Muon Monitors for the Long-Baseline Neutrino Experiment

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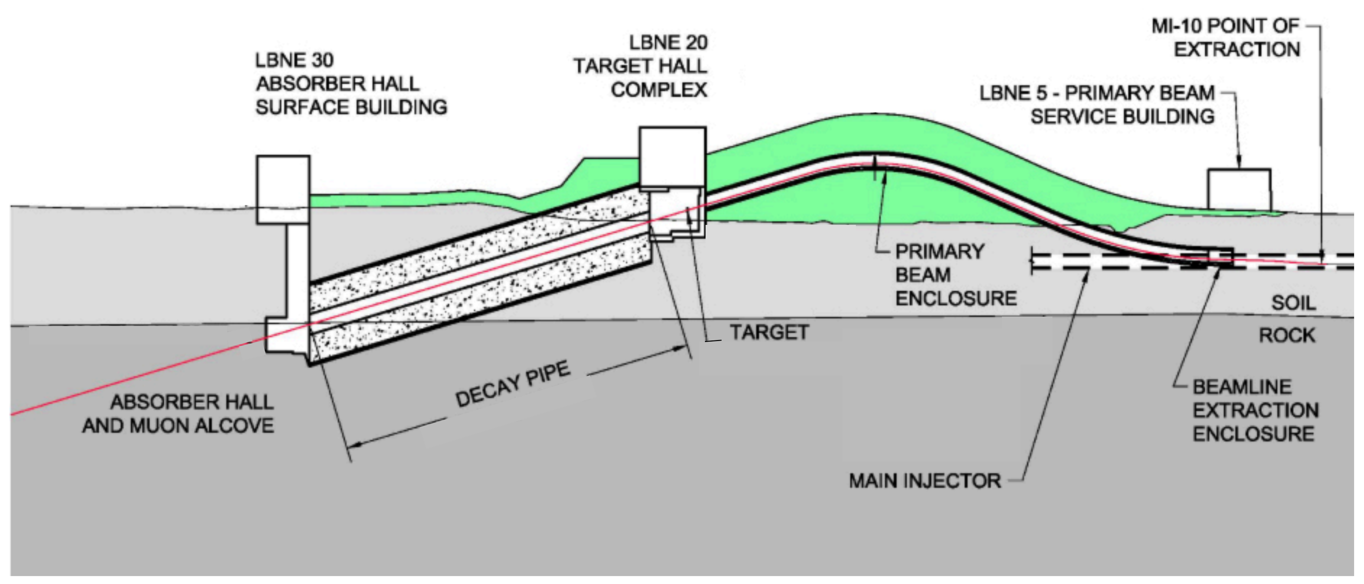
LBNE Beamline



The Long-Baseline Neutrino Experiment (LBNE) beamline will originate with 60-120 GeV protons at Fermilab. The protons will strike a graphite or beryllium target, producing hadrons including pions and kaons. Two magnetic horns will focus the secondary hadrons. The hadrons will be allowed to decay in a 204-m long decay pipe. A water-cooled aluminum, steel and concrete absorber will sit at the end of the decay pipe. A deep muon alcove located in the absorber hall will house a series of detectors to measure the flux of muons exiting the absorber.

