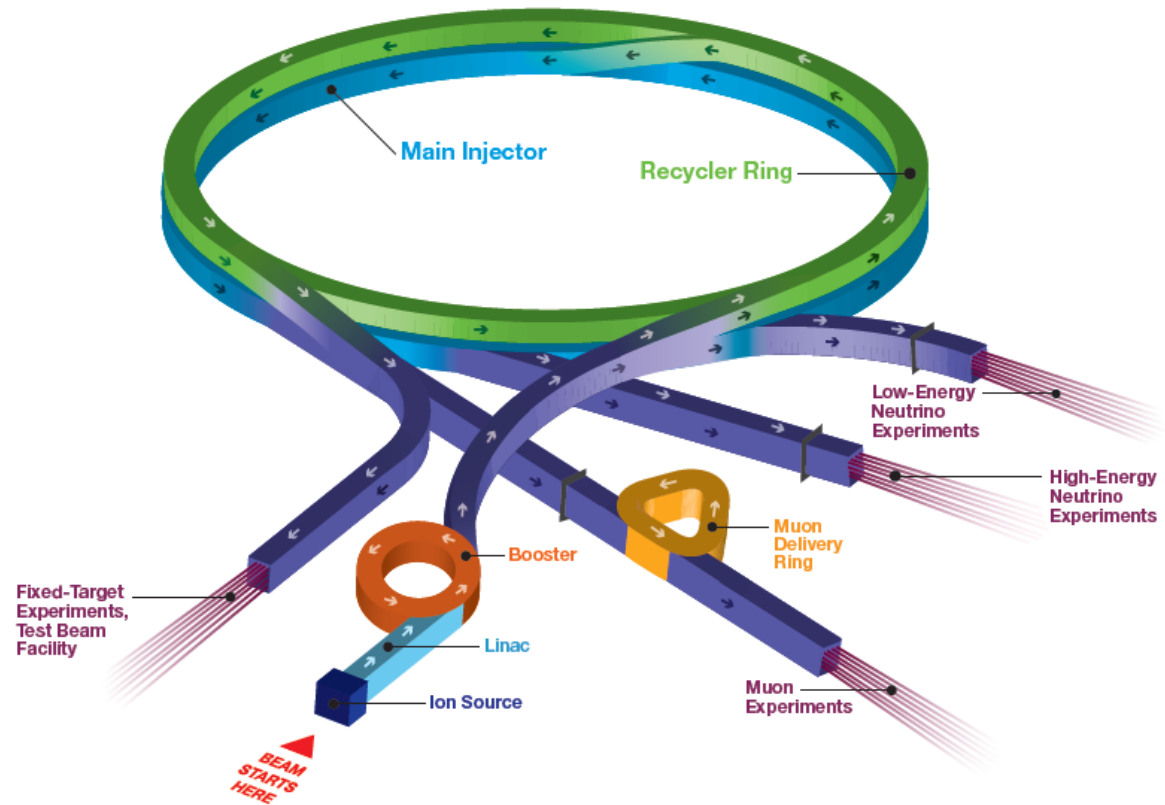




# Accelerator Expectations for FY17

Mary Convery  
PAC meeting  
20 June 2016

# Fermilab Accelerator Complex



- BNB: MicroBooNE
- NuMI: MINOS+, MINERvA, NOvA
- Fixed Target: SeaQuest, LArIAT, Test Beam Facility
- Muon: g-2, Mu2e (future)

# Fermilab Experiments' Run Schedule

		FY 2016				FY 2017				FY 2018				FY 2019				
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
NuMI	MI		MINOS+															v
		MINERvA		MINERvA		MINERvA			MINERvA									
		NOvA		NOvA		NOvA			NOvA									
BNB	B		MicroBooNE			MicroBooNE			MicroBooNE		SBN:MicroB		SBN: MicroBooNE				μ	
				SBN: ICARUS		SBN:ICARUS	SBN: ICARUS											
				SBN: SBND		SBN: SBND			SBN: SBND									
Muon Campus			g-2			g-2			g-2			g-2					p	
		Mu2e		Mu2e		Mu2e			Mu2e									
SY 120	MT		FTBF - MTEST			FTBF - MTEST			FTBF - MTEST			FTBF - MTEST						
	MC	OPEN FTBF - LArIAT		OPEN		OPEN			OPEN									
	NM4	SeaQuest		SeaQuest		SeaQuest ?			SeaQuest ?									
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	



RUN / DATA

Length of mid-year maintenance shutdowns for FY16 and beyond under discussion



STARTUP/COMMISSIONING

Transition from SeaQuest to Polarized-DY under consideration



INSTALLATION/COMMISSIONING

MINOS+ runs through FY16 and is then completed.



M&D (SHUTDOWN)

g-2 hope to get some data during the commissioning period in FY17, just before the summer shutdown

# Accelerator Operations Priorities for FY16-18

- Ramp up beam power to 700 kW for NOvA, achieve performance metrics, and support full experimental program
- Continue carrying out the Proton Improvement Plan to reach  $>2 \times 10^{17}$  protons/hour in the Booster and ensure a useful operating life of the proton source through at least 2030
- Complete the Muon Campus construction in FY17, on budget and on schedule
- Commission and operate beam to the g-2 experiment starting in FY17
- Build an upgraded horn and power supply in the Booster Neutrino Beam target station for Short Baseline Neutrino

## **FY16 performance:**

**Ramp up beam power to 700 kW for NOvA, achieve performance metrics, and support full experimental program**

# Booster 15 Hz Running

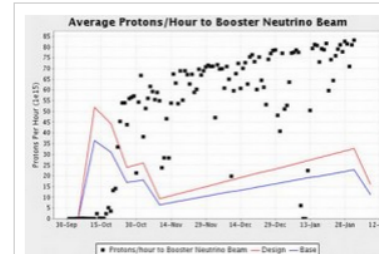
- Capable of 15 Hz Booster beam since June 2015
- Delivering record proton flux!
- Enables us to supply beam to NuMI (at 700 kW), BNB, and the future Muon Campus

News

## Booster Neutrino Beam reaches record beam intensity

February 2, 2016 | Mary Convery

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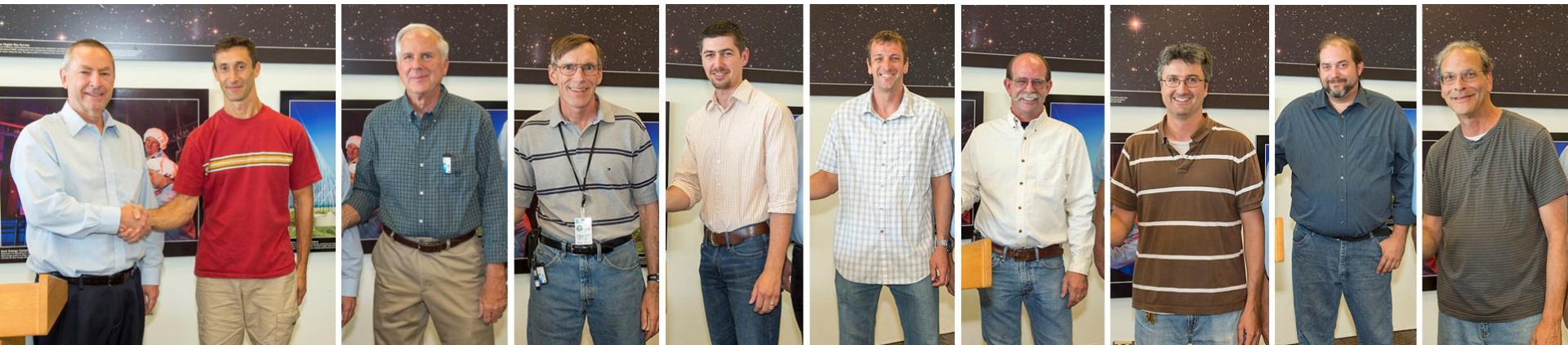


The black data points give the number of protons per hour provided to the Booster Neutrino Beam. The actual beam delivery intensity is well above the design intensity (red curve).

On Jan. 25, the Booster delivered a record  $5 \times 10^{12}$  protons per pulse at 5 Hz for half an hour while delivering 8.3-Hz beam to Recycler. The protons in the beam strike a target, and the resulting particles decay into neutrinos. The high-intensity proton beam translates into the highest-intensity neutrino beam sent down the Booster Neutrino Beamline (BNB) in its history.

BNB provides beam to MicroBooNE and several other small experiments and is the future home of the Short Baseline Neutrino experiments.

