ILLINOIS INSTITUTE OF TECHNOLOGY

NuMI Beam Monitoring Simulation and Data Analysis

YIDING YU

NEW PERSPECTIVES 2020

24 AUG 2020

Outline

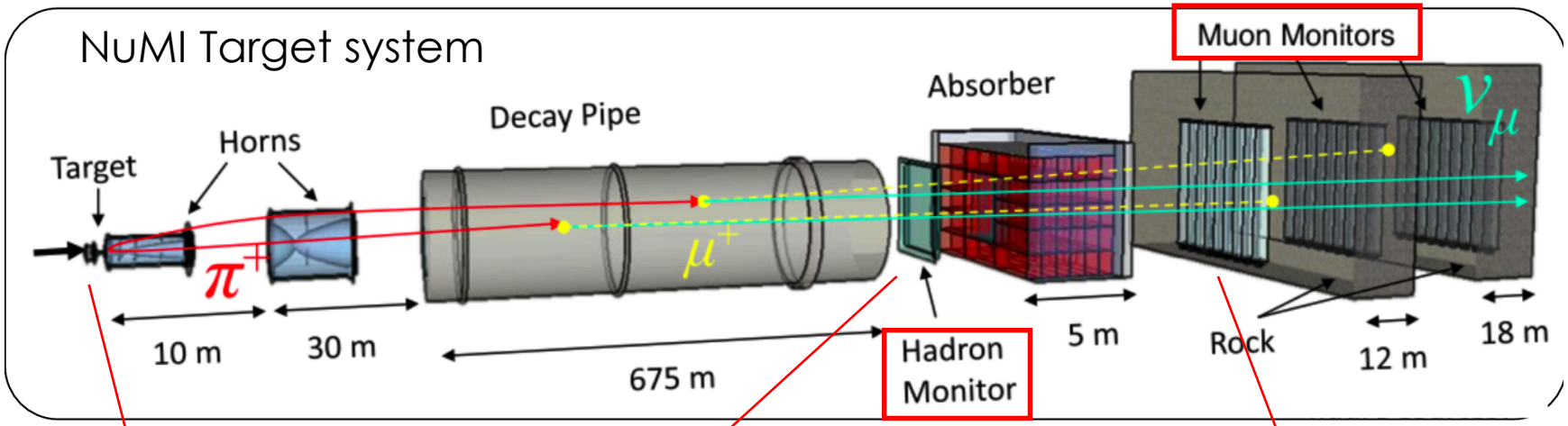
- Motivation of muon monitor simulation and data analysis
- Introduction to hadron, muon monitors and simulation
- Correlation between muons and neutrinos
- Beam & Horn current scan
  - Data analysis
  - Simulation
  - Spectrum of muons and neutrinos
- Machine learning application in NuMI Target system
- Summary

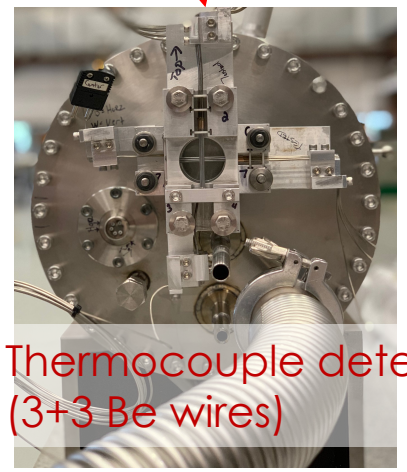
Data analysis and simulation

- Without MINOs data, we rely on muon monitors
- Muon monitors are crucial tools to monitor the beam profiles
  - Incoming proton beam
  - Neutrino flux

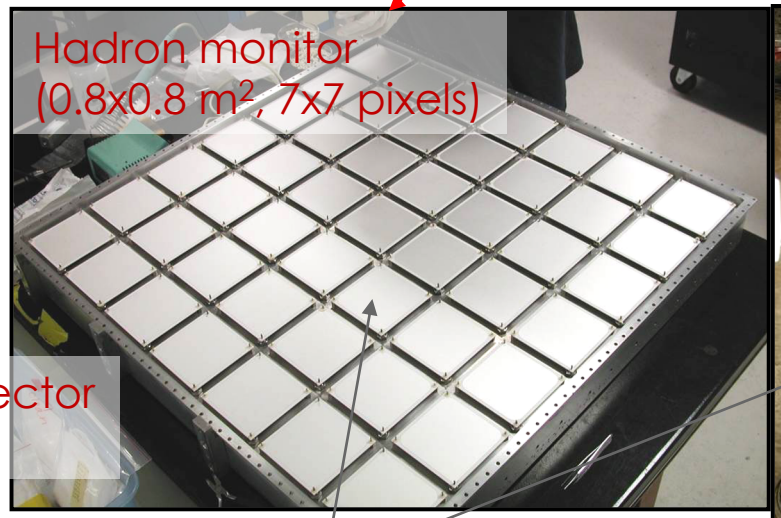
- Purposes
  - Find correlation between MM data and simulation
  - Use a combination of data and simulation to identify issues with beam
- We simulate the effect of the variation in
    - Beam position
    - Horn current

NuMI Beam Monitor System

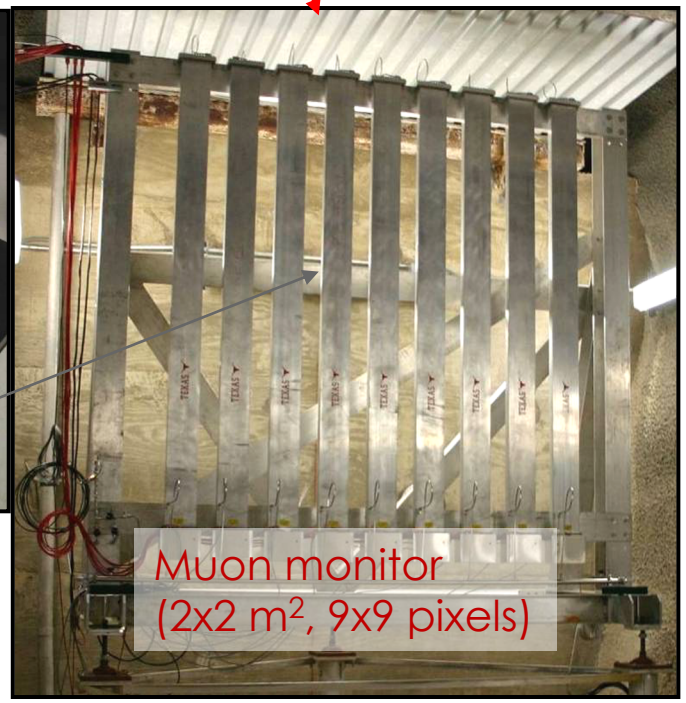




Thermocouple detector
(3+3 Be wires)



Hadron monitor
(0.8x0.8 m^2, 7x7 pixels)

