Proton Improvement Plan

PIP

Feb 4, 2014

William Pellico
Bob Zwaska
Outline

- This talk will focus on Proton Improvement Plan’s (PIP) recent work and management. Historical reference will be given to help give perspective of where we were and where we are going.
- Initialization
  - Why do we need PIP
  - Goals
- First two years
- Present Effort
- Plans
- Management and Controls
  - PIP structure
  - PIP controls
  - PIP planning
Proton Source Historic Proton Flux

- Run II
- NuMI slipstacking
- Jan '08
- NuMI-May '05
- Pbar slipstacking
- Aug '04
- MiniBooNE
- April '02
- NOvA shutdown
- Integrate Protons

Protons Delivered per hour

1.4E+17
1.2E+17
1.0E+17
8.0E+16
6.0E+16
4.0E+16
2.0E+16
1.0E+16
1.0E+00

Beam loss limits were set at levels with personnel safety (ALARA) first – flux output increases came with efficiency….
(from ~68% to over 90%)

A ten-fold increase in hourly rates, lower loses and higher uptime. The flux ramp-up for the intensity frontier took time, money and labor….

Almost 8 years of effort before the PS was able to exceed beam requests.
Adjusted to program planning

**Requested Proton Flux**

- **Main Injector**
- **Booster Neutrinos**
- **g-2**
- **mu2e**
- **Total**

**Protons/Hour**

- 2.50E+17
- 2.00E+17
- 1.50E+17
- 1.00E+17
- 5.00E+16
- 0.00E+00

**Timeline**

- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
- 2021

**Events**

- NOvA Shutdown
- 8 GeV ν
- 120 GeV ν
- LBNE
- g-2
- Mu2e

**William Pellico, Bob Zwaska, Feb 4, 2014**
S. Henderson (and DOE)

- If we make a commitment to the physics program, we must deliver on that commitment.
- Conversely, we should not make plans for the experimental program if they’re not supported by plans for delivering the beam.
- Failure to deliver on today’s programmatic commitments jeopardizes tomorrow’s plans.
- This planning process serves very important functions of 1) developing a path to achieve the program goals we have already signed up for, 2) providing a basis for realistic planning going forward.
- Therefore
  - I view the completion of the PIP, and our execution of it as an urgent, extremely high-priority activity.
  - I have made the completion of the PIP a priority for AD management.
  - I will commit to working at the Directorate level to funding a plan of reasonable scope.
**PIP – Original schedule**

An aggressive 5 year plan

31 initial level 4 projects

Lots of documentation, controls, meetings and presentations

**Work** –

Can be divided into 3 parts:

- Reliability/Viability
- Flux
- Cycle Repetition Rate

Lots has changed

Bob will give details ….
Effort to reduce high extractor spark rates:
• Improved materials (molybdenum inner anode cover plates, tungsten extractor cone tips, titanium outer anode cover plate)
• New magnets and Yoke
• Better understanding of Cs flow rates
  • Monitoring of source body and Cs tube temperatures

Operations:
• We have swapped sources 3 times
  • with practice could be <20min
• Adjusting tuning parameters

RFQ Injector Line (RIL)

First PIP task to be completed: FY12

In house expertise: Ion Sources, RFQs, novel chopping, LE beam dynamics & compact beam elements

Ongoing projects:
• Gas valve replacement
• 2 stage extraction
• DTI extractor pulsers
• Fiber optic links to HV rack
• Spectrometer looking at Cs to H ratio
• Cs handling (change boiler to accept Cs without ampule)
• Better heaters (right now the heaters are too interactive)
• Current regulated arc modulator
• Optical spectrometer installed for Cs monitoring in the plasma. Will be operational soon.

Future RIL Talk
### Flux
- Laser Notching
- Beam Physics
- Upgraded diagnostics/software
  - BPMs
  - Toroids

### Vulnerability
- Modulators, Driver Solid State RF source
- Burle 7835 tube system

### Utilities
- Vacuum (Roughing stations, pumps, valves…)
- LCW (pumps, plumbing)
- Power (transformers, MCC, breakers, distribution)
Laser Notching (After RFQ – 750 KeV)

Progressing in a Pre-Acc notching
- Working of timing electronics
- Vacuum chamber complete
- Final assembly – FY14 Q1

Upcoming talk D. Johnson

200 MHz pulses

450 kHz
Linac Beam Physics

Goals: To obtain accurate on line Linac model from RFQ injector to Booster injection (foils).

