Alignment with the help of the alignment service

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1 Overview

In the past, we used markings on the floor and on the wall behind the bending magnet before Miniball (viewed by opening a port-hole in the magnet) to set up the theodolite, so that it was directly over the point on the floor and looking at the point on the wall. This meant the theodolite was looking along the direction exactly opposite the beam direction. So if the target was centred on the crosshairs of the theodolite, it was correct.

With HIE-ISOLDE it is no longer possible to open up a port-hole in the magnet and there is, in any case, no line of site to the wall and no mark on the wall. Instead there is a mark at the point where the beam intersects the wall after Miniball. There is also a mark on the floor after the beam dump. So in principle, we could mount the theodolite over the mark on the floor, line up to the one on the wall and rotate 180° and we would be looking also as before. Note that there are two ways to rotate the theodolite through 180°:

- rotating about the vertical axis and using the scale to determine the number of degrees to rotate
- rotating just the telescope about the horizontal axis and using the spirit level to get it level before and after the rotation.

However, in 2015, we tried a new method for aligning, with the help of the alignment people (Michal Rebisz, Antje Behrens and Benoit Cummer). This new method is described in this document.

2 The Leica AT401 Absolute Tracker

The alignment service have a Leica AT401 Absolute Tracker, which is first set up using known points fixed in the floor and walls at ISOLDE, where they mount prisms and the AT401 uses a laser to determine is position relative to these points.

After that, they can place a prism at any point and determine its absolute position in the CERN Coordinate System.

3 The CERN Coordinate System

The CERN Coordinate System has its origin at the PS, but there are offsets of about 2 km added to each coordinate, so it cannot be confused with any other system. The coordinates are either given as x_{CCS}, y_{CCS}, and z_{CCS} or x_{CCS}, y_{CCS}, and H_{CCS}. The relationship between z_{CCS} and H_{CCS} is given by:

$$z_{CCS} = H_{CCS} + 2000.00079 - \frac{d^2}{2(R+h)}$$

where

$$d = \sqrt{(x_{CCS} - 2000)^2 + (y_{CCS} - 2097.7927)^2}$$

and R is the mean radius of the earth in metres given by

$$R = 6371000$$

To go in the other direction, we use

$$h_{CCS} = \frac{\left(z_{CCS} - 2000.00079 + \frac{d^2}{2R}\right)}{\cos\left(\frac{d}{R}\right)}$$

Using the MADX calculation from 15/06/2015, which is in version 1.1 of the EDMS document 1323585 (`https://edms.cern.ch/document/1323585/1.1`) in the file XT01_survey_ccs.txt.

we have the coordinates of the Miniball target position:

x=1864.28940, y=2282.82486, z=2437.48881, h=437.49215 [m]

Figure 1: The Leica AT401 Absolute Tracker.

We define a Miniball coordinate system with the origin at the nominal target position, the y direction in the direction of the beam and the z-direction vertically upwards. So the z-axis is in the same direction as that of the CERN one, but it is rotated by -257.85485997° = -4.5004162987 radians[1], relative to the CERN coordinate system. Note, however, that we use millimetres not metres.

Angle between coordinate systems = -257.85485997° = -4.5004162987 radians

Note that the Miniball CAD diagram is offset by 25 mm relative to the Miniball coordinate system. This is because it was designed for a nominal beam height of 1750 mm, but at ISOLDE the beam height is nominally at 1725 mm.

