To:

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Subject: Proton Improvement Plan

Project Quarterly Summary FY18 Q1

Report #21 February 18th , 2018

Project Milestones

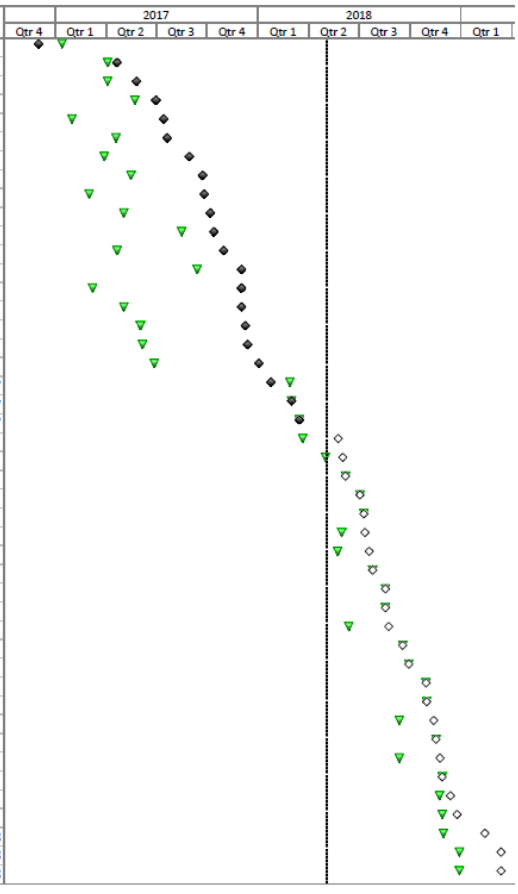
On January 29, the Booster achieved a record proton flux of 2.4E17 protons per hour. This achievement is the result of implementation of the Proton Improvement Plan (PIP) over the last five years. The PIP not only consisted of challenging engineering and beam physics, but included activities addressing viability and reliability of Fermilab's Proton Source. The record proton flux is about two and half times higher than what the Booster was capable before the PIP. With the Booster operating at 15 Hz, the 2.4E17 protons per hour allow the NuMI beamline, Booster Neutrino Beamline and Muon Campus to operate simultaneously. The successful PIP ensures that the Proton Source can deliver the beam necessary to perform Fermilab's and Nation's HEP program.

Project Milestones

There was one Linac milestone this quarter: Modulator #2 ready for installation. This milestone was not achieved and later on this report an explanation of why is provided. Booster had three forecasted milestones in FYQ1+. All three were completed, with only one milestone missing baseline by two weeks.