Muon Monitor Goals and Layout

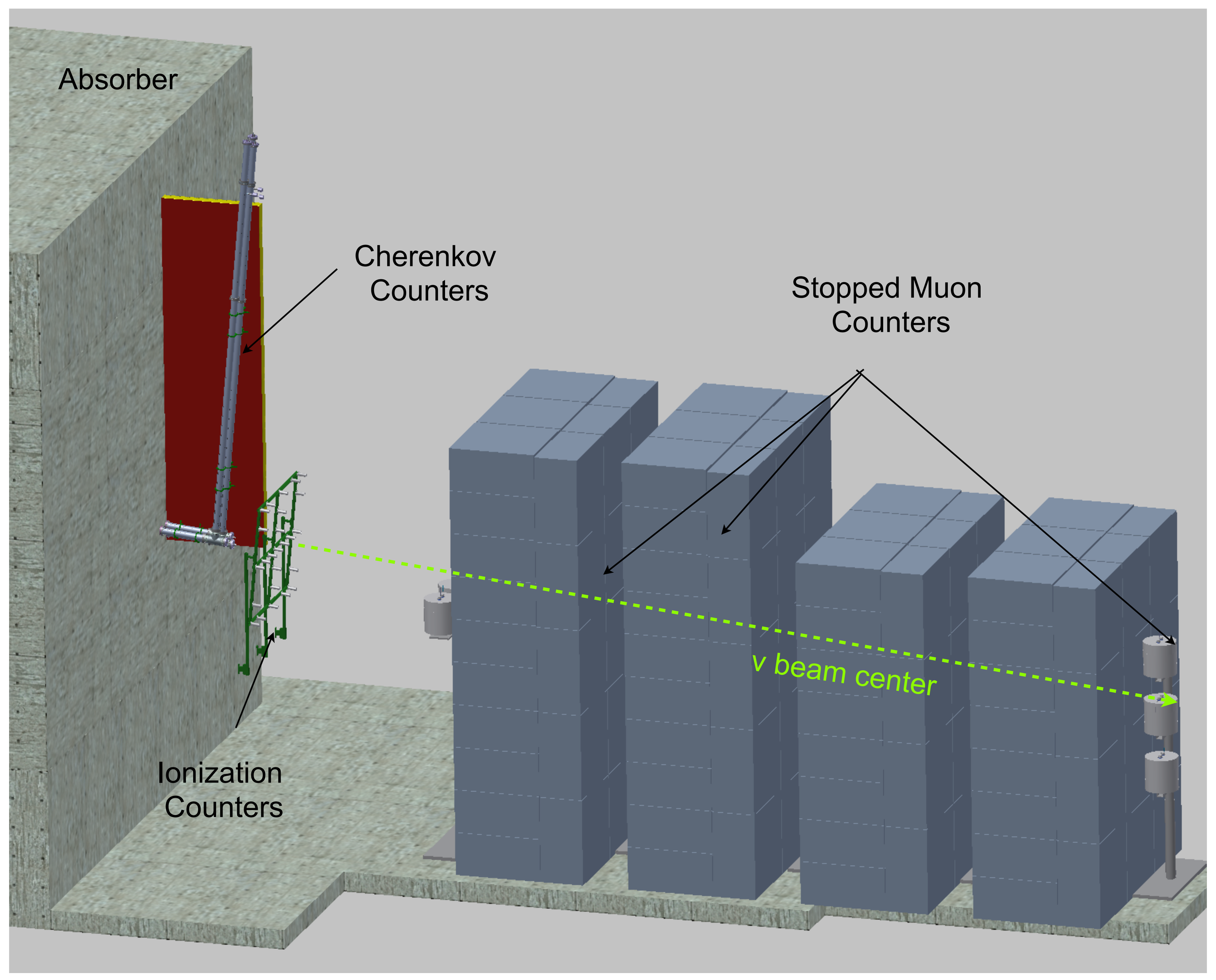
The design goals for the LBNE muon monitors are to:

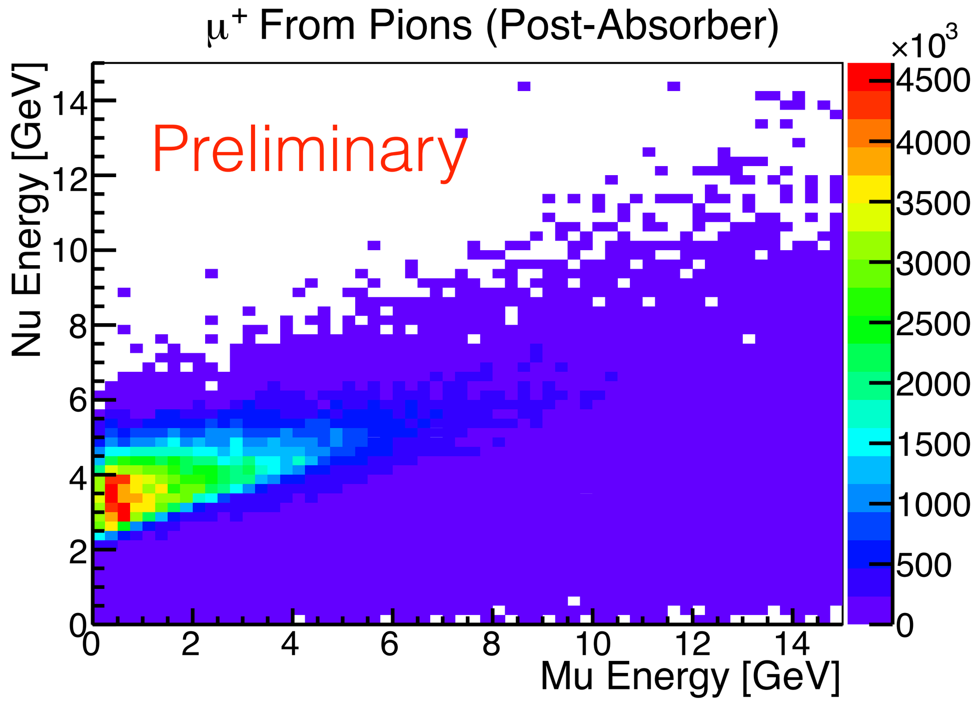
- Monitor the intensity, beam center, and beam width on a spill-by-spill basis
- Discriminate between muons and other sources of ionizing radiation
- Provide an absolute normalization of the muon flux at the <5% level
- Provide information about the energy spectrum of the muons

