Updates and Lessons Learned from NuMI Beamline at Fermilab

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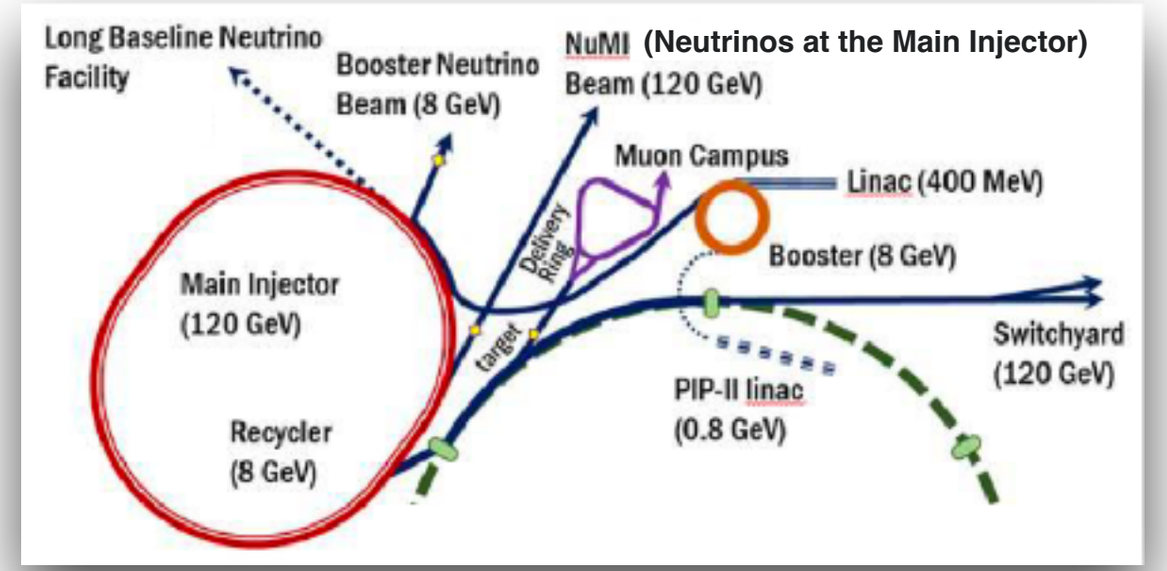
NuFACT 2024

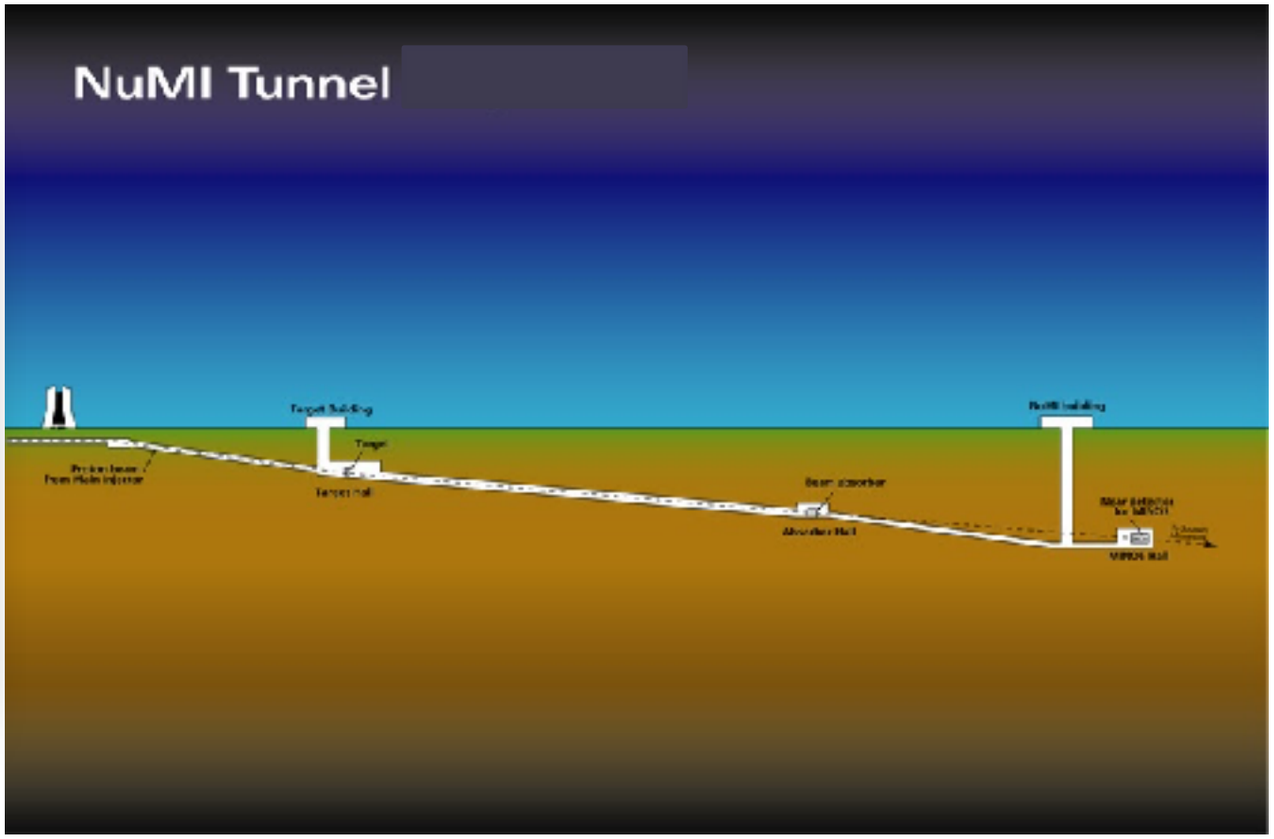
Argonne National Laboratory

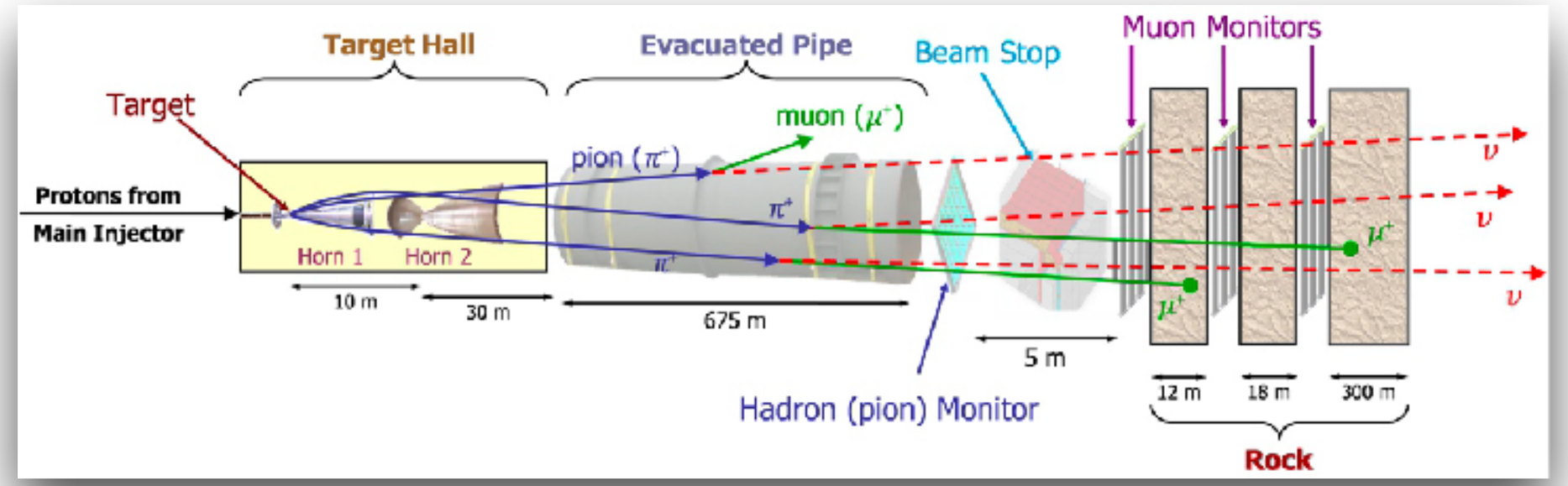
Outline

- Overview of NuMI beamline
- Beamline updates
  - Target / horn / baffle
- Testing 1 MW challange
- Future targets and horns
- Future NuMI beam operation plans

