# Table of Contents

*Forward*

This has been an enjoyable experience for me to be able to write documentation on the MiniBooNE experiment. One of the first people to ask me what I was doing this summer for the Operations Department was Denton Morris. When I told him, the final product being this document, he smiled and laughed a little while saying, “Oh, you are writing a Mini-Rookie Book for MiniBooNE.” Well, needless to say, the name stuck.

There are many people I would like to thank for helping to make this assignment a success. First, I would like to thank Bob Mau, John Crawford and Dan Johnson for allowing me to have the opportunity to work here this summer. Secondly, I would like to thank Paul Allcorn, Terry Asher, Darren Crawford, Stan Johnson and Oliver Kiemschies for giving me initial feedback before the document went to the experts. Third, I would like to thank Steve Baginski for helping with drawings and Bruce Worthel for helping me with miscellaneous questions. Lastly, I would like to thank Ioanis Kourbanis, Eric Prebys and, most of all, Al Russell for their feedback and helping me clarify points that definitely needed them!

Michelle M. Gattuso
August 9, 2002

**A. Background Information**

The purpose of MiniBooNE (Booster Neutrino Experiment) is to independently confirm or refute findings from the Liquid Scintillator Neutrino Detector (LSND) at Los Alamos National Laboratory in New Mexico, which took data from 1993-1998. They found that muon anti-neutrinos oscillate into electron neutrinos. Other experiments, such as the Sudbury Neutrino Observatory (SNO) in Ontario, Canada, found that electron neutrinos from the Sun transform into neutrinos of another type. In addition, the Super-Kamiokande near Tokyo, Japan, has evidence that shows that atmospheric muon neutrinos oscillate into tau neutrinos. If neutrinos can oscillate, then they have mass. "Why is this important?" you may ask. It is important because the Standard Model (figure 1) currently says that neutrinos have zero mass. Theory says that particles of equal mass (zero or nonzero) cannot transform into one another; that is "mix." If you start off with a beam composed purely of muon neutrinos, $\nu_\mu$, and sometime later detect electron neutrinos, $\nu_e$, in the beam you have to conclude that mixing has occurred and that at least one of the neutrinos is not massless. The mixing is what is so intriguing.

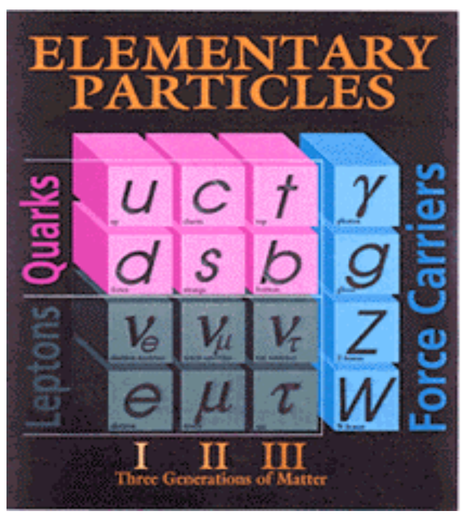


Figure 1: Standard Model

Neutrinos are subatomic elementary particles in the set of building blocks for the universe. There are three flavors of neutrinos currently theorized: electron, muon, and tau neutrino. Each flavor neutrino also has an anti-neutrino. It has been widely accepted that the mass of each of the neutrinos is zero.

In 1930, Wolfgang Pauli proposed the existence of a neutral particle as a solution to a frustrating problem in a nuclear process called beta decay. It seemed that examination of the reaction products always indicated that some variable amount of energy was missing. Pauli concluded that the products must include a third neutral particle, but one which did not react strongly enough for it to be detected. In 1933, Enrico Fermi called this particle the neutrino, which meant "little neutral one." In 1956, physicists Reines and Cowan found evidence of neutrino interactions by monitoring a volume of cadmium chloride with scintillating liquid near to a nuclear reactor.

Current evidence shows that neutrinos do oscillate. As stated above, this indicates that neutrinos do have mass. But, LSND reveals that their data supports that they have seen a muon anti-neutrino cross over to an electron neutrino. This type of oscillation with mixing of flavors is difficult to explain using only the three known types of neutrinos. Therefore, there might be a fourth neutrino, which is currently being called a "sterile" neutrino that interacts more weakly than the other three neutrinos. Hence, if MiniBooNE can confirm these findings, it would have a massive impact on the standard model not to mention the implications for future research in various fields of physics.

MiniBooNE is an 8 GeV experiment that is part of the low-energy program at Fermilab. It is called "mini" because it can be thought of as the first part of a possible two part series. Fermilab has approximately until mid-2004 to collect all the data MiniBooNE needs. If MiniBooNE establishes evidence for neutrino oscillations, it will be upgraded to BooNE, a two-detector experiment. The site, where MiniBooNE is, was chosen to allow a second detector to be placed anywhere from 250 m to 2 km away. BooNE will be designed to accurately determine the oscillation parameters and possibly yield further information about the mass of a neutrino.

*Booster's Role*

The Booster, needless to say, is a key factor in the success of MiniBooNE. The Booster needs to output more beam in one year of running than it has produced in the last 30 years. MiniBooNE requires protons from the Booster at a rate of 5 Hz with $5 \times 10^{12}$ protons per pulse at 8 GeV for $4 \times 10^{7}$ seconds of Booster running. High intensity is crucial for MiniBooNE's success. The Booster is an ideal machine because the protons can be used to produce a neutrino beam of low energies, between 0.3 and 1 GeV, with high beam intensity.

