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

Overview, Requirements, ES&H and Interfaces

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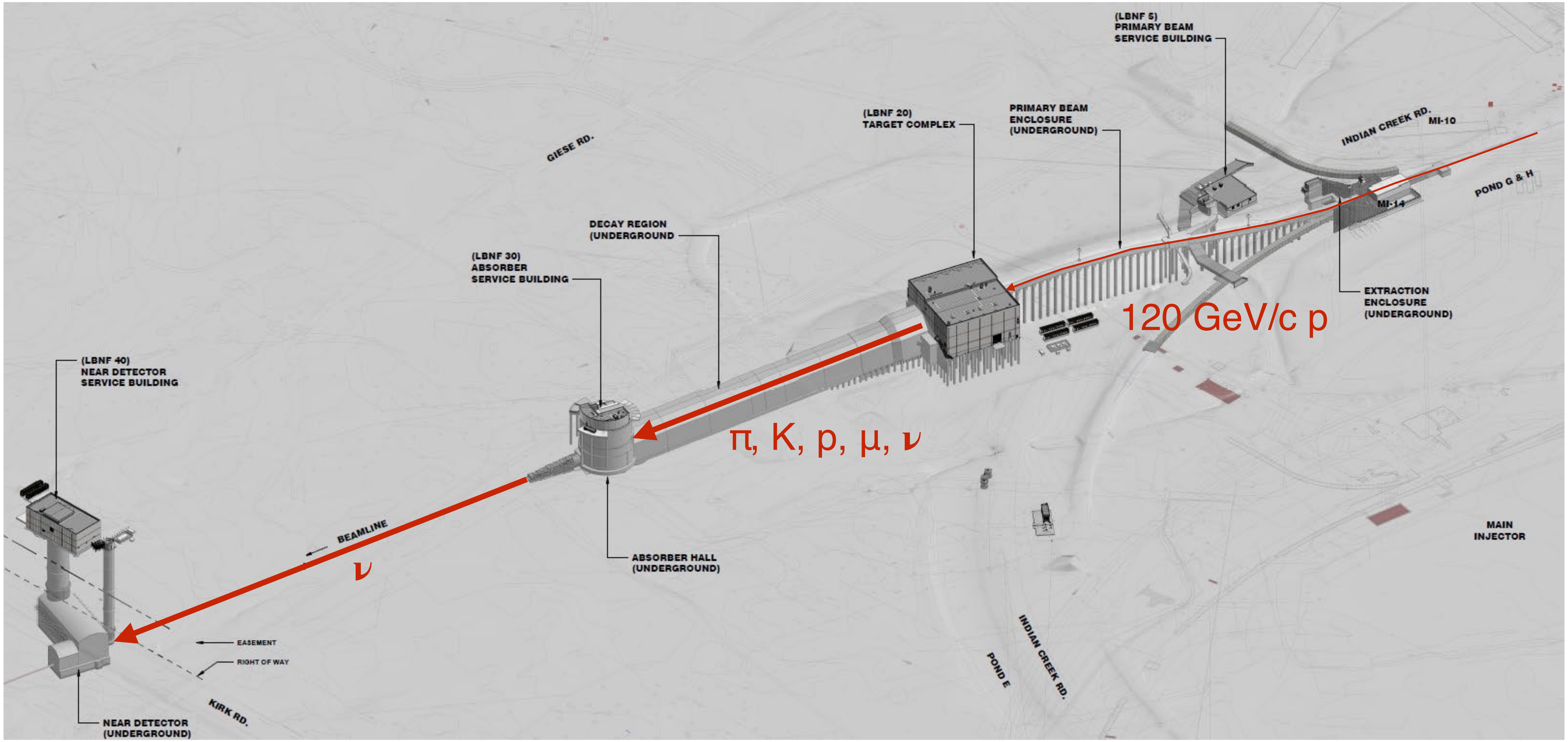
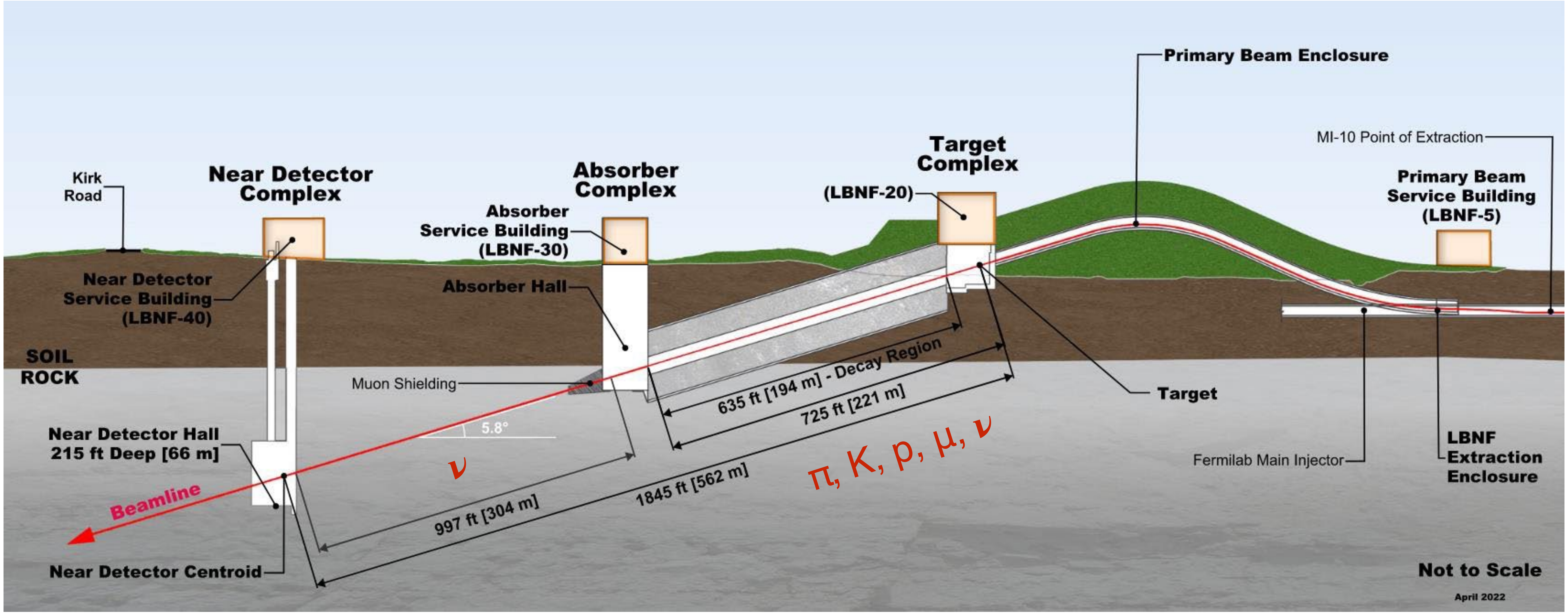
About Me

- Neutrino Division Scientist
- Joined Fermilab in 2015, prior to that I was an associate scientist at ANL
- As a postdoc at Indiana University, I worked on MIPP, MINOS and NOvA
- As a scientist at both ANL and Fermilab, I have worked mostly on NOvA until the past few years. Have been focused on neutrino flux and cross sections:
  - 2015-2021: NOvA near detector analysis co-convener, focus on neutrino-nucleus cross sections
  - Co-spokesperson of the EMPHATIC collaboration ("table-top" hadron production measurements for neutrino flux predictions)
  - Co-spokesperson of NuSTEC (Neutrino Scattering Theory Experiment Collaboration)
- Joined the LBNF Project as the L4 of the NBI in 2018. Transitioning to DUNE FD Cold Electronic L3 position now.

Overview


(LBNF 5)
PRIMARY BEAM
SERVICE BUILDING
(LBNF 20)
TARGET COMPLEX
PRIMARY BEAM
ENCLOSURE
(UNDERGROUND)
INDIAN CREEK RD.
MI-10
POND G & H
MI-14
GIESE RD.
DECAY REGION
(UNDERGROUND)
(LBNF 30)
ABSORBER
SERVICE BUILDING
EXTRACTION
ENCLOSURE
(UNDERGROUND)
120 GeV/c p
(LBNF 40)
NEAR DETECTOR
SERVICE BUILDING
π, K, p, μ, ν
BEAMLINE
ν
ABSORBER HALL
(UNDERGROUND)
MAIN
INJECTOR
EASEMENT
RIGHT OF WAY
INDIAN CREEK RD.
POND E
KIRK RD.
NEAR DETECTOR
(UNDERGROUND)