NuMI (Neutrinos at the Main Injector) Beamline







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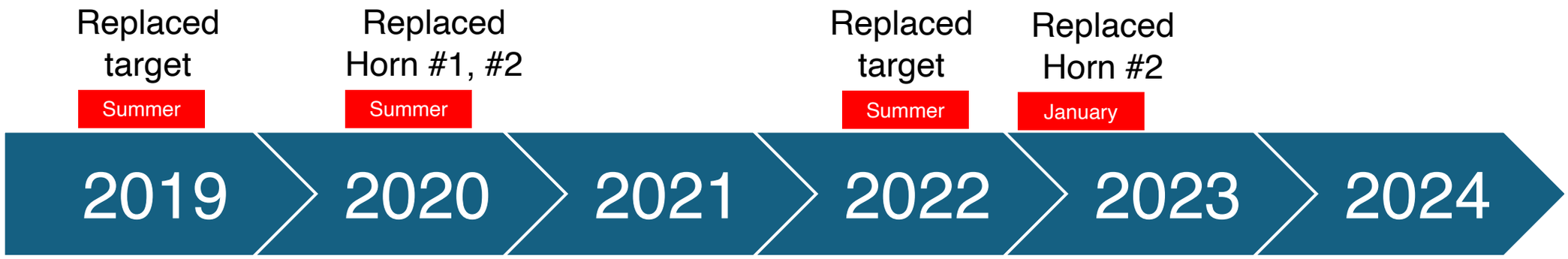
Major Upgrades for 1 MW Challenges

Beamline updates for 1 MW operations



1-MW NuMI target

1MW horn 1

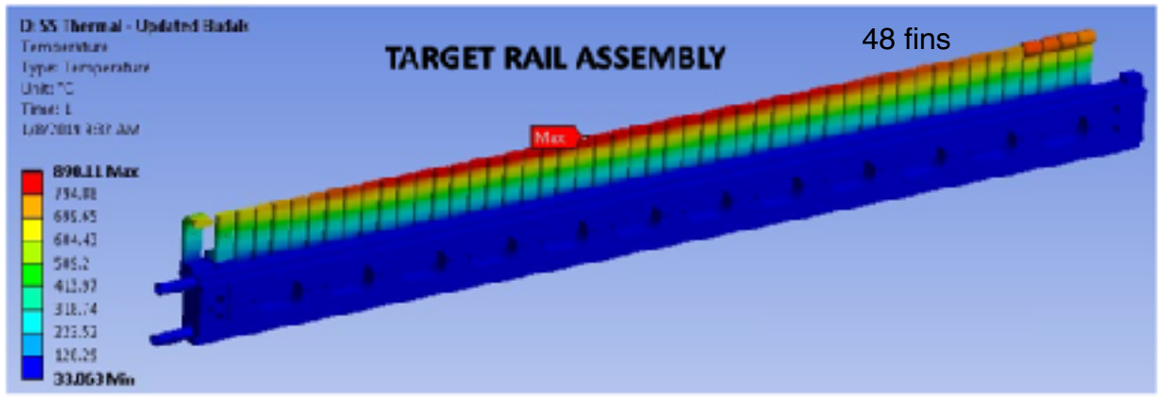
- 2019 summer: Replaced the 700 kW target with 1 MW target.
- 2020 summer: Updated horn 1 and 2 for 1 MW operations.

- 2022 summer: Replaced the 1 MW target after completing the service duration.
- 2023 January: Replaced the horn 2 after having a stripline failure.

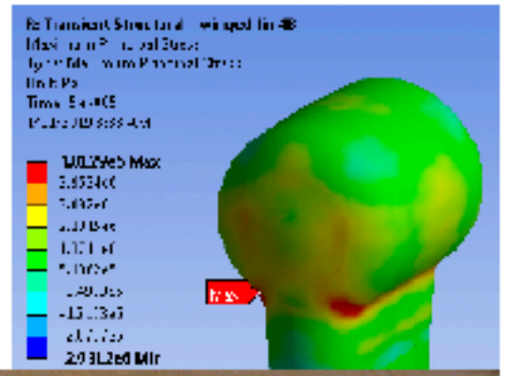
1MW horn 2

Target updates for 1 MW beam

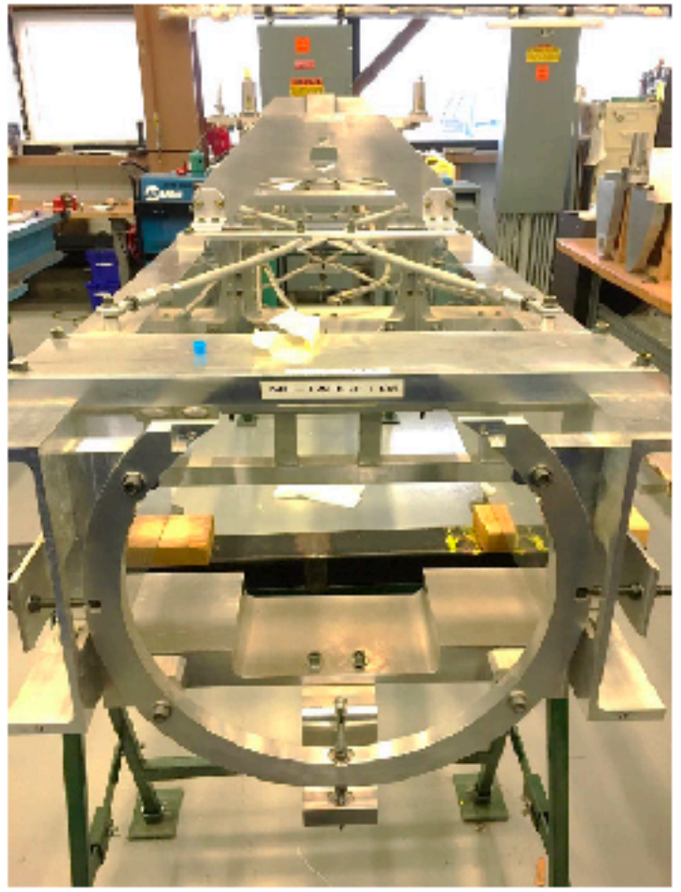
Simulated temperature distribution

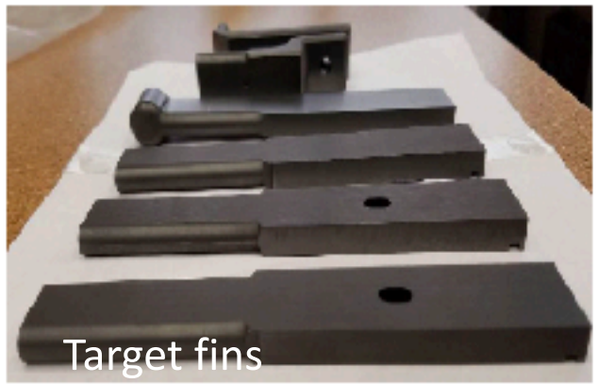


Principal stress of a fin at an accidental condition

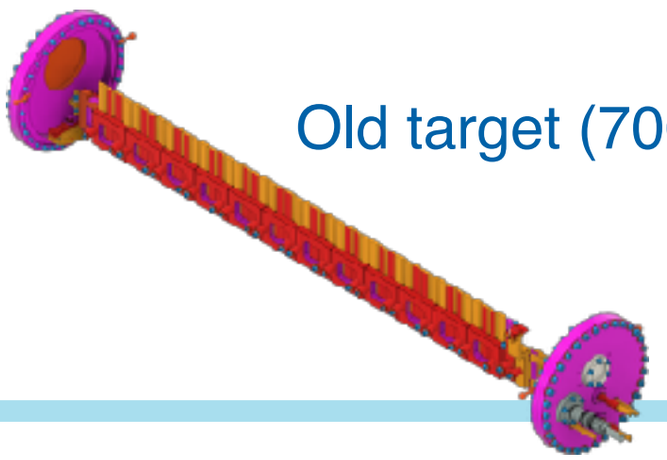


Target chase frame





Old target (700 kW)



	Old (700 kW)	*New (1 MW)*
Width (mm)	*7.4*	*9.0*
Height (cm)	*14.30*	*15.53*
Segment length	*2.5*	*2.5*