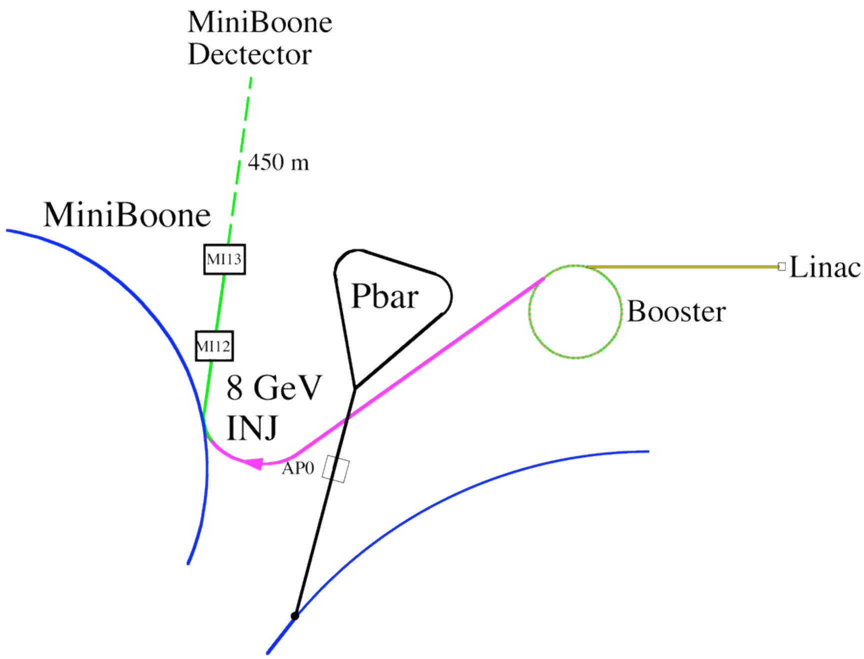


Figure 2: Site overview for beam to MiniBooNE

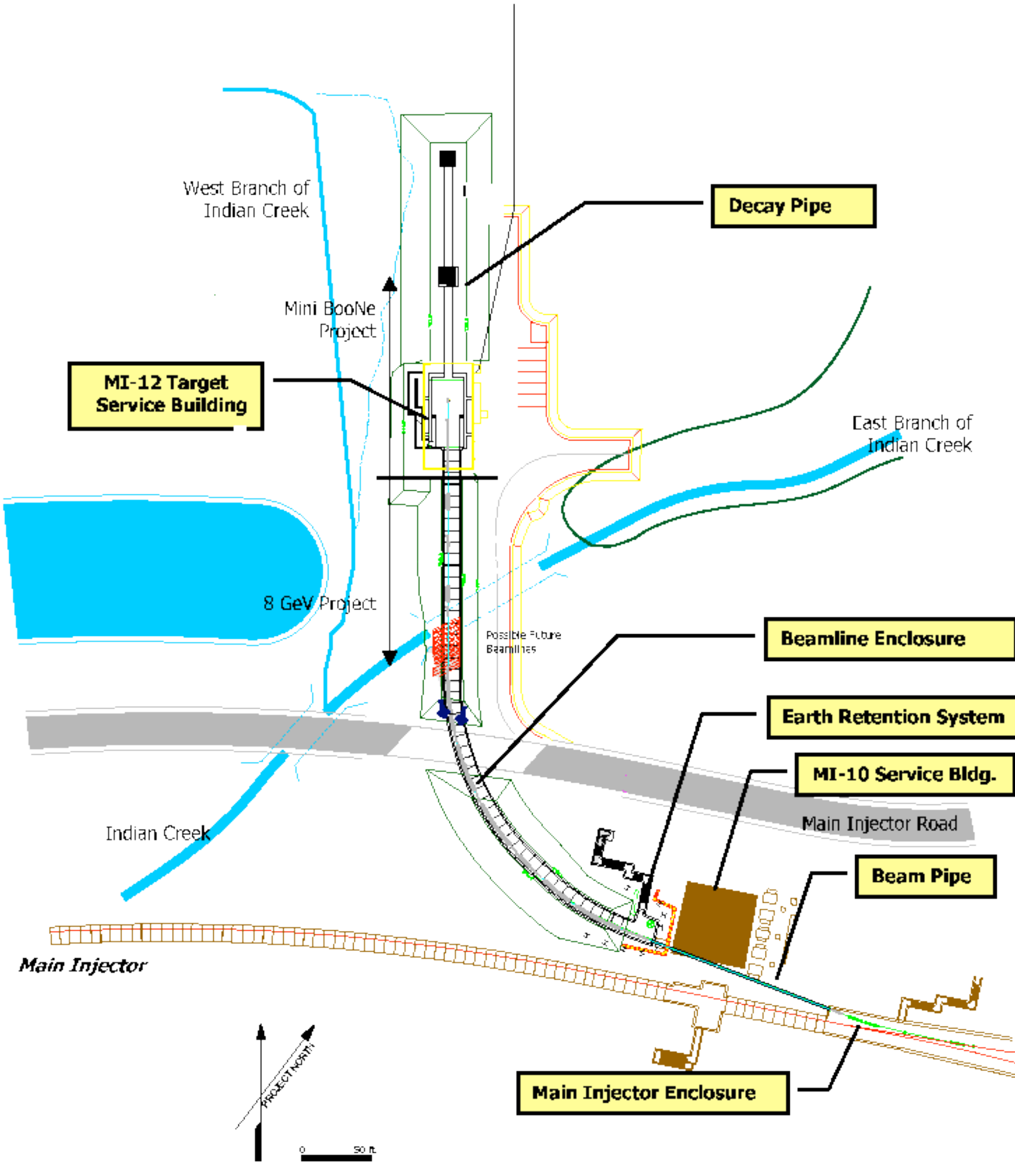


Figure 3: Target Hall, Target Service Building and Decay Pipe

## B. Proton Beam Elements

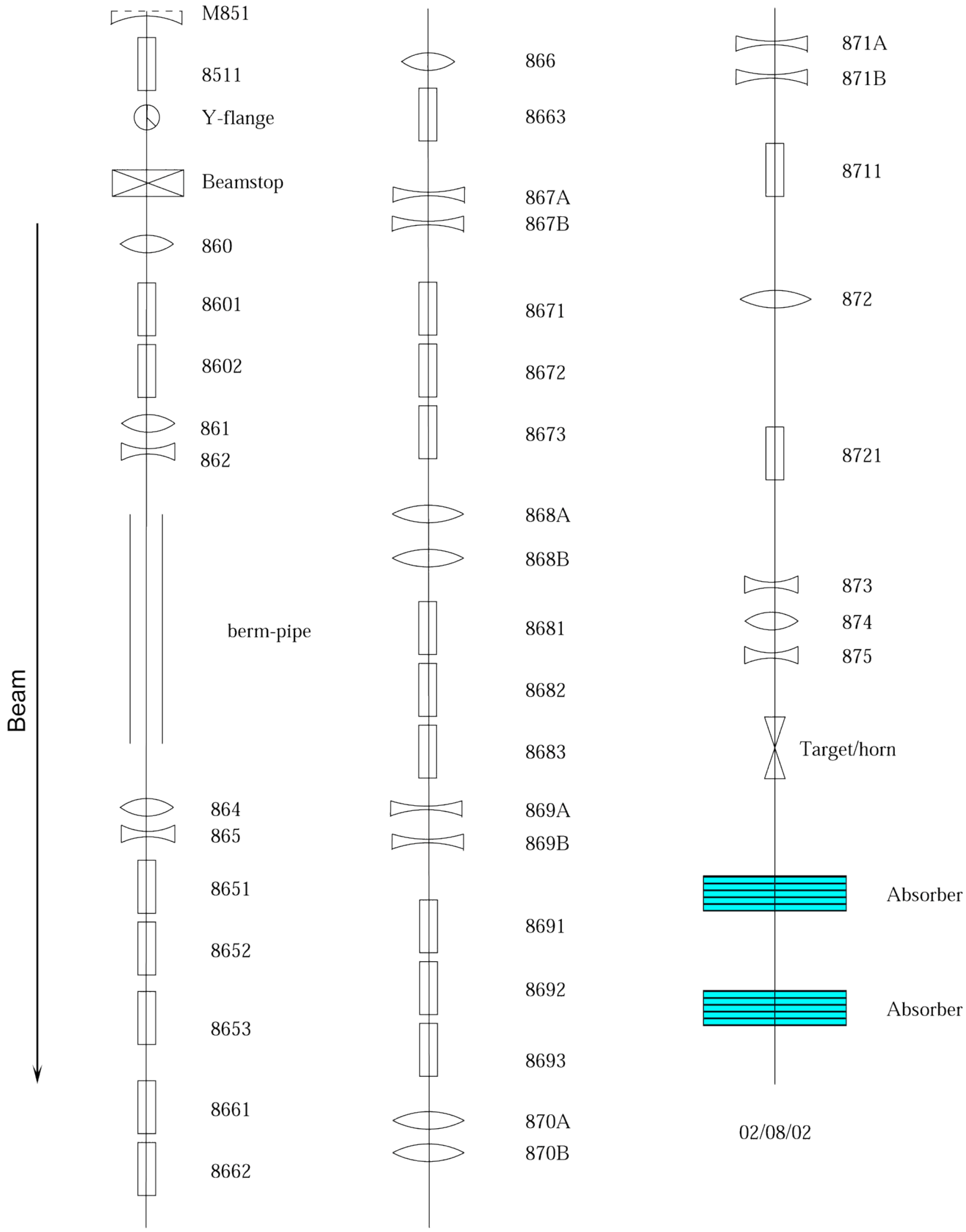


Figure 4: MiniBooNE Beamline

MiniBooNE Beamline accepts 8 GeV proton beam from Booster. The 8 GeV beam leaves the Booster enclosure as it would for the Main Injector, down the MI-8 Line. It travels in the MI-8 Line through Q851. A switch, magnet, MBEX (E:H851), located downstream of Q851, deflects selected Booster batches into the MiniBooNE beamline. The next three quadrupoles, Q860, Q861 and Q862, capture the beam and focus it for transport through the 42 m drift tube (also know as the Jack Pipe) under the MI-10 service building. Before the drift tube is also where MiniBooNE beam leaves the MI enclosure, near the 101 location in the MI. After the drift tube, quadrupoles Q864, Q865 and Q866 are used to match the beam to the FODO cells of the arc that provides the major bend to direct the beam toward the experimental area. Beam will then strike a target. The secondaries will travel to a focusing element where the desired secondary particles will be focused into the decay pipe before traveling to the detector itself.

## C. Neutrino Beam Elements

Before beam can reach the detector, it must go through four sections: the target, horn, decay region and the beam absorber (figure 5). These elements sit in the Target Hall and decay pipe.

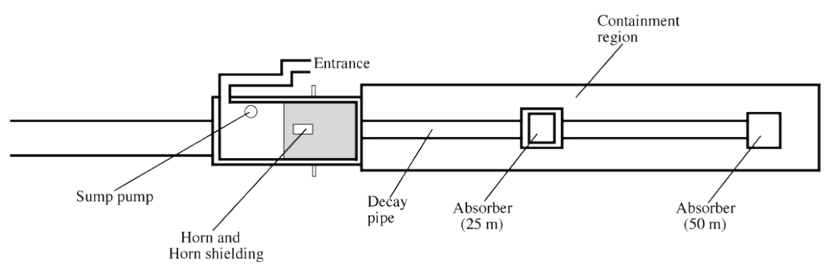


Figure 5: Below-grade plan view of the Target Hall, decay pipe and absorbers

*Target*

Protons from the primary beam will strike a 71 cm beryllium target. This will produce many different types of secondaries. MiniBooNE is interested in one particular secondary: positive pions. These will decay into positive muons and muon neutrinos. MiniBooNE is looking to see if these muon neutrinos oscillate into electron neutrinos. Beryllium is used for the target because it produces less thermal heat, will become less radioactive over time, has a high pion production yield, and is resistant to material fatigue. Material fatigue is an issue due to the large number of beam cycles that is expected.

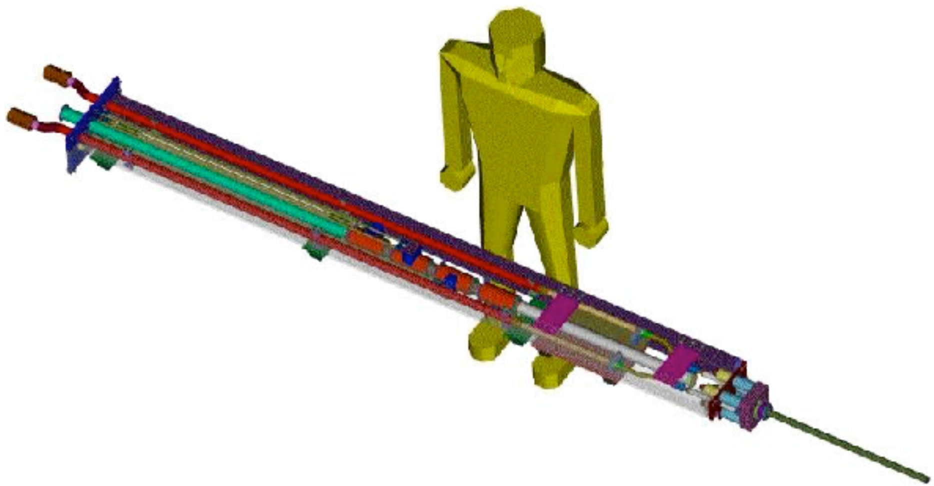

Figure 6: Overall view of the target module.

The target is located within and concentric with the magnetic focusing horn, but is physically separated from the horn (the horn is discussed in the sub-section immediately following this one). This allows the target to be extracted without removing the horn itself in the event of a target failure. The target is entirely independent of the horn assembly and does not use the horn cooling system.

The target is cooled by a closed, high-pressure gas system. External fan motors are placed in a sealed housing unit. Gas is delivered and returned via pipes to the inner target pile. Filters are located on these lines to inhibit radioactive particulate material from contaminating the fan motor housing. Two fan motors run in parallel to make the system more fault resistant.

