Installation, alignment, and commissioning of primary and secondary beamline components for LBNF

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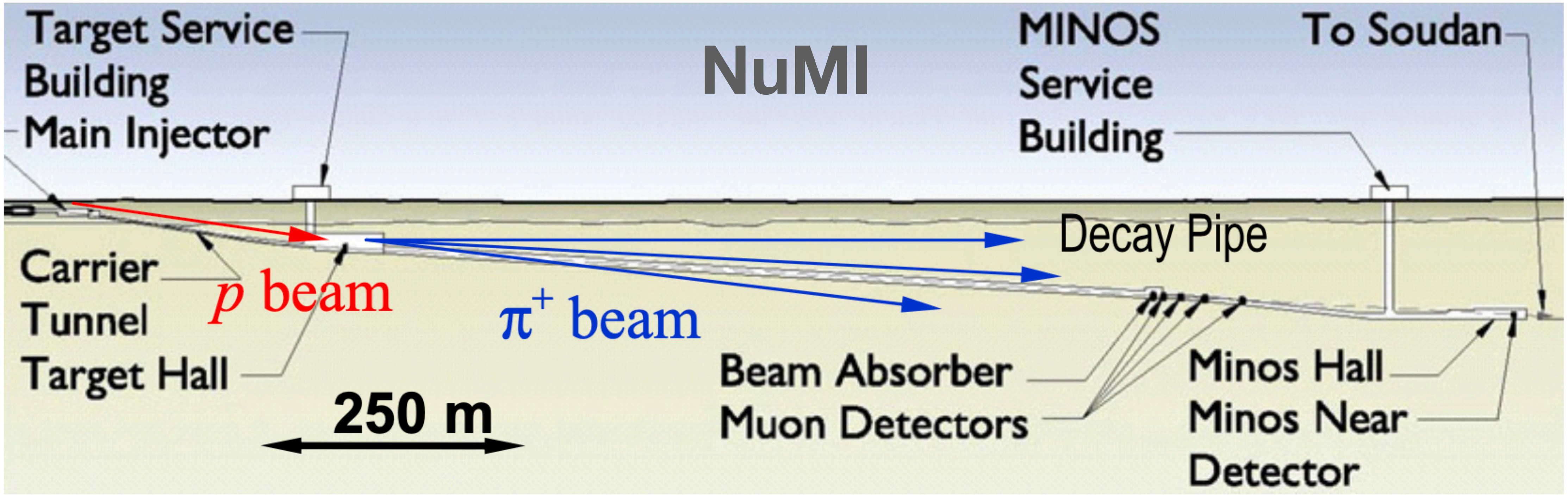
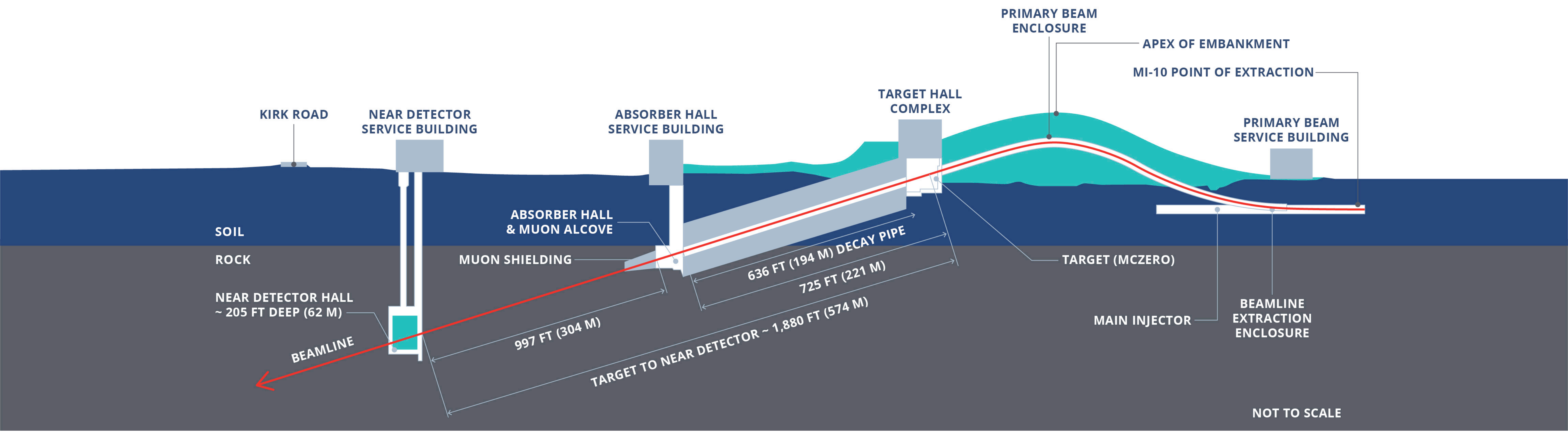
Past experience

- Installation and commissioning plans building on past experience (particularly NuMI)
- NuMI beam extracted from Main Injector into 350m long transport line
- NuMI commissioning
  - Transport line in the MI tunnel completed during 12 week shutdown in 2004
  - 3 short commissioning runs
    - Dec 2004 - Extracted beam, hit absorber on 10th pulse (target not inserted)
    - Jan 2005 - Beam with target and horns on
    - Feb 2005 - Higher intensity beam delivered



LBNF

- Primary protons 60-120 GeV
- Initially 1.2MW, upgradeable to 2.4MW
- ~370m proton transport line+~220m target hall/decay pipe
- Near detector @570m, and Far detector @1300km (~1500m deep)



Requirements

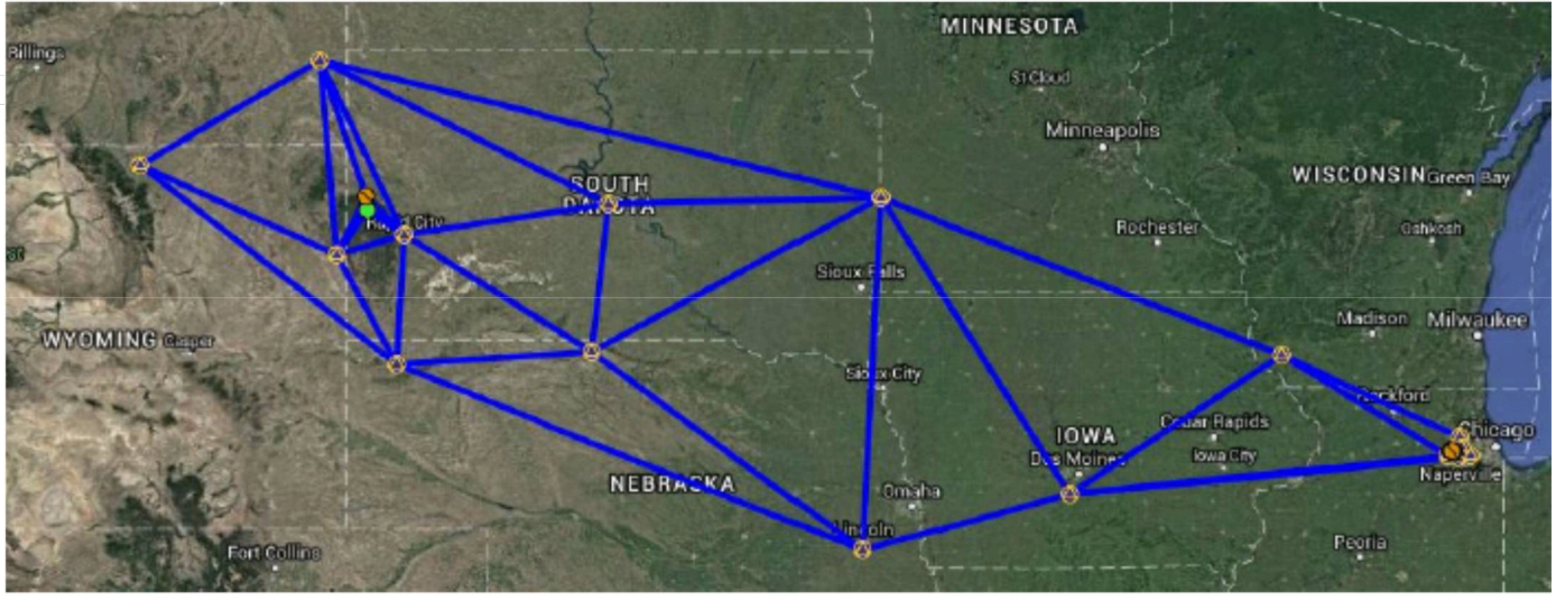
- Require well controlled neutrino beam with minimal systematic errors
- No significant contribution to neutrino flux systematic error or impact on physics measurements
- Tolerances
  - Proton beam angle: 70 μrad
  - Proton beam position: 0.5mm, profile: 10%
  - Baffle beam scraping: 1%
  - Target and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