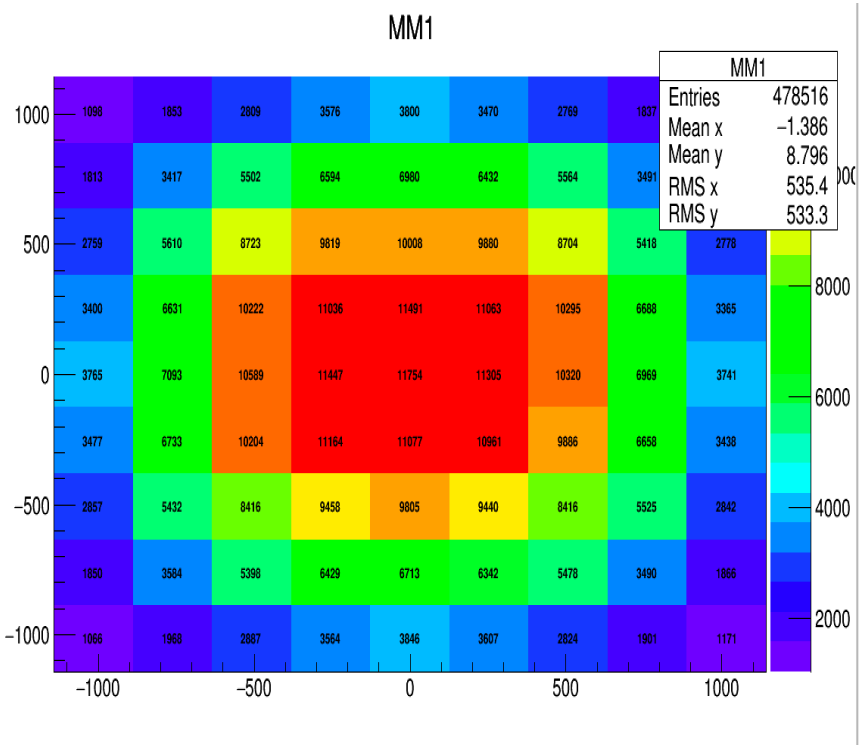


Muon monitor
(2x2 m^2, 9x9 pixels)

Multi-pixel ionization chamber

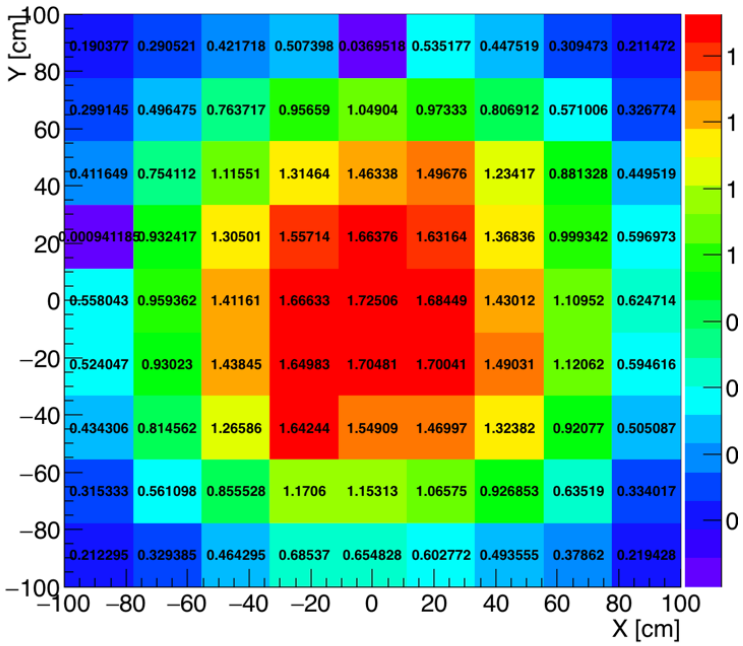
Muon monitor simulation

Data



- This 2-D histogram shows how the muons are distributed at MM1.
- There are 81 pixels at each muon monitor.
- The number on each pixel is the number of muons hitting that area.

Data _ signal voltage at MM1

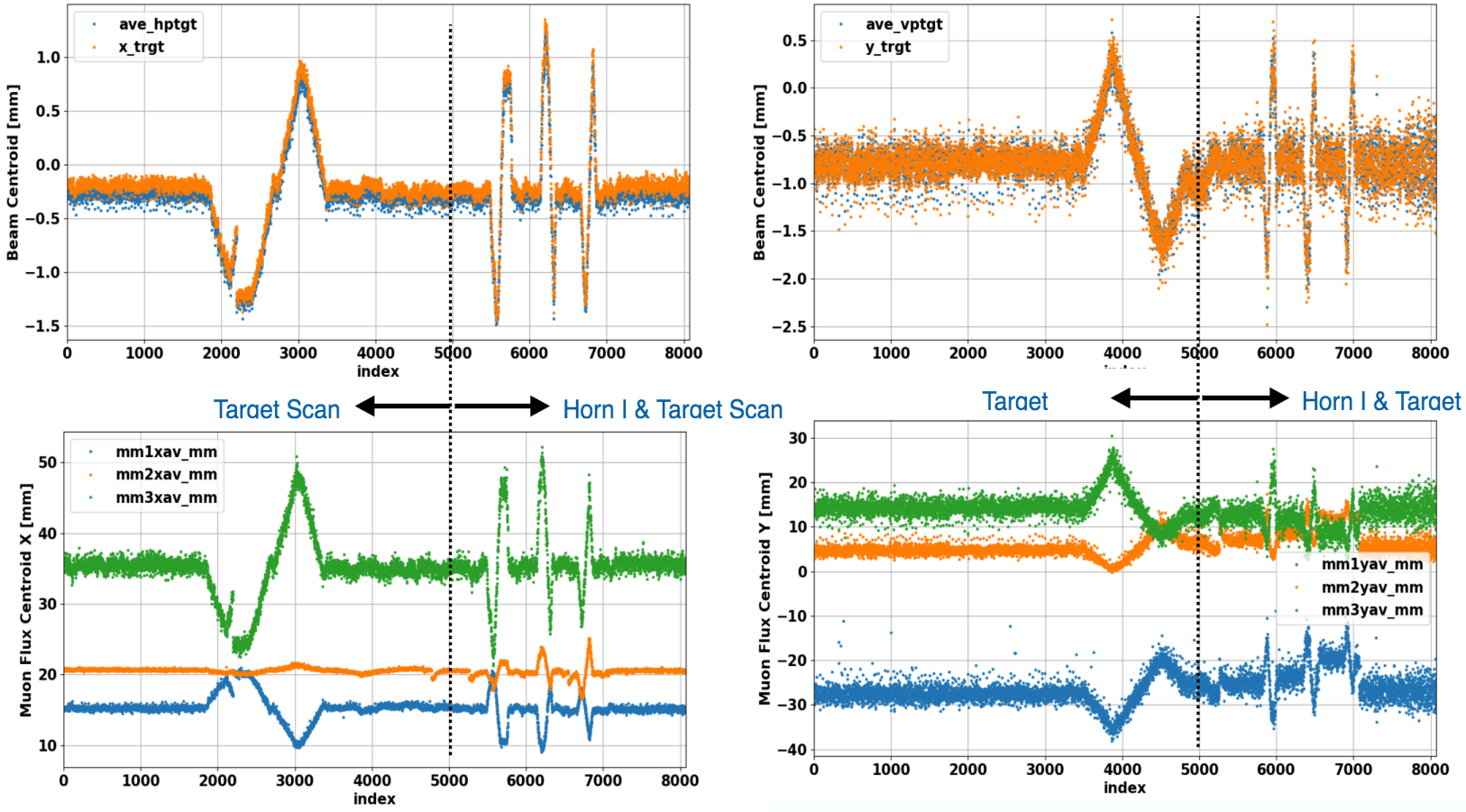


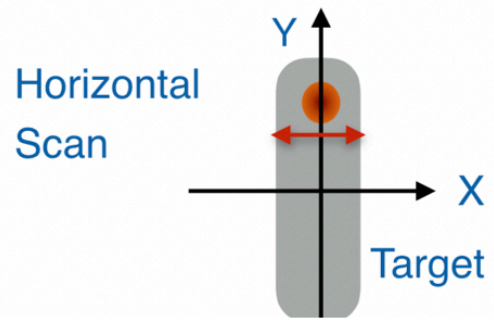
What we have for muons in simulation

- Horizonal position, Vertical position
- Momentum at MMs in x, y and z directions
- Production Momentum in x, y and z directions