The temperature and pressure of the supply and return gases are monitored in order to insure proper operation of the system. Any excursion from a steady state would be a sign of difficulty. Flow sensors are also monitoring the presence of airflow on the supply and return sides. These are interlocked to the beam delivery system.

The primary target element consists of seven cylindrical slugs of beryllium. The slugs are 4" long and 1 cm in diameter. It also has three radial cooling fins placed symmetrically around the axis. Dividing the target into short segments minimizes any forces on the assembly due to off-axis, asymmetrical heat loads from the primary proton beam.

The upstream end of the inner tube is brazed into the aluminum manifold block. Its downstream end is left open in order to duct coolant gas back toward the manifold. The outer beryllium tube serves to support the inner tube, and to function as a duct for the target's gas coolant. The upstream end of the outer tube is brazed to the manifold block. A beryllium end cap is brazed to the downstream end of the tube. There is also a stainless steel bellows fastened to the manifold block in order to make an electrical connection with the horn. This serves to prevent arcing between the horn and the target assembly.

*Horn*

Pions produced in the beryllium target by the 8 GeV protons make a large range of angles with respect to the incident beam direction. The neutrinos produced by the pion decays move close to the parent pion direction. Unless the pions are focused toward the detector, many of the neutrinos would miss the detector and be lost to the experiment. The pions coming off of that target are focused by the solenoidal magnetic field generated from a high-current carrying device called the horn. It is important to focus the pions toward the detector before they decay into muon neutrinos. Once the pions decay into the neutrinos, it is impossible, to focus the electrically neutral neutrinos. Therefore, in order for the neutrinos to be directed where experimenters want them to be, it must be done before the pions decay. All other secondaries will be bent with different directions from the horn due to variations in their masses and energies. The horn was designed to select the positive pions with the prescribed energies experimenters are looking for.

A horn was chosen because it gives angular and momentum acceptances that other focusing systems cannot. It was made to withstand high radiation levels, have cylindrical symmetry, and also give sign selection. The normal configuration preferentially selects $\pi^+$ mesons whose decay, $\pi^+ \rightarrow \mu^+ + \bar{\nu}$, yields the muon antineutrinos used by the experiment. Reversing the sign of the current in the horn selects $\pi^-$ mesons and, via $\pi^- \rightarrow \mu^- + \nu$, a beam of muon neutrinos. (The horn produces a solenoidal magnetic field. Think about how a charged particle exiting the target is bent in such a field.)

