Executive Summary

In a 1997 summer study, a team led by Steve Holmes formulated a development plan for the Fermilab proton source and described the results in TM-2021. Subsequently, at the end of 1998, a task group was formed to prepare a detailed design of a high intensity facility called the Proton Driver to replace the Fermilab Booster. In the past two years the design effort has attracted more than fifty participants, mostly from the Beams Division. Physicists and engineers from the Technical Division and FESS as well as other institutions, including the Illinois Institute of Technology (IIT), Stanford University, University of Hawaii, CERN in Switzerland, Rutherford Appleton Laboratory in England and the IHEP in Russia also contributed heavily. The results of that effort are summarized in this document describing the design of a 16 GeV synchrotron, two new beam transport lines (a 400 MeV injection line and a 12/16 GeV extraction line), and related improvements to the present negative ion source and the 400 MeV Linac. A construction cost estimate is presented in Appendix A.

The conventional wisdom in the particle accelerator world is that high energy machines and high intensity machines furnish complementary capabilities, with high energy accelerators providing the potential for new discoveries while high intensity accelerators enable precision measurements. However, that distinction is blurring because colliders at the energy frontier, such as the Tevatron in Run II, require high intensity injectors in order to achieve the substantial integrated luminosity that is necessary to make discoveries. Moreover, neutrino factories and muon colliders, which have both attracted considerable interest in the high energy physics community, require a high intensity proton source for muon beam production. An intense proton source is also useful for the production of high-intensity secondary particle beams of pions, kaons, muons, neutrons and neutrinos. A physics study focusing on applications of the Proton Driver is underway at Fermilab, with a report due in several months.

The Proton Driver is a rapid-cycling high-intensity 16-GeV synchrotron that serves a number of purposes in the Fermilab HEP program. In the near term, it replaces the present Booster and increases the proton beam intensity in the Main Injector by a factor of four, thereby providing an upgrade path for NuMI and other 120 GeV fixed target programs. It also helps increase the Tevatron collider luminosity after the antiproton source takes necessary measures to accommodate more antiprotons. The Proton Driver also opens the avenue for new physics programs based on its stand-alone capabilities as a source of intense proton beams. In the medium term, it could serve a neutrino factory by generating intense short muon bunches from a target. These muon bunches would then be phase rotated, cooled, accelerated and stored in a muon storage ring in order to generate intense beams of muon neutrinos and electron neutrinos. In the long term, the Proton Driver could be upgraded to a 4 MW proton source (by adding a 600 MeV linac and a 3 GeV Pre-Booster) in order to serve a muon collider.

At present, the Booster is the bottleneck that limits the proton beam intensity in the Fermilab accelerator complex. Its upstream machine, the Linac, is capable of providing

3.4×10^{13} particles per cycle at 15 Hz. However, due to numerous problems, the Booster intensity is limited to 5×10^{12} particles per cycle. After some modest upgrades, the downstream machine, the Main Injector, is capable of accelerating four times more protons than the Booster can provide. The Proton Driver, as a complete functional replacement for the Booster, removes this bottleneck and makes full use of the capabilities of the Linac and Main Injector.

This report presents a staged design of the Proton Driver having two phases. Phase I, the focus of this report, provides 1 MW of beam power. Phase II, which is discussed only briefly in Appendix C, is an upgrade path to 4 MW. Furthermore, Phase I has two stages. Stage 1 provides a maximum beam energy of 12 GeV with a 53 MHz rf system, whereas Stage 2 increases the beam energy to 16 GeV with a new 7.5 MHz rf system. There are several reasons for this two-stage implementation. In Stage 1, when there is no neutrino factory for the Proton Driver to serve, the 53 MHz rf system matches that of the Main Injector. Besides, one may reuse the rf system of the present Booster (with some modifications) and thus reduce the capital cost in this stage. In order to match the acceptance of the Main Injector to that of the Proton Driver, the Main Injector injection energy is raised to 12 GeV in Stage 1. In Stage 2, it is envisioned that a neutrino factory will require a small number of proton bunches. Therefore, a low frequency (7.5 MHz) rf system replaces the 53 MHz system. Another reason for choosing 7.5 MHz is that it provides the bunch spacing (132 ns) required by the Tevatron Collider in Run IIb, thereby obviating the need for beam coalescing in the Main Injector. The maximum beam energy of the Proton Driver is increased to 16 GeV in Stage 2 in order to generate enough muons for a neutrino factory.

In order to achieve the demanding performance specifications of the Proton Driver, a number of state-of-the-art features are incorporated in its design. The guide-field magnets are arranged in a transition-free FMC (flexible momentum compaction) lattice having large momentum acceptance and dynamic aperture. The injection scheme employs transverse painting to reduce space charge effects. The power supply uses a dual-harmonic resonant system (15 Hz plus 12.5% of 30 Hz component), thereby lowering the peak rf power requirement by 25%. The 7.5 MHz rf cavities employ a new type of alloy called Finemet for their magnetic cores. The main advantages of the Finemet cores are high accelerating gradient and wide bandwidth. The magnets employ external vacuum skins like those in the Booster, have large apertures like those in the Fermilab Accumulator, and use stranded conductors for the coil in order to reduce eddy current losses. Metallic stripes or liners are used to provide a low-impedance environment for the beam. A sophisticated beam collimator system collects about 99% of the lost particles in a small area, thereby allowing hands-on maintenance in the rest of the enclosure.

In addition to high intensity, another main requirement on the Proton Driver is short (1 ns rms) bunch lengths. In order to meet this requirement, the design adopts various measures to preserve the beam longitudinal emittance and to provide large (±2.5%) momentum acceptance. Bunch compression will be used at the end of the cycle when it is necessary to shorten the bunches.

This report also includes a chapter on related improvements to the H^- source and the present Linac. The main goal of these improvements is to increase the beam current by a factor of two while reducing the transverse emittances by the same factor, thereby increasing the transverse brightness by a factor of four. These improvements are necessary not only to provide the required beam intensity but also to control the linac beam losses during high intensity operations.

A main consideration in this design study is to minimize possible interruptions to the ongoing Fermilab HEP program, specifically Run II. Therefore the Proton Driver is located on the west side of Kautz Road, where construction can proceed without interfering with the operation of the existing machines and where two new beam transport lines can conveniently connect the Proton Driver to the Linac and Main Injector. A new 400 MeV line connects the Linac to the Proton Driver, and a new 12/16 GeV line connects the Proton Driver to the Main Injector. A large portion of the MI-8 enclosure can be reused for the latter line. Only the connections between the new beam transport lines and the existing accelerators require a machine shutdown. (This is similar to how the Main Injector was integrated into the existing accelerator chain.) Space is also reserved for a future new Linac and a Pre-Booster.

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