

Re-commissioning the Recycler Storage Ring at Fermilab

Martin Murphy, Fermilab

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The Fermi National Accelerator Laboratory is a U.S. Department of Energy (DOE) research laboratory, operated under DOE contract by Fermi Research Alliance (LLC), a joint partnership of the University of Chicago and the Universities Research Association (URA).

Outline

- Introduction & Physical Geography
- Original design & function of Recycler Ring
- Motivation for Re-purposing
- Decommissioned systems
- Upgrades & new hardware
- Impact on & roles of Accelerator Ops

Aerial View of Fermilab



Original Recycler Ring (RR) Design

- Shared tunnel with the Main Injector synchrotron
- Designed to be an 8.8 -GeV antiproton storage ring comprised primarily of permanent magnets 2.5-miles in circumference.
- Powered dipoles, quad, and sextupoles for control over closed orbit, tunes, & chromaticity.

Original RR Design

- Employed four 5-KW, 2.5-MHz RF cavities for beam capture/manipulation.
- Employed stochastic and electron cooling systems for longitudinal and transverse cooling.
- Beam tube vacuum $\sim 10^{-11}$ Torr maintained by ion pumps and titanium sublimation pumps.

Original RR Design

- Two beam transfer lines comprised of permanent and powered bend/focus elements.
- BPMs resonant at 2.5-MHz.
- Transverse and longitudinal beam damper systems were employed.

With the end of Tevatron collider physics came the end of the RR as an antiproton storage ring.



Tunnel View

- Recycler physically above the Main Injector – the green magnets.
- The Main Injector is a 120 GeV synchrotron – the cyan and red magnets on floor stands.

