PIP-II R&D Plan

8 June 2015

This document presents the research and development plan for the Proton Improvement Plan-II. Included are the scope of work, deliverables, and organization plan.

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Introduction:

This document describes the research and development plan Proton Improvement Plan-II (PIP-II). Included are the scope of work, deliverables, schedule, , and organization plan. The goal of this plan is to be prepared for a construction start of PIP-II and associated improvements to the other machines in the 1st quarter of FY2019.

PIP-II encompasses a number of improvements and additions to the Fermilab accelerator complex with a goal of providing proton beam power capability of at least 1 MW delivered to the neutrino production target at the initiation of LBNE (Long Baseline Neutrino Experiment) operations. This plan is responsive to the vision articulated in the 2013 Snowmass report[1], and the subsequently issued report from the Particle Physics Projects Prioritization Panel[2] (P5), which highlight the opportunity for the U.S. to host a world-leading long baseline neutrino research program that would anchor a broader program of intensity frontier research. The plan is structured to deliver in a cost effective manner more than 1 MW of beam power to LBNE. In addition, it creates a flexible platform for longer-term development of the Fermilab complex to multi-MW capabilities in support of a broader research program, as future resources become available. These elements are expected to form the basis of the Mission Need Statement required for CD-0, and represent the fundamental design criteria for PIP-II.

The starting points of this plan are the recently completed upgrades to the Recycler and Main Injector for the NOvA experiment, the Proton Improvement Plan[3] currently underway, and the PIP-II Reference Design Report[4].The Proton Improvement Plan (PIP) consolidates a set of improvements to the existing Linac, Booster, and Main Injector aimed at supporting 15 Hz beam operations. In combination, the NOvA upgrades and the PIP create a capability of delivering 700 kW from the Main Injector at 120 GeV.

Design Concept

A complete design concept that meets the design criteria has been developed and documented in the PIP-II Reference Design Report[4]. PIP-II comprises a new 800-MeV superconducting linac, injecting into the existing 8-GeV Booster, augmented by a set of improvements in the existing (Booster, Recycler, Main Injector) proton complex. Constructing the linac with continuous wave (CW) capable cavities and cryomodules offers a straightforward future upgrade path with

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[1] Planning for the Future of U.S. Particle Physics: Report from the 2013 Community Sumer Study, R. H. Bernstein et al (editors), http://www-public.slac.stanford.edu/snowmass2013/docs/preliminarypublic10-30/SnowmassSummary-10-30.pdf

[2] P5 Report, May 2014

[3] Proton Improvement Plan website, http://www-ad.fnal.gov/proton/PIP/PIP_index.html

[4] Proton Improvement Plan-II Reference Design Report, https://projectx-docdb.fnal.gov:440/cgi-bin/RetrieveFile?docid=1370&filename=PIP-II_RDR.pdf&version=2

minimal additional up-front costs. This approach maintains the full breadth of opportunities described in the RDR while meeting the design criteria described above. More specifically the PIP-II design concept includes:

- An 800 MeV superconducting linac (SCL), constructed of CW-capable accelerating structures and cryomodules, operating with a peak current of 2 mA and a beam duty factor of 1%;
- Beam transport from the end of the SCL to the new Booster injection point, and to a new 800 MeV dump;
- Upgrades to the Booster to accommodate 800 MeV injection, and acceleration of 6.4×10^{12} protons per pulse;
- Upgrades to the Recycler to accommodate slip-stacking of 7.7×10^{13} protons delivered over twelve Booster batches;
- Upgrades to the Main Injector to accommodate acceleration of 7.5×10^{13} protons per pulse to 120 GeV with a 1.2 second cycle time, and to 60 GeV with a 0.8 second cycle time.

The first two elements are covered in the PIP-II project, with Booster, Recycler, and Main Injector elements covered in operational programs. The necessary R&D for all five elements is described in this document. High-level performance goals for PIP-II are given in Table 1.

Table 1: PIP-II high level performance goals

Performance Parameter	**Requirement**	
Linac Beam Energy	800	MeV
Linac Beam Current	2	mA
Linac Beam Pulse Length	0.55	msec
Linac Pulse Repetition Rate	20	Hz
Linac Upgrade Potential	CW	
Booster Protons per Pulse	6.5×10^{12}	
Booster Pulse Repetition Rate	20	Hz
Booster Beam Power @ 8 GeV	120	kW
8 GeV Beam Power to LBNE	80-120*	kW
Beam Power to 8 GeV Program	80-40*	kW
Main Injector Protons per Pulse	7.6×10^{13}	
Main Injector Cycle Time @ 120 GeV	1.2	sec
Main Injector Cycle Time @ 60 GeV	0.8	sec
LBNE Beam Power @ 60 GeV	0.9	MW
LBNE Beam Power @ 120 GeV	1.2	MW
LBNE Upgrade Potential @ 60-120 GeV	>2	MW

*First number refers to Main Injector operations at 120 GeV; second number to 60 GeV. The PIP-II configuration is capable of maintaining 1.2 MW down to 80 GeV.

