Fermilabs Neutrino Beamlines, a Short History and the Current Status*

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Abstract

Neutrino experiments need high intensity due to the small cross section that neutrinos have with matter. This normally leads to concerns about targets and horns. There is not so much concern for the LBNF Primary beam and a large reason is the success of the present NuMI Beam and we will discuss how the Booster Neutrino Beam (BNB) lead the way for the efficient operation of the NuMI Beamline. The main components of the efficient operation are: Large aperture compared to the size of the beam, automatic checking of beamline parameters using a Beam Permit System, and finally an automatic beamline tuning system which is generically called Autotune.

INTRODUCTION

An overview of the Fermilab Accelerator complex is given in figure 1. Both a short baseline neutrino program and a long baseline neutrino program are supported. Schematic depictions of these programs are given in figures 2 and 3.

As indicated both near detectors see neutrinos from the other beam lines.

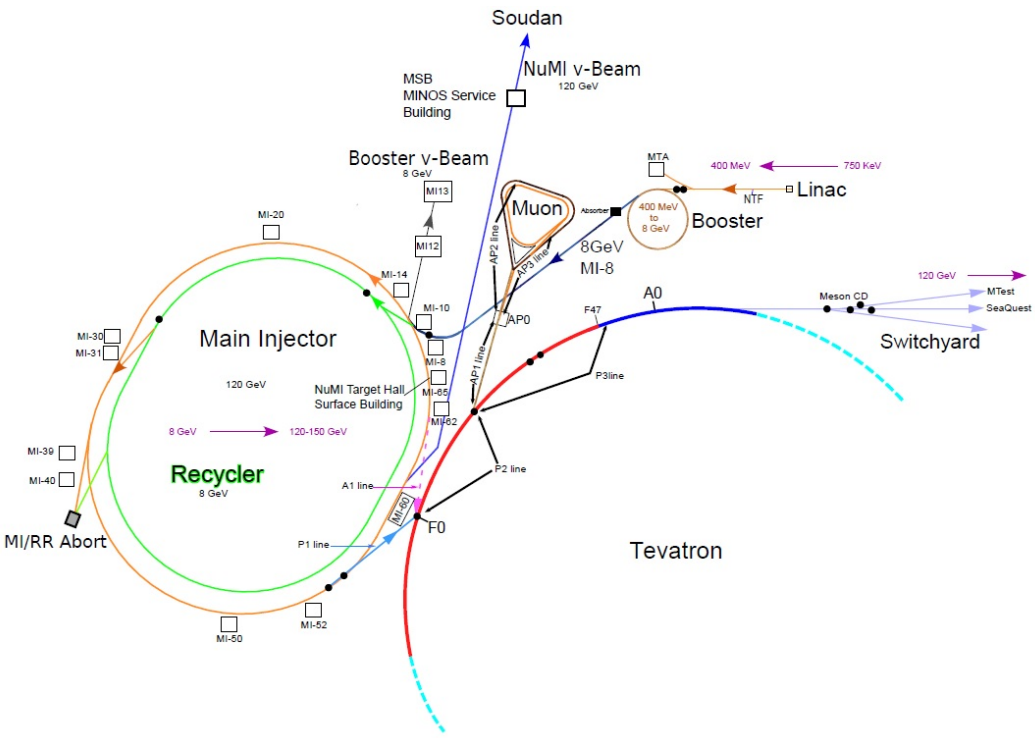

FIG. 1: Fermilab Accelerator Complex

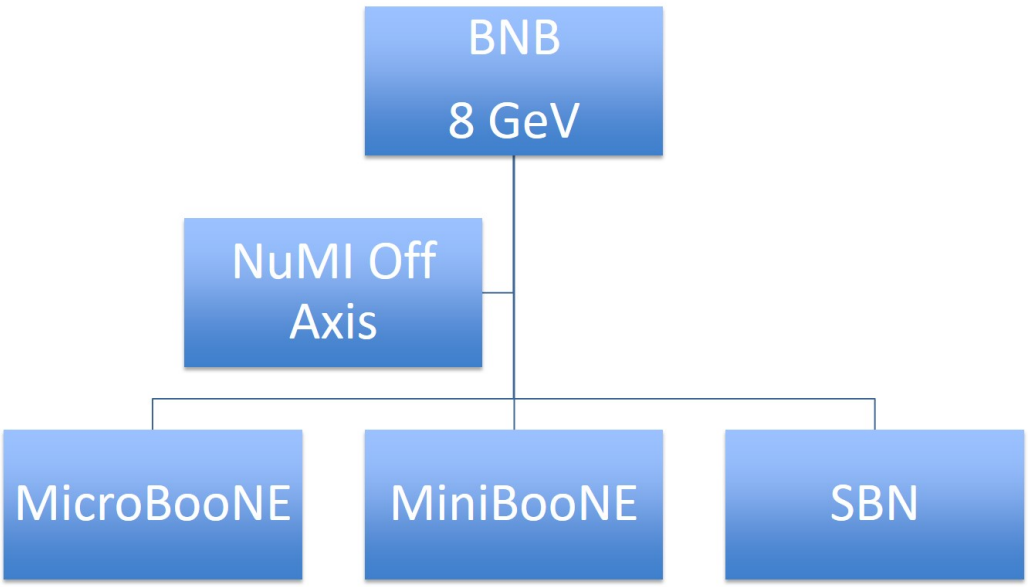