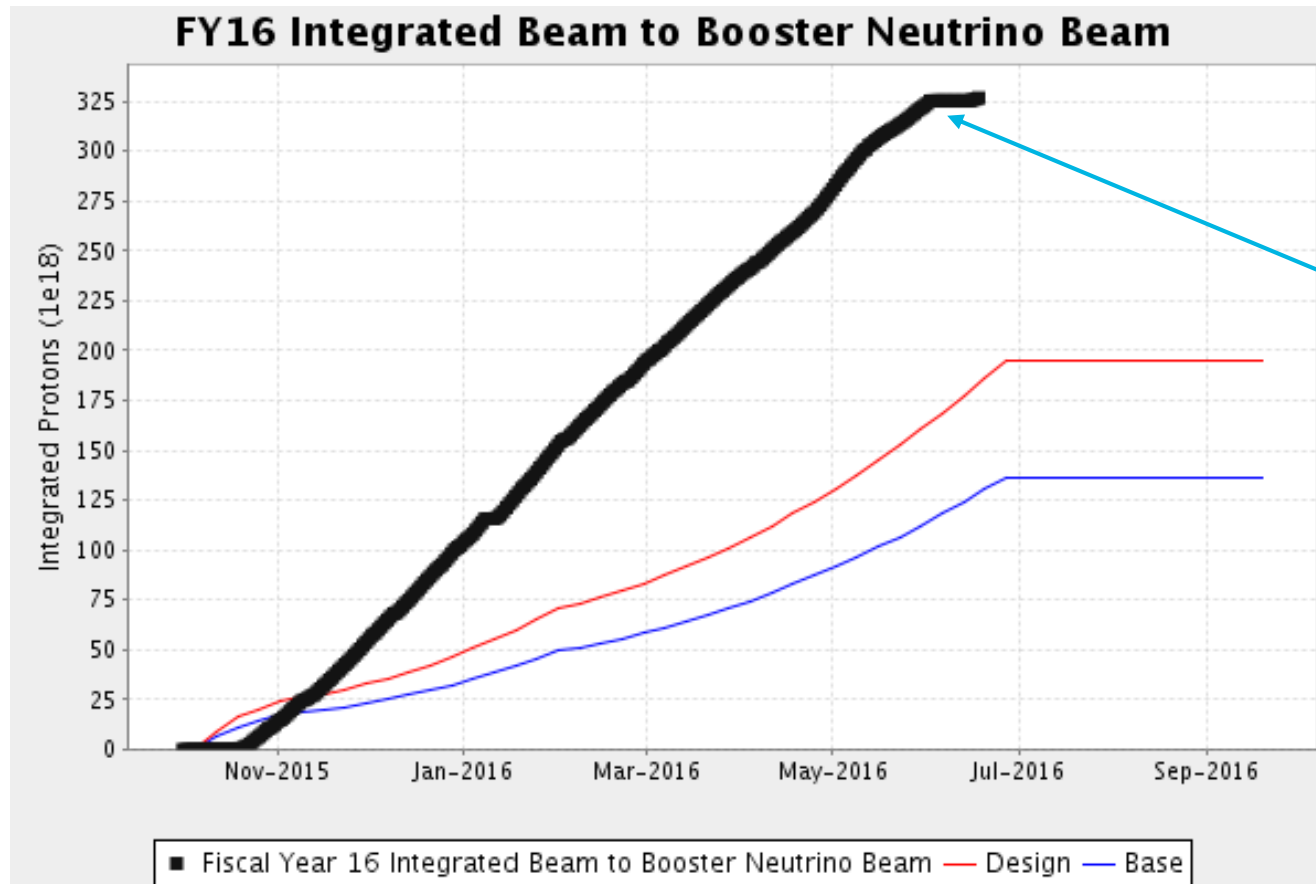
As a result of the Proton Improvement Plan, the Proton Source is now fully capable of 15-Hz operation, which will enable NOvA, the BNB experiments and the future Muon Campus experiments to run concurrently. Strategic efforts to improve beam delivery and reduce losses have additionally allowed increases in intensity to BNB.



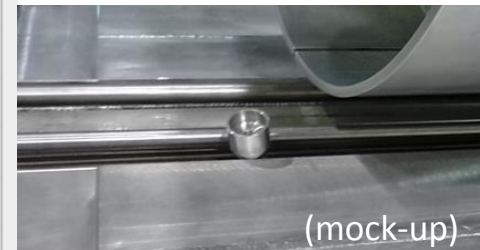
2015 Employee Performance Recognition Awards for 15 Hz in Booster



# FY16 Goals for Beam to BNB

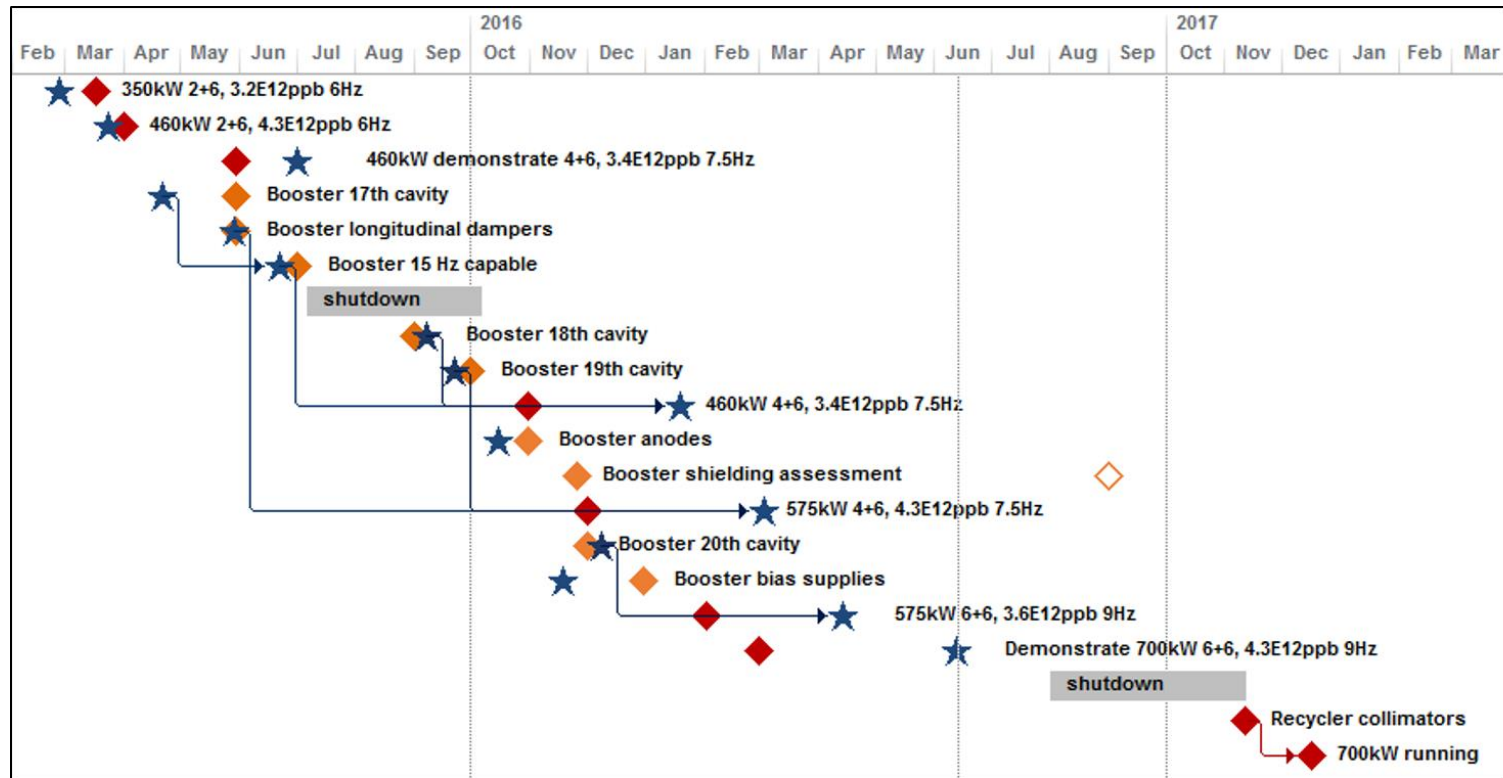


ground fault due to displaced cap on horn bolt to prevent corona discharge



- Booster ramp-up in flux (15 Hz and intensity) much faster than assumed
- Had extended running at 5-Hz repetition rate (target station design limit)
- Increasing NuMI power has not significantly impacted beam to BNB

