



The Importance of Muon Monitors in the NuMI beamline

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Budker Seminar, Fermilab
10 Feb 2020

1. Introduction to the muon monitors

● *Introduction*

● *Things to do with muon monitor data*

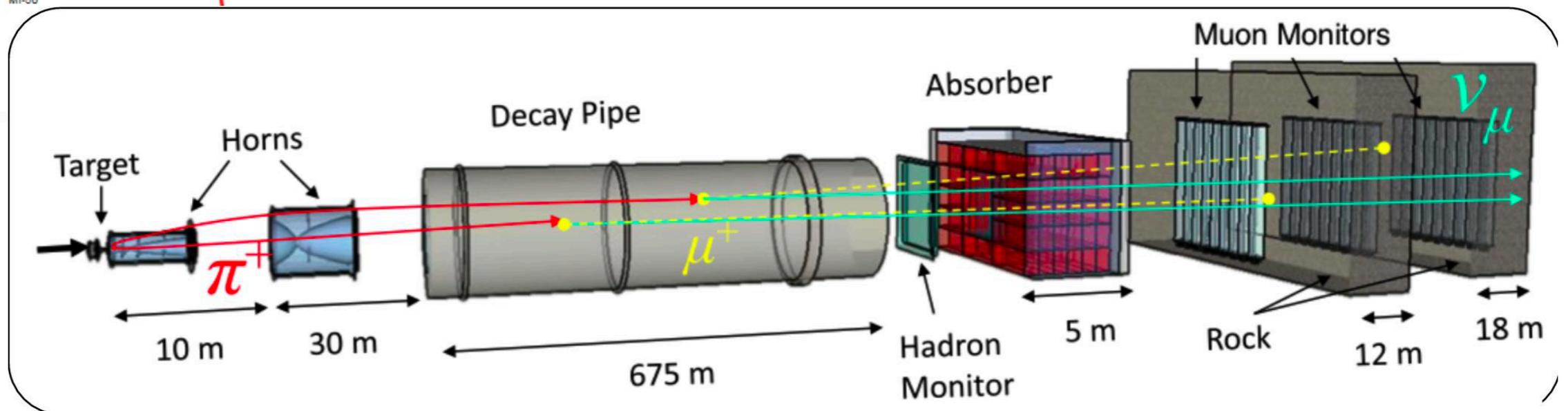
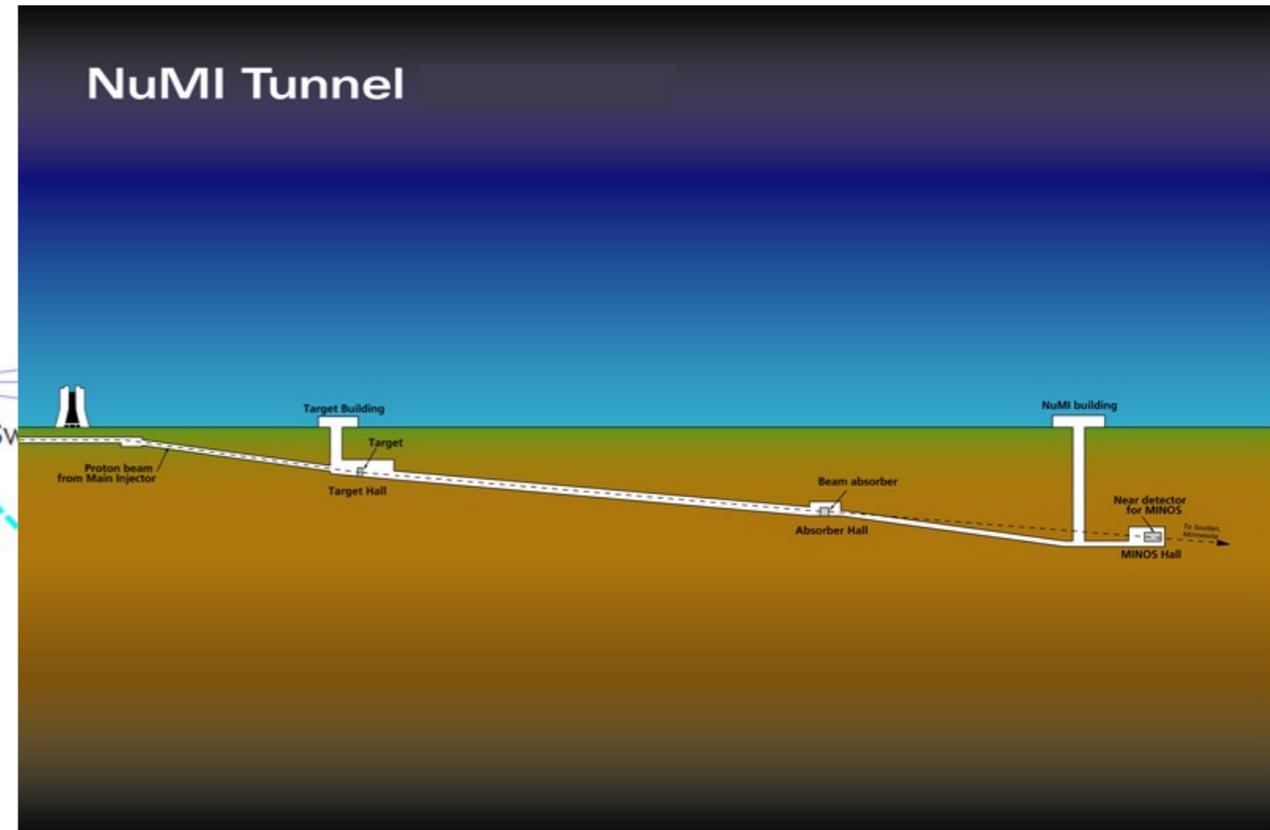
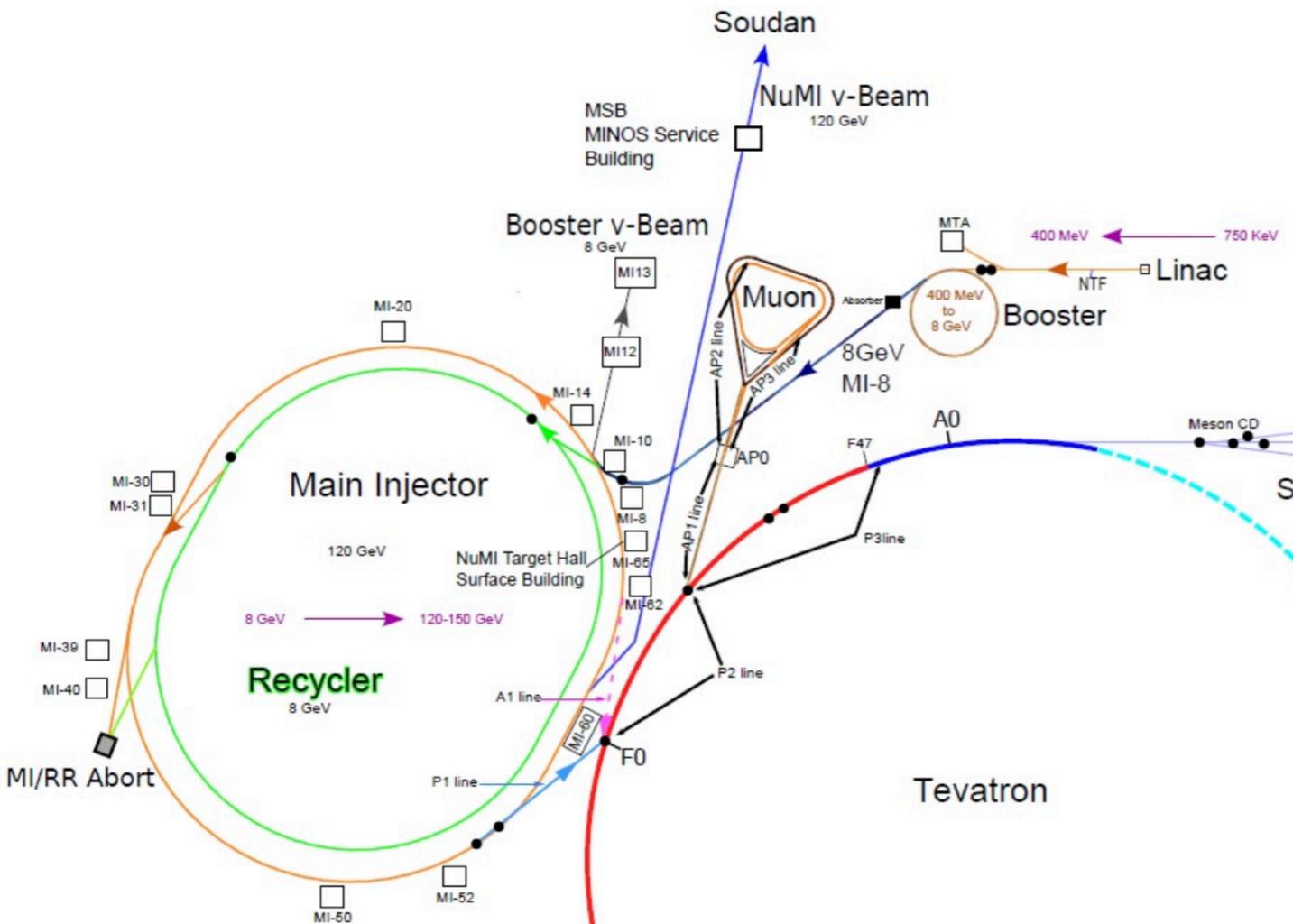
2. Beam & Horn current scans

3. Machine Learning Applications

4. Simulation Efforts and Hardware updates

5. Summary

NuMI beamline



Why Do We Need Muon Monitors?

Recalling the neutrino production in the NuMI beam line



**Muon Monitors
Data**

Helping to understand
beamline performance

Helping to understand
neutrino beam

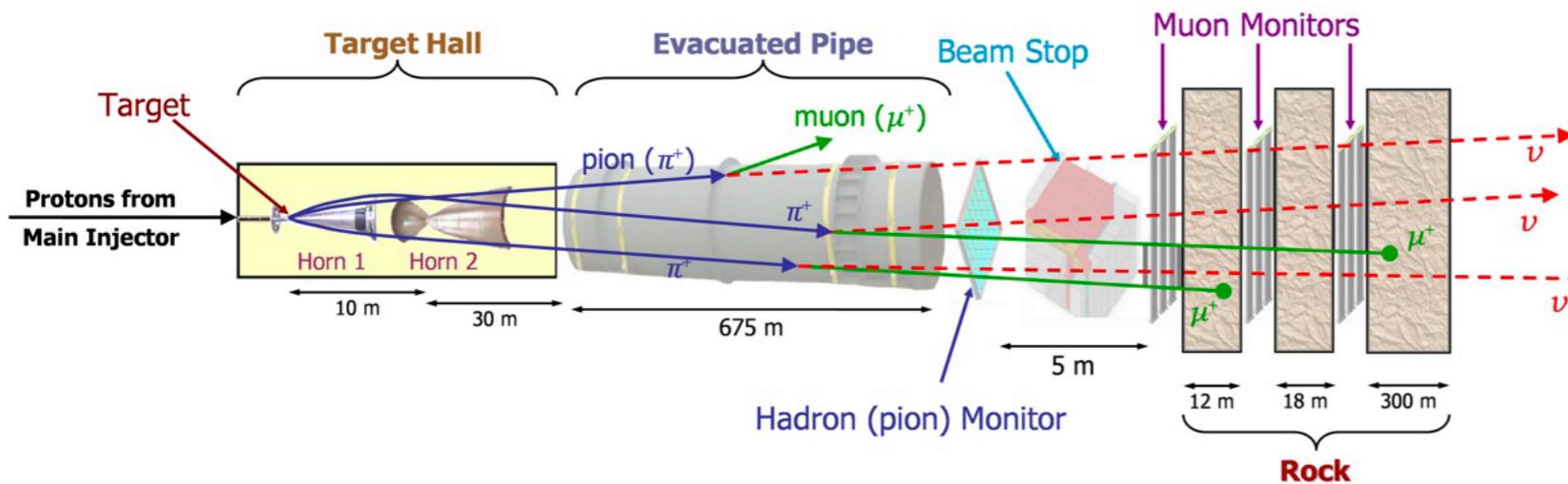
Accelerator Division:

- **Beam performance**
- **Horn current stability**
- **Beam alignment**
- **Target status**
- **Probably for beam Auto-tune**

Neutrino Experiments:

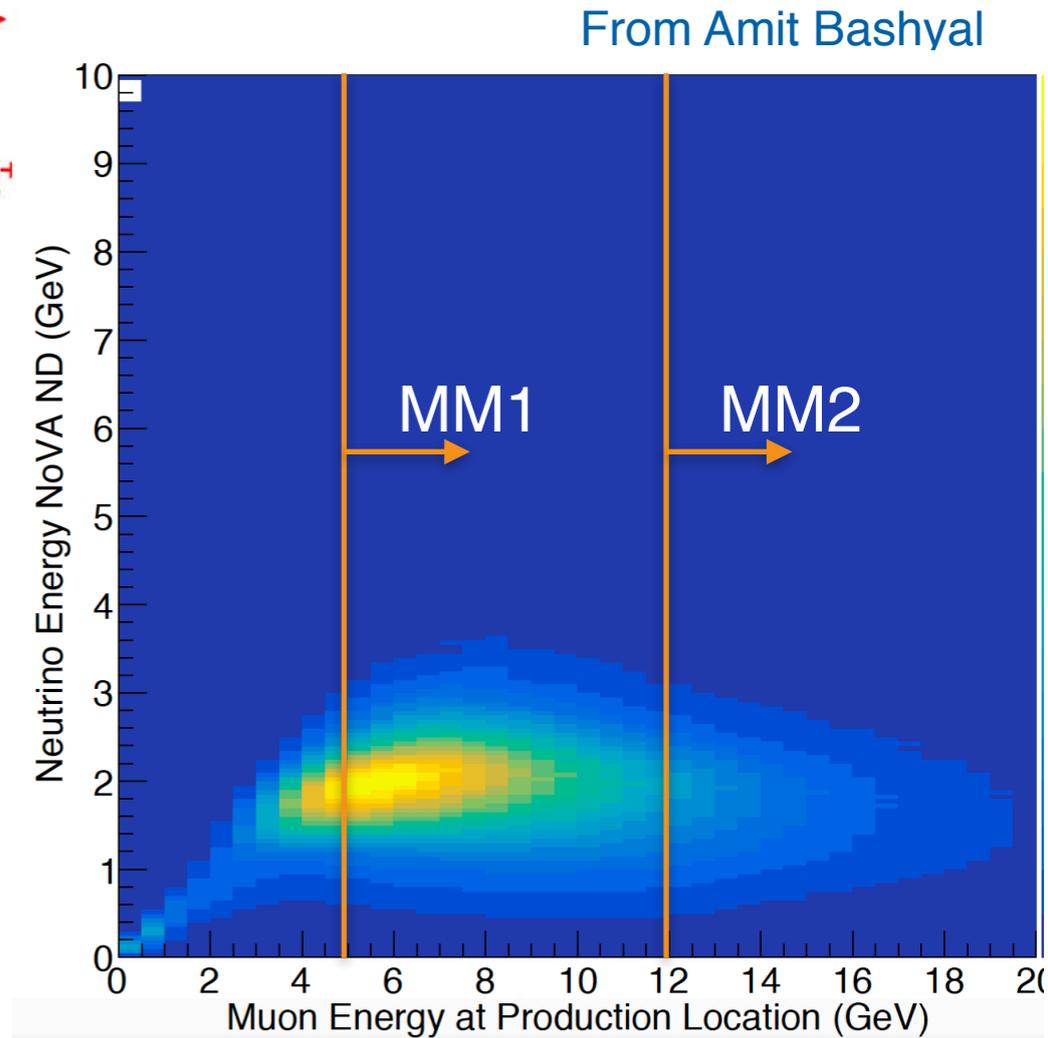
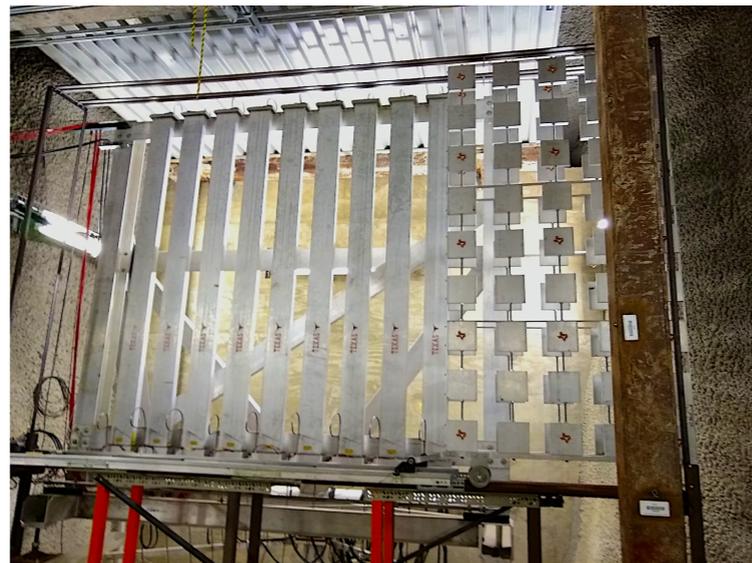
- **Neutrino beam stability**
- **To Reduce flux systematic errors**

Introduction to Muon Monitors



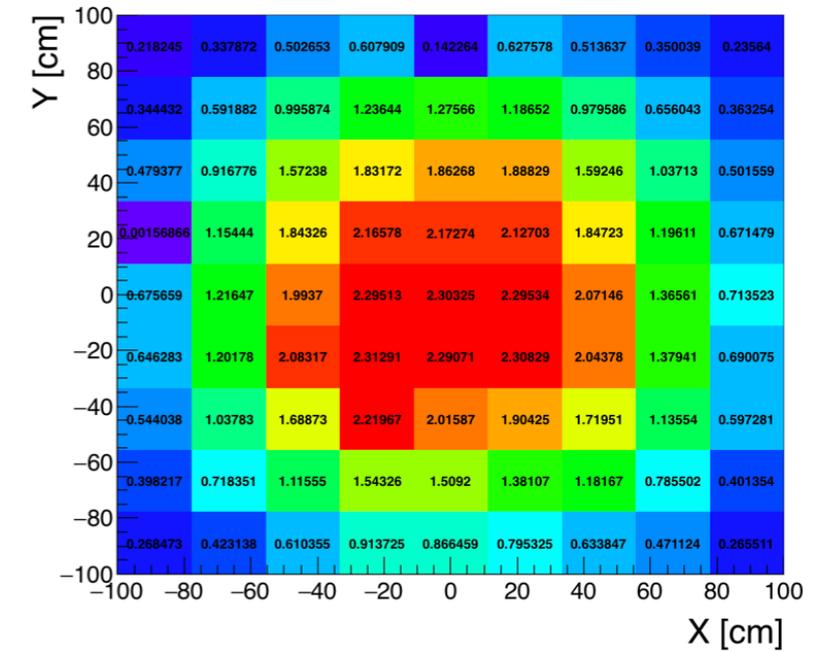
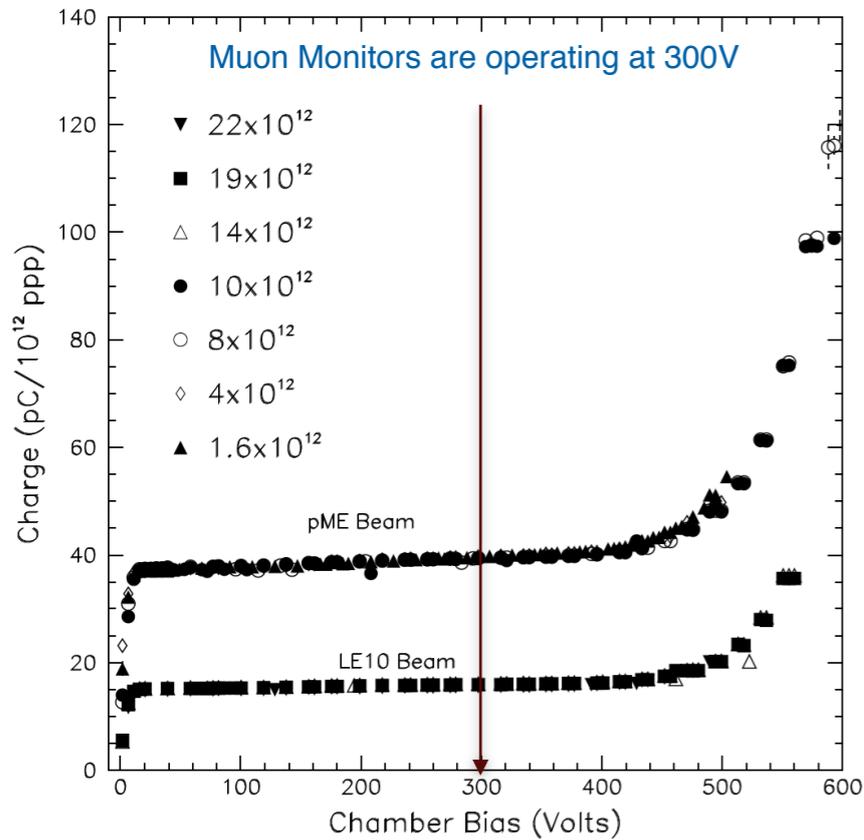
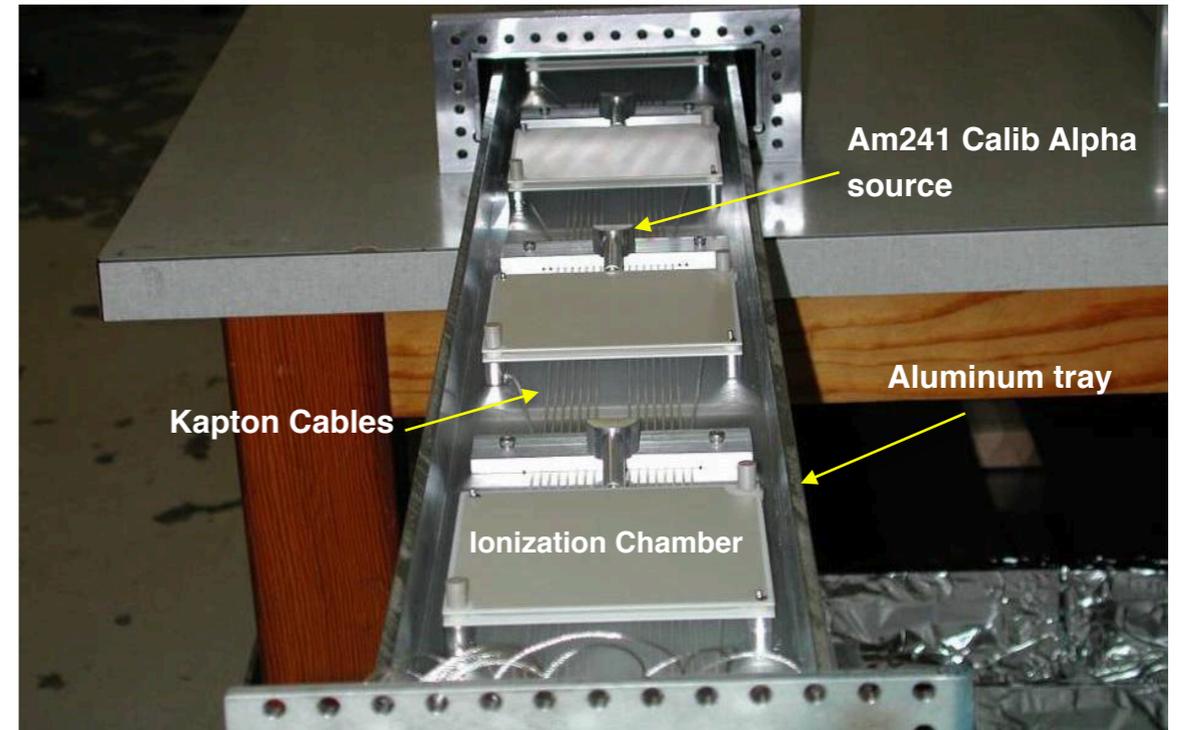
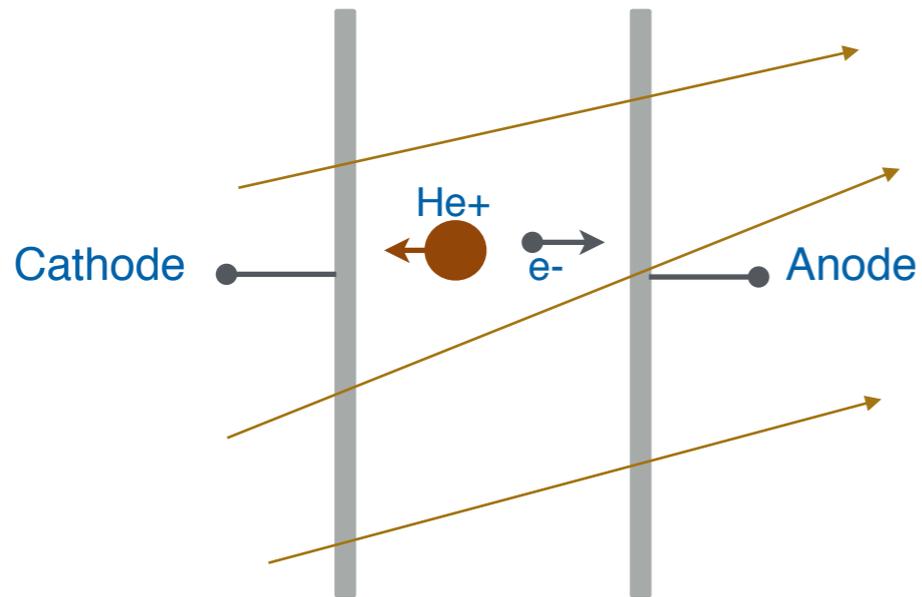
- Three muon monitors are located in the downstream of the hadron absorber
- Each muon monitor consist of 9x9 arrays of ionization chambers
- Each ionization chamber consists of two ceramic parallel plates with the separation of 3 mm gap
- The chambers are filled with He gas

Muon monitor array

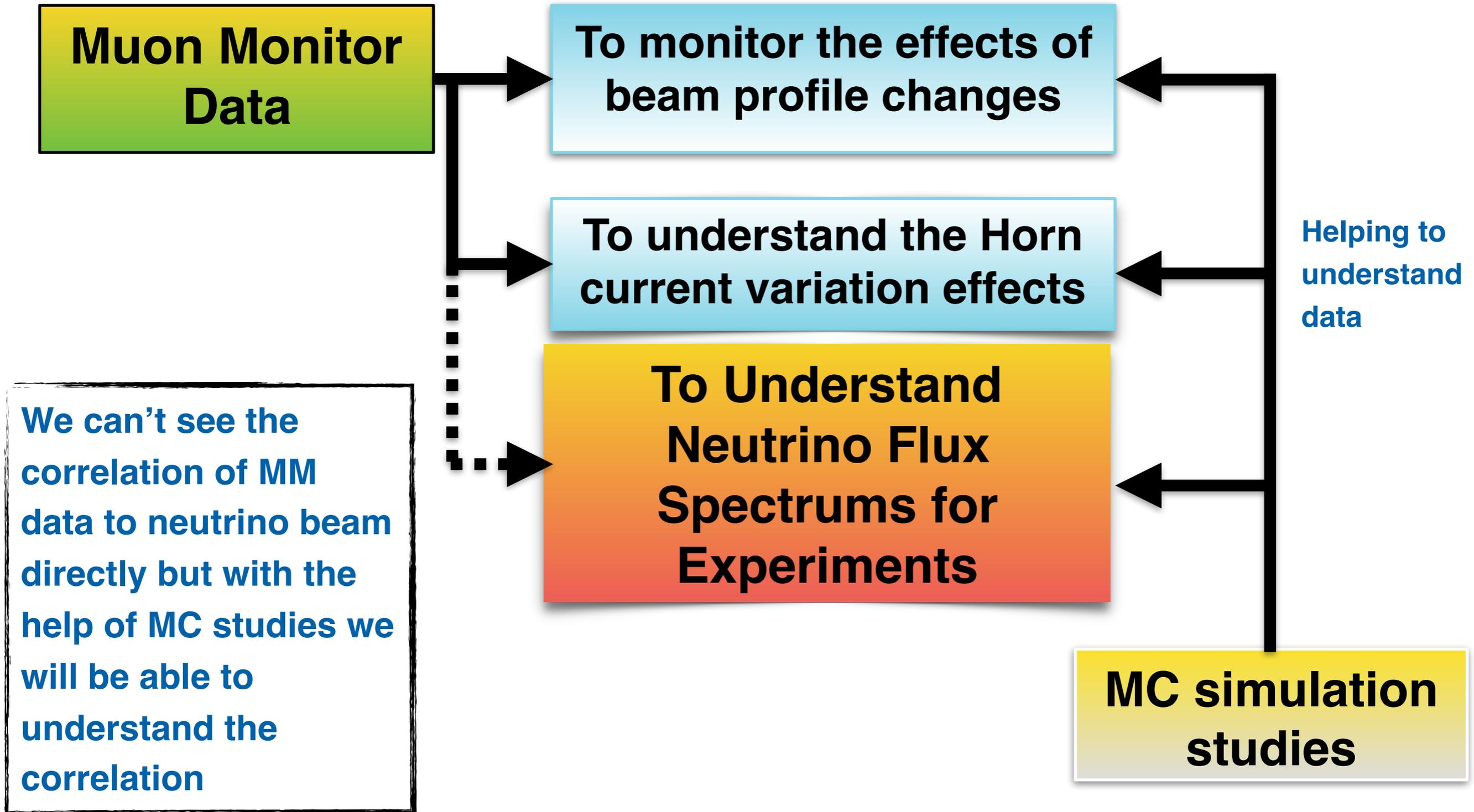


- According to the MC studies, MM1 has a good sensitivity to see the correlation of neutrino beam to muons

Introduction to Muon Monitors



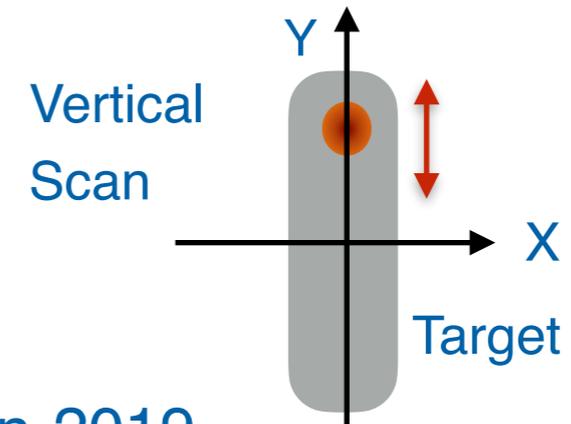
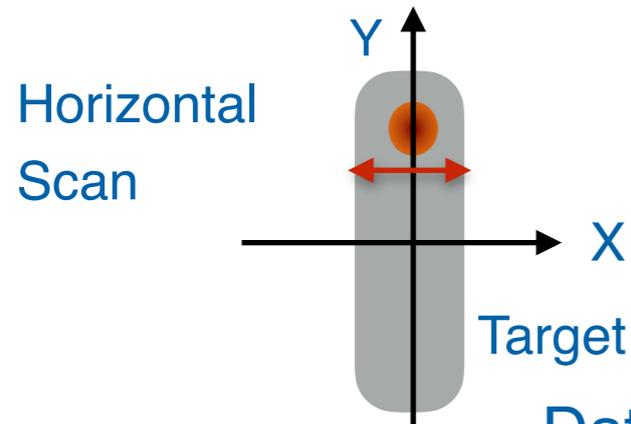
What can we do with Muon Monitor data?



