

A Proposed 100-400 MeV Beam Facility at Fermilab

C. Johnstone, C. Ankenbrandt, S. Bjerklie, D. Boehnlein, M. Foley, T. Kroc, J. Lackey, A. Lennox, A. Leveling, E. McCrory, M. Popovic, C. Schmidt, K. Vaziri
Fermi National Accelerator Laboratory*
P.O. Box 500, Batavia, IL 60510 USA

Abstract*

An extraction beamline and an experimental area have been designed for the Fermilab Linac. The design exploits attributes of the Linac in order to adapt it to a wide range of applications and purposes. Charge stripping of H^- ions enables beam manipulations which contribute enormously to the capabilities and flexibility of the facility. The proposed Linac Experimental Area would provide facilities for research and development in accelerator physics, medical physics, health physics, and atomic physics.

I. INTRODUCTION

Some of the same characteristics which make the Fermilab Linac well-suited for its primary role as an injector for a synchrotron--short duty cycle, fixed beam parameters and even high intensity--would seem to limit its utility for other applications, which often require much lower intensity and flexible control of parameters. The facility design presented here circumvents many of these limitations in a variety of ways. The most important method is charge stripping of the H^- beam, which allows intensity, transverse phase space distributions, and momentum spread to be simultaneously controlled over wide ranges. For example, this technique allows intensity to be adjusted from a few protons/pulse to more than 10^{13} protons/pulse, emittances to be controlled from $.1-6\pi$ mm-mrad, and momentum spread to be reduced well below its normal value. In addition, the controls system developed for the Linac allows for pulse-to-pulse changes in output energy from 100-400 MeV in discrete steps [1].

Construction of such a facility at Fermilab became especially practical and economical following the recent upgrade of the Fermilab Linac. The Linac Upgrade Project raised the Fermilab Linac beam energy from 200 to 400 MeV, making it more useful for the proposed research. It also left behind considerable civil construction and resources (magnets, utilities, etc.). Furthermore, the proposed program could use the many beam cycles which are presently available on the Fermilab Linac without interfering with the high energy physics program.

A workshop[2] was held at Fermilab in October, 1993 to examine the research potential of such a facility and to gauge

outside interest. A number of research groups in the aforementioned subfields of physics participated actively, and several groups subsequently submitted written proposals and expressions of interest. The proposed activities would foster symbiotic interactions and cooperation among these subfields of physics. Much of the proposed medical research requires an operationally flexible, well-calibrated proton beam, which is currently not available in this energy regime. Likewise, a well-characterized beam offers special opportunities for health physics research, particularly in the areas of dosimetry, radiation damage, and optimization of shielding. Thus an important goal was to design a beam having variable parameters but well-established properties. The overall design of the area promotes cooperative initiatives between diverse research efforts and thereby achieves a number of advantages, as detailed in the following sections.

II. PERFORMANCE GOALS AND BEAM OPTICS

A major design challenge was to deliver a wide range of beam parameters required by the proposed experimental program without perceptible impact on the laboratory's high energy physics program or on accelerator operational resources. In order to meet the required beam specifications and to satisfy operational constraints, the extraction beamline was designed to regulate intensity, phase-space attributes, and momentum spread in a precise, reliable, and operationally simple, manner.

Performance goals that can be realistically achieved with the present beamline design when the full capability of the Fermilab Linac is taken into consideration are given in the table below.

Table 1. Operational Parameters of the Linac Experimental Area.

Beam Energy Range	100-400 MeV
Intensity Control	few protons/pulse [3] to 10^{13} protons/pulse
Emittance Selection	$.1\pi$ to 6π mm-mrad
Pulse Length	picosecs [3] to $40\mu\text{sec}$
Transverse Beam Size	.5 mm to 75 mm
Momentum Spread, $\Delta p/p$	0.3%-0.05%
Energy Calibration [4]	$\pm 10^{-4}$
Determination of $\Delta p/p$ [5]	$\pm 10^{-5}$

*Operated by the University Research Association, Inc. under contract with the US Department of Energy.