FIG. 2: A schematic depiction of the Short Baseline Program

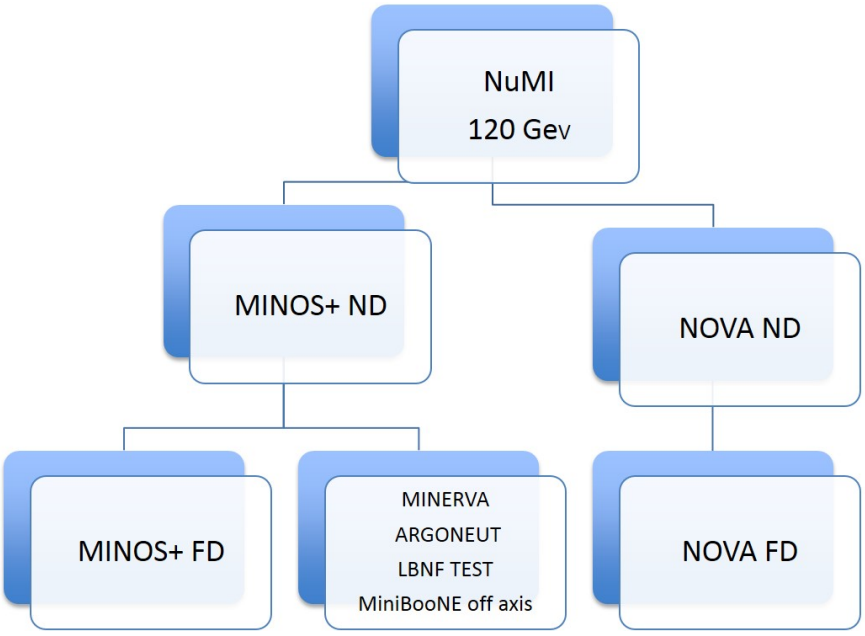

FIG. 3: A schematic depiction of the Long Baseline Program

BOOSTER NEUTRINO BEAM (BNB)

The BNB was constructed to send beam to the MiniBooNE experiment and that experiment took more intensity in a year than was delivered during 17 years of Fixed Target Running. The experiment can run at 18000 $\frac{pulses}{hour}$ at $5E12$ protons per pulse. Due to the

large intensity per hour and the rapid repetition rate much care was devoted to dealing with the radiation issues associated with these large intensities. Early on it was decided to utilize magnets, which had a large aperture, and the beamline was designed to ensure that the clearance of the aperture was large with respect to the size of the beam at the aperture location. Due to the rapid repetition rate of the beam an automated correction system (Autotune) was used to find and correct minor beam wandering, which is difficult to do manually because of the 5 Hz rate. Finally a MiniBooNE Beam Permit System was installed that is able to check various digital and analogue information against nominal values on a pulse-by-pulse basis.

