Study of NuMI Beam Spot Size to Build a Regression Model

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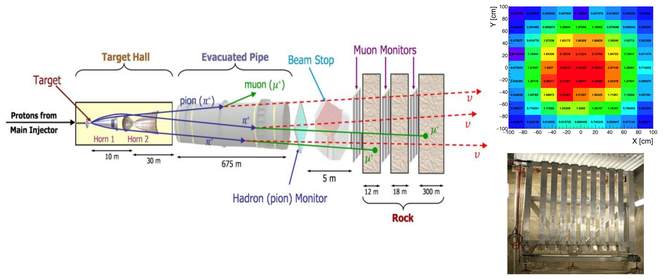
Introduction/Background/Purpose

- The NuMI project began operations at Fermilab in 2005. Colliding 120 GeV protons with a fixed graphite target, NuMI beamline produces muon neutrinos for neutrino experiments from the decay of hadrons. We collect muons at the muon monitors as a by-product of the decay of hadrons.
- In this project, we study beam spot size with the beam optics and muon monitor signal studies. We build a Machine Learning model to predict the beam spot size by taking account muon monitor signal as inputs.



Pictured Above: On the left is a diagram of the NuMI beamline, on the top right is a map of the muon monitor signal divided into the 81 pixels, on the bottom right is a picture of an actual muon monitor

Methods and Tools

All data analysis and plots were done using Jupyter Notebook with Python. Coming from a background with no experience using these tools I learned:

- How to write a script
- How to analyze data using a script
- How to make plots and adjust parameters
- How to pinpoint what is causing problems in the script and how to fix said problems.

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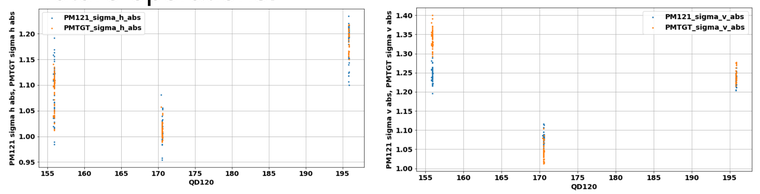
NuMI Beam Optics Study

Multiple data sets were evaluated to determine which would be used for the model, including data from a beam optics study led by Katsuya Yonehara. With this optics study, I was tasked with:

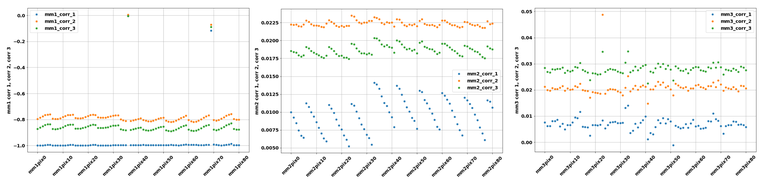
- Making plots of the different variables (QD120, PM121 vertical and horizontal sigma values, and PMtgt vertical and horizontal sigma values) versus the beam intensity.
- Finding the averages and standard deviation for each variable.
- Using the studies I was tasked with, they can use my results to set up the best beam optics options for future operations.



Two plots including three magnetic field configurations from the beam optics study for the horizontal and vertical beam spot size changes at different profile monitors (PM121 and PMtgt).

Correlation Studies with Muon Monitor Data

I was also tasked with finding correlation between the readout of the muon monitor signals and beam intensity, and both vertical and horizontal beam spot size.

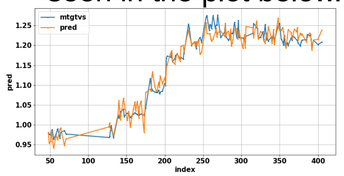


MM1, MM2, and MM3 shown above in correlation plots with correlation to beam intensity and vertical and horizontal beam spot size. Each plot and correlations were analyzed and used to decide what data should be used in the model that would be made.

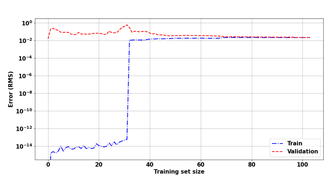
Machine Learning Model

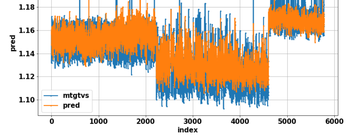
Using the correlation coefficients found previously, a linear regression model was made.

- The correlation coefficients that had the most correlation to beam spot size and the least correlation to beam intensity were used to filter the data set and make a selection of what data would be used for the linear regression model.
- The inputs are the selected muon monitor pixel data and the outputs are beam spot size.
- Using this data allowed for the most accurate predictions compared to actual values, as can be seen in the plot below.



The results from the model, or validation plot showing the predicted values along with the actual value.To the left is the first attempt at the model, below is a model made with more data sets to increase accuracy. This plot can be used to easily compare the two values for accuracy in the prediction.





Performance plot showing the accuracy and error of the linear regression model.

Conclusion

- By using the correlation studies from the muon monitors, we were able to build a Machine Learning model that was mostly accurate (the plots show where there was deviation in the beginning) in predicting the beam spot sizes. This can be used to help with future projects involving needing to knowbeam spot sizes.
- The plots, averages, and standard deviations found during the beam optics study was used to help determine which of the three optics options would work best for future studies and other uses.