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FNAL - THE PROTON IMPROVEMENT PLAN (PIP)*

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Abstract

The Fermilab Proton Source has an upgrade plan called the Proton Improvement Plan (PIP) [1]. The PIP has several key objectives which were laid out by laboratory management in 2011. The plan should address the necessary hardware modifications for increased repetition rate to 15 Hz, capable of delivering 2.25E17 protons/hour while maintaining 2012 activation levels, ensuring viable operation of the proton source through 2025 with availability greater than 85%. Fermilab believes the PIP goals are necessary to ensure that the laboratory delivers on the commitment to the physics program. PIP is therefor considered an urgent and a high-priority activity. The PIP effort started in 2011 and official task management and funding schedule approval in 2012. Largely an accelerator effort, several other laboratory divisions are playing critical roles. The progress of PIP is going to be discussed in this paper.

OPERATIONS AND PIP

In operations for over 40 years, the Fermilab Proton Source (PS) is composed of three distinct areas. The Pre-Accelerator, which delivers 750 keV H^- beam, a 15 Hz Linac which delivers 400 MeV beam and the 15 Hz Booster synchrotron which delivers 8 GeV beam. During the past 40 years, the PS has had several significant modifications which were required to meet the laboratory program goals. The proton beam flux history from 1992 to present is shown in Figure 1. For about 30 years the flux requirement for the PS was minimal due to the downstream machine operations and HEP requests. However, with the start of the laboratory neutrino program in 2002 the demands on the PS drastically increased. Some significant past upgrades would include the increase in Linac energy from 200 MeV to 400 MeV (Three 201 MHz DTL tanks were replaced with 804 MHz SCL cavities), and the Proton Plan upgrades (included Booster ramped correctors, collimation system, new injection girder, removal of beam dump and related aperture restrictions). The upgrades were very successful, allowing the PS to reach record flux levels. A tenfold increase in flux was achieved allowing the PS to deliver on the laboratory's goals (the MicroBooNE and NuMI neutrino experiments were the two major beam users during the 2002 to 2012 period).

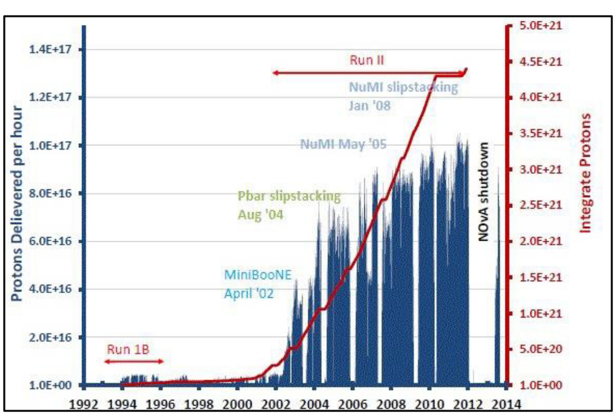

Figure 1: Booster flux history.

However, the laboratory/DOE HEP program is continuously expanded to the needs of the community and in 2010/2011 it became apparent that the PS work was not done. After a review of the Proton Source, the Proton Task Force Report [2] was released. This report laid out the tasks required to meet the laboratories updated HEP program plan. Figure 2 shows Fermilab's program plan and approved flux requests.

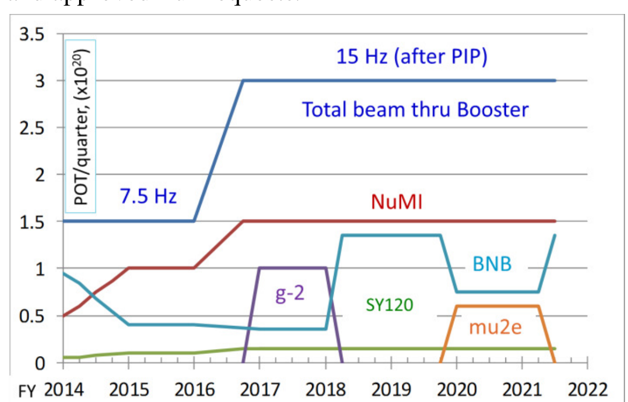

Figure 2: Fermilab's planned proton flux and user.

An outline of required tasks along with resources was then developed into the project like plan called Proton Improvement Plan in 2011 and documented in the PIP document. In FY12, PIP was officially begun with a schedule, management controls, charge code and management structure, and funding.

Reviews and discussions with laboratory and DOE management were used to develop a plan based upon the priorities and laboratory resources. PIP worked and reported off the initial plan till changes in funding profile required an update to the RLS in 2014. PIP, initially a five year plan has now been extended out to 7.5 years due funding constraints. Planning of PIP activities has and will continue to be impacted by changes to laboratory operations and planning.

