Letter of Interest in a Linac-based 8 GeV Accelerator for Booster Replacement and other Applications

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Abstract

Higher intensity for the Fermilab LBNF (Long Baseline Neutrino Facility) requires a "booster replacement" 8 GeV accelerator to take beam from the 800 MeV PIP-II accelerator to the Recycler/Main Injector. Fermilab has considered both linear and circular accelerator solutions for this application. Recent advances in SRF (superconducting rf) technology and performance may make a linac-based approach particularly desirable. A new design of an $\sim$ 8 GeV linac based on SRF systems that incorporate these improvements should be developed. The new accelerator will also provide beam to other experiments and facilities at Fermilab and those capabilities should also be explored.

Introduction

To reach Main Injector (MI) beam power greater than $\sim$1.2 MW on the LBNF neutrino-producing beamline, beam power injection must be increased beyond the capabilities of the Fermilab Booster; a "booster replacement" is required. This requirement is the expected sequel to the PIP-II Linac, [1] which provides the first 800 MeV of acceleration for the replacement of the MI 8 GeV injector. This replacement was the goal of the Project X design. [2] Project X considered an 8 GeV Linac or a 3 GeV Linac plus a rapid-cycling synchrotron (RCS) for this application. An 8 GeV Linac solution would avoid the complication of an intermediate ring, with its limitations. Because of the high intrinsic efficiency of cw SRF acceleration, it could potentially have more intensity available for other applications. We propose to investigate the Linac-based version of this upgrade, adapting it to the current and future beam requirements and incorporating improvements in SRF design and performance.

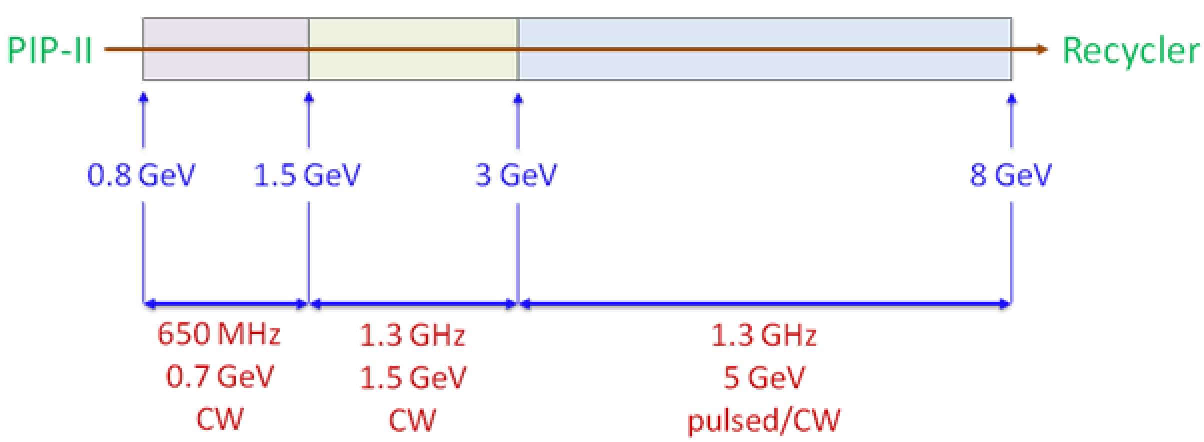

Figure 1: Components of an 8 GeV Linac scenario. [3]

SRF and Beam Design Approaches

SRF technology has advanced significantly since the development of Project X. [4] [5] [6] A significant advance is in the procedure of nitrogen doping or infusion of rf cavities, which has been shown to reduce the BCS surface resistance below previously perceived limits. Also, effective magnetic flux expulsion by fast, high thermal gradient, cooldown has achieved record low residual resistances. These innovations combined with continuing optimization of cavity treatments have greatly increased useable gradients, with increased Q values. Most recently, a 75/120 K modified low temperature bake improved Q by 50 per cent, and increased rf gradient to 50 MV/m for 1300 MHz cavities. [7] This and other advances and expcerience in cavity construction and processing should enable substantially larger operating gradients and improved acceleration efficiency. Niobium-Tin coatings could allow further improvements.

Changes in beam requirements have also changed the optimal booster replacement Linac. The Project X version had a 3 GeV cw Linac followed by a 3 to 8 GeV pulsed Linac. Updating these requirements according to future physics needs could change the parameters of the cw Linac in energy and intensity, as well as the 8 GeV requirements for pulsed current. The cost and benefit of a cw 8 GeV linac should be considered. Injection into the Recycler and/or Main Injector should also be reevaluated and optimized, considering injection losses and acceptances and changes in the Main Injector since Project X. Injection foil heating and beam losses are an important challenge. Laser-assisted injection could be developed for this application. Because of the high injection energy, infrared lasers can be used.

R&D

Following studies on parameter optimization, the Linac-based scenario must be updated to include the improved gradients and Q-values that have been developed in the Fermilab SRF program . The changes in Linac location and beam requirements should also be incorporated into a design that fits within the Fermilab site and can properly inject into the Recycler and Main Injector. A self-consistent model of the PIP-II to RR/MI linac with transport should be developed, matched to the existing Fermilab facilities, including the current PIP-II placement. This model should be used for simulation tests of beam losses, stability and performance.

The design study should identify critical hardware prototypes needed to implement the upgrade. This would include test cavities establishing the best practices in obtaining efficient high-gradient acceleration at Booster replacement parameters. Components for laser-assisted stripping could be developed and tested. Other components could be developed, including resonance control (RC) components and algorithms, which allow pulsed regime at small bandwidth, new inexpensive HP couplers and new cryomodules having low static heat load.

The 8 GeV linac version should be compared in performance and cost to other potential approaches, which would include versions of an extended linac (to 2 or 3 GeV) coupled to a rapid-cycling synchrotron (RCS). The linac studies would also contribute to the development of the linac portion of RCS scenarios. The other physics applications should be considered. Some experiments, such as mu2e and mu-e-gamma, prefer cw beam, which would be best served by a cw linac. Other experiments prefer pulsed beam, and these may or may not be matched to a pulsed linac output. Some experiments may require an accumulator ring to obtain intense proton pulses, which could add significant costs.

References

[1] M.Ball et al. The PIP-II Conceptual Design Report. Fermilab report (October 2017).

[2] S. Holmes et al. Project X Accelerator Reference Design, Physics Opportunities, Broader Impacts. Fermilab technical memo TM-2557 (June 2013).

[3] M. Checchin. PIP-III SRF Linac Costs. presentation to the 2018 Fermilab Scientists Retreat.

[4] A Grassellino et al. Nitrogen and argon doping of niobium for superconducting radio frequency cavities. *Superconductor Science and Technology*, 26(10):102001, 2013.

[5] A. Romanenkov et al. Dependence of the residual surface resistance of superconducting radio frequency cavities on the cooling dynamics. *J. Appl. Phys.*, 115:188, 2014.

[6] A. Grassellino et al. Unprecedented quality factors at accelerating gradients up to 45 MV/m in niobium superconducting resonators via low temperature nitrogen infusion. *Superconducting Sci. Tech.*, 30:094004, 2017.

[7] D. Bafia et al. *Proc. 19th Int. Conf. on RF Superconductivity. Dresden*, page 588, 2019.