To:

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Subject: Proton Improvement Plan

Project Quarterly Summary FY17 Q1

Report #17 January 9th, 2016

Project Milestones

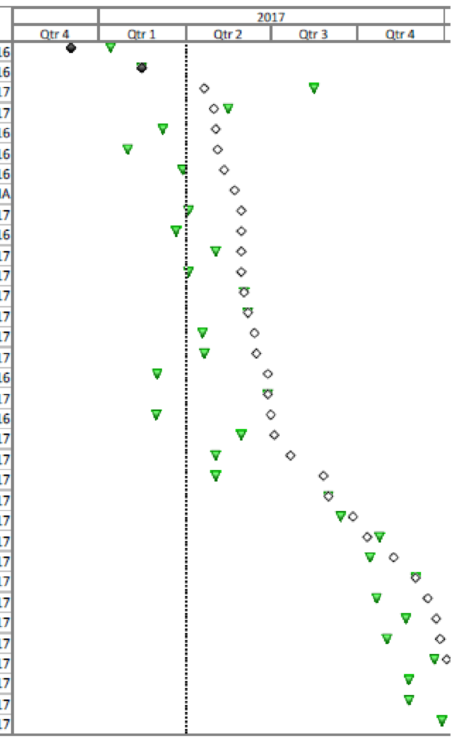
Project Milestones

There were five Linac milestones this quarter. They were all Level 3. Four of them were related to the Linac Laser Notch task and they were all delayed for reasons what will be explained below. The fifth milestone, *Prototype Modulator Installed*, was complete. Booster had one level 4 milestone, 19 Tuner Assembly Complete, which was finished in the previous quarter.

Table 1 PIP milestones

Baseline Milestone ▼ Fcst Milestone ◇ Milestone Complete ◆

Level	WBS	Name	Baseline Finish
4	1.02.01.06.03.04	MILESTONE: 19 New Tuner Assemblies Complete	10/14/16
4	1.01.02.03.10.04	MILESTONE: Laser Notcher External Review Complete	11/15/16
2	1.02.01.09.03.02.10	MILESTONE: PA Amplifier Testing Complete	5/16/17
3	1.02.02.05.08	MILESTONE: Booster Collimation Complete	2/14/17
3	1.01.02.03.09.09	MILESTONE: Laser Diagnostics complete	12/7/16
4	1.01.02.03.04.19	MILESTONE: Free Space Amplifier Complete	11/1/16
4	1.01.02.03.07.08	MILESTONE: All Linac Notcher Timing & Controls Hardware Integrated into LabView	12/28/16
3	1.01.01.02.01.10.06.98	MILESTONE: Modulator Prototype Operational	NA
3	1.01.01.02.02.03.08	MILESTONE: Prototype Modulator Installed	1/3/17
3	1.01.02.03.10.07	MILESTONE: Ion Beam Diagnostics Complete	12/21/16
2	1.01.02.03.14.10	MILESTONE: Linac Notcher System Operational	2/1/17
3	1.02.01.10.03.03	MILESTONE: Cavities 21 & 22 Rework Complete	1/3/17
4	1.02.01.09.02.07.02	MILESTONE: Perpendicular Cavity Design & Drawings Complete	3/3/17
4	1.02.01.09.02.09	MILESTONE: Perpendicular Cavity Final Dwgs Approved	3/7/17
3	1.02.01.10.04.05	MILESTONE: Cavities 21 & 22 Testing Complete	1/18/17
3	1.02.01.10.04.06	MILESTONE: Cavities 21 & 22 Installed	1/20/17
3	1.01.02.03.12.10	MILESTONE: Laser system ready for commissioning	12/1/16
2	1.01.02.03.17	MILESTONE: Linac Notcher Complete	3/28/17
3	1.02.03.01.02.01.03	MILESTONE: Booster BPM Production Procure/Assembly Complete	11/30/16
3	1.02.03.01.01.04.03	MILESTONE: BPM Front End Programming Complete	2/28/17
3	1.02.03.01.01.03.06	MILESTONE: Testing of the Prototype System with Booster BPMs Complete	2/1/17
3	1.02.03.01.02.02.02	MILESTONE: Booster BPM Production Module Testing Complete	2/1/17
3	1.02.01.11.09	MILESTONE: RF Stations 21 & 22 Work Complete	6/1/17
3	1.01.01.02.02.04.12	MILESTONE: Modulator #1 Ready for Installation	6/13/17
2	1.02.03.01.02.03.02	MILESTONE: Booster BPM System Installation & Checkout Complete	7/24/17
2	1.02.01.07.02.04	MILESTONE: Booster Cavity Initial Design Complete	7/14/17
2	1.02.01.11.11	MILESTONE: RF Stations 21 & 22 Commissioned	9/1/17
3	1.01.01.02.02.05.12	MILESTONE: Modulator #2 Ready for Installation	7/21/17
2	1.02.03.01.02.04.02	MILESTONE: Booster BPM Upgrade Complete	8/21/17
3	1.02.01.11.02.02.07	MILESTONE:Cavity 21 Bias Supply Tested & Completed	8/1/17
3	1.01.01.02.02.03.09	MILESTONE: Mod #1 Installed	9/20/17
3	1.02.01.11.02.03.05	MILESTONE:Cavity 22 Bias Supply Tested & Completed	8/24/17
3	1.02.01.11.10	MILESTONE: RF Stations 21 & 22 Infrastructure Complete	8/24/17
3	1.01.01.02.02.03.10	MILESTONE: Mod #2 Installed	9/28/17



