LBNF Beamline Tech Board Review - Neutrino Beam Instrumentation and Beam-based Alignment

HADeS and MuMS

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December 15, 2021

Hadron Alignment Detector System (HADeS)

- In NuMI, known as the hadron monitor, even though we don't really use it for monitoring
- Physics-based requirements: doc-dB 20846

1. The HADeS must be capable of measuring the angle of the primary proton beam to within 70 μrad. With a beam pathlength of approximately 220 m, this translates to a measurement of the position of the beam to within 1.5 cm.

2. The HADeS must be capable of measuring the positions of the cross-hairs on horns B and C with 0.5 mm accuracy. Specifically, the peak primary beam loss rate for beam traversing the cross-hairs on horns B and C must be measurable with 0.5 mm accuracy, with no target and horn A installed, during a transverse beam scan across the aperture of the horns.

3. The HADeS must be capable of measuring the vertical and horizontal edges of the bafflette and target with 0.5 mm accuracy with all horns and target installed, but no baffle.

4. The HADeS must be capable of measuring the vertical and horizontal edges of the baffle and target with 0.5 mm accuracy with all horns, target and baffle installed.

Beam/Device	End	Tolerance
Beam position	Upstream	0.45 mm
Beam angle	Upstream	70 μrad
Target position	Both	0.50 mm
Horn A position	Both	0.50 mm
Horn B position	Both	0.50 mm
Horn C position	Both	0.50 mm

Table 1: Position and angular tolerances of the neutrino production target and horns. Numbers taken from the CDR.

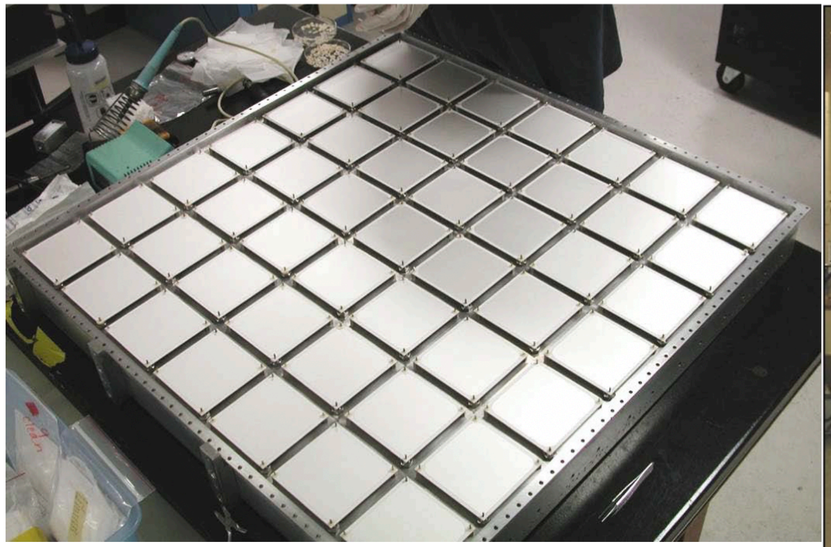
5. The HADeS must be capable of being installed and removed from its nominal position remotely. Removal via remote handling will be necessary to avoid radiation damage from prolonged exposure to beam during normal beam operation. The accuracy of the remote installation must meet the requirements of 1.

