LBNF Beamline Preliminary Design Review - Neutrino Beam Instrumentation and Beam-based Alignment

MuMS and HADeS

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May 11, 2022

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.

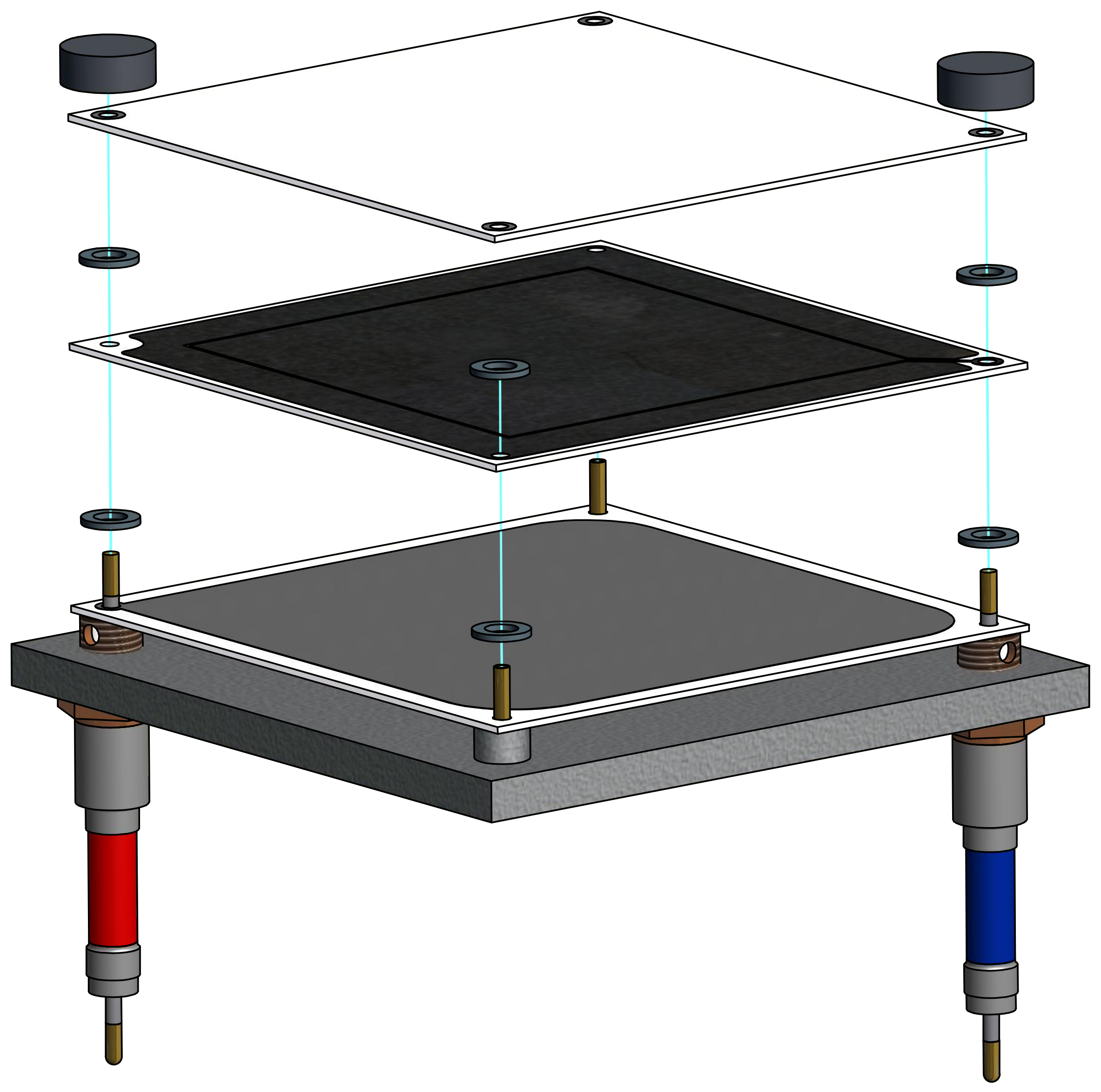
Finally,

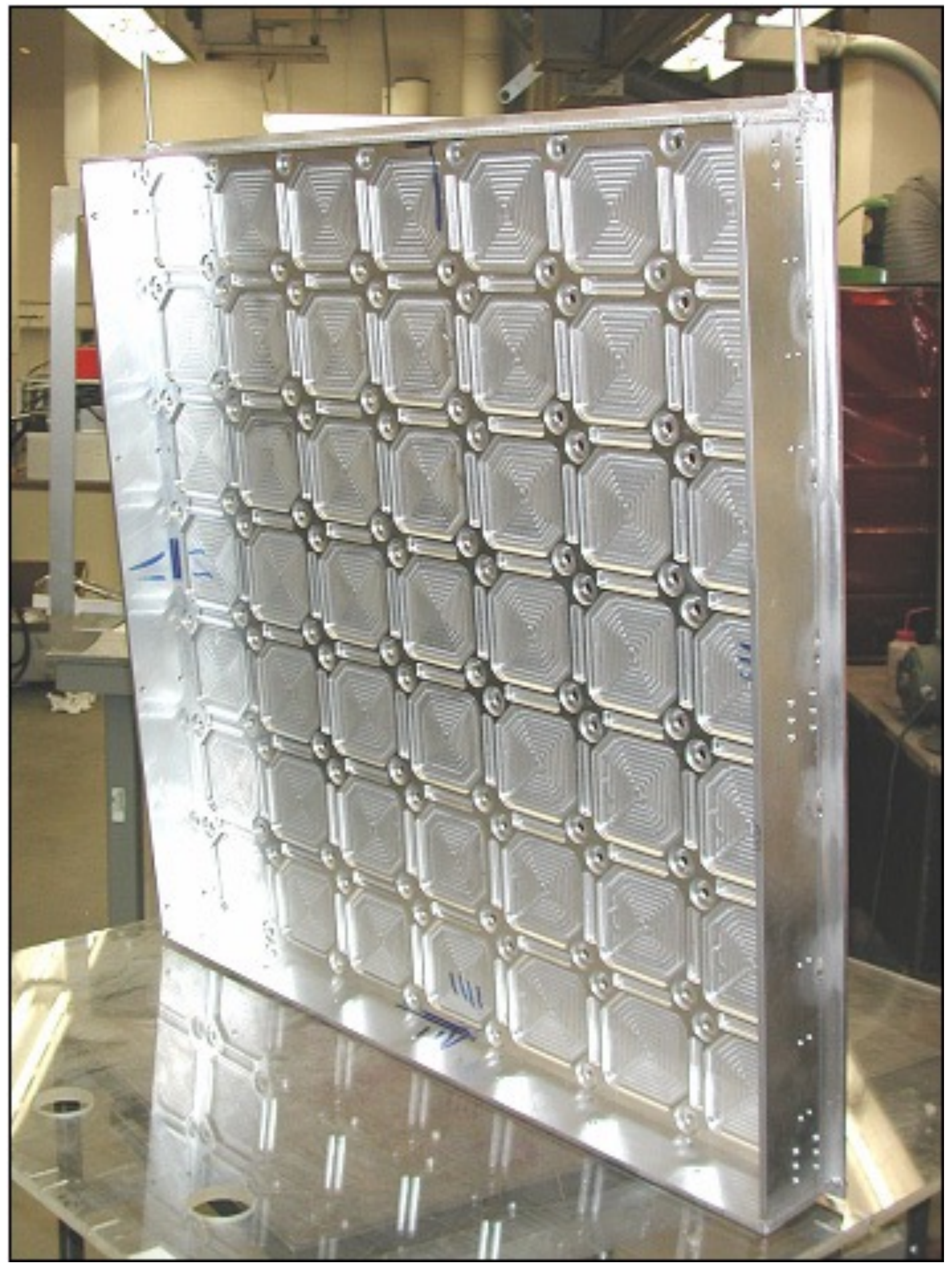
6. Relevant data will be permanently recorded and made available to LBNF stakeholders.

HADeS Conceptual Design

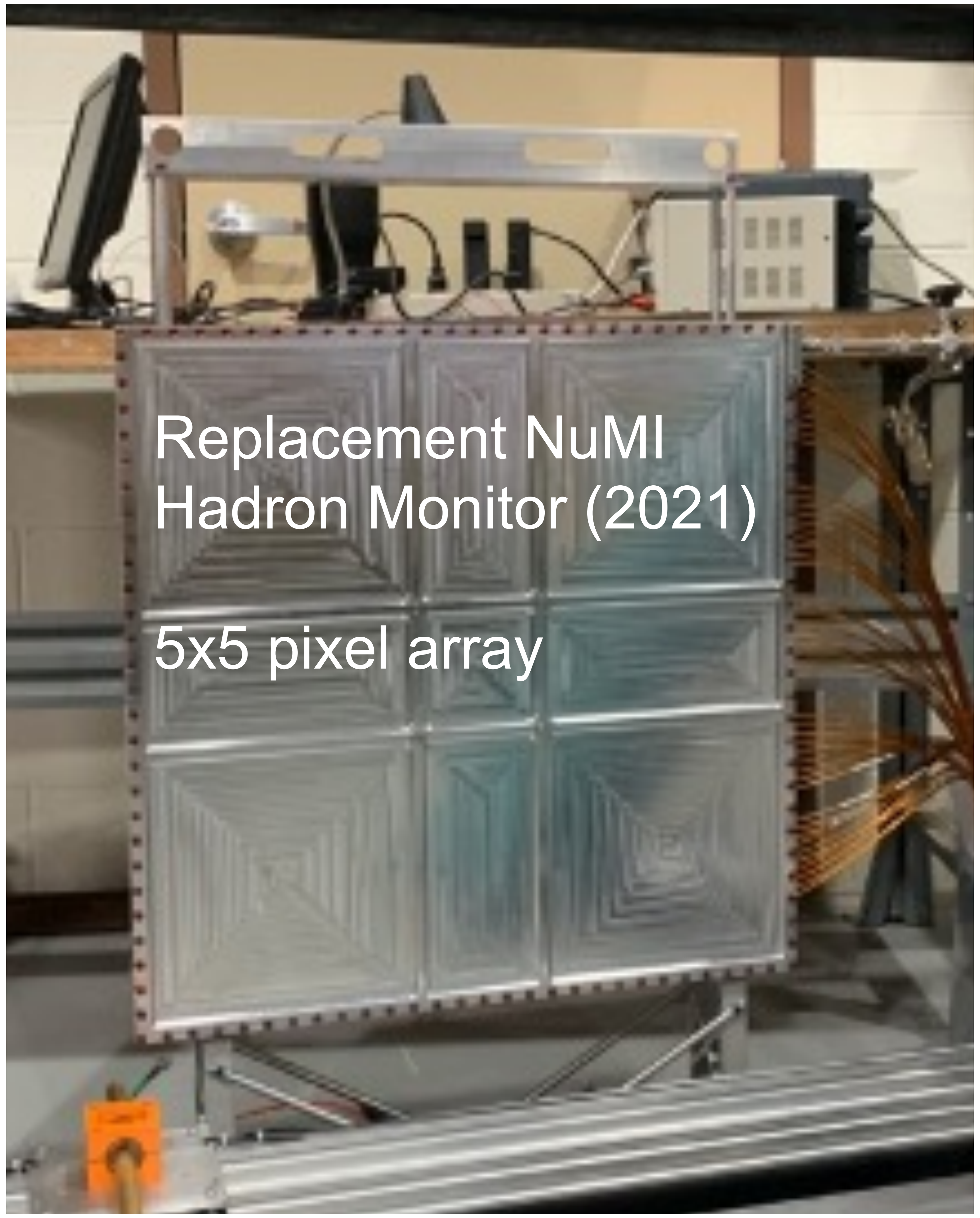
- Preliminary design is based on technology used in NuMI

