NP04 Geometry and Detector Simulation

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Abstract

This note describes the NP04 geometry, as implemented in the LArSoft detector simulation, and the position of NP04 with respect to the simulated SPS-T2 beam axis. The methodology to achieve a correct displacement between the T2 target and NP04 is demonstrated and the final calculation presented.

Contents

1 Introduction

It is expected that protons from the SPS impacting on the T2 target will produce neutrinos – or perhaps beyond-standard-model (BSM) particles – that travel towards NP04 approximately 720 m downstream [1]. A simulation of the NP04 detector is available in the LArSoft framework and physics events of interest coming from the T2 beam can be generated by providing simulated particle fluxes to the event generators embedded in LArSoft. Figure 1 illustrates the cone of neutral particles created when SPS protons hit the T2 target. The centre of the T2 cone in Figure 1 is the referred to as the T2 beamline.

Neutrino interactions can be generated in LArSoft using GENIE and an input neutrino flux [2]. BSM events (only HNLs so far) are currently generated using HEPEVT format text files, however other file input formats may implemented in the future. The LArSoft environment to run these simulations is contained on GitHub with instructions on how to run the code [3].

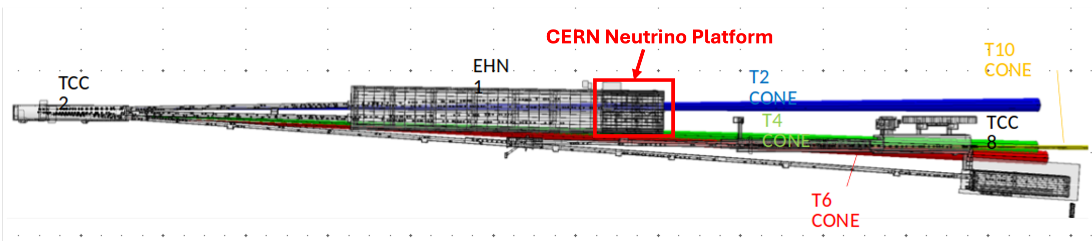

Figure 1: Protons with momentum of approximately 400 GeV hit the T2 target, which is illustrated on the left of the diagram. The resulting flux of hadrons that decay into neutrinos (and perhaps some BSM particles) is contained in the T2 cone, which passes directly though ENH1, where the Neutrino Platform and ProtoDUNE detectors are located.

2 NP04 Geometry in LArSoft

NP04 consists of a cryostat filled with liquid argon in which sits a single-phase wire plane readout TPC. The total TPC is the combination of four separate drift volumes corresponding to four anode plane arrays (APAs). The APAs are numbered 1, 2, 3 and 4 and correspond to TPC drift volumes 1, 5, 2 and 6 respectively. There is a central cathode plane with APAs 1 and 2 on one side and APAs 3 and 4 on the other side. TPC drift volumes 1, 4, 3 and 7 are on the opposite side of the APAs to the central cathode and are not considered at the time of writing. These arrangements are illustrated in Figure 2.

LArSoft uses a right-handed coordinate system. The origin point is located at the centre of the bottom edge of the total TPC. This corresponds to the front-bottom corner of the central cathode. The right of the origin is the negative x-direction and to the left is the positive x-direction. The y-axis points upwards and the z-axis points forwards parallel to the cathode and perpendicular to the electron drift direction. The H4 beamline enters the NP04 TPC in the TPC

