



Fermilab Main Injector: Promises Kept *and More*

Bruce C. Brown

2019 Fermilab Users Meeting

12 June 2019

Fermilab Main Injector: Promises Kept *And More*

Dedication of
Fermilab
Main Injector
June 1999

20th Anniversary of
Fermilab
Main Injector
June 2019



Fermilab Main Injector:

Promises Kept

And

Dedication of
Fermilab
Main Injector
June 1999

Your
Picture
Here



Fermilab Main Injector:

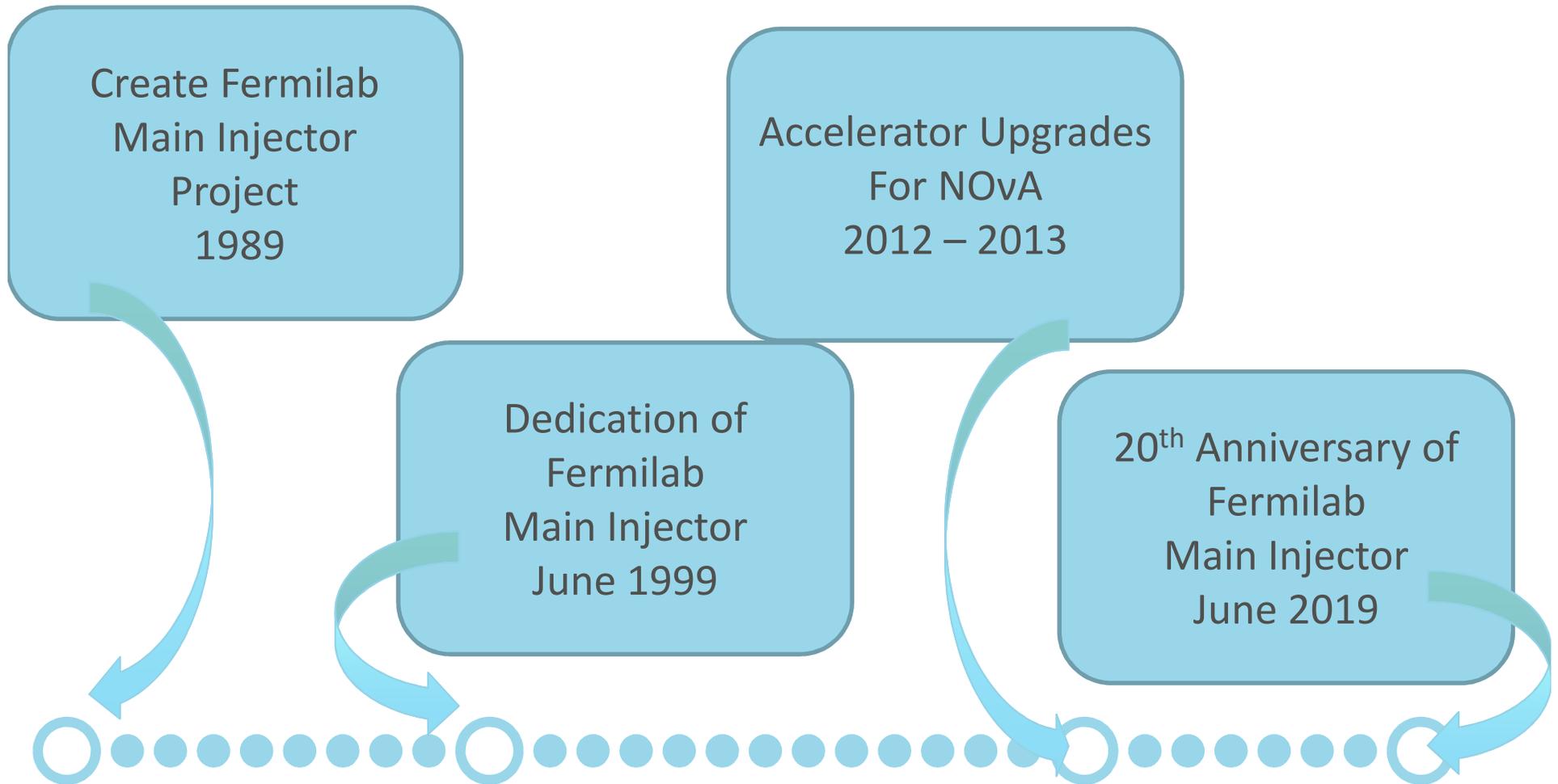


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Your
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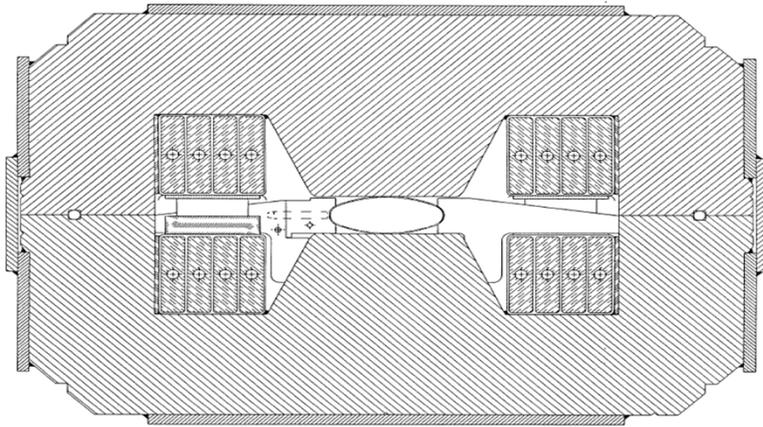
Main Injector Project – Promises Kept *and More*



Main Injector Project – Promises

- Tevatron Luminosity
 - More AntiProtons Collected
 - Better Proton and AntiProton Beam Quality
 - Improved Beam Transfers
 - x20 Integrated Luminosity
- Fixed Target Operations
 - Protons at 120 GeV for Neutrino Production
 - Slow Spill at High Intensity
- Year Around Test Beam Facilities

Magnet Designs for Main Injector and Recycler



FMI DIPOLE
TYPICAL CROSS SECTION
Figure 3.1-2. Cross-Section of the Main Injector Dipole Magnet.

Stan Snowdon

- Main Ring Dipoles and Quads
- Tevatron Dipoles and Quads
- Pbar Dipoles and Quads
- Main Injector Dipole

The Card Punches and Card Readers for computer input were kept around so Stan could use them !!!

