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Accelerator Status and Plans

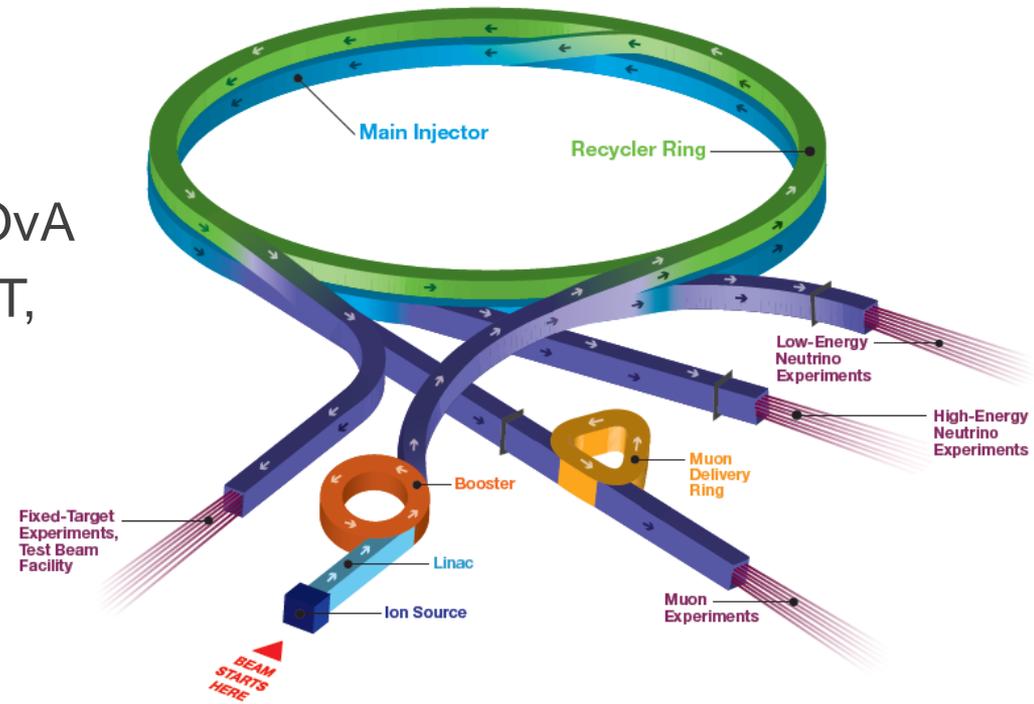
Mary Convery

Fermilab Physics Advisory Committee Meeting

23 June 2015

Fermilab Accelerator Complex

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



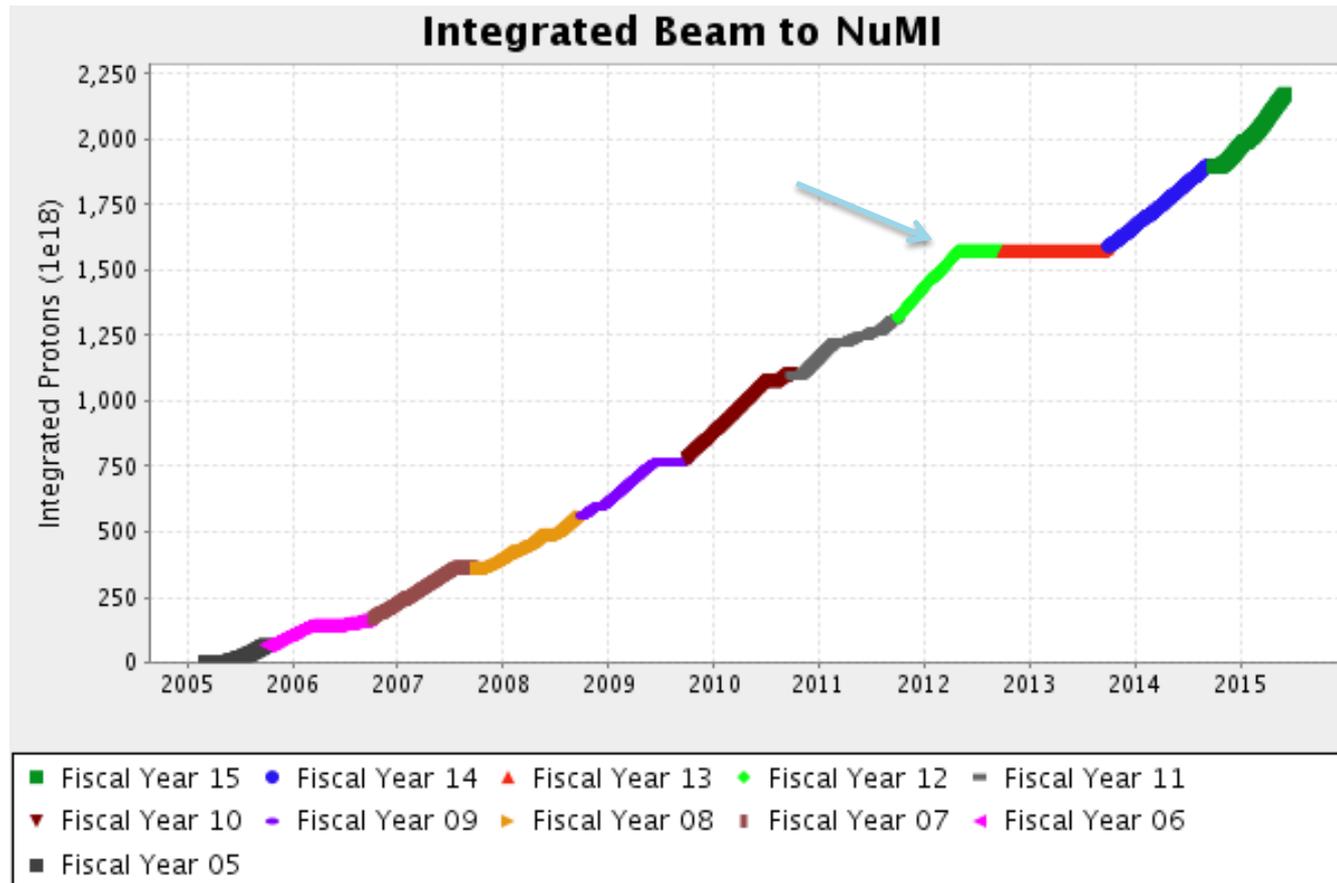
- Meeting experiments' needs in FY16 and beyond requires running beam at 15 Hz in the Booster

Objectives for the next few years

- Ramp up beam power to 700 kW for NOvA, achieve performance metrics, and support full experimental program
- Achieve 15 Hz beam pulse repetition rate as soon as possible by carrying out Proton Improvement Plan
- Complete Muon Campus construction on budget and on schedule and commission g-2 experiment in FY17
- Make Booster Neutrino Beam operations more robust
 - Target and horn spares production and testing
 - Study of horn upgrade for Short Baseline Neutrino on-going

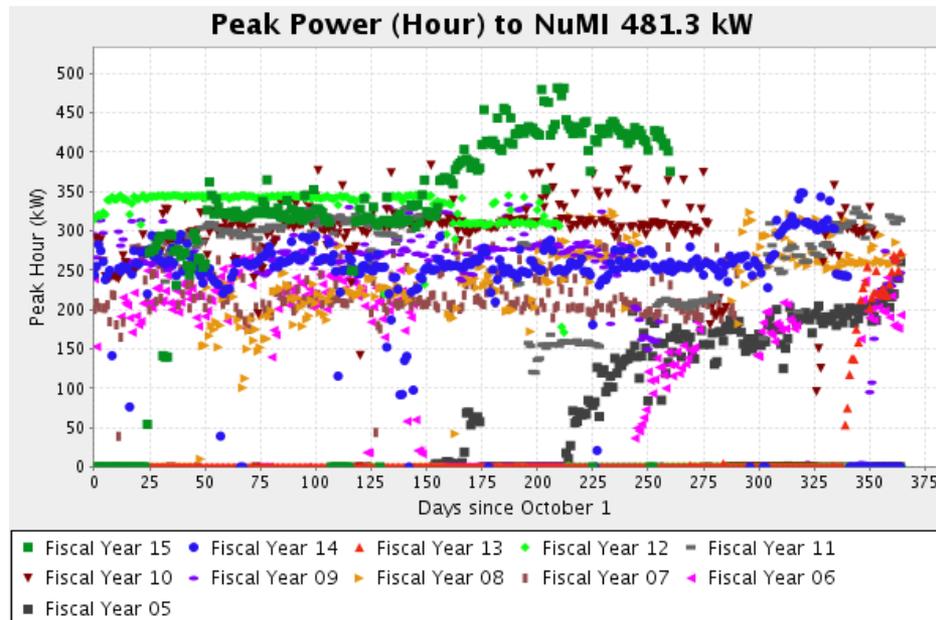
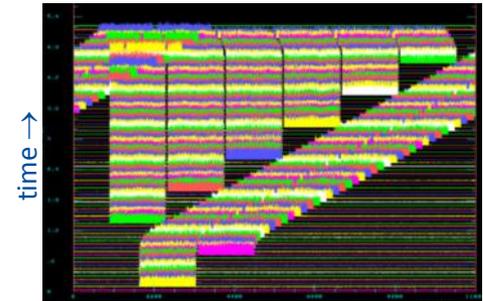
Accelerator performance for NuMI

- Started delivering protons to NuMI in 2005
 - $\sim 1.55 \times 10^{21}$ in 7 years; NOvA goal is 3.6×10^{21}
 - Most intense high energy neutrino beam in the world



