Department of Energy
Office of Science
Washington, DC 20585

JUL 31 2015

MEMORANDUM FOR: JAMES SIEGRIST
ASSOCIATE DIRECTOR
OF THE OFFICE OF SCIENCE
FOR HIGH ENERGY PHYSICS

FROM: STEPHEN W. MEADOR
DIRECTOR
OFFICE OF PROJECT ASSESSMENT

SUBJECT: Final Report on the DOE/SC Review of the PIP-II, June 2015

Attached for your consideration and use is the final report on the Department of Energy/Office of Science review of the Proton Improvement Plan (PIP-II). The PIP-II review was conducted on June 16-17, 2015, at the Fermi National Accelerator Laboratory in Batavia, Illinois.

If you have any questions or would like to discuss the report further, please contact me.

Attachment

cc:
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U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Project Assessment
Review Report on the

Proton Improvement Plan II (PIP-II)

at Fermi National Accelerator Laboratory

June 2015

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the Proton Improvement Plan II (PIP-II) was conducted on June 16-17, 2015 at the Fermi National Accelerator Laboratory (FNAL) in Batavia, Illinois. The review was conducted by the Office of Project Assessment (OPA) and chaired by Stephen W. Meador, Director of OPA at the request of James Siegrist, Associate Director of the Office of Science for High Energy Physics. The purpose of the review was to evaluate PIP-II's proposed cost range, and the readiness of FNAL to begin conceptual design.

The PIP-II scope consists of an upgrade to the FNAL proton accelerator complex to produce a proton beam of one megawatt or higher by the time of the first operation of the new Long-Baseline Neutrino Facility. By delivering the increased beam power, PIP-II will support long-term physics research goals for the U.S. neutrino program and will provide a platform for future studies. In addition to U.S. efforts, FNAL developed a proposal for PIP-II that includes international in-kind contributions.

The project presented a preliminary Total Project Cost (TPC) range of $465–695 million (with the point estimate at $382 million without contingency) and a Critical Decision (CD) 4, Approve Project Completion, date of September 2024.

The proposed project is well advanced, beyond what is required at this stage. Specifically, the proposed technical concept, including both new construction and modifications to existing infrastructure most likely will satisfy the Particle Physics Project Prioritization Panel (P5) recommendation. The presented cost range appears reasonable. For the most part, the scheduling strategy fits with other major projects at FNAL. Considering the stage of this proposed project, there is significant R&D that still needs to be performed in order to implement the proposed concept. Significant technical risks have been identified, but cost risks needs to be further evaluated. The laboratory identified resource needs to complete the R&D in a timely manner. Currently, the management team possesses the requisite expertise and experience and is appropriately organized and staffed to initiate PIP-II activities.

After the funding profile for the higher end TPC of $695 million was established, the Committee judged that the project is ready to proceed to CD-0, Approved Mission Need. After CD-0 is approved, and in preparation for CD-1, Approve Alternative Selection and Cost Range, PIP-II needs to:

- Develop a resource loaded schedule and update of project plans;
- Perform regular reviews on the status of the execution of the R&D plan; and
- Evaluate in more detail cost and schedule risks and the resulting cost and schedule estimates including realistic schedule contingency.

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1. INTRODUCTION

In 2014, the Particle Physics Project Prioritization Panel (P5) subpanel of the High Energy Physics Advisory Panel (HEPAP) called for Fermi National Accelerator Laboratory (FNAL) to establish a neutrino accelerator program that would extend its current leadership with the most powerful neutrino beam in the world. Since then, the world community has come together to form the Deep Underground Neutrino Experiment (DUNE), a collaboration that plans a 40 kiloton liquid argon detector deep underground at the Sanford Underground Research Facility (SURF), in South Dakota. The DUNE experiment will be supported in both Illinois and South Dakota by the Long Baseline Neutrino Facility (LBNF) project.

P5 also recognized the need to deliver higher power proton beams to the neutrino-generating target that serves the LBNF/DUNE program, calling for a capability of 1.2 MW on target at 120 GeV when DUNE comes on-line. This need for higher proton beam power will come at a time when many components of the existing accelerator complex that delivers beam to the Main Injector—especially the linac and the Booster—would be about 50 years old. Thus, the Proton Improvement Plan II (PIP-II) is proposed to meet two main goals: higher beam power and ensuring sustained high reliability operation.

