To:

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Subject: Proton Improvement Plan

Project Quarterly Summary FY17 Q2

Report #18 April 9th, 2017

Project Milestones

Project Milestones

There were four Linac milestones this quarter all related to the Linac Laser Notch task and they were all delayed for reasons what will be explained below. The Booster had 6 level 3 and 2 level 2 milestones for FY17 Q2. The two that dealt with the BPM work were not completed due to labor being pulled for the Muon Campus G-2 work. The others had to do with cavity 21 and 22 testing and installation. As will be discussed below, the work was completed several weeks after the close of the Q2 and so does not appear compete in the milestone table below. The completion of the cavity work must be timed with Accelerator shutdown days – and one did not occur for cavity 22 install till the third week of April. These milestones are now complete.

Table 1 PIP milestones

WBS	Name	Baseline Finish	Fcst Fin
1.02.01.06.03.04	MILESTONE: 19 New Tuner Assemblies Complete	10/14/16	9/2/16
1.01.02.03.10.04	MILESTONE: Laser Notcher External Review Complete	11/15/16	11/15/16
1.02.01.10.03.03	MILESTONE: Cavities 21 & 22 Rework Complete	1/3/17	2/24/17
1.01.01.02.01.10.06.98	MILESTONE: Modulator Prototype Operational	2/21/17	3/31/17
1.02.03.01.01.04.03	MILESTONE: BPM Front End Programming Complete	2/28/17	4/4/17
1.02.01.09.03.02.10	MILESTONE: PA Amplifier Testing Complete	5/16/17	4/7/17
1.01.02.03.04.19	MILESTONE: Free Space Amplifier Complete	11/1/16	4/14/17
1.02.02.05.08	MILESTONE: Booster Collimation Complete	2/14/17	4/14/17
1.02.01.10.04.05	MILESTONE: Cavities 21 & 22 Testing Complete	1/18/17	4/20/17
1.02.01.10.04.06	MILESTONE: Cavities 21 & 22 Installed	1/20/17	4/24/17
1.02.01.09.02.07.02	MILESTONE: Perpendicular Cavity Design & Drawings Complete	3/3/17	4/28/17
1.01.02.03.07.08	MILESTONE: All Linac Notcher Timing & Controls Hardware Integrated into LabView	12/28/16	5/1/17
1.02.01.09.02.09	MILESTONE: Perpendicular Cavity Final Dwgs Approved	3/7/17	5/2/17
1.01.02.03.10.07	MILESTONE: Ion Beam Diagnostics Complete	12/21/16	5/25/17
1.01.02.03.14.10	MILESTONE: Linac Notcher System Operational	2/1/17	5/25/17
1.02.03.01.02.01.03	MILESTONE: Booster BPM Production Procure/Assembly Complete	11/30/16	6/1/17
1.02.01.11.09	MILESTONE: RF Stations 21 & 22 Infrastructure Complete	8/24/17	6/9/17
1.02.01.11.02.02.07	MILESTONE:Cavity 21 Bias Supply Tested & Completed	8/1/17	6/16/17
1.01.02.03.09.09	MILESTONE: Laser Diagnostics complete	12/7/16	6/22/17
1.01.02.03.12.10	MILESTONE: Laser system ready for commissioning	12/1/16	6/22/17
1.01.02.03.17	MILESTONE: Linac Notcher Complete	3/28/17	6/23/17
1.02.01.11.02.03.05	MILESTONE:Cavity 22 Bias Supply Tested & Completed	8/24/17	7/12/17
1.02.01.11.10	MILESTONE: RF Stations 21 & 22 Work Complete	6/1/17	7/12/17
1.01.01.02.02.03.08	MILESTONE: Prototype Modulator Installed	1/3/17	7/17/17
1.01.01.02.02.04.12	MILESTONE: Modulator #1 Ready for Installation	6/13/17	7/18/17
1.02.03.01.01.03.06	MILESTONE: Testing of the Prototype System with Booster BPMs Complete	2/1/17	7/25/17
1.02.03.01.02.02.02	MILESTONE: Booster BPM Production Module Testing Complete	2/1/17	7/28/17
1.02.01.11.11	MILESTONE: RF Stations 21 & 22 Commissioned	9/1/17	8/9/17
1.02.01.07.03.12	MILESTONE: Acceptance of 3 Tuners	8/30/17	8/30/17
1.02.03.01.02.03.02	MILESTONE: Booster BPM System Installation & Checkout Complete	7/24/17	9/11/17
1.01.01.02.02.05.12	MILESTONE: Modulator #2 Ready for Installation	7/21/17	9/27/17
1.02.01.07.03.10	MILESTONE: Prototype Cavity Tested (Upstairs)	5/1/17	10/2/17
1.01.01.02.02.03.09	MILESTONE: Mod #1 Installed	9/20/17	10/4/17
1.02.03.01.02.04.02	MILESTONE: Booster BPM Upgrade Complete	8/21/17	10/9/17
1.02.01.07.03.11	MILESTONE: Booster Prototype Cavity Operated with Beam	5/10/17	10/11/17
1.01.01.02.02.03.10	MILESTONE: Mod #2 Installed	9/28/17	12/14/17

