LBNF Instrumentation

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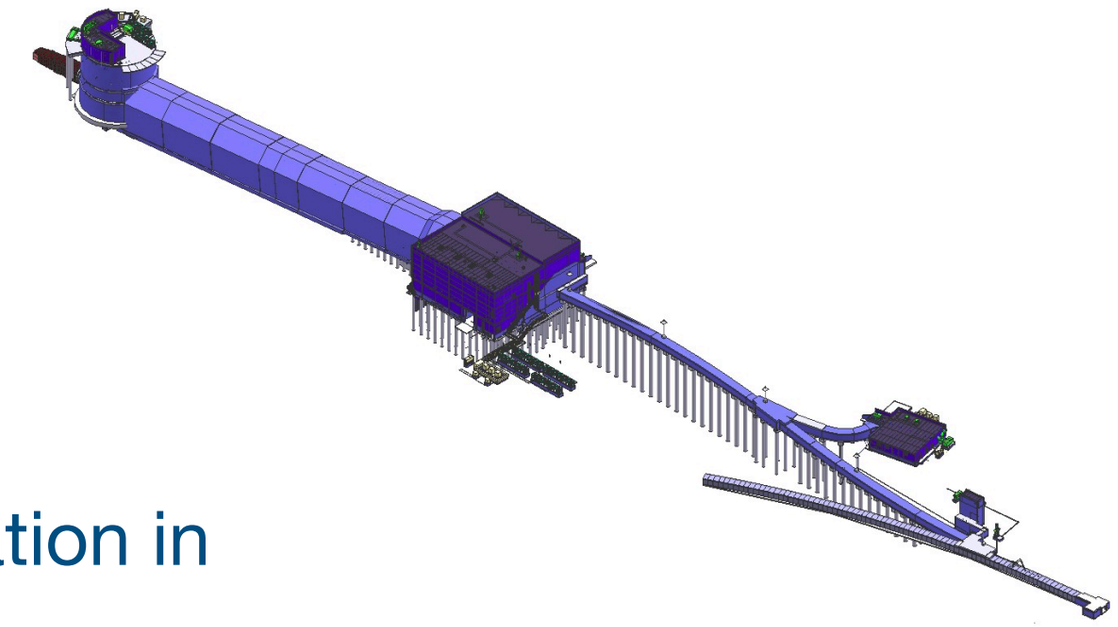
Requirements

- Require well controlled neutrino beam with minimal systematic errors
- No significant contribution to neutrino flux systematic error or impact on physics measurements
- Tolerances
  - Proton beam angle: 70 μrad
  - Proton beam position: 0.5mm, profile: 10%
  - Baffle beam scraping: 1%
  - Target and Horn A/B/C displacement (transverse/tilt): 0.5mm

Instrumentation

- Systems designed to meet the requirements
- Align beamline elements within the tolerance
  - Beam based alignment - BPMs, **Cross Hairs/BLMs, HADeS**
- Monitor the beamline elements during running
  - **HLS, MuMS**
- Maintain the beam on target
  - **TPT**
- Next slides cover the instrumentation in upstream to downstream order

