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BNB Upgrade

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Fermilab Physics Advisory Committee
22 June 2015

Upgrade Options for the Booster Neutrino Beam

Design Concepts

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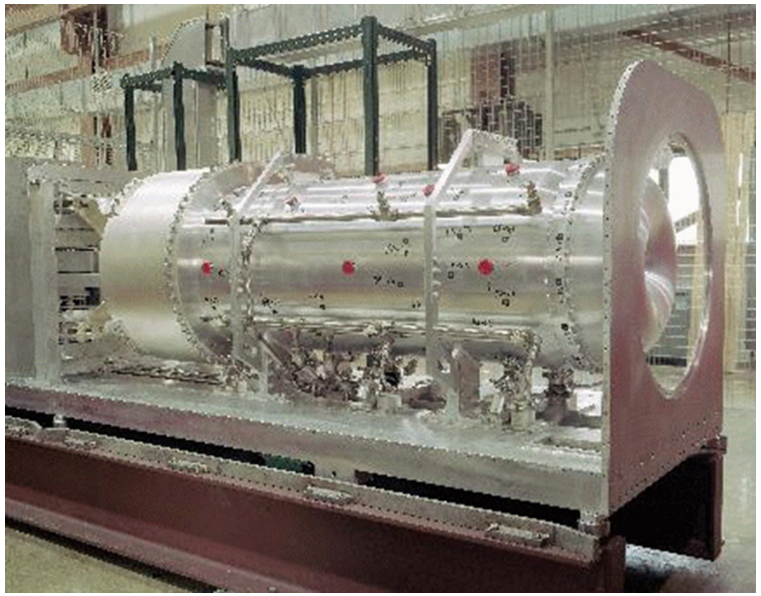
Outline

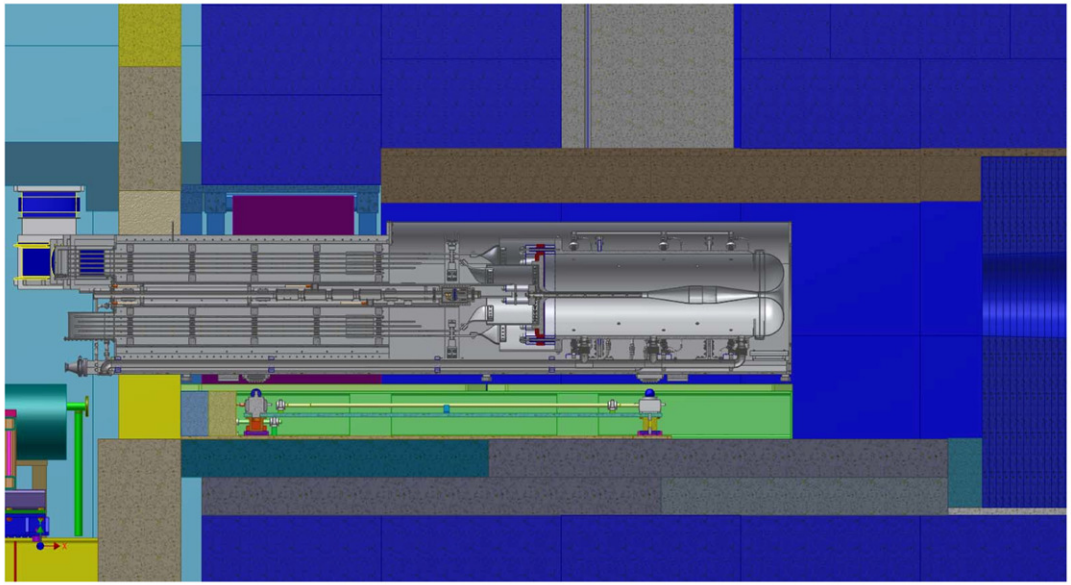
- Current BNB configuration and operation mode
- Scope of the proposed upgrades
- Proton economics and pulsing rate increase
- Optimization of the focusing efficiency
  - option1 ⟷ option2
  - status of the engineering analysis
- Horn power supply modifications
- Conclusions