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

On January 10^{th}, the first attempt was made to have the 54-cell prototype power the 7835 on LRF5. It ran successfully overnight with some regulation issues. LRF5 was switch back to the old modulator for a week while fixes and improvements were made to the Marx code. On January $19^{th,}$ the station was switch back to the Marx again, where it stayed until January 24^{th} when the station was unable to recover from repeated spark trips. Modifications were made to the transmission line to reduce the energy deposited by a spark, meanwhile various improvements to the controls and signals were implemented. On February 7^{th}, LRF5 was switched back to the Marx and has remained there since. Picture 1 below of Marx in location.

Some minor design modifications were made to the Gate Drive and Gate Clamp boards for the cell assemblies. Two of each board were stuffed in house, and were subsequently installed in spare cells from the 54-cell prototype to be tested. After successful testing, the cards for the production run were fabricated, and cards and parts sent to an outside company (Manutec) for stuffing.

Picture 1 54 Cell Marx in Location

Significant work was done on cell construction for the first two production modulators. Currently this effort slow down as the team awaits the return of the Gate Clamp and Gate Drive card from Manutec.

Final design modifications were made to the four of the five card for the controls crate, and three of those four have been laid out, fabricated, and are currently at Manutec. The fourth board, the Analog board, is currently being laid out.

At the start of the quarter, charging supplies for the Marx production were being delivered in batches as they were manufactured, and testing of the supplies was beginning. All charging supplies have since arrived, and have all been tested. A handful were found to have problems, were returned to the factory for repairs, and have since been returned to us and tested. We have all supplies in hand and tested.

The internal assembly of the Marx cabinets began at the end of Q1, and continued through Q2. The major plastic assembly inside the first two modulators is complete. The blowers and some of the electrical wiring have been installed. Now, the team is still waiting on the internal bus work, which was delayed in procurement but has finally been approved.

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

The focus during the second quarter was the implementation of the laser system improvements identified during the summer commissioning period. The new additions include: a 100 kHz line width seed source matched to the gain peak of the free space Nd:YAG amplifiers; a phase modulator and it's RF amplifier to increase the pump power threshold for inhibiting the non-linear SBS instability in the LMA fiber amplifier; a Booster pre-amplifier to increase the amplitude of the input seed power into the next stages of the fiber amplifier system; a Pockels cell to act as a pulse picker for the output of the pulsed fiber amplifier thus selecting only the Notch pulses which will interact with the H-ions to be amplified in the free space amplifier system; and a new optical cavity and vacuum flange to allow the monitoring of the laser bounces inside the optical cavity when installed in the linac.

