Muon Monitor Data To Maintain The Quality Of The NuMI Neutrino Beam at Fermilab

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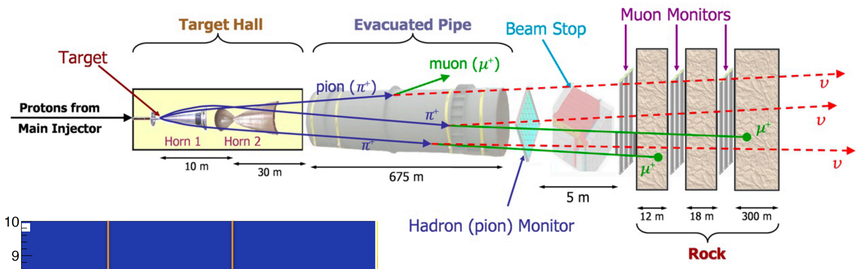
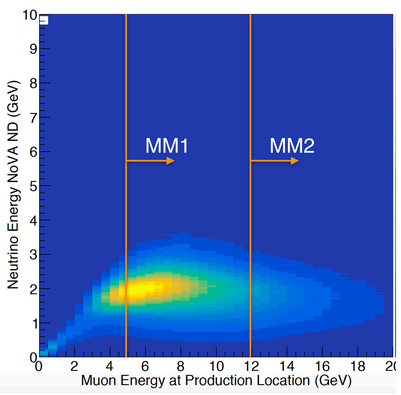
Introduction

We studied the response of muon monitors with the proton beam position on the target and the focusing strength of the horn. The results were evaluated for future NuMI AIP 1MW operations. The response function needs to be modeled by using Machine Learning algorithms which will be implemented into a muon monitor signal analyzer. The new analyzer will forecast the neutrino beam quality and control the beam position on the target if needed. Upgrading the helium gas handling system is the other key to improve the stability of the muon monitor signal.

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 produce muons and muon-neutrinos. This muon-neutrino beam is delivered to neutrino experiments such as NOvA.

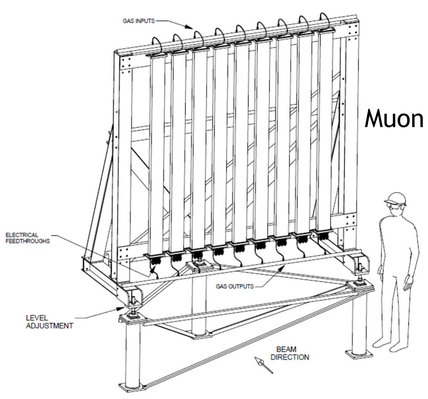




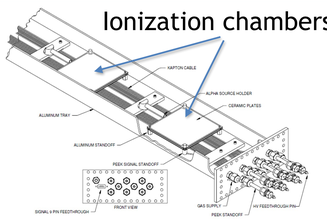
According to the MC studies, MM1 has a good sensitivity to see the correlation of neutrino beam to muons

From Amit Bashyal

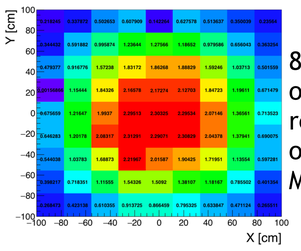
Muon Monitors



Muon Monitor



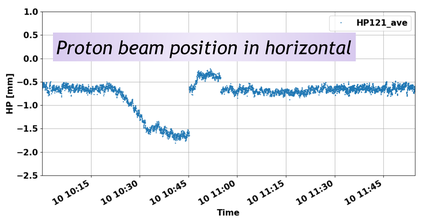
- Three muon monitors are located in the downstream of the hadron absorber
- Each muon monitor consist of 9x9 arrays of ionization chambers
- Each ionization chamber consists of two parallel plate electrodes with the separation of 3 mm gap
- The chambers are filled with He gas



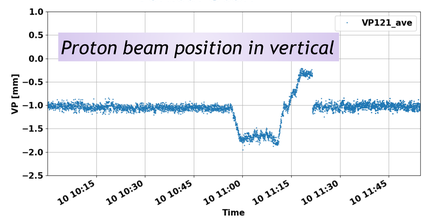
81 pixels of signal readouts on Muon Monitor 1

