

1-GeV LINAC UPGRADE STUDY AT FERMILAB*

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Abstract

A linac injector for a new proton source complex at Fermilab is assumed to have a kinetic energy of 1 GeV. This linac would be sized to accelerate 100 mA of H^- beam in a 200 microsecond pulse at a 15 Hz repetition rate. This would be adequate to produce $\sim 10^{14}$ protons per pulse allowing for future improvements of the new proton source complex. An alternate proposal is to add 600 MeV of side coupled cavity linac at 805 MHz to the existing 400 MeV Linac. This addition may either be in a new location or use the present Booster tunnel. A discussion of these possibilities will be given.

1 INTRODUCTION

This study investigates a possible upgrade of the Fermilab Linac to meet hypothetical muon collider needs, increased antiproton production and higher neutrino fluxes. Muon collider is the most demanding and anticipates 1.25×10^{14} protons per pulse at 15-Hz rate and an energy of 1 GeV. Presently, the Linac can deliver 45-50 mA peak current at 15 Hz with a pulse length of 35 to 57 μs for high energy physics or cancer therapy respectively[1]. With a small effort it is likely that pulses of 60 mA and 90 μs can be achieved at 400 MeV[2]. This represents a beam of 3.4×10^{13} protons per pulse at 15 Hz. Producing 20000 μs - mA, 1.25×10^{14} protons per pulse, is significantly more difficult and would require modifications at every stage of acceleration. For 1 GeV as a final energy, an additional accelerating structure is needed. Two options have been considered. Moving the operating Linac to a new location and extending the present side-coupled accelerating structure to 1 GeV. The other is to leave the operating Linac where it is, extend the side-coupled structure through part of the Booster tunnel and use existing tunnels to transfer the 1-GeV beam to a new booster[3].

2 1-GEV EXTENSION

To have a 1 GeV linac at Fermilab site which will satisfy the muon collider needs, there are three possible options, (Figure 1);

- Build a completely new Linac based on designs adopted for spallation neutron sources,
- Build a new Linac tunnel near the Main Injector which will house the whole linac and a new Booster. Move the existing linac into the new tunnel, make necessary modifications needed for higher beam peak cur-

rent and longer pulse length, and add-additional accelerating structures to reach 1 GeV as the final kinetic energy.

- Leave the existing linac at its present location, make necessary modifications needed for higher beam peak current and longer pulse length, and use the existing Booster tunnel and galleries to house accelerating structure for acceleration from 400 MeV to 1 GeV.

The first option is the least controversial but may be the most expensive. The second option assumes increasing the linac energy in a conventional way, simply adding new structure to the existing Linac in the new tunnel to achieve 1 GeV. The additional 600 MeV structure is assumed to be an extension of the recent Linac Upgrade using the same side coupled cavity modules. A preliminary design requires 11 modules for acceleration and a “half” module for controlling the energy spread of the exiting linac beam. The total physical length of the structure is 131.3 meters. The design is based on the following assumptions:

- Values for transit time, E_{max}/E_0 and ZTT are extrapolated from the fits calculated with SUPERFISH for the values of β from 0.46 to 0.72.
- Maximum allowed electric field is 1.55 Kilpatrick which for 804.96 MHz is equal to 40.3MV/m.
- Maximum power for a four section module should be less than 9 MW. This power limit includes power to the copper and power needed to accelerate 75 mA of beam.

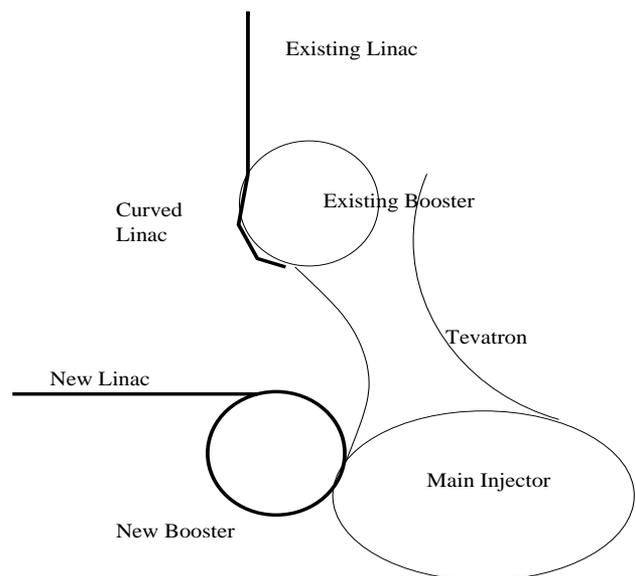


Figure 1: Location(s) of extended Linac and new Booster

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- ZTT used in the calculations is 85% of the value extrapolated from SUPEFISH calculations.
- Each module is made of four sections. The sections are made of 16 cavities of equal β . The value of β is equal to the beam's β at the mid point of the section. The sections are connected with bridge couplers and spaced for $3/2\lambda\beta$.
- Acceleration phase is -32 degrees.
- A FODO lattice is assumed using quads between each section with a phase advance of 90 degrees.