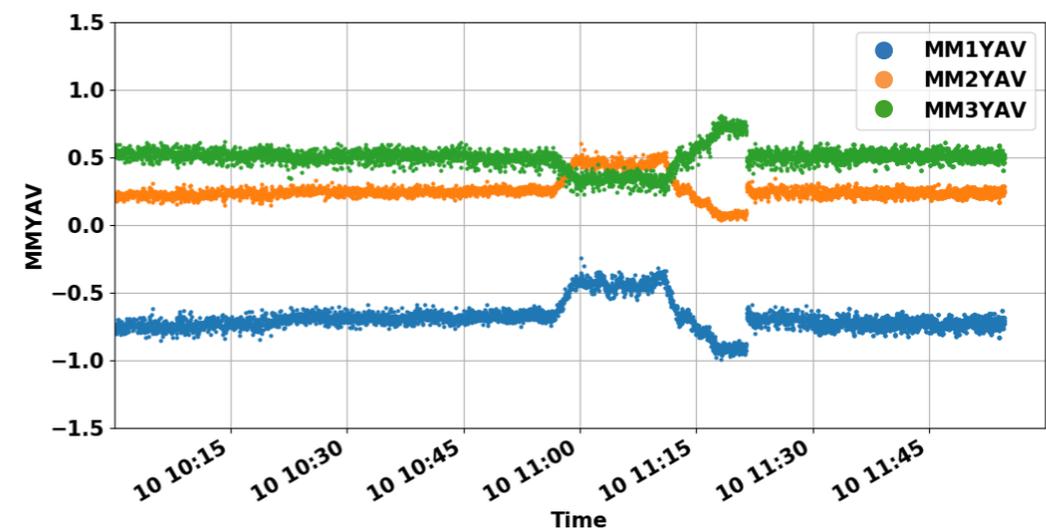
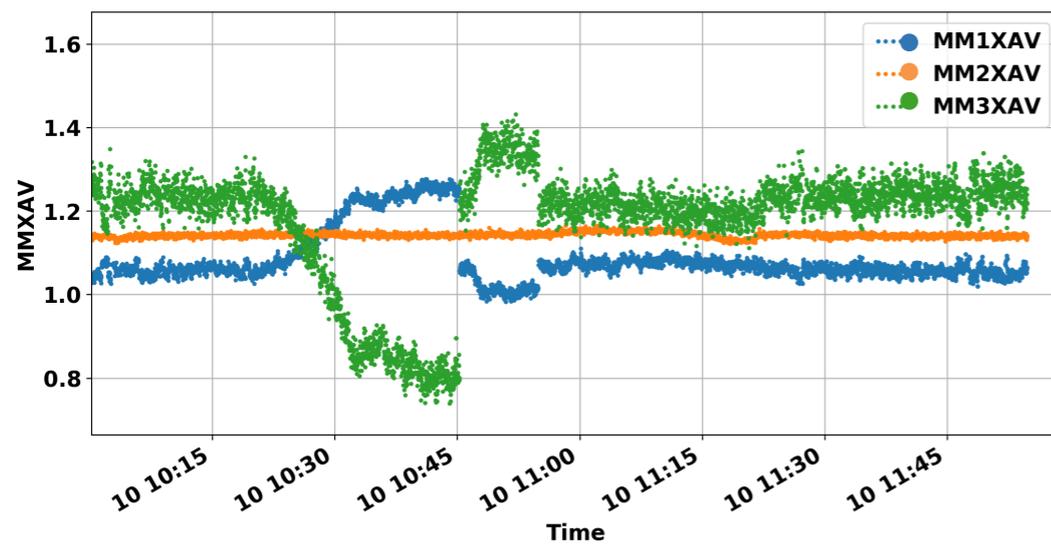
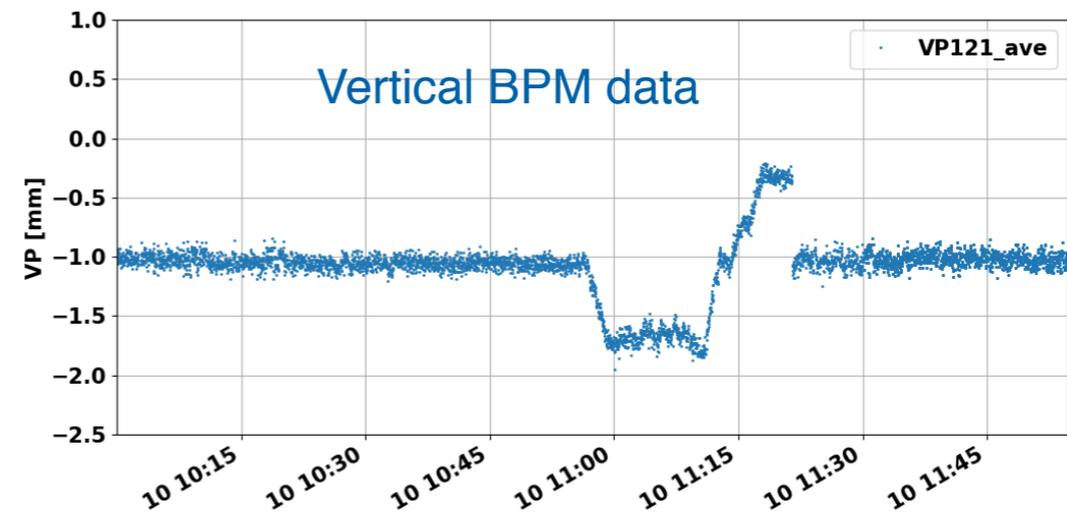
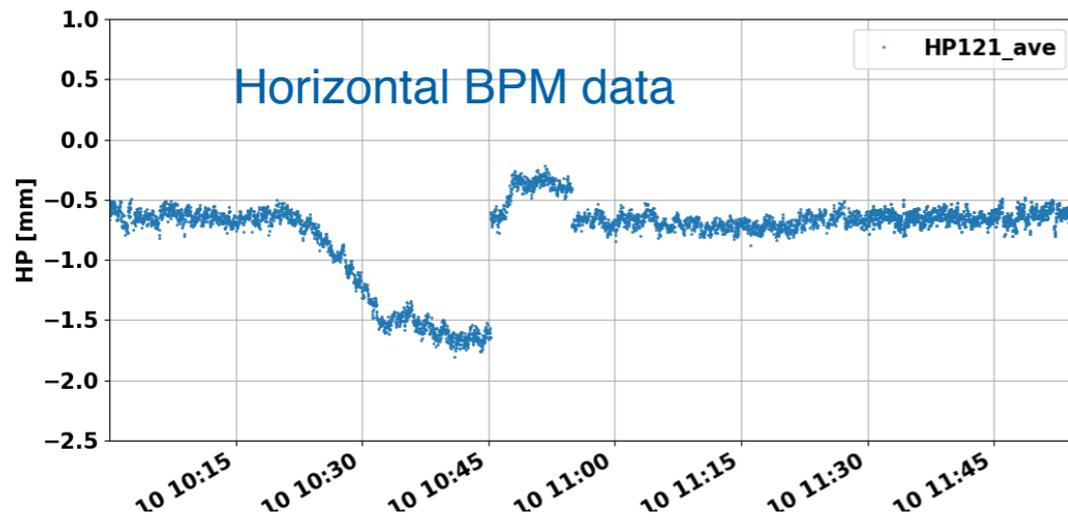
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- 2. Beam & Horn current scans**
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**Beam Scan Data:
Anti-neutrino mode
10-JAN-2019**

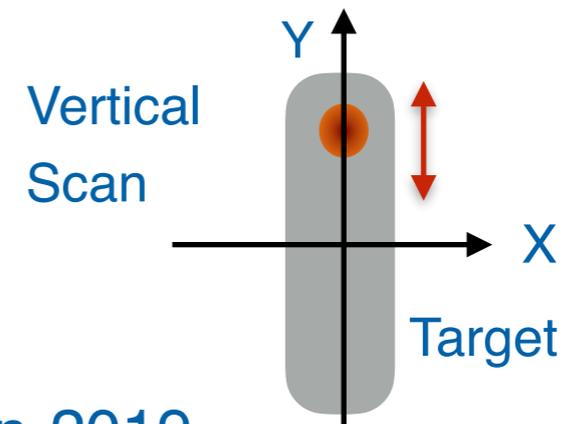
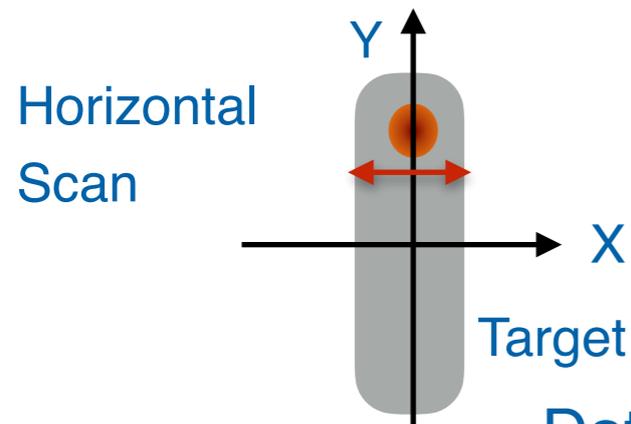
Beam scan study: Anti-neutrino mode



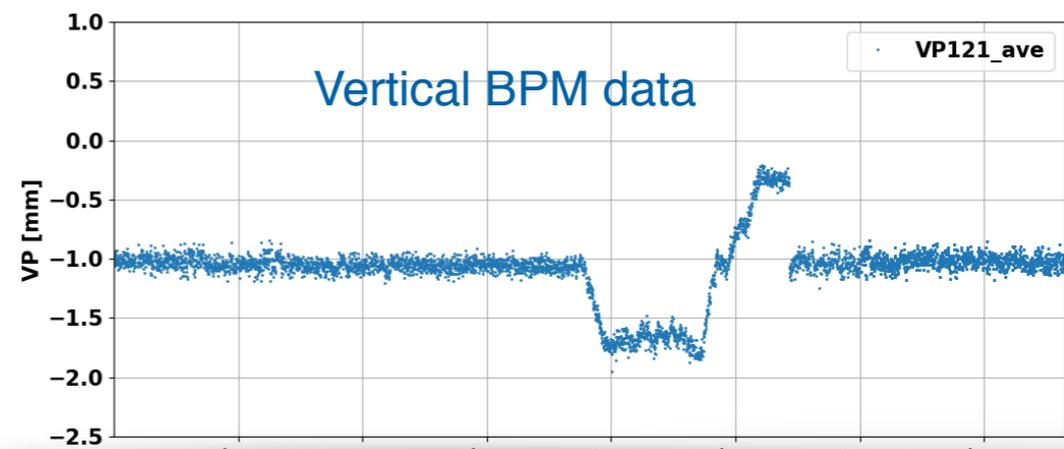
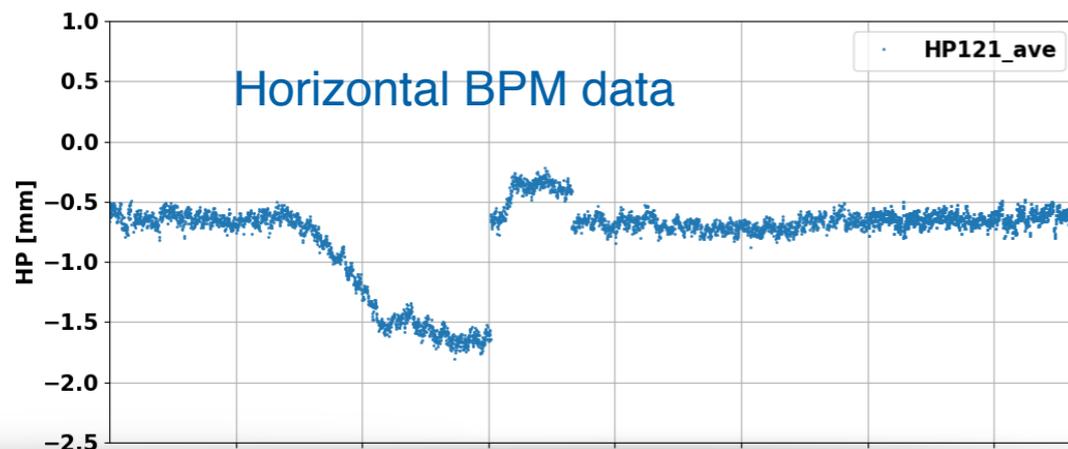
Data has been taken on 10-Jan-2019



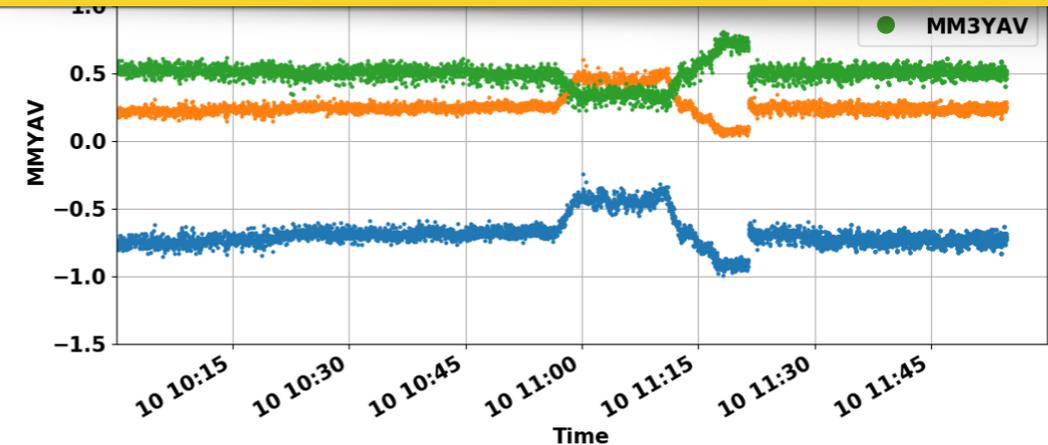
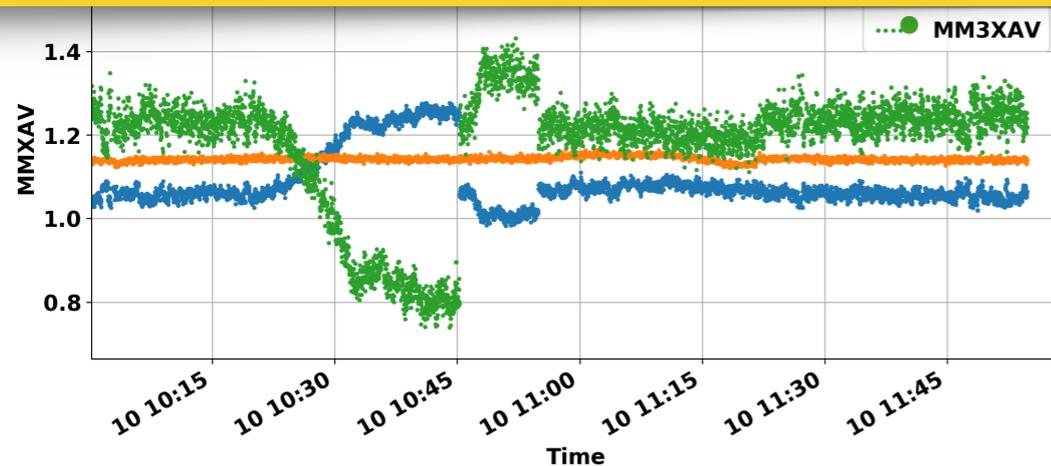
Beam scan study: Anti-neutrino mode



Data has been taken on 10-Jan-2019



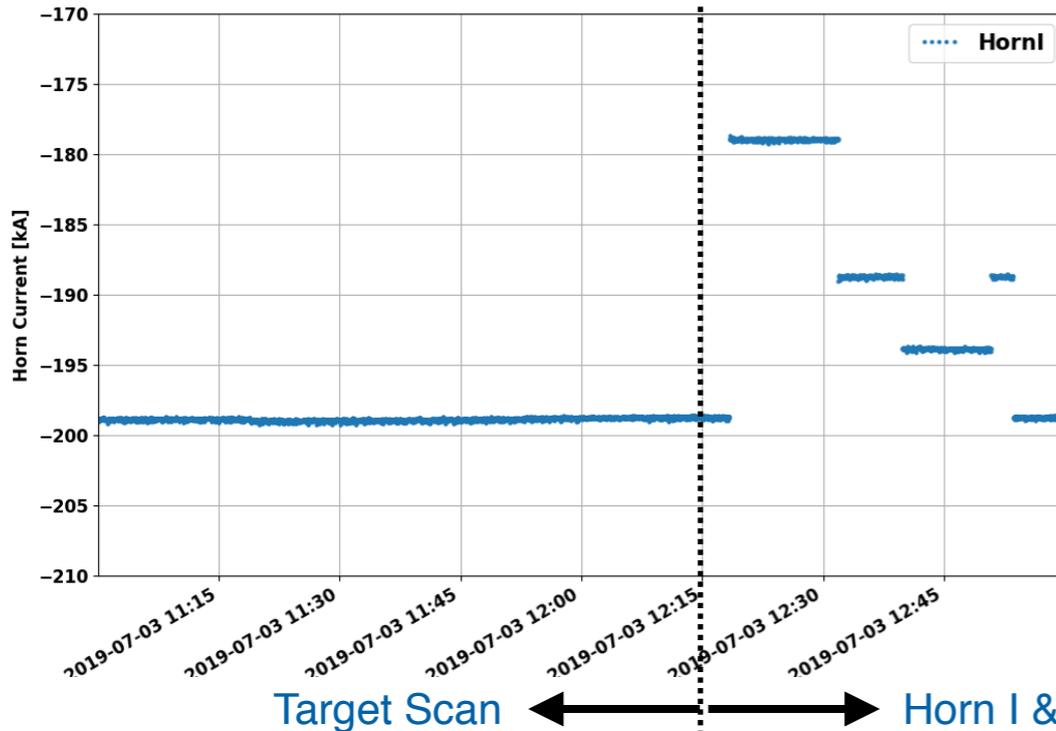
- The target scan study shows how each muon monitor responds to the proton beam variations



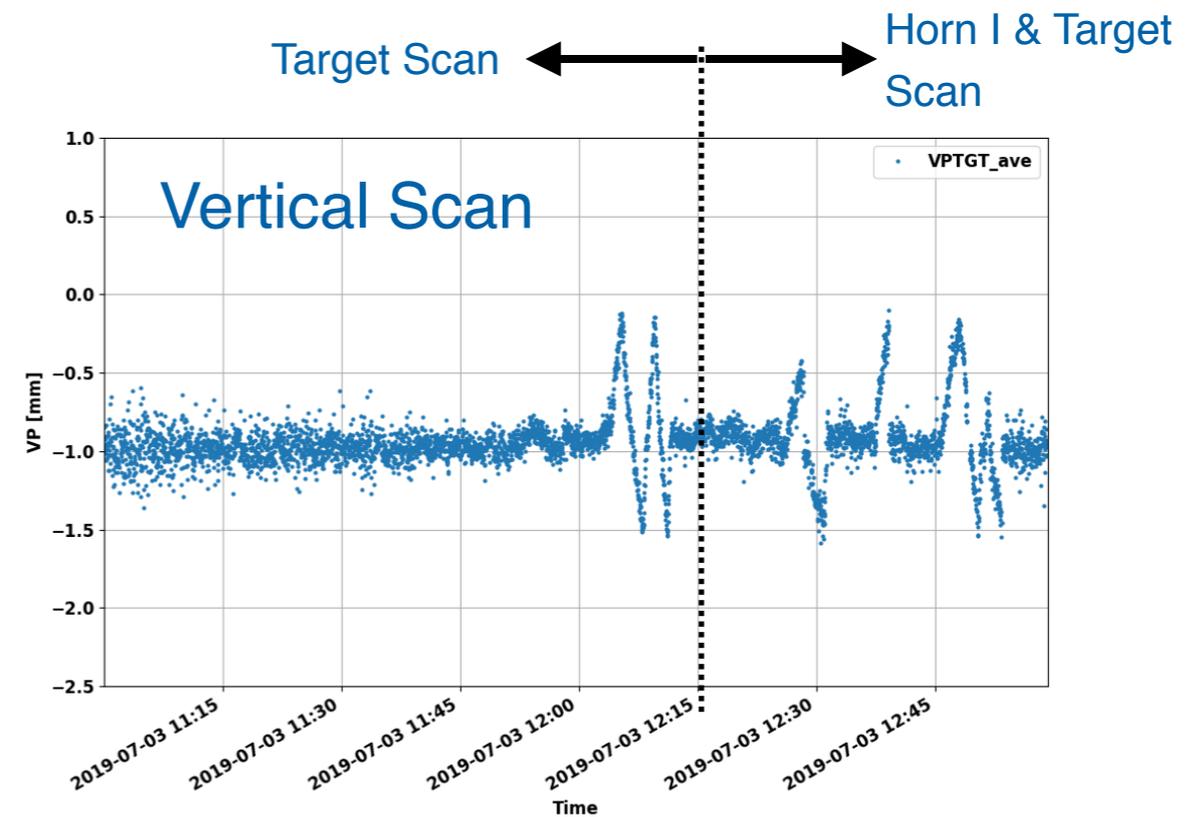
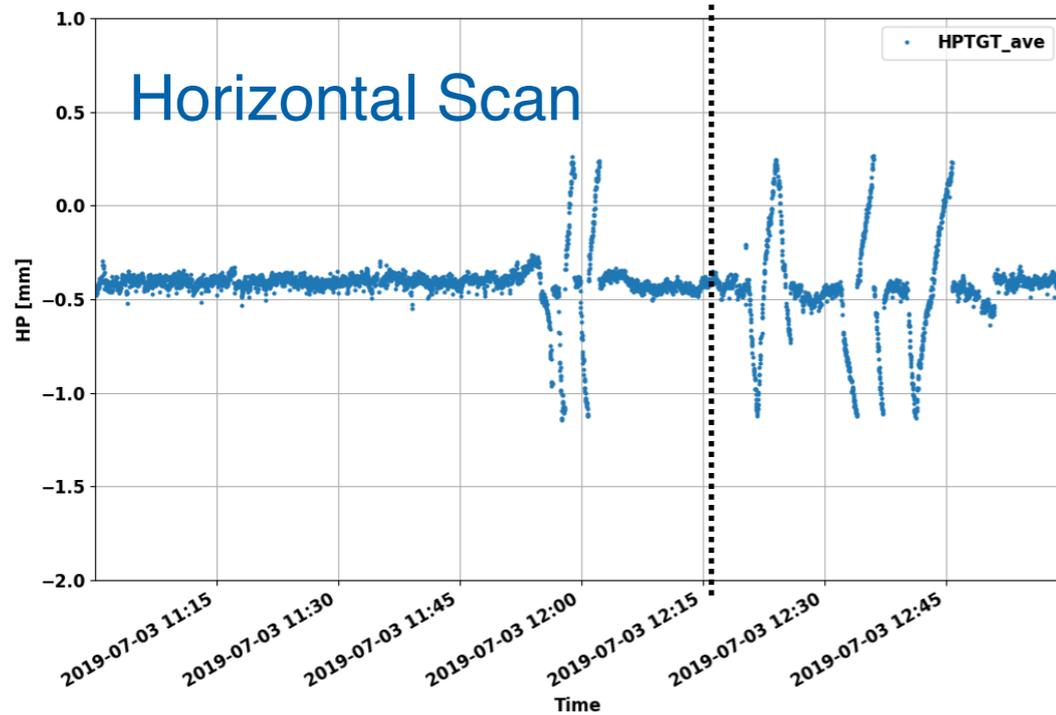
**Beam and Horn Current Scan Data:
neutrino mode
03-JUL-2019
12-Dec-2019**