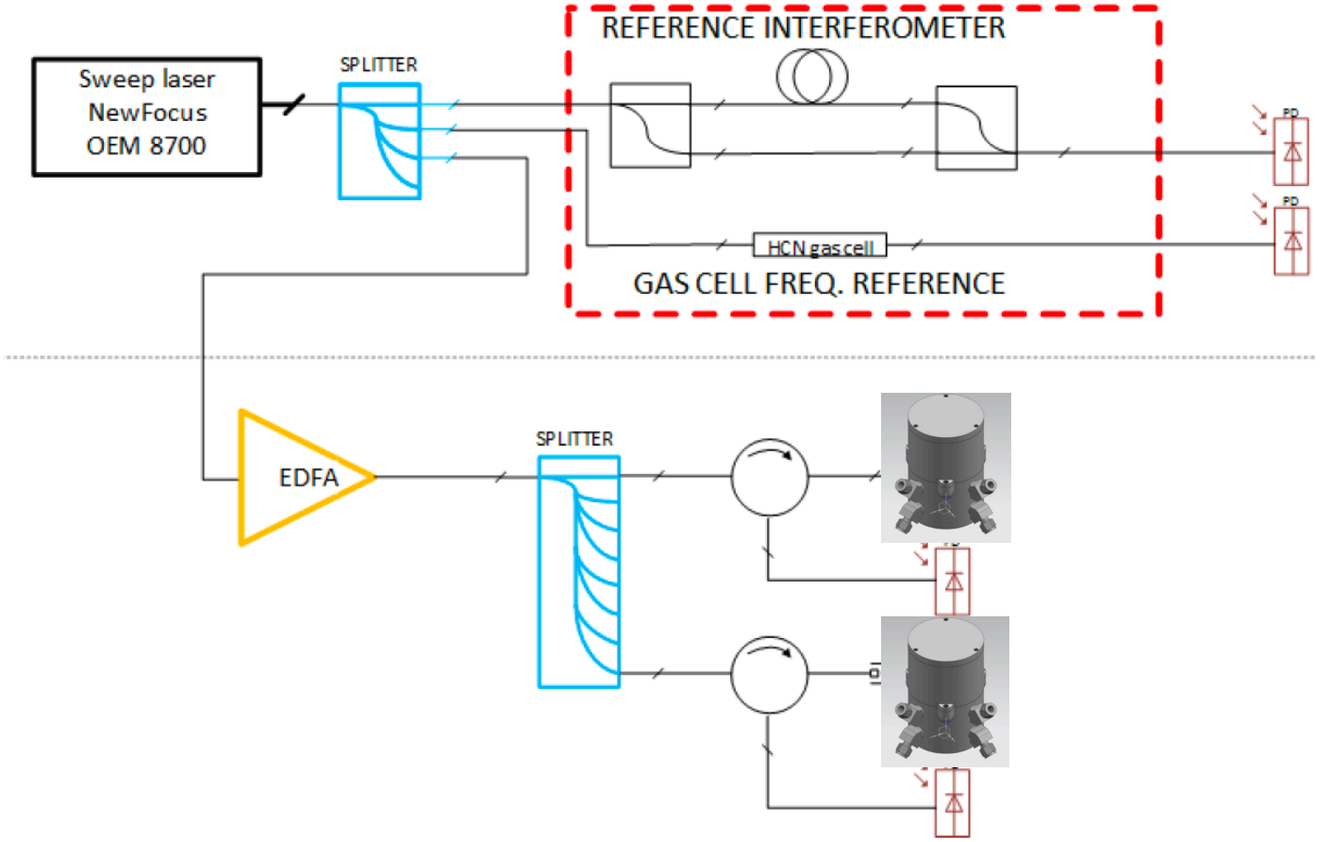


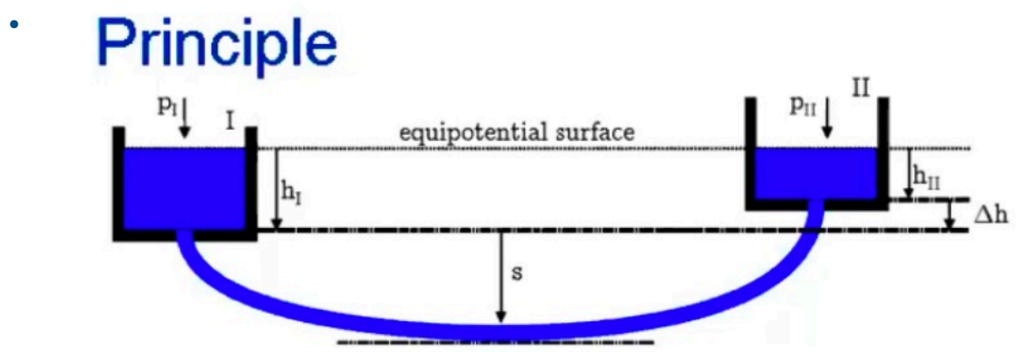
Hydrostatic/Horn Level System

- Monitor vertical shifts of beamline components (pre target BPMs, Baffle, Horns)
- Motivation
  - After aligning beamline no direct measurement of movement (thermal expansion, mechanical failure, shielding settling)
  - NuMI experience
    - Bushing failed on horn support, one end of horn moved 3 mm down vertically
      - Did not diagnose this until 1 year later during beam-based alignment
    - Calibration of one pre-target proton Beam Position Monitor drifted made it seem like target moved

HLS

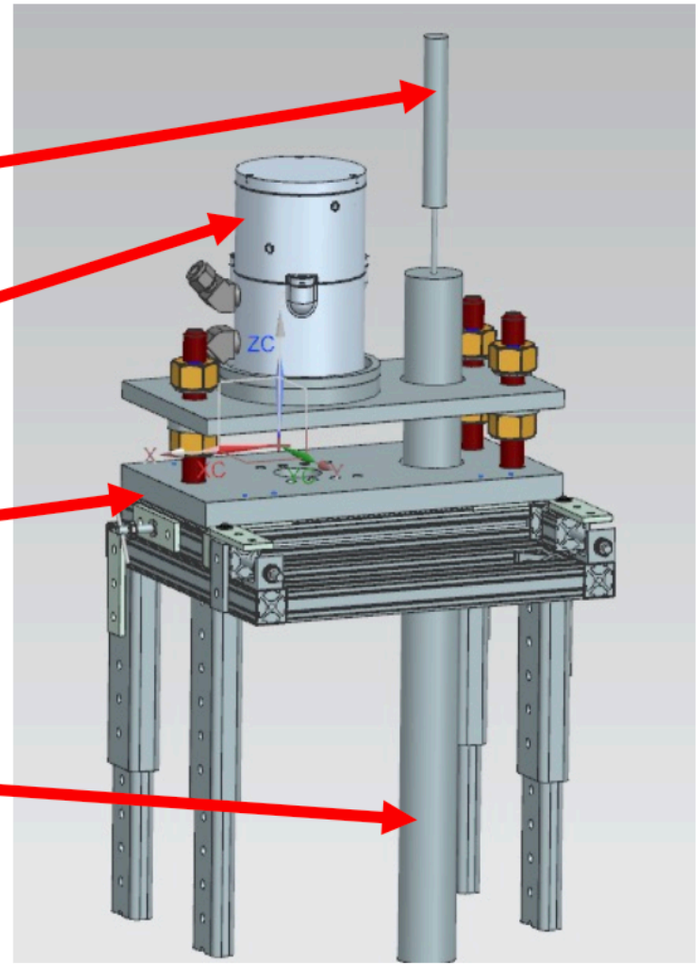
- Uses water level to transfer height between sensors
- CERN sensors based on Frequency Scanning Interferometry (FSI)
- Simultaneously compare multiple interferometers to same reference
- Can sustain radiation on top of LBNF modules (5 to 50 Kilo-rad)