Generate beam envelope (Twiss-Parm) - emittance and efficiency
TRACEWIN, TOUTATIS, PARMILA, PARMTEQM and MAD

Optimize quad settings, loss reduction and ability to find new settings when a quad fails inside DTL tank.

PIP Linac Physics work has made big improvements and continues to add to previous efforts

Not done – accurate model still not completed
Linac optics is difficult – DTL Tank (especially 1) issues

The task seems nearly impossible (many issues): alignment of elements, lack of diagnostics, steering issues, quad strengths & tank modeling (inter-tank).
Envelopes along the Linac + transfer line

Work continues to try and match actual performance with design.

Transverse Optics (envelope)

Longitudinal Optics (envelope)
The new digital BPM system is commissioned:

- **ACNET and Java applications**
- **Hardware/Diagnostics software**

Provide average Position, Intensity, & Relative Phase over each beam pulse for every BPM

@15Hz

15 Crates – over 60 BPMs
Modulators – From tube based to solid state

The Linac DTL 7835 tube modulator is ~45 years old and is increasing difficult to maintain. Rebuild and replace (old or obsolete parts) was considered but a fully modern system was decided.

Designs being considered:
- In house IGBT (EE/PS dept)
- SLAC – Marx generator

Testing Underway - Future Talk

IGBT, Snubber, and Main Storage Capacitor

9-cell construction
Linac 200 MHz Power Systems
7835 triode

The high power RF 7835 tube is a Linac vulnerability with reliability issues. This has been a concern for many years for FNAL and other laboratories. After considering several options which looked at cost, labor, schedules and risk, a plan was developed and approved by laboratory management.

1. The buildup of a 4 year 7835 inventory
2. To design and build a new solid state modulator (keep 7835)
3. Replace tube systems in driver with Solid State when possible
4. Investigate 7835 replacement
   1. Investigate LANL option
   2. Investigate Klystron option
      1. Budget and plan for prototype with eventual system option
The purchase of a 200 MHz Klystron has just been completed. The device will arrive in FY15 and then tested. This will be the first of its kind and will need to be fully tested before proceeding.

Some key specs:
5 MW Single Beam Klystron
450µs pulse
~19 feet

(F. Garcia, A. Moretti led effort – scheduled talk)
Linac Utilities

The Linac power distribution system is under powered, has obsolete parts and is largely buried in the Linac lower gallery – new system will replace only part of present system.

Critical vacuum systems update such as the LE roughing stations – along with flanges and valves.

Substation Enclosure >18,000 lbs

Will be lowered through hatch (FY15?)

Linac Roof Hatch

Updated Roughing Pumps
Booster PIP

- 15 Hz operation
  - RF cavity refurbishment
  - Bias Supplies
  - Anode Supplies

Flux
- Beam Physics
  - Optics and Alignment
  - Cogging
- Notch System
- Collimation
- RF Harmonic
- Dampers
- Shielding

Reliability
- RF Solid State
- Low Level Upgrades
- RF Cavities and tuners
- Utilities (LCW, Power Systems, Vacuum)
- BPMs

Many tasks have multiple benefits - Reliability, Flux, 15Hz operation but also skills and accelerator technology.
Booster PIP - Refurbishment of 40 year old cavities (facelift)

Weeks

- Cool-down
- Cavity Removal
- Rebuild - Cones & Tuners
- Remove Tuners
- Rebuild - Cones & Tuners
- Rebuild Stems/Flanges
- Re-Assemble
- Testing
- Re-Assemble
- Testing

Cavity Removal - Stripping

Tuners Rebuild

Rebuild and Test
Fun Facts

You need all cavities in tunnel to be refurbished before higher rate operations.

After refurbishment is completed – higher flux will require time.

After refurbishment is completed – the cavities will still be OLD.

There is likely to be failures as cavities are run harder.

Talk at later date by Matt Slabaugh and John Reid.
Presently we are at a 9-10 week per cavity rate:
The refurbishment rate has been consistent with allotted labor.
Anode Supplies and Bias Supplies (15 Hz operation)

- Modern Anode
- Transformer Heat Sinks
- Refurbishment

Design is nearly complete. Install this summer both anode supplies: (EE / RF Dept.)