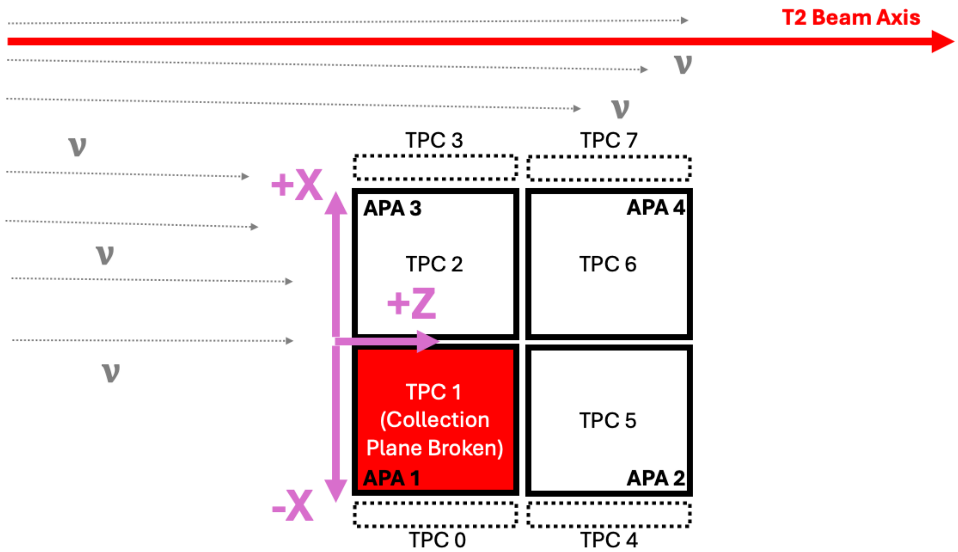

Figure 2: Illustration of layout of the TPCs within NP04. LArSoft uses a right-handed coordinate system where the negative x-direction is to the right of the origin. The T2 beam axis is illustrated at the top of the diagram, which is the centre of the flux of neutrinos coming from the T2 target.

1 drift volume and the beam plug and the approximate dimensions of the total TPC volume are illustrated in Figure 3.

3 Displacement Between T2 and NP04

An accurate simulation of neutrino and BSM fluxes at NP04 arriving from the T2 target requires the displacement between the T2 target and NP04 to be well-known. Sylvain Girod provided the displacement between T2 and a point in NP04 known as *DUNE-CNTR*. The coordinate system used for this displacement vector is aligned with the NP04 cryostat, where the z-axis is parallel to the cryostat wall and the x and y-axis origins are on the T2 beam axis. The displacement between T2 and *DUNE-CNTR* is

$$\mathbf{D} = (-8.38, 4.811, 722.592)\ \mathrm{m}, \tag{1}$$

where the x-direction is negative because a right-handed coordinate system is used.

The point *DUNE-CNTR* is not in the centre of the NP04 cryostat or the centre of the active TPC inside the cryostat. It is a point roughly in the centre of the NP04 chosen as a target for the H4 beamline that enters NP04 via a beam plug in TPC 1. Figures 4 and 5 show the position of *DUNE-CNTR* with respect to the surroundings of the ENH1 area from the top and side view respectively. Particularly in Figure 4, it can be seen that the *DUNE-CNTR* point lies on the right side of the NP04 volume. The flux simulation for either neutrinos or BSM particles requires the displacement between T2 and NP04 to be with respect to the centre of the TPC, not the *DUNE-CNTR* point. A translation must therefore be applied to the displacement vector **D**.

