Adaptation of the Fermilab Proton Source to Support New Muon Facilities

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TUPC41
FERMILAB-POSTER-24-0050-AD

Near-term Fermilab Upgrade Plans

LBNF is a new Main Injector beamline that takes up to 2.4 MW of 120 GeV protons and generates an intense horn-focused neutrino beam for the **DUNE** neutrino program.

PIP-II includes a 0.8-GeV H^-, 2mA CW-capable SRF linac, an upgrade in Booster ramp rate to 20 Hz. PIP-II also includes upgrades to Booster, Recycler, and Main Injector to support 1.2+ MW LBNF.

Linac	Achieved	PIP-II	ACE-MIRT
Current	20-25 mA	2 mA	2 mA
Energy	0.4 GeV	0.8 GeV	0.8 GeV
Booster	Present	PIP-II	ACE-MIRT
Intensity	4.8e12	6.5e12	6.5e12
Energy	8 GeV	8 GeV	8 GeV
Rep. Rate	15 Hz	20 Hz	20 Hz
8-Gev Power*	25 kW	80 kW	12-24 kW
Main Injector	Present	PIP-II	ACE-MIRT
Intensity	58e12	78e12	78e12
Cycle Time	1.133s	<1.2 s	~0.65 s
120-GeV Power	0.96 MW	~1.2 MW	1.9-2.3 MW

Table 1: Parameters for Fermilab proton complex. *8-GeV beam power given for what is available simultaneous with 120-GeV program.

ACE-MIRT is a newly conceived, P5-recommended, Fermilab accelerator upgrade to reduce the Main Injector cycle time to ~0.65s, deliver 2+ MW to LBNF, develop high-power neutrino targetry, and to modernize Fermilab accelerators to improve reliability.

Ideally, ACE-MIRT would begin as soon as possible and be completed by the end of mu2e physics run (projected ~2033).

Proposed Muon Collider R&D, not currently in scope, but here are areas of muon collider R&D synergistic with Fermilab capabilities:

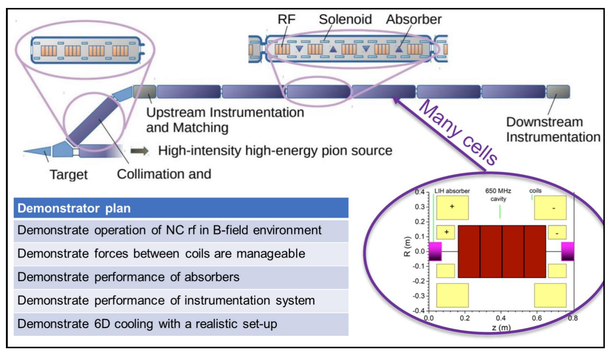
1) Engage Fermilab technical expertise on facility design & prototyping.

2) Extend R&D program in targetry and irradiated materials to include materials and targer concepts related to high power muon-production.

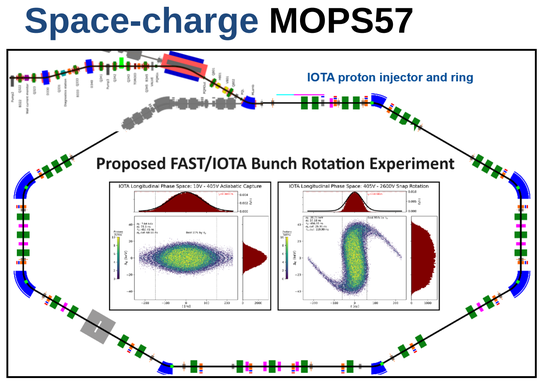
3) Fermilab Muon Campus is a possible site for a muon cooling demonstrator facility, either with 0.8 GeV or 8 GeV protons.