Target and horn scan study

Scan data 2019-12-12

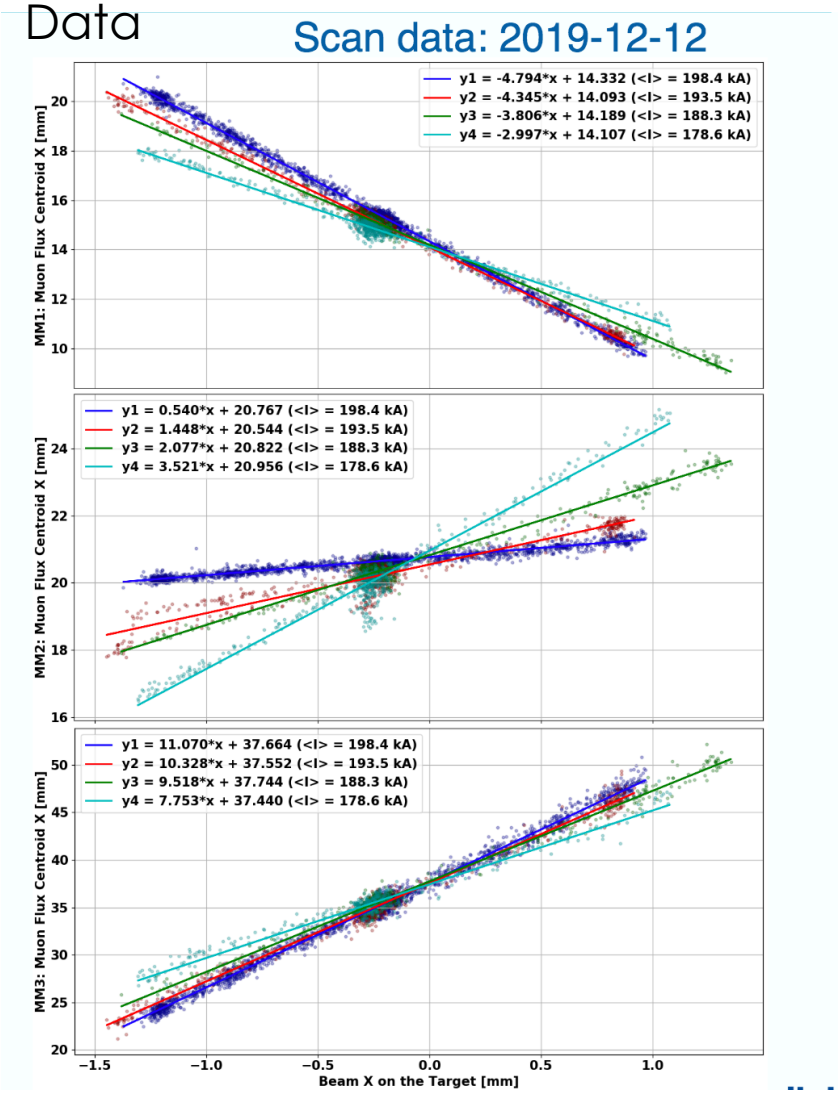




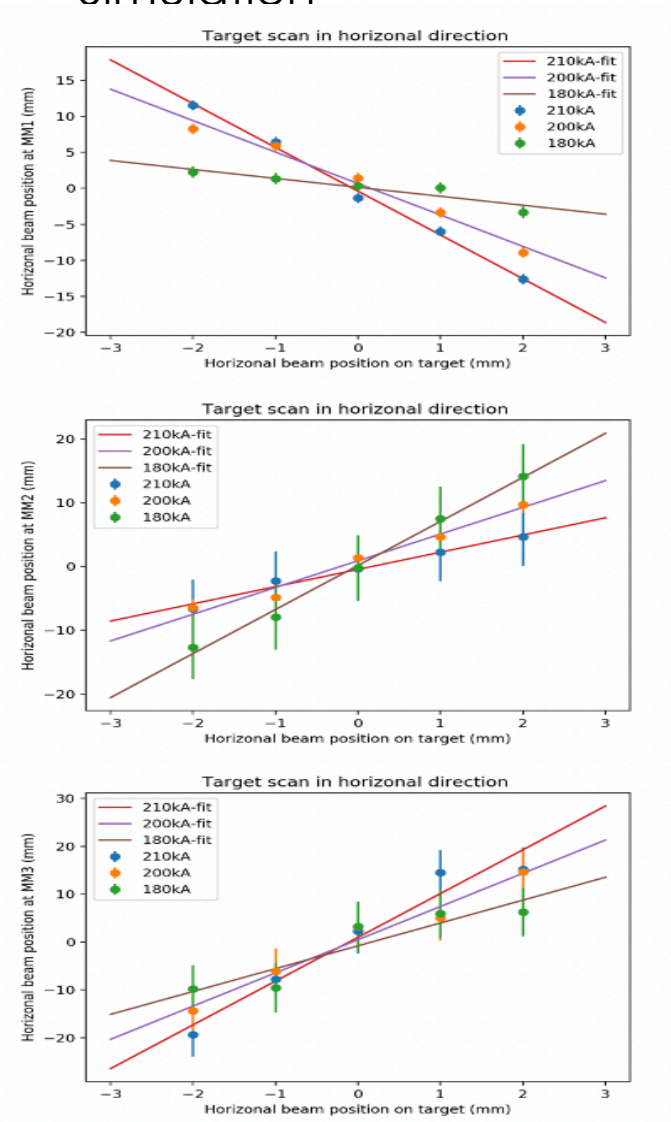
- Target scans show how each muon monitor responds to beam position variations in horizontal and vertical directions.
- The observed beam centroid on muon monitors shows a linear response. Different slopes show the focus effect for different energy range of muons

Data vs Simulation (Horizontal)

Data



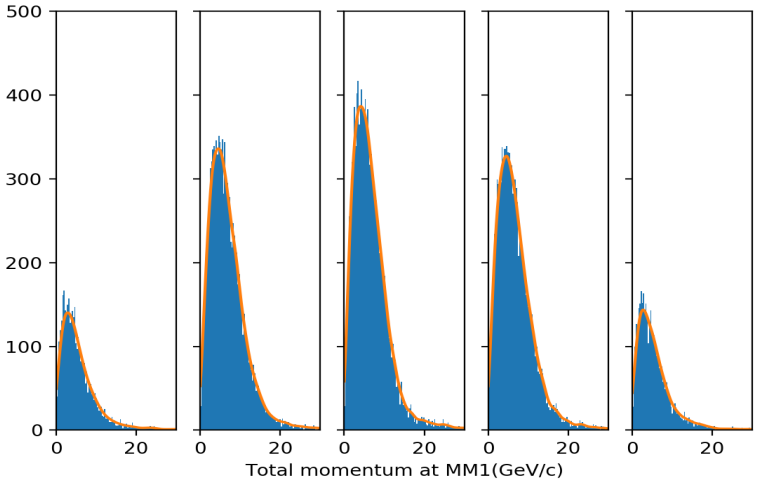
Simulation



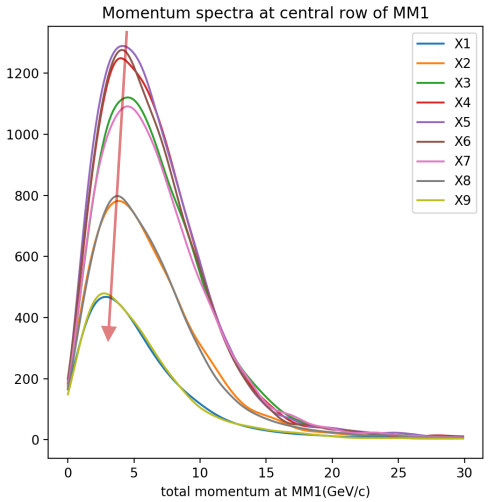
- The trends of simulation are consistent with data.

