The Status of the Fermilab Main Injector Project

D. Bogert, W. Fowler, S. Holmes, P. Martin and T. Pawlak
Fermi National Accelerator Laboratory*
P. O. Box 500, Batavia, IL 60510

Abstract

The Fermilab Main Injector Project is a new 150 GeV synchrotron now under construction at the Fermi National Accelerator Laboratory. The FMI has been designed to support a luminosity in excess of 5×10^{31} $cm^{-2}sec^{-1}$ in the Tevatron proton-antiproton collider while simultaneously providing a 2 microAmp resonantly extracted 120 GeV beam which will present unique capabilities in the realm of rare neutral K decays and long baseline neutrino oscillation experiments. Expected performance characteristics of the Main Injector will be reviewed, and the status of the project and the schedule for completion will be discussed

The Fermilab Main Injector is the final piece of a program, known as Fermilab III, which is designed to produce an approximate factor of 10 increase in the Tevatron Collider luminosity as compared with the current performance of 6×10^{30} $cm^{-2}sec^{-1}$. [1] In itself, the Fermilab Main Injector (FMI) is designed, and expected, to yield a factor of 5 increase over the luminosity achieved by all the other modifications installed in the Tevatron complex prior to the commissioning of the Main Injector. The primary design goal is to achieve an operating luminosity in the Tevatron Collider of at least 5×10^{31} $cm^{-2}sec^{-1}$. All components of the Fermilab III program built and commissioned to date have met or exceeded their design performance, yielding a hope of not only achieving the 5×10^{31} $cm^{-2}sec^{-1}$ luminosity, but perhaps reaching a level of performance up to 1×10^{32} $cm^{-2}sec^{-1}$. The exact expectation can be more precisely stated after operation of the Tevatron Collider with the Linac Upgrade (an earlier part of Fermilab III) is achieved in late 1993.

The FMI project goal is to functionally and physically replace the operation of the 150 GeV accelerator (the original Fermilab conventional magnet "Main Ring") which presently shares the 6.3 km circumference main tunnel of the Fermilab accelerator complex with the superconducting Tevatron. The 150 GeV accelerator is the third accelerator of the four accelerator cascade at Fermilab (Linac, 8 GeV Booster, 150 GeV accelerator, Tevatron). After the aforementioned Linac Upgrade Project is operational, protons will be injected at 400 MeV into the Booster.

The FMI is an approximately circular (rather more elliptical due to siting considerations) accelerator 28/53 the circumference of the present "Main Ring." Twelve (12) "Booster batches" are presently used to fill the Main Ring and transferred to the Tevatron for injection and acceleration for fixed target physics. Two FMI acceleration cycles will be required to fill the Tevatron for fixed target physics at Tevatron energies. The FMI will permit several operational scenarios which either do, or would, conflict with collider operations at present. The production of antiprotons, for example, requires the repeated excitation of the present Main Ring to 120 GeV on a 2.5 sec cycle. Small, but annoying proton losses during the acceleration cycle require the 'blanking' of the D0 collider detector for brief periods of time each cycle. This results in an approximately 15% loss of available collider luminosity at D0, as compared to CDF at B0. This is a result of the fact that the Main Ring runs partially through the D0 detector (only avoiding the central portion of the detector), rather than completely over the CDF detector at B0.

The critical justification for replacing the Main Ring with the FMI, however, is the very small admittance of the present configuration of the Main Ring (approximately 12 π mm.mrad at 8 GeV). This limitation (which is a distinct reduction of the original admittance of the Main Ring when it was commissioned 20 years ago) is the result of the introduction of vertical dispersion from the CDF and D0 'overpasses', even though the D0 overpass is only a few feet in vertical dimension. Also, the increase in the number of Main Ring injection and extraction devices has further limited the aperture. The FMI is designed with an admittance at 8 GeV in excess of 40 π mm.mrad. Great care has been taken to place injection and extraction devices at advantageous locations in the lattice. Also, a 1.5 second cycle time to 120 GeV for antiproton production and a 1.8 second cycle time for neutrino production is envisioned. These requirements have implied the necessity of designing new conventional copper and iron magnets of good field quality over a large aperture with cost effective high rate ramping characteristics. Power supplies and rf capabilities to match these specifications are also critical. On the other hand, certain items may be 'recycled' from the existing Main Ring to the extent that quantities are available and the expected lifetimes are reasonable. Main Ring quadrupoles are such an example of devices planned for re-utilization. Other items can be used for different purposes; for example, the 8 GeV transfer line from the Booster to the Main Injector is approximately 750 meters long and will utilize one type of Main Ring dipole.

