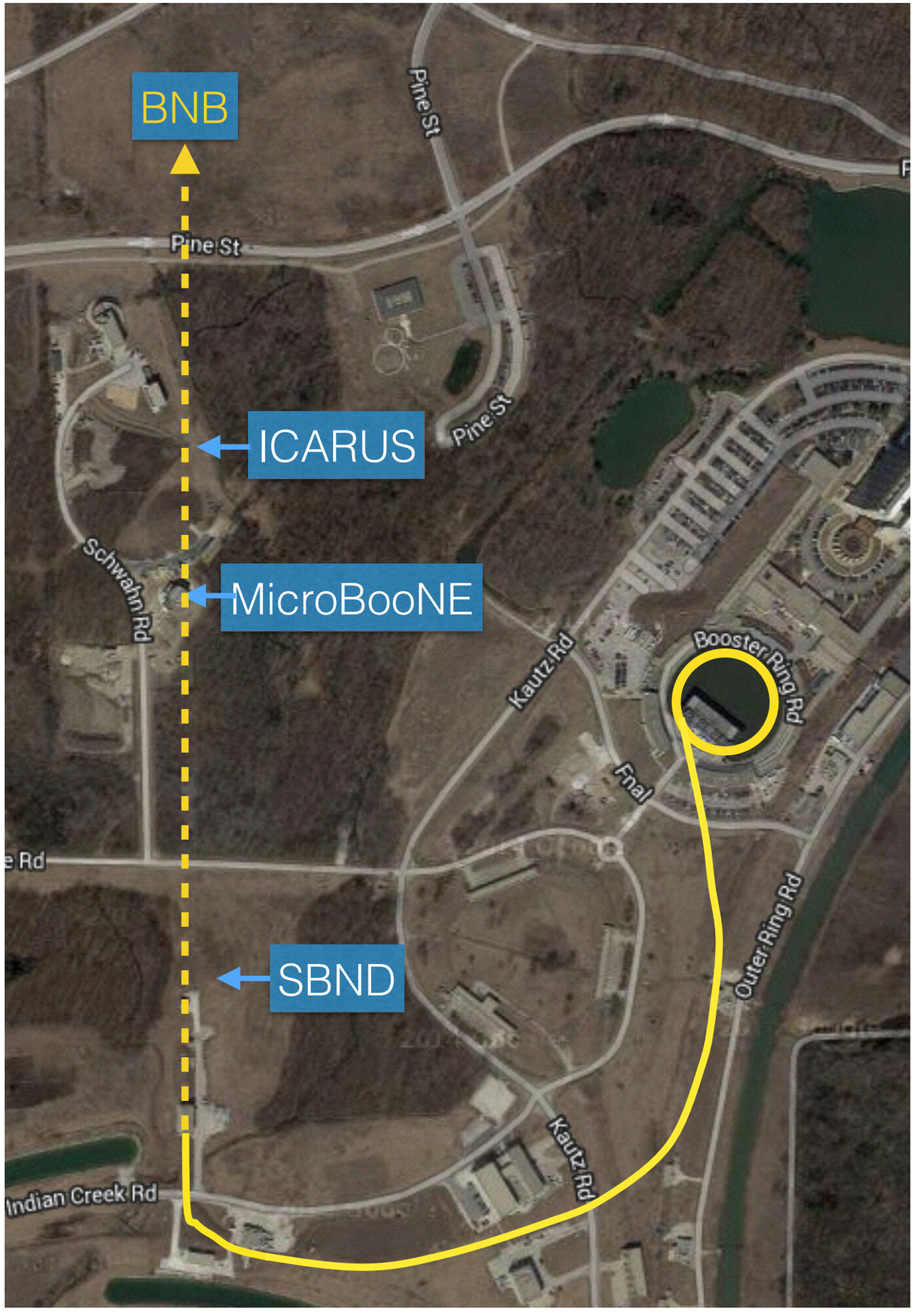
Horn	Pulses	POT
1	97M	3.7E+20
2	375M	1.6E+21





Future running

- MicroBooNE running starting October 2015
  - 6.6e20 POT to be delivered
- MITPC, ANNIE, SciBath
- Short baseline program currently under construction (SBND + ICARUS) 2018-
  - additional 6.6e20 POT
  - http://arxiv.org/abs/1503.01520
- Possible BNB upgrades considered for SBN program and future running
  - better focusing with new longer horn capable of running at higher rate and current



Upgrade paths

1. Increase focusing efficiency of the 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 the horn system can run at

    - Booster will operate at 15Hz

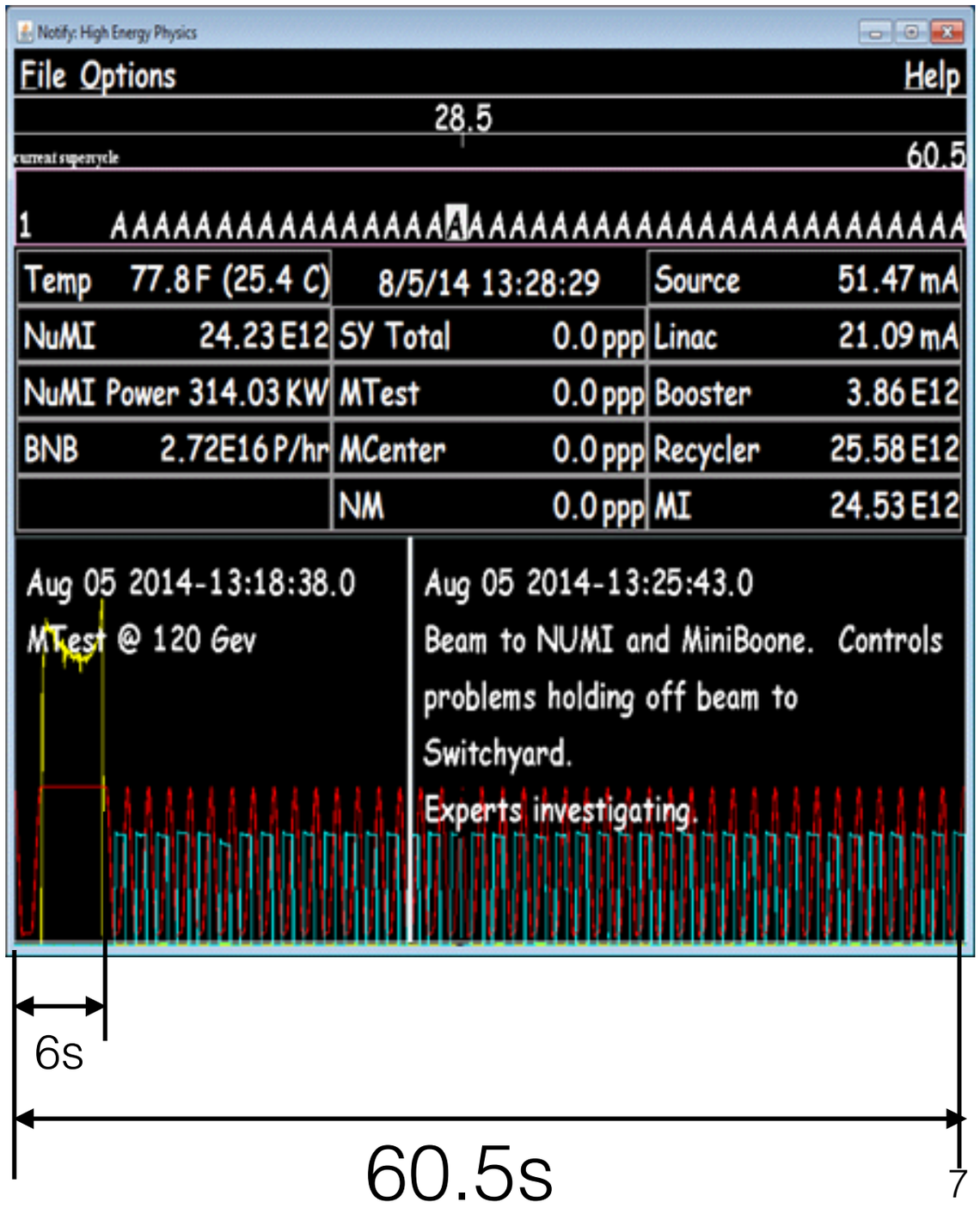
    - Maximize use of available cycles (beyond those sent to NuMI and muon program)

    - Requires improvement in horn power supply, mechanical integrity of horn (both depend on horn current)