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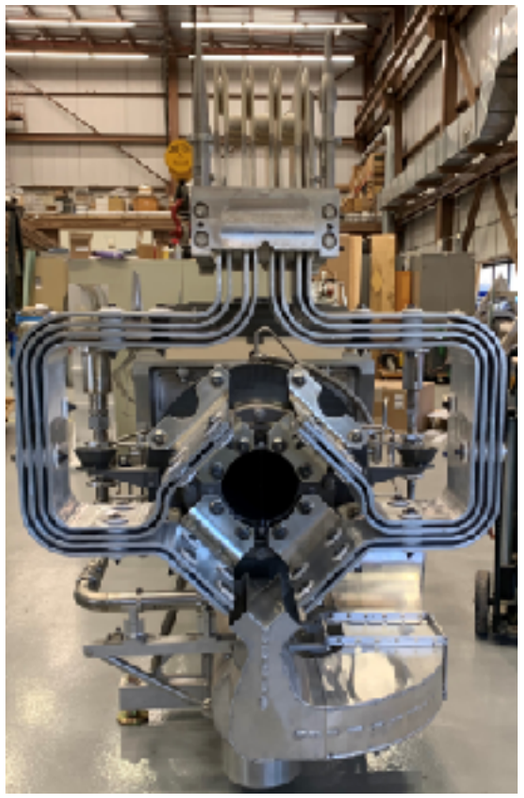
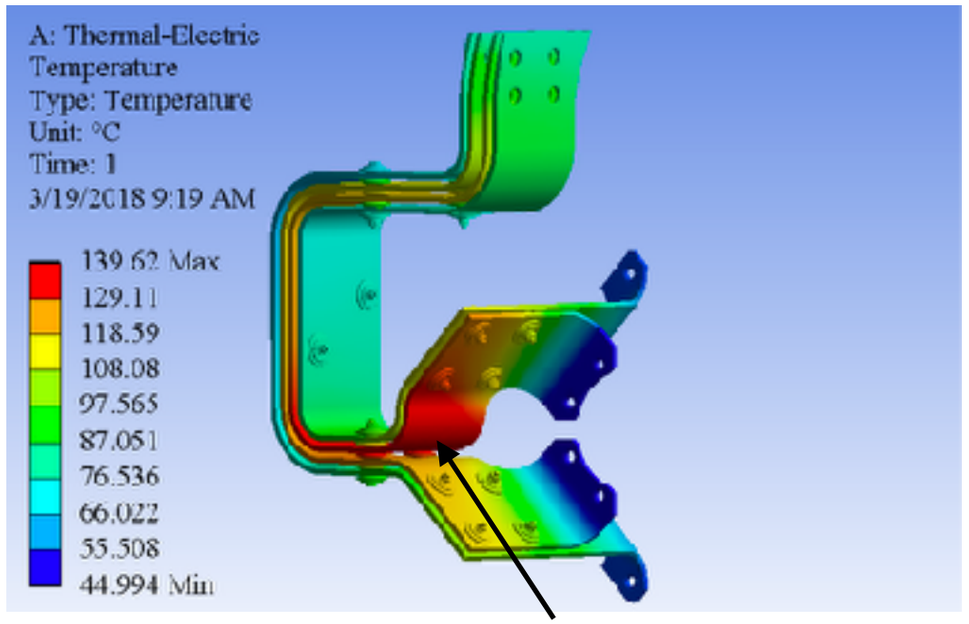
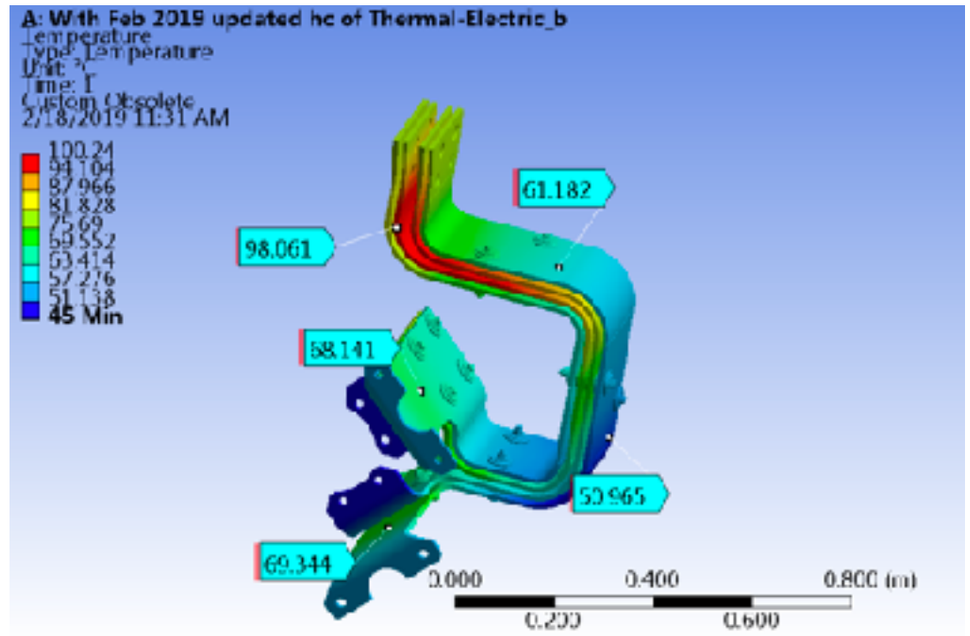
Horn updates for 1 MW beam



Pre-air diverter



Post-air diverter



Max.Temp Location

The 1 MW horn system has been constructed with powerful cooling capabilities. The stripling is cooled by an air diverter.

- **The temperature of the Max.Temp location has been reduced by ~70 C.**
- **The overall stripline temperature has been reduced significantly after adding the air diverter.**