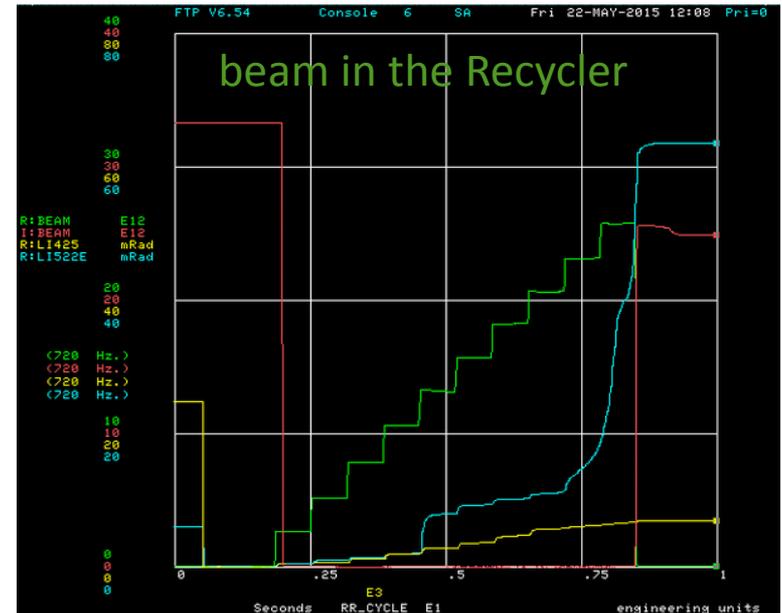
Current high power operation and plans

- Commissioned slip-stacking in the Recycler
- Currently slip-stacking 2+6 batches, 3.1×10^{13} ppp every 1.333 sec
 - Reconfigured Recycler transverse dampers
 - Commissioned MI collimators
 - Increased number of Booster turns
 - Beam power >450 kW (400 kW with SY120)

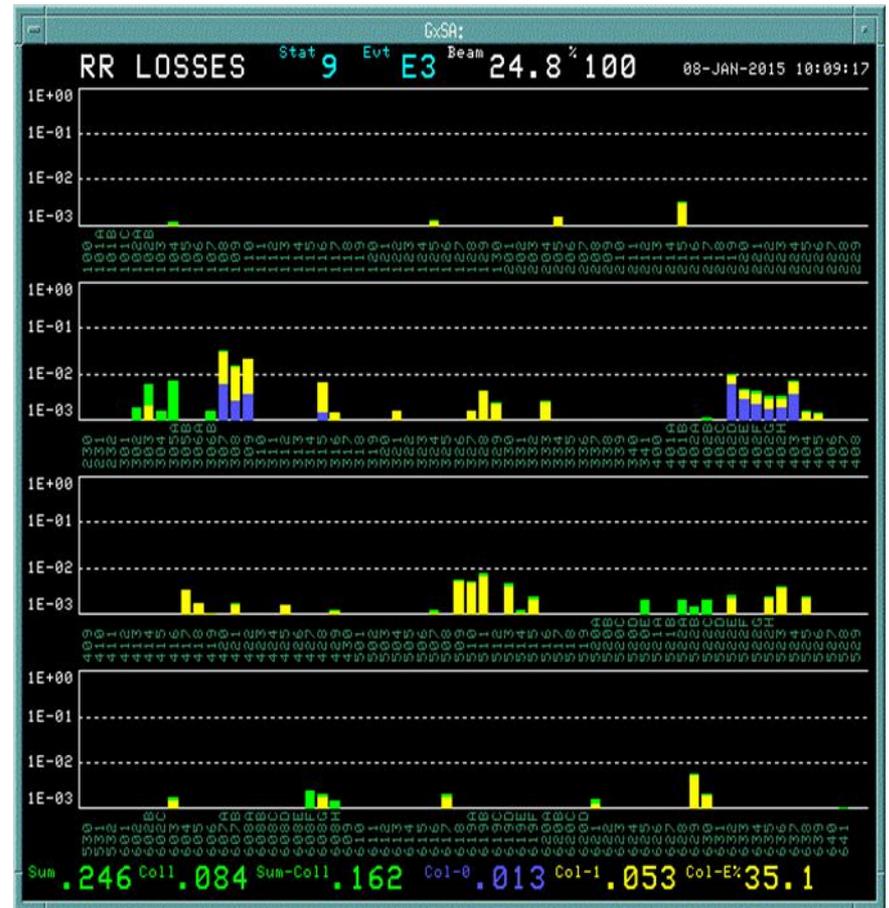
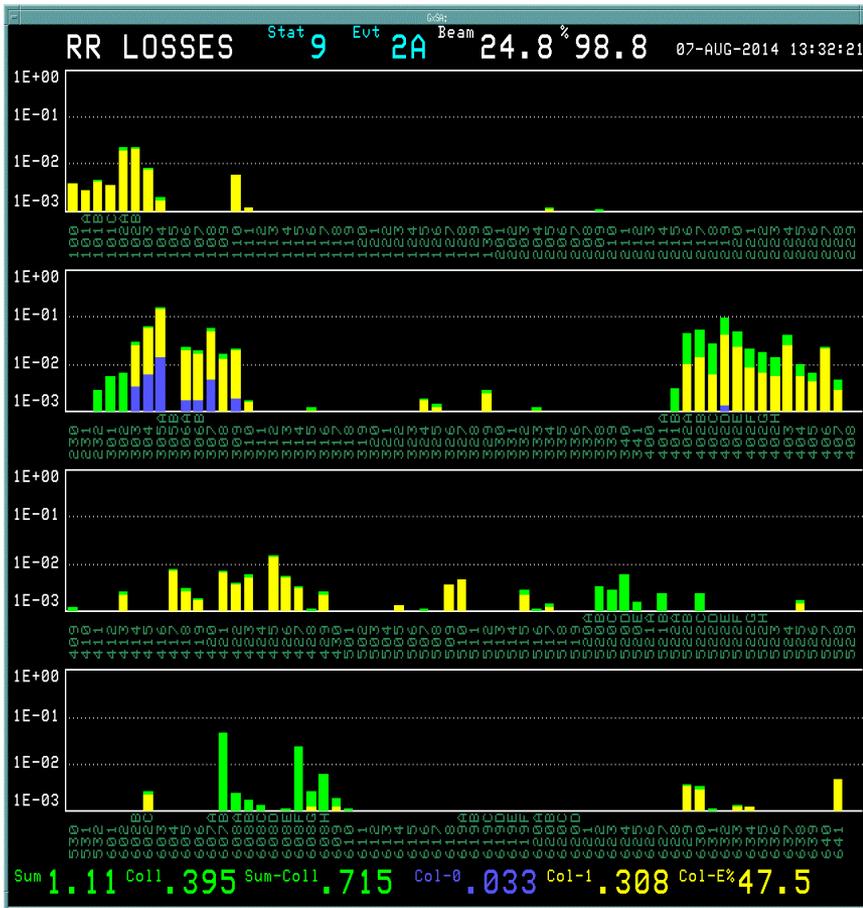


Current high power operation and plans

- Testing 4+6 operation (460 kW) prior to the summer shutdown with current Booster rep rate (7.5 Hz, no beam to BNB)
- Also would like to test low intensity beam at 15 Hz
- After shutdown will have
 - At least 18 refurbished Booster RF stations installed
 - New Booster shielding assessment taking into account use of Total Loss Monitors to allow higher flux in Booster
- Increase intensity with 4+6, commission beam at 15 Hz in Booster, commission 6+6
- Challenge is keeping losses low

