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Possible Development of μSR Capacity at Fermilab Project X

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The proposed high intensity linac Project X at Fermilab can produce milliamp beams of protons at an energy of 1 GeV in its first construction phase. The beams have a programmable timing structure which allows for a wide variety of applications. Such a beam may be used to produce surface muons at a number of targets. In addition to particle physics applications, dedicated targets can be used for pulsed or bulk CW μSR with adjustable power. A surface target can also form part of a high-power facility, and can generate Low Energy Muons for a variety of studies. The status of the conceptual design is discussed.

KEYWORDS: linear accelerator, muon, material science

1. Introduction

Fermilab is considering the possibility of construction of a very high power linac, known as Project X, to facilitate experiments in particle physics at what is known as the Intensity Frontier. Here we discuss a wider application of Project X to problems in material science, specifically through the creation of a facility to exploit polarized, low-energy muons created via the decay of pions, which can be copiously produced by proposed Project X beams. Such a facility would be unique in the United States and significantly increase global capacity for Muon Spin Rotation (μSR) [1].

2. Project X

The Project X Project at Fermilab is a staged program based on a CW linac using superconducting RF technology. The first stage of the proposed accelerator produces the capability for a quasi-CW 1 GeV beam of approximately 1 MW in power. This beam can be directed onto a target to generate neutrons for fundamental physics and for applications. Figure 1 shows a possible layout of the Project X complex on the Fermilab Site. Further details concerning the project can be found at [2].

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One of the unique features of Project X is its ability to provide a completely programmable beam structure. This is accomplished by a high frequency chopper which can give an arbitrary structure to an underlying beam comprised of narrow (~ 50 ps) bunches occurring at 160 MHz. Further separation of this structure for various uses is obtained by the use of RF separating cavities operating at fractions of the principal frequency. A way to use this to obtain beams for CW or pulsed μSR operations is shown in Figure 2.

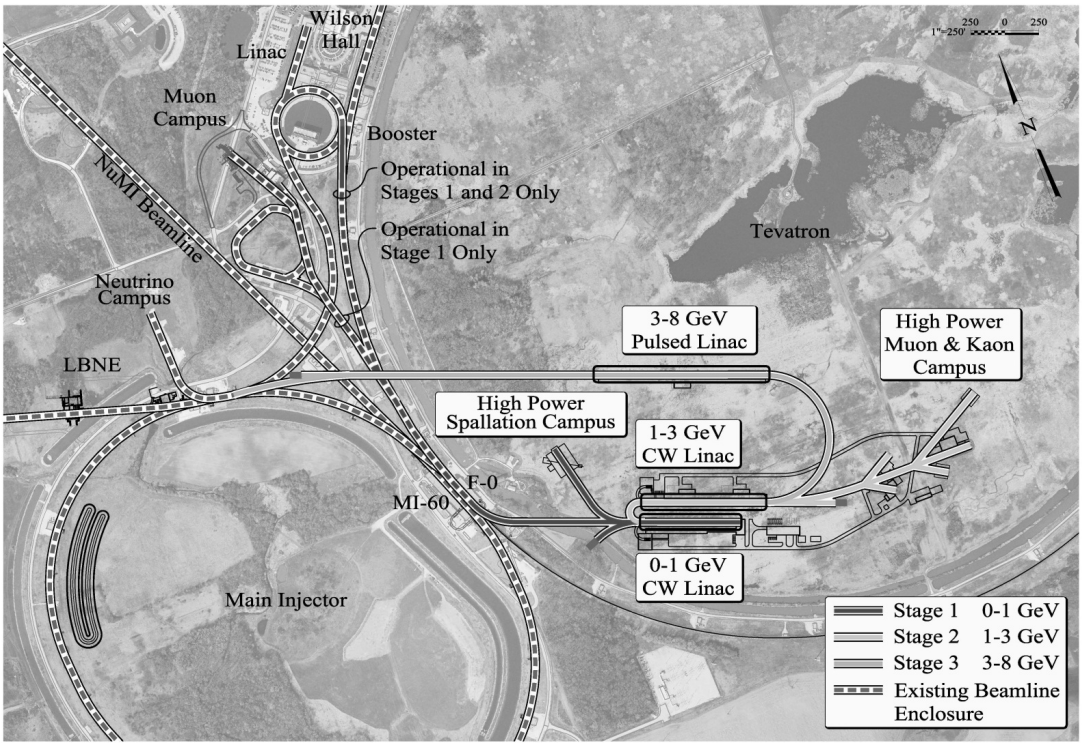

Fig 1. Layout of Project X on Fermilab Site. The 1 GeV beam can be sent to the area labled "High Power Spallation Campus". In addition the program at Stage 1 sends beam to the Booster for use in particle physics experiments and further acceleration in the Main Injector.