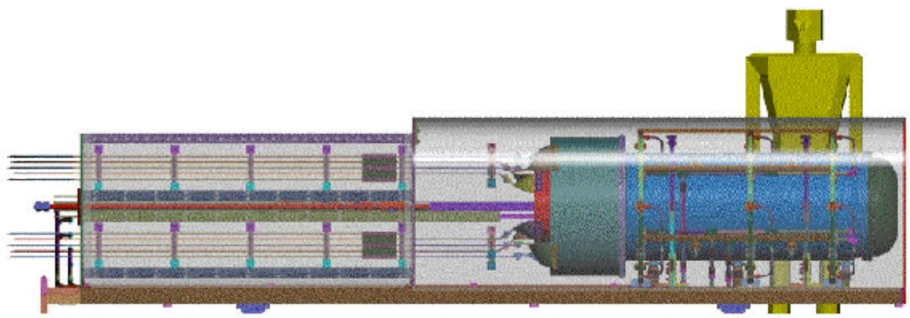

Figure 7: Side view of the horn, stripline and target
with the target box rendered transparent.

The horn operates up to a 5 Hz rate when there is beam, with each 170 kA pulse lasting for 150 μs with a maximum magnetic field of 1.5 T. It was designed to maximize neutrino beam intensity and quality (also called flux) with energies from 0.5 to 1 GeV. Without the horn, the neutrino flux at the detector would be reduced by a factor of 10. The horn's design has a narrow neck and a conical inner conductor made out of an aluminum alloy. It has a total length of 73" and an inner conductor radius that varies from .87" to 2.58". The outer conductor diameter is 23.62".

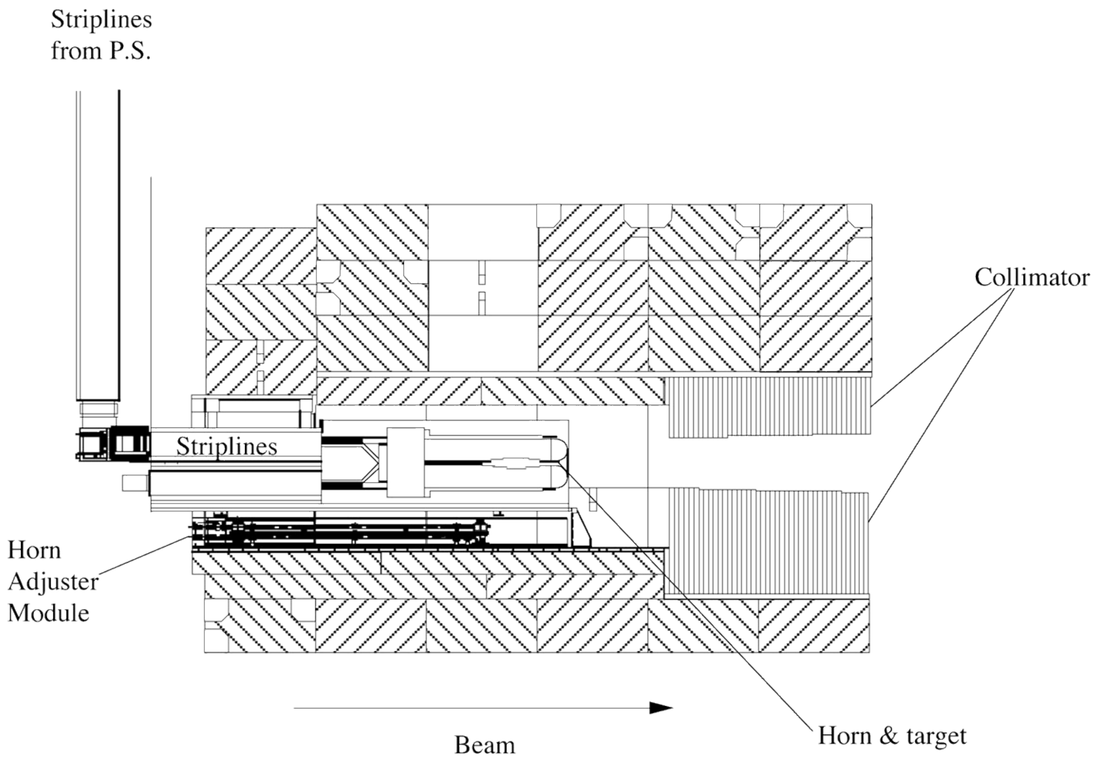


Figure 8: An elevation view of the Target Pile including the horn.
The stripline extends upward at the left.

A target pile provides for radiation shielding that is required in the Target Hall (figure 8). It has about six feet of steel between the secondary beam centerline and the outside edge of the target pile. The target pile provides a cavity into which the horn is inserted from the upstream end. The horn is contained within an airtight box that has connections for: two horn striplines, water supply and return lines, the beampipe/target assembly. The water lines are used for the horn cooling system that uses a spray water-cooling system (discussed further in the Water subsection of the Utilities section). The beampipe/target assembly consists of the beampipe, four BPMs, a titanium vacuum window, and the beryllium target assembly

*Decay Region*

The horn focuses pions into a 50 m steel decay pipe, which is two meters in diameter. As is evident by the name, this is the space in which the positive pions will decay into muon neutrinos.

There is also a collimator attached to the downstream end of the target pile, at the very upstream end of the decay pipe. The purpose of this device is to stop secondaries that would hit the enclosure wall because the horn does not focus them to the decay pipe. The collimator's upstream radius is 30 cm at the distance of 259 cm from the target. It flares out to a radius of 35.5 cm at the downstream face, 473 cm from the target.

*Beam Absorber*

At the end of the decay pipe, which is 50 m from the target, is a beam absorber. This stops all the secondaries from the target except, the neutrinos. Located 25 m from the target is an intermediate absorber that can be lowered into the beam. This feature was introduced to provide a test signal versus the background.

The 50 m absorber is permanently located at the downstream end of the decay pipe. It has been fabricated from steel that has a weight of about 10 tons and has dimensions of approximately 52" x 52" x 26". Twenty-eight of these are required for the 50 m beam absorber.

The 25 m beam absorber was designed so that it could be lowered into the beam. It is constructed from steel, 10' x 10' x 2" plates. These plates are assembled into modules 1' thick, weighing about 10 tons. One module is permanently in a horizontal position, with its top surface just below the bottom of the decay pipe. The beam absorber will become one of the most radioactive elements in the beam enclosure because it absorbs most of the beam power.

The neutrinos will then travel 440 m through the ground to the MiniBooNE Detector. These neutrinos will range in energies from 300 MeV to 1.5 GeV.

### D. The MiniBooNE Detector Plant

The MiniBooNE Detector Plant is located about 550 m north of the pion production target and southwest of the Leon Lederman Science Center. The Detector Plant consists of two main elements: the Detector Containment and the Support Plant (figure 9). The Detector Containment includes the detector itself, which is a 40 ft (12.2 m) diameter spherical tank that stands inside a 45 ft (13.7 m) diameter cylindrical vault. The Support Plant lies above the Detector Containment and includes space for access into the tank, electronics and utilities.