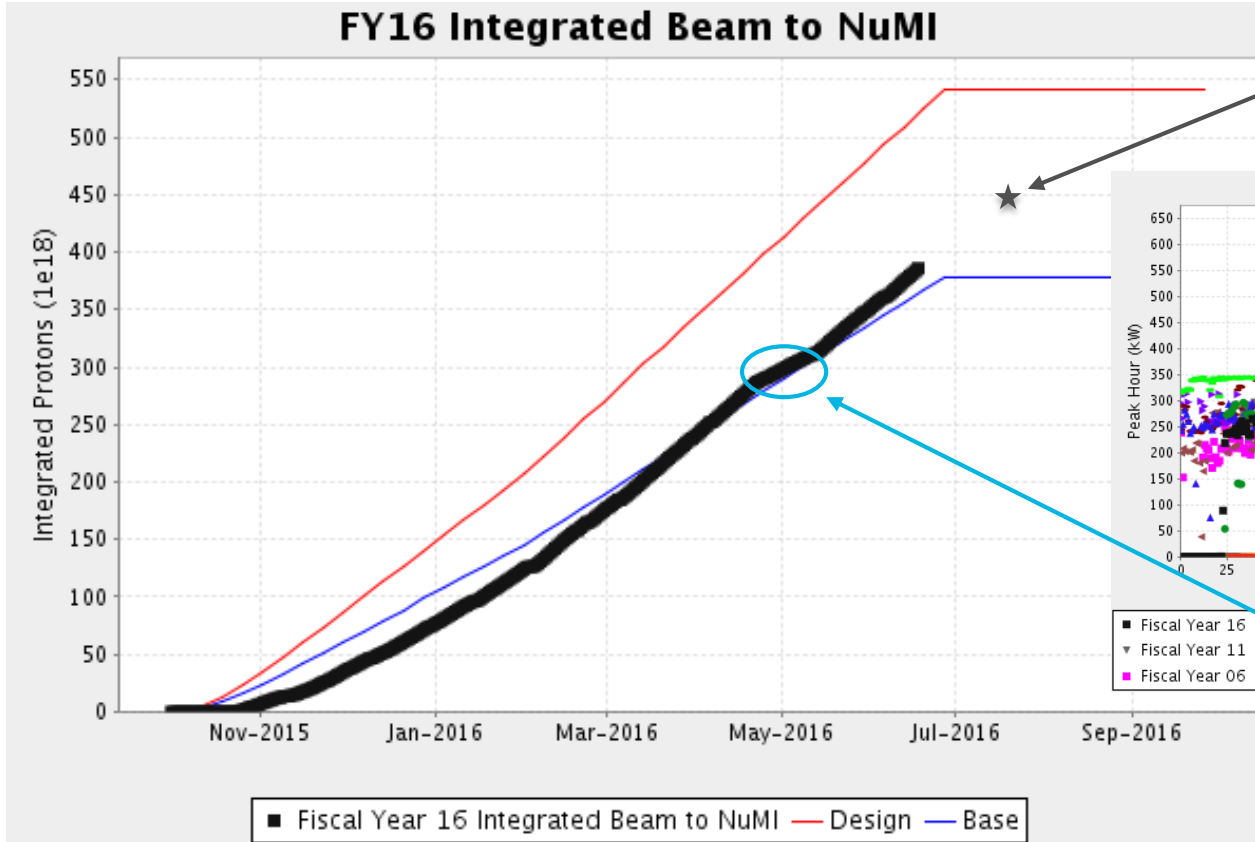
# Achieving Milestones for 700 kW Beam Power from MI



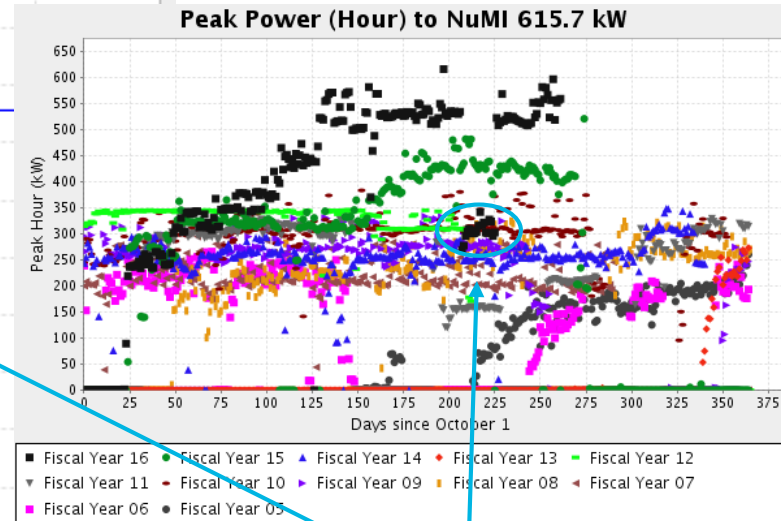
◆ Recycler milestone    ◆ Booster milestone    ◇ Milestone forecast date    ★ Milestone achieved

- Routinely running 6+6 slipstacking with beam power close to 600 kW
- Have demonstrated 700 kW, 1-hour record 615 kW
- Need Recycler collimators for full-time 700 kW operation

# FY16 Goals for Beam to NuMI



Projection takes into account likelihood of turning off when cooling pond temps too high

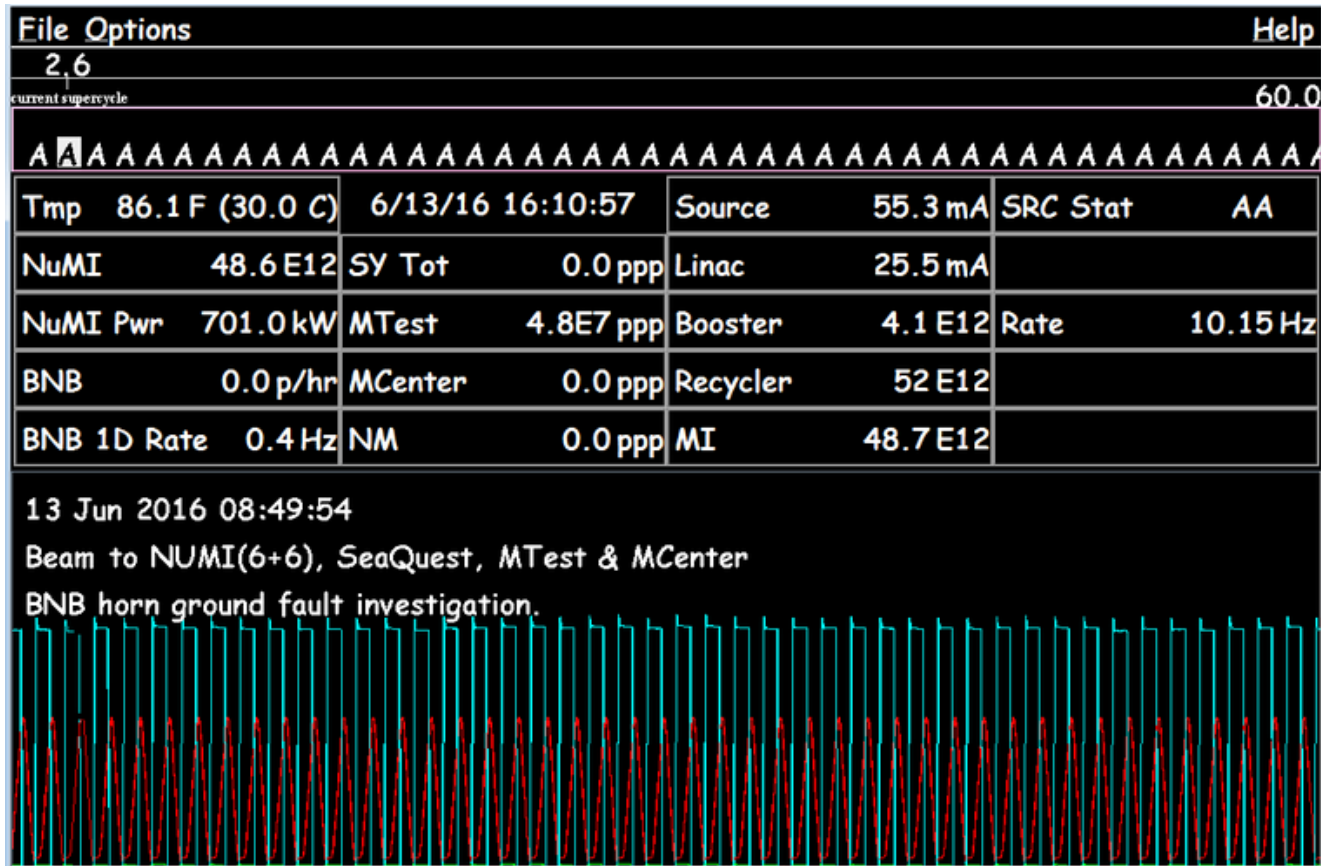


Recycler RF anode power supply transformer failure



- Based on milestones for achieving 700 kW beam power
- Beam startup delayed to allow upgrade of Booster anode supplies
- Recycler startup slowed by aperture restrictions which were fixed
- Now running consistently at highest power to date

