Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Horn B&C alignment and beam on target monitoring

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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 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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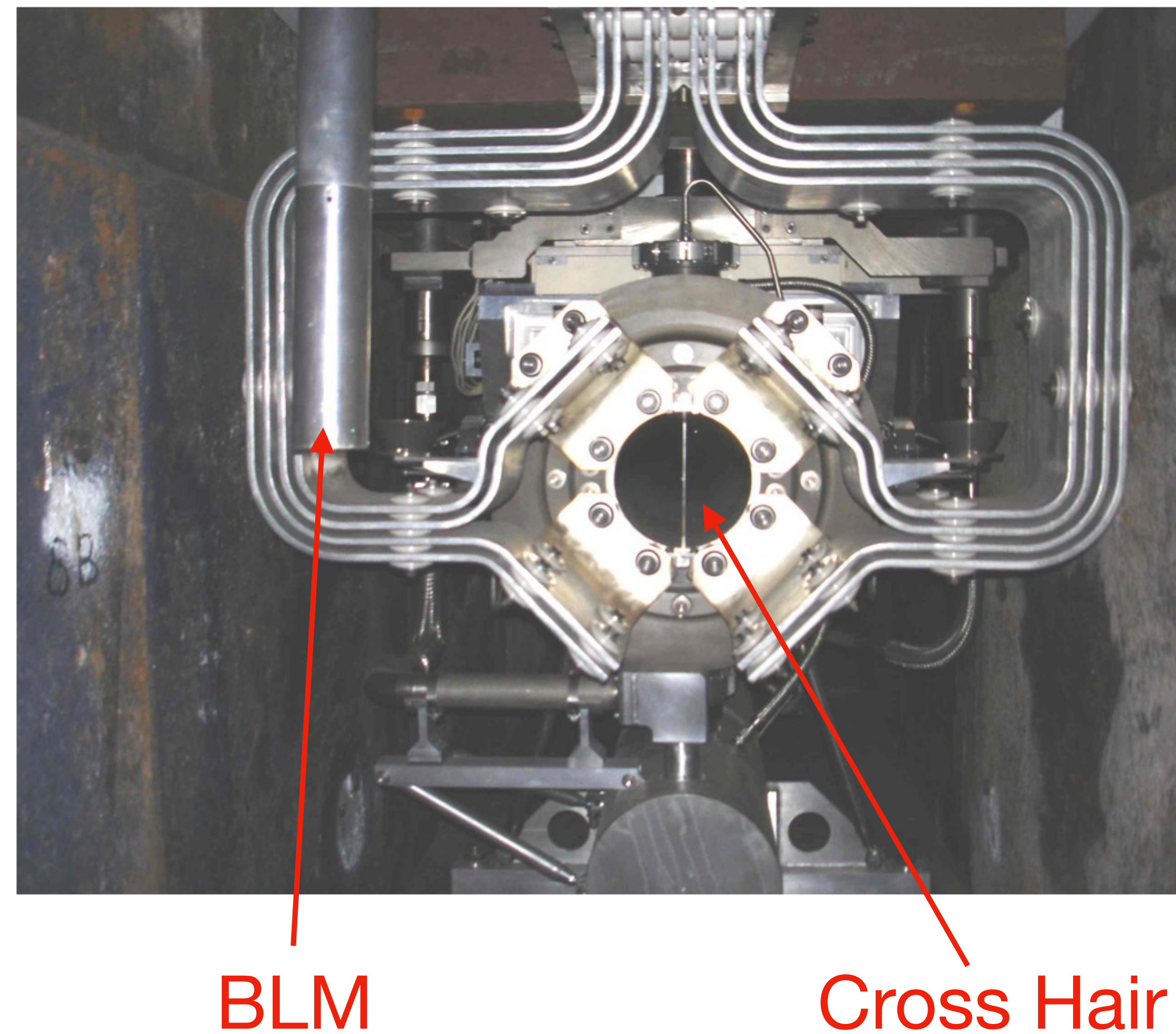
Beam based alignment

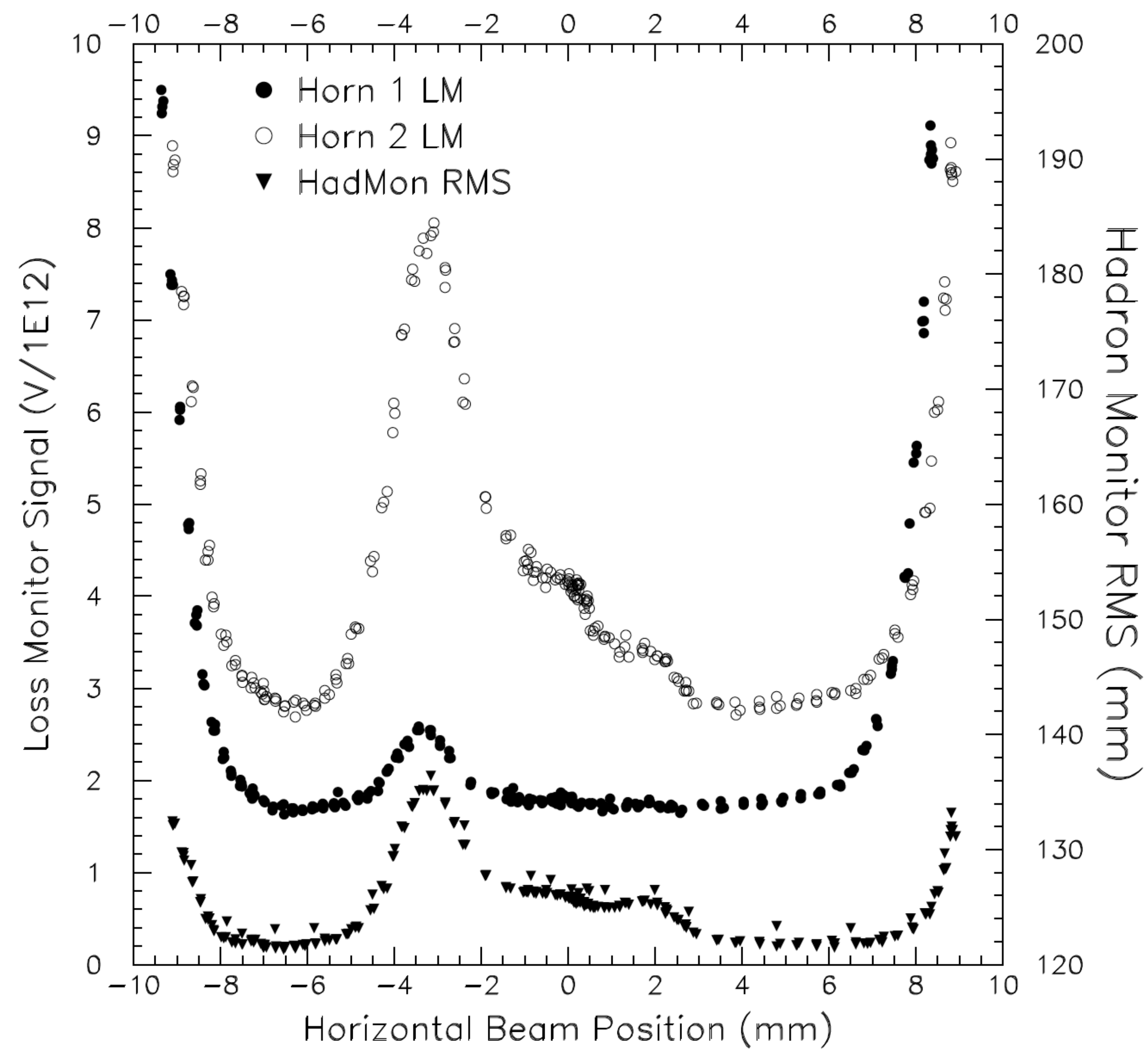
- Horn B & C aligned as part of the beam based alignment
- Scan beam across the known physical features to locate each element
- Use cross hairs at upstream and downstream ends of horns B & C
- Beam loss monitor to detect beam scatter from cross hairs