Current BNB configuration

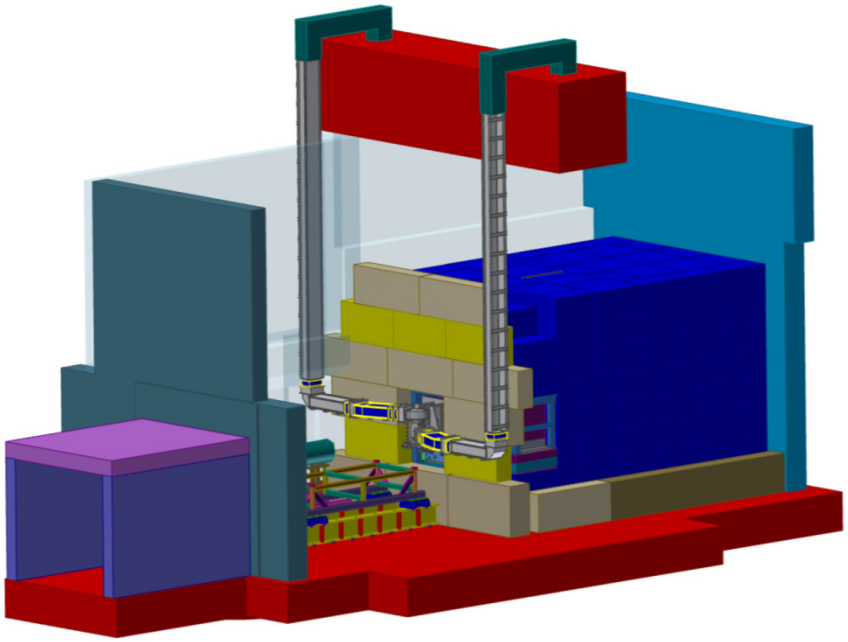


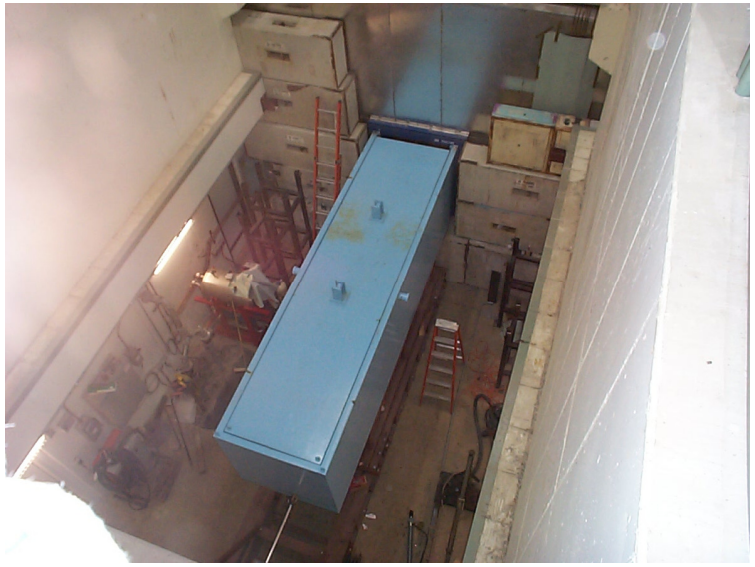
- 8 GeV protons, ~4.5×10^{12} protons/spill
- 70 cm Be target (1.7 λ_I), inserted in the horn neck
- 1.8 m long horn, pulsed at 172 kA, 6.1 kV, 145 μs pulse width
- max average rate of 5 Hz, up to 10 pulses in a row at 15 Hz

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



Scope limitations



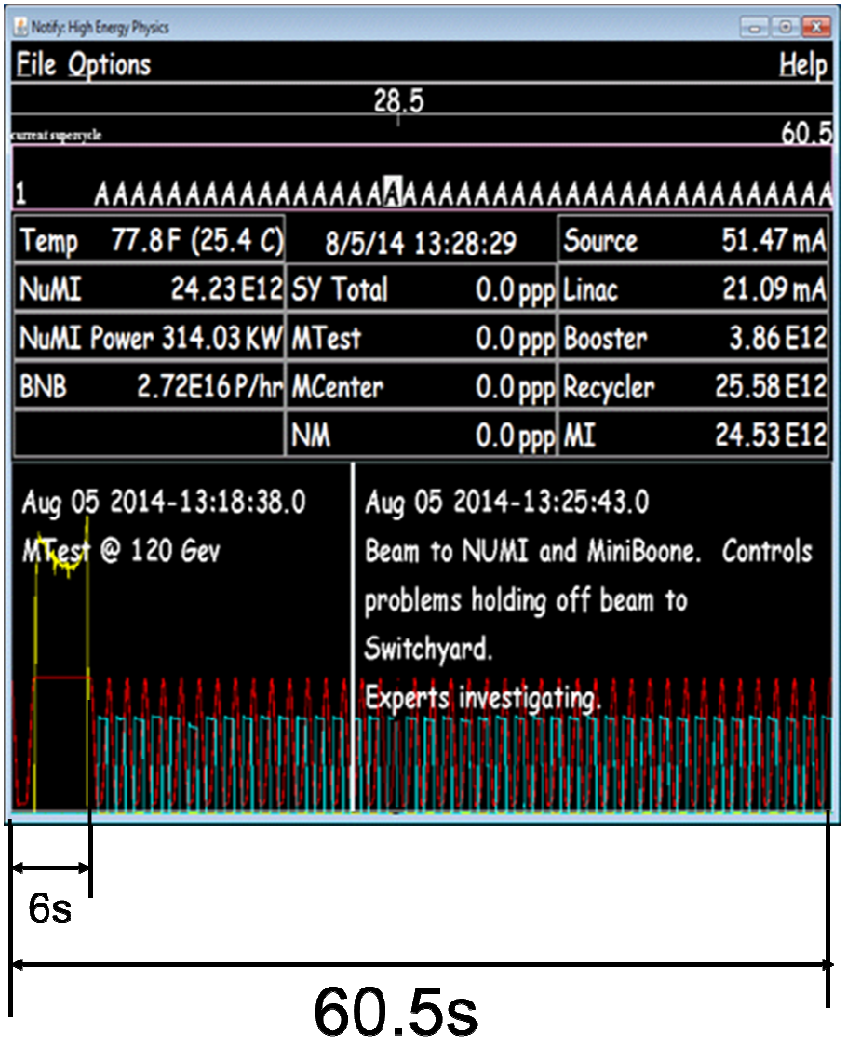


- **Target pile shielding**
  - Dismantling and rebuilding the target hall shielding will cost ~$15M and require 12 to 18 months
- **Building hatch size matched to the coffin length**
- **Upgrade options limited to what can fit within the present shielding/building**
  - More extensive upgrades (e.g. 2 horn options) precluded

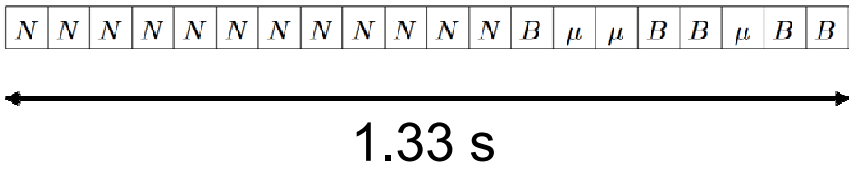
Upgrade paths

- Increase the focusing efficiency of the target/horn system
  - Horn simultaneously optimized for length, inner conductor shape, and current
  - Horn + stripline length limited to what can fit within the present shielding
  - Horn diameter matched to the present collimator
- Increase the rate the horn system can run at
  - By 2016, the Booster will operate at a rate of 15 Hz
  - It's beneficial to have the flexibility to take advantage of more cycles
  - This requires improvements to the horn power supply & mechanical integrity of the horn (as a function of the horn current)
- The scope of the upgrade is limited by considering options that fit within a budget of ~$6M

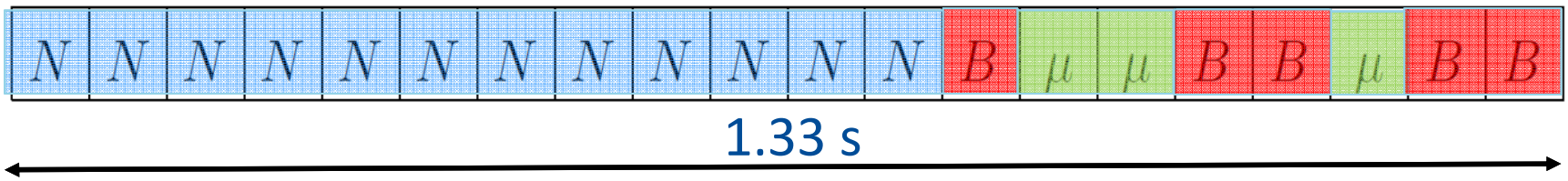
Proton delivery



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



Proton economics



N → NuMI

B → BNB (3.76 Hz)