The centerpiece of the PIP-II proposal is the design, construction, and commissioning of a new 800 MeV superconducting proton linac that would entirely replace the current 400 MeV normal-conducting linac, at a new location nearby the Booster. The higher-energy linac would enable delivery of more than 1 MW of beam power from the Main Injector over an energy range from 60 GeV to 120 GeV. This higher performance also requires a number of ancillary upgrades further down the injection chain, including: a new injection straight into the Booster; a higher Booster repetition rate of 20 Hz; radio frequency (RF) upgrades in Booster, Recycler, and Main Injector; and enhanced (or new) transition-crossing systems in the Booster and Main Injector. The location of the proposed PIP-II linac is adjacent to the Booster and the Wilson Hall high-rise (see Figure 1-1).

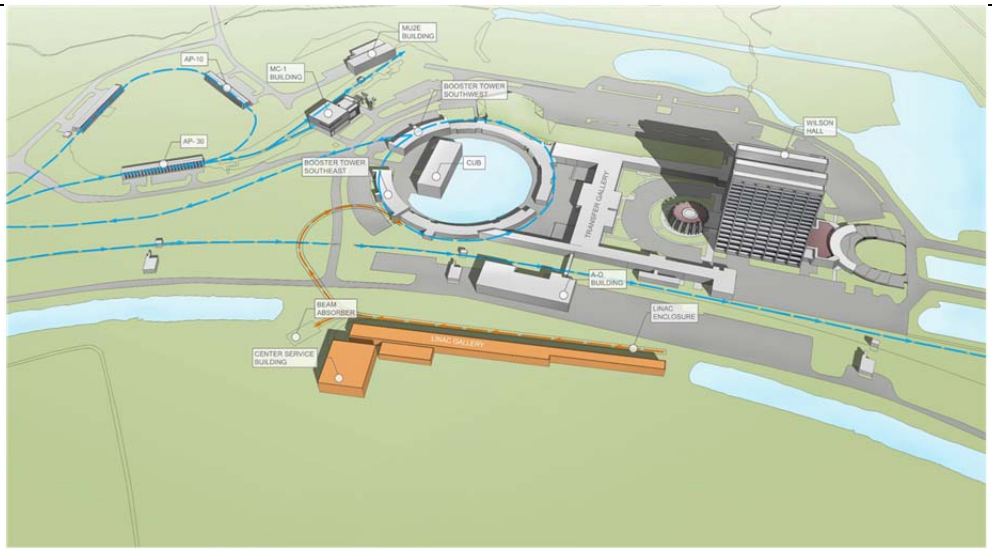

Figure 1-1. Location of the PIP-II Linac

PIP-II capabilities are designed to conform with the eventual replacement of the Booster, a major upgrade that could have the capability, later, to deliver 2.4 MW to the LBNF/DUNE target, as recommended by P5. The PIP-II platform would also provide the potential for other upgrade possibilities, including a potential upgrade path for the Muon Electron Conversion Experiment (Mu2e), through the selection of a design that preserves continuous-waveform (CW) capabilities. The choice of CW-compatibility is also consistent with the desire of major partners in the PIP-II collaboration, funded by the Indian Department of Atomic Energy (DAE), to build a CW linac in India.

The proposed Total Project Cost range is $465–695 million, assuming a contribution from Indian, and potentially European collaborators, equivalent to a direct cost of $108 million. The project nominally runs from FY 2016 until FY 2024, with commissioning beginning at the low energy end of the linac in FY 2023, concluding with 1.2 MW power capability at 120 GeV in FY 2024. This is consistent with the requirements of the LBNF/DUNE schedule.

2. TECHNICAL

This report addresses the review charge questions pertaining to whether the technical design meets requirements, possible scheduling conflicts with other FNAL programs, and the R&D that remains to be done.