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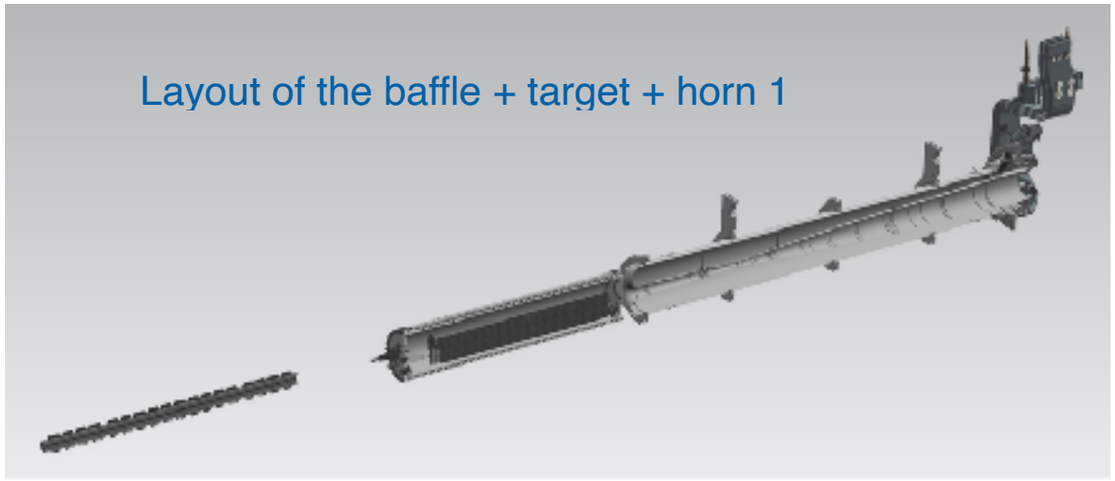
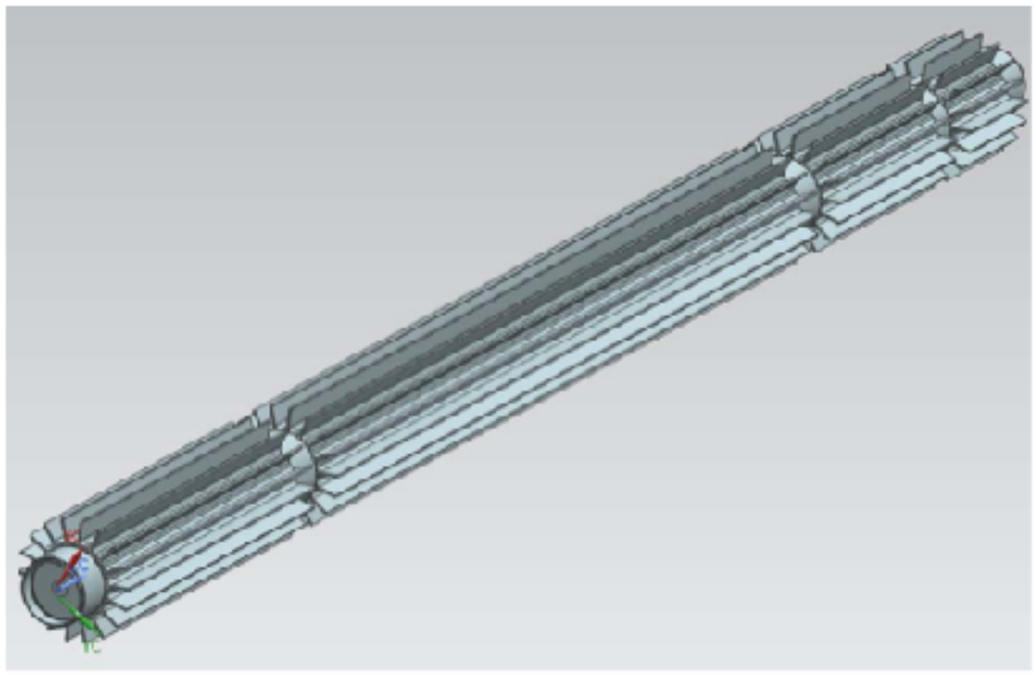
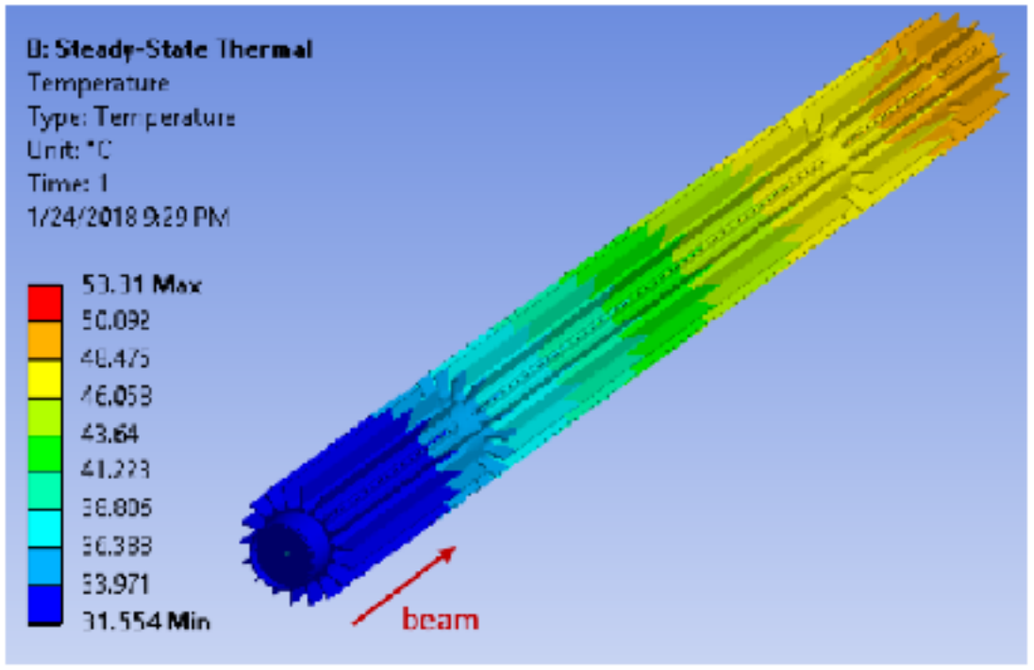
Baffle updates for 1 MW beam







- **Enlarged the baffle hole diameter from 13 mm to 15 mm for 1 MW operations.**
- **Based on the thermal analysis, the peak Graphite and Aluminum temperature is ~50 °C for normal operation.**

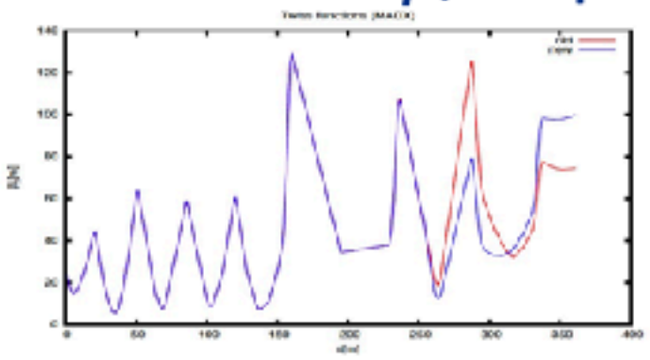
Beam spot size optimization

Quad current list (unit Amp)

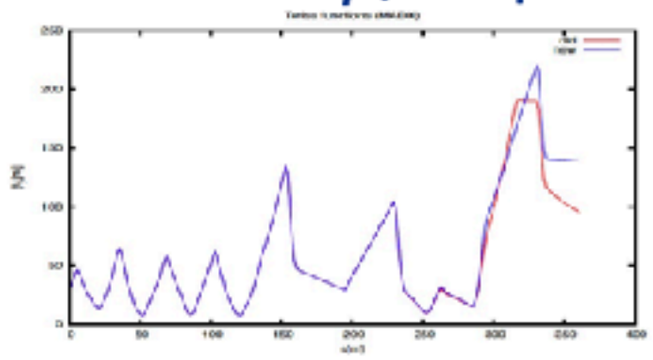
	Present	Option 1	Option 2
QF109	61.194	61.194	61.194
QD110	-25.340	-25.340	-25.340
QD111	-325.491	-325.490	-325.491
QF112	342.141	342.140	342.141
QD113	-341.895	-342.060	-338.100
QF114	326.580	326.080	323.071
QF115	14.092	25.340	43.800
QD116	-63.165	-71.658	-75.698
QF117	50.513	51.199	57.202
QD118	-36.901	-32.500	-42.391
QF119	-6.084	-23.190	-4.040
QD120	-156.016	-170.700	-196.339
QF121	35.143	44.299	46.946

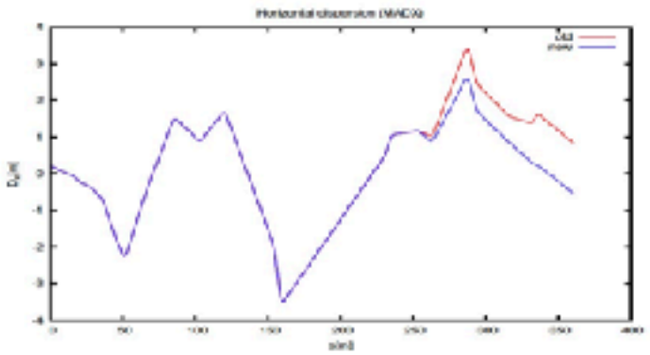
QF: Quadrupole Focusing in horizontal plane
QD: Quadrupole Defocusing in horizontal plane
Number: Location (bigger is closer to the NuMI target)

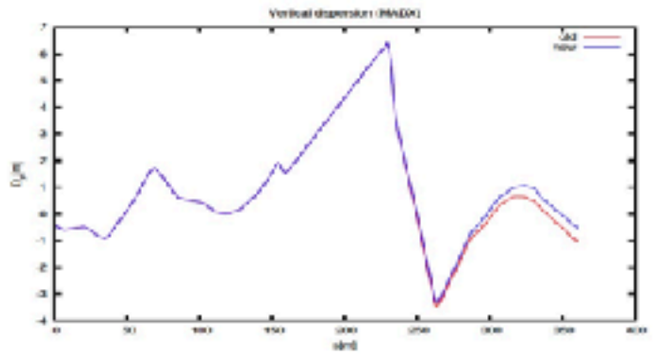
Horizontal β, Disp.



Vertical β, Disp.