μ → muon campus

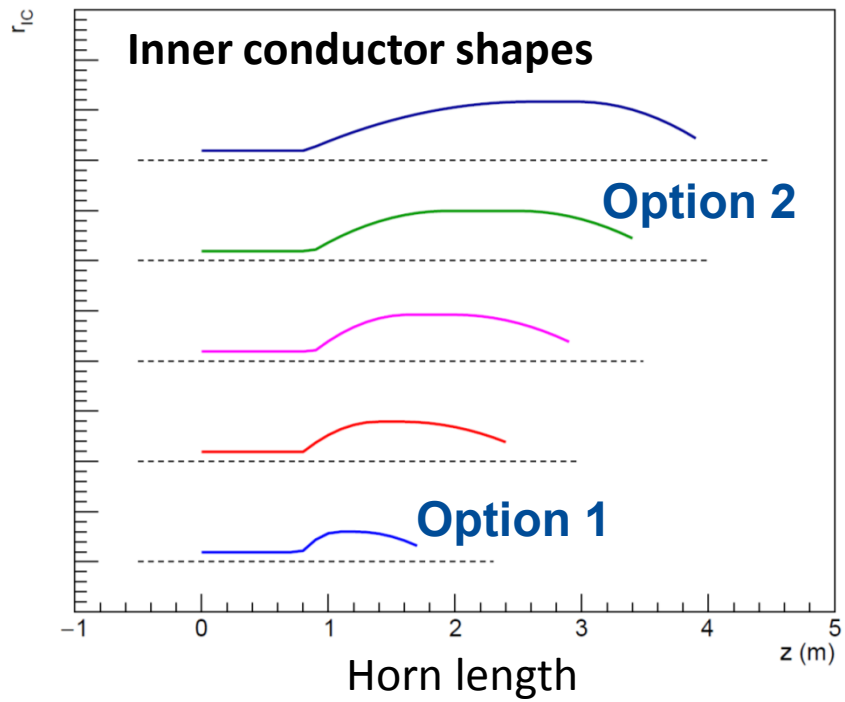
Additional beam to BNB (relative to max 5 Hz Running)

$$= 2.4\, f_{NuMI} + 0.6\, f_{\mu} + 0.22$$

- f_{NuMI}: % NuMI downtime; 2.4: BNB @ 12.8 Hz
- f_{μ}: % Muon campus downtime; 0.6: BNB @ 6 Hz
- 0.22: Slow extraction; BNB @ 15 Hz

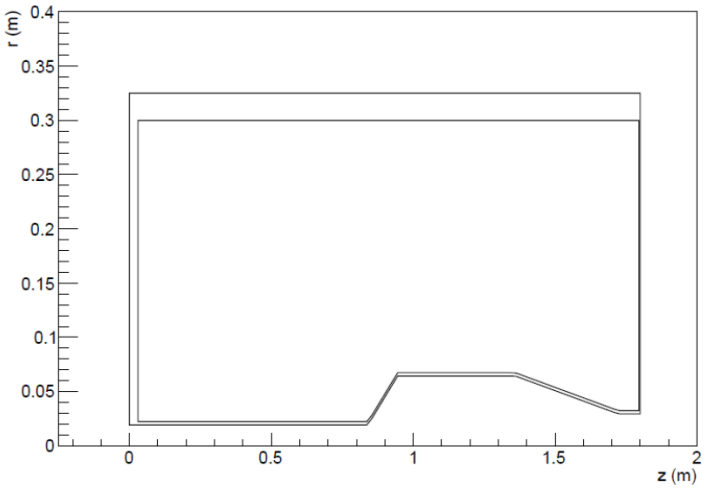
Optimization of the focusing efficiency

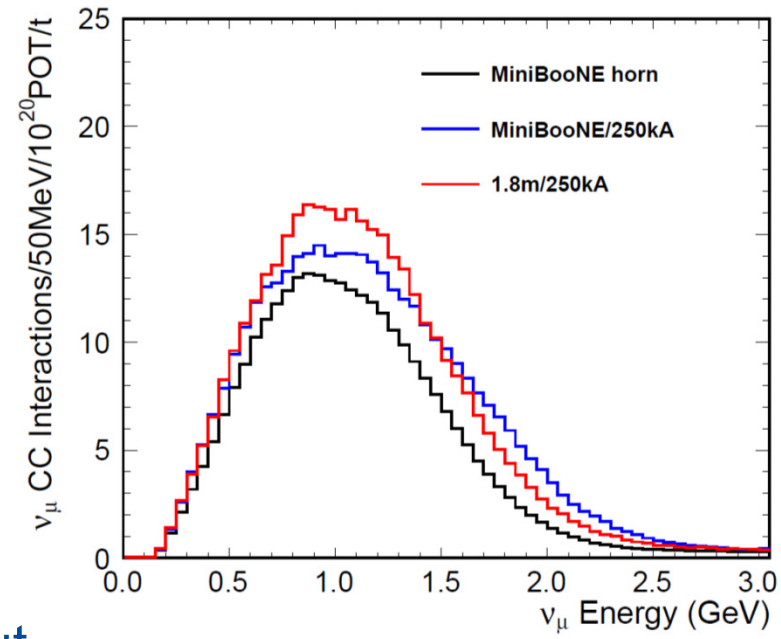
- Optimization by shaping the magnetic field in the focusing horn to direct sign selected secondary particles toward the detectors
- **Inner conductor shape (seven parameters) is the single most important aspect considered here**
- Horn current is integral to the conductor shape, and tends to be as large as possible
- **Adopted figure of merit is total number of neutrino interactions**



