LBNF Cross Hairs and TPT

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Presenter Background

- Fermilab (May 2014-Present)
  - ND/TSD/Operations Support Group (Group Leader)
  - MicroBooNE
  - DUNE
    - BIWG co-convener
- Previously worked on:
  - MINOS/MINOS+
    - NuMI beam primary & secondary beam instrumentation
    - Beam simulation
  - MiniBooNE

Requirements

- Need to keep beam systematics constrained to achieve DUNE physics goals
- Well controlled and stable beam
  - Align beamline elements within tolerances
  - Steer beam on target
- Both systems discussed here heavily rely on abundant experience with NuMI

Quantity	1-sigma Shift	Notes	In TDR
Horn A Transverse Displacement	0.5 mm	X and Y shifted separately, added in quadrature	Y
Horn A Transverse Tilt	0.5 mm	X and Y shifted separately, added in quadrature; upstream and downstream ends shifted in different directions	N
Horn B Transverse Displacement	0.5 mm	X and Y shifted separately, added in quadrature	Y
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Horn C Transverse Displacement	0.5 mm	X and Y shifted separately, added in quadrature	N
Horn C Transverse Tilt	0.5 mm	X and Y shifted separately, added in quadrature; upstream and downstream ends shifted in different directions	N
Target Transverse Displacement	0.5 mm	X and Y shifted separately, added in quadrature	N
Target Transverse Tilt	0.5 mm	X and Y shifted separately, added in quadrature; upstream and downstream ends shifted in different directions	N
Horn A Longitudinal Displacement	2 mm		N
Horn B Longitudinal Displacement	3 mm		N
Horn C Longitudinal Displacement	3 mm		N
Proton Beam Transverse Position	0.5 mm	X and Y shifted separately; added in quadrature	Y
Proton Beam Radius	10%	Updated from 0.1 mm for NuMI	Y
Proton angle on target	70μ rad	X and Y shifted separately; added in quadrature	Y
Decay Pipe Radius	0.1 m		Y
Horn Currents	1%	Changed in all three horns simultaneously	Y
Baffle Scraping	0.25%	To Be Updated	N
Bafflet Scraping	0.25%	To Be Updated	N
Target Density	2%		Y
Horn Water Layer Thickness	0.5 mm	Changed in all three horns simultaneously	Y
Upstream Target Degradation			N
# Protons on Target	2%		Y
Near Detector Position			N
Far Detector Position			N
Field in Horn Necks			N
Decay Pipe Position	20 mm		N

Table 1: Sources of alignment and focusing uncertainties in the neutrino fluxes at DUNE. Sources that were considered in physics studies in the TDR are marked with a 'Y' in the 'In TDR' column.

DUNE-DocDB-19942

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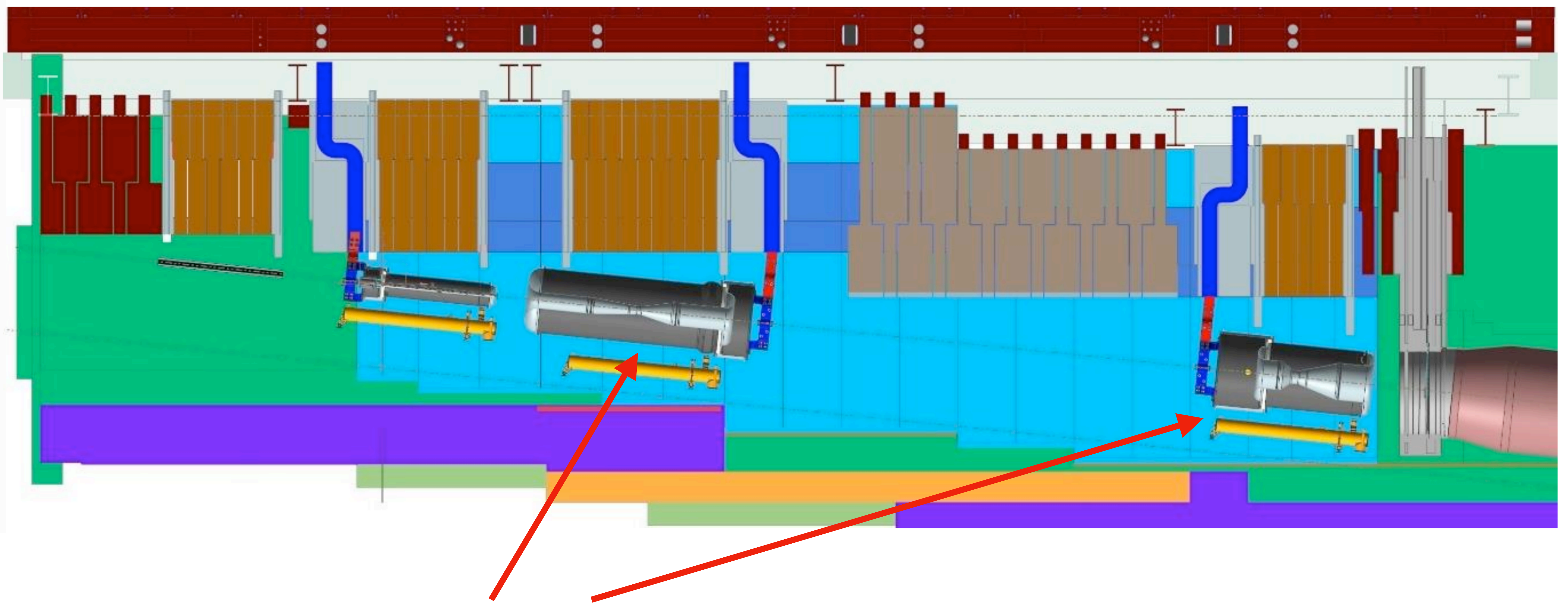
DUNE-DocDB-19942

Horn B & C alignment

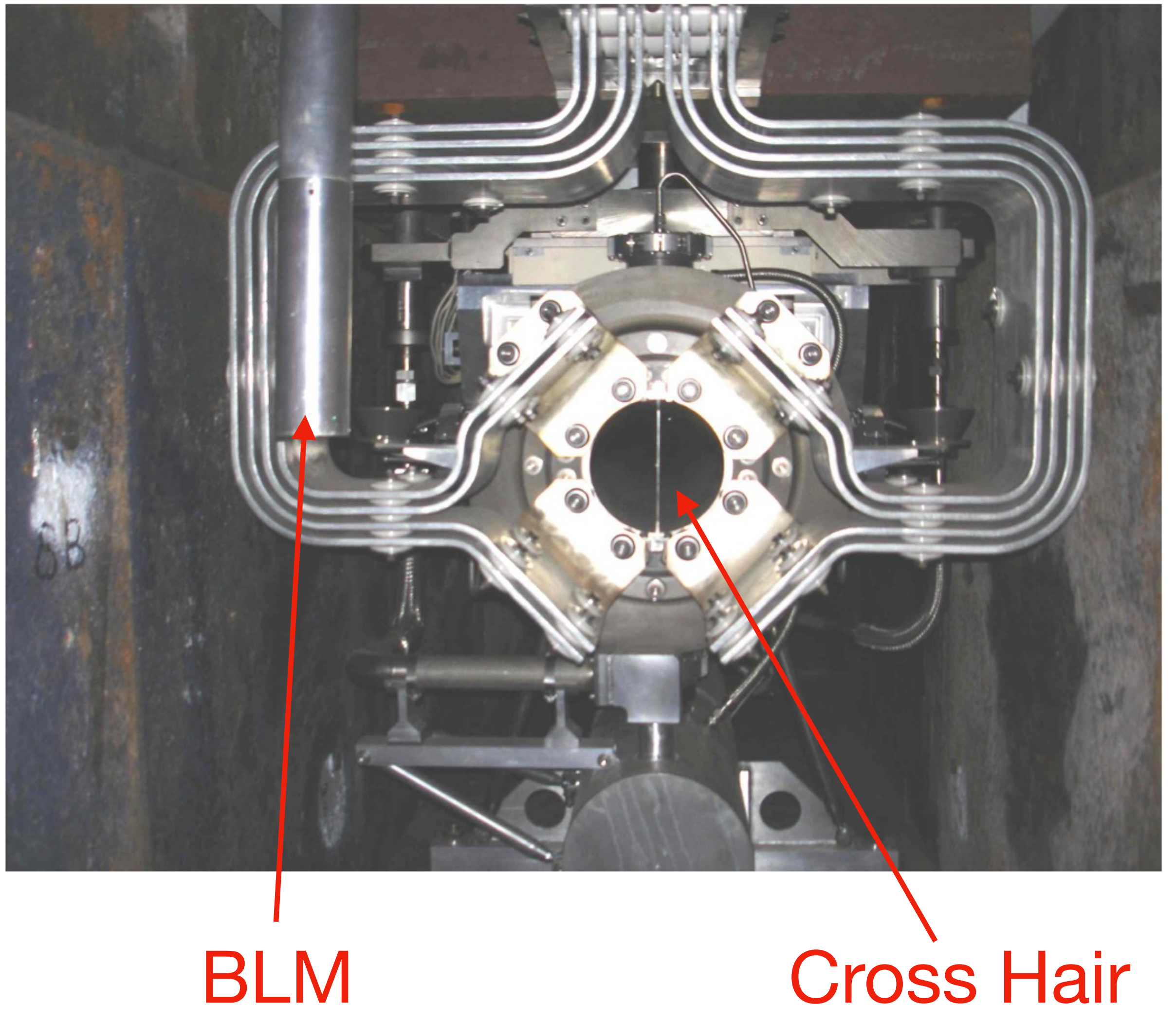


- Determine Horn B & C transverse (mis)alignment and/or tilt
- Measure independently misalignment of upstream and downstream horn ends

Beam based alignment

- 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



NuMI experience

- Cross hair downstream end of Horn 1, and both upstream and downstream end of Horn 2
- Aluminum bars used as cross hairs 1mm wide, and 12mm or 18mm deep along the beam axis
- Low intensity beam <1e12PPP, with $\sigma_{x,y}$~1mm
- Alignment within 0.5mm
- Some lessons learned
  - Horn 2 upstream cross hair (18mm) giving much bigger signal then downstream (12mm), making it hard to see signal from downstream cross hair
  - Hard to find short horizontal nubs
  - Overlapping cross hairs (due to limited space) harder to locate