NuMI Horn



NuMI experience

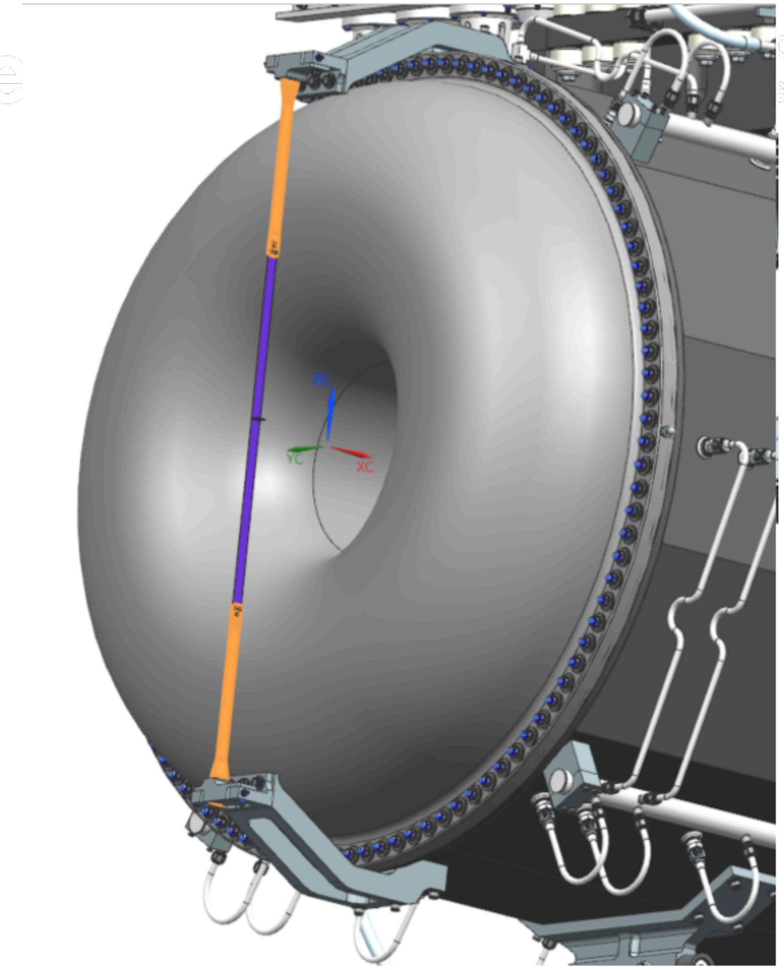
- Cross hair downstream end of Horn 1, and both upstream and downstream end of Horn 2
- Aluminum bars used as cross hairs 1mm wide, and 6mm or 18mm deep along the beam axis
- Low intensity beam <1e12PPP, with $\sigma_{x,y}$~1mm
- Alignment within 0.5mm
- Some lessons learned
  - Horn 2 upstream cross hair (18mm) giving much bigger signal then downstream (6mm), 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