- LAr TPC detectors more tolerant of high energy tail

Option 1: ν_μ CC spectrum

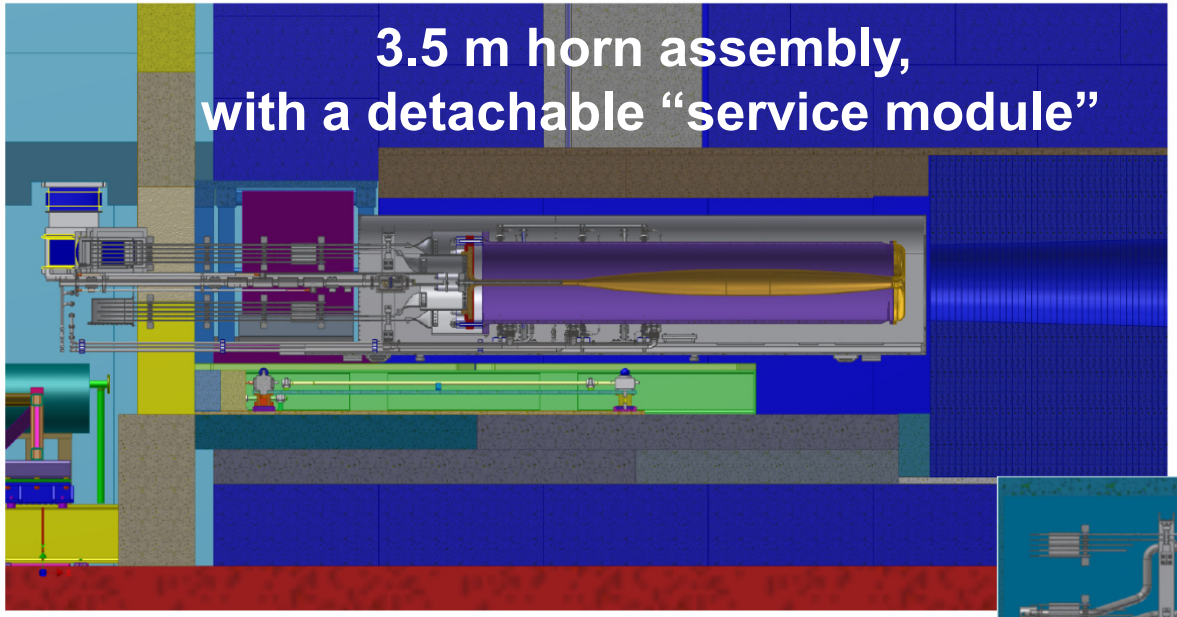




Install an improved inner conductor, but maintain the current horn length (180 cm)

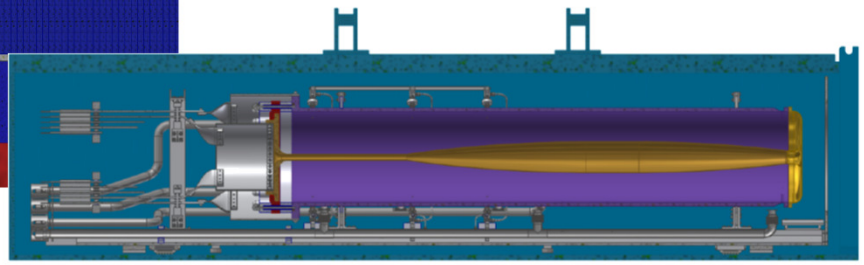
Option	Current (kA)	Relative Yield	Rel. Peak Yield
MiniBooNE (nominal)	172	1.00	1.00
MiniBooNE	250	1.28	1.08
Opt 1	250	1.30	1.24

Option 2: mechanical assembly

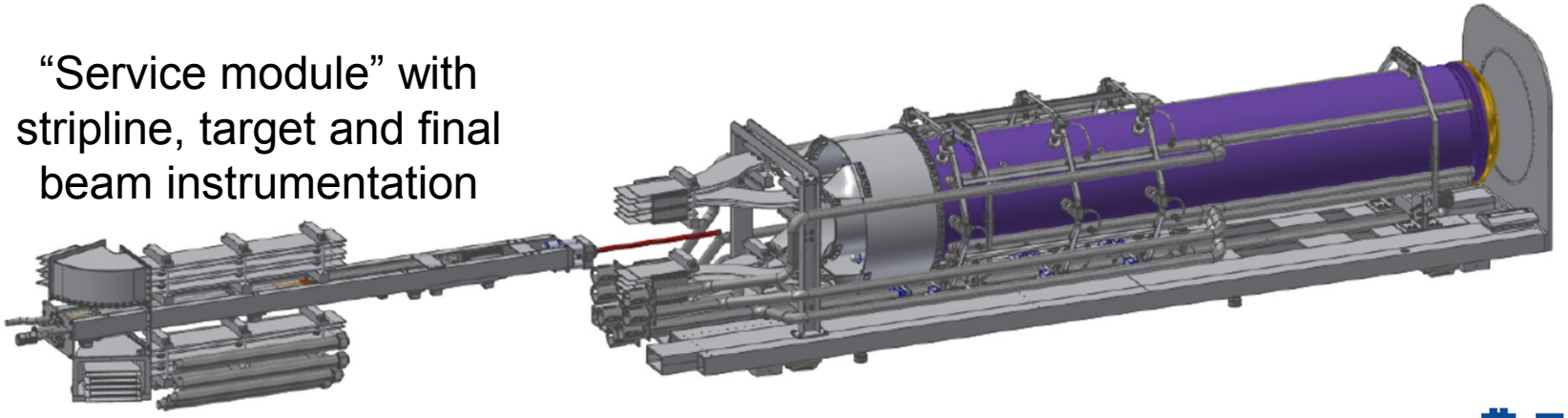


Target position moves upstream 44 cm relative to MiniBooNE horn

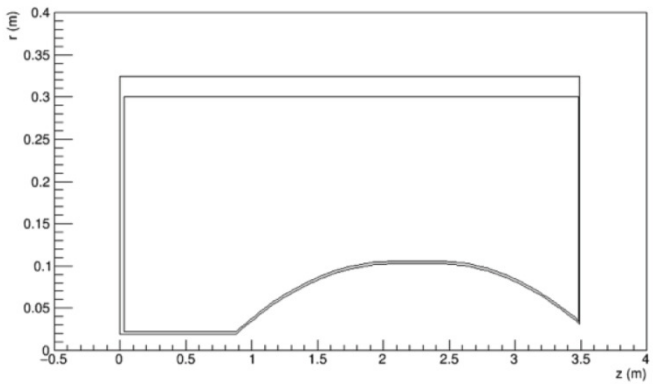
Horn with stripline connection inside the shielded coffin

