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# ACCELERATOR REPORT

Ioanis Kourbanis

Users Meeting

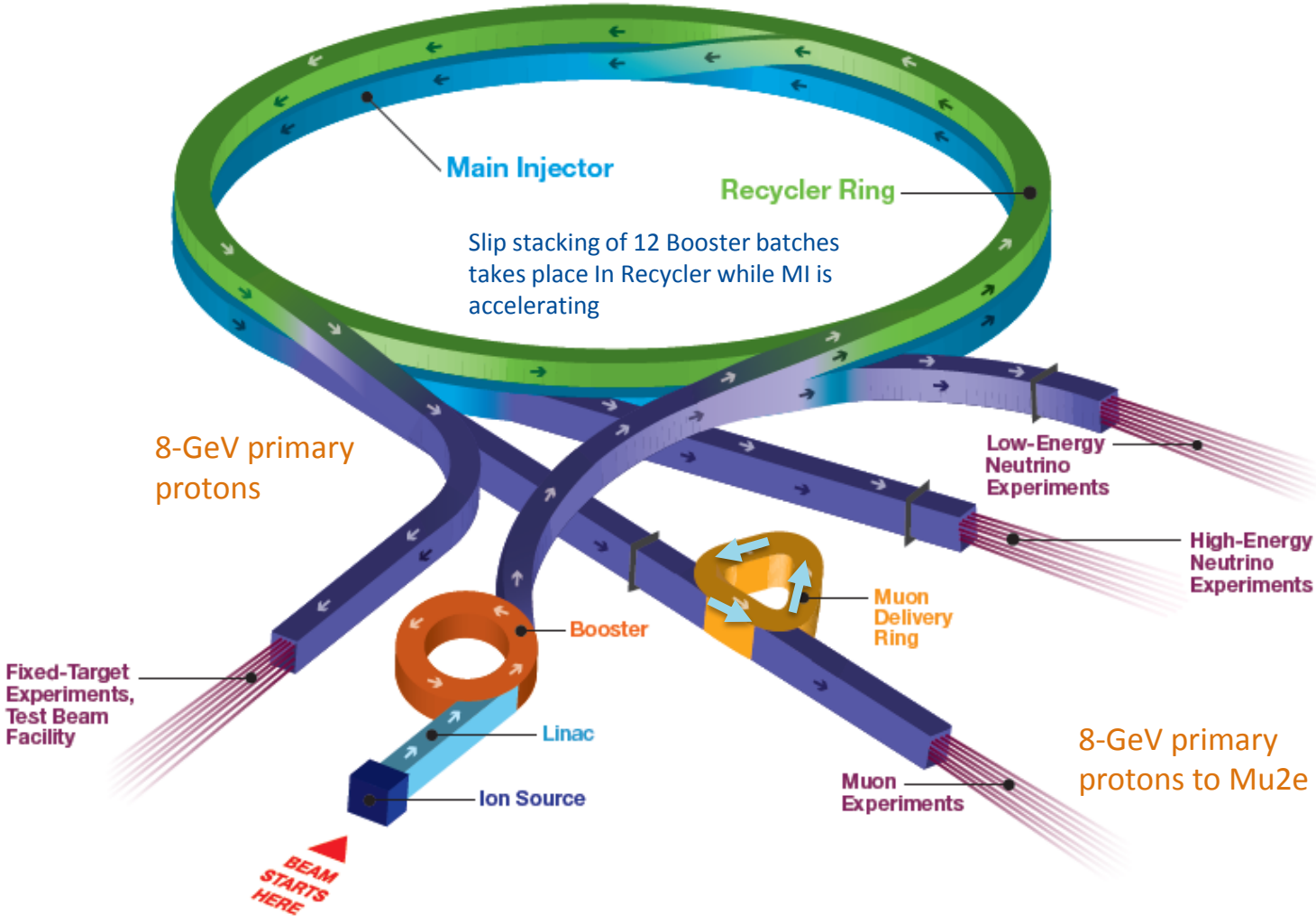
06/08/2017

# Outline

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- Accelerator Complex
- Plans for FY17
- Accelerator Improvements/Highlights
- Accelerator Performance
- Muon g-2 commissioning
- FAST/IOTA
- PIP-I+
- Conclusions

# Accelerator Complex



# Our Plans for FY17

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- Operate the Booster at 15 Hz delivering more than  $2E17$  p/hr.
  - Finish the Booster shielding assessment.
  - Reduce losses.
- Deliver 700 KW to the NuMI target.
  - Install Recycler Collimators.
  - Control losses.
- Deliver beam to the Muon g-2 experiment.
  - Install 2.5 MHz Cavities in Recycler for bunch formation.
  - Finish the construction and component installation in the muon rings and beamlines.

# Linac Highlights

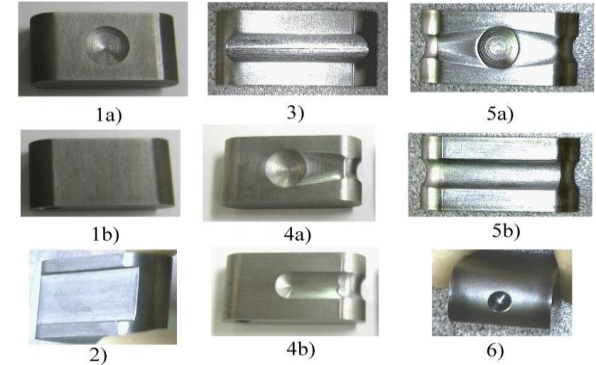
- Injector:** Have developed ion sources that operate entire year



