To:

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Subject: Proton Improvement Plan

Project Quarterly Summary FY16 Q3

Report #15 July 1st, 2016

Project Milestones

Project Milestones

There were two Linac milestones this quarter. They were all Level 3. The *Linac Notch Beam Shaping, Diag., Dump ready for installation* was not delivered due to difficulties with the equipment in the lab setup. However, at the end of the quarter, the group was getting ready to install the equipment at the injector area for a fully beam notch demonstration before the planned lab shutdown began, in August 1st. The second milestone, *CPS System Tested & Qualified,* was also not met. In this case, the delayed was largely due to a resources available and unforeseen delays on some components which were shipped off-site for manufacturing. The Booster had one level two milestone scheduled to be completed. The replacement Booster cavity design scheduled for June has been delayed a year to allow laboratory management and PIP management to align plans for Booster and PIP II/PIP III. Cavities will be a critical part of future operations and understanding their planned operations needs to be completed before design/build stages. Recent reviews have approved PIP plans but agreed that a cautionary approach is best.

Table 1 PIP milestones

L	WBS	Description	Baseline	Fcst Fin
3	1.02.01.02.03.16	Finish program of gutting & assembling Bias Supply enclosures	4/15/15	11/11/16
4	1.01.01.01.02.01	Final Cost Estimate for Linac Gallery Civil Construction	4/21/15	4/21/16
3	1.01.02.03.04.14	Linac Notch FSLA Operational on Bench - ready to install	4/23/15	9/28/15
3	1.02.03.01.05.02	Booster BPM Production Procure/Assembly Complete	5/15/15	3/1/17
3	1.02.01.11.05	RF Station 20 Commissioned	7/6/15	10/6/15
4	1.01.02.03.06.33	Linac Notch Beam Shaping, Diag., Dump ready for installation	9/21/15	7/05/16
3	1.02.01.02.03.16	Finish program of gutting & assembling within Bias supply enclosures	10/19/15	11/11/15
2	1.02.01.01.13	Anode Power Supply Operational	10/21/15	10/14/15
2	1.02.01.01.14	All Anode Supply Documentation Complete	10/21/15	1/21/16
3	1.02.01.02.04.12	Complete Bias Supply testing	10/26/15	11/18/15
2	1.02.01.02.05.12	Complete Bias Supply installation (upgrade ends)	11/2/15	11/25/15
2	1.02.01.05.03.20	Booster RF Cavity Refurbishment Complete	12/3/15	12/8/15
4	1.01.01.01.02.01.02	Completion of Final Acceptance Test (at CPI)	1/5/16	12/14/15
3	1.01.01.02.10.03.41	CPS System Tested & Qualified	1/26/16	7/29/16
2	1.02.01.09.02.02.09	PA Amp Testing Complete	5/13/16	9/16/16
2	1.02.01.07.02.04	Booster Cavity Initial Design Complete	6/2/16	9/2/17
2	1.02.01.11.09	RF stations 21 & 22 Commissioned	9/2/16	9/2/17

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

Work is progressing well on developing a prototype modulator capable of replacing the present tube based design.

For the entirety of the quarter, LRF1 ran on the 28 cell prototype Marx Modulator. During that time, there was a failure of the special cell caused by the configuration of the charging circuit. The cell was replaced and the problem rectified. The failed cell has since been repaired.

At the beginning of the quarter, the cells for the 54 cell prototype were mostly constructed, waiting on modifications to the gate drive card before the final assembly could be completed. The cell construction was completed, and all cells were subsequently tested. Most of the internally assembly of the Marx cabinet was done this quarter. The cell support structures, cells, bus work, fans, and air flow interlocks are all installed. The output filter is currently being worked on. The fibers from the controls rack to the cells were cut to length and terminated.

Testing of the charging supplies was completed early in the quarter, and they were installed in the CPS rack. The control cards for the charging supplies were fabricated and then tested, along with their crate. The charging supply cabinet had breakers installed and wired to each charging supply. The summing plate is still under construction.