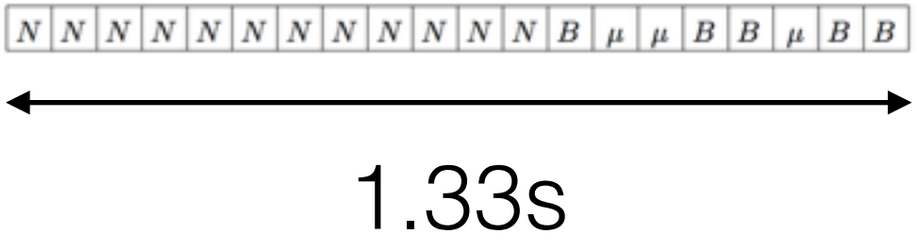
- Account for coupling between paths, i.e. higher focusing efficiency with higher current, but mechanical integrity and power supply push maximal rate down

- Fit within budget of ~6M$

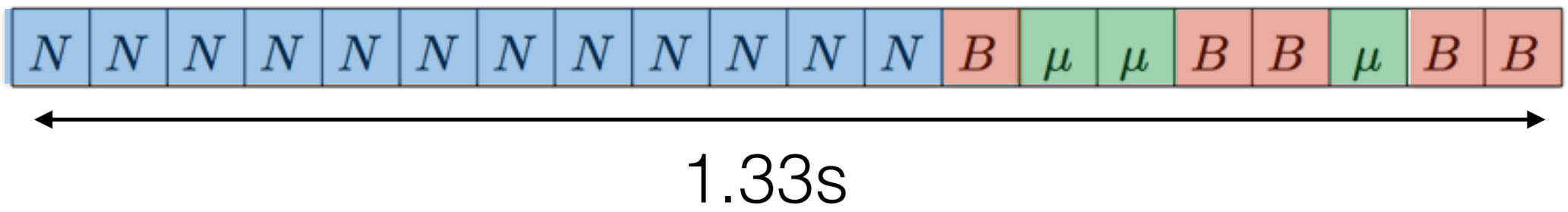
Proton delivery



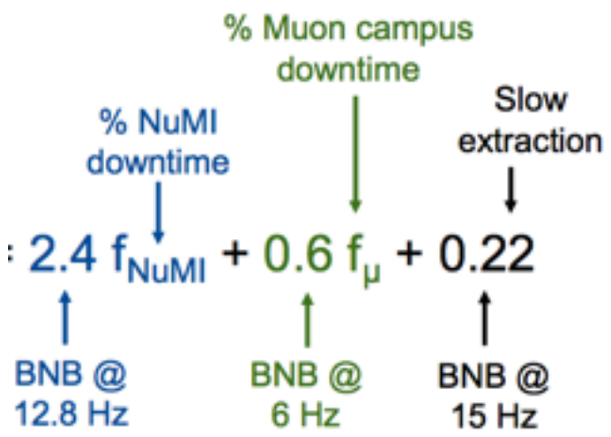
- Supercycle 60.5 sec long
- 1 MI slow extraction (6 sec)
  - beam to BNB
- 41 NuMI cycles each 1.33sec (54.5 sec)
  - beam to BNB, NuMI and muon campus



Proton delivery

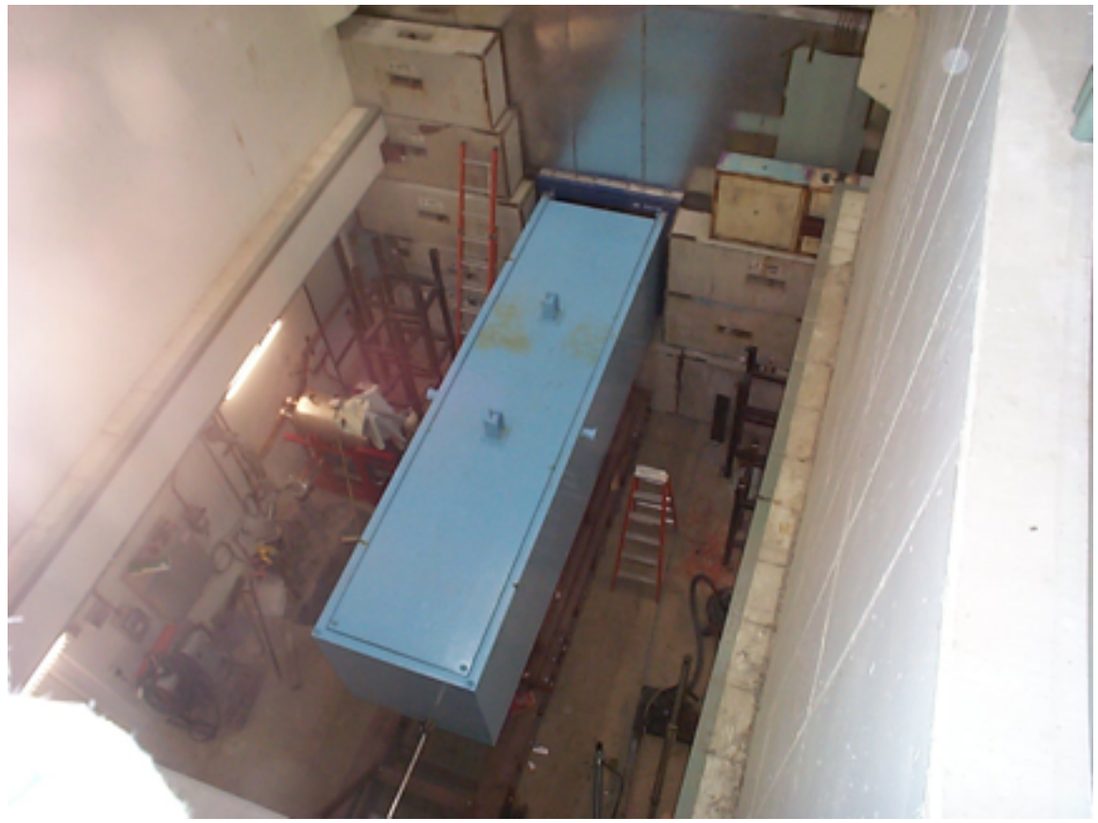


- Booster runs at 15Hz => 20 booster cycles within 1.33s
- Protons shared between **NuMI (N)**, **muon program (μ)** and **BNB (B)**
- 5 proton beam batches to BNB over 1.33s long cycle (corresponds to 3.76Hz average rate)
- Additional rate if capable running at 15Hz:

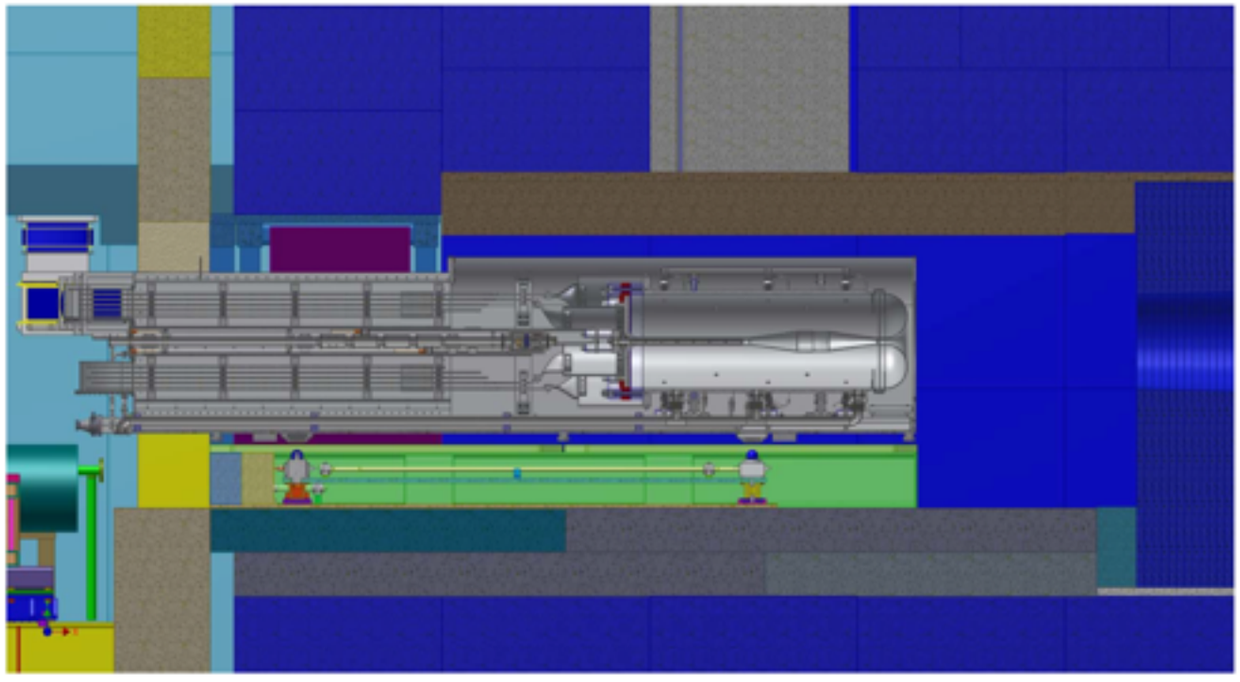


Physical constraints

- Target pile shielding
  - rebuilding prohibitively expensive and would require long downtime