Target Scan Studies

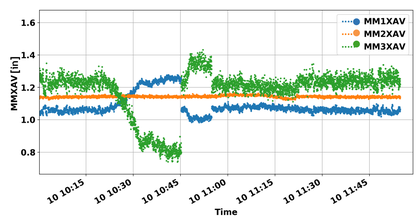
Horizontal Scan



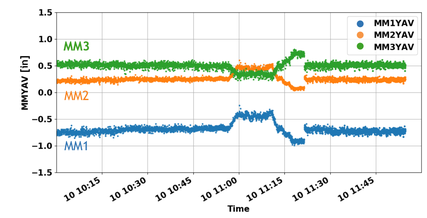
Vertical Scan



Muon Monitor Response: <X>



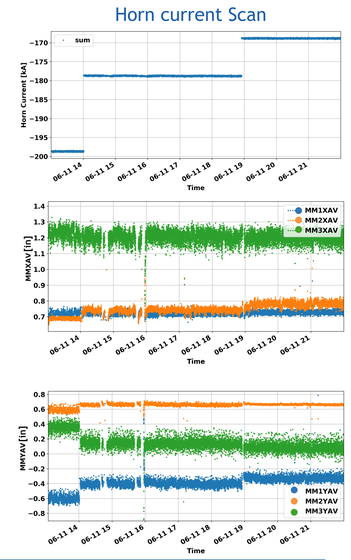
Muon Monitor Response: <Y>



Horn Current Scan Studies

- The target scan study shows how each muon monitor responds to the beam position variations in horizontal and vertical directions
- According to the horn current scan, the muon monitors have the capability to observe the horn current changes (specially the vertical position measurements)

Horn current Scan



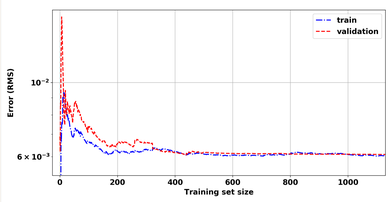
Machine Learning Applications to Monitor the Beam

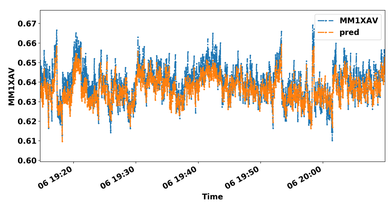
We are working on modeling ML algorithms to understand the neutrino beam variations with the help of the muon monitor data and simulation studies

An Example of predicting the muon beam centroid with a ML prediction

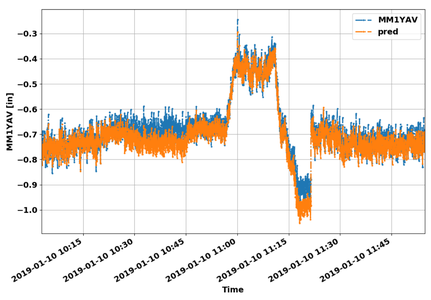
The muon beam centroids on each muon monitor have been modeled by taking account incident beam profile measurements and the horn current data as input variables

$$prediction = f(X_b, Y_b, \sigma_X, \sigma_Y, P_{beam}, I_{horn})$$

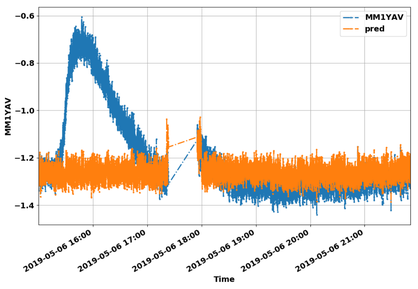




- ML model is trained by using a randomly selected past data sample
- Model predictions are following the trend of the muon monitor measurements with < 5 % difference

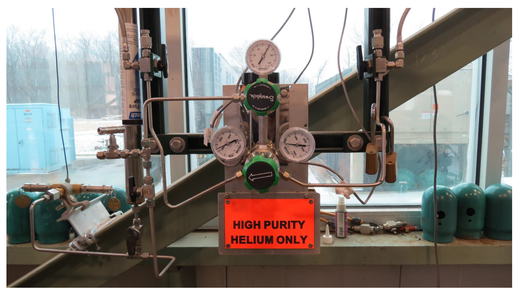


- Example of trained model predictions on target scan data
- Predictions are following the muon monitor responses
- This method has an ability to identify the unusual responses of the muon monitors due to the unexpected factors



- This model prediction is useful to monitor the muon beam quality, recover missing data and observe the long term trend of the beam variations

Gas system upgrades to improve the muon monitor signal



Gas Regulator with 3-way auto-switch

He Gas Bottle Farm

- Planing to replace the old gas system
- Cleaning up the unused gas lines
- Need to upgrade the system with a calibrated transducers

Future Plans

- We are planing to run beam scan, horn current and beam power scan studies
- Hardware upgrades: Gas system upgrades
- Hope to apply Unsupervised learning algorithms on data clustering to categorize the events as “Good” or “Bad”
- Deep Learning applications on muon monitor data patterns to understand the neutrino beam variations with the help of the simulation studies

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