Since turning on the BNB has transported 2.3E21 protons and the horns have pulsed half-a-billion times.

NUMI BEAMLINE

Because of ground water issues NuMI losses were even more of a concern than BNB. A brute force solution was adopted in that the beamline was designed with a larger acceptance than the largest beam emittance that could be accelerated the Main Injector. Of course the beam could still be steered into an aperture restriction so an Autotune program was needed and due to operational considerations the NuMI Autotune was more sophisticated than the one used by BNB. The NuMI Beam Permit System checks more than 250 items. These loss control systems lead to a fractional beam loss prior to the target profile monitor of $3E-7$. Far detector considerations implied we needed to have excellent accuracy and stability of targeting. We achieve angular stability of +15 microradians and a positional stability of +100 microns.

There were several changes for the NOvA medium Energy Run. The experiment requested a movement of the second horn to improve the desired flux at their far detector. In order to deal with the increased intensity several changes were made in the target area: a new baffle with 13 mm diameter was installed, a new and more robust target was installed and additionally the beam spot size was increased to 1.3 mm rms in both directions to reduce the stress on the target.

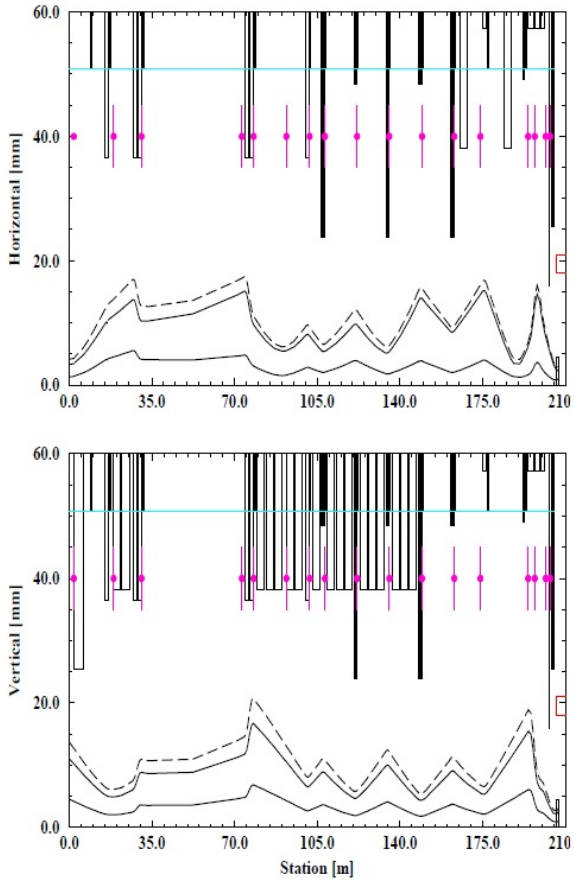

FIG. 4: Beam envelope and apertures. The lower beam envelope is the one sigma and the upper two traces are 95% and 99% with momentum folded in. The assumed emittances were 20π and $\frac{dp}{p}$ of .1%. The line indicates the total loss monitor coverage and the dots indicate the location of individual loss monitors.