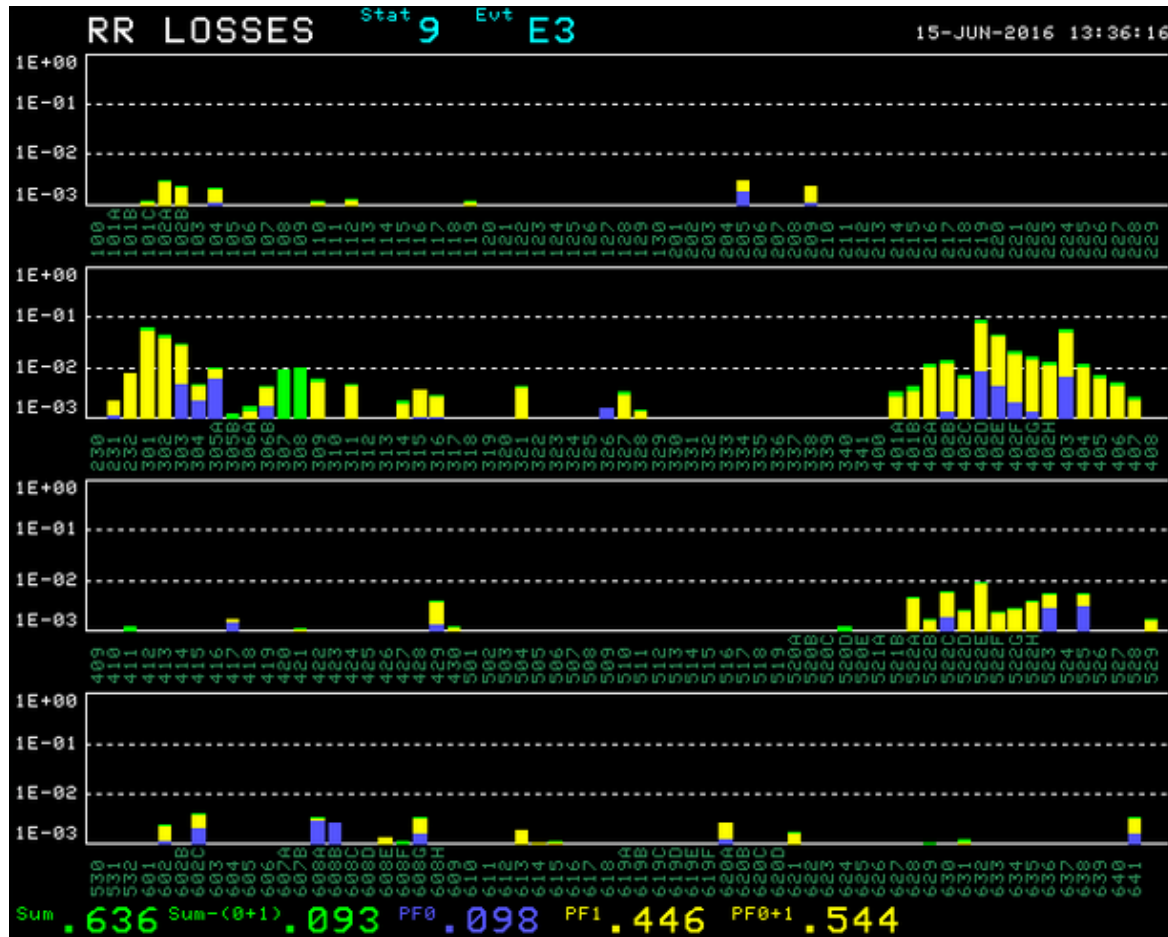
# 700 kW Beam to NuMI



- Have also met our internal goals
  - Run above 500 kW for 100 hours during one week with 10% of the timeline dedicated to slow extraction as usual (equivalent to beam power of 550 kW without slow extraction)
  - Run for 1h at 600 kW with 6+6 slip stacking without slow extraction

# Recycler Collimators

- Installing collimators in Recycler in order to run 700 kW continuous without significant irradiation of tunnel components



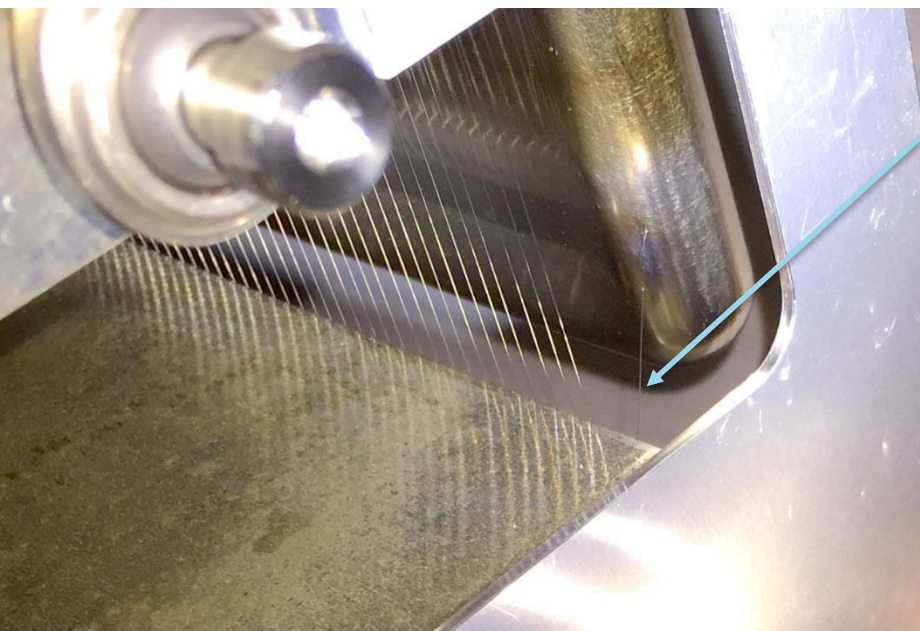
# Recycler Upgrades for NOvA Operations

- Conversion of vacuum system from titanium sublimation pumps to ion pumps, better suited for current Recycler operations
  - 1<sup>st</sup> phase complete, 2<sup>nd</sup> phase FY16 shutdown, final phase FY17
- Collimators in Recycler
  - Needed to run 700 kW continuous without significant irradiation of tunnel components
  - Design based on Main-Injector collimators
  - Primary and two secondaries in FY16
  - Two additional secondary collimators in FY17



## SY120 (120 GeV fixed target program)

- Delivering beam to Fixed Target Test Beam Facility as needed (the facility is fully subscribed)
- Supporting a second test beam for LArIAT liquid argon TPC
- Providing requested intensity to SeaQuest



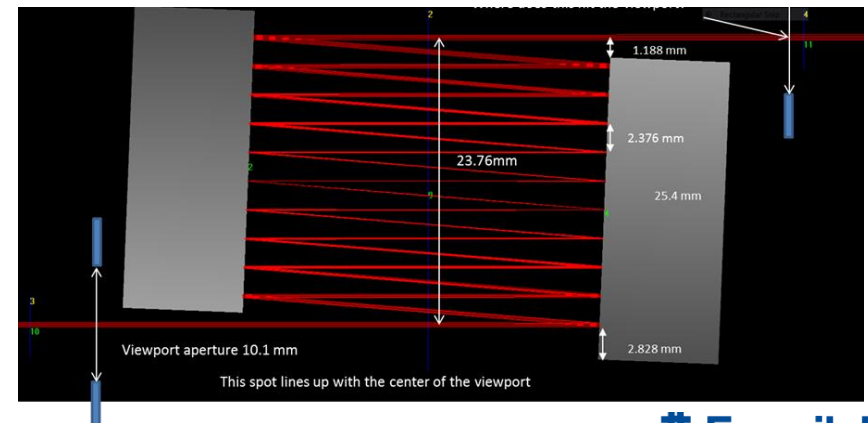
- Extraction septum 2 broken wires
  - Have two 2-mil spares
  - Plan to rebuild a 4-mil spare
- Improved beam-inhibit system with quadrupole input
- Worked with Test Beam Facility to improve particle identification

## **Proton Improvement Plan:**

**Continue carrying out the PIP to reach  $>2 \times 10^{17}$  protons/hour in the Booster and ensure a useful operating life of the proton source through at least 2030**

# PIP – Linac Upgrades

- 200 MHz Klystron – power-tested and delivered
  - First 200 MHz Klystron ever made
  - This device is capable of replacing our tetrode 7835
  - Developed replacement plan should it be needed
- 7835 Modulator – 28-cell unit operating in station 1, building 54-cell to install during shutdown
  - Greatly improved gradient stability



