Fermilab's Accelerator Complex: Current Status, Upgrades and Outlook

Mary Convery

ICHEP

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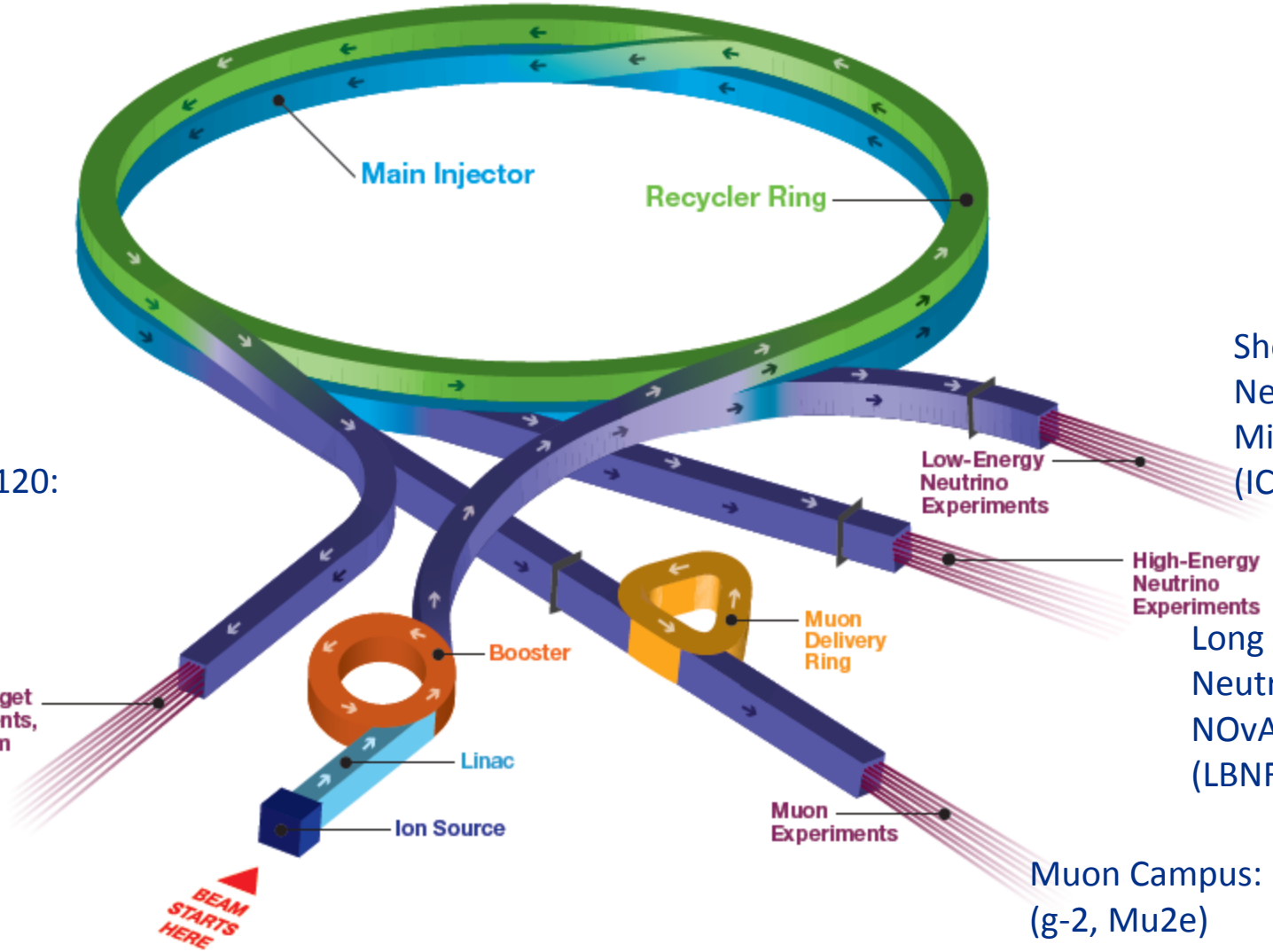
Fermilab Accelerator Complex



Short Baseline Neutrino: MicroBooNE (ICARUS, SBND)

SwitchYard 120: SeaQuest, LArIAT, test beam

Long Baseline Neutrino: NOvA, MINERvA (LBNF/DUNE)

Muon Campus: (g-2, Mu2e)

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+																ν
		MINERvA				MINERvA				MINERvA				MINERvA				
		NOvA				NOvA				NOvA				NOvA				
BNB	B	MicroBooNE				MicroBooNE				MicroBooNE / SBN:MicroB				SBN: MicroBooNE				
						SBN: ICARUS				SBN: ICARUS / SBN:ICARUS				SBN: ICARUS				
						SBN: SBND				SBN: SBND				SBN: SBND				
Muon Campus		g-2				g-2				g-2				g-2				μ
		Mu2e				Mu2e				Mu2e				Mu2e				
SY 120	MT	FTBF - MTEST				FTBF - MTEST				FTBF - MTEST				FTBF - MTEST				p
	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	

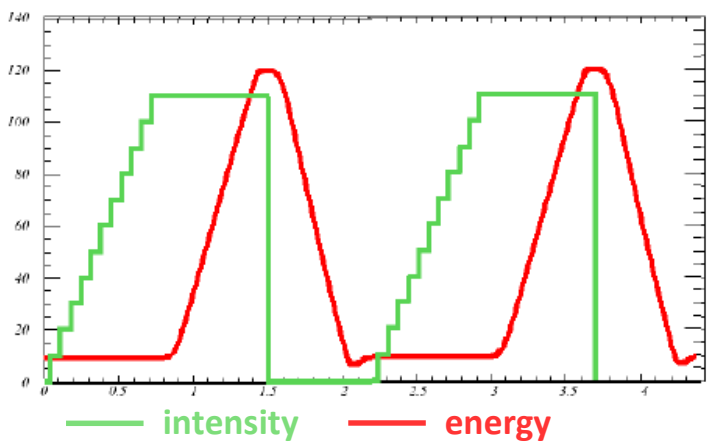
RUN / DATA	Length of mid-year maintenance shutdowns for FY16 and beyond under discussion
STARTUP/COMMISSIONING	Transition from SeaQuest to Polarized-DY under consideration
INSTALLATION/COMMISSIONING	MINOS+ runs through FY16 and is then completed.
M&D (SHUTDOWN)	g-2 hope to get some data during the commissioning period in FY17, just before the summer shu