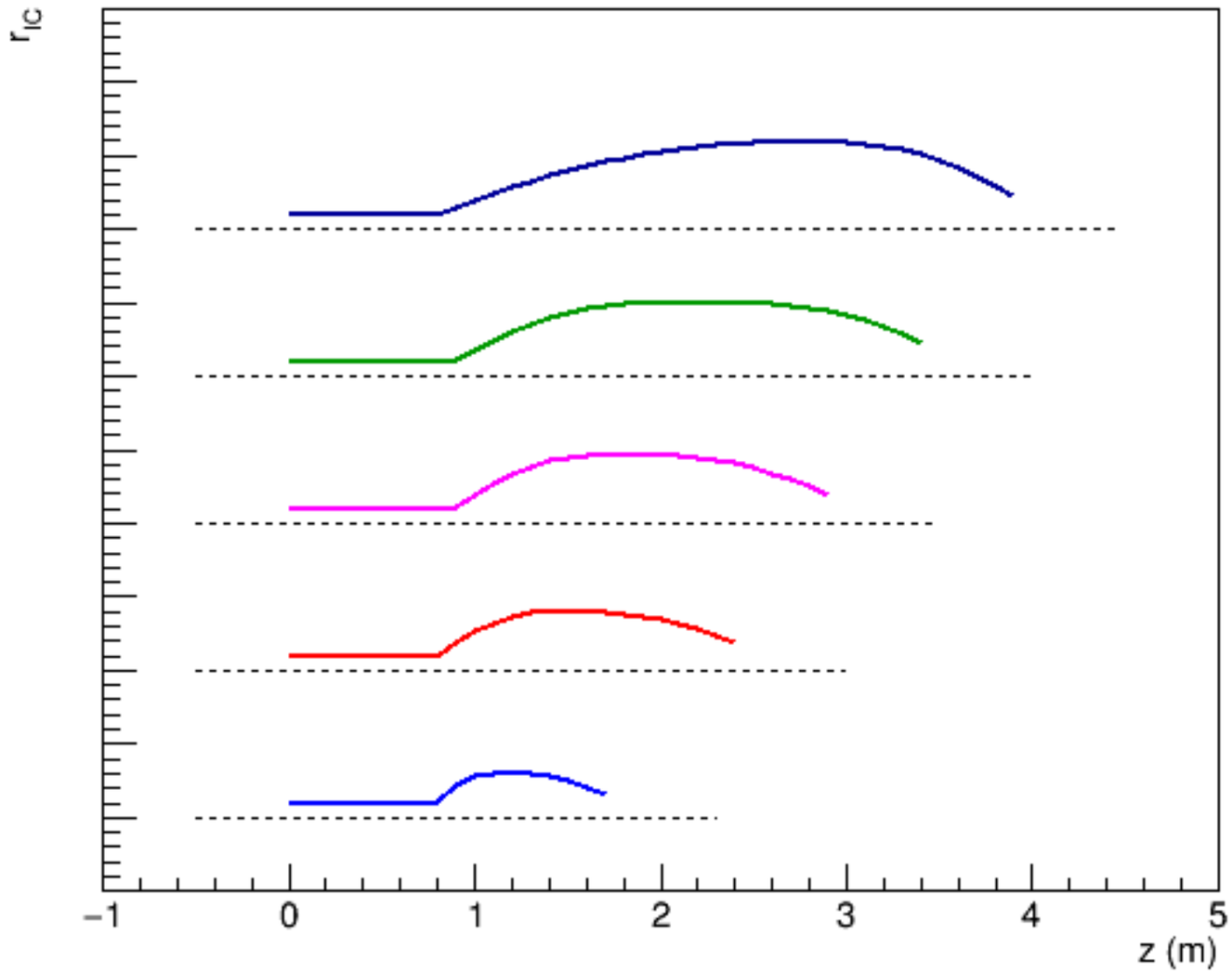


- Hatch size matched to the coffin length
- Collimator at the entrance to decay pipe (r=30cm)
  - matched horn outer conductor radius



Optimization procedure

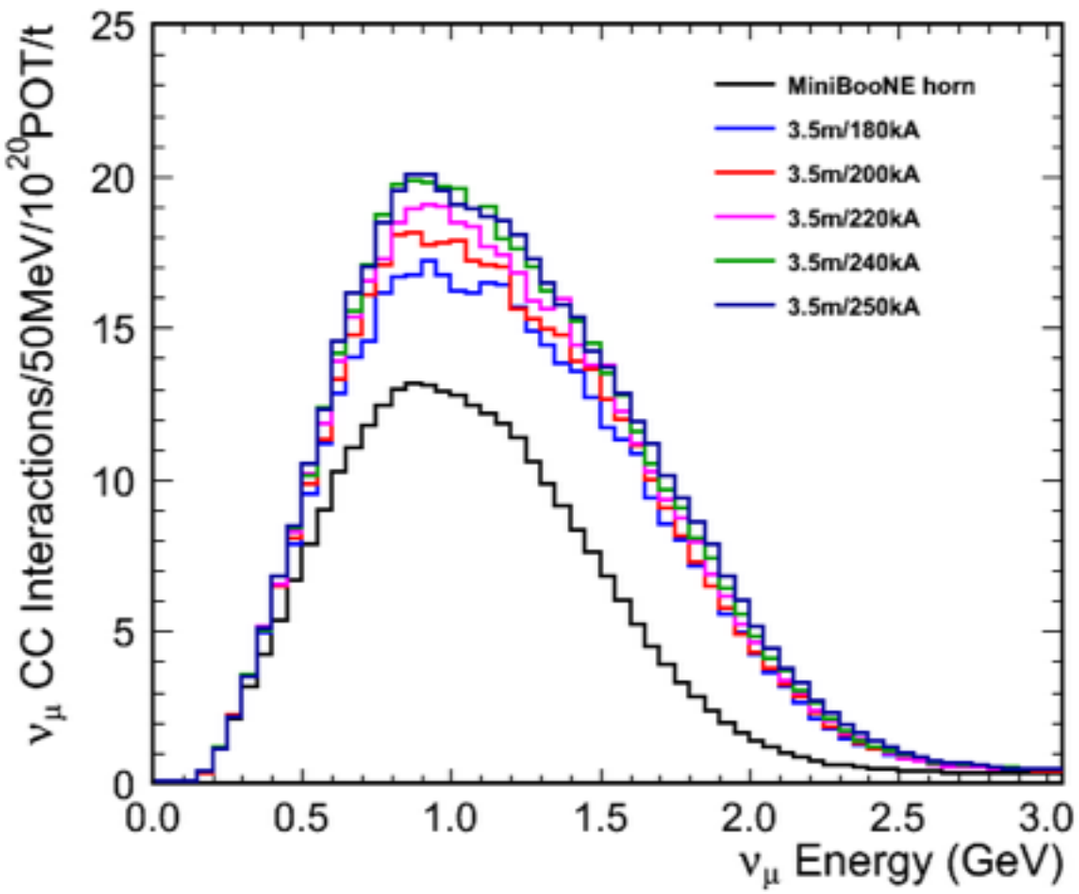
- Fast MC used for fitting
- Genetic algorithm
  - 7 inner conductor shape parameters, horn current
- Optimized for most neutrino events
- Full BNB MC with optimized horn to calculate real gain

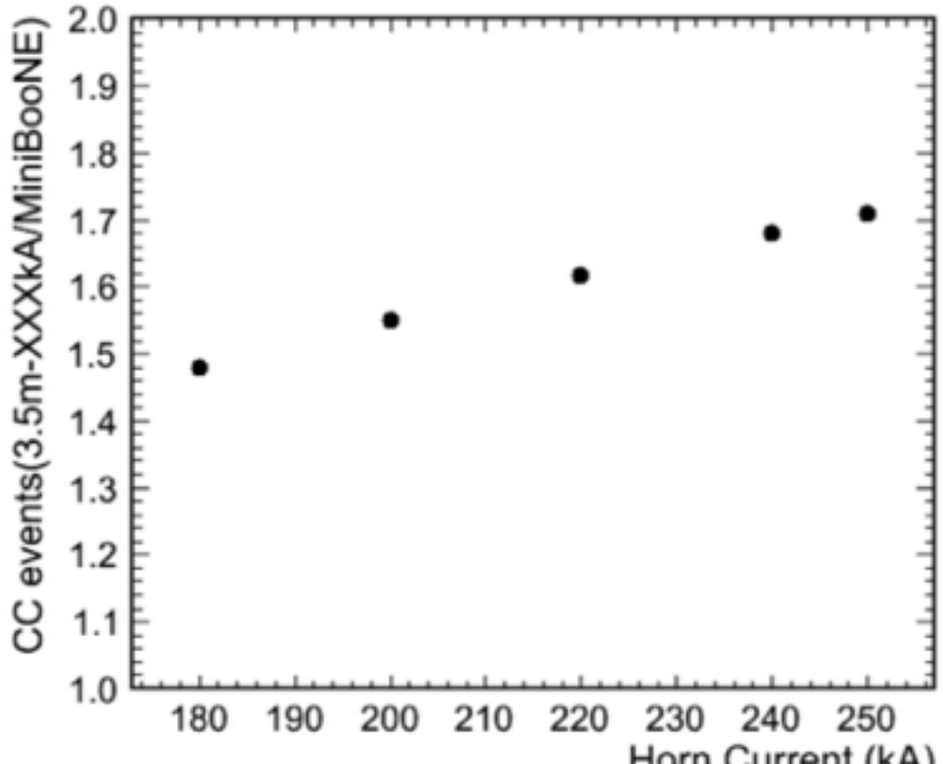


Optimization

- Longer horns and higher current preferred
- LArTPC more tolerant of high energy tail (MiniBooNE was optimized to increase flux at low energy and keep high energy which produces backgrounds in Cherenkov detector low)
- Longest horn that can fit 3.5m
- Higher stress on PS and horn at 250kA

