

Executive Summary

In a charge dated January 10, 2002 (Appendix 3), the Fermilab Director requested a design study for a high average power, modest energy proton facility. As pointed out in the Director's charge, the HEPAP Subpanel report identified such a facility as a possible candidate for a construction project in the U.S. starting in the middle of this decade. The worldwide renaissance in neutrino physics gives added impetus to this call. An intensity upgrade to Fermilab's 120-GeV Main Injector represents an attractive concept for such a facility, which would leverage existing beam lines and experimental areas and would greatly enhance physics opportunities at Fermilab and in the U.S. The key technical element in such an upgrade is the replacement of the 8-GeV Booster, which provides beam to the Main Injector. This new machine, dubbed the "Proton Driver", has potential for a significant stand-alone physics program in addition to its primary mission of providing input beams for the Main Injector.

This report is not yet complete and is being issued now in a preliminary version with limited distribution. When completed the report will be in three parts. Part A describes an 8-GeV synchrotron-based proton driver. Part A is a continuation and extension of Proton Driver Study I (PD1), completed in December 2000 and documented in FERMILAB-TM-2136. Part B describes modifications and upgrades of the Main Injector (MI) and associated beam lines. Part C describes an 8-GeV superconducting proton linac, an interesting alternative option to the synchrotron-based injector. Part A, the description of a synchrotron-based proton driver is complete. The material for part C is not yet finished. When part C is finished it will be incorporated into this report, and part B, will be expanded to cover the impact on the Main Injector and beam lines of either proton driver option.

A physics study focusing on applications of the Proton Driver is completed at Fermilab and a report is published elsewhere. [1]

The previous study, PD1, described a 16-GeV Proton Driver synchrotron as one option for such a facility. The current study, PD2, presents another option, an 8-GeV Proton Driver. Compared to PD1, the 8-GeV option would fit better into the Fermilab accelerator complex and be focused on improving the performance of existing machines and diversifying the research program.

In Part A of this report, the design of an 8-GeV synchrotron-based Proton Driver is presented. Compared with the 16-GeV design, it reduces the up front cost by about 1/3. The 8-GeV synchrotron is the same size as the present Booster (474.2-m circumference) but with a beam power 10 times higher (0.5-MW). A future upgrade to 2-MW is also possible because a large space (254-m) has been reserved between the linac and the ring for a future linac energy upgrade to as high as 1.9-GeV.

Many design features of the 8-GeV synchrotron are similar to the 16-GeV machine in PD1: a transition-free lattice having zero-dispersion straight sections and large dynamic

aperture; an injection scheme employing transverse painting to reduce space charge effects; a power supply using a dual-harmonic resonant system (15 Hz plus 12.5% of 30 Hz component), thereby lowering the peak rf power requirement by 25%; main magnets employing external vacuum skins like those in the Booster, with large apertures like those in the Fermilab Accumulator, and equipped with metallic perforated liners to provide a low-impedance environment for the beam; a sophisticated 2-stage beam collimation system collecting about 99% of the lost particles in a small areas around the circumference, thereby allowing hands-on maintenance in the rest of the enclosure. On the other hand, there are also some important differences between PD1 and PD2. For example, PD2 uses a new doublet lattice with racetrack geometry. The stranded conductor coils adopted in PD1 are replaced by solid conductor coils with parallel connections. In this report, we highlight the differences in the two designs and recommend reading the PD1 and PD2 (Part A) reports side-by-side in order to get a complete picture of the design.

Part A also includes a chapter on related improvements and upgrades of the H⁻ source and the present Linac. The main goals are to increase the linac energy by 200 MeV for a total of 600 MeV and to increase the beam transverse brightness by a factor of four. The former is necessary to reach the required beam intensity (2.5×10^{13} particles per cycle) in the Proton Driver, and the latter to control linac beam losses during high intensity operation.

In Part B, a 2-MW Main Injector is described. The baseline design parameters of the present Main Injector are 3×10^{13} particles per cycle, 1.867-sec cycle time (6-batch operation) and 0.3-MW beam power. With a Proton Driver, either synchrotron-based or linac-based, the beam intensity of the MI is expected to be increased by a factor of five to 1.5×10^{14} particles per cycle. Accompanied by a shorter cycle (1.533-sec), the beam power would reach 1.9-MW. This would make the MI a more powerful machine than either of the two large accelerator projects currently under construction: the SNS (1.4-MW) and the JHF (2 rings, 1-MW and 0.75-MW, respectively). Moreover, the high beam energy (120-GeV) and the tunable energy range (8 - 120 GeV) of the MI are unique features compared to any other high power proton facilities.

The main upgrade required to operate the Main Injector with 2 MW beam power is the radiofrequency (rf) system. The number of power amplifiers driving each cavity needs to double and two more cavities need to be added. In addition, one needs a γ -jump system, several large aperture quadrupoles, passive dampers and active feedback systems, a collimation system, large aperture kickers, and modest upgrades in power supplies, beam dump and rf cooling system. These upgrades are discussed in detail in the relevant chapters of Part B. Each of them (perhaps with the exception of the rf) is of a scale that can be accomplished via an accelerator improvement project (AIP).

Part B also discusses the modifications and upgrades of the NuMI, MiniBooNE and other beam lines. With modest investments, both the NuMI and MiniBooNE beam lines

are able to take full advantage of the high beam power from the Proton Driver and MI upgrade.

A construction cost estimate of the synchrotron-based 8-GeV Proton Driver and a cost estimate for the MI and beam line upgrades are presented in Appendix 1. An R&D program is outlined in Appendix 2.

Part C of this report, when completed will describe an 8-GeV superconducting linac. A possible siting for this facility is shown on the cover of this report. The linac is largely based on replicating successful technologies from other projects. This minimizes the R&D required. The linac front end and DTL are based on commercially available designs. Superconducting linac cavities similar to those of the SNS would be used up to 1.2 GeV. TESLA-style cryomodules operating at 1207.5 MHz would be used to accelerate the proton beam from 1.2 to 8 GeV. This would be followed by H^- stripping injection into the Main Injector.

The 8 GeV linac on alternate cycles can accelerate H^- , protons or electrons. Therefore besides its primary mission of injecting into the MI, the many unused cycles could be used for other physics missions. This provides many potential benefits for the US HEP program.

There would be major benefits to the neutrino and fixed-target programs; proton economics problems would be solved. An 8 GeV superconducting linac using TESLA technology would be a 1.5% scale demonstration of TESLA economics and would establish a stronger U.S. position in linear collider technology. Clearly, there would be benefits to the muon collider and neutrino factory R&D programs, e.g. a CEBAF-style recirculating linac could be made. An XFEL driver and antiproton deceleration are other interesting possible uses for the facility.

A group of accelerator physicists and engineers from Fermilab's Beams Division, Technical Division, and FESS and ES&H sections contributed to this study. A number of physicists from University of California in Los Angeles (UCLA), Oak Ridge National Laboratory, University of Hawaii, Stanford University and Rutherford Appleton Laboratory in England also participated and played important roles. The Editors express our thanks to them for their commitment and contributions to this study.

References:

- [1] A draft version of the Proton Driver Physics Study Report can be found on the web:
<http://projects.fnal.gov/protondriver/>