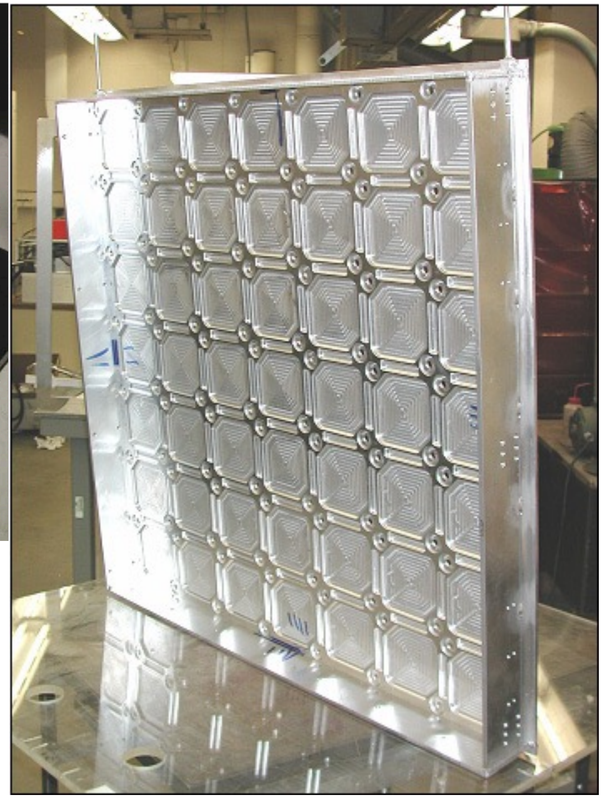
Finally,

6. Relevant data will be permanently recorded and made available to LBNF stakeholders.

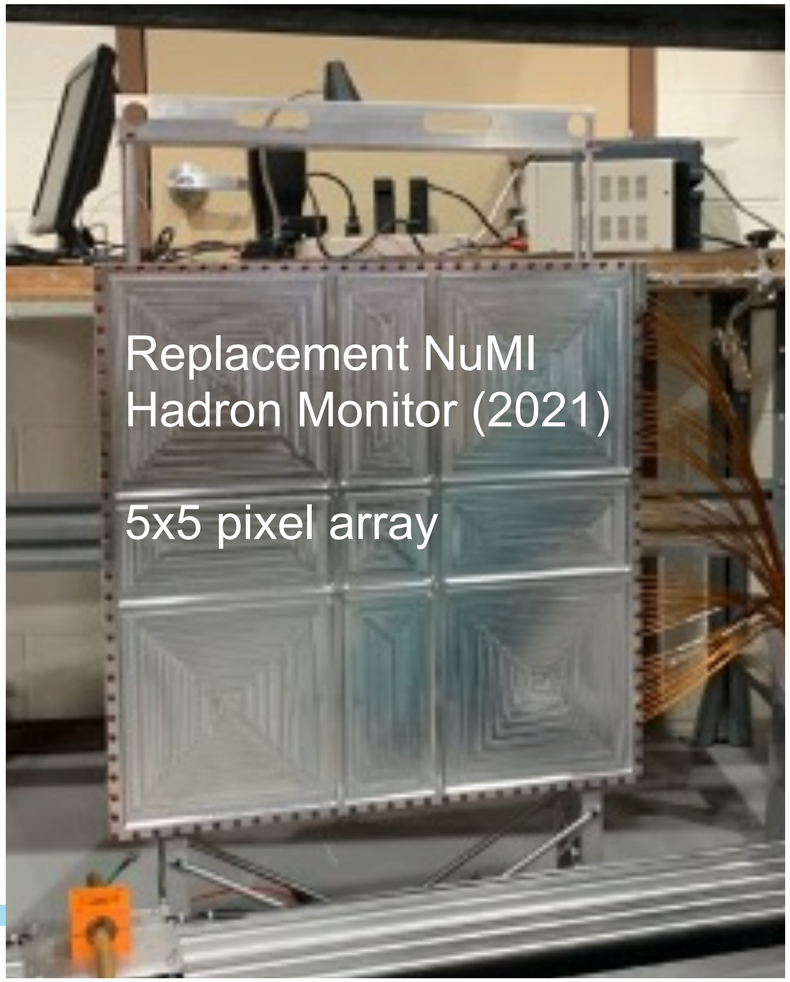
HADeS Conceptual Design

- Preliminary design is based on technology used in NuMI.
  - Pixel size [number of channels] will likely need to be decreased [increased] due to ~3x shorter decay pipe