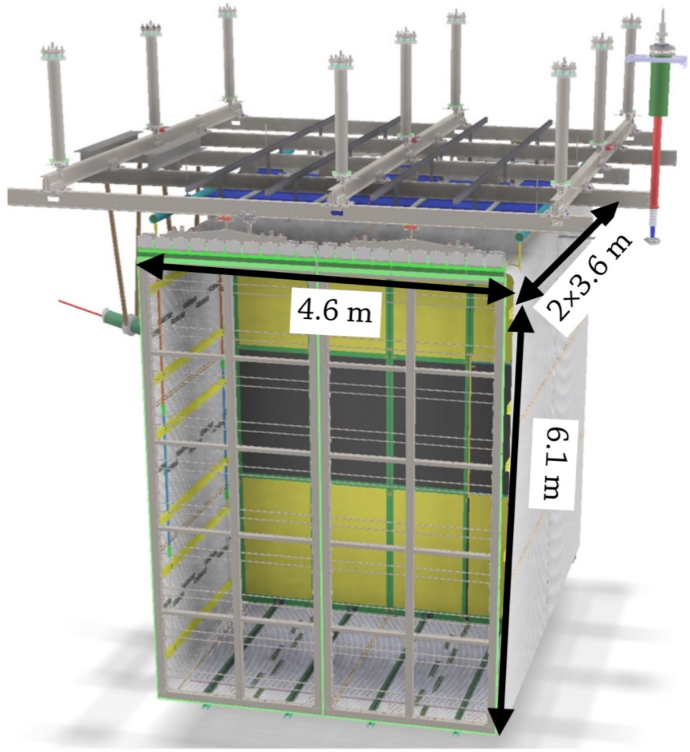

Figure 3: Diagram of total TPC within the NP04 cryostat. The approximate dimensions of the total TPC volume are given. The H4 beam plug can be seen entering the TPC from the left. The origin of the LArSoft coordinate system lies at the bottom left corner of the central cathode as viewed in this diagram.

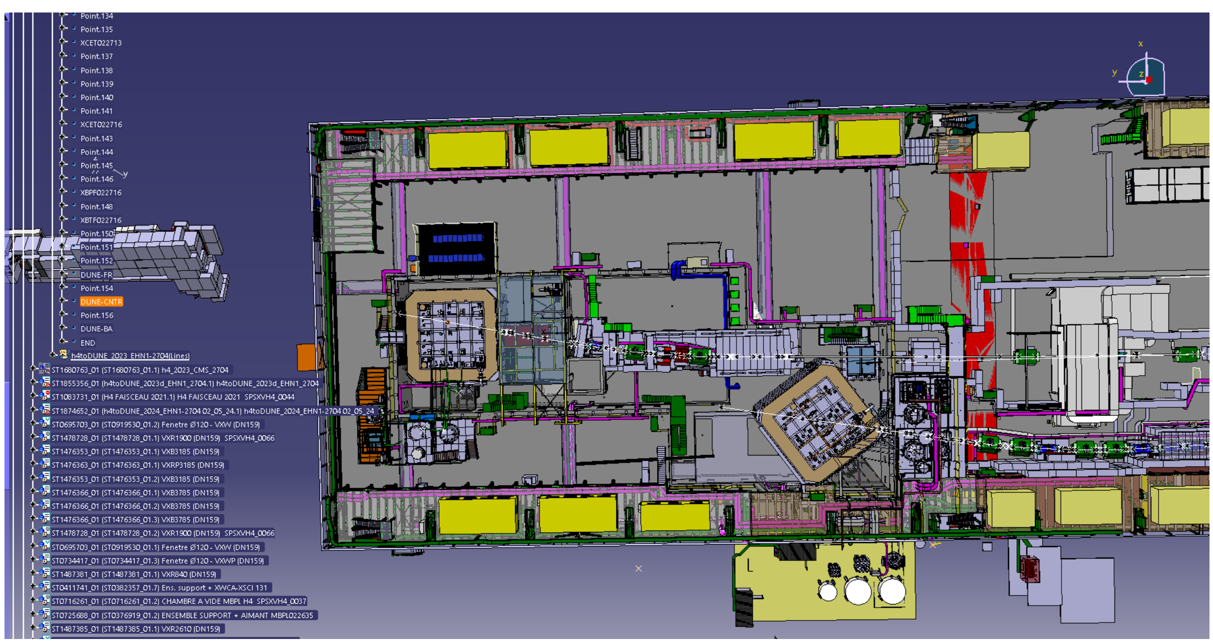

Figure 4: Top view of NP04 with the H4 beamline drawn as a line through NP04. The *DUNE-CNTR* point lies in the middle-right side of NP04.