1. Does the NBI preliminary design meet the functional requirements identified?
2. Is the design maturity presented for the NBI, interfaces, and ancillary systems at a level appropriate for a Preliminary Design?
   a. Based on acceptable progress for a Preliminary Design to be 50 to 70% complete, with 100% meaning ready for procurement.
   b. Are areas where components are awaiting forthcoming development well understood?
3. Have suitable engineering analyses been performed and documented, and reviewed/peer reviewed and approved, where applicable?
4. Are the appropriate codes and standards adequately applied to the design?
5. Are there any significant ES&H issues been identified and analyzed appropriately?
6. Have potential design, manufacturing, and installation risks and challenges been identified within the scope of work, and has it been adequately planned to address these during the final design? Are difficult design features and possible prototyping issues identified?
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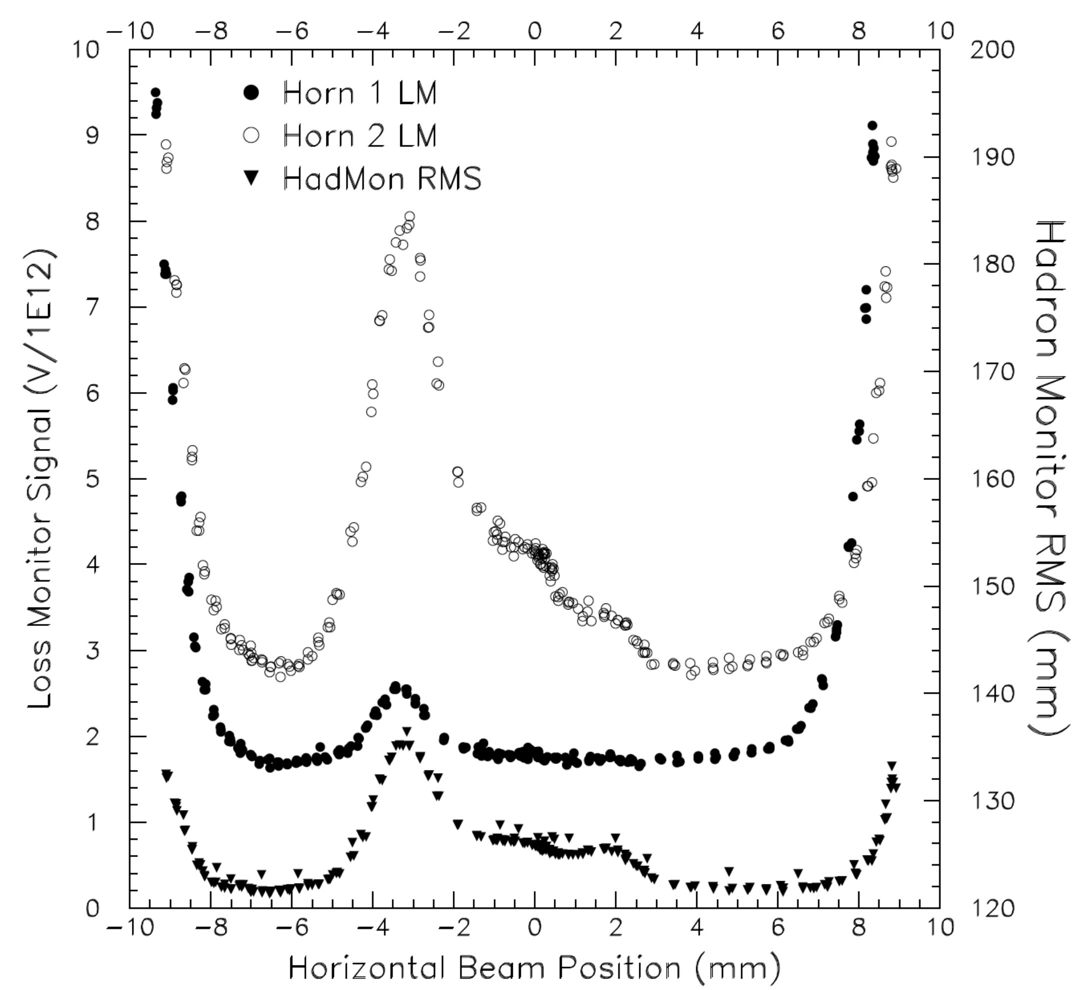
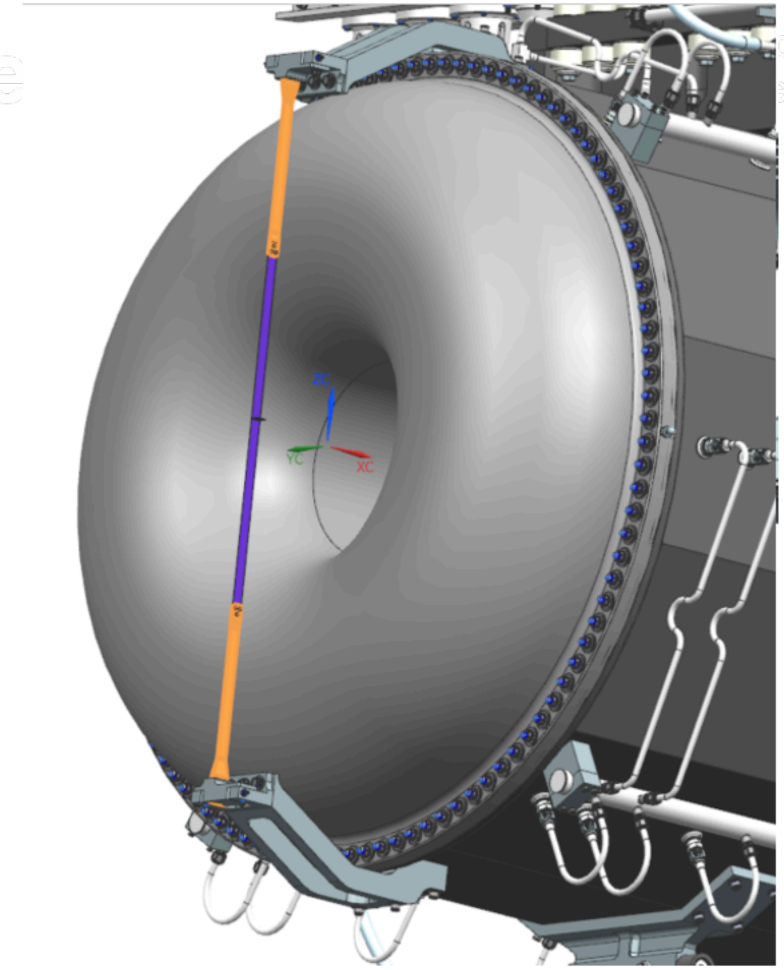
8. Are there any issues concerning the schedule for the NBI?

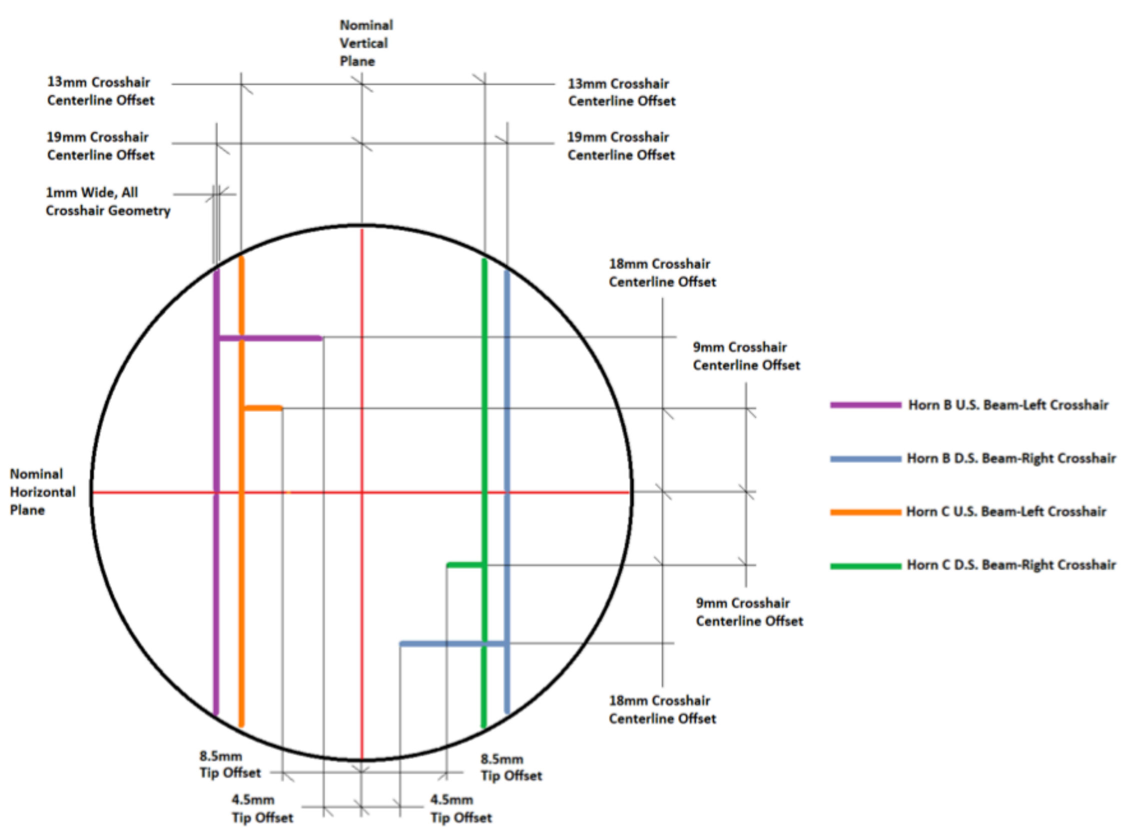


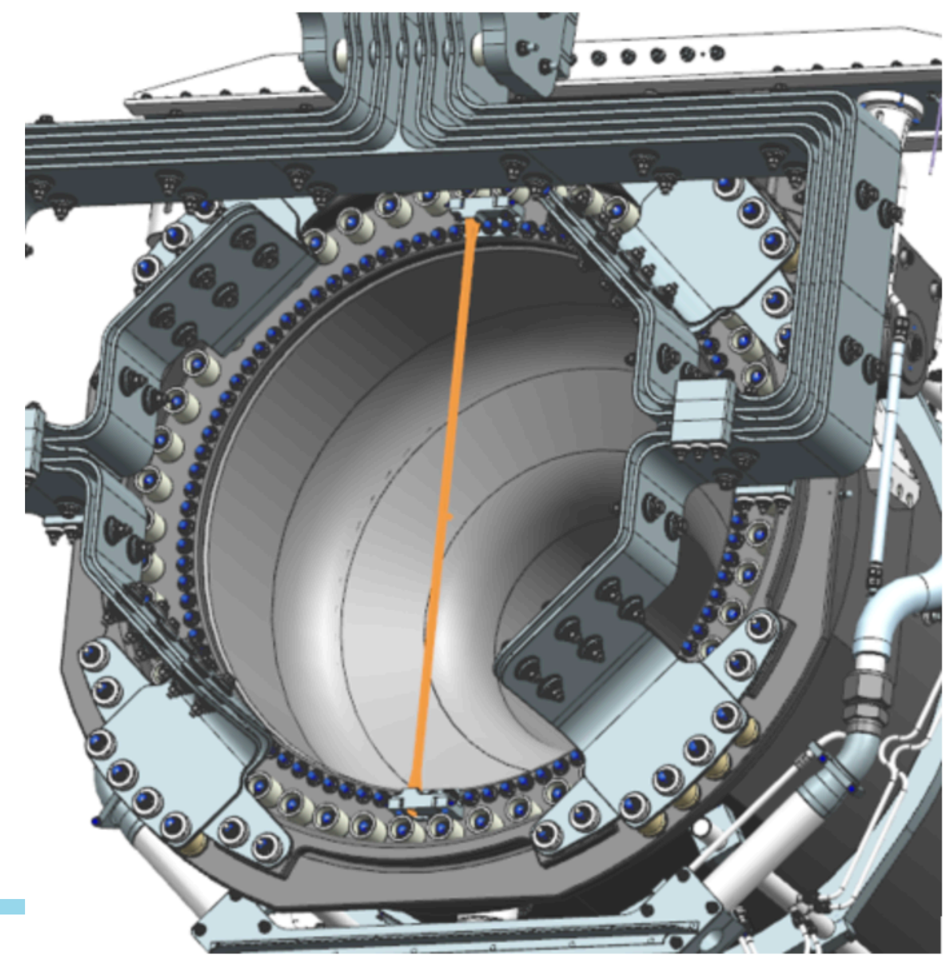
LBNF



- Positioned without overlaps allowing resolving between signals from each of the cross hair, while minimizing the likelihood of direct full beam hit

	Horizontal offset (mm)	Vertical offset (mm)	Horizontal nub length (mm)
Horn B upstream	-19	18	14.5
Horn B downstream	19	-18	14.5
Horn C upstream	-13	9	4.5
Horn C downstream	13	9	4.5





Engineering document

- Horn B&C cross hairs, stresses, deformations, and Finite Element Analysis described in ***DUNE-DocDB-23108***

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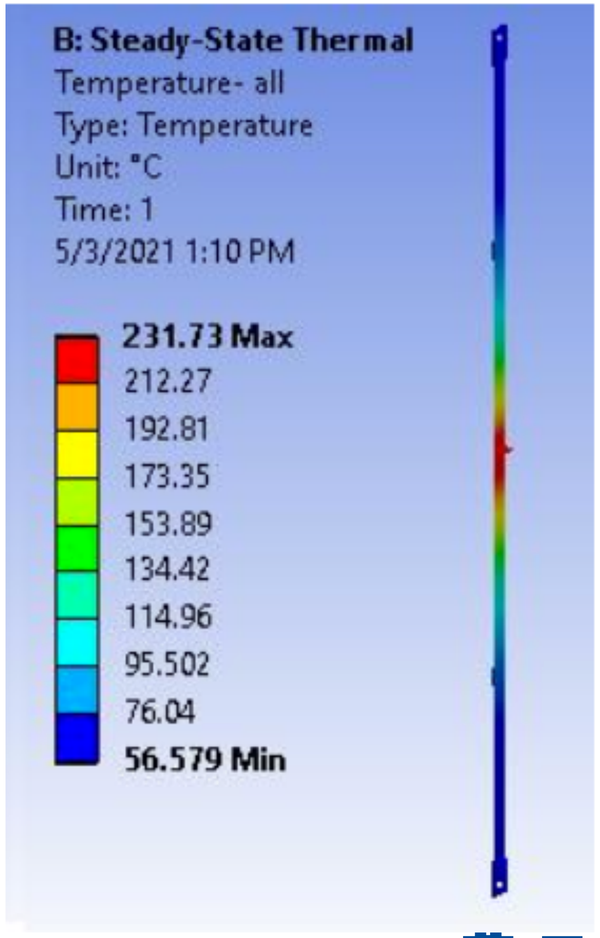
Table of Contents