See later talk on LBNF instrumentation

Instrumentation

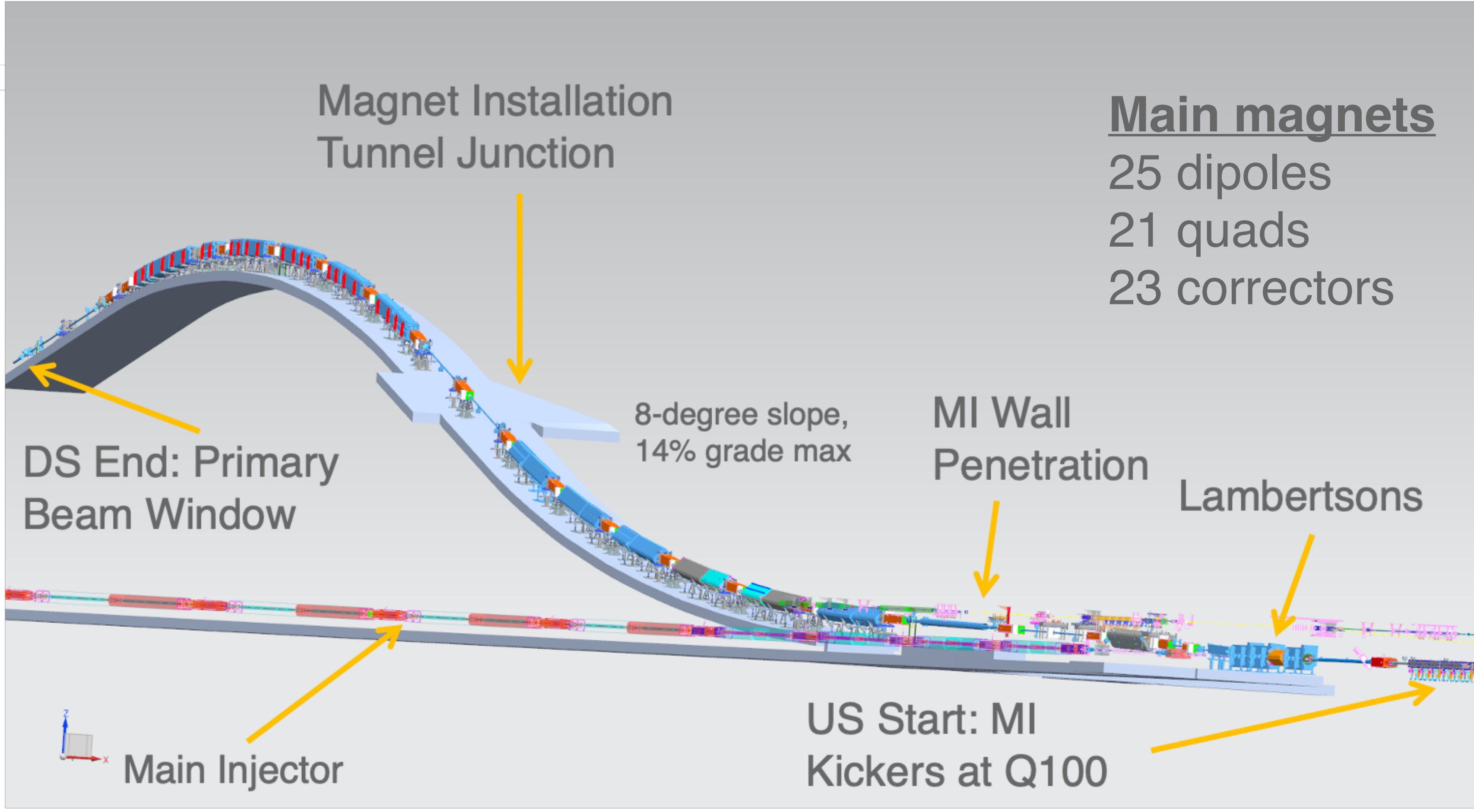
- Beam Position Monitors, Profile Monitors, Toroids, Beam Loss Monitors
- Target Position Thermometer (Hylen device)
- BLMs in target hall (for Beam Based Alignment)
- Hydrostatic/Horn Leveling System (HLS)
    - Monitor vertical shifts of beamline components (BPMs, Baffle, Horns; both in primary and secondary beamline
- Hadron monitor (HADeS) and Muon monitors (MuMS)

Alignment



- Use MI extraction point and the Homestake Mine as reference points in Fermi coordinate system to establish the beamline trajectory
  - In 2016 comprehensive surveying campaign took place to refine the global positions of FNAL and the 4850 Level of the Sanford Lab
    - Surface GPS network accuracy is within ±10 mm
    - Transfer to 4850ft level using 1 mile long plumb line
- Build network in the enclosures
- Components alignment requirements very similar to NuMI:
  - Primary beam magnets and instrumentation aligned to ±0.25 mm
  - Target station components aligned to ±0.5 mm
- Survey and rough alignment as components are installed

Primary Beam Installation



- Install:
  - LCW pipes and bus
  - Magnet stands and align
    - six degrees of freedom for precise adjustment
  - Magnets and rough align
  - Beam tube and instrumentation
    - Beam Position Monitors, Beam Loss Monitors, Toroids, Profile Monitors, HLS
- Magnet installation and support based on NuMI and MI experience (with some modifications)
- In parallel outfit the support building (power supplies, pumps, etc), cable everything
- Reconfigure MI for extraction (kickers, lambertsons, extraction dipoles and quads)
- Ramp magnets, pull vacuum, and final alignment

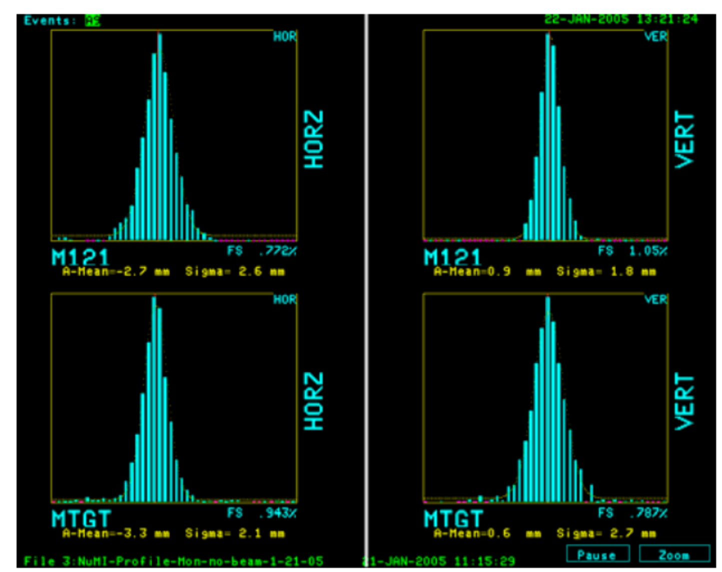
Beam permit system

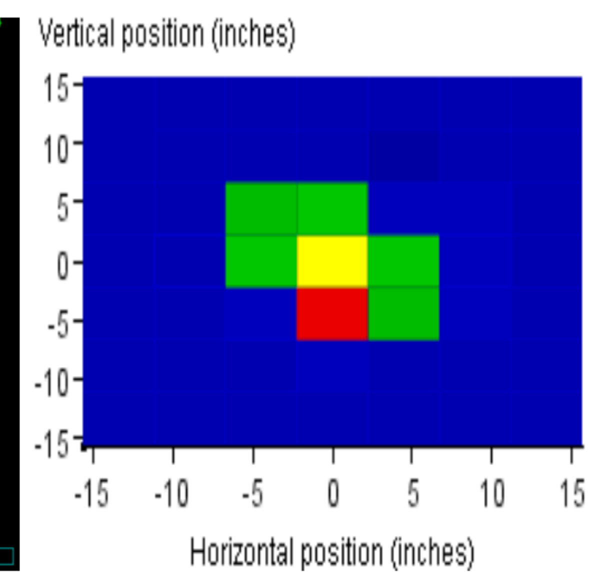
- Commission the beam permit system
- Prevents beam delivery under any fault condition
- Taking input from beamline instrumentation
- Predict initial limits for signals based on:
  - Specifications of power supplies
  - MARS studies
  - Accelerator studies
  - Desired operational values

Beam extraction

- Setup alarms & limits
- Ensure devices are reading back, data logging, BPS active,
- Extract the beam from MI and down the beam-line, get the beam to hadron absorber
- Low intensity, multiwires in
- Time in the kicker
- Adjust trims to “walk” the beam down the beamline
- Optimize major bend currents; hopefully do not need to realign
- Adjust autotune