The linac energy is selected to support a 50% increase in Booster beam intensity, accompanied by a 30% reduction of the space-charge tune shift, as compared to current operations. The linac is constructed nearly entirely of components that are capable of operating in CW mode – the primary exception being the cryogenics system, which is aligned with the low duty factor requirements. The incremental cost in constructing the linac from CW-compatible components is minimal.

Upgrades to a number of systems in the Booster, Recycler, and Main Injector will be required to support the higher Booster injection energy and higher beam intensities. These include upgrades to the Booster injection system, the rf systems in all rings, and various feedback systems. The upgrade to the Booster injection system is the most significant of these.

PIP-II provides a variety of straightforward and cost effective upgrade paths.

Technical Requirements

The linac portion of PIP-II is shown schematically in Figure 1. The linac requires a significant number of radiofrequency accelerating cavities and cryomodules. Requirements are listed in Table 2. Development of accelerating modules meeting these requirements will be a significant undertaking during the PIP-II development phase.

Scope, Resources, & Schedule

The scope of work during the PIP-II development phase encompasses the R&D required to validate basic feasibility of the technical approach selected for the project.

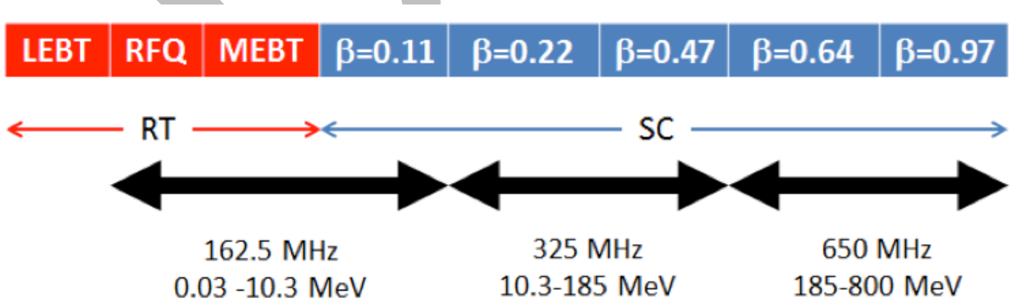

Figure 1: The SC Linac technology map. Items in red are at room temperature, items in blue are superconducting. β values represent the optimal values for each cavity type.

Table 2: PIP-II Cavity and Cryomodule Requirements.

Section	β_G	β_{Opt}	Freq (MHz)	Energy Range (MeV)	Cav/mag/CM	Type
RFQ			162.5	0.03-2.1		
HWR	0.094	0.112	162.5	2.1-10.3	8/8/1	Half-Wave Resonator
SSR1	0.186	0.222	325	10.3-35	16/8/ 2	Single Spoke Resonator
SSR2	0.398	0.475	325	35-185	35/21/7	Single Spoke Resonator
LB 650	0.631	0.647	650	185-500	33/11/11	5-cell elliptical
HB 650	0.947	0.971	650	500-800	24/4/4	5-cell elliptical

R&D Program/Risk Mitigation

The purpose of the R&D program is to mitigate technical risks, by validating the choices made in the PIP-II facility. The context of the R&D program is provided by the PIP-II Reference Design Report.

Technical risks refer to risks that could impair the ability to meet fundamental performance goals. The R&D program addresses these risks through initiatives in five primary areas:

- Development and integrated systems testing of PIP-II Front End components (PXIE);
- Development and demonstration of cost effective superconducting radio frequency acceleration systems at three different frequencies and with rf duty factors ranging from 10% to 100%;
- Development of a Booster injection system design capable of accepting extended beam pulses from the PIP-II linac;
- Development of systems designs capable of supporting a 50% increase in the proton beam intensity accelerated and extracted from the Booster/Recycler/Main Injector complex;
- Development of requisite capabilities at international partner institutions to successfully contribute to PIP-II construction.

These are augmented by continuing interaction with the development of the overall PIP-II facility design, supported by extensive computer modeling and simulations. The details are summarized below.

PXIE

The goal of the PXIE program is to validate critical technologies required to support the PIP-II concept. PXIE will provide a platform for demonstrating operations of PIP-II front end components at full design parameters. Specific goals of this integrated systems test are:

- Deliver 2 mA average current with bunch-by-bunch chopping of beam delivered from the RFQ.

- Demonstrate efficient acceleration with minimal emittance dilution through at least 15 MeV.

Low loss delivery of high intensity proton beams requires a linac front end capable of efficient acceleration of low-β beams with minimal halo formation. The utilization of superconducting accelerating structures in this regime presents significant technical challenges.