Beam & Horn Current Scan: Jul 3rd 2019

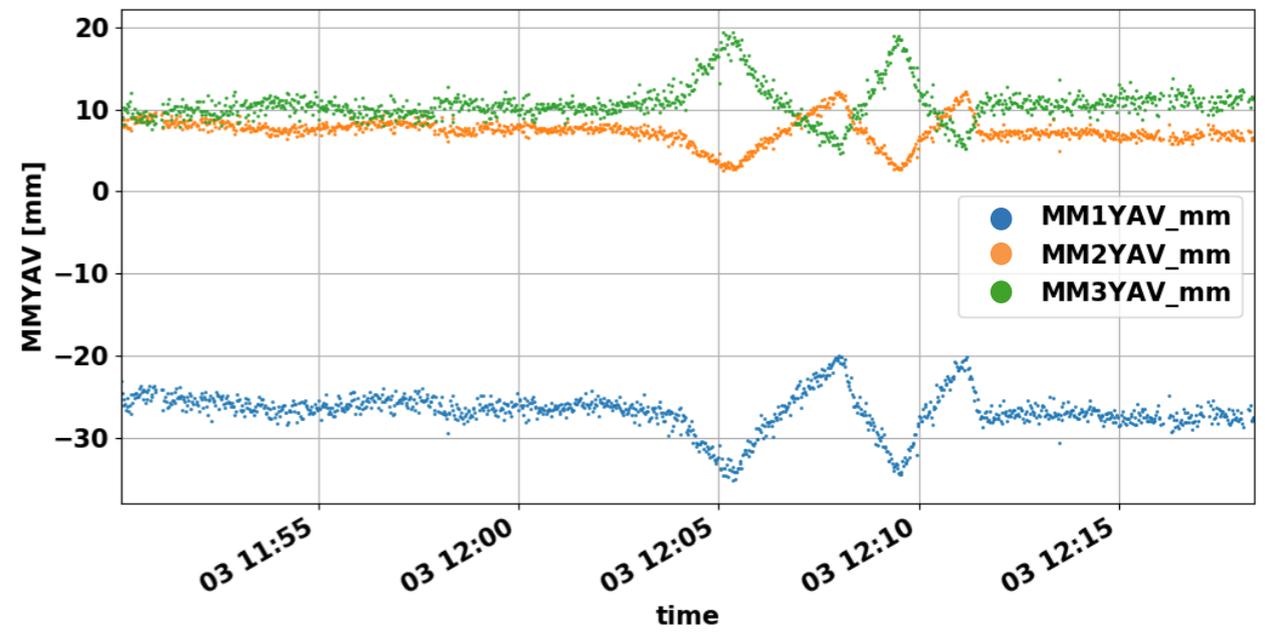
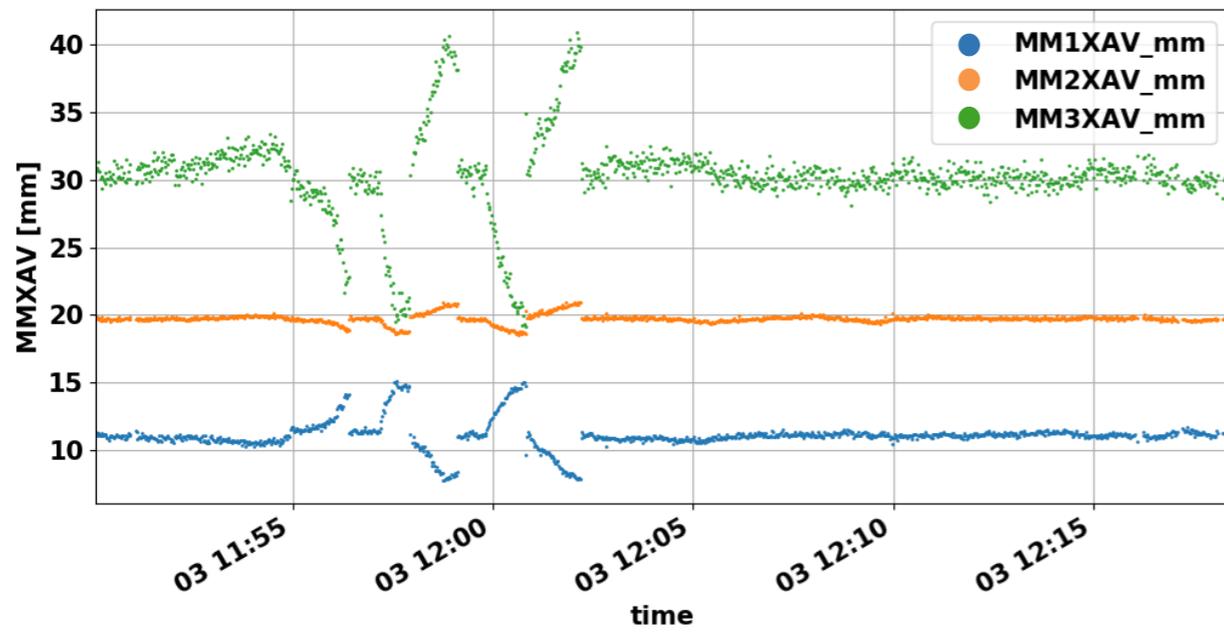
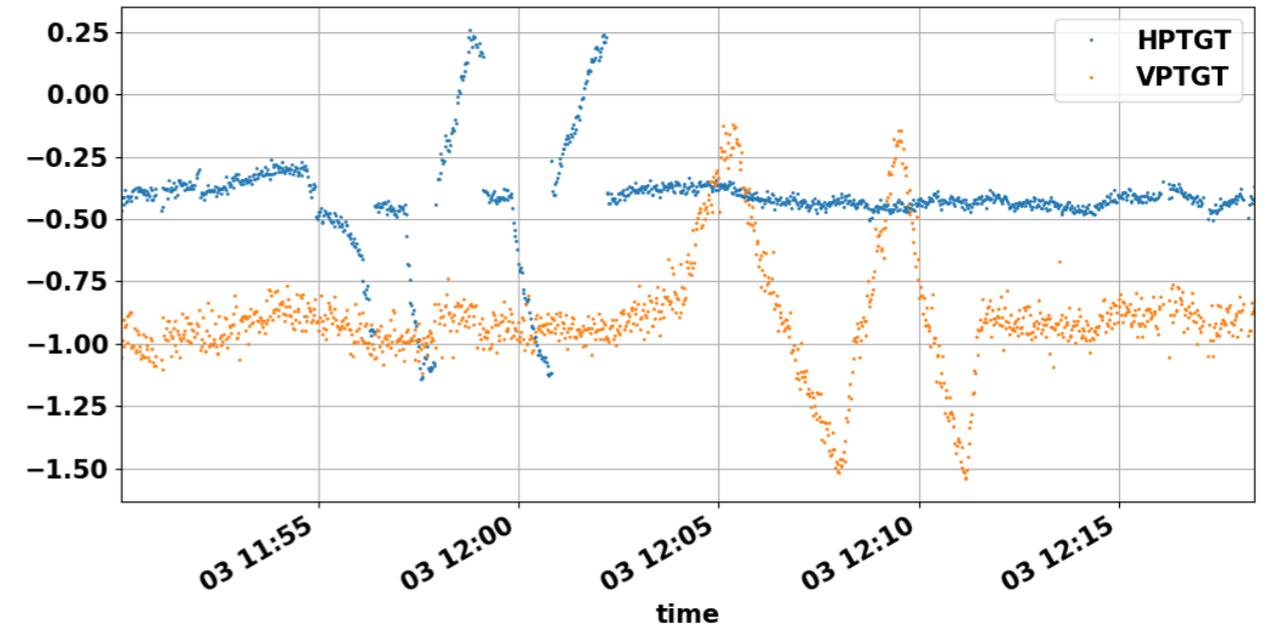
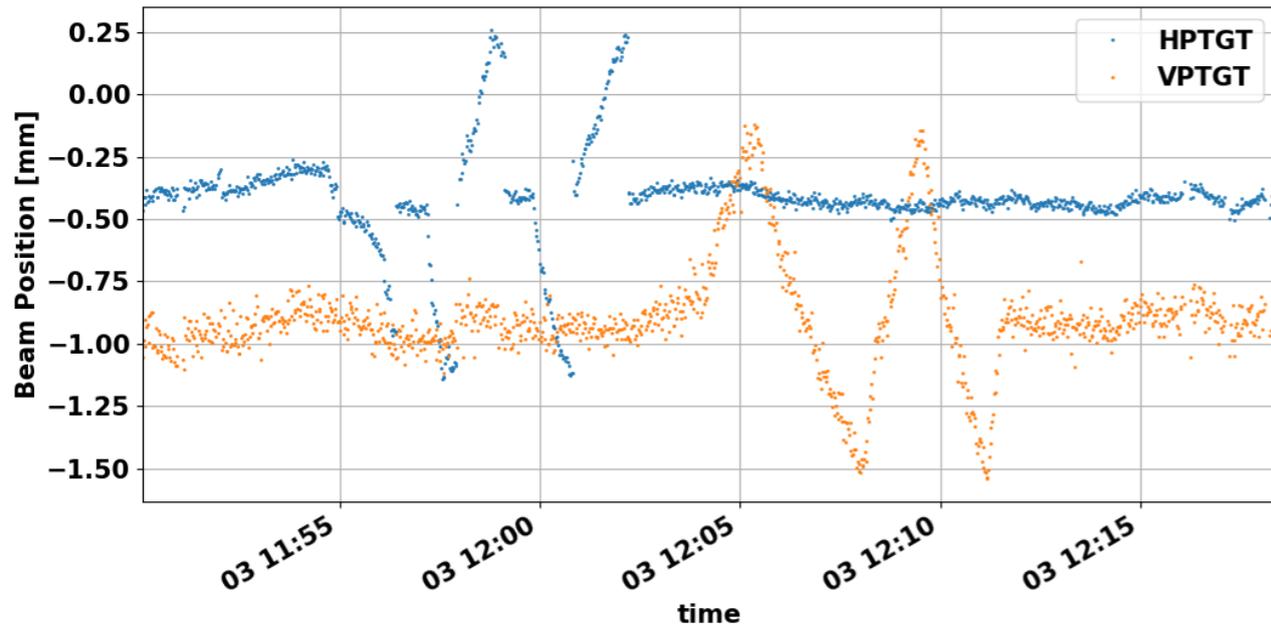
Data: 03-Jul-2019



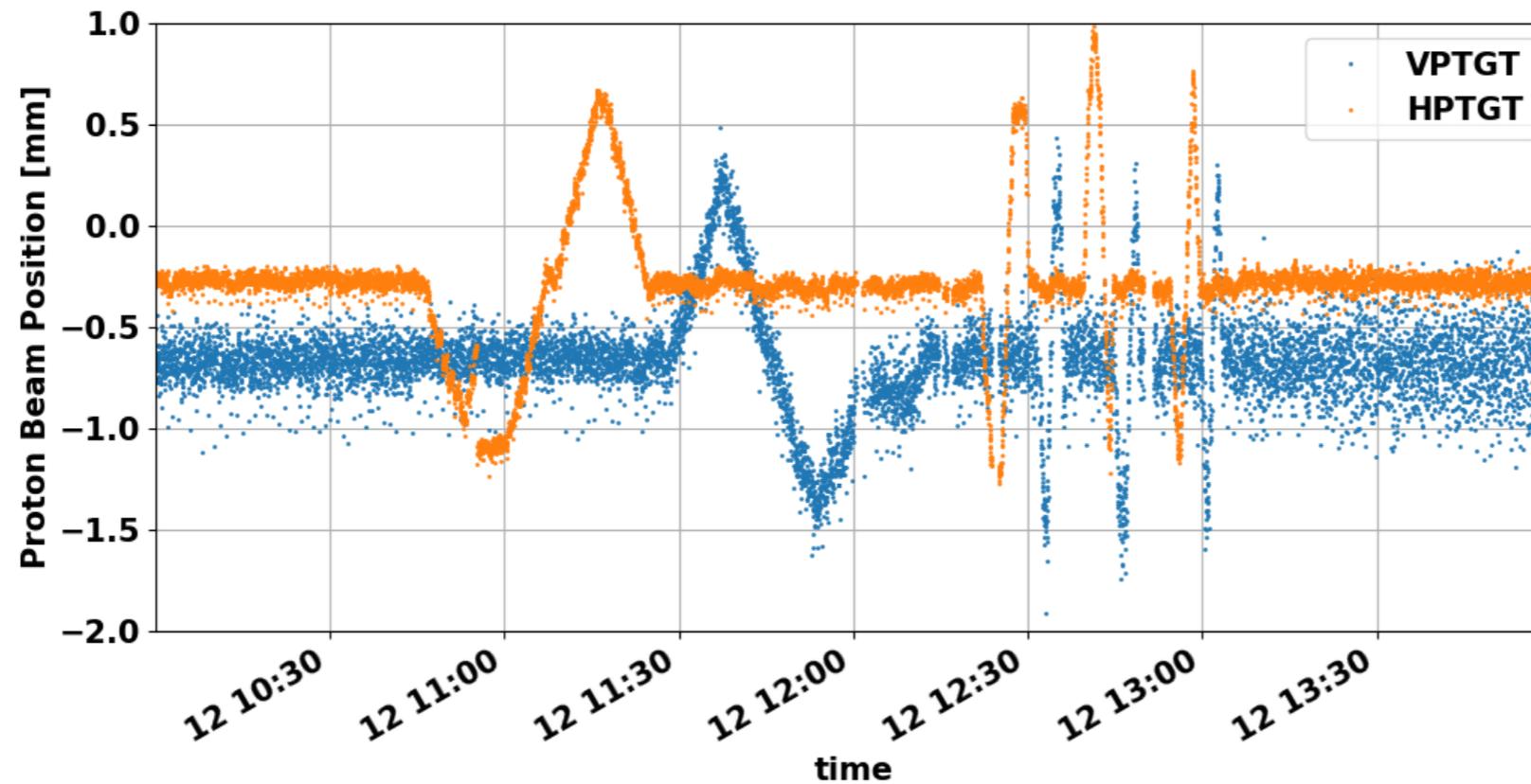
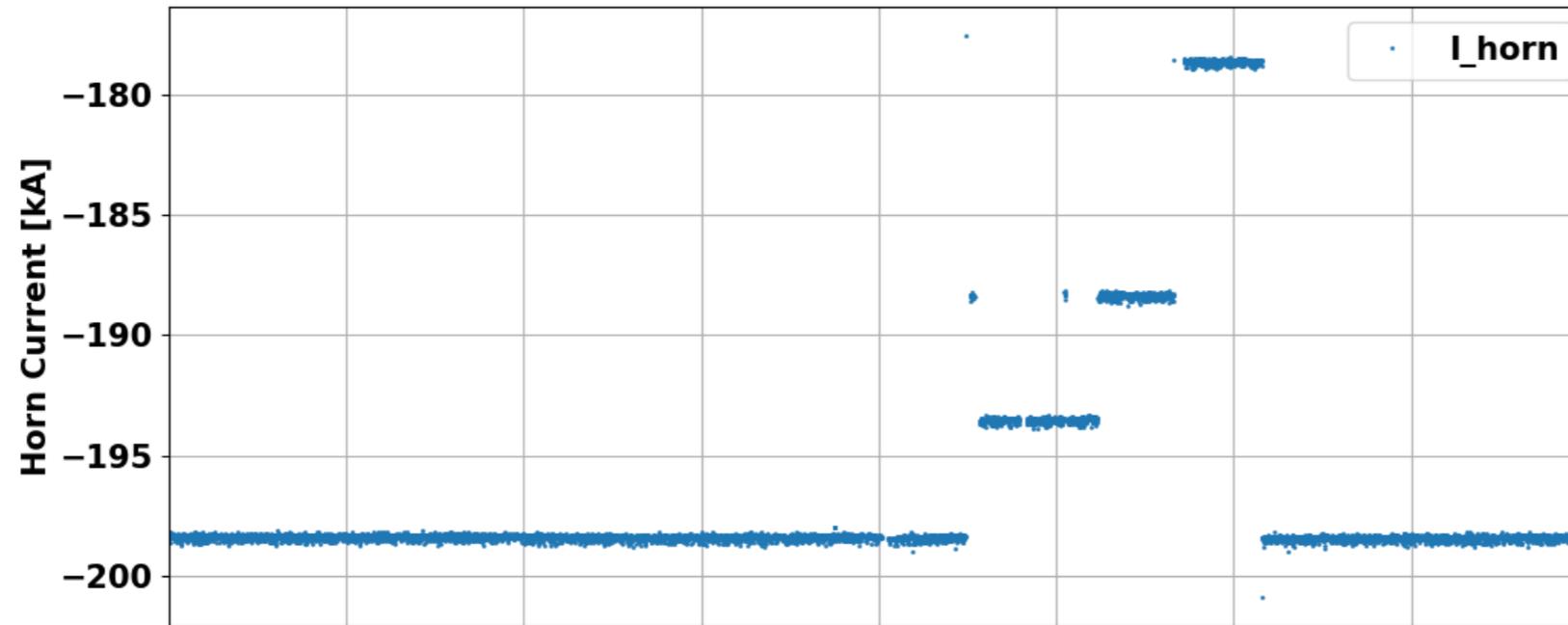
- * We have recorded target scan data and Horn current data on 07/03/2019
- * Data includes horizontal, vertical target scans and horn current scans with the beam position correlations



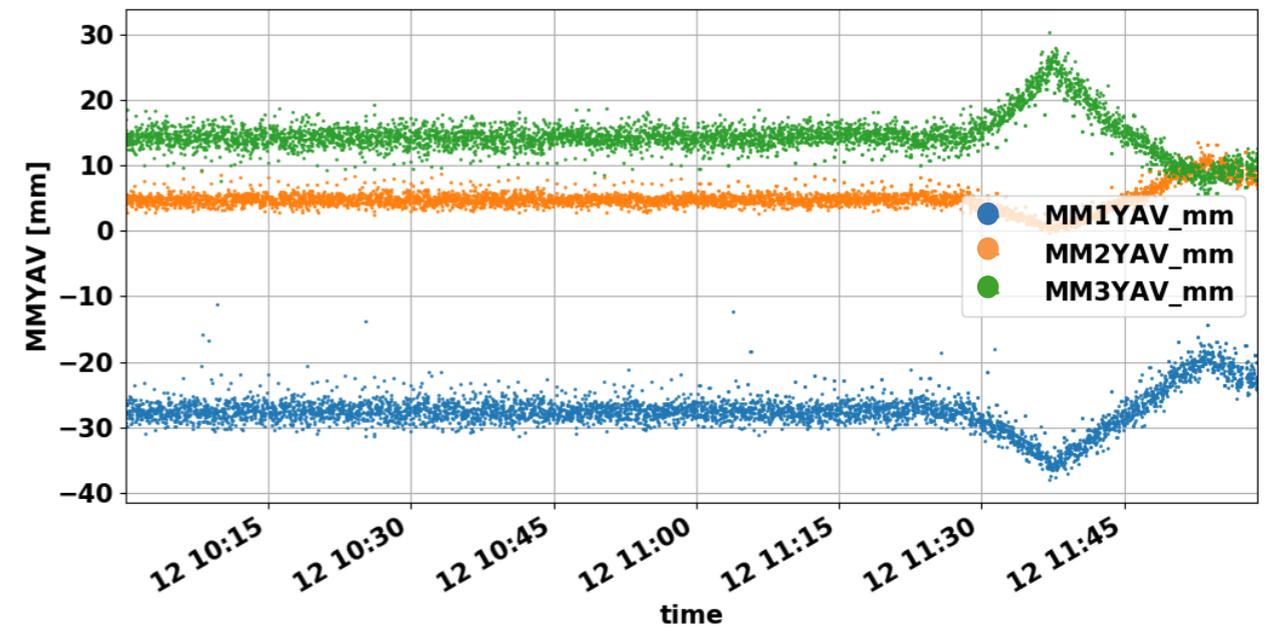
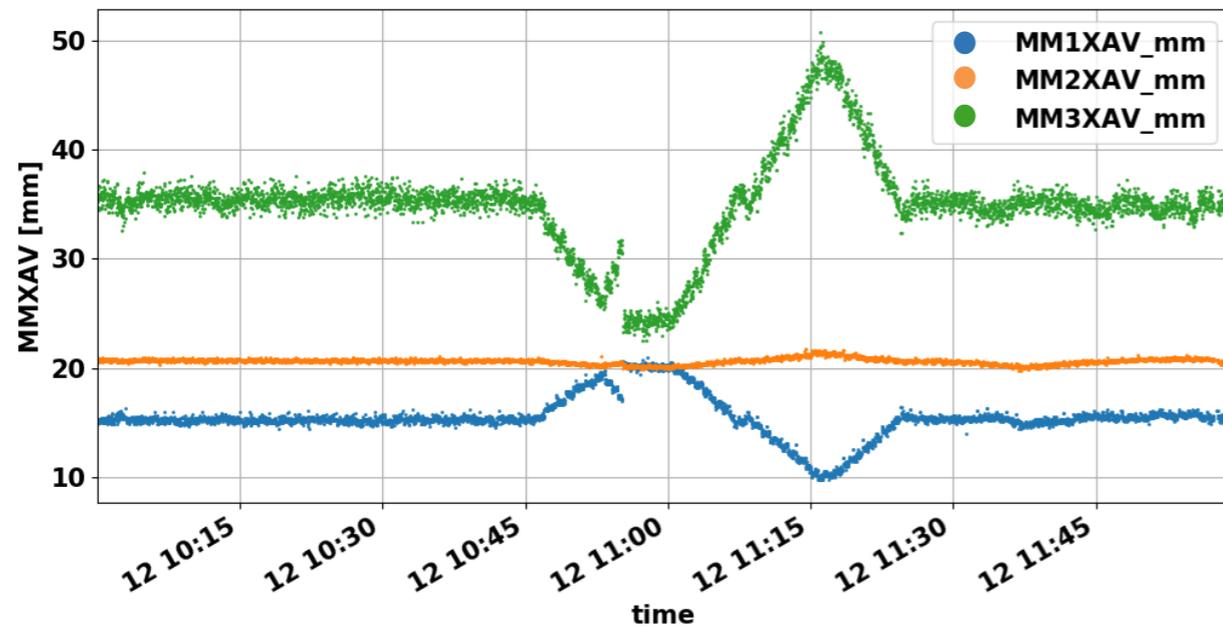
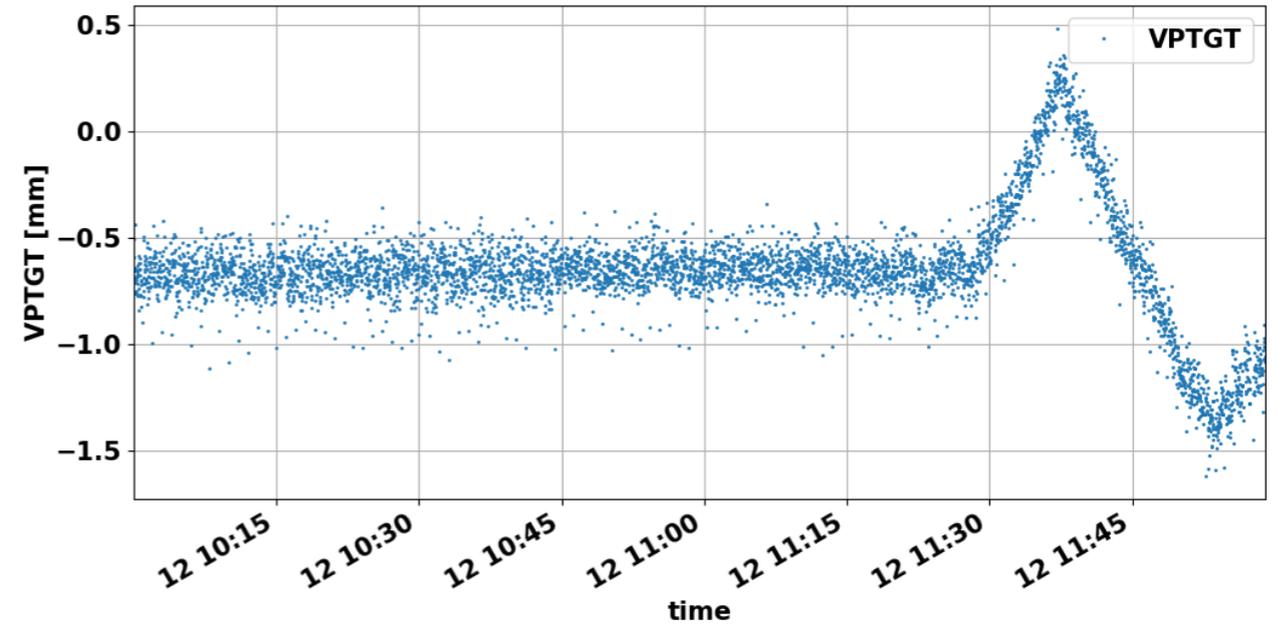
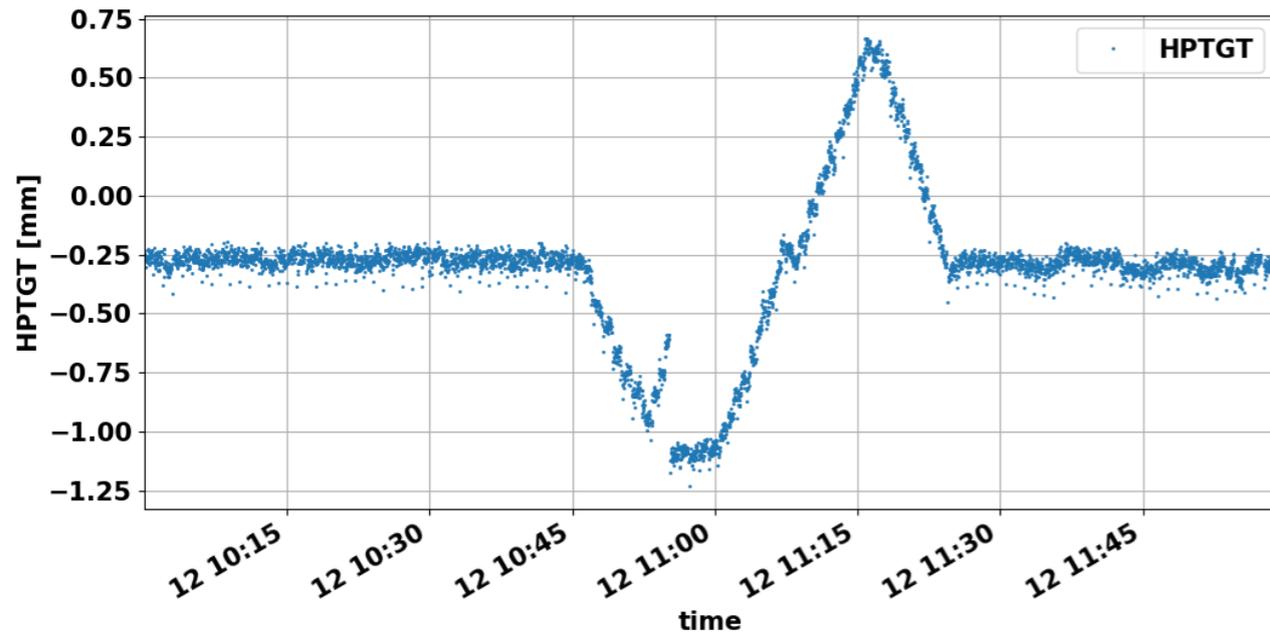
Beam Scan: Horizontal and Vertical (July 3rd)



Beam and Horn Current Scans: Dec 12th 2019

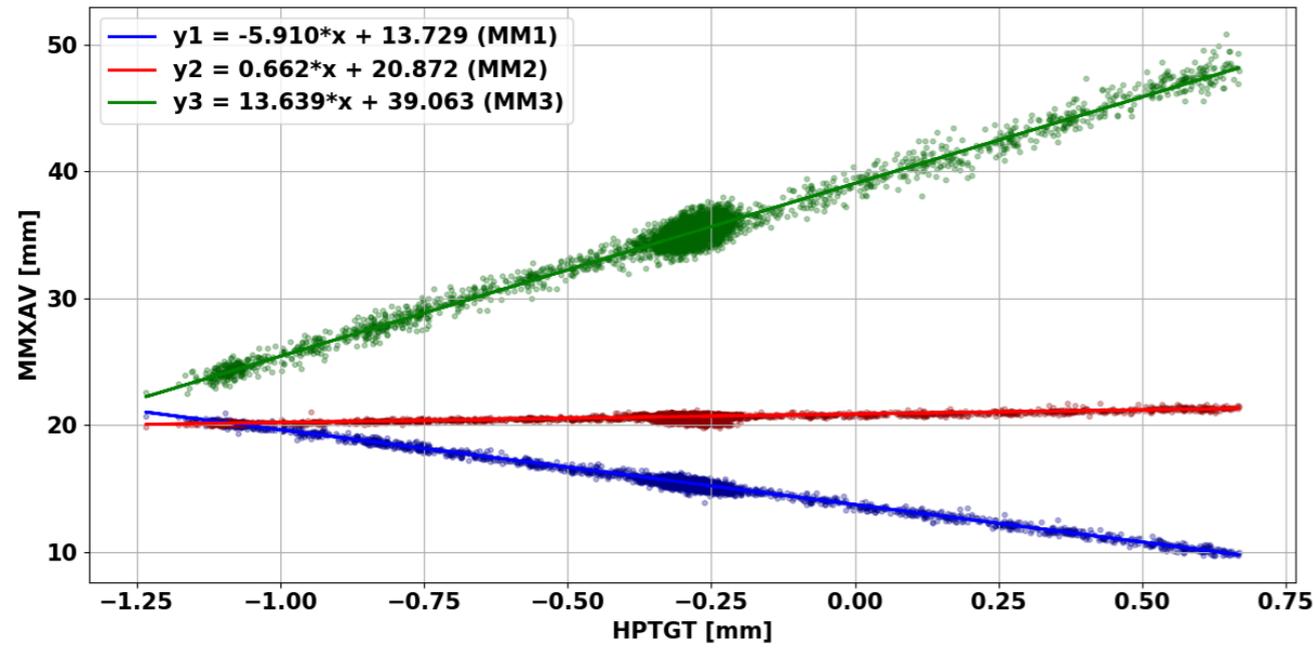


Beam Scan: Horizontal and Vertical (Dec 12th)