Different spectra for different pixels

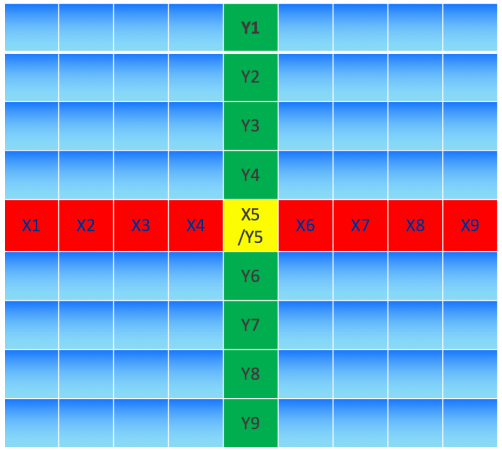
Total momentum at central row of MM1



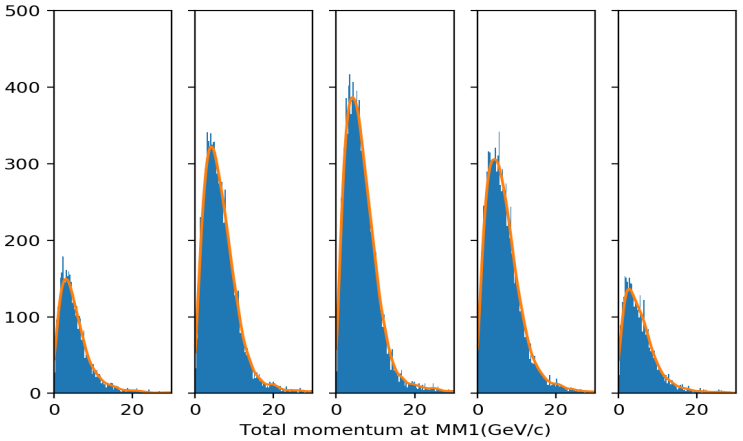
X1 X3 X5 X7 X9



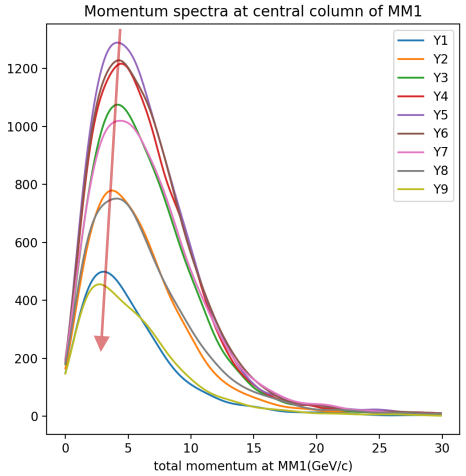
MM1



Total momentum at central column of MM1

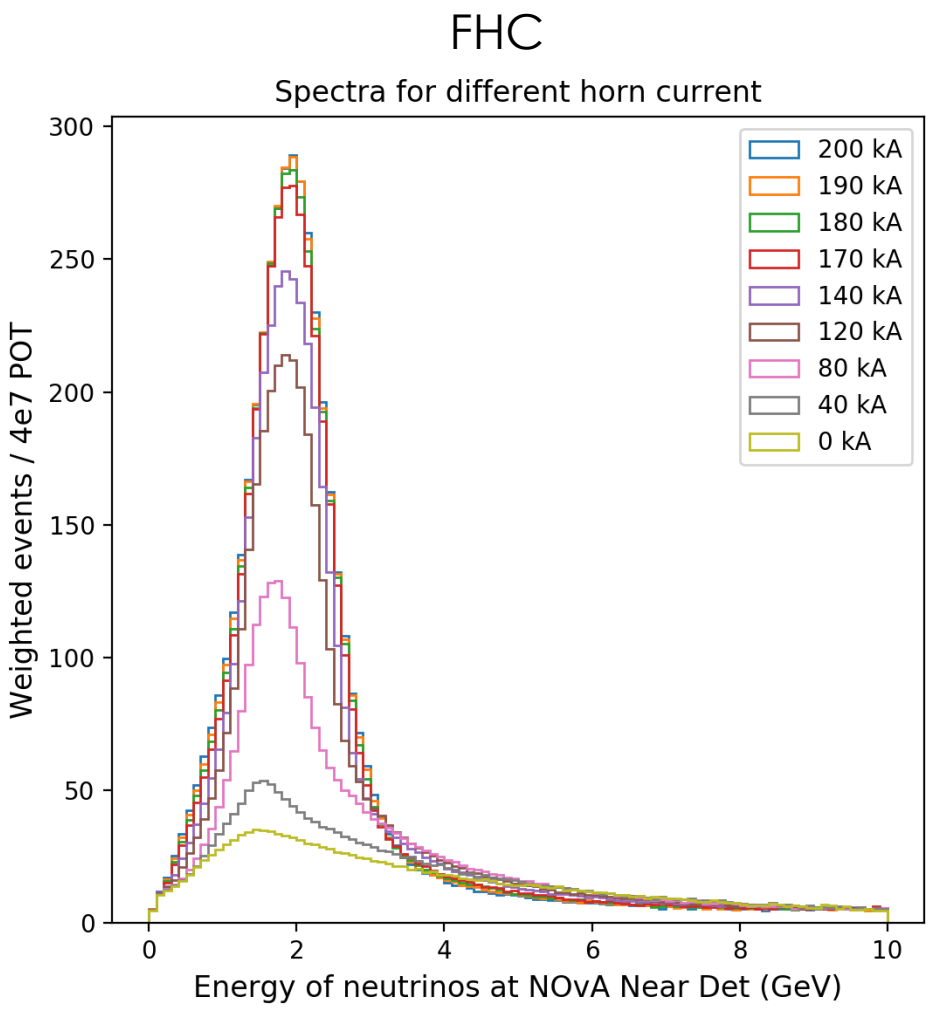


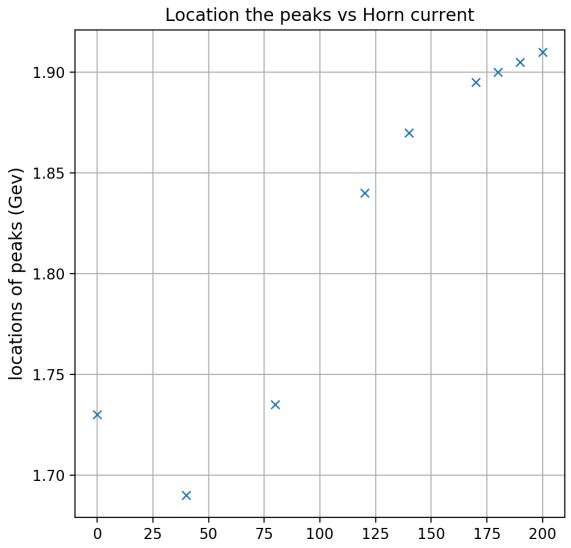
Y1 Y3 Y5 Y7 Y9



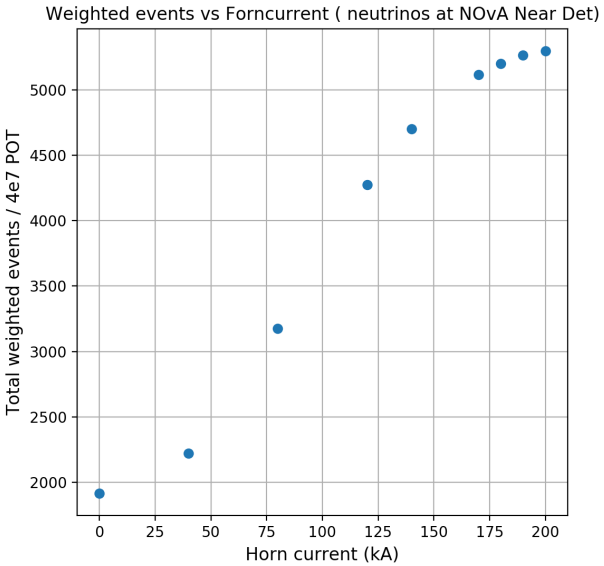
- The peaks of the spectra move to low momentum from center to edge of MM1.

