SUMMARY OF THE FERMILAB PROTON DRIVER DESIGN STUDY*

W. Chou† and C. Ankenbrandt, FNAL, Batavia, IL 60510, USA

Abstract

This paper is a summary report of the Proton Driver design study that has recently been completed at Fermilab. It describes the design of a new 16 GeV high intensity rapid cycling synchrotron as a replacement of the present Booster. The major design goals are: (1) 1 MW beam power; (2) 1 ns (r.m.s.) bunch length. The construction will be staged. It has also an upgrade path to 4 MW.

1 INTRODUCTION

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 Ref. [1]. 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. The results of that effort are summarized in Ref. [2]. The design includes 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

The Proton Driver 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 opens the avenue for new physics programs based on its stand-alone capabilities as a source of intense proton beams. In the long term, it could serve an intense muon source, a neutrino factory and a muon collider by generating intense short muon bunches from a target. The design also allows an upgrade path to a 4 MW proton source by adding a 600 MeV linac and a 3 GeV Pre-Booster.

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.

2 MACHINE LAYOUT & PARAMETERS

The layout of the Proton Driver is shown in Figure 1. The existing 400 MeV Linac will be reused. The H^- beam will be extracted from the Linac to the new 400 MeV transport line and injected into the Proton Driver in the same way as in the present Booster, namely, through a charge exchange process. The H^+ (proton) beam will then be accelerated to 16 GeV (or 12 GeV in Stage 1) in about 38 ms and extracted to the 12/16 GeV transport line. It is then either injected into the MI-10 section of the Main Injector or directed to a target for fixed target experiment.

The Proton Driver has a circumference of 711.3 m, which is exactly 1.5 times the size of the present Booster (474.2 m). It is of a triangular shape and has 3-fold symmetry. It has three arcs and three long straight sections. Each arc is about 173 m long and each straight section about 64 m long. These straight sections are used for injection, collimation, rf cavities and extraction.

In order to minimize any possible interruption to the ongoing Fermilab HEP program, the site of the Proton Driver is chosen at the west side of Kautz Road. In this layout, the new 400 MeV beam line includes 150 m free space for a future Linac upgrade. A future Pre-Booster can also easily fit in. About two thirds of the new 12/16 beam line will be in the existing enclosure. The elevation of the Proton Driver is the same as that of the Main Injector. This ensures appropriate radiation shielding.

The design presents a 2-stage implementation of the Proton Driver. 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. The reasons for this staged implementation are: (1) In Stage 1, one may reuse the rf system of the present Booster and thus reduce the capital cost. (2) A 53 MHz rf system matches that of the Main Injector. (3) In order to match the acceptance of the Main Injector (40p mm-mrad at 8 GeV) to the emittance of the Proton Driver beam (60p mm-mrad, normalized), the Main Injector injection energy needs to be raised to 12 GeV. (4) In Stage 2, it is envisioned that a neutrino factory will be in place. It requires a small number of proton bunches. Therefore a low frequency (7.5 MHz) rf system replaces the 53 MHz system. The maximum beam energy of the Proton Driver is also increased to 16 GeV in order to generate enough muons for a neutrino factory.

The major design parameters of the Proton Driver in Stage 1 and 2 are listed in Table 1. As a comparison, the parameters of the present Linac and Booster are also listed.

*Work supported by the Universities Research Association, Inc., under contract DE-AC02-76CH03000 with the US Dept. of Energy.

†chou@fnal.gov

3 TECHNICAL SYSTEMS

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.