Table 1 PIP milestones

Level	WBS	Name	Baseline Finish	Fcst Fin
4	1.02.01.06.03.04	MILESTONE: 19 New Tuner Assemblies Complete	10/14/16	9/2/16
3	1.01.01.02.02.03.08	MILESTONE: Prototype Modulator Installed in LRF5	1/3/17	1/20/17
3	1.02.01.10.03.03	MILESTONE: Cavities 21 & 22 Rework Complete	1/3/17	2/24/17
4	1.01.01.02.01.10.06.98	MILESTONE: Modulator Prototype Operational	2/21/17	3/31/17
4	1.01.02.03.04.19	MILESTONE: Free Space Amplifier Complete	11/1/16	4/14/17
3	1.02.01.10.04.05	MILESTONE: Cavities 21 & 22 Testing Complete	1/18/17	4/20/17
4	1.01.02.03.07.08	MILESTONE: All Linac Notcher Timing & Controls Hardware Integrate	12/28/16	5/31/17
3	1.02.02.05.08	MILESTONE: Booster Collimation Complete	2/14/17	6/23/17
3	1.01.02.03.12.10	MILESTONE: Laser system ready for commissioning	12/1/16	6/26/17
3	1.02.03.01.01.03.06	MILESTONE: Testing of the Prototype System with Booster BPMs Com	2/1/17	7/7/17
2	1.02.01.09.04.02.11	MILESTONE: PA Amplifier Testing Complete	5/16/17	7/13/17
3	1.02.01.10.04.06	MILESTONE: Cavities 21 & 22 Installed	1/20/17	7/31/17
3	1.01.01.02.02.04.10	MILESTONE: Modulator #1 Ready for Installation	6/13/17	9/1/17
3	1.01.02.03.09.09	MILESTONE: Laser Diagnostics complete	12/7/16	9/1/17
2	1.01.02.03.14.10	MILESTONE: Linac Notcher System Operational	2/1/17	9/1/17
4	1.02.01.09.03.07.02	MILESTONE: Perpendicular Cavity Design & Drawings Complete	3/3/17	9/8/17
4	1.02.01.09.03.09	MILESTONE: Perpendicular Cavity Final Dwgs Approved	3/7/17	9/12/17
4	1.01.02.03.17	MILESTONE: Linac Notcher Complete	3/28/17	10/2/17
3	1.01.01.02.02.03.09	MILESTONE: Mod #1 Installed	11/27/17	10/24/17
3	1.02.03.01.02.01.03	MILESTONE: Booster BPM Production Procure/Assembly Complete	11/30/17	11/30/17
2	1.02.01.07.02.04	MILESTONE: Booster Cavity Initial Design Complete	12/14/17	12/14/17
3	1.02.03.01.01.04.03	MILESTONE: BPM Front End Programming Complete	12/20/17	2/22/18
3	1.02.03.01.02.02.02	MILESTONE: Booster BPM Production Module Testing Complete	1/30/18	3/2/18
4	1.02.01.07.03.13	MILESTONE: Receipt of all Components	3/7/18	3/7/18
3	1.02.01.11.09	MILESTONE: RF Stations 21 & 22 Infrastructure Complete	4/2/18	4/2/18
2	1.02.01.09.04.05.04	MILESTONE: 1st Perpendicular Cavity Assembled	4/9/18	4/9/18
3	1.01.01.02.02.05.13	MILESTONE: Modulator #2 Ready for Installation	2/28/18	4/11/18
4	1.02.01.07.03.12	MILESTONE: Acceptance of 3 Tuners	2/21/18	4/19/18
3	1.02.01.11.02.02.07	MILESTONE:Cavity 21 Bias Supply Tested & Completed	4/25/18	4/25/18
3	1.02.01.11.02.03.05	MILESTONE:Cavity 22 Bias Supply Tested & Completed	5/18/18	5/18/18
3	1.02.01.11.10	MILESTONE: RF Stations 21 & 22 Work Complete	5/18/18	5/18/18
2	1.02.03.01.02.03.02	MILESTONE: Booster BPM System Installation & Checkout Complete	3/13/18	5/24/18
2	1.02.01.11.11	MILESTONE: RF Stations 21 & 22 Commissioned	6/18/18	6/18/18
2	1.02.01.09.04.05.12.07	MILESTONE: Perpendicular Cavity #1 Installed	6/29/18	6/29/18
2	1.02.01.09.04.05.14	MILESTONE: Perpendicular Cavity #1 Commissioned	7/30/18	7/30/18
3	1.01.01.02.02.03.10	MILESTONE: Mod #2 Installed	7/31/18	7/31/18
2	1.02.03.01.02.04.02	MILESTONE: Booster BPM Upgrade Complete	6/12/18	8/13/18
4	1.02.01.07.03.10	MILESTONE: Prototype Cavity Tested (Upstairs)	8/17/18	8/17/18
3	1.01.01.02.02.06.13	MILESTONE: Modulator #3 Ready for Installation	6/12/18	8/24/18
1	1.02.01.07.03.11	MILESTONE: Booster Prototype Cavity Operated with Beam	8/28/18	8/28/18
3	1.01.01.02.02.08.10	MILESTONE: Modulator #5 Ready for Installation	8/23/18	9/12/18
3	1.01.01.02.02.03.11	MILESTONE: Mod #3 Installed	8/28/18	9/24/18
3	1.01.01.02.02.07.12	MILESTONE: Modulator #4 Ready for Installation	8/30/18	11/13/18
4	1.01.01.02.02.03.07	MILESTONE: Modulator Upgrade Complete	9/28/18	12/12/18
3	1.01.01.02.02.03.12	MILESTONE: Mod #4 Installed	9/28/18	12/12/18



PIP Highlights by WBS Section

WBS 1.1 Linac

The vulnerabilities associated with the LINAC are the 200 MHz accelerating system, including power amplifier tubes and other associated systems such as the modulator; utilities for power distribution and vacuum systems; better need for reliable instrumentation along the Linac to improve beam transport and realistic machine model supported by real beam measurements. There are four largest elements of WBS Level 2 in Linac which are further subdivided at Level 3.

