Fermilab Accelerator Complex Evolution (ACE): The Main Injector

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Motivation: New Accelerator Front End & New Beam Line for Neutrino Physics Means MORE POWER for Beam on Target.

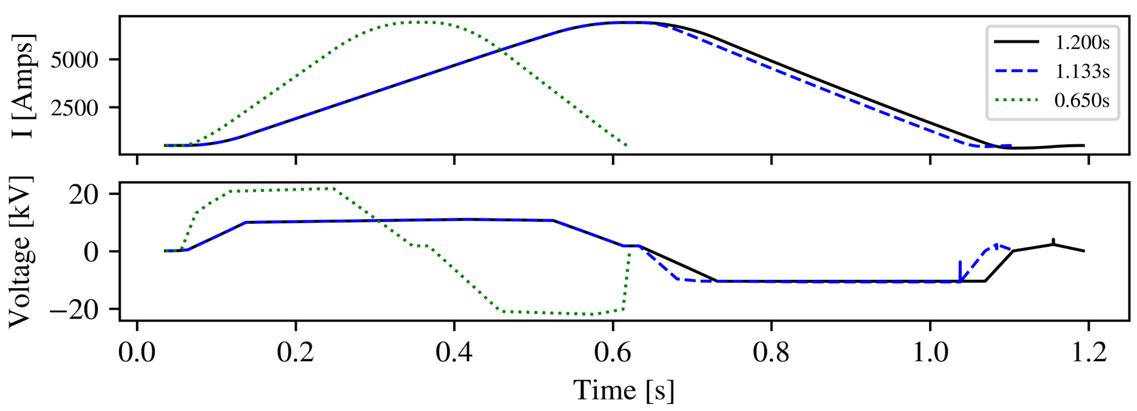
The existing FNAL linear accelerator (LINAC) operates at 15 Hz and was commissioned in 1970. It will be replaced by a new CW SRF Linac once the PIP-II project is complete in 2029. In the near term this beam will feed the 8 GeV Booster synchrotron, which will be upgraded to cycle at 20 Hz.

Additionally, a new 120 GeV proton beam line and target hall will be built to support the Long Baseline Neutrino Facility (LBNF) program and the Deep Underground Neutrino Experiment (DUNE) in South Dakota, USA.

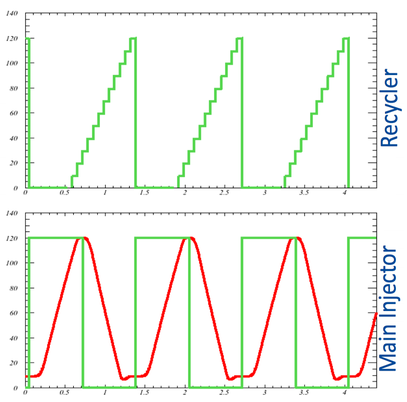
Increasing beam power increases neutrino flux. The Main Injector (MI) currently ramps to 120 GeV once every 1.2 sec at 5 x10^{13} Protons on Target. Operating at this rate & intensity with a 20 Hz source yields around 1.25 MW beam power.

If we can increase the ramp rate (GeV/sec) then beam power goes up. One goal of the Accelerator Complex Evolution project will be to cut the MI duty period almost in half, from 1.2 seconds to 0.65 sec. To achieve this goal additional magnet power supplies will need to be installed as it requires doubling the power supply operating voltage.

New Main Injector Ramp Profile



Above: Comparison of bend magnet power supply current and voltage across ramp periods of 1.2 sec, 1.133 sec and 0.65 sec. Notice the volage required for the 0.65 sec mode is about twice the current operating voltage. Peak dP/dt will almost double: 240 -> 430 [GeV/c/s]. Existing power supplies cannot meet this demand. New power supplies for bend and quad strings will be necessary for adequate voltage.