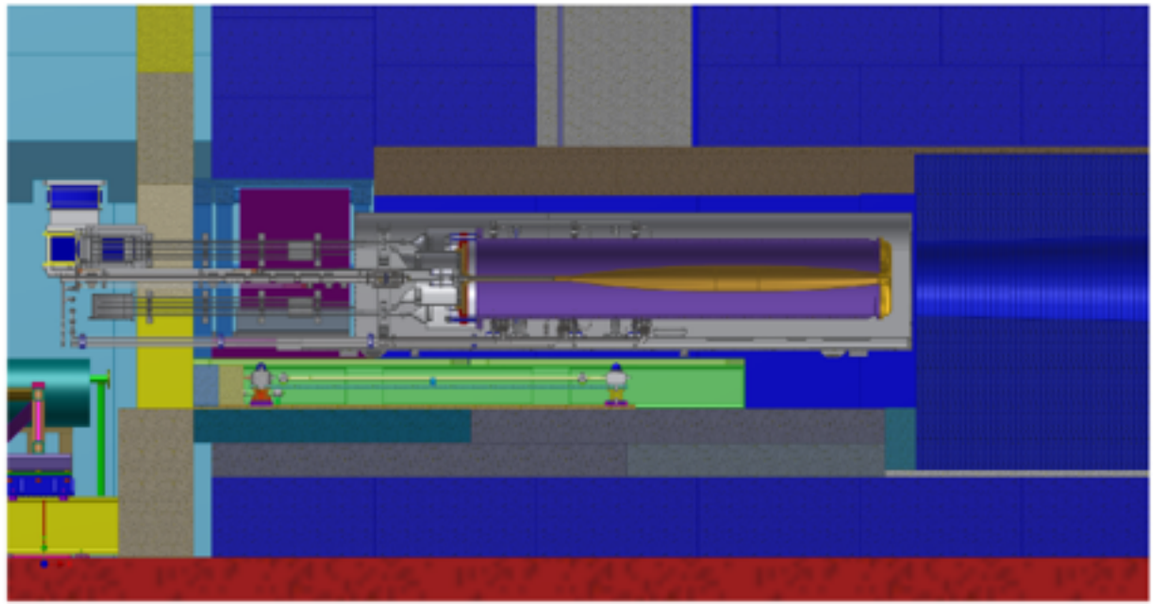
	Overall rate/ MiniBooNE
MiniBooNE	1
3.5m/180kA	1.48
3.5m/200kA	1.55
3.5m/220kA	1.62
3.5m/240kA	1.68
3.5m/250kA	1.71

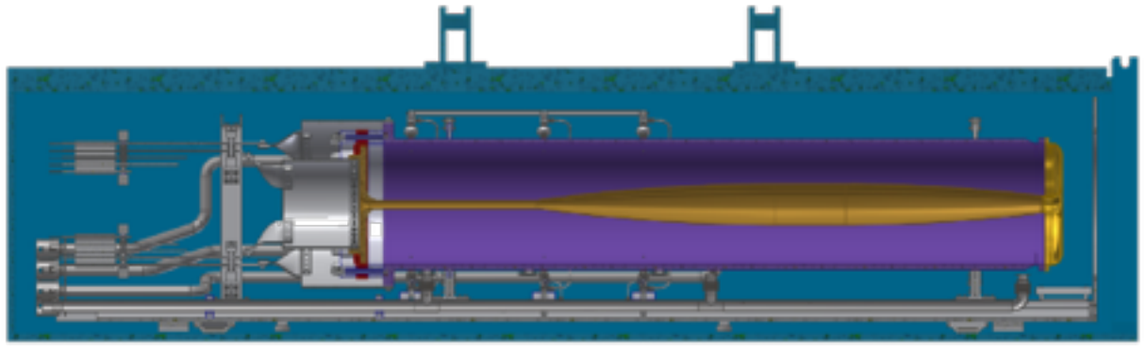


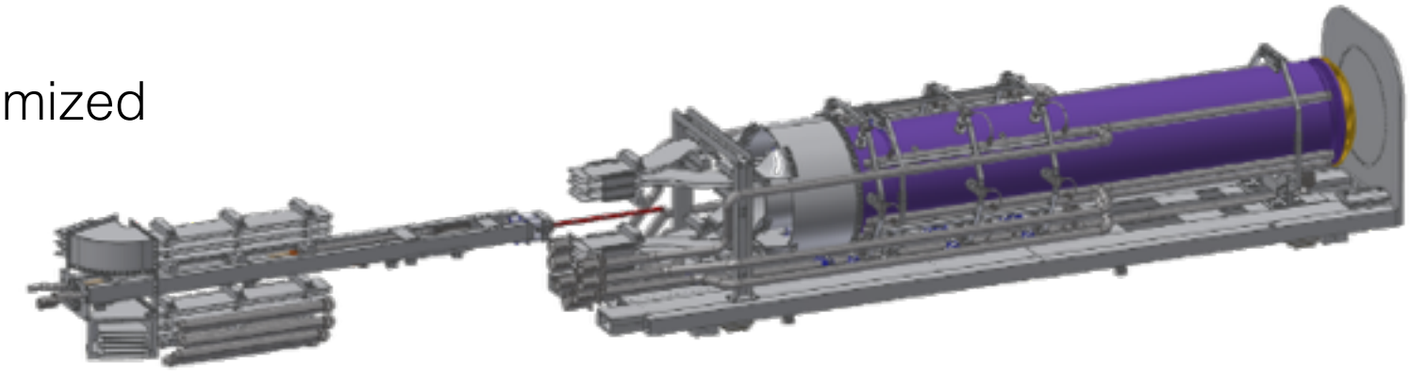


Horn engineering

- Larry Bartoszek build 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 $\sim 10^8$ cycles/year
- Preliminary finite element studies of optimized horn
    - Feedback to design options