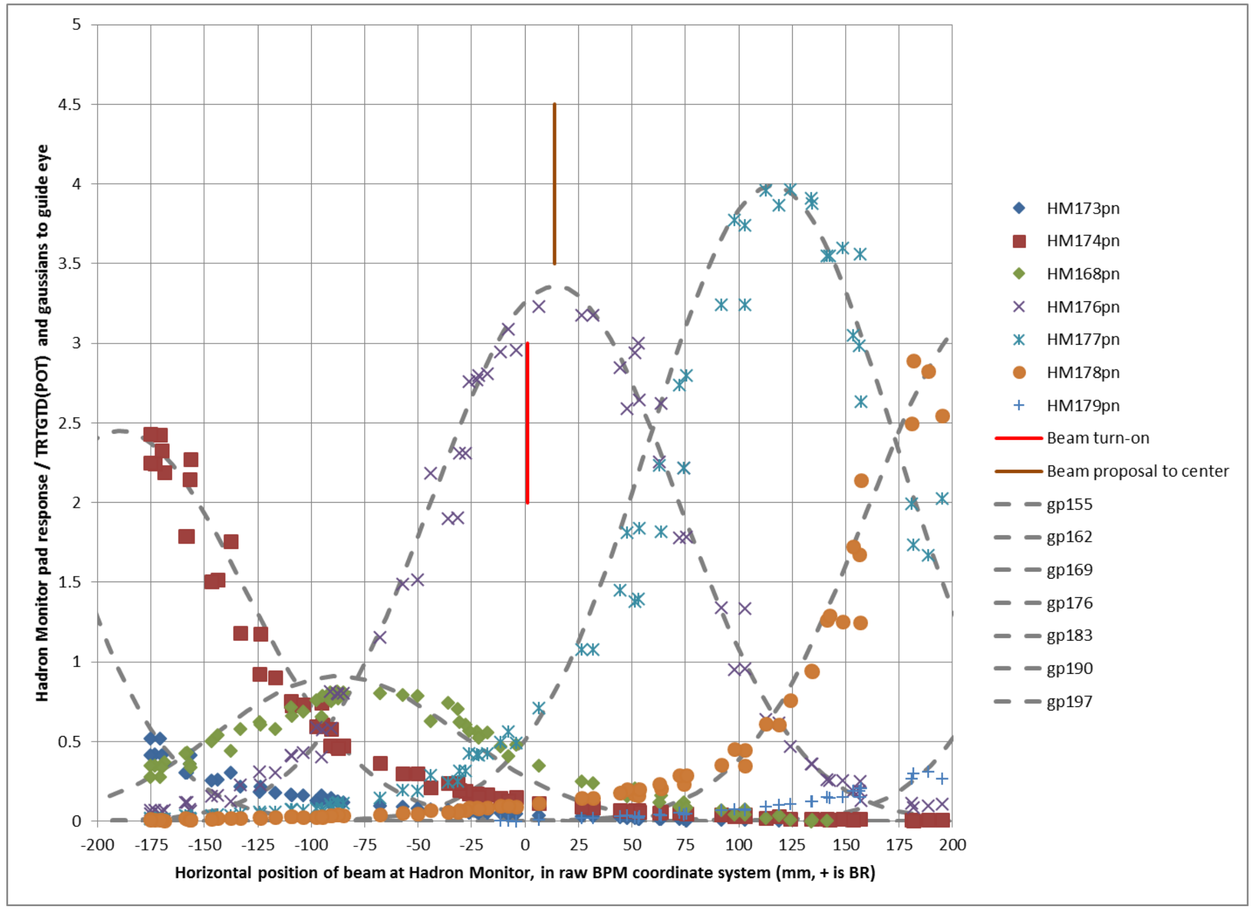
Original 7x7 hadron monitor built by UT Austin



HADeS Requirement 1

1. The HADeS must be capable of measuring the angle of the primary proton beam to within 70 μrad. With a beam pathlength of approximately 220 m, this translates to a measurement of the position of the beam to within 1.5 cm.