An active Research and Development program, expected to cost $16.7M, is nearing completion. All the R&D program is expected to be concluded in approximately 18 months. This program has included the development and testing of new FMI dipole magnets, the associated dipole magnet power supplies, specialized quadrupole and sextupole magnets, and rf power amplifiers. The first two prototype

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dipoles were completed in 1991 and extensively measured while 'endpack' designs were developed. In conformance with a U.S.Department of Energy (DOE) business strategy recommendation in 1992, a program to execute the majority of the dipole magnet construction using outside commercial vendors was developed. Twelve (12) additional R&D dipole magnets are now under construction, with Fermilab acting as the general contractor for the work, but with only final assembly (and less than 10% of the value added) being accomplished at Fermilab. Contracts, some with options to extend to production quantities, have been bid and negotiated (some using Source Evaluation Boards) for copper coils, coil insulation, magnet lamination steel, and steel 'half-core stacking.'

A prototype dipole power supply is under construction and nearing completion at site E4R where a ground level tunnel enclosure was created for an SSC magnet test string operated at Fermilab. The SSC testing is complete, and the equipment has been removed, and the site is available for a FMI test string utilizing the R&D dipole power supply powering a string of the R&D dipoles. A second R&D dipole power supply will also be built. The rf R&D program has included a comparison of commercially available components with the performance requirements. Units will be load tested this year.

Congress first appropriated funding for the FMI in FY92 in the amount of \$15M. This was later reduced by Congressional recision to \$11.65M. For FY93 an additional \$15M was appropriated, bringing the total appropriated to date to \$26.65M. The latest approved FMI total project estimated cost (TEC), completed for the Title I review, is \$194M in \$FY\$91, which translates to \$222.5M in \$FY\$Then Year with the presently assumed Office of Management and Budget (OMB) schedule for funding and escalation. The Total Project Cost (TPC) including R&D, spares, and Pre-Operating is \$FY\$91 220.5M and \$FY\$Then Year 252.5M.

No part of the FY92 appropriation was released by DOE until late in FY92, and then only for very limited purposes. The development of FMI conceptual designs, FMI environmental assessment documents, approval of wetlands mitigation designs, and the selection of an outside A&E firm (Fluor Daniel) has been previously reported [2]. These efforts were directed towards obtaining DOE Acquisition Executive approval of the first Key Decisions (KD's) in May 1992 and the acceptance by DOE of the FMI Environmental Assessment as indicated by the publication of a "Final FONSI" (Finding Of No Significant Impact) in the Federal Register. The FONSI was published in early July 1992. At that time, based upon a very limited approval from the Acquisition Executive, civil work began on the wetlands mitigation. The May 1992 KD's (KD-0 and KD-1) accepted the project baseline based upon the latest conceptual design report (CDR 3.1) and authorized the release of FMI Project funds for the development of Title I. This was the first federal funding spent on the FMI at the A&E firm; all earlier work in support of the Environmental Assessment and the Wetlands Mitigation bid package was performed using State of Illinois Challenge Grant funding. On August 15, 1992, the Title I package (in five volumes: technical systems, civil construction, technical components cost estimates, civil cost estimates, and an energy conservation report) was submitted to DOE. After review, this material was accepted and in September 1992 the Acquisition Executive approved KD-2 (develop civil and technical Title II - i.e. bid packages - for the entire project) and a limited KD-3 (start project construction) which was further augmented (but is still limited) in April 1993. As a result, almost all of the available FMI appropriations are now under contract; the exception being that to date no annual contingency funding has been required or requested. As soon as the planned FY93 bidding activity is complete, some of the contingency may be requested for schedule advancement. It will also be necessary to have an 'unlimited' KD-3.