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PIP TASKS

PIP has a work breakdown structure (WBS) that has three top level activities or categories; RFQ – Injector, Linac and Booster. Under the top level WBS categories, a level 3 and level 4 task function structure was made as similar as possible for the three groups. The Pre-Accelerator injector upgrade work, which was started before PIP, used a reduced task structure. Presently, there are 30 level 4 WBS tasks in PIP. Each level 4 task has multiple charge codes associated and mapped to the task structure. There are 138 charge codes of which 42 are active associated with the 30 PIP tasks. The tasks can be grouped into three function categories; 15 Hz beam cycle rate, beam flux and machine reliability. However, many of the tasks serve multiple functions.

Pre-Accelerator Injector

The replacement of Fermilab's Cockcrorft-Waltons was begun in 2009 and completed in 2012. The oldest accelerator at the laboratory and with an increase in failures the reliability had become a concern. A new line which used Radial Frequency Quadruple (RFQ) and based upon the Brookhaven Laboratory injector was chosen. Figure 3 shows the final design of the RFQ injector line. The work on the RFQ injector line was begun in 2009. Beam commissioning took approximately two weeks with minor adjustments continuing over the next several months. Issues with the RFQ extracted beam energy caused a three month delay in the installation. A correction to the RFQ extraction face plate corrected the energy error. The new injector line has performed extremely reliably with beam parameters matching the design goals. The final beam measurements and operational parameters were published in a Fermi Accelerator Beams document [3].

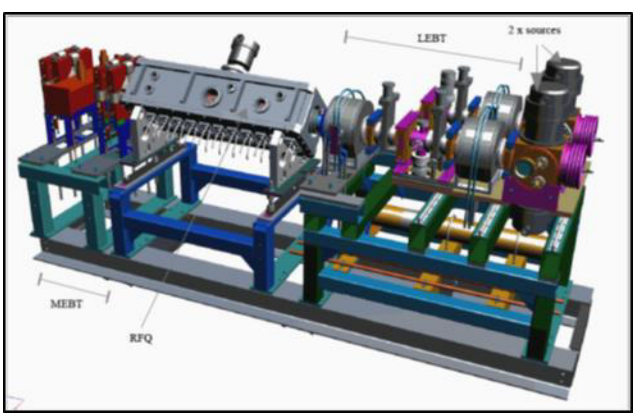

Figure 3: RFQ injector line.

Linac

There are 8 level 4 Linac tasks in the PIP. The list includes High Level RF, Linac modulator, 201 MHz Final Power Amplifier plan, simulations and studies, Linac notch creation (MEBT line), beam position monitor (BPM), power distribution and vacuum systems.

The High Level RF task is an effort to address the long term viability of the high power drive system of the 201 MHz DTL system. Options were investigated and a formal proposal was presented to laboratory management in 2013. A 200 MHz klystron is being considered if a long-term replacement is desired.

The Linac modulator task is to find a replacement of the present 40+ year old DTL system. Both Fermilab and SLAC have been involved with design and testing of hardware over the past two years. The SLAC design is based upon their ILC Marx modulator while Fermilab, also using insulated-gate bipolar transistor (IGBT) technology, is looking at a more Linac specific design. Both look promising and a decision point to build more will be done early in FY15.

The Linac simulations and studies task is the grouping of work related to Linac beam dynamics and operations. Most of the effort in this task has been dedicated to understanding and optimizing the Linac low energy. Beam studies and simulations will be used to optimize quadrupoles and dipole settings.

Linac notch creation has been an effort to design, test and install a laser notcher in MEBT just downstream of the RFQ. The notcher would create the Booster extraction notch at 750 keV therefore reducing Booster losses. The vacuum chamber with mirrors and laser port is scheduled to be installed during this summer shutdown (2014).

Linac BPM task was to replace the original analogue hardware frontends with modern digital VME boards. This task was successfully completed in 2013 and was the first of the Linac tasks to be finished.

Linac power distribution and vacuum systems are two separate tasks are related to identifying obsolete components/systems. These two areas were identified as a high concern due to recent failures. A complete replacement of Linac vacuum pumps and related hardware is well underway and is expected to be completed in 2015. The Linac power systems work is approximately half way with completion set for 2014.

Booster

There are 22 level 4 Booster tasks in the PIP. The list includes anode supplies, bias supply, cavity test stand, cavity and tuner refurbishment, new tuners, new cavities, cavity 1013 (20th cavity), simulations and studies, alignment and aperture, Booster notcher, cogging, collimation, radiation and shielding, beam position monitor (BPM), dampers, low-conductivity water systems (LCW), power distribution, vacuum systems, solid state amplifier, solid state driver, modulator, and solid state installation.