3.1 Conversion from CERN to Miniball coordinate system

$$
\begin{aligned}
x_{MB} &= 1000 \cdot (0.97761779 \cdot (y_{CCS} - 2282.824858) - 0.21038884 \cdot (x_{CCS} - 1864.289396)) \\
y_{MB} &= 1000 \cdot (-0.97761779 \cdot (x_{CCS} - 1864.289396) - 0.21038884 \cdot (y_{CCS} - 2282.824858)) \\
z_{MB} &= 1000 \cdot (z_{CCS} - 2437.488812) \\
&\text{or} \\
z_{MB} &= 1000 \cdot (H_{CCS} - 437.492155)
\end{aligned}
$$

where

$$
\begin{aligned}
0.97761779 &= \sin(-257.854860^\circ) \\
0.21038884 &= \cos(-257.854860^\circ)
\end{aligned}
$$

where the values with the CCS subscript are in the CERN Coordinate System and those with the MB subscript are in the Miniball coordinate system. The Miniball coordinate system has its origin at the nominal target position, with the y direction representing the beam and x horiziontal and z vertical.

3.2 Conversion from Miniball to CERN coordinate system

$$
\begin{aligned}
x_{CCS} &= 1864.289396 - 0.97761779 \cdot y_{MB}/1000 - 0.21038884 \cdot x_{MB}/1000 \\
y_{CCS} &= 2282.824858 + 0.97761779 \cdot x_{MB}/1000 - 0.21038884 \cdot y_{MB}/1000 \\
z_{CCS} &= z_{MB}/1000 + 2437.488812 \\
H_{CCS} &= z_{MB}/1000 + 437.492155
\end{aligned}
$$

4 Alignment of the frame

To align the frame, we determined the absolute coordinates of the rings onto which the arcs are attached. There are three such rings below the target chamber and three above,on each side. By measuring at least three points on a ring, they can fit a circle and determine the centre of the circle. This should be exactly below or above the nominal target position.

From the CAD diagrams, we know the positions of the centre of the top and bottom faces of each ring. If we number the rings from top to bottom, so the highest ring is ring 1 and the lowest is ring 12, we have the following coordinates for the centre of the top and bottom flat surfaces of each ring:

[1] Angle also taken from EDMS document 1323585

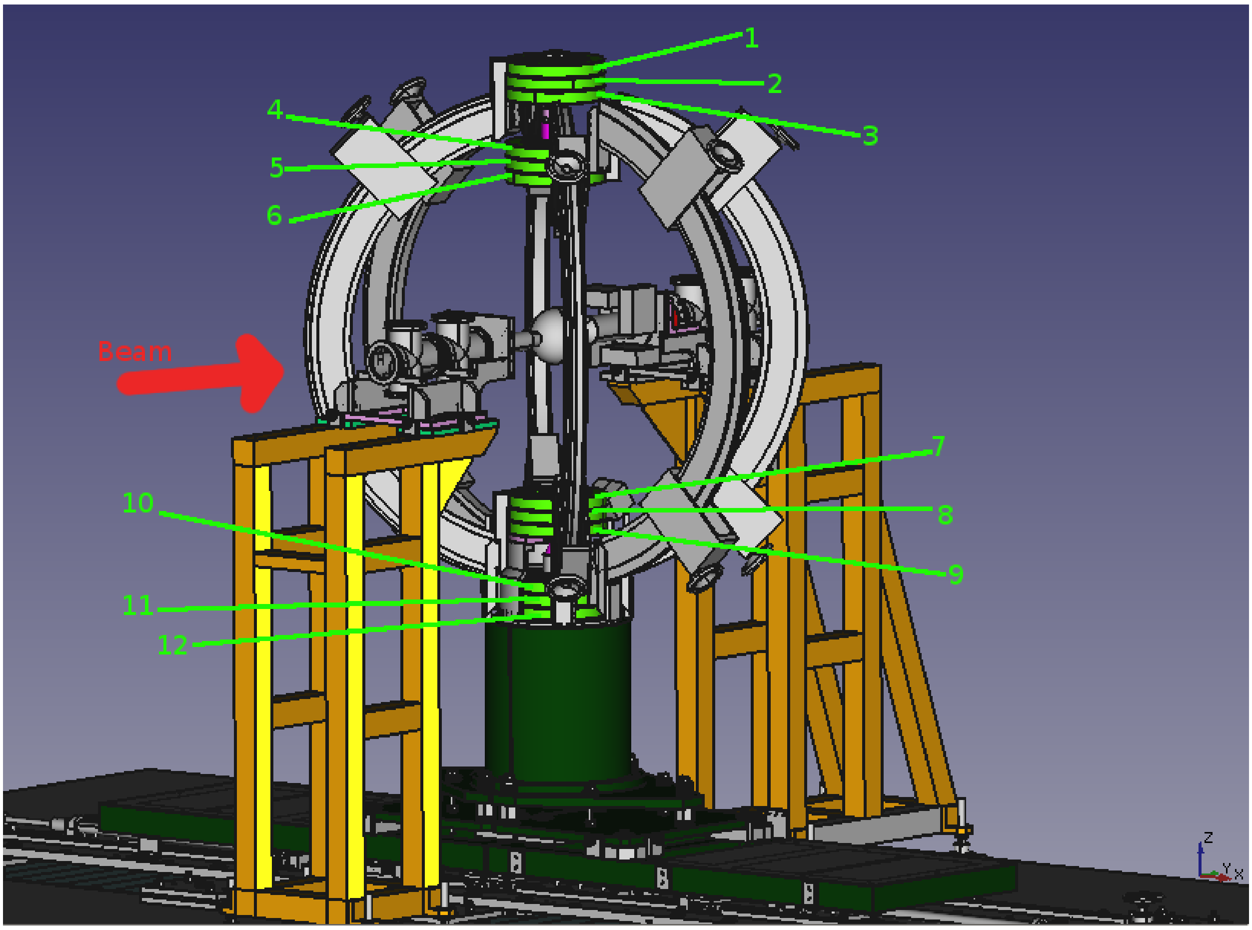

Figure 2: The Miniball frame, showing the 12 rings (bright green), numbered 1 to 12 from top to bottom. The beam goes into the page from left to right.

Ring	Surface	x_{MB}, y_{MB}, z_{MB} [mm]	x_{CCS}, y_{CCS}, z_{CCS}, H_{CCS} [m]
1	Top	0, 0, +835	1864.28940, 2282.82486, 2438.32381, 438.32715
1	Bottom	0, 0, +795	1864.28940, 2282.82486, 2438.28381, 438.28715
2	Top	0, 0, +795	1864.28940, 2282.82486, 2438.28381, 438.28715
2	Bottom	0, 0, +755	1864.28940, 2282.82486, 2438.24381, 438.24715
3	Top	0, 0, +755	1864.28940, 2282.82486, 2438.24381, 438.24715
3	Bottom	0, 0, +717	1864.28940, 2282.82486, 2438.20581, 438.20915
4	Top	0, 0, +585	1864.28940, 2282.82486, 2438.07381, 438.07715
4	Bottom	0, 0, +547	1864.28940, 2282.82486, 2438.03581, 438.03915
5	Top	0, 0, +547	1864.28940, 2282.82486, 2438.03581, 438.03915
5	Bottom	0, 0, +507	1864.28940, 2282.82486, 2437.99581, 437.99915