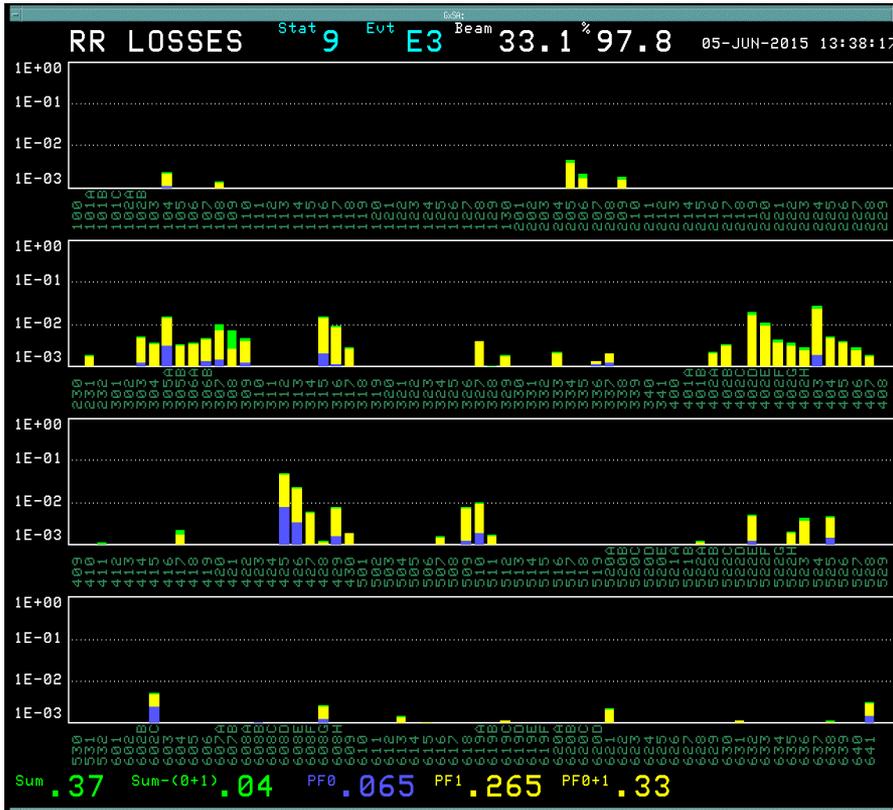


Recycler Losses before and after the shutdown



- Reduced Recycler losses by a factor a 4 by improving Recycler aperture

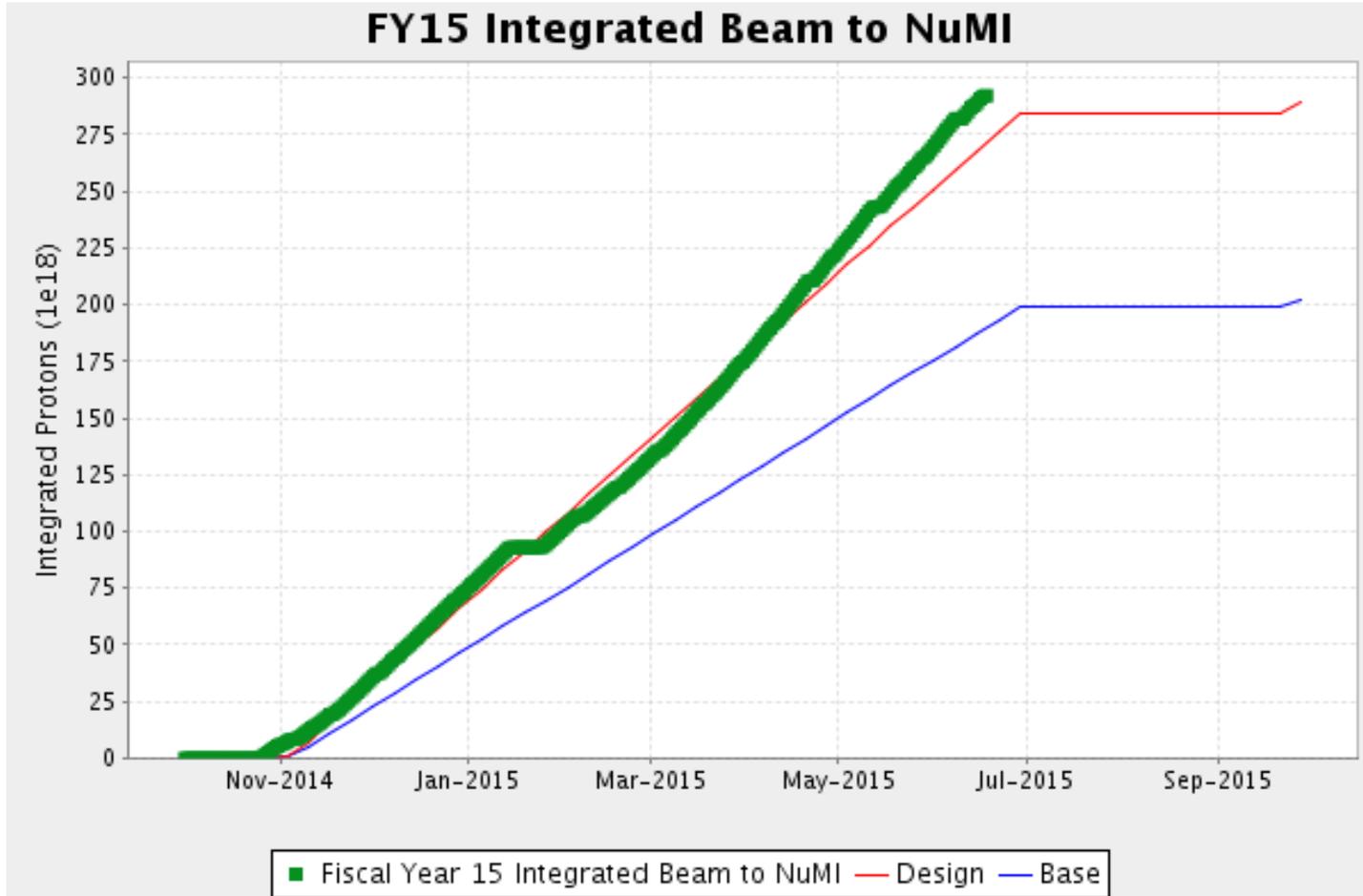
Current RR/MI Losses with 2+6 slip stacking



Collimation efficiency

- Continuing to address Recycler misalignment and aperture issues to further reduce losses

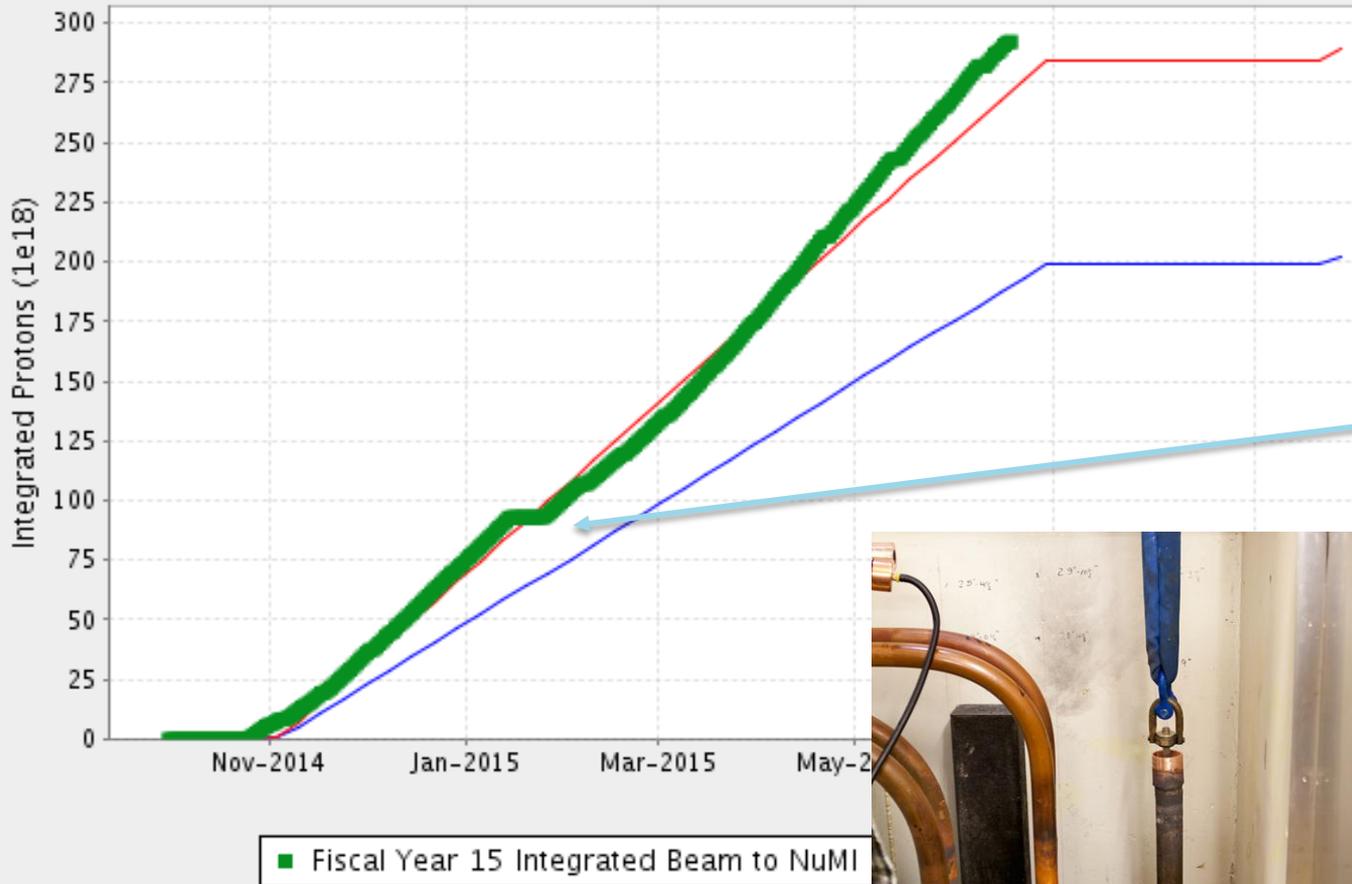
Beam power in FY15 on track and increasing



- Goals for FY16 still under discussion, but think we can ~double POT to NuMI relative to FY15 goals

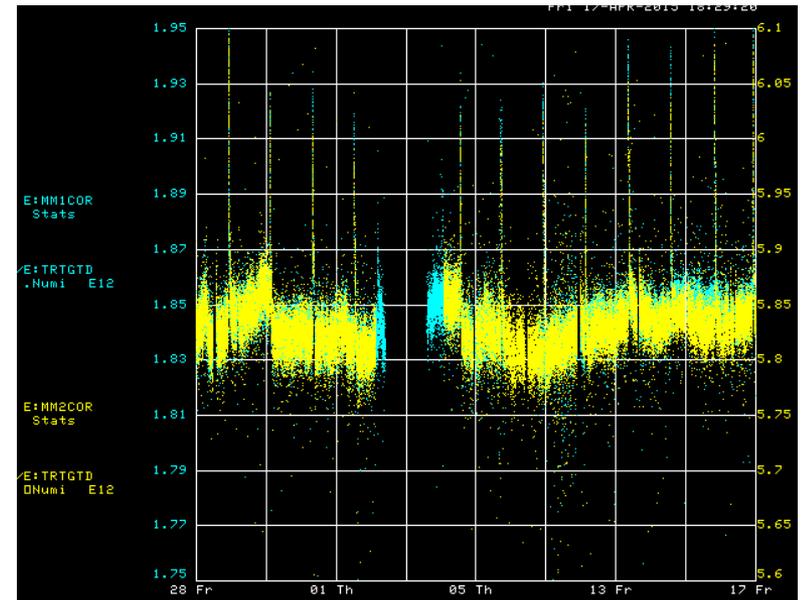
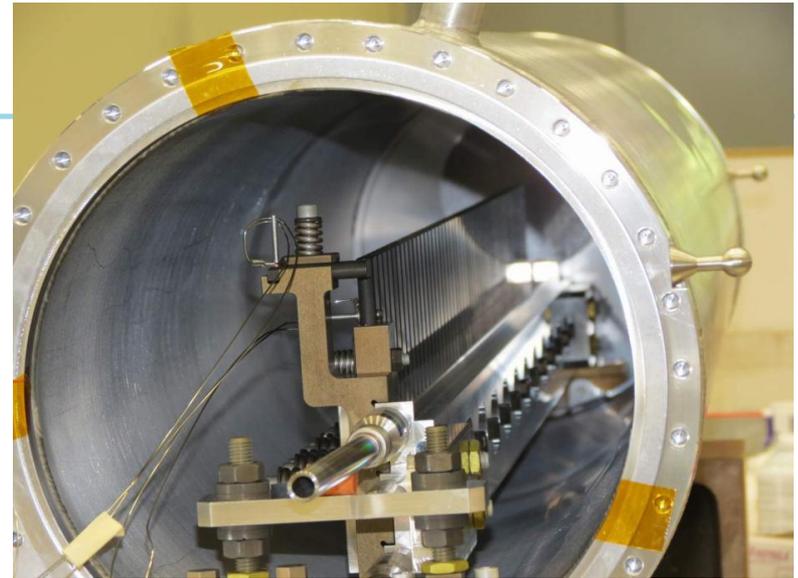
Excellent uptime in FY15