The scope of PXIE includes:

- A DC H- source delivering 5 mA at 30 keV
- A low energy beam transport (LEBT) with beam pre-chopping
- A CW RFQ operating at 162.5 MHz and delivering 5 mA at 2.1 MeV
- A medium energy beam transport (MEBT) with integrated wide band chopping system capable of generating arbitrary bunch patterns 162.5 MHz bunch patterns and disposing of up to 5 mA average beam current
- Low β superconducting cryomodules capable of accelerating 2 mA of beam to at least 15 MeV
- Associated beam diagnostics
- Beam dump capable of accommodating 2 mA at full beam energy for extended periods.
- Associated utilities and shielding

Figure 2 shows the PXIE layout, with associated energy breakpoints. A detailed technical description can be found in the PXIE Design Handbook [5]

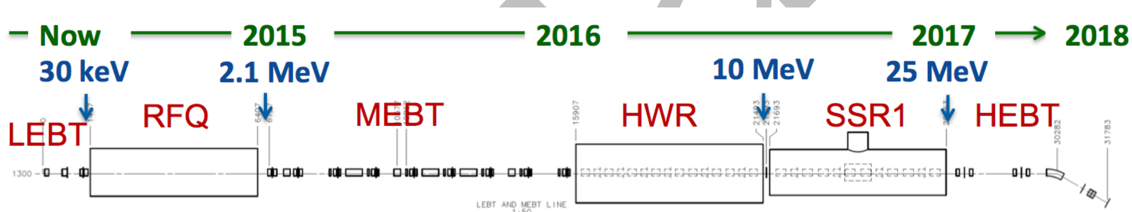

Figure 2: PXIE layout, including energy breakpoints and approximate schedule for operation.

The purpose of PXIE is to demonstrate that the technologies selected for the PIP-II front end can indeed meet the performance requirements established in the Reference Design, thereby mitigating the primary technical risk element associated with PIP-II. PXIE will utilize components constructed to PIP-II specifications wherever possible. The results will provide feedback into the PIP-II Front End design regarding the following specific technical concerns:

- LEBT pre-chopping
- Vacuum management in the LEBT/RFQ region,
- Validation of chopper performance
- MEBT chopper performance

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[5] PXIE Design Handbook, edited by S. Nagaitsev, https://projectx-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=1148

- Extinction level of removed bunches
- Survival and lifetime of MEBT beam absorber
- MEBT vacuum management
- Operation of HWR in proximity to 10 kW absorber
- Operation of SSR1 with pulsed beam
- Emittance preservation and beam halo formation through the front end

PXIE will be developed by U.S. and Indian institutions that are expected to participate in the proposed PIP-II construction. PXIE will thus provide an opportunity to develop the working relationships and management processes necessary for the construction phase. The PIP-II linac will use all PXIE components proven to satisfy PIP-II requirements.

Ion Source and LEBT

As of May 2015, the Ion Source and LEBT are installed and commissioned. Beam parameters have met the specifications.

RFQ

The RFQ is being built as a Fermilab – LBNL collaboration. Operating at 162.5 MHz, the RFQ accelerates beam from 30 keV to 2.1 MeV. Delivery to Fermilab is expected in July 2015, with commissioning to follow.