Under the authority of the Acquisition Executive, several major contracts have been awarded. A fixed-price contract (\$5.6M) has been signed with the architectural and engineering firm Fluor Daniel for the delivery of all the civil Title II by April 1994. The point of closet approach of the FMI to the Tevatron (near tangency) is known as MI-60 in the FMI lattice. This is the location of the FMI rf straight section. It is also, above ground, the location of the largest of the FMI service buildings, housing the FMI rf and power supplies for one-sixth of the FMI. It is also the location of the 'drop hatch' and associated underground labyrinth for FMI component delivery. Because of its proximity to the existing Tevatron, and the necessity to operate the Tevatron during construction, it is a complex civil construction project. Significant amounts of sheet piling need to be driven in a line parallel to the existing Tevatron rf straight section labeled F0. Radiation shielding must be maintained. The structural integrity of the Tevatron enclosure and F0 buildings must be maintained. The pile driving must not disrupt the operation of the Tevatron with colliding beam. It was decided to work on this complicated project first. The civil work was divided, after discussion, into two pieces (mostly below grade and mostly above grade) and bid separately, with the above grade work to follow the labyrinth construction. Advantageous bids, below the Title I and Title II estimates, were obtained. These were for approximately \$3.6M for the below grade and \$2.5M for the above grade construction. The below grade construction began in March 1993, and by the first week of May 1993 approximately one-third of the sheet piling area was driven to grade (of an expected total of about 7,000 square meters [1.75 acres] steel surface). Excavation had begun to the level of below grade bracing. All construction at the MI-60 area should be complete by April 1994. The next civil package to be prepared for bids is for site preparations, including most of the underground electrical and control cable conduit construction, various water systems around the FMI, and provision for temporary power on aerial lines. Also, construction roads for access for enclosure construction, located over the utilities, is required. This bid period closes at the end of May, with award and construction expected to begin in June 1993. In FY94 construction on the FMI Ring

Enclosure, in a counter-clockwise (viewed from above) fashion from MI-60 should commence, contingent upon Acquisition Executive approval and funding.

Also, consistent with Acquisition Executive approvals received in April 1993, contracts for the first production quantities of dipole magnet copper coils and magnet steel will shortly be signed. It is already known, however, that as in the case of civil contracts to date, the pricing for these first technical component contracts is very favorable.

Additional accomplishments of the past year include the approval of the FMI Preliminary Safety Analysis Report (PSAR) and DOE concurrence with the classification of the facility as 'Low Hazard.' A Technical Safety Review Committee concurred with the PSAR and accompanying presentations. As recommended by the Technical Safety Review, a Civil Safety Implementation Plan was written and approved, based upon the Fermilab Civil Safety Procedures. As suggested by the Technical Safety Review panel, a document to address the non-civil construction safety considerations of the FMI is under draft. The Project Management Plan was approved by DOE March 15, 1993. The Configuration Management Plan and a Project Control System are in various stages of draft and circulation and review with DOE. Advanced Procurement Plans were written and approved for the FMI dipoles and dipole power supplies, including the procedures for using Source Evaluation Boards. A FMI Project Specific Quality Implementation Plan (SQIP) was written, and associated SQIPs for various support organizations were prepared. These are under review. A DOE audit of the FMI Project Quality Assurance (QA) plans and procedures was held in late April 1993.

The specifications for the FMI were prepared by the staff of the Fermilab Accelerator Division. Based upon these specifications, staff from the Main Injector Department and the Accelerator Physics Department of the Accelerator Division have done a large amount of simulation (tracking) to confirm that the dipole magnet design and lattice design are acceptable. These studies have included confirmation of the injection and extraction system design specifications, so that technical component design may proceed. Also, staff from these departments have worked to ensure that a variety of fixed target physics options based upon research with protons originating directly from the FMI will be available, and that technical and civil designs are consistent with these requirements.

The project schedule is, at present, completely funding limited. An example of this statement is the fact that based upon the actual commitment of over $20M for civil and technical contracts in FY93 (using funds from FY92 and FY93) the latest DOE/ER review of the FMI project in March 1993 agreed that not only could the FMI project responsibly commit $52M as proposed in the DOE worksheets provided at that review; the review committee wrote in its report that the FMI could easily and responsibly commit $75M in FY94. The President's budget request shows $25M for FY94, which severely limits progress towards the FMI and is estimated to add about 13 months to the schedule. Unless some relief of this constraint is obtained project completion could extend to late in 1998.

FMI project management is very encouraged by the progress of the project to date. Formal groundbreaking was held on March 22, 1993. Progress on all civil and technical design and R&D efforts has been rapid given the available funding and Acquisition Executive approval rate. Actual contracts have been placed at very favorable pricing. The physics priority of this project (second only to the SSC) for the national program has been repeatedly endorsed. These endorsements are found in the HEPAP subpanels reports known as "Sculli" and "Witherell" reports. Project management is anxious to complete the job and to provide the research community the advantages of this excellent research facility.

REFERENCES

[1] S. D. Holmes, "Achieving High Luminosity in the Fermilab Tevatron," *Conference record of the 1991 IEEE Particle Accelerator Conference, San Francisco, California,* May 6-9, 1991, pp. 2896.

[2] D. Bogert, W. Fowler, S. Holmes, and P. Martin, "The Status of the Fermilab Main Injector," XV^{th} International Conference on High Energy Accelerators, Hamburg, Germany, Vol. 1, p. 492, (July 20-24, 1992).