WBS 1.1.1 200 MHz RF Power System

The 200MHz RF Power System represents approximately 40% of the total scope of the PIP project. There are 3 level 4 elements which will be described below.

WBS 1.1.1.1 High Level RF

Linac Level-4 WBS completed (FY16-Q2).

WBS 1.1.1.2 Linac Modulator

The major activities at the beginning of FY18Q1 were the commissioning of Marx prototype in LRF2 and P1-Marx-54 in LRF3 followed by the machine star-up effort after the maintenance shutdown 2017. pMarx-54 has been running flawlessly since its installation and commissioning. On the other hand, P1-Marx-54 installed on LRF3 station was problematic. Marx modulator tripped often, multiple times. First set of troubleshoot was to investigate Marx controllers itself. Despite efforts, no clear culprit was identified.

In parallel the amplifier was tuned up to mitigate the spark strips. No measurable progress was achieved. Eventually the tube/socket assembly was replaced, and the downtime related with spark trips ceased. The amplifier is back to the test station for further investigation.

Progress on assembly of P2-Marx-54 has also occurred during this period. The Marx Cabinet was moved to the Linac gallery in November before the really cold weather season. Assembly is ongoing. A total of 50 cells were assembled, and installed in the Marx cabinet. Another build sequence was initiated before holiday break followed by tested and installation in the cabinet by the end of calendar year. The charging supply cabinet is complete.

The P2 Marx low power test was expected to be initiated by the end of the quarter. This was not accomplished. However, the unit was tested and started operations in late January, about 3 weeks behind the baseline schedule. This delay is not expected to inhibit our final Marx modulator installation schedule.

WBS 1.1.1.3 7835 Procurement

Linac Level-4 WBS completed (FY15-Q1).

WBS 1.1.2 Accelerator Physics

WBS 1.1.2.1 Simulations and Studies

Linac Level-4 WBS completed (FY15-Q1).

WBS 1.1.2.2 *Not Used*

Some WBS numbering is nonconsecutive at lower levels because of account closings and rearrangements after financial codes were initially established during the period of setting up PIP.

WBS 1.1.2.3 Linac Notch Creation

As mentioned in the last report, the Linac Notch system was declared operational by the end of the run period. This past quarter was utilized to make some minor modifications to the laser box, purchase spare components to support system operations. Linac Level-4 WBS is complete (FY17-Q4).

WBS 1.1.3 Instrumentation

WBS 1.1.3.1 Beam Position Monitors

First Linac Level-3 WBS completed (FY13-Q2).

WBS 1.1.4 *Not Used*

Some WBS numbering is nonconsecutive at lower levels because of account closings and rearrangements after financial codes were initially established during the period of setting up PIP.

WBS 1.1.5 Utilities

The Linac Utilities, such as power distribution, water and vacuum systems are composed of mostly 40-year-old equipment beyond its practical service life. There are three Level 4 elements in this WBS.

WBS 1.1.5.1 Power Distribution

Linac Level-4 WBS completed (FY14-Q4).

WBS 1.1.5.2 LCW distribution

Linac Level-4 WBS completed (FY15-Q1).

WBS 1.1.5.3 Vacuum System

Linac Level-4 WBS completed (FY14-Q4).

WBS 1.2 Booster

Part of the PIP effort for the Booster Accelerator is to address the increase proton beam flux that will be demanded by the Fermilab program in the upcoming years. The increased flux will be achieved by providing beam on more/all of the Booster cycles; certain equipment will increase from an average 7.5 Hz to 15Hz. Overheating of old components is a major concern; several Booster PIP tasks are to upgrade/refurbish equipment to run at 15 Hz. Enough PIP tasks have been completed so that in FY16Q1 the Booster was capable of operating at 15 Hz. As of FY18Q1 Booster has reached periods of 2.4E17 protons per hour as a result of various PIP features coming on line.

The aging original equipment and infrastructure of the Booster are vulnerable due to obsolescence and increase wear due to the increase of flux. Some of the PIP effort is to replace these possible reliability problems.