3. Technical Concept

Here we describe a two-pronged beam structure for μSR. For the purposes of LEM μSR the achieved efficiencies of the thermalization process are small. Therefore the total beam power is a relevant figure of merit. For this purpose we propose to add a surface muon target and associated beamlines for LEM in the high-power 1 GeV beamline. Such beamlines typically consume 10% of the available proton power, a parameter that can be tuned by detailed target design. Current or future LEM

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technologies can be used with the surface muons to create the desired thermalization. The needs of the user community must determine the exact configuration of beamlines.

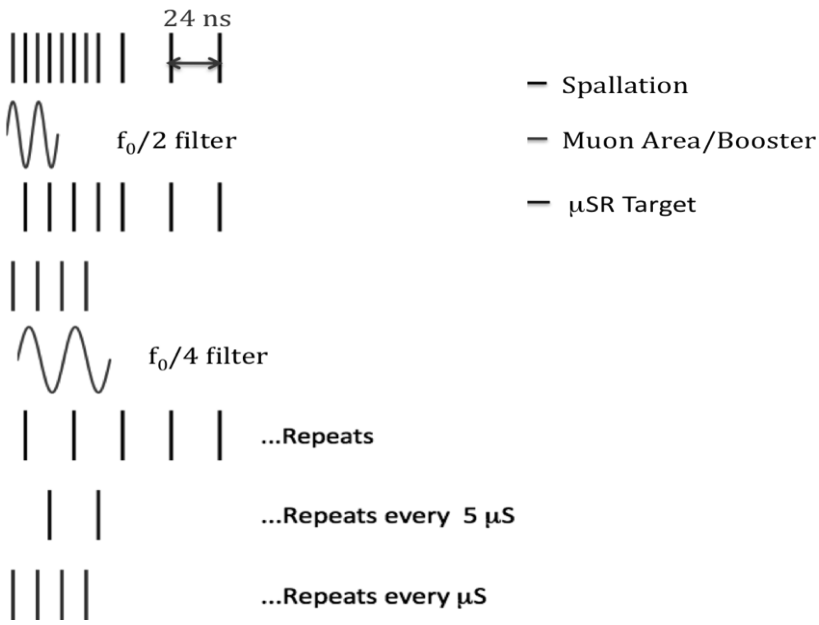

Fig 2. Possible timing structure for Project X Phase I beams. Pulses in the second row from the bottom can be used for a suite of μSR beamlines, programmed to be pulsed or conventional as required by the experimental requirements. The original pulse train is separated by RF separation cavities.

Independently, we can create a set of μSR beamlines which use low-power targeting. By programming the high-frequency chopper at the low-energy end of the Project X Linac, we can produce the beam structure shown in Figure 2, which can supply multiple programs. The μSR pulses are groups of pulses separated by 24 ns. Repeating the structure every 5 ms gives the possibility of using a series of programmable kickers [3] to separate the resulting surface muon beams to service 4 end stations with a repetition rate per station of 50 kHz (20 ms between pulses). The number of pulses given to each endstation per 20 μS interval is programmable, and the endstation receiving each of the 4 independent pulse trains can also be selected by programming the sequence of kicker pulses. The combination of programmable pulse structure and selectable endstations gives a high, perhaps unprecedented, level of flexibility to the facility. A possible overall layout is shown in Figure 3.