FY15 Integrated Beam to NuMI



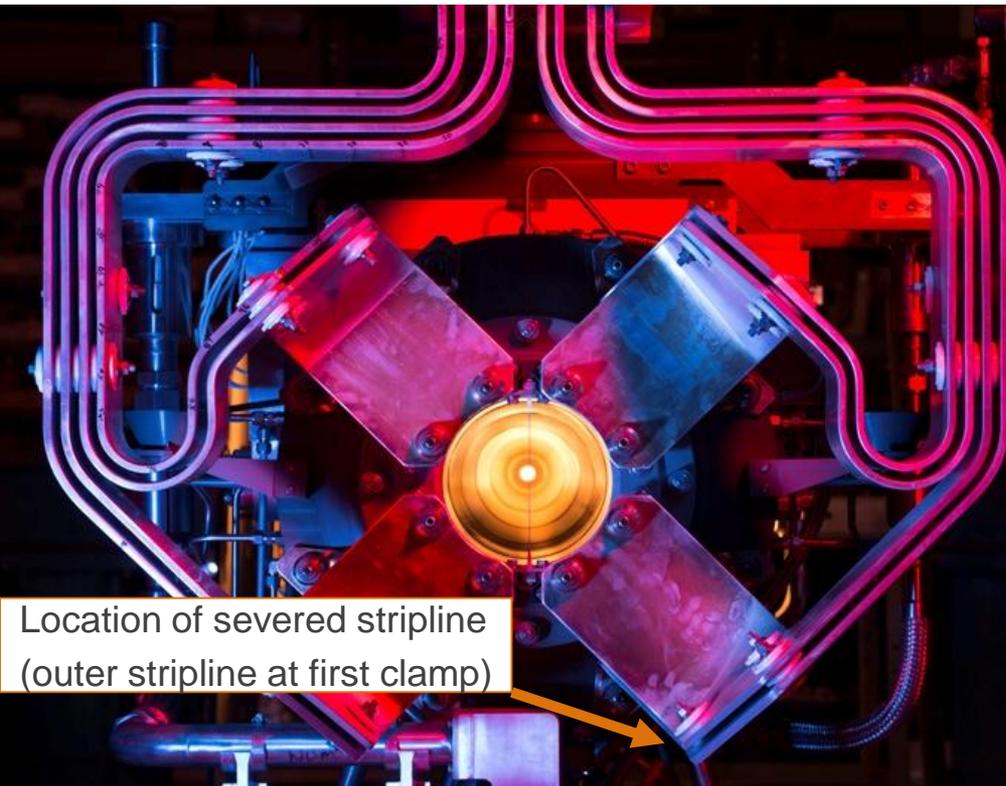
NuMI Target

- First NOvA target still healthy
 - MET-01 has integrated 6.1×10^{20} protons
- Neutrinos experiments looked for deviations in neutrino rate
 - No changes observed which would indicate target degradation
 - Few percent changes are observed, but related to either slip-stacking or detector pile-up
- Muon monitors show consistent response
 - Variation of $\sim 0.5\%$ consistent with fluctuations in spot size and beam intensity
- First round of spares are ready, more are in production
 - Spare production has been impacted by redirection of effort to BNB



NuMI Horn Replacement

- Horn PH1-04 has severed stripline
 - First 700 kW capable horn, in service since Sept 2013, accumulated ~ 27 million pulses
 - Running in horn-off mode for 3 weeks prior to shutdown
 - Will replace during shutdown
- Spares of various condition are in hand
 - Under discussion which to use and which modifications to make

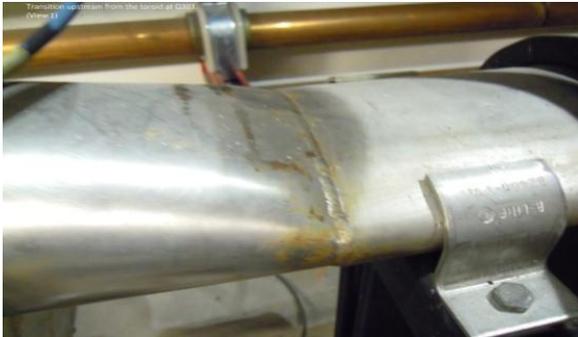


Location of severed stripline
(outer stripline at first clamp)



MI/Recycler upgrades

- Recycler vacuum
 - Recycler titanium sublimation pump (TSP)-based vacuum system has exceeded design lifetime; not suitable for a proton machine
 - Plan for replacement of ~400 TSPs with ion pumps will take 3 long shutdowns (lots of cutting and welding)
- Replacing MI beam pipe in MI-30 collimation region with duplex stainless pipe with higher corrosion resistance



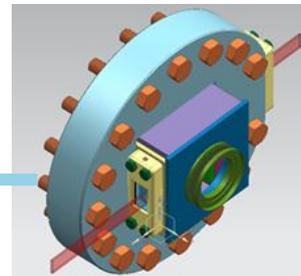
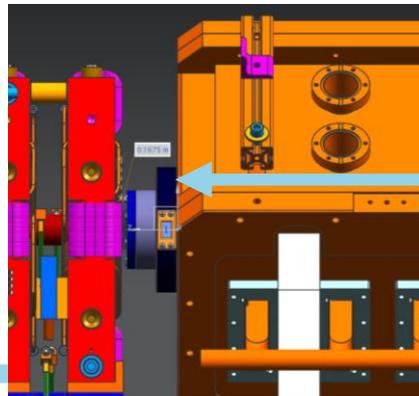
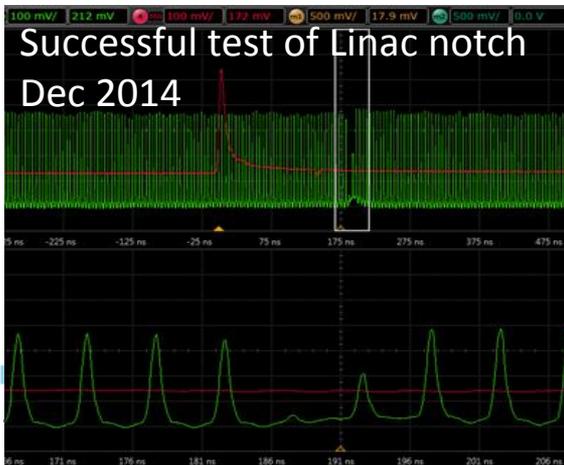
- Designing collimation system for Recycler

Proton Improvement Plan

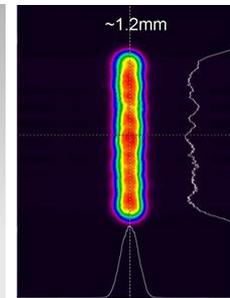
- Increase the beam repetition rate from the present ~ 7.5 to 15 Hz
 - Need at least 9 Hz for NOvA 12-batch slip-stacking
 - Requires refurbishment of Booster RF cavities
- Eliminate major vulnerabilities and maintain reliability at present levels ($>85\%$) at the full repetition rate
- Eliminate major obsolescence issues
- Increase the proton source throughput, with a goal of reaching $>2 \times 10^{17}$ protons/hour
 - Presently operating at $<1 \times 10^{17}$ protons/hour
- Ensure a useful operating life of the proton source through at least 2030 (PIP-II)
- Main challenge: keep beam losses at present level while increasing protons on target

Booster loss and Linac laser notch

- Doubling the beam repetition rate so need to cut the losses per Booster cycle in half
- Addressing each of the three main areas of Booster beam loss:
 - Injection
 - Notching the beam to create a gap for extraction kickers to fire
 - Transition, related to RF during acceleration
- Phased improvements to notch creation
 - Most recent was new cogging system which allowed notching at 400 MeV instead of 700 MeV → lower energy losses
 - Final phase is to install laser notcher in Linac PreAcc during shutdown



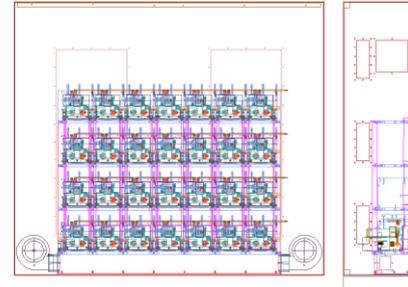
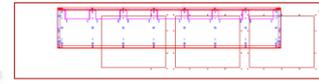
Optical cavity
(attached end of RFQ)



Laser profile

PIP recent progress

- Linac replacement high-voltage modulator for RF power amplifier prototype assembly in progress
- Booster replacement RF anode power supplies
 - Had trouble finding vendor that can meet specifications but progressing
 - Hope to install during shutdown
- Booster RF bias supplies being upgraded for reliable 15-Hz operation; expect complete early FY16
- Booster new RF cavity tuners
 - Vendor has now met specs for ferrites; Tech Division producing new tuners
- Preparing new Booster shielding assessment w/ Total Loss Monitors



Anodes & Transformer for testing



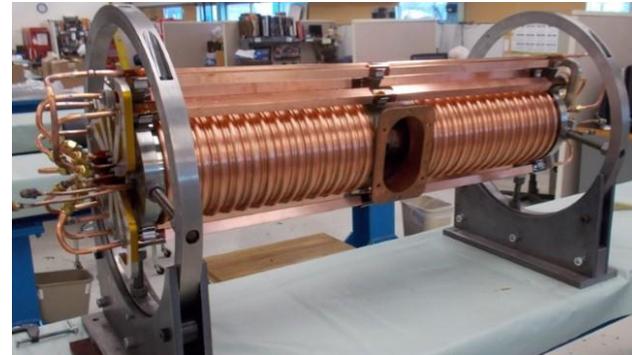
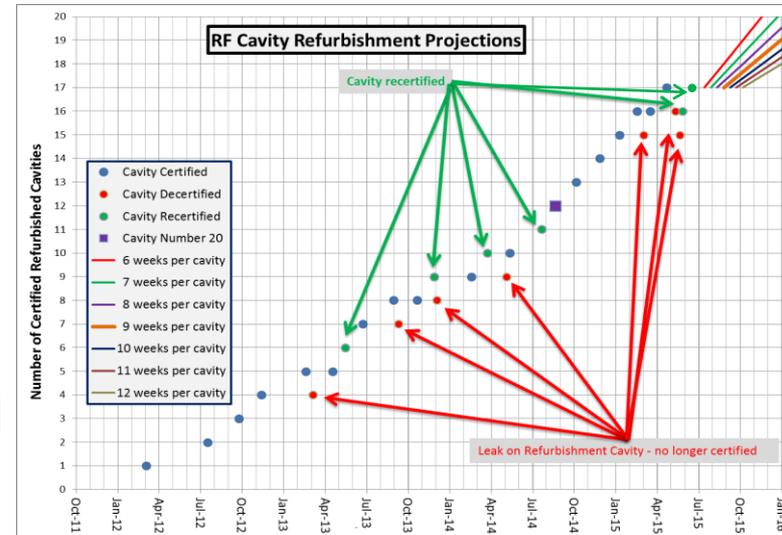
Water Cooled Resistors