3 plates w/ 0.75 mm gap



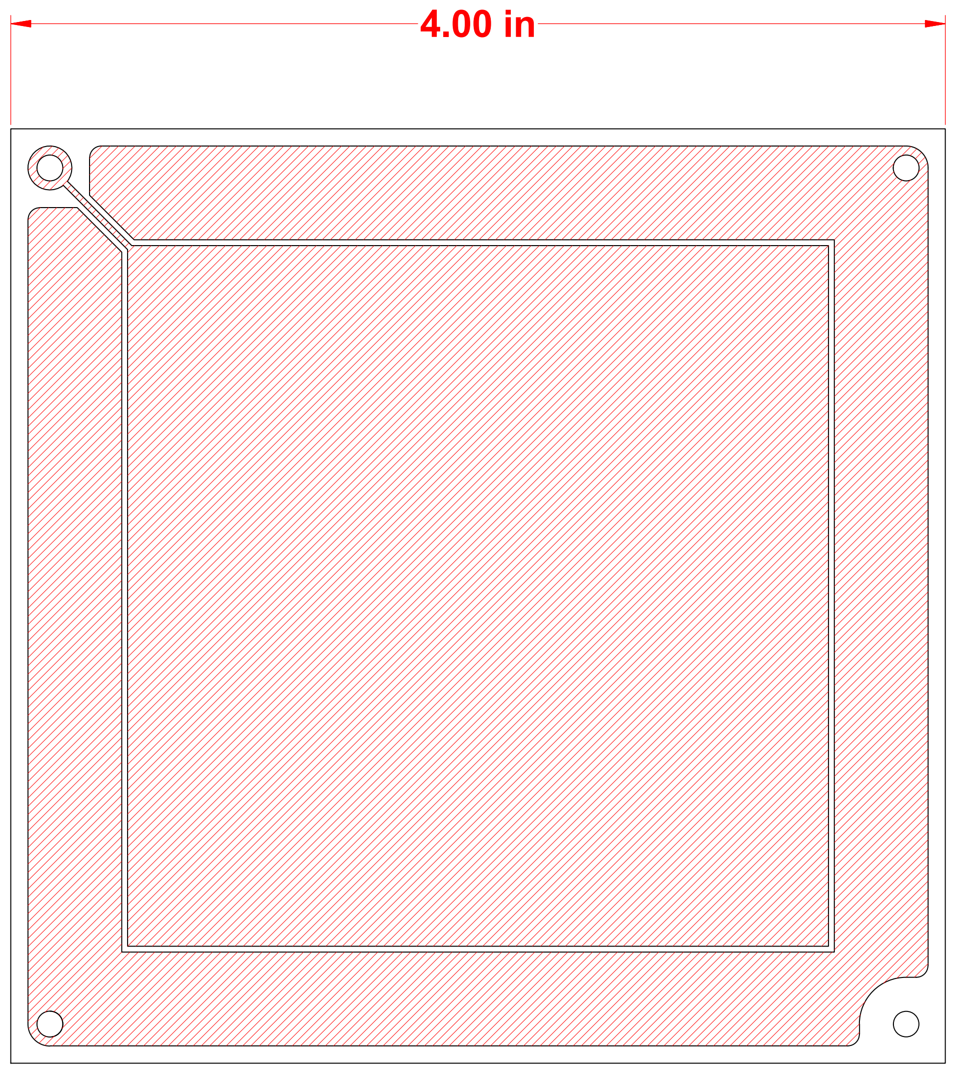


Original 7x7 hadron monitor built by UT Austin

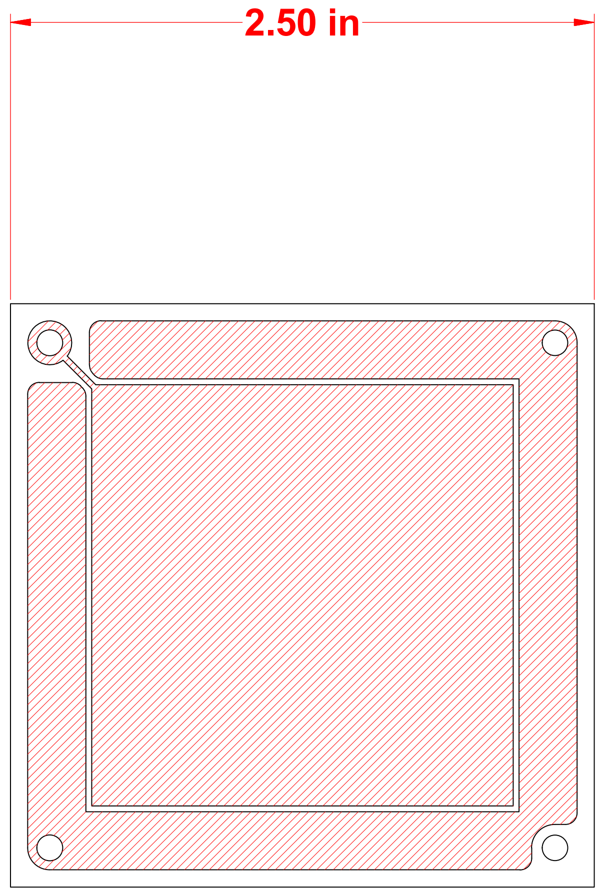


HADeS Conceptual Design

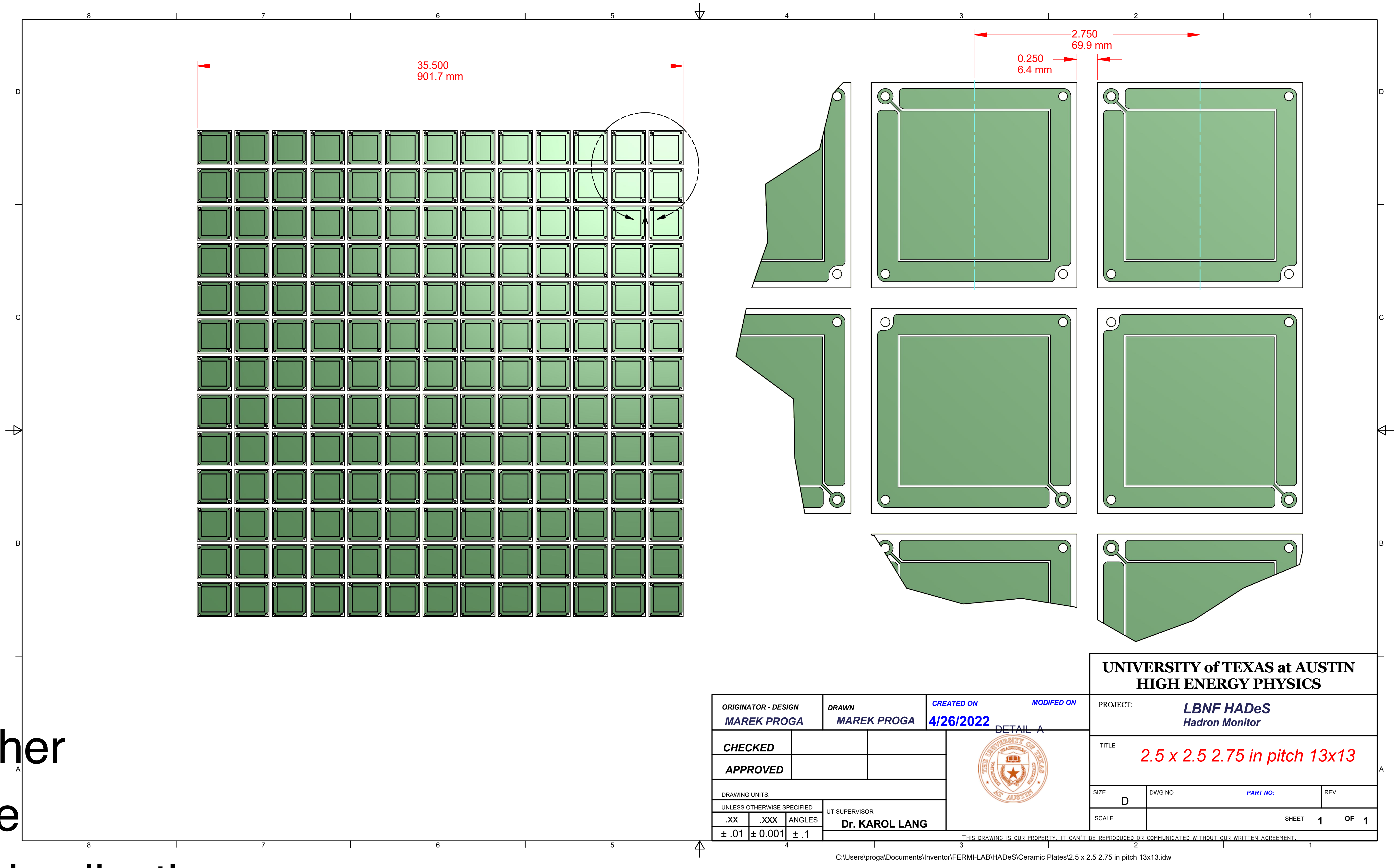
- LBNF pixel size [number of channels] will likely need to be decreased [increased] due to ~3x shorter decay pipe



NUMI 4" X 4" PLATE
(SENSING AREA 9 SQ IN)



HADES 2.5" X 2.5" PLATE PROPSAL
(SENSING AREA 3.25 SQ IN)

