NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

December 15, 2021

Computed Tomography Specialist's Factual Report

DCA21FA085

A. ACCIDENT

Location:	Broomfield, CO
Date:	February 20, 2021
Time:	1309 mountain standard time
Airplane:	Boeing 777-222, N772UA

B. GROUP

Computed Tomography Specialist:	Scott Warren National Transportation Safety Board Washington, D.C.

C. SUMMARY

On February 20, 2021, about 1309 mountain standard time (MST), United Airlines flight 328, a Boeing 777-222, N772UA, experienced a failure of the right engine, a Pratt & Whitney PW4077, while climbing through an altitude of about 12,500 feet mean sea level (msl) shortly after takeoff from Denver International Airport (DEN), Denver, Colorado. There were no injuries to the 239 passengers and crew onboard, and the airplane sustained minor damage. The regularly scheduled domestic passenger flight was operating under the provisions of Title 14 Code of Federal Regulations (CFR) Part 121 from DEN to Daniel K. Inouye International Airport (HNL), Honolulu, Hawaii.

The internal configuration of the engine driven pump (EDP) supply shutoff valve located on the right engine of the accident aircraft was documented using radiographic images that were collected from March 10 – April 30, 2021, in Chicago, Illinois. A total of 12,609 computed tomography (CT) slice images were examined, processed, and analyzed by the NTSB to evaluate the components.

Review of the images determined that, when the scans were conducted, the following indications were noted:

1. The connections between the motor, gear train, output shaft, and valve blade did not show any indications of breaks or disconnects.

2. Indications of high density particles were noted in various locations such as the outside of the motor case, a seal between the connector and motor cases, and on the insulation of several wires.

3. There were no indications noted of any sort of blockage or obstruction within the valve blade guides.

4. There were indications of wire strand breaks within the wires attached to the connector. The break indications were noted in only a few of the strands; the other strands appeared to be intact.

5. There were indications of high density particles within the motor coil wires.

D. DETAILS OF THE INVESTIGATION

1.0 General

The engine driven pump (EDP) supply shutoff valve located on the right engine of the accident aircraft was subjected to x-ray radiograph and computed tomography (CT) scanning to document the valve's internal condition. The scanning was conducted from March 10 – April 30, 2021, by Varex, Inc under the direction of the NTSB using the Actis 250/500 microfocus CT system.

For the CT scans, the component was loaded into the imaging unit and placed on a turntable. The component was then rotated in front of the x-ray source, and the x-rays were captured by a detector after they went through the part. The x-ray source produced a cone shaped beam of x-rays, and the portion of the part imaged was adjusted slightly after each scan was completed until the entire assembly (or region of interest of the part) was scanned. The x-ray energy levels measured by the detector were recorded at several thousand different points during each rotation, and this information was converted into slice images using reconstruction algorithms.

The components were scanned using a total of 12,609 slices, and the total size of the combined data sets was approximately 110 GB. The complete scan protocols are given in table 1. The digital radiograph and CT axial slice images were provided by Varex to the NTSB where they were examined, processed, and analyzed to evaluate the components.

For selected areas within the component, target CT techniques were used. The target CT techniques used geometric magnification[1] to provide for enhanced resolution within a component. The field of view during these scans is reduced, but the resolution within that field of view is much better than in the overall component scans.

The windings within the valve motor were "virtually unrolled" using the CT image visualization software. This process required the identification of a path for the software to use when unrolling the data set, and it resulted in a cylindrical structure being "unrolled" to show a round surface as a flat planar image.

[1] Geometric magnification is a scanning technique where the component is moved closer to the x-ray source. The x-ray beam passes through a smaller region within the component, and that smaller region's image information is spread across the x-ray detector. The resulting image is created at a higher resolution.

Table 1
Scan Protocols

Component	Motor Overall Scan	Valve Overall Scan	Motor Target CT	Microswitches Target CT	Relay and Connector Wires Target CT	Exemplar Relay Target CT
Number of slices	2,701	3,281	2,451	550	2,068	1,558
Voxel[2] Size - X Direction (millimeter(mm))	0.064	0.064	0.015	0.022	0.029	0.014
Voxel Size - Y Direction (mm)	0.064	0.064	0.015	0.022	0.029	0.014
Voxel Size - Z Direction (mm)	0.06	0.06	0.02	0.02	0.03	0.015
Image Projections per Revolution	1800	1800	1800	2520	1800	1800
Exposure time (milliseconds)	285.6	285.6	285.6	285.6	285.6	285.6
Frames to Avg (frames per projection)	2	2	2	2	2	2
X-ray Source Voltage (kilovolts)	222	222	223	223	222	223
X-ray Source Current (milliamps)	0.550	0.550	0.550	0.550	0.550	0.550
Source Filter Thickness (mm)	1	1	1	1	1	1
Source Filter Material	brass	brass	brass	brass	brass	brass
Image Matrix Size (pixels)	2048 x 2048	2048 x 2048	2048 x 2048	2048 x 2048	2048 x 2048	2048 x 2048

The data sets of slice images were examined, processed, and analyzed by the NTSB using the VGStudioMax software package to convert the axial slice data into orthogonal slice images and a three-dimensional reconstructed image of the component. As part of the evaluation, some sections of the components were digitally removed or rendered transparent to allow closer observation of interior parts. In the images, the higher density areas were shown as brighter shades of gray and lower density areas were shown as darker shades of gray. The pointers shown in some of the images denote specific areas of interest within that image.

[2] A voxel is a three-dimensional picture element (pixel).

The images of the components were examined for any signs of missing or damaged parts, contamination, or any other anomalies. Specific results (including example images) are presented in subsequent sections of this report.

2.0 Computed Tomography Results

The computed tomography (CT) results for the components are shown in figures 1 through 72. Review of the images determined that, when the scans were conducted, the following indications were noted:

1. The connections between the motor, gear train, output shaft, and valve blade did not show any indications of breaks or disconnects.

2. Indications of high density particles were noted in various locations such as the outside of the motor case, a seal between the connector and motor cases, and on the insulation of several wires.

3. There were no indications noted of any sort of blockage or obstruction within the valve blade guides.

4. There were indications of wire strand breaks within the wires attached to the connector. The break indications were noted in only a few of the strands; the other strands appeared to be intact.