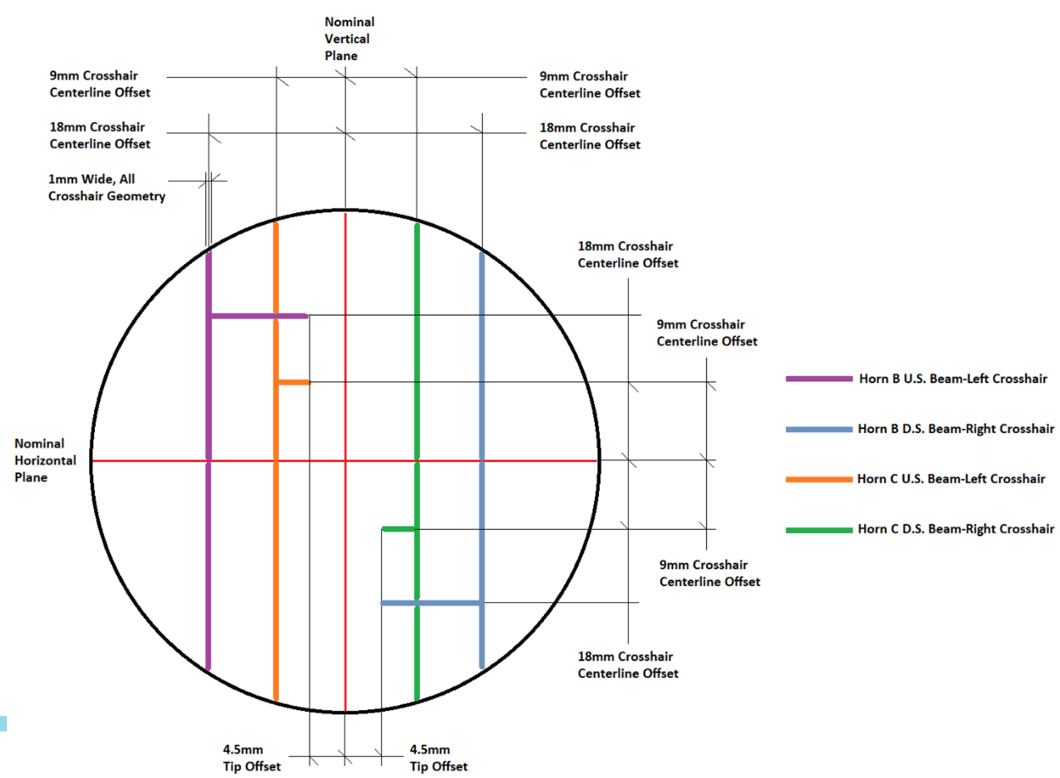
LBNF

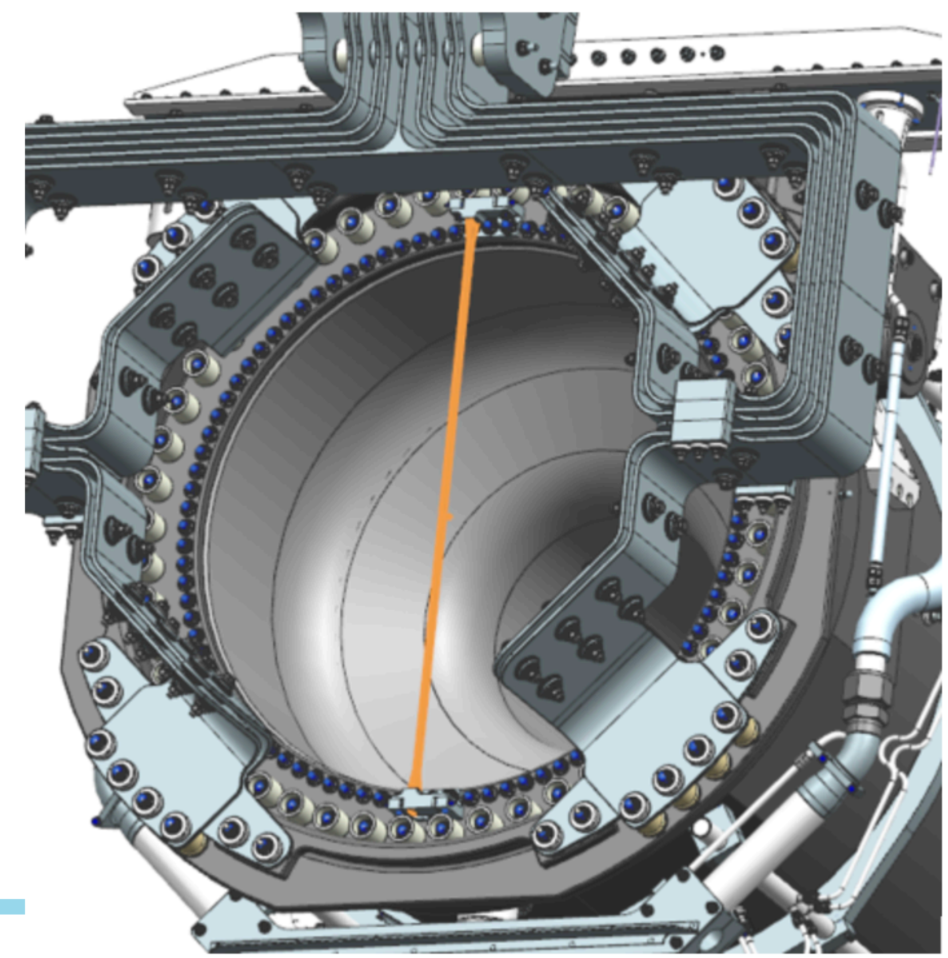
- Engineering document describing Horn B&C cross hairs, stresses, deformations, and Finite Element Analysis
  C. Crowley DUNE-DocDB-23108

- All cross hairs 1mm wide, 18mm along beam



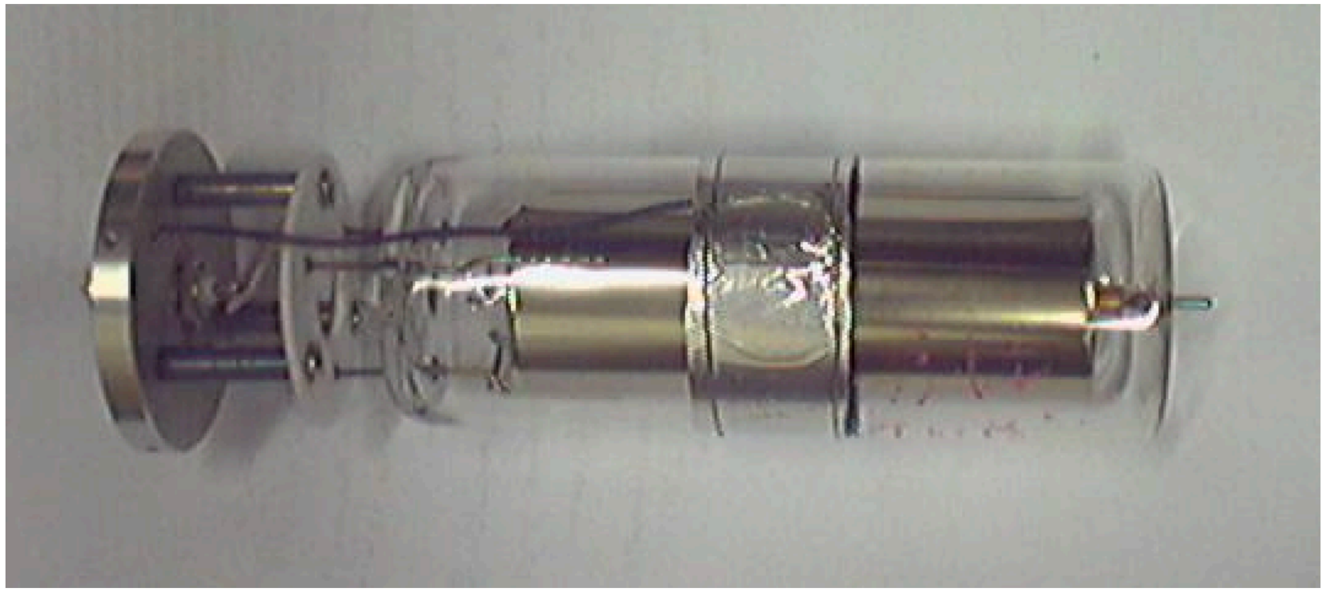
	Horizontal offset (mm)	Vertical offset (mm)	Horizontal nub length (mm)
Horn B upstream	-18	18	13.5
Horn B downstream	18	-18	13.5
Horn C upstream	-9	9	4.5
Horn C downstream	9	9	4.5

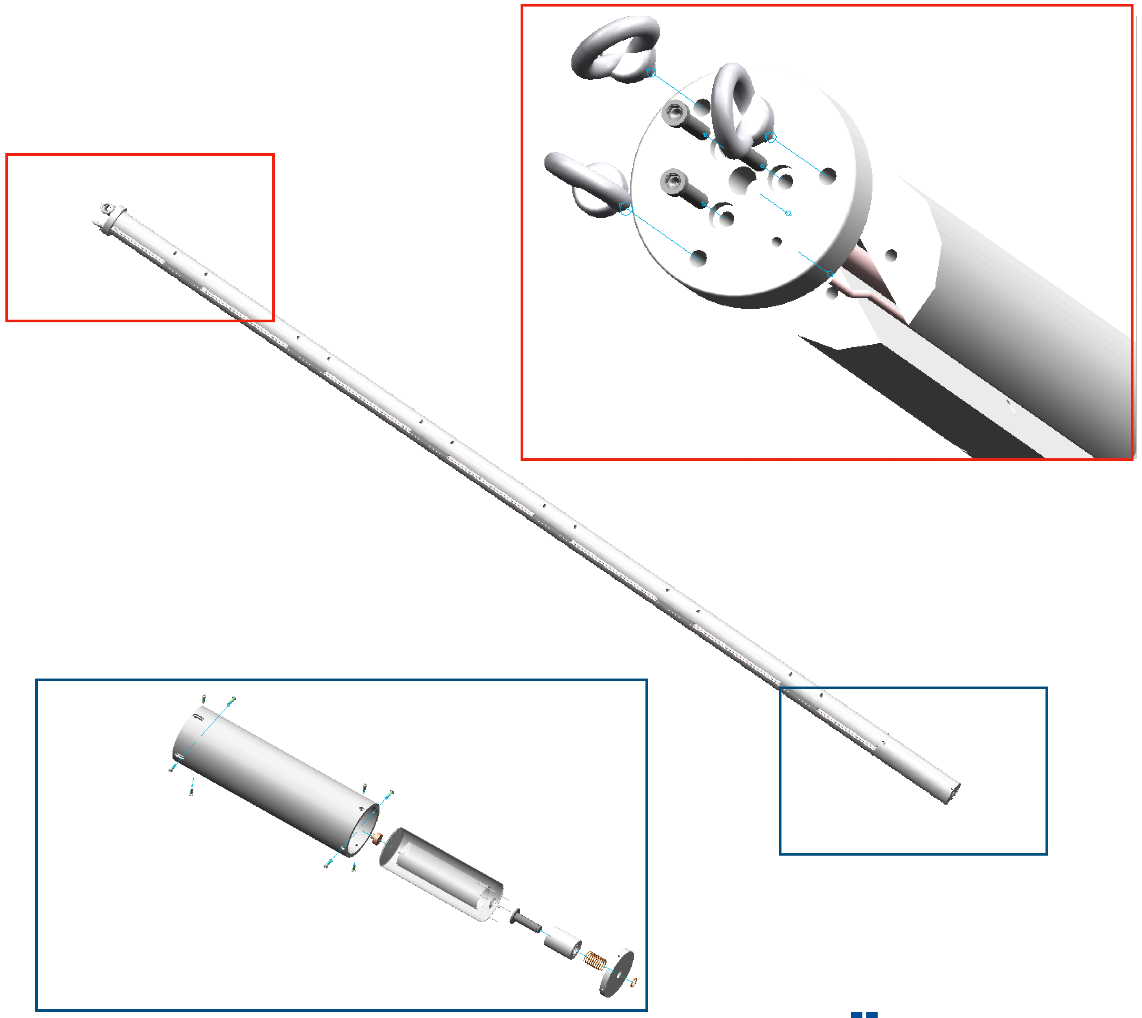




Beam Loss Monitors - NuMI

- 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)