NuMI on 10th pulse



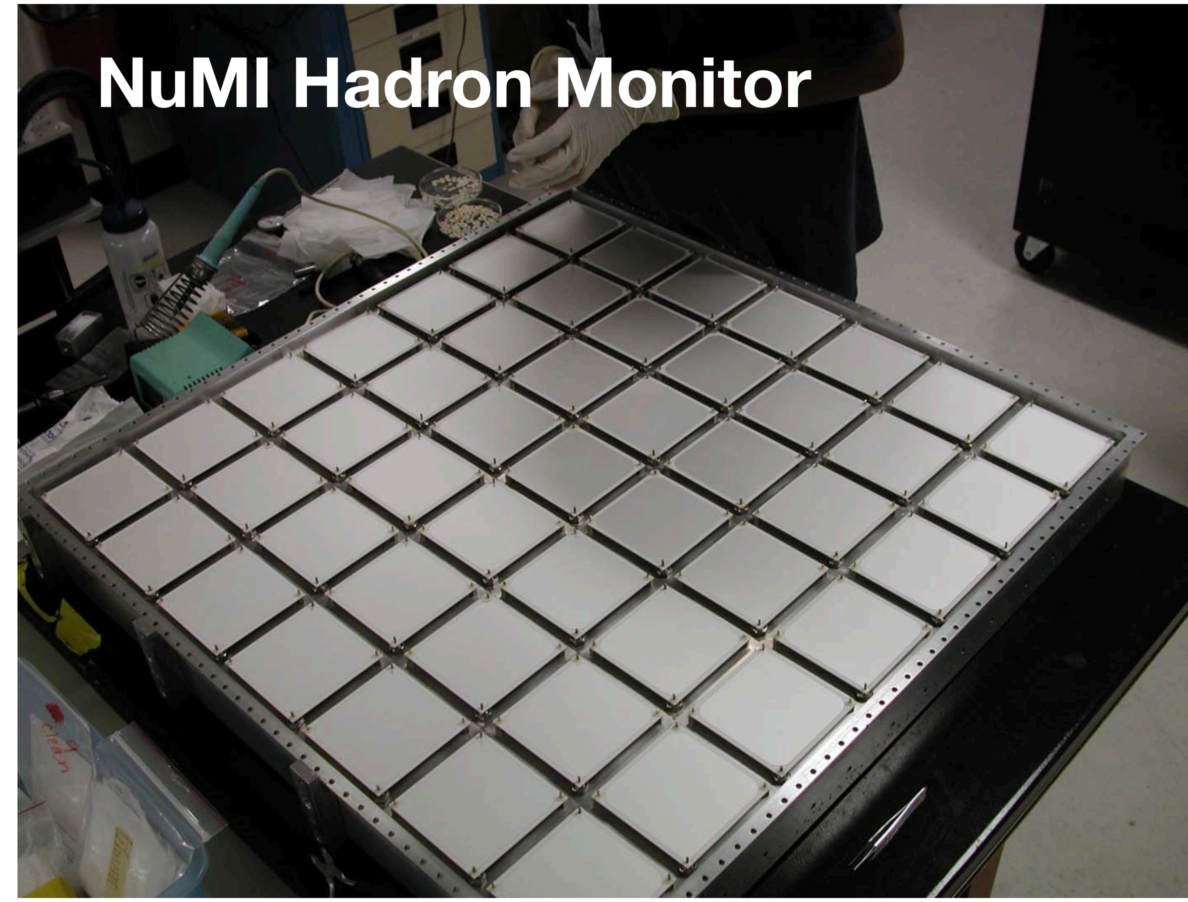


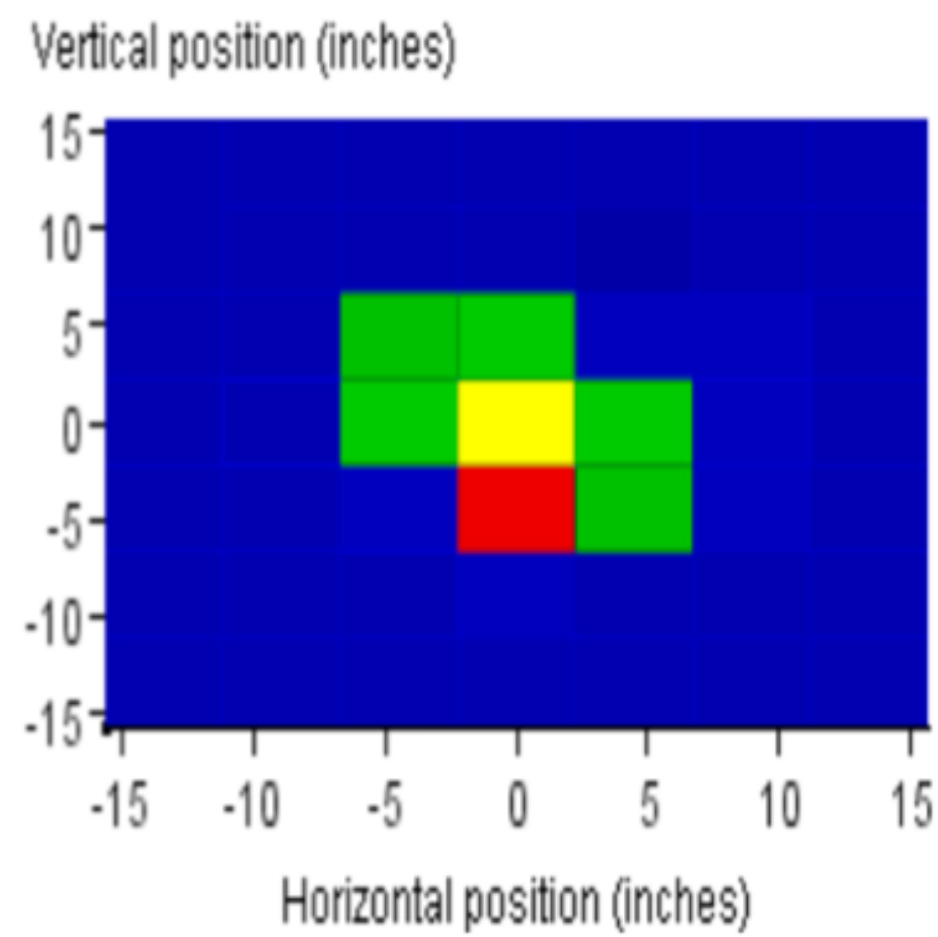
Beam Based Alignment (BBA)

- Final alignment of the neutrino beam components is done with scans of the proton beam across the components
  - Heavy shielding may cause components to shift and direct survey no longer possible
  - Thermal expansion
  - Beam position monitors calibration drift
- Study done with special beam conditions
  - Use 1 mm sigma beam spot size for scanning
  - Low intensity and low rate
  - Scan beam parallel to nominal beam axis, up/down and left/right, +/- 25 mm
- Done in several steps (Beam direction, Baffle, Horn B&C, Target, Final alignment)
- Using HADeS and Beam Loss Monitors