WBS 1.2.1 RF

WBS 1.2.1.1 Anode Supply

This task is complete.

WBS 1.2.1.2 Bias Supply

This task is complete.

WBS 1.2.1.3 *Not Used*

Some WBS numbering is nonconsecutive at lower levels because of account closings and rearrangements after financial codes were initially established during the period of setting up PIP.

WBS 1.2.1.4 Cavity Test Stand

The cavity test stand task will not be done since there will be no benefit to PIP.

WBS 1.2.1.5 Cavity and Tuners Refurbishment

This task is complete.

WBS 1.2.1.6 New Tuners

This task is complete.

WBS 1.2.1.7 Replacement Cavities

Tests of cooling rates were done to compare with the simulation. Detailed temperature measurements were done during cavity and tuner set refurbishment certification (WBS 1.2.1.5); the last set of measurements were done during the final refurbished cavity tuner set certification. Simulation model verification continues. Further cooling tests done using a wide bore cavity that will be reworked as well for a reworked cavity (WBS 1.2.1.10); analysis of these measurements will further confirm some details of the simulation.

The task has been renamed from new to replacement. Fermilab has recognized that any new/replacement cavities should work with PIP II. Requirements satisfying now and for the future have been determined. A review of the technical specifications was held as well as presented to the Fermilab Accelerator Advisory Committee (AAC). The review panel and AAC agreed that the specifications meet the needs of PIP and PIP II.

Cavity tuners are being milled and adjusted for the wide aperture cavity replacement. Tuner sub-assemblies have been machined. The cavity stand is near completion. Machining of the main cavity body is still in progress due to difficulties in the manufacturing process.

WBS 1.2.1.8 Cavity 1013

This task is complete.

WBS 1.2.1.9 Second Harmonic Cavity

The investigation of possible benefits of using a higher order harmonic cavity continues; in particular, for beam capture and transition crossing. The investigation is focused upon a perpendicular biased cavity. Work previously done at SSC and TRUIMF was our starting point. Modelling and simulations progress has led to improvement over the old designs. Most drawings have been completed and vendors selected for cavity fabrication with some parts being fabricated. Some machined components have been received with need for correction as vendor was not able to meet tolerances. Various aspects of the project fabrication are moving forward even with some areas requiring correction. Parts and tooling have been received by Technical Division for the solenoid. Cables have been run between gallery components down to the accelerator tunnel location point of installation.

WBS 1.2.1.10 Rework of Two Cavities

This task is complete.

WBS 1.2.1.11 Three New RF Stations

PIP will implement three additional RF stations to bring the total number of Booster RF stations to 22. This requires electrical work, water cooling work, assembly of power equipment and cable pulling.

Work is complete. (bias supply spares are still being built)

WBS 1.2.2 Accelerator Physics

WBS 1.2.2.1 Simulations and Studies

The people assign to the task of organizing, performing and analyzing beam studies has been consistent for the last few quarters. The main work is being done by accelerator scientists in the Proton Source Department as well as some simulation work done by members of APC and CD.

Studies have been done investigating of injecting beam earlier. By injecting beam earlier, the resulting beam should have a smaller energy spread. A plan to slowly implement the early beam injection scheme has been implemented. Studies continue.

WBS 1.2.2.2 Alignment and Aperture

Currently, no further magnets are scheduled to be moved. There are a few candidate magnets, but current simulation and beam studies (WBS 1.2.2.1) do not suggest that there will be noticeable improvement. The centers of the apertures have been designated as the ideal orbit (see WBS 1.2.2.1). We may return to this task in the future.

WBS 1.2.2.3 Booster Notcher

This task is complete.

WBS 1.2.2.4 Booster Cogging

Booster magnets cogging is complete. Laser notching is now operational with synchronized Booster notch cogging and laser notching. Day to day adjustment continue to optimize performance.

WBS 1.2.2.5 Booster Collimation

Task is complete.

WBS 1.2.2.6 Radiation Shielding

We are now operating with a 2.7E17 limit incorporating the TLM system.