Creating the Main Injector Project

MEETING NOTICE

Time: 10:30 AM

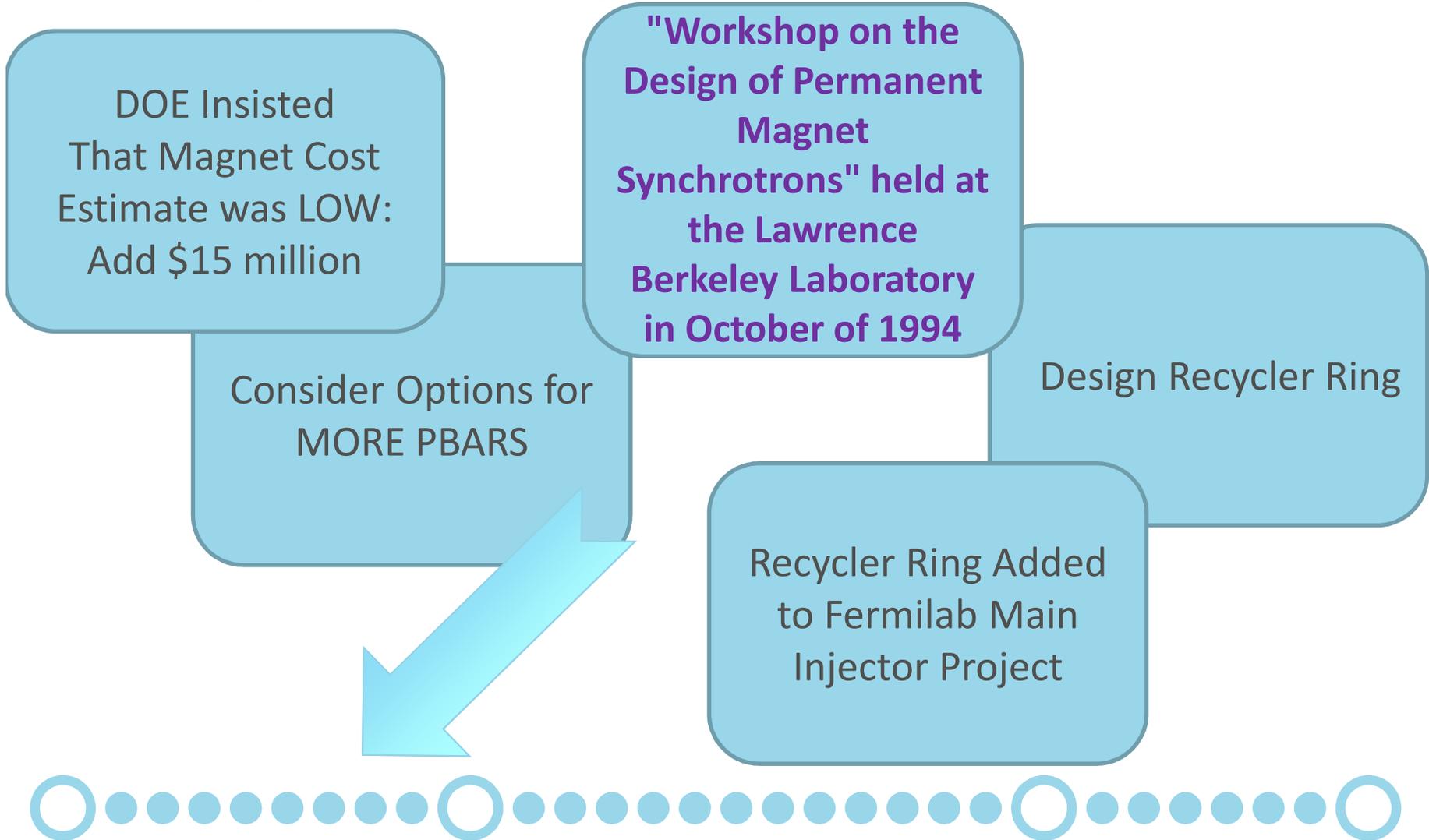
Date: Friday, September 8, 1989

Place: Headquarters Conference Room

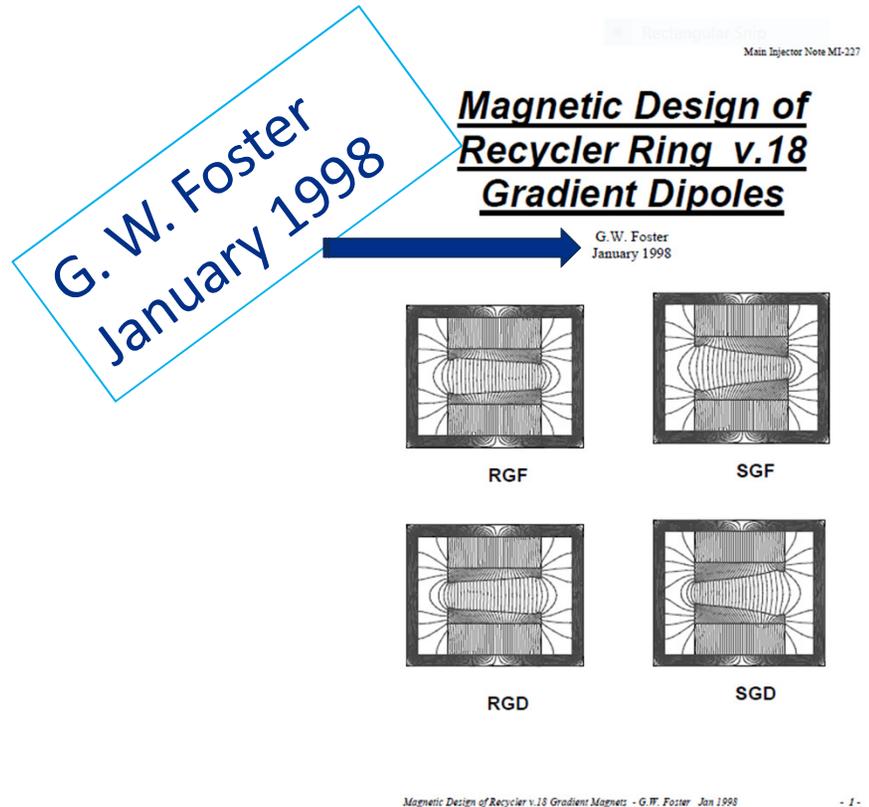
Subject: Main Injector Cost Estimate Final Review

Please bring your final cost estimates and copies for distribution.