Cap Bank & Bleeders

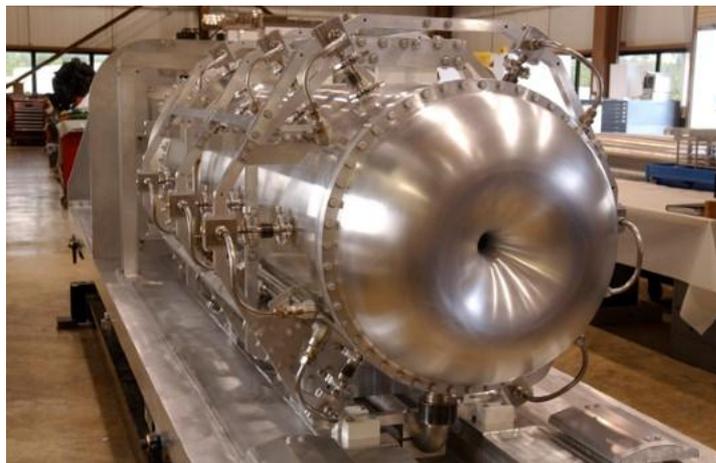
Booster RF cavity refurbishment

- Expect to have at least 18 cavities certified to run at 15Hz when start up after summer shutdown
 - Installed 17th ahead of schedule
 - Ran at 15 Hz for 6 h
 - A cavity developed tuner problems and was no longer certified; another developed a vacuum leak
 - Had similar issues when first started running east gallery at 15 Hz
 - Hope to try again before shutdown
- Many tuners still have dings and dents that will likely leak at later time
 - TD making new tuners



Booster Neutrino Beam

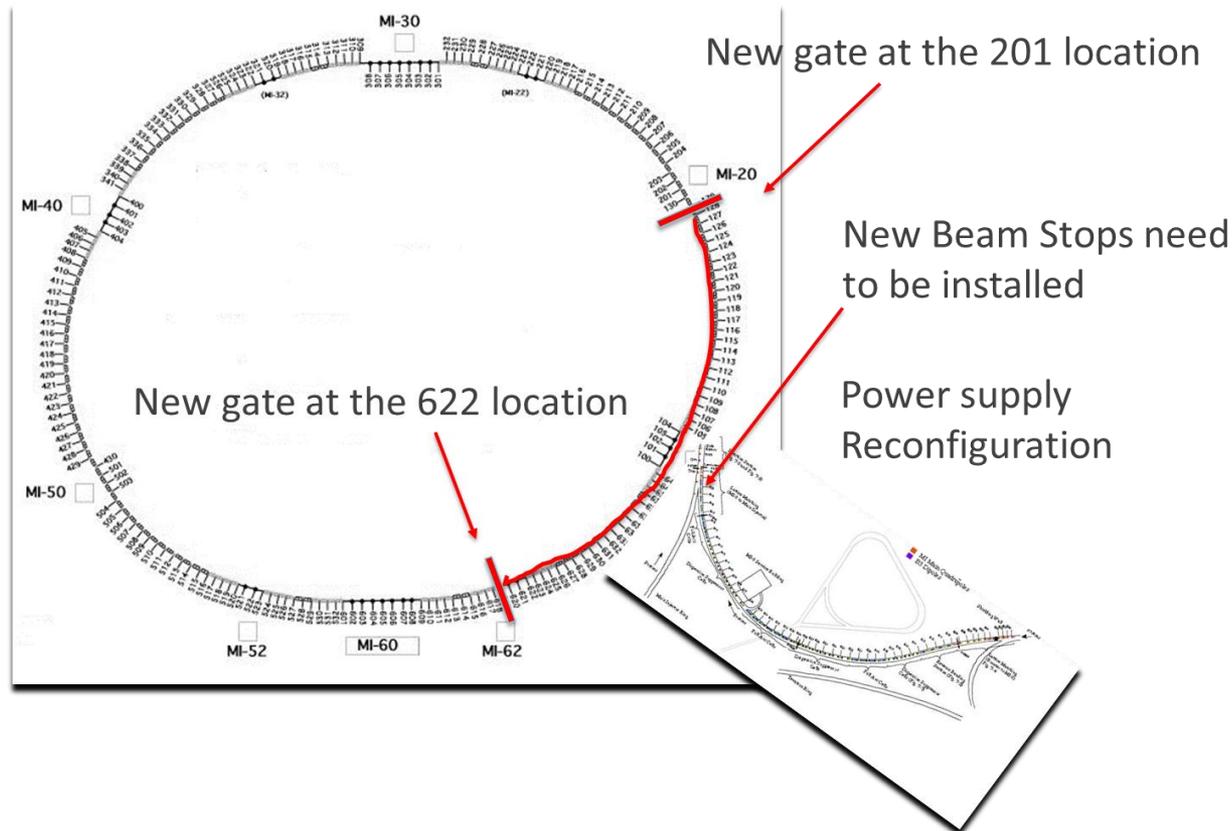
- Preparing to run to MicroBooNE
- Replaced horn which lasted ten years and >400M pulses
 - Expected lifetime was about one year and 100M pulses
 - Had to also redesign and replace adjustor platform and horn extraction mechanism (was not designed to last this long)



- Looking into requests for upgrades for Short Baseline Neutrino program but limited resources

Modifications to allow beam to BNB during MI access

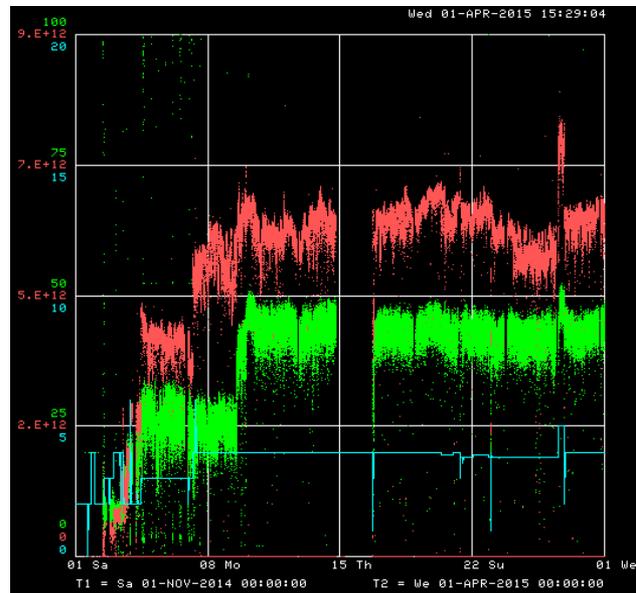
- Install new gates and safety system FY15 shutdown
- Fabricate new beam stops and install FY16 shutdown
- Estimate 1.5×10^{18} POT/day assuming 5 Hz operation



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 (repurposed ArgoNeuT liquid argon time projection chamber)
- Modified primary beamline to allow clean transport of higher intensity beam to SeaQuest

Intensity
Duty factor
Booster turns



Able to provide
requested intensity
to SeaQuest

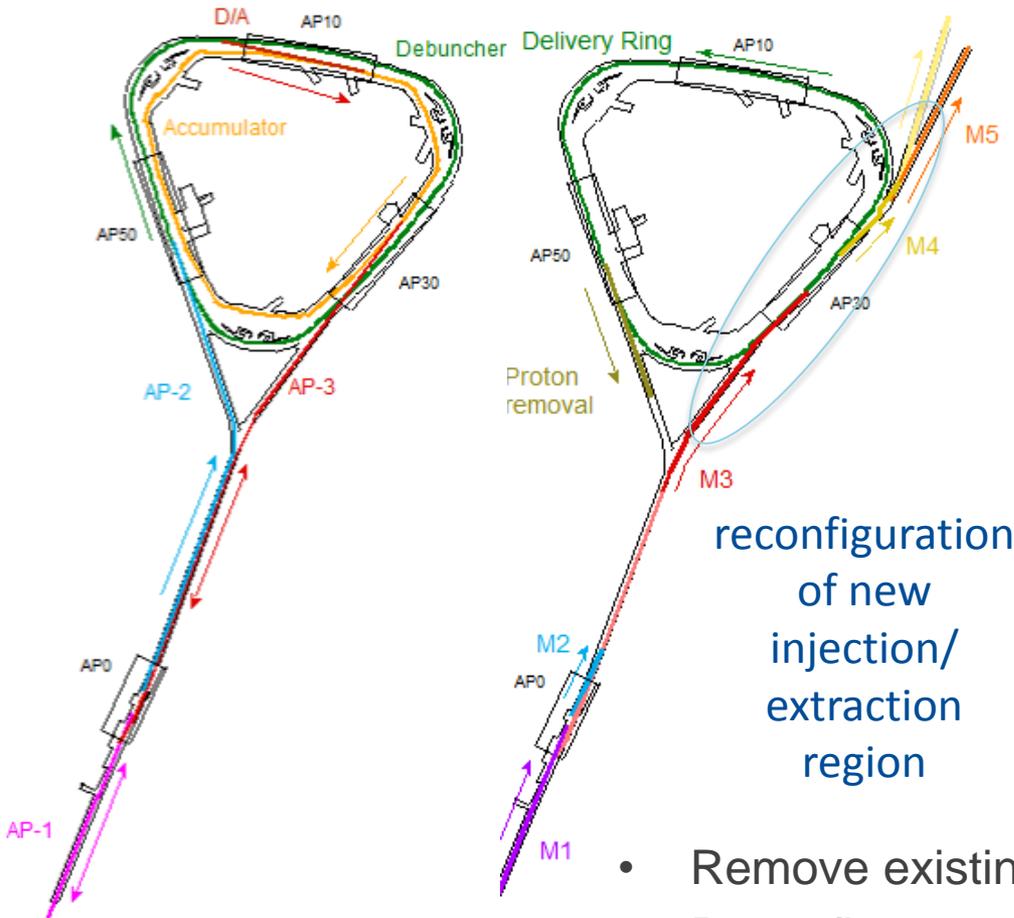
Muon Campus construction



- New beamline enclosure for connection from Delivery Ring (former antiproton rings) to g-2 and Mu2e experiments nearing completion