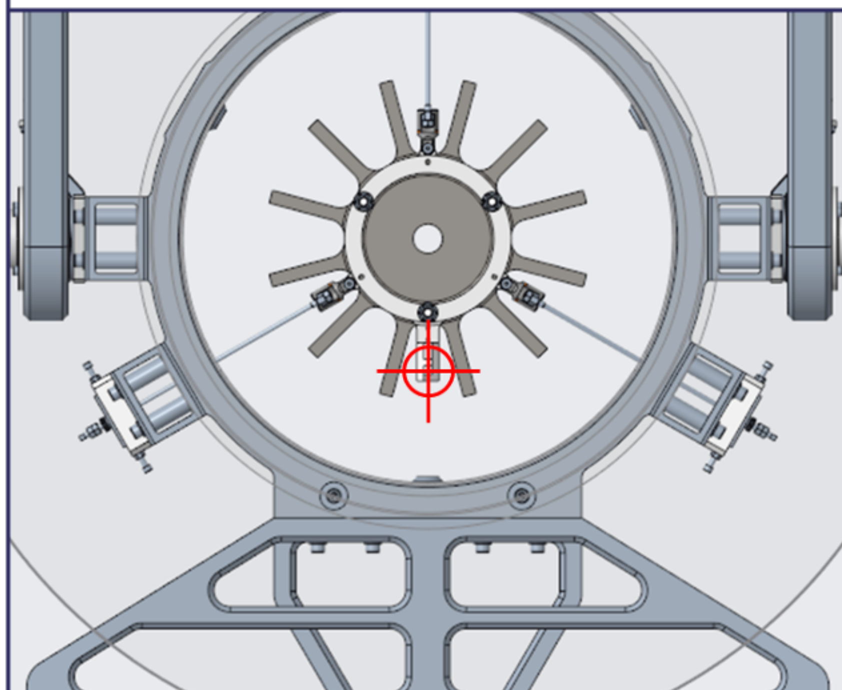
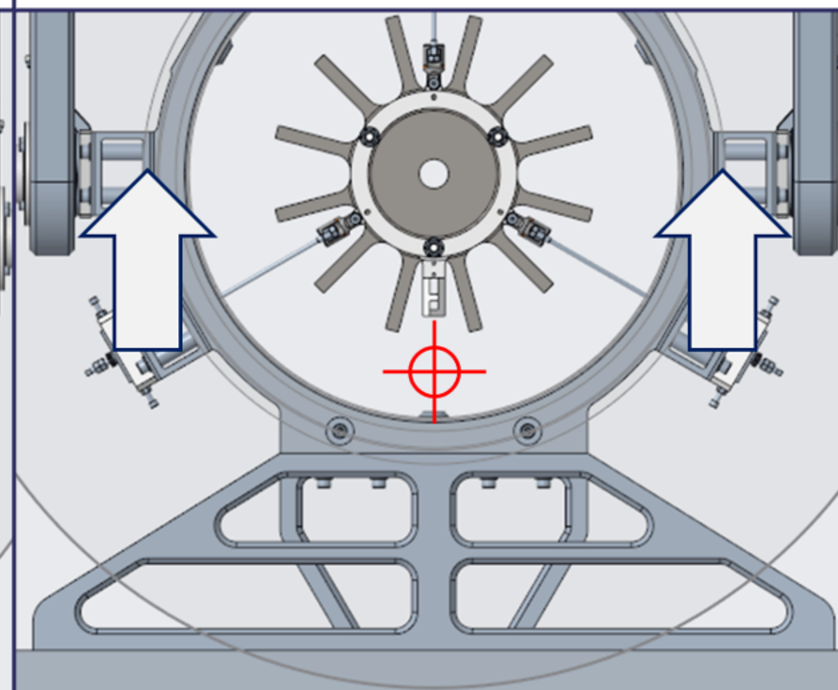
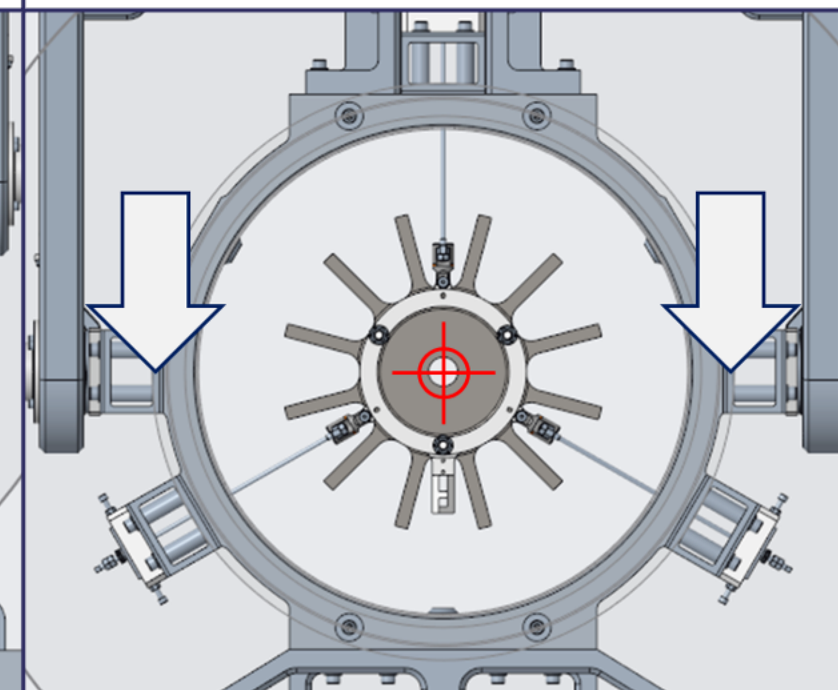
BBA
Beam direction

- Horn/target not in the beam
- Baffle in “clear shot” position
- Aim the beam at the hadron absorber, establish the beam center
- HADeS precision at 1.5cm
- With lever arm ~220m lever arm, get <70 μrad precision



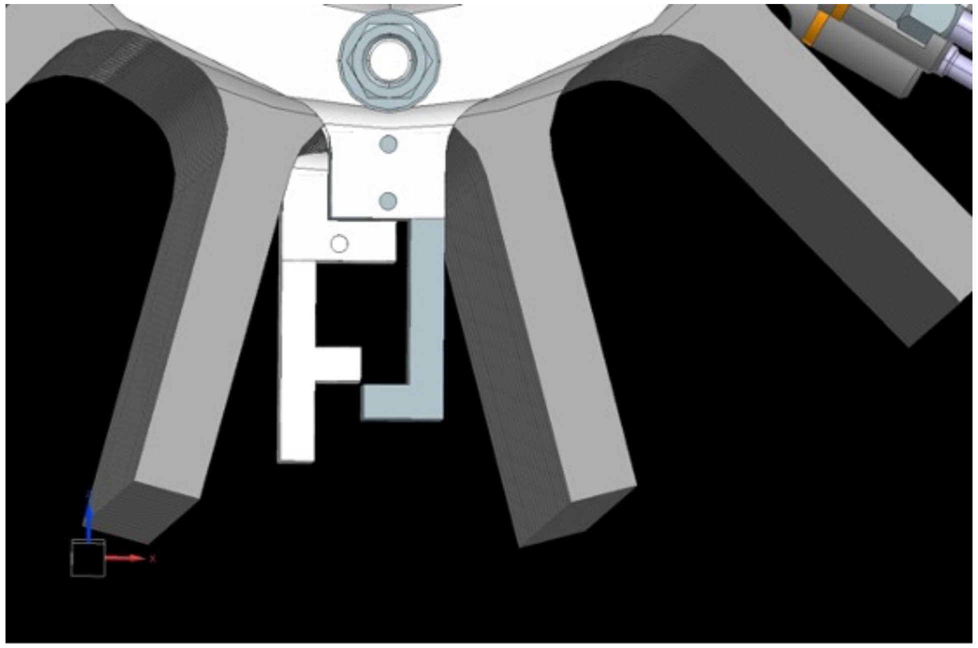


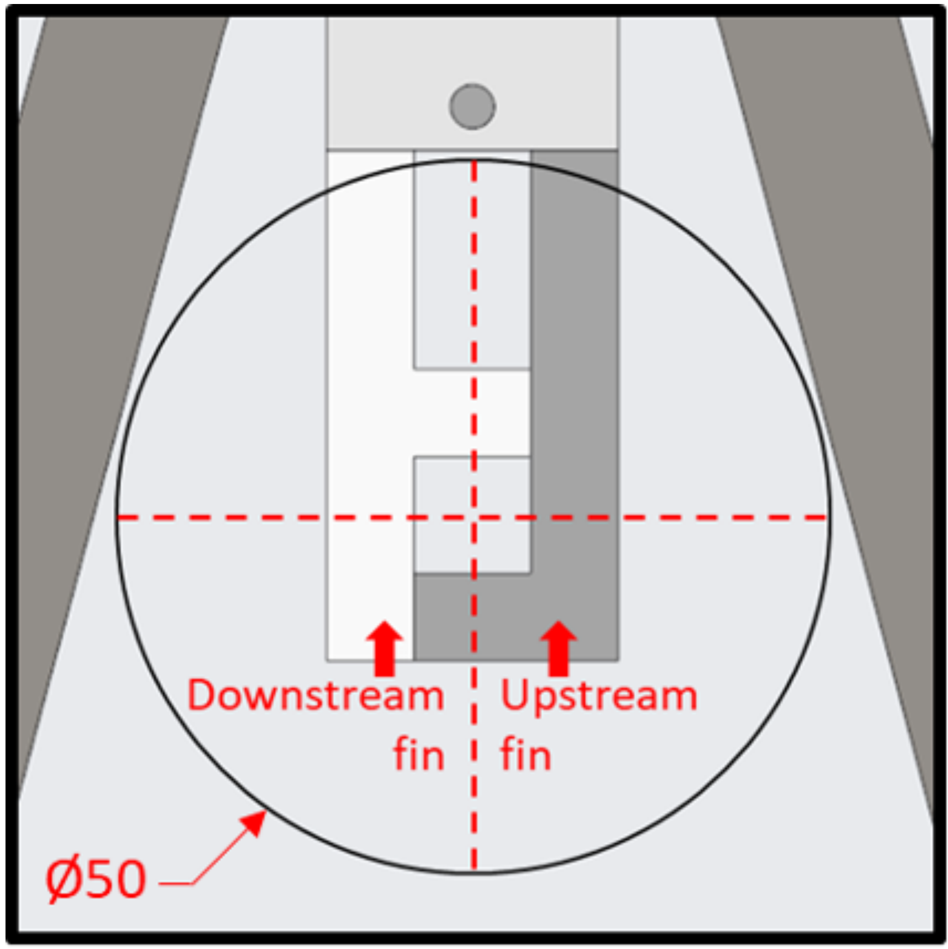
Baffle positions

"Baffle BBA" Position	*"Clear Shot"* Position	*"On-Axis"* Position
		
NB no Target / Horn-A in Chase Baffle driven to "Baffle BBA" position Beam-scan baffle BBA features, perform angular alignment	Baffle raised to "clear-shot" position Enables BBA of downstream components	Baffle lowered to "on-axis" position Beam-scan baffle bore to verify correct position prior to running high intensity beam