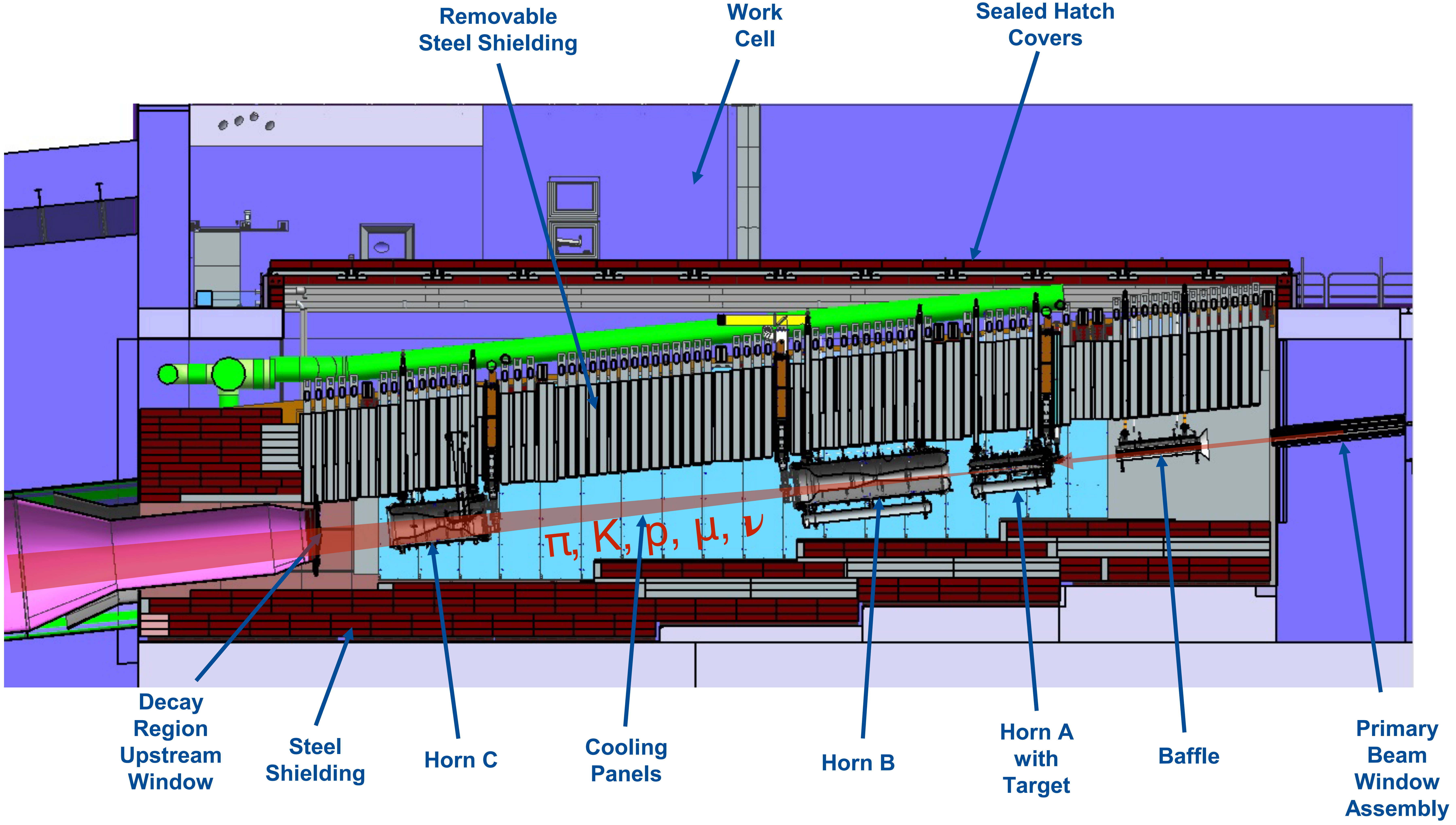
Overview



NBI is responsible for aligning and monitoring the secondary and teriary beams.

Overview

Left Section View of LBNF-20 Target Hall Complex's Target Bunker



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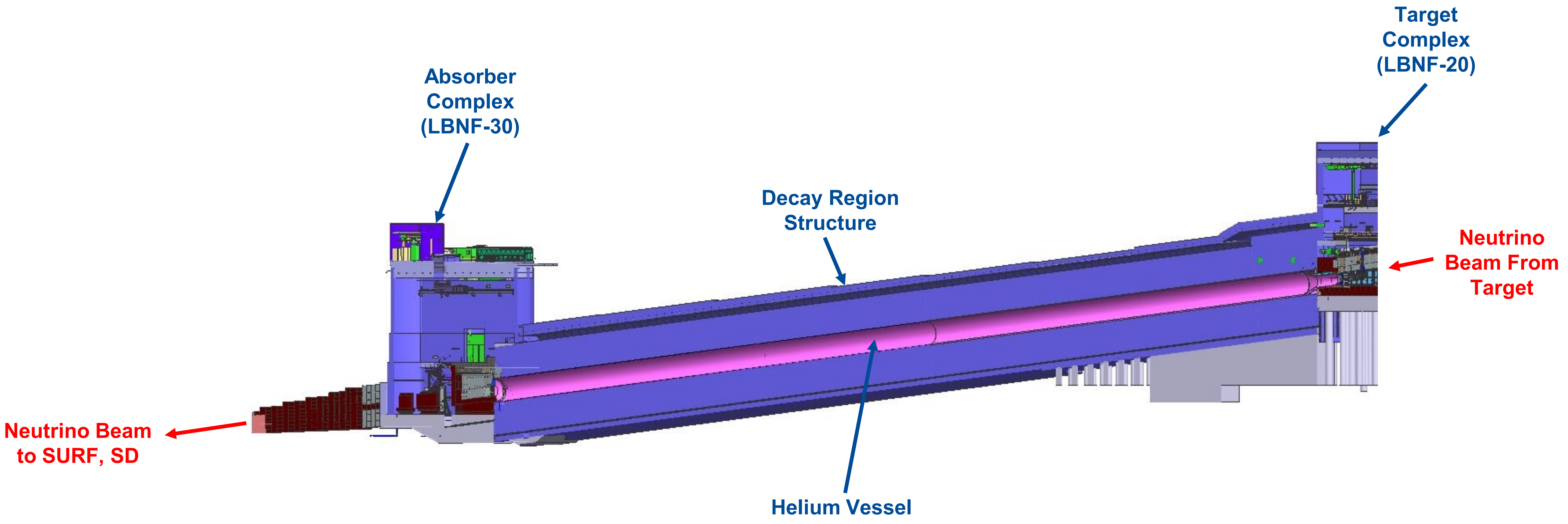
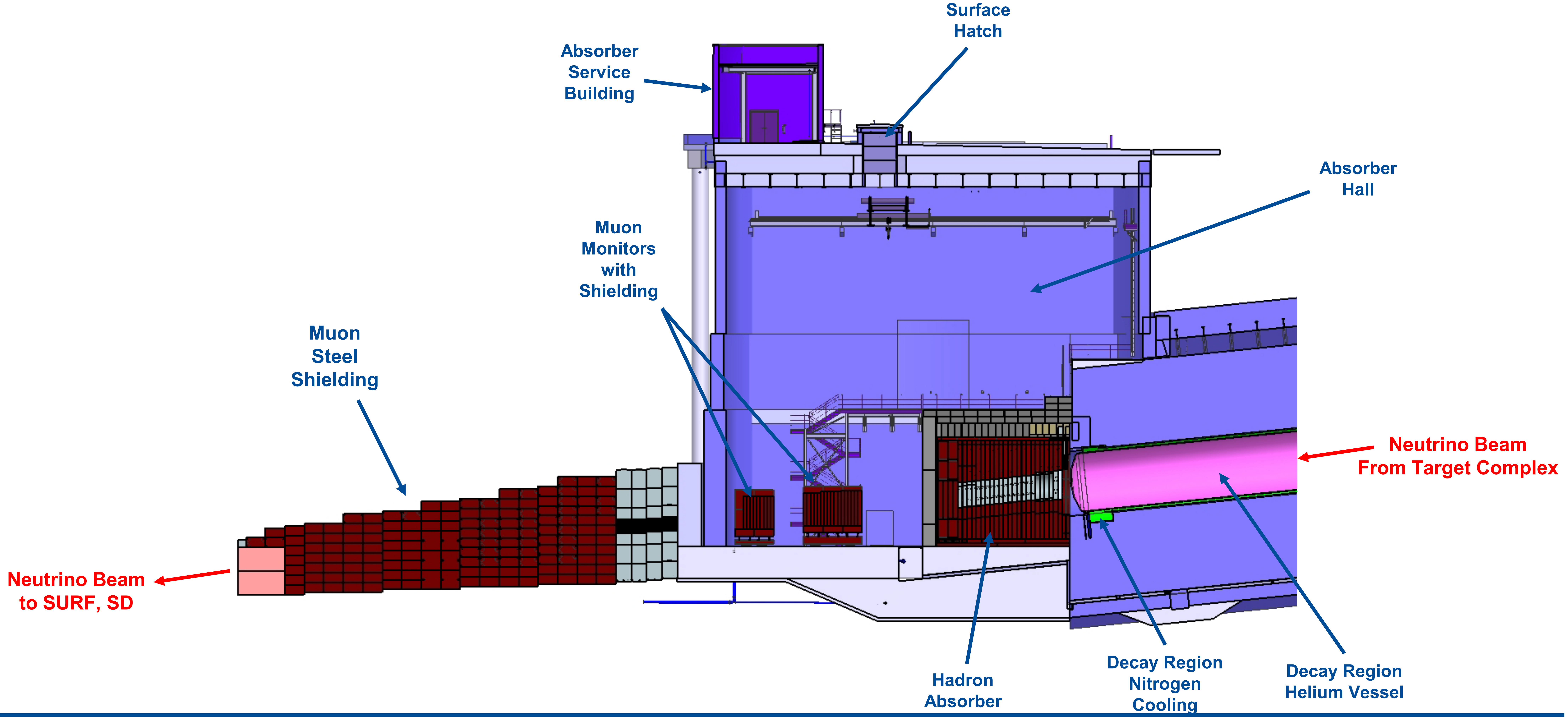
Overview

Semi-Left Section View of Decay Region Structure and LBNF-30 Absorber Complex



Overview

Left Section View of LBNF-30 Absorber Complex



Beam-based Alignment and Monitoring

- Neutrino beam-based alignment is done using:
  - Beam Position Monitors (BPMs, upstream of target, not under our purview)
  - Hadron Alignment Detector System (HADeS), in front of the absorber, at end of the decay pipe)
  - Horn cross-hairs and beam-loss monitors (BLMs)
- Monitoring of the neutrino beam intensity and direction is done using:
  - Target position thermometer (TPT): if the position of the beam on the target changes w/ no corresponding change in the position on the BPMs, this is could be an indication that the target itself has moved.
  - Muon monitor system (MuMS): track the intensity, beam center and width on a spill-by-spill basis.
  - Horn-leveling system (HLS): independent measurement of the positions of the focusing horns.