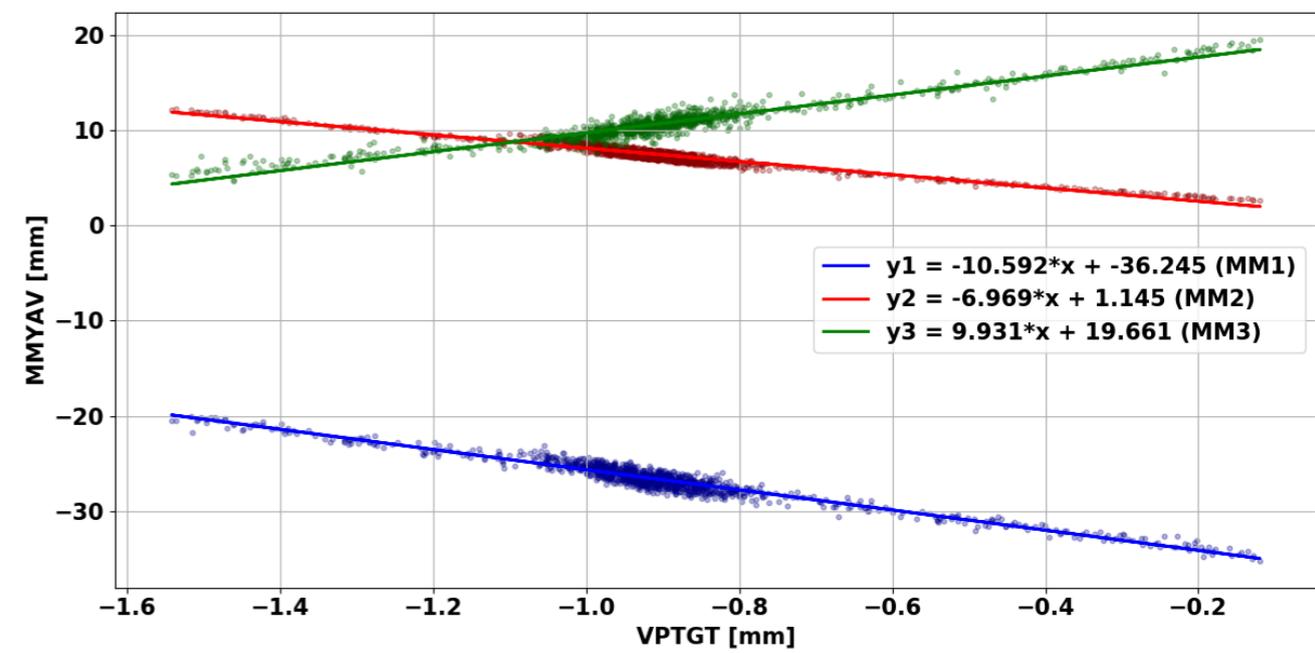
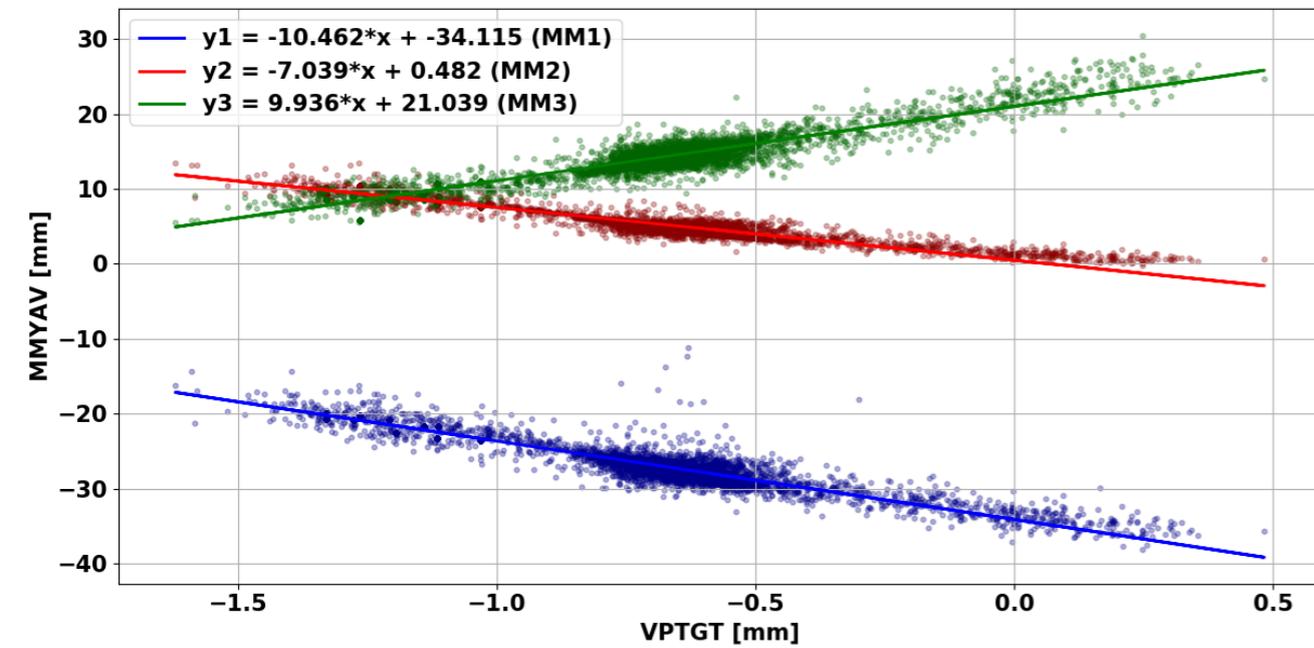
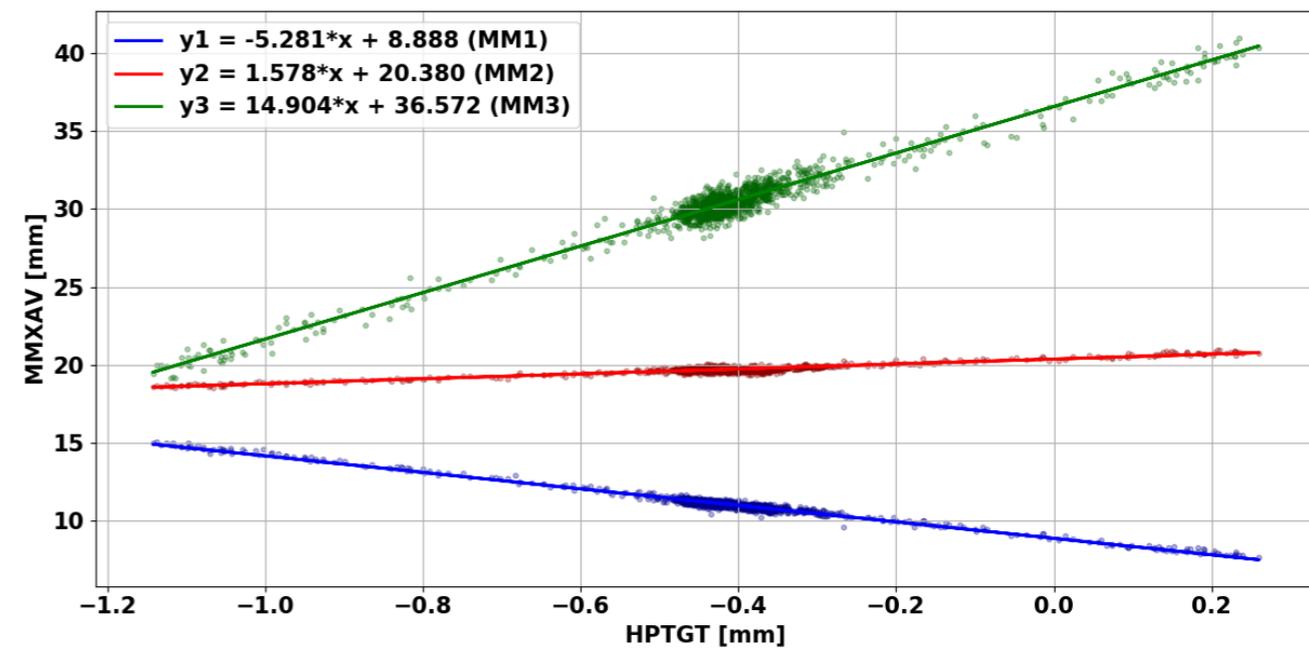


Beam Scan: Correlations

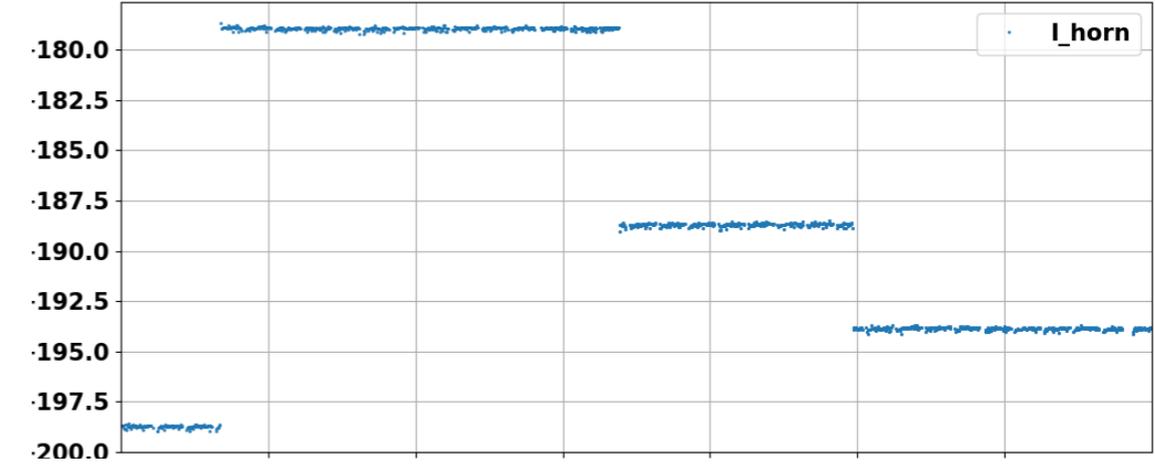
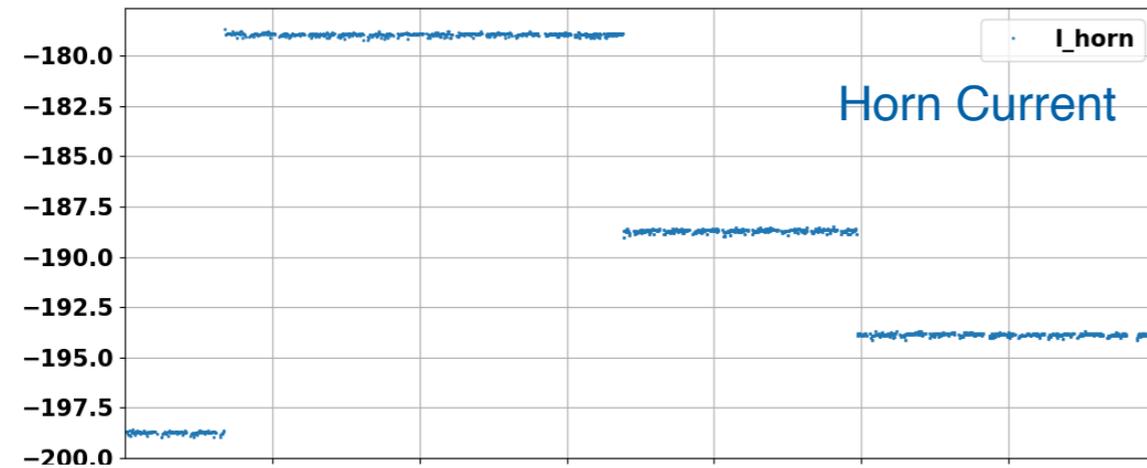
2019-Dec-12



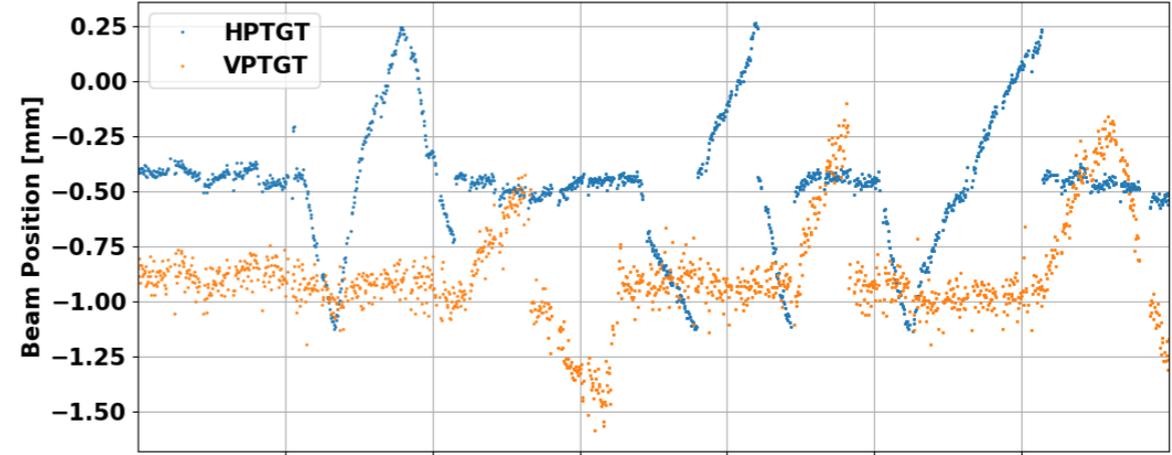
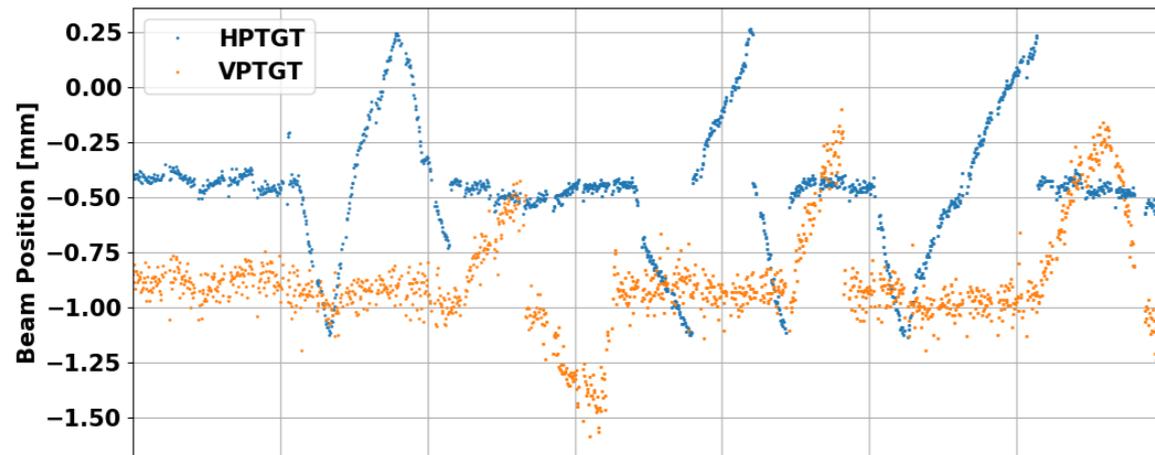
2019-Jul-03



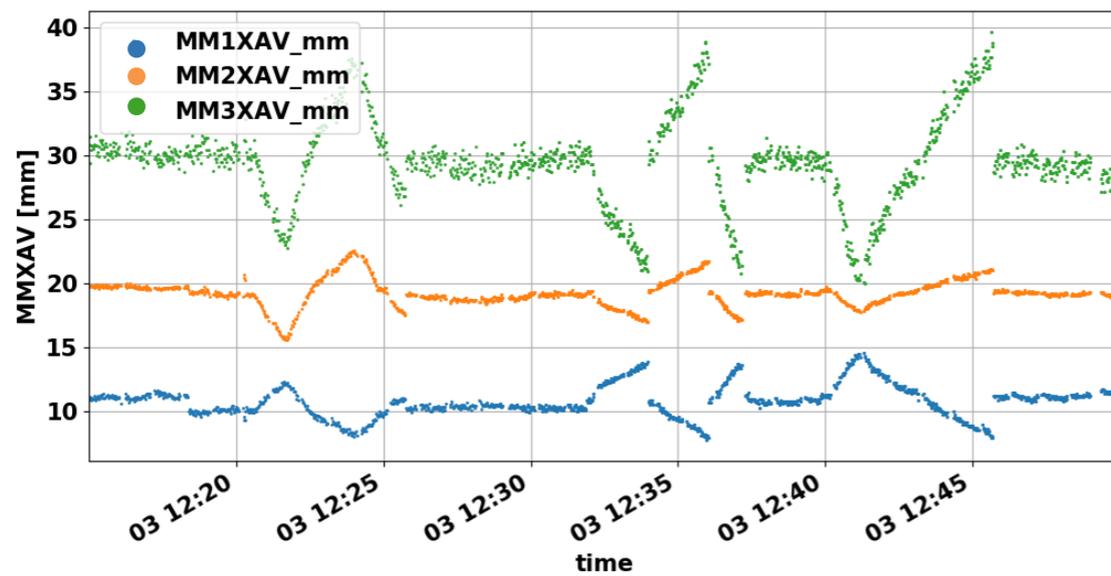
Horn Current Scan: 2019-Jul-03



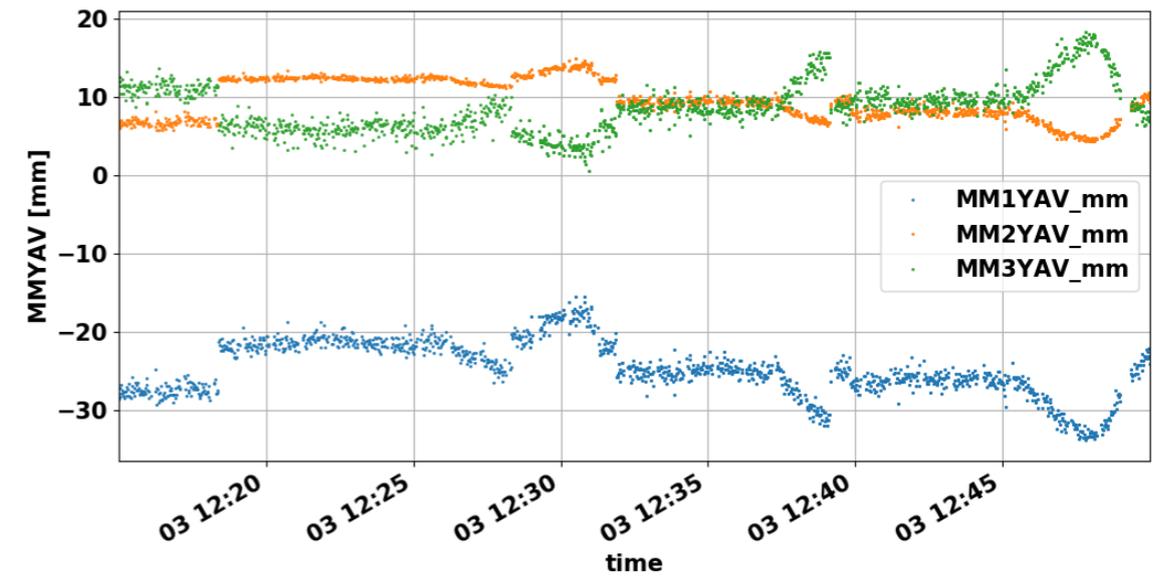
Proton beam X & Y



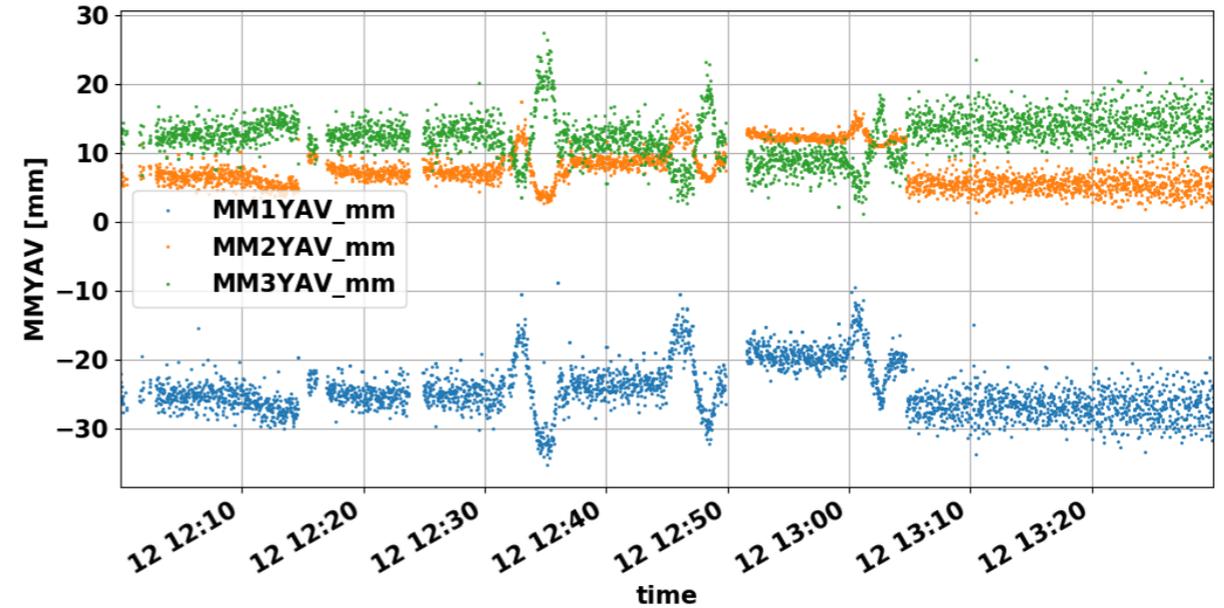
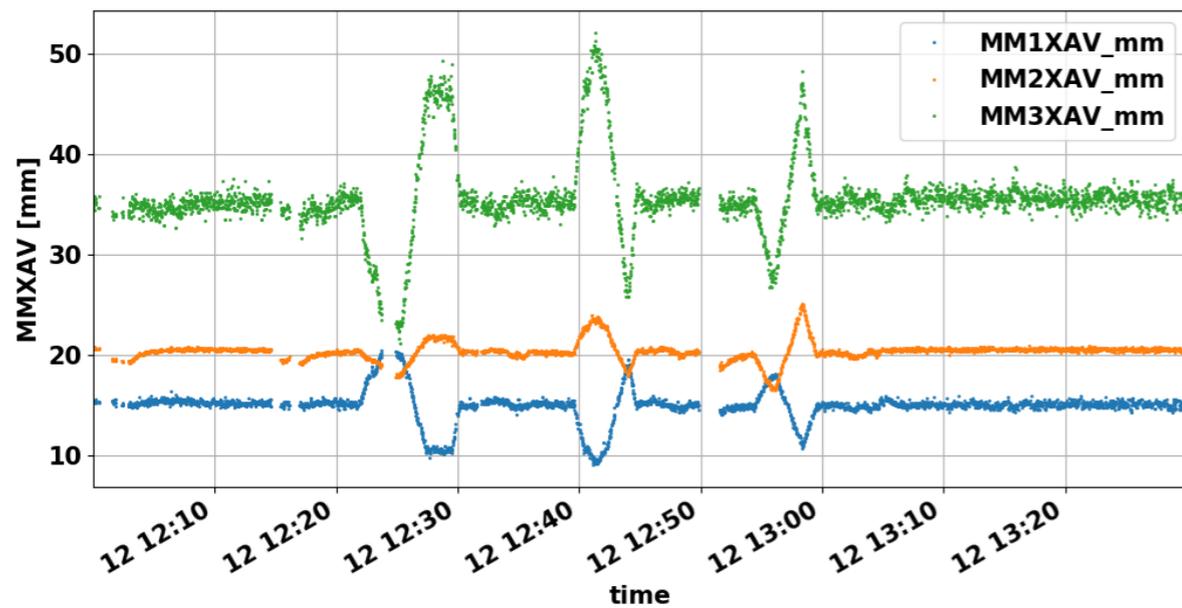
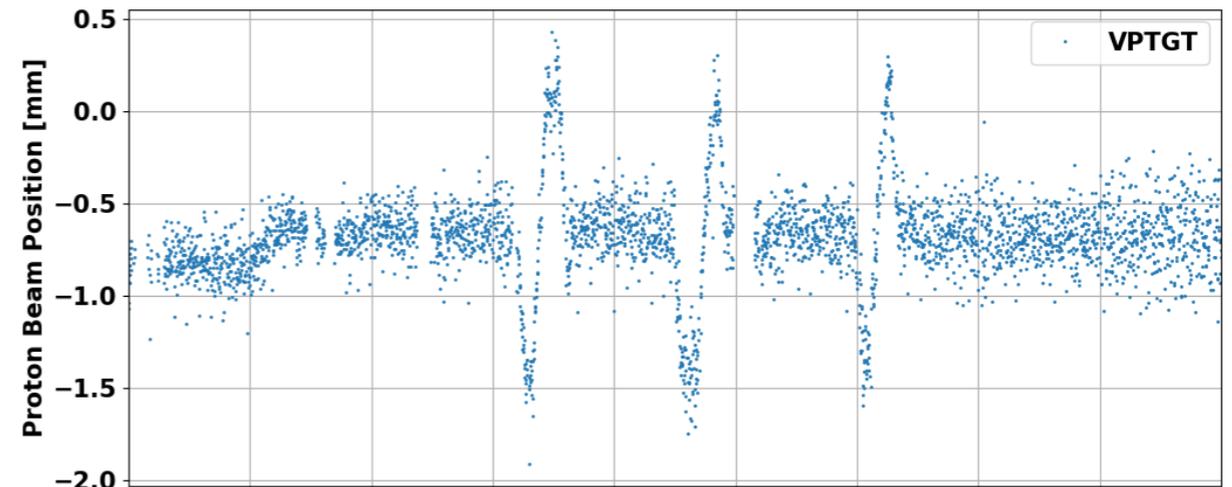
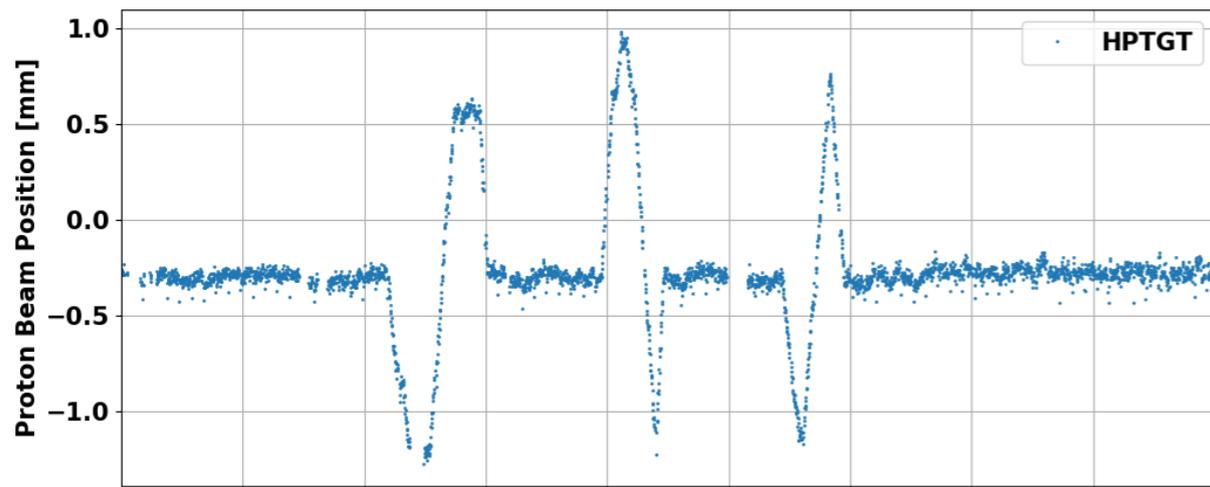
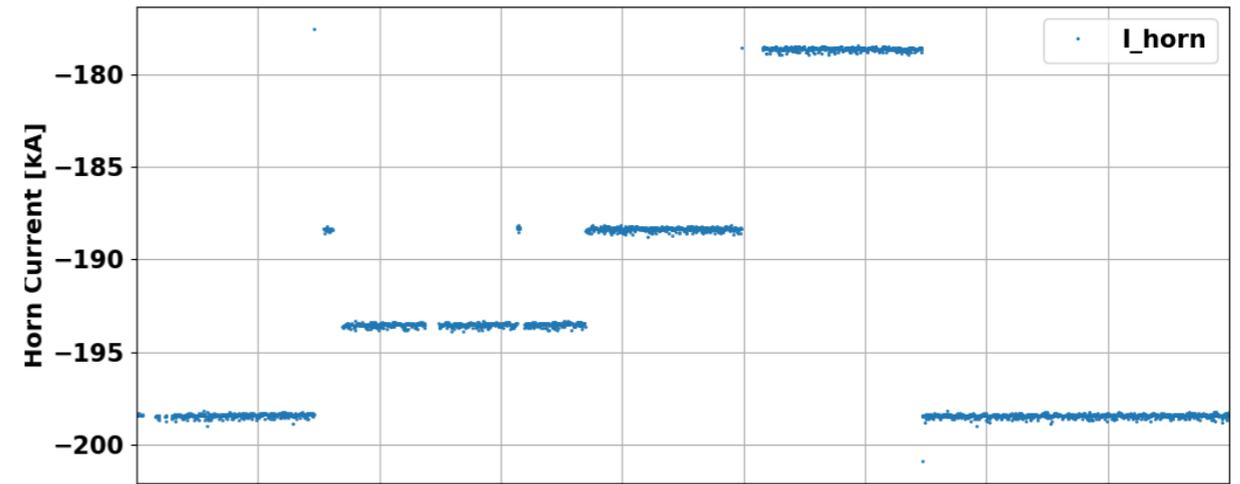
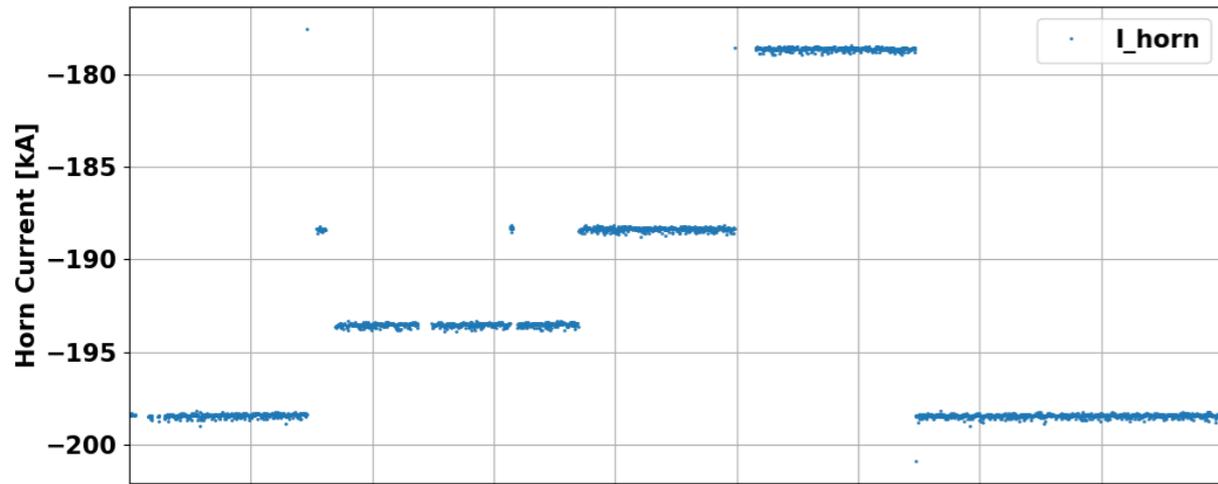
Muon Monitors Centroid: X