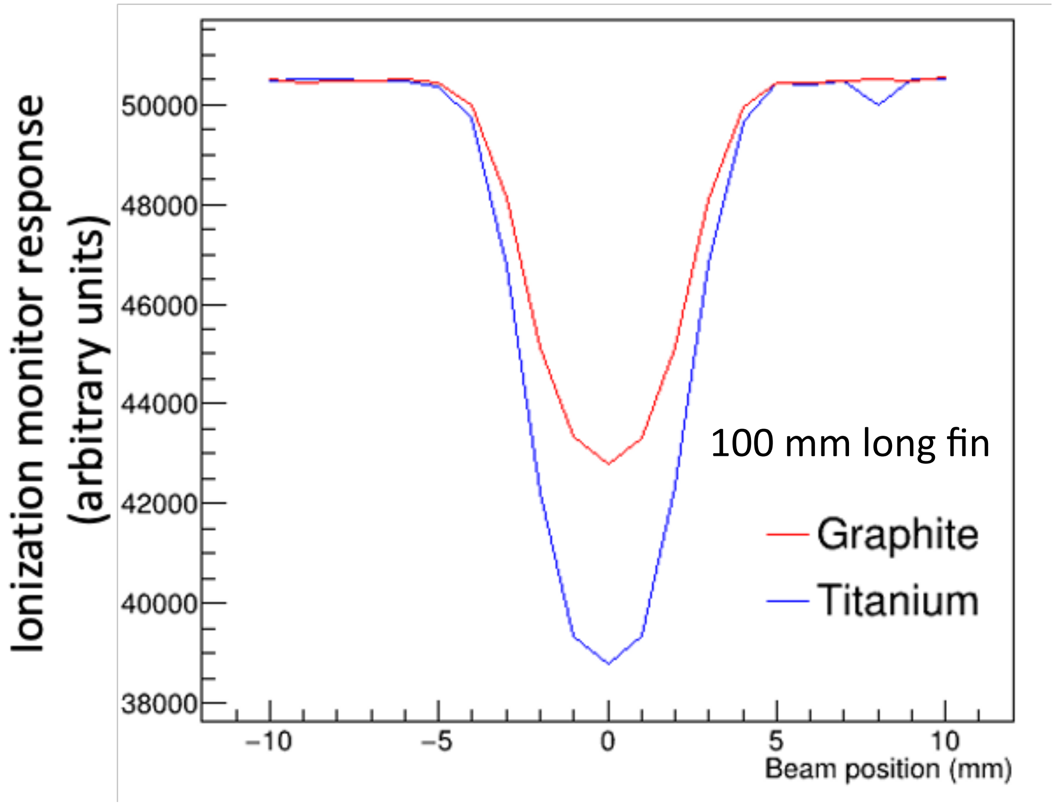
BBA

Baffle scan





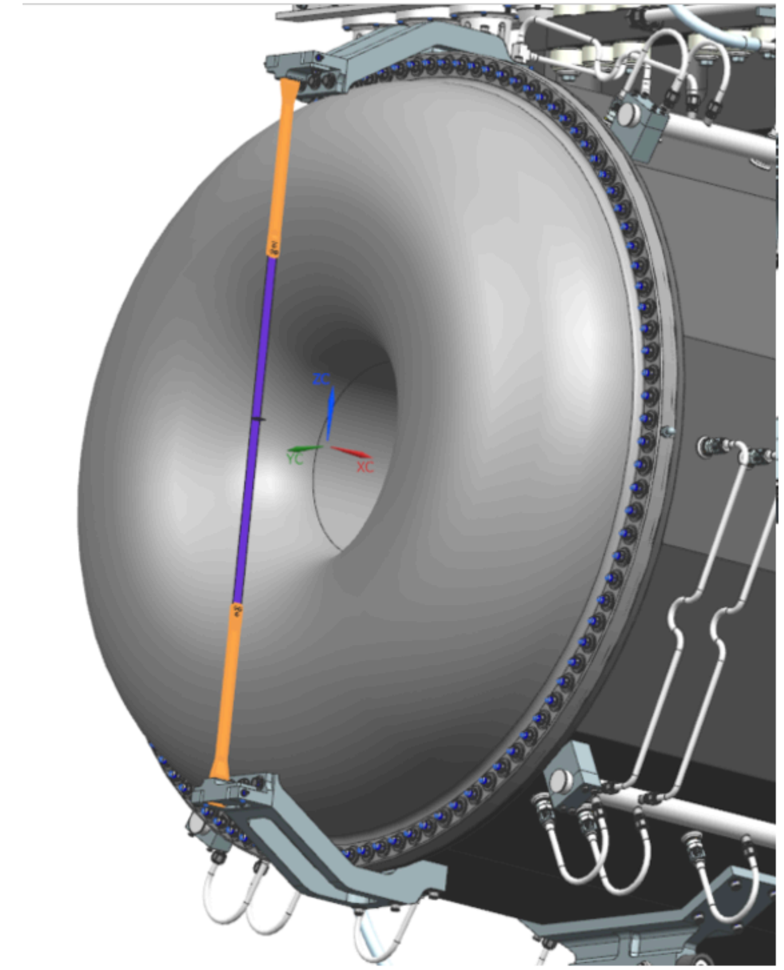
- Baffle moved to angle alignment position
- Scan beam across fins and determine position using HADeS
- Infer position after subsequent moves using module motor drives and LVDT position readback
- Require alignment within 2mm with respect to the target (follows from <1% baffle beam scraping requirement and adequate protection of downstream elements)