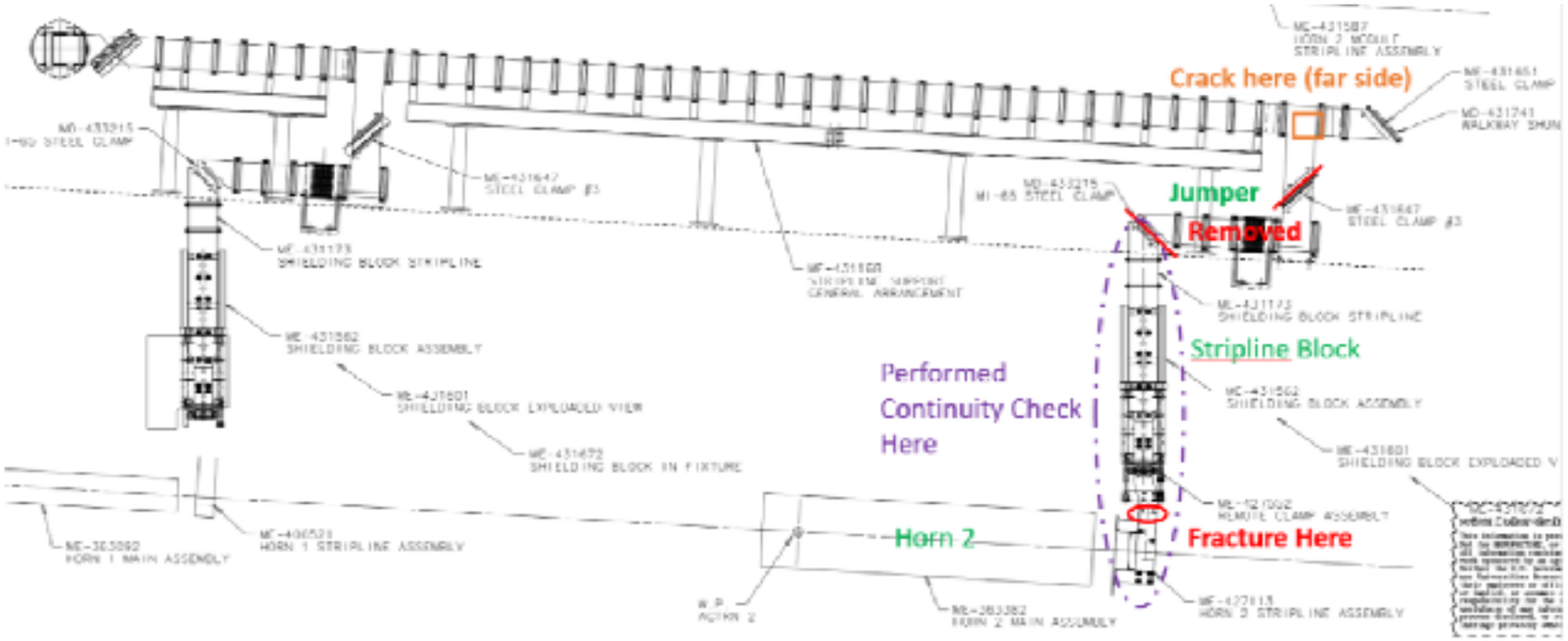
Red: Present
Blue: Option2

- Option 1 is lower current strength but dispersion at the target is non-zero
- Option 2 is higher current but dispersion at the target is close to zero

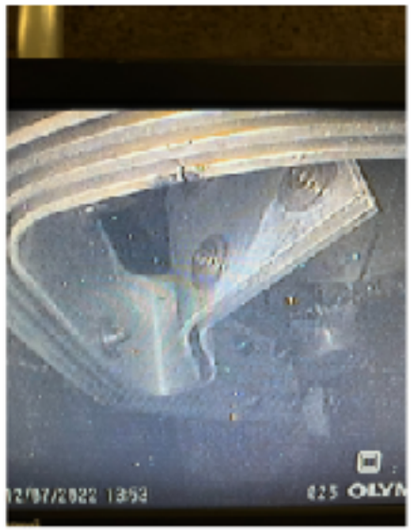
Beam spot size is optimized archiving the minimal dispersion at the target

Lessons learned

Horn 2 failure (12-03-2022)



A crack was found on the walkway stripline near Horn 2



A fracture was located on conductor #4

- Found a crack facing out from the target pile on the outermost stripline at the very end of the right above the Horn 2 penetration.
- Found a fracture on one of the localized stripline conductors mounted on Horn 2.

- This is not an issue with the stripline design
- Uneven load on the bend stripline resulted metal fatigue failure
- Found a small defect that may have contributed for this issue

Sources of Baffle Temperature Increments

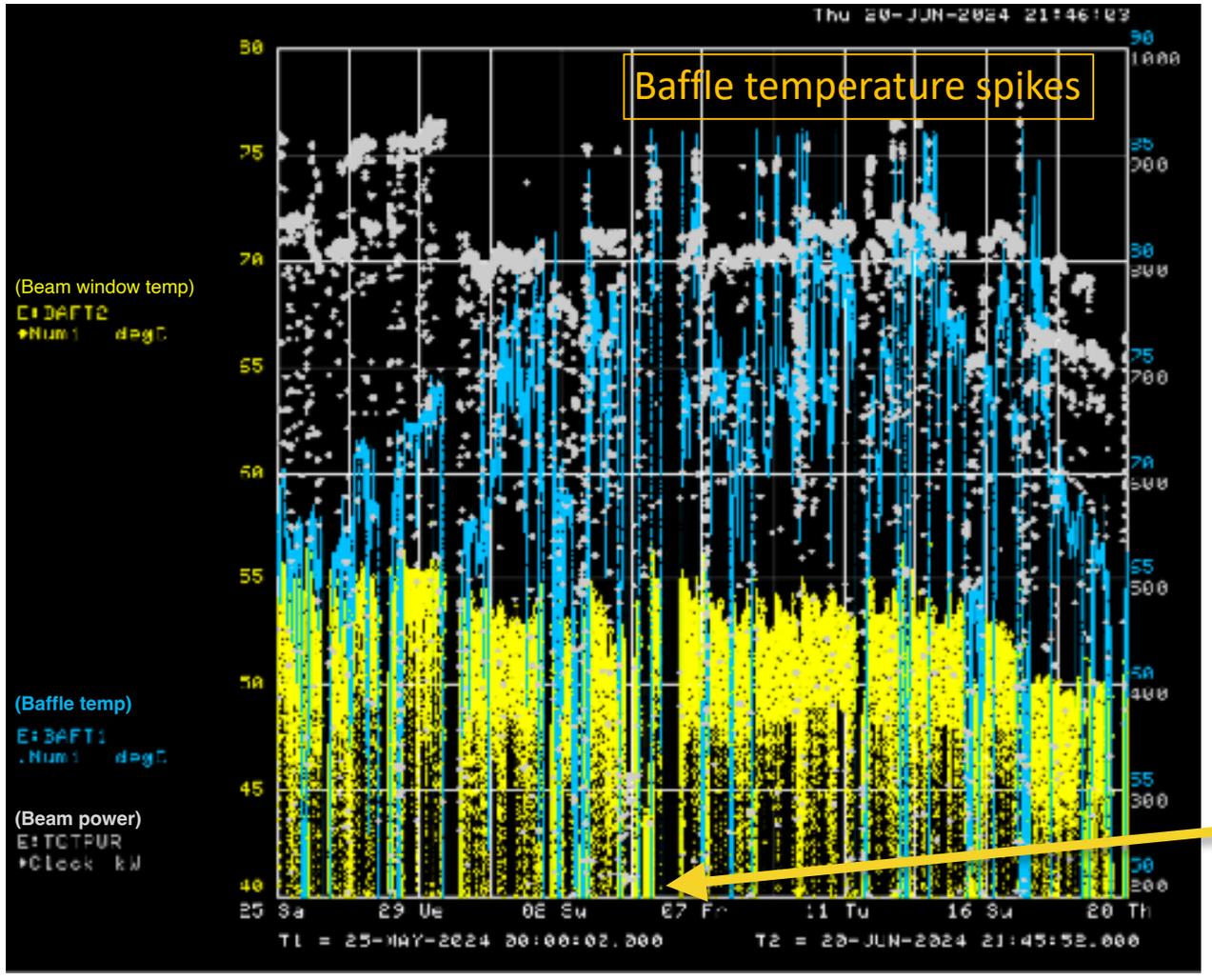
- **The baffle temperature goes up when the beam scrapes through the baffle.**
- **Back scattered particles from the target also contribute for the baffle temperature increments**