6	Top	0, 0, +507	1864.28940, 2282.82486, 2437.99581, 437.99915
6	Bottom	0, 0, +467	1864.28940, 2282.82486, 2437.95581, 437.95915
7	Top	0, 0, -473	1864.28940, 2282.82486, 2437.01581, 437.01915
7	Bottom	0, 0, -513	1864.28940, 2282.82486, 2436.97581, 436.97915
8	Top	0, 0, -513	1864.28940, 2282.82486, 2436.97581, 436.97915
8	Bottom	0, 0, -552	1864.28940, 2282.82486, 2436.93681, 436.94015
9	Top	0, 0, -552	1864.28940, 2282.82486, 2436.93681, 436.94015
9	Bottom	0, 0, -591	1864.28940, 2282.82486, 2436.89781, 436.90115
10	Top	0, 0, -723	1864.28940, 2282.82486, 2436.76581, 436.76915
10	Bottom	0, 0, -761	1864.28940, 2282.82486, 2436.72781, 436.73115
11	Top	0, 0, -761	1864.28940, 2282.82486, 2436.72781, 436.73115
11	Bottom	0, 0, -801	1864.28940, 2282.82486, 2436.68781, 436.69115
12	Top	0, 0, -801	1864.28940, 2282.82486, 2436.68781, 436.69115
12	Bottom	0, 0, -841	1864.28940, 2282.82486, 2436.64781, 436.65115