Pbar to Muon reconfiguration for Muon Campus / g-2 / Mu2e



reconfiguration
of new
injection/
extraction
region

- Remove existing magnets
- Reconfigure cables, cooling water, electrical bus, lighting
- Install injection and extraction lines
- Reinstall Delivery Ring magnets

Muon Campus Recycler modifications



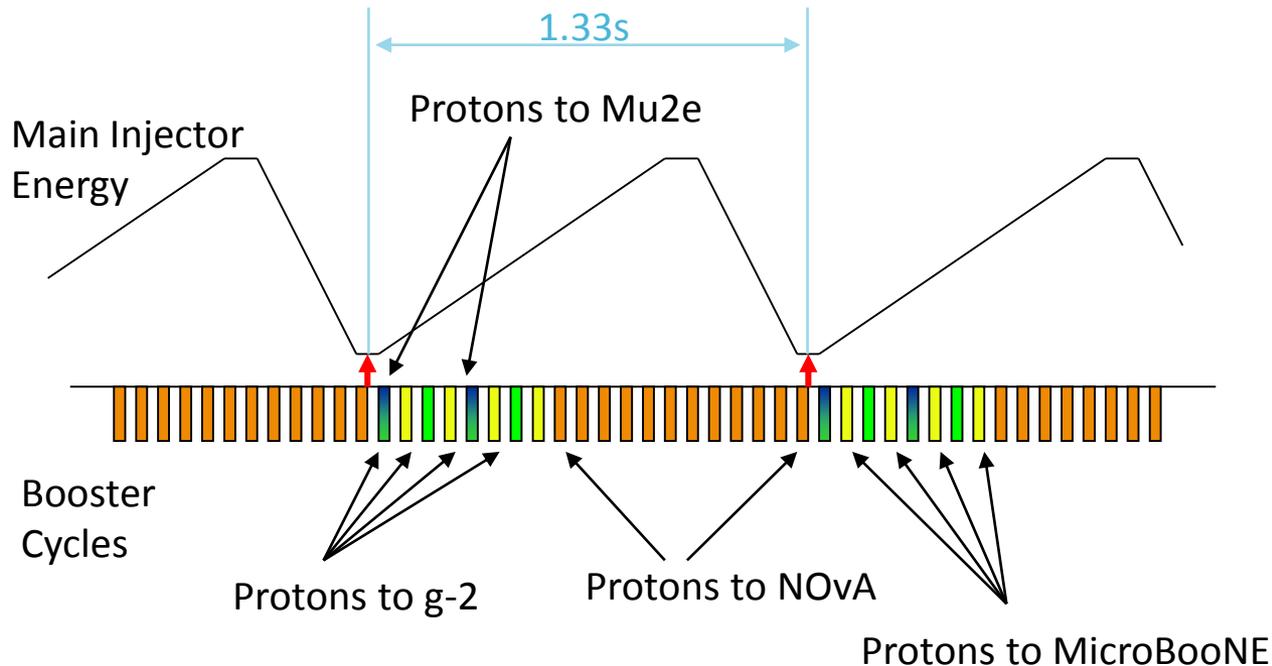
Assembling new RF cavities to install in FY16



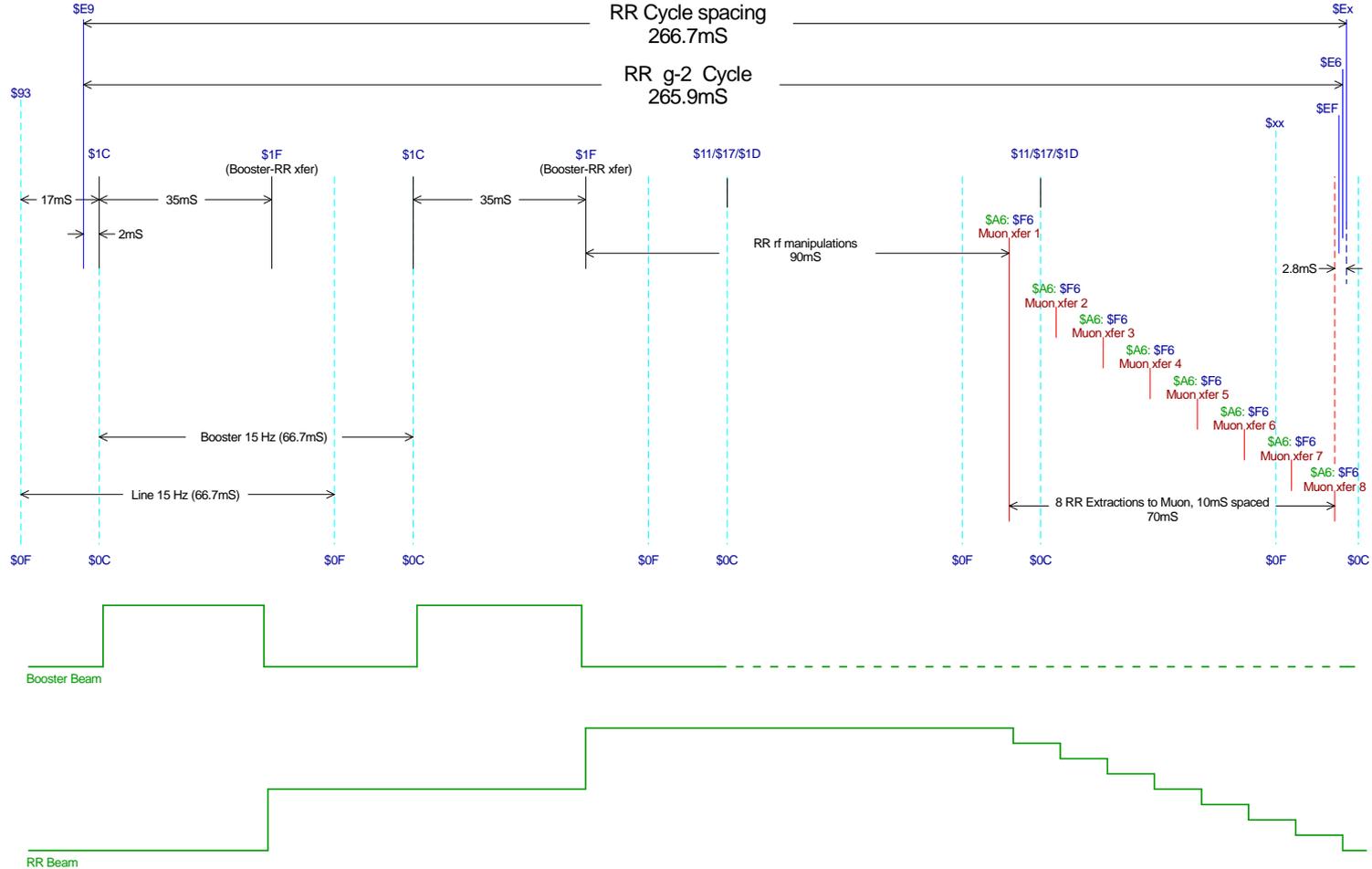
New connection from RR to P1-line to be installed this summer (Drives the length of the shutdown)

Protons to Muon Campus

- In Recycler, use 2.5 MHz RF to rebunch Booster batch of 4×10^{12} protons into 4 bunches of 10^{12} protons to Muon Campus experiments
- Had a conceptual design which provided 16 bunches to g-2, 8 to Mu2e in a 1.33s NOvA cycle (12 Hz / 6 Hz, 3 Hz to BNB)



Timing of protons to Muon Campus

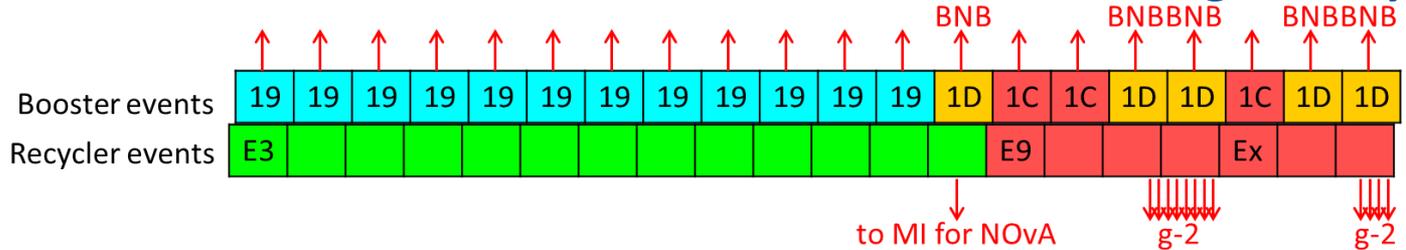


- Detailed planning found some modifications needed to timing of bunches to Muon Campus and possibly to NOvA cycle

Possible pulse schemes for protons to g-2 (late FY17)

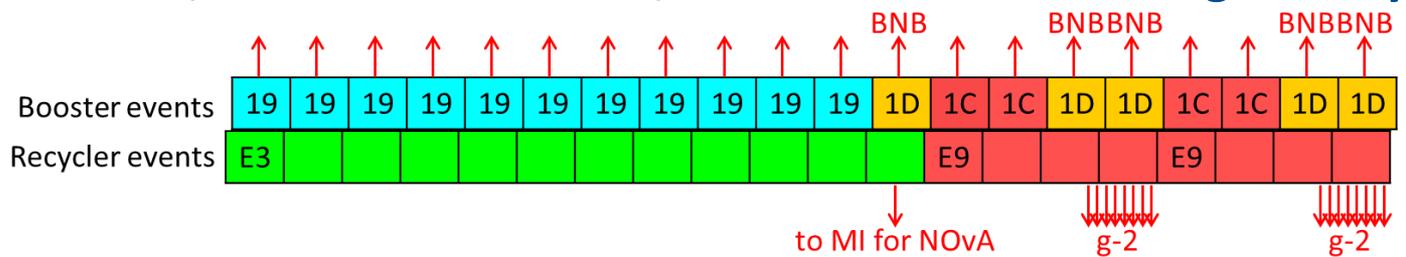
20 ticks, 12 batches to NOvA, 12 2.5-MHz bunches to g-2 every 1.33s