Accelerator Operations Priorities for FY16-18

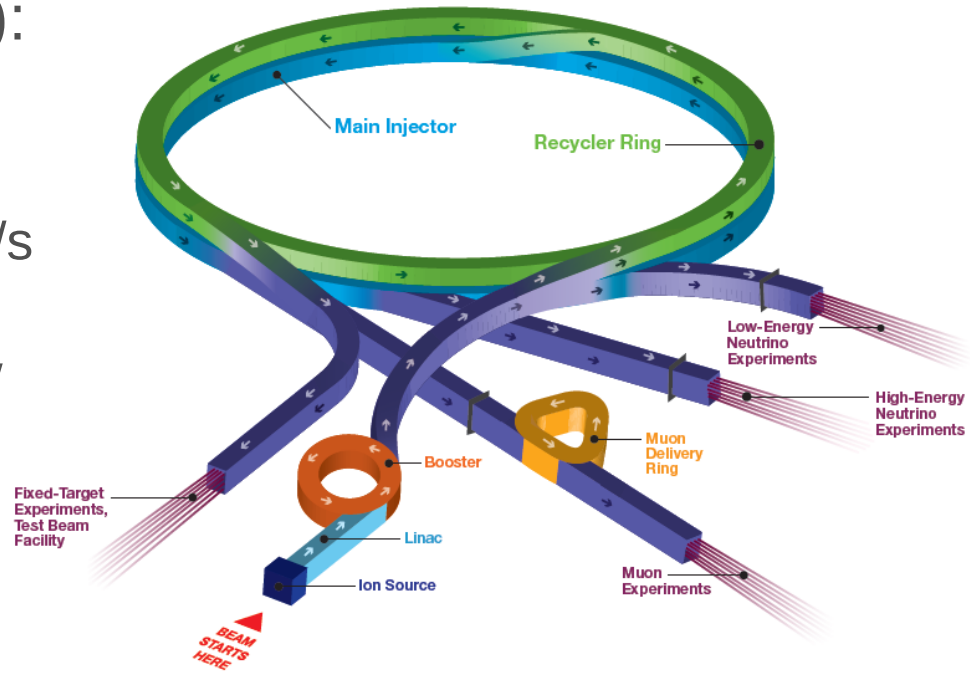
- Ramp up beam power to 700 kW for NOvA, achieve performance metrics, and support full experimental program
- Continue carrying out the Proton Improvement Plan to reach $>2x10^{17}$ protons/hour in the Booster and ensure a useful operating life of the proton source through at least 2030
- Complete the Muon Campus construction in FY17, then start to commission and operate beam to the g-2 experiment
- Build an upgraded horn and power supply in the Booster Neutrino Beam target station for Short Baseline Neutrino

Neutrino Beam from Main Injector (NuMI)

- Previous operation (320 kW):
  - 11 pulses (at 15 Hz) into Main Injector with RF slip-stacking
  - Ramp to 120 GeV at 204 GeV/s and extract to NuMI target
  - 3.7e13 / 2.2 s cycle → 323 kW



  - Recycler used for storing antiprotons for the Tevatron



Main Injector:

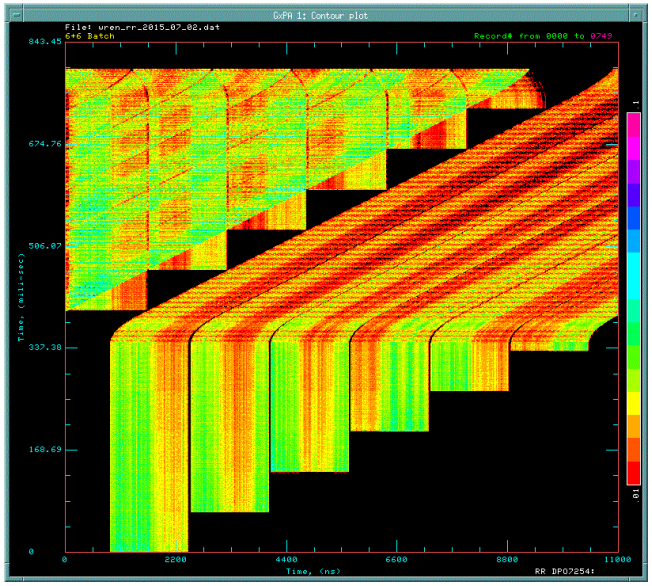
Accelerates 8 → 120 GeV (150 GeV for Tevatron)

Recycler:

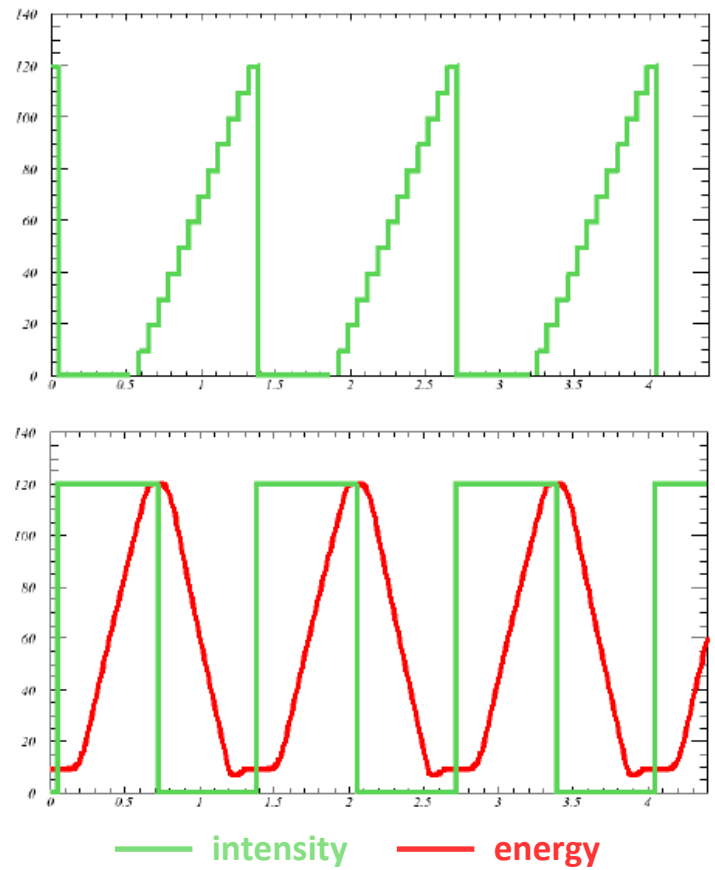
Fixed 8 GeV KE ring

Increasing Beam Power to 700 kW

- Move slip-stacking to Recycler
- Increase number of batches 11→12
- Increase Main Injector ramp rate
  - 204 GeV/s → 240 GeV/s
- Can reach 700 kW with only ~10% increase in per-pulse intensity