Creating the Main Injector Project

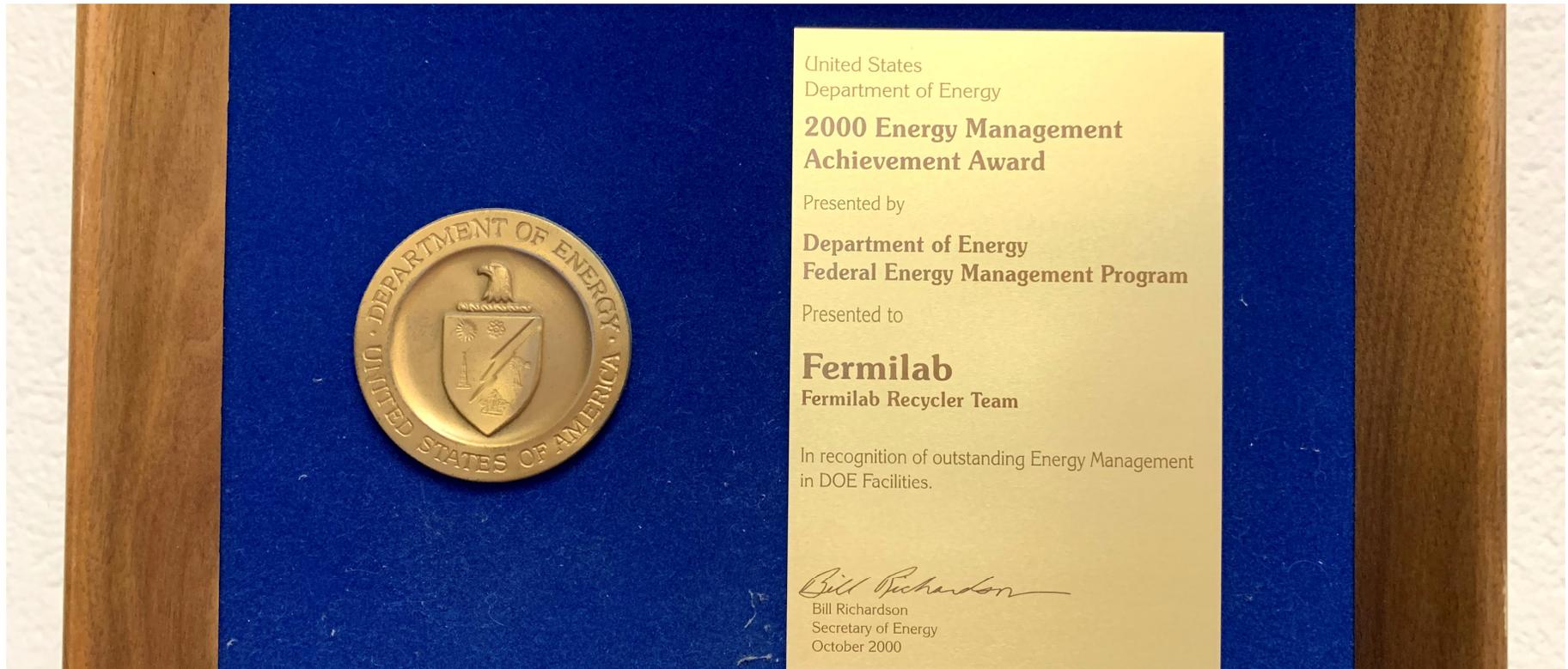


Magnet Designs for Main Injector and Recycler



Bill Foster: RR Magnets
Gradient Magnets
Dipoles and Quads
Lambertsons

Booster to Main Injector Transfer Line 2000 Energy Management Achievement Award



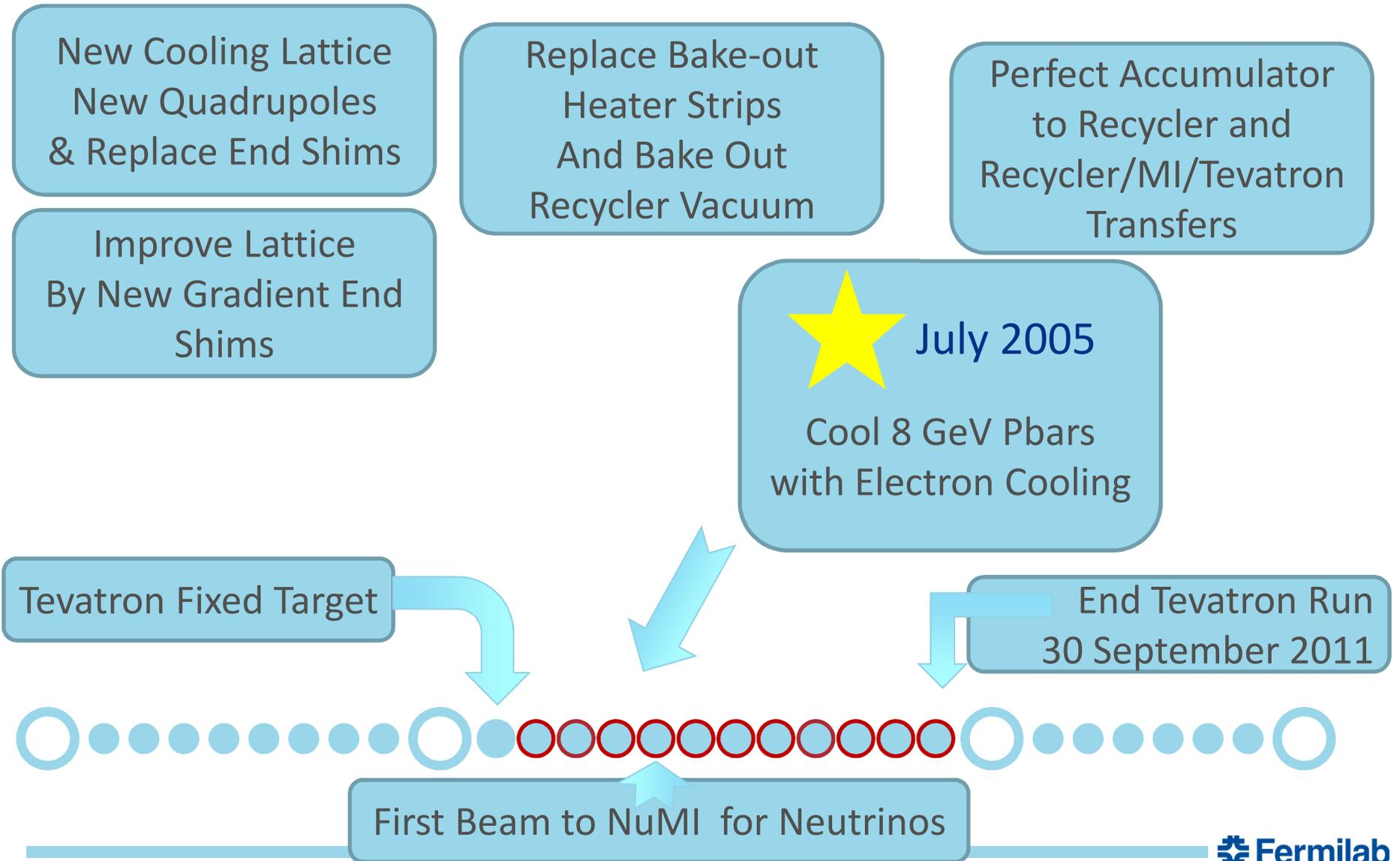
Fermilab Recycler Team

Main Injector and Recycler As Commissioned



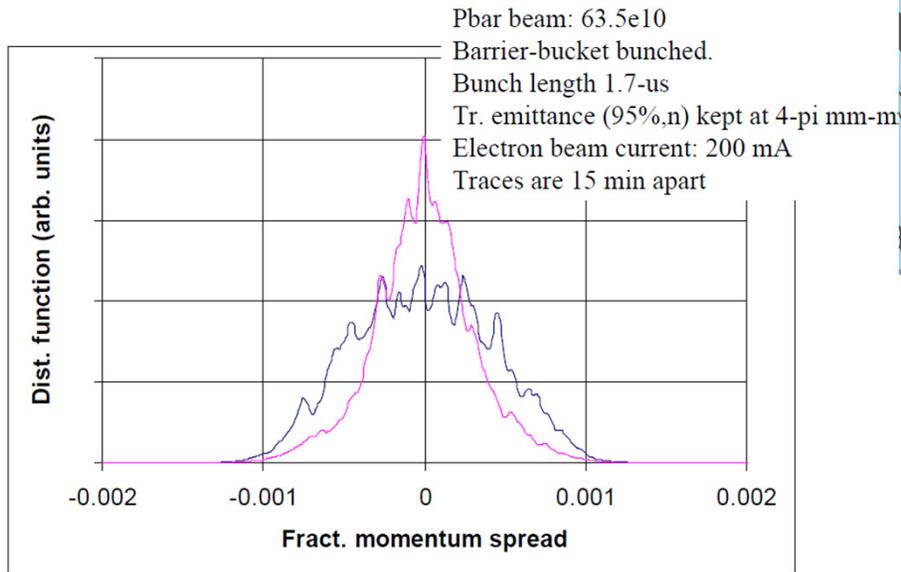
Here we are in the tunnel at MI52 with the Recycler above the Main Injector. The beamline to the right transfers beam toward the Tevatron and brings PBars from the PBar source