- Power Distribution
- LCW
- Solid State Drive System

East gallery complete. West gallery supplies work underway but slow – will be finished FY15.
Beam Physics – Aperture, Tunes, Beta Beating, Coupling, Chromaticity and Orbit Control

- Improve acceptance with goal of reducing beam loss
- Two magnets were realigned prior to 2012 shutdown as a bench test to verify procedure

Orbit response

Tune Control Through Cycle

Better tune control at high energy

William Pellico, Bob Zwaska, Feb 4, 2014
LOCO corrections — making progress on Booster Beta corrections

At injection

Beta x comparison at 3.098301 ms

Beta y comparison at 3.098301 ms

At extraction

Beta x comparison at 27.871090 ms

Beta y comparison at 27.871090 ms

H - Beta

Y - Beta
The new absorber system is working well. Building of new PS and short kickers underway.

The above plot shows current notch simulation. Shorter kickers will have faster rise times, cleaner notch and reduced kick on circulating beam. Testing complete of 4 short kickers – 2 more later.

Booster Short Kickers – drop in replacements

1.1 Meter

William Pellico, Bob Zwaska, Feb 4, 2014
The two plots show the difference between two rad surveys after running similar flux for a week. The new system has greatly reduced residual activation in several areas of Booster. The new absorber system directs the beam to an absorber – old system was not designed for high flux and the kicked beam ‘notch’ into collimators was uncontrolled.
Specifications for Design of New Accelerating Cavities for the Fermilab Booster underway with testing of current cavities to confirm modeling.

- Harmonic cavity work is underway to help with beam capture, transition and possibly extraction.
  - Based upon work at TRIUMF and LANL
  - Simulations look promising
  - University interest – Illinois Institute of Technology

55 KV, 15Hz

Magnetic loss density (100 kV)
PIP – Booster Solid State Upgrade Completed

With the completion of the SS upgrade, the Booster RF power system can now cycle at 15 Hz. Other expected benefits include higher uptime, lower exposure, ability to do beam loading compensation and lower operating cost by ~1M/year

Started in 2004 (1 cavity only) completed only after PIP initiated
Booster Utilities

Replacing Original Equipment

Vacuum:
Turbos, Roughing Stations, Ion pumps and Valves

LCW: Valves, New plumbing, Pumps, Hoses, Bypasses in galleries and general repairs

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<th>Account</th>
<th>M&amp;S k$</th>
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<tr>
<td>2103.02.05.03.AD AD-Booster PIP Vacuum Systems Replacement</td>
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<td>2103.02.05.01.AD AD-Booster PIP Transformer Acquisitions</td>
<td>$62</td>
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2 Utility Substations (1000kva) Breakers & MCC

Accessible Filtering

Isolation Valve

New LCW Return System
A Booster shielding assessment is underway:
Several rounds of scans have been performed
First round of analysis completed
Preparing for another set of measurements – based upon earlier results

Need to finish by FY15

Assessment Beam Parameters
Shielding Requirements
Longitudinal Shielding Summary
Transverse Shielding Summary
Labyrinths and Penetrations
Air Activation
Ground Water and Surface Water
Soil Activation
Muons
Residual Dose Rates
Active Shielding Controls
What is a project?

- **Angst** of what *is*, and what *is not* a “project”
  - Jargon of “project-lite”
- **DOE O 413.3b** applies to only a very narrow subset of projects
  - Large “acquisition of capital assets”, or construction projects
- In general (outside of DOE-world), projects are efforts with a temporary existence and specific goals
  - **PIP is a project!** (by any conventional definition)
- So, how does PIP fit into our understanding of projects from DOE?
  - PIP is supported by operations and applies to existing machines
  - Previously, this may have been termed a campaign or program
- Regardless of the above, **PIP must implement a project management methodology to be successful, though not specifically covered by 413.3b**
- This will be an interesting (subjectively) study of how to manage a major project outside 413.3b
Managing PIP

- Developed useful processes that are familiar, though different than 413.3b
  - PIP Project Management Plan
    - c.f. Project Execution/Implementation Plans
  - PIP Design Handbook
    - c.f. CDR / TDR
  - Cost/Schedule
    - Bottoms-up RLS
  - Reporting
    - Regular reports
    - PMGs
- Had input from lab management, DOE, project
## PIP Development Timetable