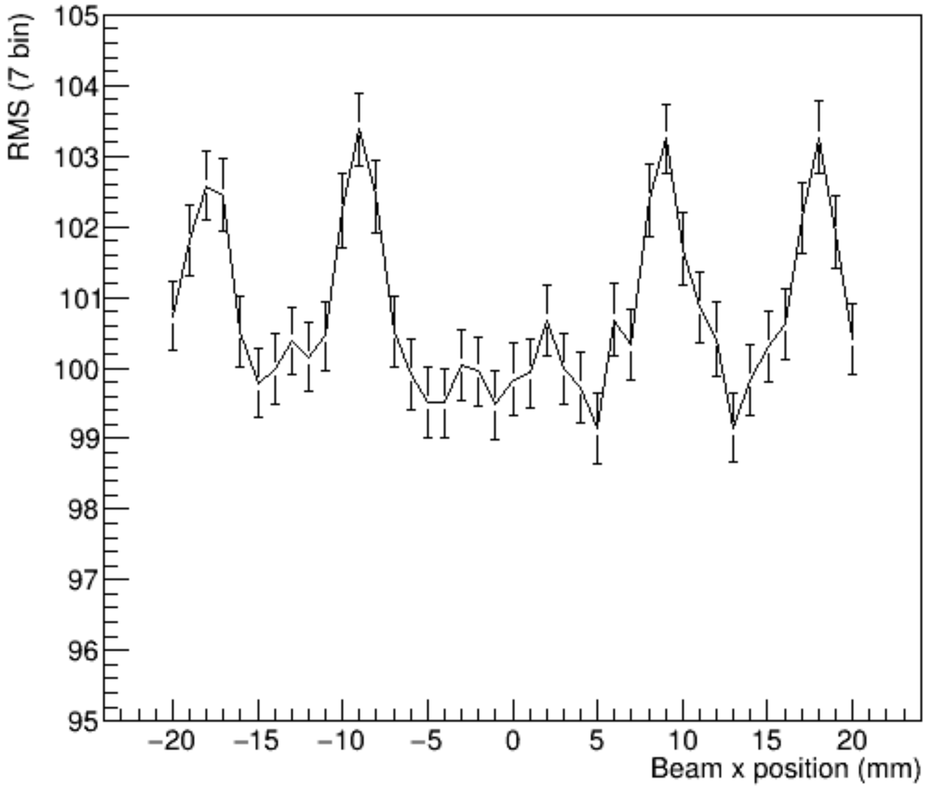
- NuMI pixel size is 3 cm, so 3 cm / 725 m = 42 urad angular precision.
- For LBNF, a 220 m decay pipe implies a 1.5 cm pixel size is needed to meet the 70 urad requirement.



HADeS Requirement 2

2. The HADeS must be capable of measuring the positions of the cross-hairs on horns B and C with 0.5 mm accuracy. Specifically, the peak primary beam loss rate for beam traversing the cross-hairs on horns B and C must be measurable with 0.5 mm accuracy, with no target and horn A installed, during a transverse beam scan across the aperture of the horns.

- Simulations (thanks, Zarko!) indicate that a ~3% change in the RMS of the beam as it hits the cross-hairs is expected.
- RMS values in plot on the right are extracted from beam profile histograms with bin sizes of 2 cm. Error bars reflect a 1% uncorrelated uncertainty.
- Studies are underway to determine if 1.5 cm pixel size will meet this requirement.