Tevatron Run II Era – Recycler Completion



Tevatron Run II Era – Recycler Completion

First e-cooling demonstration - 07/15/05

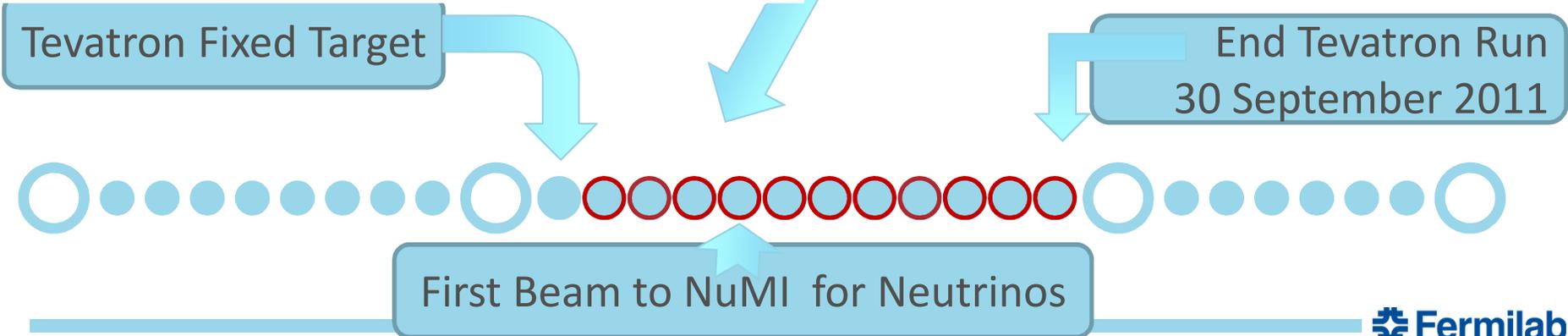


Take-out
strips
Out
vacuum

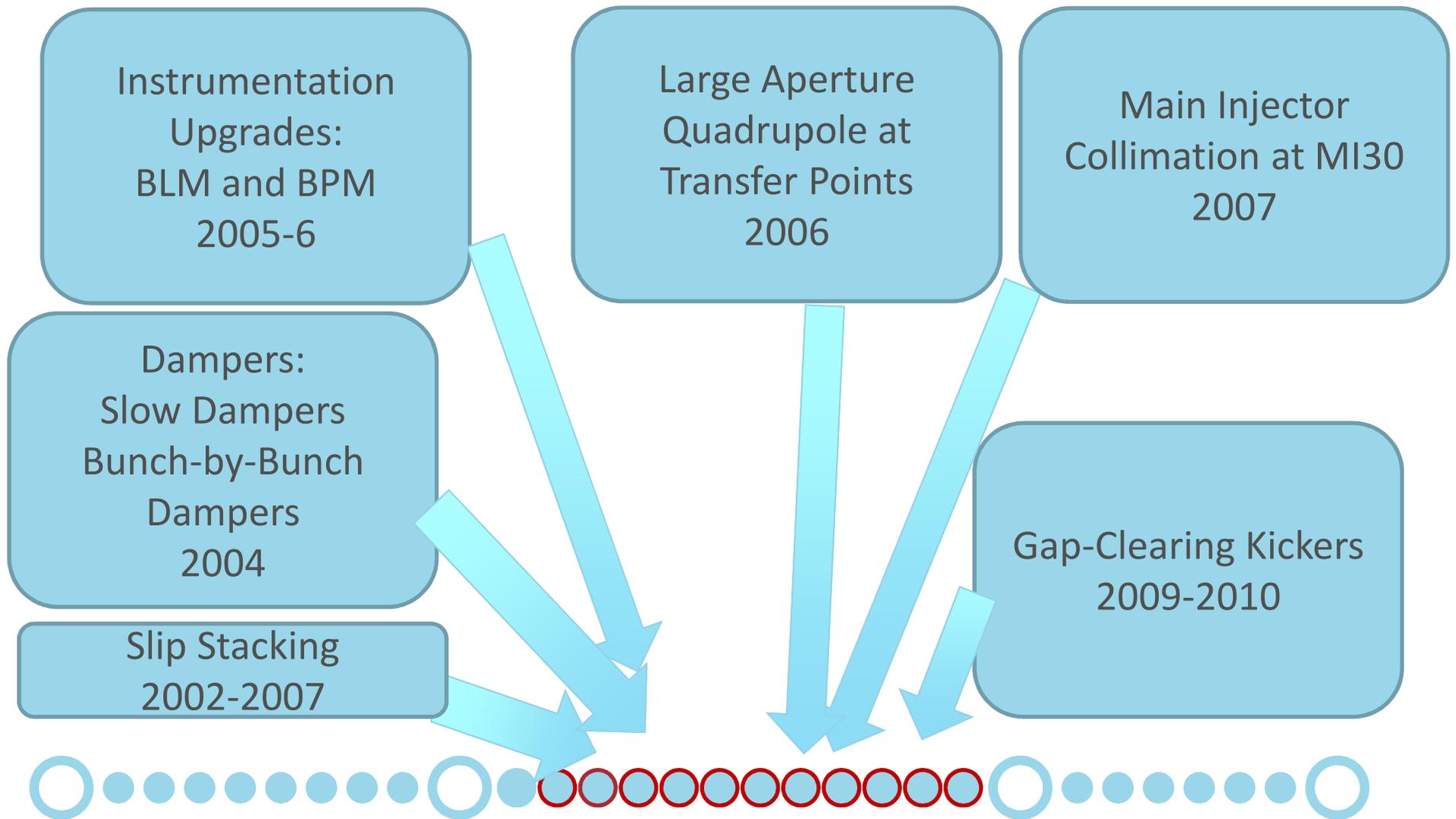
Perfect Accumulator
to Recycler and
Recycler/MI/Tevatron
Transfers

★ July 2005
Cool 8 GeV Pbars
with Electron Cooling

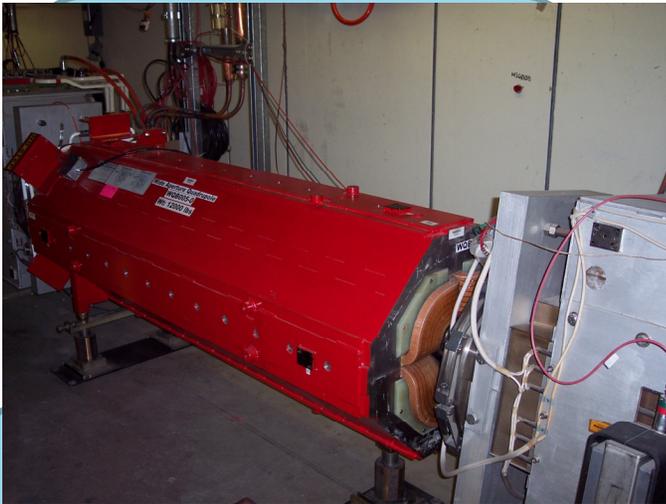
Sergei Nagaitsev (Fermilab)