Muon Monitors Centroid: Y

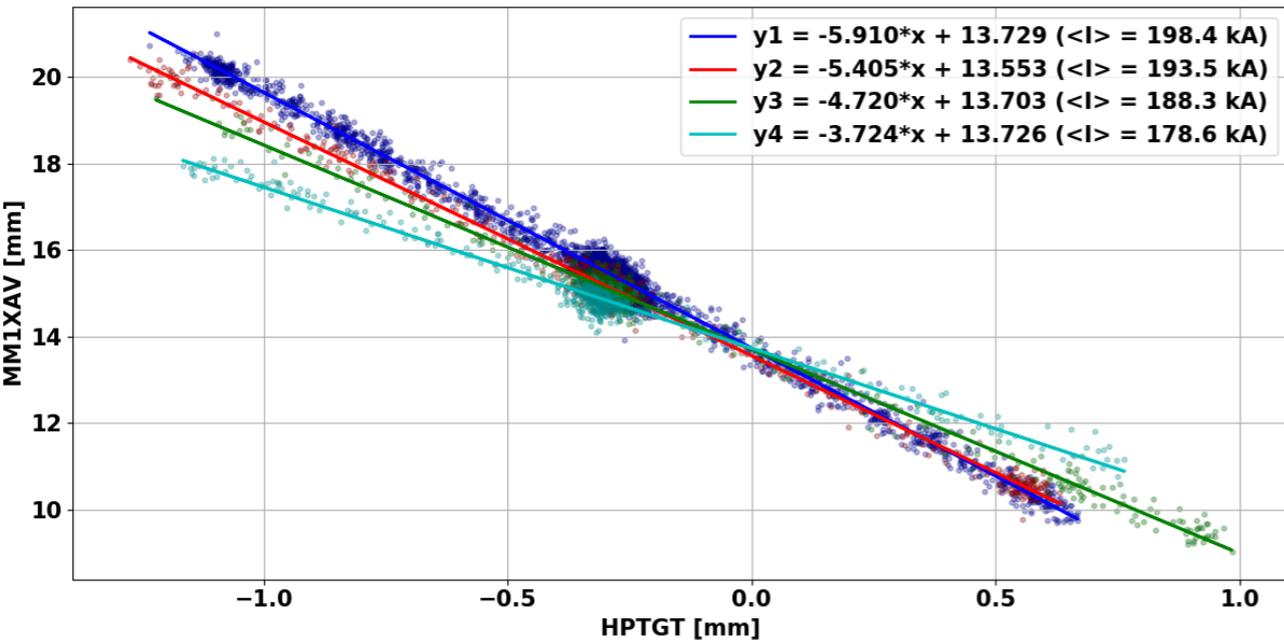


Horn Current Scan: 2019 Dec 12

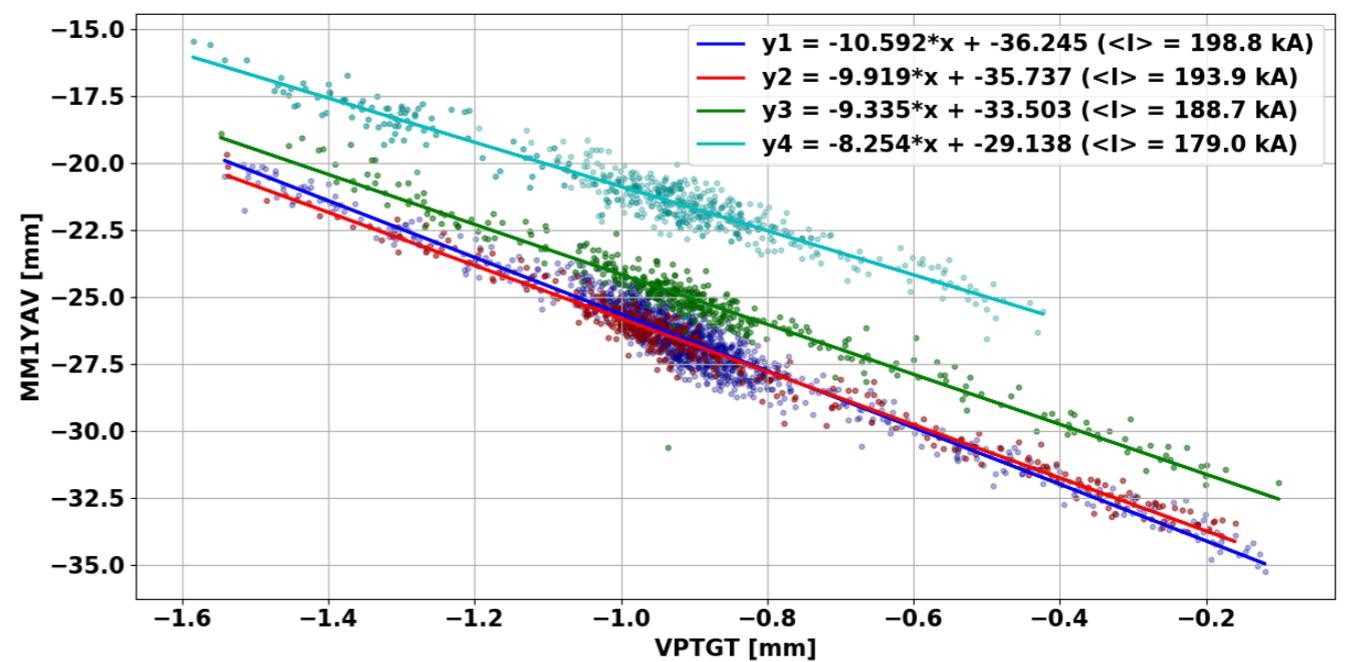
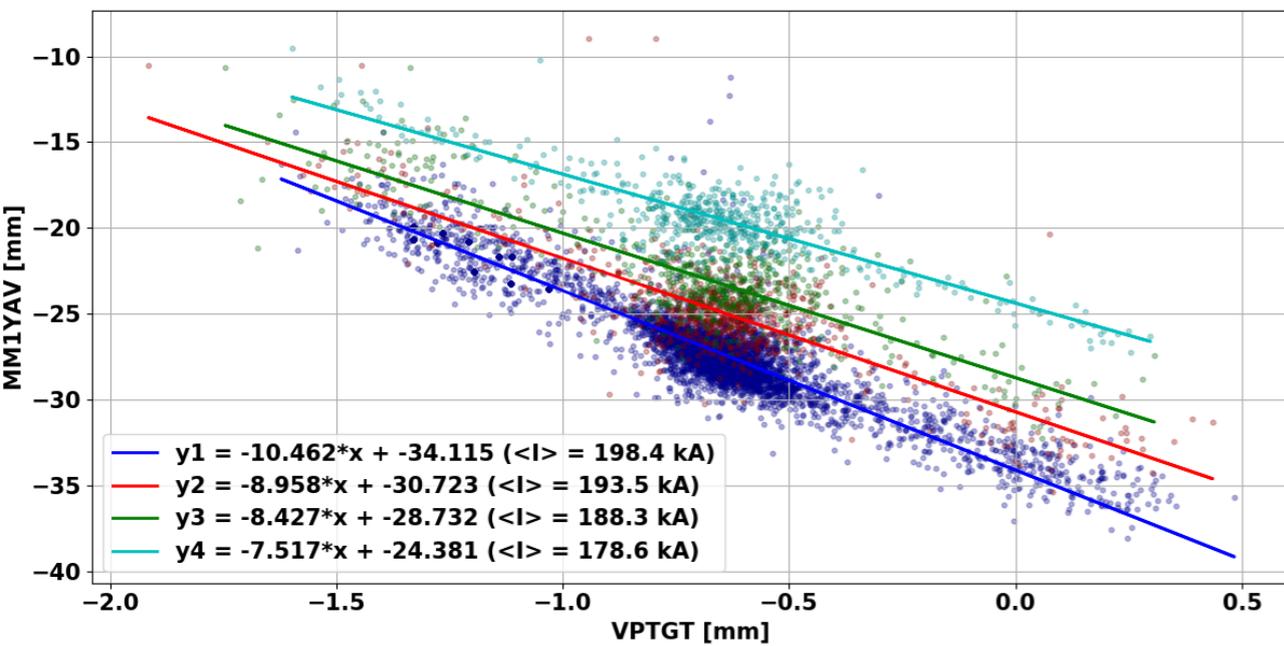
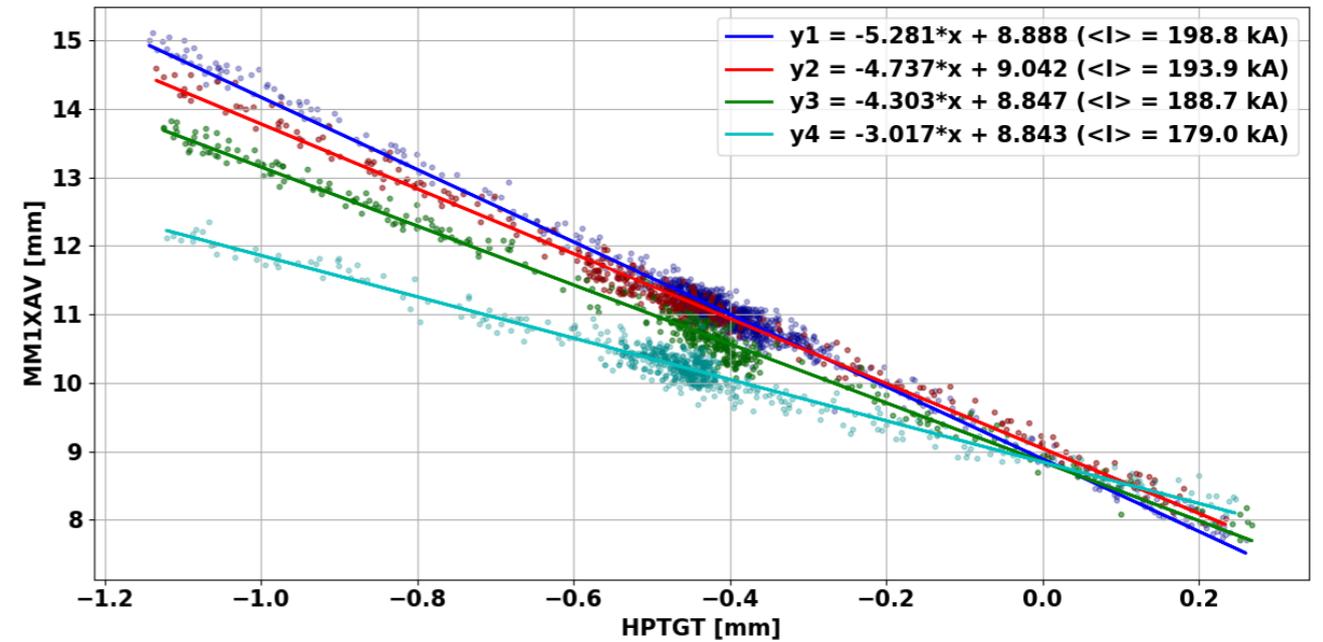


Horn Current Scan: Muon Monitor1

2019-Dec-12



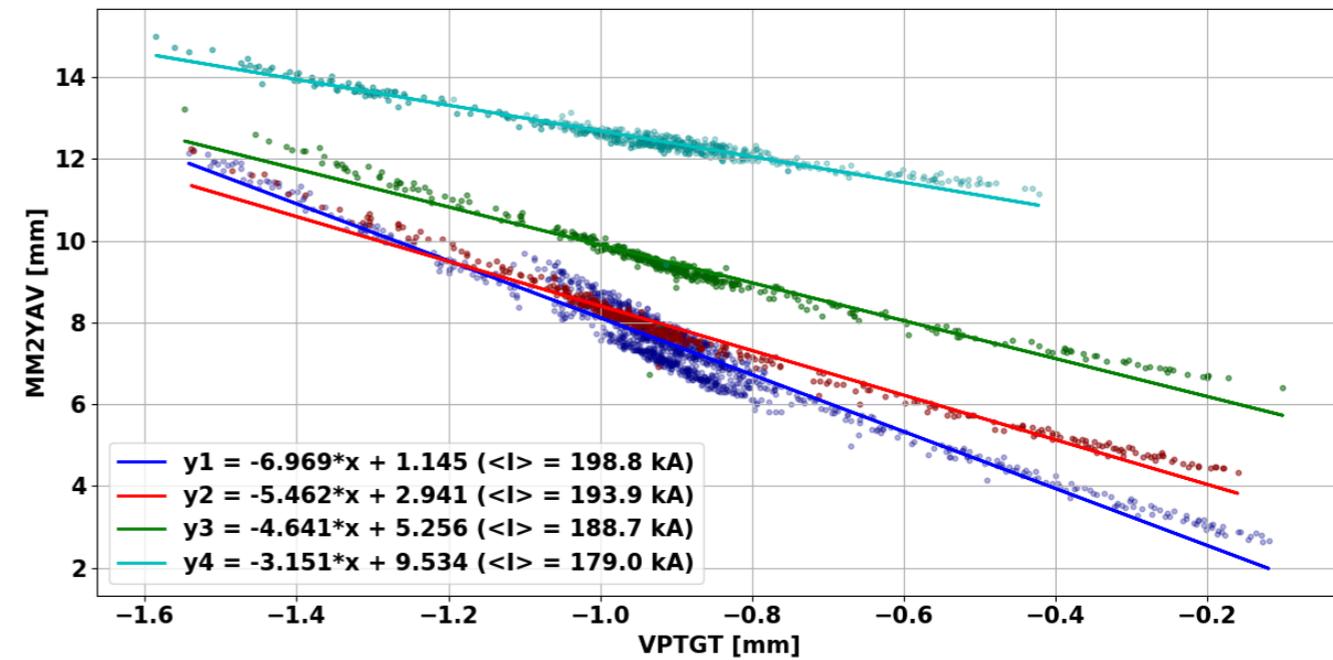
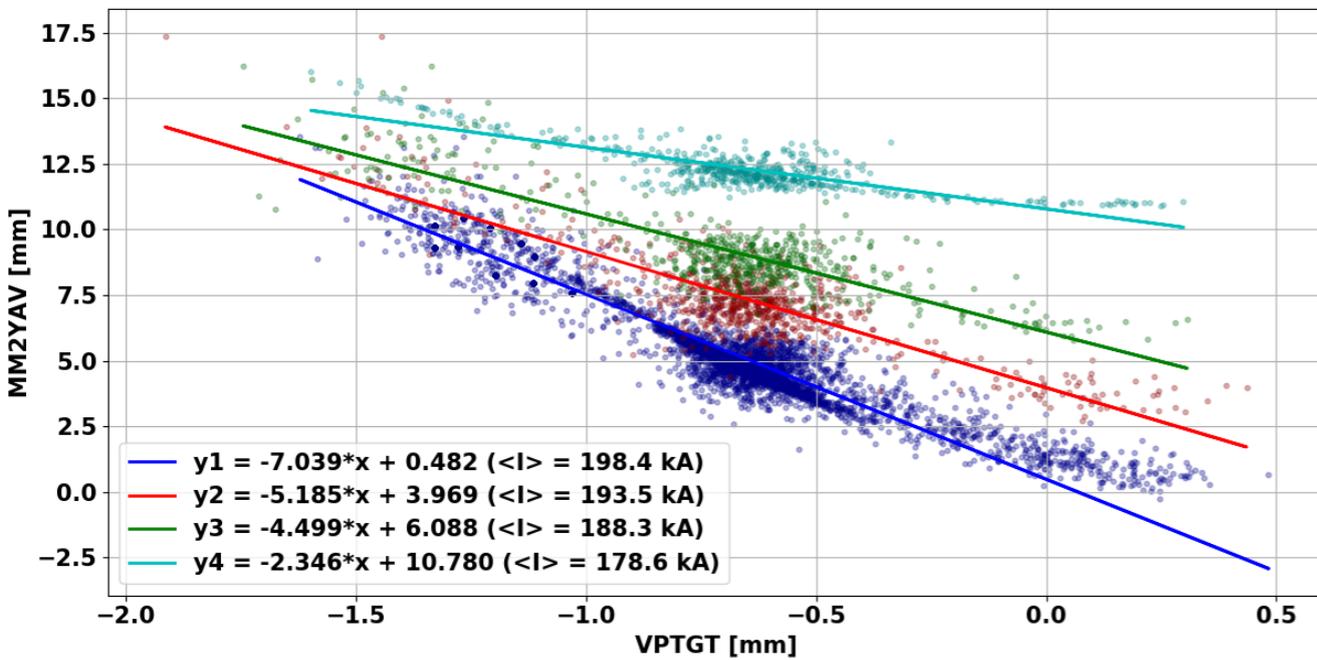
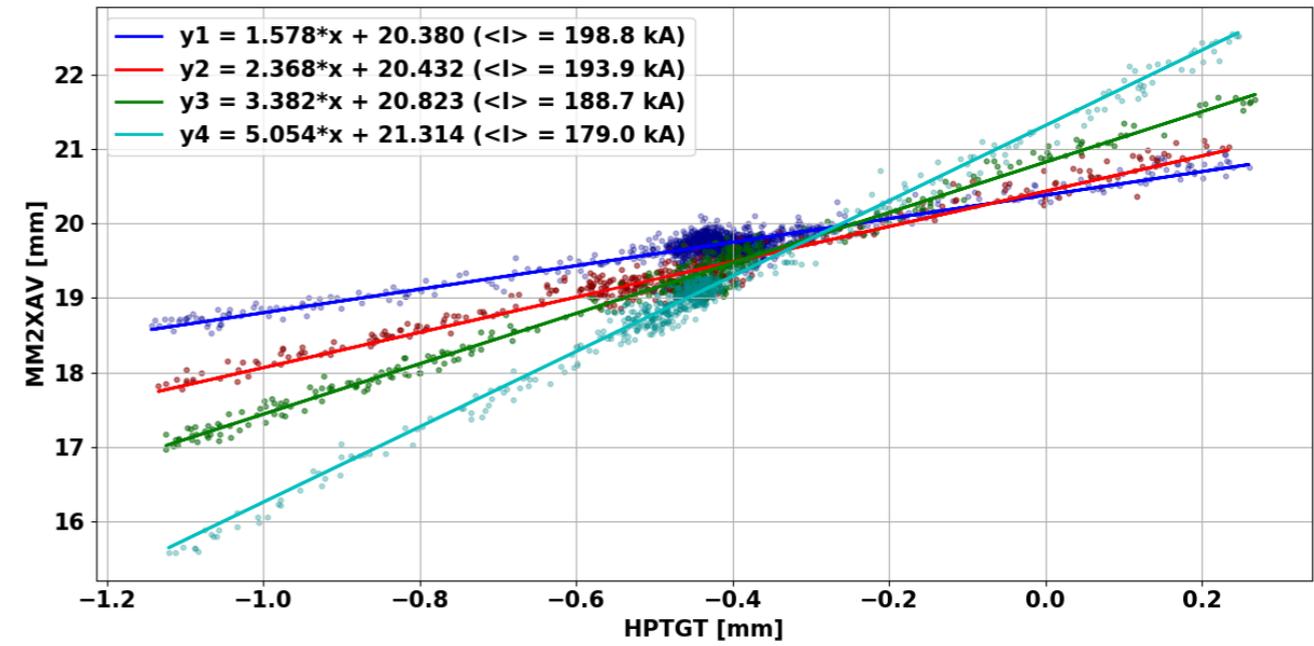
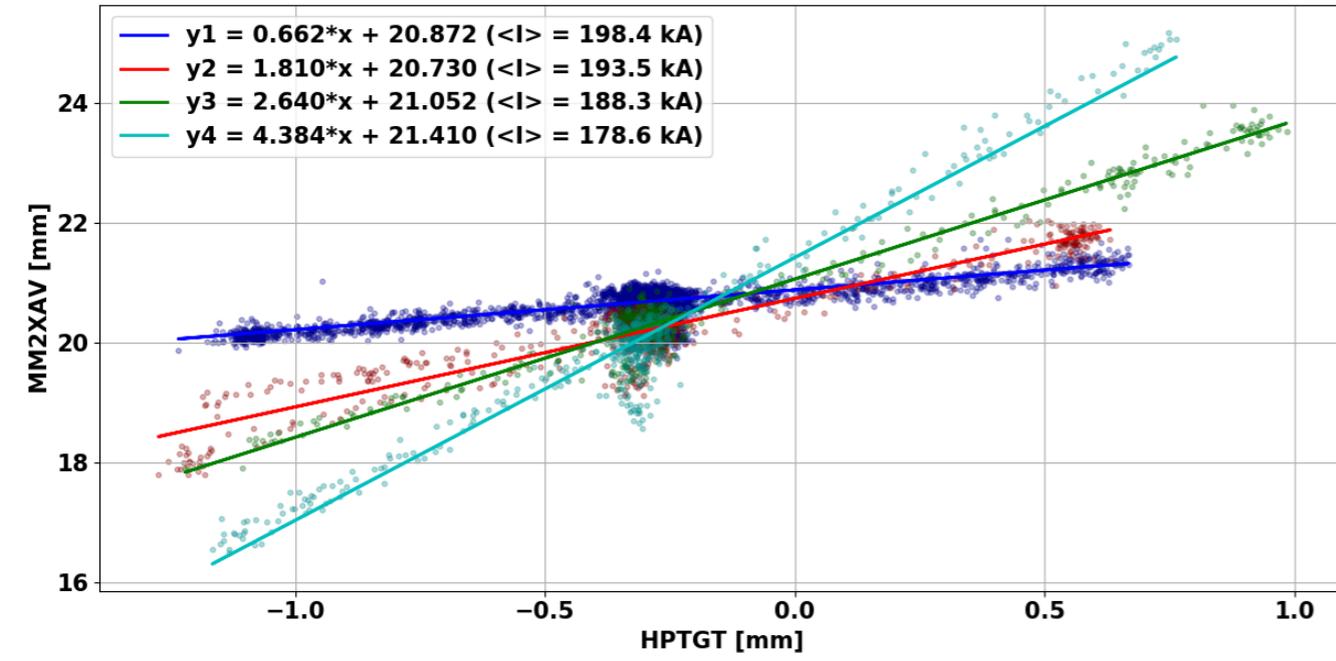
2019-Jul-03



Horn Current Scan: Muon Monitor2

2019-Dec-12

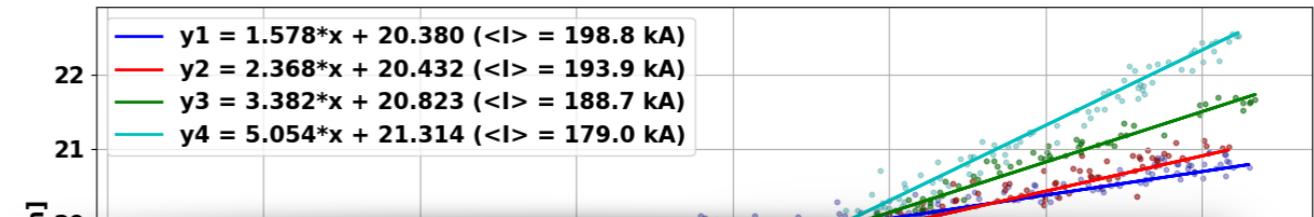
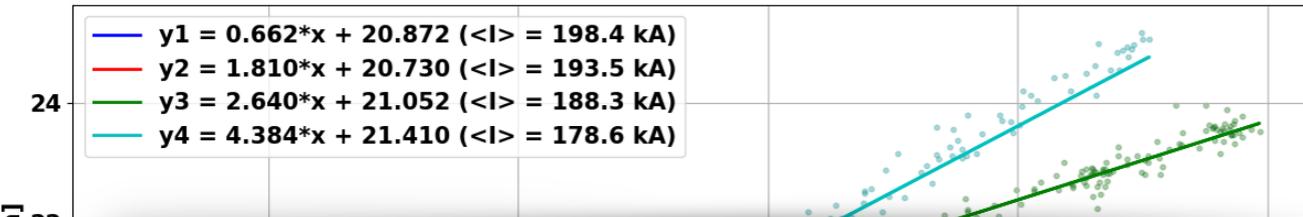
2019-Jul-03