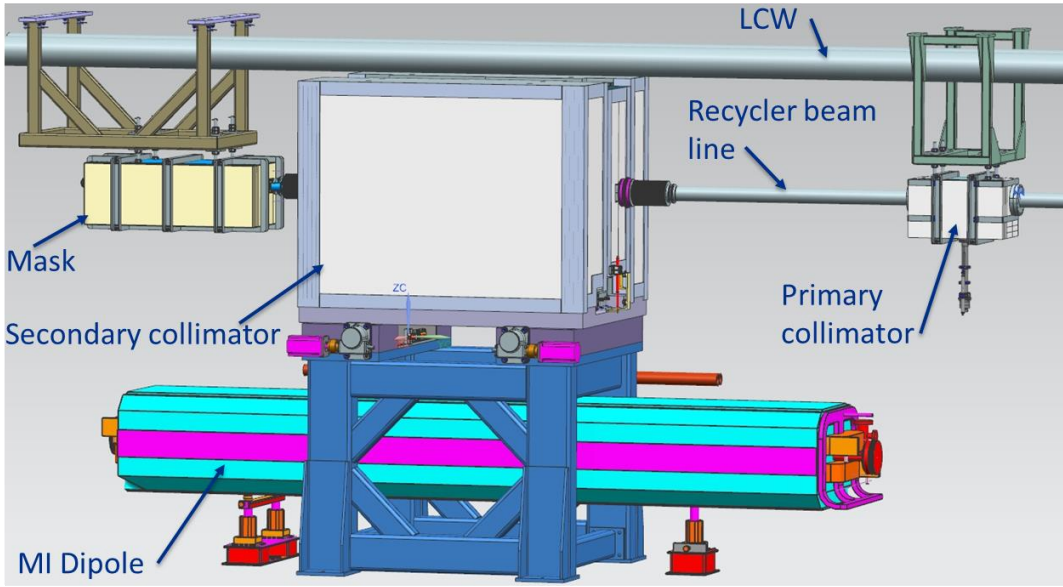


slip-stacking
6+6 batches



Other Requirements for 700 kW Beam to NuMI

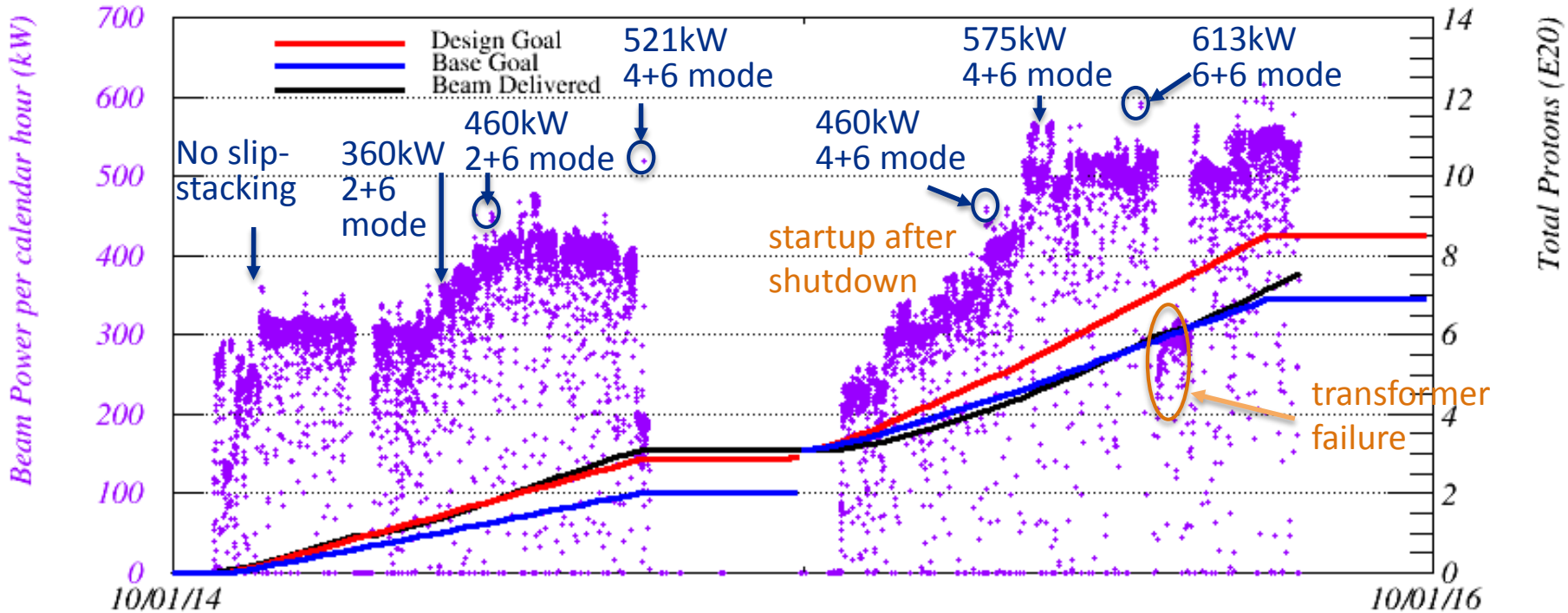
- Beam from Booster at 9 Hz (15 Hz to support full program)
- Reliability improvements
  - Recycler vacuum upgrade: replacing depleted titanium sublimation pumps with ion pumps – better suited for new mode
  - Corrosion resistant beampipe in high radiation areas
- Maintain high efficiency and control losses
  - Collimators in Recycler to capture losses that would otherwise irradiate limited-aperture injection and extraction magnets




Main Injector secondary collimator

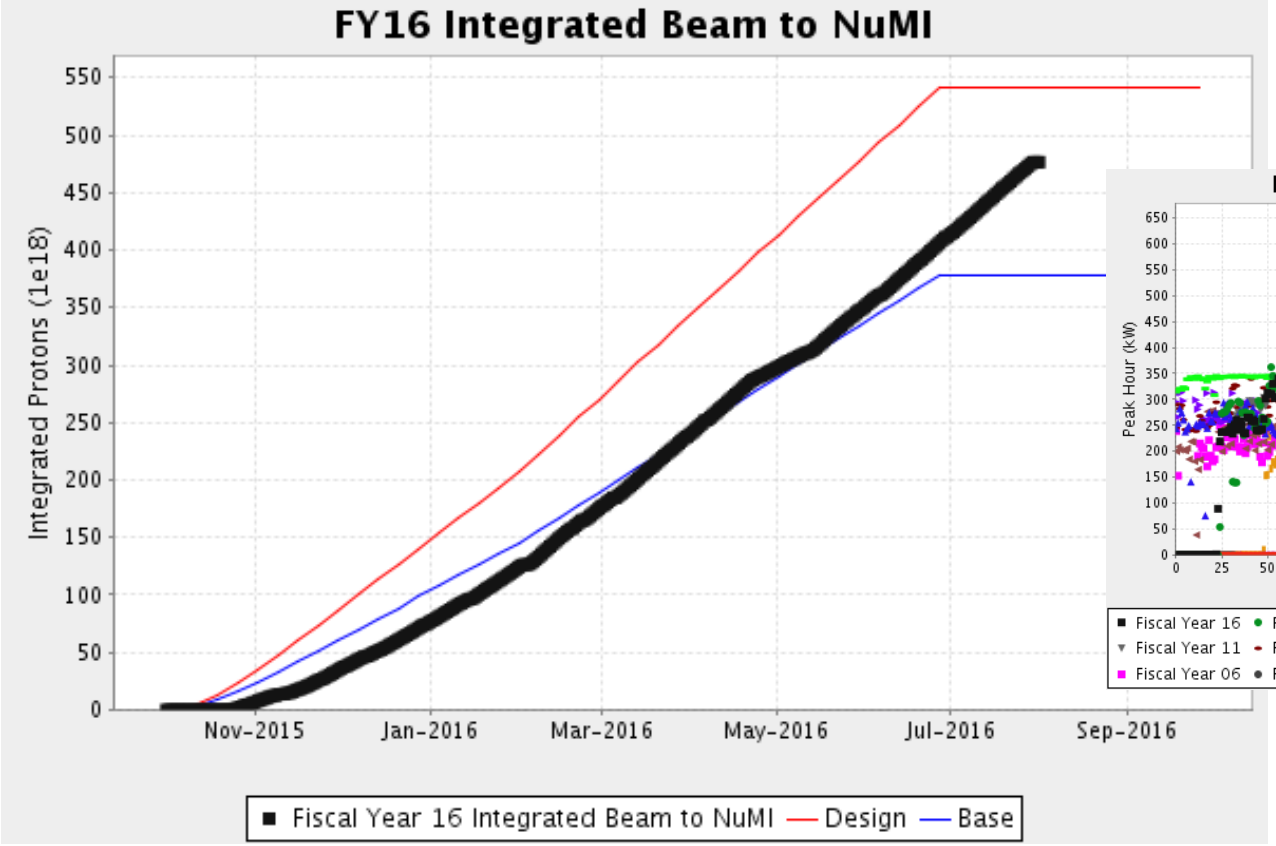
Ramping up Beam Power to 700 kW for NOvA

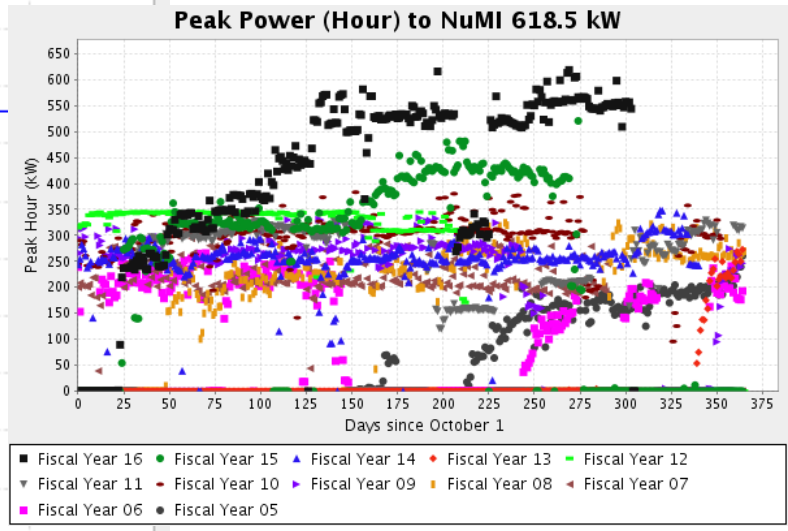
- (Note that SY120 takes 10% of timeline, 700 kW → 630 kW)