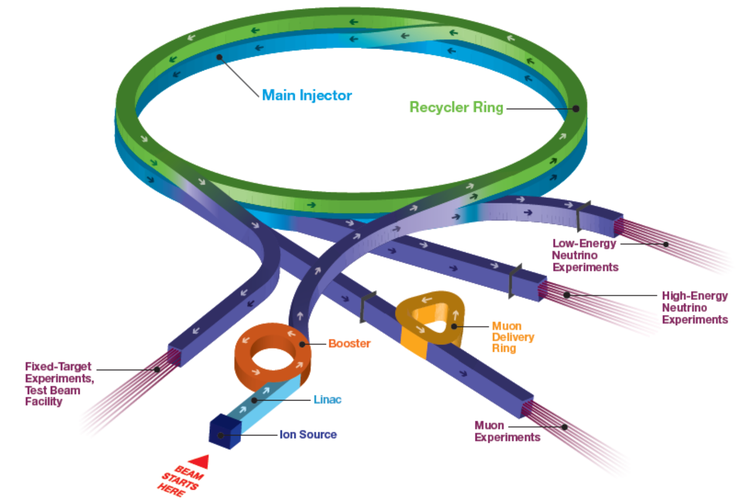
The plots at left represent the current process of proton stacking, transfer and acceleration for a typical 120 GeV pulse for neutrino production (NuMI Program) using the 15 Hz Proton Source.

The top plot at left shows the beam intensity in the Recycler Ring. Each step represents one injection of 8 GeV protons from the Booster (~ 5x10^{12} protons per injection). The height of each step represents the intensity of each injection with a period of 1/15 second (66 msec)

Utilizing a process called slip stacking those protons are injected into the Main Injector and accelerated to 120 GeV. The bottom plot at left represents proton intensity in the MI (green) overlayed with the MI bend magnet current (red). Cutting this period in half doubles beam power.

Impact on Accelerator Operations

- PIP-II, LBNF and ACE will necessitate physics beam shutdown for two+ years. Operations needs to maintain staffing, training, etc., which is more difficult to do during long shutdowns.
- Restarting beam post-PIP-II & LBNF will be a challenge. Aside from commissioning a new Linac and beam line the accelerator controls system will transition from ACNET to a new controls system (likely EPICS based).
- Many new console applications & procedures coupled with operations staff turn-over will present challenges for commissioning. New (not yet hired) operators will play a crucial role in the success of the plan as they work along side experts from the Proton Source and Main Injector departments.
- In addition to commissioning the upgraded Main Injector, operators will also be commissioning a cryogenic linac (PIP-II), an upgraded Booster and new extraction beam line and target hall (LBNF). All of these changes will directly impact operational readiness, machine reliability, and ultimately performance.
- Knowledgeable and experienced people are going to leave the lab during the long shutdown. **Building the processes to ensure smooth transition from commissioning to operation will be integral to our success.**



Current Fermilab Accelerator Configuration: After the PIP-II & LBNF/DUNE projects are complete a new SRF linac will provide beam to the existing Booster, which will continue to inject protons into the Recycler (proton stacker). Cutting MI ramp period in half will serve to nearly double the beam power to the LBNF/DUNE target.

Main Injector Systems Needing Upgrades for ACE Plan:

- MI bend & quad magnet power supplies.
- MI LCW & ponds (e.g. additional evaporative cooling towers added).
- Power substation upgrades (e.g. new 345 kV transformers added) along with new feeder/bus cables.
- Upgrade/modify existing power feeders/bus across the MI.
- New RF Anode Supplies & cavities. Doubling beam power means doubling RF power.
- Correctors & beam line power supplies need to be upgraded for fast ramp.

The ACE Plan Includes the Following Key Components:

- Upgrades to Main Injector accelerator systems and infrastructure to enable beam power above 1.2 MW through faster cycle time and efficient operations of the complex with the aim of achieving DUNE goals as fast as possible.
- Accelerated profile of high-power target system R&D to enable above 1.2 MW operations in DUNE Phase I.
- Establishment of a project for Booster replacement with superior capacity, capability, and reliability to be tied to the accelerator complex at a time determined by the DUNE physics.

The ACE Plan Capitalizes on the PIP-II Investment & Delivers:

- More protons-on-target to LBNF than PIP-II alone can provide.
- A Booster Replacement that will provide:
  - Higher per pulse intensity out of Booster replacement, which will eliminate necessity for slip-stacking.
  - A modern and flexible Fermilab Accelerator Complex that enables new capabilities (e.g. a muon collider program).