The controls cabinet was wired internally and tested. It is complete aside from the FPGA card. The FPGA card was in the process of being redesigned from the 28 cell version at the beginning of the quarter, a task which took significant time. Once the redesign was complete, it was sent to drafting where it is still being worked on.

Cable tray was installed in the Marx test area between LRF5 and LRF7. The 480/208 VAC transformer for the 54 cell prototype was ordered and delivered. An adaptation for the 7835 sockets was designed to receive high voltage from the Marx instead of the old tube modulators. Parts were corona tested, and it

is undergoing low pressure testing currently. Power distribution options were considered for all stations, the likely solution will be to take power from the A3 power center.

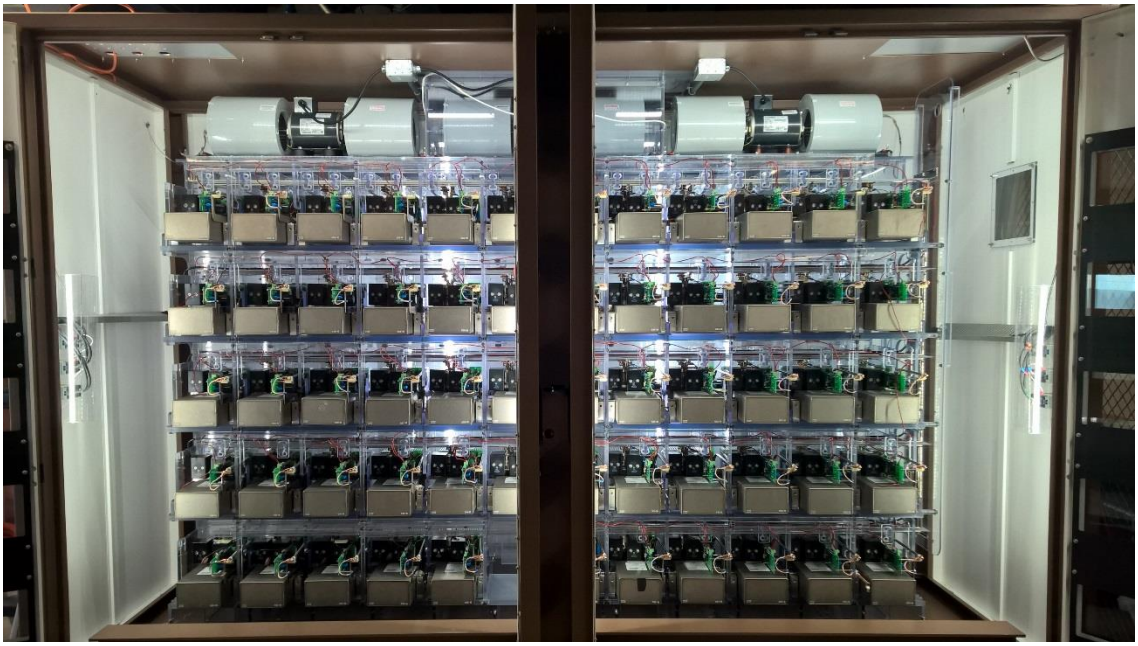

Figure 1: Linac Marx-Modulator : 54 cells prototype unit

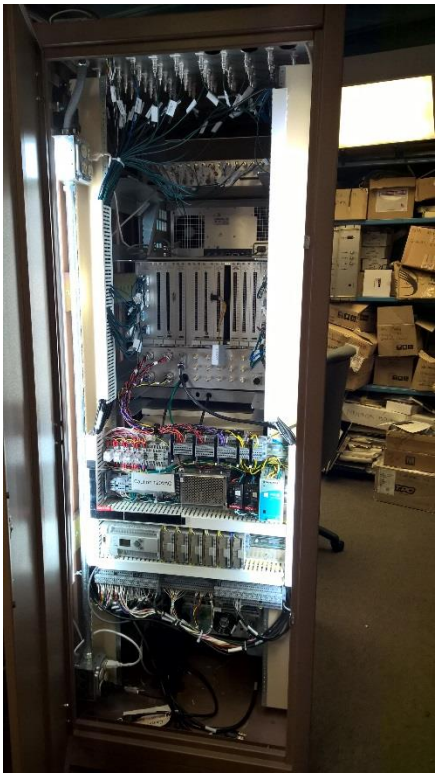

Figure 2: Linac Marx-Modulator Control Rack assembly (left-hand side) and cell testing (right-hand side)