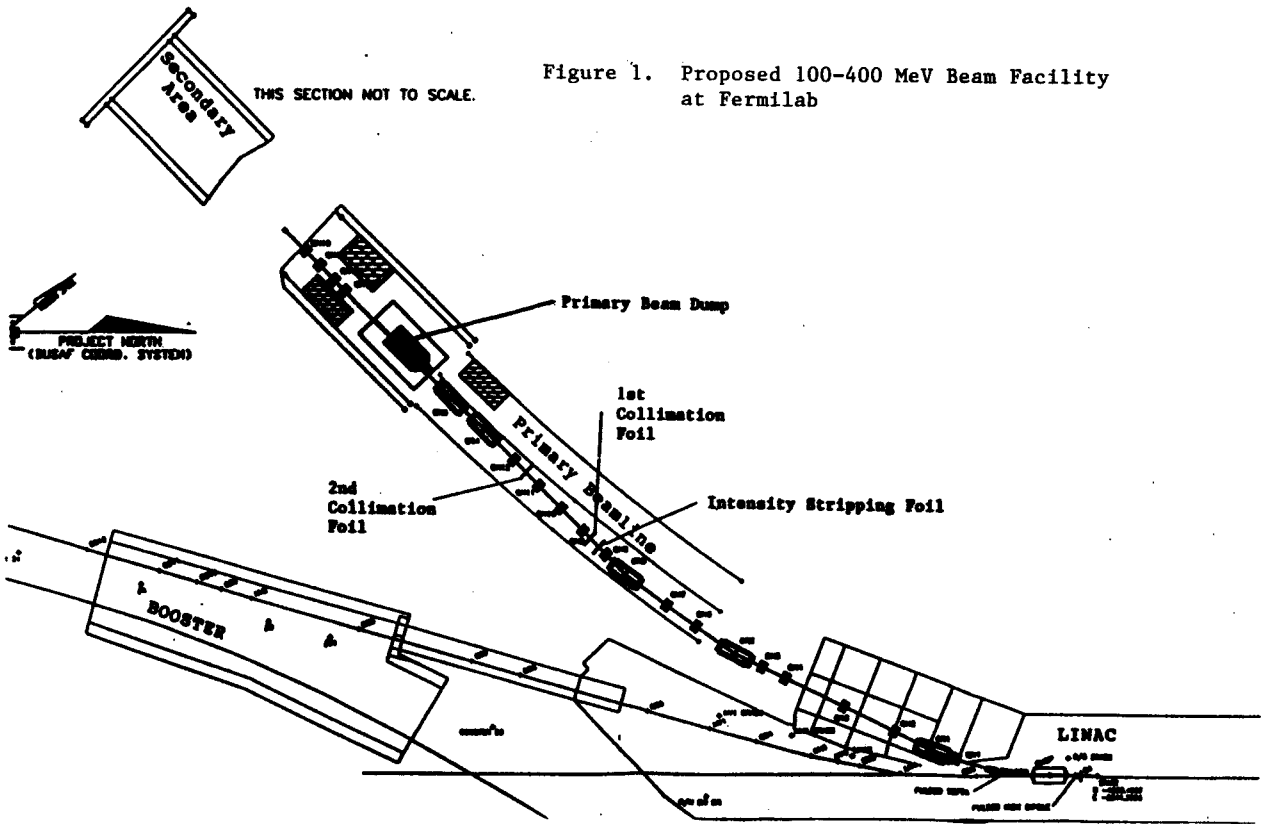


Figure 1. Proposed 100-400 MeV Beam Facility at Fermilab

III. BEAM OPTICS

A. Beam Extraction

The Linac can generate beam pulses from 1-60 μsec long at a repetition rate of 15 Hz. For extraction, a pulsed magnet system will deflect individual complete beam bursts through a bend angle of 15° toward the proposed experimental area. This approach not only maintains operational simplicity but also minimizes the impact on accelerator operations and the laboratory's high energy physics program. However, it also necessitates a shielded enclosure and a primary beam dump capable of coping with the full Linac intensity. A plan view of the primary beamline is given in Figure 1.

B. Beam Intensity

To control the beam intensity, the instantaneous beam current can easily be varied by about a factor of two and the duration of the beam pulse by about a factor of sixty. The H^- intensity can be further reduced when necessary by stripping foils of varying thicknesses. The intensity of the H^- beam can be limited by the transmission foil to a fraction of a percent of the initial Linac (by thicknesses in the range 50-300 $\mu\text{g}/\text{cm}^2$ for 400-MeV beam).