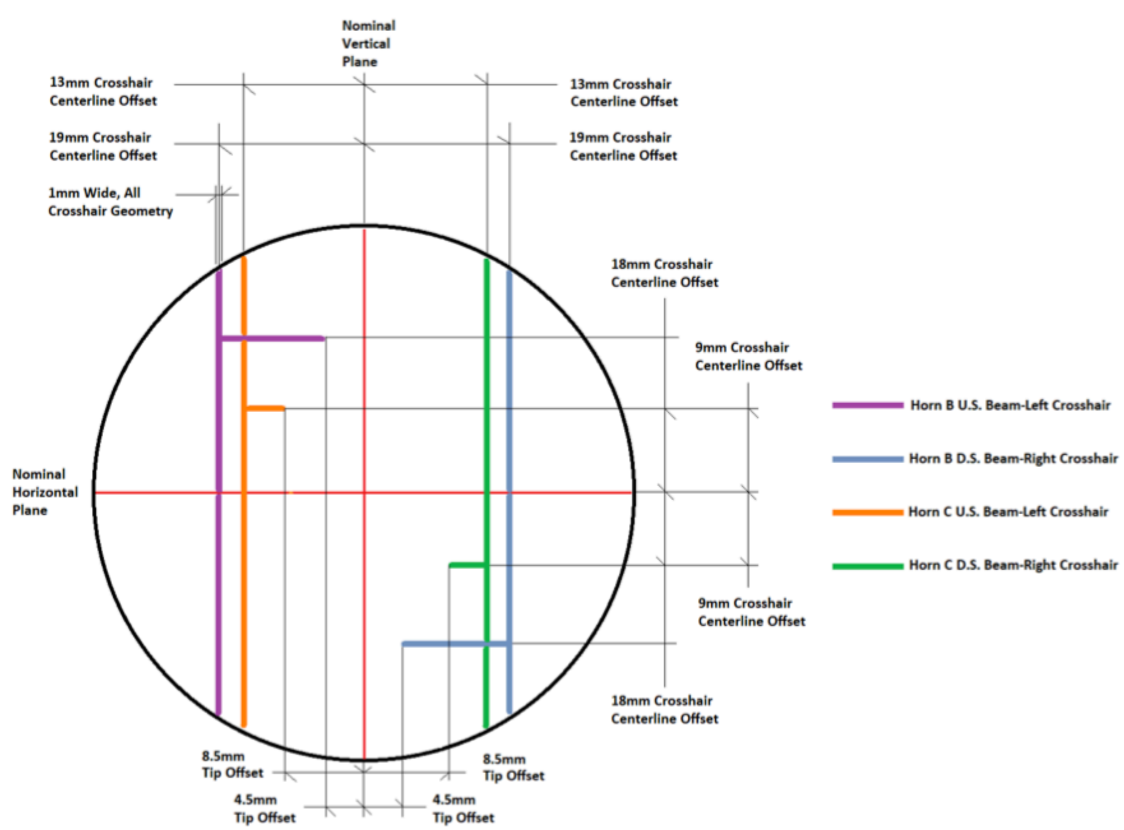


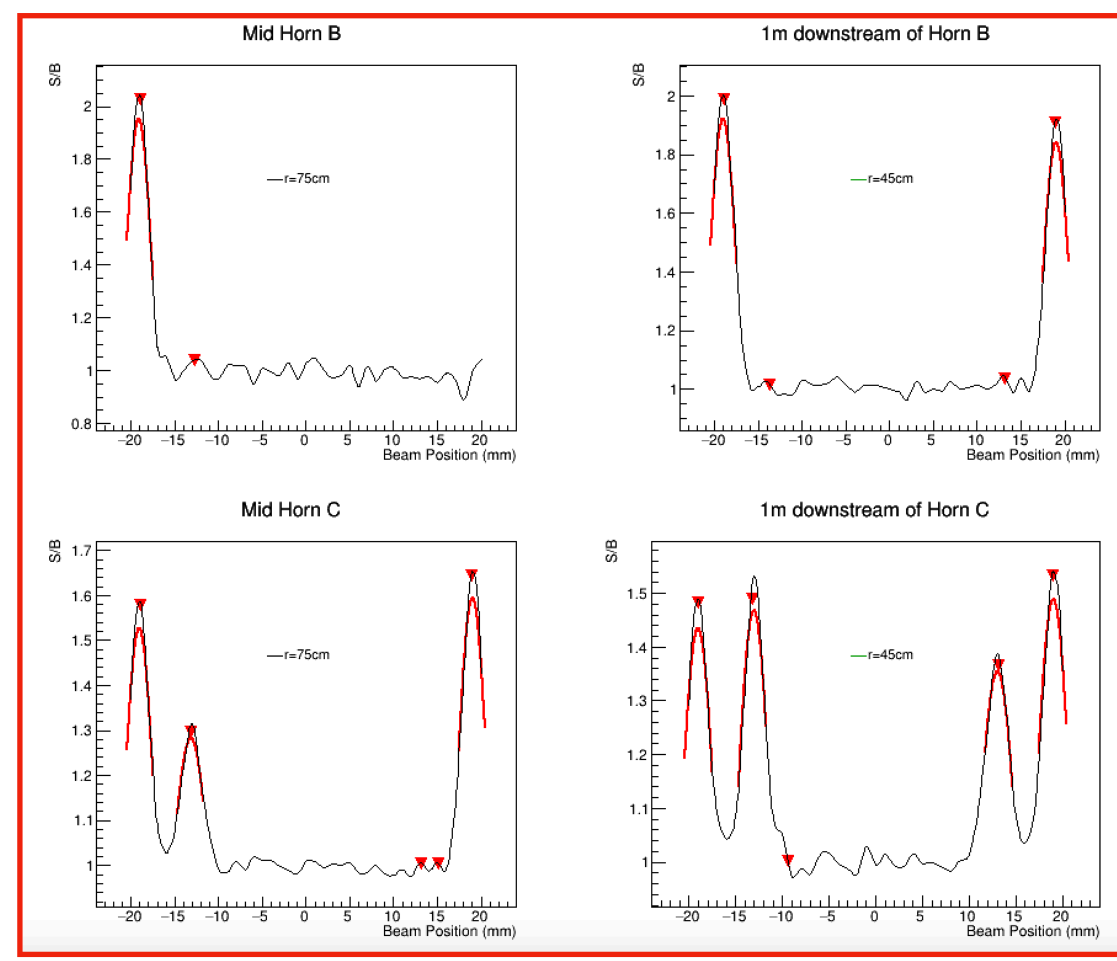
BBA

Horns B&C

- Scan across the cross hairs
- Using primarily BLMs
- BLMs installed in 4 planes with each one following horn US/DS cross hair