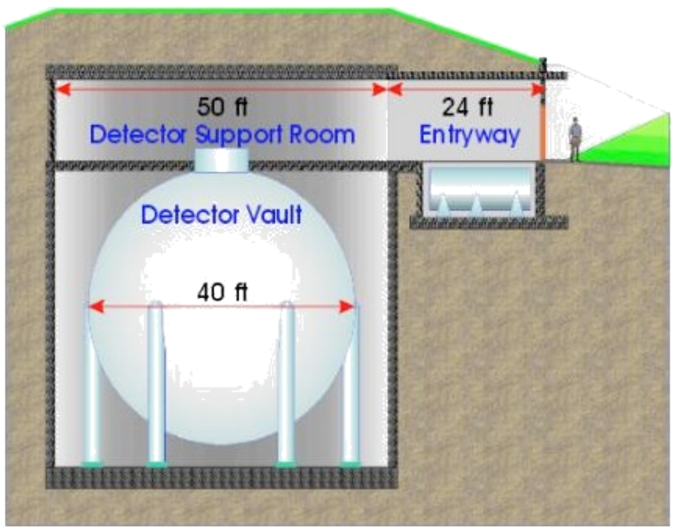


Figure 9: MiniBooNE Detector Plant

*The Detector Containment*

Inside the spherical tank is an inner tank structure with a 37.8 ft (11.5 m) diameter. The inner tank structure supports over one thousand 8-inch photomultiplier tubes (PMTs). The PMTs cover about ten percent of the inner tank's wall surface. Those PMTs are pointed inward and are optically isolated from the outer region of the tank.

In additional, there are 330 veto PMTs facing outward. These 330 outward-looking phototubes are in a thin shell (about 1 m thick) at the outside wall of the detector tank and are used to veto events for which a charged particle is detected entering the tank. A charged particle entering the detector, most commonly a cosmic ray muon, is background noise for the experiment. The veto region is optically isolated from the central part of the detector where the real events are detected

The inner tank is filled with 807 tons of pure mineral oil. The cylindrical vault serves as the secondary containment for the oil in case of leakage. An overflow pipe in the access portal connects to a storage tank that defines the oil level in the inner tank. Nitrogen gas is bubbled into the tank at various levels that helps maintain a small nitrogen overpressure in the access portal. The nitrogen is also used to purge oxygen and water from the oil.

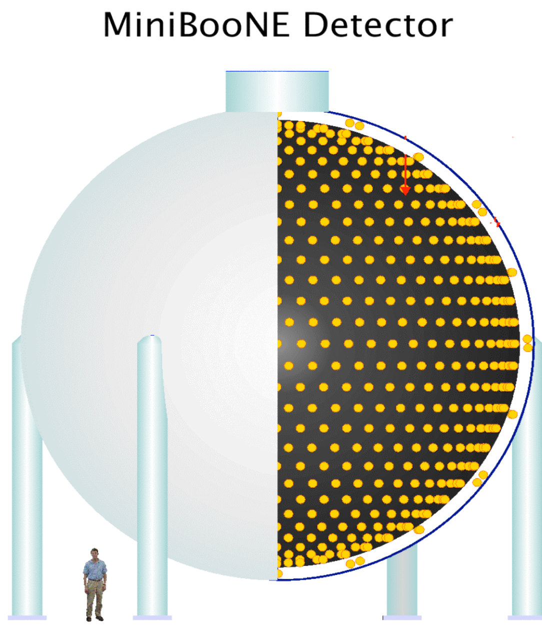


Figure 10: MiniBooNE Detector

The primary focus of MiniBooNE is to confirm or refute the observation by LSND of $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ or, equivalently, $\nu_\mu \rightarrow \nu_e$ oscillations. With some simplification, this is done by detecting reactions like $\bar{\nu}_\mu N \rightarrow \bar{\mu} X$ and $\bar{\nu}_\mu N \rightarrow eX$. Detection depends on scintillation and Cerenkov light produced by the final state (charged) muon or electron. A muon will produce well-defined cone of light and illuminate a relatively well-defines ring of PMTs. In contrast, electrons shower and illuminate a fuzzier ring of PMTs.

The pure mineral oil produces light from incident particles made up of 75% Cerenkov light and 25% scintillation light; the precise fractions are not crucial. The PMTs detect the light coming from the particle interactions in the tank. Then, the PMTs convert this light level into an electrical signal that is carried via an RG58 cable to be interpreted by the data acquisition system. There is one cable per PMT. The RG58 signal cable also supplies high voltage to the PMT. There are also six small scintillator cubes, 5 cm on each side, inside the inner tank, that are used for tracking cosmic rays.

*Support Plant*

The Support Plant is located above the detector tank and consists of areas for electronics, utilities and tank access. The utilities' area includes a reservoir tank to accommodate the variations in oil volume due to small deviations in temperature. It also includes the active plumbing elements necessary for oil and nitrogen circulation and the laser used for calibration of the PMTs. The electronics' area encompasses fast electronics, a data acquisition system, a farm of workstations, and a taping system, while the tank access area contains the PMT preamplifier electronics and is the access point for personnel and equipment into the detector tank. An HVAC system, located in and adjacent to the utilities' area, is provided for the enclosure and detector vault.

## E. Diagnostics

Since the beam going to MiniBooNE and MI share the same beamline from Booster to the 851 location in the MI-8 Line, I will only address diagnostic equipment downstream of there. The upstream equipment has already been documented in either the MI or Booster Rookie Books.

It is important to note that the only instrumentation located in the Jack Pipe under the MI-10 Service Building is a distributed Total Loss Monitor (TLM). The Jack Pipe only houses the actual beam tube, two 4" LCW pipes (one return and one supply pipe), two 4" PVC pipe for utilities, and the Heliax cable that constitutes the TLM.

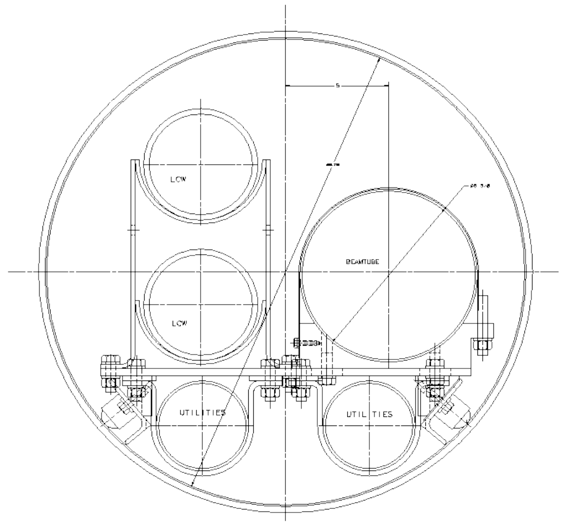


Figure 11: Cross section of the Jack Pipe. The TLM is not indicated in this figure.

Primary proton beam position, profile and intensity will be monitored to maintain the highest possible beam intensity, to constrain beam simulations and to prevent losses. Multiwires will be used to measure beam profiles. BPMs will be used to measure beam position, and a beam current toroid will measure beam intensity.

*Beam Position Monitors (BPMs)*

There are twenty-two BPMs placed in the beamline for beam tuning. Eight H/V BPM pairs are required. The first pair is placed at the beginning of the MiniBooNE beamline, between B8511 and Q860. The second is upstream of the doublet at the entrance to the Jack Pipe under MI-10. The third is located at the end of the Jack Pipe and upstream of the doublet, which sets the optics going into the arc and the FODO channel. The fourth is located at Q870, at the end of the arc. The fifth and sixth pair will be at each end of the final focus. The seventh and eighth are two redundant pairs, which are located upstream of the target.

Six individual BPMs are also placed in the MiniBooNE beamline. The last two BPM pairs upstream of the target will be of special design to fit in the tight space between the stripline. Special electronics are being used for better accuracy near the target where tolerances for position monitoring are smaller. The remainder are the same design as in the MI-8 Line. Beam position data and the lattice definition will be used as input to a beamline auto tune program. The program will monitor the beam position and make corrections pulse by pulse in the future.

