Delivering Muons to the MuCool Test Area

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Abstract

A new way to produce a muon beam for the MuCool Test Area is described. The key idea is to use existing Linac beam-splitting capabilities, based on a fast electrostatic chopper, to split individual 15-Hz Linac beam pulses between the Booster and the MTA, thereby taking advantage of the ability of the Linac to deliver longer beam pulses than the Booster can accelerate. The momentum-analyzing bend at the end of the Linac would be extended so that the 400-MeV H^- beam is steered past the momentum dump toward the MTA. Then it would strike a pion production target to generate muons. Such a beam line, located in existing enclosures, could parasitically deliver at least 50 μs of spill containing up to 1.4×10^{13} protons to the production target at a 15 Hz rate (i.e. 0.75 ms of spill and 2.1×10^{14} protons per second). Linac pulse length extensions could provide further improvements.

Introduction

The MuCool Test Area (MTA) [1] is designed to support a variety of activities related to muon cooling research and development. Before the end of this year, a new beam transfer line [2] will be installed to deliver 400-MeV H^- beam from the Linac to the MTA. The implementation of that line will allow individual 15-Hz Linac beam cycles not needed by the Booster to be sent to the MTA. A primary purpose of the initial experimental program with H^- beam is to assess the response of muon cooling devices such as pressurized RF cavities [3] to ionizing radiation. Although that program typically requires high instantaneous fluxes, low duty cycles and repetition rates of order 1 Hz are acceptable.

Recently thoughts have turned to the possibility of producing a low-energy muon beam for additional tests of muon cooling concepts and techniques. That experimental program would benefit from higher duty cycles and repetition rates. One possibility that has been investigated [4] is to use the 400 MeV H^- beam from the Linac to produce muons in the MTA where suitable cryogenics, RF, and hydrogen facilities already exist. However, if the beam were extracted from the Linac using the magnets [2] now being installed to transfer H^- beam into the MTA, there would be limitations in beam current and duty factor, since only those Linac pulses not destined for the Booster can be delivered by that means to the MTA. For example, if the Booster is using 13 pulses per second, only two MTA pulses of 80 μs and 2.25×10^{13} protons per second would be available (i.e. 0.16 ms of spill and 4.5×10^{13} protons per second).

The concept that is described in this note could increase the spill length and proton intensity available to the MTA by almost a factor of 5 compared to the example above. If the Linac pulse can be made longer than 80 μs, the improvement can be larger.

Reasonable modifications could extend the Linac pulse length to 110 μs, which implies an improvement factor of 5.5 and a spill length of 1.65 ms per second. For comparison, the MICE apparatus is designed to record 600 muons per second using the ISIS beam spill length of 1 ms per second [5]. The improvement factor applies both to a muon experiment such as MICE that uses the single-particle analysis technique and to the macro-particle approach that is being investigated at Fermilab [4].

Present Linac Operation

The Fermilab 400 MeV Linac can accelerate 80 μs H^- beam pulses, with 45 mA peak current, at a 15 Hz repetition rate. The 400 MeV beam is transferred to the Booster using the switchyard located in the Linac diagnostic area. To provide flexibility of operations and to insure the best possible beam and desired intensity, two electrostatic choppers and a Lambertson magnet are used to send the beam to the Booster. Currently, the length of the pulse to be accelerated in the Linac is determined by the Booster intensity requirement. Figure 1 shows the beam current in the different parts of the switchyard.