- Increase number of batches slip-stacked in Recycler in steps
- At each step, increase intensity while tuning for efficiency, losses
- Successfully demonstrated 700 kW for one cycle
- Regular 700 kW operation after collimators installed this shutdown

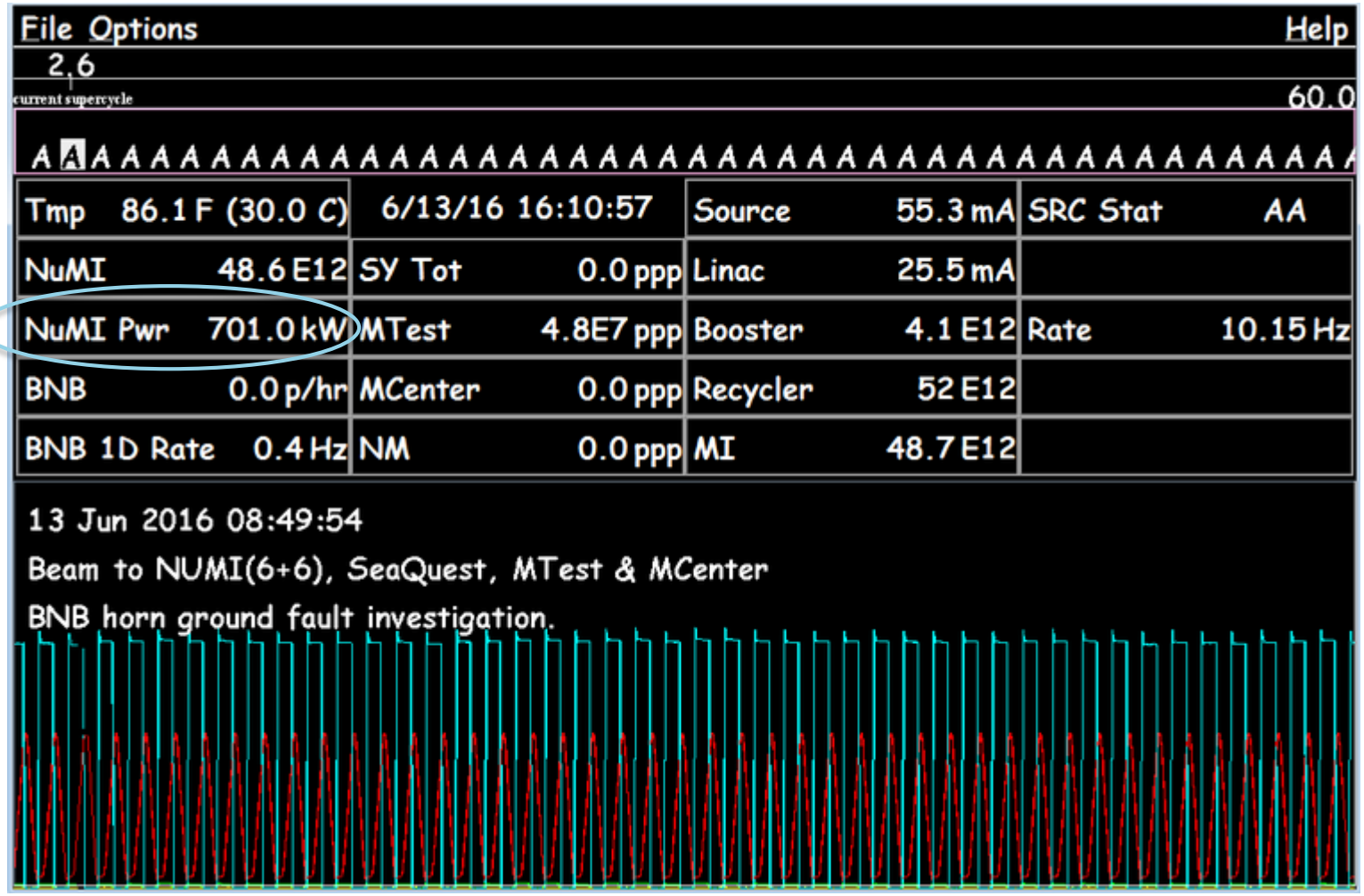
Achieved FY16 Goals for Beam to NuMI





- Based on milestones for achieving 700 kW beam power
- Now running consistently at 550 kW, make last ~10% push once collimators installed

700 kW Beam to NuMI

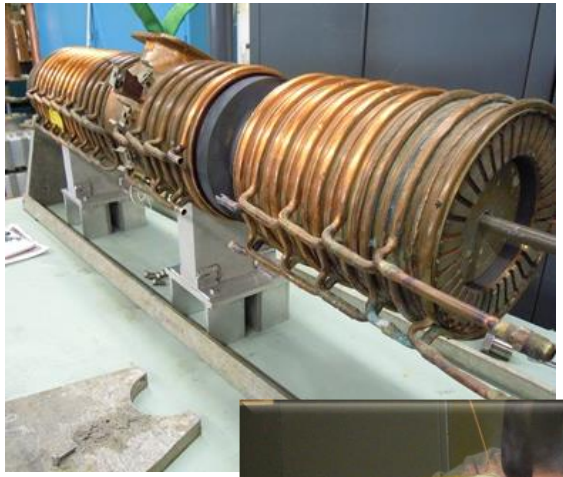
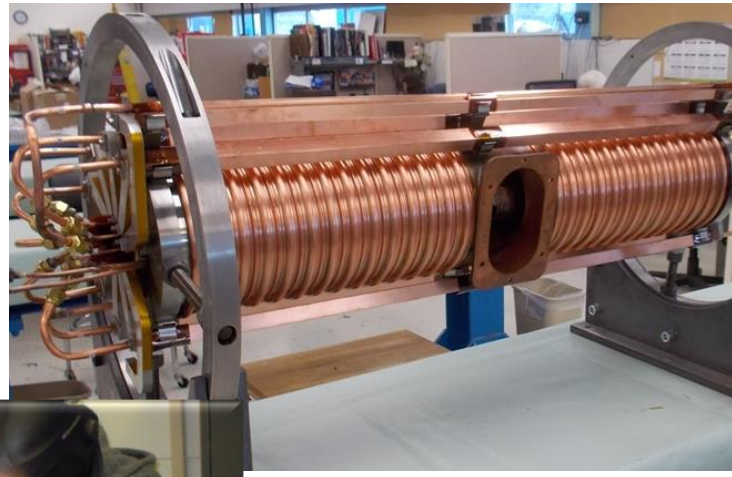


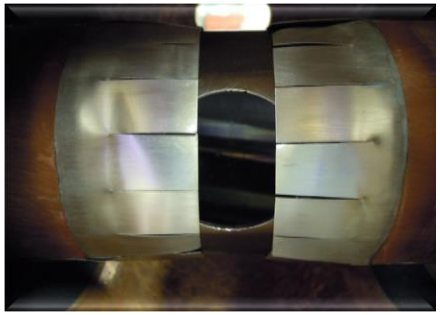
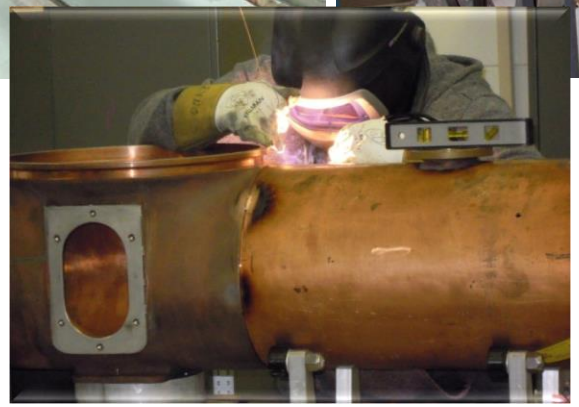
Proton Improvement Plan