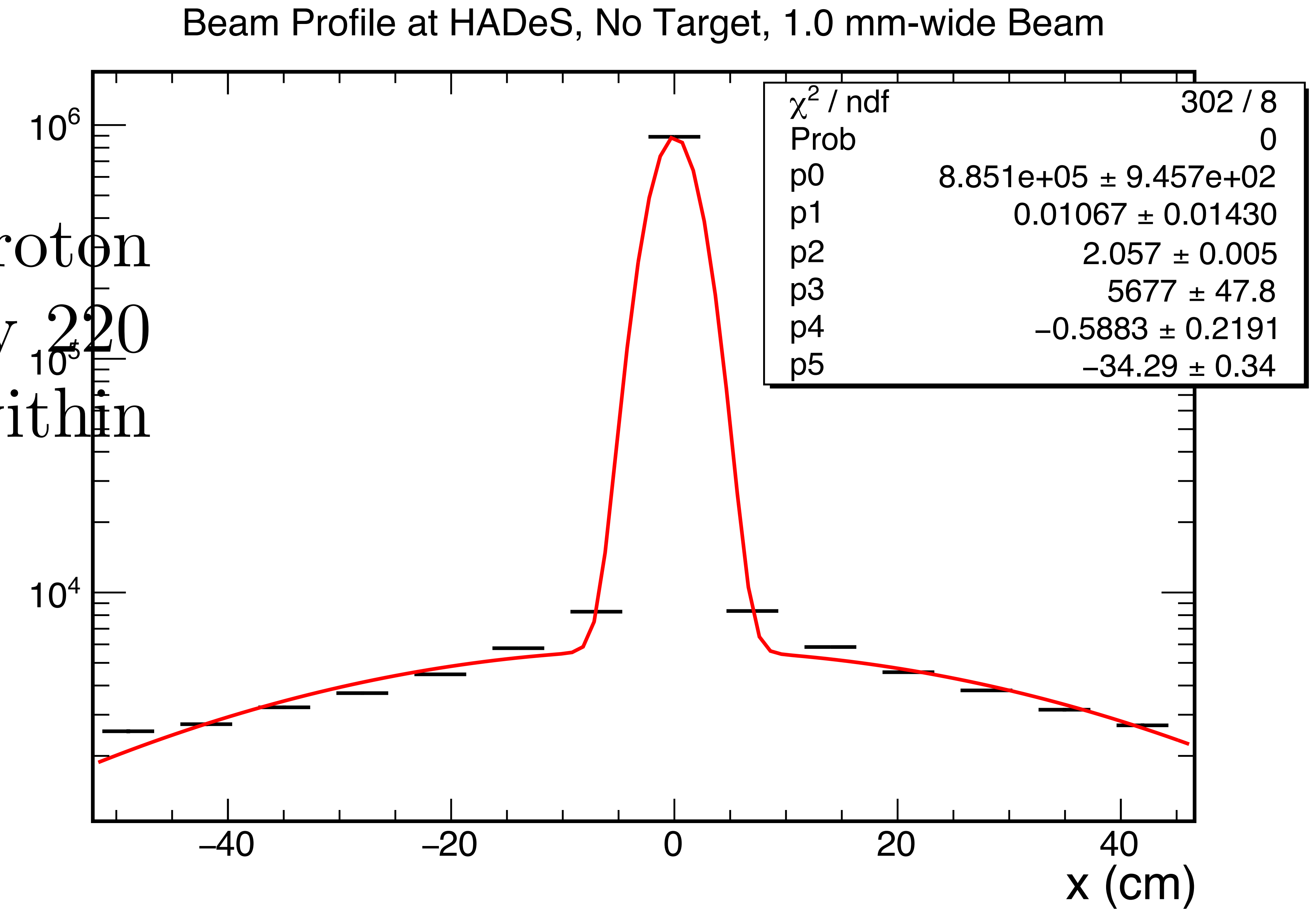


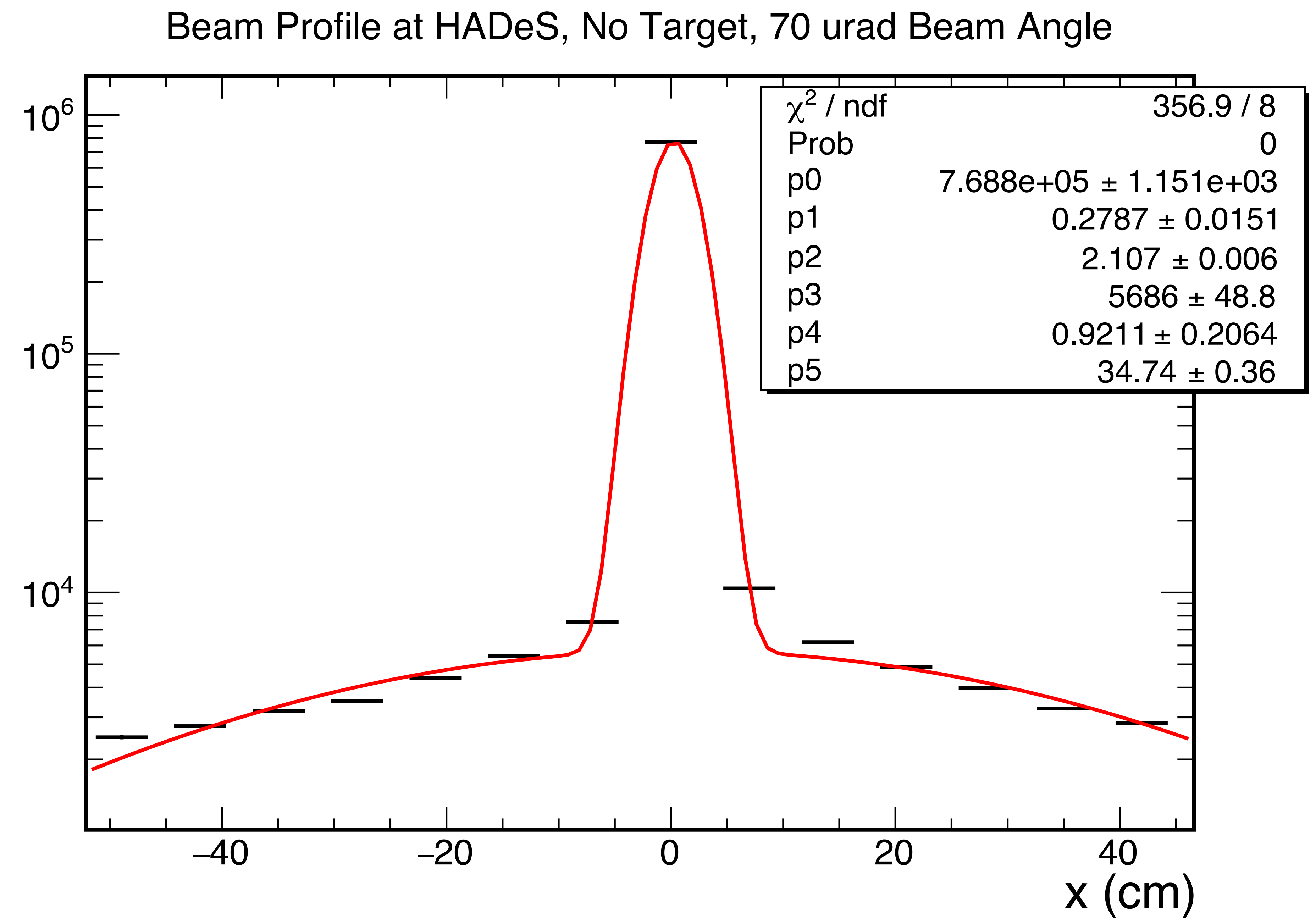
Note: the smaller pixel size may require some further design changes. UT Austin is planning to do some R&D/prototyping to make sure we understand the implications.

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.

- Fits to simulated beam profiles (no target+horn A) indicate we can measure the beam center to less than 1 cm.
- If the beam direction is off by 70 urad, we will see a sizable asymmetry in the profile, and measure a beam centroid that is inconsistent with it being centered.

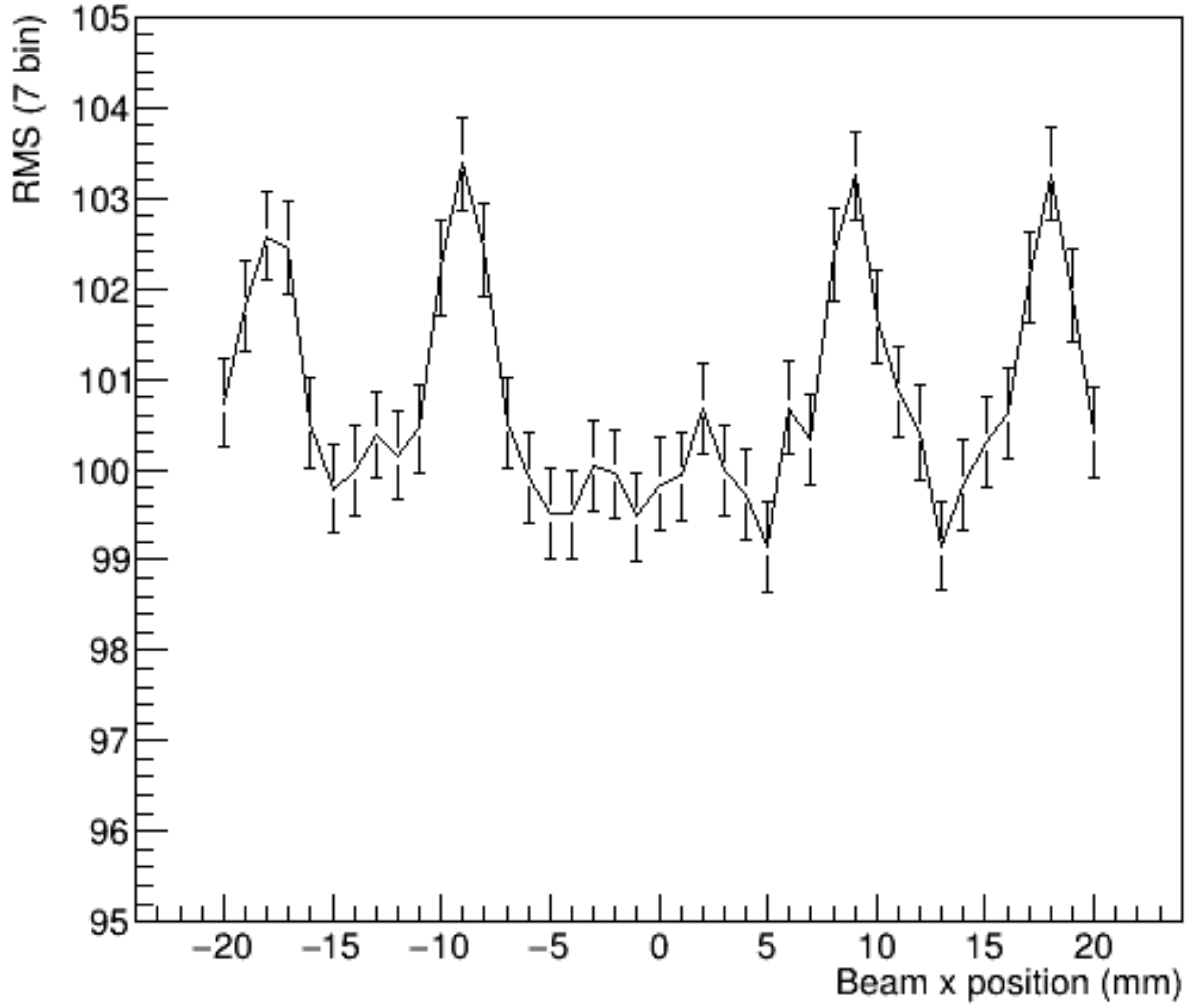




HADeS Requirement 2

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 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 on previous slide indicates the primary beam width can be measured to better than 1%.

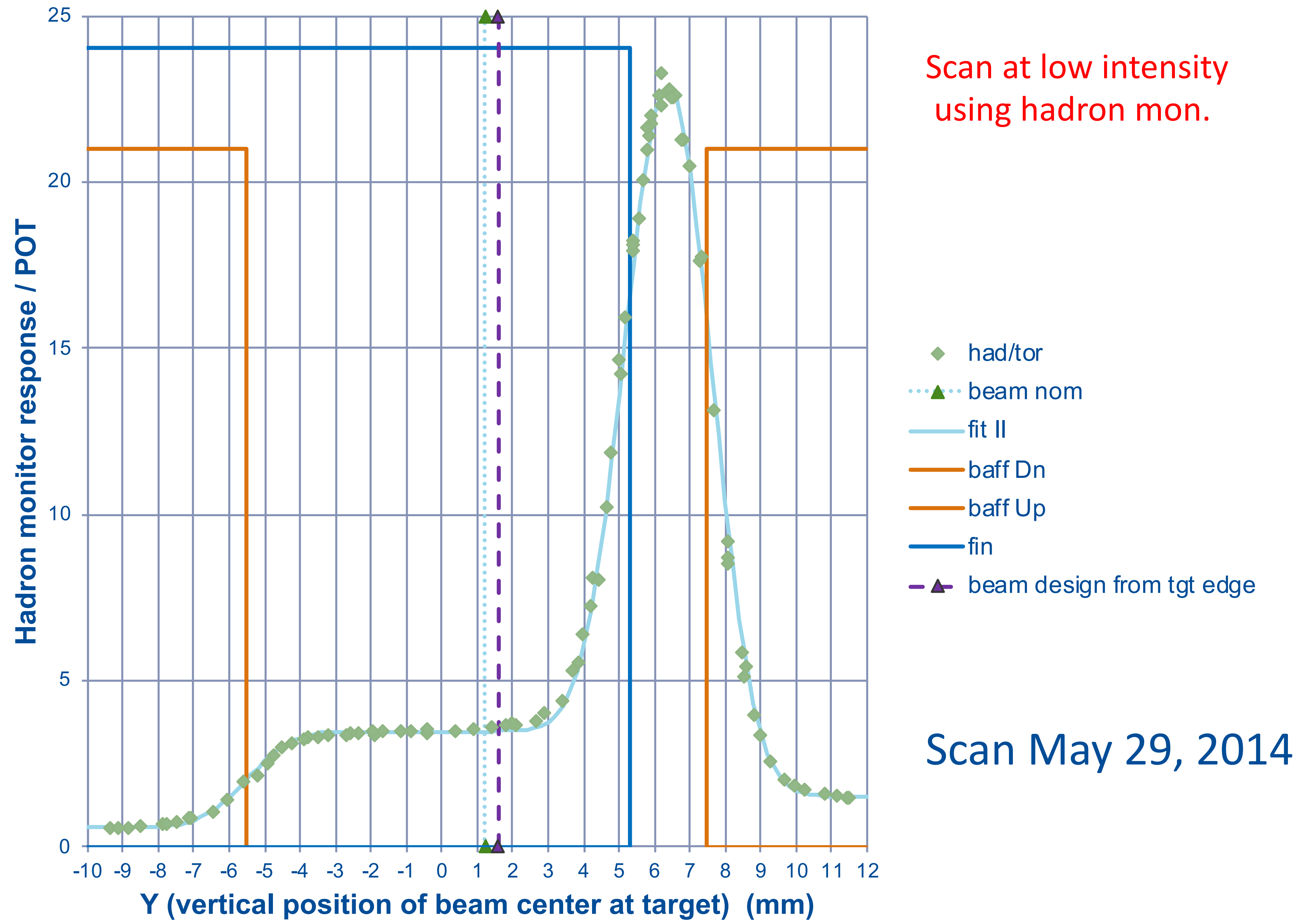


HADeS Requirements 3 & 4

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.

- The bafflette and target represent 100x more interaction lengths than the cross-hairs, so the effect on the beam profile [width] should be enormous.
- As was done in NuMI, we can rely on measurements of the change in flux at the HADeS as we scan the beam across these features.