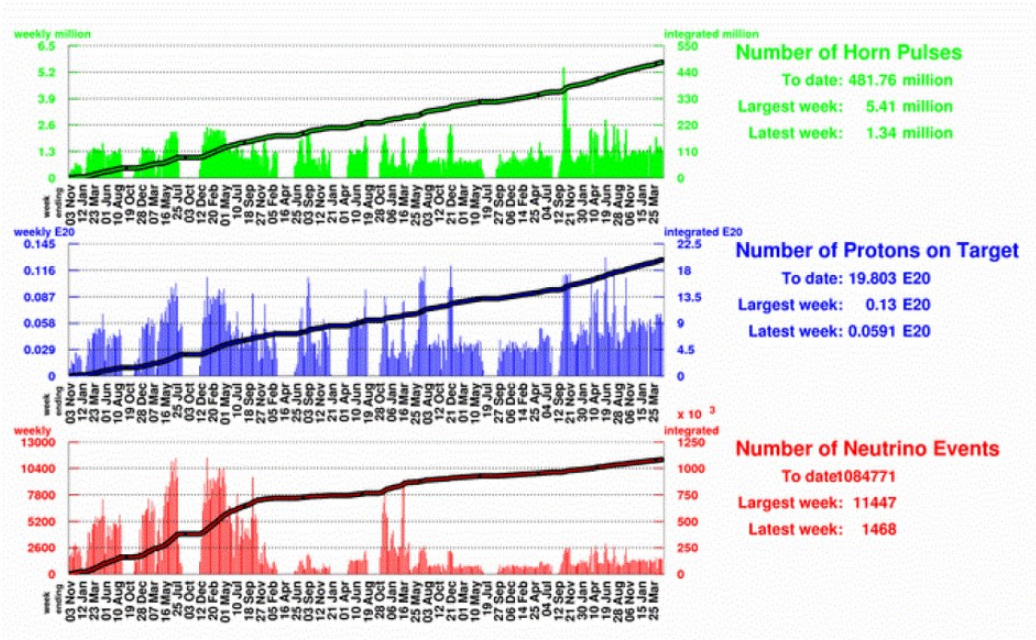

FIG. 5: 2002 2012 performance plots.

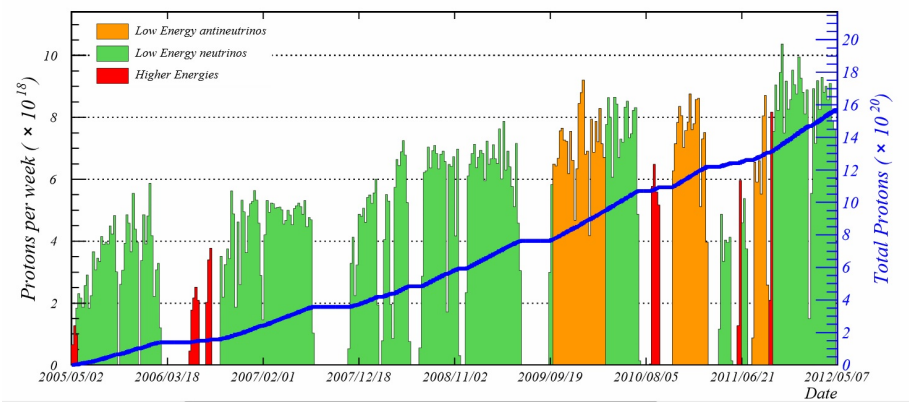

FIG. 6: The cumulative POT on the NuMI Target over the MINOS run. The total POT was $1.56E21$ in various beam configurations. Green is neutrino, orange is antineutrino and red is special runs (e.g. horn off).