5. There were indications of high density particles within the motor coil wires.

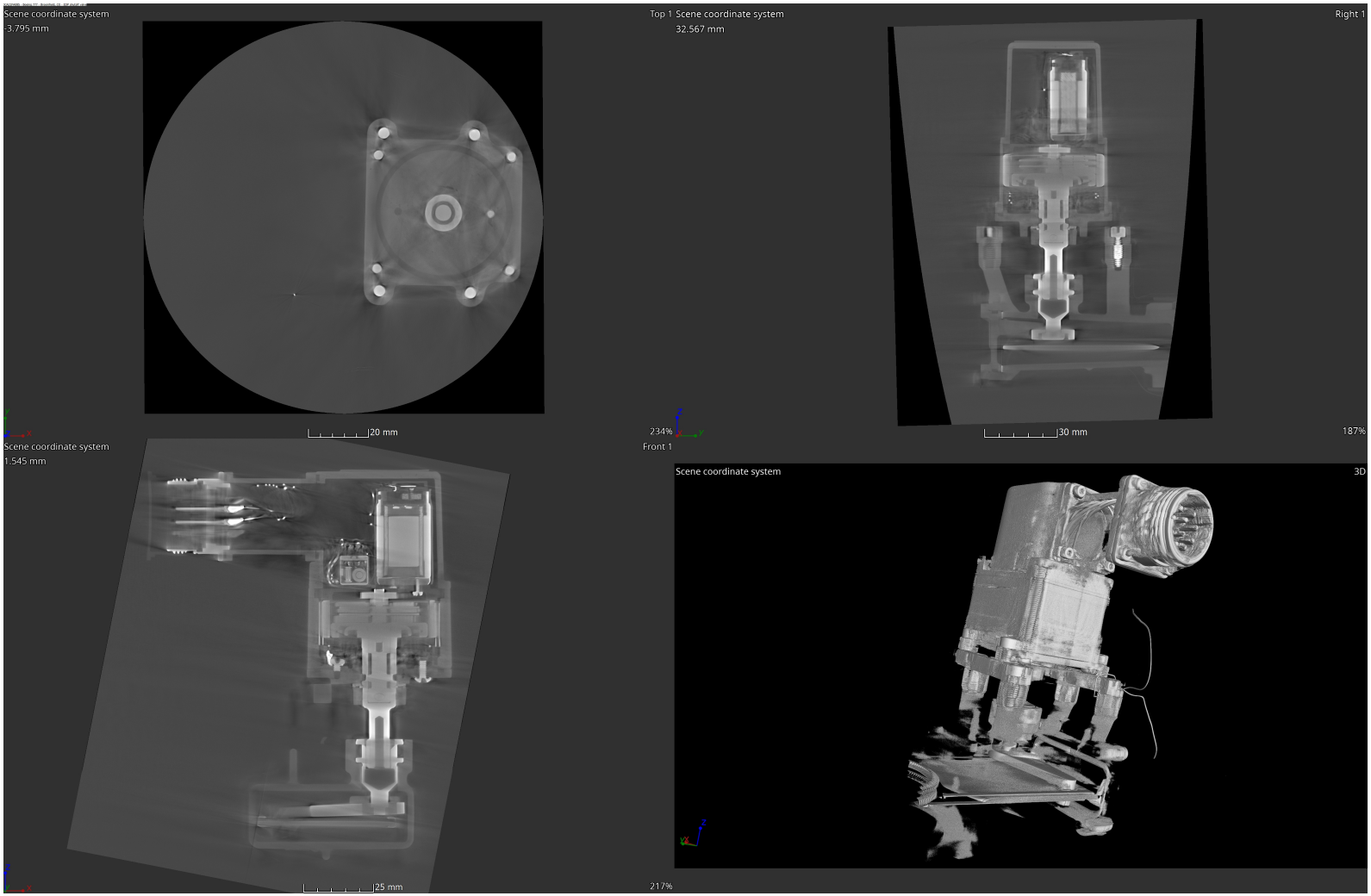


Figure 1
EDP supply shutoff valve – motor components - overview

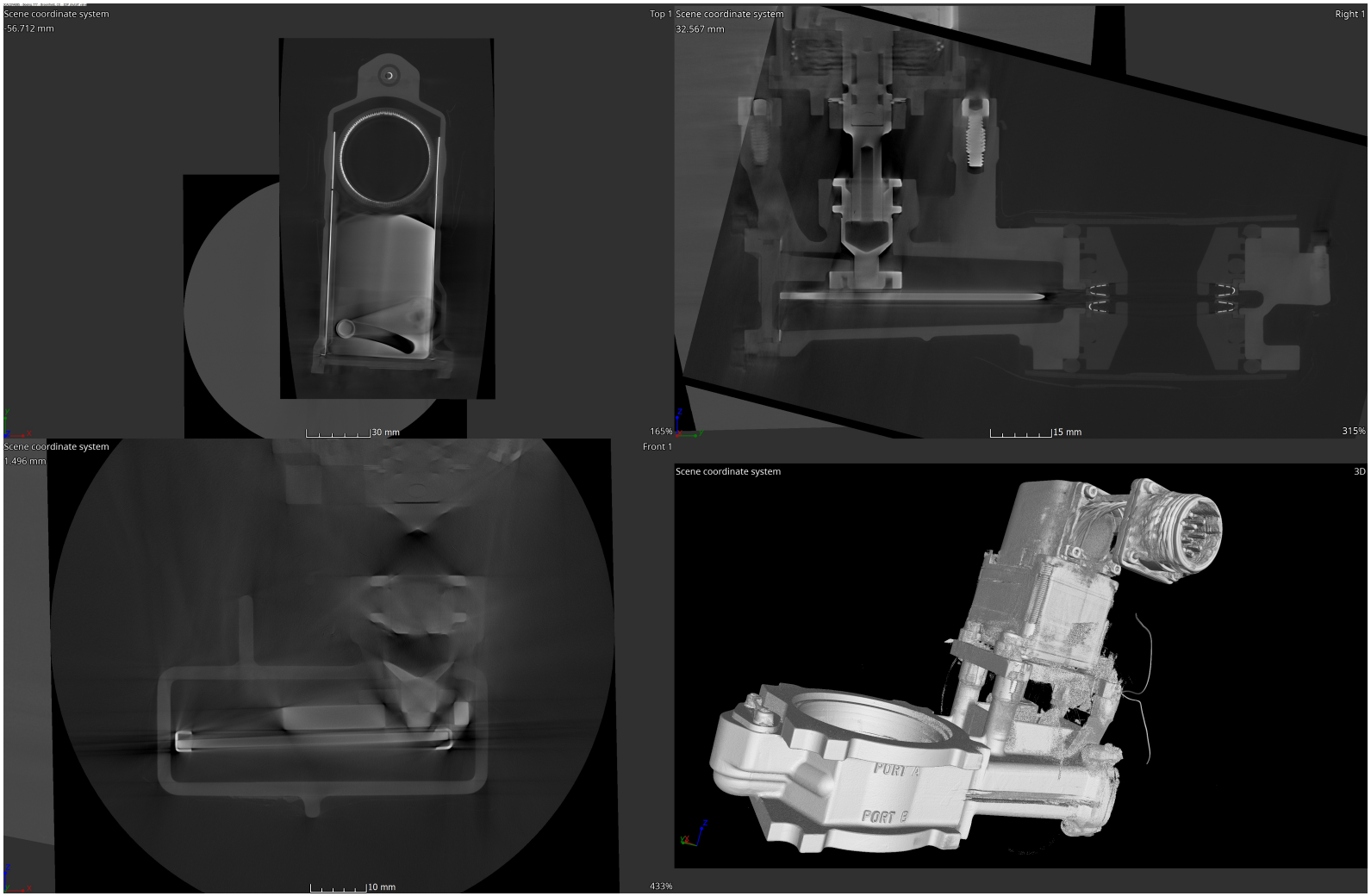


Figure 2
EDP supply shutoff valve – valve components - overview

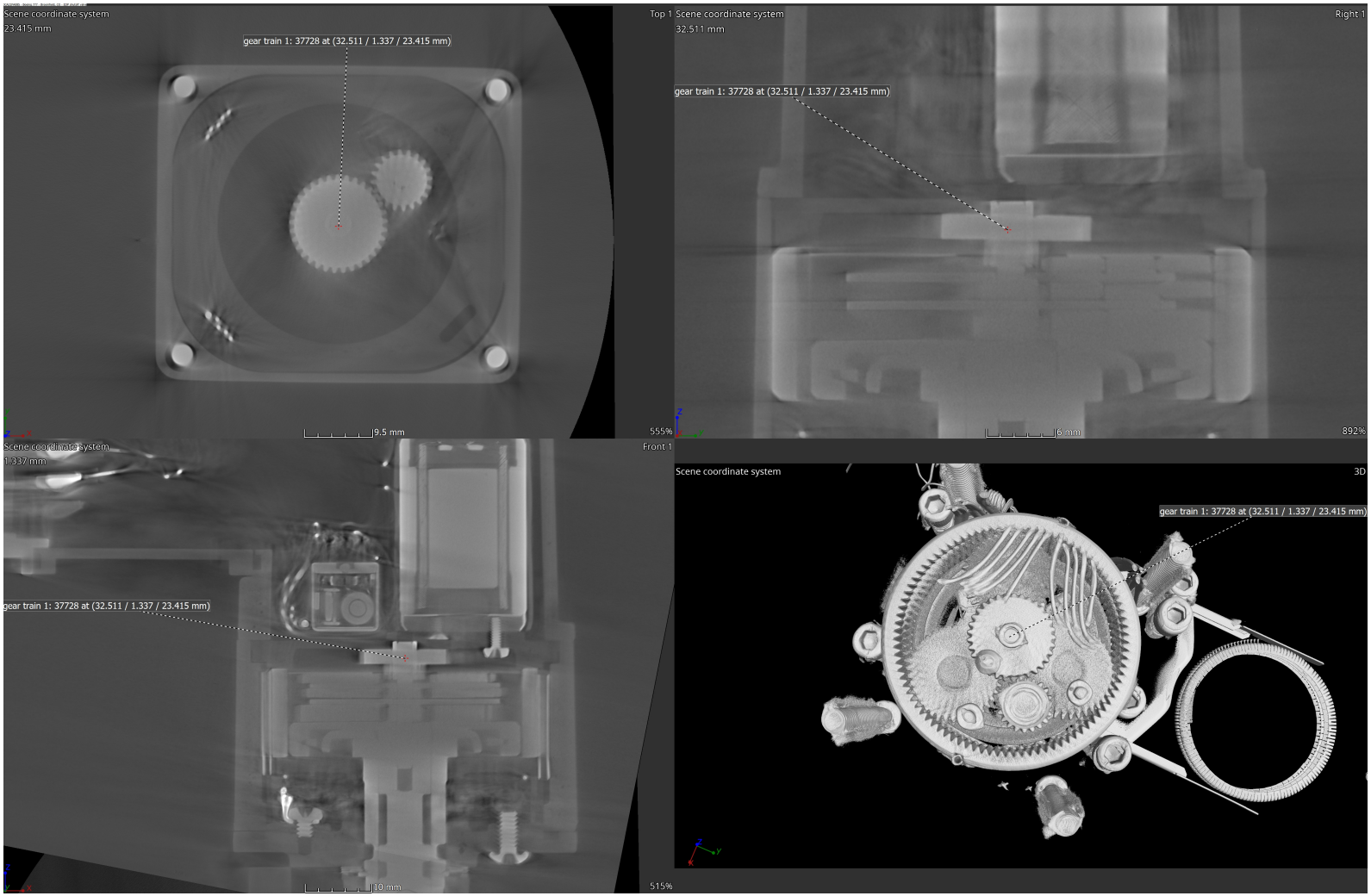


Figure 3
EDP supply shutoff valve – gear train 1

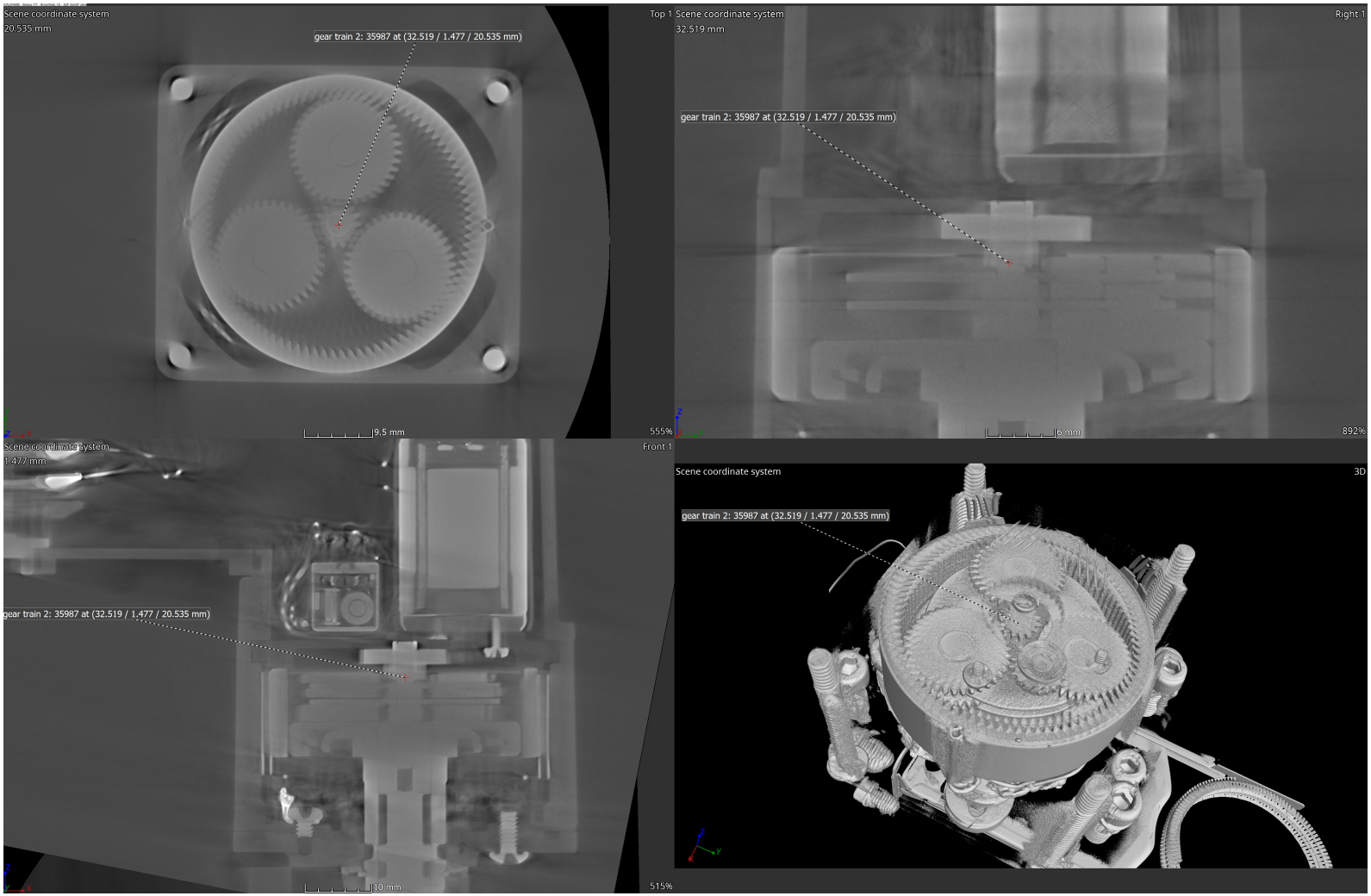


Figure 4
EDP supply shutoff valve – gear train 2

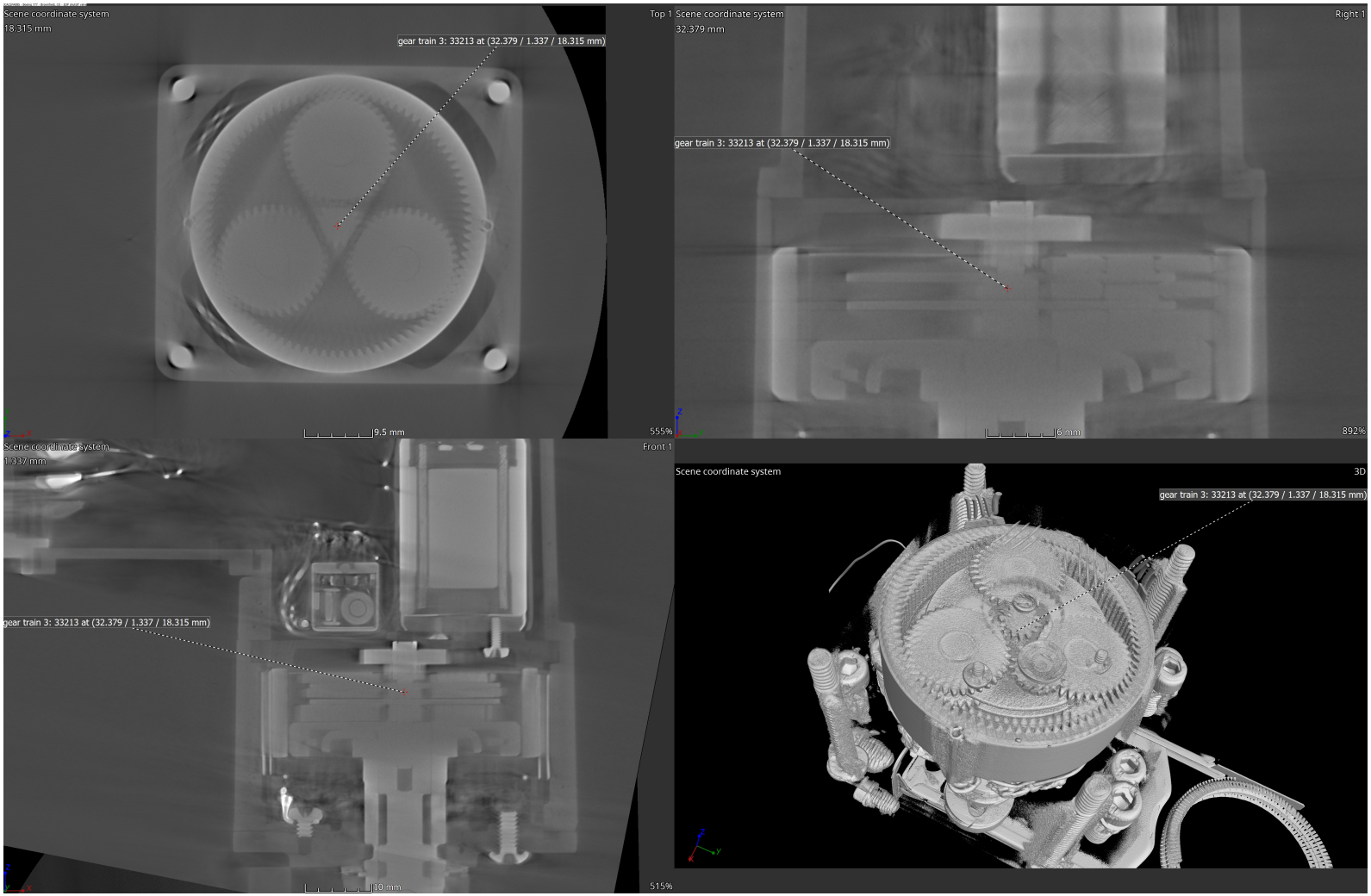


Figure 5
EDP supply shutoff valve – gear train 3

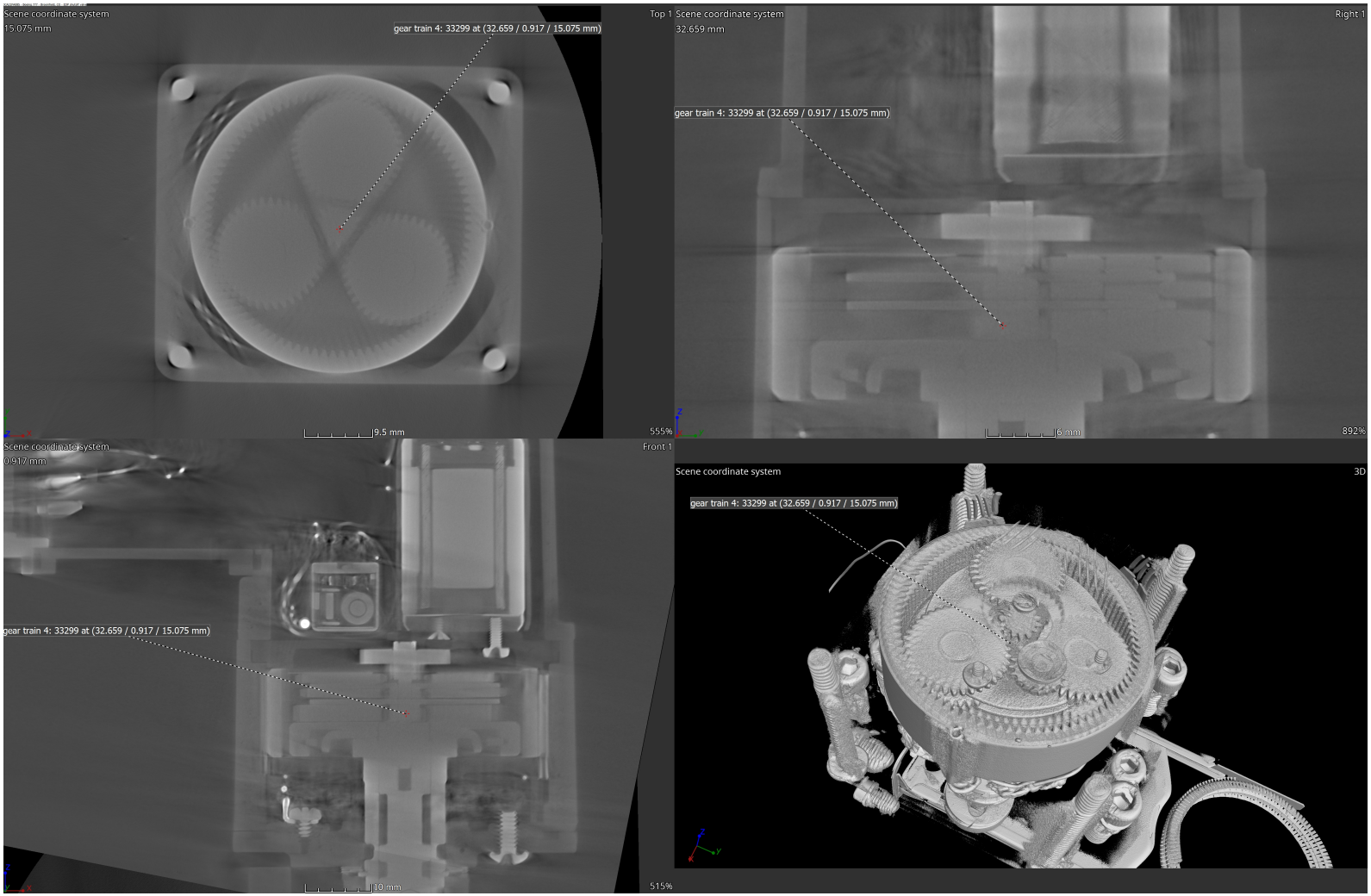


Figure 6
EDP supply shutoff valve – gear train 4

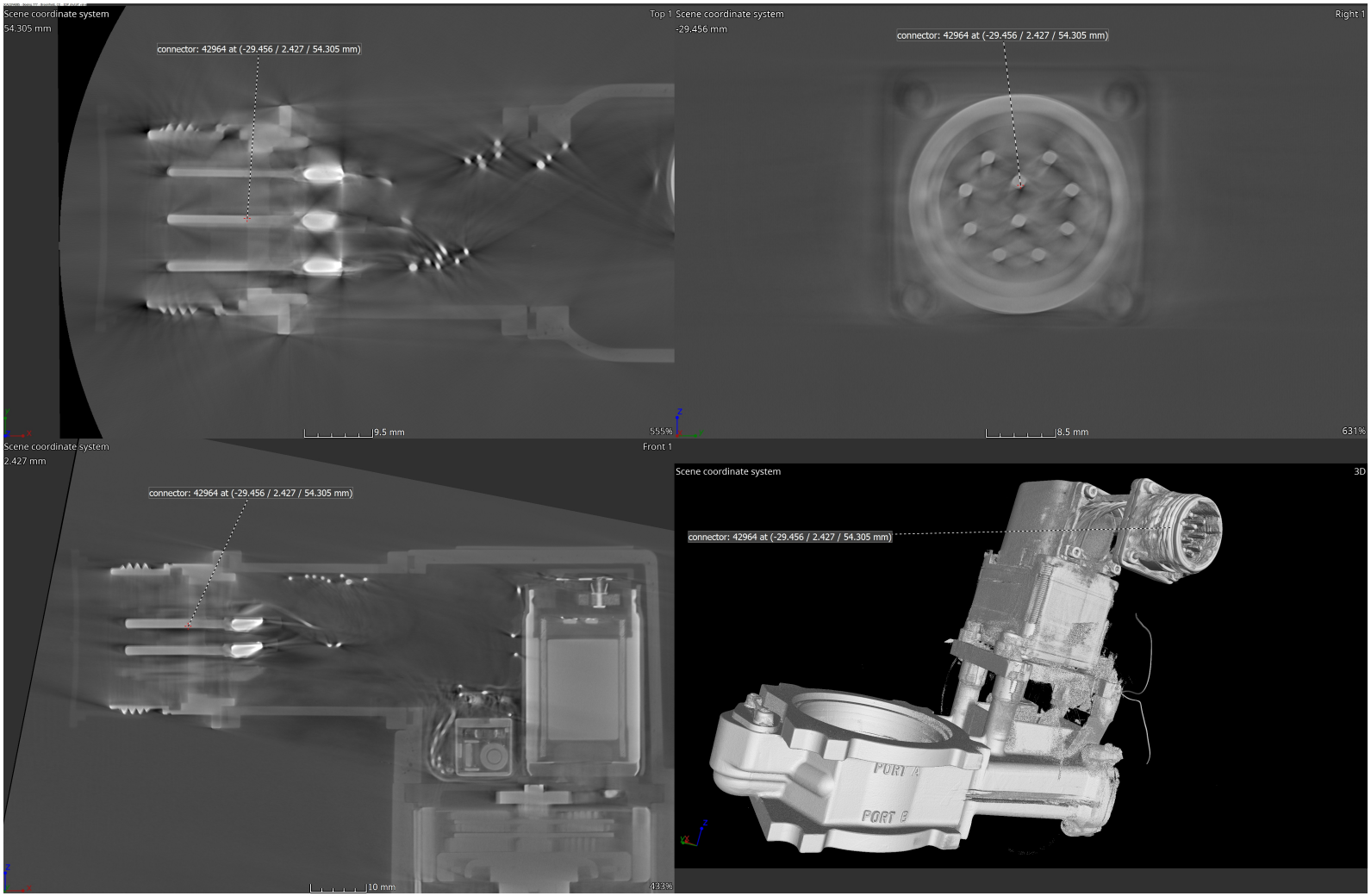


Figure 7
EDP supply shutoff valve – connector

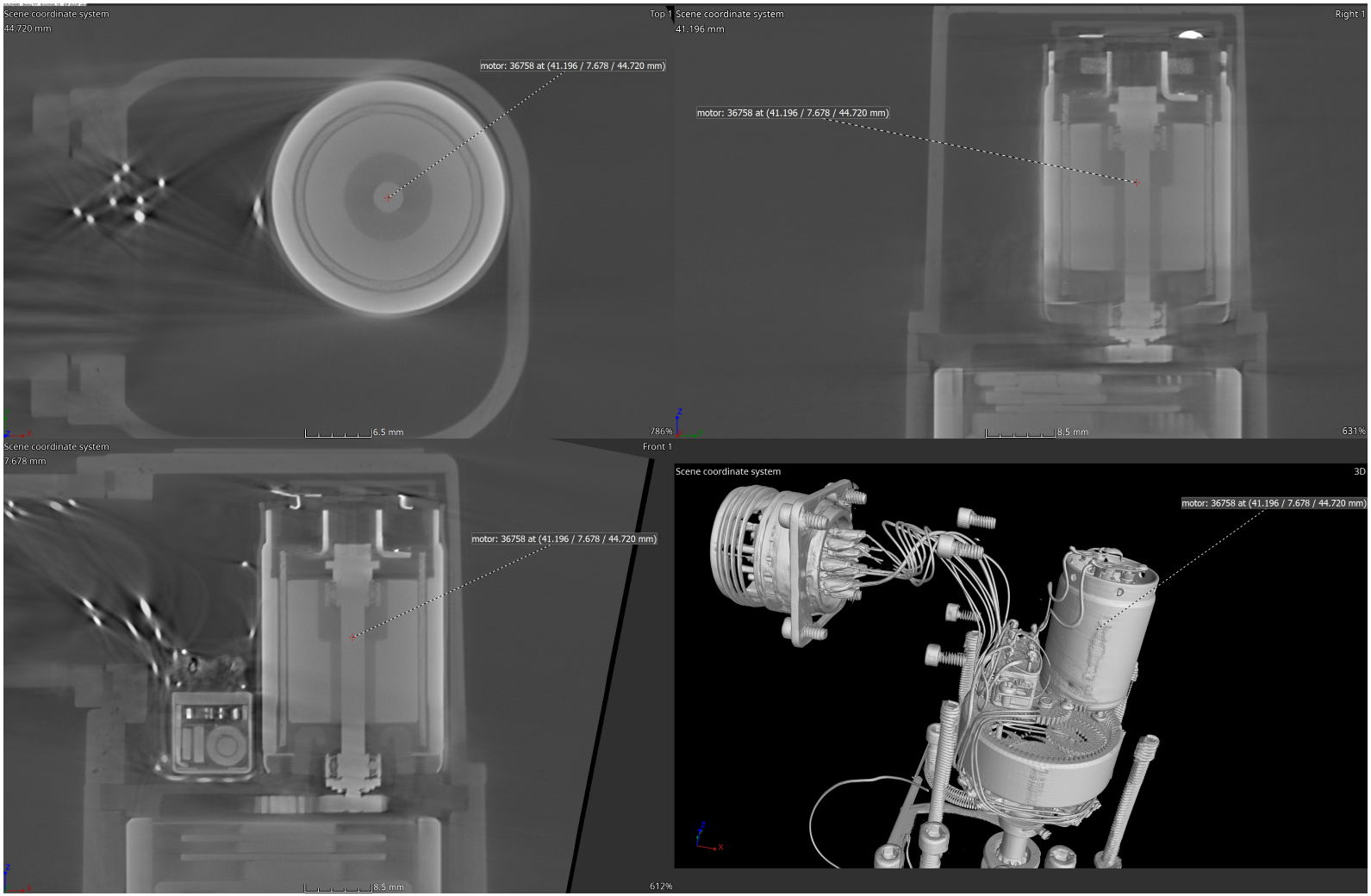


Figure 8
EDP supply shutoff valve – motor

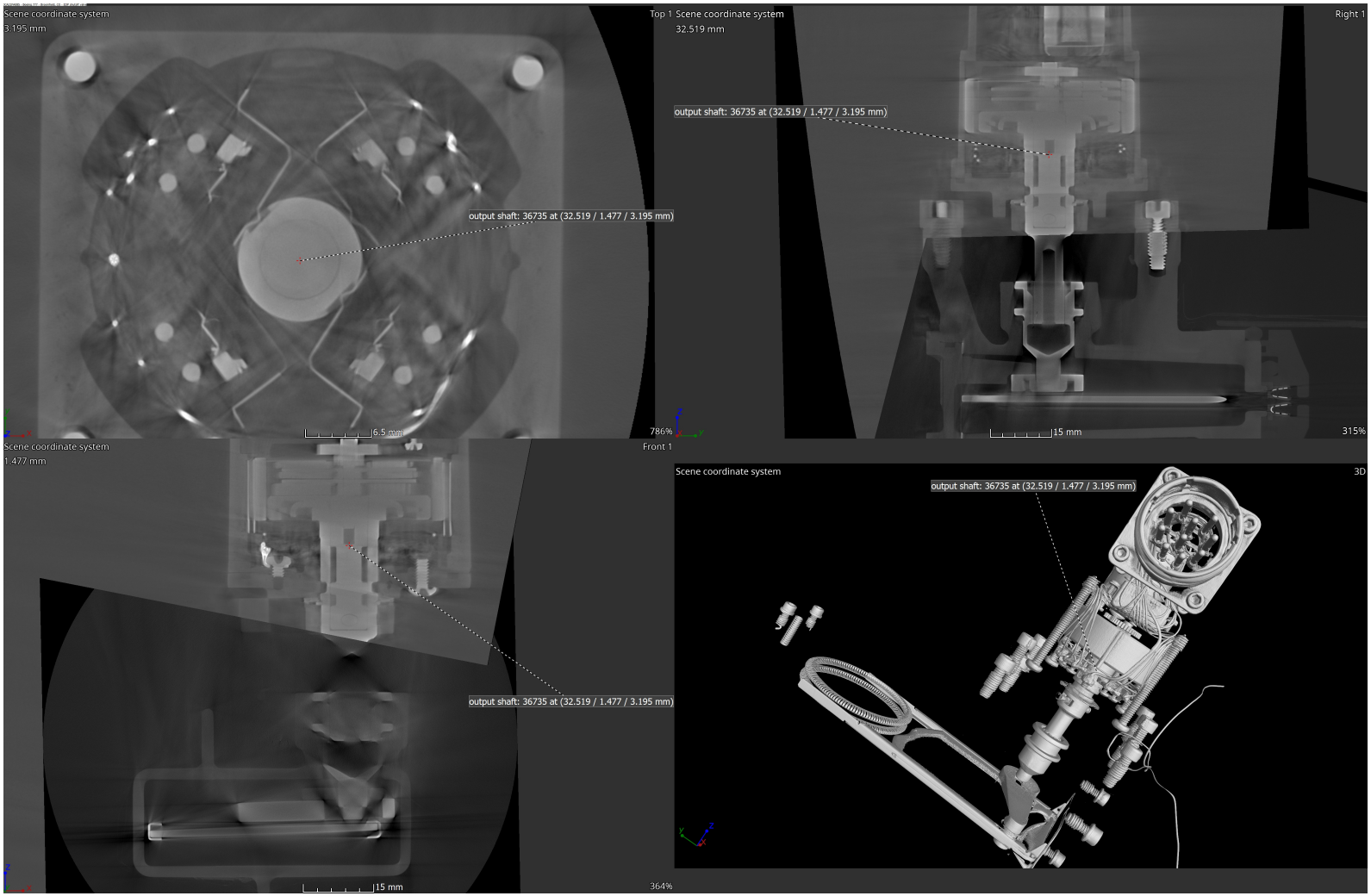


Figure 9
EDP supply shutoff valve – output shaft

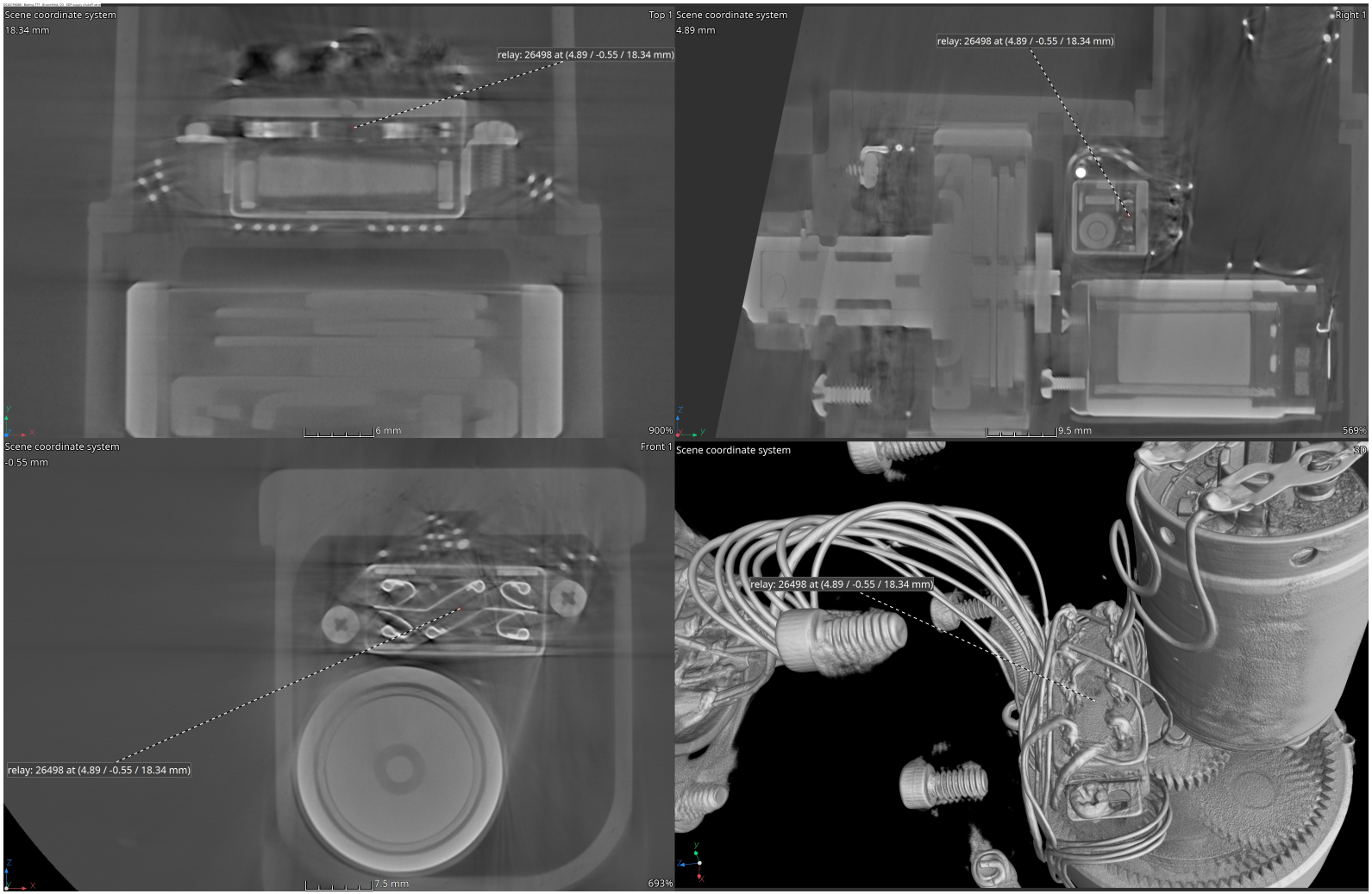


Figure 10
EDP supply shutoff valve – relay

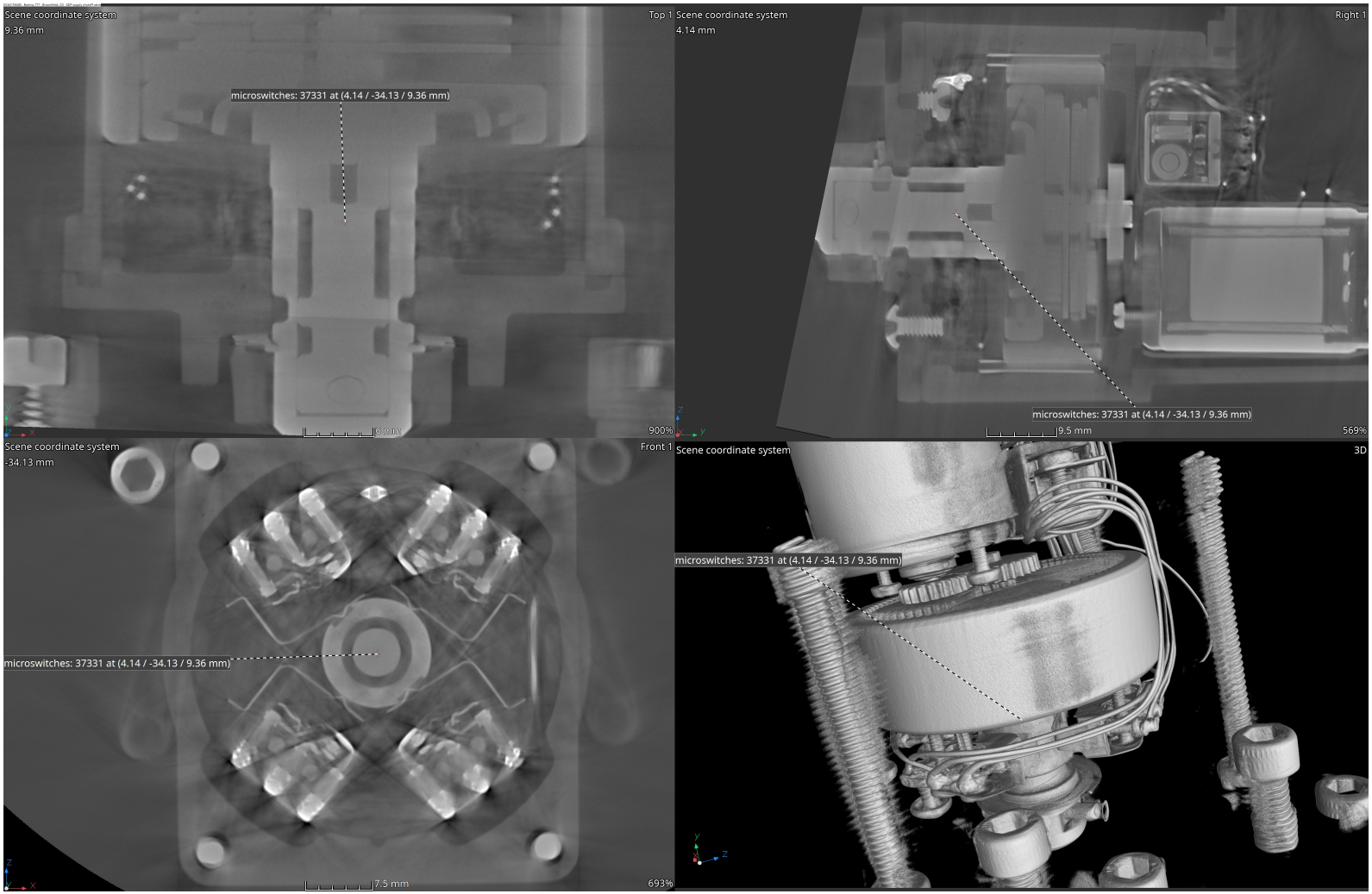


Figure 11