Horn B upstream xhair (Be+Al)



Fermilab

Cross hairs

- All cross hairs 1mm wide, 18mm along beam
- Horn B upstream cross hair made out of Beryllium, all others fully Aluminum
    - Steady temperature gets too high for Aluminum crosshair

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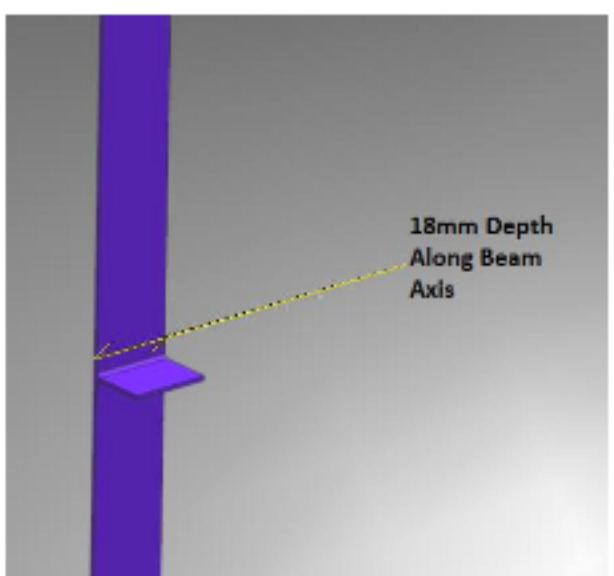
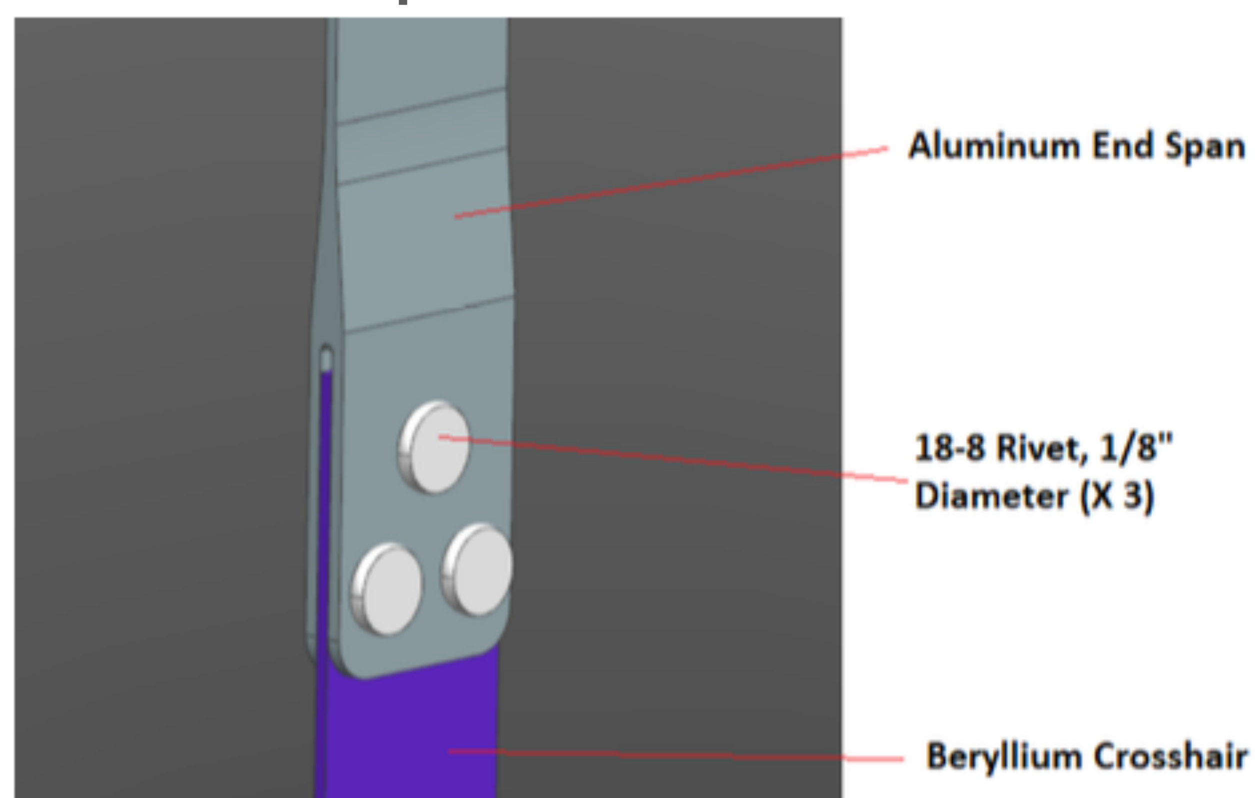
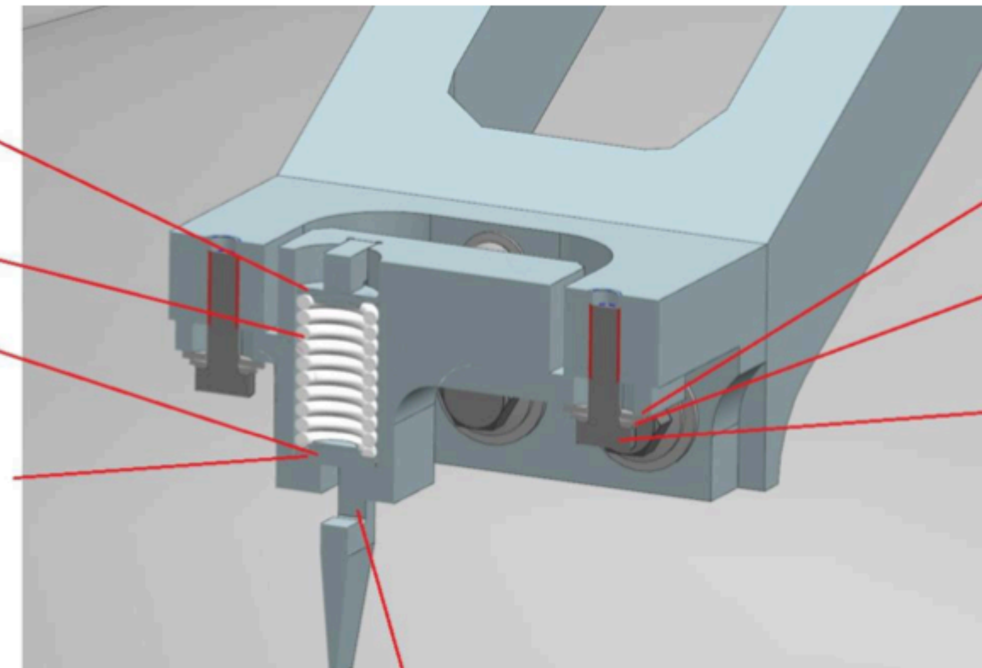


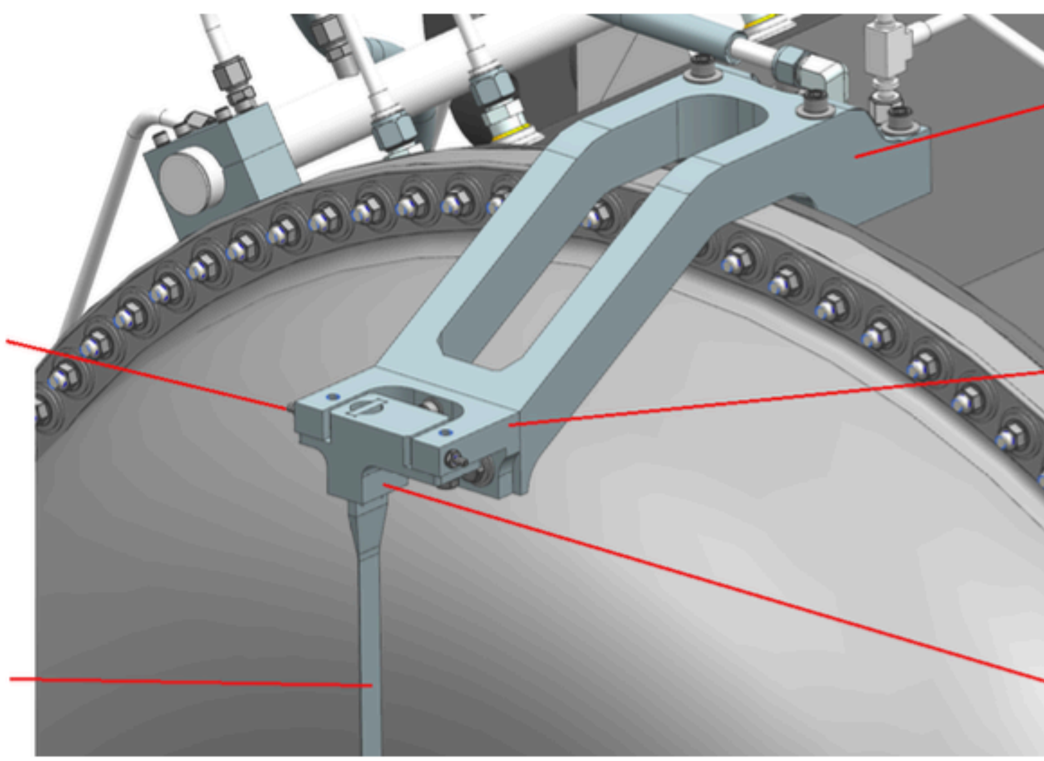
Horn B upstream



Cross hair alignment

- Crosshairs position will be checked by survey prior to operation
- Possible to fine tune into the nominal position
- Vertical adjustable +-0.060” (1.5mm) using shims with 0.010” resolution
- Horizontal adjustable +-0.125” (3.18mm) with infinite resolution