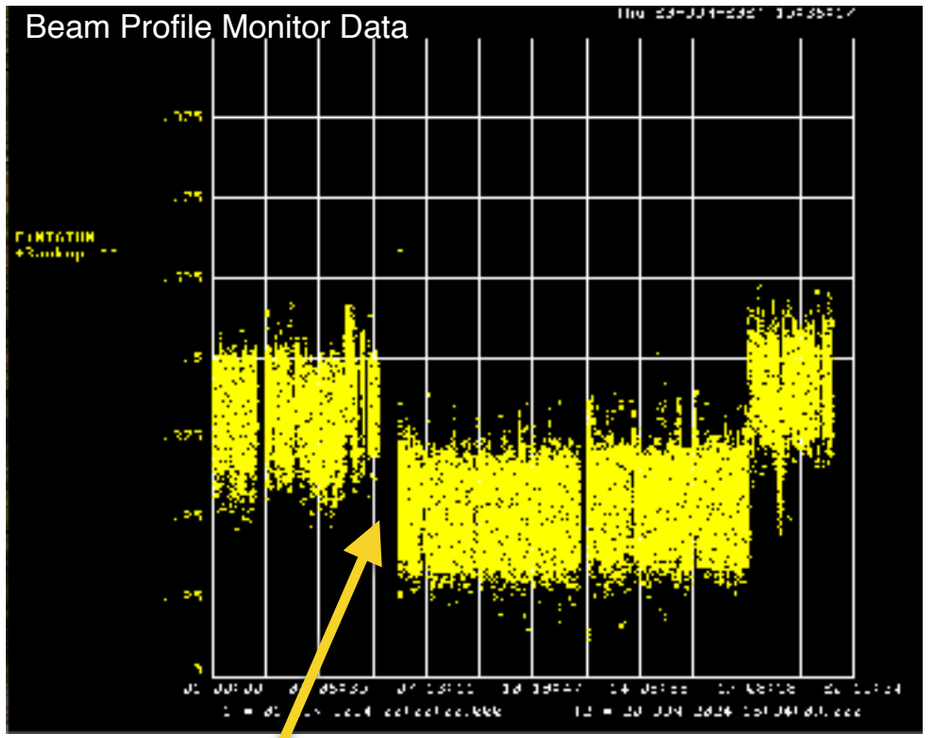
A Naive Estimation of the Fraction of Beam Scraping at the Baffle

- **Based on the baffle temperature increment of 40 C degrees for 800 kW beam, the estimated fraction of the protons scrape through the baffle is ~ 4.5 E-4.**
- **This is below the beam loss limit ~1.0 E-3.**

Baffle Temperature Issues

- Baffle temperature became unstable after June 1st.
- Unstable temperatures pulled the beam permit limit.
- Noticed a beam position shift after replacing the digitizer card.





Replaced the Echotek card on BPM:TGT (Jun 6th)

Studied the optimal beam position to minimize the baffle temperature.

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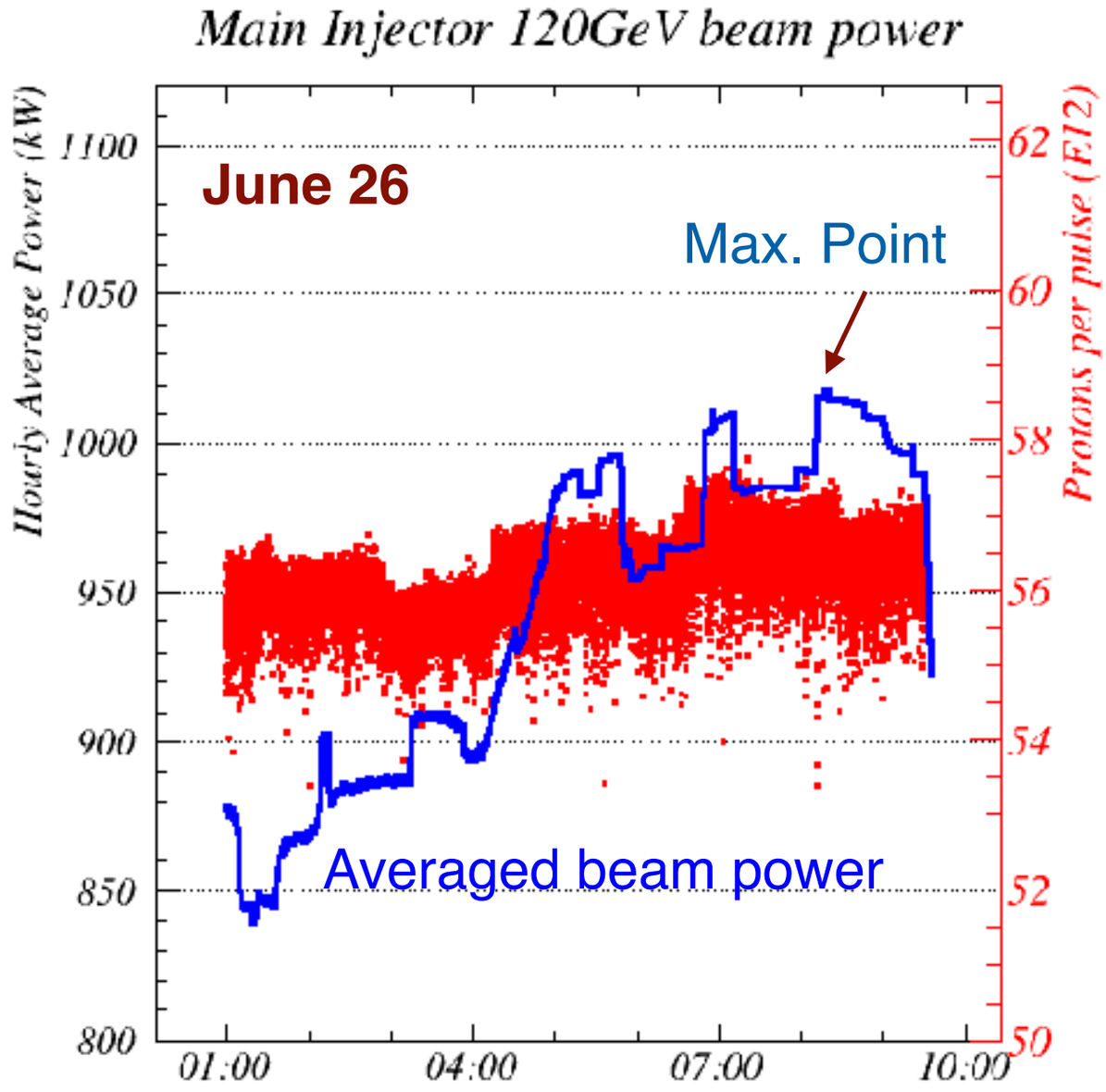
Tuning the MI beam for 1 MW challenge

- Tuned the MI chromaticity to achieve optimal beam spot size at the baffle for 1 MW challenge.
- Ramped up the beam power step by step.
- 04:12 to 06:53 – Solidified MW capabilities
  - Occasional RF trips and LINAC downtime
- 06:53:20 – Achieved averaged 1 MW challenge
- 08:21:02 – Achieved one full hour of 1 MW beam with ZERO trips



(Credit to Adam Schreckenberger)

Finally we recorded the averaged highest beam power 1.018 MW !!

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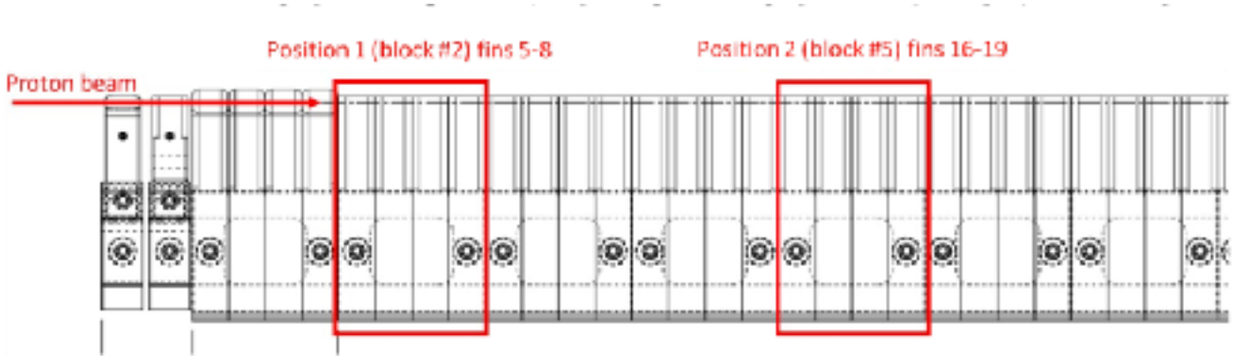
Future Plans

Future Targets and Spare Horns

- **We are currently finishing new 1 MW target to support LBNF targetry.**



- **Testing a new type of graphite.**
- **This provides a better thermal conductivity.**
- **Planning to install this new target in FY25.**
- **Finishing weld of spare horn 1.**
- **Will start welding NuMI spare horn 2 in early 2025.**