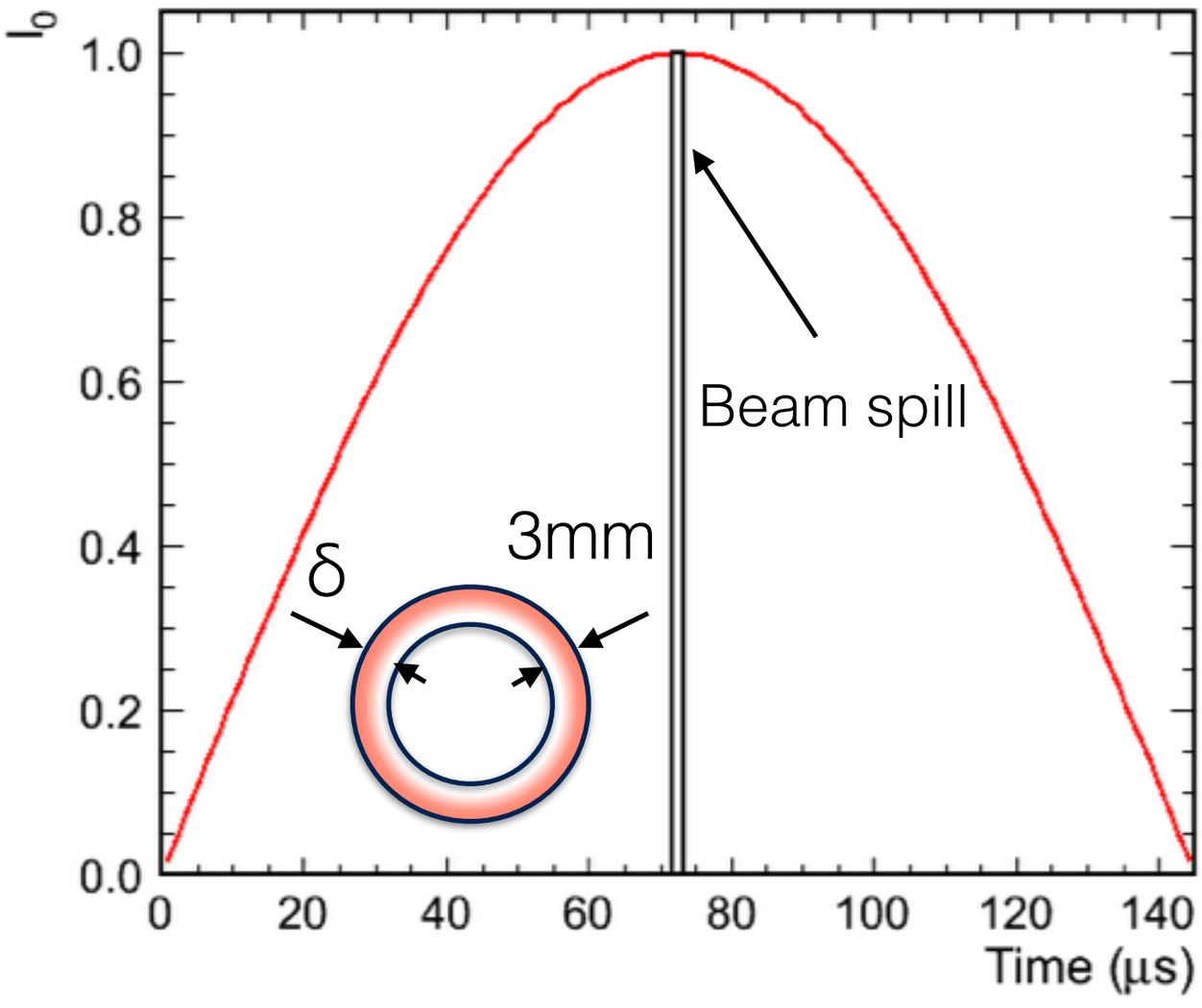


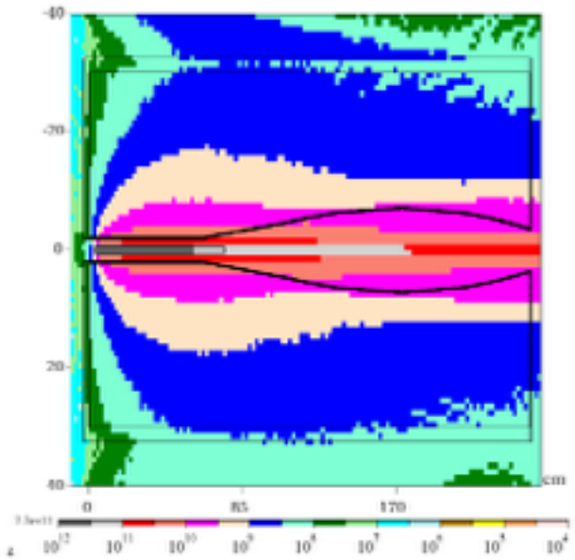


Bartoszek engineering

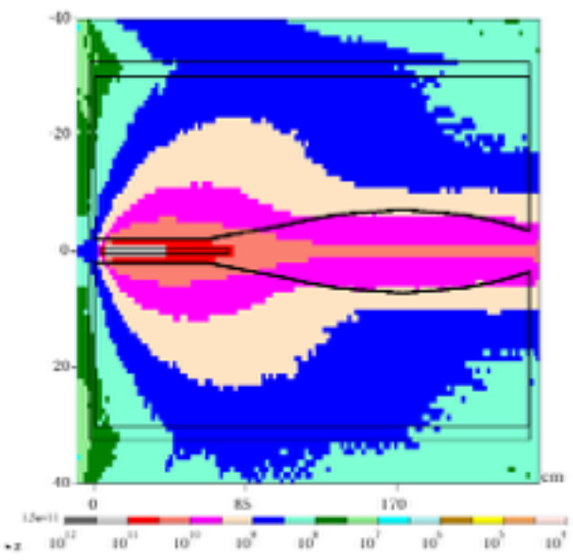
Heat load

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

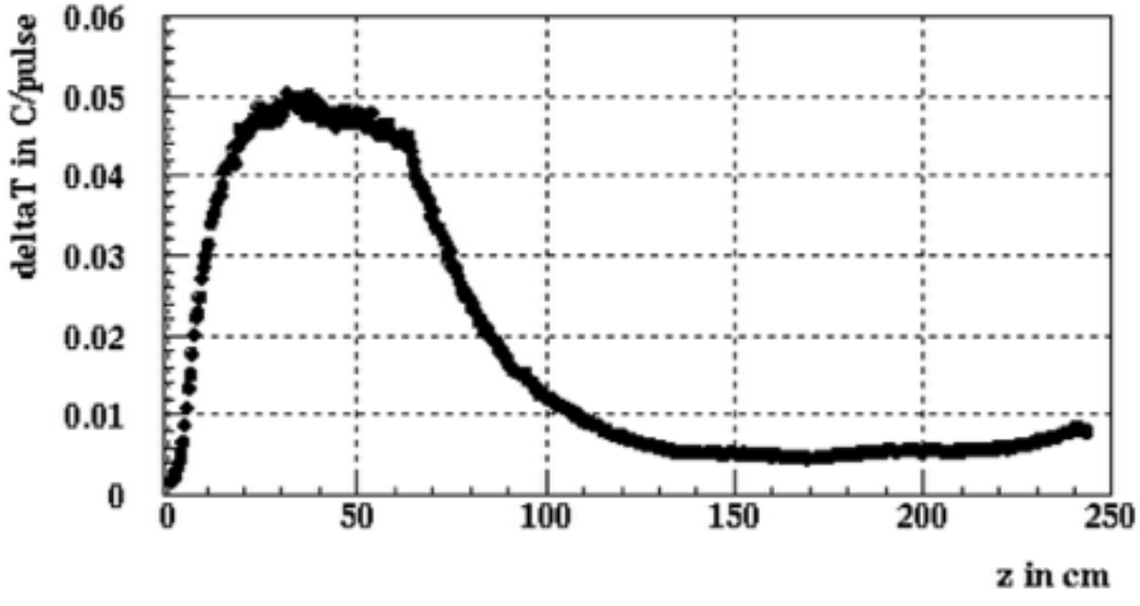




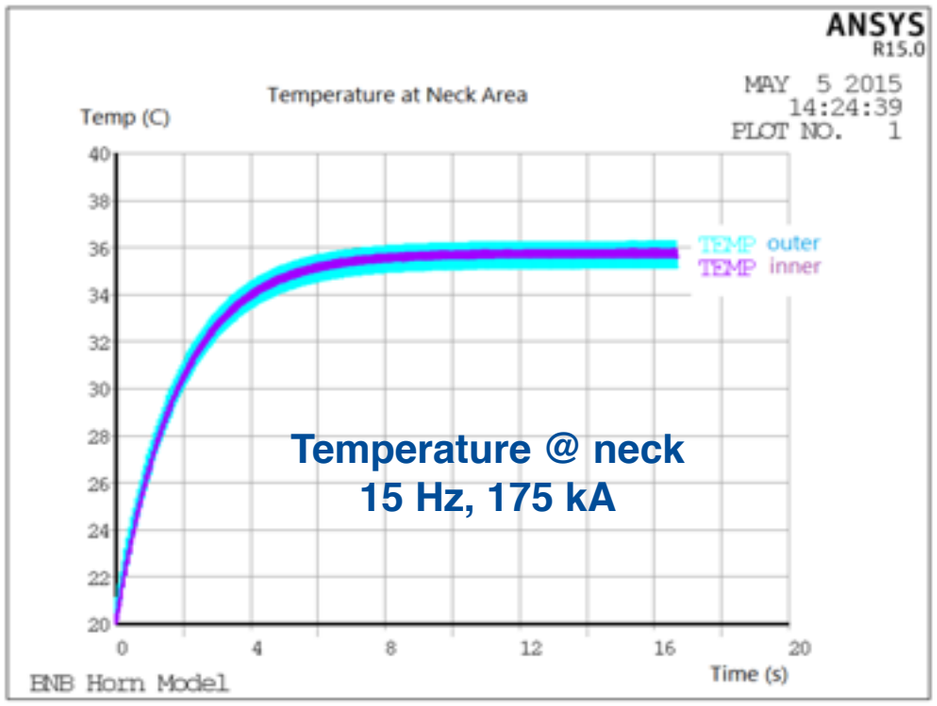
protons