To achieve these goals, three different muon monitoring systems are being designed:

- An array of Ionization Detectors
- Stopped Muon Counters
- Threshold Gas Cherenkov Detectors

Layout of the Muon Alcove in the Absorber Hall





The detectors will see an expected flux of millions of muons per cm^2 per beam pulse.

The detailed design of the LBNE absorber is not finalized. But for the conceptual design for the absorber, the muons that exit absorber originate from pions in the same regions of phase space that contribute to neutrino flux above 4 GeV.

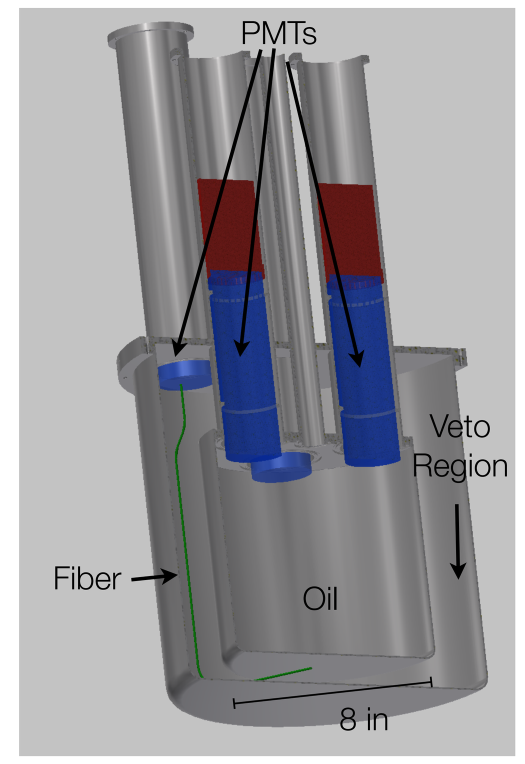
Ionization Detectors

An array of ionization detectors will be used to monitor the beam position and profile on a spill-by-spill basis. Long term stability and radiation hardness are crucial factors in the design. The technologies under consideration for these detectors are CVD diamond detectors and secondary emission detectors.

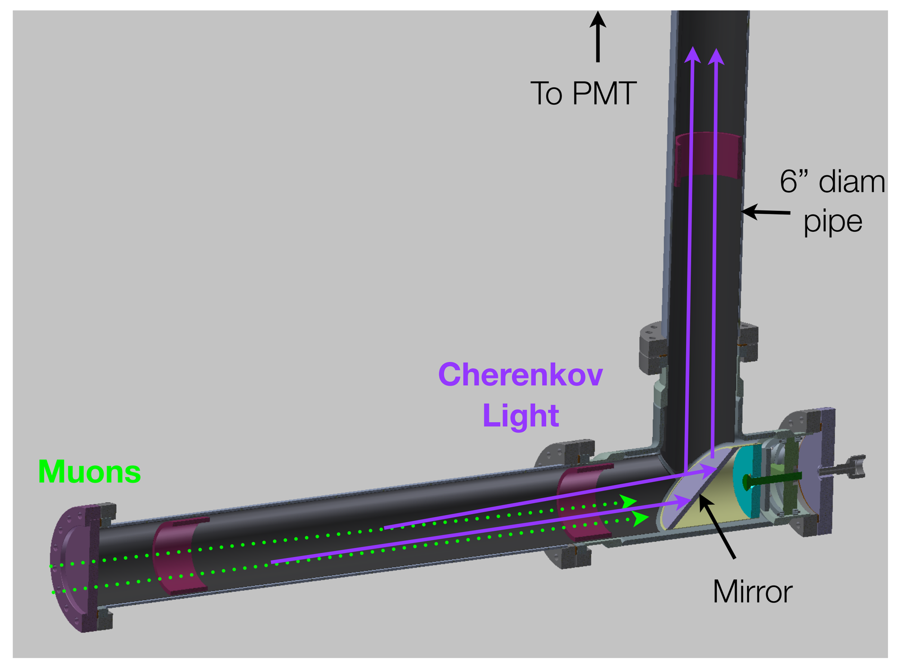
Stopped Muon Detectors

These will look for muons that stop in non-scintillating oil in the central region. After the beam pulse, the Cherenkov signal for the muon decay electrons will be detected. An optically isolated veto region will be filled with an oil-based liquid scintillator and wavelength-shifting fibers to reject external events such as slow neutrons. To isolate the signal associated with anti-neutrinos these detectors will also look for the ^{12}B decay (τ~30 msec, E_{max}=13.4 MeV) following μ^- capture on ^{12}C. By measuring the amplitudes of the appropriate lifetimes, these detectors isolate the muon signal from other backgrounds.