EDP supply shutoff valve – microswitches

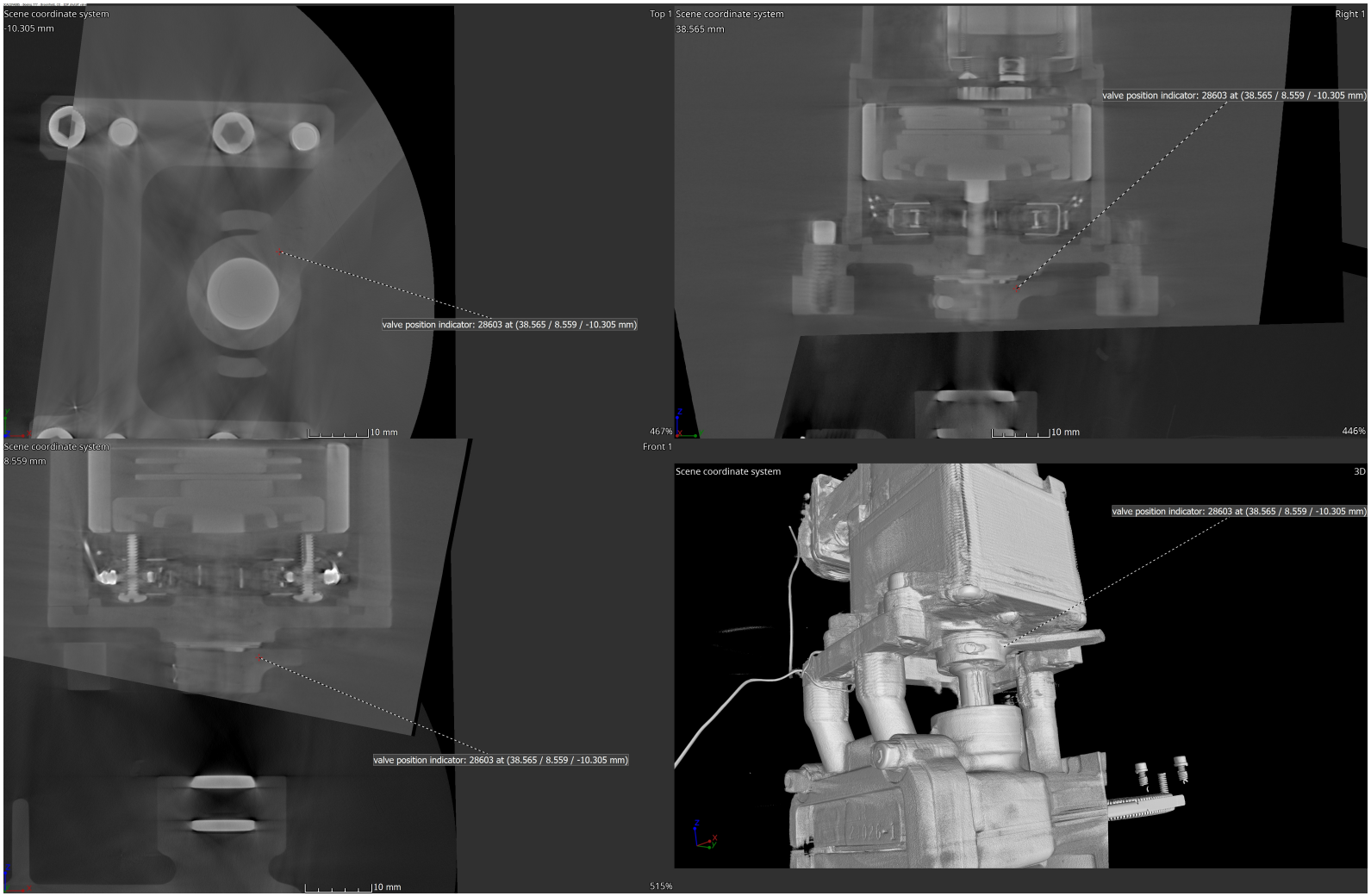


Figure 12
EDP supply shutoff valve – valve position indicator

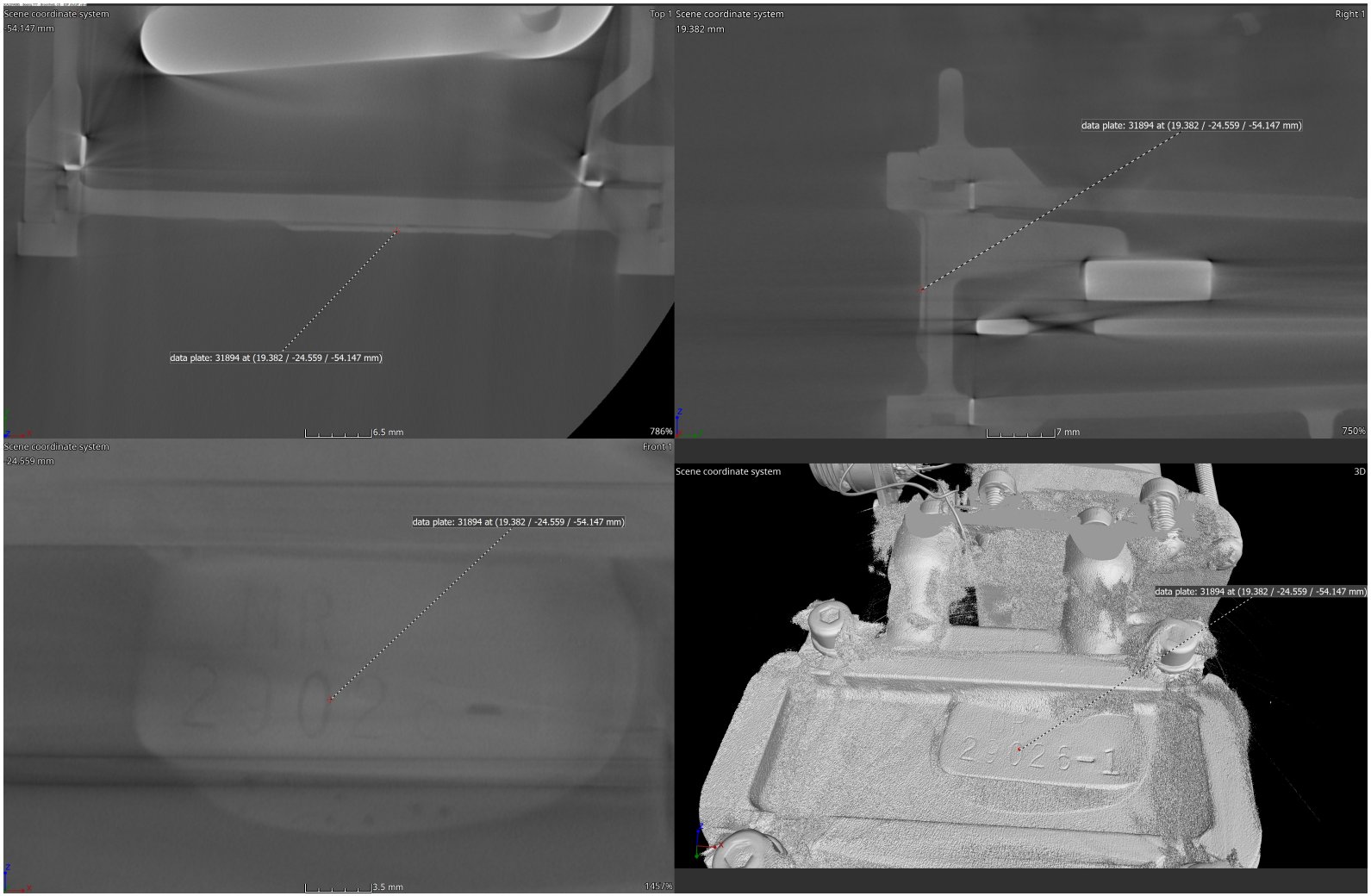


Figure 13
EDP supply shutoff valve – data plate

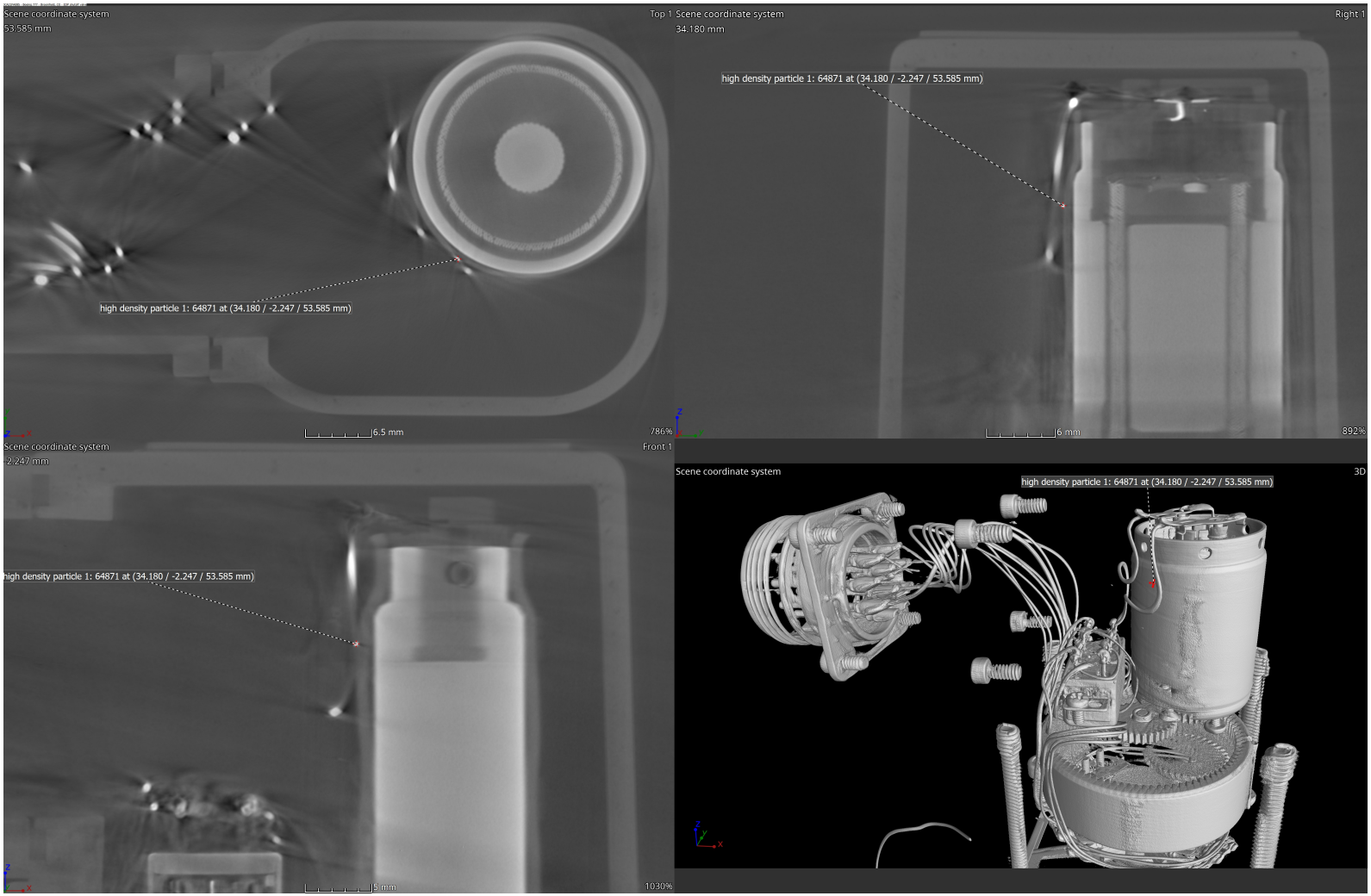


Figure 14
EDP supply shutoff valve – high density particle 1



Figure 15
EDP supply shutoff valve – high density particle 2

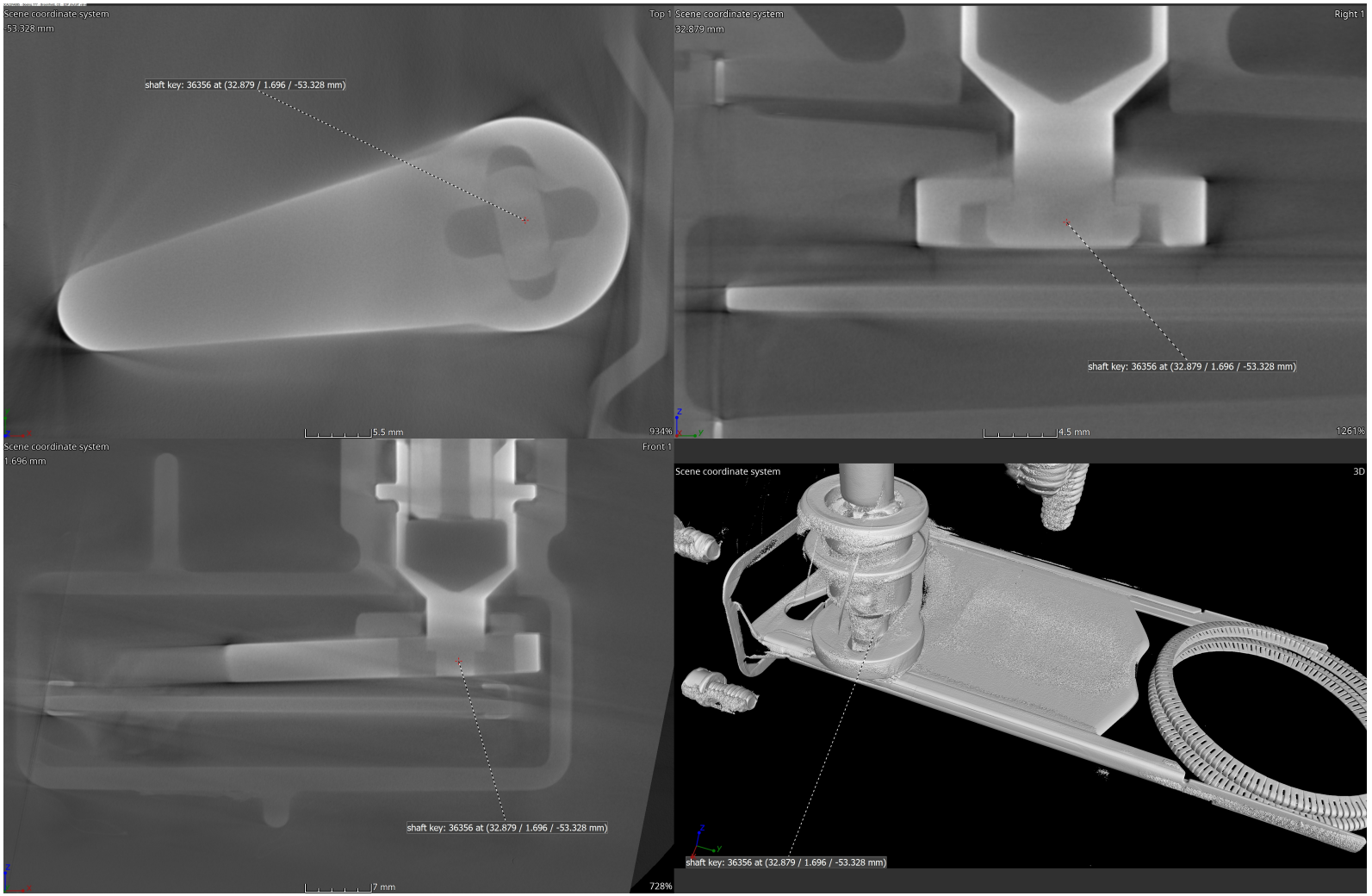


Figure 16
EDP supply shutoff valve – shaft key

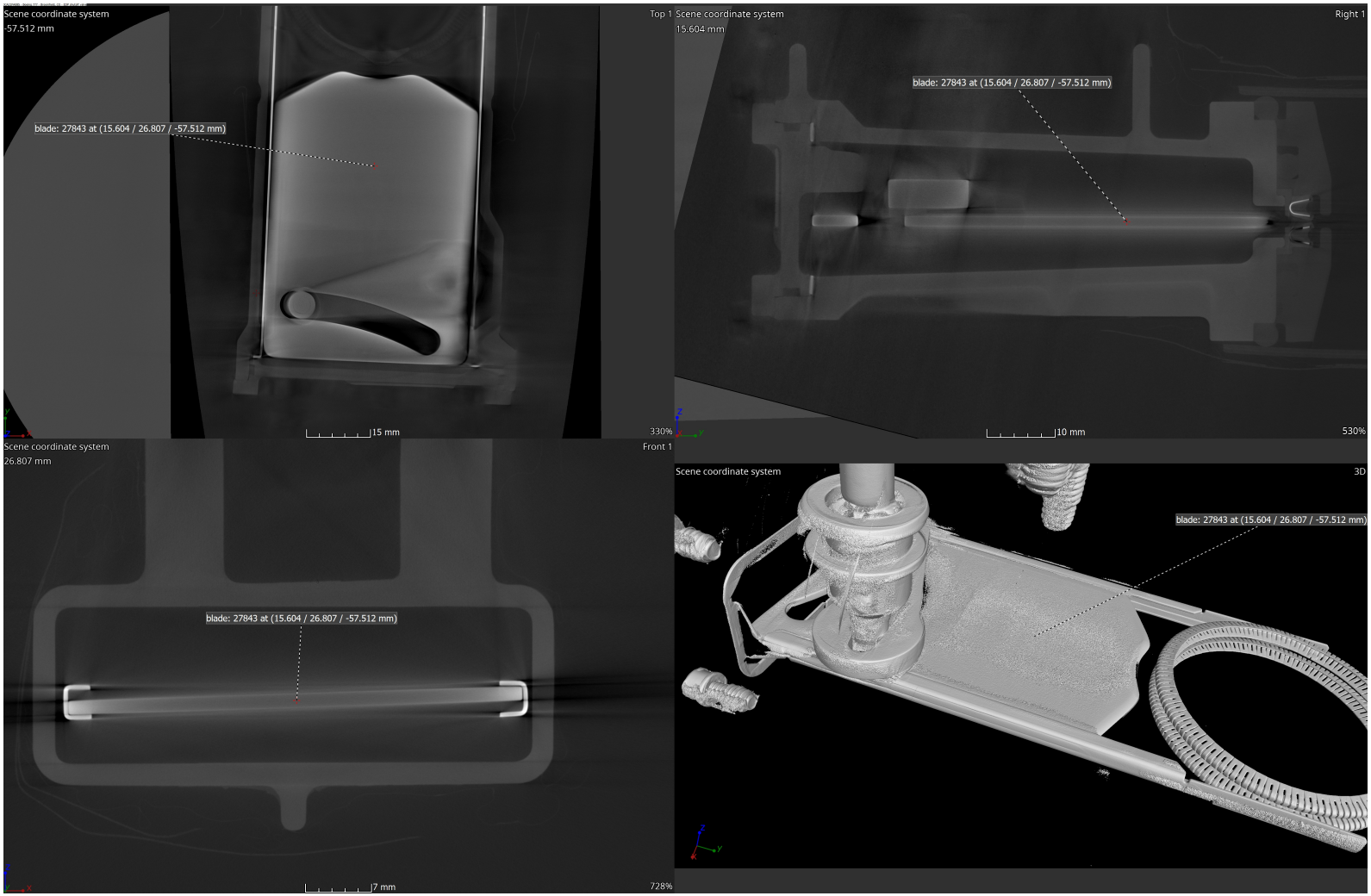


Figure 17
EDP supply shutoff valve – valve blade

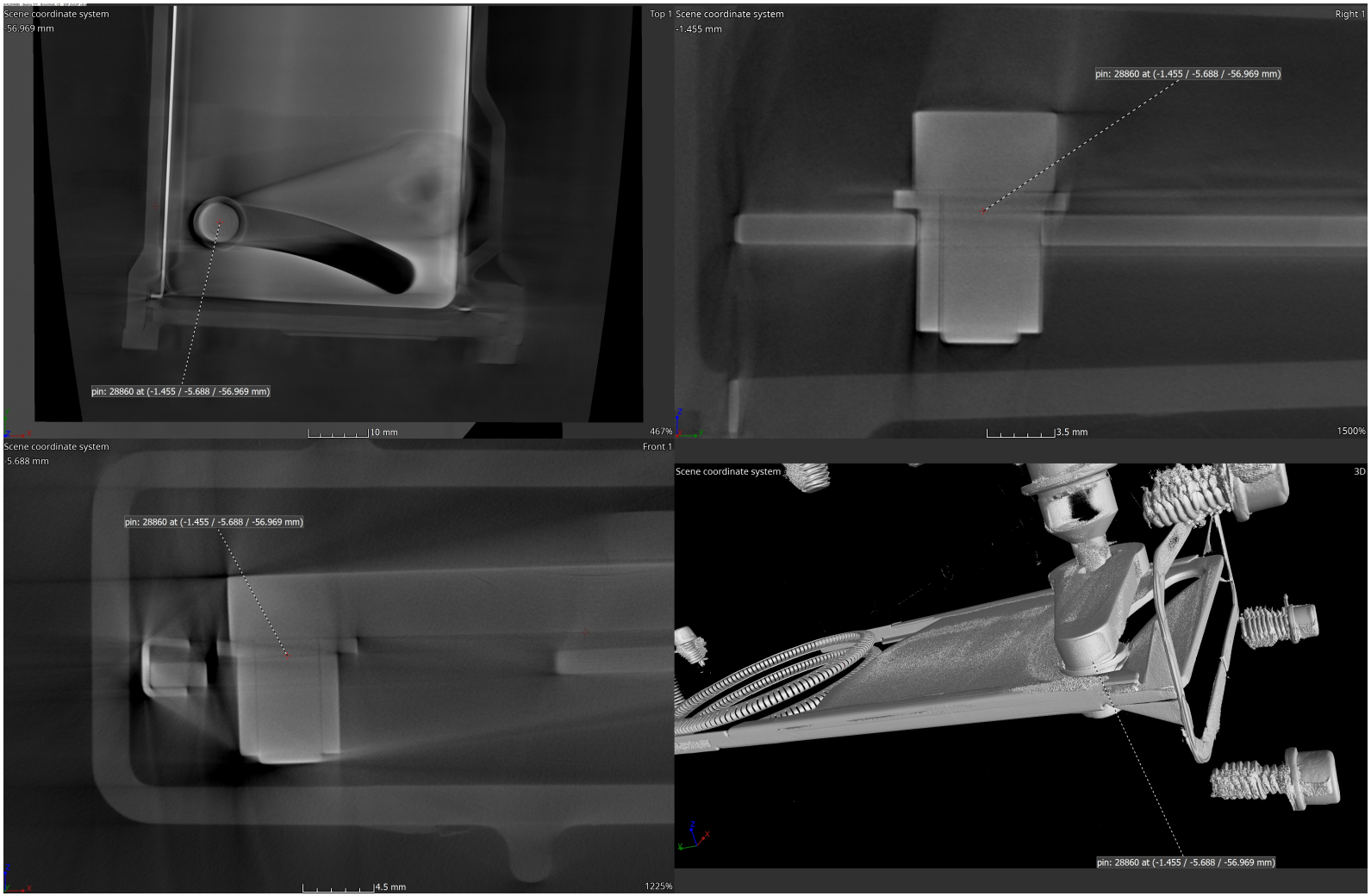


Figure 18
EDP supply shutoff valve – pin

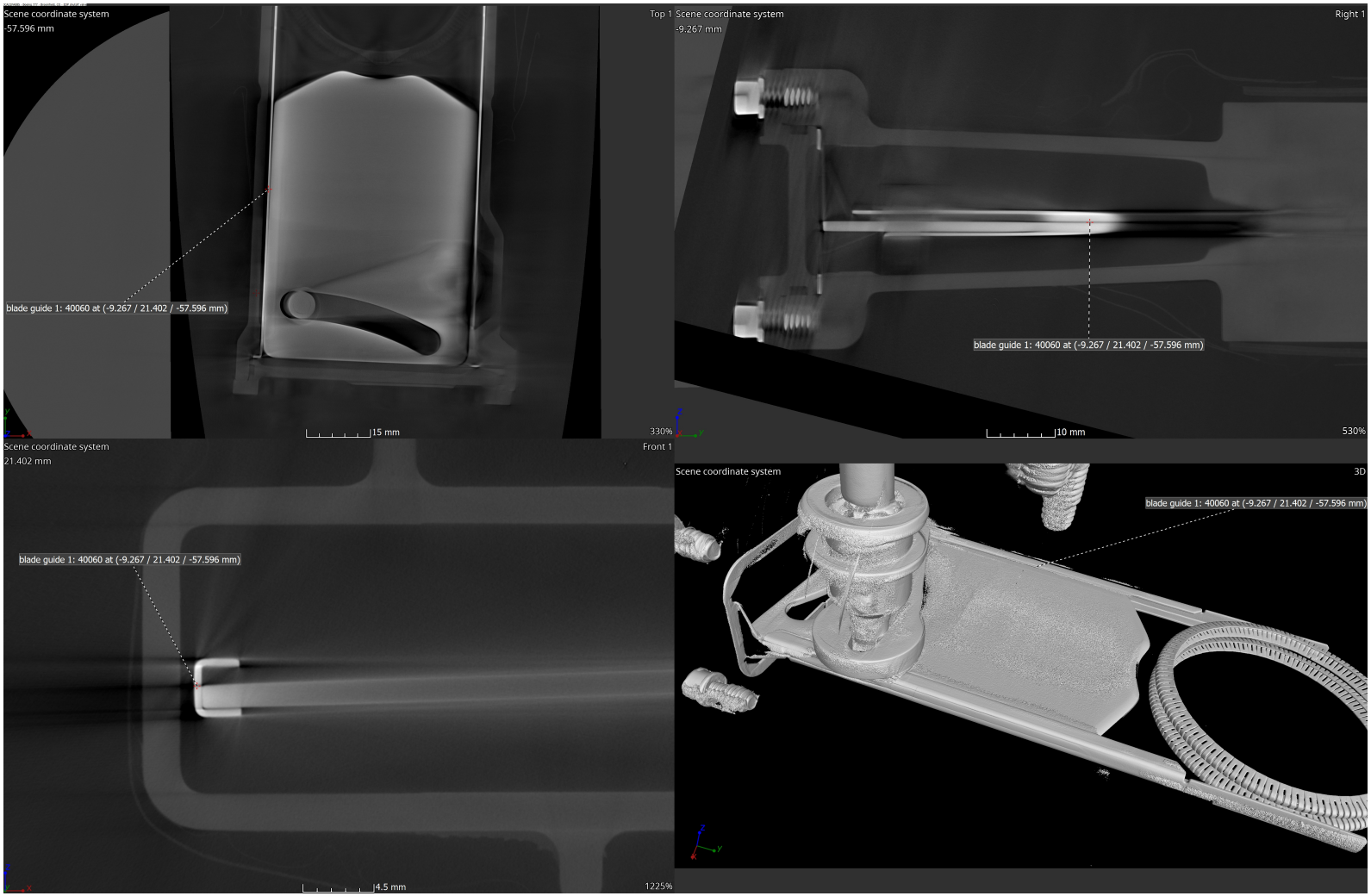


Figure 19
EDP supply shutoff valve – blade guide 1

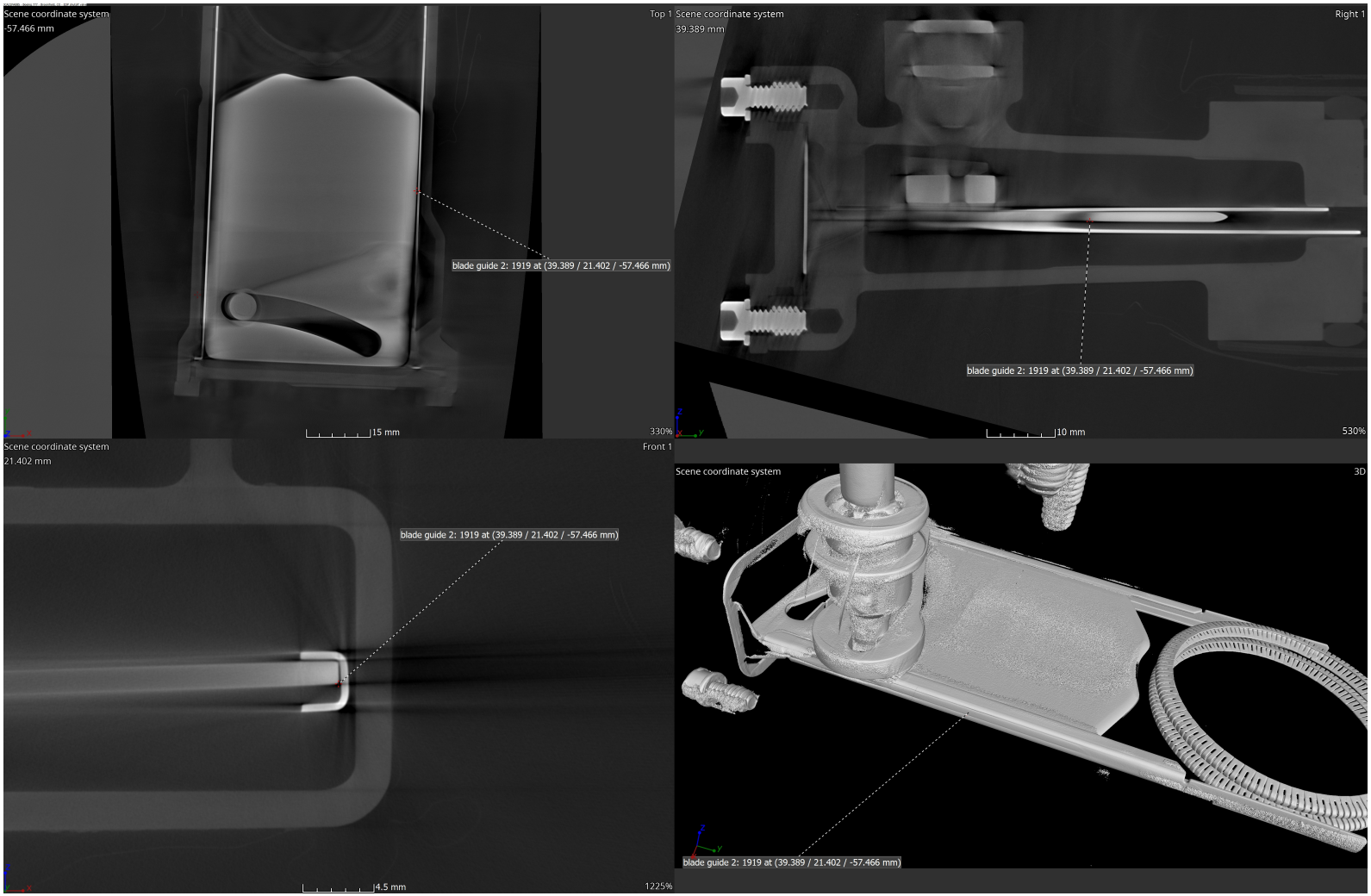


Figure 20
EDP supply shutoff valve – blade guide 2

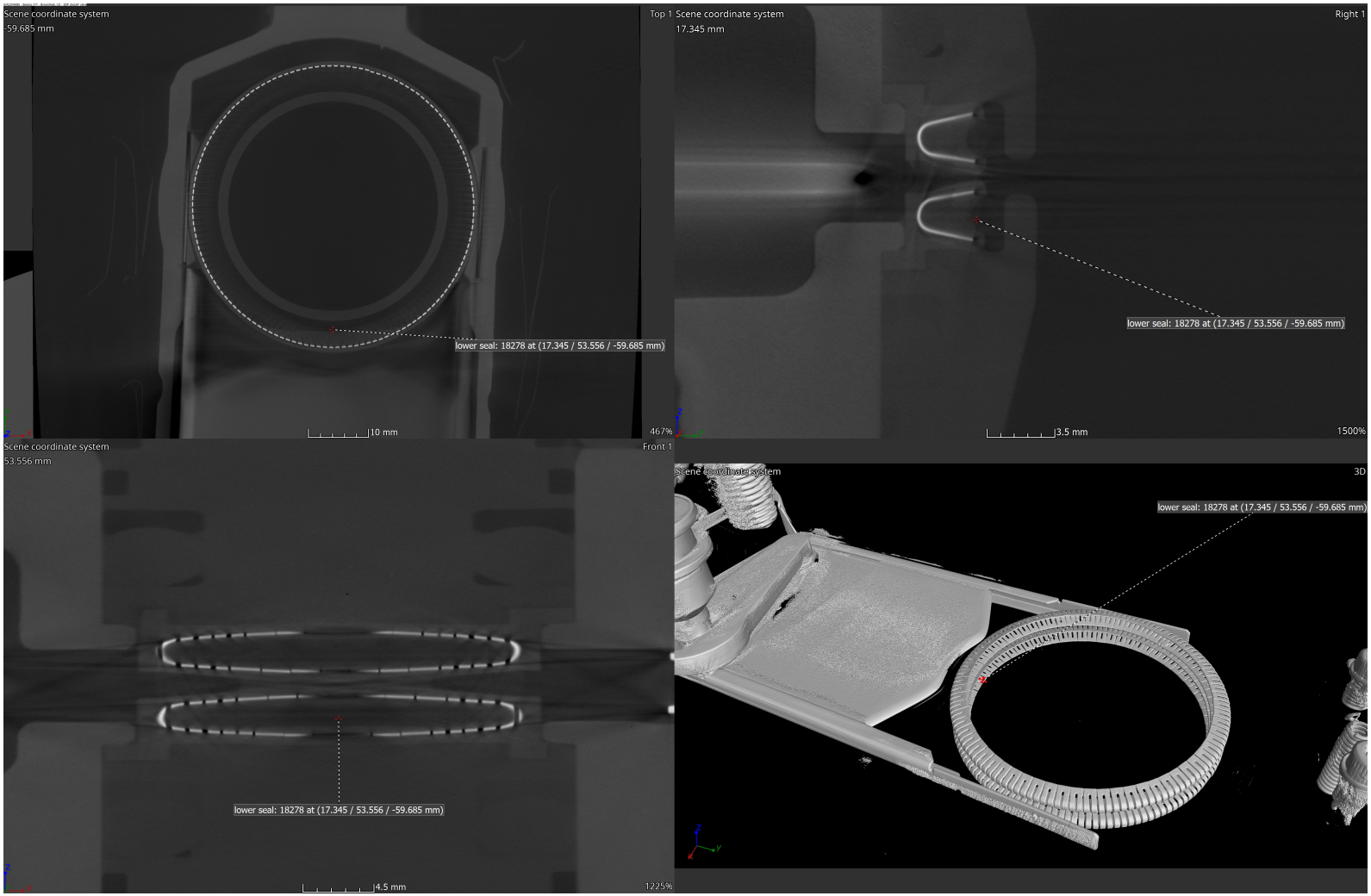


Figure 21
EDP supply shutoff valve – lower seal

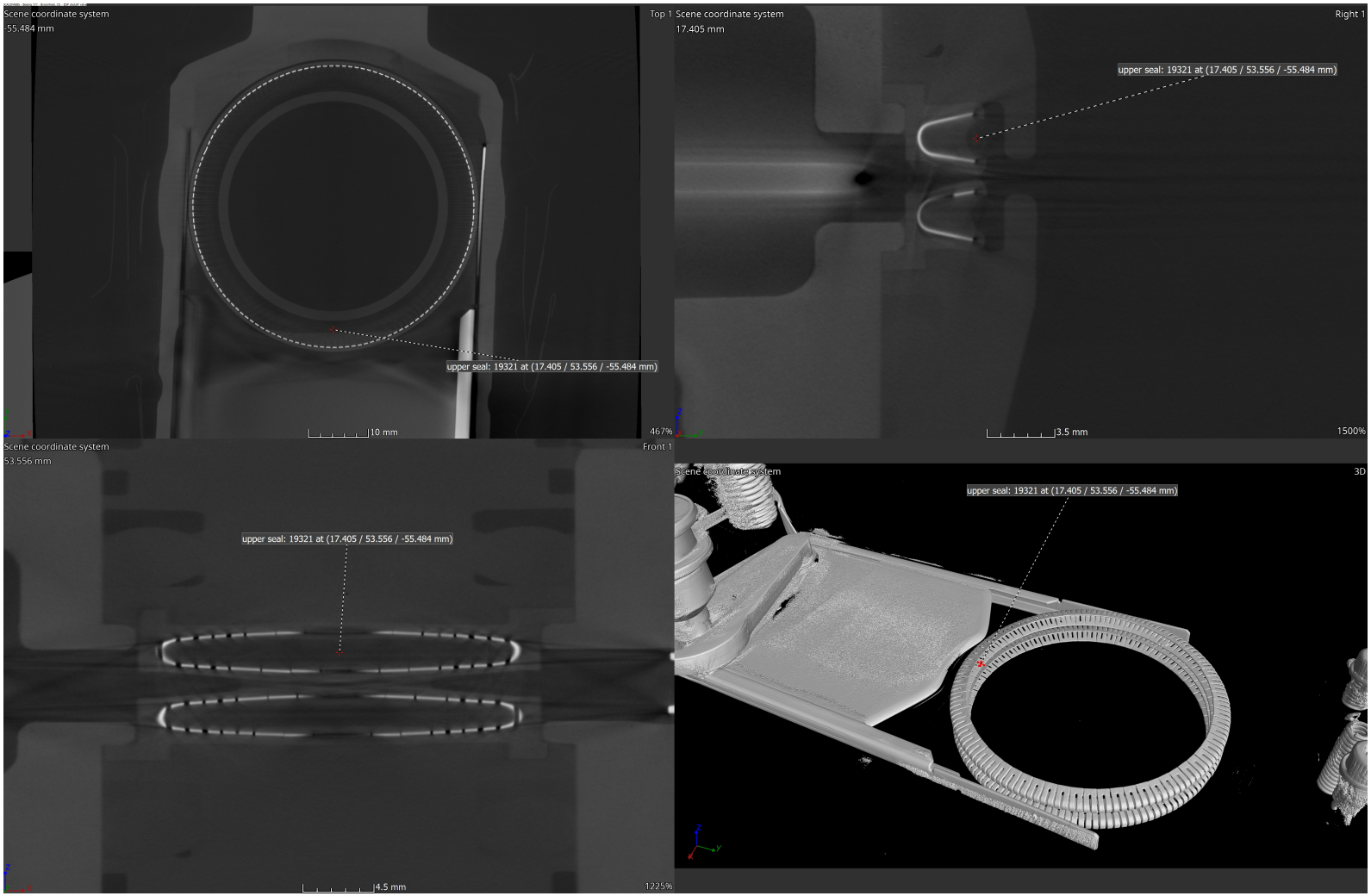


Figure 22
EDP supply shutoff valve – upper seal

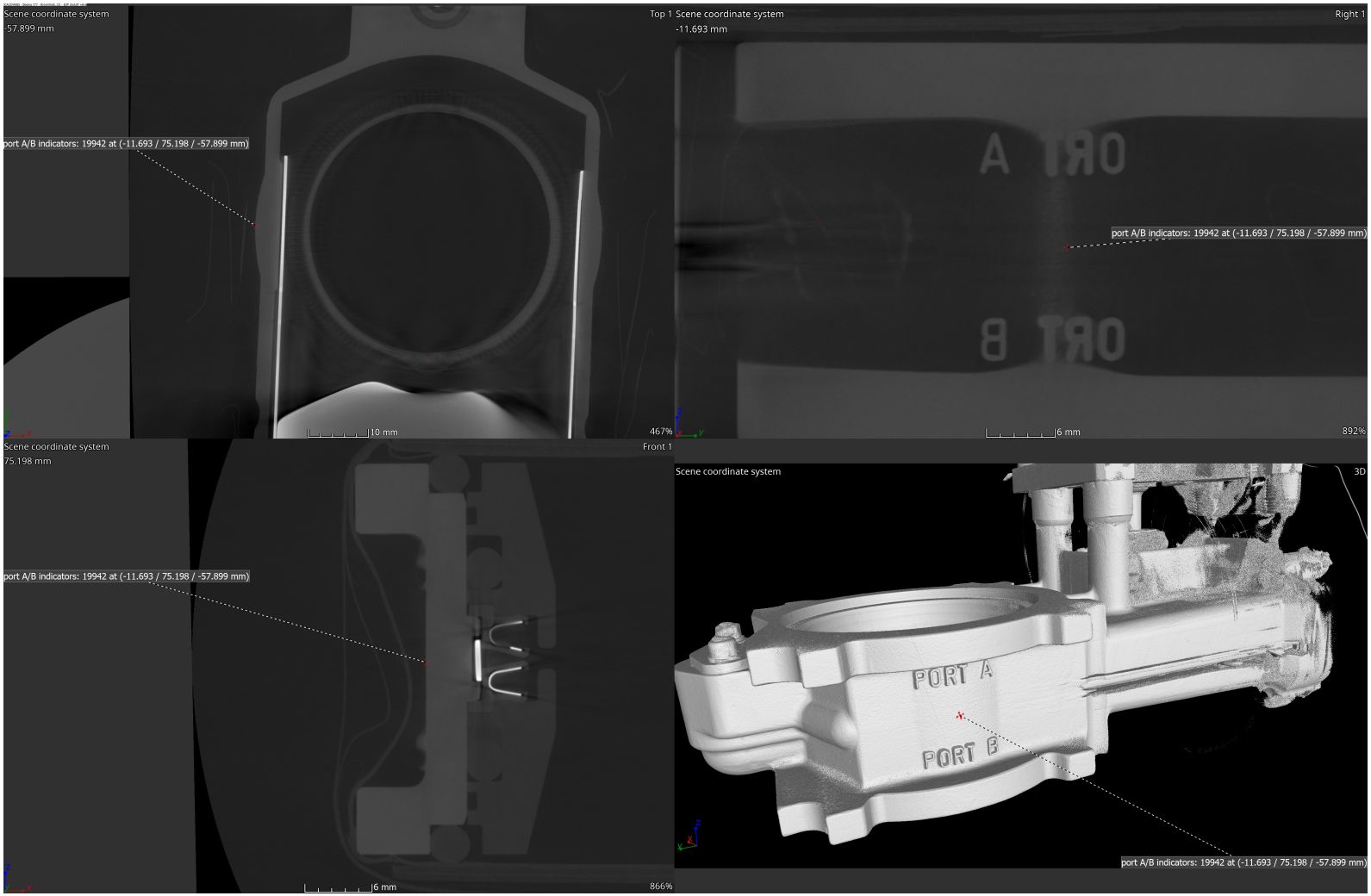