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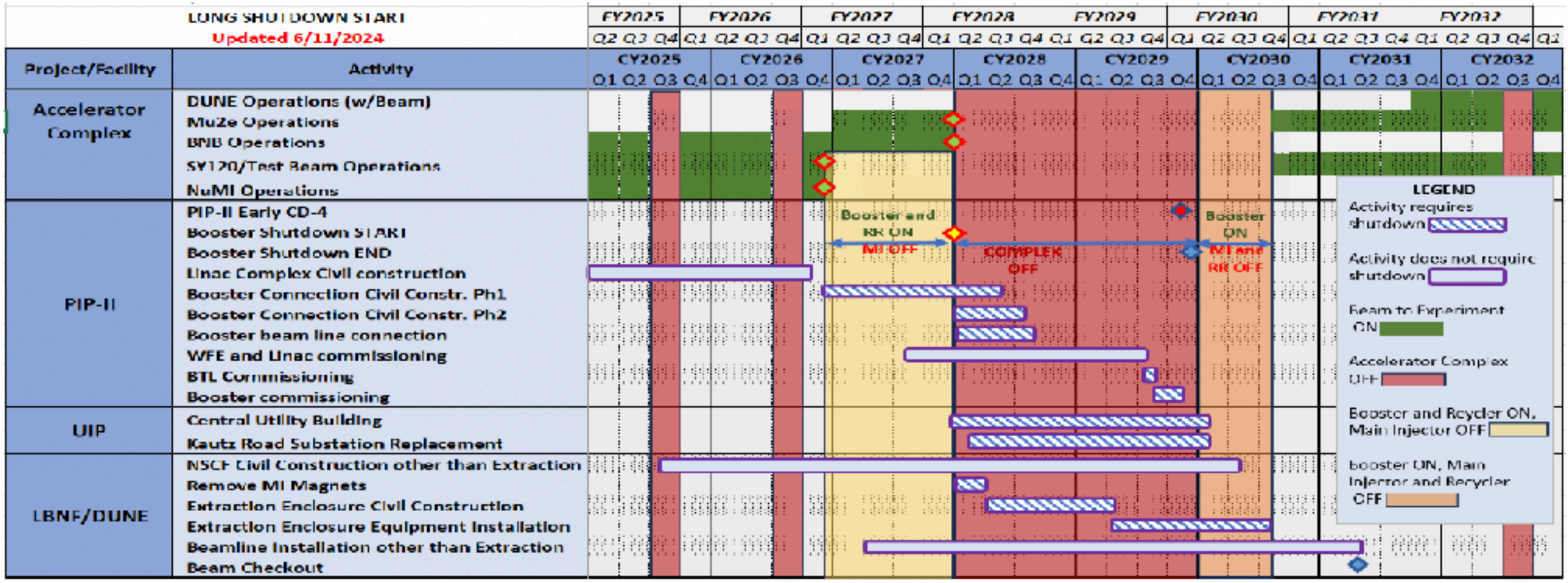
Future Accelerator Operations Plan



Planning to run the NuMI beam operations until the end of CY 2026.

Note: More details about the operation plan will be presented by Bob Zwaska

Fermilab accelerator plans and schedule — *Robert Zwaska*

APS- Building 402, Argonne National Laboratory — 08:30 - 09:00

Summary

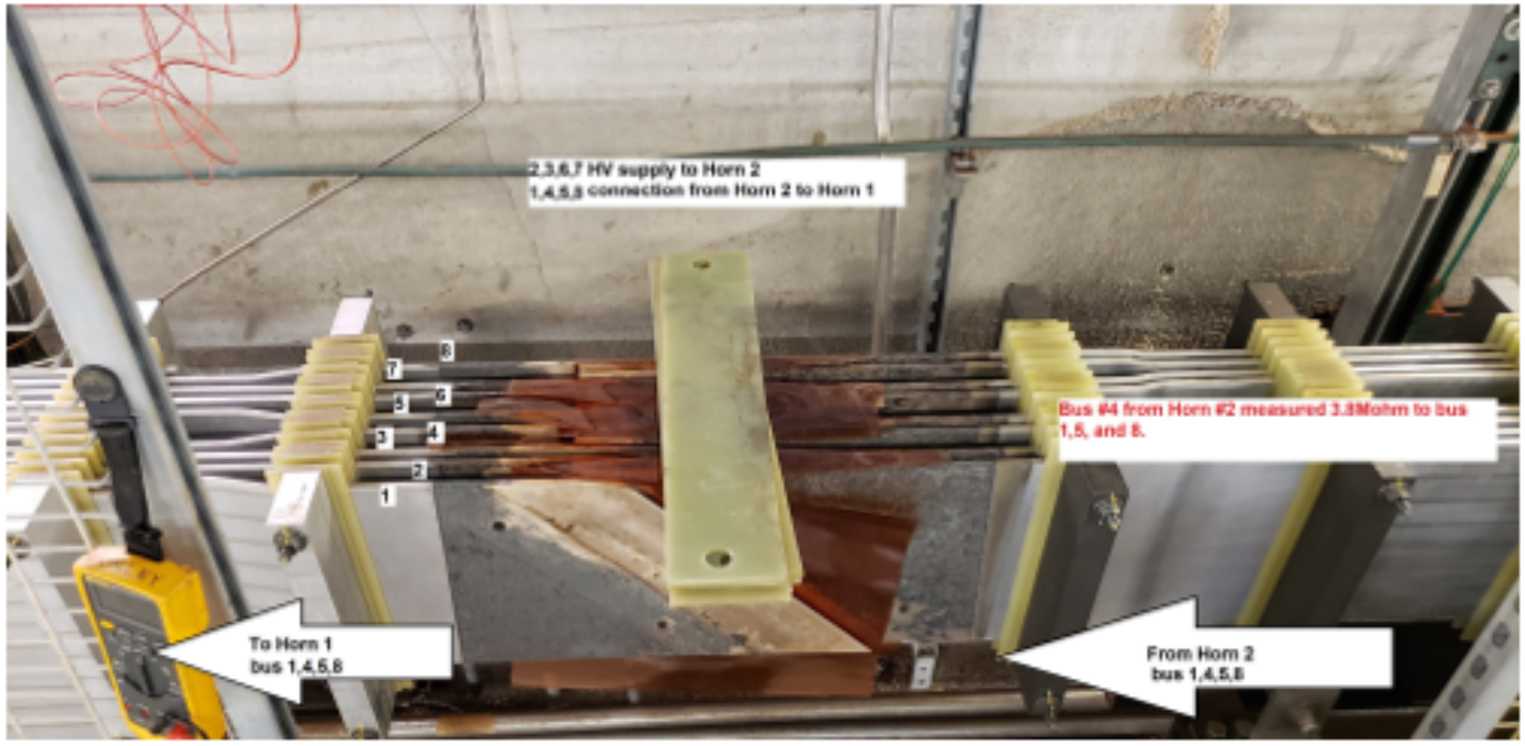
- Updated the target-baffle and horn system to achieve 1 MW operations.
- Optimized the beam spot size.
- Learned lessons from Baffle temperature issue and horn failures.
- Demonstrated the 1 MW challenge capability.
- Will test a new graphite composition to support the LBNF targetry studies.
- Preparing spare horns for future beam operations.
- Planning to run the NuMI beam until CY 2026.

Thanks!