Task is complete

WBS 1.2.3 Instrumentation

WBS 1.2.3.1 Beam Position Monitors

This task is proceeding slowly due to personnel being redirected to solving instrumentation problems concerning other Fermilab projects. Beam tests with production boards continues as the new system is integrated with the existing system for evaluation and testing. Efforts both in hardware production and software development continues. We have had several hardware delays due to vender production quality control issues and defective board assemblies. These issues are currently being assessed and plan of correction is being developed.

WBS 1.2.3.2 Dampers

This task is complete.

WBS 1.2.4 *Not Used*

Some WBS numbering is nonconsecutive at lower levels because of account closings and rearrangements after financial codes were initially established during the period of setting up PIP.

WBS 1.2.5 Utilities

WBS 1.2.5.1 Low Conductivity Water System

The task is complete.

WBS 1.2.5.2 Power Distribution

This task is complete.

WBS 1.2.5.3 Vacuum System

Task is complete.

WBS 1.2.7 Solid State Upgrade

The task is complete.

PIP Budget – Costs, Labor and Obligations Updates (FY18 Q1)

Like FY17, the FY18 first quarter and first part of the second quarter operated with the laboratory under a continuing resolution. However, we again were provided guidance that did not restrict PIP M&S or labor from proceeding with plans. We used the planned labor with much of the labor being directed at modulators, perpendicular cavity and beam physics work. PIP management wanted to bring up the Linac 54 cell modulators under beam operations to verify its performance before proceeding with the buildup of additional modulators. The new modulators testing has gone well and we are proceeding with the remaining modulators. However, once again labor was removed from PIP to assist with g-2 and other laboratory priorities. We were able to rebalance and re-assign operations types to make up for labor shortages. The net loss of labor has slowed the modulator work but we have made up ground and on pace to complete the task this FY. Other work continues with plans in place to finish up PIP is FY18. This is the goal of laboratory management and PIP is doing what it can to meet this difficult goal. Figure 1 below shows how labor was reduced from PIP requests. Coming out of the FY17 summer shutdown and the commissioning of G-2 had a significant impact on PIP.

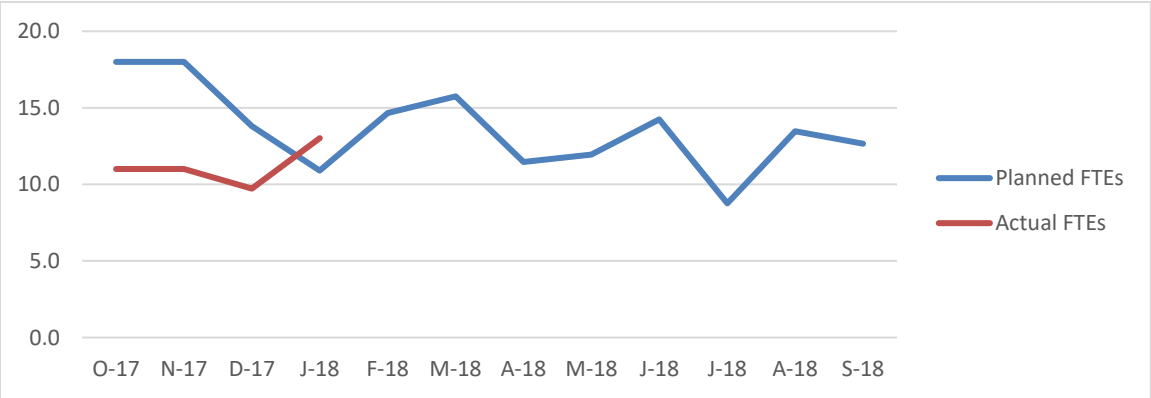


Figure 1PIP Labor Request vs Actual

PIP FY18 budget is shown in table two below. PIP has been conservative in the first quarter due to uncertainty in the continuing resolution and the ability to pay labor throughout FY18. PIP planning is forecasting a bump in the second quarter as the assembly of both the second harmonic and parallel bias prototype cavity begin assembly and possibly testing.

Table 2 PIP Budget

FY18 PIP OBL BUDGET K$ **	OBL BUDGET	YTD OBL	RIP	BUDGET BAL
M&S	1,651.5	184,4	13.5	1,467.1
Labor	2,594.4	713.8		1,880.6
FY18 Sums	4,245.9	898.2	13.5	3,347.7