Beam Loss Monitors - NuMI

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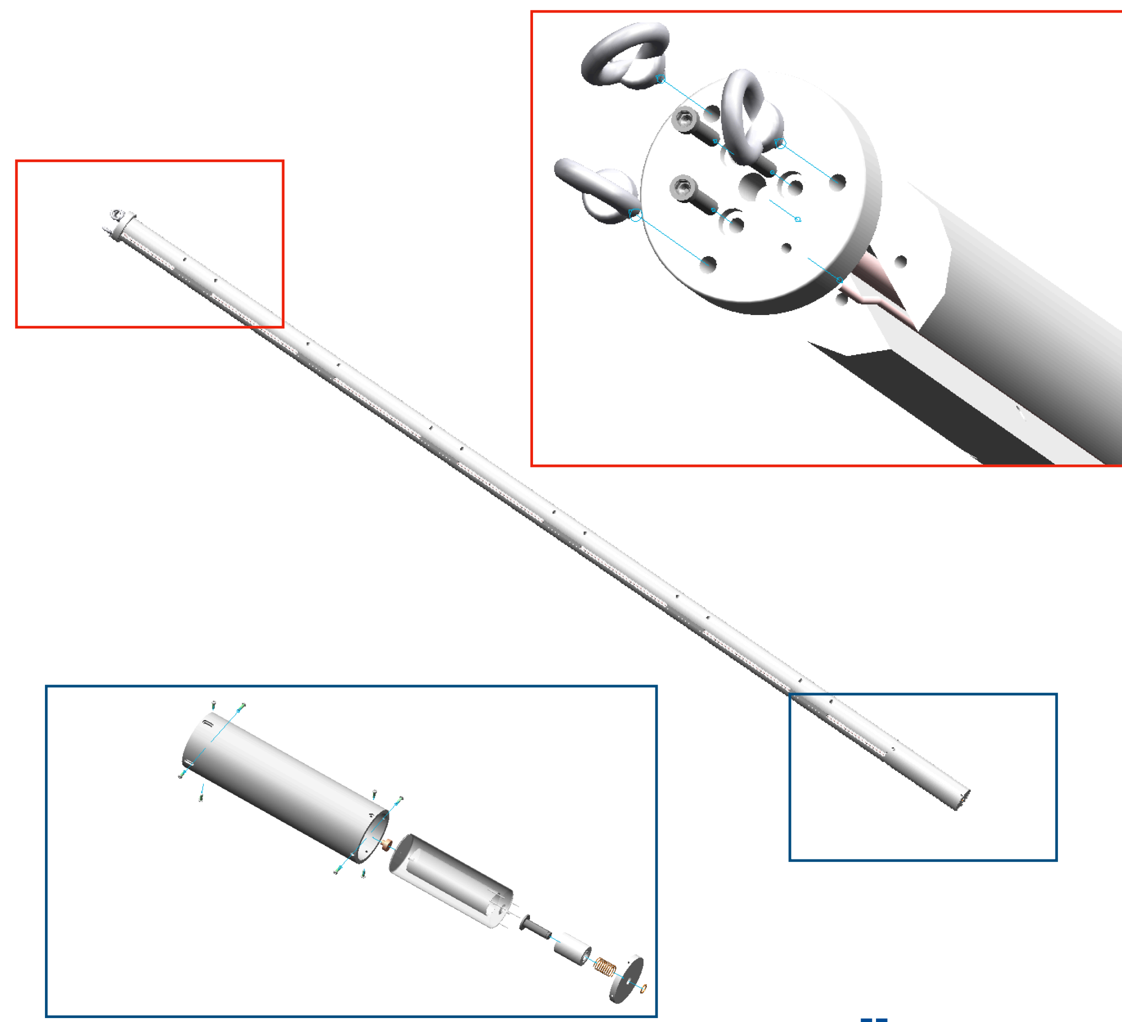
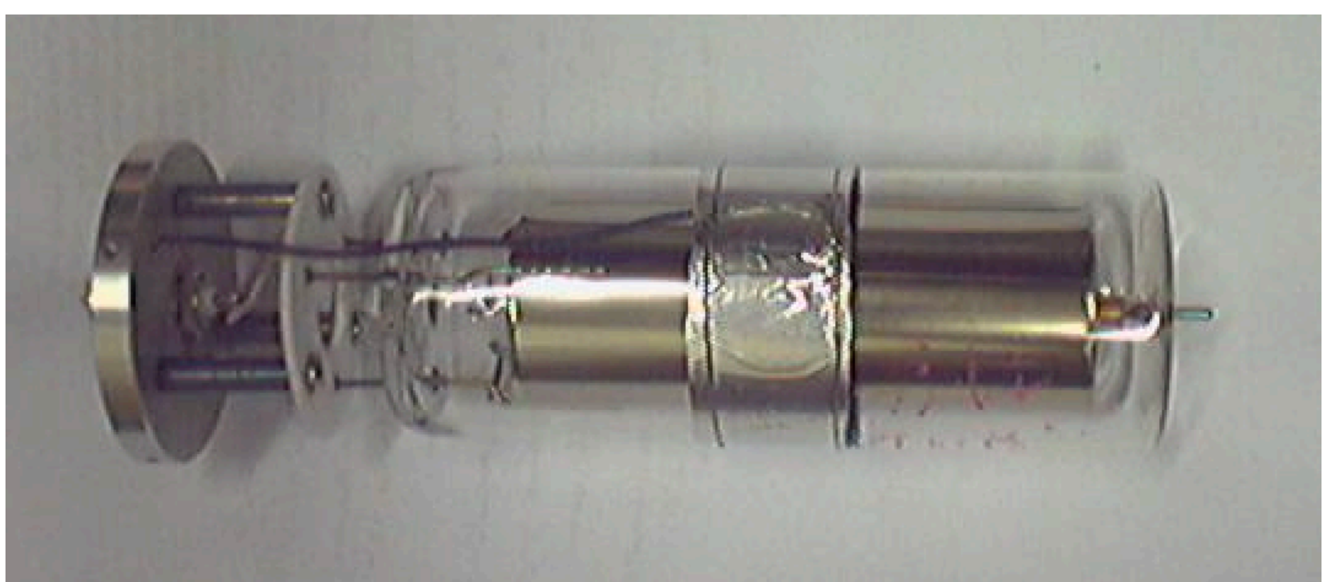
- Fermilab BLMs adapted for NuMI alignment use
- Support structure
  - 2.7m long, 7cm diameter aluminum cylinder
  - Carries radiation-hard signal, HV, and ground wiring
  - Lower end has a cup to hold BLM
  - Upper end has support structure
- Can be inserted or pulled out of the beam
- Electronics setup to give 1V per 10^7 particles (expectation from MC was few 10^7 per 10^{12} protons (90% of signal current shunted to ground)

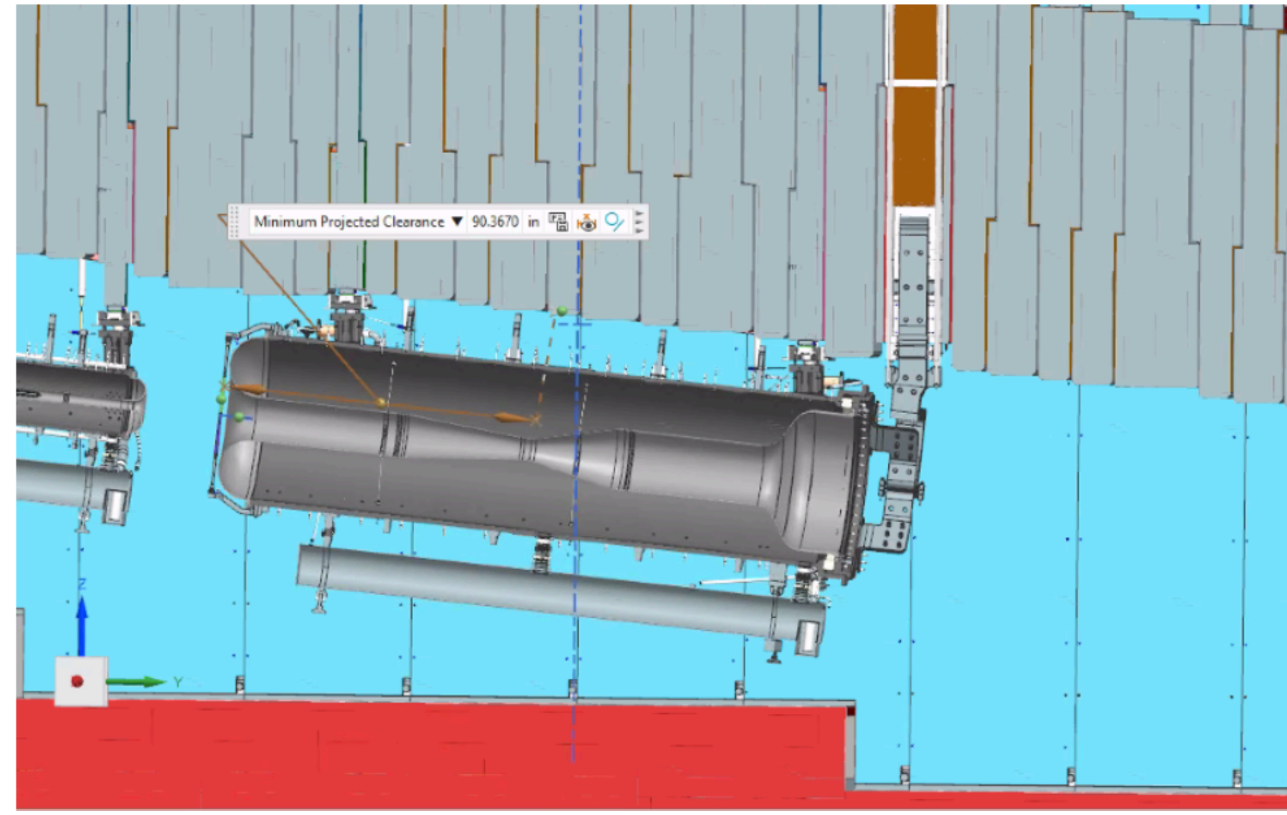


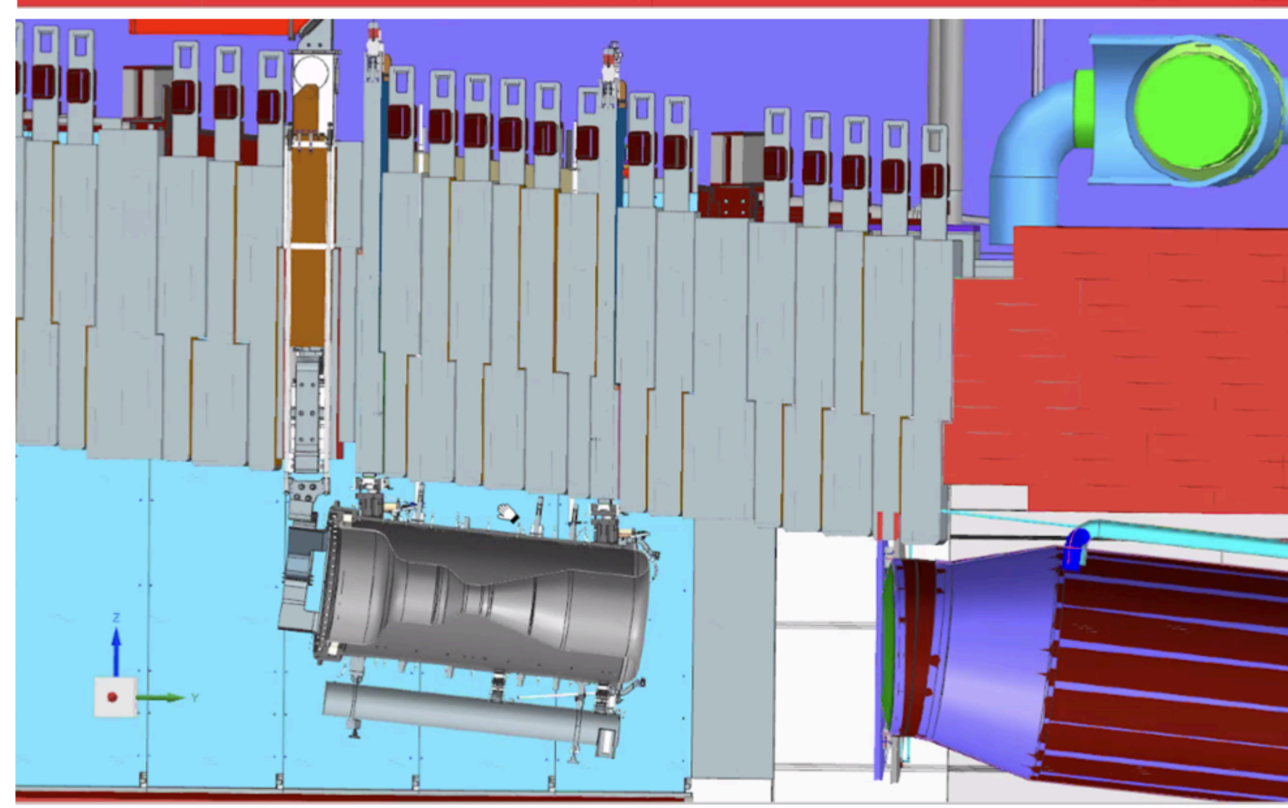


Fermilab

Beam Loss Monitors in LBNF

- Building upon NuMI BLMs
- BLM following each cross hair
- Limited space mid horn, and needs to be outside horn envelope
- More space downstream
- Note that it is not necessary to know precise location of BLMs, just looking for relative change in signal





Beam Loss Monitors in LBNF

- Working with Beamline project engineers identified physically possible locations for BLMs