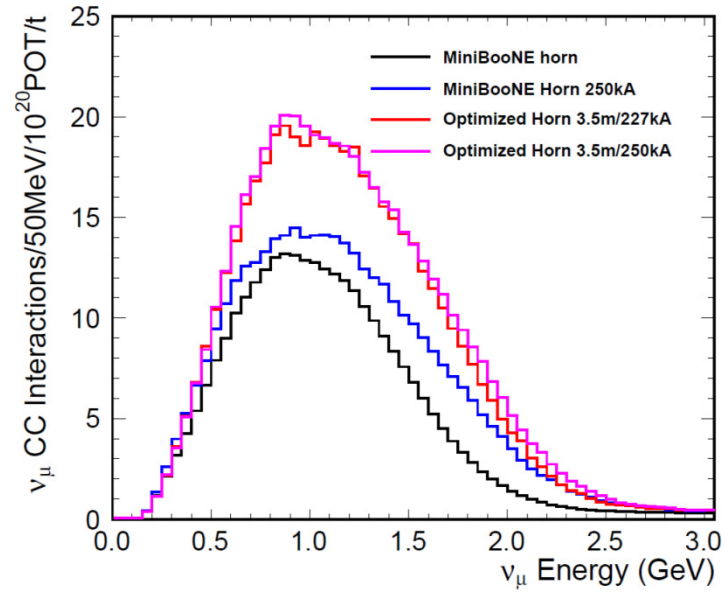


"Service module" with stripline, target and final beam instrumentation



Option 2: ν_μ CC spectrum

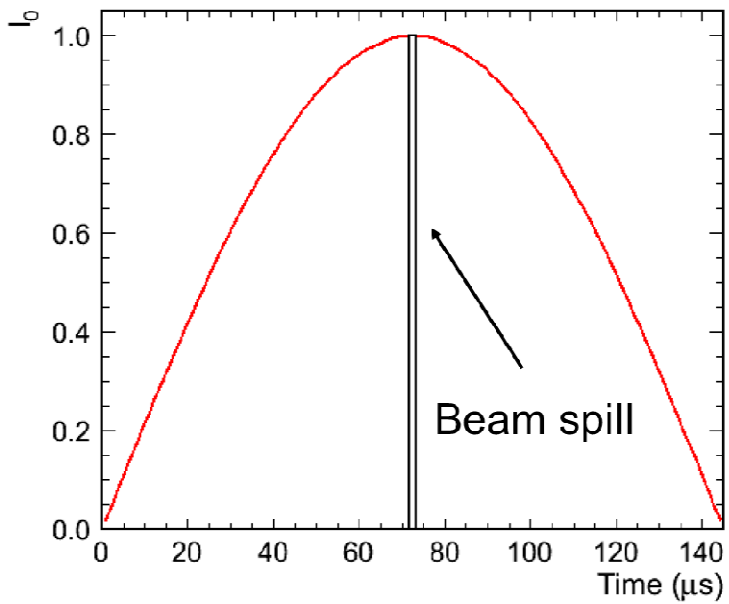


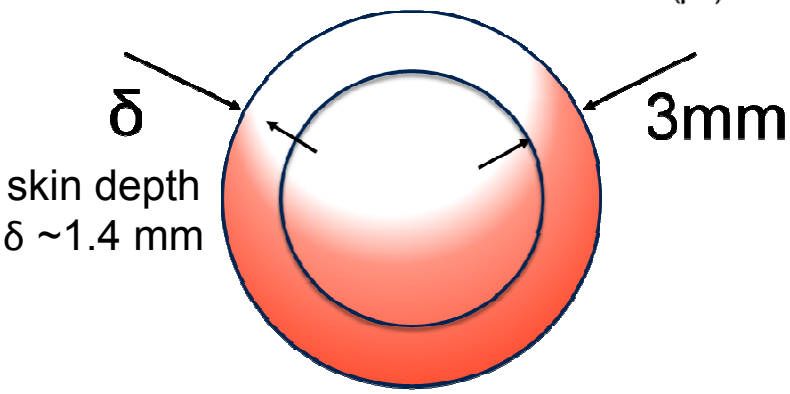


3.5 m long horn with the inner conductor optimized for each specific current

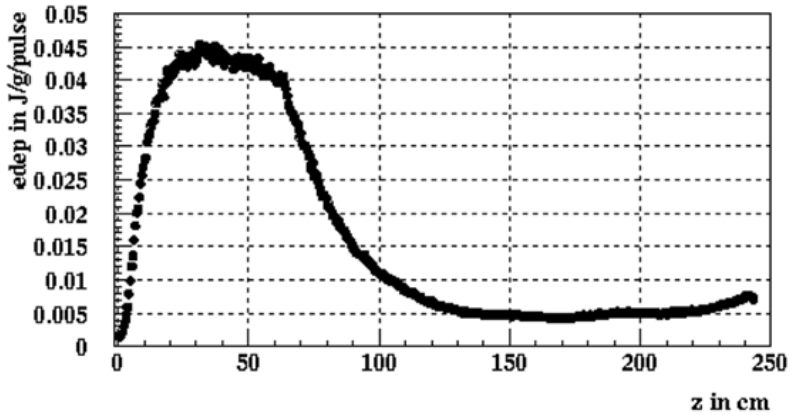
Option	Current (kA)	Relative Yield	Rel. Peak Yield
MiniBooNE	178	1.00	1.00
Opt 2	180	1.48	1.29
Opt 2	200	1.55	1.38
Opt 2	220	1.62	1.45
Opt 2	240	1.68	1.52
Opt 2	250	1.71	1.52

Horn heat loads

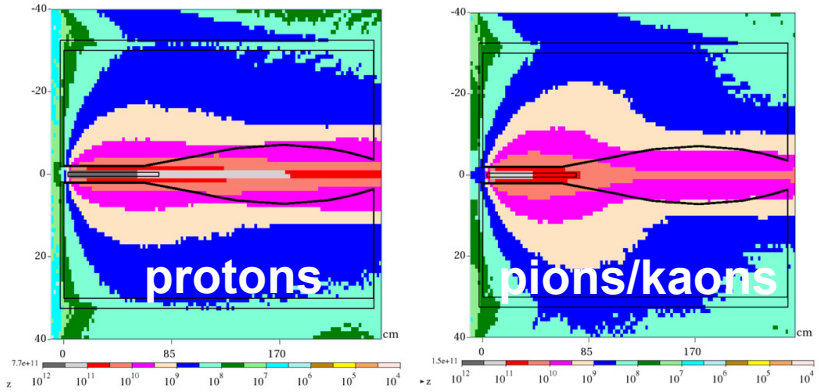




- Beam heating @ 4.5×10^{12} pot/pulse
- Beam heating small compared to expected Joule heating (<10% at 175kA)