The third option, a 1-GeV linac extension in the present Booster tunnel, could prove to be economically and operationally viable. The H- beam from the 400 MeV Linac would be transported with the present 400 MeV transfer line to the Booster tunnel. To preserve the bunched beam we will use a buncher cavity at the entrance to the chute and/or retune the phase of the last module of the 400 MeV Linac. Recent experiments show that bunch length can be preserved for injection into the side coupled cavity. In this experiment linac pulses with pulse lengths less than a full Booster turn were injected in the Booster. The wall current monitor which is 334.3 meters from the injection point to the Booster was used to observe changes in the bunch length as a function of the debuncher phase and/or phase of the last accelerating module. The debuncher is located in the transfer line 33.2 meters from the exit of the Linac. The total length of 400 MeV transfer line is 62.2 meters, and by design it is dispersion free in both planes. Figure 2, shows the signal from the wall current monitor. The upper trace is a

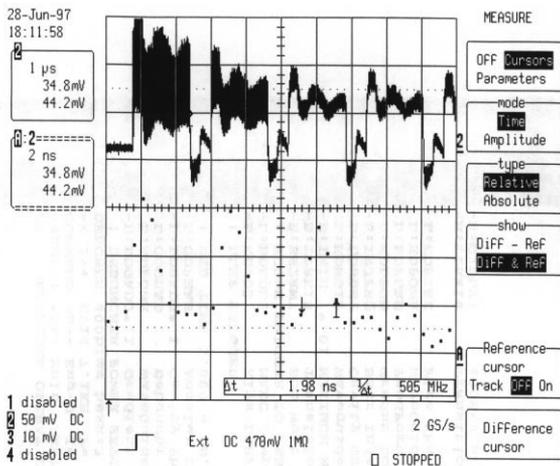


Figure 2: Bunch length at injection in the Booster

record of a little more than four Booster turns. The width of the trace is a measure of the strength of the 200-MHz signal. The lower trace is an expansion of the last three 200-MHz bunches seen by a detector on the first turn, after injection. The full width measured at this point is 1.98ns and this is at a location which is 396.6 meters away from the exit of the linac. On the second turn (474 meters away) the full width of the same bunch was measured to be 3.52ns. In the Booster tunnel the new linac will start 30 meters from

the exit of the 400 MeV linac and will have two horizontal bends. The first bend is after three modules at a beam energy of 557 MeV. The bend consists of one FODO cell with two 11 degrees bend magnets. The next bend is at 703 MeV with the same type of bending magnets. The magnets are two meters long with a field of $\sim 3kG$. The H^- stripping probability is less than 4×10^{-12} at 557 MeV and less than 5×10^{-8} at 704 MeV. Each bend will introduce horizontal dispersion. TRACE3D calculations show an “increase” in horizontal emittance. Figure 3 shows the output

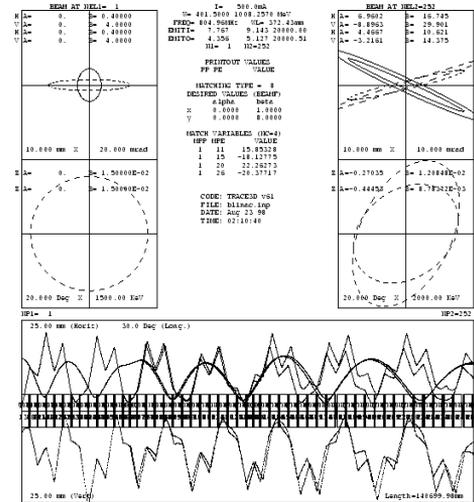


Figure 3: 1GeV Linac with bends

of TRACE3D where the beam was traced for two different cases. Input to the calculations is the linac as describe above, 13 accelerating modules and four bending magnets. The first trace simulates a “no bend” situation. In these calculations the bending angles were set to be 0.1 degree and the radius of curvature was adjusted to have the length of the “magnet” 2 meters. The second trace is for the case of four 11 degree bends. The output emittance printed by TRACE3D in this case is about two times bigger than for the “no bend” situation. In these calculations there was no attempt to adjust dispersion trough the linac after the first bend. The three quadrupoles around each bend can be tuned to minimum dispersion. The phase advance to the second bend can be arranged to suppress if not cancel the dispersion.

3 PRESENT LINAC

To achieve 1.25×10^{14} protons per pulse will require considerable upgrading of the operating Fermilab Linac at the source, preaccelerator, low-energy linac and the high-energy linac. The maximum current the Linac is likely to achieve is 80-100 mA. This is limited by many constraints, most strongly by the ion source, RF power of the low-energy linac and the lattice design of the high-energy linac. Extending the pulse length is the other option, given that the

repetition rate is fixed at 15 Hz. The lower limit of 80 mA beam current sets the pulse length at 250 μs . These parameters set the conditions to which the present Linac must be capable.

