

PIP-II to Advance Intense Particle Beam Physics

With the power of PIP-II, Fermilab (CSA CSM) is planning to construct and operate the foremost facility in the world for particle physics research utilizing intense beams.

In 2014, the Particle Physics Prioritization Panel published a report that examined ways to keep the US at the forefront of particle physics and recommended investing a larger portion of the DOE budget in the construction of new experimental facilities, and especially muon and neutrino programs. The panel advocated that building a world-leading neutrino program hosted in the US should be one of the nation's top priorities.

"Proton Improvement Plan-II (PIP-II) is a necessary upgrade to Fermilab facilities in order to pursue this new direction," said Tom Nicol, mechanical engineer and group leader, told *Cold Facts* when we visited Fermi National Accelerator Laboratory in April. Nicol described PIP-II as a scaled-back version of Project-X, which was proposed in 2011 as a new high intensity proton accelerator complex and planned to produce beams of up to 8 GeV.

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PIP-II will be an upgrade to the laboratory's existing facilities, providing powerful, high intensity proton beams and supplying power for neutrino experiments. The Mu2e and Muon g-2 experiments and the Long-Baseline Neutrino Facility (LBNF) will all rely on PIP-II as the source for beam.

How does it work?

In PIP-II, protons are emitted from a source and formed into a beam, which is then sent down a 250-meter-long superconducting linear accelerator (linac) to an energy of 800 MeV, or 800 million electronvolts.

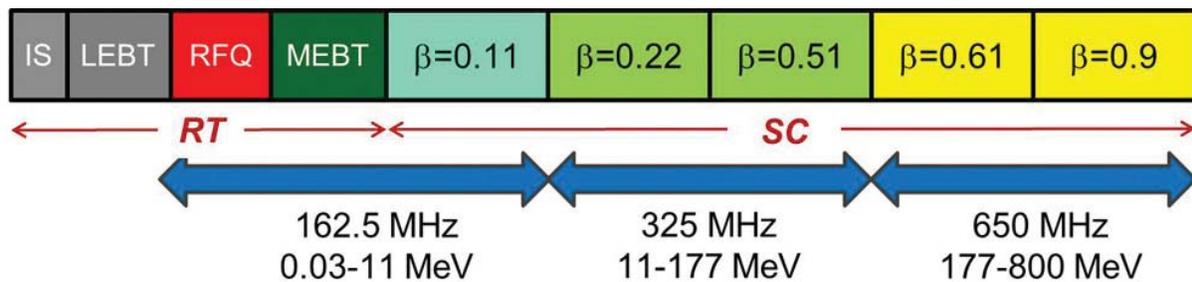


Figure 1: This schematic shows the layout of the PIP-II linear accelerator. The room temperature (RT) section is comprised of an ion source (IS), low energy beam transport line (LEBT), radio frequency quadrupole (RFQ) and medium energy beam transport line (MEBT). Beam then travels through the five superconducting (SC) accelerating sections. Image: Fermilab

Once the proton beam exits the linac it is steered toward the existing booster accelerator, where it is then accelerated to 8 GeV, or 8 billion electronvolts. From there, the protons will be sent toward various targets and strike them, initiating strings of newly produced particles, some of which will eventually decay into muons. These short-lived particles will be captured within the MC-1 building, where they will enter a detector so that scientists can study them.

The other protons exiting the booster will be steered down a different path in the accelerator chain to the existing main injector-recycler complex, a set of rings 3.3 kilometers in circumference. There, the protons will be accelerated to an energy of 120 GeV before they strike a target to produce neutrinos. The neutrinos will travel 1,300 kilometers at nearly the speed of light to the LBNF, to be built in Homestake, South Dakota, where scientists will study their behavior.

SRF technology

Beam acceleration in PIP-II relies on superconducting radio frequency (SRF) components, like those developed for the International Linear Collider, to accelerate

beam quickly and efficiently. These cavities are highly polished, nearly perfectly shaped niobium structures tasked with generating the electric fields needed to achieve particle acceleration—without creating wasted heat. A string of SRF cavities is housed in a cryomodule, where they are bathed in liquid helium to keep the cavities at the extremely cold temperature necessary for their operation.

There are five types of cavities in PIP-II: half-wave resonator cavities, two types of single-spoke resonator cavities (SSR1 and SSR2) and two types of elliptical cavities.

PIP-II capitalizes on both Fermilab's expertise in SRF technologies and the expertise of cooperating scientific institutions, including Argonne National Laboratory (CSA CSM), which is building the half-wave resonator cryomodule. Fermilab is building the SSR1 cryomodule now and working on the design of the rest of the cryomodules.

Linac design

The heart of PIP-II is the linac (Figure 1), which consists of a warm front-end and a series of five superconducting accelerating sections that the beam passes through to reach 800 MeV.

The warm front-end is a room temperature section composed of an ion source (IS), low energy beam transport line (LEBT), radio frequency quadrupole (RFQ) and medium energy beam transport line (MEBT). The ion source produces H⁻ beam at 30 keV. The LEBT brings the beam up to 30 keV before transporting it to the 162.5 MHz RFQ, which accepts and accelerates the beam to 2.1 MeV. By the end of the MEBT, the beam is in the desired bunch structure for injection into the superconducting sections of the linac.

The first superconducting accelerating section of the PIP-II linac includes eight 162.5 MHz half-wave resonator cavities and an equal number of solenoids inside a single cryomodule. The solenoids, a type of electromagnet, are used to focus the beam as it travels. The next two accelerating sections are composed of 325 MHz single-spoke resonator cavities—two SSR1 cryomodules each containing eight cavities and four solenoids, followed by seven SSR2 cryomodules with five cavities and three solenoids.

The final accelerating sections are of 650 MHz elliptical cavities, one at low beta (LB650) and one at high beta (HB650). Beam in the 11 LB650 and four HB650 cryomodules is focused not by solenoids but by normal conducting quadrupole doublets located outside of the cryomodules.

The PIP-II accelerator complex is planned to deliver beam in the early part of the next decade, enabling the exploration of new physics by accelerating intense particle beams. It will also help pave the way for future advances in accelerator technology.



PIP-II will feature five types of SRF cavities, including (clockwise from top left) single-spoke resonator cavities, five-cell, 650-MHz cavities and half-wave resonator cavities. Images: Fermilab