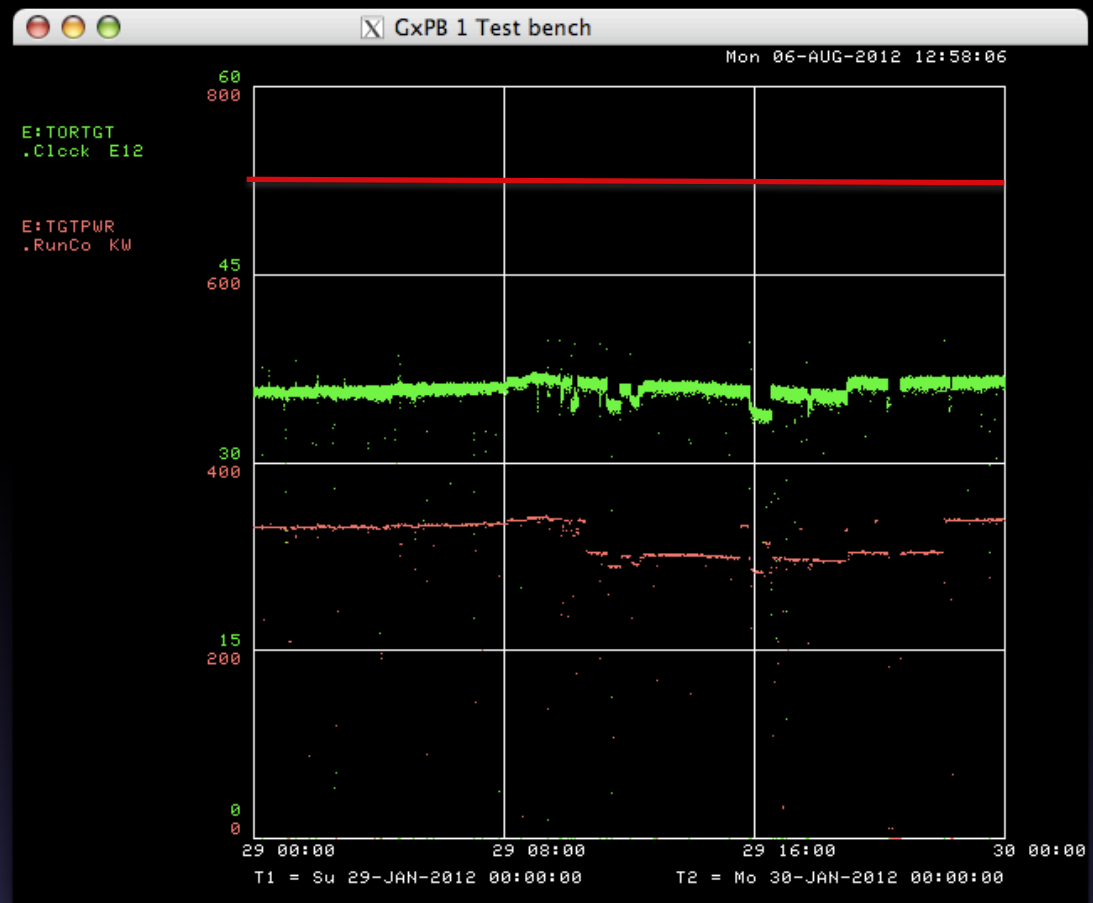


Motivation for Re-Purposing

- $\text{NO}\nu\text{A}$: A high power neutrino program ~ 750 KW beam power on target.
- Existing FNAL proton front end limits operation Main Injector to ~350 KW due to duty cycle (~8 Hz) limitations.

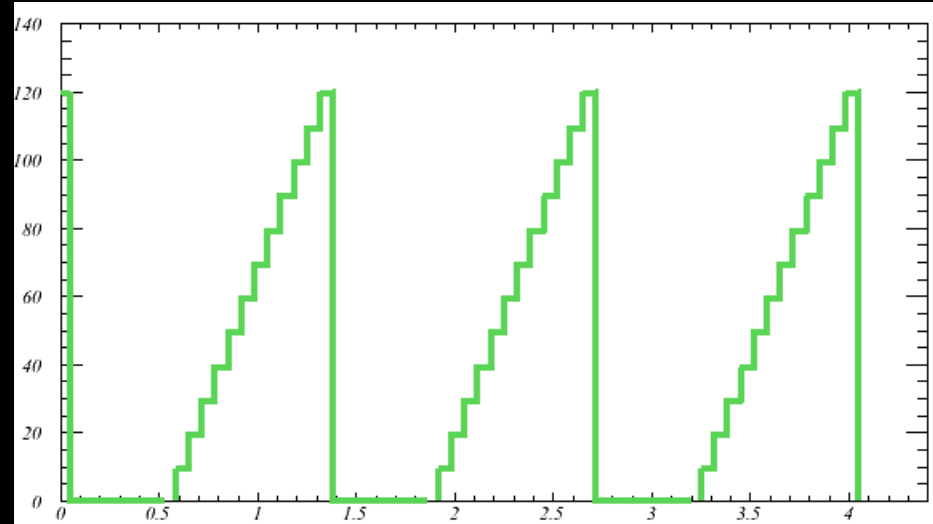
Motivation for Re-Purposing

- Historic operation of PS & MI used 11 fills from Booster at ~ 4.3 E12 per fill.
- The MI cycle time was 2.2 seconds.
- 0.75 seconds was spent on proton injection process.
- Incorporating the RR will allow us to raise beam power on target without increasing the intensity of the PS.

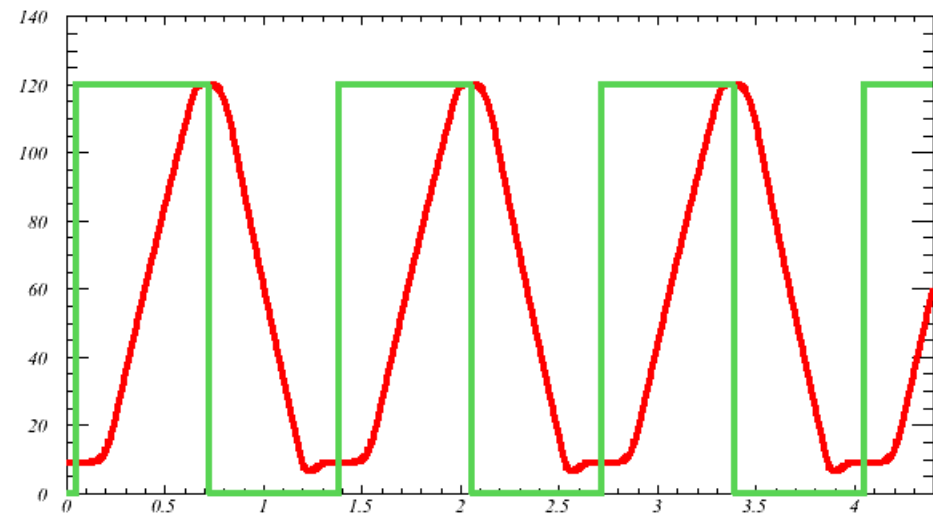


Motivation for Re-Purposing

- 120-GeV ramp time
~1.3 seconds
- PS duty cycle of 66 mS
(15 Hz)
- 12 proton batches
from PS injected into
MI takes 0.8 sec.
- Almost double MI duty
cycle by using RR for
proton injection!
- Beam power -> 350
KW to 700 KW.