The optical cavity and flange was assembled, the cavity mirrors aligned and used to test its operation in the lab and the operation of the video camera before the cavity was installed in the Linac at the beginning of March. Figure 1 shows a mechanical drawing of the new flange with the expanded input viewport, the video camera output of the leakage from the bounces in the cavity, and an analysis result of the bounces. This will be a very important diagnostic.

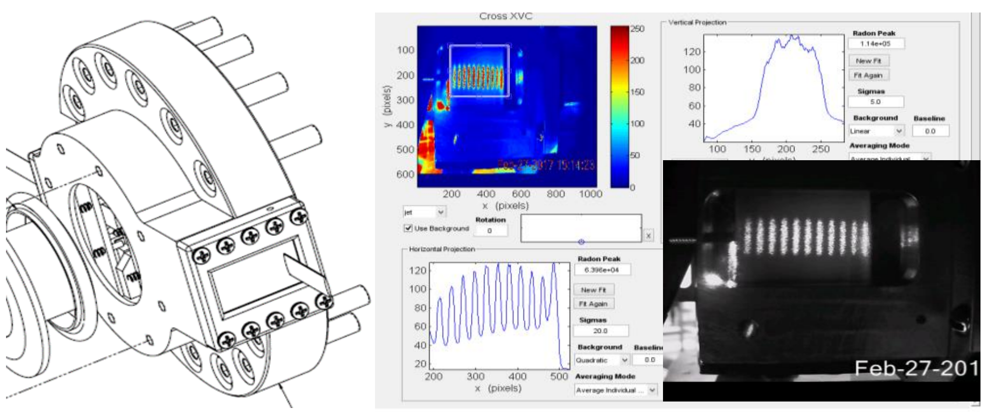


Figure 2: Shows a mechanical drawing of the new vacuum flange with the expanded input viewport, a video image showing the leakage of the bounces in the cavity, and a false color image with intensity profiles in both dimensions.

A significant effort was required to implement the new seed source and phase modulator to determine the modulation frequency and amplitude to move the threshold of the non-linear SBS instability in the first fiber power amplifier beyond the expected maximum pump intensity of the gain fiber. Based upon the instability measurements, an RF amplifier module was designed, constructed and interlocked to the fiber amplifier to remove it's permit if the phase modulation drops a predetermined threshold. This module has been integrated into the system.

Once the Pockels cell was installed and aligned in the Optics Box between the fiber port and the Faraday isolator for the first free space gain module, power testing of the free space amplifiers began. Figure 2 shows a set of four traces from the laser system. The top two traces are from the fiber amplifier system while the bottom two represent the output of the two free space amplifier modules after the Pockels cell.

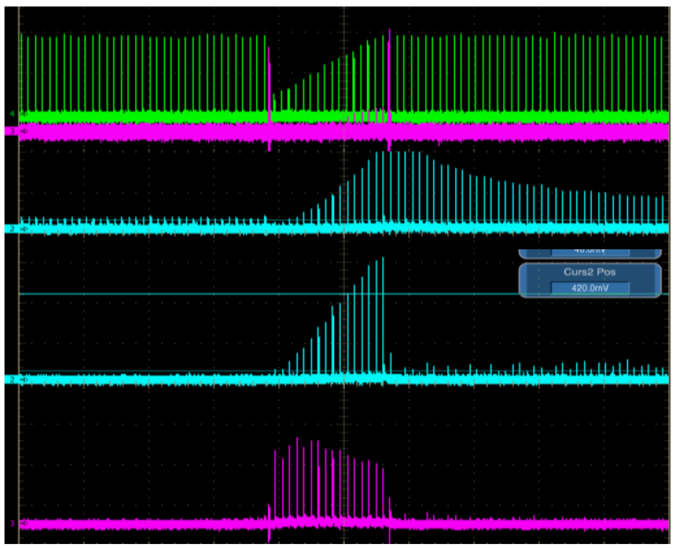


Figure 2: Photodiode signals of the 450 kHz laser pulses through various stages of amplification. From the top down is the RF waveform showing uniform keep-alive pulses and the pre-distorted Notch pulses, the output of the pulsed fiber amplifier, the output of the first free-space amplifier after the Pockels cell picks out only the Notch pulses, and on the bottom the output of the second free space amplifier. These laser pulses will be transported to the optical cavity for interaction with the H-. Each pulse shown in the traces represents a single Notch and contains sixteen 201.25 MHz laser pulses to match ion beam structure.