Figure 23
EDP supply shutoff valve – port A/B indicators

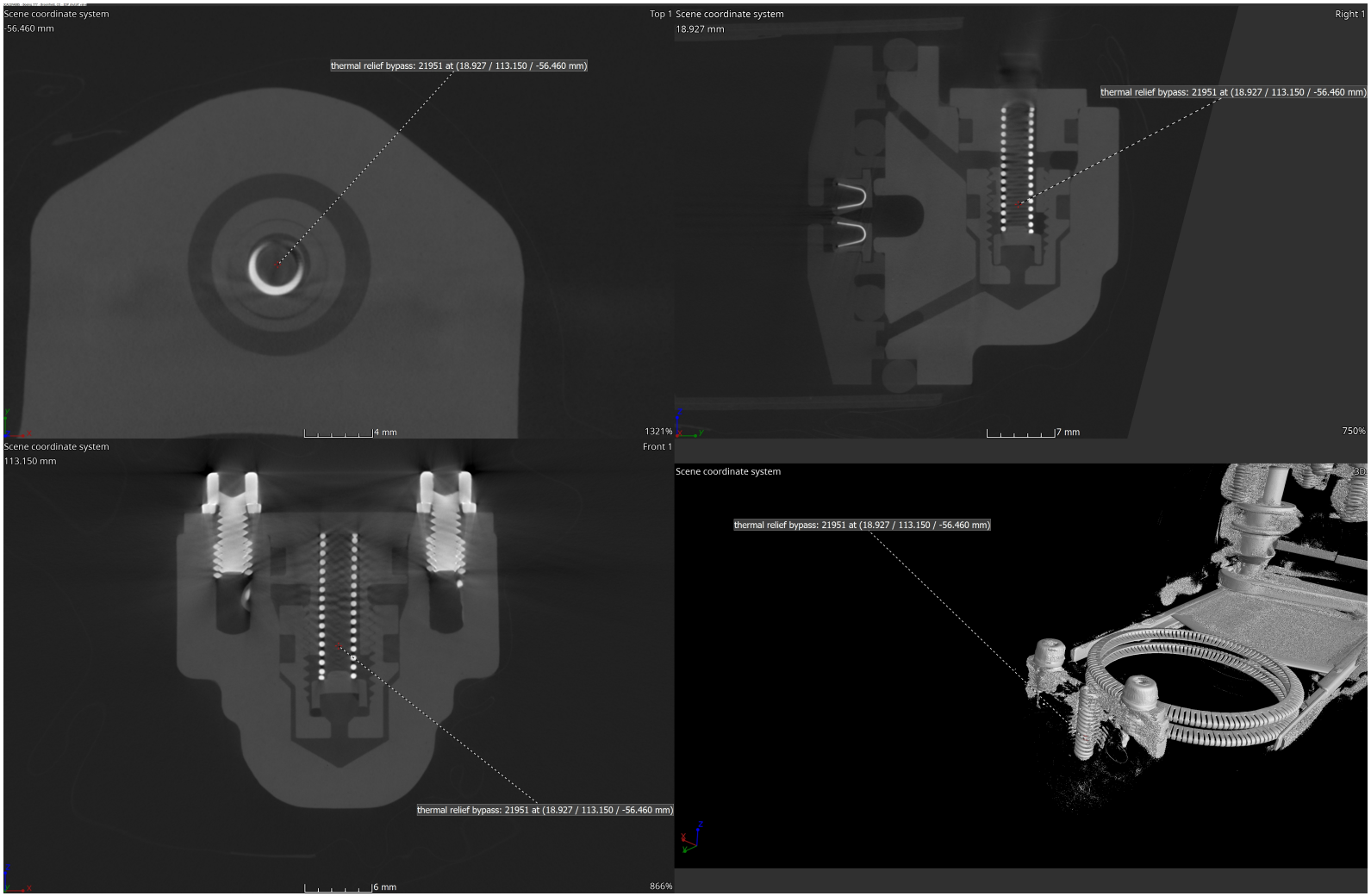


Figure 24
EDP supply shutoff valve – thermal relief bypass

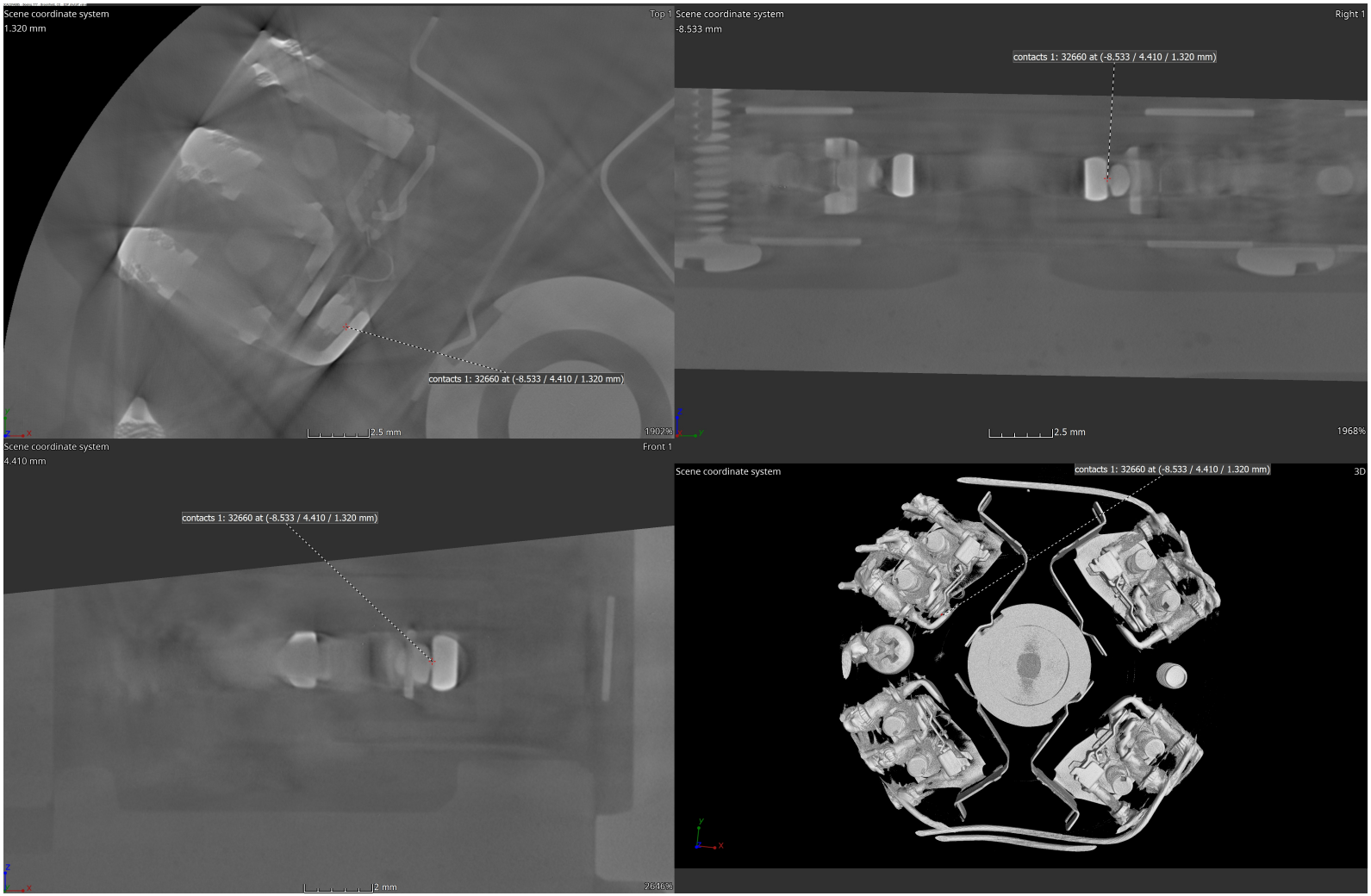


Figure 25
EDP supply shutoff valve – microswitches – contacts 1

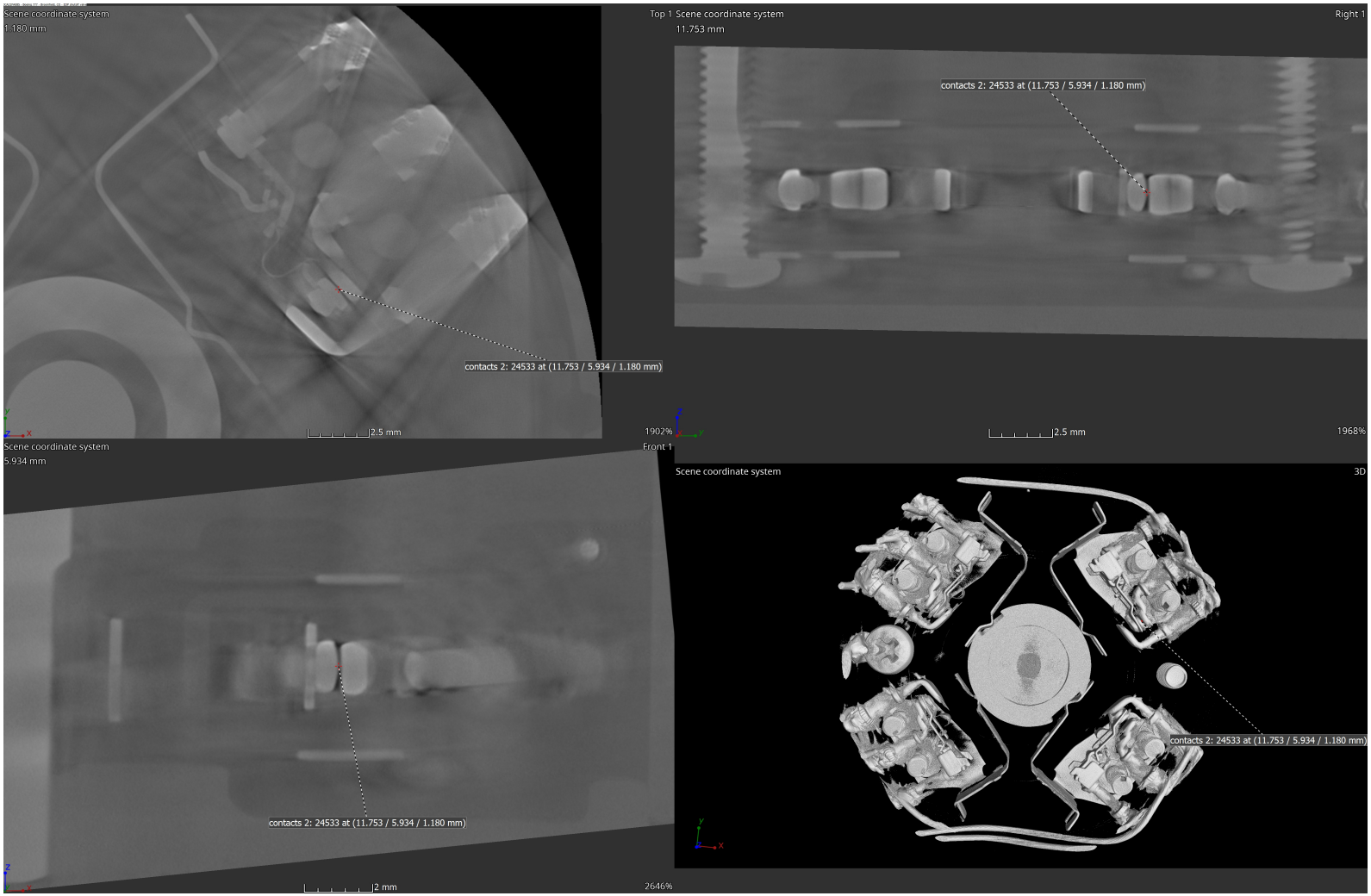


Figure 26
EDP supply shutoff valve – microswitches – contacts 2

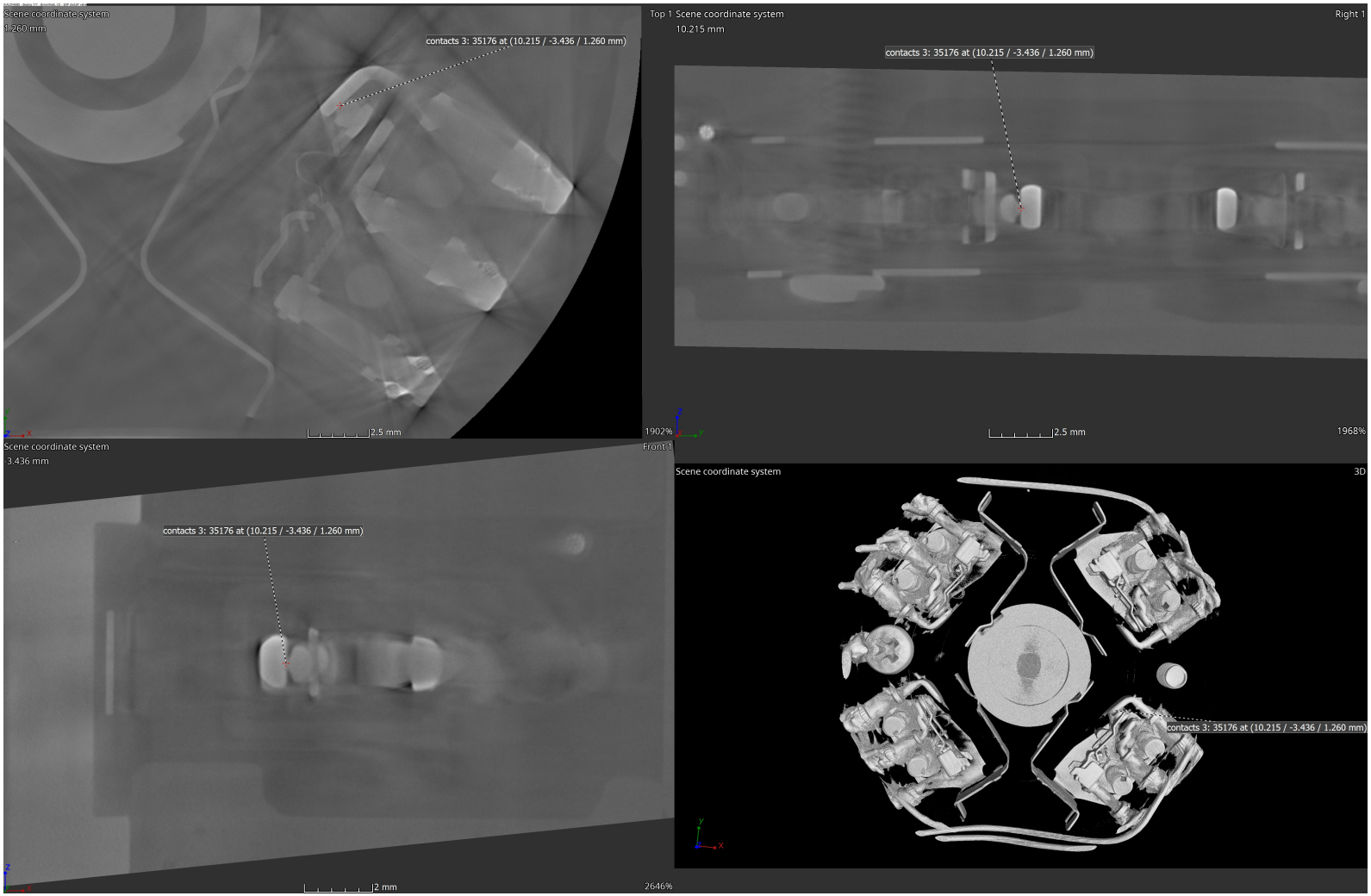


Figure 27
EDP supply shutoff valve – microswitches – contacts 3

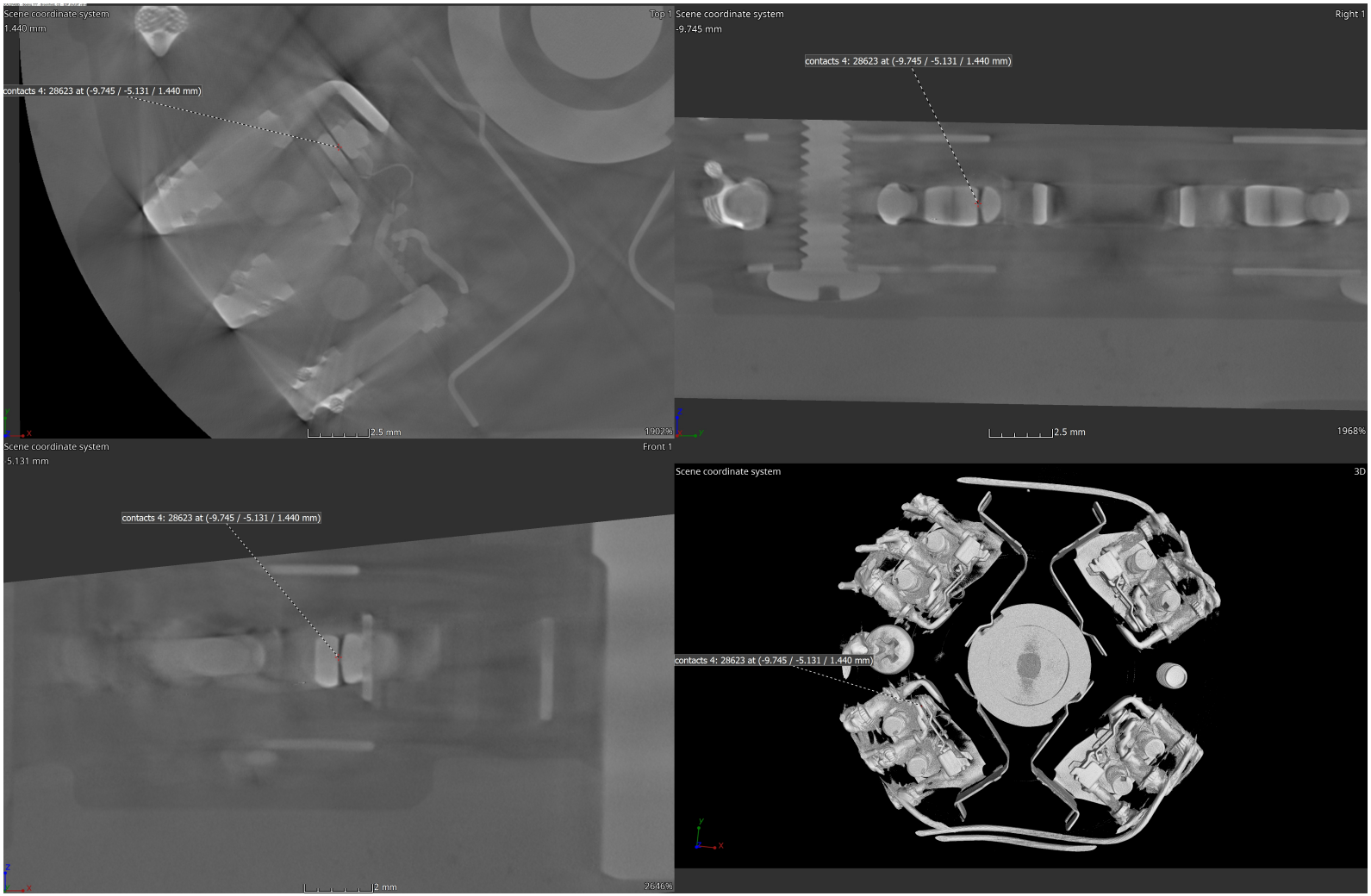


Figure 28
EDP supply shutoff valve – microswitches – contacts 4

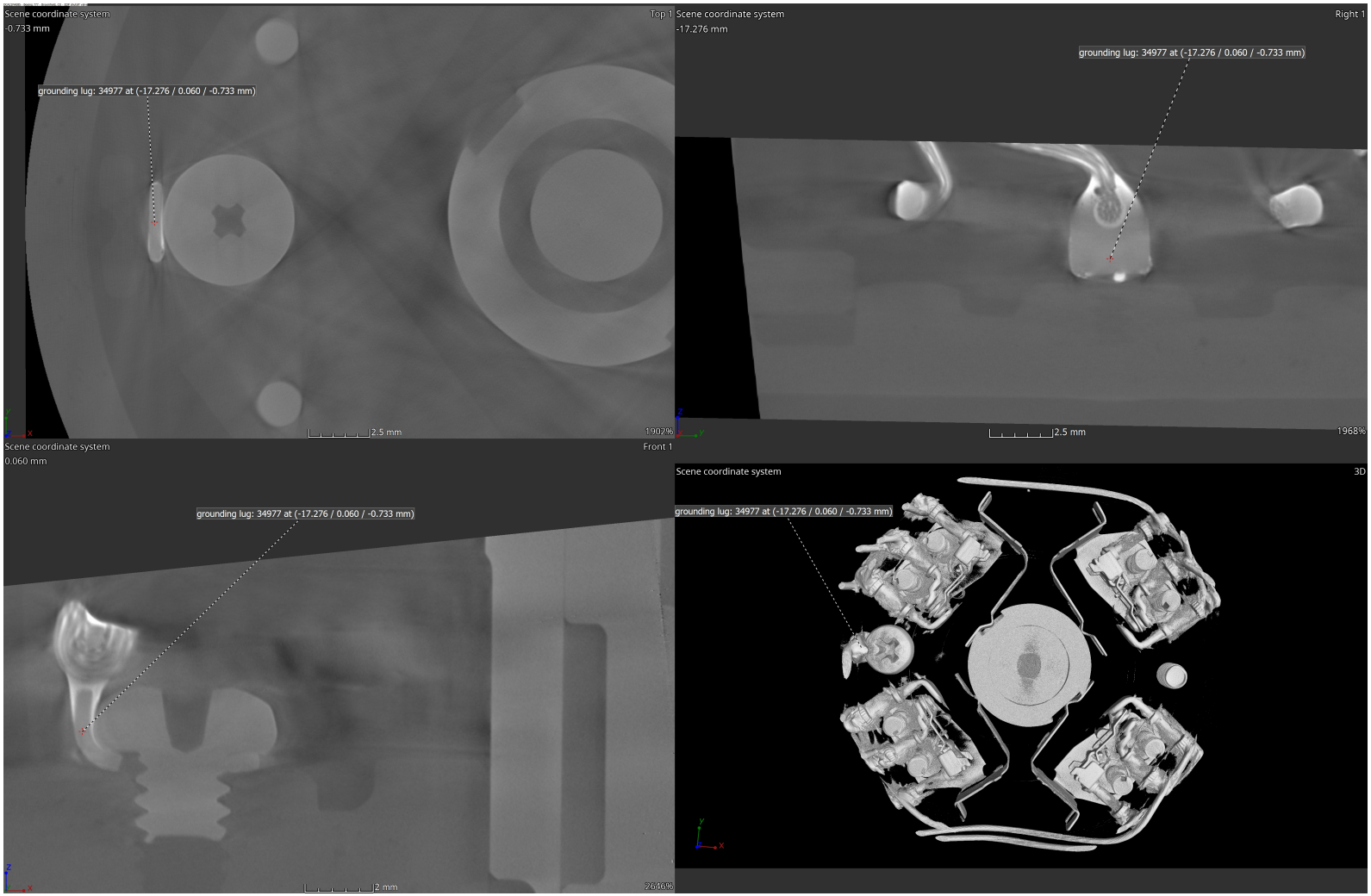


Figure 29
EDP supply shutoff valve – microswitches – grounding lug

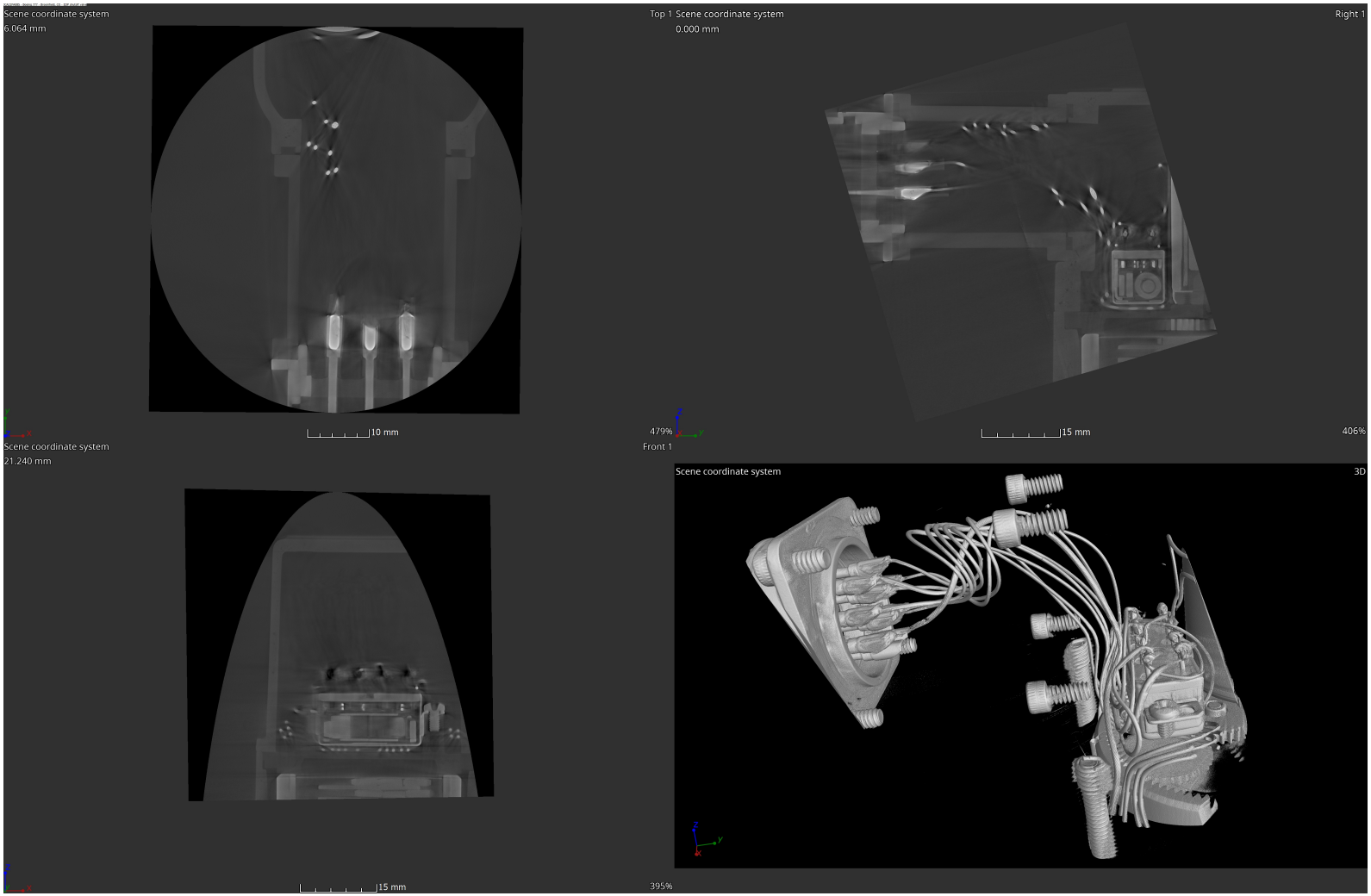


Figure 30
EDP supply shutoff valve – connector wires and relay – overview

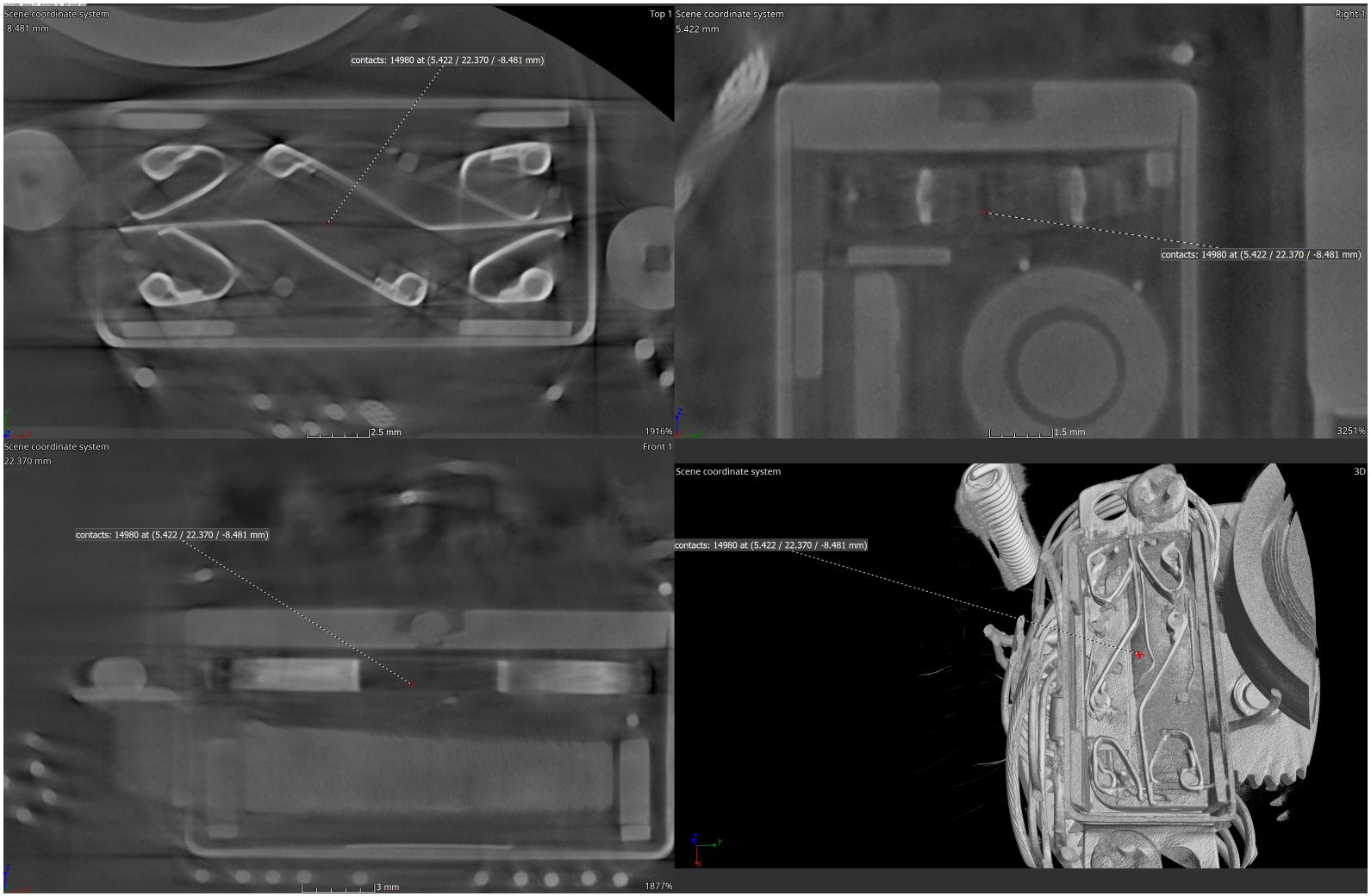


Figure 31
EDP supply shutoff valve – relay contacts

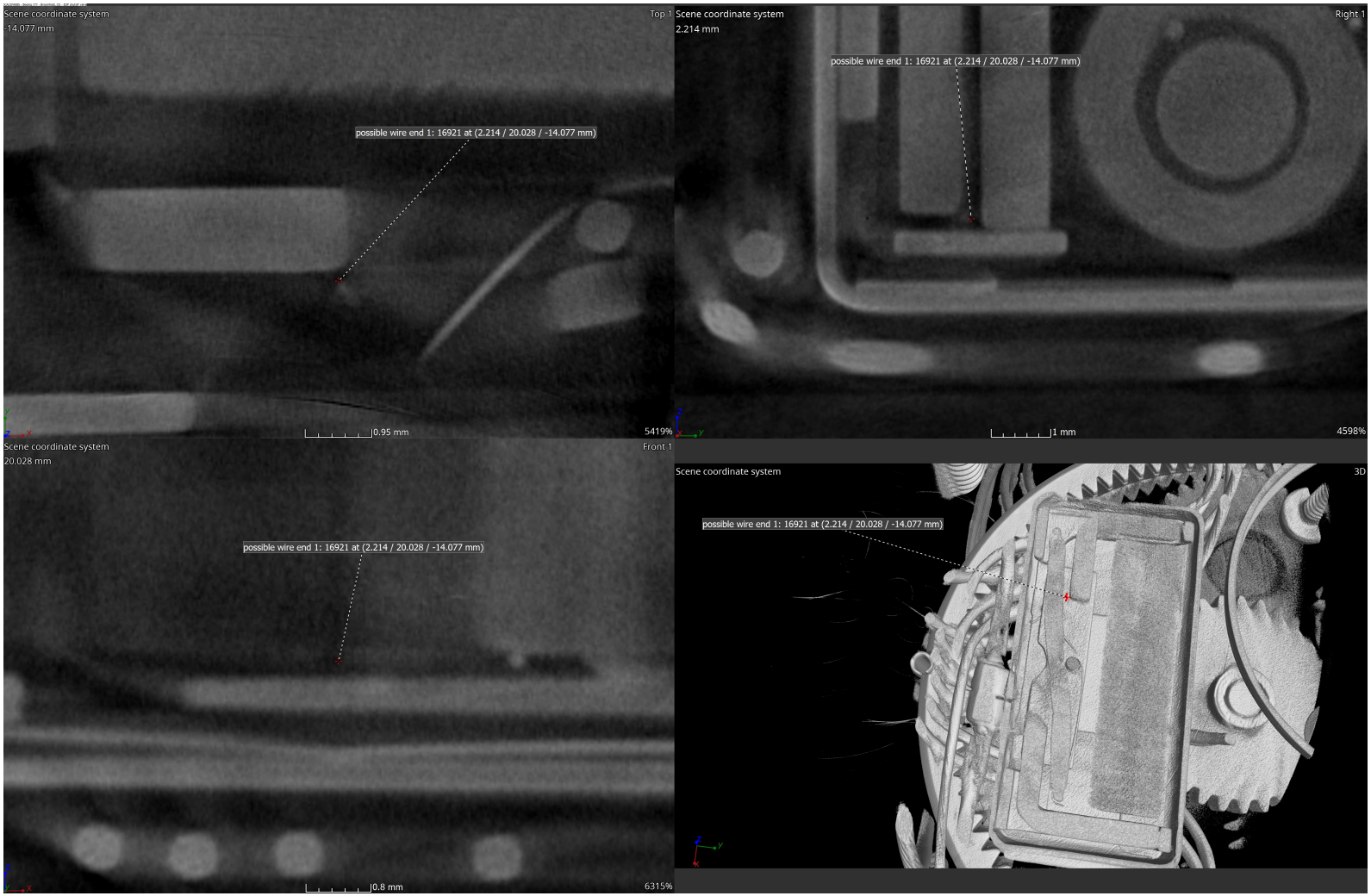


Figure 32
EDP supply shutoff valve – relay – possible wire end 1

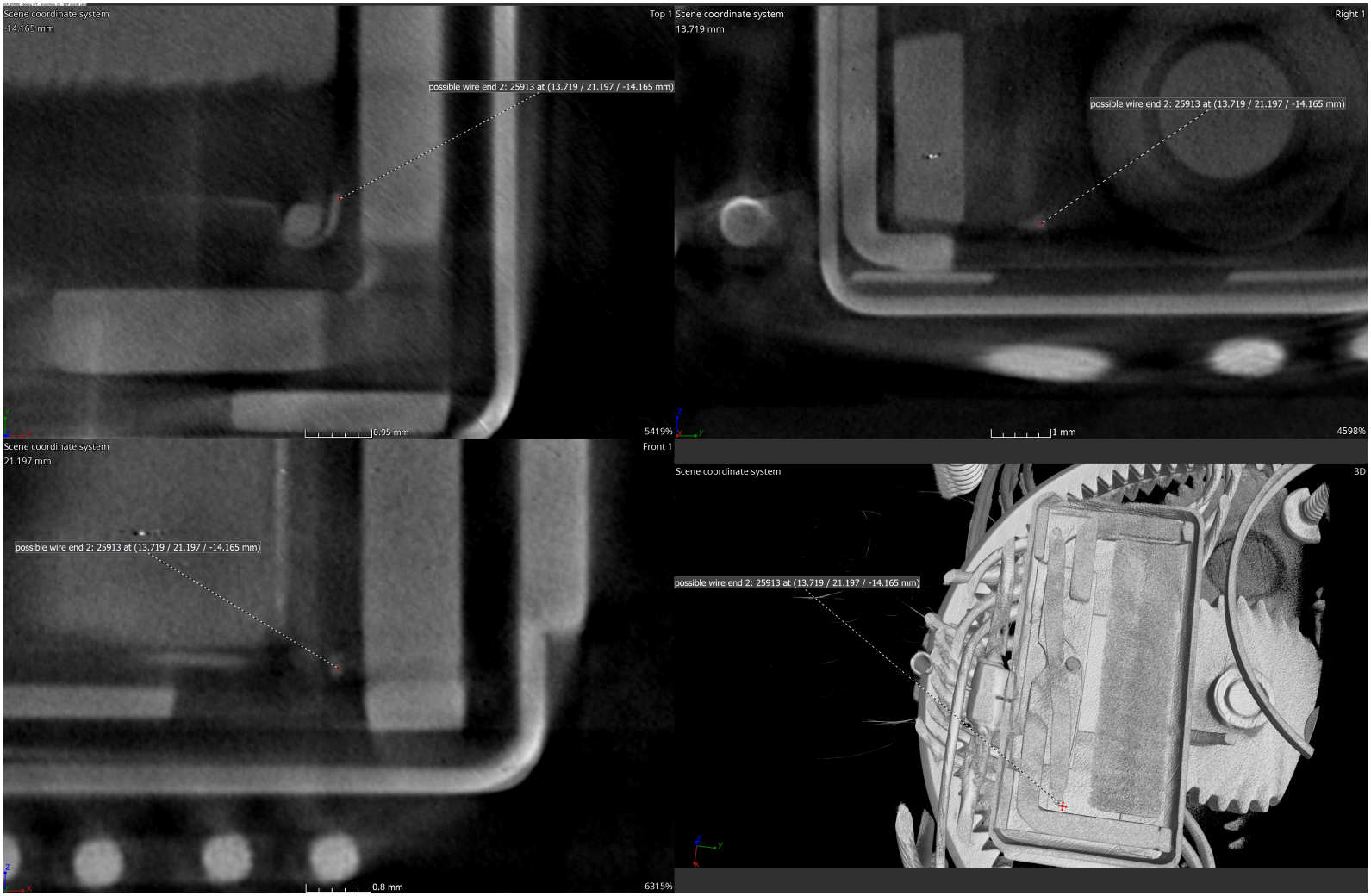


Figure 33