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<tr>
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<th>Event</th>
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<td>August 2010</td>
<td>Task Force Report</td>
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<tr>
<td>December 2010</td>
<td>Proton Source Workshop</td>
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<tr>
<td>February 2011</td>
<td>Proton Source Improvement Plan Proposal</td>
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<tr>
<td>August 2011</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Proton Improvement Plan Manager Meeting</td>
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<tr>
<td>October 2011</td>
<td>Proton Improvement Plan FY12 M&amp;S Uploaded</td>
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<tr>
<td>January 2012</td>
<td>Proton Improvement Plan Design Handbook</td>
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<td>Proton Improvement Plan Management Plan</td>
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<td>Proton Improvement Plan RLS Baselined</td>
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<tr>
<td>June 2012</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Proton Improvement Plan Quarterly Report</td>
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<tr>
<td>August 2012</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Proton Improvement Plan PMG</td>
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Proton Source Task Force Report

Fermi National Accelerator Laboratory

August 17, 2010

- Analyzed risks within the proton source
  - Experts considered every system for reliability and maintainability through 2025
  - Identified many vulnerabilities, assessed risk and costs of upgrades
- 15 Hz pulse items were identified at this point, but the issues of increased flux were specifically not addressed
  - Future users were still not so clear, nor how to pay for upgrades
Proton Source Workshop, Dec 2010

- Discuss reliability, longevity, 15 Hz, and flux for two days
  - 50 participants
  - 25 presentations

- Combined with the task force report to produce the *Proton Source Improvement Plan*
  - Initial selection of scope for what would become PIP

- PIP would eventually start that next fall (FY2012)
  - Worked out how to manage the project
  - Scope was refined, particularly for consideration of flux
PIP Project Management Plan

- Derived from implementation and execution plans
- Spells out the basic practices for the project
- Still run the project off of this document
PIP Design Handbook

- Similar to CDR or TDR
  - Has a description of scope for every item in the project and some estimates of cost and schedule
• 31 Subprojects
• 8 complete as of today
Within the Larger Organization

Director
N. Lockyer
Associate Director for Accelerators
S. Henderson

Accelerator Division
S. Nagaitsev, Head

Proton Improvement Plan
Project Manager
B. Pellico
Deputy Project Manager
B. Zwaska

Legend
- Reporting
- Resources
- Advisory

Stakeholder Experiments

External Collaborators

Legend
- Reporting
- Resources
- Advisory

Acclerator Physics Center
Computing Sector
Particle Physics Division
Technical Division

PIP Management Board

WBS 1.1
Linac
F. G. Garcia

WBS 1.2
Booster
K. Gollwitzer

WBS 1.3
RFQ Injector
C. Y. Tan
Project Management Board

- Stays in constant communication over all aspects of the process
  - Technical – financial – managerial
- Composed of project “office” & L2s
  - Pellico, Zwaska, Domann, Lebedev, Garcia, Gollwitzer
    - All part-time
    - Team approach allows us to stand in for each other
  - Previously also: Tan, Evans-Peoples, Convery (Webber)
- Small, consistent group eases flow of information
Communications

- Email lists
  - PIP: proton_improvement_plan@fnal.gov
    - Open list to anyone interested
  - PMB: pip_management_board@fnal.gov

- Regular Meetings
  - PMB meets every week “briefly”
  - General project/technical ~ biweekly
  - Specific technical ~ biweekly
  - AD management biweekly
  - Financial monthly
  - Lab PMG quarterly

- Elog
- Quarterly report submitted to lab management & DOE
Welcome to Proton Improvement Plan Web Page

Objectives

Develop a plan to increase Proton Source throughout while maintain good availability and acceptable residual activation. The plan must address hardware modifications to increase repetition rate and improve beam loss while ensuring viable operation of the proton source through 2025. [S. Henderson, Dec 2010]

Goal:

PIP should enable Linac/Booster to deliver:
- Deliver 1.80E17 protons per hour (12 Hz) by May 1, 2013
- Deliver 2.25E17 protons per hour (15 Hz) by January 1, 2016
while maintaining Linac/Booster availability > 95%
and residual activation at acceptable levels
and ensuring a useful operation life of the proton source through 2025. [S. Henderson, Dec 2010]

http://www-ad.fnal.gov/proton/PIP/PIP_index.html
Project Schedule - RLS

- We currently have 31 subprojects being managed
  - Most tasks have multiple charge codes
  - Every task was reviewed, baselined, fully burdened and entered into the PIP RLS
- Tasks were categorized then inputted into the RLS
  - Present RLS has 2020 lines
- M&S
- Labor (by name, if possible)
- Milestones
- Constraints (engineering, external, funding)
- Progress is reported monthly by individual tasks
RLS – Status Reporting