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

Significant progress was made on a number of tasks during the third quarter. Probably the most significant was a breakthrough in resolving the instability in the output of the 2W fiber amplifier that had been plaguing us for some time. The instability is a nonlinear phenomenon known as Stimulated Brillion Scattering (SBS) which manifests itself in spikes in the reverse power which are sometimes reflected and re-amplified to yield big forward power pulses which cannot be tolerated. The power threshold at which it appears has a dependence on the seed laser spectral linewidth among other parameters which we had already optimized. By reverting back to the original seed source and started operating it at a colder temperature shifted the threshold at which it appears to a higher power, thus stabilized the SBS at the operational power. This dropped the spiked in the reverse power from the multiple volt range to just a few millivolts as shown in Figure 3.

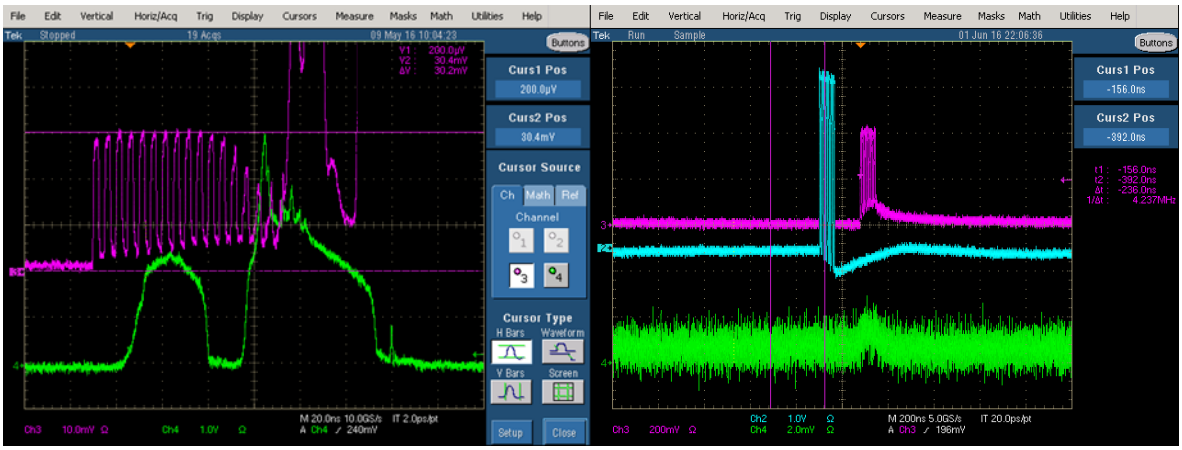

Figure 3: Scope trace of forward 200 MHz notch pulses (magenta) and reverse power (green). The plot on the left shows the impact of operating above the SBS threshold while the trace on the right shows the present level of SBS. The amplifier was operating at the same power level for both plots.

Team continued to work in the development of the LabView program which controls and monitors all devices associated with the Laser Notcher. Development of an on line program, interfaced to LabView to create notch pulse RF waveforms (and to pre-distort them if necessary) was achieved. Optimization

of laser instrumentation, laser steering algorithms, alignment techniques, the development of operational procedures, and safety procedures. During this quarter all fiber and solid state amplifiers were operated together at their nominal pump currents and performed an initial estimate of the pulse energy produced. The current pulse energy is estimated to be 30% of that the design. Based upon the demonstration experiment in January of 2015 where a pulse energy of 0.5 mJ produced about 70% neutralization. There are several areas for improvement and the design pulse energy of 2 mJ level is expected to be reached. Installation is planned for the first week in July.

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 with the delivery of the final documentation.

WBS 1.2.1.2 Bias Supply

This task is complete.

WBS 1.2.1.3 *Not Used*

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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

The nineteenth cavity tuner set was refurbished and put into operation during FY16Q1. This task is complete.