EDP supply shutoff valve – relay – possible wire end 2

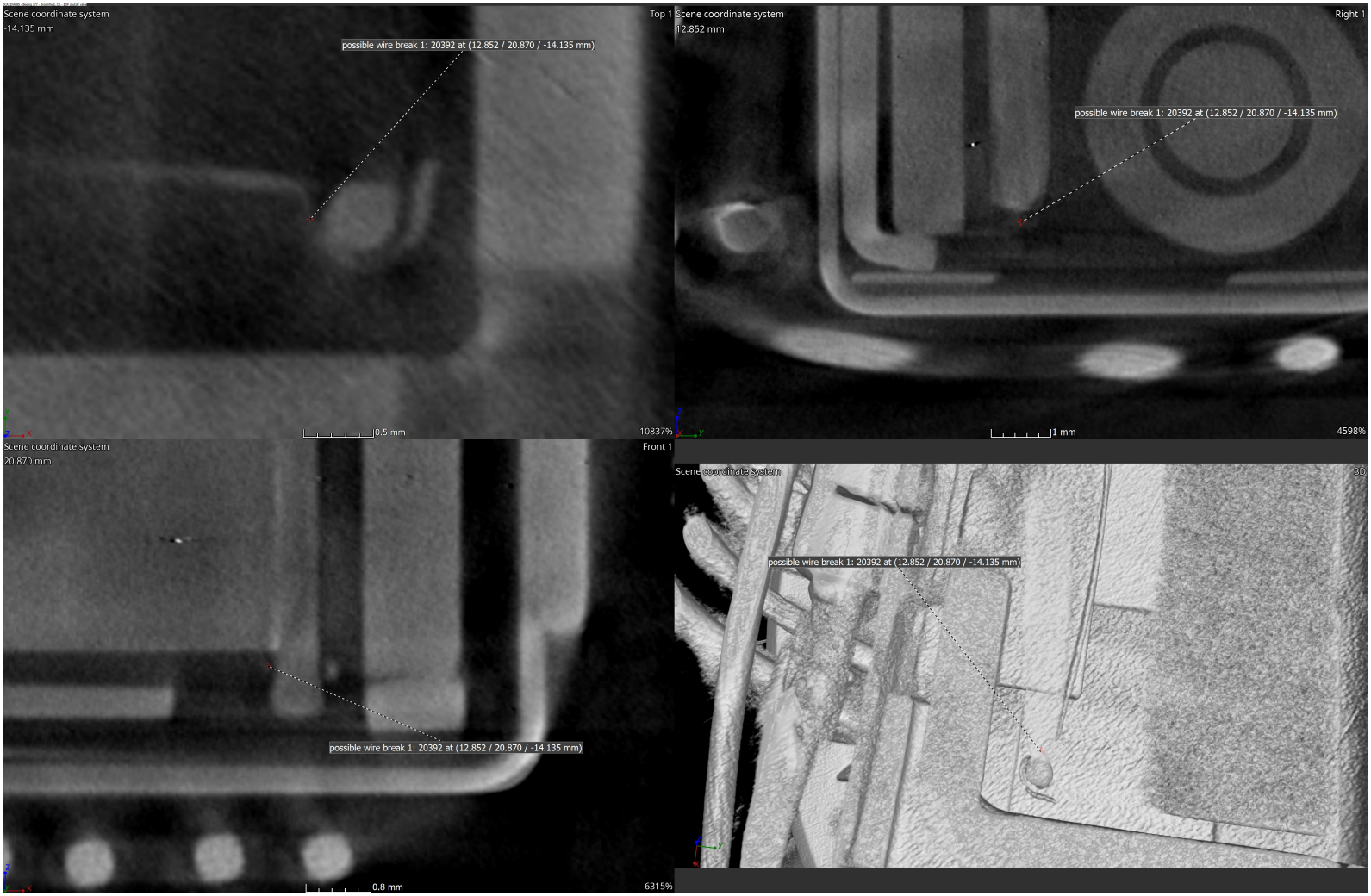


Figure 34
EDP supply shutoff valve – relay – possible wire break 1

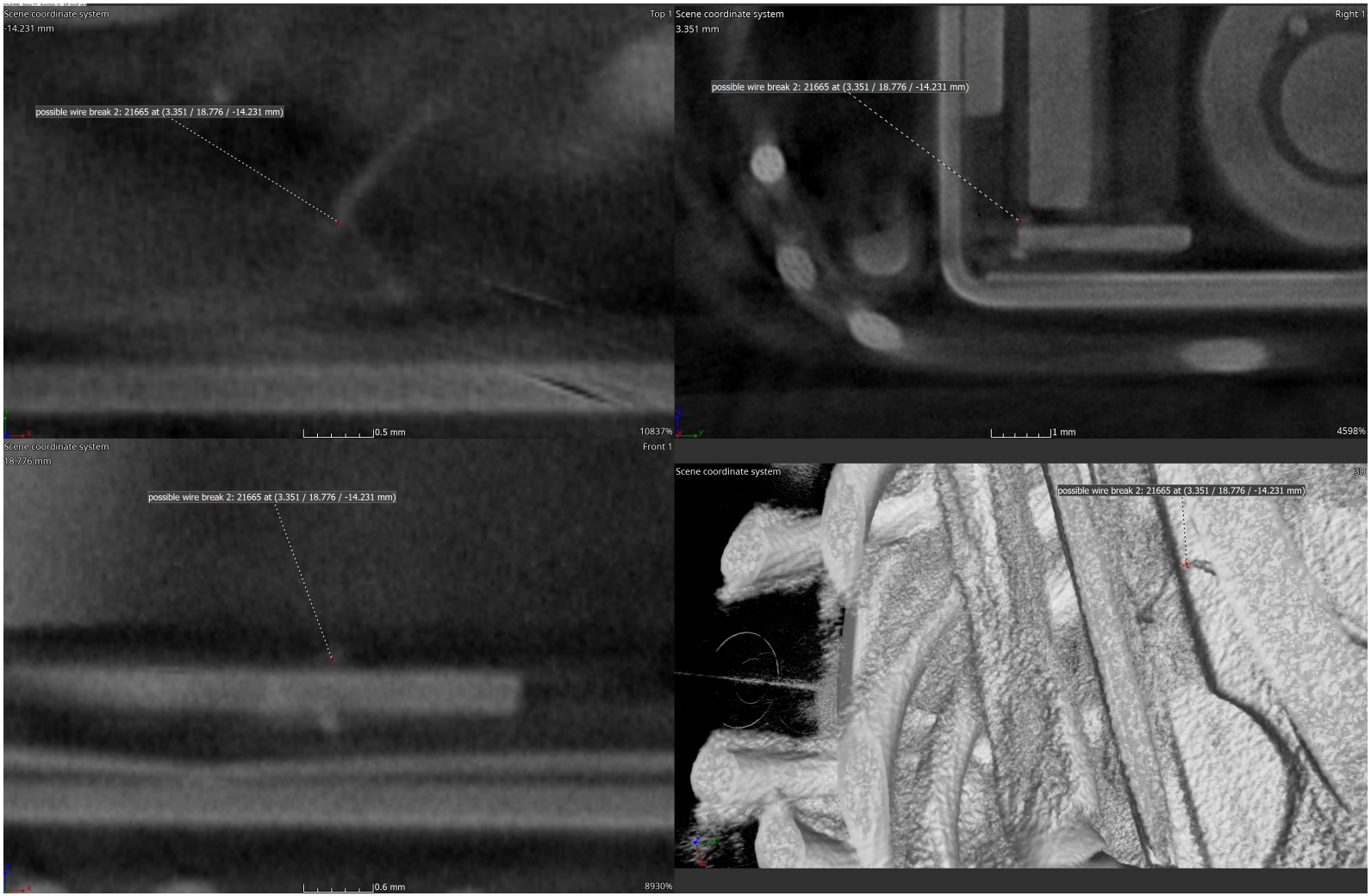


Figure 35
EDP supply shutoff valve – relay – possible wire break 2

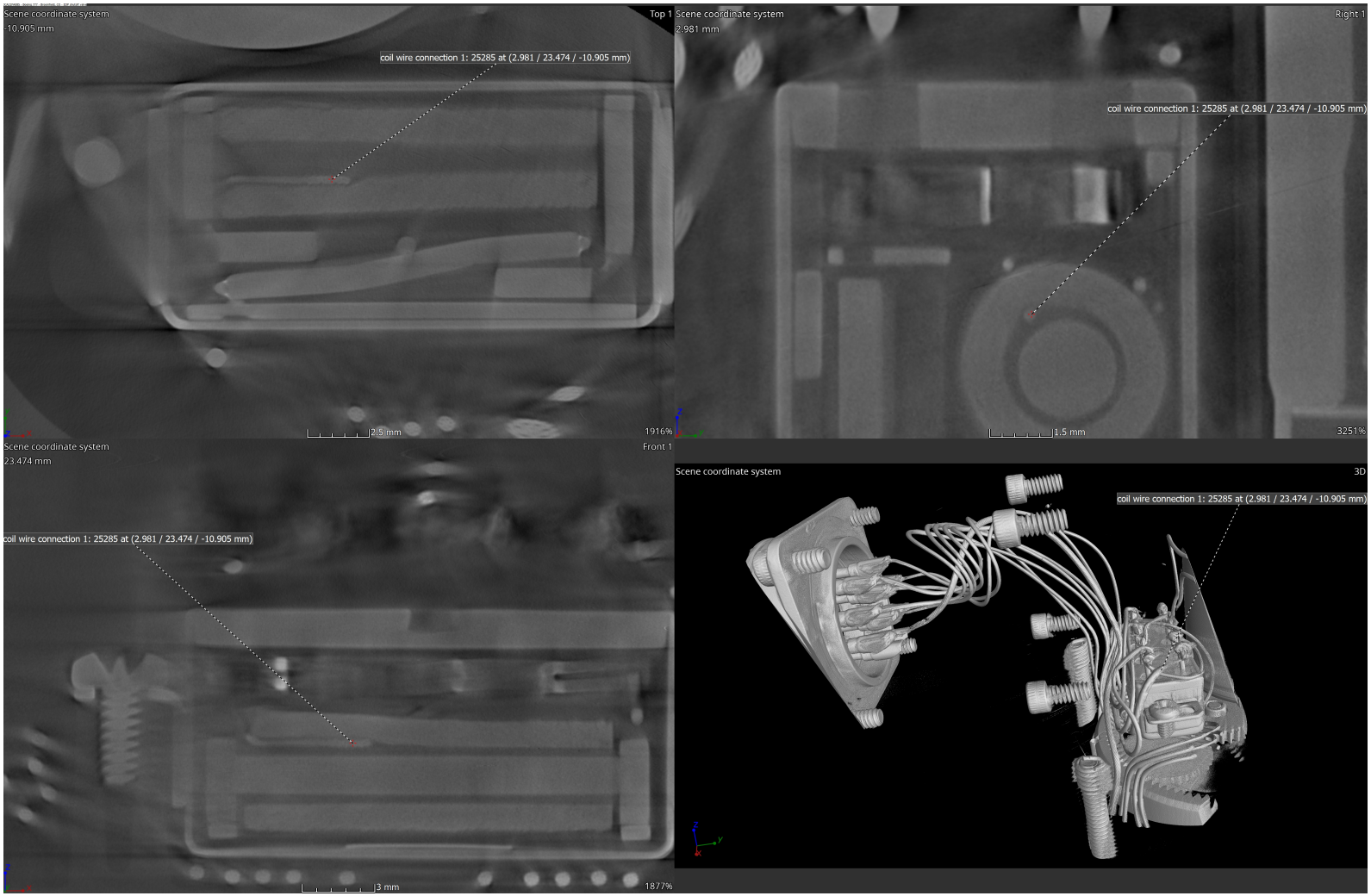


Figure 36
EDP supply shutoff valve – relay – coil wire connection 1

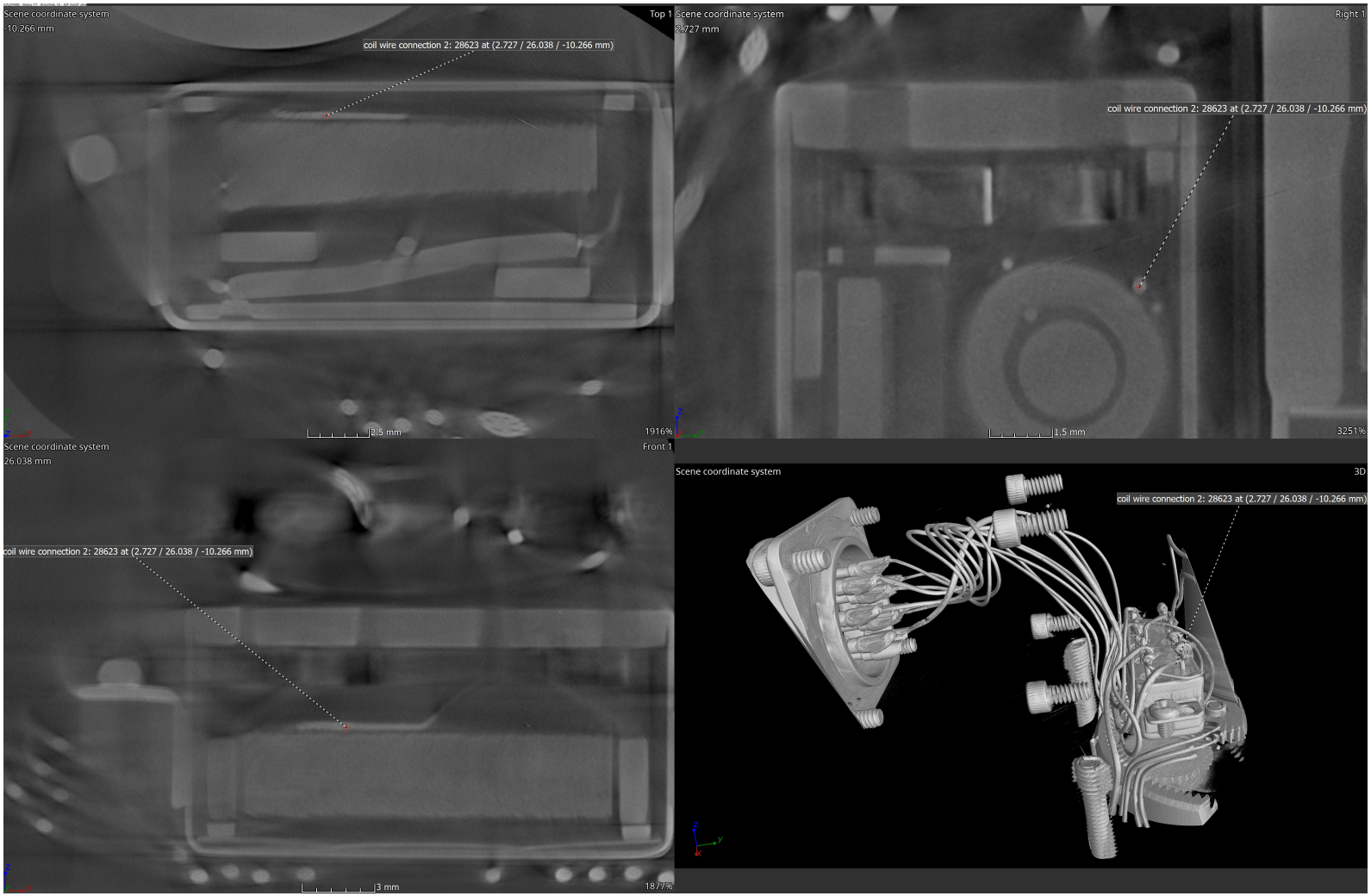


Figure 37
EDP supply shutoff valve – relay – coil wire connection 2

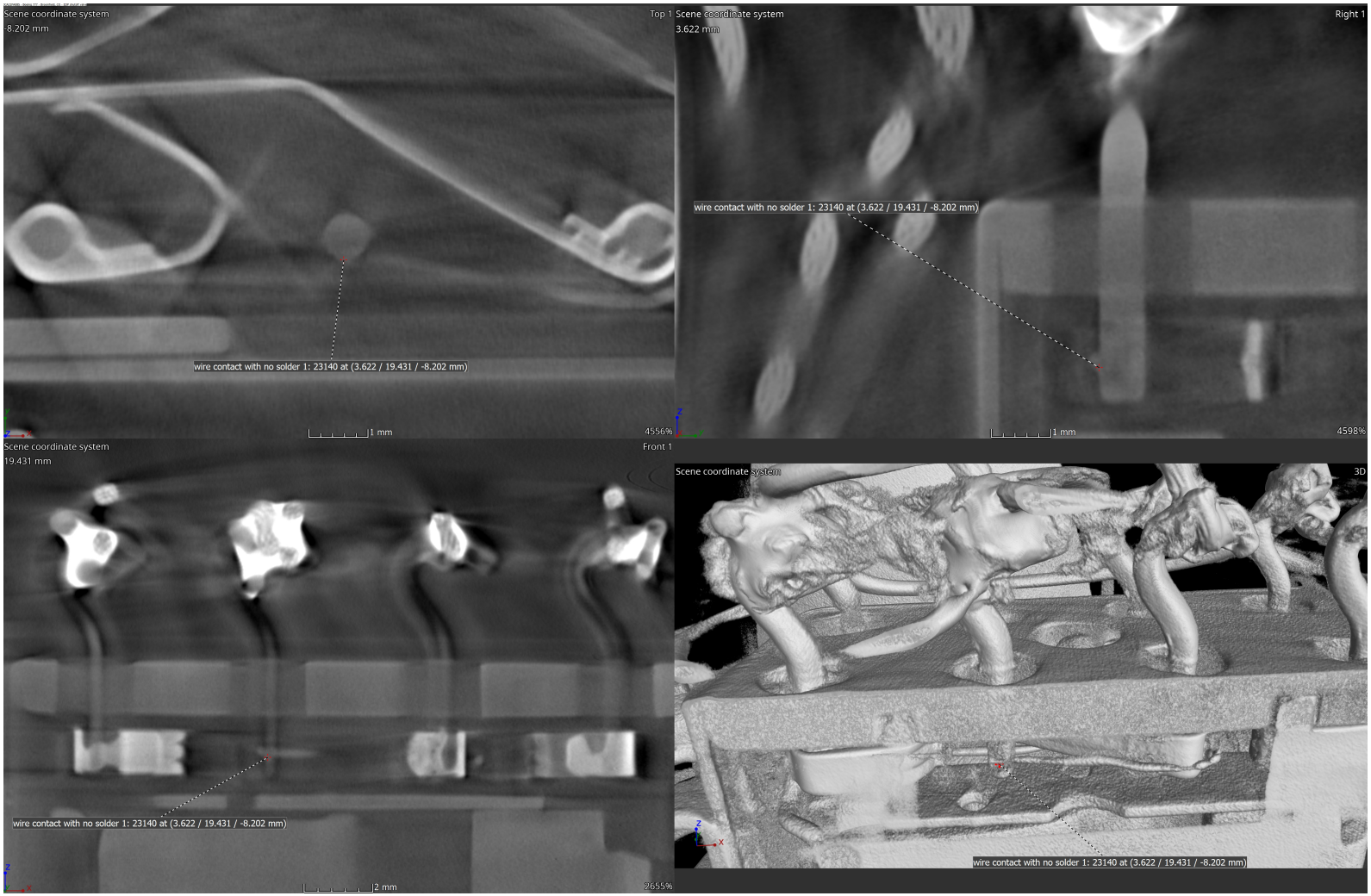


Figure 38
EDP supply shutoff valve – relay – wire contact with no solder 1



Figure 39
EDP supply shutoff valve – relay – wire contact with no solder 2

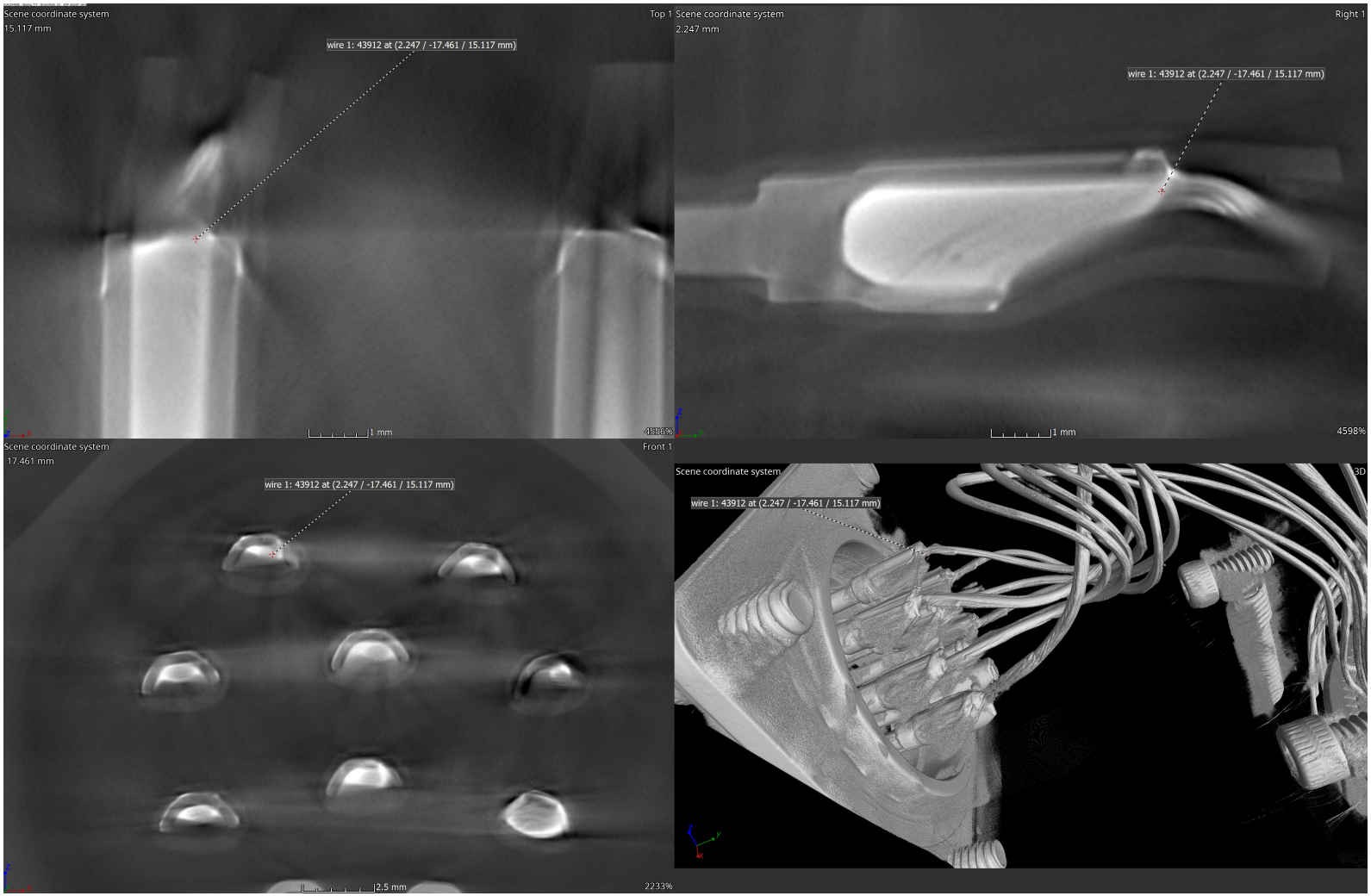


Figure 40
EDP supply shutoff valve – connector – wire 1

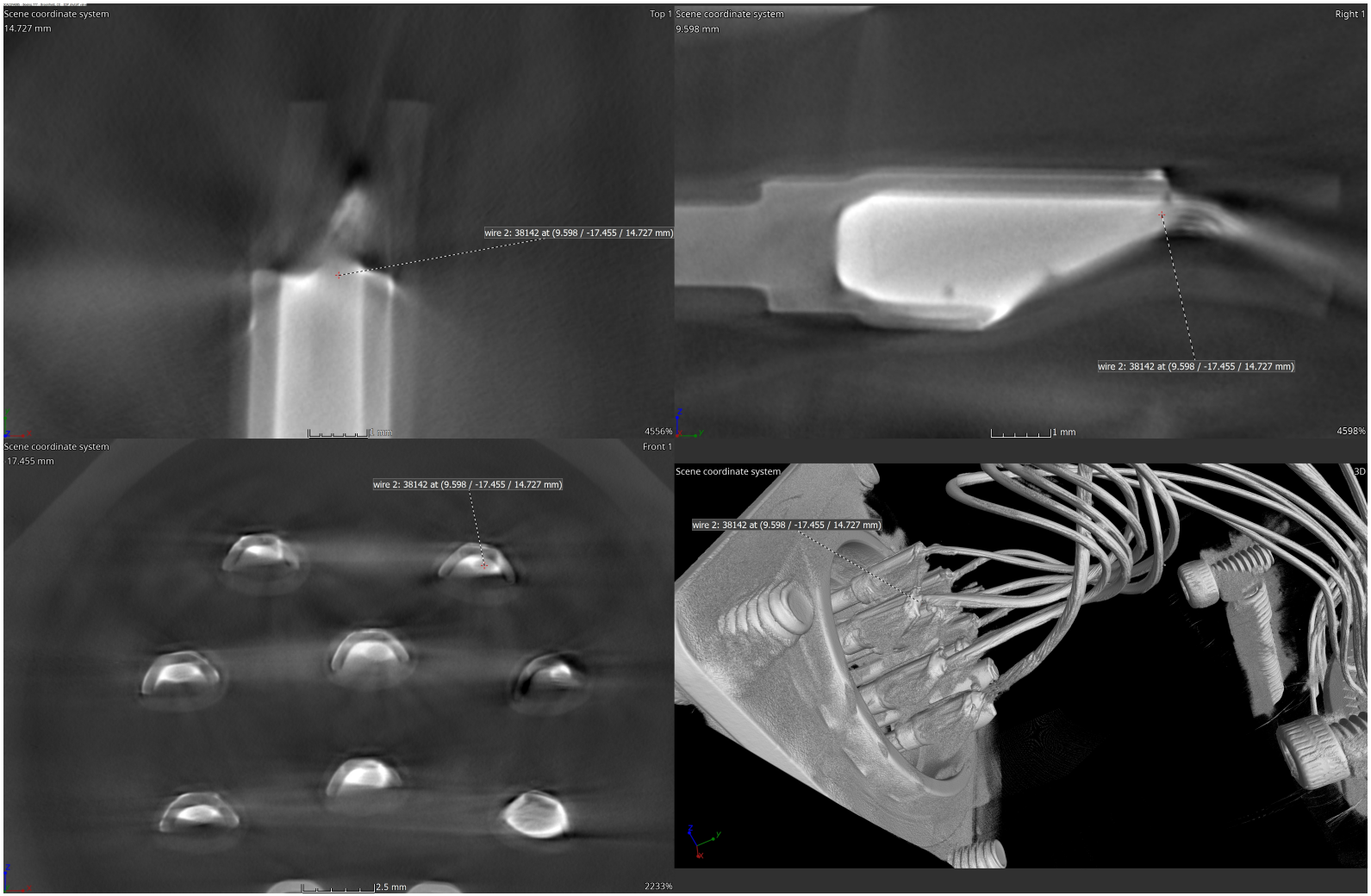


Figure 41
EDP supply shutoff valve – connector – wire 2

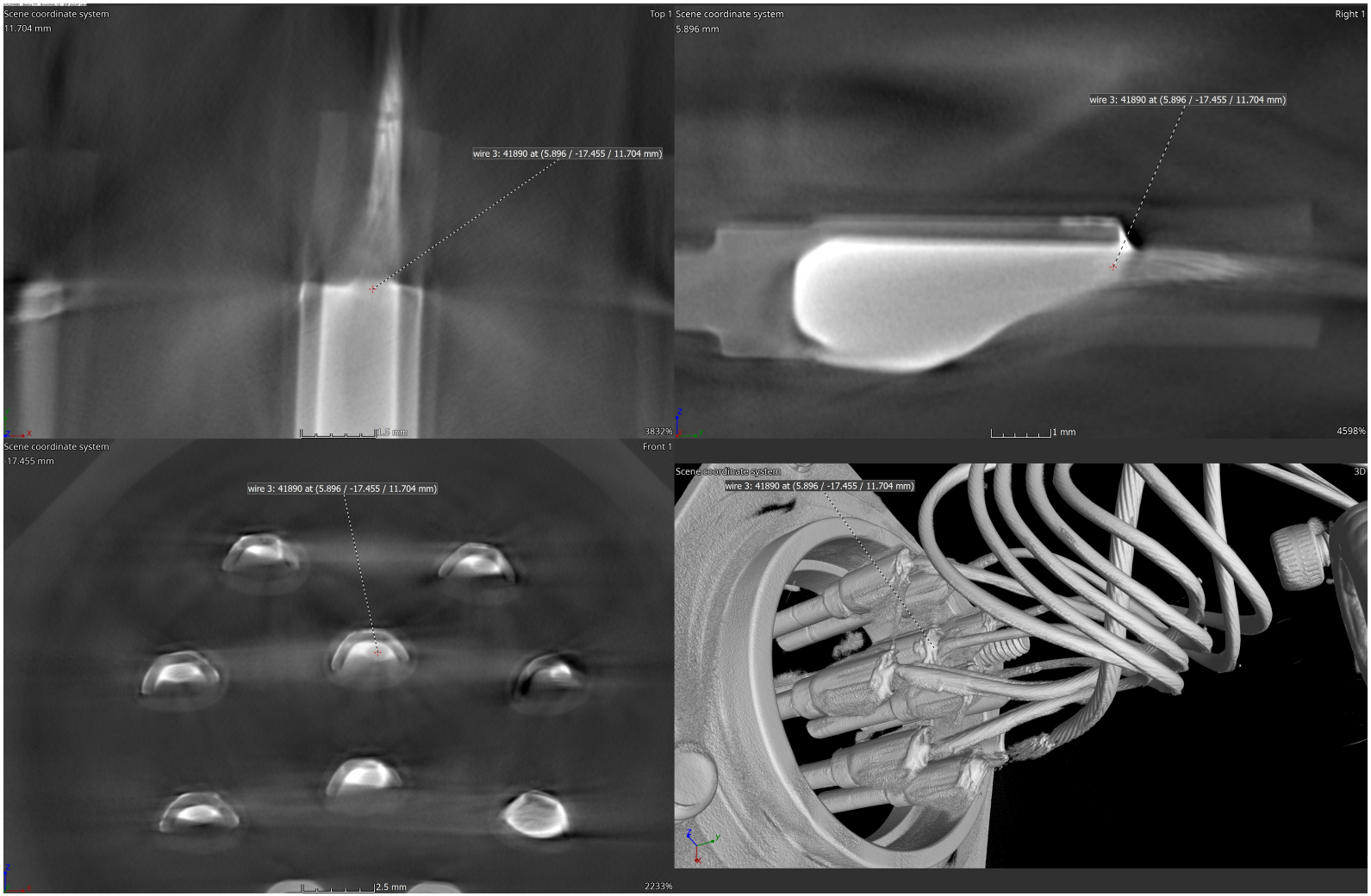


Figure 42
EDP supply shutoff valve – connector – wire 3

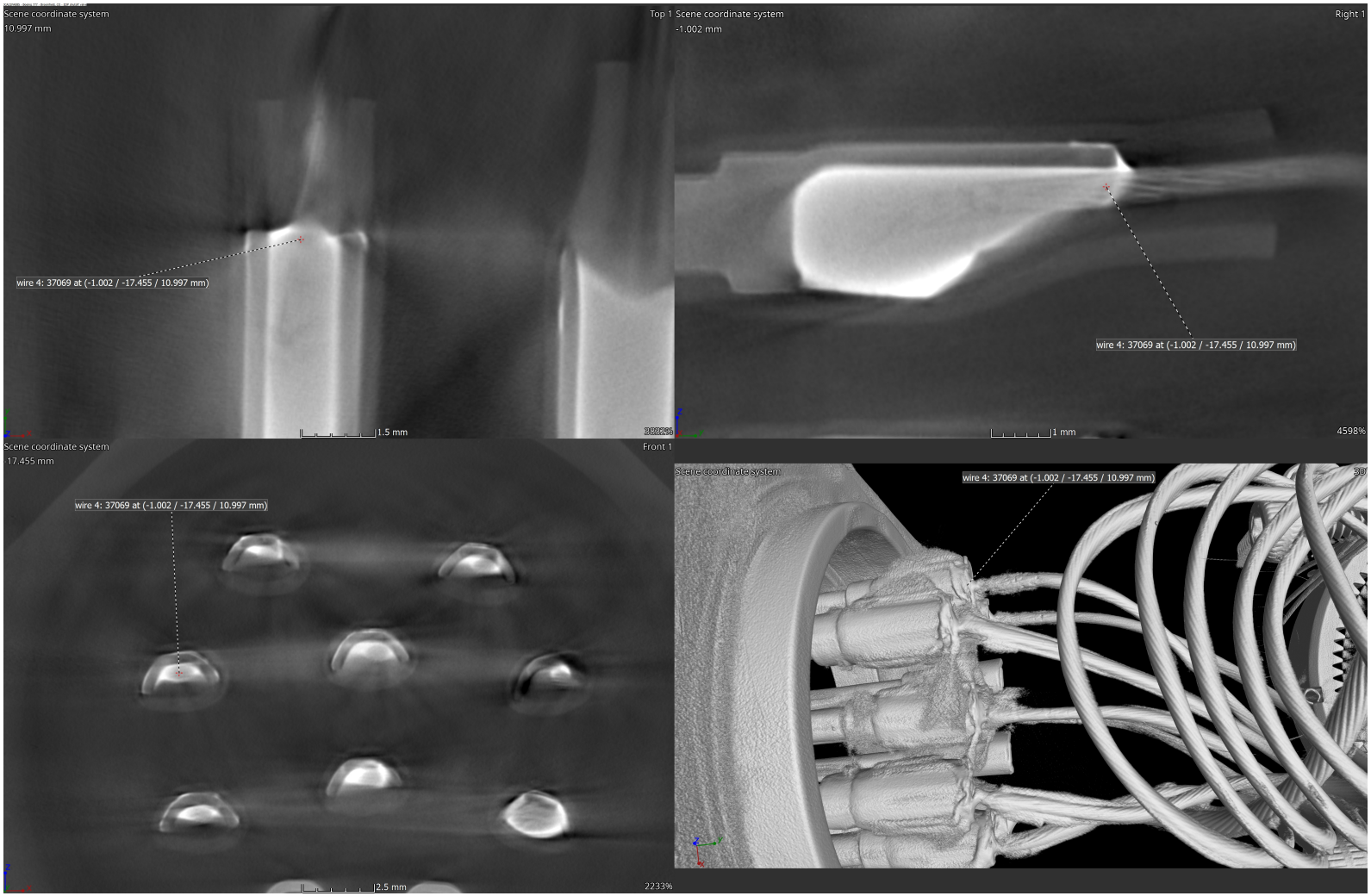


Figure 43
EDP supply shutoff valve – connector – wire 4