Requirements - Origins

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
Horn B Transverse Tilt	0.5 mm	X and Y shifted separately, added in quadrature; upstream and downstream ends shifted in different directions	N
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

- From dune-docB 19942
- Many of these are tolerances, which are assumed to be a 1-sigma uncertainty.
- Most of the NBI requirements are driven by these uncertainties.
- Some NBI requirements also come from [radiation] safety considerations.

Requirements - Origins

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
Horn B Transverse Tilt	0.5 mm	X and Y shifted separately, added in quadrature; upstream and downstream ends shifted in different directions	N
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

Monitored by HLS, TPT, MuMS

Alignment using HADeS, XHairs

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Requirements - Origins

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.

Monitored by MuMS, HLS (If longitudinal displacement is coupled to transverse displacement)

Monitored by TPT, MuMS

Aligned with HADeS

Aligned with XHairs

Monitored by MuMS

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Requirements - Origins

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
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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

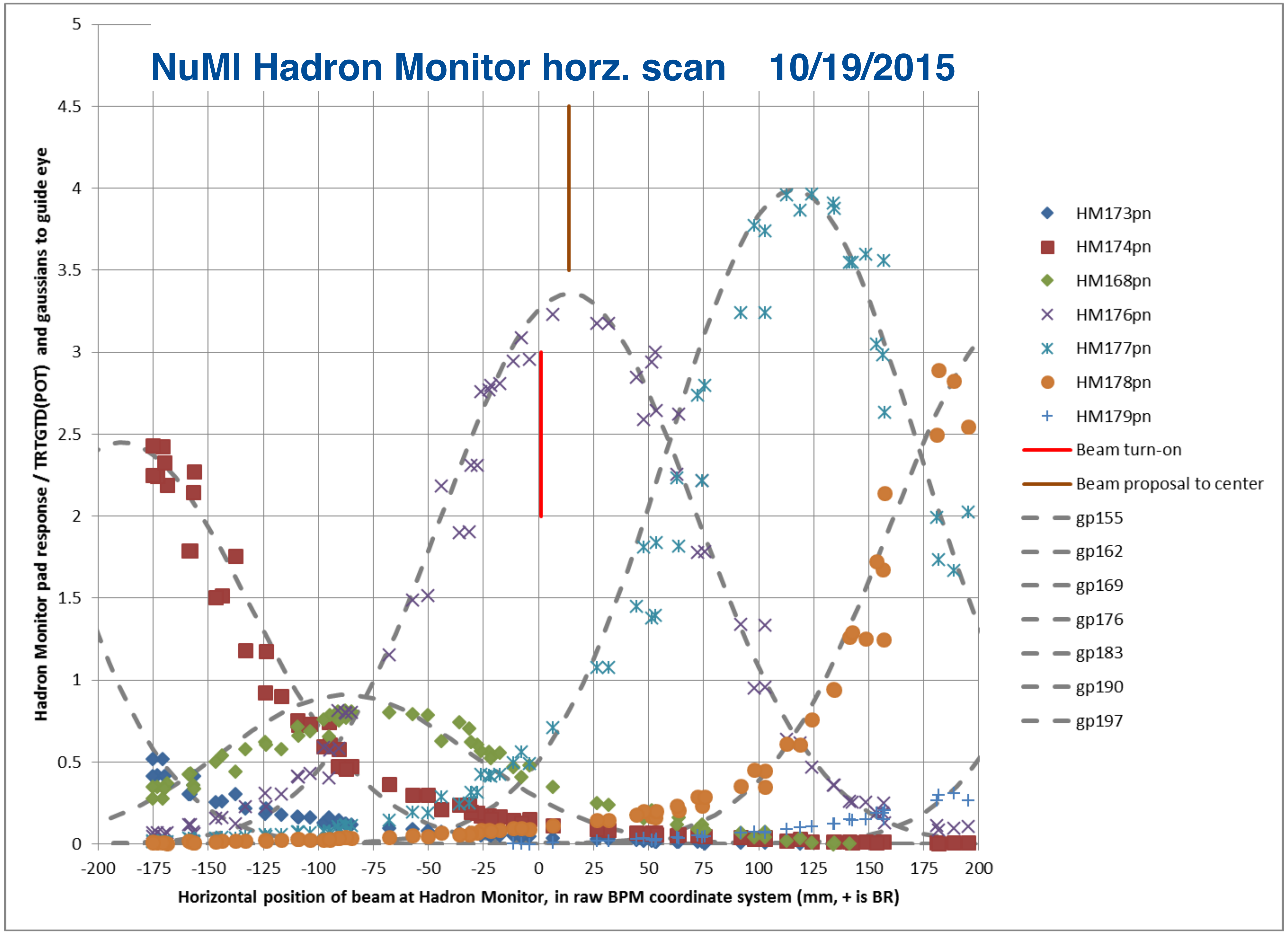
Table 1: Sources of alignment and focusing uncertainties in the neutrino fluxes at DUNE. Sources that were considered in physics studies in the TDR are marked with a 'Y' in the 'In TDR' column.

The individual requirements of each system will be given in the upcoming talks.

Alignment

Step 1: Establish Beam Direction

- With no horns and/or only horns B&C installed, use beam scan across the face of the HADeS to determine beam direction.
- More on this in Jon's talk.



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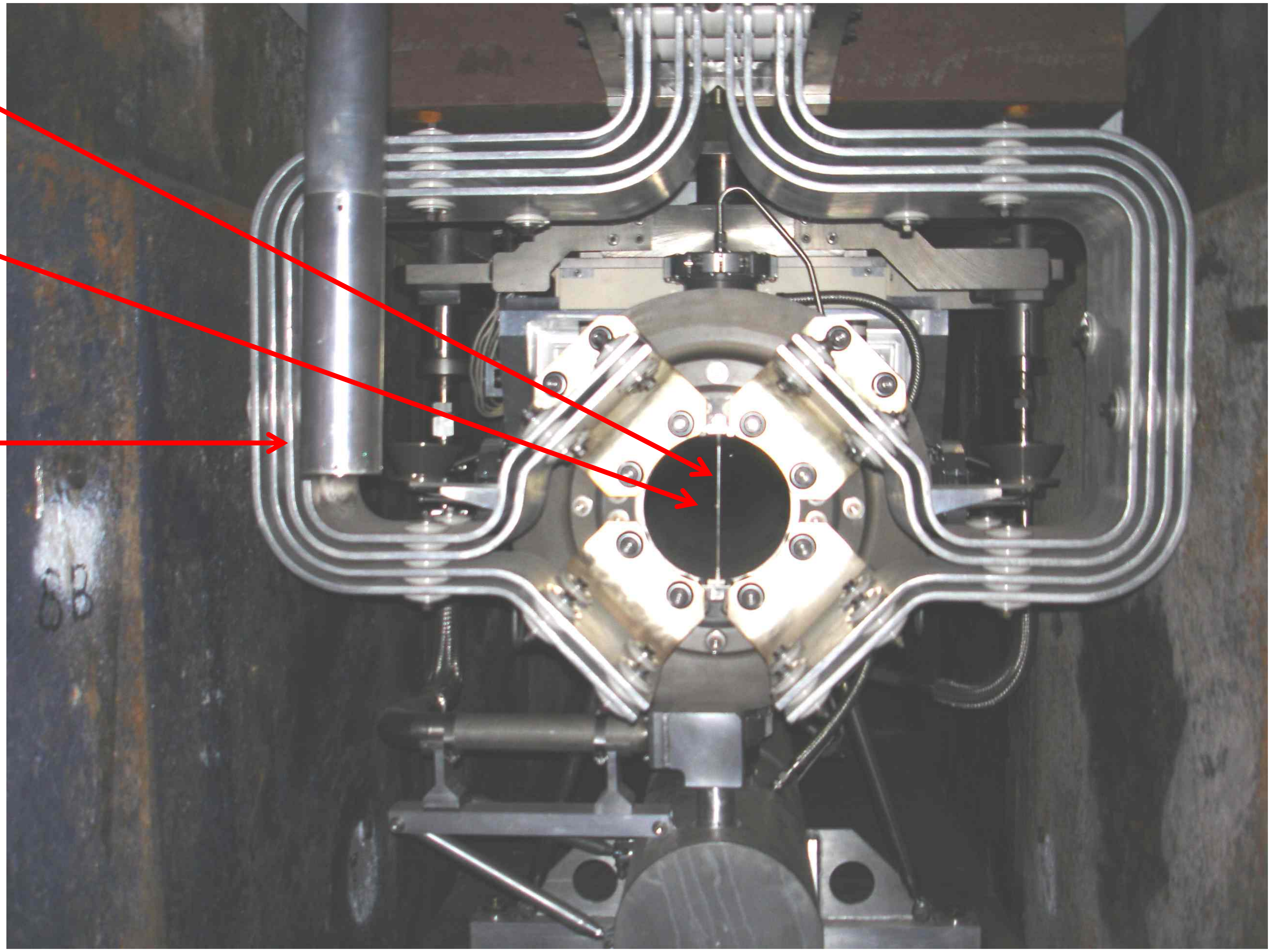
Step 2: Downstream Horn Alignment

- Use X-Hairs + BLMs on the upstream and downstream end of horns B&C to determine position of the horns.
- More on this in Zarko’s talk.