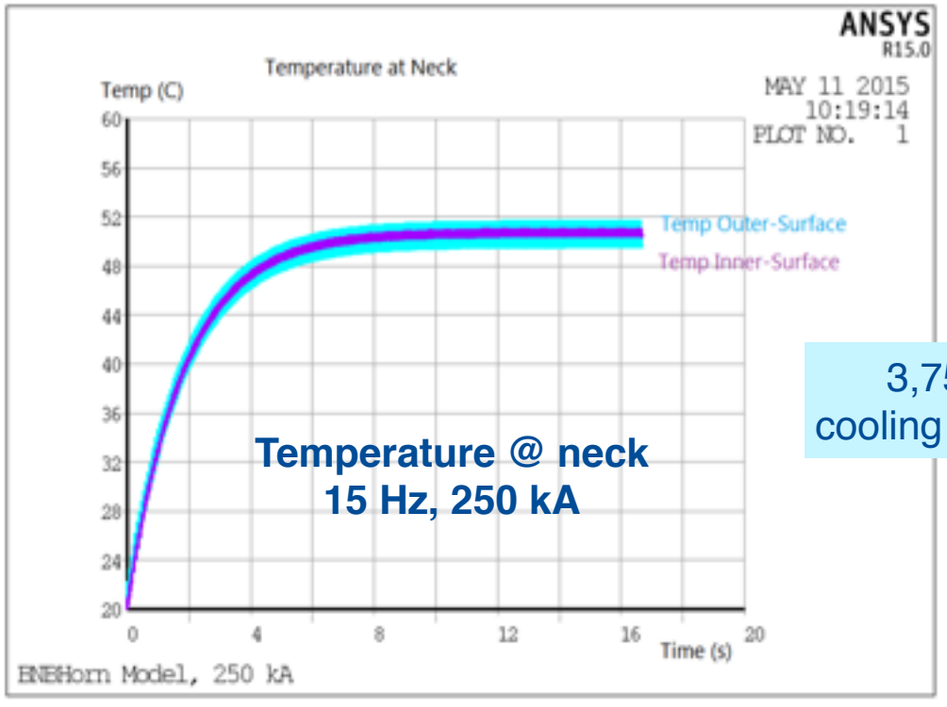


mesons

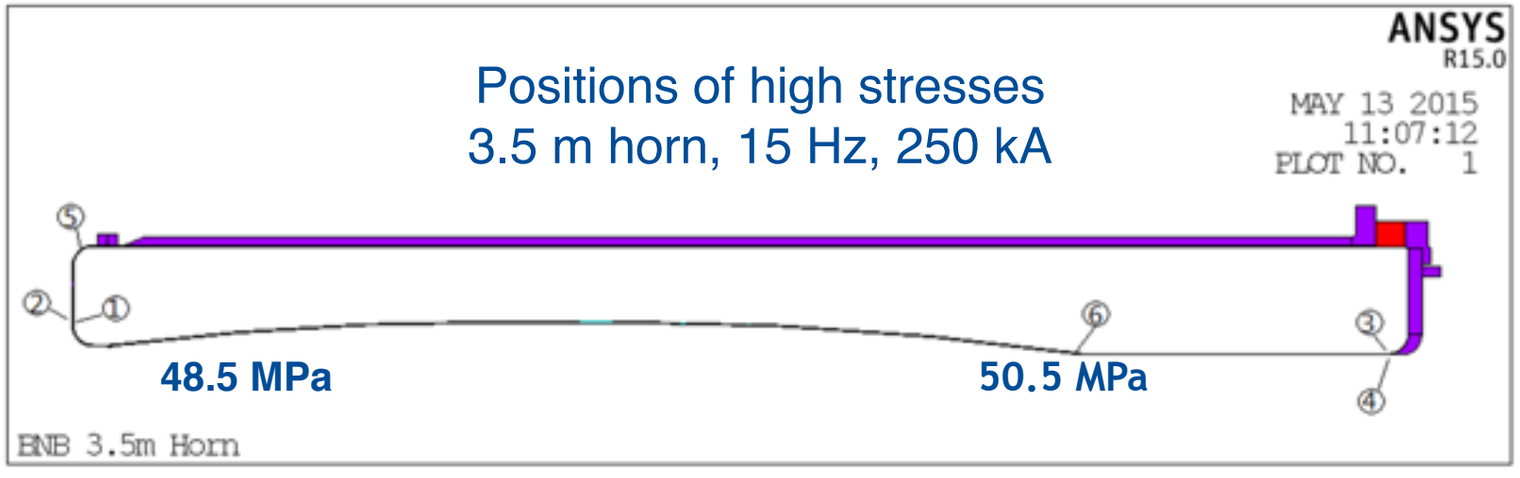


FE analysis





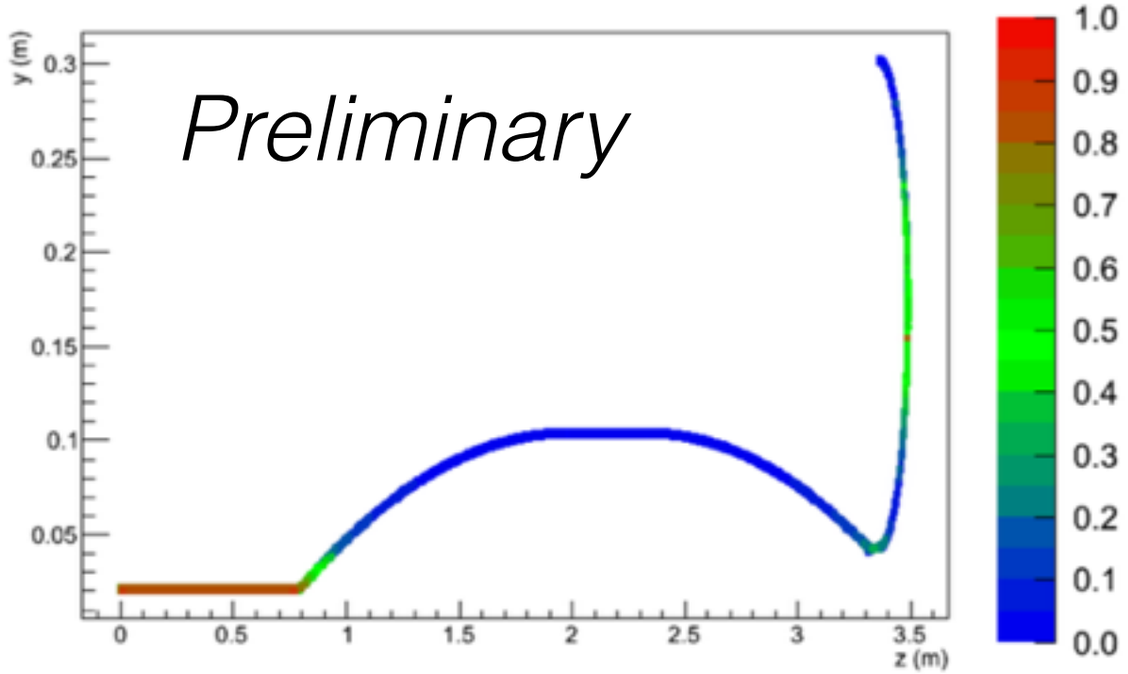
3,750 W/m^2 C
cooling film coefficient

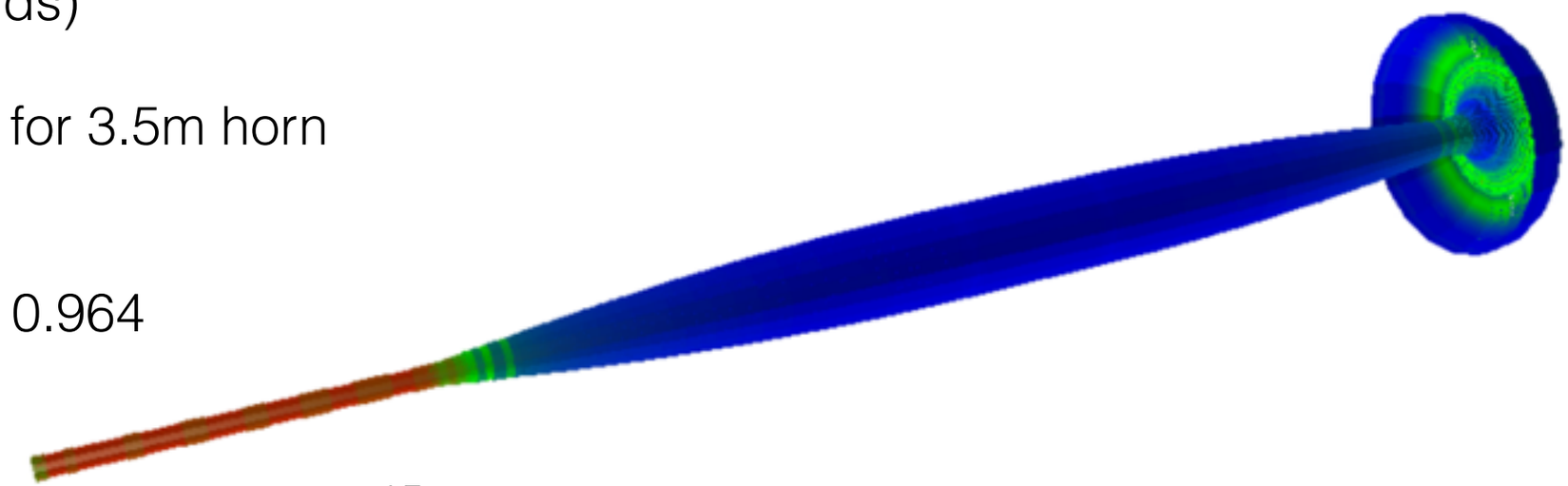


- Identify high stress points, use full stress history for each element in fatigue analysis