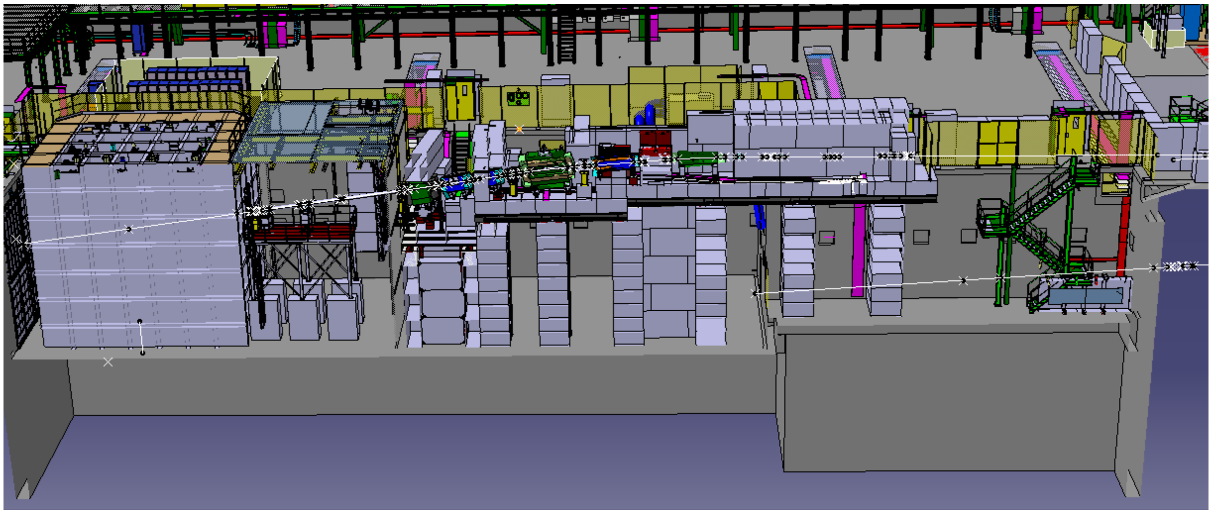

Figure 5: Side view of NP04 with the H4 beamline drawn as a line through NP04. The *DUNE-CNTR* point lies in the middle of NP04.

3.1 Conversion to Centre of TPC

It is necessary to translate vector **D** (Equation 1) to be with respect to the TPC centre, which is the centre of the active volume. The first step is to understand where exactly *DUNE-CNTR* is inside NP04. Figures 6, 7 and 8 were provided by Beatriz Sutil that illustrate the position of *DUNE-CNTR* with respect to the outer cryostat walls. From Figures 6, 7 and 8, the displacement of *DUNE-CNTR* from the bottom front-right corner of the outer cryostat wall is found to be

$$\mathbf{C_{outcorner}} = (408.6089, 531.0474, 704.5791) \text{ cm}, \tag{2}$$

where the 'front' side of NP04 is the side that faces the T2 target. It is necessary to know the location of *DUNE-CNTR* and the TPC centre in a common coordinate system. I choose to work in the LArSoft coordinate system, which is a right-handed coordinate system centred in the middle of the lower edge of the active TPC within NP04, as described in Section 2.

From LArSoft it is known that the inner walls of the cryostat form a box of dimension (855.04 $\times$ 790.24 $\times$ 855.04) cm. From the dimensions of the outer cryostat walls taken from Figures 6, 7 and 8 it is calculated that the cryostat wall thickness is 1.4268 m. This wall thickness is then subtracted from the x, y and z displacements from the outer cryostat walls (Equation 2) to give the displacement of *DUNE-CNTR* with respect to the inner cryostat walls. This displacement is with respect to the bottom front-right corner of the cryostat inner wall. Therefore, the displacement of the *DUNE-CNTR* point from the cryostat corner is

$$\mathbf{C_{corner}} = (265.9289, 388.3674, 561.8991) \text{ cm}, \tag{3}$$

where a right-handed coordinate system is still assumed. This location of the the *DUNE-CNTR* with respect to the bottom front-right corner of the inner cryostat wall is then converted into a point in the LArSoft coordinate system.