WBS 1.2.1.6 New Tuners

Previously, a high power test stand for ferrite cores showed that one of four different core sets (two different permeabilities from two vendors) was acceptable. The acceptable core samples have been implemented into a tuner and been certified. The tuner was installed on a re-furbished cavity; the cavity has been operation since FY14Q4. A purchase order for enough ferrite cores to build twenty tuners was placed. During FY15Q4, the vendor has delivered, and we have accepted, the balance of one set of ferrites. The vendor had encountered a problem making the second set of ferrites (low value of permeability). The vendor has corrected the problem; the balance of ferrites were delivered FY16Q2.

Fermilab Technical Division is using the ferrite cores with other sub-assemblies to build new tuners. The assembly group has gained experience building the new tuners. Now, assembly is about three weeks to complete a tuner. Eighteen tuners have been built and passed acceptance tests.

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 have been started using a wide bore cavity that will be reworked (WBS 1.2.1.10); 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

The cavity was put into operation in FY14Q4 and was operational during FY15Q1. There have been no problems with this reworked cavity. This task is considered 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.

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 are being 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 will be ready for testing early in FY16Q4. The 22nd cavity is undergoing testing/cooling measurements for the Replacement Cavity design simulation (WBS 1.2.1.7). When cavity 21 is undergoing acceptance testing, cavity 22 rework will begin.

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.

The remaining two RF stations will be completed in the 2016 summer shutdown. Civil work to retrofit a room for the RF stations electronics and power systems has begun. Some material for the installation has been ordered/purchased.

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 would be considered complete with the exception of some modified components are more activated than expected. Part of the upstream absorber mask was removed. By removal, of the activated mask, the area upstream of the absorber will hopefully not be susceptible to as much gamma ray shine from activated components. The part of the mask that remained, is further into the absorber shielding and hence workers in the area will have less exposure. During FY16, activation measurements of components of the absorber and the near the absorber will be done to see if the activation caused by the notch beam is contained within the absorber. Studies have been done and the upstream absorber will be removed while an extension to the absorber jaw will added during the 2016 shutdown.

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 in FY16 or 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 have been done and analysis is 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. The assembly, testing and installation of the needed electronics was completed during FY15Q2. Beam loss tests and measurements have continued. The analyses and write-up investigating beam loss as well as TLM responses was completed. The documentation has been sent to the Shielding Assessment Review Panel. The TLM and radiation shielding assessment need to be concluded before much more proton flux can be attempted.

Further measurements are being done to understand the radiation dose during nominal operations. Previous studies focused upon possible radiation dose from accident conditions.

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.

WBS 1.2.3.2 Dampers

Studies were conducted which showed that the damper board and code work and will perform the needed function. During FY15Q4, the final programming was done. The dampers were commissioned in FY16Q1 and are part of operations. This task is essentially complete with the exception of the final documentation.

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 aged components will be replaced as opportunities present themselves with downtime of the Booster. Previously purchased vacuum equipment awaits opportunities for installation. During the shutdown, some vacuum work was done. The last procurement was started at the end of FY15. The end of the PIP vacuum work will be done during the 2016 summer shutdown.

WBS 1.2.7 Solid State Upgrade

The task is done.

PIP Budget – Costs, Labor and Obligations Updates (FY16 Q1)

The FY16 third quarter started with the assumption that carryover and other funds removed from PIP after FY15 would not return. However, during this quarter we were provided guidance that PIP FY15 carry-over was allotted back for PIP use. PIP mangers had to change plans to the meet the updated funding guidance. Managers had to once again re-assess all remaining tasks in an effort to utilize the updated M&S number. A recent RLS developed to meet the lower funding guidance was thrown out and PIP management outlined a new outline RLS for PIP and the remaining FY16. A final PIP budget for FY16 and including out years has not yet been formally provided. Our plans for the remaining FY are based upon the numbers shown in the table below. PIP mangers have a concern that rapid changes in funding is difficult to adjust to since engineering and planning resources can't be adjusted quickly.