Fatigue limit

- Stresses calculated in FE analysis used in fatigue limit 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	573
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

- 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	250 130	4.3 15
4 new charging supplies	250 140	5.1 15
Recovery choke + Charging supplies	250 160	6.4 15

Total gains

Max rate depending on PS capabilities and horn load

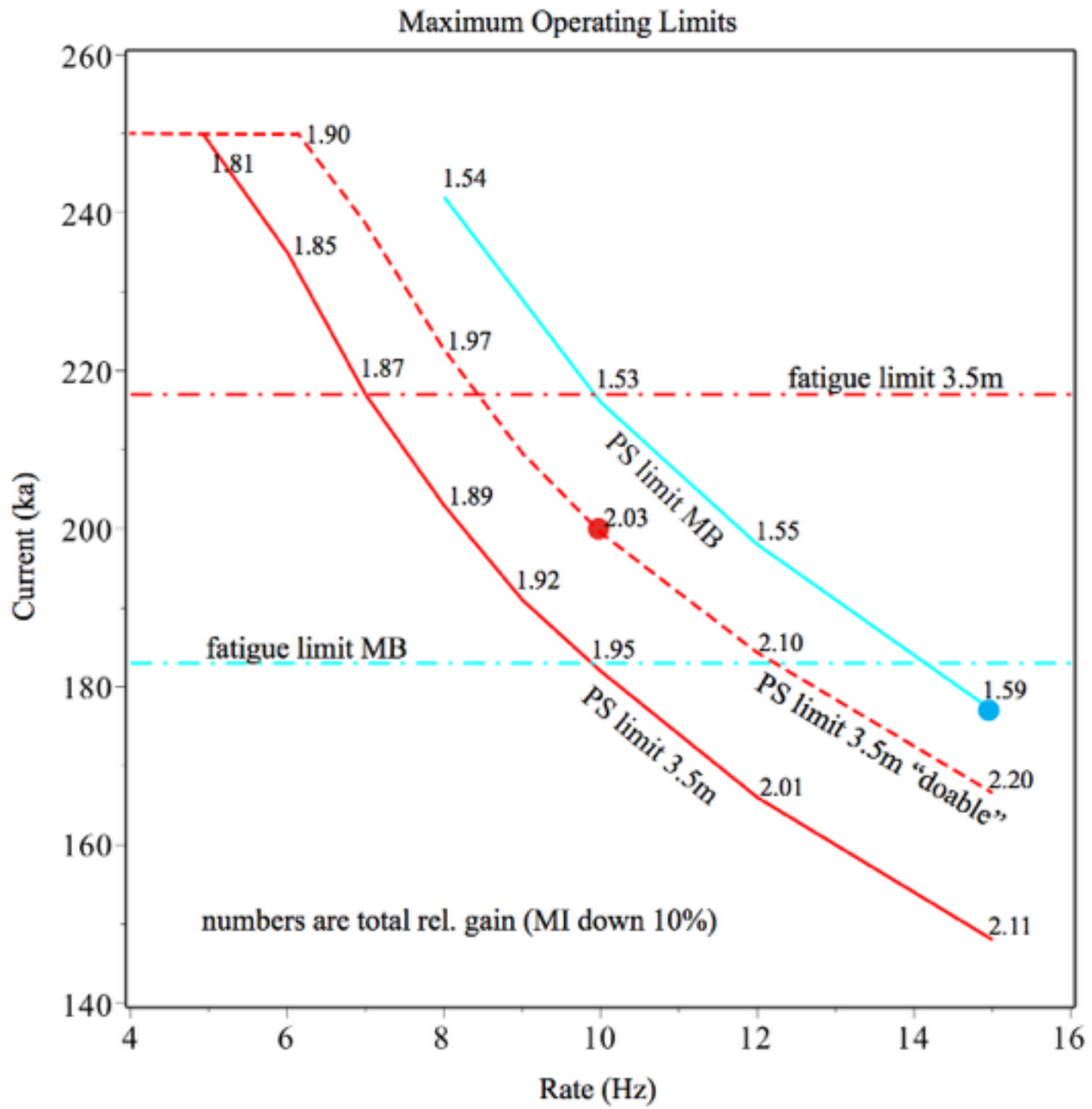
Gain from better focusing

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

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

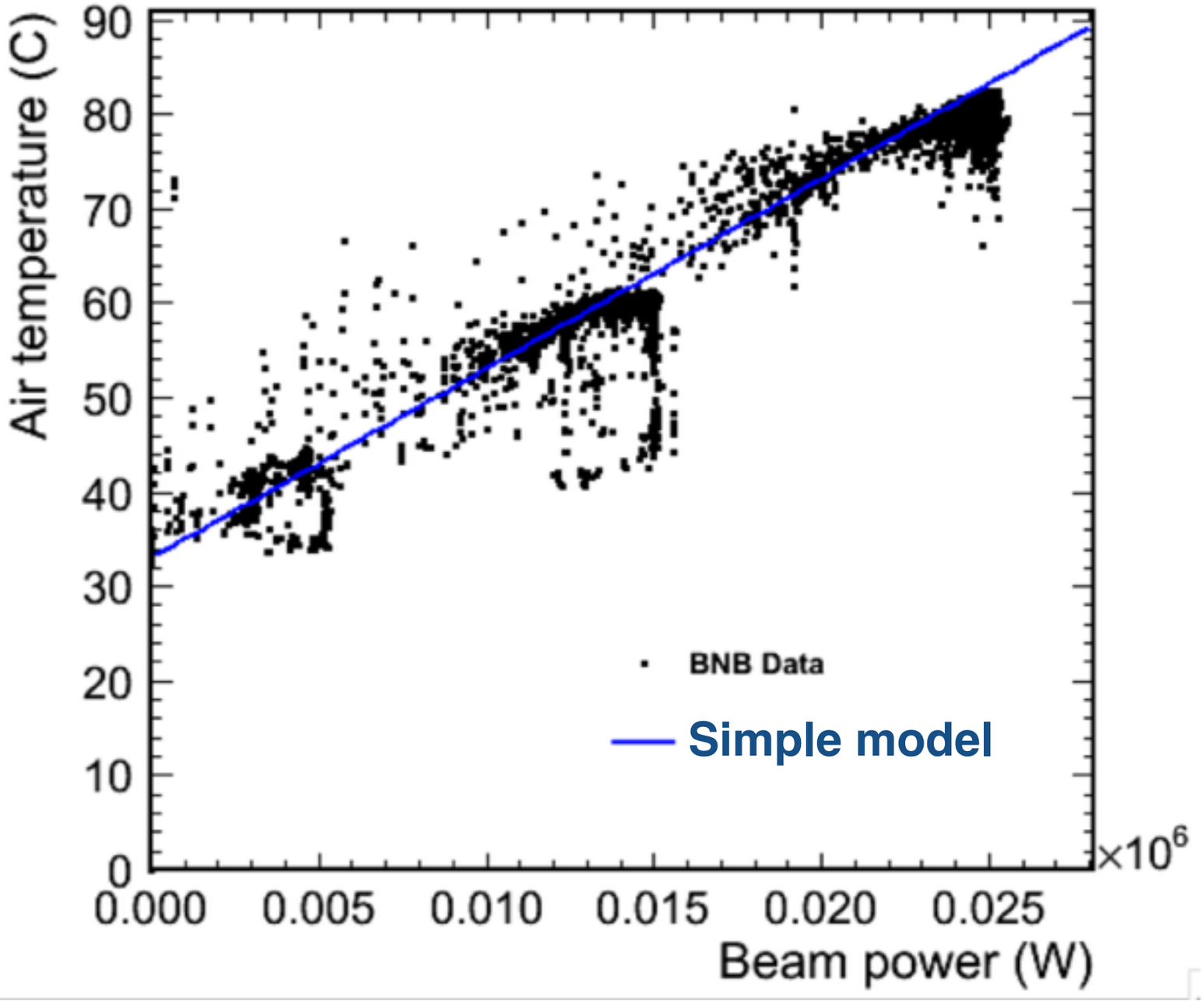
Horn current	Max rate (Hz)	Gain (focusing)	Total Gain (focusing*rate)	Total Gain (10% BNB only)
180kA	12.3	1.48	1.77	2.11
200kA	10	1.55	1.77	2.03
220kA	8.2	1.62	1.78	1.97
250kA	6.4	1.71	1.81	1.93