HADeS Requirements 3 & 4

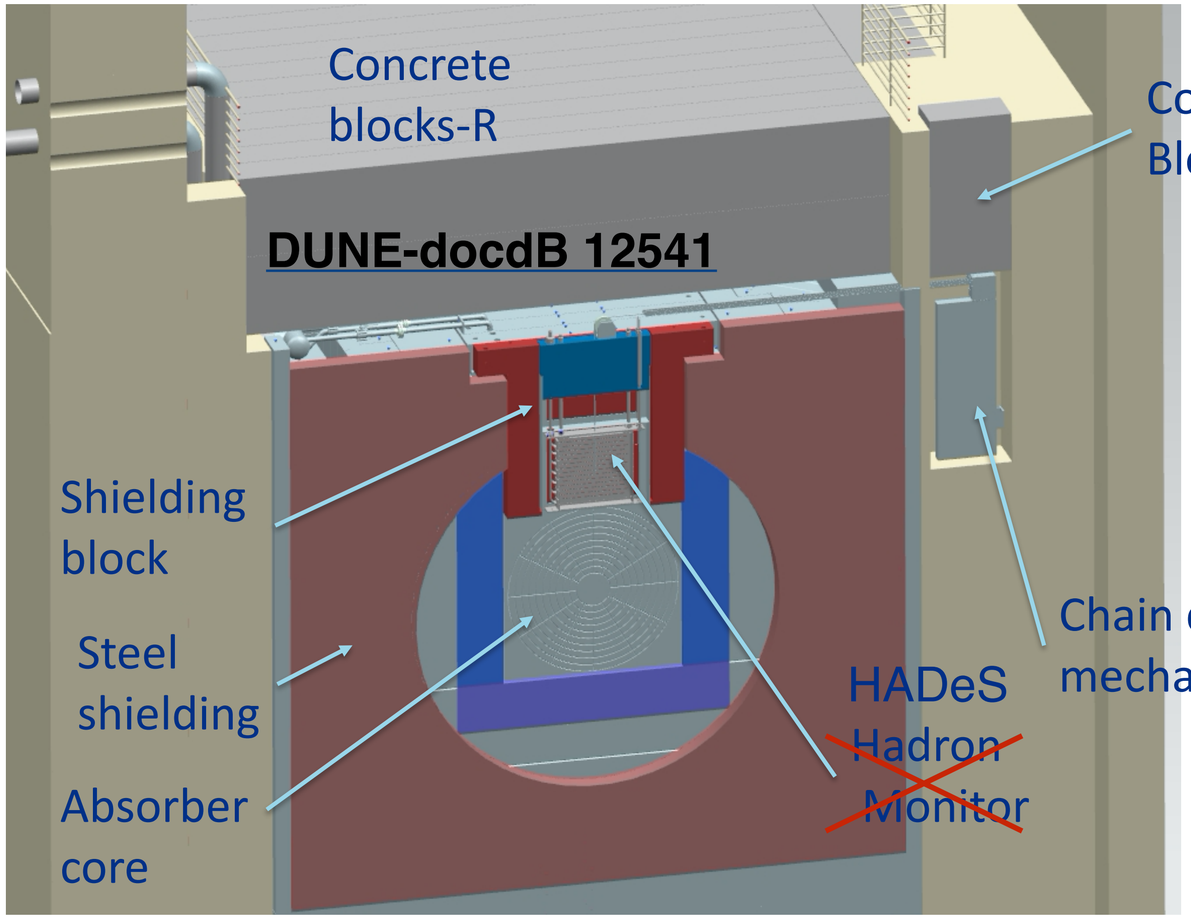
3. The HADeS must be capable of measuring the vertical and horizontal edges of the bafflette and target with 0.5 mm accuracy with all horns and target installed, but no baffle.

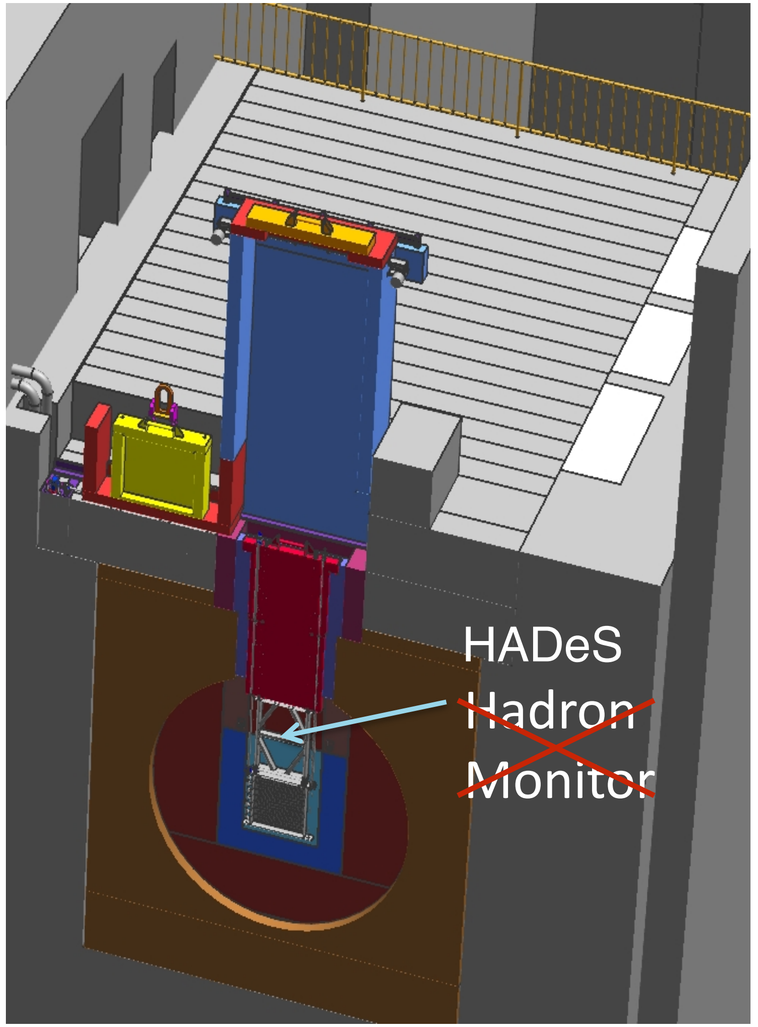
4. The HADeS must be capable of measuring the vertical and horizontal edges of the baffle and target with 0.5 mm accuracy with all horns, target and baffle installed.