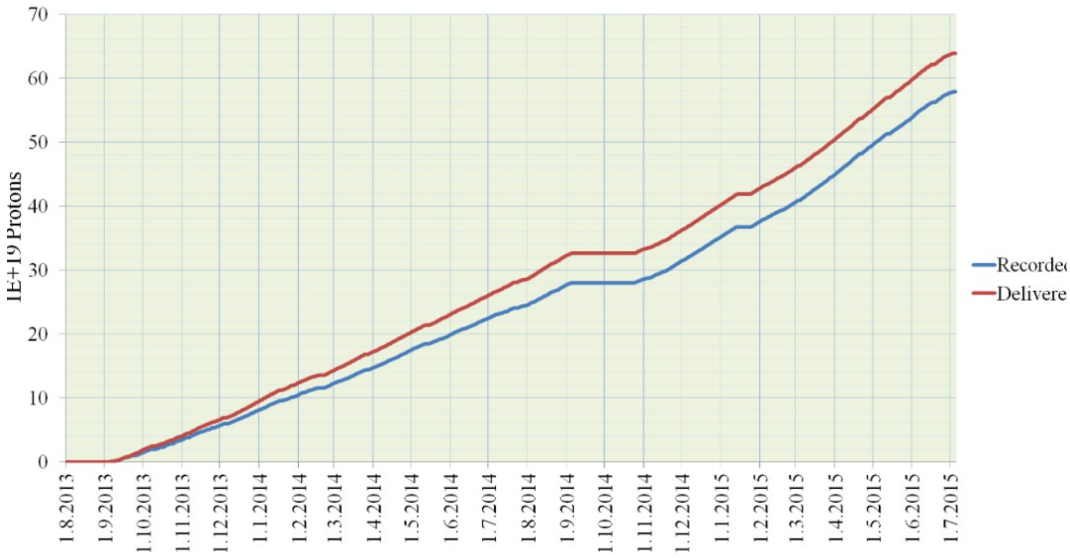

FIG. 7: NOvA Protons on Target

HORN STATUS

In the recent past we have had Horn 1 failures on both NuMI and BNB.

For NuMI, horn PH1-04 had a stripline fracture after about 30M pulses, which is believed to have been the result of a design change. PH1-05 is a ready 700 kW design horn however it shares the same stripline design as PH1-04 and one might expect a similar lifetime. There is a strong preference to modify this horn before installation. PH1-03 was designed as a 400 kW horn but it does not have the same stripline design as PH1-04. There are some modifications that can be rapidly implemented to increase the allowable power towards the 700 kW level. These include enhanced downstream water-cooling to reduce stripline flag and contact terminal temperatures along with using an air diverter to supply more air-cooling to stripline flags. PH1-03 was installed and all NuMI experiments are running. The current plan is to study and modify the PH1-05 stripline to enhance fatigue lifetime. It is possible that there would be a preventative horn replacement in the FY16 shutdown but this is to be determined. The situation for NuMI horn 2 is much better due in part to the fact that there is less radiation at its location. There has been one Horn 2 failure (PH2-01) however PH2-02 has well over 60 M pulses and shows no problems. The spare situation is quite well in hand with PH2-03 as a ready spare and PH2-04 very close to completion.

BNB-2 had over 400 M pulses when it was decided to change it out for BNB-3. BNB-2 had plugged water spray nozzles and two leaking water supply manifolds that were previously valved out. There were many challenges some of which were the result of the long running period and the resultant corrosion of movable parts. An important change was the design of a new rad-hard positioning platform, which will make future changes much easier. Also an upgraded RAW skid and pre-target instrumentation were installed. At present BNB does not have a spare horn but over 90% of the hardware has been procured for BNB-4. It is expected that BNB-4 will be completed in the latter part of FY16.

TARGET STATUS

There have been no BNB target failures and parts exist to make a target for BNB-4. However there have been several failures of the Low Energy (LE) targets used in the MINOS running and also an indication of target degradation. This degradation is shown in figure 8 and figure 9 shows the historical POT. There is no sign of neutrino yield degradation for the first NOvA medium energy target MET-01 and this is checked on a weekly basis with plots similar to figure 8. Since the POT on MET-01 is similar to the POT on NT-02 we are encouraged. It may be that NT-02 had a still not understood problem. The lab is in good shape with spare medium energy targets. MET-02 is a ready spare with 3 Be fins (out of 48) to investigate how Be acts with respect to graphite. MET-03 is almost complete and MET-04 and MET-05 are projected to finish in FY16.