Fin for beam horz. alignment

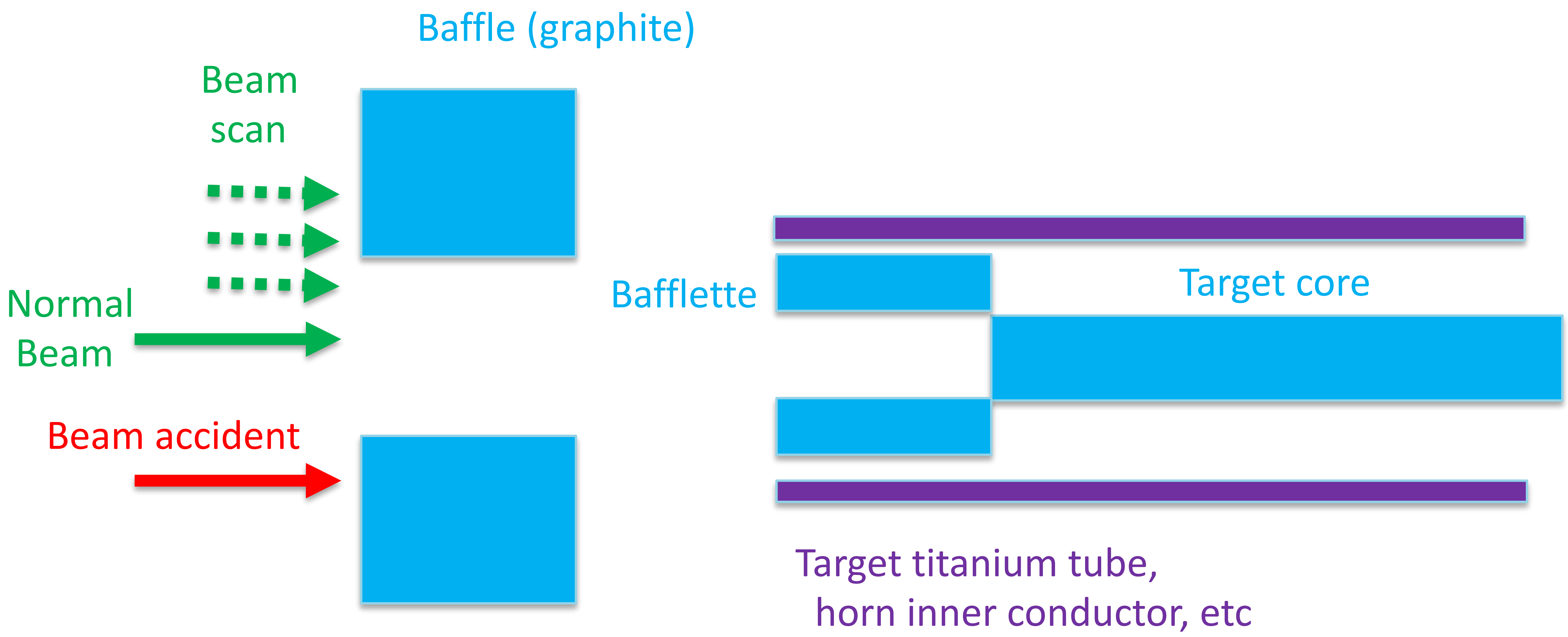
Nub for beam vert. align

Beam loss mon. to detect beam scatter from fin (“cross-hair”)



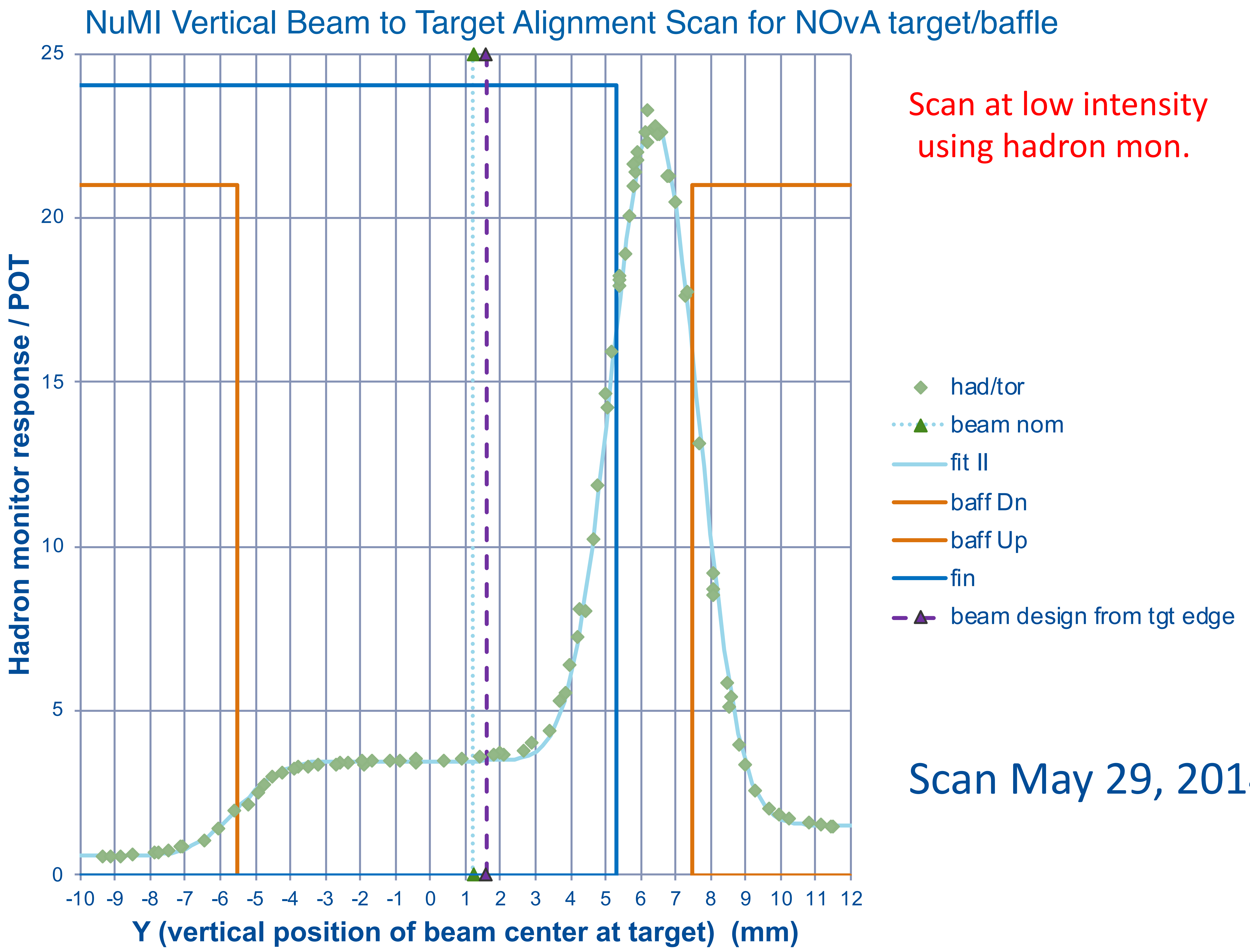
Step 3: Target and Horn A Alignment

- Baffle protects target utilities and horn from mis-steered beam. Bafflette protects the decay pipe windows and absorber.
- Use both baffle and bafflette for alignment with a beam scan across and look for change in signal in the HADeS.



- After target + horn A are installed, scan without baffle in place to get location and angle in (x,y)
- Next, install baffle and perform another scan.