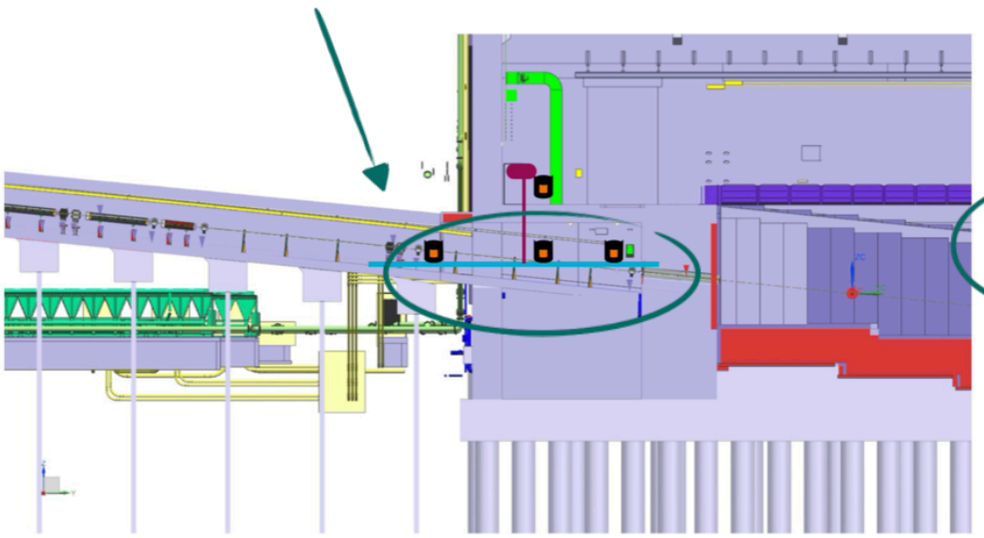


LBNF HLS

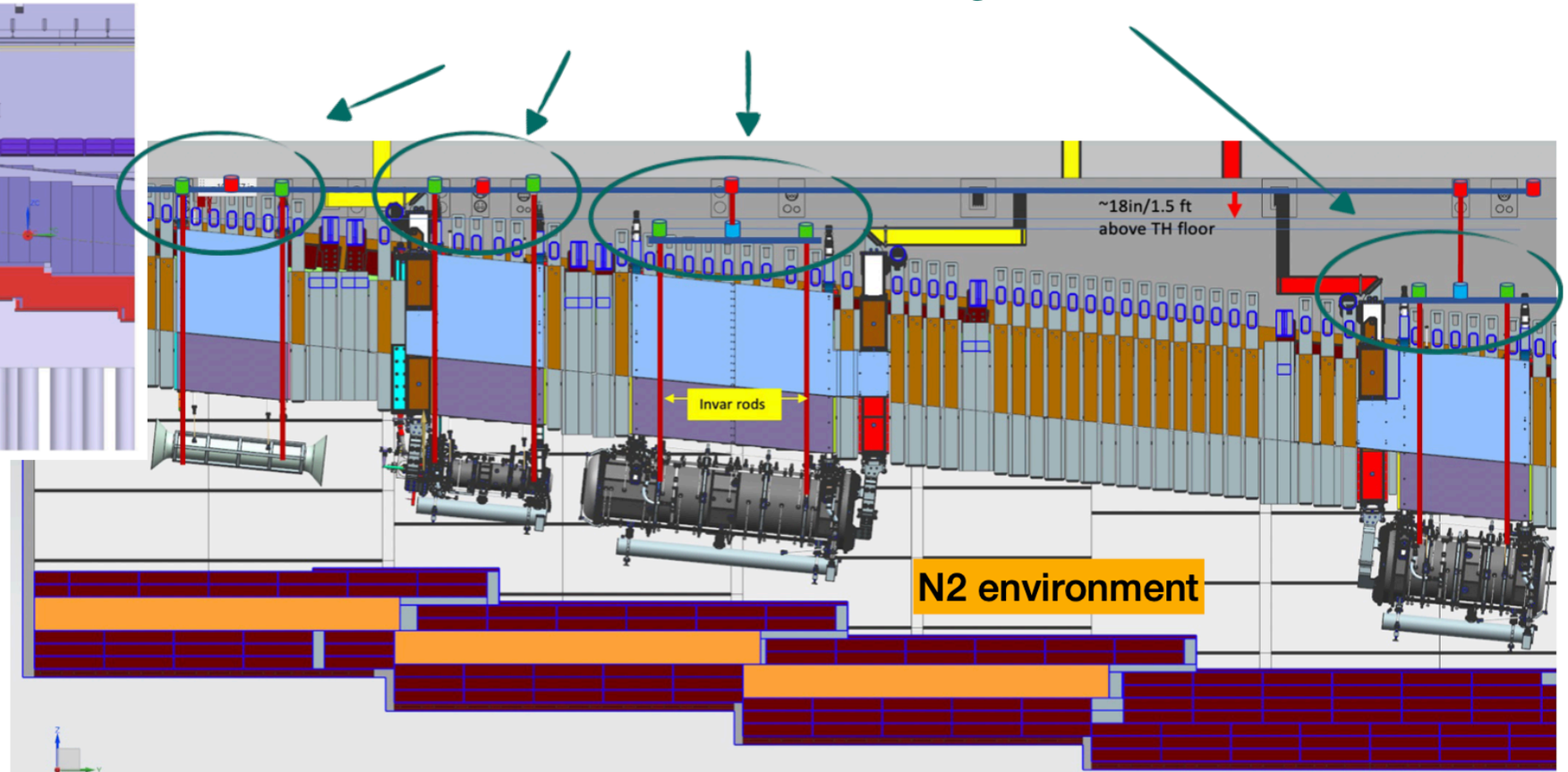
- In target hall HLS sitting on a stand on top of T-blocks, measure movement of T-block w.r.t battlement
- Invar rods connected to horn(baffle), monitored with LVDTs



Next to BPMs in Primary Beamline (PBE)



Above baffle and horns inside target chase

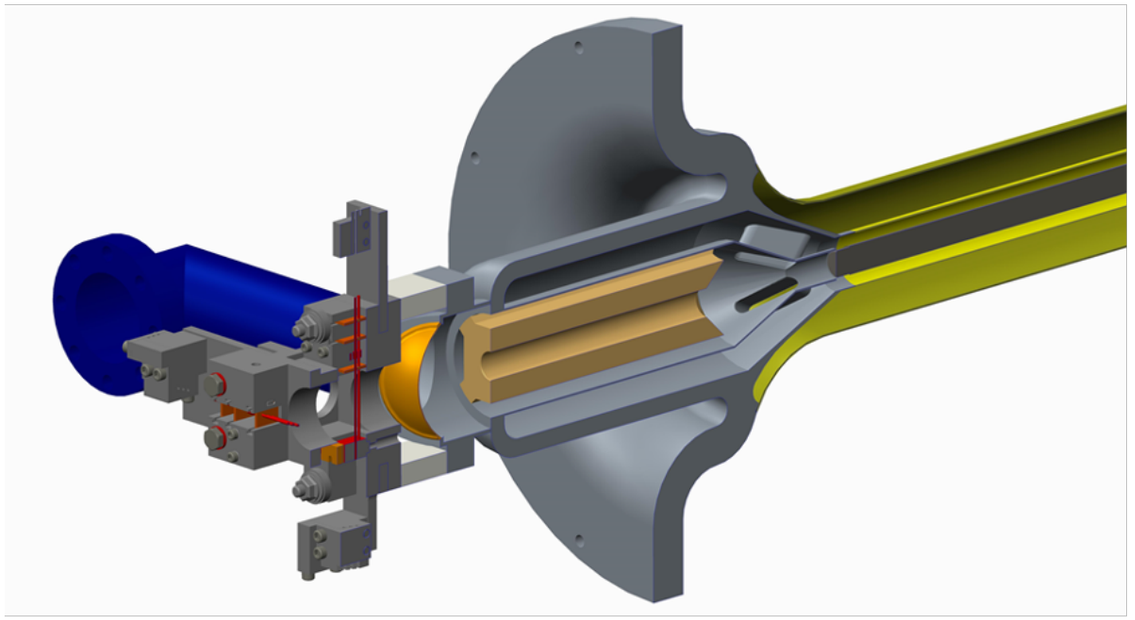


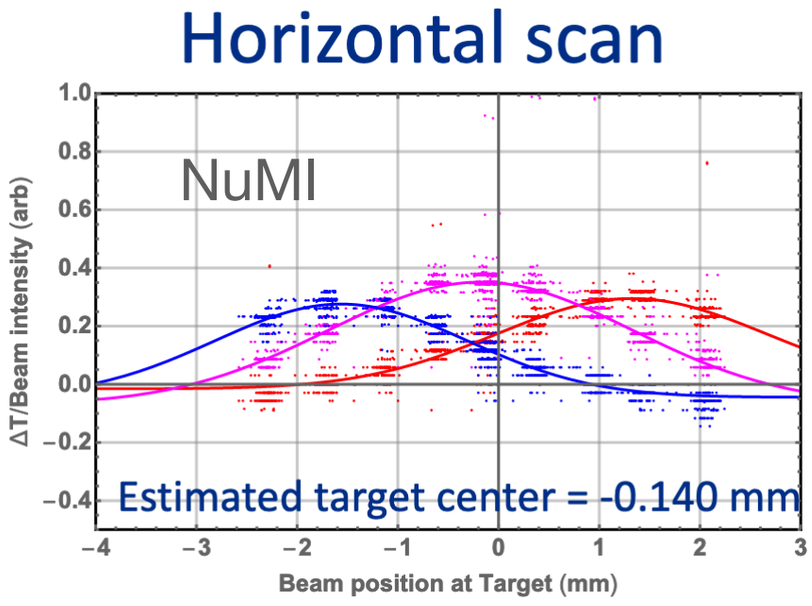
Monitoring beam on target

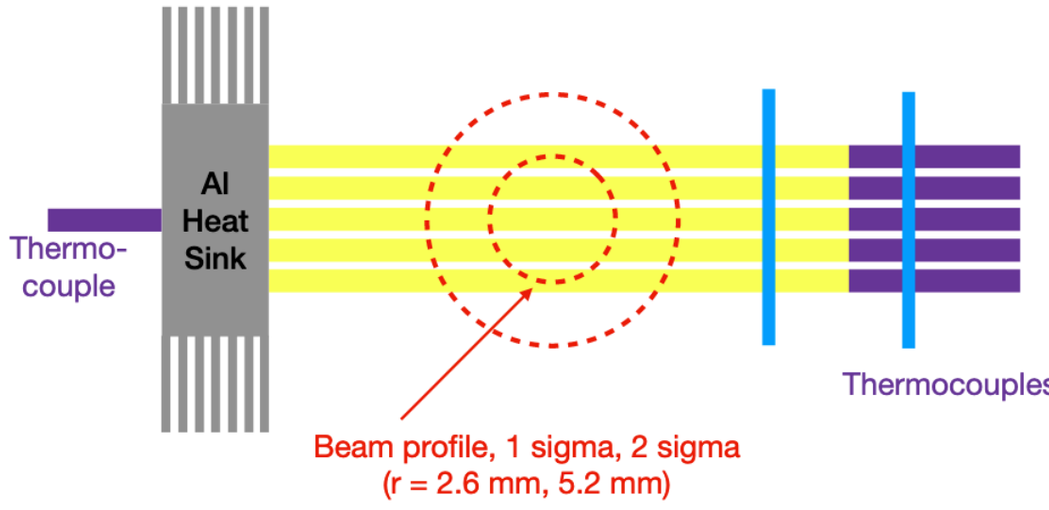
- Beam position monitors will be used to steer beam on target
- Beam based alignment finds the target and all other elements within BPM coordinates
  - Dedicated study time (occasional - beginning/end of run)
    - Low intensity/single batch, 1mm RMS beam size
- Need to control for:
  - BPM intensity dependence
  - Calibration drift (geometric vs electrical center)