Downstream of the foil, the beam contains protons as well as H^- atoms. Two dipoles of equal strength and opposite polarity just upstream of the primary dump separate the two

charge species. The unwanted charge species (usually protons) is deposited in the beam dump while the intensity-moderated beam (H^-) is transported through the dump and into a secondary experimental beamline and area (see Figure 1). The beam optics downstream of the stripping foil successfully transports beams of both polarities to their intended destinations.

C. Transverse Beam Properties and Momentum Spread

After the beam intensity is attenuated by the transmission foil, the transverse beam parameters and momentum spread are adjusted by means of strategically located stripping-foil collimators. Two stripping collimators with pinholes are used to control phase space attributes such as emittance and divergence. For example, the acceptance of stripping collimators with .5 mm pinholes separated by 3m is 0.1 mm-rad for transmission of an H^- beam. Since the collimators are located at highly dispersed horizontal foci, momentum spread is also adjustable. The initial momentum spread of the full Linac beam ($\sim .2\%$) can be reduced by about a factor of 4 or 5 through the use of pinhole collimators (Figure 1).

D. Beam Energy

The beam energy can be varied by allowing the beam to drift through unpowered or misphased individual sections of the Linac. Almost continuous control over the output energy can be attained through inter-tank phasing. The Linac quadrupoles are pulsed at 15 Hz, and the timing of the pulse can be adjusted to maintain the usual Linac transverse focussing as the beam energy varies.

IV. OVERVIEW OF APPLICATIONS

The potential for medical research, in particular for activities related to proton therapy, is especially compelling. For example, the development of pulsed-beam scanning techniques has been proposed for delivering uniform doses that conform accurately to irregular three-dimensional tumor volumes. Also, there is considerable interest in proton radiography and tomography, particularly in conjunction with proton therapy, to produce images of patients immediately preceding treatment. Other proposed applications would take advantage of the versatile beam parameters to test beam delivery techniques and of the well-known properties of the beam to cross-calibrate dose-measuring devices.

The broad spectrum of proposed applications in accelerator research ranges from basic beam characterization and device calibration to development of new beam detectors and other advances in accelerator technology. To illustrate the symbiotic nature of the proposed program, precise experimental techniques and tools pioneered in the field of atomic physics will not only further experiments in atomic physics, but also serve as the basis for new accelerator diagnostic tools, such as, for example, the advanced laser techniques developed for the study of relativistic H^- beams [4,5]. The same laser apparatus and setup proposed for atomic physics research will make possible accurate and absolute determination of a class of beam and device parameters which address accelerator performance issues. In a similar vein, the well-calibrated beam desired for medical applications offers special opportunities for health physics research in the areas of dosimetry, radiation damage, and shielding optimization.

IV. SUMMARY

The design of a multipurpose Linac experimental facility that satisfies a variety of experimental requirements on beam intensity, phase space distributions, and momentum spread is described. The present design boasts flexible and independent control over all of these parameters, primarily by selective stripping of an H^- beam. This versatile facility design meets requirements of numerous applications and experiments in medical, accelerator, health, and atomic physics, for both basic research and applied technology.

IX. REFERENCES

- [1] Elliott McCrory and Chuck Schmidt, private communication.
- [2] Chuck Ankenbrandt and Carol Johnstone, editors, *Proceedings of the 400-MeV Beam International Workshop*, Fermilab, October 1993.
- [3] A few protons/pulse is achieved by neutralizing the H^- beam using a laser and then extracting and stripping the neutrals in a foil. Laser intensity is lowered until only a few neutrals; i.e. a few protons/pulse are generated. Picosecond pulse lengths can also be attained using laser photodetachment.
- [4] E. P. MacKerrow, et al, "Laser Diagnostics for H^- Beam Momentum and Momentum Spread," *Proceedings of the 400-MeV Beam International Workshop*, Fermilab, October 1993., 147.
- [5] P. G. Harris, et. al., "Measurement and Reduction of Momentum Spread in the LAMPF Linac Beam," *Nucl. Inst. and Meth.*, A292, 254-258 (1990).