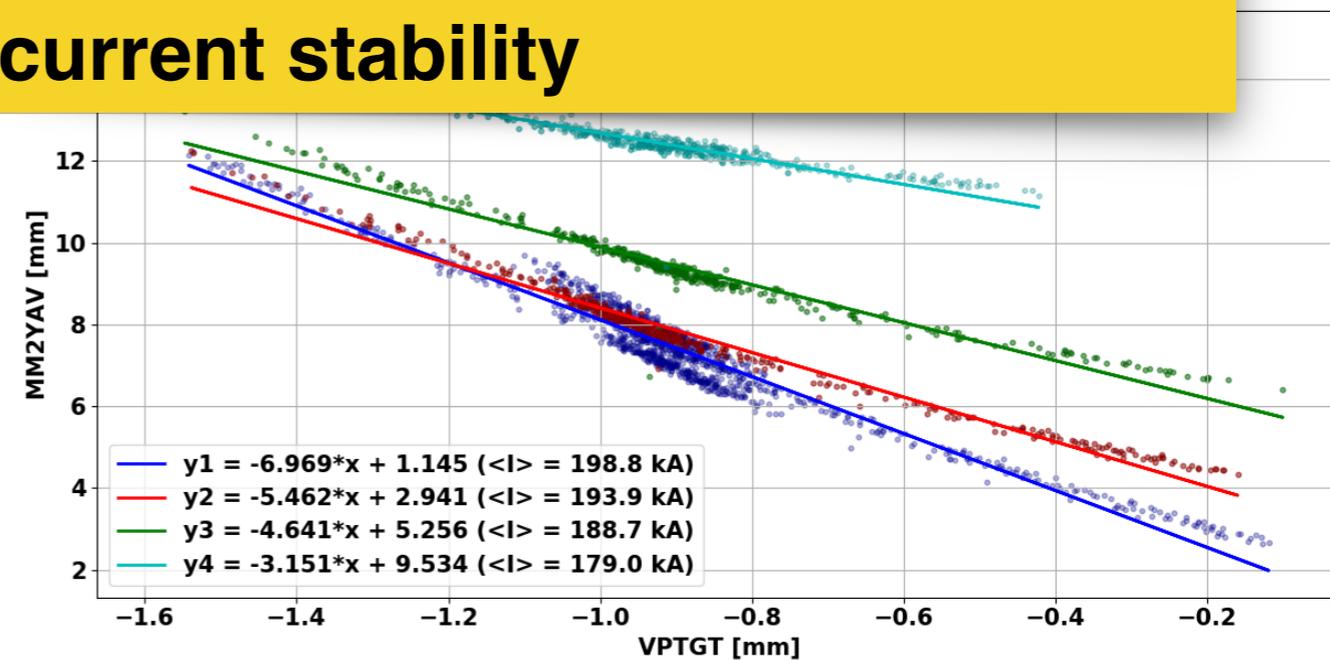
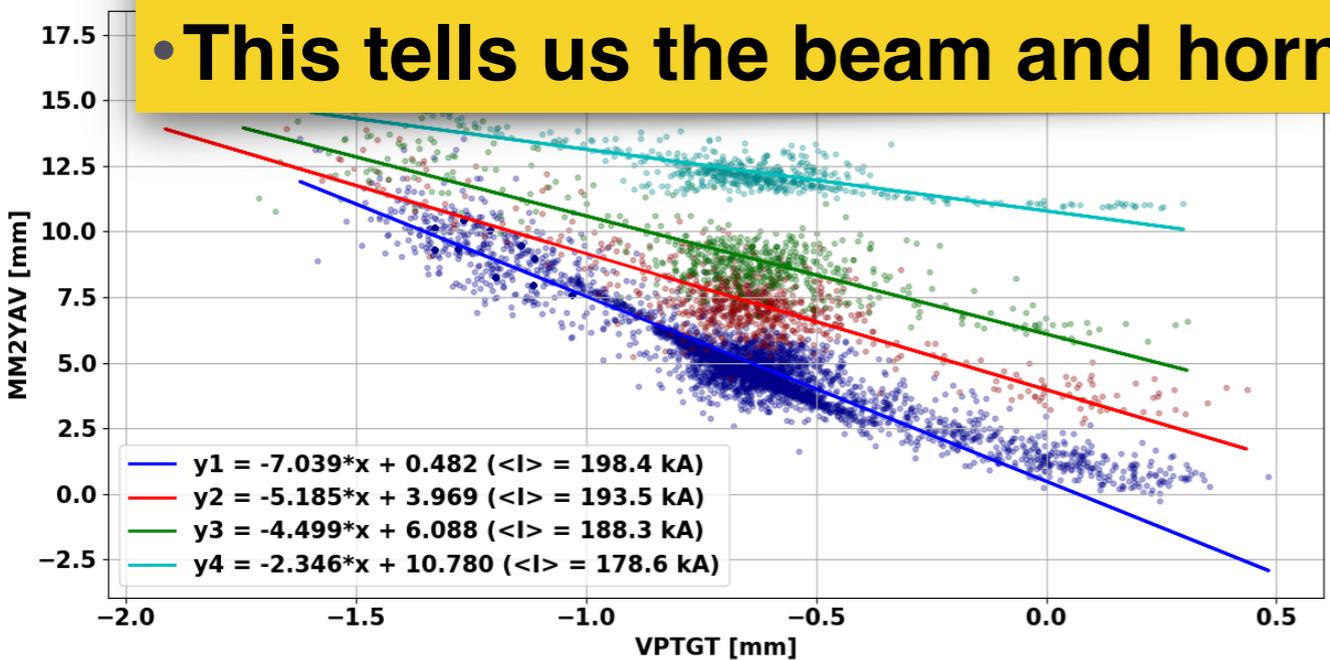
Remarks:

2019-Dec-12

2019-Jul-03



- We understand the correlation of the muon flux centroid to the beam position with different horn current settings
- That shows us the uniqueness of each muon monitors responding to the beam line variables
- This tells us the beam and horn current stability



Pressure Corrected Integrated Signal

Integrated Signal with calibrations

$$\text{Integrated Signal} = \frac{1}{\text{POT}} \sum_i^{81} (\text{Signal}[i] - \text{Pedestal}[i]) \cdot \text{Cal}[i] \cdot [1 - \alpha(P_{\text{gas}} - P_C)]$$

$P_C = 800$ Torr

P_{Gas} = Gas Pressure Measurement

POT = Beam Intensity

$\alpha = 0.00105$ (calibration constant)

$\text{Signal}[i]$ = Signal value on the i^{th} pixel

$\text{Pedestal}[i]$ = Pedestal value on the i^{th} pixel

$\text{Cal}[i]$ = Calibration value on i^{th} pixel

Measurement indicates:

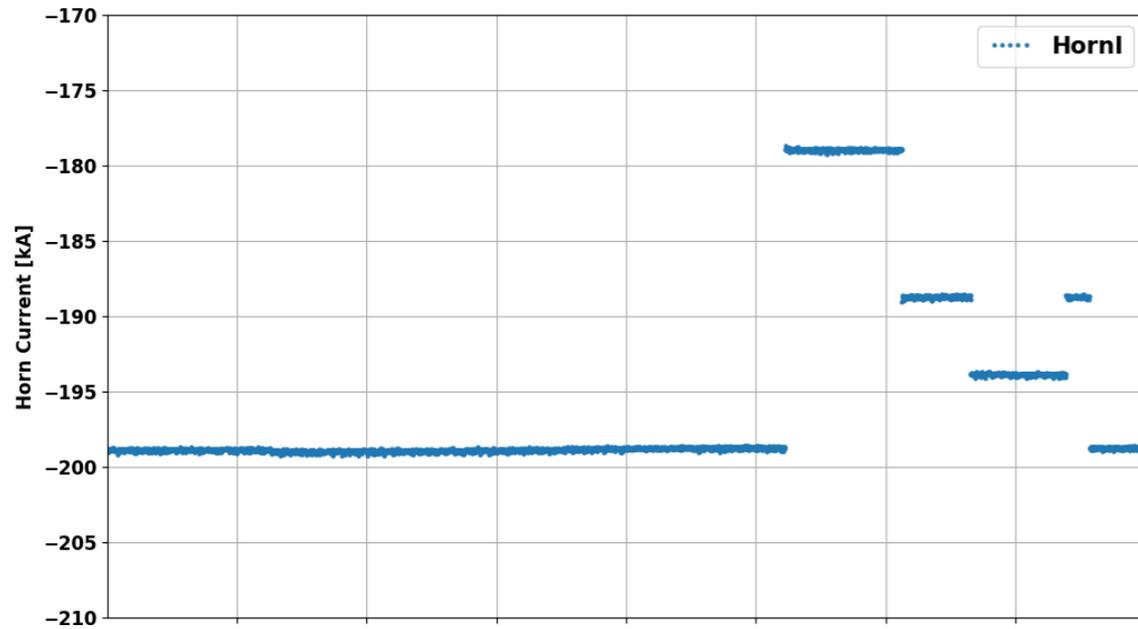
- **Proportional to the total muon flux passing through the detector per proton**
- **Proportional to the total muon energy lost in the detector**

Importance of the measurement:

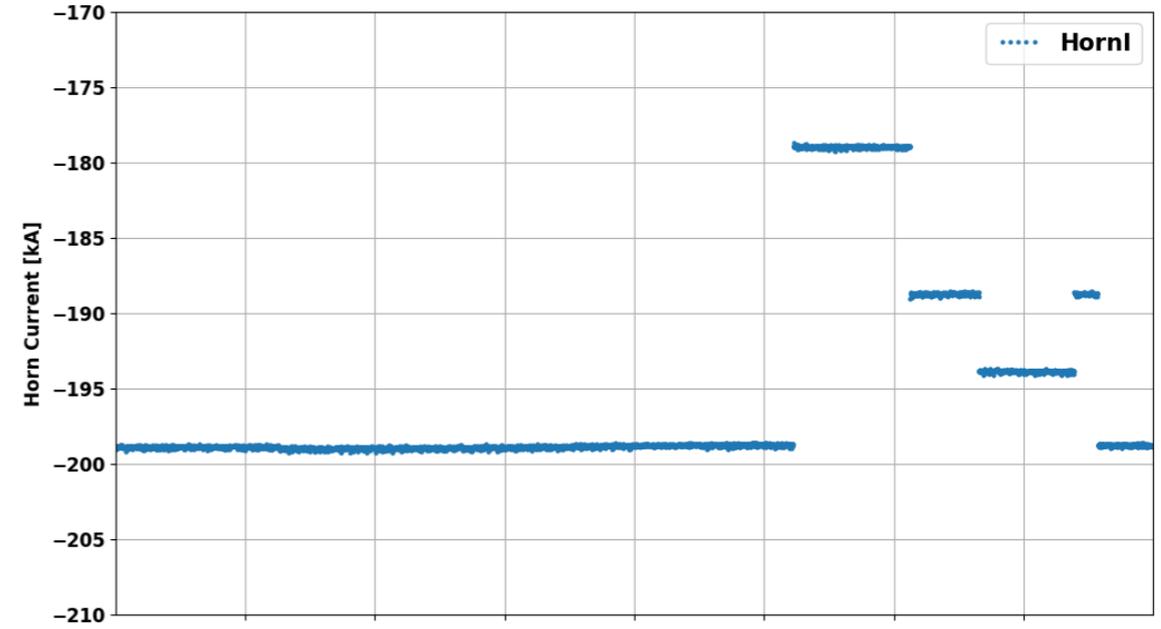
- **Indicates the hadron production related to the target profile**
- **Sensitive to the horn current variations**

Pressure Corrected Integrated Signal

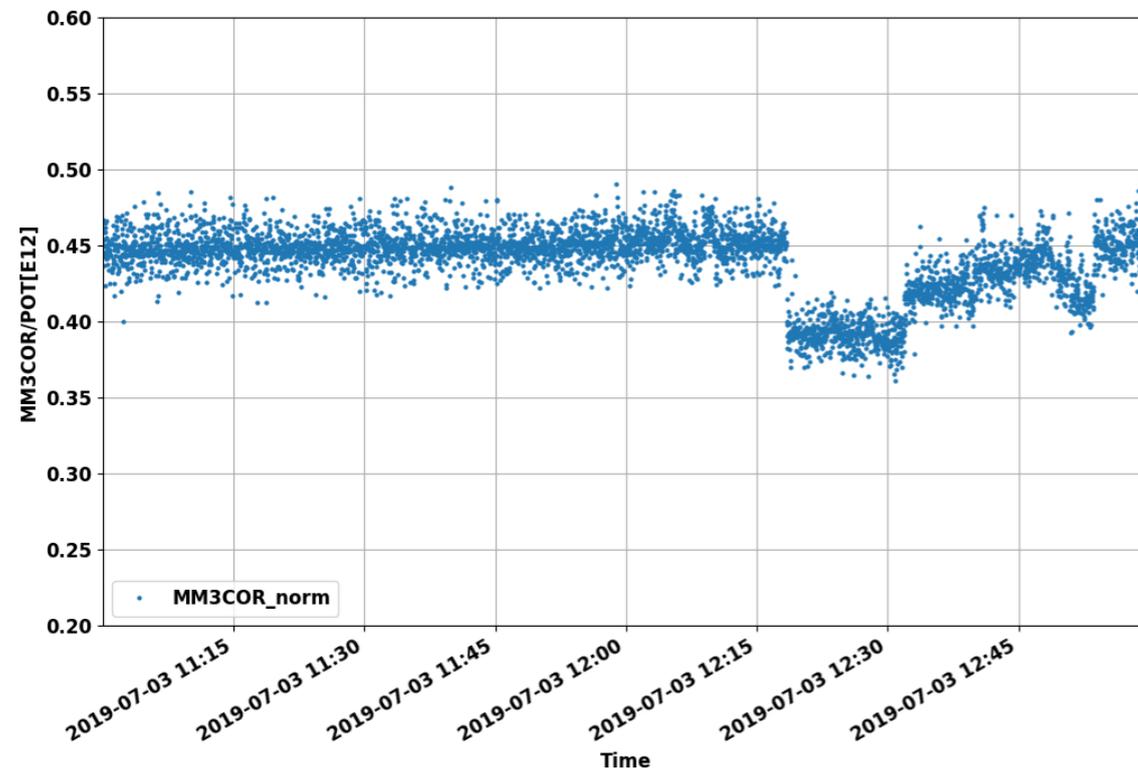
Horn Current



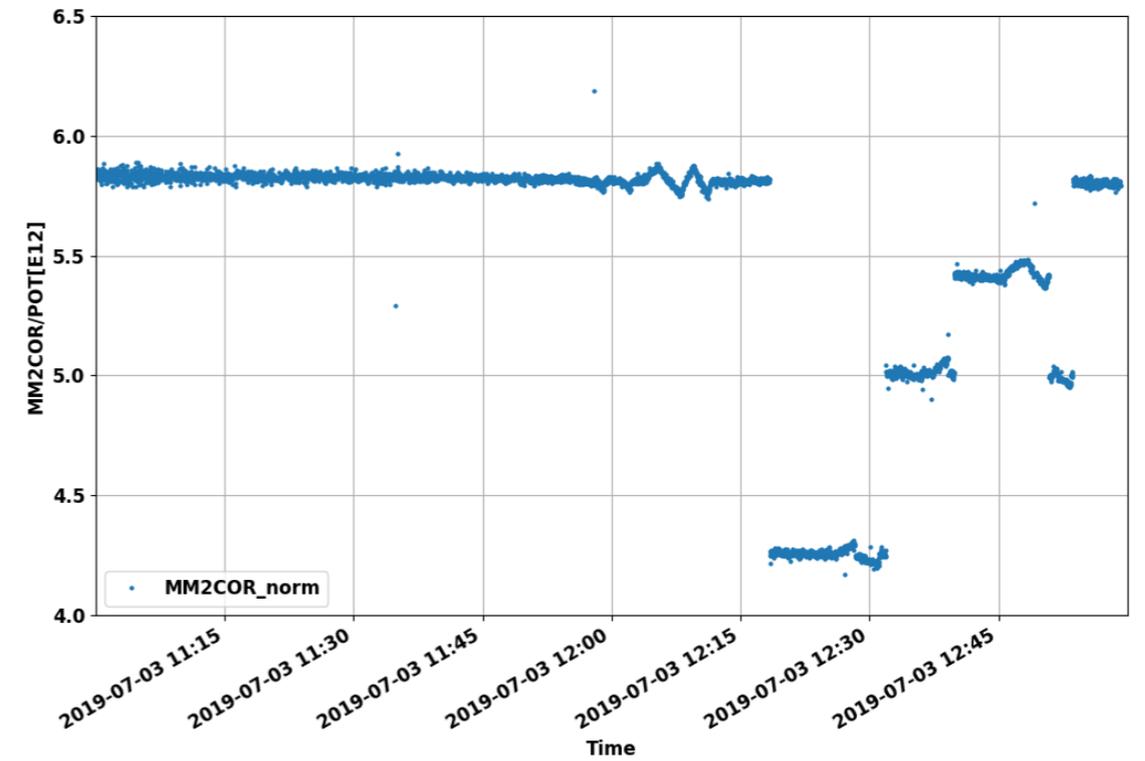
Horn Current



MM3COR

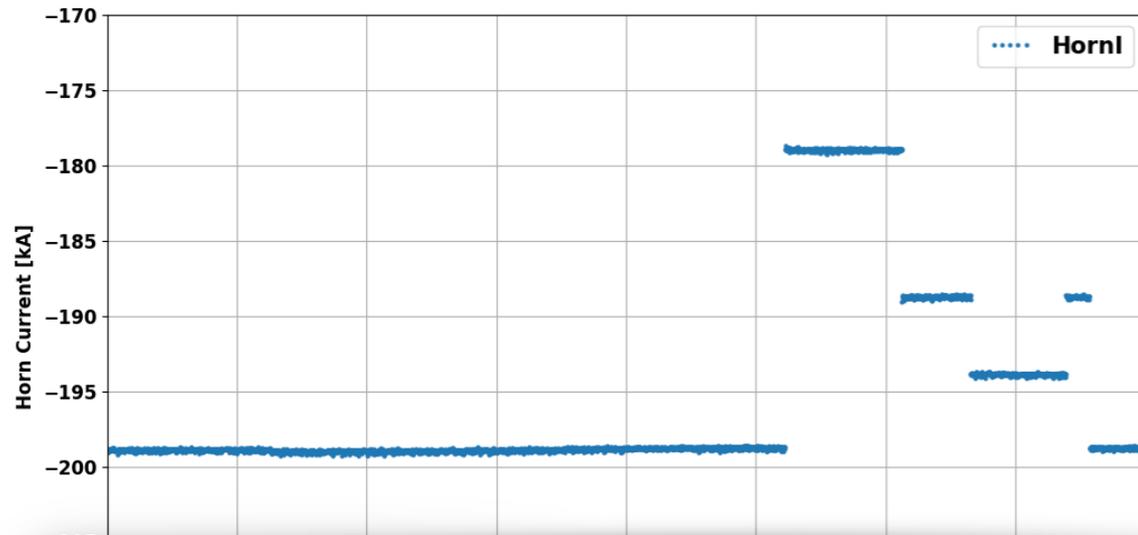


MM2COR

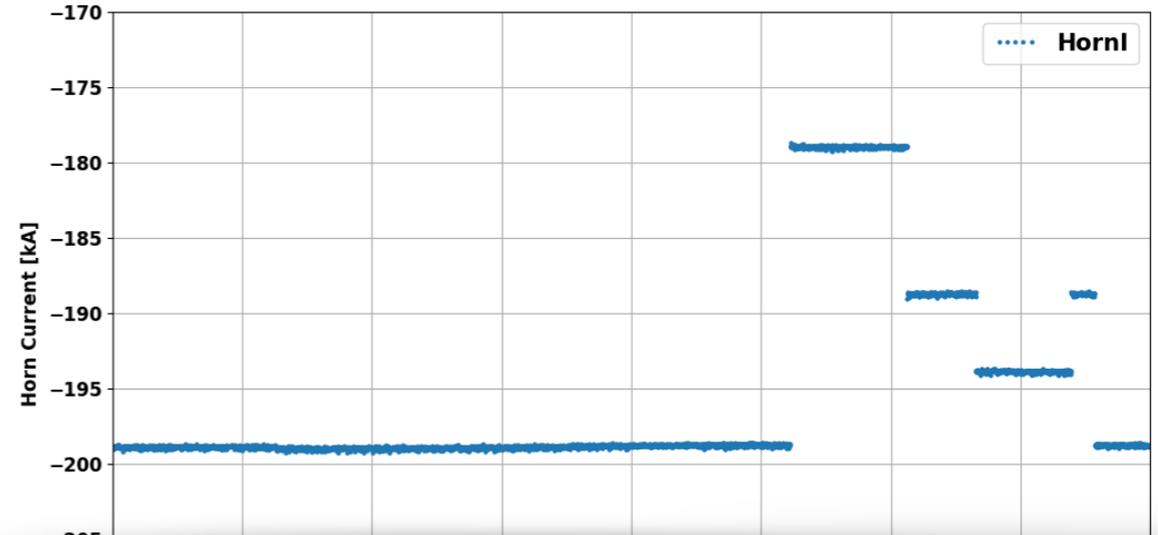


Pressure Corrected Integrated Signal

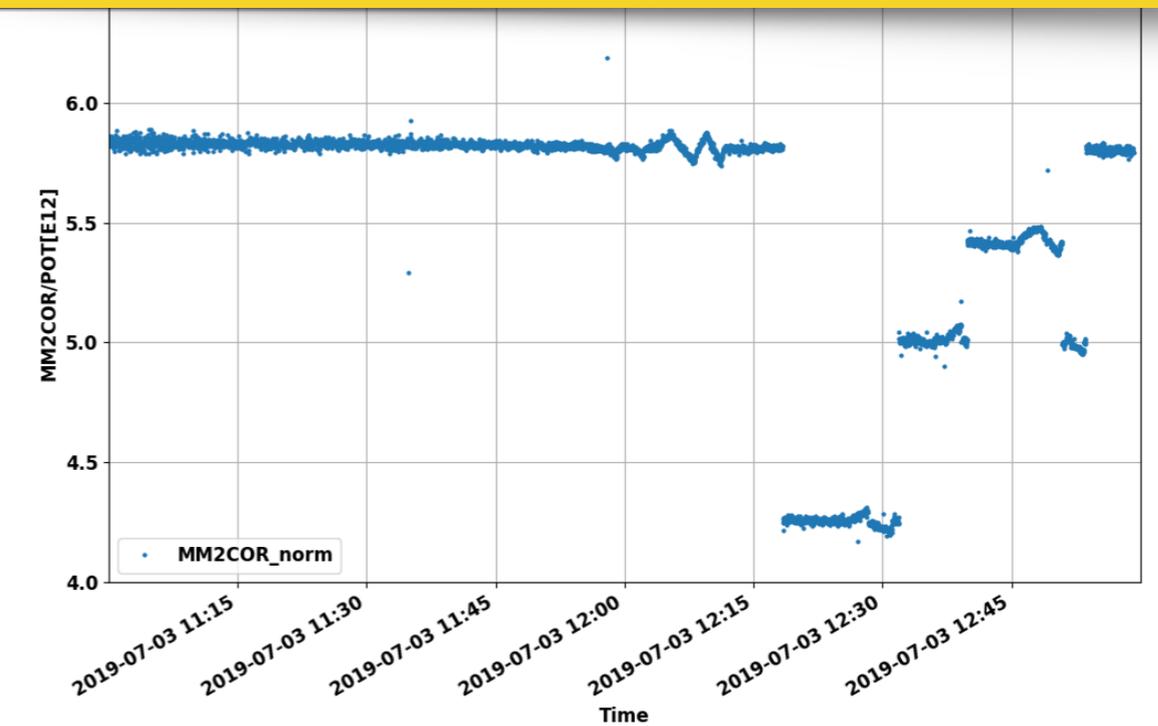
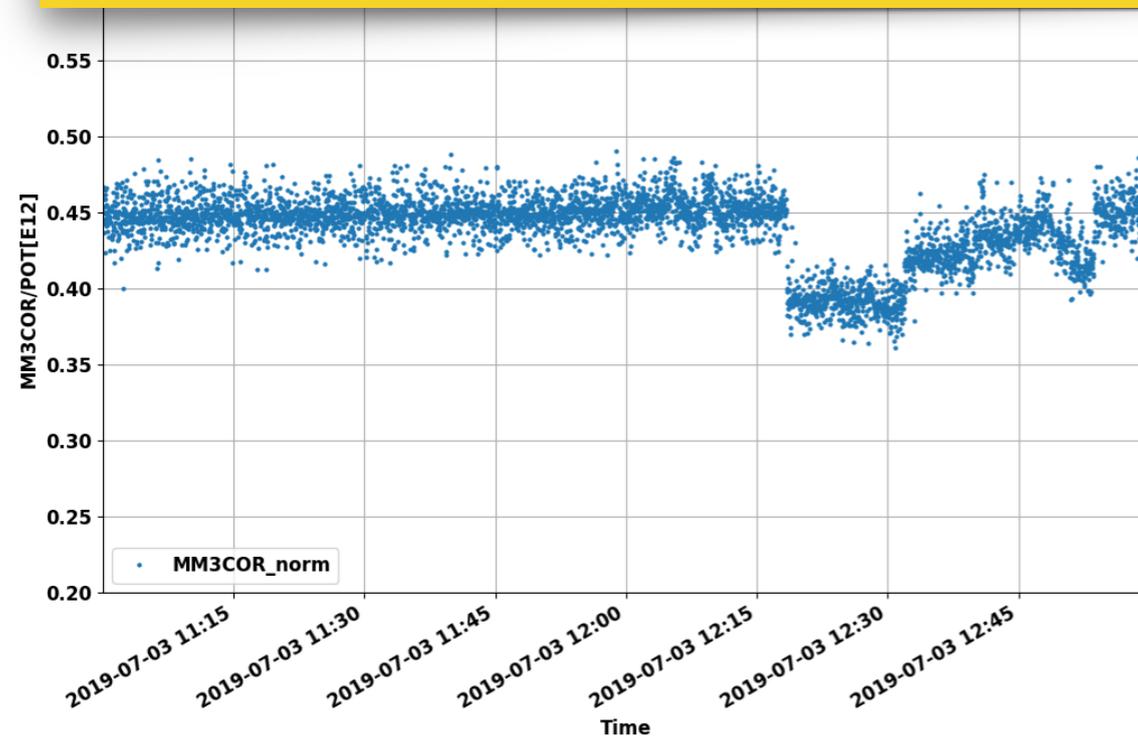
Horn Current



Horn Current



- Signal gain is very useful to see the response of the muon monitors to the horn current changes

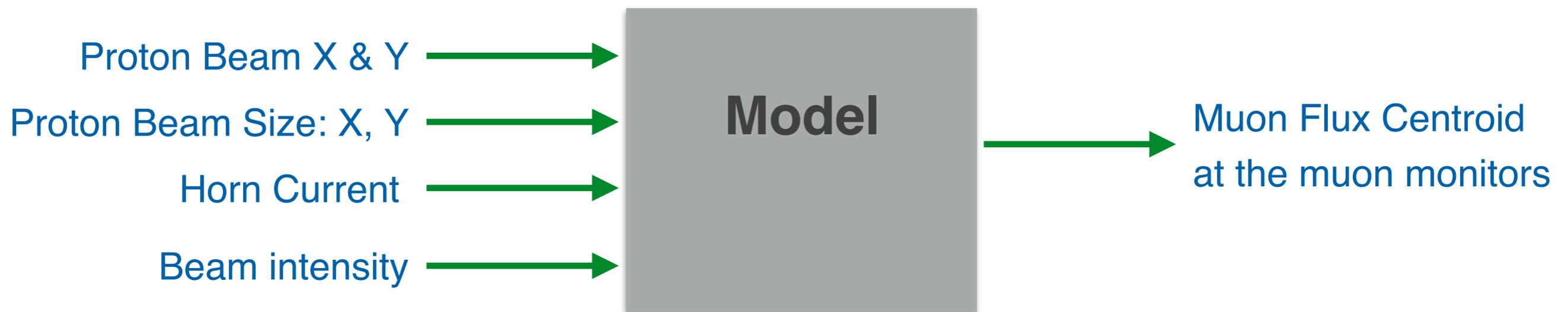


Next

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Predicting Muon Monitor Centroid from beam and horn parameters

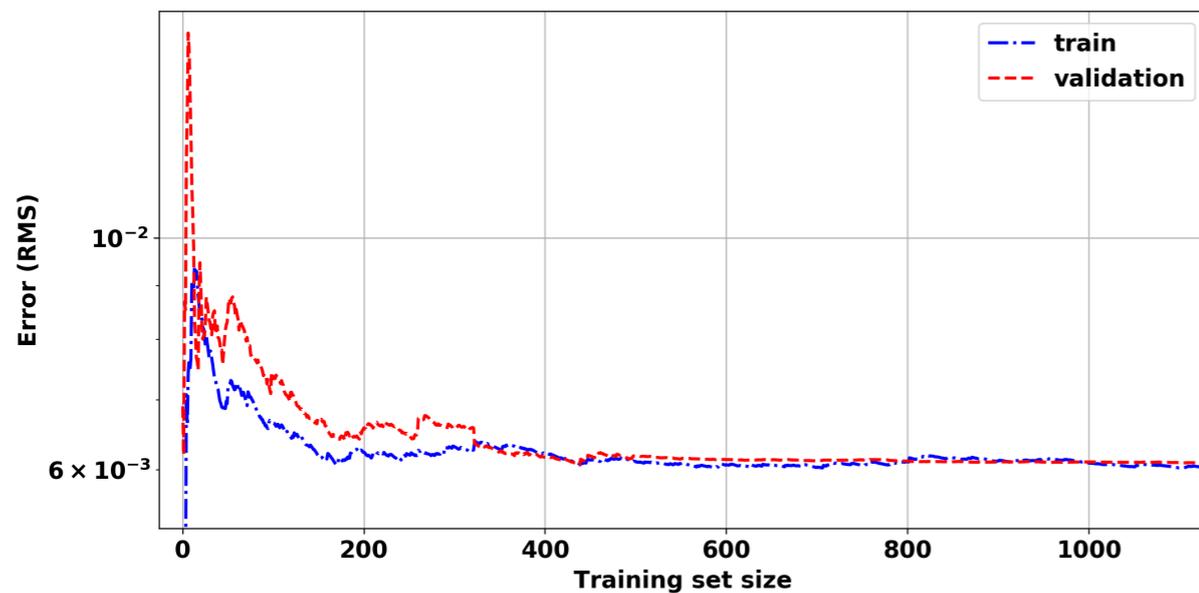
MOTIVATION: Developing a muon flux centroid prediction model by taking account upstream variables such as horn current and proton beam profile changes as inputs