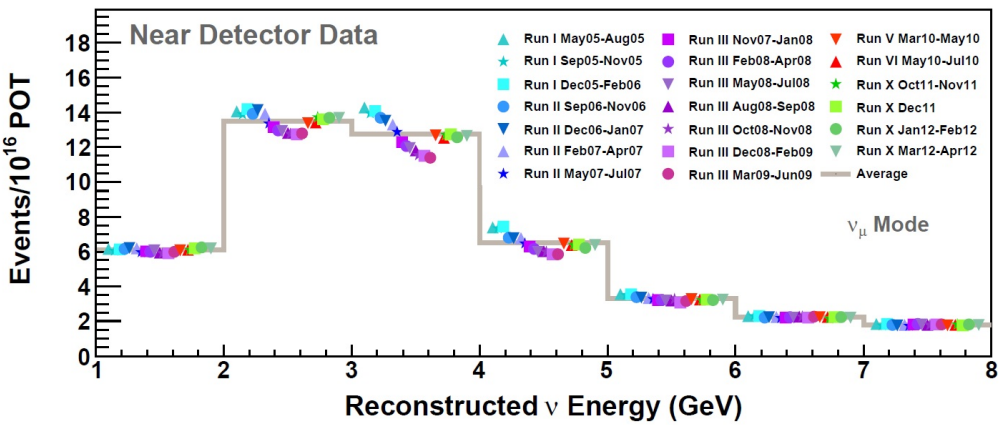

FIG. 8: All time MINOS LE reconstructed Neutrino Spectrum. The solid line is the POT weighted average spectrum over the whole data taking period while the points represent the data for specific runs. The significant drop in the 2nd, 3rd, and 4th bins is due to NT02 target degradation.

CURRENT STATUS

Both neutrino beamlines are up and running after the summer shutdown. For the BNB, MicroBooNE and MiniBooNE are running and there are three small experiments DCTPC, ANNIE, and SCIBATH. Studies are under way to upgrade the facility for the upcoming Short Baseline program. The NuMI beamline is delivering neutrinos for NOvA, MINOS+, MINERVA, and test setup for LBNF with the goal of safely and efficiently delivering 700 kW.

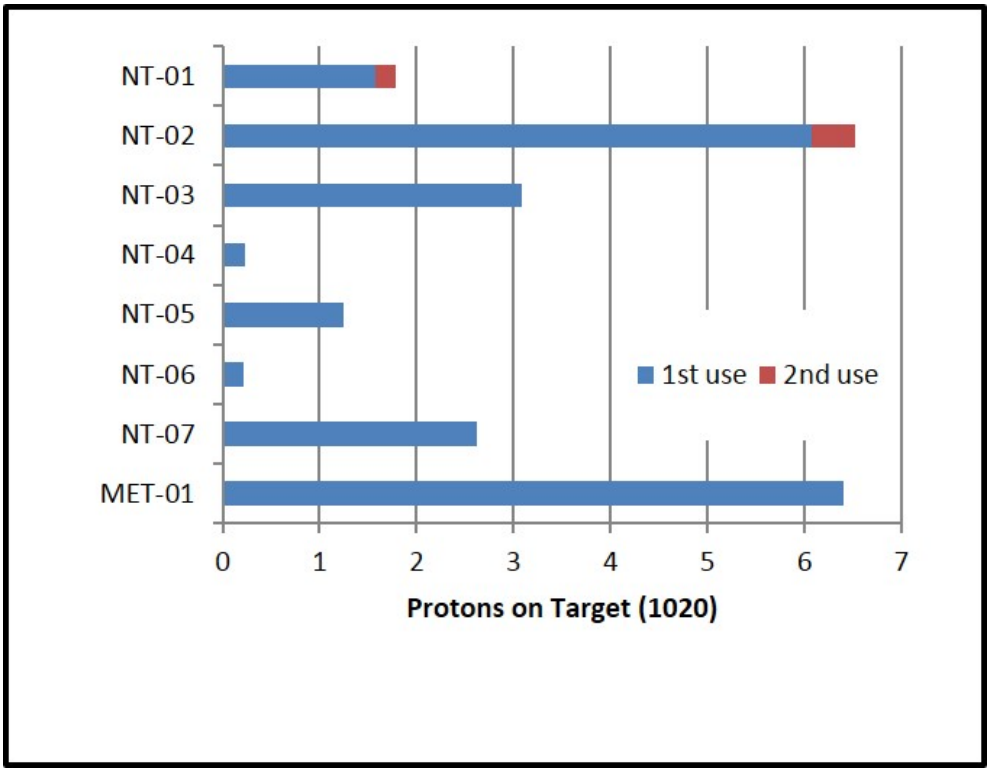

FIG. 9: Protons on target for the NuMI LE targets and the first NOvA medium energy target.

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