Target Position Thermometer (Hylen device)

- Simple and robust device to measure beam on target
  - Measurements with full intensity
  - NuMI experience resolution and stability below **0.1mm**
- Complementary to BPMs
  - Slow device, not pulse by pulse measurement
- LBNF modifications:
  - Change from 3 -> 5 strips
  - Heat sink with cooling fins



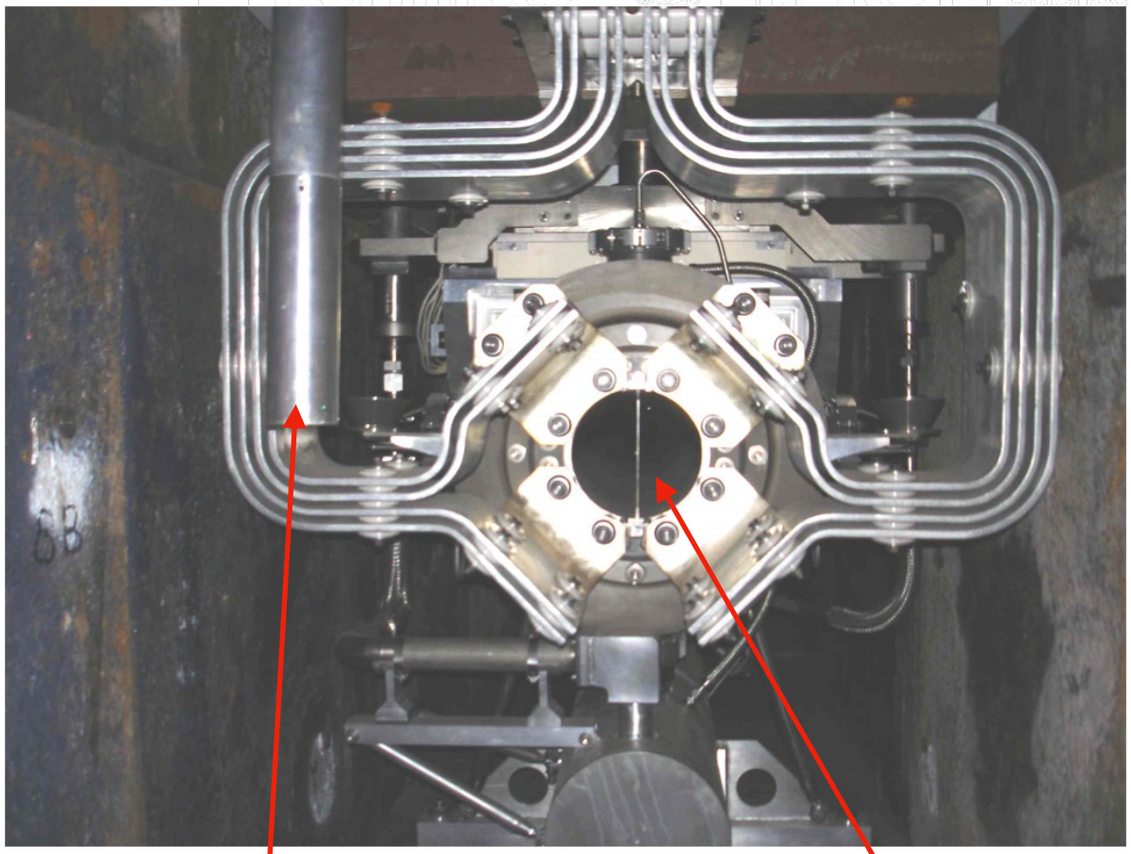


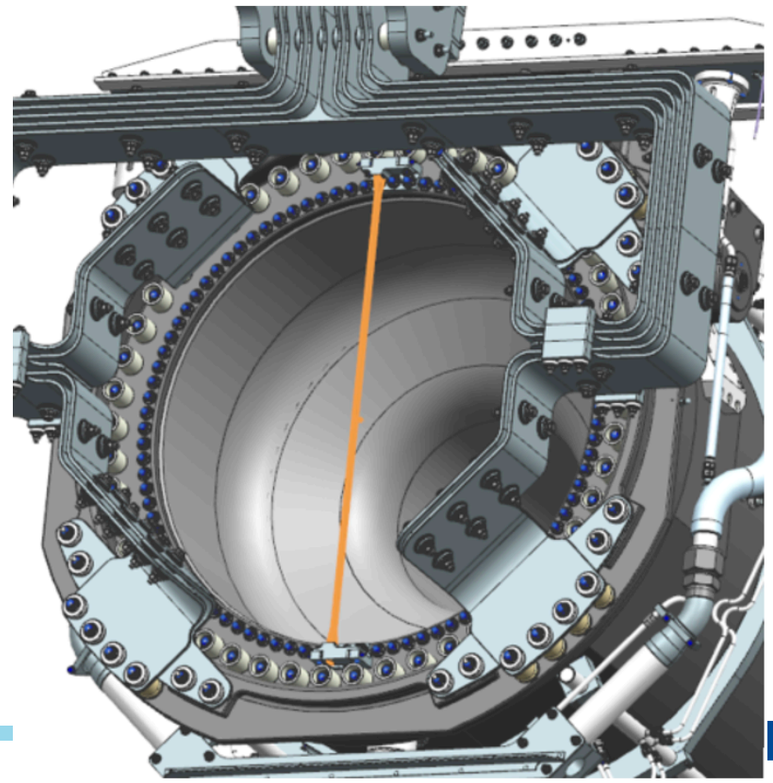


Cross Hairs/BLMs

- Horn B & C aligned as part of the beam based alignment
- Scan beam across the known physical features to locate each element
- Use cross hairs at upstream and downstream ends of horns B & C
- Beam loss monitor to detect beam scatter from cross hairs