- Multi-year campaign funded through accelerator operations
- Includes RF upgrades, instrumentation and beam physics improvements, utilities…
- Initiated in 2011; ~60% complete
- Goals:
  - Increase the beam repetition rate from ~7 Hz to 15 Hz
  - Eliminate major reliability 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 > $2x10^{17}$ protons/hour (from $1.1x10^{17}$)
  - Ensure a useful operating life of the proton source through at least 2025 – later changed to 2030

PIP Highlights – RF Cavity Refurbishment and New Tuners

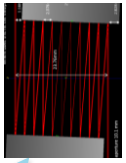
- Spent 4 years refurbishing water, vacuum, electrical and mechanical connections of 19 cavities to run at 15 Hz
- Also built new tuners to allow quick repairs
- Rebuilding 3 additional older cavities (one already installed)

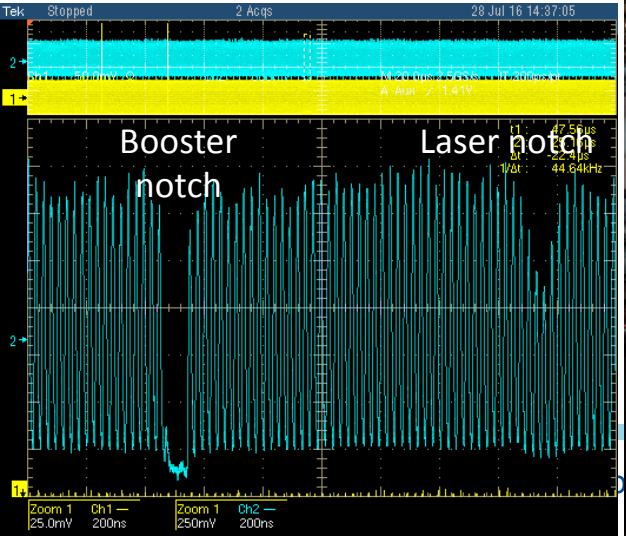




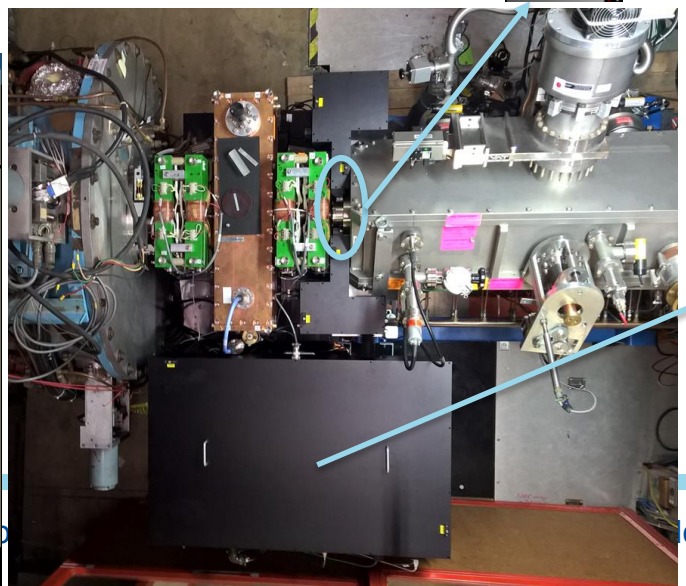




PIP Highlights – Laser Notcher

- Currently use collimator system in Booster to notch out beam where Booster extraction kicker fires
- Significantly reduce Booster losses by notching beam upstream in the PreAcc (lower energy losses) using laser
- New accelerator development – never been done before!
- Recent installation and successful testing
- Finish commissioning and start routine operation after shutdown