Horn details

	Horn 1	Horn 2
Horn shape	Double Parabolic	Double Parabolic
Construction	Nickel plated aluminum inner conductor Anodized aluminum outer conductor	Nickel plated aluminum inner conductor Anodized aluminum outer conductor
Minimum aperture field-free neck	9 mm radius	3.9 cm radius
Inner conductor thickness	2 mm (min) – 4.5 mm (max at neck)	3 mm (min) - 5 mm (max)
Outer conductor	11.75 inch I.D. 13.75 inch O.D.	29.134 inch I.D. 31.134 inch O.D.
Horn Length	300 cm focus region, 132 inches overall	300 cm focus region, 143 inches overall
Current	200 kA	200 kA
Motion control	±1 cm H x ±1 cm V each end (motor drive)	None
Horn cooling	RAW spray, 30 gal/min	RAW spray, 30 gal/min

A crack was found on the walkway stripline near Horn 2



-Nick Gurly 12/4/22

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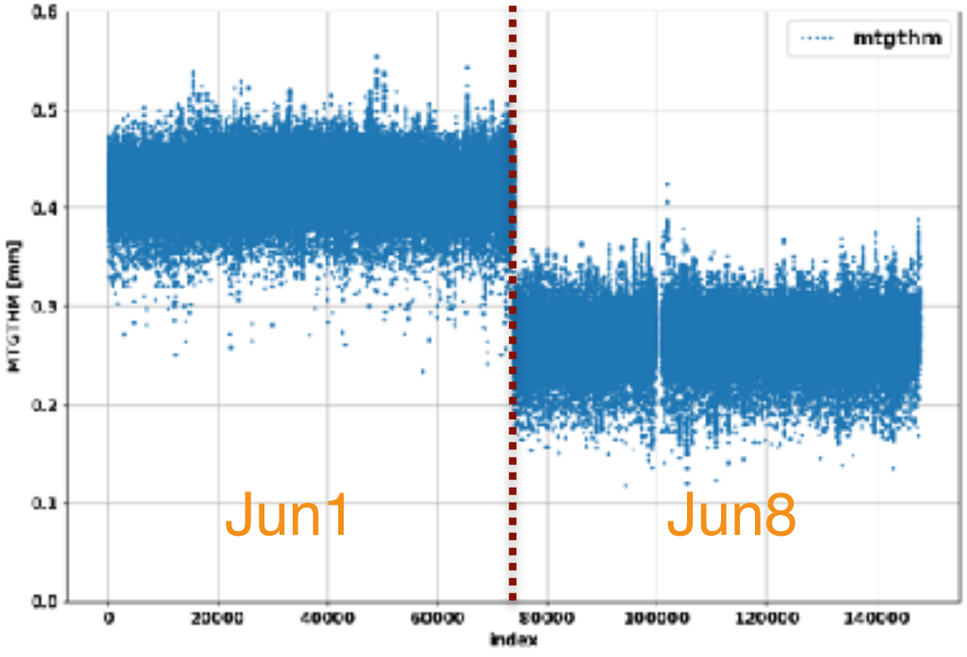
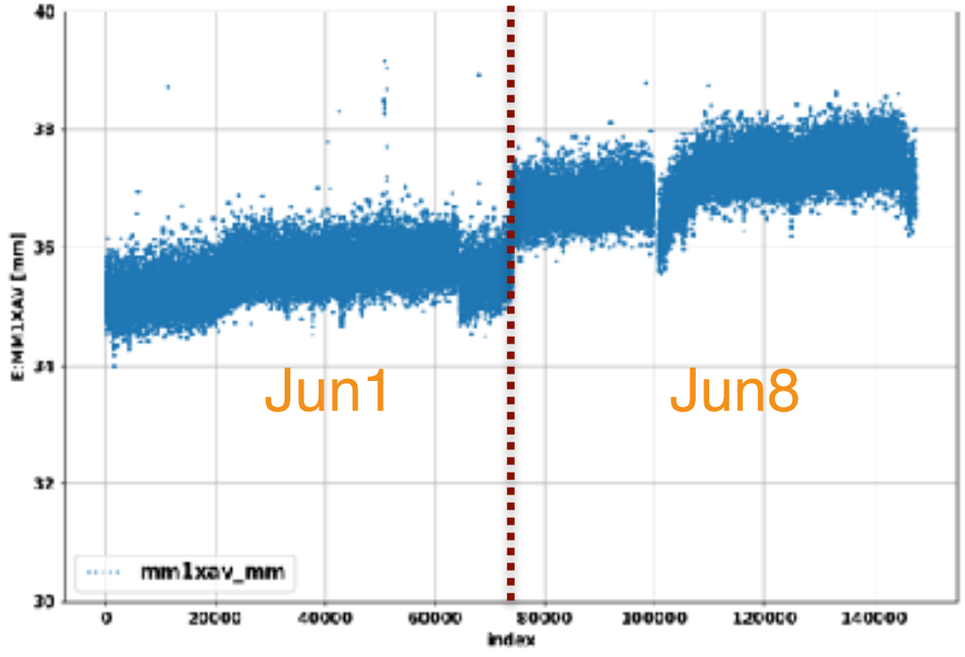
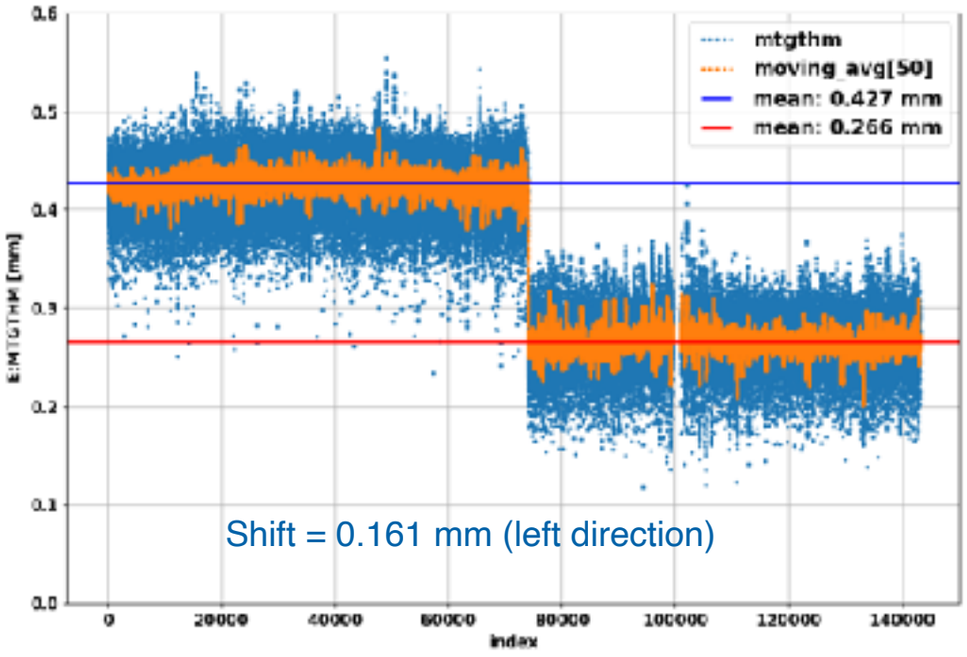
Baffle Temperature Issues

Beam Profile Monitor

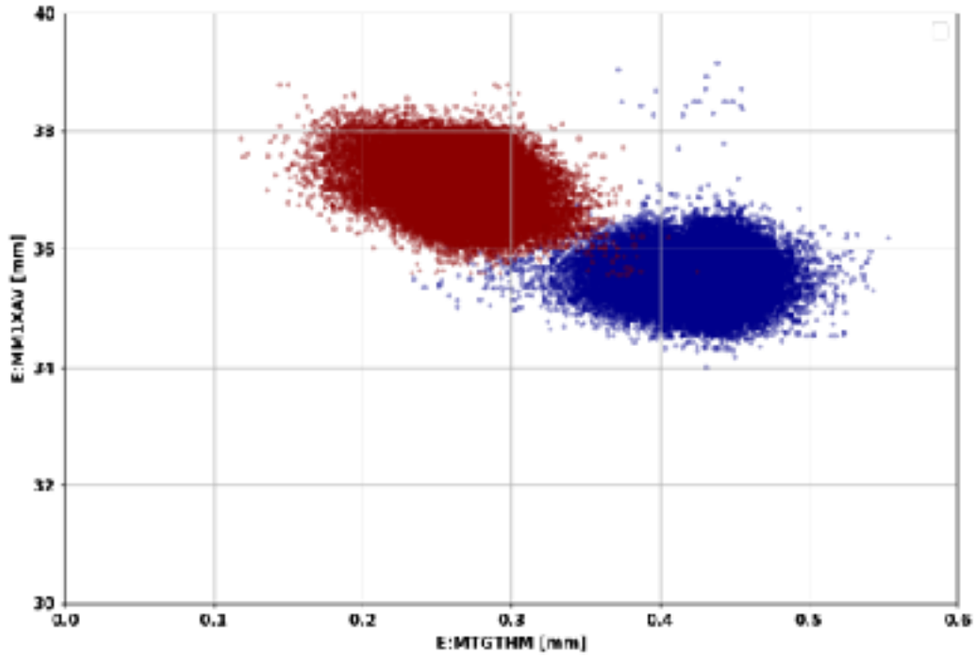


Muon Monitor





MM vs PM:H



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