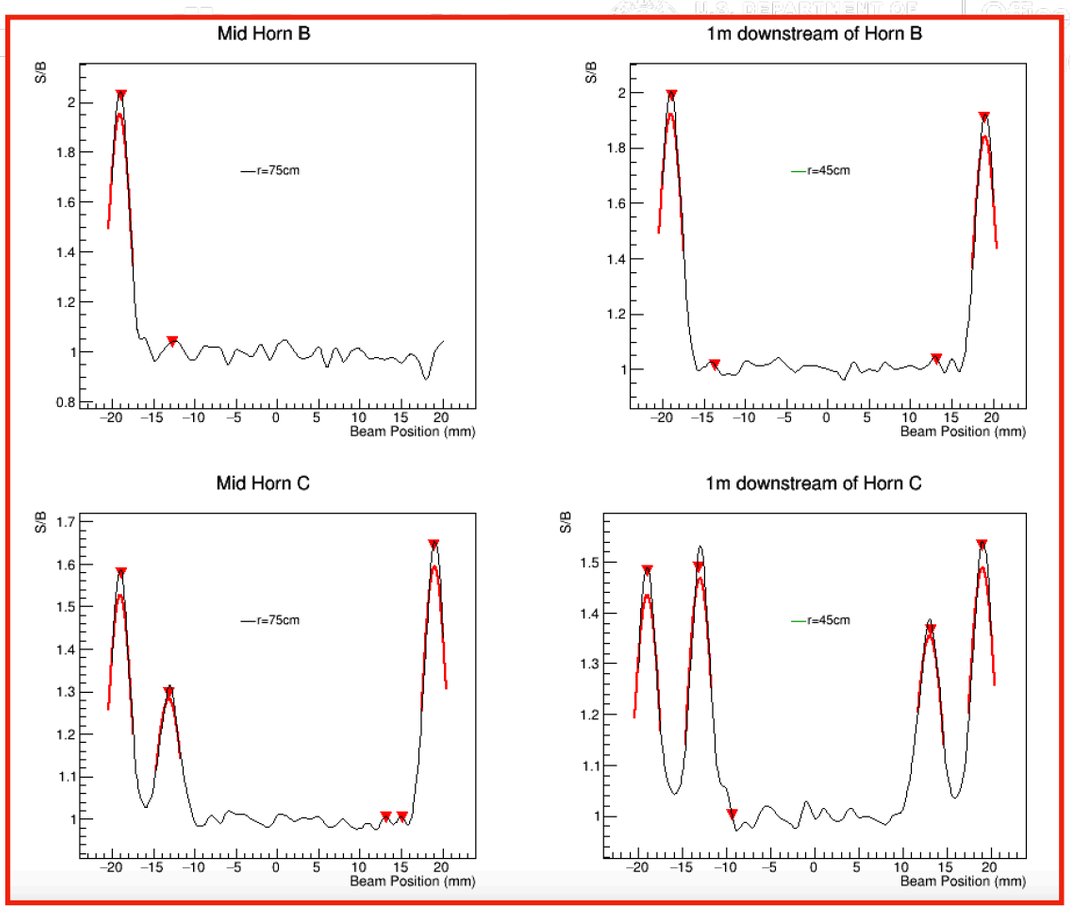
NuMI Horn

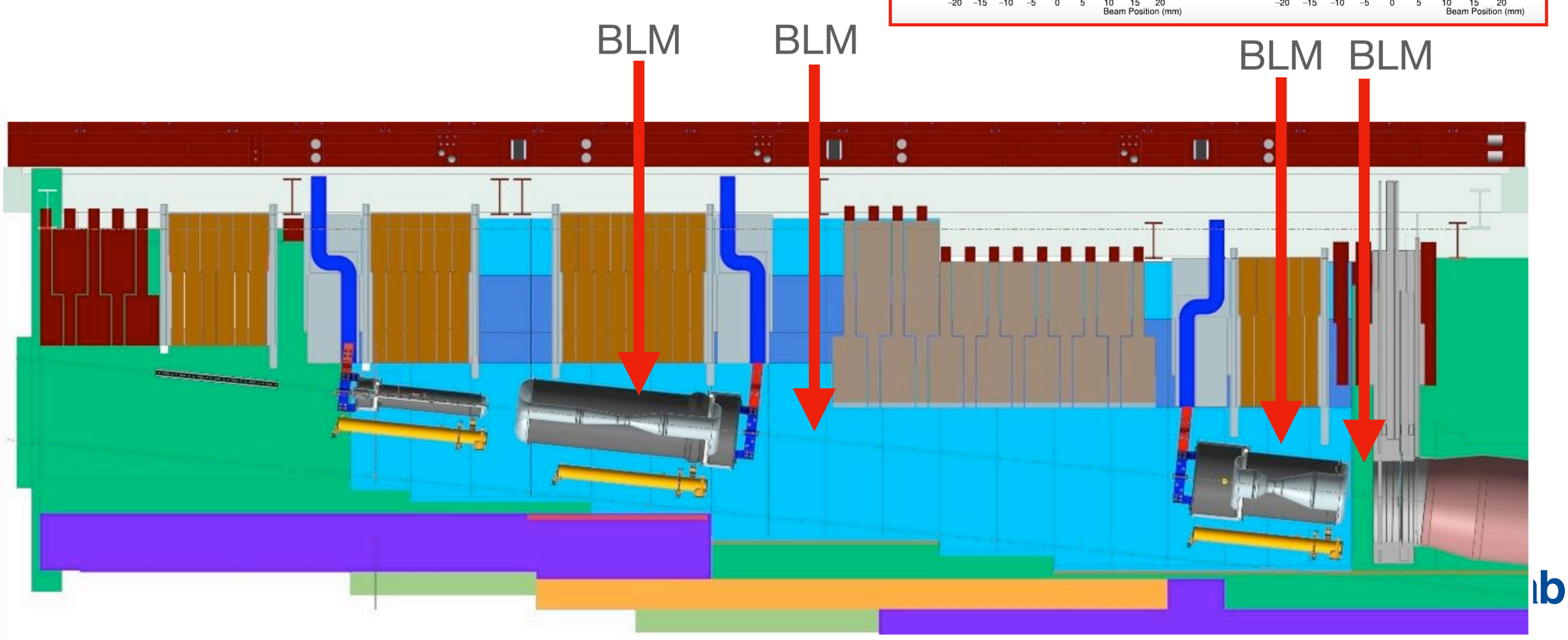




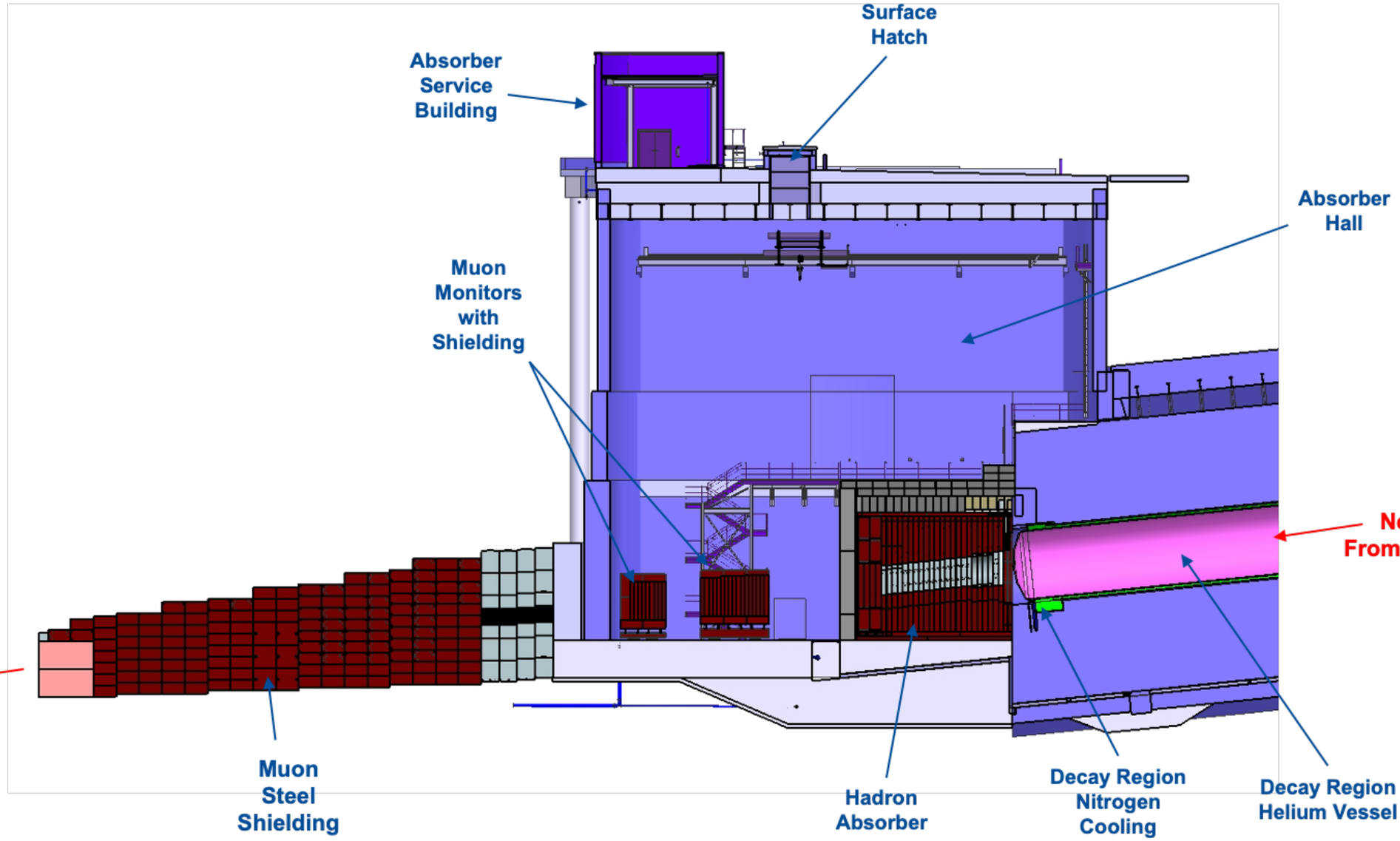
Cross Hairs/BLMs

- BLMs in 4 planes on left and right beam side following the US/DS cross hairs on horn B & C



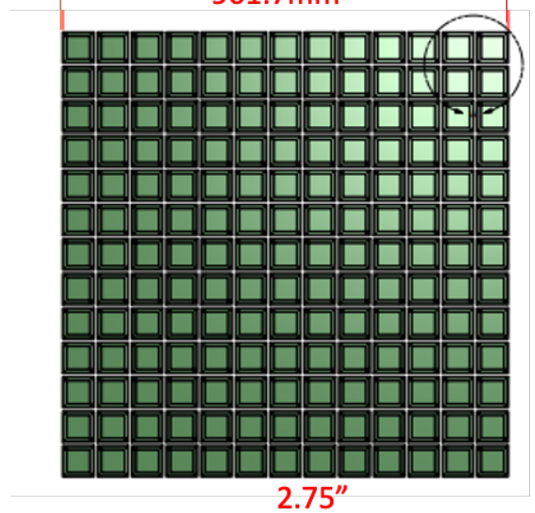


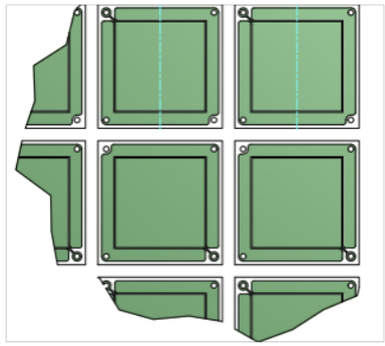
HADeS & MuMS

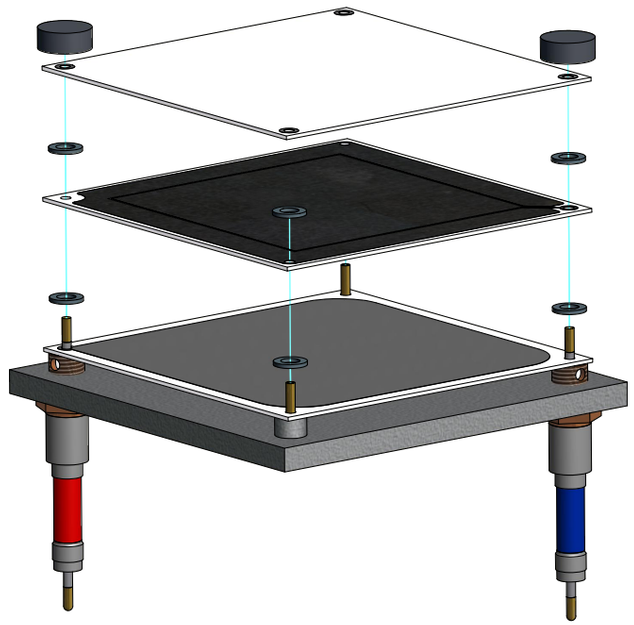

Surface Hatch
Absorber Service Building
Absorber Hall
Muon Monitors with Shielding
Neutrino Beam From Target Complex
Neutrino Beam to SURF, SD
Muon Steel Shielding
Hadron Absorber
Decay Region Nitrogen Cooling
Decay Region Helium Vessel

Hadron Alignment Detector System (HADeS)

- Used to establish beam direction, and for beam based alignment of Target/Horn A and Baffle
- Preliminary design is based on technology used in NuMI
  - Array of ionization chambers
- Measure centroid position, integrated intensity, RMS changes
- Optimize pixel size and number of channels for LBNF