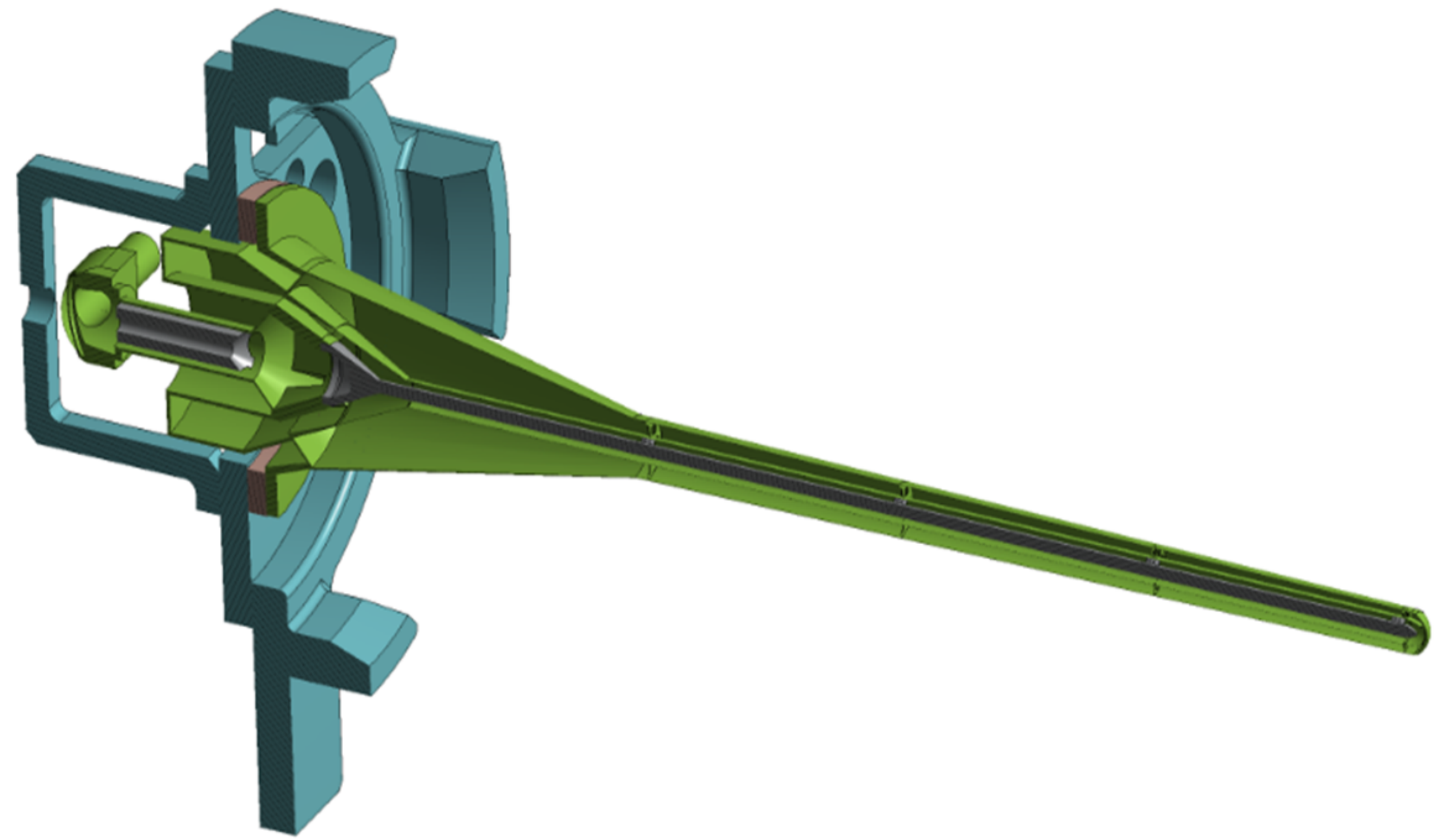


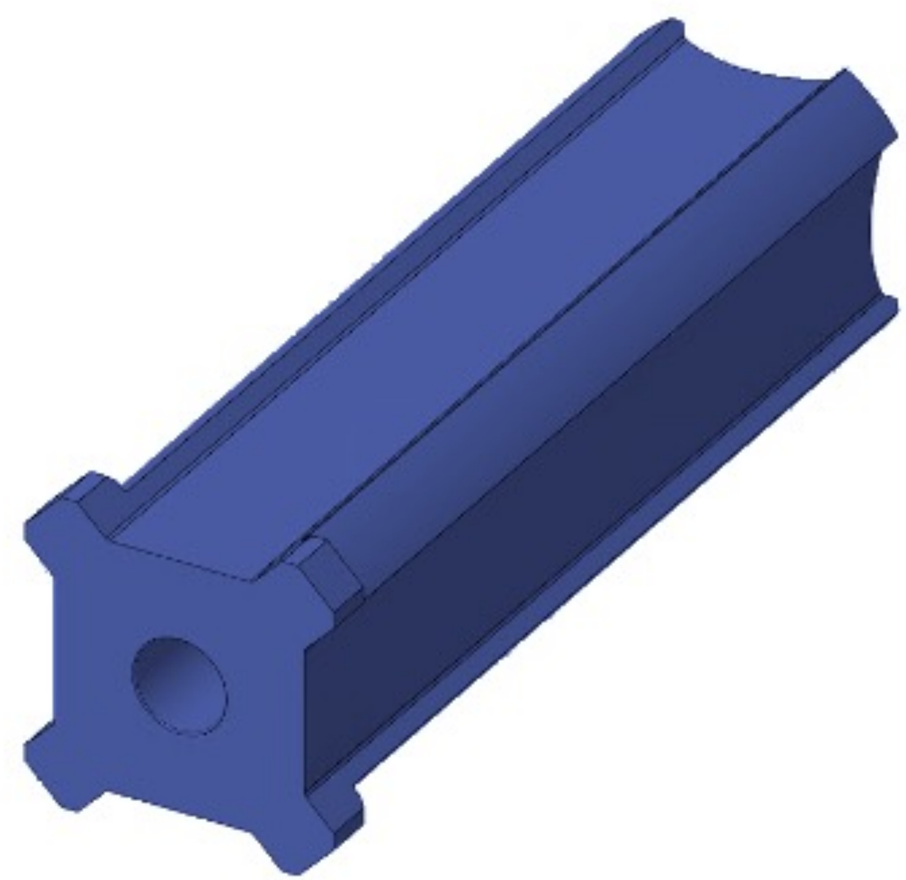




BBA

Target



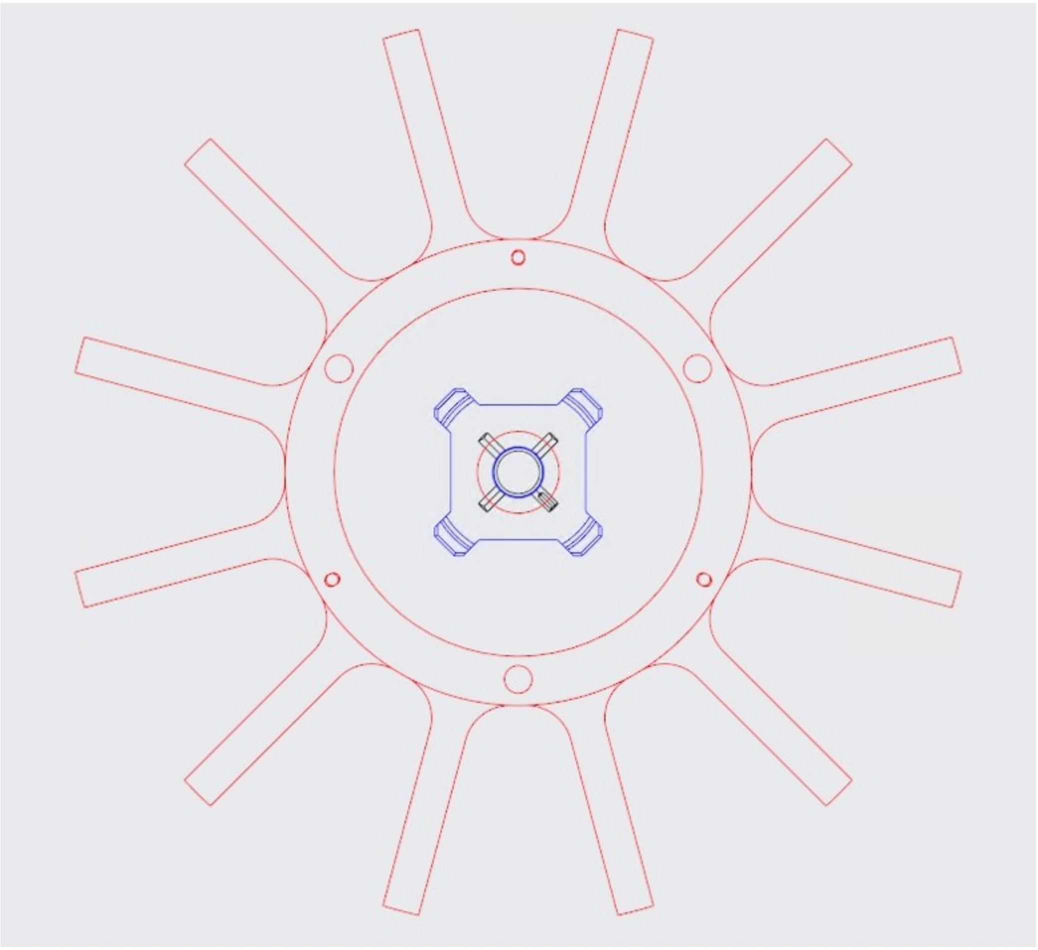


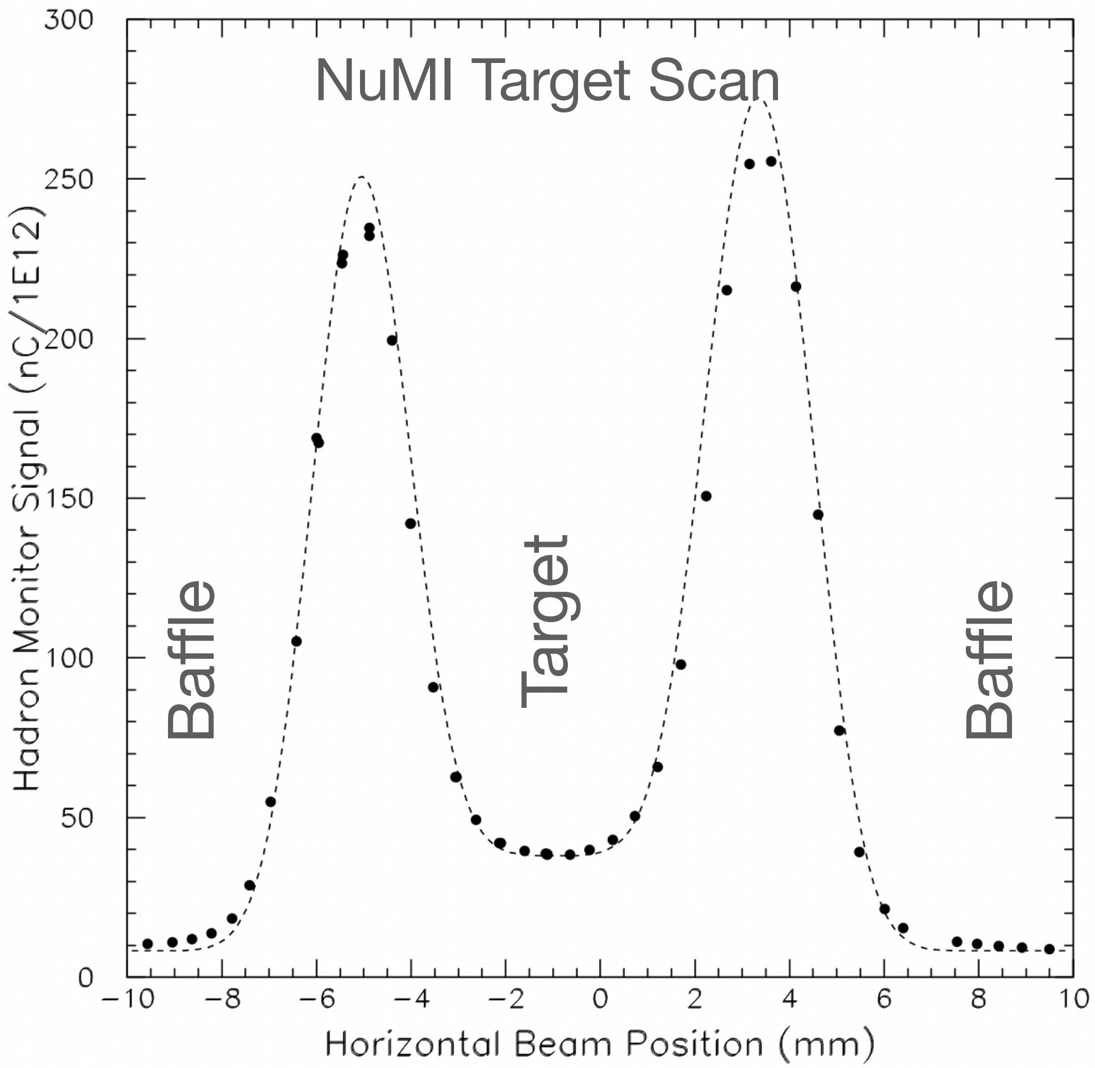
- Scan beam over target/ bafflet
- Bafflet (0.18m) is on upstream end of target (1.5m) - clear difference in HADeS signal
- X, Y position of bafflette edges, and of target mass centroid
- Determines target position and angle