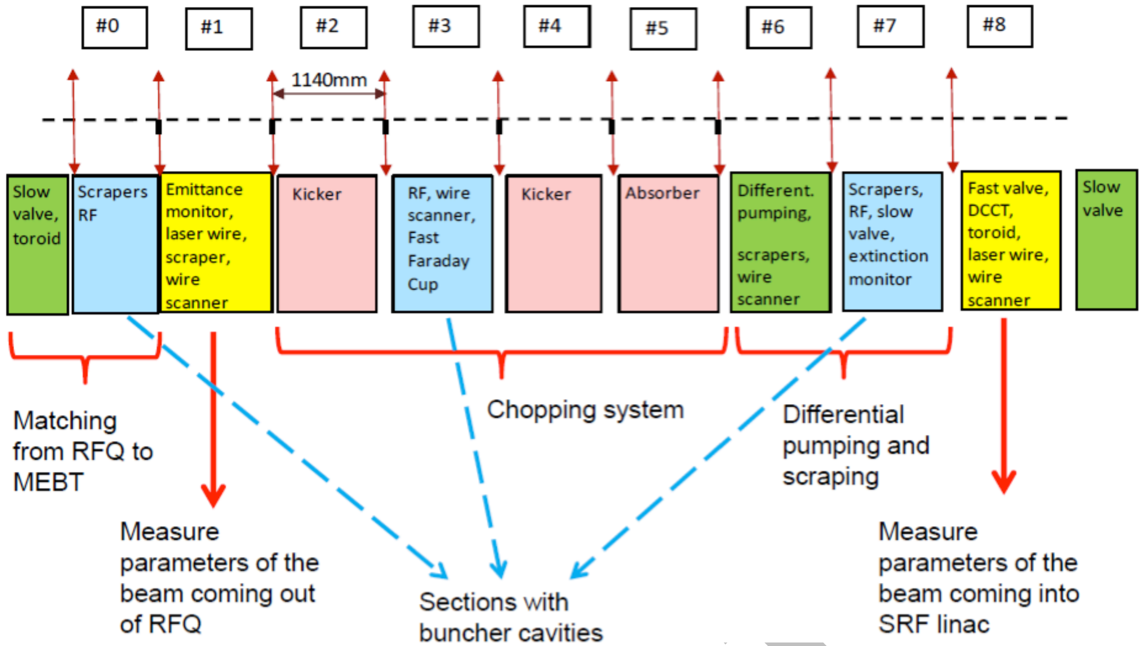
MEBT

The PXIE MEBT serves the following functions:

- Forms the bunch structure required Booster injection ;
- Matches optical functions between the RFQ and the SRF cavities;
- Includes tools to measure the properties of the beam coming out of the RFQ and transported to the SRF cavities;
- Plays a role in a machine protection system.

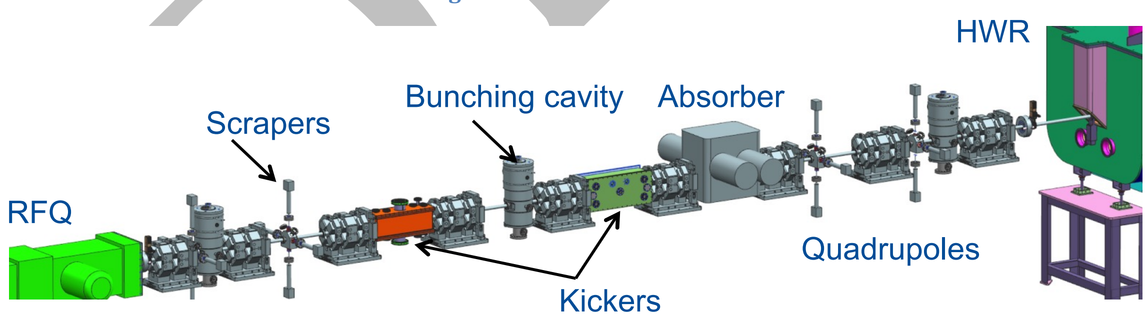
The MEBT has a periodic transverse focusing structure comprised of 9 drift sections (65 cm each) separated by quadrupole triplets (or doublets in the case of the first shorter section), as shown in Figure 3 and Figure 4. The overall length of the MEBT is about 10 m. To reduce the kick voltage, the MEBT chopper employs two kickers separated by 180 deg. in betatron phase. The RFQ frequency was chosen sufficiently low so as to reduce the kicker bandwidth to a manageable value (≤1 GHz). The MEBT beam absorber is being designed to absorb the beam power of 21 kW allowing operations with up to 10 mA beam current. The differential pumping section isolates the absorber and the cryomodules to reduce the gas load to the cold section. The vacuum at the HWR cryomodule entrance was specified to be at or below 10^{-9} Torr to prevent potential performance degradation of the SRF cavities because of high vacuum pressure.

Figure 3: MEBT Schematic showing 9 drift sections.



The MEBT will be installed in several stages. Stage 1, installed along with the RFQ during the fall of 2015, consists of 2 quadrupole doublets, 1 Buncher cavity, and diagnostics necessary to characterize the beam coming out of the RFQ. The second stage (Q3FY16) will add 4 quadrupole triplets, a 2nd buncher cavity, and the initial chopper kicker prototypes. The third stage (Q1FY17) will complete the MEBT with absorber, 3 quadrupole triplets, the 3rd buncher cavity, and the differential pumping section. MEBT magnets were designed as part of the India Institutes Fermilab Collaboration (IIFC), with fabrication at the Bhabha Atomic Research Center (BARC) in Mumbai.