Recycler



Main Injector

Decommissioning RR

- Electron and stochastic cooling systems.
- Existing transfer lines removed.
- High & Low Level RF systems
- Diagnostics: BPMs, BLMs, schottky pick-ups, ect.
- Timing scenarios, beam synchronization, etc.

Decommissioning RR

Electron Cooling



- 5 MeV electrons were injected parallel to the stored pbars.
- Pbars exchanged momentum with much cooler electrons, thus cooling the stash.
- Electrons were returned from the RR to the Pelletron, where they were decelerated and collected.

Decommissioning e-Cool

Budgets are tight, so...

reddit: the front page of the int... Photography - Search - Online ... 02-0058-07.jpg (JPEG Image, 8... 5 MeV Pelletron

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5 MeV Pelletron Electro-static Accelerator - Gently Used

Item condition: --
Time left: 3d 03h (Aug 11, 2012 18:19:33 PDT)

Current bid: **US \$149.99** [1 bid]

Place bid

Enter US \$152.49 or more

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Subject to credit approval. See terms

Shipping: **\$9.95** One-day Shipping | See all details
Item location: MARTINSVILLE, VA, United States
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Delivery: Estimated on or before **Thu. Aug. 16** to 94305

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Fermilab AD (2138 ★)
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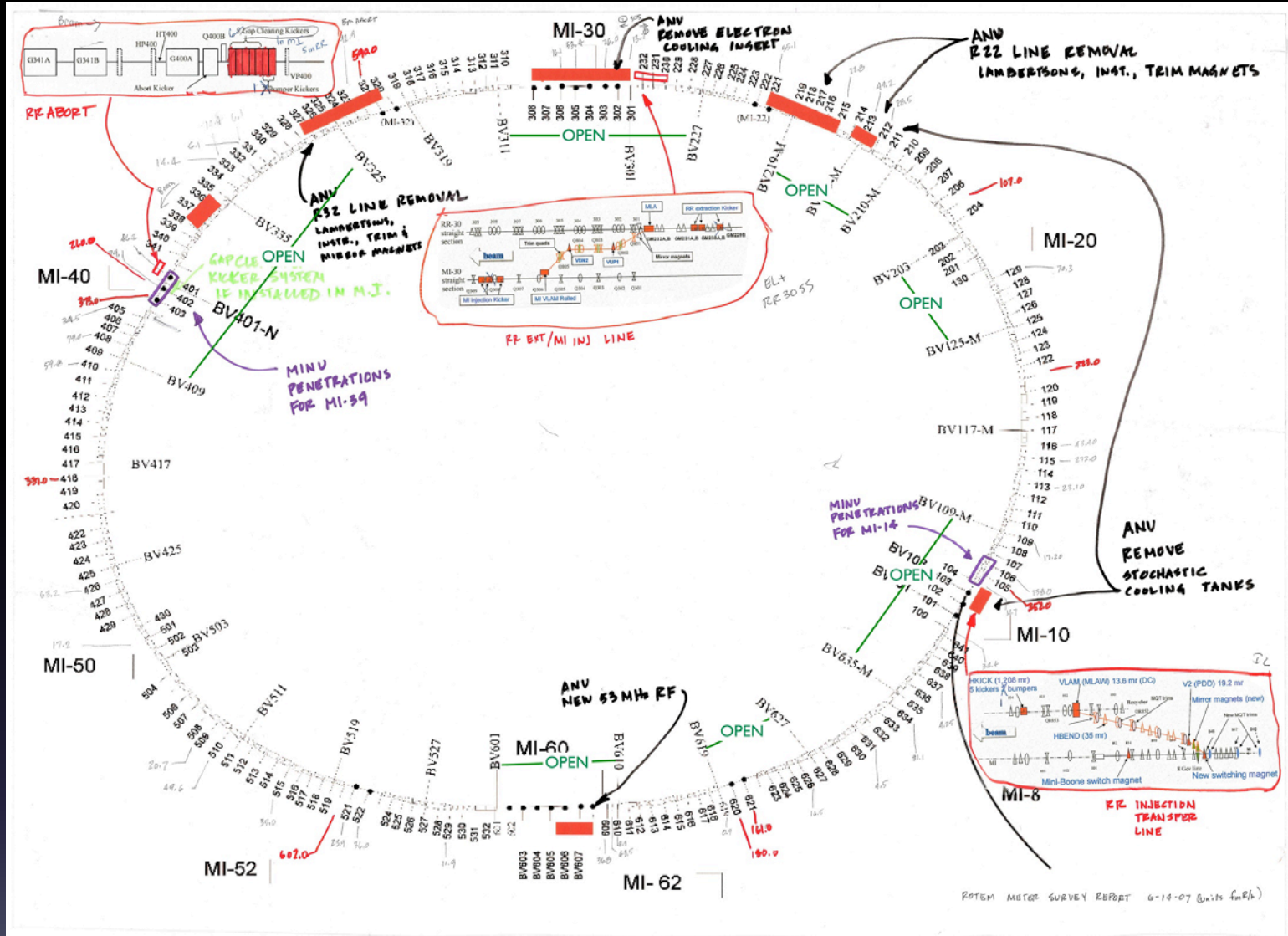
- Consistently receives highest buyers' ratings
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The last slide was joke. The Pelletron is not for sale on eBay.