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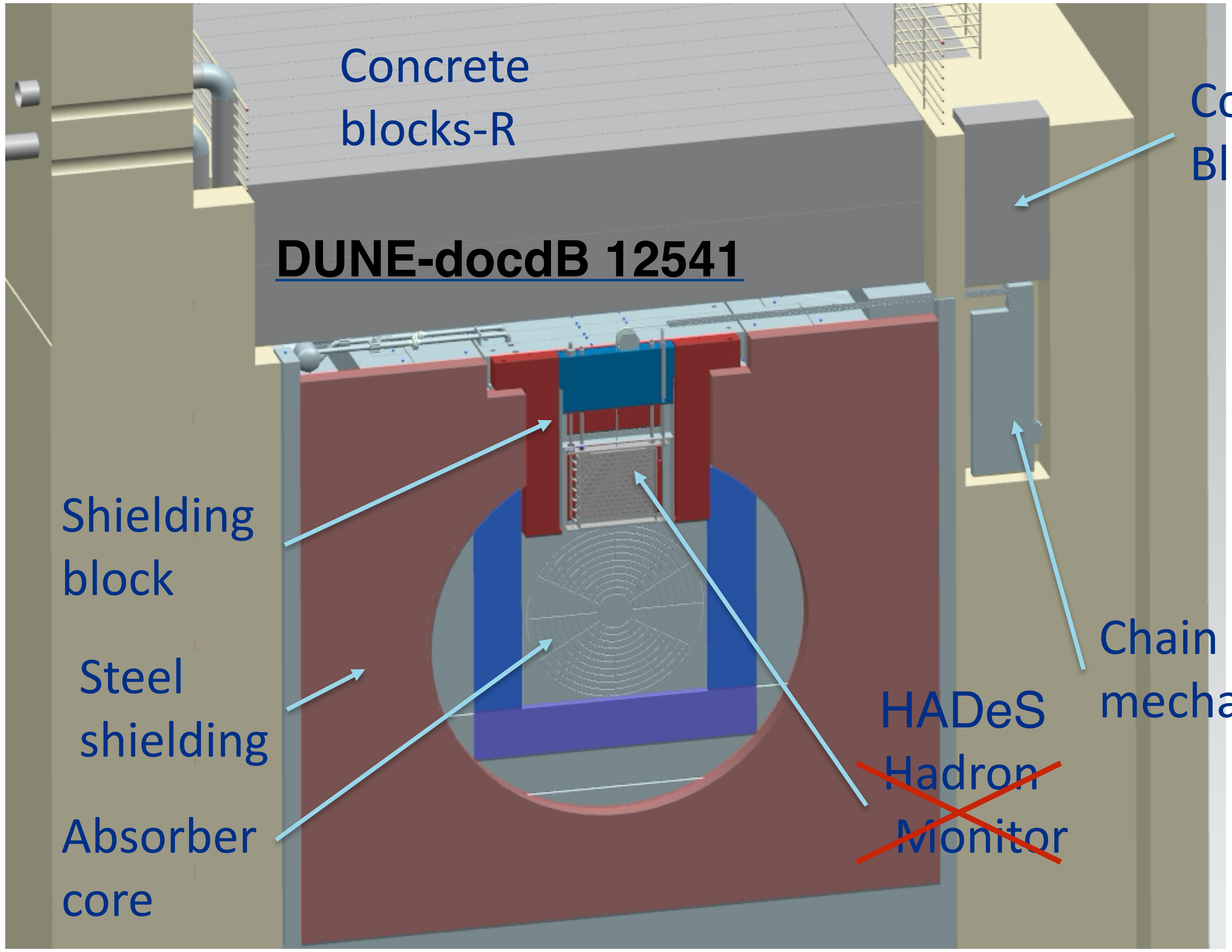
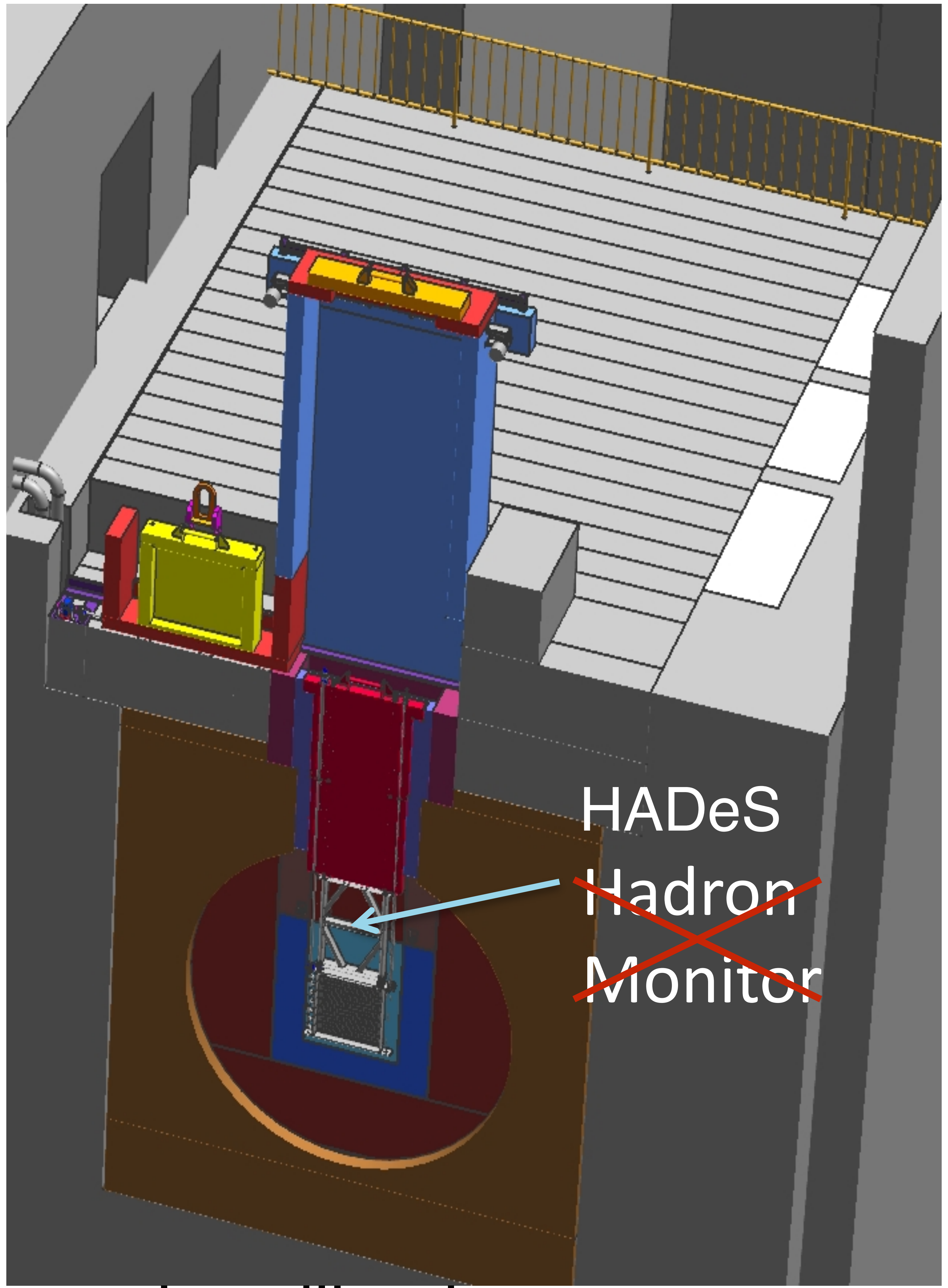
HADeS Requirement 5 - Remote Handling

LBNF Absorber, Hadron Monitor inside shielding block





Note: this is an interface, NBI is not responsible for the remote handling but We are working with remote-handling experts.

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HADeS Requirement 6 - Readout and Data Access

- Planning to use SWIC readout, used by many other AD systems.
  - Output will go into ACORN (future version of ACNET), and data we be readily available to anyone who needs it via, eg, the ifbeam interface.
- One SWIC readout board can take up to 192 channels. So for the 13x13 design, we need only one SWIC board.

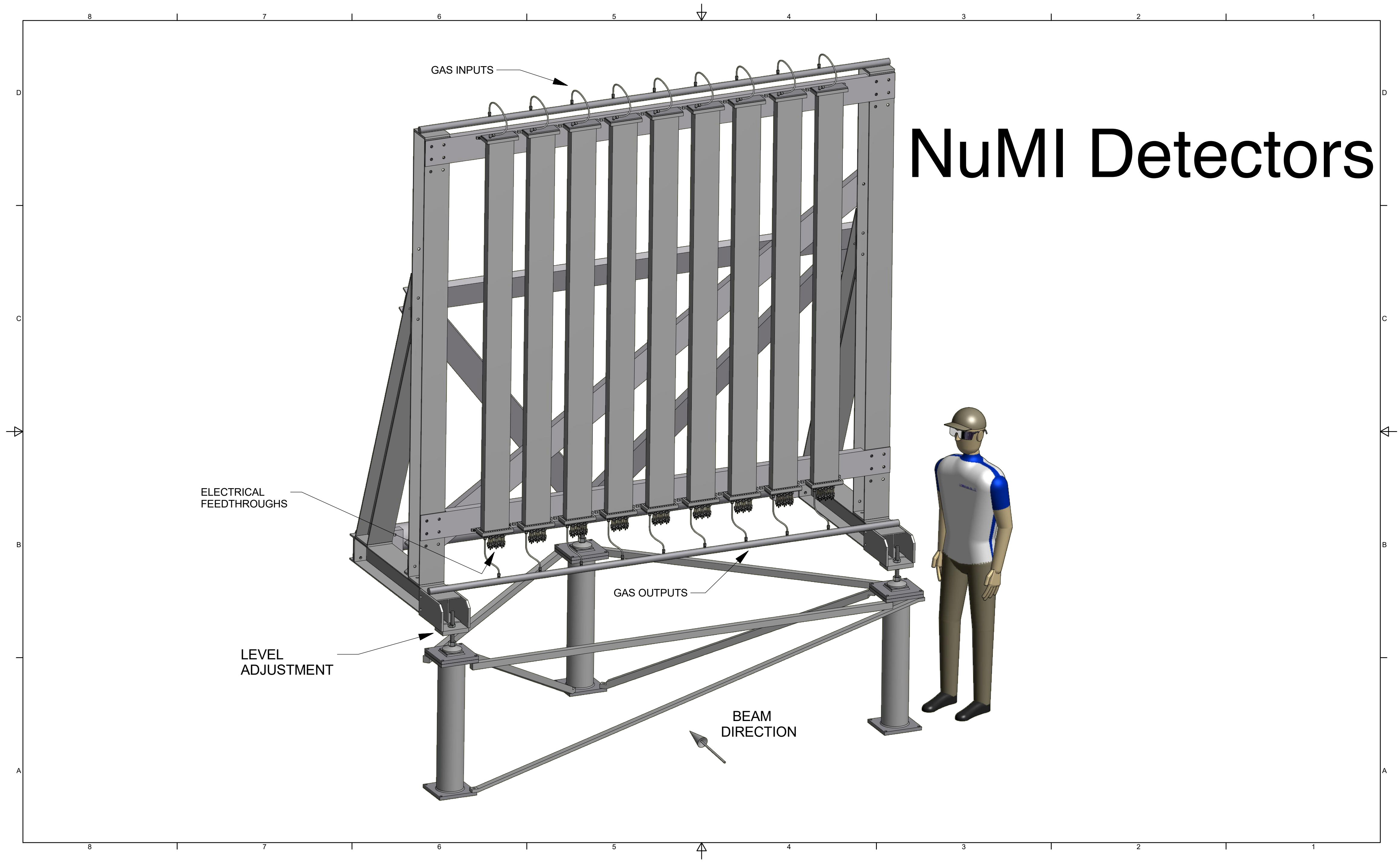
Muon Monitor System (MuMS)

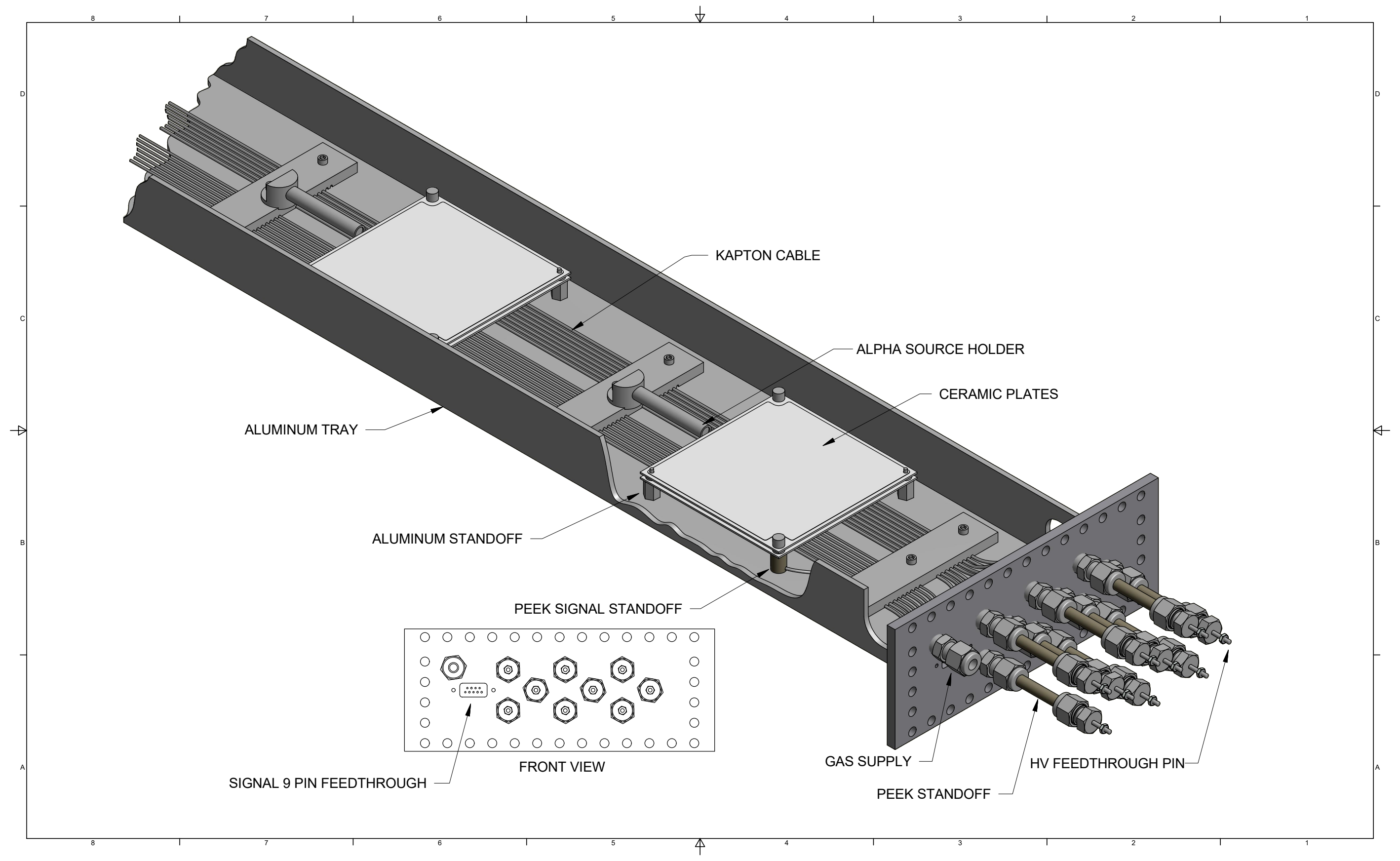
- Monitors the tertiary muon beam profile downstream of the absorber; presence of muons indicates presence of neutrinos (converse is also true, and is an indicator of a potentially serious problem).
- Physics-based requirements: doc-dB 20849