The PIP effort was developed over a short period of time however, several tasks had work that was ongoing or previously started but not completed for various reasons. The Booster solid state upgrade (and associated tasks) was one of those tasks. The Booster operates with 19 RF stations/cavities. One of the stations was converted over to a solid state drive system back in 2004 as a feasibility demonstration. Although not needed for running at low

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beam cycle repetition rates, PIP's 15 Hz beam operation required all RF stations be updated to solid state. The conversion of the remaining stations to solid state took 1.5 years and finished in 2013. The 15 Hz solid state upgrade had four level 4 tasks. This was a critical upgrade and keystone to Booster 15 Hz beam operations.

Another task started prior to PIP but bumped in priority by PIP was the Booster LCW upgrade. Required by the RF systems for 15 Hz operation, the work included an increase in the LCW flow rate and repair or replacement obsolete components. This task is 90% complete with the remaining work pending the 2014 summer shutdown.

Two Booster PIP tasks resolve long term reliability/viability issues. These are the vacuum system, and utility power systems tasks. Booster has been operating with original vacuum pumps and hardware and maintenance was becoming increasing difficult. The Booster power systems, which are mainly yard transformers, had experienced recent failures. Two of the Booster's four transformers have been replaced with the remaining two scheduled for the 2014 summer shutdown.

The Booster flux rate increase is impacted by many of the tasks but one critical to beam loss is the removal of three bunches required for clean extraction due to kicker rise time constraints. The PIP notcher task included the construction of a beam absorber, fast short kickers and pulsed power system. The absorber was completed first and commissioned in 2013. The pulsed power system has just recently finished final testing and is ready for operations. The short kicker's effort is to replace three 1-meter long kickers with six half-meter kickers. The first set of the short kickers have been tested and work has just begun on the build-up of the remaining kickers. The schedule for full replacement and testing is set for this summer. The fully commissioned system is expected to be completed by the fall of 2014.

The Booster PIP beam physics and aperture tasks are continuation of ongoing efforts in these areas. Inclusion of the work into PIP gave the work additional resources and is an important to the effort of understanding the issues and remedies to operate the Booster at twice the flux with no increase in residual tunnel activation. The aperture task has revolved around alignment of magnets and software to scan and analyse the apertures. A significant increase in aperture in two areas has resulted from the work. It is expected that the remaining magnet re-alignments will be finished in either the 2014 shutdown but may require the 2015 shutdown for completion. The beam physics task has to date focused on two areas of concern; beta beating and harmonic control. A large part of this task is software development. A means to excite the beam, accurately measure the response and then record and analyse the data quickly has and continues to require a significant amount of labor. The results have been very positive with tunes, chromaticity and coupling now controlled through the cycle. The Booster beam has recently obtained and is now operating at its highest throughput efficiency. More work is required to reach the hourly beam loss rates required by PIP and this task is expected to continue through to the end of the PIP effort.

Booster cavity refurbishment is another task that has an impact on all the PIP objectives. The Booster cavities due to age and design have a maximum repetition rate well below 15 Hz. The refurbishment task is to remove all the cavities from the tunnel, repair all found and known structural issues, and then test the cavity at 15 Hz for one week. The critical parts of this task is adding/repair cooling channels, repair of the cavities' 3 ferrite loaded tuners and repair of mechanical RF mating joints. The refurbishment task is labor intensive and after 2.5 years the task is just over half way complete. The task is expected to continue until the fall of 2015. After the completion of this task it is expected that the Booster beam cycle rate will gradually be increased to 15 Hz.

A final Booster PIP task is new cavities. This is an area of significant research and development. The task is divided into several areas with the first being the building and testing of a small number of new cavities. Testing and design is underway (see Figure 4 below) with the first new cavities planned for delivery in 2016. However, due to the complexity and significant amount of work, this task will continue for the next four years.

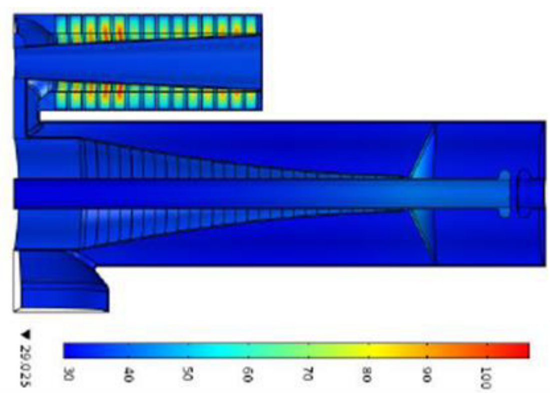

Figure 4: Thermal simulation of booster cavity.

CONCLUSION

Fermilab's PIP project is now well underway, having started in the fall of 2011. We presently anticipate being able to provide full-power 15 Hz beam (2.25 x 10^{17} p/hr.) to users in early 2016. Further enhancements will occur over the next few years to modernize key components of the facility to allow maintenance and maintain reliability. We further look forward to an upgrade of the Booster to accommodate 800 MeV injections from a new Linac - an effort termed PIP-II.

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