Step 3: Target and Horn A Alignment

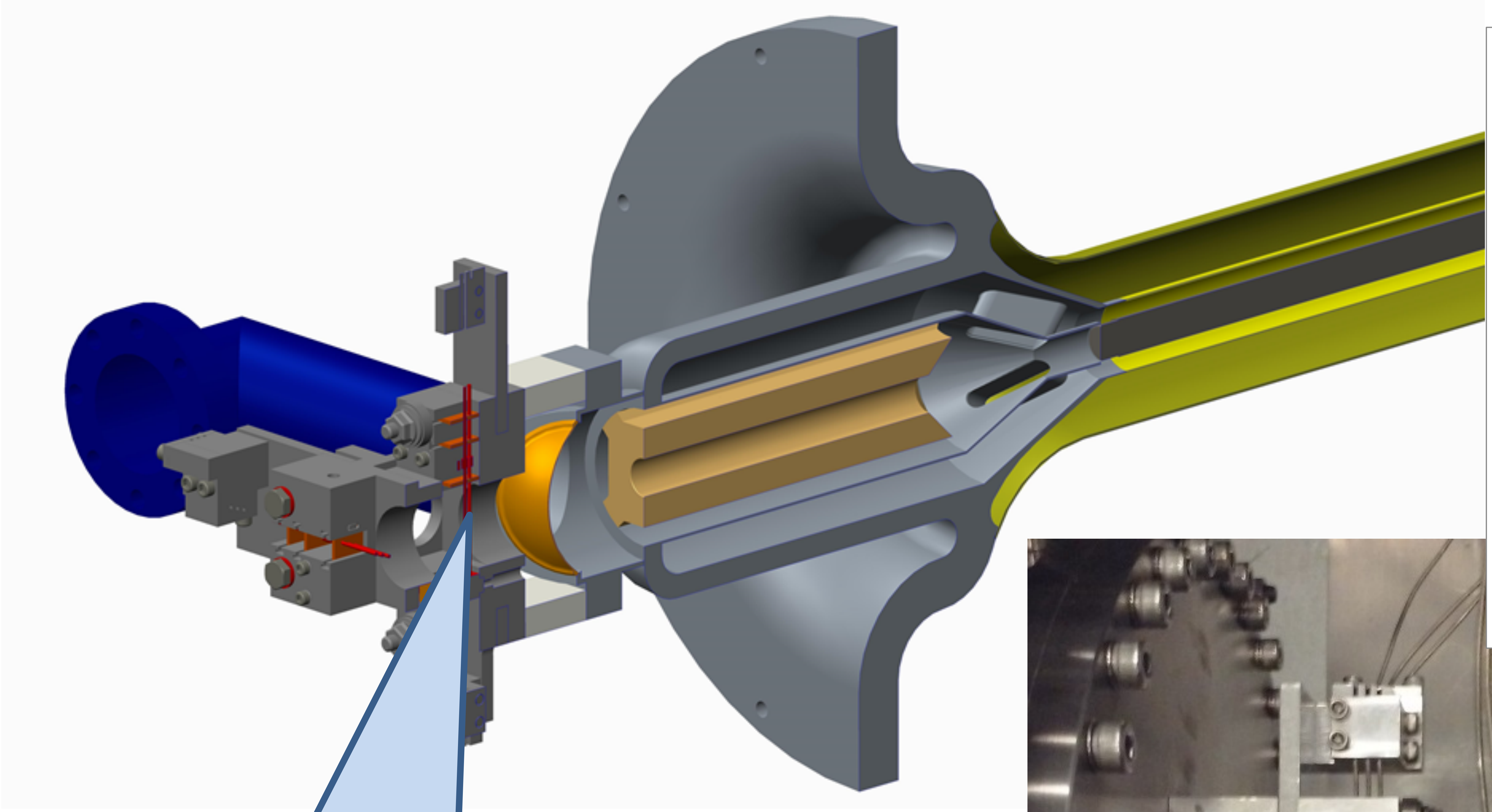


Scan at low intensity using hadron mon.

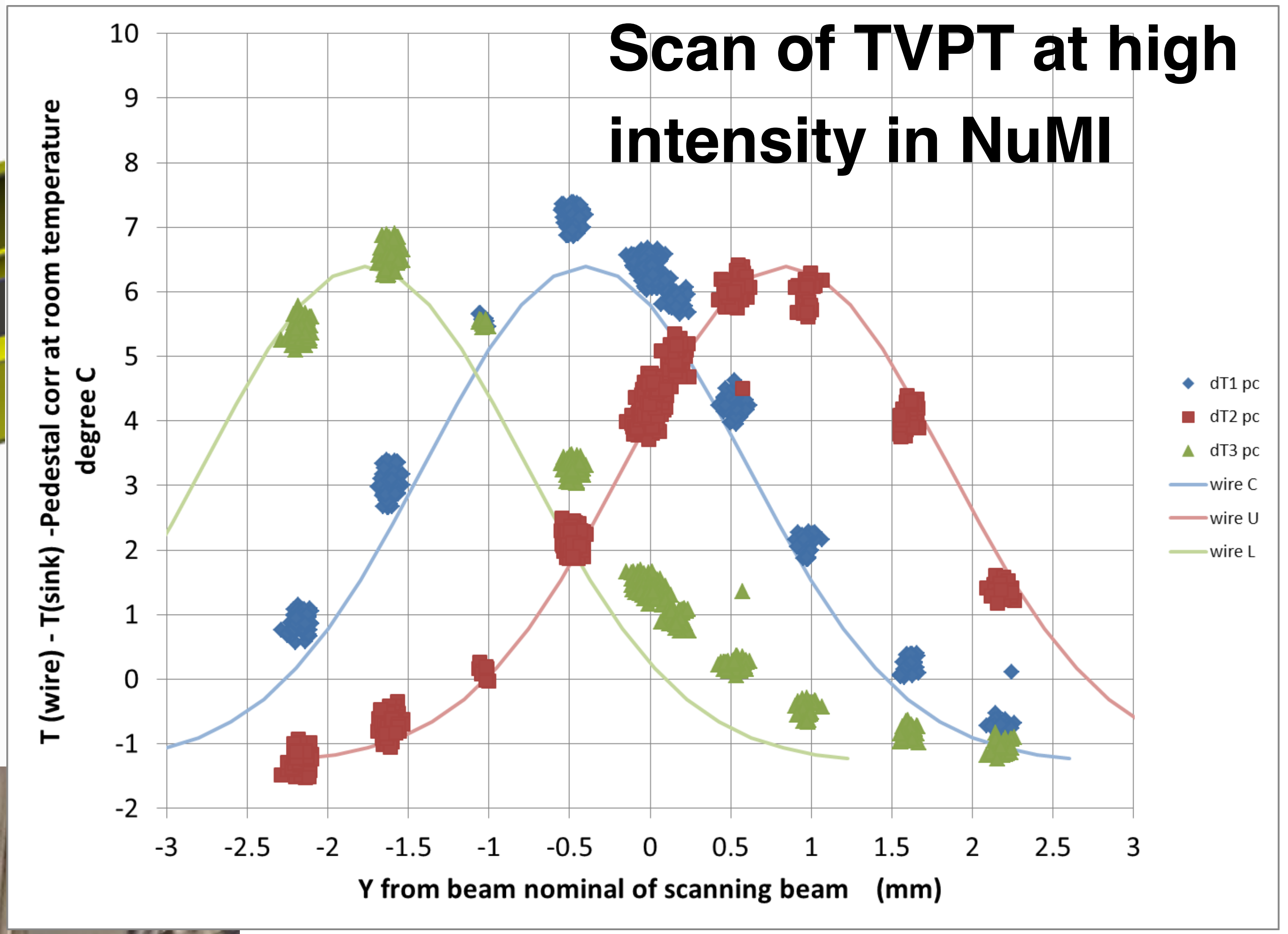
Scan May 29, 2014

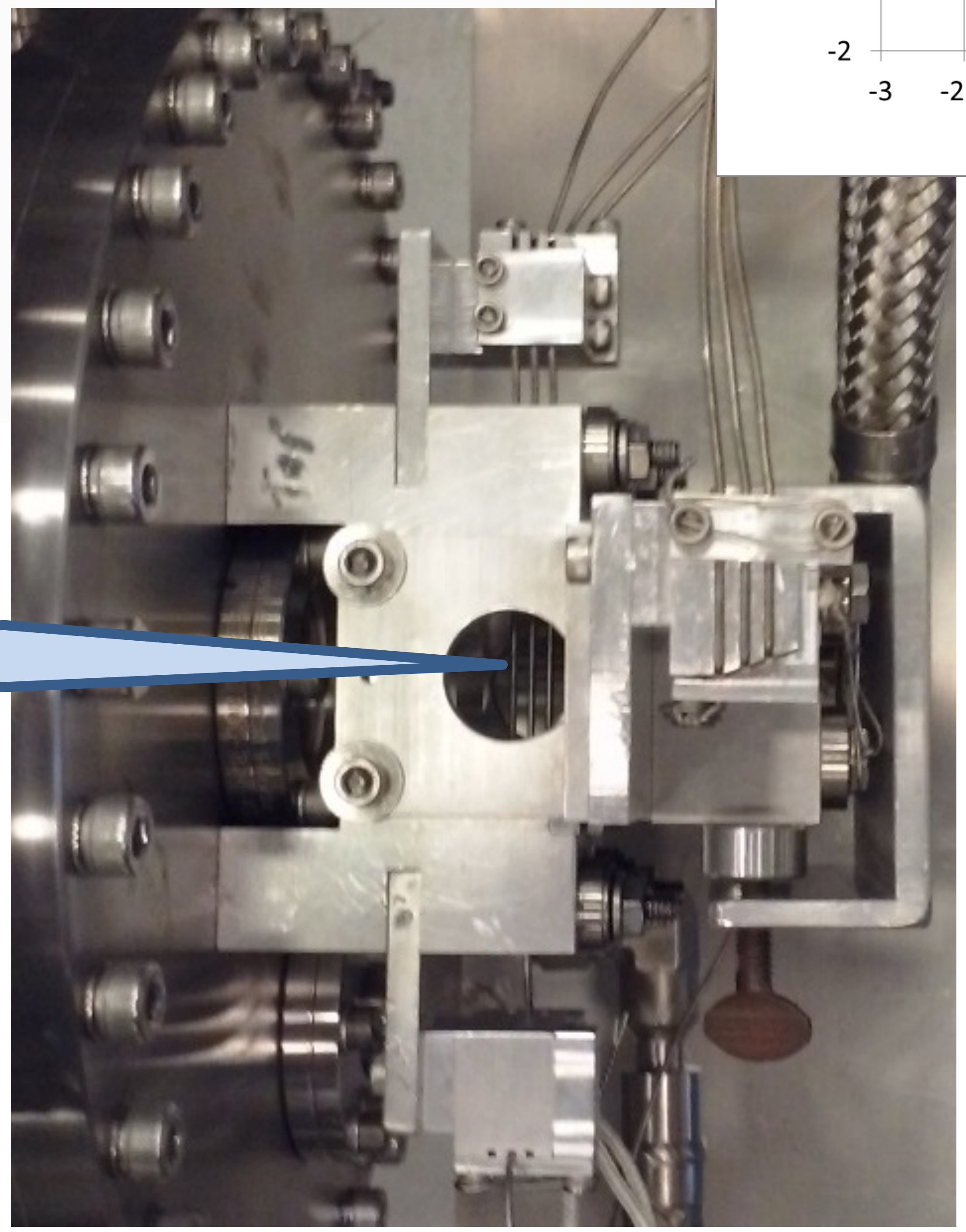
Monitoring

Target Position Thermometer



Thermocouples attached to ends of 3x3 array of beryllium rods serves as online Beam Position Monitor