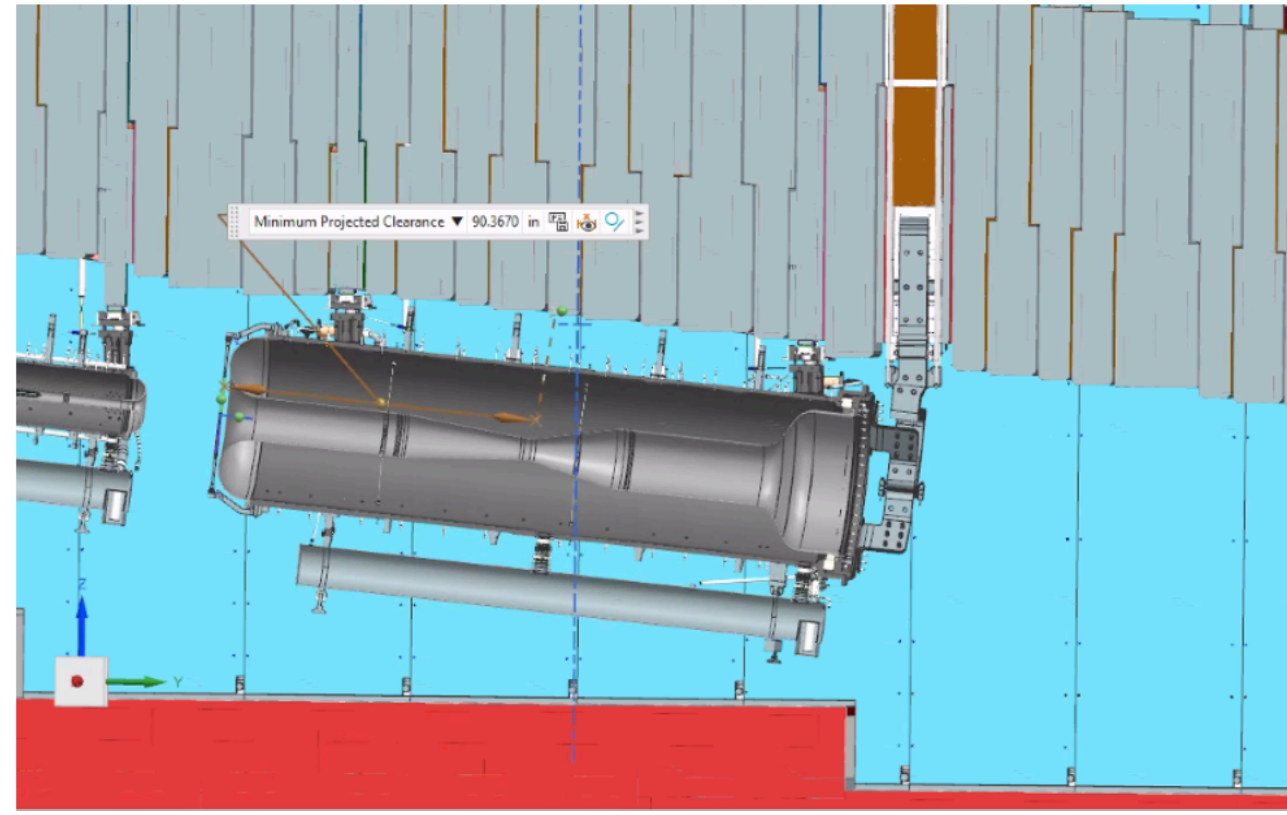


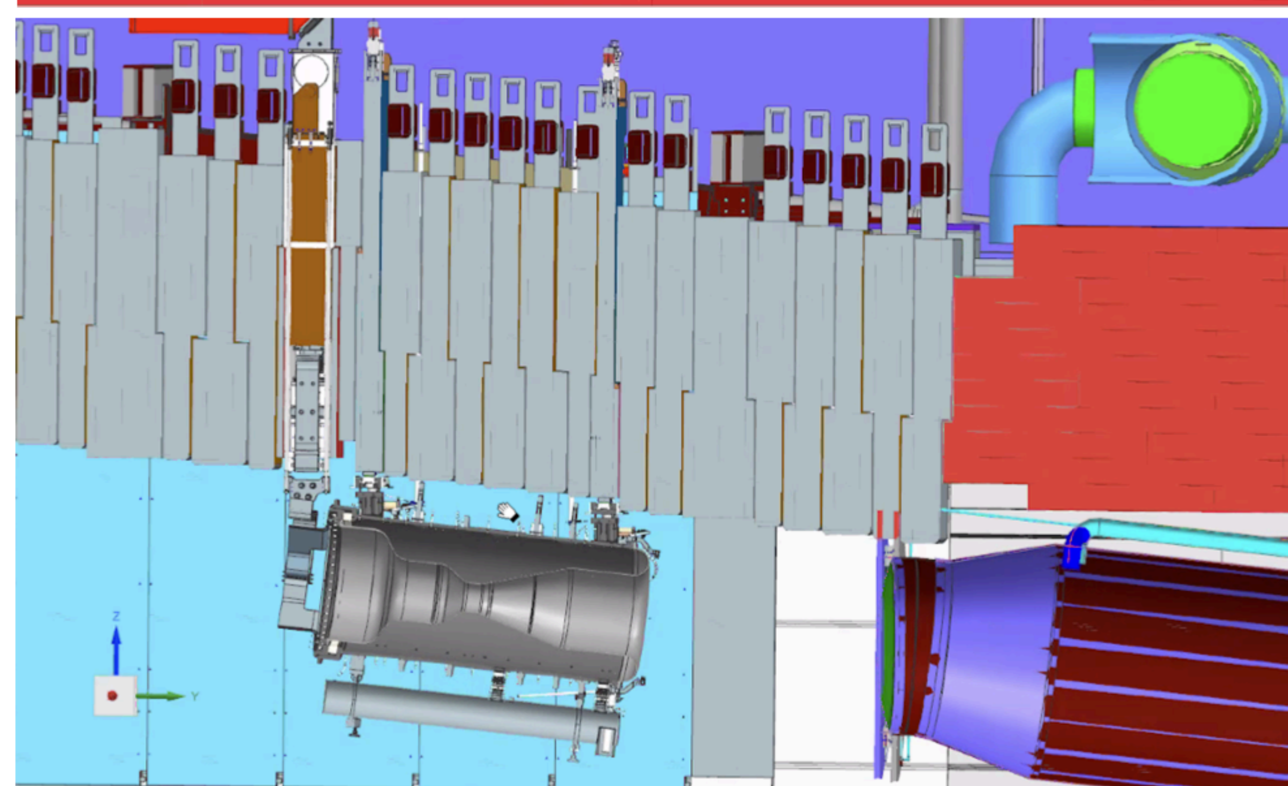


Fermilab

Beam Loss Monitor placement

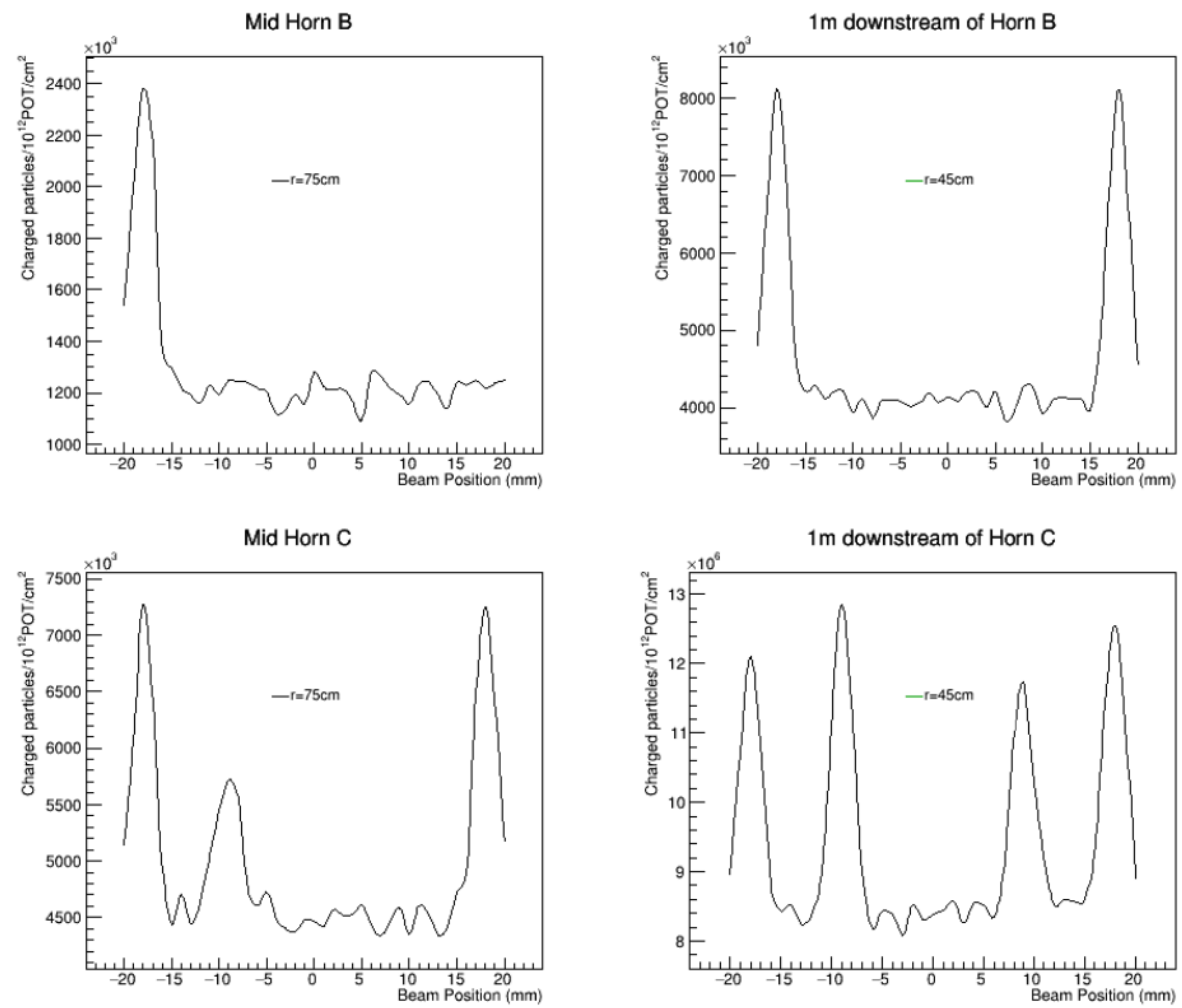
- Preliminary discussions where to install the BLMs
- Ideally have BLM following each cross hair
- Limited space mid horn, and needs to be outside horn envelope