Figure 4: MEBT 3D model

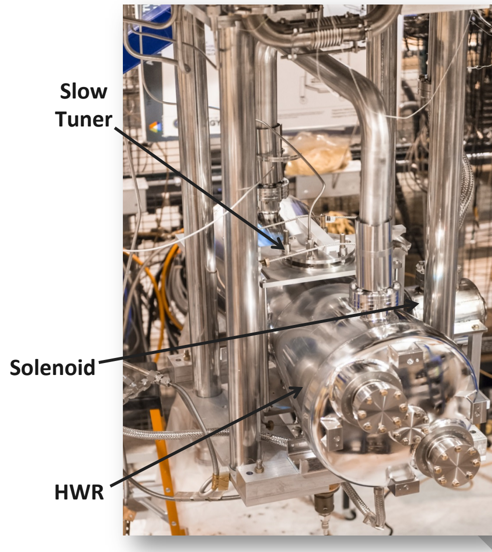


HWR

The half-wave resonator (HWR) cryomodule is designed and being fabricated at Argonne National Laboratory. The HWR CM is ~5.9 m long and accelerates the beam from 2.1 MeV to ~11 MeV. It has eight HW $\beta = 0.11$ cavities operating at 162.5 MHz and separated by 8 superconducting focusing solenoids. The nominal operational accelerating gradient was chosen to be 1.75 MV/cavity (at $\beta = 0.11$). The gradient is reduced at the first few cavities to avoid longitudinal beam overfocusing. Each solenoid accommodates a pair of transverse corrector coils and a BPM.

Figure 5 shows a HWR cavity, with associated solenoid and tuner, being prepared for testing at ANL.

Figure 5: HWR cavity test setup at ANL



All design work is complete, fabrication of the 7 production cavities and solenoids is in progress. Testing of all production cavities and solenoids will take place during FY16, with cryomodule assembly completion in FY17. We expect delivery and installation at Fermilab in Q4FY17.

SSR1

The single-spoke resonator (SSR1) cryomodule is being designed by Fermilab. It consists of eight 325-MHz single-spoke resonators (β = 0.22) and 4 focusing solenoids. Similar to the HWR CM, all solenoids will have corrector coils and BPMs. Its overall length (flange-to-flange) is about 5.3 m and it accelerates the beam from 11 to ~25 MeV. The operational accelerating gradient was chosen to be 2 MV/cavity. PXIE requires 1 SSR1 cryomodule, the PIP-II design has 2.

Cavity design is complete. 10 cavities have been fabricated at Fermilab and 2 cavities have been fabricated at Inter-University Accelerator Center (IUAC) in New Delhi. Cryomodule design is progressing, with fabrication and assembly scheduled for completion and installation in Q3FY17. A decision on which 8 of the 12 fabricated cavities will be installed in the first CM will be made in Q4FY16.

SRF

PIP-II is developing 5 different SRF cavity types and cryomodules at 3 different frequencies (half wave resonator @ 162.5 MHz, 2 single spoke resonators at 325 MHz, and 2 elliptical cavities at 650 MHz). R&D is being done in collaboration with Argonne National Lab (HWR) and within the IIFC (SSRs and 650 MHz ellipticals).

At the end of this R&D, PIP-II will have tested one each of 162.5, 325 and 650 MHz Cryomodule, first two with beam. PIP-II will have tested cavities of two other types (SSR2 and LB650) with RF Power and will have successfully demonstrated the technical capabilities of the collaborating Indian Institutions and industries. Indian Institutions will have successfully produced, tested and integrated major accelerator components and demonstrated readiness for the construction phase.

SSR2

The SSR2 cryomodule consists of 5 325 MHz single spoke resonators (β=0.47) and 3 focusing solenoids. All solenoids will have corrector coils and BPMs. There are 7 SSR2 cryomodules in PIP-II, accelerating beam from 35 MeV to 185 MeV. The average accelerating gradient is 4.3 MeV/cavity.

The IIFC, with BARC as the lead laboratory, is working on the design of Single Spoke Resonator 2 (SSR2) cavities. Two cavities will be built at BARC and processed and tested at Fermilab. These cavities are larger than SSR1, but the design of the Helium Vessel and Tuner could be adopted from SSR1 as well as manufacturing techniques. Design work is underway. Fully dressed cavities will be tested by Q1FY19.

LB650

The LB650 cryomodule consists of 3 650 MHz 5 cell elliptical cavities (β=0.64). Focusing elements are outside the cryomodule. There are 11 LB650 cryomodules in PIP-II, accelerating beam from 185 MeV to 500 MeV.

The IIFC, with contributions from Variable Energy Cyclotron Center (VECC) in Kolkata and Fermilab, is working on the design of a Low Beta 650 MHz Cavity (LB650). The design of the LB650 cavity end group, helium vessel and tuner will be similar to the HB650. Two cavities will be fabricated, processed, and tested in India, with contributions from VECC, IUAC, and Raja Ramana Center for Advanced Technology (RRCAT) in Indore. Fully dressed cavities will be tested to full gradient by Q1FY19.

HB650

The HB650 cryomodule consists of 6 650 MHz 5 cell elliptical cavities (β=0.97). Focusing elements are outside the cryomodule. There are 6 HB650 cryomodules in PIP-II, accelerating beam from 500 MeV to 800 MeV.