Note, however, that these values are only achieved if the ball is closed and the locking pins are in place. However, it is rather hard to measure in this configuration, so it may be necessary to compromise. The rings above the target chamber are most affected by the absence of the locking pins.

5 Alignment of the Coulex target chamber

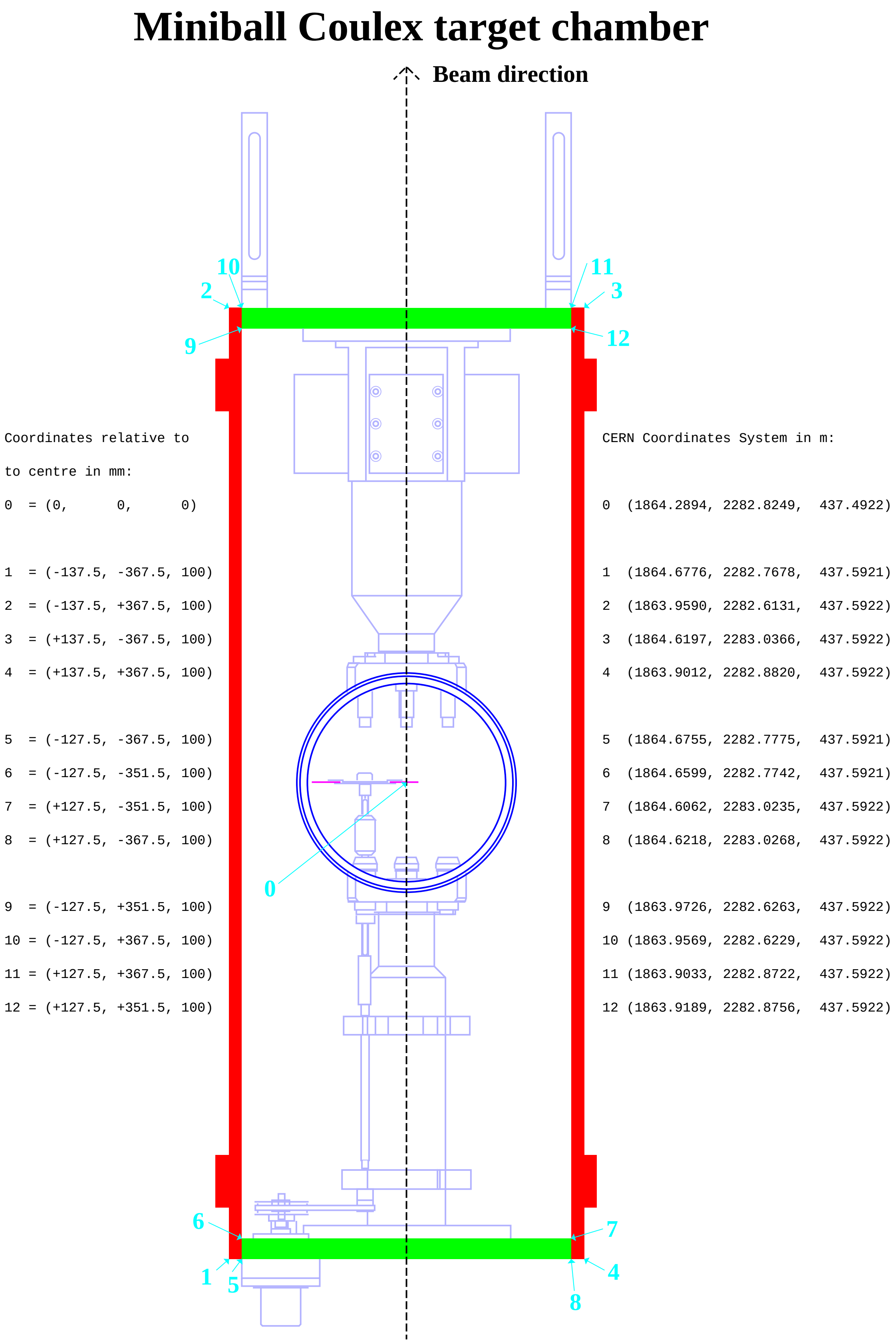

Figure 3: The target chamber alignment

There are two ways to determine the alignment of the chamber:

Figure 4: The Leica retro-reflective targets mounted on the Miniball target wheel

- Using the upper corners of the front and back plates
- Using the sphere of the chamber itself

The former method relies on the information in figure 3. In practise, it is not possible to use the points on the side plates, as there is a small difference depending how the side plates are mounted. However, you must have the side plates on to change the alignment, otherwise you could damage the target chamber. So it is really points 6, 7, 9 and 12 which need to be used.

Point (See fig. 3)	x_{MB}, y_{MB}, z_{MB} [mm]	x_{CCS}, y_{CCS}, z_{CCS}, H_{CCS} [m]
6	-127.5, -351.5, 100	1864.65985, 2282.77416, 2437.48881, 437.59215
7	+127.5, -351.5, 100	1864.60620, 2283.02346, 2437.48881, 437.59215
9	-127.5, +351.5, 100	1863.97259, 2282.62626, 2437.48881, 437.59215
12	+127.5, +351.5, 100	1863.91894, 2282.87555, 2437.48881, 437.59215

The latter method involves measuring several points on the outer surface of the sphere and fitting a sphere to those points. For this, the side plates need to be removed (at least on one side), so it is not feasible to adjust the chamber this way, but it is a good check after using the other method.

6 Alignment of the targets

There are two ways to do this:

- set up the theodolite so that it is looking in the inverse direction of the beam and check the crosshairs of the theodolite are centred on the target
- use the absolute method with some special Leica retro-reflective targets (see fig. 4) mounted on the target wheel.

The former method has the disadvantage that it doesn't measure the offset of the target along the beam direction.

The nominal target position is[2]:

Point (See fig. 3)	x_{MB}, y_{MB}, z_{MB} [mm]	x_{CCS}, y_{CCS}, z_{CCS}, H_{CCS} [m]
0	0, 0, 0	1864.28940, 2282.82486, 2437.48881, 437.49215