Machine Learning Applications

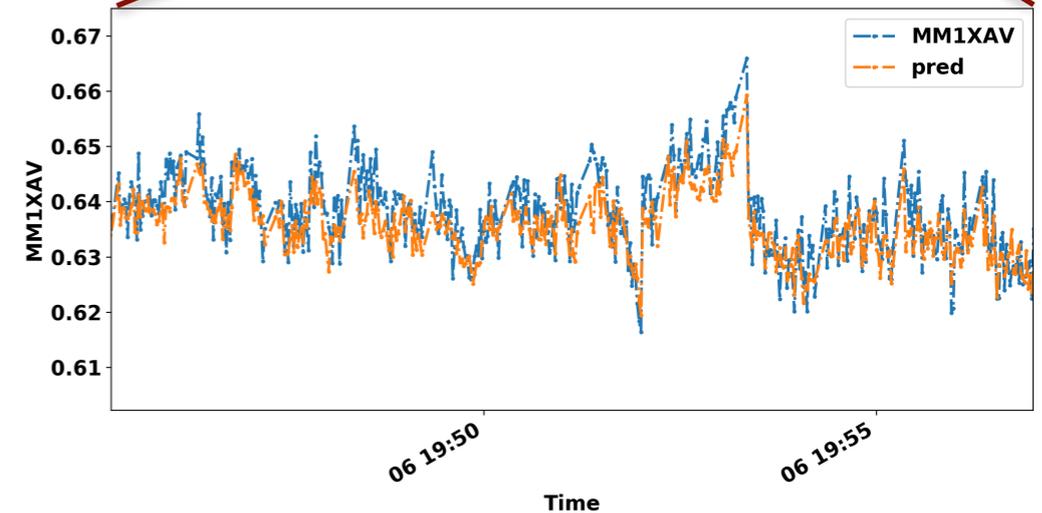
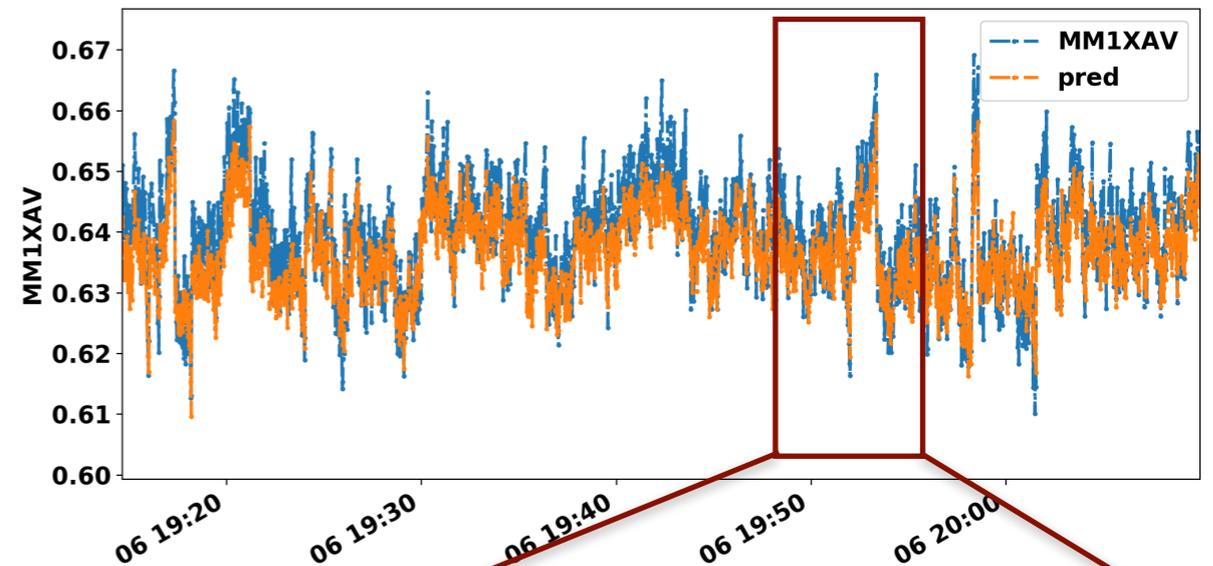
$$\text{prediction} = f(X_b, Y_b, \sigma_X, \sigma_Y, \text{Intensity}_{\text{beam}}, I_{\text{horn}})$$

Training performance for a random data set



The predictions are accurate as ± 0.1 mm in X and ± 0.5 mm in Y

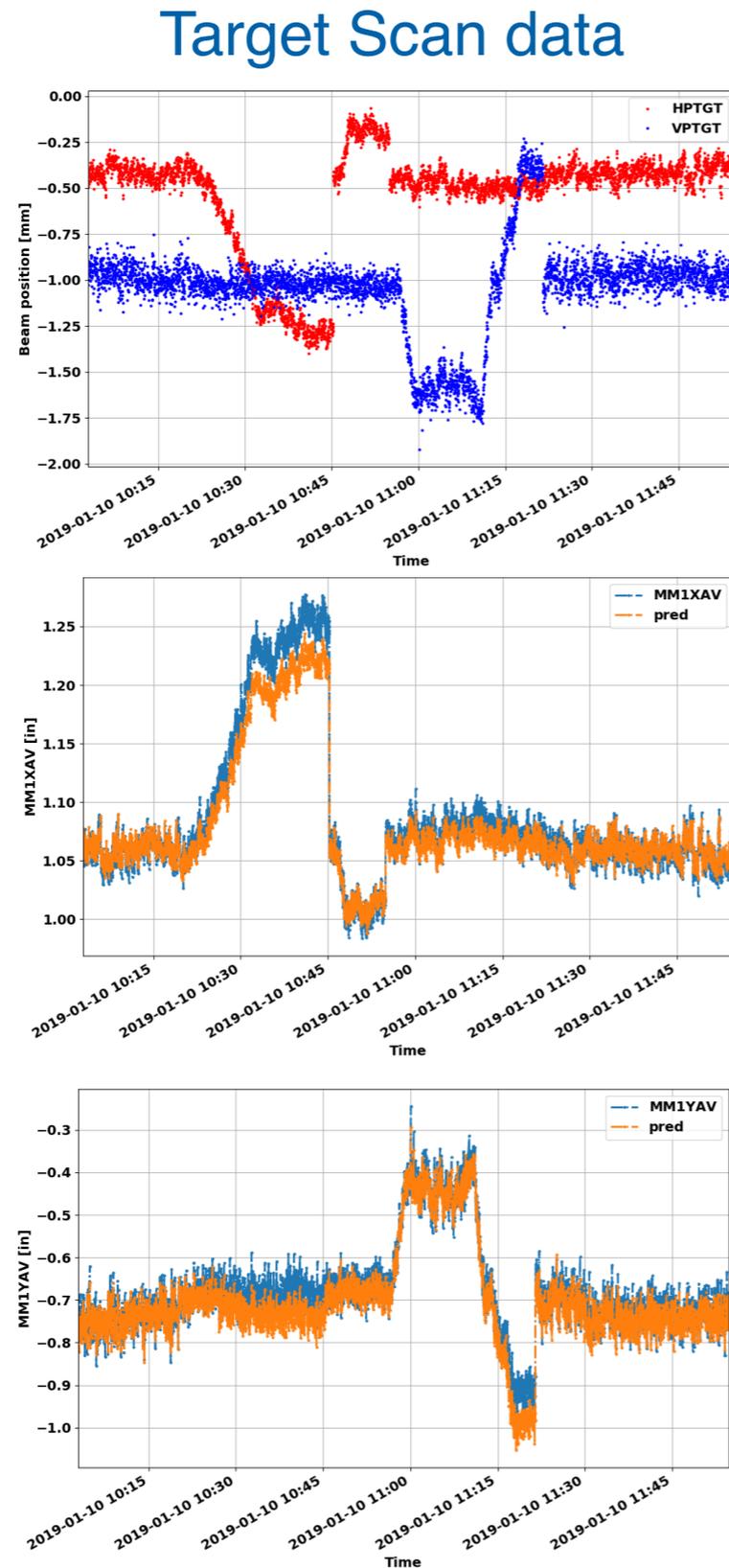
Prediction for muon monitor1 $\langle X \rangle$



MM Centroid Prediction Examples

Example1

Proton beam

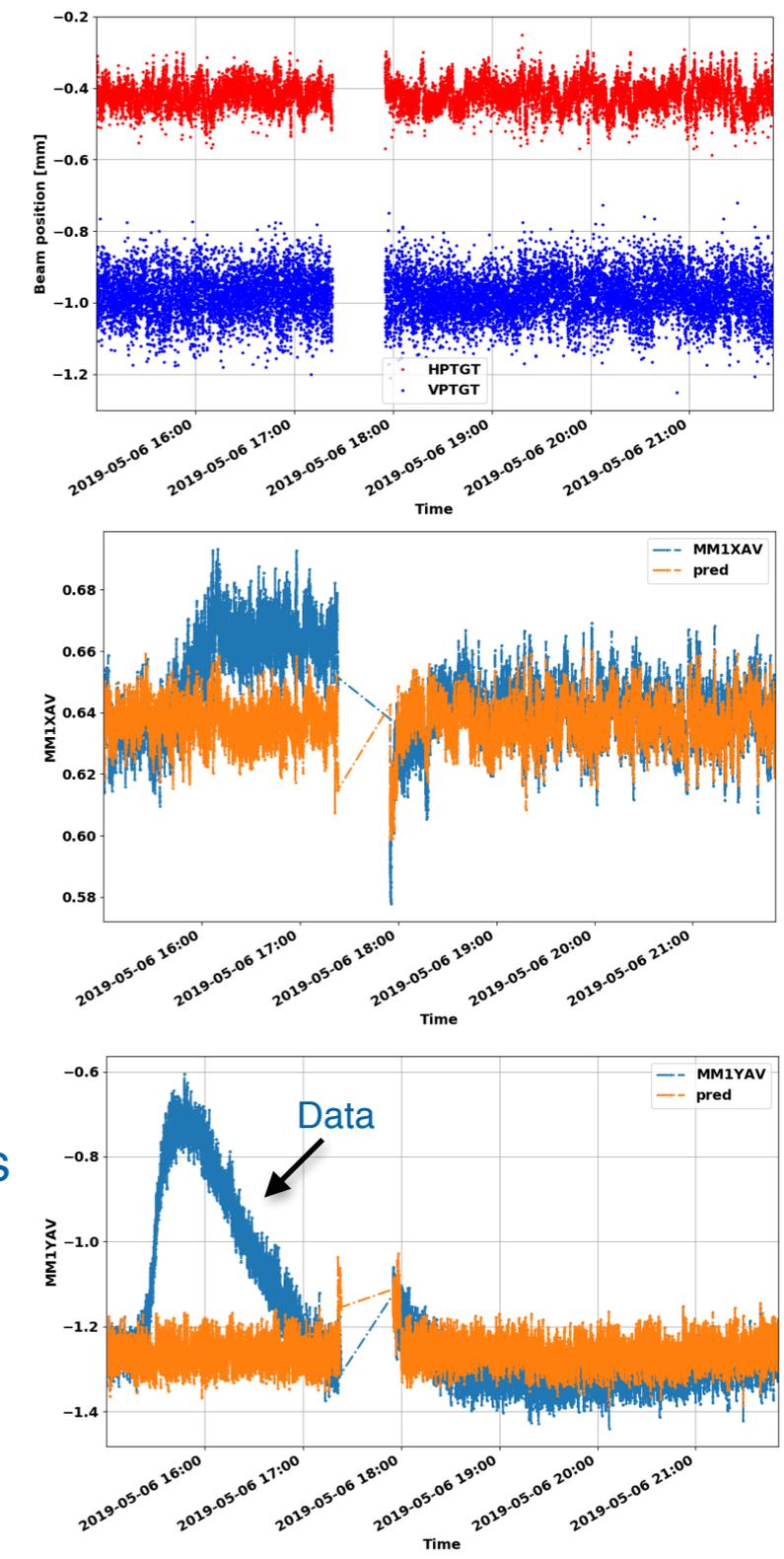


- Model is trained by a randomly selected past data set
- The prediction for the target scan is following the trend as we expected from the muon monitor data

Example2

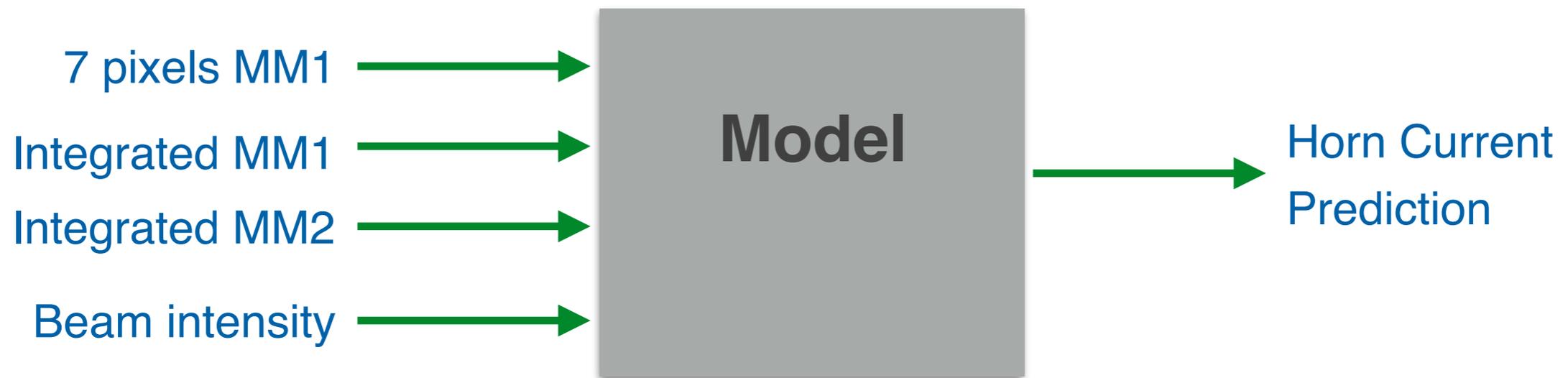
Proton beam

- The data has an unusual blip due to an uncounted parameter in the process of model training
- We are able to identify such events beforehand easily with ML applications



Predicting Horn Current from Muon Monitor Data

MOTIVATION: That would be a very useful tool if we have a model to predict the horn current behaviors by taking account muon monitor signals



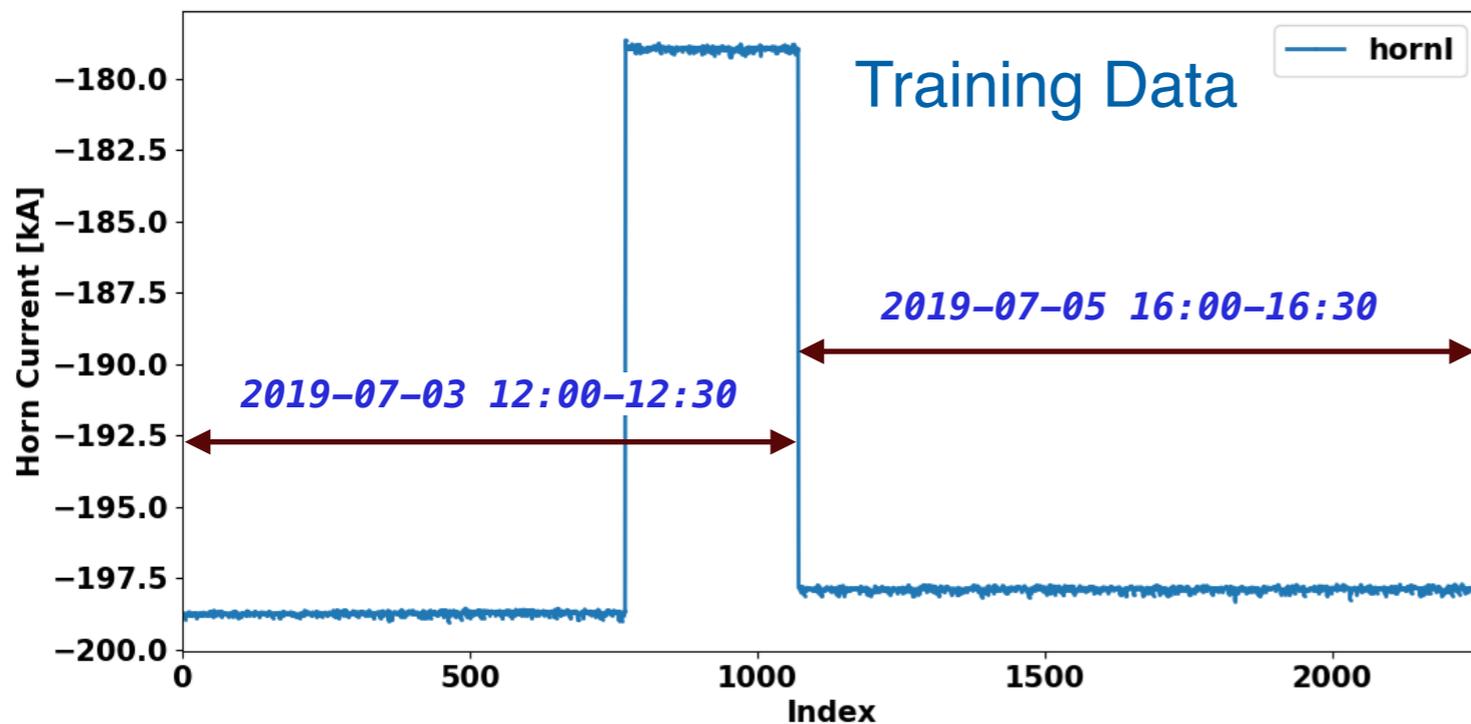
Pixels with Higher Correlation Coefficients

- Studied the correlation between the signals of individual pixel with the horn current variations
- According to the correlation study results, we have selected following highly correlated pixels from muon monitor 1

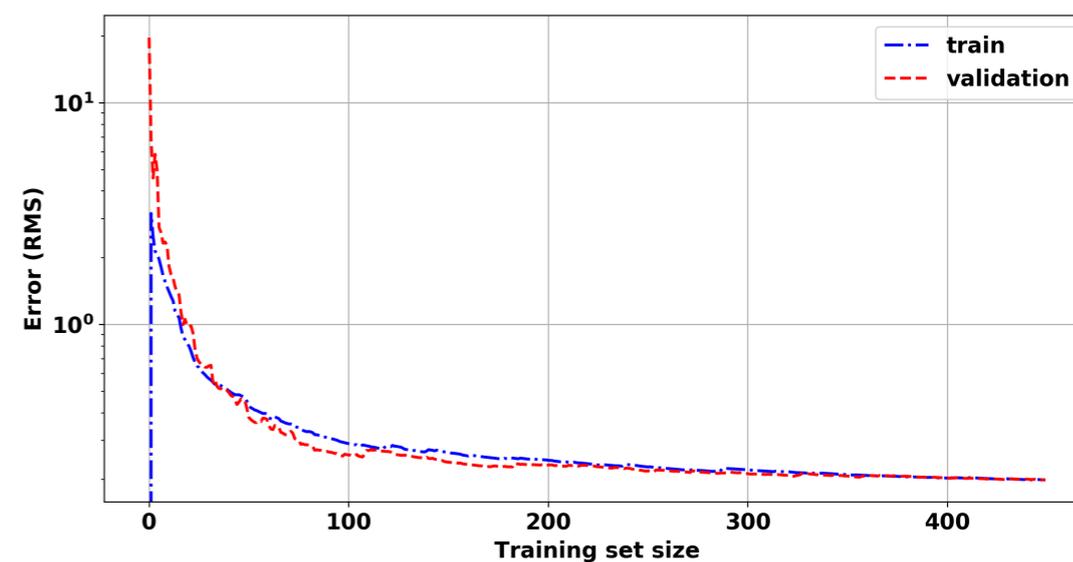
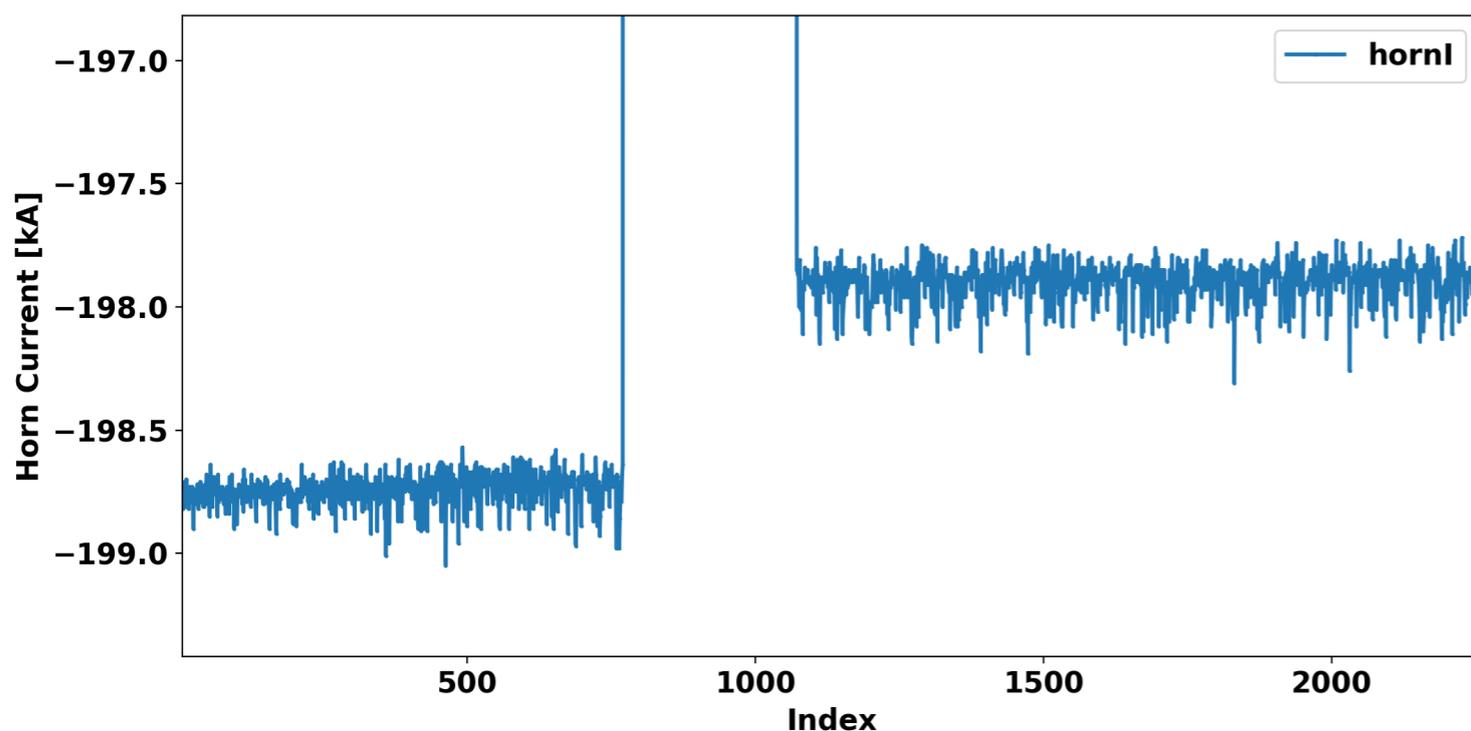
33	42	51	60	69	78	6	15	24
34	43	52	61	70	79	7	16	25
35	44	53	62	71	80	8	17	26
36	45	54	63	72	0	9	18	27
37	46	55	64	73	1	10	19	28
38	47	56	65	74	2	11	20	29
39	48	57	66	75	3	12	21	30
40	49	58	67	76	4	13	22	31
41	50	59	68	77	5	14	23	32