Neutrinos spectra for different horn current





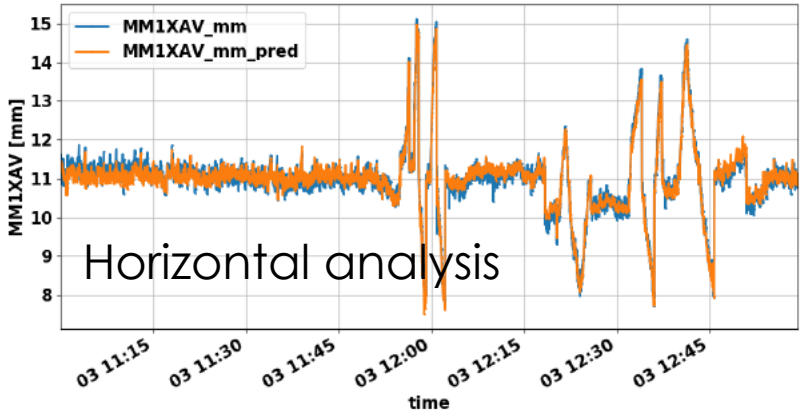
The peak location of spectra are quite stable to a 10 kA change in horn current(7 MeV change to 10 kA).

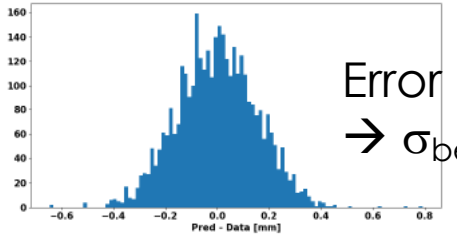


The flux of neutrinos are insensitive to a 10 kA change in horn current(2% change to 10 kA).

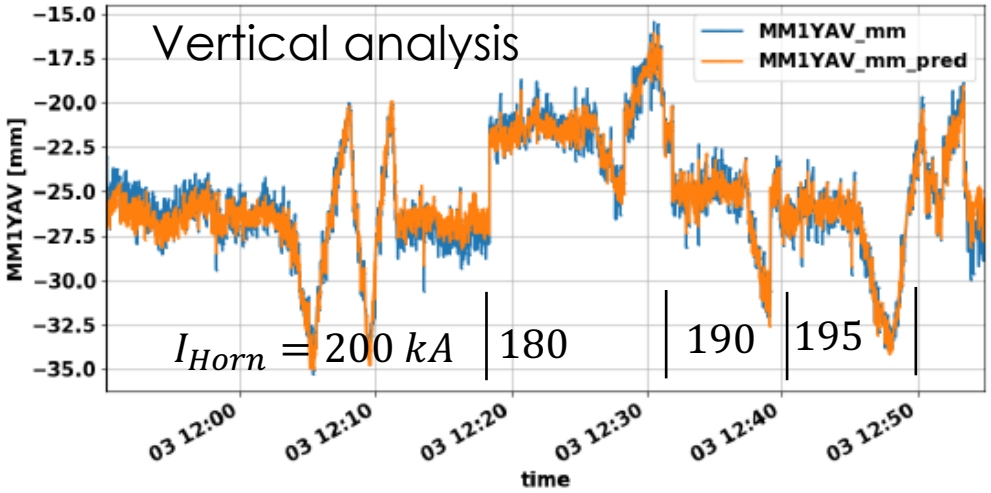
Machine learning in NuMI Beamline

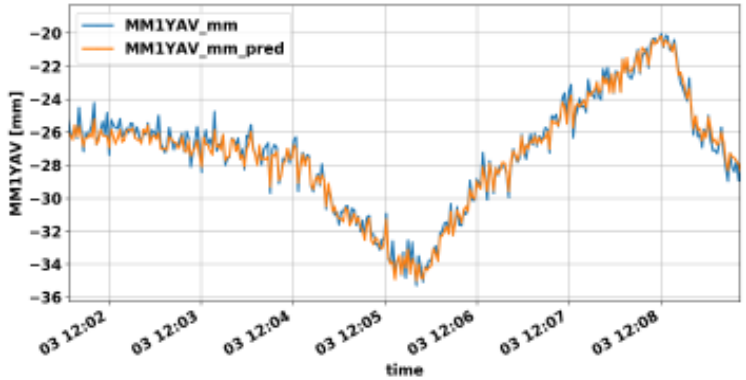
Predicted Muon Flux Centroid Position(ML)

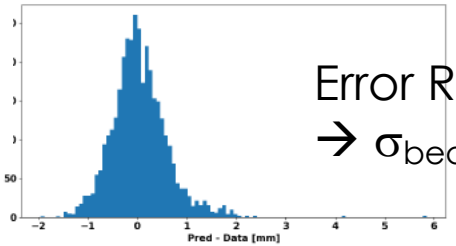




Error RMS = 0.15 mm
→ $\sigma_{\text{beam X}}$ = 0.03 mm

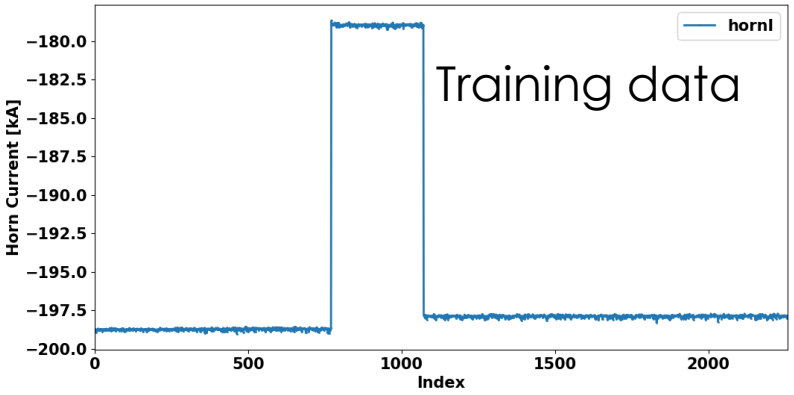


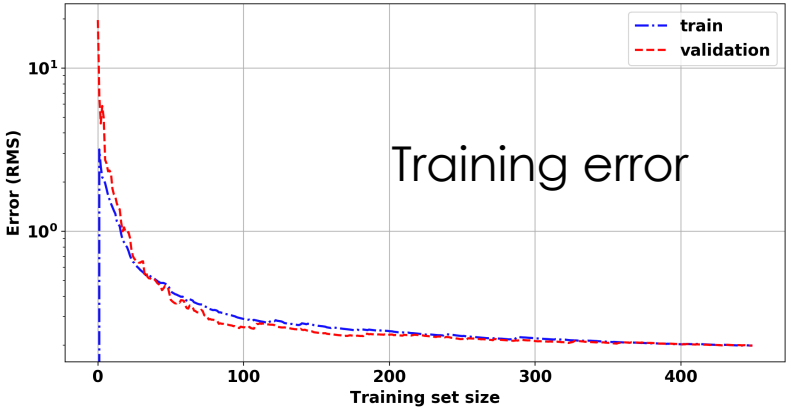




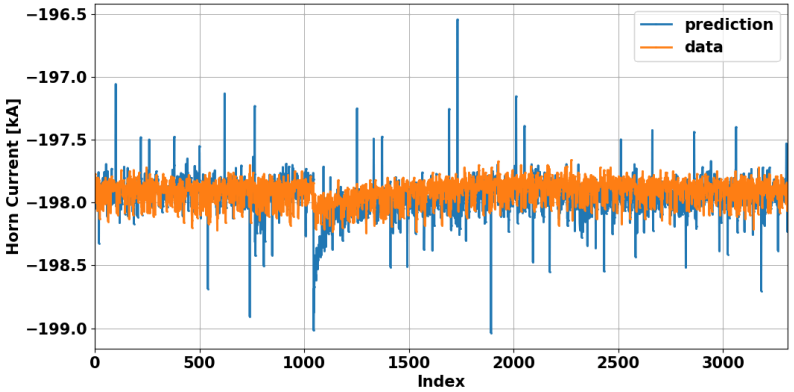
Error RMS = 0.58 mm
→ $\sigma_{\text{beam Y}}$ = 0.06 mm