A full day of plenary talks were presented by the PIP-II collaboration covering all aspects of the project including the physics program it supports, the technical design of the 800 MeV superconducting proton linac, modifications required to the Booster, Recycler, and Main Injector to provide higher proton beam power (up to 1.2 MW), the current and proposed future R&D programs, the cost and schedule, international contributions, safety issues, and organization and management plans. Some Committee members also toured the PIP-II related facilities at FNAL, one day prior to the review.

As the project is still in the pre-CD-0 phase and this review was not meant to evaluate the technical design in detail, this report mainly covers high level aspects of the PIP-II proposal. For a more detailed technical evaluation, one should refer to the PIP-II Machine Advisory Committee (MAC) reports from the last two years.

2.1 Findings and Comments

The basic plan to deliver 1.2 MW of protons for the long baseline neutrino program appears sound (it has been developed over many years), and provides a great basis for further increases in proton power at FNAL for future programs. In particular, it replaces the aging injector system, which is currently a bottleneck to higher beam power.

The PIP-II Reference Design Report is a great start on the Conceptual Design Report (CDR) in addressing technical issues. However, plans beyond installation—in particular, the strategy for transitioning to the new proton source—are not well defined. More importantly, there is not a clear delineation of initial versus future capabilities, especially in regard to CW operation.

Major alternatives for other technical choices were not addressed in this review.

In-Kind Contributions

The in-kind contribution plan is still evolving, but is a great win-win strategy for this program, with both development and acquisition risks being shared roughly equally with the Indian collaboration. The initial R&D phase of the Indian program is currently funded and is making good progress, and the Committee was given no reason to believe that it would not continue on track.

The recent decision by the Indian collaboration to fund a 2.5 kW 2 K cryoplant at FNAL, which would allow CW operation of the linac, will provide much flexibility for future programs, and essentially eliminates the risk that the PIP-II linac will not have adequate cryogenic cooling for its low duty factor operation.

Scheduling Strategy

It will take a concerted effort to complete the approximately three-year R&D phase, approximately four-year production/installation phase and the two-year commissioning program for the full beamline chain (linac, Booster, Recycler, and Main Injector) on the time scale proposed (CD-4 in FY 2024). Without a resource loaded schedule, a facilities sharing plan and a fairly mature Acquisition Strategy, it is hard to fully evaluate the viability of this plan.

The facilities for PIP-II still need a lot of improvement to allow both Linac Coherent Light Source II (LCLS-II) cryomodule production and PIP-II R&D to proceed with minimal interference. The plan to setup a cryomodule assembly facility in the FNAL 'village' makes sense, given the lack of space in the current Superconducting Radio Frequency (SRF) areas that are now focused on LCLS-II R&D and cryomodule production.

As noted above, a detailed plan for transitioning to the new source has not been developed. In particular, the experimental program schedule has not been integrated with PIP-II, including contingency plans if PIP-II is delayed.

Research and Development

The R&D required is extensive, but the plan is well developed and aimed appropriately at the major risks, which are categorized below.

Beam Transport—moderate risk. There are a number of challenges to increasing the bunch charge and repetition rate: individually, they are not insurmountable (the recent MAC review gives specific concerns), but collectively, they pose a risk to a smooth turn-on.

Superconducting Accelerator—low to moderate risk. The designs are fairly mature for the pre-CD-0 phase and are not large extrapolations from existing ones. The gradient stabilization will be challenging, but is likely achievable, especially if the cavity-fill period is lengthened, which the large cryogenic overhead should allow.

Schedule—high risk. The engineering design and development for the five types of cryomodules is daunting and has not been coordinated in detail.

Costs—low risk. The linac component costs do not seem out of line with other projects (SNS and LCLS-II). However, EDIA type costs are not fully developed (e.g., only 10% on cavities and cryomodules, and none on some of the other major items).

R&D—moderate risk. The cavities will likely operate at the design gradients, but meeting all requirements (vacuum, cooling, conditioning, regulation) will likely take longer than planned.

2.2 Recommendations

Given the early stage of this project, the Committee just listed priorities for going forward to CD-1, after CD-0 has been approved:

1. Develop a resource loaded R&D schedule and plan for developing the facilities for doing this work.

2. Provide more realistic estimates of the development costs (defining specifications, vendor selection and qualification, reviews, etc.) and schedule.