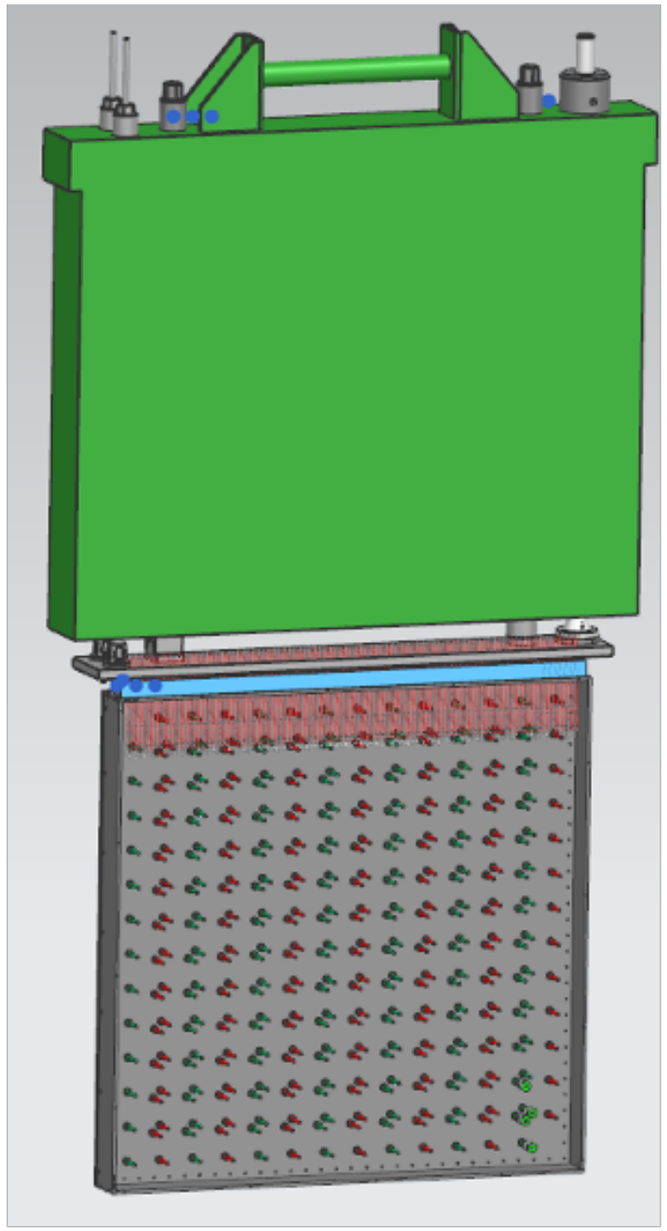






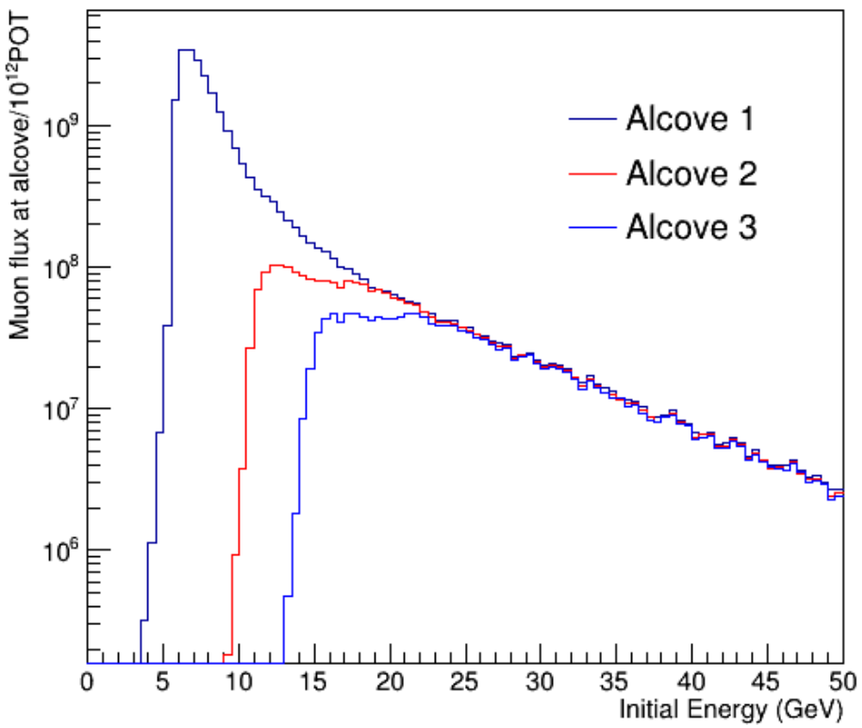
HADeS

- Need ability to replace in case of failure
- Inserted in the beam only for alignment, retracted during normal operation
- Required 0.5mm alignment precision when inserting

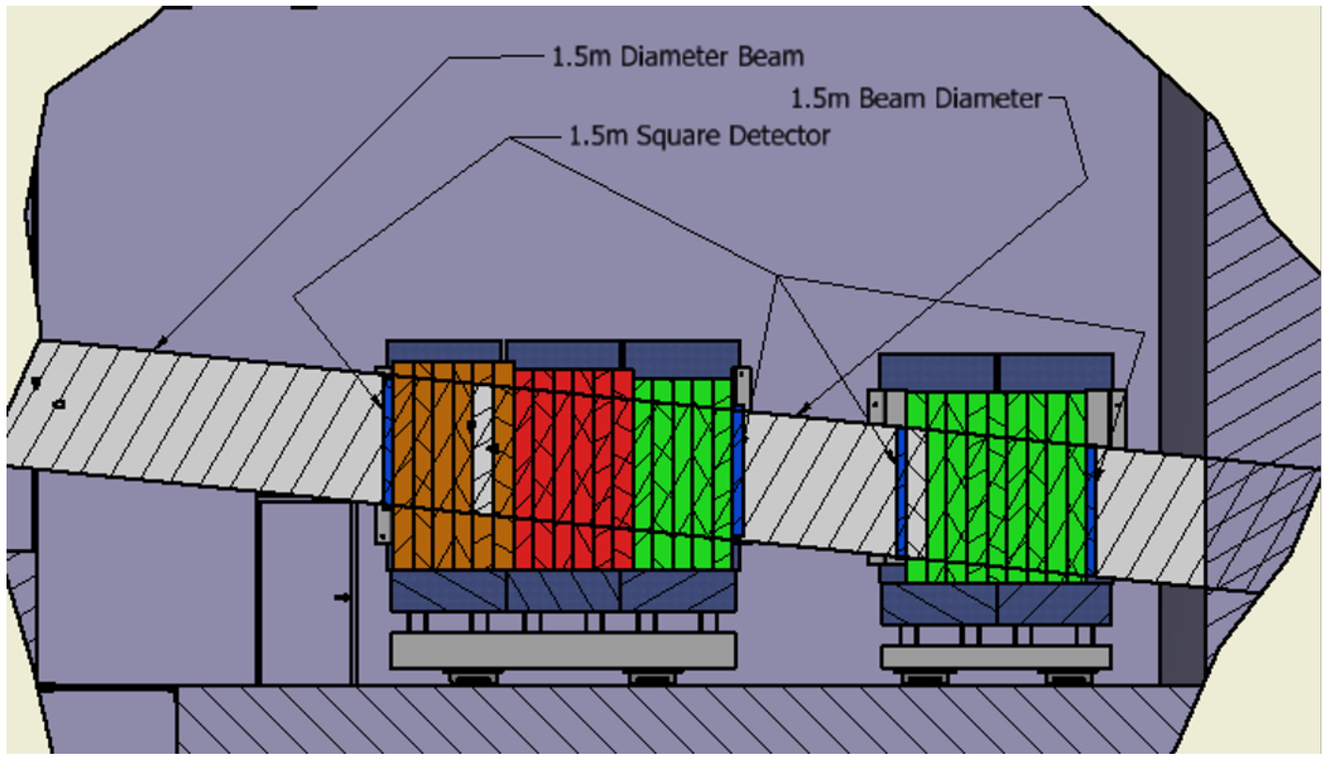


Muon Monitor System (MuMS)

- Sensitive to beam focusing problems, and measure beam centroid
- Similar to NuMI approach, same technology as HADeS
  - Improved gas system to maintain 1% spill-to-spill integrated flux normalization
- 3 stations with muon thresholds at 5, 11 and 15 GeV
- Stations separated by steel blue blocks (staggered in x and y)