- Currently working on T-blocks to accommodate them

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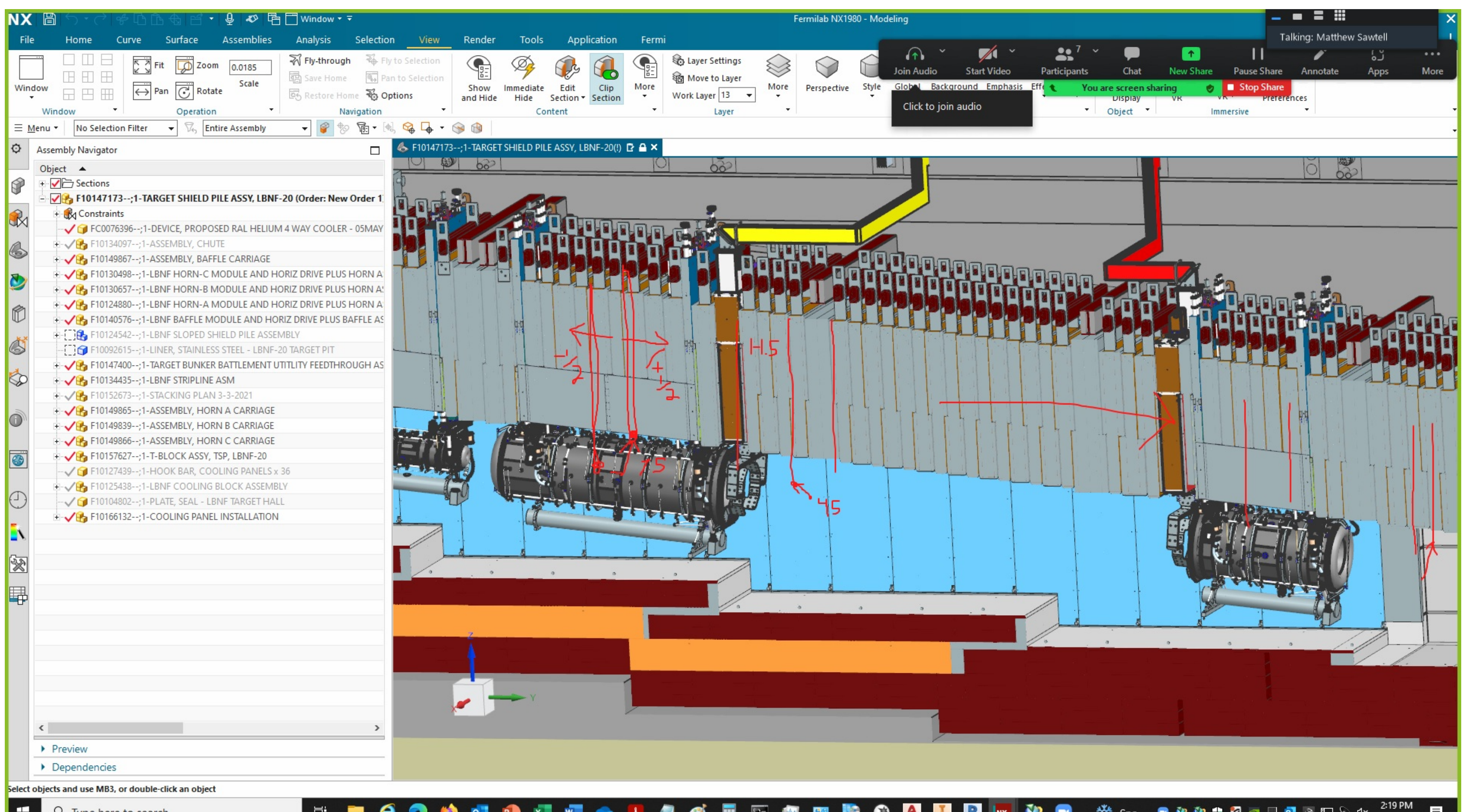

Simulation studies

- Using g4lbnf with added cross hair geometry and particle tracing mid-horn, and planes downstream of the horns B&C
- Scan beam from -20 to 20mm along x(y) axis
- Simulation predicts of the order of 10^7 particles/10^{12} protons per pulse (lower for mid horn positions)
- Identify BLM/xhair location, geometry to get adequate signal

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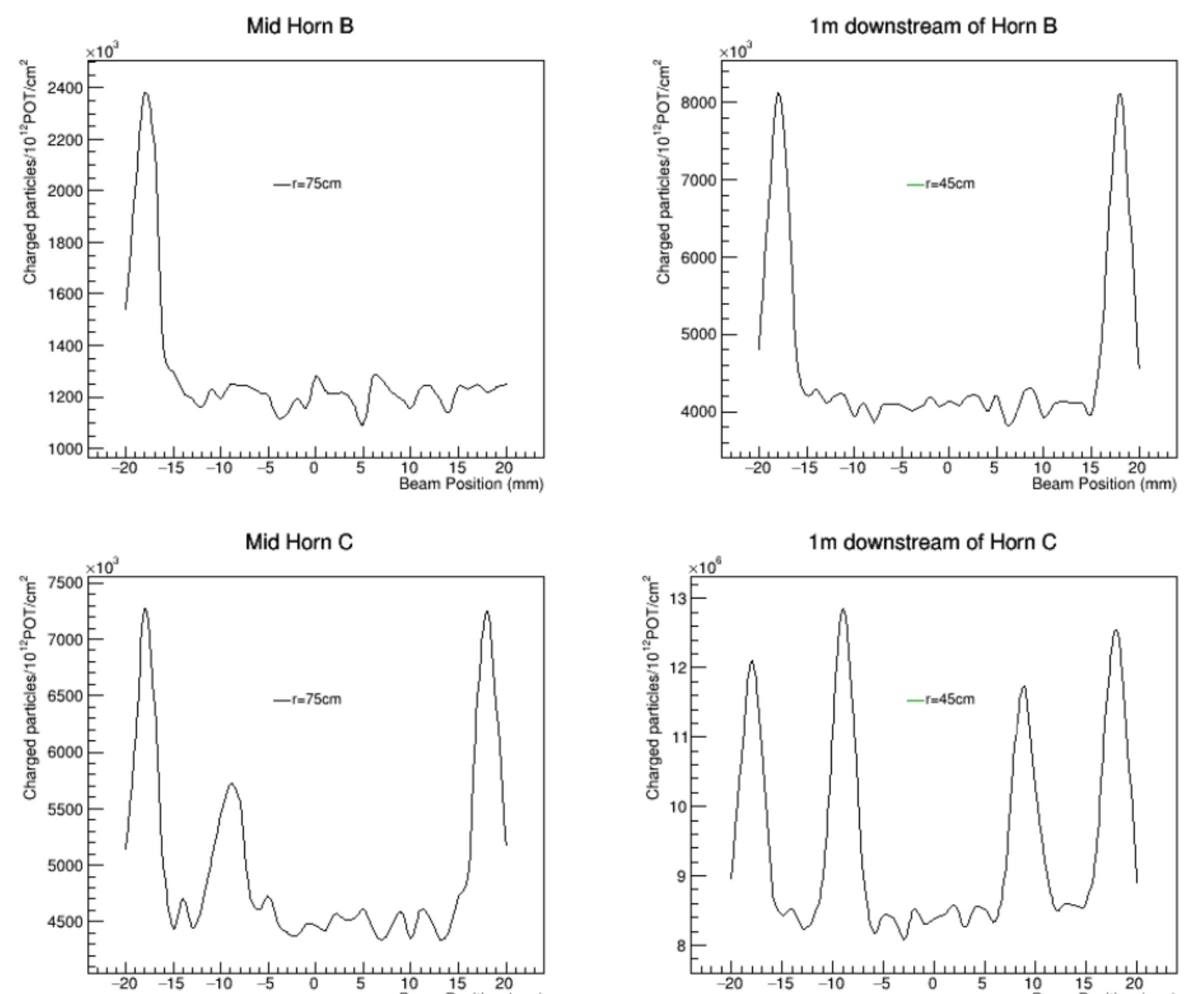
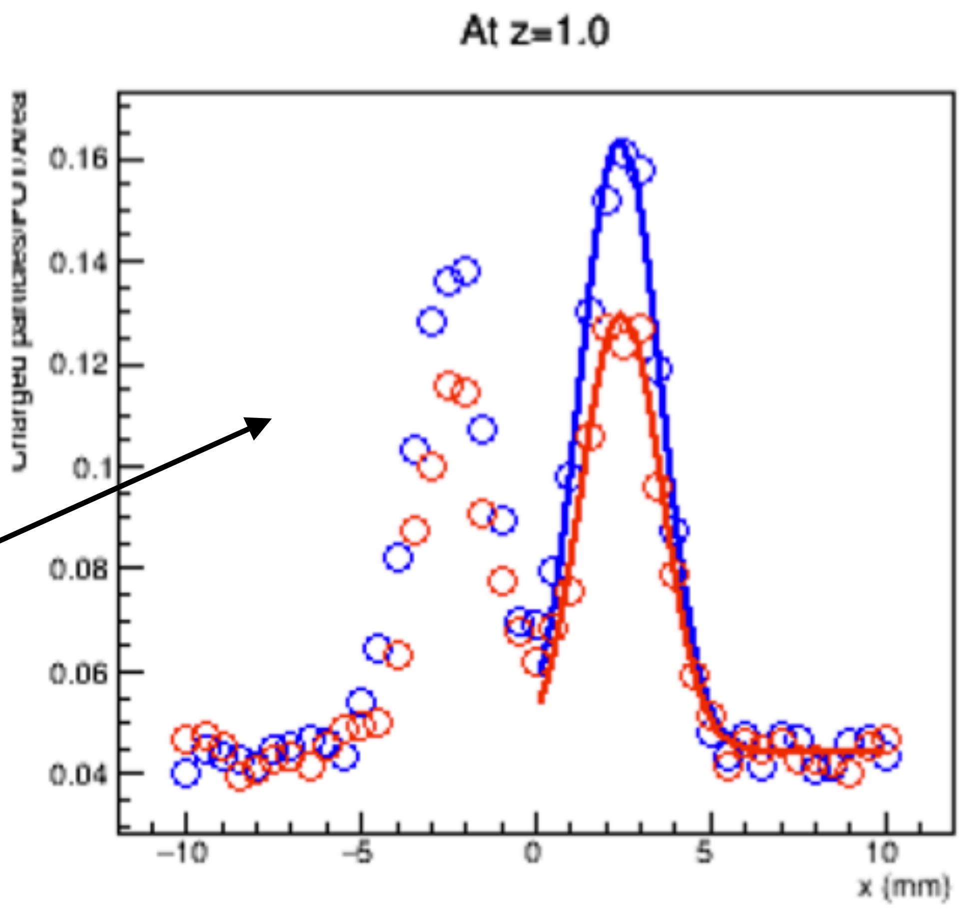


DUNE-DocDB-24586

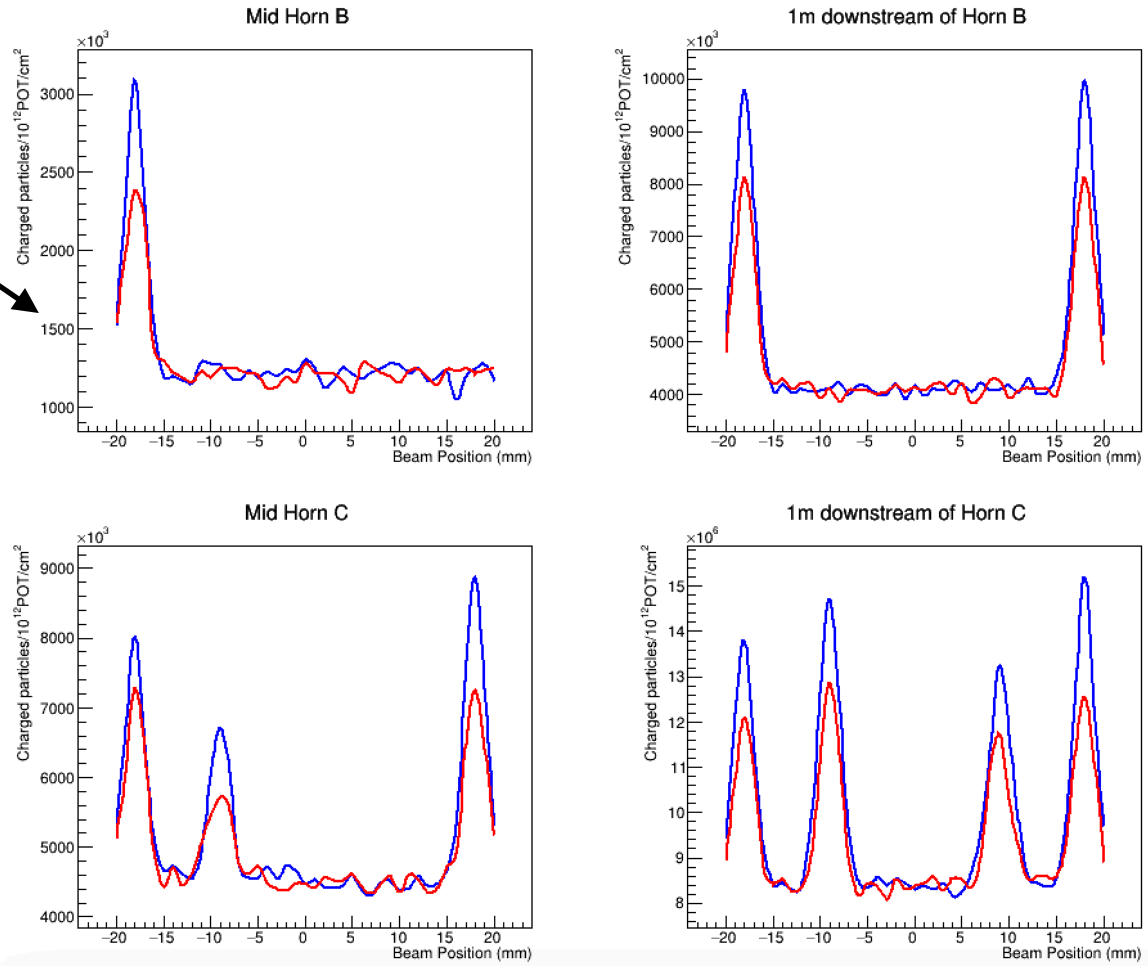
Fermilab

Simulation studies

- Current design using Beryllium for horn B upstream cross hair
- From simulation expect ~20% lower signal