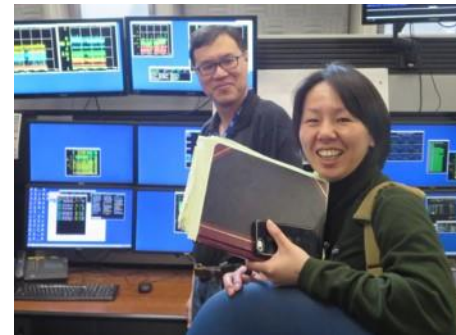
- Laser Notcher testing in progress

# PIP – Booster Upgrades

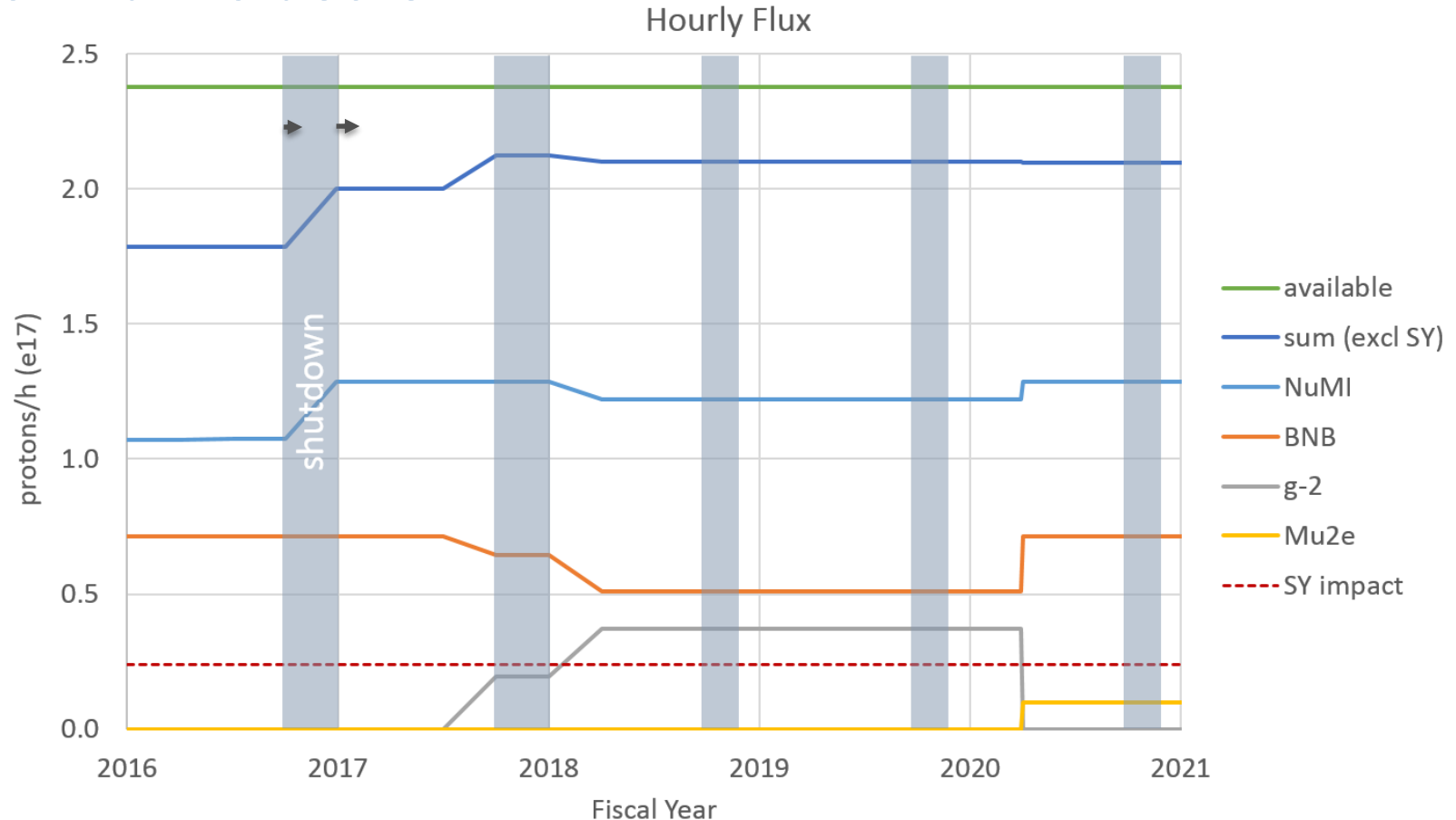
- RF cavity refurbishment complete, 20 stations installed, can run 15 Hz
- Additional new RF cavity tuners being produced by Technical Division
- Anode power supplies needed to run 20+ stations installed during shutdown
- Additional cavities 21 & 22 – retrofitting large-bore cavities
- Beam physics improvements and new instrumentation in progress
- Prototyping second-harmonic (perpendicular bias) cavity
- Designing replacement cavities compatible with PIP-II requirements



Workshop on Booster Performance and Enhancements Nov '15



# Proton flux to users



- Presently limited to  $1.8 \times 10^{17}$  proton/h by Booster shielding assessment
  - New assessment taking into account use of Total Loss Monitors being reviewed
- Switch from 1.33s to 1.4s cycle time starting in FY18 to accommodate g-2
  - NOvA and g-2 each get 95% of what they consider nominal

# **Accelerator Improvement Projects:**

## **Complete the Muon Campus construction in FY17, on budget and on schedule**

# Muon Campus Accelerator Improvement Projects

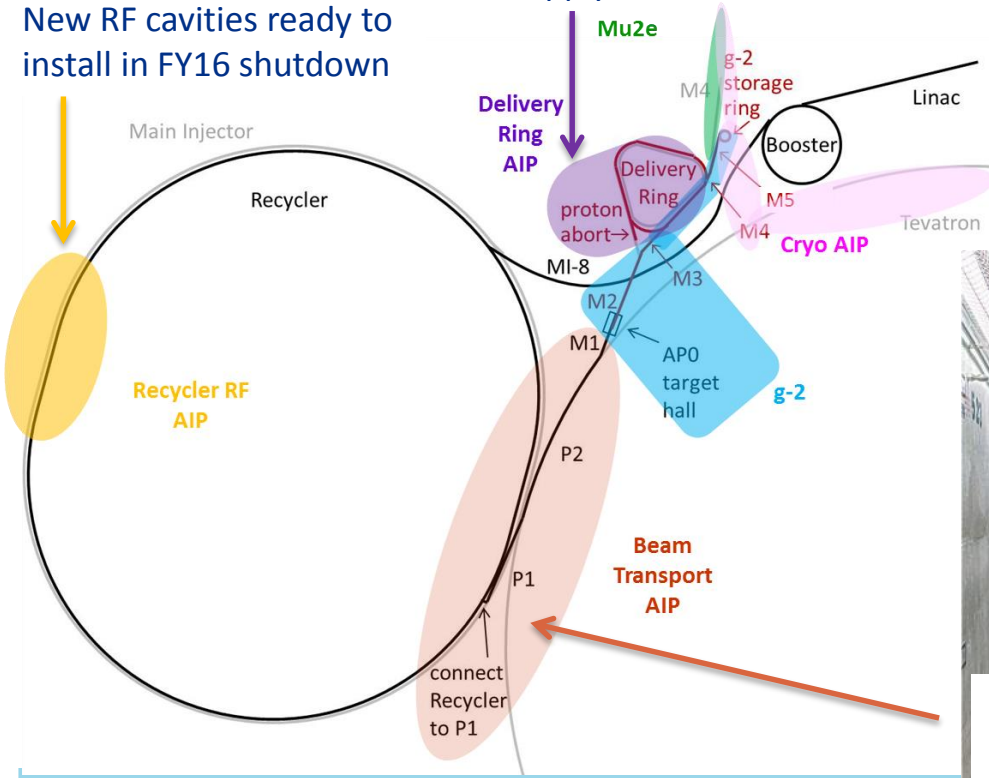
- AIPs under budget and on schedule to be ready in time for g-2



New RF cavities ready to install in FY16 shutdown

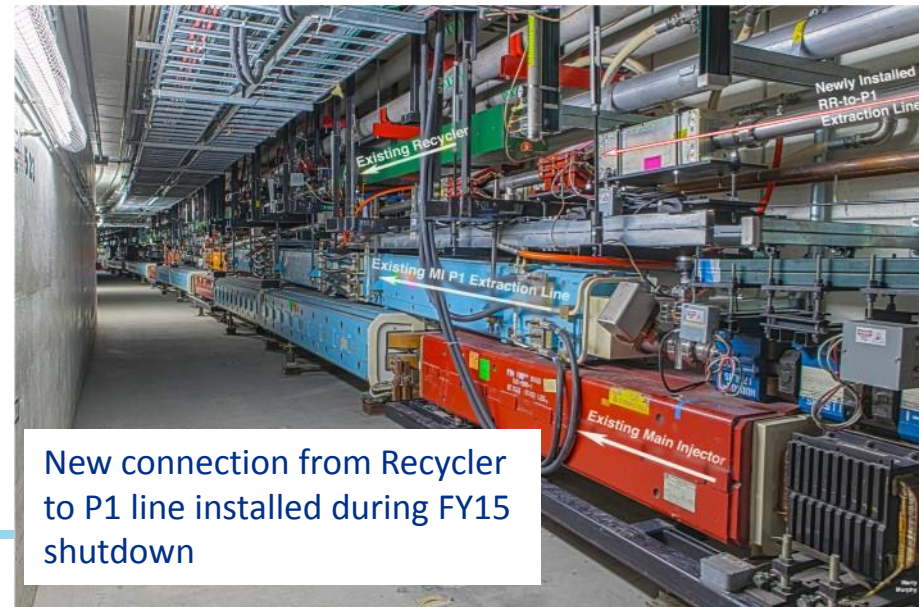


Pulsed septum power supply under construction



AIP	Total Project Cost	% complete
Delivery Ring AIP	\$9.7M	58
Recycler RF AIP	\$7.9M	81
Beam Transport AIP	\$6.5M	99
Cryo AIP	\$9.5M	68*