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 quarter began with testing of the 54 cell Prototype into the dummy load in the EE Support test cage. After several dummy load failures, the pulse width was reduced to allow testing at full repetition rate. The tests were being performed using the spare FPGA card for the 28 cell prototype while the new FPGA card was being manufactured. This limited controls but was sufficient for spark testing and thermal scans.

During that time, power distribution was being installed in the test area at LRF6. Late in October, the Marx was moved over to the LRF6 area and reassembled. The new FPGA card arrived shortly before this and time was spent debugging it while the Marx was being moved. It took most of November to reassemble the Marx, and into early December before the FPGA was successfully communicating with the PLC. The remaining weeks of the quarter were spent debugging the learning system and beam loading compensation.

During the quarter, most of the major components for the production run arrived. Assembly of the Marx cabinets began at A0 in late November, and cell construction began in December. Rough a third of the charging supplies have been tested and installed in the charging supply racks.

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

During this quarter, the Laser Notcher had a 2 week commissioning period in the RFQ Injector Linac (RLI). This commissioning period were useful in identifying a number of operational improvements that have been implemented during this quarter. At the time of the commissioning period there were two known loss points that reduced the laser pulse energy by almost a factor of four. The first was a mismatched isolator on the LMA amplifier output and the second was an instability in the solid state amplifier system, whose cause was unknown at the time of the commissioning. After a tireless troubleshooting period, the later was isolated to the spectral qualities of the signal seed source. The central wavelength was at the too far off the gain peak of the Nd:YAG, the spectral width was too large, and the diode was operating in a “gain competition” mode where all the power was moving between different longitudinal lines. Plans were developed to eliminate this instability and the corrective action was implemented. The ultimate solution for the problem was to use a single frequency seed source that was better matched to the gain peak of the Nd:YAG amplifiers and a phase modulator to spread the power among a number of frequency sidebands to prevent the SBS instability in the fiber system. The result of the new seed source and phase modulation can be seen in Figure 1.

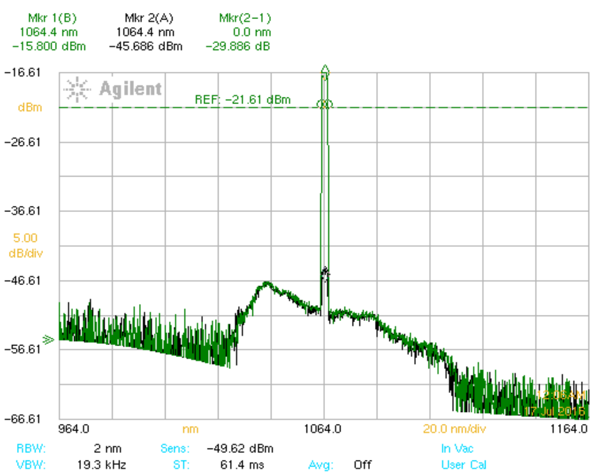


Figure 1 LMA amplifier backwards spectrum at maximum power with new single frequency seed and phase modulator off (green) and on (black).

