

Table of Contents

| | |
|--|------|
| Executive Summary..... | vi |
| 1. Introduction | |
| 1.1. Overview..... | 1-1 |
| 1.2. Present performance of the proton source..... | 1-2 |
| 1.3. Design criteria for the Proton Driver..... | 1-5 |
| 1.4. Why do we need a new Booster?..... | 1-5 |
| 2. Machine Layout and Performance | |
| 2.1. Overview..... | 2-1 |
| 2.2. Siting..... | 2-4 |
| 2.3. Major design parameters..... | 2-4 |
| 2.4. Comparison with other high intensity proton machines..... | 2-8 |
| 2.5. Operation modes..... | 2-8 |
| 3. Beam Optics | |
| 3.1. Lattice design considerations..... | 3-1 |
| 3.2. Lattice design..... | 3-3 |
| 3.3. Lattice analysis..... | 3-7 |
| 3.4. Magnet errors and corrections..... | 3-12 |
| References..... | 3-21 |
| 4. Space Charge and Beam Stability | |
| 4.1. Space charge and image effects..... | 4-1 |
| 4.2. Coherent single bunch instabilities..... | 4-13 |
| 4.3. Coupled bunch instabilities..... | 4-17 |
| 4.4. Electron-proton instability..... | 4-19 |
| References..... | 4-21 |
| 5. RF Systems | |
| 5.1. Introduction..... | 5-1 |
| 5.2. Stage 1 (53 MHz) rf system..... | 5-4 |
| 5.3. Stage 2 (7.5 MHz) rf system..... | 5-22 |
| 5.4. R&D plans and proposals..... | 5-33 |
| References..... | 5-34 |
| 6. Magnets | |
| 6.1. Introduction..... | 6-1 |
| 6.2. Dipoles..... | 6-2 |
| 6.3. Quadrupoles..... | 6-11 |
| 6.4. Sextupoles..... | 6-11 |
| 6.5. Trim magnets..... | 6-13 |
| 6.6. Beam pipe induced field distortion..... | 6-15 |

| | |
|--|-------|
| 6.7. Research and development | 6-17 |
| References | 6-20 |
| 7. Power Supplies | |
| 7.1. Introduction | 7-1 |
| 7.2. Dipole and quadrupole power supply | 7-1 |
| 7.3. Quadrupole tracking and correction power supply | 7-6 |
| 7.4. Horizontal dipole correction power supply | 7-8 |
| 7.5. Vertical dipole correction power supply | 7-10 |
| 7.6. Sextupole power supply | 7-11 |
| 7.7. Power distribution system | 7-12 |
| 7.8. Required R&D | 7-12 |
| References | 7-13 |
| 8. Vacuum | |
| 8.1. Design overview | 8-1 |
| 8.2. System components | 8-3 |
| 8.3. Magnet vacuum | 8-4 |
| 8.4. Beam tubes | 8-6 |
| 8.5. Vacuum performance | 8-14 |
| 8.6. R&D efforts | 8-15 |
| References | 8-17 |
| 9. Beam Loss and Collimation | |
| 9.1. Introduction | 9-1 |
| 9.2. Deduction of tolerable beam loss | 9-1 |
| 9.3. Goals and principles of collimation | 9-5 |
| 9.4. Collimation system design analysis | 9-6 |
| 9.5. Sensitivity analysis | 9-18 |
| 9.6. Beam accident | 9-22 |
| 9.7. Collimators | 9-24 |
| 9.8. Conclusions | 9-26 |
| References | 9-26 |
| 10. Radiation Shielding and Activation | |
| 10.1. Introduction | 10-1 |
| 10.2. Regulatory requirements | 10-2 |
| 10.3. Ground water activation | 10-2 |
| 10.4. Radiation analysis methodology | 10-3 |
| 10.5. Beam transport line shielding | 10-7 |
| 10.6. P10, P30 and P50 arc shielding | 10-8 |
| 10.7. P20 long straight shielding | 10-13 |
| 10.8. P40 and P60 long straight shielding | 10-16 |
| References | 10-16 |