- Signal proportional to cross hair thickness (along beamline)
  - 27 vs 18mm cross hairs - 15-20% increase in signal



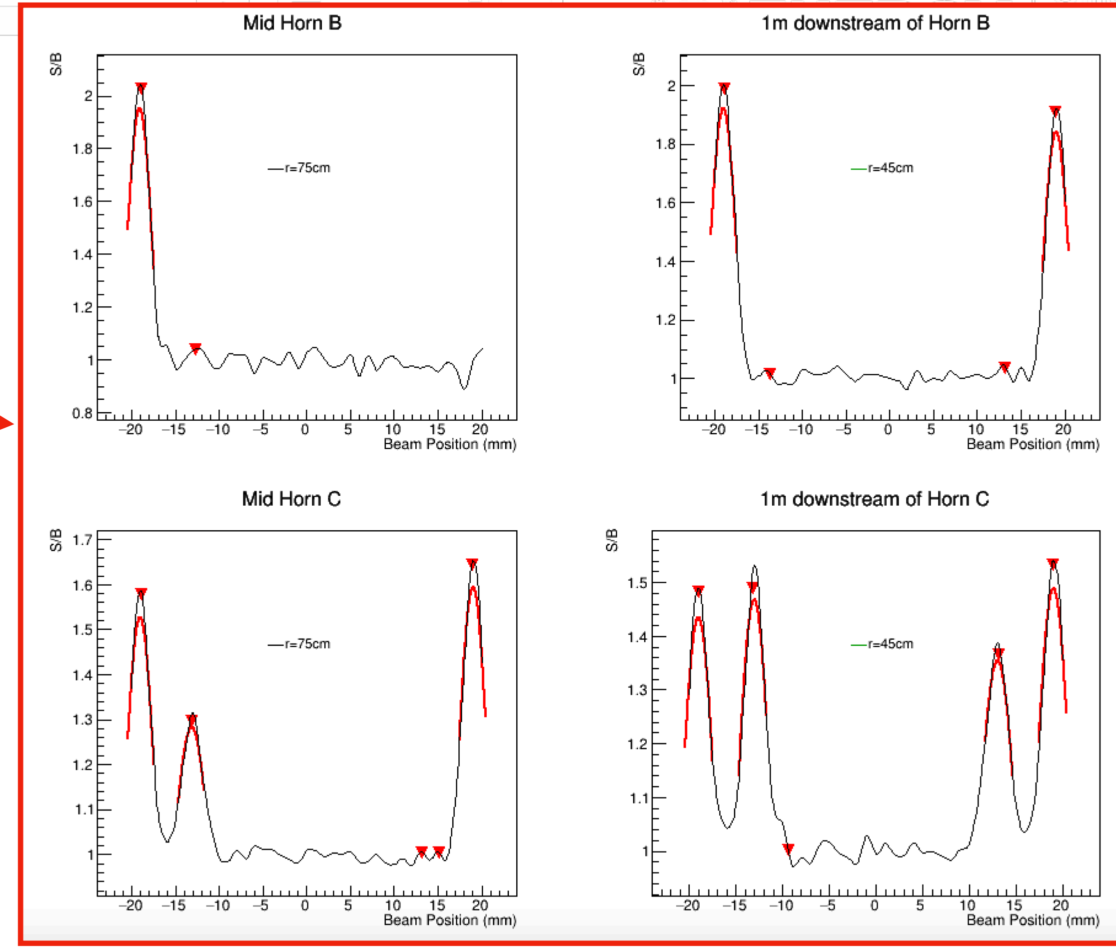
Beam based alignment

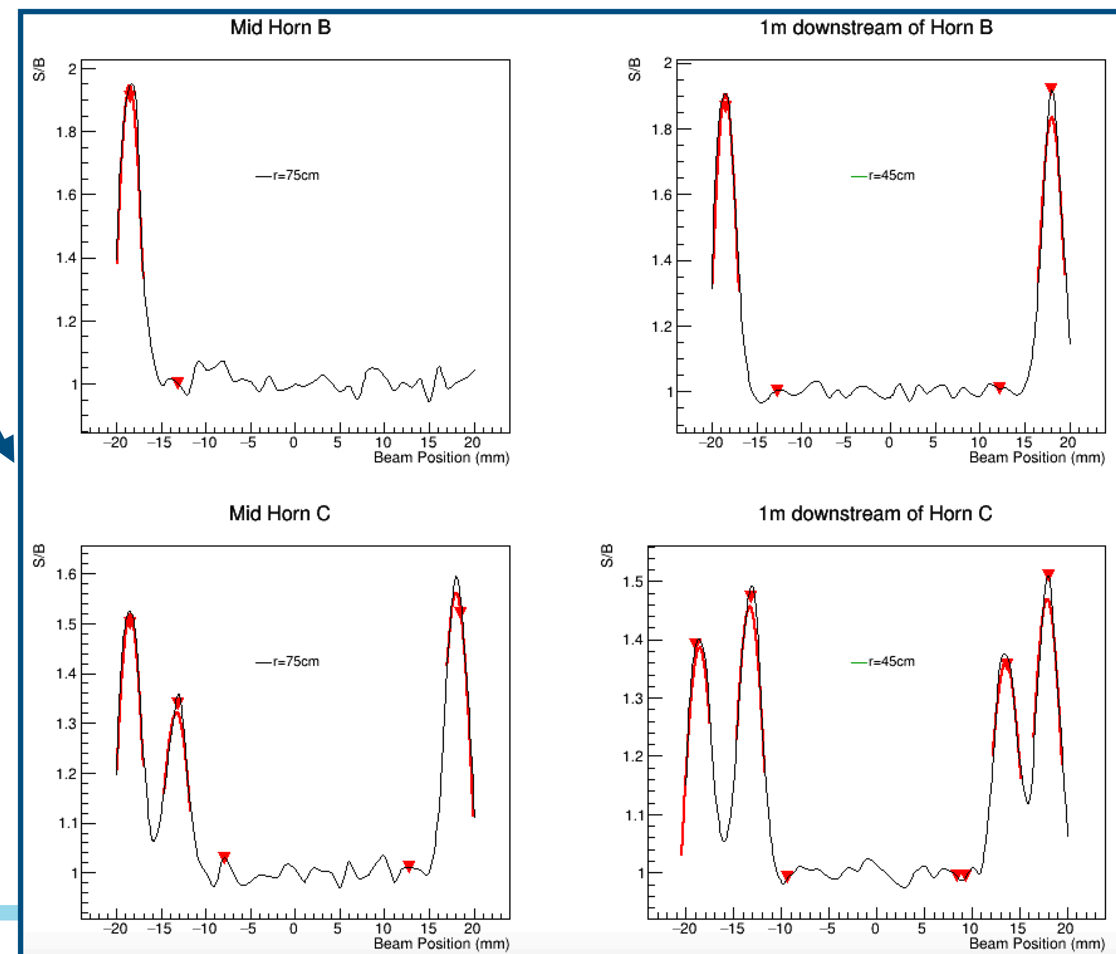
- Nominal position

  vs

  Horns tilted
  (Horn B: downstream -1.5mm, upstream +0.5mm,
  Horn C: downstream +1.0mm, upstream -0.5mm)

- Redundant information, with assumed tilts peaks resolvable using most downstream BLM





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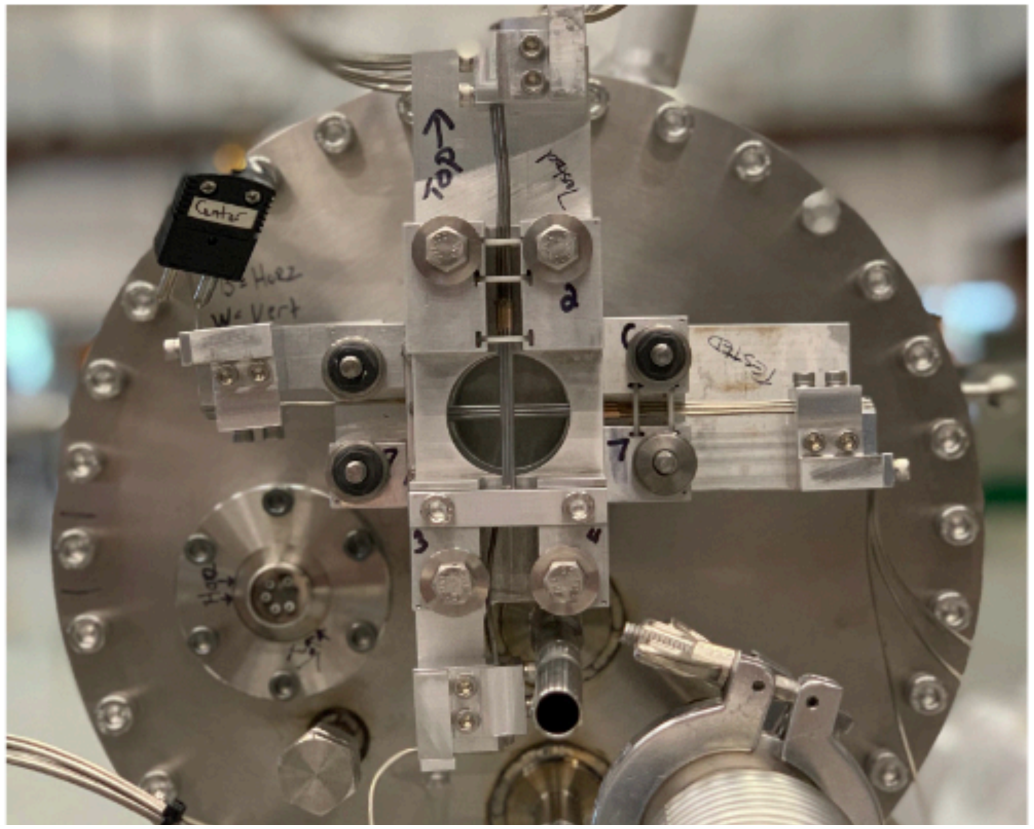
DUNE-DocDB-19942