- More space downstream
- Note that it is not necessary to know precise location of BLMs, just looking for relative change in signal





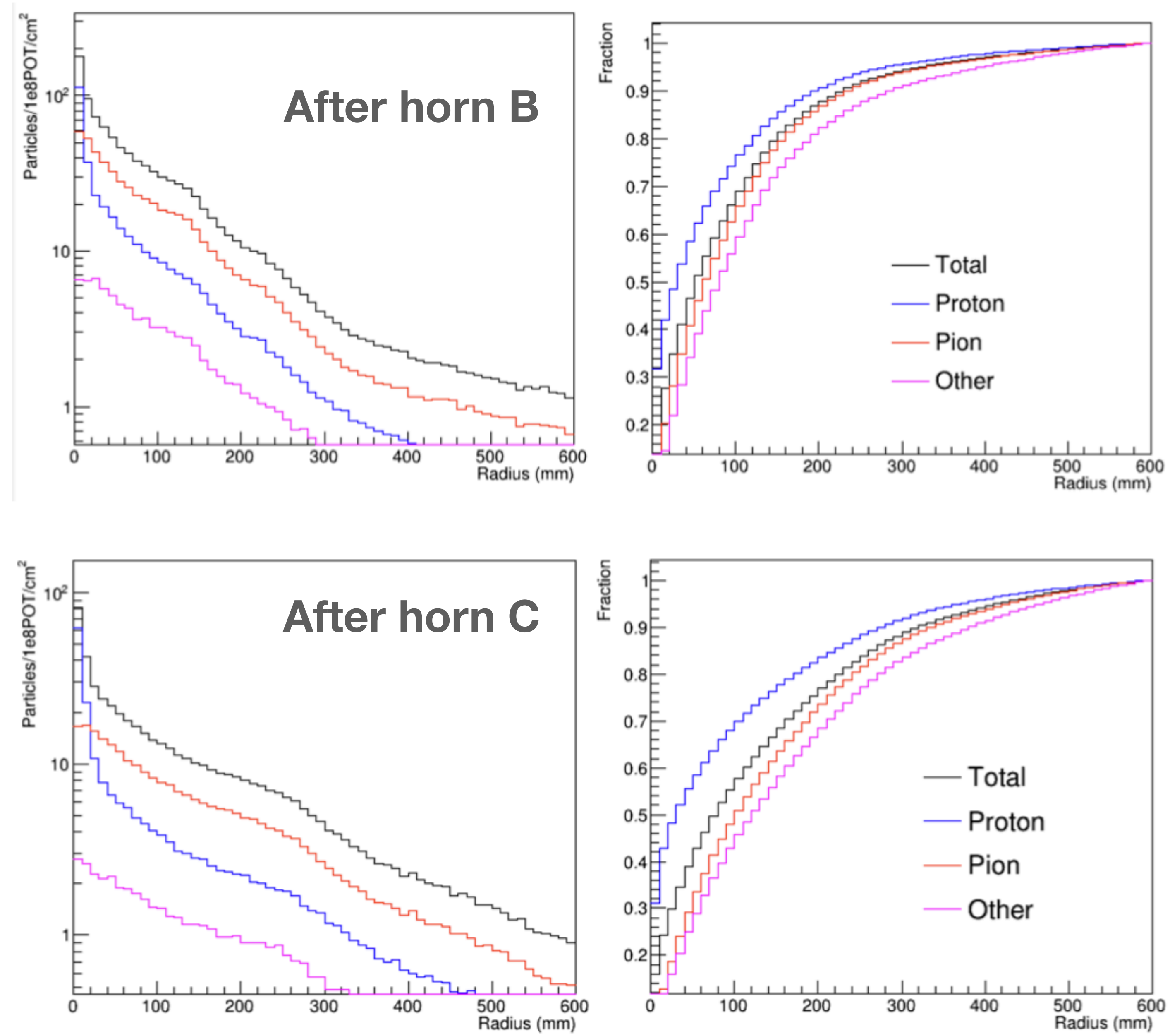
Simulation studies

- 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)
- Need to optimize location, xhair geometry to get adequate signal