*Beam Loss Monitors (BLMs)*

Seventeen loss monitors are placed along the beamline to monitor beam losses. The loss monitors will inhibit the beam permit when a prescribed threshold is reached. This is done for equipment safety. This is of particular importance in the target/horn region. The loss monitor electronics have been modified to respond to the beam pulses at 15 Hz.

There are also five Total Loss Monitors (TLMs) to provide coverage over the length of the beamline, including through the Jack Pipe. They detect beam losses that occur anywhere along the length of the beamline. Beam will be inhibited if the total losses exceed a threshold value.

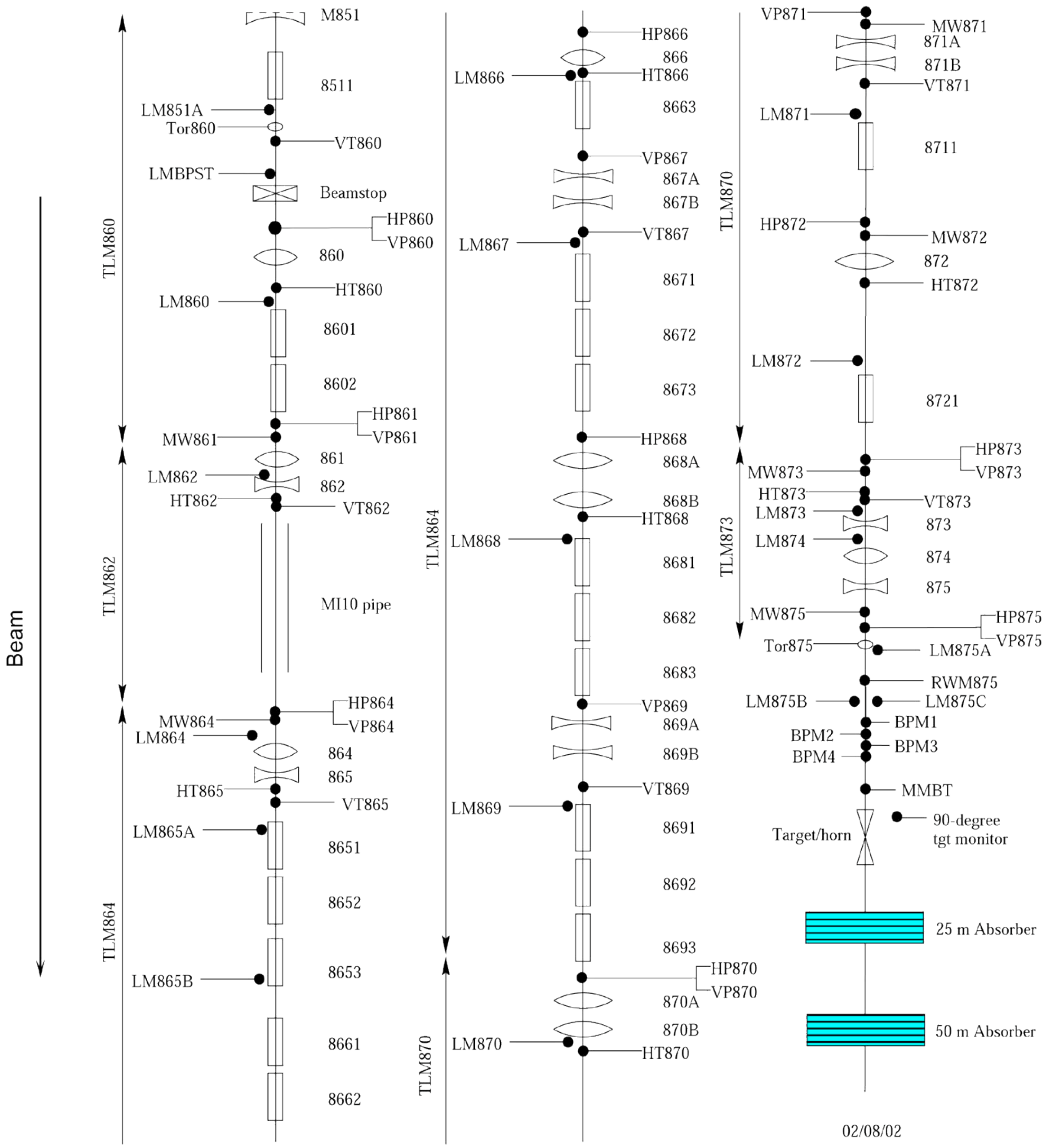


Figure 12: Schematic overview of location of instrumentation in the primary proton beamline.

*Multiwires*

Six low precision retractable multiwires are located at strategic places in the beamline to monitor beam shapes and to help calibrate absolute position on some of the BPMs. These devices are more radiation hardened than the Switchyard's SWICs and present less material to the beam. In addition, no gas is required in the operation of these multiwires. These devices have already been used, successfully, for high intensity, 8 GeV, beam in Booster. They have also been upgraded recently to provide better reliability and reproducibility. The most downstream multiwires and BPM pair will be used to determine the targeting angle of the primary proton beam.

*Other Devices*

There are a few other devices used to monitor the beam in MiniBooNE. First, there is a 90º target monitor employed to verify targeting efficiency. This monitor is located directly above the target, hence the term 90º, in the MI-12 Service Building. Secondaries coming off of the target will encounter a Cerenkov counter that is located just above the shielding on top of the target. Light will be emitted from the counter due to the secondaries coming in contact with it. That light will be reflected 180º via mirrors, up through an air pipe, to the 90º monitor. The 90º monitor is another PMT. Currently, this device is not read back through CAMAC, but via an oscilloscope located in the service building.

Another device used in MiniBooNE is a beam halo monitor, which is also known as a muon monitor. This is used to measure the beam quality of the secondary beam. It is located after the 50 m decay pipe following the target. It is an instrumented absorber with a cross section of embedded BLMs in the absorber.

A resistive wall monitor is also a device MiniBooNE uses for diagnostics. This is used to detect individual buckets of beam. This information will be transmitted to the experimental electronics for timing purposes.

The beam current toroids are located at either end of the beamline to measure the beam intensity as part of the e-berm system. (E-berms are discussed further in the safety section.) Typical signal strength from these toroids is 0.5 volt per ampere. This would yield about 250 mV for one beam pulse at nominal intensity.

## F. Utilities

*Electrical*

Power supplies (PS) for the MiniBooNE beamline are located in the MI-10 Service Building and the MI-12 Target Service Building. The MiniBooNE supplies located in MI-10 are those for the pulsed magnet, the quads, the trims and two additional dipoles located in the MI tunnel. The dipole power supplies are located here for both safety and operational reasons.

Power supplies for the vertical dogleg, the four final focus quads and one additional dipole in the MiniBooNE beamline enclosure are located in MI-12. This minimizes the congestion in MI-10 and avoids the difficulty of getting additional DC power cables from MI-10 to the MiniBooNE beamline enclosure.

The Horn's power supply is also located at MI-12. Energy is stored in a capacitor bank (1,344 □F) and switched via a parallel array of sixteen silicon controlled rectifier (SCR) switches into the horn load. The circuit is divided into sixteen parallel capacitors, each with its own SCR switch. A parallel strip transmission line is used to connect the power supply to the focusing horn. The horn needs a series of pulses that repeat with a period of 67 ms, to match the 15 Hz Booster cycle.