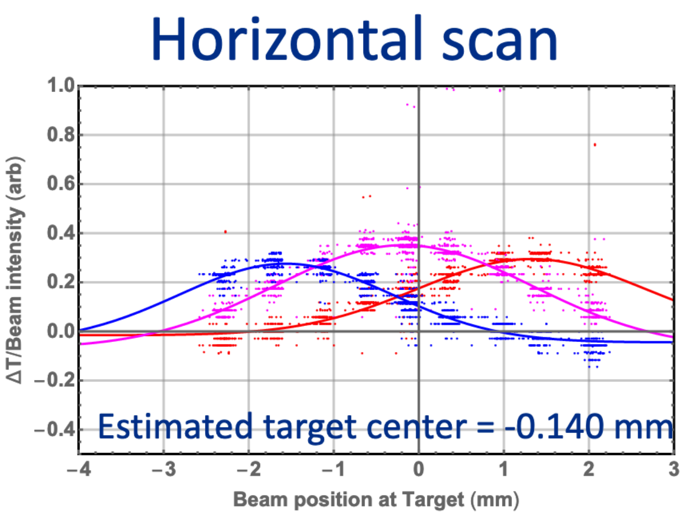
Beam position on target

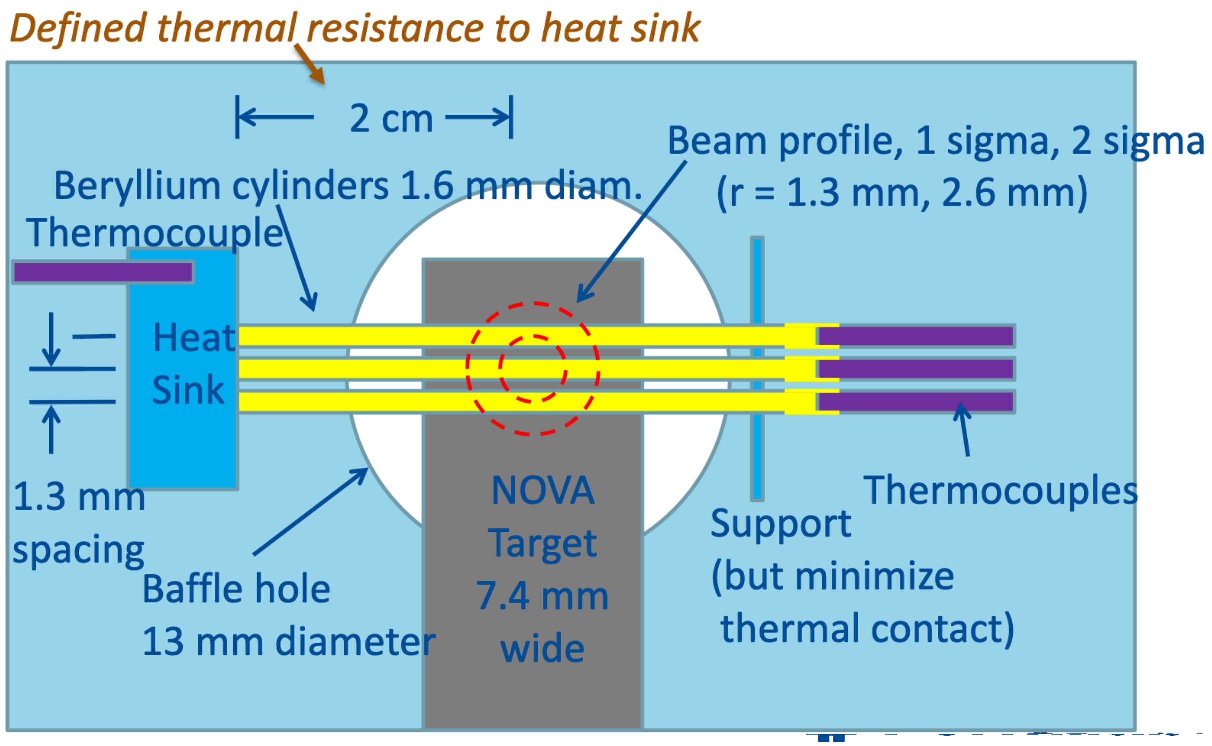
- Use beam position monitors to steer beam on target
- Beam based alignment finds the target and all other elements within BPM coordinates
  - Dedicated study time (occasional - beginning/end of run)
  - Low intensity/single batch, 1mm RMS beam size
- Need to control for:
  - BPM intensity dependence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







Requirements for the LBNF Target Position Thermometer

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8. Are there any issues concerning the schedule for the NBI?

- Short document listing the requirements: DocDB 23169

1. The TPT must be capable of measuring a 0.1 mm deviation of the beam vertical and horizontal position during normal beam operations (a minimum spill intensity of 7.5×10^{12} POT and maximum spill intensity of 7.5×10^{13} POT).

2. A measurement of the beam position to within 0.1 mm much be achievable within 5 minutes of beam exposure. Data from the TPT will be recorded on a spill-by-spill basis and made available to LBNF stakeholders.

- Demonstrated in NuMI that TPT system can satisfy the requirements

LBNF TPT

- Reoptimize system for LBNF operating parameters
  - 1.2MW beam - 7.5×10^{13}PPP
  - 2.7mm RMS beam size
  - Use 5 bars to accommodate wider beam, and heat sink with cooling fins
- To do heat transfer studies
- RAL working on engineering and integration with target
- NBI (using Fermilab engineer familiar with NuMI system) will work on Be thermocouple assemblies

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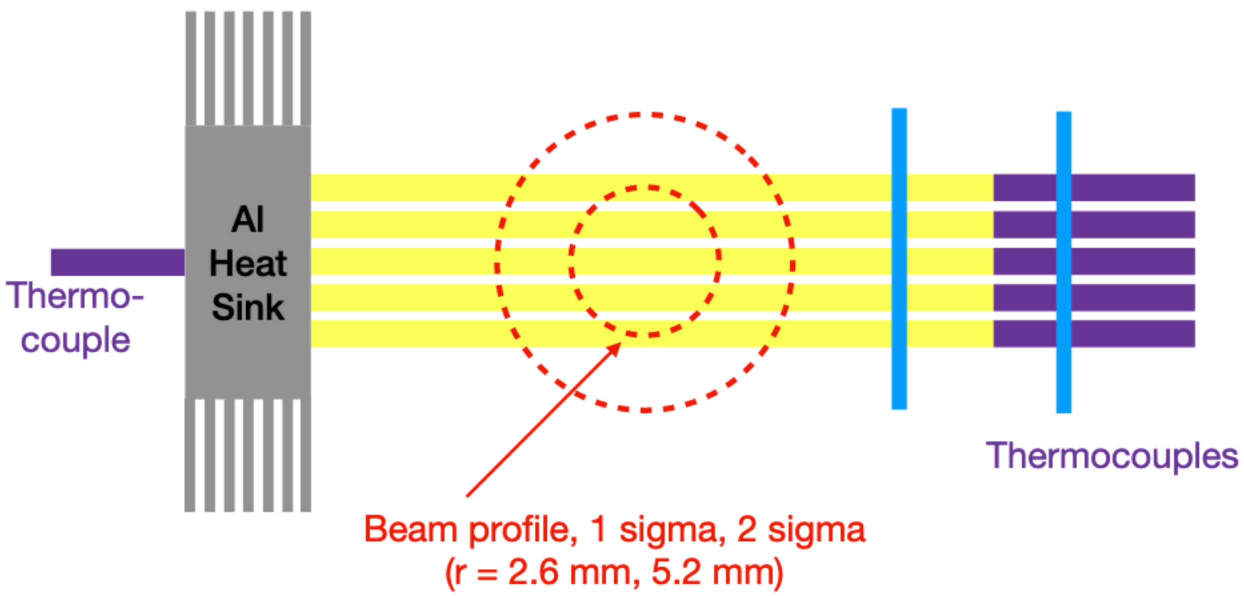
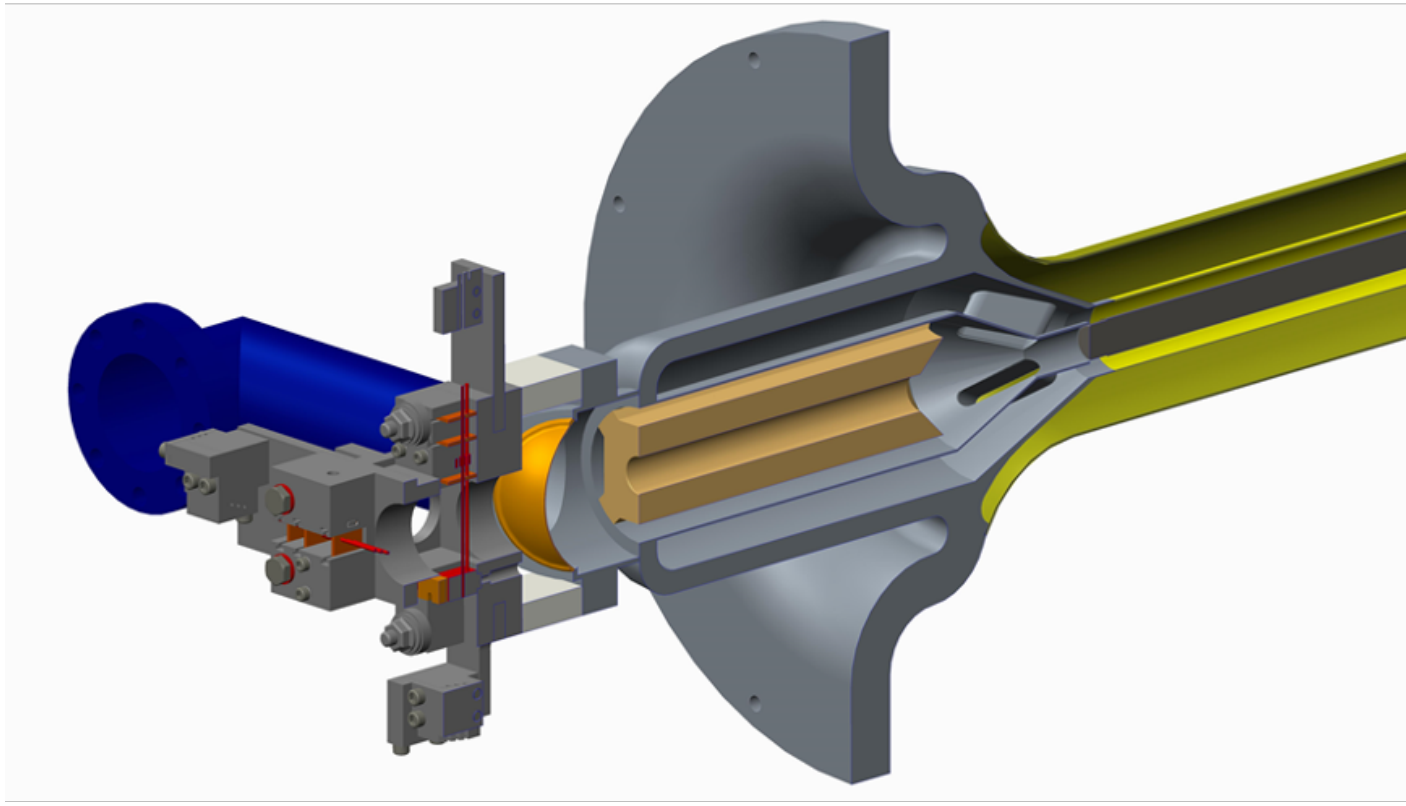
8. Are there any issues concerning the schedule for the NBI?