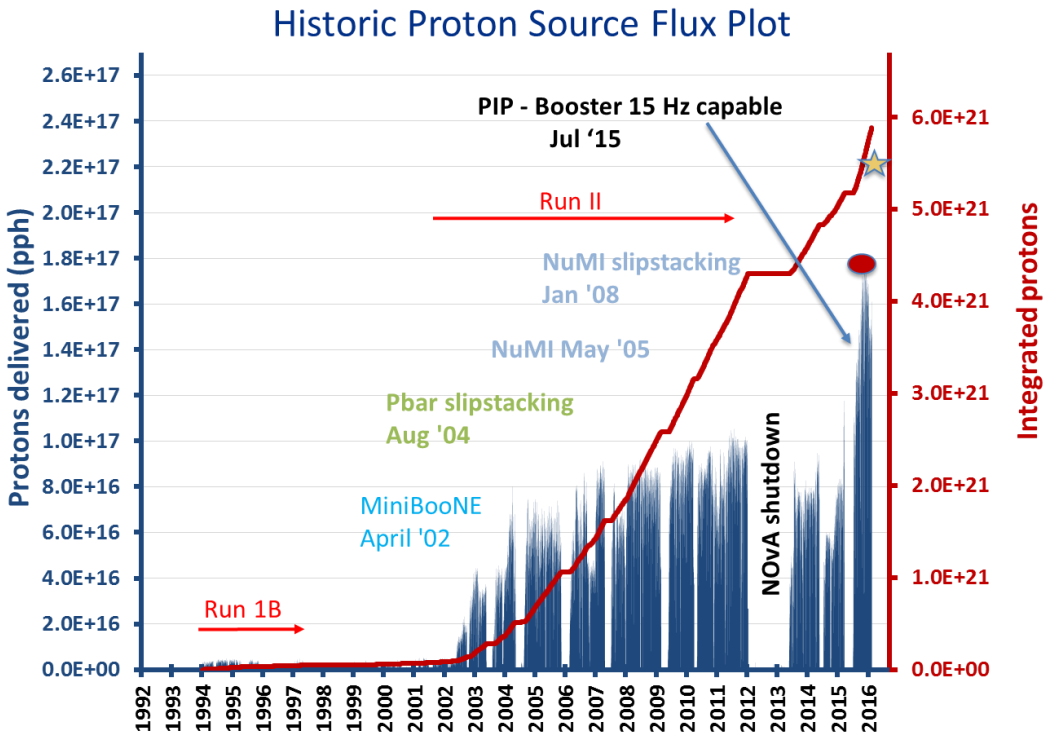






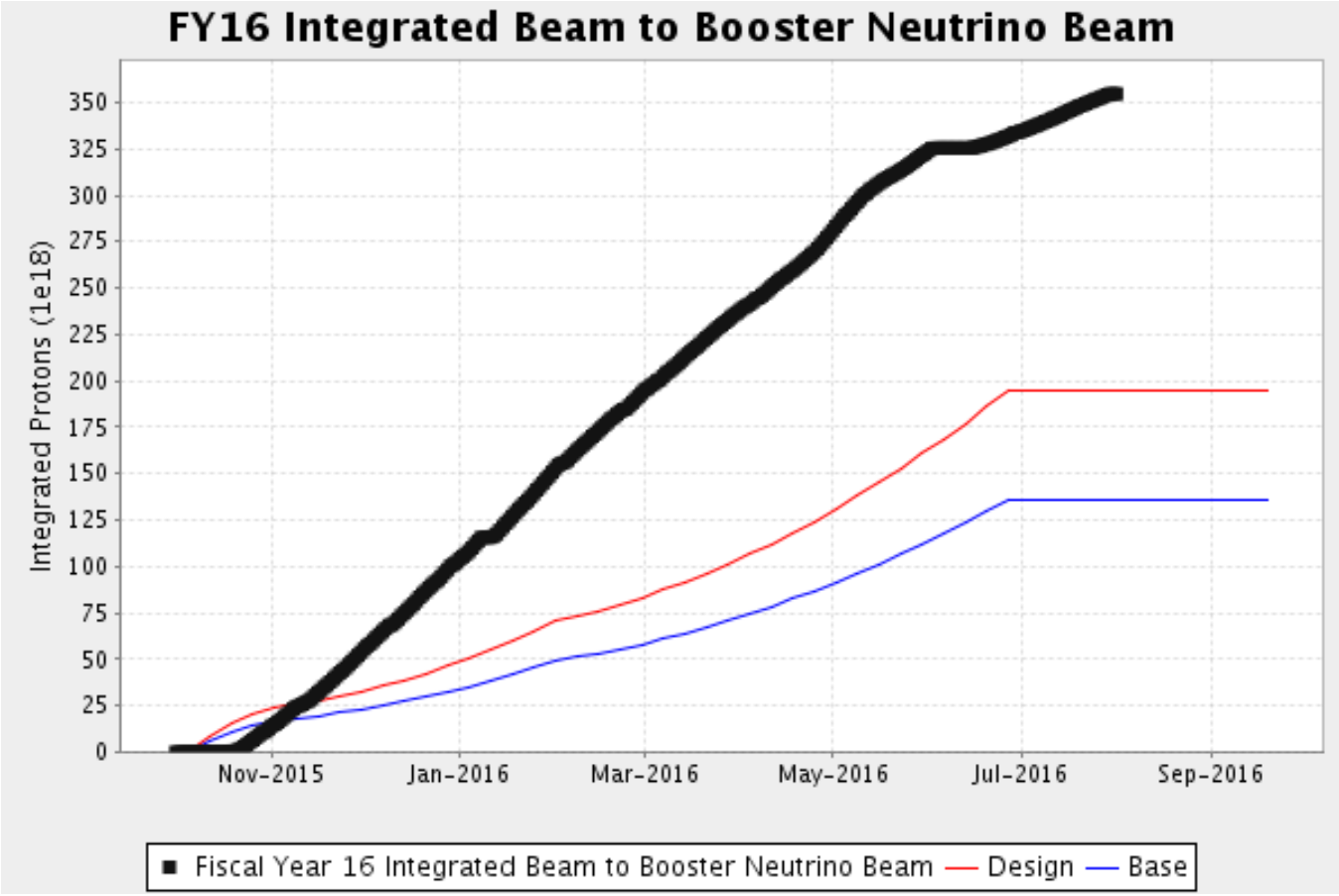
Booster 15 Hz Running

- 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



Currently limited by Booster shielding assessment – new assessment taking into account use of Total Loss Monitors to allow 2.5×10^{17} pph under review

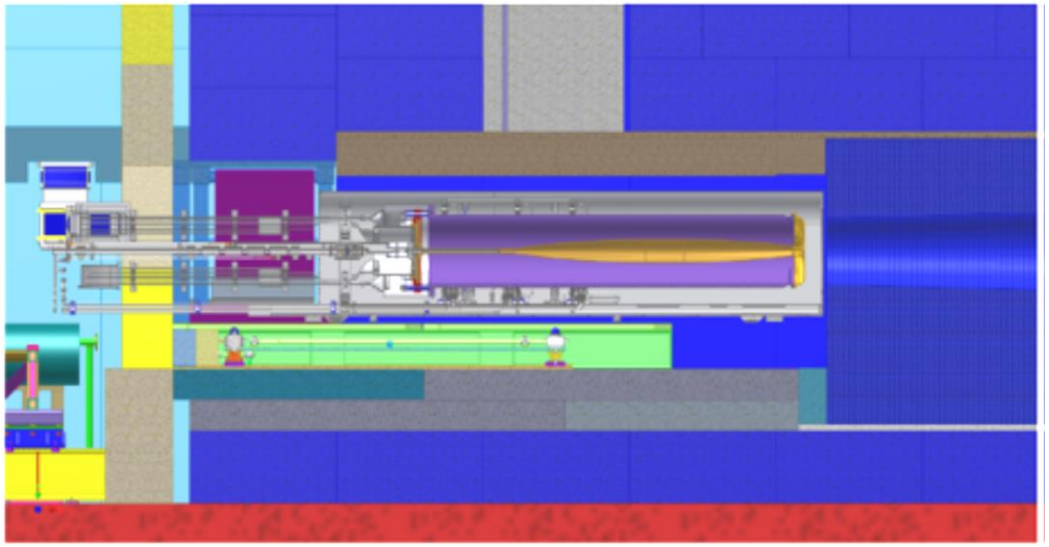
Surpassed FY16 Goals for Beam to BNB

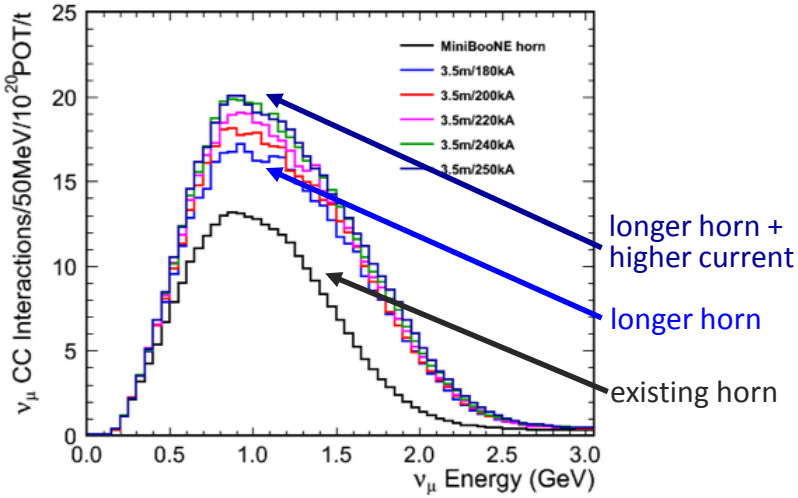


- Booster ramp-up in flux (15 Hz and intensity) much faster than assumed

BNB Upgrade for Short Baseline Neutrino Program

- 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





- Requesting funding for Accelerator Improvement Projects within the SBN Program for FY18-FY20