75% rate to g-2
NOvA unaffected
(BNB 3.8 Hz)



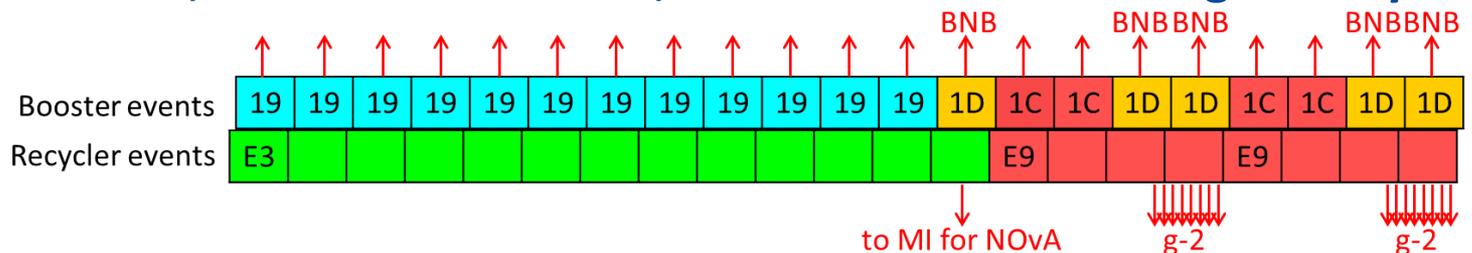
20 ticks, 11 batches to NOvA, 16 2.5-MHz bunches to g-2 every 1.33s

100% rate to g-2
8% reduction in
NOvA intensity
(BNB 3.8 Hz)



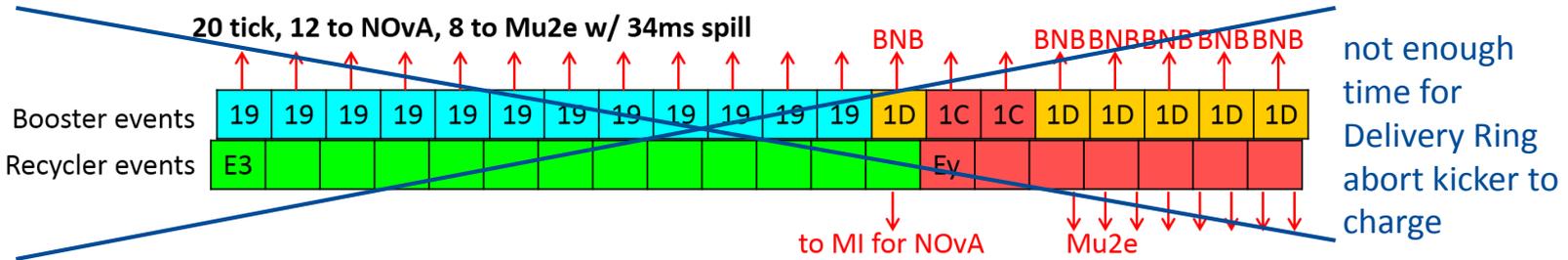
21 ticks, 12 batches to NOvA, 16 2.5-MHz bunches to g-2 every 1.40s

95% rate to g-2
5% reduction in
NOvA rate
(BNB 3.6 Hz)

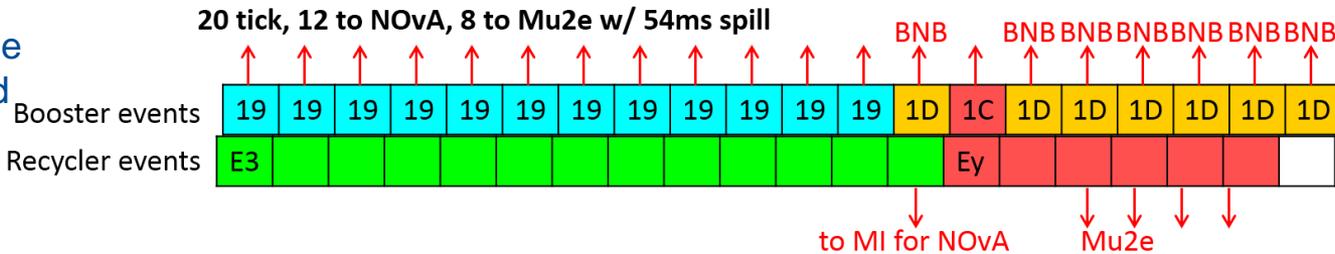


- Should be able to switch back and forth between these options if desired

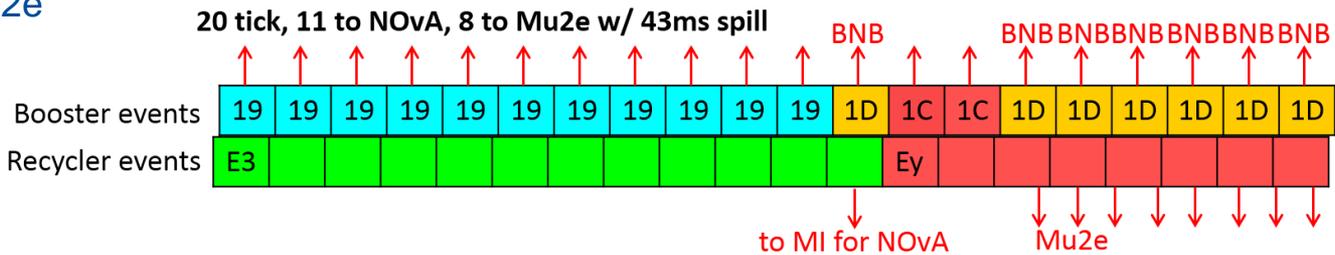
Possible pulse schemes for protons to Mu2e (FY20)



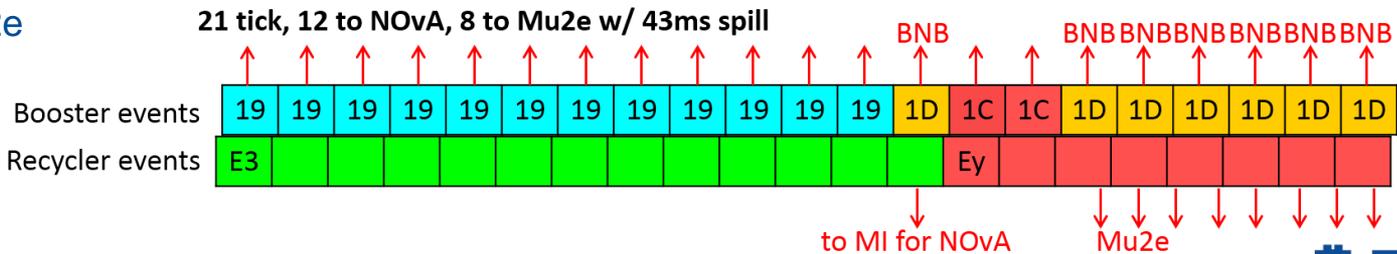
50% rate to Mu2e
NOvA unaffected
(BNB 3.8 Hz)



100% rate to Mu2e
8% reduction in
NOvA intensity
(BNB 3.8 Hz)

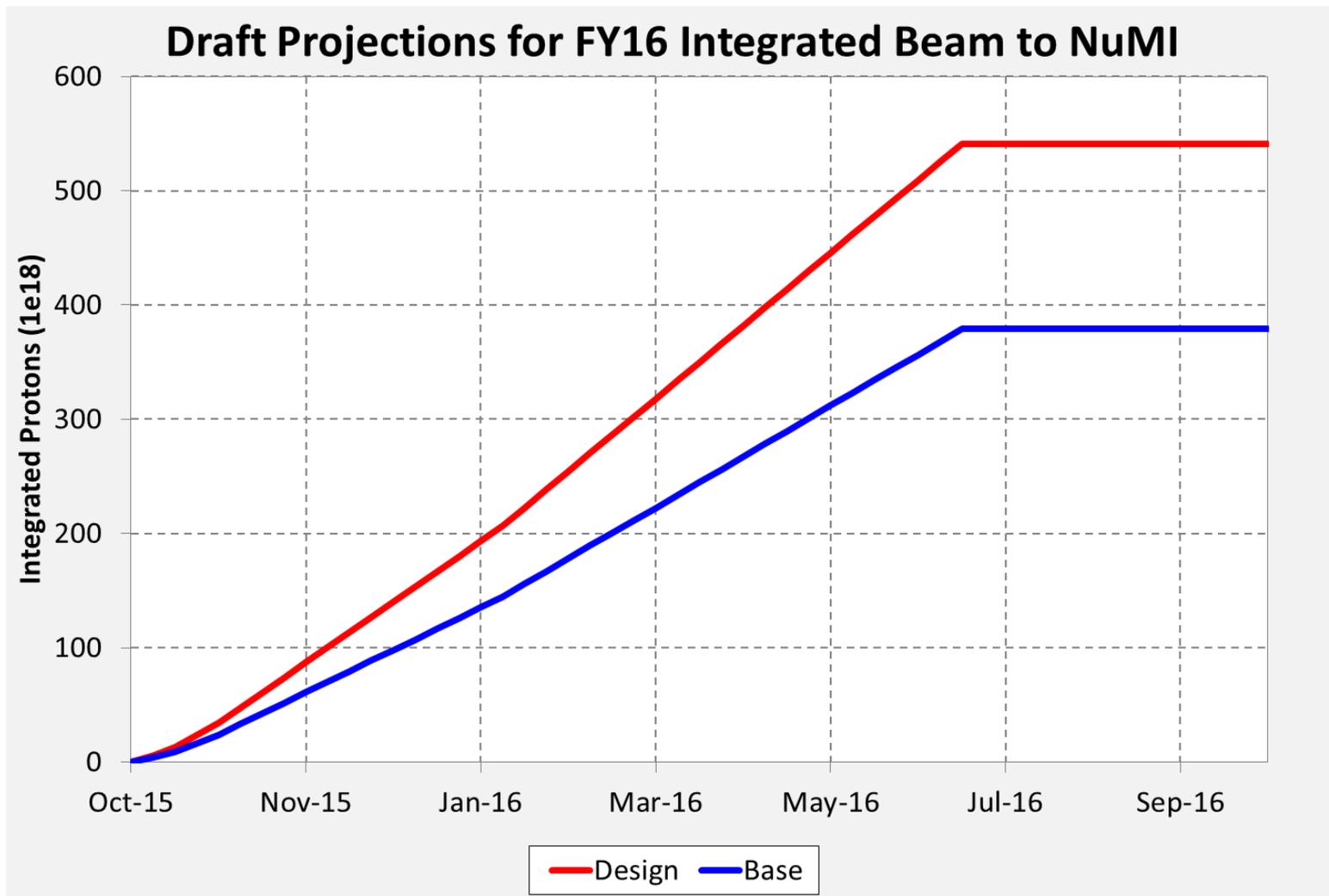


95% rate to Mu2e
5% reduction in
NOvA rate
(BNB 3.6 Hz)

