Fermilab – The Proton Improvement Plan

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INTRODUCTION

The Proton Improvement Plan (PIP) began in December 2010 to ensure that the 50 years old Proton Source remains **viable** and **capable** of delivering 2.25E17 protons/hour (at 15 Hz) while maintaining Linac/Booster availability > 85%, and maintaining residual activation at acceptable levels for the next decade.

The Proton Source is comprised of the three machines: Pre-Accelerator (Pre-Acc), 400 MeV Linear Accelerator (Linac) and 8 GeV Booster Synchrotron.

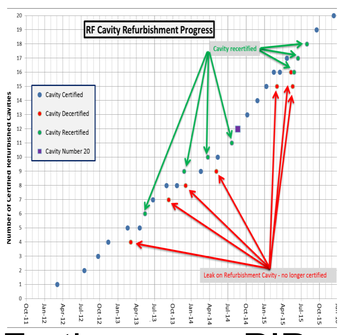
PIP strategy built on three fronts

15 Hz Operation

RF systems to accelerate beam on every Booster cycle

Refurbishment of cavities

Prior PIP, Booster operated with 19 RF cavities.
All original cavities were removed from the tunnel and re-installed cycle ~ 6-12wks/cav.



Required intensive and highly specialized manpower.
4 years to complete.

Furthermore, PIP successfully rebuilt 3 additional cavities once categorized as inoperable and installed in the Booster enclosure to improve reliability and uptime – provide 20% overhead.

Replacement of original power system with solid state based system

Upgrade bias and Anode power supplies

SS Driver - Modulator - Bias supply

Anode Power Supplies:

Original main rectifier transformer overheated at high rep rates.

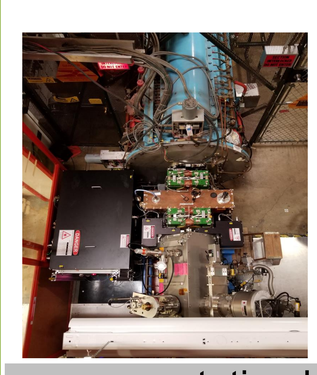
Output 32KVDC/48Amp

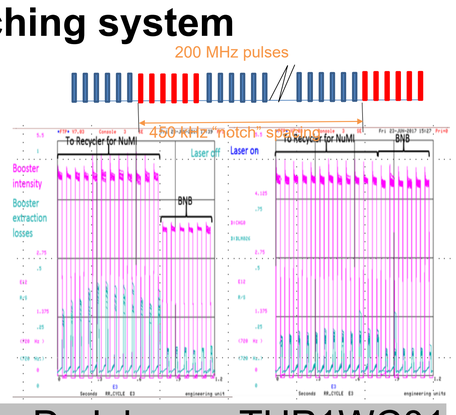
Input: 13.8KV/75Amp

Proton Flux

Double proton throughput without increasing loss/activation levels

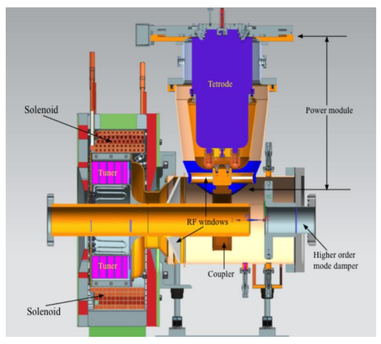
Control beam losses
Linac Laser Notching system





see presentation by D. Johnson THP1WC01

Booster 2nd harmonic cavity



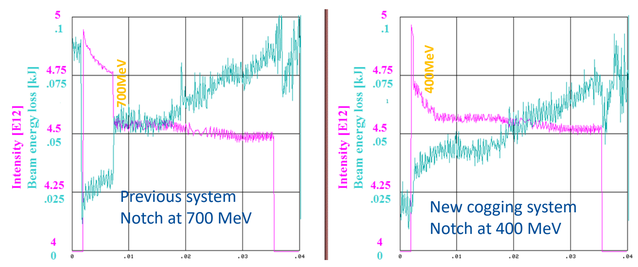
Length: 8.44m
Aperture: 0.76m
Peak gap V: 100kV
Ferrite: NM-AL-800
Q: 3200-5700
f min/max: 75.7/105.6 MHz

see presentation by R. Madrak THP2WC01

Magnetic Cogging

Keeps beam on central orbit notch created after injection

$$\frac{\Delta f_{rev}}{f_{rev}} = \frac{1}{\gamma^2}\frac{\Delta P}{P} - \frac{\Delta L}{L}$$



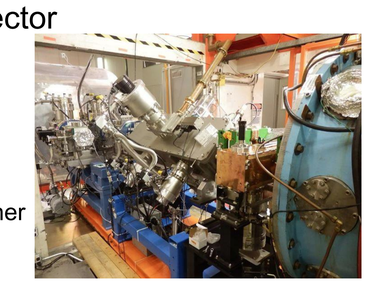
Viability & Reliability

Replace systems with obsolete parts and significant contribution to machine downtime

Upgrade Injector line to RFQ

Design based upon BNL injector

LEBT – composed of 2 solenoids
Einzel lens chopper
200 MHz 750keV RFQ 4-rod
length 1.2 m,
peak cav. power 185 kW
MEB T - 2 sets of doublets and buncher cavity

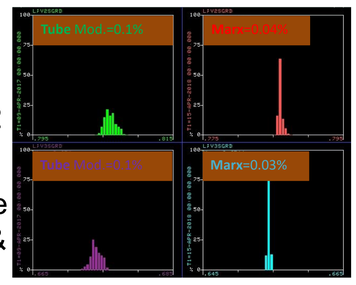


Linac 200 MHz system Marx Modulator

Marx Modulator Regulation

Cells fire via fiber optic pulses
Individual control via FPGA
Feedforward control algorithm
Slow start during turn-on
Programable gradient waveform
Pulse-to-pulse learning algorithm
Direct real-time feedback

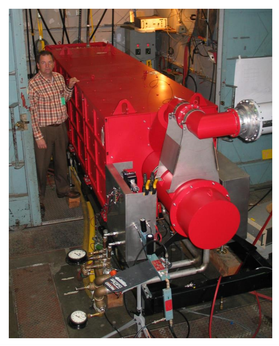
Marx Modulator Performance



Improvements:
Gradient. flatness by factor of 2
Slew rate by factor of 5
Achieved < 0.1% pulse-to-pulse gradient stability with learning & feedback

200 MHz Klystron

viable technology to drive the DTLs



DTL
f_0: 201.25 MHz
Saturated efficiency: > 48%
Perveance: 2.0 mA/V$^{1.5}$
PRF: 15 Hz, J_{cath} : 1 A/cm^2
Pulse length: 450 msec
Expected lifetime :> 200 khrs

CONCLUSION

PIP enabled proton source to run consistent at 2.4E17 protons per hour.

The benefits have been significant and have made possible Fermilab to deliver the protons needed for HEP program.

PIP will be complete in fall of 2018.