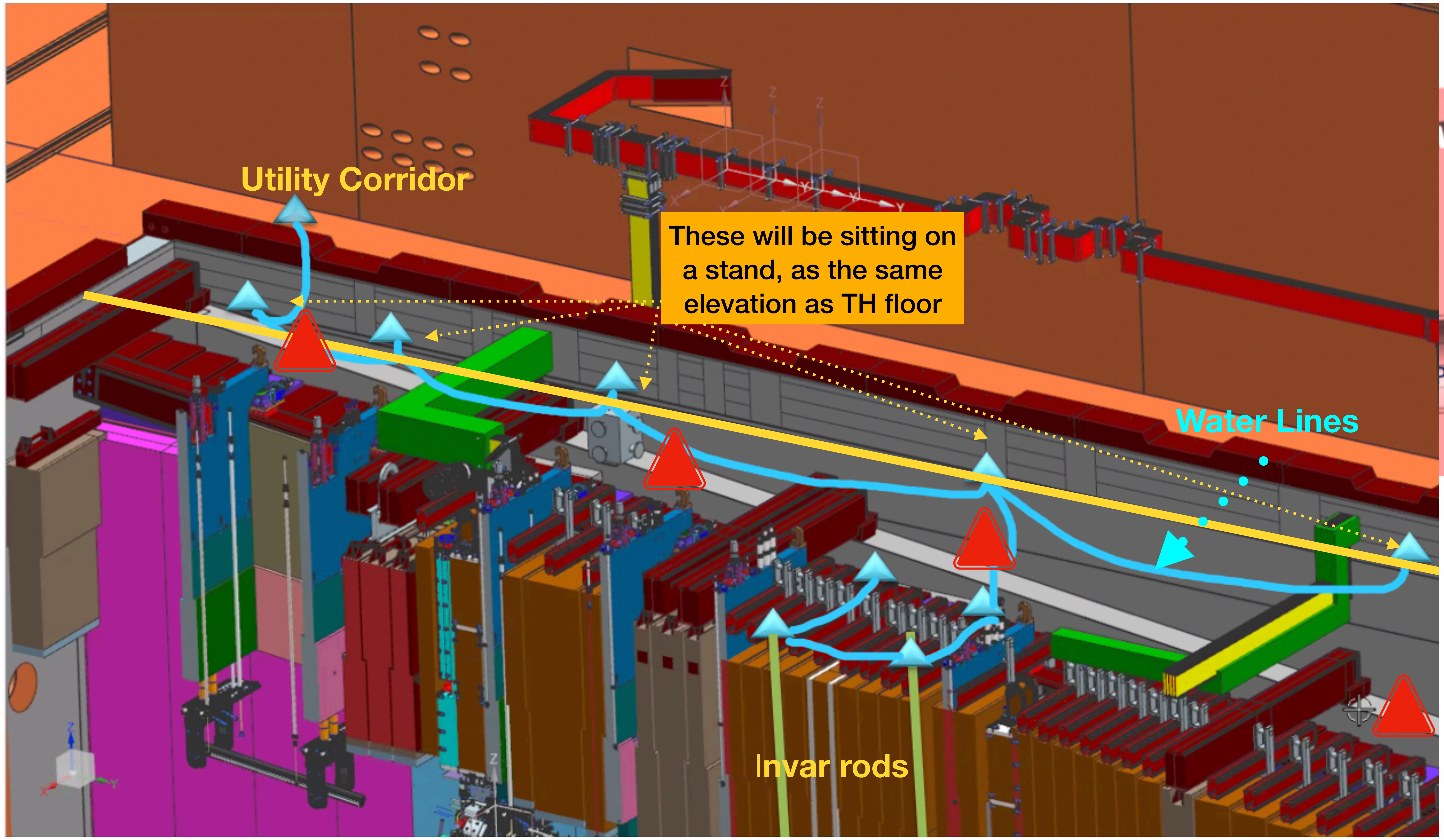




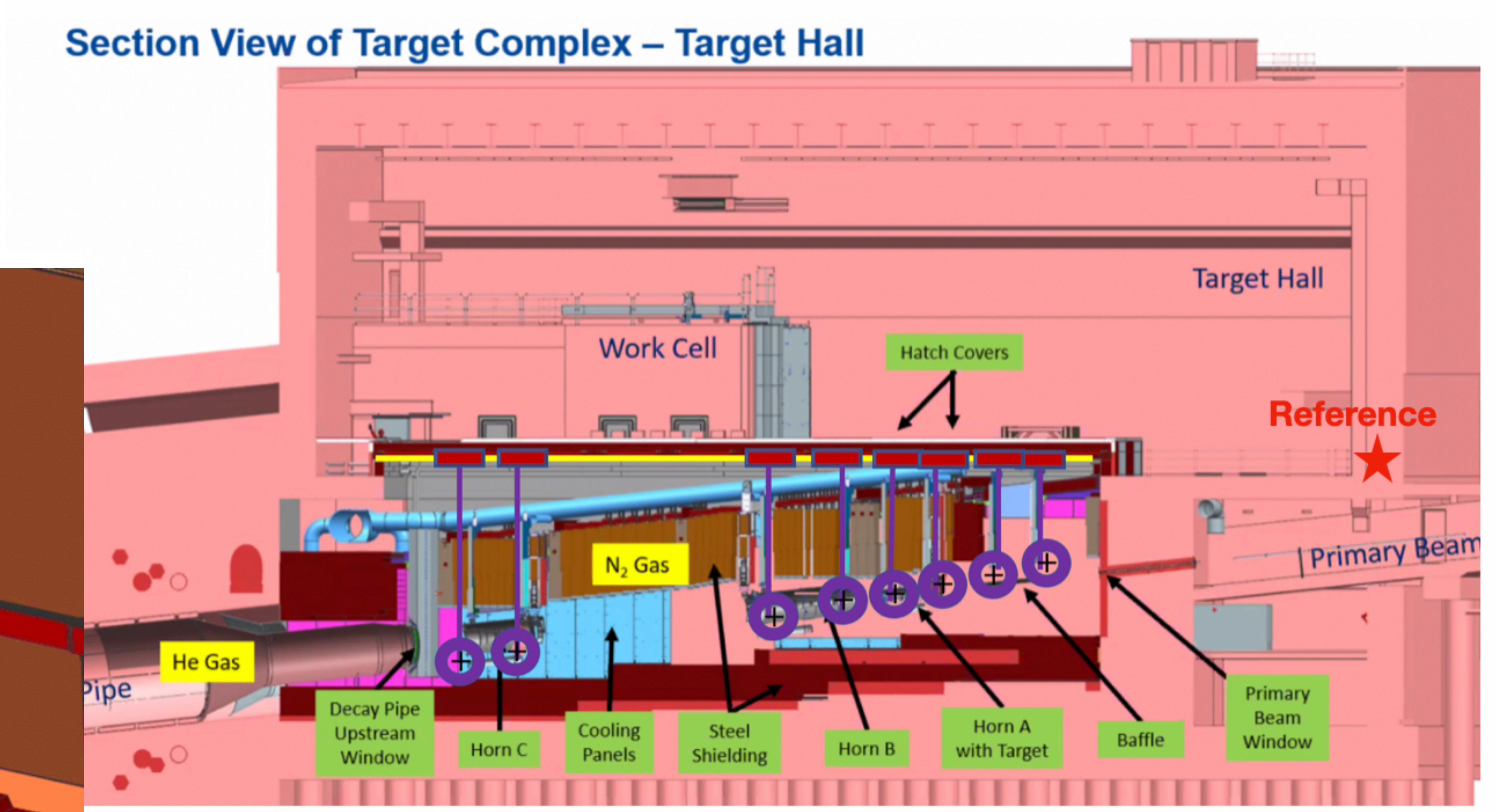
Existing NuMI design

More on this in Zarko's talk

Horn Leveling System (HLS)