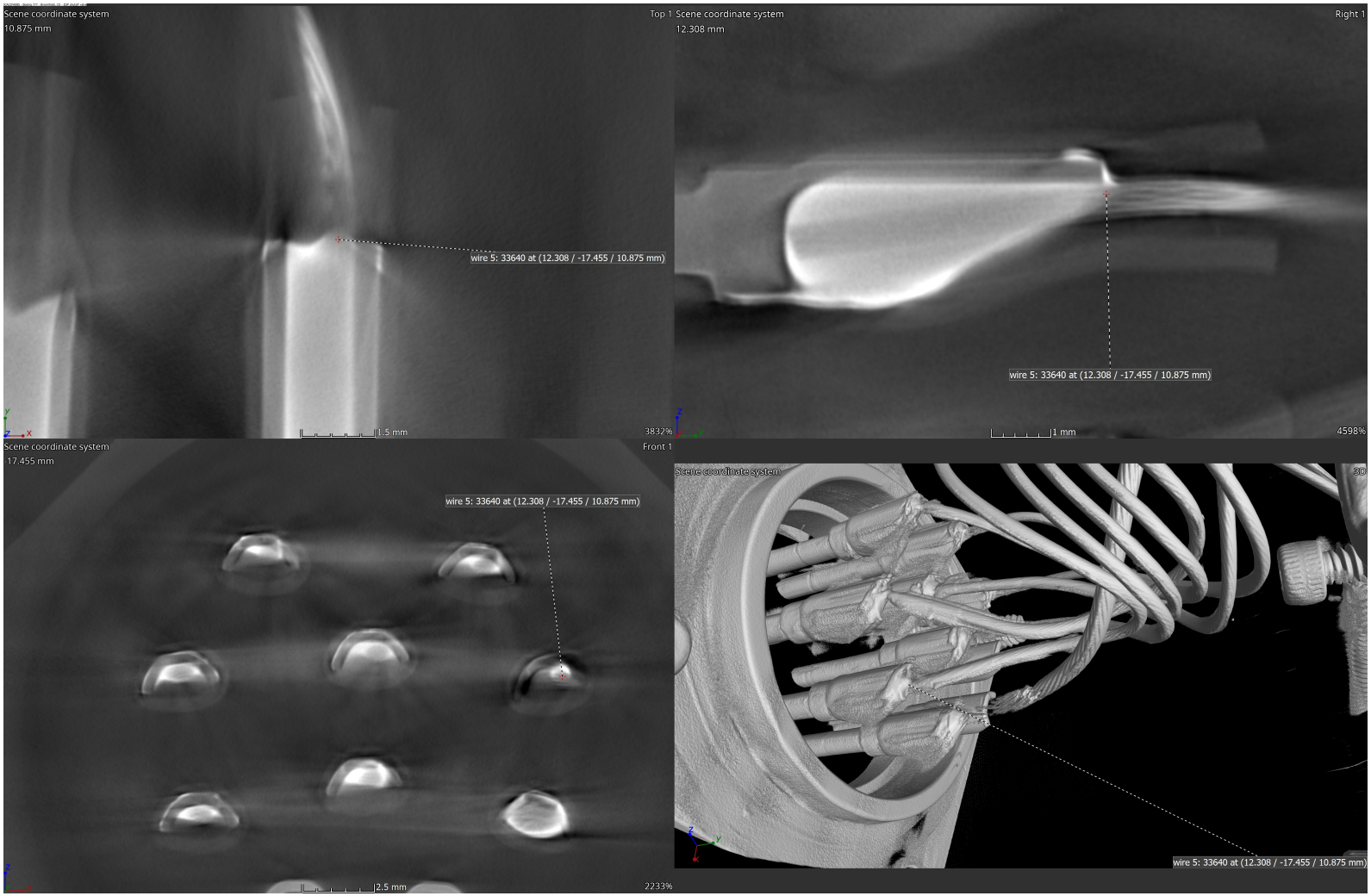


Figure 44
EDP supply shutoff valve – connector – wire 5

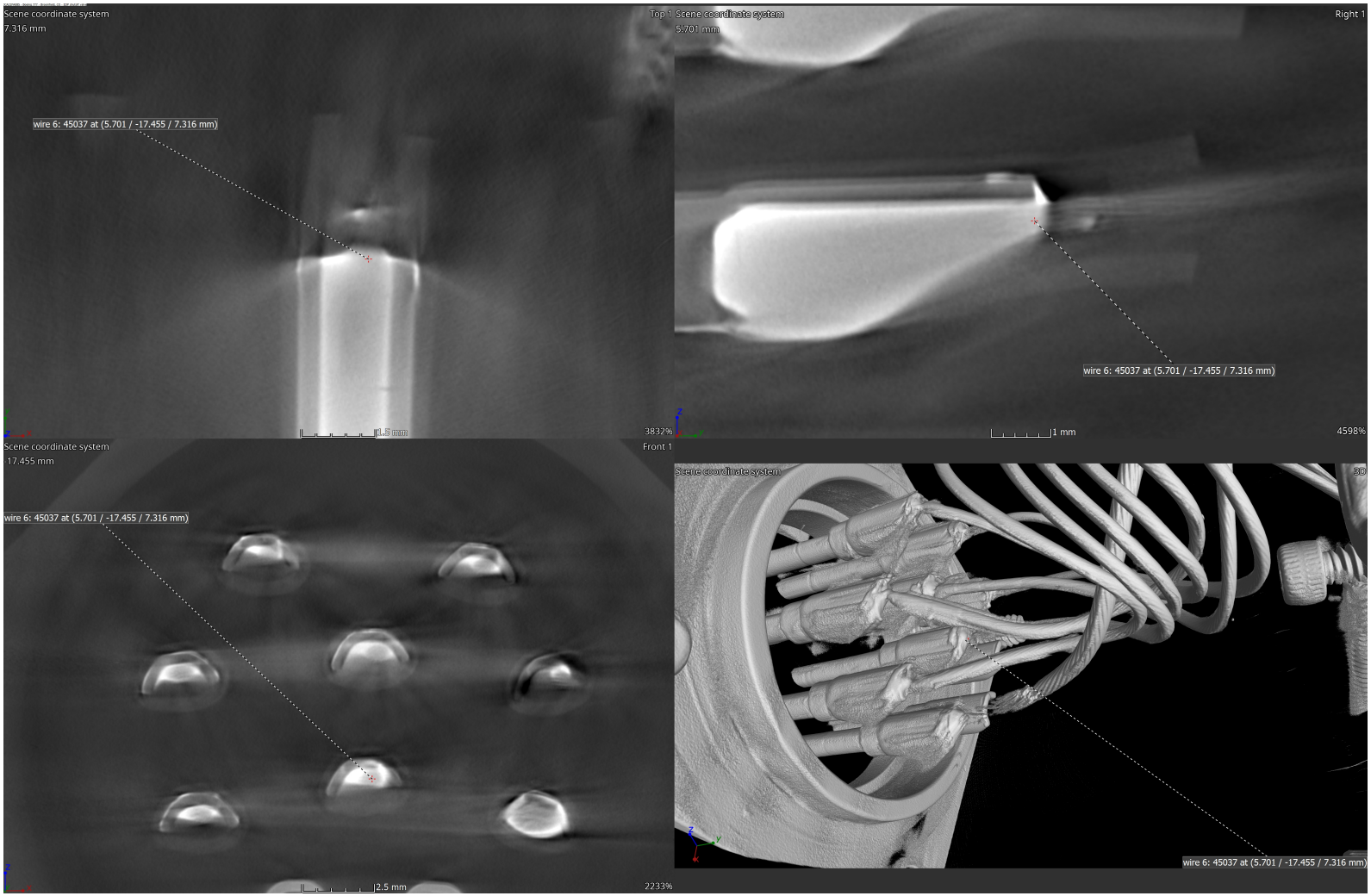


Figure 45
EDP supply shutoff valve – connector – wire 6

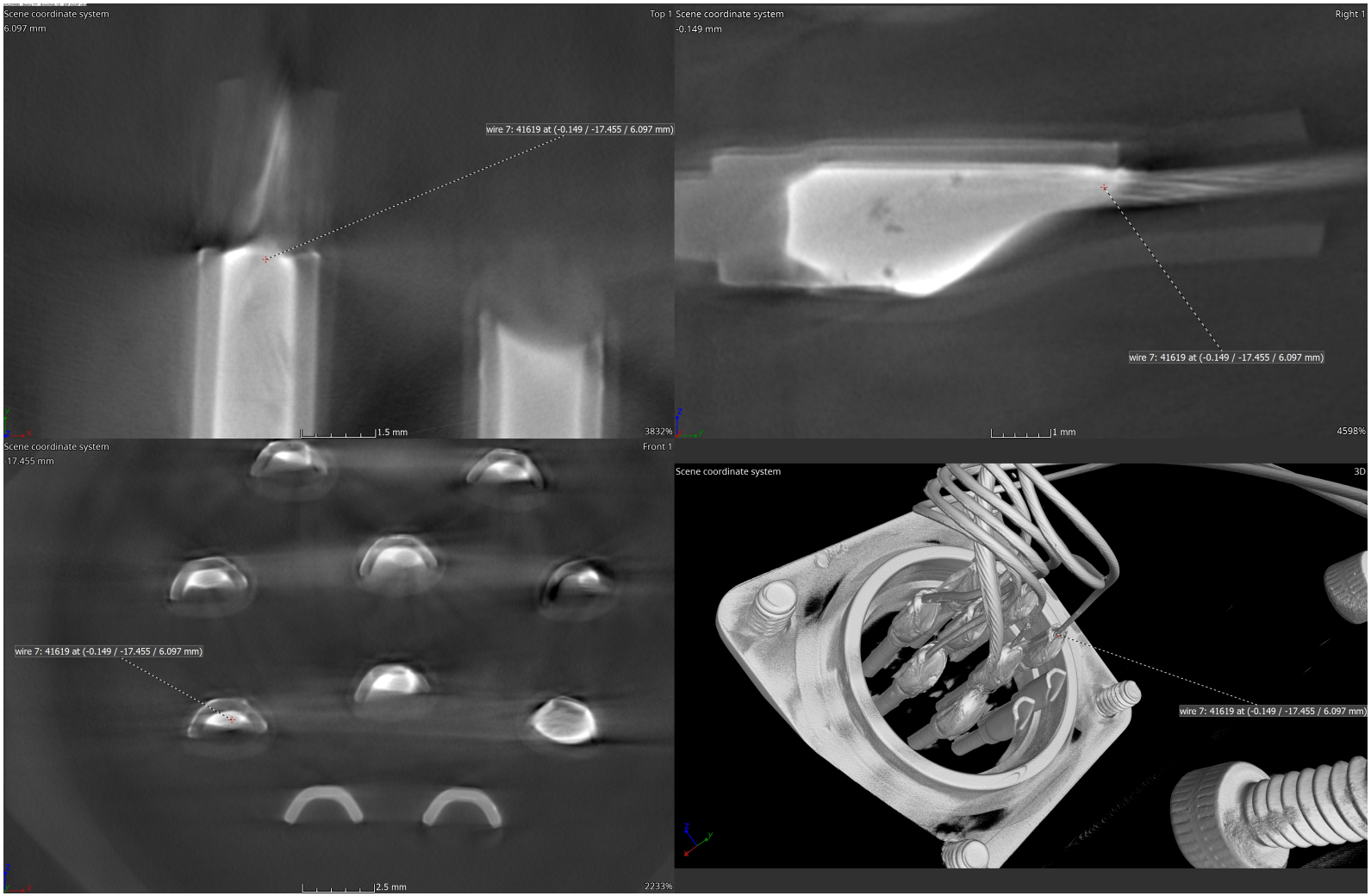


Figure 46
EDP supply shutoff valve – connector – wire 7

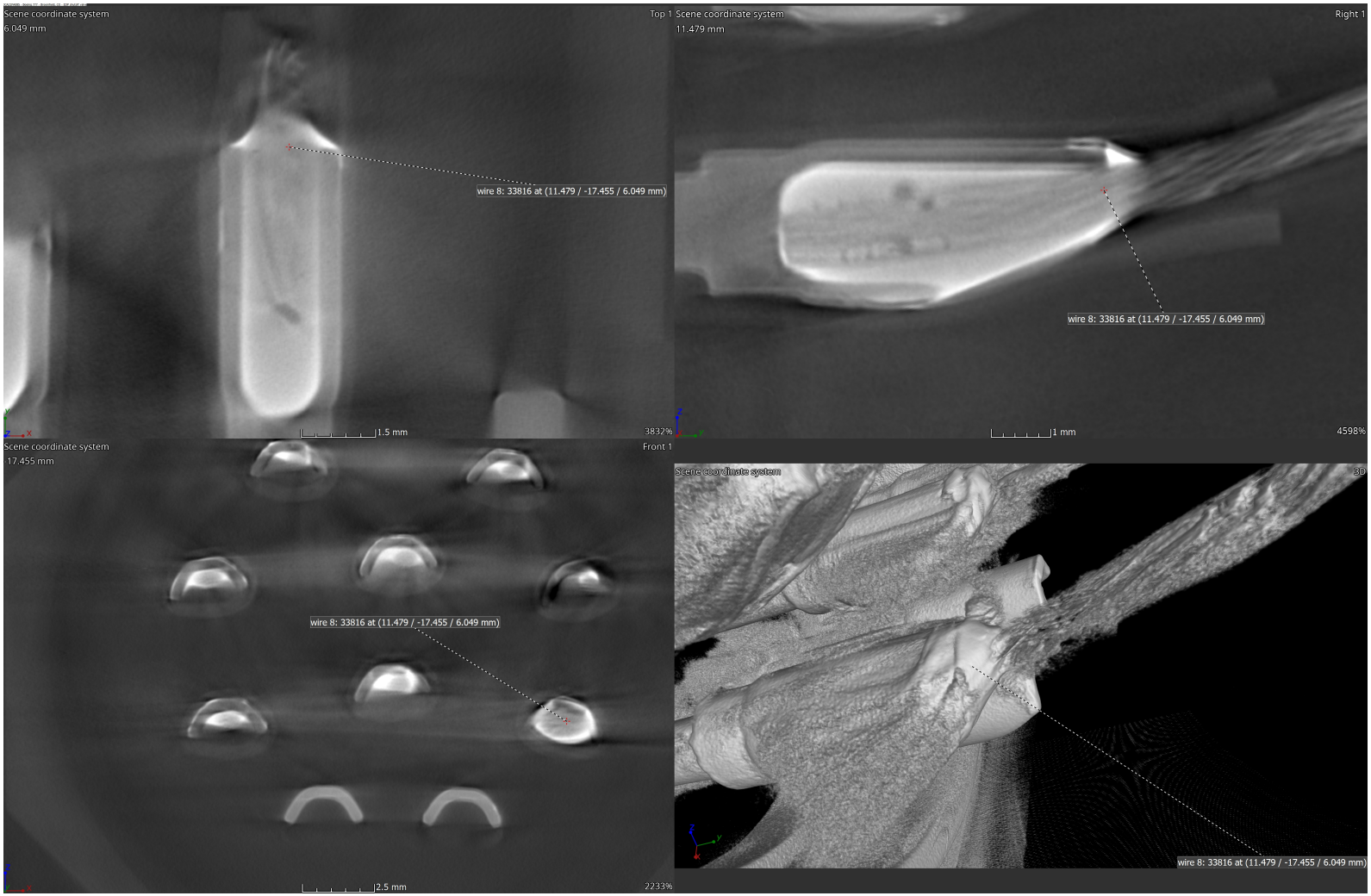


Figure 47
EDP supply shutoff valve – connector – wire 8

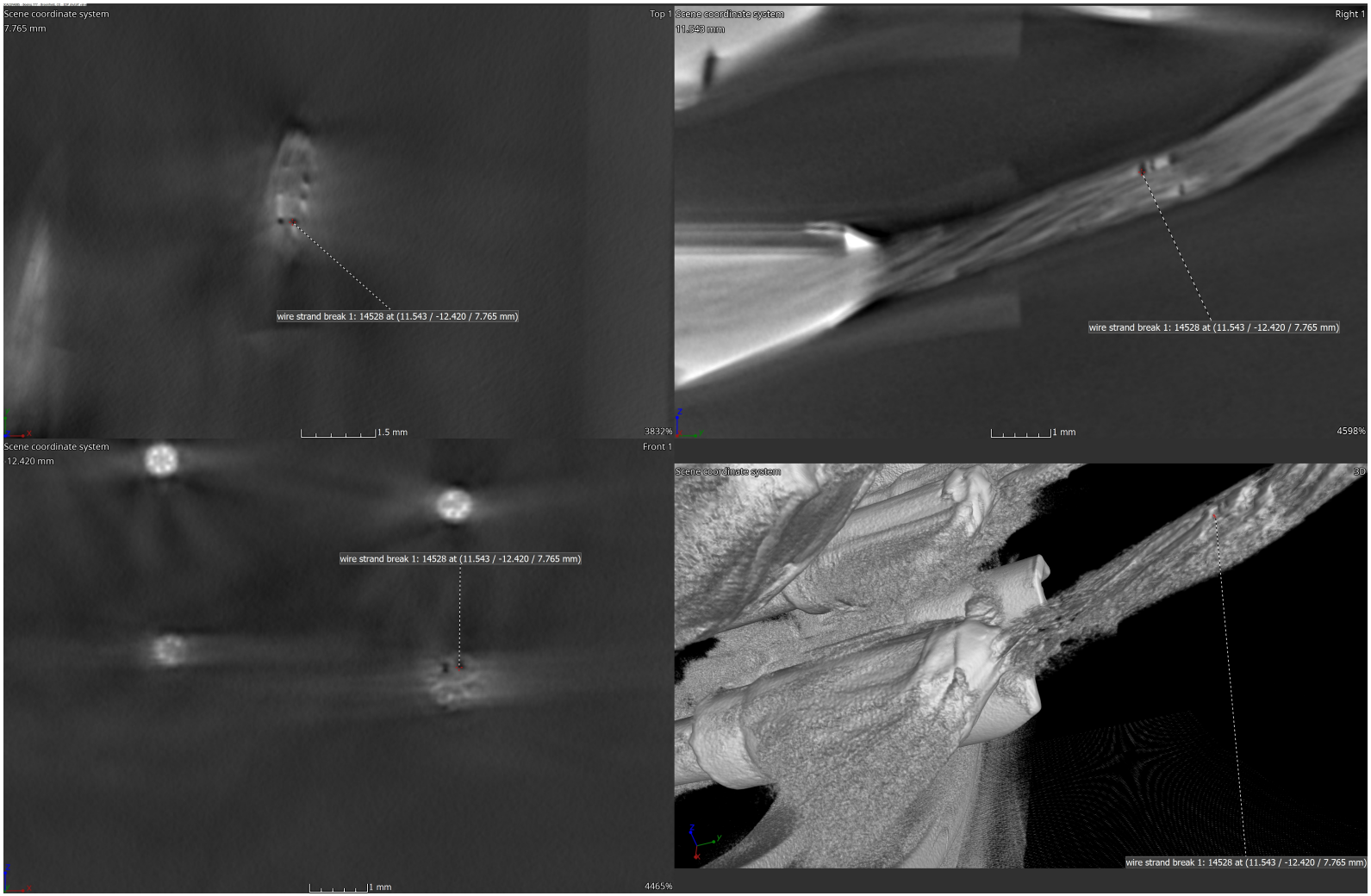


Figure 48
EDP supply shutoff valve – connector – wire strand break 1

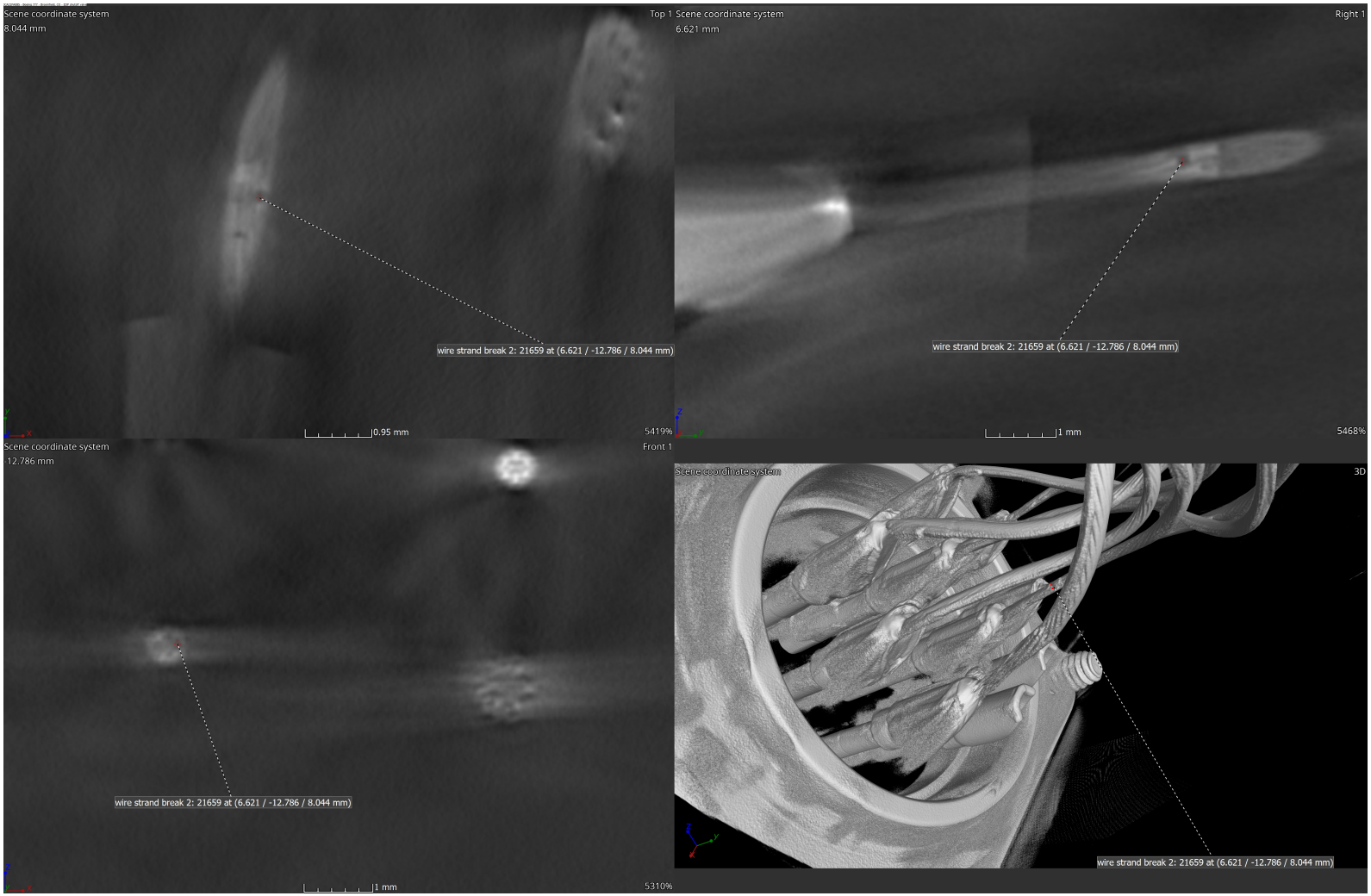


Figure 49
EDP supply shutoff valve – connector – wire strand break 2

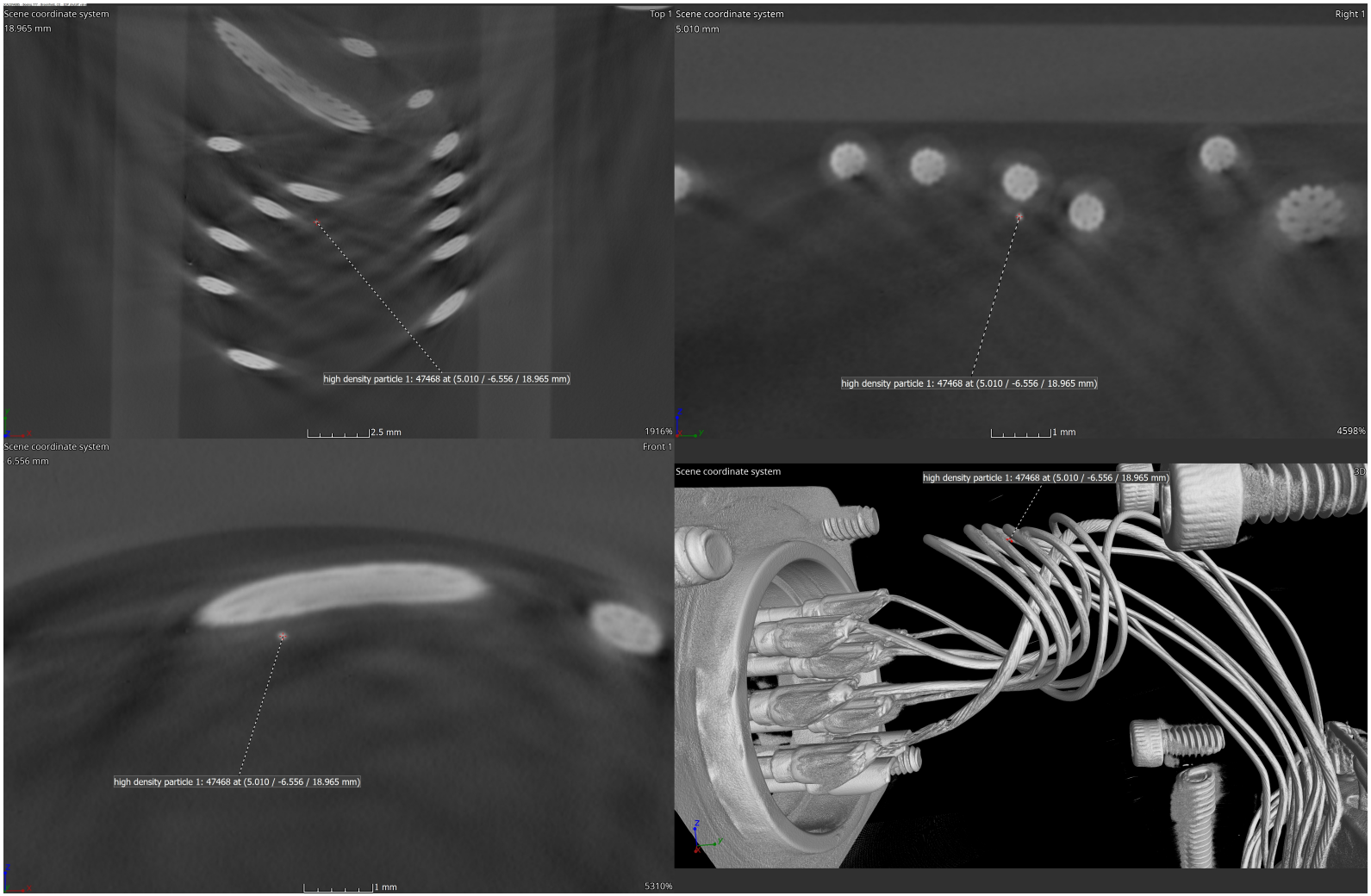


Figure 50
EDP supply shutoff valve – connector – high density particle 1

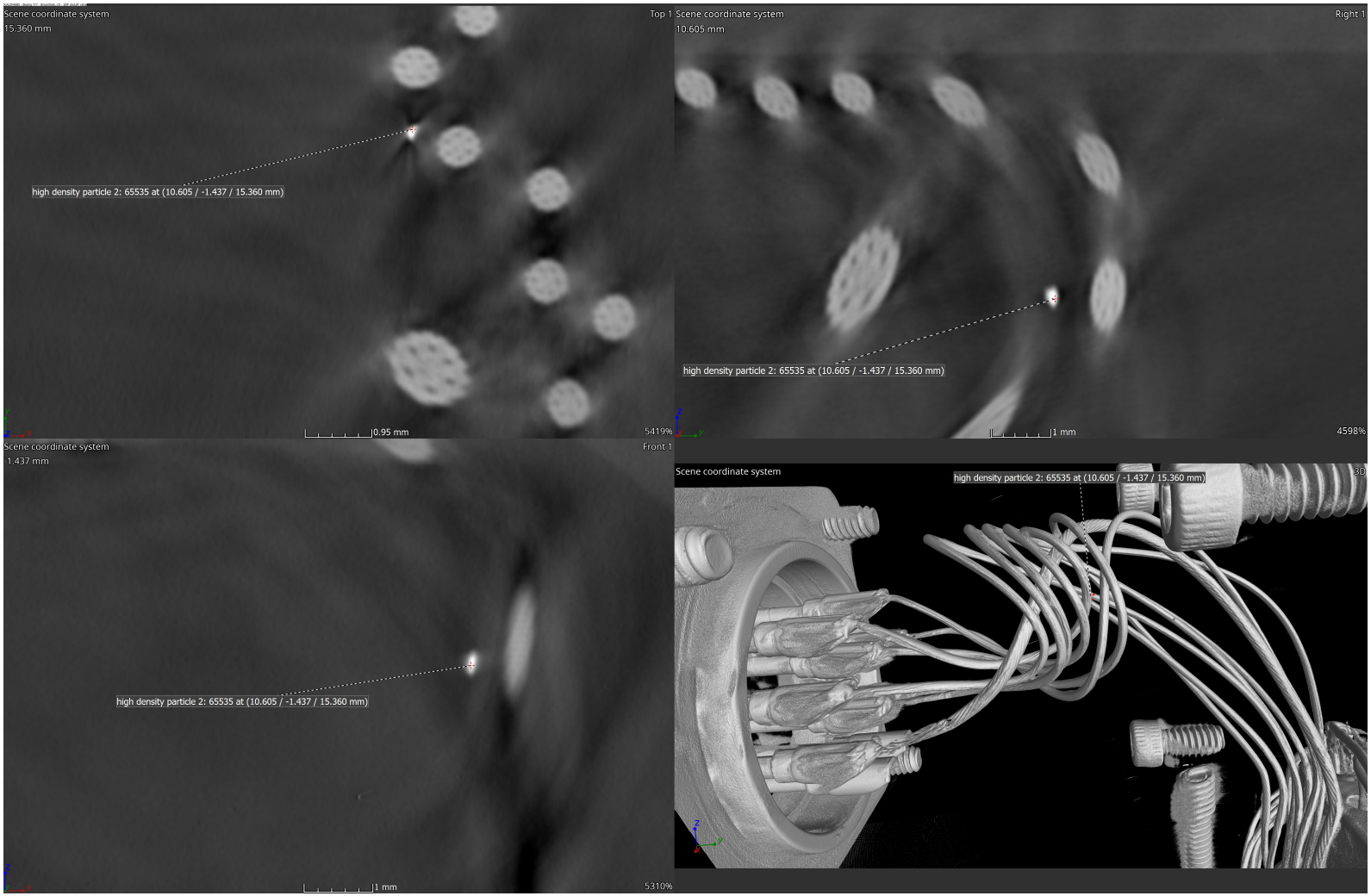


Figure 51
EDP supply shutoff valve – connector – high density particle 2

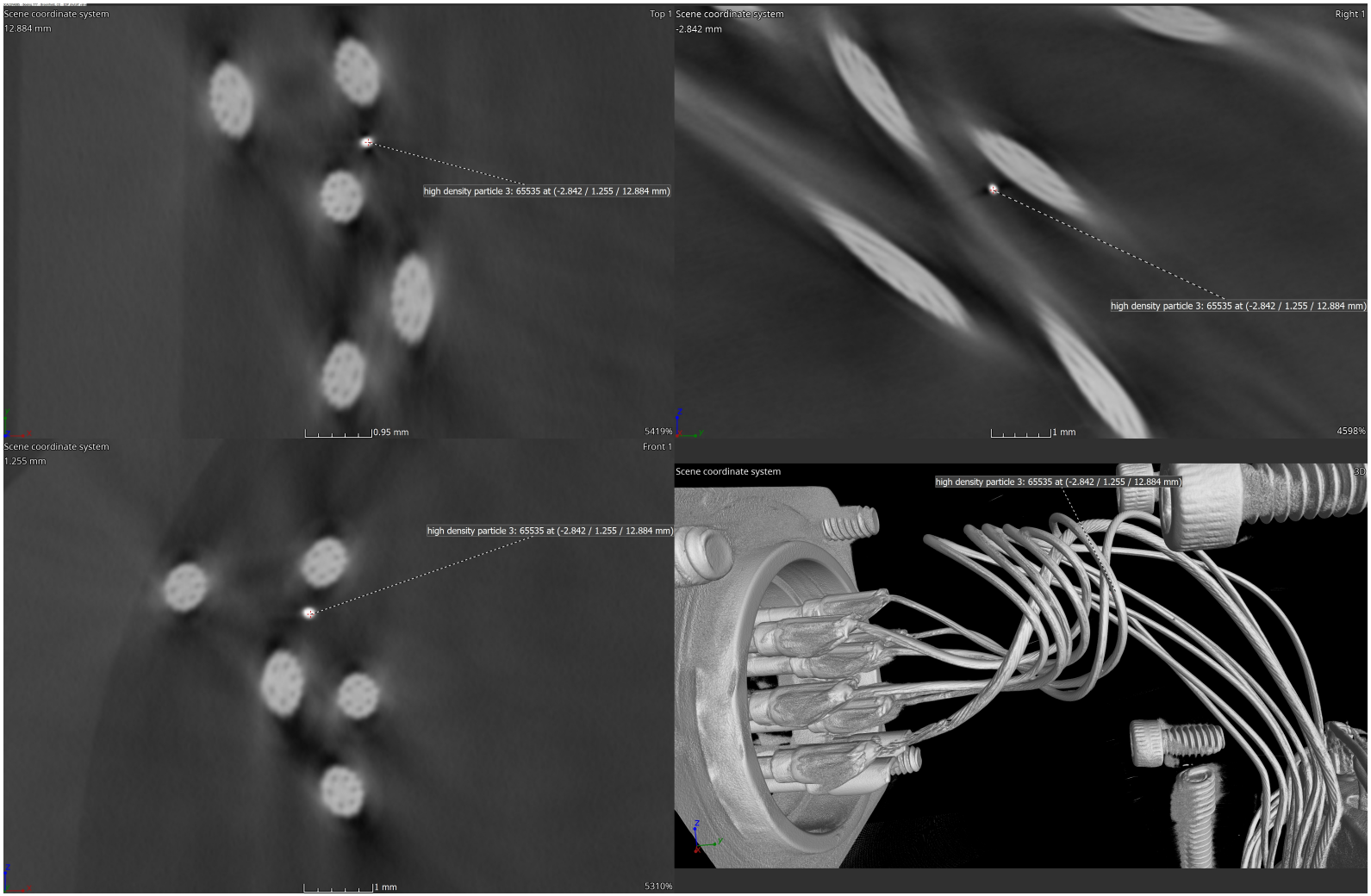


Figure 52
EDP supply shutoff valve – connector – high density particle 3

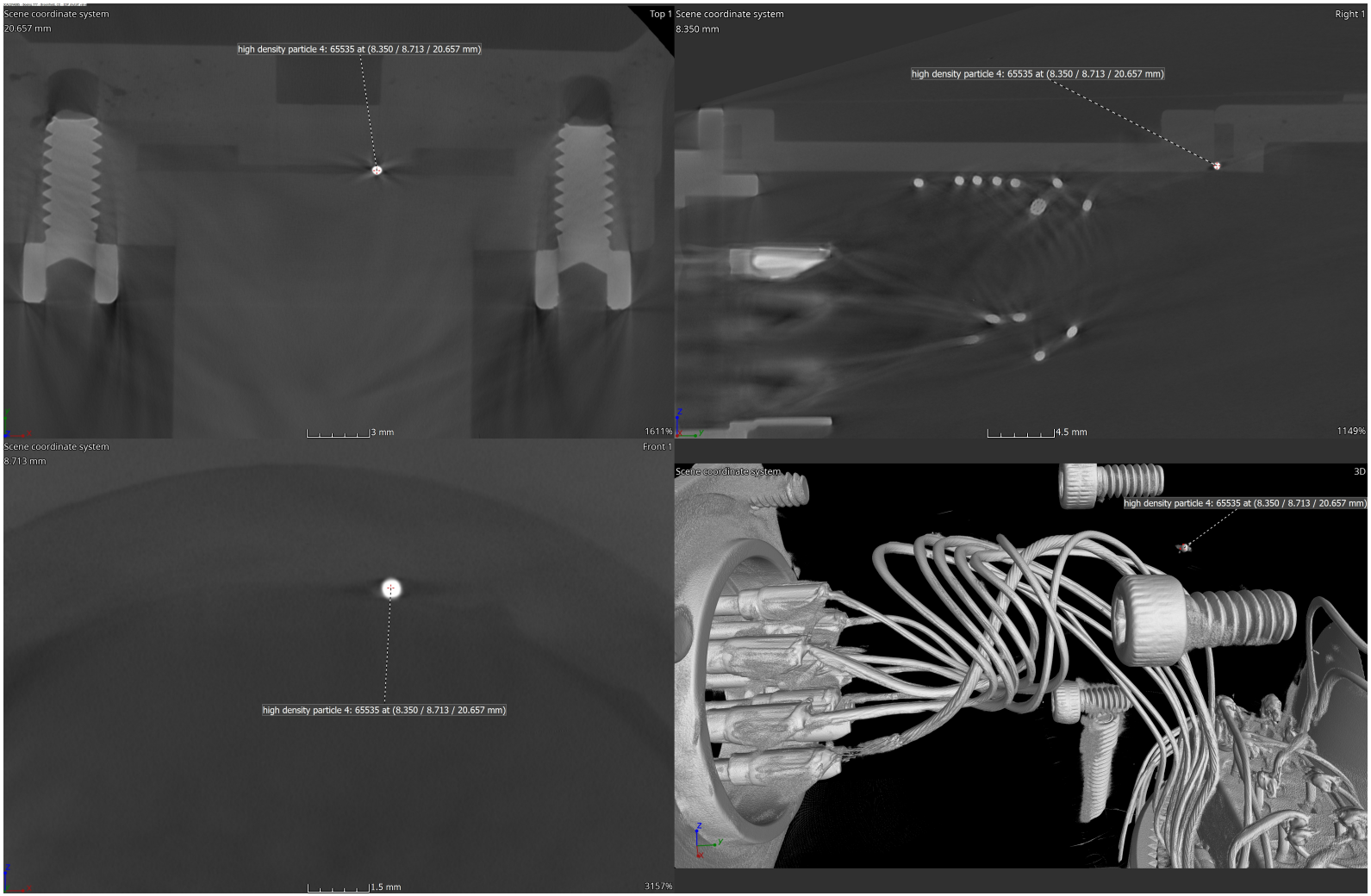


Figure 53
EDP supply shutoff valve – connector – high density particle 4