\* cryo work needed for g-2 is 100% complete



# Muon Campus Beamline Construction

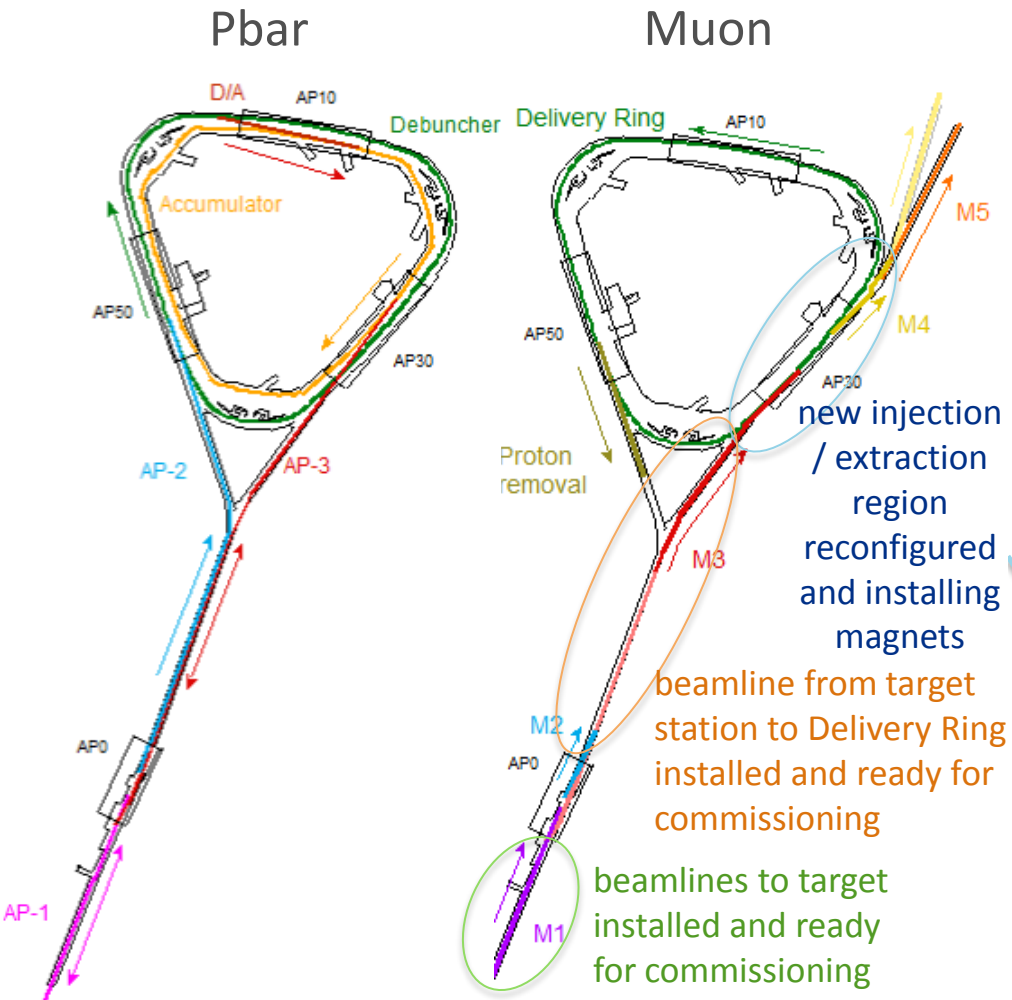


beamline from target station to Delivery Ring installed and ready for commissioning

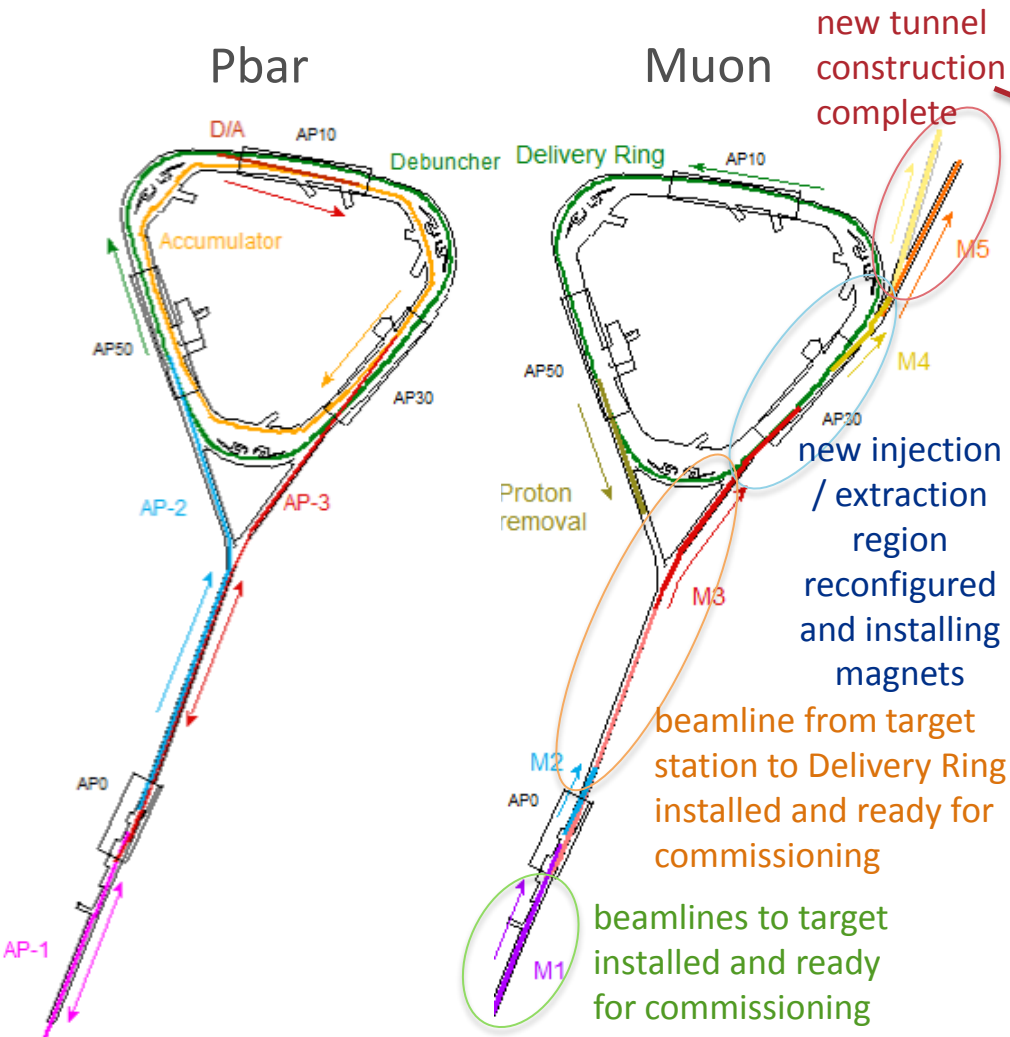
beamlines to target installed and ready for commissioning