Fermilab has ordered eight cavities of an earlier version of HB650 cavity design. These cavities are at various stages of manufacturing, processing and testing. Fermilab has developed a new HB650 cavity design, which is designed to accelerate higher beam current, a requirement of the Indian accelerator program. This design is in final stages to ensure the operation of this cavity in both Pulsed and Continues Wave mode of SRF linac. IIFC is working on finalizing the cavity end group, helium vessel and tuner design. Cryomodule design will be complete in Q1FY17. 6 HB650 dressed cavities (3 fabricated at Fermilab, 3 fabricated at RRCAT) will be tested by Q1FY18. A fully assembled cryomodule will be ready for testing in Q4FY18.

HTS

A 650 MHz Cavity Horizontal Test Stand (HTS-2) is needed to High Power test the dressed HB650 and LB650 cavities. The IIFC is working to finalize the design of

HTS-2, which is based on experience gained by Fermilab in design, construction, integration and operation of a 1.3 GHz Cavity Horizontal Test Stand (HTS-1) at Fermilab. This test stand will also serve as a systems integration test for the 650 MHz low level RF, RF protection, 30 kW high power RF, instrumentation, cryogenics, and controls. Commissioning of HTS-2 will begin in Q1FY17, with first testing of dressed HB650 cavities in Q2FY17.

Booster

R&D in the Booster is currently focused on 4 areas: Injection, RF, 20 Hz operation, and Beam Quality. In the sections below we provide a short explanation of the area of R&D.

Injection

A new Booster injection area needs to be built to support the higher intensity, energy, and location for injection. We will install a new injection girder at the Long 11 straight section, which will include a stripping foil system, an absorber for H^-/H^0, and components for transverse painting (space charge mitigation). This R&D will cover investigations into gradient magnet and absorber design.

RF

The Proton Improvement Plan is developing a new cavity design that takes into account the PIP-II requirements. Fabrication will take place under the Proton Improvement Plan.

In the context of PIP-II, we will investigate several areas for the Booster RF system. The Recycler Requirements set the longitudinal emittance at extraction. Working backwards, we need to understand injection emittance and emittance evolution through the cycle. The current plan is for direct injection from the SCL into the Booster bucket. Longitudinal emittance preservation through transition is the key step in the evolution through the cycle. We are currently investigating three approaches: (1) RF focusing, (2) RF focus free via flattening of the RF amplitude, and (3) a γ_t jump system. The RF focus free method would require 2^{nd} or 3^{rd} harmonic cavities.

Beam Quality and Collimation

With the peak intensity going up by 50%, the pulse frequency going up by 33%, and the total power loss budget staying constant, beam quality and loss control are important elements. We intend to continue to investigate and understand the beam dynamics, looking at emittance control, loss control, and collimation. Included in this investigation is the question on the applicability of the existing collimation system for future operations.

20 Hz Operations

The Booster is a resonant synchrotron at 15 Hz. Changes to the capacitor bank are required to change the resonant frequency to 20 Hz. We anticipate building and testing a girder (gradient magnets, choke, capacitor bank, power supply) at 20 Hz. Pulsed power systems (kickers, septa, correctors) will also require some upgrades, we will document the necessary changes to run at 20 Hz. As the controls and timing system has been built around the 15 Hz clock, effort is required to understand what needs to be upgraded/modified, including the Time Line Generator, the TCLK system, the front ends, and data collection and sampling. Some will be specific to Booster operation, some will have more global impact.

Main Injector

R&D in the Main Injector is currently focused on 2 areas: RF power sources and Loss Control. In the sections below we provide a short justification as well as resources and schedule as they are currently understood.

RF Power Sources

Table 3 summarizes MI RF capabilities and requirements. While the existing RF system has enough voltage to match the required energy gain per turn, it does not have enough power to accelerate the required intensity. With the assumption that we will continue with the existing 20 cavities, we are investigating two possible solutions to increase the power.

Table 3: Required MI RF Capabilities

Performance Parameter	Present Capability	PIP-II Requirement	
Beam Intensity	$6.2\text{x}10^{13}$	$7.5\text{x}10^{13}$	
Harmonic Number	588	588	
Number of Filled Buckets	504	504	
RF Frequency Range	52.811-53.104	52.811-53.104	MHz
Acceleration Rate	240	240	GeV/s
Main Injector Cycle Length	1.2	1.2	S
# Accelerating Cavities	20	20	
Maximum Accelerating Voltage	235	235	kV/cavity
Total Available Accelerating Voltage	4.7	4.7	MV
Total Required Accelerating Voltage (V sin ϕ_s)	2.7	2.7	MV
Total Required Cavity Power	204	240	kVA/cavity
Robinson Stability Factor	4	4	

The plan is to operate the current RF cavities with two power tubes instead of one in a push pull configuration. A second option under consideration is running the RF cavities with a more powerful power tube. The first test is to modify the spare RF station to be able to run with 2 PAs. After this testing is complete, modifications to one of the operational MI RF stations in the tunnel will be made and tested during normal operations. A more powerful tube will be bought for testing as well.