In the LArSoft coordinate system, the bottom front-right corner point of the cryostat, $\mathbf{P_{corner}}$, has coordinates

$$\mathbf{P_{corner}} = (-391.52, -65.1706, -193.854) \text{ cm}, \tag{4}$$

Therefore, getting *DUNE-CNTR* in LArSoft coordinates requires adding the displacement of *DUNE-CNTR* with respect to the inner cryostat walls ($\mathbf{C_{corner}}$) to the vector $\mathbf{P_{corner}}$ (Equation 4). This provides a *DUNE-CNTR* point with LArSoft coordinates of

$$\begin{aligned}\mathbf{C_{DUNE}} &= \mathbf{P_{corner}} + \mathbf{C_{corner}} \\ \mathbf{C_{DUNE}} &= (-125.5911, 323.1968, 368.0451) \text{ cm},\end{aligned} \tag{5}$$

where $\mathbf{C_{DUNE}}$ is the *DUNE-CNTR* point in LArSoft coordinates. The centre of the TPC within NP04 has LArSoft coordinates

$$\mathbf{C_{TPC}} = (0, 303.75, 231.86) \text{ cm}, \tag{6}$$

where $\mathbf{C_{TPC}}$ is the centre of the TPC in LArSoft coordinates. Therefore, the translation transformation between *DUNE-CNTR* and the centre of the TPC is

$$\begin{aligned}\mathbf{T} &= \mathbf{C_{TPC}} - \mathbf{C_{DUNE}} \\ \mathbf{T} &= (125.5911, -19.4468, -136.1851) \text{ cm}.\end{aligned} \tag{7}$$

This translation is then applied to the T2 to *DUNE-CNTR* displacement to convert $\mathbf{D}$ (Equation 1) to the displacement between T2 and the centre of the TPC in NP04. Therefore, the final displacement between T2 and the NP04 TPC is

$$\begin{aligned}\mathbf{D_{TPC}} &= \mathbf{D} + \mathbf{T} \\ \mathbf{D_{TPC}} &= (-7.12409, 4.616532, 721.23015) \text{ m},\end{aligned} \tag{8}$$

where $\mathbf{D}$ and $\mathbf{T}$ are the displacement vector in Equation 1 and the translation vector in Equation 7 respectively and $\mathbf{D_{TPC}}$ is the displacement between T2 and NP04 with respect to the center of the TPC.

References

[1] P. Coloma, J. López-Pavón, L. Molina-Bueno, and S. Urrea, "New physics searches using ProtoDUNE and the CERN SPS accelerator," *JHEP*, vol. 01, p. 134, 2024. arXiv: 2304.06765 [hep-ph].

[2] C. Andreopoulos *et al.*, "The GENIE Neutrino Monte Carlo Generator," *Nucl. Instrum. Meth. A*, vol. 614, pp. 87–104, 2010. arXiv: 0905.2517 [hep-ph].

[3] E. Snider and G. Petrillo, "Larsoft: Toolkit for simulation, reconstruction and analysis of liquid argon tpc neutrino detectors," *Journal of Physics: Conference Series*, vol. 898, no. 4, p. 042 057, Oct. 2017.