The optical spectrum shown in the figure is the backward power emanating from the LMA amplifier at peak pump power. The output was measured at maximum pump current yielding greater than 2.2W. The broad peak in the spectrum is the ASE generated in the amplifier. The narrow peak at 1064.4 nm (as measured in vacuum), is a measure of the backward power at the signal wavelength. This is in the center of the gain peak for the Nd:YAG amplifier modules which assures maximum gain in these modules. A large exponentially increasing signal at this wavelength is an indication of the SBS instability. Two traces are shown: the green trace is with the phase modulator OFF and the black trace is with the phase modulator ON. A reduction of 30 dB in the power of this SBS peak is obtained. This reduction is critical in the stable operation of the fiber amplifier system as seen in Figure 2.

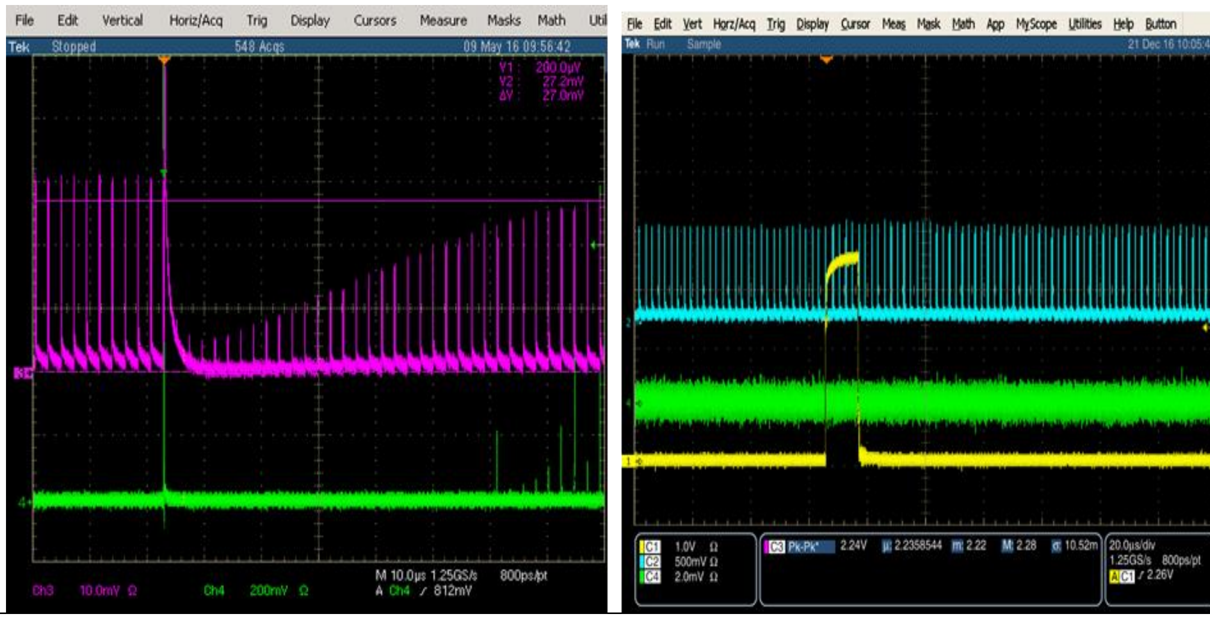


Figure 2 (a) First 9 notches seen in Linac beam on Griffin detector and WCM. (b) Scope traces showing the output of fast photodiodes for the backwards power (green trace in both) and the forward output power (magenta and cyan) from the LMA amplifier at maximum pump power. The plot on the left is before the addition of the new seed source and phase modulator and the plot on the right is after.

The scope traces show the output pulses (magenta and cyan) and backward pulses (green) from the LMA amplifier at peak excitation. The traces on the left are without the new seed source and phase modulation while the traces on the right are with the new seed source and phase modulation. The magenta trace in the left plot shows a very large output pulse that robs the gain fiber of its gain and the slow recovery of the gain. These large forward power pulses can be orders of magnitude larger than the nominal pulse energies and can destroy downstream fiber systems. The large green spike seen associated with this large power spike is the backward Stokes wave associated with the SBS instability which can trigger these large forward pulses. The scope traces on the right are with the new seed source and phase modulator. Note the scale for the backwards power on the right plot is a factor of 100 smaller than the left. This indicates that the threshold of this instability was moved beyond the maximum pump power of the LMA amplifier to allow stable operation of the fiber amplifier at maximum power.