| | |
|---|-------|
| 11. Injection | |
| 11.1. Introduction | 11-1 |
| 11.2. Painting injection scheme | 11-1 |
| 11.3. Stripping foil | 11-7 |
| 11.4. Septum and kicker magnets parameters | 11-17 |
| 11.5. Stripping foil design | 11-17 |
| 11.6. Conclusions | 11-19 |
| References | 11-19 |
| 12. Extraction and Abort | |
| 12.1. Introduction | 12-1 |
| 12.2. Extraction system | 12-1 |
| 12.3. Notcher system | 12-4 |
| 12.4. Abort system | 12-5 |
| 13. H⁻ Source and Linac Improvements | |
| 13.1. Introduction | 13-1 |
| 13.2. General description of Linac low energy improvements | 13-2 |
| 13.3. Description of the ion source and LEBT | 13-9 |
| 13.4. Description of the radio frequency quadrupole (RFQ) structure | 13-13 |
| 13.5. The double alpha phase space imaging system (MEBT) | 13-16 |
| 13.6. Chopper | 13-18 |
| 13.7. The new 10 MeV drift tube cavity | 13-19 |
| 13.8. Linac controls and diagnostics | 13-19 |
| 13.9. Retuning the Linac for brighter beam | 13-21 |
| 13.10. Shielding considerations | 13-21 |
| 13.11. Short range plans: The R&D program | 13-23 |
| References | 13-26 |
| 14. Beam Transport Lines | |
| 14.1. Introduction | 14-1 |
| 14.2. Injection transfer line | 14-1 |
| 14.3. Extraction transfer line | 14-5 |
| 15. Beam Instrumentation | |
| 15.1. Introduction | 15-1 |
| 15.2. Beam properties and special requirements | 15-1 |
| 15.3. 400 MeV injection line | 15-2 |
| 15.4. Synchrotron | 15-4 |
| 15.5. 16 GeV extraction line | 15-9 |
| 15.6. Equipment protection system | 15-9 |
| References | 15-10 |
| 16. Control System | |
| 16.1. Overall architecture of Fermilab controls | 16-1 |

| | |
|--|-------|
| 16.2. Data acquisition hardware | 16-3 |
| 16.3. Linac controls | 16-5 |
| 16.4. Controls for the 400 MeV transport line | 16-5 |
| 16.5. Synchrotron controls | 16-6 |
| 16.6. RF controls | 16-6 |
| 16.7. Water system controls | 16-7 |
| 16.8. Vacuum controls | 16-7 |
| 16.9. Diagnostics interface | 16-7 |
| 16.10. Commercial instrument interface | 16-7 |
| 16.11. Software | 16-8 |
| 16.12. Beam permits, beam inhibit, e-berm | 16-8 |
| 16.13. R&D program | 16-8 |
| | |
| 17. Civil Construction | |
| 17.1. Introduction | 17-1 |
| 17.2. Overview of civil construction | 17-1 |
| 17.3. Detailed facilities descriptions | 17-2 |
| 17.4. Requirements and assessments | 17-5 |
| 17.5. Estimated schedule for civil construction | 17-7 |
| 17.6. Cost estimate model | 17-8 |
| | |
| 18. Environment, Safety and Health Considerations | |
| 18.1. Introduction | 18-1 |
| 18.2. Overall view of procedure/regulatory matters | 18-1 |
| 18.3. Environment, safety, and health considerations during construction | 18-4 |
| 18.4. Environment, safety, and health considerations during operation | 18-4 |
| 18.5. Summary | 18-8 |
| 18.6. Need for work on environmental and safety issues | 18-9 |
| References | 18-10 |
| | |
| 19. R&D Program | |
| 19.1. Introduction | 19-1 |
| 19.2. Category A | 19-1 |
| 19.3. Category B | 19-2 |
| 19.4. Category C | 19-2 |
| | |
| Appendix A. Cost Estimate | |
| A.1. Introduction | A-1 |
| A.2. Two-stage cost estimate | A-1 |
| | |
| Appendix B. Cost and Performance as a Function of Energy | |
| B.1. Introduction | B-1 |
| B.2. Important parameters | B-2 |
| B.3. First study: Cost as a function of T_{max} | B-5 |
| B.4. Second study: Comparison of operating costs | B-7 |

| | |
|--|-----|
| B.5. Third study: Cost as a function of B_{\max} | B-7 |
|--|-----|

Appendix C. Upgrade to 4 Megawatts (Phase II)

| | |
|---|-----|
| C.1. Introduction | C-1 |
| C.2. The muon collider requirements..... | C-2 |
| C.3. Synchrotron design concepts for muon production..... | C-4 |
| C.4. Meeting the needs of the rest of the program..... | C-7 |

Appendix D. Intensity Upgrade of the Main Injector

| | |
|--|------|
| D.1. Main Injector modes of operation..... | D-1 |
| D.2. Crossing transition in the Main Injector with high intensity bunches..... | D-1 |
| D.3. Necessary upgrades in the Main Injector..... | D-8 |
| References..... | D-10 |