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



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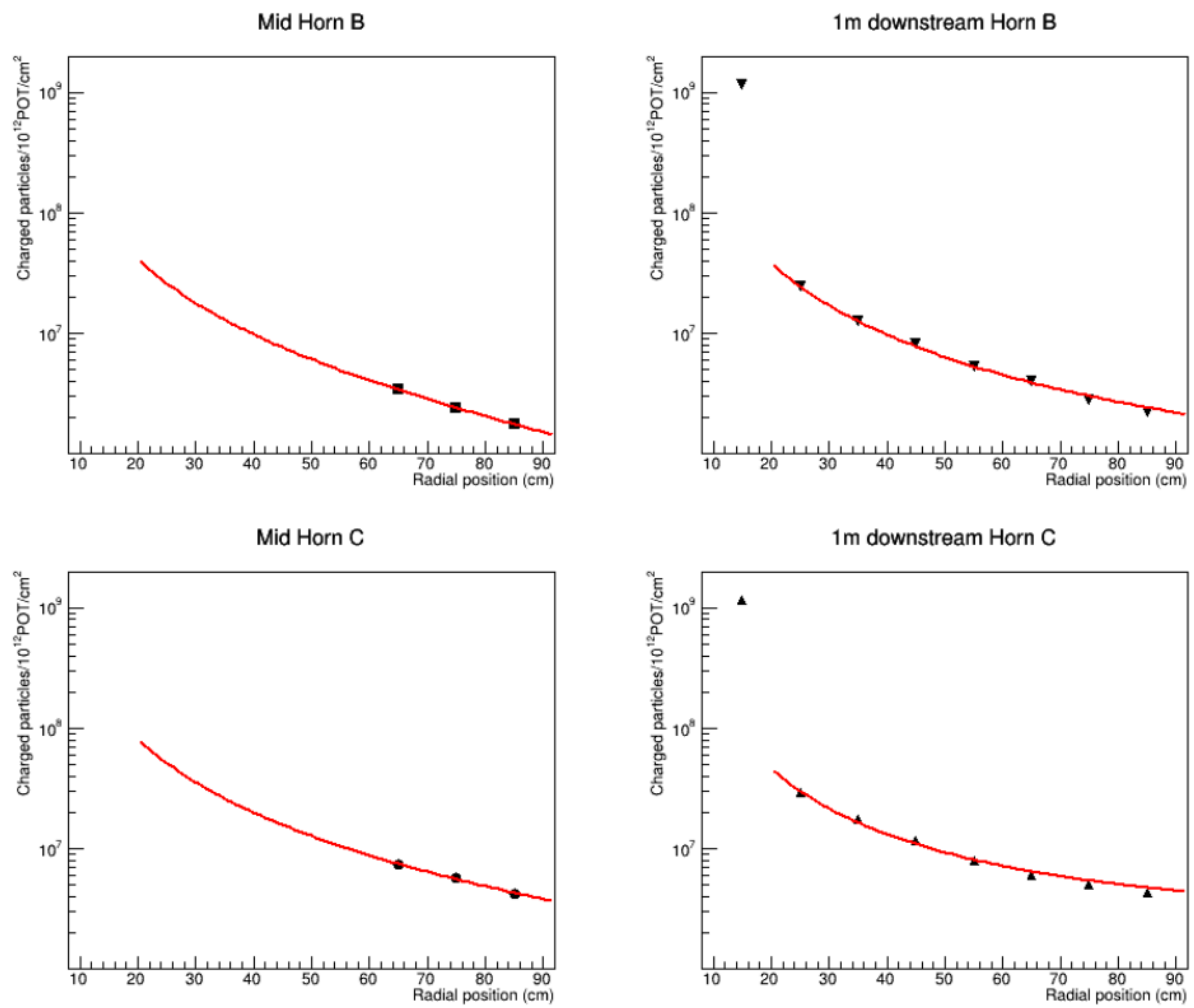
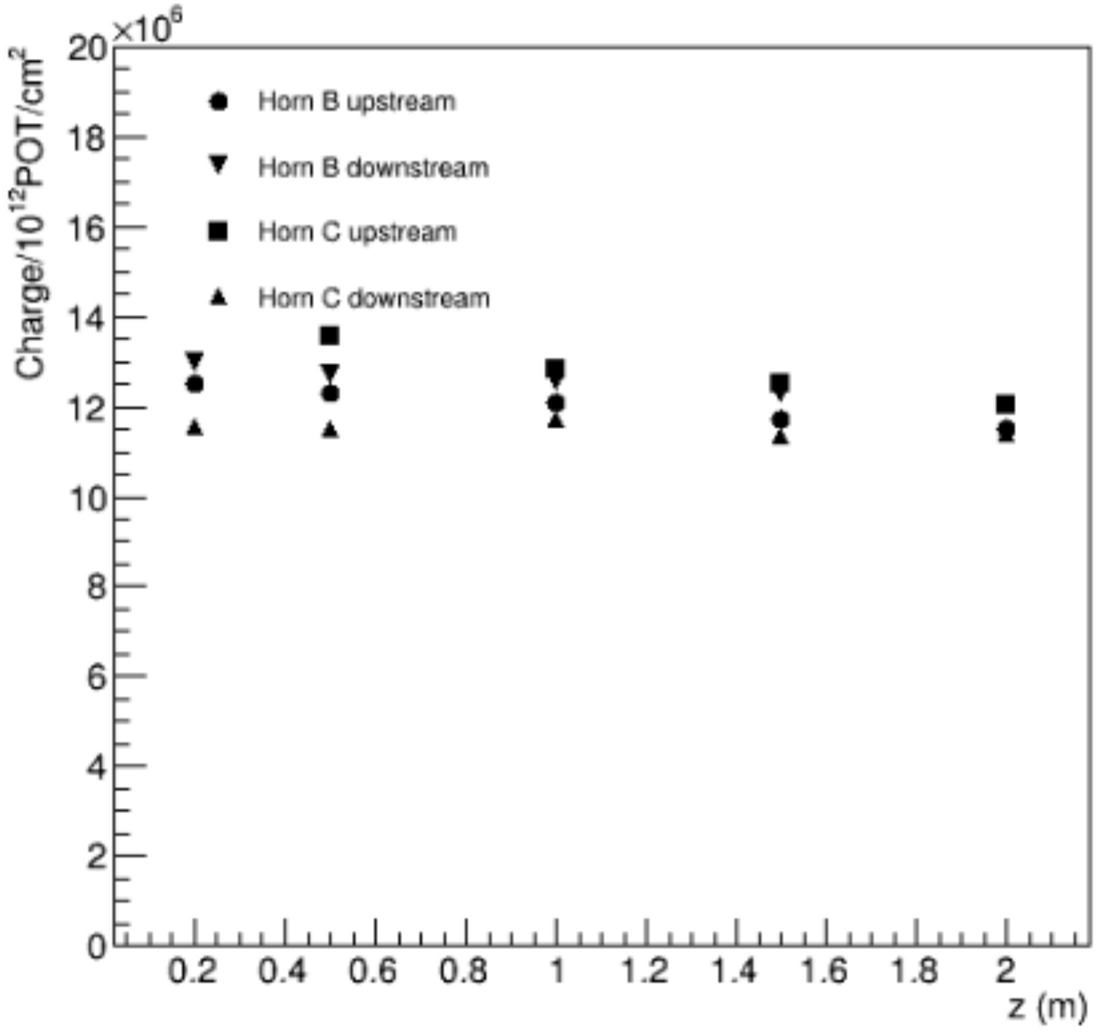
- 95% of pions contained within the r<33cm after horn B, and r<43cm after horn C
- Signal falling off roughly as $1/r^2$
- Signal over background remains fairly flat