Loss Control

We have determined by beam simulations that we will need a γ_t jump in order to avoid losses during transition crossing in MI. A preliminary design of the γ_t pulsed quadrupole design has been completed as part of the "Proton Driver Study II" (Fermilab-TM-2169). It is a first order jump system with a small dispersion increase with the following goals:

- $\Delta\gamma_T = \pm 1$ within 0.5 ms
- $d\gamma /dt = 4000$ 1/s

which correspond to a change that is 16x faster than the normal ramp. It requires 8 sets of quadrupole triplets and associated power supplies and Inconel beam pipe. We plan to finalize the quadrupole design and then build and test a prototype magnet.

With the increase in intensity, electron cloud driven instabilities are possible. Previous simulation studies have shown that keeping the secondary electron yield smaller than 1.4 will be sufficient for suppressing the electron cloud in both the MI and the Recycler. We are actively monitoring the SEY in the MI and have seen that beam scrubbing is effective in reducing the SEY, as seen in Figure 6. As we continue to raise intensities, we anticipate that the SEY will continue to drop. We do not anticipate any specific R&D measures at this time.

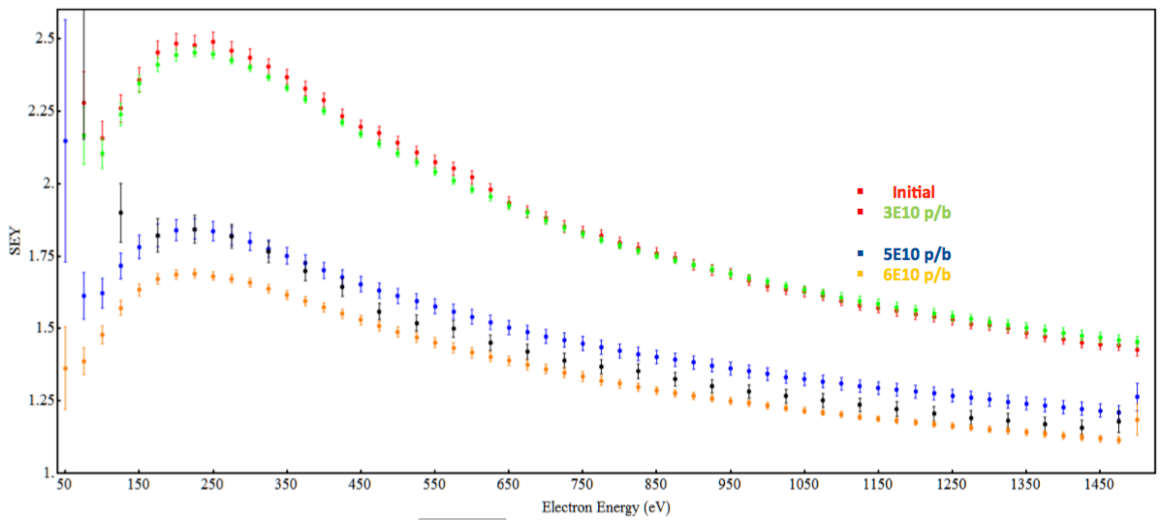


Figure 6: Initial measurements of SEY in the Main Injector as a function of Electron Energy and bunch intensities.