- Lattice: This is a transition-free FMC (flexible momentum compaction) lattice. It uses 270°/270° FODO modules in the arcs. It has large momentum acceptance and dynamic aperture. [3]
- Magnets: 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. [4]
- Power supplies: 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 trim coils in the main quadrupoles use finite number of current harmonics (up to the 7th) for tracking error correction. [5]
- Vacuum and beam pipe: Because the magnets are in vacuum, the beam pipe is made of metallic stripes or perforated liners (like that in the LHC) to provide a low-impedance environment for the beam. [6]
- RF: In Stage 2, 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. [7]
- Injection: To keep space charge tune spread under control, the transverse charge distribution of the injected beam will be made as uniform as possible by the painting technique. [8]
- Collimation: A sophisticated 2-stage 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. [9]
- H^- source: A noiseless Dudnikov-type-source will increase the beam intensity by a factor of two (to 115 mA) from that of the present source. [10]
- Linac front-end: This system consists of two RFQ sections and a double-alpha transport line in between. The latter provides a perfect match between the two RFQ's. [11]
- RF chopper: A new type of chopper, which is similar to a beam transformer, has been designed, manufactured and tested in a collaboration between Fermilab and the KEK. [12,13]
- Inductive inserts: These are ferrite modules for compensating space charge effects. There has been a successful beam experiment at the LANL. These modules help increase the beam intensity in the PSR without any adverse effect. [14]

4 R&D PROGRAM

A complete list of the R&D program can be found in Chapter 19 of Reference [2]. An important category of the program are those items that are not only needed by the Proton Driver but will also be useful for improving the performance of the present proton source. Therefore, they have the highest priority. These include:

- High brightness H^- source development
- Linac front-end improvement
- Booster 53 MHz rf cavity modification
- Finemet 7.5 MHz rf cavity development
- Beam loading compensation system development
- Inductive inserts study in the present Booster
- Booster magnet ac field and impedance measurement

Several other items are also currently underway:

- Material outgassing rate test
- Stranded conductor coil study
- Chopper development
- High gradient, low frequency rf system

A number of other R&D items have to wait until more resources can be made available.

5 ACKNOWLEDGEMENTS

In the past two years the design effort has attracted more than fifty participants, mostly from Fermilab. Physicists from the IIT, Stanford Univ., Univ. of Hawaii, CERN, RAL and IHEP (Russia) also contributed heavily. The authors are deeply indebted to all of them. The support from Fermilab management to this study is greatly appreciated.

6 REFERENCES

[1] S. Holmes, editor, FERMILAB-TM-2021 (1997).

[2] W. Chou, C. Ankenbrandt and E. Malamud, editors, FERMILAB-TM-2136 (2000).

[3] W. Chou et al., "An Imaginary ?$_t$ Lattice for the Fermilab Proton Driver," this conference.

[4] F. Ostiguy and F. Mills, "Large Aperture Magnets for a Future High Power Proton Synchrotron," this conference.

[5] C. Jach and D. Wolff, "Proton Driver Power Supply System," this conference.

[6] T. Anderson et al., "FNAL Proton Driver Canned Vacuum System Design," this conference.

[7] D. Wildman et al., "A Prototype 7.5 MHz Finemet Loaded RF Cavity and 200 kW Amplifier for the Fermilab Proton Driver," this conference.

[8] C. Prior, " H^- Injector Studies for the Fermilab Proton Driver," this conference.

[9] A. Drozhdin et al., "Beam Loss and Collimation in the Fermilab 16 GeV Proton Driver," this conference.

[10] V. Dudnikov, "30 Years of High-Intensity Negative Ion Sources for Accelerators," this conference.

[11] D. Young et al., "Low Energy Improvements to the Fermilab 400 MeV Linear Accelerator," this conference.

[12] W. Chou et al., KEK Report 98-10 (1998).

[13] Y. Mori et al., "Fast Beam chopper with MA Cores," Proc. 2000 EPAC (Vienna).