# Muon Campus Beamline Construction



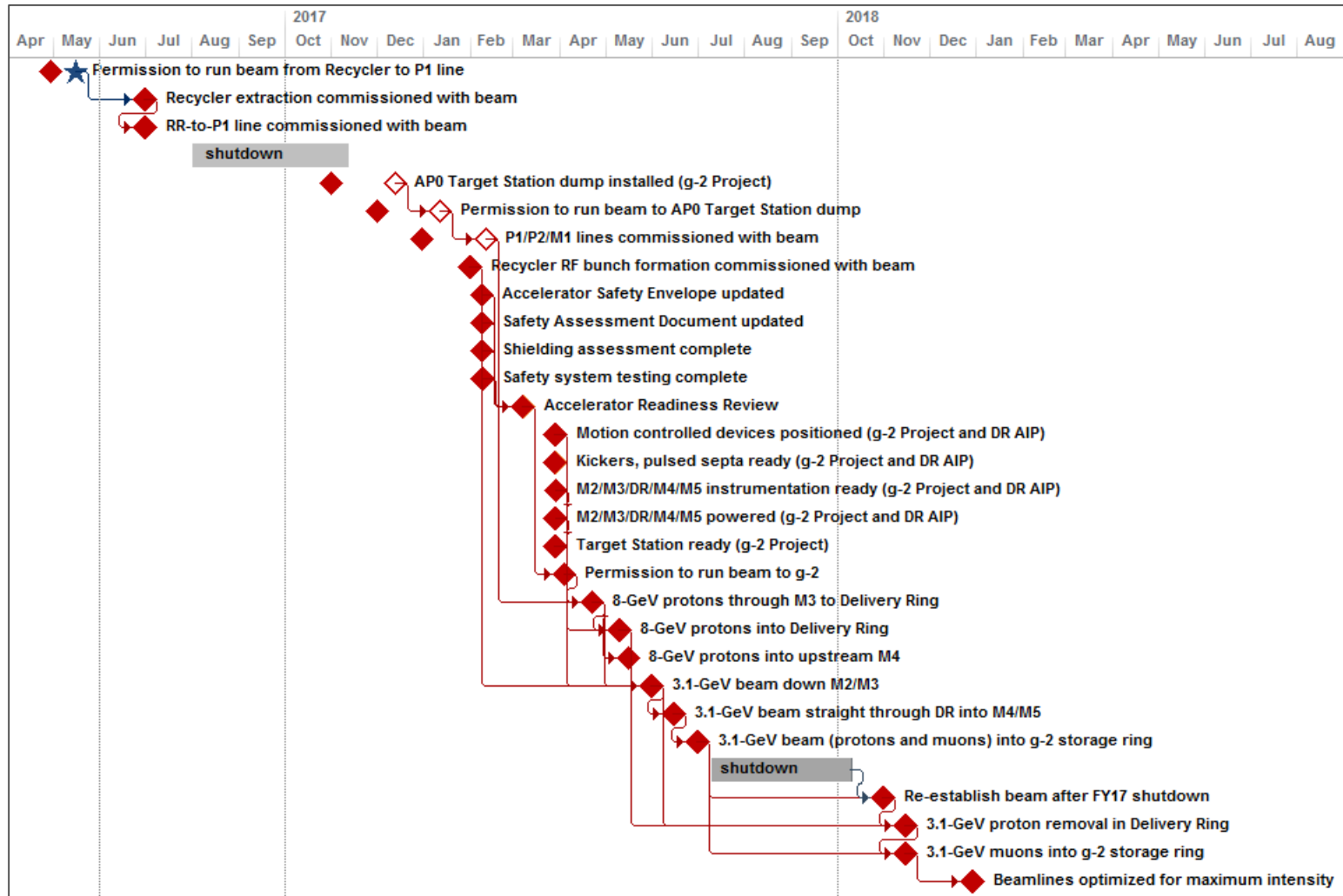
# Muon Campus Beamline Construction



- Installation for g-2 complete end of March 2017

# Muon Campus Commissioning and Operations

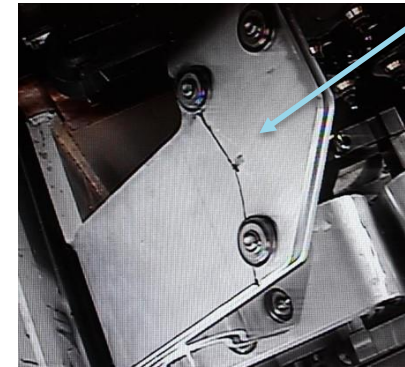
- Commissioning beam to g-2 will be a priority in FY17



# Target Systems

# Target Systems Operations

- Assembling and preparing to test BNB-4 horn during FY16 shutdown
- NuMI horn 1 PH-104 (700 kW design) failed in FY15 with stripline fracture from fatigue due to vibrations
  - Current horn PH-103 designed for 400 kW but air diverters increase cooling to allow 700 kW
  - Retrofitting PH-105 with new design (more rigid, larger radii turns, air diverter), ready in FY17
  - PH-106 with new design ready in FY17
- Will replace NuMI target during FY16 shutdown
  - Outlived design lifetime but not at design power (700 kW)
- NuMI dehumidification
  - Needed to prevent tritium
  - Equipment affected by high radiation exposure
- Working to replace AP-0 (former Pbar) target station beam dump for g-2
  - Water leaks in both cooling lines of existing dump
  - Difficulty removing since bolt on one end no longer attached

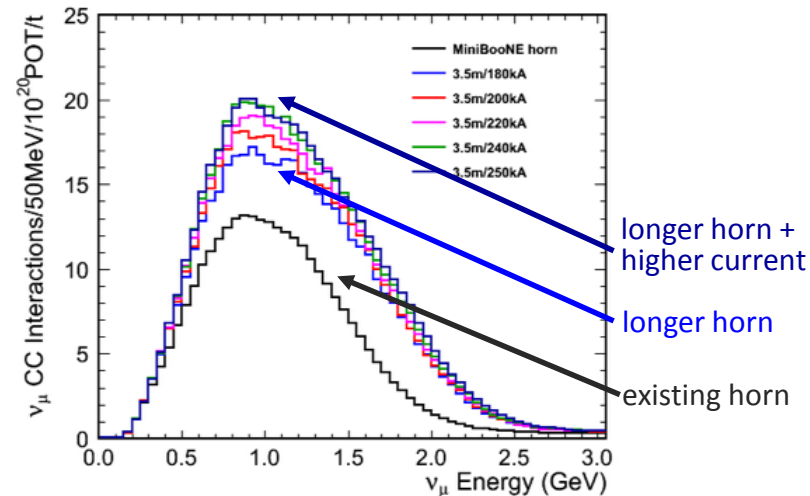
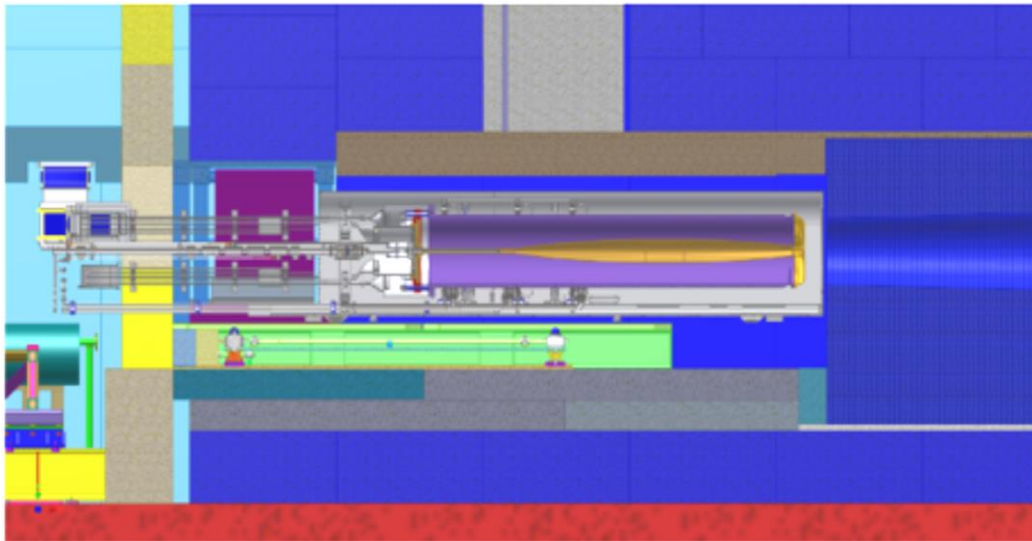


# Target Systems Consumables

Device	Installed	Future
NuMI target	TA-01	TA-02 ready TA-03 complete FY16 TA-04 complete FY17 TA-05 complete FY17 TA-06,07 procuring parts TA-08,09 beginning procurements
NuMI horn 1	PH1-03	PH1-05 retrofit based on PH1-04 failure, complete FY17 PH1-06 complete FY17 PH1-07 procuring parts
NuMI horn 2	PH2-02	PH2-03 ready PH2-04 complete FY16 PH2-05 complete FY17
BNB horn	BNB-3	BNB-4 complete FY16
AP-0 target	18	1 spare + spares of old design
AP-0 lithium lens	10mm-4	3 spares, parts for 4 more
AP-0 pulsed magnet	PMAG-12	2 spares

# BNB Upgrade - SBN

- Optimized horn design can increase neutrino yield by up to 70%
  - Inner conductor shape optimized for given length and current for efficient focusing
  - Longer horn
- Upgrade power supply to allow running at higher current and/or repetition rate