- We don’t have simulations where beam hits the bafflette. Necessary?
- The bafflette and target represent 100x more interaction lengths than the cross-hairs, so the effect on the beam profile [width] should be enormous.
- We should be able to simply rely on measurements of the change in flux at the HADeS as we scan the beam across these features.

HADeS Requirement 5 - Remote Handling

LBNF Absorber, Hadron Monitor inside shielding block





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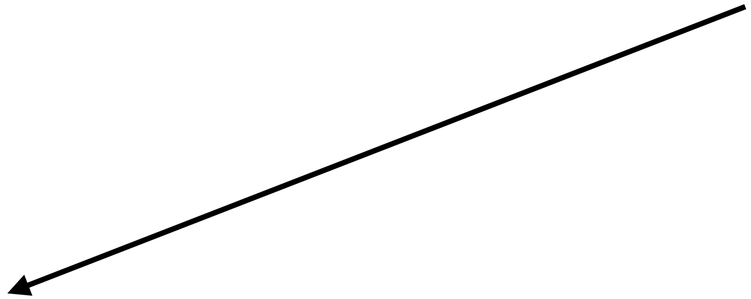
Muon Monitor System (MuMS)

- Monitors the tertiary muon beam profile downstream of the absorber; presence of muons indicates presence of neutrinos (converse is also true, and is an indicator of a potentially serious problem).
- Physics-based requirements: doc-dB 20849



1. The MuMS must be capable of measuring the relative muon flux for each neutrino beam spill, and capable of providing feedback within the spill duty cycle such that beam can be shut-off before the next spill, at a minimum spill intensity of 7.5×10^{12} POT and maximum spill intensity of 7.5×10^{13} POT.
2. The MuMS must be capable of measuring the muon beam center to within 1 cm within a few spills of normal beam operation.
3. The MuMS must be capable of measuring the relative integrated muon flux passing through the detector to within 1% spill-to-spill.
4. The MuMS must be capable of measuring the integrated flux of the muon beam above 5 GeV and two other higher energies separated by at least 3 GeV each.

MuMS Conceptual Design

- Conceptual design is to use the same detector [technology] as for the HADeS.
  - Similar to NuMI approach
  - Initial proposal is to use larger (150 cm x 150 cm) HADeS detectors, but with fewer channels and/or larger pixels
    - At first glance, UT Austin agreed this should work
    - But maximum travel range of CNCs at UT Austin shop is 50 cm x 100 cm.
      - The NuMI 1x1m^2 detector was constructed by moving the detector once.
      - Not clear if moving it more often is realistic for the larger LBNF muon monitors
      - Construct the detector from smaller pieces (eg, 3x3 grid of 50 cm x 50 cm mini-HADeS detectors)
- Discussions with UT Austin underway

MuMS Requirement 2

2. The MuMS must be capable of measuring the muon beam center to within 1 cm within a few spills of normal beam operation.

- NuMI experience indicates that there will be enough signal (stats) for such a measurement.
- Studies are underway to determine necessary pixel size.