[14] J.E. Griffin et al., FERMILAB-FN-661 (1997)

Table 1: Proton Driver Parameters of Present , Stage 1 and Stage 2

Parameters	Present	Stage 1 (MI)	Stage 2 (MI + ν-fact)
Linac (operating at 15 Hz)			
Kinetic energy (MeV)	400	400	400
Peak current (mA)	40	60	60
Pulse length (μs)	25	90	90
H^- per pulse	6.3×10^{12}	3.4×10^{13}	3.4×10^{13}
Average beam current (μA)	15	81	81
Beam power (kW)	6	32	32
Booster (operating at 15 Hz)			
Extraction kinetic energy (GeV)	8	12	16
Protons per bunch	6×10^{10}	2.4×10^{11}	1.7×10^{12}
Number of bunches	84	126	18
Total number of protons	5×10^{12}	3×10^{13}	3×10^{13}
Normalized transverse emittance (mm-mrad)	15π	60π	60π
Longitudinal emittance (eV-s)	0.1	0.1	0.4
RF frequency (MHz)	53	53	7.5
Extracted bunch length σ_t (ns)	0.2	1	1
Average beam current (μA)	12	72	72
Target beam power (MW)	0.1	0.9	1.2

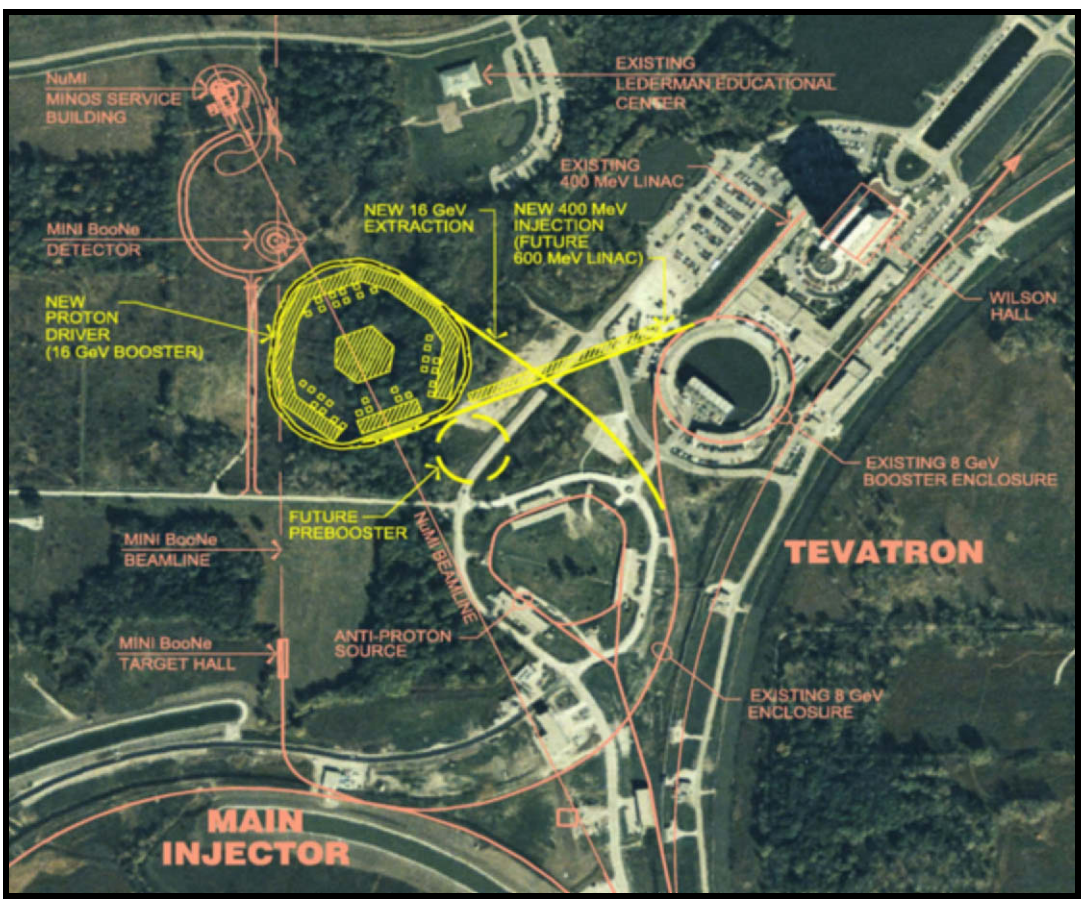

Figure 1: Proton Driver Layout.