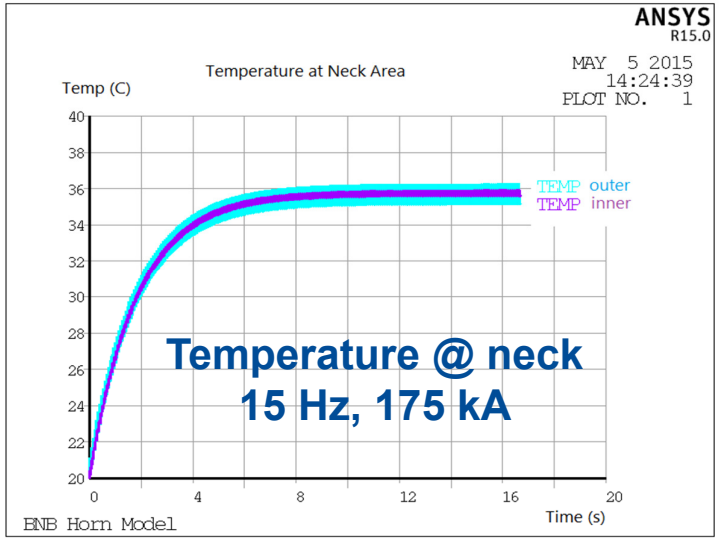
Particle flux /m²/pulse

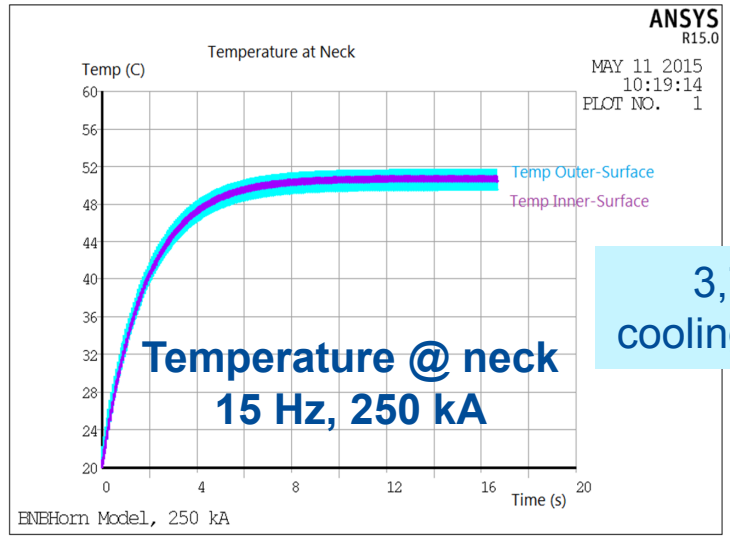


Horn engineering analysis

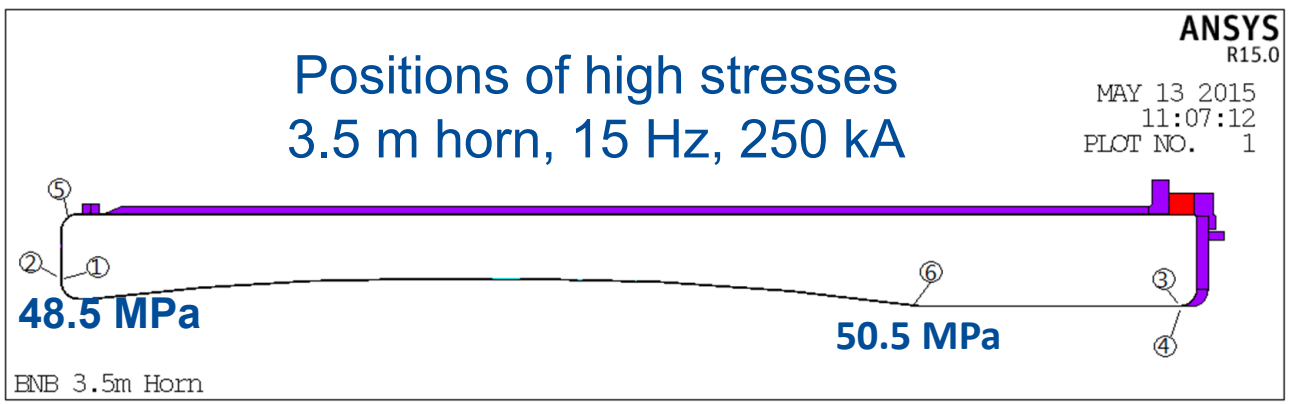
- **Heat loads dominated by horn current**
- **Stresses are due to heat loads and magnetic forces**
- **Compared with other neutrino beams, the BNB horn cycles much more rapidly**
  - it will experience ~10^8 cycles/year, so fatigue lifetime needs careful evaluation
- **Engineering studies for BNB horn upgrades are in the early stages**
  - design adjustments to reduce horn conductor stresses need to be studied and iterated
  - some synergy with the design of optimized horns for LBNF (first horn starts with a similar shape)

Some preliminary FEA analysis





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



Need design adjustments & fatigue lifetime evaluation

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 the power supply** (enclosure, internal connections, SCR,…)

- **Considered upgrades**
  - add cooling to the recovery choke to increase the max current by 20-30%
  - add charging supply to decrease the charge time (needed for longer horns)
  - replace capacitors with a higher RMS current (need to contact vendors)

Horn power supply "minor" modifications

Option 1

PS mods	Max.current(kA)	Max. rate (Hz)
No mods	162	15
	250	6.3
RC	178	15
	250	7.6

Recovery choke limit @ 145 A

Option 2

PS mods	Max.current(kA)	Max. rate (Hz)
No mods	130	15
	250	4.3
RC	130	15
	250	4.3
RC + CS	150	15
	250	5.4

Recovery choke limit @ 145 A

… + 25% additional power supplies

Conclusions I

- **We have presented a set of upgrade options for BNB which could result in a gain of 1.3 to 2 in the numbers of neutrino events**

- **Upgraded power supply:**
  - will provide a gain in Protons on Target of ~15-30% due to the opportunistic use of beam pulse
  - will allow to increase the current and/or the rep rate, especially for longer horns
  - the entire range of upgrades, such as the availability of capacitors with different specifications, has not yet been explored
- **Optimization of the focusing efficiency:**
  - with the same horn length as the present horn, we could gain a max of 30% in the neutrino yield/pot
  - with the maximum horn length that could fit in the present shielding/building, we could we could gain ~50 to 70% in the neutrino yield/pot, depending on the horn current
  - engineering analyses of the horn are in the early stages

Conclusions II

- **The total gain will be a combination of the focusing efficiency & rep rate, with reasonable assumption on the NuMI/muon campus downtime**