In addition, the input power into the fiber pre-amplifier was increased by an additional “Booster” amplifier so the pre-amplifier could operate in a saturated mode. Another implementation that occurred was the addition of Pockel cells between the fiber and solid state amplifier systems to maximize the gain in the solid state system. To further increase the laser pulse energy for neutralization and operational stability, we made several additional improvements: replacement of a high loss output isolator on the LMA amplifier, addition of a reverse power tap to the PCF fiber amplifier to monitor the SBS instability, the expansion of the input view port to the optical cavity to allow and monitor better steering of the laser into the cavity. There are also a number of instrumentation and software projects being actively worked on that will assure the successful operation of the Laser Notcher.

Furthermore, during this quarter the group held in November a successful two-days external review of the project with laser experts from SNS and LBNL.

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.

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

A final shipment of thirty ferrites has passed acceptance tests in FY17Q1. 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.

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. Garnet sample testing show that it is suitable for a perpendicular biased cavity. A mock-up of the tuner was built and measurements have been made. An analysis of the measurements is underway to compare with the simulations. Tests of the final power amplifier (PA) is ongoing to make certain that the PA will work sufficiently at the higher frequencies. Procedures for the assembly of the ferrite with the cooling material is being developed while designs of the prototype are being finalized. The first complete garnet ring is being produced by a vendor; the ring will be tested for acceptance in FY17Q1. The final mechanical design is underway.

WBS 1.2.1.10 Rework of Two Cavities

Although not new cavities, PIP has decided to reclaim two other cavities and rework them to be the 21st and 22nd Booster cavities (similar to the rework done for cavity 1013; WBS 1.2.1.8). Long lead time items have been procured. This work has commenced with the completion of the refurbishment task (1.2.1.5). Tuners will be provided by work done by the New Tuner task (1.2.1.6).

The 21st cavity has been certified. The 21st cavity will undergo more testing/cooling measurements for the Replacement Cavity design simulation (WBS 1.2.1.7). Cavity 22 rework has begun: inner parts of the cavity have been sent to the Fermilab machine shop for rework.

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.

The 20th RF station was completed during the 2015 shutdown. This new station was commissioned and put into operation in FY16Q1.

Booster enclosure work for the remaining two RF stations was performed during the 2016 summer shutdown; one location was complete to accept a cavity while the other will require more than a few day shutdown to finish its preparation.

Civil work to retrofit a room for the RF stations electronics and power systems is nearly complete. Work for connection to the infrastructure (power and cooling) was done during the 2016 long shutdown.

Procurement of power and control systems is in progress. The building of the bias supplies needed for the new RF stations has begun with sub-assembly work.

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

Studies of the new cogging board and code were concluded in FY15Q3. The cogging board was put into operation. This task is finished with the exception for interfacing with Linac laser notching system during the first half of FY17.

WBS 1.2.2.5 Booster Collimation

The collimation task is to control Booster beam loss after implementing the above notcher and cogging systems. A group has started studies of using existing collimation components. These studies include simulations, beam loss observations and exercising collimators movements. A new primary collimator has been built; it was installed during FY16Q2. Studies and analyses are on-going.

WBS 1.2.2.6 Radiation Shielding

Beam studies concerning the beam loss profile and measurements of beam loss radiation through penetrations have been done. Simulation studies involve the effectiveness of the passive shielding, active detectors and radioactive source terms for penetrations are nearly complete.

A Total Loss Monitor (TLM) system of eight long detectors has been installed; each detector covers three Booster periods. Beam loss tests and measurements have been done. The analyses and write-up investigating beam loss as well as TLM responses was completed. The documentation was sent to the

Shielding Assessment Review Panel. The TLM and radiation shielding assessment need to be concluded before increasing the proton flux can be attempted.

Further measurements requested by the Shielding Assessment Review Panel were being done to understand the radiation dose during nominal operations. Previous studies focused upon possible radiation dose from accident conditions. The results of the analyses are being incorporated into a new version of the Booster Shielding Assessment. The Shielding Assessment Review Panel is nearly finished and should recommend acceptance of the documentation early in FY17Q1.