Tevatron Run II Era – Main Injector Upgrades



Tevatron Run II Era – Main Injector Upgrades



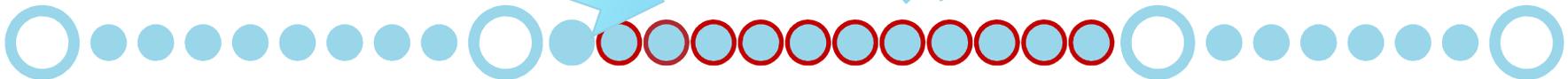
Large Aperture
Quadrupole at
Transfer Points
2006

Main Injector
Collimation at MI30
2007

Slow Dampers
Bunch-by-Bunch
Dampers
2004

Slip Stacking
2002-2007

Gap-Clearing Kickers
2009-2010



Tevatron Run II Era – Main Injector Upgrades

Instrumentation
Upgrades:
BLM and BPM
2005-6

Large Aperture
Quadrupole at
Transfer Points
2006

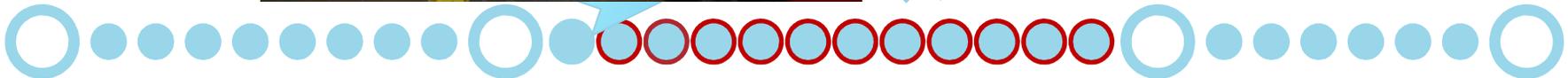
Main Injector
Collimation at MI30
2007

Dampers:
Slow Damp
Bunch-by-
Damp
200

Slip Sta
2002-2

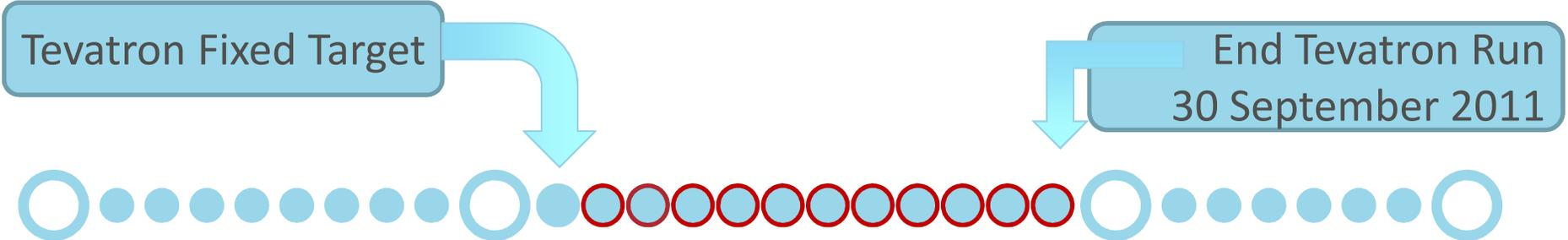


Gap-Clearing Kickers
2009-2010

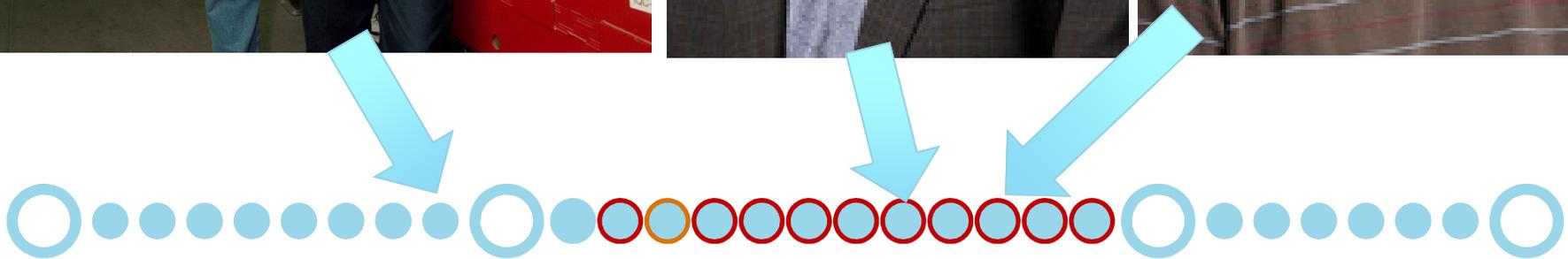


Tevatron Run II Era

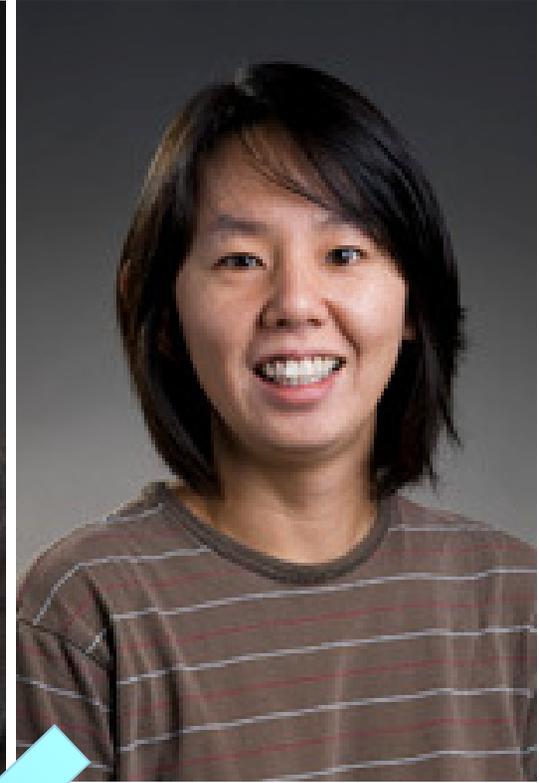
Numerous Enhancements to
Booster
Pbar Source
Beam Transfer
Tevatron
Operational Sequences