These detectors will be placed behind different depths of shielding. Unlike the ionization detectors, this does not integrate flux above some energy, but picks out a specific energy since the muons range out at stop in a specific location.

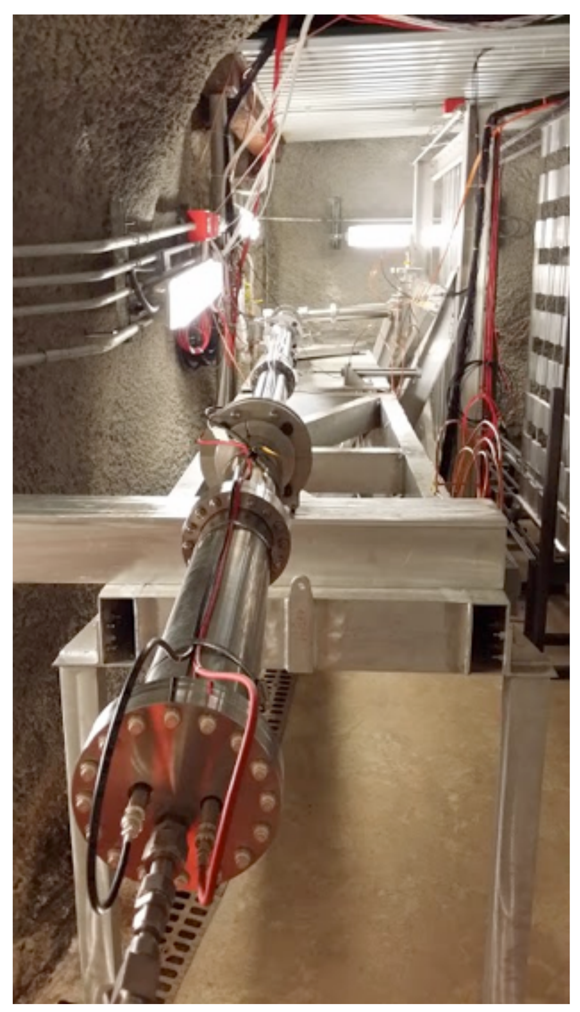


Threshold Gas Cherenkov Detectors



These devices consist of L-shaped pipes filled with argon gas at variable pressures (from vacuum to ~10 atm). By looking for the Cherenkov signal from muons, these detectors are insensitive to background neutrons. Cherenkov light reflects off of a flat mirror to a PMT that is located several meters away in a lower radiation environment. The detector will not image single Cherenkov rings, but will see the integrated signal. By varying the pressure, the contributions from muons of different energies can be mapped out. The apparatus can also be rotated to map out the angular profile of the muons.

Prototype Testing in NuMI Beam

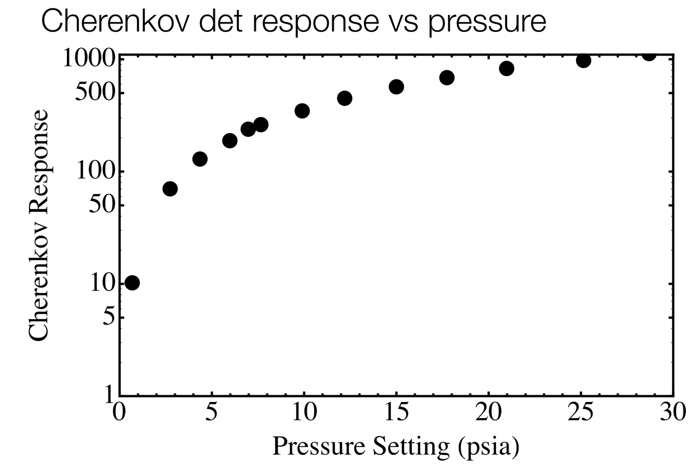


Gas threshold Cherenkov detector

A prototype threshold Cherenkov detector and stopped muon counter have been deployed in the second muon alcove of the NuMI beam.

Stopped Muon Detector

Cherenkov det response vs pressure



Typical NuMI beam pulse in Gas Cherenkov Detector