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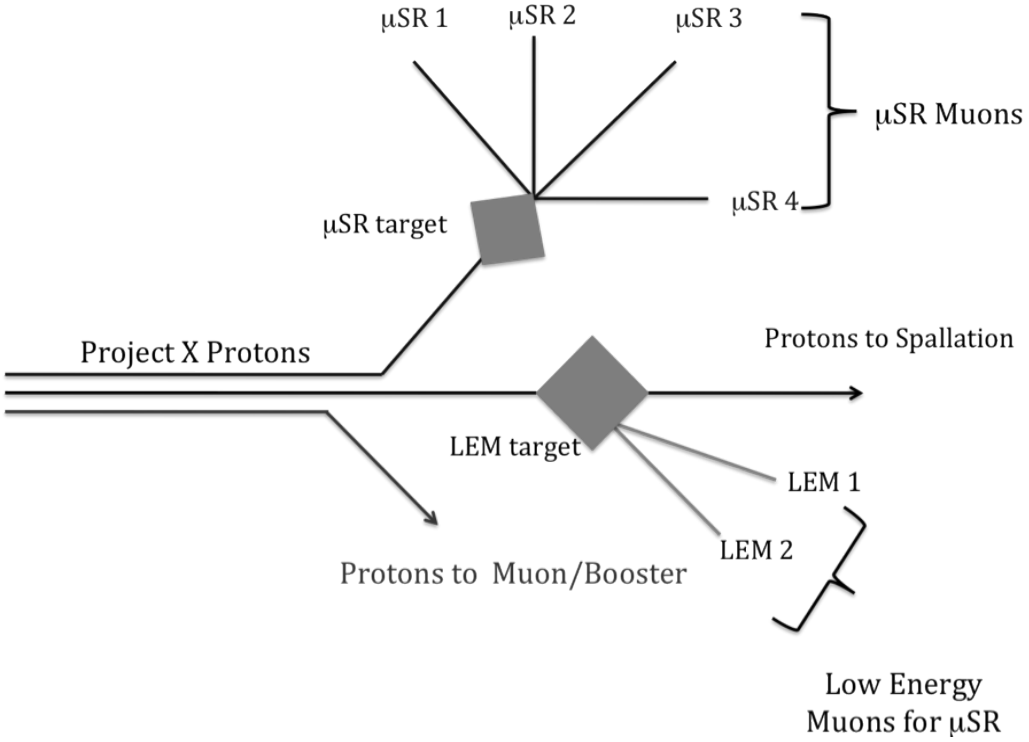

Fig. 3. Conceptual Layout of Project X Phase I beamlines All programs can be run simultaneously. Beamlines μSR1 to μSR4 are separated by kickers downstream of the μSR production target.

4. Intensities

For conceptual purposes we assume a dedicated beam structure with two sets of pulses as shown in figure 2, and two single pulses. The single pulses are appropriate for single-muon μSR, while the double pulses can service a pulsed μSR experiment. Importantly, this beam is independent of the high power pulse train which goes to the spallation area and services LEM experiments. We assume 2 LEM beamlines will be made available.

For the purposes of estimating intensity, we use the following parameters, based on experience at the PSI μE4 beamline:

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i) *A conversion factor between protons on target and muons at the experiment of* 2×10^{-7}. This factor consists of 5×10^{-8} achieved performance and a factor of 4 from anticipated possible optimizations of a new, dedicated system [4].

ii) *A number of protons per Project X bunch of* 1.3×10^{8}. This is consistent with a current of 0.9 mA and 40 bunches/ms.

iii) *A conversion efficiency for creation of LEM muons of* 1.0×10^{-5}.

With these assumptions we obtain:

i) 2.6×10^{6} *muons/sec for each of 2 pulsed μSR beamlines.*

ii) *A saturated rate of* 5×10^{4} *muons/sec for each of 2 conventional single-muon μSR beamlines.*

iii) 1.1×10^{4} *LEM muons for each of 2 stations.*

It should be noted that all of these can run simultaneously. The total power demands of the dedicated μSR proton lines in this reference concept are 6.8 kW, with each pulsed target receiving 2.25 kW and each conventional station 1.1 kW.

5. Conclusion

The need for μSR facilities may grow in the next decade, for example in the use of LEM to explore finite size and interface effects in thin magnetic films. LEM muons are of very high current interest, and require MW scale hadron facilities to produce the requisite fluxes of keV muons, because of the inherent inefficiencies in the known conversion processes. The LEM beamlines discussed in the previous section would add invaluable capacity to a very limited set of world facilities in this area. Including such a capability from an early point in the Project X design will allow us to take advantage of optimizations in acceptance and targetry, an exciting possibility not always available to older facilities. In this way the intensity of the LEM beams we discuss can be made very high, on a scale that is competitive with or exceeds beamlines in Europe or Asia..

The design concept is extremely flexible. The beamlines μSR1-μSR4 can be programmed by a combination of the proton time structure from the Project X linac, the system of muon kickers downstream of the muon production target, and the demand for muons from the experiments. The intensity of the pulsed muon beamlines will be as high or higher than similar lines in ISIS and JPARC. It should be pointed out that the μSR beam area will also be available for fundamental physics experiments with surface muons. It will be possible to leave space for additional beamlines if desired, which can be fed from more frequent pulses in the Project X linac as the stages of that machine evolve.

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The proposed μSR facility offers a window on the materials world which could contribute significantly to the world community. As part of Project X, it would provide an opportunity to establish such a capability in a way which would complement the broad range of fundamental and applied science available at a high power proton linear accelerator.

Acknowledgment

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