Training the Model

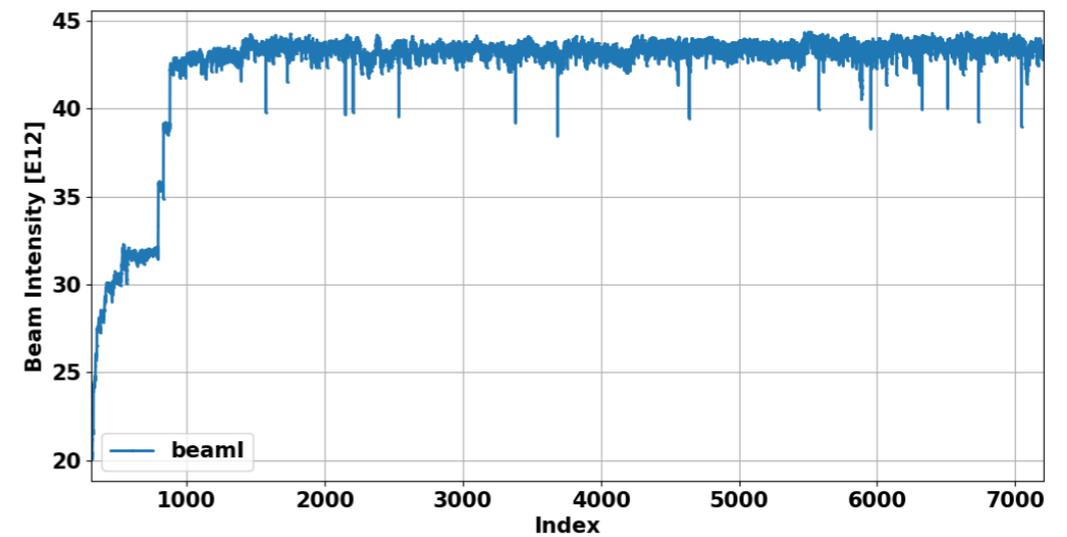
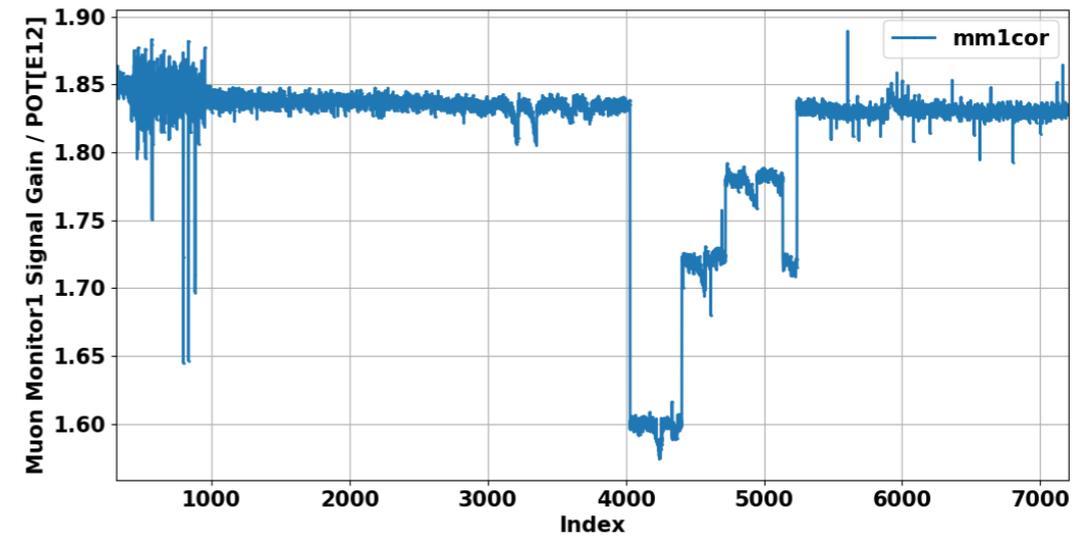
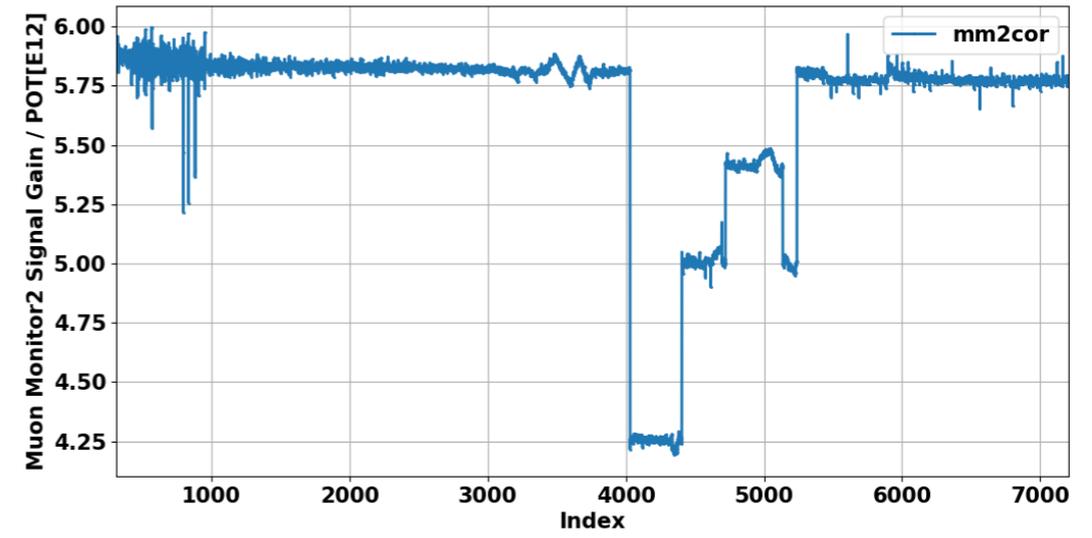
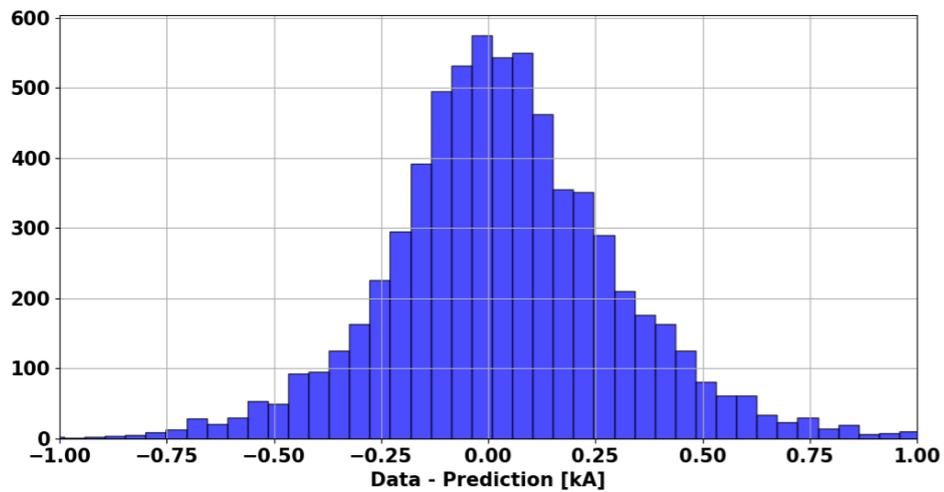
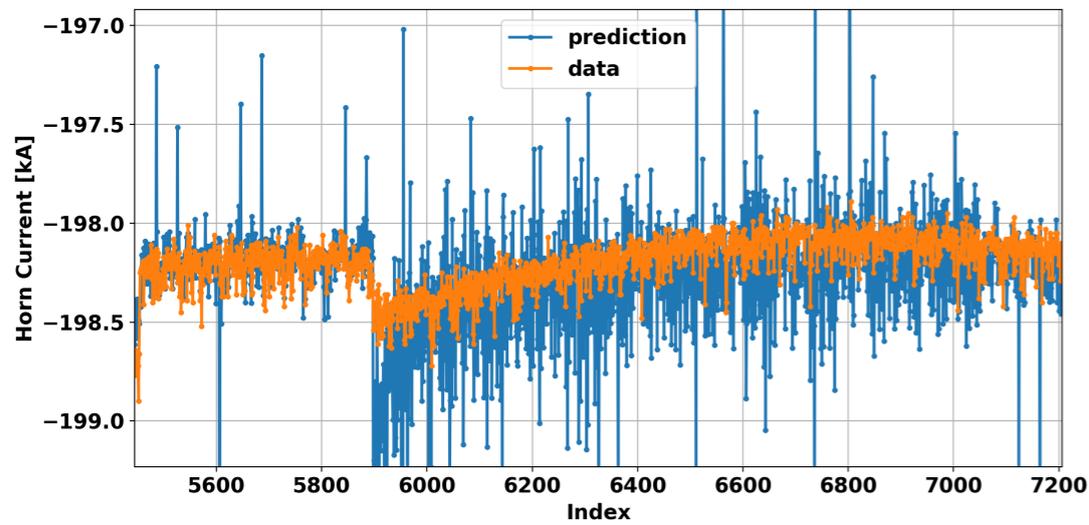
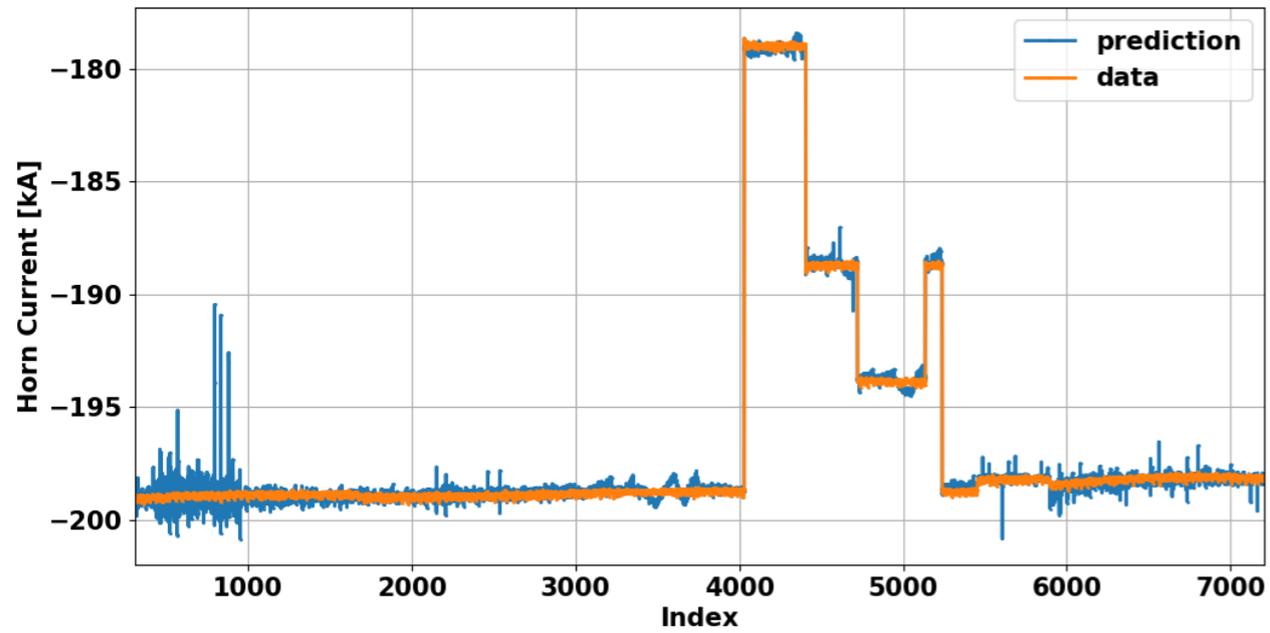
Pred Horn I = $f(\text{MM1PIXELs}, \text{MM1COR}$ and $\text{MM2COR}, \text{beam Intensity})$



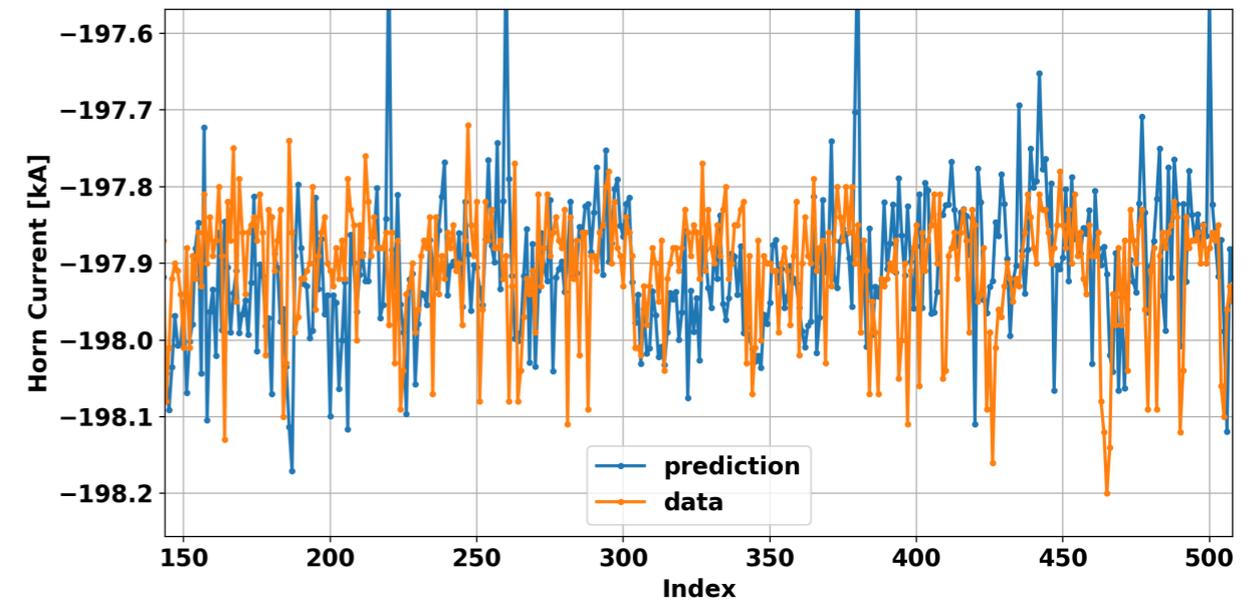
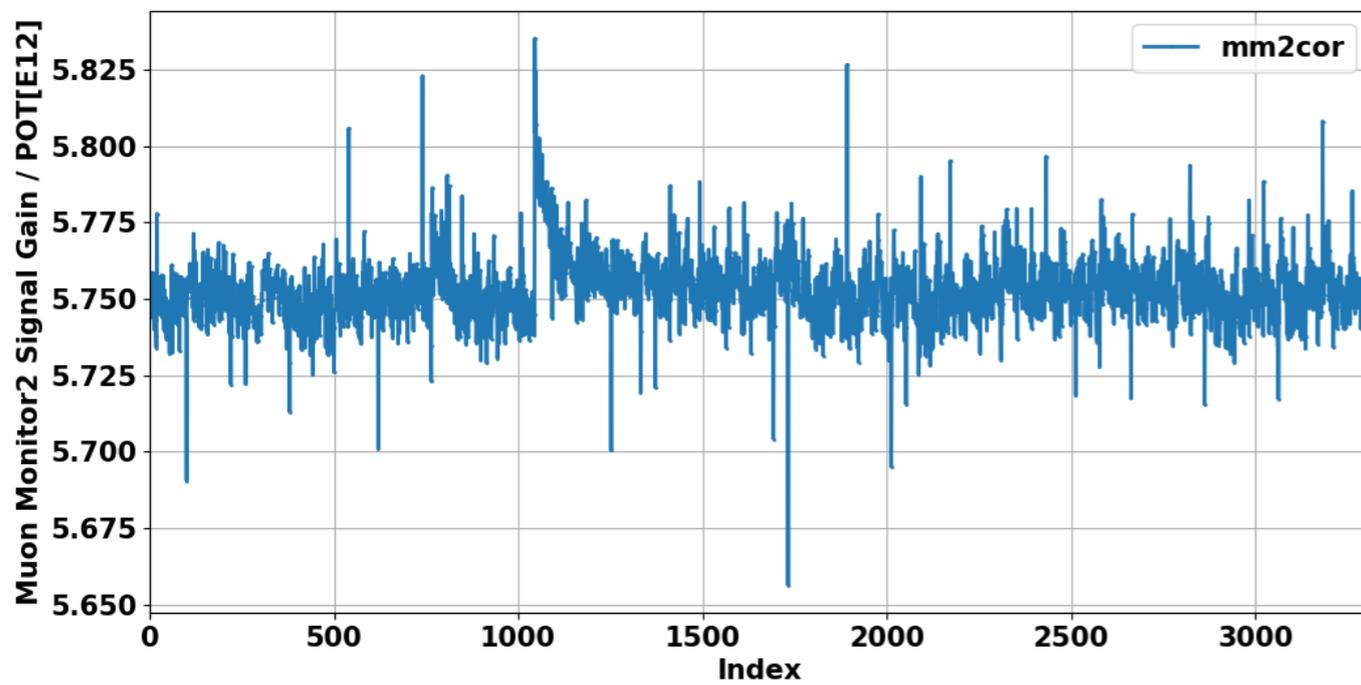
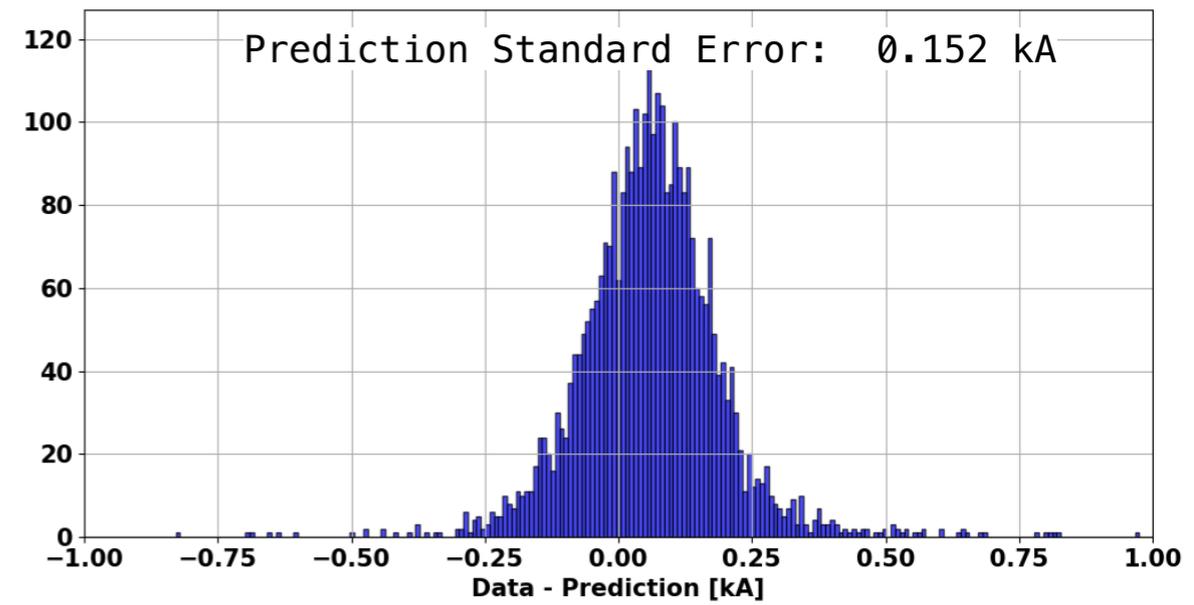
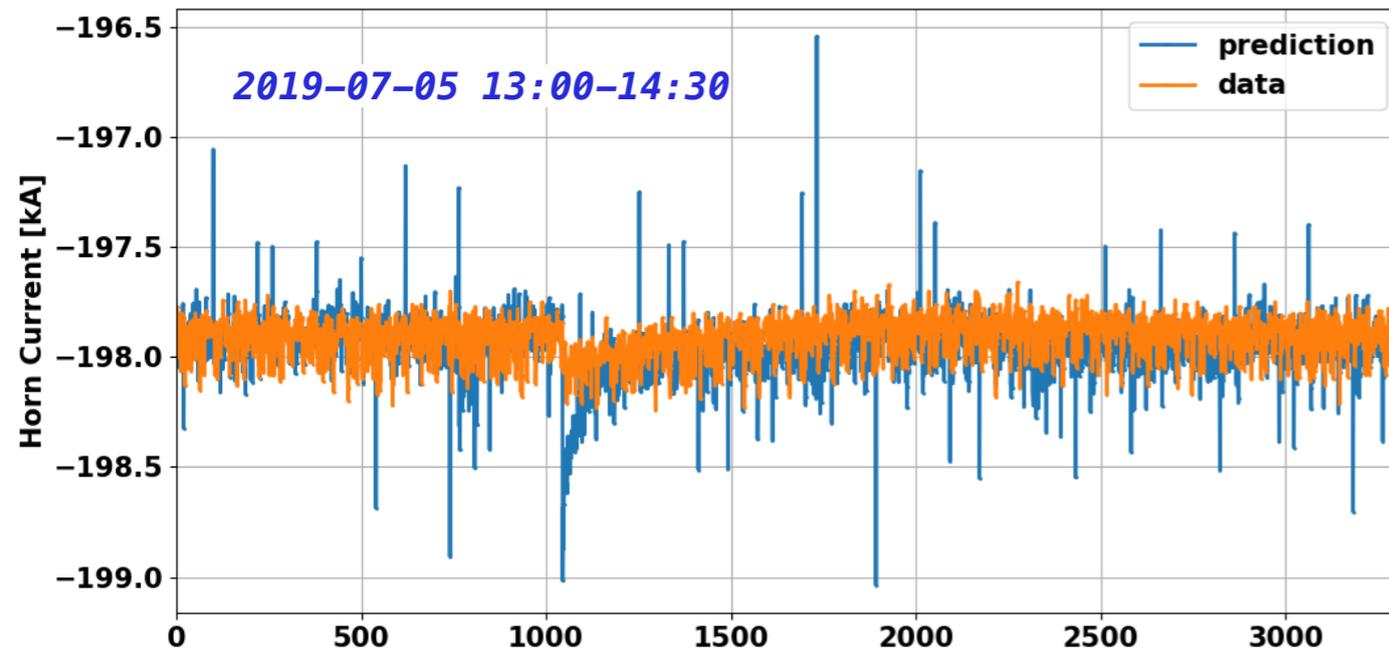
We use 10 input variable to train the model



Predictions



Predictions



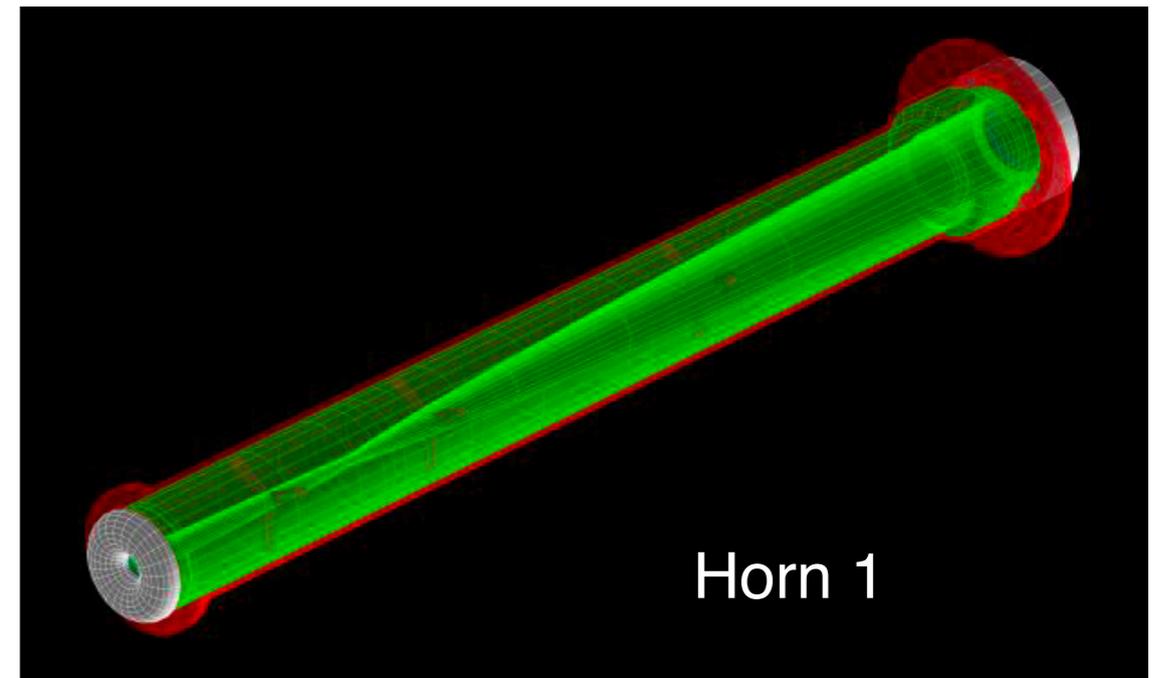
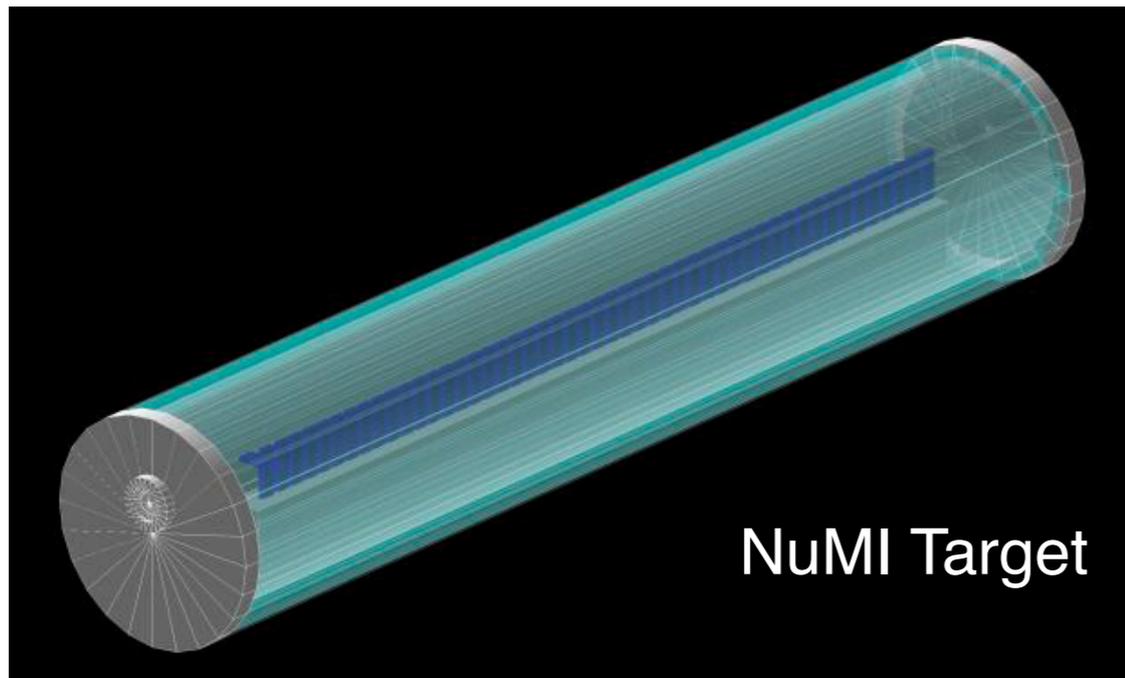
Remarks on ML studies

- **ML model prediction techniques are useful to monitor beam profile changes, beam quality and horn current related issues.**
- **Possible to recover missing data**
- **We have a capability to identify any accidental events**
- **This may be useful tool for the beam auto-tune and horn current tuning**

Next

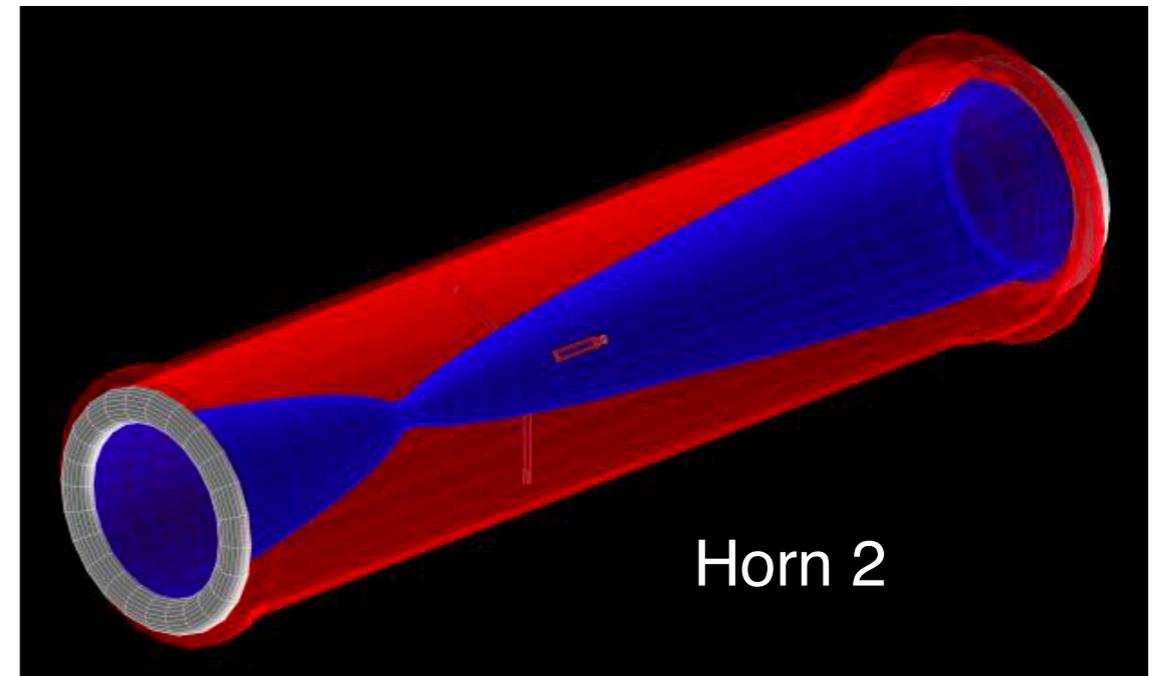
1. Introduction to the muon monitors
 1. *Introduction*
 2. *Things to do with muon monitor data*
2. Beam & Horn current scans
3. Machine Learning Applications
4. **Simulation Efforts and Hardware updates**
5. Summary

Simulation Studies



Main simulation tools:

- G4NuMI: we use this for Muon Monitor simulations
- G4beamline: use for hadron monitor simulation, quick tasks such as producing pion trajectories
- Both codes are based on Geant4 platform



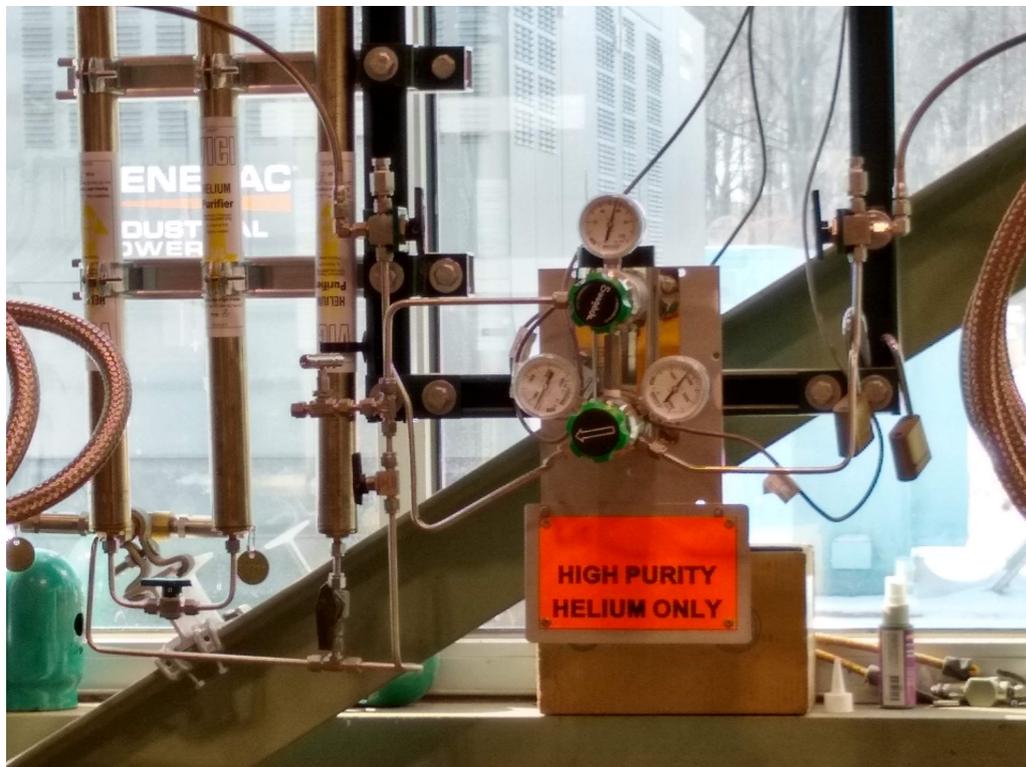
Future Hardware Updates



He Gas Bottle Farm



Gas lines behind the rack



Gas Regulator with 3-way auto-switch

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

Summary

- **According to the studies, we have learned the importance of the muon monitors in the NuMI beamline**
- **We learned the unique features of each muon monitors in responding to the beam and horn current changes**
- **We will implement machine learning tools to monitor the beam and horn current related issues**
- **Planing to reducing neutrino flux uncertainty which is related to the beam parameters and horn current**
- **We have a good progress in simulation studies**
- **Hardware upgrades are on going**

Muon Monitor Working Team

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- Tyler Rehak, Drexel University

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Muon Monitor is a very useful tool to make the communication bridge between accelerator physics and neutrino experiments

Thank You !!!

Backup

Horn Current Scan: MM3

2019-Dec-12

2019-Jul-03