3. Estimate the costs (and schedule risks) for providing CW capabilities, as well as the additional costs that would be required to eventually run the 800 MeV linac with 2 mA beams.

4. Give high priority to beam physics verification efforts, in particular, to Booster impedance studies and slip stacking evaluation.

5. Develop a unifying plan to deal with the large number of SC components and vendors as this will be critical for meeting the schedule.

3. COST and SCHEDULE

The point estimate for the DOE scope is $516 million, which includes $133 million contingency (35%). Assuming the range to be -10% to +35% of the point estimate, the Total Project Cost (TPC) range is $465 million to $695 million. The CD-4 date is FY 2024. At this point in the project, there is no real schedule contingency identified. The non-DOE total is approximately $223 million, mainly assuming approximately $193 million from India and approximately $30 million from other international contributions.

3.1 Findings

The high end of the TPC is $695 million. The point cost estimate without contingency is $382.3 million, with a delta of $312 million. The planned CD-4 date is FY 2024. Basis of estimates include vendor quotes, historical data, and benchmarking with similar projects (SNS). Escalation is 2.4%, which is applied from 2013 to FY 2020. Technical risks have been identified. Activities are loaded with cost estimates developed at Level 2 and 3 of the Work Breakdown Structure (WBS). The CD-4 scope includes international contributions. The assumed funding profile is shown in Table 3-1.

Table 3-1. PIP-II Assumed Funding Profile

	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24
R&D	16.0	23.3	29.5	20.0					
Civil	1.0	1.2	10.0	20.0	40.0	40.0	13.0	0.0	
Management	1.8	5.0	8.5	9.2	10.0	10.3	10.8	10.8	8.5
Construction				32.0	33.0	35.0	55.2	55.8	13.2
Carryover	1.0	2.0	12.0	10.8	7.8	2.5	3.5	6.9	0.0
Total TPC DOE	**19.8**	**31.5**	**60**	**80**	**80**	**80**	**80**	**70**	**14.8**

3.2 Comments

The PIP-II definition and data were found to be well beyond the CD-0 stage and well on their way to CD-1. The project used data from the SNS project for benchmarking purposes. With this benchmark, the SNS actual cost was $777 million. In order to do a proper comparison, PIP-II removed costs for dissimilar scope. This brought the actual costs for SNS down to $701 million. Compared to the PIP-II estimated cost of $568 million (including contribution from India)—this makes for a very good benchmark.

The Committee noted that escalation was applied to labor and M&S from FY 2016 to FY 2020, the midpoint of the project. It is important that labor rates be escalated to FY 2024, not just at FY 2020, to better understand the impact of escalations.

Considering the SNS benchmarking, and the amount of contingency available at the high-end TPC range, the PIP-II cost appears reasonable.

There are significant R&D tasks that still need to be completed in order to implement the proposed concept, and the project has initiated identification of technical risks. At this stage, the contingency is not linked to risks, as more detailed cost risks have not been identified.

The laboratory has a plan for resource needs. This plan has identified (and the laboratory is aware) that the PIP-II project will use the same type of expertise that is necessary to execute the LCLS-II project at SLAC National Accelerator Laboratory. As a result, resource limitations could pose a risk to LCLS-II and PIP-II. However, the project could mitigate this risk by making use of the expertise of the collaboration with India for the PIP-II project.

3.3 Recommendations

6. Prior to CD-0, the project should escalate all labor costs from FY 2013 to FY 2024 to evaluate the cost differences from FY 2013 to FY 2020.

7. As a part of the Mission Need Statement, the project is required to include a funding profile for the higher end TPC of $695 million.

4. PROJECT MANAGEMENT

4.1 Findings

In that this Independent Project Review (IPR) was conducted prior to CD-0, it contained unique charge questions. As noted, one asked the Committee to get an independent assessment of the PIP-II cost range of the project for use in the Mission Need Statement. The Committee agreed that the cost range is credible and based on sound estimates and benchmarking.

The Committee was asked to look into project scheduling issues, the progress of the R&D to date, the R&D plan leading up to construction, and the management organization including the international collaborators. At present, the sole international collaborator is India.