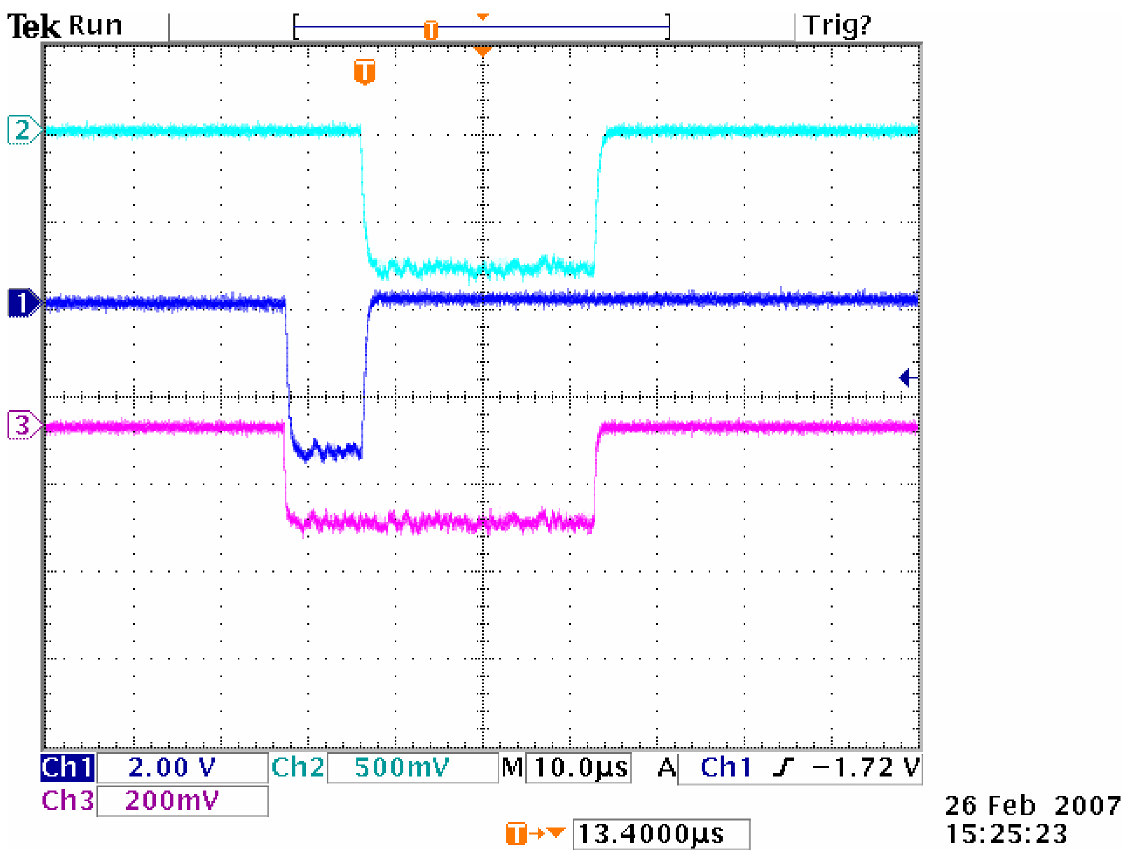

Figure 1: Present switchyard operation: the Magenta trace is the Linac pulse, the Blue trace is the beam pulse directed to the momentum dump and the Cyan trace is the beam pulse directed to the Booster. In the technique proposed in this paper, the Blue and Magenta pulses would be extended an additional 50 μs (at the 30 μs point of the display) and the Cyan pulse to the Booster would be delayed by 50 μs. The beam heading for the momentum dump would be redirected to the MTA muon production target.

During normal operation, the ion source produces a 90 μs H^- pulse with 45 mA peak current. At the upstream end of the Linac, at 750 keV, the low energy chopper removes the initial 6 μs of H^- beam. This part of the pulse is considered not useful because it is produced during the time needed by the source to reach a steady state. At the downstream end of the Linac, the first 5 μs of the remaining beam pulse is chopped by the high energy chopper and directed to the so-called momentum dump, and the rest of the beam is sent to the Booster. (The first 5 μs of the pulse is considered to be damaged in the 750 keV line during the process of charge neutralization and along the Linac due to the slow response of regulation loops.)

The high energy chopper is also used to define the exact amount of beam needed for the Booster, so that the tail of the beam pulse (normally only a fraction of a μs) is sent to the momentum dump. The length of the tail is defined by the low energy chopper and can be extended. For pbar production, which is the most demanding mode of operation, 5×10^{12} protons are accelerated in the Booster using a 28 μs, 35 mA peak current Linac pulse. Even in the pbar production mode of operation there are about 80-28=52 μs of Linac beam that are potentially available.

Overview of Switchyard and H^- Beam Extraction to the MTA

As described above and as shown in Figure 2 below, in normal operation the beam pulse is split at the end of the Linac using the high energy chopper. Most of the H^- beam goes to the 400 MeV transfer line for injection into the Booster. The front and tail of the beam are sent to the Diagnostic Line, where they are bent by the spectrometer magnet and deposited in the momentum dump.