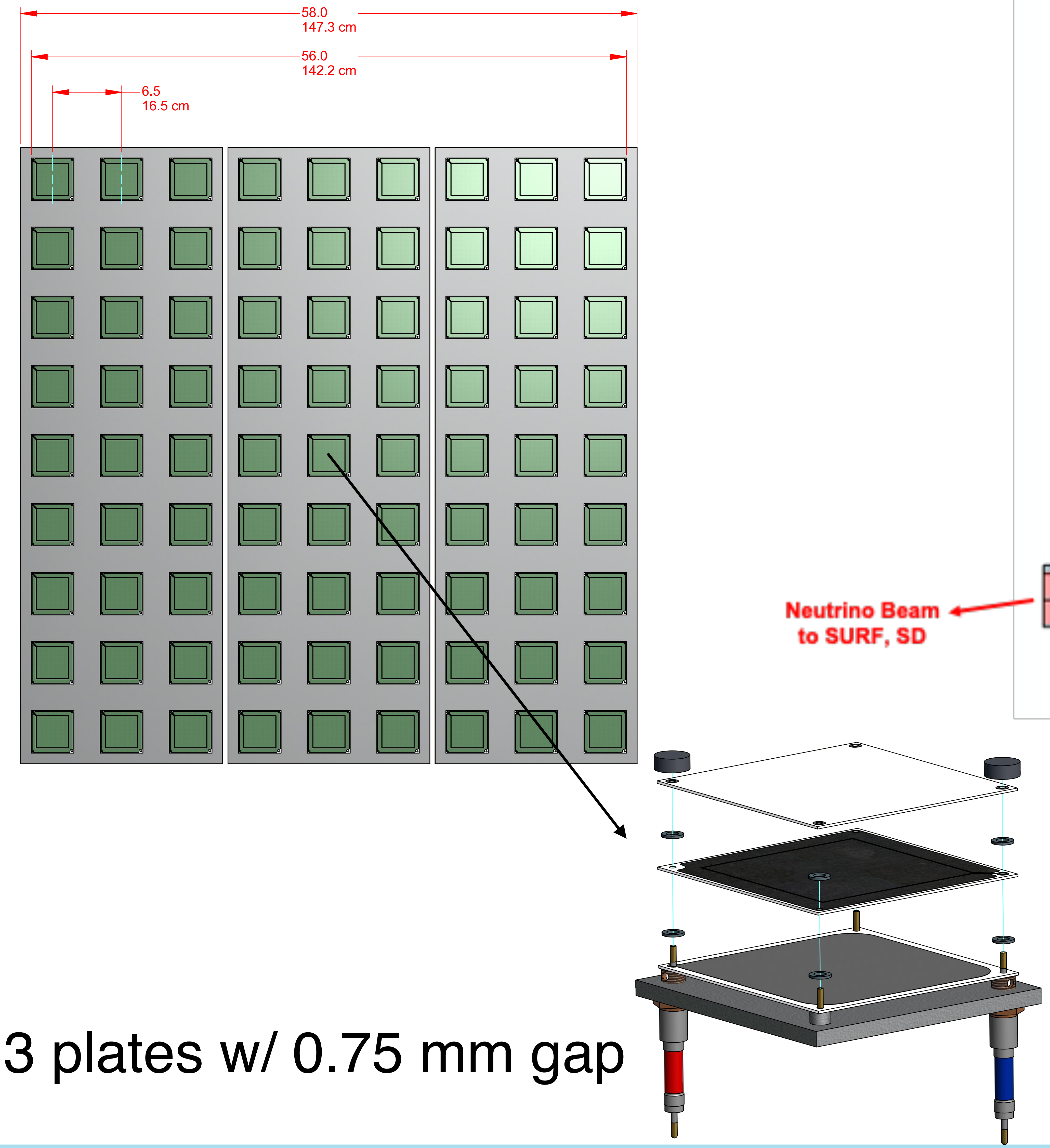
The sensors in red will be at the same height as the ones on the stand above horn modules. Run 4 Invar rods from Target Hall floor level inside battlement to the level of stand for each of sensors

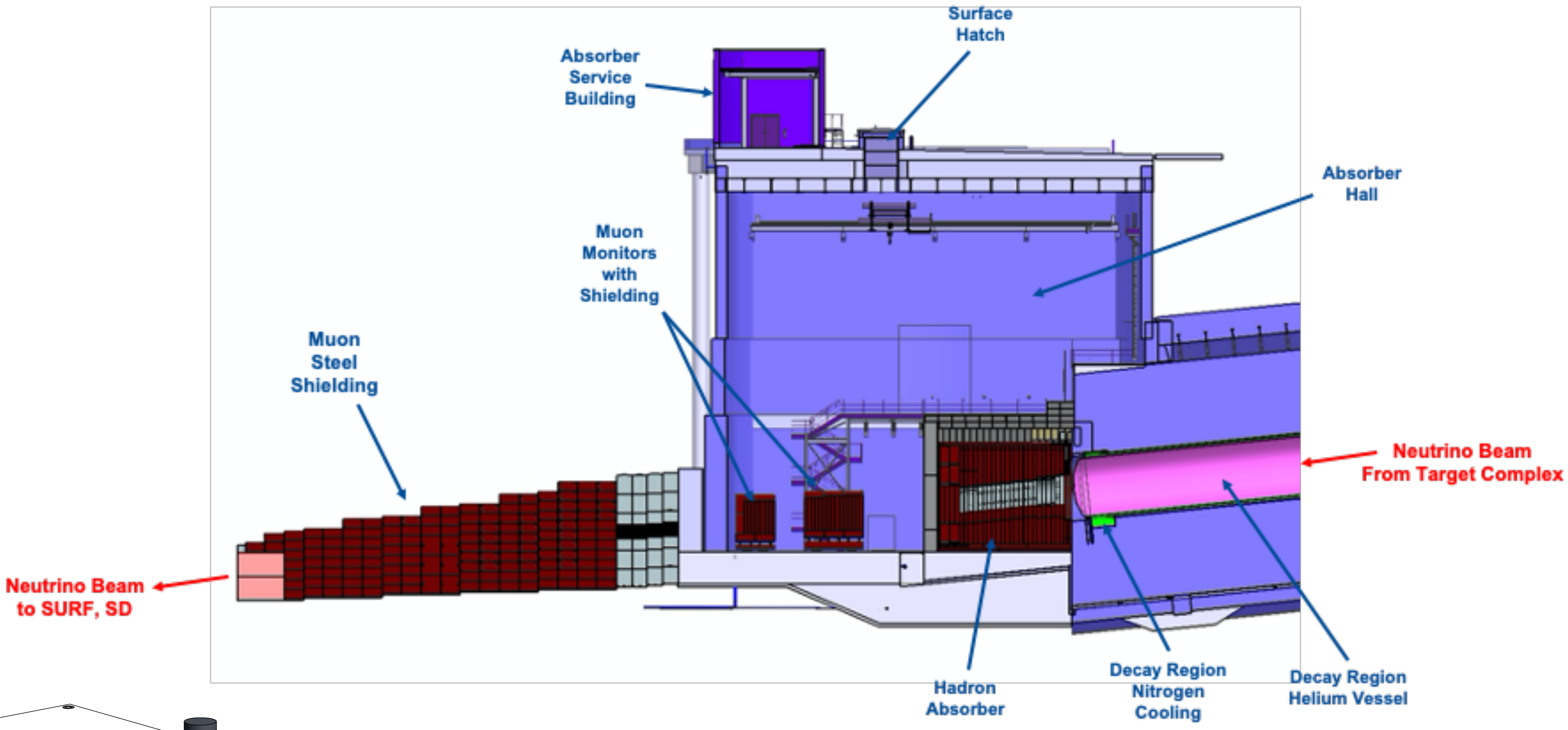


Location	Invar Rod Counts	LVDT Counts	Thermo couple counts	Invar Rod length
Horn C	4	4	4	18ft
Horn B	4	4	4	14ft
Horn A	4	4	4	13ft
Baffle	4	4	X	12ft

More on this in Sudeshna’s talk

Muon Monitor System (MuMS)





More on this in Jon's talk

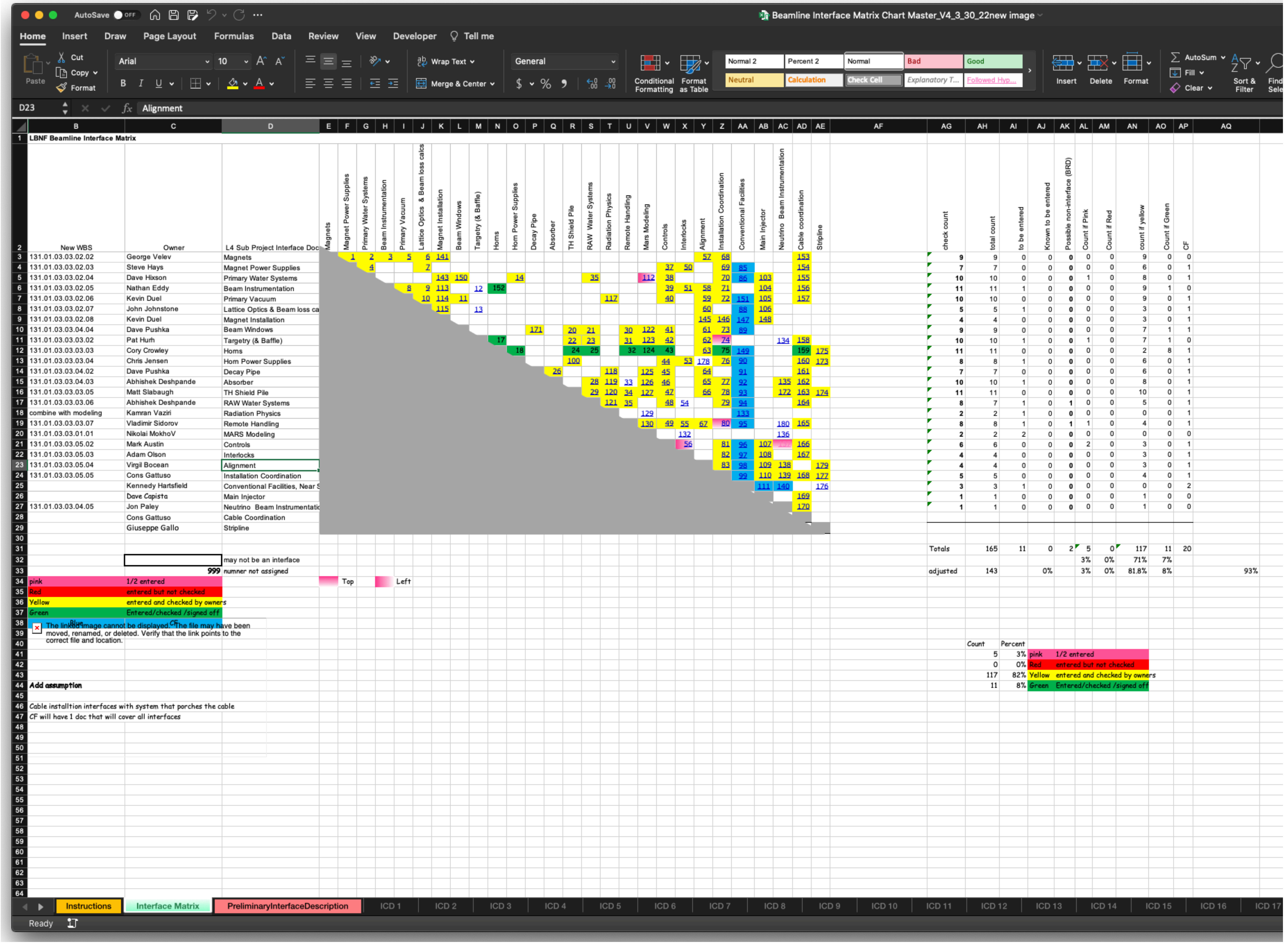
3 plates w/ 0.75 mm gap

ES&H

- All NBI activities follow the Fermilab Environmental Safety and Health Manual, https://eshq.fnal.gov/manuals/feshm/
- Unique considerations:
  - HLS laser
  - Possible ODH in the MuMS detector room (unlikely, but we will do the calculation)