Table 1 PIP FY16 (through June) budget table

FY16 PIP OBL BUDGET K$ **	OBL BUDGET	YTD OBL	RIP	BUDGET BAL
M&S	3,978.8	1,314.3	1,016.8	1,647.7
Labor	6,142.5	4,237.9		1,904.6
FY15 Sums	10,121.3	5,552.2	1,016.8	3,552.3

Chart 1 and 2 below shows that labor has been consistent this past quarter except again for instrumentation – which was pulled off of PIP to resolve issues with the Recycler DCCT and other items. We had expected this to be remedied in the past two quarters but it has taken longer and now looks to be getting back on track in FY16 Q4! PIP's overall forecasted labor and has been in good agreement.

Chart 1 Labor: Forecasted vs Actual for FY16

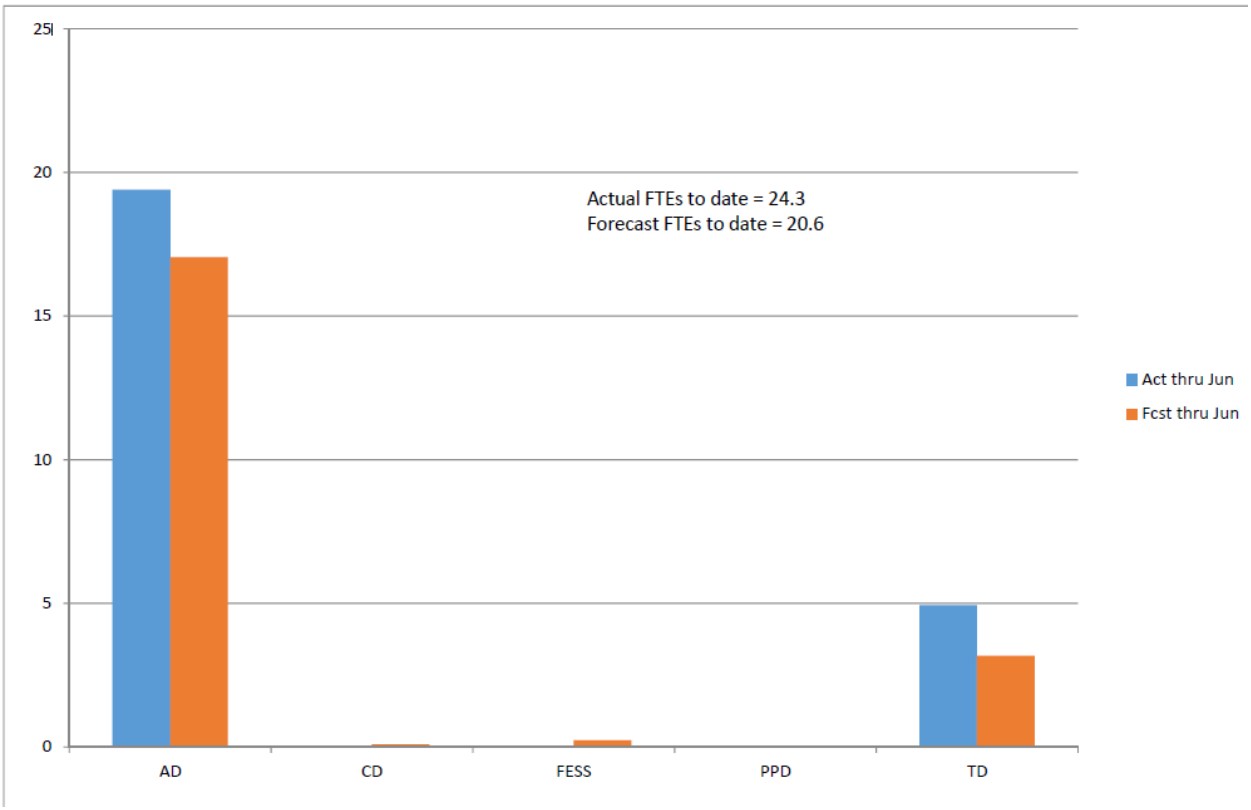

Chart 2 Labor trends – for FY14 to FYQ3 FY16