During the period of power testing, it was realized that the optical models for the laser envelope (size and divergence) throughout the free space optical system were not able to predict the impact of telescope lens spacing adjustments. The optical model should provide guidance for adjusting the lens spacing to achieve the optical requirements of the system, i.e. beam size through the two free-space gain modules, the beam size and divergence at the input of the stacker, and the beam size and divergence through the optical cavity. Since all the telescopes are in series, a focusing error at the upstream end of the optical system can have a detrimental impact on the whole system and yield expected tuning procedures invalid until this focusing error is resolved. A significant effort was required to modify the model to accurately describe the laser beam coming out of the fiber port and fiber telescope and agree with precise profile measurements. The model can now accurately predict the behavior of the fiber telescope responsible for launching the laser into the remainder of the free space optics. The description of the remainder of the telescopes such that the model can accurately predict their behavior is still a work in progress.

Other activities this quarter included:

- The construction and testing of a seven channel Photodiode module, with two channels providing interlock protection against abnormal reverse powers in the two fiber power amplifiers. The output of the fast amplifiers for the photodiodes requires additional processing for sampling by the DAQ.
- A novel IR laser alignment tool was constructed. Developing the amplifiers for the four quadrants of the sensor has been a challenge due to the very low output from the IR position sensitive detector. Good progress on the amplifiers is being made and a resolution of the issues is expected soon.
- A system of temperature sensors for monitoring fiber amplifier and electronic rack temperatures was installed and integrated into the control software.
- During the alignment process of the laser into the optical cavity using two piezoelectric mirror mounts, the controller developed cross talk between channels, which caused significant confusion because suddenly we could not control the position and angle into the cavity. The controller was replaced and the required new drivers were installed in the control system.
- The LabView control software is responsible for controlling and monitoring all devices associated with the Linac Notcher laser system. Any changes or addition of hardware requires integrating the device into LabView control state machine. In addition, many new software features have been integrated into the control system, some of which are designed to simplify operation, make the communication between the control computer and hardware more robust, provide additional software diagnostics and interface to the main accelerator control system ACNET.

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 can operate 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

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 FY17Q2. The final mechanical design is underway. Garnet is being test and evaluated. Some components are being purchased. Electrical infrastructure is being assessed. Figure 3 below shows an image of the cavity as planned to be built.

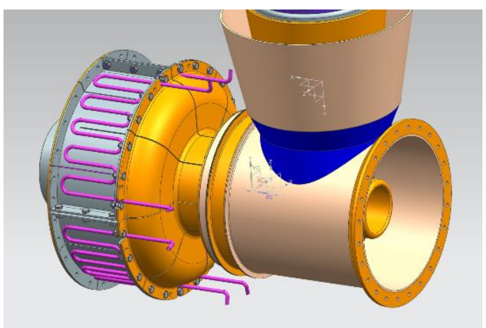


Figure 3 2nd Harmonic Final Design

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 (like the rework done for cavity 1013); WBS 1.2.1.8

The 21st cavity has been certified and installed. Cavity 22 rework was completed in certified in April. The cavity is now installed and waiting for completion of WBS 1.2.1.11 power systems, to allow its operation.

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 and cavity installed. The final cavity will be installed during the FY17 summer shutdown.

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. Water work and electrical work is almost complete.

Procurement of power and control systems is in progress. The building of the bias supplies needed for the new RF stations has been underway 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. Laser notching is almost ready for commissioning, within the month

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 of results have been competed – a final report is due in FY17 Q3 and will then complete the task.