Safer and more reliable Cesium loading

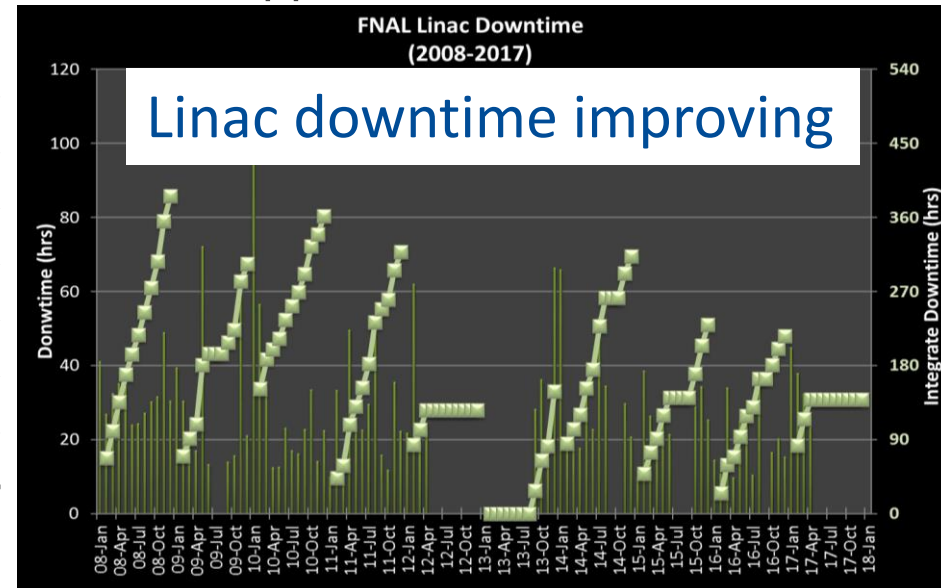
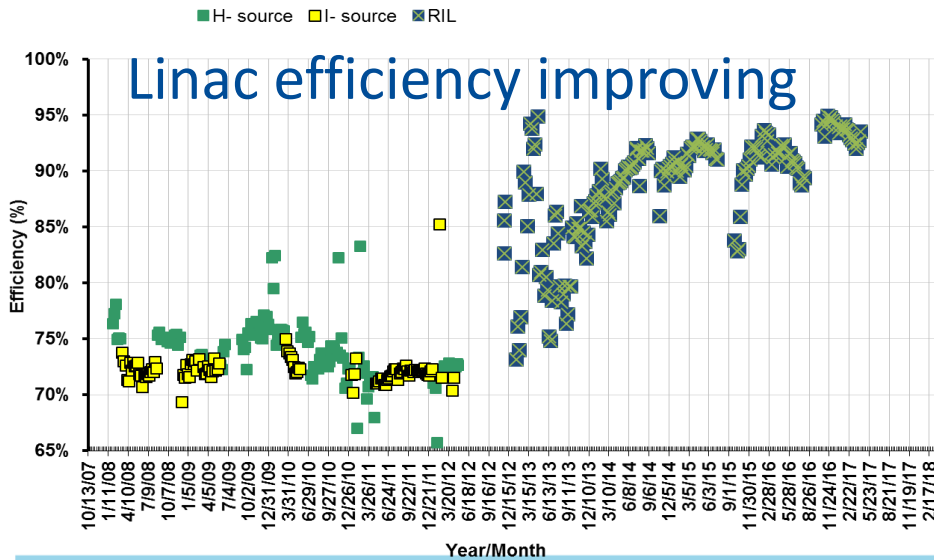


New Cesium boiler



Cathode geometries studied

- Linac:** Upgraded reference sources, driver RF supplies and 2 modulators

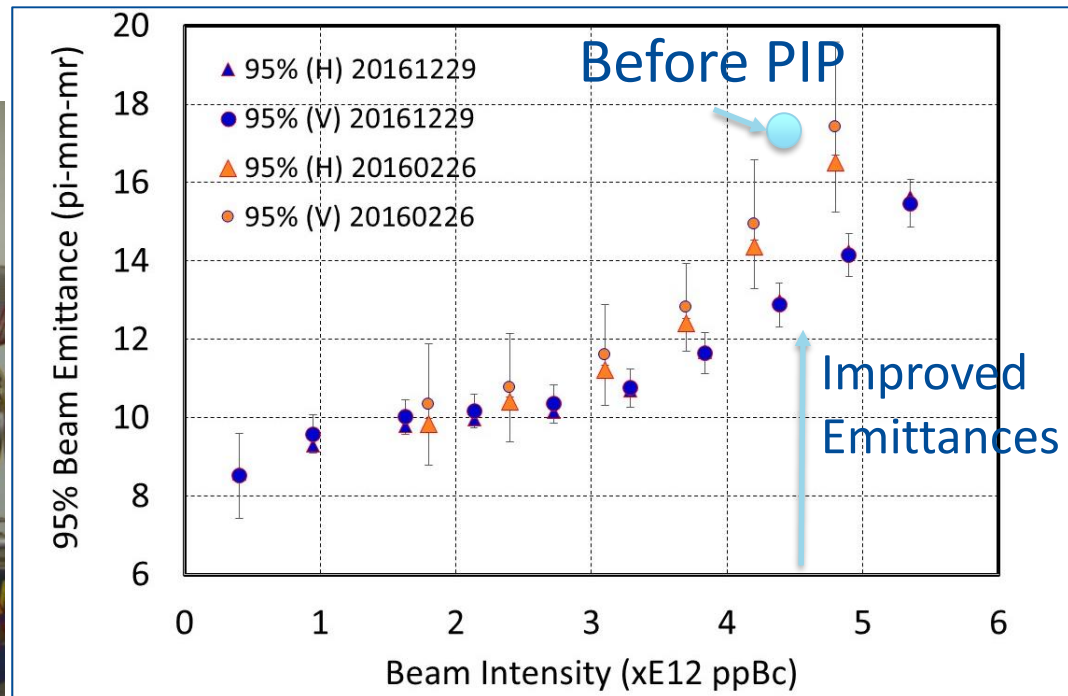


# Booster Highlights

- RF cavities: 21 installed with the 22 completed by FY17 shutdown
- New low level source and control cards
- Added several more longitudinal damper modes
- Upgrade transition timing
- Improved emittances

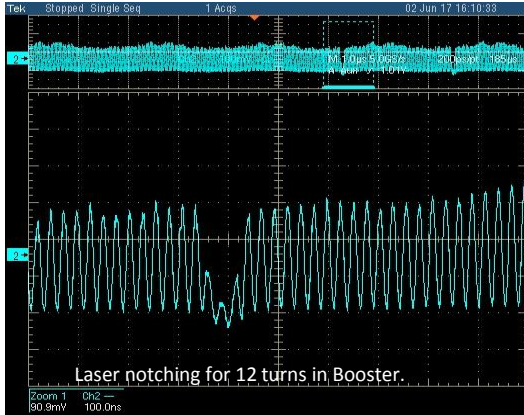


## Recent emittance measurements



# Recent PIP (Proton Improvement Plan) Highlights

## Laser Notching



- Testing of new system under way.
- Booster efficiency improvement by 2% are expected.
- PIP Goal of  $2.4E17$  p/hr to be demonstrated before the shutdown.

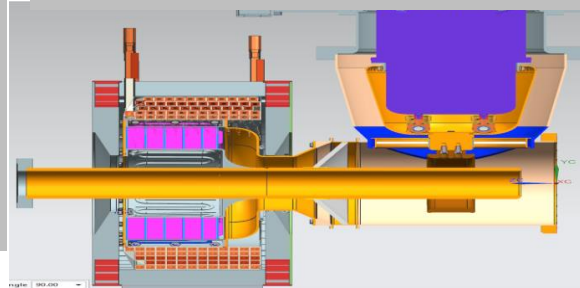
- Operating 2 Marx Modulators.
- Laser notch studies/ops.
- Completed Booster RF cavity 21.
- Second harmonic Booster cavity for improving injection and transition crossing.
- New Booster lattice corrections
- New Booster Low Level system
- Booster Replacement Cavity (starting to build prototype)
- **Booster Shielding Assessment (New Limit of  $2.7E17$  pph)**

