Study of Muon Monitor Data to Maintain the Quality of the NuMI Neutrino Beam at Fermilab

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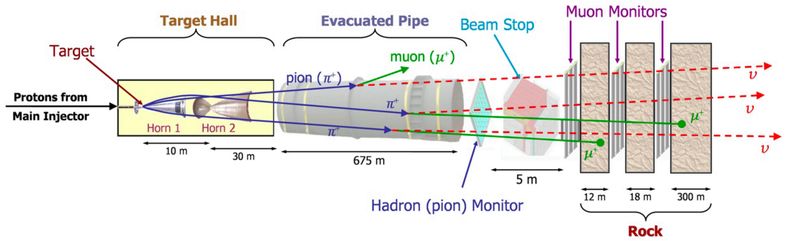
Introduction

A muon monitor which measures muon beam profile, is a key beam element to maintain the quality of muon neutrino beam. Three arrays of muon monitors located in the downstream of the hadron absorber provide the measurements of the primary beam quality. We studied the response of muon monitors with the proton beam profile changes and focusing horn current variations. The responses of muon monitors have been used to implement Machine Learning (ML) algorithms to monitor the beam quality.

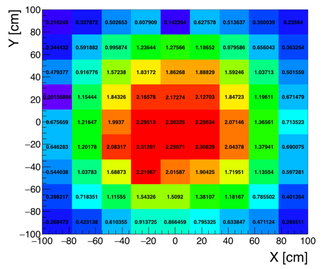
NuMI neutrino beam at Fermilab

120 GeV/c momentum protons from the Main Injector are striking with a graphite target to produce mesons. Charged mesons are focused into the decay pipe. The decay of pions and kaons produces muons and muon-neutrinos. This muon-neutrino beam is delivered to neutrino experiments such as NOvA.

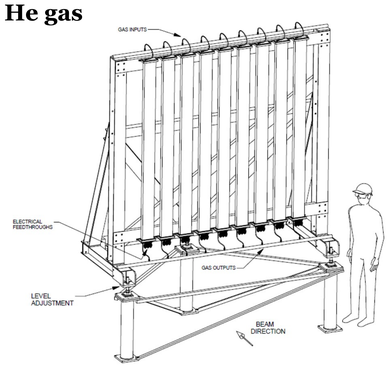


Muon Monitors

- **Three muon monitors are located in the downstream of the hadron absorber**
- **Each muon monitor consists of 9×3 arrays of ionization chambers**
- **Each ionization chamber consists of two parallel plate electrodes with the separation of 3 mm gap**
- **The chambers are filled with He gas**

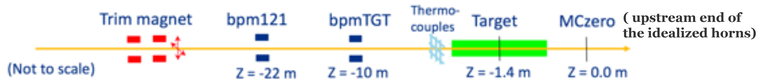


81 pixels of signal readouts on Muon Monitor 1



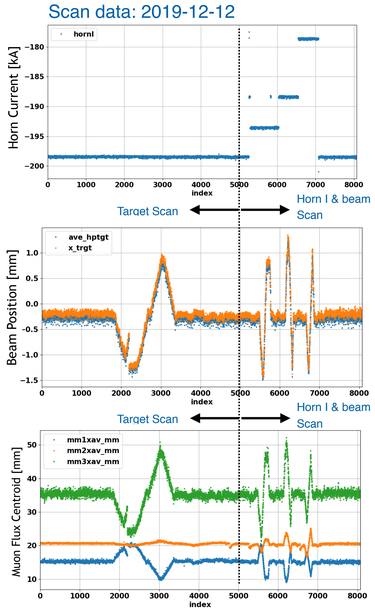
Beam and Horn Current Scan Studies

During this scan, the proton beam position has been varied horizontally and vertically to study the muon flux centroid correlation to the beam position for different horn current settings. Two BPM measurements are used to extrapolated the beam on to the target



Locations of the beam position monitors 121, TGT and the target relative to the MCzero point