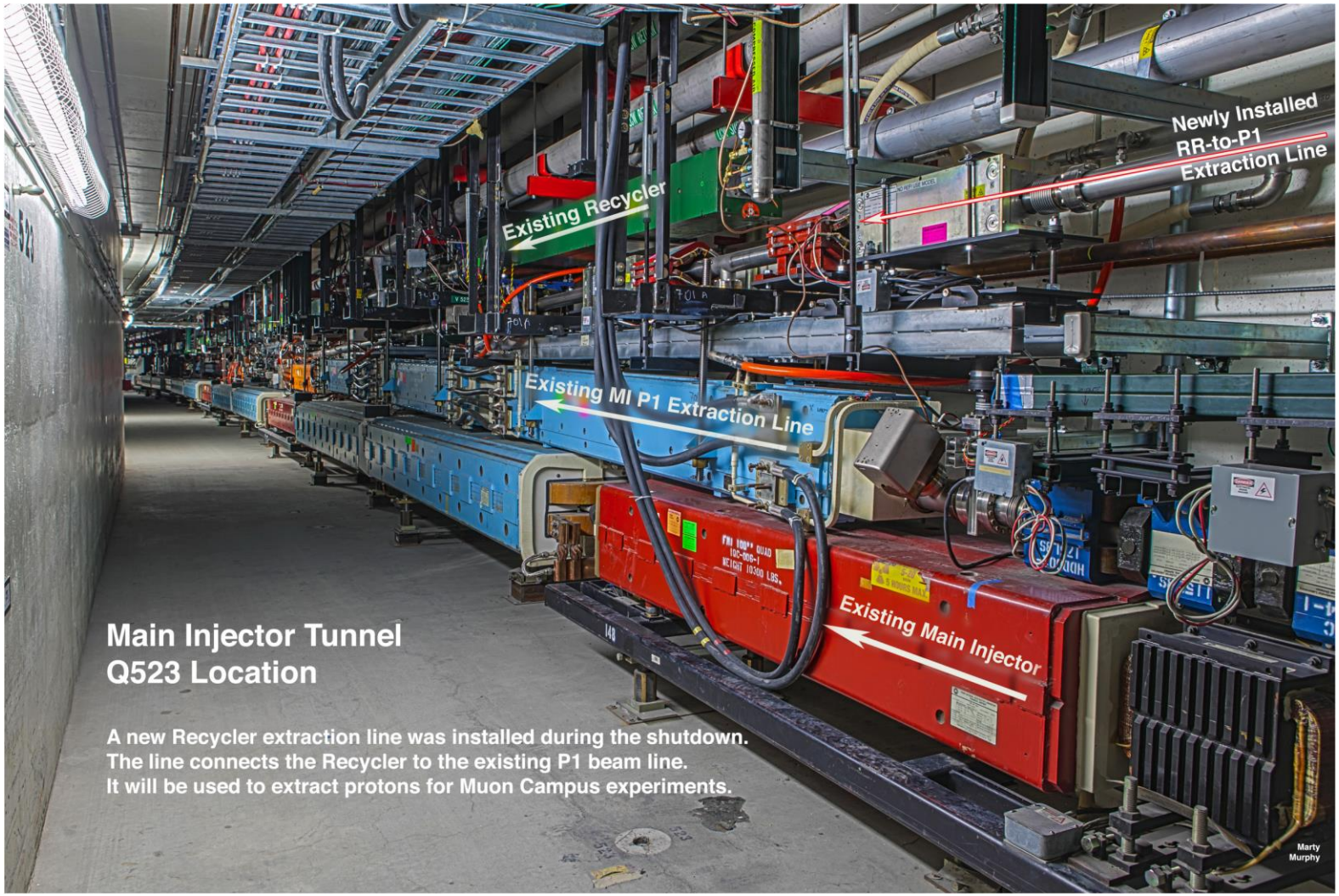
Muon Campus

- New RF in Recycler for re-bunching primary protons
- New connection from Recycler to Muon Campus (protons to Antiproton Source came from Main Injector)
- Re-use of Pbar target station for g-2 with new pulsed power supplies (100 Hz burst rate)
- Pbar Debuncher ring converted to Delivery Ring
  - Beamline (4 turns) for π decay and μ capture for g-2
  - Resonant extraction of primary protons to Mu2e
- New beamlines from Delivery Ring to g-2 storage ring and to Mu2e target
  - Using magnets from decommissioned Pbar Accumulator as well as from BNL g-2 beamline

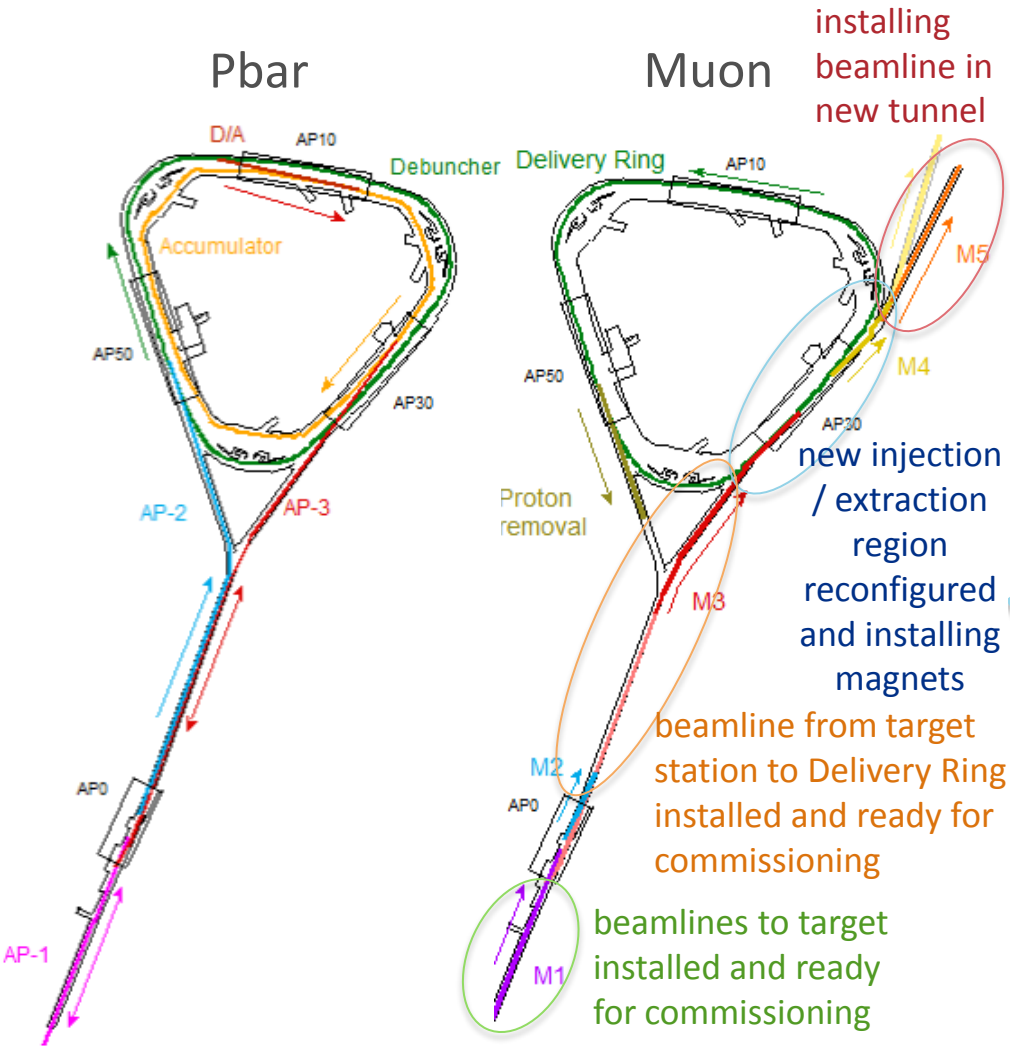
Recycler Modifications for Muon Campus

- Pbar used to take 120 GeV beam from Main Injector
- Muon Campus will take 8 GeV beam from Recycler
- Bunch of 4×10^{12} protons from Booster will be rebunched into 4 bunches of 10^{12} protons using new 2.5 MHz RF in the Recycler which will be extracted in 100 Hz bursts