## Marx Modulator



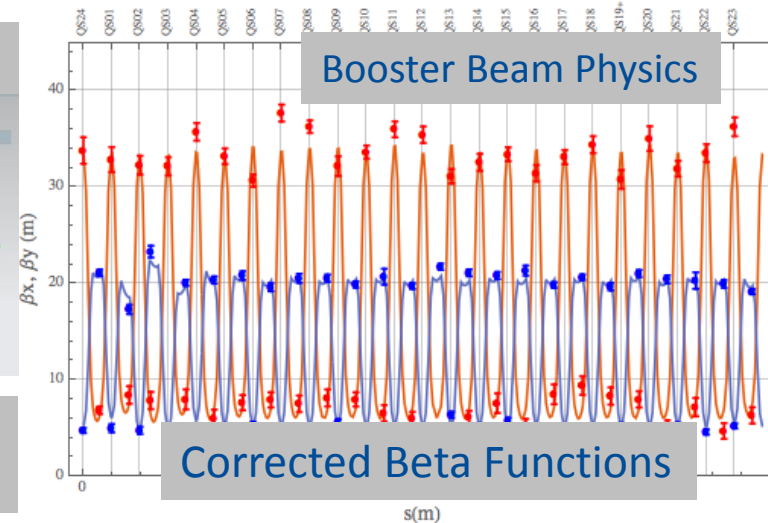
Operating in LLRF #5

## 2<sup>nd</sup> Harmonic Cavity



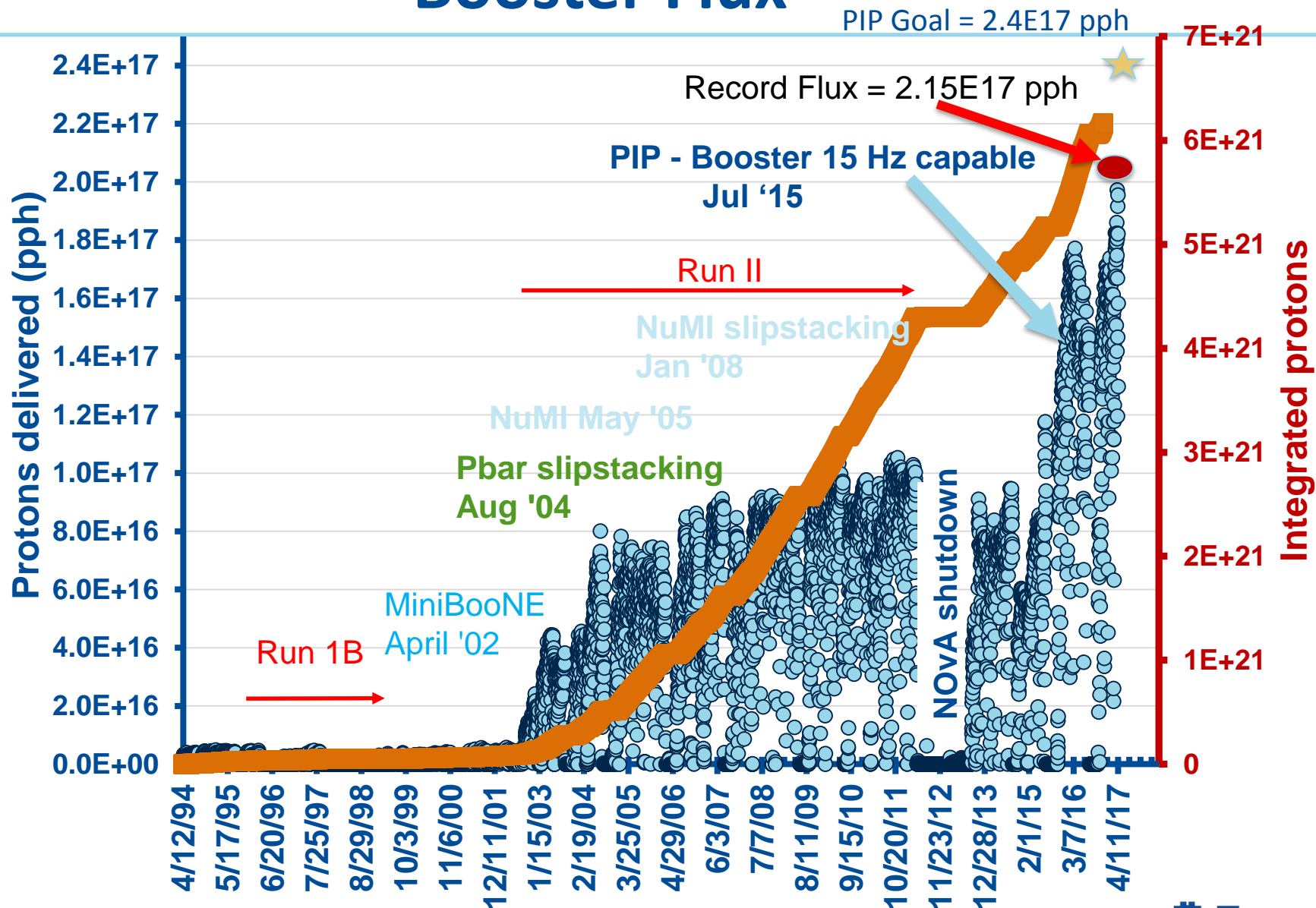
- Frequency range: 76 – 106 MHz
- Length of cavity is 27 inches
- 100 KV Gap Voltage

Combined measurements at 3 ms



Corrected Beta Functions

# Booster Flux





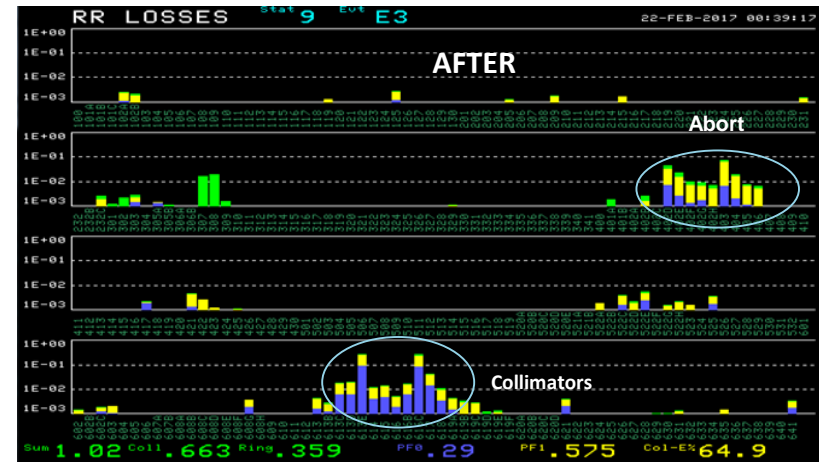
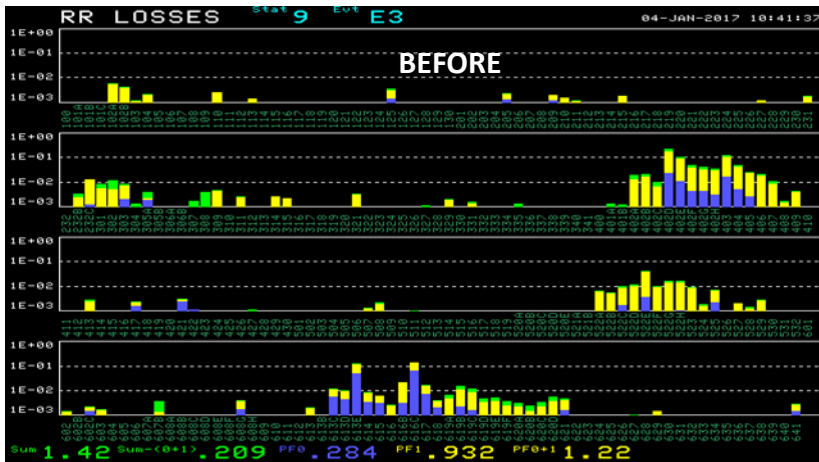
# Recycler Collimators and New Damper (Reduce and control losses)