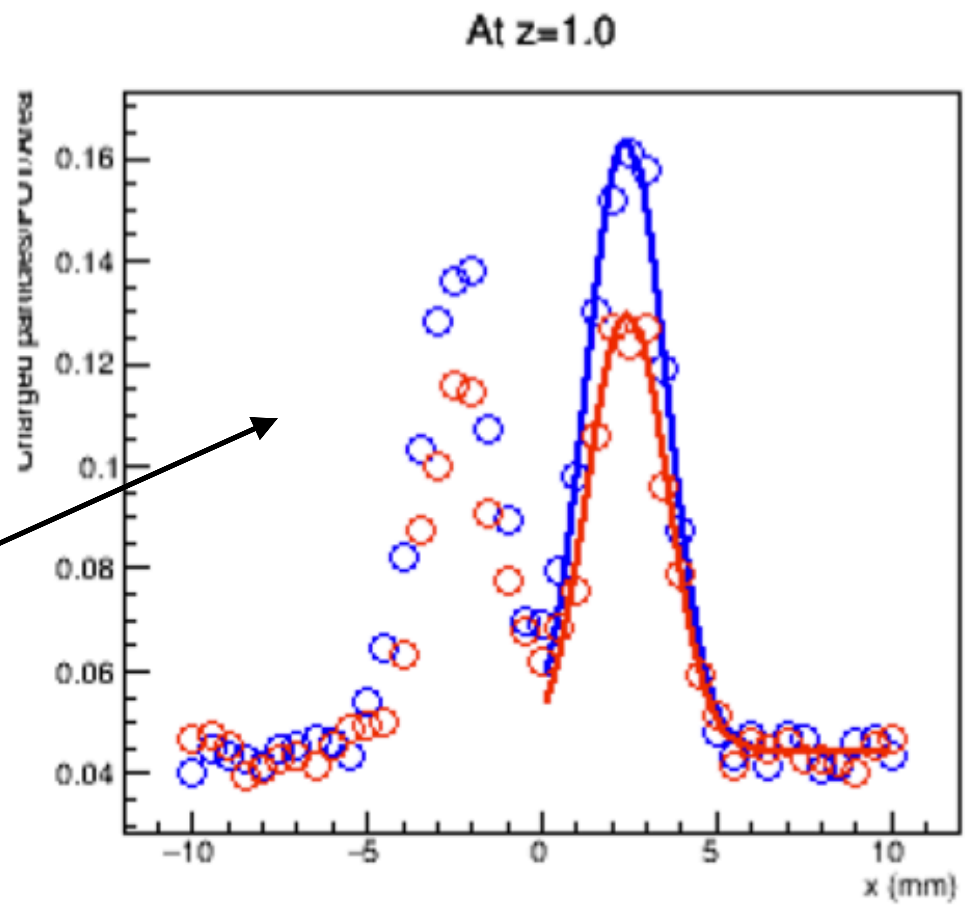
Simulation studies - longitudinal position