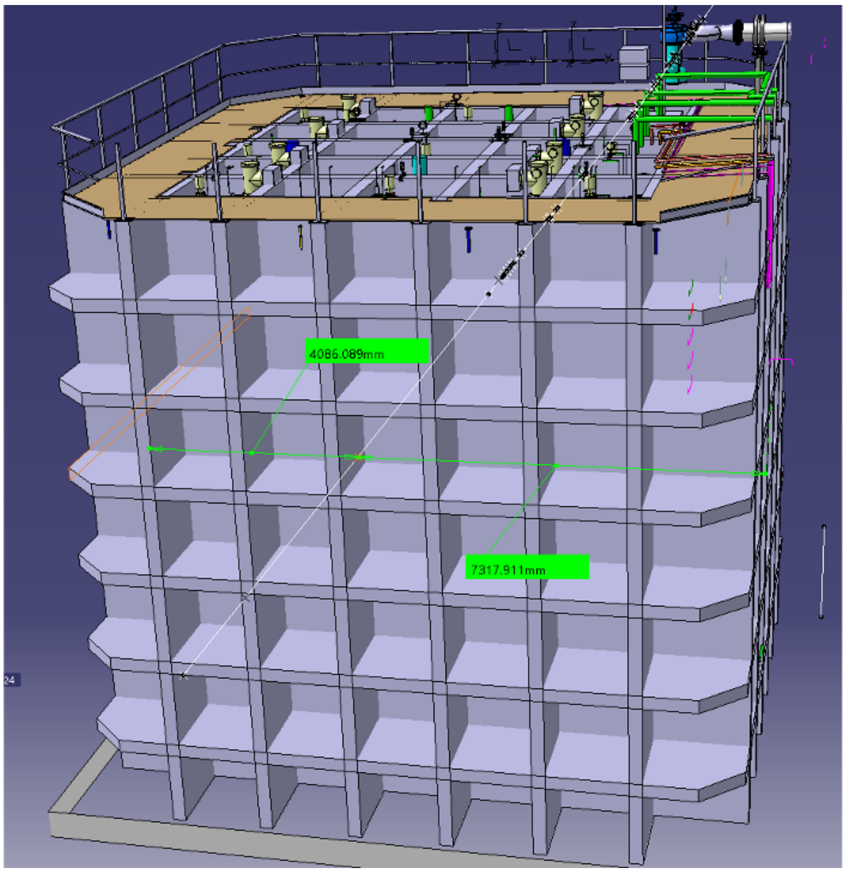

Figure 6: The x-displacement of the $DUNE\text{-}CNTR$ point with respect to the outer cryostat walls.