Prizes Awarded for Our Colleagues



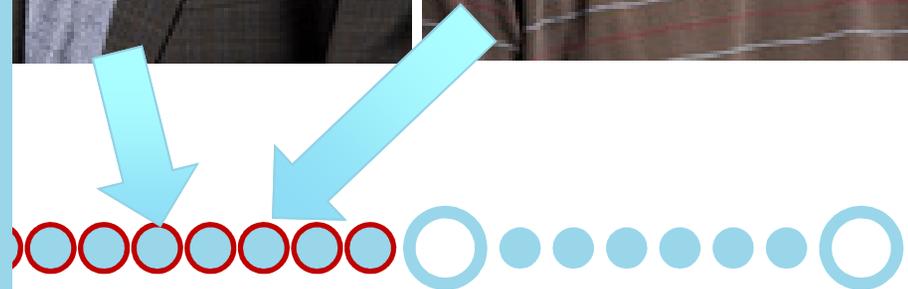
Prizes Awarded for Our Colleagues



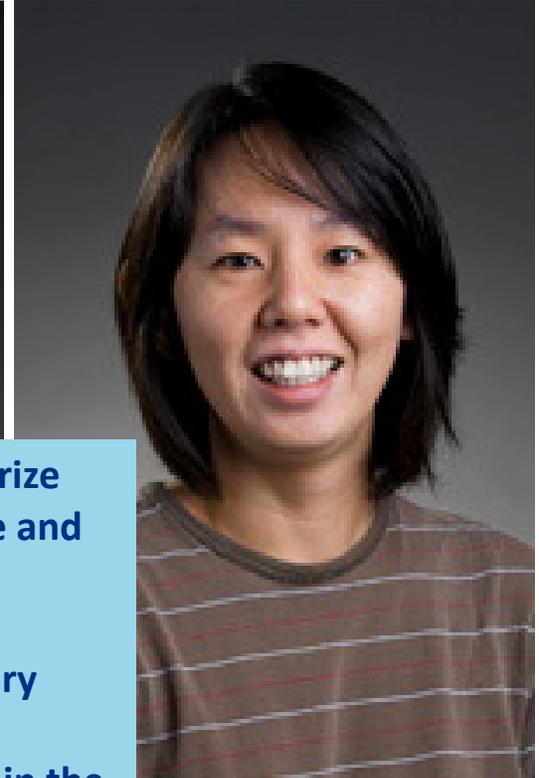
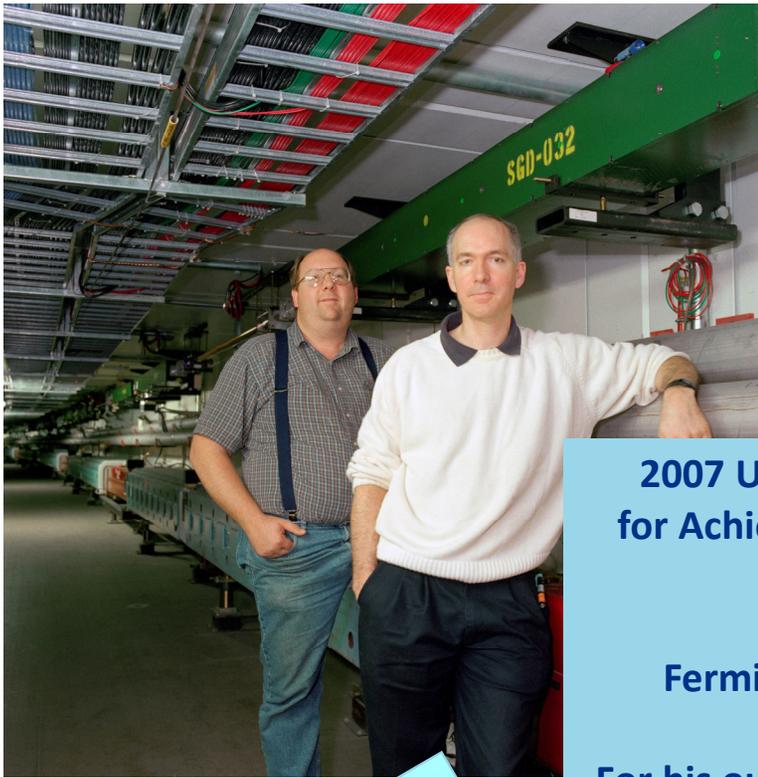
**1999 IEEE Nuclear and Plasma Sciences
Particle Accelerator Science and Technology
Award**

**G William Foster and Gerald P. Jackson,
Fermi National Accelerator Laboratory**

**For their leading roles in the conceptualization,
design, and development of the first large-
scale application of permanent magnet
technology for beam transport, in the forms of
the 8 GEV Booster to Main Injector transfer
line and the Recycler Ring at Fermilab.**



Prizes Awarded for Our Colleagues



**2007 US Particle Accelerator School Prize
for Achievement in Accelerator Science and
Technology**

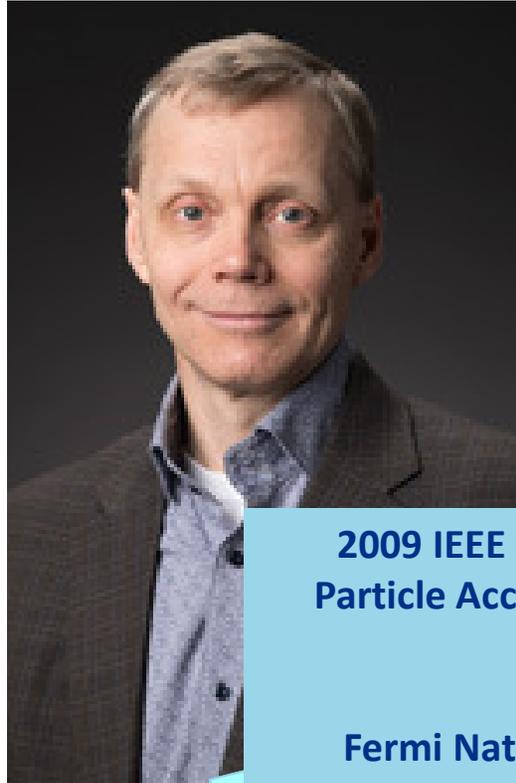
Sergei Nagaitsev

Fermi National Accelerator Laboratory

**For his outstanding scientific leadership in the
demonstration of non-magnetized relativistic
electron cooling of hadron beams to improve
collider luminosity.**



Prizes Awarded for Our Colleagues



**2009 IEEE Nuclear and Plasma Sciences
Particle Accelerator Science and Technology
Award**
**Kiyomi Seiya,
Fermi National Accelerator Laboratory**

**For developing and successfully implementing
slip stacking of proton batches injected into
the Fermilab Main Injector resulting in a
significant increase beam intensity.**



What is needed for High Intensity Proton Delivery

We need Many, Many Protons per Main Injector Ramp Cycle

The Main Injector is 7 times the Booster circumference

With a gap for Injection and can stack 6 Booster Batches

With Slip Stacking we can Stack 12 Booster Batches.