### Direct Diode Detection (3D) – the idea

- Peak detection of signals from a position pick-up electrode, a simple sample-and-hold, with the sampling triggered by the beam pulses.
- An RF Schottky diode can handle up to 50 V of beam pulses; more is possible with a few diodes in series (LHC detectors have 6 diodes).
- Betatron modulation is down-mixed to a low frequency range, as after the diodes the modulation is in such longer pulses.
- Revolution frequency background gets converted to the DC and removed by series capacitors, while the betatron modulation is passed for amplification and filtering ("collecting just the cream").
- Most of the betatron modulation amplitude is passed to the following circuitry, resulting in very high sensitivity of the method.
- The diode detectors can be put on any position pick-up.
- Low frequency operation after the diodes allows:
  - very efficient signal conditioning and processing with powerful components for low frequencies; using 24-bit inexpensive audio ADCs (160 dB dynamic range possible).
- What is new with respect to the classical peak detectors used in the past for BE applications:
  - Slow discharge, in the order of 1 % per turn (for LHC 100 MΩ resistors required).
  - Usage of high impedance amplifiers, not easy to build in the past if low noise was required.
  - Brutal filtering to the band 0.1 – 0.5 of  $f_{rev}$ .
  - Notch filter for the first  $f_{rev}$  harmonic, resulting in the total  $f_{rev}$  attenuation beyond 100 dB.

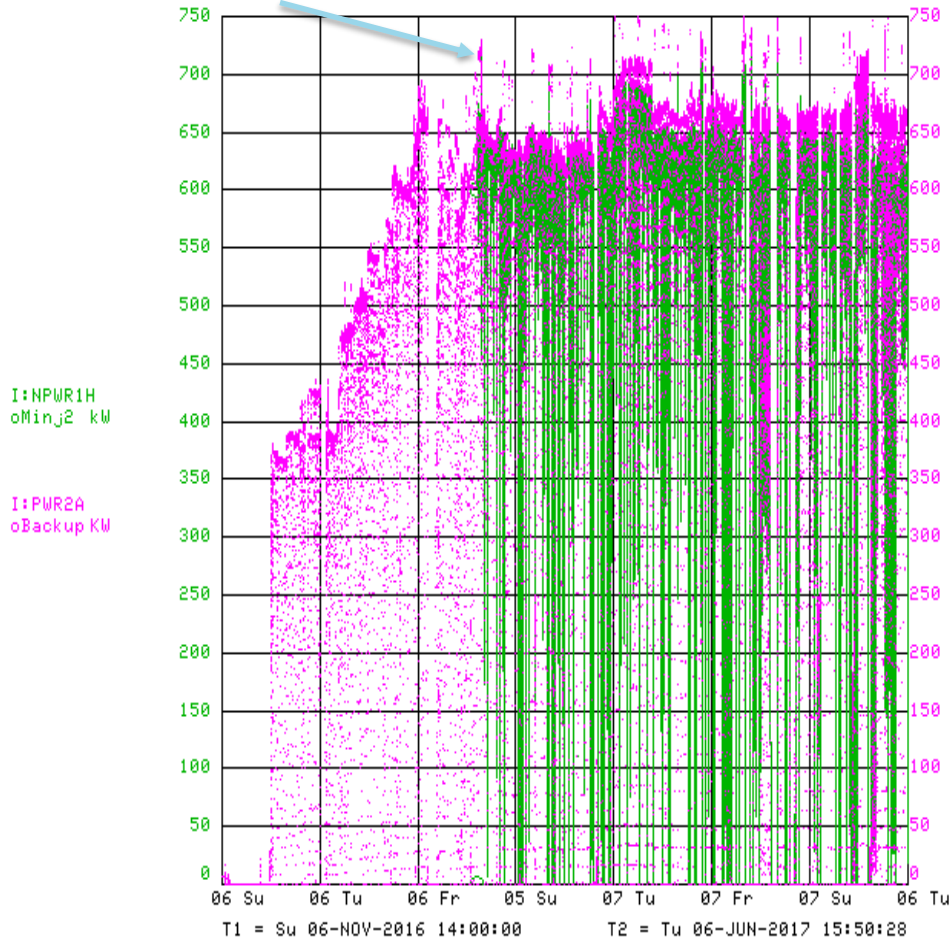
M Gasior, CERN-BE-BI High Sensitivity Tune Measurement using Direct Diode Detection 25



# MI Beam Power in FY17

Achieved 700 KW (01/24/17)

Tue 06-JUN-2017 15:51:02



- PWR2A: Average Power per Suprcycle (60 sec)
- NPWR1H: Average Hourly Power

- 636KW to NuMI target with SY120 is equivalent to 700KW with NuMI only.

- Record power to NuMI target : 727 KW (shielding assessment limit).
- Record power to NuMI with SY120: 690 KW
- Record beam intensity in MI at 120 GeV: 55E12 (NOvA Target Limit)
- Record RR Beam Intensity: 56.6E12

# Beamlines

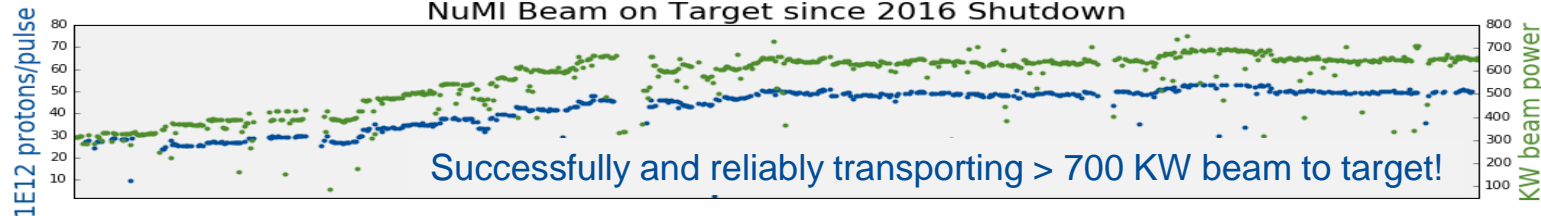
## NuMI beamline

Upgraded dipole power supply regulation to new digital system (“B $\mu$ LB”), running consistently since shutdown

Updating total loss monitor instrumentation for improved reliability and redundancy



NuMI Beam on Target since 2016 Shutdown



## Booster Neutrino Beamline

8 GeV Proton beam delivering over 8E16 Protons/Hour

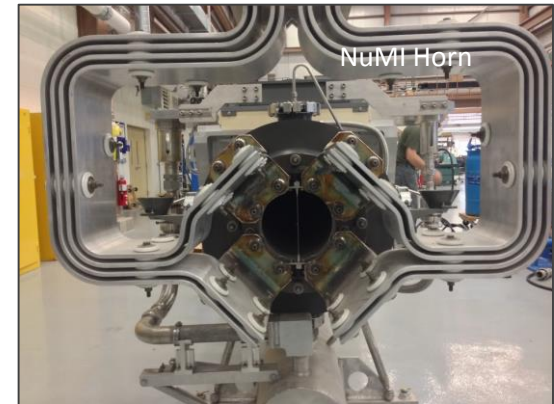
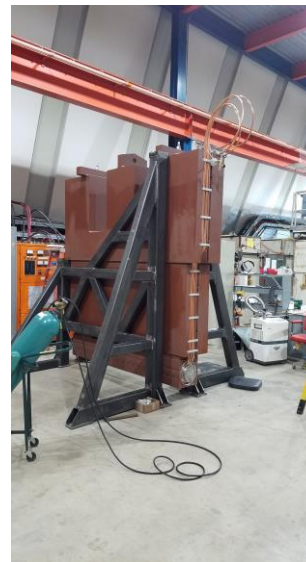