MuMS Requirement 3

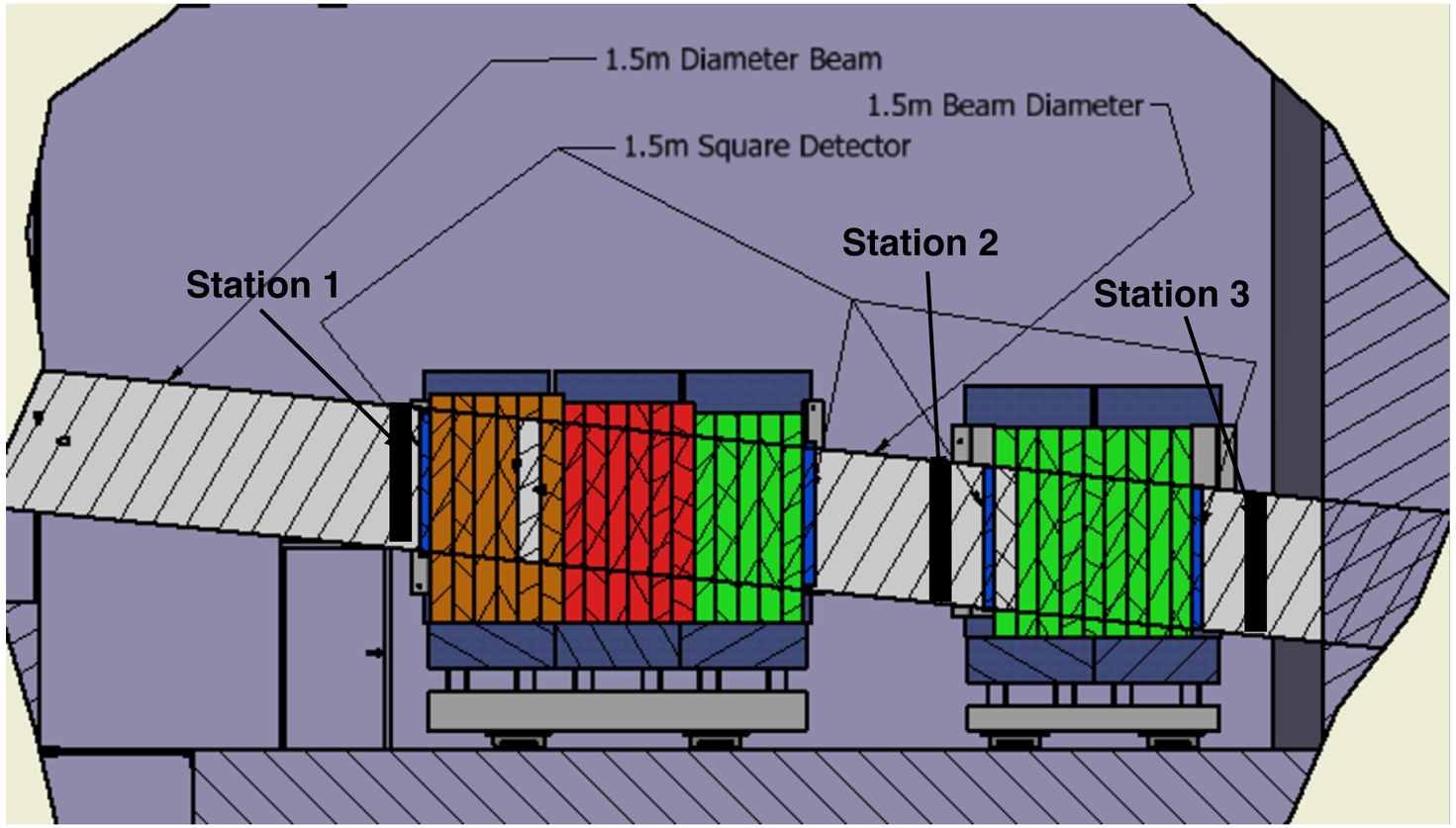
3. The MuMS must be capable of measuring the relative integrated muon flux passing through the detector to within 1% spill-to-spill.

- NuMI experience indicates this is possible.
- Care must be taken to avoid impurities introduced to the system during gas bottle changes.
  - Will be partially mitigated by using larger helium tanks stored outside.
  - Will consider further gas monitoring and calibration techniques.

MuMS Requirement 4 - Shielding

4. The MuMS must be capable of measuring the integrated flux of the muon beam above 5 GeV and two other higher energies separated by at least 3 GeV each.

- Steel plates to be used for shielding, supported by blue blocks and steel frame
- Station 1 sees muons above 5 GeV (absorber stops muons below 5 GeV)
- Station 2 sees muons above ~11 GeV
- Station 3 sees muons above ~16 GeV



From Vic Guarino (ANL)

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Common Infrastructure

- Gas system
- Power supplies
- Readout electronics