WBS 1.2.3 Instrumentation

WBS 1.2.3.1 Beam Position Monitors

The design work for the beam position monitor system is complete and procurement has started. This task has stalled due to personnel being redirected to solving instrumentation problems concerning Fermilab achieving 700 KW. Beam test with a prototype system will occur FY17Q1.

WBS 1.2.3.2 Dampers

This task is complete.

WBS 1.2.4 *Not Used*

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WBS 1.2.5 Utilities

WBS 1.2.5.1 Low Conductivity Water System

The task is done.

WBS 1.2.5.2 Power Distribution

This task is complete.

WBS 1.2.5.3 Vacuum System

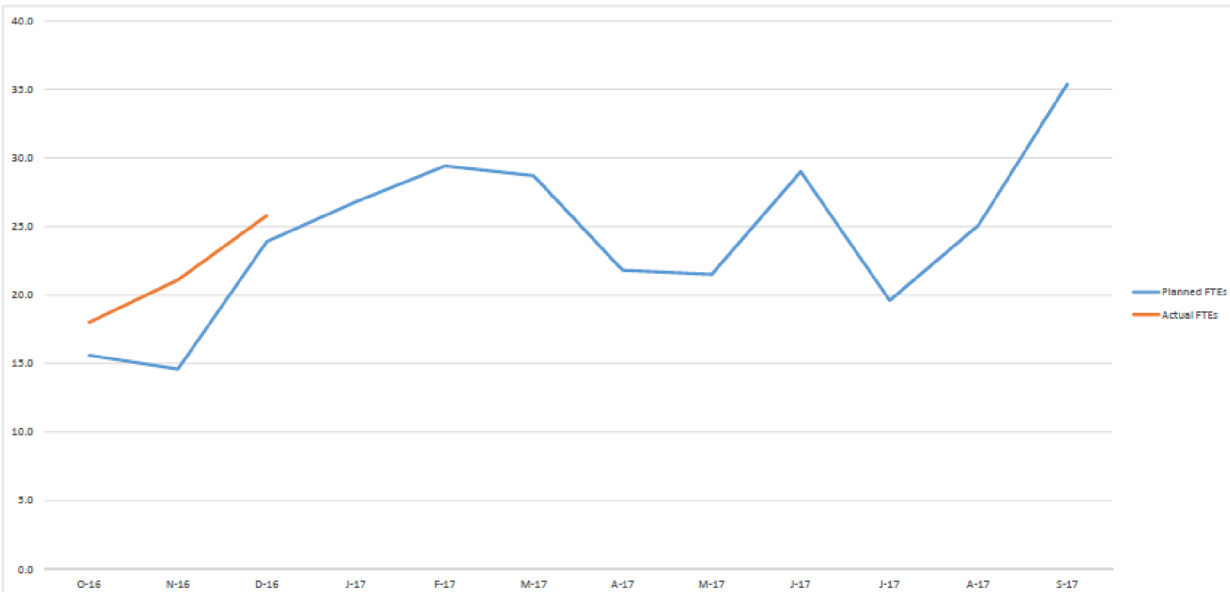
The end of the PIP vacuum work was completed during the 2016 summer shutdown.

WBS 1.2.7 Solid State Upgrade

The task is done.

PIP Budget – Costs, Labor and Obligations Updates (FY17 Q1)

The FY17 first quarter started with the laboratory under a continuing resolution. However, during this quarter we were provided guidance that did not restrict PIP M&S or labor from proceeding with plans. We used more than planned labor with most of the additional labor being directed at Linac modulators and perpendicular cavity work. PIP management wanted to bring up the first full 54 cell modulator under beam operations to verify its performance before proceeding with the buildup of additional modulators. The extra labor allowed the Linac modulator test to proceed quickly.



We have had no significant changes to the FY17 PIP budget. It is expected that PIP will meet its milestones with the forecasted labor and M&S. This year PIP is expected to see the completion of several key tasks and reach the project goal of 2.4 protons per hour capability.

FY16 PIP OBL BUDGET K$ **	OBL BUDGET	YTD OBL	RIP	BUDGET BAL
M&S	3,343.3	962.0	0.0	2,381.3
Labor	5,850.8	1,302.0		4,548.8
FY15 Sums	9,194.1	2,263.9	0.0	6,930.2