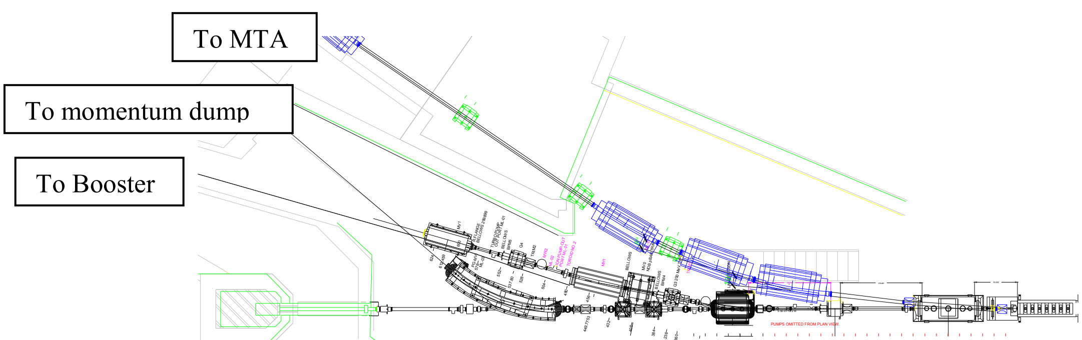

Figure 2: The switchyard as envisioned at the end of 2007 (without the modifications proposed herein). The elements shown in blue are part of the new beam line to send H^- beam to the MTA.

This year an additional transfer line will be built to take individual Linac H^- pulses and transfer them to the MTA. The beam will be bent just before and after the high energy chopper using two pulsed magnets as shown in Figure 3. The rest of the beam line to the MTA is similar to the line shown in blue in Figure 2.

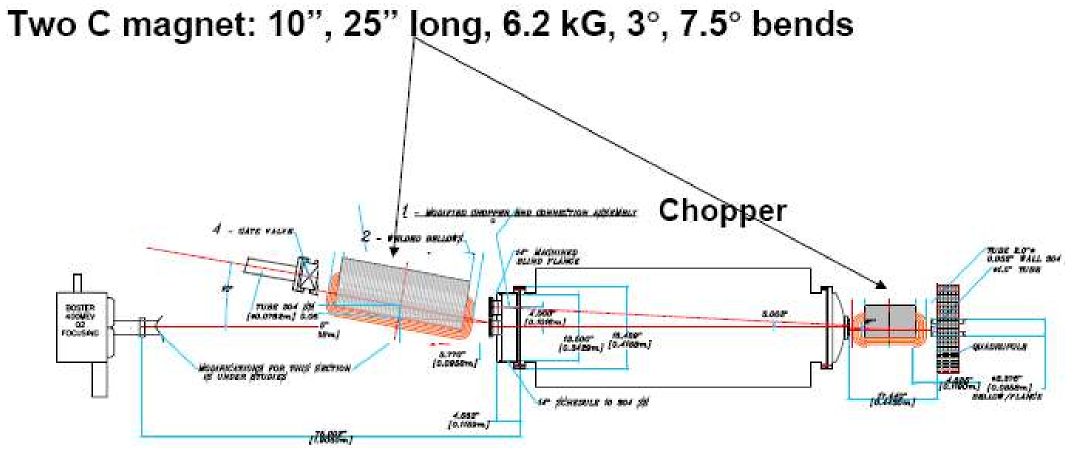

Figure 3: Pulsed magnets before and after the high-energy chopper are used in the H^- transfer line for the MTA. These magnets are fast enough to select individual 15 Hz pulses from the Linac, but they cannot direct parts of a single pulse to be deflected toward the MTA.

The Proposed Muon Beam Production Scheme

All of the Linac beam that is not needed by the Booster can be deflected to the MTA using the scheme indicated in red in Figure 4. As described above and indicated in Figure 1, we can use the front portion of about 50 μs of the beam for the MTA even if the Booster is taking beam at a full 15 Hz rate.

To connect the beam line after the spectrometer magnet to the beam line in the MuCool transfer hall we will need to drill a hole in the wall and add two bending magnets (red elements in Figure 4) and one quad magnet (green element in Figure 4).