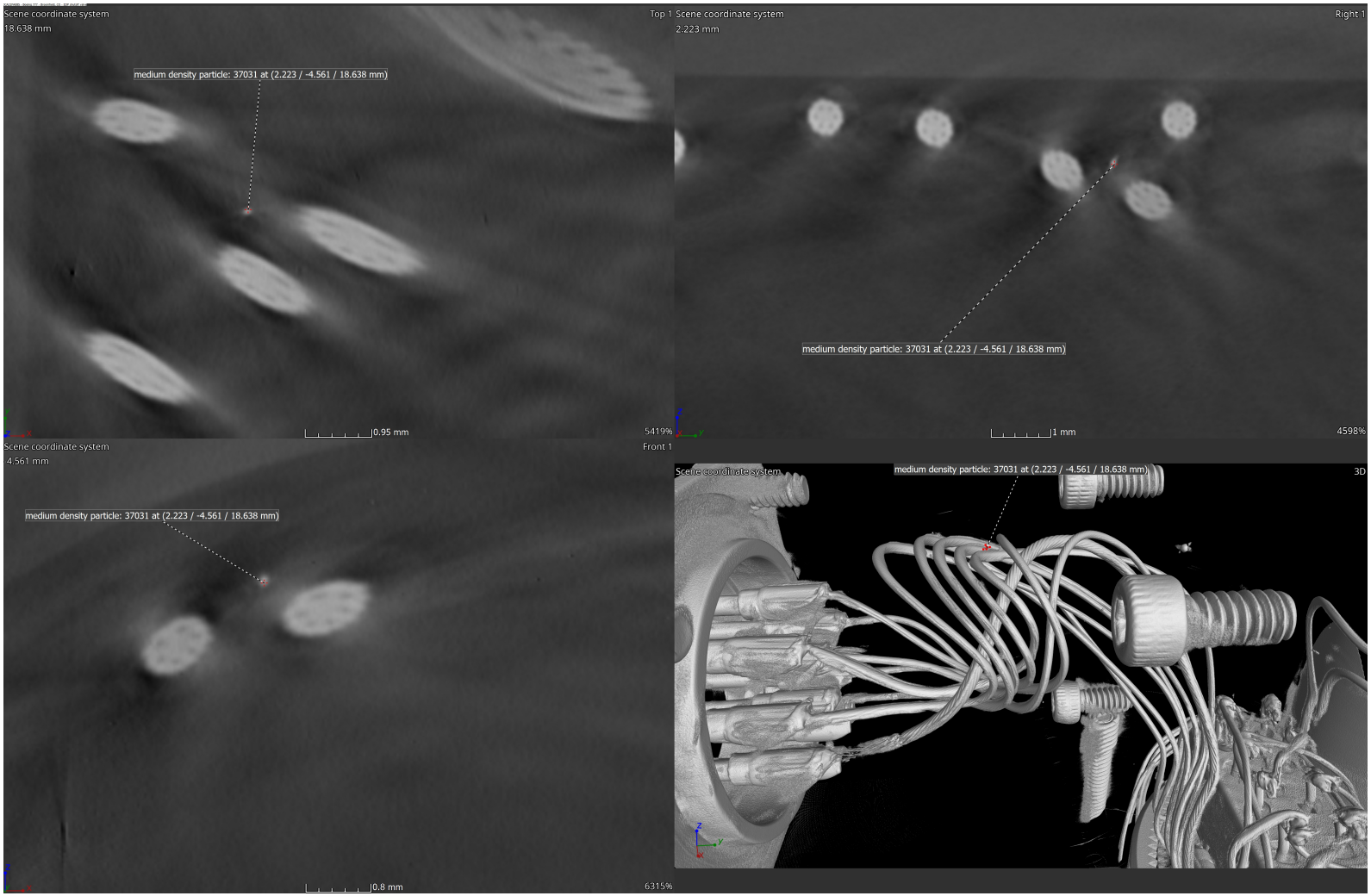


Figure 54
EDP supply shutoff valve – connector – medium density particle

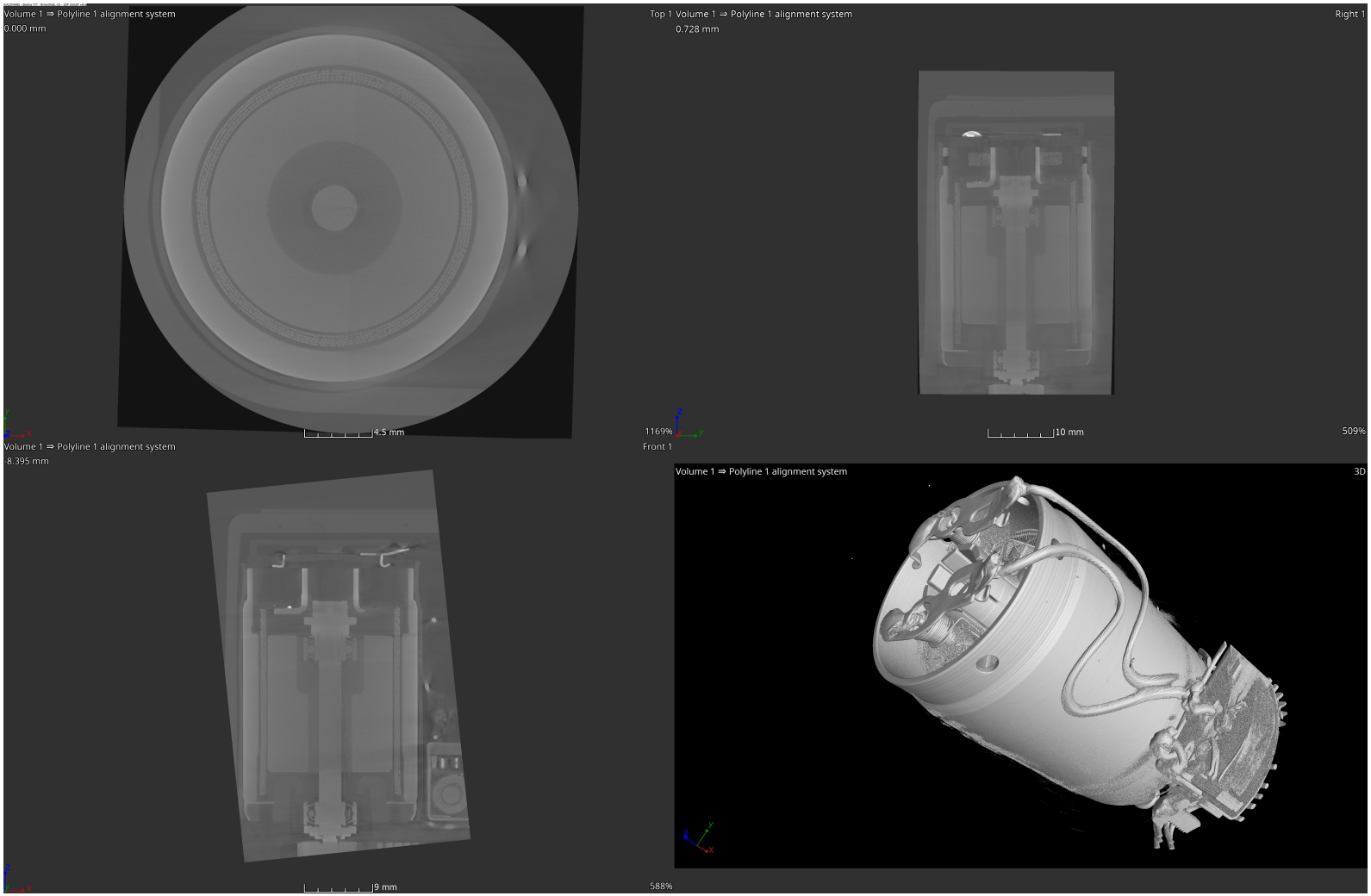


Figure 55
EDP supply shutoff valve – motor – overview

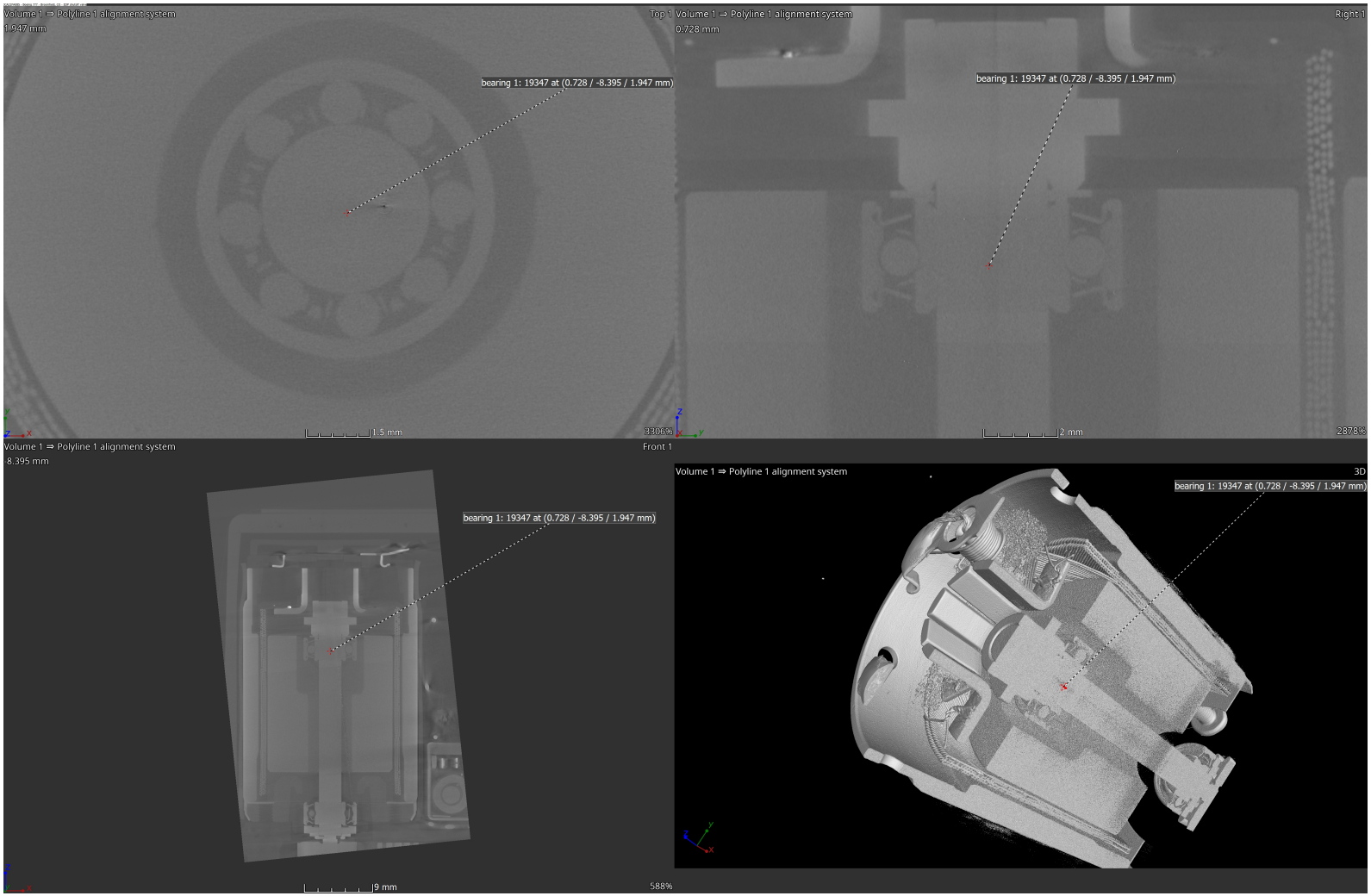


Figure 56
EDP supply shutoff valve – motor – bearing 1

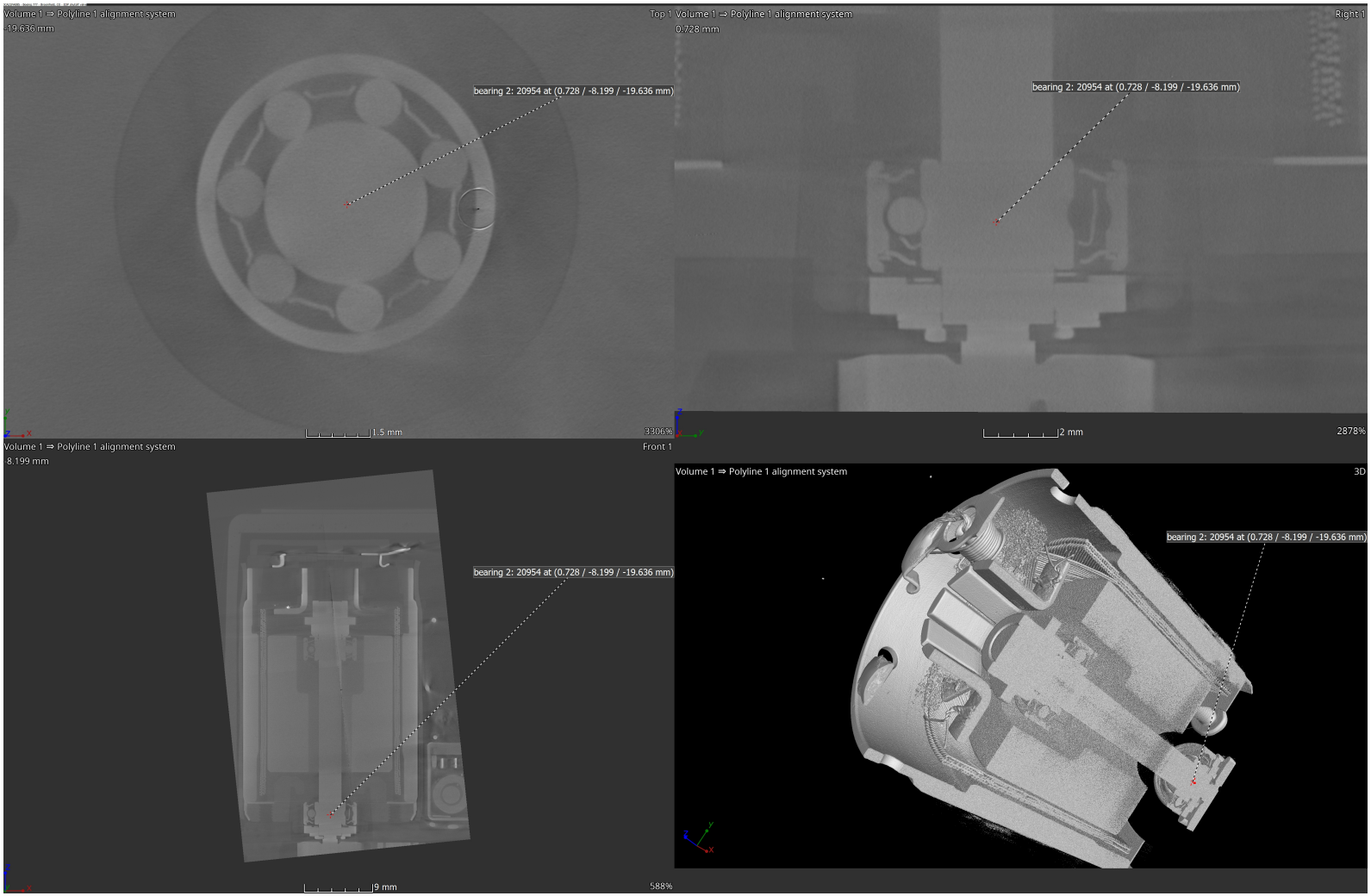


Figure 57
EDP supply shutoff valve – motor – bearing 2

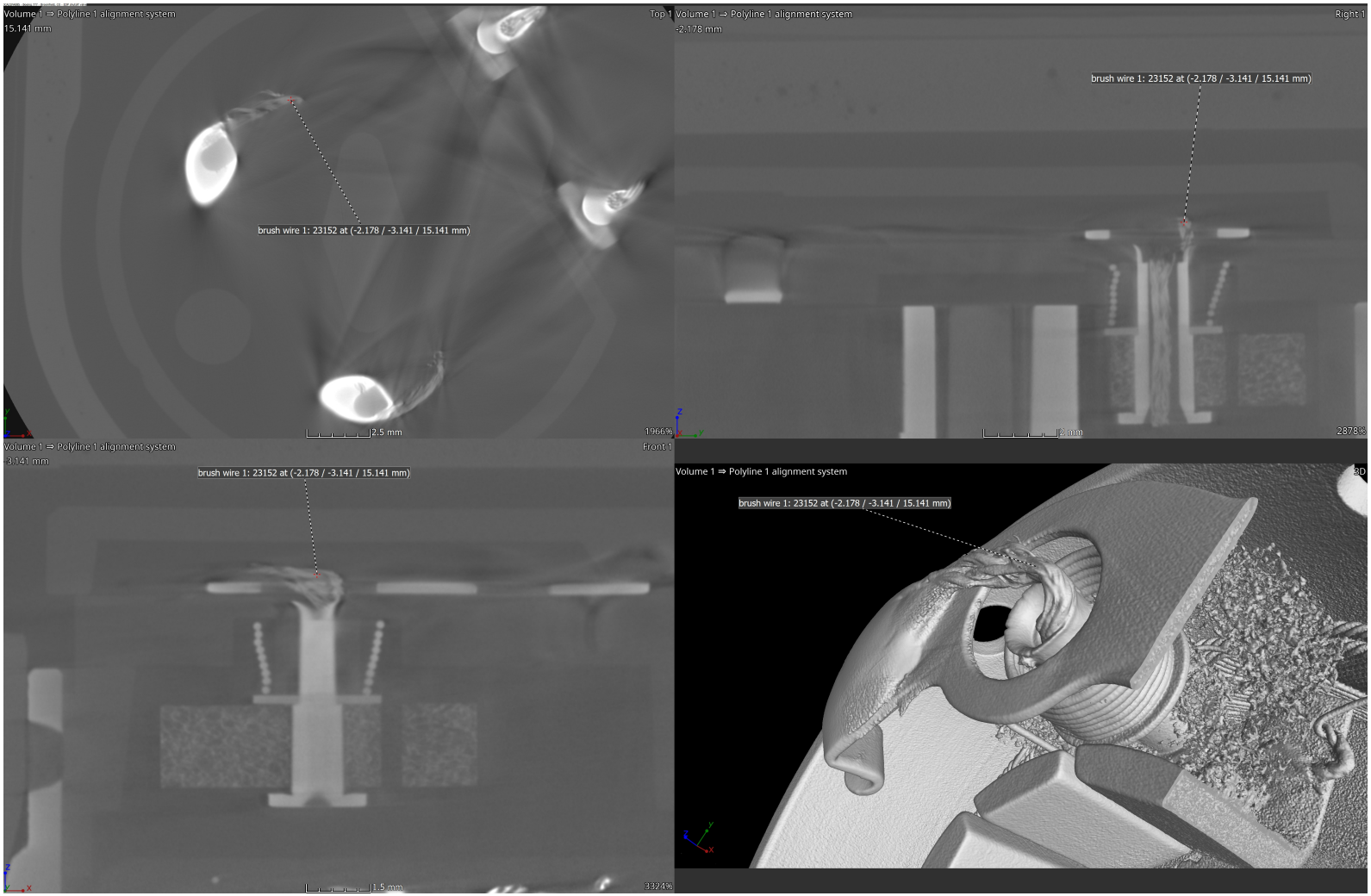


Figure 58
EDP supply shutoff valve – motor – brush wire 1

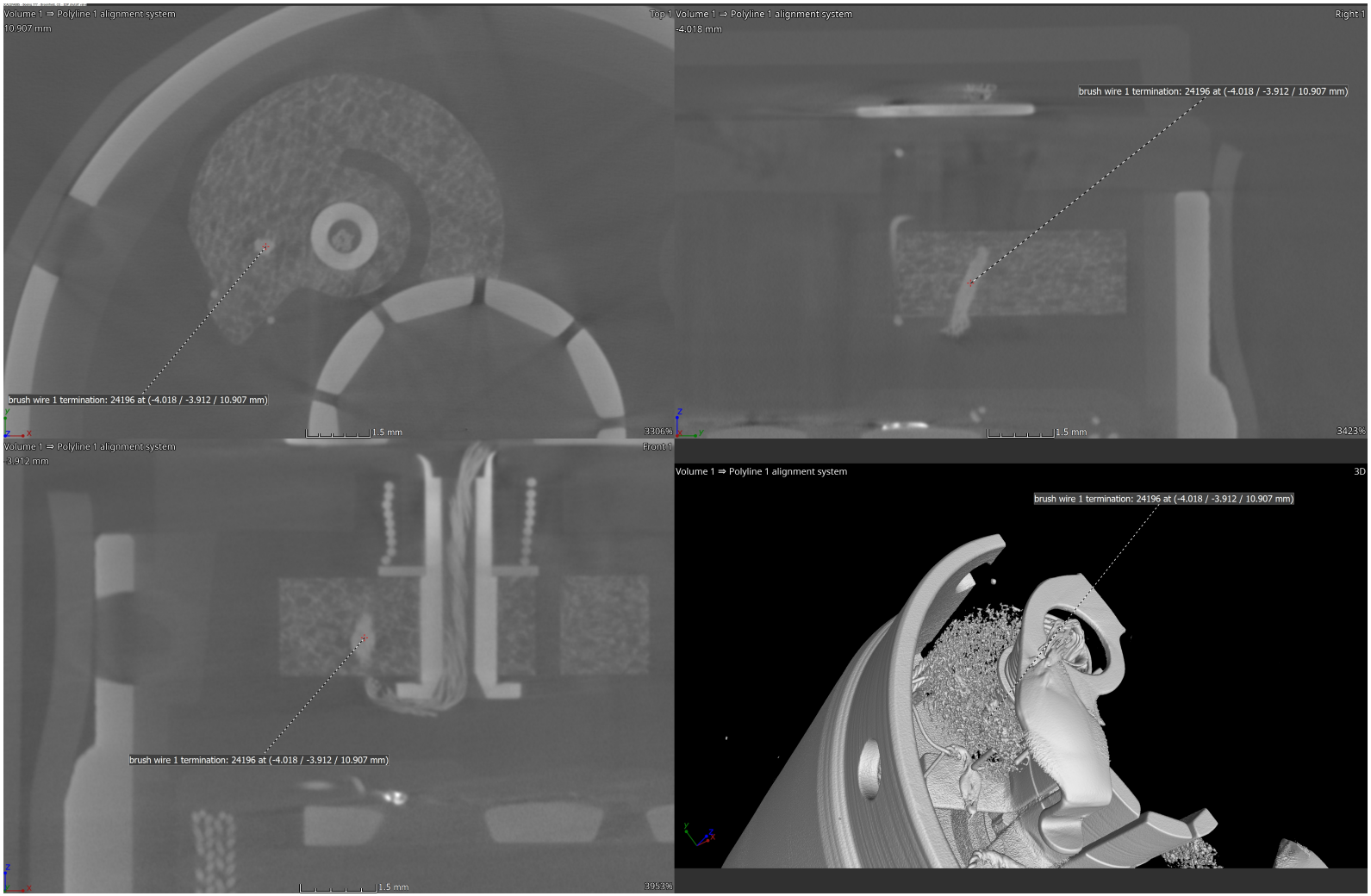


Figure 59
EDP supply shutoff valve – motor – brush wire 1 termination

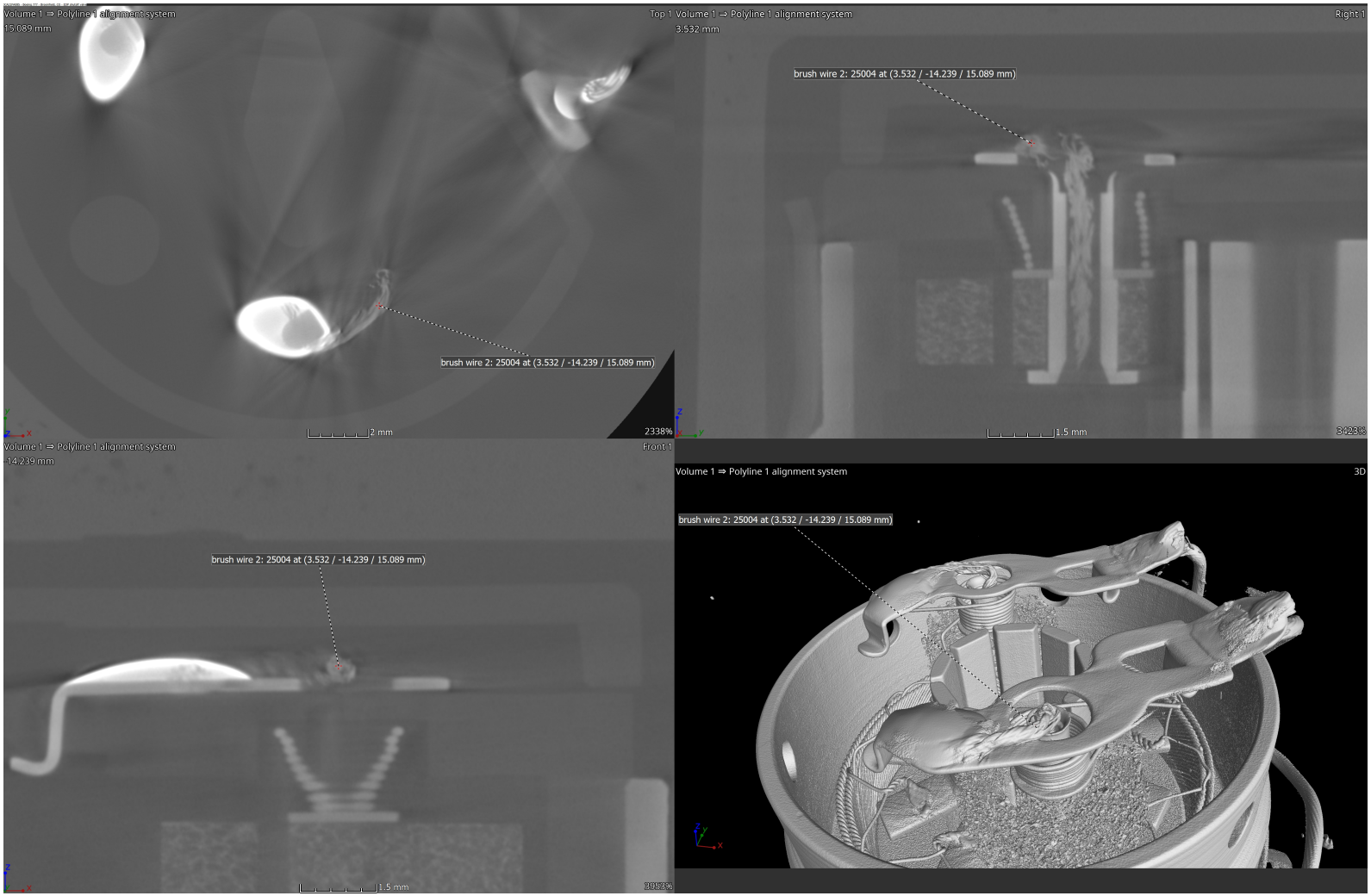


Figure 60
EDP supply shutoff valve – motor – brush wire 2

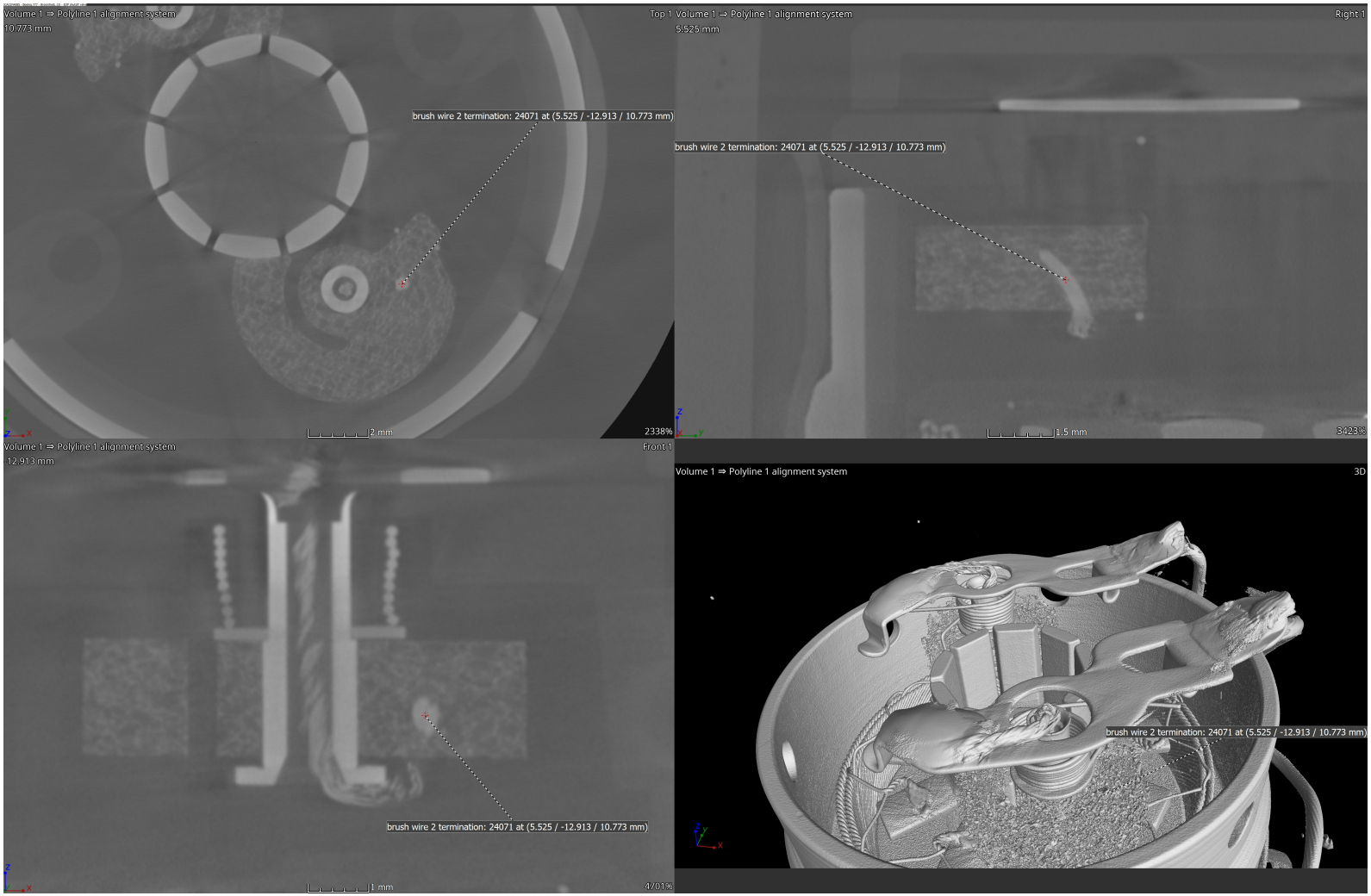


Figure 61
EDP supply shutoff valve – motor – brush wire 2 termination

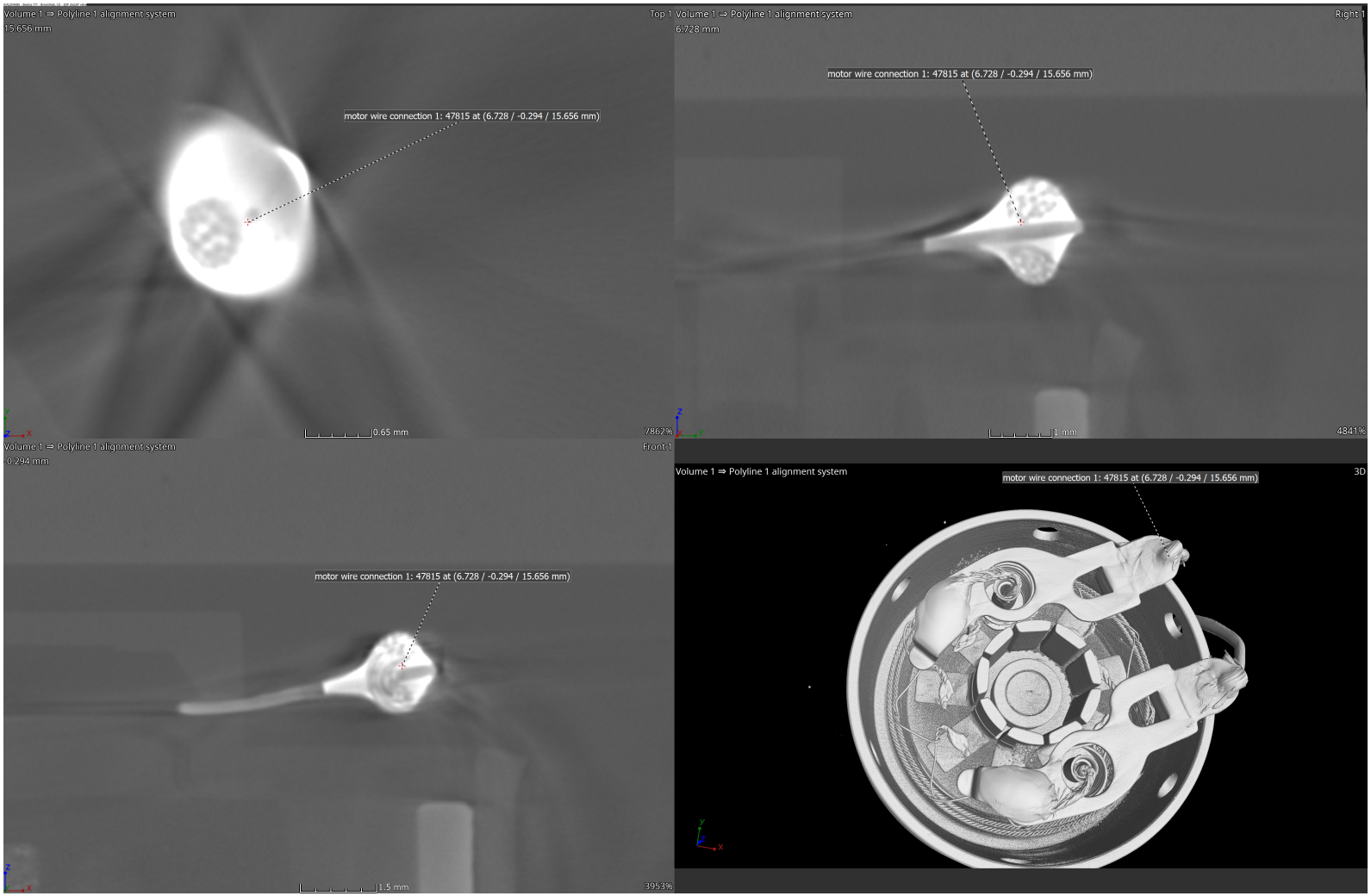


Figure 62
EDP supply shutoff valve – motor – motor wire connection 1

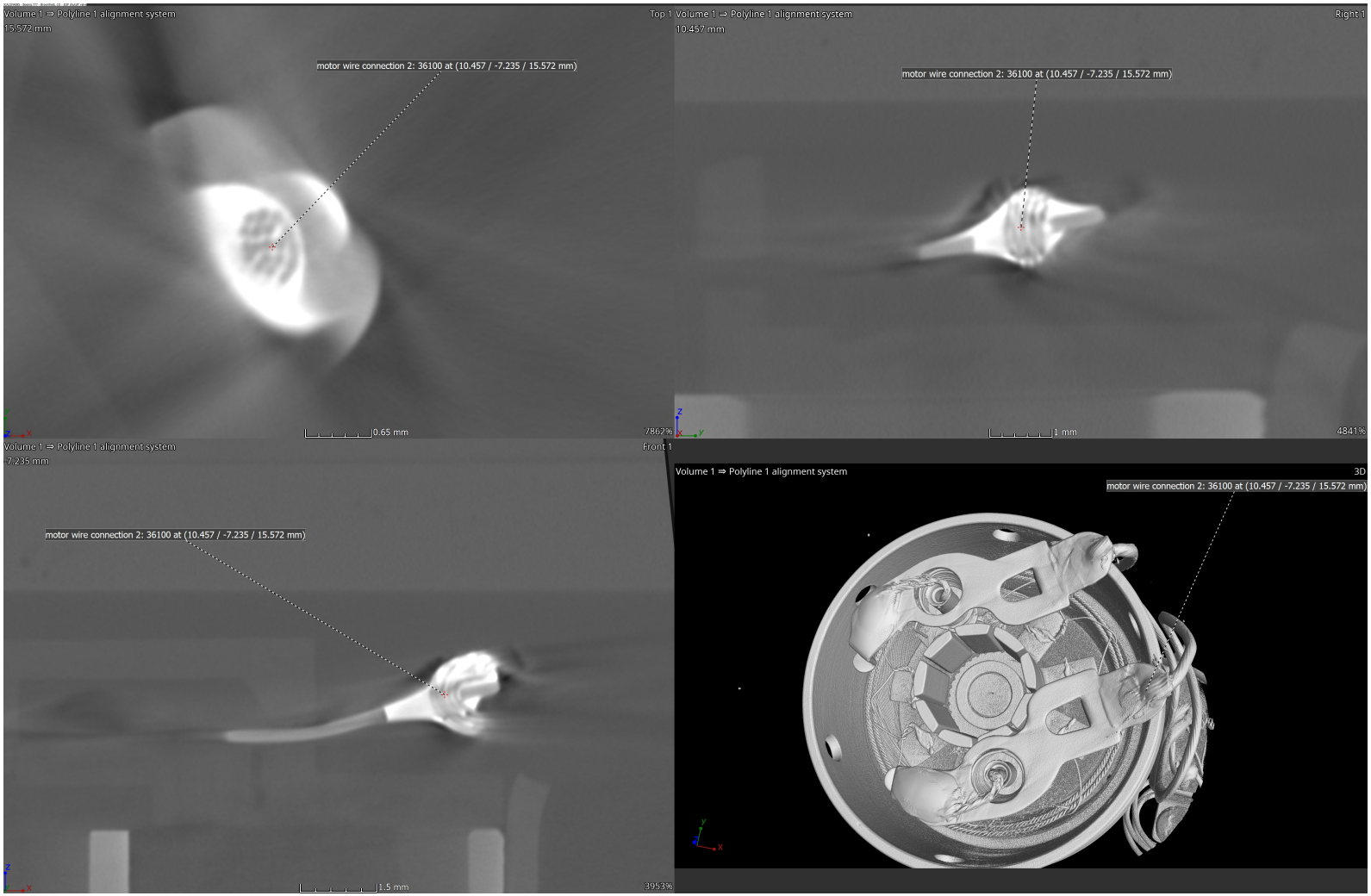


Figure 63
EDP supply shutoff valve – motor – motor wire connection 2