New Connection from Recycler to P1 Line for Muon Campus

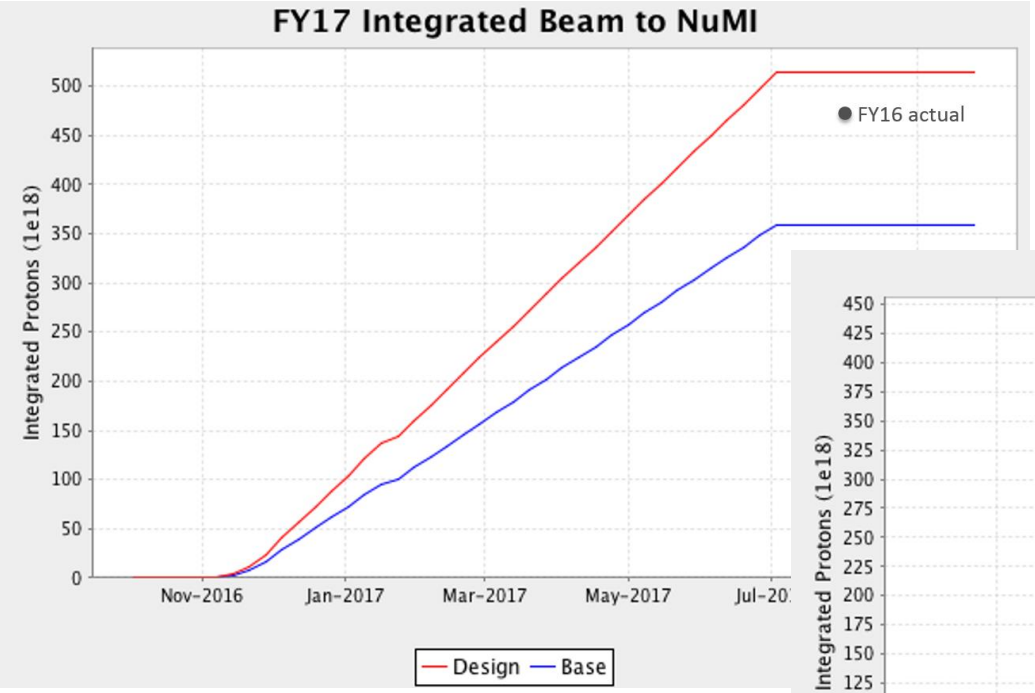


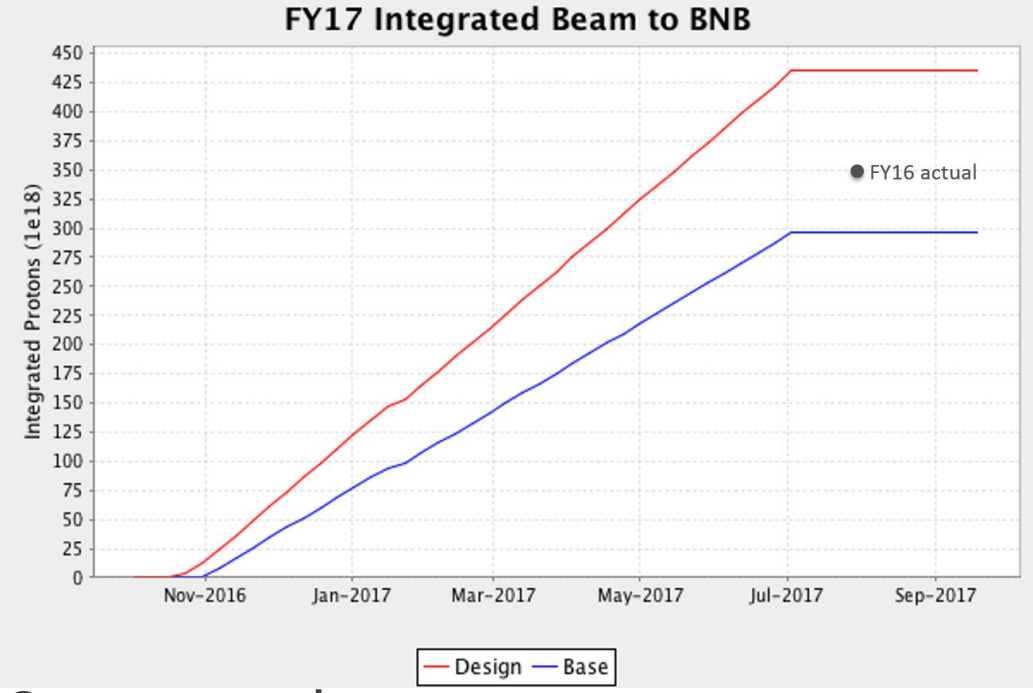
Muon Campus Beamline Construction



Goals for FY17

- Accelerator shutdown expected to end early November
- Expect similar integrated beam to NuMI and BNB as FY16

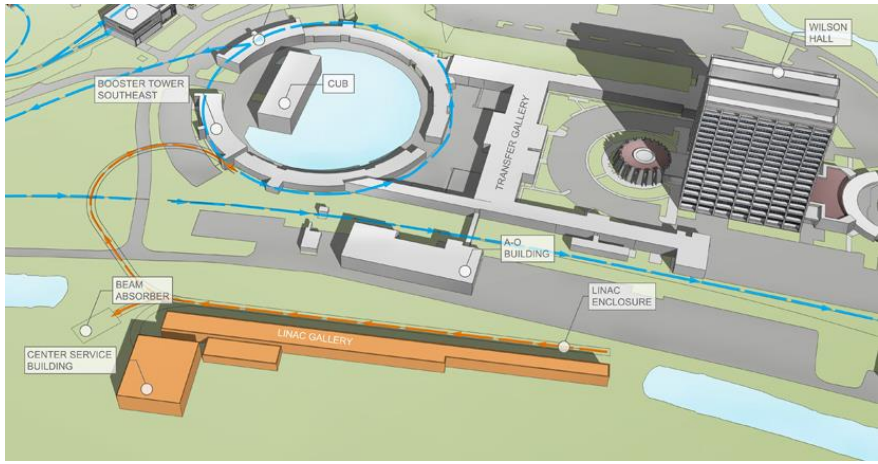




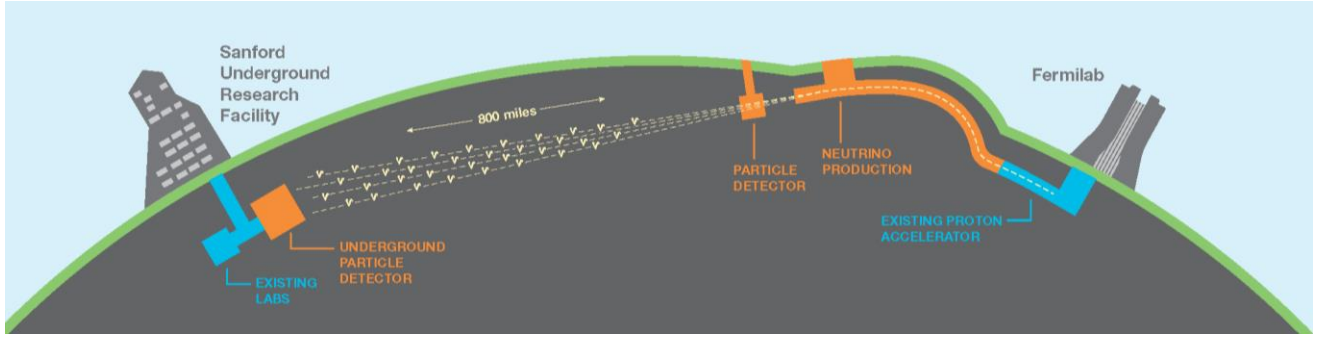
- Establish muons to the g-2 storage ring

Future Outlook

- PIP-II
  - 800-MeV superconducting linear accelerator to provide >1MW proton beam to LBNF
  - DOE CD-0 approval 2015
  - Aiming to start operating 2025
  - Also improvements to Booster, Main Injector, Recycler



- Long Baseline Neutrino Facility
  - CD-3a review for South Dakota excavation expected Sept 2016
  - Beamline Optimization Task Force aiming for August 2017



Conclusions

- Ready to run 700 kW beam power for NOvA after summer shutdown
- Many of the PIP improvements in beam delivery have been realized already; work to ensure reliability remains
- Muon Campus construction is on track and 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%

- PIP-II project is underway to provide >1 MW beam in 2025
- LBNF project also underway, optimizing new beamline at Fermilab