One immediate user of the suggested extraction system can be the recently proposed Macroparticle Muon Cooling Experiment [4]. That experiment needs as many protons as possible and a long pion decay channel to reduce pion contamination in the muon beam. An initial estimate is that the 400 MeV proton beam on a 40 cm carbon target can produce enough muons for the experiment [6]. The target has a 5 mm radius and is embedded in a 5 T solenoidal field. The pion decay channel is assumed to be more than 20 meters long.

To satisfy these requirements, the first bending magnet is a combined-function 40-degree bend and the second bend is a 40-degree pure dipole with a larger gap. Each of these magnets can be like the existing spectrometer magnet. The pole tip of the combined function magnet will be machined according to the required focusing strength. We may be able to use the existing MTA 5 T superconducting solenoid around the target. It is 60 cm long with 44 cm inner diameter. The bore is big enough to contain the target and thermal and radiation shields.

Initial Trace3D simulations show that the H^- beam can be focused to a radius of less than 5 mm at the entrance to the solenoid. Figure 5 shows the Trace3D model with final beam ellipses at the entrance to the solenoid. Figure 6 shows a Trace3D calculation of pion beam optics.

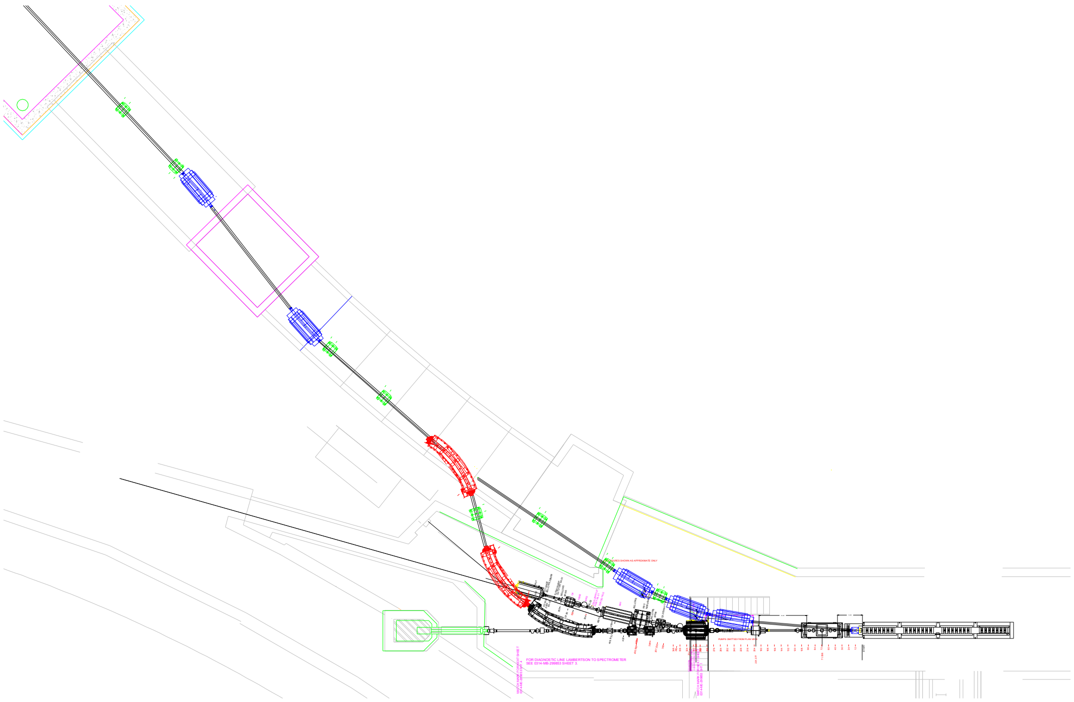

Figure 4. The elements drawn in black are the existing beam lines and the Linac. The blue elements are part of the new H⁻ beam line now under construction. The red elements are part of the muon production system proposed in this note.