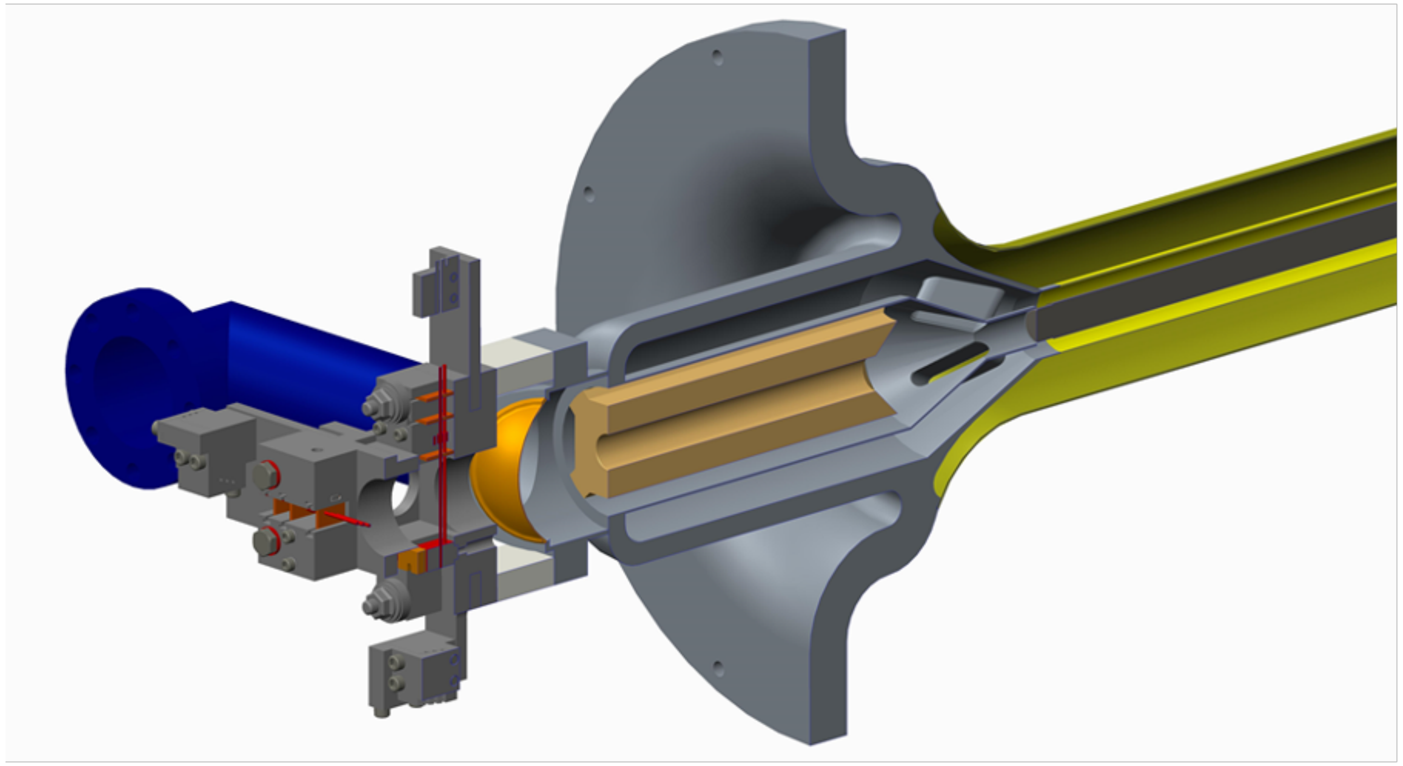
BBA

Final scan

- Baffle moved to in beam position
- Final scan, confirm baffle position
- Confirm beam centered on target using TPT as ramping intensity



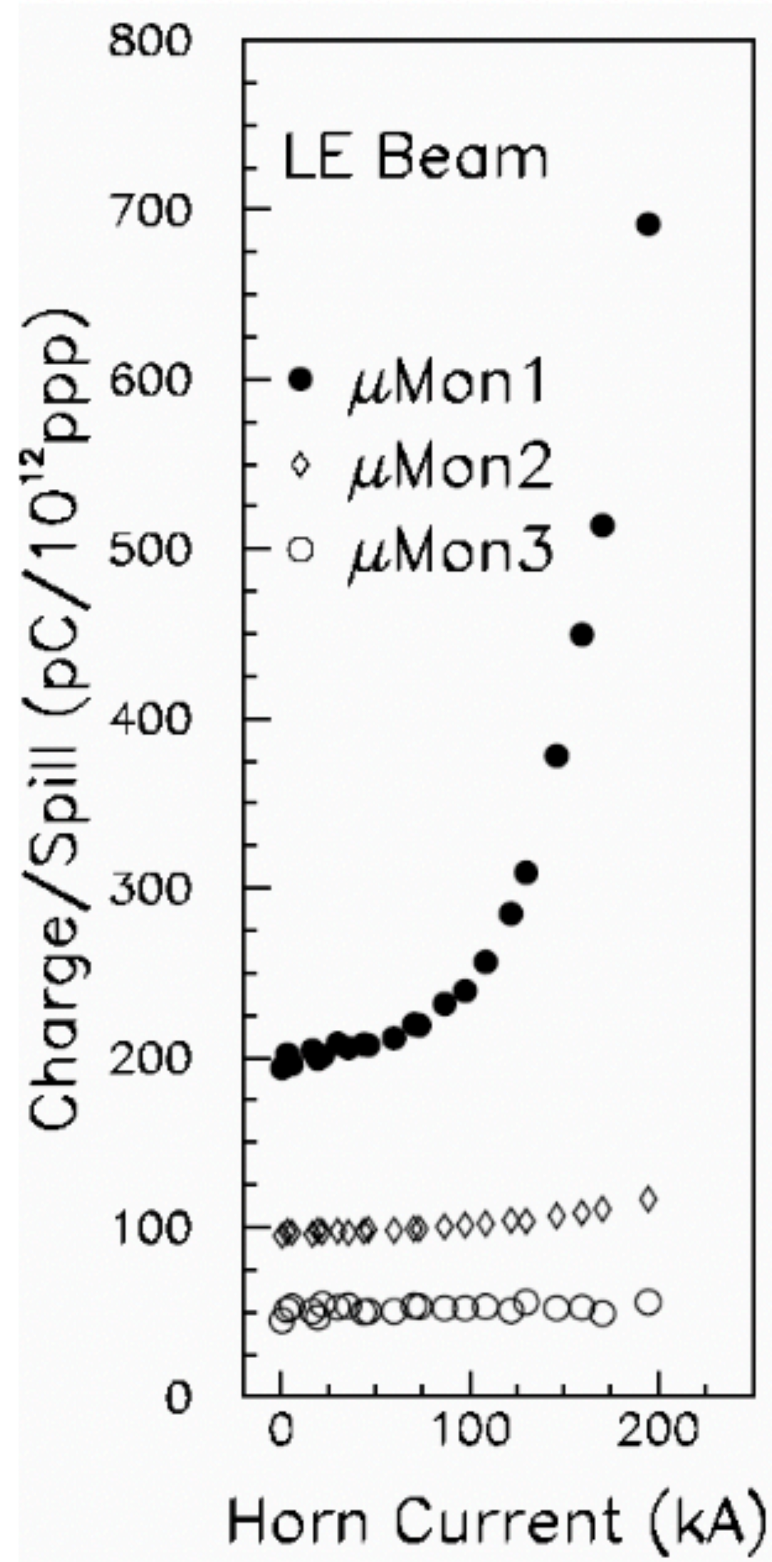




Horns on

- Beam on target, horns powered
- HADeS out of the beam for normal running
- Observe the muon flux in muon monitors
  - Flux increase as ramping up horn current
- Keep raising intensity

NuMI



Summary

- LBNF will provide an intense and well controlled neutrino beam for DUNE experiment
- Installation, alignment and commissioning builds on extensive experience with neutrino beams at Fermilab (NuMI in particular)
- Alignment requirements are similar to NuMI
- Beam based alignment procedure provides precise placement of beamline components and beam direction
- Instrumentation designed to allow Beam Based Alignment and meet the monitoring needs to satisfy the requirements