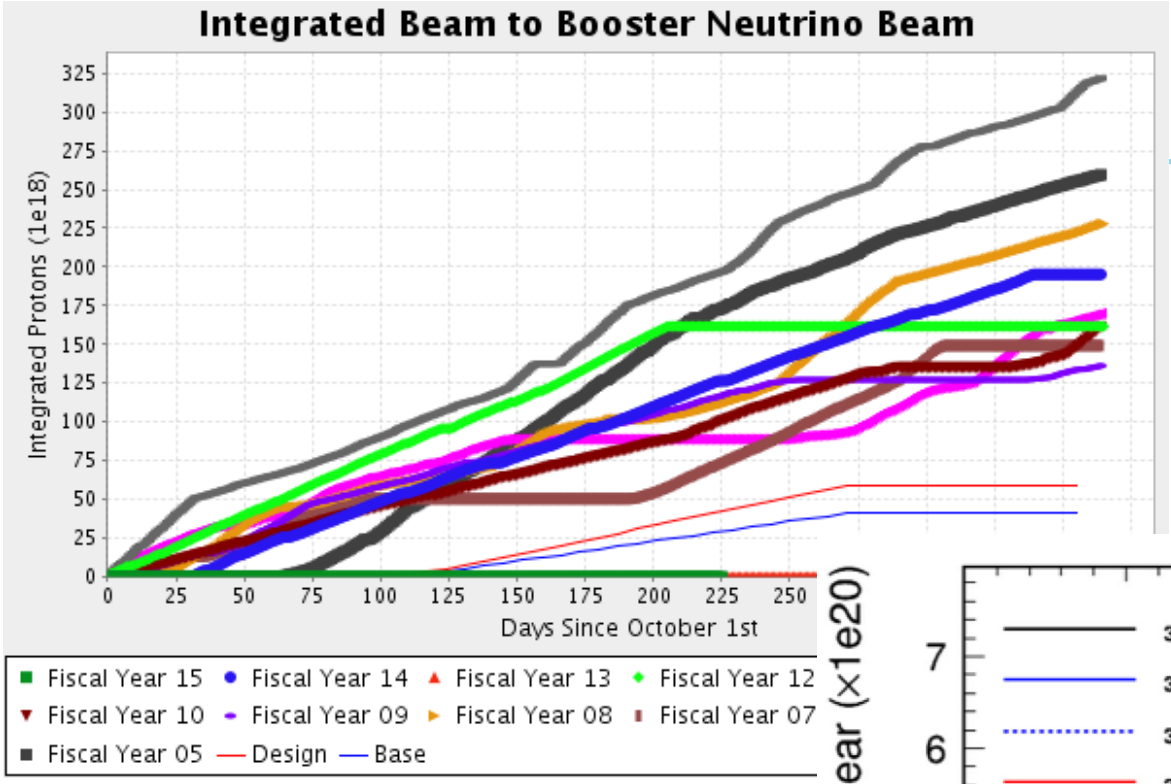
- **Not yet able to determine the "best" option**
  - the estimated performance of each option is preliminary at this time and subject to further engineering

- **Preliminary and somewhat conservative assumptions for the costs:**
  - $1.5M for horn power supply upgrades
  - $1M for Option 1 optimized horn
  - $5M for Option 2 optimized horn

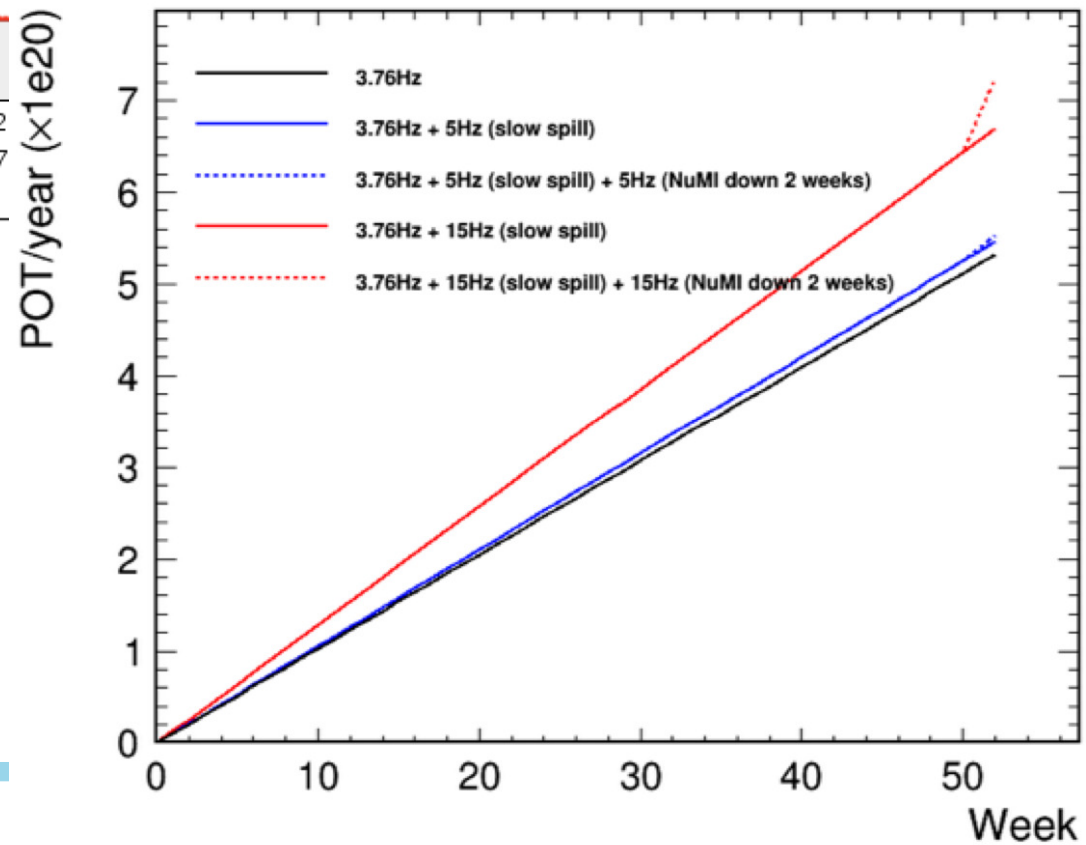
- **We would like to have the availability of resources to complete the conceptual design in 2016**