Relating to the progress on technology development issues by the international collaborator, the Committee requested and received a report from a senior FNAL technical specialist, who had recently visited India, in the area of superconducting RF and associated infrastructure. As noted in the comments, the Committee was reasonably assured that these contributions will come as needed by the project, and that there are also contingency plans to address this issue.

Other Findings

- Much of the technical design, management structure, and international collaboration of PIP-II is based on years of activity related to Project-X.

- The international collaboration with India has been functioning since 2007 in support of R&D relevant to PIP-II.

- The notional schedule for PIP-II is based on the premise that 1.2 MW beam will need to be delivered to LBNF in the timeframe of FY 2024-2025. Critical decisions are derived by working backwards from this date (CD-3 in FY 2019, CD-2 in FY 2018, CD-1 in FY 2017, and a CD-0 near the end of FY 2015).

- The PIP-II project plans to make several key hires once CD-0 is approved. These are: Associate Project Manager for Planning and Reporting; and a Project Controls Manager. By CD-1 the project will add: an Associate Project Manager for ESH&Q; a Procurement Manager; and two Level 2 managers, one for the Superconducting Linac effort and the other for the Booster/Recycler Ring/Main Injector portions of the project.

4.2 Comments

The proposed schedule appears reasonable to meet the CD-4 beam delivery date by FY 2024-2025. In order to meet this, the funding profile needs to be sufficient, and CD-0 is needed in the next year.

The Committee was somewhat concerned that the notional schedule shows the FNAL complex shutting down to install LBNF and PIP-II at the same time. This is an efficient use of downtime, but puts great pressure on PIP-II to perform quickly and deliver beam for an experiment that will expect high power. Fermilab needs to monitor this schedule strategy as the project progresses.

The Committee was asked how the PIP-II schedule fits with other FNAL projects. It is difficult to answer this without a full description of other projects, and without a resource loaded scheduled for PIP-II (see recommendations).

The project scope appears to be well defined, including items that are not part of the Superconducting Linac. PIP-II should be continue to ensure the scope is carefully defined, particularly that which is not related to the linac.

The Environment, Safety and Health (ES&H) and National Environmental Protection Act (NEPA) issues are well understood and planned.

The experience with Indian laboratories and industry during the R&D phase has been positive and leads to optimism that this agreement will deliver during the construction phase.

The execution of the R&D plan, both at FNAL and in India, should be carefully monitored over the next three years to ensure that the plan is executed as outlined. Formal documentation of reviews should be regularly captured by project management. These reviews should address resource allocation (see recommendations).

At CD-1, design alternatives should consider any impact of potential Booster replacement requirements on the PIP-II design.

The management team is very experienced and has a good track record. Succession planning for potential departures is in place, and the Committee encouraged continued planning.

As this project has not yet reached CD-0, a resource loaded schedule has not been developed. However, the development of a resource loaded schedule including the R&D activities, will answer many questions raised at this review, and should be a high priority once CD-0 is awarded (see recommendations).

4.3 Recommendations

8. Throughout the remaining R&D phase, perform regular reviews on the status of the execution of the R&D plan.

9. Once CD-0 is awarded, place emphasis on the development of a resource loaded schedule.

Appendix A Charge Memo

DOE F 1325.8
(08-93)

United States Government **Department of Energy**

memorandum

DATE: April 13, 2015

REPLY TO
ATTN OF: Office of High Energy Physics, SC-25

SUBJECT: DEPARTMENT OF ENERGY/OFFICE OF SCIENCE REVIEW OF THE PROTON IMPROVEMENT PLAN (PIP-II)

TO: Stephen Meador, Director, Office of Project Assessment, SC-28

I request that OPA organize and conduct for the Office of High Energy Physics (HEP) an Office of Science Independent Project Review (IPR) of the Proton Improvement Plan (PIP-II) at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, on June 16-17, 2016.