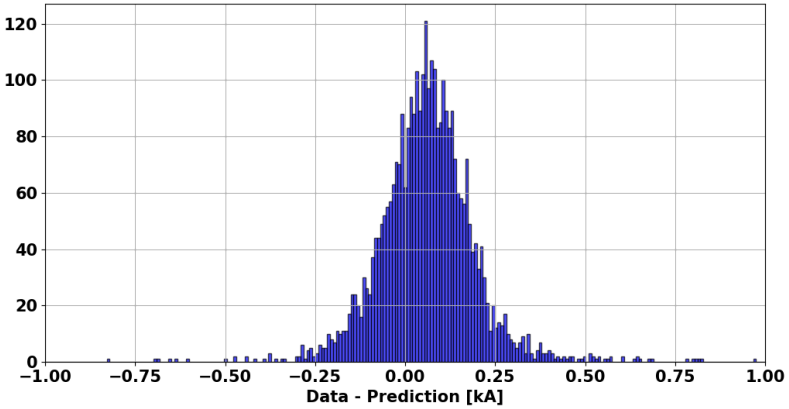
Predicted Horn Current (ML)





As applied to data





2019-07-05 13:00-14:30

Horn current error RMS = 0.152 kA

Summary

- Data study with different parameters (beam position, horn current)
- Simulation
  - For different proton beam position and horn current, simulation results are consistent with true data
  - Different pixels have different spectra
  - Proton beam profile vs the spectrum of neutrinos
- Our final goal is to use pattern recognition on MM1 & MM2 to be able to tell what the proton beam status is and how it affects the neutrino beam quality.
- Results of our studies will inform LBNF/DUNE design efforts

Muon and Hadron Monitor Working Team

- Pavel Snopok, Yiding Yu, Illinois Institute of Technology
- Katsuya Yonehara, Athula Wickremasinghe, Leonidas Aliaga Soplin, Fermi National Accelerator Laboratory
- Amit Bashyal, Oregon State University
- Tyler Rehak, Drexel University
- Pierce Weatherly, Drexel University
- Karol Lang, University of Texas Austin
- Nilay Bostan, University of Iowa
- Tom Carroll, University of Wisconsin
- Jennifer Thomas, University of Wisconsin / University College of London

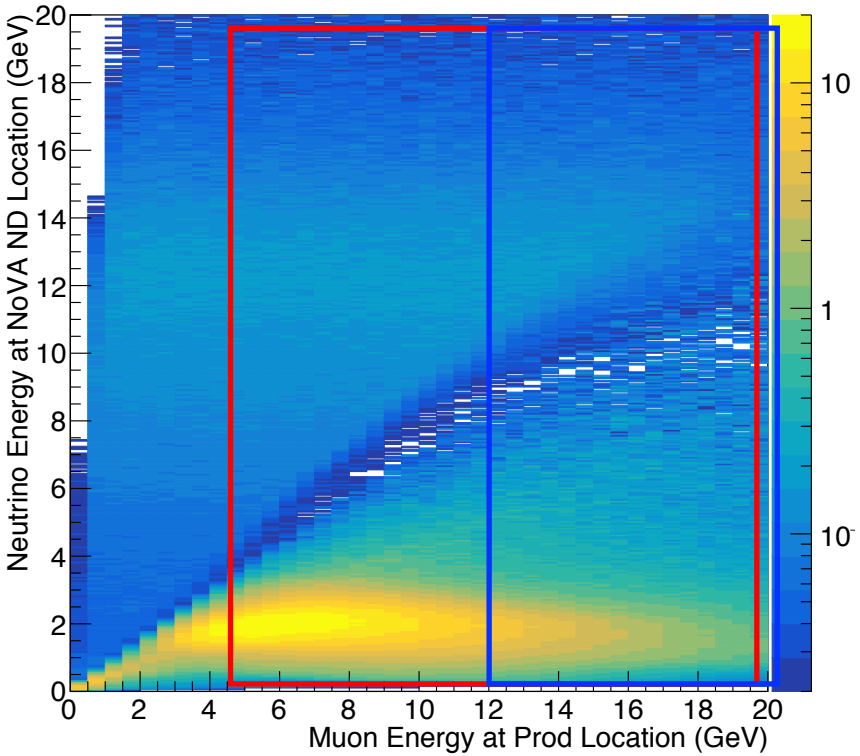
Please contact yyu79@hawk.iit.edu for any questions

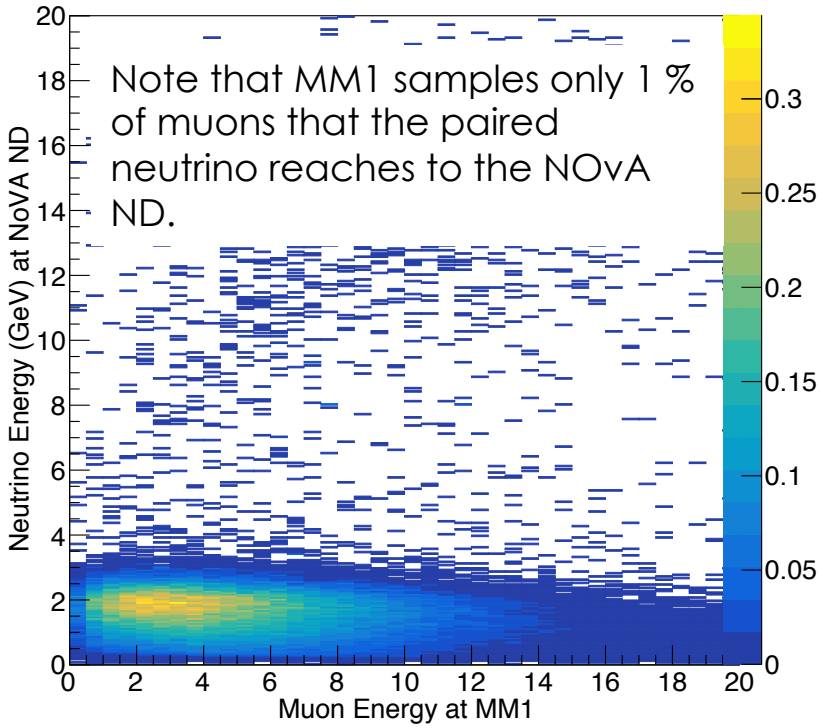
Thank You !!!