New Trim Allows Rates to BnB in Excess of 5 Hz

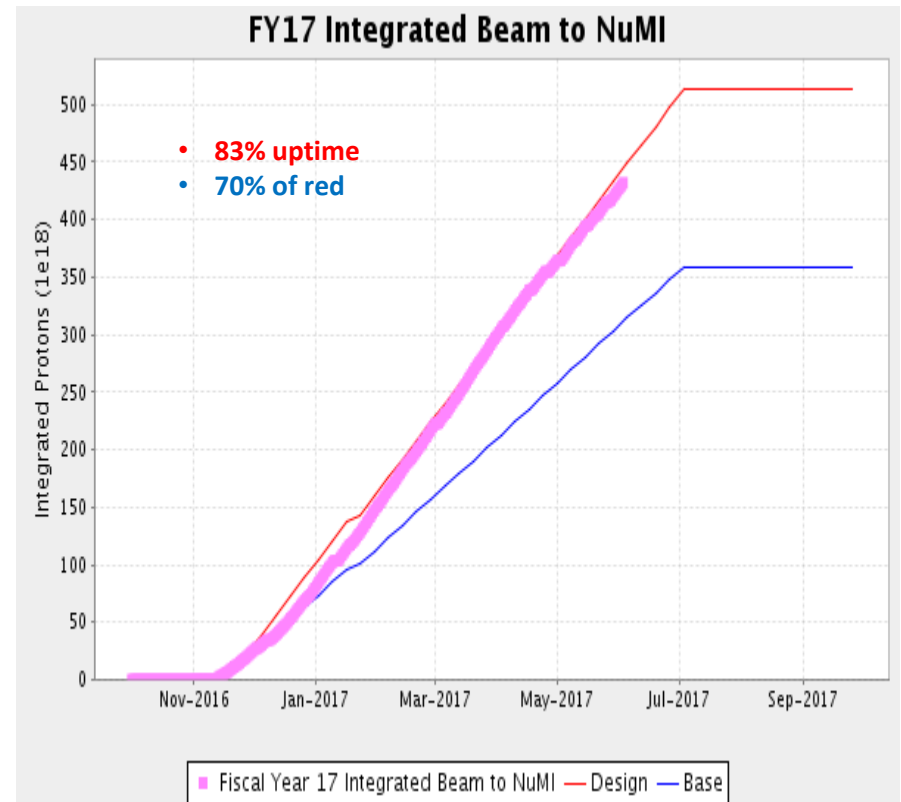
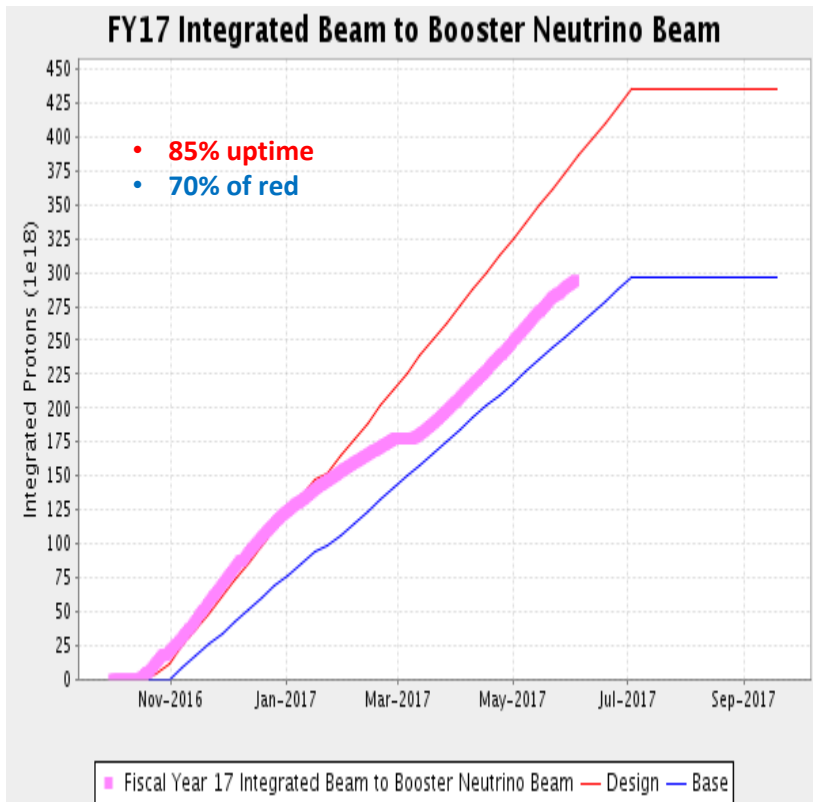
- SciBooNE Hall
- Short Baseline Near Detector
- MicroBooNE Liquid Argon Detector
- MiniBooNE Detector
- Short Baseline Far Detector

# Target Systems Department: Target Halls

- 1. BNB** operating at or near design limits
  - BNB-4 successfully test pulsed & nearing completion
- 2. NuMI** operating at or above design limits (750 kW)
- 3. Muon g-2** starting up now
  - Repurposing of the Antiproton Source AP0 hall
  - Installing new target station beam dump.