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 has approved new shielding assessment. We are now operating with a 2.7E17 limit incorporating the TLM system.

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. Prototype boards being built.

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 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.

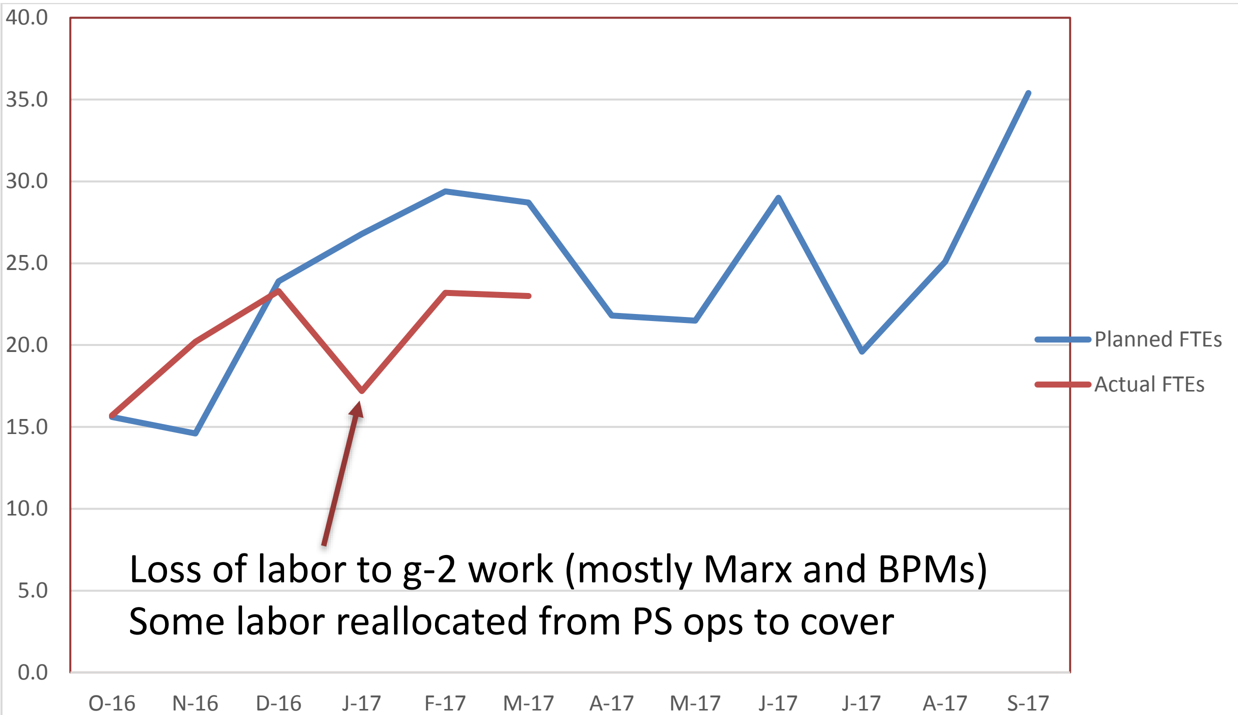
Complete.

WBS 1.2.7 Solid State Upgrade

The task is done.

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

The FY17 first quarter and most of the second quarter operated with the laboratory under a continuing resolution. However, we 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 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. This modulator test went well and we are proceeding with the remaining modulators. However, as seen in the graph below, labor was removed from PIP to assist with g-2. The loss of labor has slowed the modulator work and at this point it looks like the task will be extended one year.



Graph 1 PIP Labor for First Two Quarters

We have had no significant changes to the FY17 PIP budget. 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.

FY17 PIP OBL BUDGET K$ **	OBL BUDGET	YTD OBL	RIP	BUDGET BAL
M&S	3,343.9	1,415.0	107.1	1,928.9
Labor	5,850.2	2,662.4		3,187.8
FY17 Sums	9,194.1	4,077.4	107.1	5,116.7