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

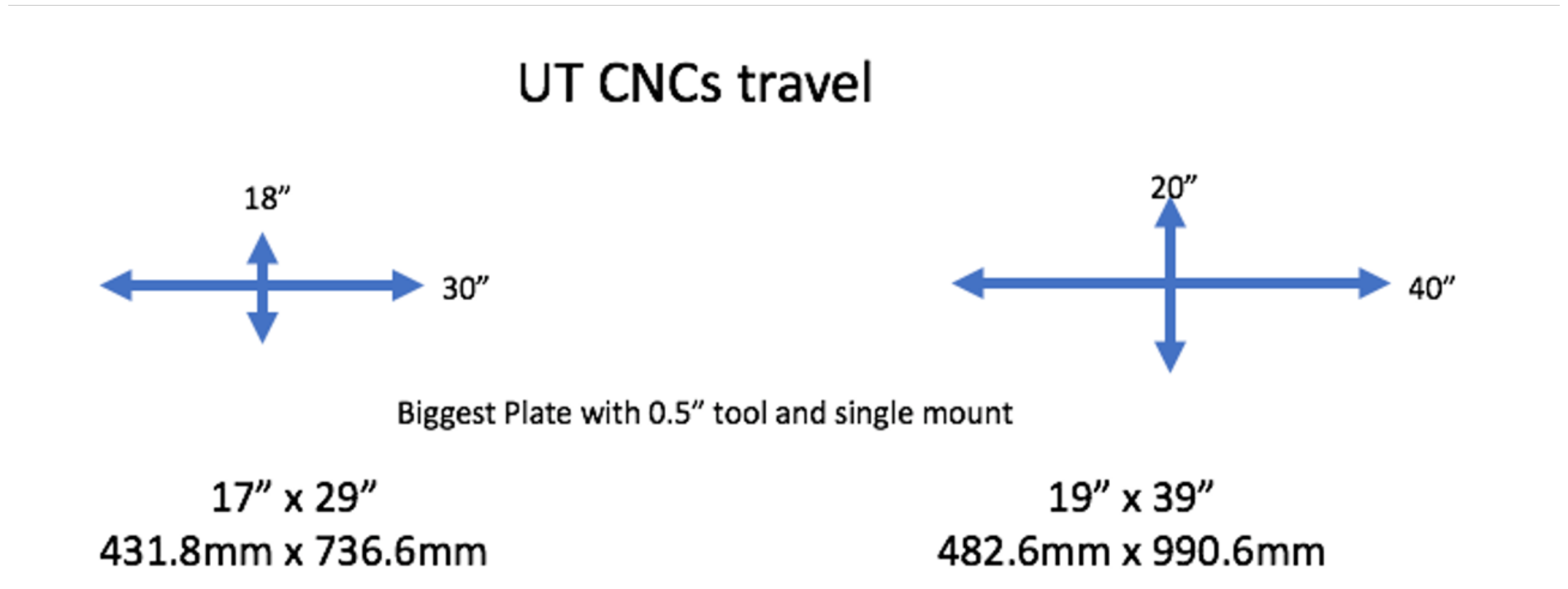
- Conceptual design is to use the same detector [technology] as for the HADeS.
  - Similar to NuMI approach
  - Initial proposal was to use larger (150 cm x 150 cm) HADeS detectors, but with fewer channels and/or larger pixels

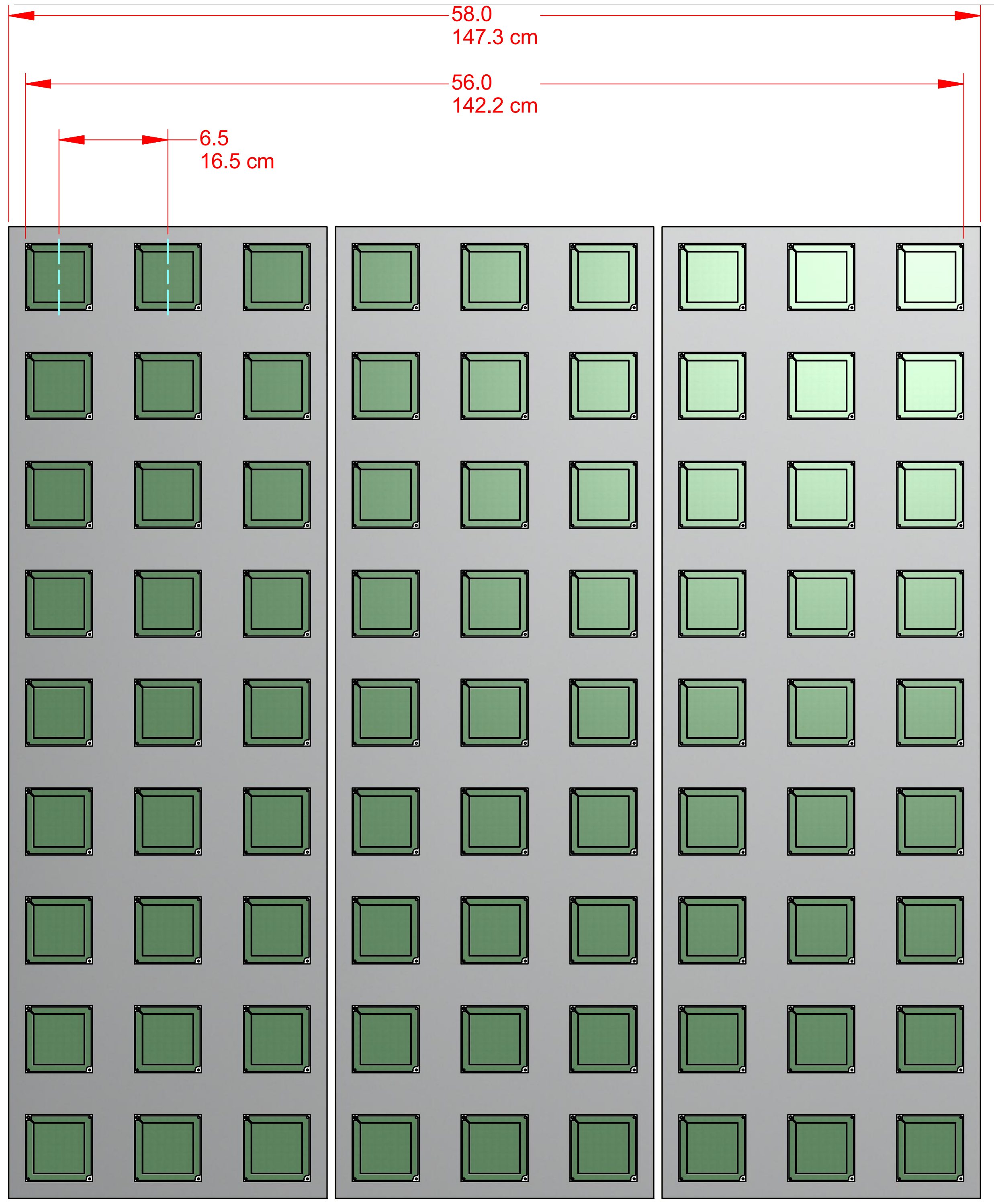


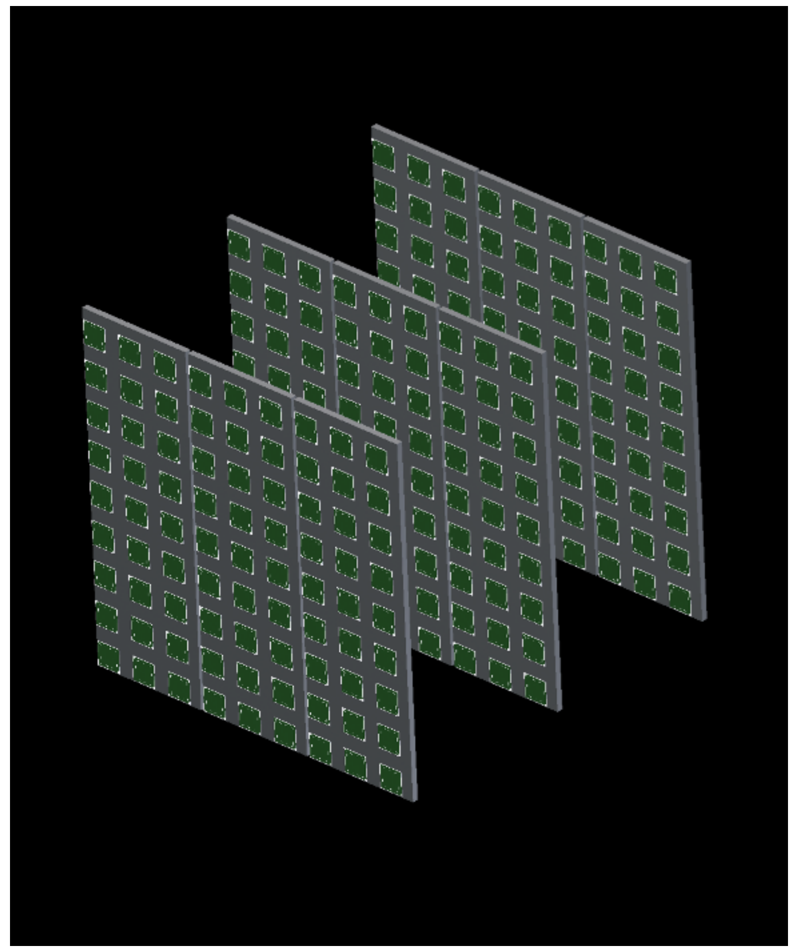


MuMS Conceptual Design

- 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 1x1m² 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, 1x3 grid of 100 cm x 50 cm mini-HADeS detectors)
- Discussions with UT Austin underway, considering design that will allow easy swapping of modules.