Back up

Correlation between muons and neutrinos

MM1 can see a core part of muons





Range of detectable muons in MM1 (MM2)

Note that muon energy at MM1 has 5 GeV less than energy at production due to energy loss in Hadron Absorber

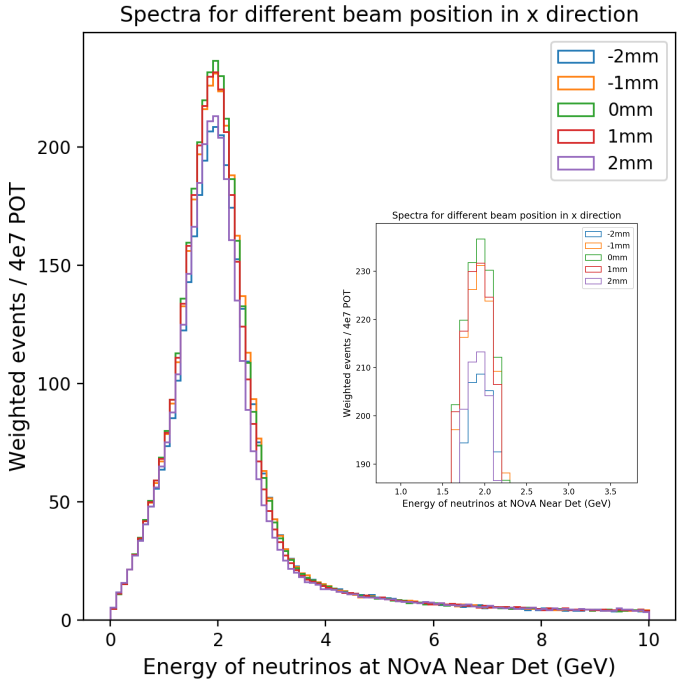
Beam target slopes

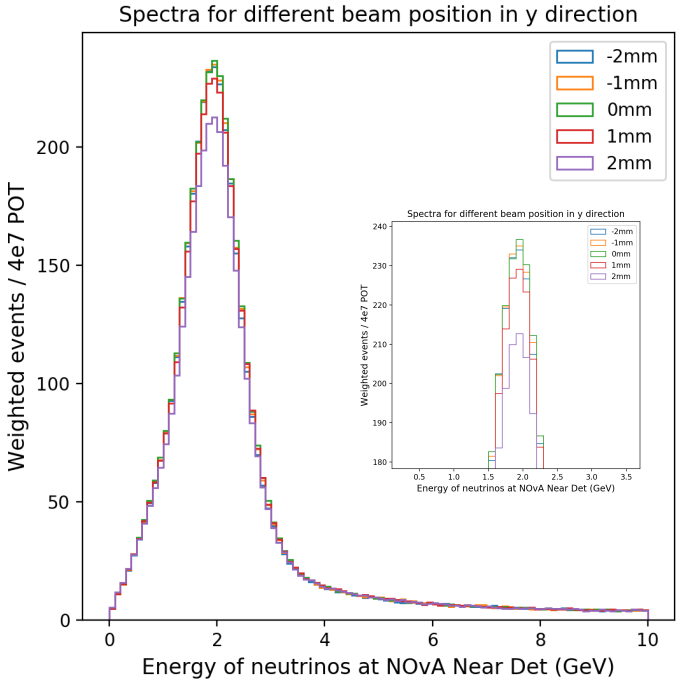
		Measurement	Slopes	Uncertainty	Ratio
MM1X	FTFP_water layer1mm	-4.794	-4.848	0.676	1.0113
	FTFP_water layer0mm		-4.349	0.547	0.9072
	QGSP_water layer1mm		-4.206	0.27	0.8773
	FTFP_no horms tilting		-5.892	0.334	1.229
MM2X	FTFP_water layer1mm	0.54	3.465	0.918	6.4167
	FTFP_water layer0mm		3.897	0.616	7.2167
	QGSP_water layer1mm		4.39	0.422	8.1296
	FTFP_no horms tilting		2.468	0.531	4.5704
MM3X	FTFP_water layer1mm	11.07	4.811	2.57	0.4346
	FTFP_water layer0mm		11.001	1.285	0.9938
	QGSP_water layer1mm		11.134	1.672	1.0058
	FTFP_no horms tilting		2.468	0.671	0.2229
MM1Y	FTFP_water layer1mm	-8.087	-9.255	0.798	1.1444
	FTFP_water layer0mm		-10.209	0.121	1.2624
	QGSP_water layer1mm		-9.39	0.286	1.1611
	FTFP_no horms tilting		-9.691	0.57	1.1983
MM2Y	FTFP_water layer1mm	-5.104	-2.584	1.293	0.5063
	FTFP_water layer0mm		-4.109	0.774	0.8051
	QGSP_water layer1mm		-2.488	0.888	0.4875
	FTFP_no horms tilting		-2.091	0.77	0.4097
MM3Y	FTFP_water layer1mm	8.335	5.208	1.506	0.6248
	FTFP_water layer0mm		5.723	1.834	0.6866
	QGSP_water layer1mm		8.106	1.08	0.9725
	FTFP_no horms tilting		5.694	2.681	0.6831

Horn current scan

	Events of muons/4e7 POT		
Horn current (kA)	MM1	MM2	MM3
0	5094	2843	781
40	5604	2980	896
80	9129	3391	912
120	22404	4740	1017
140	31405	6304	1087
160	42795	9332	1097
170	47916	11249	1159
180	53186	13921	1226
190	58565	16632	1345
200	63610	19365	1403