Main Injector Cycle consists of Injection Dwell Time Plus Acceleration Ramp

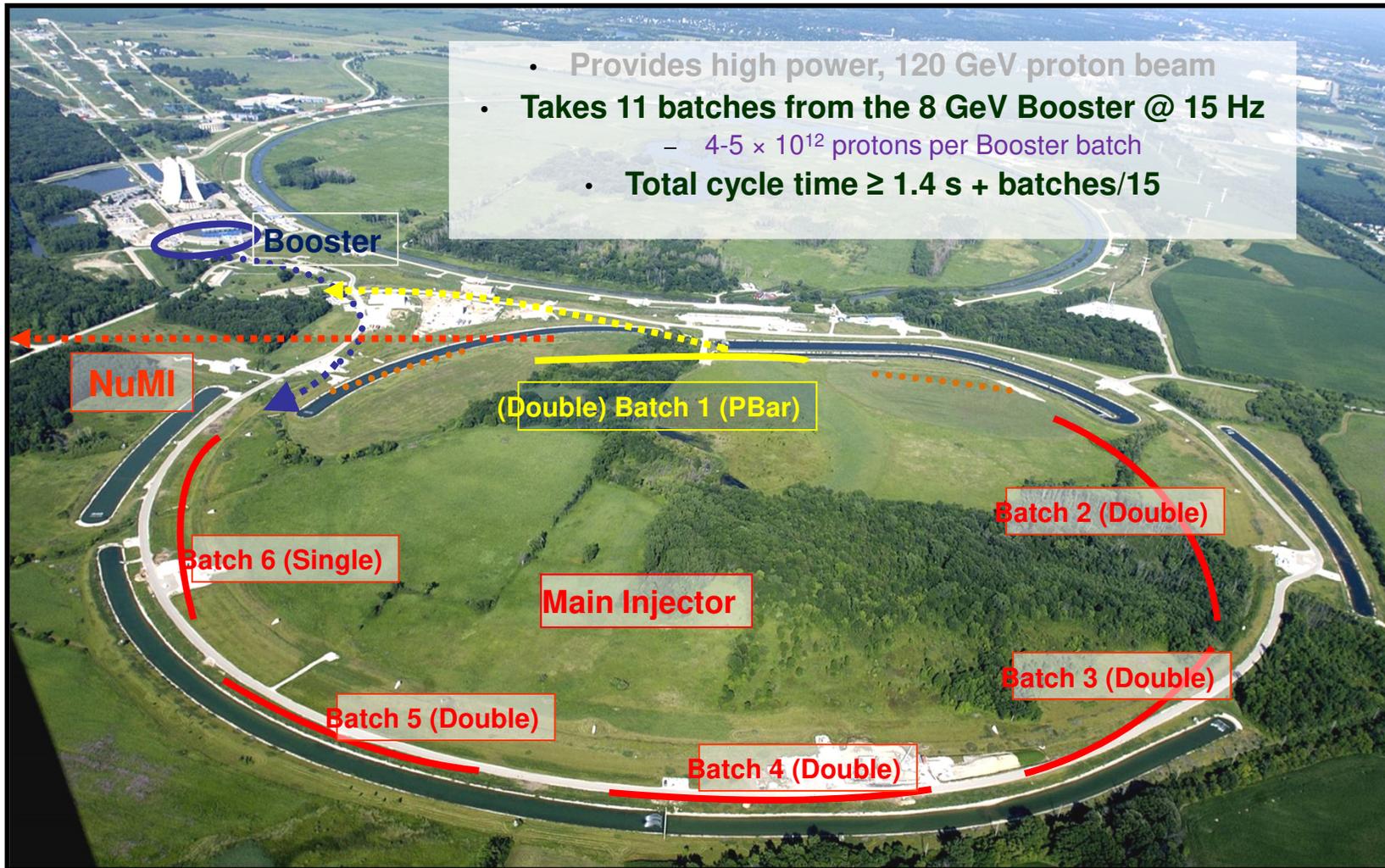
Slip Stacking in the Main Injector employed 2.2 Second repetitions limited by the time to accumulate PBars in the Accumulator.

By using the Recycler Ring to slip stack high intensity proton batches, we essentially eliminate the Injection Dwell Time.

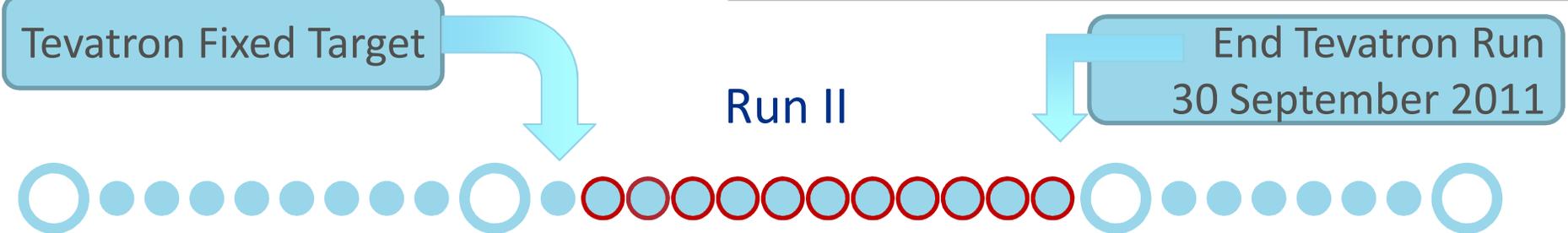
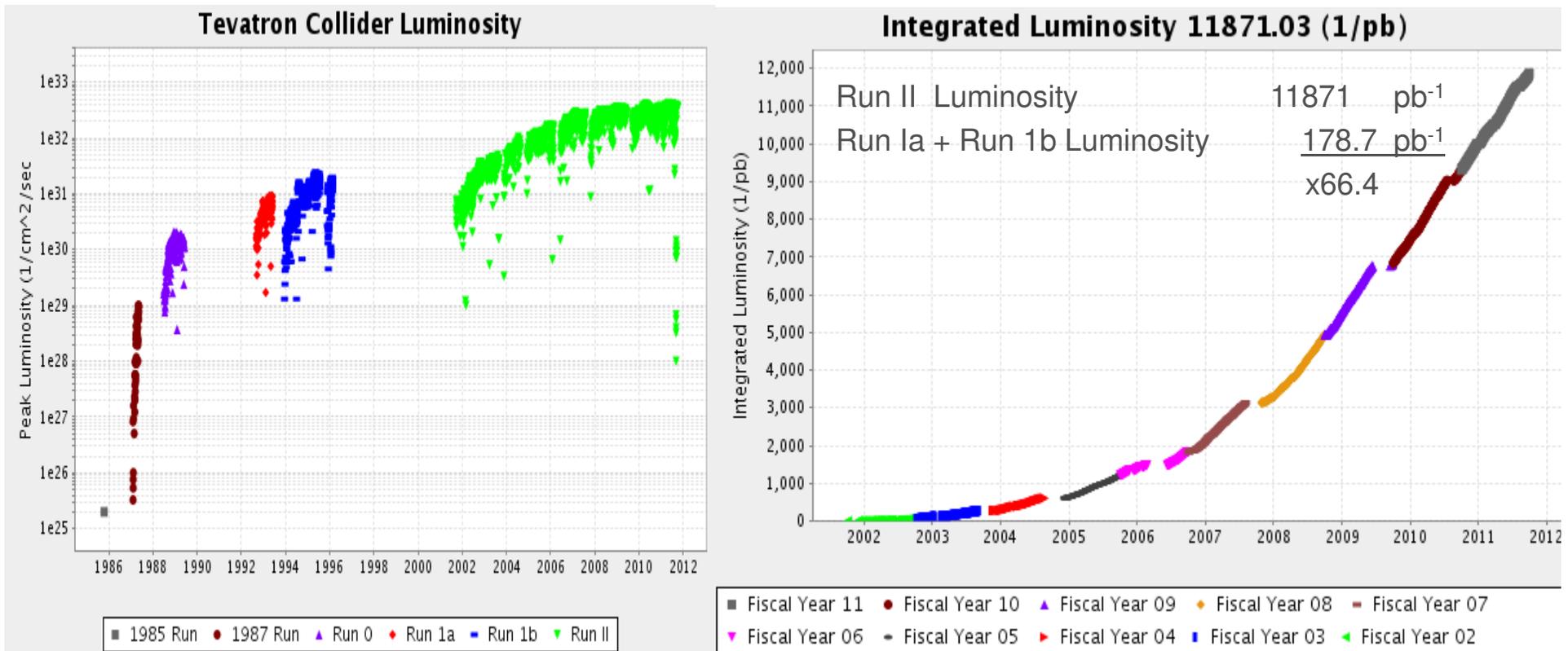
Achieved 1.33 Second repetitions for Main Injector Cycles for 2013-19