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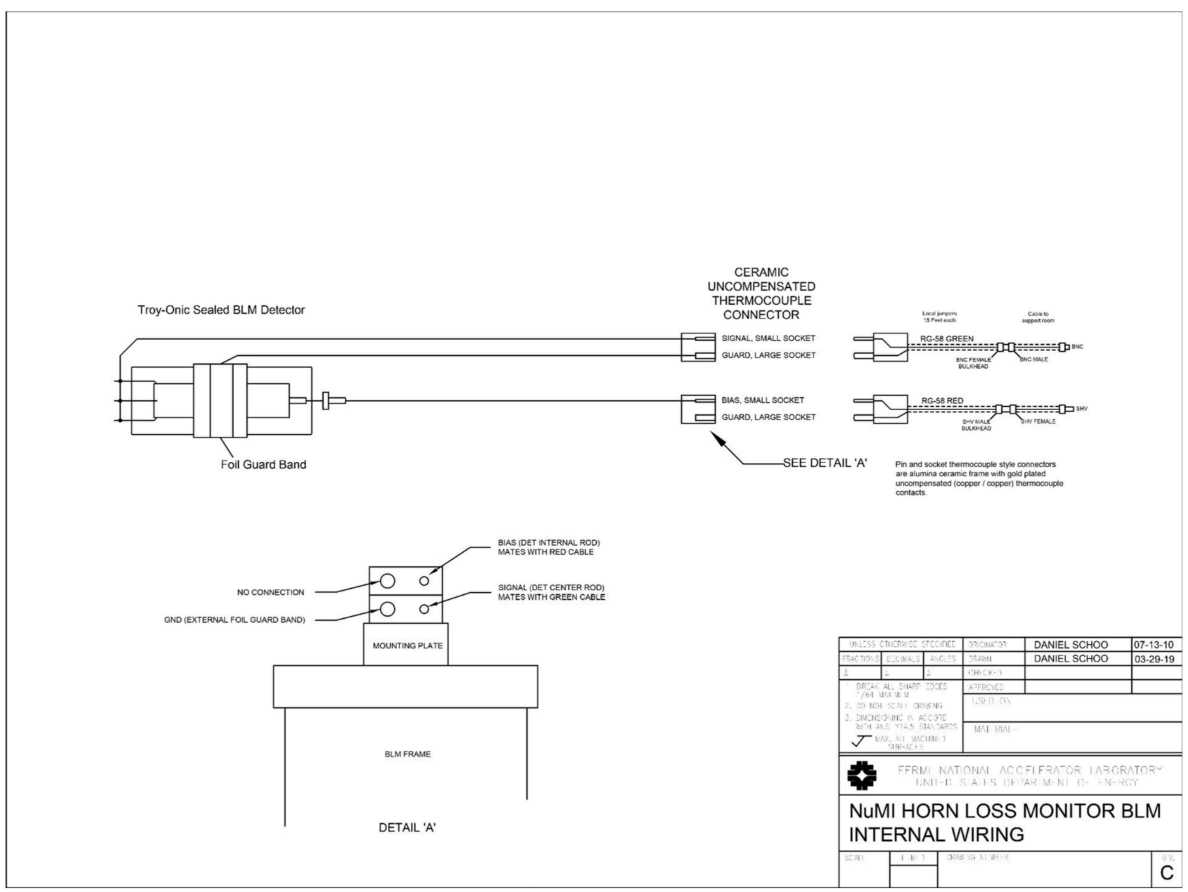
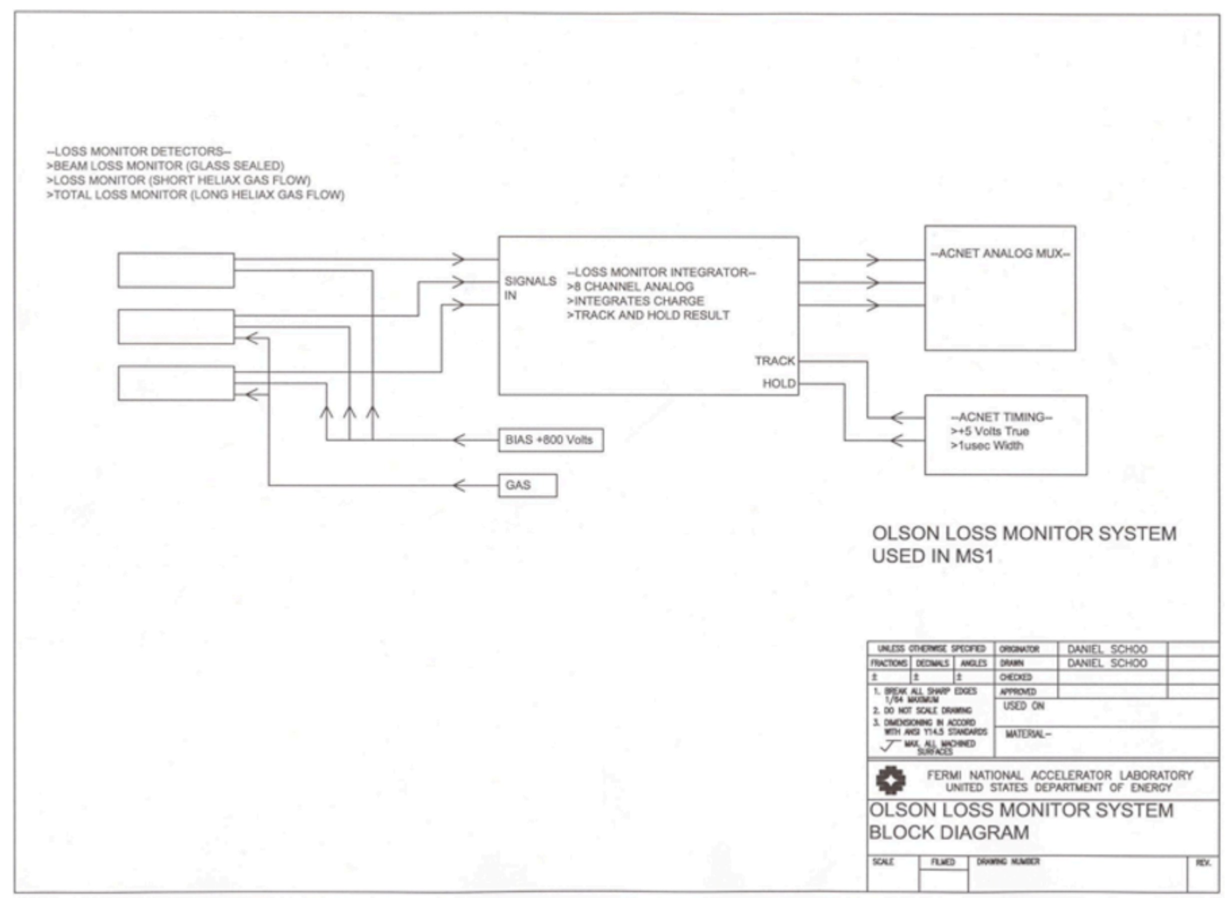
Fermilab

Detector readout and data access

- Both BLMs and TPT will use standard readout used by AD
  - Similar electronics to what is used now for NuMI
  - BLM signal goes to Olson Integrator with modified gate timing card
  - Thermocouples going through Acromag single channel thermocouple conditioners (for better resolution) and into HRM chassis
- Data will be fed to ACORN (ACNET replacement) and provided to users via systems like IFBEAM database





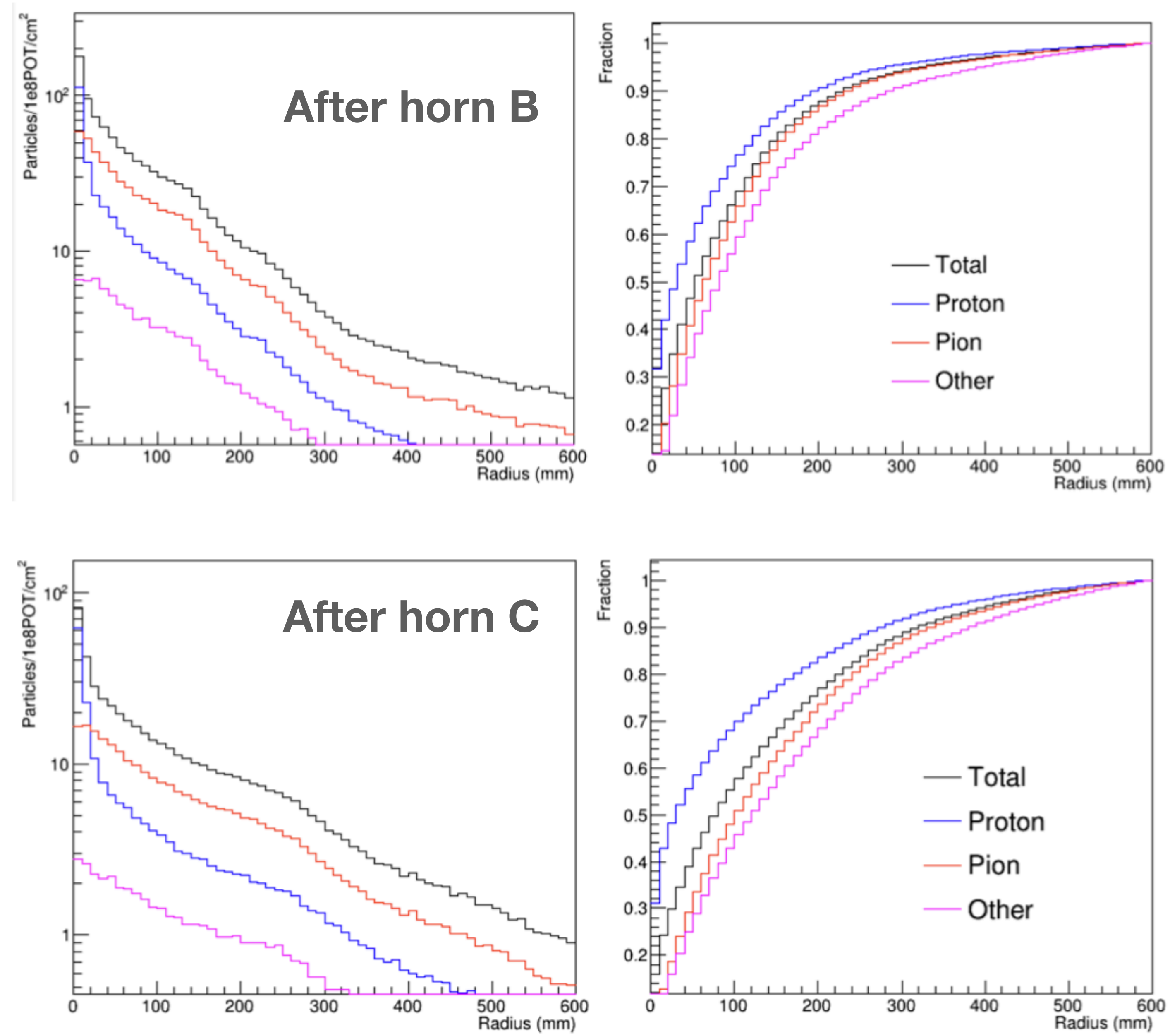
Summary

- Both Cross hair system and the Target Position Thermometer build on exhaustive experience with NuMI
  - Adapting existing design
  - Demonstrated required functionality
- Using beam based alignment cross hairs and BLMs provide a way to identify the horn B&C misalignments at the level necessary to satisfy physics requirements
- The Target Position Thermometer will provide information complementary to Beam Position Monitors, tying together beam based alignment and full intensity operations

Backup

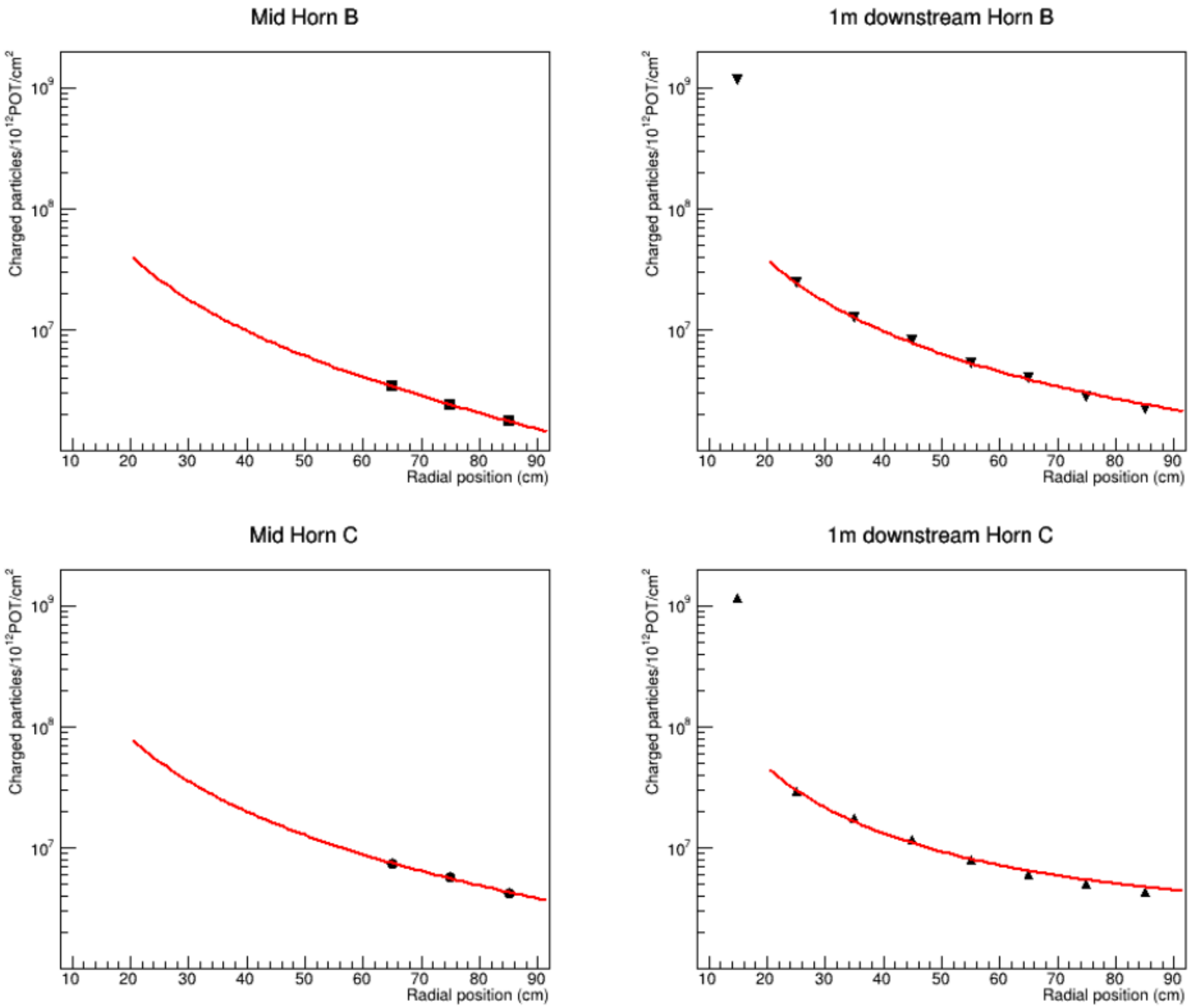
Simulation studies - radial position

- Radially - more signal closer to axis, but preferably avoid bulk of the beam during normal running (if monitors stay inserted)
- 95% of pions contained within the r<33cm after horn B, and r<43cm after horn C



Simulation studies - radial position

- Radially - more signal closer to axis, but preferably avoid bulk of the beam during normal running (if monitors stay inserted)
- 95% of pions contained within the r<33cm after horn B, and r<43cm after horn C
- Signal falling off roughly as $1/r^2$
- Signal over background remains fairly flat



Simulation studies - longitudinal position

- Peak signal vs the downstream plane position relatively flat
- Only concern far off-axis if BLM less than 1m downstream of the cross hair