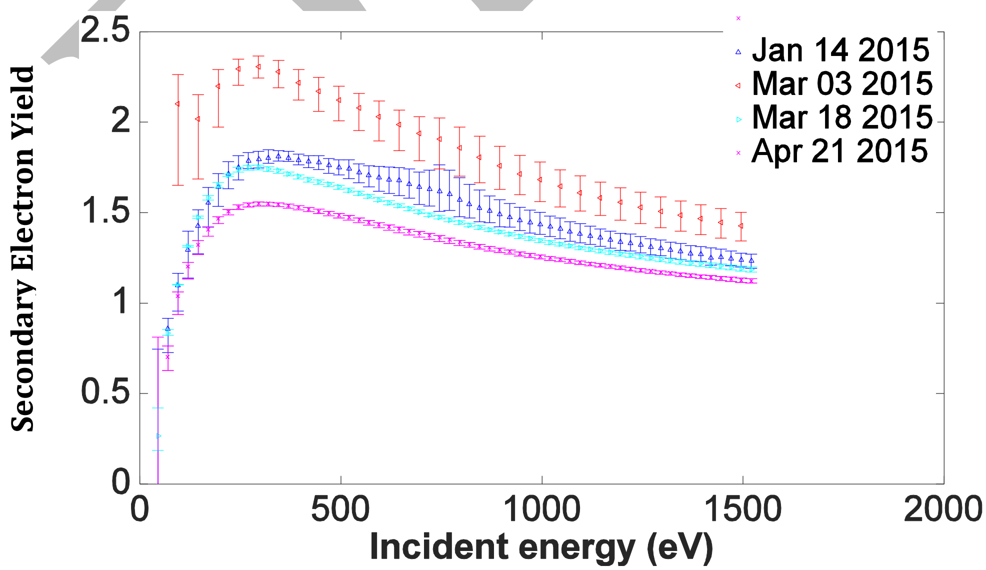


Figure 7: More recent measurements of SEY. Starting in February, the particles/bunch in the Main Injector increased by ~25%. Initially, the SEY went up with increased intensity but has now come down. We anticipate another 50% increase in intensity and then continued reduction in SEY.

Recycler

R&D in the Recycler is currently focused on 2 areas: RF cavity design and Loss Control. In the sections below we provide a short justification as well as resources and schedule as they are currently understood.

RF Cavity Design

The Recycler 53 MHz cavities used for slip stacking have a high power dissipation (90 KW, 60% DF) because of the low R/Q (13 Ohms). Running MI at energies as low as 60 GeV will require the slip stacking cavities to run CW which would not work with the current power dissipation and cooling. Operating slip stacking at 20 Hz instead of 15 Hz will also require higher RF voltage (140 KV instead of 80 KV). We will need a different cavity design with higher R/Q and active beam loading compensation. A prototype 53 MHz cavity, based on initial design work for a new MI 53 MHz cavity, will be built and tested.

Loss Control

With the higher intensities in the Recycler, we need to understand and control the space charge losses. In the Main Injector, the collimators intercept most of these losses. To better understand the Recycler performance with current intensities, realistic space charge simulations using SYNERGIA are under way. We anticipate that current operational requirements will lead to the design and installation of Recycler collimators in the next several years, with the future higher intensities also being considered in the design stage.

Deliverables

A complete set of deliverables for PIP-II R&D has been developed. A subset of the primary R&D deliverables is presented here. The primary R&D deliverables associated with the PXIE program are listed in Table 4. For the SRF program, deliverables are listed in Table 5. For the downstream machines, deliverables are listed in Table 6.

Table 4: PXIE Deliverables

Deliverables	Date
PXIE	
RFQ	Q4FY15
MEBT Dipoles and Quadrupoles	Q3FY16
HWR Cryomodule Delivery	Q3FY17
162.5 MHz LLRF and HLRF Distribution system	Q3FY17
HWR Integration and Commissioning	Q3FY17

Deliverables	Date
SSR1 Cryomodule Delivery	Q3FY17
325 MHz LLRF and HLRF Distribution system	Q3FY18
SSR1 Integration and Commissioning	Q3FY18

Table 5: SRF Deliverables

Deliverables	Date
SRF	
HTS-2 Cryostat Delivery	Q3FY16
HTS-2 Integration and Commissioning	Q1FY17
HB650 CryoModule Design	Q1FY17
Tested HB650 Dressed Cavity	Q2FY17
650 MHz LLRF and HLRF Distribution system	Q3FY18
HB650 Cryomodule Delivery	Q4FY18
HB650 Cryomodule Testing	Q1FY19
2 LB650 Dressed Cavity Testing	Q1FY19
2 SSR2 Dressed Cavity Testing	Q1FY19

Table 6: Downstream Machine R&D deliverables

Deliverables	Date
Booster	
20 Hz Girder Test Complete	Q4FY17
Qualification of Existing Collimation System Complete	Q4FY17
Initial Gradient Magnet / Absorber Design Complete	Q3FY18
Main Injector	
MI RF Station modified to operate with 2 PAs	Q4FY16
Higher power tube delivered	Q2FY17

Deliverables	Date
Prototype γ_t quad tested	Q4FY17
Recycler	
Prototype RF Cavity Design	Q2FY17
Prototype RF Cavity Fabricated	Q4FY18

Organization Plan

The R&D is being organized through the PIP-II Project Office, which is in the PIP-II Department of the Accelerator Division. The PXIE program is under the guidance of the Deputy Project Manager for Accelerator Integration, the SRF program under the guidance of the Deputy Project Manager for Construction Coordination. Both PXIE and SRF are supported through the BR code KA 22 03 02 for PIP-II. The Booster/MI/RR program is organized within the Accelerator Division, under the guidance of the Associate Head for Intensity Improvements and the PIP-II Department Head. Initial funding will be through the PIP-II Department in the Accelerator Division. Implementation funding is anticipated to come through Accelerator Improvement Projects.

The IIFC is led by the Fermilab Director, who has designated technical responsibility to the Chief Technology Officer and Deputy Project Manager for Construction Coordination. The laboratory, the DOE, and the Indian DAE have agreed on the responsibilities and deliverables of Fermilab and the India Institutes.