Will Run with 1.2 Second repetitions starting in Fall 2019

Main Injector High Power Operation (Mixed Mode)



Tevatron Run II – 2002 - 2011



NOvA Project: ANU(Accelerator & NuMI Upgrades) Prepare for Stacking Protons in the Recycler Ring

New Transfer Line from Recycler to Main Injector at MI30
MI8 Transfer Line Extension for Recycler Injection from Booster
New Recycler Lattice for Transfers => New Gradient End Shims
Faster MI Magnet Ramps
Two More 53 MHz RF Cavities for Main Injector
53 MHz RF System (3 cavities) for Recycler Ring
Move Gap-Clearing Kickers MI=>RR
New Instrumentation (esp. BPM's)
[2.5 MHz => 53 MHz]



Recycler Upgrades for High Intensity Slip Stacking

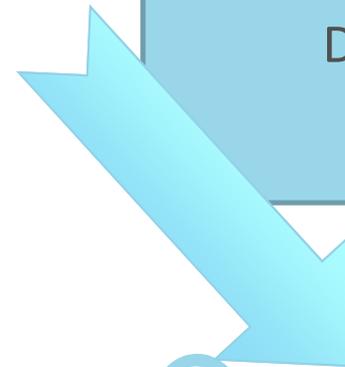
Lattice Control to Reduce Vertical Beam Size Excursions plus Beam Pipe Replacements

Recycler Collimation

Vacuum Upgrade: Sublimation Pumps => Ion Pumps (3 Shutdowns Needed)

Electron Cloud Instabilities ('Scrub' Beam Pipe for Reduced Secondary Emission)

Diode (Multibunch) Dampers



Recycler Upgrades for High Intensity Slip Stacking

Lattice Control to Reduce Vertical Beam Size Excursions plus Beam Pipe Replacement

Recycler Collimation

Vacuum Upgrade: Sublimation Pumps => Ion Pumps (2 shutdowns needed)

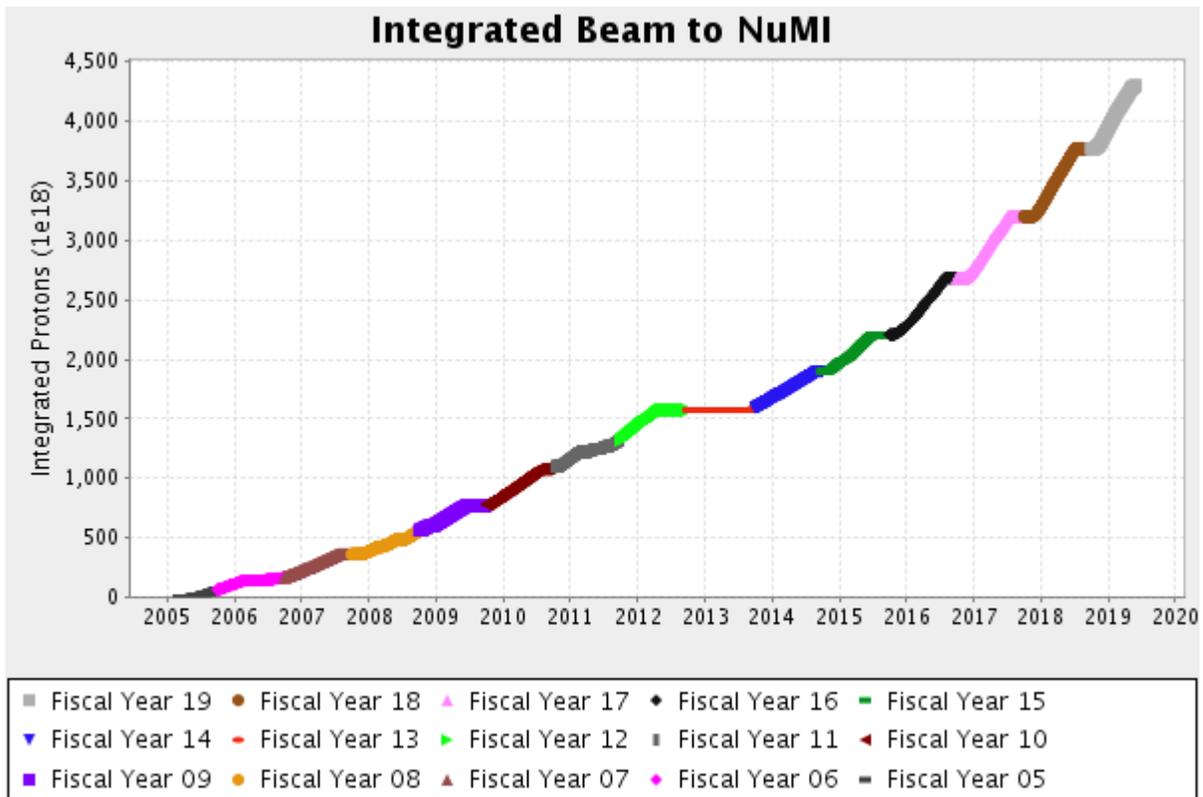
Electron Instability ('Scrub') for Reduction of Secondary

Mode (Multibunch) Dampers



Performance of Main Injector

The Main Injector reached a record beam power average of 757.75 kW for one hour on April 04, 2019.



NuMI Target Limits Reached:

2005-11 Configuration:
44E12 p/pulse
2013-19 Configuration:
54E12 p/pulse
2019 --- Configuration
73E12 p/pulse

Main Injector Department - 2019



Meiqin Xiao, David Capista, Ioanis Kourbanis, Bruce Brown, Ming-Jen Yang
Denton Morris, Kyle Hazelwood, Robert Ainsworth, Phil Adamson



Main Injector Project – Promises Kept *and More*



Many Talents – Much Dedication – Lasting Results

Main Injector Project – Promises Kept *and More*

Acknowledgments:

Lab Directors:

John Peoples, Michael Witherell, Piermaria Oddone,
Nigel Lockyer

Accelerator Division Heads: Steve Holmes, David Finley,
John Marriner, Roger Dixon, Sergei Nagaitsev, Mike
Lindgren

Main Injector Project Head: Steve Holmes

Main Injector Department Head: Phil Martin, Shekhar
Mishra, Ioanis Kourbanis, David Capista

Accelerator Division, Technical Division

and The Rest of The Fermilab Staff

Fermilab Users

**Special Thanks Today to the Organizers of
the 2019 Fermilab Users Mtg**



Backup Slides