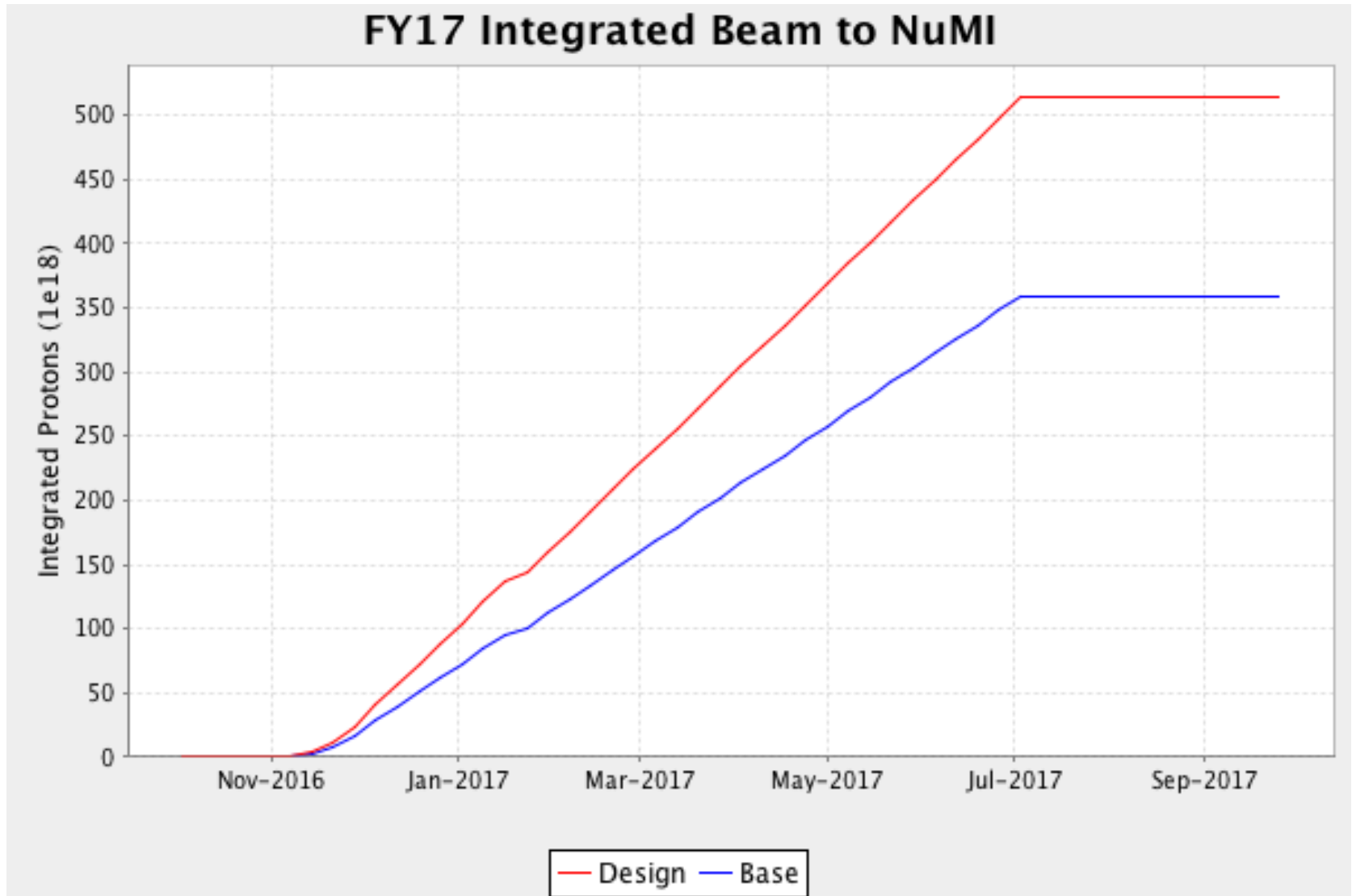
- Propose to manage this as two AIPs within the SBN Program (FY18-FY20)

# Projections for FY17

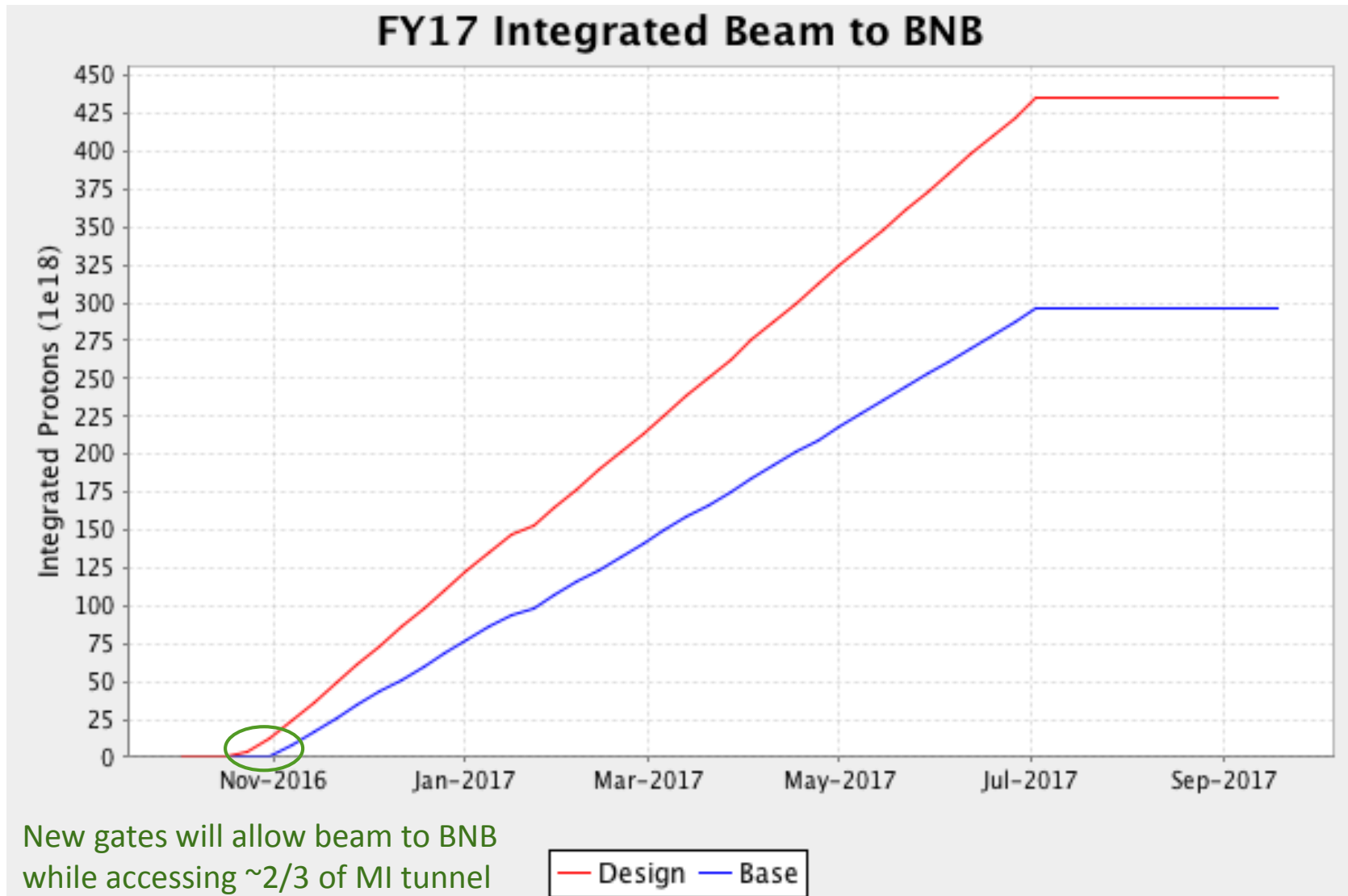
# Shutdowns

- FY16 summer shutdown (Aug 1 – Nov 11)
  - Delayed due to Recycler collimator readiness
  - Lengthened due to lack of labor availability (13→15 weeks)
  - Major jobs:
    - Second phase of Recycler TSP2IP upgrade
    - Installation of Recycler collimators
    - Installation of 2.5 MHz RF in Recycler for Muon Campus
    - Replacement of NuMI target and dehumidifiers
- Switch back to running on Master Substation (~2 days in Jan)
- FY17 summer shutdown (July-Sept)
  - Expect 12-13 weeks driven by final phase of TSP2IP upgrade and second phase of Recycler collimator installation

# FY17 Goals for Beam to NuMI



# FY17 Goals for Beam to BNB



## FY17 Goals for Beam to g-2

- Establish muons to the g-2 storage ring
  - Proton removal likely not commissioned before July (100x more p than  $\mu$ )

# Conclusions

- We are making good progress towards 700 kW beam power for NOvA
- Many of the PIP improvements in beam delivery have been realized already; work to ensure reliability remains
- Muon Campus construction is on track and we will be ready to commission and operate beam to g-2 starting in FY17
  - This will be a primary focus of our efforts in FY17 and FY18
- Optimizations for the SBN program of building an upgraded horn and power supply could increase neutrino yield by up to 70%
  - We are planning to start this 3-year project in FY18