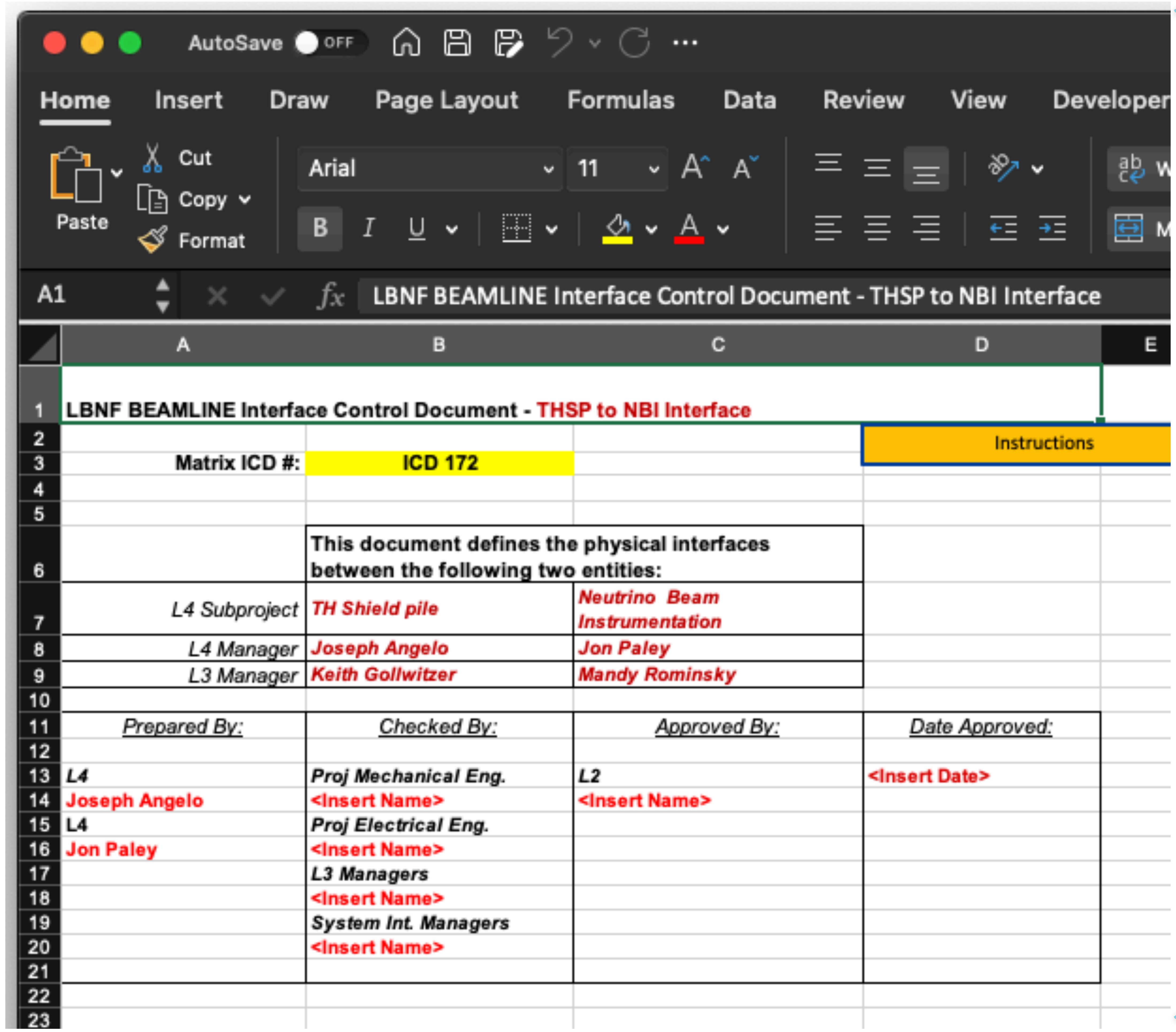
Interfaces

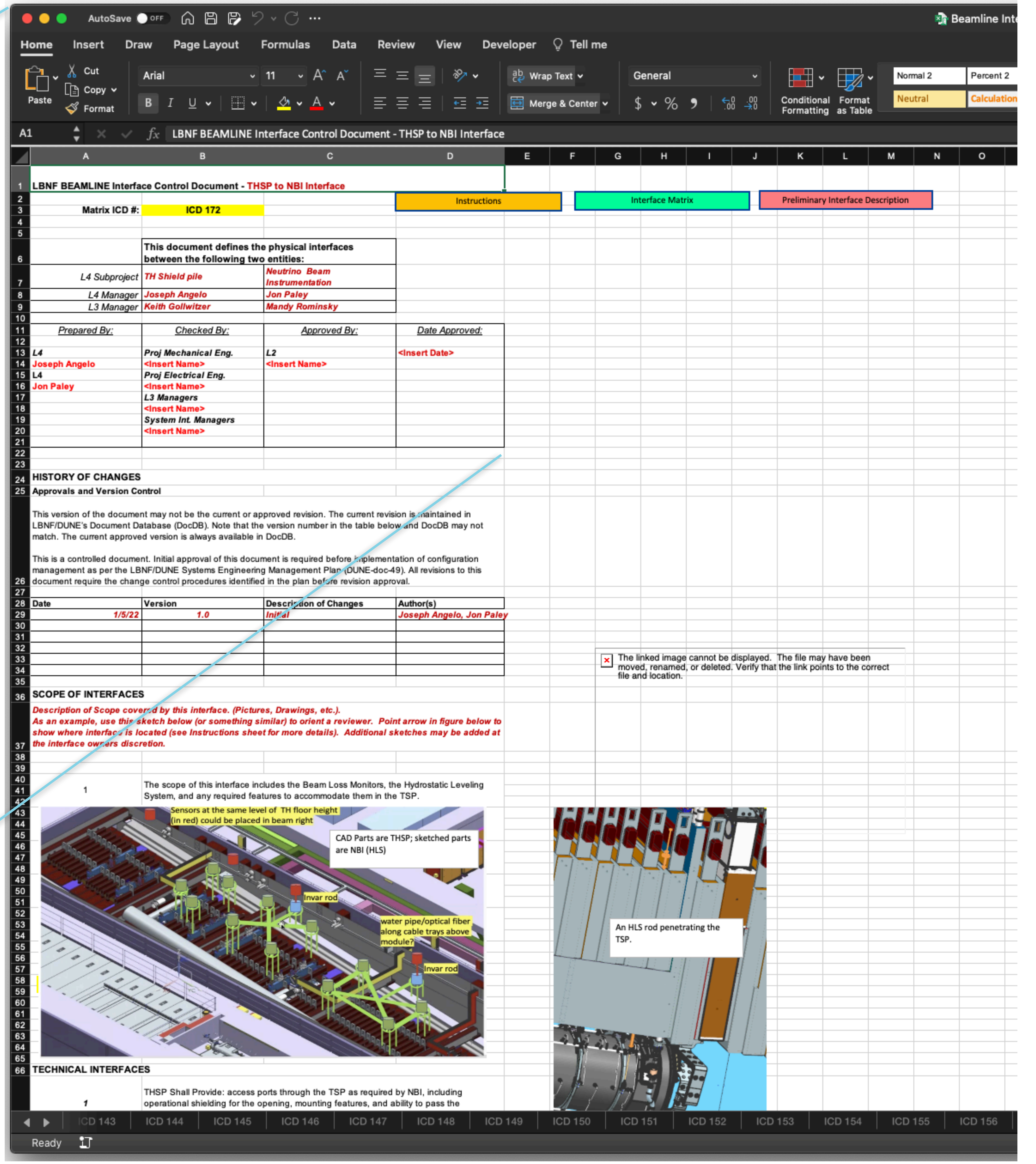
- NBI interface with quite a few other systems:
  - Targetry & Baffle (TPT, X-Hairs, HLS)
  - Absorber (HADeS)
  - Target Hall Shield Pile (HLS, X-Hairs)
  - Remote Handling (HADeS)
  - MARS Modeling (MuMS)
  - Controls (MuMS)
  - Alignment (TPT, X-Hairs, HADeS, MuMS)
  - Installation Coordination (all)
  - Conventional Facilities (all)
  - Cable Coordination (all)



- LBNF Beamline Interface Matrix spreadsheet that includes interface control documents
- Green interfaces indicate that discussions are well under way (but in many cases undocumented in the spreadsheet)
- Installation and alignment discussions have not happened yet

Interface Control Documents





- The ICD defines the boundaries (who is responsible for what) and points to specs and parameter docs.

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