MuMS Requirement 1

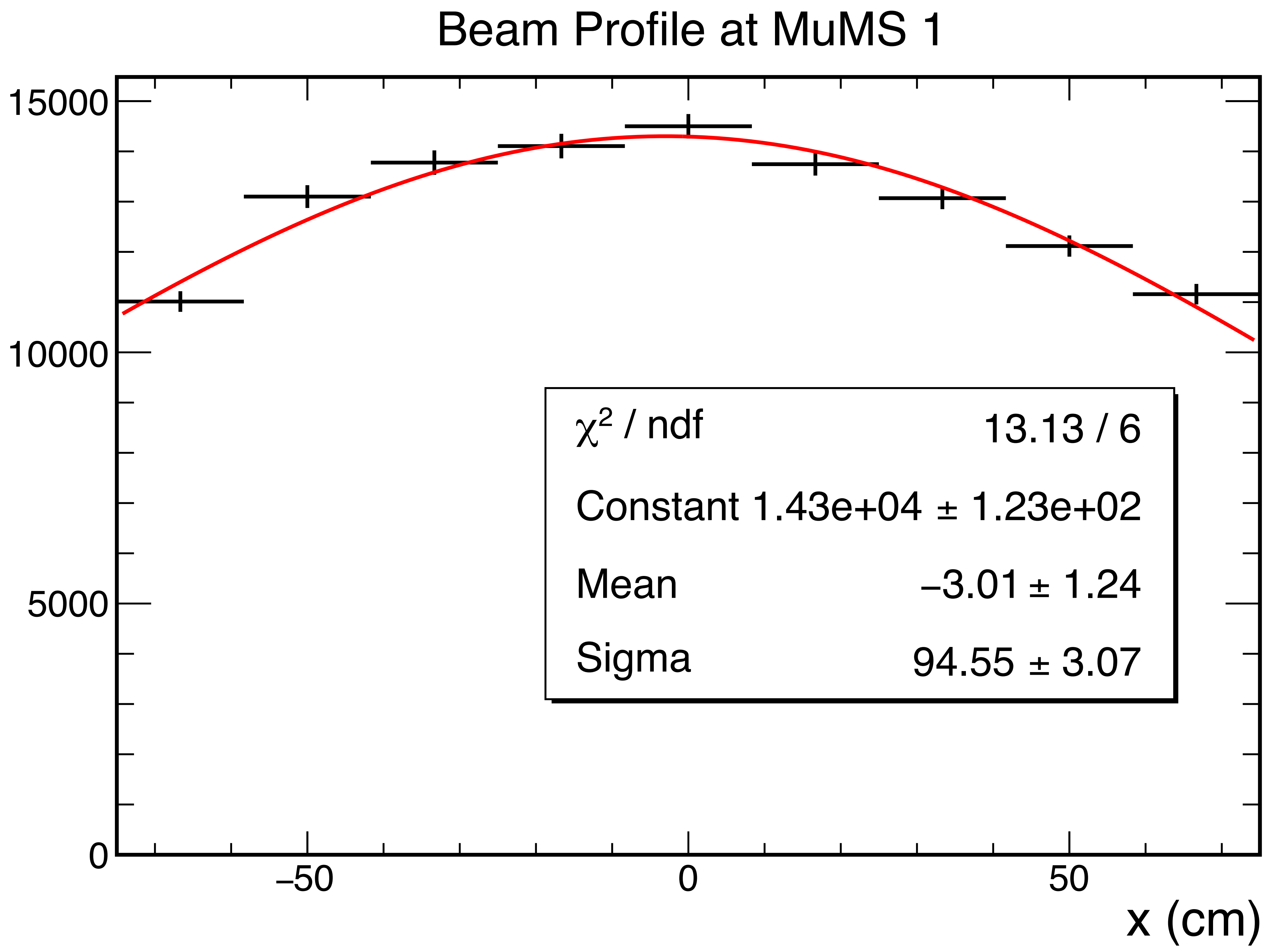
1. The MuMS must be capable of measuring the relative muon flux for each neutrino beam spill, and capable of providing feedback within the spill duty cycle such that beam can be shut-off before the next spill, at a minimum spill intensity of 7.5×10^{12} POT and maximum spill intensity of 7.5×10^{13} POT.

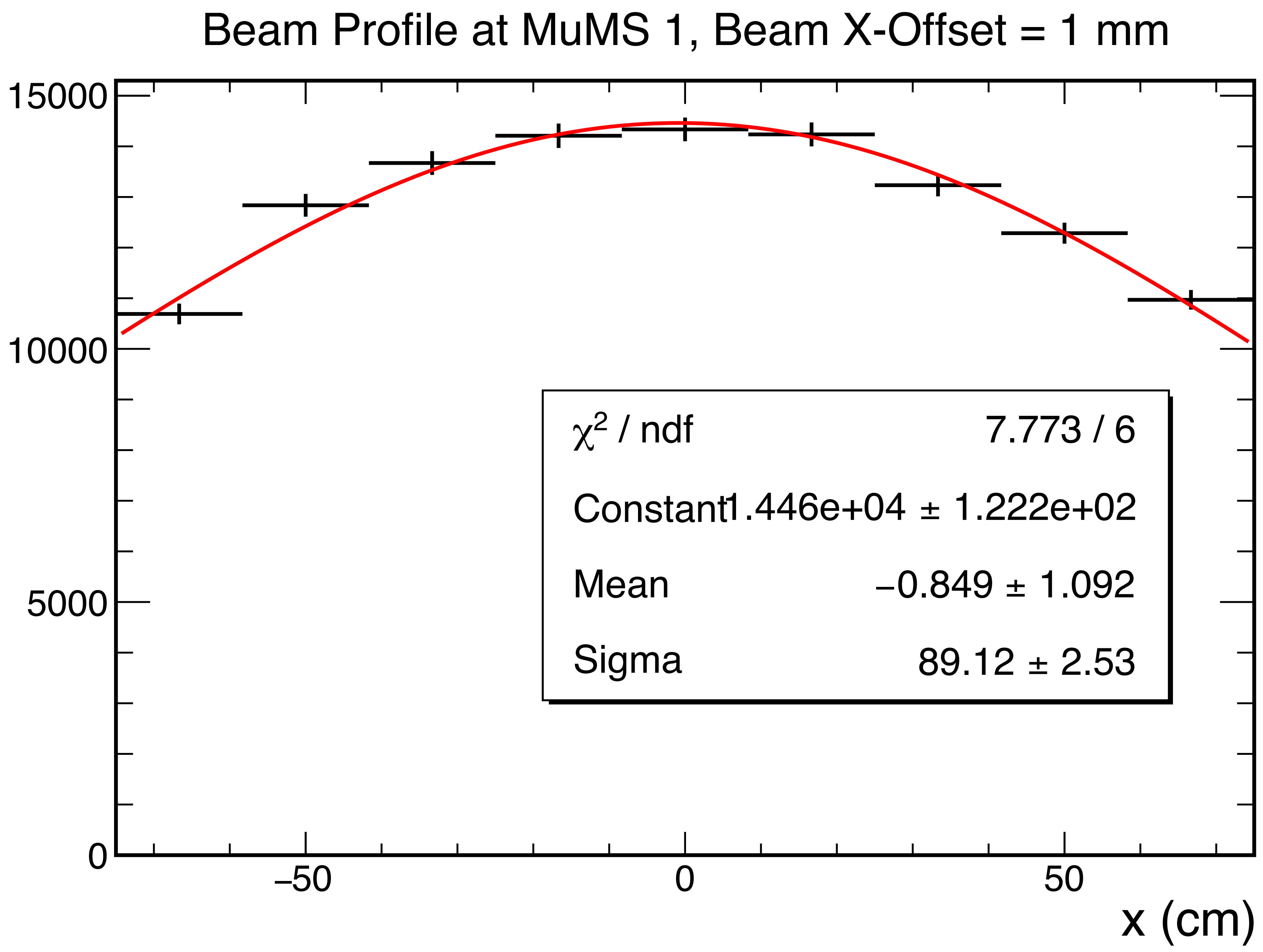
- We know from NuMI experience that these detectors meet this requirement.

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.

- Fits to simulated beam profiles indicate a ~1 cm uncertainty on the mean position.





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MuMS Requirement 3

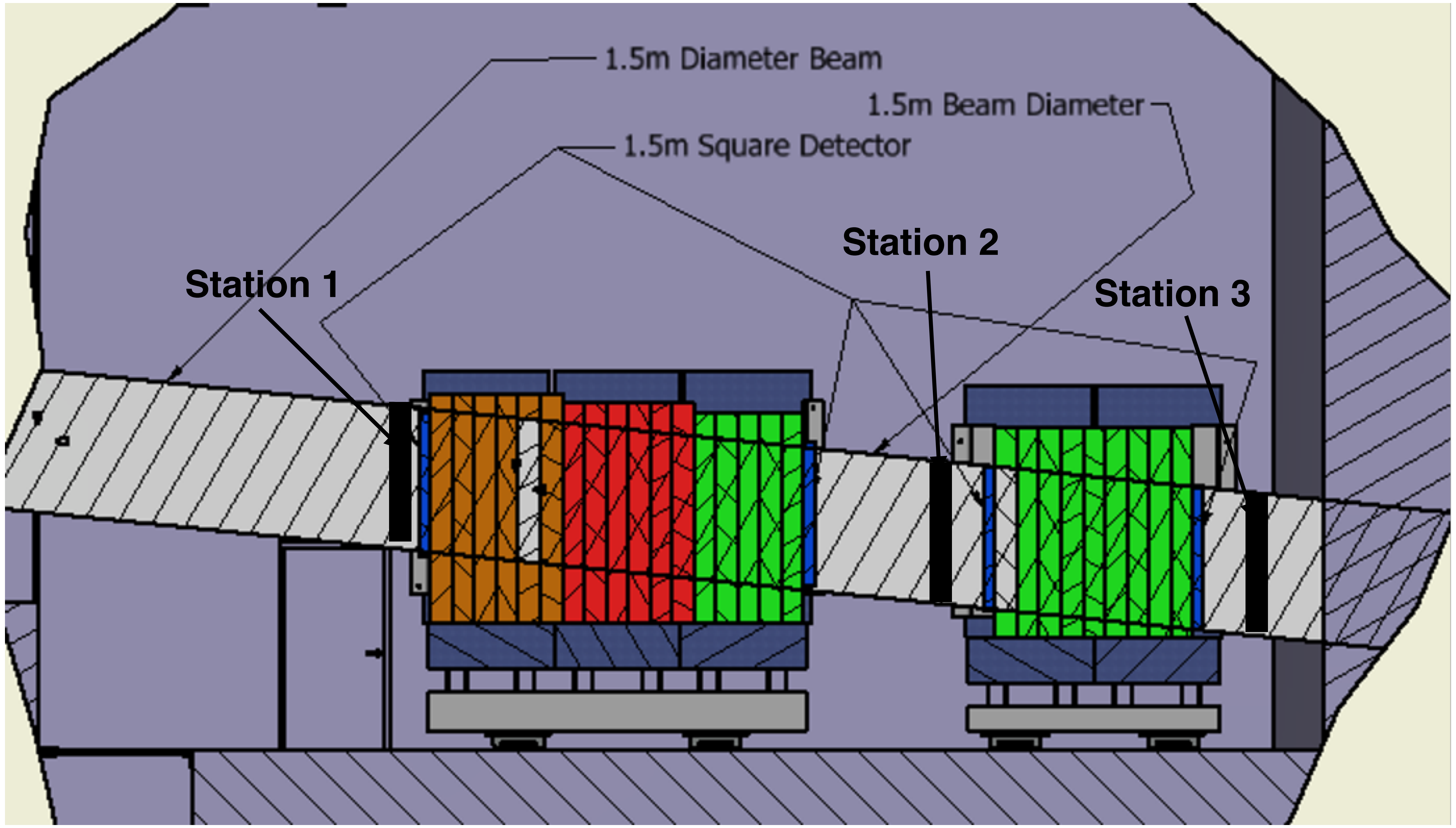
3. The MuMS must be capable of measuring the relative integrated muon flux passing through the detector to within 1% spill-to-spill.