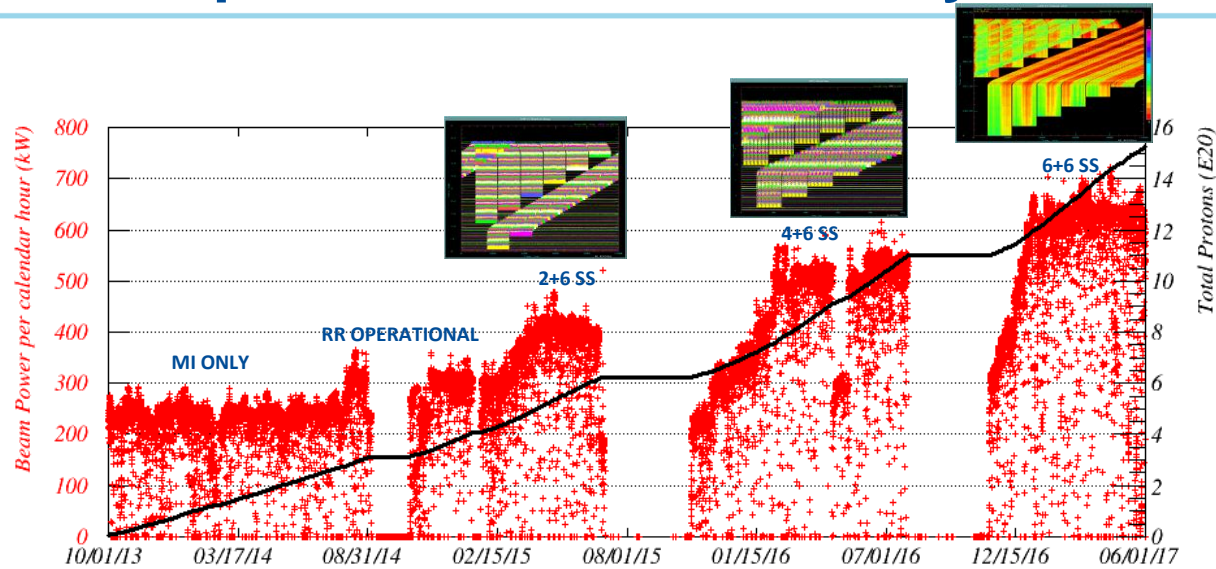


# AD Operations: Goals and Performance



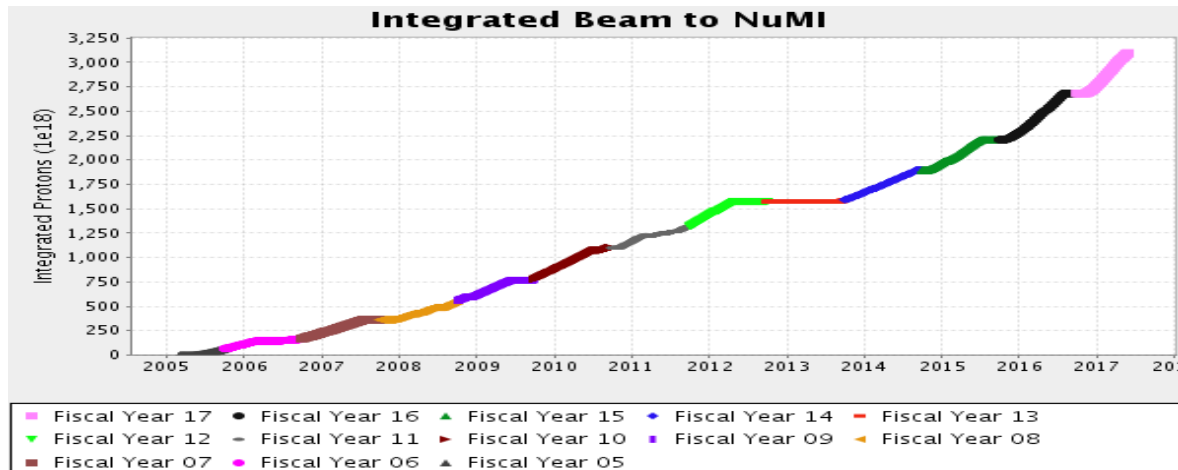
Since Jan. 2017 we are delivering  $0.7E20$  p/month!

# MI Beam power and beam delivery to NuMI



**MI Beam Power and Beam Delivered since the ANU Shutdown**

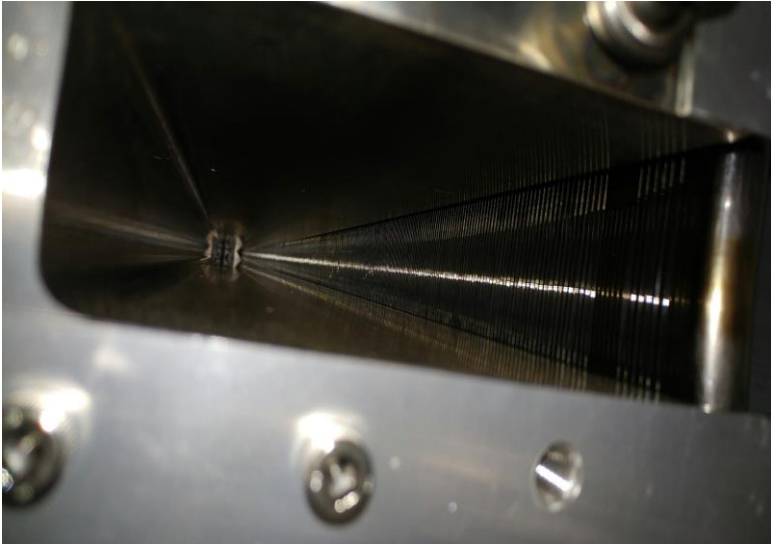
Delivered 12E20 of  
36E20 approved to NOvA



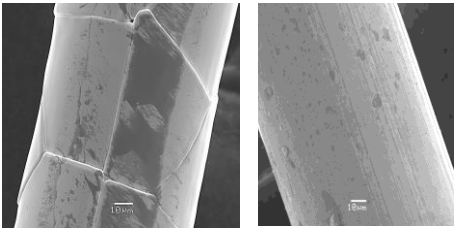
**Integrated Beam to NuMI target since FY05**

# Slow Extraction Program: Replaced both septa in MI

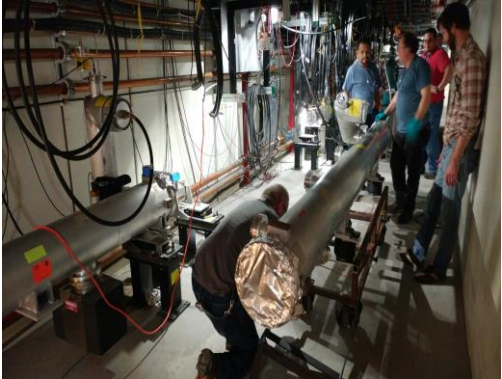
Broken Wires



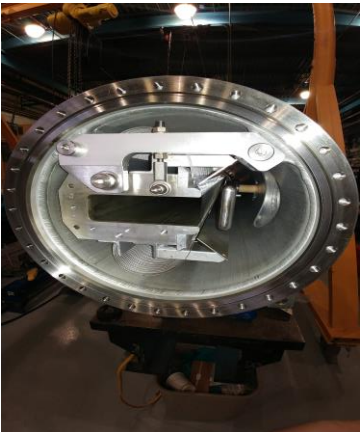
Examining Broken Wires



Replacing Septa In MI Tunnel



Replacing Broken Wires



# Slow Extraction Performance

## Meson and Neutrino Muon Areas

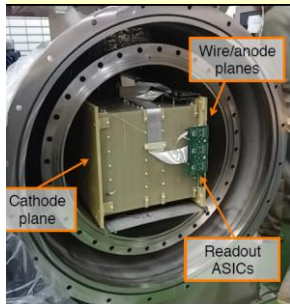
### Test Beams 2016: MTEST and MCENTER

- Users from 31 institutions; 6 countries
  - 11 publications from FTBF experiments; 4 in progress
- Supported running modes:
  - 120 GeV primary protons, 0.2- 60 GeV mixed hadron beams, 1-32 GeV mixed hadron+lepton beams
- Experiments and Detector R&D included
  - High-Luminosity LHC (ATLAS and CMS)\*
  - sPHENIX calorimeter for RHIC; also eRHIC
  - Detector R&D for g-2 and Mu2e
  - LArIAT ( $\mu$ BooNE, SBND, DUNE, ICARUS)
  - General detector R&D