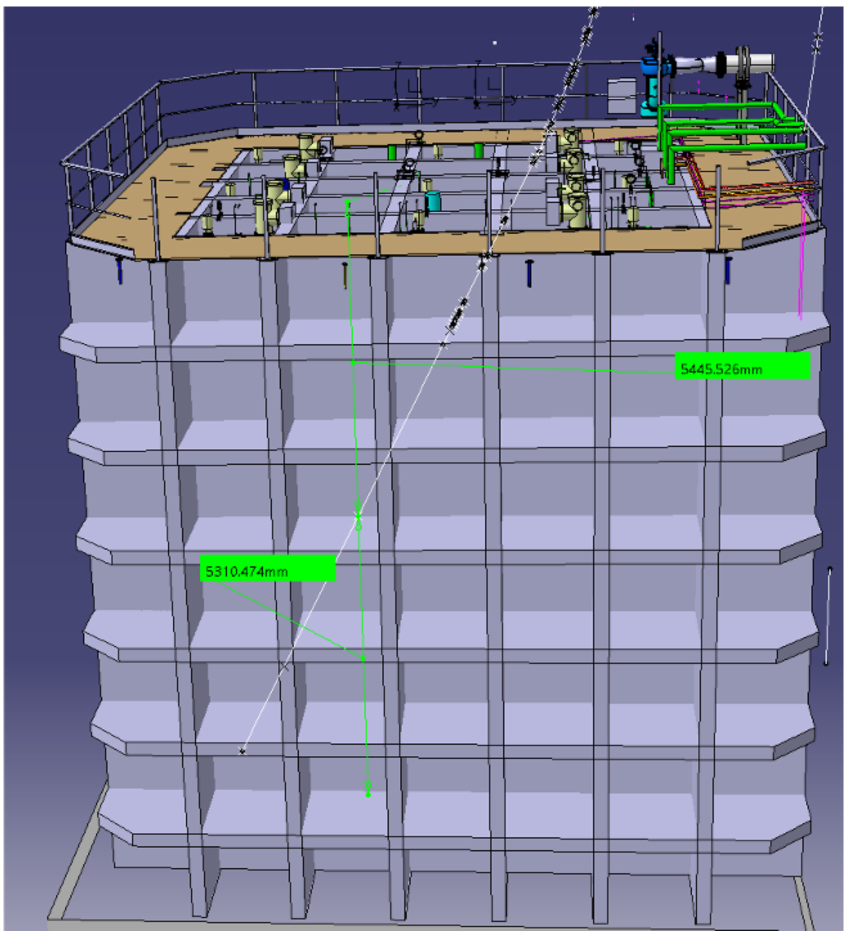

Figure 7: The y-displacement of the *DUNE-CNTR* point with respect to the outer cryostat walls.

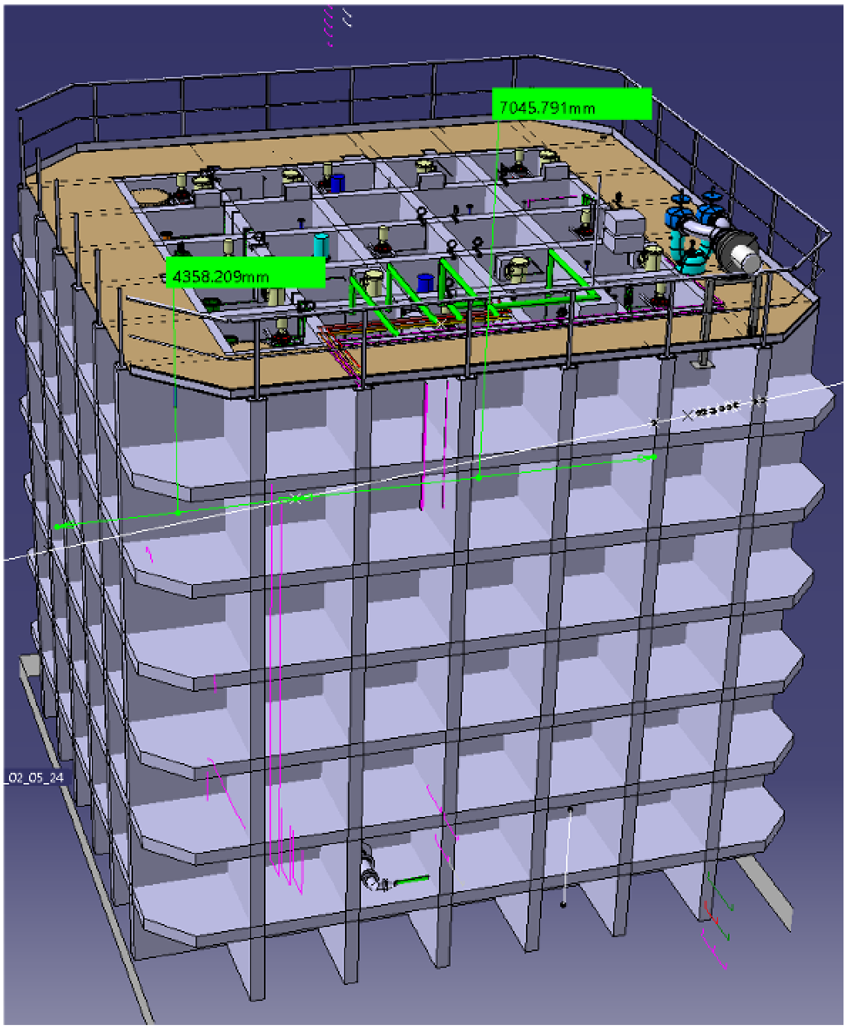

Figure 8: The z-displacement of the *DUNE-CNTR* point with respect to the outer cryostat walls.