- Reporting period of 1 month
- Balance between keeping up-to-date and overworking the system
RLS – Tracking Progress

- **Budget Reports**
  - Issued on a monthly basis from AD Headquarters
  - Used to load M&S and SWF actuals into RLS
  - Each month actual and status values are computed and compared to the schedule (EVMS quantities)

- **Effort Reports**
  - Issued on a weekly basis from AD Headquarters
  - Compare labor effort to plan and verify SWF charges (people reporting appropriately)
  - Determine FTE % to compare to labor allocations
    - Useful in discussions with departments and divisions about labor
    - Getting labor matrixed in to the project is often complicated and/or difficult

- All reported at a monthly project-wide meeting
Example

PIP Labor usage in FY2013

Actual FTEs to date = 19.5
Forecast FTEs to date = 21.3
Budgeting

- A great difficulty for PIP has been how to account for budget and how the funding profile is managed
- Budget methodology:
  - PIP (with lab & DOE guidance) was initially budgeted with direct M&S and FTE counts
    - Note: division budgets are in direct dollars
  - Next iteration was with burdened M&S and FTE counts
  - Finally, we settled on a TPC-like number of burdened M&S and SWF
- Funding profile further complicated
  - Translation between budget types was not obvious
  - Profile changes several times a year
    - We have to adjust schedule continuously
  - What was initially a 5-yr project now appears to be 7 or 8
- Financial support provided through the AD division office
  - Meet on a regular basis and take part in all divisional and lab-wide budgeting exercises
  - Budget authority list established for different level managers
Reviews

- Various scales of technical reviews applied to efforts
  - Major items get specific reviews with external panels
    - For example: RFQ, L13 Absorber, klystron, cavities, …
  - Numerous internal reviews of subprojects
    - At specific or project-wide meetings
  - Individual items are subject to engineering reviews, usually within their departments

- Schedule and budget reviews held periodically within the project, usually by the PMB
  - RLS was recently completely updated – review is pending
Collaboration

- Technical coordination with other labs:
  - BNL on RFQ Injector
  - LANL on 200 MHZ power amplifiers
  - SLAC on klystrons and modulators
  - ANL on several items

- Ideally, would collaborate with interested institutions from experiments
  - Distributed a list with ~40 topics for collaboration to all relevant experiments

- Effort nature: Scientific, Technical, or Machining
  - Some initial interest expressed
  - A few pieces built at Virginia Tech

- Now hampered by DOE “loan” rules
  - Few more collaboration items on the table, but has not really developed without a model/system for involvement
Conclusion

• PIP has been proceeding since it’s startup in FY12
  • Project structure built to suit
  • Issues with funding have required flexibility and delays in the final PIP completion date
• Several technical achievements already complete in the project
  • RFQ, Solid-State, Notch Absorber, Utilities
• Laboratory prioritization will continue to be the determining factor in what PIP does and completion dates
  • New Cavities
  • Klystrons
  • Linac Modulators
# Upcoming PIP talks

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<th>Title</th>
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<td>CY Tan, Fermilab</td>
<td>TBA</td>
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<tr>
<td>03/04/2014</td>
<td>Matt Slabaugh &amp; John Reid Fermilab</td>
<td>TBA</td>
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<tr>
<td>02/18/2014</td>
<td>Trevor Butler &amp; Fernanda G. Garcia Fermilab</td>
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<td>** LOCATION: Curia II **</td>
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<tr>
<td>02/11/2014</td>
<td>Dave Johnson, Fermilab</td>
<td>Linac Laser Notcher Project in the Proton Improvement Plan</td>
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<tr>
<td>02/06/2014</td>
<td>Dan Bollinger, Fermilab</td>
<td>35 Years of H+ Ions at Fermilab 03/25/2014</td>
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<tr>
<td>** DATE: Thursday **</td>
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<tr>
<td>** LOCATION: Curia II **</td>
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Xtra Slides
- Increased arc current to ~20A
- Onset of sparking caused by gas pressure
- Able to recover
- Source B running well for 40 days with very little sparking < 2 sparks a day.
- Higher arc current, cathode and body temps
- Lower gas pressure
- Operations since last May
- Shows that we have used both sources
- Lots of extractor sparking initially

Note: HRM resets represent extractor sparks

Yellow = Source B
Green = Source A

Beam currents

Increased arc current to ~20A

Onset of sparking caused by gas pressure
Able to recover
Linac efficiency is higher with new source but we are/will be running at lower currents (RFQ design)