3.1 Ion Source

The magnetron H^- ion source currently in use delivers a current of 65-75 mA with a pulse length of 90 μs [4]. Of this $\sim 5\%$ is lost in transport and 70% is captured in Tank 1 for a linac current of ~ 45 mA through the Linac. To achieve the desired current of 80 mA an H^- ion source of ~ 120 mA is necessary. BNL achieves 90 mA from a slightly modified magnetron source at an extraction voltage of 35 kV with a pulse length of 500 μs at 7.5 Hz[5]. The Fermilab source extracts at 18 kV. It is expected that a higher extraction voltage could give the desired current. A RF-driven H^- volume source may be another possibility having long lifetime. Such a source is undergoing R&D for other accelerator projects to produce 60 mA, 6% duty factor and a normalized emittance of 0.2π mm-mr[6].

3.2 Preaccelerator and low energy transport

Two 750-kV Cockcroft-Walton generators are used as injectors to the Linac. Since neither has a bouncer, a voltage drop of ~ 7 kV occurs for present beam pulses. At higher currents and pulse lengths a bouncer or other correction will be required. If the Linac were to be moved, one could consider a new tank 1 from 2 or 2.5 to 10.25 MeV, the energy of tank 2, and a set of RFQ's replacing the preaccelerators. This could also significantly improve the emittance[7].

3.3 Low-energy linac

The Fermilab Linac was designed for 75 mA and four turns of beam to the Booster (12 μs plus RF stabilizing time)[8]. At 90 mA the 5-MW RF power tubes will limit the beam current. However they can handle longer pulse lengths as shown by other U.S. accelerator facilities in table 1.

Table 1: US Proton Linacs

Beam	BNL	FNAL	LAMPF
Peak Current(mA)	37	48	18
Pulse Length(μsec)	500	57	900
Repetition rate(Hz)	7.5	15	120

Thus pulse lengths of 250 μs are possible with only a modest modification of the RF systems. To achieve longer pulses the quadrupole system for the drift tube linac will need modification. The pulsed power supplies will need to incorporate a second harmonic to give a relatively flat 250 μs pulse.

3.4 High-energy linac

The upgraded high-energy linac had a design goal[9] for the side-coupled accelerating cavities of 50 mA. The bridge

couplers connecting the cavities were cut for a power level corresponding to 35 mA of beam, the traditional beam current when the upgrade was built. The cavities and couplers have handled up to 50 mA of beam. Whether they can handle 80-90 mA is questionable, and this is probably an upper limit. It may require rebuilding the bridge couplers. For 90 mA the 12 MW klystrons would need to be increased to 14.5 MW. The modulators, cooling systems, pulse transformers, oil tanks and low level rf systems would need to be redesigned for the higher power and pulse length.

3.5 Shielding and Losses

At the 1.0×10^{14} protons per pulse and 15Hz, the enclosure shielding, extrapolated from our present running, appears adequate except for a few areas that can be corrected. The radiation at the exterior high energy berm may exceed the permissible limit for an open unmarked area but could be corrected with a fence and signs or by adding soil. The door at the 400 MeV labyrinth into the Linac tunnel and the 400 MeV cable penetrations may exceed their allowed limits. This may require closing off the labyrinth and sealing the cable penetrations. The worst possible loss is the case of a spark in the last accelerating module if the extended structure for 1 GeV is located in the Booster tunnel. In this case about 2 μs of the beam located between the end of the 400 MeV Linac and the end of the 1 GeV linac will be lost in the Booster tunnel. This is less than the present losses in the Booster during normal operations. The beam in the 400 MeV part of the Linac will be dumped in the present Linac dump.

4 REFERENCES

- [1] L.J. Allen, M. Popovic and C.W. Schmidt. "Operation and Improvements of the Fermilab 400 MeV Linac". Proceedings of the 1996 Linear Accelerator Conference, September 1996, CERN, p329.
- [2] M. Popovic, "Present Near Future and Future Performance of Fermilab Linac", Fermilab-Pub-96/046
- [3] S.D. Holmes(editor). "Development Plan for the Fermilab Proton Source", TM- 2021, August 1997, Fermilab.
- [4] C.W. Schmidt. "Review of Negative Hydrogen Ion Sources", Proceedings of the 1990 Linear Accelerator Conference, September 1990, Albuquerque, NM, USA, p259.
- [5] J.G Alessi et al.. "Upgrade of the Brookhaven 200 MeV Linac", Proceedings of the 1996 Linear Accelerator Conference, September 1996, CERN, p329.
- [6] L. Schroeder et al., editors. "Proceedings of the Ion Source Issues Relevant to a Spallation Neutron Source". LBL, October 24-26, 1994, LBL-36347 CONF-9410233 UC-404.
- [7] C. Schmidt et al., "Redesign of the Low Energy Section of the Fermilab Linac to Improve Beam Brightness". Proceedings of the 1988 Linear Accelerator Conference, October 1988, Newport News, Virginia, USA, p188.
- [8] Design Report, Nacional Accelerator Laboratory, July 1968.
- [9] Fermilab Linac Upgrade Conceptual Design, Revision 4A, November 1989.