- 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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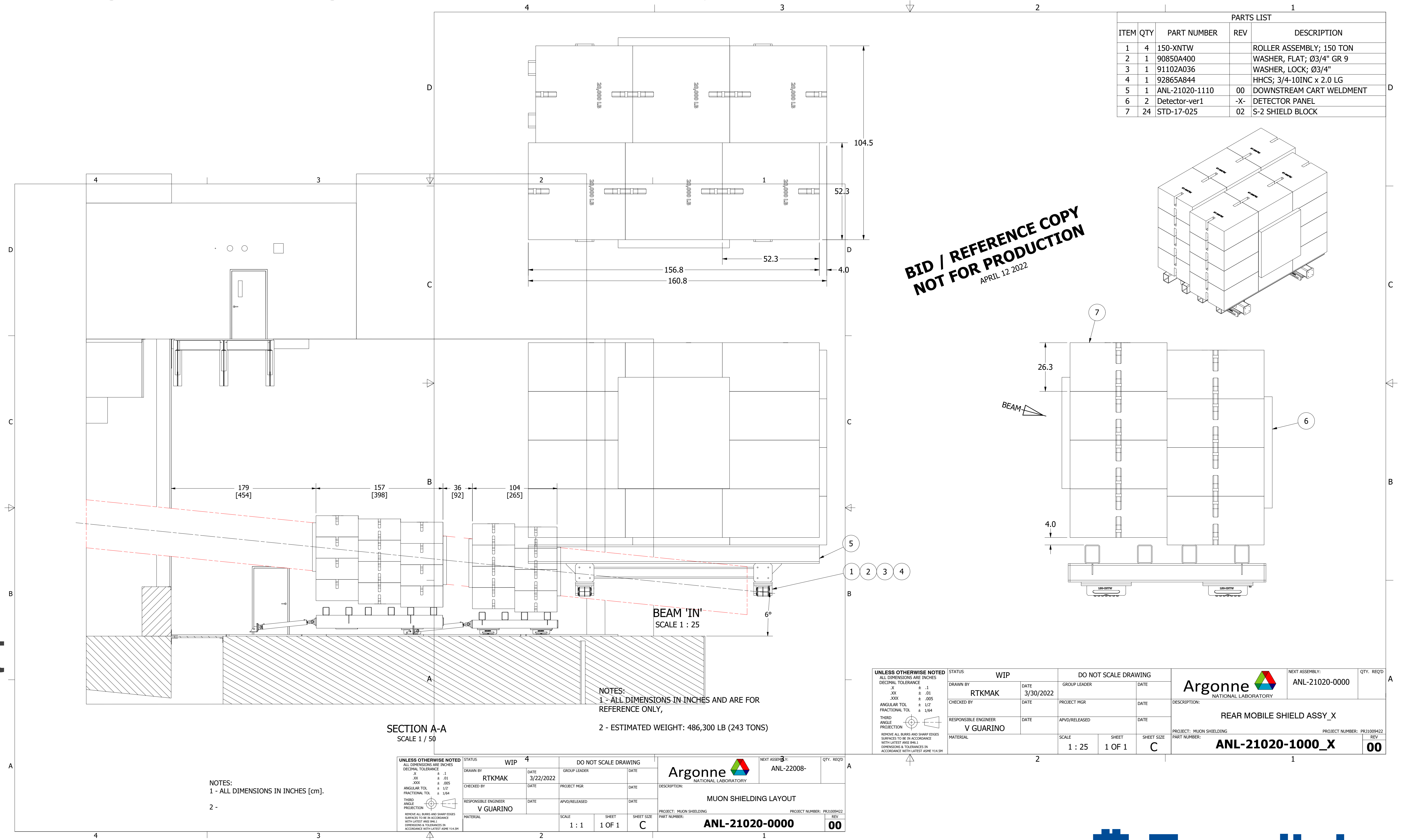
MuMS Requirement 4 - Shielding

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.

- Replacing the uniform steel plates with steel blue blocks significantly simplifies the design and assembly, and is much less expensive.
- However, this introduces small gaps, of up to 0.25” in size.
- Blocks will be staggered so that there will be no continuous gap through the shielding.



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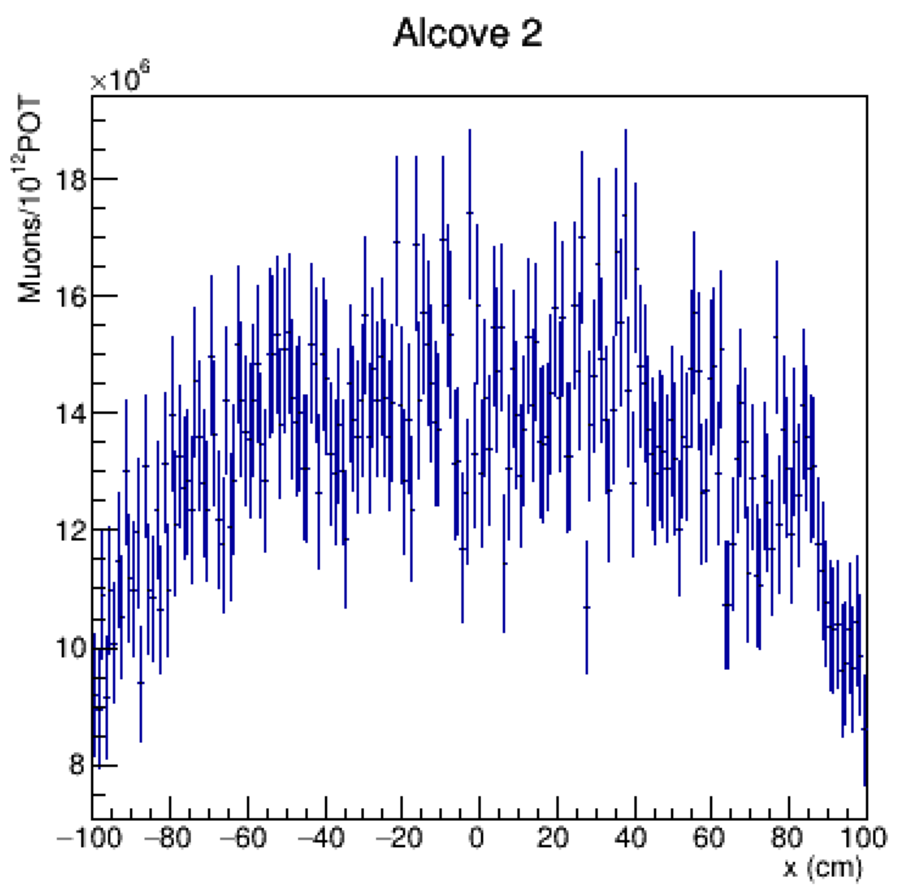
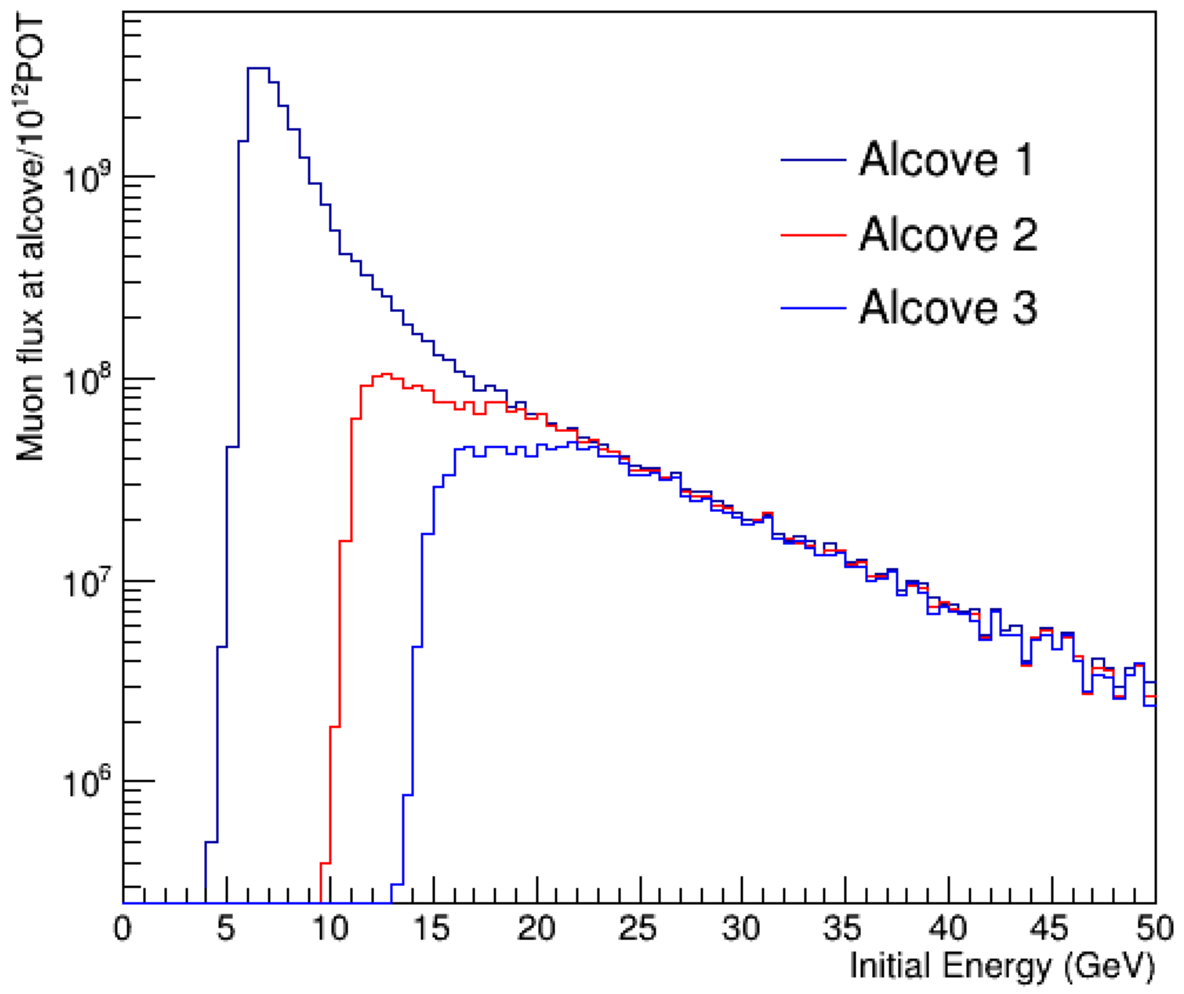
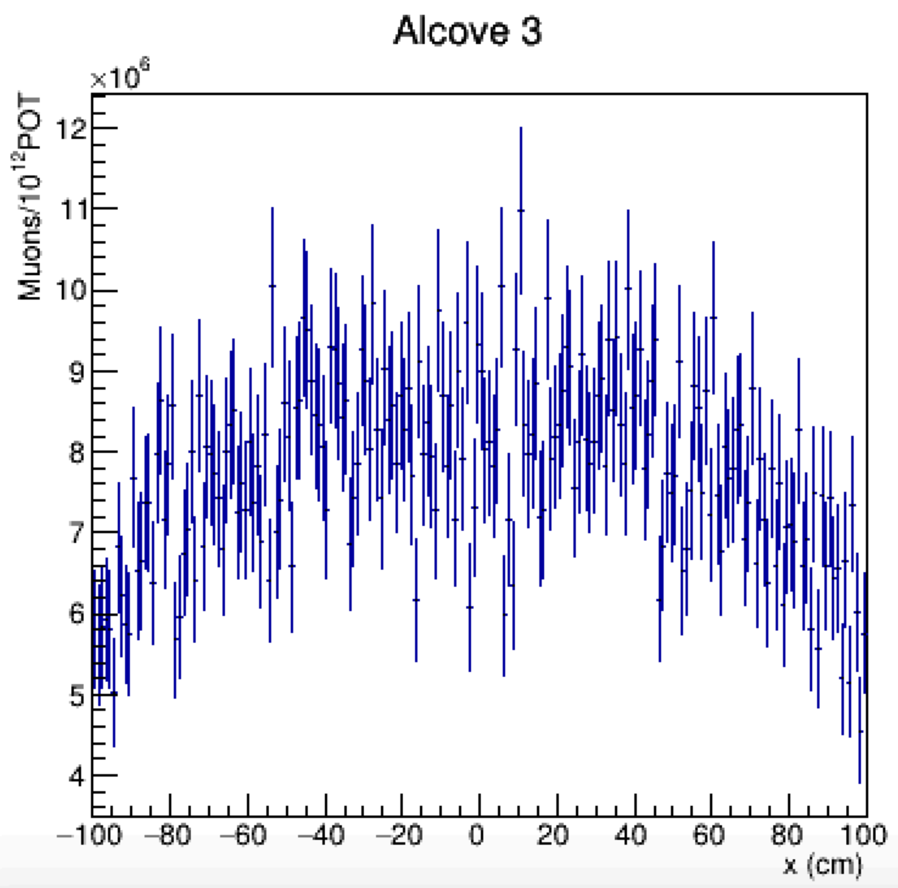
MuMS Requirement 4 - Shielding

No gaps

Preliminary studies, more simulations are being run to get more stats.