The charging supply recharges the capacitor back by a 168 kW switch-mode power supply array. Diodes are used between the charging power supply and the separate sections of the capacitor bank. This permits charging of each of the capacitor bank cells while keeping them isolated from one another for safety. The series diodes also prevent the capacitor bank's stored energy from being delivered backwards to the charging power supply in the event of a fault internal to the charging supply.

A safety system will monitor operating parameters of the power supply and will shut it down if out-of-tolerance conditions are detected. Monitored parameters include overvoltage and overcurrent conditions of the charging supply, overvoltage and overcurrent conditions of the capacitor bank, ground fault currents, excessive temperatures, loss of cooling to the power supply or horn, and personnel safety, just to name a few. When fault conditions are detected, the charging supply will be turned off and the capacitor bank will be discharged via a redundant arrangement of dump resistors and shorting relays to remove stored energy. The dump resistor is rated to absorb the maximum stored energy capability of the capacitor bank, 74 kJ.

House power is supplied via feeder 52 and 53 for MI-10 and MI-12. Feeder 44 supplies power for the MiniBooNE Detector Building. As usual, if there is a need to rack out any of these buildings, the Duty Electrician must be notified to perform this job.

*Vacuum*

Since the beam going to MiniBooNE and MI share the same beamline from Booster to the 851 location in the MI-8 Line, I will only address vacuum equipment downstream of there. The upstream equipment has already been document in either the MI or Booster Rookie Books.

The first vacuum element unique to the MiniBooNE beamline is a special vacuum chamber in the pulsed magnet which allows the MiniBooNE beamline to split off from the MI-8 Line. Immediately following the split, on the MiniBooNE side, is a gate valve. This was installed to allow the MiniBooNE beamline to be isolated from the MI-8 Line if the need arises. An additional gate valve is located at 864 on the downstream end of the Jack Pipe.

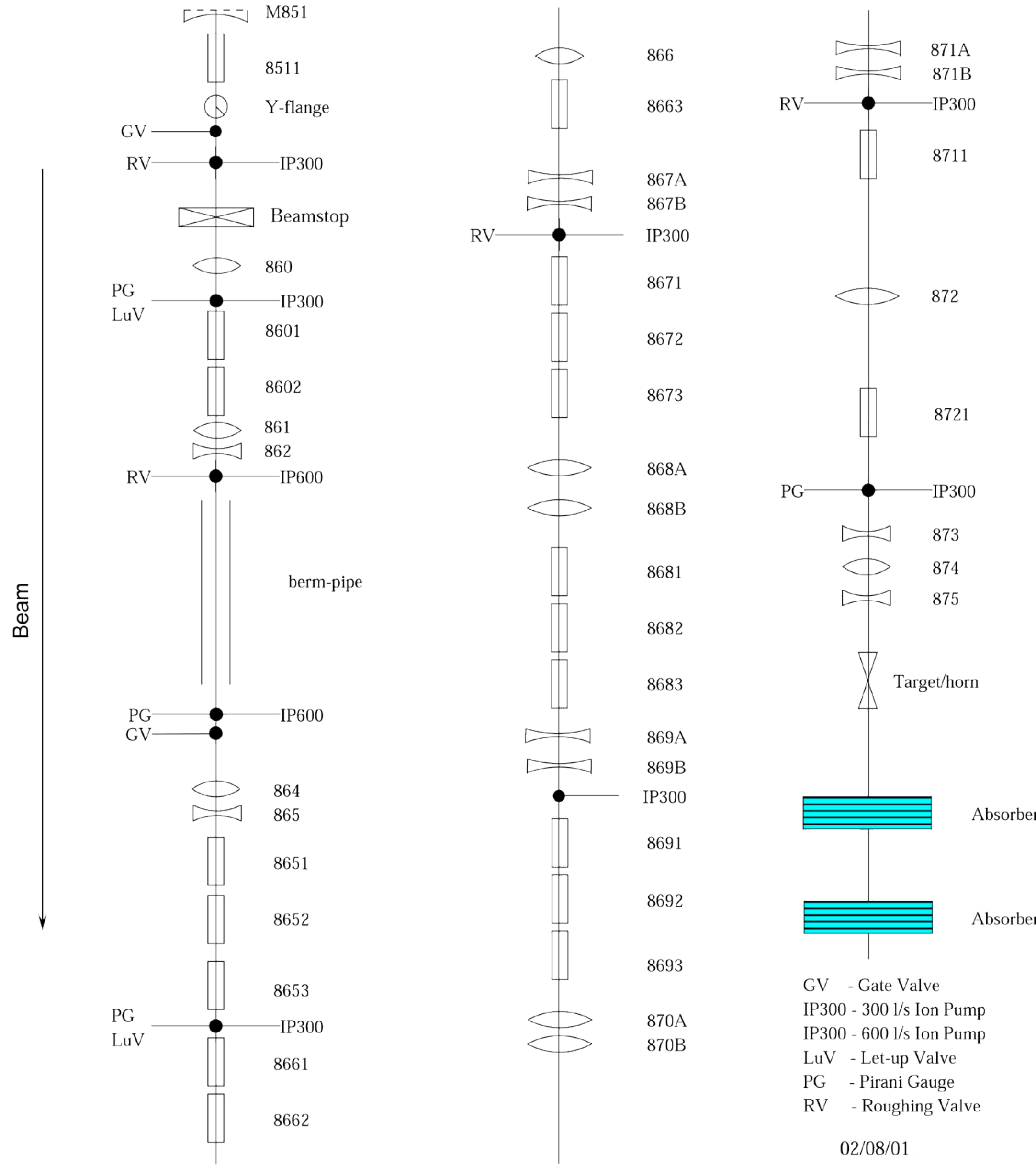


Figure 13: Schematic overview of the vacuum layout for the MiniBooNE 8 GeV Beam.

There are six 300 l/s ion pumps distributed along the beamline at various locations. There are two additional 600 l/s ion pumps located at either end of the Jack Pipe. The vacuum in the beamline is expected to be about $10^{-8}$ Torr, except in the Jack Pipe and near multiwires where it is expected to be about $10^{-7}$ Torr. The vacuum pipe ends after the instrumentation that follows the final-focus triplet. A titanium vacuum window, located within the target, terminates the vacuum pipe.

*Water*

The LCW for the magnets taps off MI LCW from MI-10. Providing LCW for the magnets within MI is straightforward. A secondary manifold taps into the 6" header at Q-101 that distributes LCW to the magnets in the 8 GeV intersection area (upstream of the Jack Pipe). 4" lines feed the remainder of the beamline, comprising the magnets downstream of the Jack Pipe, the target hall, PS located in MI-12 and the RAW system.

The 4" lines run along the wall side of the tunnel, above and behind the magnet string, until B-8711, whereupon they tee. One side of the tees connects a set of 1½" lines with hoses and ball valves. It will continue along this wall to the triplet magnets and girder. On other side of the tees the 4" lines reduce to 3", cross the tunnel overhead, and continue along the aisle side to the first two of the four vertical penetrations to MI-12. Splits from this point will feed the Radio Active Water (RAW) skid and the stripline Fan Coil Units (FCUs).

The RAW skid, located in MI-12, is a closed loop system for the horn. The controls for the RAW skid system are located in MI-12. The normal operating pressure of this system is 50 psi with flow rates of 10 to 12 gpm. Only one main pump may run at a time. The RAW system has two temperature readouts and one flow readout. These are analog readouts and may be processed by the main computer system. There are thirteen status points available from the system along with the three analog points. These points will indicate if a pump is operating, if the flows are proper, if the temperature is within tolerance, or if the surge tanks are at the proper level.