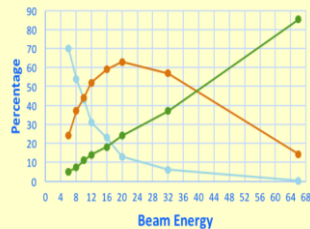
### Neutrino Muon: SEAQUEST

- From <30 to 50% increased beam duty factor
- Up to 1E13 ppp (60 second rep rate)

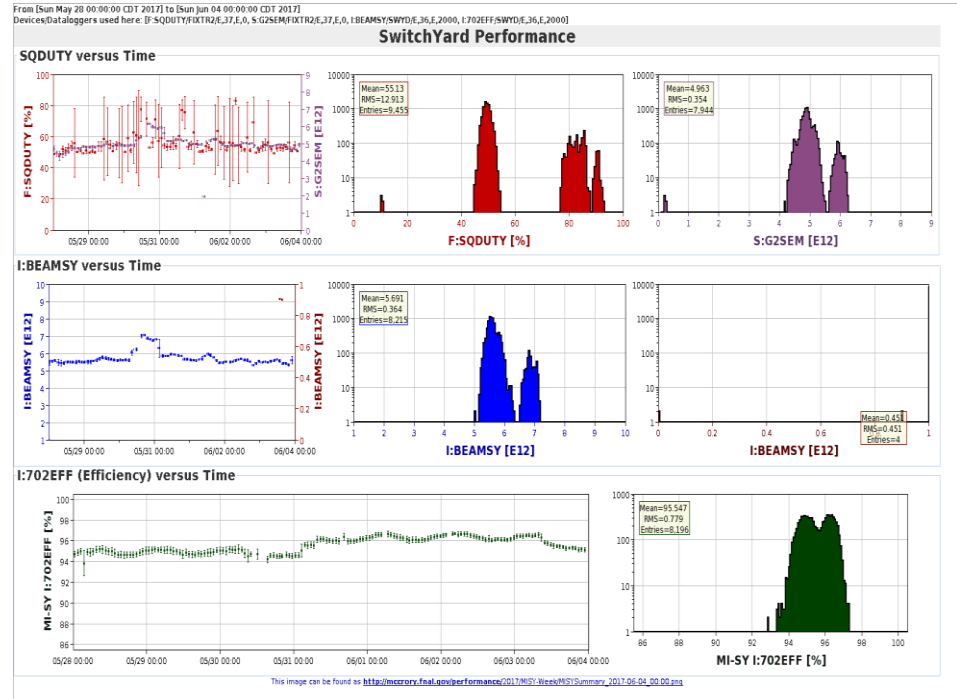
#### LArIAT TPC, FTBF



FTBF Committee Report, Nov. 2016



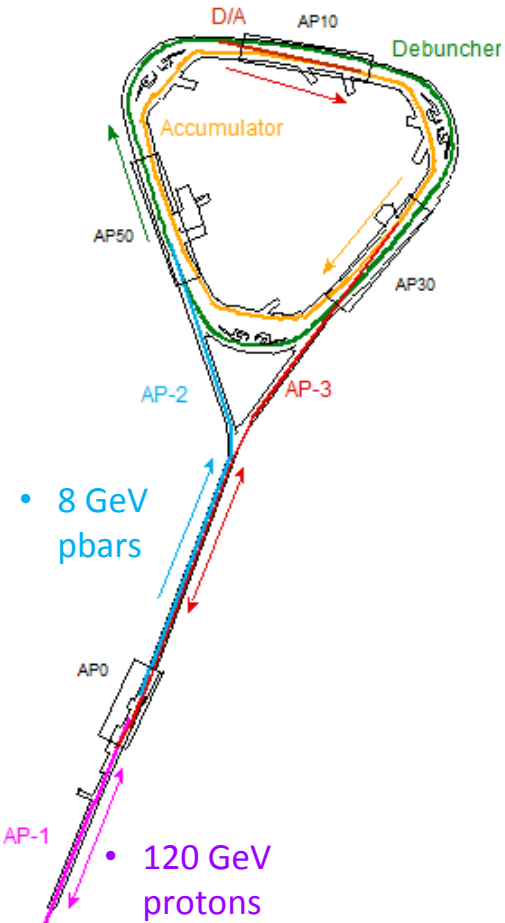
Cerenkov data >30 GeV positrons!





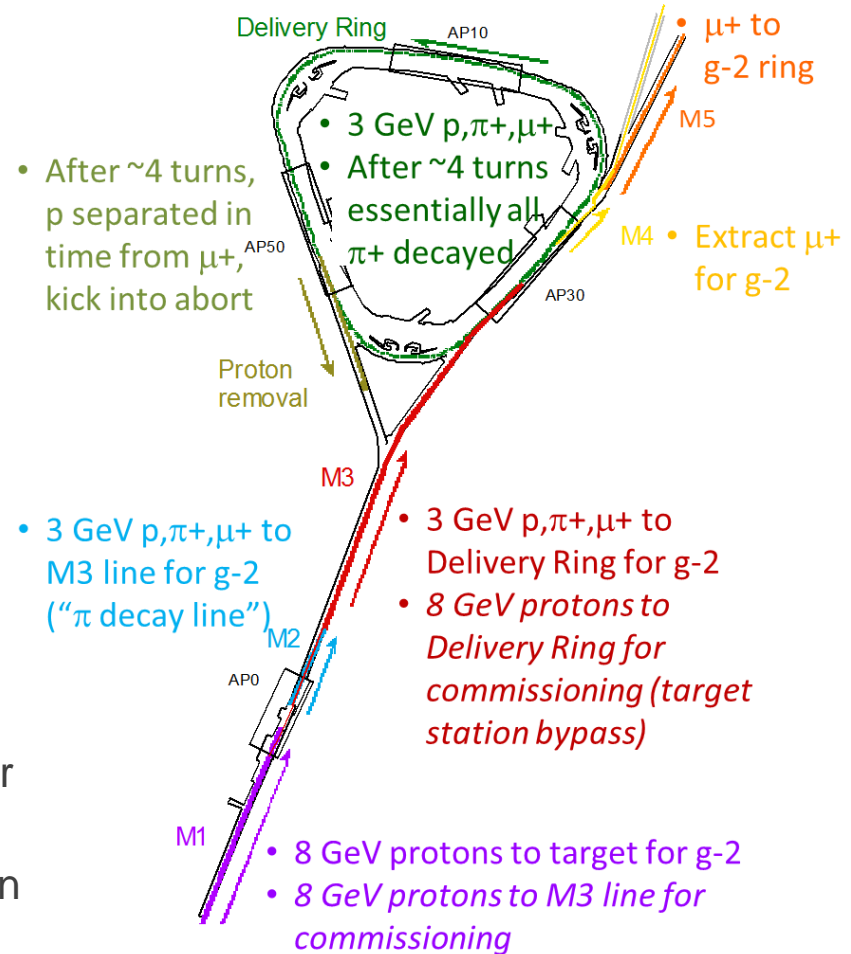
# Conversion from Antiproton Source to Muon Campus