Total gains (cont'd)



Target heating

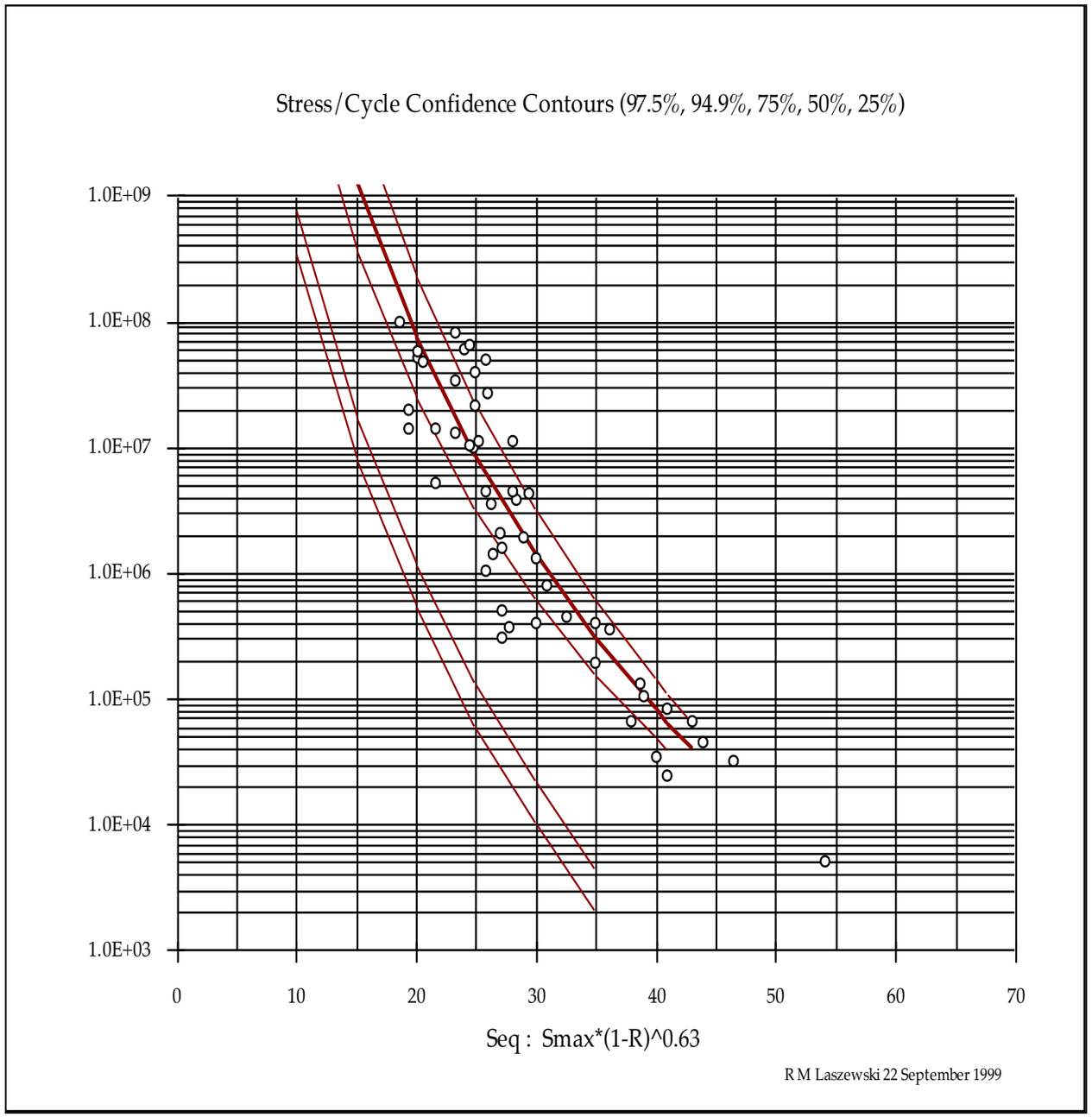
- Air cooled target
- Simple heat transfer model taking into account energy deposition (~600W@5Hz/5e12) and air flow describes observed data well
- Predicts manageable target temperature at 10Hz with 5e12 per spill (260C)
- Detailed analysis underway to study impact on horn inner conductor



Conclusion

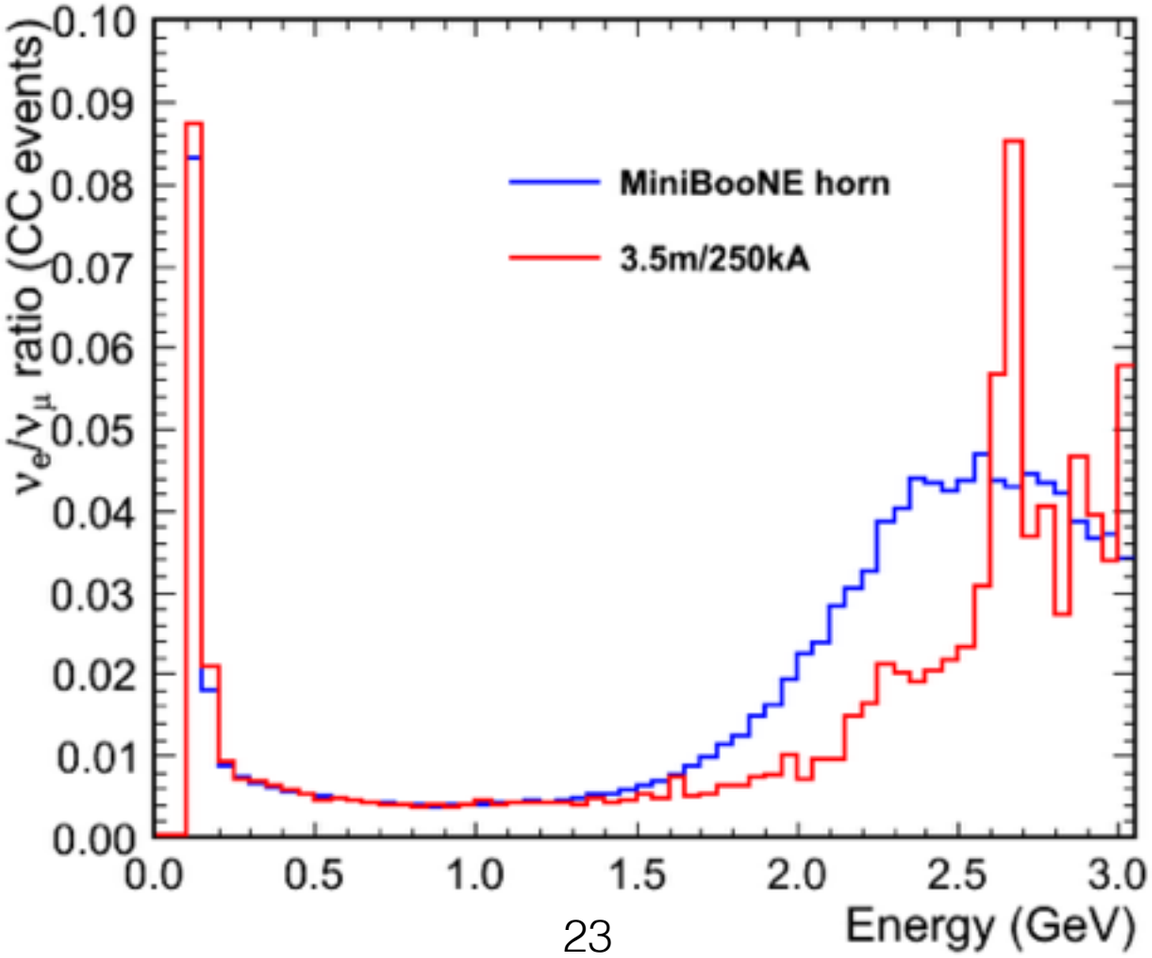
- Significant gains (~1.8) with upgraded horn system
- Combination of improvements of focusing system and power supply
- Preliminary studies taking into account target hall constraints, horn power supply capabilities, upgraded horn mechanical properties, realistic expected beam rate favors 3.5m long horn pulsed at ~210kA@10Hz
- Ongoing studies of:
  - Radiological impact of moving target upstream
  - Target cooling

Allowable stress



Neutrino flux

- Expect similar fractional contamination with intrinsic electron neutrinos



Anti-neutrino running

- Gain 1.8@250kA and 1.56@200kA
- Intinsic electron neutrinos fractionally the same
- Big suppression of wrong sings which stay the same as with MiniBooNE horn