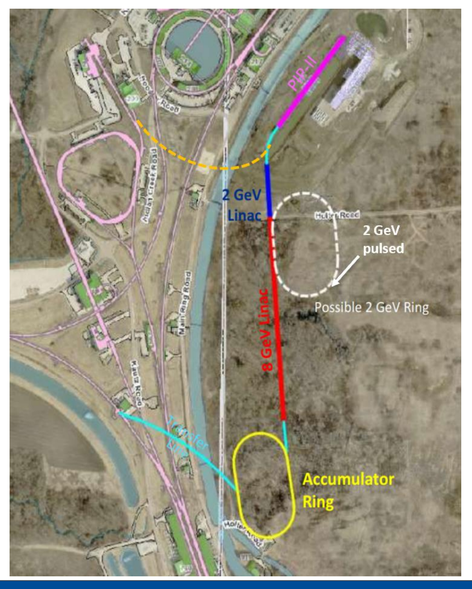
4) Extreme space-charge & bunch compression R&D.

Muon Cooling Demonstrator



IOTA Experiment for Proton Pulse Compression at Extreme Space-charge MOPS57





ACE Booster Replacement Concept 8-GeV Linac and 8-GeV Accumulator Ring

Neuffer et al. “An 8 GeV linac as the Booster replacement in the Fermilab Power Upgrade”

This concept was developed with a post-ACE-MIRT upgrade of the DUNE/LBNF neutrino program as a core focus.

However this technical design provides relevant analysis for many of the challenges facing a muon collider proton driver.

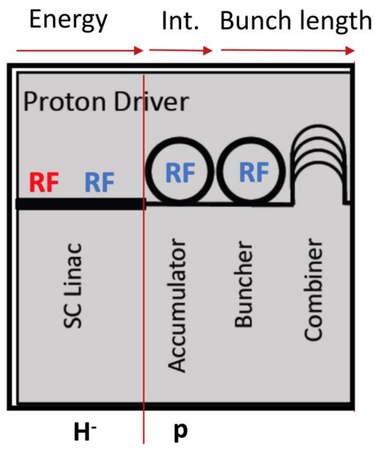
Fermilab Site-Filling Muon Collider

WECD3
“The US effort towards making a Muon Collider”

WEPR35
“A High-Energy Muon Collider at Fermilab”

SUPC067
“Lattice design of a pulsed synchrotron for a muon collider fitting within the Fermilab site boundary”

Example Fermilab Muon Collider Proton Driver



Energy	8 GeV
Pulse Intensity	320 e12
Number of Bunches	4
Pulse Rate	10 Hz
Beam Power	4 MW
Bunch Length (AR)	20-40 ns
Bunch Length (CR)	1-3 ns
Ring Circumferences	300-500 m
95% Norm. Emittance	120-216 π mm mrad
Laslett Space-Charge limit	0.2-0.6

Table 2: Example parameters for Fermilab proton driver.

8-GeV H- Linac For a 2ms pulses every 10 Hz, 4 MW beam power corresponds to 25mA average current.

Concept for ILC-type cavities, LCLS-II cryomodule, E-XFEL klystrons.

If accumulated in four 20ns bunches in 300m ring, then 92% of the beam must be chopped and the remaining 8% must average 312mA. Therefore likely will use a longer linac pulse, longer accumulated bunches, and/or multiple linac frontends.

Accumulator Ring (AR) A 500m conventional ring or 300m superconducting ring at 8 GeV. H^- laser stripping injection may be necessary for controlling injection losses in the the high power beam.

Option of injecting at lower energy (4 or 6 GeV) and accelerating to 8 GeV.

Compressor Ring (CR) uses snap bunch rotation to compress four 20-40 ns bunches into four 1-3 ns bunches

Likely a separate ring from AR, differs by phase-slip factor, different requirements for injection and RF. But similar aperture and circumference.

At 3 ns, 4 MW, and a stable Laslett space-charge tune-shift parameter of 0.2, the 95% normalized emittance must rise to 216 π mm mrad. Further performance gains may be achievable with extreme space-charge R&D.

Combiner directs the four bunches to converge on the target as simultaneous and narrow pulse. Longitudinally the bunches overlap but transversely the bunches are side-by-side, increasing the effective emittance of the beam on target by at least a factor of four.

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