The HEP strategic plan developed by the Particle Physics Project Prioritization Panel (P5) and documented in the 2014 report, *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context,* calls for an upgrade of the Fermilab accelerator complex to support the planned physics of the next decade. In particular recommendation 14 states:

> *Upgrade the Fermilab proton accelerator complex to produce higher intensity beams. R&D for the Proton Improvement Plan II (PIP-II) should proceed immediately, followed by construction, to provide proton beams of >1 MW by the time of first operation of the new long-baseline neutrino facility.*

Fermilab has developed a proposal for PIP-II that includes international in-kind contributions. The purpose of this review is to evaluate the PIP-II proposal, the proposed cost range, and the readiness of the laboratory to begin conceptual design. The results of your review will provide support for the Mission Need Statement to be developed by HEP.

The committee should address the following specific items:

1. Is the proposed technical concept, including both new construction and modifications to existing infrastructure, likely to satisfy the P5 recommendation? Are there major alternative technical choices? How well understood are the international in-kind contributions?

2. Is the presented cost range based on sound reasoning, consistent with experience of similar projects? Is it likely to bound the actual cost when PIP-II is built?

3. Does the scheduling strategy fit with other major projects at Fermilab?

4. Is there significant R&D that still needs to be carried out in order to implement the proposed concept? Are all the significant technical and cost risks identified? Does the laboratory have a plan, and sufficient resources, to complete the R&D in a timely manner?

5. Does the management team possess the requisite expertise and experience? Is it appropriately organized and staffed to initiate PIP-II activities?

Dr. Stephen Peggs oversees PIP-II in the Office of High Energy Physics and will serve as the OHEP contact person for the review.

We appreciate your assistance in this matter. As you know, these reviews play an important role in our program. I look forward to receiving your Committee's report within 60 days of the review.

for JS

James Siegrist
Associate Director of Science
for High Energy Physics

cc:
K. Fisher, SC-28
S. Peggs, SC-25.2
M. Procario, SC-25.2
M. Weis, FSO
P. Carolan, FSO
S. Holmes, Fermilab

Appendix B Review Committee

DOE/SC Review of the
Proton Improvement Plan II (PIP-II) at FNAL
June 16-17, 2015

REVIEW COMMITTEE PARTICIPANTS

DOE Chairperson

Stephen W. Meador, DOE/SC

Review Committee

SC 1—Technical

*Chris Adolphsen, SLAC
Mike Blaskiewicz, BNL
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SC 2—Cost and Schedule

*Julia Chaffin, SLAC
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Appendix C Review Agenda

DOE/SC Review of the
Proton Improvement Plan II (PIP-II) at FNAL
June 16-17, 2015

AGENDA

Tuesday, June 16, 2015—Comitium (WH2SE)

8:00 am	DOE Full Committee Executive Session.....S. Meador
8:45 am	Welcome and Laboratory Strategy—**One West (WH1W)**..... N. Lockyer
9:05 am	Mission Need ..... G. Rameika
9:30 am	Introduction to PIP-II.....S. Holmes
10:25 am	Break—**Outside One West**
10:40 am	PIP-II Technical Description .....V. Lebedev
11:20 am	PIP-II R&D Program .....P. Derwent
12:00 pm	Discussion
12:15 pm	Lunch—**2nd Floor Crossover**
1:00 pm	Reviewer Photo—**Atrium**
1:15 pm	International Contributions .....S. Mishra
1:45 pm	Cost Range .....D. Mitchell
2:15 pm	Warm Front End and PXIE Status .....A. Shemyakin
2:40 pm	PIP-II SRF Program.....S. Yakovlev
3:05 pm	Discussion
3:20 pm	Break—**Outside One West**
3:35 pm	ES&H Strategy..... J. Anderson
3:55 pm	NEPA Strategy.....V. Kuchler
4:10 pm	Organization and Management Plan.....S. Holmes
4:30 pm	Accelerator Division View ..... S. Nagaitsev
4:45 pm	Discussion
5:00 pm	DOE Full Committee Executive Session—**Comitium (WH2SE)** .....S. Meador
6:00 pm	Adjourn

Wednesday, June 17, 2015—Comitium (WH2SE)

8:00 am	PIP-II Response to Questions
8:30 am	Subcommittee Working Session/Report Writing
10:00 am	Full Committee Executive Session/Dry Run .....Committee
12:00 pm	Box Lunch Provided to Reviewers
1:00 pm	Closeout Presentation to PIP-II and Laboratory Management—**One West**
2:00 pm	Adjourn