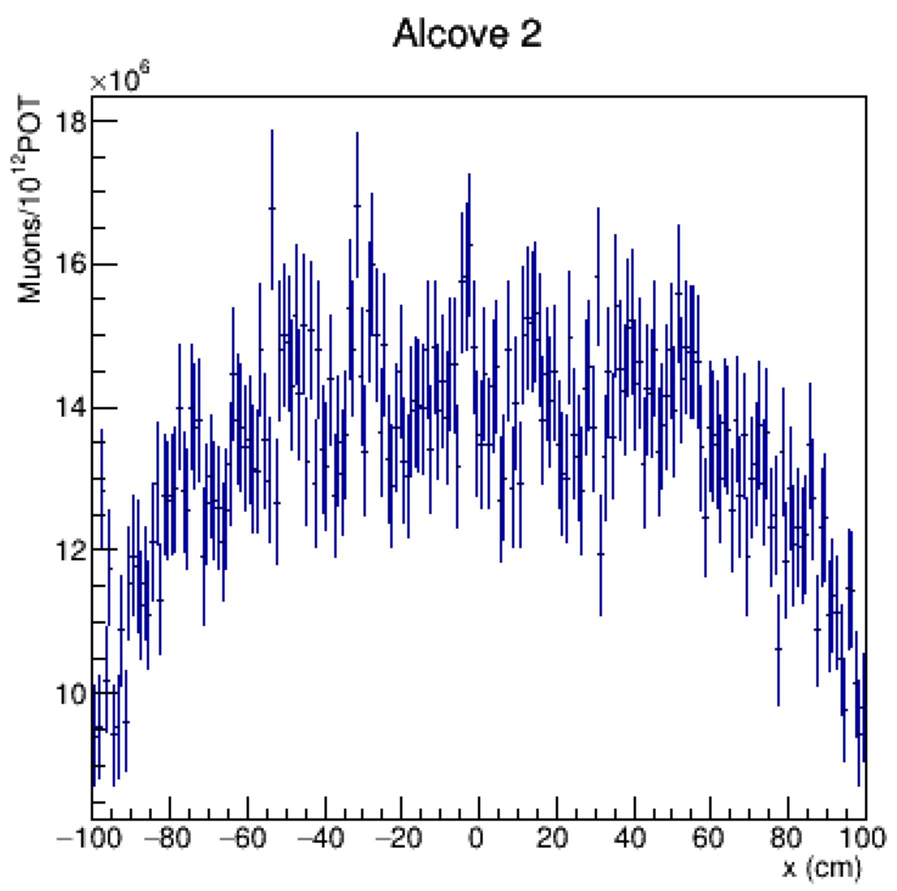


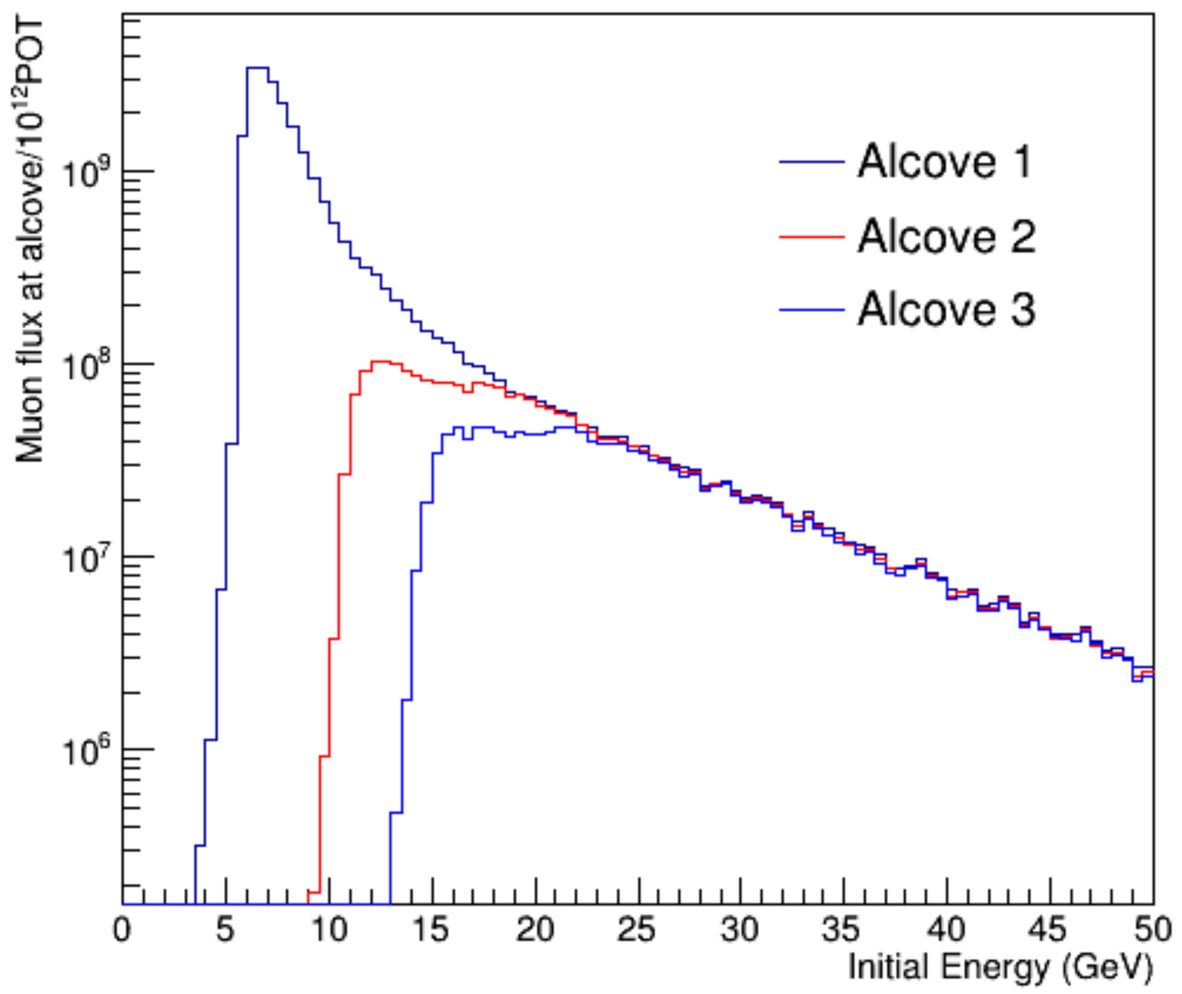


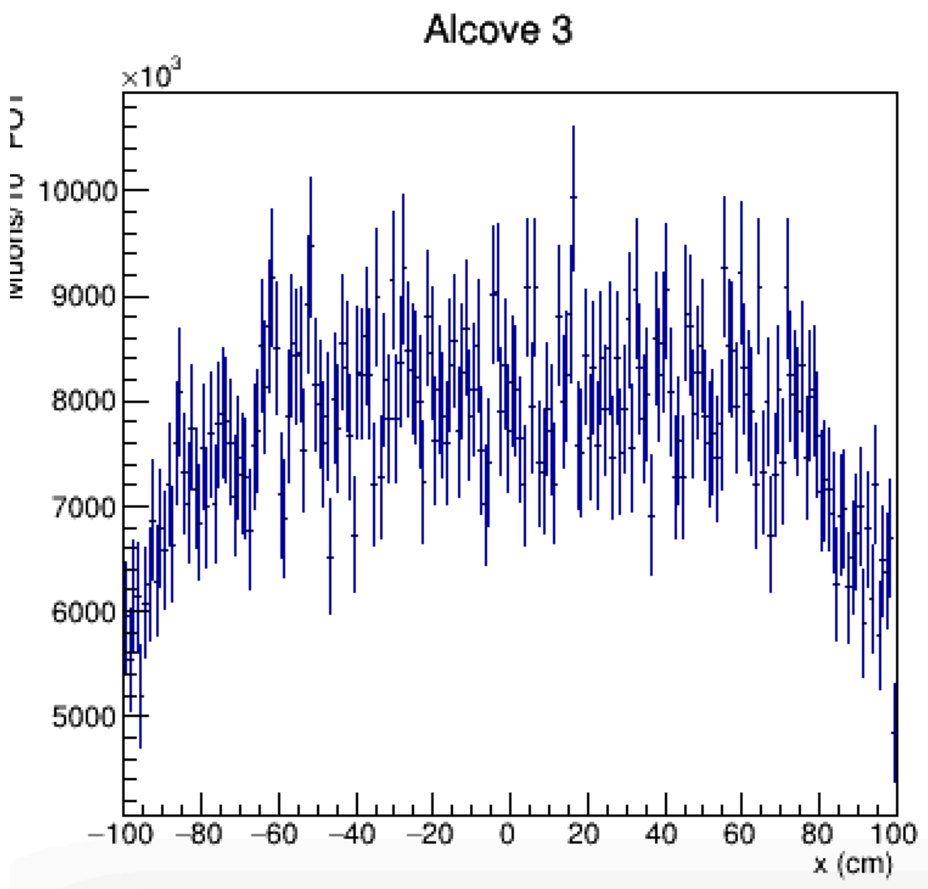


5mm gap

Preliminary results show no obvious signs of an impact from 5 mm gaps.







MuMS Requirement 5 - Readout and Data Access

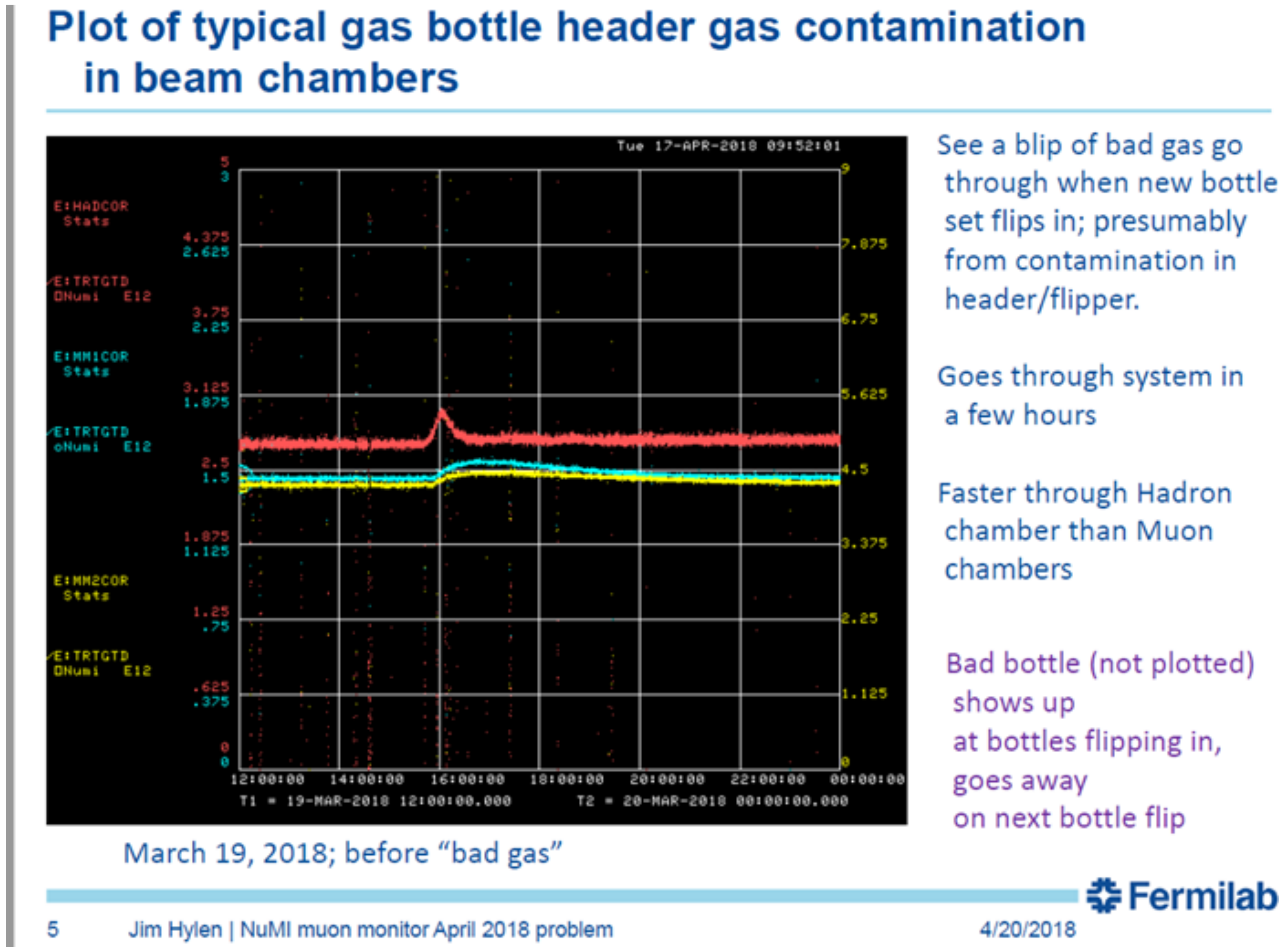
- Will use same electronics as for HADeS (SWIC)
- Will need 2 SWICs for 3 9x9 detectors.

Interfaces - Cables

- Infrastructure for running cables from the instrumentation room in LBNF30 to the detectors is being planned for.
- Cable runs and trays are in the CF designs.
- We will install 200(300) signal and 200(300) power cables for the HADeS(MuMS).

Interfaces - Gas System

- Will use a similar gas distribution system to that of NuMI.
- One line will run from the surface to the 2nd level of LBNF 30. Gas lines will split off there to both HADeS and MuMS.
- Will use He gas tanks (trailer size) to minimize the frequency of gas changeovers. Pumping and back-filling the gas lines also being considered.
- Gas lines are in the CF drawings.



Preliminary Installation Plan

- Gas lines and cables will be run prior to installation
- HADeS goes in after absorber is installed
- MuMS shielding will be installed before shielding overhead (via crane)
- MuMS detectors will be installed after shielding.
  - Likely will install most-downstream first.
  - Shielding is on rails and will be moved to install the detectors. Most important for the most downstream station.