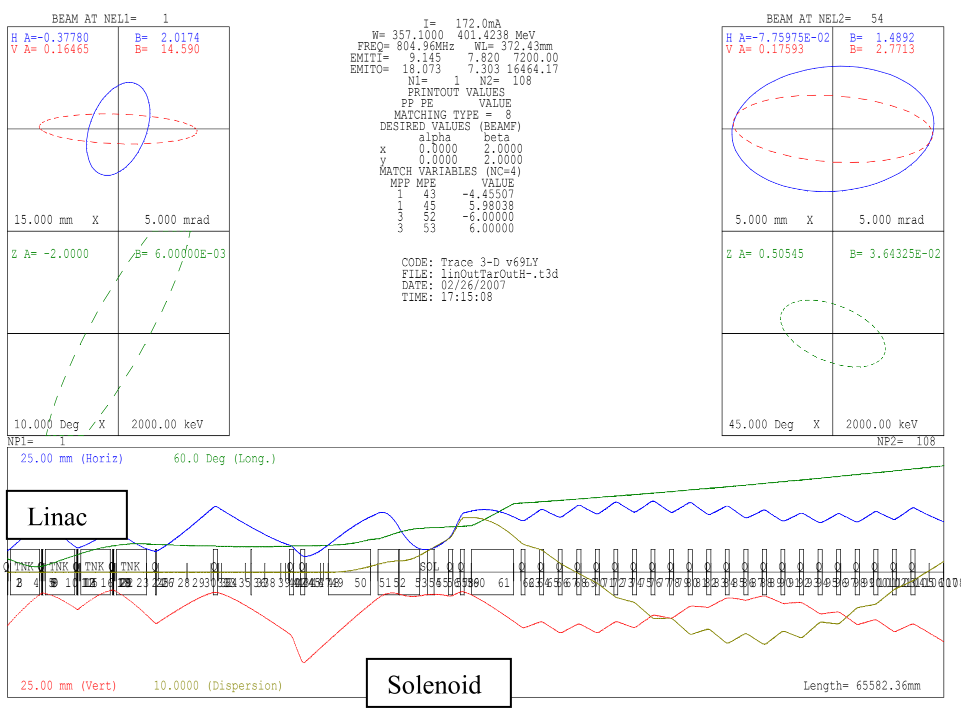

Figure 5: H⁻ beam from the last Linac accelerating module to the MTA hall with target removed. The blue and red traces are horizontal and vertical beam envelopes (95%). The green and brown lines are bunch length and horizontal dispersion. The input beam ellipses are from beam measurements.

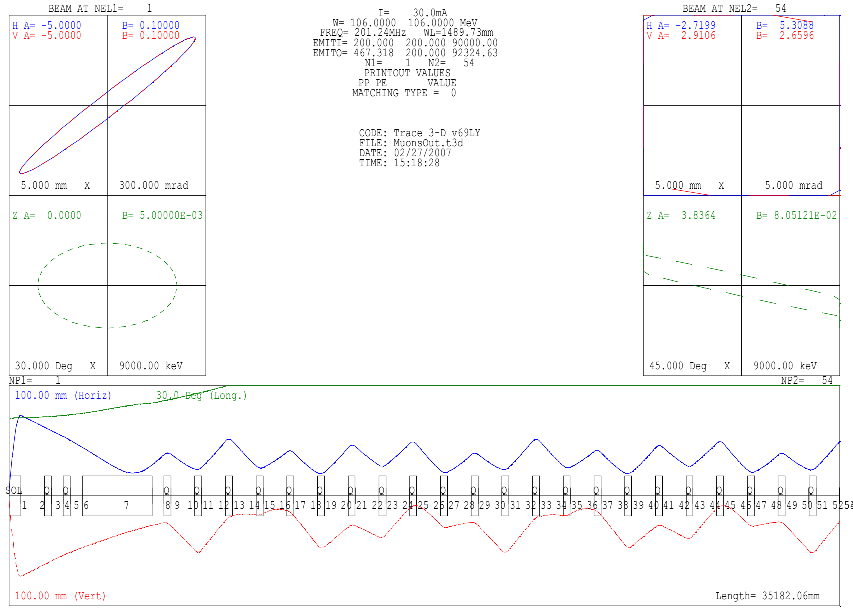

Figure 6: Pion beam with 200 MeV/c momentum collected off the target using a 5 Tesla Solenoid. The large box represents a 40 degree dipole. The rest of the line is a pion decay channel.

Conclusion

A relatively straightforward modification to the Linac switchyard allows a significant improvement in the duty factor and flux of protons on target to produce muons for the MTA.

References

[1]M. Popovic, MuCool Test Area
[2] C. Johnston et al., MuCool Beam Line
[3] R. E. Hartline et al. MuCool Note 285
[4] A. Jansson et al. http://www.muonsinc.com/mcwfeb07/presentations/Broemmel_021407.pdf
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