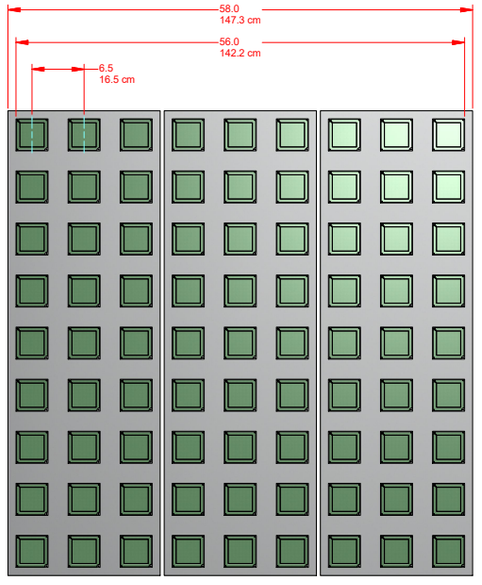


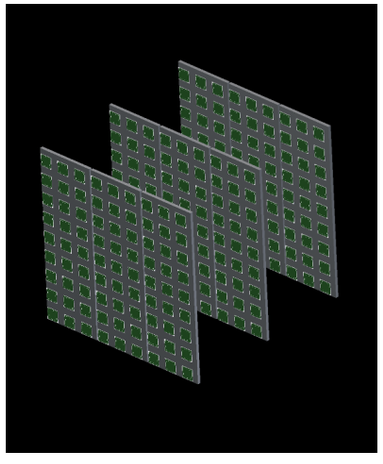
Beam

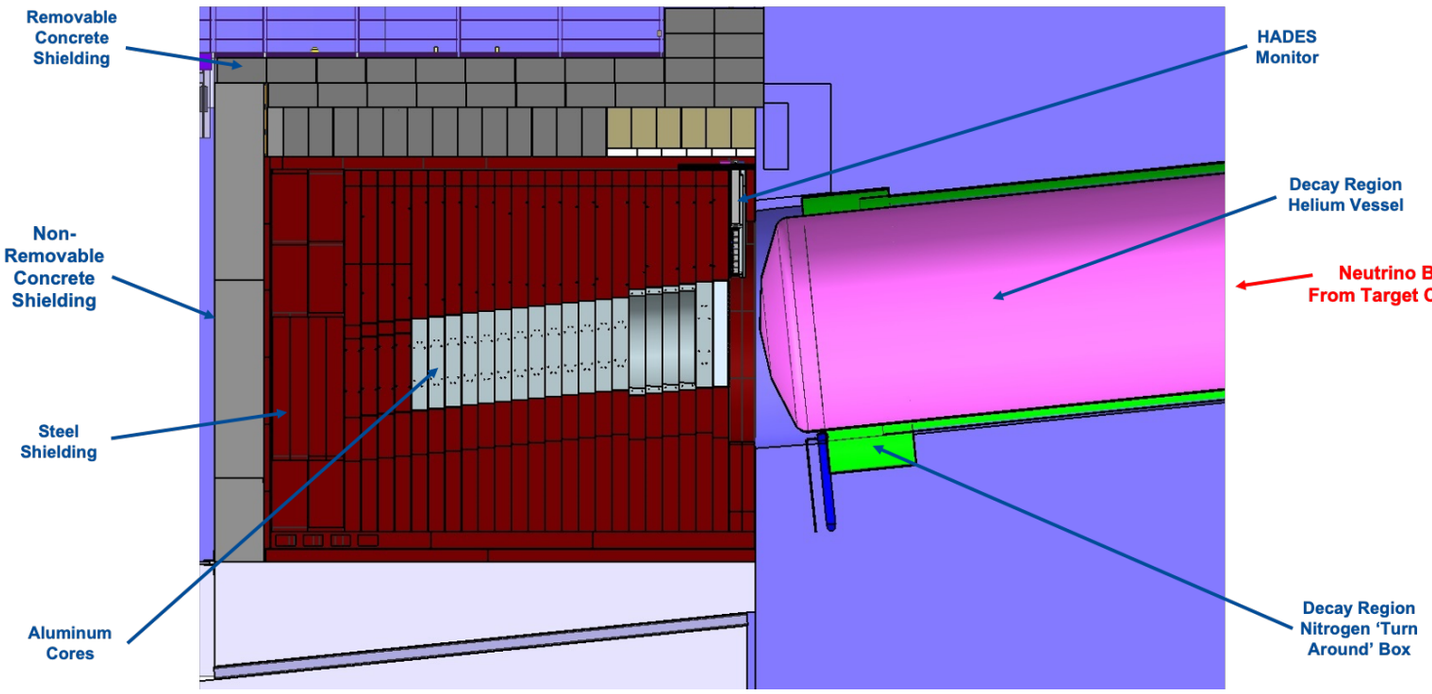


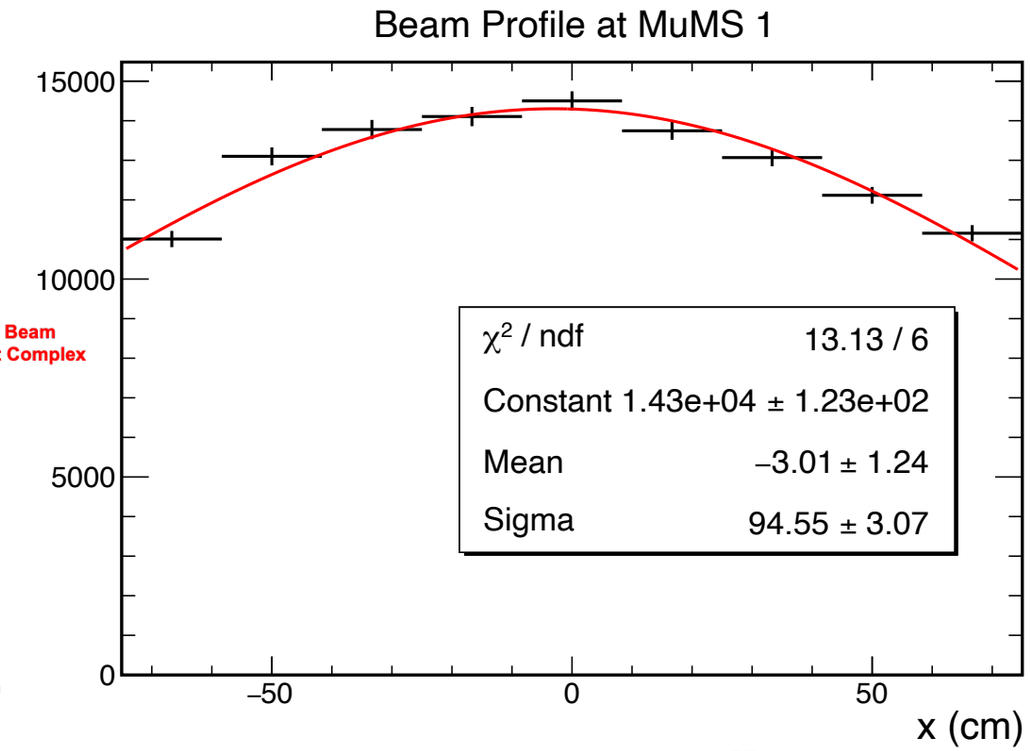
Beam profile at MuMS

- Expect to see beam profile with O(1cm) precision on centroid
- Sensitive to beam misalignment
- Sculpting by hadron absorber - introduces some model dependence on centroid absolute position









Summary

- Target Position Thermometer, Cross hair/BLM system, HADeS, and MuMS build on exhaustive experience with NuMI
  - Adapting existing design
  - Demonstrated required functionality
- Developing new HLS system to monitor vertical displacements
  - Prototype test to take place next summer