Spectra for different position on target





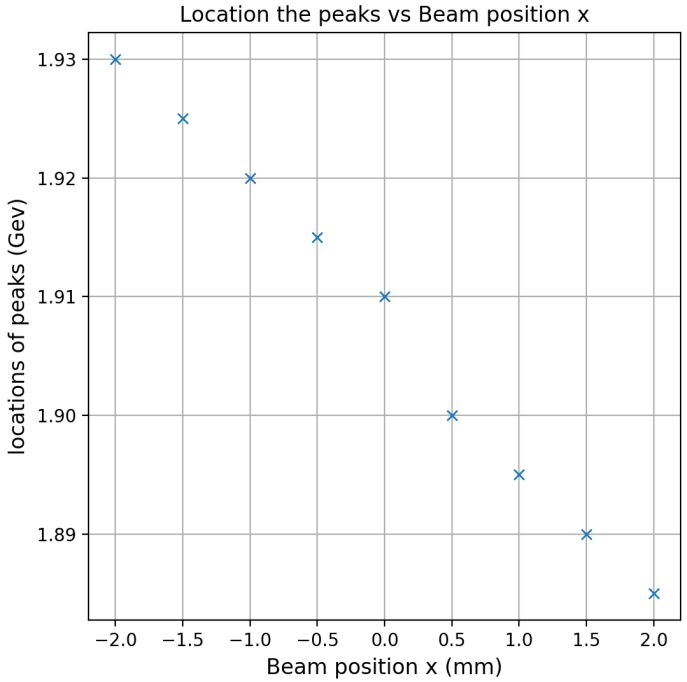
Different horizonal position on target

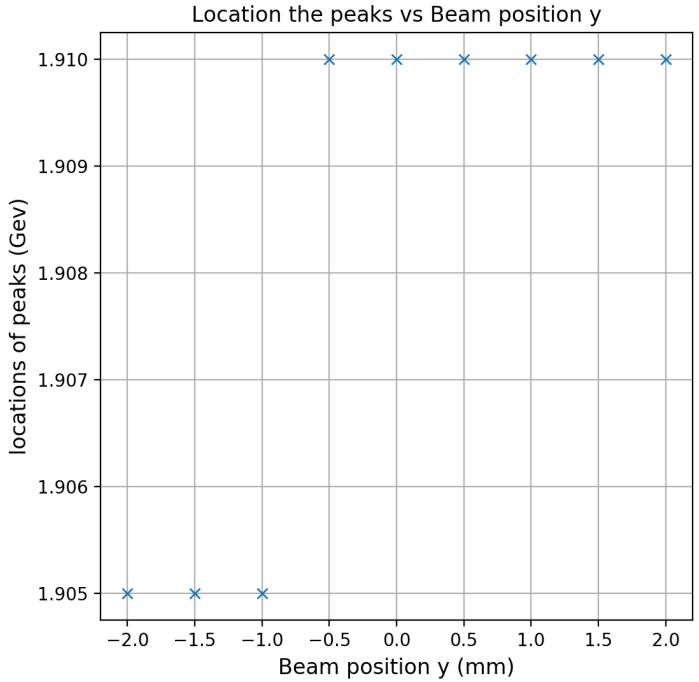
Roughly symmetrical

Different vertical position on target

Asymmetrical

Peak locations for different positions on target





Different horizonal position on target

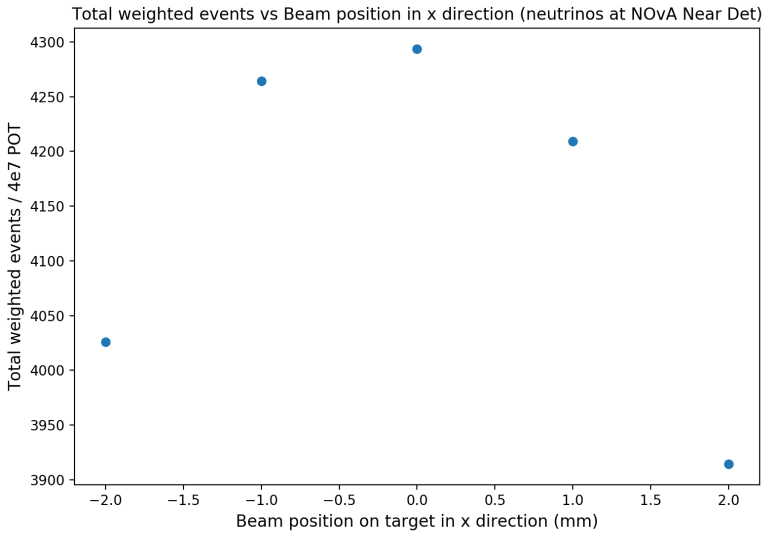
Peak location shift is inverse to shift on target.

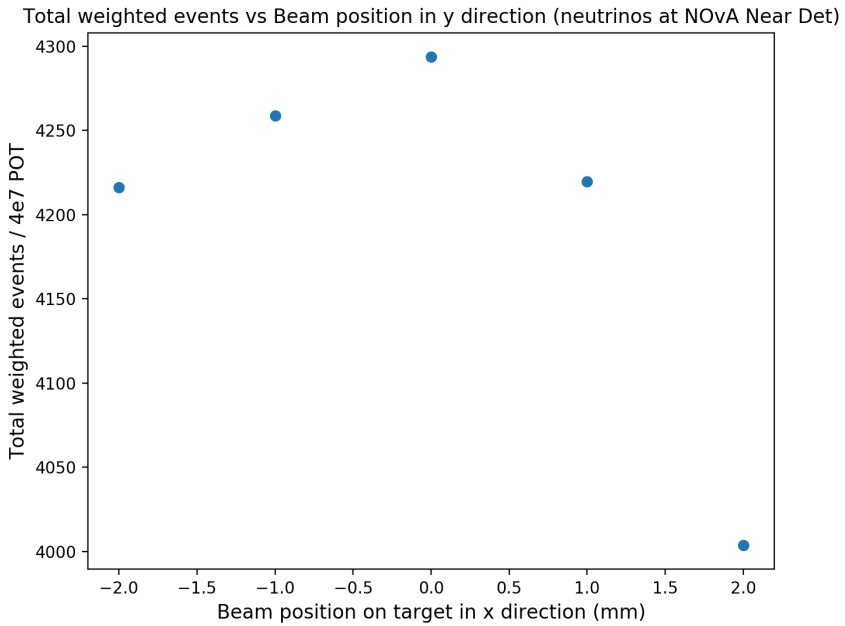
Possible reason: NOvA Near detector are off-axis in horizonal direction.

Different vertical position on target

Peak location does not change.

Total weighted events for different position on target





Different horizonal position on target

Asymmetrical

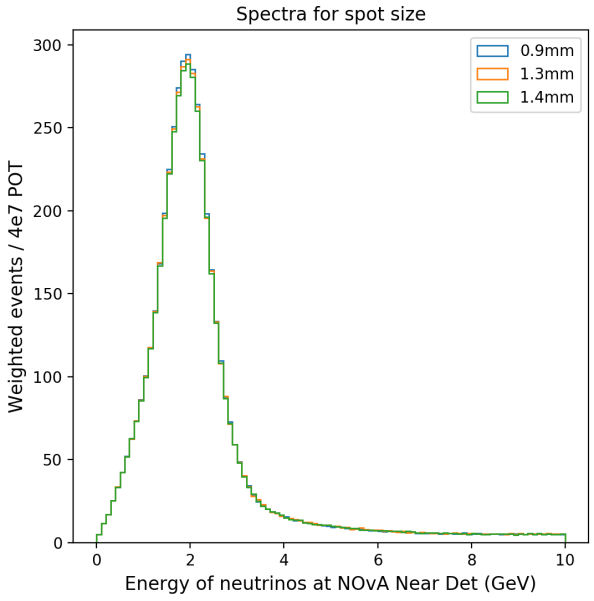
Possible reason: NOvA Near detector are off-axis in horizonal direction.

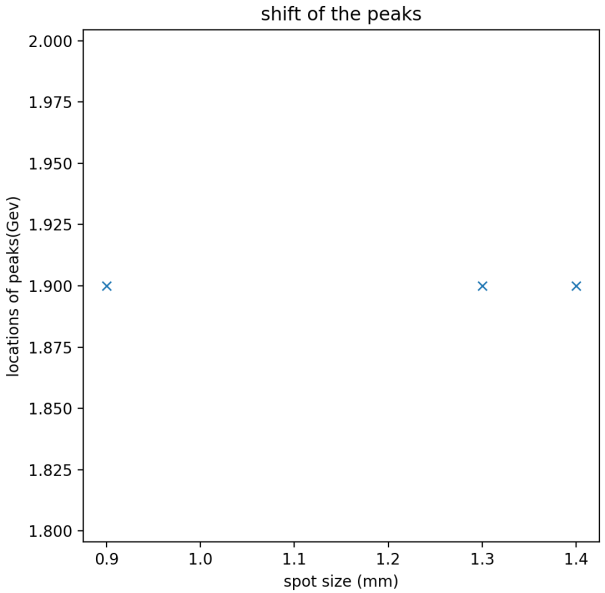
Different vertical position on target

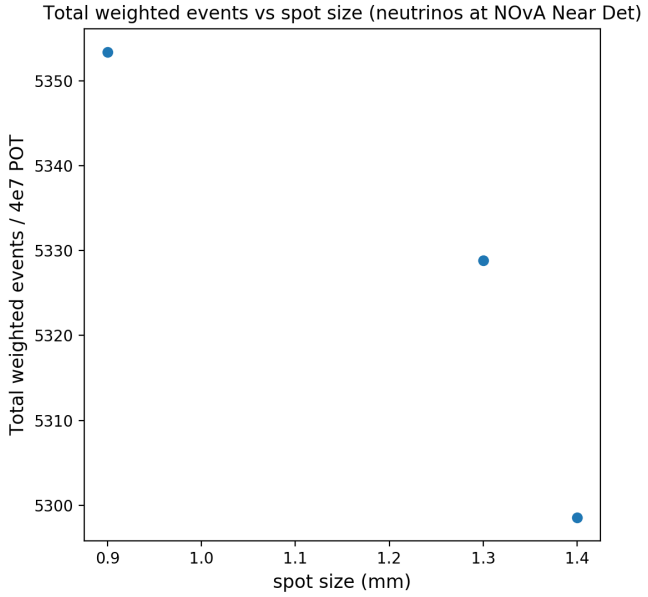
Asymmetrical

Possible reason: The target is asymmetrical in vertical direction.

Spectra for different spot size







Spectra for different spot size

Neutrino spectra are insensitive to change of spot size.

Neutrinos events for different spot size

In the simulation, POT is same. So, small spot size of proton beam will have more flux.