Backup

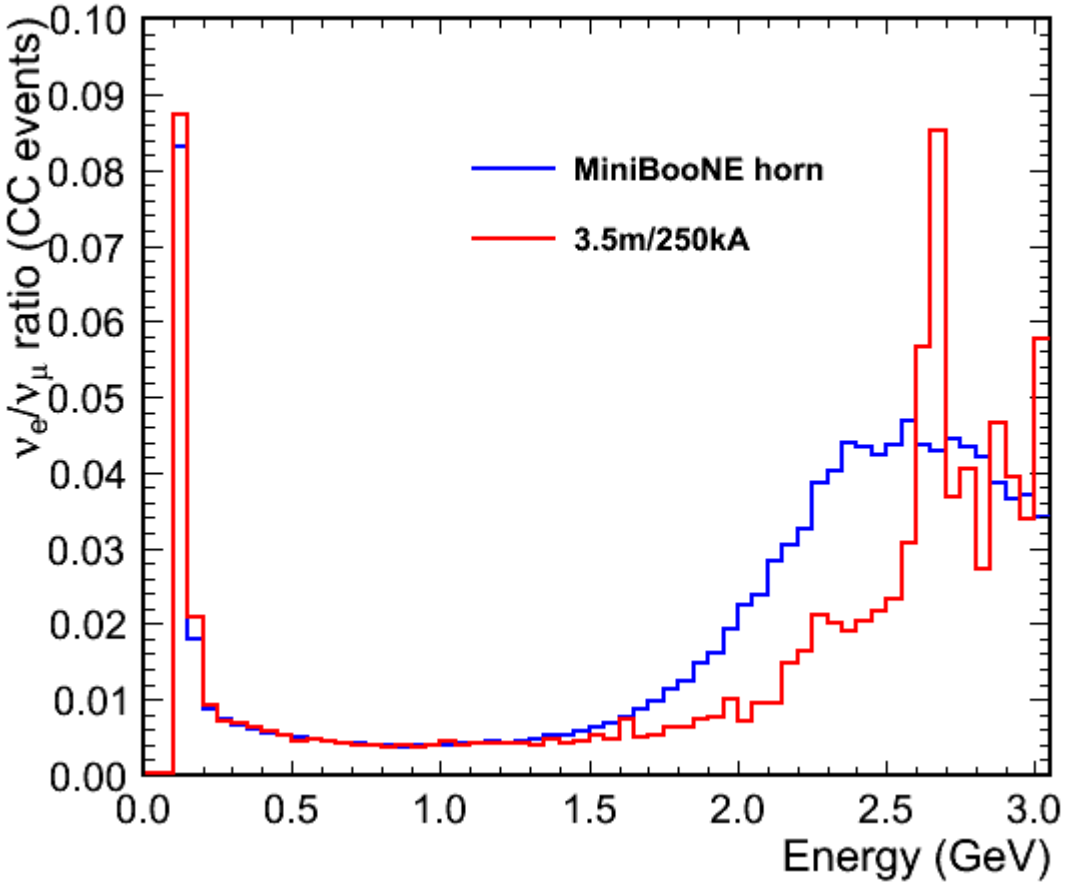
Future vs past running



- Best year of running had 3.2e20 POT
- With 3.76Hz average running and 15Hz during 6s long spill expect 6.4e20 (@100% beam uptime)

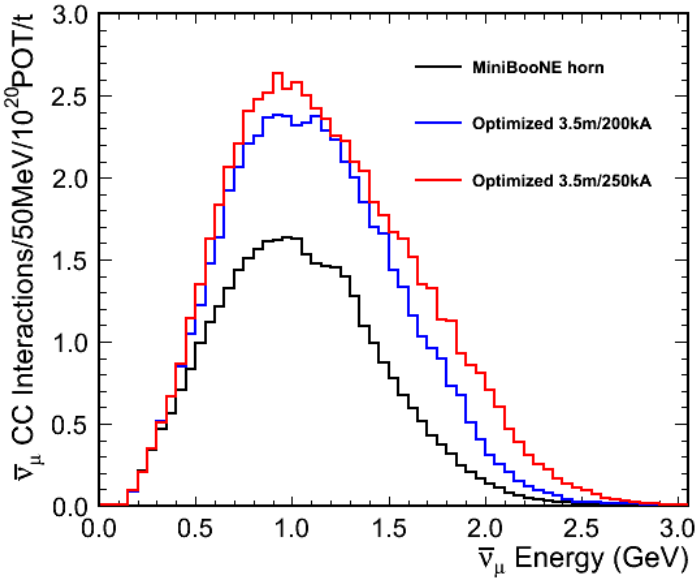


ν_e background for neutrino mode

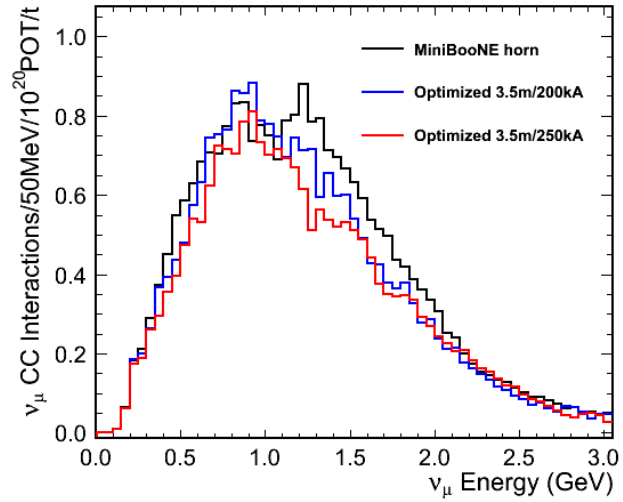
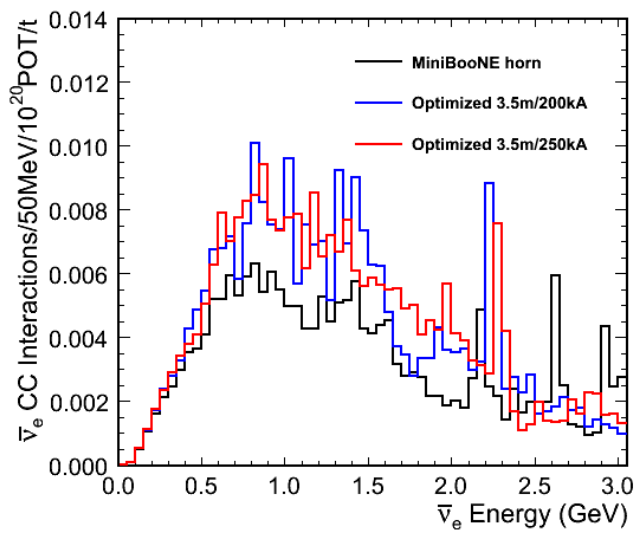


Anti-neutrino running mode

Gain of 1.8 @ 250 kA,
1.56 @ 200 kA



significant reduction in
wrong-sign component



fractionally smaller
ν_e-bar background