7 Alignment of the SPEDE target chamber

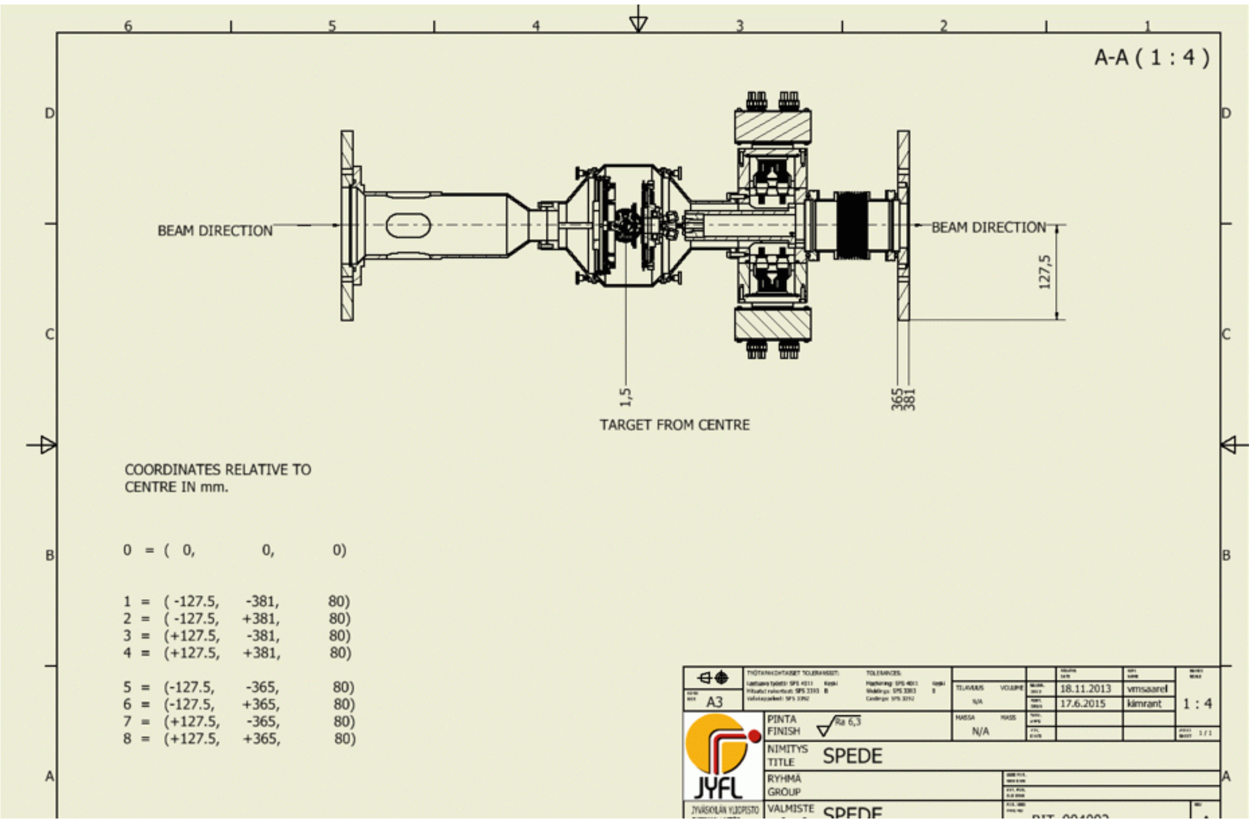

Figure 5: The SPEDE chamber

The SPEDE target chamber is 27 mm longer than the Coulex one. As with the Coulex chamber, the target is centred between the two flanges, which are compatible with the Coulex ones.

The points in the following table correspond to points 0, 5-11 in 3. i.e. without the side plates. The width (±127.5 mm) is the same, but the lengths (±365 and ±381 mm) are longer than those of the Coulex chamber (±351.5 and ±367.5 mm).

Point (See fig. 5)	x_{MB}, y_{MB}, z_{MB} [mm]	x_{CCS}, y_{CCS}, z_{CCS}, H_{CCS} [m]
0	0.00, 0.00, 0.00	1864.28940, 2282.82486, 2437.48881, 437.49215
1	-127.50, -381.00, 80.00	1864.68869, 2282.78037, 2437.56881, 437.57214
2	-127.50, 381.00, 80.00	1863.94375, 2282.62005, 2437.56881, 437.57216
3	127.50, -381.00, 80.00	1864.63504, 2283.02966, 2437.56881, 437.57215
4	127.50, 381.00, 80.00	1863.89010, 2282.86935, 2437.56881, 437.57216
5	-127.50, -365.00, 80.00	1864.67305, 2282.77700, 2437.56881, 437.57214
6	-127.50, 365.00, 80.00	1863.95939, 2282.62342, 2437.56881, 437.57216
7	127.50, -365.00, 80.00	1864.61940, 2283.02630, 2437.56881, 437.57215
8	127.50, 365.00, 80.00	1863.90574, 2282.87271, 2437.56881, 437.57216

[2]The nominal target position is taken from version 1.1 of the EDMS document 1323585.