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

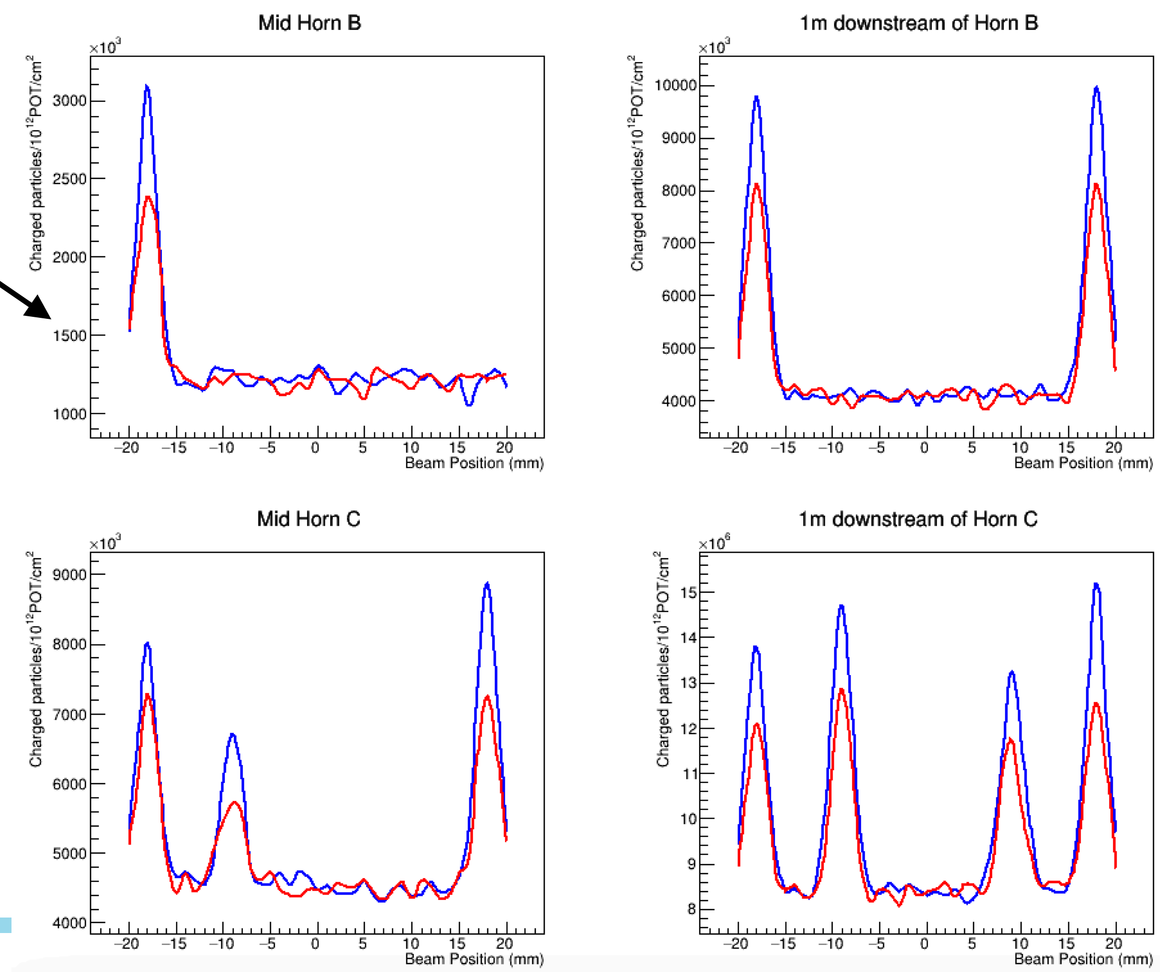


Simulation studies

- 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



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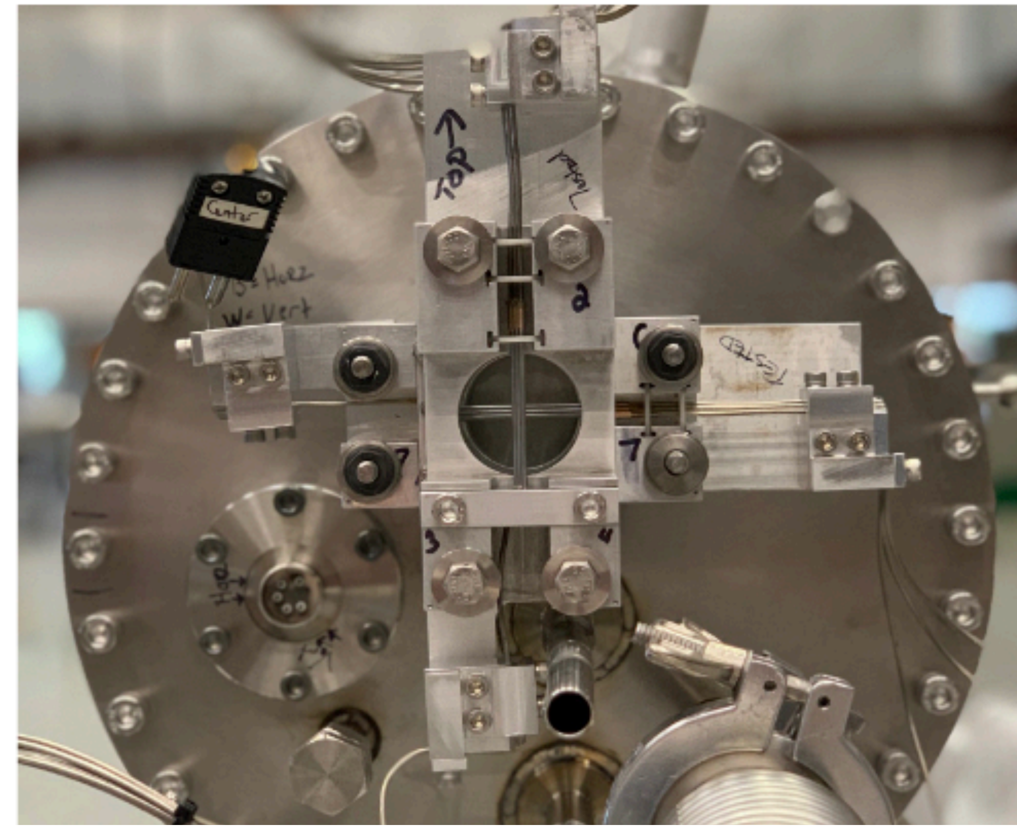
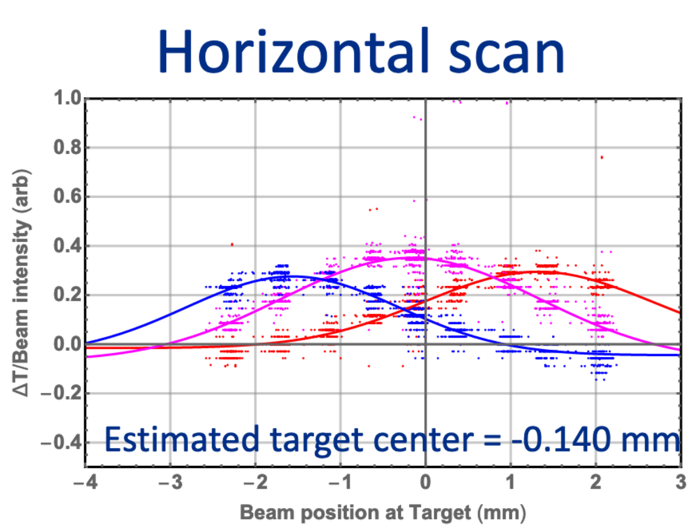
Beam position on target

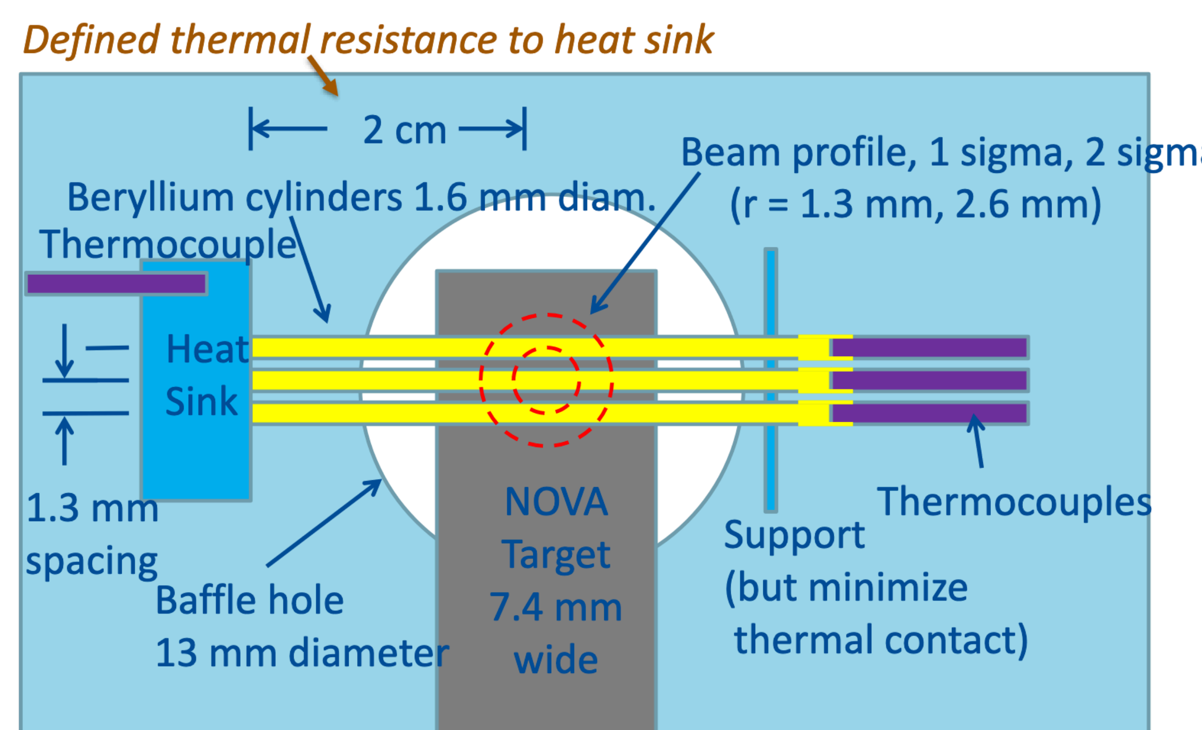
- Use beam position monitors to steer beam on target
- Beam based alignment finds the target and all other elements within BPM coordinates
  - Dedicated study time (occasional - beginning/end of run)
  - Low intensity/single batch, 1mm RMS beam size
- Need to control for:
  - BPM intensity dependence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







LBNF TPT

- Reoptimize system for LBNF operating parameters
  - 1.2MW beam - $7.5x10^{13}$PPP
  - 2.7mm RMS beam size
  - Use 5 bars to accommodate wider beam
- Studies under way
- RAL provides engineering and integration with target