Scan data: 2019-12-12



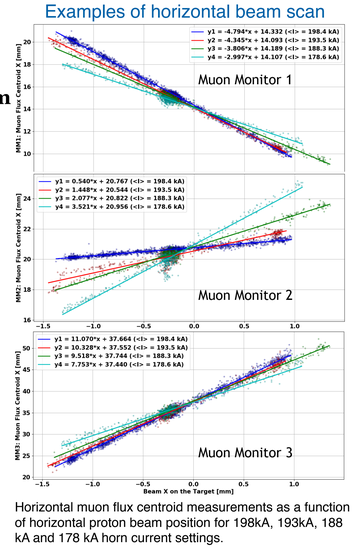
Horn current scan:
We have changed the horn current for certain time period to record the data as shown in the figure

Proton beam scan:
Proton beam has been changed horizontally and vertically for selected horn current settings

Muon Monitor Responses:
Muon monitors are responding uniquely to the horn current and beam variations

- **We have studied horizontal and vertical beam scans with selected horn current settings**
- **The beam scan study shows how each muon monitor responds to the beam position variations in horizontal and vertical directions**
- **The horn current scan shows how the horn focusing effects on the muon flux and the uniqueness of the muon monitor responses**
- **This observations indicate the physics of muon flux related to the hadron production, horn focussing and the target geometry**
- **The study is important for neutrino experiments to model the correlation of the muon monitor observations to the neutrino beam flux**

Examples of horizontal beam scan



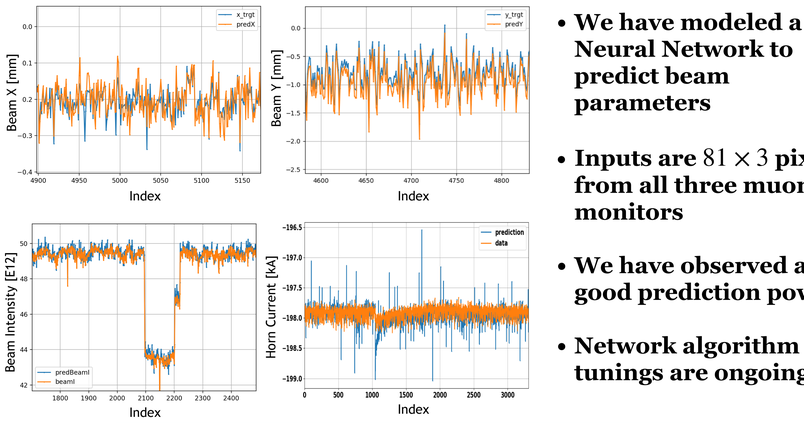
Horizontal muon flux centroid measurements as a function of horizontal proton beam position for 198kA, 193kA, 188 kA and 178 kA horn current settings.

Machine Learning Applications

Building Machine Learning tools to predict the proton beam profile and horn current changes by using muon monitor signals are helping us not only to understand beamline stability but also to reduce the neutrino flux systematics.

Predicting Beam Parameters and Horn Current

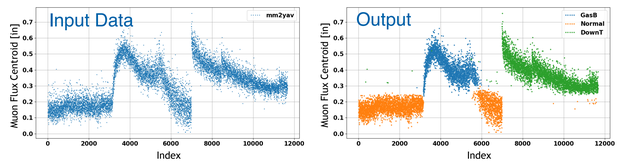
MOTIVATION: A tool to predict beam parameters and horn current by taking account muon monitor signals



- **We have modeled a Neural Network to predict beam parameters**
- **Inputs are 81×3 pixels from all three muon monitors**
- **We have observed a good prediction power**
- **Network algorithm tunings are ongoing**

Identifying / predicting Incidents

MOTIVATION: A tool to predict and identify incidents or anomalies from the spill-by-spill. This helps operators and experts to aware about the incidents



- **In this example, we have taken account two recognized incidents: Gas bottle incidents (GasB) and after the beam downtime behaviors (DownT)**
- **After the training, the model has predicted/identified incidents as expected**

Conclusion

- **Beam and horn current scan studies are helping us the understand the physics of muon flux related to the hadron production, horn focussing and the target geometry**
- **Tested ML applications show a good prediction accuracy**
- **Model tuning and building applications are ongoing projects**

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