Scope of Shutdown Jobs



Completely New RF Installation

- Original RR RF was a low power 2.5 MHz system.
- NOvA era RF will be (comparatively) high power 53 MHz system.
- Slip stacking will take place in the Recycler.
- New LLRF, Anode Supply, Modulators & Power Amplifiers.
- Old RF will be used as transverse & longitudinal dampers.



Converting RR to Proton Storage Ring

- New 8-GeV injection line directly from the Booster.
- Three new 53 MHz RF cavities (original 2.5 MHz RF cavities will serve as longitudinal and transverse dampers).
- New extraction line to Main Injector.
- Injection gap clearing kickers (reduce losses during injection process).

Converting RR to Proton Storage Ring

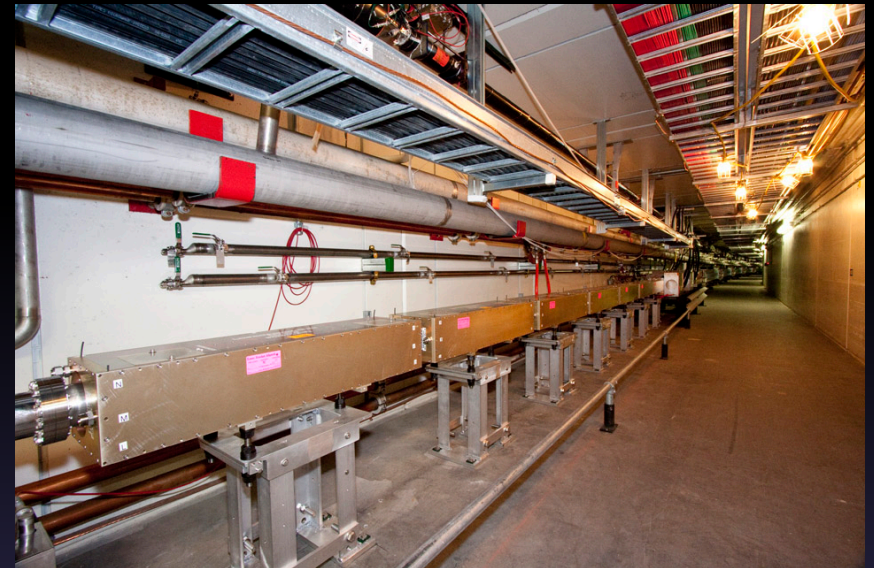
- New BPM system: Dual 2.5 & 53 MHz boards to support NOvA and Muon Rings operation (g Minus 2 & μ -to-e experiments)
- New beam loss measurement process – how do you differentiate loss from MI & RR?
- New Diagnostics: e.g. Ion Profile Monitors
- New time-line paradigm.