## Pbar



- New M4/M5 line to transport beam to g-2 muon ring
- Decommission Accumulator and use magnets for new beamlines
- Delivery Ring largely unchanged from Pbar Debuncher
- Former AP3 line connected to Accumulator – new connection from M3 to Delivery Ring
- Increase number of quads in M2/M3 lines for muon capture efficiency
- Reuse AP0 target station
- Lower beam energy

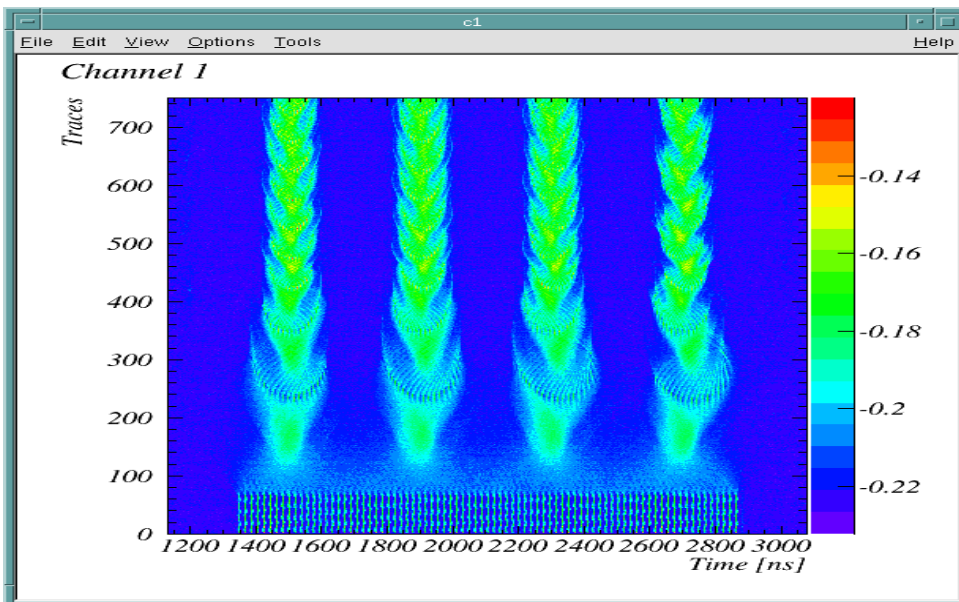
## Muon



## 2.5 MHz Cavities in RR – getting ready for the Muon g-2

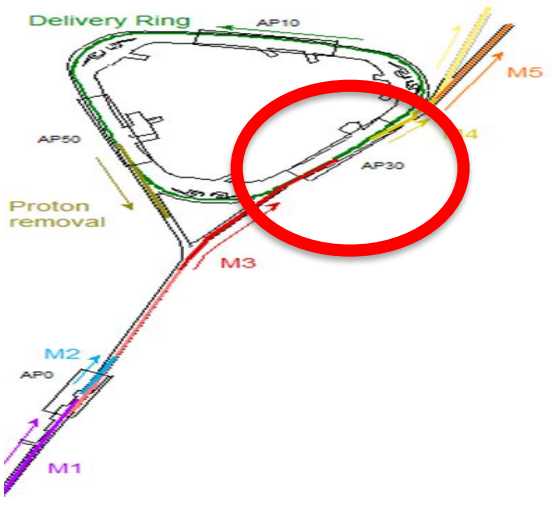
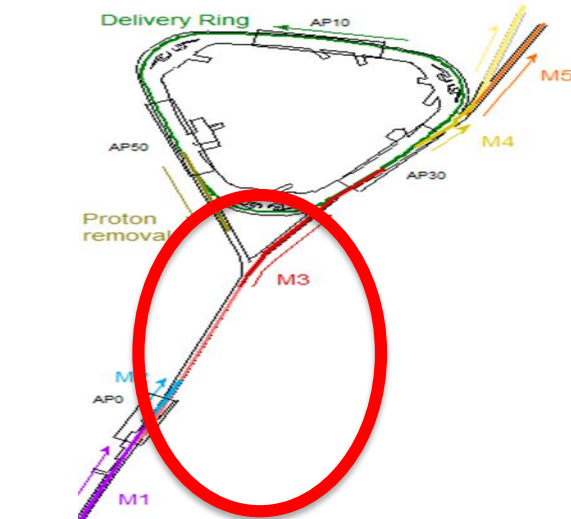


- Installed 6 2.5-MHz cavities in the Recycler for g-2/mu2e bunch formation.
- Cavities are now operational.



- **One Booster batch formed into 4 2.5 MHz bunches in RR.**

# Muon Campus construction



# Muon g-2 beam commissioning overview

- 1) 8 GeV protons bypass target, through shared M4
  - If time also around Delivery Ring



- 2) 8 GeV protons to target, 3.1 GeV secondaries to g-2 ring (100:1 protons to muons)

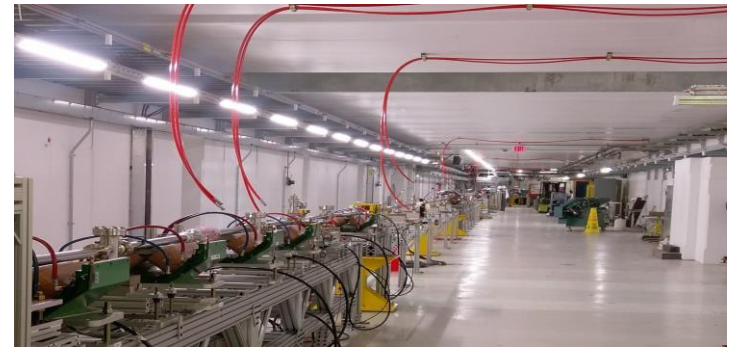


- 3) 8 GeV protons to target, 3.1 GeV secondaries around Delivery Ring, proton removal, muons to g-2 ring - after shutdown



# FAST/IOTA

Accelerator Test Facility for supporting Research and Development of Accelerator Technology for the next generation of Particle Accelerators



- 300 MeV electron linac nears completion-beam in July 2017
- 2-month experimental program in June-July
  - Experiments driven by external collaborators
- IOTA Ring beam to follow in 2018
- June 6-FAST/IOTA Annual Collaboration Meeting
  - 25 national and international partners

# PIP-I+

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- Proton Improvement Plan (PIP) has been very successful
- PIP-I+ is proposed as a follow-on to PIP, before PIP-II
  - More flexible “campaign” like PIP, not “project” like PIP-II
- Aim at increasing NuMI beam power to 1 MW prior to PIP-II
- Address many improvements needed in the accelerator complex for the PIP-II era.
- Infrastructure needs that are too big for operations budget
- Strategy
  - Upgrade NuMI target station to be robust up to 1 MW
  - Increase protons per pulse (further reduce losses in Booster)
  - Gamma-t Jump for MI/New Shielding Assessment

PIP → 0.7 MW, PIP-I+ → 1MW, PIP-II → 1.2MW, PIP-III → 2.4MW

# Summary

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- We are operating the Booster at 15 Hz achieving proton fluxes greater than  $2.0 \times 10^{17}$  p/hr.
- We have achieved 700 KW beam power from MI.
  - $0.7 \times 10^{20}$  Protons on Target per month
- Beam has been delivered to the Muon g-2 Ring.
- We have started looking into ways to further increase the MI beam power.
  - Our vision: beam powers of up to 2.4 MW