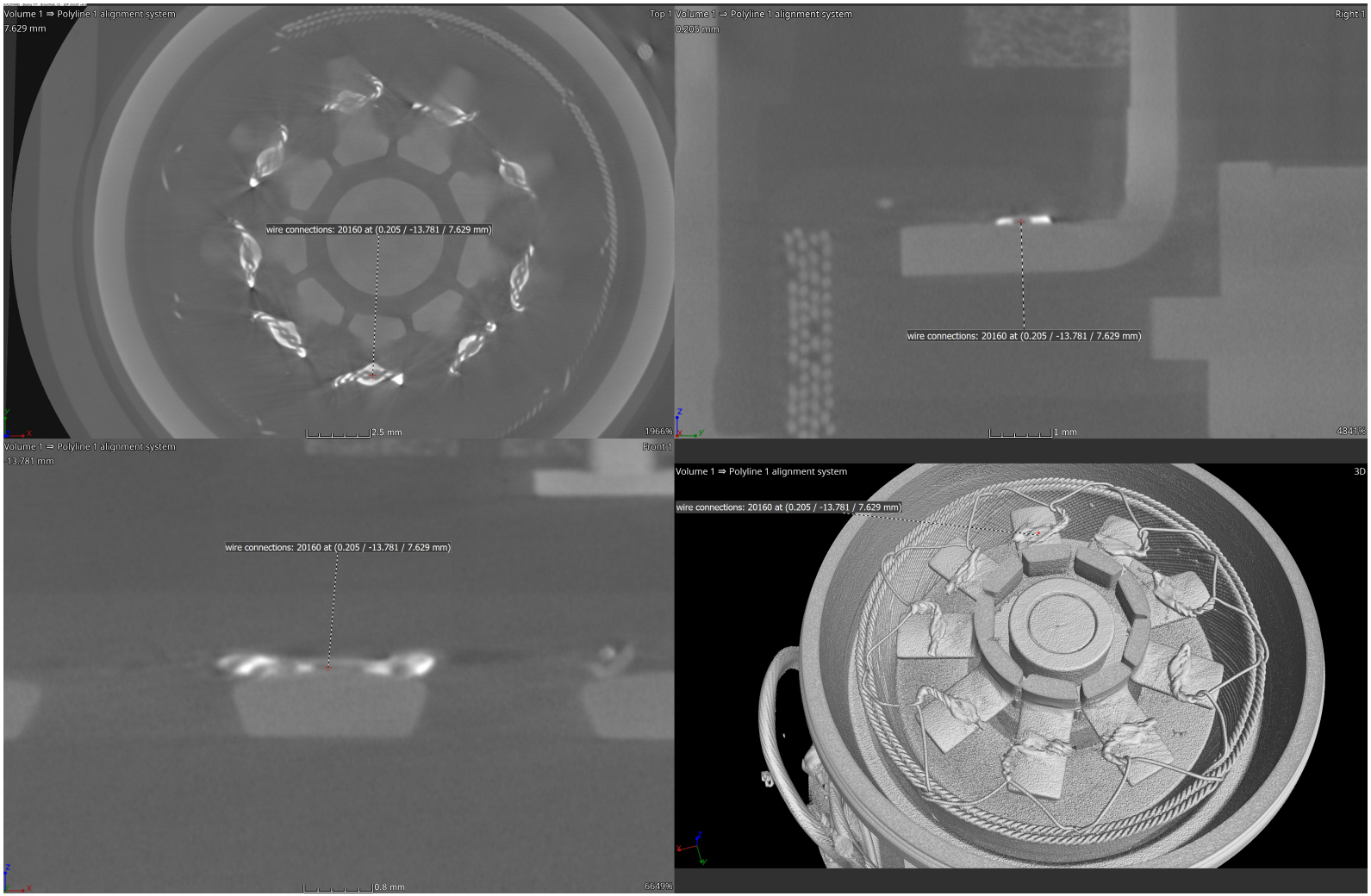


Figure 64
EDP supply shutoff valve – motor – wire connections

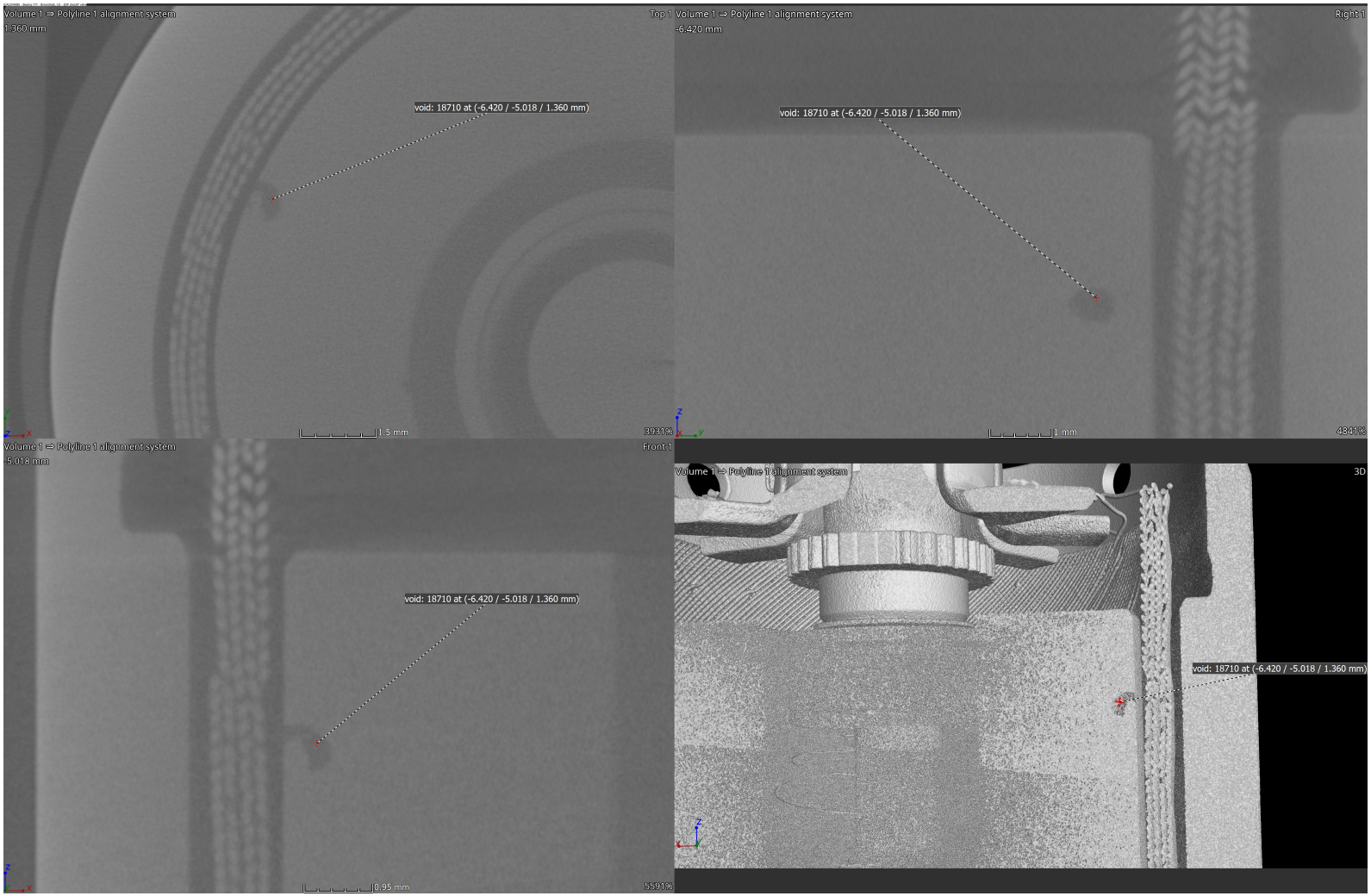


Figure 65
EDP supply shutoff valve – motor – void

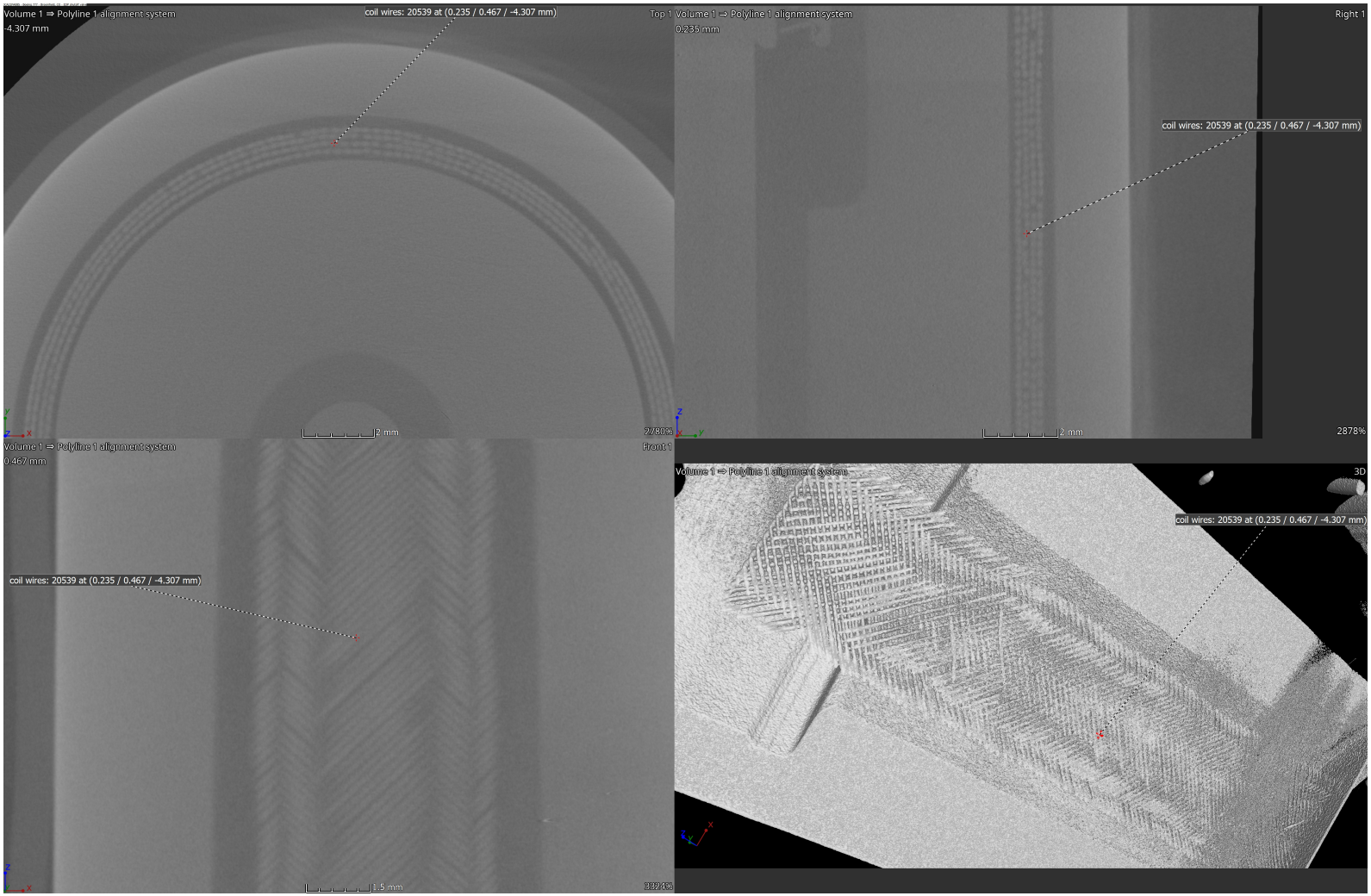


Figure 66
EDP supply shutoff valve – motor – coil wires



Figure 67
EDP supply shutoff valve – motor – coil wires virtually unrolled

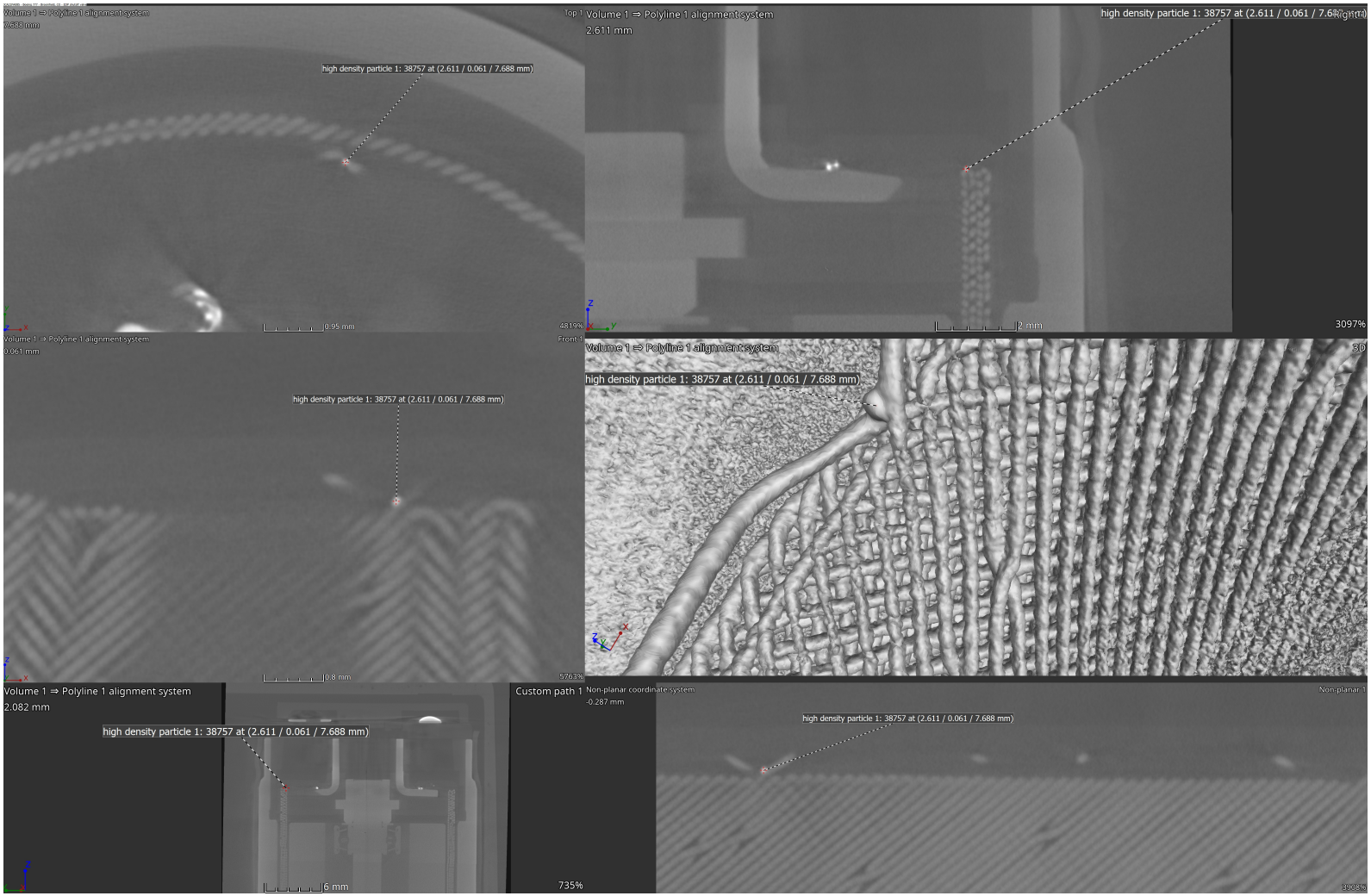


Figure 68
EDP supply shutoff valve – motor – high density particle within coil wires 1

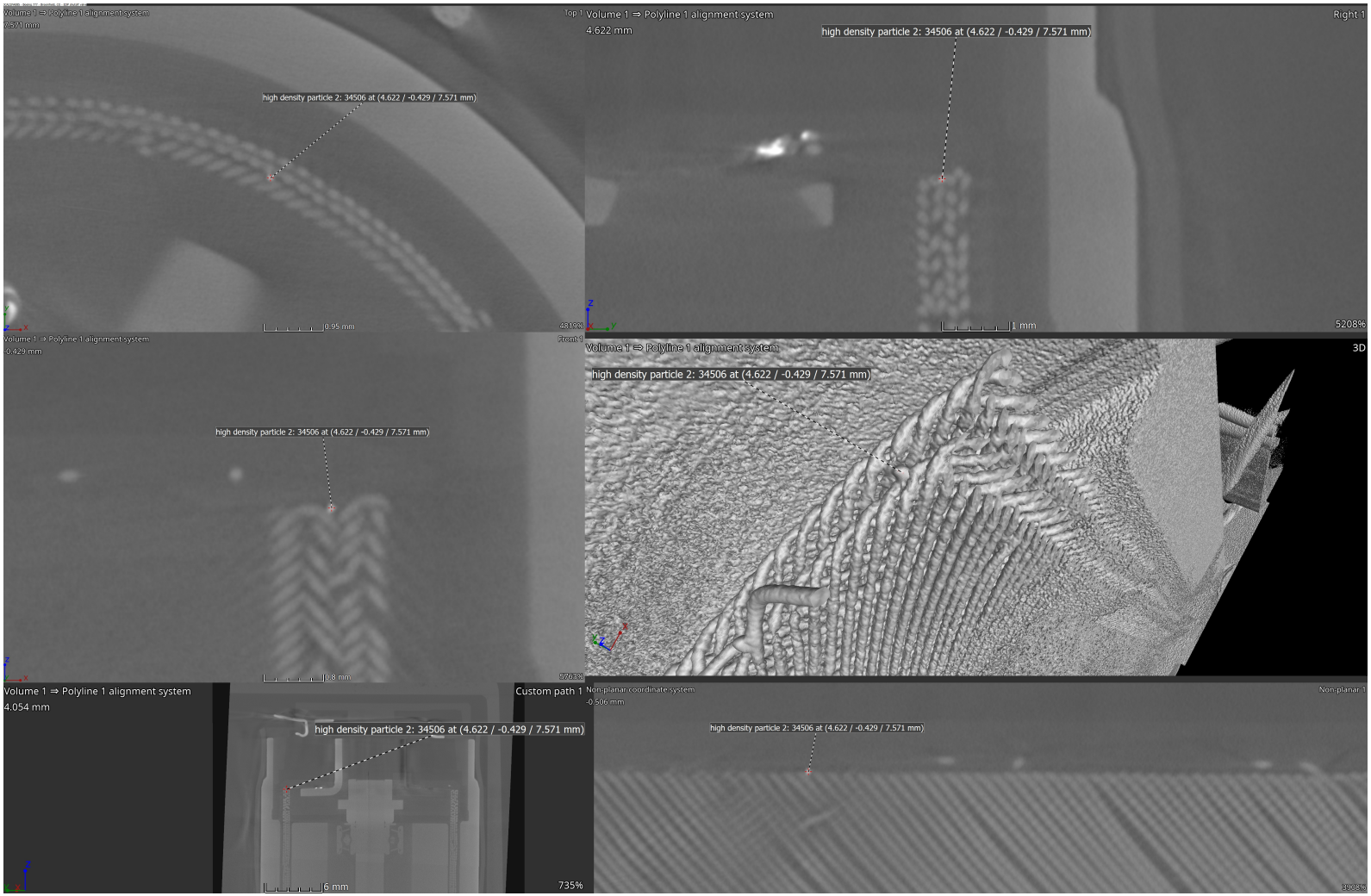


Figure 69
EDP supply shutoff valve – motor – high density particle within coil wires 2

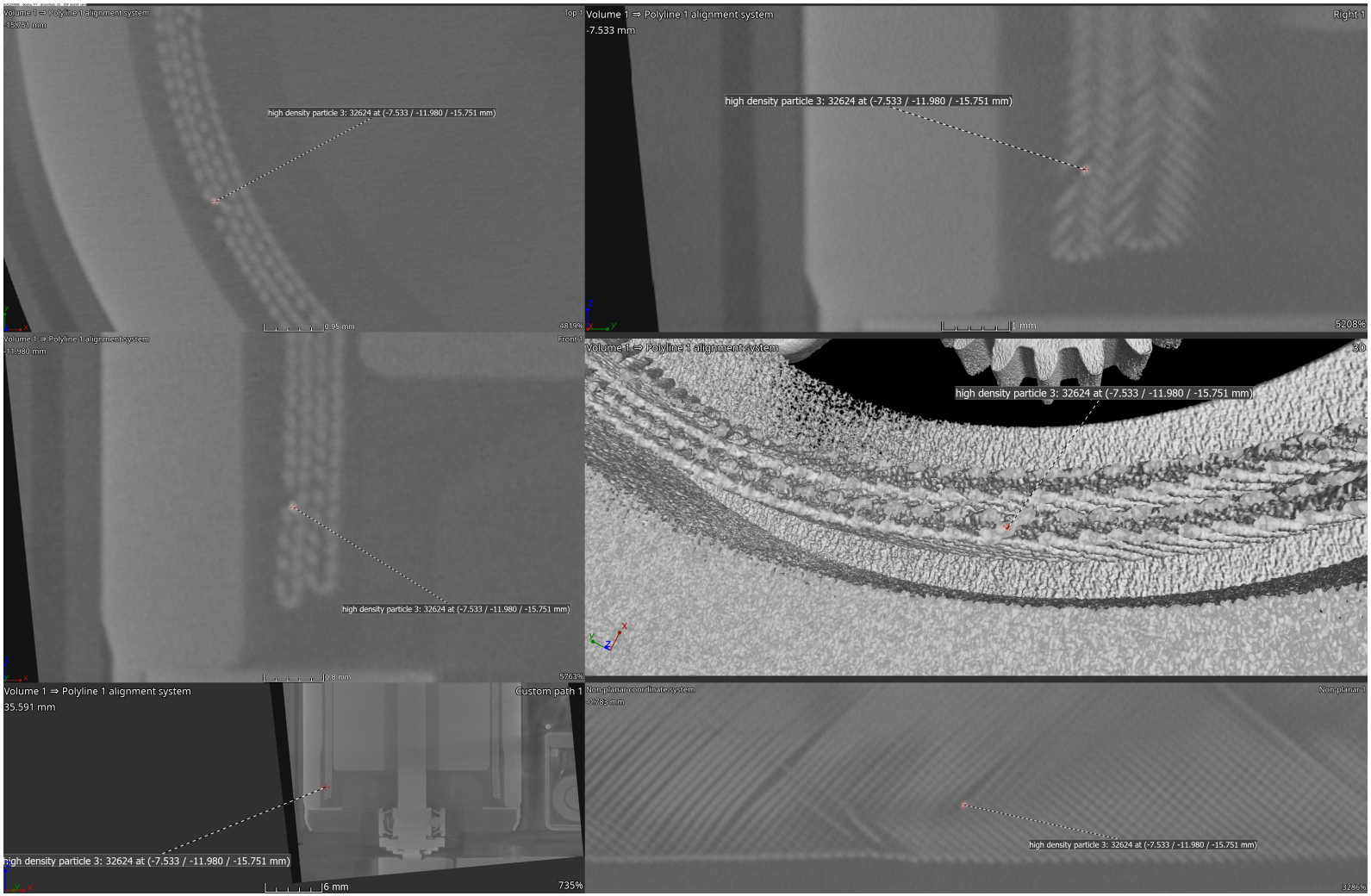


Figure 70
EDP supply shutoff valve – motor – high density particle within coil wires 3

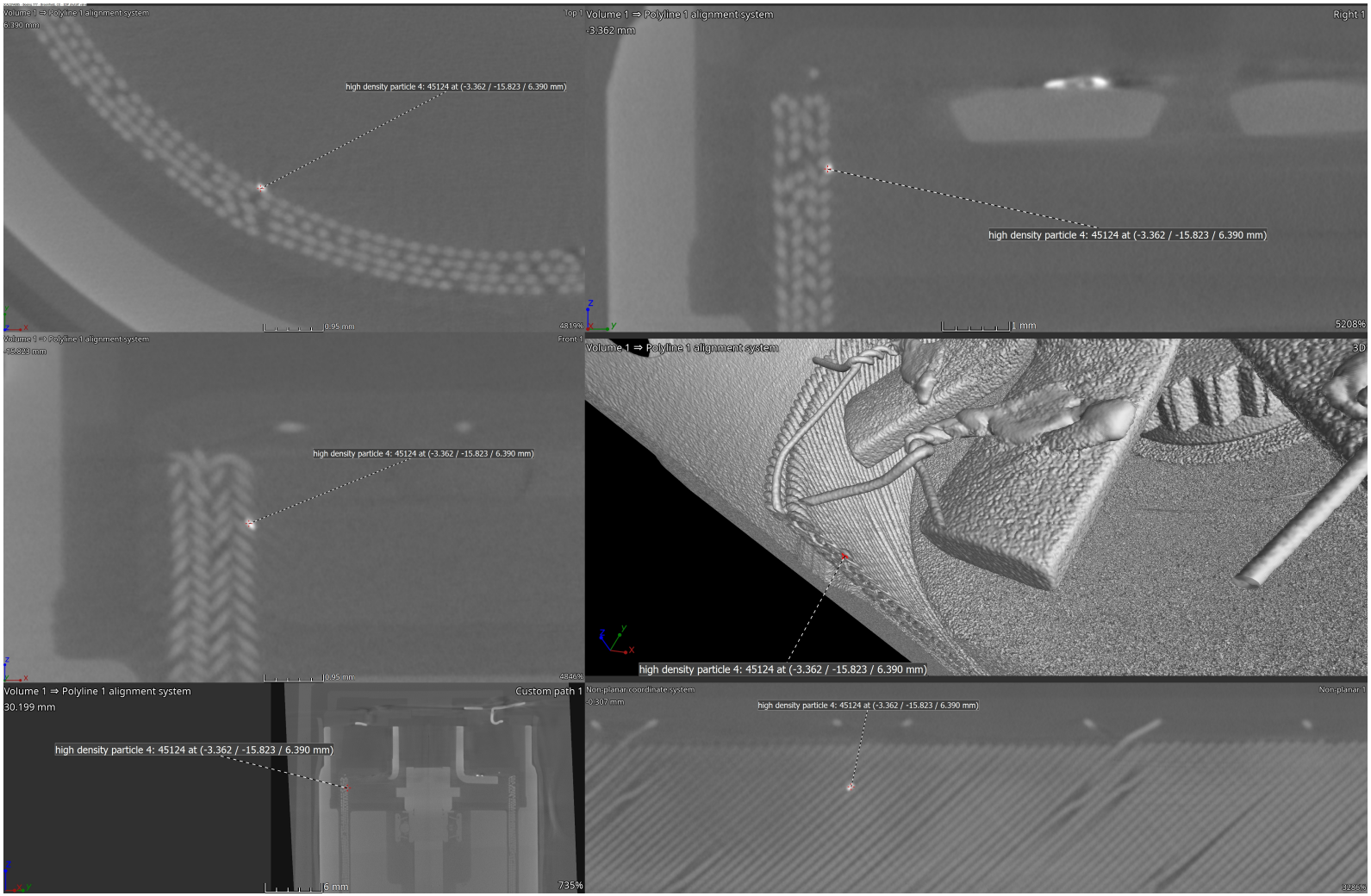


Figure 71
EDP supply shutoff valve – motor – high density particle within coil wires 4

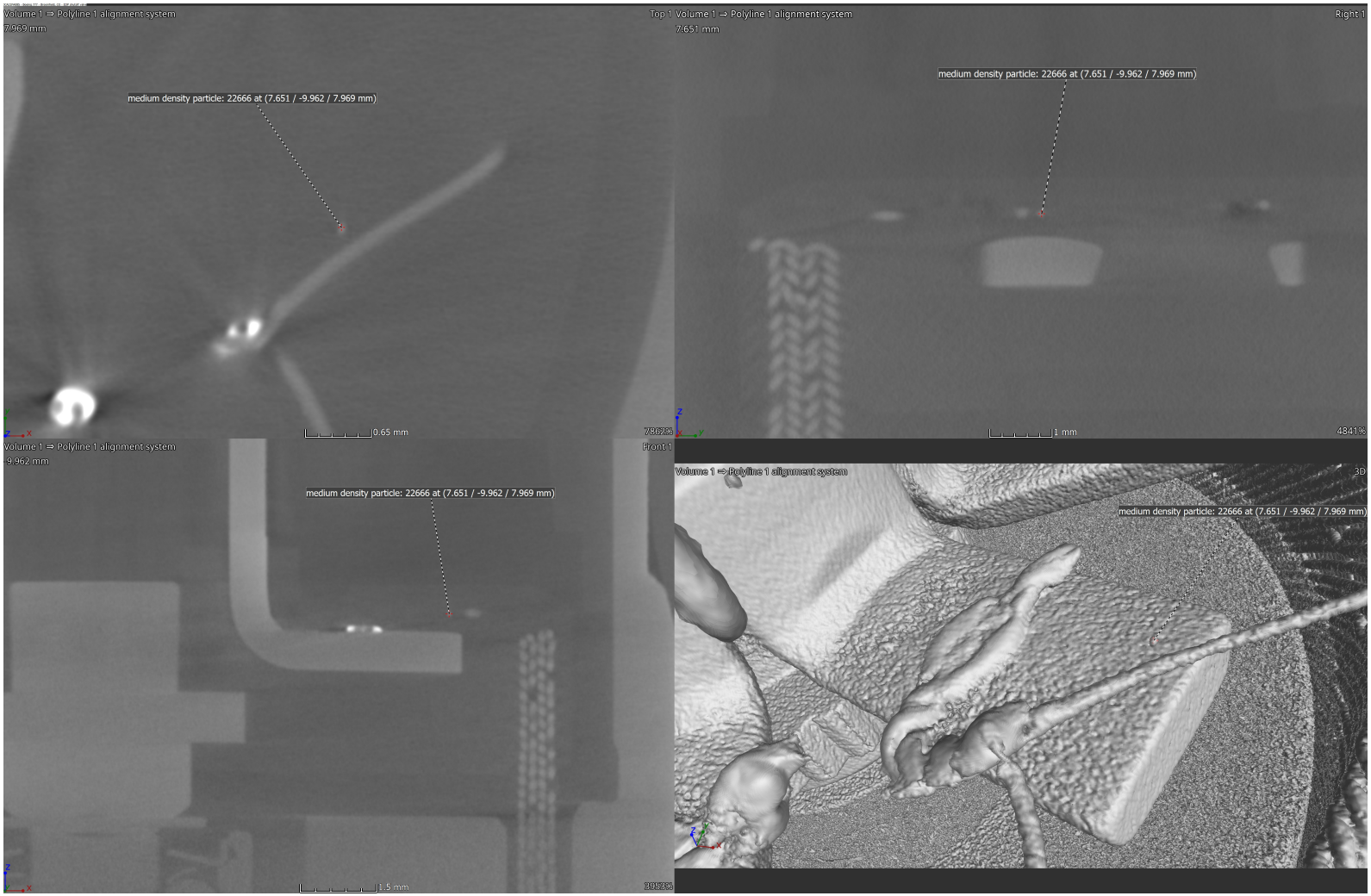


Figure 72
EDP supply shutoff valve – motor – high density particle within coil wires 4

Scott Warren
Lead Aerospace Engineer
(Computed Tomography Specialist)