New Service Buildings

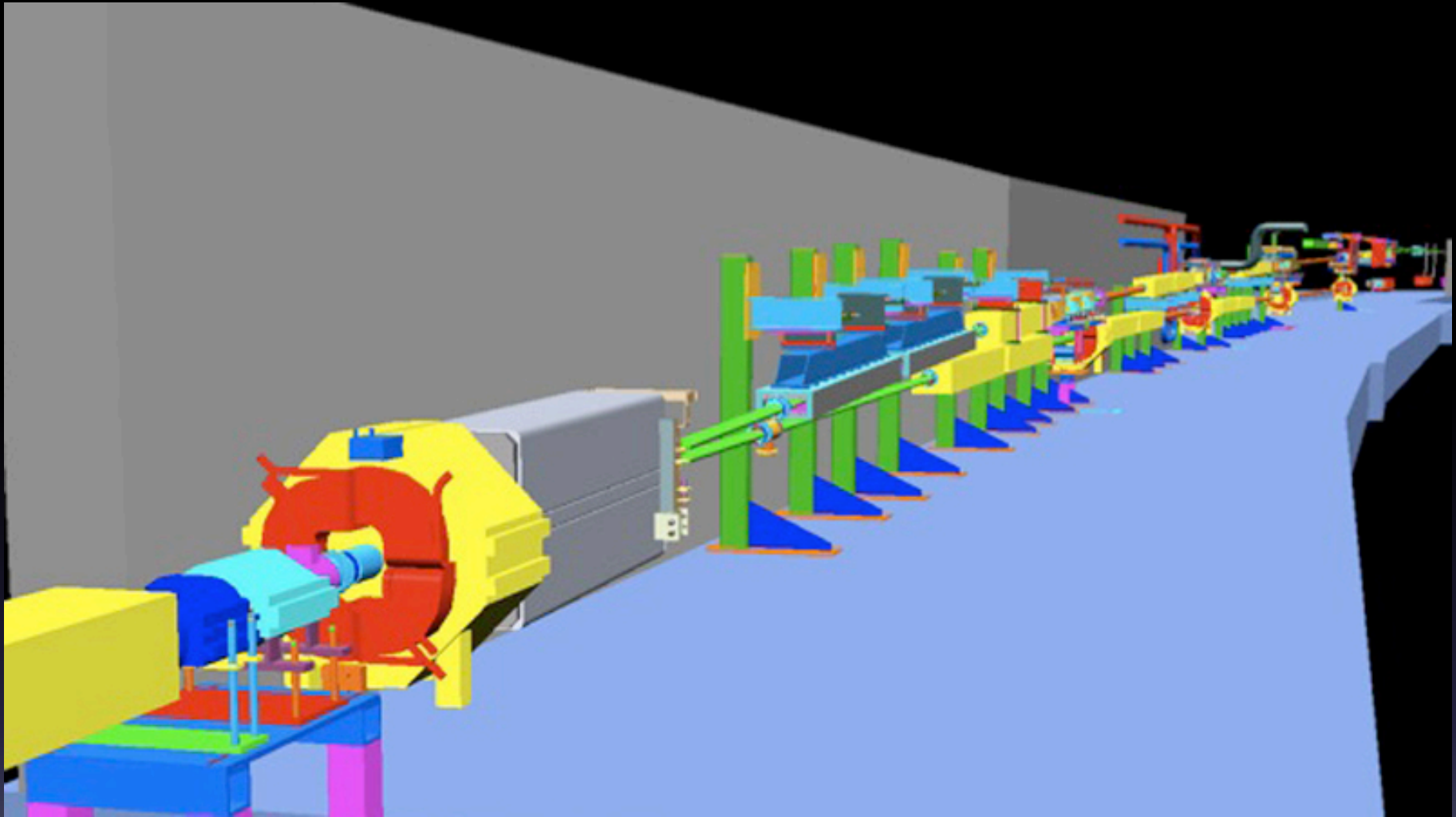
**MI14 – Injection Kicker Power
Supplies & controls**



MI39 – Gap Clearing Kickers



3D Draft of New Injection Line: Booster to RR



RR-8 Line Magnet Installation



Impact on Operations

- Some operators on loan to other groups during shutdown (e.g. Alignment, Instrumentation, etc.)
- Brand new operating paradigm.
- Constant supply of high power protons in MI/RR tunnel -> Beam Envelope & radiation safety (shielding!) considerations.
- Many new applications to be written and learned.

Operator involvement

- Writing new console applications.
- Building new utilities – e.g. Electronic Logbook.
- Maintain skeleton crews during shutdown.
- Tunnel work –
 - Removal of obsolete instrumentation
 - Alignment
 - Terminating new BPM cables

Other Upgrades of Note

- New H^- ion source!
- Renovation the Booster RF cavities and modulators.
- Two additional RF cavities will be installed in the Main Injector.
- New targets for neutrino production.
- New slow extraction septa for switchyard programs.

Summary

- Fermilab's mission has shifted from the "Energy Frontier" to the "Intensity Frontier."
- We need to double power onto the NuMI target without significantly increasing the Proton Source output.
- To meet this goal we're converting the Recycler to a proton storage ring and upgrading many other systems.

Thanks for your attention.

- Questions?

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