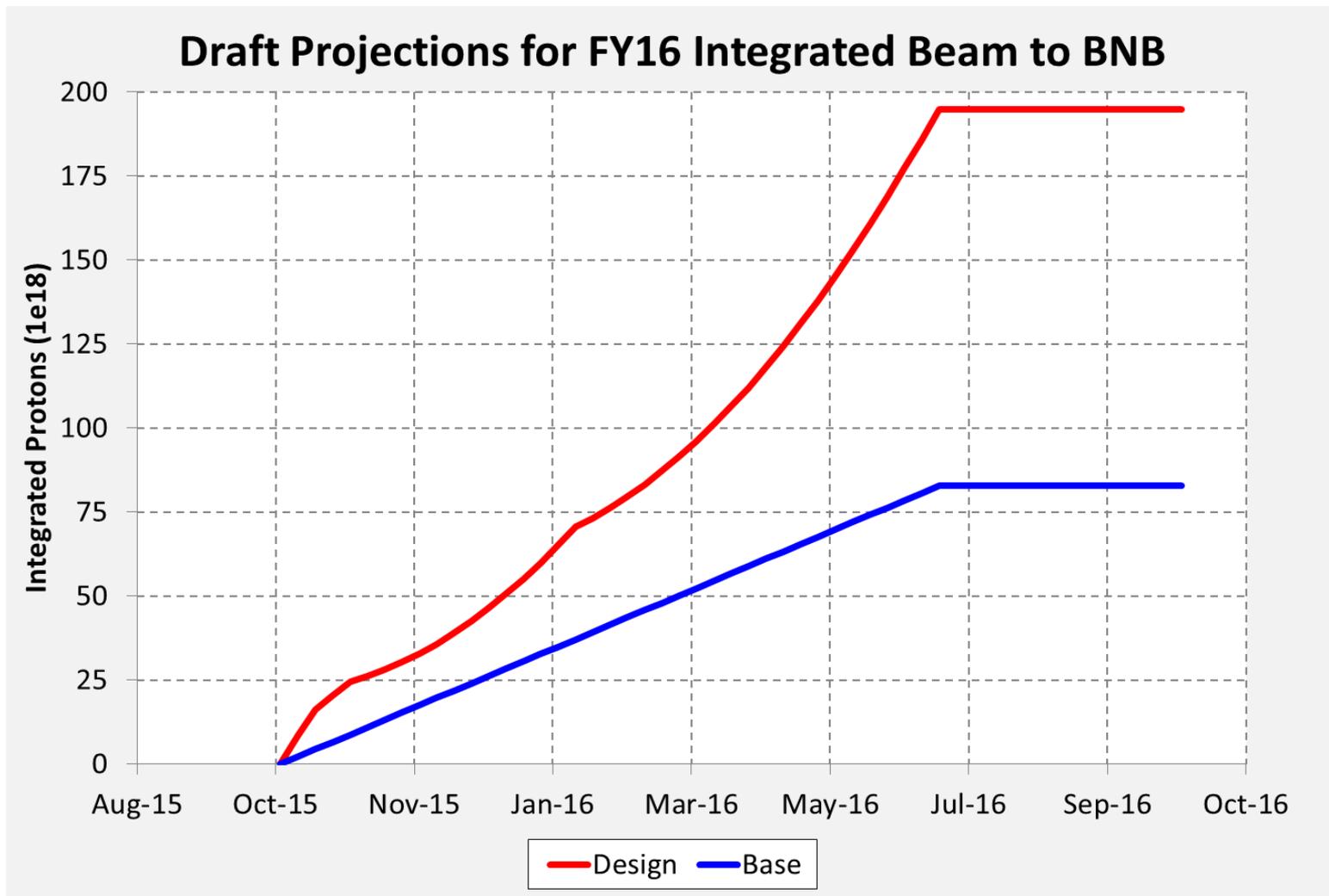


Projections for FY16

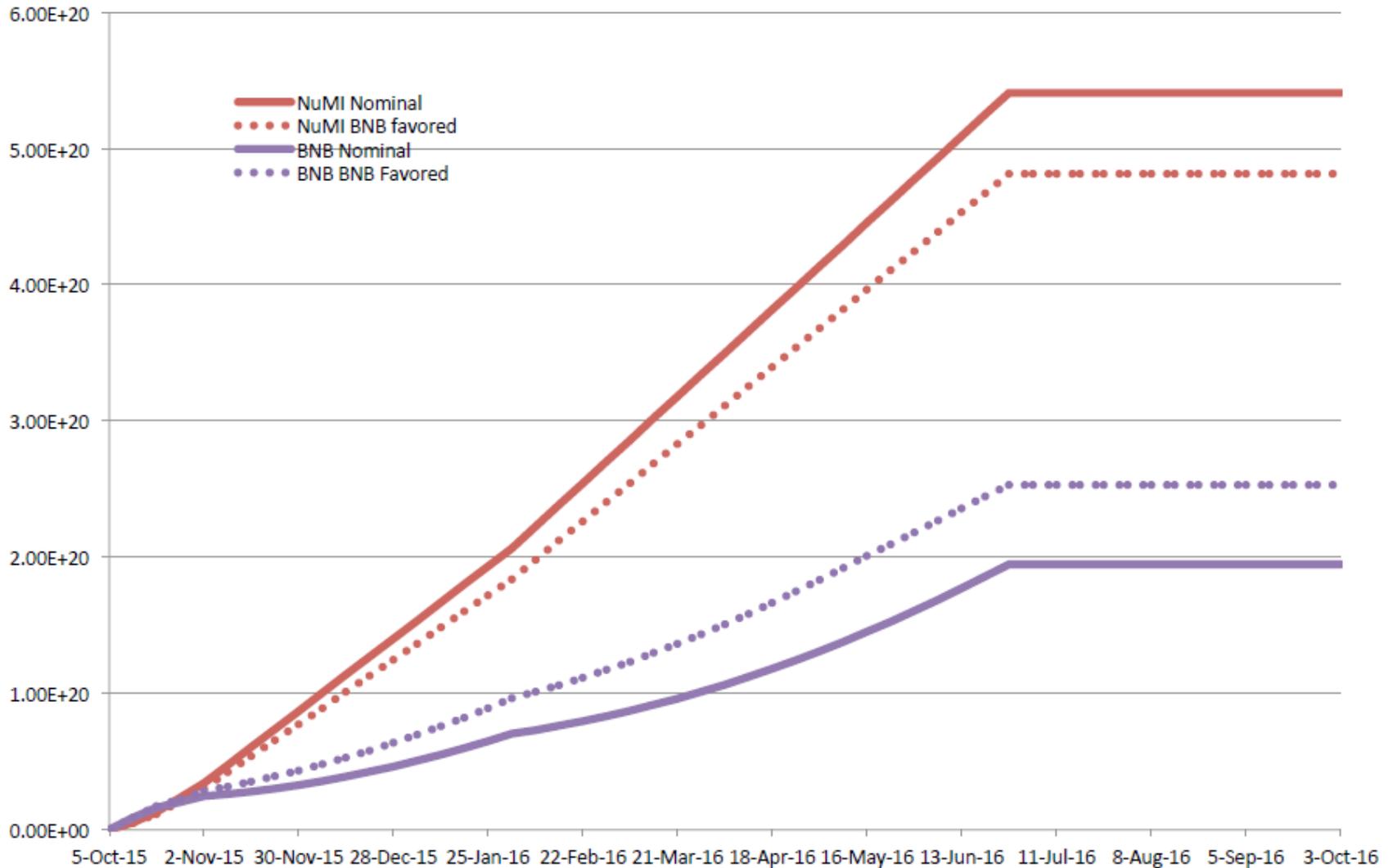
FY16 NuMI POT Projections (Maximize Beam to NuMI)



FY16 BNB POT Projections (Maximize Beam to NuMI)



Possible to send more beam to BNB at expense of NuMI



Accelerator summer shutdowns

- 2015 shutdown begins July 6 (beam off July 4)
 - 13 weeks
 - First of three phases in Recycler TSP2IP project
 - Connection from Recycler to Muon Campus beamlines
 - General maintenance
- 2016 shutdown
 - Estimate 10-12 weeks
 - Complete phase two of TSP2IP project
 - Install 2.5-MHz Recycler RF cavities for beam to Muon Campus
 - Rework MI-30 extraction
- 2017 shutdown
 - Estimate 8-10 weeks
 - Complete phase three of TSP2IP project
- Shutdowns expected to occur July-Aug to optimize MI performance

Master Substation replacement

- Laboratory typically powered by two substations
 - Kautz Road Substation (KRSS)
 - Typically powers Main Injector and Recycler
 - Master Substation (MSS)
 - Typically powers the remainder of the site
- Successfully ran on Kautz Road Substation as a test from Nov 2014 – Apr 2015
- Will be ready for Master Substation to go offline in Sept 2015 for about one year for replacement

Impact of proposed CAPTAIN MINERvA experiment

- Requires only the usual maintenance and operation of the NuMI beamline and target system already being operated for beam to NOvA

Impact of LOI: Direct Search for Dark Photon and Dark Higgs Particles with the SeaQuest Spectrometer

- Requires the continued maintenance and operation of the Neutrino Muon beamline
- Impacts beam available from MI along with other SY120 experiments

Summary

- Running with high reliability with record beam power to NOvA
- Preparing to run beam at 15 Hz
- Increasing protons on target to NOvA with goal of 700 kW next spring
- Providing beam to SeaQuest, LArIAT, test beams
- Replaced BNB horn and will be ready to run beam to MicroBooNE
- Will be ready to run beam to Muon Campus in FY17