One additional item to note: the RAW skid is located in MI-12B enclosure near the door in the tunnel to the stairs. This just happens to be located in a close proximity to the enclosure's sump pump. The sump pump is protected from the RAW skid with a steel wall (in the event of a hose spraying water). The ground around the sump is also elevated so in a case of a RAW water leak the water will accumulate on the floor and will not contaminate the pump. In the event of a RAW water leak on the skid, it might still be wise to breaker off the skid in the MI-12 Target Building. This would be done to ensure that the RAW water does not go where Safety believes it should not be.

## G. Controls

Controls for MiniBooNE are handled through CAMAC and ACNET via the MI Front End. There is one CAMAC crate located at each service building: currently $E1 at MI-12 and $17 at MI-10. The beamline magnets will be controlled through CAMAC modules, mostly C453 ramp modules, and read out via CAMAC MADC's (C190 or C290). (For further information on the CAMAC cards, refer to the Beams Divisions – Accelerator Controls home page on the web and look under CAMAC Modules.) The horn, at MI-12, will be controlled and read out through an Internet Rack Monitor (IRM). BPMs and BLMs will also be read out through IRMs.

## H. Safety

A Safety Interlock system is required to prevent individuals from entering the enclosure while the beam is present (Radiation Safety System) or power supplies are energized (Electrical Safety System). For radiation safety purposes the MiniBooNE beamline enclosure is divided into two portions: MI-12A upstream, and MI-12B downstream. Personnel may not enter MI-12A when beam is enabled in the MI-8 beamline or in the Main Injector. Personnel can access MI-12B, the target hall, and MI-13 if beam is inhibited in the MiniBooNE beamline. Critical devices are used to inhibit beam and protect individuals from accidental exposure when entering the enclosure during periods when beam is present in the accelerator or in other remote areas. Critical devices must provide redundancy for this protection. That is, at least two critical beam elements, in a different upstream enclosure, are turned off upon access to an enclosure.

For the MiniBooNE beamline, the first critical device is the set of two dipoles at 862 (E:HV860). These magnets must be energized to bend the selected beam to MiniBooNE through the Jack Pipe under MI-10. The second critical device is a refurbished beam stop from the Meson Area. Either of the critical devices is sufficient to keep beam from entering the enclosures to MiniBooNE. Hence, this set of critical elements is more than sufficient to protect individuals upon entry to MI-12B (Target Hall) or MI-13 Man Hole. Controls for the safety interlocks are housed in the MI-10 and 12 service buildings.

It is easy to find the inputs to the Critical Device Controller (CDC) via the Interlock Display. First, the electrical permits for the enclosures, MI-12A, MI-12B/MI-13, must be made up. The 1000 cubic feet per minute (cfm) intake and exhaust fans must also be off, with the louvers closed, and the MI-12 service building radiation monitor must not be reading counts outside its threshold value. Once all these inputs are good, all that is left is to reset the CDC for MiniBooNE via ACNET. Another item to note - the MI-12A Electrical Safety System (ESS) must be made up in order to reset the MI CDC. Therefore, MI-12A shares a radiation permit with both the MI and MiniBooNE. MI-12A has its own electrical permit whereas MI-12B and MI-13 share an electrical permit.

As mentioned in previous sections, there is continuous loss monitoring coverage of the MiniBooNE beamline with TLMs. However, this is not a fail safe and redundant system. There are some individual loss monitors on selected elements; but it may be possible to lose some beam on unprotected devices. For this reason, there is a system to trip the beam permit if significantly more beam is detected at the upstream end of the beamline than at the downstream. This is commonly known at Fermilab as an electronic berm (e-berm). This prevents beam from being lost upstream of the target for more than one or two pulses. These systems have been used successfully at Fermilab in the past, Meson East for example (but not necessarily during a lightning storm), and it allows for the use of less dirt over the berm while maintaining the same level of safety.

High intensity toroids are used in this e-berm system. It was designed to have a trip level when 6% of the beam is lost on a single beam pulse or when 2% of the beam is lost on a ten-pulse average. The comparison of the intensities will be done in a fail-safe manner as was done in previous applications of the e-berm method at Fermilab. For this to work as intended, the toroids must be timed in correctly to ensure that both of them are looking at the same appropriate window of beam.

Another radiation concern in the MiniBooNE enclosures is air activation. There are two 1000 cfm fans involved in the MI-12A & B enclosures, one exhaust and one intake. The intake fan is the inlet part of the HVAC system and brings dehumidified air into the enclosure. The second fan powers the air exhaust from the enclosure at the MI-10 end of the enclosure. Both fans must be off and louvers closed when beam is on. This is to prevent venting contaminated air to the outside atmosphere either directly via the exhaust fan or indirectly via over pressurizing the enclosure with the intake fan. Upon closure of the louvers, a switch is activated that is monitored for these conditions. These conditions are input into the CDC, to make certain that air is not sent into or out of the enclosure.

These fans must not operate for a designated period of time, which is specified in the run conditions, before they can be turned on due to an access for example. This allows any short lived isotopes time to decay before personnel can make an access into the enclosure. There is also an air contamination monitor (M1) located at the exhaust fan to monitor and record the contaminants released to the atmosphere.

Ensuring that the desired air pressure and flow are maintained in the enclosures while beam is on also prevents venting contaminated air to the outside atmosphere in an unknown and uncontrolled way. This is done with 100 cfm of airflow towards the upstream end of the enclosures. This is accomplished with two 50 cfm intake fans located at MI-12 and one 100 cfm exhaust fan at MI-10. These fans are interlocked to the beam permit for MiniBooNE via a variable air valve that maintains the airflow within a range of 90 to 110 cfm. The louvers on the 100 cfm fan must be open when beam is on and will activate a switch that is monitored for these conditions. These conditions are inputs into the beam permit. In addition, M1 will monitor contaminations in this 100 cfm airflow.

## I. References

This is a list of references of where I obtained information. I did NOT properly document any material since this was not being turned into a professor nor was it intended for publication. There is a lot of good and interesting information in these references that I have listed. Most of the web sites have links to other high quality and interesting sites that I, unfortunately, simply did not have time to get to. I hope that you have found this "MiniBooNE Mini-Rookie Book" interesting and useful, yet not very boring.

*********************************************************************

*Talks on Video for Operations*
Eric Prebys' talk taped on 05-02-02
Peter Kasper's talk taped on 05-17-02

*Conference Talks: 3rd International Workshop on Neutrino Beams and Instrumentation*
"MiniBooNE Horn." I. Kourbanis. NBI, March 2002
"MiniBooNE Overview." P. Kasper. NBI, March 2002
"Radiation Protection for MiniBooNE and NuMI." S. Childress. NBI, March 2002.

*Reports*
"The MiniBooNE Detector Technical Design Report." I. Stancu et al. May '01.
"Technical Design Report for the 8 GeV Beam." The BooNE Collaboration. July '01.
"Technical Design Report for the MiniBooNE Neutrino Beam." I. Stancu et al. May '01.

*Web Sites*
http://proj-cngs.web.cern.ch/proj-cngs/2002_workshop/workshop_programme.html
http://www-boone.fnal.gov/public/introduction/Introduction.html
http://www.lanl.gov/worldview/news/release/archive/01-122.shtml
http://www.physics.hawaii.edu/~jpl/nuosc_story.html
http://www.ps.uci.edu/physics/news/nuexpt.html
http://www-sk.icrr.u-tokyo.ac.jp/doc/sk/index.html
http://www.sno.phy.queensu.ca/